POLARIZED BEAMS and VIOLENT COLLISIONS of SPINNING PROTONS: PAST, PRESENT and POSSIBLY at FERMILAB

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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

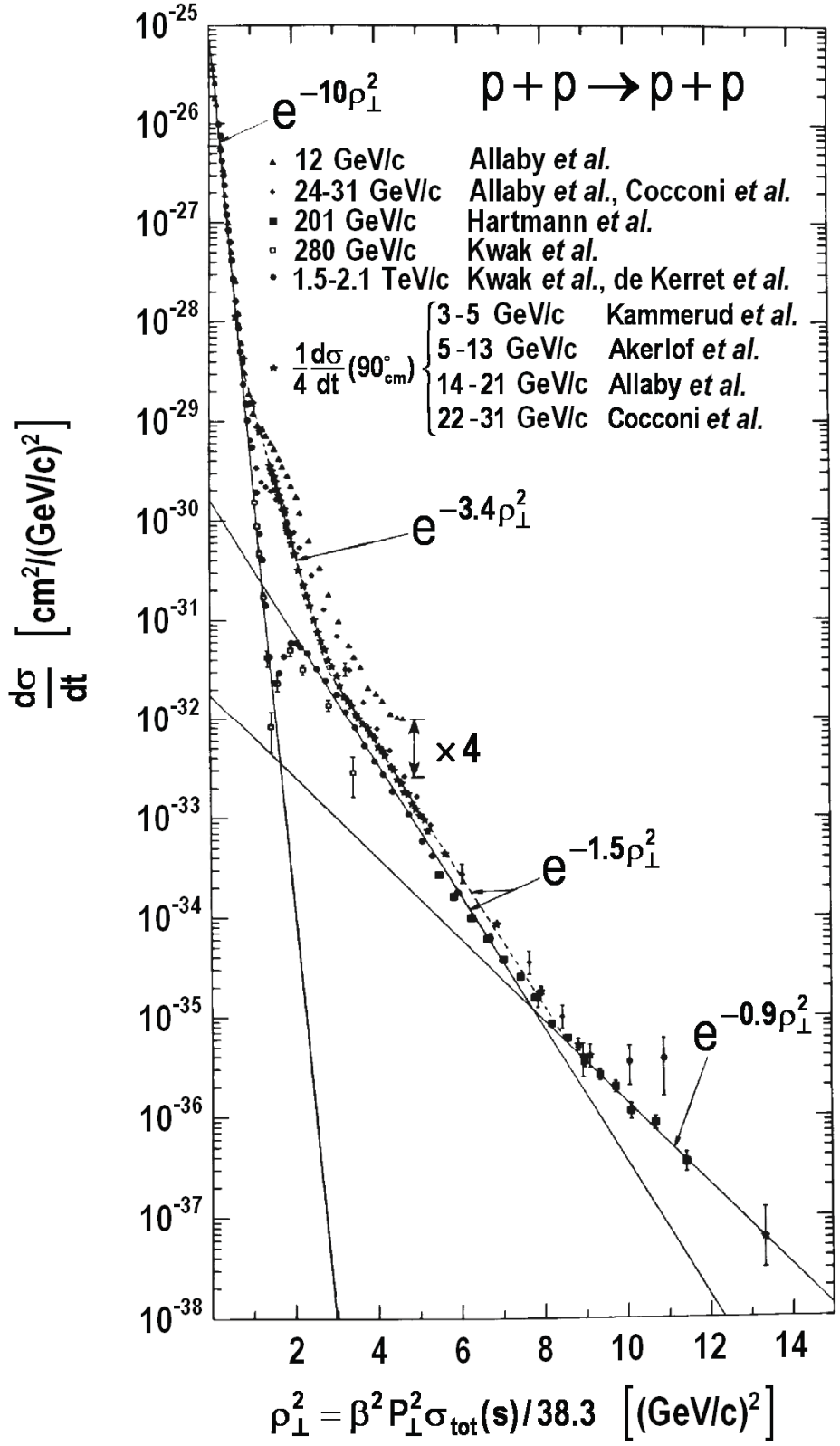
N_i and N_{ij} = NORMALIZED ELASTIC EVENT RATES

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



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

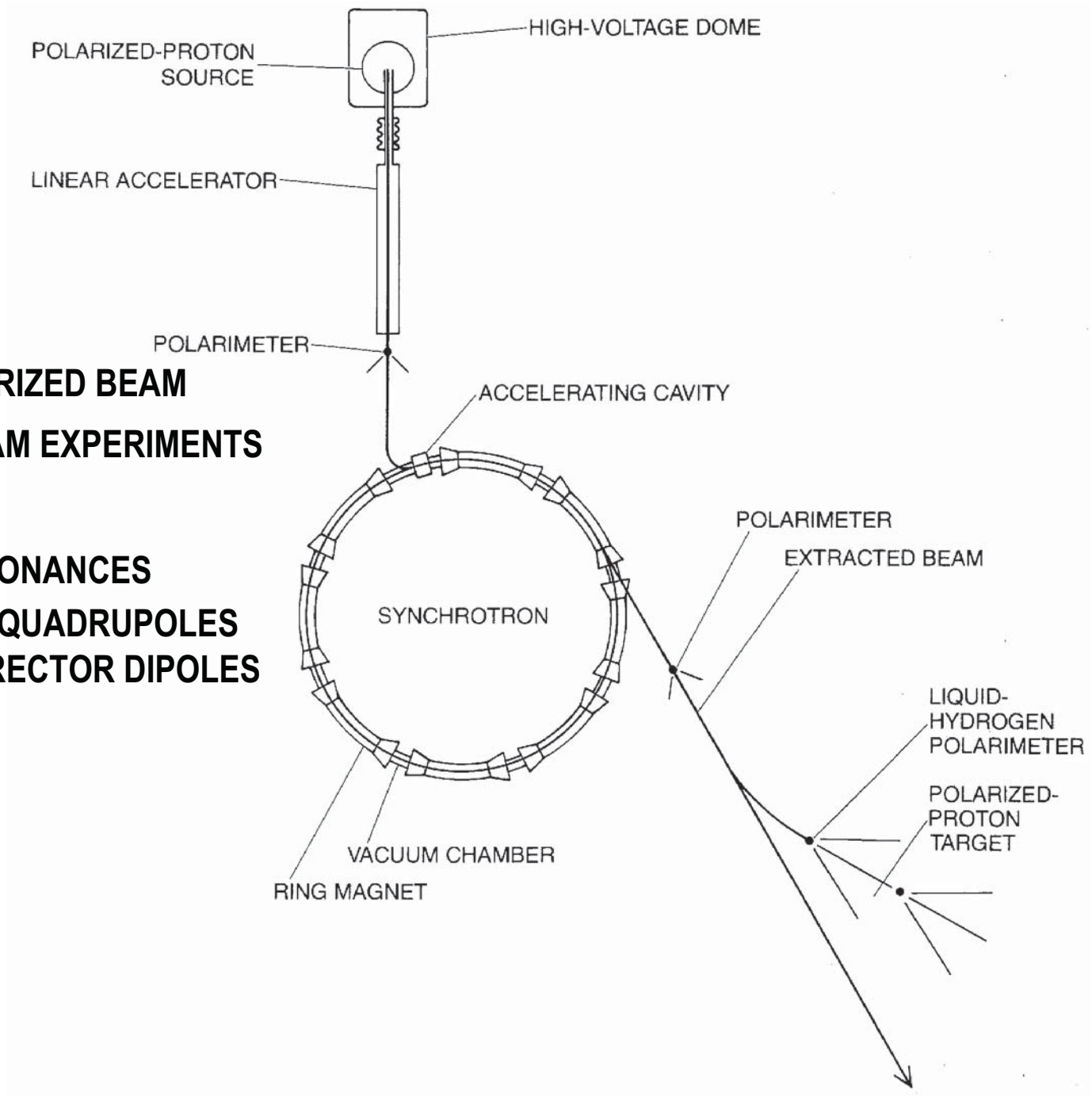
1969-1973 DEVELOP POLARIZED BEAM

1973-1979 POLARIZED BEAM EXPERIMENTS

DEPOLARIZING RESONANCES

INTRINSIC: PULSED QUADRUPOLES

IMPERFECTION: CORRECTOR DIPOLES



2-SPIN PROTON-PROTON ELASTIC CROSS SECTIONS

12 GeV ZGS

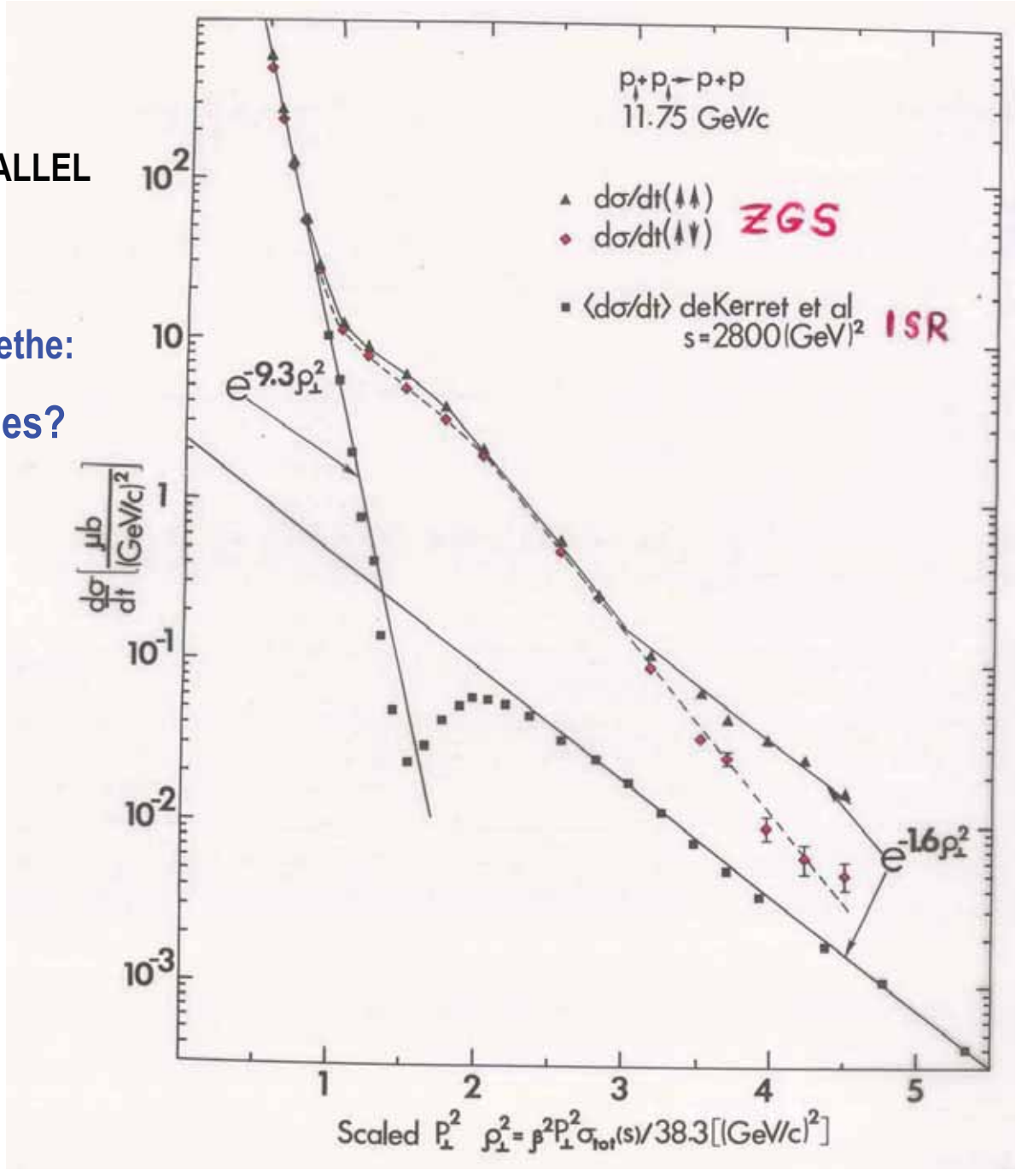
1977-1978

SPINS PARALLEL 4x SPINS ANTIPARALLEL

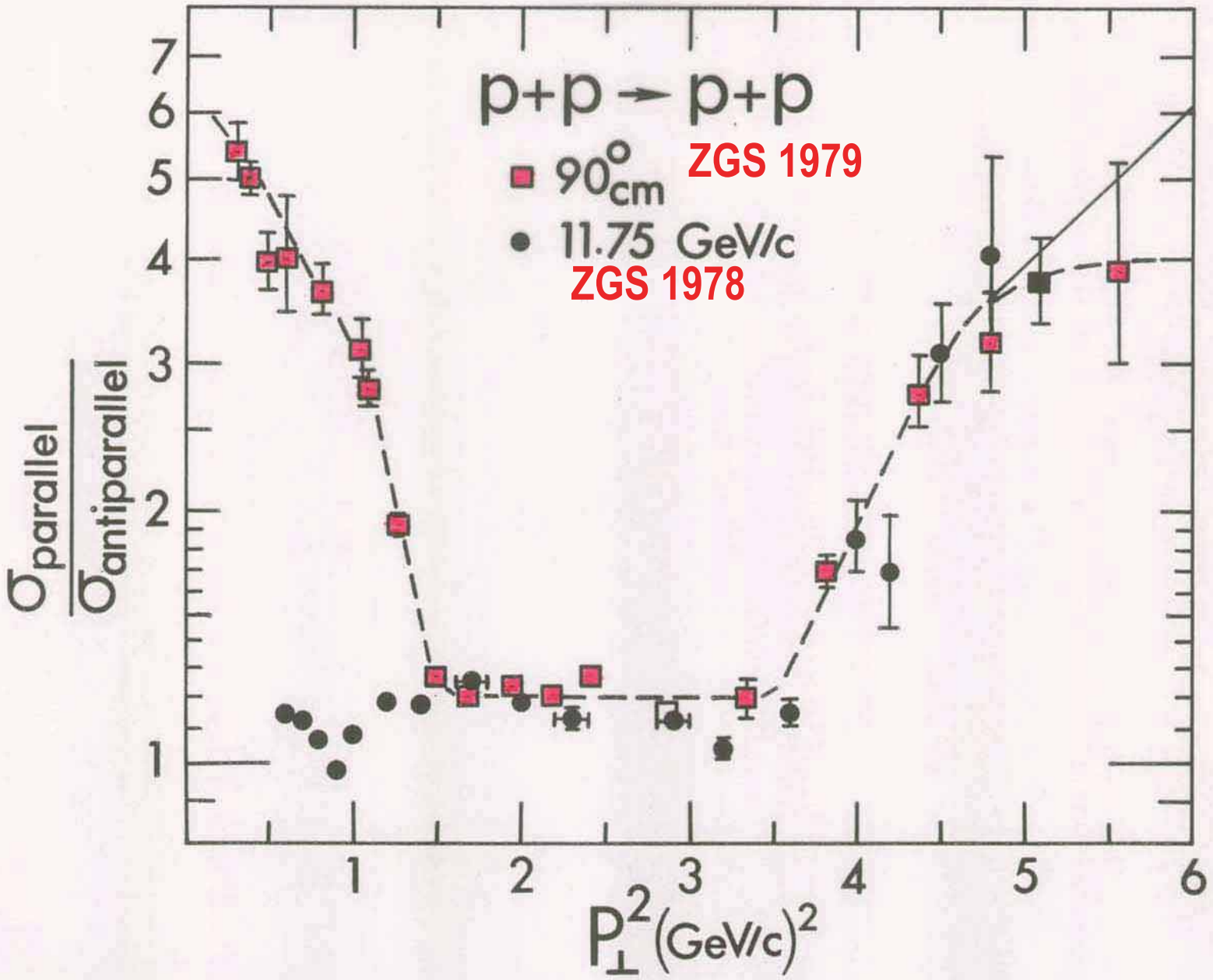
TOTALLY UNEXPECTED

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

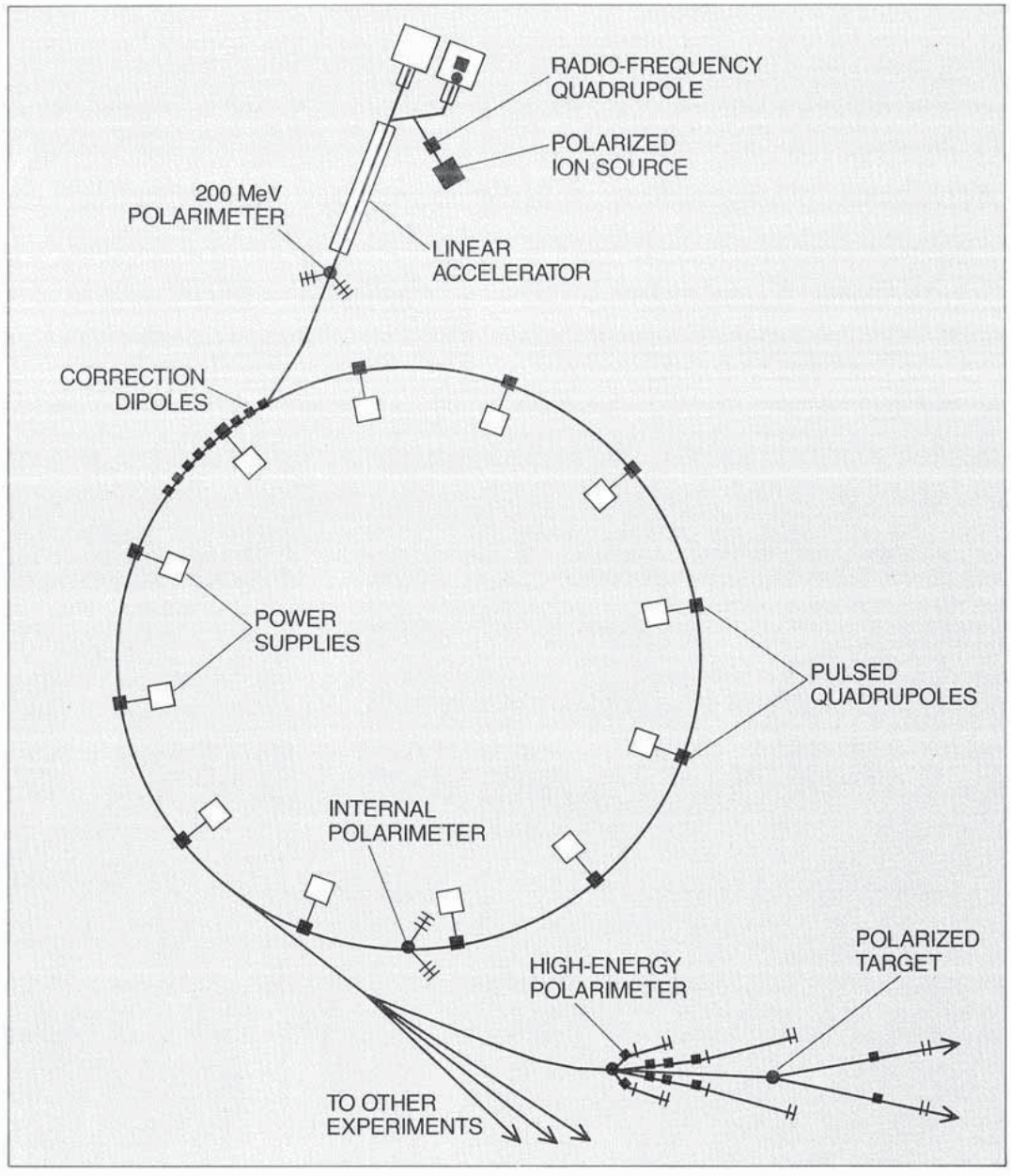
12 Pulsed Quads 96 Correction Dipoles

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?

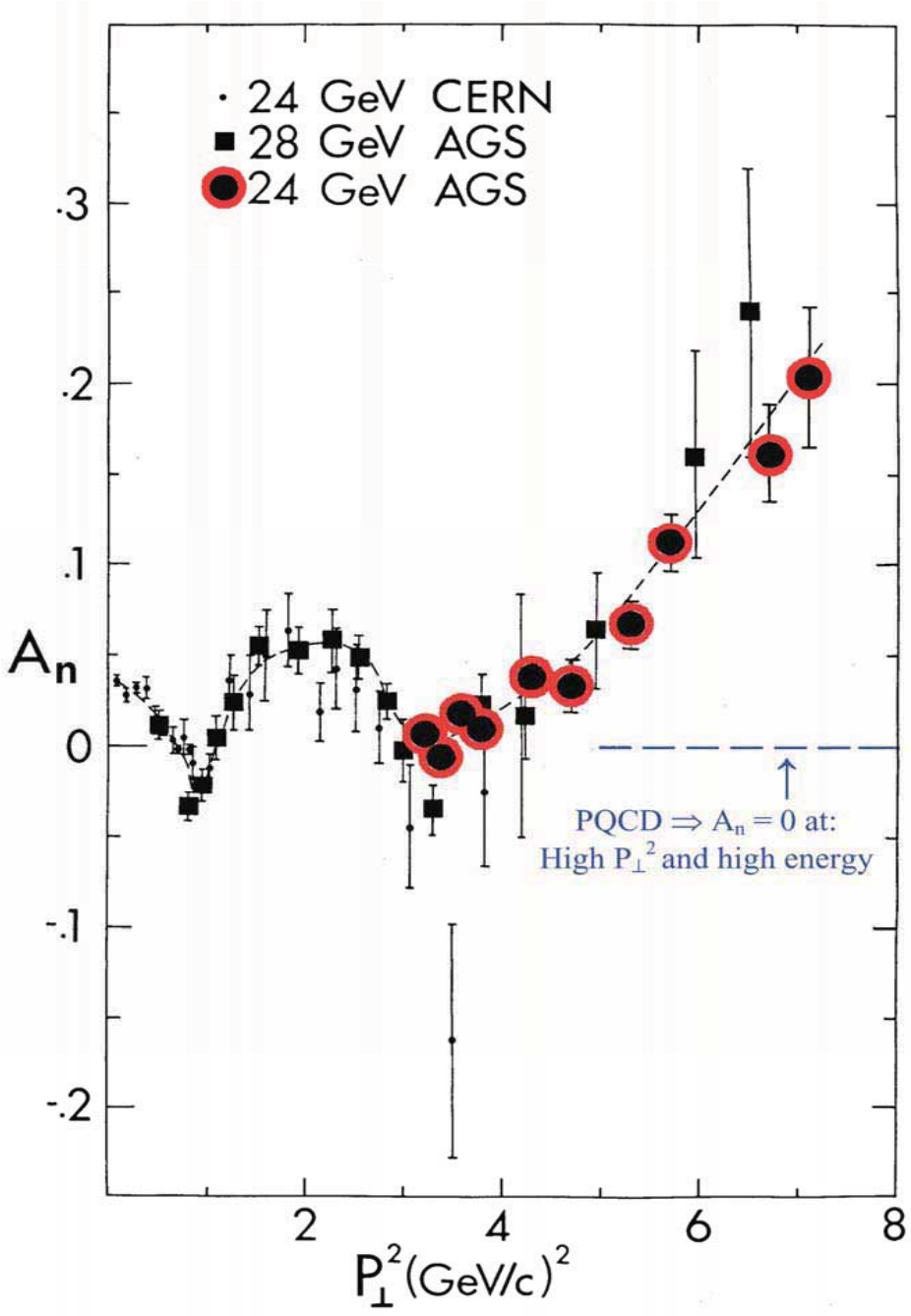
NO MODEL can EXPLAIN ALL

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

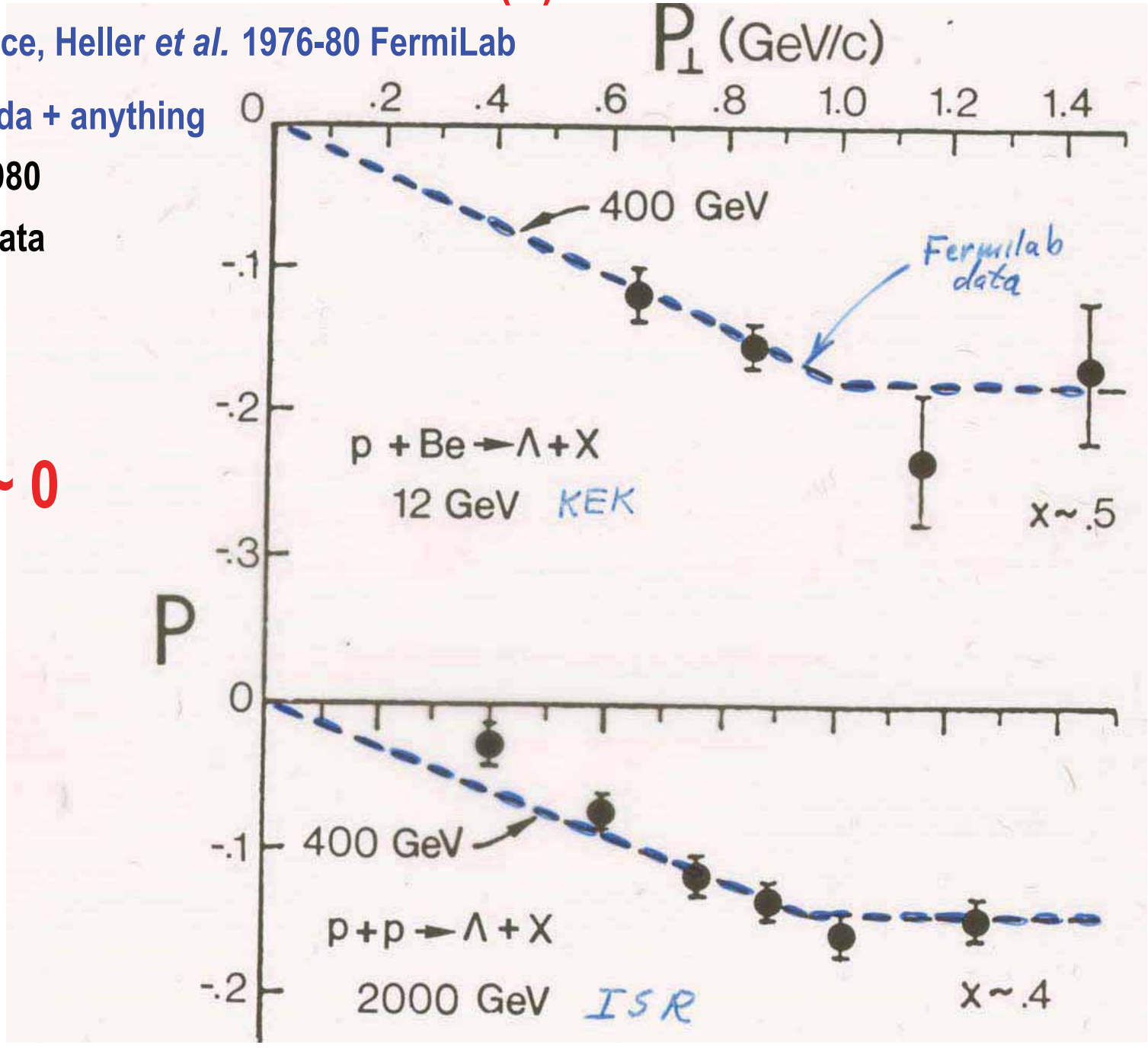
400 GeV p+p -> Lambda + anything

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

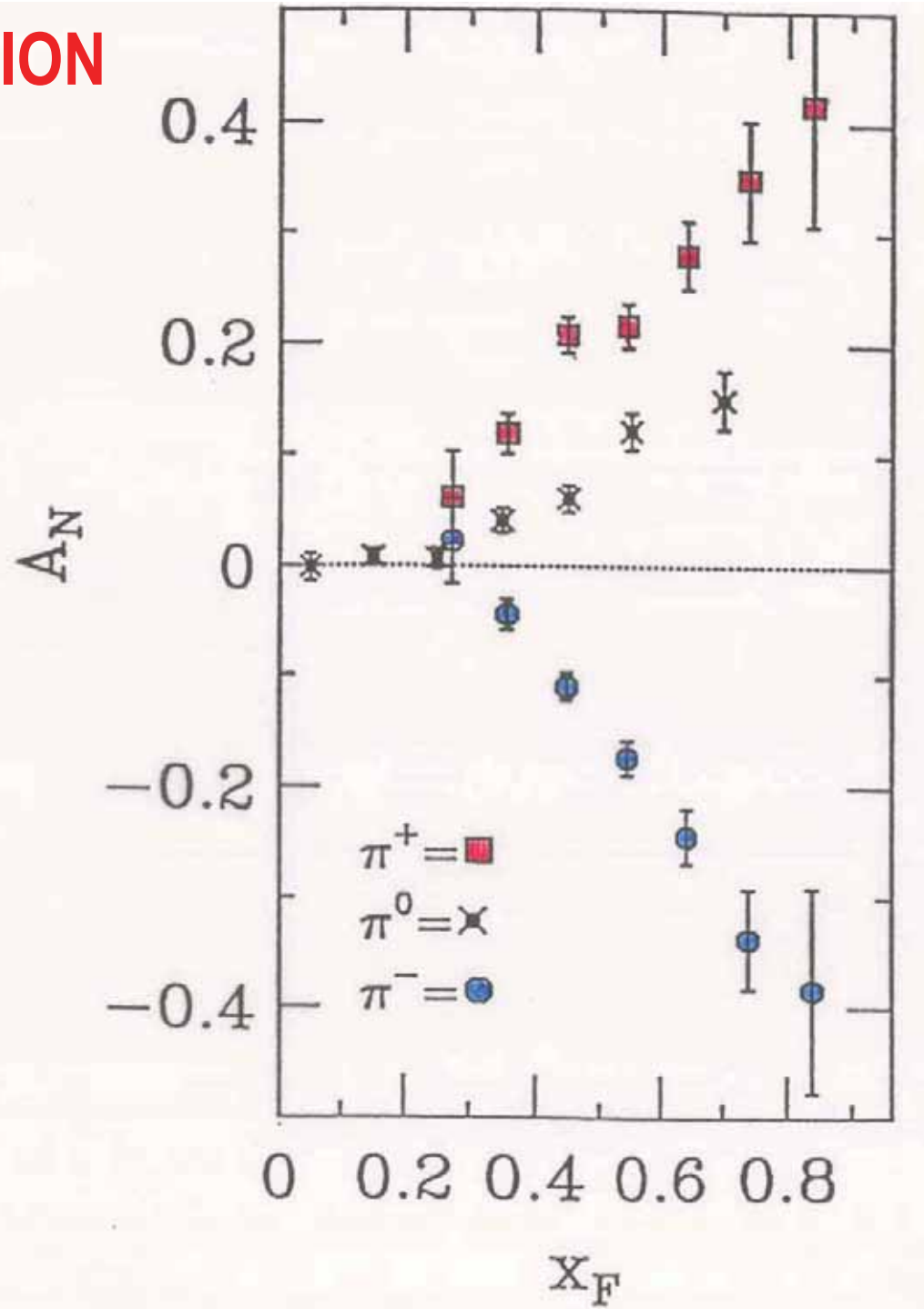
1990s Fermilab E-704

Yokosawa *et al.*

Phys Lett B264, 462 (1991)

$A_n \sim 40\%$

QCD said $A_n \sim 0$



POLARIZED BEAMS at SSC 1985

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.

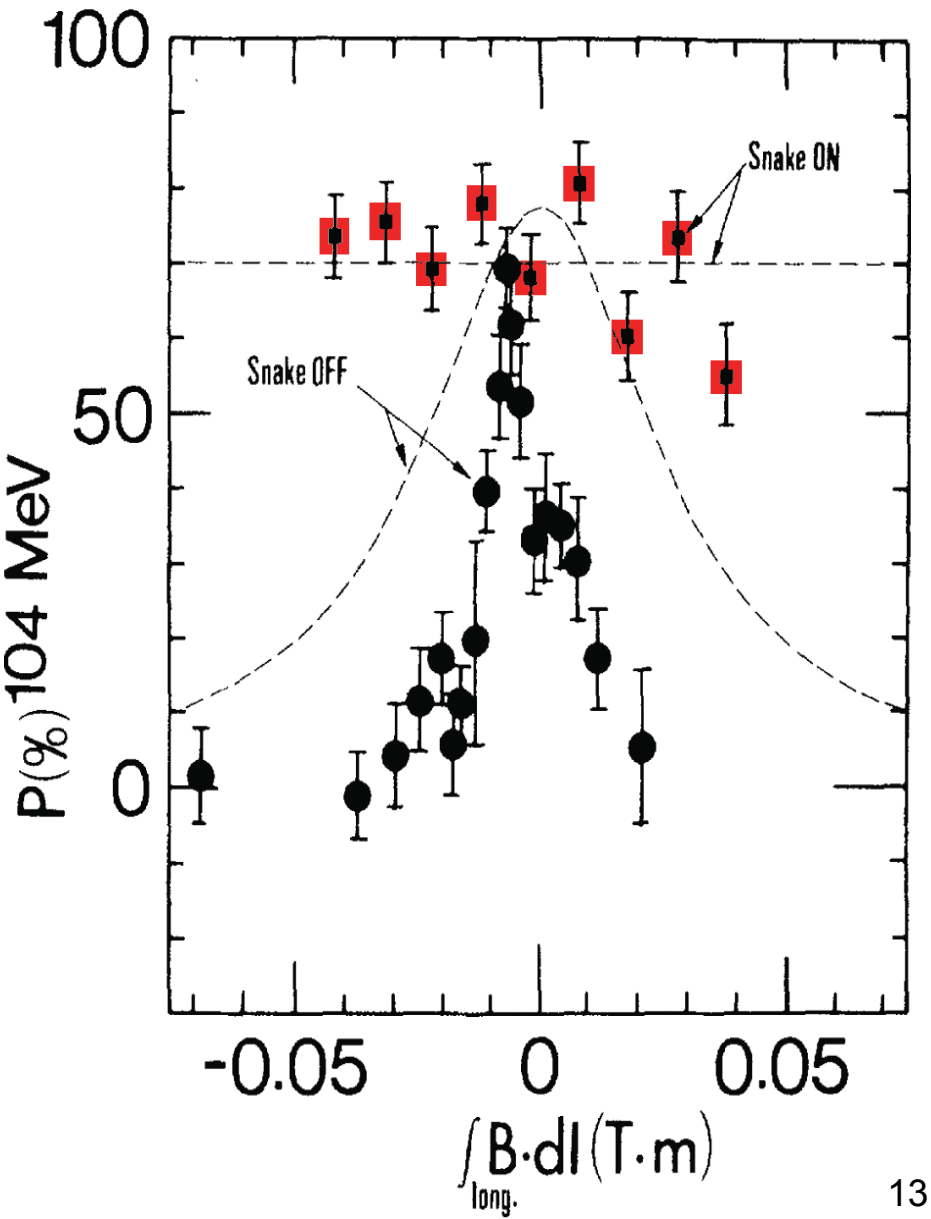
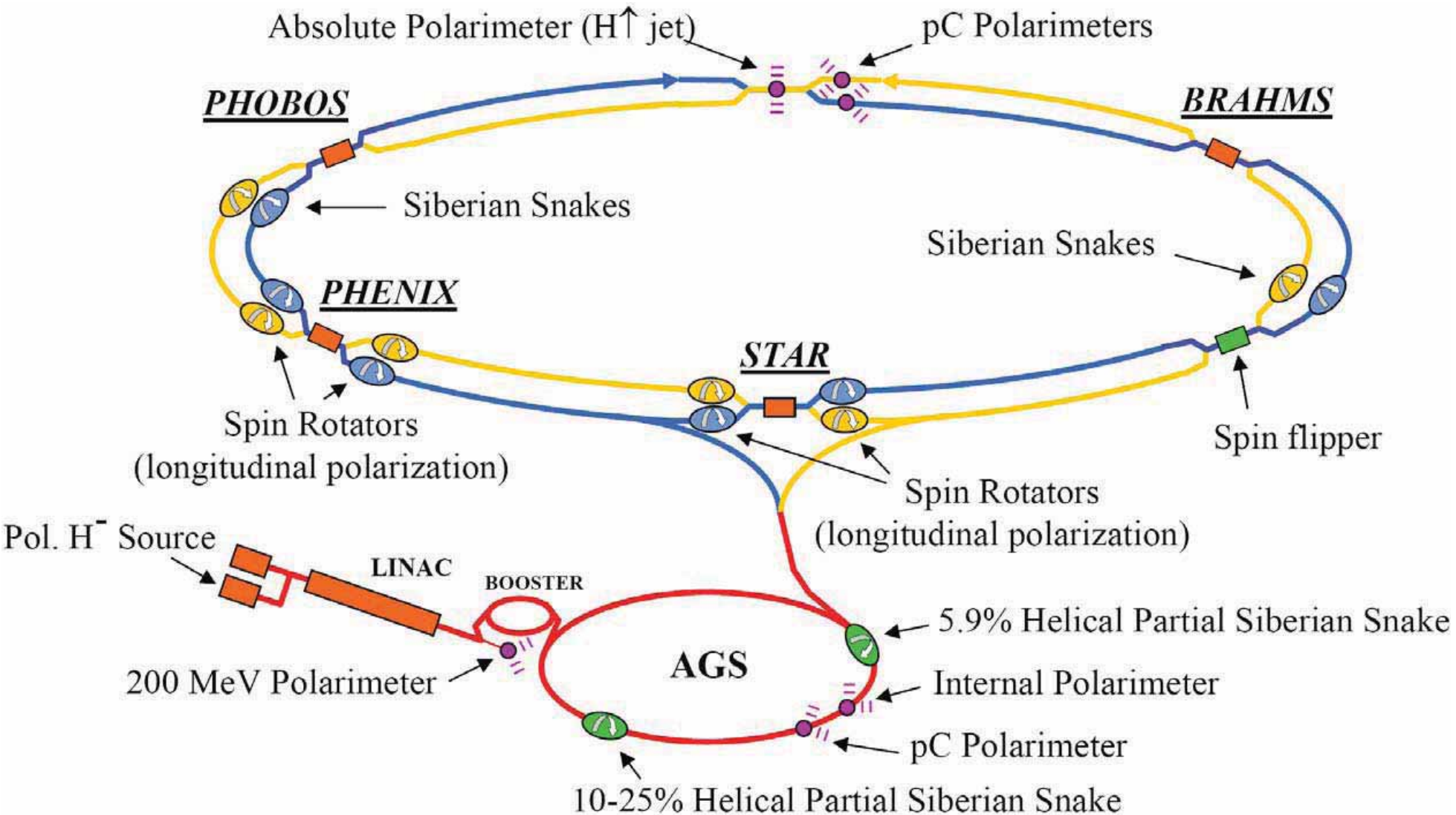


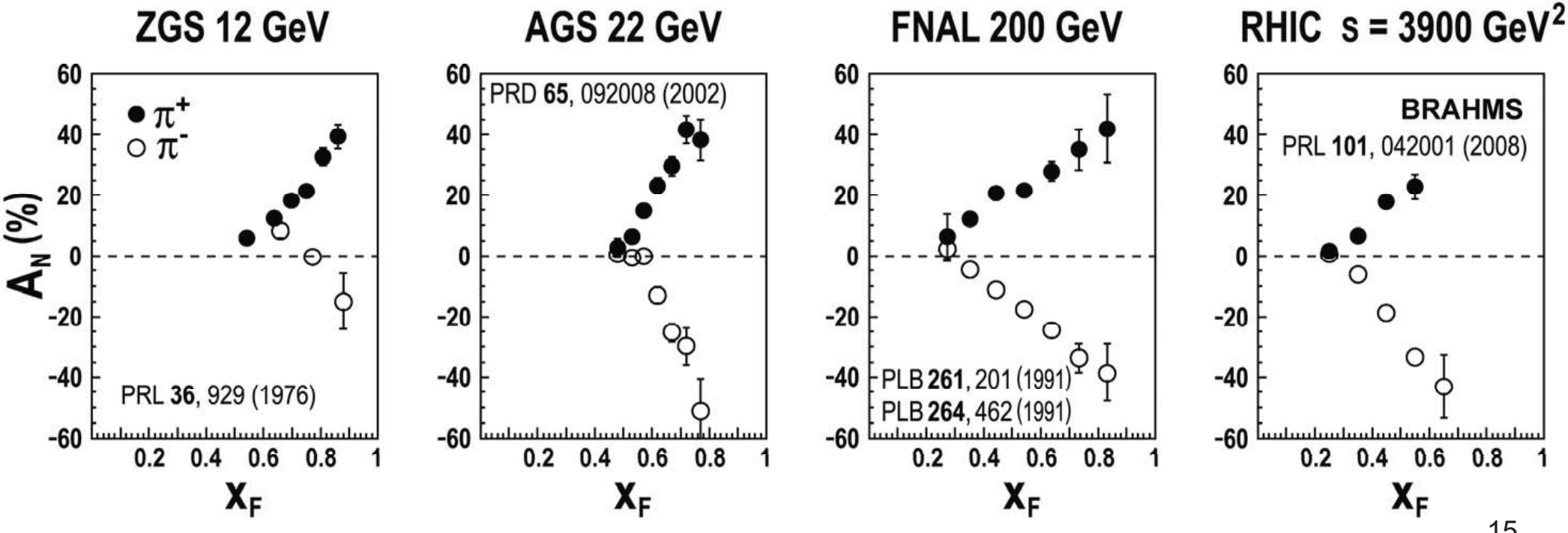
FIG. 4. The beam polarization in each stable polarization direction at 104 MeV is plotted against the longitudinal magnetic field integral in the Cooler Ring solenoids. The circles are the vertical polarization with the snake off and the injection of vertically polarized protons. The squares are the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

RHIC POLARIZED BEAM COMPLEX



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 GeV/c at Fermilab

SPIN@FERMI Collaboration

Michigan, Fermilab, Jefferson Lab, Virginia, Argonne, Bonn, TRIUMF,IHEP-Protvino, Novosibirsk

SPIN@FERMI collaboration is updating its 1991-95 Reports commissioned by Fermilab on polarized protons acceleration.
The 26 August 2011 Updated Report can be found at **arxiv.org:1110.3042.**
It contains:

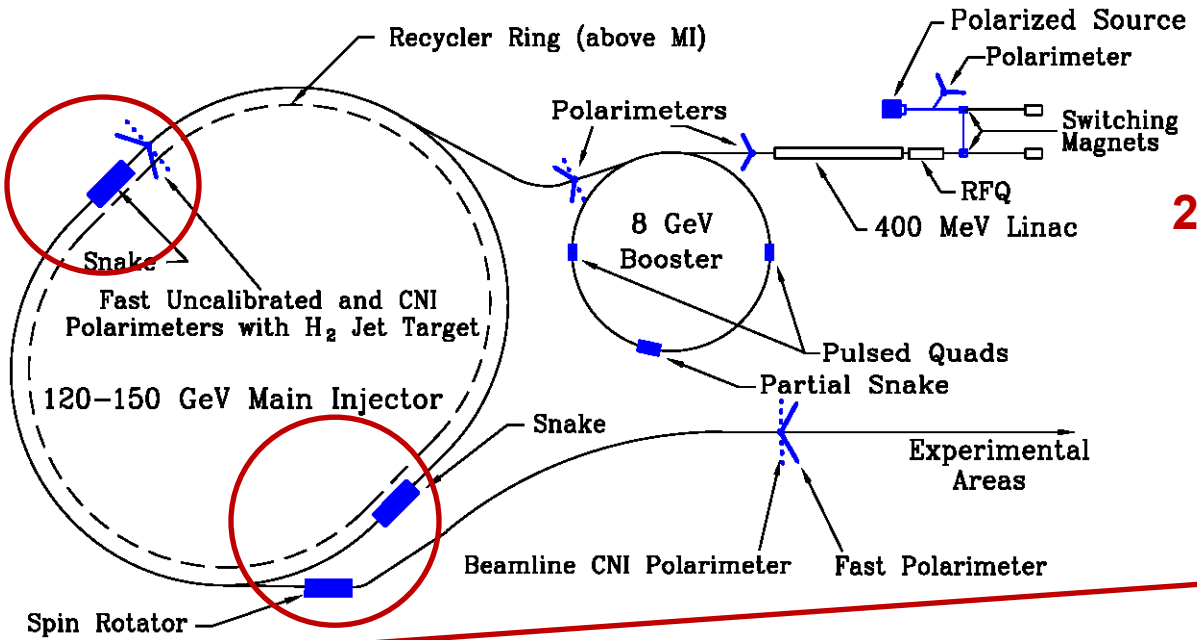
- Updated Physics Goals for 120 GeV/c polarized proton beam:
  -Polarized Drell-Yan.
  -Perhaps Polarized High-P_T p-p Elastic & Inclusive Scattering.
- Updated Modifications & Hardware needed for Polarized Main Injector beam.
- Updated Schedule & Budget.

Some highlights of not-yet-finished 2013 Update are:

- One simple superconducting Siberian snake in 120 GeV/c Main Injector;
- One simple superconducting solenoid in 8.9 GeV/c Recycler Ring;
- A 4% partial warm solenoid snake 8.9 GeV/c Booster (oscillating with the Booster frequency);
- Polarized ion source intensity 1.0-1.5 *mA*
- Some other minor hardware

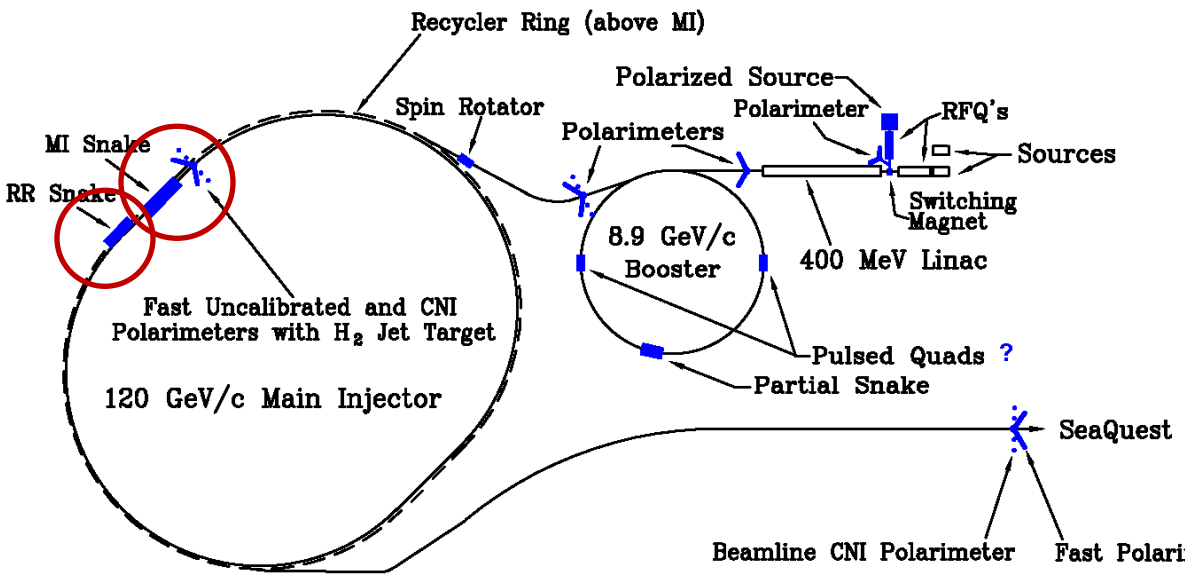
Should allow 65-75% polarization to be maintained & manipulated in the
RFQ, Linac, Booster, Recycler Ring & Main Injector, & then extracted to experiments.

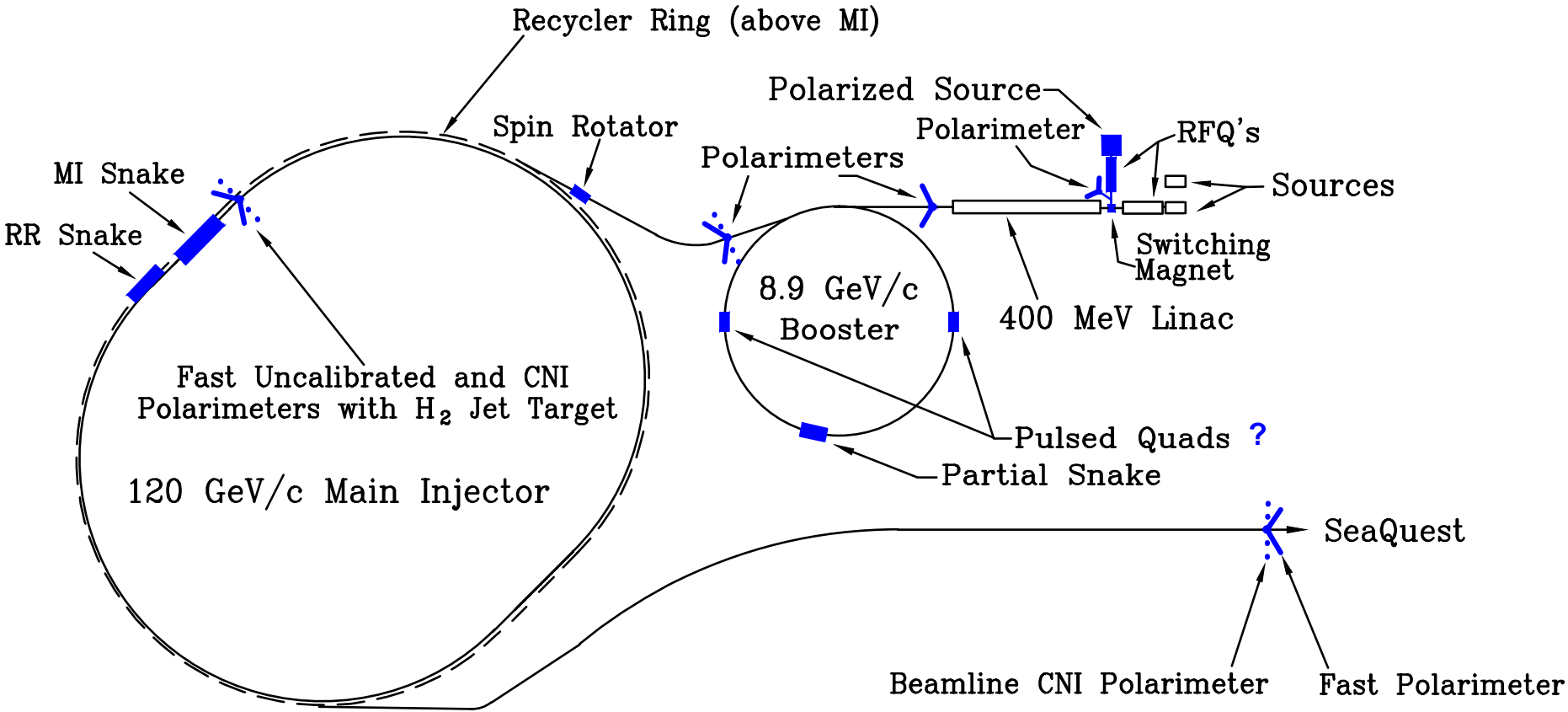
FROM 2 Siberian Snakes + 1 Spin Rotator TO 1 Snake

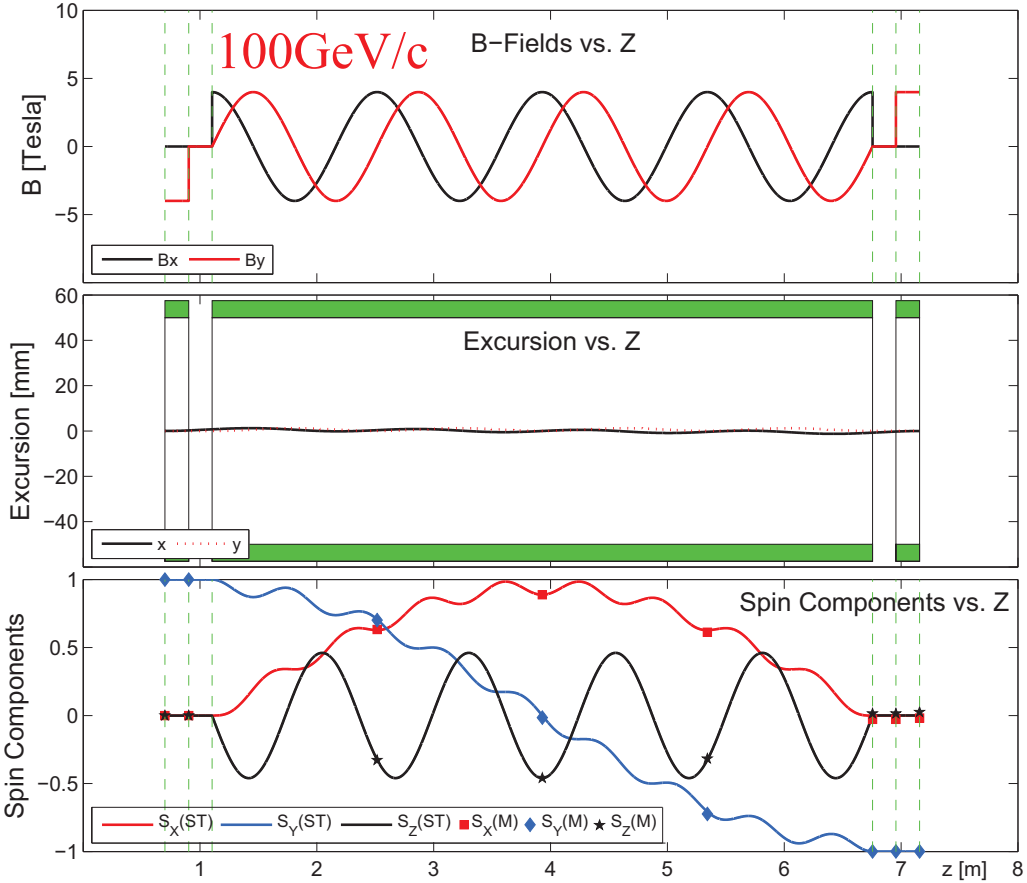


2 Siberian Snakes in MI
(not enough space)

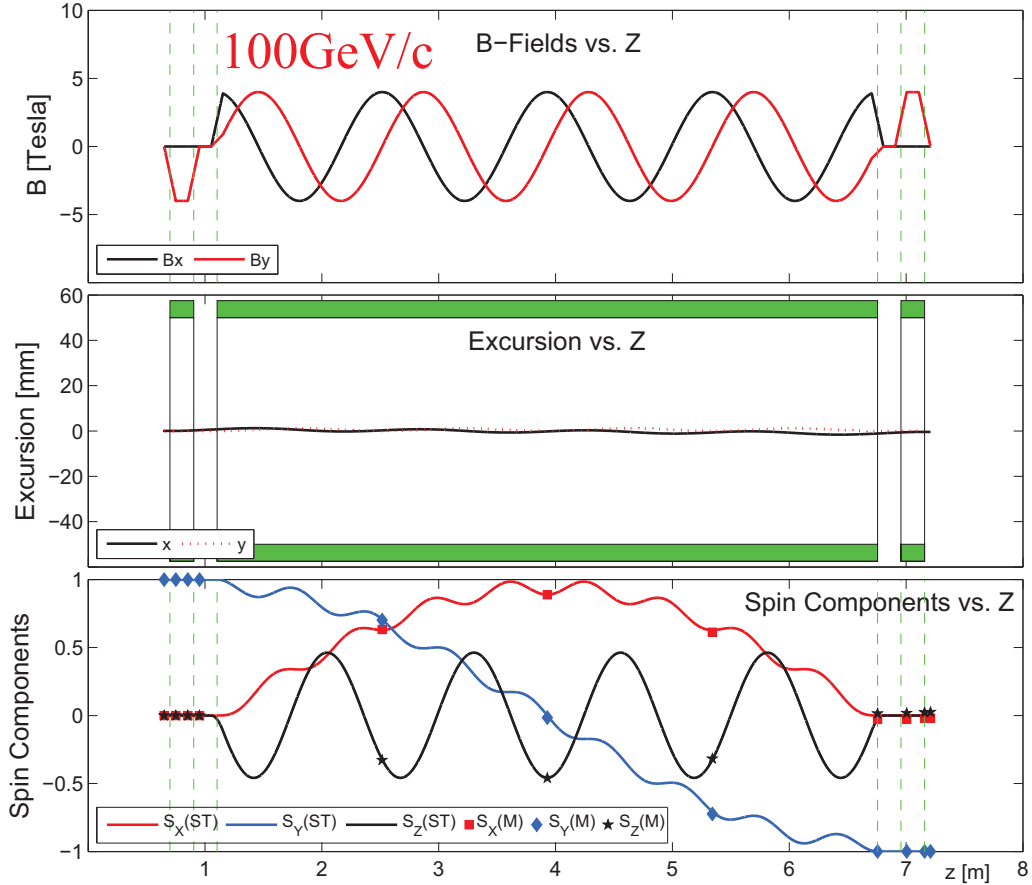
1 Siberian Snake in MI
(fits well)
plus 1 solenoid snake in RR



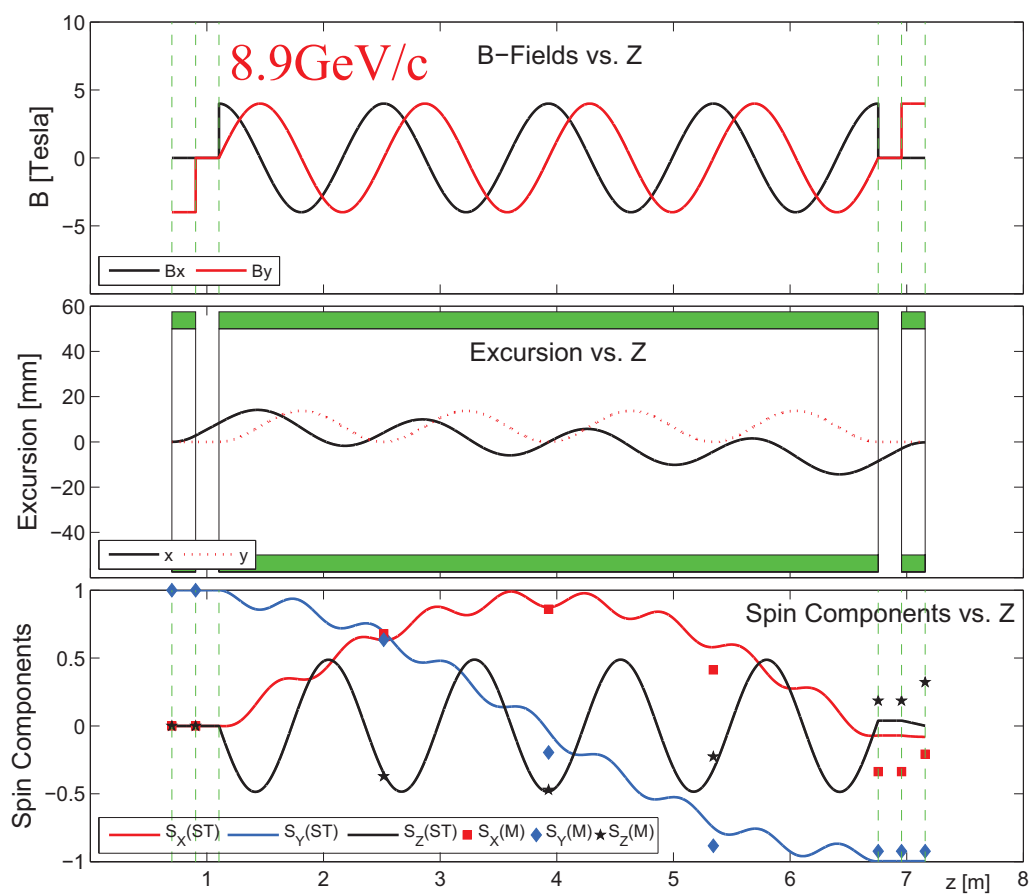

Recycler Ring (above MI)
Polarized Source
Spin Rotator
Polarimeter
RFQ's
MI Snake
Polarimeters
Sources
RR Snake
Switching
Magnet
8.9 GeV/c
Booster
400 MeV Linac
Fast Uncalibrated and CNI
Polarimeters with H_2 Jet Target
Pulsed Quads ?
120 GeV/c Main Injector
Partial Snake
SeaQuest
Beamline CNI Polarimeter
Fast Polarimeter



Plots for: 4T 5.6530m 4−Twist Helix with 4T 0.2030m Dipoles and 0.2m Gap:
Spin Tracking(ST): +/−0cm Fringe Fields for Dipoles and for Helix.
Matrix(M): +/−0cm Fringe Fields for Dipoles; 0 for Helix



Plots for: 4T 5.6530m 4−Twist Helix with 4T 0.2030m Dipoles and 0.2m Gap:
Spin Tracking(ST): +/−5cm Fringe Fields for Dipoles and for Helix.
Matrix(M): +/−5cm Fringe Fields for Dipoles; 0 for Helix



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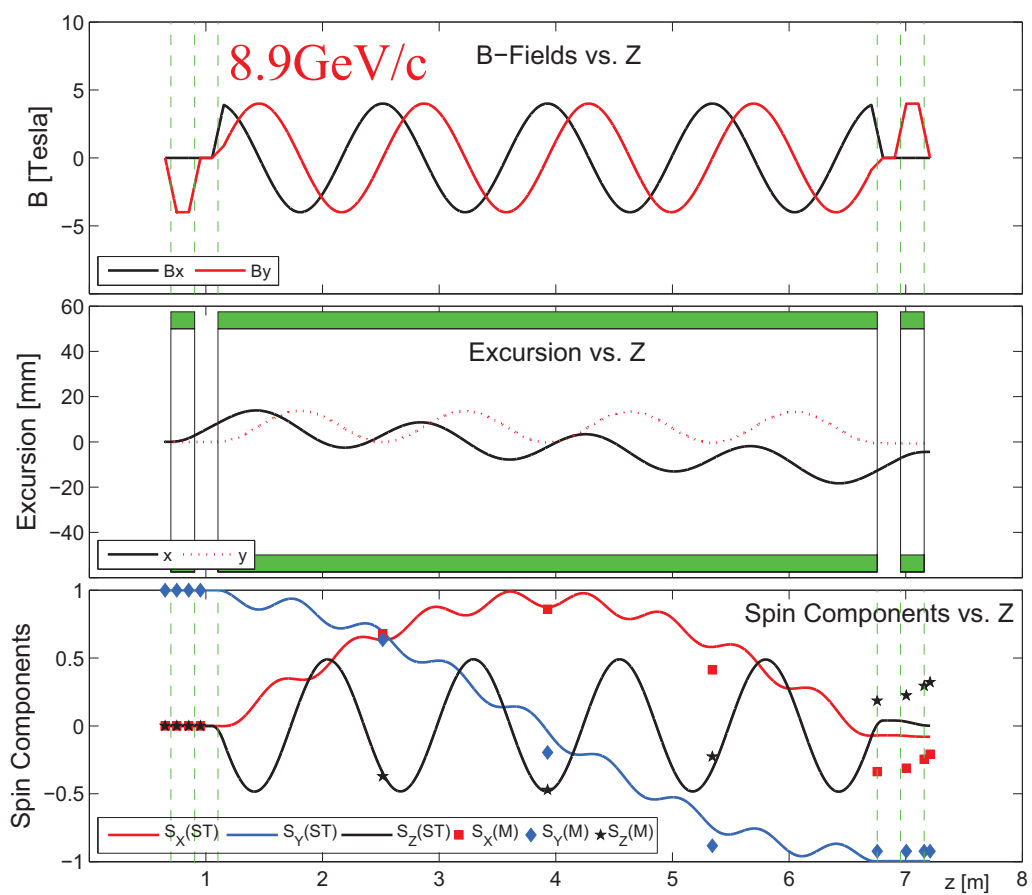
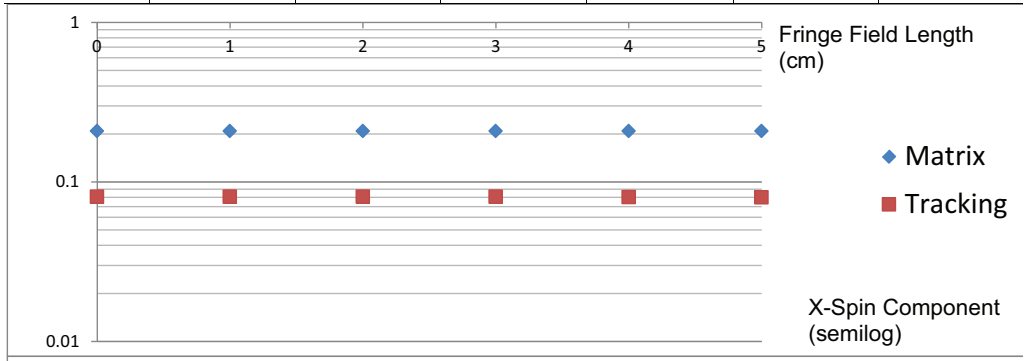


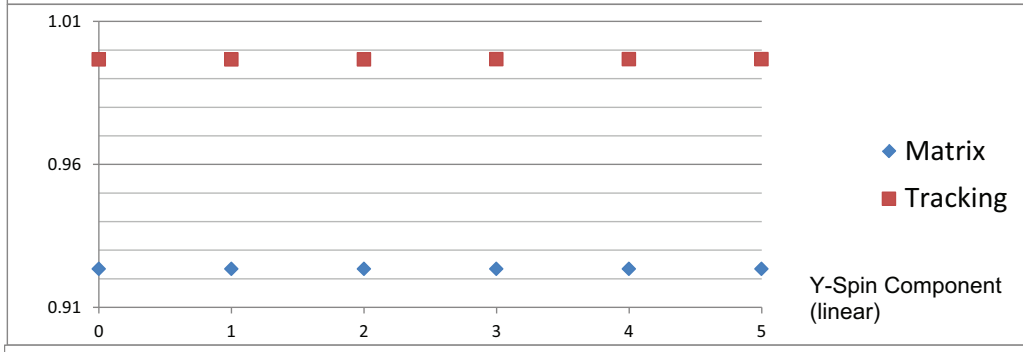
Plots for: 4T 5.6530m 4−Twist Helix with 4T 0.2030m Dipoles and 0.2m Gap:
Spin Tracking(ST): +/−5cm Fringe Fields for Dipoles and for Helix.
Matrix(M): +/−5cm Fringe Fields for Dipoles; 0 for Helix

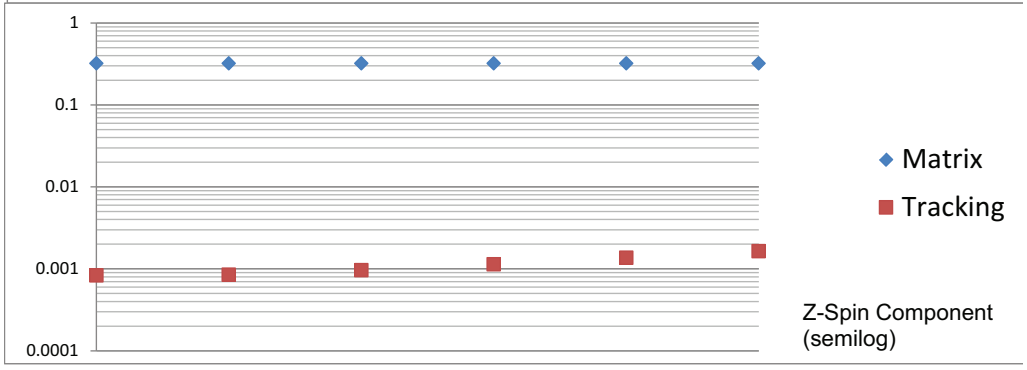
8.9GeV/c

17April2013

	X spin component		Y spin component		Z spin component	
Fringe Field	Matrix	Tracking	Matrix	Tracking	Matrix	Tracking
±0 (cm)	-0.2082552	-0.08078967	-0.9234424	-0.9967308	0.3223102	8.32E-04
±1 (cm)	-0.2082552	-0.08078838	-0.9234424	-0.9967309	0.3223102	8.46E-04
±2 (cm)	-0.2082552	-0.08073822	-0.9234424	-0.9967349	0.3223102	9.60E-04
±3 (cm)	-0.2082552	-0.08060145	-0.9234424	-0.9967458	0.3223102	1.14E-03
±4 (cm)	-0.2082552	-0.08033281	-0.9234424	-0.9967672	0.3223102	1.37E-03
±5 (cm)	-0.2082552	-0.07988473	-0.9234424	-0.9968028	0.3223102	1.64E-03



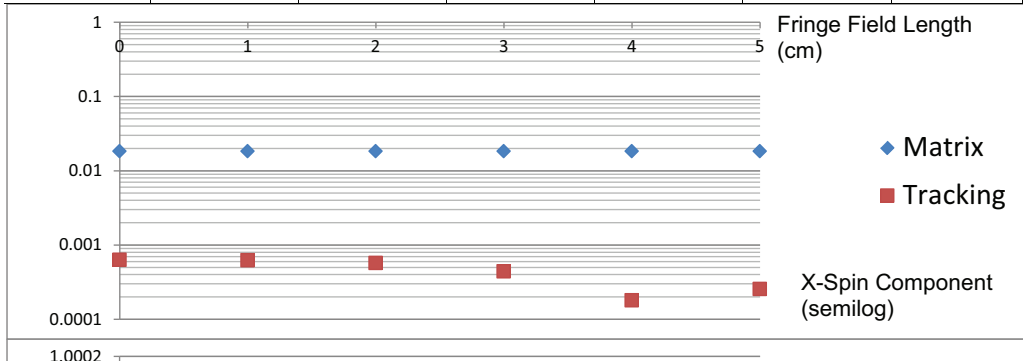


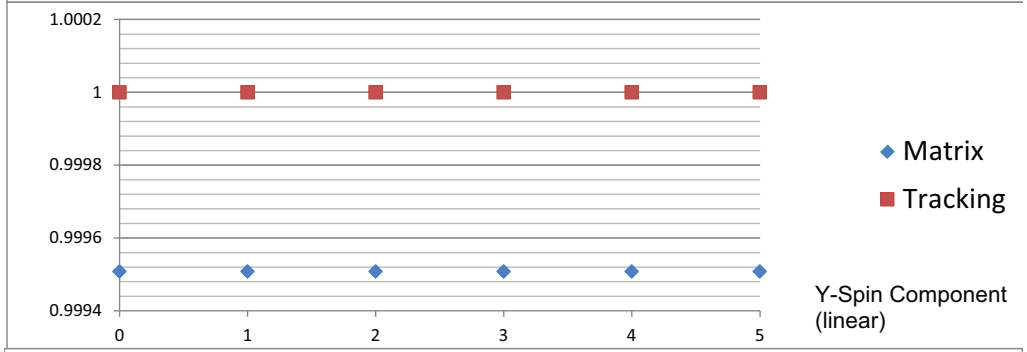


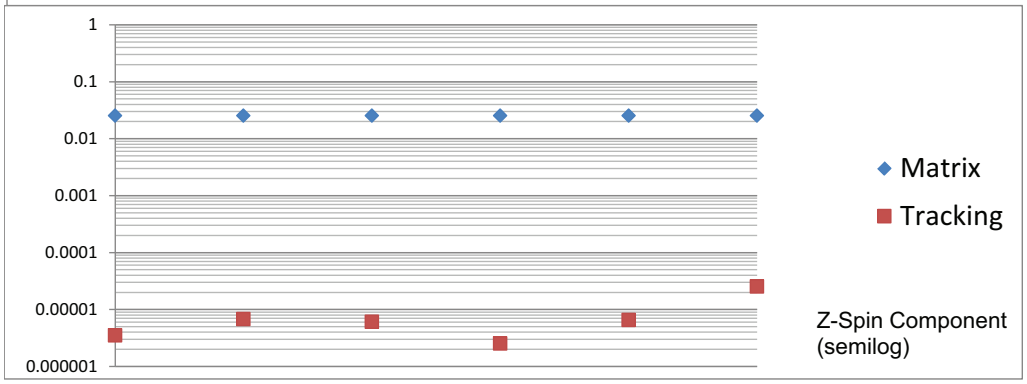
100GeV/c

17April201

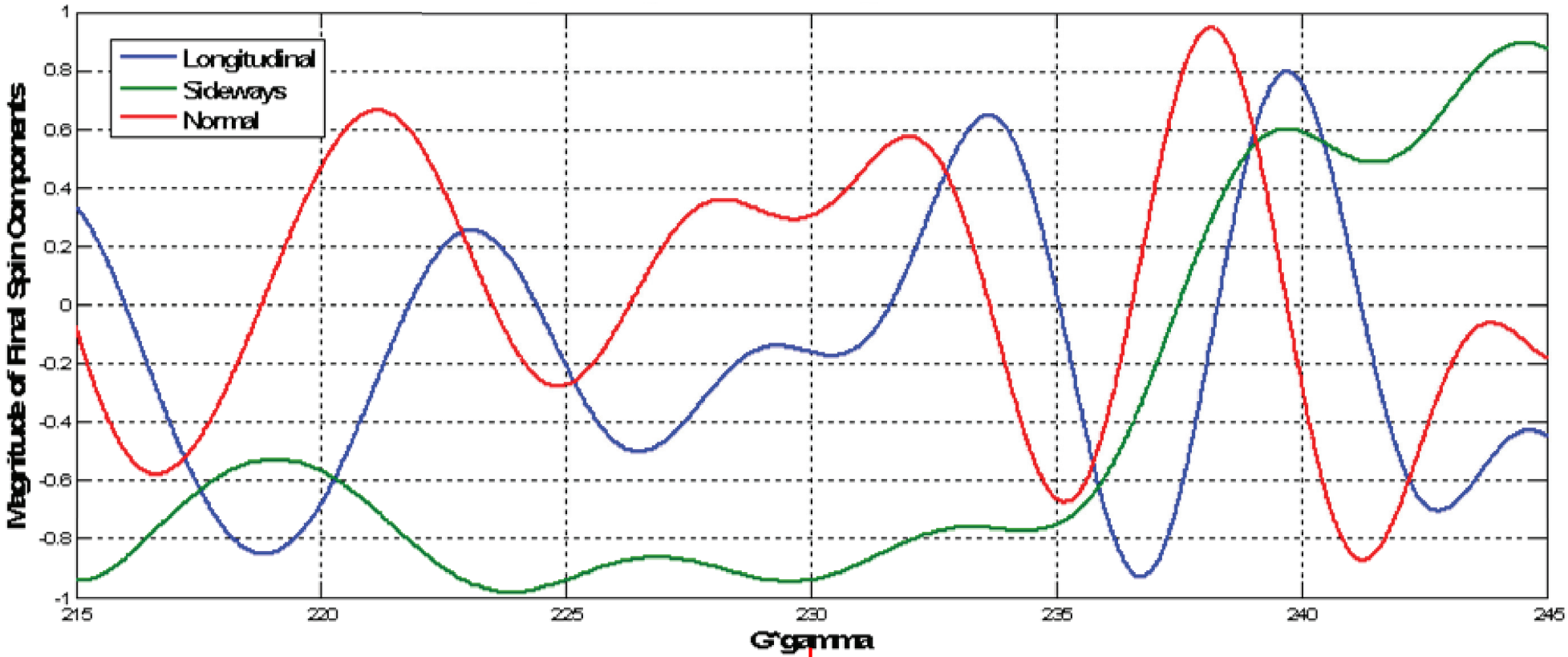
	X spin component		Y spin component		Z spin component	
Fringe Field	Matrix	Tracking	Matrix	Tracking	Matrix	Tracking
±0 (cm)	-0.0183628	-0.0006289	-0.9995076	-0.9999998	0.0254426	-0.000003522
±1 (cm)	-0.0183628	-0.0006211	-0.9995076	-0.9999998	0.0254426	0.000006825
±2 (cm)	-0.0183628	-0.0005725	-0.9995076	-0.9999998	0.0254426	0.000006062
±3 (cm)	-0.0183628	-0.0004398	-0.9995076	-0.9999999	0.0254426	0.000002532
±4 (cm)	-0.0183628	-0.0001792	-0.9995076	-1.0000000	0.0254426	-0.000006556
±5 (cm)	-0.0183628	0.0002549	-0.9995076	-1.0000000	0.0254426	-0.000025294







LONGITUINAL, VERTICAL & TRANSVERSE SPIN COMPONENTS at SEAQUEST



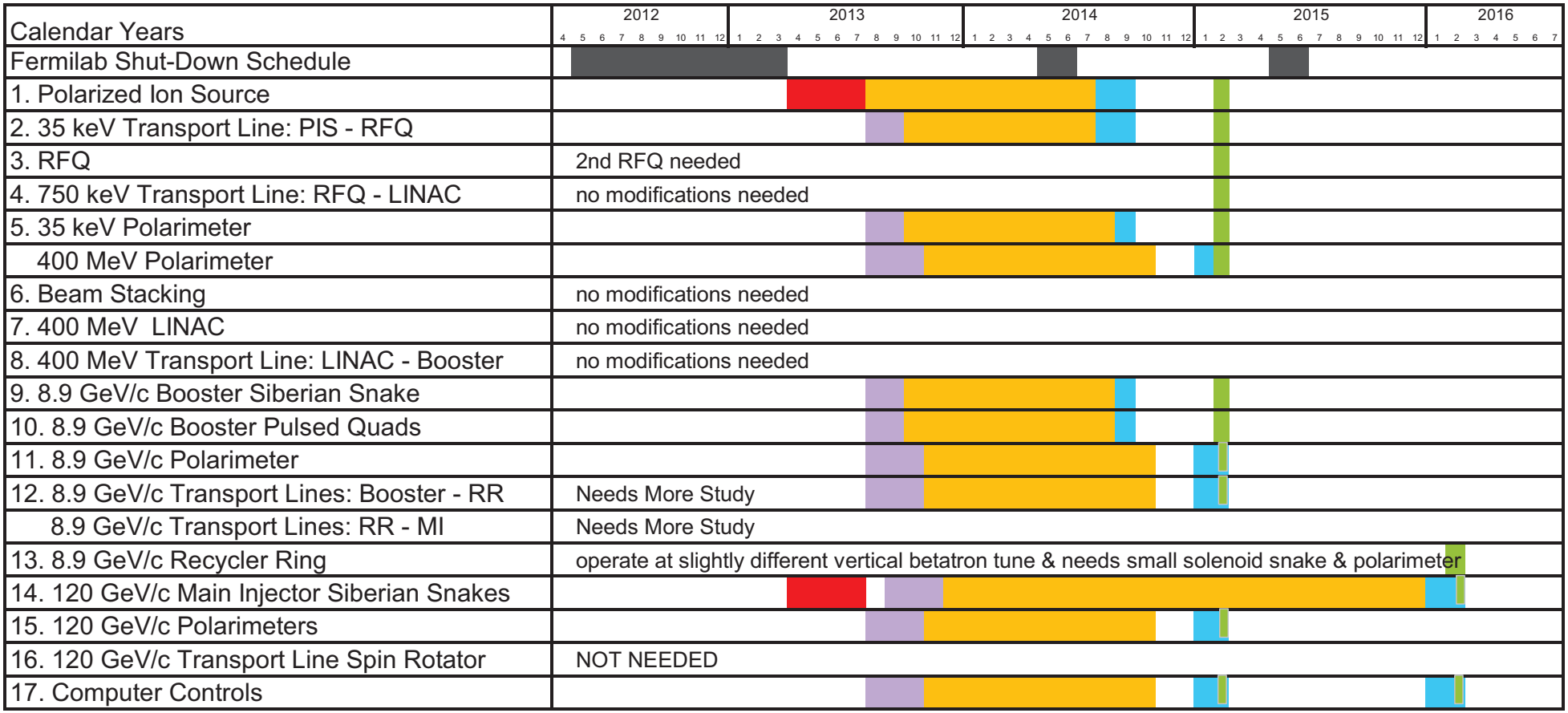
P = 120 GeV/c

POSSIBLE POLARIZED BEAM PROJECT CHART

NEEDS MORE STUDY

12 May 2013

A.Tai, D.A.Nees, P.D. Myers, M.A. Leonova, A.D.Krisch



Summary

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

- The world's highest intensity polarized proton beam, with the simple hydrogen target, should allow precise studies of polarized Drell-Yan processes.
- This high intensity 120 GeV polarized beam should allow precise measurements of spin-asymmetries out to $P_\perp^2$ of 50-70 $(GeV/c)^2$ for inclusive hadron production.
- With a solid polarized proton target, it could also allow precise 1-spin, 2-spin and spin-averaged studies of elastic proton-proton collisions out to $P_\perp^2$ of 12 $(GeV/c)^2$.

➢ Being forced to switch from 2 snakes to 1 snake resulted in inventing a simple new Siberian Snake, which reduced the total polarized proton beam cost from **~$26 Million to ~$10 Million.**

➢ Producing, installing & testing the hardware should take ~2-3 years after approval and funding.