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VALENCE QUARK EFFECTS IN BEAM REMNANTS IN HIGH E_t PROTON-PROTON COLLISIONS AT $\sqrt{s}$ = 27.4 GeV*

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Charged particle trajectories have been reconstructed in pp collisions with transverse energies (E_t) ranging from 1 GeV to 20 GeV. Data were collected by triggering on E_t in a highly segmented calorimeter with full azimuthal coverage. Minimum bias triggers were also used. Valence quark effects are known to appear at low E_t in the differences between positive and negative multiplicities in the forward direction. We reproduce these known prominent effects at low E_t, but find them not present in the collisions with large E_t, disappearing by about $E_t = 8$ GeV. Furthermore, events with high planarity do not show a strong forward net flow of charge and disagree with the predictions of ISAJET. The results suggest that for the triggers studied, more than a single pair of proton constituents scatter at this energy.

Hadron-hadron collisions with large transverse energy (E_t) arise from several mechanisms. At collider energies, $\sqrt{s}$ = 540 GeV, the hard scattering of a pair of partons[1] gives clear production of pairs of back-to-back transverse jets[2]. Other mechanisms, e.g. an extension of soft hadron collision properties[3], a modification of beam fragmentation in the hard scatters[4], or the scattering of multiple parton pairs during one hadron collision[5], have also been suggested at other collision energies. In all these processes, the debris of the incoming hadrons remains to form a flow of hadrons in the forward and backward directions. The transverse jets and energy flows have been extensively studied[6], but data on the forward and backward directions are not extensive[7] and model predictions of the production of hadrons in these kinematic regions are not well tested.

We present properties of hadrons produced in the forward direction in pp collisions at $\sqrt{s}$ = 27.4 GeV over a range of E_t from low, where data can be compared to previous results, to high values. The results shown here concentrate on the difference between positive and negative particle multiplicities in order to look for effects related to the debris of the incoming (positive) proton.

The experiment was performed at Fermilab (E557) using 400 GeV/c protons incident on a hydrogen target in the M6W Multiparticle Spectrometer. The apparatus, which has been described in detail in previous publications[8], consisted of a calorimeter with electromagnetic and hadronic sections segmented into 126 towers and a spectrometer of 22 planes of multiwire proportional chambers (MWPC), 24 planes of magnetostrictive spark chambers, and a magnet that provided 0.2 GeV/c p_t kick. Fig. 1 shows polar angle (θ) cones used in analysis superimposed on the face of the calorimeter for photons at various angles as measured in the pp c.m. frame. The calorimeter measured particles in the approximate angular range corresponding to photon c.m. angles of 47^0 to 125^0. The E_t for an event was calculated only from energy deposits (E) in calorimeter modules and was equal to the sum of $E\sin\theta_{lab}$ for all modules. Charged tracks were reconstructed from the MPWC's and spark chambers in the range $0^0 < \theta_{cm} < 130^0$, and the uncertainty in momentum from the reconstruction of a full length track was $\Delta p/p = p/p_0$ where $p_0 = 270$ GeV/c. Track finding efficiencies were estimated to be 80-90% overall; this estimate was derived from comparisons, some discussed below, to published data or known reults.

Data were obtained using two types of trigger : "interacting-beam" trigger(IB) which used a small veto counter downstream of the spectrometer magnet along with a twice minimum ionisation detector immediately downstream of the target; and a "global" trigger which selected the total E_t detected in the calorimeter above an adjustable threshold. After all cuts (discussed below), the resulting data sample contained 11090 events for $1<E_t<6$ GeV, 3382 events for $6<E_t<12$ GeV, and 5289 events for $12<E_t<20$ GeV. The lower threshold global data and the IB trigger data were used for checking data against already known results.

The laboratory momentum of particles increases on the average as their polar angle decreases. Since momentum measurement error increases with momentum and the magnetic field was low in this experiment, forward tracks with small polar angle can have large momentum uncertainty and perhaps even be uncertain in charge. Events affected by this problem were removed by a cut at 500 GeV on a laboratory energy sum formed of the calorimeter energy and of the energy of all detected charged tracks inside the central hole of the calorimeter (see Fig. 1). This cut removed 16% of events with E_t below 4 GeV, and 10% of events with E_t above 14 GeV, and was linearly dependent on E_t. We have not corrected the data for the effects of this cut since the correction is model dependent. We have however simulated[9,10] the effect of the cut and find that, for all E_t, the main change is to reduce multiplicity in a forward laboratory cone of 5 mrad. by about 20%. The losses are less than 5% outside this cone. We have also checked that results are not sensitive to variation in the value of 500 GeV chosen for the cut.

For a check on the data, Fig. 2 show the charged multiplicity distribution observed in the polar angle range corresponding to c.m photon angles of 0^0 through 90^0 from the interacting beam trigger. Besides the removal of events by the energy sum cut discussed above, a further cut of events with E_t below 1 GeV was applied; this removed those events which had low reconstruction efficiency in primary vertex finding owing to the lack of wide angle tracks. Also shown in Fig. 2 are distributions obtained from a low p_t Monte Carlo (ISAJET-MINBIAS[11]) after application of the same two cuts along with a correction for a 7% average probability of secondary scattering of produced particles in material following the primary vertex. Reasonable agreement between the data and the MINBIAS simulation in Fig. 2 indicates that systematic errors in multiplicity measurement are sufficiently understood.

Fig. 3(a) shows the dependence on E_t of the average charged multiplicity in the forward hemisphere defined by a photon c.m. angle of 90°. The same cuts were applied as for the previous figure. For comparison, the average E_t in the data of the previous figure was 3.5 GeV. Also shown in Fig 3(a) is the average charged multiplicity in a forward cone limited by a c.m. angle of 45°. At large E_t, we observed on the average 10 charged particles in the forward hemisphere and 4 in the 45° cone.

Shown in Fig. 3(b) is the average net charge $\langle Q(90)\rangle$ in the forward hemisphere as a function of E_t, where Q is (positive - negative) partial multiplicity for an event. Since pp collisions are symmetric about $\theta_{c.m.} =$ 90° on the average, and the net charge is +2, then $\langle Q(90)\rangle$ in the forward hemisphere should be +1. The use of this expectation as another check on the data is discussed following. The secondary particle scattering and event cuts discussed previously reduce $\langle Q(90)\rangle$ by about 7%. In addition, since particle masses were unknown, the forward hemisphere selection was done using the laboratory angle of photons at 90° in the c.m. Leakage of backward hemisphere particles into the measurement of $\langle Q(90)\rangle$ therefore occurs, and comes mostly from particles that have momentum small compared to their mass in the c.m. frame. Because of their larger mass, protons have a larger phase space than pions to contribute to leakage. However, no data exists at high E_t on the proton cross-section in this region so we have used ISAJET and the LPS model[12] to estimate the leakage. We find that the leakage (mostly protons) causes an increase in $\langle Q(90)\rangle$ of 0.1 charges at E_t=5 GeV, rising linearly to 0.2 charges at E_t=20 GeV, with an uncertainty caused by the lack of data to anchor the model of 0.1 charges. The prediction of ISAJET for $\langle Q(90)\rangle$, after applying the full simulation of apparatus and analysis cuts discussed earlier, appears as the solid curve in Fig. 3(b). The resulting curve is still close to constant value of +1 and we take the deviations between data and simulation curve for <Q(90)> as an estimate of the track finding efficiency and wrong assignment of track charge.

The average net charge in the forward cone of c.m. angle 45°, <Q(45)>, is shown in the same Fig. 3(b). At low E_t, this cone takes almost all of the net charge of the hemisphere but at high E_t>15 GeV it takes less than 35%. Most of the incoming proton positive charge is scattered out of the 45° cone in collisions with large E_t.

The distribution of net charge about the forward direction is studied in more detail in Fig. 4, which shows the laboratory polar angle distribution of the net charge for several E_t slices. Hadron collisions with low E_t are known to show a leading particle effect[13] and its resultant forward flow of positive charge can clearly be seen in the narrow forward cone of 5 mrad. The forward peak of charge flow quickly spreads out, however, as E_t increases, and has disappeared by about E_t of 8 GeV.

Some spreading of a forward peak can be expected by kinematics and energy/momentum conservation. As E_t (measured in the calorimeter, i.e. in the 45° to 125° c.m. range) increases, less energy is available to go forward, so that spectator fragmentation with a fixed transverse component in momentum can be expected to occupy larger polar angle cones. The ISAJET curves, although not expected[10] to fit the data at high E_t, are shown in order to see these kinematic effects in a model with a known leading particle component and fixed transverse momentum fragmentation. In contrast to the data, ISAJET's forward peak only gradually spreads out, never completely disappearing. The same conclusion is obtained by studying the difference between forward flows of energy of positive and negative particles[9].

Results presented here so far have been for events which do not exhibit clear pairs of back-to-back transverse jets. Experiments at energies below about $\sqrt{s}$ = 60 GeV[8,14] have depended on the strong selection of events to obtain agreement with hard scattering models such as ISAJET. A variable frequently used to characterize the "jettiness" of events is the planarity variable[15]. Thus, to compare the forward charge distributions to a hard scattering model such as ISAJET, and to study how the selection of events influences the forward charge distributions, we show in Fig. 5 the charge contained in three forward cones as a function of E_t for 3 slices in planarity. The average planarity in global triggers[8] was 0.42. For E_t above 8 GeV, the higher ranges of planarity show no dramatic restoration of the forward flow of charge as seen below 8 GeV, although on the average, the forward charge flow is larger for higher planarity. Predictions of ISAJET are also shown in Fig. 5; the data at higher planarity show less forward charge than is predicted by the model.

Thus we find that, for pp events of high E_t, the incoming proton charge is scattered over a large range of polar angle. Well-established models of jet fragmentation[1] have local compensation of charge, except in the leading hadron region; the charge of this region is influenced by the parton forming the jet. Thus, for the low planarity data, a plausible assumption to interpret the wide angle scattering of the proton charge is that more constituents are involved in a collision[5] than the single pair of the hard scattering model.

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References

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10. The simulation was done using model ISAJET(reference 11). At low E_t, the MINBIAS mechanism of ISAJET represents acceptably well general features of events such as multiplicity distribution and Feynman-x inclusive cross-sections. At large total E_t, however, the TWOJET hard scattering component does not fit data obtained with the global trigger (see reference 9). We use ISAJET, however, to study effects of cuts, acceptances, etc., because it shows us a worst case scenario at high E_t in the forward direction.

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15. For the definition of planarity see C. De Marzo et al, Phys. Lett. 112B,173 (1982). Events with most transverse energy concentrated into two opposite and small regions of azimuth angle have planarity near 1.0. Events with an isotropic azimuthal distribution of transverse energy have planarity near 0.4 for our multiplicities. Planarity is calculated in this data from the calorimeter energy deposits.

Figure Captions

Fig.1 View of calorimeter face along the beam direction. Cones of various c.m. polar angles, and equivalent laboratory angles, that were used in the analysis are shown superimposed. The calorimeter division into 126 towers is not shown.

Fig.2 Distribution of charged multiplicity measured in a forward cone that corresponds to 90° c.m. for photons. The data is for the interacting beam trigger. Cuts are discussed in the text. The curve shows the simulation of events by a low p_t Monte Carlo (ISAJET-MINBIAS)

Fig.3 (a) Average charged multiplicity $\langle N_{ch} \rangle$ in 2 cones as a function of E_t. The cones are for laboratory angles corresponding to photon angles of 90° and 45° in the c.m. Cuts are discussed in the text.

(b) Net charge <Q> in the same two cones. Net charge is the difference between positive and negative particle multiplicities in a cone. The curve indicates the expected value of net charge for the 90° cone for the model of ISAJET after experimental effects were taken into account.

Fig.4 Polar angle distribution of net charge <Q> for various slices of E_t. The energy sum cut has been applied. The curves show the simulation of events by ISAJET. For E_t above about 6 GeV, the ISAJET curves are known not to fit the data, but are used to show expected kinematic effects in the spread of the forward charge.

Fig.5 Effects of planarity on the forward net charge <Q> in 3 cones: (a) 8.5° c.m., (b) 22.5° c.m., (c) 45° c.m. Three slices of planarity were selected for each cone and the forward charge <Q> is shown as a function of E_t for each. The curve shows the prediction of ISAJET.

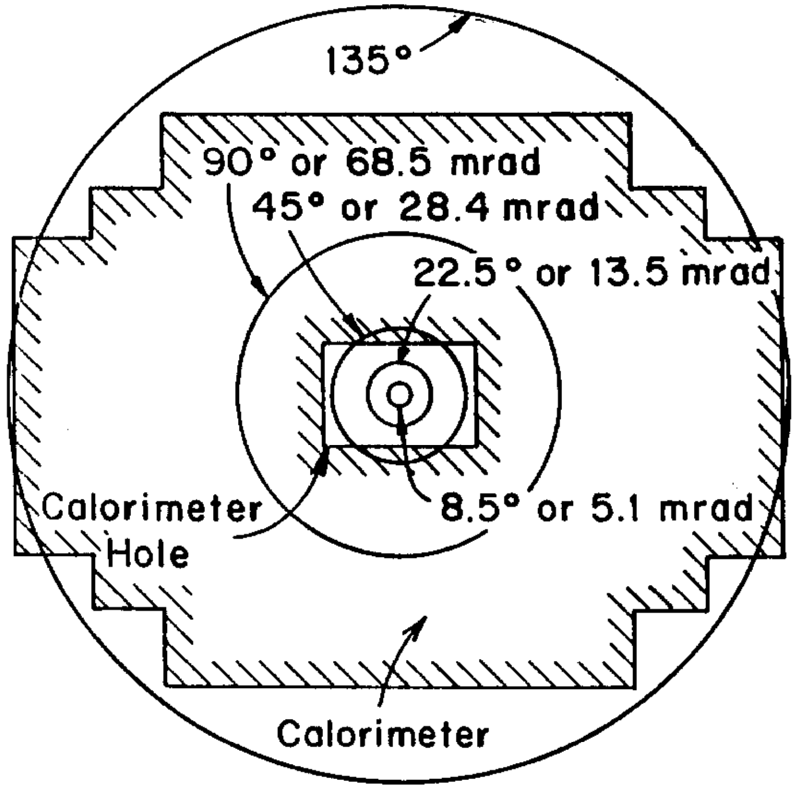
135°
90° or 68.5 mrad
45° or 28.4 mrad
22.5° or 13.5 mrad
8.5° or 5.1 mrad
Calorimeter
Hole
Calorimeter

Fig. 1

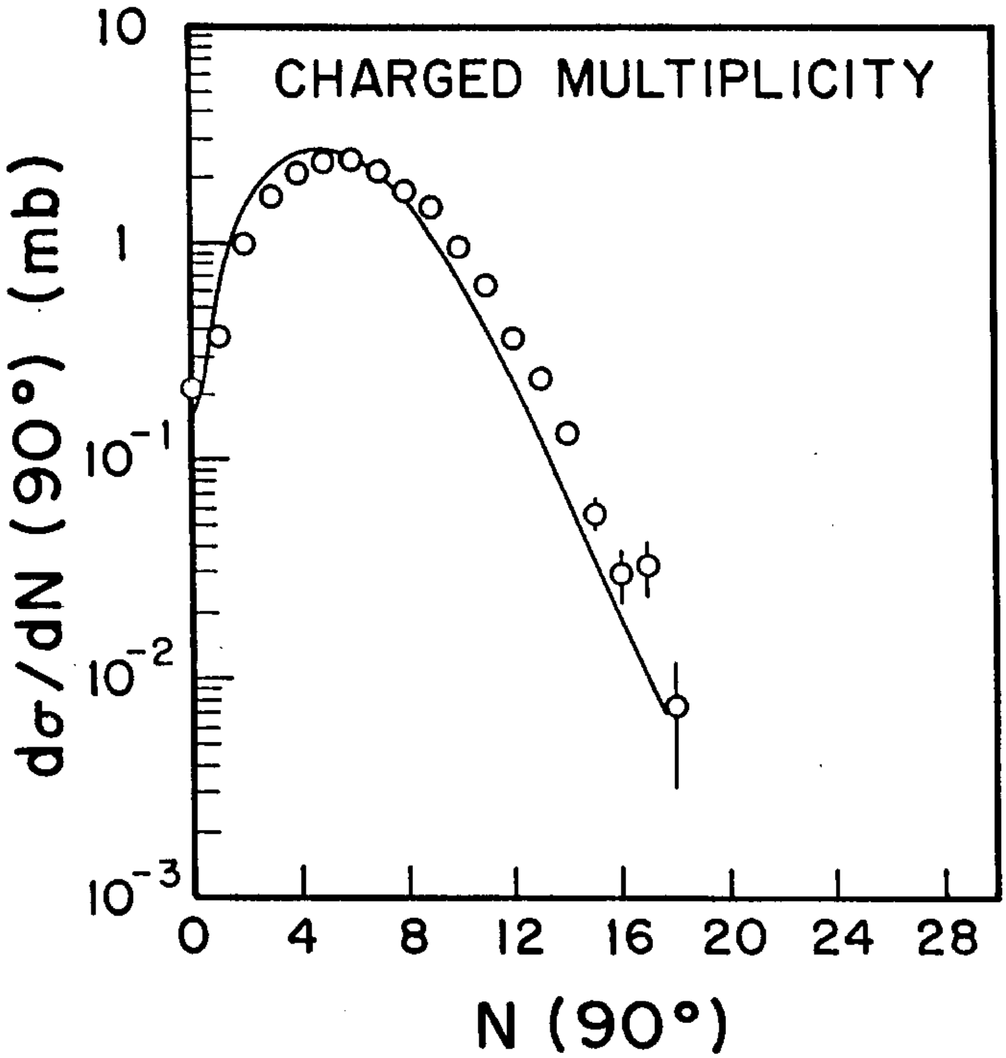
CHARGED MULTIPLICITY
dσ/dN (90°) (mb)
10
1
10⁻¹
10⁻²
10⁻³
0 4 8 12 16 20 24 28
N (90°)

Fig. 2

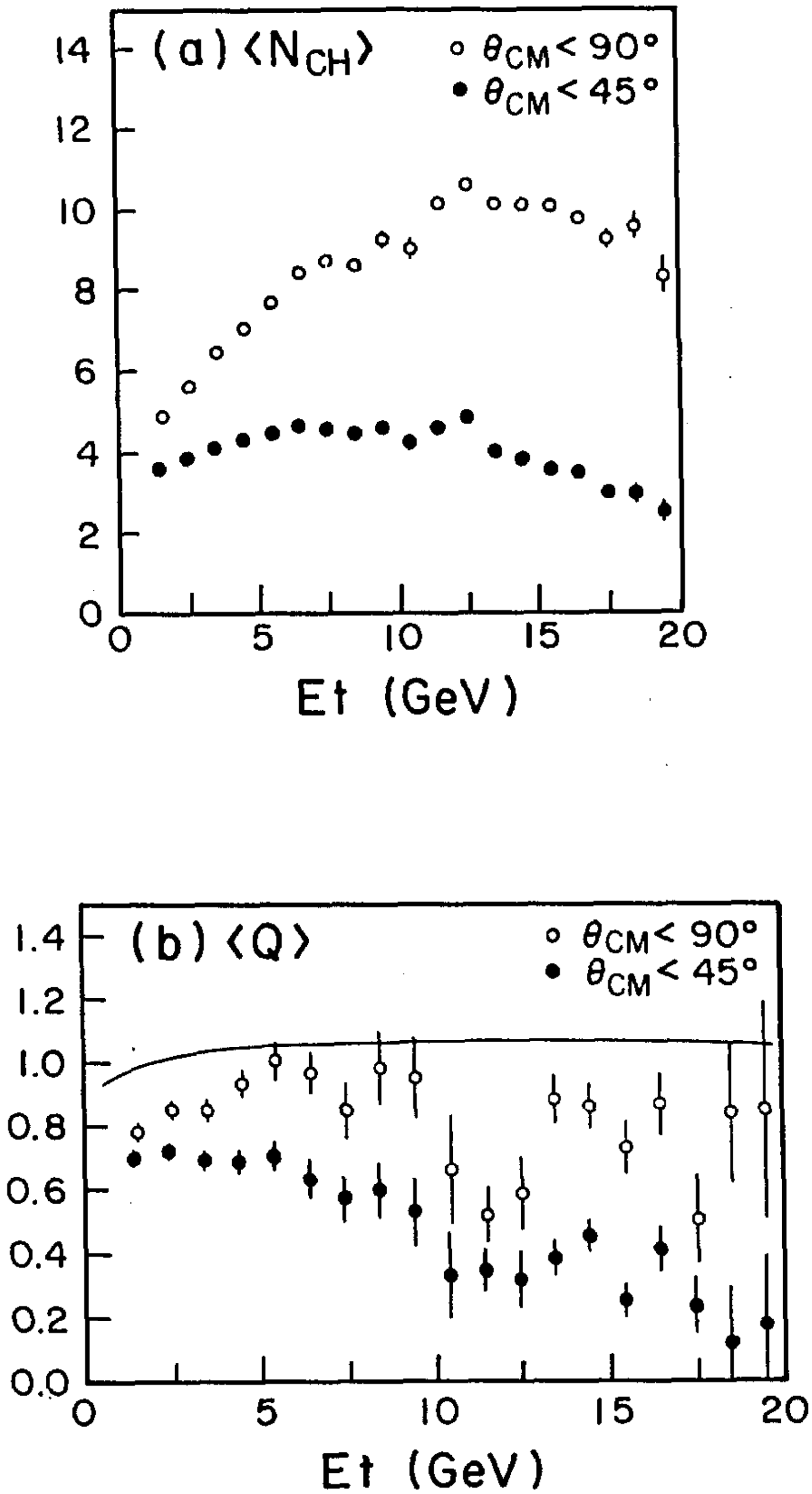
(a) ⟨N_CH⟩
○ θ_CM < 90°
● θ_CM < 45°
0 2 4 6 8 10 12 14
0 5 10 15 20
Et (GeV)
(b) ⟨Q⟩
○ θ_CM < 90°
● θ_CM < 45°
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
0 5 10 15 20
Et (GeV)

Fig. 3

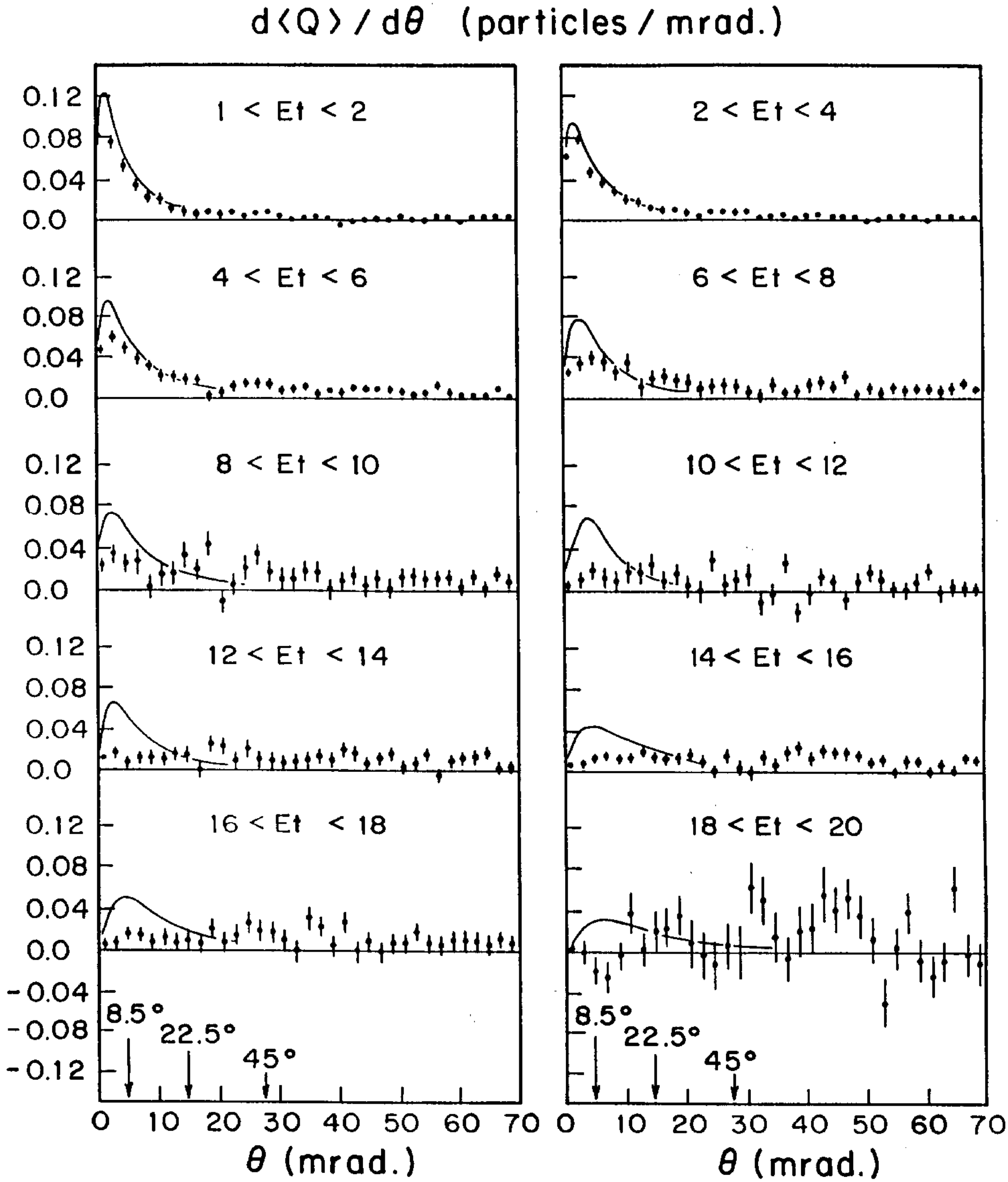
d⟨Q⟩ / dθ (particles / mrad.)
1 < Et < 2
2 < Et < 4
4 < Et < 6
6 < Et < 8
8 < Et < 10
10 < Et < 12
12 < Et < 14
14 < Et < 16
16 < Et < 18
18 < Et < 20
0.12
0.08
0.04
0.0
-0.04
-0.08
-0.12
8.5°
22.5°
45°
0 10 20 30 40 50 60 70
θ (mrad.)

Fig. 4

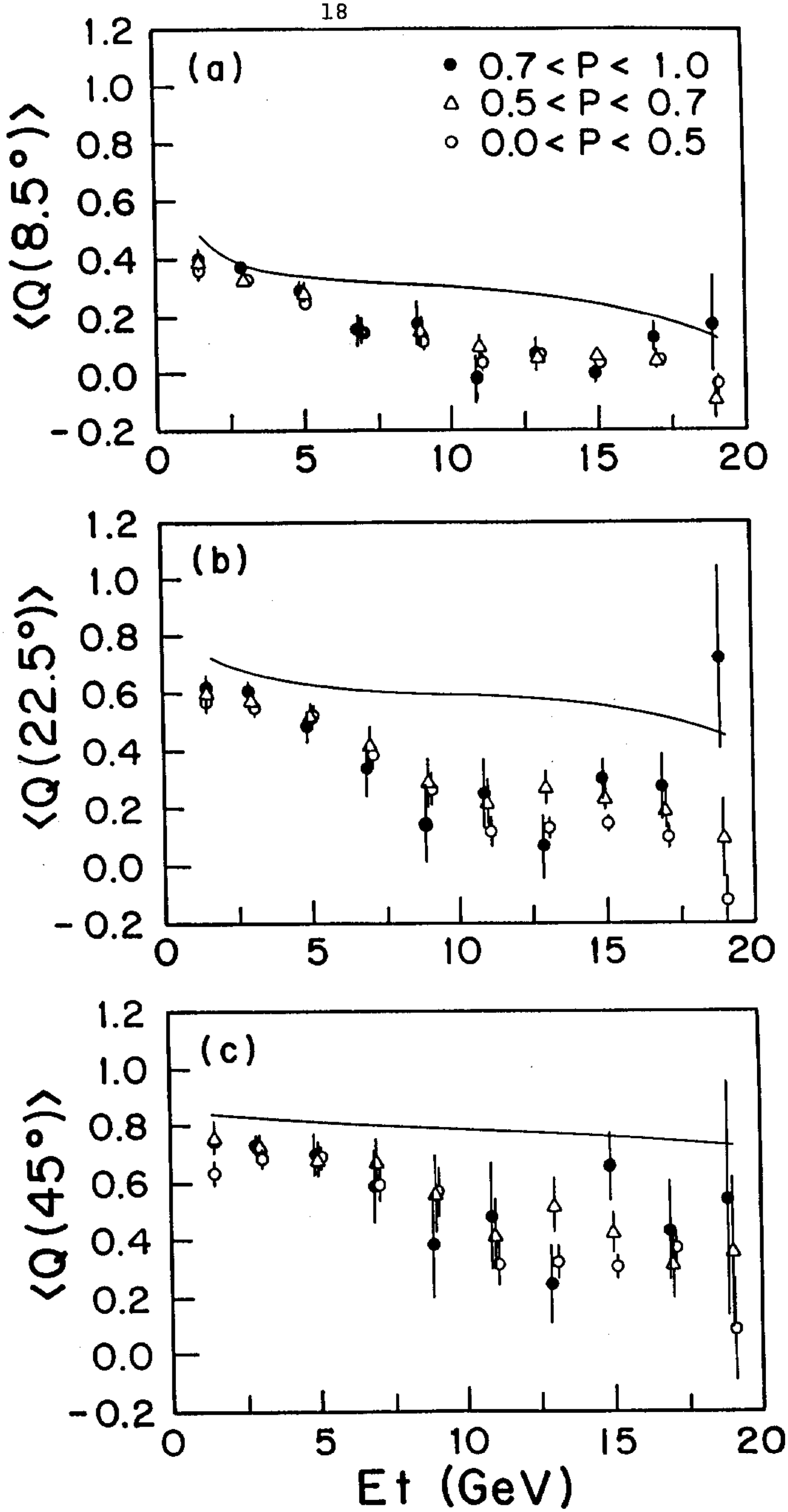
(a)
● 0.7 < P < 1.0
△ 0.5 < P < 0.7
○ 0.0 < P < 0.5
⟨Q(8.5°)⟩
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
5
10
15
20
(b)
⟨Q(22.5°)⟩
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
5
10
15
20
(c)
⟨Q(45°)⟩
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
5
10
15
20
Et (GeV)

Fig. 5