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VIOLENT COLLISIONS of SPINNING PROTONS:
PAST, PRESENT & FUTURE
$p + p \rightarrow p + p$

- 12 GeV/c  Allaby et al.
- 24-31 GeV/c  Allaby et al., Cocconi et al.
- 201 GeV/c  Hartmann et al.
- 280 GeV/c  Kwak et al.
- 1500-2100 GeV/c  Kwak et al., de Kerret et al.
- $\frac{1}{4} \frac{d\sigma}{d\Omega (90^\circ_{cm})}$
  - 3-5 GeV/c  Kammerud et al.
  - 5-13 GeV/c  Akerlof et al.
  - 14-21 GeV/c  Allaby et al.
  - 22-31 GeV/c  Cocconi et al.
SPIN FORCES
in HIGH -$P_1^2$
$p + p \rightarrow p + p$

$P = \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)}$

UNPOLARIZED $\Rightarrow \langle \frac{d\sigma}{dt} \rangle$

BEAM OR TARGET POLARIZED $\Rightarrow$ ONE-SPIN $A_n$

BEAM AND TARGET POLARIZED $\Rightarrow$ SPIN-SPIN $A_{nn}$
ZERO GRADIENT SYNCHROTRON accelerates polarized protons to an energy of 12 billion electron volts (GeV). The polarized-proton source is enclosed in a high-voltage dome; protons leaving the dome acquire an energy of 750,000 electron volts. A linear accelerator then raises their energy to 50 million electron volts before they are injected into the synchrotron itself. On each pass through the accelerating cavity of the synchrotron the particles gain 12,000 electron volts; in order to reach 12 GeV they must therefore circle the ring about a million times, which requires a little less than a second. The accelerator is called the zero gradient synchrotron because the fields of the ring magnets are uniform, a feature that aids in maintaining beam polarization. When the particles reach 12 GeV, they are extracted from the ring and directed by steering magnets to the target. Polarization is monitored just before injection and just after extraction by polarimeters that measure the left-right asymmetry in scattering events. The asymmetry is related to the spin orientation and hence to the beam polarization.
AGS
Polarized Proton Beam

Polarized Ion Source
RFO
Linac
200 MeV Polarimeter

Correction Dipoles
Pulsed Quadrupoles
Power Supplies
Internal Polarimeter

High Energy Polarimeter
To Experiments

1977 → 1984
1984 →

Hardware
$10 Million ($1980)
Tune-up time
3-7 weeks
proton-proton elastic
\[ p + p \rightarrow p + p \]

- 24 GeV CERN - 1980
- 28 GeV AGS - 1985
- 24 GeV This Exper.

BNL AGS 1990

\[ \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \]

PQCD \( \Rightarrow A_N = 0 \) at High \( p_T^2 \) High Energy

\[ P_L^2 (\text{GeV/c})^2 \]
DeVlin Pondrum

Inclusive Hyperon Polarization
Fermilab 1980's

$PQCD \Rightarrow A = 0$ at high energy

$p + Be \rightarrow \Lambda + X$
12 GeV KEK

$p + p \rightarrow \Lambda + X$
2000 GeV ISR

$P_\perp$ (GeV/c)

Fermilab data

$400$ GeV

$x \sim .5$

$x \sim .4$
$A_N$ for $\pi^+$ (squares) and $\pi^-$ (circles) production in the $p^\uparrow p$ reaction versus $x_F$ integrated over $p_\perp$. For comparison, $\pi^0$ data (crosses) are also plotted.
CIS-Cooler Layout

G Region
RF Spin Flip Solenoid
Polarimeter

A Region

C Region
275 keV e-system

"COOLER"
Electron Cooled Storage Ring
3.6 Tm

CIS
Partial Snake
Cooler Solenoid
SC Spin Solenoid

SC Spin Solenoid

7 MeV H-LINAC
BL9A
Polarimeter

LEBT
25 keV H-

CIPIOS

Scale

0
5 m
First Test of the Siberian Snake Magnet Arrangement to Overcome Depolarizing Resonances in a Circular Accelerator

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(Received 25 July 1989)

We studied the $G\nu=2$ imperfection depolarizing resonance at 108 MeV, both with and without a Siberian snake, by varying the resonance strength while storing beams of 104- and 120-MeV polarized protons at the Indiana University Cooler Ring. We used a cylindrically symmetric polarimeter to simultaneously study the effect of a depolarizing resonance on both the vertical and radial components of the polarization. At 104 MeV we found that the Siberian snake eliminated the effect of the nearby $G\nu=2$ depolarizing resonance.

![Graph](image)

**FIG. 4.** The beam polarization in each stable polarization direction at 104 MeV is plotted against the longitudinal magnetic field integral in the Cooler Ring solenoids. The circles are the vertical polarization with the snake off and the injection of vertically polarized protons. The squares are the radial polarization with the snake on and the injection of horizontally polarized protons. We combined all data into bins of width 0.00115 Tm. There is a systematic normalization uncertainty of about ±5%. The dashed curve is the predicted behavior. The straight dashed line is a fit.
Overcoming Intrinsic and Synchrotron Depolarizing Resonances with a Siberian Snake

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(Received 7 March 1990)

We overcame the strong $G \gamma = -3 + \nu_y$ intrinsic depolarizing resonance using a Siberian snake acting on a stored beam of 177-MeV polarized protons at the Indiana University Cooler Ring. We also saw the first evidence for a synchrotron depolarizing resonance in a proton ring. Two synchrotron resonances were studied by varying the rf accelerating voltage and the imperfection field at 104 MeV. The Siberian snake also overcame these synchrotron depolarizing resonances.
1994 Adiabatic Snake turn-on

Fig. B9 The transverse polarization $P_t = \sqrt{P_x^2 + P_y^2}$, at 370 MeV is plotted against the number of times the 25% partial Siberian snake was turned on or off. The dashed line is the best fit to the data, which show no depolarization within our 2% precision.\cite{86}

Fig. B10 The measured transverse polarization $P_t$ at 140 MeV is plotted against the imperfection $\int B \cdot dl$ with no snake and with a 10% partial Siberian snake. The dashed line is the best constant-polarization fit to the snake-on data. The beam was accelerated from 95 to 140 MeV.\cite{85}

1995-96 spin-flipping through an intrinsic resonance by strengthening it

Fig. B11 The narrow dip $\nu_y$-shift of 0.059±0.001 is equal to the 0.050 change in $\nu_x$, as predicted for the $\nu_x = \nu_y - \nu_{\alpha} + 1$ second-order resonance.\cite{92}

Fig. B12 The polarization spin-flips when the kicker is pulsed before crossing the resonance.\cite{94}
Polarized Proton Collisions at BNL

$\mathcal{L}_{\text{max}} = 2 \times 10^{32} \text{ s}^{-1} \text{ cm}^{-2}$

$\sim 70\%$ Polarization

$\sqrt{s} = 50 - 500 \text{ GeV}$

**RHIC**

**PHENIX**

**STAR**

**AGS**

$2 \times 10^{11}$ Pol. Protons / Bunch

$\epsilon = 20 \pi \text{ mm mrad}$

Replace with OPPIS:

500 $\mu$A, 300 $\mu$s, 7.5 Hz

**Accumulation of 20 Pulses**

$4 \times 10^{11}$ Pol. Protons / Bunch

$\epsilon = 10 \pi \text{ mm mrad}$

35 $\mu$A, 350 $\mu$s, 5 Hz

80 $\%$ Polarization
MARK-II ULTRA-COLD POLARIZED HYDROGEN JET TARGET.

|1>, |2>, |3>, |4> (unpolarized)
|1>, |2> (electron polarized)
|1>, |4> (proton polarized) (after |2> to |4> trans)
|1> (proton polarized)

Refrigerator (100mW @ 300mK)
Helium Tank
RF Dissociator
12T Solenoid
Separation Cell with Mirror
RF Transition Unit
Superconducting Sextupole
Mini-catcher
Interaction Region Vacuum Box
Catcher
H Maser Polarimeter

Polarized Protons:

THICKNESS: $1.1 \times 10^{-2}$ cm$^2$
BEAM SIZE: $\sim 3 \times 3$ mm x mm

MAY 2001
70 GeV Proton Synchrotron (2 \times 10^{13} \text{protons/pulse})
C. Michigan Solid Polarized Proton Target

The Center is continuing to test and improve the state-of-the-art 5 T at 1 K Michigan Solid Ammonia NH3 Polarized Proton Target (PPT) and to prepare it for a later shipment to Protvino or now possibly Japan. Since our first SPIN@U-70 shipment is still impounded by Russian Customs, we will not ship the PPT to Russia until the first shipment is properly released and until we receive written assurances from MINATOM that subsequent shipments will not be impounded. Because of the impoundment, we may instead use the still-unimpounded Solid PPT for a similar experiment at the new very high intensity 50-GeV Proton Synchrotron in Japan, which is scheduled for first beam in 2007.

Recent improvements in the Michigan Solid-PPT have focused on increasing its reliability and include:
- new uni-polar power supply for the 5 T highly uniform superconducting magnet;
- new coil configuration for the NMR system;
- new wiring, Kel-F material holder, and RuO temperature sensor for the $^4$He evaporation refrigerator;
- new Varian power supply for the 140 GHz microwave system.

Figure 4. The state-of-the-art Michigan Solid Polarized Proton Target: the superconducting magnet produces a highly uniform 5 T field; the He$^4$ cryostat produces 0.9 W of cooling power at 1 K; the 140 GHz microwaves are focused into the small target cavity filled with irradiated ammonia NH$_3$; the proton polarization in frozen NH$_3$ at 5 T and 1 K is over 90%. An expanded view of the NH$_3$ cavity is shown on the right.
SPIN@J-PARC Letter of Intent

to

JAPAN 50 GeV J-PARC

Analyzing power $A_n$ in 50 GeV very-high-$P_T^2$ proton-proton elastic scattering

SPIN@J-PARC Collaboration:
Michigan, Virginia, KEK, RCNP, TokyoTech, TRIUMF


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  d Portland Physics Inst
\( p + p \rightarrow p + p \)

\[ A_n = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \]

\( P_{\perp}^2 (\text{GeV/c})^2 = 2 \rightarrow 4 \rightarrow 6 \rightarrow 8 \)

\( p \text{QCD} \rightarrow \) at high-\( P_{\perp}^2 \), high-energy
Figure 2. Diagram of the Michielen polarized-proton-target. The superconducting magnet produces a highly uniform $B_0$ field. At 1 K, the He cryostat provides about 1 watt of cooling power to the target material in the small cavity at the right. Expanded views of the target cavity are shown on the left.
This PPT target had an average polarization of 85% during a 3-month-long AGS run\textsuperscript{[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\textsuperscript{[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\textsubscript{3} beads, the He\textsuperscript{4} or the container. The dilution factor was determined experimentally at the AGS by measuring the event rate with hydrogen-free Teflon (CF\textsubscript{2}) beads in place of the NH\textsubscript{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)$^2$\textsuperscript{[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\textsuperscript{[28]} Therefore, inclusive measurements would be very difficult with this PPT.

\textbf{Fig. 3.} Spin polarization of the free protons in NH\textsubscript{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\textsubscript{3} data at 2.5 T and 0.5 K are triangles\textsuperscript{[4, 27]}
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\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig3.png}
\caption{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.\textsuperscript{4,27}}
\end{figure}
Proton-proton elastic cross-sections plotted against the scaled $P_{\perp}^2$ variable
\[ \frac{\sigma_{\uparrow \uparrow} - \sigma_{\downarrow \downarrow}}{\sigma_{\uparrow \uparrow} + \sigma_{\downarrow \downarrow}} \]

RATIO OF SPINS-PARALLEL TO SPINS-ANTIPARALLEL CROSS SECTIONS

\[ P_{\text{Lab}} \text{ (GeV/c)} \]

\[ P_{\perp}^2 \text{ (GeV/c)}^2 \]