$\Sigma^- p$, $\Xi^- p$, and $\pi^- p$ Elastic Scattering at 23 GeV/c

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We present results from a measurement of the differential cross sections for $\Sigma^- p$, $\Xi^- p$, and $\pi^- p$ elastic scattering at 23 GeV/c. We have collected samples of 6200 $\Sigma^- p$ events, 67 $\Xi^- p$ events, and 30 000 $\pi^- p$ events in the interval $0.10 < |t| < 0.23$ (GeV/c)^2.

In this paper we report the results of a measurement of the elastic scattering of negative hyperons at high energies. The experiment, performed in the negative hyperon beam at the Brookhaven National Laboratory alternating-gradient synchrotron, measured the differential elastic cross sections of Σ^- and Ξ from protons; a simultaneous measurement of $\pi^- p$ elastic scattering provided a check on the apparatus and analysis.

The hyperon beam, essentially a short curved magnetic channel, delivers a flux of about 10^4 π^-, 100 Σ^-, and 1 Ξ^- per machine pulse at a momentum of 23 GeV/c with a spread of 10% full width at half-maximum.[1] Figure 1 depicts the beam and associated detection apparatus; a detailed description appears elsewhere.[2] Beam particles of mass less than 1 GeV/c^2 are tagged by a threshold Cherenkov counter (C_B) which forms part of the channel. A cluster of high-pressure, high-resolution (100 μm) spark chambers[3] determines the momentum of the emerging beam particle to ± 1%. A 40-cm-long, 4.45-cm-diam liquid-hydrogen scattering target (2.80 g/cm^2) is followed by by a second high-resolution spark-chamber cluster. The high-resolution chambers determine the scattering angle to ± 1 mrad. A set of five small scintillation counters (B) defines the beam. A scintillator-lead-scintillator hole veto counter (VH) immediately downstream of the hydrogen target discriminates against hyperons decaying upstream of the decay region and inelastic scattering with π^0 production.

The hydrogen target is surrounded by a recoil detector (Fig. 2) which selects scattering events. An inner, 0.32-cm-thick, scintillator (DE) defines the minimum recoil proton kinetic energy ($\simeq$ 30 MeV) and measures dE/dx. The protons are stopped in a 10-cm-thick scintillator (E) which measures their total kinetic energy. Surrounding counter E is a scintillator-lead-scintillator veto counter (RV) which defines the maximum recoil kinetic energy ($\simeq$ 150 MeV) and discriminates against π^0's from inelastic events. The recoil detector covers 270° of azimuth. A threshold requirement on the recoil counter pulse heights prevents delta rays from dominating the trigger rate.

A 1.4-m decay region downstream of the second high-resolution chamber is followed by a magnetic spectrometer with conventional wire

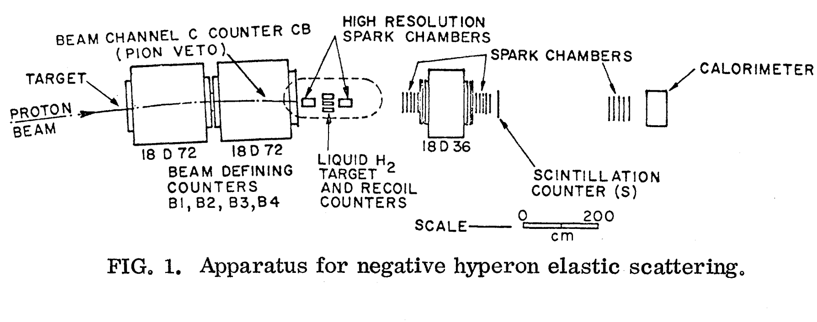

FIG. 1. Apparatus for negative hyperon elastic scattering.

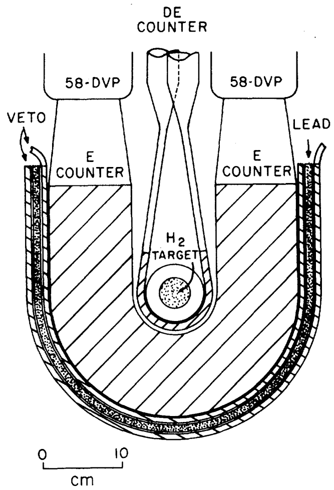

FIG. 2. Recoil detector.

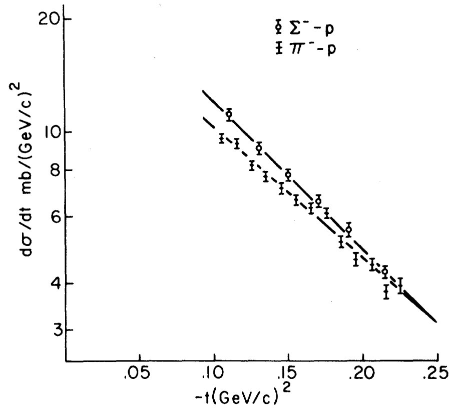

FIG. 3. Elastic differential cross sections for 23-GeV/c π^- and Σ^-.

spark chambers. This spectrometer measures the momentum of the slow pion (<10 GeV/c) from the dominant decay $\Sigma^- \rightarrow n\pi^-$ to about 5%. The scintillation counter (S) assures the presence of a charged particle in this spectrometer. Finally, an iron-scintillator calorimeter (CAL) is used to discriminate against background muons which might simulate hyperon scatterings or decays in the trigger. The triggers for scattered hyperons and pions are then, respectively,

$$\overline{C}_B \cdot B \cdot \overline{VH} \cdot \text{RECOIL} \cdot S \cdot \text{CAL},$$

$$C_B \cdot B \cdot \overline{VH} \cdot \text{RECOIL} \cdot S \cdot \text{CAL}.$$

Unscattered particles are detected simultaneously with the scattered particles by removing the recoil requirement from the trigger. Unscattered triggers and scattered π^- triggers are prescaled to give a total trigger rate of a few per machine pulse. For each trigger we record the configuration of scintillation counter hits, the pulse heights from counters E, DE, and CAL, and the spark chamber data.

In the analysis, we require the following criteria: a beam track pointing to the hyperon production target and inside the beam channel; scattering vertex inside the hydrogen target fiducial volume; scattering angle greater than 7.5 mrad; recoil proton predicted within the azimuthal acceptance of the recoil detector; and a good negative track through the spectrometer. For Σ^- and Ξ^- we require that the decay vertex be inside the decay region and that the laboratory decay angle be greater than 5 mrad.

The final requirement on the scattered events is their "elasticity." The scattering angle of the beam particle is predicted from the energy deposited in the thick recoil counter (E), assuming the scattering to be elastic, and required to agree with the measured angle to within 5 mrad (4 mrad) for Σ^- (π^-). We also require the energy deposited in the thin recoil counter (DE) to be within 4 MeV of the value predicted from the beam particle momentum and scattering angle, assuming the scattering to be elastic.

A Monte Carlo simulation of inelastic events using the inelastic spectrum measured[4] in pp interactions at 24 GeV/c indicates that with these cuts, 2.0% (1.7%) of the remaining Σ^-p (π^-p) events are inelastic. Target-empty runs show that 1.9% (1.5%) of the Σ^-p (π^-p) events are not from hydrogen. After applying corrections for these effects, the remaining 6200 (30 000) Σ^-p (π^-p) events in the interval $0.10 < |t| < 0.23$ (GeV/$c)^2$ are fitted by maximum likelihood with the form

$$d\sigma/dt = A(t)e^{a+bt},$$

where $A(t)$ is the geometric acceptance of our apparatus determined by Monte Carlo methods. The results of the fit are[5]

$$b_{\pi^- p} = 7.89 \pm 0.24 \ (\text{GeV}/c)^{-2},$$

$$\chi^2 = 15.5/(12 \text{ degrees of freedom});$$

$$b_{\Sigma^- p} = 8.99 \pm 0.39 \ (\text{GeV}/c)^{-2},$$

$$\chi^2 = 25.1/(12 \text{ degrees of freedom}).$$

The data for Σ^-p and π^-p elastic scattering with the acceptance correction, target-empty subtraction, and target-absorption correction applied are shown in Fig. 3. The scattering events are normalized to analyzed scattering-free events recorded simultaneously with the scattering

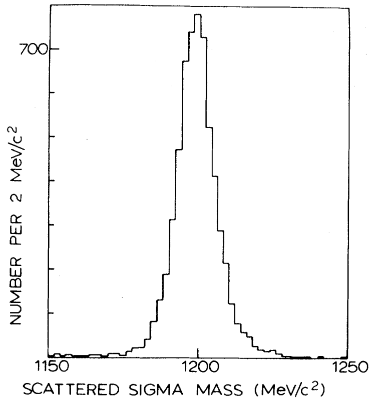

FIG. 4. Reconstructed mass of beam particle for scattered Σ^- events.

events.

If we assume that the Σ^- have scattered elastically, we can reconstruct the beam particle mass from a once-overconstrained fit. Figure 4 shows the reconstructed beam particle mass for all events in the elastically scattered Σ^- data. The width of the peak is consistent with our resolution.

The π^- slope is in agreement with other measurements.[6] A simple quark model[7] leads one to expect that the difference between the Σ^-p and the pp elastic slopes should be approximately equal to the difference between the K^-p and π^-p elastic slopes:

$$b_{\Sigma^-p} - b_{pp} = b_{K^-p} - b_{\pi^-p}.$$

This equation predicts $b_{\Sigma^-p} = 9.0 \pm 1.0$ $(\mathrm{GeV}/c)^{-2}$.[8]

Optical models have been quite successful in fitting small-angle elastic scattering. A simple optical model gives the formula

$$b_{\Sigma^-p} = b_{pp}\,\sigma_{\mathrm{tot}}(\Sigma^-p)/\sigma_{\mathrm{tot}}(pp).$$

This calculation yields $b_{\Sigma^-p} = 8.7 \pm 0.5$ $(\mathrm{GeV}/c)^{-2}$.[9] Our result is thus in good agreement with these predictions.

The total cross section for Σ^-p scattering has been measured at CERN with the result $\sigma_{\mathrm{tot}}(\Sigma^-p) = 34 \pm 1$ mb.[9] Under the assumption of purely imaginary amplitudes, the optical theorem predicts

$$(d\sigma/dt)_{t=0} = 59 \text{ mb } (\mathrm{GeV}/c)^{-2}$$

Our experimental result with a linear extrapolation to $t = 0$ is

$$(d\sigma/dt)_{t=0} = 30 \pm 3 \text{ mb } (\mathrm{GeV}/c)^{-2}.$$

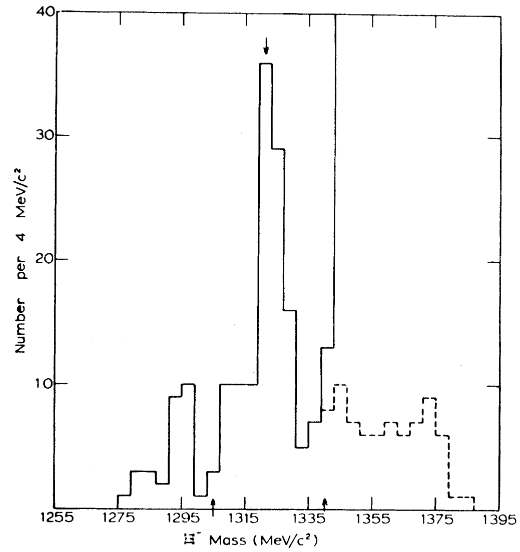

FIG. 5. $\Lambda^0\pi^-$ mass. Dashed curve shows events before $n\pi^-$ mass cut.

We believe that our normalization is accurate to 10%. The value of our π^-p cross section (summed over our t interval) is about 7% below that given by Antipov *et al.*[6] To make our data consistent with the optical theorem we need to assume a significant change of slope in the differential cross section at small t. A similar change of slope at $t \simeq -0.14$ $(\mathrm{GeV}/c)^2$ has been observed in p-p elastic scattering at high energies.[10]

Our flux of Ξ^- is $\frac{1}{100}$ that of Σ^-; however, we are able to isolate a small sample of Ξ^-p elastic scatterings. We impose the same elasticity requirements as on the Σ^-p events, but select those events which do not fit the Σ^-p hyphothesis by eliminating events with a reconstructed $n\pi^-$ mass greater than 1176 MeV/c^2. We reanalyze the remaining events under the hypothesis

$$X^-p \to X^-p, \quad X^- \to \Lambda^0\pi^-.$$

Figure 5 shows the $\Lambda\pi$ mass spectrum. The dashed curve shows the full data sample before the $n\pi^-$ mass cut has been applied. The peak at the Ξ^- mass contains 67 events. We estimate that about 20% of these events could be background (probably Σ^- from the tail of the reflection of the $\Sigma^- \to n\pi^-$ events).

The differential cross section for these 67 events with no background subtraction is shown in Fig. 6. The slope is

$$b_{\Xi^-p} = 7.0 \pm 3.5 \ (\mathrm{GeV}/c)^{-2};$$

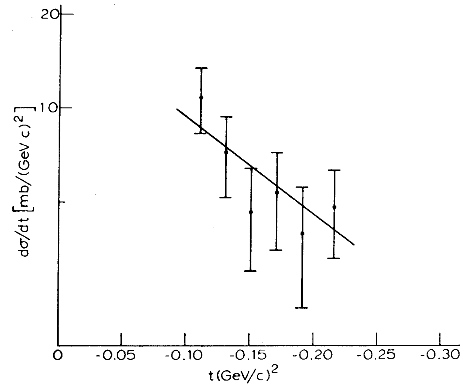

FIG. 6. Elastic differential cross section for Ξ^-.

the forward cross section is

$$(d\sigma/dt)_{t=0} = 19^{+14}_{-8}\ \text{mb}\ (\text{GeV}/c)^{-2}.$$

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[2]V. Hungerbuehler *et al.*, Nucl. Instrum. Methods 115, 221 (1974).

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[4]J. V. Allaby *et al.*, Phys. Lett. 34B, 435 (1971).

[5]J. J. Blaising *et al.* [Phys. Lett. 58B, 121 (1975)] have recently published a measurement of the $\Sigma^- p$ elastic slope at 17.2 GeV/c, in the interval $0.12 < |t| < 0.38$. Their result is $b = 8.12 \pm 0.35$ (GeV/c)$^{-2}$.

[6]A. R. Dzierba *et al.*, Phys. Rev. D 7, 725 (1973); Yu. M. Antipov *et al.*, Nucl. Phys. B57, 333 (1973).

[7]Masaaki Kawaguchi *et al.*, Prog. Theor. Phys. 38, 1178 (1967), and 40, 594 (1968); R. Majka, "Sigma Minus–Proton Elastic Scattering at 23 GeV/c," Ph.D. thesis, Yale University, 1974 (unpublished).

[8]The forward slopes for $\pi^- p$ and $K^- p$ elastic scattering have been fitted as a function of t and s (square of c.m. energy) by Antipov *et al.* (Ref. 6) with the form $b = b_0(t) + 2\alpha(t)\ln(s/s_0)$. The fits give $b_{\pi^- p} - b_{K^- p} = 0.68$–$1.20$ (GeV/c)$^{-2}$ for our energy and t range. In addition, we take $b_{pp} = 10.0 \pm 0.5$ (GeV/c)$^{-2}$ from O. Benary *et al.*, Lawrence Berkeley Laboratory Report No. UCRL-20000 NN, 1970 (unpublished).

[9]We use the $\Sigma^- p$ total cross section (34± 1 mb) measured at 19 GeV/c by J. Badier *et al.*, Phys. Lett. 41B, 387 (1972), and a pp total cross section of 39 mb.

[10]G. Barbiellini *et al.*, Phys. Lett. 39B, 663 (1973).