Fermi National Accelerator Laboratory

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Production of π^0 Mesons at High-p_T in π^-Be and pBe Collisions at 500 GeV/c

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We present new measurements of π^o production at high transverse momenta (p_T) for π^- and p interactions on Be and Cu targets at 500 GeV/c. The observed dependence of the yields as a function of p_T and rapidity (y) is compared with expectations from leading-log QCD over a kinematic range in which the inclusive cross sections fall by more than four orders of magnitude.

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The measurement of inclusive single-particle production at high tranverse momenta in hadron-induced collisions can be viewed as a high energy analog of the Rutherford scattering experiment. Within the framework of quantum chromodyamics (QCD), high-p_T processes are understood to proceed through the pointlike scattering of quarks and gluons, which subsequently fragment into jets of hadrons. Although the presence of hadronization complicates the detailed analysis, the study of secondary particle production at high transverse momenta has nevertheless proved to be one of the most valuable probes of hadronic matter at the constitutent level.[1]

In this paper, we present new measurements of π^0 production for π^- and p interactions on Be and Cu targets at 500 GeV/c, and compare these results to leading-log (LL) QCD calculations. The data were acquired during the initial run of experiment E706 at the Fermi National Accelerator Laboratory (Fermilab). A layout of the spectrometer, which is located in Fermilab's MWEST area, is presented in Fig. 1. The apparatus consists of the following two subsystems (additional details can be found in the literature[2]):

(1) A 3 meter diameter liquid argon calorimeter (LAC) located 9 meters downstream of the interaction target. This device consists of a 30 radiation length electromagnetic detector (EMLAC), subdivided for readout purposes into front (1/3) and back (2/3) sections, followed by an 8 interaction length hadron detector (HALAC). The EMLAC consists of lead absorber plates interleaved with r-ϕ readout boards focussed on the target. The r-strips are 5.5 mm in width and are read out by octant. The ϕ-strips are subdivided at a radius of 40 cm, and have angular widths of $\pi/192$ and $\pi/384$ at small and large radii, respectively. Amplified signals from the r-strips are used to form the high-p_T electromagnetic trigger through summing the energies of neighboring channels using weights proportional to their radii. The HALAC consists of 52 one inch thick steel plates, and is read out via focussed triangular towers, each subtending a transverse area of $\sim$50cm^2. The LAC has a helium-filled beampipe passing through its center; this angular region is covered by a steel and scintillator calorimeter positioned downstream of the LAC cryostat.

(2) A charged particle tracking system consisting of 14 planes of silicon microstrip detectors (SSDs) located upstream of a large aperture analysis magnet, and 16 planes of proportional wire chambers (PWCs) placed downstream of this magnet. Each of the SSDs has 50 μm pitch, and they are configured as X-Y doublets: 6 planes upstream of the interaction target and 8 downstream. The PWCs are configured into 4 separate stations, ranging in size from $[1.6 \times 1.2]$ m^2 to $[2.4 \times 2.4]$ m^2, each containing 4 planes of wires in an X-Y-U-V geometry; the wire spacing is 2.54 mm in all views. The target consisted of twenty 2 mm Be sheets preceded by two 0.8 mm Cu foils.

Beam particle identification is provided by a differential Cherenkov counter. Interaction counters covering the angular range 5 to 200 mrad, in coincidence with upstream beam-defining counters, specify the interaction time for an event. Time-to-voltage converters on the LAC amplifiers are used off-line to eliminate electromagnetic showers that are out of time. Two walls of veto counters, located downstream of a massive hadron shield, are used to eliminate random coincidences between beam-induced interactions and muons in the beam halo, which occasionally deposit energy in the EMLAC, thereby simulating high-p_T photons.

The data accumulated correspond to integrated luminosities per nucleon of approximately 0.8 events/pb for positive beam, and 0.5 events/pb for negative beam. We collected a total of 2×10^6 and 1.5×10^6 high-p_T triggers for proton and π^- interactions, respectively. Typical beam intensities were 2×10^6/sec, provided over a 20 sec beam spill. Data were accumulated using several p_T trigger thresholds between 3 and 4 GeV/c. The mean value of beam momentum was 500 GeV/c, with a momentum bite of about $\pm$ 4%.

Figure 2(a) displays the reconstructed mass spectrum of photon pairs having $p_T \geq$ 3.5 GeV/c and $-0.7 \leq y \leq 0.7$. The standard deviations of the π^o and η mass peaks are 8 and 24 MeV, respectively. Figure 2(b) depicts the energy asymmetry distribution (defined as $|E_{\gamma 1} - E_{\gamma 2}|/[E_{\gamma 1} + E_{\gamma 2}]$) for $\gamma\gamma$ pairs falling within the π^o mass region (defined as 110 to 160 MeV). The data in Fig. 2(b) have been corrected for background under the

π^o peak by subtracting the corresponding energy asymmetry distributions for mass pairs falling into two sideband regions: 75 to 100 MeV and 170 to 195 MeV. Also shown in Fig. 2(b) is a Monte Carlo simulation, which agrees very well with the subtraction-corrected data. The lower histogram in Fig. 2(a) is the mass spectrum of photon pairs having an energy asymmetry less than 0.75. The signal-to-background is seen to improve relative to the uncut data, and this restriction is therefore employed to select an especially clean sample of events for studying inclusive π^o production.

Table I presents the invariant cross sections per nucleon for inclusive π^o production in π^-Be and pBe collisions at 500 GeV/c. The data are for $-0.7 \leq y \leq 0.7$, and have been corrected for acceptance and trigger effects, and for background via sideband subtraction. The results in Table I are in general agreement with trends displayed by earlier experiments, which in the case of π^--induced collisions[3] are all at lower energy, whereas for p-induced collisions[4] the energy of this experiment falls between those of previous fixed-target and ISR experiments. We have also measured the inclusive production of π^0s from Cu. To within our statistical accuracy, the Cu results are simply scaled versions of those obtained on Be. When the Cu to Be cross section ratios are parameterized in the form A^α, the best fit value for α is 1.08 $\pm$0.02, in both π^-- and p-induced collisions. This result is similar to previous observations at high p_T.[5]

Figures 3(a) and 3(b) display our results for three rapidity intervals. Shown for comparison purposes are the results of LL QCD calculations by Owens[6] for two representative values of the scale parameter Q^2 (p_T^2 and $p_T^2/4$), using a recently extracted set of nucleon structure functions[7] that update the earlier Duke-Owens parameterizations.[8] Comparison of the measured data and the QCD predictions reveals approximate agreement over a p_T range in which the inclusive cross sections decrease by more than four orders of magnitude. However, the data are observed to fall more rapidly with p_T than predicted by the QCD calculations. (Other LL QCD formulations exhibit similar behavior[9].) These differences do not appear to originate from nuclear effects since we measure the same p_T dependence in

Be and Cu. When the discrepancies between the measured cross sections and the LL QCD predictions are parameterized as intrinsic transverse momentum (k_T) smearing, we require an effective $< k_T >$ of approximately 1.25 GeV/c (and $Q^2 \sim p_T^2/2$); this is consistent with what is expected from extrapolation of lower energy results on Drell-Yan and diphoton production to our energy.[10] It should be noted, however, that such effective $< k_T >$ values are strongly model dependent, since they depend not only upon the specific parton structure functions used and the level of QCD dynamics included in the calculations, but also on the definition of Q^2 and the quark and gluon fragmentation functions employed.

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References

1. For a comprehensive recent review of this subject, see W. M. Geist *et al.*, Phys. Reports **197**, 263 (1990).
2. F. Lobkowicz *et al.*, Nucl. Instr. and Meth. **A235**, 332 (1985); E. Engels, Jr. *et al.*, *ibid.* **A253**, 523 (1987); *ibid.* **A279**, 272 (1989).
3. See, for example, M. Bonesini *et al.*, Z. Phys. C. **37**, 39 (1987); J. Badier *et al.*, *ibid.* **30**, 45 (1986); C. De Marzo *et al.*, Phys. Rev. D **36**, 16 (1987); G. Donaldson *et al.*, Phys. Rev. Lett. **36**, 1110 (1976).
4. See, for example, M. Bonesini *et al.*, Z. Phys. C **38**, 371 (1988); C. De Marzo *et al.*, Ref. 3; J. Badier *et al.*, Ref. 3; G. Donaldson *et al.*, Ref. 3; J. Povlis *et al.*, Phys. Rev. Lett. **51**, 967 (1983); T. Åkesson *et al.*, Phys. Lett. **158B**, 282 (1985); A. Angelis *et al.*, *ibid.* **79B**, 505 (1978).

5. D. Antreasyan *et al.*, Phys. Rev. D **19**, 764 (1979); H. Frisch *et al.*, *ibid.* **27**, 1001 (1983).
6. J. F. Owens, Rev. Mod. Phys. **59**, 469 (1987).
7. J. F. Owens, Florida State Preprint FSU-HEP-910606 (June 1991), and private communication.
8. D. W. Duke and J. F. Owens, Phys. Rev. D **30**, 49 (1984); J. F. Owens, *ibid.* 943 (1984).
9. H. Bengtsson and T. Sjöstrand, Computer Phys. Comm. **46**, 43 (1987).
10. E. Bonvin *et al.*, Phys. Lett. **B236**, 523 (1990), and references therein.

Table I. Invariant cross sections per nucleon for inclusive π^0 production in π^-Be and pBe collisions at 500 GeV/c, averaged over $-0.7 \leq y \leq 0.7$ and the indicated p_T bands. In addition to the indicated statistical uncertainties, there is also a p_T-dependent systematic uncertainty that varies from 15% at low-p_T to 10% at high-p_T.

p_T	$\pi^- + Be \rightarrow \pi^0 + X$	$p + Be \rightarrow \pi^0 + X$
(GeV/c)	(pb/GeV^2)	
$3.5 - 3.75$	18370 ± 400	–
$3.75 - 4.0$	8880 ± 240	–
$4.0 - 4.25$	4370 ± 110	3536 ± 89
$4.25 - 4.5$	2330 ± 70	1893 ± 55
$4.5 - 4.75$	1080 ± 40	919 ± 31
$4.75 - 5.0$	660 ± 28	437 ± 19
$5.0 - 5.5$	280 ± 12	195.2 ± 8.2
$5.5 - 6.0$	86.6 ± 6.1	50.3 ± 3.9
$6.0 - 7.0$	13.0 ± 1.6	8.8 ± 1.1
$7.0 - 8.0$	1.79 ± 0.55	0.35 ± 0.18
$8.0 - 10.0$	0.20 ± 0.14	0.107 ± 0.076

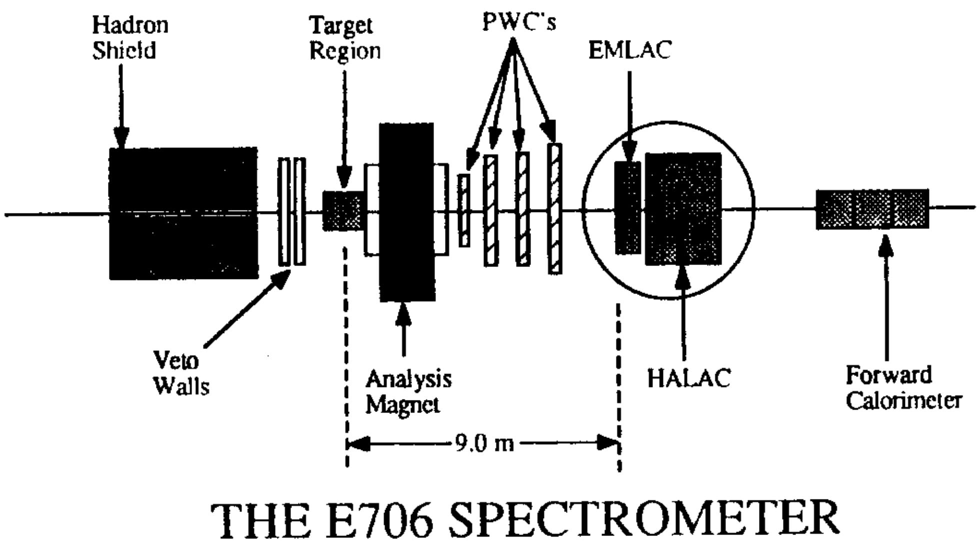

Figure 1. Schematic of the E706 spectrometer (not to scale) as used in the first run of the experiment.

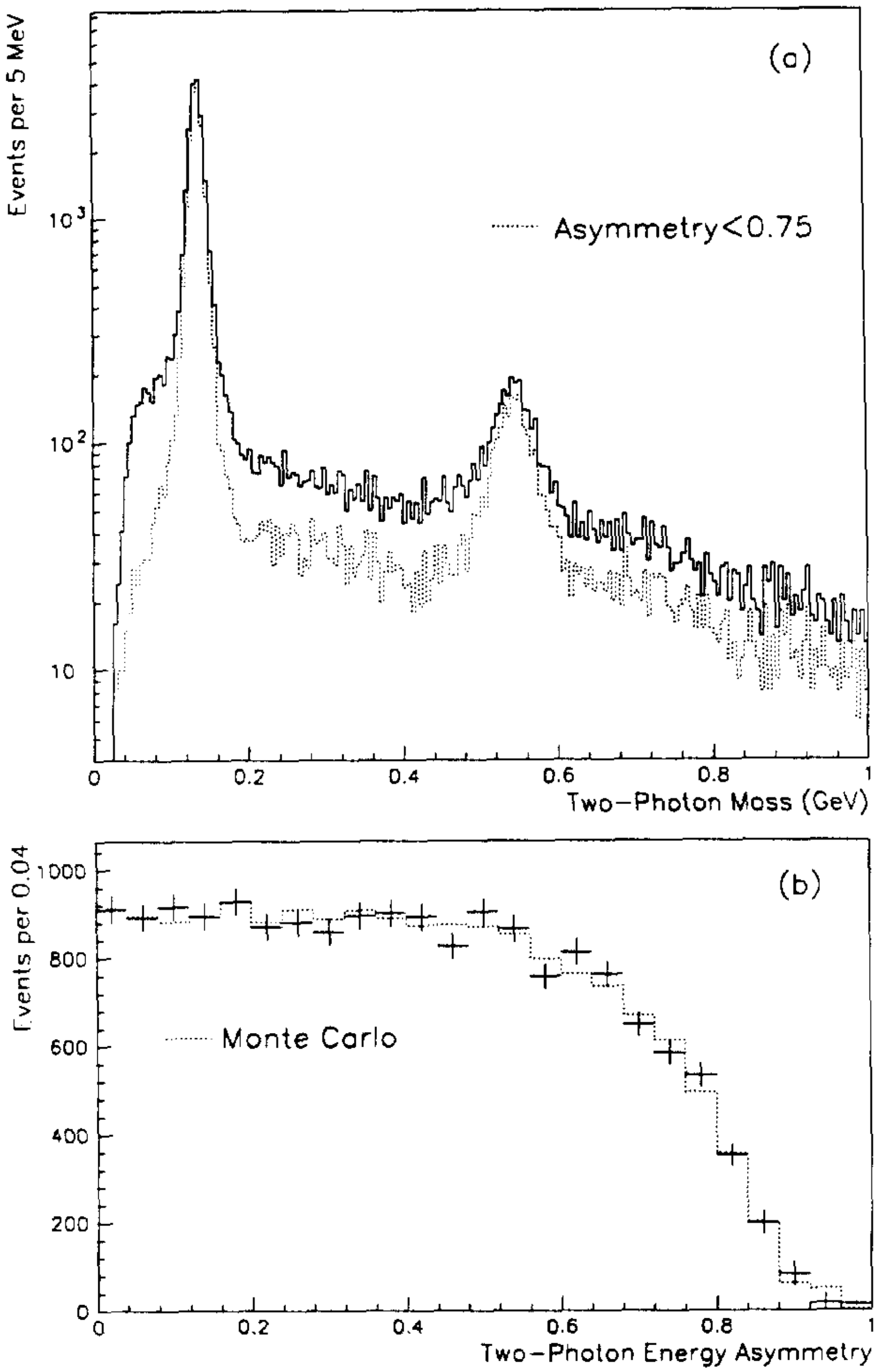

Figure 2. (a) The inclusive two photon mass distribution for 500 GeV/c positive and negative data combined, for $\gamma\gamma$ p_T values > 3.5 GeV/c and $|y|$ values < 0.7. The lower set of data points correspond to photon pairs with energy asymmetries < 0.75; (b) The background-subtracted energy asymmetry distribution for photon pairs having an invariant mass between 110 and 160 MeV. The dotted histogram represents a Monte Carlo simulation of this distribution.

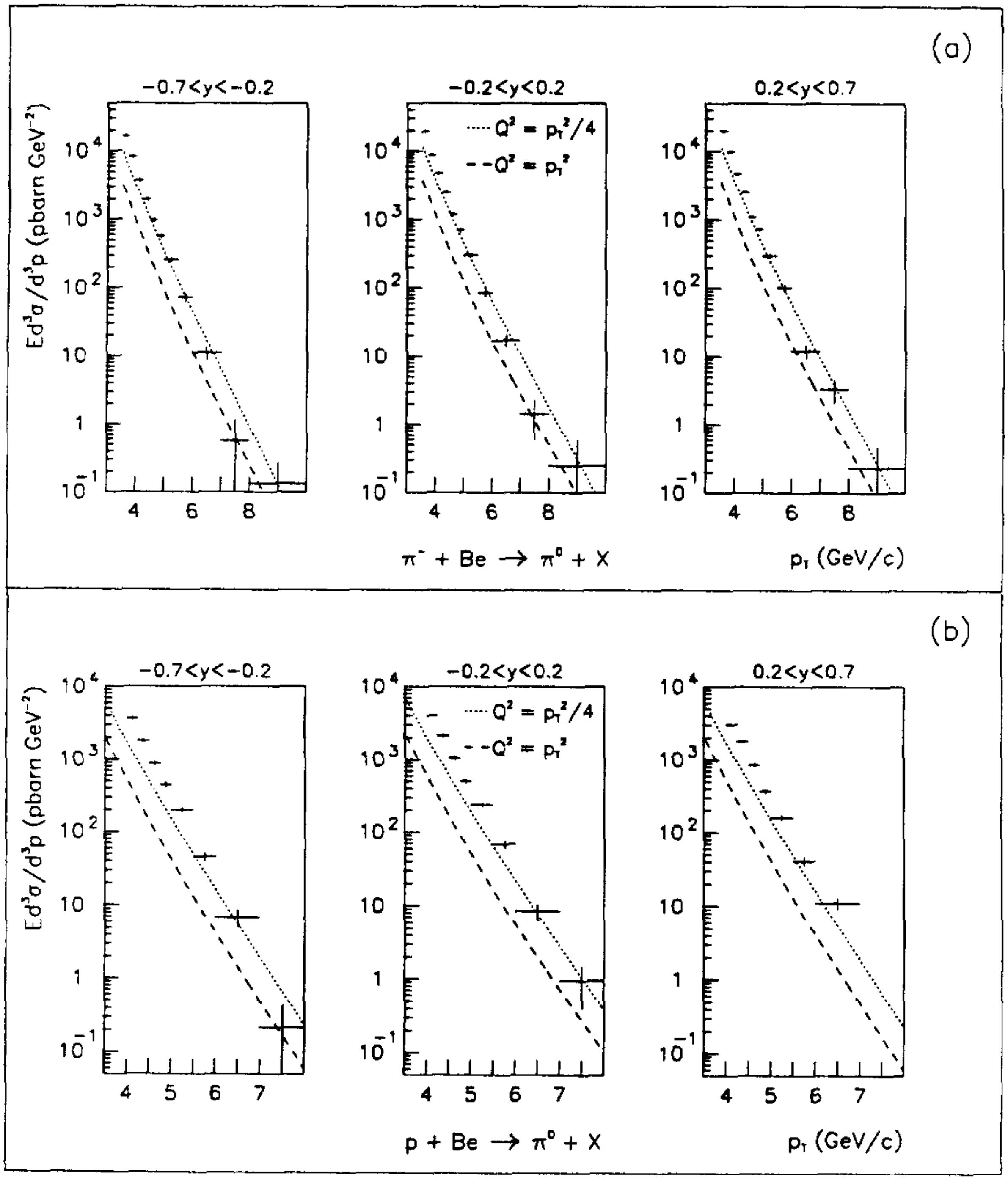

Figure 3. Comparison with LL QCD (Owens, Refs. 6 and 7) of the inclusive cross sections per nucleon versus p_T for π^o production at 500 GeV/c for the indicated rapidity intervals; (a) for π^-Be collisions and (b) for pBe collisions.