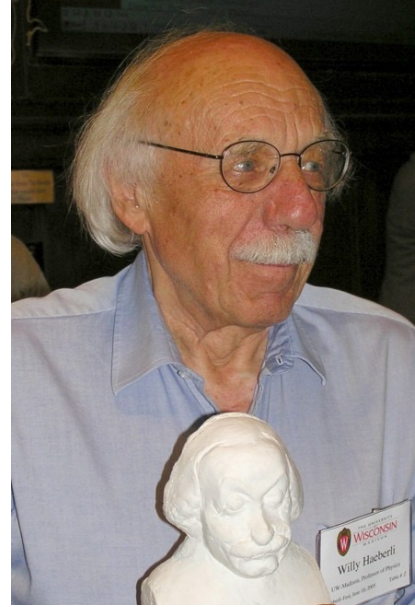


The Polarization Story

Thomas Roser
RHICfest
July 9, 2026

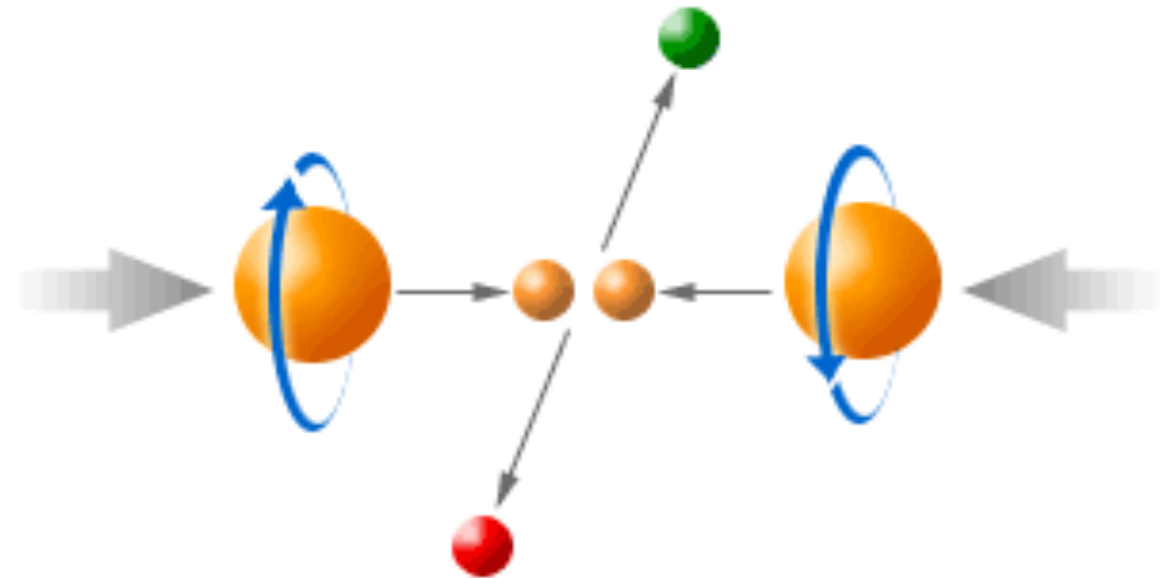
The polarization story is also a personal story

- I did my Ph.D. experiment at SIN (PSI), Switzerland, on parity violation in $p - {}^4\text{He}$ elastic scattering with 50 MeV polarized protons from an atomic beam “Haeberli-type” source under Markus Simonius and with Willy Haeberli in the group.
- In 1984 I came to Brookhaven as post-doc in Alan Krisch’s Michigan group doing measurements of high energy polarized proton elastic scattering at the AGS, the first accelerator of high energy polarized protons.
- After being involved in the tedious effort of setting up the AGS with polarized beams I switched from particle physics to accelerator physics and proposed the partial Siberian snake for accelerating polarized protons in medium energy accelerators.
- As co-spokesperson of the RHIC Spin Collaboration I was responsible for the design of polarized proton acceleration to 250 GeV.



Polarized proton acceleration and collisions

- Although not part of the initial design, polarized proton collisions became an essential part of RHIC's success. Many aspects of a polarized collider were never demonstrated and RHIC and the AGS became both the demonstrators as well as the first operational polarized collider. Much of the spin hardware was funded by Riken, Japan.
- High intensity polarized H^- source
- Polarized proton acceleration in AGS without a full Siberian snake
- Polarized proton acceleration in RHIC with two full Siberian snakes
- Lifetime of beam polarization with high luminosity collisions

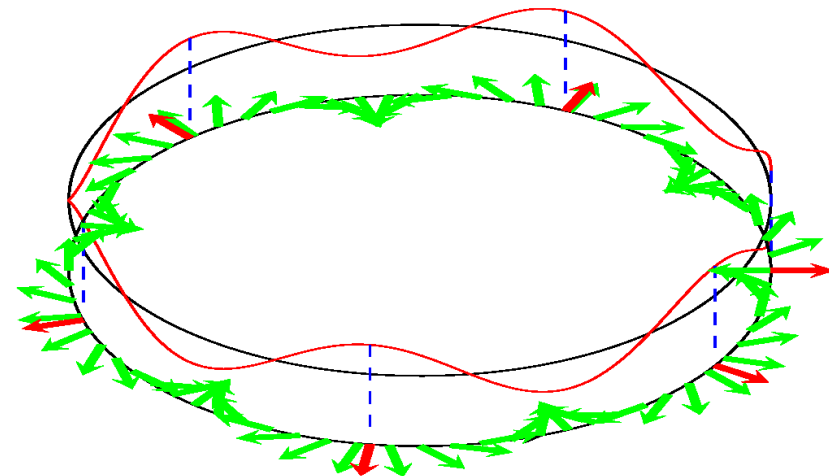


Spin precession and spin tune

- Precession Equation in Laboratory Frame: (Thomas [1927], Bargmann, Michel, Telegdi [1959])

$$dS/dt = - (e/\gamma m) [(1+G\gamma)B_{\perp} + (1+G) B_{\parallel}] \times S \quad (G=(g-2)/2; \gamma = E/m)$$
- Lorentz Force equation:

$$dv/dt = - (e/\gamma m) [\quad B_{\perp} \quad] \times v$$
- For pure vertical field: Spin rotates $G\gamma$ times faster than motion; spin tune $\nu_{sp} = G\gamma$
- Unlike the betatron tune, the spin tune increases with energy, and all resonances are crossed during acceleration.
- Partial Siberian snakes (local spin rotators) open gaps in spin tune for avoiding spin resonances
- Full Siberian snake (180° spin rotator) make the spin tune $\frac{1}{2}$ avoiding all spin resonances.



First Siberian Snake Test at IUCF, Indiana University

VOLUME 63, NUMBER 11

PHYSICAL REVIEW LETTERS

11 SEPTEMBER 1989

- First full Siberian snake: 180° spin rotator without changing particle orbit and optics.

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

A. D. Krisch, S. R. Mane,^(a) R. S. Raymond, T. Roser, J. A. Stewart, K. M. Terwilliger,^(b) and B. Vuaridel

Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan 48109

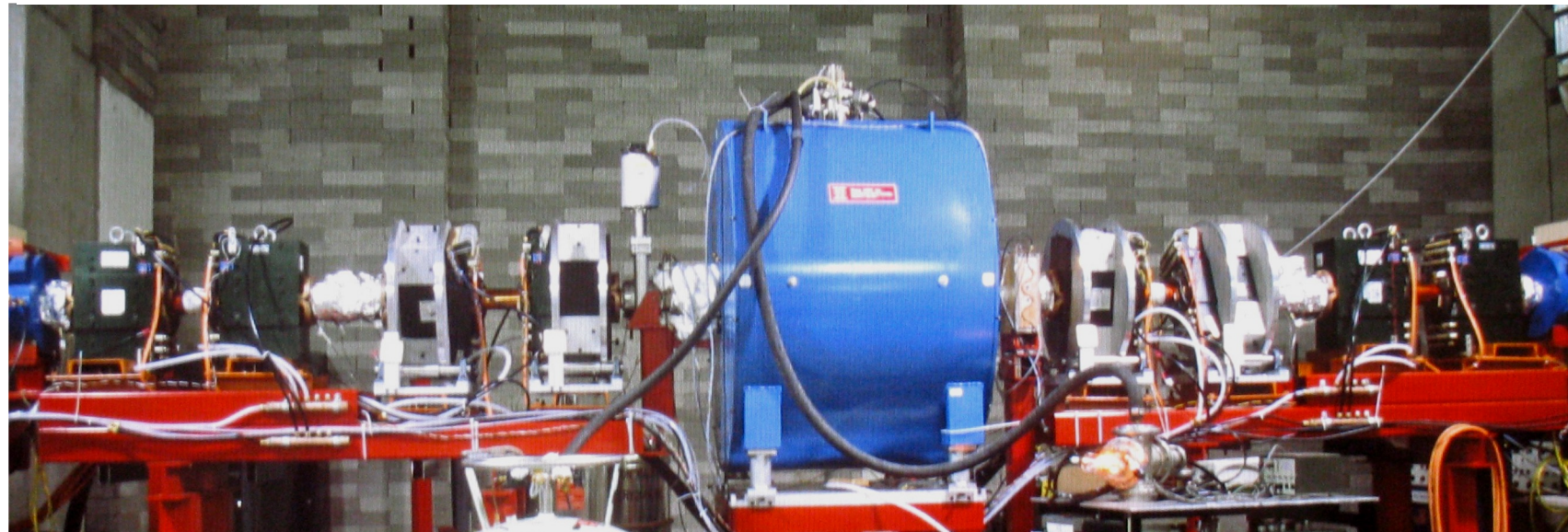
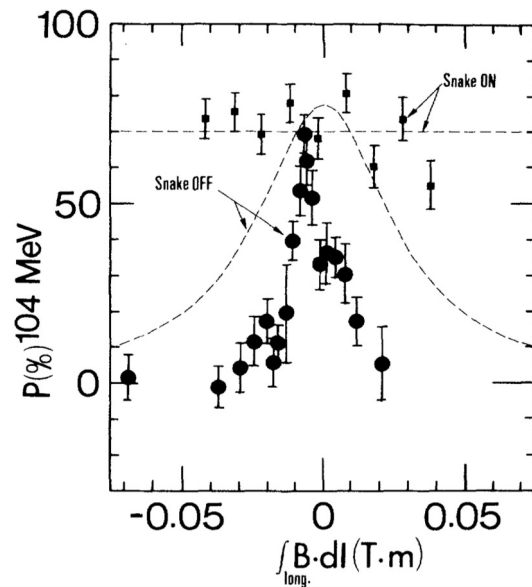
J. E. Goodwin, H-O. Meyer, M. G. Minty, P. V. Pancella, R. E. Pollock, T. Rinckel, M. A. Ross, F. Sperisen, and E. J. Stephenson

Indiana University Cyclotron Facility, Bloomington, Indiana 47408

E. D. Courant, S. Y. Lee, and L. G. Ratner

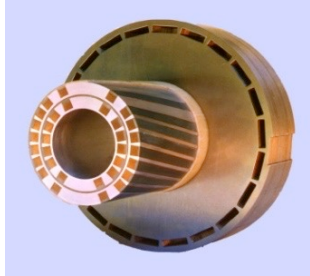
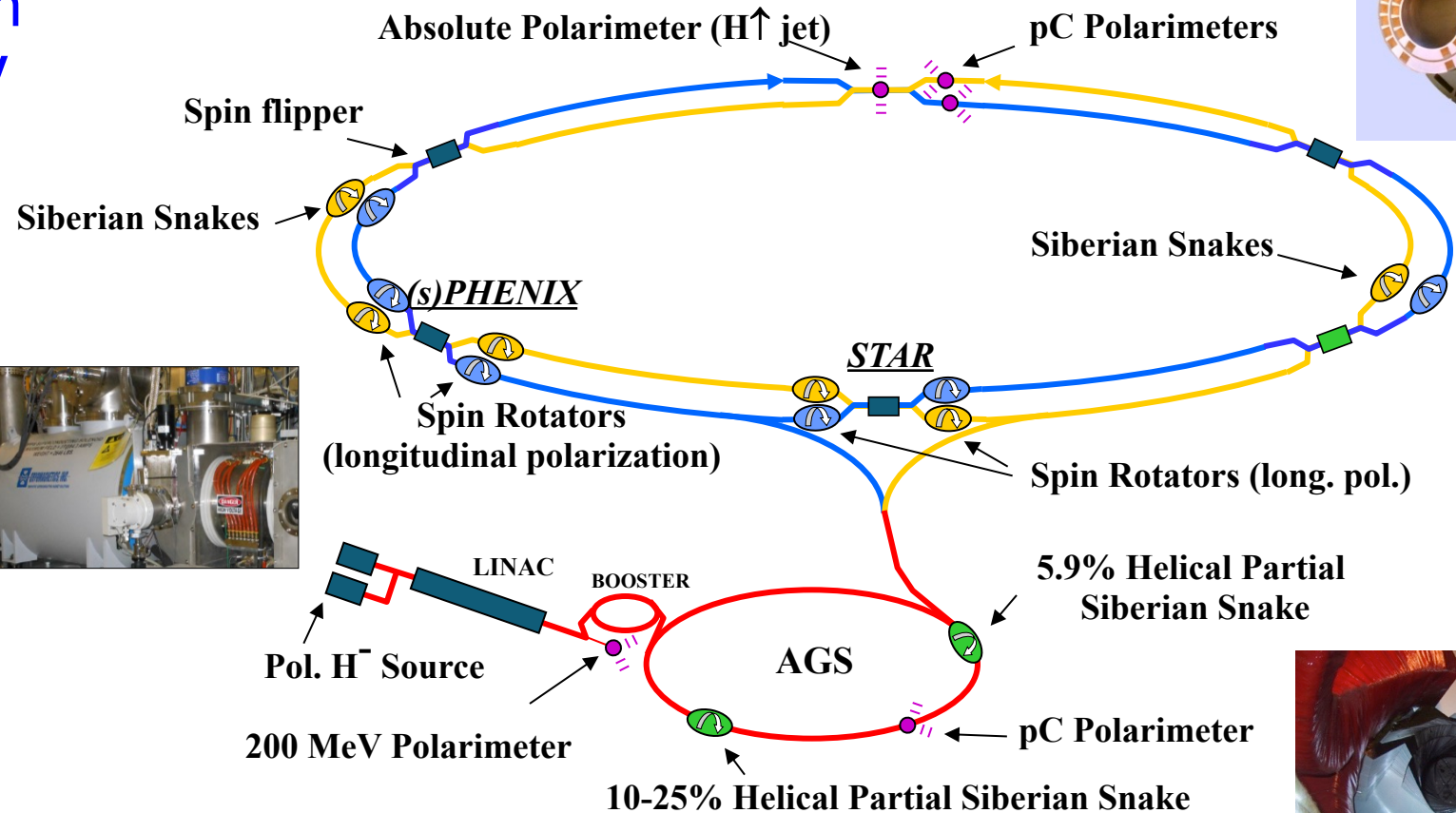
Brookhaven National Laboratory, Upton, New York 11973

(Received 25 July 1989)



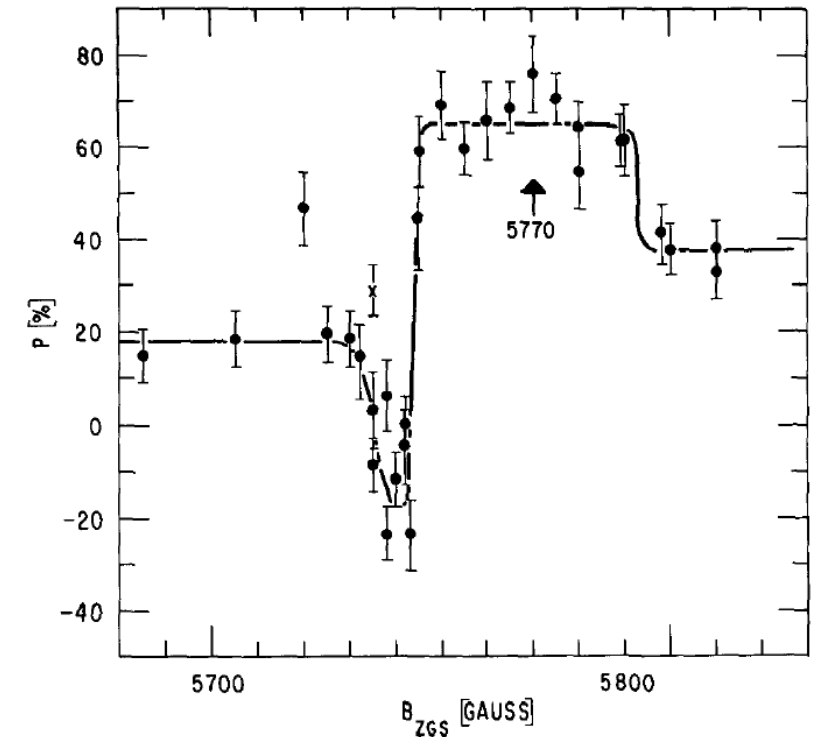
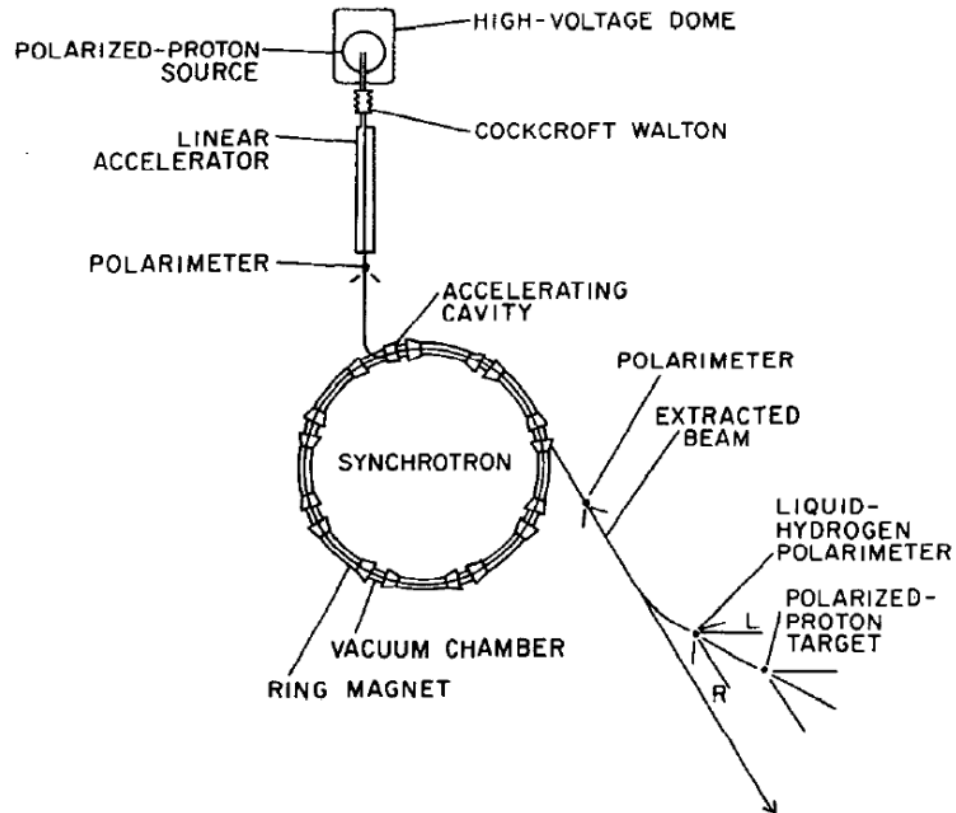
RHIC – First Polarized Hadron Collider

- Two full Siberian snakes per ring preserve proton polarization to 255 GeV
- Spin direction control at detectors with spin rotators
- Minimally invasive polarimeters; also measure polarization profiles
- Absolute polarimeter using world's most intense polarized H jet



It all started at the Argonne ZGS

- Alan Krisch et al. accelerated polarized beams in the ZGS.
- ZGS (up to 70% at 12 GeV/c):
Weak resonances ($\varepsilon_{\max} \sim 0.002$)
- Timing of betatron tune jump using polarization measurement



First Effort to Accelerate Polarized Protons in AGS

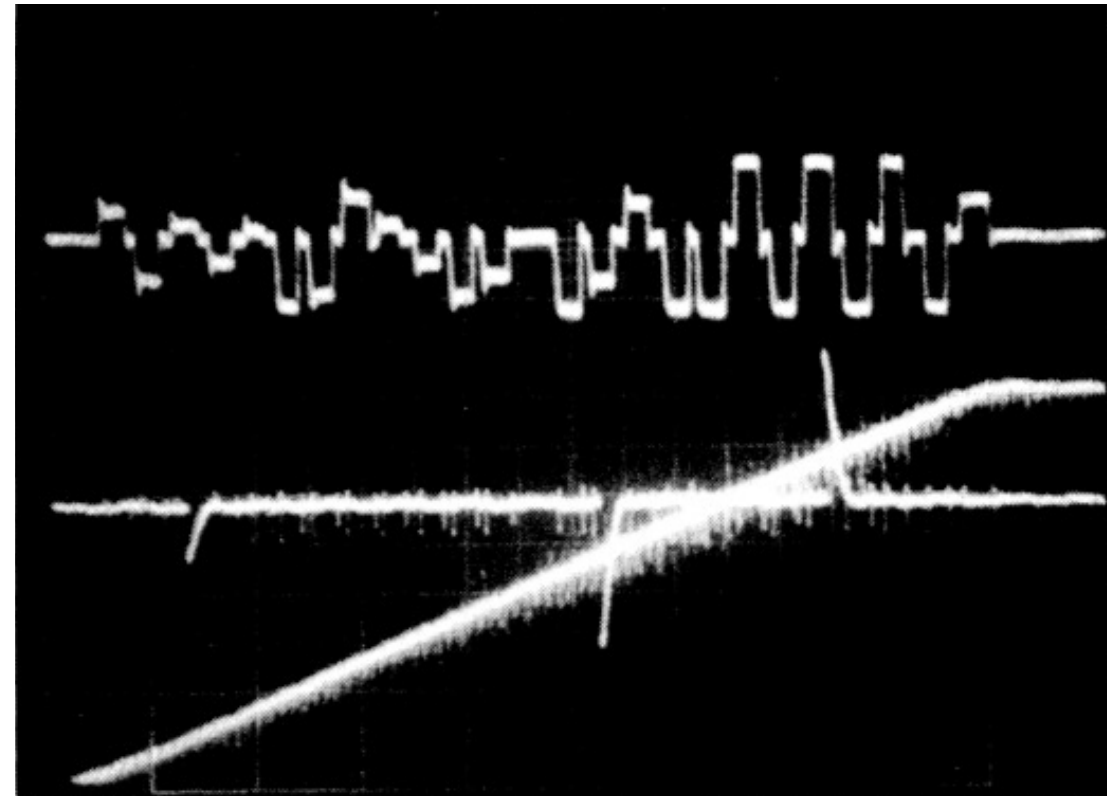
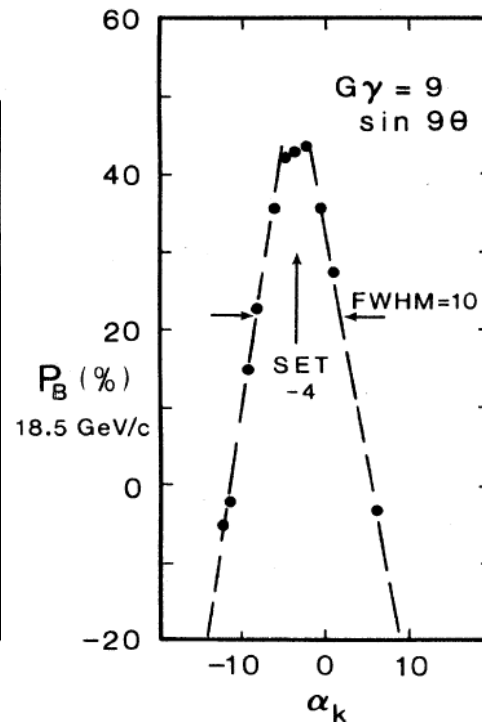
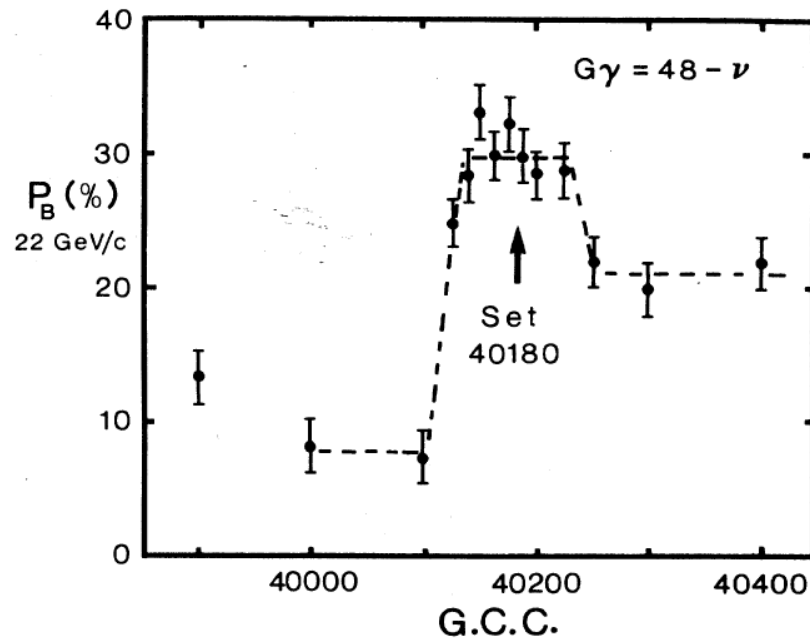
- In the 1980s, Alan Krisch and Larry Ratner led the first effort to polarize the AGS by correcting the approximately 50 imperfection and intrinsic depolarizing resonances. This was a truly heroic effort!
- Team to work on polarized proton acceleration in the AGS:
Alan Krisch, Larry Ratner, Kent Terwilliger,
Fatah Khiari, TR (Univ. of Michigan);
Leif Ahrens, Woody Glenn (BNL)
(Fatah and I are the sole survivors of this group)
- Without partial Siberian snakes 45 intrinsic and imperfection depolarizing spin resonances had to be crossed using 95 correction magnets and 10 fast pulsed quadrupoles to reach a kinetic energy of 22 GeV with a polarization of 42%.



Alan Krisch and Larry Ratner in the old old AGS control room

Tuning for polarization in the AGS without a partial snake

- Timing of betatron tune jump and adjusting dipole correction strength using **polarization measurements**, each taking 5 - 30 minutes! Total tuning effort took weeks.
- Setting up polarized proton acceleration to 22 GeV required: 6 pulsed quadrupole timingscans and 70 harmonic corrector scans (sin + cos).

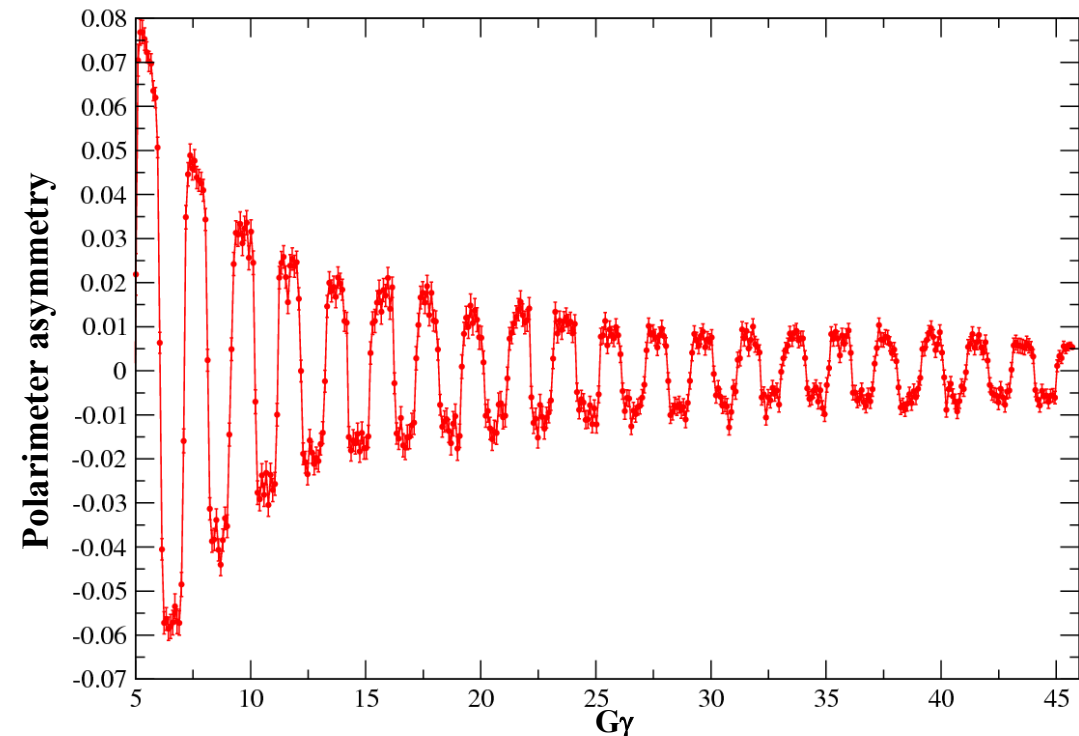


1/95 correction dipole; 1/10 pulsed quadrupole; main field

Polarized Protons in the AGS

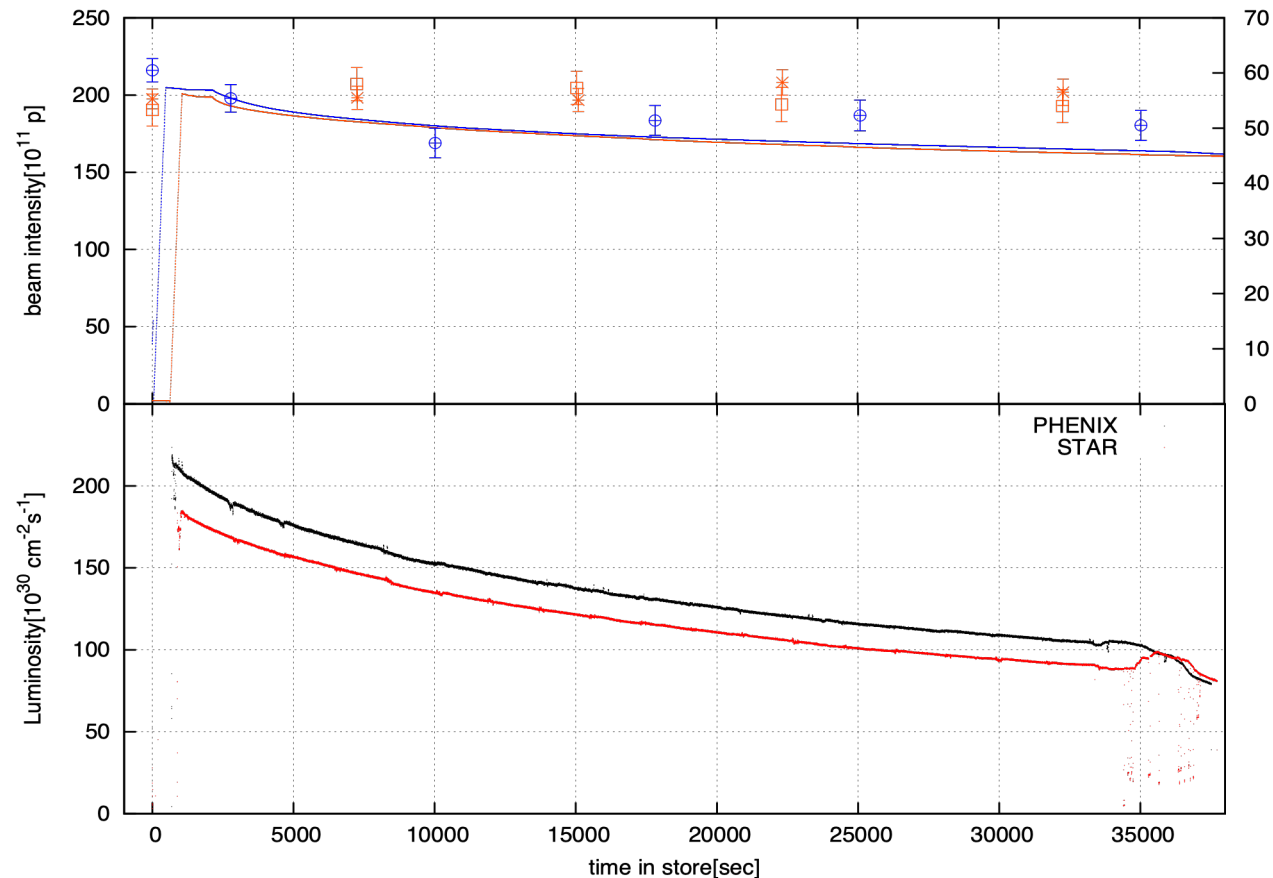
- Two strong partial Siberian snakes using variable-pitch helical dipoles
- Vertical betatron tune at 8.98 to place vertical intrinsic spin resonances inside the spin tune gap.
- Pulsed quadrupoles to jump across the many weak horizontal spin resonances driven by the partial snakes.
- **No tuning using beam polarization measurements!**

Larry Ratner, Haixin Huang and TR in old AGS MCR.



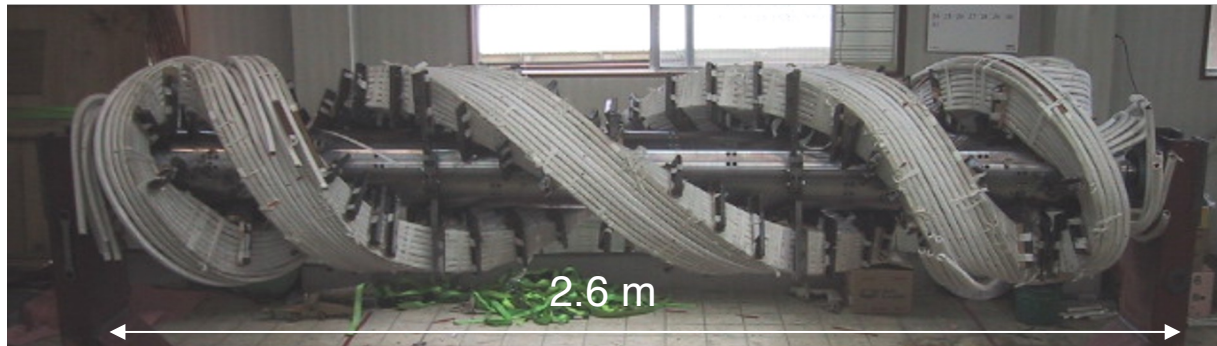
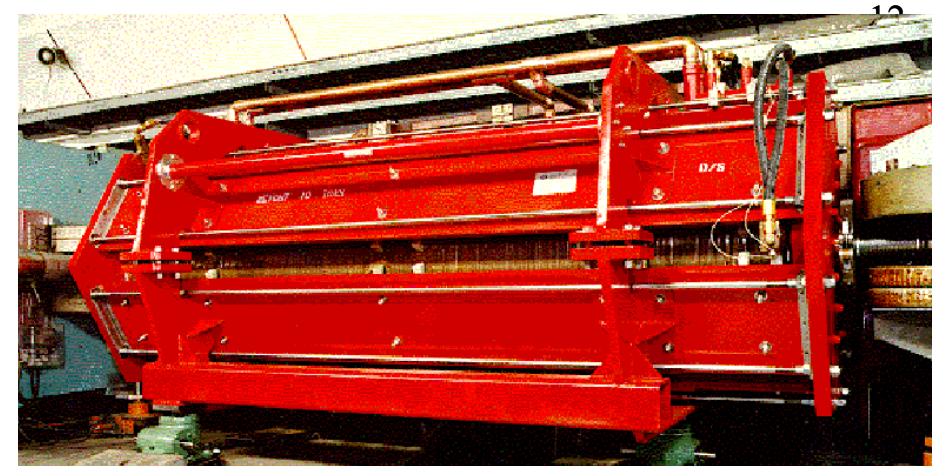
Polarized Protons in RHIC

- Two full Siberian Snakes in each ring. Each snake consists of four 4 Tesla full-twist superconducting helical dipoles,
- Reached $\sim 57\%$ average polarization in 14 best stores
- Little polarization loss on ramp and during store.
- Peak luminosity: $2.5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
- Requires excellent control of orbit, tune and coupling, but **no tuning using beam polarization measurements.**
- First test of polarized beam acceleration was nerve racking since there is nothing to tune!

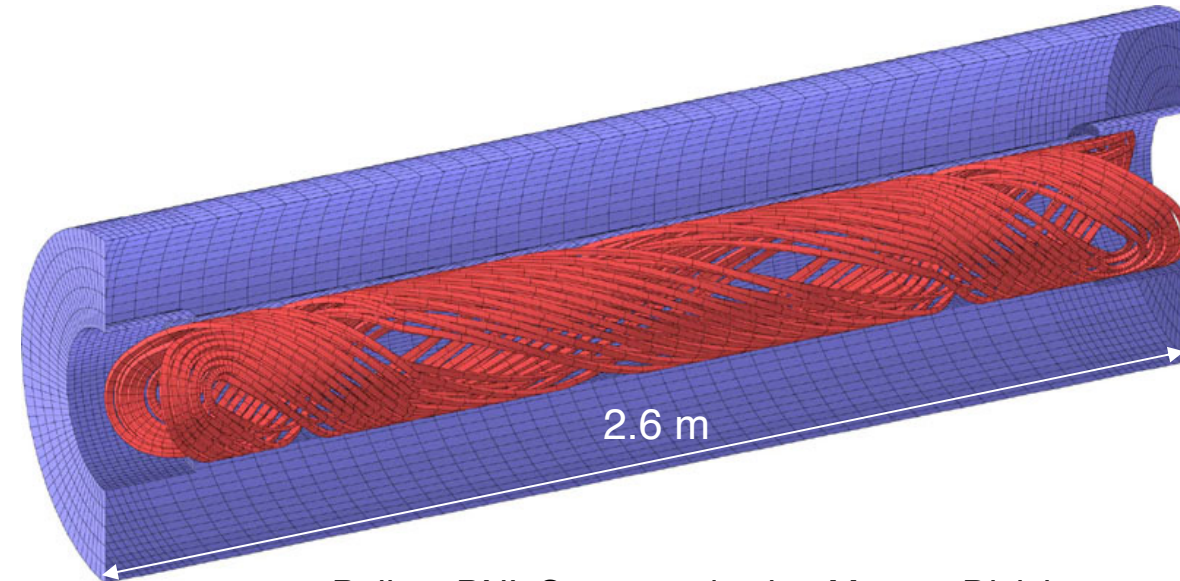


Designs of partial Siberian snakes for AGS

- The first partial snake was a 4.7 Tm solenoid or 5% snake. Thesis of Haixin Huang.
- Next came first a warm (6%) and then superconducting (20%) partial Siberian snake using variable-pitch helical dipoles that fit into the AGS 3 m straight sections (my design).



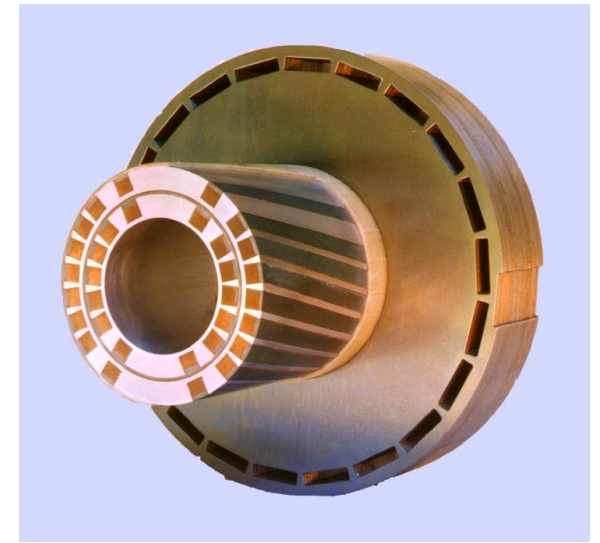
Built in Japan under Masahiro Okamura's direction



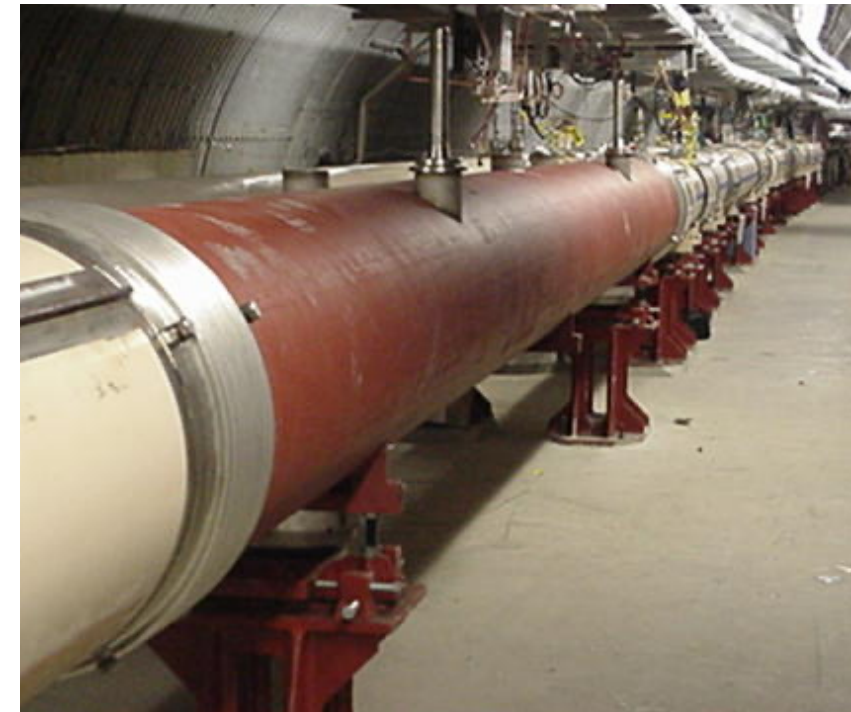
Built at BNL Superconducting Magnet Division

Design of full Siberian snakes at RHIC

- There were many designs for a full Siberian snake (180° spin rotation around a horizontal axis w/o affecting the beam orbit) e.g., Steffen snake by Klaus Steffen or Helical snake by Ernest Courant.
- Vadim Ptitsyn, then a student of Yuri Shatunov, designed a flexible snake for RHIC: four 4 Tesla superconducting helical dipoles, each 2.4 m long and with full 360-degree right-handed twist.
- It fit into the RHIC dummy sections, and the same configuration could be set up for a rotation axis pointing 45° towards inside or outside.
- The same design but with two left-handed helices could be used as spin rotators for STAR and PHENIX.



Cross section of helical dipole built at Superconducting Magnet Division



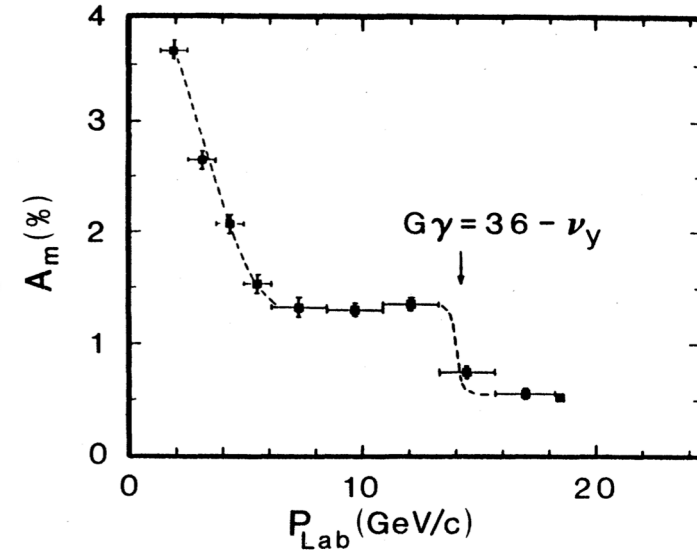
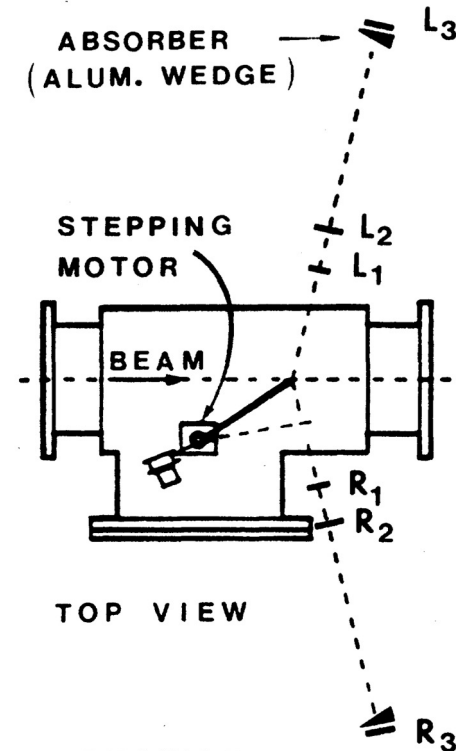
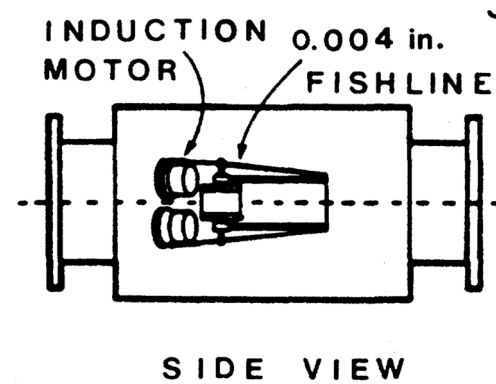
Polarized H^- sources at BNL

- The first polarized H^- source, built in the 1980s, was an atomic beam source using Stern-Gerlach separation plus rf transitions to polarize the protons.
- The second source was a high intensity Optically Pumped Polarized Ion Source (OPPIS).
- It was developed as a BNL, TRIUMF (Anatoly Zelenski), KEK (Yoshi Mori), INR collaboration
- 1.0 mA in 300 μ s (1.8×10^{12} protons per pulse); 83% polarization
- One source pulse is captured and accelerated for one bunch in RHIC
- With inefficiencies and scraping to lower emittance and higher polarization bunch intensity in RHIC is 2.5×10^{11} polarized protons

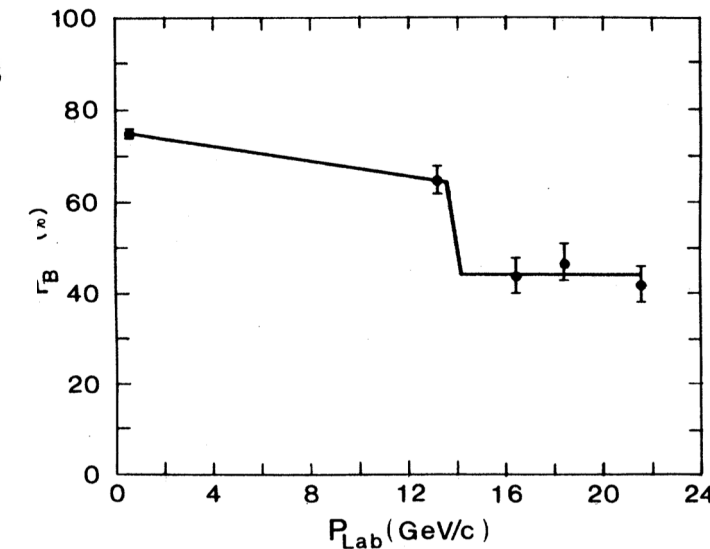
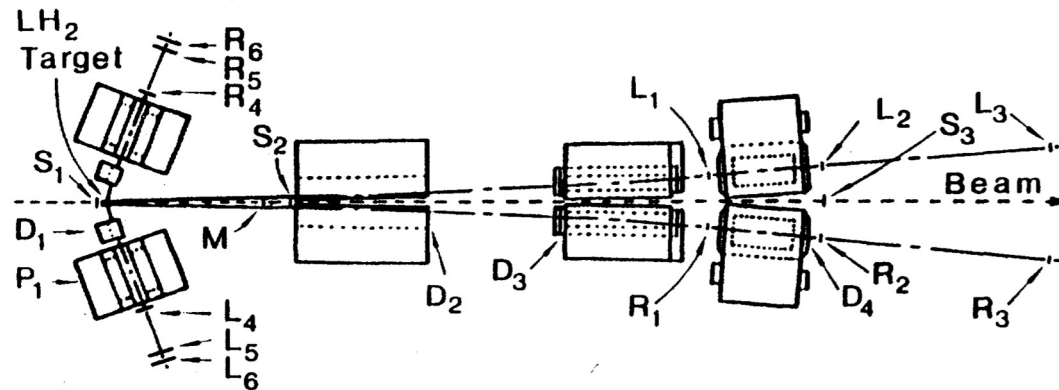


Polarimeter story: early AGS

- Internal polarimeter: scattering from Nylon (fishing) line, measurement took about 5 minutes

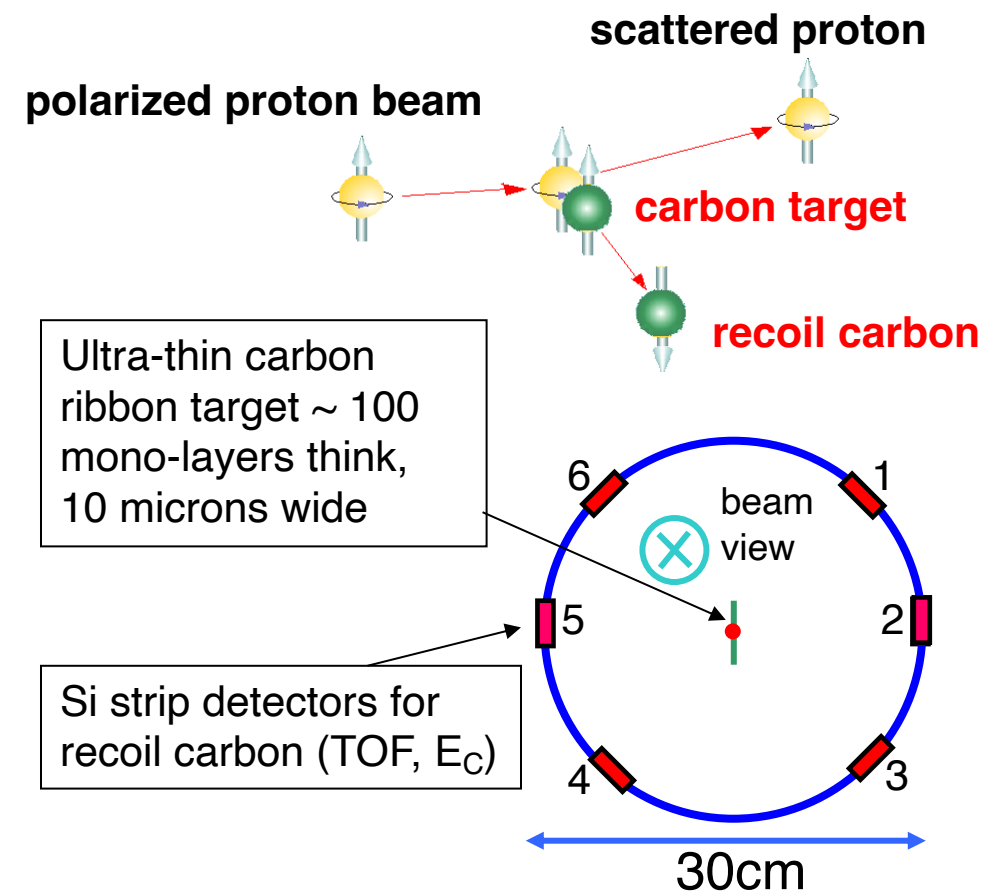


- External polarimeter: elastic scattering from liquid hydrogen target, double arm spectrometer, measurement took about 30 minutes

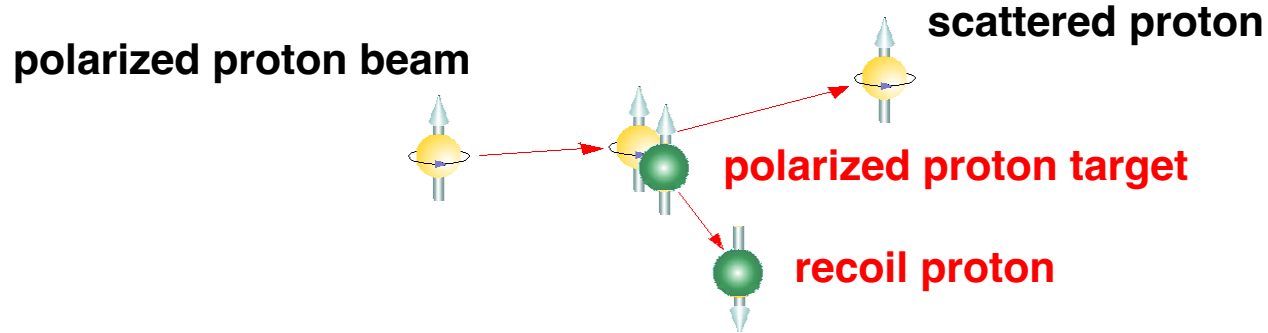


Fast proton-Carbon polarimeter in AGS and RHIC

- Small angle pC scattering (CNI region): high cross section and analyzing power ($A_N \approx 0.015$), fast measurements (~ 2 minutes)
- Detect only slow recoil Carbon from ultra-thin ribbon target, allows for time-of-flight measurement from beam bunch crossing
- Due to radiation cooling carbon target survives beam heating
- Measures horizontal and vertical polarization profiles; negligible emittance growth per polarization measurement
- This type of polarimeter using ultra thin Carbon targets was developed at IUCF by H.O. Meyer et al.



Absolute proton-proton polarimeter in RHIC



- Polarized hydrogen jet target allows for absolute beam polarization measurement:
$$P_{\text{Beam}} = P_{\text{Target}} \frac{\varepsilon_{\text{Beam}}}{\varepsilon_{\text{Target}}}$$
- Record polarized jet target thickness of $\sim 1 \times 10^{12} \text{ cm}^{-2}$
- Jet pol. $92 \pm 2 \%$ measured with Breit-Rabi polarimeter
- Analyzing power $A_N \sim 0.044$ (24 – 255 GeV)
- Many contributors:
Y. Makdisi, A. Nass, A. Zelenski (BNL), W. Haeberli, T. Wise (Wisconsin), E. Stephenson (Indiana), ...



Summary

- Creating 500 GeV CoM polarized proton collisions seemed like an almost impossible dream 40 years ago. Just about everything was unproven:
 - production of intense enough polarized proton bunches,
 - acceleration of polarized protons to 250 GeV without losing all polarization,
 - maintaining polarization during long stores and high luminosity collisions
 - measuring beam polarization without destroying the bunches or the polarization.
- All of these challenges were overcome through a large international collaborative effort and a dedicated team here at BNL.
- **Thank you all!**