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Pion-Proton Elastic Scattering at 20 and 50 GeV/c
Incident Momenta in the Momentum Transfer Range
 $0.7 < |t| < 8.0 \text{ (GeV/c)}^2$

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Abstract

Measurements of the differential elastic cross-sections for π^-p scattering at incident momenta of 20 and 50 GeV/c and π^+p at 50 GeV/c in the momentum transfer range $0.7 < |t| < 8.0 \text{ (GeV/c)}^2$ are presented. The data are compared with various models of elastic scattering.

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Measurements of the differential elastic cross-sections at large momentum transfers ($0.7 < |t| < 8.0 \text{ (GeV/c)}^2$) for $\pi^\pm p$ at 50 GeV/c and $\pi^- p$ at 20 GeV/c, performed recently at the CERN SPS are presented. Results on $\bar{p}p$ elastic scattering at 50 GeV/c⁽¹⁾ in the same angular range and on $\pi^\pm p$ elastic scattering at very large angles at 20 and 30 GeV/c⁽²⁾ have already been published.

The apparatus used, which is shown schematically in figure 1, consisted of a double arm spectrometer viewing a liquid hydrogen target upon which an unseparated, high intensity ($\sim 2 \times 10^7$ ppb) secondary beam was incident. The position of the beam particle was determined from a beam hodoscope consisting of three planes each containing forty scintillator fingers 2mm wide. A differential Cerenkov counter (CEDAR) was used to tag one of the minority beam components, and a threshold beam Cerenkov was used to identify the incident π^+ at 50 GeV/c where protons accounted for 27% of the beam. The trigger, imposing rough geometrical and kinematical constraints, was constructed from correlations of elements in the hodoscope arrays (PR1, PR3, H1 and H2 in figure 1), together with information from the large atmospheric pressure Cerenkov counters (C1, C2), which was used to identify the forward scattered particle. Scintillation counters around the target were used to veto events with two or more particle trajectories outside the acceptance of the apparatus, while multiplicity constraints in the trigger hodoscope arrays reduced multi-particle events. A silica-aerogel threshold Cerenkov counter (C3) enabled high velocity recoil particles, mainly pions, to

be rejected. The spectrometer magnet in the forward arm had an integrated field strength of 1.8Tm , allowing the momentum of the forward scattered particle to be determined to $\pm 6\%$ at 20 GeV/c and $\pm 15\%$ at 50 GeV/c .

The multi-wire proportional chamber (MWPC) digitisings, together with the hodoscope information, enabled the particle trajectory in each arm to be reconstructed using a total of 38 wire planes. The triggers containing at least one fully reconstructed vertex, satisfying rough cuts upon the kinematical variables, were then fitted using Runge-Kutta tracking through the magnetic field, with elastic kinematical constraints being applied at the vertex. The background was then estimated, for each t bin separately, upon the basis of the χ^2 distribution from the fit, with the aid of the coplanarity and $\Delta\theta$ distributions, the latter being the difference between the measured forward scattering angle and that predicted from the recoil trajectory for an elastic event. In each case the number of elastic events was found by subtraction of the background distribution, after extrapolation underneath the elastic peak, from the total event sample. At small $|t|$ the ratio of background to elastic events for χ^2 degree of freedom ≤ 35 was approximately 10% and although this proportion increased at higher $-t$ there was a clear elastic signal in all cases except the region near the π^+p dip. The data have been corrected for the angular dependent efficiencies of the forward arm Cerenkov counters and MWPC

track reconstruction. Global corrections, at each energy, for hodoscope and beam Cerenkov efficiencies, muon beam component, livetime, random and δ -ray vetoes have been applied. The π^-p event sample at 50 GeV/c contains a contamination of approximately 5% K^-p events, since the CEDAR was used to identify incoming $\bar{p}$'s in order to permit the measurement of the $\bar{p}p$ elastic cross-section, and the forward arm Cerenkov counters were not capable of efficiently separating π^- 's from K^- 's at 50 GeV/c. (The K^-/π^- ratio in the beam was less than 5% and it is assumed that the differential cross-sections are similar for the two meson types).

The π^-p differential elastic cross-section at 20 GeV/c is shown in figure 2, together with the very large angle data from the first phase of this experiment⁽²⁾ and the 9.7 GeV/c results of ref. (3). It can be seen that the prominent dip visible at $|t| = 2.8 \text{ (GeV/c)}^2$ in the lower energy data has all but disappeared at 20 GeV/c, leaving in its place a shoulder with a very shallow dip, as seen by Cornillon et al.⁽⁴⁾ at 22.6 GeV/c. Beyond the dip the new data join smoothly to the large angle measurements and the entire region $|t| > 4 \text{ (GeV/c)}^2$ can be described by the Constituent Interchange Model⁽⁵⁾ (CIM) fit of ref.(2).

At 50 GeV/c the π^-p differential cross-section shown in figure 3 illustrates that the dip at $|t| = 2.8 \text{ (GeV/c)}^2$ has now totally disappeared, although there is still a change of slope at this point. There is no evidence in these data for

the prominent dip observed at $|t| = 4 (\text{GeV}/c)^2$ by Baker et al⁽¹¹⁾ in π^-p elastic scattering at 200 GeV/c, (see figure 4).

Figure 5 illustrates the close identity of the $|t| < 2.5 (\text{GeV}/c)^2$ π^-p cross-sections over the momentum range 20-200 GeV/c, suggesting that this part of the angular range is dominated by diffraction, even at incident momenta as low as 20 GeV/c.

The π^+p elastic differential cross-section at 50 GeV/c, illustrated in figure 6, has a slightly shallower slope than the π^-p data at the same energy, and a small dip at $|t| = 3.8 (\text{GeV}/c)^2$. It is also found that both the π^-p cross-sections and the π^+p cross-section reported here lie on a single geometrical scaling curve of

$$\frac{1}{\sigma_t} \frac{d\sigma}{dt} \text{ vs } \sigma_t \cdot t$$

There are several predictions for a dip structure in this region, notably in the eikonal picture of Chou and

Yang⁽¹²⁾. It is necessary, however, to extrapolate the pion form factor F_π to high q^2 in order to calculate the large four-momentum transfer dependence of the elastic cross-section in the geometrical model. The assumption of vector meson dominance of the pion form factor has been shown by Chan, Lo, Low and Phua⁽⁶⁾ to lead to the prediction of a dip at $|t| = 5.1 (\text{GeV}/c)^2$ for π^+p scattering at 175 GeV/c, at which energy the total cross-section is only 0.6mb larger

than at 50 GeV/c. The same authors also postulate the form factor $F_{\pi}(q^2) = F_p(q^2)^{2/3}$, based upon the additive quark model, which gives a narrower central peak, in good agreement with the measured π^+p cross-section except near the dip. The shallow dip predicted by Chan et al.⁽⁶⁾ at $|t| \approx 4 \text{ (GeV/c)}^2$ using this form factor does not persist if a more precise parametrization of the form factor product $F_{\pi}(q^2)F_p(q^2)$, is used in their calculation, the resulting curve being shown in figure 6. This form does not describe the 50 GeV/c π^-p data so well, giving a central peak that is still too wide. In both channels the geometrical model requires a steeper t dependence of the pion form factor than that given by vector dominance if it is to describe the data.

Barger, Luthe and Phillips⁽⁷⁾ have generalized the geometrical scaling concept to treat channels with different σ_{el}/σ_T , but only the rescaling of the unabsorbed overlap function from the measured pp elastic cross-section gives predictions comparable to $\pi^\pm p$ data and these have a very prominent narrow dip at $|t| = 4 \text{ (GeV/c)}^2$ as illustrated in figure 3 for the π^-p case. It should be noted, though, that 50 GeV/c is a rather low momentum for the application of geometrical scaling to πp scattering, so that there may still be substantial contributions present from the real part of the scattering amplitude. Even at 200 GeV/c, where the π^-p data of Baker et al.⁽¹¹⁾ have a strong dip, the detailed shape of the cross-section is not well represented.

An alternative approach, which has been applied to pp and $\bar{p}p$ elastic scattering⁽⁸⁾⁽⁹⁾, is to explain the cross-section by two mechanisms : a hard process dominating at large $|t|$ and a diffractive process dominant at small $|t|$. The two amplitudes may then interface to produce structure in the cross-section when they are of comparable magnitude. It is expected that at sufficiently high s and $|t|$, the hard scattering interaction should lead smoothly to a quark interchange mechanism, with a consequent power law fall-off in $|t|$.

Finally, it should be noted that the large $|t|$ for $-t > 5(\text{GeV}/c)^2$ behaviour of the π^+p 50 GeV/c differential cross-section is not inconsistent with a $|t|^{-7}$ dependence, as expected at high energy in the multiple scattering model⁽¹⁰⁾.

The measurements reported here made extensive use of apparatus and analysis procedures developed for the very large angle experiment and we wish to thank the authors of ref.2 for the use of their work.

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Figure Captions

1. Schematic view of the apparatus.
2. π^-p elastic scattering at 20 GeV/c, compared with the data of Owen et al.⁽³⁾ The solid line is the Constituent Interchange Model fit of ref.(2).
3. π^-p elastic scattering at 50 GeV/c. The solid line is the rescaled pp differential cross-section from 1496 GeV/c, obtained by scaling the unabsorbed overlap function, of ref.7.
4. A compilation of π^-p elastic scattering data between 20 and 200 GeV/c. The cross-sections at 50 and 200 GeV/c have been scaled down by 10 and 100 respectively.
5. A comparison of π^-p smoothed elastic differential cross-sections.

6. π^+p elastic scattering at 50 GeV/c. The dashed line indicates the Chou-Yang model calculation using $F_\pi(q^2) = F_p(q^2)^{2/3}$ following the calculation of Chan et al.⁽⁶⁾, but with refitted parameters. The solid line illustrates $|t|^{-7}$ behaviour.

CHO-10 MWPC's
 Č1-3 Cerenkov counters

Fig. 1

Fig. 2

figure 3

Fig. 4

Fig. 5

fig. 6