A Dependence of the Inclusive Production of Hadrons with High Transverse Momenta

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We present new data on the A dependence of the inclusive production of high–transverse-momentum hadrons, both singles and symmetric pairs. These data qualitatively support the hypothesis that the observed A dependence results from multiple scattering of quarks and gluons within the target nucleus.

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Approximately ten years ago Antreasyan *et al.*, a Chicago-Princeton collaboration,[1] (CP) found that single-hadron production at large transverse momentum (p_T) varies as A^α with $\alpha > 1$. Here A is the number of nucleons (atomic weight) in the target nucleus. Early explanations of this collective effect were unsuccessful, partly because of the strong dependence observed on the quantum numbers of the final hadron. Multiple scattering at the quark level, however, can cause a strong quantum-number dependence,[2] and recent detailed calculations[3] using constituent multiple scattering have proved reasonably successful in reproducing the observed A dependence of single mesons and symmetric meson pairs.[4]

We present here single-hadron and symmetric–hadron-pair data. Our apparatus (Fig. 1) is a magnetic pair spectrometer[5] using drift chambers and multiwire proportional chambers to track particles over an aperture covering approximately 0.5 sr near 90° in the proton-nucleon center-of-momentum frame. A calorimeter[6] was used to reject background and trigger the experiment on hadrons. A ring-imaging Cherenkov counter[5] was used to identify these hadrons up to momenta of 200 GeV/c over half of the spectrometer aperture. Data were read out by the Nevis Data Transport System[7] and recorded on magnetic tape. Cross sections from these data will be presented elsewhere.[8]

We used the 400-GeV/c primary proton beam at an intensity of typically 5×10^9 p/s incident on the three targets described in Table I. After traversing the target, noninteracting beam protons and low-p_T secondaries were buried in a dump located in our upstream spectrometer magnet. Positive and negative hadrons with large p_T were accepted simultaneously, above and below the beam dump. The upstream magnet deflected the remaining low-p_T charged particles out of the aperture and focused the particles of interest onto our detector. The dump was configured so that neutral particles originating in the target could not exit from the upstream magnet.

The dominant singles rates were caused by low-energy photons generated presumably by π^0-initiated showers in the coils of the upstream magnet. Resulting chamber rates were high (up to 50 MHz per plane) but, through the use of heavy redundancy, tracks were cleanly reconstructed in the presence of our uncorrelated photon background. Each hadron track was defined by 29 projective measurements (18 wire-chamber measurements, 5 scintillation-counter measurements, and 6 calorimeter measurements) in addition to its ring-imaging Cherenkov measurements. Comparison of track momentum (measured with our downstream magnet) to track energy (measured by our calorimeter) indicates that spurious tracks are not present in our data (less than 1% of the sample). This statement is independent of the hadron's p_T.

The efficiency of each component of our system was measured by observation of the fraction of tracks reconstructed with the component missing. On average, 15.5 of 18 chambers recorded a hit along a given track, whereas our reconstruction algorithm requires a minimum of 12 hits. Our reconstruction efficiency was calculated with use of the measured efficiency of each element in the reconstruction algorithm. This calculation was checked by a Monte Carlo calculation which indicated that correlations among the chamber

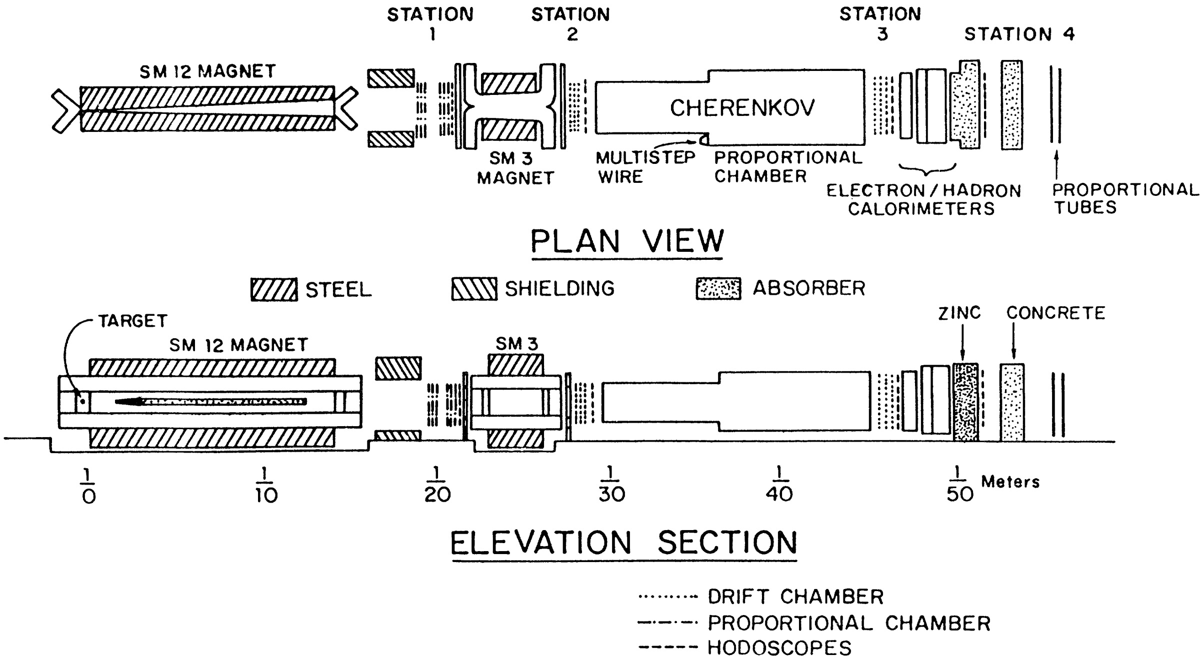

FIG. 1. Layout of the experimental apparatus.

inefficiencies are negligible. The reconstruction efficiency remained adequate while the data discussed here were recorded (typically 95% per track). Particle yields have been corrected for reconstruction inefficiency on a run-by-run basis.

We recorded events which exceeded a calorimeter-pulse-height threshold. The efficiency of this trigger requirement was monitored as a function of track position and momentum by use of prescaled hadron events triggered with a lower threshold. The energy deposited in horizontal segments of the calorimeter was recorded for each track by analog-to-digital converters. This information was used to calculate the calorimeter trigger efficiency for each event. We have performed the analysis presented here requiring various minimum values of this trigger efficiency. Our results are independent of this minimum value as it ranges from 50% to 95%. Hence we conclude that any target dependence of our trigger efficiency was sufficiently small that it does not affect these results.

The rate of incident protons interacting in the target was monitored by a four-counter telescope oriented at 90° in the laboratory frame with respect to the incident beam. The calibration of the relative number of monitor counts expected per incident proton on each target was carried out with use of a secondary emission monitor to normalize beam profile scans. Uncertainties in this procedure affect all α measurements presented here by less than ± 0.03 (limit of error). Since this uncertainty does not affect point-to-point comparisons (it shifts all measurements of α by the same amount), we do not include it in the error bars shown below. Data were taken in cycles of the three targets, with a run on each target lasting approximately 1 h.

The three targets have slightly different acceptances and resolutions in p_T because of their differing lengths and multiple scattering properties. We have simulated these differences via Monte Carlo methods. Resulting corrections to α, included below, are generally smaller than 0.01 in magnitude, but become as large as 0.02

TABLE I. Targets.

Material	Density (g/cm^3)	Length (cm)	Height (mm)	A	Integrated luminosity Per nucleon (10^{39} cm^{-2})	Integrated luminosity Per nucleus (10^{41} cm^{-2})
Be	1.85	10.18	0.996	9.01	0.222	2.46
Cu	8.96	2.578	0.914	63.54	0.317	0.499
W	19.3	1.306	1.059	183.8	0.276	0.150

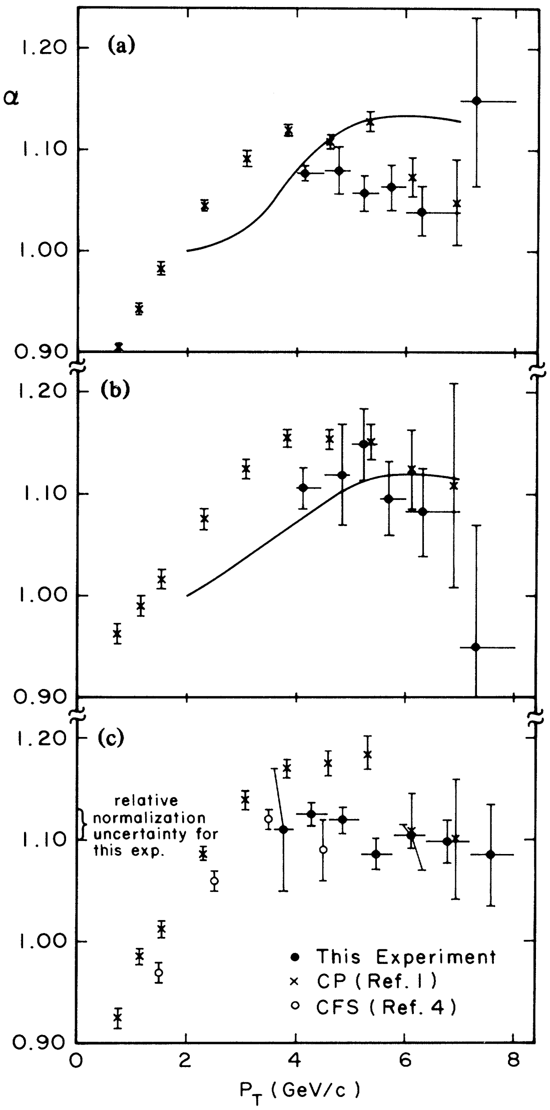

FIG. 2. The power α of the A dependence vs p_T for (a) π^+, (b) K^+, and (c) h^+ (all positive hadrons). The curves are from Ref. 3.

near the edges of our acceptance for the bins shown.

The data from the three targets are consistent with the form yield/(luminosity per nucleus) = const × A^α. In Fig. 2 we show measurements of α for π^+ and K^+ production, compared to earlier Chicago-Princeton measurements[1] and the calculation of Lev and Petersson.[3] Their constituent-multiple-scattering (CMS) model does show a rise in α as p_T varies from 2 to 4 GeV/c (to an α value which is affected by regularization of singularities[3]) but does not show the drop suggested by the CP data near $p_T = 6$ GeV/c. A drop in high p_T seems difficult to reconcile with a CMS explanation.[9] In Fig. 2(c), in order to bring as much information as possible to bear on this point, we show α for all positive[10] single hadrons, comparing our results to those of CP[11] and those of McCarthy *et al.*[4] Our data show little or no drop in α near $p_T = 6$ GeV/c. The error bars represent the total point-to-point rms errors. Note that our systematic normalization uncertainty quoted above and indicated in Fig. 2(c) could improve the agreement between our results and the CP results to the point of marginal consistency but will not change the shape of our α-vs-p_T curve since we measure the yields from each target at all p_T values simultaneously (unlike CP).

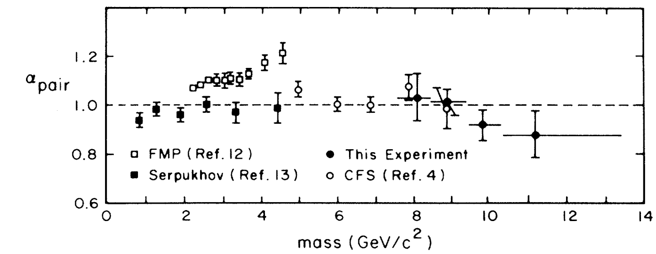

FIG. 3. The power α of the A dependence vs mass for h^+h^-, unlike-sign dihadrons. All data shown were taken with 400-GeV/c protons incident except those from Ref. 13 (70-GeV/c).

In Fig. 3 we plot α for h^+h^- pairs (without regard to particle type) versus mass, in comparison to data from Ref. 4, Finley *et al.*,[12] and a recent experiment by Abramov *et al.*[13] All data shown, with the exception of those from Ref. 12, are consistent with $\alpha = 1$ for hadron pairs (summed over net p_T). This result is expected within the CMS model[3] and indicates that symmetric pairs (which dominate the present data) result from single hard constituent collisions. A single collision tends to produce a hadron pair with a net p_T near 0 since the net p_T of the pair is limited by the p_T's of

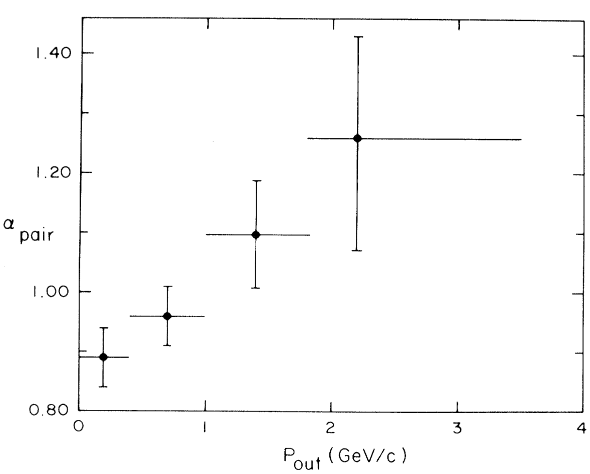

FIG. 4. The power α of the A dependence vs $p_{\rm out}$ for h^+h^-, unlike-sign dihadrons.

the incident constituents.

For fixed mass, the CMS picture[3] expects α for h^+h^- pairs to rise versus net p_T as the pair enters the region which can be most easily reached by multiple scattering. The present data are limited in net p_T by the acceptance of our upstream magnet. Hence we cannot verify the rise versus net p_T previously observed by McCarthy *et al.* (who used two separate spectrometers). However, if we define p_{out} for a pair as the component of the lower-p_T hadron's momentum perpendicular to both the beam and the higher-p_T hadron's momentum, we see in Fig. 4 that α does appear to rise as p_{out} increases. We expect such a rise[14] within the CMS picture, because of the limited p_T's of the incident constituents mentioned above.

In summary, we have made three measurements which qualitatively support the constituent-multiple-scattering model of the A dependence of hadron production at high p_T: α for single hadrons shows little or no drop near $p_T = 6$ GeV/c, while α for pairs is on average consistent with 1 but rises with p_{out}.

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9A slow decrease in α is predicted on the basis of the modification of structure functions in nuclei (discovered by the European Muon Collaboration) by T. Ochiai, S. Daté, and H. Sumiyoshi, Rikkyo University Report No. RUP-85-4 (to be published).

10These data were taken during our test run, during which the primary beam hit our target at an angle with respect to the spectrometer axis, favoring the acceptance of positive hadrons. The statistical precision of our negative hadron data is poor compared to the precision of our positive data.

11We use α values and particle ratios quoted in Ref. 1 to calculate the CP α values for h^+ shown in Fig. 2(c).

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14A value of $\alpha < 1$ at $p_{\text{out}} = 0$, as favored by our data, is not expected in Ref. 3. This aspect of our data may favor Ref. 9.