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Polarization in p-p Elastic Scattering at High Energies

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Results are presented from an experiment conducted at Fermilab to measure the polarization parameter in p-p elastic scattering at momenta between 20 and 200 GeV/c at $|t|$ values between 0.3 and 1.0 (GeV/c)^2. Recoil protons from the interaction of the circulating Fermilab beam and a hydrogen gas jet were spin analyzed in a carbon polarimeter and significant polarizations were observed. The results are compared with the predictions of exchange models.

We report here the results of an experiment conducted in the internal-target area at Fermilab to measure polarization in p-p elastic scattering at incident momenta between 20 and 200 GeV/c for values of t between -0.3 and -1.0 (GeV/c)^2.

The experimental layout is shown in Fig. 1. The circulating proton beam in the accelerator interacted with a jet of hydrogen gas. The jet was normally pulsed five times during the acceleration of the beam to obtain data at five incident momenta. The luminosity was typically 0.5×10^{34}/cm^2 per accelerator cycle.

Recoil protons were momentum analyzed by a superconducting magnetic spectrometer consisting of two quadrupoles (Q1 and Q2), a dipole magnet, multiwire proportional chambers (SPC1–11),

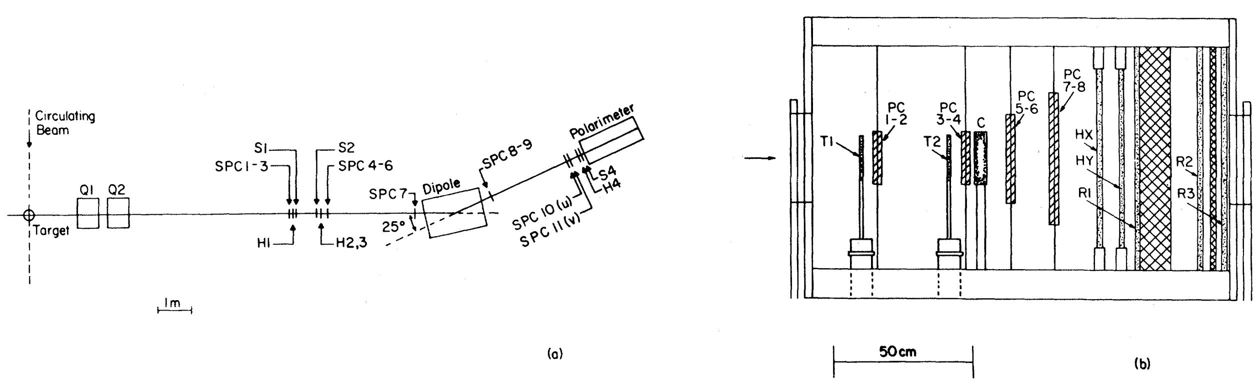

FIG. 1. (a) Plan view of internal-target superconducting spectrometer. Q1 and Q2 are quadrupole magnets. SPC1–11 are multiwire proportional chambers. H1–4 are hodoscopes and S1–4 are trigger counters. (b) Elevation view of the polarimeter. T1 and T2 are trigger counters. PC1–4 are multiwire proportional chambers. HX and HY are hodoscope counters. R1–3 form a range telescope. Protons rescatter in the carbon block, C.

scintillation hodoscopes (H1–4), and scintillation trigger counters (S1,2,4). The momentum acceptance of the spectrometer was ± 5% and the angular acceptance was 4×10^{-4} sr. To a good approximation the width of the distribution in square of missing mass is proportional to the product of the incident momentum and the recoil momentum. At $t=-0.6$ $(\mathrm{GeV}/c)^2$ where the recoil momentum is 0.838 GeV/c and at an incident momentum of 45 GeV/c, $\Delta M^2=\pm 0.2$ $(\mathrm{GeV}/c^2)^2$. The spectrometer was movable so that different values of t could be remotely selected. At each setting of the spectrometer elastically scattered protons were accepted at essentially a constant t independent of the incident momentum.

The polarization of the recoil protons was determined by measuring the left-right asymmetry, ϵ, of a second scattering in a carbon polarimeter. The asymmetry is proportional to the polarization, $\epsilon = P_{\mathrm{recoil}}A$, where A, the analyzing power, depends on the incident energy and the acceptance of the scattered particle. A had been measured as a function of energy in a similar apparatus using a beam of known polarization at the Argonne National Laboratory zero-gradient synchrotron.[1]

The polarimeter consisted of multiwire proportional chambers (PC1–8) placed upstream and downstream of a carbon block (C) as shown in Fig. 1. At values of $|t|$ greater than 0.3 $(\mathrm{GeV}/c)^2$ a 5-cm-thick block was used. At lower $|t|$ a 1.25-cm-thick block was used because the thicker block would have absorbed and degraded the protons excessively. The entire polarimeter assembly could be rotated through 180° about the polarimeter axis. Data were taken alternately in the 0° and 180° positions so as to eliminate effectively the principal sources of instrumental asymmetry.

Only protons which scatter in the carbon through an angle between 6° and 22° contribute significantly to the analyzing power. Most of the incident protons, however, scatter into the region less than 6°. The useless events were eliminated by a hardware preprocessor which examined the proportional chamber data and made a decision in about 2 μsec. This device increased the effective data rate by a factor of about 20 when the 5-cm block was used and was essential to the success of the experiment. An example of the effect of this device is shown in Fig. 2. Numerous tests confirm that the preprocessor did not introduce any biases between 6° and 22°.

The asymmetry is determined simply by $\epsilon=(L-R)/(L+R)$, where L and R refer to the number of left and right scatterings in the carbon into

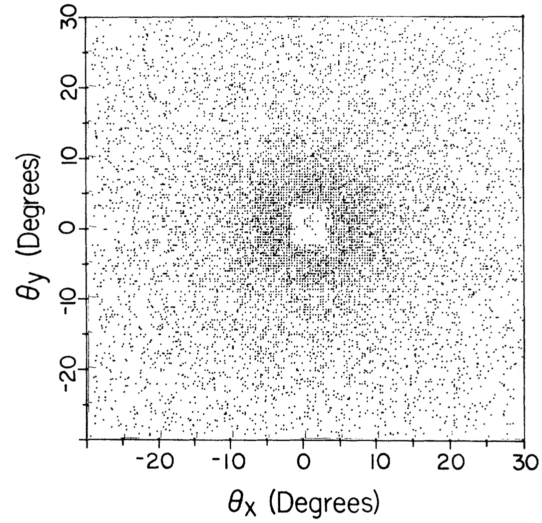

FIG. 2. Scatter plot of vertical (y) and horizontal (x) scattering in the carbon block. The strong central multiple-Coulomb-scattering peak has been suppressed in our trigger by a hardware processor.

the correct angular region. In order to keep from introducing a systematic error one must be careful to use exactly the same event selection criteria for left and right scatterings. For example: (1) The chambers must be aligned very carefully so that the accepted angular region is the same on both sides. The alignment was checked continually by taking some data with mostly noninteracting particles in each run. (2) The selection of a good event when more than one track is observed must be done in an unbiased way. Track segments in the upstream and downstream chambers were required to meet within a specific tolerance in the carbon scatterer. If more than one upstream track or more than two downstream tracks were found, the entire event was rejected. If two downstream tracks were found (at most, 3% of the events), the one making the smaller angle was used if it fell within the angular acceptance. This procedure is consistent with the one used to measure the analyzing power. It keeps events which would be difficult to remove in an unbiased way.

A correction for chamber efficiency was made on an event-by-event basis using the information from the hodoscopes which occupy a position just behind the downstream chambers. The hodoscopes defined a 12×12 array. Efficiencies in the four downstream chambers were calculated in a first pass through the data for each element of the array. The calculated efficiences were then used to weight each event depending on which element was occupied. The change in the left-right asymmetry due to this correction was very small because of the uniformity of the chambers.

Some of the data required correction for inelastic background. The spectrum of missing mass was divided into several inelastic regions and the elastic region. The polarization of the background was calculated for each inelastic region and then extrapolated to the elastic region. By fitting the elastic peak the amount of residual background was found and used with the extrapolated inelastic polarization to calculate the correction to the elastic polarization. This procedure always resulted in a correction of less than half the statistical error.

Four consistency checks were available to check our results:

(1) Our data at 22 and 45 GeV/c were compared with previously published results.[2,3] Good agreement was found in all cases.

(2) About 10^6 pion events were taken during the course of the experiment and analyzed in the same way as the proton events. Within a statistical uncertainty of 0.003 these events were found to be consistent with zero asymmetry.

(3) Up-down asymmetries for all t values and energies were found to be zero within statistical error.

(4) The data from the 0° and 180° positions of

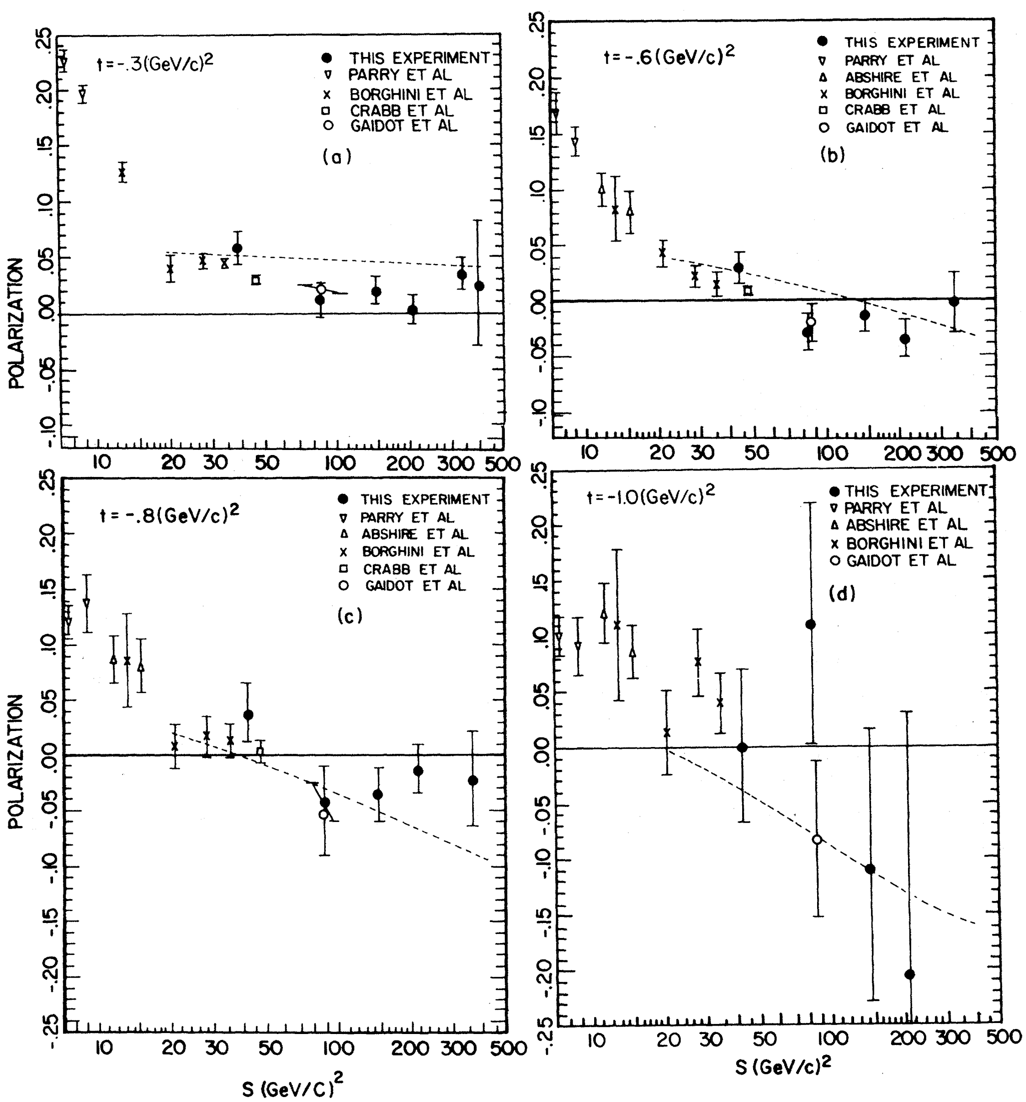

FIG. 3. Polarization results at fixed t. The curves shown are predictions of the model in Ref. 9. (a) $t = -0.3$ (GeV/c)^2, (b) $t = -0.6$ (GeV/c)^2, (c) $t = -0.8$ (GeV/c)^2, and (d) $t = -1.0$ (GeV/c)^2.

the spectrometer were analyzed separately and found to agree within at most $1\frac{1}{2}$ standard deviations. On averaging of the two orientations even these small differences cancel and the residual instrumental asymmetry in the final result is much less than 1 standard deviation.

The polarization of proton-proton elastic scattering measured at t values of -0.3, -0.6, -0.8, and -1.0 $(\mathrm{GeV}/c)^2$ is shown for beam momenta from 20 to 200 GeV/c in Figs. 3(a)–3(d). These figures also include data from previous lower-energy experiments.[2,3,4-6] The general features of these data are a decreasing value of the polarization with increasing s and a negative value for the polarization for $-t \gtrsim 0.6$ $(\mathrm{GeV}/c)^2$ and $s \gtrsim 50$ $(\mathrm{GeV})^2$. The decrease with s is characteristic of Regge models. The negative value of the polarization is expected from some Regge models in which absorption is important[7] and from some optical models.[8] According to these models the polarization should attain ~ -0.3 near $t = -1.4$ $(\mathrm{GeV}/c)^2$ for $400 \lesssim s \lesssim 1000$ $(\mathrm{GeV})^2$. The trend of our data is consistent with such models.

Another idea which was advanced by Pumplin and Kane[9] is that diffractive scattering with the exchange of two pions may become important at large s. This mechanism can account for the change in slope at small t in the high-energy elastic t-p differential cross-section data. It can also cause a polarization which persists to very high energy because one pion can couple with a spin flip while the other does not. To show that this mechanism is consistent with our data for $-t \gtrsim 0.6$ $(\mathrm{GeV}/c)^2$ we have plotted the prediction of this model in Figs. 3(a)–3(d).

We wish to express our appreciation to the staff at the Fermilab Internal Target Area for their efforts in bringing into operation a major new spectrometer and target system. We also wish to acknowledge the many contributions made by the E198 collaboration (University of Rochester, Rutgers University, Imperial College) in the design, construction, and implementation of the spectrometer and target operation. We are indebted to several Indiana University staff members and students for their assistance in this project. These include M. Daskovsky, F. Fredericksen, B. Martin, P. Smith, E. Shoemaker, R. Sherman, and M. Cummins. We also wish to acknowledge useful discussions concerning this experiment with A. Hendry, D. Lichtenberg, G. Kane, G. Fox, and F. Halzen.

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