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ABSTRACT

Proton-proton interactions with four or more charged particles in the final state are studied over a range of incident momenta between 13 and 28.5 GeV/c. Topology cross sections are presented. The center-of-mass momentum distributions of π^+ and π^- are determined and are successfully parameterized. The π^+ and π^- momentum spectra are found to have approximately the same shape. Multiple fireball production is not required by our data.

We report the results of an experiment containing 40 000 inelastic proton-proton interactions observed in the Brookhaven National Laboratory 80-inch hydrogen bubble chamber. We find that the momentum spectra of the positive and negative secondary pions are fitted very well by the simple parameterizations used by Elbert et al.[1] in their study of π^--p interactions, and we observe a similar correlation between the multiplicity of pions and the distributions of both longitudinal and transverse momenta.

The experiment was to study nonstrange-particle production over a wide range of incident momenta. Our exposure was divided into five roughly equal parts corresponding to incident proton beam momenta of 12.88, 18.00, 21.08, 24.12, and 28.44 GeV/c. At each momentum the flux of incident protons corresponds to about 1/2 event/μb. Events containing only two charged particles in the final state and obvious strange-particle productions were excluded from this sample of events, although some background of charged K mesons is contained in our final sample. On the basis of other experiments we estimate our K-meson contamination as about 5% of the secondary tracks.[2]

Thus, our events correspond to unknown combinations of three interactions:

$$p + p \rightarrow p + p + N\pi^{+} + N\pi^{-} + \text{possible missing neutrals},$$

$$p + p \rightarrow p + n + (N+1)\,\pi^{+} + N\pi^{-} + \text{possible missing neutrals},$$

$$p + p \rightarrow n + n + (N+2)\,\pi^{+} + N\pi^{-} + \text{possible missing neutrals},$$

where $N \geq 1$.

Figure 1 shows the topological cross sections as a function of the incident momentum. Fits to the four-, six-, and eight-prong production are the results of calculations by G. F. Chew and A. Pignotti using a multiperipheral bootstrap model containing two parameters.[3] The fits to the four- and six-prong production appear quite good, but because of threshold effects the model is unable to accommodate the steeply rising eight-prong cross section. The dashed lines through 10-, 12-, and 14-prong curves are our freehand curves.

The principal experimental problem involved in determining the secondary pion momentum spectra is the separation of the π^{+} from the protons (we assume that all negative tracks are π^{-}). We are able to use the forward-backward symmetry of the proton-proton collision together with the reaction kinematics to subtract the proton contamination from the π^+ sample.[4] The following systematic procedure is used:

1. Identify all backward tracks in the laboratory frame as pions, since in endothermic equal-mass collisions neither the beam nor the target particle may go backwards. Transform this momentum distribution to c.m. to determine a portion of the backward π^+ c.m. momentum distribution.
2. Reflect this π^+ c.m. momentum distribution through the origin of the c.m. rest frame to obtain an estimate of the corresponding portion of the forward π^+ c.m. momentum distribution, since pp collisions are forward-backward symmetric.
3. Subtract the momentum distribution of these "forward" π^+ from the forward positive track distribution to get an estimate of part of the forward proton distribution. Because of the forward-backward symmetry of the c.m. spectrum, the c.m. momentum distribution of the very forward protons in the example above can then be used subsequently to estimate the proton background for a new portion of the backward π^+ c.m. spectrum.

In other words, this procedure is iterative. Starting with the π^+ momentum spectra of backward tracks in the laboratory frame and using the forward-backward symmetry, one determines the entire backward π^+ c.m. distribution.[5]

The longitudinal and transverse momentum distributions of the secondaries are presented in Fig. 2 for one typical charge multiplicity and one typical incident momentum. These distributions are fitted to functions of the form[1]

$$\frac{dN}{dp_\perp} = N_T \frac{a_\perp^{5/2} p_\perp^{3/2} e^{-a_\perp p_\perp}}{3/4 \sqrt{\pi}} \qquad (1)$$

$$\frac{dN}{dp_{\parallel}} = N_T a_{\parallel} e^{-a_{\parallel} P_{\parallel}} \qquad (2)$$

where $P_{\parallel}$ indicates the component of pion c.m. momentum parallel to the beam direction, $P_\perp$ indicates the component in the plane perpendicular to the beam direction, and N_T is the total number of tracks. Functions containing exponentials in the momentum components have been suggested and used by a number of authors.[6,7] The 3/2-power dependence in Eq. 1 is a result of descriptions of the spectra based on the thermodynamic model.[8]

The pion data were divided by incident beam momentum, number of charged prongs, and charge, producing 38 different histograms for each transverse and longitudinal distribution (four-, six-, and eight-prong events were used at all momenta, ten-prong events were used only at the four highest momenta). For each sample of data we found that a χ^2 minimization in one parameter gave excellent confidence levels (with typically 20 or more degrees of freedom). Equation 2, which implies a nonzero slope at the origin, cannot be accurate for values of $P_{\parallel}$ very close to zero. All the data were systematically lower than the fitted distribution in the first 0.05-GeV/c bin.

The following observations can be made about the fitted coefficients $a_\perp$ and $a_{\parallel}$ (see Fig. 2):

1. The coefficients $a_\perp$, $a_{\parallel}$ at a given beam momentum have a linear dependence on the number of charged prongs produced. (Similar behavior in 24-GeV/c π^-p interactions was reported by Elbert et al.) For example, our π^- distributions at 21 GeV/c are given by a $a_\perp = (6.54 \pm 0.05) + (0.28 \pm 0.01)n$ and $a_{\parallel} = (0.76 \pm 0.03) + (0.41 \pm 0.01)n$, where n is the number of charged prongs.

2. The coefficients $a_{\parallel}$ describing the longitudinal c.m. momentum distributions for a particular number of charged prongs decrease with increasing beam momentum.

3. The coefficients $a_{\perp}$ describing the transverse c.m. momentum distributions for a particular number of charged prongs decrease with increasing beam momentum more slowly than for the longitudinal momentum distributions, appearing to approach a constant value.

4. The difference between the coefficients describing the c.m. momentum distributions of π^+ and π^- from a particular beam momentum and number of charged prongs is always less than 10% of the values of the coefficients. Many of the coefficients are in excellent agreement.

For pp interactions at 12.5 GeV/c, Ratner et al. have reported the production of pions through the decay of fireballs moving in the center of mass.[9] Certain characteristics of fireballs facilitate the observation of their presence. A fireball that decays isotropically gives rise to a pion momentum spectrum that is most populated, in the fireball rest frame (frf), around $(P_{\parallel})_{frf} = 0$ (corresponding to the maximum $P_{\perp}$). Consequently, in the reaction c.m. frame, histograms of $P_{\parallel}$ should show a maximum away from $P_{\parallel} = 0$, the shift being determined by the relative velocity of the frf with respect to the reaction center of mass. This maximum corresponds to pions without longitudinal motion in the frf, and therefore should be pronounced if one looks only at tracks with high transverse momentum. Ratner et al. have observed such a maximum at $P_{\parallel} = 0.4$ GeV/c and $P_{\perp} = 0.63$ GeV/c, corresponding to fireballs of mass ≈ 2100 GeV, moving with $\beta = 0.5$ in the reaction center of mass.

We searched for a maximum in histograms of our π^- tracks for each topology at both 13 and 28.5 GeV/c. Sets of "integral" histograms of π^- longitudinal momenta were made for all tracks with $P_\perp$ greater than 0.0 GeV/c, 0.1 GeV/c, 0.2 GeV/c, up to the point where statistics were insignificant (typically 0.8 GeV/c). Similarly, "differential" histograms of π^- longitudinal momenta were made for all tracks with $P_\perp$ lying in a 100-MeV/c-wide band centered around 0.05, 0.15, 0.25, and 0.35 GeV/c, continuing up to (typically) 0.65 GeV/c. We found no statistically significant maxima away from $P_{\parallel} = 0$ in the center of mass.

Plotting our π^- data from 12.88 GeV/c in the coordinate system of $d^2N/(d\cos\theta dp)_{c.m.}$ vs $P_{\parallel}$, we can compare directly with the results of Ratner et al.; see Fig. 3.

In conclusion, we find that pion c.m. momenta spectra produced in pp interactions over a wide range of energies are well fitted by the expressions 1 and 2. The π^+ and π^- distributions have very similar shapes. The coefficients describing the c.m. momentum distributions agree with a linear dependence upon the number of final charged particles for any given beam momentum, similar to that reported for π^-p interactions. The coefficients are seen to decrease with increasing beam momentum. We find our data to be inconsistent with a moving fireball model.

We wish to thank Mr. Jon Aymong for his extensive help in the analysis of the experiment. We have enjoyed many stimulating discussions with Professor Ronald Ross. The support and encouragement of Professor Luis W. Alvarez are sincerely appreciated.

References and Footnotes

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FIGURE CAPTIONS

Fig. 1. Nonstrange-topology cross sections as a function of beam momentum. The continuous curves through the 4-, 6-, and 8-prongs are the results of a multiperipheral model fit to our data. The dashed curves were hand-drawn to distinguish the 10-, 12-, and 14-prongs.

Fig. 2. Typical fits to the π^- (a) transverse and (b) c.m. longitudinal momentum spectra, and similarly (c, d) to the π^+ spectra for 8-prongs at 21 GeV/c. The errors in the number of tracks/bin are purely statistical for the π^- histograms and are larger than statistical for the π^+ histograms that result from subtractions. Only half the π^+ tracks are shown. Coefficients (e, f, g, h) resulting from fits to our distributions $(dN/dP_\perp)$, $(dN/dP_\parallel)$ according to Eqs. 1 and 2 of the text.

Fig. 3. Histogram of $d^2N/(dp d\cos\theta)_{c.m.}$ for negative track momenta with $0.60\ \mathrm{GeV}/c \leq P_\perp \leq 0.66\ \mathrm{GeV}/c$ from our 12.88 - GeV/c pp interactions. The boxes are similar data from Ratner et al. at $P_\perp^2 = 0.4\ (\mathrm{GeV}/c)^2$ normalized to the total number of tracks.

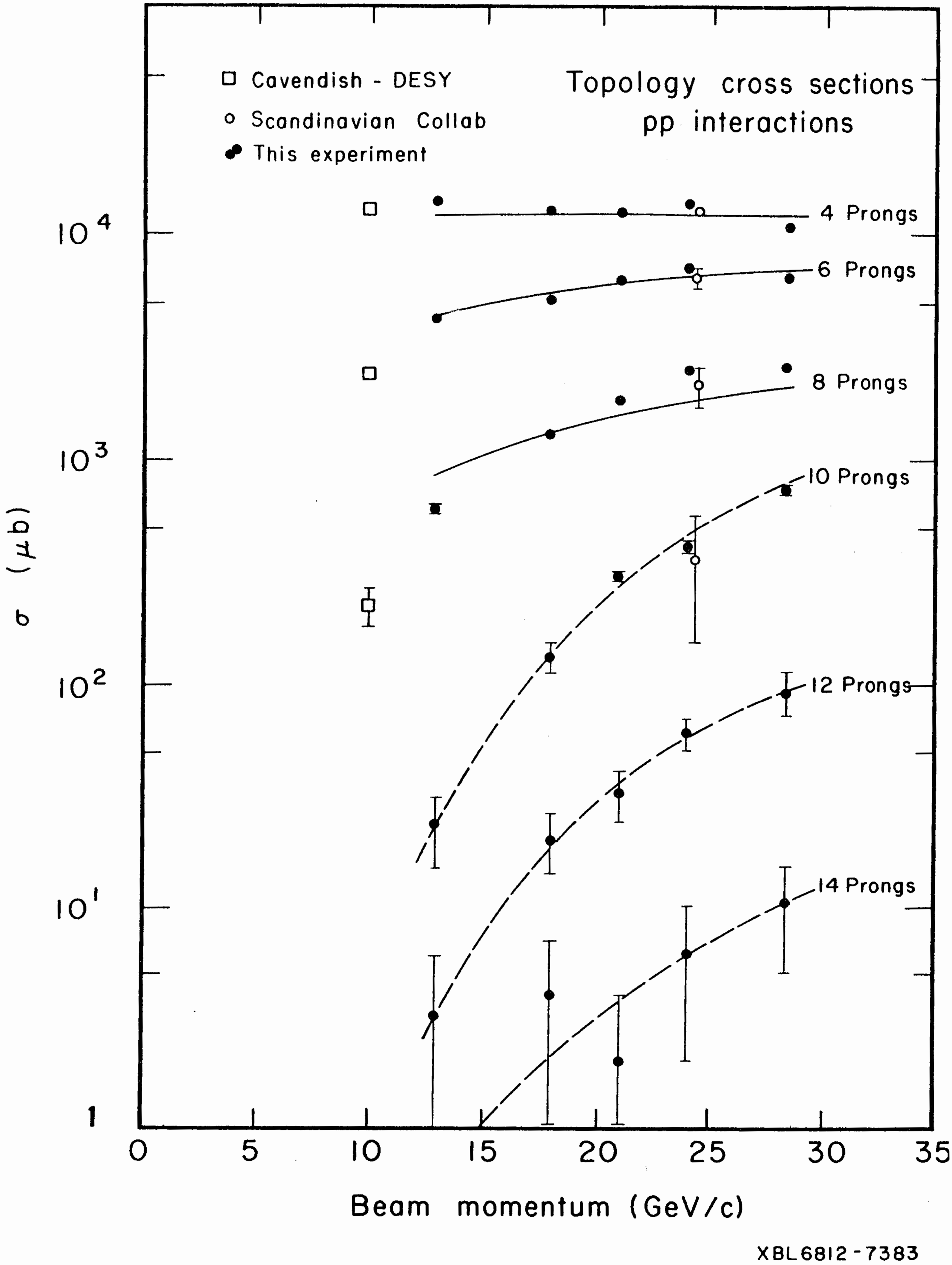

Cavendish - DESY
Scandinavian Collab
This experiment
Topology cross sections
pp interactions
4 Prongs
6 Prongs
8 Prongs
10 Prongs
12 Prongs
14 Prongs
σ (μb)
Beam momentum (GeV/c)
XBL6812-7383

Fig. 1

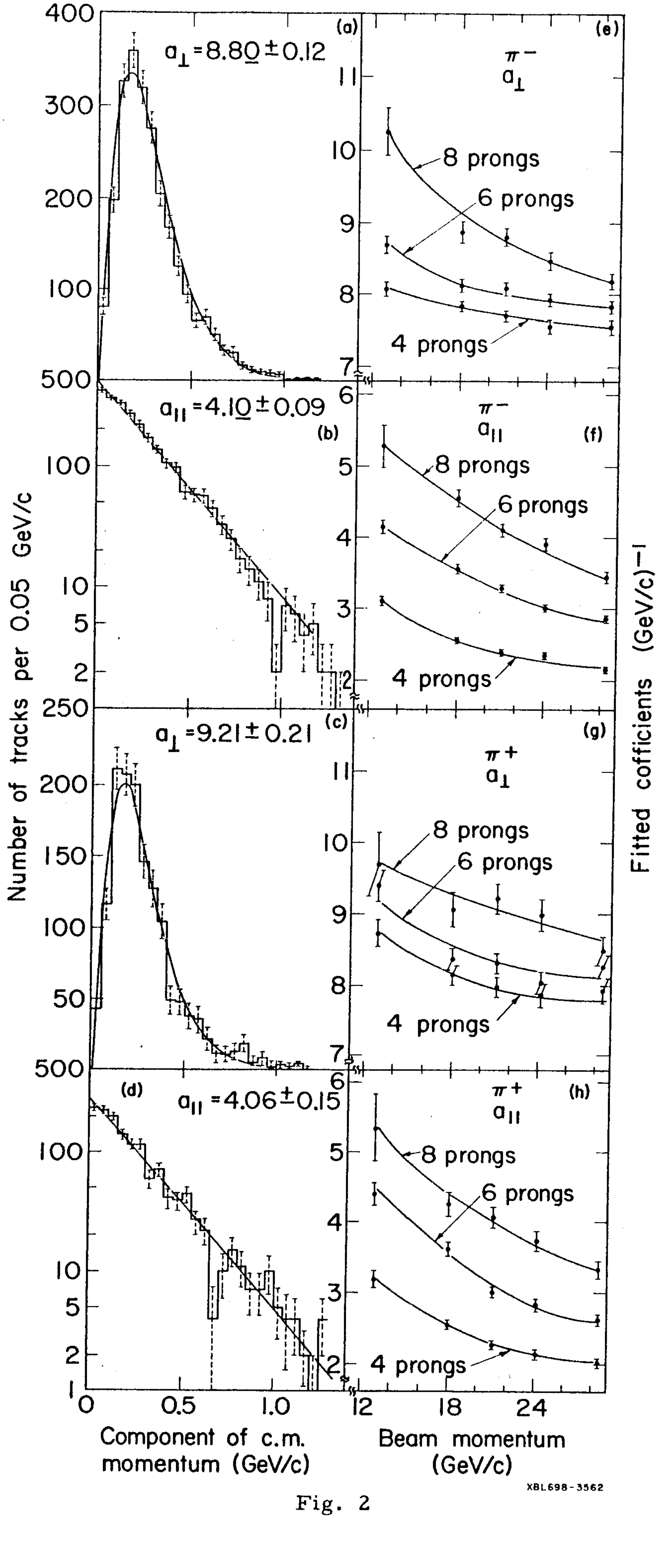
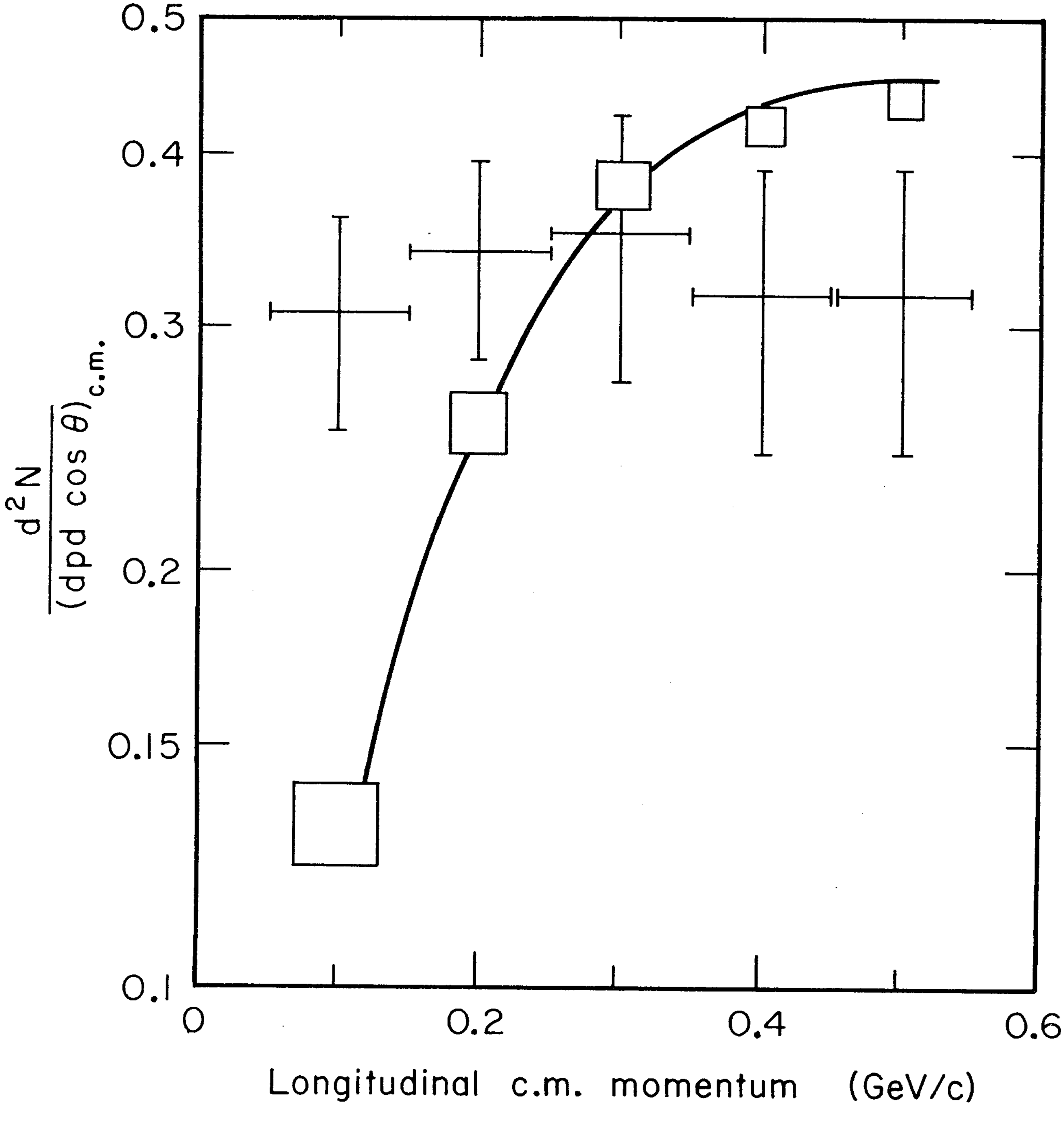

(a)
$a_\perp = 8.8\underline{0} \pm 0.12$
(b)
$a_{\parallel} = 4.1\underline{0} \pm 0.09$
(c)
$a_\perp = 9.21 \pm 0.21$
(d)
$a_{\parallel} = 4.06 \pm 0.15$
(e)
π^- $a_\perp$
(f)
π^- $a_{\parallel}$
(g)
π^+ $a_\perp$
(h)
π^+ $a_{\parallel}$
8 prongs
6 prongs
4 prongs
Number of tracks per 0.05 GeV/c
Fitted cofficients (GeV/c)$^{-1}$
Component of c.m. momentum (GeV/c)
Beam momentum (GeV/c)
XBL698-3562

Fig. 2



XBL698-3563

Fig. 3