MEASUREMENT OF THE POLARIZATION PARAMETER IN SMALL ANGLE PROTON-PROTON ELASTIC SCATTERING AT 6 GeV/c^{*}

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ABSTRACT

The polarization parameter in pp elastic scattering was measured at 6 GeV/c with fine t resolution for $0.02 < -t < 0.5 \text{ GeV}^2$ using a polarized proton beam with the Effective Mass Spectrometer at the Zero Gradient Synchrotron. The polarization rises like $\sqrt{-t}$ in the interval $0.02 < -t < 0.1 \text{ GeV}^2$. No statistically significant structure was found in this region of momentum transfer.

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Previous experiments¹⁻² which have measured the polarization parameter P (analyzing power) in proton-proton elastic scattering near 6 GeV/c have been limited to the momentum transfer range $-t > 0.1 \text{ GeV}^2$ as a result of using a polarized target as the source of polarized protons, and have had rather coarse t resolution. Any rapid variation in P near $-t = 0.1 \text{ GeV}^2$, where there is a break in the exponential dependence of the differential cross-section at high energy,³ would thus have been missed. This letter describes an experimental determination of P in pp elastic scattering at small values of $-t$ using the new polarized proton beam⁴ at the Argonne National Laboratory Zero Gradient Synchrotron (ZGS). These measurements have better resolution in t , and they extend to much smaller values of $-t$ than were previously accessible.

The Argonne Effective Mass Spectrometer (EMS) was used for this experiment.^{5,6} A beam of transversely polarized 6 GeV/c protons was incident on a 50 cm liquid hydrogen target. The magnitude of the polarization was typically 56%, and the sign of the (vertical)polarization was reversed approximately every two hours. Forward scattered particles were measured in five sets of magnetostrictive wire spark chambers placed before, within, and behind a magnet with large aperture. The mean resolution in $-t$ was $\pm .006 \text{ GeV}^2$.

Two different triggers were employed during the course of the experiment. Both used a large array of scintillation counters downstream of the magnet to detect forward scattered particles and a veto counter located

on the deflected beam line just behind this array to reject unscattered beam protons. Scintillation counters were also placed on both sides of the hydrogen target to detect recoil protons. The first trigger, for scattering events with $-t > 0.04 \text{ GeV}^2$, required a beam particle signal in coincidence with a recoil particle signal, a forward particle signal, and no signal from the beam veto counter. For $-t < 0.04 \text{ GeV}^2$ elastic recoil protons stop in the target. Thus the second trigger which provided our sample of these very-small-angle events, did not require a signal from either of the recoil counters.

The apparatus was, to a good approximation, symmetric for right and left scatters and for both directions of bending in the analyzing magnet. Data were taken with both signs of the magnetic field to obtain two partially independent measurements and thus to provide an internal check on our understanding of the apparatus.

In order to obtain a pure sample of elastic events, several cuts were applied to the data. The most important of these were a cut on the chi-squared of the fit to the measured trajectory and a cut on the missing mass calculated assuming the forward particle was a proton. Residual inelastic contamination is estimated to be less than 2%.⁶

Denoting the beam polarization by P_B , the left-right scattering asymmetry is given by

$$a(t) = P_B P(t) = K \frac{N_L(t) - N_R(t)}{N_L(t) + N_R(t)}, \quad (1)$$

where N_L and N_R are the numbers of left and right scatters respectively, and K is a constant determined by the range of azimuthal angles accepted. The recoil counters limited the azimuthal acceptance to $\pm 24^\circ$ from the horizontal, yielding $K = 1.029$. For data taken without the recoil counters in the trigger, the full 2π range was accepted. Each of these events was weighted by the absolute value of the cosine of the angle between the scattering plane and the horizontal before it was added to N_L or N_R . In this case $K = 4/\pi$.

The asymmetries for the two signs of beam polarization were averaged to remove time-independent instrumental biases.⁷ The asymmetries for the two trigger modes, which were statistically consistent in their region of overlap, were combined according to their statistical weights. The data without the recoil counters in the trigger made an important contribution only at the point $-t = 0.03 \text{ GeV}^2$ where there was no data with the recoil counters.

At this point in the analysis the data were still divided into two approximately equal parts depending on the direction of bending in the spectrometer magnet. A comparison of these two subsamples showed no statistically significant difference, demonstrating that time-dependent instrumental asymmetries, as might arise from variations in spark chamber efficiencies between runs, were small. (This type of asymmetry might not have been fully eliminated by averaging the data with opposite signs of beam polarization.) The data were then combined to give the final values of $\alpha(t)$.

The beam polarization was expected a priori to be between 50% and 70%.⁴ A more precise value was obtained by normalizing our data to agree on the average with the results of Ref. 1 in the interval $0.1 < -t < 0.5 \text{ GeV}^2$. This gave a mean beam polarization of $(56 \pm 4\%)$, where the dominant uncertainty is the absolute normalization in Ref. 1.

The final results for $P(t)$, determined from 3×10^5 pp elastic scatters at 6 GeV/c, are shown in Fig. 1 and presented numerically in Table I. The indicated errors are purely statistical. There is, in addition, a systematic scale uncertainty of $\pm 7\%$ in all values of $P(t)$ due to the uncertainty in the beam polarization as discussed above. Other sources of systematic error are not expected to contribute significantly.

Our results combined with those of Ref. 1 are well fit ($\chi^2 = 17$ for 22 degrees of freedom) by the empirical formula

$$P(t) = (0.506 \pm 0.021) \sqrt{-t} \exp [(2.52 \pm 0.18)t] \quad (2)$$

over the interval $-t = 0.02$ to 0.5 GeV^2 , as shown by the curve in Fig. 1.

Using the notation of Halzen and Thomas,⁸

$$\frac{d\sigma}{dt} = |N_0|^2 + 2 |N_1|^2 + |N_2|^2 + |A|^2 + |\pi|^2 \quad (3)$$

$$P \frac{d\sigma}{dt} = 2 \text{Im} (N_0 - N_2)^* N_1. \quad (4)$$

Note that Eq. 4 only depends on the amplitudes N_0 , N_1 , and N_2 , all with natural-parity exchange in the t channel; it does not depend on π and A , the unnatural-parity exchange amplitudes corresponding to π and A_1 quantum

number exchange. The nonflip amplitude N_0 has a large diffractive component and is the dominant amplitude near the forward direction. Using results from a previous experiment⁶ with the same apparatus,

$$|N_0| \approx \sqrt{d\sigma/dt} = 9e^{3.8t} (\text{mb/GeV}^2)^{1/2}. \quad (5)$$

Ignoring the double-flip amplitude N_2 , one can use the polarization to estimate the component of the single-flip amplitude orthogonal to N_0 in the complex plane,

$$N_{1\perp} \approx \frac{1}{2} P \sqrt{d\sigma/dt} = 2.3 \sqrt{-t} e^{6.3t} (\text{mb/GeV}^2)^{1/2}. \quad (6)$$

The ratio of amplitudes, $N_{1\perp} / |N_0| \approx P/2$, is approximately 6% over the region $-t = 0.06$ to 0.5 GeV^2 .

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Figure Caption

Figure 1. The polarization parameter P for pp elastic scattering at 6 GeV/c as a function of $-t$. Results from this experiment (solid circles) are shown along with those of Ref. 1 (open triangles). The curve is the empirical formula discussed in the text, Eq. 2.

Table Caption

Table 1. The polarization parameter for pp elastic scattering at 6 GeV/c. The errors are statistical only, and do not include the $\pm 7\%$ systematic scale uncertainty discussed in the text.

Table 1.

$-t$ (GeV ²)	P	ΔP
.03	.085	$\pm .021$
.05	.100	.009
.07	.120	.009
.09	.119	.010
.11	.122	.010
.13	.117	.011
.15	.130	.012
.17	.157	.013
.19	.145	.014
.22	.129	.011
.26	.144	.013
.30	.111	.016
.34	.109	.018
.38	.148	.021
.42	.140	.025
.46	.072	.029