LBL-80
August 1972

A COMPILATION OF DATA ON INCLUSIVE REACTIONS

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(Data complete as of May 1972)

* Work supported by the United States Atomic Energy Commission

** Work supported by the National Science Foundation

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in the Western Hemisphere and Far East; users elsewhere should order from CERN, Geneva

MASTER

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TABLE OF CONTENTS

I. Introduction	3
II. Data on Inclusive Spectra	
A. pp	9
B. p-Nucleus	327
C. $\overline{p}p$	389
D. K^+p	399
E. π^+p	485
F. ep (up)	569
G. γp	607
H. Comparative Plots	637
I. Two-Body Correlations	699
III. Inclusive Spectra: Kinematics and Phenomenology . .	727
(A detailed table of contents for Section III is on page 727.)	

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MASTER

I. Introduction

A. Objective

With the current interest in multiparticle inclusive reactions, our objective is to provide a relatively self-contained compilation of most relevant graphs and references on this subject. This is not meant to be a review article, although we present a section on Kinematics and Phenomenology by J. Kasman, but is meant to contain in a single package a fairly complete set of data for ready reference.

B. Procedures and Scope of Compilation

We do not claim this to be an exhaustive survey of inclusive reactions although we have attempted to be as complete as possible within the limits of practicality. In addition to published data, we have included more recent data which has appeared either in preprint form or in review articles. Our intention is that this compilation be of a modular form, so that as new data become available pages can be added or replaced. The compilation consists mainly of the published data graphs which have been blown up to fit neatly onto a standard 8 1/2" x 11" page. As an aid to the reader, we have superimposed grids on these plots (when physically possible) so that it will be easier to read points off the graphs. A bibliography is also provided to supplement the information contained in the graphs. We wish to emphasize that we compile the experimental results of others, and it is inappropriate to give us credit for their countless hours of effort. We urge that citations be given directly to original articles, and also suggest that these articles be examined for qualifying remarks pertaining to the data.

C. Notation and Organization

1. Notation

A table of contents is provided for quick reference. The reader who wishes to learn more details about the phenomenology

and how and why various quantities are plotted is referred to Section III written by J. Kasman. Here we give a short summary of the notation used in this compilation. We list here only the more common variables. In cases where a less conventional variable is used, the reader should consult the references on the reverse side of each graph. The notation is as follows:

a. The energy variables

$p_{INC} \equiv$ incident particle momentum

$E_{INC} \equiv$ incident particle energy

$\sqrt{s} \equiv$ total center-of-mass energy

b. The longitudinal variables

$p_{||}^{LAB}, p_{||}^{BEAM}, (p_{||}^{PROJ}), p_{||}^{CM}$

$\equiv$ parallel component of a particle in the target rest frame, projectile rest frame, or center-of-mass frame, respectively

$x \equiv$ the Feynman scaling variable $\sim 2p_{||}^{CM}/\sqrt{s}$ for s large.

Several definitions for x are:

$p_{||}^{CM}/p_{INC}^{CM}, p_{||}^{CM}/(p_{||}^{CM})_{MAX}, 2p_{||}^{CM}/\sqrt{s}$

$y \equiv 1/2 \ln[(E + p_{||})/(E - p_{||})]$, the rapidity variable

c. The transverse variables

$p_{\perp} \equiv$ the perpendicular component of momentum of a secondary particle

$m_{\perp} \equiv (p_{\perp}^2 + m^2)^{1/2}$, the transverse mass for a particle of mass m

$t \equiv$ the four-momentum-transfer squared

$t' \equiv t - t_{MINIMUM}$

d. The cross sections

$N \equiv$ number of events or counts

$d\sigma =$ the yield of secondary particles into a specified region of phase space

$\sigma_{\text{TOTAL}}, \sigma_{\text{ELASTIC}} \equiv$ the total or elastic cross section

For conciseness, abbreviations have been used in the references to data. Universities or institutions are designated by the four-letter code of the Particle Data Group, in their Review of Particle Properties. The experimental technique for data is identified by the following:

CNTR: electronic counters

HBC: hydrogen bubble chamber

SPRK: spark chamber

EMUL: emulsion stack

IONC: ionization calorimeter

THEOR: theoretical discussion

REVU: review of data

2. Data Organization

The single particle spectra $ab \rightarrow cX$ are collected according to the nature of the beam and target:

$pp, p\text{-Nucleus}, \bar{p}p, K^{\pm}p, \pi^{\pm}p, ep (\mu p), \gamma p.$

Within each category, plots are arranged in order of increasing beam momentum. A set of references follows each section; these references include some papers from which no graphs were reproduced. Sections on comparative plots and two-body correlations are also provided.

II-A. Data on Inclusive Spectra: pp

$pp \rightarrow N_{\text{PRONGS}}$

$pp \rightarrow N_{\text{PRONGS}}$

Cross sections for fixed numbers of charged particles vs.

the beam momentum p_{INC}

D. B. Smith, UCRL #20632 (1971), and D. B. Smith, R. J. Sprafka
and J. A. Anderson, *Phys. Rev. Letters* 23, 1064 (1969)

Proton-Proton inelastic cross sections

 $E_{\text{INC}} = 10 \text{ to } 1000 \text{ GeV}$

Proton-Proton inelastic cross sections vs. energy.

L. W. Jones et al., Michigan-Wisconsin-Colorado-BNL-ANL collaborations,
The Properties of Proton-Proton Interactions Between 100 and 1000 GeV
from a Cosmic Ray Experiment, UM-HE-71-46 (Revised) 1972

$PP \rightarrow N_{\text{PRONGS}}$
 $P_{\text{INC}} = \sim 10 + 1000 \text{ GeV/c}$

CHARGED PRONG CROSS SECTIONS FOR P-P INTERACTIONS

$$PP \rightarrow N_{\text{PRONGS}}$$

$$P_{\text{INC}} = \sim 10 + 1000 \text{ GeV/c}$$

The charged-prong cross sections vs. energy. The data from below 30 GeV are from accelerator bubble chamber experiments, the data above 30 GeV are cosmic ray data. The smooth curves are Poisson distributions and the dotted curves are to guide the eye. Data from this cosmic ray experiment was normalized to $\sigma_{pp}(\text{inelastic}) = 30 \text{ mb}$.

L. W. Jones et al., Michigan-Wisconsin-Colorado-BNL-ANL collaboration, The Properties of Proton-Proton Interactions Between 100 and 1000 GeV from a Cosmic Ray Experiment, Univ. of Michigan preprint UM HE 71-46 (Revised), 1972

$$PP \rightarrow N_{\text{PRONGS}}$$

$$E_{\text{INC}} = \sim 10 - 1000 \text{ GeV}/c$$

The 2- and 4-prong cross sections vs. energy. The authors note, that in view of the large systematic uncertainties, care should be exercised in interpreting the 2-prong data. Data below 30 GeV is accelerator bubble chamber data while that above 30 GeV is cosmic ray data.

L. W. Jones et al., Michigan-Wisconsin-Colorado-BNL-ANL collaboration, The Properties of Proton-Proton Interactions Between 100 and 1000 GeV from a Cosmic Ray Experiment, Univ. of Michigan preprint, UM HE 71-46 (Revised), 1972

$$pp \rightarrow K^+ X$$

$$E_{\text{INC}} - m_p = \bar{y}_p = 2.54 \text{ GeV}$$

$\gamma p \rightarrow K^+ X$

$$E_{INC} - m_p = T_p = 2.54 \text{ GeV}$$

$(d\sigma/dpd\Omega)^{CM}$ vs. p^{CM} for produced K^+ ($\theta^{LAB} = 20^\circ, 30^\circ, 40^\circ$), when the incident proton has kinetic energy $T_p = E_{INC} - m_p = 2.54 \text{ GeV}$.

The dotted lines represent phase space, normalized to the area under the curve.

W. J. Hogan, P. A. Piroué and A. J. S. Smith, Phys. Rev. 166, 1472 (1968)

-Princeton-Pennsylvania Accelerator; counter experiment

$pp \rightarrow K^+ X$

$$T_p = E_{INC} - m_p = 2.54, 2.88, 3.03 \text{ GeV}$$

$$\text{The ratio } \left(\frac{d\sigma}{dpd\Omega} \right)_{\text{EXPERIMENT}}^{\text{CM}} \left| \left(\frac{d\sigma}{dpd\Omega} \right)_{\text{PHASE SPACE}}^{\text{CM}} \right.$$

for kaons produced at $\theta^{\text{LAB}} = 20^\circ, 30^\circ, 40^\circ$

W. J. Hogan, P. A. Piroué and A. J. S. Smith, Phys. Rev. 166, 1472 (1968)

-Princeton-Pennsylvania Accelerator; counter experiment

$pp + K^+X$

$$T_p = E_{INC} - m_p = 2.85 \text{ GeV}$$

$pp \rightarrow K^+ X$

$$T_p = E_{INC} - m_p = 2.85 \text{ GeV}$$

$(d\sigma/dp d\Omega)^{CM}$ for K^+ produced by incident protons of kinetic energy
 $T_p = 2.85 \text{ GeV}$ vs. p^{CM} ($\theta^{LAB} = 0^\circ, 17^\circ, 32^\circ$); the CM angle is also shown
 on a scale.

The dotted curve is the sum of all phase space contributions, normalized to
 the area under the curve.

J. T. Reed, A. C. Melissinos, N. W. Reay, T. Yamanouchi, E. J. Sacharidis,
 S. J. Lindenbaum, S. Ozaki and L. C. L. Yuan, Phys. Rev. 168, 1495 (1968)

-Cosmotron; counter experiment

$$pp \rightarrow \pi^{\pm} X$$

$$p_{INC} = 2.9 \text{ GeV}/c$$

$d\sigma/dp d\Omega)^{LAB}$ vs. p^{LAB} of the produced pion ($\theta^{LAB} = 0^\circ, 17^\circ, 32^\circ$)

A. C. Melissinos, G. G. Fazio, T. Yamanouchi, S. J. Lindenbaum and
L. C. L. Yuan, Phys. Rev. Letters 7, 454 (1961)

-BNL Cosmotron; counter experiment

pp → pX

$p_{INC} = 5.5, 6.6 \text{ GeV/c}$

pp + pX

 $p_{INC} = 5.5, 6.6 \text{ GeV}/c$

$$d\sigma/dp_{\perp}^2 \text{ vs. } p_{\perp}^2,$$

for inelastic protons produced when pions (top) and kaons (bottom) are also produced. The coefficients shown are from fits of the form

$$d\sigma/dp_{\perp}^2 = \exp(a + bp_{\perp}^2 + cp_{\perp}^4).$$

The authors note that six-prong and higher topologies which account for less than 5% of the inelastic cross section have been omitted. They also note that events in which only charged strange particles were produced have been omitted--these constitute only about 10% of the total strange particle cross section with protons in the final state.

M. A. Abolins, G. A. Smith, Z. M. Ma, E. Gellert and A. B. Wicklund,
Phys. Rev. Letters 25, 126 (1970)

$pp \rightarrow p\bar{X}$ $p_{\text{INC}} = 5.5, 6.6 \text{ GeV}/c$

$$d^2\sigma/dp_{\perp}^2 dp_{\parallel}^{\text{CM}} \text{ vs. } p_{\parallel}^{\text{CM}}$$

for produced (non-elastic) protons when (top) pions are also produced and (bottom) when kaons are also produced, for various intervals of $p_{\perp}^2$.

The authors note that six-prong and higher topologies which account for less than 5% of the inelastic cross section have been omitted. They also note that events in which only charged strange particles were produced have been omitted--these constitute only about 10% of the total strange particle cross section with protons in the final state.

M. A. Abolins, G. A. Smith, Z. M. Ma, E. Gellert and A. B. Wicklund,
Phys. Rev. Letters 25, 126 (1970)

$P_{INC} = 5.5, 6.6 \text{ GeV/c}$

$p\bar{p} + p\bar{p}$

pp → pX

 $p_{INC} = 5.5, 6.6 \text{ GeV/c}$

$$d\sigma/dp_{||}^{CM} \text{ vs. } p_{||}^{CM}$$

for produced(non-elastic) protons when (top) pions are also produced and (bottom) when kaons are also produced.

The authors note that six-prong and higher topologies which account for less than 5% of the inelastic cross section have been omitted. They also note that events in which only charged strange particles were produced have been omitted--these constitute only about 10% of the total strange particle cross section with protons in the final state.

M. A. Abolins, G. A. Smith, E. M. Ma, E. Gellert and A. B. Wicklund,
Phys. Rev. Letters 32, 126 (1973)

$pp \rightarrow \pi^- X$
 $P_{INC} = 6.6 \text{ GeV}/c$

$pp \rightarrow \pi^- X$

$p_{INC} = 6.6 \text{ GeV/c}$

(upper left) $E \frac{d^3\sigma}{dp^3}$ vs. x for five intervals in $p_{\perp}$

(upper right) $\left(E \frac{d^3\sigma}{dp^3} \right) / \left(E \frac{d^3\sigma}{dp^2} \Big|_{x=0} \right)$ vs. $p_{\perp}$ for various intervals in x . The symbols with horizontal error bars represent $p_{\perp, \text{MAX}}$ for each x -interval.

(lower) $E \frac{d^3\sigma}{dp^3}$ vs. y^{LAB} for various intervals in $p_{\perp}$

Eugene Gellert, The Inclusive Reaction $pp \rightarrow \pi^- + \text{Anything}$ at 6.6 GeV/c Compared to Higher Energies, Lawrence Radiation Laboratory preprint 784 (1972)

pp $\rightarrow \pi^- X$ $p_{\text{INC}} = 6.6 \text{ GeV}/c$

$pp \rightarrow \pi^- X$ $p_{INC} = 6.6 \text{ GeV/c}$

(top) $E \frac{d^3\sigma}{dp^3}$ vs. y^{LAB} for various intervals in $p_{\perp}^2$

(lower left) $E \frac{d^3\sigma}{dp^3}$ vs. x for various intervals in $p_{\perp}^2$

(lower right) $\frac{d^2\sigma}{dp_{\perp} dp_{||}^{LAB}}$ vs. $p_{||}^{LAB}$ for various intervals in $p_{\perp}^2$

Note that in the three figures the 6.6 GeV/c data are compared to 12.4 GeV/c pp data of Akerlof et al. [Phys. Rev. D3, 645 (1971)]. A broken line joins points having $|x| = 0.489$.

Eugene Gellert, The Inclusive Reaction $pp \rightarrow \pi^- + \text{Anything}$ at 6.6 GeV/c Compared to Higher Energies, Lawrence Radiation Laboratory preprint 784 (1972)

π^- FROM pp

$$\left[\frac{E}{W} \frac{d^2\sigma}{dx dp_T^2} \times 10^{27} \text{ cm}^2/\text{GeV}^2 \right] / F(p_T^2)$$

$pp \rightarrow \pi^- X$

Plot of $\frac{1}{\sqrt{s}} E \frac{d\sigma}{dx dp_{\perp}^2}$ vs. $x = \frac{2p_{\parallel}^{CM}}{\sqrt{s}}$ for produced pions (Here $W = \sqrt{s}$).

The data was compiled by Drs. Nagashima and Tollestrup of Cal Tech from:

$$P_{INC} = 12.2 + 12.5 \text{ GeV/c}$$

J. L. Day et al., Phys. Rev.

Letters 23, 1055 (1969);

C. W. Akerlof et al., Phys. Rev.

D3, 645 (1971)

$$P_{INC} = 19.2 \text{ GeV/c}$$

J. V. Allaby et al., CERN

report 70-12 (April 1970)

$$P_{INC} = 29.7 \text{ GeV/c}$$

E. W. Anderson et al., Phys. Rev.

Letters 19, 198 (1967)

$$E_{INC} = 70 \text{ GeV/c}$$

Yu. B. Bushnin et al.,

Phys. Letters 29B, 48 (1969);

F. Binon et al., Phys. Letters

30B, 506 (1969);

Yu. M. Antipov et al., Phys.

Letters 34B, 164 (1971)

S. D. Drell, Invited paper, conference on Expectations for Particle Reactions at the New Accelerators (University of Wisconsin, April 1970)

pp + pX

pp → pX

A plot of $30/p_{INC} (d\sigma/dpd\Omega)^{LAB}$ vs. $R = p^{LAB}/p_{INC}$, for production angles

$30/p_{INC} \times \theta^{LAB}$; the plot attempts a test of the scaling law

$$\frac{1}{p_{INC}} \frac{d\sigma}{dpd\Omega} = f(p_{INC}, p/p_{INC}).$$

The data used is from

$p_{INC} = 12.4 \text{ GeV/c}$	G. J. Marmer et al., Phys. Rev. Letters <u>23</u> , 1469 (1969)
$p_{INC} = 18.8 \text{ GeV/c}$	D. Dekkers et al., Phys. Rev. <u>137</u> , B96. (1965)
$p_{INC} = 19.2 \text{ GeV/c}$	J. V. Allaby et al., CERN report 70-12 (1970)
$p_{INC} = 20 \text{ GeV/c}$	W. F. Baker et al., Phys. Rev. Letters <u>7</u> , 101 (1961)
$p_{INC} = 30 \text{ GeV/c}$	E. W. Anderson et al., Phys. Rev. Letters <u>19</u> , 198 (1967)

J. C. Vander Velde, Physics Letters 32B, 501 (1970)

$pp \rightarrow \pi^- X$ $p_{\text{INC}} = 12, 24 \text{ GeV/c}$

$pp \rightarrow \pi^- X$ $p_{INC} = 12, 24 \text{ GeV/c}$

$$\frac{1}{\pi} \frac{d^2 \sigma}{dy^{CM} dp_{\perp}^2} \text{ vs. } y^{CM}$$

for various intervals in $p_{\perp}$.

The symbols are difficult to distinguish--note for reference that the 24 GeV/c data is always above the 12 GeV/c data at $y^{CM} = 0$.

H. J. Mück et al., BONN-DESY-HAMB-Max Planck collaboration, Physics Letters
39B, 303 (1972)

$$pp \rightarrow \pi^- X$$

$$+ \pi^+ X$$

$$p_{T,inc} = 12, 24 \text{ GeV}/c$$

$pp \rightarrow \pi^- X$
 $\rightarrow \pi^+ X$

$P_{INC} = 12, 24 \text{ GeV/c}$

$$\frac{1}{\pi} \frac{d^2\sigma}{dy^{CM} dp_{\perp}^2} \text{ vs. } y^{CM}$$

for π^- production (top) and π^+ production (bottom) for $p_{\perp} = 0.2 \text{ GeV/c}$.
 Comparisons are made with CERN-ISR data.

$pp \rightarrow \pi^+ X$
 $p_{\text{INC}} = 12, 24 \text{ GeV/c}$

$pp \rightarrow \pi^+ X$
 $P_{INC} = 12, 24 \text{ GeV/c}$

$$\frac{1}{\pi} \frac{d^2\sigma}{dy^{CM} dp_{\perp}^2} \text{ vs. } y^{CM},$$

for various intervals in $p_{\perp}$.

The symbols used are difficult to distinguish--note for reference that the 24 GeV/c data is always above the 12 GeV/c data at $y^{CM} = 0$.

pp → ΛX $p_{\text{INC}} = 12, 24 \text{ GeV}/c$

pp → AX

 $p_{INC} = 12, 24 \text{ GeV/c}$

$$\frac{1}{\pi} \frac{d\sigma}{dy}_{LAB} \text{ vs. } y^{LAB}$$

$$\frac{E^{CM}}{\pi p_{||}^{CM}, MAX} \frac{d\sigma}{dx} \text{ vs. } x, (x = p_{||}^{CM}/p_{||}^{CM}, MAX)$$

$$\frac{1}{\pi} \frac{d\sigma}{dp_{\perp}^2} \text{ vs. } p_{\perp}^2$$

Note that the Λ spectrum contains Λ from Σ^0 decays. The authors state that the Λ spectrum is still preliminary.

H. J. Murr et al., BBNB-BBNB-BAMB-Max Planck collaboration, Inclusive Particle Production in pp Interactions at 12 and 24 GeV/c (Parts I and II) Internal Report BBNB-BI-70/L (1970)

pp $\rightarrow$ pX $p_{\text{INC}} = 12, 24 \text{ GeV/c}$

pp → pX

p_{INC} = 12, 24 GeV/c

$$\frac{2E_{\text{CM}}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{\perp}^2} \quad \text{vs.} \quad x, \quad (x = 2p_{\parallel}^{\text{CM}}/\sqrt{s})$$

for various intervals in $p_{\perp}$. Comparisons are made with CERN-ISR data.

2

H. J. Mück et al., BONN-DESY-HAMB-Max Planck collaboration, Inclusive Particle Production in pp Interactions at 12 and 24 GeV/c (Parts I and II), Internal Report DESY-F1-72/1 (1972)

pp → pX

 $P_{INC} = 12, 24 \text{ GeV/c}$

$$\frac{1}{\pi} \frac{d^2\sigma}{dy^{LAB} dp_{\perp}^2} \text{ vs. } y^{LAB} \text{ for intervals in } p_{\perp}$$

$$\frac{1}{\pi} \frac{d^2\sigma}{dy^{LAB} dp_{\perp}^2} \text{ vs. } p_{\perp}^2 \text{ for intervals in } y^{LAB}$$

Comparisons are made with CERN-ISR data.

H. J. Mück et al., BONN-DESY-HAMB-Max Planck collaboration, Inclusive Particle Production in pp Interactions at 12 and 24 GeV/c (Parts I and II), Internal Report DESY-F1-72/1 (1972)

$pp \rightarrow K_S^0 X$
 $p_{\text{INC}} = 12, 24 \text{ GeV}/c$

$$pp \rightarrow K_S^0 X$$

$$P_{INC} = 12, 24 \text{ GeV}/c$$

$$\frac{1}{\pi} \frac{d\sigma}{dy}_{LAB} \text{ vs. } y^{LAB}$$

$$\frac{2E^{CM}}{\pi\sqrt{s}} \frac{d\sigma}{dx} \text{ vs. } x, (x = 2p_{||}^{CM}/\sqrt{s})$$

$$\frac{1}{\pi} \frac{d\sigma}{dp_{\perp}^2} \text{ vs. } p_{\perp}^2$$

H. J. Mück et al., BONN-DESY-HAMB-Max Planck collaboration, Inclusive Particle Production in pp Interactions at 12 and 24 GeV/c (Parts I and II),
Internal Report DESY-F1-72/1 (1972)

$pp \rightarrow \pi^+ X$
 $p_{INC} = 12, 24 \text{ GeV}/c$

$$pp \rightarrow \pi^+ X$$

$$p_{INC} = 12, 24 \text{ GeV}/c$$

$$\frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{\perp}^2} \text{ vs. } x, x = 2p_{\parallel}^{CM}/\sqrt{s}$$

for indicated reactions and $p_{\perp}$ intervals. The data are compared to CERN-ISR data.

H. J. Mück et al., BONN-DESY-HAMB-Max Planck collaboration, Inclusive Particle Production in pp Interactions at 12 and 24 GeV/c (Parts I and II), Internal Report DESY-F1-72/1 (1972)

$pp \rightarrow \pi^+ X$
 $p_{TMC} = 12, 24 \text{ GeV}/c$

$pp \rightarrow \pi^{\pm} X$ $p_{INC} = 12, 24 \text{ GeV/c}$

$$\frac{1}{\pi} \frac{d^2 \sigma}{dy_{LAB} dp_{\perp}^2} \text{ vs. } p_{\perp}^2$$

for the indicated reactions and cuts on laboratory rapidity.

H. J. Mück et al., BONN-DESY-HAMB-Max Planck collaboration, Inclusive Particle Production in pp Interactions at 12 and 24 GeV/c (Parts I and II), Internal Report DESY-F1-72/1 (1972)

$pp \rightarrow p\pi^+X, pp \rightarrow ppX$

$p_{INC} = 12.3 \text{ GeV}/c$

The distribution dN/dm_X^2 of events vs. m_X^2 = square of missing mass for

(a) $pp \rightarrow p\pi^+X$ (1234 events)

(b) $pp \rightarrow ppX$ (6331 events)

H. L. Anderson, S. Fukui, D. Kessler, K. A. Klare, M. V. Sherbrook,
H. J. Evens, R. L. Martin, E. P. Hincks, N. K. Sherman and
P. I. P. Kalmus, Phys. Rev. Letters 18, 89 (1967)

-ANL ZGS; counter experiment

$$pp \rightarrow \pi^+ X$$

$$P_{INC} = 12.2, 12.5 \text{ GeV/c}$$

$pp \rightarrow \pi^{\pm} X$
 $p_{INC} = 12.2, 12.5 \text{ GeV}/c$

$(d\sigma/dp d\Omega)^{CM}$ vs. $p_{\perp}^2$ (for fixed $p^{CM} = 0.6 \text{ GeV}/c$) of the produced pion

C. W. Akerlcf, D. G. Crabb, J. L. Day, N. P. Johnson, P. Kalbaci, A. D. Krisch, M.T. Lin, M. L. Marshak, J. K. Randolph, P. Schmueser, A. I. Read, K. W. Edwards, J. G. Asbury, G. J. Marmer and L. G. Ratner, Phys. Rev. D 3, 645 (1971)

J. L. Day, N. P. Johnson, A. D. Krisch, M. L. Marshak, J. K. Randolph, P. Schmueser, G. J. Marmer and L. G. Ratner, Phys. Rev. Letters 23, 1055 (1969)

-ANL/ZGS; counter experiment

$pp \rightarrow \pi^+ X$
 $p_{INC} = 12.4, 12.5 \text{ GeV/c}$

$pp \rightarrow \pi^+ X$
 $p_{INC} = 12.4, 12.5 \text{ GeV/c}$

$(d\sigma/dp d\Omega)^{CM}$ vs. $p_{||}^{CM}$ (for fixed values of $p_{\perp}^2$) of the produced pion

C. W. Akerlof, D. G. Crabb, J. L. Day, N. P. Johnson, P. Kalbaci, A. D. Krisch,
M. T. Lin, M. L. Marshak, J. K. Randolph, P. Schmueser, A. L. Read,
K. W. Edwards, J. G. Asbury, G. J. Marmer and L. G. Ratner, Phys. Rev. D 3,
645 (1971)

J. L. Day, N. P. Johnson, A. D. Krisch, M. L. Marshak, J. K. Randolph,
P. Schmueser, G. J. Marmer and L. G. Ratner, Phys. Rev. Letters 23,
1055 (1969)

-ANL/ZGS; counter experiment

$p\bar{p} \rightarrow \pi^- X$ $P_{INC} = 12.4, 12.5 \text{ GeV/c}$

$pp \rightarrow \pi^- X$
 $p_{INC} = 12.4, 12.5 \text{ GeV/c}$

 $(d\sigma/dp d\Omega)^{CM}$ vs. $p_{||}^{CM}$ (for fixed values of $p_{\perp}^2$) of the produced pion

C. W. Akerlof, D. G. Crabb, J. L. Day, N. P. Johnson, P. Kalbaci,
 A. D. Krisch, M. T. Lin, M. L. Marshak, J. K. Randolph, P. Schmueser,
 A. L. Read, K. W. Edwards, J. G. Asbury, G. J. Marmer and L. G. Ratner,
 Phys. Rev. D 3, 645 (1971)

J. L. Day, N. P. Johnson, A. D. Krisch, M. L. Marshak, J. K. Randolph,
 P. Schmueser, G. J. Marmer and L. G. Ratner, Phys. Rev. Letters 23,
 1055 (1969)

-ANL/ZGS; counter experiment

$pp \rightarrow pX$
 $p_{INC} = 12.4, 12.5 \text{ GeV/c}$

pp → pX

 $P_{INC} = 12.4, 12.5 \text{ GeV}/c$

$(d\sigma/d\Omega dp)^{CM}$ vs. $p_{\perp}^2$ for the produced proton (with a fixed energy loss ΔE
in the CM frame

C. W. Akerlof, D. G. Crabb, J. L. Day, N. P. Johnson, P. Kalbaci, A. D. Krisch,
M. T. Lin, M. L. Marshak, J. K. Randolph, P. Schmueser, A. L. Read,
K. W. Edwards, J. G. Asbury, G. J. Marmer and L. G. Ratner, Phys. Rev. D3,
645 (1971)

J. L. Day, N. P. Johnson, A. D. Krisch, M. L. Marshak, J. K. Randolph,
P. Schmueser, G. J. Marmer and L. G. Ratner, Phys. Rev. Letters 23,
1055 (1969)

-ANL/ZGS; counter experiment

pp → pX

 $p_{INC} = 12.5 \text{ GeV/c}$

pp + pX

 $p_{INC} = 12.5 \text{ GeV/c}$

$2E \frac{d\sigma}{d^3p}$ vs. $x' = p_{||}^{CM} / \sqrt{(p_{MAX}^{CM})^2 - p_{\perp}^2}$ (for fixed $p_{\perp}^2$) of the
produced proton

Data is from C. W. Akerlof et al., Phys. Rev. D $\underline{3}$, 645 (1971), and
is interpolated to lines of fixed $p_{\perp}^2$

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra pp + cX

$pp \rightarrow pX$ $p_{INC} = 12.5 \text{ GeV/c}$

pp → pX

 $p_{\text{INC}} = 12.5 \text{ GeV}/c$

$$2E \frac{d\sigma}{d^3p} \text{ vs. } p_{\parallel}^{\text{LAB}} \text{ (for fixed } p_{\perp}^2 \text{) of the produced proton}$$

Data is from C. W. Akerlof et al., Phys. Rev. D3, 645 (1971), and is interpolated to lines of fixed $p_{\perp}^2$

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra pp → cX

$pp \rightarrow cX$ $p_{INC} = 12.5 \text{ GeV}/c$ $pp \rightarrow cX \text{ (12.5 GeV/c)}$

$pp \rightarrow cX$ $p_{INC} = 12.5 \text{ GeV}/c$

$$2E \frac{d\sigma}{d^3p} \text{ vs. } p_{||}^{LAB} \text{ (for fixed } p_{\perp}^2) \text{ of produced } \pi^{\pm}, K^{\pm}, p^{\pm}$$

Data is from C. W. Akerlof et al., Phys. Rev. D3, 545 (1971)

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra $pp \rightarrow cX$

$pp \rightarrow \pi^+ X$
 $P_{TNC} = 12.5, 30 \text{ GeV}/c$

$pp \rightarrow \pi^+ X$

$p_{INC} = 12.5, 30 \text{ GeV/c}$

A plot of $\ln \left(\frac{d\sigma}{dp_\pi d\Omega} \right)^{CM} / s G(r, z)$ vs. r , for different values of z ,

where $r = \left(\frac{p_\pi}{p_p} \right)^{CM}$ and $z = \cos \theta^{CM}$. The quantity

$$G(r, z) = (1 + rz) \ln(1 + rz) + (1 - rz) \ln(1 - rz) - (1 + r) \ln(1 + r) - (1 - r) \ln(1 - r)$$

is obtained from the 6-point dual resonance model, where

$$\left(\frac{d\sigma}{dp_\pi d\Omega} \right)^{CM} \rightarrow \sigma_0 e^{bsG(r, z)} \quad \text{in the limit } r, z \text{ fixed, } s \rightarrow \infty; \text{ here } b$$

is the Regge slope parameter.

The data is taken from:

E. W. Anderson et al., Phys. Rev. Letters 19, 198 (1967), $p_{INC} = 30 \text{ GeV/c}$

C. W. Akerlof et al., Phys. Rev. D3, 645 (1971), $p_{INC} = 12.5 \text{ GeV/c}$

K. Huang and G. Segrè, Phys. Rev. Letters 27, 1095 (1971)

pp + pX

 $p_{INC} = 12.5, 20, 30 \text{ GeV/c}$

A plot of $\ln \left(\frac{d\sigma}{dp_\pi d\Omega} \right)^{CM} / sG(r, z)$ vs. r , for different values of z ,

where $r = \left(\frac{p_\pi}{p_p} \right)^{CM}$ and $z = \cos\theta^{CM}$. The quantity

$$G(r, z) = (1 + rz) \ln(1 + rz) + (1 - rz) \ln(1 - rz) - (1 + r) \ln(1 + r) - (1 - r) \ln(1 - r)$$

is obtained from the 6-point dual resonance model, where

$$\left(\frac{d\sigma}{dp_\pi d\Omega} \right)^{CM} \rightarrow \sigma_0 e^{bsG(r, z)} \quad \text{in the limit } r, z \text{ fixed, } s \rightarrow \infty; \text{ here } b$$

is the Regge slope parameter.

The data is taken from:

E. W. Anderson et al., Phys. Rev. Letters 19, 198 (1967), $p_{INC} = 20, 30 \text{ GeV/c}$

C. W. Akerlof et al., Phys. Rev. D3, 645 (1971), $p_{INC} = 12.5 \text{ GeV/c}$

K. Huang and G. Segrè, Phys. Rev. Letters 27, 1095 (1971)

$pp \rightarrow \pi^- X$
 $p_{INC} = 12.5, 30 \text{ GeV/c}$

A plot of $\ln \left(\frac{d\sigma}{dp_\pi d\Omega} \right)^{CM} / sG(r, z)$ vs. r , for different values of z ,

where $r = \left(\frac{p_\pi}{p_p} \right)^{CM}$ and $z = \cos\theta^{CM}$. The quantity

$$G(r, z) = (1 + rz) \ln(1 + rz) + (1 - rz) \ln(1 - rz) - (1 + r) \ln(1 + r) - (1 - r) \ln(1 - r)$$

is obtained from the 6-point dual resonance model, where

$$\left(\frac{d\sigma}{dp_\pi d\Omega} \right)^{CM} \rightarrow \sigma_0 e^{bsG(r, z)} \quad \text{in the limit } r, z \text{ fixed, } s \rightarrow \infty; \text{ here } b$$

is the Regge slope parameter.

The data is taken from:

E. W. Anderson et al., Phys. Rev. Letters 19, 198 (1967), $p_{INC} = 30 \text{ GeV/c}$

C. W. Akerlof et al., Phys. Rev. D 3, 645 (1971), $p_{INC} = 12.5 \text{ GeV/c}$

K. Huang and G. Segrè, Phys. Rev. Letters 27, 1095 (1971)

$pp \rightarrow \pi^+ X$
 $p_{INC} = 12.5 \text{ GeV}/c$

$p\bar{p} \rightarrow \pi^+ X$ $p_{INC} = 12.5 \text{ GeV}/c$

$(d\sigma/d\Omega dM_X)^{CM}$ vs. missing mass M_X , for scattering angle $\theta = 0^\circ$

R. C. Lamb, R. A. Lundy, f. B. Novey, D. D. Yovanovitch and R. Lander,
Phys. Rev. Letters 17, 100 (1966)

-ANL/AGS; counter experiment

pp + pX

 $P_{\text{INC}} = 30 \text{ GeV/c}$

pp → pX

 $P_{INC} \approx 30 \text{ GeV}/c$

$d\sigma/dp d\Omega)^{LAB}$ vs. p^{LAB} for the "produced" proton ($\theta^{LAB} = 14, 23, 43, 60, 100, 160 \text{ mrad.}$)

E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
R. A. Canigan Jr., R. M. Edelstein, M. C. Hien, T. J. McMahon and
I. Nadelhaft, Phys. Rev. 19, 198 (1967)

-BNL/AGS; counter experiment

$$\frac{d^2\sigma}{dp_{\perp}^* dp_{\parallel}} \text{ mb}/(\text{BeV}/c)^2$$

pp → pX

 $p_{INC} \approx 10, 20, 30 \text{ GeV}/c$

$$\left(\frac{d\sigma}{dp_{||}^{CM} d/p_{\perp}^{CM}} \right)^{CM} \text{ vs. } p_{\perp}^{CM} \text{ for "produced" protons } (0.2 < p_{||}^{CM} < 3 \text{ GeV}),$$

using incident beams of differing momenta

E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
 R. A. Canigan Jr., R. M. Edelstein, F. C. Hien, T. J. McMahon and
 I. Nadelhaft, Phys. Rev. 19, 198 (1967)

-BNL/AGS; counter experiment

$pp \rightarrow pX$ and $\pi^- X$

$p_{INC} = 30 \text{ GeV}/c$

$\left(\frac{d\sigma}{dp_{||}^{CM} dp_{\perp}^{CM}} \right)^{CM}$ vs. $p_{||}^{CM}$ for the produced particles (p or π), at a fixed value of

$$p_{\perp}^{CM} = (0.18 \pm 0.02) \text{ GeV}/c \text{ or } 1.00 \pm 0.04 \text{ GeV}/c$$

E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
R. A. Canigan Jr., R. M. Edelstein, N. C. Hien, T. J. McMahon and
I. Nadelhaft, Phys. Rev. 19, 198 (1967)

-BNL/AGS; counter experiment

$pp \rightarrow pX$ $P_{INC} = 10, 20 \text{ GeV}/c$

pp → pX

 $p_{INC} = 10, 20 \text{ GeV/c}$

$(d\sigma/dpd\Omega)^{LAB}$ vs. p^{LAB} for the "produced" proton ($\theta^{LAB} = 100 \text{ mrad. at } p_{INC} =$
 $10 \text{ GeV/c; } \theta^{LAB} = 160 \text{ mrad at } p_{INC} = 20 \text{ GeV/c}$)

E. W. Andersson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
 R. A. Canigan Jr., R. M. Edelstein, N. C. Hien, T. J. McMahon and
 I. Nadelhaft, Phys. Rev. 19, 198 (1967)

-BNL/AGS; counter experiment

pp $\rightarrow$ pX $p_{INC} = 6.2, 9.9, 15.1, 20, 29.7 \text{ GeV/c}$

pp $\rightarrow$ pX

$$p_{\text{INC}} \approx 6.2, 9.9, 15.1, 20, 29.7 \text{ GeV/c}$$

Plot of $d\sigma/dtd(M_X^2/S)$ vs. $M_X^2/S (= y)$ at different $|t|$ values of
 (a) 0.055, (b) 0.095, (c) 0.264, (d) 0.814, (e) $1.85 (\text{GeV/c})^2$. The
 symbols $\diamond$, ∇ , $\circ$, Δ , $\square$ correspond to beam momenta 6.2, 9.9, 15.1, 20, and
 29.7 GeV/c. Open symbols are used for $M_X \leq 1.8 \text{ GeV/c}^2$ and solid symbols
 for $M_X \geq 1.9 \text{ GeV/c}^2$.

The data is taken from E. W. Anderson et al., Phys. Rev. Letters 16, 855 (1966)
 R. M. Edelstein et al., Phys. Rev. D5, 1073 (1972)

R. M. Edelstein, V. Nitzenberg and H. R. Rubinstein, Phys. Letters 35B,
 408 (1971)

$pp \rightarrow \pi^{\pm} X$ $P_{INC} = 30 \text{ GeV}/c$

$(d\sigma/dp d\Omega)^{LAB}$ vs. p^{LAB} for the produced pion ($\theta^{LAB} = 15, 96, 160 \text{ mrad.}$)

E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
R. A. Canigan Jr., R. M. Edelstein, N. C. Hien, T. J. McMahon and
I. Nadelhaft, Phys. Rev. 19, 198 (1967)

-BNL/AGS; counter experiment

MISSING MASS SPECTRA AT 9.9 GeV/c

MISSING MASS SPECTRA

pp + pX

$P_{\text{INC}} = 6.2, 9.9, 15.1, 20, 29.7 \text{ GeV}/c$

pp $\rightarrow$ pX

$$P_{\text{INC}} = 6.2, 9.9, 15.1, 20, 29.7 \text{ GeV/c}$$

Plots of $d\sigma/dtdM_X$ vs. missing mass M_X ($\equiv W$)

$$(a), (b) \quad P_{\text{INC}} = 9.9 \text{ GeV/c}, \quad t = 0.023 \rightarrow 2.12 \text{ (GeV/c)}^2$$

$$(c) \quad P_{\text{INC}} = 6.2 \rightarrow 29.7 \text{ GeV/c}, \quad t \approx 0.044 \text{ (GeV/c)}^2$$

$$(d) \quad P_{\text{INC}} = 9.9 \rightarrow 29.7 \text{ GeV/c}, \quad t \approx 0.88 \text{ (GeV/c)}^2$$

The plots use data taken at fixed θ^{LAB} , with the quoted t value corresponding to $M_X = 1.5 \text{ GeV/c}^2$

R. M. Edelstein, R. A. Carrigan, Jr., N. C. Hien, T. J. McMahon, I. Nadelhaft,
E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes and
F. Turkot, Phys. Rev. D5, 1073 (1972)

pp + pX

 $P_{TMC} = 9.9, 15.2, 20.1, 29.7 \text{ GeV}/c$

pp $\rightarrow$ pX $P_{INC} = 9.9, 15.2, 20.1, 29.7 \text{ GeV/c}$
 $\frac{d\sigma}{d|t|dM_X}$ vs. missing mass $M_X(=W)$ for fixed momentum transfer

 $|t| = 0.042 \text{ (GeV/c)}^2$ and for various incident momenta

E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
 R. A. Carrigan, Jr., R. M. Edelstein, W. C. Hien, T. J. McMahon and
 I. Nadelhaft, Phys. Rev. Letters 16, 855 (1966)

-BNL/AGS

$pp \rightarrow pX$ $P_{INC} = 9.9, 15.2, 20.1, 29.7 \text{ GeV/c}$

pp + pX

 $P_{INC} = 9.9, 15.2, 20.1, 29.7 \text{ GeV/c}$

$\frac{d\sigma}{d|t|dM_X}$ vs. missing mass M_X for fixed momentum transfer $|t| = 0.082 \text{ (GeV/c)}^2$,

and for various incident momenta

E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
 R. A. Carrigan, Jr., R. M. Edelstein, N. C. Hien, T. J. McMahon and
 I. Nadelhaft, Phys. Rev. Letters 16, 855 (1966)

-BNL/AGS

$pp \rightarrow pX$ $P_{INC} = 15.1 \text{ GeV/c}$

pp + pX

 $p_{INC} = 15.1 \text{ GeV/c}$

$\frac{d\sigma}{d|t|dM_X}$ vs. missing mass $M_X (=W)$ for momentum transfers

$$|t| = .25, .44, .67, 2.06 \text{ (GeV/c)}^2$$

E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
 R. A. Carrigan, Jr., R. M. Edelstein, N. C. Hien, T. J. McMahon and
 I. Nadelhaft, Phys. Rev. Letters 16, 855 (1966)

-BNL/AGS

pp $\rightarrow$ pX $P_{INC} \approx 15.1 \text{ GeV}/c$

pp + pX

P_{INC} = 15.1 GeV/c

$\frac{d\sigma}{d|t|dM_X}$ vs. missing mass $M_X(=W)$ for momentum transfers

$$|t| = .024, .045, .089, .138 \text{ (GeV/c)}^2$$

E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot,
 R. A. Carrigan, Jr., R. M. Edelstein, N. C. Hien, T. J. McMahon and
 I. Nadelhaft, Phys. Rev. Letters 16, 855 (1966)

-BNL/AGS

$P_{INC} = 8 \text{ and } 16 \text{ GeV}/c$
 $P_{INC} = 15 \text{ GeV}/c$

$$\pi^- p \rightarrow \pi^- X$$

$$pp \rightarrow pX$$

$$P_{INC} = 8 \text{ and } 16 \text{ GeV/c}$$

$$P_{INC} = 15 \text{ GeV/c}$$

$d\sigma/dtdM_X$ plotted vs. missing mass M_X , where the momentum transfer t between the beam particle and produced particle is in the range
 $0.06 < |t| < 0.10 \text{ (GeV/c)}^2$

E. W. Anderson, E. J. Bleser, H. R. Blieden, G. B. Collins, D. Garelick.

J. Menes, F. Turkot, D. Birnbaum, R. M. Edelstein, N. C. Hien, T. J. McMahon,

J. F. Mucci and J. S. Russ, Phys. Rev. Letters 25, 699 (1970)

$$\pi^- p \rightarrow \pi^- X$$

$$pp \rightarrow p X$$

$$p_{\text{INC}} = 8 \text{ and } 16 \text{ GeV/c}$$

$$p_{\text{INC}} = 15 \text{ GeV/c}$$

$\pi^- p \rightarrow \pi^- X$ $P_{INC} = 8 \text{ and } 16 \text{ GeV}/c$ $pp \rightarrow pX$ $P_{INC} = 15 \text{ GeV}/c$

$d\sigma/dtdM_X$ plotted vs. missing mass M_X , where the momentum transfer t between the beam particle and produced particle is in the range
 $0.06 < |t| < 0.10 \text{ (GeV}/c)^2$

E. W. Anderson, E. J. Bleser, H. R. Blieden, G. B. Collins, D. Garelick,
J. Menes, F. Turkot, D. Birnbaum, R. M. Edelman, N. C. Hien, T. J. McMahon,
J. F. Mucci and J. S. Russ, Phys. Rev. Letters 25, 699 (1970)

$pp \rightarrow \pi^- X$
 $\quad \quad \quad \rightarrow \pi^+ X$

$p_{INC} = 13, 18, 21, 24, 28 \text{ GeV/c}$

$$pp \rightarrow \pi^- X$$

$$\rightarrow \pi^+ X$$

$$p_{INC} = 13, 18, 21, 24, 28 \text{ GeV/c}$$

- (a) $dN/dp_{\perp}$ vs. $p_{\perp}$ for produced π^- from 8-pronged events at 21 GeV/c
- (b) $dN/dp_{||}^{CM}$ vs. $p_{||}^{CM}$ for produced π^- from 8-pronged events at 21 GeV/c
- (c) $dN/dp_{\perp}$ vs. $p_{\perp}$ for produced π^+ from 8-pronged events at 21 GeV/c
- (d) $dN/dp_{||}^{CM}$ vs. $p_{||}^{CM}$ for produced π^+ from 8-pronged events at 21 GeV/c
- (e) - (h) Coefficients resulting from fits to experimental distributions

$$\frac{dN}{dp_{\perp}} = \frac{N_T (a_{\perp})^{5/2} (p_{\perp})^{3/2} \exp(-a_{\perp} p_{\perp})}{3/4 \sqrt{\pi}} \quad \text{and}$$

$$\frac{dN}{dp_{||}^{CM}} = N_T a_{||} \exp(-a_{||} |p_{||}|) \quad \text{vs. beam momenta.}$$

$pp + \pi^+ X$

$p_{\text{INC}} = 13, 18, 21, 24, 28 \text{ GeV}/c$

$pp \rightarrow \pi^- X$ $P_{INC} = 13, 18, 21, 24, 28 \text{ GeV}/c$

$$(a) \quad 2 \frac{d^2 \sigma}{dp_{||}^2 dp_{\perp}} \text{ vs. } p_{\perp}$$

$$(b) \quad 2 \frac{d^2 \sigma}{dp_{\perp} dp_{||}} \text{ vs. } p_{||}^{\text{LAB}}$$

Note that a factor of 2 has been inserted on the vertical scale to correct a reported error in earlier versions of this graph.

D. B. Smith, UCRL-20632 (1971)

D. B. Smith, R. J. Sprafka and J. A. Anderson, Phys. Rev. Letters 23,
1064 (1969)

$pp + \pi^- X$
 $p_{INC} = 12.88, 28.44 \text{ GeV}/c$

$pp \rightarrow \pi^- X$
 $p_{INC} \approx 12.88, 28.44 \text{ GeV/c}$

(upper left) dN/dx vs. x at 28.44 GeV/c divided by that at 12.88 GeV;
the curve is the prediction of scaling. Division of the points
by the curve produces the points in the lower left subfigure.

(right) $dN/dp_{||}^{CM}$ vs. $p_{||}^{CM}$

Data for these plots: D. B. Smith, UCRL-20632 (1971)

L. Michejda, paper submitted to the Amsterdam Conference (1971), also
Warsaw Report #1329/VI/PH (1971); Nucl. Phys. B35, 287 (1971)

$pp + \Lambda \bar{K} X$
 $+ \bar{K} K X$

L3

$P_{\text{INC}} = 13, 18, 21, 24, 28 \text{ GeV/c}$

$pp \rightarrow \Lambda KX$
 $\rightarrow K\bar{K}X$

$p_{INC} = 13, 18, 21, 24, 28 \text{ GeV/c}$

Total cross-sections for $pp \rightarrow \Lambda K$ plus anything and $pp \rightarrow K\bar{K}$ plus anything. The cross sections were obtained as follows:

$$\sigma(\Lambda K + \text{anything}) = 3/2[\sigma(\Lambda, \text{seen alone}) + \sigma(\Lambda K_1^0, \text{both seen})]$$

$$\sigma(K\bar{K} + \text{anything}) = 4[\sigma(K_1^0, \text{seen alone}) - \sigma(K_1^0 K_1^0, \text{both seen})]$$

$$-1/2\sigma(\Lambda K_1^0, \text{both seen})$$

Equal cross sections for $K^+ \bar{K}^0$, $K^0 K^-$, $K^0 \bar{K}^0$ and $K^+ K^-$ were assumed in the derivation of the second equation.

E. L. Berger, B. Y. Oh and G. A. Smith, Test of Limiting
 Behavior for Λ^0 and K_1^0 Produced in Inclusive Proton-Proton
 Interactions Between 13 and 28 GeV/c, Argonne National
 Laboratory Report #ANL/HEP 7132

pp + K₁⁰X

P_{INC} = 13, 18, 21, 24, 28 GeV/c

- (a) $\frac{2E^{CM}}{\sigma_{TOTAL}\sqrt{s}} \frac{d\sigma}{d|x|}$ vs. $|x|$, $x = 2p_{||}^{CM}/\sqrt{s}$.
- (b) $\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}}$ vs. $p_{||}$; note that each K⁰ is plotted twice--once in the laboratory frame and once in the projectile frame.
- (c) $\frac{2E^{CM}}{\sigma_{TOTAL}\sqrt{s}} \frac{d\sigma}{d|x|}$ vs. beam momentum for selected $|x|$ intervals.
- (d) $\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}}$ vs. beam momentum for selected $p_{||}$ intervals.

Note that K₁⁰ from both forward and backward hemispheres are included in the above plots and that the x plots have been folded.

E. L. Berger, B. Y. Oh and G. A. Smith, Test of Limiting Behavior for Λ^0 and K₁⁰ Produced in Inclusive Proton-Proton Interactions Between 13 and 28 GeV/c, Argonne National Lab. report ANL/HEP 7132, Phys. Rev. Letters 28, 322 (1972)

$pp \rightarrow \Lambda^0 X$
 $\rightarrow K_1^0 X$

$P_{INC} = 13, 18, 21, 24, 28 \text{ GeV/c}$

$pp \rightarrow \Lambda^0 X$
 $\quad \rightarrow K_1^0 X$

$P_{INC} = 13, 18, 21, 24, 28 \text{ GeV/c}$

(a) $\frac{E^{CM}}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{\perp}^2}$ vs. $p_{\perp}^2$

(b) and (c) $\frac{E^{CM}}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{\perp}^2}$ vs. beam momentum for selected intervals of $p_{\perp}^2$

E. L. Berger, B. Y. Oh and G. A. Smith, Test of Limiting Behavior for
 Λ^0 and K_1^0 Produced in Inclusive Proton-Proton Interactions Between
13 and 28 GeV/c, Argonne National Lab. report ANL/HEP 7132;
 Phys. Rev. Letters 28, 322 (1972)

pp + $\Lambda^0 X$ p_{INC} = 13, 18, 21, 24, 28 GeV/c

pp + Λ^0 X $P_{INC} = 13, 18, 21, 24, 28 \text{ GeV/c}$

$$(a) \quad \frac{2E^{CM}}{\sigma_{TOTAL}\sqrt{s}} \frac{d\sigma}{dx} \text{ vs. } x, \quad x = 2 \frac{P^{CM}}{\sqrt{s}}$$

$$(b) \quad \frac{2E^{CM}}{\sigma_{TOTAL}\sqrt{s}} \frac{d\sigma}{dx} \text{ vs. beam momentum for selected intervals in } x.$$

Only Λ^0 which are backward in the overall center of mass are plotted.

E. L. Berger, B. Y. Oh and G. A. Smith, Test of Limiting Behavior for Λ^0 and K^0 Produced in Inclusive Proton-Proton Interactions Between 13 and 28 GeV/c, Argonne National Lab. report ANL/HEP 7132; Phys. Rev. Letters 28, 322 (1972)

$pp \rightarrow \pi^- X$ $p_{\text{INC}} = 19 \text{ GeV}/c$

 $dN/dp_{\perp} \text{ vs. } p_{\perp}$

H. Bøggild, K. H. Hansen and M. Suk, Nucl. Phys. B27, 1 (1971)

$pp \rightarrow \pi^- X$ $p_{INC} = 19 \text{ GeV}/c$

Average value of transverse momentum
of π^- from $pp \rightarrow \pi^- X$ as a function of $p_{||}^{CM}$

H. Bøggild, K. H. Hansen and M. Suk, Nucl Phys. B27, 1 (1971)

$p\bar{p} \rightarrow \pi^+ X$ $p_{INC} = 19 \text{ GeV}/c$

$$E^{CM} \frac{dN}{dp_{||}^{CM}} \text{ vs. } p_{||}^{CM}$$

The solid line represents a parameterization of the data.

H. Bøggild, K. H. Hansen and M. Suk, Nucl. Phys. B27, 1 (1971)

$pp \rightarrow \pi^- X$ $p_{INC} = 19 \text{ GeV}/c$

$pp \rightarrow \pi^- X$ $p_{INC} = 19 \text{ GeV}/c$

 $d\sigma/dy^{CM} \text{ vs. } y^{CM}$

H. Bøggild, E. Dahl-Jensen, M. Gavrilas, K. H. Hansen and H. Johnstad,
Niels Bohr Institute--Univ. of Copenhagen, paper submitted to the
Amsterdam Conference (1971)

$pp \rightarrow \pi^- X$ $p_{INC} = 19 \text{ GeV}/c$

$pp \rightarrow \pi^- X$ $p_{INC} = 19 \text{ GeV}/c$

$$\frac{d^2 \sigma}{dy^{CM} dp_{\perp}^2} \text{ vs. } y^{CM}$$

for various intervals in $p_{\perp}$

H. Bøggild, E. Dahl-Jensen, M. Gavrilas, K. H. Hansen and H. Johnstad,
preprint Scandinavian Bubble Chamber collaboration, paper submitted to
the 1971 Amsterdam Conference.

$pp \rightarrow \pi^- X$ $P_{INC} = 19.2 \text{ GeV/c}$

$pp + \pi^- X$

$p_{INC} = 19.2 \text{ GeV}/c$

(top) Average value of $p_{\perp}$ vs. $p_{||}^{CM}$. Note that only tracks with $p_{\perp} \leq 1 \text{ GeV}/c$ are included.

(bottom) Average value of $(E^{CM} \cdot p_{\perp})$ vs. $p_{||}^{CM}$. Note that only tracks with $p_{\perp} \leq 1 \text{ GeV}/c$ are included and that each track is weighted by the pion energy in the center of mass.

H. Bøggild, E. Dahl-Jensen, M. Gravilas, K. H. Hansen and E. Johnstad,

Angular and Rapidity Distributions of the Pions Emitted in High Energy Proton-Proton Collisions, preprint, Scandinavian Bubble Chamber collaboration (1972)

$pp \rightarrow \pi^+ X, pp \rightarrow K^+ X$
 $p_{INC} = 19, 24 \text{ GeV/c}$

$pp \rightarrow \pi^+ X, pp \rightarrow K^+ X$
 $p_{INC} = 19, 24 \text{ GeV}/c$

Cross section $(d\sigma/dp d\Omega)^{LAB}$ vs. p^{LAB} ($\theta^{LAB} = 116 \text{ mrad.}$) for the produced particle

- Δ $pp \rightarrow \pi^+ X$ (time-of-flight technique)
- $\bullet$ $pp \rightarrow \pi^+ X$ (Čerenkov counter technique)
- Δ $pp \rightarrow \pi^- X$ (time-of-flight technique)
- $\circ$ $pp \rightarrow \pi^- X$ (Čerenkov counter technique)
- $\blacksquare$ $pp \rightarrow K^+ X$ (Čerenkov counter technique)
- $\square$ $pp \rightarrow K^- X$ (Čerenkov counter technique)
- $\times$ $pp \rightarrow \pi^0 X$ (interpolations from the data of M. Fidecaro et al.,
Nuovo Cimento 24, 73 (1962))

The upper plot has $p_{INC} = 19 \text{ GeV}/c$; the lower has $p_{INC} = 24 \text{ GeV}/c$.
Systematic error (not shown) = 7%.

A. N. Diddens, W. Galbraith, E. Lillethun, G. Manning, A. G. Parham,
A. E. Taylor, T. G. Walker and A. M. Wetherell, Nuovo Cimento 31,
961 (1964)

-CERN proton synchrotron; counter experiment; tabulated dat. is provided

$pp \rightarrow pX, pp \rightarrow dX, pp \rightarrow \bar{p}X$
 $p_{INC} = 19, 24 \text{ GeV}/c$

$pp \rightarrow pX, pp \rightarrow dX, pp \rightarrow \bar{p}X$
 $p_{INC} = 19, 24 \text{ GeV}/c$

Cross section $(d\sigma/dp d\Omega)^{LAB}$ vs. p^{LAB} ($\theta^{LAB} = 116 \text{ mrad.}$) for the produced particle

- ▲ $pp \rightarrow pX$ (time-of-flight technique)
- $pp \rightarrow pX$ (Čerenkov counter technique)
- $pp \rightarrow dX$ (time-of-flight technique)
- $pp \rightarrow dX$ (Čerenkov counter technique)
- $pp \rightarrow \bar{p}X$ (Čerenkov counter technique)

The upper plot has $p_{INC} = 19 \text{ GeV}/c$; the lower has $p_{INC} = 24 \text{ GeV}/c$.
Systematic error (not shown) = 7%.

A. N. Diddens, W. Colbraith, E. Lillethun, G. Manning, A. G. Parham,
A. E. Taylor, T. G. Walker and A. M. Wetherell, *Nuovo Cimento* 31,
961 (1964)

-CERN proton synchrotron; counter experiment; tabulated data

$\frac{d\sigma}{d\eta} / \frac{d\sigma}{d\eta}|_{p_{1NC}}$ [0.74 GeV/c]

pp → pX

 $p_{INC} = 19.20 \text{ GeV}/c$

$(d\sigma/dp d\Omega)^{LAB} \text{ cm}^2 \text{ ster}^{-1} (\text{GeV}/c)^{-1}$ vs. p^{LAB} of the produced proton

$(\theta^{LAB} = 40 \text{ mrad.})$

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier,
 J. P. Feigneux, E. J. Sacharidis, K. Schllpmann, M. Spighel,
 J. P. Stroot, A. M. Thorndike and A. M. Wetherell, Physics Letters 28B,
 229 (1968)

-counter experiment

pp + pX

 $P_{INC} = 19.20 \text{ GeV/c}$

pp $\rightarrow$ pX $p_{INC} = 19.20 \text{ GeV}/c$

$(d\sigma/dp d\Omega)^{LAB} \text{ cm}^2 \text{ ster}^{-1} (\text{GeV}/c)^{-1}$ vs. p^{LAB} of the produced proton

$(\theta^{LAB} = 100 \text{ mrad.})$

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier,
 J. P. Peigneux, E. J. Sacharidis, K. Schlüpmann, M. Spighel,
 J. P. Stroot, A. M. Thorndike and A. M. Wetherell, Physics Letters 28B,
 229 (1968)

-counter experiment

$p\bar{p} \rightarrow pX$ $P_{INC} = 19.20 \text{ GeV}/c$

pp → pX

p_{INC} = 19.20 GeV/c

$(d\sigma/dp d\Omega)^{\text{LAB}} \text{ cm}^2 \text{ ster}^{-1} (\text{GeV}/c)^{-1}$ vs. p^{LAB} of the produced

$(\theta^{\text{LAB}} = 70 \text{ mrad.})$

J. V. Allaby, F. Binon, A. H. Diddens, P. Duteil, A. Klovning, R. Meunier,
 J. P. Peigneux, E. J. Sacharidis, K. Schlupmann, M. Spighel,
 J. P. Stroot, A. M. Thorndike and A. M. Wetherell, Physics Letters 28B,
 229 (1968)

-counter experiment

pp, pBe, pAl $\rightarrow \pi^{\pm}X$

$$\frac{30}{p_{INC}} \left(\frac{d\sigma}{dpd\Omega} \right)^{LAB} \text{ vs. } \frac{p}{p_{INC}}^{LAB}$$

This plot tests a scaling hypothesis of the form

$$\frac{1}{p_{INC}} \left(\frac{d\sigma}{dpd\Omega} \right)^{LAB} = f(\theta^{LAB}_{p_{INC}}, p^{LAB}/p_{INC}).$$

The upper curves compare:

pp $\rightarrow \pi^{\pm}X$ at $p_{INC} = 30$ GeV/c, $\theta^{LAB} = 15$ mrad.

E. W. Anderson et al., Phys. Rev. Letters 19, 198 (1967)

pp $\rightarrow \pi^{\pm}X$ at $p_{INC} = 19.2$ GeV/c, $\theta^{LAB} = 15(30/19.2) = 23.4$ mrad.)

(interpolated from 20 and 30 mrad.)

J. V. Allaby et al., CERN Report 70-12 (April 1970)

pAl $\rightarrow \pi^{\pm}X$ at $p_{INC} \approx 70$ GeV/c, $\theta^{LAB} = 15(30/70) = 6.4$ mrad.

(interpolated from 0, 6, 12 mrad.)

Yu. B. Bushnin et al., Physics Letters 29B, 48 (1969);

F. Binon et al., Physics Letters 30B, 506 (1969)

This cross section is divided by 9, for comparison with pp.

The inset curves compare pBe $\rightarrow \pi^{\pm}X$ at $\theta^{LAB} = 0^{\circ}$, $p_{INC} = 18.3$ and 23.1 GeV/c from D. Dekkers, Phys. Rev. 137, B962 (1965)

J. C. Vander Velde, Physics Letters 32B, 501 (1970)

$pp \rightarrow pX$ $p_{INC} = 19.20 \text{ GeV/c}$
 $(d\sigma/d^3p)^{CM}$ vs. $p_{||}^{CM}$ ($p_{\perp}$ fixed), and

 vs. $p_{\perp}$ ($p_{||}^{CM}$ fixed)

 for protons observed in pp collisions.

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier,
 J. P. Peigneux, E. J. Sacharidis, K. Schlüpmann, M. Spighel, J. P. Stroot,
 A. M. Thorndike and A. M. Wetherell, High-Energy Particle Spectra from
Proton Interactions at 19.2 GeV/c, CERN Report 70-12 (23 April 1970)

$pp \rightarrow \pi^- X$

147

$P_{\text{INC}} \approx 19, 20 \text{ GeV/c}$

$pp + K^+ X$

149

$P_{INC} = 19, 20 \text{ GeV/c}$

$pp \rightarrow K^+ X$
 $p_{\text{INC}} = 19.20 \text{ GeV/c}$

 $(d\sigma/d^3p)^{\text{CM}}$ vs. $p_{||}^{\text{CM}}$ ($p_{\perp}$ fixed) and $(d\sigma/d^3p)^{\text{CM}}$ vs. $p_{\perp}$ ($p_{||}^{\text{CM}}$ fixed)

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier,
 J. P. Peigneux, E. J. Secharidis, K. Schlüpmann, M. Spighel, J. P. Stroot,
 A. M. Thorndike and A. M. Wetherell, CERN Report 70-12 (23 April 1970),
High-Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

$pp \rightarrow \widetilde{p}X$
 $p_{INC} = 19.20 \text{ GeV}/c$

 $(d\sigma/d^3p)^{CM} \text{ vs. } p_{||}^{CM} (p_{\perp} \text{ fixed}) \text{ and } (d\sigma/d^3p)^{CM} \text{ vs. } p_{\perp} (p_{||}^{CM} \text{ fixed})$

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier,
 J. P. Peigneux, E. J. Sacharidis, K. Schlüpmann, M. Spighele, J. P. Stroot,
 A. M. Thorndike and A. M. Wetherell, CERN Report 70-12 (23 April 1970),
High-Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

$pp \rightarrow \pi^+ X$

$P_{INC} = 19, 20 \text{ GeV/c}$

$pp \rightarrow \pi^+ X$ $p_{INC} = 19.20 \text{ GeV}/c$

$(d\sigma/d^3p)^{CM}$ vs. $p_{||}^{CM}$ ($p_{\perp}$ fixed) and $(d\sigma/d^3p)^{CM}$ vs. $p_{\perp}$ ($p_{||}^{CM}$ fixed)

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier,
 J. P. Peigneux, E. J. Sacharidis, K. Schlupmann, M. Spighel, J. P. Stroot,
 A. M. Thorndike and A. M. Wetherell, CERN Report 70-12 (23 April 1970),
High-Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

$pp \rightarrow K^- X$

$P_{INC} = 19.20 \text{ GeV/c}$

$pp \rightarrow K^- X$ $p_{INC} = 19.20 \text{ GeV}/c$

$(d\sigma/d^3p)^{CM}$ vs. $p_{||}^{CM}$ ($p_{\perp}$ fixed), and $(d\sigma/d^3p)^{CM}$ vs. $p_{\perp}$ ($p_{||}^{CM}$ fixed)

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier,
 J. P. Peigneux, E. J. Sacharidis, K. Schlüpmann, M. Spighel, J. P. Stroot,
 A. M. Thorndike and A. M. Wetherell, CERN Report 70-12 (23 April 1970),
High-Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

$pp \rightarrow K^- X$ $P_{INC} = 19.2 \text{ GeV}/c$

$pp \rightarrow K^- X$ $P_{INC} = 19.2 \text{ GeV}/c$

$$2E \frac{d\sigma}{d^3p} \text{ vs. } x' = p_{||}^{CM} / \sqrt{(p_{MAX}^{CM})^2 - p_{\perp}^2} \quad (\text{for fixed } p_{\perp}^2)$$

The data of J. V. Allaby et al., CERN report 70-12 (April 1970)
is interpolated to values of fixed $p_{\perp}^2$.

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra $pp \rightarrow cX$

pp $\rightarrow$ K⁺Xp_{INC} = 19.2 GeV/c

$$2E \frac{d\sigma}{d^3p} \text{ vs. } x' = \frac{p_{||}^{CM}}{\sqrt{(p_{MAX}^{CM})^2 - p_{\perp}^2}} \text{ (for fixed } p_{\perp}^2)$$

The data of J. V. Allaby et al., CERN report 70-12 (April 1970)
is interpolated to values of fixed $p_{\perp}^2$.

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra pp $\rightarrow$ cX

$pp \rightarrow \bar{p}X$ $P_{INC} \approx 19.2 \text{ GeV}/c$ $pp \rightarrow \bar{p}X \text{ (19.2 GeV}/c)$

$pp \rightarrow p\bar{X}$ $p_{INC} = 19.2 \text{ GeV}/c$

$$2E \frac{d\sigma}{d^3p} \text{ vs. } x' = p_{||}^{CM} / \sqrt{(p_{MAX}^{CM})^2 - p_{\perp}^2} \text{ (for fixed } p_{\perp}^2)$$

The data of J. V. Allaby et al., CERN report 70-12 (April 1970) is interpolated to values of fixed $p_{\perp}^2$.

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra $pp \rightarrow cX$

pp → pX

 $p_{INC} = 19.2 \text{ GeV}/c$

$$2E \frac{d\sigma}{d^3p} \text{ vs. } x' = p_{||}^{CM} / \sqrt{(p_{MAX}^{CM})^2 - p_{\perp}^2} \quad (\text{for fixed } p_{\perp}^2)$$

The data of J. V. Allaby et al., CERN report 70-12 (April 1970)
is interpolated to values of fixed $p_{\perp}^2$.

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra pp → cX

$pp \rightarrow \pi^+ X$

$pp \rightarrow \pi^+ X$ $p_{INC} = 19.2 \text{ GeV}/c$

$$2E \frac{d\sigma}{d^3p} \text{ vs. } x' = p_{||}^{CM} / \sqrt{(p_{MAX}^{CM})^2 - p_{\perp}^2} \quad (\text{for fixed } p_{\perp}^2)$$

The data of J. V. Allaby et al., CERN report 70-12 (April 1970)
is interpolated to values of fixed $p_{\perp}^2$.

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra $pp \rightarrow cX$

$pp \rightarrow \pi^- X$ $P_{INC} = 19.2 \text{ GeV}/c$ $pp \rightarrow \pi^- X (19.2 \text{ GeV}/c)$

$pp \rightarrow \pi^- X$ $p_{INC} = 19.2 \text{ GeV}/c$

$$2E \frac{d\sigma}{d^3p} \text{ vs. } x' = p_{||}^{CM} / \sqrt{(p_{MAX}^{CM})^2 - p_{\perp}^2} \text{ (for fixed } p_{\perp}^2)$$

Data is from J. V. Allaby et al., CERN report 70-12 (April 1970), and is interpolated to values of fixed $p_{\perp}^2$.

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra $pp \rightarrow cX$

$pp \rightarrow \pi^- X$ $P_{INC} = 19.2 \text{ GeV/c}$

Plot of $\frac{1}{\pi} \frac{d\sigma}{dtd(M_X^2/s)}$ vs. $\ln \frac{1}{M_X^2} (s' \equiv M_X^2)$

Data is taken from J. V. Allaby et al., CERN report 70-12
(23 April 1970), High Energy Particle Spectra from Proton
Interactions at 19.2 GeV/c.

M.-S. Chen, L.-L. Wang and T. F. Wong, Phys. Rev. D 5, 1667 (1972)

pp + pX

171

$P_{INC} = 19.2 \text{ GeV}/c$

pp → pX

p_{INC} = 19.2 GeV/c

$$\frac{1}{\pi} \frac{d\sigma}{dt dM_X^2} \quad \text{vs.} \quad \ln \frac{1}{M_X^2} \quad (s' \equiv M_X^2)$$

$$\left(\frac{X}{s} \right)$$

Data is taken from:

J. V. Allaby et al., CERN Report 70-12 (23 April 1970), High Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

M.-S. Chen, L.-L. Wang and T. F. Wong, Phys. Rev. D₅, 1667 (1972)

$pp \rightarrow K^+ X$

$P_{INC} = 19.2 \text{ GeV}/c$

Plot of $\frac{1}{\pi} \frac{d\sigma}{dtd(M_X^2/S)}$ vs. $\ln \frac{1}{M_X^2} (S' \equiv M_X^2)$

Data is taken from J. V. Allaby et al., CERN report 70-12
(23 April 1970), High Energy Particle Spectra from Proton
Interactions at 19.2 GeV/c.

M.-S. Chen, L.-L. Wang and T. F. Wong, Phys. Rev. D $\underline{5}$, 1667 (1972)

$p p \rightarrow \bar{p} X$ $P_{INC} = 19.2 \text{ GeV}/c$

Plot of $\frac{1}{\pi} \frac{d\sigma}{dtd(M_X^2/S)}$ vs. $\ln \frac{1}{M_X^2} (S' \equiv M_X^2)$

Data is taken from J. V. Allaby et al., CERN report 70-12
(23 April 1970), High Energy Particle Spectra from Proton
Interactions at 19.2 GeV/c.

M.-S. Chen, L.-L. Wang and T. F. Wong, Phys. Rev. D $\underline{5}$, 1667 (1972)

$pp \rightarrow K^- X$
 $p_{INC} = 19.2 \text{ GeV/c}$

$PP + K^- X$
 $P_{INC} = 19.2 \text{ GeV}/c$

Plot of $\frac{1}{\pi} \frac{d\sigma}{dtd(M_X^2/S)}$ vs. $\ln \frac{1}{M_X^2} (S' \equiv M_X^2)$

Data is taken from J. V. Allaby et al., CERN report 70-12
(23 April 1970), High Energy Particle Spectra from Proton
Interactions at 19.2 GeV/c.

M.-S. Chen, L.-L. Wang and T. F. Wong, Phys. Rev. D $\underline{5}$, 1667 (1972)

$$pp \rightarrow \pi^+ X$$

$$p_{INC} = 19.2 \text{ GeV}/c$$

$$pp \rightarrow \pi^+ X$$

$$p_{INC} = 19.2 \text{ GeV}/c$$

Plot of $\frac{1}{\pi} \frac{d\sigma}{dt dM_X^2} \frac{1}{S}$ vs. $\ln \frac{1}{M_X^2}$ ($s' \equiv M_X^2$)

Data is taken from J. V. Allaby et al., CERN report 70-12
(23 April 1970), High Energy Particle Spectra from Proton
Interactions at 19.2 GeV/c.

M.-S. Chen, L.-L. Wang and T. F. Wong, Phys. Rev. D 5, 1667 (1972)

$pp \rightarrow pX$ $P_{INC} = 19.20 \text{ GeV}/c$

$d\sigma/dt dM_X^2$ plotted against the momentum transfer t (for fixed missing mass $M_X = M$)

The data is from J. V. Allaby et al., CERN report 70-12 (23 April 1970),
High Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

C. Risk, Phys. Rev. D₅, 1685 (1972)

XBL715-3622

$pp \rightarrow \pi^- X$ $P_{INC} = 19.20 \text{ GeV}/c$

$d\sigma/dtdM_X^2$ plotted against the momentum transfer t (for fixed missing mass $M_X = M$)

The data is from J. V. Allaby et al., CERN report 70-12 (23 April 1970),
High Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

C. Risk, Phys. Rev. D5, 1685 (1972)

$pp \rightarrow \pi^+ X$ $P_{INC} = 19.20 \text{ GeV}/c$

$d\sigma/dt dM_X^2$ plotted against the momentum transfer t (for fixed missing mass $M_X = M$)

The data is from J. V. Allaby et al., CERN report 70-12 (23 April 1970),
High Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

C. Risk, Phys. Rev. D 5, 1685 (1972)

$p p \rightarrow K^+ X$

$p_{\text{INC}} = 19.20 \text{ GeV}/c$

$pp \rightarrow K^+ X$ $P_{INC} = 19.20 \text{ GeV}/c$

$d\sigma/dt dM_X^2$ plotted against the momentum transfer t (for fixed missing mass $M_X = M$)

The data is from J. V. Allaby et al., CERN report 70-12 (23 April 1970),
High Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

C. Risk, Phys. Rev. D 5, 1685 (1972)

pp $\rightarrow$ pXp_{INC} = 19, 29 GeV/cp + p $\rightarrow$ p + X

CERN-BNL

pp → pX

P_{INC} = 19, 29 GeV/c

Lorentz invariant cross section as a function of s'/s , for indicated values of four-momentum transfer t . Note that s' is the missing mass squared (M_X^2).

Data used are 19 GeV/c of Allaby et al., and 29 GeV/c of Anderson et al.

T. F. Wong, Test of Factorization in $\pi^- p \rightarrow pX$ and $pp \rightarrow pX$ Near the Kinematical Limit, preprint Rutgers Univ. (1972)

$pp \rightarrow K^+ X, pBe \rightarrow K^+ X$
 $p_{INC} = 18.8, 23.1 \text{ GeV}/c$

$pp \rightarrow K^+ X, p\bar{p} \rightarrow K^+ X$

$p_{INC} = 18.8, 23.1 \text{ GeV}/c$

The spectrum $(d\sigma/dpd\Omega)^{LAB}$ vs. p^{LAB} (for $f' = 0$ and $\theta^{LAB} = 0, 100 \text{ mrad.}$)
of the K^+ produced in (a) p-p collisions, (b) $p\bar{p}$ collisions.

D. Dekkers, J. A. Geibel, R. Mermod, G. Weber, T. R. Willitts,
K. Winter, B. Jordan, M. Vivargent, N. M. King and E. J. N. Wilson,
Phys. Rev. 137, B962 (1965)

-CERN proton synchrotron; counter experiment; tabulated data provided

$pp \rightarrow \pi^+ X, p\bar{p}e \rightarrow \pi^- X$
 $P_{INC} = 18.8, 23.1 \text{ GeV}/c$

$pp \rightarrow \pi^- X, p\bar{p} \rightarrow \pi^- X$

$p_{INC} = 18.8, 23.1 \text{ GeV}/c$

The spectrum $(d\sigma/dp d\Omega)^{LAB}$ vs. p^{LAB} (for fixed $\theta^{LAB} = 0, 100 \text{ mrad.}$)
of the π^- produced in (a) p-p collisions, (b) $p\bar{p}$ collisions

D. Dekkers, J. A. Geibel, R. Mermod, G. Weber, T. R. Willits,
K. Winter, B. Jordan, M. Vivargent, N. M. King and E. J. N. Wilson,
Phys. Rev. 137, B962 (1965)

-CERN proton synchrotron; counter experiment; tabulated data provided

$pp \rightarrow K^- X, pBe \rightarrow K^- X$
 $p_{\text{INC}} = 18.8, 23.1 \text{ GeV/c}$

$pp \rightarrow K^- X, p\bar{p}e \rightarrow K^- X$
 $p_{INC} = 18.8, 23.1 \text{ GeV}/c$

The spectrum $(d\sigma/dpd\Omega)^{LAB}$ vs. p^{LAB} (for fixed $\theta^{LAB} = 0, 100 \text{ mrad.}$)
of the K^- produced in (a) p - p collisions, (b) $p\bar{p}e$ collisions

D. Dekkers, J. A. Geibel, R. Mermod, G. Weber, T. R. Willitts,
K. Winter, B. Jordan, M. Vivargent, N. M. King and E. J. N. Wilson,
Phys. Rev. 137, B962 (1965)

-CERN proton synchrotron; counter experiment; tabulated data provided

$$p p \rightarrow \pi^+ X, pBe \rightarrow \pi^+ X$$

$$P_{INC} = 11.8, 18.8, 23.1 \text{ GeV}/c$$

(b)

(a)

$pp \rightarrow \pi^+ X, p\bar{p}e \rightarrow \pi^+ X$

$p_{INC} = 11.8, 18.8, 23.1 \text{ GeV}/c$

The spectrum $(d\sigma/dpd\Omega)^{LAB}$ vs. p^{LAB} (for fixed $\theta^{LAB} = 0, 100 \text{ mrad.}$)
of the π^+ produced in (a) p-p collisions, (b) p $\bar{p}e$ collisions

D. Dekkers, J. A. Geibel, R. Mermod, G. Weber, T. R. Willitts,
K. Winter, B. Jordan, M. Vivargent, P. M. King and E. J. N. Wilson,
Phys. Rev. 137, B962 (1965)

-CERN proton synchrotron; counter experiment; tabulated data provided

$pp \rightarrow pX, pBe \rightarrow pX$
 $p_{INC} = 11.8, 18.0, 23.1 \text{ GeV}/c$

$pp \rightarrow pX, pBe \rightarrow pX$ $P_{INC} = 11.8, 18.8, 23.1 \text{ GeV/c}$

The spectrum $(d\sigma/dpd\Omega)^{LAB}$ vs. p^{LAB} (for fixed $\theta^{LAB} = 0, 100 \text{ mrad.}$)
of the p produced in (a) p - p collisions, (b) pBe collisions

D. Dekkers, J. A. Geibel, R. Mermod, G. Weber, T. R. Willitts,
K. Winter, B. Jordan, M. Vivargent, N. M. King and E. J. N. Wilson,
Phys. Rev. 137, B962 (1965)

-CERN proton synchrotron; counter experiment; tabulated data provided

pp, pBe, pPb + $\bar{p}X$ $p_{INC} = 23.1 \text{ GeV}/c$

pp, pBe, pPb + $\bar{p}X$

$P_{INC} = 23.1 \text{ GeV}/c$

The number $(dN/dpd\Omega)^{LAB}$ of $\bar{p}$ produced per interaction vs. p^{LAB}
 ($\theta^{LAB} = 0, 100 \text{ mrad.}$) using hydrogen, beryllium, and lead targets.

D. Dekkers, J. A. Geibel, R. Mermod, G. Weber, T. R. Willitts, K. Winter,
 B. Jordan, M. Vivargent, N. M. King and E. J. N. Wilson, CERN-Orsay-
 Rutherford, Phys. Rev. 137, B962 (1965)

-CERN proton synchrotron; counter experiment; tabulated data

$p\bar{p} \rightarrow D\bar{X}$
 $p_{\text{INC}} = 21.1 \text{ GeV}/c$

pp + DX

 $P_{INC} = 21.1 \text{ GeV}/c$

$(d\sigma/dpd\Omega)^{LAB}$ vs. P^{LAB} for the deuteron. ($\theta^{LAB} = 40 \text{ mrad.}$)

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning,
R. Meunier, J. P. Peigneux, E. J. Sacharidis, K. Schlüpmann,
M. Spighele, J. P. Stroot, A. M. Thorndike and A. M. Wetherell,
Physics Letters 29B, 198 (1969)

pp $\rightarrow$ DX $p_{INC} = 21.12 \text{ GeV/c}$

40 mrad (LAB)

pp $\rightarrow$ DX $p_{INC} = 21.12 \text{ GeV/c}$

$(d\sigma/dp d\Omega)^{LAB}$ for deuterons vs. p^{LAB} ($\theta^{LAB} = 40 \text{ mrad.}$)

The crossed points give the empty target background; the dashed line is a hand-drawn fit to the continuum. The inset shows the spectrum after subtraction of the continuum.

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier,
J. P. Peigneux, E. J. Sacharidis, K. Schlüpman, M. Spighel, J. P. Stroot,
A. M. Thorndike and A. M. Wetherell, Physics Letters 29B, 198 (1969)

-CERN proton synchrotron; counter experiment

pp + γ X $P_{INC} = 23.1 \text{ GeV}/c$

$pp \rightarrow \gamma X$ $p_{INC} = 23.1 \text{ GeV}/c$

The plots give $d\sigma/dp d\Omega$ vs. E_γ (at fixed θ) for produced photons, in the CM system and the lab. system.

γ s were detected with a high-energy telescope, and their energy measured with a total absorption, lead glass Cerenkov counter.

M. Fidecaro, G. Finocchiaro, G. Gatti, G. Giacomelli, W. C. Middelkoop and t. Yamagata, Nuovo Cimento 34, 1277 (1962)

$pp \rightarrow \pi^0 X$ $p_{INC} = 23.1 \text{ GeV/c}$

$pp \rightarrow \pi^0 X$ $p_{INC} = 23.1 \text{ GeV/c}$ $(d\sigma/dp d\Omega)^{LAB}$ for π^0 production vs. p^{LAB} (for $\theta^{LAB} = 1.75^\circ, 3^\circ, 6^\circ, 10^\circ, 16^\circ, 27^\circ$),

derived from measured spectra for $pp \rightarrow \gamma X$, assuming $\pi^0 \rightarrow \gamma\gamma$. The expected error $\lesssim 30\%$ for $p^{LAB} > 2 \text{ GeV/c}$.

The dashed curves are predictions for $pp \rightarrow \pi^0 X$ at $p_{INC} = 25 \text{ GeV/c}$ from the statistical model of R. Hagedorn, Nuovo Cimento 15, 434 (1960).

M. Fidecaro, G. Finocchiaro, G. Gatti, G. Giacomelli, W. C. Middelkoop
and T. Yamagata, Nuovo Cimento 24, 1277 (1962)

-CERN proton synchrotron; lead glass total absorption $\checkmark$ Cerenkov counter
and γ -telescope

$p\bar{p} + \gamma X$ $P_{INC} = 23.1 \text{ GeV}/c$

pp + γ X $p_{INC} = 23.1 \text{ GeV}/c$

Left: Spectra $(d\sigma/dpd\Omega)^{CM}$ vs. E_Y^{CM} of the produced photons
 (θ^{CM}_{fixed})

- $\theta^{CM} = 21.5^\circ$
- △ $\theta^{CM} = 21.3^\circ$
- ▲ $\theta^{CM} = 41.1^\circ$
- + $\theta^{CM} = 64.1^\circ$
- $\theta^{CM} = 90.3^\circ$
- $\theta^{CM} = 119.1^\circ$

Right: Spectra $(d\sigma/dpd\Omega)^{CM}$ vs. θ^{CM} of the produced photons
 ($E^{CM}_{fixed} = 0.2, 0.4, 0.6, 0.8, 1.0, 1.2 \text{ GeV}$)

M. Fidecaro, G. Finocchiaro, G. Gatti, G. Giacomelli, W. C. Middelkoop
 and T. Yamagata, Nuovo Cimento 24, 1277 (1962)

$pp \rightarrow pX$ $P_{INC} = 24 \text{ GeV}/c$

$d\sigma/dtdM_X$ vs. missing mass M_X for several values of

$$\theta^{LAB} = 15, 27, 57, 107 \text{ mrad.}$$

$$(|t| = 0.1, 0.4, 1.8, 6 \text{ GeV}^2)$$

U. Amaldi, R. Biancastelli, C. Bosio, G. Matthiae, J. V. Allaby, A. N. Diddens,
 R. W. Robinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlupmann and
 A. M. Wetherell, Physics Letters 34B, 435 (1971)

-CERN, counter experiment

pp + π[±]X

P_{INC} = 13, 18, 21, 24, 28 GeV/c

pp $\rightarrow$ pX $P_{INC} = 24 \text{ GeV/c}$

The spectrum $d\sigma/dtdM_X$ vs. missing mass M_X for fixed scattering angles

$$\theta^{LAB} = 15.1 + 112.0 \text{ mrad.}$$

The data is from U. Amaldi, R. Biancastelli, C. Bosio, G. Mathiae, J. V. Allaby, A. N. Diddens, R. W. Dolinson, A. Klovning, J. LiH, L. S. Rochester, K. Schlupmann and A. M. Wetherell, Physics Letters 34B, 435 (1971)

O. Koefoed-Hansen, Nuclear Physics B39, 61 (1972)

pp + pX

 $p_{\text{INC}} = 24 \text{ GeV}/c$

pp + pX

 $P_{INC} = 24 \text{ GeV/c}$

Invariant cross section $\frac{\sqrt{s(s - 4m_p^2)}}{\pi} \frac{d\sigma}{dt dM_X^2}$ vs. momentum transfer t (for fixed missing mass M_X), and vs. $\left(\frac{M_X}{\sqrt{s} - m_p}\right)^2$, for fixed momentum transfer t .

The data are interpolated.

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlupmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

$$pp \rightarrow \pi^+ X$$

$$E \frac{d\sigma}{d^3p} \text{ vs. } p_{\perp}, \text{ for fixed } x \equiv p_{\parallel}^{\text{CM}}/p_{\text{MAX}}^{\text{CM}} = 0.28$$

Sources for the data are:

$p_{\text{INC}} = 12.5 \text{ GeV/c}$	C. W. Akerlof et al., Phys. Rev. <u>D3</u> , 645 (1971)
$p_{\text{INC}} = 19.2 \text{ GeV/c}$	H. Bøggild et al., Nucl. Phys. <u>B27</u> , 1 (1971)
$p_{\text{INC}} = 19.2, 24 \text{ GeV/c}$	J. V. Allaby et al., CERN Report 70-12 (April 1970) and Oxford Conference Report (April 1972)
$p_{\text{INC}} = 29.7 \text{ GeV/c}$	E. W. Anderson et al., Phys. Rev. Letters <u>19</u> , 198 (1967)

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt,
L. S. Rochester, K. Schlöppmann, A. M. Wetherell, U. Amaldi,
R. Biancastelli, C. Bosio and G. Mathiae, CERN-Rome collaboration,
"Comparison of Momentum Spectra of Secondary Particles Produced in
Proton-Proton Collisions at 14.2, 19.2 and 24 GeV/c," Report at The
Fourth International Conference on High-Energy Collisions, Oxford
(April 1972)

$P_{INC} = 24 \text{ GeV}/c$

$pp \rightarrow p^+ X$
 $pp \rightarrow K^+ X$

$$pp \rightarrow p^{\pm} X$$

$$pp \rightarrow K^{\pm} X$$

$$p_{INC} = 24 \text{ GeV/c}$$

A comparison of the invariant spectra $E \frac{d\sigma}{d^3p}$ vs.

$p_{\perp}$ ($x = p_{\perp}^{CM}/p_{MAX}^{CM}$ fixed) at several incident momenta.

Sources for data are:

$$p_{INC} = 3.67 \text{ GeV/c}$$

J. T. Reed et al., Phys. Rev.

166, 1472 (1968)

$$p_{INC} = 3.70, 3.86 \text{ GeV/c}$$

W. J. Hogan et al., Phys. Rev.

168, 1495 (1968)

$$p_{INC} = 12.5 \text{ GeV/c}$$

C. W. Akerlof et al., Phys. Rev.

D3, 645 (1971)

$$p_{INC} = 14.25, 19.2, 24 \text{ GeV/c}$$

J. V. Allaby et al., Oxford

Conference report (April 1972)

$$p_{INC} = 19.2 \text{ GeV/c}$$

J. V. Allaby et al., CERN report

70-12 (April 1970)

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

pp + K⁻Xp_{INC} = 24 GeV/c

$pp \rightarrow K^- X$
 $P_{INC} = 24 \text{ GeV}/c$

$$E \frac{d\sigma}{d^3p} \text{ vs. } p_{\perp} \text{ (for fixed } p_{||}^{CM})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester,
 K. Schlöpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and
 G. Matthiae, CERN-Rome collaboration report at the Fourth International
 Conference on High-Energy Collisions (Oxford, April 1972), Comparison of
 Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions
 at 14.2, 19.2, 24 GeV/c

pp + $\bar{p}X$ $p_{INC} = 24 \text{ GeV}/c$

$pp + \bar{p}X$ $P_{INC} = 24 \text{ GeV/c}$

$$E \frac{d\sigma}{d^3p} \text{ vs. } p_{\perp} \text{ (for fixed } p_{||}^{CM})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester,
 K. Schlöppmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and
 G. Matthiae, CERN-Rome collaboration report at the Fourth International
 Conference on High-Energy Collisions (Oxford, April 1972), Comparison of
Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions
at 14.2, 19.2, 24 GeV/c

$pp \rightarrow \pi^- X$
 $p_{TNC} = 24 \text{ GeV}/c$

$pp + \pi^- X$ $p_{INC} = 24 \text{ GeV}/c$

$$E \frac{d\sigma}{d^3p} \text{ vs. } p_{\perp} \text{ (for fixed } p_{||}^{CM})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester,
 K. Schlupmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and
 G. Matthiae, CERN-Rome collaboration report at the Fourth International
 Conference on High-Energy Collisions (Oxford, April 1972), Comparison of
 Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions
 at 14.2, 19.2, 24 GeV/c

$pp \rightarrow \pi^- X$ $p_{INC} = 6.6 \text{ GeV/c}$

(top) $E \frac{d^3\sigma}{dp^3}$ vs. y^{LAB} for various intervals in $p_{\perp}^2$

(lower left) $E \frac{d^3\sigma}{dp^3}$ vs. x for various intervals in $p_{\perp}^2$

(lower right) $\frac{d^2\sigma}{dp_{\perp} dp_{||}^{LAB}}$ vs. $p_{||}^{LAB}$ for various intervals in $p_{\perp}^2$

Note that in the three figures the 6.6 GeV/c data are compared to 12.4 GeV/c pp data of Akerlof et al. [Phys. Rev. D3, 645 (1971)]. A broken line joins points having $|x| = 0.489$.

Eugene Gellert, The Inclusive Reaction $pp \rightarrow \pi^- + \text{Anything}$ at 6.6 GeV/c Compared to Higher Energies, Lawrence Radiation Laboratory preprint 784 (1972)

$pp \rightarrow K^+ X$
 $p_{INC} = 24 \text{ GeV}/c$

$$E \frac{d\sigma}{d^3p} \text{ vs. } p_{\perp} \text{ (for fixed } p_{||}^{CM})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

$p \rightarrow \pi^+ X$
 $p_{\text{INC}} = 24 \text{ GeV}/c$

$$pp \rightarrow \pi^+ X$$

$$p_{INC} \approx 24 \text{ GeV}/c$$

$$E \frac{d\sigma}{d^3p} \text{ vs. } p_{\perp} \text{ (for fixed } p_{||}^{CM})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

pp → pX

 $p_{\text{INC}} = 24 \text{ GeV}/c$

$p\bar{p} + pX$ $P_{INC} = 24 \text{ GeV}/c$

$$E \frac{d\sigma}{d^3p} \text{ vs. } p_{\perp} \text{ (for fixed } p_{||}^{CM})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester,
 K. Schlupmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and
 G. Matthiae, CERN-Rome collaboration report at the Fourth International
 Conference on High-Energy Collisions (Oxford, April 1972), Comparison of
Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions
at 14.2, 19.2, 24 GeV/c

$$pp \rightarrow \pi^{\pm} X$$

$$p_{INC} = 24 \text{ GeV}/c$$

A comparison of the invariant spectra $E \frac{d\sigma}{d^3p}$ vs. $x =$

$\frac{P_{||}^{CM}}{P_{MAX}^{CM}}$ ($p_{\perp}$ fixed) at several incident momenta.

The sources for the data are:

$p_{INC} = 3.67 \text{ GeV}/c$	A. C. Melissinos et al., Phys. Rev. <u>128</u> , 2373 (1962)
$p_{INC} = 12.5 \text{ GeV}/c$	C. W. Akerlof et al., Phys. Rev. D <u>3</u> , 645 (1971)
$p_{INC} = 19.2 \text{ GeV}/c$	H. Baggild et al., Nucl. Phys. B <u>27</u> , 285 (1971)
$p_{INC} = 19.2 \text{ GeV}/c$	J. V. Allaby et al., CERN report 70-12 (April 1970)
$p_{INC} = 24 \text{ GeV}/c$	J. V. Allaby et al., Oxford conference report (April 1972)
$p_{INC} = 29.7 \text{ GeV}/c$	E. W. Anderson et al., Phys. Rev. Letters <u>19</u> , 198 (1967)

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2 24 GeV/c

$pp \rightarrow K^+ X$
 $P_{INC} = 24 \text{ GeV}/c$

A comparison of the invariant spectra $E \frac{d\sigma}{d^3p}$ vs. $x =$

$P_{||}^{CM}/P_{MAX}^{CM}$ ($P_{\perp}$ fixed) at several incident momenta .

Sources for the data are:

 $P_{INC} = 3.67 \text{ GeV}/c$

J. T. Reed et al., Phys. Rev.
166, 1472 (1958)

 $P_{INC} = 3.70, 3.86 \text{ GeV}/c$

W. J. Hogan et al., Phys. Rev.
168, 1495 (1968)

 $P_{INC} = 12.5 \text{ GeV}/c$

C. W. Akerlof et al., Phys. Rev.
D3, 645 (1971)

 $P_{INC} = 14.25, 19.2, 24 \text{ GeV}/c$

J. V. Allaby et al., Oxford
Conference report (April 1972)

 $P_{INC} = 19.2 \text{ GeV}/c$

J. V. Allaby et al., CERN report
70-12 (April 1970)

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt,
L. S. Rochester, K. Schlupmann, A. M. Wetherell, U. Amaldi, R. Biancastelli,
C. Bosio and G. Matthiae, CERN-Rome collaboration report at the
Fourth International Conference on High-Energy Collisions (Oxford,
April 1972), Comparison of Momentum Spectra of Secondary Particles
Produced in Proton-Proton Collisions at 14.2, 19.2 24 GeV/c

$$p\bar{p} + pX, \bar{p}X$$

$$p_{INC} = 24 \text{ GeV}/c$$

$pp \rightarrow pX, \bar{p}X$

$$P_{INC} = 24 \text{ GeV}/c$$

A comparison of the invariant spectra $E \frac{d\sigma}{d^3p}$ vs. $x = p_{||}^{CM}/P_{MAX}^{CM}$

($p_{\perp}$ fixed) at several incident momenta.

The sources for the data are:

$$P_{INC} = 6 \text{ GeV}/c$$

M. A. Abolins et al.,

Phys. Rev. Letters 25, 126 (1970)

$$P_{INC} = 12.5 \text{ GeV}/c$$

C. W. Akerlof et al., Phys. Rev.

D3, 645 (1971)

$$P_{INC} = 9.9, 20, 24.7 \text{ GeV}/c$$

E. W. Anderson et al., Phys. Rev.

Letters 19, 198 (1967)

$$P_{INC} = 19.2$$

J. V. Allaby et al., CERN report

70-12 (April 1970)

$$P_{INC} = 14.25, 19.2, 24 \text{ GeV}/c$$

J. V. Allaby et al., Oxford

Conference report (April 1972)

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlupmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2 24 GeV/c

$p\bar{p} \rightarrow \pi^- X$ $p_{\text{INC}} = 24 \text{ GeV}/c$

$pp \rightarrow \pi^- X$ $p_{INC} = 24 \text{ GeV}/c$

$$E \frac{d\sigma}{d^3p} \text{ vs. } x \equiv p_{||}^{CM}/p_{MAX}^{CM} \text{ (for fixed } p_{\perp})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester,
 K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and
 G. Matthias, CERN-Rome collaboration report at the Fourth International
 Conference on High-Energy Collisions (Oxford, April 1972), Comparison of
Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions
at 14.2, 19.2, 24 GeV/c

$PP \rightarrow K^+ X$
 $p_{INC} = 24 \text{ GeV}/c$

$pp \rightarrow K^+ X$ $p_{INC} = 24 \text{ GeV}/c$

$$E \frac{d\sigma}{d^3p} \text{ vs. } x \equiv p_{||}^{CM}/p_{MAX}^{CM} \text{ (for fixed } p_{\perp})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlöpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

$pp \rightarrow \pi^+ X$
 $p_{INC} = 24 \text{ GeV}/c$

$$pp \rightarrow \pi^+ X$$

$$P_{INC} = 24 \text{ GeV}/c$$

$$E \frac{d\sigma}{d^3p} \text{ vs. } x \equiv P_{||}^{CM} / P_{MAX}^{CM} \text{ (for fixed } p_{\perp})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

$pp \rightarrow K^- X$ $p_{\text{INC}} = 24 \text{ GeV}/c$

$pp \rightarrow K^- X$ $p_{INC} = 24 \text{ GeV}/c$

$$E \frac{d\sigma}{d^3p} \text{ vs. } x \equiv p_{||}^{CM}/p_{MAX}^{CM} \text{ (for fixed } p_{\perp})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester,
 K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosic and
 G. Matthiae, CERN-Rome collaboration report at the Fourth International
 Conference on High-Energy Collisions (Oxford, April 1972), Comparison of
Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions
at 14.2, 19.2, 24 GeV/c

pp $\rightarrow$ pX $p_{\text{INC}} = 24 \text{ GeV}/c$

pp → pX

$$p_{\text{INC}} = 24 \text{ GeV}/c$$

$$E \frac{d\sigma}{d^3p} \text{ vs. } x \equiv p_{||}^{\text{CM}}/p_{\text{MAX}}^{\text{CM}} \text{ (for fixed } p_{\perp})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlömann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

pp + $\bar{p}X$ $p_{THC} = 24 \text{ GeV}/c$

$pp \rightarrow \bar{p}X$ $p_{INC} = 24 \text{ GeV}/c$

$$E \frac{d\sigma}{d^3p} \text{ vs. } x \approx p_{||}^{CM}/p_{MAX}^{CM} \text{ (for fixed } p_{\perp})$$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

PP $\rightarrow$ pX $P_{INC} = 14.25, 19.2, 24 \text{ GeV/c}$

pp → pX

 $P_{INC} = 14.25, 19.2, 24 \text{ GeV/c}$

Plot of the normalized invariant cross-section $\frac{2E}{\sigma_{TOTAL}} \frac{d\sigma}{d^3p}$ vs. $x \approx$

$\frac{P_{||}^{CM}}{P_{MAX}^{CM}}$ for protons observed at several incident momenta.

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpman, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio, G. Matthiae and CERN-Rome collaboration, report at the Helsinki Colloquium on Multiparticle Dynamics (May 1971), Comparison of Momentum Spectra of Secondary Particles Produced in 14.25, 19.2, and 24 GeV/c pp Collisions

$p_{INC} = 12.5, 19.2, 30, 70 \text{ GeV}/c$
 $pp \rightarrow \pi^+ \pi^-$

pp → π⁻Xp_{INC} = 12.5, 19.2, 30, 70 GeV/c

Comparison of the invariant spectra

$$\rho \equiv \frac{2E}{\sigma_{\text{TOTAL}}(s)} \frac{d\sigma}{d^3p} \quad \text{vs.} \quad x \equiv \frac{\frac{p_{||}}{p_{\text{INC}}}}{\frac{p_{||}}{p_{\text{CM}}}} \quad \text{at } p_{\perp} = 0.$$

The CERN-Rome data is extrapolated from larger p_⊥, assuming ρ ∝ e^{-9p_⊥²}, and combined with the Scandinavian collaboration data to give a complete spectrum at p_{INC} = 19.2 GeV/c.

Data sources are:

- p_{INC} = 12.5 GeV/c C. W. Akerlof et al., Phys. Rev. D3, 645 (1971)
 - p_{INC} = 19.2 GeV/c H. Bøggild et al., Nucl. Phys. B27, 1 (1971)
 - p_{INC} = 19.2 GeV/c J. V. Allaby et al., CERN Report 70-12 (1970)
 - p_{INC} = 30 GeV/c E. W. Anderson et al., Phys. Rev. Letters 19, 198 (1967)
 - Δ p_{INC} ~ 70 GeV/c Yu. B. Bushnina et al., Physics Letters 29B, 48 (1969)
- (This p-Al data is divided by A^{2/3} = 9)

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpman, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration, "Comparison of Momentum Spectra of Secondary Particles Produced in 14.25, 19.2 and 24 GeV/c pp Collisions," Report at The Amsterdam International Conference on High Energy Physics (June 1971)

$pp \rightarrow \pi^- X$

$P_{INC} = 19, 19.2, 30 \text{ GeV}/c$

The invariant distribution $\rho \equiv \frac{2E}{\text{TOTAL}(s)} \frac{d\sigma}{d^3p}$ vs.

$P_{||}^{\text{LAB}}$ for $p_{\perp} = 0$

Data is extrapolated from larger $p_{\perp}$, assuming $\rho \propto p_{\perp}^{-2}$. The dotted curve for $pp \rightarrow \pi^+ X$ may be compared with the solid curves for $pp \rightarrow \pi^- X$.

Sources for the data are:

$P_{INC} = 19 \text{ GeV}/c$	H. Bøggild et al., Nucl. Phys. B27, 1 (1971)
$P_{INC} = 19.2 \text{ GeV}/c$	J. V. Allaby et al., CERN Report 70-12 (April 1970) and
Amsterdam Conference Report
$P_{INC} = 30 \text{ GeV}/c$	E. W. Anderson et al., Phys. Rev. Letters 19,
198 (1967)

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt,
L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli,
C. Bosio and G. Matthiae, CERN-Rome collaboration, "Comparison of
Momentum Spectra of Secondary Particles Produced in 14.25, 19.2 and
24 GeV/c pp Collisions," Report at The Amsterdam International
Conference on High Energy Physics (June 1971)

$pp \rightarrow \pi^+ X$ $p_{\text{INC}} = 14.25, 24.04 \text{ GeV/c}$

$$\rho \equiv \frac{1}{\sigma_{\text{TOTAL}}(\text{s})} \cdot 2E \frac{d\sigma}{d^3p} \quad \text{vs.} \quad x \equiv \frac{p_{\parallel}^{\text{CM}}}{p_{\text{INC}}^{\text{CM}}} \quad \text{for } p_{\perp} = 0.1 \text{ GeV/c}$$

The data is interpolated to $p_{\perp} = 0.1$ for fixed θ^{LAB} data, assuming $\rho \propto p_{\perp}^{-2}$

The location of π^+ from the decays of $N^*(1236)$, $N^*(1690)$, and $N^*(2190)$ is shown, as well as the peak from $pp \rightarrow \pi^+ d$.

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlupmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration, "Comparison of Momentum Spectra of Secondary Particles Produced in 14.25, 19.2 and 24 GeV/c pp Collisions," Report at The Amsterdam International Conference on High Energy Physics (June 1971)

$pp \rightarrow \pi^+ X$

$P_{TNC} = 14.25, 19.2, 24 \text{ GeV}/c$

261

pp $\rightarrow \pi^+ X$

$p_{INC} = 14.25, 19.2, 24 \text{ GeV/c}$

$$\rho \equiv \frac{2E}{\sigma_{TOTAL}(s)} \frac{d\sigma}{d^3p} \text{ vs. } p_{||}^{LAB}, \text{ for } p_{\perp} = 0.$$

Data is extrapolated to $p_{\perp} = 0$ from larger $p_{\perp}$, assuming $\rho \propto e^{-9p_{\perp}^2}$

The location of π^+ from the decays of $N^*(1236)$, $N^*(1690)$ and $N^*(2190)$ is shown.

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpman, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio and G. Matthiae, CERN-Rome collaboration, "Comparison of Momentum Spectra of Secondary Particles Produced in 14.25, 19.2 and 24 GeV/c pp Collisions," Report at The Amsterdam International Conference on High Energy Physics (June 1971)

See also: J. V. Allaby et al., CERN Report 70-12 (April 1970)

$p_{INC} = 24.9, 28.6 \text{ GeV}/c$

$pp + V_0 X$
 $K_0 X$

$p\bar{n} \rightarrow \Lambda^0 X$
 $\quad \quad \quad + K^0 X$

$P_{INC} = 24.9, 28.6 \text{ GeV}/c$

$dN/dy^{CM} \text{ vs. } y^{CM}$

Shading indicates that the K^0 curve is above the Λ^0 curve;
 otherwise no shading occurs. Only Λ^0 and K^0 backward in the
 center of mass are plotted.

J. J. Lee, V^0 and $V^0\gamma$ Production in 24.9 GeV/c and 28.6 GeV/c Proton-
Proton Interactions, thesis, Rutgers Univ. (1971)

pp $\rightarrow \Lambda^0 X$
 $\rightarrow K^0 X$

$p_{INC} = 24.9, 28.6 \text{ GeV}/c$

$pp \rightarrow \Lambda^0 X$
 $\rightarrow K^0 X$

$P_{INC} = 24.9, 28.6 \text{ GeV/c}$

$$dN/dx \text{ vs. } x; \quad x = p_{||}^{CM}/E_{BEAM}^{CM}$$

Shading indicates that the K^0 curve is above the Λ^0 curve; otherwise no shading occurs. Only Λ^0 and K^0 backward in the center of mass are plotted.

J. J. Lee, V^0 and $V^0\gamma$ Production in 24.9 GeV/c and 28.6 GeV/c
Proton-Proton Interactions, thesis, Rutgers Univ. (1971)

pp + Λ^0 X
+ K^0 X

$P_{\text{INC}} = 24.9, 28.6 \text{ GeV}/c$

$pp \rightarrow \Lambda^0 X$
 $\rightarrow K^0 X$

$$P_{INC} = 24.9, 28.6 \text{ GeV}/c$$

$$dN/dp_{\perp}^2 \text{ vs. } p_{\perp}^2$$

Shading indicates that the K^0 curve is above the Λ^0 curve; otherwise no shading occurs. Only Λ^0 and K^0 backward in the center of mass are plotted.

J. J. Lee, V^0 and V^0_{γ} Production in 24.9 GeV/c and 28.6 GeV/c Proton-Proton Interactions, thesis, Rutgers Univ. (1971)

$pp \rightarrow \pi^- X$ $p_{\text{INC}} = 28.5 \text{ GeV}/c$

- (a) Fitted values of the parameters a , b , and c from the expression

$$E \frac{d^2\sigma}{dp^3} = a \exp(b|x| + cx^2), \text{ as a function of } p_{\perp}^2, \text{ for inclusive } \pi^-$$

production. ($x = p_{\parallel}^{\text{CM}}/p_{\text{MAX}}$)

- (b) Fitted values of the parameters a' , b' , c' , and d' from the

$$\text{expression } E \frac{d^3\sigma}{dp^3} = a'[\exp(b'p_{\perp}^2) + c' \exp(d'p_{\perp}^2)], \text{ as a function}$$

of x , for inclusive π^- production.

Note: All data are normalized to represent the cross section of one hemisphere.

W. H. Sims, J. Hanlon, E. O. Salant, R. S. Panvini, R. R. Kinsey, T. W. Morris and L. von Lindern, Pion Spectra from the Reaction $pp \rightarrow \pi^+ + \text{anything}$ at 28.5 GeV, Vanderbilt Univ. preprint (1972), to be published in Nucl. Phys. B.

pp $\rightarrow$ π^- X $p_{INC} = 28.5$

(a) The function $F(x) = \int_0^{\infty} \frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{\perp}^2} dp_{\perp}^2$ plotted against x for various multiplicities. The smooth curves are data fit to the function $F(x) = a \exp(b|x| + cx^2)$.

(b) The function $G(p_{\perp}^2) = \int_0^1 \frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{\perp}^2} dx$ plotted against $p_{\perp}^2$ for various multiplicities. The smooth curves are data fit to the function $G(p_{\perp}^2) = a'[\exp(b'p_{\perp}^2) + c' \exp(d'p_{\perp}^2)]$.

Note: All data are normalized to represent the cross section of one hemisphere.

W. H. Sims, J. Hanlon, E. O. Salant, R. S. Panvini, R. R. Kinsey, T. W. Morris and L. von Lindern, Pion Spectra from the Reactions pp $\rightarrow$ $\pi^{\pm}$ + anything at 28.5 GeV, Vanderbilt Univ. preprint (1972), to be published in Nucl. Phys. B

pp + $\pi^- X$ $p_{INC} = 28.5 \text{ GeV/c}$

(a) The function $H(y^{CM}) = \frac{1}{\pi} \int_{\alpha}^{\beta} \frac{d^2 \sigma}{dy^{CM} dp_{\perp}^2} dp_{\perp}^2$ plotted against y^{CM} for the intervals $\alpha \leq p_{\perp}^2 \leq \beta$ indicated in the figure. The smooth curves are fits to the function $H(y^{CM}) = A \exp(B|y^{CM}|) + C|y^{CM}|^2$.

(b) The function $K(p_{\perp}^2) = \frac{1}{\pi} \int_{\alpha}^{\beta} \frac{d^2 \sigma}{dy^{CM} dp_{\perp}^2} dy^{CM}$ plotted against $p_{\perp}^2$ for the intervals $\alpha \leq y^{CM} \leq \beta$, indicated in the figure. The smooth curves are fits to the function $K(p_{\perp}^2) = A'[\exp(B'p_{\perp}^2) + C' \exp(D'p_{\perp}^2)]$.

Note: All data are normalized to represent the cross section of one hemisphere.

W. H. Sims, J. Hanlon, E. O. Salant, R. S. Panvini, R. R. Kinsey, T. W. Morris and L. von Lindern, Pion Spectra from the Reaction pp + π^+ + anything at 28.5 GeV, Vanderbilt Univ. preprint (1972), to be published in Nucl. Phys. B.

$P_{INC} = 28.5 \text{ GeV/c}$

$pp + \pi^- X$

$pp \rightarrow \pi^- X$ $p_{INC} = 28.5 \text{ GeV}/c$

- (a) Fitted values of the parameters A, B, and C from the expression

$$E \frac{d^3\sigma}{dp^3} = A \exp(B|y^{CM}| + C|y^{CM}|^2), \text{ as a function of } p_{\perp}^2 \text{ for}$$

inclusive π^- production.

- (b) Fitted values of the parameters A', B', C', and D' from the

$$\text{expression } E \frac{d^3\sigma}{dp^3} = A' [\exp(B' p_{\perp}^2) + C' \exp(D' p_{\perp}^2)] \text{ as a function}$$

of y^{CM} for π^- production.

Note: All data are normalized to represent the cross section of
one hemisphere.

W. H. Sims, J. Manlon, E. O. Salant, R. S. Parvini, R. R. Kinsey, T. W. Morris
 and L. von Lindern, Pion Spectra from the Reaction $pp \rightarrow \pi^+ + \text{anything}$
at 28.5 GeV, Vanderbilt Univ. preprint (1972), to be published in
 Nucl. Phys. B.

$pp \rightarrow \pi^+ X$ $p_{INC} = 28.5 \text{ GeV}/c$

(a) The function $F(x) = \int_{\alpha}^{\beta} \frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{\perp}^2} dp_{\perp}^2$ plotted against x for the intervals $\alpha \leq x \leq \beta$, indicated in the figure. The smooth curves are fits to the function $F(x) = a \exp(b|x| + cx^2)$.

(b) The function $G(p_{\perp}^2) = \int_{\alpha}^{\beta} \frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{\perp}^2} dx$ plotted against $p_{\perp}^2$ for the intervals $\alpha \leq x \leq \beta$, indicated in the figure. The smooth curves are fits to the function $G(p_{\perp}^2) = a'[\exp(b'p_{\perp}^2) + c' \exp(d'p_{\perp}^2)]$.

Note: All data are normalized to represent the cross section of one hemisphere.

W. H. Sims, J. Hanlon, E. O. Salant, R. S. Panvini, R. R. Kinsey, T. W. Morris and L. von Linder, Pion Spectra from the Reaction $pp \rightarrow \pi^+ + \text{anything}$ at 28.5 GeV, Vanderbilt Univ. preprint (1972), to be published in Nucl. Phys. B

$pp \rightarrow \pi^+\chi$ $P_{INC} = 28.5 \text{ GeV}/c$

$pp \rightarrow \pi^{\pm} X$
 $P_{INC} = 28.5 \text{ GeV}/c$

$$E \frac{d^3\sigma}{dp^3} \text{ vs. } x, x = p_{||}^{CM}/p_{MAX}$$

The curves are fits to the data using a parameterization of the form:

$$E \frac{d^3\sigma}{dp^3} = A \exp(B|x| + Cx^2)$$

Comparisons are made with CERN-ISR data.

R. S. Panvini, R. R. Kinsey, T. W. Morris, J. Hanlon, E. O. Salant and
W. H. Sims, Physics Letters B38, 55 (1972)

pp + π^+ X

$P_{INC} = 28.5 \text{ GeV}/c$

$pp \rightarrow \pi^+ X$ $P_{INC} = 28.5 \text{ GeV}/c$

$$E \frac{d^3\sigma}{dp^3} \text{ vs. } y^{LAB}$$

The curves are parameterizations of the data. Comparisons are made with CERN-ISR data.

R. S. Panvini, R. R. Kinsey, T. W. Morris, J. Hanlon, E. O. Salant and
W. H. Sims, Physics Letters B38, 55 (1972)

$pp \rightarrow \pi^\pm X$ $P_{INC} = 28.5 \text{ GeV}/c$

$pp \rightarrow \pi^+ X$ $P_{INC} \approx 28.5 \text{ GeV}/c$

$$E \frac{d^3\sigma}{dp^3} \text{ vs. } p_{\perp}^2$$

The curves are fits to the data using a parameterization of the form:

$$E \frac{d^3\sigma}{dp^3} = A[\exp(Bp_{\perp}^2) + C \exp(Dp_{\perp}^2)].$$

Comparisons are made with CERN-ISR data.

R. S. Panvini, R. R. Kinsey, T. W. Morris, J. Hanlon, E. O. Salant and
W. H. Sims, Physics Letters, B38, 55 (1972)

$pp \rightarrow pX$ $P_{INC} = 29 \text{ GeV}/c$

pp + pX

 $p_{INC} = 29 \text{ GeV/c}$

$d^2\sigma/dM_X dt$ vs. $(-t)$ for pp + pX in various intervals of M_X .

The smooth curve and circles represent counter and bubble chamber data respectively. The solid and broken histograms show the bubble chamber measurements for the reactions $pp \rightarrow p(n\pi^+)$ and $pp \rightarrow p(p\pi^+\pi^-)$ respectively.

W. E. Ellis, R. R. Kinsey, T. W. Morris, R. S. Panvini and F. Turkot,
Physics Letters 32B, 641 (1970)

p Nucleon + charged particles

 $p_{INC} = 67 \text{ GeV/c}$

p Nucleon + charged particles

 $P_{INC} = 67 \text{ GeV/c}$

The angular distributions $dN/d\cos\theta^{CM}$ of charged particles produced in pp collisions (from emulsion measurements), for various numbers n_c of charged secondaries.

M. G. Antonova et al., Alma-Ata, Cracow, Dubna, Leningrad, Moscow, Tashkent, Ulan-Bator collaboration, Physics Letters 39B, 282 (1972)

-Serpukhov accelerator; emulsion data

See also : E. V. Anzon et al., Physics Letters 31B, 237 (1970)

M. G. Antonova et al., Physics Letters 39B, 285 (1972)

$pp \rightarrow \gamma X$ $\sqrt{s} = 6.7, 30.2, 44.7, 52.7 \text{ GeV}$

pp + γX $\sqrt{s} = 6.7, 30.2, 44.7, 52.7 \text{ GeV}$

Energy spectra $\frac{1}{\sigma_{\text{INELASTIC}}} (d\sigma/dk d\Omega)^{\text{CM}}$ for photons produced at $\theta^{\text{CM}} = 90^\circ$,

where k = photon energy in the CM system

G. Neuhofer, F. Niebergall, J. Penzias, M. Regler, K. R. Schubert,
P. E. Schumacher, W. Schmidt-Parzefall and K. Winter, Phys. Letters 37B,
438 (1971)

-ISR; counter experiment

4

$pp \rightarrow \gamma X$
 $\sqrt{s} = 30.2, 44.7, 52.7 \text{ GeV}$

$$\frac{1}{s_{\text{cm}}} \frac{d\sigma}{d\Omega} [\text{GeV}^{-1} \text{sr}^{-1}]$$

a)

b)

c)

pp + γ X $\sqrt{s} = 30.2, 44.7, 52.7$ GeV

Energy spectra $\frac{1}{\sigma_{\text{INEL.}}} \left(\frac{d\sigma}{dKd\Omega} \right)^{\text{CM}}$ of γ -rays vs.

K^{CM} ($\theta^{\text{CM}} = 10.2^\circ, 16.4^\circ, 23.5^\circ, 90^\circ$)

for CM energies $\sqrt{s} = 30.2, 44.7, 52.7$ GeV

G. Neuhofer, F. Niebergall, J. Penzias, M. Regler, W. Schmidt-Parzefall,
K. R. Schubert, P. E. Schumacher, M. Steuer and K. Winter, Physics
Letters 38B, 51 (1972)

See also: G. Neuhofer et al., Physics Letters 37B, 438 (1971)

$pp \rightarrow \gamma X$ $\sqrt{s} = 6.8, 30.2, 44.7, 52.7 \text{ GeV}$

pp $\rightarrow \gamma X$ $\sqrt{s} = 6.8, 30.2, 44.7, 52.7 \text{ GeV}$

$$\frac{1}{\sigma_{\text{INELASTIC}}} k \frac{d\sigma}{d^3k} \text{ vs. } x = \frac{2k_{\perp}^{\text{CM}}}{\sqrt{s}} \text{ (for fixed } k_{\perp})$$

at several CM energies.

Solid lines are interpolations

$$\frac{1}{\sigma_{\text{INELASTIC}}} k \frac{d\sigma}{d^3k} = \frac{1.48}{k_{\perp}} \exp\left(\frac{-k_{\perp}}{0.162}\right) \exp\left(\frac{-x}{0.083}\right),$$

in units of GeV.

G. Neuhofer, F. Niebergall, J. Penzias, M. Regler, W. Schmidt-Parzefall,
K. R. Schubert, P. E. Schumacher, M. Steuer and K. Winter, CERN-Hamburg-
Vienna collaboration, Physics Letters 38B, 51 (1972)

See also: Physics Letters 37B, 439 (1971)

-CERN ISR; counter experiment

$pp \rightarrow \pi^+ X$ $P_{TNC} = 225, 500, 1100, 1500 \text{ GeV}/c$

$pp \rightarrow \pi^- X$ $p_{INC} = 225, 500, 1100, 1500 \text{ GeV/c}$ Invariant cross-section $E \frac{d\sigma}{d^3p}$ plotted(a) vs. x ($p_{\perp}$ fixed = 0.2, 0.4, 0.8 GeV/c)(b) vs. $p_{\perp}^2$ (x fixed = 0.076, 0.151, 0.189),where $x = p_{\parallel}^{CM} / p_{MAX}^{CM}$

Solid lines are interpolations of the data from C. W. Akerlof et al., Phys. Rev. D 3, 645 (1971) ($p_{INC} = 12.5 \text{ GeV/c}$); J. V. Allaby et al., CERN report 70-12 (April 1970) and Oxford conference report (April 1972) ($p_{INC} = 14.2, 19.2, 24 \text{ GeV/c}$)

A. Bertin, P. Capilucci, A. Cristallini, M. D'Agostino-Bruno,
R. J. Ellis, G. Giacomelli, C. Maroni, F. Mercatali, A. M. Rossi
and G. Vannini, Phys. Letters 38B, 260 (1972)

-ISR; counter experiment

pp $\rightarrow$ cX $p_{\text{INC}} = 500, 1100, 1500 \text{ GeV}/c$

pp + cX

 $P_{INC} = 500, 1100, 1500 \text{ GeV/c}$

The ratios of invariant cross sections $E \frac{d\sigma}{d^3p}$ for π^+/π^- and

$\bar{p}/\pi^-$ plotted vs. $x = p_{||}^{CM}/P_{MAX}^{CM}$ ($p_{\perp} = 0.4 \text{ GeV/c}$)

Solid lines are interpolations of the data from J. V. Allaby et al.,
CERN-Rome collaboration, Oxford Conference report (April 1972)

A. Bertin, P. Capilucci, A. Cristallini, M. D'Agostino-Bruno,
R. J. Ellis, G. Giacomelli, C. Maroni, F. Mercatali, A. M. Rossi
and G. Vannini, Phys. Letters 38B, 260 (1972)

-ISR; counter experiment

$p\bar{p} \rightarrow pX, \pi^+X$
 $P_{\text{INC}} = 500, 1100, 1500 \text{ GeV}/c$

$pp \rightarrow pX, \pi^+ X$
 $P_{TNC} = 500, 1100, 1500 \text{ GeV}/c$

Invariant spectra $E \frac{d\sigma}{d^3p}$ plotted vs. $p_{\perp}^2$ [for $x = p_{\parallel}^{CM}/(p_{\parallel}^{CM})_{MAX}$ fixed]

L. G. Ratner, R. J. Ellis, G. Vannini, B. A. Babcock, A. D. Krisch
and J. B. Roberts report, Rochester conference on High Energy Physics
(31 August 1971)

-ISR; counter experiment

$pp \rightarrow (p, k^+, \pi^+)X$
 $P_{\text{INC}} = 500, 1100, 1500 \text{ GeV}/c$

$pp \rightarrow (p, K^+, \pi^+)X$

$P_{INC} = 500, 1100, 1500 \text{ GeV/c}$

Invariant spectra $E \frac{d\sigma}{d^3p}$ plotted vs. $x = p_{||}^{CM}/P_{MAX}^{CM}$ ($p_{\perp}$ fixed)

L. G. Ratner, R. J. Ellis, G. Vannini, B. A. Babcock, A. D. Krisch
and J. B. Roberts report, Rochester conference on High Energy Physics,
APS/DPF (31 August 1971)

-ISR; counter experiment

$p p \rightarrow (\pi^+, K^+, p) X$
 $p_{TINC} = 12, 500, 1500 \text{ GeV}/c$

$pp \rightarrow (\pi^+, K^+, p)X$
 $p_{INC} = 12, 500, 1500 \text{ GeV/c}$

 $\frac{E \frac{d\sigma}{d^3p}}{d^3p}$ plotted vs. $x = p_{||}^{CM}/p_{MAX}^{CM}$ [for fixed $p_{\perp}^2 = 0.16 \text{ (GeV/c)}^2$] and

 vs. $p_{\perp}^2$ (for $p_{||}^{CM} = 4 \text{ GeV/c}$)

L. G. Ratner, R. J. Ellis, G. Vannini, B. A. Babcock, A. D. Krisch and J. B. Roberts, Phys. Rev. Letters 27, 68 (1971), (ISR; Counter experiment)

pp → charged particles

 $\sqrt{s} = 30.2, 44.7, 52.7 \text{ GeV}$

pp $\rightarrow$ charged particles $\sqrt{s} = 30.2, 44.7, 52.7$ GeV

Distribution $dN/d\eta$ vs. $\eta = |\log \tan(\theta_{CM}/2)|$ for all charged particles observed in pp collisions. The angular distributions may be parametrized by $1/\sigma_{\text{INELASTIC}}(d\sigma/d\Omega)^{CM} = A(s)/(\sin\theta_{CM})^2$, where $A = 0.21 \pm 0.02, 0.25 \pm 0.025, 0.25 \pm 0.025$ (sr.) $^{-1}$ at $\sqrt{s} = 30.2, 44.7, 52.7$ GeV, respectively.

G. Barbiellini, M. Bozzo, P. Darriulat, G. Diambrini-Palazzi, G. DeZorzi, M. Holder, A. McFarland, G. Maderni, P. Mery, S. Orito, J. Pilcher, C. Rubbia, G. Sette, A. Staude, P. Strolin and K. Tittel, Phys. Letters 39B, 294 (1972), (ISR; Counter experiment)

pp + charged particles +

$P_{INC} = 1500 \text{ GeV/c}$

Plot of the center-of-mass angular distribution $d\sigma/d[\log \tan (\theta^{CM}/2)]$
for charged relativistic particles produced at angles $\theta^{CM} = 90^\circ, 67.1^\circ,$
 $44.8^\circ, 28.4^\circ$

The result is compared with the cosmic ray data of J. Gierula and W. Wolter,
Acta Physica Polonica B2, 95 (1971)

Bombay-CERN-Cracow collaboration, Phys. Letters 36B, 611 (1971)

-ISR; emulsion experiment

p - Cosmic ray collisions

 $E_{INC} = 203 \text{ GeV}$

p - Cosmic ray collisions

 $E_{INC} = 203 \text{ GeV}$

A modified Duller-Walker plot:

$\log_{10} \frac{F^2(\theta)}{1 - F^2(\theta)}$ vs. $\log_{10} \tan \theta_p$ for events with more (or less than) 6 charged particles, where $F(\theta) =$ fraction of particles with $\theta_p^{LAB} < \theta$, and $\tan \theta_p = \frac{p_{\perp}^{PROJECTED}}{p_{||}^{LAB}}$, with $p_{\perp}^{PROJECTED}$ = the transverse momentum of a secondary particle projected onto a fixed plane containing the beam-particle momentum. Isotropic C.M. distributions yield a straight line on this plot: N. M. Duller and W. D. Walker, Phys. Rev. 93, 215 (1954).

See also: L. W. Jones et al., University of Michigan reports UM HE 70-15; UM HE 71-46 (January 1972); Phys. Rev. Letters 25, 1679 (1970); Phys. Rev. Letters 26, 728 (1971); Phys. Letters 36B, 509 (1971)

D. E. Lyon, Jr., Report at the Symposium on High Energy Interactions and Multiparticle Production, Proton-Proton Interactions Between 90 and 800 GeV/c: Experimental Results from Echo Lake Cosmic Ray Studies, Argonne National Lab. Report ANL/HEP 7107 (November 1970)

p - Cosmic ray collisions

 $E_{INC} = 203 \text{ GeV}$

p - Cosmic ray collisions

 $E_{INC} = 203 \text{ GeV}$

The angular distribution $dN/d\eta$ of charged particles vs.

$n = \log_{10} \tan \theta_p$, where

$$\tan \theta_p = p_{\perp}^{PROJECTED} / p_{||}^{LAB}, \text{ and } p_{\perp}^{PROJECTED} =$$

the transverse momentum of a secondary particle projected onto a fixed plane containing the beam-particle momentum, for events with $\leq 6 (> 6)$ prongs.

See also: L. W. Jones et al., University of Michigan reports UM HE 71-15 (January 1972); Phys. Rev. Letters 25, 1679 (1970); Phys. Rev. Letters 26, 728 (1971); Phys. Letters 36B, 509 (1971)

L. W. Jones, A. E. Bussian, G. C. DeMeester, B. W. Loo, D. E. Lyon, Jr., P. V. Ramana Murthy, R. F. Roth, P. R. Vishwanath, J. G. Learned, D. D. Reeder, R. J. Wilkes, K. N. Erickson, F. E. Mills and Bruce Cork, University of Michigan UM HE 71-46 (January 1972), (Cosmic rays; ionization calorimeter; $E_{INC} \approx 100 \rightarrow 700 \text{ GeV}$)

$pp \rightarrow (\text{charged prongs})X$ $P_{\text{INC}} = 100 \text{ to } 1000 \text{ GeV/c}$

pp → (charged prongs)X

$P_{INC} = 100 \text{ to } 1000 \text{ GeV/c}$

$dN/d(\log_{10} \tan \theta_p)$ vs. $\log_{10} \tan \theta_p$

where θ_p is the projected prong angle.

Only events with three or more prongs

are included.

L. W. Jones et al., Michigan-Wisconsin-Colorado-BNL-ANL collaboration,
The Properties of Proton-Proton Interactions Between 100 and 1000 GeV
from a Cosmic Ray Experiment, UM-HE-71-46 (Revised) 1972

(cosmic rays)p + (charged particles)x
 pp + (charged particles)x

$P_{INC} \approx 10000 \text{ GeV/c}$

$P_{INC} \approx 28.5 \text{ GeV/c}$

(cosmic rays)p + (charged particles)X	$P_{INC} = \sim 10000 \text{ GeV/c}$
pp + (charged particles)X	$P_{INC} = 28.5 \text{ GeV/c}$

$$d\sigma/d[\log_{10}(\tan\theta_{LAB})] \text{ vs. } \log_{10}(\tan\theta_{LAB})$$

Note: $\log_{10}(\tan\theta_{LAB})$ is closely related to y^{LAB} (see Section III).

<u>P_{INC}(GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
1.35, 2.1, 2.9	Chadwick	PRL	<u>4</u> 611 (1960)	BNL-ROCH-CARN-AERE	CNTR
1.35, 2.1, 2.9	Chadwick	PR	<u>128</u> 1823 (1962)	BNL	CNTR
2.4, 2.85	Reed	PR	<u>168</u> 1495 (1968)	ROCH-BNL	CNTR
2.5 + 3.0	Hogan	PR	<u>166</u> 1472 (1968)	PRIN	CNTR
2.85 + 7.88	Blair	PRL	<u>17</u> 789 (1966)	AERE-QMCL-RHEL	CNTR
2.9	Melissinos	PRL	<u>7</u> 454 (1961)	ROCH-BNL	CNTR
3 + 7	Ankenbrandt	PR	<u>170</u> 1223 (1968)	LRL	CNTR
3.6, 11.8	Cocconi	PL	<u>8</u> 134 (1964)	CERN	CNTR
5.4, 6.6	Abolins	PRL	<u>25</u> 126 (1970)	MSU-LRL	HBC
6.6	Gellert	preprint LRL # 784		LRL	HBC
"The Inclusive Reaction pp + π ⁻ + Anything at 6.6 GeV/c Compared to..."					
7.1	Ankenbrandt	NC	<u>35</u> 1052 (1965)	LRL	CNTR
8, 16	Anderson	PRL	<u>25</u> 699 (1970)	BNL	CNTR
8.65, 11.8, 18.8, 23.1	Dekkers	PR	<u>137B</u> 962 (1965)	CERN-ORSA-RHEL	CNTR
6, 10, 15, 20, 30	Anderson	PRL	<u>16</u> 855 (1966)	BNL-CARN	CNTR
6/2 + 29.7	Edelstein	PR	<u>D5</u> 1073 (1972)	BNL-CARN	CNTR
9 + 25	Cocconi	PRL	<u>6</u> 231 (1961)	CERN	CNTR
10.0	Almeida	PR	<u>174</u> 1638 (1968)	CAVE-DESY-HAMB	HBC
10.0	Holmgren	NC	<u>51A</u> 305 (1967)	STOH	HBC

<u>P_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
10.0	Holmgren	NC	<u>57A</u> 20 (1968)	STOH	HBC
10, 20, 30	Anderson	PRL	<u>19</u> 198 (1967)	BNL-CARN	CNTR
10, 20, 30	Anderson	PRL	<u>19</u> 201 (1967)	BNL-CARN	CNTR
10 + 26	Foley	PRL	<u>19</u> 397 (1967)	BNL	CNTR
10, 19, 26	Belletini	PL	<u>18</u> 167 (1965)	CERN	CNTR
12.0, 24.0	Mück	PL	<u>39B</u> 303 (1972)	BONN-DESY-MPIM	HBC
12.0, 24.0	Mück	preprint DESY F1-72/1		BONN-DESY-MPIM	HBC

"Inclusive Particle Production in pp Interactions at 12 and 24 GeV/c..."

12.2 + 12.5	Akerlof	PR	<u>D3</u> 645 (1971)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Asbury	PR	<u>178</u> 2086 (1969)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Day	PRL	<u>23</u> 1055 (1969)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Marmer	PRL	<u>23</u> 1469 (1969)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Ratner	PR	<u>166</u> 1353 (1968)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Ratner	PRL	<u>18</u> 1218 (1967)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Crabb	PRL	<u>21</u> 830 (1968)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Asbury	PRL	<u>21</u> 1097 (1968)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Akerlof	PRL	<u>17</u> 1105 (1966)	MICH-NAL-ANL-IOWA	CNTR
12.2 + 12.5	Krisch	PRL	<u>19</u> 1149 (1967)	MICH-NAL-ANL-IOWA	CNTR

<u>P_{INC} (GeV/c)</u>	<u>First Author</u>	<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
12.3	Anderson	PRL <u>18</u> 89 (1967)	CHIC-ANL-OTTA-MCGI-QMCL	CNTR
12.5	Lamb	PRL <u>17</u> 100 (1966)	ANL-UCSD	CNTR
12.99 26.02	Cocconi	PRL <u>7</u> 450 (1961)	CERN	CNTR
13.0 + 24.2	Ma	PRL <u>24</u> 1031 (1970)	MSU	HBC
13.0 + 28.5	Smith	PRL <u>23</u> 1064 (1969)	LRL-MSJ-UCB	HBC
13.0 + 28.5	Smith	UCRL 20632	LRL	HBC
13.0 + 28.5	Lander	Proc. Rochester Conf. 71(1971)	LRL	HBC
13.0 + 28.5	Berger	PRL <u>28</u> 322 (1972)	ANL-MSU	HBC
14.25, 19.2, 24.0	Allaby	Oxford Conf. Report (April 1972)	CERN-ROMA	CNTR
"Comparison of Momentum Spectra of Secondary Particles Produced in pp Collisions at 14.2, 19.2, 24 GeV/c"				
Diddens	"Particle Production in Proton-Proton Collisions," CERN Report (1971)			CNTR
Allaby	"Comparison of Momentum Spectra of Secondary Particles Produced in 14.25, 19.2, and 24 GeV/c p-p Collisions" (Amsterdam Conf., June 1971)			CERN-ROMA CNTR

<u>P_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
15.2, 20, 29.7	Carrigan	PRL	<u>24</u> 683 (1970)	BNL-CARN	CNTR
19.0	Bøggild	NP	<u>B27</u> 1 (1971)	SCAND	HBC
19.0	Bøggild	NP	<u>B27</u> 285 (1971)	SCAND	HBC
19.0	Bøggild	"Angular and Rapidity Distributions of the Pions Emitted in High Energy pp Collisions" (Report at the Helsinki Conf., 1971)			HBC
19.0	Bøggild	NP	<u>B16</u> 503 (1970)	SCAND	HBC
19.0	Bøggild	PL	<u>B30</u> 369 (1969)	SCAND	HBC
19, 24	Diddens	NC	<u>31</u> 961 (1964)	CERN	CNTR
19.2	Allaby	CERN 70-12	(1970)	CERN	CNTR
"High Energy Particle Spectra from Proton Interactions at 19.2 GeV/c"					
19.2	Allaby	PL	<u>28B</u> 229 (1968)	CERN	CNTR
19.2, 21.1	Allaby	PL	<u>28B</u> 67 (1968)	CERN	CNTR
21.12	Allaby	PL	<u>29B</u> 198 (1972)	CERN	CNTR
23.0	Friedman	PRL	<u>28</u> 191 (1972)	LRL	HBC
23.1	Fidecaro	NC	<u>24</u> 1277 (1962)	CERN	CNTR
24.0	Dodd	AIX-CONF	433 (1961)	BIRM-LOIC-OXF	HBC

<u>P_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
24.0	Amaldi	NP	B39 39 (1972)	CERN-ROMA	CNTR
24.0	Amaldi	PL	34B 435 (1971)	CERN-ROMA	CNTR
24.9, 28.6	Lee	thesis		RUTG	HBC
	"V ⁰ and V ⁰ _γ Production in 24.9 GeV/c and 28.6 GeV/c pp..."				
28.5	Moffeit	SLAC-PUB-1004	(1971)		HBC
	"A Study of the Inclusive Reaction $\gamma p + \pi^- + \dots$ "				
28.5	Swanson	SLAC-PUB-979	(1971)	SLAC-LRL-UCD	HBC
	"Comparison of the Inclusive π^- Distributions from pp, γp , Kp..."				
28.5	Risk	PRL	27 353 (1971)	LRL	HBC
28.5	Chen	PRL	26 585 (1971)	BNL-ROCH-WISC	HBC
28.5	Ellis	PL	32B 641 (1970)	BNL	HBC
28.5	Ellis	PRL	21 697 (1968)	BNL	HBC
28.5	Ellis	BNL 13671		BNL	HBC
	"A Description of the Final States with Three, Four, and Five Particles..."				
28.5	Connolly	BNL 13694		BNL	HBC
	"Analysis of 28.5 GeV/c pp Interactions Producing Six or More..."				
28.5	Kinsey	BNL 14934		BNL	HBC
	"Multiparticle Production in pp Collisions at 28.5 GeV/c..."				

<u>P_{INC}</u> (GeV/c)	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
28.5	von Lindern	PRL	<u>27</u> 1745 (1971)	BNL-VAND	HBC
28.5	von Lindern	PRL	<u>28</u> 70 (1971)	BNL-VAND	HBC
28.5	Panvini	PL	<u>38B</u> 55 (1971)	BNL-VAND	HBC
28.5	Sims	preprint	(1972)	BNL-VAND	HBC
	"Pion Spectra from the Reaction $pp \rightarrow \pi^{\pm} + \text{Anything at 28.5 GeV}$ "				
28.5	Hanlon	preprint	(1972)	BAND-BNL	HBC
	"A Comparison of the Reactions $pp \rightarrow \pi^{\pm} + \text{Anything}$ "				
28.5	Foster	preprint	(1972)	STON-VAND	HBC
	"Azimuthial Correlations of High Energy Collision Products"				
67.0	Antonova	PL	<u>39B</u> 282 (1972)	ACDLMTU	EMUL
67.0	Antonova	PL	<u>39B</u> 285 (1972)	ACDLMTU	EMUL
100 + 1000	Jones	UM-HE 71-46		MICH-COLO-BNL-ANL	IONC
+	"Properties of pp Interactions Between 100 and 1000 GeV..."				
100 + 1000	Lyon	PRL	<u>26</u> 728 (1971)	MICH-COLO-BNL-ANL	IONC
100 + 1000	Jones	PRL	<u>25</u> 1679 (1970)	MICH-COLO-BNL-ANL	IONC
100 + 1000	Jones	PRL	<u>25</u> 1683 (1970)	MICH-COLO-BNL-ANL	IONC
100 + 1000	Jones	PL	<u>36B</u> 509 (1971)	MICH-COLO-BNL-ANL	IONC
100 + 1000	Erickson	University of Michigan (He-70-4)		COLO	IONC
225, 500, 1100, 1500	Bertin	PL	<u>38B</u> 260 (1972)	BGNA	CNTR

<u>p_{INC} (GeV/c)</u>	<u>First Author</u>	<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
500, 1100, 1500	Ratner	PRL <u>27</u> 68 (1972)	ANL-BGNA-MICH	CNTR
500, 1100, 1500	Ratner	A. D. Krisch, Rochester Conf. Report, "Inelastic pp Scattering at Very High Energy."	ANL-BGNA-MICH	CNTR
500, 1100, 1500	Barbiellini	PL <u>39B</u> 294 (1972)	AACH-CERN-HARV-GENO-TORI	CNTR
26.5, 500, 1100, 1500	Neuhofer	PL <u>37B</u> 439 (1971)	CERN-HAMB-VIEN	CNTR
	Neuhofer	PL <u>38B</u> 51 (1972)	CERN-HAMB-VIEN	CNTR
1500	Bombay-CERN- Cracow	PL <u>36F</u> 64 (1971)	BOMB-CERN-CRAC	CNTR
COSMIC	Barashenkov	Fort. Phys. <u>14</u> 357 (1966)	JINR	REU
COSMIC	Barashenkov	Fort. Phys. <u>15</u> 435 (1967)	JINR	REU
COSMIC	Yukawa	Prog. Theor. Phys. (Suppl.) 1967		REU
COSMIC		Can. J. Phys. <u>46</u> (1968)		CNTR
		Proc. Tenth International Conference on Cosmic Rays-Calgary (1968)		REU
COSMIC		Proc. Eleventh International Conference on Cosmic Rays-Budapest (1969)		REU
COSMIC	Fujimoto	Handbuch der Physik 46/2-Springer (1967)		REU

II-B. Data on Inclusive Spectra: p-Nucleus

$pBe \rightarrow \pi^{\pm} X$
 $p_{INC} = 8.65, 11.8, 18.8, 23.1 \text{ GeV}/c$

(a)

(b)

$p8e \rightarrow \pi^{\pm} X$

$p_{INC} = 8.65, 11.8, 18.8, 23.1 \text{ GeV}/c$

$(d\sigma/dp d\Omega)^{LAB}$ per nucleus vs. p_{INC} , for fixed $\theta^{LAB} = 0^\circ$ and $p^{LAB} = 4 + 12 \text{ GeV}/c$

Extensive tables of data on $p8e \rightarrow \pi^{\pm}, p, \bar{p}, K^{\pm}$ are provided.

D. Dekkers, J. A. Geibel, R. Mermod, G. Weber, T. R. Willitts,
K. Winter, E. Jordan, M. Vivargent, N. M. King and E. J. N. Wilson,
Phys. Rev. 137, B962 (1965)

-CERN proton synchrotron; counter experiment

$p\bar{p} \rightarrow \pi^+ X$
 $p_{INC} = 10, 20 \text{ GeV}/c$

$$p\bar{p}e \rightarrow \pi^+ X$$

$$p_{INC} = 10, 20 \text{ GeV}/c$$

$(dN/dpd\Omega)^{LAB}$ = particle yield per circulating proton vs. p^{LAB} of the produced pion (θ^{LAB} fixed = $4.75^\circ, 9^\circ$)

W. F. Baker, R. L. Cool, E. W. Jenkins, T. F. Kycia, S. J. Lindenbaum,
W. A. Love, D. Llers, J. A. Niederer, S. Ozaki, A. L. Read, J. J. Russell
and L. C. L. Yuan, Phys. Rev. Letters 7, 101 (1961)

$pBe \rightarrow cX$ $p_{INC} = 10, 20, 30 \text{ GeV/c}$ $pAl \rightarrow cX$ $p_{INC} = 30 \text{ GeV/c}$

9° PRODUCTION ANGLE

pBe $\rightarrow$ cX

p_{INC} = 10, 20, 30 GeV/c

pAl $\rightarrow$ cX

p_{INC} = 30 GeV/c

The ratios of production cross sections $(d\sigma/dpd\Omega)^{\text{LAB}}$ for different types of particles plotted vs. p^{LAB} of the particle ($\theta^{\text{LAB}} = 9^\circ$)

W. F. Baker, R. L. Cool, E. W. Jenkins, T. F. Kycia, S. J. Lindenbaum,
W. A. Love, D. Lüers, J. A. Niederer, S. Ozaki, A. L. Read, J. J. Russell
and L. C. L. Yuan, Phys. Rev. Letters 7, 101 (1961)

pBe $\rightarrow$ cXpAl $\rightarrow$ cX $P_{INC} = 10, 20, 25, 30 \text{ GeV/c}$ $P_{INC} = 30 \text{ GeV/c}$

4.75° PRODUCTION ANGLE

pBe + cX

 $P_{INC} = 10, 20, 25, 30 \text{ GeV/c}$

pAl + cX

 $P_{INC} = 30 \text{ GeV/c}$

The ratios of production cross section $(d\sigma/dp d\Omega)^{LAB}$ for different types of particles plotted vs. p^{LAB} of the particle ($\theta^{LAB} = 4.75^\circ$)

W. F. Baker, R. L. Cool, E. W. Jenkins, T. F. Kycia, S. J. Lindenbaum,
W. A. Love, D. Lüers, J. A. Niederer, S. Ozaki, A. L. Read, J. J. Russell
and L. C. L. Yuan, Phys. Rev. Letters 7, 101 (1961)

-BNL AGS; counter experiment

pBe + π^- X $p_{INC} = 12.5$ GeV/c

$pBe + \pi^- X$

$p_{INC} = 12.5 \text{ GeV}/c$

$(d\sigma/d\Omega dp)^{LAB}$ per nucleus vs. p^{LAB} for produced π^- (θ^{LAB} fixed $\approx 2^\circ + 16^\circ$)

R. A. Lundy, T. B. Novey, D. D. Yovanovitch and V. L. Telegdi, Phys. Rev. Letters 14, 504 (1965)

$p\text{Be} \rightarrow \pi^+ X$
 $P_{\text{INC}} = 12.5 \text{ GeV/c}$

$pBe \rightarrow \pi^+ X$
 $p_{INC} = 12.5 \text{ GeV/c}$

$(d\sigma/d\Omega dp)^{LAB}$ per nucleus vs. p^{LAB} for produced π^+ (θ^{LAB} fixed = $0^\circ + 16^\circ$)

R. A. Lundy, T. B. Novey, D. D. Yovanovitch and V. L. Telegdi, Phys. Rev. Letters 14, 504 (1965)

-ANL ZGS; counter experiment

pBe $\rightarrow$ pX $p_{INC} = 12.5 \text{ GeV/c}$

pBe + pX

 $p_{INC} = 12.5 \text{ GeV/c}$

$(d\sigma/dpd\Omega)^{LAB}$ per nucleus vs. p^{LAB} for "produced" protons (θ^{LAB} fixed = $2^\circ \rightarrow 16^\circ$)

R. A. Lundy, T. B. Novey, D. D. Yovanovitch and V. L. Telegdi, Phys. Rev. Letters 14, 504 (1965)

$pBe \rightarrow \pi^+ X$
 $p_{INC} = 12.5 \text{ GeV/c}$

$$pBe \rightarrow \pi^{\pm} X$$

$$p_{INC} = 12.5 \text{ GeV/c}$$

$(d\sigma/d\Omega dp)^{LAB}$ per nucleus vs. p^{LAB} of the produced pion (θ^{LAB} fixed = $12^{\circ} \rightarrow 16^{\circ}$)

Also plotted is data from R. A. Lundy et al., Phys. Rev. Letters 14, 504 (1965)

J. G. Asbury, Y. Cho, M. Derrick, L. G. Ratner, T. P. Wangler, A. D. Krisch and M. T. Lin, Phys. Rev. 178, 2086 (1969)

$p\text{Be} + p\bar{\chi}$ $P_{\text{INC}} = 12.3 \text{ GeV}/c$

$pBe + pX$ $p_{INC} = 12.3 \text{ GeV}/c$

 $(d\sigma/dpd\Omega)^{LAB}$ vs. θ^{LAB} for the produced proton (p^{LAB} fixed) $p^{LAB} = 500, 820, 1000 \text{ MeV}/c$

G. J. Marmer, K. Reibel, D. M. Schwartz, A. Stevens, R. Winston, D. Wolfe,
C. J. Rush, P. R. Phillips, E. C. Swallow and T. A. Romanowski,
Phys. Rev. 179, 1294 (1969)

-ANL/ZGS; counter experiment

$p\bar{p} \rightarrow K^+ X$ $P_{INC} = 12.3 \text{ GeV}/c$

 $(d\sigma/dp d\Omega)^{LAB}$ vs. θ^{LAB} for the produced kaon (p^{LAB} fixed)

G. J. Marmer, K. Reibel, D. M. Schwartz, A. Stevens, R. Winston, D. Wolfe,
C. J. Rush, P. R. Phillips, E. C. Swallow and T. A. Romanowski,
Phys. Rev. 179, 1294 (1969)

-ANL/ZGS; counter experiment

$pBe \rightarrow \pi^+ X$
 $p_{INC} = 12.3 \text{ GeV}/c$

$p\text{Be} + \pi^+ X$
 $p_{\text{INC}} = 12.3 \text{ GeV}/c$

$(d\sigma/dpd\Omega)^{\text{LAB}}$ vs. θ^{LAB} for the produced pion (p^{LAB} fixed)

G. J. Marmer, K. Reibel, D. M. Schwartz, A. Stevens, R. Winston, D. Wolfe,
C. J. Rush, P. R. Phillips, E. C. Swallow and T. A. Romanowski,
Phys. Rev. 179, 1294 (1969)

-ANL/ZGS; counter experiment

$pBe \rightarrow KX$ and $pBe \rightarrow \pi X$
 $P_{INC} = 12.3 \text{ GeV/c}$

pBe $\rightarrow$ KX and pBe $\rightarrow$ π XP_{INC} = 12.3 GeV/c

Ratios of cross-sections $(\frac{d\sigma}{dpd\Omega})_{K^+}^{\text{LAB}} / (\frac{d\sigma}{dpd\Omega})_{\pi^+}^{\text{LAB}}, (\frac{d\sigma}{dpd\Omega})_{K^-}^{\text{LAB}} / (\frac{d\sigma}{dpd\Omega})_{\pi^-}^{\text{LAB}},$

and $(\frac{d\sigma}{dpd\Omega})_{\pi^+}^{\text{LAB}} / (\frac{d\sigma}{dpd\Omega})_{\pi^-}^{\text{LAB}}$ vs. p^{LAB} (θ^{LAB} fixed)

The graph compares the data of:

G. J. Marmer et al., Phys. Rev. 179, 1294 (1969)

R. A. Lundy et al., Phys. Rev. Letters 14, 504 (1965); 14, 730(E) (1965)

W. F. Baker et al., Phys. Rev. Letters 7, 101 (1961)

D. Dekkers et al., Phys. Rev. 137, B962 (1965)

G. J. Marmer, K. Reibel, D. M. Schwartz, A. Stevens, R. Winston, D. Wolfe,

C. J. Rush, P. R. Phillips, E. C. Swallow and T. A. Romanowski, Phys. Rev. 179, 1294 (1969)

-ANL/ZGS; counter experiment

$$p\bar{p} \rightarrow \pi^+ \pi^-$$

$$p_{INC} = 12.3 \text{ GeV/c}$$

$$d^2\sigma/d\Omega dp [10^{-27} \text{ cm}^2/\text{sr (GeV/c)}]$$

$pBe \rightarrow \pi^{\pm} X$

$P_{INC} = 12.3 \text{ GeV/c}$

The pion yield per nucleus, $(d\sigma/d\Omega dp)^{LAB}$, is plotted vs. p^{LAB} for the produced pion ($\theta^{LAB} = 3^{\circ}$). Error bars include systematic uncertainty.

The data is compared with that of:

G. J. Marmer et al., Phys. Rev. 179, 1294 (1969)
(Ref. 5; plotted as open squares)

R. A. Lundy et al., Phys. Rev. Letters 14, 504 (1965)
(Ref. 4; plotted as open circles)

G. J. Marmer and D. E. Lundquist, Phys. Rev. D3, 1089 (1971)

-ANL ZGS; counter experiment

$p\bar{p}e + \pi^+ X$

The data of:

Y. Cho et al., ANL/HEP report 7109 (May, 1971), $p_{INC} = 12.4$ GeV/c

J. G. Asbury et al., Phys. Rev. 178, 2086 (1969)

G. J. Marmer et al., Phys. Rev. 179, 1294 (1969)

G. J. Marmer and D. Lundquist, Phys. Rev. D3, 1089 (1971)

are plotted as $(d\sigma/d\Omega dp)^{LAB}$ vs. p^{LAB} for the produced pion (θ^{LAB} fixed =

$0^\circ + 14^\circ$)

The data are fitted by an empirical formula of J. R. Sanford and C. L. Wang
(BNL AGS internal report, 1967, Phys. Rev. Letters 25, 1068 (1970)

$$d\sigma/d\Omega dp = C_1 p^{C_2} (1 - p/p_{INC}) \exp [- C_3 p^{C_4} / p_{INC}^{C_5} - C_6 \theta (p - C_7 p_B \cos \theta)^{C_8}],$$

= differential particle yield (in the lab. frame) per interacting proton

The fitted parameters are:

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
π^+	200	1.01	2.26	2.45	2.11	5.66	0.141	27.3
π^-	162	0.850	1.61	1.75	1.24	5.00	0.149	32.1

Y. Cho, M. Derrick, G. Marmer, T. P. Wangler, J. L. Day, P. Kalbaci, M. L. Marshak,
J. K. Randolph and A. W. Key, Argonne National Lab. report ANL/HEP 7109 (May, 1971),
Pion Production in $p\bar{p}e$ Collisions at 12.4 GeV/c; -ZGS AGS; counter experiment

$p\text{Be} \rightarrow \pi^+ X$
 $P_{\text{INC}} = 12.4 \text{ GeV/c}$

$p8e \rightarrow \pi^+ X$
 $p_{INC} = 12.4 \text{ GeV}/c$

 $(d/dp d.)^{LAB}$ vs. p^{LAB} for produced pions (θ^{LAB} FIXED $\approx 0^\circ + 16^\circ$)

Also plotted is the data from:

J. G. Asbury et al., Phys. Rev. 178, 2086 (1969)

G. J. Marmer et al., Phys. Rev. 179, 1294 (1969)

G. J. Marmer and D. Lundquist, Phys. Rev. D3, 1089 (1971)

The data for this experiment is tabulated.

Y. Cho, M. Derrick, G. Marmer, T. P. Wangler, J. L. Day, P. Kalbaci,
M. L. Marshak, J. K. Randolph and A. W. Key, Argonne National Lab. Report
ANL/HEP 7109 (May, 1971)

$pBe \rightarrow \pi^+ X$ $P_{INC} = 13.4 \text{ GeV/c}$

$pBe \rightarrow \pi^+ X$

$p_{INC} = 13.4 \text{ GeV}/c$

These authors fit data on pp , $pBe \rightarrow (\pi, K, \bar{p})X$ with an empirical formula:

$$\begin{aligned}
 (d\sigma/dp d\Omega)^{LAB} &= A p^B (1 - p/p_{INC}) \exp [-c \frac{p^D}{p^E} p_{INC} - F\theta(p - G p_{INC} \cos^H \theta)] \\
 &\sim A p_{INC}^{1/2} e^{-c p_{INC}^{1/2}} (1 - x) e^{-Bx^{5/3}} \quad \text{where } p, \theta = \text{lab. frame}
 \end{aligned}$$

momentum and angle of the observed particle and $x = p/p_{INC}$.

The data is from R. A. Lundy et al., Phys. Rev. Letter 14, 504 (1966)

C. L. Wang, Phys. Rev. Letters 25, 1068 (1970)

J. R. Sanford and C. L. Wang, Brookhaven National Lab. Internal Reports
BNL 11299 (March 1, 1967) and BNL 11479 (May 1, 1967)

pBe $\rightarrow$ pX
 $\rightarrow$ nX

$P_{INC} = 19, 24 \text{ GeV/c}$

pBe $\rightarrow$ pX
 $\rightarrow$ nX

$P_{INC} = 19, 24 \text{ GeV/c}$

$(d\sigma/d\Omega dp)^{LAB}$ for the observed nucleon vs. $P_{||}^{LAB}/P_{INC}$

- ▲ $P_{INC} = 19 \text{ GeV/c}, \theta^{LAB} = 12.5 \text{ mrad.}, pBe \rightarrow pX$
- $P_{INC} = 24 \text{ GeV/c}, \theta^{LAB} = 0^\circ, pBe \rightarrow nX$
- $P_{INC} = 19 \text{ GeV/c}, \theta^{LAB} = 50 \text{ mrad.}, pBe \rightarrow nX$
- $P_{INC} = 19 \text{ GeV/c}, \theta^{LAB} = 50 \text{ mrad.}, pBe \rightarrow pX$

The normalization of the neutron spectra is only approximate.

Data of J. Engler, W. Flauger, B. Gibbard, E. Mönig, K. Runge and
 H. Schopper (Karlsruhe, 1972)

found in A. N. Diddens and K. Schlüpman, Particle Production in Proton-Proton Collisions, CERN report (1971)

$pp \rightarrow dX, p\bar{p}e \rightarrow dX, pC \rightarrow dX, pA\bar{L} \rightarrow dX$
 $P_{INC} = 19 + 30 \text{ GeV}/c$

$pp \rightarrow dX, pBe \rightarrow dX, pC \rightarrow dX, pAl \rightarrow dX$

$p_{INC} = 19 + 30 \text{ GeV/c}$

$(d\sigma/dpd\Omega)^{LAB}$ (cross-section per nucleon) vs. p^{LAB} (θ^{LAB} fixed) for produced deuterons in pp, pBe collisions.

The sources for the data are:

(a) pBe ($p_{INC} = 30 \text{ GeV/c}, \theta^{LAB} = 45^\circ$)	V. L. Fitch, S. L. Meyer,
P. A. Piroué, Phys. Rev. <u>126</u> ,
1849 (1962)
(b) pBe ($p_{INC} = 30 \text{ GeV/c}, \theta^{LAB} = 90^\circ$)	V. L. Fitch, S. L. Meyer,
P. A. Piroué, Phys. Rev. <u>126</u> ,
1849 (1962)
(c) pC ($p_{INC} = 26.6 \text{ GeV/c}, \theta^{LAB} = 11.25^\circ$)	U. Amaldi et al., Nuovo
Cimento <u>30</u> , 973 (1963)
(d) pBe ($p_{INC} = 33 \text{ GeV/c}, \theta^{LAB} = 13^\circ$)	V. L. Fitch et al., Phys.
Rev. <u>126</u> , 1849 (1962)
(e) pAl ($p_{INC} = 25 \text{ GeV/c}, \theta^{LAB} = 16^\circ$)	V. T. Cocconi et al.,
Phys. Rev. Letters <u>5</u> , 19 (1960)
(f) pBe ($p_{INC} = 29.5 \text{ GeV/c}, \theta^{LAB} = 30^\circ$)	A. Schwarzschild and
Č. Zupančič, Phys. Rev. <u>129</u> ,
854 (1963)
(g) pp ($p_{INC} = 19, 24 \text{ GeV/c}, \theta^{LAB} = 6.6^\circ$)	A. N. Diddens et al.,
Nuovo Cimento <u>31</u> , 961 (1964)

See also: J. V. Allaby et al., Phys. Letters 29B, 198 (1969)

($pp \rightarrow dX, p_{INC} = 21.1 \text{ GeV/c}$)

A. N. Diddens, W. Galbraith, E. Lillethun, G. Manning, A. G. Parham,
A. E. Taylor, T. G. Walker and A. M. Wetherell, Nuovo Cimento 31, 961 (1964)

-CERN proton synchrotron; counter experiment; tabulated data

$p\text{Al} \rightarrow \pi^- X$

$P_{\text{INC}} = 19.2, 70 \text{ GeV/c}$

$p\bar{A}L \rightarrow \pi^- X$ $P_{INC} = 19.2, 70 \text{ GeV/c}$ $(d\sigma/d\Omega dp)^{LAB}$ vs. p^{LAB}/P_{INC} (θ^{LAB} fixed) for produced π^- .

The data are taken from:

$P_{INC} = 19.2 \text{ GeV/c}$	J. V. Allaby et al., CERN report 70-12 (April 1970) (_____)
$E_{INC} = 70 \text{ GeV/c}$	Yu. B. Bushnin et al., Phys. Letters <u>29B</u> , 48 (1969) F. Binon et al., Phys. Letters <u>30B</u> , 506 (1969) Yu. M. Antipov, Phys. Letters <u>34B</u> , 164 (1971) (●, ▲, -----)

The labelled angle is $\theta^{LAB} \times 70/19.2$.

$P_{INC} = 30, 300 \text{ GeV/c}$ Theoretical curves of R. Hagedorn and J. Rønft,
Suppl. Nuovo Cimento 6, 169 (1968) at $\theta^{LAB} = 0$.

Liland and Pilkuhn suggest a scaling law (in LAB coordinates):

$d\sigma/dp'd\Omega' (p', \theta') = d\sigma/dpd\Omega (p, \theta)$ where $p'/p'_{INC} = p/p_{INC}$ and $p'\theta' = p\theta$
at incident momenta p'_{INC} and p_{INC} , respectively.

A. Liland and H. Pilkuhn, Phys. Letters 29B, 663 (1969)

$p_{INC} = 24 \text{ GeV/c}$

$pd + pX$

$p\bar{d} \rightarrow pX$

$p_{INC} = 24 \text{ GeV}/c$

$(d\sigma/d\Omega dp)^{LAB}$ vs. p^{LAB} , for fixed $\theta^{LAB} = 13.5 \pm 107 \text{ mrad}$.

U. Amaldi, R. Biancastelli, C. Bosio, G. Matthiae, J. V. Allaby, A. N. Diddens,
R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlupmann
and A. M. Wetherell, Nucl. Phys. B39, 39 (1972)

p + Tungsten + (π^- , K^- , Σ^- , Ξ^- , $\bar{p}$)X

$p_{INC} = 24 \text{ GeV}/c$

Fig 3 a

Fig 3 b

$p + \text{Tungsten} \rightarrow (\pi^-, K^-, \Sigma^-, \Xi^-, \bar{p})X$

$p_{\text{INC}} = 24 \text{ GeV}/c$

The number $(dN/dpd\Omega)^{\text{LAB}}$ of produced particles per interacting proton, using a Tungsten target,

(a) vs. p^{LAB} ($\theta^{\text{LAB}} = 10 \text{ mrad.}$)

(b) vs. θ^{LAB} ($p^{\text{LAB}} = 17.2 \text{ GeV}/c$)

J. Badier, R. Bland, J. C. Chollet, T. Devlin, J. -M. Gaillard,
J. Lefrançois, B. Merkel, R. Meunier, J. -P. Repellin, G. Sauvage
and R. Vanderhaghen, Physics Letters 39B, 414 (1972)

-CERN proton synchrotron; counter experiment; tabulated data

$p\text{Be} \rightarrow cX$ $p_{INC} = 29.5 \text{ GeV/c}$

pBe + cX

 $P_{INC} = 29.5 \text{ GeV/c}$

Yields $(dN/dp d\Omega)^{LAB}$ [particles per circulating proton] of particles c
 in pBe + cX vs. p^{LAB} ($\theta^{LAB} = 30^\circ$)

This paper also contains pBe, pAl, pFe, pC + (p, $\pi^\pm$, d, t)X data.

A. Schwarzschild and Č. Zupanić, Phys. Rev. 129, 854 (1963)

-BNL/AGS; counter experiment

pBe + cX

P_{INC} = 29.5 GeV/c

pBe $\rightarrow$ cX $p_{INC} = 29.5 \text{ GeV}/c$

Particle yields $(dN/dpd\Omega)^{LAB}$ per circulating proton for produced $\pi^{\pm}$, p, $\bar{p}$, $K^{\pm}$, d, t vs. p^{LAB} of the produced particle ($\theta^{LAB} = 30^{\circ}$)

A. Schwarzschild and Č. Zupanič, Phys. Rev. 129, 854 (1963)

$$pBe \rightarrow \pi^+ X, pX$$

$$p^A L \rightarrow \pi^+ X, pX$$

$$p_{INC} = 30 \text{ GeV}/c$$

$PBe \rightarrow \pi^+ X, pX$
 $pAl \rightarrow \pi^+ X, pX$

$p_{INC} = 30 \text{ GeV}/c$

$(dN/dpd\Omega)^{LAB}$ = particle yield per circulating proton vs. p^{LAB} of the
 produced particle (θ^{LAB} fixed = $4.75^\circ, 9^\circ, 13^\circ$)

W. F. Baker, R. L. Cool, E. W. Jenkins, T. F. Kycia, S. J. Lindenbaum,
 W. A. Love, D. Lüers, J. A. Niederer, S. Ozaki, A. L. Read, J. J. Russell
 and L. C. L. Yuan, Phys. Rev. Letters 7, 101 (1961)

-BNL AGS; counter experiment

$pBe + cX$
 $pAl + cX$

$P_{INC} = 30 \text{ GeV}/c$

pBe + cX

$p_{INC} = 30 \text{ GeV}/c$

pAl + cX

The yield $(dN/dpd\Omega)^{LAB}$ per circulating proton of p, $\pi^{\pm}$, d, t

vs. p^{LAB} of the secondary particle for

(left) pBe + cX, pAl + cX at $\theta^{LAB} = 45^{\circ}$
 and (right) pBe + cX at $\theta^{LAB} = 90^{\circ}$

In the dashed part of the curves, multiple scattering connections exceed 15%.

V. L. Fitch, S. L. Meyer and P. A. Piroué, Phys. Rev. 126, 1849 (1962)

-BNL AGS; counter experiment

$pA\ell \rightarrow cX \quad (c = \pi^-, K^-, \bar{p})$
 $E_{INC} = 20, 35, 43, 52, 70 \text{ GeV}$

Fig. 34b

$$pA\ell \rightarrow cX \quad (c = \pi^-, K^-, \bar{p})$$

$$E_{\text{INC}} = 20, 35, 43, 52, 70 \text{ GeV}$$

The ratios of particle yields, $R(K^-) = \langle dN/dpd\Omega \rangle_{K^-}^{\text{LAB}} / \langle d\sigma/dpd\Omega \rangle_{\pi^-}^{\text{LAB}}$ and $R(\bar{p}) = \langle dN/dpd\Omega \rangle_{\bar{p}}^{\text{LAB}} / \langle dN/dpd\Omega \rangle_{\pi^-}^{\text{LAB}}$, are plotted vs. $p^{\text{LAB}} / \langle p^{\text{LAB}} \rangle_{\text{MAX}}$ of the produced particles ($\theta^{\text{LAB}} \lesssim 12 \text{ mrad.}$)

The $p_{\text{INC}} = 19.2 \text{ GeV/c}$ data is taken from J. V. Allaby et al., paper at the Fourteenth International Conference on High-Energy Physics (Vienna, 1968); CERN report 70-12 (1970)

F. Binon, S. P. Denisov, P. Duteil, V. A. Kachanov, V. M. Kutyin, J. P. Peigneux, Yu. D. Prokoshkin, E. A. Razuvaev, R. S. Shuvalov, M. Spighel and J. P. Stroot, Phys. Letters 30B, 506 (1969)

$$pAL + cX \quad (c = \pi^-, K^-, \bar{p})$$

$$E_{INC} = 35, 52, 70 \text{ GeV}$$

Fig. 34a

$pA\ell \rightarrow cX \quad (c = \pi^-, K^-, \bar{p})$

$E_{INC} = 35, 52, 70 \text{ GeV}$

Ratio I. of particle yields $(dN/dpd\Omega)^{LAB}$ vs. p^{LAB} ($\theta^{LAB} \lesssim 12 \text{ mrad.}$) of the produced particle

See also Yu. B. Bushnin et al., Physics Letters 29B, 48 (1969)

Yu. M. Antipov et al., Physics Letters 34B, 164 (1971)

F. Binon, S. P. Denisov, P. Duteil, V. A. Kachanov, V. M. Kutvin,
J. P. Peigneux, Yu. D. Prokoshkin, E. A. Razuvaev, R. S. Shuvalov,
M. Spighel and J. P. Stroot, Physics Letters 30B, 506 (1969)

-IHEP, Serpukhov; counter experiment

$pAl + cX \quad (c = \pi^-, K^-, \bar{p})$
 $E_{INC} = 70 \text{ GeV/c}$

$$pA\ell + cX \quad (c = \pi^-, K^-, \bar{p})$$

$$E_{INC} = 70 \text{ GeV}/c$$

The yield $(d\sigma/d\Omega dp)^{LAB}$ per $A\ell$ nucleus is plotted vs. p^{LAB} of the produced particles π^- , K^- , $\bar{p}$ and interpolated to $\theta^{LAB} = 0$ mrad. from data at $\theta^{LAB} < 5$ mrad. (solid points) and $5 < \theta^{LAB} < 15$ mrad (open points)

See also: F. Binon et al., Phys. Letters 30B, 506 (1969)

Yu. M. Antipov et al., Phys. Letters 34B, 164 (1971)

Yu. B. Bushnin, S. P. Denisov, S. V. Donskov, A. F. Dunaitsev, Yu. P. Gorin, V. A. Kachanov, Yu. S. Khodirev, V. I. Kotoy, V. M. Kutvin, A. I. Petrukhin, Yu. D. Prokoshkin, E. A. Razuvaev, R. S. Shuvalov, D. A. Stoyanova and J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, G. Giacomelli, R. Meunier, J. P. Peigneux, K. Schupmann, M. Spighel, C. A. Stahlbrandt, J. P. Stroot and A. M. Wetherell, Physics Letters 29B, 48 (1969)

-IHEP, Serpukhov; counter experiment

$pp, pBe, pAl \rightarrow \pi^- X$

pp, pBe, pAl $\rightarrow \pi^- X$

π^- production cross section $(d\sigma/dp d\Omega)^{LAB}$ vs. $x = p^{LAB}/p^{INC}$ at $\theta^{LAB} = 0^\circ$
in pp, pBe, pAl collisions.

In (a), pAl data at $p^{INC} = 71$ GeV/c is converted to pBe data by dividing by a factor of 2.08

The data is taken from:

- pBe W. F. Baker et al., Phys. Rev. Letters 7, 101 (1961), $p^{INC} = 30.9$ GeV/c
D. Dekkers et al., Phys. Rev. 137, B962 (1965), $p^{INC} = 18.8$ GeV/c
R. A. Lundy et al., Phys. Rev. Letters 14, 504 (1966), $p^{INC} = 13.4$ GeV/c
J. G. Asbury et al., Phys. Rev. 178, 2086 (1969), $p^{INC} = 12.3$ GeV/c
- pAl Yu. B. Bushnain et al., Phys. Letters 29B, 48 (1969), $p^{INC} = 71$ GeV/c
- pp J. V. Allaby et al., CERN report 70-12 (1970), $p^{INC} = 19.2$ GeV/c
E. W. Anderson et al., Phys. Rev. Letters 19, 198 (1967), $p^{INC} = 30$ GeV/c
D. Dekkers et al., Phys. Rev. 137, B962 (1965), $p^{INC} = 18.8$ GeV/c

The BNL reports contain data on π and K production, plotted in the form
 $(d\sigma/dp d\Omega)^{LAB}$ vs. p^{LAB} (θ^{LAB} fixed).

- C. L. Wang, Phys. Rev. Letters 25, 1068 (1970)
J. R. Sanford and C. L. Wang, BNL Reports 11299 (March 1, 1967) and 11479
(May 1, 1967)

REFERENCE LIST OF INCLUSIVE DATA: p-NUCLEUS COLLISIONS

<u>P_{INC}(GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Target</u>
8.65, 11.8, 18.8, 23.1	Dekkers	PR	<u>137B</u> 962 (1965)	CERN-ORSA-RHEL	p, Be, Al
10, 20, 30	Baker	PRL	<u>7</u> 101 (1961)	BNL	Be, Al
12.3	Marmer	PR	<u>179</u> 1294 (1969)	OHIO-CHIC-ANL-WASH	Be, Cu
12.3	Marmer	PR	<u>D3</u> 1089 (1971)	ANL	Be
12.4	Cho	Argonne preprint ANL-HEP 7109(1971)ANL-MICH-NAL			Be
12.5	Lundy	PRL	<u>14</u> 504 (1966)	ANL-CHIC	Be
12.5	Asbury	PR	<u>178</u> 2036 (1969)	ANL-MICH	Be, Al
19.2	Allaby	PL	<u>30B</u> 549 (1969)	CERN	d
19.2	Allaby	CERN Report 70-12 (1970)		CERN	B ₄ C, Be, Al, Cu, Pb
"High-Energy Particle Spectra from Proton Interactions at 19.2 GeV/c"					
19.3, 21.5	Belletini	NP	<u>79</u> 609 (1966)	CERN	Li, Be, C, Al, Cu, Pb
24.0	Amaldi	NP	<u>B39</u> 39 (1972)	ROMA-CERN	d
24	Badier	PL	<u>39B</u> 414 (1972)	CERN-EPOL-ORSA	W, Al, B ₄ C
25	Cocconi	PRL	<u>5</u> 19 (1960)	CERN	Al
26.6	Amaldi	NC	<u>30</u> 973 (1963)	CERN	C
30	Schwarzschild	PR	<u>129</u> 854 (1962)	BNL	C, Al, Be, Fe
30, 33	Fitch	PR	126 1849 (1962)	PRIN	Be, Al

<u>p_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	
20.1, 43.1, 70	Bushnin	PL	<u>29B</u> 48 (1969)	IHEP-CERN	Al
43, 52, 70	Pinon	PL	<u>30B</u> 506 (1969)	IHEP-CERN	Al
35, 70	Antipov	PL	<u>34B</u> 164 (1971)	IHEP	Al

II-C. Data on Inclusive Spectra: $\bar{p}p$

$$\bar{p}p \rightarrow \pi^+ X$$

$$p_{INC} = 2.23 \text{ GeV}/c$$

$$\Delta P_L = 0.05 \text{ GeV}/c$$

$$\bar{P}_L = 0.025 \text{ } \circ$$

$$0.2375 \text{ } \circ$$

(b)

$$\bar{p}p \rightarrow \pi^+ X$$

$$p_{INC} = 2.23 \text{ GeV}/c$$

$$d^2\sigma/dp_{\perp}^2 dp_{||}^{CM} \text{ vs. } p_{\perp}^2$$

for various intervals of $p_{||}^{CM}$

T. F. Hoang, D. Rhines and W. A. Cooper, Phys. Rev. Letters 27, 1681 (1971)

$$\bar{p}p \rightarrow \pi^+ K$$

$$p_{INC} \approx 2.23 \text{ GeV}/c$$

- (a) Distribution in the average value of $p_{||}^{CM}$ vs. $p_{\perp}^2$
- (b) Distribution in the average value of $p_{\perp}^2$ vs. $|p_{||}^{CM}|$

T. F. Hoang, D. Rhines and W. A. Cooper, Phys. Rev. Letters 27, 1681 (1971)

$\bar{p}p \rightarrow \pi^+ X$ $P_{INC} = 2.23 \text{ GeV}/c$

$$\bar{p}p \rightarrow \pi^+ X$$

$$p_{INC} = 2.23 \text{ GeV}/c$$

$$d^2\sigma/dp_{\perp}^2 dp_{||}^{CM} \text{ vs. } p_{||}^{CM}$$

for various intervals of $p_{\perp}^2$

T. F. Hoang, D. Rhines and W. A. Cooper, Phys. Rev. Letters 27, 1681 (1971)

REFERENCE LIST OF INCLUSIVE DATA: $\bar{p}$ p COLLISIONS

<u>p_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
1.09 + 2.90	Oh	NP	B40 151 (1972)	MSU	DBC
2/23	Hoang	PRL	27 1681 (1971)	ANL-BUCK	HBC
2.23	Hoang	NP	B38 333 (1972)	ANL-BUCK	HBC

II-D. Data on Inclusive Spectra: K^+p

$K^- p \rightarrow \Lambda X$ $p_{INC} = 10.1 \text{ GeV}/c$

$$\frac{d^2\sigma}{d\Omega dp} \Big|_{LAB} \text{ vs. } p_{LAB} \text{ for various values of } \theta_{LAB}$$

Events are weighted by $1/2\pi \sin \theta_{LAB}$ to correct for the summation over large solid angles.

Events in which additional strange particle decays accompany the Λ have been removed. The authors point out that this removal amounts to about 5% of the inclusive Λ sample.

J. Bartsch et al., Aachen-Berlin-CERN-London-Vienna Collaboration,
Study of Lambda Production in 10 GeV/c K^-p Interactions, CERN/
 D.Ph.II/Phys. 71-27 (1972); Nucl. Phys. B40, 103 (1972)

$P_{\text{INC}} = 10.1 \text{ GeV}/c$

$K^- p \rightarrow \Lambda X$

$$K^- p \rightarrow \Lambda X$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$$\frac{d\sigma}{dt} \Big|_{p \rightarrow \Lambda} \text{ vs. } t \Big|_{p \rightarrow \Lambda}$$

$$\frac{d\sigma}{dt'} \Big|_{p \rightarrow \Lambda} \text{ vs. } t' \Big|_{p \rightarrow \Lambda}$$

$$\frac{d\sigma}{du'} \Big|_{p \rightarrow \Lambda} \text{ vs. } u' \Big|_{p \rightarrow \Lambda}$$

Events in which additional strange particle decays accompany the Λ have been removed. The authors point out that this removal amounts to about 5% of the inclusive Λ sample.

J. Bartsch et al., Aachen-Berlin-CERN-London-Vienna Collaboration,
Study of Lambda Production in 10 GeV/c K^-p Interactions. CERN/D.Ph.II/
 Phys. 71-27 (1972); Nucl. Phys. B40, 103 (1972)

$K^- p \rightarrow \Lambda X$ $p_{INC} = 10.1 \text{ GeV}/c$

$$K^- p \rightarrow \Lambda X$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$$\frac{d\sigma}{dM_X} \text{ vs. } M_X$$

Events in which additional strange particle decays accompany the Λ have been removed. The authors point out that this removal amounts to about 5% of the inclusive Λ sample.

J. Bartsch et al., Aachen-Berlin-CERN-London-Vienna Collaboration,
Study of Lambda Production in 10 GeV/c K^-p Interactions, CERN/D.Ph. II-
 Phys. 71-27 (1972); Nucl. Phys. B40, 103 (1972)

$K^- p \rightarrow \Lambda X$ $p_{INC} = 10.1 \text{ GeV}/c$

$$K^- p \rightarrow \Lambda X$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$\frac{d\sigma}{dt'}$ vs. $t'_p \rightarrow \Lambda$ for various multiplicities

Events in which additional strange particles accompany the Λ have been removed. The authors point out that this removal amounts to about 5% of the inclusive Λ sample.

J. Bartsch et al., Aachen-Berlin-CERN-London-Vienna Collaboration,
Nucl. Phys. B40, 103 (1972)

$K^-p \rightarrow \Lambda X$

407

$P_{\text{INC}} = 10.1 \text{ GeV/c}$

$K^- p \rightarrow \Lambda X$ $P_{INC} = 10.1 \text{ GeV}/c$

Effective mass spectrum $\frac{d\sigma}{dM}$ of the pions associated with different multiplicities in the final states.

J. Bartsch et al., Aachen-Berlin-CERN-London-Vienna Collaboration,
Nucl. Phys. B40, 103 (1972)

$K^+ p \rightarrow \pi^- X$ $p_{INC} = 11.8 \text{ GeV}/c$

$$K^+ p \rightarrow \pi^- X$$

$$p_{INC} = 11.8 \text{ GeV}/c$$

Negative pion production-cosine distributions in the center of mass system at various E^{CM} of the π^- .

J. Erwin, W. Ko, R. L. Lander, D. E. Pellett and P. M. Yager,
Phys. Rev. Letters 27, 1534 (1971)

$K^+ + p \rightarrow \pi^- + \text{ANYTHING}, 12 \text{ GeV}/c, \text{ C. N.}$

$P_{INC} = 11.8 \text{ GeV}/c$

$K^+ p \rightarrow \pi^- X$

$$K^+ p \rightarrow \pi^- X$$

$$P_{INC} = 11.8 \text{ GeV/c}$$

The quantity $\frac{d^3\sigma}{dp^3}$ for produced π^- versus the center of mass energy of the π^- . The solid curve is a fit by the function $(e^{E^{CM}/kT} - 1)^{-1}$ while the dashed line is a straight line fitted to the region of E^{CM} between 0.2 and 0.3 GeV.

J. Erwin, W. Ko, R. L. Lander, D. E. Pellett and P. M. Yager,
Phys. Rev. Letters 27, 1534 (1971)

$K^+ p + \pi^- X$
 $P_{INC} = 11.8 \text{ GeV}/c$

$$K^+ p \rightarrow \pi^- X$$

$$p_{INC} = 11.8 \text{ GeV}/c$$

$$M_X^2 \frac{d^2\sigma}{dM_X^2 dt} \quad \text{vs. } \ln(M_X^2) \quad \text{for fixed intervals of } t \text{ where } M_X \text{ is}$$

the missing mass recoiling against the π^- . The solid straight lines are fits to the data for $M_X^2 < 16 \text{ GeV}$.

Winston Ko, Richard L. Lander and Clifford Risk, Phys. Rev. Letters 27, 1476 (1971)

$K^+p + \pi^-X$ $P_{INC} = 11.8 \text{ GeV}/c$

$$K^+ p \rightarrow \pi^- X$$

$$p_{INC} = 11.8 \text{ GeV}/c$$

The double differential cross section $\frac{d^2\sigma}{dM_X^2 dt}$ vs. t for various

intervals in M_X^2 , where M_X is the missing mass recoiling against the π^- .

Winston Ko, Richard L. Lander and Clifford Risk, Phys. Rev. Letters 27, 1476 (1971)

$K^+ + p \rightarrow \pi^- + \text{ANYTHING}$, 12 GeV/c
IN THE CM
29801 ENTRIES

$K^+ p \rightarrow \pi^- X$

L27

$P_{INC} = 12 \text{ GeV/c}$

$$K^+ p \rightarrow \pi^- X$$

$$P_{INC} = 12 \text{ GeV/c}$$

$\frac{d\sigma}{dx}$ vs. x ; $x = 2 \frac{p_{||}^{CM}}{\sqrt{s}}$. The dashed lines represent the data for

$\pi^- p \rightarrow \pi^- X$ at 25 GeV/c: Elbert et al., Phys. Rev. D 3, 2042 (1971).

W. Ko and R. L. Lander, Phys. Rev. Letters 26, 1064 (1971)

$$K^+ p \rightarrow \pi^- X$$

$$p_{INC} = 12 \text{ GeV}/c$$

$K^+ + p \rightarrow \pi^- + \text{ANYTHING}$, 12 GeV/
IN THE CM
359410 π^- 's

$$K^+ p \rightarrow \pi^- X$$

$$p_{INC} = 12 \text{ GeV}/c$$

$$\frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{\perp}^2} \text{ vs. } x; \quad x = 2p_{\parallel}^{CM}/\sqrt{s}$$

W. Ko and R. L. Lander, Phys. Rev. Letters 26, 1064 (1971)

$K^+ p \rightarrow \pi^+ X$
 $P_{INC} = 12 \text{ GeV/c}$

421

$$K^+ p \rightarrow \pi^- X$$

$$p_{INC} = 12 \text{ GeV}/c$$

The Lorentz-invariant differential cross section plotted
vs. $p_{\perp}^2$ for various values of $x = 2p_{||}^{CM}/\sqrt{s}$.

W. Ko and R. L. Lander, Phys. Rev. Letters 26, 1064 (1971)

$$K^+ p \rightarrow K^0 X$$

$$\rightarrow \bar{\Lambda}^0 X$$

$$\rightarrow \Lambda^0 X$$

$$p_{INC} = 12.7 \text{ GeV}/c$$

$\frac{d\sigma}{dp_2}$ vs. p_2

$$K^+ p \rightarrow K^0 X$$

$$\rightarrow \bar{\Lambda}^0 X$$

$$\rightarrow \Lambda^0 X$$

$$P_{INC} = 12.7 \text{ GeV/c}$$

$$(a) \text{ and } (b) \quad \frac{d\sigma}{dp_{||}^{PROJ}} \text{ vs. } p_{||}^{PROJ} \quad (\text{all quantities evaluated in projectile rest frame})$$

$$(c) \quad \frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } p_{||}^{LAB}$$

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c $K^+ p$ and 7 GeV/c $\pi^+ p$ Collisions, Univ. of Rochester preprint, UR-875-349 (Revised), (1972); Phys. Rev. D 5, 1621 (1972)

$$K_p^+ \rightarrow \Lambda^0 X$$

$$\rightarrow \bar{\Lambda}^0 X$$

$$p_{TINC} = 12.7 \text{ GeV}/c$$

RAPIDITY - ω

$$K^+ p \rightarrow \Lambda^0 X$$

$$\rightarrow \bar{\Lambda}^0 X$$

$$P_{INC} = 12.7 \text{ GeV}/c$$

$\frac{d\sigma}{dy^{CM}}$ vs. y^{CM} for produced Λ^0 and $\bar{\Lambda}^0$.

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c K^+p and 7 GeV/c π^+p Collisions, Univ. of Rochester preprint, UR-875-349 (Revised), (1972); Phys. Rev. D 5, 1621 (1972)

$$P_{INC} = 12.7 \text{ GeV}/c$$

RAPIDITY - ω

$$K^+ p \rightarrow \pi^- X$$

$$\rightarrow K^0 X$$

$$p_{INC} = 12.7 \text{ GeV}/c$$

$\frac{d\sigma}{dy^{CM}}$ vs. y^{CM} for produced π^- and K^0 .

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c and 7 GeV/c $\pi^+ p$ Collisions, Univ. of Rochester preprint, UR-875-349 (Revised), (1972); Phys. Rev. D 5, 1621 (1972)

$K^+p \rightarrow \pi^- X$ $p_{INC} = 12.7 \text{ GeV}/c$

$$K^+ p \rightarrow \pi^- X$$

$$P_{INC} = 12.7 \text{ GeV}/c$$

$$\frac{d\sigma}{dp_{||}^{CM}} \text{ vs. } p_{||}^{CM}$$

S. Stone, D. Cohen, M. Farber, T. Ferbel, R. Holmes, P. Slattery
and B. Werner, Nucl. Phys. B32, 19 (1971)

$$\begin{aligned} K^+ p &\rightarrow \pi^+ X \\ K^- p &\rightarrow \pi^+ X \end{aligned}$$

$$\begin{aligned} P_{INC} &= 13 \text{ GeV/c} \\ P_{INC} &= 13 \text{ GeV/c} \end{aligned}$$

$K^{\pm} p \rightarrow \pi^{\pm} \text{ at } 13 \text{ GeV/c}$

a.) • $K^+ p$ Yalex $K^+ p$ Rochesterb.) $K^- p$ by Topology

$$K^+ p \rightarrow \pi^- X$$

$$P_{INC} = 13 \text{ GeV/c}$$

$$K^- p \rightarrow \pi^+ X$$

$$P_{INC} = 13 \text{ GeV/c}$$

$$\frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } p_{||}^{LAB}$$

- for: (a) all topologies
 (b) separately by topology

T. Ludlam, Multiparticle Production in Hadron Collisions,
 invited talk at Cambridge Meeting of APS (1971) ✓
 Yale University preprint #3075-2

$K^+p \rightarrow K^0 n \text{ (charged particles) } X$
 $P_{INC} = 5, 8.2, 16 \text{ GeV/c}$

$K_p^+ + K^0$ (charged particles) X

$P_{INC} = 5, 8.2, 16 \text{ GeV}/c$

$\frac{E_{CM}}{\sigma_n} \frac{d\sigma_n}{dp_{||}^{CM}}$ vs. x for various numbers (n) of charged prongs.

P. V. Chliapnikov et al., CERN-Bruxelles-Birmingham-Saclay-
Paris Collaboration, Physics Letters 39B, 279 (1972)

$$K^+ p \rightarrow K^0 \pi^+ X$$

$$P_{INC} = 8.2 \text{ GeV}/c$$

$$K^+ p \rightarrow K^0 \pi^+ X$$

$$p_{INC} = 8.2 \text{ GeV}/c$$

left: Effective mass of the $(K^0 \pi^+)$ system for $|t'| = (0 + 1) \text{ GeV}^2$
and for several missing mass intervals

right: Effective mass of the $(K^0 \pi^+)$ system for missing mass
less than 2.5 GeV and for several t' intervals

P. Chliapnikov, O. Czyzewski, Y. Goldschmidt-Clermont, M. Jacob
and P. Herquet, Nucl. Phys. B37, 336 (1972)

$K^+ p \rightarrow K^0 X$
 $\rightarrow K^{*+}(890) X$
 $\rightarrow K^{*+}(1420) X$

$p_{INC} = 8.2 \text{ GeV}/c$

$$K^+ p \rightarrow K^0 X$$

$$\rightarrow K^{*+}(890)X$$

$$\rightarrow K^{*+}(1420)X$$

$$P_{INC} = 8.2 \text{ GeV}/c$$

$$\frac{d\sigma}{dt'} \text{ vs. } -t'; \quad t' = t - t_{MIN}$$

P. Chliapnikov, O. Czyzewski, Y. Goldschmidt-Clermont, M. Jacob
and P. Herquet, CERN preprint CERN/D.Ph.II/Phys. 71-44 (1971);
Nucl. Phys. B37, 336 (1972)

$K^+ p \rightarrow K^0 X$
 $\rightarrow K^{*+}(890) X$

$p_{INC} = 8.2 \text{ GeV}/c$

$$K^+ p \rightarrow K^0 X$$

$$\rightarrow K^{*+}(890) X$$

$$P_{INC} = 8.2 \text{ GeV}/c$$

$$E^{CM} \frac{d\sigma}{dp_{||}^{CM}} \text{ vs. } x; \quad x = p_{||}^{CM}/p_{||}^{CM, \text{ MAX}}$$

P. Chliapnikov, O. Czyzewski, Y. Goldschmidt-Clermont, M. Jacob
and P. Herquet, CERN preprint CERN/D.Ph.II/Phys. 71-44 (1971);
Nucl. Phys. B37, 336 (1972)

$$p_{INC} = 8.2 \text{ GeV}/c$$

$$\begin{aligned}
 K^+ p &\rightarrow K^0 X \\
 &\rightarrow K^{*+}(890) X
 \end{aligned}$$

$$P_{INC} = 8.2 \text{ GeV}/c$$

$$\frac{d\sigma}{dp_{\perp}^2} \text{ vs. } p_{\perp}^2$$

ed. note: The labels designating the two reactions seem to be reversed in the drawing

P. Chliapnikov, O. Czyzewski, Y. Goldschmidt-Clermont, M. Jacob and P. Herquet, CERN preprint CERN/D.Ph.II/Phys. 71-44 (1971); Nucl. Phys. B37, 336 (1972)

$$K^+ p \rightarrow K^0 X$$

$$\rightarrow K^{*+}(890)X$$

$$\rightarrow K^{*+}(1420)X$$

$$p_{INC} = 8.2 \text{ GeV}/c$$

$$K^+ p \rightarrow K^0 X$$

$$\rightarrow K^{*+}(890)X$$

$$\rightarrow K^{*+}(1420)X$$

$$P_{INC} = 8.2 \text{ GeV}/c$$

$$\frac{d^2\sigma}{dt'dM_X} \text{ plotted vs. } M_X \text{ for various values of } t' = t - t_{MIN}$$

P. Chliapnikov, O. Czyzewski, Y. Goldschmidt-Clermont, M. Jacob
and P. Herquet, CERN preprint CERN/D.Ph.II/Phys. 71-44 (1971);
Nucl. Phys. B37, 336 (1972)

$$K^+ p \rightarrow K^0 X$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$p_{\text{INC}} = 8.2 \text{ GeV/c}$$

$$p_{\text{INC}} = 10.1 \text{ GeV/c}$$

$$t'_{K K^0} = |t - t_{\min}|, \text{ GeV}^2$$

$$K^+ p \rightarrow K^0 X$$

$$p_{INC} = 8.2 \text{ GeV}/c$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$\frac{d\sigma}{dt'}$ vs. t' for various values of M_X

$$t' = |t - t_{MIN}|$$

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and
Bruxelles-CERN collaborations, Nucl. Phys. B30, 381 (1971)

$$\begin{aligned} & \bar{K}^+ p \rightarrow \bar{K}^0 X \\ & K^+ p \rightarrow K^0 X \end{aligned}$$

$$\begin{aligned} P_{INC} &= 10.1 \text{ GeV/c} \\ P_{INC} &= 8.2 \text{ GeV/c} \end{aligned}$$

447

$$\begin{aligned} K^- p &\rightarrow \bar{K}^0 X \\ K^+ p &\rightarrow K^0 X \end{aligned}$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$$p_{INC} = 8.2 \text{ GeV}/c$$

$$\left. \frac{d^2\sigma}{dp d\Omega} \right|_{LAB} \text{ vs. } p_{LAB} \text{ for various values of } \theta_{LAB}$$

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and
Bruxelles-CERN collaborations, Nucl. Phys. B30, 381 (1971)

$$K^- p \rightarrow \bar{K}^0 \pi^- X$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$$K^+ p \rightarrow K^0 \pi^+ X$$

$$p_{INC} = 8.2 \text{ GeV}/c$$

$$K^- p \rightarrow \bar{K}^0 \pi^- X$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$$K^+ p \rightarrow K^0 \pi^+ X$$

$$p_{INC} = 8.2 \text{ GeV}/c$$

Number of $K\pi$ combinations vs. $K\pi$ effective mass.

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and
Bruxelles-CERN collaborations, Nucl. Phys. B30, 381 (1971)

$$K^+ p \rightarrow K^0 X$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$p_{INC} = 8.2 \text{ GeV}/c$$

$$10.1 \text{ GeV}/c$$

$$K^+_p \rightarrow K^0 X$$

$$K^-_p \rightarrow \bar{K}^0 X$$

$$P_{INC} = 8.2 \text{ GeV}/c$$

$$10.1 \text{ GeV}/c$$

$$\frac{d\sigma}{dt}, \text{ vs. } t'; \quad t' = |t - t_{MIN}|$$

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and
Bruxelles-CERN collaborations, Nucl. Phys. B30, 381 (1971)

$$K^+ p \rightarrow K^0 X$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$P_{INC} = 8.2 \text{ GeV/c}$$

$$P_{INC} = 10.1 \text{ GeV/c}$$

$$K^+ p \rightarrow K^0 X$$

$$p_{INC} = 8.2 \text{ GeV}/c$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$$\frac{d\sigma}{dp}_{LAB} \text{ vs. } p^{LAB}$$

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna
and Bruxelles-CERN collaborations, Nucl. Phys. B30, 381 (1971)

$$K^+ p \rightarrow K^0 X$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$P_{INC} \approx 8.2 \text{ GeV/c}$$

$$P_{INC} \approx 10.1 \text{ GeV/c}$$

$$K^+ p \rightarrow K^0 X$$

$$P_{INC} = 8.2 \text{ GeV/c}$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$P_{INC} = 10.1 \text{ GeV/c}$$

$$\frac{d\sigma}{dp_{\perp}^2} \text{ vs. } p_{\perp}^2$$

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and
Bruxelles-CERN collaborations, Nucl. Phys. B30, 381 (1971)

$$p_{INC} = 9 \text{ GeV/c}$$

$$P_{INC} = 9 \text{ GeV/c}$$

$$E^{LAB} \frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } \left(p_{||}^{LAB} - p_{||}^{LAB}, \text{ MIN} \right)$$

Margaret C. Foster, Fragmentation Products of the Target and the Projectile in K^-p Interactions at 9 GeV/c, SUNY at Stony Brook preprint, Stony Brook, N.Y., (April 1972)

$$K^- p \rightarrow \pi^+ X$$

$$\rightarrow \Lambda^0 X$$

$$\rightarrow \bar{K}^0 X$$

$$p_{INC} = 9 \text{ GeV/c}$$

$$P_{INC} = 9 \text{ GeV}/c$$

$$E^{FROJ} \frac{d\sigma}{dp_{||}^{PROJ}} \quad \text{vs.} \quad \left(p_{||}^{PROJ, MAX} - p_{||}^{PROJ} \right) \quad \text{where all}$$

quantities are evaluated in the rest frame of the projectile.

Margaret C. Foster, Fragmentation Products of the Target and the Projectile in K^-p Interactions at 9 GeV/c, SUNY at Stony Brook preprint, Stony Brook, N.Y., (April 1972)

$K^- p \rightarrow \pi^- X$
 $K^- p \rightarrow \pi^+ X$
 $P_{INC} = 9 \text{ GeV}/c$
 $P_{INC} = 9 \text{ GeV}/c$

$$K^-p \rightarrow \pi^-X$$

$$P_{INC} = 9 \text{ GeV/c}$$

$$K^-p \rightarrow \pi^+X$$

$$P_{INC} = 9 \text{ GeV/c}$$

$\frac{d\sigma}{dx}$ vs. x , for $K^-p \rightarrow \pi^+X$, $x > 0$ and
for $K^-p \rightarrow \pi^-X$, $x < 0$.

The solid line represents a fit to the normalized distribution of $K^+p \rightarrow \pi^-X$ at 12 GeV/c: data of W. Ko and R. L. Lander, Phys. Rev. Letters 26, 1064 (1971). The dashed line represents a fit to the normalized distribution of $\pi^-p \rightarrow \pi^-X$ at 25 GeV/c: data of J. W. Elbert, A. R. Erwin and W. D. Walker, to be published.

M. Foster, J. A. Cole, E. Kim, J. Lee-Franzini, R. J. Loveless, C. Moore and K. Takahashi, Phys. Rev. Letters 27, 1312 (1971)

$K^- p \rightarrow \Lambda X$ $p_{INC} = 10.1 \text{ GeV}/c$

Polarization of Λ as a function of total multiplicity of particles in the final state.

The polarization is defined as:
$$p = \frac{3}{\alpha N} \sum_{i=1}^N (q_i \cdot n_i)$$

where q_i is a unit vector along the orientation of the decay proton in the Λ rest frame and $n = p_\Lambda \times p_K / |p_\Lambda \times p_K|$ is the normal to the production plane in the CM system. α is the asymmetry parameter ($\alpha = 0.65$) and N is the number of observed lambdas.

Events in which additional strange particle decays accompany the Λ have been removed. The authors point out that this removal amounts to about 5% of the inclusive Λ sample.

J. Bartsch et al., Aachen-Berlin-CERN-London-Vienna collaboration, Study of Lambda Production in 10 GeV/c K^-p Interactions, CERN/D.Ph. II/Phys. 71-27 (1972); Nucl. Phys. B40, 103 (1972); Nucl. Phys. B40, 103 (1972)

$K^- p \rightarrow \Lambda X$

465

$P_{\text{INC}} = 10.1 \text{ GeV/c}$

$K^- p \rightarrow \Lambda X$ $p_{INC} = 10.1 \text{ GeV/c}$ Polarization of Λ vs. $P_{||}^{CM}$ The polarization is defined as:
$$P = \frac{3}{\alpha N} \sum_{i=1}^N (q_i \cdot n_i)$$
where q_i is a unit vector along the orientation of the decay proton inthe α rest frame and $n = p_{\Lambda} \times p_K / |p_{\Lambda} \times p_K|$ is the normal to the productionplane in the CM system. α is the asymmetry parameter ($\alpha = 0.65$) and N

is the number of observed lambdas.

Events in which additional strange particle decays accompany the Λ have been removed. The authors point out that this removal amounts to about 5% of the inclusive Λ sample.

J. Bartsch et al., Aachen-Berlin-CERN-London-Vienna collaboration, Study of Lambda Production in 10 GeV/c $K^- p$ Interactions, CERN/D.Ph.II/Phys. 71-27 (1972)

$K^- p \rightarrow \Lambda X$

$p_{TMC} = 10.1 \text{ GeV}/c$

$K^-p \rightarrow \Lambda X$ $p_{INC} = 10.1 \text{ GeV}/c$ $\frac{d\sigma}{dx} \text{ vs. } x; \quad x = p_{||}^{CM}/p_{MAX}^{CM}$ $\frac{d\sigma}{dp_{\perp}^2} \text{ vs. } p_{\perp}^2$

Events in which additional strange particle decays accompany the Λ have been removed. The authors point out that this removal amounts to about 5% of the inclusive Λ sample.

J. Bartsch et al., Aachen-Berlin-CERN-London-Vienna Collaboration,
Study of Lambda Production in 10 GeV/c K^-p Interactions, CERN/
 D.Ph.II/Phys. 71-27 (1972); Nucl. Phys. B40, 103 (1972)

$$K^+ p \rightarrow \pi^+ X$$

$$p_{\text{INC}} = 4.2 \text{ GeV}/c$$

$$K^- p \rightarrow \pi^- X$$

$$p_{INC} = 4.2 \text{ GeV}/c$$

$$\frac{d\sigma}{dx} \text{ vs. } x$$

R. Blokzijl et al., Amsterdam-Nijmegen collaboration, presented at the Amsterdam International Conference on Elementary Particles, Amsterdam, 1971

See also: Nucl. Phys. B39, 141 (1972)

Fig. 37

$$\bar{K}^0 p \rightarrow \bar{K}^0 \chi$$

$$p_{INC} = 4.2, 10 \text{ GeV/c}$$

$$\frac{d\sigma}{dx} (\mu\text{b}) \text{ vs. } x$$

$$\frac{2E_{CM}}{\sqrt{s}} \frac{d\sigma}{dx} (\mu\text{b}) \text{ vs. } x$$

M. Deutschman, Many-Particle Reactions

Rapporteur's talk given at the Amsterdam International Conference on Elementary Particles, Amsterdam, 1971.

4.2 GeV/c data from R. Blokzijl et al., Amsterdam-Nijmegen Collaboration, presented at the Amsterdam International Conference on Elementary Particles, Amsterdam, 1971.

10 GeV/c data from J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and Bruxelles-CERN Collaborations, Nucl. Phys. B30, 381 (1971)

$K^-p \rightarrow \Lambda + X$ $p_{\text{INC}} = 4.2 \text{ and } 10.1 \text{ GeV/c}$

$K^- p \rightarrow \Lambda X$ $p_{INC} = 4.2 \text{ and } 10.1 \text{ GeV}/c$

$$\frac{E_{CM}}{p_{MAX}^{CM}} \frac{d\sigma}{dx}, \frac{d\sigma}{dx}, \text{ and } \frac{1}{\sigma(\Lambda)} \frac{d\sigma}{dx} \text{ vs. } x;$$

$$x = p_{||}^{CM} / p_{MAX}^{CM}$$

Events in which a visible K_1^0 decay accompanies the Λ have been removed. The authors point out that this has the effect of removing about 1/4 of the events corresponding to $K^- p \rightarrow \Lambda K^0 X$, and amounts to the removal of less than 5% of the inclusive Λ sample.

M. Deutschmann et al., Aachen-Berlin-CERN-London-Vienna and Amsterdam-Nijmegen Collaborations, Scaling Properties of the Inclusive Reaction $K^- + p \rightarrow \Lambda + \text{anything}$, CERN/D.Ph.II/Phys. 71-48 (1972); Nucl. Phys. B39, 133 (1972)

$$K^+ p \rightarrow K^0 X$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$P_{INC} = 5 \text{ and } 8.2 \text{ GeV/c}$$

$$P_{INC} = 10.1 \text{ GeV/c}$$

$$K^+ p \rightarrow K^0 X$$

$$K^- p \rightarrow \bar{K}^0 X$$

$$p_{INC} = 5 \text{ and } 8.2 \text{ GeV}/c$$

$$p_{INC} = 10.1 \text{ GeV}/c$$

$$\frac{d\sigma}{dM_X} \text{ vs. } M_X$$

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and
Bruxelles-CERN collaborators, Nucl. Phys. B30, 381 (1971)

$K^+p \rightarrow K^0X$
 $p_{INC} = 5.0, 8.2 \text{ GeV}/c$
 $K^-p \rightarrow K^0X$
 $p_{INC} = 10.0 \text{ GeV}/c$

$$K^+ p \rightarrow K^0 X$$

$$p_{INC} = 5.0, 8.2 \text{ GeV}/c$$

$$K^- p \rightarrow K^0 X$$

$$p_{INC} = 10.0 \text{ GeV}/c$$

Longitudinal momentum distributions of neutral kaons in the rest frames of the incident kaons for $K^+ p$ at 5.0 and at 8.2 GeV/c and $K^- p$ at 10.0 GeV/c.

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and Bruxelles-CERN Collaborations, Nucl. Phys. B30, 381 (1971)

$P_{INC}^{K^+} = 10.1 \text{ GeV/c}$
 $P_{INC}^{K^0} = 5 \text{ and } 8.2 \text{ GeV/c}$

$$K^- p \rightarrow \bar{K}^0 X$$

$$P_{INC} = 10.1 \text{ GeV/c}$$

$$K^+ p \rightarrow K^0 X$$

$$P_{INC} = 5 \text{ and } 8.2 \text{ GeV/c}$$

$$\frac{d\sigma}{dx} \text{ vs. } x; x = p_{||}^{CM}/p_{||}^{CM}, \text{ MAX}$$

J. V. Beaupre et al., Aachen-Berlin-CERN-London-Vienna and
Bruxelles-CERN collaborations, Nucl. Phys. B30, 381 (1971)

REFERENCE LIST OF INCLUSIVE DATA: K_p COLLISIONS

<u>P_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
4.2	Blokzijl	NP	B39 141 (1972)	AN	HBC
4.2, 10.1	Deutschmann	NP	B39 133 (1972)	ABCLV-AN	HBC
5.0	Bassompierre	NP	B9 295 (1969)	CB	HBC
5.0	DeBaere	NP	B22 131 (1970)	CB	HBC
5.0, 8.2, 16.0	Chliapnikov	PL	B39 279 (1972)	CBBFS	HBC
5.0, 8.2, 10.1	Beaupre	NP	B30 381 (1971)	ABCLV-BC	HBC
8.2	Chliapnikov	NP	B37 336 (1972)	CB	HBC
9.0	Foster	PRL	27 1312 (1971)	STONY	HBC
9.0	Foster	preprint	(1972)	STONY	HBC
"Cross Sections and Correlations for 2-Particle Inclusive Reactions in K^-p Collisions at 9 GeV/c"					
9.0	Foster	preprint	(1972)	STONY	HBC
"Fragmentation Products of the Target and the Projectile..."					
9.0	Foster	preprint	(1972)	STONY-VAND	HBC
"Azimuthal Correlations of High Energy Collision Products"					
10.1	Bartsch	NP	B40 103 (1972)	ABCLV	HBC
11.8	Erwin	PRL	27 1535 (1971)	UCD	HBC
11.8	Ko	PRL	26 1284 (1971)	UCD	HBC
11.8	Ko	PRL	28 935 (1972)	UCD	HBC
11.8	Ko	PRL	28 1010 (1972)	UCD	HBC

<u>P_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
11.8	Ko	PRL	<u>26</u> 1064 (1971)	UCD	HBC
11.8	Ko	PRL	<u>27</u> 1476 (1972)	UCD	HBC
11.8	Swanson	preprint-SLAC-PUB-979		SLAC-UCD-LRL	HBC
"Comparison of the Inclusive π^- Distributions from γp , $K p$, and pp COLLISIONS"					
11.8	Swanson	Cornell Conf (1971) preprint		SLAC-UCD	STRM-HBC
"Factorization in the Inclusive Reactions $\gamma p \rightarrow \pi^- + \text{Anything}$ and $K^+ p \rightarrow \pi^- + \text{Anything}$ "					
12.7	Jain	NP	<u>B19</u> 568 (1970)	BUFF-ROCH	HBC
12.7	Stone	PL	<u>B32</u> 515 (1970)	ROCH	HBC
12.7	Stone	PR	<u>D5</u> 1621 (1972)	ROCH	HBC
12.7	Stone	NP	<u>B32</u> 19 (1971)	ROCH	HBC
12.7	Chen	PRL	<u>26</u> 1585 (1971)	ROCH-BNL-WISC	HBC

482

ABCLV = Aachen-Berlin-CERN-London-Vienna Collaboration

AN = Amsterdam-Nijmegen Collaboration

CB = CERN-Bruxelles Collaboration

CEBPS = CERN-Bruxelles-Birmingham-Paris-SACLAY Collaboration

II-E. Data on Inclusive Spectra: π^+p

$P_{||} = 2.15 - 6 \text{ GeV/c}$

$\pi^- p + \pi^+ X$

$$\pi^- p \rightarrow \pi^+ X$$

$$\pi^- p \rightarrow \pi^- X$$

$$p_{INC} = 2.15 - 6 \text{ GeV}/c$$

(a) and (b) $\frac{d^2\sigma}{dp_{||}^{LAB} dp_{\perp}^2}$ vs. beam momentum for various values of $p_{||}^{LAB}$.

The solid lines indicate the average cross section at fixed $p_{||}^{LAB}$ for beam momenta of 3.95 - 6 GeV/c; the dashed curves are drawn to guide the eye.

(c) $\frac{d^2\sigma}{dp_{||}^{LAB} dp_{\perp}^2}$ vs. $p_{||}^{LAB}$ for $\pi^- p$ and pp collisions.

$$p_{\perp}^2 = 0$$

The solid lines are a fit discussed by the authors.

R. W. Anthony, C. T. Coffin, E. S. Meanley, J. E. Rice, K. M. Terwilliger and
R. M. Stanton, Phys. Rev. Letters 26, 38 (1971)

- optical spark-chamber data

$P_{TMC} = 5 - 6 \text{ GeV/c}$

$\pi^- + \pi^- + \pi^- + \pi^-$

$$\begin{aligned}\pi^- p &\rightarrow \pi^+ X \\ &\rightarrow \pi^- X\end{aligned}$$

$$P_{\text{INC}} = 5 - 6 \text{ GeV}/c$$

$\frac{d^2\sigma}{dp_{||}^{\text{LAB}} dp_{\perp}^2}$ vs. $p_{\perp}^2$ for fixed values of $p_{||}^{\text{LAB}}$ for π^+ and π^- production. The solid lines are fits to the data of the form $\exp[-bp_{\perp}^2]$ and the resulting values of b are tabulated. Dashed lines indicate regions omitted from the fit.

R. W. Anthony, C. T. Coffin, E. S. Meanley, J. E. Rice, K. M. Terwilliger
and R. M. Stanton, Phys. Rev. Letters 26, 38 (1971)

-optical spark-chamber data

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 7 \text{ GeV}/c$$

$d\sigma/dy^{\text{CM}}$ vs. y^{CM} for the reaction $\pi^+ p \rightarrow \pi^- X$

S. Stone, T. Ferbel, P. Slattery and B. Werner, Phys. Rev. D5, 1621 (1972)

$$\pi^+ p \rightarrow \pi^- X$$

$$P_{INC} \approx 7 \text{ GeV}/c$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 7 \text{ GeV}/c$$

$$d\sigma/dp_{\parallel}^{\text{CM}} \text{ vs. } p_{\parallel}^{\text{CM}}$$

S. L. Stone, D. Cohen, M. Farber, T. Ferbel, R. Holmes, P. Slattery and
B. Werner, Rochester preprint UR-875-335, Nucl. Phys. B 32, 19 (1971)

$$\pi^+ p \rightarrow pX$$

$$p_{INC} = 6, 22 \text{ GeV}/c$$

$\pi^+ p \rightarrow pX$ $p_{INC} = 6, 22 \text{ GeV/c}$

$\frac{E_{LAB}}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{LAB}}$ vs. $p_{||}^{LAB}$, and the ratio (R) of this function at 22 GeV/c

to that at 6 GeV/c.

$\frac{2E_{CM}}{\sigma_{TOTAL} \sqrt{s}} \frac{d\sigma}{dx}$ vs. x , and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c, ($x = 2p_{||}^{CM}/\sqrt{s}$).

The authors note that the π^+/p ambiguity is less than 10% for $x < -0.5$ and for $p_{||}^{LAB} < 0.8 \text{ GeV/c}$.

D. J. Crennell, H. A. Gordon, M. I. Ioffredo and Kwan-Wu Lai, A Study of Inclusive Reactions of $\pi^+ p \rightarrow X + \text{Anything}$ ($X = \pi^+, \pi^-, K_S^0$, and p) at 6 and 22 GeV/c, Brookhaven National Laboratory Report BNL-16417 (1971)

$$\pi^+ p \rightarrow \pi^+ X$$

$$p_{INC} = 6, 22 \text{ GeV}/c$$

$$\pi^+ p + \pi^+ X$$

$$P_{\text{INC}} = 6, 22 \text{ GeV/c}$$

(top) $\frac{E^{\text{LAB}}}{\sigma_{\text{TOTAL}}^{\text{LAB}}} \frac{d\sigma}{dp_{||}}^{\text{LAB}}$ vs. $p_{||}^{\text{LAB}}$, and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c.

(middle) $\frac{2E^{\text{CM}}}{\sigma_{\text{TOTAL}}^{\text{CM}} \sqrt{s}} \frac{d\sigma}{dx}$ vs. x , and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c, ($x = 2p_{||}^{\text{CM}}/\sqrt{s}$)

(bottom) $\frac{E^{\text{PROJ}}}{\sigma_{\text{TOTAL}}^{\text{PROJ}}} \frac{d\sigma}{dp_{||}}^{\text{PROJ}}$ vs. $p_{||}^{\text{PROJ}}$, and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c.

The authors note that the π^+/p ambiguity is a 5 - 30% effect on the π^+ spectrum for $p_{||}^{\text{LAB}} > 1.0 \text{ GeV/c}$. This effect is $\sim 2 - 6\%$ for $x < 0$.

$$\pi^+ p \rightarrow K_S^0 X$$

$$p_{TNC} = 6, 22 \text{ GeV/c}$$

$$\pi^+ p \rightarrow K_S^0 X$$

$$p_{\text{INC}} = 6, 22 \text{ GeV/c}$$

(top) $\frac{E^{\text{LAB}}}{\sigma_{\text{TOTAL}}} \frac{d\sigma}{dp_{||}^{\text{LAB}}}$ vs. $p_{||}^{\text{LAB}}$, and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c.

(middle) $\frac{2E^{\text{CM}}}{\sigma_{\text{TOTAL}} \sqrt{s}} \frac{d\sigma}{dx}$ vs. x , and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c, ($x = 2p_{||}^{\text{CM}}/\sqrt{s}$).

(bottom) $\frac{E^{\text{PROJ}}}{\sigma_{\text{TOTAL}}} \frac{d\sigma}{dp_{||}^{\text{PROJ}}}$ vs. $p_{||}^{\text{PROJ}}$, and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c.

D. J. Crennell, H. A. Gordon, M. I. Ioffredo and Kwan-Wu Lai, Phys. Rev. Letters 28, 643 (1972)

$$\pi^+ p + \pi^- X$$

$$p_{INC} = 6, 22 \text{ GeV/c}$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{INC} = 6, 22 \text{ GeV/c}$$

(top) $\frac{E^{LAB}}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{LAB}}$ vs. $p_{||}^{LAB}$, and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c.

(middle) $\frac{2E^{CM}}{\sigma_{TOTAL} \sqrt{s}} \frac{d\sigma}{dx}$ vs. x , and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c, ($x = 2p_{||}^{CM}/\sqrt{s}$).

(bottom) $\frac{E^{PROJ}}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{PROJ}}$ vs. $p_{||}^{PROJ}$, and the ratio (R) of this function at 22 GeV/c to that at 6 GeV/c.

D. J. Crennell, H. A. Gordon, M. I. Ioffredo and Kwan-Wu Lai, Phys. Rev. Letters 28, 643 (1972)

$$\pi^- p \rightarrow \pi^- X$$

$$p_{INC} = 8 \text{ GeV}/c$$

Plot of $d\sigma/dM_X d\Omega_{LAB}$ vs. missing mass M_X , indicating the separations of the cross section into background and resonance contributions at momentum transfers $0.026 < |t_{\pi\pi}| < 0.050 \text{ (GeV/c)}^2$

E. W. Anderson, E. J. Bleser, H. R. Blieden, G. B. Collins, D. Garelick, J. Menes, F. Turkot, D. Birnbaum, R. M. Edelstein, N. C. Hien, T. J. McMahon, J. F. Mucci and J. S. Russ, Phys. Rev. Letters 25, 699 (1970)

$\pi^- p \rightarrow pX$ $p_{TINC} = 8, 16 \text{ GeV}/c$

$\pi^- p \rightarrow pX$ $p_{INC} = 8, 16 \text{ GeV/c}$

Plots $d\sigma/d\Omega_{LAB} \frac{dM_X^2}{M_X^2}$ vs. M_X^2 for near-forward protons [$M_X \leq 1.0 (\text{GeV/c})^2$],
 where the proton has:

- (a) $\theta^{LAB} = 20 \rightarrow 26 \text{ mrad.}$ [$t_{pp} \sim -0.02 (\text{GeV/c})^2$] and $p_{INC} = 8 \text{ GeV/c}$
- (b) $\theta^{LAB} = 58 \rightarrow 76 \text{ mrad.}$ [$t_{pp} \sim -0.29 (\text{GeV/c})^2$] and $p_{INC} = 8 \text{ GeV/c}$
- (c) $\theta^{LAB} = 20 \rightarrow 26 \text{ mrad.}$ [$t_{pp} \sim -0.13 (\text{GeV/c})^2$] and $p_{INC} = 16 \text{ GeV/c}$
- (d) $\theta^{LAB} = 30 \rightarrow 38 \text{ mrad.}$ [$t_{pp} \sim -0.30 (\text{GeV/c})^2$] and $p_{INC} = 16 \text{ GeV/c}$

E. W. Anderson, E. J. Bleser, K. R. Blieden, G. B. Collins, D. Garelick,
 J. Menes, F. Turkot, D. Birnbaum, R. M. Edelstein, N. C. Hien, T. J. McMahon,
 J. Mucci and J. Russ, Phys. Rev. Letters 22, 102 (1969)

-BNL AGS; counter experiment

$$\pi^+ p \rightarrow pX$$

$$p_{INC} = 8, 16 \text{ GeV}/c$$

$$\left(E \frac{d\sigma}{dp_{||}} \right)^{LAB} \text{ vs. } p_{||}^{LAB}$$

J. V. Beaupre et al., Phys. Letters 37B, 432 (1971)
 (ABECCHN Collaboration)

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{INC} = 8, 16 \text{ GeV}/c$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 8, 16 \text{ GeV}/c$$

$$\frac{2E^{\text{CM}}}{\pi\sqrt{s}} \frac{d\sigma}{dx} \text{ vs. } x.$$

J. V. Beaupre et al., Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw
collaboration, Physics Letters 37B, 432 (1971)

$(2E^2/\pi\sqrt{s}) \cdot (d\sigma/dx) \cdot \mu b$

$p_{||}^{INC} = 8, 16 \text{ GeV}/c$

$\pi^+ p \rightarrow \pi^+ X$

$$\pi^+ p \rightarrow \pi^+ X$$

$$p_{INC} = 8, 16 \text{ GeV}/c$$

$$\frac{2E}{\pi\sqrt{s}} \frac{d\sigma}{dx} \text{ vs. } x.$$

J. V. Beaupre et al., Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw
collaboration, Physics Letters 37B, 432 (1971)

$$\pi^+ p \rightarrow \pi^+ X$$

$$P_{INC} = 8, 16 \text{ GeV/c}$$

$$\pi^+ p \rightarrow \pi^+ X$$

$$p_{INC} = 8, 16 \text{ GeV}/c$$

$$E_{LAB} \frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } p_{||}^{LAB} \text{ for backward emitted } \pi^+.$$

J. V. Beaupre et al., Aschen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw
collaboration, Physics Letters 37B, 432 (1971)

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 8, 16 \text{ GeV/c}$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{INC} = 8, 16 \text{ GeV}/c$$

$$E_{LAB} \frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } p_{||}^{LAB} \text{ for backward emitted } \pi^-.$$

J. V. Beaupre et al., Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw
collaboration, Physics Letters 37B, 432 (1971)

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^+ X$$

$$p_{INC} = 0, 18.5, 24.8 \text{ GeV/c}$$

$$p_{INC} = 18.5 \text{ GeV/c}$$

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^+ X$$

$$p_{INC} = 8, 18.5, 24.8 \text{ GeV}/c$$

$$p_{INC} = 18.5 \text{ GeV}/c$$

$$\frac{2E^{CM}}{\pi\sqrt{s}} \frac{d\sigma}{dx} \text{ vs. } x$$

..

W. D. Shephard et al. (Notre Dame, Wisconsin), Phys. Rev. Letters 27,
1164 (1971)

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^- X$$

$$P_{INC} = 8, 18.5, 24.8 \text{ GeV/c}$$

$$P_{INC} = 18.5 \text{ GeV/c}$$

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^- X$$

$$P_{INC} = 8, 18.5, 24.8 \text{ GeV/c}$$

$$P_{INC} = 18.5 \text{ GeV/c}$$

$$\frac{E_{LAB}}{(\sigma_{TOTAL})_{\infty}} \frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } p_{||}^{LAB}$$

W. D. Shephard et al. (Notre Dame, Wisconsin), Phys. Rev. Letters 27,
1164 (1971)

$$\pi^- p \rightarrow \pi^- X$$

$$p_{INC} = 8, 18.5 \text{ GeV/c}$$

$$\pi^- p \rightarrow \pi^- X$$

$$p_{INC} = 8, 18.5 \text{ GeV}/c$$

$\frac{2E^{CM}}{\pi\sqrt{s}} \frac{d\sigma}{dx}$ vs. x , and the ratio of this function at 18.5 GeV/c to the same function at 8 GeV/c.

N. N. Biswas et al., Univ. of Notre Dame preprint #71-44

$\pi^- p \rightarrow \pi^- X$ $P_{INC} = 8.05 \text{ GeV/c}$ $\pi^- p \rightarrow \pi^- X$ $P_{INC} = 18.5 \text{ GeV/c}$ $\pi^+ p \rightarrow \pi^- X$ $P_{INC} = 18.5 \text{ GeV/c}$

$$\pi^- p \rightarrow \pi^- X$$

$$P_{INC} = 8.05 \text{ GeV}/c$$

$$\pi^- p \rightarrow \pi^- X$$

$$P_{INC} = 18.5 \text{ GeV}/c$$

$$\pi^+ p \rightarrow \pi^- X$$

$$P_{INC} = 18.5 \text{ GeV}/c$$

$$d\sigma/dy^{CM} \text{ vs. } y^{CM}$$

W. D. Shephard, J. T. Powers, N. N. Biswas, N. M. Cason, V. P. Kenney and
D. W. Thomas, Phys. Rev. Letters 28, 703 (1972)

$$\pi^+ p \rightarrow \pi^- X$$

$$P_{INC} = 3.7, 7, 18.5 \text{ GeV/c}$$

$$\pi^+ p \rightarrow \pi^- X$$

$$P_{\text{INC}} = 3.7, 7, 18.5 \text{ GeV/c}$$

$$G(P_{||}^{\text{PROJ}}) = \frac{E^{\text{PROJ}}}{\sigma_{\text{TOTAL}}} \frac{d^2 \sigma}{dP_{||}^{\text{PROJ}} dP_{\perp}^2} dP_{\perp}^2 \text{ vs. } P_{||}^{\text{PROJ}}$$

The inset table shows the integral of $G(P_{||}^{\text{PROJ}})$ over $0 < P_{||}^{\text{PROJ}} < 0.4 \text{ GeV/c}$

Margaret Alston-Garnjost et al., Berkeley-Notre Dame collaboration,
 Physics Letters 39B, 402 (1972)

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^+ X$$

$$\pi^+ p \rightarrow \pi^+ X$$

$$P_{INC} = 6.05, 18.5 \text{ GeV/c}$$

$$P_{INC} = 3.7, 7, 18.5 \text{ GeV/c}$$

$$P_{INC} = 3.7, 7, 18.5 \text{ GeV/c}$$

$$\begin{array}{l} \pi^- p \rightarrow \pi^- X \\ \pi^+ p \rightarrow \pi^+ X \\ \pi^+ p \rightarrow \pi^+ X \end{array}$$

$$\begin{array}{l} P_{\text{INC}} = 8.05, 18.5 \text{ GeV/c} \\ P_{\text{INC}} = 3.7, 7, 18.5 \text{ GeV/c} \\ P_{\text{INC}} = 3.7, 7, 18.5 \text{ GeV/c} \end{array}$$

$$G(p_{||}^{\text{LAB}}) = \int \frac{E^{\text{LAB}}}{\sigma_{\text{TOTAL}}} \frac{d^2 \sigma}{dp_{||}^{\text{LAB}} dp_{\perp}^2} dp_{\perp}^2 \text{ vs. } p_{||}^{\text{LAB}}$$

Margaret Alston-Garnjost et al., Berkeley-Notre Dame collaboration,
Physics Letters 39B, 402 (1972)

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^+ X$$

$$\pi^+ p \rightarrow \pi^+ X$$

$$p_{INC} = 8.05, 18.5 \text{ GeV/c}$$

$$p_{INC} = 3.7, 7, 18.5 \text{ GeV/c}$$

$$p_{INC} = 3.7, 7, 18.5 \text{ GeV/c}$$

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^+ X$$

$$P_{INC} = 8.05, 18.5 \text{ GeV/c}$$

$$P_{INC} = 3.7, 7, 18.5 \text{ GeV/c}$$

$$P_{INC} = 3.7, 7, 18.5 \text{ GeV/c}$$

$$F(x) = \sqrt{\frac{1}{\sigma_{TOTAL}} \frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{\perp}^2} dp_{\perp}^2} \text{ vs. } x$$

M. Alston-Garnjost, K. W. Barnham, M. S. Rabin, A. Barbaro-Galtieri,
 S. M. Flatte, J. H. Friedman, G. R. Lynch, J. N. MacNaughton, F. T. Solmitz,
 C. Risk, W. D. Shephard, J. T. Powers, N. N. Biswas, N. M. Cason,
 V. P. Kenney and D. W. Thomas, Physics Letters 39B, 402 (1972)

$$\pi^+ p \rightarrow \pi^+ X$$

 $P_{\text{INC}} = 8.5 \text{ GeV/c}$

$$\pi^+ p \rightarrow \pi^+ X$$

8.5 GeV/c

$$\begin{array}{l} \pi^+ + \pi^+ X \\ \quad \quad \rightarrow \pi^- X \end{array}$$

$$p_{\text{INC}} = 8.5 \text{ GeV}/c$$

$$\frac{1}{\sigma_{\text{TOTAL}}} \frac{d\sigma}{dp_{\perp}^2} \text{ vs. } p_{\perp}^2 \text{ for } \pi^+ \text{ production (left) and } \pi^- \text{ production (right)}$$

R. J. Loveless, J. A. Cole, J. Lee-Franzini and P. Franzini, Inclusive Particle Distributions for 8.5 GeV/c π^+ p Interactions, SUNY (Stony Brook), paper presented at the Divisional Meeting of the APS, Division of Particles and Fields, Rochester (August 1971)

$$\pi^+ p \rightarrow \pi^+ X$$

$$\pi^- X$$

$$p_{INC} = 8.5 \text{ GeV}/c$$

$$\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{PROJ}} \text{ vs. } F_{||}^{PROJ} \text{ for } \pi^- \text{ production (left) and } \pi^+ \text{ production (right)}$$

R. J. Loveless, J. A. Cole, J. Lee-Franzini and F. Franzini, Inclusive Particle Distributions for 8.5 GeV/c π^+ p Interactions, SUNY (Stony Brook), paper presented at the Divisional Meeting of the APS, Division of Particles and Fields, Rochester (August 1971)

$$\pi^+ p \rightarrow \pi^+ X$$

$$p_{\text{INC}} = 8.5 \text{ GeV/c}$$

$$\pi^+ p \rightarrow \pi^- X$$

$$8.5 \text{ GeV/c}$$

$$\pi^+ p \rightarrow \pi^+ X \\ + \pi^- X$$

$$p_{INC} = 8.5 \text{ GeV/c}$$

$$\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dx'} \text{ vs. } x', \text{ for } \pi^- \text{ production (left) and } \pi^+ \text{ production (right)}$$

$$x' = \frac{p_{||}^{CM}}{p_{||, MAX}^{CM}}, \text{ where } p_{||, MAX}^{CM} = \sqrt{(p_{MAX}^{CM})^2 - p_{\perp}^2}; \text{ note that as } s \rightarrow \infty, x' \rightarrow x.$$

R. J. Loveless, J. A. Cole, J. Lee-Franzini and P. Franzini, Inclusive Particle Distributions for 8.5 GeV/c $\pi^+ p$ Interactions, SUNY (Stony Brook), paper presented at the Divisional Meeting of the APS, Division of Particles and Fields, Rochester (August 1971)

$\pi^+p \rightarrow \pi^+X$
 $+ \pi^-X$

$p_{||NC} = 8.5 \text{ GeV/c}$

$$\pi^+ p \rightarrow \pi^+ X$$

$$\quad \rightarrow \pi^- X$$

$$p_{\text{INC}} = 8.5 \text{ GeV}/c$$

$$\frac{1}{\sigma_{\text{TOTAL}}} \frac{d\sigma}{dp_{||}^{\text{LAB}}} \text{ vs. } p_{||}^{\text{LAB}} \text{ for } \pi^+ \text{ production (left) and } \pi^- \text{ production (right)}$$

R. J. Loveless, J. A. Cole, J. Lee-Franzini and P. Franzini, Inclusive Particle Distributions for 8.5 GeV/c $\pi^+ p$ Interactions, SUNY (Stony Brook), paper presented at the Divisional Meeting of the APS, Division of Particles and Fields, Rochester (August 1971)

$$\pi^- p \rightarrow \pi^- X$$

$$\rightarrow \pi^+ X$$

$$p_{\text{INC}} = 16 \text{ GeV/c}$$

$$\begin{aligned}\pi^- p &\rightarrow \pi^- X \\ &\rightarrow \pi^+ X\end{aligned}$$

$$P_{INC} \approx 16 \text{ GeV/c}$$

$\frac{d^2\sigma}{dp_{\perp}^2 d\xi}$ vs. ξ for various $p_{\perp}^2$ intervals for the reactions

$$(a) \quad \pi^- p \rightarrow \pi^+ X$$

$$(b) \quad \pi^- p \rightarrow \pi^- X$$

where the reduced rapidity, $\xi = \frac{y_a^{CM} - y_b^{CM}}{y_a^{CM} - y_b^{CM}}$, and y_a^{CM} and y_b^{CM} are the rapidities of the beam and target respectively and y^{CM} is the rapidity of the produced pion.

Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw collaboration, results quoted by M. Deutschmann in Many Particle Reactions, Rapporteur's talk given at the Amsterdam International Conference on Elementary Particles, Amsterdam (1971)

$$\pi^- p \rightarrow \pi^+ X$$

$$p_{THC} = 16 \text{ GeV}/c$$

$$\pi^- p \rightarrow \pi^+ X$$

$$p_{\text{INC}} = 16 \text{ GeV}/c$$

$$\frac{2E^{\text{CM}}}{\pi\sqrt{s}} \frac{d^2\sigma}{dp_{\perp}^2 dx} \text{ vs. } x,$$

$$x = 2p_{\parallel}^{\text{CM}}/\sqrt{s}, \text{ for a range of } p_{\perp}^2$$

The π^- data is compared with CERN-ISR data.

Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw collaboration, quoted by M. Deutschmann in Many Particle Reactions, a Rapporteur's talk at the Amsterdam International Conference on Elementary Particles (1971)

$$\pi^- p \rightarrow \pi^- X$$

$$\rightarrow \pi^+ X$$

$$p_{INC} = 16 \text{ GeV/c}$$

$$\begin{array}{l} \pi^- p \rightarrow \pi^- X \\ \quad \rightarrow \pi^+ X \end{array}$$

$$p_{INC} = 16 \text{ GeV}/c$$

$$\frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dp_{\perp}^2 dx} \text{ vs. } x \text{ for the reactions}$$

$$(a) \quad \pi^- p \rightarrow \pi^+ X$$

$$(b) \quad \pi^- p \rightarrow \pi^- X$$

Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw collaboration, results quoted by M. Deutschmann in Many-Particle Reactions, Rapporteur's talk given at the Amsterdam International Conference on Elementary Particles, Amsterdam (1971)

$\pi^- p + \pi^- X$
+ pX

$$\pi^- p \rightarrow \pi^- X$$

$$+ pX$$

$$P_{INC} = 16 \text{ GeV}/c$$

(left) $\frac{d\sigma}{dp_{\perp}^2}$ vs. $p_{\perp}^2$ for the reaction $\pi^- p \rightarrow \pi^- X$.

(right) $\frac{d\sigma}{dp_{\perp}^2}$ vs. $p_{\perp}^2$ for the reaction $\pi^- p \rightarrow pX$.

The solid curves are the results obtained by fitting a sum of two exponentials to the data. The dashed lines indicate the steep behavior near $p_{\perp}^2 = 0$.

U. Gensch and H. J. Schreiber, Square of Transverse Momentum Distributions and Influence of Isobars in Pion Induced Reactions, preprint, Institut für Hochenergiephysik, Deutsche Akademie der Wissenschaften zu Berlin, Berlin-Zeuthen DDR (1971)

$p_{TMC} = 16$ GeV/c

$\pi^- p \rightarrow \pi^+ X$

$$\pi^- p \rightarrow \pi^+ X$$

$$p_{\text{INC}} = 16 \text{ GeV}/c$$

(left) $\frac{d\sigma}{dp_{\perp}^2}$ vs. $p_{\perp}^2$ for the reaction $\pi^- p \rightarrow \pi^+ X$.

(right) mean $p_{\perp}^2$ vs. x unweighted by E^{CM} (top) and weighted by E^{CM} (bottom).

The solid curves are the results obtained by fitting a sum of two exponentials to the data. The dashed lines indicate the steep behavior near $p_{\perp}^2 = 0$.

U. Gensch and H. J. Schreiber, Square of Transverse Momentum Distributions and Influence of Isobars in Pion Induced Reactions, preprint, Institute für Hochenergiephysik, Deutsche Akademie der Wissenschaften zu Berlin, Berlin-Zeuthen DDR (1971)

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{INC} = 18.5 \text{ GeV}/c$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 18.5 \text{ GeV/c}$$

(a) $\frac{dN}{dp_{\perp}^2} (\text{GeV/c})^{-2}$ vs. $p_{\perp}^2 (\text{GeV/c})^2$ for particles with

$0 < x < 0.1$, for all 4-, 6-, 8- and 10-prong events separately.

(b) $\frac{dN}{dp_{\perp}^2} (\text{GeV/c})^{-2}$ vs. $p_{\perp}^2 (\text{GeV/c})^2$ for 4-prong events, in various regions of x .

N. N. Biswas, N. M. Mason, V. P. Kenney, J. T. Powers, W. D. Shephard
and D. W. Thomas (Notre Dame), *Phys. Rev. Letters* 26, 1589 (1971)

$\pi^+ p \rightarrow \pi^- X$

$P_{INC} = 18.5 \text{ GeV}/c$

$$\pi^{\pm} p \rightarrow \pi^{\mp} X$$

$$p_{INC} = 18.5 \text{ GeV}/c$$

- (a) $\frac{dN}{dx}$ vs. x for $\pi^+ p$ data for all 4-, 6-, 8- and 10-prong events.
- (b) as (a) above for $\pi^- p$ data.

N. N. Biswas, N. M. Cason, V. P. Kenney, J. T. Powers, W. D. Shephard
and D. W. Thomas (Notre Dame), Phys. Rev. Letters 26, 1589 (1971)

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{TNC} = 18.5 \text{ GeV}/c$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{INC} = 18.5 \text{ GeV}/c$$

$dN/dp_{\perp}$ vs. $p_{\perp}$ for various regions of x .

N. N. Biswas, N. M. Cason, V. P. Kenney, J. T. Powers, W. D. Shephard and
D. W. Thomas (Notre Dame), Phys. Rev. Letters 26, 1589 (1971)

$$\pi^- p \rightarrow \pi^- X$$

$$P_{INC} = 25 \text{ GeV}/c$$

$$\frac{d\sigma}{dp_{||}^{CM}} \text{ vs. } p_{||}^{CM}$$

J. W. Elbert, A. T. Erwin and W. D. Walker (Wisconsin), Phys. Rev. D 3,
2042 (1971)

$$\pi^- p + \pi^+ X$$

$$p_{\text{INC}} = 25 \text{ GeV}/c$$

$\frac{d\sigma}{dp_{||}^{\text{CM}}}$ vs. $p_{||}^{\text{CM}}$ for "produced" pions, (i.e., eliminating the leading π^- by

choosing π^- only in backward hemisphere. To eliminate protons only +ve tracks in the forward hemisphere are used, and these are assumed to be pions.)

J. W. Elbert, A. R. Erwin and W. D. Walker (Wisconsin), Phys. Rev. D3,
2042 (1971)

$\pi^- p + (\pi^+ \text{ or } p) X$ $P_{\text{INC}} = 25 \text{ GeV/c}$ 25 GeV/c $\pi^- p$

LABORATORY LONGITUDINAL MOMENTUM DISTRIBUTION

LABORATORY LONGITUDINAL MOMENTUM (GeV/c)

$\pi^- p \rightarrow (\pi^+ \text{ or } p) X$
 $P_{\text{INC}} = 25 \text{ GeV}/c$

$$d\sigma/dp_{||}^{\text{LAB}} \text{ vs. } p_{||}^{\text{LAB}} \text{ for all positive tracks.}$$

A. R. Erwin, Review on Multiparticle Production--Experimental, Proceedings of the International Conference on Expectations for Particle Reactions at the New Accelerators, Univ. of Wisconsin, Madison (April 1970)

$$\pi^- p \rightarrow \pi^- X$$

$$P_{INC} = 25 \text{ GeV}/c$$

$$25 \text{ GeV}/c \quad \pi^- p$$

LABORATORY LONGITUDINAL MOMENTUM DISTRIBUTION

LABORATORY LONGITUDINAL MOMENTUM (GeV/c)

$$\pi^- p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 25 \text{ GeV/c}$$

$$d\sigma/dp_{\parallel}^{\text{LAB}} \text{ vs. } p_{\parallel}^{\text{LAB}}$$

A. R. Erwin (Wisconsin), Review on Multiparticle Production, Madison Conference, March 1970

$$\pi^- p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 25 \text{ GeV}/c$$

$$\pi^- p \rightarrow \pi^- X$$

$$p_{INC} = 25 \text{ GeV}/c$$

$$d\sigma/dp_{||}^{BEAM} \text{ vs. } p_{||}^{BEAM}$$

A. R. Erwin (Wisconsin), Review on Multiparticle Production, Madison Conference, March 1970.

REFERENCE LIST OF INCLUSIVE DATA: πp COLLISIONS

<u>P_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
0 + 30	Wroblewski	PL	<u>32B</u> 145 (1970)	WARS	THEOR
1.4 + 4.0	Crouch	PRL	<u>21</u> 845 (1968)	BHPWM	SPRK
2.15 + 6.0	Anthony	PRL	<u>26</u> 38 (1971)	MICH-OHIO	SPRK
2.15 + 6.0	Chen	PRL	<u>26</u> 280 (1971)	BNL	THEOR
2.45	Buhl	preprint	(1971)	WISC	TRIG-HBC
"Meson and Strange Baryon Production in a Bubble Chamber..."					
3.7 + 18.5	Alston-Garnjost	PL	<u>39B</u> 402 (1972)	LBL-UCB-NDAM	HBC
6, 22	Crennell	PRL	<u>28</u> 643 (1972)	BNL	HBC
6, 22	Crennell	BNL-16417		BNL	HBC
"Study of Inclusive Reactions of $\pi^+ p \rightarrow X + \text{anything}...$ "					
7.0	Chen	PRL	<u>26</u> 1585 (1971)	WISC-BNL-ROCH	HBC
7.0	Stone	NP	<u>B32</u> 19 (1971)	ROCH	HBC
7.0	Stone	PR	<u>D5</u> 1621 (1972)	ROCH	HBC
7.5, 20.0	Balea	Rev Roum Phys	<u>16</u> 189 (1971)	BUCH	HBC
8.0	Balea	Rev Roum Phys	<u>15</u> 233 (1970)	BUCH	HBC
8.0	Coghen	NP	<u>B32</u> 189 (1971)	CRAC	HBC
8, 16	Anderson	PRL	<u>25</u> 699 (1970)	BNL	CNTR

<u>PINC</u> (GeV/c)	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
8, 16	Anderson	PRL	<u>22</u> 102 (1969)	BNL	CNTR
8, 16	Beaupre	PL	<u>37B</u> 432 (1971)	ABBCCHW	HBC
8, 18.5	Shephard	PRL	<u>28</u> 703 (1972)	NDAM	HBC
8, 18.5, 25	Shephard	PRL	<u>27</u> 1164 (1971)	NDAM-WISC	HBC
8, 18.5, 25	Shephard	PRL	<u>28</u> 260 (1972)	NDAM-WISC	HBC
8, 11, 16	Piotroska	PL	<u>32B</u> 71 (1970)	WARSAW	RVUE
8.5	Cole	PR	<u>D4</u> 627 (1971)	STON	HBC
8.5	Loveless	preprint	(1971)	STON	HBC
"Inclusive Particle Distribution for 8.5 GeV/c π^+ p Interactions"					
10 + 26	Folley	PRL	<u>19</u> 397 (1967)	BNL	CNTR
11.0	Caso	preprint	(1968)	GENOA-DHMS	HBC
"Some Experimental Results on Many Body Collisions in π^- p at 11 GeV/c"					
16.0	Honecker	NP	<u>B13</u> 571 (1969)	ABBCCHW	HBC
16.0	Honecker	NP	<u>B32</u> 141 (1971)	ABBCCHW	HBC
16.0	Gensch	preprint PHE	71-15 (1971)	BERL	HBC
"Square of Transverse Momentum Distributions and Influence of..."					
18.5	Biswas	PRL	<u>26</u> 1589 (1971)	NDAM	HBC
20.0	Lee-Franzini	preprint	(1972)	NDAM	HBC
"Target Recoil Spectra in 20 GeV π^- p Interactions"					

<u>p_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
25	Elbert	PRL	<u>20</u> 124 (1968)	WISC	HBC
25	Elbert	NP	<u>B19</u> 85 (1970)	WISC	HBC
25	Elbert	PR	<u>D3</u> 2042 (1971)	WISC	HBC
25	Erwin	WISC CONF	(1970)	WISC	HBC
			"Multiparticle Production"		
25	Elbert	thesis		WISC	HBC
			"High Multiplicity Pion Production in 25 GeV/c π^-p Collisions"		
60	Anzon	PL	<u>31B</u> 2.17 (1970)	ALMA-ATA-CDMSTUB	EMUL

(I-F. Data on Inclusive Spectra: ep (μ p)

$ep \rightarrow eX$ $E_{INC} = 4.879 \text{ GeV}$

$(d\sigma/d\Omega dE)^{LAB}$ vs. E^{LAB} (or missing mass $W \equiv M_X$) at an angle $\theta^{LAB} = 10^\circ$

W. Bartel, B. Dudelzak, H. Krehbiel, J. McElroy, U. Meyer-Berkhout,
W. Schmidt, V. Walther and G. Weber, Physics Letters 28B, 148 (1968)

ep + epX

$$E_{\text{INC}} = 4, 4.9, 5.4 \text{ GeV/c}$$

$ep \rightarrow epX$ $E_{INC} = 4, 4.9, 5.4 \text{ GeV/c}$

The missing-mass-squared spectrum dN/dM_X^2 for $ep \rightarrow epX$ for incident electrons

of energy: (a) 4.0 GeV
 (b) 4.9 GeV
 (c) 5.4 GeV

C. Driver, K. Heinloth, K. Hühne, G. Hofmann, P. Karow, G. Pfeffer,
D. Schmidt, G. Specht, J. Rathje, DESY-Hamburg, Nucl. Phys. B39, 106 (1972)

$\gamma \nu p + X$
 $(\gamma_\nu \equiv \text{virtual } \gamma)$

$\gamma_V^P \rightarrow X$

Plot of the structure function $\frac{\omega_2}{\omega_W} \equiv \frac{\omega v_W^2}{\omega_W}$ vs. $\omega_W \equiv \frac{2Mv + M_W^2}{q^2 + a^2}$ for

$W > 1.8 \text{ GeV}$ and $q^2 > 3(\text{GeV})^2$, $q^2 < 1 (\text{GeV})^2$, $q^2 = 0$. Here the authors

assume $R \equiv \frac{\sigma_s}{\sigma_T} = \frac{q^2}{v^2}$. M_W^2 and a^2 are free parameters, here fitted by

$M_W^2 = 1.53 \pm 0.06 (\text{GeV})^2$ and $a^2 = 0.41 \pm 0.02 (\text{GeV})^2$, to obtain the solid

scaling curve.

Data is taken from:

G. Miller et al., SLAC-PUB -815 (April, 1971)

M. Breidenbach, thesis, M.I.T. Report 2098-635 (May, 1970)

J. Ballam et al., Phys. Rev. Letters 23, 498 (1969)

H. Meyer et al., Physics Letters 33B, 189 (1970)

W. P. Hesse, thesis, University of California, Santa Barbara (1971)

F. W. Brasse, E. Chazelas, W. Fehrenbach, K. H. Frank, E. Ganssauge,

J. Gayler, V. Korbel, J. May, M. Merwitz, V. Rittenberg, H. R. Rubinstein,

DESY-Weizmann, Nucl. Physics B39, 421 (1972)

$ep \rightarrow eX$ $E_{INC} = 7, 10, 13.5, 16 \text{ GeV}$

$ep \rightarrow eX$ $E_{INC} = 7, 10, 13.5, 16 \text{ GeV}$

Plots of the structure function νW_2 vs. $\omega = 2M\nu/q^2$ for various assumptions about $R = \sigma_s/\sigma_{TOTAL}$.

(a) $q^2 > 0.5 \text{ (GeV/c)}^2$, $R = 0$, $\theta^{LAB} = 10^\circ$, $E_{INC} = 10, 13.5, 16 \text{ GeV}$

(c) $q^2 > 0.5 \text{ (GeV/c)}^2$, $R = \infty$, $\theta^{LAB} = 6^\circ$, $E_{INC} = 10, 13.5, 16 \text{ GeV}$

(e) $q^2 < 0.5 \text{ (GeV/c)}^2$, $R = 0$ and $R = \infty$, $\theta^{LAB} = 6^\circ$, $E_{INC} = 7 \text{ GeV}$

M. Breidenbach, J. I. Friedman, H. W. Kendall, E. D. Bloom, D. H. Coward,
H. DeStaebler, J. Drees, L. W. Mo and R. E. Taylor, MIT-SLAC, Phys.
Rev. Letters 23, 935 (1967)

$$E_{\text{INC}} = 7, 10, 11, 13.5, 15.2, \\ 16, 17.7 \text{ GeV}$$

 $ep \rightarrow eX$

ep $\rightarrow$ eX

$$E_{\text{INC}} = 7, 10, 11, 13.5, 15.2, 16, 17.7 \text{ GeV}$$

Plots of the structure function νW_2 vs. $\omega = 2M\nu/q^2$ for various assumptions about $R = \sigma_s/\sigma_{\text{TOTAL}}$

$$(b) \quad q^2 > 0.5 \text{ (GeV/c)}^2, R = 0, \theta^{\text{LAB}} = 10^\circ, E_{\text{INC}} = 10, 13.5, 16 \text{ GeV}$$

$$(d) \quad q^2 > 0.5 \text{ (GeV/c)}^2, R = \infty, \theta^{\text{LAB}} = 10^\circ, E_{\text{INC}} = 7, 11, 13.5, 15.2, 17.7 \text{ GeV}$$

M. Breidenbach, J. I. Friedman, H. W. Kendall, E. D. Bloom, D. H. Coward,
 R. DeStaebler, J. Drees, L. W. Mo and R. E. Taylor, MIT-SLAC, Phys.
 Rev. Letters 23, 935 (1969)

ep + eX

 $E_{\text{INC}} = 7, 16, 17.7 \text{ GeV}$

$ep \rightarrow eX$ $E_{\text{INC}} = 7, 16, 17.7 \text{ GeV}$ $(d\sigma/d\Omega dE)^{\text{LAB}}$ vs. missing mass $W \equiv M_X$ for

$$(a) \quad \theta^{\text{LAB}} = 6^\circ, \quad 0.2 \leq q^2 \leq 0.5 \text{ (GeV/c)}^2, \quad E_{\text{INC}} = 7 \text{ GeV}$$

$$(b) \quad \theta^{\text{LAB}} = 6^\circ, \quad 0.7 \leq q^2 \leq 2.6 \text{ (GeV/c)}^2, \quad E_{\text{INC}} = 16 \text{ GeV}$$

$$(c) \quad \theta^{\text{LAB}} = 10^\circ, \quad 1.6 \leq q^2 \leq 7.3 \text{ (GeV/c)}^2, \quad E_{\text{INC}} = 17.7 \text{ GeV}$$

The spectra contain radiative corrections; elastic peaks are not shown.

E. D. Bloom, D. H. Coward, H. DeStaebler, J. Drees, G. Miller, L. W. Mo,
 R. E. Taylor, M. Breidenbach, J. I. Friedman, G. C. Hartmann and
 H. W. Kendall and SLAC-MIT, Phys. Rev. Letters 23, 930 (1969)

$ep \rightarrow eX$ $E_{INC} = 10 \text{ GeV}$

$(d\sigma/dQdE)^{LAB}$ vs. missing mass $W \equiv M_X$

Figure (a) shows the spectrum before radiative corrections (with the elastic peak reduced by a factor of 6); Fig. (b) shows the corrected spectrum. Fig. (c) shows the ratio $(d\sigma)_{CORRECTED}/(d\sigma)_{UNCORRECTED}$.

No systematic errors are shown.

E. D. Bloom, D. H. Coward, H. DeStebler, J. Drees, G. Miller, L. W. Mo,
R. E. Taylor, M. Breidenbach, J. I. Friedman, G. C. Hartmann and
H. W. Kendall, SLAC-MIT, Phys. Rev. Letters 23, 930 (1969)

ep $\rightarrow$ eX

$$E_{\text{INC}} = 7 + 17.7 \text{ GeV}$$

The structure function νW_2 vs. $\omega \equiv 2M\nu/q^2$ in the resonance region, after the fitted resonances have been subtracted, assuming

$$R = \sigma_S/\sigma_T = 0.2. \quad \theta^{\text{LAB}} = 6^\circ, 10^\circ.$$

Statistical errors from the fits are shown.

E. D. Bloom, G. Buschhorn, R. L. Cottrell, D. H. Coward, H. DeStaebler, J. Drees, C. L. Jordan, G. Miller, L. Mo, H. Piel, R. E. Taylor, M. Breidenbach, W. R. Ditzler, J. I. Friedman, G. C. Hartmann, H. W. Kendall and J. S. Poucher, SLAC-MIT collaboration, Recent Results in Inelastic Electron Scattering, SLAC-PUB-796 (1970)

See also: E. D. Bloom et al., Phys. Rev. Letters 23, 930 (1969)
M. Breidenbach et al., Phys. Rev. Letters 23, 935 (1969)

ep $\rightarrow$ eX

$$E_{INC} \approx 4 + 20 \text{ GeV}$$

The structure function νW_2 vs. $\omega \equiv 2M\nu/q^2$ for $M_X > 2 \text{ GeV}$ and $q^2 > 1 \text{ (GeV/c)}^2$, assuming $R = \sigma_S/\sigma_T = 0.18$.

The data is taken at $\theta^{LAB} = 6^\circ, 10^\circ, 18^\circ, 24^\circ, 36^\circ$.

E. D. Bloom, G. Buschhorn, R. L. Cottrell, D. H. Coward, H. DeStaebler, J. Drees, C. L. Jordan, G. Miller, L. Mo, H. Piel, R. E. Taylor, M. Breidenbach, W. R. Ditzler, J. I. Friedman, G. C. Hartmann, H. W. Kendall and J. S. Poucher, SLAC-MIT collaboration, Recent Results in Inelastic Electron Scattering, SLAC-PUB-796 (1970)

ep $\rightarrow$ eX $E_{INC} \sim 4 \rightarrow 20$ GeV

The structure function $2M W_1$ vs. $\omega \equiv 2M\nu/q^2$ for $M_X > 2$ GeV
 and $q^2 > 1$ (GeV/c) 2 , assuming $R = \sigma_S/\sigma_T = 0.18$.

The data is taken at $\theta^{LAB} = 6^\circ, 10^\circ, 18^\circ, 24^\circ, 36^\circ$.

E. D. Bloom, G. Buschhorn, R. L. Cottrell, D. H. Coward, H. DeStaebler,
 J. Drees, C. L. Jordan, G. Miller, L. Mo, H. Piel, R. E. Taylor,
 M. Breidenbach, W. R. Ditzler, J. I. Friedman, G. C. Hartmann, H. W. Kendall
 and J. S. Poucher, SLAC-MIT collaboration, Recent Results in Inelastic
 Electron Scattering, SLAC-PUB-796 (1970)

$\gamma_V P \rightarrow X$
 $(\gamma_V \equiv \text{virtual } \gamma)$

$$E_{\text{INC}} = 4 + 20 \text{ GeV}/c$$

$$\gamma_V p \rightarrow X$$

$$E_{INC} = 4 + 20 \text{ GeV/c}$$

Plot of the structure function νW_2 vs. $\omega = \frac{2M\nu}{q^2}$, for various assumptions

about $R = \sigma_L/\sigma_T$, based on preliminary data of the SLAC-MIT collaboration

at $\theta^{LAB} = 18^\circ, 26^\circ, 34^\circ$.

R. E. Taylor, Proceedings of the International Conference on Expectations for Particle Reactions at the New Accelerators, Univ. of Wisconsin (April, 1970)

ep + ex
ed + ex

$E_{\text{INC}} = 4 + 20 \text{ GeV}$

ep $\rightarrow$ eX

$$E_{\text{INC}} = 4 + 20 \text{ GeV}$$

ed $\rightarrow$ eX

Plots of the ratio $\frac{D}{H} - 1 \equiv \frac{(\nu W_2)_d}{(\nu W_2)_p} - 1$ vs. $\omega' = \frac{2M\nu + M^2}{q^2}$ from

preliminary data of the SLAC-MIT collaboration.

Upper figure: $\theta^{\text{LAB}} = 6^\circ$ and 10° ; $E_{\text{INC}} = 4.5 + 19.5 \text{ GeV}$; $q^2 > 1.0 (\text{GeV}/c)^2$

Lower figure: $\theta^{\text{LAB}} = 18^\circ, 24^\circ, 36^\circ$; $E_{\text{INC}} = 4.5 + 18 \text{ GeV}$; $q^2 > 1.5 (\text{GeV}/c)^2$

The data displayed comes from the regions $M_X > 2 \text{ GeV}/c^2$ and $E^{\text{LAB}} \geq 2.5 \text{ GeV}$.

H. W. Kendall, report at the 1971 International Symposium on Electron and Photon Interactions at High Energies, Cornell Univ., (1971), Deep Inelastic Electron Scattering in the Continuum Region

ep + ex
ed + ex

$E_{INC} = 4 + 20 \text{ GeV}$

ep $\rightarrow$ eX

$$E_{\text{INC}} = 4 \rightarrow 20 \text{ GeV}$$

ed $\rightarrow$ eX

Plots of the structure function νW_2 vs. $\omega' = \frac{2M\nu + M^2}{q^2}$ from preliminary

data of the SLAC-MIT collaboration at

$$\theta^{\text{Lab}} = 6^\circ, E_{\text{INC}} = 4.5, 7, 10, 13.5, 16, 19.5 \text{ GeV}$$

$$\text{and } \theta^{\text{LAB}} = 10^\circ, E_{\text{INC}} = 4.9, 7, 9, 11, 13.5, 15.2, 17.7, 19.3 \text{ GeV.}$$

The data displayed comes from the regions $q^2 > 1.0 \text{ (GeV/c)}^2$, $M_X > 2 \text{ GeV/c}^2$
and $E^{\text{LAB}} \geq 2.5 \text{ GeV}$.

Only statistical errors are shown.

H. W. Kendall, report at the 1971 International Symposium on Electron and Photon Interactions at High Energies, Cornell Univ., (1971), Deep Inelastic Electron Scattering in the Continuum Region

ep + ex
ed + ex

595

$E_{INC} = 4 + 20 \text{ GeV}$

ep $\rightarrow$ eX

$$E_{\text{INC}} = 4 + 20 \text{ GeV}$$

ed $\rightarrow$ eX

Plots of the structure function νW_2 vs. $\omega' \approx \frac{2M\nu + M^2}{q^2}$

from preliminary data at $\theta^{\text{LAB}} = 5.99^\circ$ of the SLAC-MIT collaboration

H. W. Kendall, report at the 1971 International Symposium on Electron and Photon Interactions at High Energies, Cornell Univ. (1971), Deep Inelastic Electron Scattering in the Continuum Region

$ep \rightarrow eX$ $E_{INC} = 4.5 + 18 \text{ GeV}$

ep + eX

 $E_{INC} = 4.5 \rightarrow 18 \text{ GeV}$

The structure function νW_2 vs. missing mass $W(= M_X)$, for fixed

$\omega = 2M_p \nu/q^2 = 1.5, 2, 3, 6, 12$ based on the assumption

$$R \equiv \sigma_S/\sigma_{TOTAL} = 0.18$$

The curved solid line represents a fit,

$$\nu W_2 = F(\omega') = (1 - 1/\omega')^3 [0.6453 + 1.902 (1 - 1/\omega') - 2.343 (1 - 1/\omega')^2],$$

where $\omega' \equiv \omega + a/q^2$, with $a = 0.95 \pm 0.07 \text{ (GeV/c)}^2$

The dashed line represents a fit

$$\nu W_2 = F(\omega) = (1 - 1/\omega)^3 [1.274 + 0.5989 (1 - 1/\omega) - 1.675 (1 - 1/\omega)^2]$$

The data was obtained for $\theta^{LAB} = 6^\circ, 10^\circ, 18^\circ, 26^\circ, 34^\circ$

G. Miller, E. D. Bloom, G. Buschhorn, D. H. Coward, H. DeStaebler, J. Drees,
C. L. Jordan, L. W. Mo, R. E. Taylor, J. I. Griedman, G. C. Hartmann,
H. W. Kendall and R. Verdier, SLAC-MIT collaboration, Phys. Rev. D 5,
528 (1972)

$ep \rightarrow eX$ $E_{INC} = 4.5 + 18 \text{ GeV}$

ep $\rightarrow$ eX

$$E_{\text{INC}} = 4.5 + 18 \text{ GeV}$$

The structure functions for $\gamma_V p \rightarrow X$, $2M_p W_1$ and W_2 vs. the scaling variable $\omega \equiv 2M_p \nu/q^2$, assuming $R = \sigma_L/\sigma_{\text{TOTAL}} = 0.18$, and using data in the range $M_X > 2.6 \text{ GeV}/c^2$, $q^2 > 1 (\text{GeV}/c)^2$.

The ep $\rightarrow$ eX data was taken at $\theta^{\text{LAB}} = 6^\circ, 10^\circ, 18^\circ, 26^\circ, 34^\circ$.

G. Miller, E. D. Bloom, G. Buschhorn, D. H. Coward, H. DeStaebler, J. Drees, C. L. Jordan, L. W. Mo, R. E. Taylor, J. I. Friedman, G. C. Hartmann, H. W. Kendall and R. Verdier, SLAC-MIT collaboration, Phys. Rev. D 5, 528 (1972)

REFERENCE LIST OF INCLUSIVE DATA: ep, ed COLLISIONS

SLAC-MIT Collaboration

- Panofsky PR 102 1392 (1956)
- Panofsky PR 110 1155 (1958)
- Panofsky Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna (September 1968)
- Hand PR 129 1834 (1963)
- Lynch PR 164 1635 (1967)
- Bloom SLAC-PUB-653 (1969)
- Bloom PRL 23 930 (1969)
- Breidenbach PRL 23 935 (1969)
- Breidenbach Thesis, MIT Report 2098-635 (1970), "Inelastic Electron-Proton Scattering at High Momentum Transfer"
- Taylor Proceedings of the Fourth International Symposium on Electron and Photon Interactions at High Energies, Daresbury (September 1969)
- Bloom SLAC-PUB-796 (September 1970), Kiev Conference Report, "Recent Results in Inelastic ep Scattering"
- Bloom SLAC-PUB-805 (1970)
- Kendall "Deep Inelastic Electron Scattering in the Continuum Region," Report at the 1971 International Symposium on Electron and Photon Interactions at High Energies, Cornell Univ., Ithaca (1971)
- Miller SLAC-PUB-815 (April 1971)
- PR D5 528 (1972)

DESY-HAMBURG Collaboration

Weber	<u>Proceedings of the International Symposium on Electron and Photon Interactions at High Energies</u> , SLAC, Stanford (September 1967), p. 59		
Brasse	NC	<u>55A</u>	679 (1968)
Bartel	PL	<u>28B</u>	148 (1968)
Albrecht	NP	<u>B13</u>	1 (1969)
Moritz	DESY Report 71/61 (1971) <u>1971 International Symposium on Electron and Photon Interactions at High Energies</u> , Cornell Univ., Ithaca (1971)		
Driver	NP	<u>B32</u>	45 (1971)
	NP	<u>B33</u>	84 (1971)
	NP	<u>B38</u>	1 (1972)
	PL	<u>35B</u> ,	77 and 81 (1971)
Galster	PR	<u>D5</u>	519 (1972)

Other Groups

Kummer	Daresbury preprint DNPL/P67 (1971)		DNPL
Hellings	NP	<u>B32</u>	179 (1971) DNPL
Cone	PR	<u>156</u>	1490 (1967); PR <u>163</u> 1854 (1967) HARV
Mistretta	PR	<u>184</u>	1487 (1969) HARV
Brown	PRL	<u>26</u>	987 and 991 (1971) HARV

REFERENCE LIST OF INCLUSIVE DATA: μp COLLISIONS

<u>p_{INC} (GeV/c)</u>	<u>First Author</u>		<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
10.1	Jain	PRL	<u>24</u> 526 (1970)	BUFF	EMUL
10.1, 15.8	Jain	preprint	(1971)	BUFF	EMUL
		"Inclusive Reaction $\mu + \text{Nucleon} \rightarrow \pi + \text{Anything} \dots$ "			
12	Toner	PL	<u>36B</u> 251 (1971)	SLAC-NMEX	CNTR

II-G. Data on Inclusive Spectra: γ p

$$\gamma + p \rightarrow n^+ X$$

$$\underline{\gamma + p \rightarrow n^+ X}$$

Average charged $\langle n \rangle$ and $\pi^- \langle n^- \rangle$ multiplicity versus $s(\text{GeV}^2)$
 The straight lines are the results of a fit to the data of
 the form $\langle n \rangle = c \ln s + d$. ($c = 0.93 \pm 0.12$, $d = 1.01 \pm 0.22$)
 and ($c^- = 0.44 \pm 0.04$, $d^- = 0.07 \pm 0.08$).

K. C. Moffeit et al., SLAC, Berkeley, Tufts Univ., Phys. Rev. D 5,
 1603 (1972); Phys. Rev. D 5, 1603 (1972)

$$\gamma + p \rightarrow N_{\text{PRONGS}}$$

$\gamma + p \rightarrow N_{\text{PRONGS}}$

Total and topological cross sections versus the center of mass energy squared $s(\text{GeV}^2)$

K. C. Morfeit et al., SLAC, Berkeley, Tufts Univ., Phys. Rev. D5, 1603 (1972); Phys. Rev. D5, 1603 (1972)

$\gamma p \rightarrow \pi^- X$ $E_{INC} = 2.8, 4.7, 9.3 \text{ GeV}$ $\gamma p \rightarrow \pi^- + (\text{ANYTHING})$

$$\gamma p \rightarrow \pi^- X$$

$$E_{\text{INC}} = 2.8, 4.7, 9.3 \text{ GeV}$$

$$d\sigma/dy^{\text{LAB}} \text{ vs. } y^{\text{LAB}}$$

The solid and broken bell-shaped curves superimposed on the 9.3 GeV data represent the 2.8 and 4.7 GeV data beneath, having the same y_{MIN} while the partial curves are the lower energy data transposed to have the same y_{MAX} .

K. C. Moffett et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reaction $\gamma p \rightarrow \pi^- + (\text{ANYTHING})$ with Polarized Photons at 2.8, 4.7 and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D 5, 1603 (1972)

$$E_{INC} = 2.8, 4.7, 9.3 \text{ GeV}$$

$$\gamma p \rightarrow \pi^- X$$

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 2.8, 4.7, 9.3 \text{ GeV}$

 $d\sigma/dy^{\text{LAB}}$ vs. y^{LAB} for various intervals in $p_{\perp}^2$

K. C. Morfeit et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reaction $\gamma p \rightarrow \pi^- + (\text{ANYTHING})$ with Polarized Photons at 2.8, 4.7 and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D 5, 1603 (1972)

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 2.8, 4.7, 9.3 \text{ GeV}$

$$F(x, \langle p_1^2 \rangle) = \frac{1}{\pi} \int_0^b \frac{E^*}{p_{\text{max}}^*} \frac{d^2\sigma}{dx dp_1^2} dp_1^2 (\mu\text{b})$$

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 2.8, 4.7, 9.3 \text{ GeV}$

$F(x, \langle p_{\perp}^2 \rangle) = \frac{1}{\pi} \int_a^b \frac{E_{\text{CM}}}{P_{\text{MAX}}} \frac{d^2 \sigma}{dx dp_{\perp}^2} dp_{\perp}^2$ vs. x , where $x = p_{\parallel}^{\text{CM}}/P_{\text{MAX}}^{\text{CM}}$, for various intervals (ab) in transverse momentum.

K. C. Moffeit et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reaction $\gamma p \rightarrow \pi^- + (\text{ANYTHING})$ with Polarized Photons at 2.8, 4.7, and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D 5, 1603 (1972)

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 2.8, 4.7, 9.3 \text{ GeV}$

$\gamma p \rightarrow \pi^- X$ $E_{INC} = 2.8, 4.7, 9.3 \text{ GeV}$

$$F(p_{\perp}^2) = \int_{-0.15}^{+0.15} E^{LAB} \frac{d^2\sigma}{dp_{\perp}^2 dp_{||}} dp_{||}^{LAB} \text{ vs. } p_{\perp}^2$$

K. C. Moffeit et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reaction $\gamma p \rightarrow \pi^- + \text{(ANYTHING)}$ with Polarized Photons at 2.8, 4.7, and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D5, 1603 (1972)

$\gamma p \rightarrow \pi^- X$ $E_{INC} = 2.8, 4.7, 9.3 \text{ GeV}$

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 2.8, 4.7, 9.3 \text{ GeV}$

$$F(p_{||}^{\text{LAB}}) = \int_0^\infty \frac{E^{\text{LAB}}}{d p_{\perp}^2 d p_{||}^{\text{LAB}}} \frac{d^2 \sigma}{d p_{\perp}^2} \text{ vs. } p_{||}^{\text{LAB}}$$

K. C. Moffeit et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reactions $\gamma p \rightarrow \pi^- + \text{(ANYTHING)}$ with Polarized Photons at 2.8, 4.7, and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D 5, 1603 (1972)

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 2.8, 4.7, 9.3 \text{ GeV}$

$\gamma p \rightarrow \pi^- X$ $E_{INC} = 2.8, 4.7, 9.3 \text{ GeV}$

$$F(x) = \frac{1}{\pi} \int_0^\infty \frac{E_{CM}}{p_{MAX}} \frac{d^2\sigma}{dx dp_\perp^2} dp_\perp^2 \text{ vs. } x.$$

K. C. Moffeit et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reactions $\gamma p \rightarrow \pi^- + \text{(ANYTHING)}$ with Polarized Photons at 2.8, 4.7, and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D 5, 1603 (1972)

$\gamma p \rightarrow \pi^- X$ $E_{INC} = 2.8, 4.7, 9.3 \text{ GeV}$

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 2.8, 4.7, 9.3 \text{ GeV}$

$$F(p_{||}^{\text{LAB}}, s) = \int_0^\infty E^{\text{LAB}} \frac{d^2 \sigma}{dp_{||}^{\text{LAB}} dp_{\perp}^2} dp_{\perp}^2 \text{ vs. } s^{-1/2}$$

for various intervals in $p_{||}^{\text{LAB}}$

K. C. Moffeit et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reaction $\gamma p \rightarrow \pi^- + (\text{ANYTHING})$ with Polarized Photons at 2.8, 4.7 and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D 5, 1603 (1972)

$$f_3(n, p_1^2) = \frac{1}{\pi} \frac{E^*}{p_{max}^*} \frac{\Delta^2 \sigma}{\Delta x \Delta p_1^2} [\mu b / (GeV/c)^2]$$

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 9.3 \text{ GeV}$

$$f_3(x, p_{\perp}^2) \equiv \frac{1}{\pi} \frac{E_{\text{CM}}}{P_{\text{MAX}}} \frac{\Delta^2 \sigma}{\Delta X \Delta p_{\perp}^2} \text{ vs. } p_{\perp}^2 \text{ for various intervals in } x = p_{\parallel}^{\text{CM}}/P_{\text{MAX}}^{\text{CM}}$$

K. C. Moffeit et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reactions $\gamma p \rightarrow \pi^- + (\text{ANYTHING})$ with Polarized Photons at 2.8, 4.7, and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D 5, 1603 (1972)

$$\gamma p \rightarrow \pi^- X$$

$$E_{INC} = 9.3 \text{ GeV}$$

$$\gamma p \rightarrow \pi^- + X^{++} \quad E_\gamma = 9.3 \text{ GeV}$$

- No Missing Neutral
- - - Single π^0 Missing
- · - Single Neutron Missing
- >1 Missing Neutral

$$\gamma p \rightarrow \pi^- X$$

$$E_{INC} = 9.3 \text{ GeV}$$

$$F(x) = \frac{1}{\pi} \int_0^x \frac{E_{CM}}{p_{MAX}} \frac{d^2\sigma}{dx dp_{\perp}^2} dp_{\perp}^2 \text{ vs. } x.$$

Function shown for 3, 5, 7, 9-prong events separately at 9.3 GeV. The curves show the contributions from events having no missing neutrals, a single π^0 missing, a single neutron missing and from multineutral events.

K. C. Moffeit et al., SLAC-LBL-Tufts collaboration, A Study of the Inclusive Reaction $\gamma p \rightarrow \pi^- + (\text{ANYTHING})$ with Polarized Photons at 2.8, 4.7 and 9.3 GeV, SLAC-PUB-1004; Phys. Rev. D 5, 1603 (1972)

$\gamma p \rightarrow \pi^- X$ $E_{INC} = 5 - 18 \text{ GeV}$

$\gamma p \rightarrow \pi^- X$ $E_{INC} = 5 - 18 \text{ GeV}$

$d \sigma / dp_{\perp}^2$ vs. $p_{\perp}^2$ for four intervals of E_{VIS} .

E_{VIS} is defined as $|\vec{p}_i|$ for each event, i.e., $E_{VIS} \leq E_{INC}$

$d \sigma / dp_{\perp}^2$ is defined on the figure.

W. P. Swanson, M. Davier, I. Derado, D. C. Fries, F. F. Liu, R. F. Mozley,
A. C. Odian, J. Park, F. Villa and D. E. Yount, SLAC, Phys. Rev. Letters
27, 1472 (1971)

$\gamma p \rightarrow \pi^- X$ $E_{\text{INC}} = 5 - 18 \text{ GeV}$

$$\gamma p \rightarrow \pi^- X$$

$$E_{\text{INC}} = 5 - 18 \text{ GeV}$$

$$d^2\sigma(E_{\text{VIS}})/dp_{\parallel}^{\text{LAB}} dp_{\perp} \text{ for } 0.1 \leq p_{\perp} \leq 0.2 \text{ GeV/c vs. } p_{\parallel}^{\text{LAB}}$$

E_{VIS} is defined as $|\vec{p}_1|$ for each event, i.e., $E_{\text{VIS}} \leq E_{\text{INC}}$

W. P. Swanson, M. Davier, I. Derado, D. C. Fries, F. F. Liu, R. F. Mozley,
A. C. Odian, J. Park, F. Villa and D. E. Yount, SLAC, Phys. Rev. Letters
27, 1472 (1971)

REFERENCE LIST OF INCLUSIVE DATA: γp COLLISIONS

<u>LAB INC</u> (GeV)	<u>First Author</u>	<u>Reference</u>	<u>Institution</u>	<u>Technique</u>
0 + 5.8		DESY 68/8 (1968)	DESY	
	"Photoproduction of Meson and Baryon Resonances..."			
0 + 5.8		DESY 66/34 (1966)	DESY	
	"Laboratory Angular and Momentum Distributions of p , K , π ..."			
0 + 6.0	Cambridge B.C.G.	PR <u>155</u> 1477 (1967)	BROW-CEA-HARV-MIT-PADO-WEIZ	HBC
	Diebold	SLAC-PUB-673 (1969)	SLAC	
	"High Energy Photoproduction"			
0 + 12.0	Ballam	PRL <u>21</u> 1541 (1968)	SLAC	
2.8, 4.7, 9.3	Moffett	PR <u>D5</u> 1603 (1972)	SLAC-IRL-TUFTS	HBC
5 + 18	Swanson	PRL <u>27</u> 1472 (1971)	SLAC	STRM
6 + 18	Swanson	SLAC-PUB-979	SLAC-UCD-LRL	STRM
	"Comparison of the Inclusive π^- Distributions from γp , $K^+ p$, and pp Collisions"			
5 + 18	Swanson	preprint Cornell Conf. (1971)	SLAC-UCD	STRM-HBC
	"Factorization in the Inclusive Reactions $\gamma p + \pi^- + \text{Anything}$ and $K^+ p + \pi^- + \text{Anything}$ "			
5 + 18	Swanson	preprint SLAC	SLAC	STRM
	"Evidence for Limiting Behavior in the Inclusive Reaction $\gamma p + \pi^- + \text{Anything}$ "			
5 + 18	Swanson	SLAC-PUB-936	SLAC	STRM
	"Study of the Inclusive Reaction $\gamma p + \pi^- + \text{Anything}$ "			

II-H. Data on Inclusive Spectra: Comparative Plots

$pp \rightarrow \pi^+ X, \pi^+ p \rightarrow \pi^+ X$
 $\rightarrow \pi^- X, \pi^+ p \rightarrow \pi^- X, \pi^- p \rightarrow \pi^- X$
 $\rightarrow \Lambda X, K^+ p \rightarrow \Lambda X$

$P_{INC} = 16, 24 \text{ GeV/c}$

$P_{INC} = 8, 12, 18, 24 \text{ GeV/c}$

$P_{INC} = 12, 12.7 \text{ GeV/c}$

$pp \rightarrow \pi^+ X, \pi^+ p \rightarrow \pi^+ X$
 $\rightarrow \pi^- X, \pi^+ p \rightarrow \pi^- X, \pi^- p \rightarrow \pi^- X$
 $\rightarrow \Lambda X, K^+ p \rightarrow \Lambda X$

$P_{INC} = 16, 24 \text{ GeV/c}$

$P_{INC} = 8, 12, 18, 24 \text{ GeV/c}$

$P_{INC} = 12, 12.7 \text{ GeV/c}$

(a) $\frac{d\sigma}{dy}_{LAB}$ vs. y^{LAB}

(b) $\frac{d\sigma}{dp_{||}}_{LAB}$ vs. $p_{||}^{LAB}$

(c) $\frac{2E^{CM}}{\pi\sqrt{s}} \frac{d^2\sigma}{dx dp_{||}^2}$ vs. x

(d) $\frac{d\sigma}{dy}_{LAB}$ vs. y^{LAB}

(e) $E^{LAB} \frac{d\sigma}{dp_{||}}_{LAB}$ vs. $p_{||}^{LAB}$

The proton beam cross sections, multiplied by the ratio $\sigma_{\pi p}^{\infty}/\sigma_{pp}^{\infty}$ or $\sigma_{K^+ p}^{\infty}/\sigma_{pp}^{\infty}$ respectively are shown as curves. The 12 and 24 GeV pp data are compared with published data from the following sources:

W. Ko et al., Phys. Rev. Letters 26, 1064 (1971)

W. D. Shephard et al., Phys. Rev. Letters 27, 1164 (1971); 28, 260(E) (1972)

J. V. Beaupre et al., Physics Letters 37, 432 (1971)

S. Stone et al., University of Rochester preprint UR-875-349

H. J. Mück et al., BONN-DESY-HAMB-Max Planck collaboration, Inclusive Particle Production in pp Interactions at 12 and 24 GeV/c (Parts I and II) Internal Report DESY-F1-72/1 (1972)

pp $\rightarrow$ cX $P_{INC} = 19.20 \text{ GeV/c}$

pp → cX

P_{INC} = 19.20 GeV/c

A comparison of $(d\sigma/dp d\Omega)^{\text{LAB}}$ vs. p^{LAB} ($\theta^{\text{LAB}} = 12.5 \text{ mrad.}$) for produced particles π^+ , π^- , K^+ , K^- , p , $\bar{p}$

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier, J. P. Peigneux, E. J. Sacharidis, K. Schlüpmann, M. Spighele, J. P. Stroot, A. M. Thorndike and A. M. Wetherell, CERN Report 70-12 (23 April 1970),
High-Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

pp + cX

 $P_{INC} = 19.2 \text{ GeV/c}$

pp → cX

p_{INC} = 19.2 GeV/c

$(d\sigma/dp d\Omega)^{\text{LAB}}$ vs. $p^{\text{LAB}}(\theta^{\text{LAB}}$ fixed) for π^+ , K^+ , p^+ produced in pp collisions.

The angles θ^{LAB} corresponding to each curve are (from top to bottom) 12, 20, 30, 40, 50, 60, 70 mrad.

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier, J. P. Peigneux, E. J. Sacharidis, K. Schlupmann, M. Spighel, J. P. Stroot, A. M. Thorndike and A. M. Wetherell, CERN report 70-12 (23 April 1970), High-Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

$PP + \pi^+, \pi^-, K^+, K^-, p, \bar{p}$
 $P_{INC} = 19.20 \text{ GeV/c}$

$pp \rightarrow \pi^+, \pi^-, K^+, K^-, p, \bar{p}$

$p_{INC} = 19.20 \text{ GeV}/c$

Extensive tabulated data on pp , $p(B_4C)$, pBe , pAl , pCu , pPb collisions are found in this report.

$(d\sigma/d^3p)^{CM}$ vs. $p_{||}^{CM}$ ($p_{\perp}$ fixed) and $(d\sigma/d^3p)^{CM}$ vs. $p_{\perp}$ ($p_{||}^{CM}$ fixed) for

produced particles $\pi^{\pm}$, $K^{\pm}$, p , $\bar{p}$

J. V. Allaby, F. Binon, A. N. Diddens, P. Duteil, A. Klovning, R. Meunier, J. P. Peigneux, E. J. Sacharidis, K. Schlüpmann, M. Spighel, J. P. Stroot, A. M. Thorndike and A. M. Wetherell, CERN Report 70-12 (23 April 1970),
High-Energy Particle Spectra from Proton Interactions at 19.2 GeV/c

pp → cY.

 $P_{THC} = 19.20 \text{ GeV}/c$

pp → cX

 $p_{INC} = 19.20 \text{ GeV/c}$

Invariant spectra $E \frac{d\sigma}{d^3p}$ plotted vs. $x = p_{||}^{CM}/p_{MAX}^{CM}$ for produced $p, \bar{p}, \pi^{\pm}, K^{\pm}$

Data is taken from J. V. Allaby et al., CERN report 70-12 (23 April 1970)

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt,
 L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli,
 C. Bosio, G. Matthiae and CERN-Rome collaboration, report at the Fourth
 International Conference on High-Energy Collisions (Oxford, April 1972),
Comparison of Momentum Spectra of Secondary Particles Produced in Proton-
Proton Collisions at 14.2, 19.2, 24 GeV/c

$pp \rightarrow cX$ $p_{INC} = 12.5 \text{ GeV}/c$ $pp \rightarrow cX \text{ (12.5 GeV}/c)$

pp $\rightarrow$ cX $P_{INC} = 12.5 \text{ GeV/c}$

$$2E \frac{d\sigma}{d^3p} \text{ vs. } x' = P_{||}^{CM} / \sqrt{(P_{MAX}^{CM})^2 - p_{\perp}^2} \text{ (for fixed } p_{\perp}^2) \text{ of produced}$$

$$\pi^{\pm}, K^{\pm}, p^{\pm}$$

Data is from C. W. Akerlof et al., Phys. Rev. D3, 645 (1971)

J. Kasman and D. P. Sidhu, SUNY (Stony Brook) report (November 1971),
A Study of Single Particle Production Spectra pp $\rightarrow$ xC

P+P, 24.0 GeV/c

$\frac{d^2\sigma}{d\eta dP} [\text{cm}^2/\text{sr} \cdot \text{GeV}/c] (\text{L.S.})$

P [GeV/c]

pp + cX

649

$P_{\text{INC}} = 24 \text{ GeV}/c$

pp + cX

 $P_{INC} = 24 \text{ GeV/c}$

$(d\sigma/dp d\Omega)^{LAB}$ vs. $p^{LAB}(\theta^{LAB} \text{ fixed})$ for $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ produced in
pp collisions

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt,
L. S. Rochester, K. Schlüpman, A. M. Wetherell, U. Amaldi, R. Biancastelli,
C. Bosio and G. Matthiae, CERN-Rome collaboration, Fourth International
Conference on High-Energy Collisions (Oxford, England; April 1972),
Comparison of Momentum Spectra of Secondary Particles Produced in
Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

$pp \rightarrow cX$ $p_{INC} = 24 \text{ GeV}/c$

pp $\rightarrow$ cX $P_{INC} = 24 \text{ GeV}/c$

Comparison of invariant spectra $E \frac{d\sigma}{d^3p}$ vs. $p_{\perp}$ for different
 produced particles and $x = p_{\perp}^{CM}/P_{MAX}^{CM} = 0.25, 0.75$

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt,
 L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli,
 C. Bosio and G. Matthiae, CERN-Rome collaboration report at the
 Fourth International Conference on High-Energy Collisions (Oxford,
 April 1972), Comparison of Momentum Spectra of Secondary Particles
 Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

$pp \rightarrow cX$ $p_{INC} = 24 \text{ GeV}/c$

pp → cX

p_{INC} = 24 GeV/c

Sketch of the spectra $(d\sigma/d\Omega dp)^{\text{LAB}}$ vs. p^{LAB} for several produced particles with $0^\circ < \theta^{\text{LAB}} < 1^\circ$

The sources of data are:

$\pi^\pm, K^\pm, p^\pm$	J. V. Allaby et al., Oxford Conference report (April 1972)
Λ, K_1^0	E. L. Berger, B. Y. Oh, G. A. Smith, Phys. Rev. Letters <u>28</u> , 322 (1972)
Σ^-, Ξ^-	J. Badier et al., Phys. Letters (1972): The data are renormalized to the π^- spectrum in $pp + \pi^- X$, since these authors measure $p(\text{Tungsten}) + \pi^-, \Sigma^-, \Xi^-$
n	J. Engler, W. Flauger, B. Gibbard, E. Mönnig, K. Runge and H. Schopper This data, from pBe collisions, is renormalized.

J. V. Allaby, A. N. Diddens, R. W. Dobinson, A. Klovning, J. Litt, L. S. Rochester, K. Schlüpmann, A. M. Wetherell, U. Amaldi, R. Biancastelli, C. Bosio, G. Matthiae and CERN-Rome collaboration, report at the Fourth International Conference on High-Energy Collisions (Oxford, April 1972), Comparison of Momentum Spectra of Secondary Particles Produced in Proton-Proton Collisions at 14.2, 19.2, 24 GeV/c

$$P_{INC} = 12.7 \text{ GeV/c}$$

$$P_{INC} = 7 \text{ GeV/c}$$

(a)

(b)

(c)

$$K^+p \rightarrow \pi^-X$$

$$p_{INC} = 12.7 \text{ GeV/c}$$

$$\pi^+p \rightarrow \pi^-X$$

$$p_{INC} = 7 \text{ GeV/c}$$

- (a) Mean transverse momentum ($p_{\perp}$) vs. $p_{||}^{CM}$ for the K^+p and the π^+p data both unweighted (upper) and weighted (lower) by the pion energy E^{CM} .
- (b) Mean and variance of $p_{||}^{CM}$ vs. $p_{\perp}^2$ for $K^+p + \pi^-X$ both unweighted (upper) and weighted (lower) by the pion energy E^{CM} .
- (c) Same as (b) for $\pi^+p + \pi^-X$.

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c K^+p and 7 GeV/c π^+p Collisions, Univ. of Rochester preprint, UR-875-349 (Revised), (1972); Phys. Rev. D₅, 1621 (1972)

$p_{\text{INC}} = 12.7 \text{ GeV}/c$
 $\begin{aligned} & K^+ p \rightarrow \pi^- X \\ & + \bar{K}^0 X \\ & + \bar{\Lambda}^0 X \\ & + \Lambda^0 X \\ & \pi^+ p \rightarrow \pi^- X \end{aligned}$
 $p_{\text{INC}} = 7 \text{ GeV}/c$

INVARIANT CROSS-SECTIONS (c.m.)

$$P_{\text{INC}} = 12.7 \text{ GeV}/c$$

$$P_{\text{INC}} = 7 \text{ GeV}/c$$

$$\frac{2}{\sqrt{s}} \sigma_{\text{TOTAL}} \int E^{\text{CM}} \frac{d\sigma}{dx dp_{\perp}^2} dp_{\perp}^2 \text{ vs. } x,$$

where $x = 2p_{\perp}^{\text{CM}} / \sqrt{s}$ and σ_{TOTAL} = total cross section.

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c $K^+ p$ and 7 GeV/c $\pi^+ p$ Collisions, Univ. of Rochester preprint, UR-875-349 (Revised), (1972); Phys. Rev. D 5, 1621 (1972)

$$\pi^- p \rightarrow \pi^- X$$

$$pp \rightarrow \pi^- X$$

$$K^+ p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{INC} = 24.8 \text{ GeV/c}$$

$$p_{INC} = 28.5 \text{ GeV/c}$$

$$p_{INC} = 12.7 \text{ GeV/c}$$

$$p_{INC} = 7 \text{ GeV/c}$$

SQUARE OF TRANSVERSE MOMENTUM OF π^-

$\pi^- p \rightarrow \pi^- X$ $P_{INC} = 24.8 \text{ GeV/c}$ $pp \rightarrow \pi^- X$ $P_{INC} = 28.5 \text{ GeV/c}$ $K^+ p \rightarrow \pi^- X$ $P_{INC} = 12.7 \text{ GeV/c}$ $\pi^+ p \rightarrow \pi^- X$ $P_{INC} = 7 \text{ GeV/c}$

$$\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{\perp}^2} \text{ vs. } p_{\perp}^2$$

for particles with $p_{\parallel}^{BEAM} < 0.5 \text{ GeV/c}$

The Curves are polynomial fits to the data.

M.-S. Chen et al., BNL, Rochester, Wisconsin, Phys. Rev. Letters 26,
1585 (1971)

LONGITUDINAL MOMENTUM OF π^- IN PROJECTILE FRAME

$\pi^- p \rightarrow \pi^- X$
 $p p \rightarrow \pi^- X$
 $K^+ p \rightarrow \pi^- X$
 $\pi^+ p \rightarrow \pi^- X$

$P_{INC} = 24.8 \text{ GeV}/c$
 $P_{INC} = 28.5 \text{ GeV}/c$
 $P_{INC} = 12.7 \text{ GeV}/c$
 $P_{INC} = 7 \text{ GeV}/c$

$$\pi^- p \rightarrow \pi^- X$$

$$pp \rightarrow \pi^- X$$

$$K^+ p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{INC} = 24.8 \text{ GeV/c}$$

$$p_{INC} = 28.5 \text{ GeV/c}$$

$$p_{INC} = 12.7 \text{ GeV/c}$$

$$p_{INC} = 7 \text{ GeV/c}$$

$$\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{BEAM}} \text{ vs. } p_{||}^{BEAM}$$

Curves are polynomial fits to the data.

M.-S. Chen et al., BNL, Rochester, Wisconsin, Phys. Rev. Letters 26,
1585 (1971)

$\pi^- p + \pi^- X$ $p p + \pi^- X$ $K^+ p + \pi^- X$ $\pi^+ p + \pi^- X$ $p_{INC} = 24.8 \text{ GeV/c}$ $p_{INC} = 28.5 \text{ GeV/c}$ $p_{INC} = 12.7 \text{ GeV/c}$ $p_{INC} = 7 \text{ GeV/c}$ SQUARE OF TRANSVERSE MOMENTUM OF π^-

$$\pi^- p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 24.8 \text{ GeV}/c$$

$$pp \rightarrow \pi^- X$$

$$p_{\text{INC}} = 28.5 \text{ GeV}/c$$

$$K^+ p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 12.7 \text{ GeV}/c$$

$$\pi^+ p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 7 \text{ GeV}/c$$

$$\frac{1}{\sigma_{\text{TOTAL}}} \frac{d\sigma}{dp_{\perp}^2} \text{ vs. } p_{\perp}^2$$

for particles with $p_{\parallel}^{\text{LAB}} \leq 0.5 \text{ GeV}/c$

The curves are polynomial fits to the data.

M.-S. Chen et al., BNL, Rochester, Wisconsin, Phys. Rev. Letters 26,
1585 (1971)

$P_{INC} = 24.8 \text{ GeV}/c$
 $P_{INC} = 28.5 \text{ GeV}/c$
 $P_{INC} = 12.7 \text{ GeV}/c$
 $P_{INC} = 7 \text{ GeV}/c$

$\pi^- p \rightarrow \pi^- X$
 $\bar{p} p \rightarrow \pi^- X$
 $K^+ p \rightarrow \pi^- X$
 $\pi^+ p \rightarrow \pi^- X$

$$\pi^- p \rightarrow \pi^- X$$

$$pp \rightarrow \pi^- X$$

$$K^+ p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^- X$$

$$P_{INC} = 24.8 \text{ GeV}/c$$

$$P_{INC} = 28.5 \text{ GeV}/c$$

$$P_{INC} = 12.7 \text{ GeV}/c$$

$$P_{INC} = 7 \text{ GeV}/c$$

$$\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } p_{||}^{LAB}$$

Curves are a polynomial fit to the data.

Each reaction is normalized by its asymptotic cross section.

M.-S. Chen et al., BNL, Rochester, Wisconsin, Phys. Rev. Letters 26,
1585 (1971)

$$\begin{array}{l} K^- p + \pi^+ X \\ \pi^- p + \pi^+ X \\ K^+ p + \pi^- X \end{array}$$

$$\begin{array}{l} P_{INC} = 9 \text{ GeV/c} \\ P_{INC} = 24.5 \text{ GeV/c} \\ P_{INC} = 12.7 \text{ GeV/c} \end{array}$$

$$\begin{aligned} K^- p + \pi^+ X \\ \pi^- p + \pi^+ X \\ K^+ p + \pi^- X \end{aligned}$$

$$\begin{aligned} p_{INC} &= 9 \text{ GeV/c} \\ p_{INC} &= 24.8 \text{ GeV/c} \\ p_{INC} &= 12.7 \text{ GeV/c} \end{aligned}$$

$$d\sigma/dp_{||}^{PROJ} \text{ vs. } p_{||}^{PROJ}$$

The histogram represents $K^- p$ data of SUNY at Stony Brook.

The dashed curve is $\pi^- p$ data of Wisconsin normalized by $\sigma_{K^- p} / \sigma_{\pi^- p}$ while the solid curve is $K^+ p$ data of Rochester normalized by $\sigma_{K^- p} / \sigma_{K^+ p}$, both from M. S. Chen et al., Phys. Rev. Letters 26, 1585 (1971)

M. Foster, J. A. Cole, E. Kim, J. Lee-Franzini, R. J. Loveless, C. Moore and K. Takahashi, Phys. Rev. Letters 27, 1312 (1971)

$$K^+ p \rightarrow \pi^- X$$

$$K^- p \rightarrow \pi^- X$$

$$\pi^- p \rightarrow \pi^- X$$

$$P_{INC} = 12.7 \text{ GeV/c}$$

$$P_{INC} = 9 \text{ GeV/c}$$

$$P_{INC} = 24.8 \text{ GeV/c}$$

$$K^+ p \rightarrow \pi^- X$$

$$K^- p \rightarrow \pi^- X$$

$$\pi^- p \rightarrow \pi^- X$$

$$P_{INC} = 12.7 \text{ GeV/c}$$

$$P_{INC} = 9 \text{ GeV/c}$$

$$P_{INC} = 24.8 \text{ GeV/c}$$

$$d\sigma/dp_{\perp}^2 \text{ vs. } p_{\perp}^2$$

The histogram represents $K^- p$ data of SUNY at Stony Brook.

The dashed curve is $\pi^- p$ data of Wisconsin normalized by $\sigma_{K^- p} / \sigma_{\pi^- p}$ while

the solid curve is $K^+ p$ data of Rochester normalized by $\sigma_{K^- p} / \sigma_{K^+ p}$, both

from M. S. Chen et al., Phys. Rev. Letters 26, 1585 (1971)

M. Foster, J. A. Cole, E. Kim, J. Lee-Franzini, R. J. Loveless, C. Moore
and K. Takahashi, Phys. Rev. Letters 27, 1312 (1971)

$$K^- p \rightarrow \pi^+ X$$

$$K^+ p \rightarrow \pi^- X$$

$$\pi^- p \rightarrow \pi^+ X$$

$$P_{INC} = 9 \text{ GeV}/c$$

$$P_{INC} = 12.7 \text{ GeV}/c$$

$$P_{INC} = 24.8 \text{ GeV}/c$$

$$\begin{aligned} K^- p &\rightarrow \pi^+ X \\ K^+ p &\rightarrow \pi^- X \\ \pi^- p &\rightarrow \pi^+ X \end{aligned}$$

$$\begin{aligned} P_{INC} &= 9 \text{ GeV/c} \\ P_{INC} &= 12.7 \text{ GeV/c} \\ P_{INC} &= 24.8 \text{ GeV/c} \end{aligned}$$

$$d\sigma/dp_{\perp}^2 \text{ vs. } p_{\perp}^2, \text{ for } p_{||}^{PROJ} < 0.5 \text{ GeV/c.}$$

The histogram represents $K^- p$ data of SUNY at Stony Brook.

The dashed curves is $\pi^- p$ data of Wisconsin normalized by $\sigma_{K^- p} / \sigma_{\pi^- p}$

by $\sigma_{K^- p} / \sigma_{K^+ p}$, both from M. S. Chen et al., Phys. Rev. Letters 26,

1585 (1971)

M. Foster, J. A. Cole, E. Kim, J. Lee-Franzini, R. J. Loveless, C. Moore
and K. Takahashi, Phys. Rev. Letters 27, 1312 (1971)

$K^- p \rightarrow \pi^- X$
 $\pi^- p \rightarrow \pi^- X$
 $p p \rightarrow \pi^- X$

$P_{INC} = 9 \text{ GeV/c}$
 $P_{INC} = 24.8 \text{ GeV/c}$
 $P_{INC} = 28.5 \text{ GeV/c}$

$K^- p \rightarrow \pi^- X$ $\pi^- p \rightarrow \pi^- X$ $pp \rightarrow \pi^- X$ $P_{INC} = 9 \text{ GeV/c}$ $P_{INC} = 24.8 \text{ GeV/c}$ $P_{INC} = 28.5 \text{ GeV/c}$

$$d\sigma/dp_{||}^{LAB} \text{ vs. } p_{||}^{LAB}$$

The histogram represents $K^- p$ data of SUNY at Stony Brook.

The dashed line is $\pi^- p$ data of Wisconsin normalized by $\sigma_{K^- p} / \sigma_{\pi^- p}$ while

the solid line is pp data of BNL normalized by $\sigma_{K^- p} / \sigma_{pp}$,

both from M. S. Chen et al., Phys. Rev. Letters 26, 1585 (1971)

M. Foster, J. A. Cole, E. Kim, J. Lee-Franzini, R. J. Loveless, C. Moore
and K. Takahashi, Phys. Rev. Letters 27, 1312 (1971)

$$\bar{E}_{\text{INC}} = 10.4 \text{ GeV/c}$$

$$P_{\text{INC}} = 11.8 \text{ GeV/c}$$

$$P_{\text{INC}} = 28.5 \text{ GeV/c}$$

$\gamma p \rightarrow \pi^- X$
 $K^+ p \rightarrow \pi^- X$
 $pp \rightarrow \pi^- X$

$\gamma p \rightarrow \pi^- X$
 $K^+ p \rightarrow \pi^- X$
 $pp \rightarrow \pi^- X$

$\bar{E}_{INC} = 10.4 \text{ GeV/c}$
 $P_{INC} = 11.8 \text{ GeV/c}$
 $P_{INC} = 28.5 \text{ GeV/c}$

$\frac{1}{\sigma_{TOTAL}} \frac{d^2\sigma}{dp_{||}^{LAB} dp_{\perp}} \text{ vs. } p_{||}^{LAB} \text{ for a range of intervals in } p_{\perp}.$

Also shown is $\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{LAB}}$ (uppermost points). The diagonal lines

at the left are intended to distinguish the $p_{\perp}$ selections at small

values of $p_{||}^{LAB}$. The approximately vertical broken lines show the

value of $p_{||}^{LAB}$ corresponding to $x = -0.5$ and $x = 0.0$ respectively,

where $x = 2p_{||}^{CM}/\sqrt{s}$.

W. P. Swanson, W. Ko, R. L. Lander, C. Risk, R. R. Ross and D. B. Smith,
Comparison of the Inclusive π^- Distributions from γp , $K^+ p$ and
 pp Collisions, SLAC PUB-979 (1971)

$pp \rightarrow \pi^- X$ $\gamma p \rightarrow \pi^- X$ $P_{INC} = 28.5 \text{ GeV}$ $E_{INC} = 10.4 \text{ GeV}$

$pp \rightarrow \pi^- X$ $P_{INC} = 28.5 \text{ GeV}$ $\gamma p \rightarrow \pi^- X$ $E_{INC} = 10.4 \text{ GeV}$

$$\frac{1}{\sigma_{TOTAL}} \left. \frac{d^2\sigma_{LAB}}{dp_{||} dp_{\perp}} \right|_{\gamma p} / \frac{1}{\sigma_{TOTAL}} \left. \frac{d^2\sigma_{LAB}}{dp_{||} dp_{\perp}} \right|_{pp} \quad \text{vs. } p_{||}^{LAB}$$

for various values of $p_{\perp}$

W. P. Swanson, W. Ko, R. L. Lander, C. Risk, R. R. Ross and D. B. Smith,
Comparison of the Inclusive π^- Distributions from γp , K^+p , and
 pp Collisions, SLAC-PUB-979 (1971)

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^- X$$

$$\gamma p \rightarrow \pi^- X$$

$$P_{INC} = 18.5 \text{ GeV/c}$$

$$P_{INC} = 18.5 \text{ GeV/c}$$

$$P_{INC} = 9.3 \text{ GeV/c}$$

$$\pi^- p \rightarrow \pi^- X$$

$$\pi^+ p \rightarrow \pi^- X$$

$$\gamma p \rightarrow \pi^- X$$

$$p_{\text{INC}} = 18.5 \text{ GeV/c}$$

$$p_{\text{INC}} = 18.5 \text{ GeV/c}$$

$$p_{\text{INC}} = 9.3 \text{ GeV/c}$$

$$\frac{1}{\sigma_{\text{TOTAL}}} \int_0^{\infty} \frac{1}{\pi} \frac{E_{\text{CM}}}{P_{\text{MAX}}} \frac{d^2\sigma}{dx dp_{\perp}^2} dp_{\perp}^2$$

vs.

$$x = p_{\parallel}^{\text{CM}} / P_{\text{MAX}}^{\text{CM}}$$

K. C. Moffeit et al., A Study of the Inclusive Reaction $\gamma p \rightarrow \pi^- + \text{Anything}$ with Polarized Photons at 2.8, 4.7, and 9.3 GeV/c, SLAC-PUB-1004 (1971)

BEAM + p $\rightarrow$ π^- + (ANYTHING)

$p p + \pi^- X$
 $K^+ p + \pi^- X$
 $\pi^+ p + \pi^- X$
 $\pi^- p + \pi^- X$
 $\gamma p + \pi^- X$

$p_{\text{INC}} = 28.5 \text{ GeV}/c$
 $p_{\text{INC}} = 12.7 \text{ GeV}/c$
 $p_{\text{INC}} = 7 \text{ GeV}/c$
 $p_{\text{INC}} = 24.8 \text{ GeV}/c$
 $p_{\text{INC}} = 9.3 \text{ GeV}/c$

$pp \rightarrow \pi^- X$ $p_{INC} = 28.5 \text{ GeV/c}$ $K^+ p \rightarrow \pi^- X$ $p_{INC} = 12.7 \text{ GeV/c}$ $\pi^+ p \rightarrow \pi^- X$ $p_{INC} = 7 \text{ GeV/c}$ $\pi^- p \rightarrow \pi^- X$ $p_{INC} = 24.8 \text{ GeV/c}$ $\gamma p \rightarrow \pi^- X$ $p_{INC} = 9.3 \text{ GeV/c}$

$$\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } p_{||}^{LAB}$$

K. C. Moffeit et al., A Study of the Inclusive Reaction $\gamma p \rightarrow \pi^- + \text{Anything}$ with Polarized Photons at 2.8, 4.7, and 9.3 GeV/c, SLAC-PUB-1004 (1971)

$\gamma_V p \rightarrow pX, \pi^+ X$
 $pp \rightarrow \pi^+ X$

$\sqrt{s} = 2.63 \text{ GeV}$

$\sqrt{s} = 5.01, 6.13 \text{ GeV}$

$$\begin{aligned} \gamma_V p + pX, \pi^+ X \\ pp + \pi^+ X \end{aligned}$$

$$\begin{aligned} \sqrt{s} &= 2.63 \text{ GeV} \\ \sqrt{s} &= 5.01, 6.13 \text{ GeV} \end{aligned}$$

Comparisons of $F(x, p_{\perp}) \equiv E \frac{d^3}{d^3p}$ for $\gamma_V p$ and pp plotted vs.

$x \equiv p_{||}^{CM}/\sqrt{s}$ ($p_{\perp} = 0$). The $\gamma_V p$ and pp data are normalized to

the same ($\gamma_V p$) total cross section.

The data are from :

$\sqrt{s} = 2.63 \text{ GeV/c}$ F. W. Brasse et al., (DESY), paper at the
1971 International Symposium on Electron and
Photon Interactions (Cornell Univ.)

$\sqrt{s} = 5.01 \text{ GeV/c}$ C. W. Akerlof et al., Phys. Rev. D3, 645 (1971)

$\sqrt{s} = 6.13 \text{ GeV/c}$ J. V. Allaby et al., CERN report 70-12 (1970)

K. Berkelman, Continuum Electroproduction by Coincidence Measurements,
Cornell preprint, Proceedings of the 1971 International Symposium on Electron
and Photon Interactions (Cornell Univ., Ithaca, August 1971)

$pp \rightarrow \pi^+ X$
 $K^+ p \rightarrow \pi^+ X$
 $\pi^- p \rightarrow \pi^+ X$

$P_{INC} = 28.5 \text{ GeV/c}$

$P_{INC} = 13 \text{ GeV/c}$

$P_{INC} = 25 \text{ GeV/c}$

$$\begin{aligned}
 pp &\rightarrow \pi^+ X \\
 K^+ p &\rightarrow \pi^+ X \\
 \pi^- p &\rightarrow \pi^+ X
 \end{aligned}$$

$$\begin{aligned}
 p_{INC} &= 28.5 \text{ GeV/c} \\
 p_{INC} &= 13 \text{ GeV/c} \\
 p_{INC} &= 25 \text{ GeV/c}
 \end{aligned}$$

$$\frac{1}{\sigma_{TOTAL}} \frac{d\sigma}{dp_{||}^{LAB}} \text{ vs. } p_{||}^{LAB}$$

Data is that of BNL, Rochester, University of California at Davis and Wisconsin groups.

R. L. Lander, Recent Experimental Results on Multiparticle Production,
 Proceedings of the 1971 Rochester Meeting of APS/DPF, p. 71, American
 Institute of Physics (New York 1971)

$pp \rightarrow \pi^+ X$
 $\pi^+ p \rightarrow \pi^+ X$
 $K^+ p \rightarrow \pi^+ X$

 $P_{INC} = 28.5 \text{ GeV/c}$
 $P_{INC} = 7.2 \text{ GeV/c}$
 $P_{INC} = 11.8 \text{ GeV/c}$

$pp \rightarrow \pi^+ X$
 $\pi^+ p \rightarrow \pi^+ X$
 $K^+ p \rightarrow \pi^+ X$

$P_{INC} = 28.5 \text{ GeV}/c$

$P_{INC} = 7.2 \text{ GeV}/c$

$P_{INC} = 11.8 \text{ GeV}/c$

$$\frac{1}{\sigma_{TOTAL}} \int_0^{\pi} \frac{E^{LAB}}{\pi} \frac{d^2\sigma}{dp_{||}^{LAB} dp_{\perp}} dp_{\perp} \text{ vs. } p_{||}^{LAB}$$

Data are that of a LBL, BNL and University of California at Davis collaboration.

R. L. Lander, Recent Experimental Results on Multiparticle Production,
 Proceedings of the 1971 Rochester Meeting of APS/DPF, p. 71, American
 Institute of Physics (New York 1971)

$pp \rightarrow \pi^- X$
 $\pi^+ p \rightarrow \pi^- X$
 $K^+ p \rightarrow \pi^- X$
 $P_{INC} = 28.5 \text{ GeV/c}$
 $P_{INC} = 7.2 \text{ GeV/c}$
 $P_{INC} = 11.8 \text{ GeV/c}$

$pp \rightarrow \pi^- X$
 $\pi^+ p \rightarrow \pi^- X$
 $K^+ p \rightarrow \pi^- X$

$p_{INC} = 28.5 \text{ GeV}/c$
 $p_{INC} = 7.2 \text{ GeV}/c$
 $p_{INC} = 11.8 \text{ GeV}/c$

$$\frac{1}{\sigma_{TOTAL}} \int_0^\infty \frac{E_{LAB}}{\pi} \frac{d^2\sigma}{dp_{||}^{LAB} dp_{\perp}} dp_{\perp} \text{ vs. } p_{||}^{LAB}$$

Data are that of a LBL, BNL and University of California at Davis collaboration.

R. L. Lander, Recent Experimental Results on Multiparticle Production,
 Proceedings of the 1971 Rochester Meeting of APS/DPF, p. 71, American
 Institute of Physics (New York 1971)

$pp \rightarrow \pi^- X$
 $K^+ p \rightarrow \pi^- X$
 $\pi^+ p \rightarrow \pi^- X$
 $P_{INC} = 28.5 \text{ GeV}/c$
 $P_{INC} = 12.7 \text{ GeV}/c$
 $P_{INC} = 7 \text{ GeV}/c$

$p\bar{p} \rightarrow \pi^- X$
 $K^+ p \rightarrow \pi^- X$
 $\pi^+ p \rightarrow \pi^- X$

$P_{INC} = 28.5 \text{ GeV}/c$
 $P_{INC} = 12.7 \text{ GeV}/c$
 $P_{INC} = 7 \text{ GeV}/c$

(Scale Factor) $\frac{d\sigma}{dy}_{CM}$ vs. y^{CM}

Data is that of the BNL-Rochester-Wisconsin collaboration.

W. R. Frazer, L. Ingber, C. H. Mehta, C. H. Poon, D. Silverman, K. Stove,
 P. D. Ting and H. J. Yesian, Rev. Mod. Phys. 44, 284 (1972)

$$\pi^- p \rightarrow \pi^+ X$$

$$pp \rightarrow \pi^+ X$$

$$p_{INC} = 16 \text{ GeV}$$

$$p_{INC} = 12 \text{ GeV/c}$$

$$\pi^- p \rightarrow \pi^+ X$$

$$pp \rightarrow \pi^+ X$$

$$p_{\text{INC}} = 16 \text{ GeV}/c$$

$$p_{\text{INC}} = 12 \text{ GeV}/c$$

$$\frac{2E^{\text{CM}}}{\pi\sqrt{s}} \frac{d^2\sigma}{dp_{\perp}^2 dx} \text{ vs. } x,$$

$$x = 2p_{\parallel}^{\text{CM}}/\sqrt{s}, \text{ for ranges of } p_{\perp}^2$$

pp data after normalization of $\sigma_{\text{TOTAL}}(\pi p)/\sigma_{\text{TOTAL}}(pp)$ fall on the πp data.

Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw collaboration, by
 M. Deutschmann in Many Particle Reactions, a Rapporteur's talk at
 the Amsterdam International Conference on Elementary Particles (1971)

$$\pi^- p \rightarrow \pi^+ X$$

$$K^- p \rightarrow \pi^+ X$$

$$p_{INC} = 16 \text{ GeV}/c$$

$$p_{INC} = 10 \text{ GeV}/c$$

$$\pi^- p \rightarrow \pi^+ X$$

$$K^- p \rightarrow \pi^+ X$$

$$p_{INC} = 16 \text{ GeV}/c$$

$$p_{INC} = 10 \text{ GeV}/c$$

$$\frac{2E^{CM}}{\sigma_{TOTAL} \pi \sqrt{s}} \frac{d\sigma}{dx} \text{ vs. } x,$$

$$x = 2p_{||}^{CM}/\sqrt{s}$$

Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw collaboration and the
 Aachen-Berlin-CERN-London-Vienna collaboration, quoted by M. Deutschmann
 in Many Particle Reactions, a Rapporteur's talk at the Amsterdam
 International Conference on Elementary Particles (1971)

II-1. Data on Inclusive Spectra: Two-Body Correlations

$pp + (\text{charged prongs}) \times$
 $K^-p + (\text{charged prongs}) \times$

$\bar{p}_{INC} = 28 \text{ GeV}/c$
 $p_{INC} = 9 \text{ GeV}/c$

$pp \rightarrow (\text{charged prongs})X$
 $K^-p \rightarrow (\text{charged prongs})X$

$P_{INC} = 28 \text{ GeV}/c$
 $P_{INC} = 9 \text{ GeV}/c$

$d\sigma/d\theta$ vs. ϕ , where ϕ is the angle between the transverse momenta of pairs of charged particles. Distributions are shown for various multiplicities. The right most graphs are the inclusive distributions for the reactions $pp \rightarrow (\text{charged pair})X$ and $K^-p \rightarrow (\text{charged pair})X$. The solid curves are model fits.

M. C. Foster, D. Z. Freedman, S. Nussinov, J. Hanlon and R. S. Panvini,
 SUNY at Stony Brook-Vanderbilt Univ. collaboration, Azimuthal Correlations
of High Energy Collision Products, preprint (1972)

$$pp \rightarrow pp \pi^+ \pi^+ \pi^- \pi^-$$

$$p_{\text{INC}} = 23 \text{ GeV}/c$$

$$pp \rightarrow pp \pi^+ \pi^+ \pi^- \pi^-$$

23 GeV/c

XBL7910-4598

$$pp \rightarrow pp\pi^+\pi^+\pi^-\pi^-$$

$$P_{INC} = 23 \text{ GeV}/c$$

Distributions in the angle between pairs of particles in the plane transverse to the beam for the reaction $pp \rightarrow pp\pi^+\pi^+\pi^-\pi^-$; namely

- (a) between the two protons
- (b) between the pions with largest positive and negative $p_{||}^{CM}$
- (c) between the pions with smallest $p_{||}^{CM}$
- (d) between the protons and the pions with the largest $|p_{||}^{CM}|$
- (e) between the two pions with second and third largest $p_{||}^{CM}$

Dashed curve—multiphipheral model

Solid curve—pionization model

$$\begin{aligned} &\pi^+p \rightarrow \pi^-\pi^+X \\ &K^+p \rightarrow K^0\pi^+X \\ &K^+p \rightarrow \Lambda^0\pi^+X \\ &K^+p \rightarrow \bar{\Lambda}^0\pi^+X \end{aligned}$$

$$\begin{aligned} P_{INC} &= 7 \text{ GeV}/c \\ P_{INC} &= 12.7 \text{ GeV}/c \\ P_{INC} &= 12.7 \text{ GeV}/c \\ P_{INC} &= 12.7 \text{ GeV}/c \end{aligned}$$

(a)

$$\pi^+p \rightarrow \pi^+\pi^+\pi^+\dots \quad (7 \text{ GeV}/c)$$

$$K^+p \rightarrow K^+\pi^+\pi^+\dots \quad (12.7 \text{ GeV}/c)$$

(b)

$$K^+p \rightarrow \Lambda^0\pi^+\pi^+\dots \quad (12.7 \text{ GeV}/c)$$

$$\pi^+ p \rightarrow \pi^- \pi^- X$$

$$K^+ p \rightarrow K^0 \pi^- X$$

$$K^+ p \rightarrow \Lambda^0 \pi^- X$$

$$K^+ p \rightarrow \bar{\Lambda}^0 \pi^- X$$

$$p_{INC} = 7 \text{ GeV/c}$$

$$p_{INC} = 12.7 \text{ GeV/c}$$

$$p_{INC} = 12.7 \text{ GeV/c}$$

$$p_{INC} = 12.7 \text{ GeV/c}$$

Distributions in the angle ϕ between the transverse momenta of the two identified outgoing particles c and d for intervals of missing mass squared M_X^2 for the reactions of the type $ab \rightarrow cdX$.

(a) $\pi^+ p \rightarrow \pi^- \pi^- X$ (left)
 $K^+ p \rightarrow K^0 \pi^- X$ (right)

(b) $K^+ p \rightarrow \Lambda^0 \pi^- X$ (upper)
 $K^+ p \rightarrow \bar{\Lambda}^0 \pi^- X$ (lower)

The solid curves are phase space.

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c $K^+ p$ and 7 GeV/c $\pi^+ p$ Collisions, Univ. of Rochester preprint UR-875-349 (Revised) 1972; Phys. Rev. D 5, 1621 (1972)

$K^+p \rightarrow K^0\pi^+\chi$
 $p_{\text{INC}} = 12.7 \text{ GeV}/c$
 $K^+p \rightarrow K^0 + \pi^+ + m \quad (12.7 \text{ GeV}/c)$

$$K^+p \rightarrow K^0\pi^-X$$

$$P_{INC} = 12.7 \text{ GeV}/c$$

Distributions in the angle ϕ between the transverse momenta of the outgoing particles c and d in the reaction $K^+p \rightarrow cdX$ for selected intervals in M_X^2 and in $|\Delta y| = |y_c - y_d|$. The solid curves are phase space.

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c K^+p and 7 GeV/c π^+p Collisions, Univ. of Rochester preprint UR-875-349 (Revised) 1972; Phys. Rev. D₅, 1621 (1972)

$$p_{INC} = 12.7 \text{ GeV/c}$$

$$p_{INC} = 7 \text{ GeV/c}$$

$$p_{INC} = 12.7 \text{ GeV/c}$$

$$p_{INC} = 12.7 \text{ GeV/c}$$

$$K^+ p \rightarrow K^0 \pi^- X$$

$$P_{INC} = 12.7 \text{ GeV}/c$$

$$\pi^+ p \rightarrow \pi^- \pi^- X$$

$$P_{INC} = 7 \text{ GeV}/c$$

$$K^+ p \rightarrow \Lambda^0 \pi^- X$$

$$P_{INC} = 12.7 \text{ GeV}/c$$

$$K^+ p \rightarrow \bar{\Lambda}^0 \pi^- X$$

$$P_{INC} = 12.7 \text{ GeV}/c$$

Distributions in the angle ϕ between the transverse momenta of the two identified outgoing particles for selected differences in rapidity (Δy) between the two particles for the reactions as indicated. The solid curves are phase space.

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c $K^+ p$ and 7 GeV/c $\pi^+ p$ Collisions, Univ. of Rochester preprint UR-875-349 (Revised) 1972; Phys. Rev. D 5, 1621 (1972)

$$p_{\text{INC}} = 12.7 \text{ GeV}/c$$

$$p_{\text{INC}} = 7 \text{ GeV}/c$$

$$p_{INC} = 12.7 \text{ GeV}/c$$

$$p_{INC} = 7 \text{ GeV}/c$$

Distribution in differences in center of mass rapidity y^{CM} of the indicated particles for the reactions:

- (a) $K^+ p \rightarrow K^0 \pi^- X$
- (b) $K^+ p \rightarrow \bar{K}^0 \pi^- X$
- (c) $K^+ p \rightarrow \Lambda^0 \pi^- X$
- (d) $\pi^+ p \rightarrow \pi^- \pi^- X$

S. Stone, T. Ferbel, P. Slattery and B. Werner, Some Aspects of Single-Particle and Two-Particle Inclusive Reactions in 12.7 GeV/c $K^+ p$ and 7 GeV/c $\pi^+ p$ Collisions, Univ. of Rochester preprint, UR-875-349 (Revised), (1972); Phys. Rev. D 5, 1621 (1972)

$K^+p \rightarrow \pi^- \pi^- X$ $p_{INC} = 12 \text{ GeV}/c$

$$K^+ p \rightarrow \pi^- \pi^- X$$

$$P_{INC} = 12 \text{ GeV}/c$$

$$G_n(y_1, y_2) = \left(\frac{d^2\sigma}{dy_1 dy_2} \right)_n - \frac{n-1}{n\sigma_n} \left(\frac{d\sigma}{dy_1} \right)_n \left(\frac{d\sigma}{dy_2} \right) \quad \text{vs. } y_2 - y_1,$$

- (a) for 6-prong events ($n = \text{number of } \pi^- = 2$)
- (b) for 8-prong events ($n = \text{number of } \pi^- = 3$)

Winston Ko, Phys. Rev. Letters 28, 935 (1972)

$$K^+ p \rightarrow \pi^- \pi^- X$$

$$P_{INC} = 12 \text{ GeV}/c$$

$$K^+ + p \rightarrow \pi^- + \pi^- + \text{ANYTHING}, 12 \text{ GeV}/c$$

134925 ENTRIES

$$K^+ p \rightarrow \pi^- \pi^- X$$

$$P_{INC} = 12 \text{ GeV}/c$$

(a) Solid histogram, coincidence $d^2\sigma/dy_1 dy_2$ of two π^- with rapidity

separation $y = y_2 - y_1$. Dotted histogram is

$1/\sigma_{TOTAL} (d\sigma/dy_1)(d\sigma/dy_2)$ also plotted vs. Δy .

(b) The difference of the two histograms in part (a). The upright

and inverted triangles show values when the absolute normalization

is $\pm 7\%$ off.

Winston Ko, Phys. Rev. Letters 28, 935 (1972)

$$K^+p \rightarrow \pi^- \pi^- X$$

$$P_{INC} = 12 \text{ GeV}/c$$

$$K^+ p \rightarrow \pi^- \pi^- X$$

$$P_{INC} = 12 \text{ GeV}/c$$

$d^2\sigma/dy_1 dy_2 = 1/\sigma_{TOTAL} (d\sigma/dy_1)(d\sigma/dy_2)$ vs. $y_2 - y_1$ for the following cuts:

$$(a) \quad -3.3 < y_1 < -1.0$$

$$(b) \quad 1.0 < y_1 < 3.3$$

$$(c) \quad -1.0 < y_1 < 0.0$$

$$(d) \quad 0.0 < y_1 < 1.0$$

Winston Ko, Phys. Rev. Letters 28, 935 (1972)

$$\pi^- p + \pi^- \pi^+ X$$

$$\pi^+ p + \pi^- \pi^+ X$$

$$P_{INC} \approx 8, 18.5 \text{ GeV}$$

$$P_{INC} \approx 18.5 \text{ GeV}$$

$$\begin{aligned}\pi^- p &\rightarrow \pi^- \pi^- X \\ \pi^+ p &\rightarrow \pi^- \pi^- X\end{aligned}$$

$$p_{INC} = 8, 18.5 \text{ GeV}$$

$$p_{INC} = 18.5 \text{ GeV}$$

Values of the correlation function

$$C(y_c^{CM}, y_d^{CM}) = \frac{1}{\pi^2 \sigma_{\infty}^2} \frac{d^2 \sigma}{dy_c^{CM} dy_d^{CM}} - \frac{1}{\pi^2 \sigma_{\infty}^2} \frac{d\sigma}{dy_c} \frac{d\sigma}{dy_d}$$

as a function of y_d^{CM} for various intervals of y_c^{CM} in the two-particle

inclusive reactions $\pi^- p \rightarrow \pi^- \pi^- X$ at 8 GeV/c (left) and 18.5 GeV/c

(center) and $\pi^+ p \rightarrow \pi^- \pi^- X$ at 18.5 GeV/c (right).

$$(a) \quad -2.6 < y_c^{CM} < -1.8 \quad (f) \quad +0.2 < y_c^{CM} < +0.6$$

$$(b) \quad -1.8 < y_c^{CM} < -1.0 \quad (g) \quad +0.6 < y_c^{CM} < +1.0$$

$$(c) \quad -1.0 < y_c^{CM} < -0.6 \quad (h) \quad +1.0 < y_c^{CM} < +1.4$$

$$(d) \quad -0.6 < y_c^{CM} < -0.2 \quad (i) \quad +1.4 < y_c^{CM} < +2.2$$

$$(e) \quad -0.2 < y_c^{CM} < +0.2 \quad (j) \quad +2.2 < y_c^{CM} < +3.0$$

Note: each unit on the vertical scale is 0.02

$\pi^- p \rightarrow \pi^- \pi^- X$ $P_{INC} = 18.5 \text{ GeV}/c$

$$\pi^- p \rightarrow \pi^- \pi^- X$$

$$P_{INC} = 18.5 \text{ GeV}/c$$

Distributions of $d\sigma/dy_c^{CM} dy_d^{CM}$ for the two-particle inclusive

reaction $\pi^- p \rightarrow \pi_c^- \pi_d^- X$ at 18.5 GeV/c. Distributions are shown as a function

of y_d for the following intervals of y_c :

(a) $-0.2 < y_c < +0.2$	(h) $+0.2 < y_c < +0.6$
(b) $-0.6 < y_c < -0.2$	(i) $+0.6 < y_c < +1.0$
(c) $-1.0 < y_c < -0.6$	(j) $+1.0 < y_c < +1.4$
(d) $-1.4 < y_c < -1.0$	(k) $+1.4 < y_c < +1.8$
(e) $-1.8 < y_c < -1.4$	(l) $+1.8 < y_c < +2.2$
(f) $-2.2 < y_c < -1.8$	(m) $+2.2 < y_c < +2.6$
(g) $-2.6 < y_c < -2.2$	(n) $+2.6 < y_c < +3.0$

W. D. Shephard, J. T. Powers, N. N. Bivas, N. M. Cason, V. P. Kenney and
D. W. Thomas, Phys. Rev. Letters 28, 703 (1972)

$$K^- p + \pi^- \pi^+ X$$

$$P_{\text{INC}} = 9 \text{ GeV}/c$$

$$K^- p \rightarrow \pi^- \pi^+ X$$

$$P_{INC} = 9 \text{ GeV}/c$$

$$d^2\sigma/dx_1 dx_2 \text{ vs. } |x_2| - |x_1| \text{ for backward } \pi^-, \text{ forward } \pi^+. \quad (x = p_{||}^{CM}/p_{MAX}^{CM})$$

The following notation was used:

(a) $0 < x_2 + x_1 < .05$	
(b) $.05 < x_2 + x_1 < .10$	
(c) $.10 < x_2 + x_1 < .15$	
(d) $.15 < x_2 + x_1 < .20$	
(e) $.20 < x_2 + x_1 < .25$	
(f) $.25 < x_2 + x_1 < .30$	
(g) $.30 < x_2 + x_1 < .35$	
(h) $.35 < x_2 + x_1 < .40$	
(i) $.40 < x_2 + x_1 < .45$	
(1) $0 < x_1 < .05$	(11) $0 < x_2 < .05$
(2) $.05 < x_1 < .10$	(12) $.05 < x_2 < .10$
(3) $.10 < x_1 < .15$	(13) $.10 < x_2 < .15$
(4) $.15 < x_1 < .20$	(14) $.15 < x_2 < .20$
(5) $.20 < x_1 < .25$	(15) $.20 < x_2 < .25$
(6) $.25 < x_1 < .30$	(16) $.25 < x_2 < .30$
(7) $.30 < x_1 < .35$	(17) $.30 < x_2 < .35$

M. Foster and C. Quigg, Cross Sections and Correlations for Two-Particle Inclusive Reactions in K^-p Collisions at 9 GeV/c, SUNY at Stony Brook (1972)

$$\pi^+ p \rightarrow \pi^+ \pi^+ X$$

$$P_{\text{INC}} = 9 \text{ GeV/c}$$

$$K^- p \rightarrow \pi^+ \pi^+ X$$

$$P_{INC} = 9 \text{ GeV/c}$$

$$d^2\sigma/dx_1 dx_2 \text{ vs. } x_2 - x_1 \text{ for forward produced } \pi^+ \pi^+ \left(x = P_{||}^{CM}/P_{MAX}^{CM} \right)$$

The following notation was used:

$$(a) \quad 0 < |x_2| + |x_1| < .05$$

$$(b) \quad .05 < |x_2| + |x_1| < .10$$

$$(c) \quad .10 < |x_2| + |x_1| < .15$$

$$(d) \quad .15 < |x_2| + |x_1| < .20$$

$$(e) \quad .20 < |x_2| + |x_1| < .25$$

$$(f) \quad .25 < |x_2| + |x_1| < .30$$

$$(g) \quad .30 < |x_2| + |x_1| < .35$$

$$(h) \quad .35 < |x_2| + |x_1| < .40$$

$$(i) \quad .40 < |x_2| + |x_1| < .45$$

$$(1) \quad 0 < |x_1| < .05$$

$$(2) \quad .05 < |x_1| < .10$$

$$(3) \quad .10 < |x_1| < .15$$

$$(4) \quad .15 < |x_1| < .20$$

$$(5) \quad .20 < |x_1| < .25$$

$$(6) \quad .25 < |x_1| < .30$$

$$(7) \quad .30 < |x_1| < .35$$

M. Foster and C. Quigg, Cross Sections and Correlations for Two-Particle Inclusive Reactions in K^-p Collisions at 9 GeV/c, SUNY at Stony Brook (1972)

III. Inclusive Spectra: Kinematics and Phenomenology

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*Work supported in part by the U.S. Atomic Energy Commission (AT(30-1)-3668B).

Table of Contents

1.	Inclusive Spectra in Perspective	727
2.	Total and Topological Cross-Sections	728
3.	Single and Many Body Distributions	729
4.	Kinematics of Single Particle Distributions	732
5.	Limiting Fragmentation and Scaling	734
	(i) Fragmentation Variables: p^*	734
	(ii) Scaling Variables: x, z^1	734
	(iii) Rapidity Variables: y, η	735
	(iv) Missing Mass and Momentum Transfer Variables: m_x, t	736
	(v) Laboratory Variables: p_{LAB}, s_{LAB}	738
	(vi) Cosmic Ray Variables	738
	(vii) Kinematics of Resonance Decay Products	739
	(viii) Relations Between Variables	740
	(ix) Approach to the High Energy Spectrum	742
6.	General Comments	744
	Choice of Variables	744
	Inclusive Single Particle Spectrum: A Sum	744
	Correlations	744
7.	Caveat Emptor: A Warning to the Reader	744
8.	References	746
9.	Bibliography of Theory and Models for Inclusive Processes	749

1. Inclusive Spectra in Perspective

Interest in inclusive cross-sections and multi-particle production, both experimental and theoretical, now waxes high. With the development of the CERN intersecting storage rings and the NAL accelerator, producing beam momenta between 200 and 1500 GeV/c, this interest will undoubtedly persist for some time. Since there exist scaling laws which predict particle distributions at asymptotic energies from those at lower energies, we are encouraged to examine anew our present accelerator and cosmic ray data.

The simplest questions one might pose about the reaction $ab \rightarrow$ particles relate to the type and number of particles produced and the total cross-section. Cosmic ray physicists, first exploring these phenomena, sought to identify the produced hadrons and examine their angular and energy distributions using emulsion stacks. With the advent of laboratory high energy accelerators and improved detection techniques (cloud chamber, spark chamber, bubble chamber, electronic counters) experimental emphasis shifted to the discovery and characterization of new particles and resonances. To ensure large particle yields from accelerators it was soon found necessary to conduct beam survey experiments; many target materials were bombarded with accelerated projectiles and the distributions $dN/dp_T dy$ of secondaries in momentum were recorded. Using accurately monitored secondary beams, it proved possible to investigate the differential cross-sections for many final state channels of low multiplicity (elastic, 2-body, quasi-elastic, etc.). Resonant correlations ("bump hunting") in inclusive channels ($ab \rightarrow$ a definite set of particles) are still the focus of many experimental high energy physicists.

As beam energies available in the laboratory increase from a few MeV to Serpukhov's 70 GeV, more final state channels open up and contribute to the

majority of the total cross-section. Moreover, the average multiplicity of charged particles increases with the energy. To study each of the high multiplicity channels available at 70 GeV/c would be a Herculean task indeed! Since we detect directly only charged particles, the only measurable cross-sections are necessarily inclusive: $ab \rightarrow \text{charged particles} + \text{unobserved neutral particles}$. Contingent upon our ability to identify the prongs, we may ask for the distribution in momentum space of all identified particles (p, m^2, E^2 , etc.). Alternatively, we may trigger an array of counters to detect all particles of a specific species (p, π^0 , etc.), emitted into a certain solid angle, whose momentum is then measured. This flux depends of particles c from ab collisions defines the single particle inclusive spectrum $ab \rightarrow cX$.

At first sight the single particle distribution appears to be too complex an object to be studied. It involves a sum over all channels in which a certain particle may be produced. We know, however, another such object; the total cross-section also represents a channel sum, but through unitarity, is related to the forward $ab \rightarrow ab$ elastic amplitude. The latter has smooth energy dependence by analyticity, and may be phenomenically parametrized by diffractive or Regge-pole models. Similarly the inclusive single particle spectrum $ab \rightarrow cX$ is related to the forward $abc \rightarrow abc$ amplitude, an analytic function. We may bring to the study of this $1 \rightarrow 1$ amplitude all the phenomenological insight garnered from studies of elastic and 2-body amplitudes. The intuition of Feynman and Yang, reflecting upon the energy dependence of quasi-elastic processes and total cross-sections, has led to the scaling hypothesis and the hypothesis of limiting fragmentation, valid in the asymptotic energy regime. This kinematic skeleton has been fleshed out into more quantitative form by many adroit model builders.

2. Total and Topological Cross-Sections

The most accessible inclusive measurement is that of the total cross-section. This may be obtained either directly, by unitarity, from the forward elastic scattering amplitude²

$$\sigma_{ab}^{\text{TOTAL}}(s) = \frac{\text{Im } T(s, 0)}{s \cdot b_0(s, m_a^2, m_b^2)}$$

or indirectly, by summing over the rates into all open channels, given by

$$\sigma_{ab}^{\text{TOTAL}}(s) = \sum_{\text{Channel } a} \sigma_{ab \rightarrow a}(s).$$

Now, because of the difficulty of measuring uncharged particles³⁰ one may measure "topological" cross-sections: that is σ_{n_p} for a fixed number n_p of charged particles ("prongs"). Note that some bubble chamber experimentalists quote σ_{n_p} including the charged V^0 's from strange neutral particle decay, while others omit the V^0 's. Another inclusive cross-section is that for $ab \rightarrow n_a$ particles of type $a + \text{anything else}$
or $ab \rightarrow n \pi + \text{anything}$
or $ab \rightarrow K\bar{K} + \text{anything}$.

Even when such information is not measured directly, it may be obtained from integrals of multi-particle spectra; for instance, if $R(p)$ is the single particle distribution for $ab \rightarrow cX$, the average number $\langle n_c \rangle$ of particles c produced may be obtained from

$$\int R(p) \frac{d^3p}{2E(2\pi)^3} = \sum_{n_c} n_c \sigma_{n_c}(s) = \langle n_c \rangle \sigma_{ab}^{\text{TOTAL}}(s).$$

While there exist many types of model³ predicting the cross-section for producing n particles at a given energy, for empirical purposes only the topological cross-sections may be fitted, leaving the charge/neutral ratio as a free parameter. $\sigma(n_p, a)$ may be examined either (at fixed a) as a function of prong number or (for a definite number of prongs) as a function of energy. While analyticity requires smooth behaviour in energy, the existence of a function with a few parameters to interpolate the n_p dependence is a pure ansatz; nonetheless, many semi-empirical functions have been proposed. Also the dependence of the average prong number $\langle n_p \rangle = \frac{\sum_{n_p} n_p \sigma(n_p, a)}{\sum_{n_p} \sigma(n_p, a)}$ upon a is frequently quoted.⁴

3. Single and Many Particle Distributions

Consider the collision ab into arbitrary numbers of all types of particles, with arbitrary momenta. If $\langle [p_1^{(a)}, p_2^{(a)}, \dots, p_{N_a}^{(a)}] T | a, b \rangle$ is the amplitude for $ab \rightarrow N_a$ particles of type a , N_b particles of type b , ..., the rate for this process ($ab \rightarrow X$) is given by the inclusive total cross-section:

$$4\pi \sqrt{s} \sigma_{ab}^{\text{TOTAL}}(s)$$

$$= \sum_a \sum_{\{N_a \geq 0\}} \int \prod_{i=1}^{N_a} d\omega_i \left| \langle [p_1^{(a)}, \dots, p_{N_a}^{(a)}] T | a, b \rangle \right|^2 (2\pi)^4 \delta^4 \left(\sum_{i=1}^{N_a} p_i^{(a)} - p_a - p_b \right)$$

$$\text{where } p^{\text{CH}} = \frac{1}{2} (s, \frac{s}{s} \frac{p_a^2 + p_b^2}{2}), \quad s = (p_a + p_b)^2, \quad \text{and } \prod_{i=1}^{N_a} d\omega_i = \prod_{i=1}^{N_a} \frac{d^3 p_i}{(2\pi)^3}$$

is the final state phase space, with $d\omega_p = \frac{d^3 p}{2E (2\pi)^3}$.

If one monitors the flux of all particles of type c into the invariant volume $d\omega_p$ and ignores all other types of particles, the rate for this process ($ab \rightarrow cX$) is given by the invariant inclusive single particle distribution:

$$4\pi \sqrt{s} R_{ab \rightarrow cX}(p_a, p_b, p) \\ = \sum_{\{N_a \geq 0\}} \int \prod_{i=1}^{N_a} d\omega_i \left| \langle [p_1^{(a)}, \dots, p_{N_a}^{(a)}] T | a, b \rangle \right|^2 (2\pi)^4 \delta^4 \left(\sum_{i=1}^{N_a} p_i^{(a)} - p_a - p_b \right) \\ \times \sum_{j=1}^{N_c} 2E_c (2\pi)^3 \delta^3(p - p_j^{(c)})$$

By monitoring the moments of all particles of types a and b only, we obtain the 2 particle distribution:

$$4\pi \sqrt{s} R_{ab \rightarrow aBX}(p_a, p_b, p_a, p_b) \\ = \sum_{\{N_a \geq 0\}} \int \prod_{i=1}^{N_a} d\omega_i \left| \langle [p] T | a, b \rangle \right|^2 (2\pi)^4 \delta^4 \left(\sum_{i=1}^{N_a} p_i^{(a)} - p_a - p_b \right) \sum_{j=1}^{N_a} \sum_{k=1}^{N_a} \\ \times 2E_a (2\pi)^3 \delta^3(p_a - p_j^{(a)}) 2E_b (2\pi)^3 \delta^3(p_b - p_k^{(b)}).$$

If the 2 particles are both of type c , however,

$$4\pi \sqrt{s} R_{ab \rightarrow c_1 c_2 X}(p_a, p_b, p_{c_1}, p_{c_2}) \\ = \sum_{\{N_a \geq 0\}} \int \prod_{i=1}^{N_a} d\omega_i \left| \langle [p] T | a, b \rangle \right|^2 (2\pi)^4 \delta^4 \left(\sum_{i=1}^{N_a} p_i^{(a)} - p_a - p_b \right) \sum_{2 \leq j < k \leq N_c} \\ \times 2E_{c_1} (2\pi)^3 2E_{c_2} (2\pi)^3 \delta^3(p_{c_1} - p_j^{(c)}) \delta^3(p_{c_2} - p_k^{(c)}).$$

The notation $R_{ab \rightarrow c}(p_a, p_b, p_c) : (2\pi)^3 2E_c \frac{d\sigma}{d^3p_c} = \frac{d\sigma}{d\omega_c}$

$$R_{ab \rightarrow c}(p_a, p_b, p_c) : (2\pi)^3 2E_a (2\pi)^3 2E_b \frac{d\sigma}{d^3p_a d^3p_b} = \frac{d\sigma}{d\omega_a d\omega_b}$$

is suggestive, indicating a hierarchy of distribution functions for many particles.

Using the definitions, we see that the distributions are normalized so that

$$\int R_{ab \rightarrow c}(p_a, p_b, p_c) d\omega_c = \sum_{N_c=1} N_c \sigma(N_c)$$

$$\int R_{ab \rightarrow c}(p_a, p_b, p_c, p_d) d\omega_a d\omega_b = \sum_{N_a, N_b=1} N_a N_b \sigma(N_a, N_b)$$

$$\int R_{ab \rightarrow c_1 c_2}(p_a, p_b, p_{c_1}, p_{c_2}) d\omega_{c_1} d\omega_{c_2} = \sum_{N_c=1} N_c (N_c - 1) \sigma(N_c).$$

Here $\sigma(N_c)$ denotes the inclusive cross-section for

$ab \rightarrow$ exactly N_c particles of type c + anything else.

More generally, consider the distribution function for n_a particles of type a , n_b particles of type b etc.

$$R_{ab \rightarrow a_1 \dots a_{n_a} b_1 \dots b_{n_b} \dots}^{(a)} \{p_1^{(a)}, \dots, p_{n_a}^{(a)}; p_1^{(b)}, \dots, p_{n_b}^{(b)}; \dots\}.$$

This distribution is normalized by

$$\int R(\{p_1^{(\lambda)}, \dots, p_{n_\lambda}^{(\lambda)}\}) \prod_{\lambda} \prod_{i=1}^{n_\lambda} d\omega_i^{(\lambda)} = \sum_{\{N_\lambda, E_{N_\lambda}\}} \prod_{\lambda} \prod_{i=1}^{N_\lambda} \frac{N_\lambda!}{(N_\lambda - n_\lambda)!} \sigma(N_\lambda, E_{N_\lambda}, \dots)$$

Let us focus upon the single particle distribution. From the definition, we see that $R(p_a, p_b, p_c) R(p_a, p_b, p_c)$ for any Lorentz transformation; this invariance makes R a function of 3 invariants only, say $p_a \cdot p_b$, $p_a \cdot p_c$, $p_b \cdot p_c$ (at least in the region where $p^0 > 0$ for a, b , and c).

$$\text{So } \int R(p_c) d\omega_c, \int p_c^\mu R(p_c) d\omega_c, \int p_c^\mu p_c^\nu R(p_c) d\omega_c \text{ are, respectively,}$$

scalar, vector and symmetric tensors which must be formed from p_a and p_b . Such integrals may be interpreted as

$$\frac{1}{\sigma_{ab}} \int R_{ab \rightarrow c}(p_a, p_b, p_c) d\omega_c = \langle n_c(s) \rangle = \text{the average number of particles } c \text{ produced in an } ab \text{ collision,}$$

$$\frac{1}{\sigma_{ab}} \int p_c^\mu R_{ab \rightarrow c}(p_a, p_b, p_c) d\omega_c = \langle p_c^\mu \rangle = \text{the average total momentum carried off by all particles of type } c \text{ in an } ab \text{ collision.}$$

We may then write some simple sum rules expressing charge and 4-momentum

$$\text{conservation: } \sum_c Q_c \langle n_c(s) \rangle = Q_a + Q_b \equiv Q$$

$$\sum_c \langle p_c^\mu \rangle = (p_a + p_b)^\mu \equiv p^\mu$$

Further sum rules³, no less trivial, relate averages over 2 particle distribution functions.

(i) 4-momentum rules

$$p^\mu p^\nu = \sum_a \int d\omega \langle a \rangle R(p\langle a \rangle) \langle p\langle a \rangle \rangle^\mu \langle p\langle a \rangle \rangle^\nu + \sum_{a,b} \int d\omega \langle a \rangle d\omega \langle b \rangle R(p\langle a \rangle, p\langle b \rangle) \langle p\langle a \rangle \rangle^\mu \langle p\langle b \rangle \rangle^\nu$$

$$(p-k)^\mu = \sum_n \int d\omega \langle n \rangle R(k, p\langle n \rangle) \langle p\langle n \rangle \rangle^\mu$$

(ii) Charge rules

$$Q^2 = \sum_a Q_a^2 \int d\omega \langle a \rangle R(p\langle a \rangle) + \sum_{a,b} Q_a Q_b \int d\omega \langle a \rangle d\omega \langle b \rangle R(p\langle a \rangle, p\langle b \rangle)$$

$$(Q-Q_a) R(p\langle a \rangle) = \sum_n Q_n \int d\omega \langle n \rangle R(p\langle a \rangle, p\langle n \rangle)$$

(iii) Mixed rules

$$Q p^\mu = \sum_{a,b} Q_a \int d\omega \langle a \rangle d\omega \langle b \rangle \langle p\langle b \rangle \rangle^\mu R(p\langle a \rangle, p\langle b \rangle) + \sum_a Q_a \int d\omega \langle a \rangle R(p\langle a \rangle) \langle p\langle a \rangle \rangle^\mu$$

$$Q Q' = \sum_{a,b} Q_a Q'_b \int d\omega \langle a \rangle d\omega \langle b \rangle R(p\langle a \rangle, p\langle b \rangle) + \sum_a Q_a Q'_a \int d\omega \langle a \rangle R(p\langle a \rangle)$$

A.H.Mueller⁶ has observed a general property of single particle distributions related to unitarity. Just as

$$\frac{4}{\Gamma_{CH}} \sqrt{s} \sigma_{ab}(s) = 2 \ln s \langle ab | T | ab \rangle$$

relates the total cross-section to the absorptive part of the forward $ab \rightarrow ab$ amplitude,

$$\frac{4}{\Gamma_{CH}} \sqrt{s} R_{ab \rightarrow cX}(p_a, p_b, p_c) = 2 \ln s \langle abc | T | abc \rangle$$

relates the inclusive single particle distribution to the absorptive part of the forward $ab \rightarrow ab \bar{c}$ amplitude (analytically continued into the physical region for $ab \rightarrow cX$). Here m_X denotes the "missing mass", defined by $m_X^2 = (p_a + p_b - p_c)^2 = (p_a + p_b + p_{\bar{c}})^2$. The same relation holds for higher order distributions where c is replaced by a cluster of particles.

Figure 1: Optical Theorem for the Single Particle Spectrum $ab \rightarrow cX$

4. Kinematics of Single Particle Distributions $ab \rightarrow cK$

In the ab collision we assume that b , the target particle at rest in the lab., is struck by projectile a , with momentum along the z -axis. The 4-momentum of any particle, mass m , is then written

$$p = (p^0, p^1, p^2, p^3) = (E, p_{\perp}, p_{\parallel}) \text{ where } p_{\perp} = (p^1, p^2) \text{ refers to components transverse to the beam, } p_{\parallel} \text{ to the component along the beam direction, and } p^2 = m^2. \text{ A most useful set of variables are } p^{\pm} \approx E \pm p_{\parallel}, \text{ with } p^+ p^- = p_{\perp}^2 + m^2 = s^2.$$

Employing the function $\Delta(x, y, z) = x^2 + y^2 + z^2 - 2xy - 2yz - 2zx$, we may specify the 4-momenta of the colliding particles in three reference frames (labelled by superscripts LAB, C.M., or PROJ.),

LAB or TARGET frame

$$p_b^{\text{LAB}} = (m_b, 0, 0) \\ p_a^{\text{LAB}} = \left(\frac{s - m_b^2 - m_a^2}{2m_b}, 0, \frac{\Delta^{1/2}(s, m_a^2, m_b^2)}{2m_b} \right) \\ (p_a + p_b)^{\text{LAB}} = \left(\frac{s + m_b^2 - m_a^2}{2m_b}, 0, \frac{\Delta^{1/2}(s, m_a^2, m_b^2)}{2m_b} \right) = (\sqrt{s} \cosh \zeta, 0, \sqrt{s} \sinh \zeta)$$

C.M. frame

$$p_a^{\text{CH}} = \left(\frac{s + m_b^2 - m_a^2}{2\sqrt{s}}, 0, \frac{\Delta^{1/2}(s, m_a^2, m_b^2)}{2\sqrt{s}} \right) = (m_a \cosh \zeta', 0, m_a \sinh \zeta') \\ p_b^{\text{CH}} = \left(\frac{s + m_b^2 - m_a^2}{2\sqrt{s}}, 0, -\frac{\Delta^{1/2}(s, m_a^2, m_b^2)}{2\sqrt{s}} \right) = (m_b \cosh \zeta, 0, -m_b \sinh \zeta) \\ (p_a + p_b)^{\text{CH}} = (\sqrt{s}, 0, 0)$$

PROJECTILE or BEAM frame

$$p_a^{\text{PROJ.}} = (m_a, 0, 0) \\ p_b^{\text{PROJ.}} = \left(\frac{s - m_a^2 - m_b^2}{2m_a}, 0, -\frac{\Delta^{1/2}(s, m_a^2, m_b^2)}{2m_a} \right)$$

$$(p_a + p_b)^{\text{PROJ.}} = \left(\frac{s + m_b^2 - m_a^2}{2m_a}, 0, -\frac{\Delta^{1/2}(s, m_a^2, m_b^2)}{2m_a} \right) = (\sqrt{s} \cosh \zeta', 0, -\sqrt{s} \sinh \zeta')$$

These frames are related by Lorentz boosts K_3 in the beam direction:

that is,

$$p^{\text{LAB}} = e^{\zeta K_3} p^{\text{CH}} \\ p^{\text{PROJ.}} = e^{-\zeta' K_3} p^{\text{CH}} \\ p^{\text{LAB}} = e^{\frac{1}{2}(\zeta + \zeta') K_3} p^{\text{PROJ.}}, \text{ where} \\ e^{2\zeta} = \frac{s + m_b^2 - m_a^2 + \Delta^{1/2}(s, m_a^2, m_b^2)}{2m_b \sqrt{s}} \quad \text{and} \\ e^{2\zeta'} = \frac{s + m_a^2 - m_b^2 + \Delta^{1/2}(s, m_a^2, m_b^2)}{2m_a \sqrt{s}}. \text{ As } s \rightarrow \infty, e^{\zeta} \sim \sqrt{\frac{s}{m_b}} \text{ and } e^{\zeta'} \sim \sqrt{\frac{s}{m_a}}.$$

In terms of $p^{\pm}, p_{\perp}$ the transformations are

$$(p^{\pm})^{\text{LAB}} = e^{\pm \zeta} (p^{\pm})^{\text{CH}} \\ (p^{\pm})^{\text{PROJ.}} = e^{\pm \zeta'} (p^{\pm})^{\text{CH}} \\ p_{\perp}^{\text{LAB}} = p_{\perp}^{\text{CH}} = p_{\perp}^{\text{PROJ.}}$$

The simplicity of transformations is even greater in terms of the rapidity variable y , defined by

$$y = \frac{1}{2} \ln \frac{E^+}{E^-} = \frac{1}{2} \ln \frac{E + p_{\parallel}}{E - p_{\parallel}} = \ln \frac{E + p_{\parallel}}{m_{\perp}} = -\ln \frac{E - p_{\parallel}}{m_{\perp}}.$$

Then

$$y^{\text{LAB}} = \frac{1}{2} \ln \left(\frac{E^+}{p^-} \right)^{\text{LAB}} = \frac{1}{2} \ln \frac{e^{\zeta} (p^+)^{\text{CH}}}{e^{-\zeta} (p^-)^{\text{CH}}} = \frac{1}{2} \ln \left(\frac{E^+}{p^-} \right)^{\text{CH}} + \zeta \\ = y^{\text{CH}} + \zeta$$

and $y_{\text{FRJ}} = y_{\text{CH}} - c'$, with $p^+ p^- = p_{\perp}^2 + m^2 = m_{\perp}^2$ the same in all 3 frames.

Because of this simple transformation property, distributions such as $\frac{d^3p}{dy}$ have the same shape in all longitudinally boosted frames.

The inverted relations between rapidity and momentum components are

$$p^{\pm} = m_{\perp} e^{\pm y} \quad \text{and} \quad E = m_{\perp} \cosh y, \quad p_{\parallel} = m_{\perp} \sinh y.$$

Note that $y = \frac{1}{2} \ln \frac{E+p_{\parallel}}{E-p_{\parallel}}$ is a function of the longitudinal velocity $\beta_{\parallel}$ only, and $y = \beta_{\parallel}$ as $\beta_{\parallel}$ becomes small.

A Choice of Variables

Because the single particle distribution is a Lorentz scalar $R(p_a, p_b, p_c, p_d, p_a, p_b)$ one has considerable freedom of choice for 3 independent variables. The energy parameter is usually taken to be

$$s = (p_a + p_b)^2 = m_a^2 + m_b^2 + 2m_a m_b \cosh(y_a - y_b)$$

$$\text{or} \quad p_{\text{INCIDENT}} \cdot p_{\text{LAB}} = \frac{1}{2} (s_a + m_b^2)$$

In the asymptotic limit $s \rightarrow \infty$, $s \sim 2m_a p_{\text{THC}} \sim m_a m_b y_a - y_b$.

For 2 other variables, it is customary to choose quantities closely related to longitudinal or transverse component of the produced particle c.

LONGITUDINAL VARIABLE TRANSVERSE VARIABLE USAGE

$p_{\parallel}^{\text{CH}}$	$p_{\perp}$	Payroll plot
$p_{\parallel}^{\text{LAB}}$ or $p_{\parallel}^{\text{FRJ}}$	$p_{\perp}^2$	Limiting Fragmentation
$x = p_{\parallel}^{\text{CH}} / p_{\text{MAX}}^{\text{CH}}$	$p_{\perp}^2$	Scaling
$p_{\perp}^{\text{LAB}}$	$0 \leq \Delta \eta$	Counter Experiments
y	$m_{\perp}$	Multiperipheral Models;
		Kinematics
$\log_{10} \tan \theta^{\text{LAB}}$		Cosmic Rays
m_x^2	$t_{ac} \cdot t_{bc}$	Multi-Regge & dual models

Since we are interested in the single particle distribution $2E \frac{d^3p}{d^3p}$, we must rewrite the Lorentz invariant volume element $\frac{d^3p}{2E}$ in terms of our many variables.

$$\frac{d^3p}{2E} = \frac{\pi p_{\perp}^2 dp_{\parallel}}{2E}$$

$$= \frac{\pi p_{\perp}^2 dx}{2x^0} \quad \text{where} \quad p_{\parallel}^{\text{CH}} = x p_{\text{MAX}}^{\text{CH}}, \quad x^0 = \frac{p_{\text{CH}}}{p_{\text{MAX}}} \sqrt{x^2 + \left(\frac{m_{\perp}}{p_{\text{MAX}}}\right)^2}$$

$$= \frac{\pi}{2} p_{\perp}^2 dy$$

$$= \frac{\pi}{2} p_{\perp}^2 \frac{dn}{2E}$$

$$= \frac{\pi}{2} \frac{dt}{h^3} \frac{d^2 m_x^2}{(s, m_a^2, m_b^2)} \quad \text{where} \quad m_x^2 = (p_a + p_b - p)^2$$

$$\text{and} \quad t = (p_a - p)^2 \quad \text{or} \quad (p_b - p)^2.$$

The kinematic boundary for $ab \rightarrow cx$ is most easily expressed in the CH frame. If m_d is the smallest mass of all clusters x recoiling against c,

$p_{\text{CH}}^{\text{CH}} \leq \frac{h^3 (s, m_c^2, m_d^2)}{2\sqrt{s}} \equiv p_{\text{MAX}}^{\text{CH}}$. For instance in $pp \rightarrow \pi^- X$, $m_d = 2m_p + m_{\pi^-}$ since $pp \rightarrow \pi^- (\pi^+ pp)$ gives maximal CH momentum to the π^- .

5. Limiting Fragmentation and Scaling

(i) Fragmentation Variables: $p^\pm$

Assume that in an ab collision fragments of the target b or projectile a have finite moments in the rest frame of the fragmenting particle, no matter how high the energy. Denoting by $\{p_a^i\}$ (or $\{p_b^i\}$) the fragments of a (or b), we write, as $s \rightarrow \infty$,

$$\langle p_b^{\pm} \rangle_{\text{LAB}} = O(1), \quad \langle p_a^{\pm} \rangle_{\text{PROJ.}} = O(1);$$

so

$$\langle p_a^+ \rangle_{\text{LAB}} = e^{+c} \langle p_a^+ \rangle_{\text{PROJ.}} \sim \frac{a}{a+b} \langle p_a^+ \rangle_{\text{PROJ.}} = O(a)$$

$$\langle p_a^- \rangle_{\text{LAB}} = e^{-(c+c')} \langle p_a^- \rangle_{\text{PROJ.}} \sim \frac{a+b}{a} \langle p_a^- \rangle_{\text{PROJ.}} = O(1/a).$$

Projectile fragments have finite values of $\langle p_a^+ \rangle_{\text{LAB}}$ and $\langle p_a^- \rangle_{\text{LAB}}$, where

$p^+ p^- = m_\perp^2$. Consider additional particles $\{p_i\}$ with

$$\langle p_i^+ \rangle_{\text{CH}} = m_\perp^2 \sim \frac{1}{\sqrt{s}} \text{MAX} \sim m_\perp^2 \left(\frac{\sqrt{s}}{a} \right)^{2\eta} \quad \text{where } \eta \text{ is finite and } -1 < \eta < 1.$$

Then

$$\langle p_i^+ \rangle_{\text{LAB}} = e^c \langle p_i^+ \rangle_{\text{CH}} \sim \frac{\sqrt{s}}{a} m_\perp^2 \left(\frac{a}{\sqrt{s}} \right)^{\frac{\eta}{2}} = O(a^{\frac{1+\eta}{2}});$$

$$\langle p_i^- \rangle_{\text{LAB}} = e^{-c} \langle p_i^- \rangle_{\text{CH}} \sim \frac{\sqrt{s}}{a} m_\perp^2 \left(\frac{a}{\sqrt{s}} \right)^{\frac{\eta}{2}} = O(a^{\frac{1-\eta}{2}}).$$

Particles $\{p_a\}$ (or $\{p_b\}$) are said to be in the target (or projectile) fragmentation region; particles $\{p_i\}$ are said to be in the central region. Only target fragment have finite lab. moments.

Consider the process $ab \rightarrow cx$, where we observe only particles c with a fixed lab. momentum, and let the beam momentum increase ($s \rightarrow \infty$). The hypothesis of limiting fragmentation⁷ asserts the existence of a limiting distribution

$$\lim_{s \rightarrow \infty} R(p_{\text{LAB}}, s) = R_{\infty}(p_{\text{LAB}}).$$

Moreover R_{∞} reflects the breakup of target particle b only (up to a normalizing factor). This process is denoted $b \rightarrow c$. Similarly, in the projectile rest frame, $\lim_{s \rightarrow \infty} R(p_{\text{PROJ.}}, s) = R_{\infty}(p_{\text{PROJ.}})$ for $a \rightarrow c$.

This hypothesis means that an experimenter whose apparatus has a finite resolution, and who is monitoring the flux of c particles with finite lab. momentum p_c , cannot determine the accelerator beam momentum (if this momentum is sufficiently large).

(ii) Scaling Variables: x, x'

Feynman⁸ prefers to discuss the asymptotic distribution in the CM frame.

Define $x \equiv \frac{p_{\text{CH}}}{p_{\text{MAX}}} \sim \frac{p_{\text{H}}}{\sqrt{s}/2}$. The kinematic boundary is then $p_{\perp} \leq p_{\text{MAX}}$ and

$$- \sqrt{1 - \left(\frac{p_{\perp}}{p_{\text{MAX}}} \right)^2} \leq x \leq \sqrt{1 - \left(\frac{p_{\perp}}{p_{\text{MAX}}} \right)^2}. \quad \text{For purposes of comparing distribu-}$$

tions in p_{H} with differing (fixed) values of $p_{\perp}$, we may also scale p_{H}^{CH} by its kinematic maximum value, by defining

$$x' \equiv \frac{p_{\text{H}}^{\text{CH}}}{p_{\text{H}}^{\text{MAX}}} \quad \text{with} \quad p_{\text{H}}^{\text{MAX}} = \sqrt{p_{\text{MAX}}^2 - p_{\perp}^2} \quad \text{and} \quad -1 \leq x' \leq 1.$$

As $s \rightarrow \infty$, $x' \sim x$.

Note that projectile and target fragments have

$$\langle p_a^+ \rangle_{\text{CH}} = e^{c'} \langle p_a^+ \rangle_{\text{PROJ.}} \sim \frac{\sqrt{s}}{a} \langle p_a^+ \rangle_{\text{PROJ.}} \quad \langle p_b^+ \rangle_{\text{CH}} = e^{-c} \langle p_b^+ \rangle_{\text{LAB}} \sim \frac{a+b}{a} \langle p_b^+ \rangle_{\text{LAB}}$$

and

$$\langle p_a^- \rangle_{\text{CH}} = e^{-c'} \langle p_a^- \rangle_{\text{PROJ.}} \sim \frac{a}{a+b} \langle p_a^- \rangle_{\text{PROJ.}} \quad \langle p_b^- \rangle_{\text{CH}} = e^c \langle p_b^- \rangle_{\text{LAB}} \sim \frac{\sqrt{s}}{a} \langle p_b^- \rangle_{\text{LAB}}.$$

$$\text{Since } p_{\parallel} = \frac{1}{2}(p^{+} - p^{-}),$$

$$x_a \sim \frac{(\frac{1}{2}p_a^{+})_{\text{PBJ}}}{a_1} \quad \text{and} \quad x_b \sim \frac{(p_b^{-})_{\text{LAB}}}{a_2}.$$

So projectile and target fragments have finite values of x as $s \rightarrow \infty$, whereas for particles in the central region

$$x \sim \frac{2a_2}{\sqrt{s}} \frac{1}{2} \left[\left(\frac{\sqrt{s}}{a_1} \right)^n - \left(\frac{\sqrt{s}}{a_2} \right)^n \right] = O \left(s^{\frac{1}{2} \left(\frac{n-1}{2} \right)} \right) \rightarrow 0 \quad \text{as } s \rightarrow \infty.$$

Feynman then conjectures that outside the "vee x " region, the single particle invariant distribution approaches a limit:

$$\lim_{s \rightarrow \infty} R(x, p_{\perp}, s) = R_{\infty}(x, p_{\perp}) \quad \text{provided} \quad |x| > O \left(\frac{a_1}{\sqrt{s_{\text{MAX}}}} \right).$$

(i.e., $p_{\parallel}^{\text{CH}}$ is confined to the region where $E^{\text{CH}} = \sqrt{p_{\parallel}^2 + a_1^2} \approx |p_{\parallel}| + \frac{a_1^2}{2|p_{\parallel}|}$).

If the same spectrum $ab \sim cX$ is observed at two large energies s_1, s_2 and the invariant spectrum at s_1 for a chosen $p_{\perp}$, $p_{\parallel}^{\text{CH}}$ is given, the invariant spectrum at s_2 has the same value for $p_{\perp}^{(2)} = p_{\perp} \cdot \frac{E^{\text{CH}(2)}}{E^{\text{CH}(1)}} = \sqrt{\frac{s_2}{s_1}} p_{\parallel}^{\text{CH}}$; this scaling permits a high energy extrapolation of the spectrum away from the vee x region.

Note that scaling applies only to the invariant distribution $E \frac{d^3p}{d^3p}$ and not to most experimental spectra. For sufficiently large s_1 and s_2

$$E^{(1)} \frac{d^3p}{d^3p(1)} \left(\frac{p_{\parallel}^{\text{CH}(1)}}{\sqrt{s_1}}, p_{\perp}^{(1)} \right) = E^{(2)} \frac{d^3p}{d^3p(2)} \left(\frac{p_{\parallel}^{\text{CH}(2)}}{\sqrt{s_2}}, p_{\perp}^{(2)} \right)$$

$$\text{provided } x = \frac{2p_{\parallel}^{\text{CH}(1)}}{\sqrt{s_1}} = \frac{2p_{\parallel}^{\text{CH}(2)}}{\sqrt{s_2}} \quad \text{and} \quad p_{\perp}^{(1)} = p_{\perp}^{(2)};$$

$$\text{then } \frac{d^3p}{dp_{\parallel}^{(1)} dp_{\perp}^{(1)}} = \sqrt{\frac{x^2 + \frac{a_1^2}{s_1}}{\frac{a_1^2}{s_1}}} \sqrt{\frac{a_2^2}{s_2}} \frac{d^3p}{dp_{\parallel}^{(2)} dp_{\perp}^{(2)}}; \quad \text{the distribution } \frac{d^3p}{dp_{\parallel} dp_{\perp}}$$

does not scale. For purposes of comparing target fragmentation ($x < -\frac{a_1}{p_{\text{MAX}}}$) in the lab. frame, however, it is not necessary to use the invariant distribution. For instance,

$$E^{(1)} \frac{d^3p}{d^3p(1)} (p_{\parallel}^{\text{LAB}(1)}, p_{\perp}^{(1)}) = E^{(2)} \frac{d^3p}{d^3p(2)} (p_{\parallel}^{\text{LAB}(2)}, p_{\perp}^{(2)}),$$

$$\text{provided } p_{\parallel}^{\text{LAB}(1)} = p_{\parallel}^{\text{LAB}(2)} \quad \text{and} \quad p_{\perp}^{(1)} = p_{\perp}^{(2)},$$

$$\text{so that } \left[\frac{d^3p}{dp_{\parallel}^{(1)} dp_{\perp}^{(1)}} \right]^{\text{LAB}} = \left[\frac{d^3p}{dp_{\parallel}^{(2)} dp_{\perp}^{(2)}} \right]^{\text{LAB}}.$$

(iii) Rapidity Variables: y, η

Advocates of a multiperipheral model⁹ prefer to discuss spectra in terms of the $O(1,2)$ variables y (rapidity), $m_{\perp}$ (transverse mass) defined by $(E, p_{\parallel}, p_{\perp}) = (m_{\perp} \cosh y, p_{\perp}, m_{\perp} \sinh y)$.

In the CH from the kinematic boundary is determined by

$$m_{\perp} \cosh y^{\text{CH}} \leq \frac{s + m_{\perp}^2 - a^2}{2\sqrt{s}} = p_{\text{MAX}}. \quad \text{For a fixed } p_{\perp} \leq p_{\text{MAX}}, \quad -Y_{\text{MAX}} \leq y^{\text{CH}} \leq Y_{\text{MAX}}$$

$$\text{where } Y_{\text{MAX}} = \frac{1}{2} \ln \frac{E_{\text{MAX}} + \sqrt{E_{\text{MAX}}^2 - p_{\perp}^2}}{E_{\text{MAX}} - \sqrt{E_{\text{MAX}}^2 - p_{\perp}^2}} \approx \ln \frac{\sqrt{s}}{a_{\perp}}.$$

Since $y_b^{\text{LAB}} = 0$ and $y_a^{\text{PBJ}} = 0$, we have $y_b^{\text{CH}} = -z \sim -\ln \frac{\sqrt{s}}{a_b}$ and $y_a^{\text{CH}} = z' \sim \ln \frac{\sqrt{s}}{a_a}$.

Consider 2 particles with rapidities y_1, y_2 . Their invariant mass is given by $s_{12} = (p_1 + p_2)^2 = m_1^2 + m_2^2 + 2[m_1^2 \cosh(y_1 - y_2) - y_1^+ y_2^+]$; we note that rapidity separations are invariant under boosts along the beam directions.

Thus $s = m_a^2 + m_b^2 + 2m_a m_b \cosh(y_a - y_b) \sim m_a m_b e^{y_a - y_b}$

where

$$y_a - y_b = y_a^{\text{LAB}} - y_b^{\text{PROJ}} = y_a^{\text{CH}} - y_b^{\text{CH}} = \tau + \tau' \sim \ln \frac{s}{m_a m_b}.$$

For a particle c to possess finite momentum in the rest frame of b (or a), we must have $y - y_b$ (or $y_a - y$) finite. On the other hand, particles in the central region with $y^{\text{CH}} = \eta y_{\text{MAX}}$ ($-1 < \eta < 1$) have $y - y_b$ and $y_a - y$ growing logarithmically with s :

$$y - y_b = \eta y_{\text{MAX}} + \tau \sim (1+\eta) \ln \sqrt{s}$$

$$y_a - y = +\tau' - \eta y_{\text{MAX}} \sim (1-\eta) \ln \sqrt{s}.$$

Multiperipheral advocates predict an invariant distribution which is flat in rapidity for the central region at sufficiently high energy. Since the invariant phase space volume $\frac{d^3p}{E} = dp_1 dp_2 dy$, one may envisage the particle distribution as that of a liquid¹⁰ in a cylindrical tube, of length $y_{\text{MAX}} - y_{\text{MIN}} \sim \ln \frac{s}{s_0}$ and radius $\langle p_\perp \rangle \sim 300 \text{ MeV}/c$. The interaction with the "walls" constrains the transverse momenta, and the particle density falls off for particles nearer than a correlation length l to the ends of the tube ($y - y_b < l$ or $y_a - y < l$).

The density of the liquid is $\frac{1}{s} \frac{d^3p}{ab} \frac{ab+cX}{dp_1 dp_2 dy}$.

More formally, we may state the predictions for the asymptotic spectrum as $\sim cX \ln s$

$$\lim_{y_a \rightarrow y_b} \frac{1}{ab(a)} R(m_a, y - y_b, y_a - y) = \begin{cases} l_{bc}(y - y_b, m_a) & y_{\text{MIN}} < y < y_{\text{MIN}} + l \\ f_c(m_a) & y_{\text{MIN}} + l < y < y_{\text{MAX}} - l \\ l_{ac}(y_a - y, m_a) & y_{\text{MAX}} - l < y < y_{\text{MAX}} \end{cases}$$

where the spectrum depends only on the indicated particles. In general particle distributions have weak dependence upon large ($> l$) rapidity separations in multiperipheral models.

(iv) Missing Mass and Momentum Transfer Variables: m_x, τ

In discussing multi-Regge models, dual N-point Veneziano models, or counter experiments, it proves useful to employ the missing mass and momentum transfer variables:

$$m_x^2 \equiv (p_a + p_b - p_c)^2$$

$$\tau_{bc} \equiv (p_b - p_c)^2 \text{ and } \tau_{ac} \equiv (p_a - p_c)^2.$$

Kinematically, the missing mass m_x is restricted to $m_d \leq m_x \leq s/a - m_c$. The lower bound m_d is the mass of the minimal cluster recoiling against c ; the upper bound is the missing mass at threshold for c production.

When c recoils opposite a cluster of mass m_x , the momentum transfer is given by

$$\tau_{bc} = m_b^2 + m_c^2 - 2m_b m_a \cosh(y - y_b) = m_b^2 + m_c^2 - 2m_b m_a \cosh(y^{\text{CH}} + \tau), \text{ with } m_a \cosh y^{\text{CH}} = \frac{s + m_c^2 - m_x^2}{2/s}.$$

Forward and backward scattering correspond to $y^{\text{CH}} = \pm \xi$, where

$$\xi \pm \xi = \frac{s + m_c^2 - m_x^2 \pm \Delta^2(s, m_c^2, m_x^2)}{2m_c/s} \quad s \sim \frac{s - m_x^2}{m_c/s},$$

and so

$$\begin{aligned}(t_{bc})_{\text{forward}} &= m_b^2 + m_c^2 - 2m_b m_c \operatorname{ch}(\xi + \gamma) \sim -(s - m_a^2) \\(t_{bc})_{\text{backward}} &= m_b^2 + m_c^2 - 2m_b m_c \operatorname{ch}(-\xi + \gamma) \\&\sim m_b^2 + m_c^2 - m_b m_c \left[\frac{m_a^2}{m_c^2} \left(1 - \frac{m_a^2}{s} \right) + \frac{m_c}{m_b} \left(1 - \frac{m_a^2}{s} \right)^{-1} \right] \\&= \frac{m_a^2}{s} \left[\frac{m_b^2}{m_c^2} - \frac{m_c^2}{1 - \frac{m_a^2}{s}} \right].\end{aligned}$$

To determine the minimal momentum transfer (for fixed m_a), consider

$$\begin{aligned}t_{bc} &= m_b^2 + m_c^2 - 2m_b m_c^{\text{LAB}}. \text{ Since } (p_H)_{\text{MINIMUM}} = m_c \operatorname{sh}(-\xi + \gamma), c \text{ is always} \\&\text{forward in the LAB when } \gamma > \xi; \text{ the least energy } c \text{ may then have is } (E^{\text{LAB}})_{\text{MIN}}, \\&= m_c \operatorname{ch}(-\xi + \gamma). \text{ When } \gamma < \xi, (E^{\text{LAB}})_{\text{MIN}} = m_c, \text{ corresponding to } c \text{ at rest in the} \\&\text{LAB. Thus}\end{aligned}$$

$$(t_{bc})_{\text{MIN}} = \begin{cases} m_b^2 + m_c^2 - 2m_b m_c \operatorname{ch}(-\xi + \gamma) & \text{when } \gamma > \xi \\ (m_b - m_c)^2 & \text{when } \gamma < \xi \end{cases}$$

$$\text{Note that } \gamma < \xi \text{ when } \frac{2}{s} \geq (m_a + m_b - m_c)^2 + \left(1 - \frac{m_c}{m_b} \right) (s - (m_a + m_b)^2).$$

As $s \rightarrow \infty$,

$$(t_{bc})_{\text{MIN}} \sim \begin{cases} (m_b - m_c)^2 & \text{when } m_c < m_b \text{ and } \frac{m_a^2}{s} < 1 - \frac{m_c}{m_b} \\ \frac{m_a^2}{s} \left(m_b^2 - \frac{m_c^2}{1 - \frac{m_a^2}{s}} \right) & \text{otherwise} \end{cases}$$

In describing reactions with variable masses, the quantity $t'_{bc} = (t_{bc})_{\text{MIN}} - t_{bc}$ is used.

For fixed m_a , maximal momentum transfer corresponds to $(t_{bc})_{\text{MAX}} = (t_{bc})_{\text{forward}}$.

Consider the fragmentation region $b \xrightarrow{a} c$ ($x < \frac{m_a}{p_{\text{MAX}}}$). Since c

has finite momentum in b 's rest frame,

$$t_{bc} = m_b^2 + m_c^2 - 2m_b p_c^{\text{LAB}} \text{ is finite.}$$

In the CM frame t_{bc} may be written

$$\begin{aligned}t_{bc} &= m_b^2 m_c^2 - (p^+ p_b^- + p^- p_b^+) \\&= m_b^2 m_c^2 - \left(\frac{m_a^2}{p^-} p_b^- + \frac{m_a^2}{p_b^-} p^- \right); \text{ now since} \\(p_b^-)^{\text{CM}} &= \frac{s + m_b^2 - m_a^2}{2\sqrt{s}} + \frac{\delta^{\frac{1}{2}}(s, m_a^2, m_b^2)}{2\sqrt{s}} \sim \sqrt{s} \text{ and}\end{aligned}$$

$$(p^-)^{\text{CM}} = \sqrt{(x p_{\text{MAX}})^2 + m_a^2} \sim x p_{\text{MAX}} \sim |x| \sqrt{s},$$

we see that

$$t_{bc} \sim m_b^2 (1 - |x|) + m_c^2 \left(1 - \frac{1}{|x|} \right) - \frac{p_a^2}{|x|}.$$

In b 's fragmentation region, the missing mass is

$$s_x^2 = s + m_c^2 - 2\sqrt{s} E_c^{\text{CM}} \approx s(1 - |x|).$$

Using the identity $s_{bc} t_{ac} = m_a^2 m_c^2 - m_b^2$, the alternate momentum transfer

$$t_{ac} \approx m_a^2 m_c^2 - s = -|x| s.$$

So as the kinematic boundary is approached ($|x| \rightarrow 1$), $\frac{m_a^2}{s} = 1 - |x| \rightarrow 0$ and

$$t_{bc} \approx -\frac{p_a^2}{|x|}.$$

Now consider particles c in the central region with $y^{\text{CM}} = \eta' y_{\text{MAX}}$

$$\text{where } \frac{m_a^2}{s} y_{\text{MAX}}^2 = \frac{c + m_c^2 - m_d^2}{2\sqrt{s}} \text{ and } -1 < \eta' < 1.$$

$$\text{Then } t_{bc} = m_b^2 m_c^2 - 2m_b m_c \operatorname{ch}(\eta' y_{\text{MAX}} + \zeta)$$

$$\sim -m_b m_c^{\eta' y_{\text{MAX}} + \zeta} = -m_b m_c \left(\frac{\sqrt{s}}{m_b} \right)^{\eta'} \frac{\sqrt{s}}{m_b} = -m_c^2 \left(\frac{\sqrt{s}}{m_b} \right)^{1+\eta'} = -\sqrt{s} (p^+)^{\text{CM}}$$

$$\text{and } t_{ac} = \frac{2}{m_a + m_c} \cdot 2m_a m_c \text{ch}(\frac{1}{2} \ln^+ y_{MAX})$$

$$\sim \frac{2}{m_a + m_c} \frac{\sqrt{s}}{m_1}^{1-\eta^+} \sim \sqrt{s} (p^-) CH$$

$$\text{since } (p^+) CH = m_1 e^{2\eta^+ y_{MAX}} \sim \frac{\sqrt{s}}{m_1} e^{2\eta^+}$$

The missing mass becomes, in the central region,

$$m_x^2 = s + m_c^2 - 2\sqrt{s} E^{CH} = s + m_c^2 - \sqrt{s} (p^+ p^-) CH$$

$$\sim s - m_1^2 \sqrt{s} \left[\left(\frac{\sqrt{s}}{m_1} \right)^{\eta^+} + \left(\frac{\sqrt{s}}{m_1} \right)^{-\eta^+} \right] \sim s - m_1^2 \left(\frac{\sqrt{s}}{m_1} \right)^{|1+\eta^+|} \sim s \text{ for } |\eta^+| < 1.$$

We then obtain

$$\frac{a^2}{s} \sim 1 - \left(\frac{\sqrt{s}}{m_1} \right)^{-1+|\eta^+|}$$

$$x = \frac{m_1 \text{sh}(\eta^+ y_{MAX})}{p_{MAX}} \sim \frac{m_1}{\sqrt{s}} \left[\left(\frac{\sqrt{s}}{m_1} \right)^{\eta^+} - \left(\frac{\sqrt{s}}{m_1} \right)^{-\eta^+} \right] \sim \text{sign } \eta^+ \left(\frac{\sqrt{s}}{m_1} \right)^{-1+|\eta^+|}$$

In this region, the relations may be inverted to give

$$(p^+) CH \sim \frac{t_{bc}}{\sqrt{s}}, \quad (p^-) CH \sim \frac{t_{ac}}{\sqrt{s}}, \quad m_1^2 = p^+ p^- \sim \frac{t_{bc} t_{ac}}{s}$$

$$\text{and } E^{CH} \sim \frac{s - m_1^2}{2\sqrt{s}}.$$

(v) Laboratory Variables: p^{LAB}_+, p^{LAB}_6

For plotting experimental data, a favorite set of variables is the pair (p^{LAB}_+, p^{LAB}_6) .

$$\text{A projectile fragment } p_a \text{ has } (p^+)^{LAB} = e^{2(\tau^+ + \tau^-)} (p^+)^{PROJ.} \sim \left(\frac{s}{m_a m_b} \right)^{\pm 1} (p^+)^{PROJ.};$$

consequently $p_H^{LAB} \sim \frac{s}{2m_a m_b} (p^+)^{PROJ.}$. A particle in the central region has

$$(p^+) CH = m_1 e^{2\eta^+ y_{MAX}} \sim \frac{m_1}{m_1} \left(\frac{\sqrt{s}}{m_1} \right)^{2\eta^+}; \text{ thus } (p^+)^{LAB} = e^{2\tau^+} (p^+) CH \sim \left(\frac{\sqrt{s}}{m_1} \right)^{2(1+\tau^+)} \left(\frac{\sqrt{s}}{m_1} \right)^{2\eta^+} m_1$$

$$\text{and } p_H^{LAB} \sim \frac{m_1^2}{2m_b} \left(\frac{\sqrt{s}}{m_1} \right)^{1+\eta^+} \text{ with } -1 < \eta^+ < 1. \text{ Since } \tan \theta^{LAB} = \frac{p_{\perp}}{p_H^{LAB}}, \text{ beam frag-}$$

ments have $\theta^{LAB} \sim \frac{p_{\perp}}{p_H^{LAB}} \frac{(2m_a m_b)}{s}$ and central region particles have

$$\theta^{LAB} \sim \frac{2m_b p_{\perp}}{m_1^2} \left(\frac{s}{\sqrt{s}} \right)^{1+\eta^+}.$$

As $s \rightarrow \infty$, only target fragments are emitted at finite angles; at a large angle θ^{LAB} the angular distribution should approach a limit as $s \rightarrow \infty$. For particles in the region $s \rightarrow c$ the invariant distribution scales in the variables $(p\theta)^{LAB}$ and $\frac{p^{LAB}}{s}$:

$$\lim_{s \rightarrow \infty} \frac{p}{s} ((p\theta)^{LAB}, \frac{p^{LAB}}{s}, s) = f_{cr} \left((p\theta)^{LAB}, \frac{p^{LAB}}{s} \right) \text{ for } |x| > \frac{2m_b}{\sqrt{s}}.$$

Since projectile fragments have $p_H^{LAB} = \frac{1}{2} \left[e^{\tau^+} (p^+) CH - e^{-\tau^-} (p^-) CH \right] \sim \frac{\sqrt{s}}{2m_b} (|x|/\sqrt{s})$,

the region $s \rightarrow c$ is given by $p_H^{LAB} > \frac{m_b}{m_1} \sqrt{s}$; since target fragments have

$$p_H^{LAB} = \frac{1}{2} \left[e^{\tau^+} (p^+) CH + e^{-\tau^-} (p^-) CH \right] \sim \frac{1}{2} \left[\frac{\sqrt{s}}{m_b} \frac{m^2}{|x|\sqrt{s}} - \frac{m_b}{\sqrt{s}} (|x|/\sqrt{s}) \right] \sim \frac{1}{2} \left[\frac{m^2}{|x|\sqrt{s}} - m_b |x| \right],$$

the region $x < -\frac{2m}{\sqrt{s}}$ is given by $p_H^{LAB} < \frac{m_b \sqrt{s}}{4m_b}$ or $\theta^{LAB} > \frac{4m_b p_{\perp}}{m_1 \sqrt{s}}$.

(vi) Comic Ray Variables

Comic ray experiments measure only the angular distribution in the lab. of charged secondaries produced by the collision of comic rays (mainly protons, some pions, with energies $\geq 1 \text{ TeV} \approx 10^3 \text{ GeV}$) with nuclei (in emulsions). Since most particles are produced in a small forward cone, variables such as $\log_{10} \tan \theta^{LAB}$ or $\log \tan \frac{\theta^{LAB}}{2}$ are used to spread out the distribution.

Consider the variable $u = -\ln \tan \frac{\theta^{LAB}}{2}$, used in the range $0 \leq \theta < \frac{\pi}{2}$.

u increases from ∞ to 0 as θ^{LAB} decreases from $\frac{\pi}{2}$ to 0. Then

$p_H^{LAB} = p_{\perp} e^u = m_{\perp} \text{sh } y^{LAB}$. If $y^{LAB} \gg 0$ we obtain $p_{\perp} e^u \approx \frac{m_{\perp}}{2} e^{y^{LAB}}$, so that

$u \approx y^{LAB} + \ln \frac{m_{\perp}}{2p_{\perp}}$ and $dy^{LAB} = \frac{dp_H^{LAB}}{p_H^{LAB}} = du \text{ th } y^{LAB} \approx du$. For particles

with large y^{LAB} , u is similar to rapidity.

Another kinematic relation exists between θ and the rapidity in the same frame, provided $p_{\perp} \gg m$.

$$\tan \frac{\theta}{2} = \frac{1 - \cos \theta}{\sin \theta} = \frac{p_{\perp}}{p_{\parallel}} \approx \frac{p_{\perp}}{p_{\parallel}} \gg \frac{E - p_{\parallel}}{m_{\perp}} = \frac{-y}{m_{\perp}} ;$$

that is, $y \approx -\ln \tan \frac{\theta}{2}$.

A common means of investigating angular distributions is the Duller-Walker plot, a graph of $\ln \frac{N(\leq \theta_{LAB})}{N(> \theta_{LAB})}$ against u , where $N(\leq \theta_{LAB})$ or $N(> \theta_{LAB})$ denote the number of charged particles produced with LAB angle less than or greater than θ_{LAB} . To see the utility of this plot, consider the transformation of angles from the C.M. to the LAB.

$$\tan \theta_{LAB} = \frac{p_{\perp}}{p_{\parallel}} \approx \frac{p_{\perp}}{p_{\parallel}} \gg \frac{2p_{\perp}}{(p_{\parallel})^2} = \frac{2p_{\perp}}{e^2 \gamma^2 (p^*)^2} \approx \frac{2m_b}{\sqrt{s}} \left(\frac{p \sin \theta}{E p \cos \theta} \right)_{CH}$$

$$\text{Now when } \frac{CH}{m} \gg 1, \tan \theta_{LAB} \approx \frac{2m_b}{\sqrt{s}} \frac{\sin \theta_{CH}}{1 + \cos \theta_{CH}} = \frac{2m_b}{\sqrt{s}} \tan \frac{\theta_{CH}}{2}.$$

$$\text{For an isotropic distribution in the L.M., } \frac{N(\leq \theta_{LAB})}{N(> \theta_{LAB})} = \frac{1 - \cos \theta_{CH}}{1 + \cos \theta_{CH}} =$$

$$\tan^2 \frac{\theta_{CH}}{2} \approx \frac{s}{4m_b^2} \tan^2 \theta_{LAB}. \text{ Then } \log \frac{N(\leq \theta_{LAB})}{N(> \theta_{LAB})} \approx -2u + \log \frac{s}{4m_b^2}, \text{ and 'r'}$$

fixed energy a the Duller-Walker plot gives a straight line; deviations from linearity provide a measure of anisotropy in the CH frame.

For particles with $p \gg m$,

$$y_{CH} \approx -\ln \tan \frac{\theta_{CH}}{2} \approx -\ln \tan \theta_{LAB} - \ln \frac{\sqrt{s}}{2m_b} = u - \ln \frac{\sqrt{s}}{2m_b}.$$

By averaging over the u distribution, for pp collisions in which $\langle y_{CH} \rangle = 0$,

$$\langle u \rangle = + \ln \frac{\sqrt{s}}{2m_b}. \text{ This is the Castagnoli method}^{28} \text{ for estimating the primary energy.}$$

The criterion for a particle to be backward in the CH is $y_{CH} < 0$ i.e., $u < \ln \frac{\sqrt{s}}{2m_b}$; so any target fragment has $\theta_{LAB} > \frac{2m_b}{\sqrt{s}}$ for large s . Any particle emitted at a finite (non-zero) lab. angle as $s \rightarrow \infty$ must be a target fragment. Consequently the hypothesis of limiting fragmentation predicts that

the distribution $\frac{dy}{du}$ for $u \rightarrow \ln \frac{\sqrt{s}}{2m_b}$ should approach a limit as $s \rightarrow \infty$.

Kinematics of Resonance Decay Products

Consider the decay of a forward-produced resonance a^* in $ab \rightarrow a^*b$, where $a^* \rightarrow a^{**}\pi$. Then in the CH frame

$$p_{a^*}^{CH} = \left(\frac{s + m_a^2 - m_b^2}{2\sqrt{s}}, 0, \frac{\Delta^{\frac{1}{2}}(s, m_a^2, m_b^2)}{2\sqrt{s}} \right) \approx (m_a^* \cosh \xi, 0, m_a^* \sinh \xi)$$

$$p_{b^*}^{CH} = \left(\frac{s + m_b^2 - m_a^2}{2\sqrt{s}}, 0, -\frac{\Delta^{\frac{1}{2}}(s, m_a^2, m_b^2)}{2\sqrt{s}} \right)$$

The transformation from the resonance a^* rest frame, denoted R_1 , to the CH is given by $p_{a^*}^{CH} = e^{\pm \xi} p_{a^*}^{R_1}$ where $e^{\pm \xi} = \frac{s + m_a^2 - m_b^2 \pm \Delta^{\frac{1}{2}}(s, m_a^2, m_b^2)}{2m_a \sqrt{s}} \sim \left(\frac{\sqrt{s}}{m_a^*} \right) \pm 1$.

Assume that π is emitted backward in the resonance rest frame:

$$p_{\pi}^{R_1} = \left(\frac{m_a^2 + m_{a^{**}}^2 - m_{\pi}^2}{2m_{a^*}}, 0, \frac{\Delta^{\frac{1}{2}}(m_a^2, m_{a^{**}}^2, m_{\pi}^2)}{2m_{a^*}} \right)$$

$$p_{\pi}^{R_1} = \left(\frac{m_a^2 + m_{\pi}^2 - m_{a^{**}}^2}{2m_{a^*}}, 0, -\frac{\Delta^{\frac{1}{2}}(m_a^2, m_{a^{**}}^2, m_{\pi}^2)}{2m_{a^*}} \right).$$

$$\begin{aligned} \text{Then } \langle p_{\pi}^{\pm} \rangle_{CH} &= e^{\pm \xi} \langle p_{\pi}^{\pm} \rangle_{R_1} \\ &= \left(\frac{s + m_a^2 - m_{a^{**}}^2 - m_{\pi}^2}{2m_{a^*} \sqrt{s}} + \Delta^{\frac{1}{2}}(s, m_{a^{**}}^2, m_{\pi}^2) \right) \pm 1 \\ &\approx m_{\pi} \left(\frac{m_a^2 + m_{\pi}^2 - m_{a^{**}}^2}{2m_{a^*} m_{\pi}} + \Delta^{\frac{1}{2}}(m_a^2, m_{a^{**}}^2, m_{\pi}^2) \right) \pm 1 \\ &\sim m_{\pi} \left(\frac{m_{a^*}^2 + m_{\pi}^2 - m_{a^{**}}^2}{2m_{a^*} m_{\pi}} + \Delta^{\frac{1}{2}}(m_{a^*}^2, m_{a^{**}}^2, m_{\pi}^2) \right) \pm 1 \end{aligned}$$

Consequently $\langle p_{\parallel} \rangle_{\text{CH}} = \frac{1}{2}(p^{+} - p^{-}) \sim \frac{\frac{2}{\pi} / s}{\frac{2}{\pi} \frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}} + \Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}$ and

$$x_{\pi} \sim \frac{\frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}} + \Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2 \frac{2}{a^{*}}}$$

Similarly $x_{a^{*}} \sim 1 - x_{\pi}$.

Assume that π is emitted forward in the resonance rest frame:

$$p_{\pi}^R = \left(\frac{\frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}}}{2 \frac{2}{a^{*}}}, 0, - \frac{\Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2 \frac{2}{a^{*}}} \right)$$

$$p_{\pi}^L = \left(\frac{\frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}}}{2 \frac{2}{a^{*}}}, 0, \frac{\Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2 \frac{2}{a^{*}}} \right).$$

Then $\langle p_{\pi}^{\pm} \rangle_{\text{CH}} = e^{\pm \eta} \langle p_{\pi}^{\pm} \rangle^R$

$$= \left(\frac{\frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}} + \Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2 \frac{2}{a^{*}} / s} \right)^{\pm 1} \frac{1}{\pi} \left(\frac{\frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}} + \Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2 \frac{2}{a^{*}} \frac{2}{\pi}} \right)^{\pm 1}$$

$$\sim \frac{1}{x_{\pi} \frac{2}{a^{*}}} \frac{\frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}} + \Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2 \frac{2}{a^{*}} \frac{2}{\pi}}^{\pm 1}.$$

$$\text{Thus } x_{\pi} \sim \frac{\frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}} + \Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2 \frac{2}{a^{*}}} \quad \text{and } x_{a^{*}} \sim 1 - x_{\pi}.$$

The decay pion from a forward resonance then has $\langle x_{\pi} \rangle_{\text{MIN}} \leq x_{\pi} \leq \langle x_{\pi} \rangle_{\text{MAX}}$

where

$$\langle x_{\pi} \rangle_{\text{MIN}}^{\text{MAX}} = \frac{\frac{2}{a^{*}} + \frac{2}{\pi} - \frac{2}{a^{*}} + \Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2 \frac{2}{a^{*}}}.$$

a^{**} might be a cluster of particles; choosing the minimal mass cluster gives the smallest $\langle x_{\pi} \rangle_{\text{MIN}}$ and largest $\langle x_{\pi} \rangle_{\text{MAX}}$ for a given a^{**} . In real situations,²⁹ of course, a^{**} is smeared over the resonance width, the resonance a^{*} is emitted into some forward cone (with probability $e^{-\eta^2 a^{**}}$), and there is a spectrum of contributing resonances, decaying anisotropically in their rest frames.

(viii) Relations between Variables

A particle in the CH frame may be described by $p_{\parallel}^{\text{CH}} = x' \sqrt{p_{\text{MAX}}^2 - p_{\perp}^2}$, with x' and $p_{\perp}$ kept fixed as $s \rightarrow \infty$. Table I expresses other kinematic variables in terms of x' , $p_{\perp}$ in the three regions: $x' < \frac{a_{\perp}}{p_{\text{MAX}}}$, $x' = 0$,

$x' > \frac{a_{\perp}}{p_{\text{MAX}}}$. Alternately, the particle may be described by the reduced rapidity

η' , given by $y^{\text{CH}} = \eta' y_{\text{MAX}}$, with η' and $p_{\perp}$ kept fixed as $s \rightarrow \infty$. Using

$$e^{\pm \eta} y_{0,X} = \frac{s + \frac{2}{a^{*}} - \frac{2}{\pi} \pm \Delta^2 (\frac{2}{a^{*}} + \frac{2}{a^{*}} + \frac{2}{\pi})}{2/s \frac{2}{a^{*}}} \sim \frac{1}{x_{\perp}}, \text{ we express other variables in}$$

terms of η' , $p_{\perp}$ in Table 2.

TABLE 1: ASYMPTOTIC VALUE OF VARIABLES IN THE CENTRAL AND FRAGMENTATION REGIONS

VARIABLE	TARGET FRAGMENTATION $x' < -\frac{a_{\perp}}{P_{\text{MAX}}}$	CENTRAL REGION $x'=0$ ($\langle p_{\perp}^{\text{CH}} \rangle_0$)	BEAM FRAGMENTATION $x' > \frac{a_{\perp}}{P_{\text{MAX}}}$
x'			
$(p^+)_{\text{LAB}}$	$\frac{a_{\perp}^2}{a_0 x' }$	$\frac{a_{\perp} \sqrt{s}}{a_0}$	$\frac{ x' }{a_0} s$
$(p^-)_{\text{LAB}}$	$a_0 x' $	$\frac{a_{\perp} a_0}{\sqrt{s}}$	$\frac{a_0^2}{ x' } s$
p_{LAB}	$\frac{1}{2} \left[\frac{a_{\perp}^2}{ x' } - a_0 x' \right]$	$\frac{a_{\perp} \sqrt{s}}{2a_0}$	$\frac{ x' }{2a_0} s$
y_{LAB}	$\ln \frac{a_{\perp}}{a_0 x' }$	$\ln \frac{\sqrt{s}}{a_0}$	$\ln \frac{ x' }{a_0} s$
$\cos \theta_{\text{LAB}}$	$\frac{2a_0 x' p_{\perp}}{a_{\perp}^2 - (a_0 x')^2}$	$\frac{2a_0 p_{\perp}}{a_{\perp} \sqrt{s}} = \frac{2p_{\perp}}{a_{\perp}} e^{-y_{\text{LAB}}}$	$\frac{2a_0 p_{\perp}}{ x' s} = \frac{2p_{\perp}}{a_{\perp}} e^{-y_{\text{LAB}}}$
$p_{\perp \text{LAB}}$	$\frac{1}{2} \left[p_{\perp}^2 + \left(\frac{a_{\perp}^2 - (a_0 x')^2}{2a_0 x'} \right)^2 \right]^{1/2}$	$\frac{a_{\perp} \sqrt{s}}{2a_0}$	$\frac{ x' }{2a_0} s$
$(p^+)_{\text{PROJ.}}$	$\frac{a_0 a_{\perp}^2}{ x' s}$	$\frac{a_0 a_{\perp}}{\sqrt{s}}$	$a_{\perp} x' $
$(p^-)_{\text{PROJ.}}$	$\frac{ x' }{a_0} s$	$\frac{a_{\perp} \sqrt{s}}{a_0}$	$\frac{a_{\perp}^2}{a_0 x' }$
$(p^+)_{\text{CH}}$	$\frac{a_{\perp}^2}{ x' /s}$	$a_{\perp}$	$ x' /s$
$(p^-)_{\text{CH}}$	$(x')/s$	$a_{\perp}$	$\frac{a_{\perp}^2}{ x' /s}$
$(p_0)_{\text{CH}}$	$x' \sqrt{s}$	0	$x' \sqrt{s}$
y_{CH}	$-\ln \frac{ x' \sqrt{s}}{a_{\perp}}$	0	$+\ln \frac{ x' \sqrt{s}}{a_{\perp}}$
n'	$-1 + 2 \frac{\ln \frac{ x' }{a_{\perp}}}{\ln \frac{s}{a_{\perp}^2}}$	0	$1 - 2 \frac{\ln \frac{1}{ x' }}{\ln \frac{s}{a_{\perp}^2}}$
a_x^2	$a(1 - x')$	s	$a(1 - x')$
t_{bc}	$a_0^2 (1 - x') + a_{\perp}^2 \left(1 - \frac{1}{ x' } \right) - \frac{p_{\perp}^2}{ x' }$	$-a_{\perp} \sqrt{s}$	$- x' s$

TABLE 2: ASYMPTOTIC VALUE OF VARIABLES IN THE CENTRAL AND FRAGMENTATION REGIONS

VARIABLE	TARGET FRAGMENTATION $\eta' = -1$	CENTRAL REGION $-2 < \eta' < 2$	BEAM FRAGMENTATION $\eta' = +2$
x'	-1	$\begin{cases} 0 & \eta' = 0 \\ \text{sign } \eta' \left(\frac{\sqrt{s}}{a_{\perp}} \right) \eta' ^{-1} & \end{cases}$	+1
$(p^+)_{\text{CH}}$	$\frac{a_{\perp}^2}{\sqrt{s}}$	$a_{\perp} \left(\frac{\sqrt{s}}{a_{\perp}} \right) \eta'$	$\sqrt{s}$
$(p^-)_{\text{CH}}$	$\sqrt{s}$	$a_{\perp} \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{-\eta'}$	$\frac{a_{\perp}^2}{\sqrt{s}}$
y_{CH}	$-\ln \frac{\sqrt{s}}{a_{\perp}}$	$\eta' \ln \frac{\sqrt{s}}{a_{\perp}}$	$\ln \frac{\sqrt{s}}{a_{\perp}}$
a_x^2	a_0^2	$a \left[1 - \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{-1} + \eta' \right]$	a_0^2
t_{bc}	$-p_{\perp}^2$	$-a_{\perp}^2 \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{1+\eta'}$	$-a_{\perp}^2$
t_{ac}	-s	$-a_{\perp}^2 \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{1-\eta'}$	$-p_{\perp}^2$
$(p^+)_{\text{LAB}}$	$\frac{a_{\perp}^2}{a_0}$	$\frac{a_{\perp}^2}{a_0} \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{1+\eta'}$	$\frac{s}{a_0}$
$(p^-)_{\text{LAB}}$	a_0	$a_0 \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{-1-\eta'}$	$\frac{a_0^2}{s}$
$p_{\perp \text{LAB}}$	$\frac{a_{\perp}^2 - a_0^2}{2a_0}$	$\frac{a_{\perp}^2}{2a_0} \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{1+\eta'}$	$\frac{s}{2a_0}$
p_{LAB}	$\left[\left(\frac{a_{\perp}^2 - a_0^2}{2a_0} \right)^2 + p_{\perp}^2 \right]^{1/2}$	$\frac{a_{\perp}^2}{2a_0} \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{1+\eta'}$	$\frac{s}{2a_0}$
y_{LAB}	$\ln \frac{a_{\perp}}{a_0}$	$(1 + \eta') \ln \frac{\sqrt{s}}{a_{\perp}} + \ln \frac{a_{\perp}}{a_0}$	$\ln \frac{s}{a_{\perp} a_0}$
$\cos \theta_{\text{LAB}}$	$\frac{2a_0 p_{\perp}}{a_{\perp}^2 - a_0^2} = \frac{2p_{\perp} a_{\perp}}{a_{\perp}^2 - a_0^2} e^{-y_{\text{LAB}}}$	$\frac{2a_0 p_{\perp}}{a_{\perp}^2} \left(\frac{\sqrt{s}}{a_{\perp}} \right)^{1+\eta'}$	$\frac{2a_0 p_{\perp}}{s} = \frac{2p_{\perp}}{a_{\perp}} e^{-y_{\text{LAB}}}$

TABLE 2 (continued)

VARIABLE	TARGET FRAGMENTATION	CENTRAL REGION	BEAM FRAGMENTATION
$-\ln \cos^2 \theta_{LAB}$	$\ln \frac{s - m_b^2}{2m_b^2 p_{\perp}^2}$	$(1 + \eta') \ln \frac{s}{m_{\perp}^2} + \ln \frac{m_{\perp}^2}{2m_b^2 p_{\perp}^2}$	$\ln \frac{s}{2m_b^2 p_{\perp}^2}$
	$p_{\perp} \gg m_b$ $\approx \ln \frac{s}{2m_b^2}$ $= y_{LAB} - \ln 2$	$p_{\perp} \gg m_b$ $\approx (1 + \eta') \ln \frac{s}{m_{\perp}^2}$ $= y_{LAB} - \ln 2$	$p \gg m_b$ $\approx \ln \frac{s}{2m_b^2 p_{\perp}^2}$ $= y_{LAB} - \ln 2$
$(p^+)^{PROJ}$	$\frac{m_a^2 m_{\perp}^2}{s}$	$m_a^2 \left(\frac{s}{m_{\perp}^2} \right)^{\eta' - 1}$	m_a^2
$(p^-)^{PROJ}$	$\frac{s}{m_a^2}$	$\frac{m_{\perp}^2}{m_a^2} \left(\frac{s}{m_{\perp}^2} \right)^{-\eta' + 1}$	$\frac{m_{\perp}^2}{m_a^2}$
$(p_{\parallel})^{PROJ}$	$-\frac{p}{2m_a}$	$-\frac{m_{\perp}^2}{2m_a} \left(\frac{s}{m_{\perp}^2} \right)^{-\eta' + 1}$	$-\frac{m_{\perp}^2 - m_a^2}{2m_a}$

(ix) Approach to the High Energy Spectrum: Regge Expansion

By examining multi-Regge or dual models for the $abc \rightarrow abc$ amplitude, we may conjecture how the single particle distribution approaches its asymptotic limit.¹¹ In the fragmentation region $b \rightarrow c$, the spectrum is given by Figure 2.

Figure 2: Multi-regge expansion of the single particle spectrum in the fragmentation region $b \rightarrow c$

Assuming that

- (1) all Regge poles have factorizable residues
- (2) the Pomeron is a Regge pole with intercept $\alpha(0) \approx 1$, we write

$$\alpha_{ab}(s) \sim \frac{1}{2} \left[\gamma_a^p \gamma_b^p s + \sum_R \gamma_a^R \gamma_b^R s^{\alpha_R(0)} \gamma_R^{(0)} + \dots \right]$$

$$R_{ab} \approx s X \sim \frac{1}{2} \left[\gamma_a^p \gamma_{bc}^p \left(t_{bc} \cdot \frac{m_{\perp}^2}{s} \right) s + \sum_R \gamma_a^R \gamma_{bc}^R \left(t_{bc} \cdot \frac{m_{\perp}^2}{s} \right) s^{\alpha_R(0)} \gamma_R^{(0)} + \dots \right].$$

$$\text{Then } \frac{R_{ab+cX}}{\sigma_{ab}} \sim \frac{F_{bc}^p \left(t_{bc}, \frac{s}{s_0} \right)}{t_{bc}^p} + G_{abc} \left(t_{bc}, \frac{s}{s_0} \right) s^{\alpha_n(0)-1} + \dots \text{ as } s \rightarrow \infty.$$

The approach to the limiting distribution is given by the leading secondary trajectories $(\rho, f, \omega, A_2, \dots)$ with $\alpha(0) \approx 1/2$.

Based on duality, various criteria have been suggested for the vanishing of the secondary contributions to R in the region $b \approx c$. This "rapid scaling" is conjectured to occur

1. if abc is exotic¹²
2. if and only if both ab and ac are exotic¹³
3. if either abc or bc is exotic¹⁴
4. if ab , abc , and ac are exotic¹⁵
5. if ab and ac are exotic¹⁶
6. if and only if all of ab , abc , ac , and bc are exotic¹⁷
7. if the transition $b \rightarrow c$ does not permit any through-going (spectator) quarks.¹⁸

When these terms vanish, the limiting distribution is approached rapidly with increased energy.

By factorization the limit of $\lim_{s \rightarrow \infty} \frac{R_{ab+cX}}{\sigma_{ab}}$ is independent of a (in the $b \approx c$ region). Also, using CPT and the isospin rotation $e^{i\pi/2}$, we may show that the fragmentation spectra $b \approx c$, $b \approx \bar{c}$, $\bar{b} \approx c$, $b' \approx c'$ are identical as $s \rightarrow \infty$; here $|a| > a$ CPT $|a| > a$ and $|a'| > a' = e^{i\pi/2}|a| > a'$. For instance $p \approx X^+$, $\bar{p} \approx K^+$, $n \approx K^0$, $\bar{n} \approx K^0$ should have equal asymptotic $\frac{R_{ab+cX}}{\sigma_{ab}}$.

Similarly, in the central region, one predicts

$$\lim_{s \rightarrow \infty} \frac{R_{ab+cX}}{\sigma_{ab}} = F_c(x_1^2), \text{ independent of } a \text{ and } b.$$

So we expect

- (1) the K/π production ratio is the same for πp and pp reactions at high energy
- (2) the π^- production spectra in pp and π^+p reactions are in the same ratio as the total cross-sections:

$$\lim_{s \rightarrow \infty} \frac{R_{pp \rightarrow \pi^- X}}{R_{\pi^+ p \rightarrow \pi^- X}} = \frac{\sigma_{pp}(s)}{\sigma_{\pi^+ p}(s)}.$$

Multi-Regge models also predict the rate of fall-off of the single particle spectrum as the kinematic boundary is approached.¹⁹ In the limit $s \rightarrow \infty$,

keeping t_{bc} and $\frac{s}{s_0}$ fixed with $\frac{s}{s_0} \ll 1$, one has

$$\begin{aligned} \frac{R_{ab+cX}}{\sigma_{ab}} &\sim F_{bc}(t_{bc}) \left(\frac{s}{s_0} \right)^{\alpha_1(t_{bc}) + \alpha_2(t_{bc}) - 1} \\ &= F_{bc}(-p_1^2) (1 - |x|)^{1 - \alpha_1(p_1^2) - \alpha_2(p_1^2)} \end{aligned}$$

in the fragmentation region $b \approx c$. This fall-off should appear in a plot of $\ln \frac{R}{\sigma}$ vs. $-\ln \frac{s}{s_0}$, which would be linear, with increasing slope as p_1^2 increases.

The approach toward the kinematic boundary may be specified, in various variables, by fixing p_1 and letting

$$\frac{s}{s_0} \sim 1 - \frac{(p_1^-)^{LAB}}{s_0} \sim 1 - \frac{s}{s_0} y^- y \sim 1 - |x| \quad \text{tend to 0.}$$

6. General Comments

Choice of Variables

Because of the bewildering array of variables, the experimenter with data to display must choose carefully. Variables such as $p_{\perp}^{\text{LAB}}$, $(p^-)^{\text{LAB}}$, ϵ_{be} are best suited for data in the target fragmentation regime, but are not suitable for the central or beam fragmentation regions. The variables $x, p^+, p_{\perp}^2$ display limiting fragmentation in both $b \rightarrow c$ and $a \rightarrow b$ on the same plot, but the limit is approached more slowly; moreover the central region is compressed into the point $x=0$ as $s \rightarrow \infty$. The rapidity y or reduced rapidity η displays the central region in detail, but crowds the fragmentation regions into small end parts of a distribution with width $\Delta y \sim \ln s$ or into points $n=1$. In the study of many-particle distributions the problem of finding a judicious choice of variables will become acute.

Inclusive Single Particle Spectra: A Sum

The invariant spectrum for $ab \rightarrow cX$ may be viewed as a sum over all exclusive channels in which a particle c is produced. Each channel a has a threshold mass $(m_a)_c$ for c production; so for a given missing mass m_x , only channels with $m_x > (m_a)_c$ contribute to $ab \rightarrow cX$. For example, in $pp \rightarrow n^+ X$, the 2 channels with smallest missing masses are $n^+ n^+ \pi^-$ and $pp \rightarrow p p^+ n^+ \pi^-$; for $2m_p + 3m_\pi > m_x > 2m_p + m_\pi$, the total inclusive spectrum comes from only one channel.

By energy-momentum conservation, the x parameters for all produced particles are constrained by $\sum_i x_i = 1$ as $s \rightarrow \infty$. The number of particles with $|x| > c$ is then bounded above by $2/c$; all other particles must have small $|x|$. Since each channel with n_c particles of type c contributes to the spectrum R with weight n_c , high multiplicity channels control the behaviour near $|x|=0$.

In summary, the number of channels contributing to the single particle spectrum increases as one moves away from the kinematic boundary $\{|x|=1\}$ toward the central region $\{|x| \ll 1\}$.

Correlations

While the study of many-body correlations is still in its infancy, and often obscured by conservation laws, we note several features which have been studied

1. Resonances: peaks in the distributions of invariant masses of several particles
2. Goldhaber-Goldhaber-Lee-Pais effect: angles between pairs of produced pions
3. Van-Hove longitudinal phase space analysis: seeking reaction mechanisms by grouping particles according to the value of x .
4. Transverse momentum correlations

The distribution of the angle ϕ between the transverse momenta $\underline{p}_{\perp}$ of 2 particles may be examined as a function of rapidity separation. The variation of $p_{\perp}$ for one particle may be studied as a function of p_2 for another particle, where $\underline{p}_{\perp} = (p_{\perp}, p_2)$ is the transverse vector of either particle.

5. Correlation Functions

The Mueller correlation parameters⁵ provide general parametrizations of multiplicity distributions. The two-particle correlation functions $U(p_1, p_2) = \frac{R(p_1, p_2)}{\sigma} = \frac{R(p_1)}{\sigma} \frac{R(p_2)}{\sigma}$ or $V(p_1, p_2) = \frac{\sigma R(p_1, p_2)}{R(p_1) R(p_2)}$ may be studied from bubble chamber²³ or double-arm spectrometer data.

7. Caveat Emptor: A warning to the Reader

Theoretical Problems

Kinematic discussion has been confined to the asymptotic regime $s \rightarrow \infty$. In asymptotic total cross-sections are flat, and moments may be expanded in powers

of s. In the lab., however, $\sigma_{ab}(s)$ may differ considerably from $\sigma_{ab}(u)$; various x 's [$\frac{\sigma_{ab}^{CH}}{p_{\text{INC}}^{CH}}, \frac{\sigma_{ab}^{CH}}{p_{\text{MAX}}^{CH}}, \frac{\sigma_{ab}^{CH}}{p_{\text{MAX}}^{CH}} \cdot \frac{\sigma_{ab}^{CH}}{(\sqrt{s}/2)}$], while identical as $s \rightarrow \infty$, may differ considerably at finite energies.

The phenomenologist must decide, in examining energy dependence, whether to normalize his single-particle spectrum by $\frac{1}{\sigma_{ab}(s)} R$ or $\frac{1}{\sigma_{ab}(u)} R$. Moreover

$\frac{1}{\sigma_{ab}} R_{ab \rightarrow CX}$ should be the same for $b \rightarrow c$ and $b \rightarrow c$ only as $a \rightarrow b$; loosely, one expects the single particle distribution to approach its limit (if it exists), more slowly than $\sigma_{ab}^{\text{TOTAL}}$ or $\sigma_{ab}^{\text{ELASTIC}}$.

There exists NO variable in terms of which a scaling hypothesis is expected to hold over all of phase space. In choosing a variable to examine data one must consider the kinematic region; for example y is best suited to examine particles slow in the CM (i.e. in the w or x region $|x| < \frac{u}{p_{\text{MAX}}}$), whereas p^+ are best suited to data in the fragmentation region.

Finally, scaling is expected to hold only up to n factors only; the Pomeron "pole" may indeed be a cut, giving rise to cross-sections $\propto s^n (\log s)^B$.

Experimental Problems

The usual experimental single particle distributions, such as $\frac{d\sigma}{dp_{\text{CM}}}$ or $\frac{d\sigma}{dp_{\text{IN}}}$, are non-invariant; they are difficult to compare in different reference frames or at different energies, because kinematic boundaries vary. Such distributions are usually plotted in terms of non-scaling variables; for example, counter data for fast secondary particles in the lab. frame is given in terms of p_{LAB} and θ_{LAB} , though the scaling variables are $\theta_{\text{LAB}}, p_{\text{LAB}}$ and $(\frac{u}{p_{\text{MAX}}})_{\text{LAB}}$.

The absolute normalization of single-particle spectra is poorly known. Though systematic errors of 10-20% are quoted, in practice the normalization error is grossly underestimated. Beam survey experiments (especially those with internal targets) have been found to require renormalisation factors up to 2 or 3.

Calibration experiments, determining to high accuracy the value of some spectra at a fixed point in phase space (say $x \sim .7$, $p_{\perp} \sim 300$ MeV/c) over a range of energies, would help considerably. For the present the reader is cautioned to compare the shapes of spectra from different experiments, not worrying overmuch about normalisations.

In determinations of single particle spectra, bubble chamber scans are most useful in the fragmentation regions of a beam or target into a particle of opposite charge (for example $p^+ \rightarrow K^+ \rightarrow \pi^+$), or for measuring strange particle production (V^0 's). By ionization techniques one cannot distinguish between a p and π^+ for p_{LAB} much above 1 GeV/c or between a K^+ and π^+ for $p_{\text{LAB}} > 400$ MeV/c. Target fragmentation into an identifiable particle of the same charge cannot easily be measured unless $p_{\text{LAB}} < 1.5$ GeV/c ($x < 0$). Counter experiments measure spectra best for small bites of phase space with $p_{\text{LAB}} > 3$ GeV/c ($x > 0$) and $\theta_{\text{LAB}} < 300$ mrad. The two techniques are complementary, but both provide poorest data in the central region (x near 0) where the single particle spectrum is usually largest.

In data representing single particle spectra no attempt is made to separate out resonance decay products. Similarly, while an inclusive cross-section for a fixed number of prongs should in principle include the decay of strange particle V^0 's, topological cross-sections are quoted with and without V^0 's in the literature.

Until nomenclature becomes standardized, the same term may be applied to different concepts or measurements.

(1) Compare the meaning of "pionisation" used by Yang²⁴, Cheng and Wu²⁵, and cosmic ray physicists²⁶.

(2) The expression "cross-section for $\bar{K}K$ pairs" may mean either the "sum of cross-sections in all channels where a $\bar{K}K$ pair is produced or the sum of such cross-sections, each weighted by the number of pairs produced.

(3) The invariant single particle distribution $R(p)$ for $ab \rightarrow cx$ is

frequently written $(2\pi)^3 2E \frac{d\sigma}{d^3p}$. We must recall that this distribution is normalized, not to the total cross-section, but to

$$\int \frac{d\sigma}{d^3p} d^3p = \sum_{N_c \geq 1} N_c \sigma(N_c, s) = \langle N_c(s) \rangle \sigma_{ab}^{TOTAL}(s),$$

where $\langle N_c \rangle$ is the average number of c's produced at energy s.

(4) Averages such as $\int_0^{\infty} E \frac{d\sigma}{dp_T^2} dp_T^2$ may be abbreviated $E \frac{d\sigma}{dp_T^2}$, even though the transverse momentum dependence in E has been integrated out.

Plots of inclusive distributions perform averages over all events. Since the "typical" event may be very different from the "average" event, especially if correlations between particles are strong, it may prove necessary to examine data on an event-by-event basis to supplement inclusive spectra.

8. Footnotes and References

1. The notation $f(s) \sim g(s)$ as $s \rightarrow \infty$ means that at high energy

$\left| \frac{f(s) - g(s)}{f(s)} \right| \ll 1$. This asymptotic expansion is often a power series expansion of $f(s)$.

2. The function Δ is defined by

$$\Delta(x, y, z) = x^2 + y^2 + z^2 - 2xy - 2yz - 2zx.$$

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