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SPIN@J-PARC Letter of Intent

to

JAPAN 50 GeV J-PARC

Analyzing power A_n in 50 GeV very-high-$P_{\perp}^2$ proton-proton elastic scattering

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Introduction

This is a Letter Of Intent (L.O.I.) to measure the analyzing power A_n in $p + p_\uparrow \to p + p$ at very high $P_\perp^2$ at J-PARC with a 50 GeV unpolarized extracted proton beam starting in 2007. We would scatter the high intensity beam from a polarized proton target and measure the quantity:

$$A_n = A_{mea} / P_T = [N_\uparrow - N_\downarrow]/([N_\uparrow + N_\downarrow]\, P_T),$$

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 goal is to determine if the large unexpected value of A_n, discovered in proton-proton elastic scattering at the AGS, persists to higher energy and higher $P_\perp^2$. At 24 GeV, the one-spin analyzing power A_n was found[1,2] to be 20.4 ± 3.9% near $P_\perp^2$ of 7 $(GeV/c)^2$, as shown in Fig 1. This large and unexpected spin effect has been difficult to reconcile with most current models of strong interactions, such as Perturbative Quantum Chromodynamics PQCD. The validity of PQCD is predicted to improve with increasing energy and increasing $P_\perp^2$. The proposed 50 GeV experiment would increase the maximum energy for A_n data at high-$P_\perp^2$ by a factor of about 2; it would also increase the maximum $P_\perp^2$ by a factor of about 1.7.

The proposed experiment would use the Michigan 1-watt solid Polarized Proton Target (PPT) containing radiation-doped frozen ammonia (NH_3) beads. This PPT[4] successfully operated with an average proton beam intensity of 10^{11} s^{-1} at the AGS, which allowed the precise high-$P_\perp^2$ measurements[1] of A_n, which are shown in Figure 1.

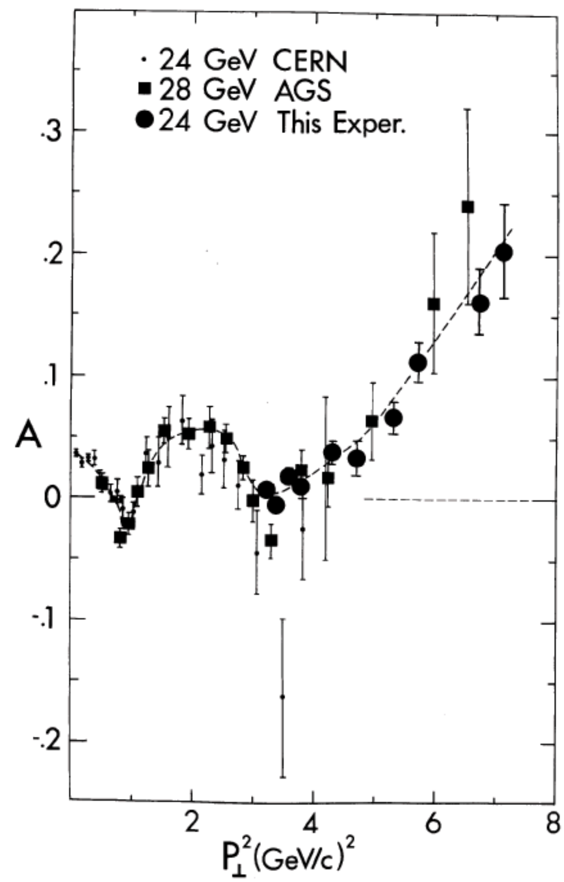


Fig. 1. The analyzing power A_n is plotted against $P_\perp^2$ for spin polarized proton-proton elastic scattering at 24[1, 3] and 28 GeV[2].

This high-cooling-power Polarized Proton Target, along with a J-PARC high intensity extracted proton beam of about $3 \cdot 10^{11}$ protons per 3 s cycle, would give a polarized proton luminosity of over $2 \cdot 10^{34}$ $s^{-1}cm^{-2}$. This would allow precise measurements of spin effects in high-$P_\perp^2$ proton-proton elastic scattering at 50 GeV out to $P_\perp^2$ of 12 $(GeV/c)^2$.

We would run in the J-PARC extracted beam area, which is well suited for this high-$P_\perp^2$ elastic scattering experiment. We would use an approximately 35-m-long recoil spectrometer, similar to the SPIN@U-70 spectrometer recently used at the 70 GeV U-70 accelerator in IHEP-Protvino.[5] The SPIN@J-PARC spectrometer would contain quadrupole and dipole magnets with considerable focusing and bending power, small medium-resolution scintillation hodoscopes, and 4 small high-resolution proportional and/or drift wire chambers. The resulting high precision measurement of the recoil momentum should allow a clear identification of elastic events, with a simple forward arm containing only small hodoscopes and no magnets. Four quadrupoles in the recoil spectrometer would focus the recoil protons; this focusing would significantly increase the solid angle acceptance and reduce the background.

This L.O.I. contains first a brief discussion of the theoretical background of spin effects in large-$P_\perp^2$ elastic scattering; we next describe the Michigan polarized proton target, the beam stability and rastering requirements, and the proposed SPIN@J-PARC spectrometer. We then calculate the expected event rates and errors for the experiment, and then finally review its equipment status.

Theoretical Background

The spin physics of large-$P_\perp^2$ hadron elastic scattering provides direct information about the short distance behavior of the hadronic constituents' interactions. According to the Quantum Chromodynamics (QCD) theory of strong interactions,[6] only the lowest Fock states with valence quarks and zero orbital angular momentum can contribute to the helicity amplitudes.

The QCD analysis of elastic scattering assumes that momentum transfer scattering is dominated by short distance quark-gluon subprocesses. Due to asymptotic freedom, this theory leads to the familiar power-law dimensional scaling quark-counting rule.[7] The power-law scaling predictions for form factors and for two-body hadron scattering cross-sections are generally consistent with unpolarized experiments at $P_\perp^2$ above a few $(\mathrm{GeV}/c)^2$.

However, this agreement with unpolarized experiments does not in itself confirm the validity of QCD. Large spin effects were discovered which cannot be explained by perturbative QCD.[8, 9] For an exclusive reaction $a+b \rightarrow c+d$, perturbative QCD gives a simple and general helicity conservation law[6]

$$\lambda_a + \lambda_b = \lambda_c + \lambda_d ,$$

where λ_i is the helicity of the i^{th} particle. This law implies that the analyzing power A_n in elastic proton-proton scattering must satisfy the relation:

$$A_n = 0 .$$

Violation of this relation would demonstrate the non-perturbative nature of hadronic dynamics. As shown in Fig. 1, the proton-proton elastic analyzing power was measured up to 28 GeV at large-$P_\perp^2$; the data clearly show that A_n is non-zero at the world's largest measured elastic $P_\perp^2$ at 7 $(\mathrm{GeV}/c)^2$.

The large spin effects observed in high-$P_\perp^2$ experiments may be caused by non-perturbative dynamics due to chiral symmetry breaking or confinement effects. Many models have been proposed for the treatment of these spin effects at large-$P_\perp^2$.[10 - 22] Some of these models involve non-perturbative mechanisms such as: strange and charmed particle production thresholds,[13] geometric mechanisms of quark scattering in an effective field[14] and quark interactions due to an infinite sequence of meson exchanges.[15] Some of these models were able to reproduce the values for the elastic spin-spin parameter A_{nn} observed at the ZGS[23, 24] near 12 GeV and $\theta_{cm} = 90°$, as well as the sparser 18.5 GeV AGS data on A_{nn}.[25] Some other models give an explanation for the large value of the analyzing power A_n discovered in high-$P_\perp^2$ elastic scattering.[1] But there is not yet any model which can explain all spin effects in large-$P_\perp^2$ proton-proton elastic scattering.

Some of the above models predict values for A_n at higher energies. For example, the quark U-matrix model[14] predicts the $P_\perp^2$-dependence for A_n in elastic proton-proton scattering at 70 GeV in the $P_\perp^2$ region of 3 to 12 $(\mathrm{GeV}/c)^2$; the predicted value of A_n at $P_\perp^2 = 12\ (\mathrm{GeV}/c)^2$ is about 10%. [26]

The proposed study of elastic scattering spin effects in this totally unexplored large-$P_{\perp}^2$ region should provide a strong test of perturbative QCD; it should also yield information on the hadronic wave function, which cannot be obtained from deep-inelastic scattering. Thus it seems quite important to measure A_n at larger-$P_{\perp}^2$ and higher energy.

Polarized Proton Target

We propose to use the University of Michigan's 1-watt-cooling-power Polarized Proton Target (PPT),[4] which is shown in Fig. 2 and described in Table 1. This PPT was used at the AGS in 1990;[1] its magnetic field of 5 T and temperature of 1 K, produced an unexpectedly high proton polarization of up to 96%.[4] Moreover, its 5 minute polarization rise-time allowed fast and frequent polarization-direction reversals. The PPT's material is 2 mm beads of radiation-doped ammonia (NH_3), with a hydrogen density of about 0.10 g cm^{-3}; its length is about 3.2 cm, and its diameter is 2 cm. The H protons in the NH_3 are polarized in the 5 T field, by a 140 GHz microwave system, using the Dynamic Nuclear Polarization method and some nearby electrons in radiation-damage centers. The polarization is monitored by a 213 MHz NMR Q-meter system. The unexpectedly high proton polarization and rapid polarization growth time are clearly shown in Fig. 3.

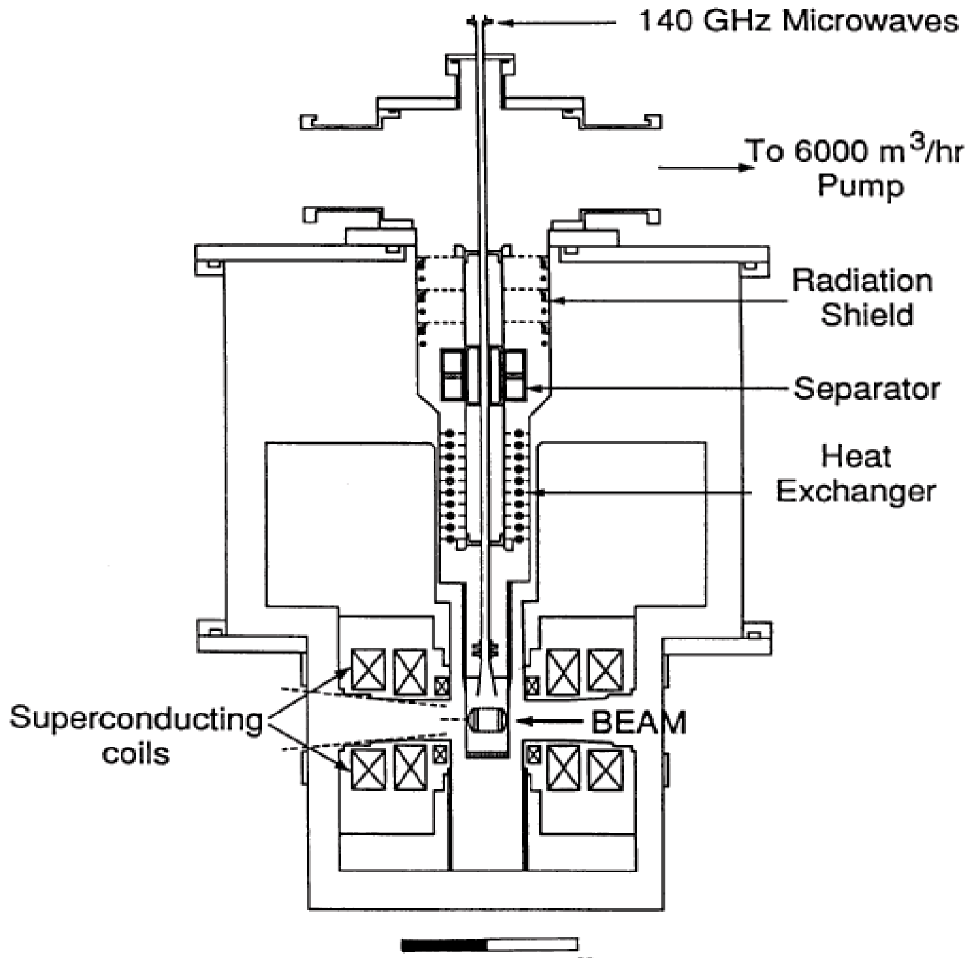


Fig. 2. Diagram of the Michigan polarized-proton-target.[4] The superconducting magnet produces a highly uniform 5T field. At 1 K, the ^4He cryostat provides about 1 watt of cooling power to the irradiated 2-mm-diameter NH_3 beads in the small cavity at the field's center. A horn feeds the 140 GHz microwaves, from a 22 watt Varian EIO, into the cavity.

This PPT target had an average polarization of 85% during a 3-month-long AGS run,[1, 27] with an average beam intensity of about $2 \cdot 10^{11}$ protons per 2.4 sec AGS cycle. This was an average beam intensity of almost 10^{11} protons per sec; it corresponds to $3 \cdot 10^{11}$ protons per 3-sec cycle at J-PARC. Our experience at the AGS[1, 4] suggests that there should be no problem due to the slightly different cycle times at the AGS and J-PARC; the thermal-time-constant of the PPT appeared to be more than a minute.

The dilution factor decreases the true proton-proton analyzing power due to quasi-elastic events or events from the heavy nuclei in the NH_3 beads, the He^4 or the container. The dilution factor was determined experimentally at the AGS by measuring the event rate with hydrogen-free Teflon (CF_2) beads in place of the NH_3 beads; it was also obtained from the "off-diagonal matrix" coincidences between the forward and recoil hodoscopes. The measured dilution factor, at $P_\perp^2 = 3.2$ $(GeV/c)^2$ was 1.06 and was about 1.6 at $P_\perp^2 = 7$ $(GeV/c)^2$.[1, 27] The dilution factor was fairly small because the AGS double-arm elastic spectrometer rather strongly discriminated against quasi-elastic events and events from nitrogen and other heavy nuclei. However, the heavy nuclei produced many inclusive events indistinguishable from the polarized protons inclusive events.[28] Therefore, inclusive measurements would be very difficult with this PPT.

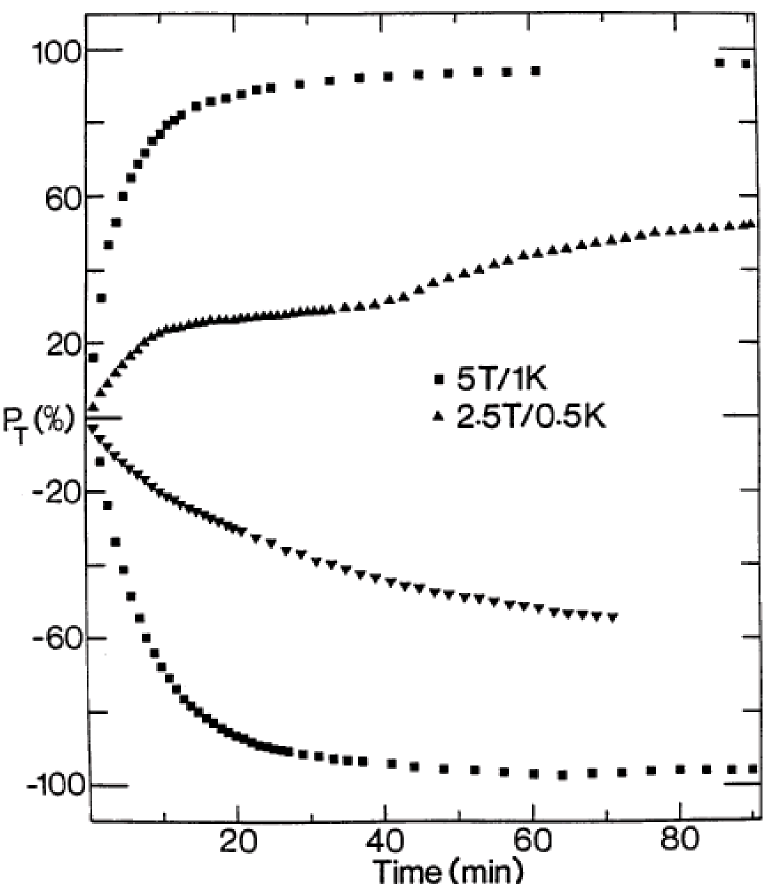


Fig. 3. Spin polarization of the free protons in NH_3 is plotted vs. the 140 (or 70) GHz microwave irradiation time. The data at 5 T and 1 K are squares; the earlier NH_3 data at 2.5 T and 0.5 K are triangles.[4, 27]

PPT parameters

Table 1 lists some specifications of the Michigan solid PPT.

1. Cryostat Temperature	1 K
2. Cooling Fluid	He^4
3. Cooling Power	0.927 watt
4. Operating Magnetic Field	5.0 T
5. Field Uniformity Region	10^{-4} in 4 cm diam. by 3 cm high cylinder
6. $\int B \cdot dl$	0.885 T·m
7. Power Supply Voltage	3 V
8. Superconducting Coil Current	66 A
9. Microwave Frequency	~140 GHz
10. NMR Frequency	213.0 ± 0.3 MHz
11. Vertical Angular Acceptance	± 6°
12. Horizontal Angular Acceptance	± 34°
13. Target Size	3.2 cm long by 2.0 cm diam. cylinder
14. Target Material	Irradiated NH_3 beads
15. Ave. Beam Intensity at 24 GeV/c	$2\ 10^{11}$ p per 1 s pulse per 2.4 s cycle
16. Max. PPT Polarization	96 %
17. Average Polarization in AGS Run	85 %

Table 1. Michigan Solid PPT Specifications.

Beam Stability Requirements

We need a stable beam centered on the PPT with about 85 % of the protons contained in perhaps a 3 mm diameter circle. High stability of the intensity, the position, and the spot size, are all needed to provide reliable data and to avoid quenching the PPT's superconducting magnet. This stability would require several high-quality beam profile monitors in addition to a position control feedback system. At the AGS, the average beam position was kept centered to within about ± 0.1 mm, by using a weak upstream corrector magnet with a fast response-time, which was controlled by the analog signal from the left-right asymmetry in a Segmented Wired Ion Chamber (SWIC) placed near the PPT. Somewhat similar precision was obtained in a recent SPIN@U-70 test run.[5] Fig. 4 shows some beam-line elements suggested for such a system at J-PARC. Since the PPT magnet has $\int B \cdot dl$ = 0.885 T·m, another downstream corrector magnet would be needed to realign the beam for possible downstream users.

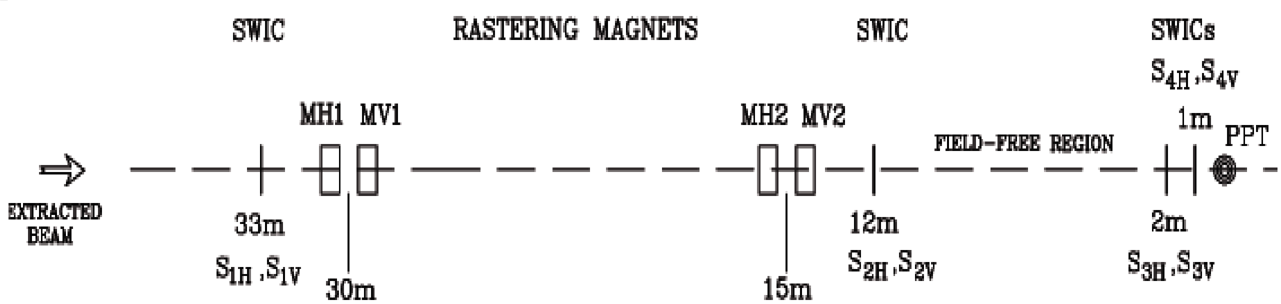
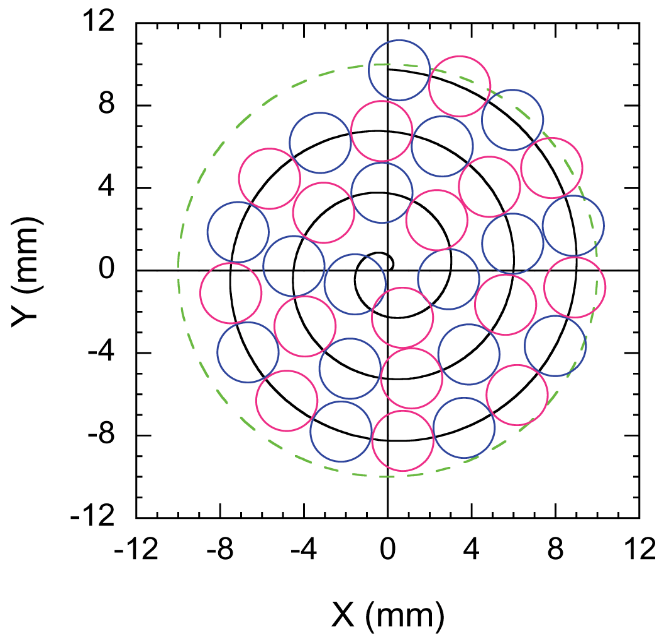


Fig. 4. Possible beam control system for rastering and stabilizing the beam on the PPT center.

Beam Rastering

We request rastering of the beam across the target, perhaps in a spiral pattern, to uniformly irradiate the PPT material. This would minimize the variation in bead irradiation and the resulting error in polarization readings from the NMR. A spiral raster pattern was used successfully with similar PPTs at SLAC and JLab by D.G. Crabb *et al.* [30] Such a pattern is shown in Figure 5. If the beam size could be as small as 3 mm, then the spiral pitch could also be about 3 mm.

Fig. 5. A possible raster pattern. The spiral could be created by simultaneously operating the same vertical and horizontal corrector magnets, shown in Fig. 4, with sine-wave power supplies slightly more than 90° out of phase.



Spectrometer

Large-$P_{\perp}^2$ elastic events would be detected using a 35-m-long focusing recoil spectrometer, similar to that of our SPIN@U-70 experiment, which was designed to study 70 GeV proton-proton elastic scattering at U-70 in Protvino.[5]

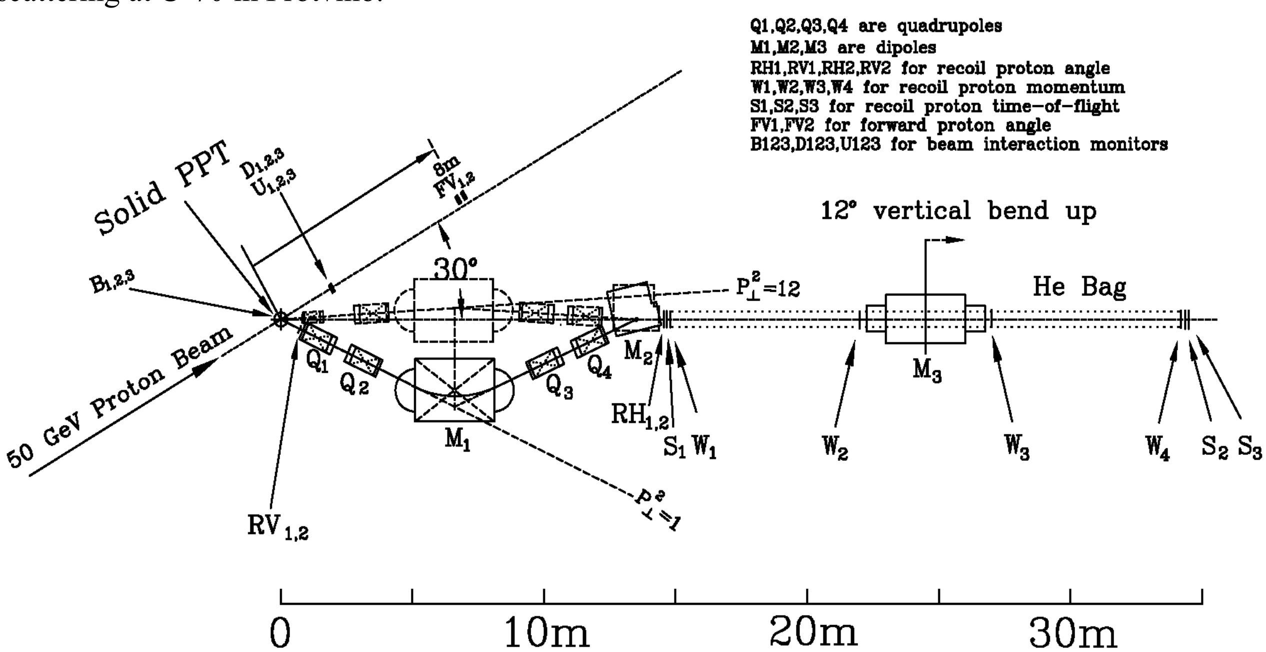


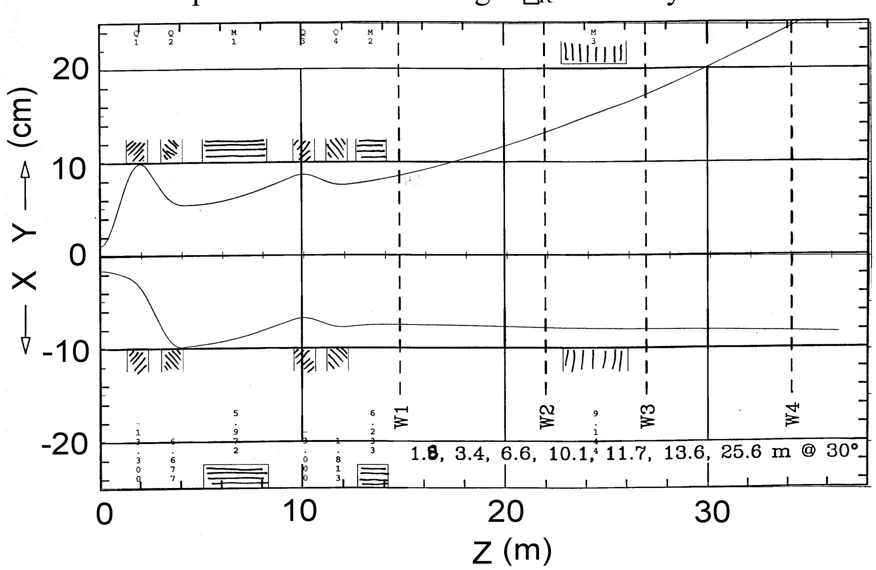
Fig. 6. The proposed 35-meter-long recoil spectrometer in the J-PARC extracted beam line.

The proposed SPIN@J-PARC spectrometer is shown in Fig. 6. Table 2 lists the angles and momenta of both the forward and recoil protons, as well as the $\int B\cdot dl^{eff}$ of each recoil spectrometer magnet for each $P_{\perp}^2$ setting. The dipole fields needed for each setting were calculated from the kinematics of the recoil protons.

$P_{\perp}^2$ (GeV/c)^2	θ_F degrees	P_F GeV/c	θ_R degrees	P_R GeV/c	$\int B\cdot dl^{eff}_{PPT}$ T·m	θ_R' degrees	$\int B\cdot dl^{eff}_{M1}$ T·m	$\int B\cdot dl^{eff}_{M2}$ T·m	$\int B\cdot dl^{eff}_{M3}$ T·m
1	1.16	49.5	61.2	1.14	0.445	54.7	3.15	-1.58	0.79
2	1.66	48.9	51.9	1.80	0.451	47.7	3.63	-1.81	1.25
3	2.05	48.4	45.8	2.42	0.456	42.7	3.57	-1.76	1.67
4	2.40	47.8	41.3	3.03	0.461	38.9	3.21	-1.57	2.09
5	2.72	47.2	37.8	3.65	0.467	35.8	2.64	-1.29	2.51
6	3.02	46.6	35.0	4.28	0.472	33.2	1.91	-0.94	2.93
7	3.30	45.9	32.6	4.92	-0.478	34.1	2.68	-1.31	3.35
8	3.58	45.3	30.5	5.58	-0.484	31.8	1.70	-0.83	3.78
9	3.86	44.6	28.7	6.26	-0.490	29.8	0.62	-0.30	4.22
10	4.13	43.9	27.0	6.96	-0.496	28.0	-0.57	0.28	4.67
12	4.68	42.4	24.2	8.45	-0.509	25.1	-3.21	1.57	5.59

Table 2. Angles and momenta of elastic protons and magnet strengths. Positive $\int B\cdot dl^{eff}$ corresponds to bending to the right for the PPT, M_1, and M_2 magnets and bending up for M_3. θ_R' is the recoil angle after the PPT magnet; it differs from θ_R by $\approx e\int B\cdot dl^{eff}_{PPT}/P_R$.

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 quadrupole magnet and the horizontally focusing Q_2; the spectrometer's vertical acceptance angle in the lab, $\Delta\phi_R' = \Delta\phi_R \sin\theta_R$, is much larger than its horizontal acceptance angle, $\Delta\theta_R$. Fig. 7 shows a typical vertical (upper) and horizontal (lower) beam envelopes through the spectrometer. The two quadrupole pairs Q_1, Q_2 and Q_3, Q_4 focus a large acceptance of about $\Delta\phi_R' =$ 140 mrad & $\Delta\theta_R$ = 22 mrad into rather small aperture detectors and magnets. Also note that the elastic recoil proton's horizontal angle θ_R is exactly correlated with its momentum P_R for each $P_{\perp}^2$.



Magnet	Position [m]	Field or Gradient
PPT	0.0	-5.00 T
Q_1	1.8	-13.3 T/m
Q_2	3.4	6.7 T/m
M_1	6.6	0.6 T
Q_3	10.1	-3.0 T/m
Q_4	11.7	1.8 T/m
M_2	13.6	-0.6 T
M_3	25.6	0.91 T

Fig. 7. The beam envelopes obtained from TRANSPORT for the recoil protons at $P_{\perp}^2 = 6$ (GeV/c)^2 for a point target. A superconducting quadrupole Q_1^{super} would be required for $P_{\perp}^2 = 7$-12 (GeV/c)^2.

The required magnets are listed in Table 3. We hope that J-PARC could provide all warm dipoles and quadrupoles, with appropriate power supplies, cables and controls. Perhaps we could later provide the superconducting quadrupole, Q_1^{super}, for the later large-$P_{\square}^2$ running; its required field gradient of 60.8 T/m for the highest recoil momentum of 8 GeV/c at $P_{\square}^2 = 12$ $(GeV/c)^2$. Note that Q_1^{super} is only 1.2 m from the PPT, its length is 0.6 m, and its aperture is 10 x 16 cm (h x v).

Magnet	Length (m)	Diameter or Gap (cm)	B'_{max} (T/m)	B_{max} (T)
Q_1,Q_2,Q_3,Q_4	1.00	20	14.8	
Q_1^{super}	0.60	10x16	60.8	
M_1,M_3	3.00	20	----	1.8
M_2	1.50	20	----	1.8

Table 3. Recoil spectrometer magnet parameters.

Table 4 lists the sizes of the detectors. The M_3 dipole's12° vertical bend, along with the 1 mm vertical resolution wire chambers (W_1-W_4), should give a precise momentum resolution near ±0.1%. The 15-channel horizontal-resolution RH_{12} hodoscope would give a rough measurement of $\square_R$. The precise P_R measurement and the $\square_R$ measurement would together discriminate against inelastic and quasi-elastic events by using the exact angle-momentum correlation for each elastic recoil proton. The vertical-resolution RV_{12} hodoscopes, along with the ± 1.5 mm vertical PPT vertex position, obtained by recording the vertical position in the beam Raster cycle, would give a rather good measurement of $\square_R$. We would also use the rastering's vertical vertex position, along with the forward FV_{12} vertical-resolution scintillator hodoscope, to measure $\square_F$; thus, we could verify, with rather good precision, coplanarity ($\square_R = \square_F$). The U_{123}, D_{123}, and B_{123} telescopes, each made of 3 scintillation counters, would point at the PPT, respectively, from 20° above, 20° below, and 90° below the beam line, to monitor the luminosity.

Detector Type	Location	Size(hxv) [mm]	Ch.	Resolution [mm]	Thickness [mm]
RV_1 Scintillator	R-0.8 m	60x160	8	10.7 V	10
RV_2 Scintillator	R-0.8 m	60x160	8	10.7 V	10
RH_1 Scintillator	R-14.2 m	200x200	8	13.3 H	10
RH_2 Scintillator	R-14.2 m	200x200	8	13.3 H	10
S_1 Scintillator	R-14.6 m	200x200	4	50 V	10
S_2 Scintillator	R-34.3 m	305x438	4	62.5 V	10
S_3 Scintillator	R-34.5 m	305x438	4	62.5 V	10
W_1 MWPC	R-15 m	200x200	192	1 V	20
W_2 Drift Chamber	R-22 m	300x500	2x32	1 V	20
W_3 Drift Chamber	R-26 m	300x500	2x32	1 V	20
W_4 Drift Chamber	R-33 m	300x500	2x32	1 V	20
FV_1 Scintillator	F-8 m	15x80*	8	1 V	10
FV_2 Scintillator	F-8 m	15x80*	8	1 V	10
U_{123} Scintillators	F-2 m 20°up	10 x10	3	--	32
D_{123} Scintillators	F-2 m 20°down	10x10	3	--	32
B_{123} Scintillators	1 m below	12x8.5	3	--	40

Table 4. List of SPIN@J-PARC detectors.

*The FV_{12} sizes are at $P_{\square}^2 = 6$ $(GeV/c)^2$; we may use other sizes at other $P_{\square}^2$ to match elastic kinematics.

We would employ a 2-level trigger system to select elastic events. The first level trigger would be a fast coincidence ($S_1 \cdot S_2 \cdot S_3$) between the large scintillator hodoscopes S_1, S_2, and S_3; its decision time would be about 5 nsec. The 4-channel vertical hodoscopes S_1, S_2, S_3 would give a momentum resolution of about $\Delta P/P = \pm 5\%$.

The second level trigger would be all FV_{12} coincidences in the (or) mode in coincidence with all $S_1 \cdot S_2 \cdot S_3$ coincidences also in the (or) mode. This $FV_{12} \cdot S_1 \cdot S_2 \cdot S_3$ coincidence would also have a 5 nsec decision time and would give a fast and simple estimate of the elastic event rate; however, it may have a high background rate, especially at high-$P_\perp^2$.

We would have two independent data analysis systems: one fast hardwired system and one slower computer system for detailed analysis. Each second level trigger would be analyzed by both systems.

We would analyze each coincidence between the recoil and forward ϕ angles measured by the 15-channel recoil hodoscope RV_{12} and the 15-channel forward hodoscope FV_{12}. Adjacent channels would be paired to form an 8x8 coplanarity coincidence matrix using a memory look-up unit (MLU) with a decision time of about 50 ns. The "off-diagonal" 8x8 matrix elements would be used for a fast estimate of the background. All 15 channels would be individually analyzed by the computer system. Moreover, for each event, time-to-digital converters (TDCs) would record the time-of-flight between S_1 and S_3 and between FV_{12} and S_3 to estimate accidental events.

For each event, the computer system would form an angle-momentum cut by comparing the correlation between the recoil angle (θ_R) measurements from the 15-channel RH_{12} hodoscopes and the precise recoil momentum (P_R) measurements from the four wire chambers W_1 to W_4. This computer analysis should take at most a few milliseconds; thus, it might be offline at small $P_\perp^2$, but it should be online at large $P_\perp^2$.

Note that the most serious problem may be the very high rates in the FV_{12} and RV_{12} scintillation hodoscopes. With a total NH_3 luminosity of more than 10^{35} $cm^{-2}s^{-1}$ at J-PARC, each channel may run at several MHz, as did similar detectors in our AGS and U-70 experiments.[1, 5, 27]

The SPIN@J-PARC collaboration would provide all detectors, along with their HV supplies, cables, logic, and data analysis computers.

In summary, we propose to install the Recoil and Forward Spectrometers, the Polarized Proton Target (PPT), and the U_{123}, D_{123} and B_{123} luminosity monitors in the J-PARC extracted beam line, as shown in either Fig. 8 or Fig. 9. The following modifications of the area would be required for the experiment:

1. Rearrangement of shielding blocks and the area around the 30° spectrometer line.
2. A 50 cm diameter hole in the shielding wall for the recoil spectrometer helium bag.
3. Possibly raising the roof shielding in the extracted beam area for the PPT and making a place for its pumps inside the shielding.

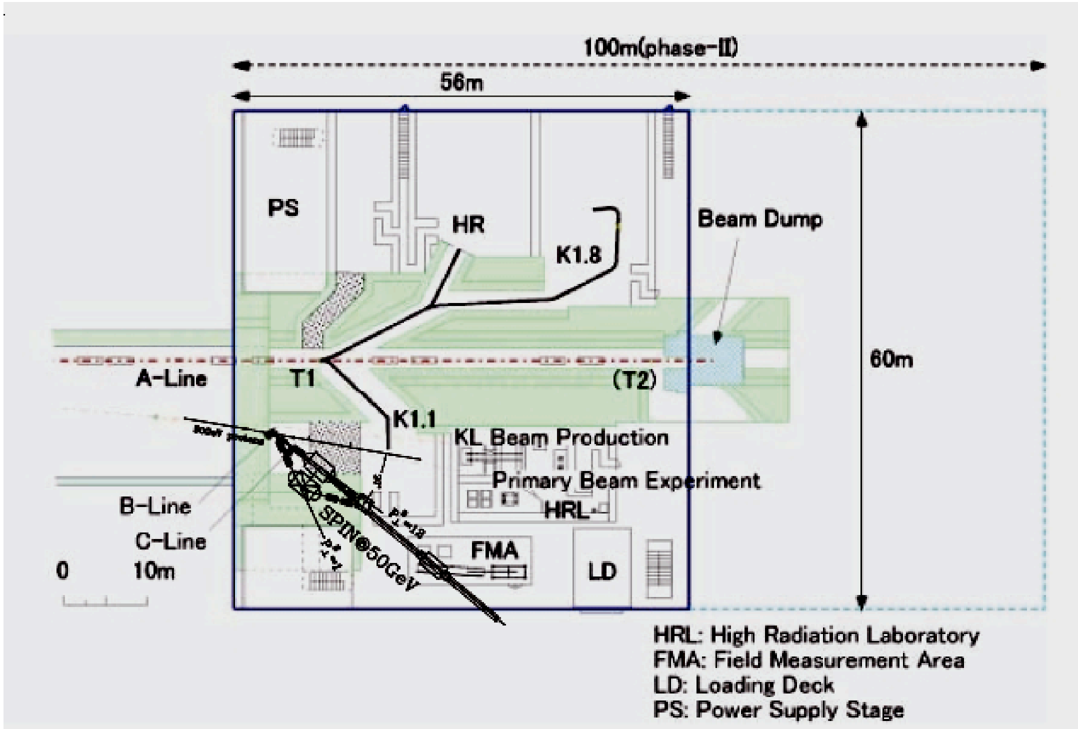


Fig. 8. A possible SPIN@J-PARC layout in the extracted proton beam area.

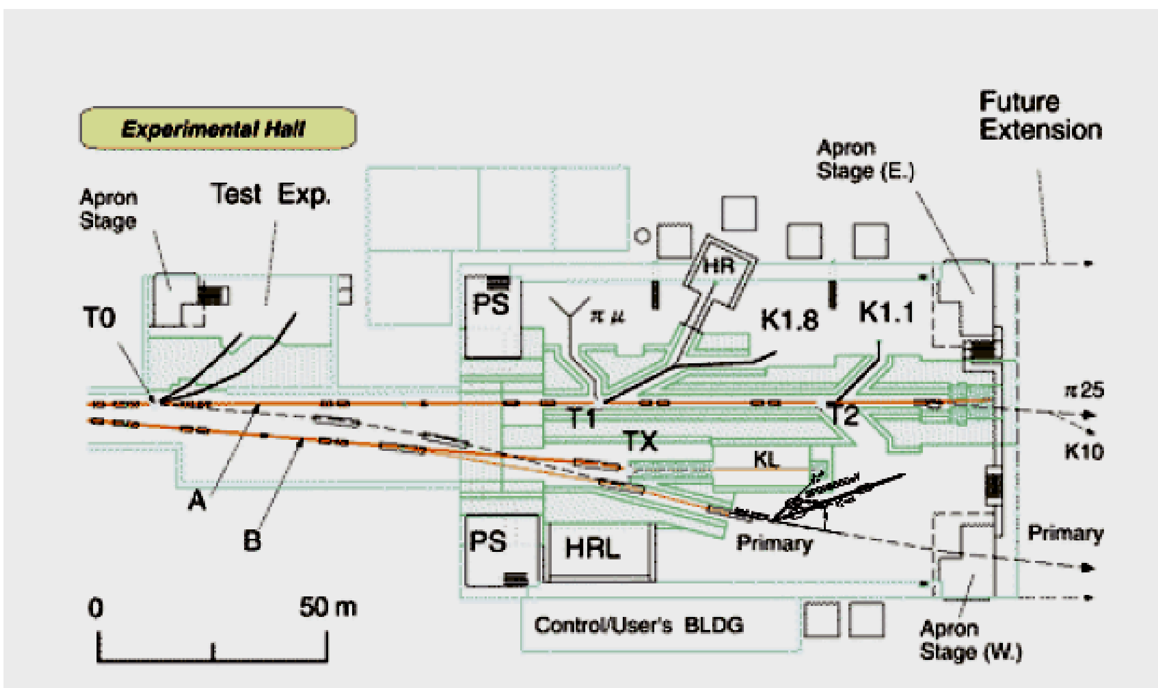


Fig 9. Another possible SPIN@J-PARC layout in the extracted proton beam area.

Event Rates

We now estimate the event rates and the errors in A_n for large-$P_\perp^2$ proton-proton elastic scattering at J-PARC using the Michigan PPT and the proposed spectrometers. The PPT thickness is about:

$$\mathbf{T = N_0(\rho)t \;=\; 6.02\; 10^{23}\; gm^{-1}\, (0.1\; gm\; cm^{-3})\; 3.2\; cm \;=\; 2\; 10^{23}\; polarized\; protons\; cm^{-2}.}$$

The J-PARC accelerator could easily supply 3 10^{11} unpublicized 50 GeV protons to the extracted area every 3 s. Then the average intensity passing through the PPT would be about $I_B = 10^{11}\ s^{-1}$ protons; therefore, the time-averaged luminosity would be:

$$\mathbf{L \;=\; I_B \cdot T \;=\; 2\; 10^{34}\;\; s^{-1}\; cm^{-2}.}$$

For each $P_\perp^2$ setting, the proposed SPIN@J-PARC Spectrometers' vertical acceptance $\Delta\phi$ was obtained from its $\Delta\theta$' of about 140 mad; they are listed in Table 5 along with the Δt acceptances, which vary from 0.06 to 1.25, as $P_\perp^2$ increases from 1 to12 $(GeV/c)^2$.

The p-p elastic cross-sections, $d\sigma/dt$, listed in Table 5, were obtained from the compilation shown in Fig. 10.[29] [Note: at 50 GeV/c, the quantity $\square^2\square_{total}/38.3$ is about 1.] We then calculated the event rate using the equation:

$$\mathbf{Events/hr \;= L\; d\sigma/dt\; (\Delta t \cdot \Delta\phi/2\pi)\; \varepsilon\, 3600\; s/hr \;=\; 6\; d\sigma/dt\; [nb]\cdot(\Delta t \cdot \Delta\phi)[mr]}\ ,$$

where $\Delta\phi$ is the azimuthal acceptance angle and the efficiency factor ε is conservatively estimated to be 50%. Table 5 lists the event rate and error in A_n for each $P_\perp^2$ point. Note that because of the excellent statistics, the data up to $P_\perp^2$ of 6 $(GeV/c)^2$ could easily be subdivided into finer bins as was done at the AGS. Thus, the data at $P_\perp^2$ of 5 $(GeV/c)^2$ could be split into two $P_\perp^2$ bins centered at about 4.9 and 5.1$(GeV/c)^2$, each with an error of about 0.7 %. Note that we may need a lower beam intensity at $P_\perp^2$ = 1 $(GeV/c)^2$.

$P_\perp^2$ $(GeV/c)^2$	Δt $(GeV/c)^2$	$\Delta\phi$ mr	$d\sigma/dt$ nb/$(GeV/c)^2$	Events per hour	Hours	Events (N)	$\delta A_n = [.85\ N]^{-1}$ (%)	
1.0	0.06	159	4000	230000	100	$2.3\cdot10^7$	**0.03**	
2.0	0.09	177	90	8600	100	$8.6\cdot10^5$	**0.1**	
3.0	0.25	194	19	5500	100	$5.5\cdot10^5$	**0.2**	
4.0	0.35	210	4.0	1800	100	$1.8\cdot10^5$	**0.3**	
5.0	0.45	225	0.9	550	100	$5.5\cdot10^4$	**0.5**	
6.0	0.56	240	0.22	180	200	$3.6\cdot10^4$	**0.6**	
7.0	0.67	254	0.055	56	200	$1.1\cdot10^4$	**1.1**	**Super Q_1**
8.0	0.79	268	0.016	20	300	$6.0\cdot10^3$	**1.5**	"
9.0	0.92	282	0.0047	7.3	400	$2.9\cdot10^3$	**2.2**	"
10.0	1.06	296	0.0017	3.2	600	$1.9\cdot10^3$	**2.7**	"
12.0	1.25	324	0.0003	0.73	800	$4.4\cdot10^2$	**4.9**	"

Total hours: 3000 + 500 (tune-up)

Table 5. Event rates and errors in A_n for 50 GeV p-p elastic scattering at J-PARC.

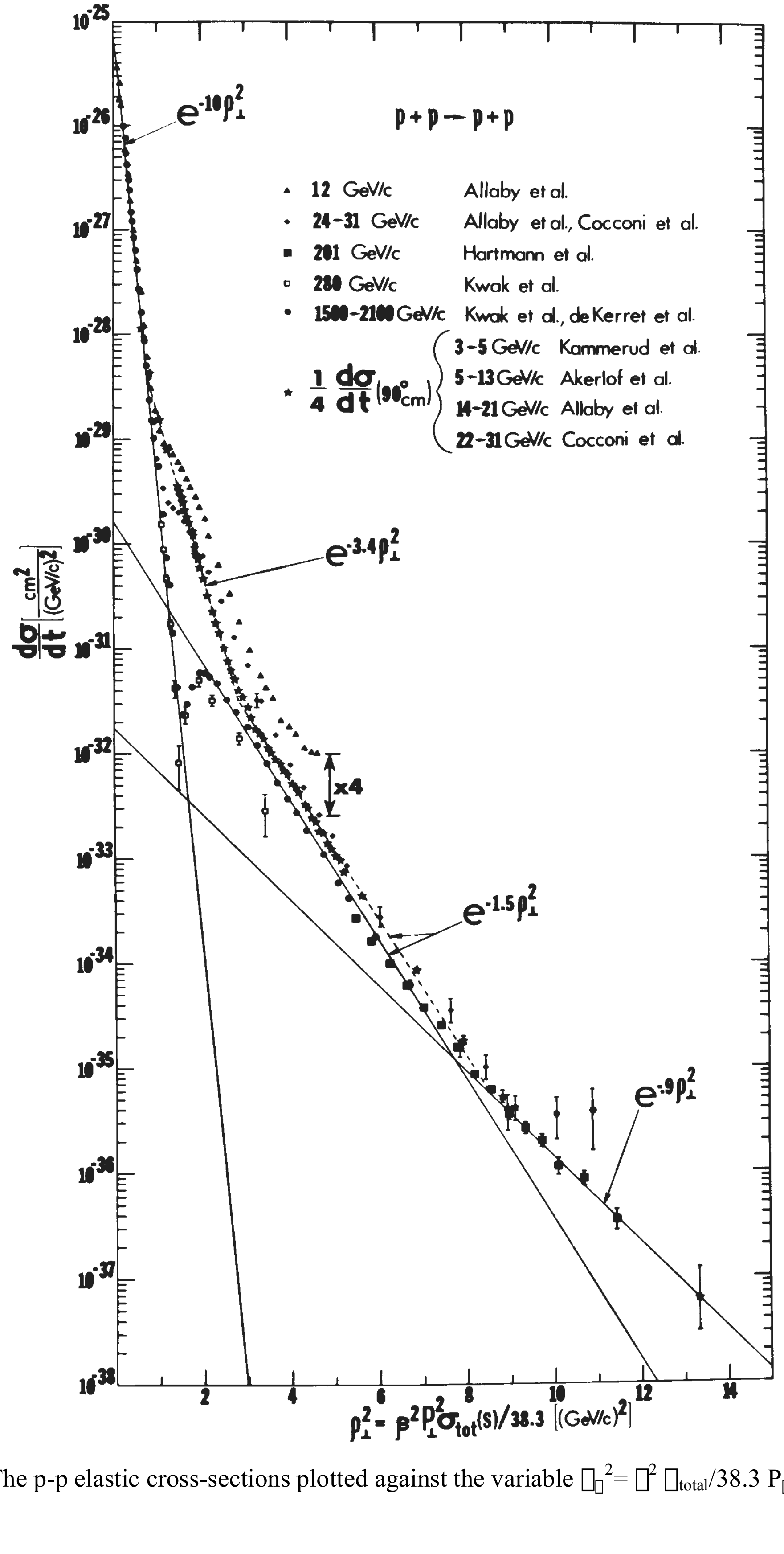


Fig.10. The p-p elastic cross-sections plotted against the variable $\rho_\perp^2 = \beta^2\ \sigma_{total}/38.3\ P_\perp^2$.[29]

Status of Equipment

Table 6 lists the status of the equipment required for the SPIN@J-PARC experiment. Some time would be needed for the careful packing, paperwork, shipping, and reassembly of the solid PPT system now at Michigan. We recently successfully tested this solid PPT at Michigan with freshly irradiated ammonia (NH_3) beads; a polarization of over 90 % was obtained.

#	**Item**	**Status**	**Suggested Action**	**Time Needed**
1.	Solid PPT, NMR, Microwaves	At Michigan	Pack, ship, reassemble	9 months
2.	PPT pumps	Need	Acquire in Japan or US	1 year
3.	PPT stand + hardware	At Michigan	Modify and ship	3 months
4.	Quadrupoles Q_1, Q_2, Q_3, Q_4	J-PARC provide		2 years
5.	Dipoles M_1, M_2, M_3	J-PARC provide		2 years
6.	Stands for: Q_1,Q_2,Q_3,Q_4 Stands for: M_1,M_2,M_3	J-PARC provide		1 year
7.	Magnets' Power Supplies	J-PARC provide		1 year
8.	Scintillators: FV_1,FV_2,S_1,S_2,S_3 RH_1,RV_1,RH_2,RV_2	Some at Michigan	Make others at Michigan; then ship	6 months
9.	Wire Chambers: W_1,W_2 W_3, W_4	At Michigan Need	Pack, ship Make at Michigan	3 months 9 months
10.	Detector Stands	At Michigan	Pack, ship	3 months
11.	Cables, Connectors, Cable ends	Mostly at Michigan	Acquire the rest, pack, ship	3 months
12.	Electronics	Mostly at Michigan	Acquire the rest, pack, ship	3 months
13.	Computers	At Michigan	Pack, ship	3 months
14.	Monitors D_{123}, U_{123}, B_{123}	At Michigan	Check, pack, ship	3 months
15.	Beam Stabilizer System	J-PARC provide		1 year
16.	Rastering System	J-PARC provide		1 year
17.	Experiment Control Room	J-PARC provide ?		1 year
18.	Shielding blocks	J-PARC provide	Plan, rearrange	1 year
19.	Magnets' movement plates	J-PARC provide	Design, build at J-PARC	1 year
20.	Liquid Helium and Nitrogen	J-PARC provide	Purchase or Liquify	??
21.	Superconducting Q_1	J-PARC or Michigan	Will need later	2 years

Table 6. Status of equipment.

Summary

We believe that these fundamental high-$P_\perp^2$ measurements of A_n in p-p elastic scattering at 50 GeV should give important information about the inner structure of the proton and about strong interactions. Moreover, SPIN@J-PARC would utilize the proven Michigan solid polarized proton target and much of the somewhat-tested SPIN@U-70 spectrometer. We should be able to precisely measure the p-p elastic analyzing power A_n from $P_\perp^2$ = 1 to 12 $(GeV/c)^2$ in 3000 hrs of data time plus about 500 hrs of tune-up time. Assuming an overall operating efficiency of about 60%, this would require about 240 days of scheduled beam time. This proposed experiment would increase the maximum measured $P_\perp^2$ for A_n elastic data by a factor of 1.7 and would about double the maximum energy for large-$P_\perp^2$ elastic A_n data.

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