noise obtained by squaring and summing the 64 interval quantized components of a test signal, with a computer.

The new experiment now is yielding about seven coincidences per day, corresponding to increases in energy exceeding $kT/100$. We are pleased to acknowledge valuable discussions with G. R. Ringo, R. Muller, N. S. Wall, H. Brandt, and D. H. Douglass.

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Measurement of σ_{tot} in Proton-Proton Scattering in Pure Spin States*†

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An experiment was done using the new accelerated polarized proton beam at the Argonne National Laboratory zero-gradient synchrotron and a polarized proton target. The total cross section for proton-proton scattering at 3.5 GeV/c was measured in the spin states ↑↑ and ↑↓ perpendicular to the beam direction. The two cross sections were found to be equal within the experimental error of ±5%.

During recent years there has been an increasing interest in the importance of spin in high-energy strong interactions. This has come from the very successful experiments using polarized proton targets at Lawrence Berkeley Laboratory,[1] CERN,[2] and Argonne National Laboratory[3] (ANL). For the past few years our group has worked together with the accelerator division at ANL on a project to accelerate polarized protons at the zero-gradient synchrotron (ZGS). A beam of 3×10^8 polarized protons has now been accelerated up to 6 GeV/c, with a polarization of $(62\pm15)\%$.

The polarized protons originate in a polarized ion source[4] which gives 8 μA of 20-keV protons with a polarization of $(75\pm7)\%$. This source was placed in the new preaccelerator constructed by the ZGS staff[5] which accelerates the protons to 750 keV in a Cockcroft-Walton accelerating column. The protons are then fed into the main LINAC line by a switching magnet and then accelerated to 50 MeV by the LINAC. The polarization at 50 MeV is measured using a "polarimeter" which continuously measures the left-right asymmetry in proton-carbon elastic scattering at 60°, where the measured asymmetry parameter is $(85\pm7)\%$.[6] We found the 50-MeV beam polarization to be $(65\pm5)\%$. The polarized protons are then injected into the ZGS, accelerated, and then extracted and sent to the high-energy polarimeter, described below, where the polarization is measured.

The main problem in accelerating polarized protons in a synchrotron is "depolarizing resonances."[7,8] These occur when the Larmor precessional frequency becomes equal to an integer multiple of the betatron oscillation frequency, so that the proton gets a similar perturbation each time it passes through a fringe field or imperfection with a horizontal component. These perturbations then add coherently and can rapidly depolarize the beam. Since the precessional frequency and the betatron oscillation frequency are respectively given by

$$\omega_p = \tfrac{1}{2} g\gamma e B_0/m, \quad \omega_b = (k \pm \nu + \gamma) e B_0/m, \tag{1}$$

the resonance condition which occurs when they are equal is

$$(g/2 - 1)\gamma = k \pm \nu, \tag{2}$$

where $g/2 - 1 = 1.9$, $\gamma = E/m$, ν is the number of betatron oscillations per turn around the ZGS (~0.82), and k is the harmonic number (8 and 16 are the most serious). The most serious resonances occur at 3.65 and 4.5 GeV/c, and these were jumped using two pulsed quadrupoles specially designed and built by the ZGS staff[9] and installed inside the ZGS. By rapidly pulsing these (10 μsec), the ν value (focal length) was changed and the beam passed through the resonance in a few turns before the coherent depolarization could build up. The timing and strength of these quadrupole pulses was tuned experimentally by maximizing the polarization measured in the high-energy polarimeter.

The high-energy polarimeter was used both to tune the ZGS and to measure the beam polarization during the data runs. As shown in Fig. 1, it consists of two double-arm spectrometers, each containing magnets and scintillation counters, which each measure proton-proton elastic scattering from a liquid-hydrogen target (one measures the scattering of the forward particle to the left while the other measures the scattering to the right). They both run simultaneously and continuously and are as identical as possible. The solid angle is defined by the counters L_3 and R_3, 6×5 in.^{2} at 850 in. from the target; $\Delta\Omega_{\text{lab}} \approx 4 \times 10^{-5}$ sr. The momentum bite defined by L_3 and R_3 is $\Delta P/P \approx \pm 6\%$. The overmatched counters L_6 and R_6 detected the recoil protons. Measuring both scattered particles gave a very clean elastic signal. Target-empty runs and magnet curves showed that the background was 2% or less.

The polarimeter contained steering magnets so that at each momentum we could choose a $P_\perp^2$ value where the asymmetry parameter was measured and large. The six magnets contain three pairs of identical magnets run in series on three power supplies so the currents are identical. The central fields were measured and agree within 0.2%. The main systematic asymmetry apparently comes from misalignments of the incident beam. The beam direction was monitored using two segmented-wire ion chambers[10] (S_1 and S_2) which measured the beam position. This systematic asymmetry was studied by flipping the beam polarization P_B between up and down (↑ and ↓) at the source. The value of P_B was monitored by the 50-MeV polarimeter and was independent of direction within 1%. When the beam was kept aligned within a few millimeters the systematic asymmetry of the high-energy polarimeter was

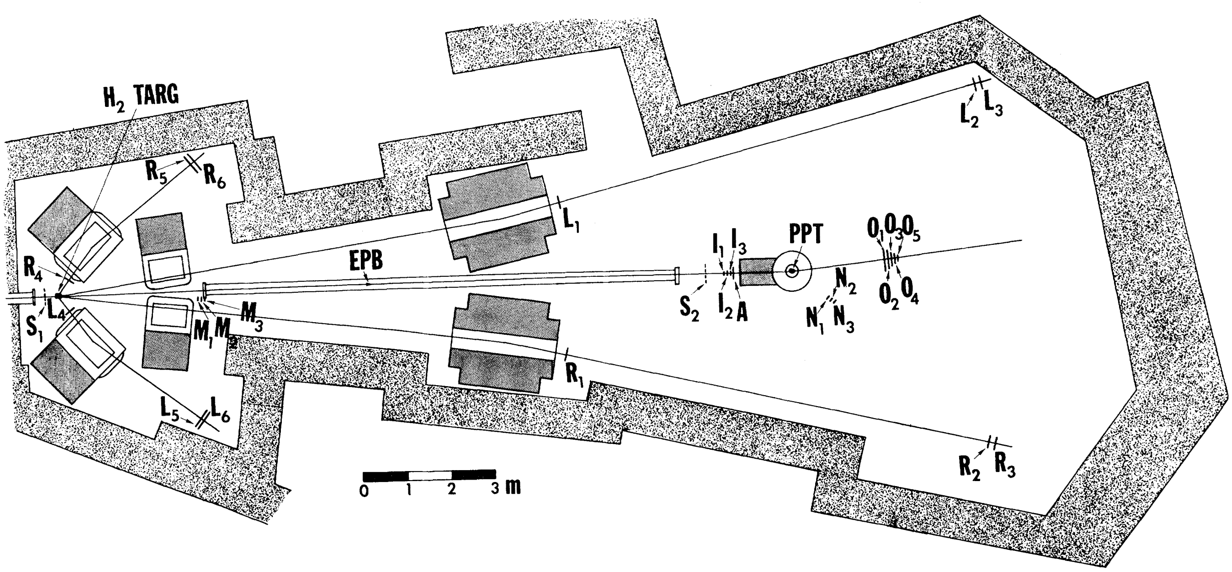

FIG. 1. Layout of the experiment. The polarized beam passes through the H_2 target and its polarization is measured by comparing the number of elastic events seen in the L and R spectrometers of the polarimeter. The beam is then counted by the counters I and attenuated in the polarized proton target. The attenuation is measured in the counters O. The counters M and N are monitors.

2% or less. The statistical accuracy was typically 10% or less. The beam polarization P_B is given by

$$P_B = A_m / A_p, \tag{3}$$

where A_p is the asymmetry parameter and A_m is the measured asymmetry. For the point $P_0 = 3.5$ GeV/c and $P_\perp^2 = 0.40$ (GeV/c)^2, A_p was taken to be 0.22 ± 0.03 by compiling, interpolating, and averaging all available data.[1-3,11] We determined P_B to be $(62 \pm 15)\%$ at GeV/c.

We used the ANL PPT-II polarized proton target[12] for the measurement of σ_{tot}. This is a target of ethylene glycol doped with $K_2Cr_2O_7$ which is placed in a field of 25 kG and maintained at a temperature of 1°K using a He^4 cryostat. The protons interact with the electrons in the Cr and are pumped into a polarized state by a 70-GHz microwave Carcinotron tube. The polarization of the protons was monitored by an NMR system working at 107 MHz. The target polarization was $P_T = (30 \pm 10)\%$.

The σ_{tot} measurement was a standard "good-geometry" attenuation experiment. As shown in Fig. 1 the incident beam was counted by the counters I_1, I_2, and I_3 which were 1, 1, and $\frac{3}{4}$ in. in diameter, respectively, and $\frac{1}{8}$ in. thick. The attenuated beam after the PPT was counted by the counters O_1–O_5 which were 10, 9, 6, 4, and 2 in. in diameter, respectively, $\frac{1}{2}$ in. thick, and about 100 in. from the target. The anticoincidence counter A had a $\frac{3}{4}$-in.-diam hole, and reduced accidentals. To reduce counting losses and accidentals we collimated the beam intensity to about 10^4/ pulse with a 100-msec spill. This low intensity gave rather poor statistics in the polarimeter. Therefore before and after each σ_{tot} run we increased the intensity to $\sim 2 \times 10^7$ and took good-statistics measurements of P_B. Since we never observed any significant variation, we assume that P_B was $(62 \pm 15)\%$ during the σ_{tot} runs.

This experiment did not measure σ_{tot} (Ave), which is well known to be about 40 mb, but instead measured

$$\Delta\sigma = \sigma_{tot}(\uparrow\uparrow) - \sigma_{tot}(\uparrow\downarrow). \tag{4}$$

This difference is rather independent of the normal extrapolations and corrections in attenuation experiments since the spin states have rather equal cross sections. We tested various systematic errors by measuring σ_{tot} in the four spin states by flipping the spin of the target and the beam. Because of rotational invariance of space σ_{tot} for the two parallel states ($\uparrow\uparrow$ and $\downarrow\downarrow$) must be equal and σ_{tot} for the two antiparallel states ($\uparrow\downarrow$ and $\downarrow\uparrow$) must be equal. Errors due to accidentals and counting losses were less than the 0.01% statistical errors. In Table I we plot the $I(O)/I$ ratios taken in a set of runs in the four spin states. Other runs were consistent but had larger errors.

The quantity $\Delta\sigma_{tot}$ is obtained from the equation

$$\Delta\sigma = \sigma(\uparrow\uparrow) - \sigma(\uparrow\downarrow) = -\frac{I(O;\ \uparrow\uparrow)/I(O;\ \uparrow\downarrow)/I}{P_B P_T N_0 \rho t}. \tag{5}$$

The difference between the ratios $I(O)/I$ is $(-7 \pm 7) \times 10^{-5}$. Recall that $P_B = 0.62 \pm 0.15$ and $P_T = 0.30 \pm 0.10$. N_0 is Avogadro's number, 6.02×10^{23}, while t is the target length, taken to be 5 cm. The density ρ of hydrogen protons in the PPT is taken to be 0.07 ± 0.015. This includes assumptions about the packing density of the target bags and that $(90 \pm 10)\%$ of the counted protons pass through the 1-in.-diam target. Adding the errors in quadrature we obtain at 3.5 GeV/c

$$\sigma_{tot}(\uparrow\uparrow) - \sigma_{tot}(\uparrow\downarrow) = +1.8 \pm 2.0 \text{ mb}. \tag{6}$$

Thus σ_{tot} is equal to about 40 mb for both the parallel and antiparallel spin states. A large difference would imply that the proton radius (R in $\sigma_{tot} = \pi R^2$) was different for different spin states. Thus our result supports a geometrical model in which the proton has a well-defined size. One may expect differences in the large-angle behavior of the different spin cross sections. We will be studying these soon.

TABLE I. Attenuation ratios for the various O counters for the different spin states for runs of $I = 10^7$.

P_B	P_T	$I(O_1O_2)/I$	$I(O_2O_3)/I$	$I(O_3O_4)/I$	$I(O_4O_5)/I$
$\uparrow$	$\uparrow$	0.88302	0.83816	0.82216	0.79451
$\downarrow$	$\uparrow$	0.88328	0.83834	0.82233	0.79472
$\downarrow$	$\downarrow$	0.88276	0.83782	0.82167	0.79438
$\uparrow$	$\downarrow$	0.88279	0.83764	0.82158	0.79435
$\frac{1}{2}(\uparrow\uparrow+\downarrow\downarrow-\uparrow\downarrow-\downarrow\uparrow)$		−0.00015	0.00000	−0.00004	−0.00009
Average			−0.00007 ± 0.00007		

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Electroproduction of Hadrons from Deuterium*

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The inclusive electroproduction of hadrons is measured from hydrogen and deuterium targets. The exchanged virtual photons are in the kinematic range $-0.25 > q^2 > -3.00$ GeV^2, $12 < s < 30$ GeV^2. Hadrons which travel in the direction of the virtual photon in the virtual-photon–nucleon c.m. system are detected. A striking difference from photoproduction is observed in the excess of positive relative to negative hadrons from both proton and neutron targets.

Electron-nucleon scattering is commonly interpreted as a process in which an electron scatters by imparting four-momentum to a virtual photon (γ^*) which in turn interacts with the nucleon. In a previous Letter[1] we reported on the inclusive production of hadrons (h) in γ^*-proton collisions:

$$\gamma^* + p \rightarrow h^\pm + \text{anything}. \qquad (1)$$

In this Letter we report the result of a similar measurement with a deuterium target, and the extraction of results for a neutron target:

$$\gamma^* + n \rightarrow h^\pm + \text{anything}. \qquad (2)$$

The γ^* is characterized by two kinematic variables—q^2, its four-momentum squared; and s, the c.m. energy squared in the γ^*-nucleon collision. The total γ^*-nucleon cross section is denoted σ_{tot}.[2] Cross sections for (1) and (2) are parametrized with three inclusive variables relative to the γ^* direction—φ, the azimuthal angle; $p_\perp^2$, the transverse momentum squared; and x, the longitudinal momentum in the γ^*-nucleon c.m. frame divided by its largest possible value.

The apparatus has been described elsewhere.[1,3] It consisted of a 19.5-GeV/c electron beam, a target which was filled sometimes with liquid hydrogen (H_2) and sometimes with liquid deuterium (D_2), and a large-aperture magnetic spectrometer. The optical spark chambers were pulsed and photographed whenever a scattered electron of greater than 4 GeV energy was detected by an array of lead-Lucite shower counters. A picture then contained the trajectory of the triggering electron along with those of any accompanying hadrons of lab momentum greater than 2 GeV,