nals 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 Cherenkov signals.

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

[5]Our kinematic correlation results are reported in D. A. Finley *et al.*, Phys. Rev. Lett. 42, 1031 (1979) (this issue).

[6]M. G. Albrow *et al.*, Phys. Lett. 65B, 295 (1976).

[7]R. J. Fisk *et al.*, Phys. Rev. Lett. 40, 984 (1978).

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

Nucleon-Number Dependence of Inclusive Dihadron Production in Proton-Nucleus Collisions at 400 GeV/c

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We have measured the nucleon-number (A) dependence of hadron-pair production in 400-GeV/c proton-nucleus collisions, using Pb and Be targets. Charged-hadron pairs were observed near rapidity $y_{\text{c.m.}} = -0.4$ with $\Delta\varphi \cong 180°$. The A-dependence exponent rises from 1.1 to 1.2 in the range $2.0 \leq |p_{\perp 1}| + |p_{\perp 2}| \leq 4.5$ GeV/c. The dihadron $p_\perp$ correlation function is significantly smaller for Pb than for Be.

Several unexpected results have recently raised interest in hadron production on heavy nuclei. The multiplicity of hadron-nucleus collisions grows with nuclear size much less rapidly than a simple cascade model would predict.[1] On the other hand, the inclusive production of high-$p_\perp$ particles rises as A^α with α significantly greater than 1.[2-4] Theoretical models which attempt to describe this behavior include multiple scattering, nucleon clusters, and decay of high-mass states.[5] We report here the results of an experiment on the A dependence of dihadron production.[6] Only charged particles were detected, and for the purposes of this paper no distinction is made between π, K, and p. The quantum-number correlations observed in lead and beryllium have been reported separately.[7]

This experiment was performed at the Fermi National Accelerator Laboratory in a 400-GeV/c proton beam, with a typical intensity of 4×10^7 sec^{-1}. Other results and a detailed description of the apparatus have been published previously.[8] The apparatus consisted of two identical magnetic spectrometers placed at 100 mrad on opposite sides of the beam. In the proton-nucleon center-of-mass system, each spectrometer was centered at $\theta = 110°$ and subtended about $\pm 10°$ in polar angle, and $\pm 17°$ in azimuth. The trigger required each hadron to have $p_\perp \geq 1$ GeV/c.

Measurements of the A dependence were made with a target of nine 1.3-mm lead segments followed by three 6.1-mm beryllium segments, all 3.8 mm wide. Data were taken on both nuclei simultaneously with targets of equal width in order to eliminate uncertainties arising from beam normalization or changes in experimental conditions. The good spatial resolution of the spectrometer drift chambers allowed unambiguous identification of the target element, as shown in Fig. 1. The acceptance of the spectrometer was uniform over the length of the target. The data were corrected for beam attenuation in the tar-

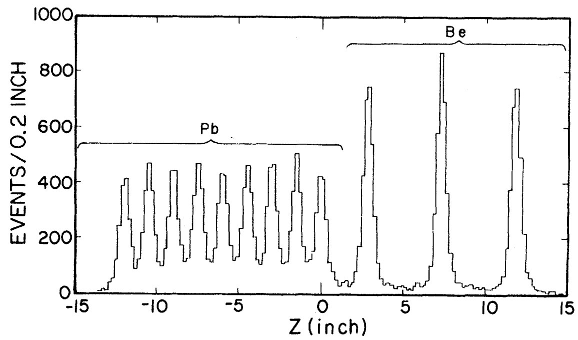

FIG. 1. Typical distribution of reconstructed target vertices along the beam line.

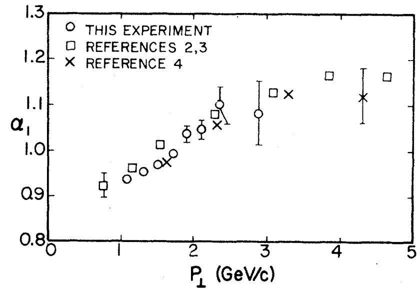

FIG. 2. Nucleon-number (A) dependence as a function of $p_\perp$ for single-hadron production. α_1 is the A-dependence exponent.

get.[9] To check our technique of A-dependence measurement, we calculated cross sections for upstream and downstream portions of another target of identical CH_2 segments; the values were equal to within 1%. Because of the relatively low beam rate and the unambiguous target-element identification, contamination of pair-production data by two independent collisions was less than 10%.

Two distinct approaches were taken in the analysis of our results. The first was simply to measure the A dependence of the dihadron cross section; the second was to extract kinematic correlation functions from the cross sections and observe their dependence on nuclear size. In order to calculate the correlations, and also as a check of our experimental technique, we measured the A dependence of inclusive single-hadron production. To compare with previous experiments, we have assumed that nucleon-number dependence is of the form A^α and that the cross sections do not vary significantly with rapidity across the narrow acceptance of the apparatus ($\Delta y = 0.25$ at $y_{\text{c.m.}} = -0.4$). The results are plotted in Fig. 2 and are in good agreement with previous experiments.[2-4] Over the $p_\perp$ range from 1.0 to 4.6 GeV/c, the exponent for single-particle production α_1 rises smoothly from 0.95 to 1.15.

The exponent α_2 for the A dependence of dihadron production is determined similarly by taking the ratio of yields from beryllium and lead. We have measured α_2 as a function of the transverse momentum of each particle. We parametrize our results as a function of the sum, $p_s \equiv |p_{\perp 1}| + |p_{\perp 2}|$, and the difference, $p_d \equiv \| p_{\perp 1}| - |p_{\perp 2}\|$, of the transverse momenta of the two detected particles. It should be noted that p_s is approximately equal to the effective mass of the dihadron pair, and p_d approximately equals the total $p_\perp$ of the pair. This choice of variables was selected because the ratio of lead and beryllium yields is essentially independent of p_d. Figure 3 exhibits α_2 as a function of p_s for neutral (+ −) pairs and for all pairs. In the p_s range from 2.2 to 4.6 GeV/c, α_2 rises from 1.10 ± 0.01 to 1.19 ± 0.03. (Also plotted in Fig. 3 are the values of α_2 obtained in another experiment.[10]) A comparison of the single- and two-particle data (Figs. 2 and 3) shows that α_1 and α_2 are approximately equal when the single-particle transverse momentum ($p_\perp$) and the two-particle sum of transverse momenta (p_s) have equal values.

We now turn to the A dependence of the two-

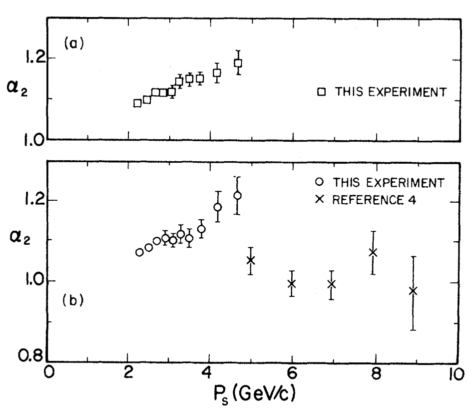

FIG. 3. The A-dependence exponent α_2 for dihadron production as a function of p_s integrated over p_d. (a) All charge combinations; (b) neutral combinations (+−, −+). The data of Ref. 4 exclude their systematic error of ±0.05 in the values of α_2. The systematic error in the values of α_2 from this experiment is estimated to be less than 0.02.

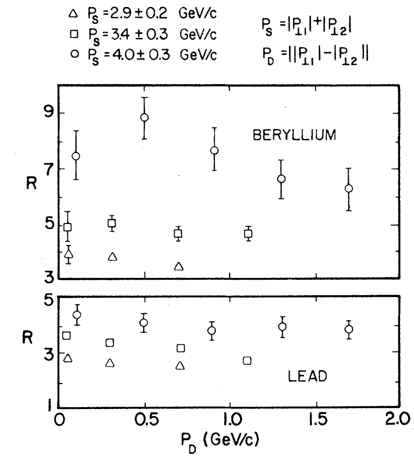

FIG. 4. The two-particle transverse-momentum correlation function R as a function of p_d for various ranges of p_s.

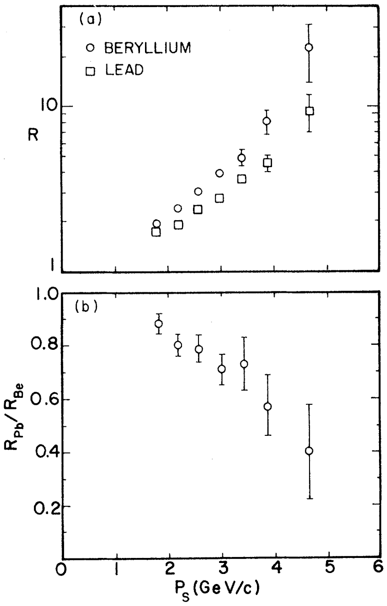

FIG. 5. (a) The two-particle transverse-momentum correlation function R as a function of $p_s = |p_{\perp 1}| + |p_{\perp 2}|$ for symmetrically produced pairs ($p_d = ||p_{\perp 1}| - |p_{\perp 2}|| \leq 0.1$ GeV/c). (b) The ratio of R for lead to R for beryllium.

hadron correlation function R defined by

$$R(p_1,p_2) \equiv \sigma_{\rm in} \frac{E_1 E_2 d^6\sigma/dp_1^3 dp_2^3}{(E_1 d^3\sigma/dp_1^3)(E_2 d^3\sigma/dp_2^3)},$$

where $\sigma_{\rm in}$ is the total inelastic cross section. R is the ratio *per inelastic event* of the probability of a particular two-particle state, to the product of uncorrelated probabilities of the corresponding single-particle states. R is unity if two-particle production is completely uncorrelated; it is greater (or less) than 1 if pair production is positively (or negatively) correlated. In Fig. 4, R is plotted for both lead and beryllium targets as a function of p_d for several ranges of p_s. This figure demonstrates the reason for our choice of kinematic variables. R shows little dependence on p_d, but varies strongly with changes in p_s. Figure 5(a) shows R as a function of p_s for symmetrically produced pairs ($p_d < 0.1$ GeV/c). R is greater than 1 throughout our range of acceptance, and increases rapidly with transverse momentum. This rise has been observed elsewhere in p-p[11] and p-nucleus[12] interactions. Our data show that pairs produced in lead are less correlated than those in beryllium. Figure 5(b) makes a direct comparison by displaying the ratio $R_{\rm Pb}/R_{\rm Be}$ as a function of p_s. As p_s increases, the correlation in lead decreases relative to the correlation in beryllium.

In summary, the A-dependence exponent for pair production with $2 \leq |p_{\perp 1}| + |p_{\perp 2}| \leq 4.5$ GeV/c is larger than unity and rises with transverse momentum in a fashion similar to that for single-particle production. The production of hadron pairs near $y_{\rm c.m.} = -0.4$ is positively correlated, and the correlation is a steeply increasing function of the sum of transverse momenta. A comparison of light and heavy nuclei shows that the correlation is lower, and a less steep function of transverse momentum, for heavy nuclei.

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[1] For a review of these results see K. Zalewski, in *Proceedings of the Seventeenth International Conference on High Energy Physics, London, 1974*, edited by J. R. Smith (Rutherford High Energy Laboratory, Didcot, Berkshire, England, 1975), p. I-93.

[2] J. W. Cronin *et al.*, Phys. Rev. D 11, 3105 (1975).

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[4]R. L. McCarthy *et al.*, Phys. Rev. Lett. 40, 213 (1978).
[5]For a review of some of the models see H. J. Frisch, in *Particles and Fields, 1976*, edited by H. Gordon and R. F. Peierls (National Technical Information Service, Springfield, Va., 1977), p. F-59.
[6]Further details may be found in D. A. Finley, Ph.D. thesis, Purdue University, 1978 (unpublished).
[7]D. A. Finley *et al.*, Phys. Rev. Lett. 42, 1028 (1979) (this issue).
[8]D. Bintinger *et al.*, Phys. Rev. Lett. 37, 732 (1976); R. Thun *et al.*, Nucl. Instrum. Methods 138, 437 (1976); C. W. Akerlof *et al.*, Phys. Rev. Lett. 39, 861 (1977); W. R. Ditzler *et al.*, Phys. Lett. 71B, 451 (1977).
[9]Total inelastic-cross-section values of 216 mb for Be and 1930 mb for Pb are from S. P. Denisov *et al.*, Nucl. Phys. B61, 62 (1973). These measurements were obtained using hadron beams with incident momenta covering the range from 7 to 60 GeV/c and targets with nucleon number from 7 to 238.
[10]Our results and those for Ref. 4 do not appear to be entirely consistent, although the lack of overlap of the data as a function of p_s makes it difficult to make direct comparisons. We note that the two experiments cover slightly different angular ranges and employ somewhat different methods.
[11]F. W. Büsser *et al.*, Phys. Lett. 51B, 311 (1974).
[12]R. J. Fisk, Ph.D. thesis, State University of New York at Stony Brook, 1978 (unpublished).

Precritical Behavior in Pionlike Nuclear Excited States

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The possible occurrence of precritical phenomena in finite nuclei due to the relative proximity of the pion condensation threshold is investigated. We point out that such precritical behavior may occur in inelastic scattering differential cross sections for the excitation of unnatural-parity states at high momentum transfers [$q \simeq (2-3)m_\pi$]. As an example, we discuss inelastic proton scattering to 1^+ states in ^{208}Pb.

The question whether pion condensation appears as a new phase of dense baryonic matter has been of continuous interest in recent years.[1-3] While early estimates[1] have suggested that the critical density for condensation in nuclear matter should be lower than normal nuclear matter density, $\rho_0 = 0.5 m_\pi^3$, more realistic approaches incorporating Δ isobars, short-range repulsive baryon-baryon correlations, and the density dependence of the effective nucleon mass come to the conclusion that pion condensation in symmetric nuclear matter is very unlikely to appear around or below ρ_0.[4] Nevertheless, the question has been raised which nuclear properties could serve as a possible indicator of critical behavior in channels carrying pion quantum numbers, even if a pionic soft mode is not expected to appear in ordinary finite nuclei.[5,6]

The possible occurrence of precritical phenomena has been suggested by Gyulassi and Greiner[7] and by Ericson and Delorme,[8] who use the term "critical opalescence" for the physical consequences of an effective enhancement of the pion field inside the nucleus, as the pion condensate is approached. Let us illustrate the nature of precritical behavior close to a pion condensate in the case of infinite nuclear matter. Consider the coupling of a low-frequency ($\omega \ll m_\pi$) pion, for example by inelastic proton scattering, to a pionlike particle-hole excitation, as illustrated in Fig. 1, through various virtual intermediate nucleon-hole and Δ-isobar-hole states. This many-body renormalization of the pion propagation

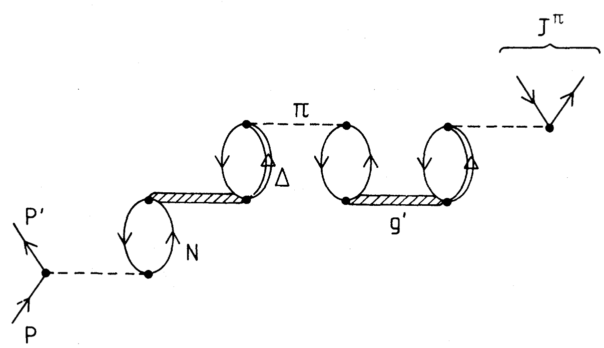

FIG. 1. Inelastic proton scattering into a low-lying "pionlike" excited state through intermediate excitation of high-lying nucleon- and isobar-hole states. Shown are one-pion-exchange pieces (π) and additional contributions from short-range baryon-baryon correlations (g').