MEASUREMENT OF PROTON PROTON ELASTIC SCATTERING IN PURE INITIAL SPIN STATES AT 11.75 GeV/c[*]

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ABSTRACT

The elastic differential cross section for proton proton scattering at 11.75 GeV/c was measured for the ↑↑, ↓↓, and ↑↓ initial spin states perpendicular to the scattering plane in the range of $p_\perp^2 = 0.6 \rightarrow 2.2$ (GeV/c)^2. The experiment was performed at the Argonne ZGS using a 50% polarized beam and a 65% polarized target. We confirmed that the asymmetry parameter, A, decreases with energy in the diffraction peak, but is approximately energy - independent at large $p_\perp^2$. We found that the spin correlation parameter C_{nn} acquires rather dramatic structure, and at large $p_\perp^2$ seems to grow with energy.

During the past few years the ZGS polarized beam has allowed new and precise measurements of the spin dependence in proton proton elastic scattering.[1,2,3,4] Recently the polarized beam operated at 11.75 GeV/c allowing the first measurements of pure spin elastic cross sections above 6 GeV/c. We present the results obtained during a one month run in February 1976. The physicists involved in the experiments are: K. Abe, R.C. Fernow, T.A. Mulera, K.M. Terwilliger from the University of Michigan, W. DeBoer from Max Planck Institute Fur Physik, A.D. Krisch[+] from Niels Bohr Institute, H.E. Miettinen from CERN, J.R. O'Fallon from St. Louis University, and L.G. Ratner from Argonne.

The polarized beam was accelerated to 11.75 GeV/c with the internal intensity as high as 7×10^9 per 4.0 sec pulse. The extracted beam intensity was as high as 4×10^9 and averaged about 2.5×10^9 per pulse. The average polarization for the entire one month run was about $P_B \approx 47\%$.

We used the Michigan-Argonne PPT V polarized proton target[5], which is maintained at 0.5°K in a magnetic field of 25 KG and contains beads of propanediol, $C_3H_8O_2$, doped with $K_2Cr_2O_7$ in a flask 4.13 cm long by 2.9 cm in diameter. The free protons in the propanediol are pumped into a polarized state by the 70 GHz microwaves from a carcinotron tube, using the highly polarized Cr electrons. The proton polarization is measured using a 107 MHz NMR system with signal averaging, which is calibrated against the known thermal equilibrium polarization with a ± 3% precision. The target polarization has been as high as $P_T = 85\%$, but the high

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[+] On leave from the University of Michigan polarized beam intensity caused radiation damage which reduced the average P_T to about 65%. Two independent NMR coils measured the variation of P_T with transverse position caused by the variation in radiation damage. The small coil was a straight wire along the beam axis; the large coil was a 1.0 cm diameter helix coaxial with the beam axis.

The beam polarization was measured using the high energy polarimeter shown in Fig. 1. At this energy the asymmetry parameter, A, is only about 5% in the diffraction peak but is much larger at large $p_\perp^2$. Thus we set the polarimeter to simultaneously measure p - p elastic scattering to the left, $L(=L_1L_2L_3L_4L_5L_6)$, and to the right, $R(=R_1R_2R_3R_4R_5R_6)$ at $p_\perp^2 = 1.4$ $(GeV/c)^2$. The beam polarization is given by

$$P_B = \frac{1}{A}\,\frac{L - R}{L + R} \qquad (1)$$

We obtained A at $p^2 = 1.4(GeV/c)^2$ by measuring elastic scattering from our downstream polarized target using the FB spectrometer shown in Fig. 1. In this calibration run the beam polarization was ignored and we used the measured polarization of the target to obtain $A = 15.83 \pm 0.80\%$. This was combined with a nearby[8] result at $p_\perp^2 = 1.42(GeV/c)^2$ and 12.33 GeV/c of $A = 14.7 \pm 2.0\%$ to give for the asymmetry parameter

$$A = 15.7 \pm 0.7\% \qquad (2)$$

which we take to be the analysing power of our polarimeter.

We used the double arm FB spectrometer to detect the elastic scattering events originating from the polarized beam and the polarized target. This spectrometer measured both the angle and momentum of both the scattered and the recoil protons, using 3 magnets and the 6 scintillation counters $F_1F_2F_3$ and $B_1B_2B_3$ as shown in Fig. 1. By varying the currents in the 3 magnets and reversing the PPT magnet we were able to cover the range $p_\perp^2 = 0.6 \rightarrow 2.2(GeV/c)^2$ by only moving the B counters. The forward scattered proton was defined by the 15×13 cm (hor. × vert.) F_3 counter placed about 18.4 from the PPT. The F_3 momentum bite was $\Delta P/P = \pm 7\%$ while $\Delta\Omega_{lab} \approx 57$ μsr. The recoil proton was defined by the 5×20 cm B_3 counter placed about 5.5 m from the PPT. The B_3 momentum bite was $\Delta P/P = \pm 3\%$ while $\Delta\Omega_{lab} \approx 330$ μsr.

The size of the B counters was not large enough to completely overmatch the solid angle subtended by the F arm. We accepted this uncertainty to obtain a very clean elastic signal by keeping tight angle and momentum constraints on both arms . Recoil magnet curves at $p_\perp^2 = 0.6$, 1.0, 1.4 and 2.2 $(GeV/c)^2$ indicated that inelastic events and events from non-hydrogen protons were typically less than 3%. The F - B accidentals were continuously monitored and subtracted and were always less than 0.3%.

We monitored the size, position, and angle of the beam at both targets using the segmented wire ion chambers (SWIC's) shown in Fig. 1 as S_1, S_2 and S_3. The beam size at the PPT was about 10mm FWHM and the beam was kept centered to about ± 0.5 mm. The beam profile indicated that more than 97% of the beam passed thru the 29 mm diameter PPT. This reduced a possible error due to variations in the fraction of the beam passing thru the PPT caused by beam movement and by variation of the beam size. This error was reduced further by flipping the direction of the beam spin every pulse and reversing the target spin about every 8 hours and then signal averaging away any variations.

We obtained the normalized event rate, N_{ij}, from the number of FB(ij) events in each of the 4 initial spin states ($\uparrow\uparrow, \uparrow\downarrow, \downarrow\uparrow$, and $\downarrow\downarrow$) using the N and K monitors (i,j = beam, target). The spin correlation parameter C_{nn} is then given by

$$C_{nn} \quad \frac{N_{\uparrow\uparrow}-N_{\uparrow\downarrow}-N_{\downarrow\uparrow}+N_{\downarrow\downarrow}}{P_B P_T \; \Sigma \, N_{ij}} \tag{3}$$

The asymmetry parameter A is obtained by averaging over either the target or beam polarization

$$A_B = \frac{N_{\uparrow\uparrow}+N_{\uparrow\downarrow}-N_{\downarrow\uparrow}-N_{\downarrow\downarrow}}{P_B \; \Sigma \, N_{ij}}$$

$$A_T = \frac{N_{\uparrow\uparrow}-N_{\uparrow\downarrow}+N_{\downarrow\uparrow}-N_{\downarrow\downarrow}}{P_T \; \Sigma \, N_{ij}} \tag{4}$$

We then calculated the 4 pure 2-spin cross sections from the equations

$$\frac{d\sigma}{dt}(\uparrow\uparrow) = \langle d\sigma/dt\rangle \left[1 + 2A + C_{nn}\right]$$

$$\frac{d\sigma}{dt}(\downarrow\downarrow) = \langle d\sigma/dt\rangle \left[1 - 2A + C_{nn}\right] \tag{5}$$

$$\frac{d\sigma}{dt}(\uparrow\downarrow) = \frac{d\sigma}{dt}(\downarrow\uparrow) = \langle d\sigma/dt\rangle \left[1 - C_{nn}\right]$$

Where $\langle d\sigma/dt\rangle$ is the measured[7] spin average cross section. The equality of A_B and A_T required by rotational invariance gave a consistancy check which held to within the errors for each $P_\perp^2$ points. By averaging A_B and A_T we obtained an even more precise value of A.

The values of A and C_{nn} at 11.75 GeV/c are plotted against $P_\perp^2$ in Fig. 2 along with other data.

The general behavior of A was known from earlier experiments[6,8,9,10] and our new more precise measurements only emphasize it. In the diffraction peak region A decreases rapidly with energy and is typically 5% near 12 GeV/c. In the large angle region beyond $P_\perp^2 = 1(\text{GeV}/c)^2$ A is quite large, typically 15%, and appears approximately independent of energy. Near $P_\perp^2 = 0.7\ (\text{GeV}/c)^2$ A has a minimum at 6 GeV/c which becomes a narrow zero at 11.75 GeV/c.

The behavior of C_{nn} is quite surprising. At 6 GeV/c C_{nn} is about 10% in the diffraction peak but drops to about 3% at large $P_\perp^2$ and has little structure. At 11.75 GeV/c C_{nn} has a very narrow dramatic zero which occurs at $P_\perp^2 = 0.9\ (\text{GeV}/c)^2$. At large $P_\perp^2$, C_{nn} has a broad maximum and is much larger at 11.75 GeV/c than at 6 GeV/c. This large $P_\perp^2$ behavior is quite interesting as it was not expected that the spin dependence of strong interactions would increase with increasing energy.

The differential cross sections are plotted in Fig. 2 as $d\sigma/dt(ij)$ against $P_\perp^2$. They are normalized to the 12.0 GeV/c measurements of $\langle d\sigma/dt\rangle$ of Allaby et al.[7] The most striking feature of the graph is the sharp change in the spin dependence at the break in the cross section. In the small $P_\perp^2$ diffraction peak, all 3 $d\sigma/dt(ij)$ drop off rapidly as $\exp(-7.1\ P_\perp^2)$ to $\exp(-7.9\ P_\perp^2)$. After the breaks at around $P_\perp^2 = 1.0$, $d\sigma/dt(\uparrow\uparrow)$ and $d\sigma/dt(\uparrow\downarrow)$ have roughly similar slopes: $\exp(-1.7\ P_\perp^2)$ and $\exp(-1.6\ P_\perp^2)$ respectively, and $d\sigma/dt(\uparrow\uparrow)$ is some 50% larger than $d\sigma/dt(\uparrow\downarrow)$. The $d\sigma/dt(\downarrow\downarrow)$ however has a much flatter slope, $\exp(-1.3\ P_\perp^2)$, after the break. It crosses $d\sigma/dt(\uparrow\downarrow)$ at about $P_\perp^2 \approx 1.8(\text{GeV}/c)^2$ and seems to be heading towards $d\sigma/dt(\uparrow\uparrow)$. We plan to see if this behavior continues at larger $P_\perp^2$.

It would be interesting to study these pure spin cross sections at very high energy where $\langle d\sigma/dt\rangle$ itself has a sharp dip at the end of the diffraction peak.[11] The behavior of the $d\sigma/dt(ij)$ may give some indication about the source of this dip. In a geometrical model, the inequality of the slopes and the magnitudes of the different $d\sigma/dt(ij)$ indicates that the proton proton interaction regions have different sizes for each different spin state.[12]

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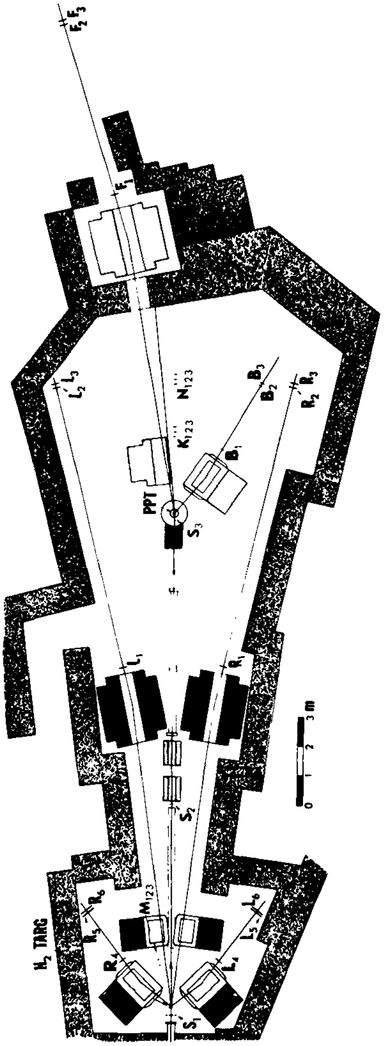

Fig. 1--The layout of the experiment.

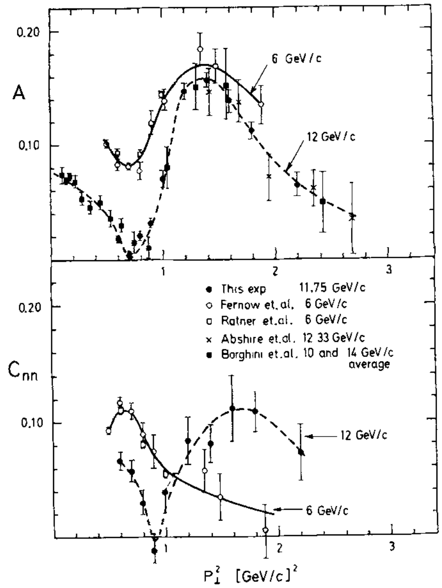

Fig. 2--The Wolfenstein parameters A and C_{NN} for pp elastic scattering near 6 and 12 GeV/c are plotted against p_t^2.

Fig. 3--The differential proton proton cross-sections $d\sigma/dt(ij)$, for each pure initial spin state are plotted against p_t^2 at 11.75 GeV/c.