TAGGING DIQUARKS BY PROTONS OF HIGH TRANSVERSE MOMENTUM
IN pp COLLISIONS AT THE ISR

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ABSTRACT

Events are analyzed in which a high transverse momentum proton was produced at polar angles of 10° , 20° and 45° . The experiment was performed with the Split Field Magnet detector at the CERN ISR at $\sqrt{s} = 62$ GeV. A 4-jet structure of these events is found [1]. The measured charge structure of spectator jets is compatible with proton production from hard diquark scattering. This is supported by a study of baryon number compensation in the towards jets. The observed charge compensation in the towards jets suggests dominance of hard (ud) scattering. Evidence for Δ^{++} production at high transverse momentum indicates the presence of an additional (uu) scattering component. The properties of the recoiling away jets are compatible with the fragmentation of a valence quark and/or of a gluon as in the case of meson triggers.

1. INTRODUCTION

Deep inelastic production of $\pi^{\pm}$ and $K^{\pm}$ mesons in pp collisions at the ISR has been studied experimentally [2-4] and is well understood in terms of quark and gluon scattering. Antiprotons may be produced by mechanisms similar to those for K^- mesons since neither contains any valence quark of the incident protons. However, there is no established mechanism which explains proton production at high transverse momentum p_T . Various schemes have been proposed in the literature [2,5-7]. This unclear situation has been partially due to a lack of inclusive data covering large regions of phase space, i.e. of polar angle θ and p_T at various c.m.s. energies $\sqrt{s}$. In addition, there has been a nearly complete absence (except refs [2,9,10]) of correlation data which were crucial for establishing the quark and gluon hard scattering mechanisms as the source of pions and kaons at high p_T . Recent data (see fig. 1, taken from refs [7,8,11]) have been used to demonstrate that proton yields relative to π^+ yields depend on p_T at fixed θ , on θ at fixed p_T , and on $\sqrt{s}$ at fixed $x_T = 2p_T/\sqrt{s}$ and θ . In contrast, relative K^+ and $\bar{p}$ yields are nearly independent of kinematic variables. Hence protons are probably not produced dominantly by hard scattering of quarks and gluons.

It was also shown recently that high mass diffraction does not contribute significantly to proton production at forward polar angles [12].

It is the aim of this study to gain a more detailed understanding of the proton production mechanism. The experiment is described briefly in sect. 2. Data on correlations between the flavour of the trigger (protons and pions), and the charge structure of the spectator jets are given in sect. 3. Evidence for inclusive Δ^{++} production at high transverse momentum is presented in sect. 4. A measurement of particle production close to the trigger particle, i.e. in the "towards jet", follows in sect. 5, including a study of charge and baryon number compensation. Finally, properties of the "away" jets recoiling against triggering protons and positive mesons are compared in sect. 6 and a summary is presented in sect. 9.

2. EXPERIMENT AND DATA

The experiment was performed at the CERN ISR using the Split Field Magnet detector. The detector consisted of a system of multiwire proportional chambers for charged particle detection over nearly the full phase space. The single track acceptance of the detector is usually better than 80%, except for small c.m.s. rapidities, i.e. $|y| < 0.2$. Scintillation counters for time-of-flight measurements covered nearly the full range of polar angles and two azimuthal wedges of about 20° . The time resolution of the system was $\sigma = 0.3$ nsec allowing the separation of (anti)-protons from charged mesons for lab momenta < 2 GeV/c [13(a)]. A trigger logic selected events with a high p_T (≥ 1 GeV/c) particle produced at $\theta \approx 10^\circ$, 20° or 45° . Two Cerenkov counters at $\theta \approx 20^\circ$ and one each at $\theta \approx 10^\circ$ and $\theta \approx 45^\circ$ were filled with freon 114 at atmospheric pressure (kaon threshold $p_{lab} \approx 9.5$ GeV/c and proton threshold $p_{lab} \approx 18.1$ GeV/c). In addition a threshold Cerenkov counter filled with freon 13 at 7.5 atm. (kaon threshold $p_{lab} \approx 4.7$ GeV/c and proton threshold $p_{lab} \approx 9.0$ GeV/c) covered the trigger region at $\theta \approx 45^\circ$. These counters were used to distinguish between pions, kaons and protons. Details of the set up, of the trigger acceptance and of the trigger scheme have been described in ref. [13(b)].

The following analysis is based on large numbers of fully reconstructed events which have been obtained by triggering on pions ($> 500,000$ events) and protons ($\approx 20,000$ events).

3. CORRELATIONS WITH SPECTATOR JETS

It was shown that K^+ and π^+ mesons at $\theta \approx 45^\circ$ and $p_T \gtrsim 4$ GeV/c are produced predominantly by the fragmentation of hard-scattered valence quarks [3,4]. This mechanism is also expected to dominate at $\theta \approx 10^\circ$. Support for this comes from data of ref. [2] for $\theta \approx 10^\circ$ and $p_T \gtrsim 2$ GeV/c. In that reference it was also suggested that high p_T protons at small θ may be produced in part by fragmenting diquarks. These ideas lead to rather well-defined predictions of flavour compositions of spectator jets at $\theta \approx 0^\circ$ for triggering $\pi^\pm$ -mesons and protons at forward angles (fig. 2): The spectator jets, at $\theta \approx 0^\circ$, should be due to a system of two valence quarks in the case of positive meson triggers and to single valence quarks for proton triggers from hard diquark scattering. In both cases, the

quantum numbers of the "trigger" quark(s) and the spectator quark(s) add up to the proton quantum numbers.

A study of the ratios

$$R^+(p/\pi^\pm) = \frac{\rho^+(p)}{\rho^+(\pi^\pm)} \quad (1a)$$

$$R^-(p/\pi^\pm) = \frac{\rho^-(p)}{\rho^-(\pi^\pm)} \quad (1b)$$

of densities of positive and negative secondary particles respectively associated with proton ($\rho^+(p)$) and $\pi^\pm$ -meson ($\rho^\pm(\pi^\pm)$) triggers allows one to discriminate between diquarks and quarks as possible sources of high p_T protons. Proton production by hard scattered u or d quarks implies naturally that $R^\pm(p/\pi^\pm) = 1$ or $R^\pm(p/\pi^\mp) = 1$ respectively for all x_F (the variable x_F associated to a particle is defined as the ratio between its longitudinal momentum and $\sqrt{s}/2$). On the other hand $R^+(p/\pi^\pm)$ should decrease with increasing x_F if trigger protons are diquark fragments (large x_F positive fragments are dominantly protons, easily produced in diquark fragmentation (π -meson trigger) whereas suppressed in single quark fragmentation as suggested by quark counting rules [14]). The ratio $R^-(p/\pi^\pm)$ of negative spectator densities generally should not decrease as x_F increases.

The experimental ratios of corrected particle densities^(*) are displayed in figs 3 and 4 for triggering particles at $\theta \approx 10^\circ$ and $p_{lab} \geq 13$ GeV/c. The measured ratios $R^+(p/\pi^+)$ and $R^+(p/\pi^-)$ in fig. 3 decrease from a value of about 1 at $x_F \approx 0$ to about 0.55 and 0.3, respectively, at $x_F \approx 0.4$. They show a roughly constant value of about 1 between $x_F \approx 0$ and $x_F \approx -0.6$. The ratios $R^-(p/\pi^+)$ and $R^-(p/\pi^-)$ (fig. 4) are equal to unity between $x_F \approx -0.6$ and $x_F \approx 0$; they increase to values of about 2 and 2.5, respectively, at $x_F > 0.2$. These data are in qualitative agreement with hard diquark scattering giving rise to high p_T protons as discussed above. Hard-scattered valence quarks may be ruled out as the dominant source of high- p_T protons, since they would yield $R^\pm(p/\pi^\pm) = 1$. Corresponding data in figs 5 and 6 for $R^\pm(p/\pi^\pm)$ for triggering $\pi^\pm$ -mesons and protons with $p_T \geq 3.5$ GeV/c at $\theta \approx 20^\circ$ and with $p_T \geq 3.3$ GeV/c at

(*) The acceptance tends to cancel in ratios of this type since it is largely independent of the flavour of the trigger particle.

$\theta \approx 45^\circ$ exhibit qualitatively similar trends. The ratio $R^+(p/\pi^+)$ obtained at $\theta \approx 45^\circ$ is larger than the ratios at $\theta \approx 20^\circ$ and $\theta \approx 10^\circ$ for $x_F > 0.2$. Hence there is a smaller difference between p and π^+ triggers at $\theta \approx 45^\circ$ which suggests a smaller diquark scattering component.

This is compatible with the observed inclusive relative proton yields [11]. In fig. 1 it was shown that the relative proton yield decreases with increasing θ at fixed p_T . Since a potential contribution of valence quarks to relative proton yields should be independent of kinematic variables such as θ , the decrease corresponds to a decreasing component from an additional production mechanism, e.g. diquark scattering. A priori, one expects a strong θ dependence for diquark scattering because of the diquark form factor [7].

Similar correlations have been observed and interpreted recently for events with high p_T trigger particles detected at $\theta = 90^\circ$ [10]. The conclusions drawn for the present analysis agree with those of refs [10] and [2].

At this point it is interesting to confront the qualitative arguments stated above with a more quantitative comparison to experimental data from deep inelastic lepton scattering. These experiments [15,16] measure charged particle densities $\rho^\pm$ as functions of the fragmentation variable $z = p/p_{\max}$ for well-defined single quarks ("current jet") and diquark systems ("target jet").

If proton triggers in pp scattering indeed originate from diquark scattering, the corresponding spectator fragments should be compared to charge densities from single quark (current) jets. For pion triggers on the other hand, the spectator particles should behave like target jets in deep inelastic lepton scattering. The only input needed to perform this comparison is the correlation between the fragmentation variable z and the reduced longitudinal momentum x_F as measured in the ISR system.

This correlation can be obtained from straight-forward parton model calculations [17] and is shown in fig. 7 for $p_T > 2$ GeV and $\theta \approx 10^\circ$. Since it is largely governed by energy-momentum conservation, the influence of different model versions or parameter variations is rather

small, as indicated by the error band in fig. 7. For each value of x_F , a well-defined range of z -values with FWHM of about 0.1 units is obtained. This is shown in fig. 7 by the inserted z -resolution curve for $x_F = 0.45$.

Rather than the spectator charge densities $\rho^\pm$, their ratio $R_\rho = \rho^-/\rho^+$ turns out to be a very sensitive indicator for the nature of the parent parton-system involved. This has to do with the fact that whenever proton production becomes prevalent, as e.g. for diquark spectator systems, R_ρ tends to become very small at large z or x_F values. For single quark spectators, even for single u -quarks, R_ρ remains substantially larger due to the dominant meson production which is more charge symmetrical.

These features are indeed borne out in the comparison of R_ρ with predictions from deep inelastic neutrino scattering [15]. In fig. 8, acceptance-corrected values of R_ρ are shown as function of x_F for different trigger particles. For π^- triggers, the spectator ratio R_ρ reaches values of about 1% at large x_F in perfect agreement with predictions from νp scattering ((uu) target jet). For π^+ triggers, R_ρ is somewhat larger (7-12% at large x_F), again in agreement with $\bar{\nu} p$ scattering ((ud) target jet).

This correspondence between π^+ (π^-) triggers and u (d) valence quark scattering has been discussed before [2] in terms of trigger cross section and correlation data. The abundant production of Δ^{++} resonances in the spectator region for π^- triggers and its complete suppression for π^+ triggers [18] is another manifestation of the same underlying physics.

Turning now to the charge density ratio R_ρ measured for proton triggers shown in fig. 8, a very substantial increase of negative charge density at large x_F , as compared to pion triggers, is clearly seen from the data.

In itself, the measured value of about 40% at the kinematic limit of the spectator jet excludes the presence of baryon number in the majority of spectator jets correlated with proton triggers. At the same time, it constitutes a very important cross-check of the diquark scattering hypothesis as the origin of large p_T protons.

A quantitative comparison of data with predictions from single quark fragmentation is shown in fig. 9. This comparison suggests a number of interesting questions connected to the nature of the diquark scattering process, in particular relevant to the diquark form factors and structure functions.

If (ud) and (uu) diquarks would scatter according to SU(6), one would expect the line at 67% u- and 33% d-quark contribution as shown in fig. 9. The data are well below this prediction. On the other hand if, as in some models (see e.g. ref. [6]), only (ud) systems would scatter at large momentum transfer, then R should correspond to single u-quark fragmentation. The data fall well above this prediction, suggesting that (uu) systems may also contribute to the large p_T proton production. Further evidence for the scattering of (uu) diquarks comes from the appearance of Δ^{++} resonances in the trigger jet as described in the following section.

In this context it should be noted that structure functions for the different diquark combinations are unknown and that form factors for scalar and vector diquarks are expected to be different [19]. However, it is apparent that the persistence of bound diquarks in the Q^2 and W range of the present experiment, which to a large extent covers the range of existing deep inelastic lepton scattering experiments, would lead to a re-interpretation of structure functions, especially concerning the gluon contributions.

Predictions for the charge density ratios R^+ and R^- shown in figs 3-6, can of course as well be obtained using the above method. Also in this case, where yields of spectator fragments of equal charge for different trigger particles are compared, predictions match the data very well as indicated by the shaded regions in fig. 3.

To summarize, the observed difference of the charge structure of spectator jets for proton and pion triggers is consistent with a strong contribution of hard diquark scattering to proton production at high p_T . This mechanism dominates at small polar angles and becomes less important with increasing θ . The data indicate that hard scattering of both (ud) and (uu) systems contribute to proton production. Hard scattering of single valence quarks apparently does not play a significant rôle in producing protons in the kinematic region considered.

4. PRODUCTION OF Δ^{++} AT HIGH p_T

Further insight into the proton production mechanism may be gained from an analysis of Δ^{++} production in the trigger jet. Uncorrected $p\pi^+$ invariant mass distributions are displayed in fig. 10; they were obtained from triggering protons at $\theta \approx 10^\circ$ ($p_T \geq 2$ GeV/c), $\theta \approx 20^\circ$ ($p_T \geq 3$ GeV/c) and $\theta \approx 45^\circ$ ($p_T \geq 4$ GeV/c). All positive secondaries other than the trigger were assumed to be pions. The distributions exhibit significant deviations from smooth non-resonant mass distributions at the expected Δ^{++} mass for all three trigger angles. A similar indication for a Δ^{++} signal was found in ref. [21].

Since a leading Δ^{++} should be produced by (uu) hard scattering and fragmentation, a non-negligible (uu) scattering component is suggested in addition to the dominant (ud) contribution to proton production at high p_T . In fact, the ratio $\Delta^{++}/p = 0.29 \pm 0.04$ is found experimentally for the sample of proton triggers at $\theta \approx 10^\circ$ discussed above. This value is substantially higher than the same ratio measured in deep inelastic muon scattering [20] both in the current jet (predominantly u-quarks) and in the target jet (mostly (ud) systems). A more complete investigation of inclusive Δ^{++} production at high p_T will be published elsewhere [22].

5. CORRELATIONS IN THE TOWARDS JET

For $\pi^\pm$ and $K^\pm$ mesons produced at $\theta \approx 45^\circ$ with $p_T \geq 4$ GeV/c an enhanced density of associated particles was measured in the nearby region of phase space, i.e. for $\Delta y = |y(\text{trigger}) - y| \leq 1$ and for relative azimuthal angles $\Delta\phi = |\phi - \phi(\text{trigger})| \leq 16^\circ$ [3,4,10]. This density is determined as a function of the variable z_F defined by:

$$z_F = \frac{\vec{p}_T^s \cdot \vec{p}_T(\text{trig})}{|\vec{p}_T(\text{trig})|^2} \quad (2)$$

where $\vec{p}_T^s$ is the transverse momentum of the associated particle. This density exceeds the one found in normal inelastic interactions in the regions where $p_T^s \gtrsim 1$ GeV/c, and provides evidence for the existence of the towards or trigger jet. It is known from ref. [23] that the slope of the

particle density distribution, when given as a function of z_F , is a measure of $\langle z_{TR} \rangle$, the average fraction of the scattered parton's momentum carried by the trigger particle. It was also verified experimentally that for K^+ and π^+ triggers, negatively charged particles in the towards jet are more abundant than positives due to charge compensation in the jet. This is illustrated schematically in fig. 11(a).

In sects 5.1 and 5.2 only data at $\theta \approx 45^\circ$ are considered since towards jets cannot easily be separated from spectator jets triggering with particles produced at $\theta \approx 10^\circ$ or 20° .

5.1 Particle densities

In the case of proton production by (ud) scattering, secondary π^- mesons in the towards jet should be about as abundant as secondary π^+ mesons in the case of π^+ triggers since one is dealing mainly with rank 2 fragments (for a definition, see ref. [24]) in both cases. In contrast, for direct proton production from (uu) scattering π^+ mesons would be the more abundant rank 2 mesons.

The corrected particle densities close to proton triggers ($\Delta y \leq 1$ and $\Delta\phi \leq 16^\circ$) with $p_T \geq 3.3$ GeV/c relative to π^+ triggers are shown in fig. 12. The ratios $R^\pm(p/\pi^+)$ for positive and negative associated secondaries are compatible with unity, i.e. for both proton and π^+ -meson triggers the secondary pions are produced at the same rate. Therefore for $\theta \approx 45^\circ$ and $p_T \geq 3.3$ GeV/c one concludes that:

- (a) A towards jet exists also for proton triggers.
- (b) The value of $\langle z_{TR} \rangle$ is nearly the same for proton triggers as for π^+ triggers, for which $\langle z_{TR} \rangle \approx 0.7$ was found [23].
- (c) A dominant contribution to high- p_T proton triggers from hard (uu) scattering seems to be excluded.

These suggest again the hard scattering of (ud) diquarks as the dominating mechanism for proton production in the region of phase space studied.

5.2 Compensation of baryon number

The idea of hard diquark scattering in high p_T proton production is substantiated by a measurement of proton and antiproton production in the towards jets associated with triggering particles at $\theta \approx 45^\circ$ and with $p_T \geq 4$ GeV/c. For this analysis only triggering charged pions were positively identified by the Cerenkov counter filled with freon 114. Particles producing no light are either (anti)-protons or charged kaons. The relative yield $f(p)$ ($f(\bar{p})$) of protons (antiprotons) was determined to be [11] $f(p) = \sigma(p)/\sigma(K^+) = 0.37 \pm 0.03$ and $f(\bar{p}) = \sigma(\bar{p})/\sigma(K^-) = 0.12 \pm 0.02$.

The uncorrected fractions $r^P(\text{trig})$ ($r^{\bar{P}}(\text{trig})$) of protons (antiprotons) among all positive (negative) secondary hadrons in the towards jets were determined by the time-of-flight system for $\Delta y = |y - y(\text{trigger})| < 0.5$ for different trigger types. To minimize the influence of absorption and multiple scattering corrections only particles with $p_T > 0.8$ GeV/c were included. These corrections and geometrical acceptances tend to cancel in the fractions r^P and $r^{\bar{P}}$. The probability for misidentification is smaller than 5%.

The fractions measured are given in fig. 13:

$$r^{\bar{P}}(K^+, p) = 0.122 \pm 0.024, \quad r^{\bar{P}}(\pi^+) = 0.026 \pm 0.009$$

$$r^P(K^-, \bar{p}) = 0.161 \pm 0.030, \quad r^P(\pi^-) = 0.060 \pm 0.009$$

A significantly larger fraction $r^{\bar{P}}$ (r^P) is therefore observed for K^+ , p (K^- , $\bar{p}$) triggers when compared to π^+ (π^-) triggers. If high p_T protons are leading fragments of scattered quarks the following relation should hold (see also fig. 11(b)):

$$r_q^{\bar{P}}(p) \approx r^P(\bar{p}) \quad (3)$$

whereas one has

$$r_{qq}^{\bar{P}}(p) \approx r^P(\pi^-) \ll r^P(\bar{p}) \quad (4)$$

for high p_T protons from scattered diquarks. The lower index in formulae (3) and (4) indicates the baryon number of the fragmenting

parton. The approximate equality of relation (4) is expected from baryon number conservation since the diquarks carry a relatively large baryon number.

On the other hand the following relations should be fulfilled for meson triggers if they are leading quark and/or gluon fragments [3,4]:

$$r^{\bar{p}}(\pi^+) \approx r^{\bar{p}}(K^+) \quad , \quad r^p(\pi^-) \approx r^p(K^-) \quad (5)$$

Using relation (5) the measured densities of secondary (anti)protons can be derived from the above mentioned measured particle ratios:

$$r^p(\bar{p}) > 0.64 \text{ (90\% CL) and} \quad (6)$$

$$r^{\bar{p}}(p) = 0.38 \pm 0.09.$$

The fact that $r^{\bar{p}}(p)$ is smaller than $r^p(\bar{p})$ indicates that a diquark scattering mechanism (see relation (4)) contributes in addition to quark scattering in case of high p_T proton production. Calling ϵ the fraction of protons originating from scattered diquarks one gets:

$$r^{\bar{p}}(p) = \epsilon r_{qq}^{\bar{p}}(p) + (1 - \epsilon)r_q^{\bar{p}}(p). \quad (7)$$

From assumptions (3) and (4) and the experimental result for $r^p(\bar{p})$ one derives $\epsilon = 0.73^{+0.04}_{-0.27}$. Note that this result is insensitive to assumption (4), because r_{qq}^p and $r^p(\pi^-)$ are much smaller than $r^p(\bar{p})$.

In the region of phase space considered here, high p_T protons are produced dominantly from fragmentation of scattered diquarks. This is in good agreement with the previous conclusions. However, it should be pointed out that ϵ is obtained only from secondary particles restricted to $p_T > 0.8 \text{ GeV/c}$ and $p_{lab} < 2 \text{ GeV/c}$. The value of ϵ could be slightly different if these cuts were relaxed.

6. CORRELATIONS WITH AWAY JETS

Previous analyses of events triggered by $\pi^\pm$ and $K^\pm$ mesons produced at $\theta \approx 45^\circ$ with $p_T \gtrsim 4 \text{ GeV/c}$ revealed the existence of a large particle density with a maximum at $y \approx 0$ and $\Delta\phi = |\phi - \phi(\text{trigger})| \approx 180^\circ$ [1,3,4,25]. This is due to the jet of fragments from partons recoiling

against the trigger particle. Detailed measurements of the charge and kinematic structures indicate that both recoiling valence quarks and gluons are the origin of these away jets [4].

The corrected densities of positive and negative particles in the away jet are shown in fig. 14 for proton triggers relative to π^+ triggers at $\theta \approx 45^\circ$ and $p_T \geq 3.5$ GeV/c. The ratios $R^\pm(p/\pi^+)$ were obtained from charged particles with $\Delta\phi \geq 140^\circ$ and $|y| \leq 2$ and are given as function of

$$x_E = - \frac{\vec{p}_T^s \cdot \vec{p}_T(\text{trig})}{|\vec{p}_T(\text{trig})|^2}, \quad (11)$$

where the minus sign is introduced because here $\vec{p}_T^s$ is pointing away from the trigger. The observation that the ratios of positive and negative secondaries are compatible with values between 0.8 and 1.1 indicates that (i) away jets are produced in the case of proton triggers and (ii) the charge structure of the away jets, and hence the flavour of the away partons, is nearly the same for proton and π^+ triggers.

In fig. 15 corrected x_E distributions are shown for positive and negative particles with $\Delta\phi \geq 155^\circ$ and $|y| \leq 4$ in events with proton and positive meson triggers (π^+ and K^+) at $\theta \approx 10^\circ$ and $p_{\text{lab}} \geq 13$ GeV/c. Similar to the results at 45° [1,3,4,25], the measured densities exceed the inclusive yield at $p_T^s \geq 1$ GeV/c. Therefore the existence of away jets is demonstrated as well for high p_T triggers at $\theta \approx 10^\circ$. Finally, the ratios $R^\pm(p/\pi^+)$ of densities from fig. 15 are shown in fig. 16. The experimental values are compatible with unity. This provides additional support for the idea that the flavour composition of recoiling partons is similar for proton and positive meson triggers at $\theta \approx 10^\circ$. Specifically, the similarity of the charge structure of away jets for π^+ -meson triggers and for proton triggers means that the differences of the trigger production mechanisms do not seriously affect the away side.

7. SUMMARY

Mechanisms for high- p_T proton production at $\theta \approx 10^\circ$, 20° and 45° were investigated. It was established that proton production is due to a hard parton scattering process giving rise to a 4-jet structure similar to

the case of high p_T meson production. A strong suppression of positive charges in the spectator jets at $\theta \approx 0^\circ$ in the case of proton triggers, when compared with π^+ triggers, is observed. While this finding rules out a large contribution to high p_T proton production from single quark scattering, it agrees with the expectation from hard scattering and subsequent fragmentation of (ud) and/or (uu) diquark systems as the dominant mechanism yielding proton triggers [7]. A measurement of baryon number conservation in the towards jet supports the diquark picture and allows one to estimate the fraction of protons due to diquark scattering to be $(0.73^{+0.04}_{-0.27})$ at $\theta \approx 45^\circ$. The way the trigger electric charge is compensated for in the towards jet indicates that (ud) systems are involved in most cases. Observation of Δ^{++} production suggests in addition a non-negligible (uu) diquark component to high p_T proton production.

The main features of the away jet produced with proton triggers are similar to those of pion triggers where the away jet has been shown to arise from valence quark and gluon fragmentation.

The conclusion that hard diquark scattering plays a significant rôle in high- p_T proton production was derived independently of specific model calculations. However, it is in qualitative agreement with predictions from a detailed hard diquark scattering model [7].

The observed importance of hard diquark scattering should lead to a reinterpretation of the structure functions of the proton.

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FIGURE CAPTIONS

- Fig. 1 Relative (anti)-proton yields $\sigma(p)/\sigma(\pi)$ as functions of a) p_T for $\theta \approx 45^\circ$ and $\sqrt{s} = 62$ GeV (ref. [11]) and b) $\sqrt{s}$ at $x_T = 2p_T/\sqrt{s} = 0.15$ at large angles θ (refs [7,8]). c) Relative (anti)-proton yields $R(p) = \sigma(p)/\sigma(\text{pos. hadr.})$ and $R(\bar{p}) = \sigma(\bar{p})/\sigma(\text{neg. hadr.})$ as functions of θ for fixed p_T (ref. [11]).
- Fig. 2 Expected flavour composition of spectator jets for pion and proton triggers.
- Fig. 3 Ratios of positive spectator secondaries associated with proton and pion triggers at $\theta \approx 10^\circ$ with $p_{\text{lab}} \geq 13$ GeV/c (π^+ trigger: a), π^- trigger: b)). The shaded regions indicated at large x_F are predictions based upon deep inelastic neutrino scattering data.
- Fig. 4 The same as fig. 3, but for negative spectator secondaries.
- Fig. 5 Ratios of positive (a) and negative (b) spectator secondaries associated with proton and π^+ meson triggers at $\theta \approx 20^\circ$ and $p_{\text{lab}} \geq 13$ GeV/c.
- Fig. 6 The same as fig. 5, but for proton and π^+ meson triggers at $\theta \approx 45^\circ$ and $p_T \geq 3.5$ GeV/c ($\langle p_T \rangle = 3.9$ GeV/c).
- Fig. 7 Correlation between Feynman- x_F and the fragmentation variable $z = p/p_{\text{max}}$ in the spectator jet as obtained from parton model calculations (shaded area). The resolution in z for fixed $x_F = 0.45$ is indicated as the smooth curve on the vertical axis.
- Fig. 8 Charge density ratio $R_\rho = \rho^-/\rho^+$ as a function of x_F for pion and proton triggers. The shaded regions are predictions based upon deep inelastic neutrino and antineutrino scattering experiments for (ud) and (uu) target jet systems.

FIGURE CAPTIONS (Cont'd)

- Fig. 9 Charge density ratio $R_\rho = \rho^-/\rho^+$ for proton triggers compared to predictions based upon deep inelastic neutrino scattering for pure u-quark fragmentation and for a mixture of 33% d-quark and 67% u-quark fragmentation.
- Fig. 10 Uncorrected $p\pi^+$ invariant mass distributions of particles in the trigger jet for proton trigger particles at $\theta \approx 10^\circ$ and $13 \text{ GeV/c} \leq p_{\text{lab}} \leq 18.1 \text{ GeV/c}$, $\theta \approx 20^\circ$ and $13 \text{ GeV/c} \leq p_{\text{lab}} \leq 18.1 \text{ GeV/c}$, and $\theta \approx 45^\circ$ and $p_T \geq 4 \text{ GeV/c}$.
- Fig. 11 (a) Schematic representation of u, (ud) and (uu) fragmentation into leading hadrons in the trigger jet.
(b) Schematic representation of quark and diquark fragmentation into rank 2 protons and antiprotons.
- Fig. 12 Ratio of negative (a) and positive (b) particle densities in the towards jet as functions of z_F for proton and π^+ meson triggers at $\theta \approx 45^\circ$ and $p_T \geq 3.5 \text{ GeV/c}$.
- Fig. 13 Fraction of protons (a) and antiprotons (b) among all positive (a) and negative (b) secondary particles in the trigger jet at $\theta \approx 45^\circ$ and $p_T \geq 4 \text{ GeV/c}$ for various trigger particles.
- Fig. 14 Ratio of positive (a) and negative (b) particle densities in the away jet as functions of x_E for proton and π^+ triggers at $\theta \approx 45^\circ$ and $p_T \geq 3.5 \text{ GeV/c}$.
- Fig. 15 Corrected x_E spectra for positive and negative particles associated with proton and positive meson (π^+ and K^+) triggers at $\theta \approx 10^\circ$ and $p_{\text{lab}} \geq 13 \text{ GeV/c}$ (away side).
- Fig. 16 Ratios of densities of positive (a) and negative (b) particles from fig. 15 (away side).

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16