VIOLENT COLLISIONS of SPINNING PROTONS at FERMILAB

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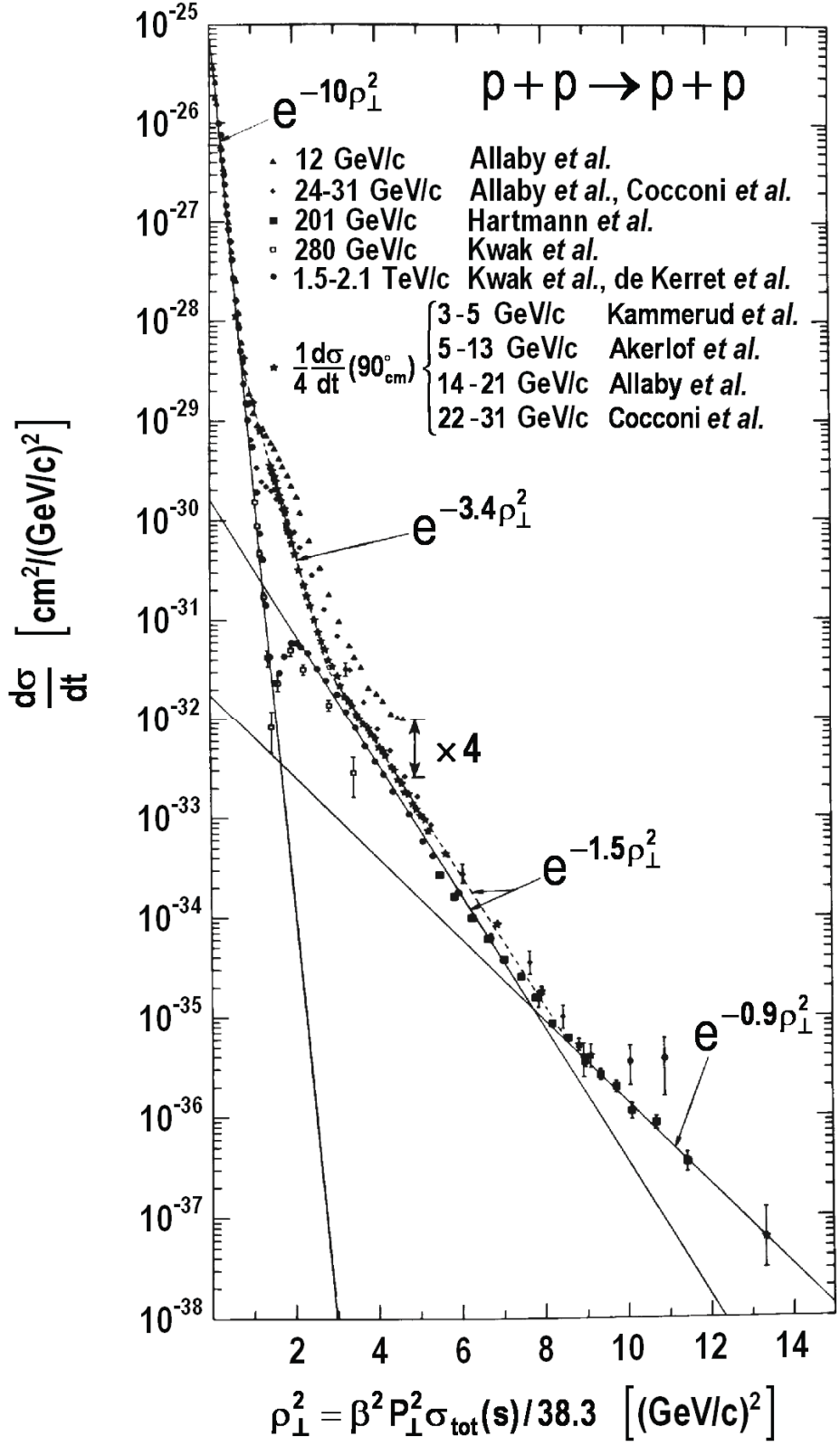
PROTON-PROTON ELASTIC CROSS-SECTION

UNPOLARIZED $d\sigma/dt$ for all
$p + p \rightarrow p + p$ data above 3 GeV
PLOTTED vs. SCALED $P_\perp^2$ VARIABLE

NOTE 4 DIFFERENT SLOPES
FIRST EVIDENCE for STRUCTURE
inside PROTON (Akerlof *et al.* 1966)

1968 Comment by Prof. Serber on x4 at 90°_{cm}
led to interest in spin & polarized beams



UNPOLARIZED BEAM and TARGET

$$\left\langle d\sigma / dt \right\rangle \propto \left(N_{\uparrow\uparrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow} + N_{\downarrow\downarrow} \right)$$

EITHER BEAM or TARGET POLARIZED (ONE-SPIN)

$$A_n = \frac{A_{meas}}{P_i} = \frac{\left(N_\uparrow - N_\downarrow \right)}{P_i \left(N_\uparrow + N_\downarrow \right)}$$

BOTH BEAM and TARGET POLARIZED (TWO-SPIN)

$$A_{nn} = \frac{A_{meas}}{P_T P_B} = \frac{\left(N_{\uparrow\uparrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow} + N_{\downarrow\downarrow} \right)}{P_T P_B \left(N_{\uparrow\uparrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow} + N_{\downarrow\downarrow} \right)}$$

A_{meas} = MEASURED ASYMMETRY

P_T and P_B = TARGET and BEAM POLARIZATIONS

N_i and N_{ij} = NORMALIZED ELASTIC EVENT RATES

ARGONNE 12 GeV ZGS WORLD'S FIRST HIGH ENERGY POLARIZED PROTON BEAM

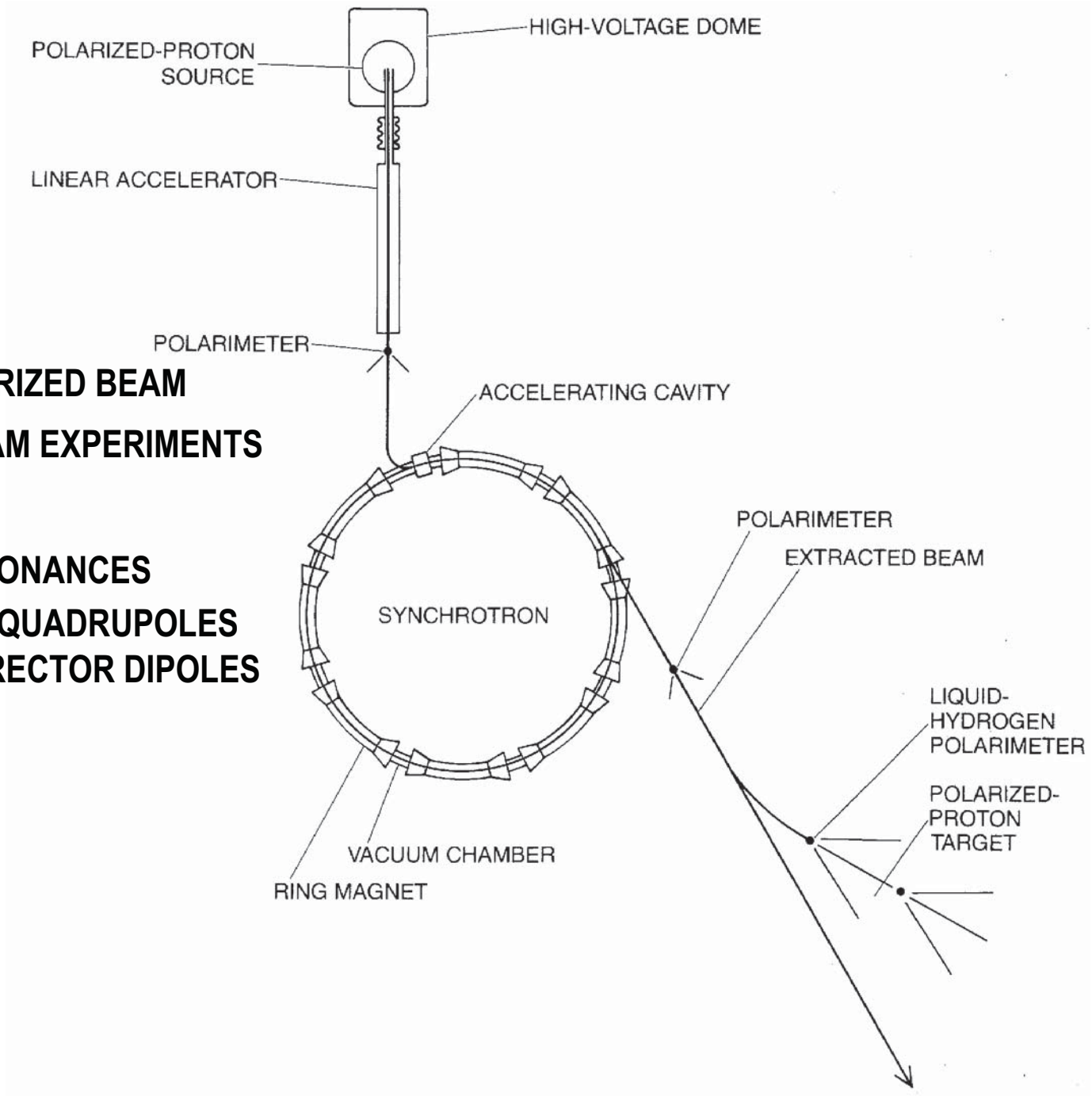
1969-1973 DEVELOP POLARIZED BEAM

1973-1979 POLARIZED BEAM EXPERIMENTS

DEPOLARIZING RESONANCES

INTRINSIC: PULSED QUADRUPOLES

IMPERFECTION: CORRECTOR DIPOLES



2-SPIN PROTON-PROTON ELASTIC CROSS SECTIONS

12 GeV ZGS

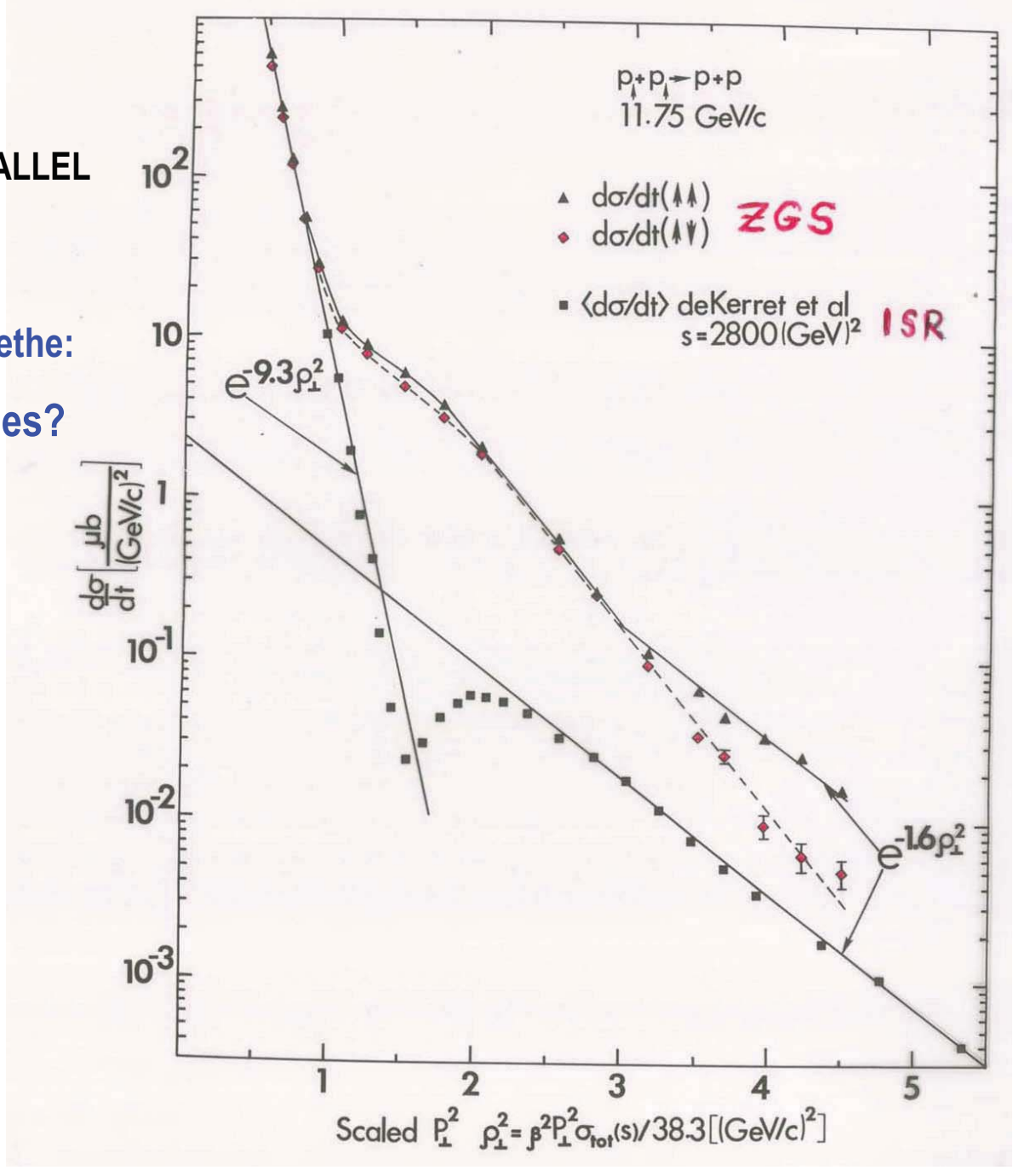
1977-1978

SPINS PARALLEL 4x SPINS ANTIPARALLEL

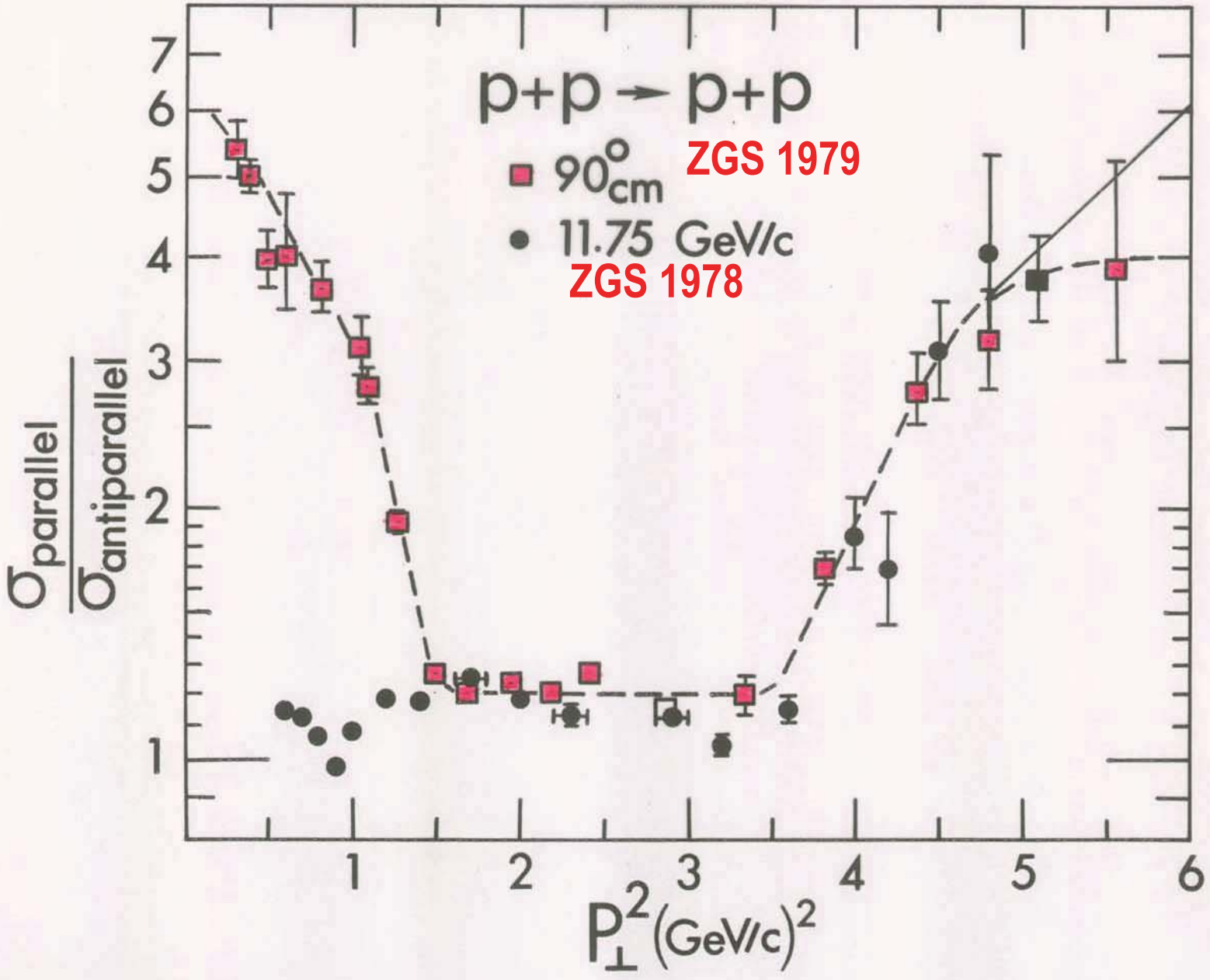
TOTALLY UNEXPECTED

Questions by Profs. Weisskopf & Bethe:

High P_T or 90°_{cm} Identical Particles?



Answer to Questions by Profs. Weisskopf & Bethe



BNL AGS: First Strong Focusing Polarized Proton Beam

1977- 84 Polarized Beam Development

1984-now Experiments & RHIC Injector

VERY DIFFICULT PROJECT

Hardware: $10 Million 1980$

45 Depol. Resonances:

INTRINSIC IMPERFECTION

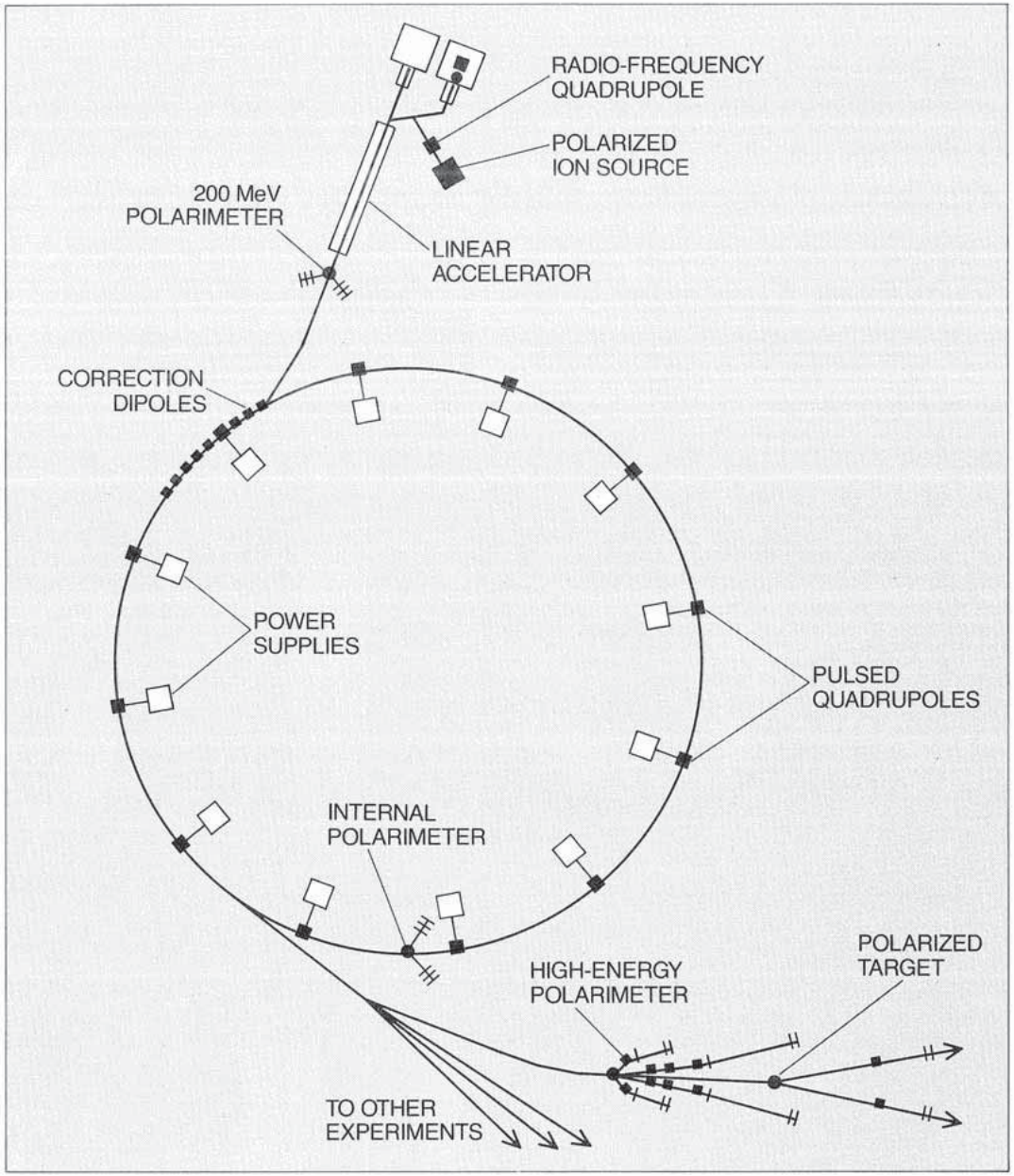
12 Pulsed Quads 96 Correction Dipoles

AGS Tune-up Time:

1984-88: 3-7 weeks each year

1988: 22 GeV/c Polarization 42%

2000-now: Better with new ideas; but still hard



AGS 1985-1990 A_n

PERTURBATIVE QCD $\Rightarrow$

$A_n = 0$ at HIGH $P_\perp^2$ and HIGH ENERGY

$A_n \neq 0 \Rightarrow$

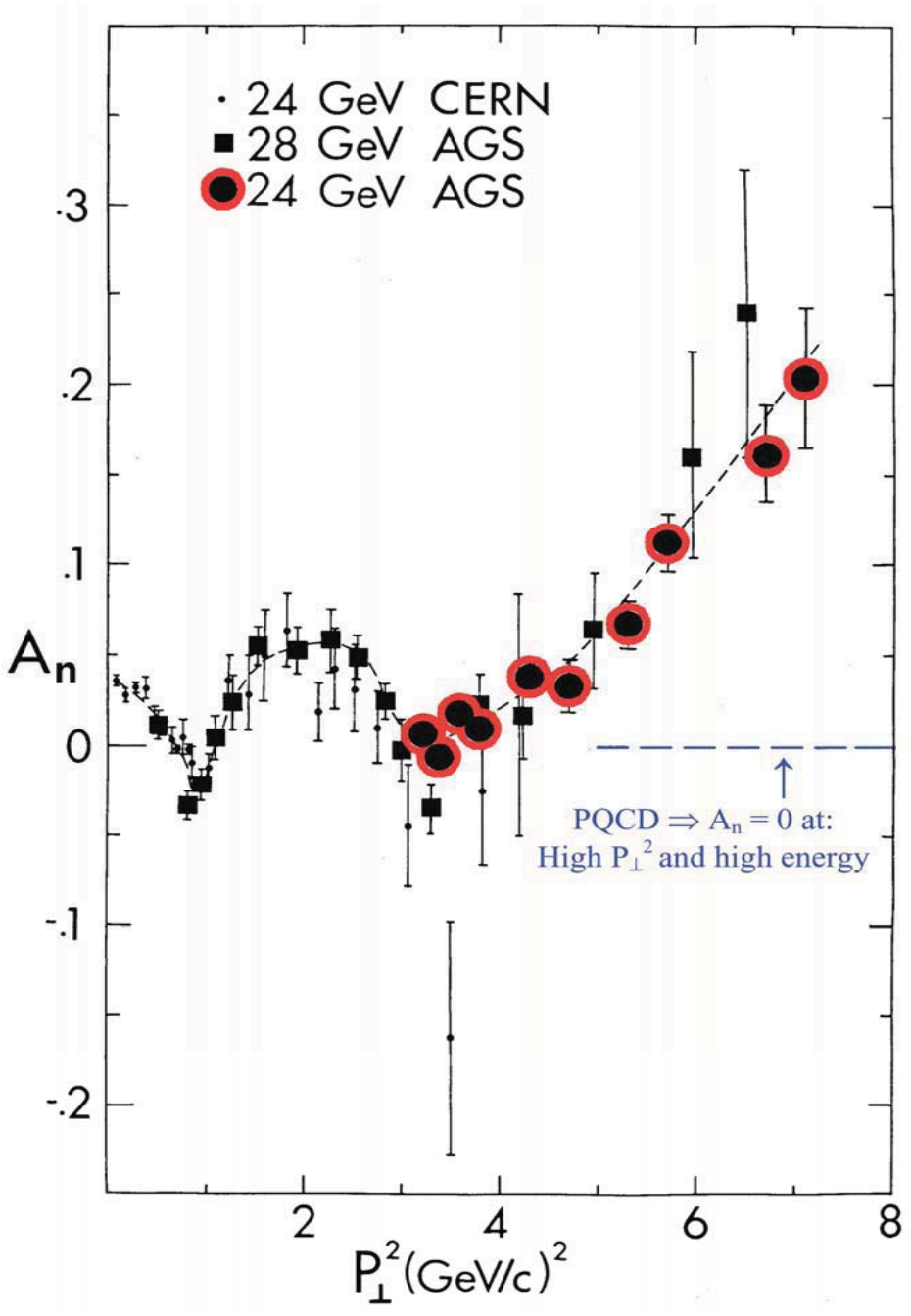
PROBLEM with PQCD?

NO MODEL can EXPLAIN ALL HIGH-$P_\perp^2$ SPIN EFFECTS (A_n & A_{nn})

GOAL

MEASURE A_n (and A_{nn})

up to $P_\perp^2 = 12$ (GeV/c)



INCLUSIVE HYPERON POLARIZATION (P)

Devlin, Pondrum, Bunce, Heller *et al.* 1976-80 FermiLab

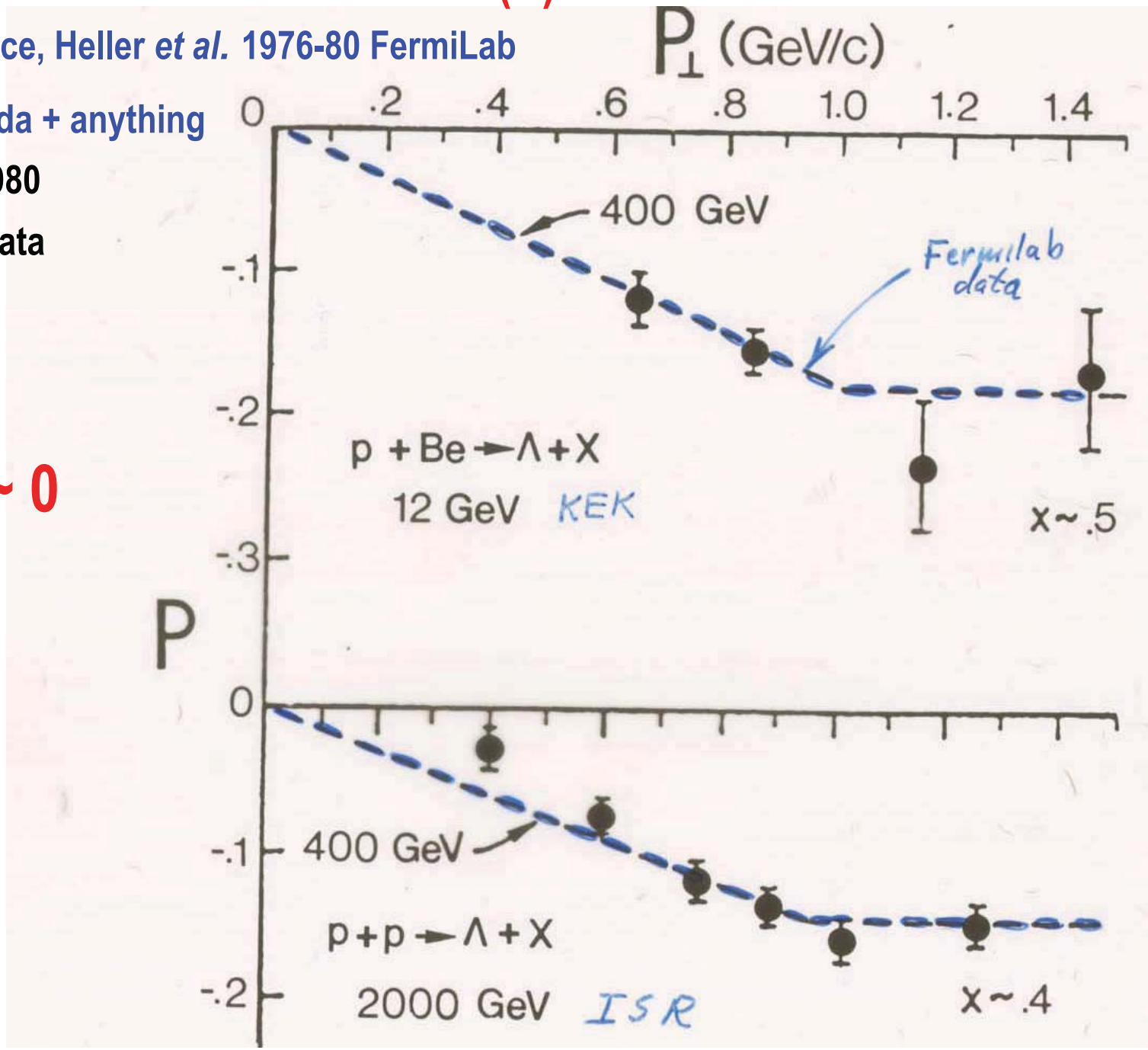
400 GeV p+p -> Lambda + anything

Plot by Heller ~1980

with KEK & ISR data

P ~ 15-20 %

QCD says P ~ 0



INCLUSIVE PION PRODUCTION

200 GeV Polarized Proton Beam

from Polarized Hyperon Decay

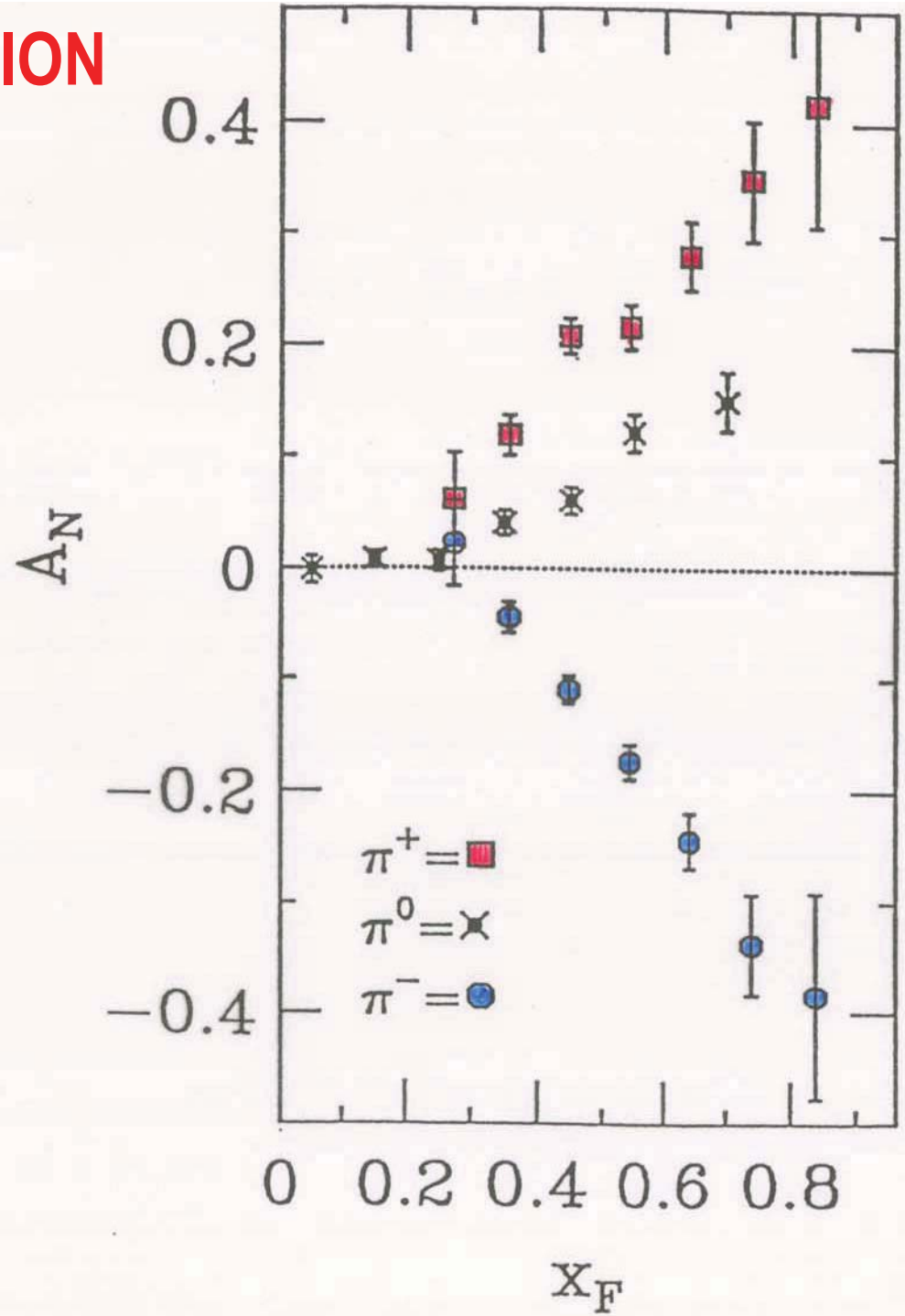
1990s Fermilab E-704

Yokosawa *et al.*

Phys Lett B264, 462 (1991)

$A_n \sim 40\%$

QCD said $A_n \sim 0$



POLARIZED BEAMS at SSC 1983

POLARIZED PROTONS at 20-20 TeV

INDIVIDUALLY OVERCOME EACH RESONANCE
- **Worked very well at 12 GeV Weak Focusing ZGS**
- **Worked painfully at 28 GeV Strong Focusing AGS**
- **Impossible at 20 TeV Strong Focusing SSC**

SIBERIAN SNAKES DERBENEV & KONDRATENKO ~1977

CHAMBERLAIN, COURANT, TERWILLIGER, ADK
1985 ANN ARBOR WORKSHOP on PPB in SSC:
CONCLUSIONS:

1. 20 TeV PPB POSSIBLE with 26 SNAKES / RING
BUT SEEMS: "TOO GOOD TO BE TRUE"

2. MUST TEST SIBERIAN SNAKE EXPERIMENTALLY

FIRST SIBERIAN SNAKE TEST 1989

ROTATES SPIN by 180° per TURN

SIBERIAN SNAKE TEST

PRL 1989

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

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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)

We studied the $G\gamma=2$ 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 $G\gamma=2$ depolarizing resonance.

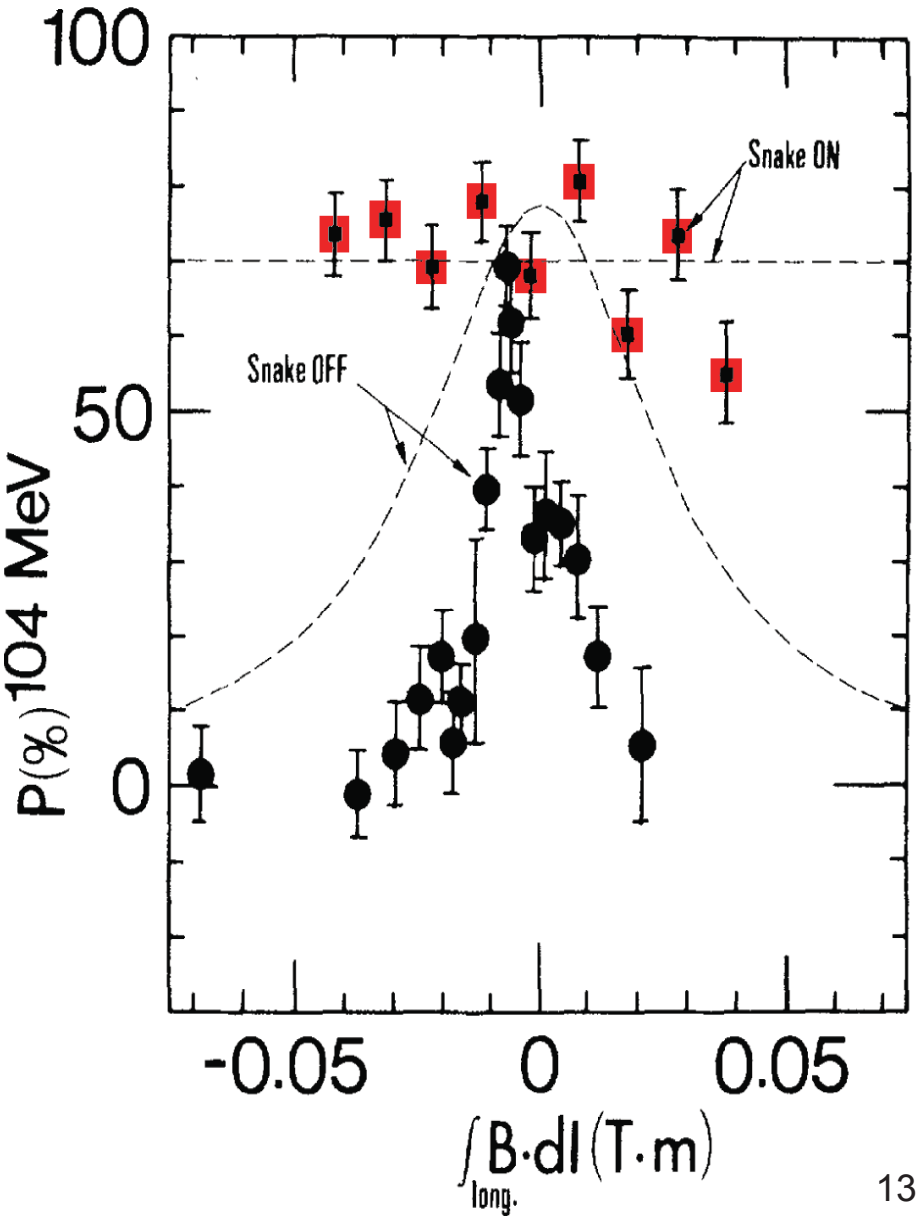
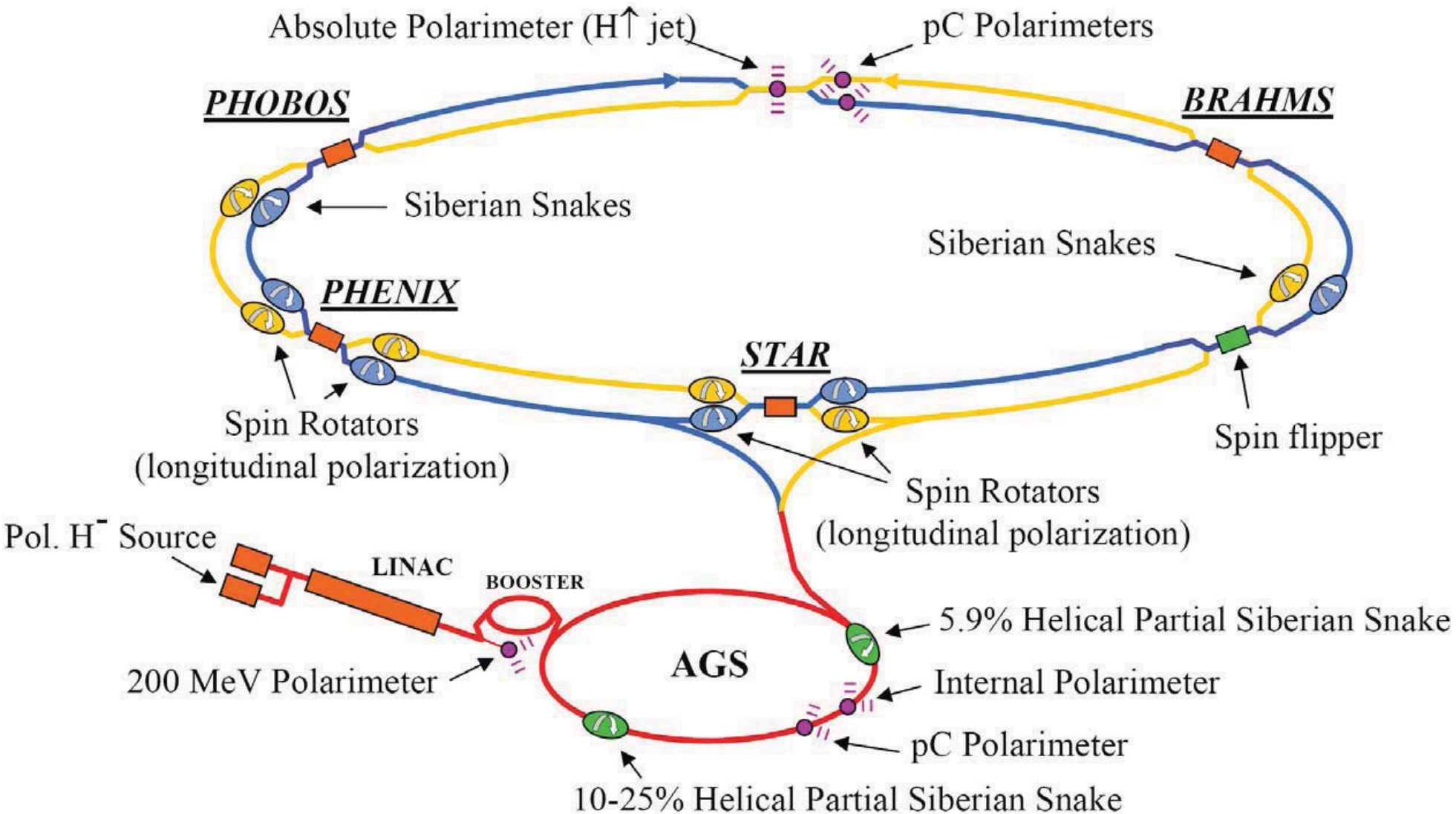


FIG. 4. The beam polarization in each stable polarization direction at 104 MeV is plotted against the longitudinal magnetic field integral in the Cooler Ring solenoids. The circles are the vertical polarization with the snake off and the injection of vertically polarized protons. The squares are the 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 $\pm 5\%$. The dashed curve is the predicted behavior. The straight dashed line is a fit.

RHIC POLARIZED BEAM COMPLEX



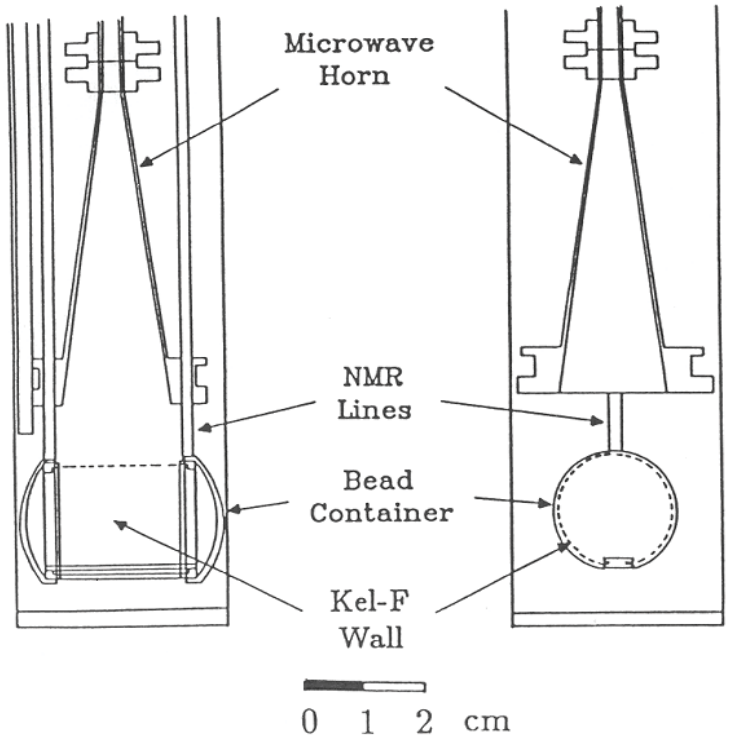
SPIN@FERMI

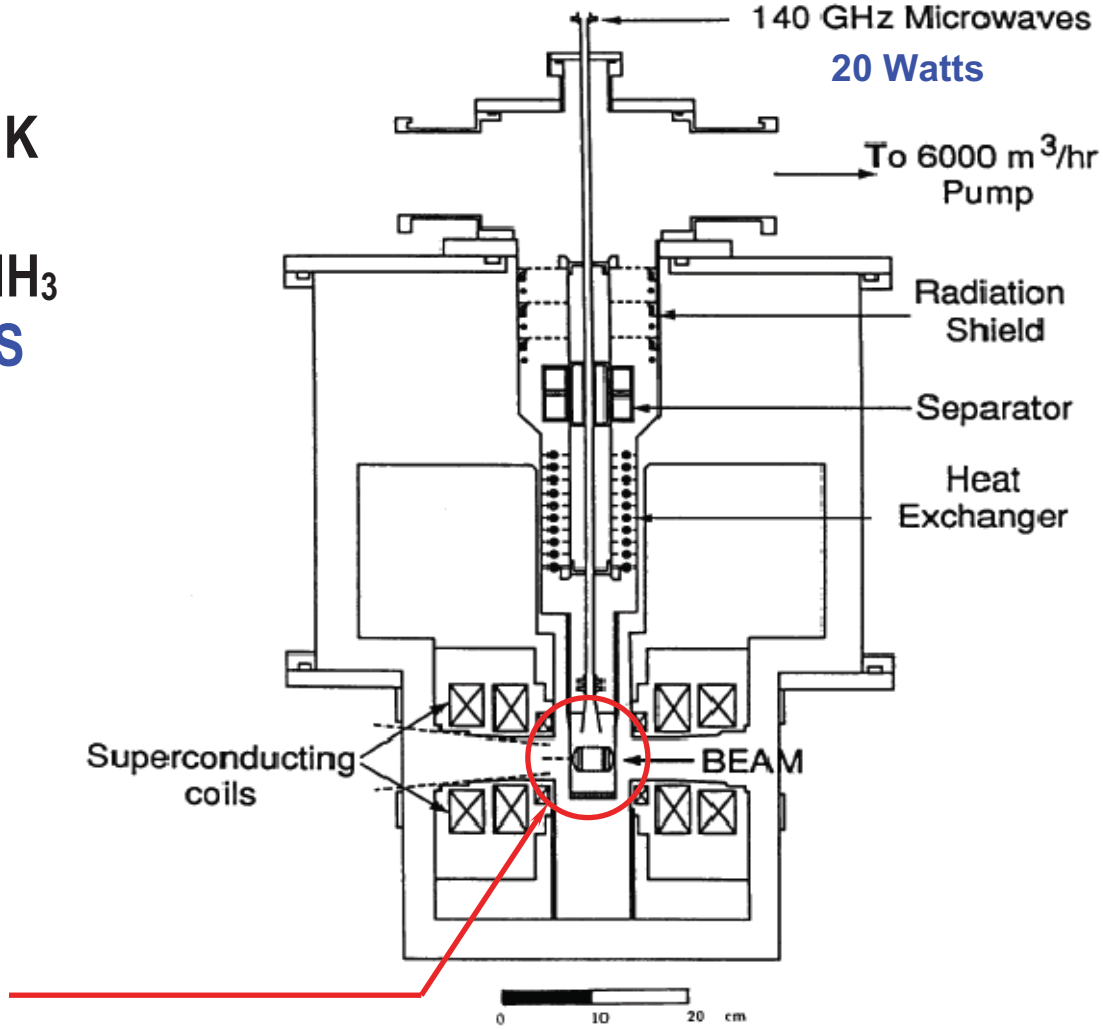
MICHIGAN SOLID POLARIZED PROTON TARGET

USED at AGS 1990 NOW on LOAN to KEK

- Highly uniform 5 T field
- 0.9 W of cooling power at 1 K
- Target cavity filled with NH_3
- 96% proton polarization in NH_3
- 85% average 3-month at AGS

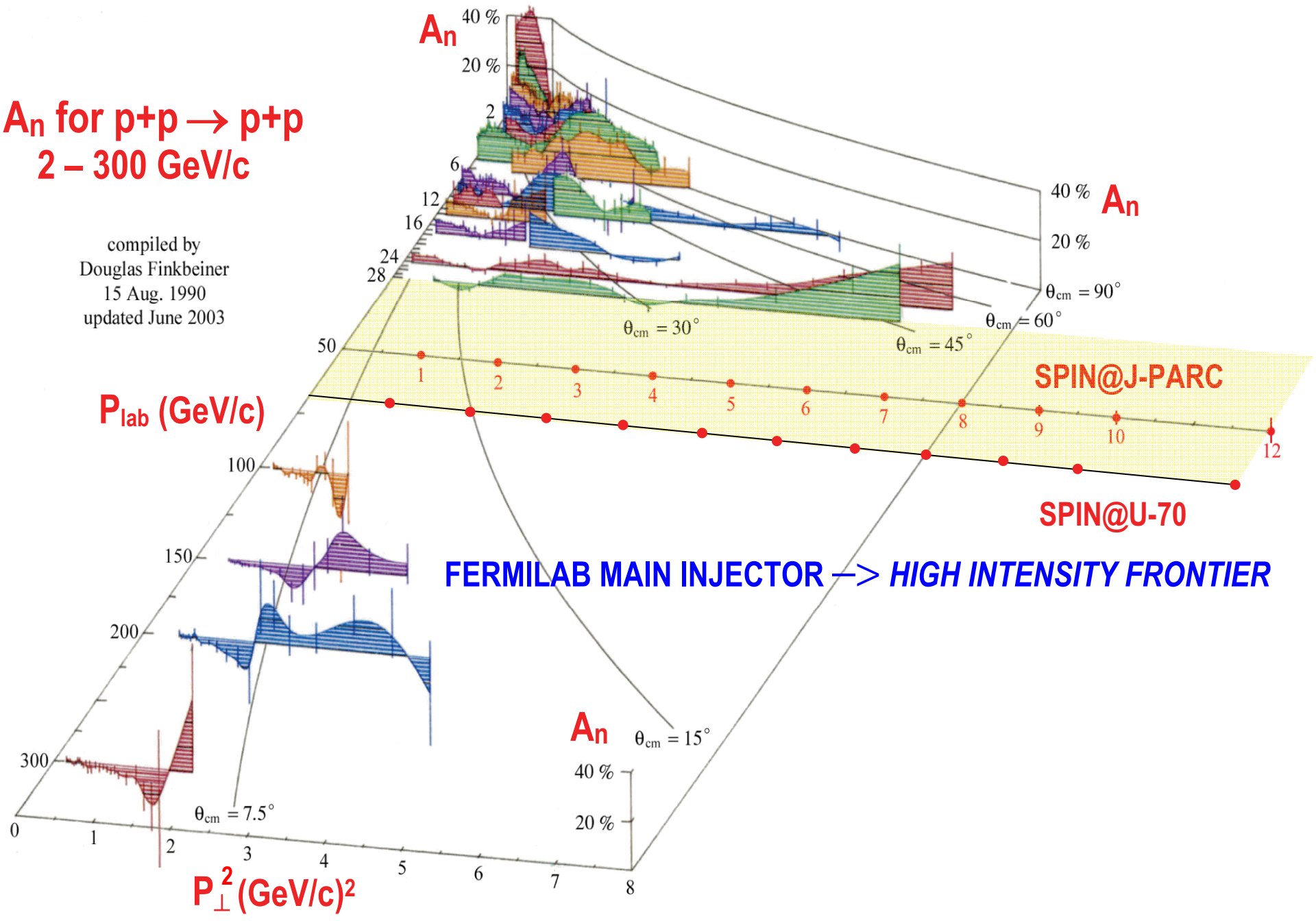
  @ 10^{11} protons/sec






SPIN@U-70 SPECTROMETER
JANUARY 2002
M1
APRIL 2002 TEST RUN
RECOIL SPECTROMETER ALONE
80:1 ELASTIC/INELASTIC

A_n for p+p → p+p
2 – 300 GeV/c



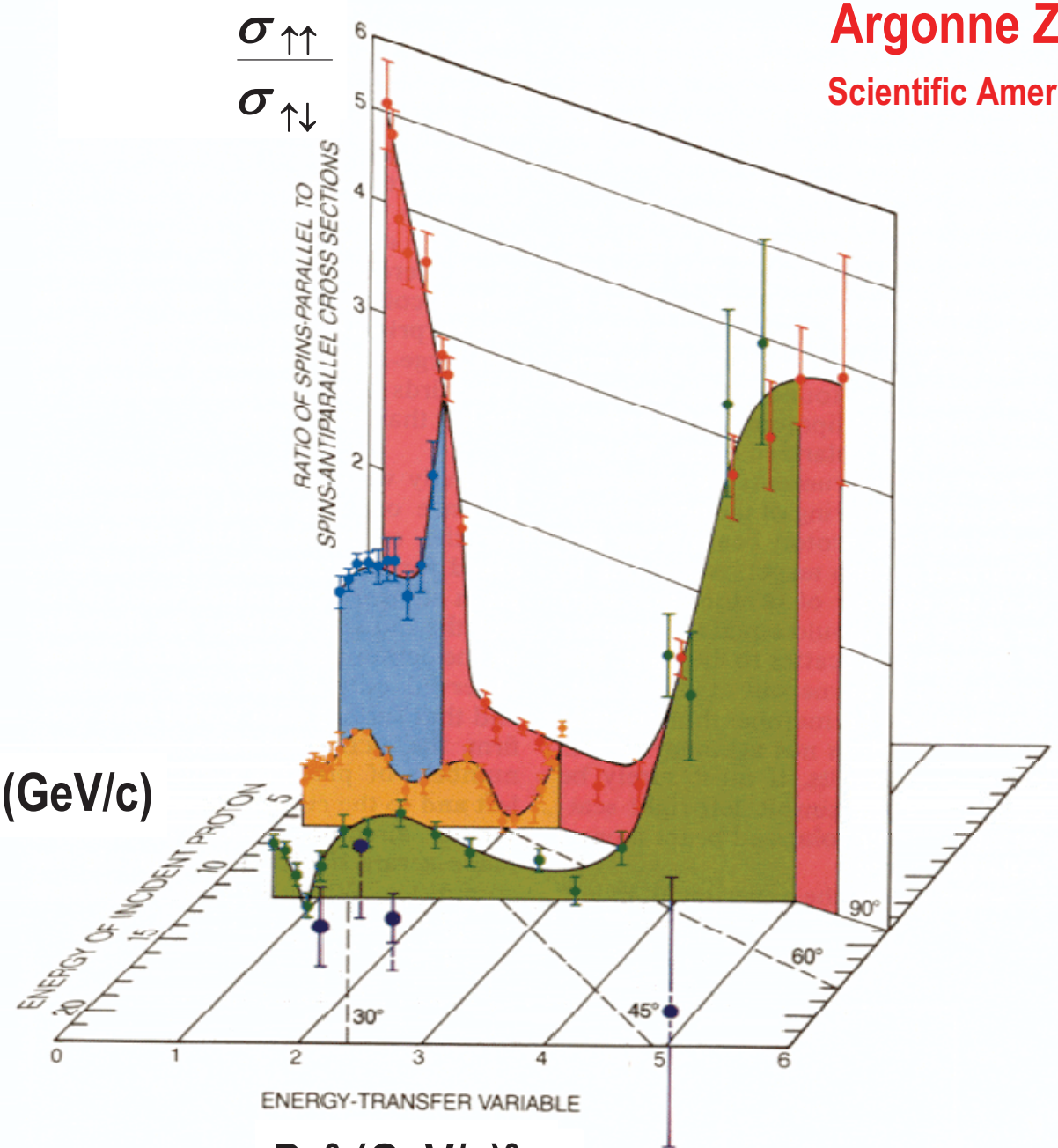
FERMILAB MAIN INJECTOR —> *HIGH INTENSITY FRONTIER*

Ratio Spin-Parallel: Spin-Antiparallel p-p Elastic Cross-Sections

Argonne ZGS 1977-79

Scientific American 1979 & 1987

$\frac{\sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow}}$

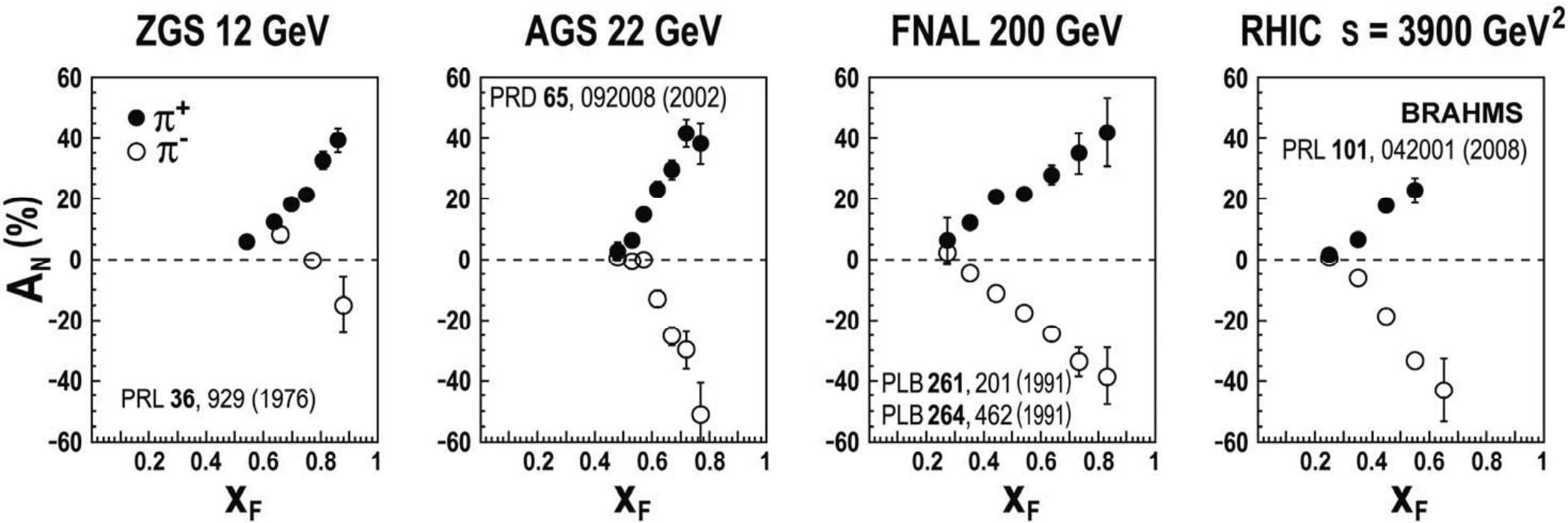


P_{Lab} (GeV/c)

$P_{\perp}^2$ (GeV/c)^2

INCLUSIVE PION ASYMMETRY IN PROTON-PROTON COLLISIONS

C. Aidala SPIN 2008 Proceeding and CERN Courier June 2009



Updated Report
Acceleration of Polarized Protons to 120-150 GeV/c at Fermilab

SPIN@FERMI Collaboration
Michigan, Fermilab, Jefferson Lab,
Virginia, Argonne, Bonn, TRIUMF,
IHEP-Protvino, Novosibirsk

The SPIN@FERMI collaboration has updated its 1991-95 Reports on the acceleration of polarized protons in Fermilab's Main Injector, which was commissioned by Fermilab. This Updated Report summarizes some updated Physics Goals for a 120-150 GeV/c polarized proton beam. It also contains an updated discussion of the Modifications and Hardware needed for a polarized beam in the Main Injector, along with an updated Schedule and Budget. For reference, also attached to the e-mail containing this Updated Report are reprints of the 1992 and 1995 Reports on Polarized Beams at Fermilab by our SPIN collaboration.

Some highlights of the Update are:

- Two superconducting Siberian snakes in the Main Injector, one superconducting 60° rotator in the 120-150 GeV/c extraction line, a 4% partial warm solenoidal Siberian snake in the 8.9 GeV/c Booster (oscillating with the Booster frequency) and some other minor hardware should allow about 75% polarization to be maintained and manipulated in the RFQ, Linac, Booster, Recycler Ring and Main Injector, and then extracted to the experiments. (See Fig. 1.9)

- Polarized ion sources now have intensities of 1.0 - 1.5 mA. With either the former IUCF Atomic Beam (ABS) type polarized ion source (which is now at Dubna), or the reconstructed and improved ZGS/AGS ABS, we expect to obtain an intensity of about 1 mA. With 10% of the beam-time polarized, SeaQuest's 50 cm long H_2 target would have a time-averaged luminosity of about $2 \cdot 10^{35}$ cm^{-2} s^{-1}.

- The estimated total cost of the project is about \$4 Million (2012 dollars). The construction time could be about 2 years after approval and funding.

The major new items or changes needed are shown below and summarized in this Updated Report, where we discuss polarized beam acceleration in the current Main Injector.

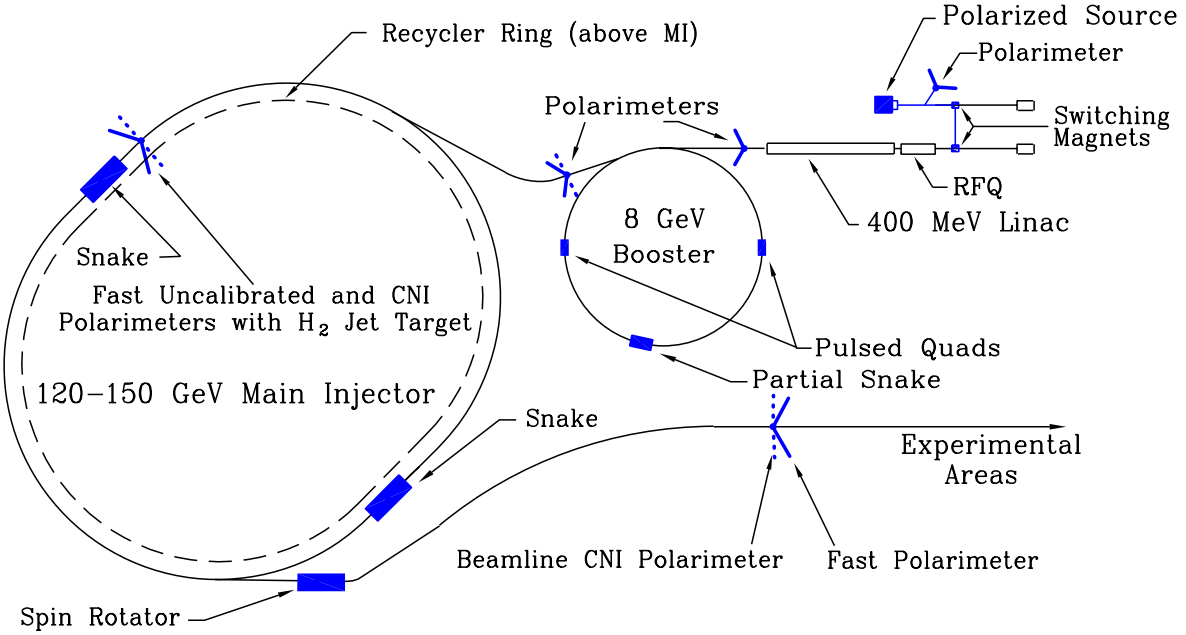


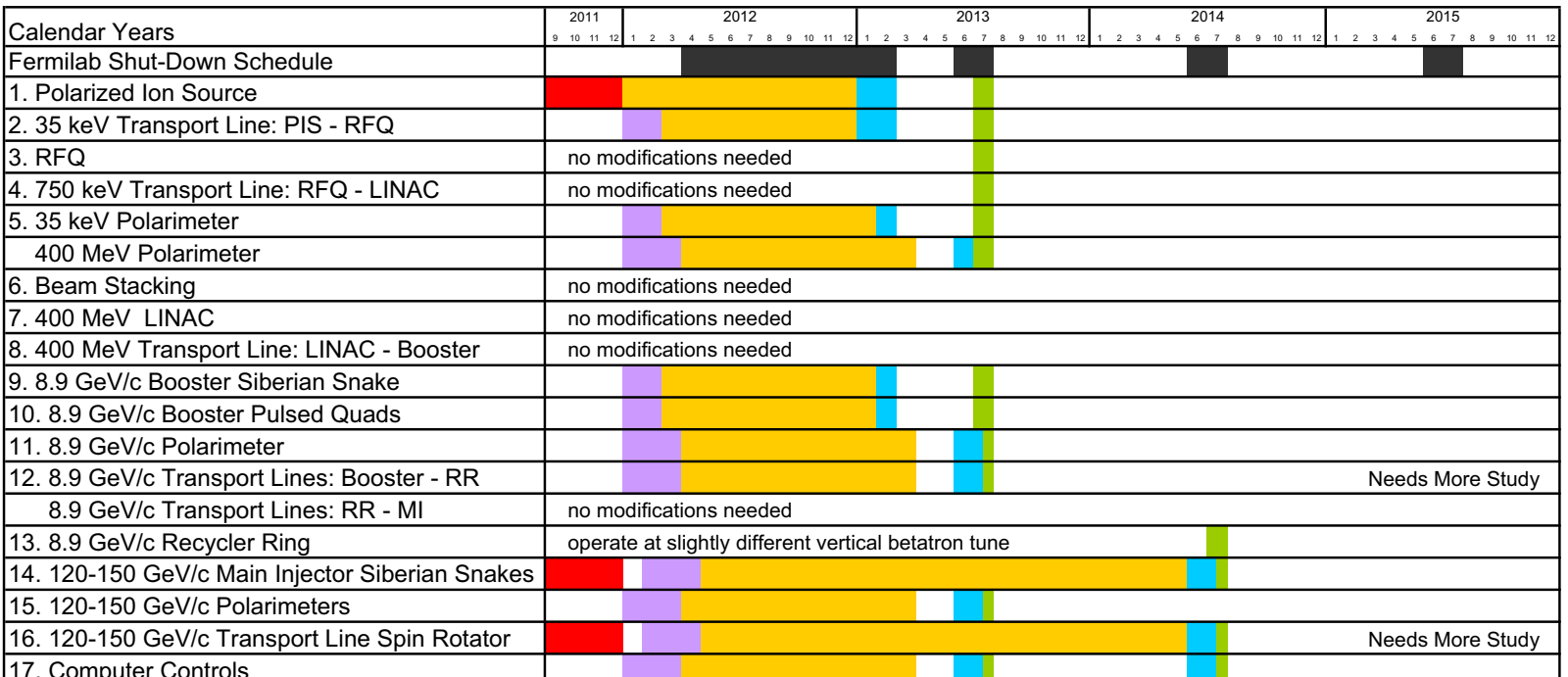
Figure 1.9: Major items needed for polarized beam at Fermilab.

POSSIBLE POLARIZED BEAM PROJECT CHART

Needs More Study

25 August 2011

A.D.Krisch / D.A. Nees / M.A. Leonova



1.9 Estimated Budget

Preaccelerator		\$0.9M
Polarized H^- ion source	\$0.6M	
35 keV polarimeter	\$0.1M	
RFQ and power supply (35 keV to 750 keV)	\$0.0M	
Beam lines, switching magnets & vacuum system	\$0.1M	
Building Modification	\$0.1M	
400 MeV LINAC		\$0.1M
400 MeV polarimeter	\$0.1M	
8.9 GeV/c Booster		\$0.6M
Solenoid partial Siberian snake (ramped warm)	\$0.2M	
Two 3 μsec pulsed quadrupoles with power supplies	\$0.1M	
8.9 GeV/c polarimeter	\$0.2M	
8.9 GeV/c transfer line spin rotator	\$0.1M	
Main Injector		\$0.9M
Two Helical Siberian snakes	\$0.6M	
Power supplies for snakes	\$0.1M	
120-150 GeV/c polarimeters (CNI & Inclusive)	\$0.2M	
120-150 GeV/c Transfer Line		\$0.5M
120-150 GeV/c polarimeters (CNI & Inclusive)	\$0.2M	
120-150 GeV/c transfer line spin rotator	\$0.3M	
Miscellaneous		\$0.2M
Computers, control modules, cables, and interface	\$0.2M	
Main Injector subtotal		\$3.2M
Contingency (~25%)		\$0.8M
MAIN INJECTOR TOTAL		**~\$4M**

Report Update Summary

With a 50 cm long liquid hydrogen target and 10% of the beam time, the time-averaged polarized beam luminosity for the Main Injector could probably be about $2 \cdot 10^{35} cm^{-2} s^{-1}$ or higher.

- This polarized luminosity should allow precise measurements of spin-asymmetries out to $P_{\perp}^{2}$ of 50-70 $(GeV/c)^2$ for inclusive hadron production.
- The world's highest intensity polarized proton beam with a 50 cm hydrogen target would also allow precise studies of polarized Drell-Yan processes.
- With a solid polarized proton target, it could also allow high-precision 1-spin, 2-spin and spin-averaged studies of violent elastic proton-proton collisions out to $P_{\perp}^{2}$ of at least 12 $(GeV/c)^2$ – a fundamental probe of the strong interaction.

The total cost of providing a 120-150 GeV/c polarized proton beam could be about $4 Million and the time needed for producing the needed hardware could be about 24 months from the time of approval and funding.