Depolarization Parameter in pp Inclusive Scattering at 6 GeV/c

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The depolarization parameter for pp inclusive scattering at an incident momentum of 6 GeV/c was measured. The D parameter for inclusive scattering indicates the dominance of natural-parity exchange at small t, except in the case of $N^*(1232)$ production, where π exchange is more important. D for elastic scattering has also been measured. This parameter shows a small decrease from unity with increasing momentum transfer.

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The importance of spin-dependent measurements is that they can provide direct experimental evidence for dynamical effects, which can only be inferred from measurements of the scattering cross section. Recent spin-dependent experiments have revealed interesting dynamical structure for both pp elastic scattering[1] and inelastic Δ production in pp collisions.[2] Although the interpretation of many spin-parameter measurements is complicated, Halzen and Thomas[3] have shown that the depolarization parameter for elastic scattering (D in the usual Wolfenstein notation[4] has a particularly simple interpretation in the limit of large s and small t in terms of the naturality of the exchanged particle. D is qualitatively a measure of the extent to which the scattered particle retains the spin orientation of the initial particle. In terms of amplitudes,

$$(1-D)\sigma = 2(|A|^2 + |\pi|^2), \qquad (1)$$

where A and π are the unnatural-parity exchange amplitudes in the t channel. D equals $+1$ or -1 means that the entire exchange amplitude is natural or unnatural parity, respectively. A D of zero implies an equal mixture of natural- and unnatural-parity exchange. A similar simple relationship exists between D and the amplitude for unnatural-parity exchange in the inclusive process $p+p \to p+X$.

Some previous measurements of D for pp elastic scattering in the high-energy region have been made,[5] but the low-t data have large uncertainties. A particular problem is the normalization, which is crucial to a comparison between D and unity. There are no existing measurements for D in high-energy inclusive scattering. Such measurements should yield direct information about exchange amplitudes in N^* production, which could be used to check the results of earlier inferential analyses.[6] Indeed, Hidaka[7] has used Bishari's[6] estimates of π exchange to predict the depolarization parameter for the inclusive process $p+p \to p+X$.

We have used the polarized proton beam of the Argonne zero-gradient synchrotron (ZGS) to make a measurement of the depolarization parameter in proton-proton inclusive and elastic scattering at an incident momentum of 6 GeV/c. The experiment, which used the double-scattering method, also measured the analyzing and polarizing powers for the elastic and inelastic channels.[8] A schematic of the apparatus is shown in Fig. 1. It is similar to that used in other experiments with the ZGS polarized beam.[9] The proton beam, polarized at about 70% in the vertical direction, normal to the scattering plane, was incident on a 10-cm-long liquid hydrogen target. The direction of the beam polarization was alternated every accelerator pulse (about 0.3 Hz), to reduce the systematic errors. The direction, size, and position of the beam were determined by two sets of proportional chambers read out in an integrated mode. The relative polarization of the beam was measured by two telescopes of three scintillation counters each, mounted in the horizontal plane, which viewed a 1.5-mm-thick polyethylene target located about 6 m upstream of the hydrogen target. The analyzing power of this polari-

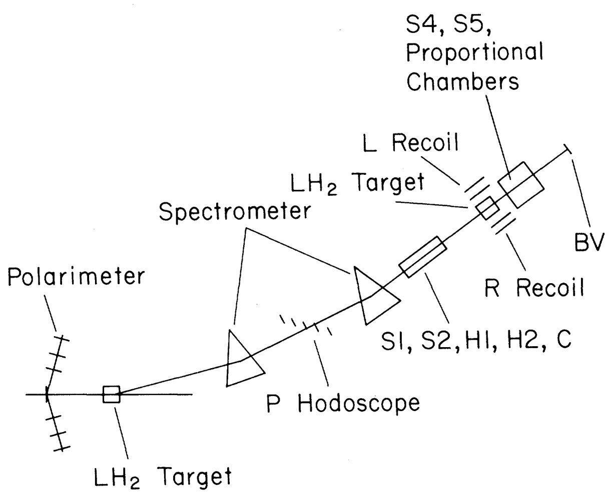

FIG. 1. The schematic layout of the spectrometer used in the experiment.

meter at 6 GeV/c was determined to be 0.046 ± 0.002 by calibration against an absolute elastic-scattering polarimeter in another experimental area.[10] Two other three-scintillation-counter telescopes viewed the liquid hydrogen target in the vertical plane. They were used principally to monitor the flux incident on the target.

Particles scattered from the hydrogen target were detected by a two-stage focusing spectrometer. The first four dipole magnets of the spectrometer were used to determine the accepted mean scattering angle. The spectrometer formed a momentum-dispersed image on a 19-bin horizontal and 3-bin vertical scintillation counter hodoscope (P) located about 15 m from the initial hydrogen target. A momentum-recombined image was formed on a second liquid hydrogen target. A momentum-recombined image was formed on a second liquid hydrogen target located at the end of the spectrometer, about 33 m from the first target. The spectrometer, and also instrumentation, included three trigger scintillation counters ($S1$, $S2$, and $S3$), two threshold Cherenkov counters, and two sets of x-y hodoscopes ($H1$ and $H2$) with 5-mm resolution.

Particles scattered in the second hydrogen target, which was 30 cm in length, were detected by a forward-recoil coincidence spectrometer. The forward arm consisted of three sets of x-y proportional chambers with an angular resolution of 4 mrad full width at half maximum. Recoil particles were detected in either a left or right arm, each of which consisted of two scintillation counters in the horizontal plane separated by range material. The counters nearest the target were operated in a coincidence mode, while those furthest from the target were used in anticoincidence. The band of accepted proton kinetic energies for the two counters extended from 17 to 82 MeV, corresponding to pp elastic-scattering momentum transfers of $0.032 < -t < 0.154$ (GeV/c)^2. Most of the remaining solid angle around the second hydrogen target was occupied by veto counters (T), including a halo veto (BH) and a noninteracted particle veto (BV).

The main trigger ($L1$) for the experiment was $S1 \cdot S2 \cdot S3 \cdot S4 \cdot S5 \cdot \overline{\mathrm{BH}} \cdot \overline{V} \cdot (L \wedge R)$. In addition to the symbols already defined, $S4$ and $S5$ were two scintillation counters interspersed among the proportional chambers, V was the logical OR of the veto counters, and L (R) was a particle passing through the first counter but not penetrating the range material in the left (right) recoil arm surrounding the second target. A second trigger ($L2$) consisted of a random sample of events meeting the condition $S1 \cdot S2 \cdot S3 \cdot \overline{\mathrm{BH}}$, without regard to a possible scattering in the second target. The occurrence of either trigger caused the latching of the outputs of all hodoscopes, Cherenkov counters, all four second-target recoil-arm counters and the outputs of the proportional chamber wires. These data, together with the type of trigger and the direction of the incident beam polarization, were written on magnetic tape for later analysis.

The off-line data analysis started with a reconstruction of each event. Data from the P, $H1$, $H2$ hodoscopes were used to calculate the momentum and angle of the particle scattered by the first target. Since the scattered particle was identified by the Cherenkov counters, it was then possible to calculate the missing recoil mass. From the width of the elastic peak, the spectrometer momentum resolution was determined to be ± 0.25%, corresponding to a missing-mass resolution $\sigma_{M_x} = 20$ MeV at $M_x = 1.5$ GeV, which is of the same order as the resolution achieved in a previous unpolarized missing-mass experiment.[11]

Information from the proportional chambers was used to reconstruct the scattering in the second target. Events with more than one track in the proportional chambers, particles in both recoil arms, forward and recoil particles on the same side of the target or vertex not in the target were discarded. A cut was also made so that the azimuthal acceptance was defined by the angle of the forward particle. The remaining events had a momentum-transfer distribution consistent with that of pp elastic scattering over the range $0.05 < -t < 0.14$ $(\mathrm{GeV}/c)^2$. The inelastic background under this distribution was less than 4%. The elastic-scattering hypothesis was verified by bending the 6-GeV/c polarized proton beam directly into the second target without a scattering in the first target. The analyzing power of the second target was measured as 0.116 ± 0.002, in good agreement with the known elastic pp analyzing power at this incident momentum.[12] This observation confirms that most of the second scatters remaining after the cuts were elastic events.

After these event analyses were completed for each set of scattering angles and scattered momenta at the first target, the following quantities were then known: incident flux (I_0) for spin up (down), incident polarization for spin up (down), scattered flux at the first target (I_1) for spin up (down) without reference to a second scattering (from the $L2$ trigger), left- (right-) scattered flux at the second target (I) for spin up (down) relative to the incident flux and the first-scattered flux. These data were corrected for target-empty effects (generally less than 20%) at the first scattering by taking data runs with the first target empty. Target-empty effects at the second scattering were included in the 4% estimate of background under the elastic peak.

The measured I_1 fluxes, normalized by the beam intensity and polarization and corrected for target-empty effects, were used to determine the analyzing power A of the scattering at the first target. The measured I_2 fluxes for left and right scattering, also corrected for target-empty effects, were summed over the incident-beam-polarization states to determine the polarizing power P. These same data, separated by incident spin direction, also determined the polarization of particles produced at the first target (f_3). D was then calculated from the equation

$$D = (1/P_B)[(1 + AP_B)f_3 - P], \tag{2}$$

where P_B is mean polarization of the incident beam.

The analyzing-power data for all processes were in agreement with previously measured results.[9,12] The polarization of the inclusively produced pions was zero within experimental statistics, as is required by the zero spin of the pion. The depolarization parameter for pp elastic scattering is shown in Fig. 2. D is consistent with unity out to $-t = 0.2$ $(\mathrm{GeV}/c)^2$ and decreases with larger momentum transfers to a value of 0.8 near $-t = 1.0$ $(\mathrm{GeV}/c)^2$. This behavior indicates an increasing contribution of unnatural-parity exchange with increasing momentum transfer.

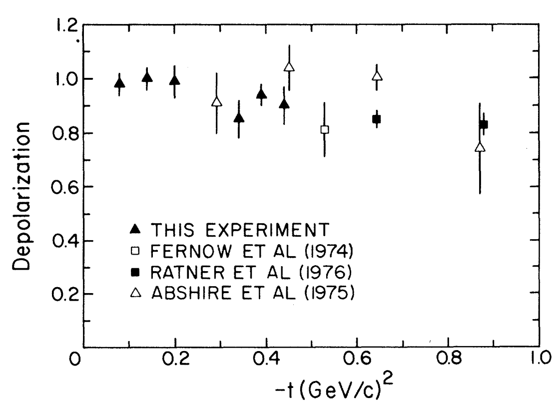

FIG. 2. The depolarization parameter for pp elastic scattering at 6 GeV/c as a function of t, the four-momentum transfer squared.

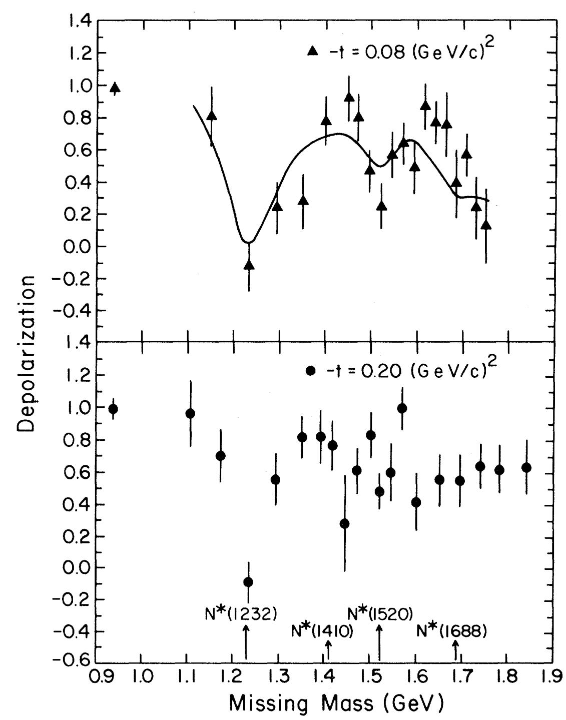

FIG. 3. The depolarization parameter for the process $p + p \to X$ at 6-GeV/c incident momentum as a function of the missing mass M_x. The upper figure is at a four-momentum transfer of 0.08 $(\mathrm{GeV}/c)^2$; the lower figure is for $-t = 0.20$ $(\mathrm{GeV}/c)^2$. The solid curve is from Ref. 7 as discussed in the text.

The D parameter for the process $p+p\rightarrow p+X$ is shown in Fig. 3. The inclusive reaction is dominated in general by natural-parity exchange, but the production of the $N^*(1232)$ is principally through pion exchange at both values of t studied in this experiment. This depolarization measurement is the most direct evidence that π exchange plays an important role in Δ production at high energies. Previous discussions of this phenomenon have relied on model-dependent analyses.[1,2,6] There is some evidence for a significant nondiffractive contribution to the $N^*(1520)$, while the $N^*(1410)$ and the $N^*(1688)$ seem to be dominated like the nonresonant background by natural-parity processes. The curve in Fig. 3, which seems in good agreement with the data, is from Ref. 7. This Regge calculation assumes pure π dominance of the unnatural-parity-exchange amplitude due to the closeness, at small t, of the pion pole to the physical region. $\alpha(t)$ is assumed to vary as $0.9(t-m_\pi^2)$. As discussed in Ref. 7, the calculated curve will vary somewhat in value but not in shape, depending on the values used for the off-mass-shell parameters. These details do not affect the conclusions of this experiment regarding the importance of pion exchange in $N^*(1232)$ production.

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