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

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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

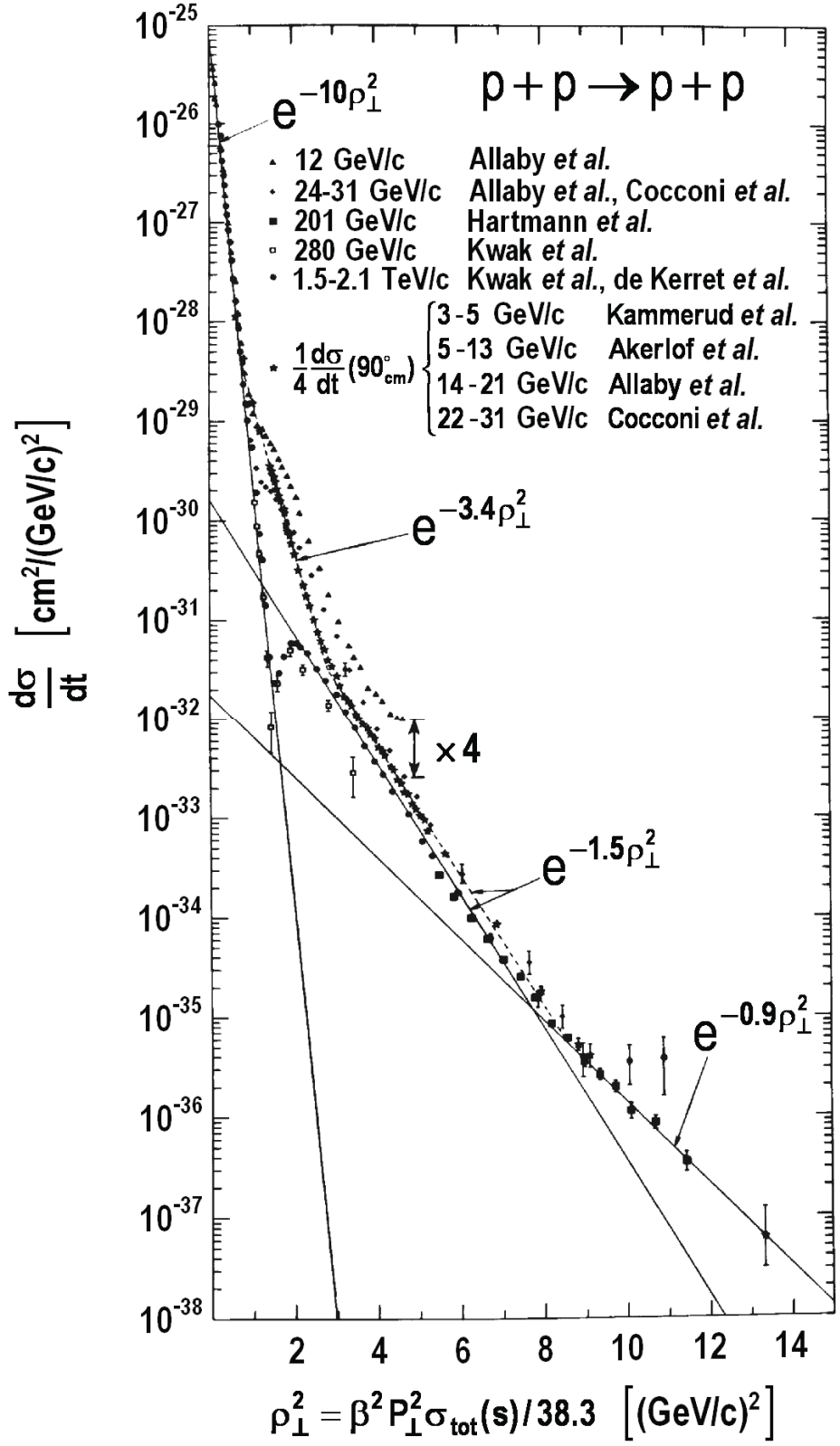
N_i and N_{ij} = NORMALIZED ELASTIC EVENT RATES

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

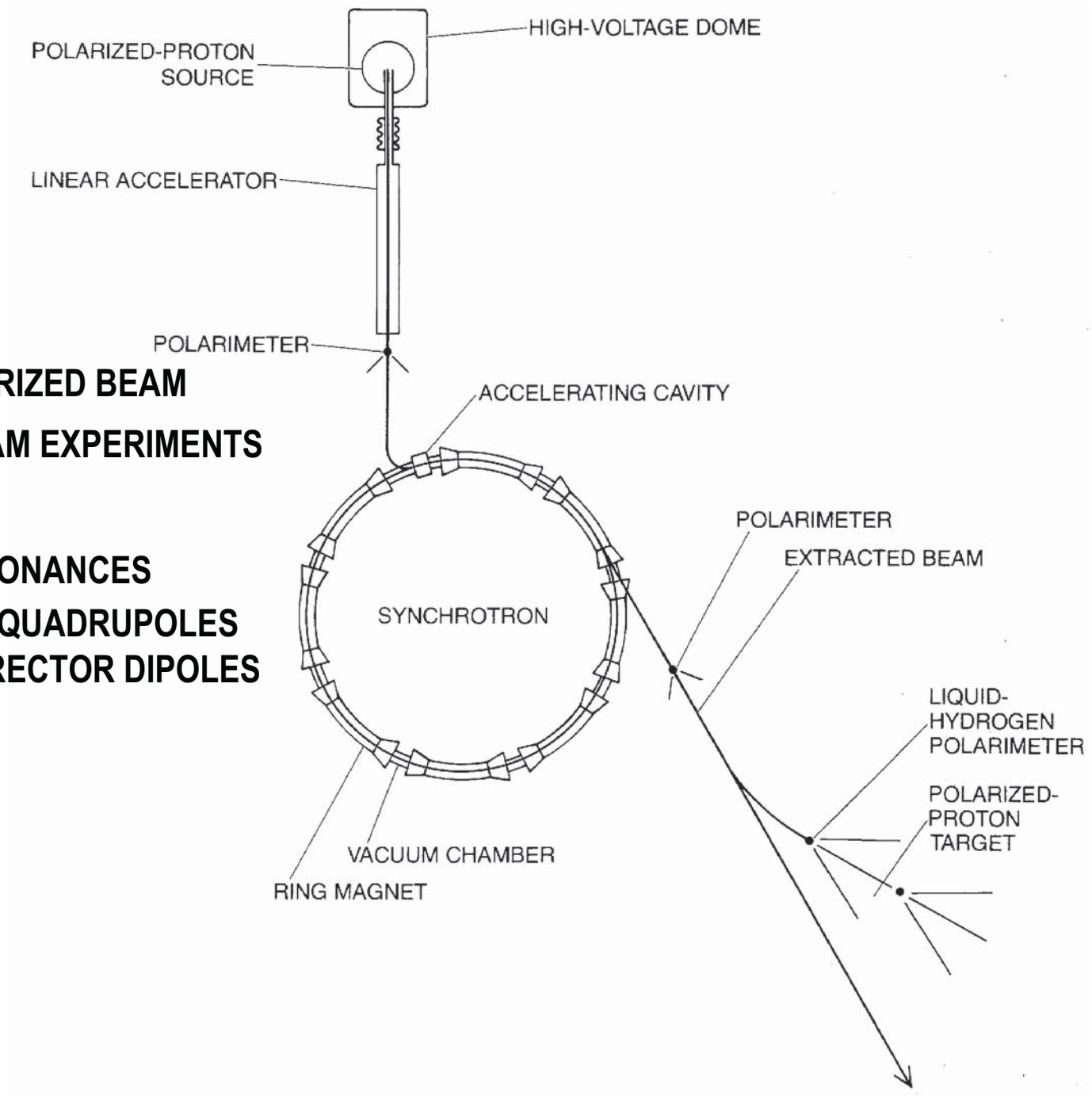
1969-1973 DEVELOP POLARIZED BEAM

1973-1979 POLARIZED BEAM EXPERIMENTS

DEPOLARIZING RESONANCES

INTRINSIC: PULSED QUADRUPOLES

IMPERFECTION: CORRECTOR DIPOLES



2-SPIN PROTON-PROTON ELASTIC CROSS SECTIONS

12 GeV ZGS

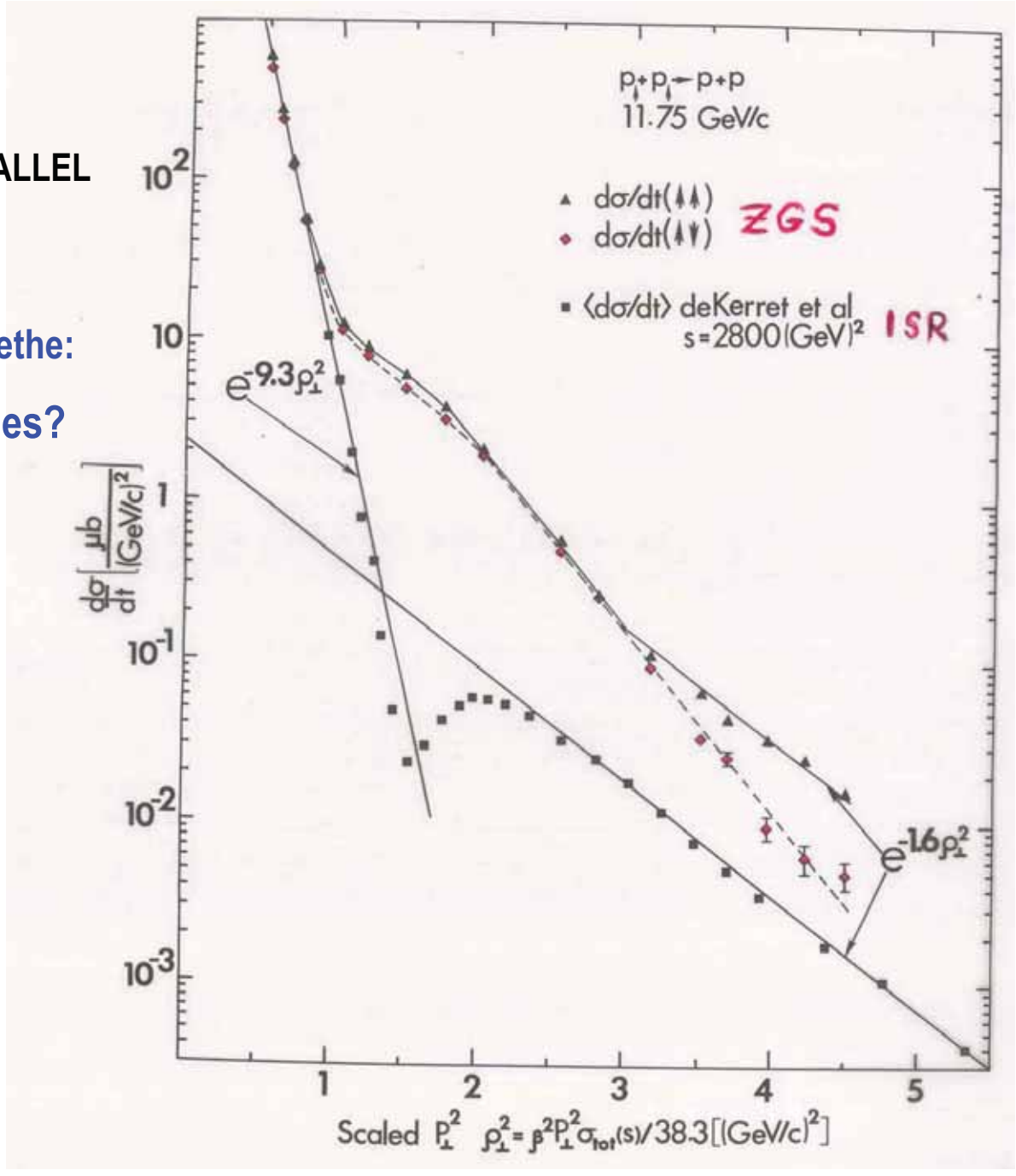
1977-1978

SPINS PARALLEL 4x SPINS ANTIPARALLEL

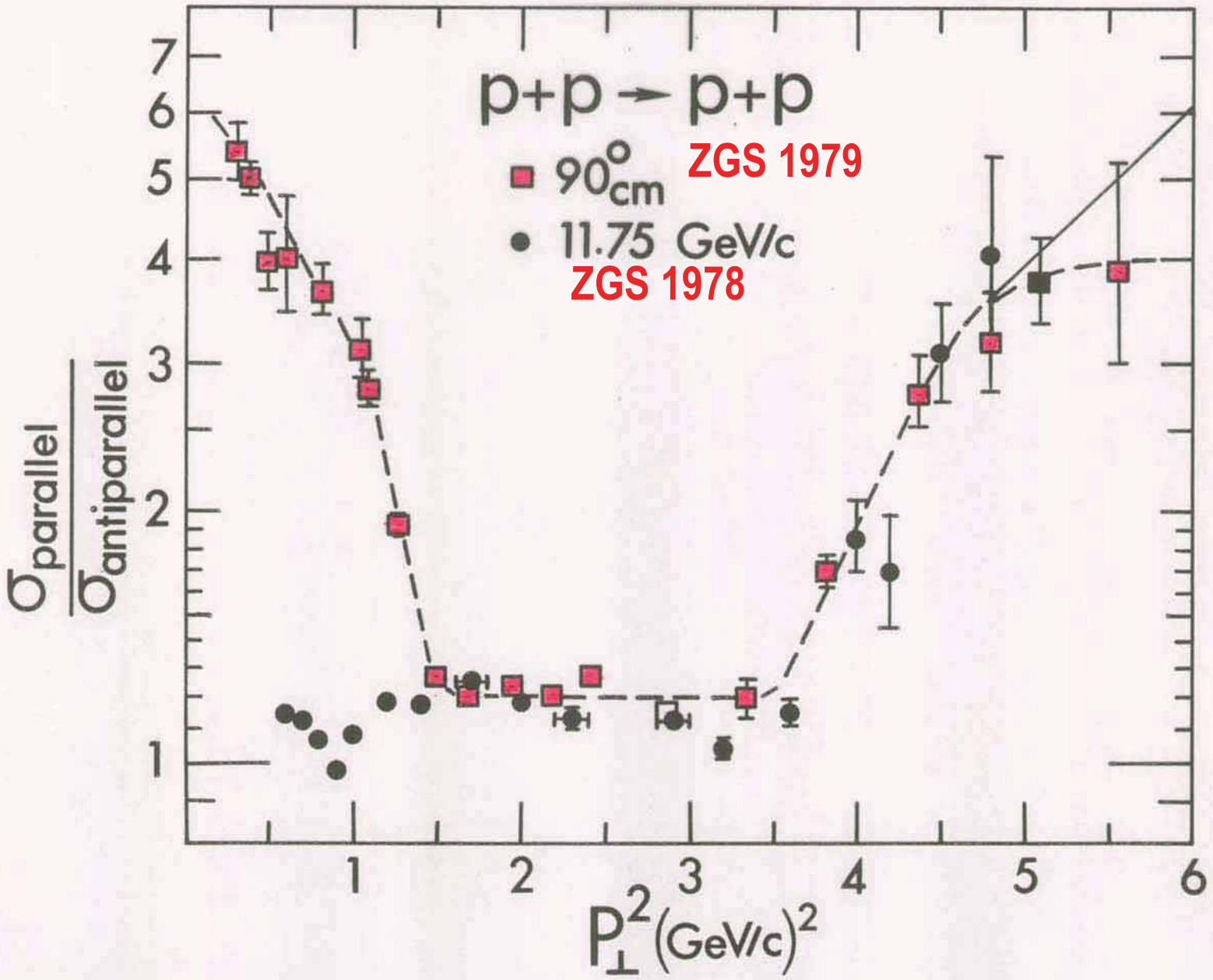
TOTALLY UNEXPECTED

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

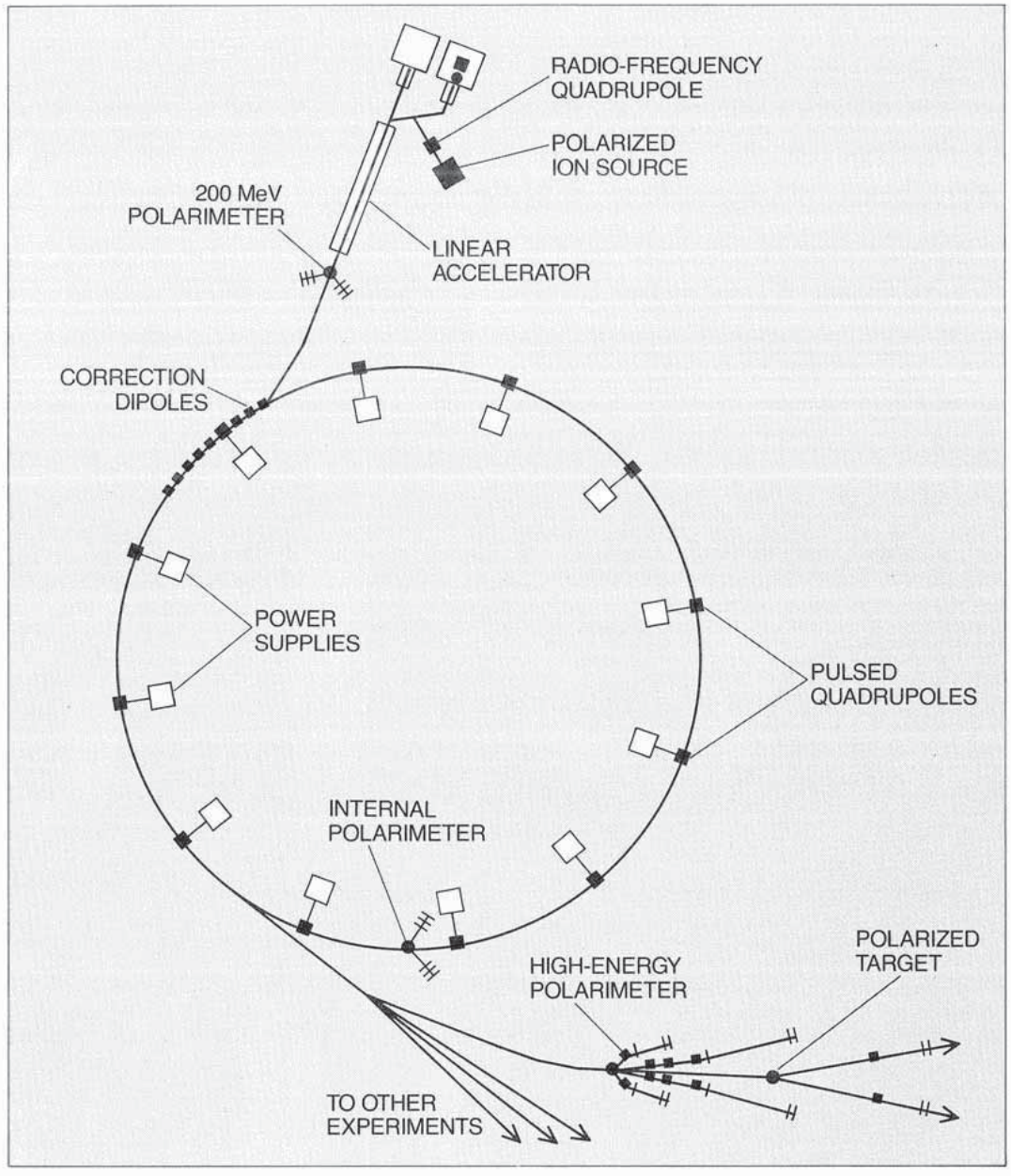
12 Pulsed Quads 96 Correction Dipoles

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?

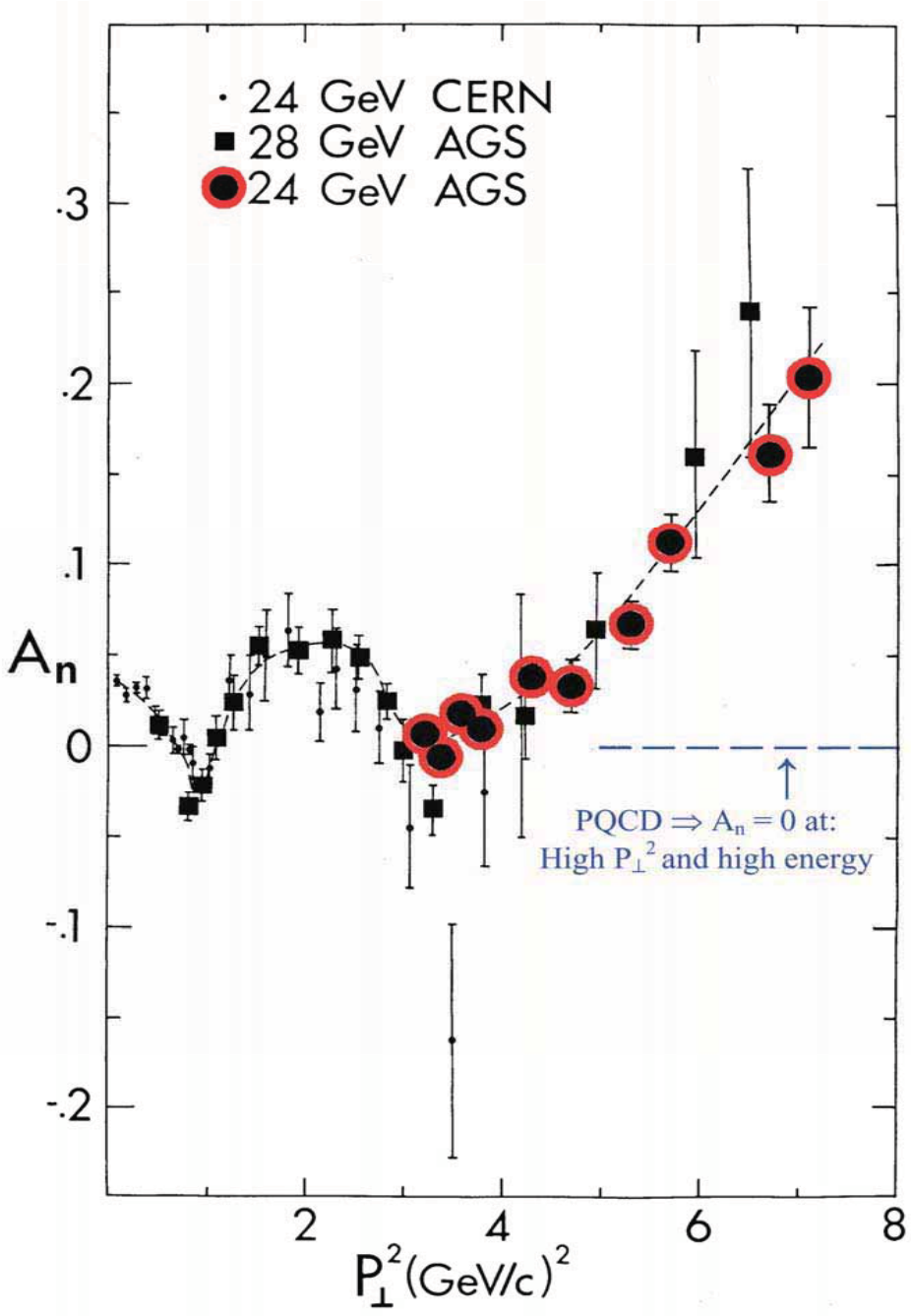
NO MODEL can EXPLAIN ALL

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

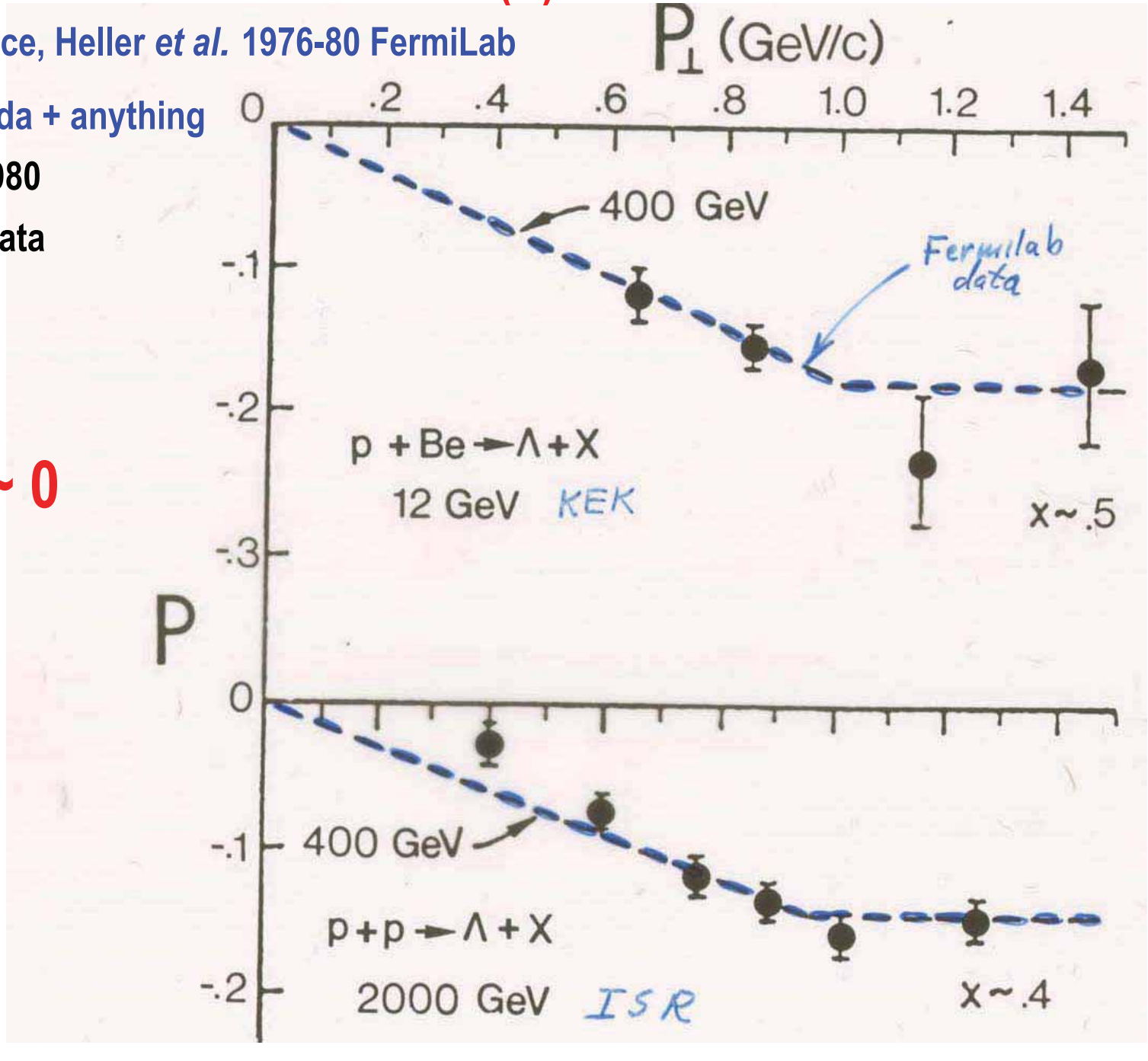
400 GeV p+p -> Lambda + anything

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

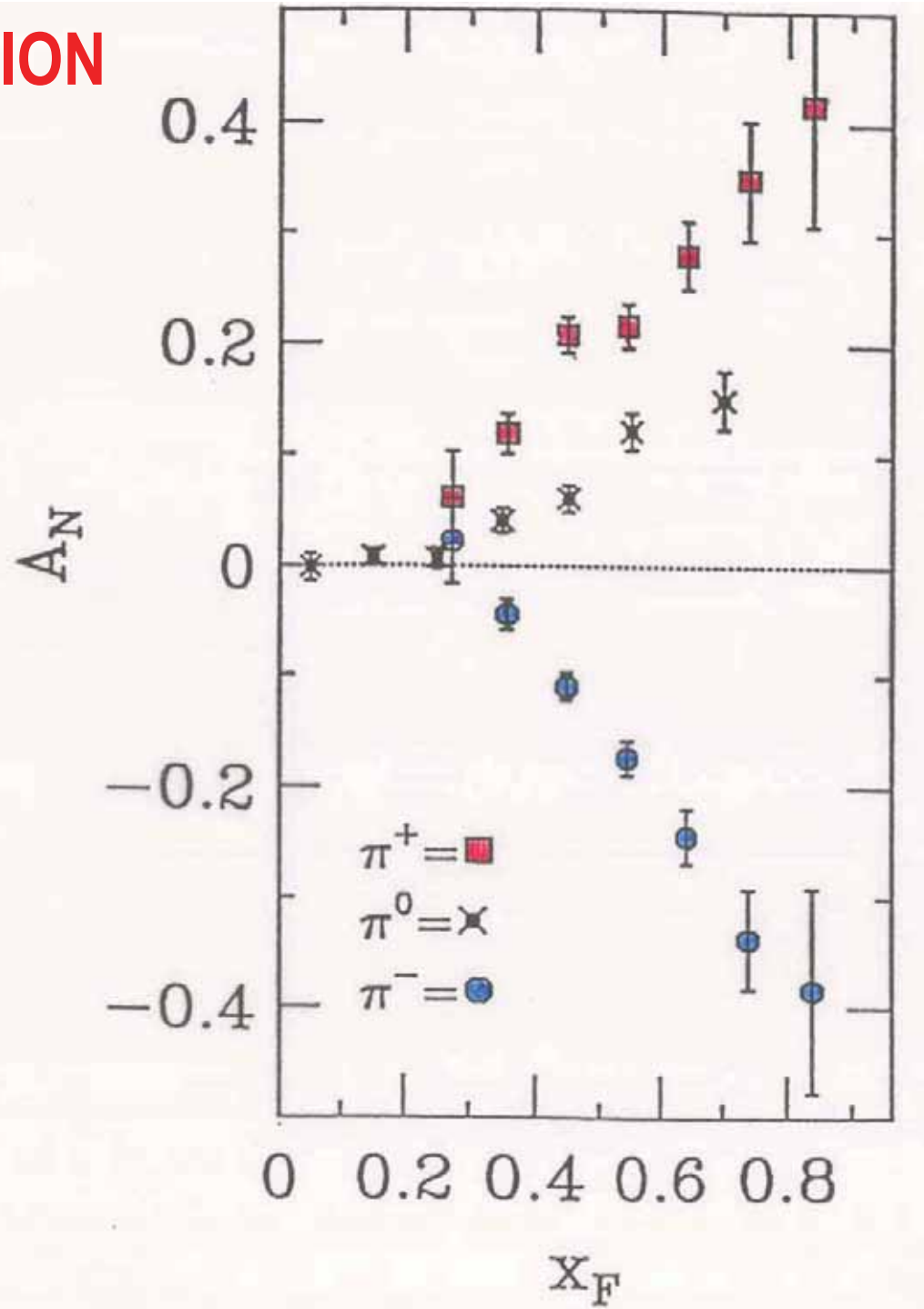
1990s Fermilab E-704

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 on 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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(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.

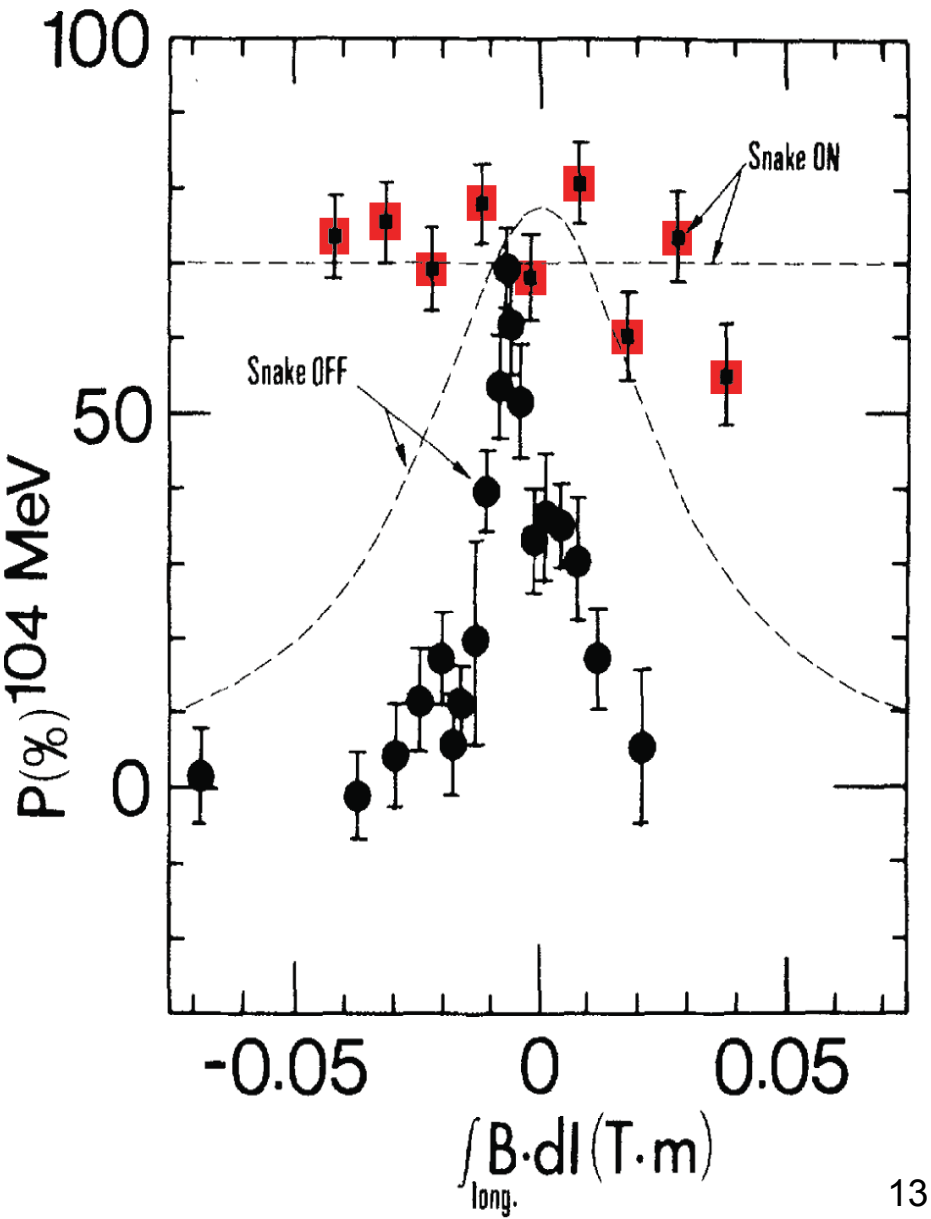
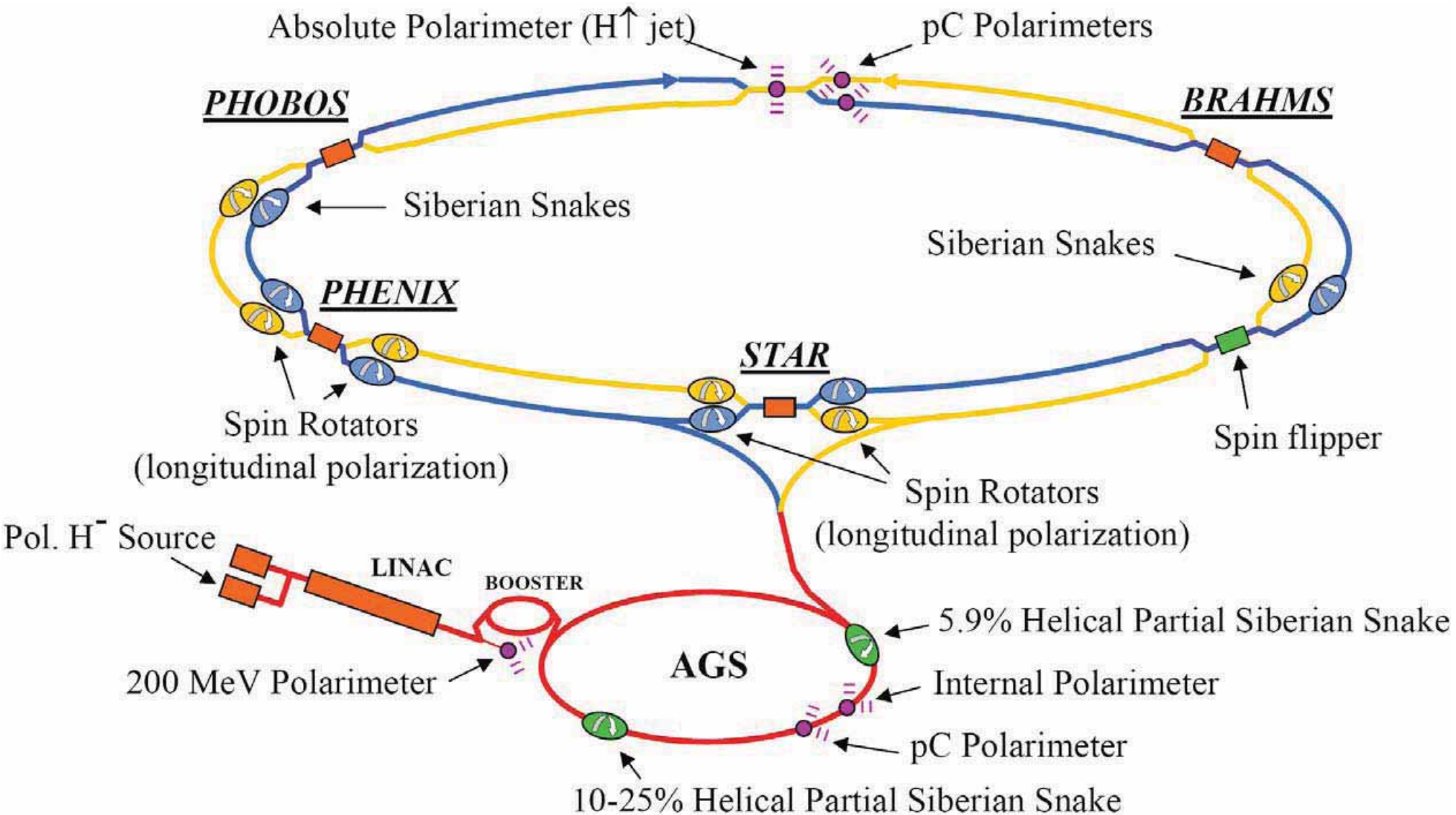


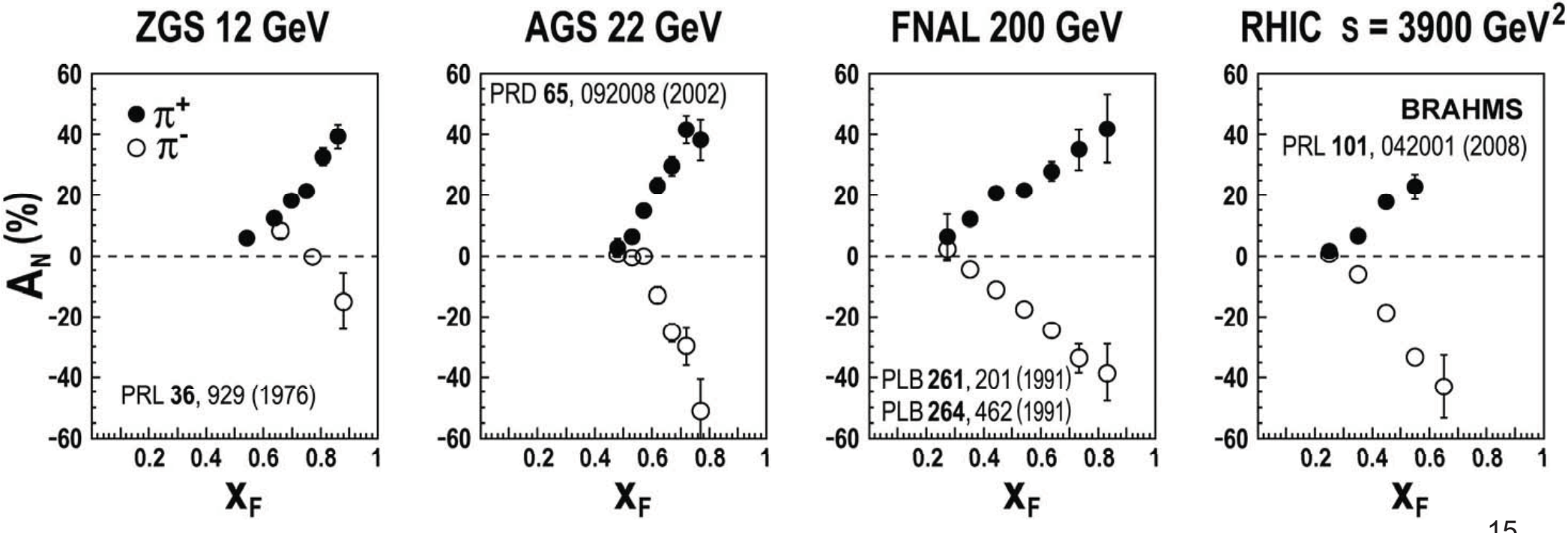
FIG. 4. The beam polarization in each stable polarization direction at 104 MeV is plotted against the longitudinal magnetic field integral in the Cooler Ring solenoids. The circles are the vertical polarization with the snake off and the injection of vertically polarized protons. The squares are the 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

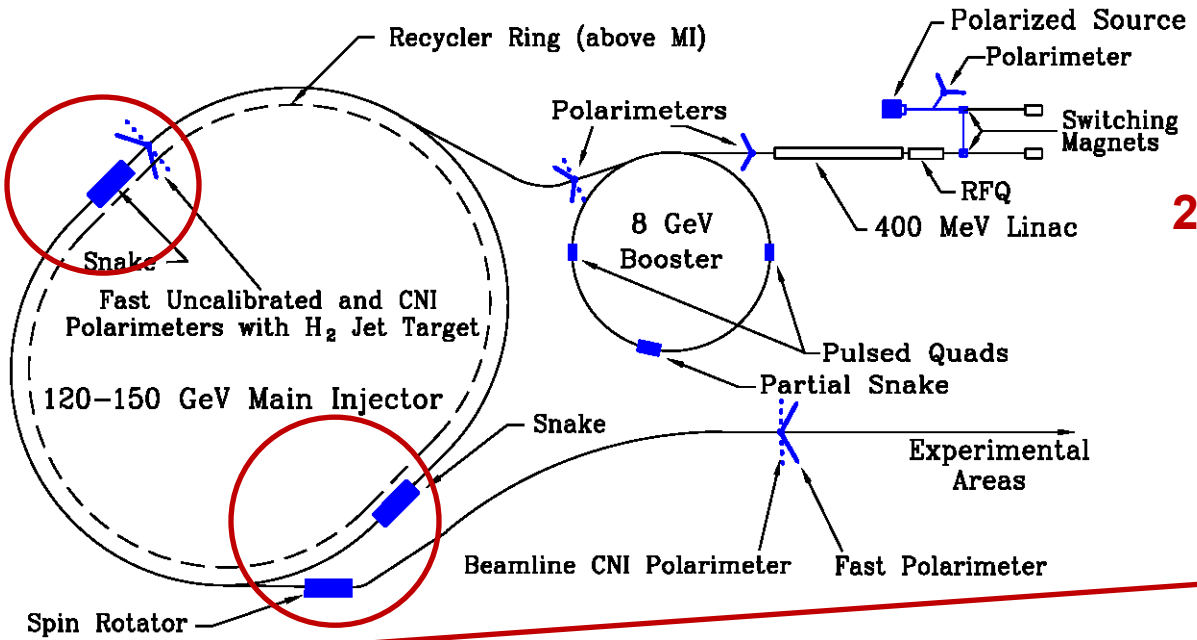


INCLUSIVE PION ASYMMETRY IN PROTON-PROTON COLLISIONS

C. Aidala SPIN 2008 Proceeding and CERN Courier June 2009

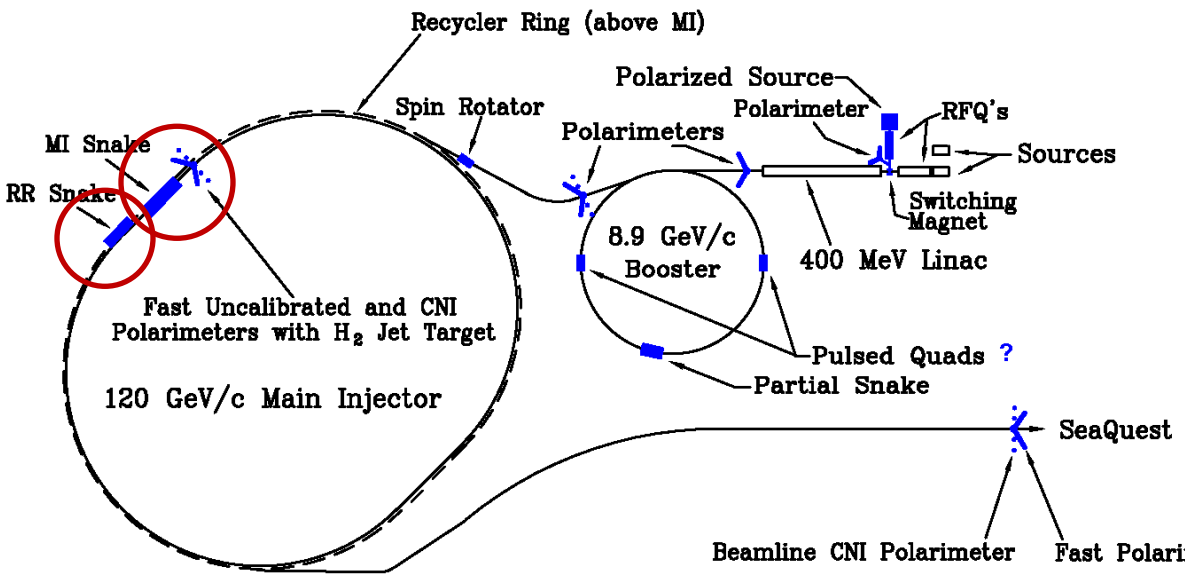


FROM 2 Siberian Snakes + 1 Spin Rotator TO 1 Snake



2 Siberian Snakes in MI
(not enough space)

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



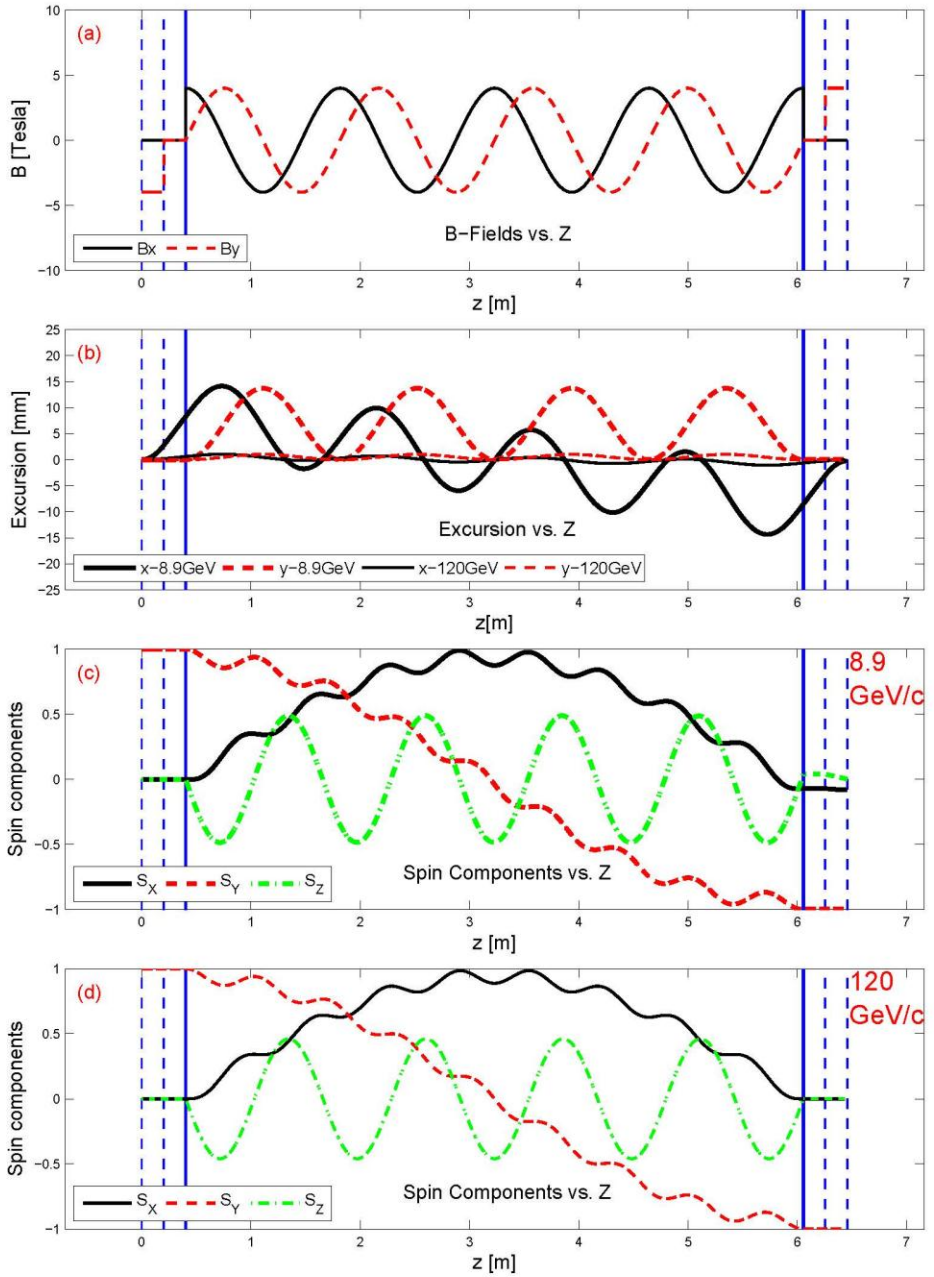
Summary Single Fermilab 4-Twist Helical Snake

(a) Graphs showing properties of Siberian Snake; vertical solid blue lines represent edges of 4-twist helix, vertical dashed blue lines represent edges of dipoles. Horizontal and vertical *B*-field components as a function of *z* for a 4 T, 5.653 m, 4-twist helical dipole with 4 T, 0.203 m dipoles and 0.2 m gaps.

(b) Horizontal and vertical orbit excursions as a function of *z*; for 8.9 (thicker lines) and 120 (thinner lines) GeV protons.

(c) Radial, vertical and longitudinal spin components as a function of *z* for a proton beam energy of 8.9 GeV.

(d) Spin components for a beam energy of 120 GeV.



Fermilab 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.**

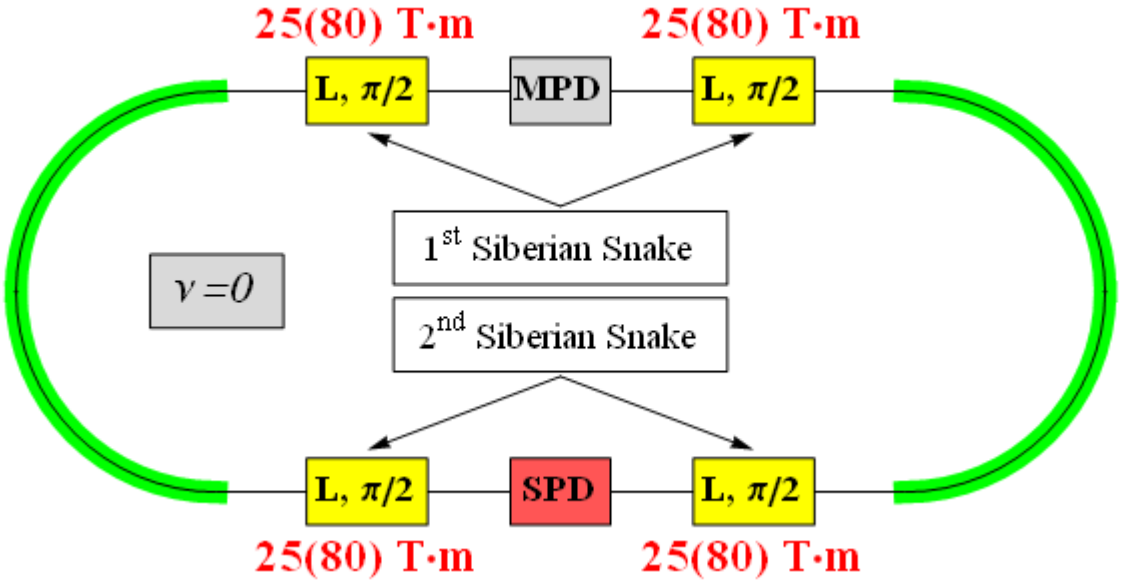
➢ Producing, installing & testing the hardware should take ~2-3 years after approval and funding.

Polarization control scheme in the Collider with spin tune $\nu = 0$

Solenoid-based Siberian Snake

$(B_{||}L)_{max}=2\times25$ T·m (protons),

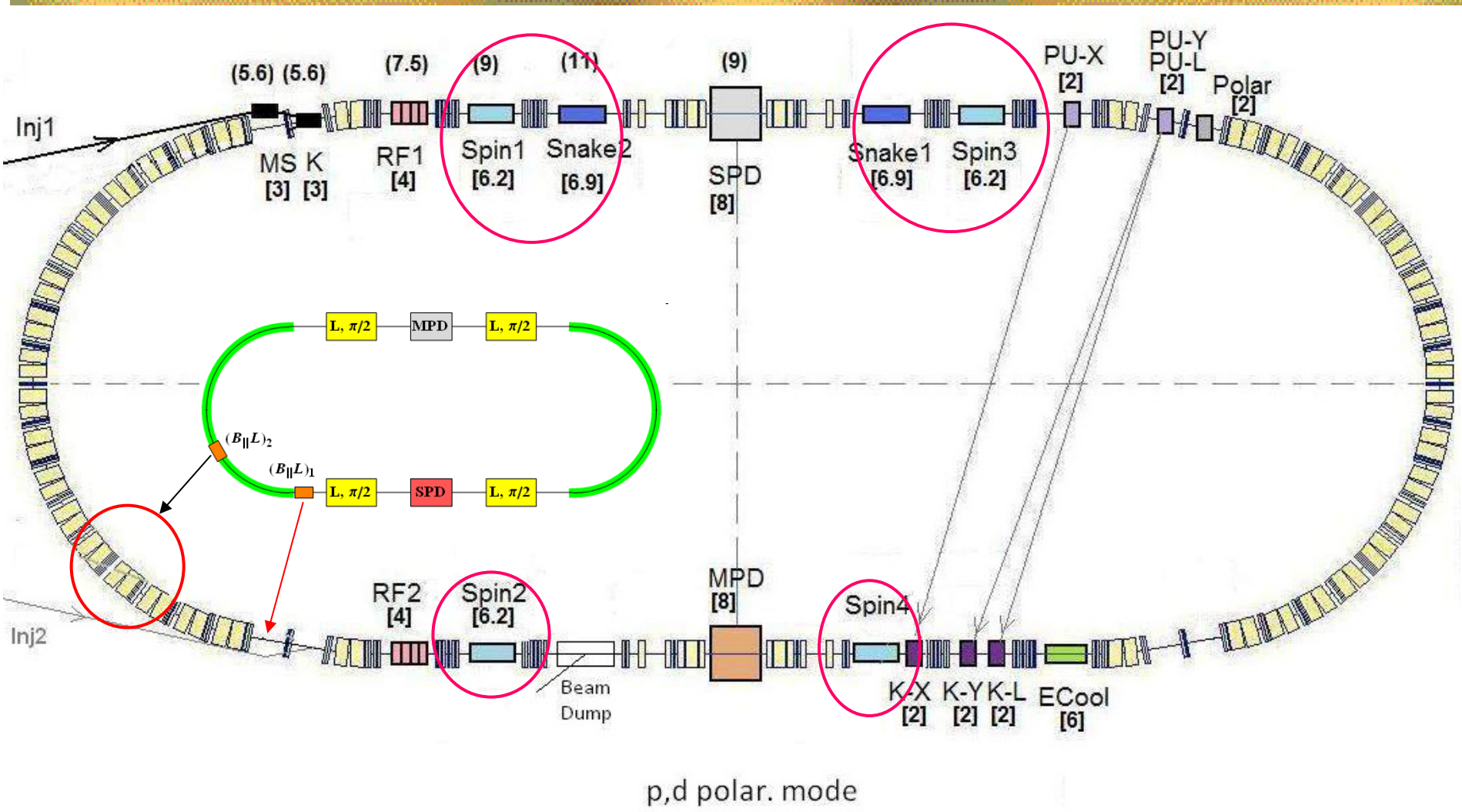
$(B_{||}L)_{max}=2\times80$ T·m (deuterons)



Solenoids with stationary fields of B_{max}~ 12.5÷17 T can be used to obtain necessary integrals of longitudinal fields.

Cooperation with the US, European and Russian Laboratories is desirable in the designing of such solenoids

Scheme of NICA collider ring



p,d polar. mode

COMMENTS on March 2013 NICA SNAKE DESIGN

The 8 or12 superconducting solenoids would each need an $\int B \cdot dl$ of about 80 T·m .

This would require Superconducting magnetic fields of 12.5 to 17 T, which is only possible using Niobium Tin, which is much more expensive than normal Niobium Titanium. It would also require operation at below ~1.8 K, which is very dangerous in an accelerator with high currents that might spark (and beams that might hit the walls) and warm the Helium above 1.8 K, where both materials cease being superconducting if the magnetic field exceeds some limit. Sparks is apparently what caused the very big problem for the LHC when they tried to operate it at ~7 TeV; but this could also happen if the beam hit the vacuum pipe walls and heated the Helium.

We had built a 12 Tesla solenoid for our Ultra Cold Polarized Jet, which was to be used at UNK. The manufacturer said it could operate at 14 T if we lowered the temperature to below ~1.8 T, but they had not tested it and could not be sure that it would not destroy itself, as did the test version of their solenoid when its forces crushed its too thin core.

I am not an expert, but the 75 T/m quadrupoles also seem to be a difficult project.

Another problem is that the scheme shows both straight sections filled with suprconducting solenoid and quadrupoles.
Except for the SPD and MPD, there is no space to do experiments no space to do small angle experiments such as the Roman pot experiments at CERN.

Another concern is that with so many different solenoids and quadrupoles they may have to be tuned during beam time to insure that they are all matched to give the 180 degree rotation needed to be a proper snake. We faced this problem in1988 at the AGS when trying to overcome 49 resonances, which took 7 weeks. That convinced us that one needed the brilliant simplicity of a single Siberian snake which took only a short time to tune to 180 degree spin rotation.

For 24 on 24 GeV protons, one might consider using only one 4 Twist transverse field Helix snake in the Nuclotron and one in NICA.
For deuterons,one can easily reach 9 GeV in the Nuclotron since its first depolarizing resonance is near 10 GeV. One could then find some energy where there are no deuteron resonances in NICA and study ~9 GeV on 9 GeV deuteron collisions.