Subm. to XXI International Conference on
High Energy Physics, July 16-31, 1982
Paris, France

BNL 32920

Conf-820718--37

OG 711

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Final States from Proton-Proton Collisions with a
Charged Trigger Particle of Large Transverse Momentum
The Axial Field Spectrometer Collaboration*

BNL--32920

DE83 012212

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TRANSVERSE MOMENTUM STRUCTURES OF CHARGED PARTICLE
FINAL STATES FROM PROTON-PROTON COLLISIONS WITH A
CHARGED TRIGGER PARTICLE OF LARGE TRANSVERSE MOMENTUM

The Axial Field Spectrometer Collaboration

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Submitted to XXI International Conference on
High Energy Physics - July 1982.

Abstract

A sample of proton-proton collisions at $\sqrt{s} = 63$ GeV with a (trigger) charged particle of transverse momentum in the range 4 - 12 GeV/c and $|\text{rapidity}| < 1$ is studied. The events were obtained with the Axial Field Spectrometer at the CERN ISR (experiment R807).

Preliminary results are reported from an investigation of the distribution of the transverse momentum vectors of the observed charged particles in the central rapidity region associated with the trigger particle.

It is found that the pattern of transverse momentum vectors of the charged particles observed in a given event is strongly dependent on the amount of transverse energy, $\sum_c E_T(\text{associated})$, which is carried by the associated charged particles observed in the event.

When $\sum_c E_T(\text{associated})$ is large (> 10 GeV/c within $|\text{rapidity}| < 1$), a large fraction ($\sim 50\%$) of the events have the transverse momentum vectors of the associated charged particles collimated in narrow jets around an axis close in azimuth (within $\sim 20^\circ$) to the trigger particle.

Introduction

Jet like structures of the radiation patterns from hadron-hadron collisions were found in final states, which contain a particle with large transverse momentum ($/, 2$), and these structures have a natural interpretation in terms of hard scatterings between a single constituent of each of the colliding hadrons.

More recent studies (3,4) of the structure of the radiation from ^{highly inelastic} collisions, which are selected by the emission of a large amount of transverse energy, $\sum E_T$, have shown that a large $\sum E_T$ does not by itself guarantee a structure with a simple reference to a single basic two-body scattering.

It has thus become an interesting subject to study relations between collisions selected by the emission of a high p_T particle in the central rapidity region and collisions selected by the emission of a large $\sum E_T$ in this region.

In the present paper we present preliminary results from an investigation of the transverse momentum structures of charged particle final states of proton-proton collisions at $\sqrt{s} = 63$ GeV, which were selected by the presence of a charged particle with large transverse momentum ($4 < p_T^{\text{cms}} < 12$ GeV/c) in the rapidity range, $|\eta(\text{trigger})| < 1.0$. In the analysis the events are classified according to the amount of transverse energy, $\sum E_T(\text{associated})$, which is carried by the charged particles associated with the trigger particle in the central region. The studied sample of events was obtained at the CERN ISR with the Axial Field Spectrometer (experiment R807).

Apparatus and data analysis

The experimental apparatus is sketched in fig.1, showing a vertical cut through the center of the ISR beam intersection region and the apparatus, perpendicular to the ISR beams. The coordinate system used is indicated in the figure.

The setup is described in detail elsewhere (5,6).

The main components are:

1. The Beam-Beam counters. Two sets of scintillation counters are placed around the downstream beam pipes, covering the range of scattering angles $1.2^\circ - 6^\circ$. They are used to record the luminosity and in the trigger for, for example, Minimum Bias events.
2. The central detectors, consisting of a barrel of 44 plastic scintillator strips (each covering 8° in azimuth from the center of the intersection), which surrounds the ISR vacuum chamber, and a cylindrical driftchamber, 1.4 m long and of radial extension 0.20 - 0.80 m. The driftchamber is segmented azimuthally into 4° sectors, each with 42 resistive sense wires, from which time signals and pulse heights are recorded at both ends. The drift chamber extends over the whole 2π of azimuth, except for two wedges, vertically upwards and downwards, each of 16° extension, which are occupied by the mechanical structure of the chamber and its support. The coordinates in the transverse plane of a point on the trajectory of a passing particle are determined from the drift time, and the position along the wire from the pulse heights at the two ends. The spatial resolution in the chamber is $230 \mu\text{m}$ (r.m.s.) in the drift distance and 1.5 cm (r.m.s.) in the axial coordinate, Z. The central detectors are situated in an axially symmetric magnetic field of 0.5 T.
3. The Cerenkov Arm. With the purpose of particle identification, about one steradian around the positive x-axis is covered by three layers of Cerenkov counters; an Aerogel counter, a high pressure Freon counter and an atmospheric pressure Freon counter. On each side of the high pressure counter there is

a proportional wire chamber, PC1 on the inside and PC2 on the outside, both with horizontal wires and with cathode strips connected to delay lines. The wire distance is 0.5 cm in PC1 and 1.0 cm in PC2.

The proportional chambers and the Cerenkov counters are subtended over the azimuthal range $-22.5^\circ < \varphi < 22.5^\circ$ and the polar angle range $45^\circ < \theta < 135^\circ$ (φ is measured from the x-axis, θ from the z-axis).

At the end of the Cerenkov Arm, 6.5 m from the intersection, a Cu calorimeter is placed, covering $1/7$ of the solid angle of the arm. It is subtended over the angular ranges $-15^\circ \leq \varphi \leq 10^\circ$, $70^\circ \leq \theta \leq 110^\circ$. The calorimeter was used in the high p_T trigger in about half of the sample discussed here in order to provide a cross check of the momentum measurement for the very large transverse momenta and to give a larger live time of the trigger, by reducing the pretrigger rate.

4. The Uranium calorimeters. The three quadrants at large azimuthal angles to the Cerenkov Arm are covered by Uranium calorimeters. Their signals were recorded for the events in the sample discussed here, but they are not used in the present analysis.

The detectors which are used for the data described in this paper are: the central detectors, PC1 and PC2 and the Cu Calorimeter.

The trigger system used to detect the presence of a high p_T charged particle and to trigger the data registration is a three level system. The first level requires a coincidence between a set of colinear elements of the barrel scintillation counter and groups of wires in PC1 and PC2. The second level requires a coincidence between a colinear set of individual PC1 and PC2 wires. This coincidence points out a few of the 4° sectors of the drift chamber, which sectors are then investigated in the third level of the trigger. From each of the sectors pointed out the time signals from 4 sets of 4 wires are read into a micro-processor called ESOP, where the drift times are investigated

for consistency with the presence of a particle track with the desired small sagitta (≈ 1 mm for a particle with $p_T = 5$ GeV/c). This so-called ESOP trigger, has acceptance inside the azimuth and rapidity ranges in cms

$$|\phi^{\text{cms}}(\text{trigger})| < 24^\circ, \quad |y^{\text{cms}}(\text{trigger})| < 1.0$$

with some variation over these ranges.

As mentioned above, half of the sample of events described in the following was obtained with a trigger, which required a coincidence between the ESOP trigger - with a threshold set to $p_T^{\text{Lab}}(\text{trigger}) = 5$ GeV/c - and a signal from the Cu calorimeter indicating an energy deposit of ≥ 2 GeV in the calorimeter. This part of the sample populates only the narrower angular regions

$$-15^\circ < \phi^{\text{cms}} < 10^\circ, \quad |y^{\text{cms}}(\text{trigger})| < 0.22$$

In the off-line data analysis the events were first analysed with the AFS driftchamber reconstruction and fitting programs (7). Tracks entering the acceptance of the Cerenkov Arm, in particular the high p_T trigger tracks, were further treated in another set of programs, which combined the driftchamber information with the signals from PC1 and PC2 (wire signals only ($\frac{1}{2}$ coordinate) or reconstructed space points (y and z coordinates)). The momentum ~~time~~ was refitted using both sets of information. This procedure served to reject track configurations simulating high p_T tracks in the driftchamber (due, for instance, to very flat decays or combinations of segments from two different tracks), to reject particles interacting in the material of the Cerenkov counters and to improve the momentum resolution to approximately $\Delta p/p = 10\%$ at $p = 10$ GeV/c. The procedure was tested using high momentum cosmic ray muons, where the momentum was measured over both half-cylinders of the driftchamber.

An event was required to have a reconstructed primary vertex inside a fiducial volume in the intersection region and a trigger track with a good fit to the combination of information from the driftchamber and the proportional wire chambers. It was further required that at least 33 (x, y) points and at least 30 z points in the driftchamber were assigned to the trigger track.

Cuts were imposed on the tracks associated with the trigger track to ensure that they belong to the event and that their momenta are reasonably well-determined. For a track with $45^\circ < \theta < 135^\circ$ it was required that $\Delta p/p < 0.06$ for $p_T < 2 \text{ GeV}/c$ and $\Delta(\frac{1}{p}) < 0.03$ for $p_T > 2 \text{ GeV}/c$. For more forward tracks this criterion was relaxed corresponding to the shorter potential radial extension of the track. For all tracks with $p_T > 2 \text{ GeV}/c$ it was required that at least 33 (x,y) points in the driftchamber were assigned to the track. All tracks with $p_T^{\text{cm}} > 5.0 \text{ GeV}/c$ were rejected. When the track momentum was transformed to the cms a pion mass was assigned to it, except when a dE/dx identification based on the driftchamber pulse heights had indicated a kaon or proton mass.

With these cuts we find, from studies of Minimum Bias events and comparisons with earlier inclusive measurements, as well as from comparisons of distributions from the Minimum Bias events and the events in the present sample, that the acceptance is nearly uniform and close to 100% for rapidity $|y^{\text{cms}}| < 0.6$, and azimuthal angles $|\phi^{\text{cms}}| < 80^\circ$ and $110^\circ < |\phi^{\text{cms}}|$. The two 30° vertical regions are influenced by the two blind 16° regions in the driftchamber. Inside these regions with uniform and high acceptance ($|y^{\text{cms}}| < 0.8$ for the Minimum Bias sample, which had a smaller beam intersection region (diamond)) we find good agreement both in shape and normalization of the p_T spectra obtained from Minimum Bias events and earlier measurements in the range $0.2 < p_T^{\text{cms}} < 5 \text{ GeV}/c$.

The distributions in azimuth, rapidity and transverse momentum of the obtained trigger particles are shown in figs. 2, 3 and 4. It is stressed that no corrections have been applied for variations of the trigger efficiency. For example, there is a variation of efficiency with p_T of the order of a factor 3.5 over the considered range $4 < p_T^{\text{cm}}(\text{trigger}) < 12 \text{ GeV}/c$.

The two samples described above - with and without the Cu calorimeter in the trigger - have very different distributions in azimuth and rapidity, which is very apparent in figs. 2 and 3, where the two samples are added. The total sample consists of 28128 events, composed of 14713 events triggered with

ESOP.Cu calorimeter and 13415 events triggered with the ESOP trigger alone. There is good agreement between the p_T^{cms} (trigger) spectra - for both trigger charges taken together - obtained in the two samples, and there is good agreement between the distributions of the particles associated with the trigger particle in the two samples.

As an example of the distributions of associated particles, fig. 5 shows the rapidity distributions on the Trigger Side and on the Recoil Side of the observed associated particles with p_T^{cms} (associated) > 1.0 GeV/c.

Preliminary results concerning structures in the transverse momentum plane.

For the large fraction of the events which have $|y^{\text{cms}}(\text{trigger})| < 0.2$ figs. 6 and 7 show the distributions in $\Delta\phi = |\phi^{\text{cms}}(\text{associated}) - \phi^{\text{cms}}(\text{trigger})|$ of the observed associated particles with $p_T^{\text{cms}}(\text{associated}) > 1.0$ GeV/c within $|y^{\text{cms}}(\text{ass})| < 0.8$.

The distribution is split into four according to the charges of the trigger particle and the associated particle. In all four distributions the reflections of the Trigger Side jet and the Recoil Side jet are clearly visible within the azimuthal regions $\Delta\phi < 24^\circ$ and $\Delta\phi > 120^\circ$ respectively. The main difference between the four distributions occurs between those for opposite and same charge configurations of the trigger/associated particle. But within each of these charge combinations there ^{also smaller} are differences between the particle densities associated with negative and positive trigger particles. The difference is in the direction of a stronger charge compensation - over a large region of the phase space - of negative trigger particles than of positive trigger particles. In particular, it is very rare that a negative trigger-particle is accompanied in the trigger jet by a negative associated particle (with $p_T^{\text{cms}} > 1.0$ GeV/c).

These charge correlations are more quantitatively expressed in the numbers in Table 1.

From the numbers in Table 1 the ratios in Table 2 follow.

We thus find that in the same charge configurations in the Trigger Side jet a positive trigger is accompanied by a positive associated particle 1.6 ± 0.2 times as often as a negative trigger is accompanied by a negative associated particle. In the oppositely charged configurations we observe a density of positive particles associated with negative triggers $(14 \pm 8)\%$ higher than that of negative particles associated with positive triggers, i.e. a weak correlation compared with the dominant others.

In the Recoil Side jet the two types of charge correlations are of similar strength. The ratios

$$\frac{\text{positive associated density}}{\text{negative associated density}}$$

are consistent with being equal, about 1.15, for the same charge and opposite charge configurations, and may be a characteristic of pp collisions rather than a correlation to the trigger charge. The value 1.06 ± 0.02 for the opposite charge/same charge ratio indicate, however, that even at the present trigger transverse momentum, $\langle p_T^{\text{cms}}(\text{trigger}) \rangle = 4.8 \text{ GeV}/c$, there is still a correlation between the trigger charge and the charge of the high p_T ($>1.0 \text{ GeV}/c$) recoil particles with $\Delta\phi > 120^\circ$.

These charge correlations are discussed in greater detail, and separately for each type of identified trigger particle in another contribution to the Conference (8).

We now turn to an investigation of the shape of the distribution, event by event, of the associated particles in the transverse plane. Very naturally the observed shape distribution is strongly dependent on the amount of associated charged transverse energy, $\sum_c E_T^{\text{cms}}(\text{associated})$, which is observed in the event. The distribution of this quantity in the whole sample is shown in fig. 8. The average value is 4.53 GeV and an average slope for $\sum_c E_T^{\text{cms}}(\text{associated}) > 6 \text{ GeV}$ is about 0.6 GeV^{-1} ; much smaller than the corresponding slope in Minimum Bias events ($\sim 1.1 \text{ GeV}^{-1}$) as reported in another contribution to the Conference (9).

The quantity $\sum_c E_T^{\text{cms}}(\text{associated})$ is strongly correlated to the momentum balance in the observed part of the event as shown in fig.9 for the momentum balance in the x-direction. This may

indicate that, when $\sum_{\text{c}} E_{\text{T}}^{\text{cms}}$ (associated) is large, the fluctuation in the charges of the associated particles and the fluctuation in the direction of the recoil jet (inside or outside the acceptance) go in such a direction that a large part of the event is observed.

The average trigger momentum changes only by 0.3 GeV/c when $\sum_{\text{c}} E_{\text{T}}^{\text{cms}}$ (associated) goes from the low to the high end of its spectrum.

The shape of the distribution in the transverse momentum plane of the particles associated with a given trigger particle is here described by the direction (relative to the trigger direction) of the axis, which minimizes the sum over the associated particles, $\sum q_{\text{T}}^2$, of the squared momentum components perpendicular to it, and the quantity

$$c = \text{circularity} = \frac{2 \cdot \text{Min} (\sum q_{\text{T}}^2)}{\sum p_{\text{T}}^2} = 1 - \text{planarity}$$

where planarity is the shape parameter used, for example, by the NA5 group (3). The parameter c, circularity, is ~ 0 for a very thin pencil-shaped event and ~ 1 for an event with many isotropically distributed particles.

If the trigger particle is included in this shape description (circularity and direction of axis), it dominates it completely. Therefore it is not included.

The shape analysis is performed only on events with three or more accepted associated particles.

The found distribution of the angular distance between the azimuthal direction, α , of the axis of the associated event and φ (trigger) (both in cms), $\Delta\varphi = |\alpha - \varphi(\text{trigger})|$ is shown in fig.10 for events with different values of $\sum_{\text{c}} E_{\text{T}}^{\text{cms}}$ (assoc).

A clear tendency is observed: when $\sum_{\text{c}} E_{\text{T}}^{\text{cms}}$ (associated) increases, the $\Delta\varphi$ distribution becomes more narrow, i.e. the associated event becomes more aligned with the trigger direction. From the distributions it appears that there is a characteristic angle, $\Delta\varphi \approx 20^\circ$, separating events with an axis "close" to the trigger particle and events with an axis "far away" from it.

The average values found for $\Delta\phi$ as a function of $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$ is given in fig. 11. $\langle\Delta\phi\rangle$ decreases with increasing $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$ and becomes smaller than 20° for $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}} > 10 \text{ GeV}$.

These characteristics make it of interest to look at the shape distributions - here distributions of circularity - separately for events with $\Delta\phi < 20^\circ$ and $\Delta\phi > 20^\circ$, in bins of $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$. Figs. 12 to 16 show examples of such circularity distributions, and fig. 17 gives the average circularity for events with $\Delta\phi < 20^\circ$ and $\Delta\phi > 20^\circ$, respectively, as a function of $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$. A clear tendency is observed that when $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$ increases, the events with $\Delta\phi < 20^\circ$ become increasingly more dominant, and the circularity of these events decreases. For $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}} > 10 \text{ GeV}$ it is found that 67% of the events have $\Delta\phi < 20^\circ$, and these events have average circularity ≈ 0.29 .

From the distributions it appears ^{to be} of interest to distinguish between small circularities, $c < 0.3$, and large circularities, $c > 0.3$.

The distributions of $\Delta\phi$ and c are thus pointing out the four classes of events:

$$\Delta\phi < 20^\circ, c \lesssim 0.3 \quad \text{and} \quad \Delta\phi > 20^\circ, c \lesssim 0.3,$$

and it is of interest to measure the relative abundancies of these classes of events as functions of $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$. These abundancies are given in fig. 18. It is observed that the class of events with $\Delta\phi < 20^\circ$, i.e. events where the axis of the associated event is close to the trigger particle, and $c < 0.3$, i.e. the associated event is "thin" and (2-jet like), becomes the dominant ($\approx 50\%$) class for $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}} > 10 \text{ GeV}$. The class of events with $\Delta\phi > 20^\circ$ and $c > 0.3$, i.e. events with the axis of the associated event far away from the trigger particle and rather isotropic, decreases continuously with increasing $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$, and appears to vanish at very high values of $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$. For the two intermediate classes $\Delta\phi < 20^\circ, c > 0.3$ and $\Delta\phi > 20^\circ, c < 0.3$ the situation at high $\sum_{\epsilon} E_{T(\text{associated})}^{\text{cms}}$ is not so clear. They may represent

more complicated processes; for example, events with multiple jets caused by gluon bremsstrahlung in an eventual basic hard scattering process. They may, however, also represent other kinds of tails to the dominant simple two-jet class with $\Delta\phi < 20^\circ$, $c < 0.3$. It seems clear that there is a transition region at $8 < \sum E_T^{\text{cms}}(\text{associated}) < 10$ GeV, which must be passed before the various types of events separate clearly in abundance.

To illustrate the difference between the above-mentioned different classes of events, the spectra $\frac{dN}{dp_T} p_T^{\text{cms}}(\text{assoc.})$ on the Trigger Side and on the Recoil Side are shown for the two extreme classes $\Delta\phi < 20^\circ$, $c < 0.3$ and $\Delta\phi > 20^\circ$, $c > 0.3$ in figs. 19 and 20 for $\sum E_T^{\text{cms}}(\text{associated}) > 10$ GeV. Very naturally the 2-jet like events, $\Delta\phi < 20^\circ$, $c < 0.3$, have relatively few low p_T particles and relatively many high p_T particles. The crossing point of the $p_T^{\text{cms}}(\text{associated})$ spectra is at $p_T^{\text{cms}}(\text{associated}) \approx 1.5$ GeV/c.

Conclusions

We have studied the structure in the transverse plane of the particle radiation from pp collisions, from which a charged (trigger) particle with $4 < p_T^{\text{cms}} < 12$ GeV/c ($\langle p_T^{\text{cms}}(\text{trigger}) \rangle = 4.82$ GeV/c) is emitted. The $\Delta\phi$ distribution of associated particles with $p_T^{\text{cms}}(\text{associated}) > 1.0$ GeV/c shows clear evidence for a Trigger Side jet and a Recoil Side jet. The charge correlations indicate a stronger charge compensation of a negative trigger particle than of a positive trigger particle.

The shape of the distribution of associated particles in the transverse plane is strongly dependent on $\sum E_T^{\text{cms}}(\text{associated})$. Above a transition region $8 < \sum E_T^{\text{cms}}(\text{associated}) < 10$ GeV, $\sim 50\%$ of the events have a 2-jet structure characterized by a circularity of the observed event associated with the trigger smaller than 0.3 and an axis for the associated event less than 20° away in azimuth from the trigger.

The amount of observed associated transverse energy may simply be a measure of the fraction of the relevant part of the event, which is observed. This is indicated by a strong correlation between $\sum_{\epsilon} E_T^{\text{cms}}$ (associated) and the degree of momentum balance in the observed part of the event. At lower values of $\sum_{\epsilon} E_T^{\text{cms}}$ (associated) we may be looking at events, in which a large fraction of the correlated particles are not observed in this experiment, either because they are neutral or because they are outside the acceptance of the detectors.

Acknowledgements

We acknowledge with thanks the work of the CERN EP, EF and ISR divisions and the workshops in our home institutions on the construction and installation of the Axial Field Spectrometer, and the contributions to the experiment of P.Dam, W.M. Evans, P. Frandsen, M.D. Gibson, J.W. Hiddleston, H. Hofman, J. v.d.Lans, J. Lindsay and A. Rudge. Support from the Research Councils in our home countries is gratefully acknowledged.

This research supported in part by the U.S. Dept. of Energy under Contract DE-AC0276CH00016.

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Table 1

Average numbers of associated particles per trigger

$$4 < p_T^{\text{cms}}(\text{trigger}) < 12 \text{ GeV/c} \quad |y^{\text{cms}}(\text{trigger})| < 0.2$$

$$\langle p_T^{\text{cms}}(\text{trigger}) \rangle = 4.8 \text{ GeV/c}$$

$$p_T^{\text{cms}}(\text{associated}) > 1.0 \text{ GeV/c} \quad |y^{\text{cms}}(\text{associated})| < 0.8$$

$$\langle p_T^{\text{cms}}(\text{associated}) \rangle = 1.5 \text{ GeV/c}$$

$$\Delta\phi < 24^\circ$$

	Q(associated) = -1	Q(associated) = +1
Q(trigger) = -1	0.025 $\pm$ 0.002	0.090 $\pm$ 0.004
Q(trigger) = +1	0.079 $\pm$ 0.004	0.040 $\pm$ 0.002

$$\Delta\phi > 120^\circ$$

	Q(associated) = -1	Q(associated) = +1
Q(trigger) = -1	0.219 $\pm$ 0.005	0.268 $\pm$ 0.006
Q(trigger) = +1	0.240 $\pm$ 0.005	0.258 $\pm$ 0.005

Table 2

Ratios between the average numbers of associated particles/trigger

	opp. ch. same ch.	pos.ch./pos.trig. neg.ch./neg.trig.	pos.ch./neg.trig. neg.ch./pos.trig.
$\Delta\phi < 24^\circ$	2.6 $\pm$ 0.2	1.6 $\pm$ 0.2	1.14 $\pm$ 0.08
$\Delta\phi > 120^\circ$	1.06 $\pm$ 0.02	1.18 $\pm$ 0.04	1.12 $\pm$ 0.03

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Figure Captions

- Fig. 1. The Axial Field Spectrometer in a view perpendicular to the collision axis. The left calorimeter wall is shown in a retracted position.
- Fig. 2. Azimuthal distribution of the accepted trigger particles. The shape of the distribution is due partly to the composition of the sample of half ESOP Trigger alone and half ESOP.Cu Calorimeter Trigger, partly to variations with ϕ of the ESOP acceptance.
- Fig. 3. Rapidity distribution of the accepted trigger particles. The shape of the distribution is dominated by the composition of the sample of half ESOP Trigger alone (acceptance for $|y| < 1$) and half ESOP.Cu Calorimeter trigger (acceptance for $|y| < 0.22$).
- Fig. 4. p_T^{cms} spectrum of the accepted triggers in the range $4 < p_T^{\text{cms}} < 12$ GeV/c. The efficiency of the trigger increases by a factor ~ 3.5 when p_T^{cms} changes from 4 to 12 GeV/c.
- Fig. 5. Rapidity distribution of accepted associated particles with $p_T^{\text{cms}} > 1.0$ GeV/c. The distribution is shown separately for particles on the Trigger Side and on the Recoil Side.
- Fig. 6. Distributions in azimuthal distance, $\Delta\phi$, from the trigger particle of associated particles with $p_T^{\text{cms}} > 1.0$ GeV/c and $|y| < 0.8$ in events with $|y(\text{trigger})| < 0.2$. The associated particle has charge opposite to the charge of the trigger particle.
- negative trigger particles; + positive trigger particles
- Fig. 7. Distributions in azimuthal distance, $\Delta\phi$, from the trigger particle of associated particles with $p_T^{\text{cms}} > 1.0$ GeV/c and $|y| < 0.8$ in events with $|y(\text{trigger})| < 0.2$. The associated particle has the same charge as the trigger particle.
- negative trigger particles;
+ positive trigger particles

Figure Captions (cont'd)

- Fig. 8. Spectrum of $\sum_c E_T^{\text{cms}}$ (associated). The summation goes over all accepted associated particles (without any corrections and without any explicit rapidity cut).
- Fig. 9. Average observed momentum balance, MBX, in the x direction as a function of $\sum_c E_T^{\text{cms}}$ (associated).

$$\text{MBX} = \sum p_x^{\text{cms}} (\text{Trigger Side}) / \sum p_x^{\text{cms}} (\text{Recoil Side}).$$
The summations go over all accepted particles (without any corrections).
- Fig. 10. Distributions in the azimuthal distance, $\Delta\phi = |\alpha - \phi(\text{trigger})|$ of the axis of the associated event from the trigger particle in bins of $\sum_c E_T^{\text{cms}}$ (associated).
- Fig. 11. Average value of the azimuthal distance $\Delta\phi = |\alpha - \phi(\text{trigger})|$ between the axis of the associated event and the trigger particle, as a function of $\sum_c E_T^{\text{cms}}$ (associated).
- Fig. 12-16. Distributions in $\Delta\phi = |\alpha - \phi(\text{trigger})|$ and circularity of the associated event, in bins of $\sum_c E_T^{\text{cms}}$ (associated).
- Fig. 17. Average values of the circularity of the associated event for $\Delta\phi = |\alpha - \phi(\text{trigger})| \lesssim 20^\circ$ as functions of $\sum_c E_T^{\text{cms}}$ (associated).
- Fig. 18. Relative abundancies of events in the four classes of event shape: $\Delta\phi = |\alpha - \phi(\text{trigger})| \lesssim 20^\circ$, circularity (associated event) $\lesssim 0.3$, as functions of $\sum_c E_T^{\text{cms}}$ (associated).
- Fig. 19. p_T^{cms} spectra of associated particles on the Trigger Side in the two classes of events:
 $\Delta\phi < 20^\circ, c < 0.3$ and $\Delta\phi > 20^\circ, c > 0.3$.
- Fig. 20. p_T^{cms} spectra of associated particles on the Recoil Side in the two classes of events: $\Delta\phi < 20^\circ, c < 0.3$ and $\Delta\phi > 20^\circ, c > 0.3$.

$$4 < p_T^{cm}(\text{trigger}) < 12 \text{ GeV}/c$$

Azimuthal distribution of the trigger particles

triggers/ $\Delta y = 0.04$

$$4 < p_T^{\text{SM}}(\text{trigger}) < 12 \text{ GeV}/c$$

Distribution of $y(\text{trigger})$

Fig.3

$$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV}/c$$

Observed rapidity distributions of associated particles
with $p_T^{CM}(\text{associated}) > 1.0 \text{ GeV}/c$

$$\frac{1}{N(\text{trigger})} \cdot \frac{dn}{dy}$$

NOT CORRECTED

- Trigger side
- Recoil side

Fig.5

$$\frac{1}{N(\text{trigger})} \frac{dn}{d\Delta\phi}$$

$$4 < p_T^{\text{CM}}(\text{trigger}) < 12 \text{ GeV/c} ; |y(\text{trigger})| < 0.2$$

rad⁻¹

Azimuthal density of associated particles with
 $p_T^{\text{CM}}(\text{associated}) > 1 \text{ GeV/c} ; |y(\text{associated})| < 0.8$

Opposite charge to the trigger particle

• negative trigger

+ positive trigger

influenced by
the up-down
blind regions

Fig.

$$\frac{1}{N(\text{trigger})} \frac{dn}{d\Delta\phi}$$

$$4 < p_T^{\text{CM}}(\text{trigger}) < 12 \text{ GeV}/c ; |y(\text{trigger})| < 0.2$$

rad⁻¹

Azimuthal density of associated particles with
 $p_T^{\text{CM}}(\text{associated}) > 1.0 \text{ GeV}/c ; |y(\text{associated})| < 0.8$

Same charge to the trigger particle

• negative trigger

+ positive trigger

Fig.7

$$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV}/c$$

$$\langle p_T^{CM}(\text{trigger}) \rangle = 4.82 \text{ GeV}/c$$

Average observed charged momentum balance in the x direction.

$$MBX = \frac{\sum p_x^{CM}(\text{Trigger Side})}{\sum p_x^{CM}(\text{Recoil Side})}$$

$$\frac{N(\sum E_T) d\Delta\phi}{d\Delta\phi}$$

$\langle \Delta \phi \rangle$

Degrees

$$4 < p_T^{cm}(\text{trigger}) < 12 \text{ GeV}/c \quad (4.8)$$

Average value of $|\alpha - \phi(\text{trigger})|$
as a function of $\sum E_T^{cm}(\text{associated})$

Fig.11

$$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV}/c$$

$$2 < \sum E_T^{CM}(\text{associated}) < 4 \text{ GeV}$$

≥ 3 accepted associated tracks

Distributions in circularity and

$$\Delta\phi = |\alpha - \phi(\text{trigger})|$$

$\langle C \rangle$

$$\Delta\phi < 20^\circ \bullet 41\% \quad 0.338 \pm 0.004$$

$$\Delta\phi > 20^\circ \times 59\% \quad 0.413 \pm 0.003$$

Fig. 12

$$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV}/c$$

$$4 < \sum E_T^{CM}(\text{associated}) < 6 \text{ GeV}$$

≥ 3 accepted associated tracks

Distributions in circularity and

$$\Delta\phi = |\alpha - \phi(\text{trigger})|$$

$\langle c \rangle$

$$\Delta\phi < 20^\circ \quad \bullet \quad 47\% \quad 0.344 \pm 0.004$$

$$\Delta\phi > 20^\circ \quad \times \quad 53\% \quad 0.455 \pm 0.004$$

$$\frac{1}{N(\sum E_T)} \frac{dN}{dc \cdot \Delta(\Delta\phi)}$$

Fig.13

$$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV}/c$$

$$6 < \sum E_T^{CM}(\text{associated}) < 8 \text{ GeV}$$

≥ 3 accepted associated tracks

Distributions in circularity and

$$\Delta\phi = |\alpha - \phi(\text{trigger})|$$

$\langle c \rangle$

$$\frac{1}{N(\sum E_T)} \frac{dN}{dc \cdot \Delta(\Delta\phi)}$$

$$\Delta\phi < 20^\circ \quad \bullet \quad 52.8\% \quad 0.342 \pm .005$$

$$\Delta\phi > 20^\circ \quad \times \quad 47.2\% \quad 0.470 \pm .005$$

Fig. 14

$$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV}/c$$

$$8 < \sum E_T^{CM}(\text{associated}) < 10 \text{ GeV}$$

≥ 3 accepted associated tracks

Distributions in circularity and

$$\Delta\phi = |\alpha - \phi(\text{trigger})|$$

Fig. 15

$$4 < p_T^{cm}(\text{trigger}) < 12 \text{ GeV}/c$$

$$10 < \sum_c E_T^{cm}(\text{associated}) < 20 \text{ GeV}$$

≥ 3 accepted associated tracks

Fig. 16

$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV}/c$
 ≥ 3 accepted associated tracks

Average circularity as a function of
 $\sum E_T^{CM}(\text{associated})$

$$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV/c}$$

$$10 \text{ GeV} < \sum E_T^{CM}(\text{associated})$$

$$4 < p_T^{CM}(\text{trigger}) < 12 \text{ GeV/c}$$

$$10 \text{ GeV} < \Sigma E_T^{CM}(\text{associated})$$

Fig.20