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A MEASUREMENT OF THE TRANSVERSE MOMENTA OF PARTONS AND OF JET FRAGMENTATION AS A FUNCTION OF $\sqrt{s}$ IN p-p COLLISIONS

(CCOR Collaboration)

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ABSTRACT

A large solid-angle apparatus consisting of a superconducting solenoid magnet, cylindrical drift chambers and two arrays of lead-glass counters was used to examine particles associated with a high transverse momentum trigger in p-p collisions with three $\sqrt{s}$ values at the CERN ISR.

The trigger was given by energy deposition in lead-glass arrays centered at 90°. The trigger transverse momentum range covered was $3 < p_{Ttrig} < 11$ GeV/c. Results are given for p_{out} for both individual charged particles, and also for the sum of charged particle momenta in the hemisphere opposite to the trigger. Mean values are then deduced for the parton transverse momentum k_T, and for the jet fragmentation momentum j_T. Results of a jet analysis are also presented.

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ABSTRACT

A large solid-angle apparatus consisting of a superconducting solenoid magnet, cylindrical drift chambers and two arrays of lead-glass counters was used to examine particles associated with a high transverse momentum trigger in p-p collisions with three $\sqrt{s}$ values at the CERN ISR.

The trigger was given by energy deposition in lead-glass arrays centered at 90°. The trigger transverse momentum range covered was $3 < p_{Ttrig} < 11$ GeV/c. Results are given for p_{out} for both individual charged particles, and also for the sum of charged particle momenta in the hemisphere opposite to the trigger. Mean values are then deduced for the parton transverse momentum k_T, and for the jet fragmentation momentum j_T. Results of a jet analysis are also presented.

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The CCOR Collaboration is engaged in a general study of high transverse momentum processes arising from p-p collisions at the CERN Intersecting Storage Rings (ISR)$^{1-4}$. This contribution reports a study of the particles on the opposite side to that of a high-momentum trigger particle. This is the first experiment capable of momentum-analysis of charged particles over the full azimuth. Thus the measurement of particle momenta out of the trigger plane p_{out} does not need acceptance corrections and jet analysis is simplified.

The apparatus consists of two arrays of lead-glass Cerenkov counters to provide a high-energy trigger^5, and an inner detector to momentum-analyse charged particles^6. The lead glass gives a transverse momentum measurement with an r.m.s. resolution of $\Delta p/p = \Delta E/E = 0.004 + 0.043/\sqrt{E}$ (E in GeV) for each counter, a 5% r.m.s. counter-to-counter variation, and a systematic scale uncertainty of 5%. The energy deposited is located in azimuth with an r.m.s. uncertainty of

$\Delta\phi = 20$ mrad. The track-finding efficiency is estimated to be 75 ± 10%, and the spatial resolution is 350 μm. This together with the number of measurements and multiple Coulomb scattering gives an r.m.s. momentum resolution $\Delta p_T/p_T = \sqrt{(0.07\ p^2) + 0.02^2}$ (p_T in GeV/c). The r.m.s. azimuthal resolution for tracks is $\Delta\phi = 10$ mrad.

Data have been taken with the ISR operating at $\sqrt{s} = 62$, 45, and 31 GeV, and at luminosities of up to 4×10^{31} cm^{-2} s^{-1}. The data were divided into nine different sets according to their $p_{T\ trig}$ and $\sqrt{s}$ values, where $p_{T\ trig}$ is the transverse momentum of the trigger particle calculated in the p-p centre-of-mass system.

Tracks were reconstructed and vertices fitted for all events. The two lead-glass arrays were denoted 'inside' and 'outside'. Each charged particle was required to have $p_T > 300$ MeV/c. Those in the hemisphere opposite to the outside array were required to have $|\eta| < 0.7$, and those in the hemisphere opposite to the inside array were required to have $|\eta| < 0.9$. These cuts ensured a uniform ϕ acceptance for the charged particles within each hemisphere. An estimate of some of the possible systematic errors involved was made by a comparison of the results of the two sides. The results agreed within the errors quoted.

For each charged track, p_{out} is the component of momentum out of the plane formed by the two beams and the trigger particle, and $x_E = -\vec{p}_{T\ track} \cdot \vec{p}_{T\ trig}/|p_{T\ trig}|^2$. Corrections were applied to $\langle|p_{out}|\rangle^2$ for charged particle momentum resolution and ϕ_{trig} resolution. These corrections, which are bigger at higher x_E^2, always decrease the value of $\langle|p_{out}|\rangle^2$, but are always less than 20%.

In parton models, finite values of p_{out} are believed to be produced by two effects: the transverse momentum (k_T) of the partons that enter the hard scattering process, and the transverse momentum relative to the jet axis (j_T) given to a particle during the fragmentation of its parent parton after scattering. In this picture the parameters of the model may be obtained from the approximate relationship[7]:

$$\langle|p_{out}|\rangle^2 \simeq 2\,\langle|k_{Ty}|\rangle^2\ x_E^2 + \langle|j_{Ty}|\rangle^2\ (1 + x_E^2)\ , \qquad (1)$$

where $\langle|k_{Ty}|\rangle$ and $\langle|j_{Ty}|\rangle$ are the average values of the components of k_T and j_T out of the scattering plane. The data do not satisfy Eq. (1) for the complete range of x_E^2. At low x_E^2 a departure from linearity is expected because j_{Ty} is kinematically constrained to be small when track momenta are small. If only those points are used which correspond to $p_{T\ track} > 1.4$ GeV/c, for which the kinematic constraint is small, reasonable χ^2/d.o.f. may be obtained for straight-line fits. Even in this region, the model's assumption that x_E is equivalent to the jet fragmentation variable z can influence the numerical results of $\langle|k_{Ty}|\rangle$. However, the trends in the data should not be sensitive to any errors introduced by this assumption.

Figure 1 shows $\langle|j_{Ty}|\rangle$ as a function of $p_{T\ trig}$ (Fig. 1a) and $\sqrt{s}$ (Fig. 1b). For Fig. 1a, $\langle|j_{Ty}|\rangle$ was constrained to be the same value for all $\sqrt{s}$ values, but was allowed to vary with $p_{T\ trig}$. There is no apparent variation of $<|j_{Ty}|>$ with $p_{T\,trig}$. Similarly, for Fig. 1b $<|j_{Ty}|>$ was constrained to be the same for all $p_{T\,trig}$ values but was allowed to vary with $\sqrt{s}$. There is no indication that $<|j_{Ty}|>$ is a function of $\sqrt{s}$. Thus it is reasonable to constrain $<|j_{Ty}|>$ to one value for all nine data samples, and fit for $<|k_{Ty}|>$ and $<|j_{Ty}|>$. This yields a χ^2 of 62 for 50 degrees of freedom, and the $<|j_{Ty}|>$ found is 0.393 ± 0.007 GeV/c. The values of $<|k_{Ty}|>$ (Fig. 2a) show an increase with both $p_{T\,trig}$ and $\sqrt{s}$, rising to $<|k_{Ty}|> \sim 0.8$ GeV/c at the highest $\sqrt{s}$ and $p_{T\,trig}$.

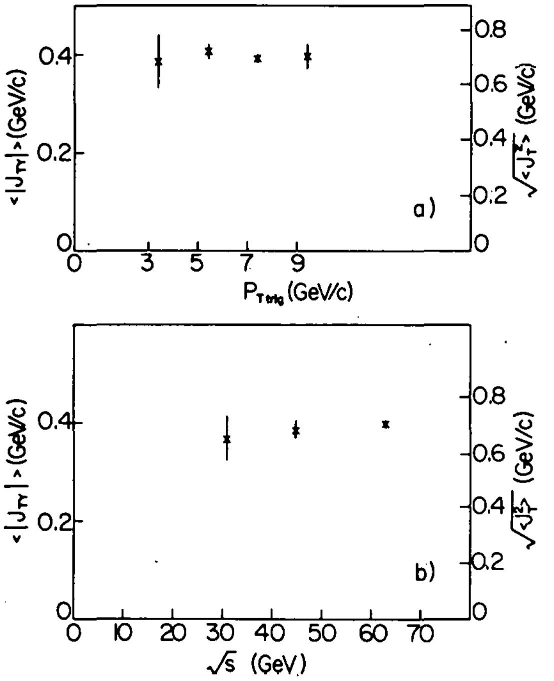

Fig. 1

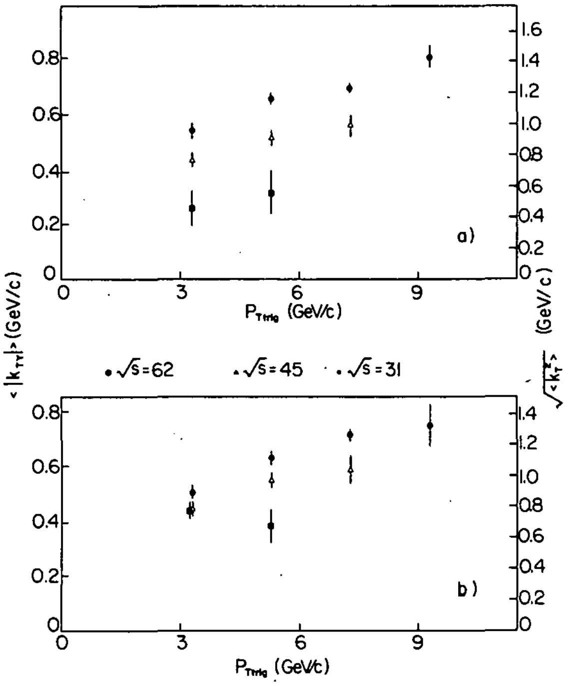

Fig. 2

Fig. 1 $\langle|j_{Ty}|\rangle$ and $\sqrt{\langle j_T^2\rangle}$ as a function of $p_{T\,trig}$ (a) and $\sqrt{s}$ (b).

Fig. 2 $\langle|k_{Ty}|\rangle$ and $\sqrt{\langle k_T^2\rangle}$ as a function of $p_{T\,trig}$ for three different $\sqrt{s}$ values obtained from single-particle (a) and multiple-particle (b) correlations.

From the vector sum of the away-side charged particles another measurement of $<|k_{Ty}|>$ may be obtained, which has different systematic uncertainties but requires no extra physics assumptions. If one selects events where the sum of the charged particle transverse momenta in the hemisphere opposite to the trigger balances the trigger transverse momentum, i.e., $\Sigma x_E \sim 1$, then the same model predicts

$$\langle|\Sigma p_{out}|\rangle = \sqrt{2\,\langle|k_{Ty}|\rangle^2 + \langle|j_{Ty}|\rangle^2}\;. \tag{2}$$

Using the value of $<|j_{Ty}|>$ found above, $<|k_{Ty}|>$ may be determined. The model does not require corrections for 'jet' containment or track efficiency. In addition, corrections to $<|\Sigma p_{out}|>$ due to momentum resolution and ϕ_{trig} resolution were found to be negligible. Events were selected with $0.9 < \Sigma x_E < 1.1$, and a small correction was applied to allow for the fact that Σx_E in this region is not exactly 1. The results for $\langle|k_{Ty}|\rangle$ thus obtained are shown in Fig. 2b.

These values are equal, within statistical errors, to the values obtained from single particles, with the exception of the $\sqrt{s}$ = 31 GeV, $p_{T\,trig}$ = 3 GeV/c point, which is higher. It is thought that formula (1) is least reliable when $k_{Ty} \sim j_{Ty}$, and thus the low threshold values in Fig. 2a have large systematic errors.

It should be noted that $\langle|k_{Ty}|\rangle$ is the average value of the component out of the scattering plane of a parton's transverse momentum. If one assumes a Gaussian distribution in k_{Ty}, then $\sqrt{\langle k_{Ty}^2\rangle} = \langle|k_{Ty}|\rangle \times \sqrt{\pi/2}$. If one assumes, in addition, that the two components of k_T are equal, $\sqrt{\langle k_T^2\rangle} = \sqrt{\langle k_{Ty}^2\rangle} \times \sqrt{2}$, and these values can be read using the right-hand scale of Fig. 2. Similarly high values of k_T have previously been reported at the ISR[2,8,9]. A calorimeter experiment[10] has measured k_T in the scattering plane as a function of $p_{T\,trig}$ and $\sqrt{s}$, and found the same trends as this experiment.

The value of $\langle|j_{Ty}|\rangle$, of 0.393 ± 0.007 GeV/c, gives $\sqrt{\langle j_{Ty}^2\rangle}$ of 0.493 ± 0.009 GeV/c assuming a Gaussian, and $\sqrt{\langle j_T^2\rangle}$ of 0.697 ± 0.013 GeV/c taking the two components to be equal[2]. This value refers only to fragments with $p_T > 1.4$ GeV/c and should not be directly compared with results obtained by integrating over all jet fragments. It is in reasonable agreement with the value obtained by another ISR group (0.62 ± 0.06 GeV/c)[9], but somewhat higher than results for e^+e^- data ($\sim$0.55 GeV/c)[11] obtained including only high-momentum hadrons. It should be stressed that the error quoted is statistical only.

A study has been made of the charged and neutral particles produced in events taken at $\sqrt{s}$ = 62.4 GeV with $P_{TRIG} > 7.0$ GeV/c. For each event, the vector sum $\vec{P}_s = \Sigma\, j_i$ is formed for all observed charged and neutral particles in the hemicylinder opposite to the π° trigger and $\vec{P}_J = \Sigma\, \vec{j}_i$ for those on the trigger side. The subsample of events selected for further analysis are those for which $\vec{P}_s$ and $\vec{P}_J$ fall within a fiducial range $|y| < 0.4$ and $|\Delta\phi| < 0.4$ rad, where $\Delta\phi$ is the deviation from the horizontal axis of the detector. Since charged particles are observed for $|y| < 0.7$ for all ϕ and neutrals within $|\overline{y}| < 0.6$ and $|\overline{\Delta\phi}| < 0.5$, approximately 93% of the momentum of the away-side and 97% of the trigger-side 'jets' is contained within the apparatus for the selected events. A correction for this loss and for charged-track inefficiency are made as appropriate.

If it is assumed that the vectors $\vec{P}_J$ and $\vec{P}_s$ represent the outgoing momenta of two quarks (gluons) which have scattered elastically, we may transform to the c.o.m. system of the colliding constituents. In that c.o.m. system (see Fig. 3), the magnitude of the equal and opposite momenta are designated as Q, at angles θ^* and ϕ^*. From this analysis, two results are given in this report.

First, for the particles which form the away-side 'jet' described by the vector $\vec{P}_s$, we have studied the distribution of the component of their momentum, $j_\perp$, transverse to the axis defined by $\vec{P}_s$ as a function of Q, the c.o.m. momentum of the scattered constituent. The observed values of $j_\perp$ at each Q are fitted by Gaussian distributions characterized by an r.m.s. width. However, it should be noted that approximately 5% of the observed particles fall in a "tail" at large $j_\perp$ which is not well described by the Gaussian fit. These particles could be due to experimental backgrounds or, possibly, to fragmentation of a radiated gluon. The results for $<j_\perp^2>^{\frac{1}{2}}$ are shown in Fig. 4 together with data from SLAC and PETRA . Since our data is an average value over particle momenta above 0.4 GeV, while those from PETRA include particles down to lower momenta, it is to be expected that the PETRA values should be somewhat lower due to the well-known "sea-gull" effect[14].

Second, we have studied the distribution of the momentum component $k_\perp$ which is required to transform from the p-p system to the c.o.m. of the colliding constituents. This component is perpendicular to the plane formed by the beam axis and the scattered constituents (see Fig. 3). In QCD models, $k_\perp$ can arise from "intrinsic" momenta of the constituents from non-perturbative binding effects and from radiation of gluons whose fragmenting particles are not observed in our apparatus. At each Q, the values of $k_\perp$ are adequately fitted by Gaussian distributions characterized by an r.m.s. value $\sigma_\perp$. They are displayed in Fig. 5. The observed values of $\sigma_\perp$ as a function of Q are adequately fit by a linear form $\sigma_\perp = (0.075 \pm 0.013)\ Q + (0.55 \pm 0.12)$. The large and Q dependent values, which are not expected from "intrinsic" effects, imply that the QCD radiative corrections due to gluon emission must be very important at these large momentum transfers.

The values of $\sigma_\perp$ deduced from the jet-jet analysis may be compared to those derived from the single particle correlation data of Fig. 2. To do so, we must make use of the approximate relation, derived from our data, that $Q \cong 0.79\ P_{TRIG}$. The results are shown in Fig. 6. The agreement between the two methods is entirely adequate when systematic uncertainties are taken into account.

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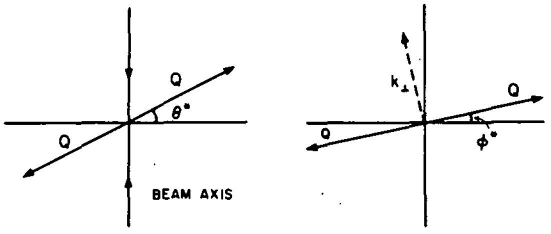
14. For a discussion of this effect see, for example, Ref. 2.



HORIZONTAL PLANE TRANSVERSE PLANE

FIG. 3

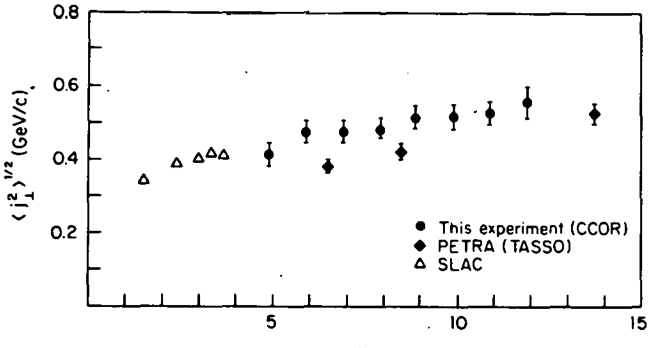


FIG. 4 - $\langle j_\perp^2 \rangle^{\frac{1}{2}}$ of jet fragmentation vs. Q.

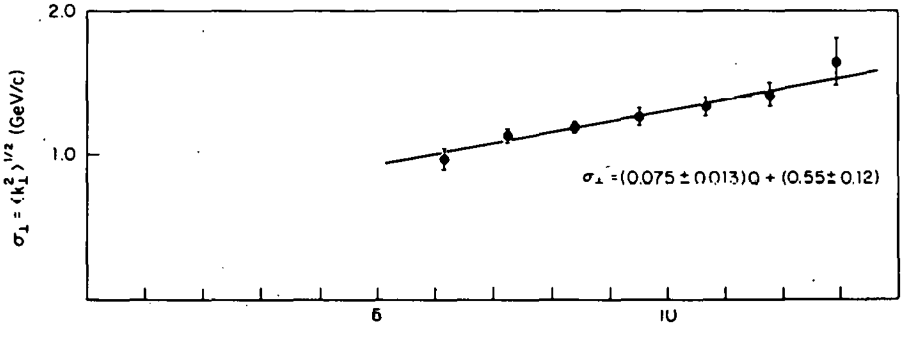


FIG. 5 - $\langle k_\perp^2 \rangle^{\frac{1}{2}}$ of "apparent" constituent momentum vs. Q.

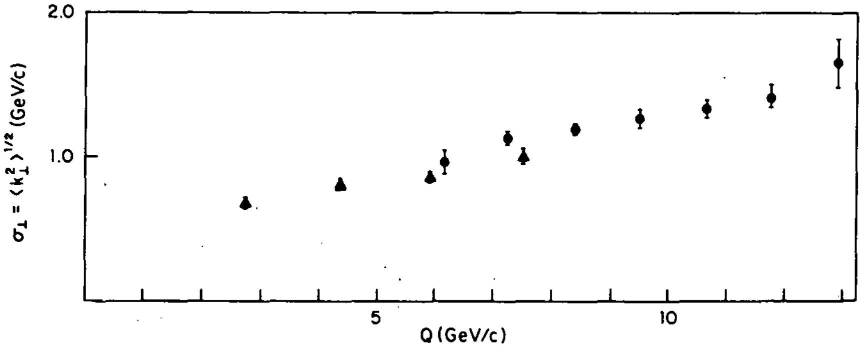


FIG. 6 - $\langle k_\perp^2 \rangle^{\frac{1}{2}}$ vs. Q; ● from dijet analysis, ▲ from $\langle p_{out} \rangle$ measurement.