Nuclear Dependence of Single-Hadron and Dihadron Production in p-A Interactions at $\sqrt{s} = 38.8$ GeV

C. N. Brown, W. E. Cooper, C. S. Mishra
Fermilab, P. O. Box 500, Batavia, IL 60510

D. M. Kaplan,* R. S. Preston, V. Tanikella
Northern Illinois University, DeKalb, IL 60115

L. D. Isenhower, M. E. Sadler
Abilene Christian University, Abilene, TX 79699

L. M. Lederman,* M. H. Schub†
University of Chicago, Chicago, IL 60637

G. Gidal, M. S. Kowitt,‡ K. B. Luk
Lawrence Berkeley Laboratory and University of California, Berkeley, CA 94720

T. A. Carey, M. J. Leitch, P. L. McGaughey, J. M. Moss, J. C. Peng
Los Alamos National Laboratory, Los Alamos, NM 87545

R. L. Childers, C. W. Darden
University of South Carolina, Columbia, SC 29208

P. K. Teng
Institute of Physics, Academia Sinica, Taipei, Taiwan

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*Present address: Illinois Institute of Technology, Chicago, IL 60616.

†Present address: University of Minnesota, Minneapolis, MN 55455

‡Present address: NASA/Goddard Space Flight Center, Greenbelt, MD 20771.

Abstract

We present a measurement of the W-to-Be per-nucleon cross-section ratio, $R_{W/Be}$, for single hadrons and for opposite-sign hadron pairs produced in p-A collisions at $\sqrt{s} = 38.8$ GeV. The data fill in regions of intermediate transverse momentum and dihadron mass that previously have revealed cross-section enhancements for scattering from nuclear targets. When combined with previous measurements, the new results help delineate the dependence of nuclear effects on the kinematic variables p_t, m, and $\sqrt{s}$. Both the single-hadron and hadron-pair enhancements in $R_{W/Be}$ seen at intermediate values of p_t and mass decrease with increasing $\sqrt{s}$, consistent with a multiple-scattering model of parton scattering.

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I. INTRODUCTION

The production of high-p_t hadrons and massive hadron pairs can serve as a probe of underlying parton-level processes. High-p_t hadron and hadron-pair production in hadron collisions is consistent with the scattering of partons carrying a high fraction of the momentum of the incident proton [1–3]. Early studies of hadron production at high p_t from nuclear targets showed enhancements of the per-nucleon yields for heavy nuclei [4]. It was hoped that the transition to single-parton-scattering dominance at high p_t could be studied by mapping out the nuclear dependence of such production processes, since single parton-parton elastic scattering is expected to be independent of target nuclear effects. In addition, the observation of high-p_t back-to-back hadron pairs with a large component of momentum out of the scattering plane, p_{out} (defined more precisely below), is a clear signal of more complicated interactions such as rescattering of the scattered partons.

We have studied the production of charged hadrons, h^+ or h^-, and opposite-sign hadron pairs, h^+h^-, in collisions of 800-GeV protons with tungsten and beryllium targets. Here we present W-to-Be per-nucleon cross-section ratios, designated $R_{W/Be}$. The single-hadron data cover $1.0 < p_t < 4.0\,\mathrm{GeV}/c$ and angles between 60° and 90° in the proton-nucleon center-of-momentum frame. The pair results are for opposite-sign hadron pairs with pair mass in the range $1.0 < m < 6.0\,\mathrm{GeV}/c^2$, and with the hadron momentum vectors approximately "back-to-back" in the center-of-momentum frame. These data help delineate the transition from the enhancement of hadron yields seen at low mass and transverse momentum [4,5] to the disappearance of these enhancements at higher values of mass and transverse momentum [6].

II. APPARATUS DESCRIPTION

The apparatus, a focusing pair spectrometer (Fig. 1), was originally constructed for Experiment 605 [7,8] and is located in the Meson East laboratory at Fermilab. The data reported here were taken as part of a subsequent experiment, Experiment 789 [9]. Primary 800-GeV protons extracted from the Tevatron were incident (along the z axis) on either a 3-mm-thick tungsten target or a 25-mm-thick beryllium target, located at $z = -1.9\,\mathrm{m}$ with respect to the entrance of the SM12 analyzing magnet. These two targets were interchanged every minute (i.e. after each acceleration cycle). The product of the proton beam flux (typically 10^9/s) and data-acquisition efficiency was monitored by observing the yield of hadrons from a fixed 1-mm-thick platinum target located at $z = -3.3\,\mathrm{m}$ (1.4 m upstream of the alternating tungsten and beryllium targets). All three targets were large enough transversely to intercept all the beam. Non-interacting beam and secondaries with laboratory production angles less than 20 mr were absorbed in a 4-m-long copper beam dump starting at $z = 2\,\mathrm{m}$. The dump was located within the large SM12 spectrometer magnet, which provided a transverse-momentum kick in the vertical plane. Data were recorded at four different settings of the SM12 magnet, ranging from 1.6 to 3.8 GeV/c transverse kick. The SM12 magnet also swept low-momentum charged particles out of the spectrometer aperture, thus allowing data taking at higher intensities as the field was increased.

High-p_t negative (positive) particles passing over (under) the beam dump were reanalyzed in a second magnet (p_t kick = 0.9 GeV/c), with field direction opposite that of the first magnet, located at $z = 24\,\mathrm{m}$. Particle trajectories were measured between the two magnets by six drift chambers, and downstream of the second magnet by two stations of six drift chambers each. RMS resolutions of $\approx 0.02\,\mathrm{GeV}/c^2$ in mass and $\approx 0.1\,\mathrm{GeV}/c$ in p_t and p_{out} were obtained. Hodoscope planes and a lead/scintillator electromagnetic calorimeter followed by a steel/scintillator hadronic calorimeter provided fast signals used to trigger data acquisition.

III. DATA ANALYSIS AND RESULTS

The analysis followed closely that described in P. B. Straub *et al.* [6]. Since the results presented here are all ratios of yields from the various targets, efficiencies and acceptances cancel. In particular, the target thicknesses were chosen to yield approximately equal rates in the spectrometer; this helped minimize target-dependent differences in the calorimeter-trigger and data-acquisition efficiencies [10].

Figure 2a shows the distribution of track intercept with the z axis in the bend view for single positive hadrons. The apparently smooth background of events with intercepts falling between the locations of the platinum monitor-target and the alternating targets was produced by 32 equally-spaced .0005"-thick aluminum-foil windows on the silicon-detector housings in this region (the silicon detectors were used in a different measurement [11]). Figure 2b displays the two-dimensional distribution of z-intercepts in the bend view for hadron pairs. The off-diagonal events in Fig. 2b give a measure of the random h^+h^- coincidences which contaminate the data at the few-percent level (the small correction made for these randoms is important only at the lowest mass values).

Figure 3 shows the p_t dependence of $R_{W/Be}$ for single hadrons. Only statistical errors are indicated. Systematic normalization and background-subtraction errors add a 5% scale error in $R_{W/Be}$ (limit of error). Both the single-hadron and dihadron data reported here cover a narrow range in longitudinal momentum, $0.0 < x_f < 0.2$. All results on $R_{W/Be}$ were observed to be independent of x_f over this range.

Also shown in Figure 3 are previous results obtained at 800 GeV [6] and at 400 GeV [4] (which have been converted from α to $R_{W/Be}$ using $R_{W/Be} = (A_W/A_{Be})^{\alpha-1}$). For both positive and negative hadrons, $R_{W/Be}$ increases with increasing p_t to about 1.3 to 1.5 near $p_t = 4\,\mathrm{GeV}/c$ and then drops, trending to a value near 1.0 for $p_t > 6\,\mathrm{GeV}/c$. The new data presented here are consistent with the previous measurements at 800 GeV. At intermediate values of p_t, the nuclear enhancement is seen to decrease with increasing $\sqrt{s}$. A quantitative comparison of the ensemble of single-hadron yields with a constituent multiple-scattering model requires a more detailed calculation than is available in the current literature [12–14].

The ratio $R_{W/Be}$ versus mass for opposite-sign hadron pairs is shown in Fig. 4. Also shown are previous results at 400 GeV [5,15] and at 800 GeV [6,7] (converted from α to $R_{W/Be}$ as above). $R_{W/Be}$ first increases with mass, reaching about 1.3 at $m \approx 4\,\mathrm{GeV}/c^2$, then drops smoothly with increasing mass. Again the comparison with the 400 GeV data in the region $2 < m < 5\,\mathrm{GeV}/c^2$ is consistent with an apparent decrease of the nuclear enhancement with increasing energy.

While some experiments [16,17] have not reported a significant nuclear suppression of very high-mass hadron pairs, the present data appear to fit smoothly with the higher-mass data at 400 and 800 GeV [6,7,15], which continue to fall to $R_{W/Be} \approx 0.75$ for masses above $10\,\mathrm{GeV}/c^2$. The experiments not observing suppression at high mass have typically had a larger kinematic acceptance, especially for non-zero coplanarity angles of the dihadron.

A common measure of the dihadron acoplanarity is the variable p_{out}, the momentum component of the lower-p_t hadron perpendicular to the plane defined by the incident beam and higher-p_t-hadron momentum vectors. Figure 5 displays the dihadron ratio $R_{W/Be}$ versus the acoplanarity of the pair as measured by p_{out}; the average mass of these pairs is $3\,\mathrm{GeV}/c^2$. Also shown are results for previous higher-mass data, $m \approx 9\,\mathrm{GeV}/c^2$ [6]. The increased acoplanar hadron-pair yield from the heavier nuclear target at both low and high masses could be the source of the apparent inconsistencies among experiments reporting on nuclear effects versus mass. Note that our acceptance in p_{out} was approximately gaussian with a half-width increasing from about 0.3 GeV/c at a mass of 2.5 GeV/c^2 to about 0.6 GeV/c at a mass of 5 GeVc^2. Thus, for our apparatus (and also in Refs. 6,7,and 15), both the resolution and the average accepted p_{out} are smaller than the values of p_{out} which characterize the increase in the W/Be ratio versus p_{out} in Fig. 5 (about 1 GeV/c for these data and about 2 GeV/c for the data of Ref. 6). The observed increase of $R_{W/Be}$ versus p_{out} at both low and high values of mass lends support to a constituent rescattering picture.

It was previously noted [6] that the EMC effect [18–20] is too small to account for the observed nuclear suppression of high-mass hadron pairs. Other factors that can deplete the yield of hadrons at large transverse momenta include the possibility of nuclear suppression in the parton fragmentation process, especially for those hadrons that carry a large fraction of the scattered-parton momentum. Since the single-hadron cross section is proportional to a single fragmentation function while the pair cross section is proportional to a product of two fragmentation functions, any suppression of fragmentation due to the nuclear medium could exert a stronger effect on pairs than on single hadrons [21]. Whether such fragmentation effects would then also contribute to the enhancements seen at low values of mass and p_t is not known.

IV. CONCLUSIONS

These data show a consistent experimental picture of the nuclear enhancement of single-hadron yields at intermediate values of p_t and of dihadron yields at intermediate values of m. The transitions from nuclear enhancement to suppression with increasing coplanar-dihadron mass, and to nuclear independence with increasing p_t for single-hadron production, are undoubtedly influenced by a number of competing effects. Since the structure of the nucleon (including the SU(2) asymmetry of the quark-antiquark sea) is now understood more precisely than previously [22], a more complete calculation of hadron production from nuclei is now possible. Such a calculation might yield better insights into the importance of the various contributions to hadron production from nuclei, but is beyond the scope of this paper.

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FIG. 1. Schematic plan view of the Meson East focusing spectrometer at Fermilab.

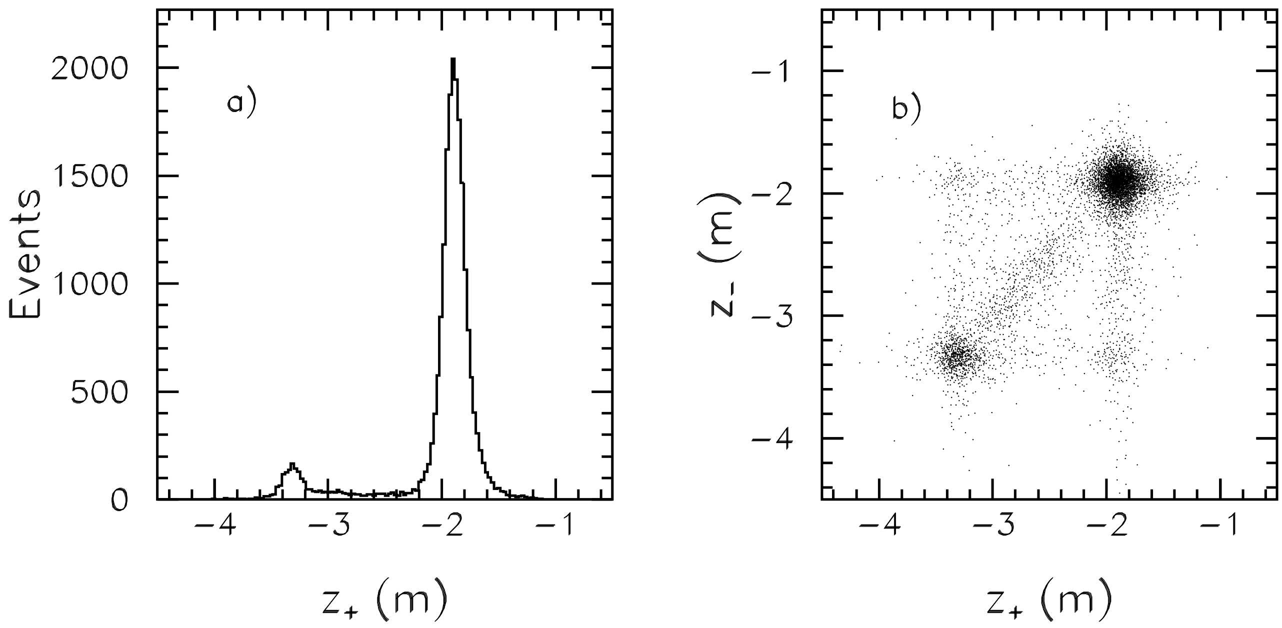

FIG. 2. (a) Retraced z-intercept in the bend plane (intersection with the beam axis) of single positive-hadron tracks; the 1-mm-thick monitor target is at $z = -3.3\,\mathrm{m}$ and the alternating beryllium and tungsten targets are at $z = -1.9\,\mathrm{m}$. (b) The z-intercepts in the bend plane of negative hadron tracks, z_-, versus those of positive-hadron tracks, z_+, for hadron-pair events. The off-diagonal events arise from random h^+h^- coincidences.

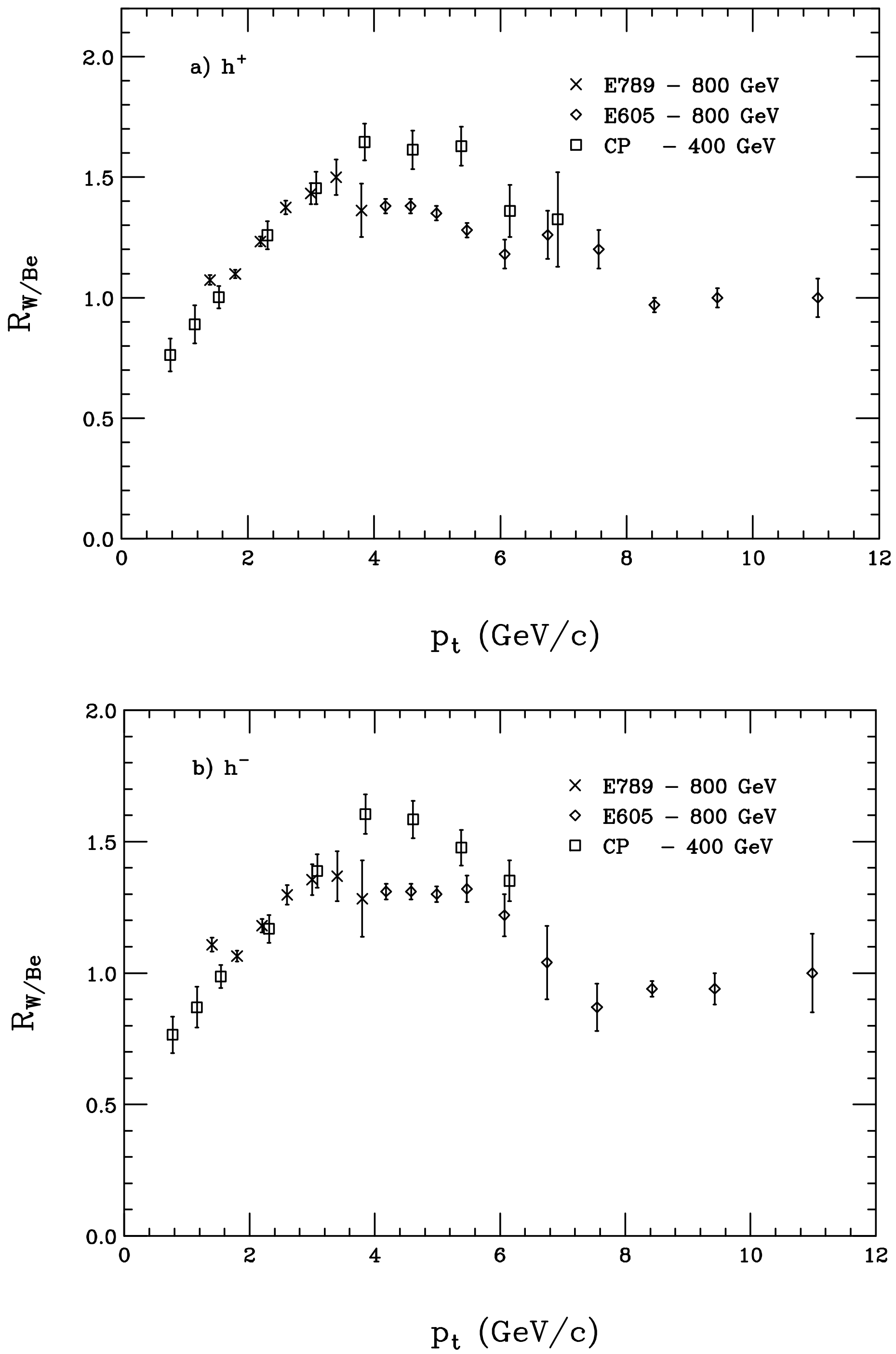

FIG. 3. The p_t dependence of $R_{W/Be}$ for a) single positive hadrons and b) single negative hadrons. The error bars indicate the statistical errors only. Systematic normalization and background-subtraction errors add a 5% scale error in $R_{W/Be}$ (limit of error). Also displayed are previous results obtained in Experiment 605 at 800 GeV (Ref. 6) and by the Chicago-Princeton group at 400 GeV (Ref. 4).

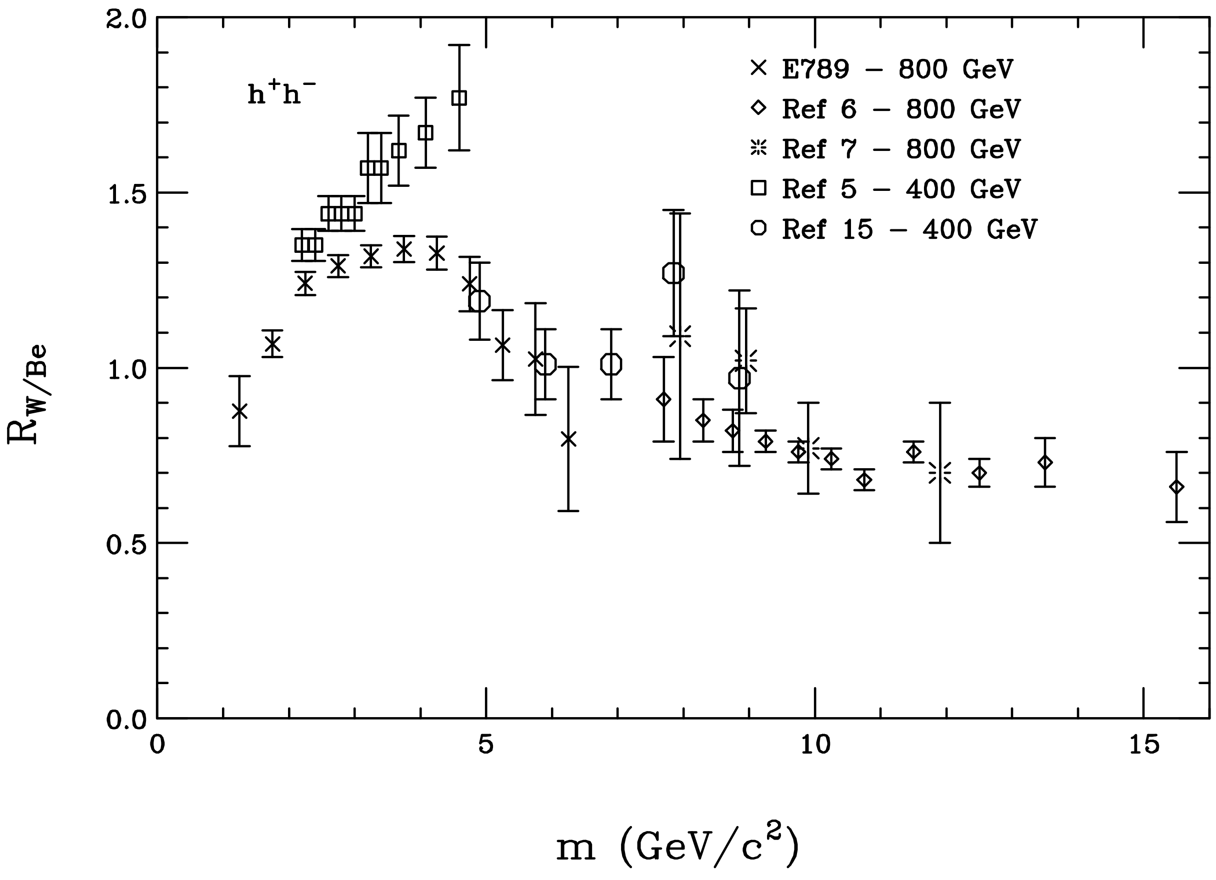

FIG. 4. The ratio of dihadron yields $R_{W/Be}$ versus mass for opposite-sign hadron pairs. Also shown are previous results at 400 GeV from Experiment 357 (Ref. 5) and Experiment 494 (Ref. 15) and at 800 GeV in Experiment 605 (Ref. 6 and 7).

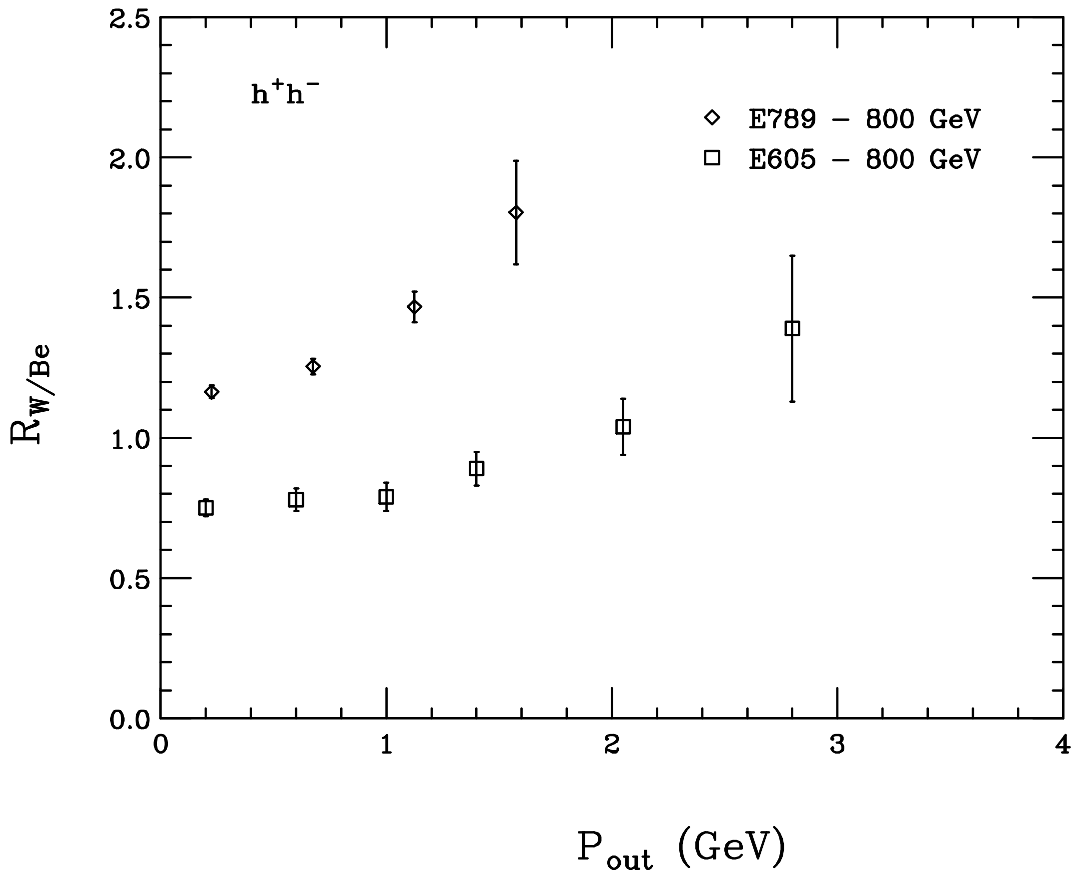

FIG. 5. The ratio of dihadron yields $R_{W/Be}$ versus the acoplanarity of the pair as measured by p_{out}. The average mass of the pairs is 3 GeV/c^2. Also shown are the data of Ref. 6 at an average mass $m \approx 9$ GeV/c^2.