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EVIDENCE FOR TWO BACK-TO-BACK HIGH- p_T JETS IN K^+p INTERACTIONS AT 70 GeV/c

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ABSTRACT

Results are reported on a study of events with high- p_T in K^+p collisions at centre of mass energy of 11.5 GeV/c. Interesting similarities with ISR results are observed both in charge and rapidity correlations among particles with a $p_T > 1$ GeV/c trigger. Properties of high- p_T jet fragmentation are found to be similar to the ones observed at the ISR and in e^+e^- annihilation.

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1. INTRODUCTION

In a previous analysis of K^+p interactions at 70 GeV/c [1] we have argued that low- p_T jets show striking similarities when compared to jets arising from e^+e^- annihilations and $\nu(\bar{\nu})N$ interactions. Furthermore, in the field of high- p_T jets, comparisons of data from different interactions have consistently indicated that a common description, based on Quark Parton Model (QPM), seems to work, even if a detailed quantitative analysis of the QPM parameters is still missing [2].

The experimental results available today [3-5] indicate that, as the centre of mass energy of two interacting hadrons increases, the data are not well reproduced by models describing either low- p_T or hard scattering, indicating the emergence of new phenomena (large cross sections for high- p_T multiparticle systems, high multiplicities, etc.) in the transition region between low- p_T and ISR energies. Furthermore, ISR data [6] have demonstrated that a number of jet parameters are smoothly changing as p_T grows in the range 1-5 GeV. Finally, in pp interactions, at relatively low centre of mass energy ($\sqrt{s} = 11.5$ GeV) [7], charged particle cross sections measured in the interval $0.48 \text{ GeV}/c \leq p_T \leq 2.21 \text{ GeV}/c$ have appeared to be in qualitative agreement with the QPM predictions.

It thus looks appealing to investigate whether there are indications of constituent hard-scattering in our K^+p experiment at $\sqrt{s} = 11.5$ GeV. The importance of such a work is also based upon the fact that there does not exist a detailed analysis of high- p_T event structure in the energy range of our experiment.

This paper is organized as follows: Sect. 2 contains the experimental procedure used to select high- p_T jet events. In sect. 3 we study charge correlations among high- p_T particles contained either in the same or in opposite hemispheres. Rapidity correlations are searched for in sect. 4. The fragmentation properties of our high- p_T jets are compared to those of jets observed at ISR and in e^+e^- annihilation in sect. 5. Finally, sect. 6 contains our main conclusions.

2. EXPERIMENTAL PROCEDURE

The data come from an exposure of the CERN BEBC bubble chamber, filled with hydrogen, to an r.f. separated K^+ beam of 70 GeV/c nominal momentum. Details of the experiment have already been published [8].

The measurements, made either on automatic or on semi-automatic devices, were processed through the HYDRA geometry.

The present analysis is based on a sample of approximately 39,000 complete, well measured, events having at least six charged outgoing tracks extracted from a total of approximately 95000 events. Events having any track $\Delta p/p > 25\%$ were rejected; on the average we have a mean momentum error on the tracks $\langle \Delta p/p \rangle \approx 2\%$. The average transverse momentum for our selected sample amounts to $\langle p_T \rangle \approx .35$ GeV/c; however, a sizeable fraction of events (5960 events) contains at least one particle with $p_T \geq 1$ GeV/c.

To investigate the features of high- p_T jet configurations, we have introduced the selection criteria summarized in table 1.

Although these criteria are inspired by previous analysis of ISR data and quite similar to those used in other experiments, table 1 needs some explanation. The towards-side is defined by the trigger particle, namely the particle having the largest transverse momentum, while the region opposite to is referred to as the AWAY-side.

An event is accepted for the analysis if p_T^{trig} and the transverse momentum of the away-trigger, namely the particle with the highest p_T in the away side (hereafter referred to as $p_T^{\text{aw.trig}}$), are both above the threshold values p_T^0 and p_T^1 respectively. For sake of simplicity, we have chosen $p_T^1 = p_T^0/2$ [table 1(a,b)]. The trigger particle has to be rather central in the CMS [table 1(c)], while the trigger and the away-trigger must be roughly back-to-back [table 1(e)]. Both these particles will be called "jet leaders". To associate particles with their respective leaders in both jets, we do not impose any cuts on their transverse momentum, but just require them to be away from the forward/backward fragments of the beam/target dissociation (table 1(d)). However, we use cones of different opening angles in the towards-side and in the AWAY-side around the triggers

to collect particles in a jet [table 1(f,g)]; in fact, because of the different thresholds mentioned above, the momentum of the towards-trigger represents a good approximation of the towards-jet momentum, while this is not the case for the away-trigger. For this reason, we use a larger cone around the leader to collect particles into the AWAY-side jet.

Finally, we require an approximate balance of the transverse momentum between the two jets [table 1(h,i)].

It is worth stressing that, because of our selection criteria, the towards-jet may often consist of only one particle, the trigger particle itself (trigger-bias effect [9]).

The above criteria introduce of course strong kinematical effects into the data. To take into account these effects, we have generated Monte-Carlo events according to the Lund fragmentation model [10], a model which was shown to describe successfully many aspects of inclusive particle production in different types of hadron-hadron interactions [11]. This model, described in detail in ref. [12], takes into account vector and pseudoscalar meson production (in the ratio 1:1) as well as baryon production and diquark fragmentation.

The version of the model used here is almost identical to the published one, with the strange sea suppression factor taken to be 0.27 [13] (instead of the default value 0.3) and with the width of the gaussian sea-quark transverse mass distribution fixed at $\sigma_p = 0.62$ GeV/c (instead of the default value 0.44 GeV/c). This latter modification was necessary as our experimental $d\sigma/dp_T^2$ is better reproduced using this width and since our analysis is based on high- p_T triggers.

3. CHARGE CORRELATIONS AMONG HIGH- p_T PARTICLES

In what follows, two "extreme" models (besides the Lund Monte-Carlo) will be used to compare our data on charge correlations. First, we will use the Field and Feynman [14] (FF) predictions which have proved to be an

useful parametrisation to describe many experimental results. Strictly speaking, the FF values have been obtained using a 10 GeV fragmenting quark; however, we may assume that for a fast leading particle L, with $z_{//} > 0.5$, where

$$z_{//} = \frac{\vec{p}_L \cdot \vec{p}_{jet}}{|\vec{p}_{jet}|^2} \quad (1)$$

the FF results do not depend critically on the initial quark momentum. In the FF ansatz, we will furthermore assume that all the quarks contained in the projectile have an equal probability to scatter on the various quarks of the target.

As a second model, we will adopt a simple model based only on charged combinatorics. In this case, we use a pure combinatorial calculation, without any additional dynamical assumption.

Before presenting our detailed results on charge correlations, we want to show that two major directions in CMS, the beam direction and the one transverse to the beam, have different charge properties in the same p_L and p_T bins. Indeed, if particles which are observed at large p_T were only a tail of the usual forward-backward jets, then we would expect to find in the transverse direction the same charge correlations [for example the same ratio $N(+)/N(-)$] as the one found among particles produced along the beam direction.

Fig. 1 shows the ratio $N(+)/N(-)$ calculated in the same longitudinal and transverse momentum intervals and within their respective angular intervals $\theta^i < 45^\circ$ or $\theta^i > 135^\circ$ and $45^\circ > \theta^{trig} > 135^\circ$. To obtain the ratio in the p_T intervals, we have used only trigger particles. One sees that the charge ratio is systematically higher for the trigger particles than for the secondary particles, also for small values of the transverse momentum. This discrepancy is even more pronounced if we compare the data with the predictions of our Lund Monte-Carlo simulation, which are represented by the triangles for the same p_T and p_L intervals as the experimental points.

In fig. 2 we show the ratio $N(+)/N(-)$ of the trigger particles as a function of the transverse momentum of the trigger itself. Our simple charge combinatorial probability (CCP) can only explain the experimental ratio at small values of p_T , while for high- p_T ($p_T > 1$ GeV/c) the charge correlations approach the FF predictions for K^+p interactions. It is interesting to note that a similar behaviour for the ratio π^+/π^- as a function of the $\pi^+(\pi^-)$ transverse momentum approaching the expected value of ~ 1.85 was recently observed at the ISR [15].

Fig. 3 displays $N(+)/N(-)$ for the leading particles in both towards an away jets as a function of p_T^0 , the threshold for accepting an event as high- p_T jet (table 1). We observe again an increase of the charge correlations from the combinatorial value (dashed line) to the FF prediction for K^+p collisions (continuous line) while for both sides the Lund predictions (dashed-dotted lines) are unable to reproduce the data. The same behaviour is seen in fig. 4, which shows the average charge of the leading particle contained in the away-jet as a function of the trigger threshold. Our data support the idea contained in the FF fragmentation model that, the higher the p_T , the better the fastest particle does remember the flavour of the jet-initiating quark. Since in our case we have four positive ($\bar{s}uuu$) and only one negative (d) fragmenting quark, we expect to find an excess of positive to negative particles in the high- p_T region. The dependence on the momentum fraction $z_{//}$ of the ratio of positive and negative fragments contained in the away-jet is shown in fig. 5 and compared to the ISR results [16]. To make a meaningful comparison, we set our trigger threshold to 1 GeV/c (≥ 3 GeV/c of visible transverse momentum for away jets in the ISR data). In both cases, the ratio increases with the momentum fraction, indicating that when we select a leading particle in a jet ($z_{//} > 0.5$) we ought to expect a strong charge correlation, much higher than the one expected on the basis of the Lund prediction.

3.1 Charge correlations between the fastest two particles within a jet

In the FF fragmentation scheme, not only the fastest particle in a jet remembers to some extent the charge of the parent quark, but there is also a charge correlation between the fastest two particles within a jet (the

ordering of particles in a jet is made according to $z_{//}(1) > z_{//}(2) > \dots$. This correlation is inherent to the hierarchy structure in the fragmentation chain, which does not allow to produce two equally charged particles in two successive steps.

To test the possible existence of such a charge correlation, we have used the correlation coefficient R [16], defined as

$$R = (\pm\mp) / [2\sqrt{(++)(--)}] \quad (2)$$

and which measures the correlation between charges of opposite sign.

If there were no correlation, one should expect R to be one only for an infinite charge multiplicity. The purely combinatorial predictions for R as a function of the charge multiplicity are shown in the insert of fig. 6. For our selected sample of events ($\langle n_{ch} \rangle \approx 8.8$) we expect $\langle R \rangle^{comb} \approx 1.33$. In fig. 6 we show the normalized correlation coefficient $\langle R \rangle^{norm} = \langle R \rangle^{exp} / \langle R \rangle^{comb}$ as a function of p_T^0 for the fastest two charged hadrons contained in both the towards and away jets. For particles in the towards-jet we require $z_{//}(1) \geq 0.5$ and $z_{//}(2) \geq 0.2$; for particles in the away-jet we require $z_{//}(1) > 0.1$, $z_{//}(2) > 0.1$. The reason for this difference selection criteria lies in our non-symmetric definition of the towards-and away-jet.

The data indicate that the normalized charge correlation function rises with the trigger threshold, as expected, while the Lund model predicts almost no correlation over the whole range of p_T . However, this growth appears to be more pronounced for the trigger-jet than for the away-jet. To understand this difference, we first note that for $p_T > 1$ GeV/c the charge multiplicity contained in the away-jet is much larger than the one in the towards-jet (in the away-jet, the ratio of number of events with $n_{ch} = 2$ and $n_{ch} \geq 3$ is equal to ≈ 1.5 to be compared with the equivalent ratio of ≈ 4.5 in the towards-jet). This is again due to our jet selection criteria, because the particle with the highest p_T in the event is automatically attributed to the towards-jet. Furthermore, in the away-jet some misassignments between the second and third fastest particles (in the FF-language) are possible, as $\langle z_{//}(2) - z_{//}(3) \rangle$ amounts to 0.13 ± 0.06 only.

To check these indications, we have evaluated the normalized correlation coefficient for events where the away-jet is similar to the towards one (namely restricting the analysis to away-jets with $n_{ch} = 2$, $z_{//}(1) > 0.5$, $z_{//}(2) > 0.1$). In this case we found $\langle R \rangle^{norm} = 1.26 \pm 0.08$ for $p_T^0 = 1$ GeV/c and $\langle R \rangle^{norm} = 1.36 \pm 0.14$ for $p_T^0 = 1.2$ GeV/c, to be compared with the values 1.17 ± 0.05 and 1.14 ± 0.09 of fig. 6 respectively. Most of the difference between the two jets has disappeared. Our results are in agreement with the values of the experimental charge correlation found in ref. [16], given as $\langle R \rangle^{exp} = 1.52 \pm 0.05$ and 1.60 ± 0.03 for a trigger jet and opposite-side jet respectively, even if the experimental conditions are not quite the same ($p_T^{trig}(\pi^0) \geq 5$ GeV/c, correlation between a pair of leading charged fragments with $p_T > 0.8$ GeV/c). Our estimate for $\langle R \rangle^{comb}$ in the ISR data is $1.1 \div 1.2$.

3.2 Charge correlations between the fastest particles of each jet

In ref. [16] no charge correlation is found between the leading charged fragments in each jet ($\langle R \rangle^{exp} = 1.00 \pm 0.03$). This result is in qualitative agreement with the expectation of quark-parton models where the flavours of the colliding quarks are uncorrelated.

Some more detailed information can be obtained using again our two "extreme" cases, the FF and the combinatorial model.

Fig. 7 contains the predictions of these models for finding a pair of leader particles (one per jet) carrying the same or opposite charge. Our data clearly indicate once again that, as the trigger threshold increases, we really move from a pure combinatorial background to a selection of the first-rank particles (in the fragmentation hierarchy) in the towards and away jets. Once again, the Lund model appears to be in disagreement with the data, the difference becoming larger with the trigger threshold. The picture shows also that the ratio $P(++)/P(--)$ could be used as a parameter sensitive to this kind of charge correlations between leaders.

4. RAPIDITY CORRELATIONS

If a jet is dynamically significant, there should be a positive correlation among pairs of particles close in direction, and thus in pseudorapidity

$$\eta = \ln \operatorname{tg} \frac{\theta}{2} \quad (3)$$

Defining a single-particle density

$$\rho(\eta_i) = \frac{1}{\int dN(\eta_i) d\eta_i} \frac{dN(\eta_i)}{d\eta_i} \quad (4)$$

and a two-particle density

$$\rho(\eta_i, \eta_j) = \frac{1}{\iint d^2N(\eta_i, \eta_j) d\eta_i d\eta_j} \frac{d^2N(\eta_i, \eta_j)}{d\eta_i d\eta_j} \quad (5)$$

where $d^2N(\eta_i, \eta_j)$ is the number of particle pairs measured with one particle having a pseudorapidity between η_i and $\eta_i + d\eta_i$ and the other between η_j and $\eta_j + d\eta_j$, we can introduce a pair correlation function

$$R(\eta_i, \eta_j) = \frac{\rho(\eta_i, \eta_j)}{\rho(\eta_i) \cdot \rho(\eta_j)} \quad (6)$$

In absence of correlations $R(\eta_i, \eta_j) = 1$, while short-range correlations cause $R(\eta_i, \eta_j)$ to peak in the vicinity of $|\eta_i - \eta_j| \approx 0$.

We define as "beam-trigger" plane the plane which contains the incident kaon and the transverse momentum of the trigger particle (as seen from the total CMS). A particle belongs to the "beam-trigger" plane if its transverse momentum has an angle of either less than 45° with respect to the p_T of the trigger ("same side" particle) or more than 135° ("opposite-side" particle).

Fig. 8(a) contains the pseudorapidity correlation function R between the trigger and "same-side" particles; the insert shows the same correlation function as obtained at the ISR [16]. We observe that the "same-side" particles are clearly correlated to the trigger, the correlation increasing with their transverse momentum, thus indicating the presence of jets on the trigger side. Furthermore, our results have the same behaviour as the ISR ones.

We do not observe either significant correlations ($R \approx 1$) between the trigger and the "opposite-side" particles (fig. 8(b)), again confirming the ISR [16] results (insert of fig. 8(b)). This result may be due either to the absence of a jet in the opposite side or, most probably, to the fact that the reaction CM does not coincide with the constituent CM. To investigate this second hypothesis, we study pseudo-rapidity correlations between two particles produced both in the opposite side with one of them being always the away trigger particle [fig. 8(c)]. In this case, our data show a clear short-range correlation at $d\eta \approx 0$, even if somewhat less pronounced than the one of fig. 8(a); this correlation [in analogy with the ISR data [16] contained in the insert of fig. 8(c)] increases as the transverse momentum increases, thus confirming the presence of a second high- p_T jet even in the opposite side.

Our experimental results are compared with the Lund predictions in fig. 8. While the model is not able to predict any kind of short-range pseudorapidity correlations for the "same-side", some correlation is given for the "opposite-side". This result supports the idea that normal events with large value of the transverse energy are able to simulate to some extent a jet-like structure. However, the absence of any p_T -dependence given by the opposite-side predictions confirms the genuineness of our high- p_T jets.

The importance of this two-jet configuration makes a more detailed study of azimuthal correlations between the trigger and the "opposite-side" particles desirable. Fig. 9 shows a sketch of two particles (trigger and an arbitrary particle) projected onto the transverse plane, and also defines the variables used in the following analysis. The angle $\alpha = 180^\circ - \phi$ is a measure of the deviation from azimuthal collinearity due to the angular spread of the fragments relative to the jet axis. In fig. 10 we give the r.m.s. deviation $\langle \alpha^2 \rangle^{1/2}$ for two different intervals of p_1 as a function of the transverse momentum of the associated particles p_2 in events with $\phi > 110^\circ$. In both cases, the r.m.s. deviation decreases as p_2 increases; moreover, for a fixed value of p_2 , $\langle \alpha^2 \rangle^{1/2}$ decreases as p_1 increases. Even if our data do not extend over such a wide p_T range as the ISR ones [17,18] we observe a qualitative agreement, in the sense that results they do

extrapolate to each other in a very smooth way in spite of being obtained in different conditions. It should be stressed that the observed $\langle \alpha^2 \rangle^{1/2}$ fall-off is expected on the basis of QCD calculations [19,20]. Fig. 10 shows, as an example, the predicted $[\ln(Q/\Lambda)]^{-1}$ dependence, compared to the ISR results for $8.0 \leq p_1 \leq 9.0$ GeV/c [17] ($Q = 2 p_T$). Note that in this case the observed $\langle \alpha^2 \rangle^{1/2}$ dependence on p_1 and p_2 is qualitatively predicted by our Monte-Carlo events (curves of fig. 10).

The ratio

$$r_T = \frac{N_{\text{ass}}(70^\circ \leq \phi \leq 110^\circ)}{N_{\text{ass}}(\phi > 110^\circ)} \quad (7)$$

where N_{ass} is the number of charged particles produced in association with the trigger particle, is shown in fig. 11 for $p_1 > 1$ GeV/c as a function of the quantity

$$E_T = p_1 + p_2 + |\vec{p}_1 + \vec{p}_2| \quad (8)$$

which, neglecting the masses, represents the transverse energy of p_1 , p_2 and of a third fictitious particle balancing 1 and 2 in the transverse plane. The ISR data contained in the same figure are from ref. [18]. One sees that up to $E_T \approx 5$ GeV r_T increases, while for larger values of the transverse energy (up to ≈ 8 GeV) r_T falls off, thus qualitatively confirming the decrease already observed in ISR results (open points). Note that the experimental points are again in disagreement with the predictions of the Monte-Carlo model (continuous line) as the transverse energy increases.

5. FRAGMENTATION PROPERTIES OF HIGH- p_T EVENTS

Having shown in previous sections that there is a great deal of evidence for the existence of high- p_T jets in our data, we want now to proceed to study their fragmentation properties. In particular we want to compare our fragmenting jets to those previously observed at ISR and SPEAR. We will mainly concentrate on the fragmentation of the away-jet, as the trigger particle, due to the trigger bias, is already representing approximately the towards-jet.

For this purpose, we introduce the quantities [21]:

$$p_{out} = \frac{[(\vec{p}_T^{trig} \times \vec{p}_{beam}) \cdot \vec{p}_i]}{|\vec{p}_T^{trig}| |\vec{p}_{beam}|}; \quad p_x = - \frac{\vec{p}_T^{trig} \cdot \vec{p}_i}{|\vec{p}_T^{trig}|}; \quad x_E = \frac{p_x}{|\vec{p}_T^{trig}|} \quad (9)$$

where p_{out} and p_x (the two components of an away-particle momentum) are sketched in fig. 9. Note that x_E represents an approximation of the fraction of the jet transverse momentum carried by the i -th away particle. Scaling in x_E (namely, the x_E -distribution of away-particles independent of the trigger transverse momentum) would indicate that the fragmentation does not depend on the momentum of the outgoing constituent. Our data, extending the ISR results to smaller p_T , show a strong scaling violation for large values of x_E (fig. 12). The same conclusion can be drawn from fig. 13 where the ISR data (obtained from combining CCFHK, BFS and CCOR results [22]) and covering a wider p_T^{trig} range indicate that the scaling violation is really significant at $p_T^{trig} \leq 3$ GeV for $x_E > 0.6$. Note that in both these comparisons the Lund model, although in rough qualitative agreement with the shape of the distributions, fails to predict the correct normalisation, especially for high x_E values.

p_{out} , which is a measure of the lack of coplanarity of the two back-to-back jets, is in the QCD model affected by both the internal transverse momentum of the partons contained in the incident particle and by the fragmentation of the scattered parton. If particles with high x_E come from jets, p_{out} should increase with x_E ; furthermore, p_{out} should increase with p_T (for fixed x_E), because of the gluon radiation. The dependence of $\langle p_{out} \rangle$ on both p_T and x_E is shown in fig. 14 (ISR data are taken from refs [22,23]) and one sees that our data indeed indicate, in qualitative agreement with the ISR results, that $\langle p_{out} \rangle$ increases with both p_T^{trig} and x_E . Note that the fall-off near $x_E \simeq 1$ is due to the kinematical constraint (fig. 9) $p_{out} = (p_2^2 - x_E^2 p_1^2)^{1/2} < p_1 (1 - x_E^2)^{1/2}$. Again, the increase with p_T^{trig} and x_E is not reproduced by the Lund model.

Comparing jets from hadron-hadron interactions to jets arising from e^+e^- annihilations, there is the problem of knowing (at least approximately) the energy of the two constituents scattering. For our analysis, we shall

assume that for $p_T^{\text{trig}} > 1$ GeV/c, the unseen neutral energy (which represents $\approx 40\%$ of the total CMS energy) is approximately equally divided between the two pairs of jets (towards + away and beam + target jets) since the average energies of charged particles are approximately equal in the two pairs of jets. We define therefore $E_{2 \text{ jets}}^{\text{tot}} = E_{2 \text{ jets}}^{\text{ch.}} + E^{\text{neutr.}}/2$, where $E^{\text{neutr.}}$ is the unseen neutral energy. The quantity $E_{2 \text{ jets}}^{\text{tot}}$ will hereafter be referred to as E_{CMS} . It follows that $\langle E_{\text{CMS}} \rangle \approx \sqrt{s}/2 \approx 5.7$ GeV and that $\text{FWHM} \approx 2.2$ GeV. In analogy with e^+e^- annihilations, we will restrict our analysis to events containing at least three charged particles in the towards and away jets. The high- p_T jet fragmentation characteristics will be compared with the predictions obtained from the Lund model for annihilation at a centre of mass energy equal to our $\langle E_{\text{CMS}} \rangle$.

The sphericity axis is defined as usual as the axis which minimizes the quantity

$$S = \frac{3}{2} \frac{\sum_i p_{Ti}^2}{\sum_i |\vec{p}_i|^2} \quad (10)$$

where all momenta belonging to the two high- p_T jets have been defined in the overall CM. $S \rightarrow 0$ for jet-like events; $S \rightarrow 1$ for phase space events.

We introduce for both towards and away-jets the quantity

$$x_{//} = 2 \frac{p_{//}}{E_{\text{CMS}}} \quad (11)$$

where $p_{//}$ is the particle momentum parallel to the sphericity axis. Using $p_{//}^{\text{max}} = p_{//}^{\text{trig}}$, we compare in fig. 15 our normalized sphericity distribution to similar distribution for e^+e^- from SPEAR [24]. For $x_{//}^{\text{max}} < 0.5$ [fig. 15(a)] the shapes of the two distributions are in strong disagreement, indicating that our selection criteria have introduced a loss of particles having a momentum approximately perpendicular to the jet direction. On the contrary, the two distributions are in excellent agreement [fig. 15(b)] if we select events with $x_{//}^{\text{max}} > 0.5$. For this reason, jet fragmentation properties will be compared to e^+e^- results only for events with $x_{//}^{\text{trig}} = x_{//}^{\text{max}} > 0.5$. The Lund model gives an excellent description using both cuts.

In fig. 16 we show $d\sigma/dx_{//}$ for two different values of $\langle E_{CMS} \rangle$ (4.0 and 5.7 GeV); both these distributions are normalized in the range $0.2 \leq x_{//} \leq 0.8$ to the corresponding SPEAR distributions at respectively 3.0 and 4.8 GeV CMS energy. As seen, the shapes are in very good agreement; the depletion at $x_{//} < 0.2$ is again due to a loss of associated particles having a large angle with respect to the sphericity axis. Fig. 17 displays $d\sigma/dx_R$ for particles contained in jets produced under the same conditions as in fig. 16 ($x_R = 2|\vec{p}|/E_{CMS}$). The two experiments scale very well and the same kind of dip is observed in both cases at $x_R < 0.2$. Our data appear to be in close agreement with Lund.

To study the transverse fragmentation properties of our high- p_T jets, we show in fig. 18 the normalized differential cross section as a function of momentum transverse to the sphericity axis. Our data agree very well with the e^+e^- results at comparable centre of mass energy and a similar agreement is observed if we broaden the cut-off to $x_{//}^{max} > 0.3$ (fig. 19). We also see that in both cases the Lund predictions are in good agreement with the data. The average values of p_T^2 for our high- p_T jet events are displayed in fig. 20 and compared to PLUTO e^+e^- results (in our case, slim-jet = towards-jet, fat-jet = away-jet). We see that the two values of $\langle p_T^2 \rangle$ corresponding to $\langle E_{CMS} \rangle = 4.0$ and 5.7 GeV extrapolate smoothly to e^+e^- annihilation results in the range $10 \div 30$ GeV [25].

6. CONCLUSIONS

We have presented experimental information on the structure of K^+p interactions at $\sqrt{s} = 11.5$ GeV in which high- p_T particles are produced. We have investigated charge and rapidity correlations among the various leading particles contained in the two back-to-back high- p_T jets; we have analyzed the longitudinal and transverse fragmentation properties of these jets and compared them to ISR and e^+e^- results. Our data have also been compared systematically with the predictions obtained from the Lund Monte-Carlo, from the Field-Feynman fragmentation mechanism and from a simple combinatorial model.

Our main experimental conclusion can be summarized as follows: The K^+p interactions at 70 GeV/c with high- p_T particles show the presence of transverse jets, with features extrapolating smoothly to those observed in ISR experiments. More specifically:

- (a) Charge correlations among leading particles with $z_{//} > 0.5$ indicate an increasing disagreement with respect to the combinatorial model as p_T^{trig} increases. For $p_T^{\text{trig}} \geq 1$ GeV, they agree very well with the FF fragmentation model;
- (b) Charge correlations among particles belonging to the away-jet (again for $p_T^{\text{trig}} \geq 1$ GeV) depend on $z_{//}$ in a way similar to the dependence observed at the ISR; furthermore, as $z_{//} \rightarrow 1$, they show a stronger disagreement with the Lund Monte-Carlo model;
- (c) Charge correlations between the two fastest particles in each jet show a growth of the fraction of opposite charge pairs as p_T^{trig} increases, in qualitative agreement with FF and what was observed at the ISR;
- (d) Longitudinal and transverse fragmentations of the away-jet agree with the properties observed at the ISR;
- (e) The internal structure of both the towards and away jets looks very similar to the one observed in e^+e^- annihilations at comparable CM energy.

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REFERENCES

- [1] M. Barth et al., Nucl. Phys. B192 (1981) 289.
- [2] For a recent review in this field:
 - (a) H.E. Montgomery, CERN/EP 82-192, Invited talk given at the Europhysics Study Conference "Jet structure from Quarks and Lepton Interactions", Erice, Sicily, 12-17 September 1982;
 - (b) H. Bøggild, CERN/EP 82-187, Invited talk given at the Europhysics Study Conference "Jet structure from Quarks and Lepton Interactions", Erice, Sicily, 12-17 September 1982;
 - (c) P.B. Renton, Oxford University Preprint 62/82, Invited Talk given at the XIII International Symposium on Multiparticle Dynamics, Volendam, The Netherlands, 6-11 June 1982.
- [3] C. de Marzo et al., Phys. Lett. 112B (1982) 173.
- [4] C. Bromberg et al., Phys. Rev. Lett. 43 (1979) 561; Phys. Rev. Lett. 43 (1979) 565.
- [5] M.D. Corcoran et al., Phys. Rev. D21 (1980) 641.
- [6] M.G. Albrow et al., Nucl. Phys. B160 (1979) 1.
- [7] V.V. Abramov et al., Nucl. Phys. B173 (1980) 348.
- [8] M. Barth et al., Z. Phys. C3 (1979) 285.
- [9] B.L. Combridge, Phys. Rev. D12 (1975) 2893;
M. Jacob and P.V. Landshoff, Nucl. Phys. B113 (1976) 395;
S.D. Ellis, Invited talk given at the American Physical Society meeting, Argonne, October 1977, RLO-1388-745.,
- [10] B. Andersson et al., Nucl. Phys. B178 (1981) 242.
- [11] See e.g. E.A. de Wolf, Proc. XIIIth Int. Symposium on Multiparticle Dynamics, Volendam (1982), Eds. W. Kittel, W. Metzger and A. Stergiou, World Scientific Singapore (1983).
- [12] T. Sjöstrand, Comp. Phys. Commun. 27 (1982) 243.
- [13] V.V. Ammosov et al., Phys. Lett. 93B (1980) 210.
- [14] R.D. Field and R.P. Feynman, Nucl. Phys. B136 (1978) 1.
- [15] D. Drijard et al., Nucl. Phys. B208 (1982) 1.
- [16] A.G. Clark et al., Nucl. Phys. B160 (1979) 397.
- [17] C. Kourkouvelis et al., Phys. Lett. 85B (1979) 147.
- [18] C. Kourkouvelis et al., Nucl. Phys. B158 (1979) 39.

REFERENCES (Cont'd)

- [19] G. Veneziano, Proceedings of the 19th Int. Conf. on High Energy Physics, Tokyo, 1978 (p. 725).
- [20] A. De Rujula, Proceedings of the 19th Int. Conf on High Energy Physics, Tokyo, 1978 (p. 236).
- [21] M. Della Negra et al., Nucl. Phys. B127 (1977) 1.
- [22] M. Jacob, Physica Scripta 19 (1979) 69.
- [23] A.L.S. Angelis et al., Physica Scripta 19 (1979) 116.
- [24] G.G. Hanson, Jets in e^+e^- annihilation, SLAC-PUB-2118 (May 1978),
Talk given at the 13th Rencontre de Moriond on High Energy Leptonic
and Hadronic Interactions, Les Arcs, Savoie, France, 12-24 March 1978.
- [25] H. Schopper, New results in e^+e^- annihilation from PETRA,
DESY 79/79, December 1979.

TABLE 1

Criteria for the selection of the TOWARDS-side and AWAY-side jets.
All the quantities are given in the total CMS. θ is the angle
relative to the beam

(a)	$p_T^{\text{trig}} \geq p_T^0 (\text{GeV/c}) =$	0.4	0.6	0.8	1.0	1.2	1.4
(b)	$p_T^{\text{aw.trig.}} > p_T^1 = p_T^0/2$	0.2	0.3	0.4	0.5	0.6	0.7
(c)	Polar angle θ^{trig}	$45^\circ \leq \theta^{\text{trig}} \leq 135^\circ$					
(d)	Polar angle θ^i of any other particle (except TRIGGER)	$25^\circ \leq \theta^i \leq 155^\circ$					
(e)	The angle between $\vec{p}^{\text{trig}}$ and $\vec{p}^{\text{aw.trig.}}$	$\geq 120^\circ$					
(f)	Particle i belongs to the TOWARDS-side jet if the angle between $\vec{p}^{\text{trig}}$ and $\vec{p}^i$	$\leq 40^\circ$					
(g)	Particle i belongs to the AWAY-side jet if the angle between $\vec{p}^{\text{aw.trig.}}$ and $\vec{p}^i$	$\leq 55^\circ$					
(h)	For $p_T^{\text{trig.}}$ in the interval (GeV/c)	0.4-0.6	0.6-0.8	0.8-1.0	1.0-1.2	1.2-1.4	> 1.4
	$p_T^{\text{aw.jet}}$ must be (GeV/c) $\geq$	0.3	0.4	0.5	0.7	0.8	1.1
(i)	With all above criteria we have for the condition (a) $\langle p_T^{\text{tow.jet}} - p_T^{\text{aw.jet}} \rangle (\text{GeV/c}) =$	0.15	0.17	0.19	0.20	0.20	0.29
	with FWHM (GeV/c)	0.4	0.5	0.6	0.6	0.6	0.8

FIGURE CAPTIONS

- Fig. 1 Ratio of positive to negative charge for different $|p_L + \Delta p_L| = |p_T + \Delta p_T|$ intervals (points). The triangles represent the predictions from the Lund model calculated in the same p_L and p_T intervals.
- Fig. 2 Ratio of positive to negative charge for the trigger as a function of the trigger transverse momentum. The dashed line is the charge combinatorial probability (CCP) prediction, while the continuous lines represent the FF and the Lund expectations.
- Fig. 3 Ratio of positive to negative charge for the leading particles contained in the towards- and in the away-jets as a function of p_T^0 (see table 1 for the definition of p_T^0). In both cases, the leading particle is selected with $z_{//} > 0.5$. The dashed and continuous lines are the CCP and FF predictions respectively, while the dashed-dotted lines are the Lund predictions for both sides.
- Fig. 4 Average charge of the leading particle (with $z_{//} > 0.5$) contained in the away-jet as a function of p_T^0 . The dashed and continuous lines are the CCP and FF predictions respectively; the Lund model gives the dashed-dotted curve.
- Fig. 5 Ratio of positive to negative fragments contained in the away-jet as a function of their momentum fraction. The ISR data are from ref. [16]. The full line is the Lund prediction.
- Fig. 6 Normalized values of the charge correlation coefficient for the two fastest particles contained in the towards- and away-jets as a function of p_T^0 . The full and the dashed-dotted lines are the Lund predictions for the towards-side and away-side jets respectively. The insert contains the charge correlation function versus the charge multiplicity calculated with pure combinatorial analysis.

FIGURE CAPTIONS (Cont'd)

Fig. 7 Normalized number of events where the leading charged particles in each jet have:

- (a) Both positive charge;
- (b) Opposite charge;
- (c) Both negative charge;

as a function of p_T^0 .

The solid lines represent the FF predictions, while the dashed lines are the combinatorial predictions. The Lund model is represented by the dashed-dotted curves. Both leaders (as for FF) are selected with $z_{//} > 0.5$.

Fig. 8 Pseudorapidity correlation function $R(\eta_i, \eta_j)$ vs $\Delta\eta$ for two different cuts on the associate particle transverse momentum (points and open points):

- (a) Between the trigger and "same-side" particles in the "beam-trigger" plane.
- (b) Between the trigger and "opposite-side" particles.
- (c) Between the away-trigger (selected in the "beam-trigger" plane) and "opposite-side" particles.

The three inserts show the corresponding $R(\eta_i, \eta_j)$ obtained at ISR [16]. The superimposed curves are the respective Lund predictions corresponding to the cuts mentioned before (the full lines correspond to the points, the dashed ones to the open points).

Fig. 9 Illustration of the quantities $p_1, p_2, \phi, \alpha, p_{out}, x_E$.

Fig. 10 Distribution of $\langle \alpha^2 \rangle^{1/2}$ vs. p_2 for two intervals of p_1 : $0.8 \leq p_1 \leq 1.2$ GeV/c (open points) and $1.2 \leq p_1 \leq 3.0$ GeV/c (full points). The curves are the corresponding Lund predictions. The ISR data used for the comparison are taken from [17,18]. The dashed-dotted curve (from [17]), is the QCD expected behaviour $[\ln(Q/\Lambda)]^{-1}$ ($Q = 2p_T$).

FIGURE CAPTIONS (Cont'd)

- Fig. 11 Distribution of r_T as a function of the transverse energy E_T (full points). The superimposed curve is the Lund prediction. The ISR (open points) are from ref. [18].
- Fig. 12 $N(\Delta x_E)/N(x_E > 0.3)$ as a function of p_T^{trig} for three different x_E intervals. The ISR data are taken from ref. [17].
- Fig. 13 Normalized number of events in x_E intervals as a function of p_T^{trig} . The combined ISR data are from ref. [22]. The Lund predictions are given by the full lines.
- Fig. 14 $\langle p_{\text{out}} \rangle$ distribution as a function of x_E for $0.6 \leq p_T^{\text{trig}} \leq 1.0$ GeV/c (full squares) and $p_T^{\text{trig}} > 1.2$ GeV/c (full points). The corresponding Lund predictions are given by the dashed and full lines respectively. ISR data are from refs [22,23].
- Fig. 15 (a) Sphericity distribution for particles in high- p_T jets with $\langle E_{\text{CMS}} \rangle = 5.7$ GeV for $x_{\text{trig}}^{\text{trig}} < 0.5$. The SLAC data [24] are at $E_{\text{CMS}} = 7.4$ GeV for $x_{\text{max}}^{\text{max}} < 0.4$. Full line is the Lund prediction.
- (b) Same as in (a) for $x_{\text{trig}}^{\text{trig}} > 0.5$ and $x_{\text{max}}^{\text{max}} > 0.4$.
- Fig. 16 $\frac{1}{N} \frac{dN}{dx_{\text{trig}}}$ as a function of $x_{\text{trig}} = 2 \frac{p_{\text{trig}}}{E_{\text{CMS}}}$ for particles with $x_{\text{trig}}^{\text{trig}} > 0.5$. Full triangles: $\langle E_{\text{CMS}} \rangle = 4.0$ GeV; full points $\langle E_{\text{CMS}} \rangle = 5.7$ GeV. SPEAR data [24] are at 3.0 and 4.8 GeV. In all cases the selection $x_{\text{trig}}^{\text{trig}} (x_{\text{max}}^{\text{max}}) > 0.5$ is used and particles corresponding to $x_{\text{trig}}^{\text{trig}} (x_{\text{max}}^{\text{max}})$ do not enter the plot.
- Fig. 17 The same as in fig. 16 for $x_R = 2 \frac{|\vec{p}|}{E_{\text{CMS}}}$.
- Fig. 18 $\frac{1}{N} \frac{dN}{dp_T}$ as a function of p_T (transverse momentum calculated with respect to the sphericity axis). e^+e^- data are at 4.8 GeV. In both cases the selection $x_{\text{trig}}^{\text{trig}} (x_{\text{max}}^{\text{max}}) > 0.5$ is used. Full curve is the prediction of Lund.

FIGURE CAPTIONS (Cont'd)

Fig. 19 The same as in fig. 18, but for $x_{//}^{\text{trig}} (x_{//}^{\text{max}}) > 0.3$.

Fig. 20 Average values $\langle p_T^2 \rangle$ of charged particles in a slim-jet (= towards-jet) and in a fat-jet (= away-jet) versus E_{CMS} in comparison with PLUTO data [25].

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig.6

Fig. 7

Fig.8

PLANE PERPENDICULAR TO THE BEAM DIRECTION IN C.M.S.

Fig.9

Fig. 10

Fig.11

Fig.12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19

Fig. 20