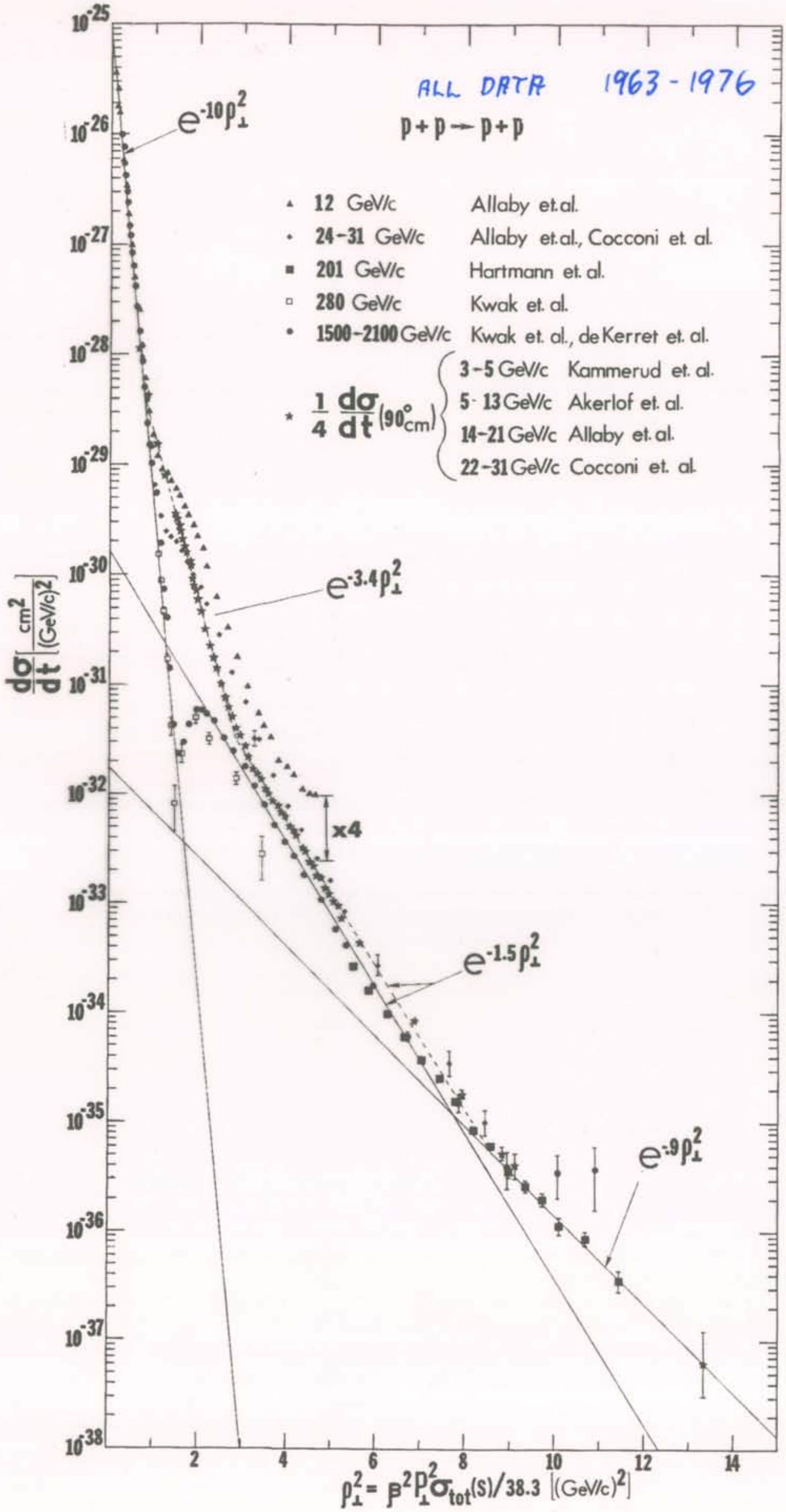
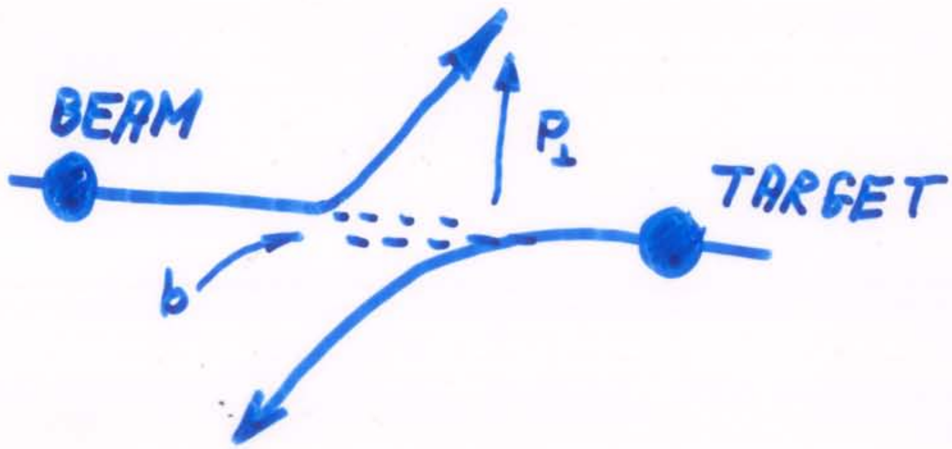
A.D. KRISCH
UNIVERSITY OF MICHIGAN

VIOLENT COLLISIONS of SPINNING PROTONS: PAST, PRESENT & FUTURE



ALL DATA 1963 - 1976
p + p → p + p
12 GeV/c Allaby et.al.
24-31 GeV/c Allaby et.al., Cocconi et. al.
201 GeV/c Hartmann et. al.
280 GeV/c Kwak et. al.
1500-2100 GeV/c Kwak et. al., de Kerret et. al.
$\frac{1}{4}\frac{d\sigma}{dt}(90^\circ_{cm})$
3-5 GeV/c Kammerud et. al.
5-13 GeV/c Akerlof et. al.
14-21 GeV/c Allaby et. al.
22-31 GeV/c Cocconi et. al.
$e^{-10\rho_\perp^2}$
$e^{-3.4\rho_\perp^2}$
$e^{-1.5\rho_\perp^2}$
$e^{-.9\rho_\perp^2}$
x4
$\frac{d\sigma}{dt}\left[\frac{cm^2}{(GeV/c)^2}\right]$
$\rho_\perp^2 = \beta^2 P_\perp^2 \sigma_{tot}(S)/38.3 \ [(GeV/c)^2]$

SPIN FORCES
IN HIGH-$P_\perp^2$
$p + p \to p + p$



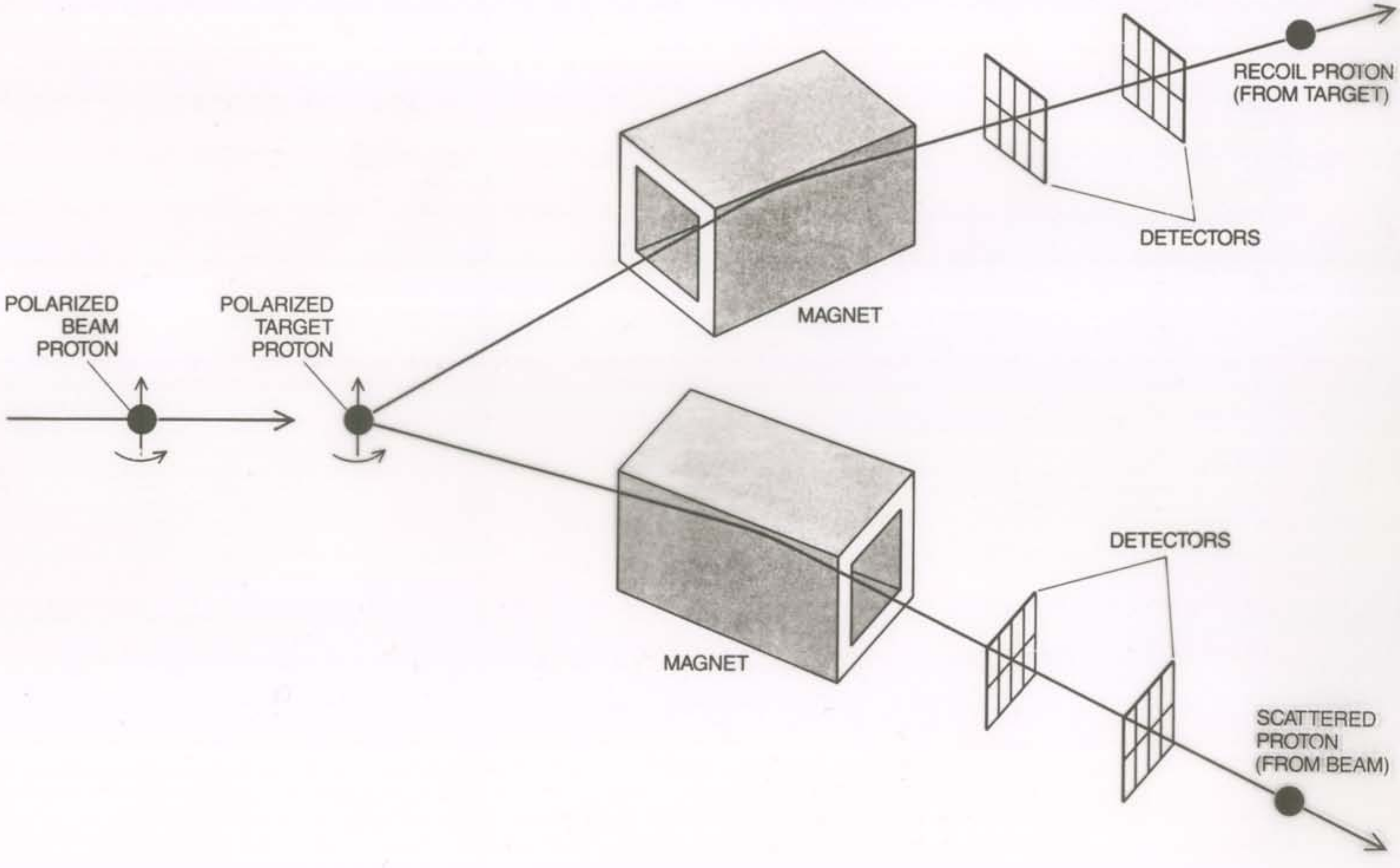
$$P = \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)}$$

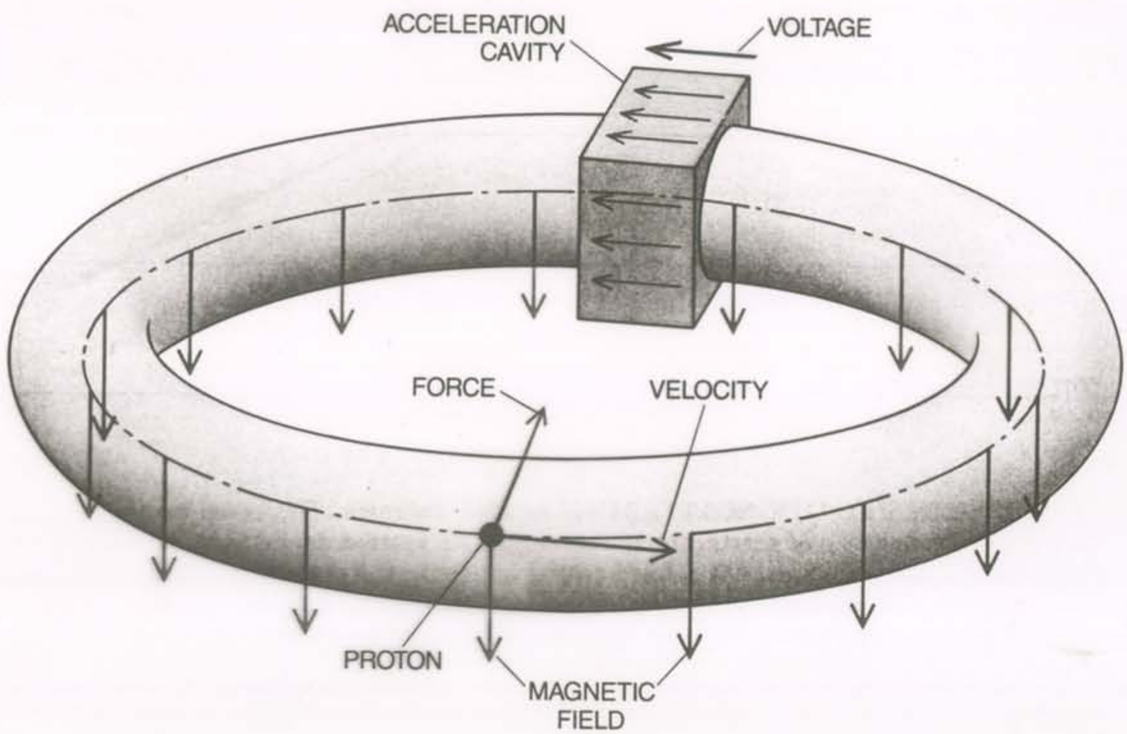
UNPOLARIZED $\Longrightarrow$ $\langle d\sigma/dt \rangle$

BEAM OR TARGET POLARIZED $\Longrightarrow$ ONE-SPIN A_N

BEAM AND TARGET POLARIZED $\Longrightarrow$ SPIN-SPIN A_{NN}

1C


RECOIL PROTON
(FROM TARGET)
DETECTORS
MAGNET
POLARIZED
BEAM
PROTON
POLARIZED
TARGET
PROTON
DETECTORS
MAGNET
SCATTERED
PROTON
(FROM BEAM)


ACCELERATION CAVITY
VOLTAGE
FORCE
VELOCITY
PROTON
MAGNETIC FIELD

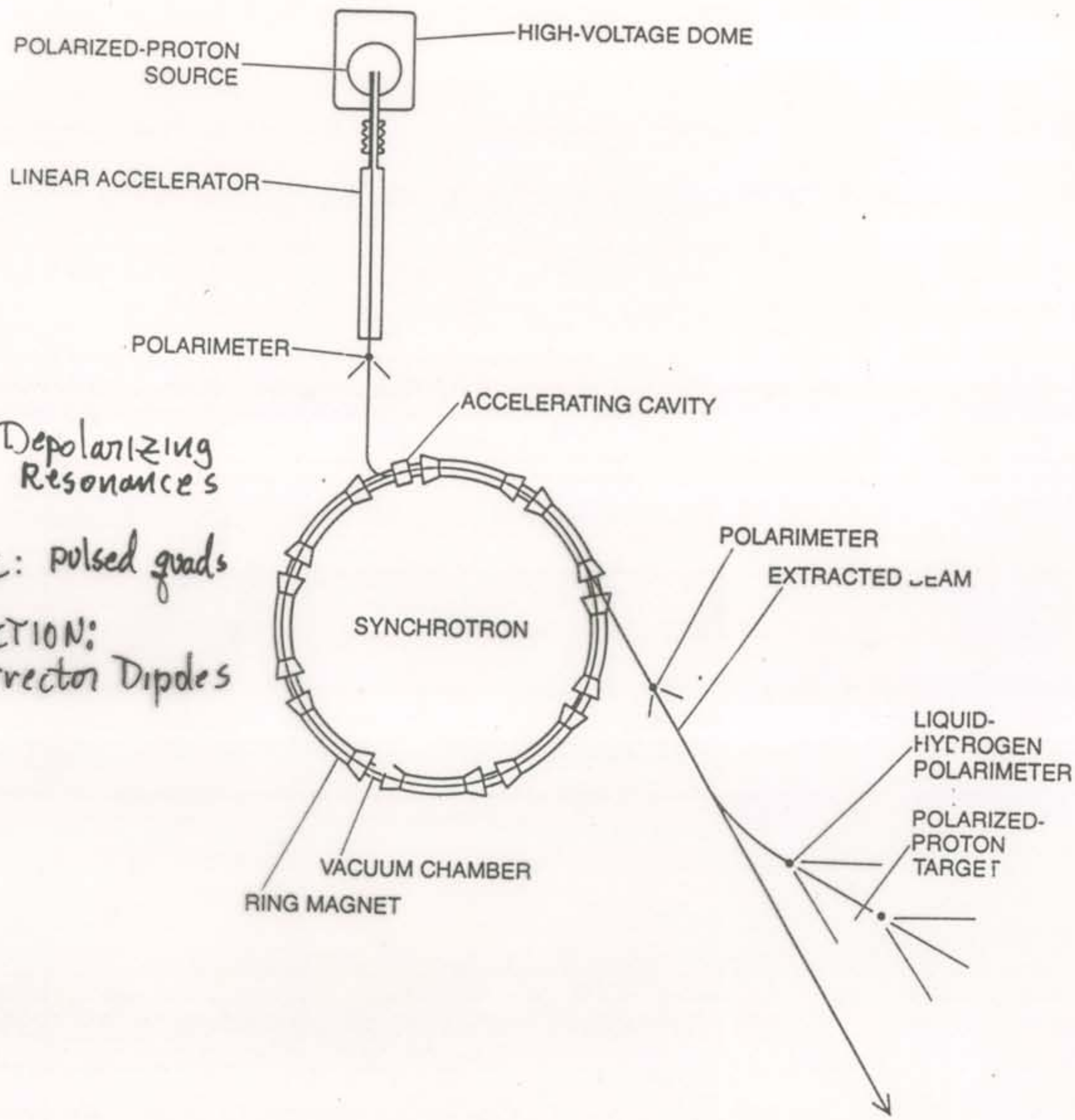
1969 – 1973
1973 ~ 1979

ZGS (ARGONNE)
POL. PROTON BEAM

Depolarizing Resonances

INTRINSIC: pulsed quads

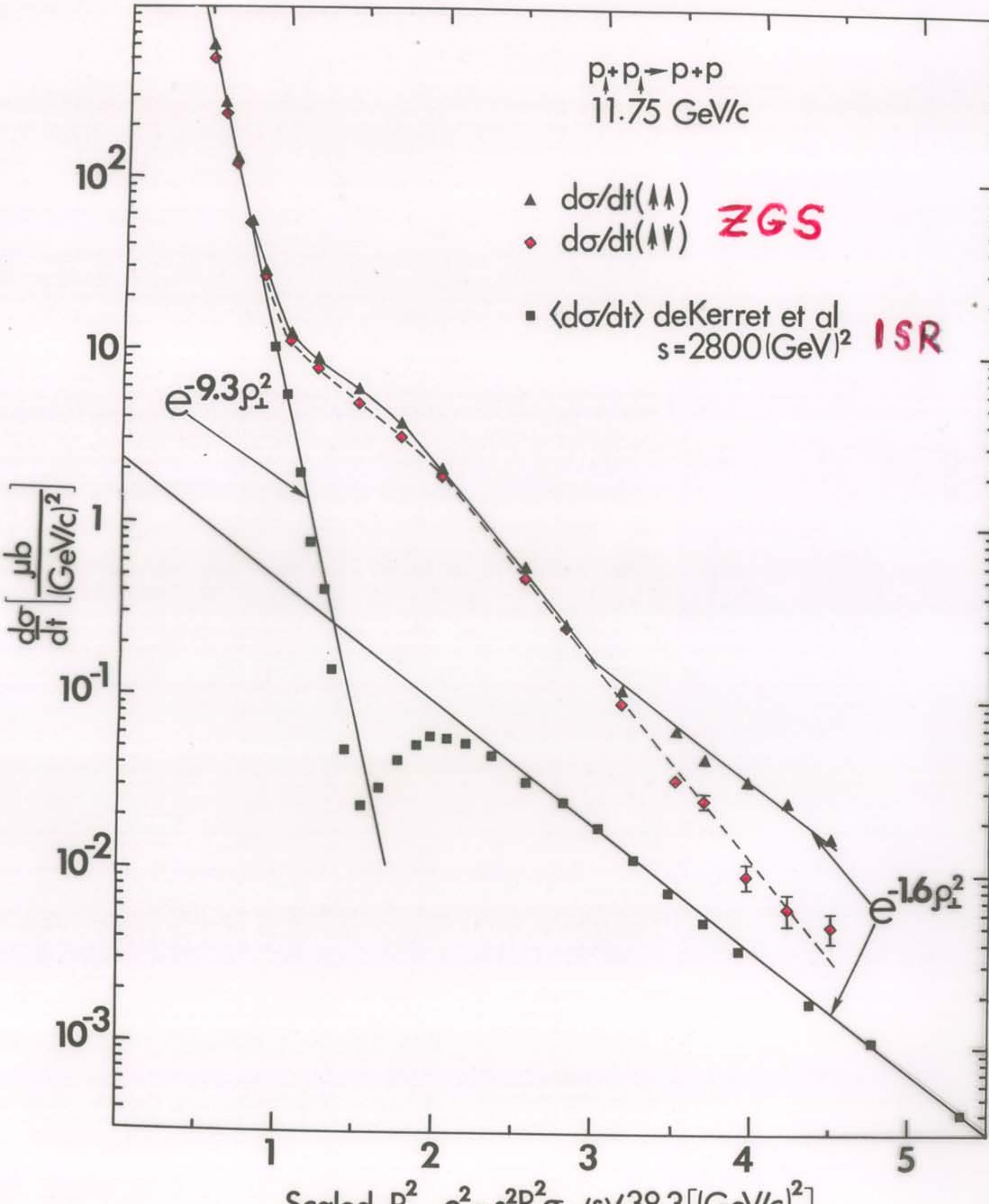
IMPERFECTION: Corrector Dipoles



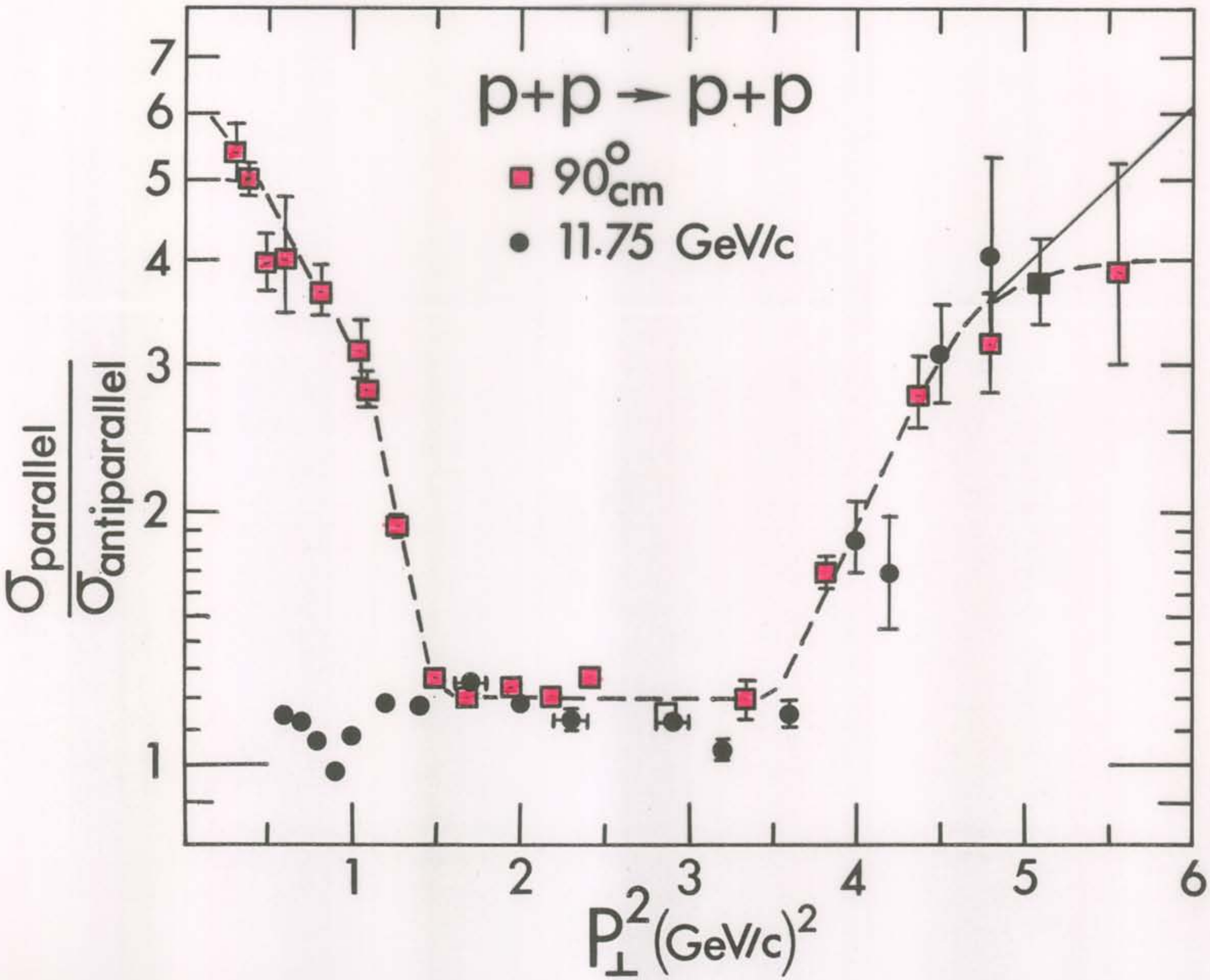
ZERO GRADIENT SYNCHROTRON accelerates polarized protons to an energy of 12 billion electron volts (GeV). The polarized-proton source is enclosed in a high-voltage dome; protons leaving the dome acquire an energy of 750,000 electron volts. A linear accelerator then raises their energy to 50 million electron volts before they are injected into the synchrotron itself. On each pass through the accelerating cavity of the synchrotron the particles gain 12,000 electron volts; in order to reach 12 GeV they must therefore circle the ring about a million times, which requires a little less than a second. The accelerator is called the zero gradient synchrotron because the fields of the ring magnets are uniform, a feature that aids in maintaining beam polarization. When the particles reach 12 GeV, they are extracted from the ring and directed by steering magnets to the target. Polarization is monitored just before injection and just after extraction by polarimeters that measure the left-right asymmetry in scattering events. The asymmetry is related to the spin orientation and hence to the beam polarization.

4

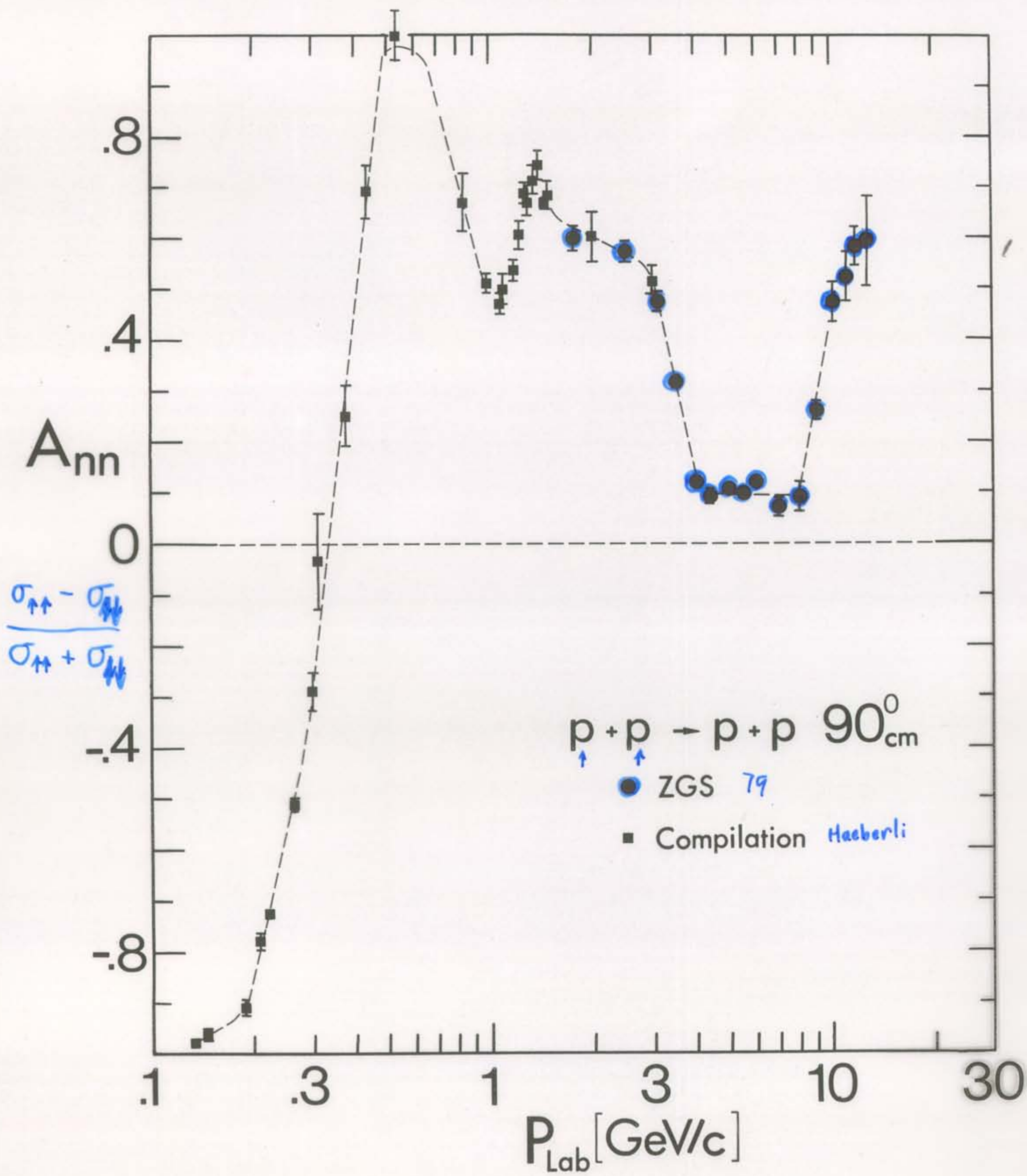
ZGS 1977-78


$p_{\uparrow}+p_{\uparrow} \to p+p$
11.75 GeV/c
▲ $d\sigma/dt(\uparrow\uparrow)$
◆ $d\sigma/dt(\uparrow\downarrow)$
ZGS
■ $\langle d\sigma/dt \rangle$ deKerret et al
$s=2800(\text{GeV})^2$
ISR
$e^{-9.3\rho_\perp^2}$
$e^{-1.6\rho_\perp^2}$
$\frac{d\sigma}{dt}\left[\frac{\mu b}{(\text{GeV/c})^2}\right]$
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
Scaled $P_\perp^2$ $\rho_\perp^2 = \beta^2 P_\perp^2 \sigma_{tot}(s)/38.3\,[(\text{GeV/c})^2]$

1979 ZGS



p+p → p+p
90°cm
11.75 GeV/c
σparallel / σantiparallel
1
2
3
4
5
6
7
1
2
3
4
5
6
P⊥² (GeV/c)²

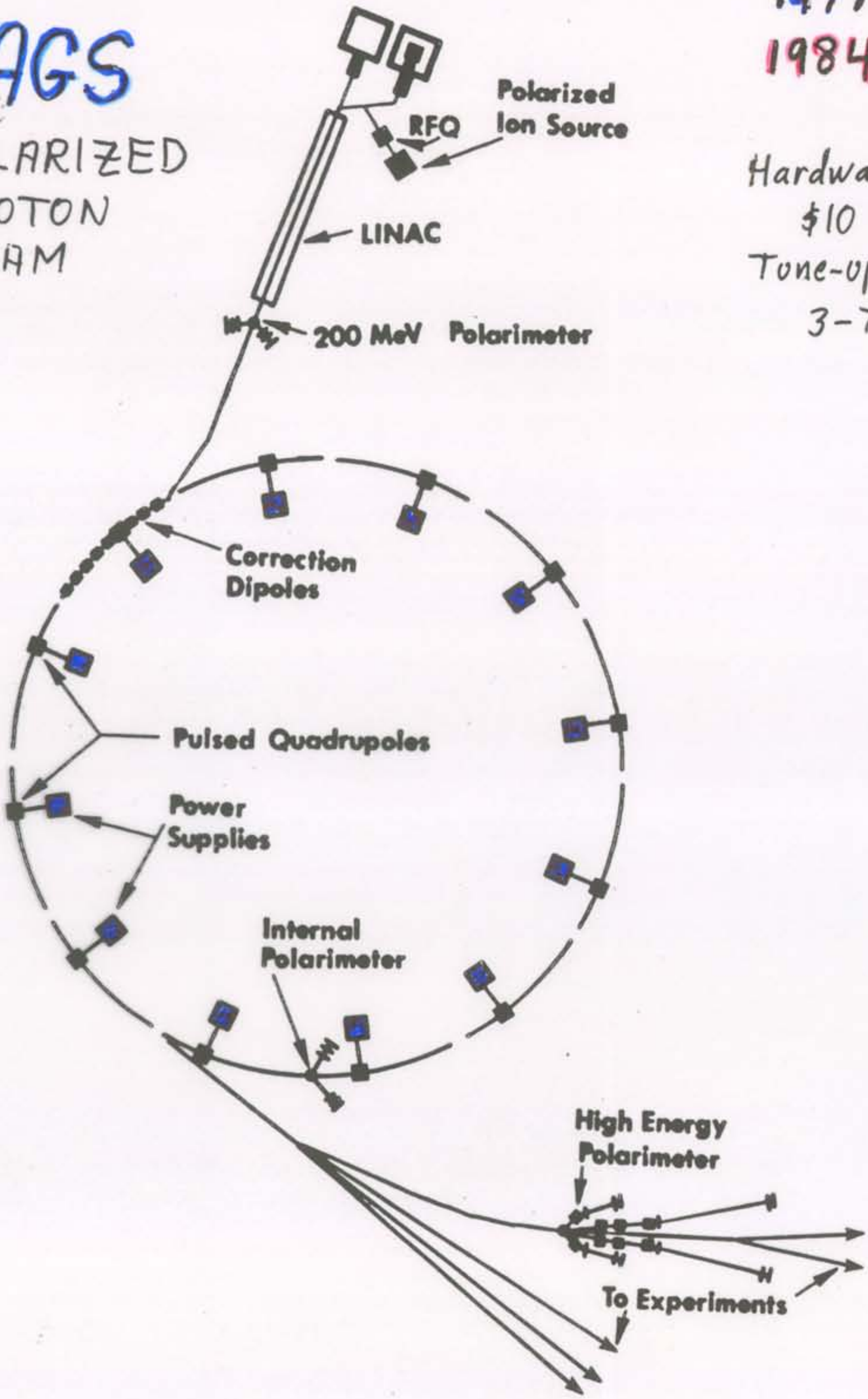

.8
.4
0
-.4
-.8
A_{nn}
$\frac{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}}{\sigma_{\uparrow\uparrow} + \sigma_{\uparrow\downarrow}}$
$p_{\uparrow} + p_{\uparrow} \rightarrow p + p \quad 90^{0}_{cm}$
ZGS 79
Compilation Haeberli
.1
.3
1
3
10
30
P_{Lab}[GeV/c]

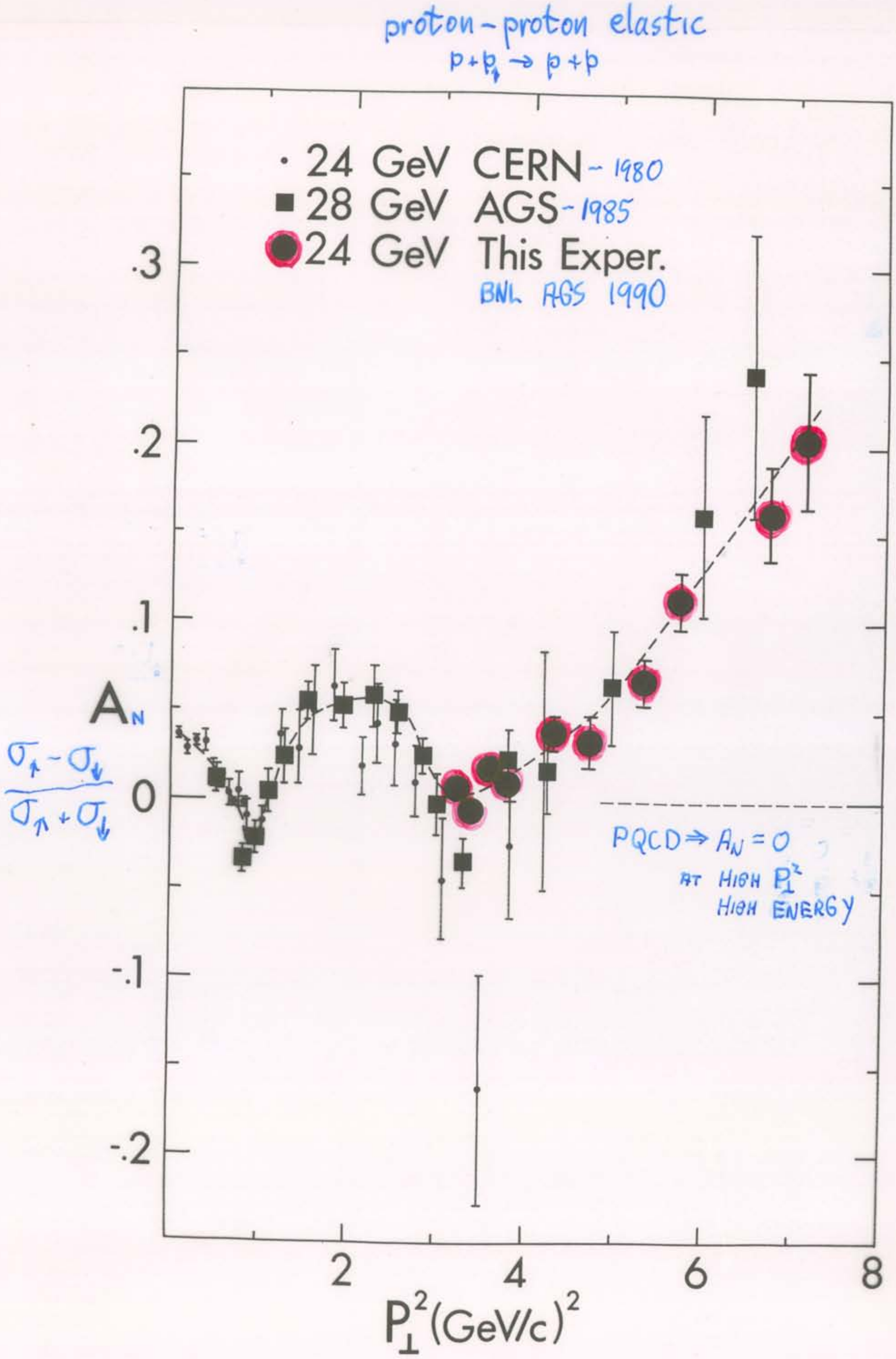
AGS

POLARIZED
PROTON
BEAM

1977 → 1984
1984 →

Hardware
$10 Million ($1980)
Tune-up time
3–7 weeks





proton-proton elastic
$p + p_{\uparrow} \to p + p$
· 24 GeV CERN - 1980
■ 28 GeV AGS - 1985
● 24 GeV This Exper.
BNL AGS 1990
.3
.2
.1
0
-.1
-.2
A_N
$\frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}}$
PQCD ⇒ $A_N = 0$
AT HIGH $P_{\perp}^2$
HIGH ENERGY
2
4
6
8
$P_{\perp}^2 (\mathrm{GeV/c})^2$

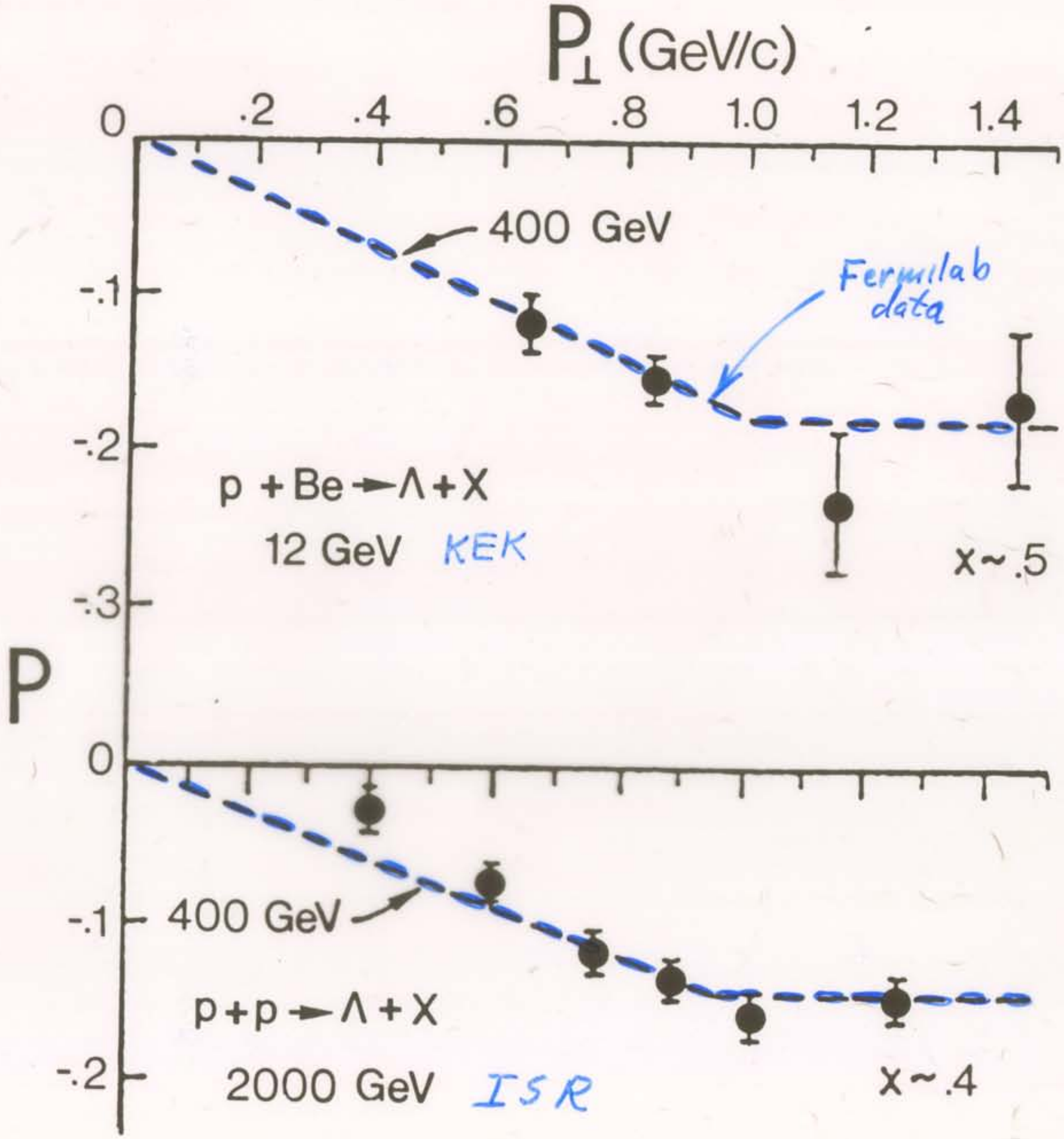
DEVLIN
PONDRUM

HELLER
BUNCE

INCLUSIVE HYPERON POLARIZATION

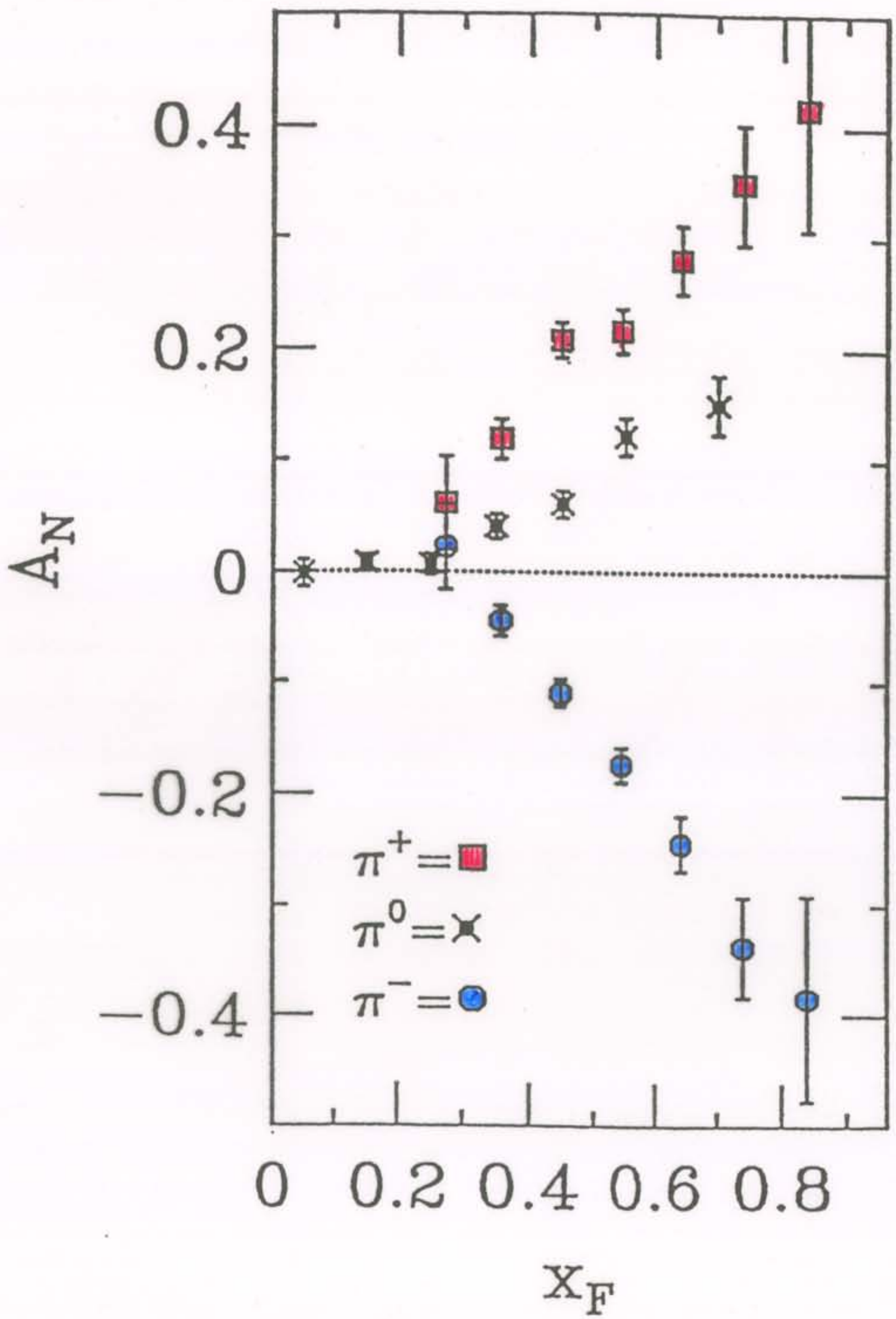
Fermilab 1980's

PQCD $\Rightarrow A = 0$ AT HIGH ENERGY



E-704
Fermilab

Inclusive $\pi^+ \pi^- \pi^0$
200 GeV p p 1990's

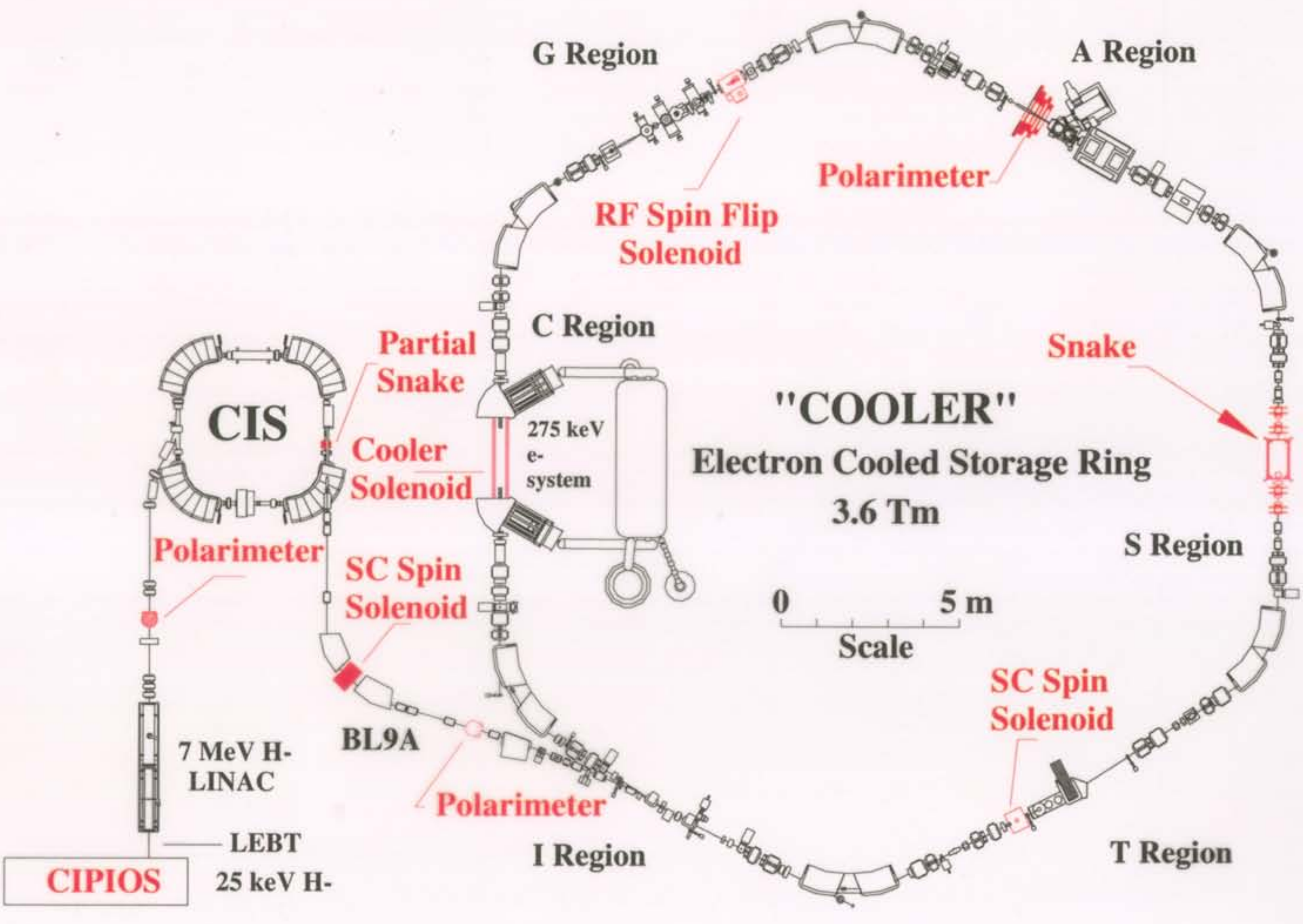


A_N for π^+ (squares) and π^- (circles) production in the $p^{\uparrow}p$ reaction versus x_F integrated over $p_\perp$. For comparison, π^0 data (crosses) are also plotted.

1985 Ann Arbor Workshop
polarized SSC
AIP Conf Proceedings
eds. ADK, A.M.T. Lin, O. Chamberlain

IUCF

CIS-Cooler Layout



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

1989

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)

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.

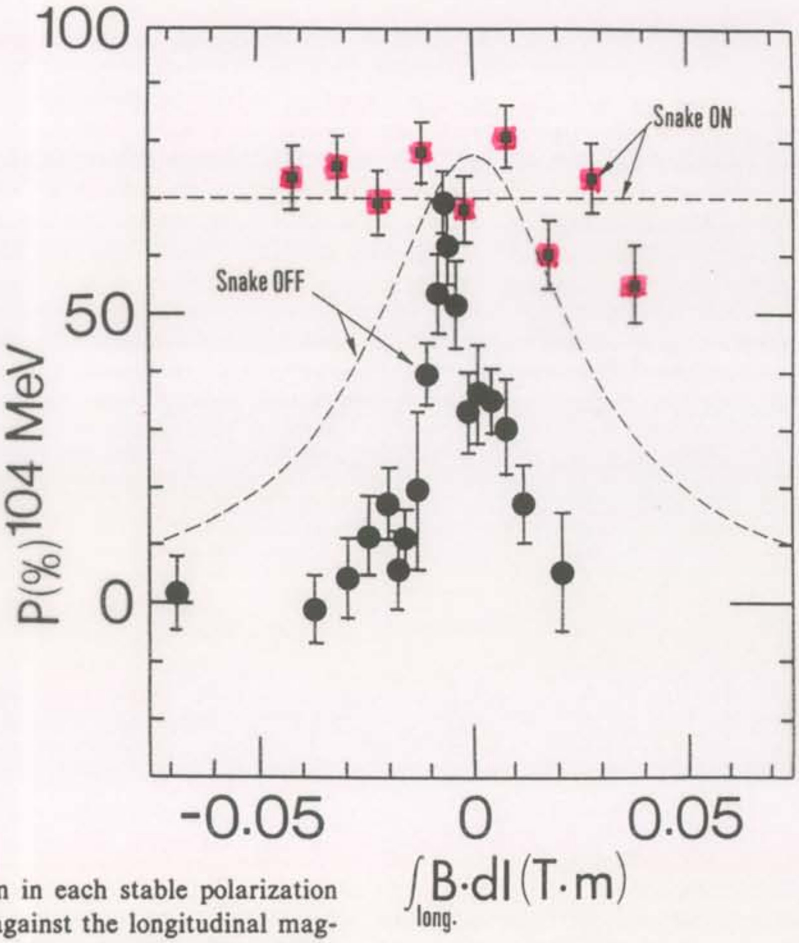


FIG. 4. The beam polarization in each stable polarization direction at 104 MeV is plotted against the longitudinal magnetic field integral in the Cooler Ring solenoids. The circles are the vertical polarization with the snake off and the injection of vertically polarized protons. The squares are the radial polarization with the snake on and the injection of horizontally polarized protons. We combined all data into bins of width 0.001 15 Tm. There is a systematic normalization uncertainty of about $\pm5\%$. The dashed curve is the predicted behavior. The straight dashed line is a fit.

Overcoming Intrinsic and Synchrotron Depolarizing Resonances with a Siberian Snake

J. E. Goodwin, H-O. Meyer, M. G. Minty, P. V. Pancella, R. E. Pollock, T. Rinckel, M. A. Ross, F. Sperisen, E. J. Stephenson, and B. von Przewoski
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

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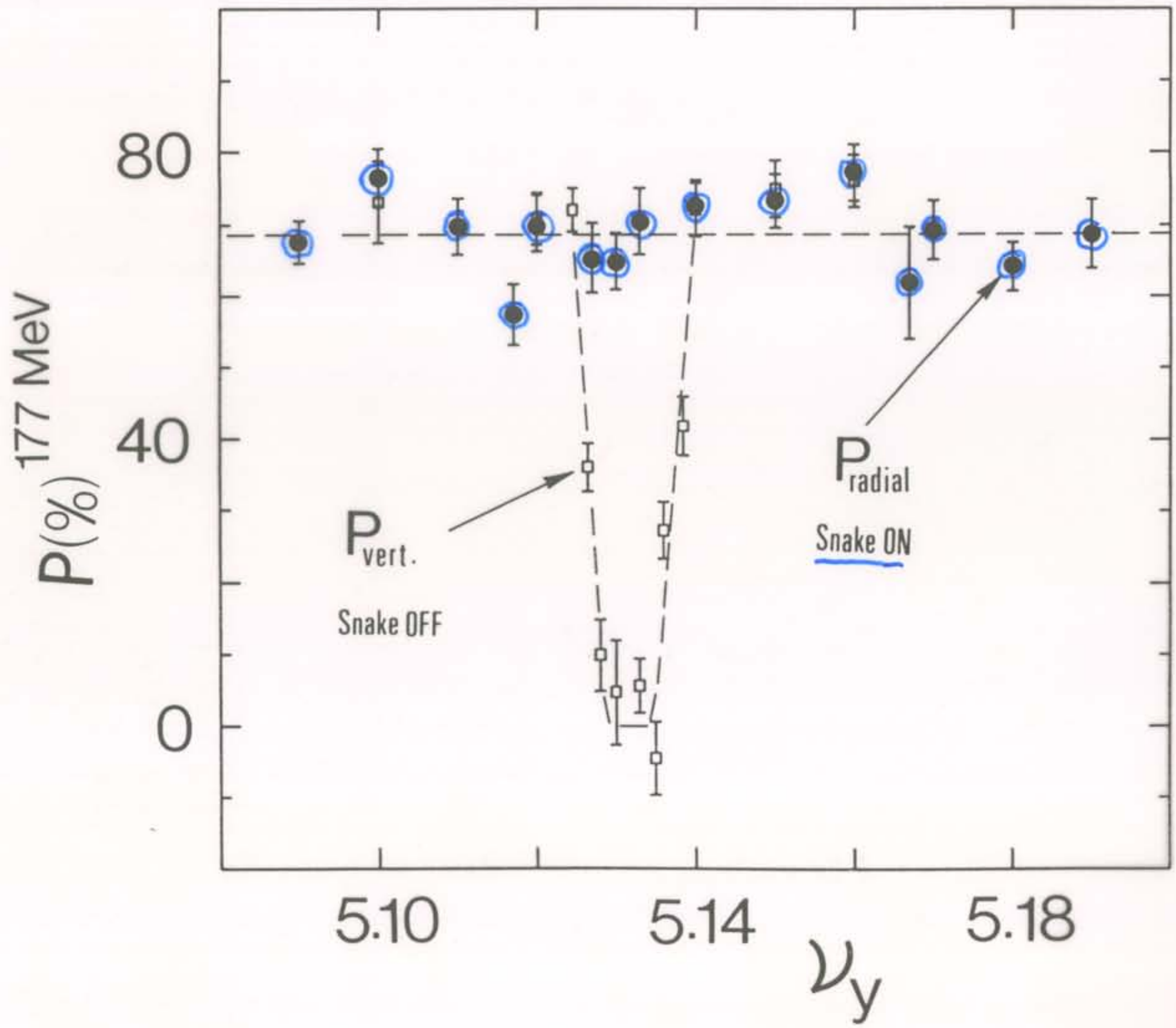
Brookhaven National Laboratory, Upton, New York 11973

A. D. Krisch, R. S. Raymond, T. Roser, J. A. Stewart, and B. Vuaridel
Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan 48109
(Received 7 March 1990)

We overcame the strong $G\gamma = -3 + \nu_y$ intrinsic depolarizing resonance using a Siberian snake acting on a stored beam of 177-MeV polarized protons at the Indiana University Cooler Ring. We also saw the first evidence for a synchrotron depolarizing resonance in a proton ring. Two synchrotron resonances were studied by varying the rf accelerating voltage and the imperfection field at 104 MeV. The Siberian snake also overcame these synchrotron depolarizing resonances.



IUCF

1994
Adiabatic Snake turn-on

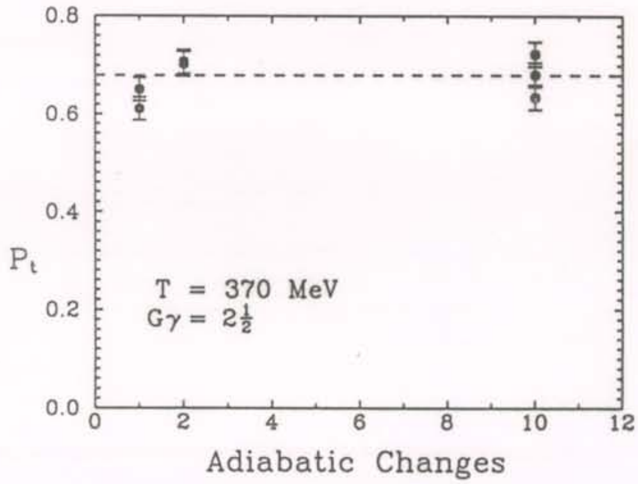


Fig. B9 The transverse polarization, $P_t=\sqrt{P_v^2+P_r^2}$, at 370 MeV is plotted against the number of times the 25% partial Siberian snake was turned on or off. The dashed line is the best fit to the data, which show no depolarization within our 2% precision.[86]

1994
Partial snake overcoming $G\gamma = 2$ during accel.

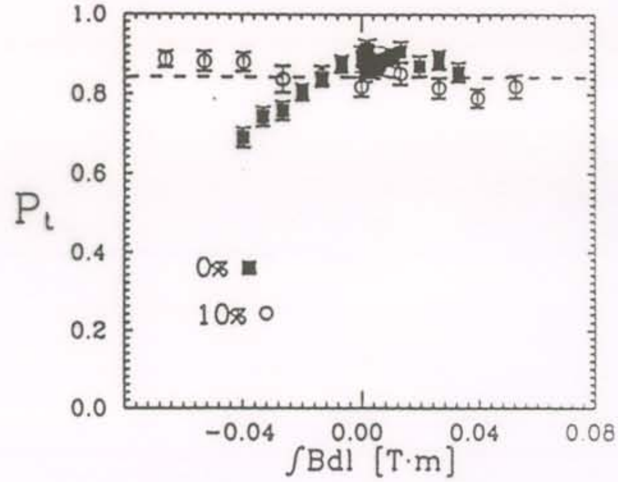


Fig. B10 The measured transverse polarization P_t at 140 MeV is plotted against the imperfection $\int B{\cdot}dl$ with no snake and with a 10% partial Siberian snake. The dashed line is the best constant-polarization fit to the snake-on data. The beam was accelerated from 95 to 140 MeV.[88]

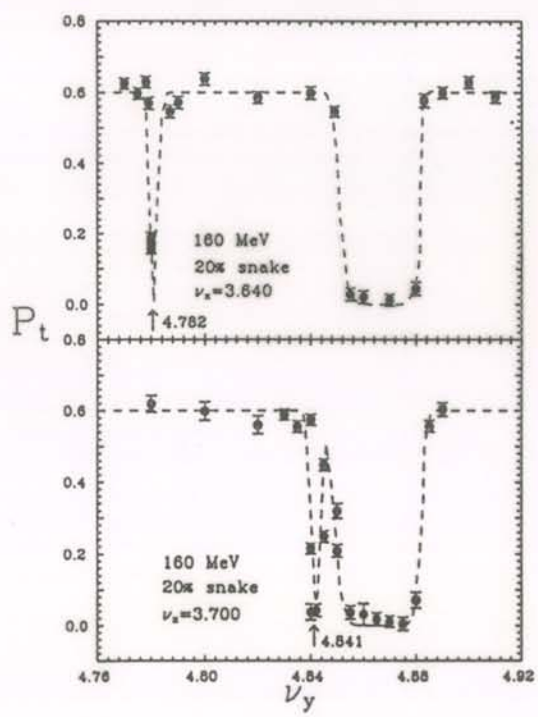


Fig. B11 The narrow dip's ν_y-shift of 0.059±0.001 is equal to the 0.060 change in ν_x, as predicted for the $\nu_s=\nu_y-\nu_x+1$ second-order resonance.[92]

2nd order depol resonance
1995

1995-96
spin-flipping through an intrinsic resonance by strengthening it

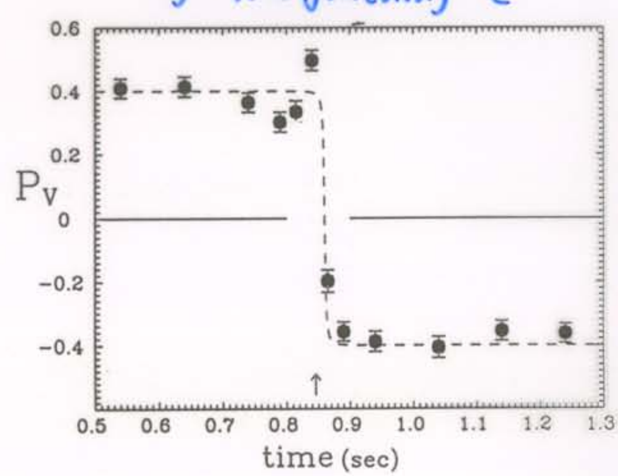
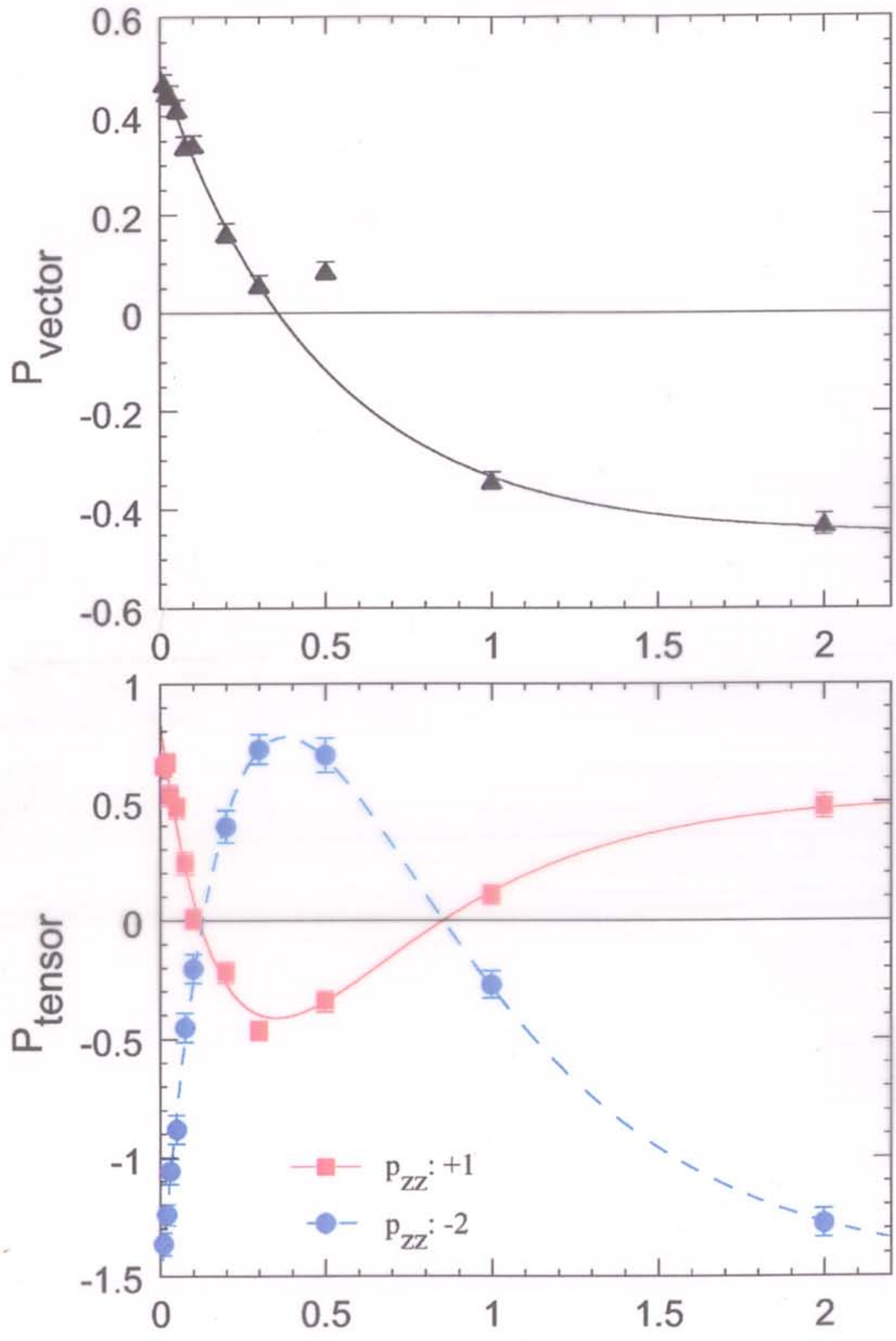
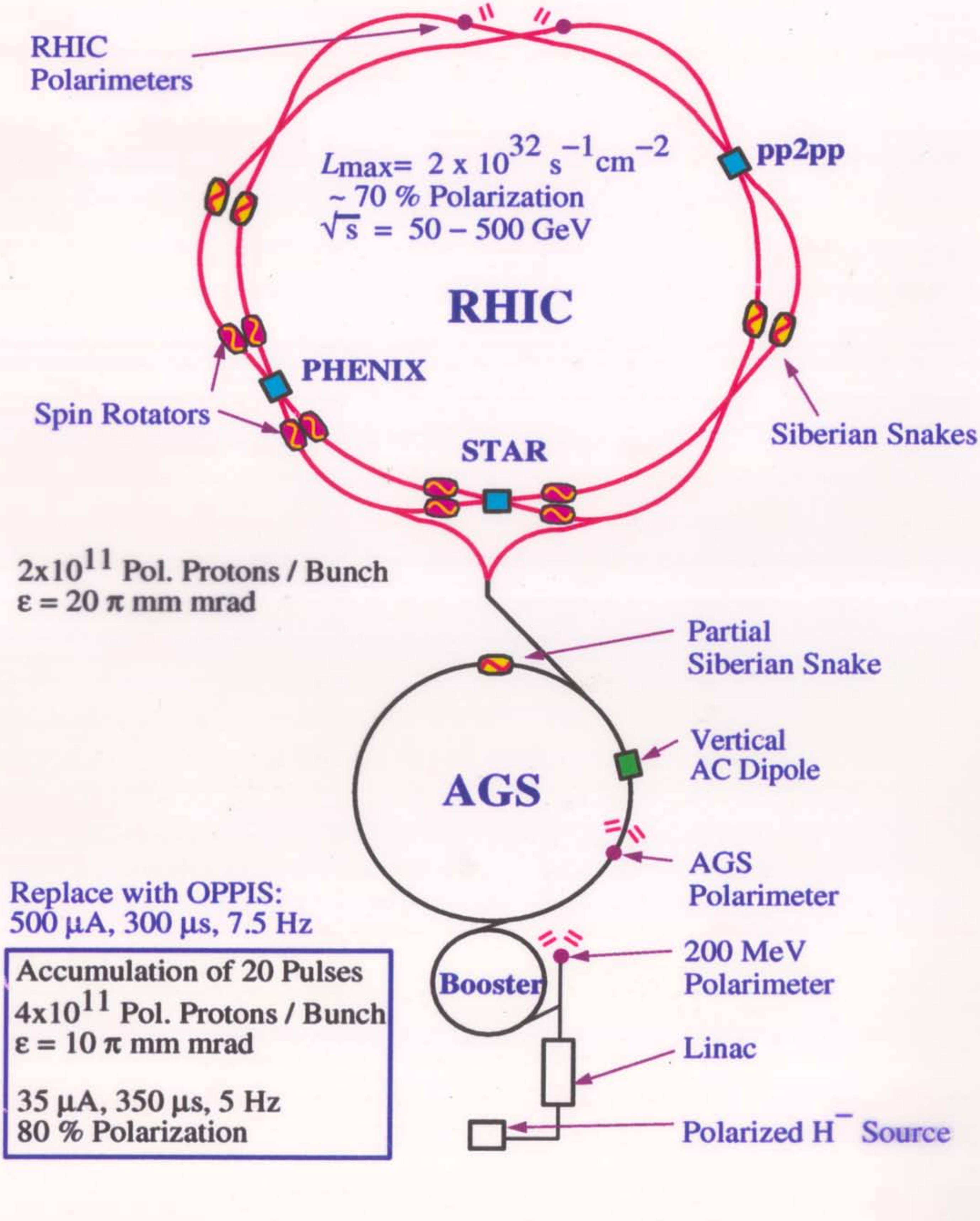


Fig. B12 The polarization spin-flips when the kicker is pulsed before crossing the resonance.[94]

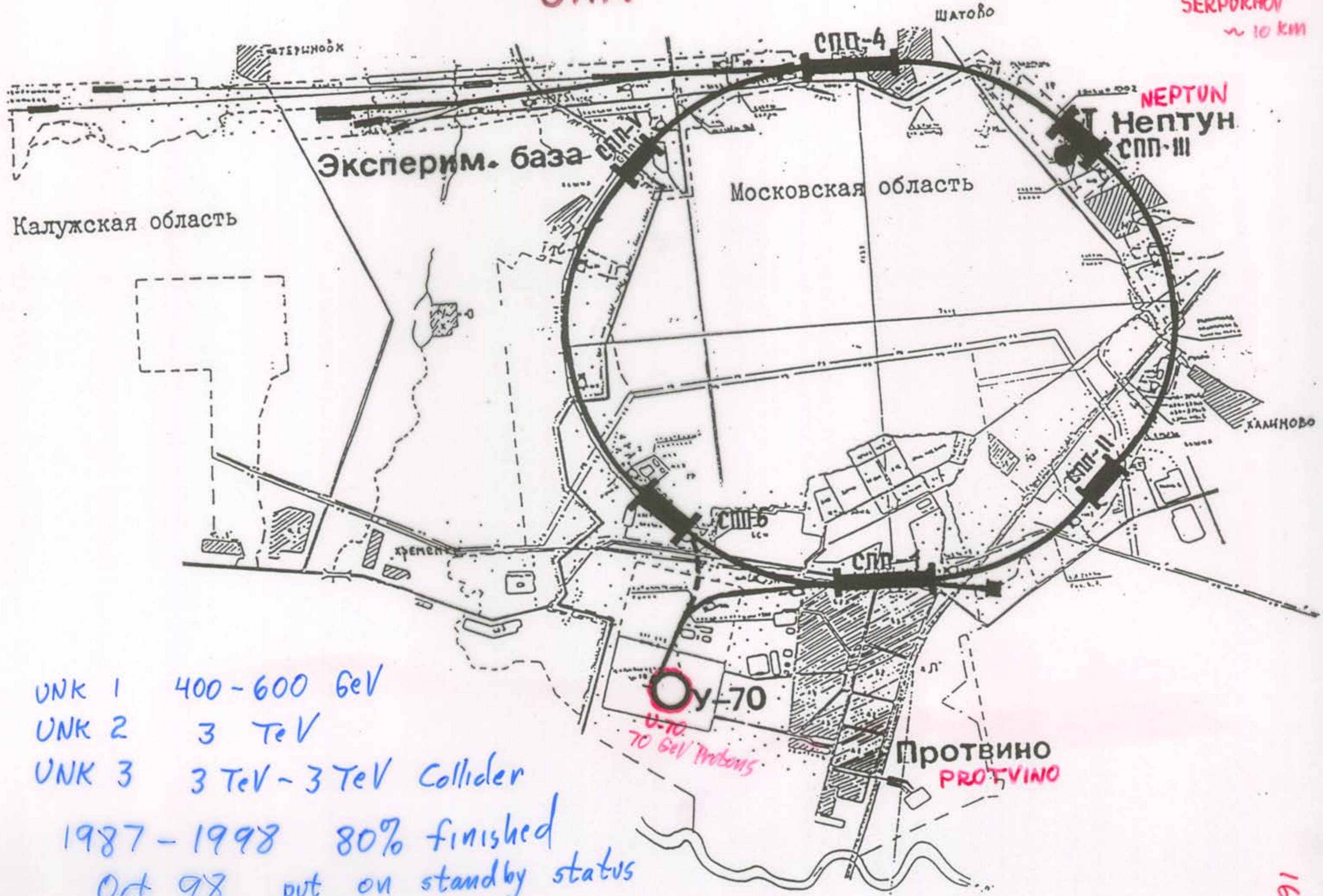


P_vector
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
0.5
1
1.5
2
P_tensor
1
0.5
0
-0.5
-1
-1.5
0
0.5
1
1.5
2
p_ZZ: +1
p_ZZ: -2
Δt (s)

Polarized Proton Collisions at BNL



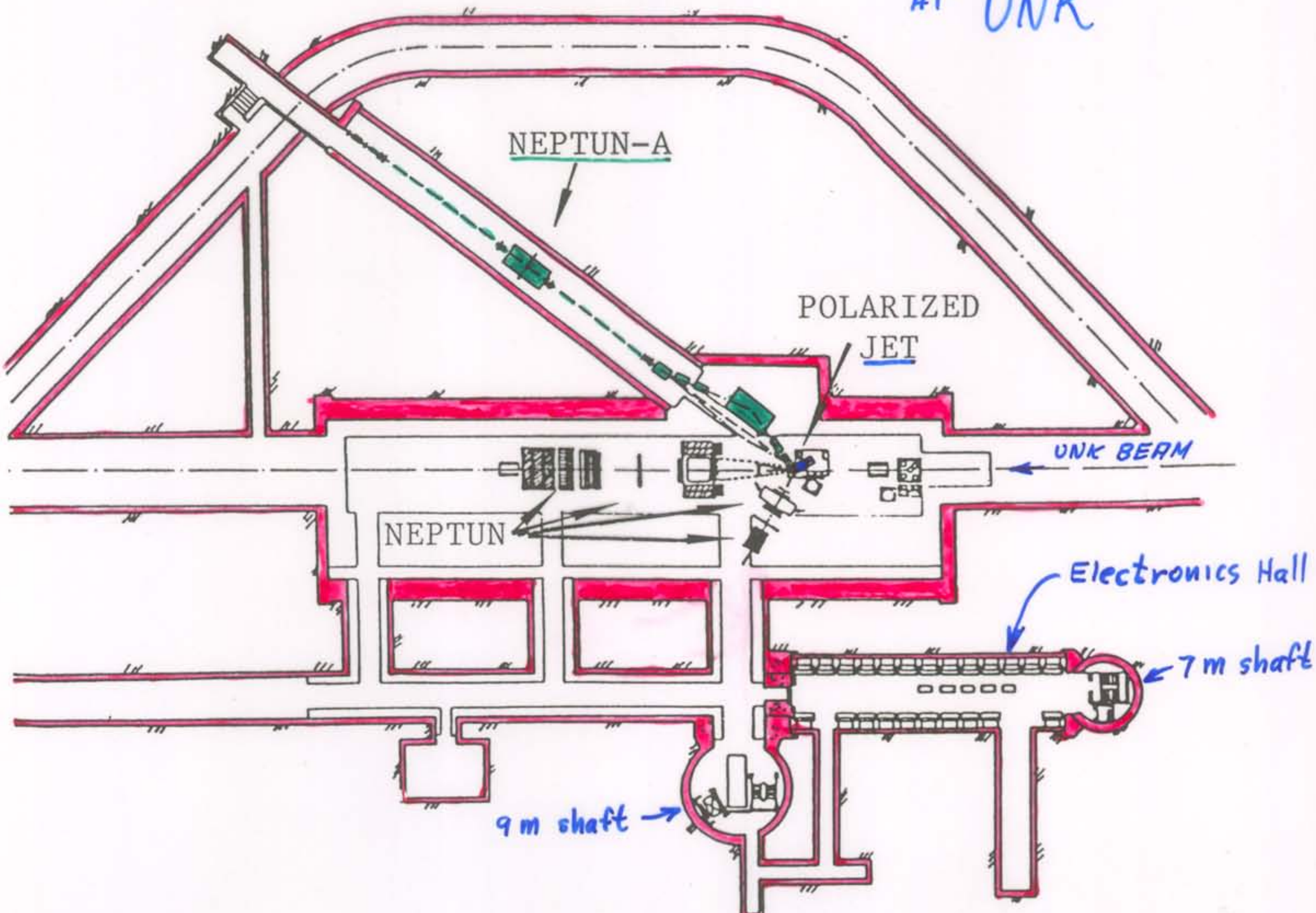
UNK



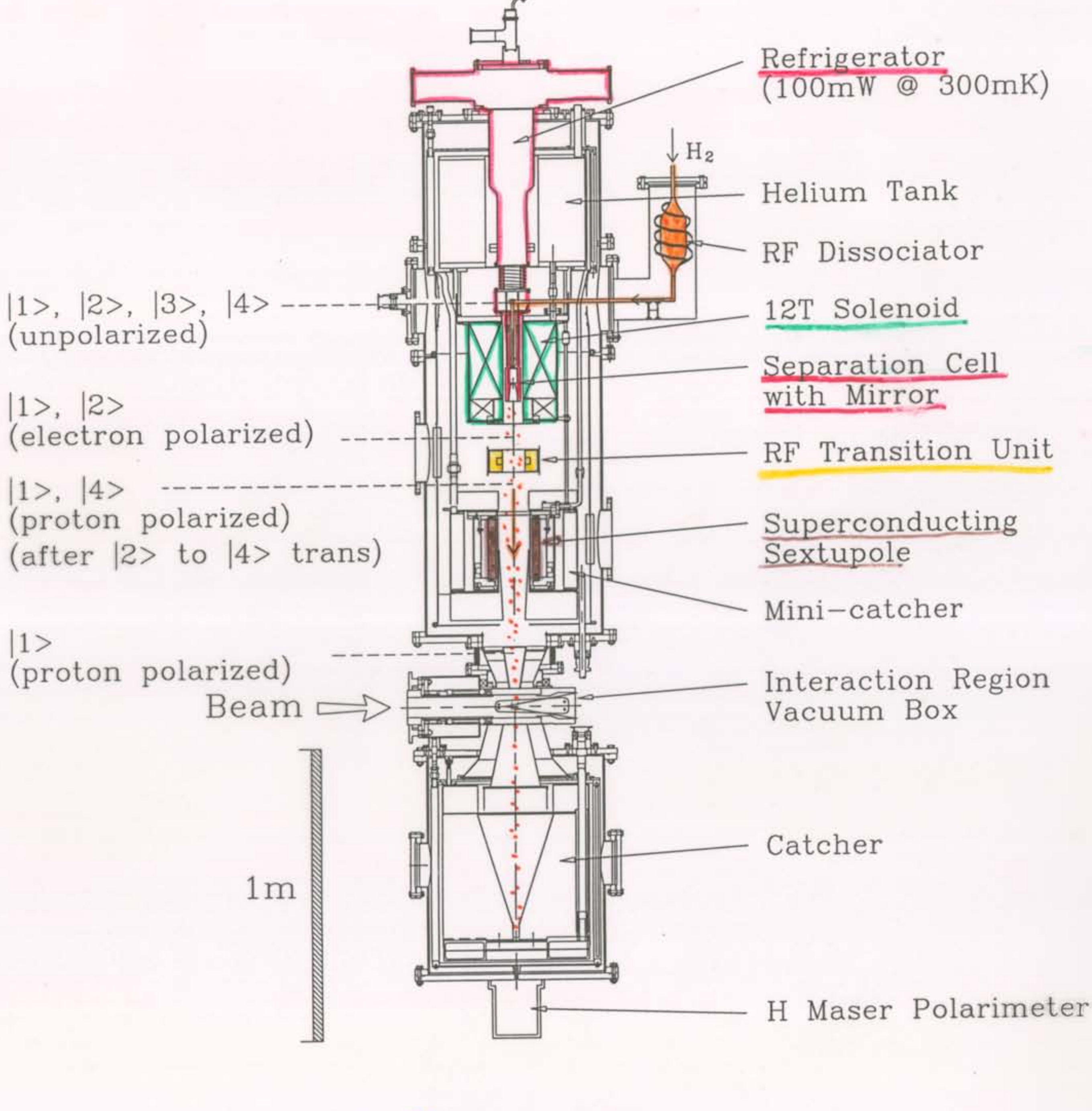
UNK 1 400 - 600 GeV
UNK 2 3 TeV
UNK 3 3 TeV - 3 TeV Collider

1987 - 1998 80% finished
Oct 98 put on standby status

HISTORY
NEPTUN-A
AT UNK



MARK-II ULTRA-COLD POLARIZED HYDROGEN JET TARGET.

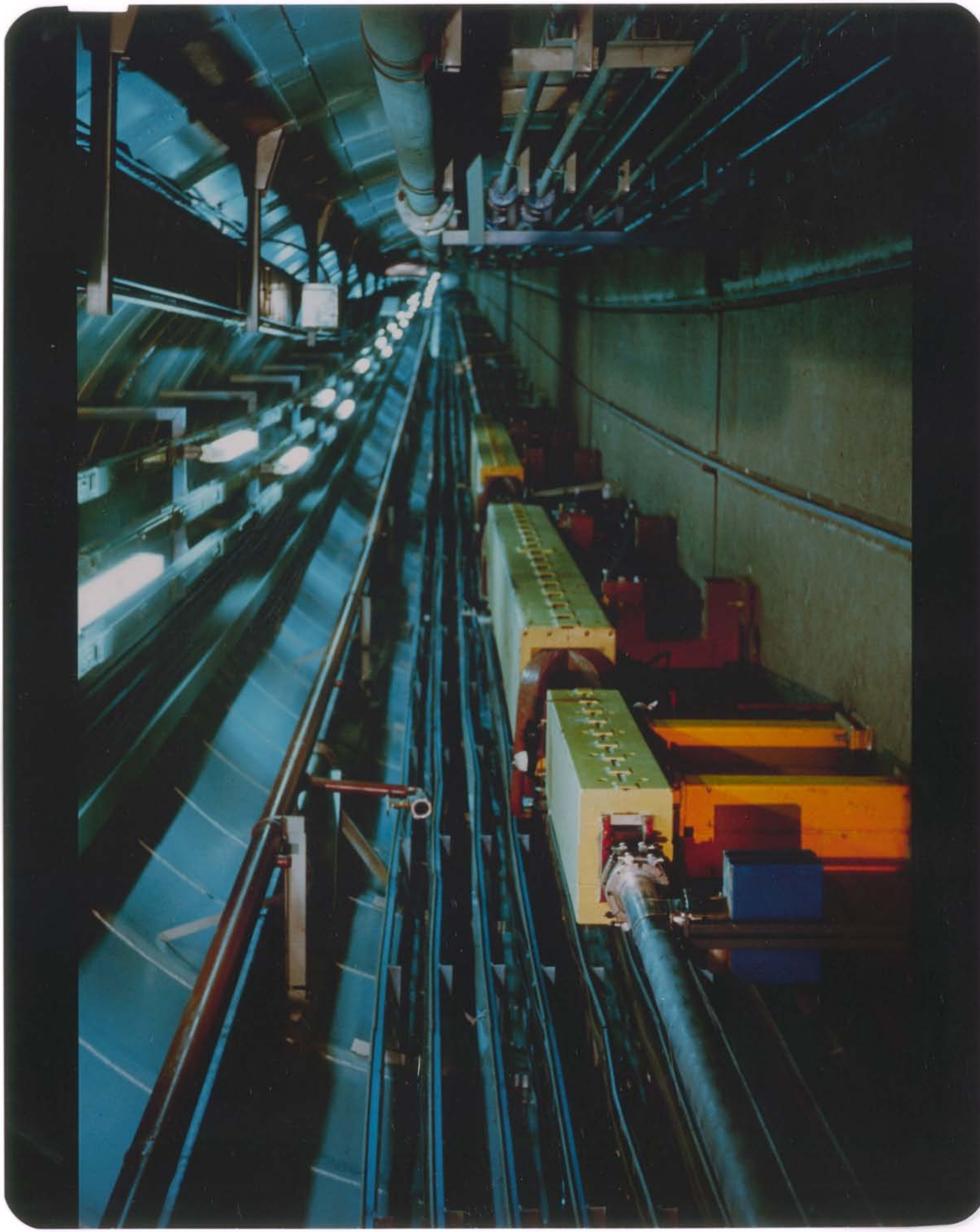


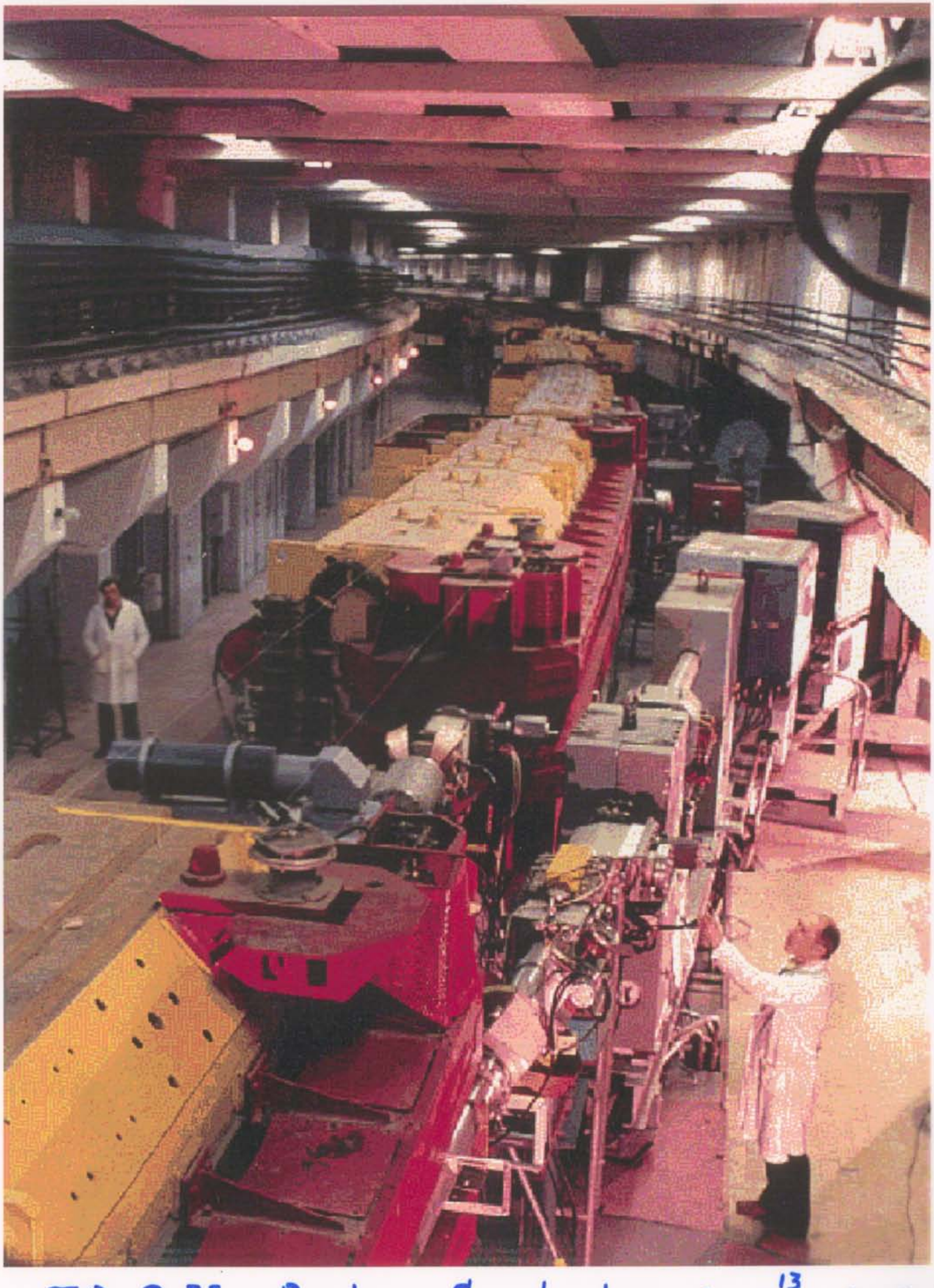
POLARIZED PROTONS:

THICKNESS: 1.1 10^{12} cm^{-2}

MAY 2001

BEAM SIZE: ~ 3 × 3 mm × mm





70 GeV Proton Synchrotron (2×10^{13} protons/pulse)

C. Michigan Solid Polarized Proton Target

The Center is continuing to test and improve the state-of-the-art 5 T at 1 K Michigan Solid Ammonia NH_3 Polarized Proton Target (PPT) and to prepare it for a later shipment to Protvino or now possibly Japan. Since our first SPIN@U-70 shipment is still impounded by Russian Customs, we will not ship the PPT to Russia until the first shipment is properly released and until we receive written assurances from MINATOM that subsequent shipments will not be impounded. Because of the impoundment, we may instead use the still-unimpounded Solid PPT for a similar experiment at the new very high intensity 50-GeV Proton Synchrotron in Japan, which is scheduled for first beam in 2007.

Recent improvements in the Michigan Solid-PPT have focused on increasing its reliability and include:

- new uni-polar power supply for the 5 T highly uniform superconducting magnet;
- new coil configuration for the NMR system;
- new wiring, Kel-F material holder, and RuO temperature sensor for the ^4He evaporation refrigerator;
- new Varian power supply for the 140 GHz microwave system.

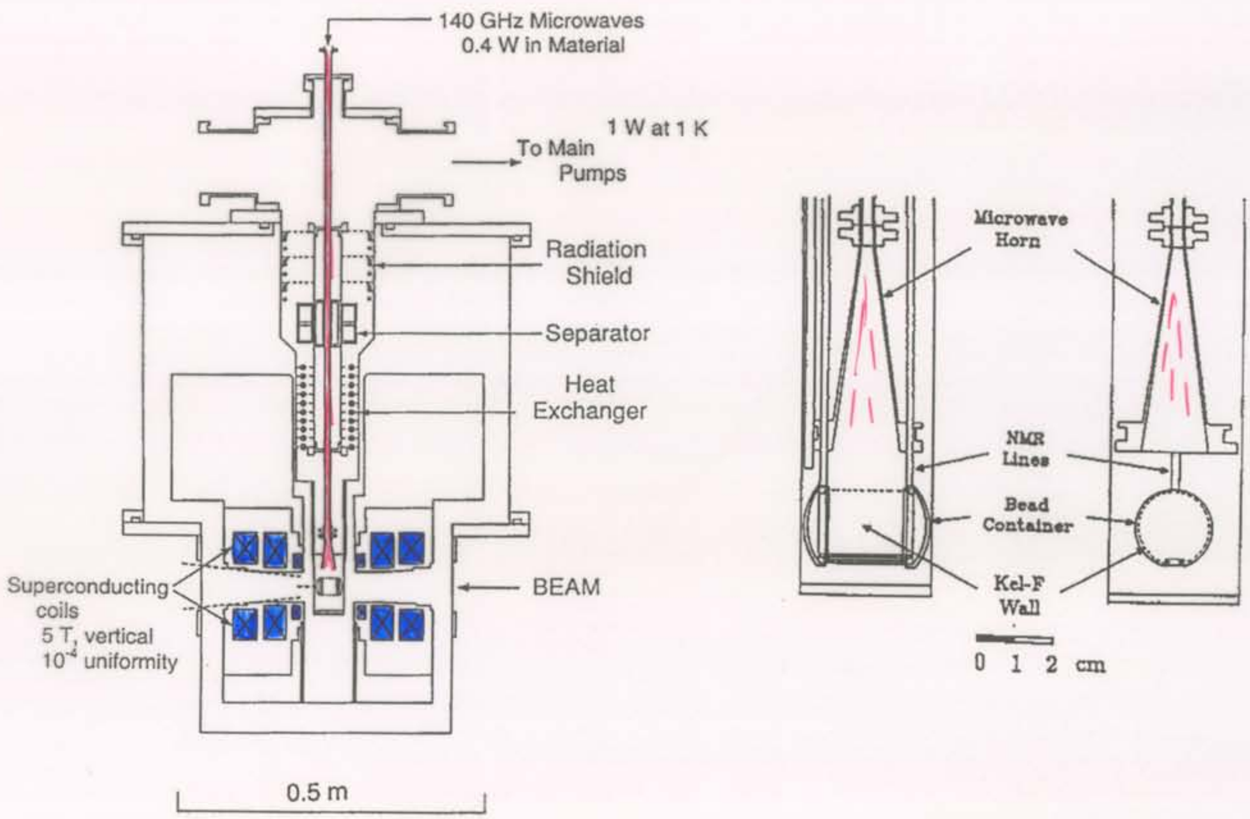
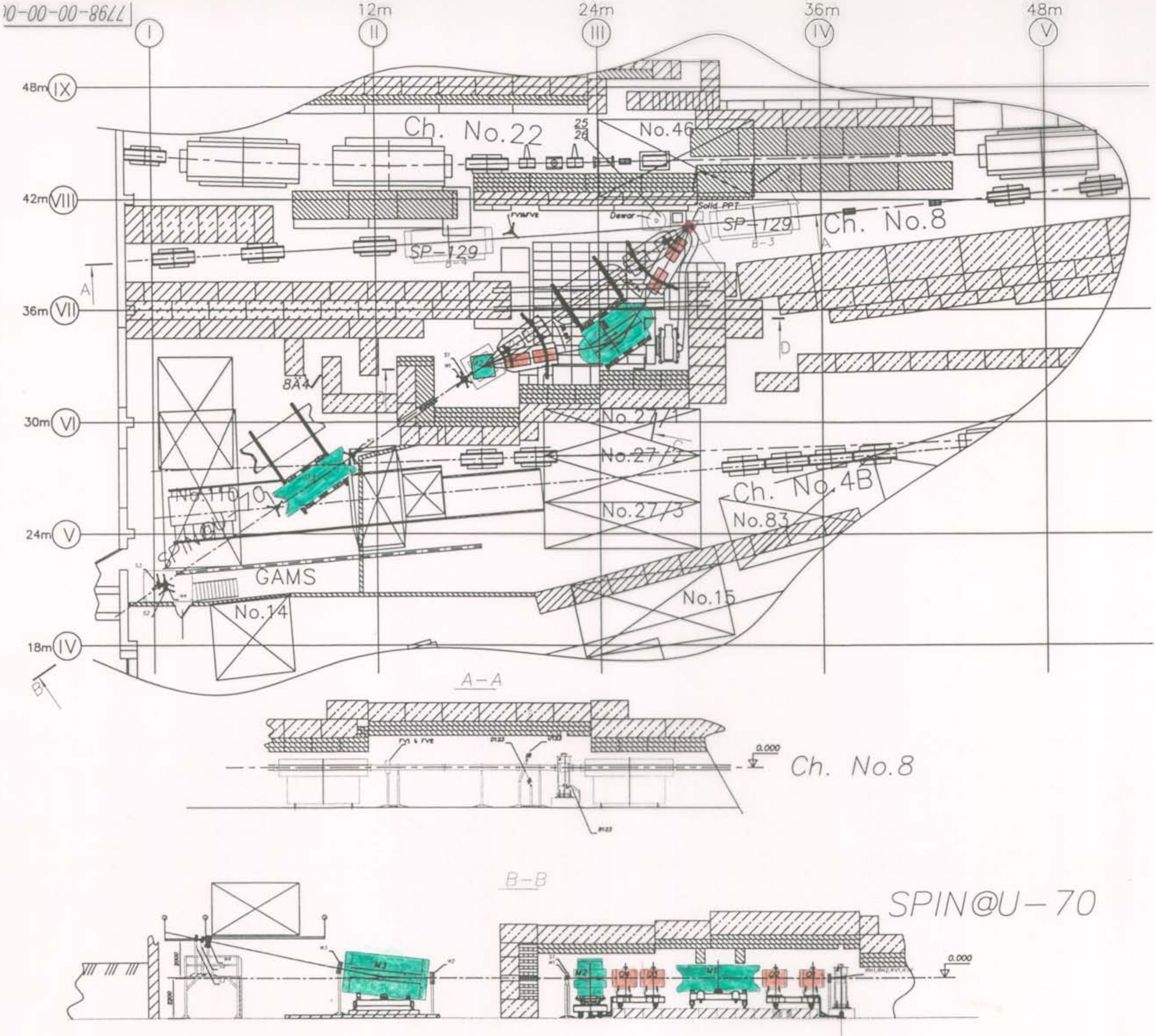
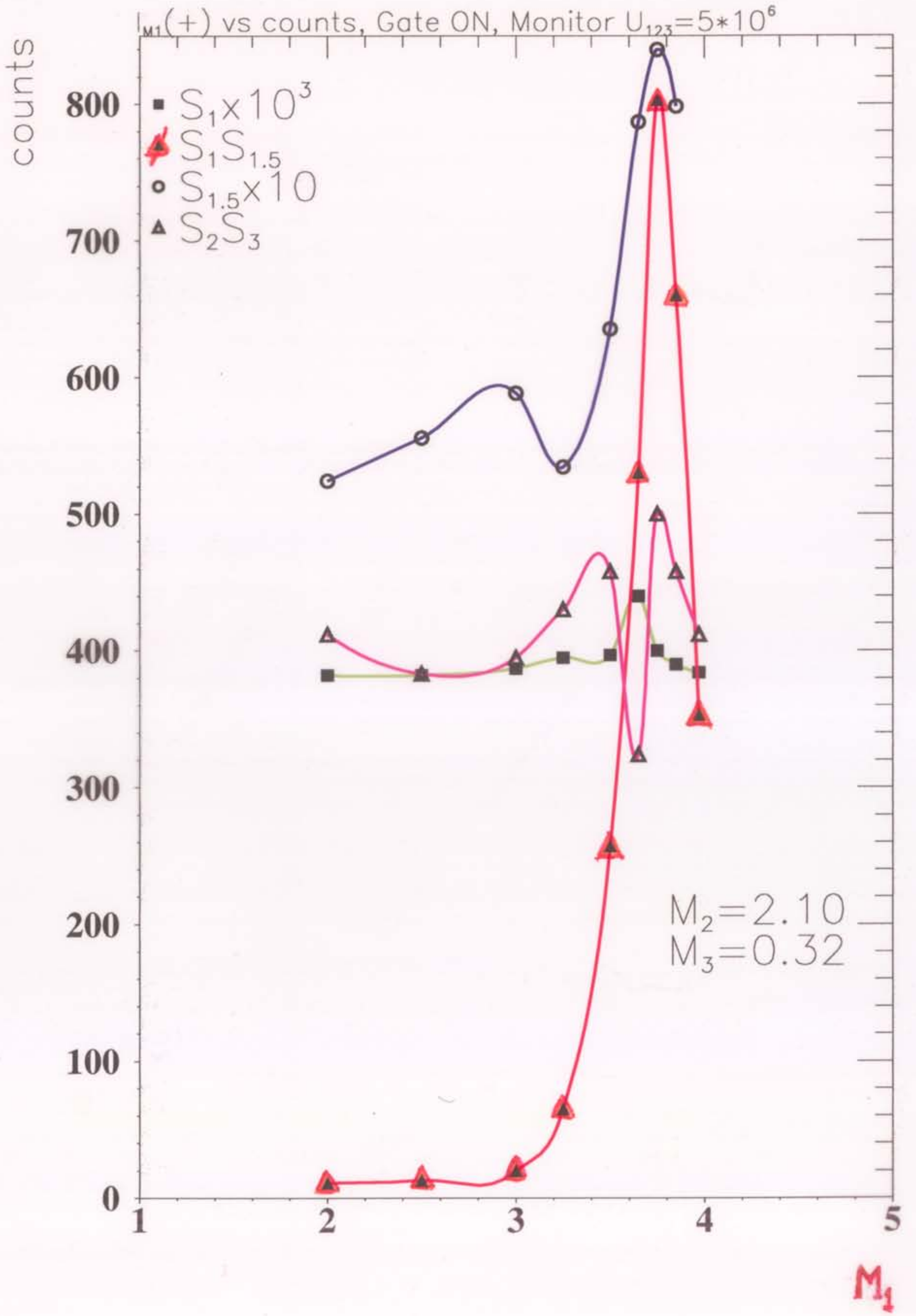


Figure 4. The state-of-the-art Michigan Solid Polarized Proton Target: the superconducting magnet produces a highly uniform 5 T field; the He^4 cryostat produces 0.9 W of cooling power at 1 K; the 140 GHz microwaves are focused into the small target cavity filled with irradiated ammonia NH_3; the proton polarization in frozen NH_3 at 5 T and 1 K is over 90%. An expanded view of the NH_3 cavity is shown on the right.


12m
24m
36m
48m
48m
42m
36m
30m
24m
18m
Ch. No.22
No.46
SP-129
Ch. No.8
8A4
No.27/1
No.27/2
No.27/3
Ch. No.4B
No.83
GAMS
No.14
No.15
Dewar
Solid PPT
A-A
0.000
Ch. No.8
B-B
0.000

SPIN@U-70



$I_{M1}(+)$ vs counts, Gate ON, Monitor $U_{123}=5*10^6$
counts
$S_1 \times 10^3$
$S_1 S_{1.5}$
$S_{1.5} \times 10$
$S_2 S_3$
800
700
600
500
400
300
200
100
0
1
2
3
4
5
$M_2=2.10$
$M_3=0.32$
M_1

26 Dec 2002

SPIN@J-PARC Letter of Intent

to

JAPAN 50 GeV J-PARC

Analyzing power A_n in 50 GeV very-high-$P_\perp^2$ proton-proton elastic scattering

SPIN@J-PARC Collaboration:
Michigan, Virginia, KEK, RCNP, TokyoTech, TRIUMF

G. Fidecaro,[a] M. Fidecaro,[a] F.Z. Khiari,[b] A.D. Krisch, M.A. Leonova, A.M.T. Lin, W. Lorenzon, V.G. Luppov, V.S. Morozov, D.C. Peaslee,[c] C.C. Peters, R.S. Raymond, D.W. Sivers,[d] K. Yonehara and V.K. Wong

UNIVERSITY OF MICHIGAN, ANN ARBOR, U.S.A.

D.G. Crabb and students

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C. Ohmori and H. Sato

KEK, TSUKUBA, JAPAN

K. Hatanaka, Y. Sakemi and students

RCNP, OSAKA, JAPAN

T. Shibata

TOKYO INSTITUTE OF TECHNOLOGY, TOKYO, JAPAN

P.P.J. Delheij and W.T.H. van Oers

TRIUMF, VANCOUVER, CANADA

* The **Spokesperson** for the SPIN@J-PARC Collaboration is:

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University of Michigan
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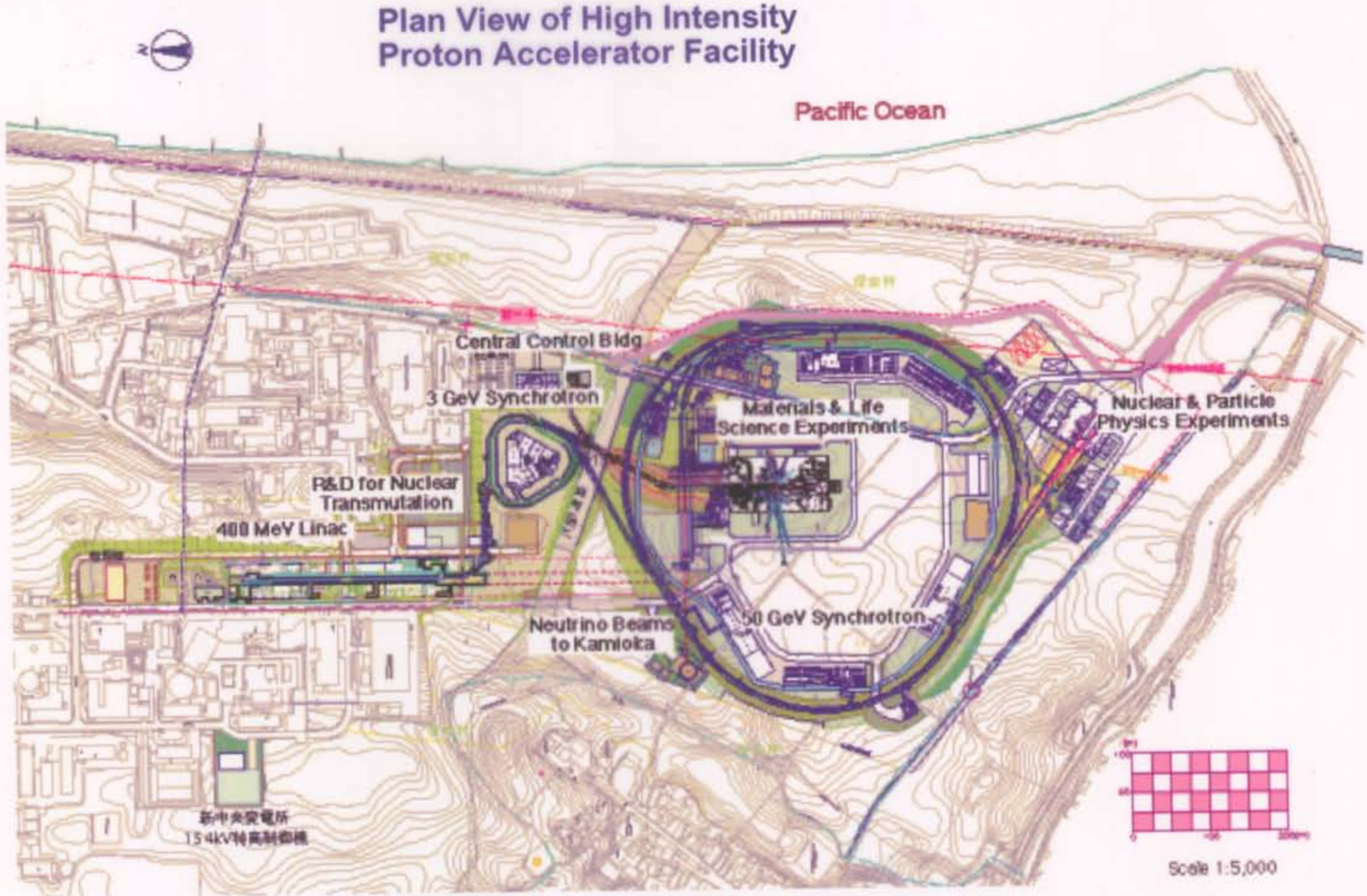
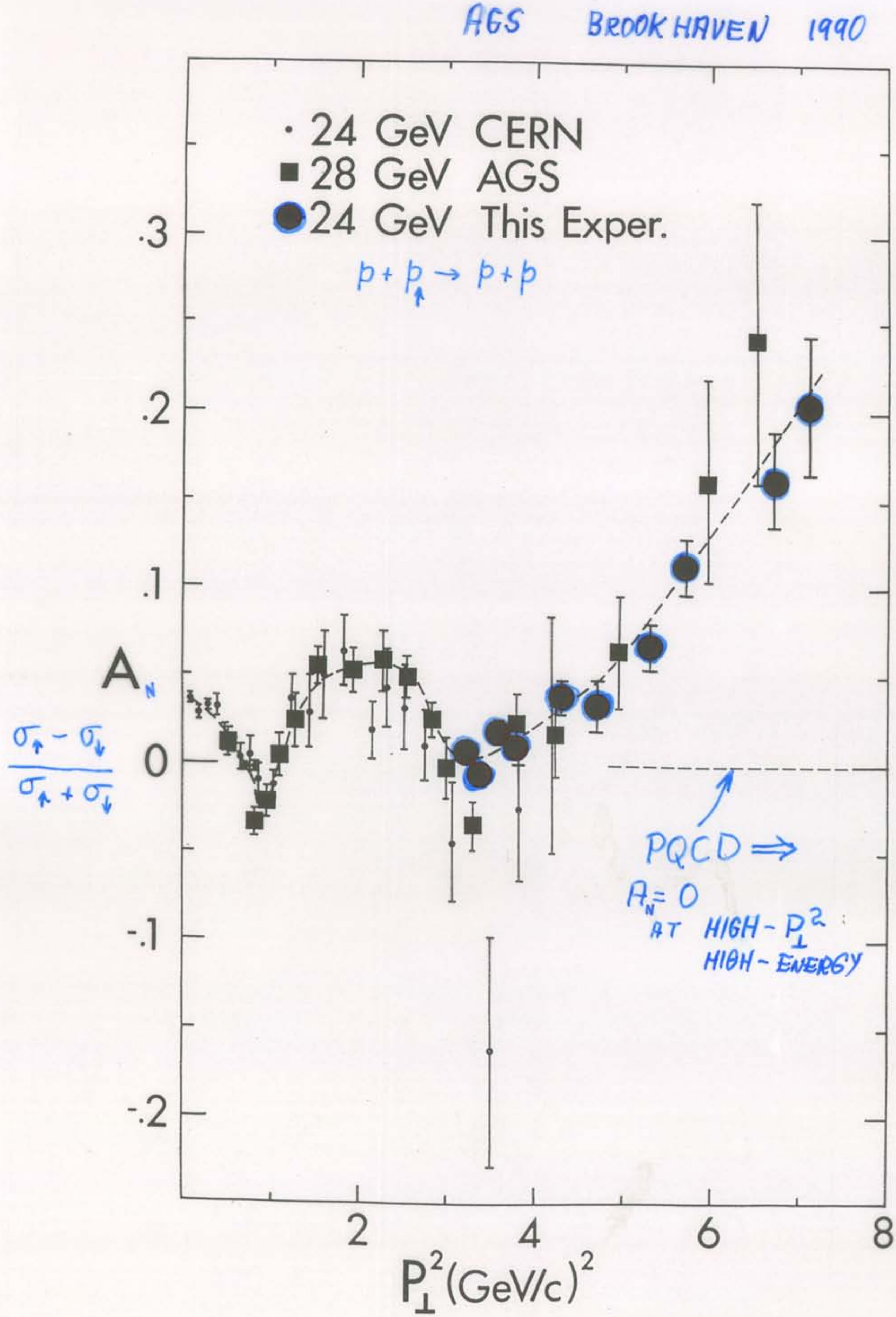
Permanent address:

[a] CERN
[b] King Fahd Univ. [not yet confirmed]
[c] Univ. of Maryland [not yet confirmed]
[d] Portland Physics Inst

Attachment 1: Details of the High Intensity Proton Accelerator Facility.

Plan View of High Intensity Proton Accelerator Facility




AGS BROOKHAVEN 1990
· 24 GeV CERN
■ 28 GeV AGS
● 24 GeV This Exper.
$p + p_{\uparrow} \to p + p$
A_N
$\frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}}$
.3
.2
.1
0
-.1
-.2
2
4
6
8
$P_{\perp}^2 (GeV/c)^2$
PQCD ⇒
$A_N = 0$
AT HIGH - $P_{\perp}^2$
HIGH - ENERGY

MICHIGAN
NH^3 PPT 5T / 1°K

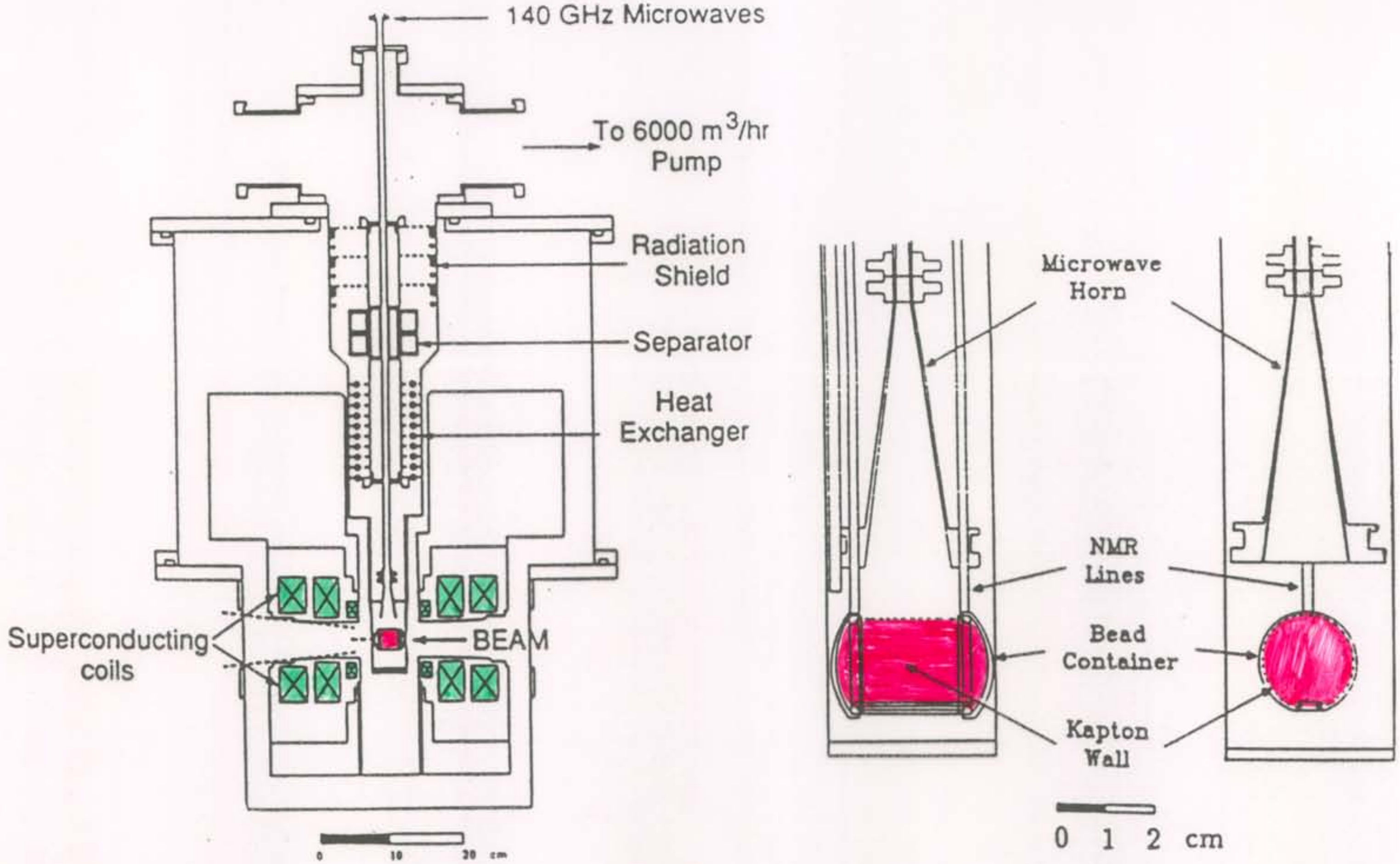


Figure 2. Diagram of the Michigan polarized-proton-target is shown on the left[4]. The superconducting magnet produces a highly uniform 5 T field. At 1 K, the ^{4}He cryostat provides about 1 watt of cooling power to the target material in the small cavity at the bottom. The 140 GHz microwaves, from a 20 watt Varian EIO, are fed into the target cavity via the horn. Expanded views of the small target cavity are shown on the right.

This PPT target had an average polarization of 85% during a 3-month-long AGS run,[1, 27] with an average beam intensity of about $2 \cdot 10^{11}$ protons per 2.4 sec AGS cycle. This was an average beam intensity of almost 10^{11} protons per sec; it corresponds to $3 \cdot 10^{11}$ protons per 3-sec cycle at J-PARC. Our experience at the AGS[1, 4] suggests that there should be no problem due to the slightly different cycle times at the AGS and J-PARC; the thermal-time-constant of the PPT appeared to be more than a minute.

The dilution factor decreases the true proton-proton analyzing power due to quasi-elastic events or events from the heavy nuclei in the NH_3 beads, the He^4 or the container. The dilution factor was determined experimentally at the AGS by measuring the event rate with hydrogen-free Teflon (CF_2) beads in place of the NH_3 beads; it was also obtained from the "off-diagonal matrix" coincidences between the forward and recoil hodoscopes. The measured dilution factor, at $P_\perp^2 = 3.2\ (\mathrm{GeV/c})^2$ was 1.06 and was about 1.6 at $P_\perp^2 = 7\ (\mathrm{GeV/c})^2$.[1, 27] The dilution factor was fairly small because the AGS double-arm elastic spectrometer rather strongly discriminated against quasi-elastic events and events from nitrogen and other heavy nuclei. However, the heavy nuclei produced many inclusive events indistinguishable from the polarized protons inclusive events.[28] Therefore, inclusive measurements would be very difficult with this PPT.

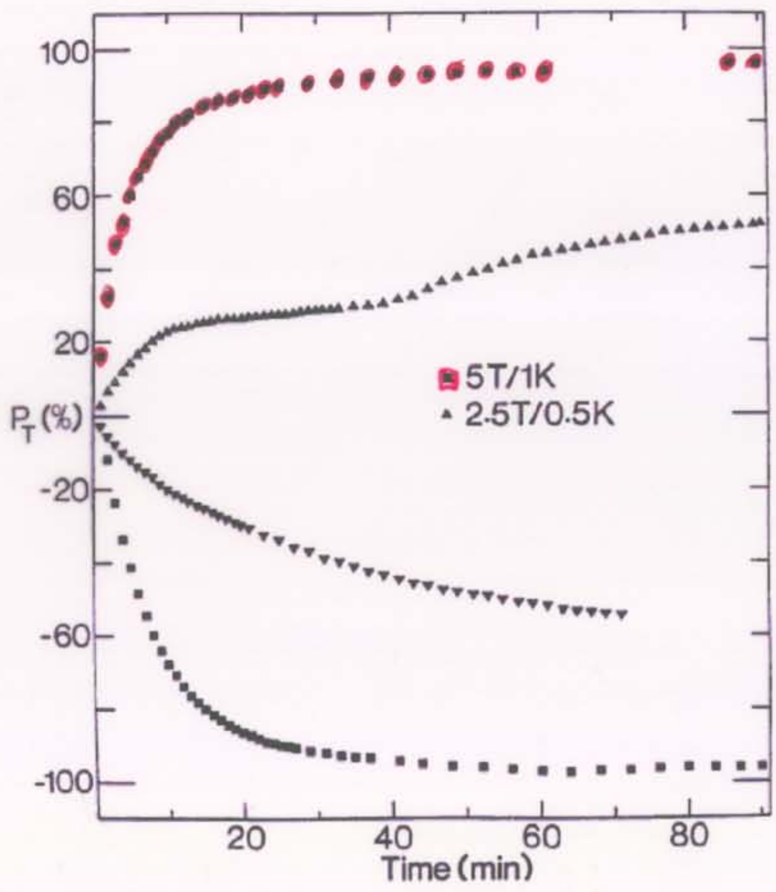


Fig. 3. Spin polarization of the free protons in NH_3 is plotted vs. the 140 (or 70) GHz microwave irradiation time. The data at 5 T and 1 K are squares; the earlier NH_3 data at 2.5 T and 0.5 K are triangles.[4, 27]

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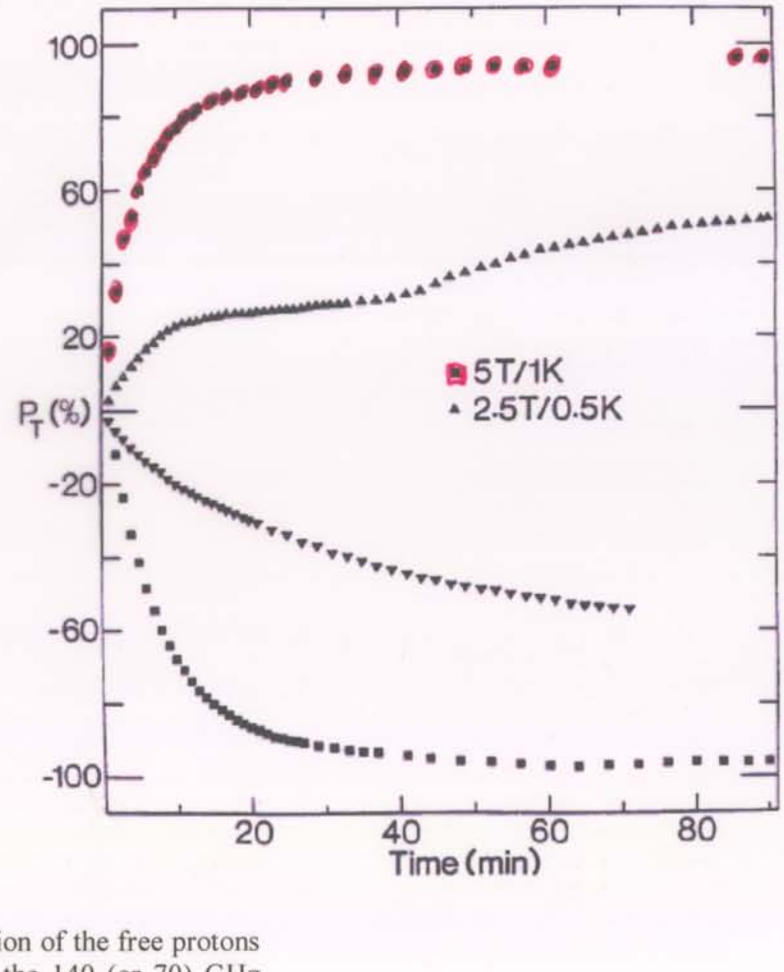

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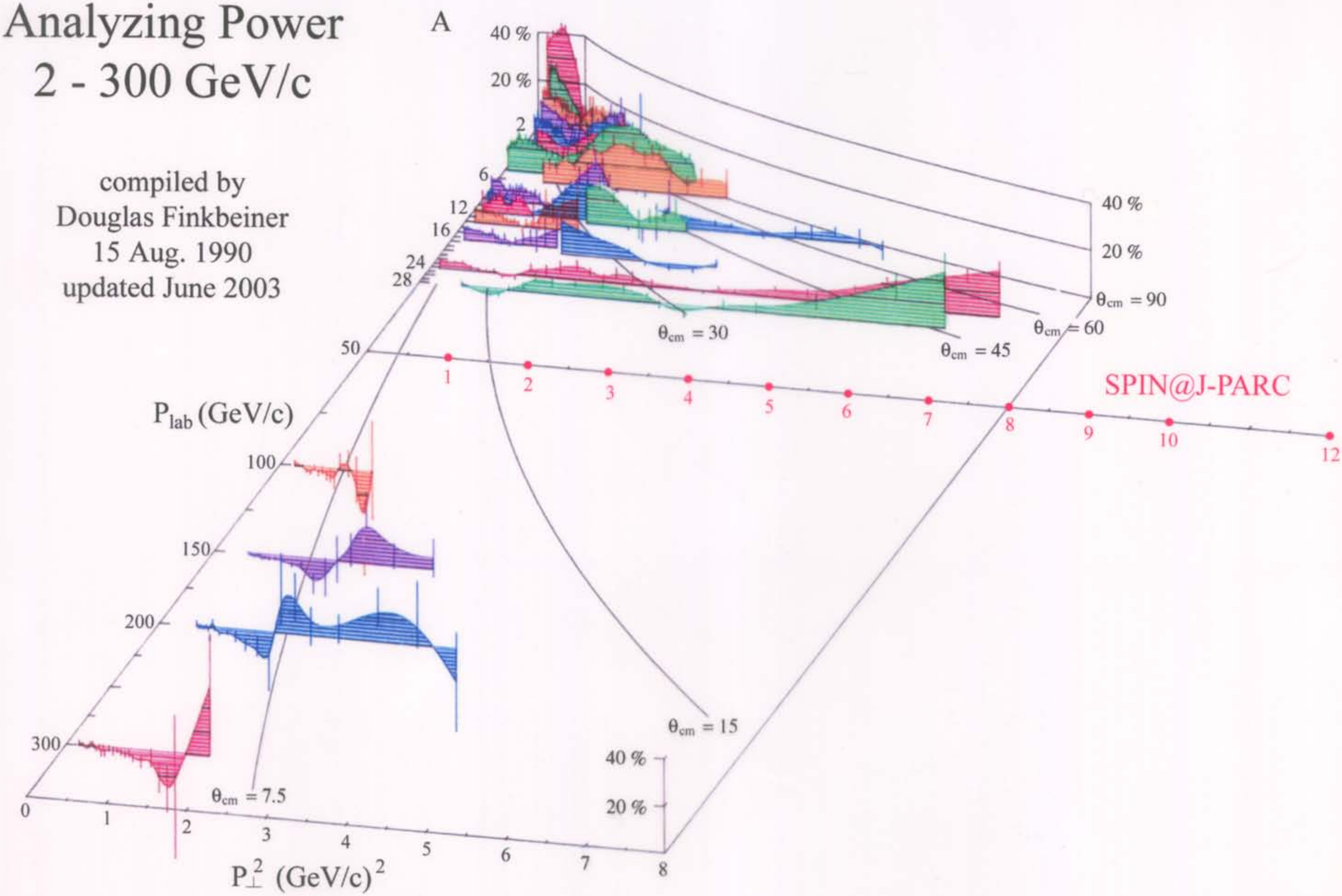
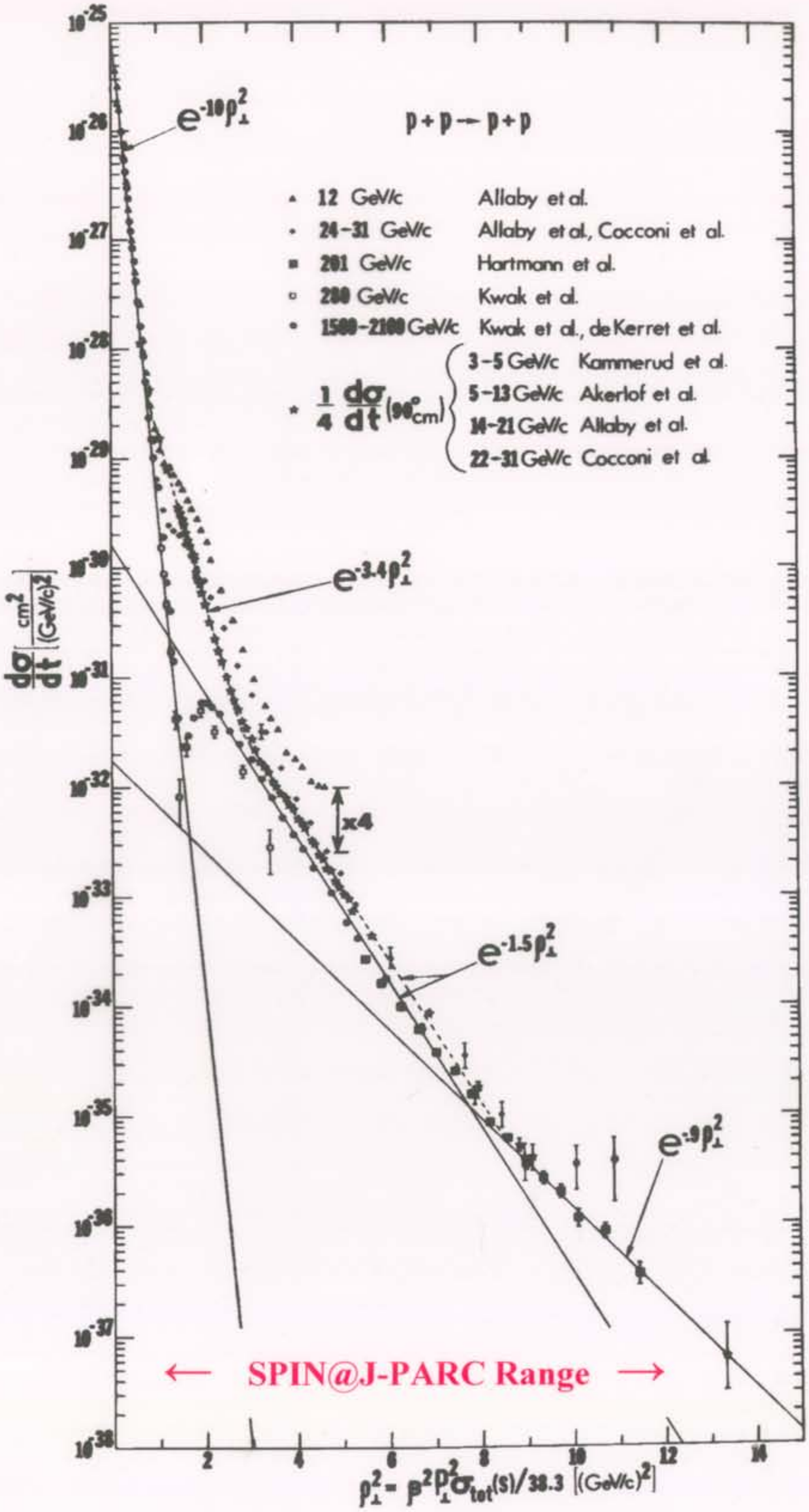
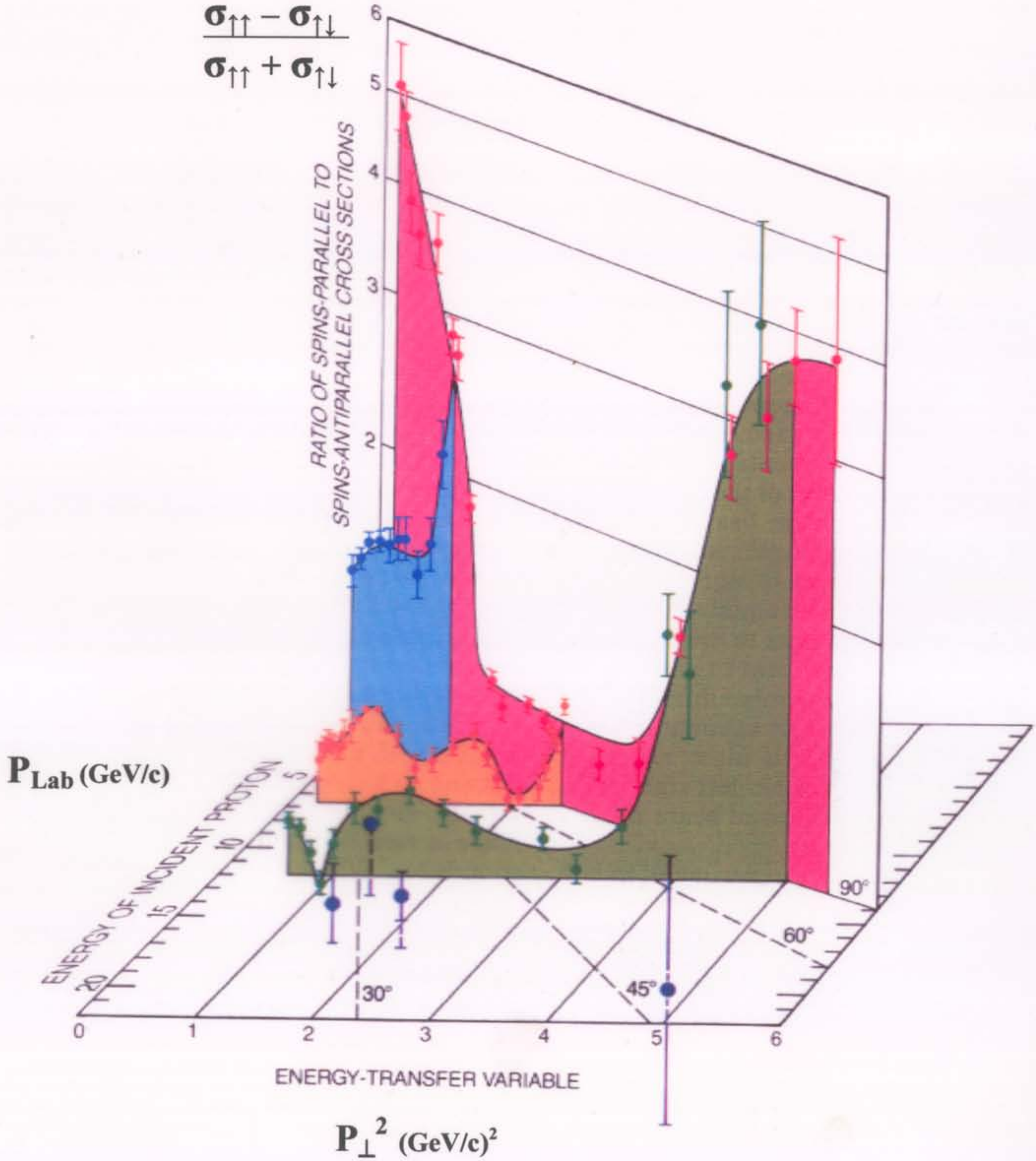
Analyzing Power
2 - 300 GeV/c

compiled by
Douglas Finkbeiner
15 Aug. 1990
updated June 2003





Proton-proton elastic cross-sections plotted against the scaled $P_\perp^2$ variable



$\frac{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}}{\sigma_{\uparrow\uparrow} + \sigma_{\uparrow\downarrow}}$
RATIO OF SPINS-PARALLEL TO SPINS-ANTIPARALLEL CROSS SECTIONS
6
5
4
3
2
P_{Lab} (GeV/c)
ENERGY OF INCIDENT PROTON
5
10
15
20
30°
45°
60°
90°
0
1
2
3
4
5
6
ENERGY-TRANSFER VARIABLE
$P_{\perp}^{2}$ $(GeV/c)^2$