RAPID COMMUNICATIONS

PHYSICAL REVIEW D VOLUME 32, NUMBER 11 1 DECEMBER 1985

Rapid Communications

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Measurement of the analyzing power for $p+p_{\uparrow} \rightarrow p+p$ at $P_{\perp}^2 = 6.5$ (GeV/c)^2

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(Received 17 July 1985)

The spin analyzing power A in 28-GeV/c proton-proton elastic scattering was measured at $P_{\perp}^2 = 6.5$ (GeV/c)^2 using a polarized proton target and a high-intensity unpolarized proton beam at the Brookhaven National Laboratory Alternating Gradient Synchrotron. The result of (24 ± 8)% confirms that the analyzing power is large and rising in the large-$P_{\perp}^2$ region.

Earlier measurements[1] of the analyzing power A for 28-GeV/c proton-proton elastic scattering suggested a rise with transverse momentum above $P_{\perp}^2 \simeq 3.5$ (GeV/c)^2. Any nonzero value for A is contrary to theoretical expectations, so in 1984 we made further measurements[2] at $P_{\perp}^2 = 5.95$ and 6.56 (GeV/c)^2 which found significant nonzero values of A. The 6.56 (GeV/c)^2 point suggested a very sharp increase to $A = (51 \pm 17)\%$. We recently repeated this measurement with considerably better statistics and found that A is indeed quite large but does not rise as sharply as suggested by the earlier larger-error data.

We measured A by detecting elastic-scattering events when a 28-GeV/c unpolarized proton beam from the Brookhaven Alternating Gradient Synchrotron (AGS) was scattered from the University of Michigan polarized proton target (PPT). The target consists of ammonia target beads cooled to 0.5 K by a ^{3}He evaporation refrigerator, in a 2.5-T magnetic field. Polarizing transitions are driven by a 70-GHz microwave system and the polarization of the free protons is measured with a 107-MHz NMR system. We modified the PPT to allow a high beam intensity, typically $5\text{–}7 \times 10^{10}$ protons per pulse, by using irradiated ammonia NH$_3$ as the target material and by using a ^{3}He-^{4}He mixture as the circulating fluid in the refrigerator. The NH$_3$ beads were given a radiation dose of about 5×10^{16} electrons/cm^2 using the MIT Bates Linac and the polarization P_T of the hydrogen protons in the target was typically 53% with the beam on and over 70% without beam.

Elastic proton events were detected by the double-arm forward-backward spectrometer, shown in Fig. 1, consisting of six magnets and a sixfold $(F_1,F_2,F_3,B_1,B_2,B_3)$ eight-channel $(A,B,C,D$; up, down) scintillation-counter hodoscope. The $P_{\perp}^2$ acceptance for these measurements was about 1 (GeV/c)^2. This sixfold spectrometer, which was

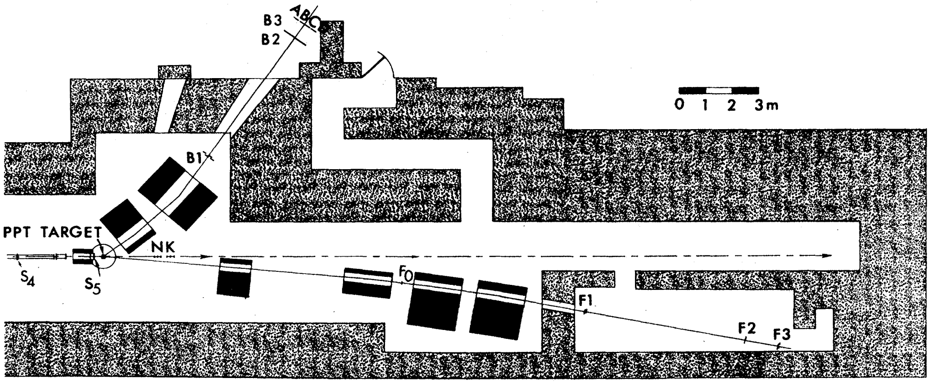

FIG. 1. Layout of the experiment. The unpolarized proton beam was scattered in the vertically polarized proton target. Elastic-scattering events were detected by the spectrometer which contains magnets for momentum analysis and the F and B scintillation-counter hodoscopes. The N and K counters were intensity monitors, while the segmented-wire ion chambers S_4 and S_5 monitored the beam's position, size, and angle.

used in a two-week run (run 2), was identical to the spectrometer used[2] in 1984 (run 1) and is described in earlier papers.[1] Unfortunately, at these high $P_\perp^2$ values the elastic cross sections are quite small, which makes accidental background and backgrounds from inelastic events and nonhydrogen nuclei in the PPT quite significant.

The analyzing power, following the Basel convention for our layout, is defined as

$$A = -\frac{1}{|P_T|}\frac{N(\uparrow)-N(\downarrow)}{N(\uparrow)+N(\downarrow)} , \tag{1}$$

where $N(\uparrow)$ and $N(\downarrow)$ are the number of events with target polarization direction up and down, respectively. Accidental coincidences between the forward and backward arms were measured continuously and subtracted from the raw number of events. An estimate of the nonhydrogenous and inelastic background events was obtained by substituting Teflon beads for the normal ammonia beads. The resulting background events were presumed to have an analyzing power of zero and were treated as a dilution of the proton-proton elastic analyzing power.

In a later three-week run (run 3), we significantly reduced these backgrounds by adding an additional set of F_0 counters $(F_{OA}, F_{OB}, F_{OC}, F_{OD})$ as shown in Fig. 1. The accidental background rate, as measured by the coincidence circuits $(F_0F_1F_2F_3)$ delayed by 225 ns into $(B_1B_2B_3)$, was reduced by a factor of about 20 to 2%. The background rate due to scattering from nitrogen nuclei in the NH_3 beads in the PPT or metal nuclei in the PPT casing was reduced from 26% to 15%. These reductions were very beneficial and allowed us to obtain a ±6.6% statistical error in our three-week run. Unfortunately, the F_0 counter appears to have caused some new types of spill-sensitive backgrounds which we only partially understand. Thus we decided to eliminate about 25% of the data where the AGS spill was bad and to add a systematic error to the remaining data. This resulted in increasing the error in these data to 10.5%.

The basic problem was that each F_0 counter was counting at about 1.5×10^6 per pulse. When the AGS spill was fairly smooth, with perhaps a 750-ms effective spill, the instantaneous rates were about 2 MHz which gave little difficulty to our RCA 8575 photomultipliers and 100-MHz LeCroy logic circuitry. However, during certain periods the AGS spill deteriorated, especially in our extracted beam line which took only about $\frac{1}{2}$% of the total beam and was thus especially sensitive to variations in the beam "halo." We then sometimes had a very poor spill which gave high instantaneous F_0 rates which caused counting losses and various other types of accidentals such as

$$\begin{aligned} &(F_1F_2F_3B_1B_2B_3) \text{ into } F_0 \\ &(F_0B_1B_2B_3) \text{ into } (F_1F_2F_3) \ . \end{aligned} \tag{2}$$

Such accidentals are normally negligible but in runs where F_0 was turned on much of the time they might be significant. We did not recognize the importance of such accidentals until the run ended, so we did not install additional circuits to monitor them.

Fortunately, early in the run we did notice strange behavior during runs with a bad spill. Therefore we installed a special accidental monitor, F_{1A} delayed by 225 ns into $B_{123A\,\text{down}}$, which gave between 350 and 1300 counts per 1-h run depending upon the spill quality of the beam. We then decided that all runs with more than 680 accidentals were bad runs. We chose this number so that we would only eliminate about 25% of the data. We also noted that for the set of "good" runs the number of FB events per run gave a $\chi^2/(N-1)$ of 1.07 while the set of "bad" runs gave a $\chi^2/(N-1)$ of 1.49. We multiplied the statistical error on each set of data by $\sqrt{\chi^2/(N-1)}$. We dwell on this elimination because the rejected data had a negative A value of (-21 ± 14)%. If these bad runs were totally dominated by counting losses and accidentals then A should be zero, but we do not understand what might cause a negative A, although it is only 1.5 standard deviations. We estimated the systematic error in the good data by comparing its A value of (13.5 ± 7.4)% with the A value obtained when the bad data were included, which was (6.0 ± 6.6)%. We took the difference, which was 7.5%, and added this in quadrature with the statistical error of 7.4% to obtain the total estimated error of 10.5% for these data, which were taken using the F_0 counter.

Thus we have three independent measurements of A

which we designate as runs 1, 2, and 3, and list below:

Run	A
1(1984, Ref.2)	$(51 \pm 17)\%$
2	$(22 \pm 26)\%$
3	$(13.5 \pm 10.5)\%$
Combined 2 and 3	$(15 \pm 10)\%$
Combined 1, 2, and 3	$(24 \pm 8)\%$

(3)

We have also listed the average A value for both later runs and the average value for all three runs, which is $A = (24 \pm 8)\%$. Notice that the run 1 value is larger than our combined runs 2 and 3 value by about 1.8 standard deviations which is probably a statistical fluctuation since we found no problems with the run 1 data. Note that the cross-section-weighted average value of $P_\perp^2$ is 6.5 $(\mathrm{GeV}/c)^2$.

We have plotted our total combined data point in Fig. 2 along with earlier CERN data[3] and combined data from the AGS.[1,2] The numerical value[2] of A at $P_\perp^2 = 5.95$ $(\mathrm{GeV}/c)^2$ is $(16 \pm 5.7)\%$. It now seems rather clear that there is a strong increase in the spin analyzing power A at large $P_\perp^2$. This rise starts at about $P_\perp^2 = 3.5$ $(\mathrm{GeV}/c)^2$, which is the starting point for the very large spin-spin effects seen at the Argonne Zero Gradient Synchrotron.[4] This is the same $P_\perp^2$ value where there is a sharp break in the unpolarized p-p elastic-scattering cross section; this break is probably the hard scattering due to the direct interactions of the protons' constituents.

Most theoretical models[5-21] such as perturbative QCD predict that one-spin effects such as A must go to zero at high $P_\perp^2$. A nonzero A value is equivalent to having helicity spin-flip terms which are not allowed at high $P_\perp^2$ in QCD. Thus if this large value of A persists at larger values of $P_\perp^2$ and energy then the usefulness of QCD in exclusive hadronic interactions will have to be questioned. We plan to extend these measurements of A to $P_\perp^2 = 7$–8 $(\mathrm{GeV}/c)^2$.

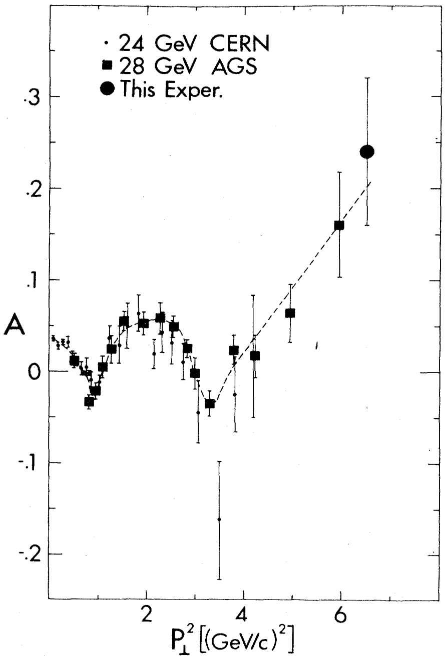

FIG. 2. Analyzing power for proton-proton elastic scattering plotted as a function of $P_\perp^2$. Some adjacent AGS data points have been combined. The curve is a hand-drawn line to guide the eye.

We would like to thank the AGS staff for the successful operation of the AGS accelerator. We thank M. L. Dowell, Y. Gialas, C. B. Higley, B. E. Hinrichs, and R. R. Raylman for their help in running the experiment and R. J. Bruni, R. L. Cummings, Dr. G. Glass, Dr. Y. Y. Lee, and Professor L. C. Northcliffe for their help in the earlier stages of this experiment. We also thank the staff of the MIT Bates Linac for their help in irradiating our NH_3 beads. This work was supported by a research contract from the U.S. Department of Energy.

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[1] D. C. Peaslee *et al.*, Phys. Rev. Lett. **51**, 2359 (1983); P. H. Hansen *et al.*, *ibid.* **50**, 802 (1983).

[2] R. S. Raymond *et al.*, in *Intersections between Particle and Nuclear Physics*, proceedings of the Conference, Steamboat Springs, Colorado, 1984, edited by R. E. Mischke (AIP, New York, 1984), p. 1123.

[3] J. Antille *et al.*, Nucl. Phys. **B185**, 1 (1981).

[4] J. R. O'Fallon *et al.*, Phys. Rev. Lett. **39**, 733 (1977); D. G. Crabb *et al.*, *ibid.* **41**, 1257 (1978); E. A. Crosbie *et al.*, Phys. Rev. D **23**, 600 (1981).

[5] C. Bourrely and J. Soffer, Phys. Rev. Lett. **54**, 760 (1985).

[6] G. R. Goldstein and M. J. Moravcsik, Phys. Rev. D **32**, 303 (1985).

[7] H. J. Lipkin, Weizmann Institute report (unpublished).

[8] S. M. Troshin and N. W. Tyurin, in *Proceedings of the 1984 Symposium on High Energy Spin Physics, Marseille,* edited by J. Soffer [J. Phys. (Paris) Colloq. **46**, C2-235 (1985)].

[9] I. I. Levintov, in *Proceedings of the 1983 Serpukhov Workshop on High Energy Spin Physics,* edited by L. D. Soloviev (Institute of High Energy Physics, Serpukhov, 1984), p. 232.

[10] F. Arash, M. J. Moravcsik and G. R. Goldstein, Phys. Rev. D **31**, 667 (1985).

[11] S. J. Brodsky and G. P. LePage, Phys. Rev. D **24**, 2824 (1981).

[12] M. Anselmino, Z. Phys. C **13**, 63 (1982).

[13] G. R. Farrar *et al.*, Phys. Rev. D **20**, 202 (1979).

[14] S. J. Brodsky, C. E. Carlson, and H. J. Lipkin, Phys. Rev. D **20**, 2278 (1979).

[15] G. R. Goldstein and M. J. Moravcsik, Phys. Rev. D **26**, 3026 (1982).

[16] G. Preparata and J. Soffer, Phys. Lett. **86B**, 304 (1979).

[17] C. Bourrely, E. Leader, and J. Soffer, Phys. Rep. **59**, 95 (1980).

[18] N. S. Craigie, K. Hidaka, M. Jacob, and F. M. Renard, Phys. Rep. **99**, 69 (1983).

[19] J. Szwed, Phys. Lett. **93B**, 485 (1980); Phys. Rev. D **25**, 735 (1982); Nucl. Phys. **B229**, 53 (1983).

[20] G. F. Wolters, Phys. Rev. Lett. **45**, 776 (1980).

[21] C. Avilez, G. Cocho, and M. Moreno, Phys. Rev. D **24**, 634 (1981).