Observation of Structure in Large-Momentum-Transfer $\pi^- p$ Elastic Scattering at 200 GeV/c

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Results are presented on the measurement of 200-GeV/c $\pi^- p$ elastic scattering at $-t$ from 0.8 to 11 (GeV/c)^2. As $-t$ is increased, $d\sigma/dt$ falls by ~ 6 decades to a prominent dip at 4 (GeV/c)^2, followed by a second maximum and than a slow decrease with increasing $-t$.

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Above ~ 10 GeV/c incident momentum, there is now a considerable amount of data on large-$|t|$ proton-proton elastic scattering,[1-4] giving information on both the energy dependence of the cross section out to $-t \sim 15$ (GeV/c)^2 (Ref. 5) and the prominent dip in the t distribution at $-t \sim 1.4$ which appears above ~ 150 GeV/c incident momentum. Recent $\bar{p}p$ data[6] at 50 GeV/c also show a dip at $-t = 1.4$. Many models have been proposed to explain features of these data—a few examples are given in Refs. 7–12.

In contrast to baryon-proton scattering, not much large-$|t|$ πp information is available at high energies; data exist near 20 GeV/c[13,14] and have recently become available at 50 GeV/c,[15] but above that beam momentum, existing data[16] extend only out to $-t \sim 2$. Some models for πp scattering exist[17-23]; a few predict dips in the t distribution similar to the baryon-nucleon case, but with no consistency in the predicted location.

The experiment described here, which was carried out in the M6E secondary beam at Fermilab, was undertaken to measure $\pi^- p$ elastic scattering at 200 GeV/c out to $-t \sim 11$, to compare with pp large-$|t|$ scattering. Data on other incident particles at both ± 100 and ± 200 GeV/c, which extend to a $-t$ of ~ 3, will be reported at a later time.

The experimental layout is shown in Fig. 1. The beam, with about 10^7 particles per 1-sec spill, was made almost parallel through the apparatus so that determination of individual particle directions was unnecessary. Magnetic spectrometers were used to detect the scattered and recoil particles over the range $0.8 < -t < 11$. Electronic logic for the four scintillation counter hodoscopes was arranged in matrices to strongly favor elastic events; 31 proportional wire chambers (PWC's) containing 7800 wires were used to record particle tracks. For the present data, a signal from the threshold Čerenkov counter, set just below the antiproton threshold, was required; in addition, there was a differential Čerenkov counter in the beam, and the absence of a signal from it was required when it was set on a particle other than a π^-. The typical trigger rate was ~40 per accelerator spill.

In the off-line analysis, the angles and momenta of the two outgoing particles were obtained from the PWC data. To determine the number of elastic events at each t value, cuts were made on the differences between measured values of forward momentum, recoil momentum, and recoil angle, and the corresponding values predicted (with use of elastic kinematics) from the measured forward angle. The cuts (at ± 3 standard deviations of each distribution) were at ± 5 GeV/c, ± 200 MeV/c, and ± 40 mrad, respectively, for the three variables. After making these cuts, the coplanarity distributions for all regions of t

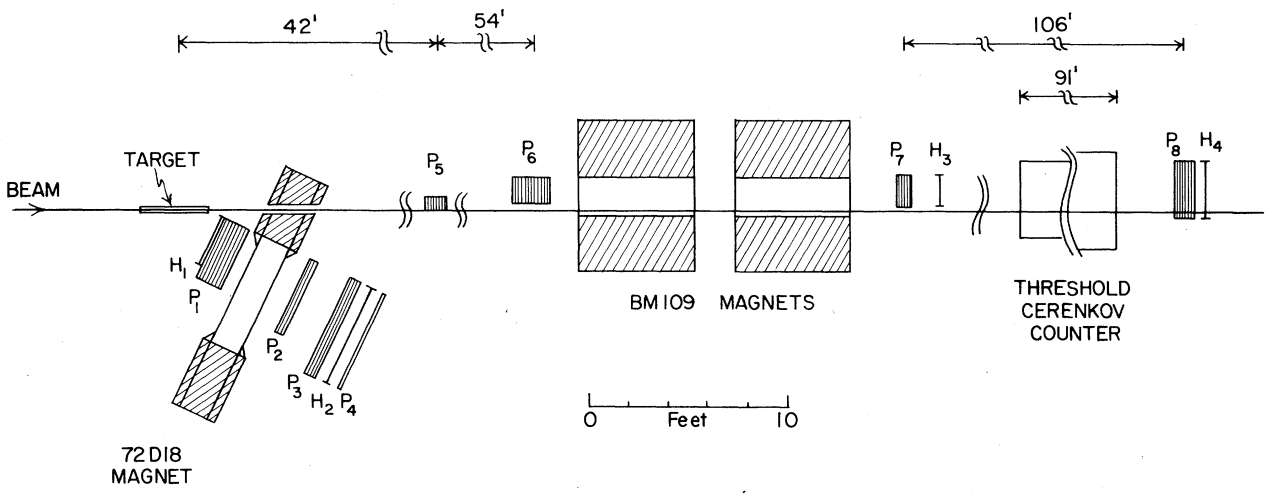

FIG. 1. Experimental layout. H_1-H_4 are scintillation counter hodoscopes; P_1-P_8 are proportional wire chamber arrays. The 72D18 field integral was 360 kG in., while the total field integral of the two BM109 magnets was 2600 kG in. Not shown are veto counters around the liquid hydrogen target, helium bags in the forward spectrometer, monitor telescopes, and apparatus in the incident beam such as scintillation counters, proportional wire chambers, segmented wire ionization chamber's, and a differential Čerenkov counter.

showed a sharp elastic peak sitting on a flat inelastic background. In the worst case ($-t>3$), the height of the inelastic tails was 2% of the height of the elastic peak. After a cut at ± 100 mrad, the inelastic background under the elastic peak was always less than 5%, and at the current stage of the analysis has not been subtracted. The overall PWC and reconstruction efficiency was determined to be ~80%. Elastic events were found to be ~4% of all triggers.

Small corrections to the data were made for particle absorption in the hydrogen target and material in the spectrometers, contamination in the pion beam, pion decay, δ rays from the hydrogen target causing vetos, and dead-time effects of the veto counters. Radiative corrections were also applied.[24] A Monte Carlo simulation was used to evaluate the geometrical acceptance of the apparatus; this varied smoothly, with a maximum azimuthal acceptance of 5%.

We estimate that systematic uncertainties on the overall normalization of the data presented here are ± 30%; this figure is expected to be reduced with further analysis.

Our results are shown in Fig. 2, while Fig. 3 compares our results with earlier data.[13-16] We agree with the earlier 200-GeV/c data[16] up to $-t\approx 2$ within the quoted normalization uncertainties.

The data show a drop of ~6 decades from $-t=1$ to a minimum at $-t=4$, followed by a second maximum and then a slow fall with increasing $-t$. The $-t=4$ dip has not previously been observed. From the t distribution of the individual elastic events observed, the probability that the

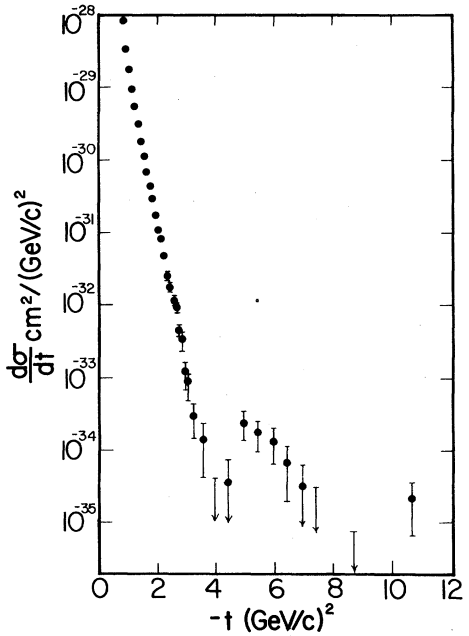

FIG. 2. Results from this experiment on 200-GeV/c $\pi^- p$ elastic scattering. Statistical errors only are shown. When no events were observed in a bin, the upper limit shown corresponds to one event.

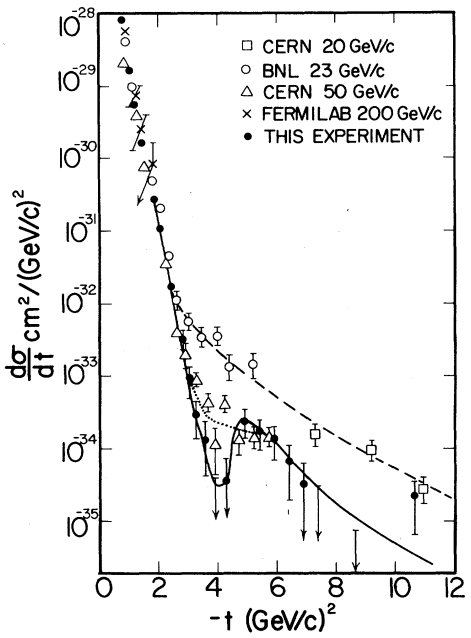

FIG. 3. Results from this experiment, together with earlier data: CERN, 20 GeV/c (Ref. 14); BNL, 23 GeV/c (Ref. 13); CERN, 50 GeV/c (Ref. 15); and Fermilab, 200 GeV/c (Ref. 16). For clarity, not all data points are shown. The curves are drawn to guide the eye.

cross section is flat in the $-t$ region 3.7 to 5.7 is only 1%. Figure 3 shows in addition that there is negligible incident-momentum dependence of the cross section between $-t$ of 1 and 3, although there is considerable dependence in the dip region.

When our data are taken together with those of Ref. 16, the shape of $d\sigma/dt$ out to $-t$ of ~ 4 is considerably more complex than a simple exponential form Ae^{Bt}. Local values of B decrease from 10 to 6.5 to 4.5 $(\mathrm{GeV}/c)^{-2}$ at $-t$ of 0, 0.6, and 2.0, respectively. At $-t \sim 3$, B increases to 5.5 $(\mathrm{GeV}/c)^{-2}$ as the dip is entered.[25] For the region $5 < -t < 11$, the value of B is determined to be 0.65 ± 0.20 $(\mathrm{GeV}/c)^{-2}$.

The observed diffractionlike shape of the $\pi^- p$ t distribution is not consistent with many of the model predictions, including QCD which gives a reasonable description of large-$|t|$ pp data.[7] The dip location, if viewed as a simple diffraction effect, seems to occur at a larger $-t$ value than might be naively expected from the πp total cross section; some eikonal models,[19,23] however, do predict dips in the $-t$ region around 3 to 5. The dip is not present in 20- or 50-GeV/c data, although an abrupt change of slope occurs there at 50 GeV/c. This behavior with increasing momentum is similar to that of the $-t = 1.4$ dip in pp scattering, which is not seen below ~ 150 GeV/c.

In conclusion, it appears now that a prominent dip in the elastic cross section, suggestive of a diffractive mechanism, may be a general phenomenon in the ~ 100 GeV/c region and above, having now been observed in pp, $\bar{p}p$, and $\pi^- p$ scattering.

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[25]This phenomenon of an increase in slope as the dip is entered is also seen in pp elastic scattering at the $-t = 1.4$ dip.

Low-Mass Electron-Pair Anomaly in 17-GeV/c $\pi^- p$ Collisions

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Inclusive e^+e^- production in 17-GeV/c $\pi^- p$ collisions has been measured. An excess of e^+e^- pairs over those from known sources for $0.1 \leq m_{ee} \leq 0.6$ GeV and $x < 0.5$ was found. No evidence is found for enhancements in specific final states involving electrons and photons or charged particles. The photon multiplicity associated with these pairs is measured.

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Recently there have been reports of both low-mass $\mu^+\mu^-$[1-3] and e^+e^-[4,5] production above what is expected from known meson decays. Dilepton production is one explanation for the anomalous single-lepton to pion ratios at low p_T.[6] However, the experimental situation regarding the existence of anomalous e/π ratios is still unsettled. We report here the first observation of e^+e^- pairs in which associated photons, as well as charged particles, are measured. The experiment was performed with a hydrogen target in the multiparticle spectrometer at the Brookhaven National Laboratory alternating-gradient synchrotron. Charged particles were observed over most of the full solid angle.[7] Electron identification was made by two Li-foil transition-radiation detectors (TRD)[8] within the magnet and two lead-scintillator shower detectors (SD)[9] outside the magnet. The back SD subtended $\pm 15°$ around the beam axis and detected e^+ and e^- above 2.5 GeV/c, as well as most produced photons above 0.5 GeV. The side SD, centered at 35°, detected e^+ between 0.8 and 1.8 GeV/c.

Two triggers were collected. Each required correlated hits in both TRD's and back SD for an e^-. Trigger PAIRA required an e^+, also in the back SD, and favored Feynmann $x > 0.45$ for the pair. Trigger PAIRB required an e^+ in the side SD; it required $x > 0.2$ and had maximum acceptance near $x = 0.4$. The pair mass acceptance was essentially flat below 1 GeV; the p_T acceptance was uniform at high x and gently falling with p_T below $x = 0.5$.

The analysis program selected good electrons by stringent cuts on TRD pulse heights and comparison of SD energy with momentum. Hadron rejections for e^-, PAIRA e^+, and PAIRB e^+ were greater than 3000, 3000, and 100, respectively. In order to survive as a direct pair, the trigger e^+ and e^- had to satisfy tight vertex cuts with the beam and produced charged particles. Each member of a direct pair was fitted to a γ hypothesis with all oppositely charged tracks. A trigger e^+ or e^- satisfying this fit with any nontrigger electron was removed from the sample. Surviving direct pairs were divided into two categories: If the pair could be constrained to a γ-fit hypothesis it was defined as low mass. If not, it was called high mass. The demarcation between these categories was about 0.1 GeV. For pair masses above 0.2 GeV there was negligible probability for the event to be in the low-mass sample. The low-mass sample contains a residual contamination from external γ conversions within 10 cm of the production point. Further details on the experiment, calibrations, and analysis are given elsewhere.[10]

The resulting mass distributions above 0.2 GeV are shown in Fig. 1. We expect contributions from three classes of sources: direct decays ρ, ω