

29 July 2010
J-LAB

POLARIZED PROTON BEAMS: PAST, PRESENT & FUTURE

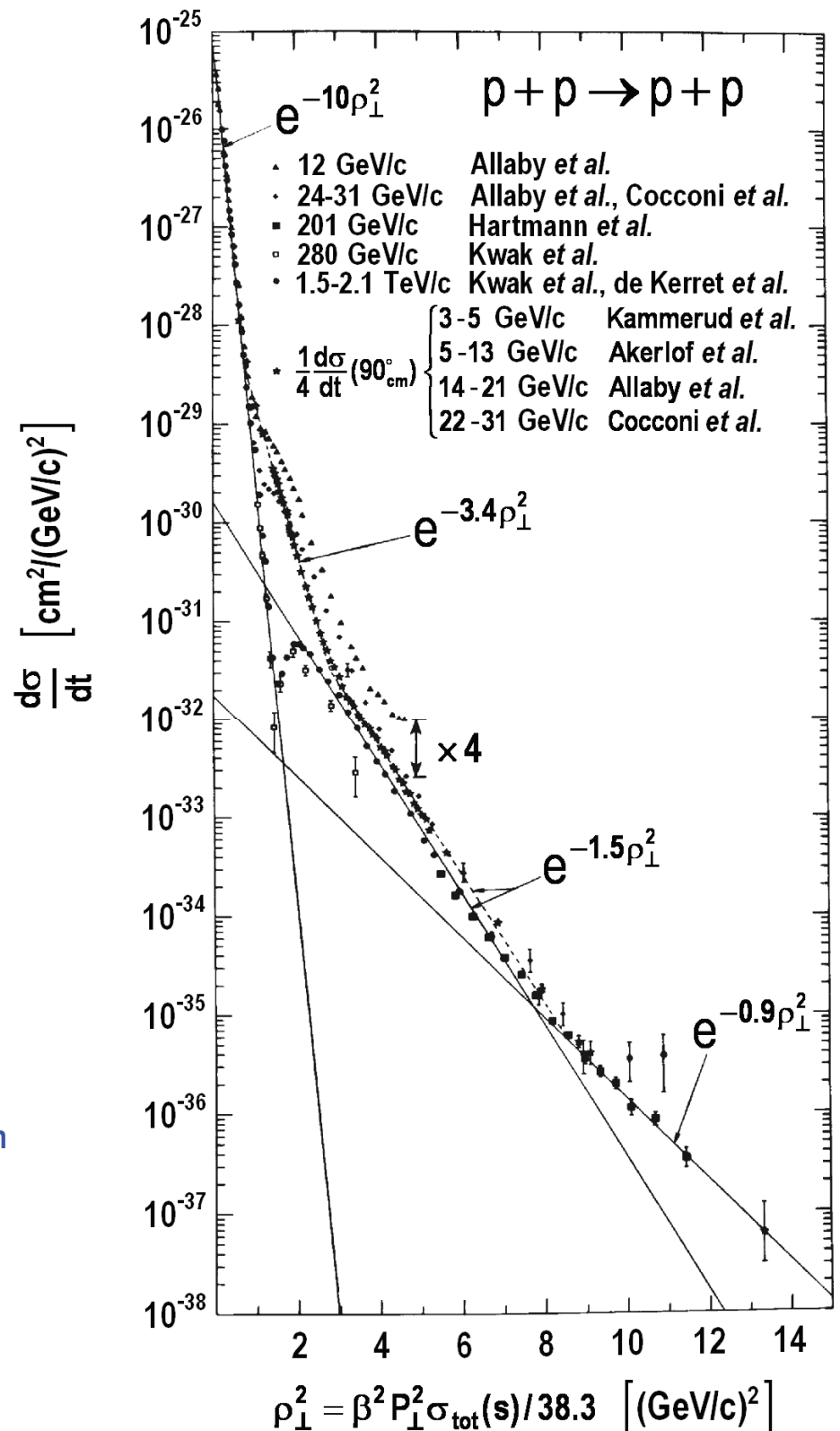
A. D. KRISCH
UNIVERSITY of MICHIGAN

PROTON-PROTON ELASTIC CROSS-SECTION

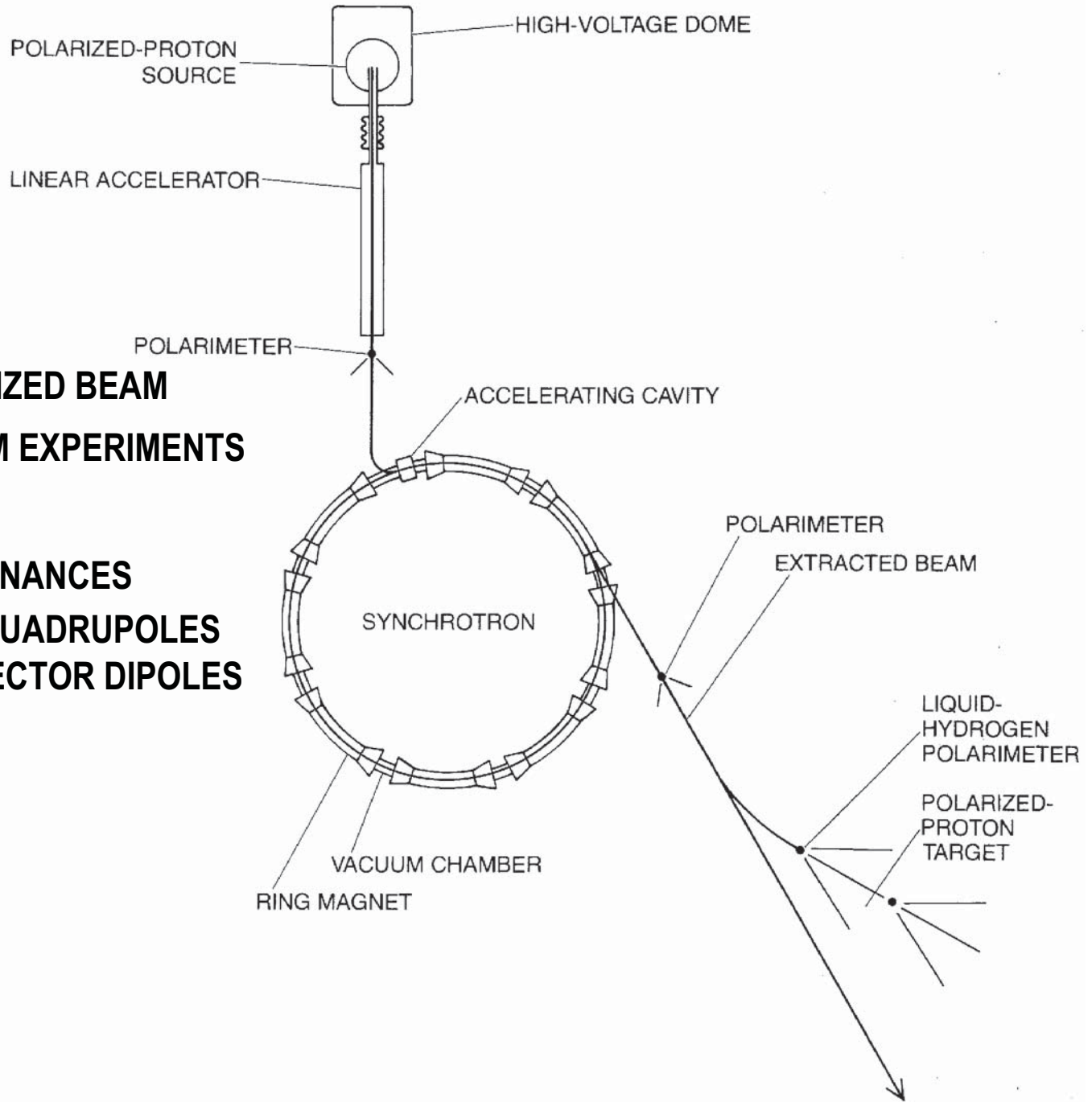
UNPOLARIZED $d\sigma/dt$ for all
 $p + p \rightarrow p + p$ data above 3 GeV
 PLOTTED vs. SCALED P_{\perp}^2 VARIABLE

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

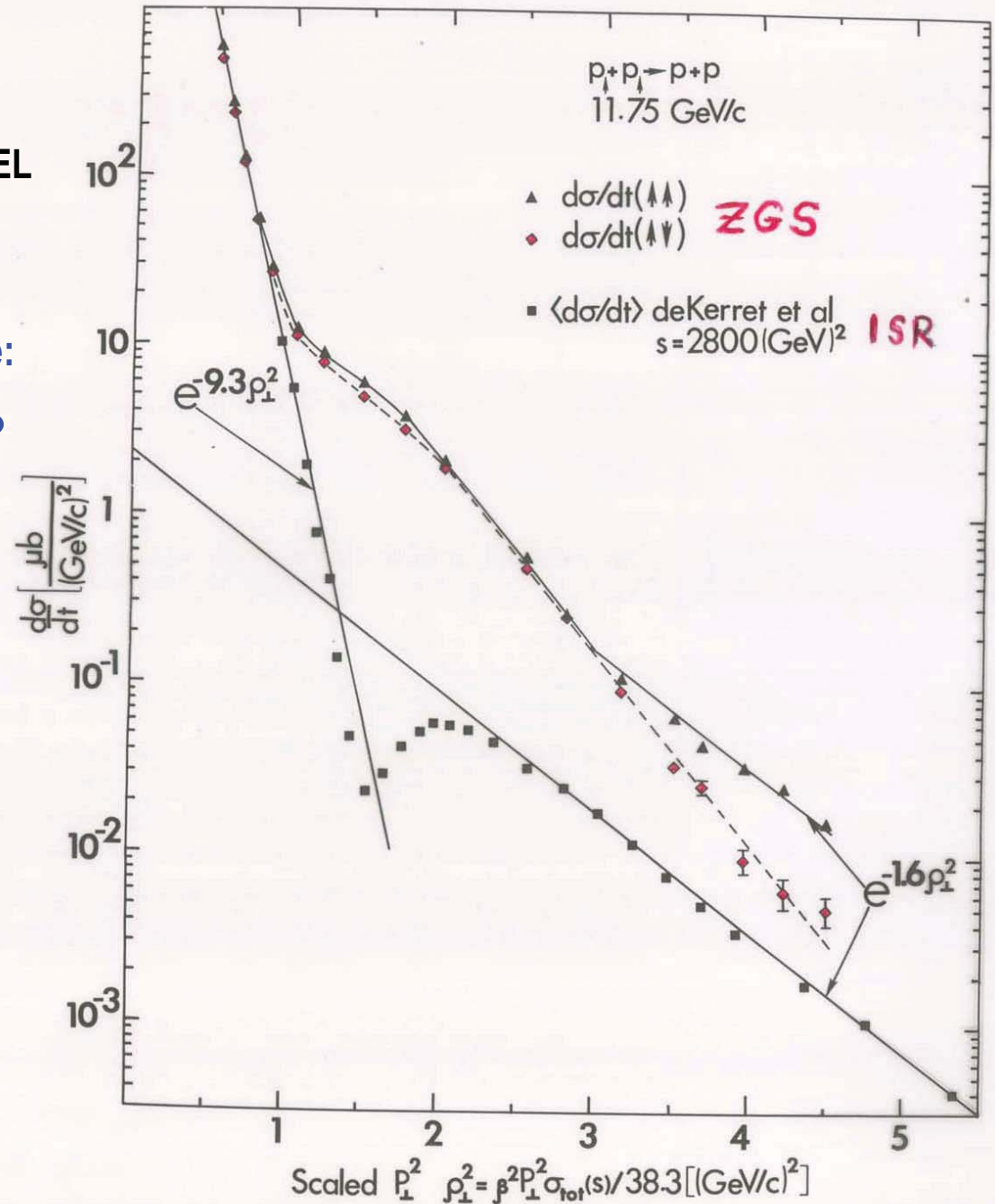
2-SPIN PROTON-PROTON ELASTIC CROSS SECTIONS

12 GeV ZGS

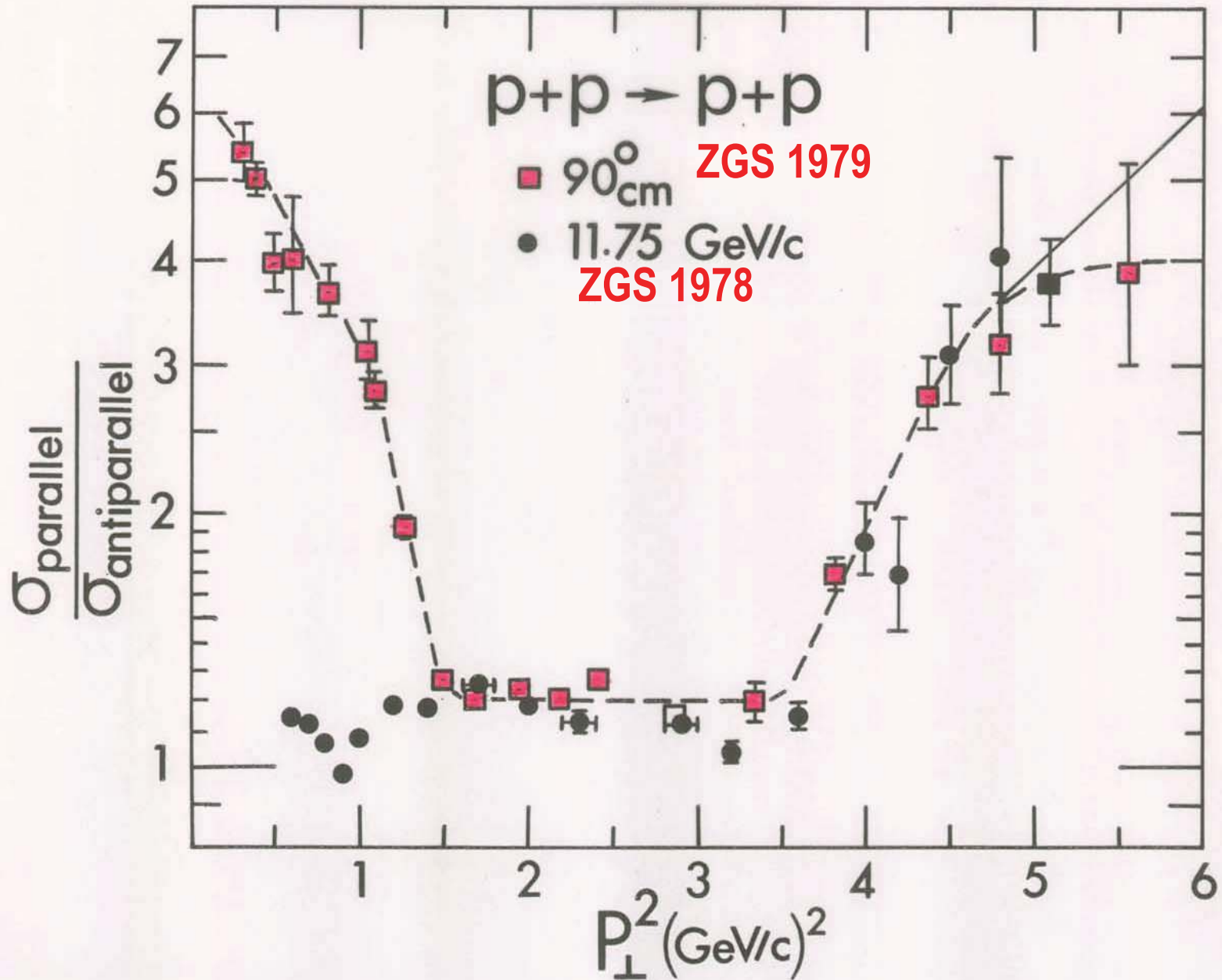
1977-1978

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

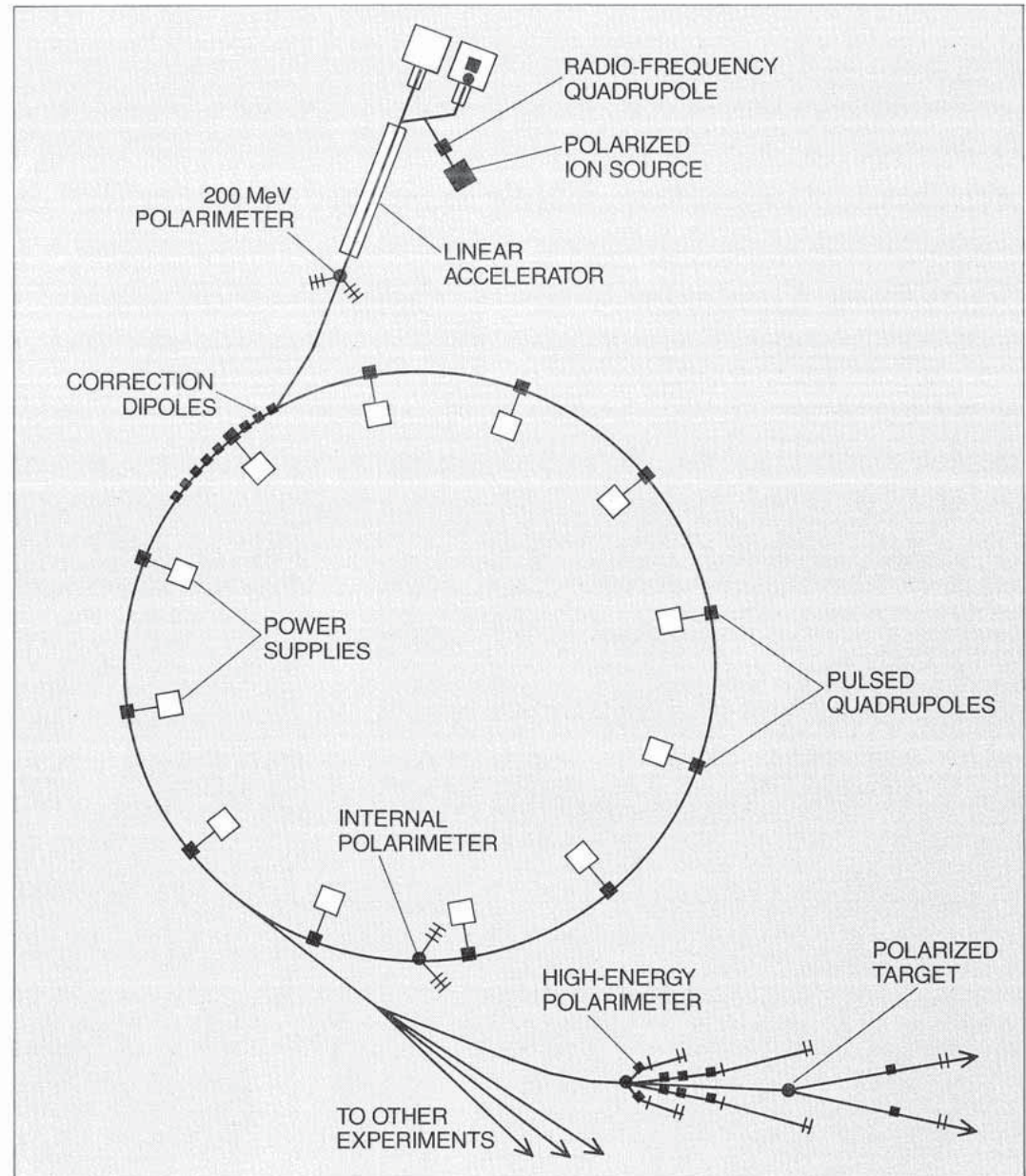
96 Correction Dipoles

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



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

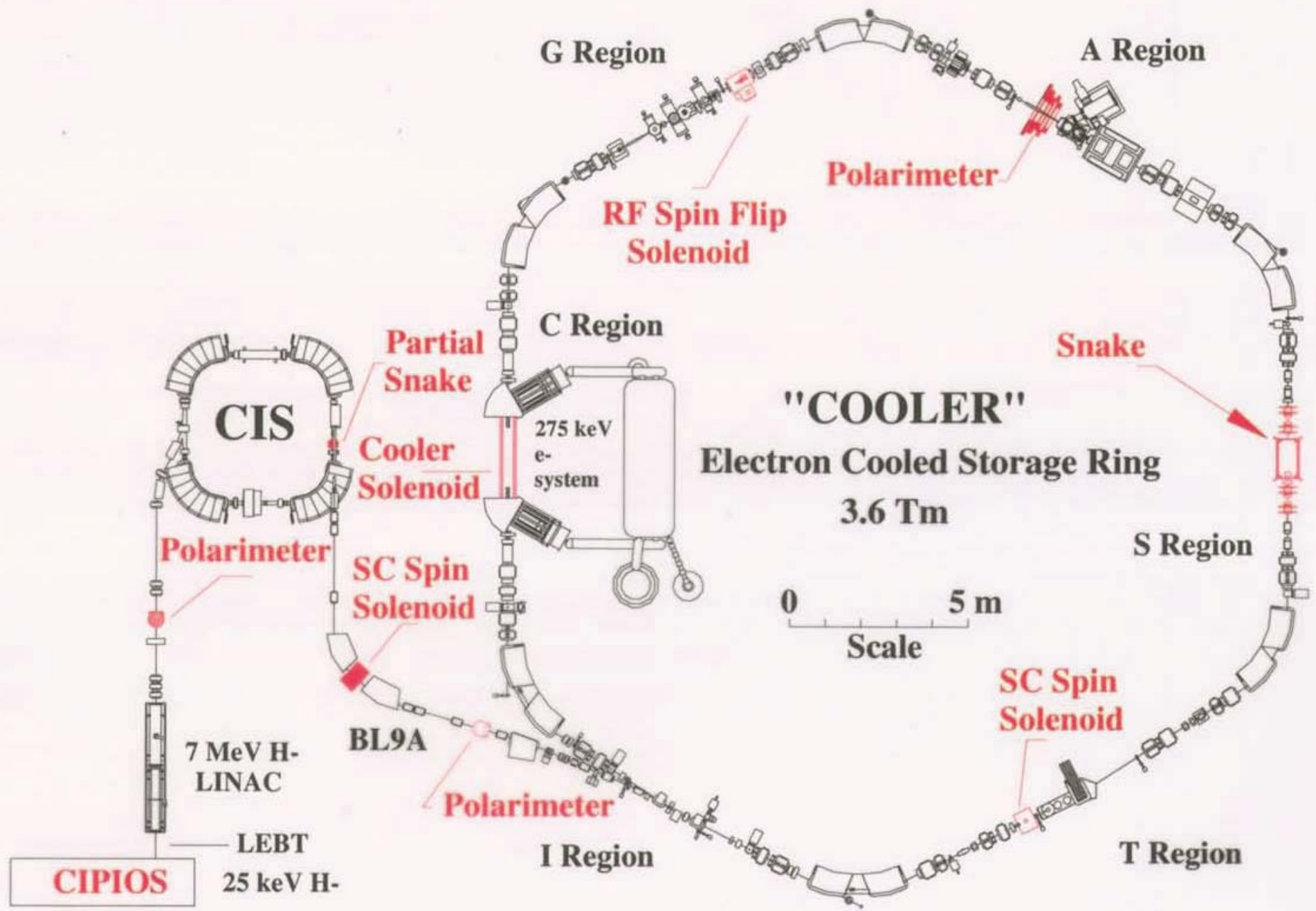
CHAMBERLAIN, COURANT, TERWILLIGER, ADK

1985 ANN ARBOR WORKSHOP on PPB in SSC:

CONCLUSIONS:

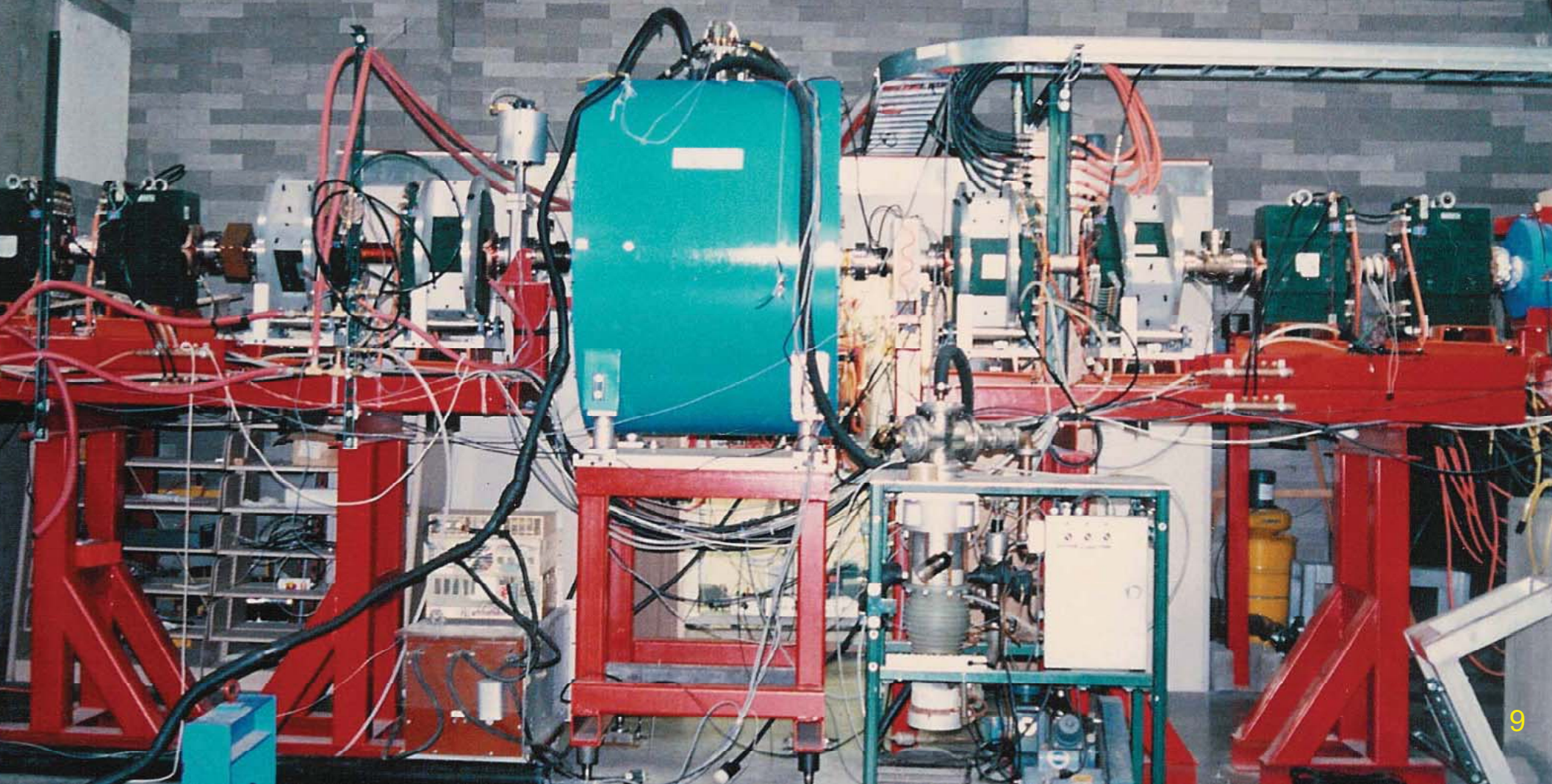
- 1. 20 TeV PPB POSSIBLE with 26 SNAKES / RING
BUT SEEMS: "TOO GOOD TO BE TRUE"**
- 2. MUST TEST SIBERIAN SNAKE EXPERIMENTALLY**

TEST SIBERIAN SNAKE IUCF COOLER RING: 1985-2002



FIRST SIBERIAN SNAKE TEST 1989

ROTATES SPIN by 180° per TURN



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

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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

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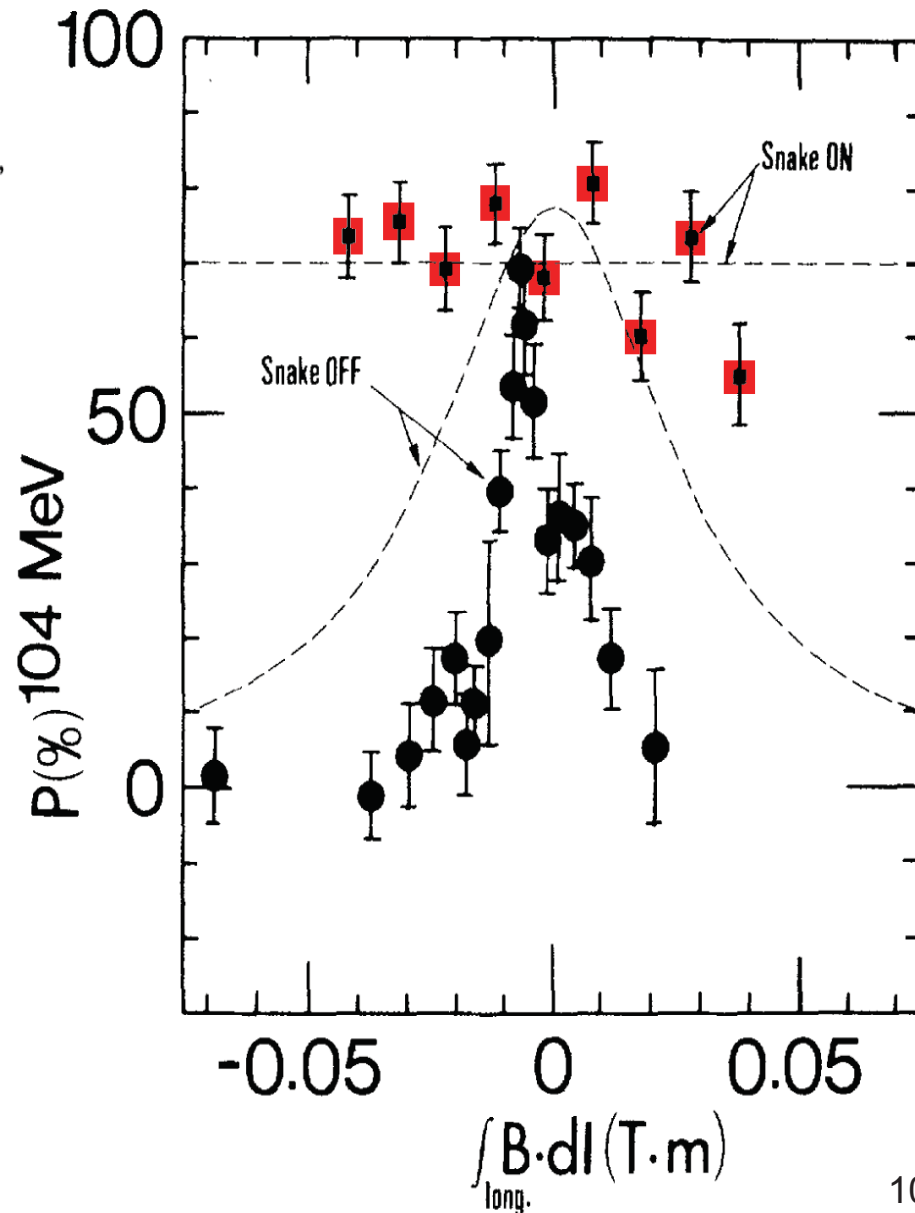
E. D. Courant, S. Y. Lee, and L. G. Ratner

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 0.0015 T.m. There is a systematic normalization uncertainty of about $\pm 5\%$. The dashed curve is the predicted behavior. The straight dashed line is a fit.



Nov 24, 2004

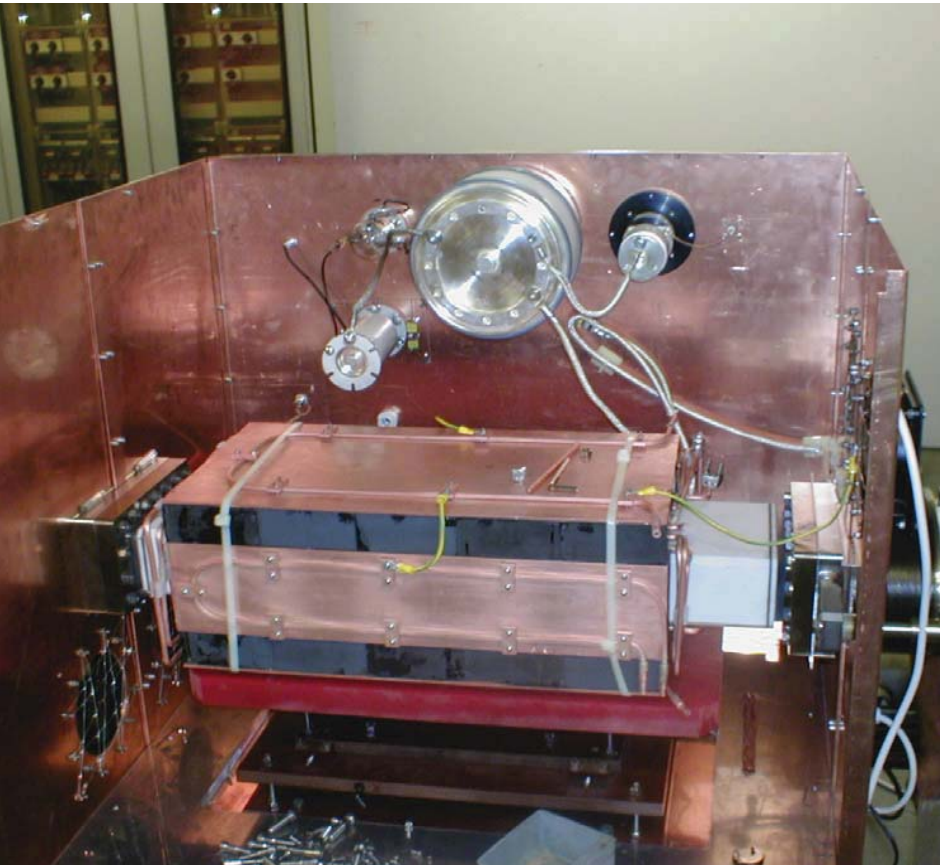
Spin-flipping crosses the Atlantic

After the venerable Cooler Ring at the Indiana University Cyclotron Facility (IUCF) passed on to accelerator heaven in autumn 2002, the polarized beam team, led by Alan Krisch, crossed the Atlantic to continue their spin-manipulation work at COSY, the cooler synchrotron at the Forschungszentrum in Jülich (figure 1). As part of the SPIN@COSY collaboration, they have been improving the polarization capabilities of the 3.5 GeV/c proton and deuteron storage ring. Recently, the collaboration - from Michigan and Brookhaven in America, COSY, Bonn and Hamburg in Germany, and KEK and J-PARC in Japan - has used a new ferrite RF-dipole magnet to flip the spins of stored 2.1 GeV/c protons with almost no polarization loss.

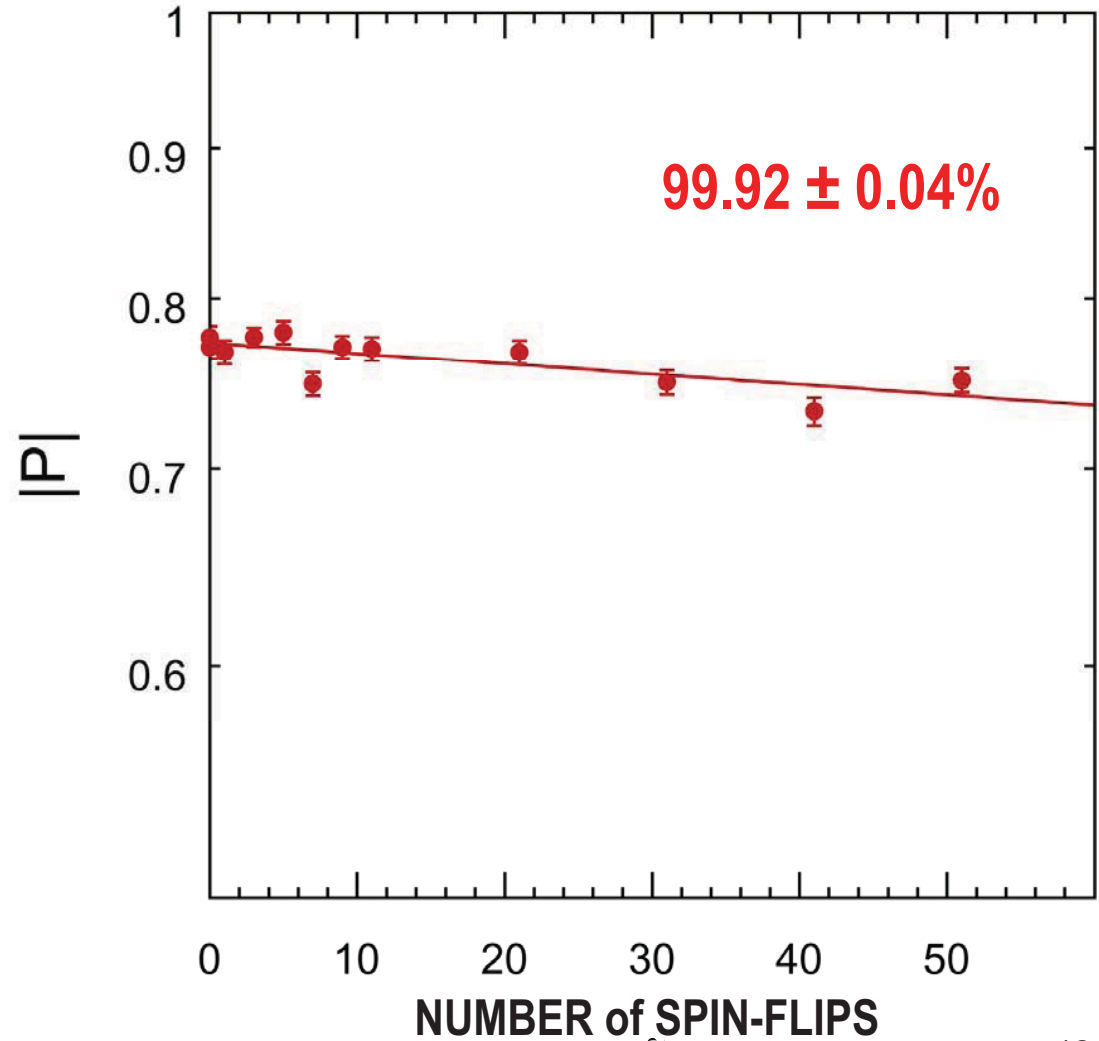
SPIN@COSY 2002-2009



VERY HIGH SPIN-FLIP EFFICIENCY with SMALL RF DIPOLE



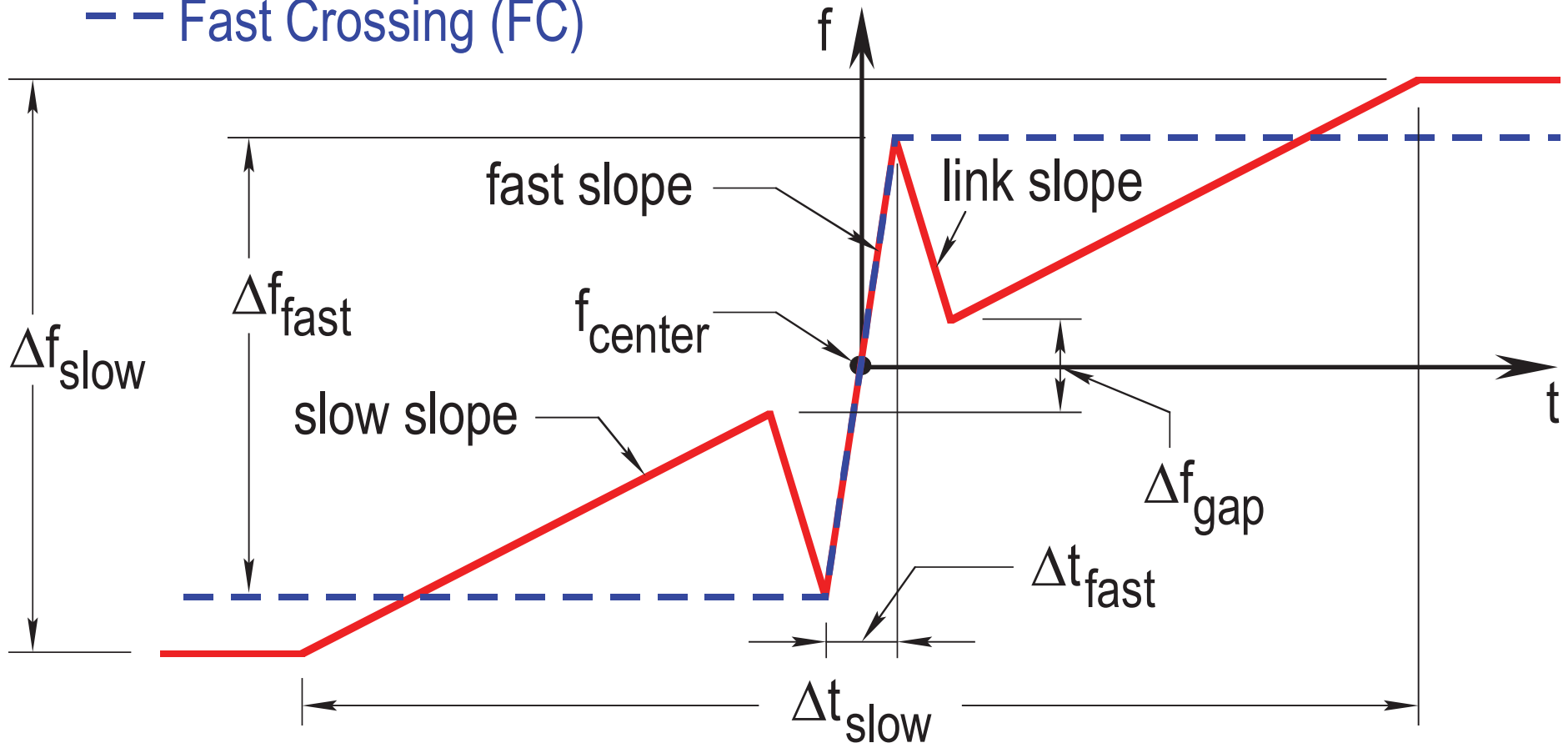
$$\int B_{rms} \cdot dl = 0.54 \text{ T}\cdot\text{mm at } \sim 917 \text{ kHz}$$



KONDRATENKO CROSSING SHAPE

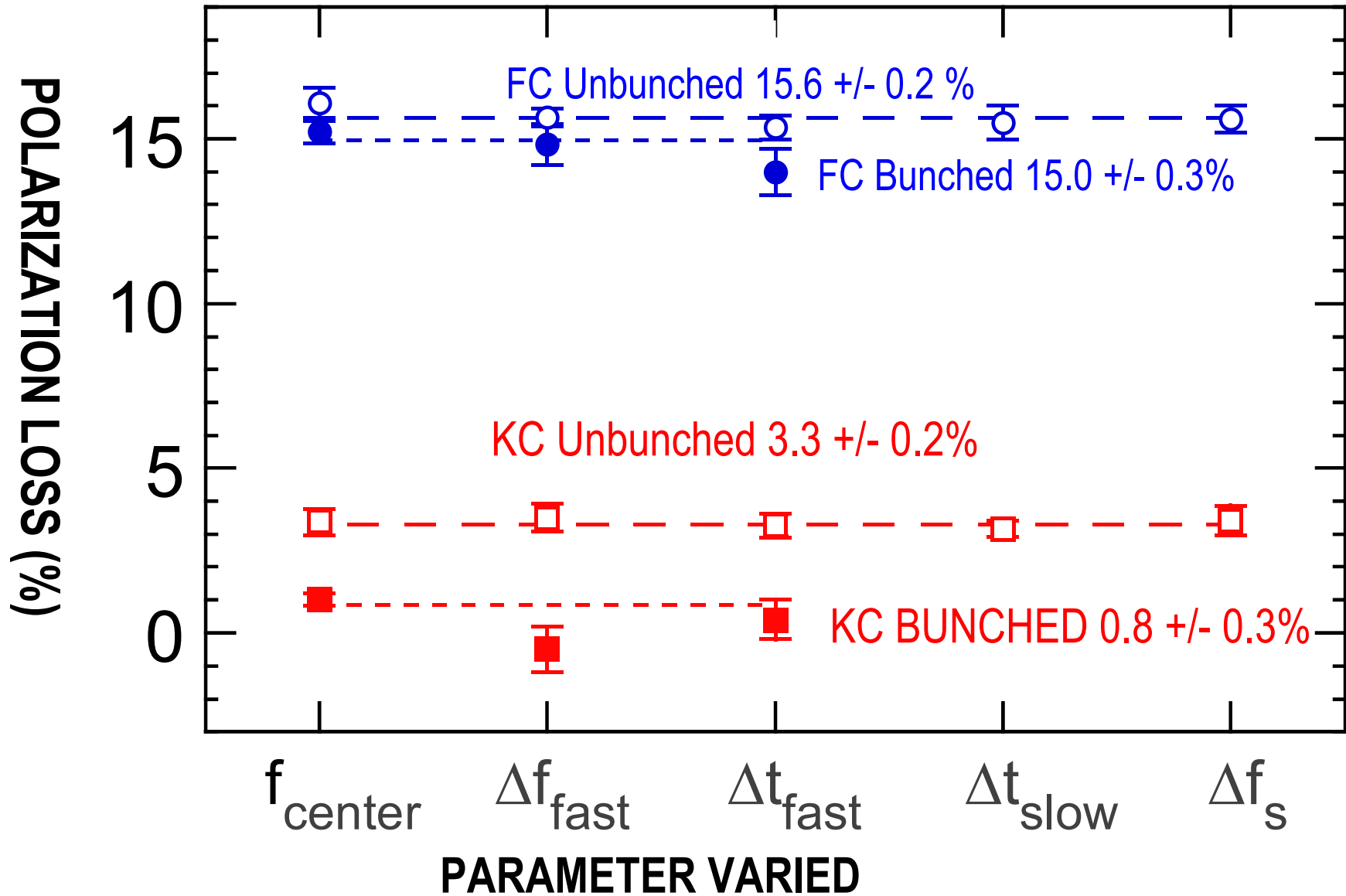
— Kondratenko Crossing (KC)

- - Fast Crossing (FC)



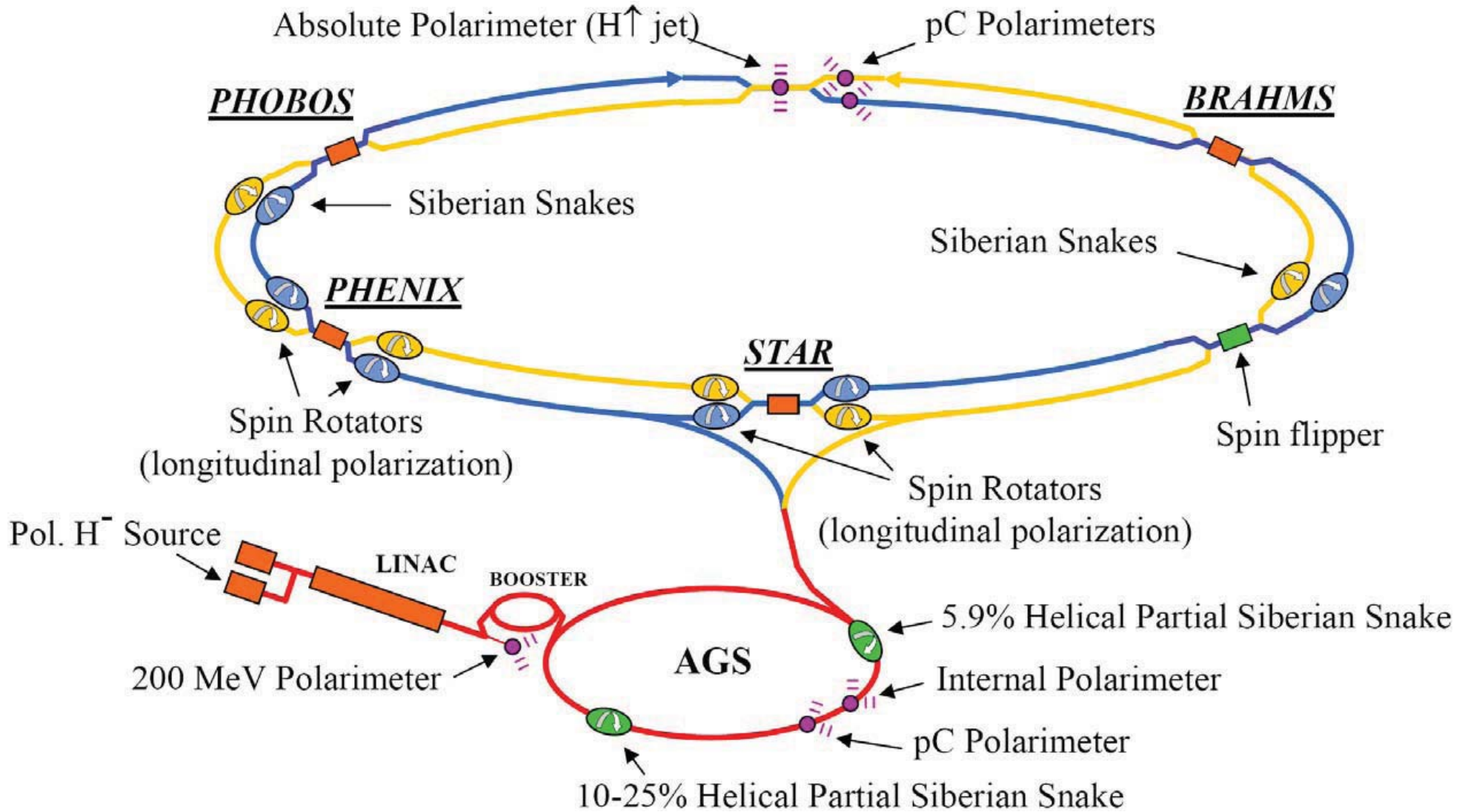
KONDRATENKO CROSSING (KC) vs. FAST CROSSING (FC)

At KC Polarization Peak At EQUAL KC and FC Crossing Speeds MAY 2008



V.S. Morozov *et al.* PRL **102**, 244801 (2009)

RHIC POLARIZED BEAM COMPLEX



BACK TO p-p SPIN EXPERIMENTS

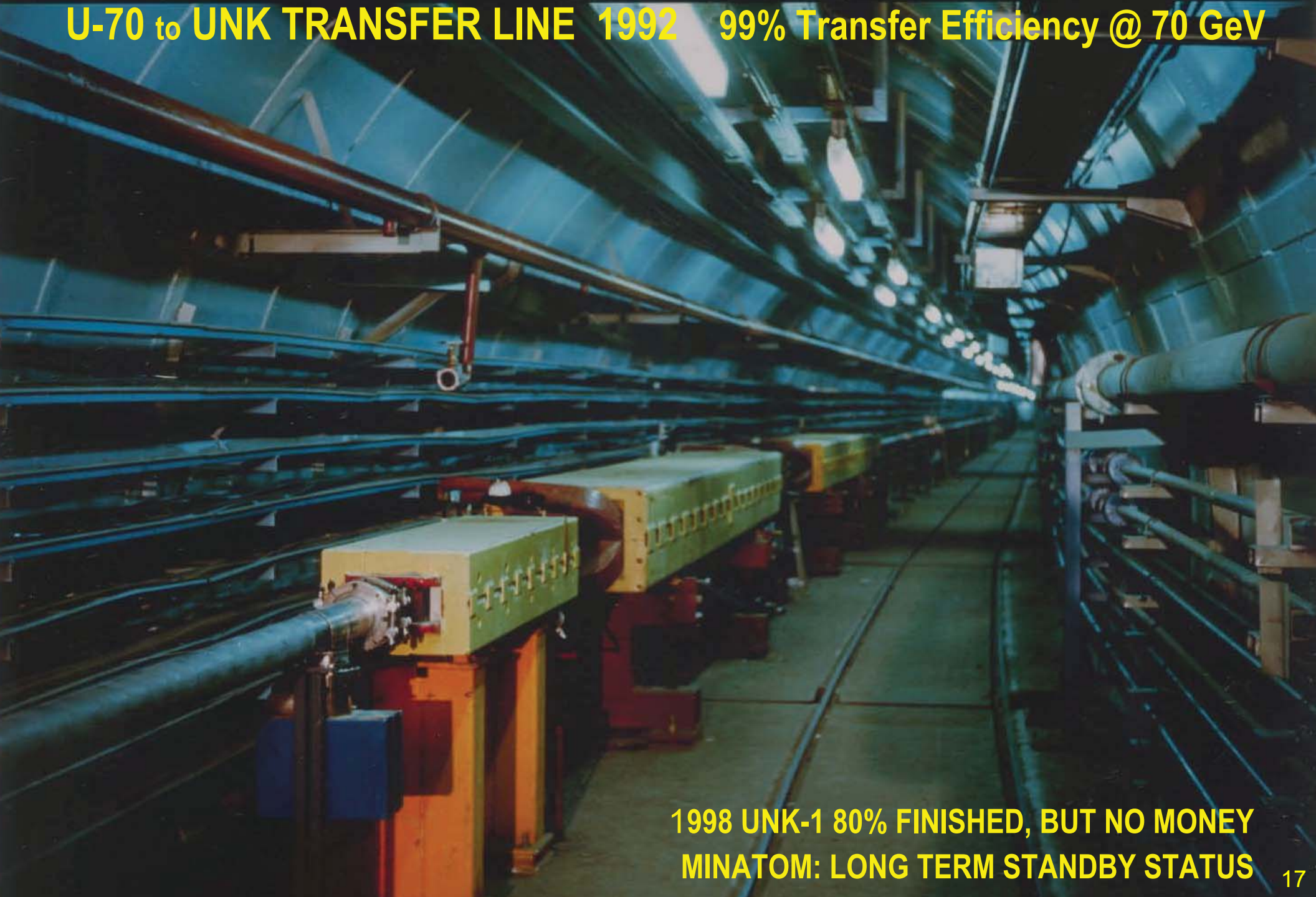
UNK

SERPUKHOV
~ 10 km



- UNK 1 400 - 600 GeV
- UNK 2 3 TeV
- UNK 3 3 TeV - 3 TeV Collider

U-70 to UNK TRANSFER LINE 1992 99% Transfer Efficiency @ 70 GeV



**1998 UNK-1 80% FINISHED, BUT NO MONEY
MINATOM: LONG TERM STANDBY STATUS**

Acceleration of Polarized Protons to 120 GeV and 1 TeV at Fermilab

SPIN Collaboration

Michigan, Indiana, Fermilab,

IHEP-Protvino, JINR-Dubna, Moscow, INR-Moscow,
BINP-Novosibirsk

KEK

TRIUMF

The SPIN collaboration has studied the acceleration of a polarized proton beam in the Fermilab Main Injector and Tevatron. The first section of this Report summarizes some physics goals for a polarized proton beam near 120 GeV and 1 TeV; it also contains a schedule and budget for the Polarized Main Injector and Polarized Tevatron-Collider projects. The rest of the Report describes the detailed plan to accelerate polarized protons and to perform polarized proton experiments in the Main Injector, the Tevatron and the Tevatron-Collider. Some highlights are:

- Nine Siberian snakes and some other minor hardware should allow 75% polarization to be maintained and manipulated in the Booster, Main Injector, and Tevatron.
- Recent progress in ABS and OPPIS polarized ion sources (0.6 mA and 1.6 mA) should allow a polarized Collider luminosity of about $7 \cdot 10^{31} \text{ cm}^{-2}\text{s}^{-1}$. We are supporting R & D for both source types to reach an even higher polarized luminosity.
- The source's 30-month preparation time makes it a critical-path item. A decision is required by *mid-August 1995* to allow installation of a polarized source and other polarized hardware during the 1998 Main Injector installation shutdown.
- To make empty spaces in the Tevatron for six Siberian snakes and four Collider-detector spin rotators, twenty new 6 T superconducting dipoles would replace thirty-six existing 4.4 T Tevatron ring dipoles. Since an *immediate* decision on the 6 T dipoles would be needed to install them and the Tevatron snakes during the 1998 Main Injector installation shutdown, we instead recommend a *phased* commissioning of the Polarized Main Injector and Polarized Tevatron.

1.2 SPIN collaboration list

July 20, 1995

L. V. Alexeeva^a, V. A. Anferov^a, B. B. Blinov^a, J. A. Bywater, D. D. Caussyn^b, C. M. Chu^c, E. D. Courant, D. G. Crabb^d, D. A. Crandell, Ya. S. Derbenev^e, S. V. Gladysheva, S-Q. Hu, F. Z. Khiari^f, A. D. Krisch, A. M. T. Lin, V. G. Luppov, T. S. Nurushev, D. C. Peaslee, R. A. Phelps, L. G. Ratner, R. S. Raymond, D. S. Shoumkin^a, J. A. Stewart^g, S. M. Varzar^a, V. K. Wong

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KEK, TSUKUBA, JAPAN

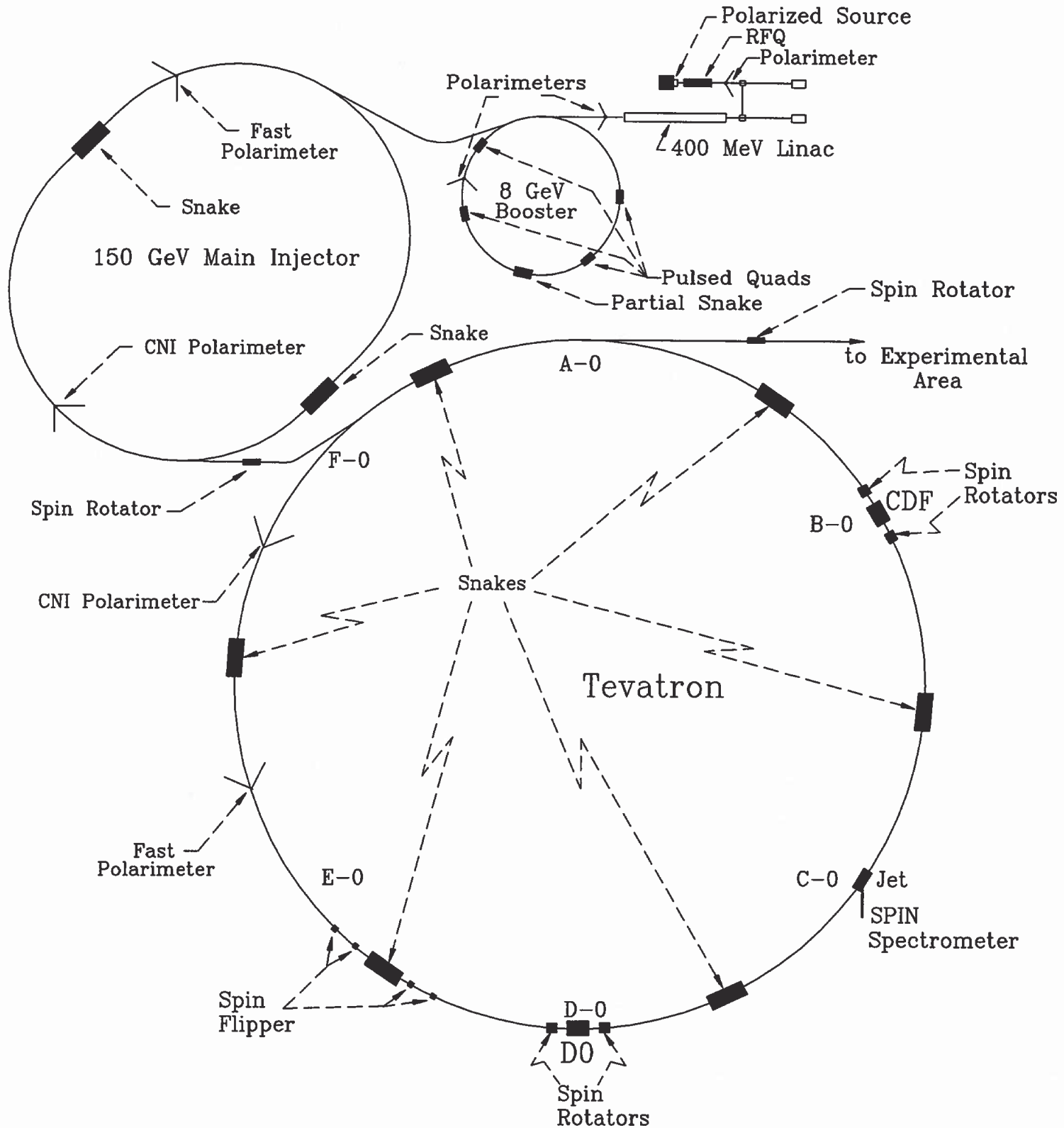
R. Abegg, P.P.J Delheij, G. Dutto, C. D. P. Levy, C.A. Miller, G. Roy^k, T. Sakae^l, P. W. Schmor, W. T. H. van Oers, A. N. Zelenski^m
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Permanent address:

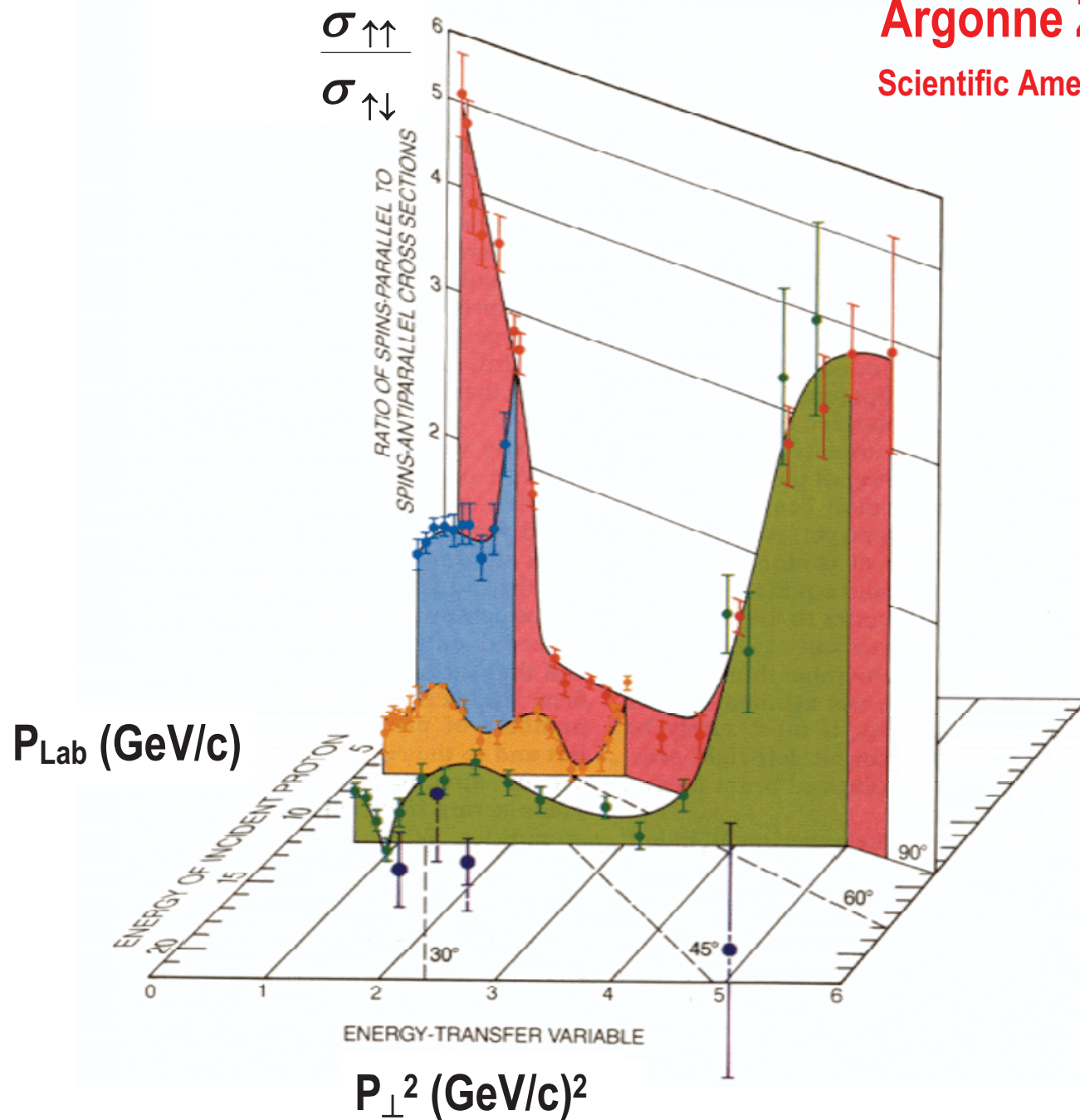
<i>a</i> Moscow State Univ.	<i>d</i> Univ. of Virginia	<i>g</i> Univ. of Liverpool	<i>j</i> Tokyo Univ.
<i>b</i> Florida State Univ.	<i>e</i> Novosibirsk; DESY	<i>h</i> TUNL	<i>k</i> Univ. of Alberta
<i>c</i> National Center Univ. -Taiwan	<i>f</i> King Fahd Univ.	<i>i</i> SLAC	<i>l</i> Kyushu Univ.
			<i>m</i> INR-Moscow



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

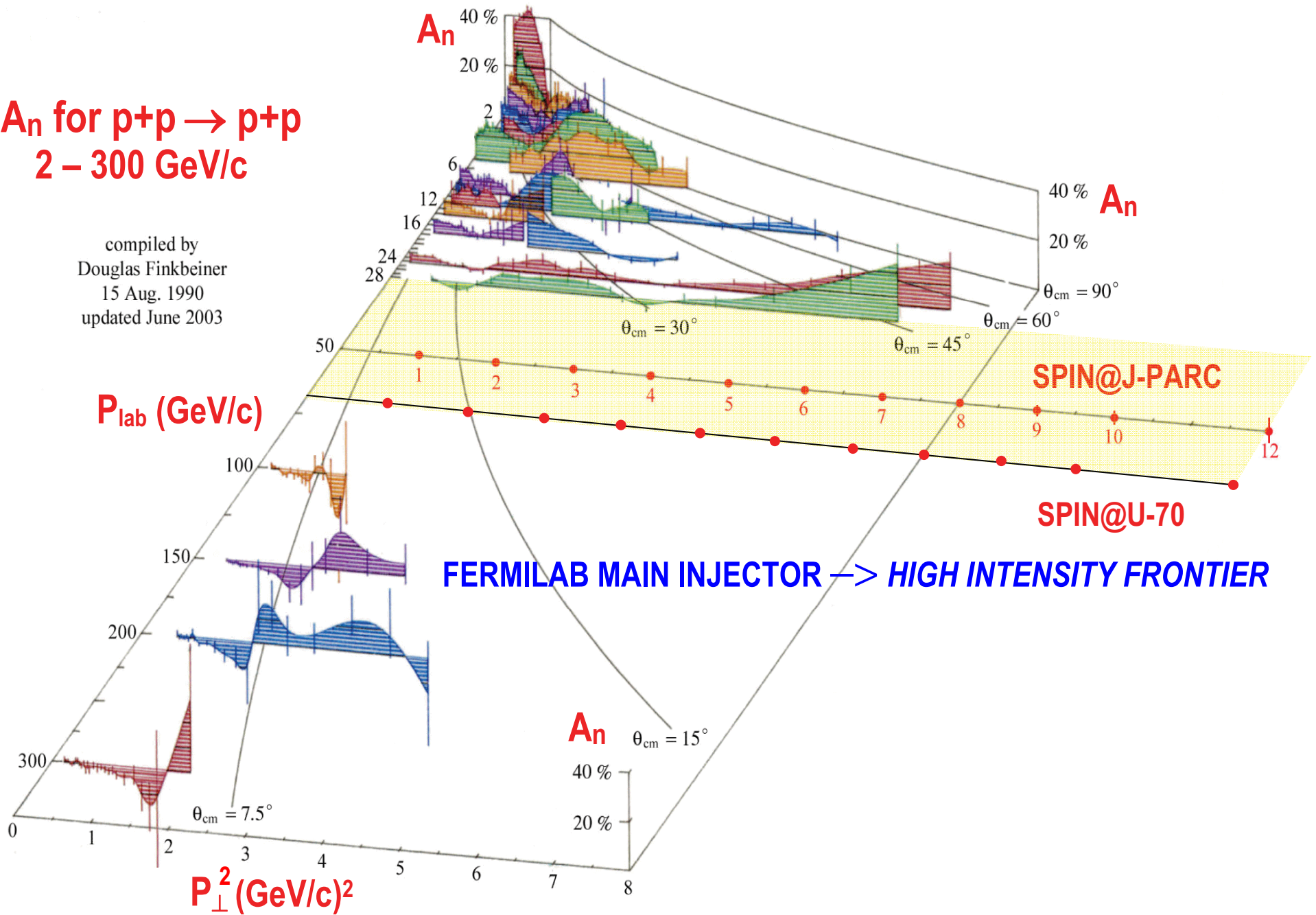
Argonne ZGS 1977-79

Scientific American 1979 & 1987



A_n for $p+p \rightarrow p+p$ 2 – 300 GeV/c

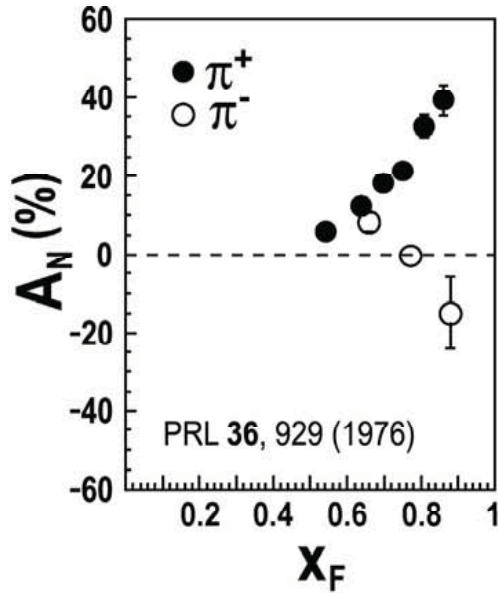
compiled by
Douglas Finkbeiner
15 Aug. 1990
updated June 2003



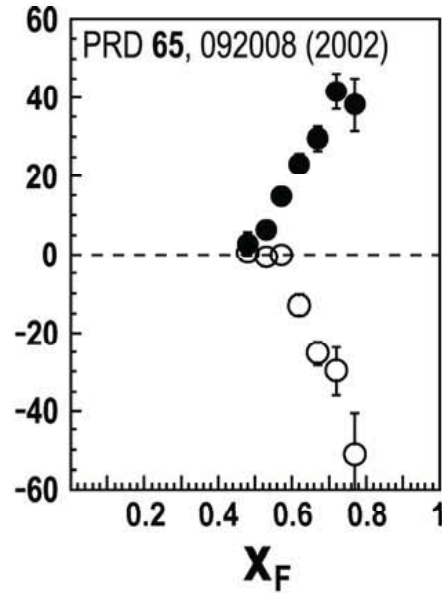
INCLUSIVE PION ASYMMETRY IN PROTON-PROTON COLLISIONS

C. Aidala SPIN 2008 Proceeding and CERN Courier June 2009

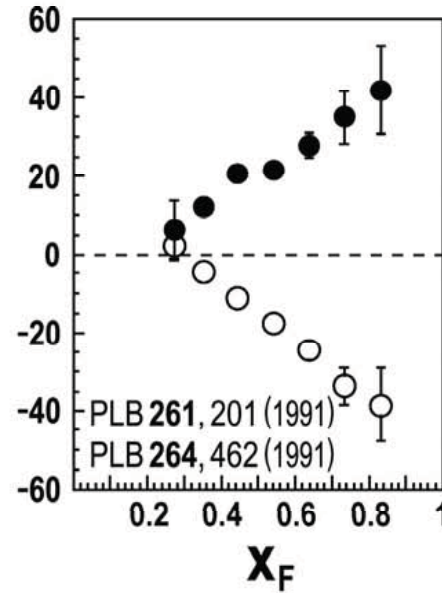
ZGS 12 GeV



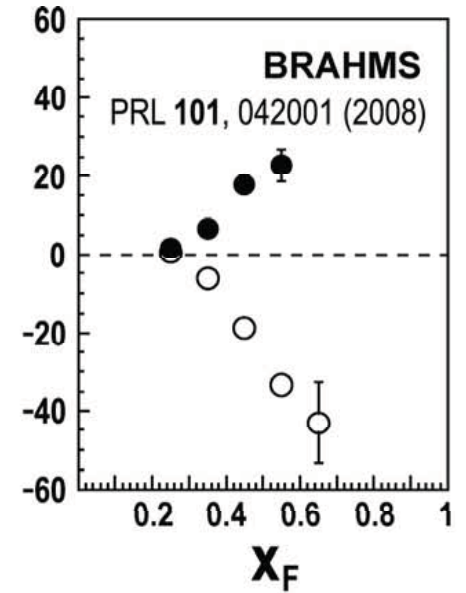
AGS 22 GeV



FNAL 200 GeV



RHIC $s = 3900 \text{ GeV}^2$



SUMMARY

For 30+ years QCD-based calculations could not explain large spin effects:

- ZGS 2-spin & AGS 1-spin p-p elastic data;
 - Fermilab large hyperon polarization
 - ZGS, AGS, Fermilab & RHIC p-p inclusive spin data.
- ★ Large spin effects do not go to zero at high-energy or high- P_{\perp} as earlier predicted.
- ★ Resulted in modifications of QCD that unpolarized experiments could not see.

BASIC PRINCIPLE OF SCIENCE:

**If theory does not agree with reproducible experimental data,
then theory must be modified.**

Derbenev & Kondratenko's Siberian Snakes allow high energy polarized proton beams:

- ★ High energy proton spin data → experimental guidance for further QCD modification.