Fermi National Accelerator Laboratory

FERMILAB-Pub-78/15-EXP
7210.494
(Submitted to Phys. Rev. Lett.)

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February 1978

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administratio

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We have studied the interactions of 400 GeV/c protons with beryllium nuclei and observed hadrons produced at large transverse momenta ($p_\perp$) back to back near 90^o in the proton-nucleon center of momentum system. When both transverse momenta exceed about 2.6 GeV/c we observe that the probability per single hadron of observing a second high $p_\perp$ hadron on the opposite side approximately scales in the ratio of the two transverse momenta (x_e scaling). Quantum number correlations between the opposite going high $p_\perp$ hadrons are weak.

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In previous letters[(1),(2)] we have presented results on the production of massive hadron pairs interpreted as decay products of intermediate states, and a measurement of the nucleon number dependence of the pair production cross sections. In this paper we present data on x_e-scaling and quantum number correlations, both of which probe the underlying interaction process.

We have studied the interactions of 400 GeV/c protons in a beryllium target and observed hadrons produced back-to-back near 90° in the proton-nucleon center of momentum system (CMS). Figure 1 shows a diagram of our double-arm magnetic spectrometer[(1-3)], equipped with Čerenkov particle identification and hadron calorimeter triggering. Calorimeter signals[(1)] were weighted with scintillation counter production angle information in order to form a signal proportional to the transverse momentum ($p_\perp$) of the hadron in each arm. The pair trigger required that the sum of the two $p_\perp$ signals exceed a preset threshold. Prescaled single hadron data were taken simultaneously with the pair data by triggering on each $p_\perp$ signal separately. The efficiencies of the data triggers were measured during runs with less restrictive triggers. Trajectories of hadrons were measured with multiwire proportional chambers. All detectors were placed downstream of the analysing magnets so that high beam intensities could be accepted. A discussion of systematic errors has been reported earlier[(1,2)].

In the following, one of the spectrometer arms will be arbitrarily designated as the "trigger arm", while the other one will be called the "away arm". We average over both possible choices where appropriate. We then define[(4)] the ratio of the transverse momenta in the two arms as $x_e \equiv p_{\perp away}/ p_{\perp trig}$. We define the away side multiplicity $n(x_e min)$ to be the conditional probability of finding an away side hadron with $x_e \geq x_e min$ for all events where a hadron with $p_{\perp trig}$ in a given range was detected in the trigger arm. We denote by dn/dx_e the corresponding differential conditional probability. In this experiment, these probabilities are given by the ratio of pair events to single hadrons within the relevant ranges in x_e and $p_{\perp trig}$. Appropriate corrections are made for Čerenkov acceptance and trigger efficiencies as a function of $p_\perp$ so that the quoted probabilities are given for all hadrons emitted into our total away side (CMS) solid angle of 65 millisteradians. This acceptance (of each spectrometer arm) in production angle (θ) and azimuth (ϕ) is closely approximated by $|\cos(\theta)| \leq 0.31$ and $|\phi(\theta)| \leq (0.0525 + 0.05 \cos(\theta))$ radians. Note that due to the small acceptance in ϕ, only nearly coplanar pairs are accepted.

The function $dn/dx_e(x_e)$ is closely related to the "quark decay function" defined in constituent scattering models[5-9] and as such should be nearly independent of $p_{\perp trig}$. This independence is called "x_e scaling". We have investigated the validity of x_e scaling by plotting $n(x_e\min)$ for various $x_e\min$ as a function of $p_{\perp trig}$. Fig. 2 shows our data on $h^{\mp} h^{\pm}$ pairs for $p_{\perp trig}$ from 2 to 6 GeV/c. (The symbol h represents a charged hadron regardless of identification.) We note that once $p_{\perp trig}$ exceeds about 2.6 GeV/c, the away side multiplicity is nearly independent of $p_{\perp trig}$, in spite of the large change in single hadron cross sections (about a factor of 10^5) between $p_\perp$ of 2.6 and 6 GeV/c.

In a constituent scattering picture, the small size of our azimuthal angle acceptance makes our measurements sensitive to the transverse momenta of the hadrons within the jets and the initial transverse momenta of the constituents within the beam and target nucleons. Therefore we compare our data with the predictions of a specific quark-quark scattering model for $\pi^+ \pi^-$ production into our apparatus[10]. We have extrapolated the model predictions from nucleon number A=1 (p and n average) to beryllium, using our measurements[2] on a tungsten target with the assumption that dihadron production cross sections are proportional to A^{α}. The essential quantity entering the extrapolation procedure is the difference between α values for pair events and single hadrons. The extrapolated model predictions are shown in Fig. 2 as bands the limits of which correspond to our uncertainty in α. The absolute level of the predictions is quite sensitive to the initial transverse momentum distribution of the constituents (which is poorly known) but the shape of the predictions reflects the constituent nature of the model[10]. The predictions have all been divided by an arbitrary factor of 3.6 (in addition to ignoring all hadrons other than pions) in order to achieve the level of agreement with the data shown in Fig. 2. At low $p_{\perp trig}$ the curves of the measured multiplicities do not exhibit the expected shapes. However, at higher $p_{\perp trig}$ the predicted approximate x_e scaling is observed.[11] Our data are consistent with results in proton-proton collisions[12,13], but our relatively high statistical precision enables us to cover a broader range in $p_\perp$ (and especially in $x_\perp = 2\, p_\perp/\sqrt{s}$). This observation of x_e scaling supports the relevance of constituent scattering models at high $p_\perp$.

Experiments in which both high $p_\perp$ hadrons are identified can, in a constituent scattering picture, differentiate models in which the underlying scattering mechanism is flavor independent from those in which quantum numbers are exchanged between the participating constituents. In the first case[5,7,8] the multiplicity of π, K and p in the away arm does not depend on the species in the trigger arm[14]. In the second case[9] one could expect an enhancement of K^+ opposite K^- (strangeness exchange) and of $\bar{p}$ opposite p (baryon number exchange).

In Fig. 3 the differential probability dn/dx_e for finding a K^- in the away arm is plotted for events triggered by π^+ and K^+. We see that both in shape and absolute level the K^- production in the away arm is independent of the trigger species. Hence we see no evidence for strangeness exchange in the region $3 \leq p_{\perp trig} \leq 4$ GeV/c.

Figure 4 shows the away side multiplicities n(0.75) for all species combinations with significant statistical accuracy in the high $p_\perp$ region. In this figure we have added a 10% systematic uncertainty in quadrature with the statistical uncertainty. The arrows show for comparison our measured single hadron ratios at $p_\perp = 3.3$ GeV/c (normalized at about the pion away side multiplicity). In all cases the away side multiplicities are roughly independent of the trigger species and similar to the single hadron ratios, supporting a flavor independent constituent scattering picture. Pion multiplicities opposite K^-, p and $\bar{p}$, however, are smaller than those opposite π^+, π^- and K^+. Hence, deviations from exact flavor independence are observed. We indicate with dashed error bars values of n extrapolated to A = 1 using our limited information[2] on the A dependence of pair cross sections as a function of species. The accuracy of the data is decreased by the extrapolation but the above conclusions are not altered. (In particular the extrapolation decreases the K^+K^- correlation relative to π^+K^-.)

Because of the excess of p over $\bar{p}$ and K^+ over K^- seen in Fig. 4, our data show an excess of h^+ over h^- opposite all meson triggers. We do not observe the strong enhancement of the h^+/h^- ratio on the away side opposite K^- and $\bar{p}$ triggers[15] reported in reference 13. However, the two experiments do cover different kinematic regions, particularly in $x_\perp$.

In summary, we have observed approximate x_e scaling of the conditional probability to observe a high $p_\perp$ hadron opposite a high $p_\perp$ trigger. Detailed calculations[10] succeed in predicting the shapes of the scaling curves but fail to predict the level. Quantum number correlations between the opposite going hadrons are weak but deviations from exact flavor independence have been observed.

We wish to thank the many people from the technical staffs of the Fermi National Accelerator Laboratory, Nevis Laboratories, and the State University of New York at Stony Brook for their assistance and efforts throughout the course of this experiment. This work was supported in part by the National Science Foundation and the U.S. Department of Energy.

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    The theory is unable to predict baryon away side multiplicities, so no predictions for $h^{\mp} h^{\pm}$ are available. Similar but less precise conclusions are reached using our $\pi\pi$ data.
11. In fact from Fig. 2 we see that this agreement holds for all points measured with $(p_{\perp trig} + p_{\perp away}) \gtrsim 5.6$ GeV/c.
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13. H. Boggild and K. Hansen, contribution to the "Workshop on Large Transverse Momentum Phenomena", Pp 21-26, BI-TP 77/39 Nov. 77, University of Bielefeld preprint.

14. The presence of neutrons in the target besides protons introduces a small flavor correlation which can be neglected here. We ignore the interference terms which should arise in the scattering of identical quarks. See Refs. 4 and 6.

15. This statement is not sensitive to the extrapolation to $A = 1$ and will be dealt with in more detail in a future publication.

FIGURE CAPTIONS

Fig. 1 Diagram of our apparatus.

Fig. 2 The away side multiplicities $n(x_e min)$ as a function of trigger transverse momentum $p_{\perp trig}$ for dihadrons $(h^{\mp}h^{\pm})$. The dashed bands give the predictions of a hard scattering model for $(\pi\pi)$[10] into our apparatus including the extrapolation from A=1 to beryllium and its uncertainty. Corrections have been made for the $p_\perp$ dependence of the apparatus acceptance (see text). The multiplicities are shown for four different values of $x_e min$. Since $dn/dx_e(x_e)$ is a steeply falling function of x_e (see Fig. 3), the multiplicities are largely uncorrelated and sample different regions of x_e.

Fig. 3 The differential conditional probability $dn/dx_e(x_e)$ for finding a K^- in the away arm for events triggered by π^+ and K^+. These are beryllium data.

Fig. 4 The away side multiplicity n(0.75) for Čerenkov identified hadrons opposite various trigger species. The arrows show our measured single hadron ratios (normalized at about the pion away side multiplicity). The points with dashed error bars have been extrapolated to A=1.

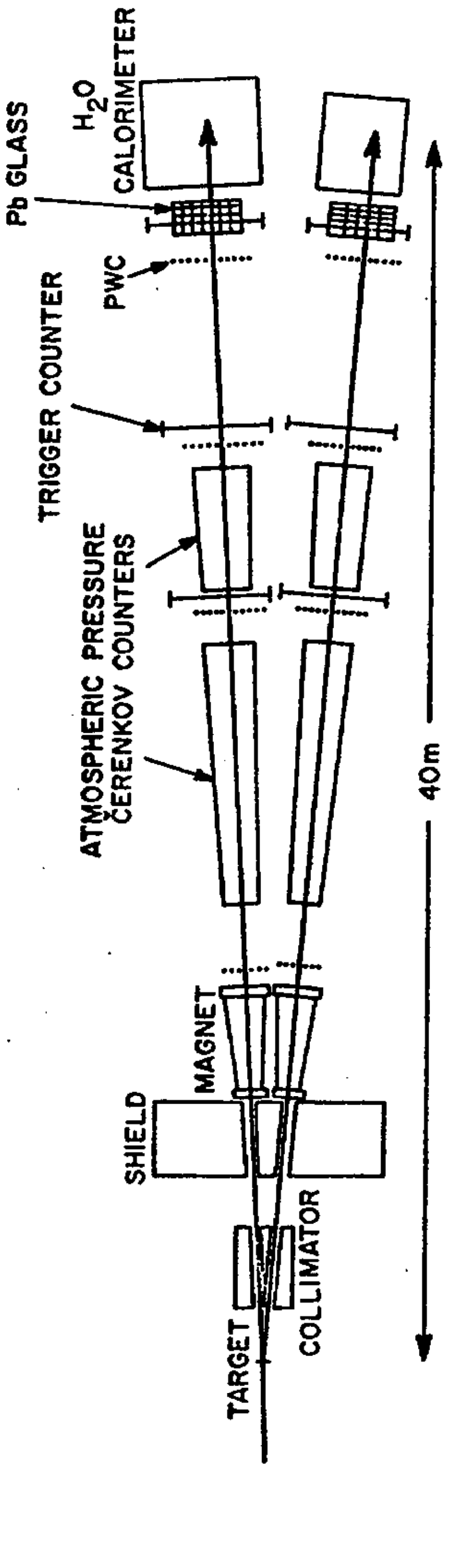
TARGET
COLLIMATOR
SHIELD
MAGNET
ATMOSPHERIC PRESSURE
ČERENKOV COUNTERS
TRIGGER COUNTER
PWC
Pb GLASS
H_2O
CALORIMETER
40m

FIG. 4.

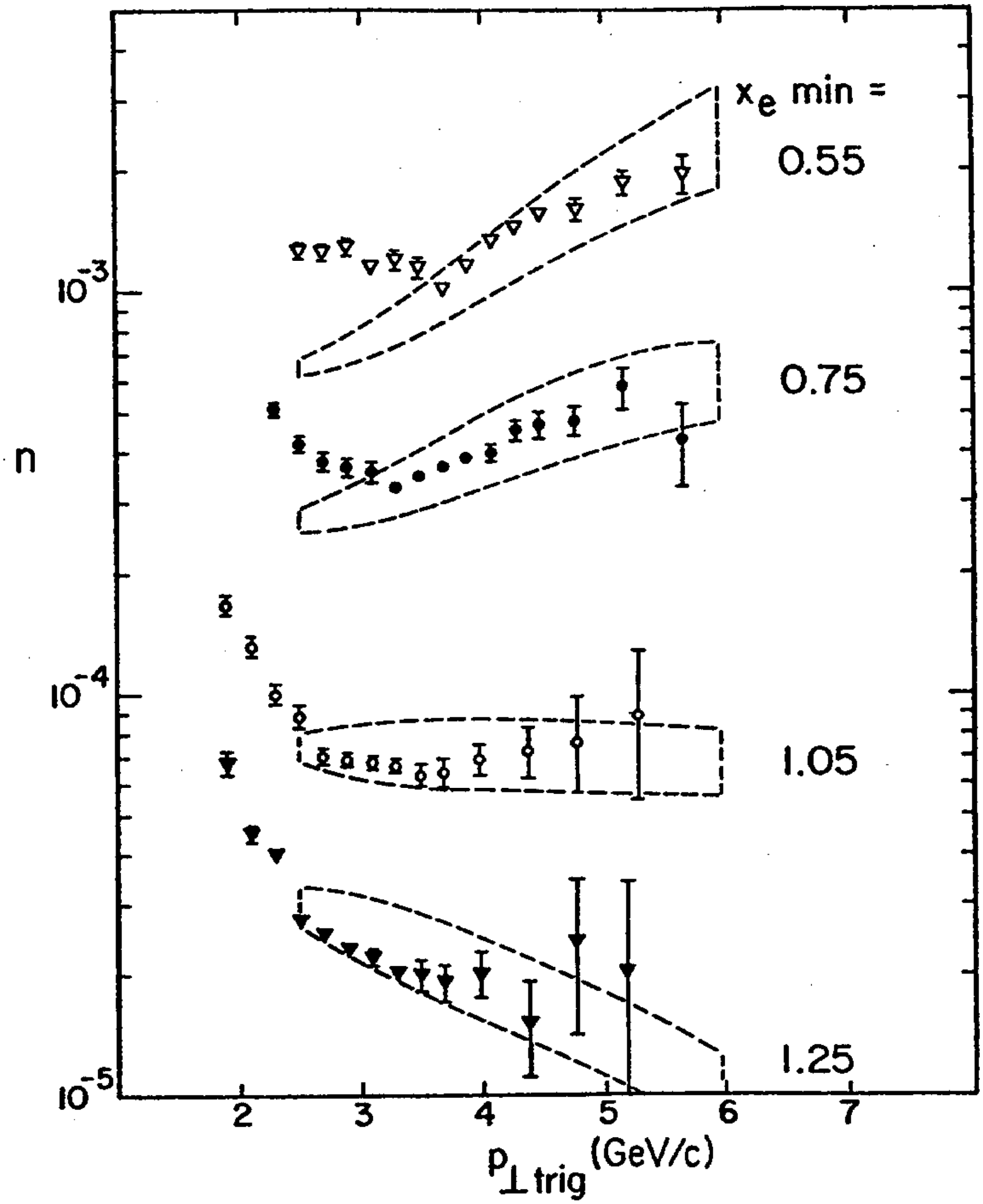

FIG. 2.

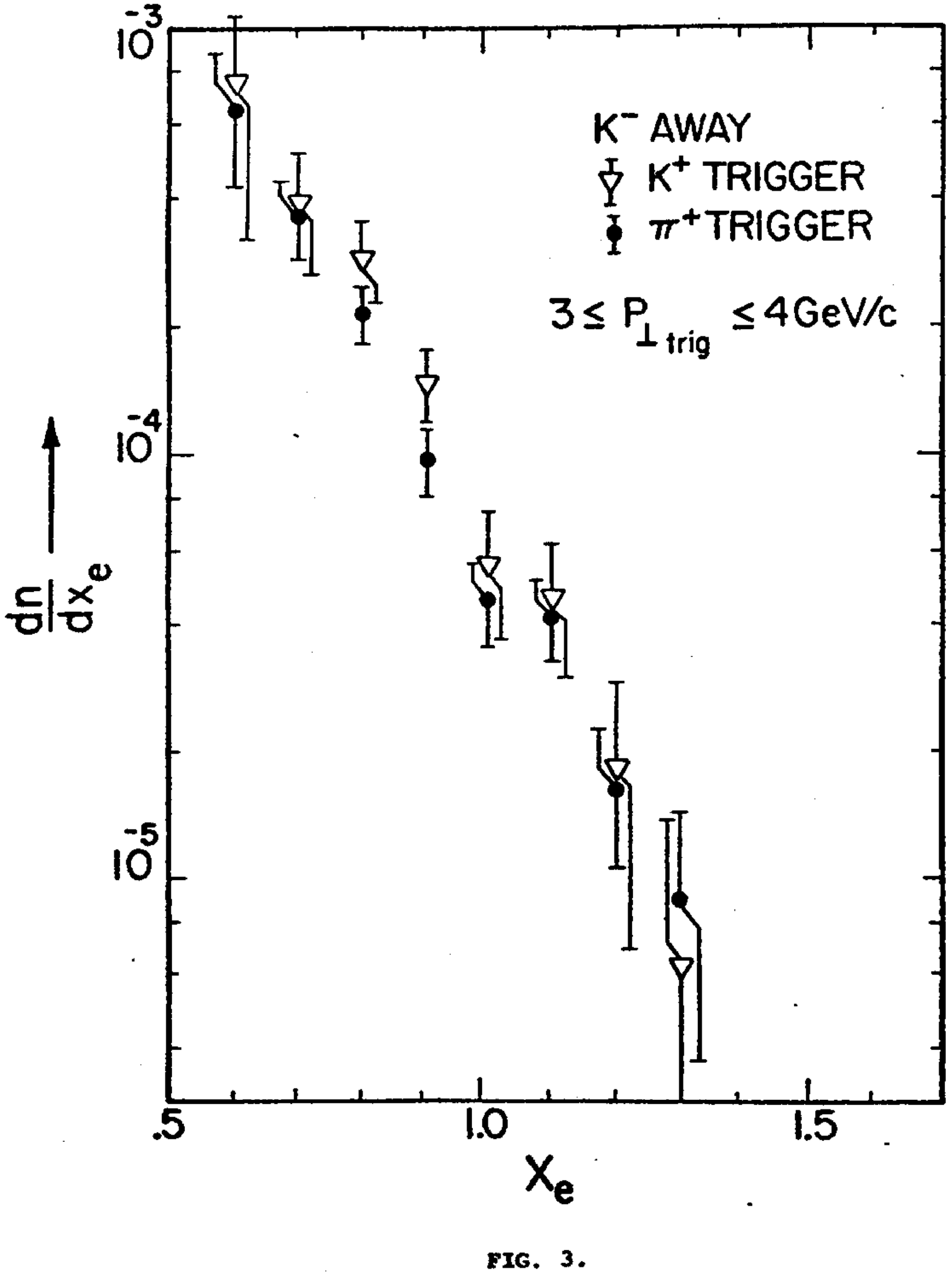
K⁻ AWAY
K⁺ TRIGGER
π⁺ TRIGGER
3 ≤ P⊥ trig ≤ 4 GeV/c
dn/dxe
Xe
10⁻³
10⁻⁴
10⁻⁵
.5
1.0
1.5

FIG. 3.

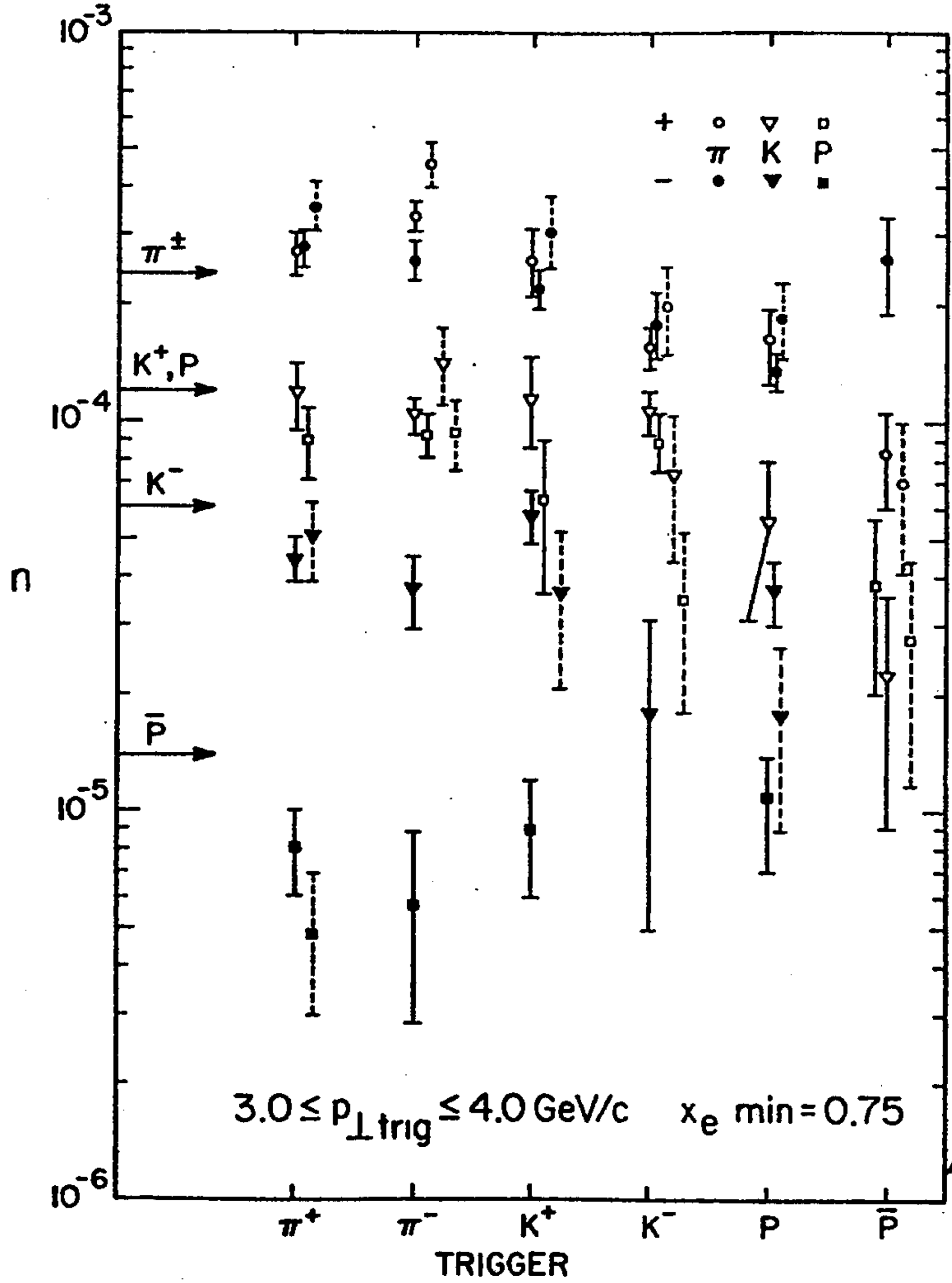
10^-3
10^-4
10^-5
10^-6
n
π±
K+, P
K−
P̄
+ π K P −
3.0 ≤ p⊥trig ≤ 4.0 GeV/c xe min = 0.75
π+ π− K+ K− P P̄
TRIGGER

FIG. 4.