Polarized Targets and Scattering

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OUTLINE

1. Argonne Days
2. Brookhaven Days
3. 1990 - Present

VOLUME 39, NUMBER 12 PHYSICAL REVIEW LETTERS 19 SEPTEMBER 1977

Spin-Spin Interactions in High-$p_\perp^2$ Elastic p-p Scattering

VOLUME 43, NUMBER 14 PHYSICAL REVIEW LETTERS 1 OCTOBER 1979

Spin-Spin Forces in 6-GeV/c Neutron-Proton Elastic Scattering

PHYSICAL REVIEW D VOLUME 23, NUMBER 3 1 FEBRUARY 1981

Energy dependence of spin-spin effects in p-p elastic scattering at $90°_{c.m.}$

PHYSICAL REVIEW D VOLUME 26, NUMBER 3 1 AUGUST 1982

Measurements of spin parameters in p-p elastic scattering at 6 GeV/c

VOLUME 51, NUMBER 26 PHYSICAL REVIEW LETTERS 26 DECEMBER 1983

Large-$P_\perp^2$ Spin Effects in $p+p \to p+p$

VOLUME 60, NUMBER 23 PHYSICAL REVIEW LETTERS 6 JUNE 1988

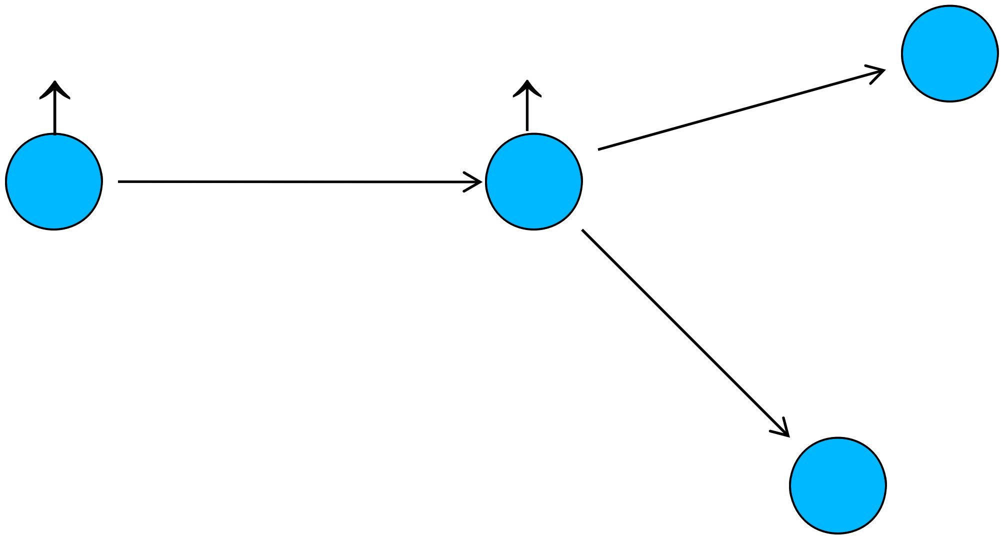
Measurement of Spin Effects in $p_\uparrow + p_\uparrow \to p + p$ at 18.5 GeV/c

VOLUME 64, NUMBER 22 PHYSICAL REVIEW LETTERS 28 MAY 1990

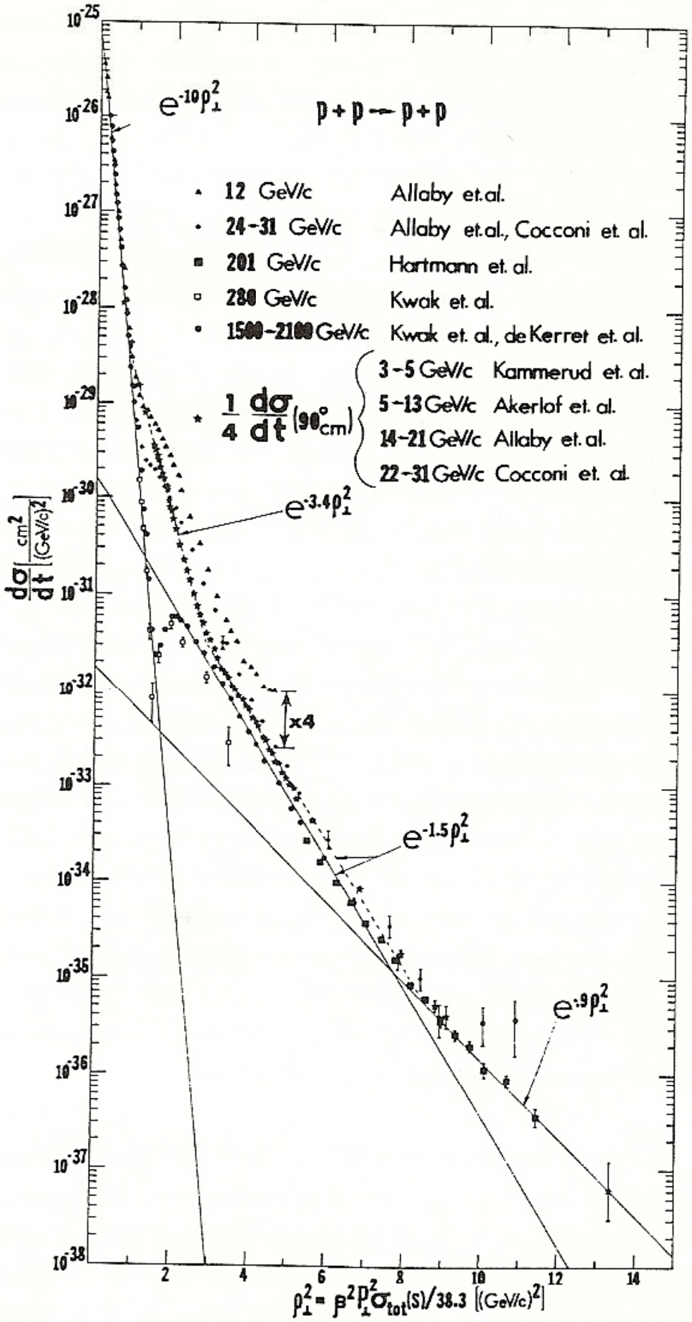
Observation of a 96% Proton Polarization in Irradiated Ammonia

UM HE 90–17
August 23, 1990

High precision measurement of A in large $P_\perp^2$ spin–polarized 24 GeV/c proton-proton elastic scattering

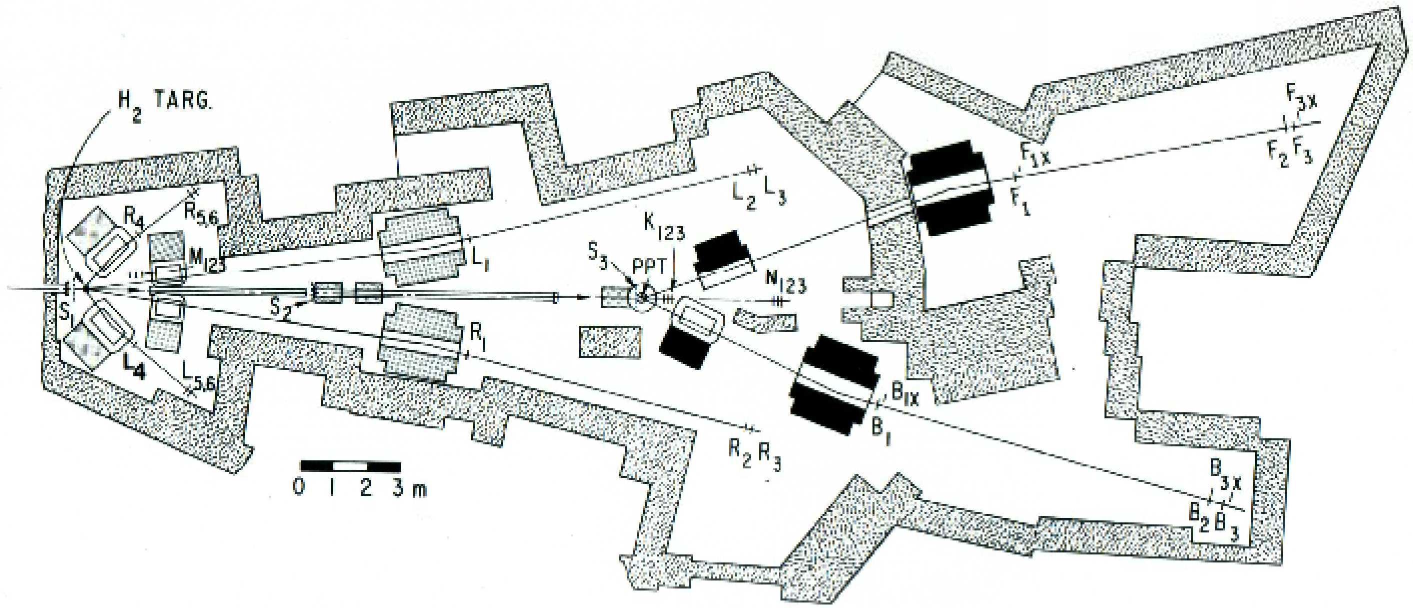


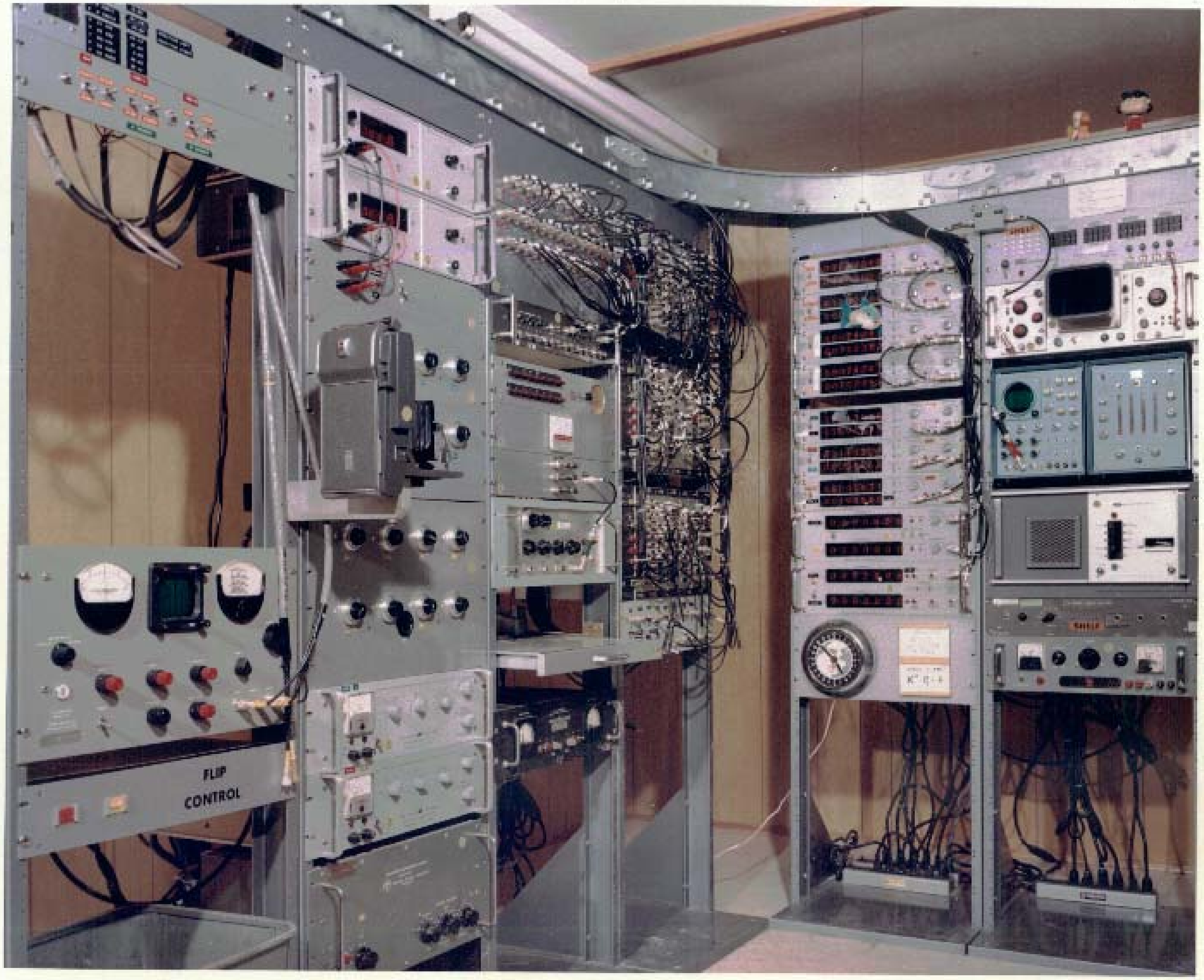
$$P^{\uparrow} + P^{\uparrow} \rightarrow\rightarrow P + P$$



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
$\frac{d\sigma}{dt}\left[\frac{cm^2}{(GeV/c)^2}\right]$
$\rho_\perp^2 = \beta^2 p_\perp^2 \sigma_{tot}(S)/38.3\ [(GeV/c)^2]$

Polarized Targets and Scattering at Argonne National Lab.


H2 TARG.
R4
R5,6
M123
S1
S2
L4
L5,6
L1
R1
0 1 2 3 m
L2 L3
R2 R3
K123
S3
PPT
N123
F1X
F1
F3X
F2 F3
B1X
B1
B3X
B2 B3


FLIP
CONTROL

$$A_N = \frac{L-R}{L+R} = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \quad \text{for pure 100\% polarized target}$$

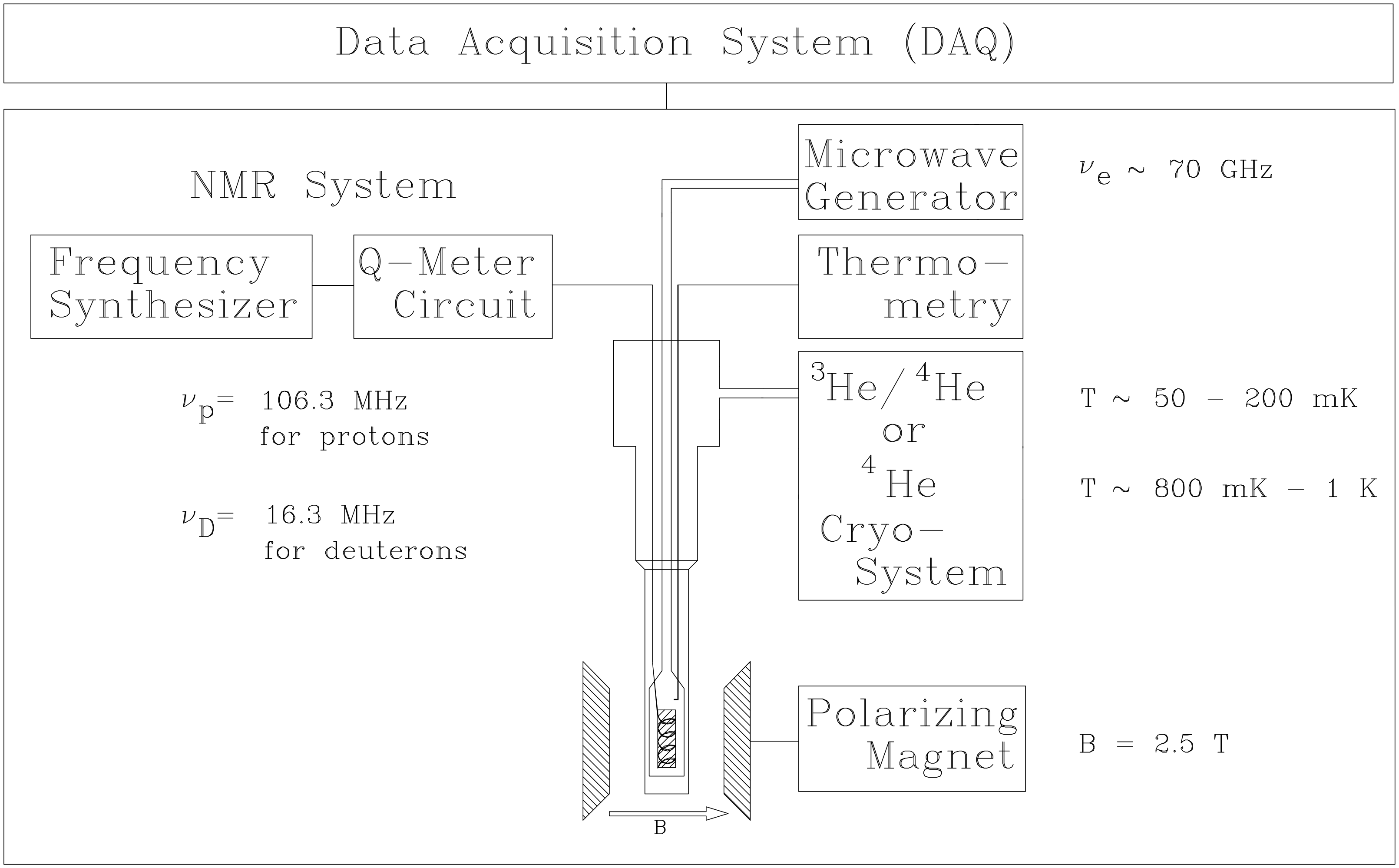
$$A_N = \frac{1}{P_T f} \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$A_{NN} = \frac{1}{P_B P_T f} \frac{N^{\uparrow\uparrow} - N^{\downarrow\uparrow} - N^{\uparrow\downarrow} + N^{\downarrow\downarrow}}{\Sigma}$$

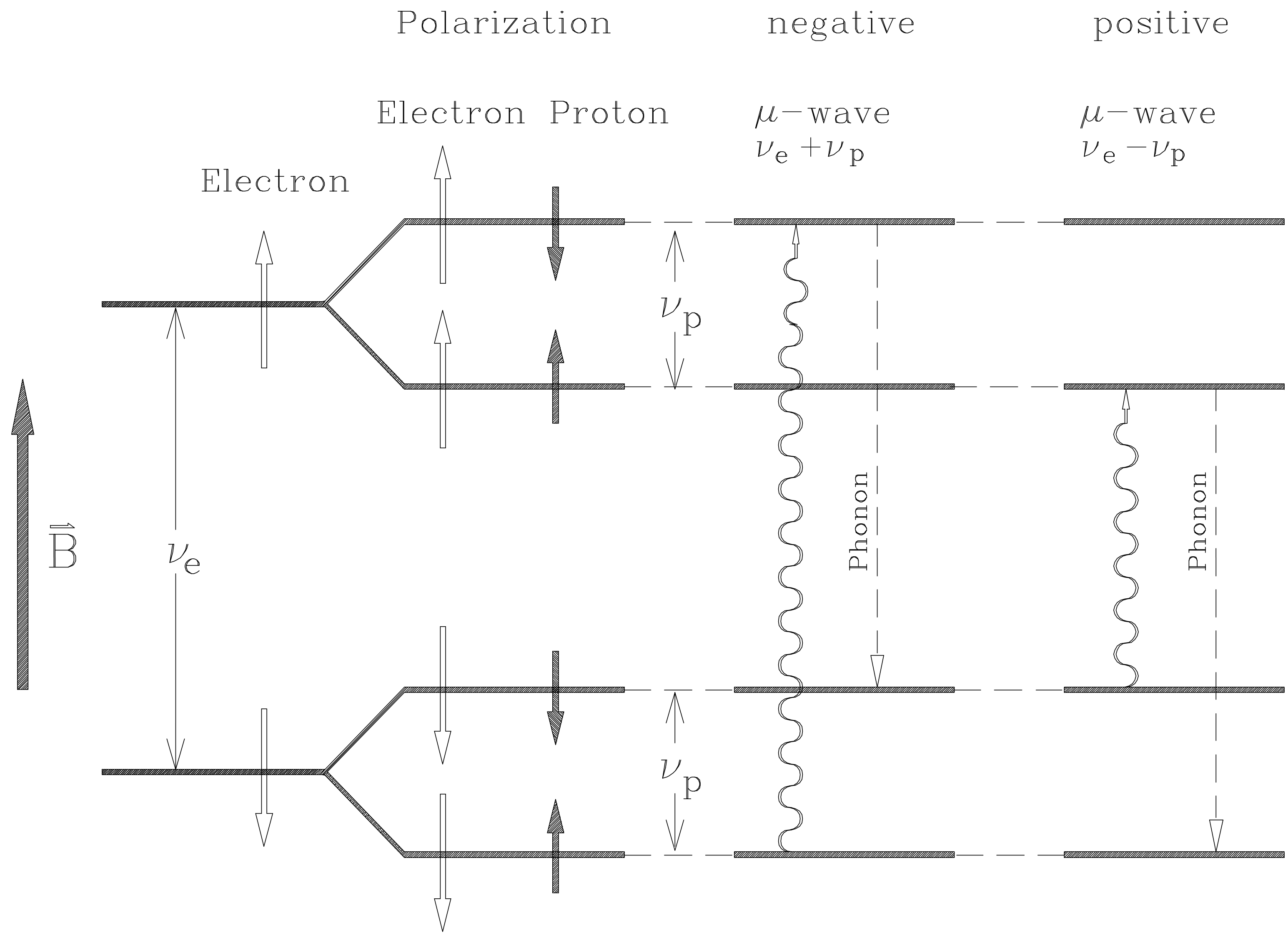
$$\Delta A = [P_B P_T f \sqrt{N_{Tot}}]^{-1}$$

$$\Rightarrow FOM \propto P_B^2 P_T^2 f^2$$

Major Polarized Target Systems



DNP

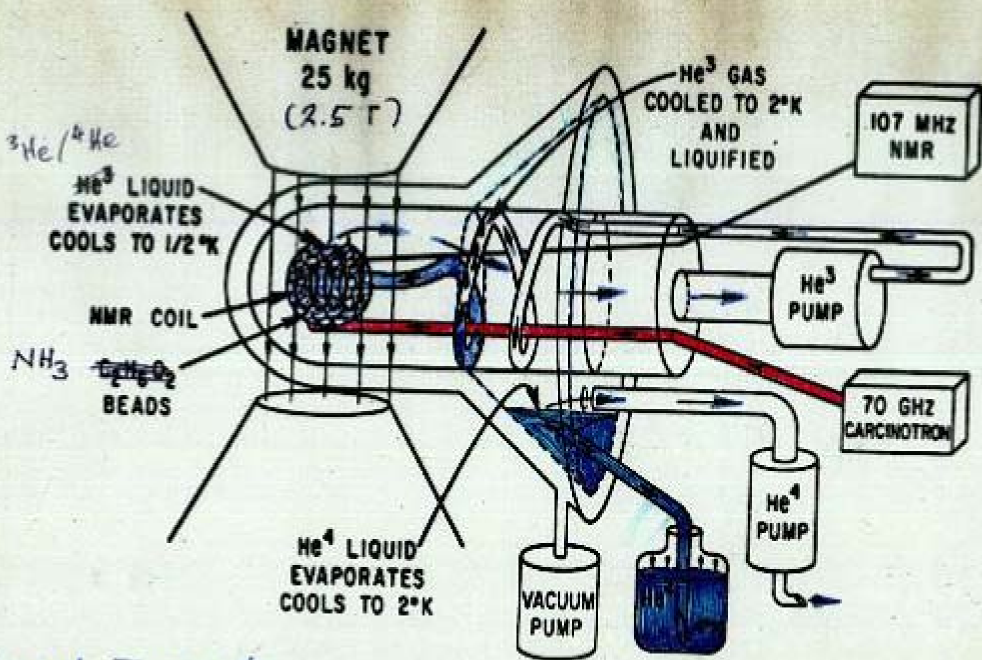


Polarization
negative
positive
Electron
Proton
μ−wave
νe +ν p
μ−wave
νe −νp
Electron
νp
B
νe
Phonon
Phonon
νp

- Polarization = $\dfrac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$

- TE Polarization
- P_{TE} = tanh[μB/kT]

- Enhanced Polarization
- P_{enh} = tanh[μB/kT_S]



Polarized Target

- Radicals in frozen NH_3 produced by irradiating with $\bar{e}$ at Bates MIT
- at $\frac{1}{2}$K and 2.5T radicals are fully electron polarized
- Polarization is dynamically transfered to protons with 70 GHz wave
- Proton Polarization is measured with 107 MHz NMR system

- Polarized Target can operate in a beam of up to 2×10^{10} protons/sec
- Polarization sign is reversed ~ every 2½ hr.

NOTES:

1. All resistors are Allen-Bradley 110 ohm, carbon except where noted to be Speer grade 1002, 220 ohm resistors.
2. Pos. refers to resistor position on 18 point switch mounted on temperature indicator control rack.

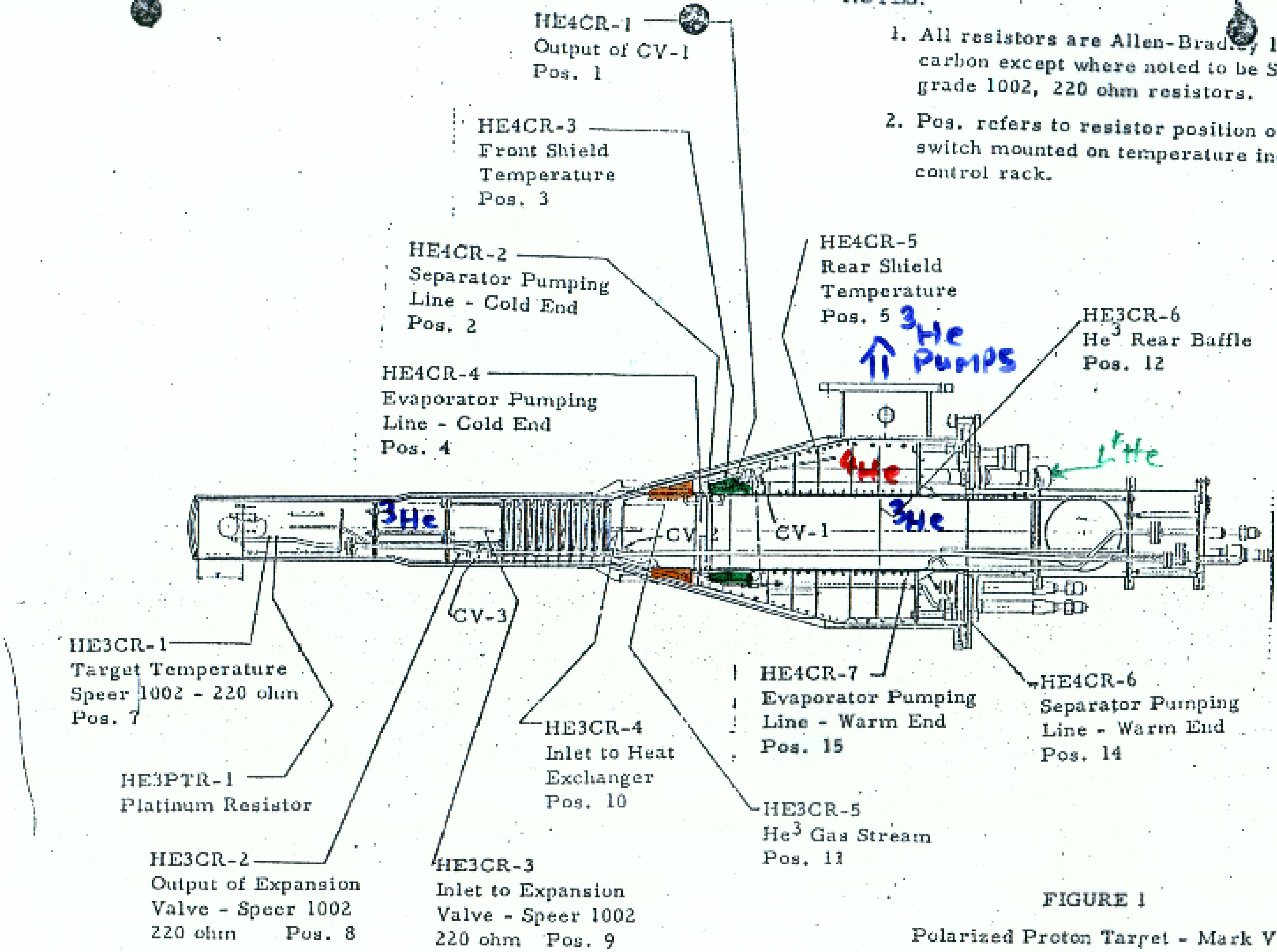


FIGURE 1

Polarized Proton Target - Mark V
General Assembly and Instrumentation Location


20X42-0
25 TON
CAUTION
STRAY MAGNETIC FIELDS.
KEEP IRON AND STEEL
OBJECTS AWAY

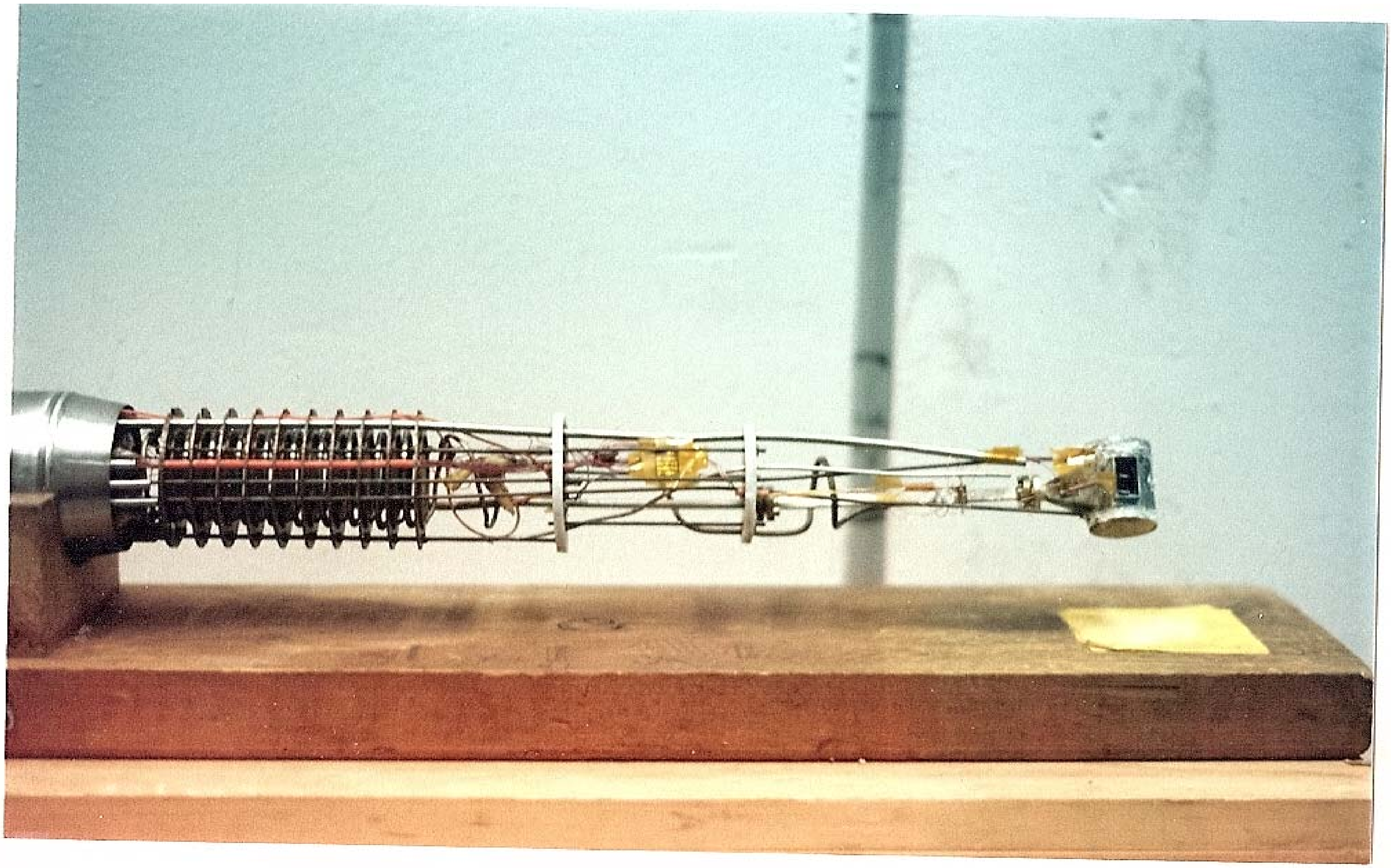


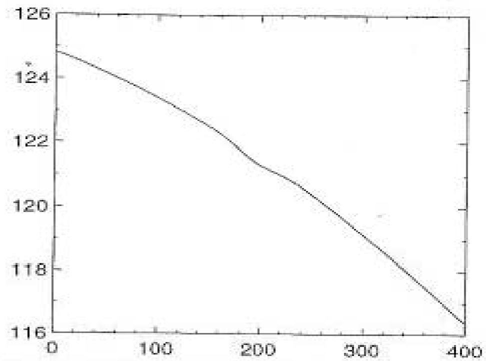
Table 1 Polarized target materials commonly used in particle scattering experiments

Materials & Chem. Comp.	Dopant[a] & Method	Polarizeable Nucleons % by weight	B/T Tesla/K	Polarization %	Radiation Characteristic Flux[b] 10^{14} particles/cm^2
LMN $La_2(Co, Mg)_3(NO)_3 \cdot 24H_2O$	Neodymium Ch	3.1	2.0/1.5	±70	~ 0.01
1,2 Propanediol $C_3H_6(OH)_2$	Cr (V) Ch	10.8	2.5/0.37	+98 −100	~ 1
1,2 Ethanediol $C_2H_4(OH)_2$	Cr (V) Ch	9.7	2.5/0.5	±80	~ 2
Butanol C_4H_9OH	EHBA Cr (V) Ch	13.5	2.5/0.3	±93	3 - 4
EABA $C_2NH_7BH_3NH_3$	EHBA Cr (V) Ch	16.5	2.5/0.5	+75 −73	7(+), 3.5(−)[c]
Ammonia $^{14}NH_3$, $^{15}NH_3$	NH_2• Ir	17.5, 16.6	5.0/1.0	+97 −100	70, 175[d]
d-Butanol C_4D_9OD	EDBA Ch	23.8	2.5/0.3	±50	not measured
d-Ammonia $^{14}ND_3$, $^{15}ND_3$	ND_2• Ir	30.0, 28.6	3.5/0.3	+49 −53	130(+), 260(−)
Lithium deuteride ^6LiD	f-center Ir	50	6.5/0.2	±70	400

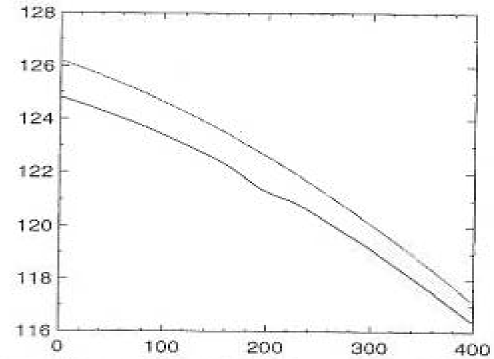
[a]Ch: chemically doped, Ir: doped through irradiation
[b]The radiation dose which reduces the polarization by e^{-1} of its value
[c]For positive and negative polarizations respectively
[d]In NH_3 there are two distinct regions of decay

Fig 6.

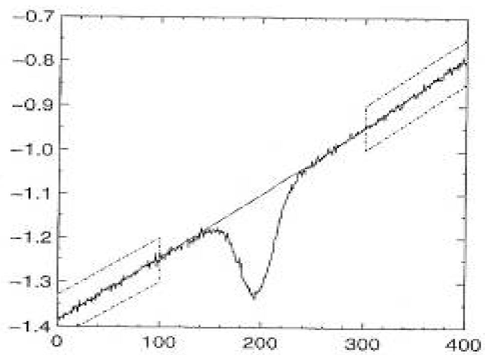
NMR Signal Analysis



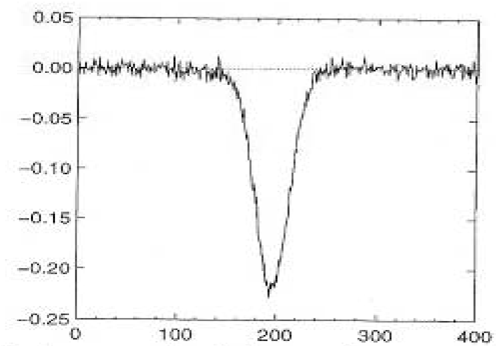
Signal is acquired by the NMR DAQ system



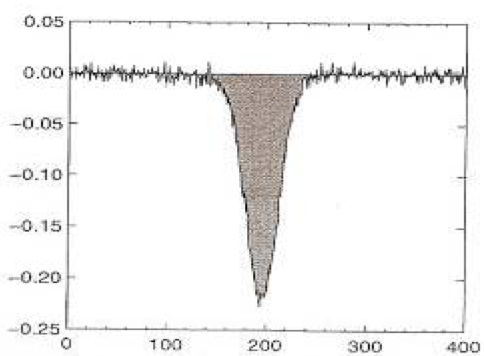
Baseline is subtracted from the signal



Polynomial is fit to wings of the signal



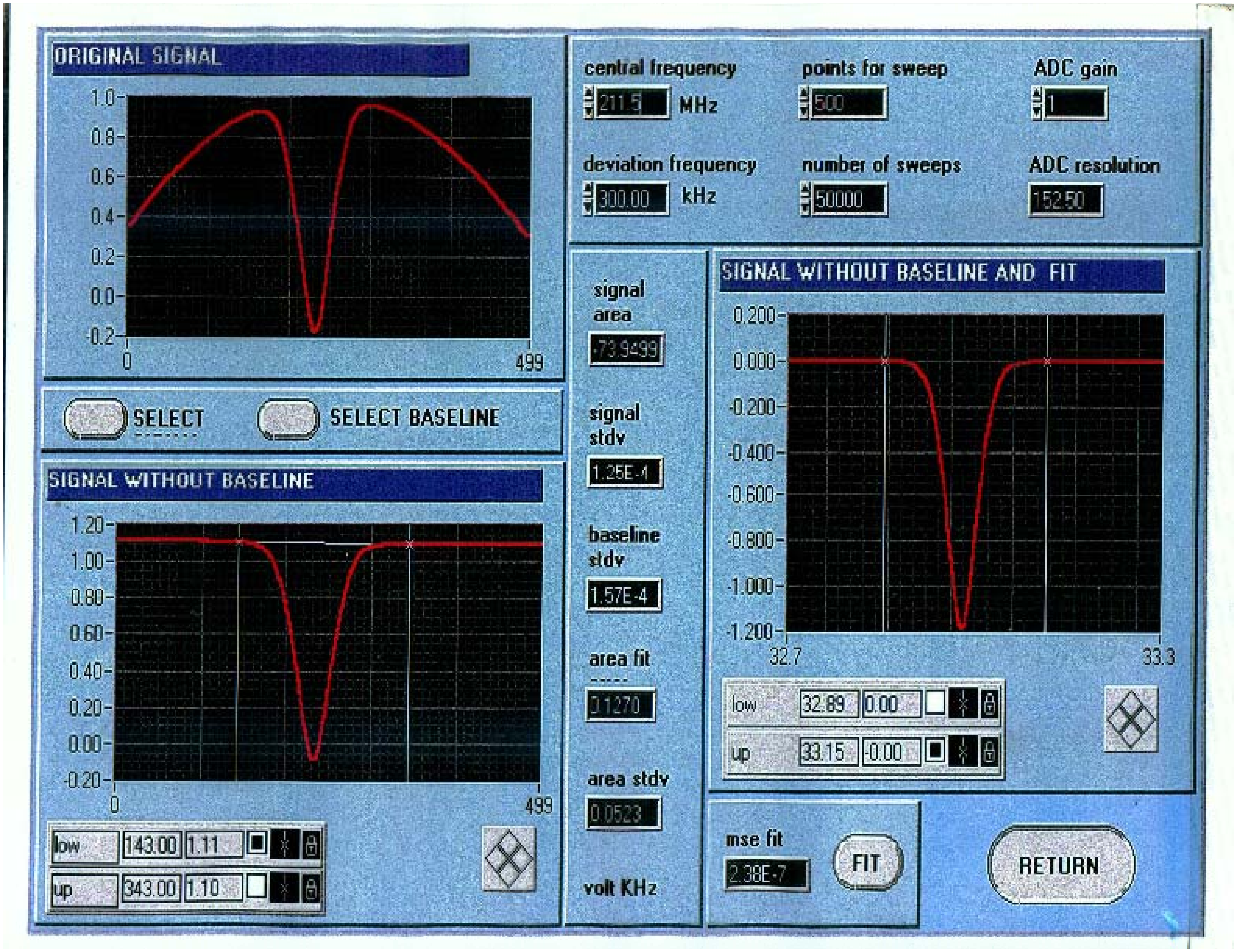
Polynomial is subtracted from the signal

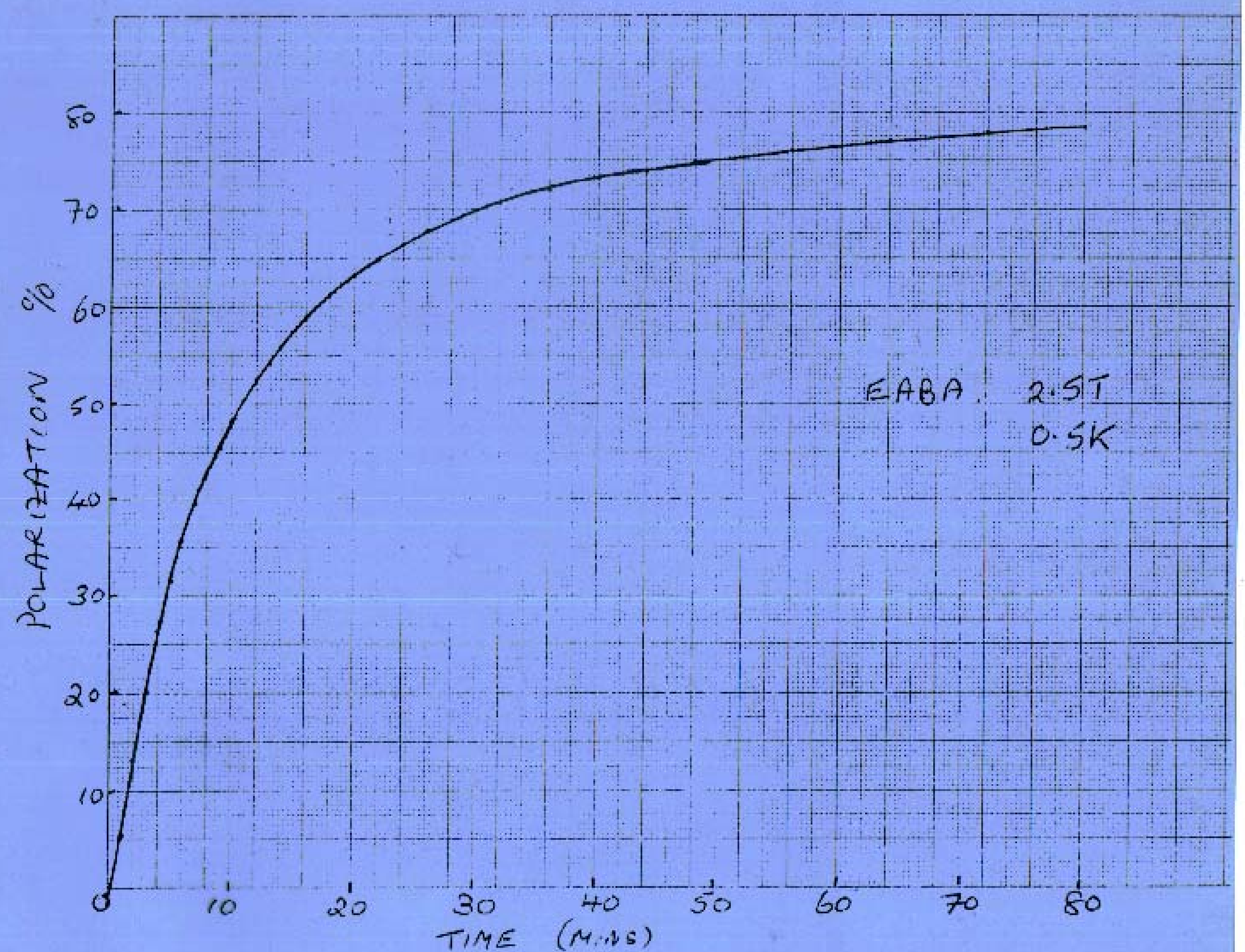


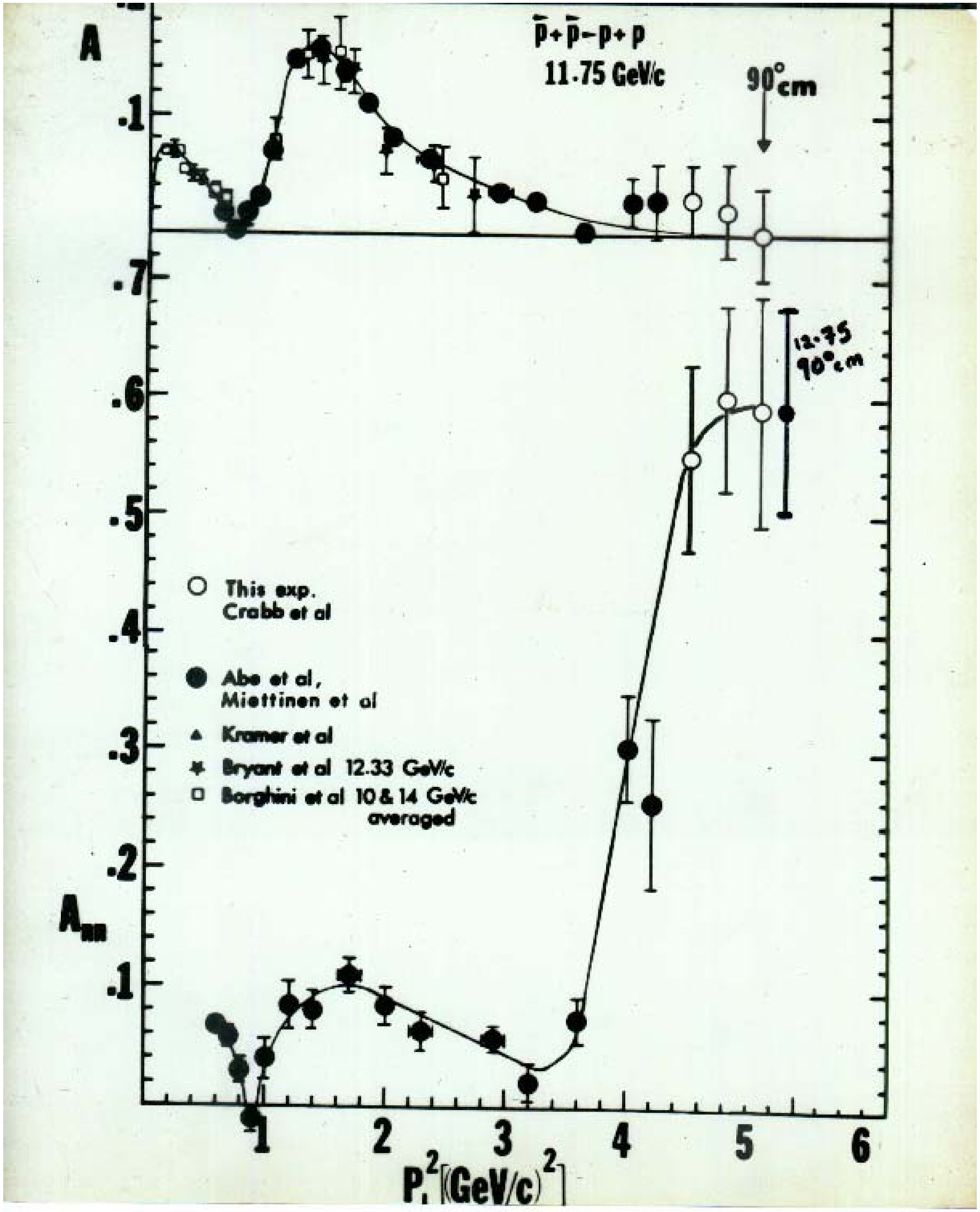
Signal is integrated, giving area

$$\text{Area} \times \text{CC} = \text{Polarization}$$

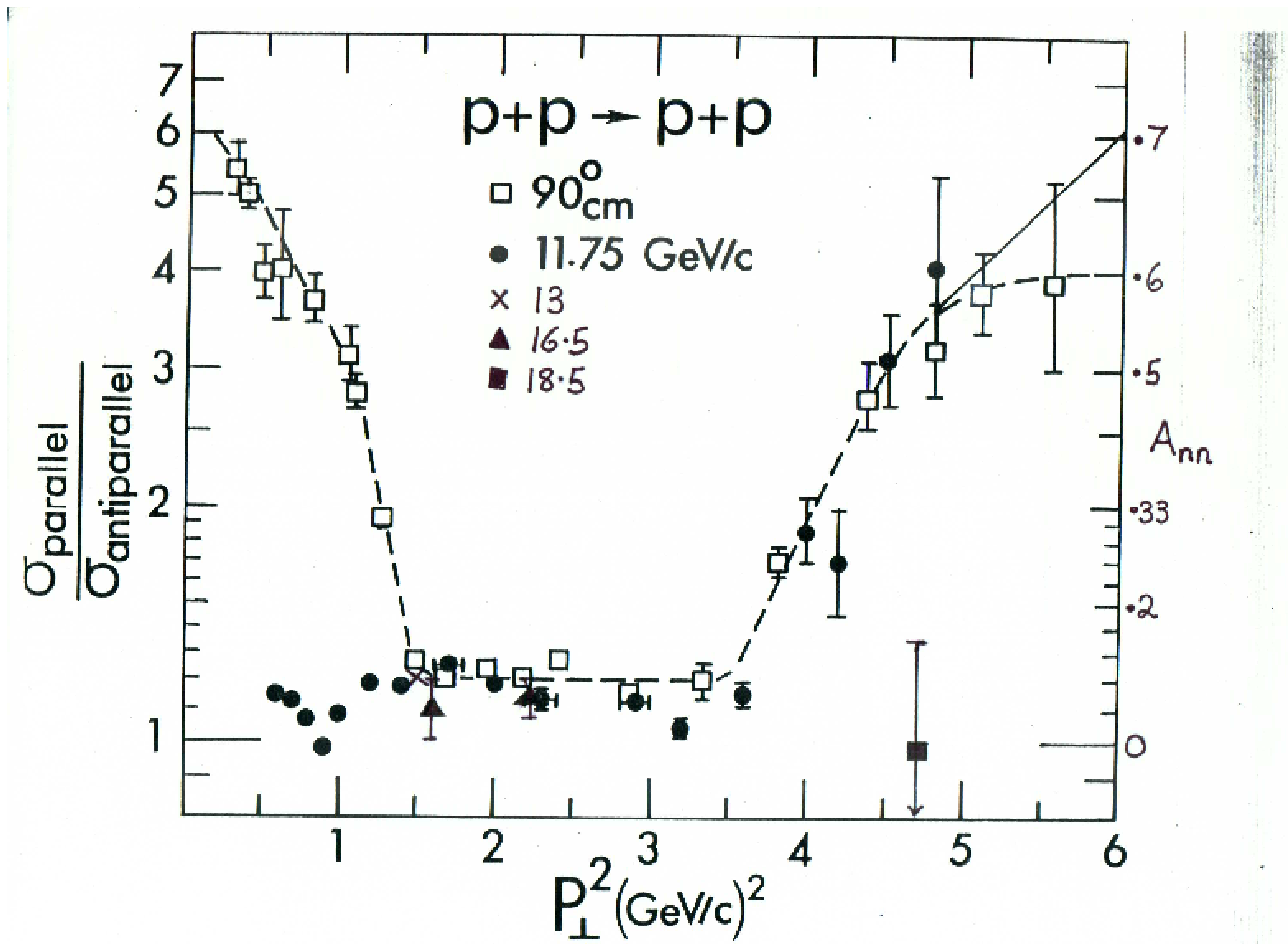
Calibrating the NMR system gives polarization


ORIGINAL SIGNAL
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
499
SELECT
SELECT BASELINE
SIGNAL WITHOUT BASELINE
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
0
499
low 143.00 1.11
up 343.00 1.10
central frequency
211.5 MHz
deviation frequency
300.00 kHz
points for sweep
500
number of sweeps
50000
ADC gain
1
ADC resolution
152.50
signal area
-73.9499
signal stdv
1.25E-4
baseline stdv
1.57E-4
area fit
0.1270
area stdv
0.0523
volt KHz
SIGNAL WITHOUT BASELINE AND FIT
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
32.7
33.3
low 32.89 0.00
up 33.15 -0.00
mse fit
2.38E-7
FIT
RETURN

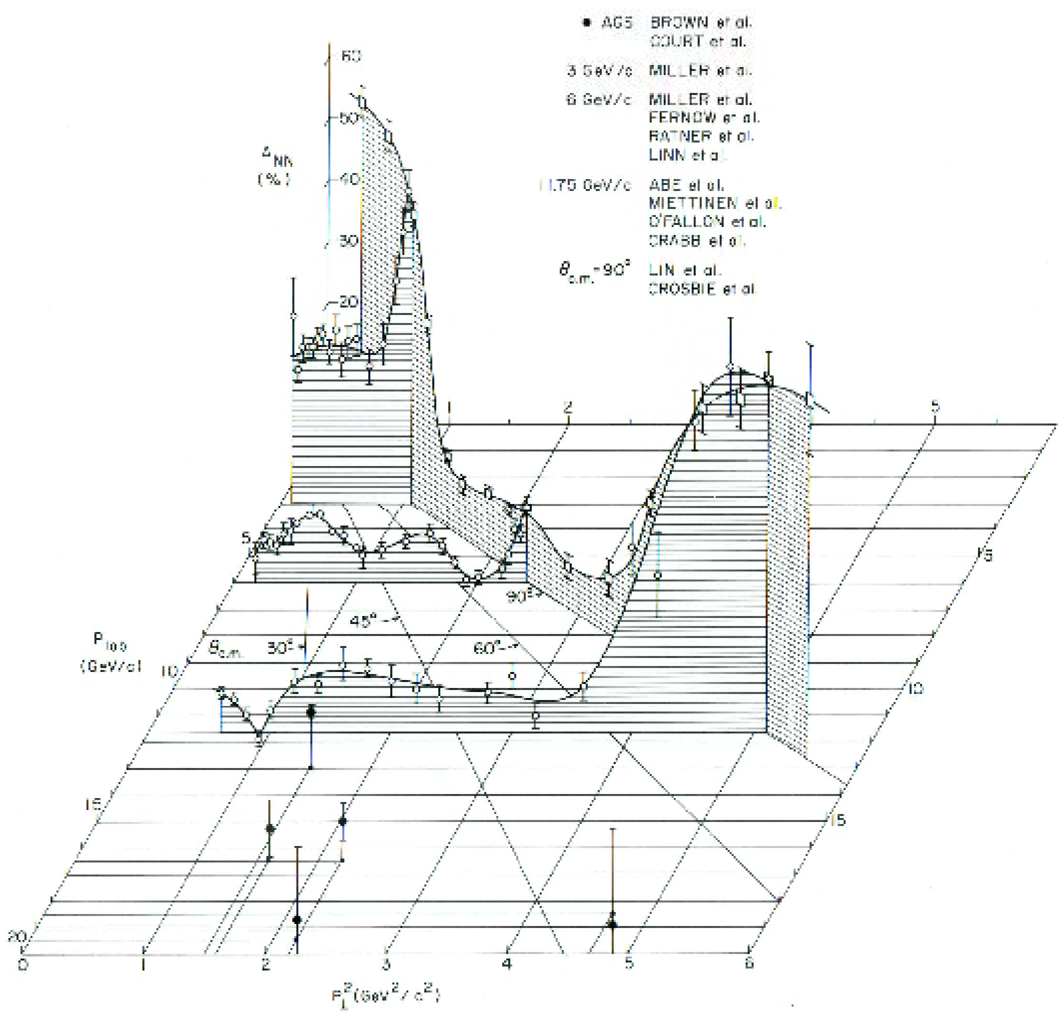

POLARIZATION %
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
TIME (MINS)
EABA. 2.5T
0.5K



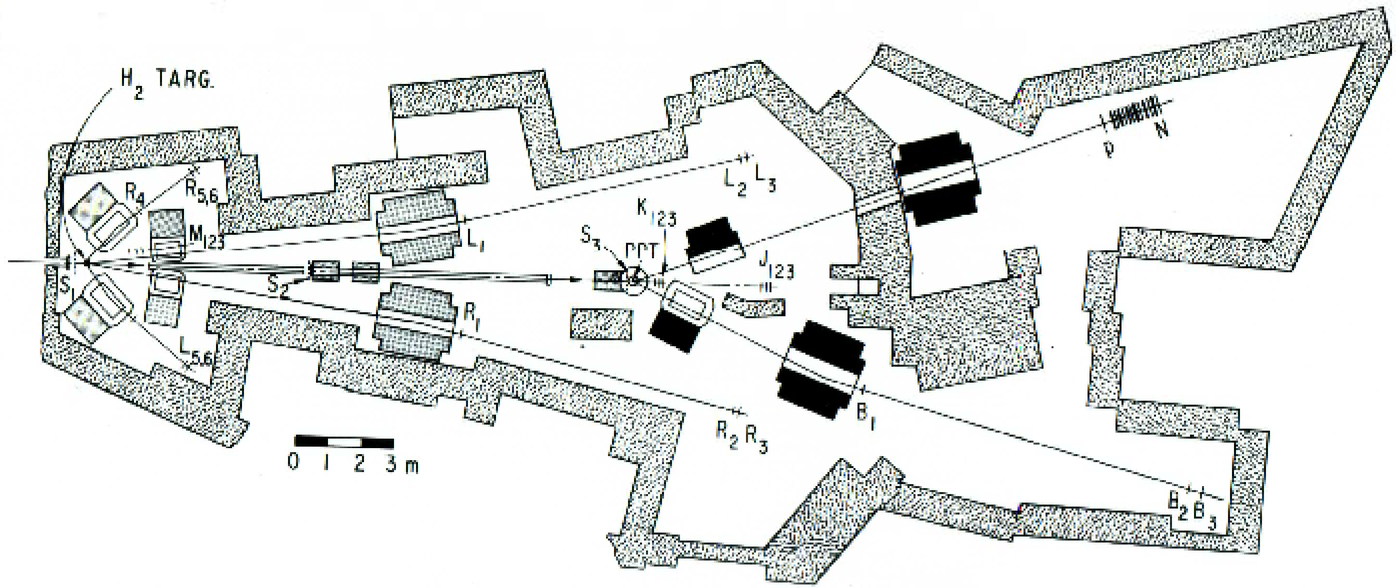
A
p̄ + p̄ → p + p
11.75 GeV/c
90°cm
.1
.7
.6
.5
.4
.3
.2
.1
12.75
90°cm
This exp.
Crabb et al
Abe et al,
Miettinen et al
Kramer et al
Bryant et al 12.33 GeV/c
Borghini et al 10 & 14 GeV/c
averaged
Ann
1
2
3
4
5
6
P⊥² [(GeV/c)²]



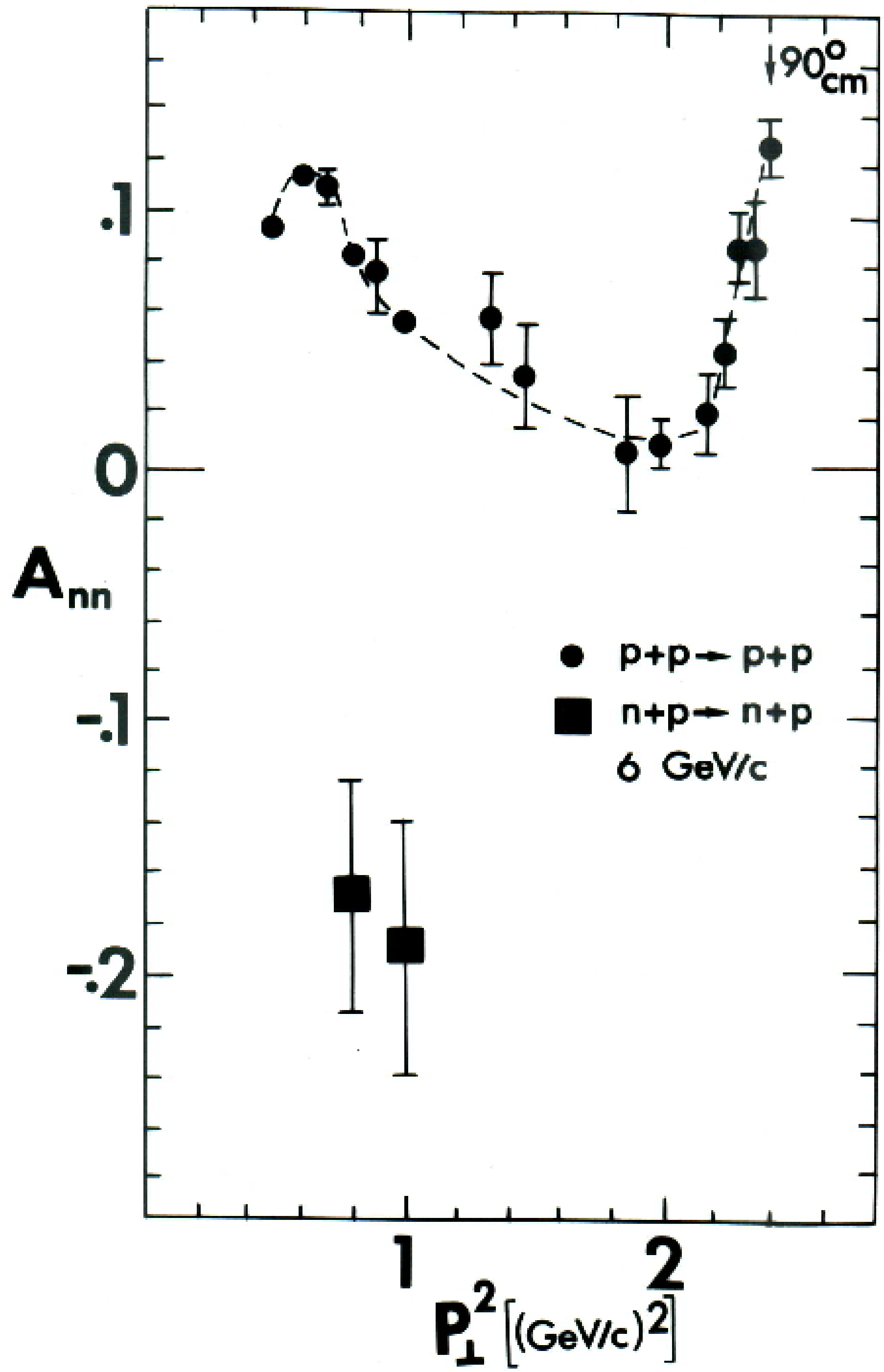
p+p → p+p
□ 90°cm
● 11.75 GeV/c
× 13
▲ 16·5
■ 18·5
σparallel / σantiparallel
7
6
5
4
3
2
1
1
2
3
4
5
6
P⊥² (GeV/c)²
Ann
•7
•6
•5
•33
•2
0



● AGS BROWN et al.
COURT et al.
3 GeV/c MILLER et al.
6 GeV/c MILLER et al.
FERNOW et al.
RATNER et al.
LINN et al.
11.75 GeV/c ABE et al.
MIETTINEN et al.
O'FALLON et al.
CRABB et al.
θc.m.=90° LIN et al.
CROSBIE et al.
A_{NN} (%)
P_{lab} (GeV/c)
θc.m.
30°
45°
60°
90°
$P_{\perp}^2$ (GeV²/c²)

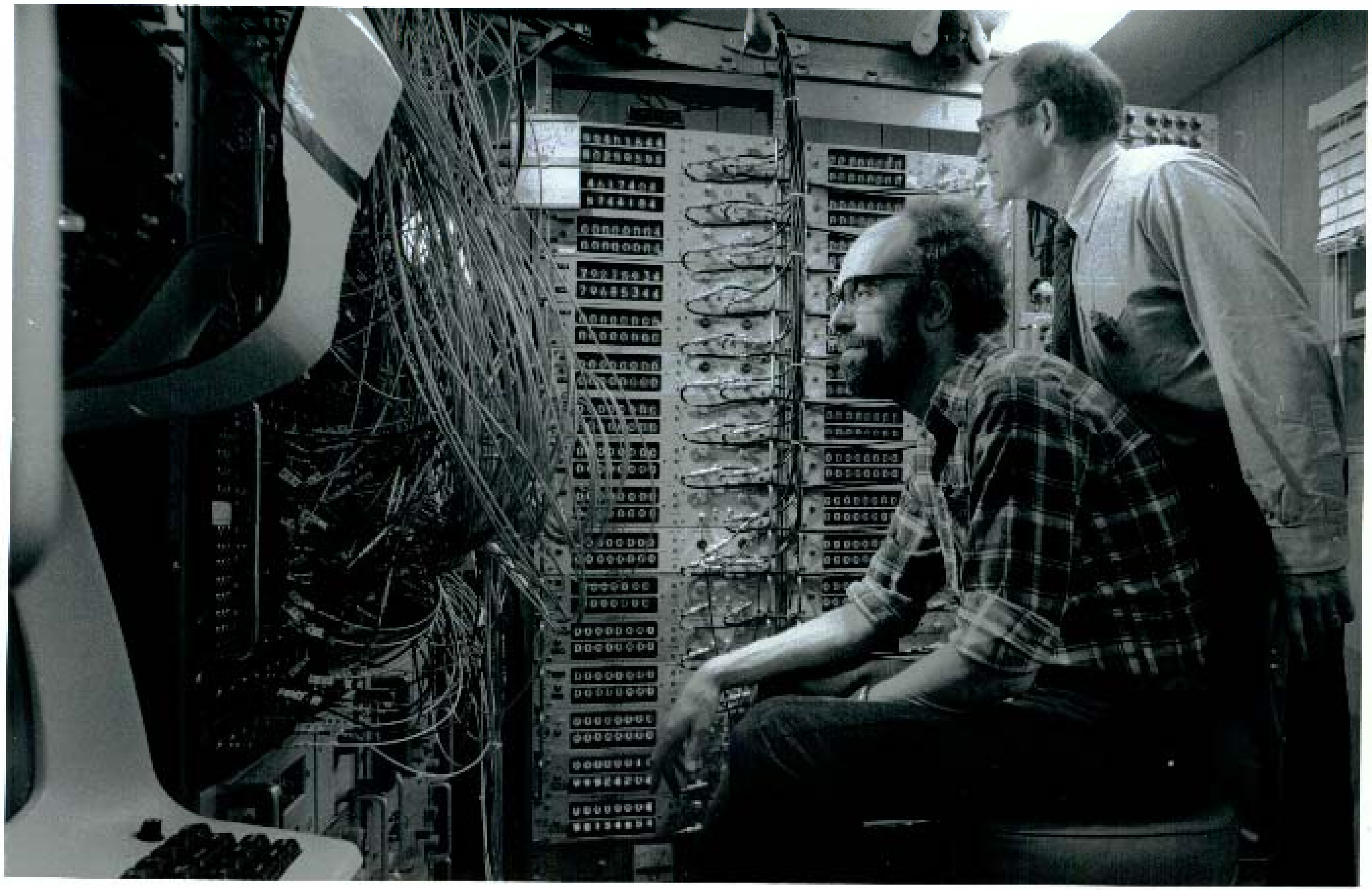


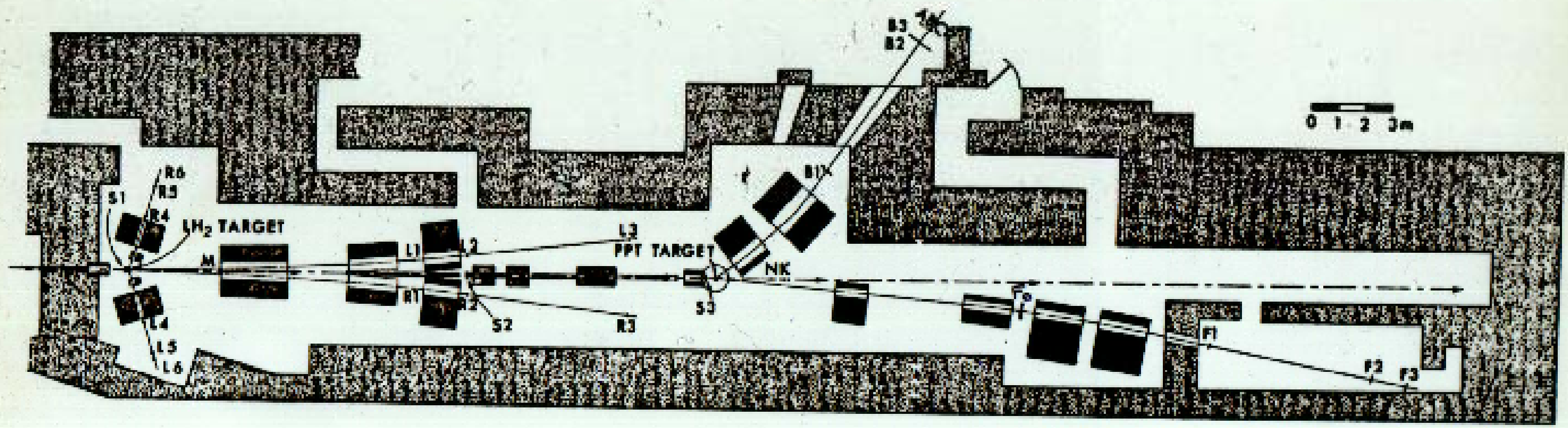
H2 TARG.
R4
R5,6
M123
S1
S2
L1
R1
L5,6
S3
PPT
K123
J123
L2 L3
R2 R3
B1
B2 B3
P
N
0 1 2 3 m



↓90°cm
.1
0
Ann
-.1
-.2
p+p → p+p
n+p → n+p
6 GeV/c
1
2
P⊥² [(GeV/c)²]

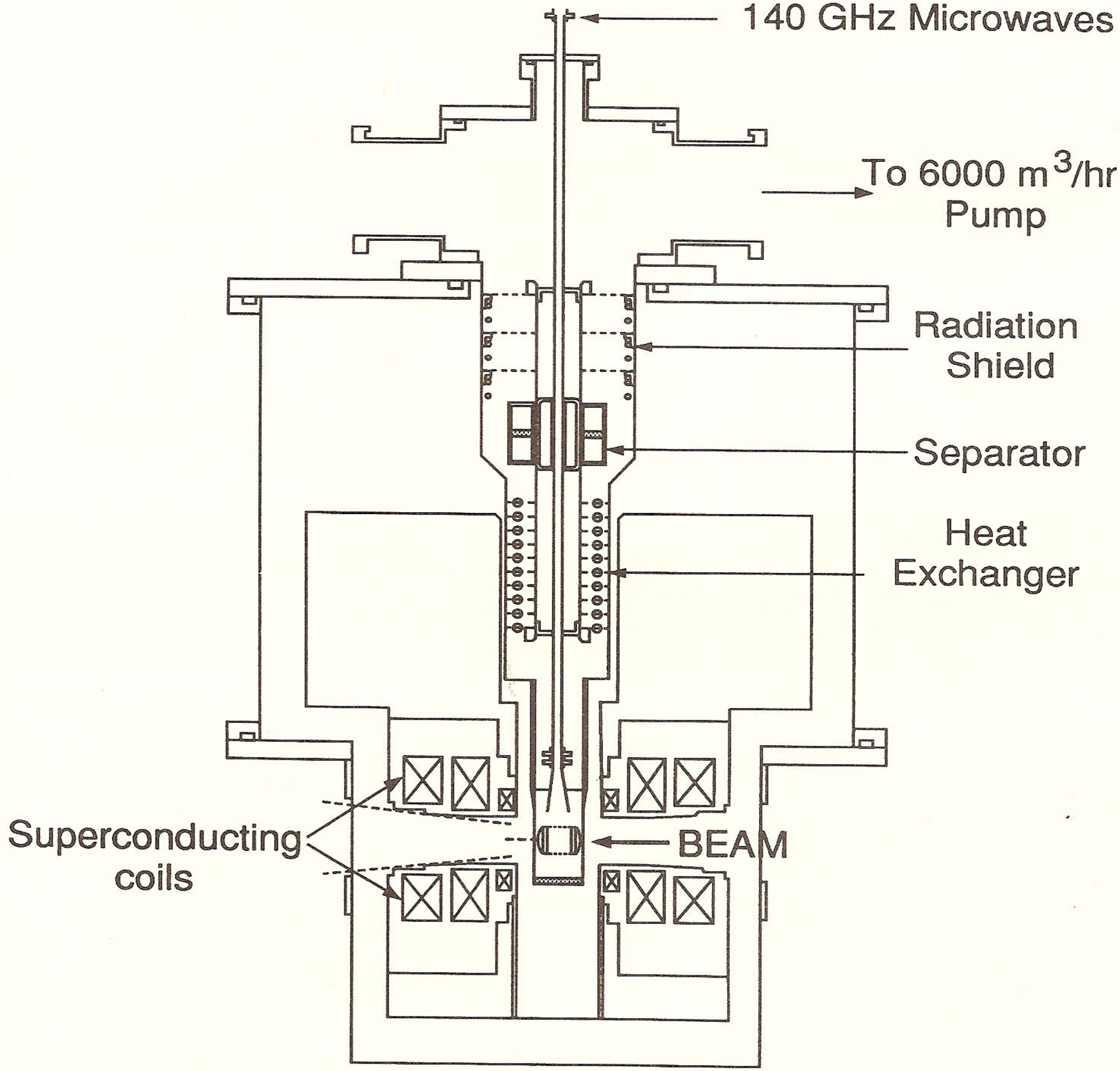
Scattering and Polarized Targets at Brookhaven National Lab.



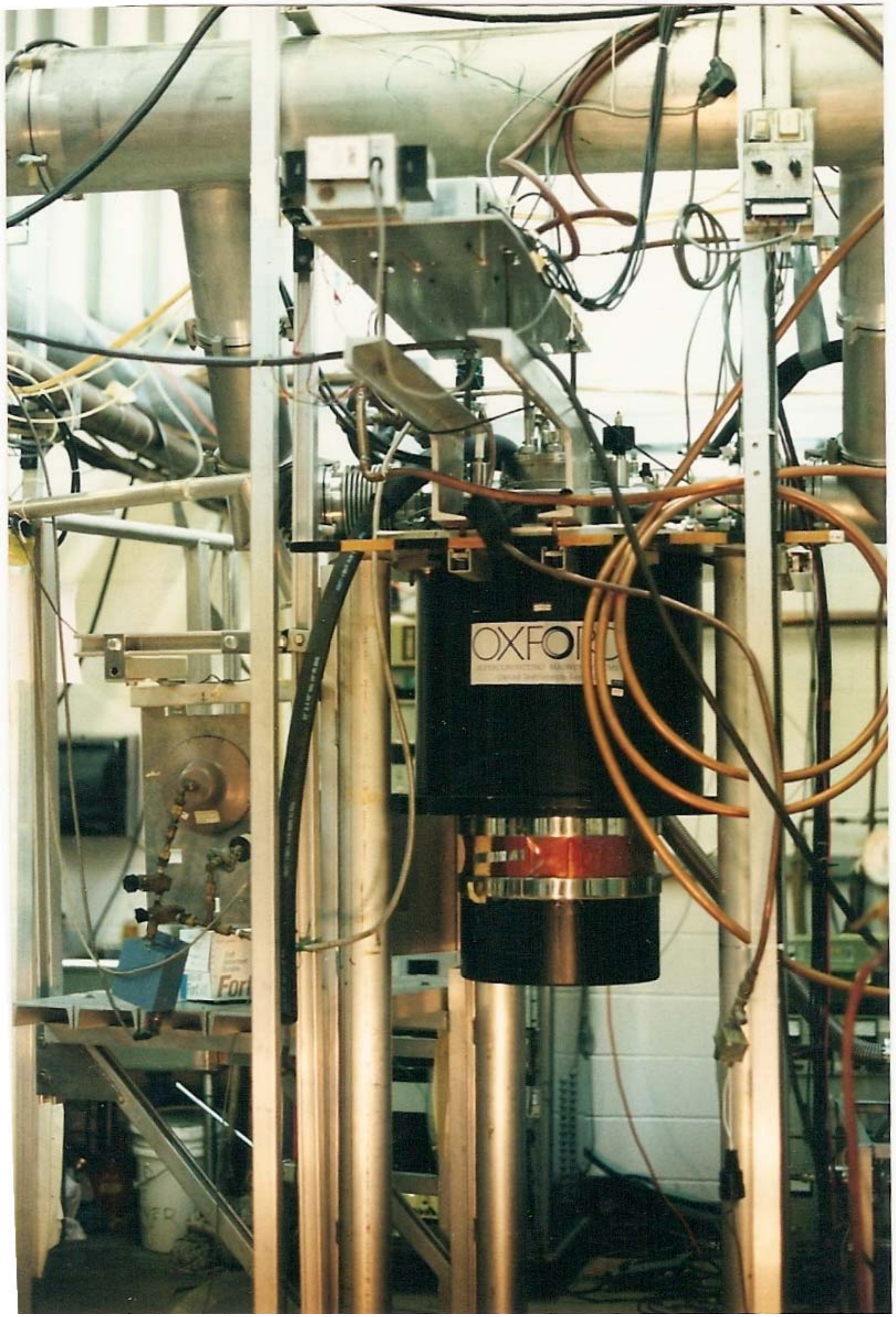


elastic event defined by 7-fold coincidence:

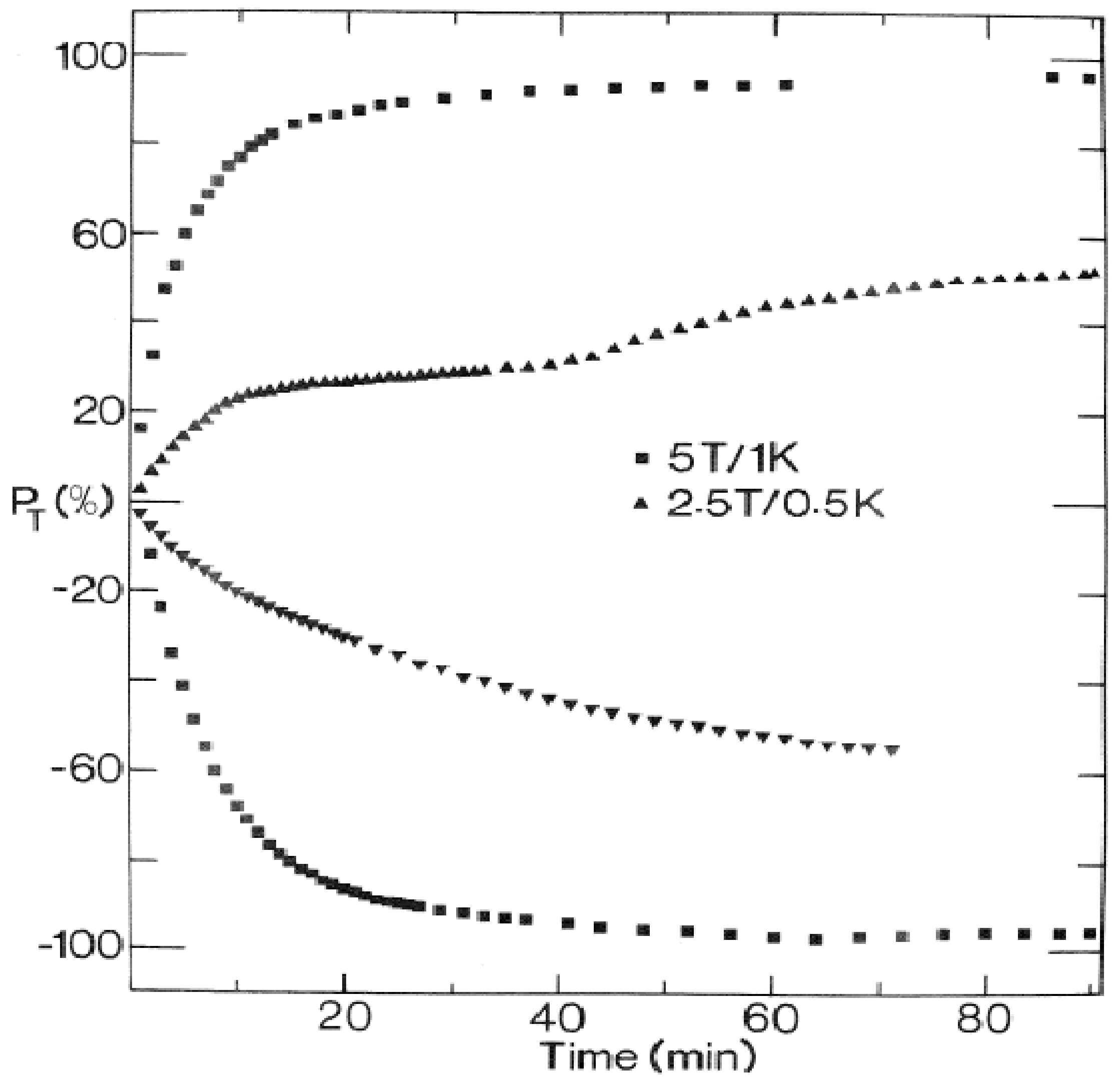
$B1 \cdot B2 \cdot B3 \cdot F\emptyset \cdot F1 \cdot F2 \cdot F3$

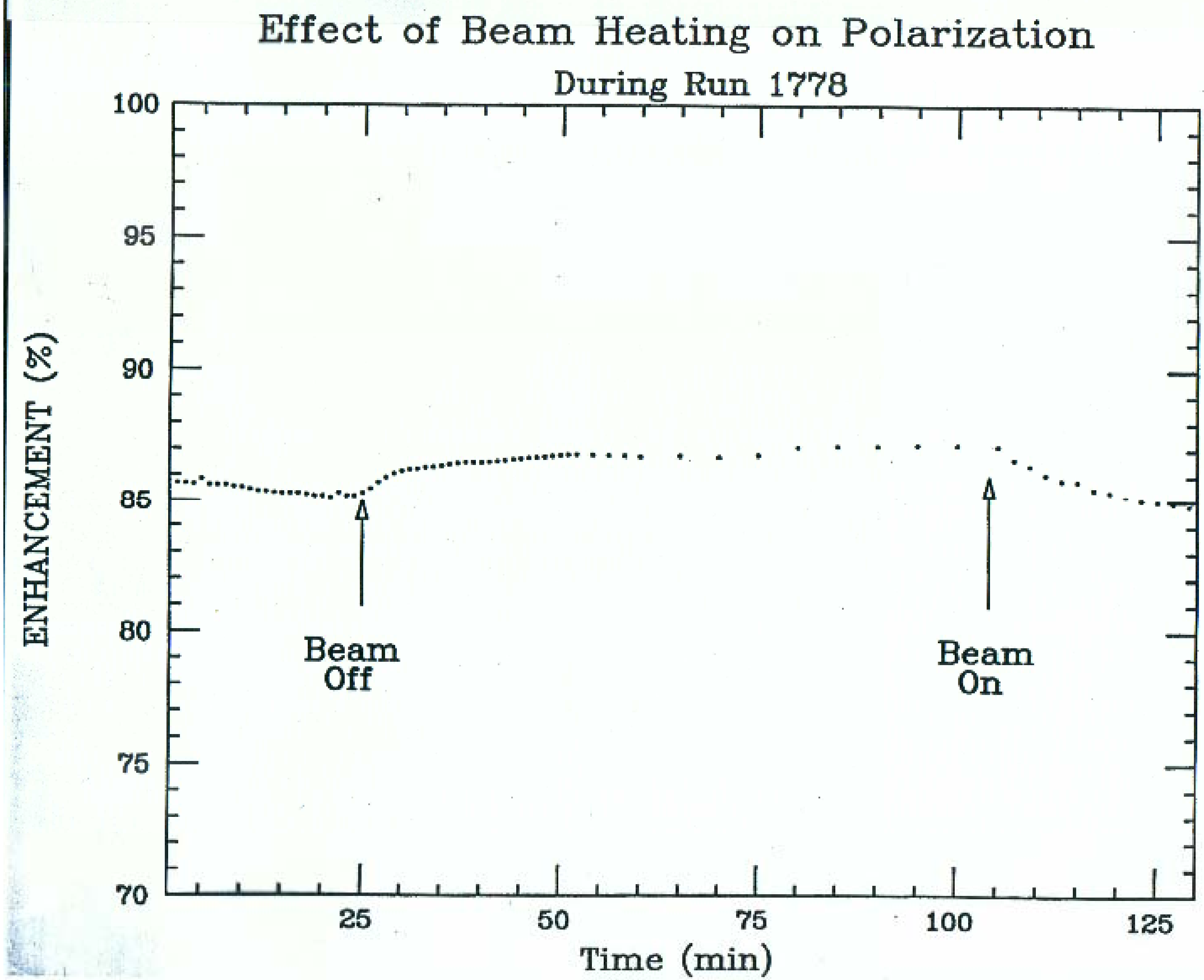


140 GHz Microwaves
To 6000 m^3/hr Pump
Radiation Shield
Separator
Heat Exchanger
Superconducting coils
BEAM



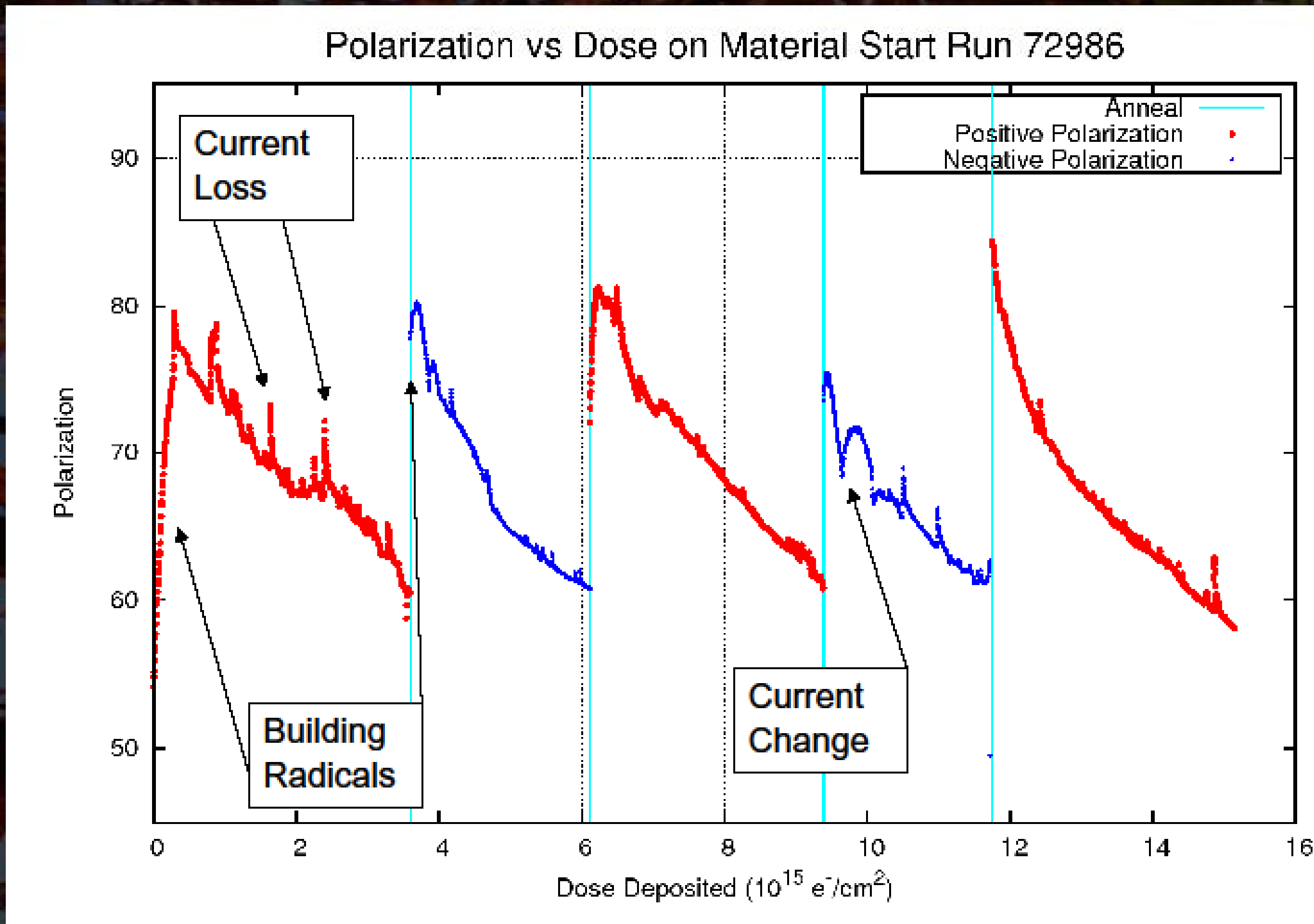
Ammonia Polarization





Effect of Beam Heating on Polarization
During Run 1778
100
95
90
85
80
75
70
ENHANCEMENT (%)
25
50
75
100
125
Time (min)
Beam Off
Beam On

SANE: Polarization Decay with Dose



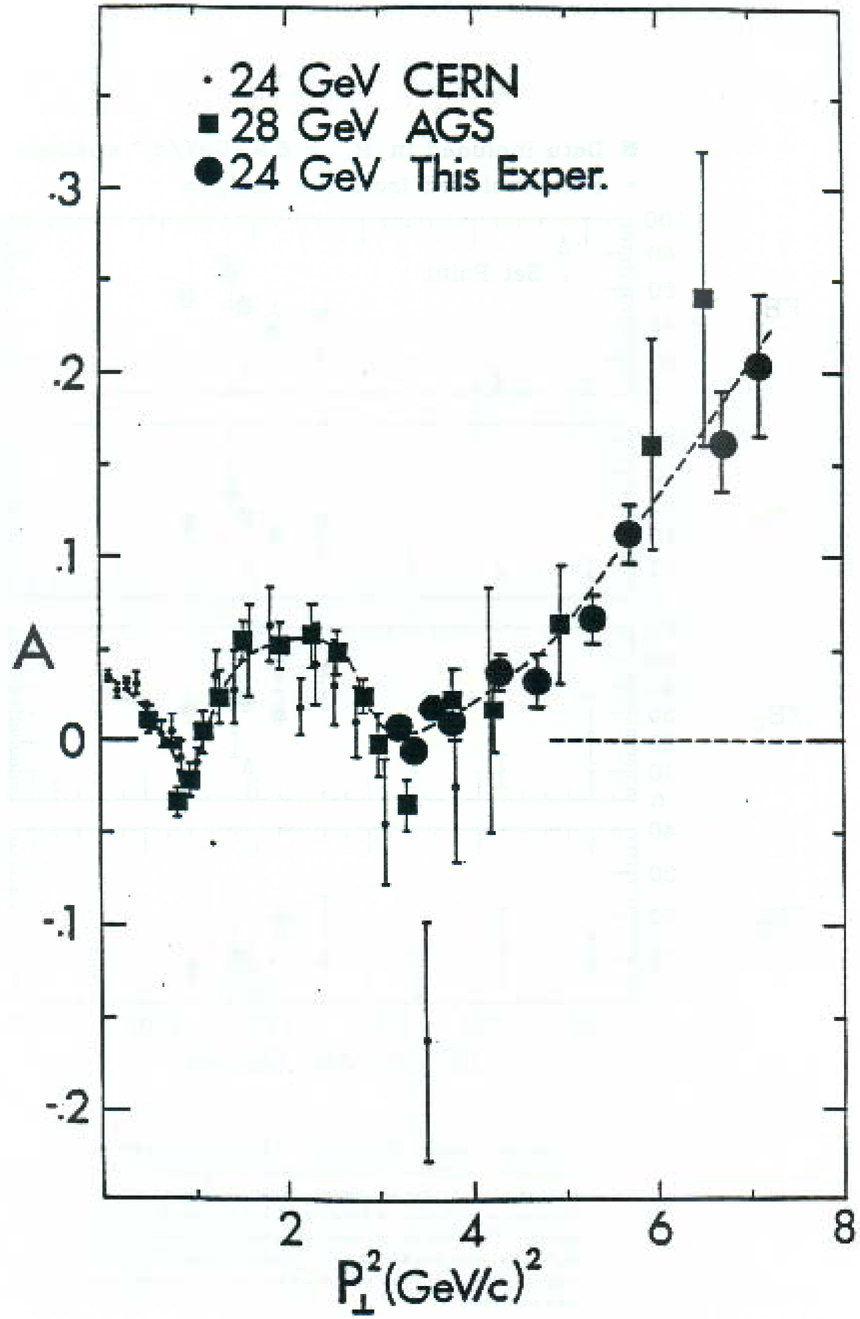


FIG. 37. The analyzing power A as a function of the momentum transfer squared $P_\perp^2$ for proton-proton elastic scattering. The new 24 GeV/c results are shown along with our older 28 GeV/c measurements and the CERN 24 GeV/c data. The dashed curve is a hand-drawn curve to guide the eye.

Ultra-cold Polarized Hydrogen Jet Target

Advantages of Ultra-Cold Polarized Atomic Hydrogen Gas Jet Target

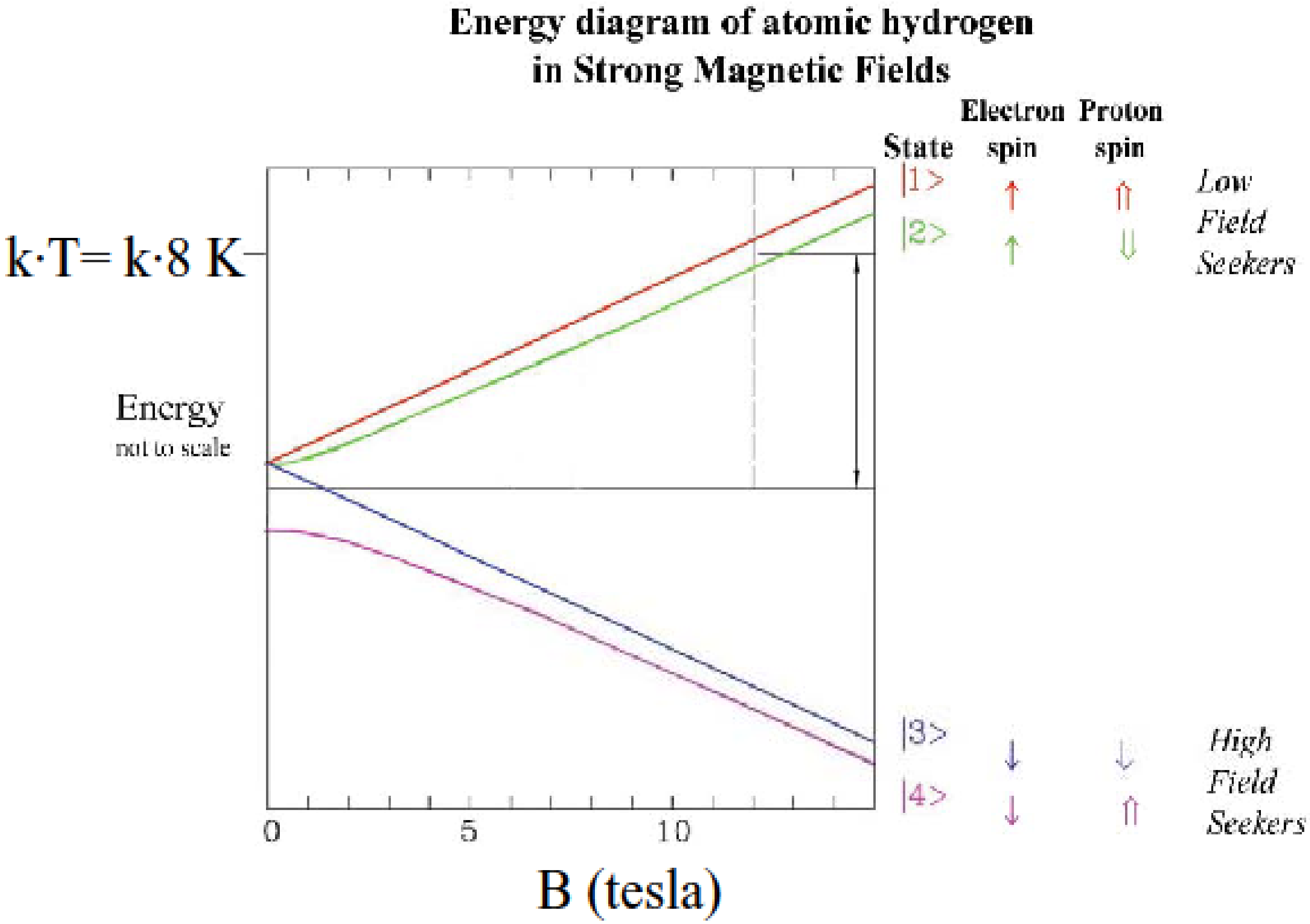
- Pure atomic hydrogen
  - No background from un-polarized nuclei in scattering experiments

3

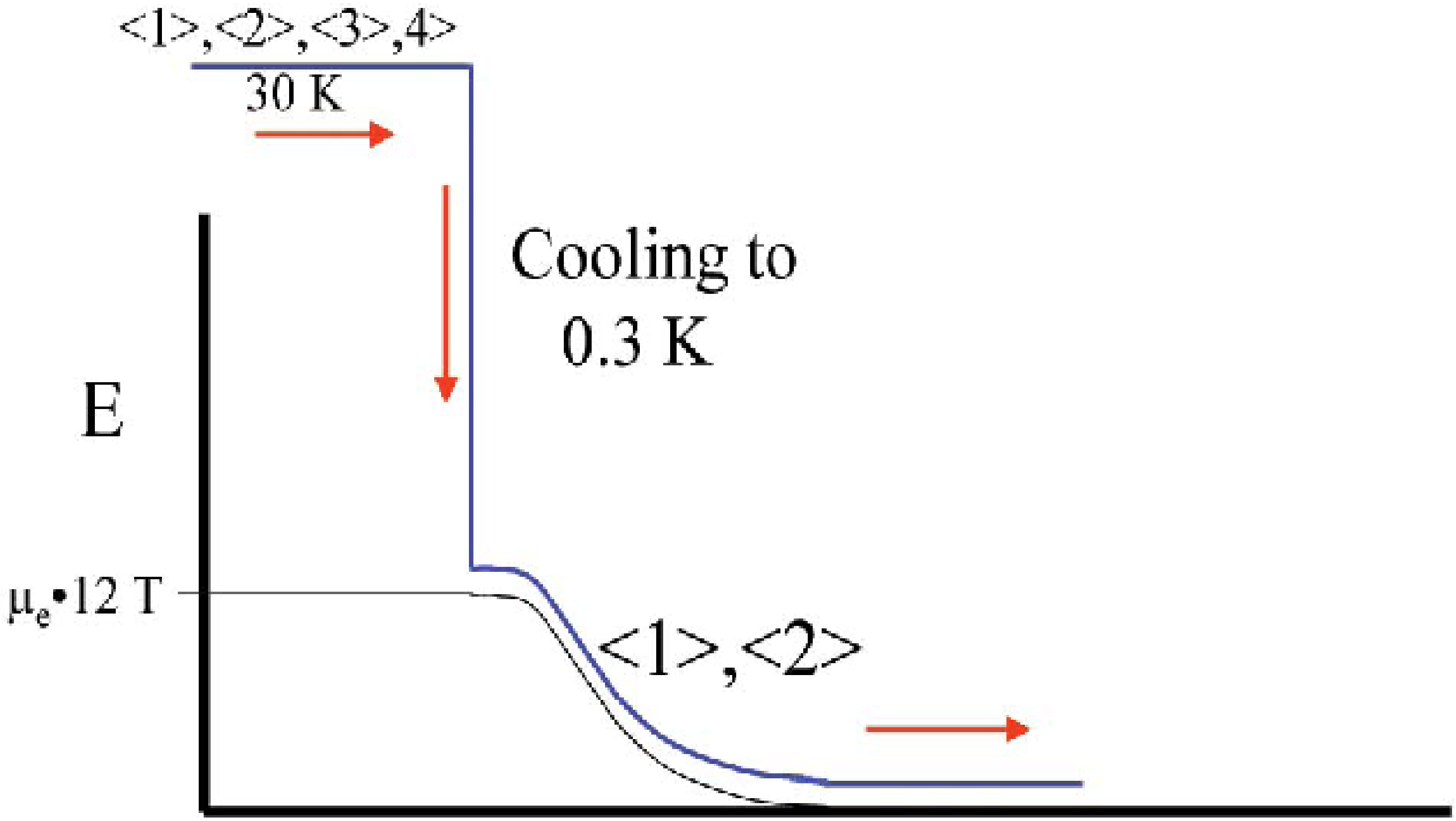
- Very monochromatic beam

  (all H atoms have the same energy)
  - Very small spot size
  - High density compared to other gas jet targets

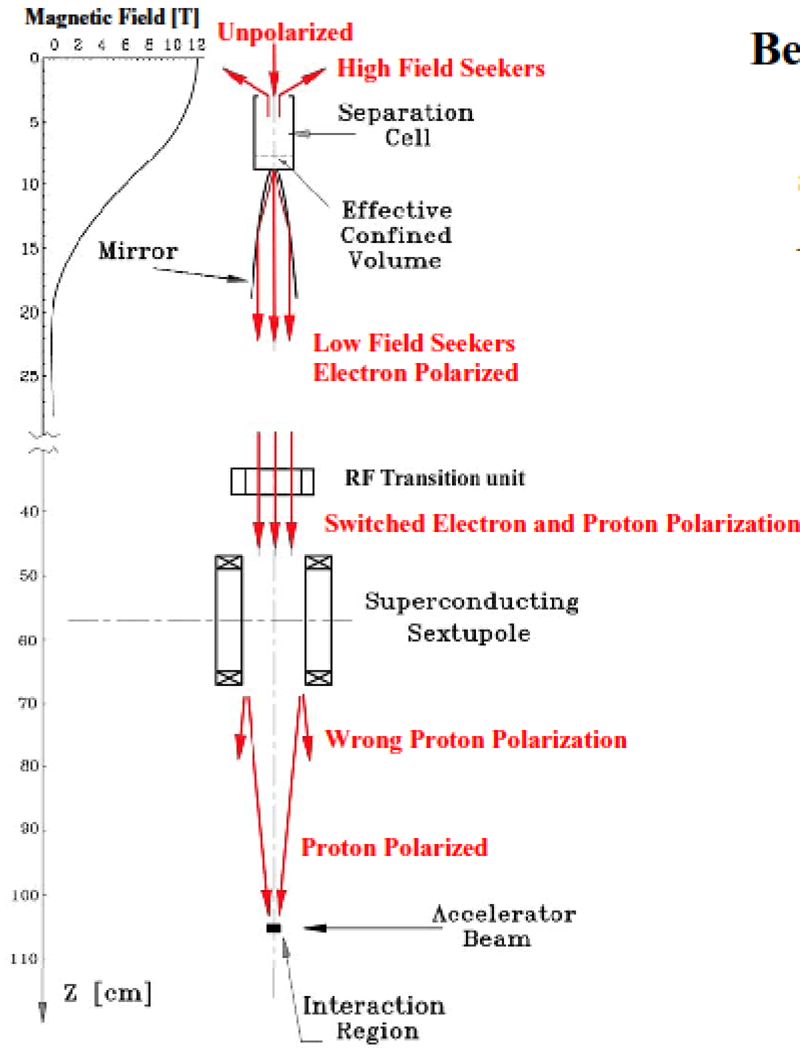
Breit-Rabi (schematic)



Beam Formation



Beam Formation



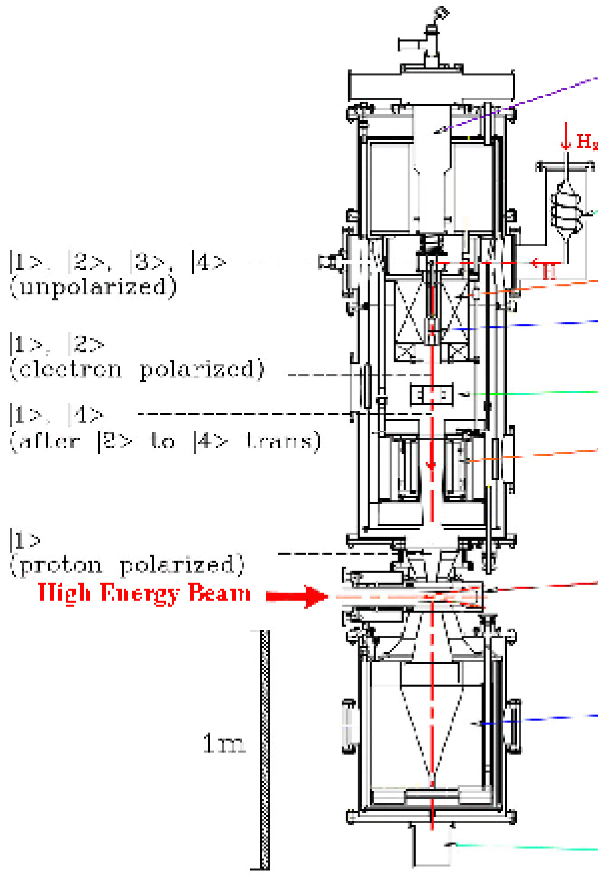
Acceleration by solenoid magnet

$F \sim -\mu_e \, \partial B_z / \partial Z$

Focusing by sextupole magnet

$F \sim -\mu_e \, \partial B / \partial r$

Michigan Ultra-Cold Jet



- **Refrigerator**
  - *75mW @ 300mK*
  - *22mW @ 170mK*
- **RF Dissociator**
  - *produces unpolarized atomic-hydrogen*
- **Superconducting 12T solenoid**
  - *separates electron-polarized states*
- **Separation cell and Mirror**
  - *cools down atoms and makes beam parallel*
- **RF transition unit**
  - *|2> to |4> transition*
- **Superconducting sextupole magnet**
  - *focuses |1> and defocuses |4>*
- **Interaction region vacuum box**
- **Catcher**
  - *cryocondensation pump 1.2x10^7 l/sec*
  - *apparently the world's largest*
- **H Maser Polarimeter**


45

Present status of Michigan Jet

- Basic parameters
  - *Velocity of atomic hydrogen* **~ 280 m/sec**
  - *Proton polarization* **~ 50 % (in low field)**

- Summary of long term flow stability
  - *Average hydrogen flux* **1.1×10^{16} H/cm^2/s**
  - *Average hydrogen jet thickness* **8×10^{11} H/cm^2**

- Record hydrogen jet density **1.4×10^{12} H/cm^3**

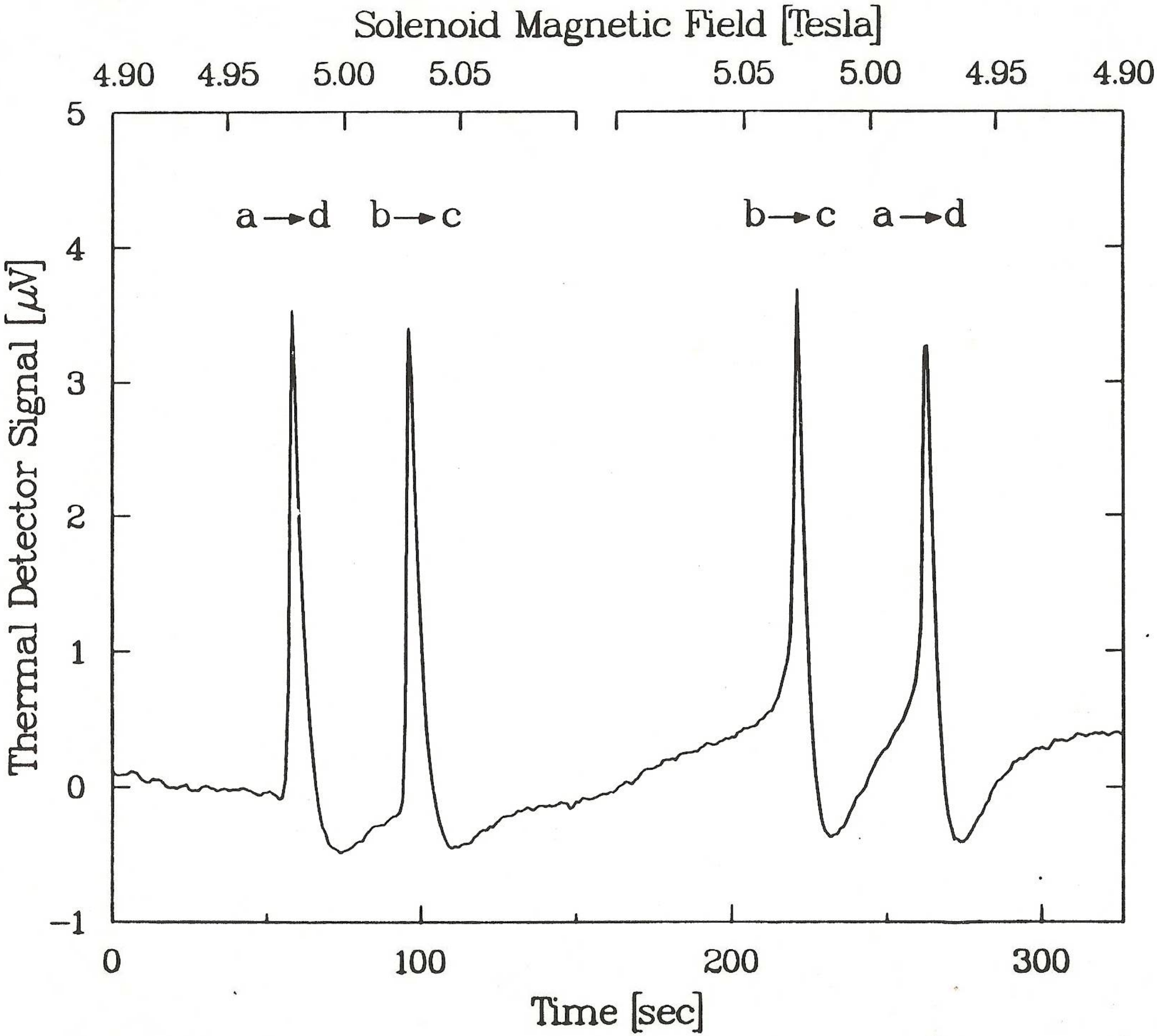

Solenoid Magnetic Field [Tesla]
4.90
4.95
5.00
5.05
5.05
5.00
4.95
4.90
a→d
b→c
b→c
a→d
Thermal Detector Signal [μV]
5
4
3
2
1
0
−1
0
100
200
300
Time [sec]

Fig 13