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ABSTRACT

We have measured two-particle quantum number correlations in 400 GeV/c proton-nucleus collisions. A double-arm spectrometer was used to detect two charged particles produced near $y_{CM} = -0.4$ in the proton-nucleon center-of-mass system. In proton-beryllium collisions we observe positive $p\bar{p}$ and K^+K^- correlations which are independent of the transverse momenta of the particles over the range $1 \leq p_\perp \leq 1.8$ GeV/c. These correlations are weaker in proton-lead interactions.

The nature of hadronic particle production at high energies has been studied extensively through measurements of inclusive single particle yields and multiparticle correlation strengths. Measurements at large transverse momenta ($p_\perp >> 300$ MeV/c) have been of particular interest in regard to testing ideas of constituent scattering[1]. The measurements reported here focus on an area which has not been explored previously in great detail, namely the dependence of two-particle correlations on the quantum numbers of the detected particles. These particles were detected with moderately high transverse momenta, $1.0 \leq p_\perp \leq 1.8$ GeV/c, a range for which the notion of hadron constituents might already be applicable.

The experiment was performed at the Fermi National Accelerator Laboratory and used a double-arm spectrometer to detect and identify two charged particles produced in 400 GeV/c proton-nucleus collisions. Components of the apparatus and other results have been described elsewhere[2]. Briefly, the spectrometer was triggered by a coincidence of two charged particles which were produced near rapidity -0.4 in the proton-nucleon center-of-mass system, with transverse momenta $p_\perp \geq 1$ GeV/c, and with azimuthal separation near 180°. The target used for the data reported in this letter consisted of thin, spatially-separated segments of beryllium and lead.

Each arm of the spectrometer was equipped with three threshold, gas-filled Cerenkov counters (C1, C2, and C3) which provided

charged hadron (p, $\bar{p}$, $K^{\pm}$, $\pi^{\pm}$) identification. The radiating media in the counters were nitrogen at 1 atm. for C1, propane at 2.16 atm. for C2, and carbon dioxide at 1.57 atm. for C3. Pion threshold momenta in the counters were determined from reconstructed particle momentum spectra to be 5.88, 2.01, and 3.68 GeV/c for C1, C2, and C3 respectively. The measured efficiencies of the counters were typically greater than 99%. Complete separation of p, K, and π was possible over a transverse momentum range $1 \leq p_{\perp} \leq 1.8$ GeV/c.

The data were corrected for meson decay and misidentification of particle type due to Cerenkov inefficiencies and spurious signals. The kaon decay correction varied from 12 to 25% depending on momentum whereas the pion decay correction was only 0.9 to 2.8%. The correction for counter inefficiencies was small: in the worst case, less than 2.5% of pions were misidentified as kaons in the raw data. Spurious Cerenkov signals from the traversal of the counters by other particles (including electromagnetic shower fragments) presented a more serious identification problem[3]. About 30% of kaons and protons gave logically invalid Cerenkov responses because of such additional particles. Events with invalid responses were rejected and their loss was properly taken into account in the calculation of correlation strengths. We stress that particles which gave valid responses were identified correctly with a high degree of confidence. Our systematic error in the correlation strengths was estimated from

a separate set of data in which events from a pure beryllium target were observed with a rearranged experimental apparatus.[4] A comparison of the correlation strengths observed in Be from the two sets of data indicates that systematic errors were equal to or smaller than the statistical errors.

It is convenient to study the quantum number correlations independently of the kinematic correlations by confining the investigation of the quantum number correlations to the two-particle inclusive measurements.[5] For these purposes we designate one of the arms of the apparatus as the trigger side and the other arm as the opposite side. Both the trigger-side and opposite-side particles are constrained to have $1 \leq p_\perp \leq 1.8$ GeV/c. The hadrons in the opposite arm are separated by electric charge and denoted by h^+ and h^-. We then calculate p, K^+, and π^+ fractions opposite a particular hadron t in the trigger arm, and denote these fractions by $(p/h^+)_t$, $(K^+/h^+)_t$, and $(\pi^+/h^+)_t$. Similarly, the negative particle fractions are denoted by $(\bar{p}/h^-)_t$, $(K^-/h^-)_t$, and $(\pi^-/h^-)_t$. The strength of the quantum number correlation between an opposite-side particle and each trigger-side particle is defined as the ratio of the fraction opposite a particular trigger hadron t to the fraction averaged over all trigger hadrons h. For example, the $p\bar{p}$ correlation is given as $(p/h^+)_{\bar{p}}/(p/h^+)_h$.

The dependence of the opposite-side particle fractions on the identity of the trigger particle is shown in Fig. 1 for p-Be and p-Pb collisions. For p-Be collisions the values of the opposite-side particle fractions show a strong dependence on the identity of the trigger-side particle. The proton fraction opposite $\bar{p}$ is

enhanced by a factor of 1.92 ± 0.09 compared to the proton fraction opposite all trigger hadrons. A similar enhancement by a factor of 1.41 ± 0.07 is observed for K^+ opposite K^-, compared to K^+ opposite all trigger hadrons. The π^+ fractions exhibit depletions opposite $\bar{p}$ and K^- which are a reflection of the strong $p\bar{p}$ and K^+K^- correlations, since the three fractions $(p/h^+)_t$, $(K^+/h^+)_t$ and $(\pi^+/h^+)_t$ must add up to unity for each trigger hadron t.

The $p\bar{p}$ and K^+K^- correlations observed in the Be data are significantly smaller in the Pb data as demonstrated in Table I. In the Pb data, the $p\bar{p}$ enhancement is only 1.26 ± 0.09, and the K^+K^- enhancement is only 1.10 ± 0.07.

We have also investigated the $p_\perp$ dependence of the quantum number correlations observed in the Be data. We divide the data sample into several ranges according to the sum $p_s = |p_{\perp 1}| + |p_{\perp 2}|$, and difference $p_d = \big||p_{\perp 1}| - |p_{\perp 2}|\big|$, of the magnitudes of the transverse momenta of each particle. (For the geometry of our apparatus, p_s is approximately equal to the effective mass of the pair, and p_d is approximately equal to the total $p_\perp$ of the pair.) For particle a (= p, K^+, π^+) we calculate the ratio of the particle fractions $(a/h^+)_{\bar{a}}/(a/h^+)_h$ at each bin. We observe no statistically significant dependence of the ratio with p_d, and hence we integrate over p_d and show the ratio as a function of p_s in Fig. 2. We find no evidence for a $p_\perp$ dependence of the correlations as we vary the $p_\perp$ of each particle over the range $1 \leq p_\perp \leq 1.8$ GeV/c.[6]

In summary, we observe proton-antiproton and K^+K^- correlations for hadron pairs produced in 400 GeV/c p-Be collisions near y_{CM}

$= -0.4$ with $\Delta\phi \simeq 180^{\circ}$ and $1 \leq p_{\perp} \leq 1.8$ GeV/c. In this kinematic region, these correlations are significantly smaller for production in large nuclei such as lead.[7] We also observe that these correlations have no strong dependence on the transverse momenta of the particles. These data should provide a fairly strict test of models which address particle production in the moderately high $p_{\perp}$ range covered by this experiment.

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[2]D. Bintinger et al., Phys. Rev. Lett. 37, 732 (1976); R. Thun et al., Nucl. Instr. and Meth. 138, 437 (1976); C. W. Akerlof et al., Phys. Rev. Lett. 39, 86 (1977); W. R. Ditzler et al., Phys. Lett. 71B, 451 (1977); D. A. Finley, Ph.D. Thesis, Purdue University, 1978 (unpublished).

[3]The relative frequency of spurious Cerenkov signals was estimated from single-particle inclusive data in which one arm was used as the trigger, and the other (untriggered) arm recorded the relative frequency of Cerenkov signals.

[4]The original configuration of the apparatus is described in D. Bintinger et al. (Ref. 2), and the rearranged configuration (for which one of the Cerenkov counters was relocated behind the magnet) is described in W. R. Ditzler et al. (Ref. 2).

[5]Our kinematic correlation results are reported in "Nucleon-Number Dependence of Inclusive Dihadron Production in Proton-Nucleus Collisions at 400 GeV/c", D. A. Finley et al., submitted to Phys. Rev. Lett.

[6]Other experiments have investigated quantum number correlations in kinematic regions which are different from ours. M. G. Albrow et al., Phys. Lett. 65B, 295 (1976), observe correlations in p-p interactions at $\sqrt{s}$ = 53 GeV which are in quantitative agreement with our p-Be results, even though their experiment covers an angular region that is very different from ours yet is in a similar effective mass region. The Stony Brook-Columbia-Fermilab collaboration [see R. J. Fisk et al., Phys. Rev. Lett. 40, 984 (1978), and R. J. Fisk, Ph.D. Thesis, State University of New York at Stony Brook, 1978 (unpublished)] have reported on correlations in 400 GeV/c p-Be collisions at a slightly different angular region but larger effective mass region than ours.

[7]The observation that heavier nuclei reduce quantum number correlations as well as kinematic correlations (see D. A. Finley et al., Ref. 2) is consistent with an inelastic multiple scattering process.

TABLE I. Comparison of ratios of particle fractions for particle-antiparticle pairs in p-Be and p-Pb interactions. These ratios would be unity if there were no quantum number correlation in the production of particle-antiparticle pairs. The error bars are statistical only.

Ratio	Be	Pb
$(p/h^+)_{\bar{p}} \;/\; (p/h^+)_h$	1.92 ± 0.09	1.26 ± 0.09
$(K^+/h^+)_{K^-} \;/\; (K^+/h^+)_h$	1.41 ± 0.07	1.10 ± 0.07
$(\pi^+/h^+)_{\pi^-} \;/\; (\pi^+/h^+)_h$	1.04 ± 0.01	1.03 ± 0.01

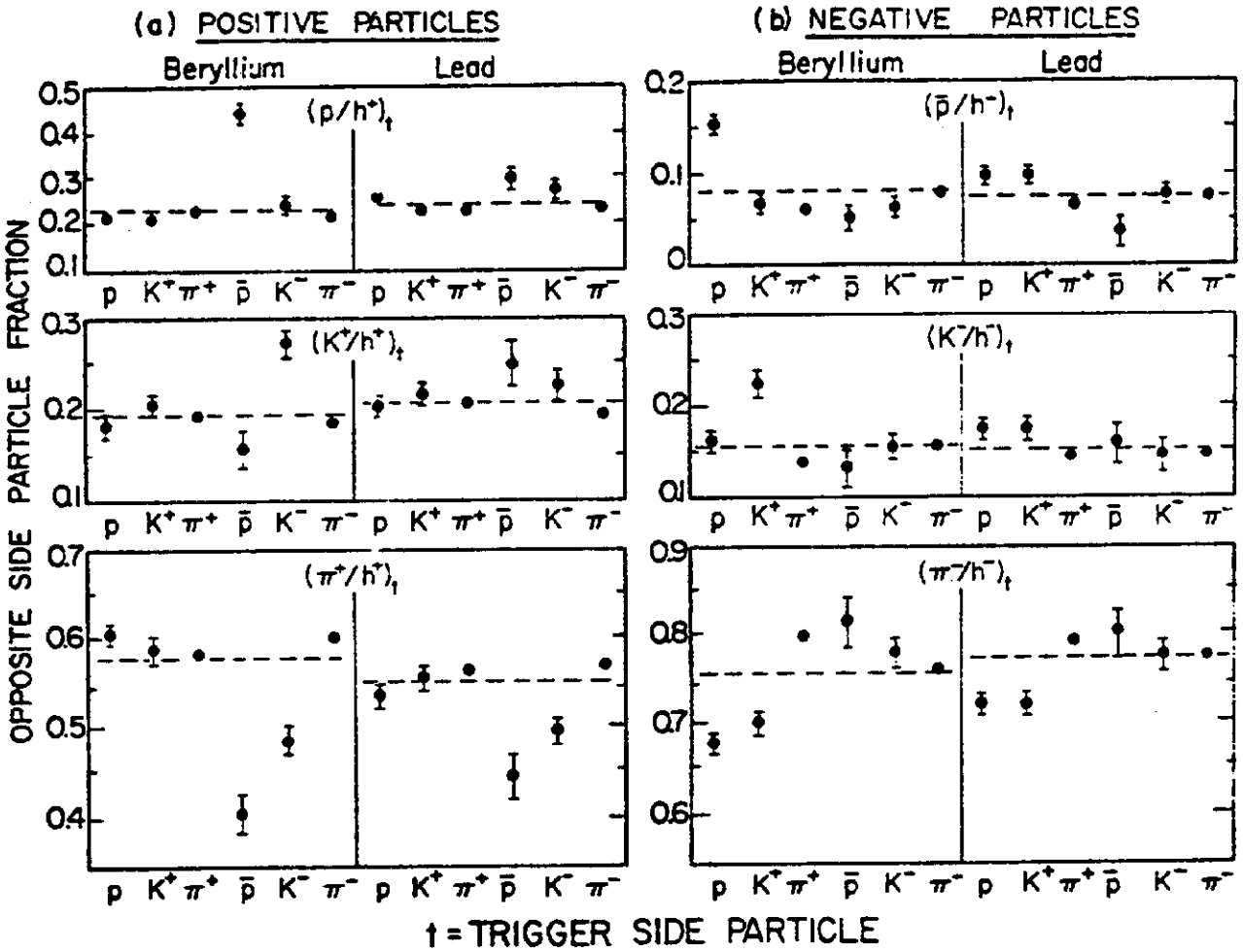

Fig. 1. Dependence of the opposite-side particle fractions on the trigger particle species for p-Be and p-Pb interactions. Part (a) shows the positive particle fractions and (b) shows the negative particle fractions. All particles are restricted to the range $1 \leq p_\perp \leq 1.8$ GeV/c. The dashed line indicates the opposite-side fraction for each case averaged over all trigger hadrons. The error bars are shown only when they are larger than the points, and are statistical only.

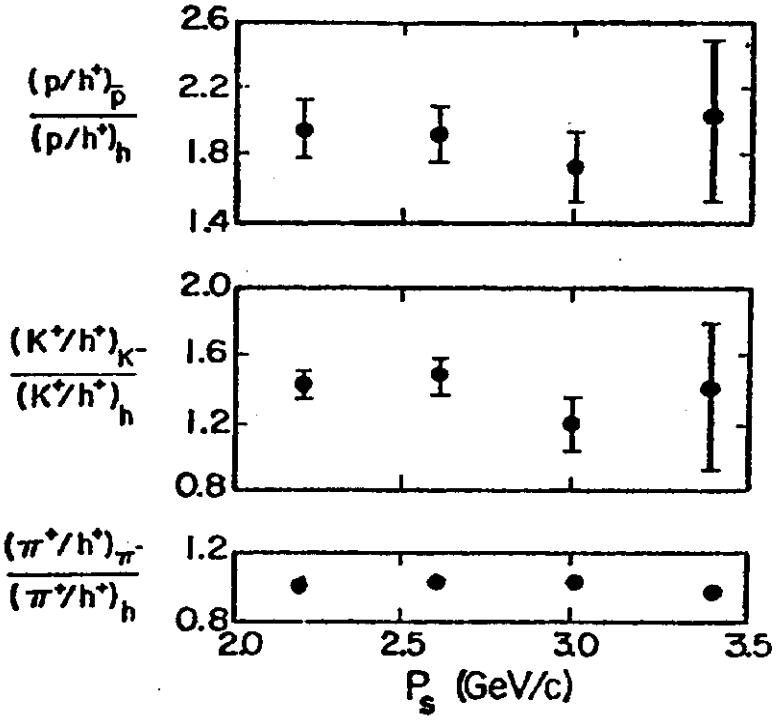

Fig. 2. p_s-dependence of particle-antiparticle quantum number correlations in p-Be collisions. p_s is the sum of the magnitudes of the transverse momenta of the two particles; the data have been integrated over $p_d = |\,|p_{\perp 1}| - |p_{\perp 2}|\,|$. The error bars are shown only when they are larger than the points, and are statistical only.