SPIN@U-70: An Experiment to Measure the Analyzing Power A_n in Very-high-$P_\perp^2$ p-p Elastic Scattering at 70 GeV*

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Abstract. The SPIN@U-70 experiment plans to measure the one-spin analyzing power A_n for 70 GeV proton-proton elastic scattering at large $P_\perp^2$ values of 1 to 12 $(\mathrm{GeV/c})^2$. The Michigan frozen NH_3 polarized proton target (Solid PPT) should later be installed in the Channel 8 extracted beam-line of the 70 GeV U-70 accelerator in IHEP, Protvino. The forward-scattered protons are detected by small scintillation counters placed at about 9 m from the PPT, while the

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recoil-scattered protons are detected by a 35-m-long focusing magnetic spectrometer, with a 12 degree vertical bend, placed at 30 degrees to the beam. A tune-up run for testing the beam and the spectrometer, using a polyethylene target, was carried out in April 2002 at IHEP. The layout and the results of the test run are presented.

The SPIN@U-70 experiment plans to use a high intensity 70 GeV unpolarized extracted proton beam from the U-70 accelerator at IHEP-Protvino in Russia to measure the analyzing power A_n in $p + p_{\uparrow} \to p + p$ at large-$P_{\perp}^2$. We would scatter the high intensity beam from a polarized proton target and measure the quantity,

$$A_n = \frac{A_{mea}}{P_T} = \frac{1}{P_T}\left[\frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)}\right],$$

where A_{mea} is the measured asymmetry, P_T is the target polarization, and $N(\uparrow)$ and $N(\downarrow)$ are the normalized elastic event rates with the spin up and spin down, respectively.

Our main goal is to determine if the unexpected large value of A_n, discovered in large-$P_{\perp}^2$ proton-proton elastic scattering at the AGS, persists to higher energy and larger $P_{\perp}^2$ [1,2]. At 24 GeV the one-spin analyzing power A_n was found to be 20.4% ± 3.9% near $P_{\perp}^2$ of 7 $(\text{GeV/c})^2$, as shown in Fig. 1. This large and unexpected spin effect has been difficult to reconcile with conventional models of strong interactions such as perturbative Quantum Chromodynamics (PQCD). The validity of PQCD is predicted to improve with increasing energy and increasing $P_{\perp}^2$. This 70 GeV experiment would increase the maximum $P_{\perp}^2$ by a factor of about 1.7; it would also increase the maximum energy for A_n data at high-$P_{\perp}^2$ by a factor of about 2.5.

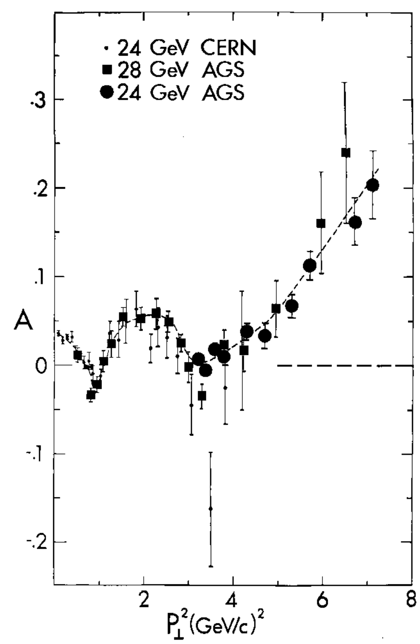

FIGURE 1. The analyzing power A_n is plotted against $P_{\perp}^2$ for spin polarized proton-proton elastic scattering at 24 and 28 GeV.

The experiment would use the Michigan 1-watt-cooling-power solid polarized proton target containing radiation-doped frozen ammonia (NH_3) beads. This target [3] successfully operated with an average polarizaton of 85% during a 3-month run at the AGS with an average beam intensity of 10^{11} protons per sec; this allowed the precise large $P_{\perp}^2$ measurements [1] of A_n shown in Fig. 1.

The SPIN@U-70 spectrometer is shown in Fig. 2. The forward-scattered protons are detected by small scintillation counters placed at about 9 m from the PPT, while the recoil-scattered protons are detected by a 35-m-long focusing magnetic spectrometer, with a 12 degree vertical bend, placed at 30 degrees to the beam. Table 1 lists the angles and momenta for both the forward and recoil protons, as well as the $\int B \cdot dl$ of the recoil-spectrometer magnets for various $P_\perp^2$. The dipole fields for the spectrometer's angles were calculated from the recoil protons' kinematics. The beam optics program TRANSPORT calculated the quadrupoles' gradients needed to focus the recoil protons to fit through the spectrometer's apertures. Most focusing is done by the vertically focusing Q_1 and the horizontally focusing Q_2; this gives the spectrometer a larger vertical acceptance angle $\Delta\varphi'_{lab} (= \Delta\varphi_{lab} \sin\theta_R)$ than its horizontal acceptance angle $\Delta\theta_{lab}$. For each $P_\perp^2$, the horizontal angle θ_R is correlated with the elastic recoil momentum P_R.

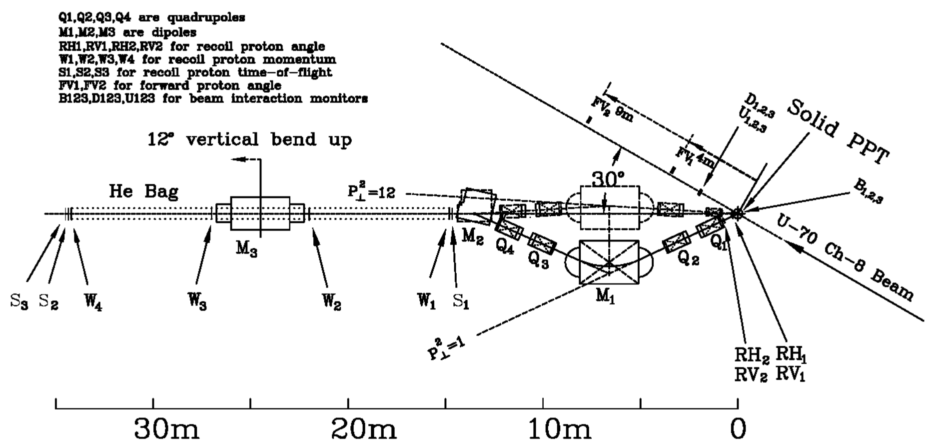

FIGURE 2. SPIN@U-70 spectrometer.

We estimated the event rates and errors in A_n for large-$P_\perp^2$ proton-proton elastic scattering at U-70 using the Michigan solid PPT and the SPIN@U-70 recoil spectrometer in U-70's Channel 8 extracted 70 GeV proton beam-line. Table 2 lists the estimated event rate and error in A_n for each $P_\perp^2$ point. We may run with a lower beam intensity at $P_\perp^2 = 1$ (GeV/c)^2 to reduce accidentals since the statistical precision is around 0.03%. Note that a superconducting quadrupole magnet Q_1 is required in the very-large $P_\perp^2$ region. The measurements of A_n should be rather precise, with an error of less than 1%, for $P_\perp^2$ up to 6.0 (GeV/c)^2, and less than 5% at $P_\perp^2 = 12.0$ (GeV/c)^2.

In spring 2001, installation of SPIN@U-70 started in the Channel 8 extracted beam-line of the 70 GeV U-70 accelerator in IHEP. The 35-m-long recoil Spectrometer's M_1, M_2, and M_3 dipoles and Q_1, Q_2, Q_3, and Q_4 quadrupole magnets, their movable stands, electric and water systems were installed. On 5-10 November 2001, a beam tune-up run showed that the Channel-8 extracted beam at the PPT

TABLE 1. Angles and momenta of elastic protons and magnet strengths. Positive Bl^{eff} corresponds to bending to the right for PPT, M_1 and M_2 and bending up for M_3. The recoil angle after the PPT magnet is θ'_R; it differs from θ_R by $\approx eBl^{eff}_{PPT} / P_R$.

$P_\perp^2$ (GeV/c)^2	θ_F degrees	P_F GeV/c	θ_R degrees	P_R GeV/c	Bl^{eff}_{PPT} kG-m	θ'_R degrees	Bl^{eff}_{M1} kG-m	Bl^{eff}_{M2} kG-m	Bl^{eff}_{M3} kG-m
1	0.825°	69.5	61.44°	1.139	4.42	54.94°	31.5	-15.8	7.94
2	1.176°	68.9	52.19°	1.790	4.46	48.08°	36.3	-18.0	12.48
3	1.452°	68.4	46.22°	2.399	4.50	43.17°	35.7	-17.6	16.73
4	1.690°	67.8	41.87°	2.997	4.54	39.44°	32.1	-15.7	20.90
5	1.906°	67.2	38.48°	3.594	4.57	36.46°	26.4	-12.9	25.06
6	2.107°	66.6	35.72°	4.196	4.61	34.00°	19.1	-9.4	29.26
7	2.296°	66.0	33.41°	4.804	-4.65	34.91°	26.8	-13.1	33.50
8	2.477°	65.4	31.44°	5.423	-4.69	32.76°	17.0	-8.3	37.82
9	2.653°	64.8	29.72°	6.051	-4.73	30.89°	6.2	-3.0	42.20
10	2.824°	64.2	28.20°	6.692	-4.77	29.26°	-5.7	2.8	46.67
12	3.159°	62.9	25.61°	8.015	-4.85	26.48°	-32.1	15.7	55.89

TABLE 2. Event rates and errors in A_n for p-p elastic scattering at U-70.

$P_\perp^2$ (GeV/c)^2	Δt (GeV/c)^2	$\Delta\phi$ mr	$d\sigma/dt$ $\frac{nb}{(GeV/c)^2}$	Events per hour	Hours	Events (N)	ΔA_n $[.85\sqrt{N}]^{-1}$	
1.0	0.06	159	4000	230000	100	$2.3\ 10^7$	0.03%	
2.0	0.09	177	90	8600	100	$8.6\ 10^5$	0.1%	
3.0	0.25	194	19	5500	100	$5.5\ 10^5$	0.2%	
4.0	0.35	210	4.0	1800	100	$1.8\ 10^5$	0.3%	
5.0	0.45	225	0.9	550	100	$5.5\ 10^4$	0.5%	
6.0	0.56	240	0.22	180	200	$3.6\ 10^4$	0.6%	
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7.0	0.67	254	0.055	56	200	$1.1\ 10^4$	1.1%	Super Q_1
8.0	0.79	268	0.016	20	300	$6.0\ 10^3$	1.5%	
9.0	0.92	282	0.0047	7.3	400	$2.9\ 10^3$	2.2%	
10.0	1.06	296	0.0017	3.2	600	$1.9\ 10^3$	2.7%	
12.0	1.25	324	0.0003	0.73	800	$5.8\ 10^2$	4.9%	

location can be as small as 2.5×2.5 mm FWHM and can stay centered within 0.5 mm. A typical beam intensity was $1 - 4 \cdot 10^{11}$ protons/pulse. During the run a vertical beam rastering system was successfully tested. During U-70's January-February 2002 shut-down, IHEP finished installing SPIN@U-70. On 11 March 2002, Michigan's shipment of detectors and electronics, needed for the April 2002 run, arrived at Moscow's SVO Airport. This shipment was then impounded by Russian Customs. [Note added: In early November 2002 it was returned to Michigan.]

Although the shipment of equipment was impounded, a short 19-26 April 2002 test run still occurred, using a polyethylene target. Some simple IHEP detectors and electronics were prepared in only a few weeks and were successfully used for the run. The resulting almost 100 to 1 signal to background rate in the $S_1 \cdot S_{1.5}$ coincidence data, shown in Fig. 3, indicates that the 35-m-long Elastic Recoil Spectrometer is quite effective in discriminating against inelastic and other background events.

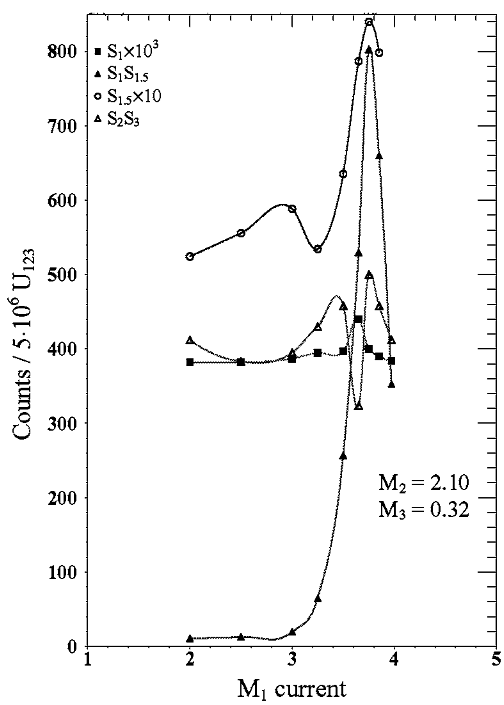

FIGURE 3. Magnet Curve: The Elastic Recoil Spectrometer event rate ($S_1 \cdot S_{1.5}$ coincidences) is plotted against the current in the 3-m-long 68-ton M_1 bending dipole magnet. Note that the ratio of the signal to background is almost 100 to 1 in the elastic peak. The single detector data rates are also shown along with the coincidences between the close-together S_2 and S_3 detectors.

Unfortunately, due to the problems with Russian Customs, the SPIN@U-70 experiment was recently suspended until the problems can be fully resolved.

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