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Observation of Correlations Between Forward Protons and 90° Trigger Protons at $\sqrt{s} = 62 \text{ GeV}$

(R608 collaboration)

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Abstract: We study the production of π^+ 's and protons at 90° with $p_t > 1.15 \text{ GeV}$ and their correlations with forward protons. Fewer forward protons are observed for a 90° proton trigger than for a π^+ trigger. This is in qualitative agreement with the idea of an effective diquark scattering mechanism. Additionally, we observe that a K^+ produced at 90° is correlated with an enhanced forward production of Λ^0 .

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The production of large transverse momentum particles signals the occurrence of a hard scattering between constituents of the colliding hadrons. The production of high- p_t mesons can be quantitatively understood by QCD [1] and the meson identity used to tag the flavour of the scattered parton [2]. However, the observed excess of high- p_t protons relative to antiprotons at large angles in pp collisions

[3,4,5] (suggesting that some of the protons are not pair-produced) is not understood within the conventional framework of quark and gluon scattering[6,7].

Recent results from the ISR[4] on the ratio of proton to meson yields have been interpreted[7] in terms of a scattering of a (tightly bound) diquark from a beam proton. Whether or not this interpretation is correct in detail, an effective diquark scattering mechanism seems to play a role in these processes.

To investigate this problem further, we present in this Letter a first study of correlations between identified forward protons and 90° π^+ and proton triggers. If effective diquark scattering is playing a role in these interactions, we expect to see a depletion of forward protons when a high- p_t proton is observed at 90° . Correlations between other identified particles are also presented.

The measurements reported here were performed with the apparatus of experiment R608, shown in Fig. 1, at the CERN Intersecting Storage Rings. The 90° spectrometer consisted of a (vertically bending) magnet with field integral 0.44 Tm, 13 drift chamber planes, 2 silica aerogel Cerenkov counters and 2 hodoscopes of scintillators. The first level trigger consisted of a coincidence between the front and back 90° hodoscopes and, when studying $0^\circ/90^\circ$ correlations, the signature for at least one track traversing the forward spectrometer. To enhance the yield of higher p_t events at 90° , a second level trigger required proper coincidences between the cells of a multiwire proportional chamber before the 90° magnet and the hodoscope array after the magnet.

The two aerogel Cerenkov counters in the 90° spectrometer each consisted of 7 horizontal cells with a photomultiplier at each end. Adjacent cells were optically isolated from one another. The π , K and proton thresholds were 0.5, 2.0 and 3.8 GeV in the first counter (C1) and 0.3, 1.0 and 2.0 GeV in the second counter (C2). Therefore π , K and protons were fully separated between 1.15 and 2.25 GeV/c in the overall center-of-mass, which is the range of the results reported here. For $\beta \approx 1$ particles, there were 5.1 ± 1.5 and 5.7 ± 2.0 photoelectrons in C1 and C2, respectively; scintillation light produced in the walls of the aerogel counters yielded an average of 0.1 photoelectron. We estimate that misidentified kaons account for 15% of the proton sample and 3% of the pion sample. Corrections are made for these backgrounds in the analysis described below but do not significantly affect any of our conclusions.

The forward spectrometer[8] has an aperture of ± 150 mradian in both the vertical and horizontal planes. A septum plate to protect the circulating beam from the magnetic field causes a blind region for $-23 < \theta < 23$ mrad in the vertical plane. The 16-cell two-threshold Cerenkov counter system in the forward spectrometer allows unique identification of pions in the momentum range 3–17 GeV, kaons in the range 10–17 GeV and protons in the range 10–32 GeV. There is an average of 2.3 tracks in the forward spectrometer in the $0^\circ/90^\circ$ correlation event sample. 74% of the events have at least one track (average 1.4) in the above ranges of momentum which is therefore uniquely identified. The correlation results presented here are for these particles.

In order to compare measurements from our experiment with those of previous experiments and also to review the yields of protons, pions and their antiparticles at 90° , we first consider the inclusive production of these particles. Fig. 2 shows the ratios of protons to all positive particles ($p/+$) and antiprotons to all negative particles ($\bar{p}/-$) vs. p_t for two ISR energies, $\sqrt{s} = 31$ and 62 GeV. The results have been corrected for decay, nuclear absorption and Cerenkov mis-identification arising from both inefficiencies and scintillation light. For comparison, we also plot results of the Chicago-Princeton collaboration[3] (CP) at $\sqrt{s} = 27$ GeV and of the British-Scandinavian collaboration[9] (BS) at $\sqrt{s} = 31$ and 62 GeV. At 31 GeV, the $p/+$ ratios of all three experiments are in good agreement. While our $\bar{p}/-$ ratios at 31 GeV are in reasonable agreement with CP, the BS ratios are systematically larger (this is probably due to systematic uncertainties in the BS data which are not included in these quoted errors[10]). At 62 GeV the BS $p/+$ and $\bar{p}/-$ ratios are also systematically larger than our results. We note the agreement of our results with CP at the lower energy and thus confirm the excess of protons compared to antiprotons observed in refs. [3,4,5]. We find $(p/+)/(\bar{p}/-) \approx 1.3$.

The curves in Fig. 2 are the results of a QCD Monte Carlo calculation[11] of leading order quark and gluon scattering using conventional structure[12] and fragmentation[13] functions. Although the limited p_t scale of a few GeV suggests uncertainties in this calculation with respect to both the perturbative part and the hadronization of not very energetic jets, we note that $\alpha_s < 0.4$ in the present calculation and that similarly low energy jets produced in other interactions are reasonably well described by the model[14]. The observed relative rates of different triggers $\pi^\pm$, $K^\pm$ and $\bar{p}$ are also quite well reproduced (not shown here). The QCD curve for $\bar{p}/-$ is seen to agree well with our values for this ratio. However, our $p/+$ results are substantially larger than the QCD expectations. This difficulty in understanding large angle proton production in a conventional way has been noticed earlier, e.g. in ref. [6] for FNAL data[3] and in [7] for ISR data.

Table I shows the data sample from our correlation measurements. There are a total of 32,374 events, each of which contains one identified trigger particle with $1.15 < p_t < 2.25$ GeV/c in the 90° spectrometer and at least one particle in the forward spectrometer. In each column the entries show the fraction of the 90° triggers which have the indicated identification for the forward particle. The fractions in a given column do not add up to unity because individual events may have zero or more than one forward identified particle, as explained above. Although the Table entries in a given column correspond to different ranges of momentum, the entries in a given row do not have this limitation and may be compared.

Table I shows that, within the available statistics, the yields of K^+ , K^- and $\bar{p}$ in the forward spectrometer are independent of the flavor of the 90° trigger particle. The remainder of the higher statistics entries in Table I, for π^+ , π^- , p and Λ^0 forward, are plotted in Fig. 3. We first note two simple charge correlations expected from the contribution of valence quark scattering. There are fewer forward π^- observed with a π^- 90° trigger than with a π^+ 90° trigger. Forward π^+ are also less abundant with a π^+ trigger than with a π^- trigger, although the statistical significance is less. A long-range strangeness correlation is also observed by the increased forward Λ^0 rate in case of a K^+ trigger. This can be understood through s-quark scattering leaving an s-quark in the proton remnant.

The result in Fig. 3 does not show a very significant effect for forward protons. However, we find that the correlation effect increases with increasing momentum of the forward proton. This is shown in Fig. 4 which is the dependence on $x_F'^{-1}$ of the ratio of forward proton entries in Table I for proton and π^+ 90° triggers. Fig. 4 demonstrates that the more leading the forward proton is, and hence the more likely it is to contain valence spectator quarks, the stronger is the correlation effect. This correlation effect is not expected if the trigger proton results from the scattering of a single quark or gluon. In fact, the QCD Monte Carlo calculation discussed above predicts the constant ratio of unity shown in Fig. 4. We note that earlier results reported in ref. [15] on the correlation between the charge of forward particles and large angle proton triggers are compatible with our results.

The observed proton correlation effect requires a mechanism which effectively scatters two valence quarks to a large angle. If a bound state diquark exists in the proton, as argued in ref. [16], it could scatter as a single entity although with a form factor suppression. Such a model was studied in ref. [7]. It was found that in order to reproduce ISR data on high- p_t proton production [4], this diquark must be a frequently occurring sub-state in the proton and also be surprisingly tightly bound or, equivalently, have a small size (≈ 0.2 fm). Although we have explicitly verified that the model in ref. [7] can be tuned to reproduce our observed correlation effect, other possible models which only require an "effective" diquark scattering may also agree with the data. In particular, our trigger protons have a smaller p_t and would therefore not necessarily require as strongly bound diquarks as is the case in ref. [7].

In conclusion, we have observed an excess of 90° trigger protons as compared to antiprotons. In events with such a proton trigger we also observe a reduced production of forward protons with $x_F' > 0.5$ in comparison with events with a π^+ 90° trigger. Neither of these effects can be understood in terms of single quark or gluon scattering. They argue, rather, for a mechanism which involves the

¹ We use a rescaled Feynman-x variable, $x_F' = x_F/(1 - 2 p_t/\sqrt{s})$, where p_t is the 90° trigger, to approximately take into account the reduced momentum of the spectator system. This choice is not, however, important for the result.

effective scattering of a diquark from the incoming proton. We also report an enhanced production of forward Λ^0 's when a K^+ is observed at 90° .

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TABLE I: Yields of Identified Forward Particles per 90° Trigger

	$\pi^+ 90^\circ$	$\pi^- 90^\circ$	$K^+ 90^\circ$	$K^- 90^\circ$	$p 90^\circ$	$\bar{p} 90^\circ$
No. Triggers	12,278	10,616	2,664	1,793	3,336	1,687
π^+ forward	$.360 \pm .005$	$.377 \pm .006$	$.373 \pm .012$	$.375 \pm .014$	$.372 \pm .010$	$.372 \pm .014$
π^- "	$.270 \pm .005$	$.244 \pm .005$	$.258 \pm .010$	$.233 \pm .012$	$.278 \pm .009$	$.235 \pm .011$
K^+ "	$.009 \pm .001$	$.011 \pm .001$	$.009 \pm .002$	$.009 \pm .001$	$.010 \pm .002$	$.007 \pm .002$
K^- "	$.053 \pm .002$	$.051 \pm .002$	$.054 \pm .004$	$.049 \pm .005$	$.055 \pm .002$	$.052 \pm .005$
p "	$.360 \pm .005$	$.371 \pm .006$	$.371 \pm .012$	$.358 \pm .014$	$.339 \pm .010$	$.372 \pm .014$
$\bar{p}$ "	$.003 \pm .001$	$.003 \pm .001$	$.002 \pm .001$	$.002 \pm .001$	$.004 \pm .001$	$.003 \pm .001$
Λ "	$.008 \pm .001$	$.007 \pm .001$	$.015 \pm .002$	$.009 \pm .002$	$.007 \pm .001$	$.009 \pm .002$

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Figure Captions

- 1. Layout of the R608 experiment at the CERN Intersecting Storage Rings.
- 2. p_t -dependence of trigger particle ratios at 90° degrees: (a,c) protons to all positive particles, (b,d) antiprotons to all negative particles. Data for two energies, $\sqrt{s} = 31$ GeV in (a,b) and $\sqrt{s} = 62$ GeV in (c,d), are shown for this experiment as well as from the Chicago-Princeton [3] and British-Scandinavian [9] collaborations. The curves are the QCD predictions discussed in the text.
- 3. Number of forward π^+ , π^- , p, Λ^0 per 90° degree trigger particle of given identity (see also Table I).
- 4. x'_F -dependence of the ratio of forward protons per 90° proton trigger to forward protons per 90° π^+ trigger.

Figure 1

Transverse Momentum (GeV/c)

FORWARD PARTICLES YIELDS