4 August 2004
Presentation at NP04
A. D. Krisch

SPIN@J-PARC and Polarized Proton Acceleration

Analyzing power A_n in 50 GeV very-high-$P_\perp^2$ (or 30 GeV proton-proton elastic scattering

SPIN@J-PARC Collaboration:
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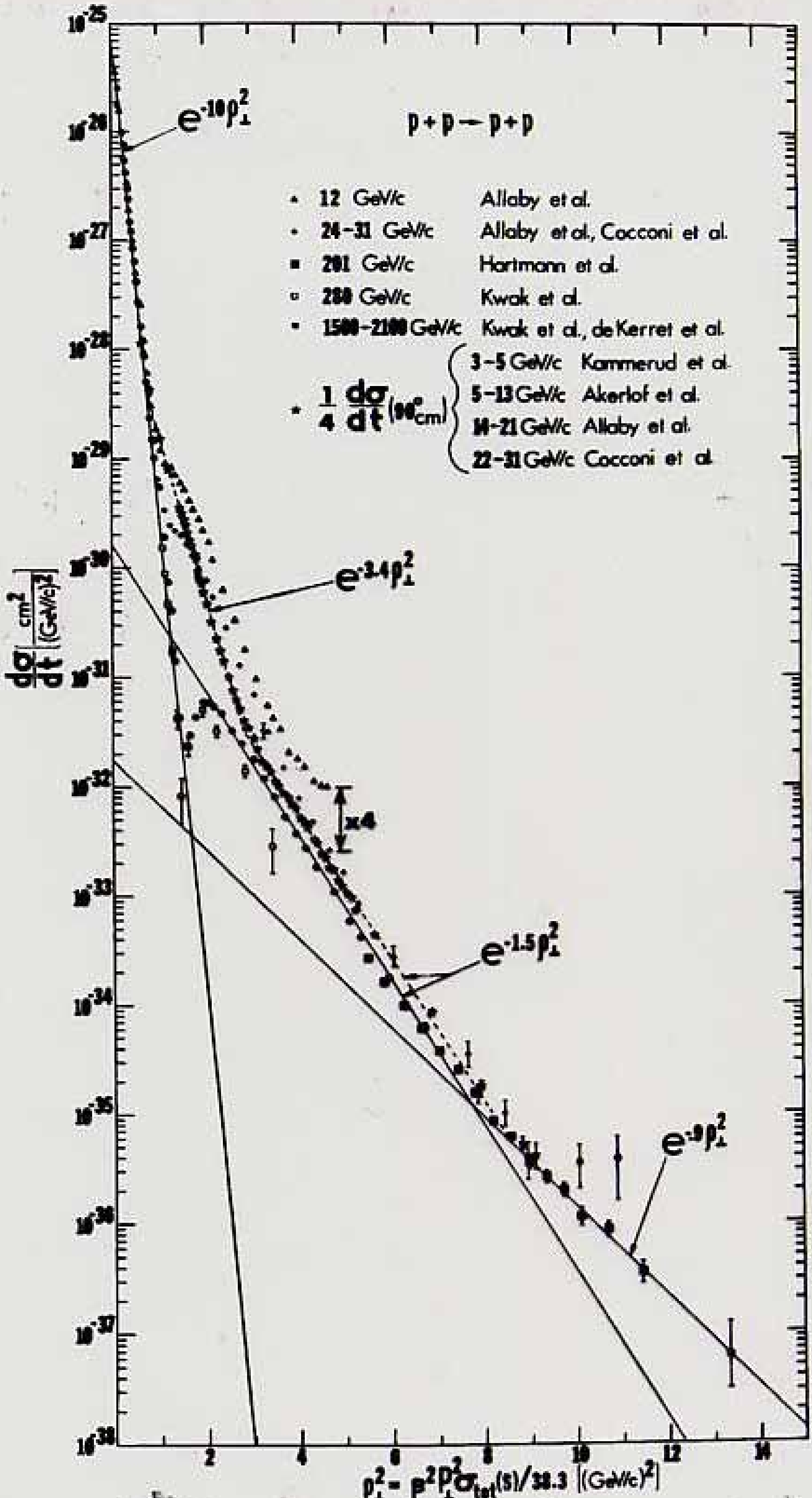
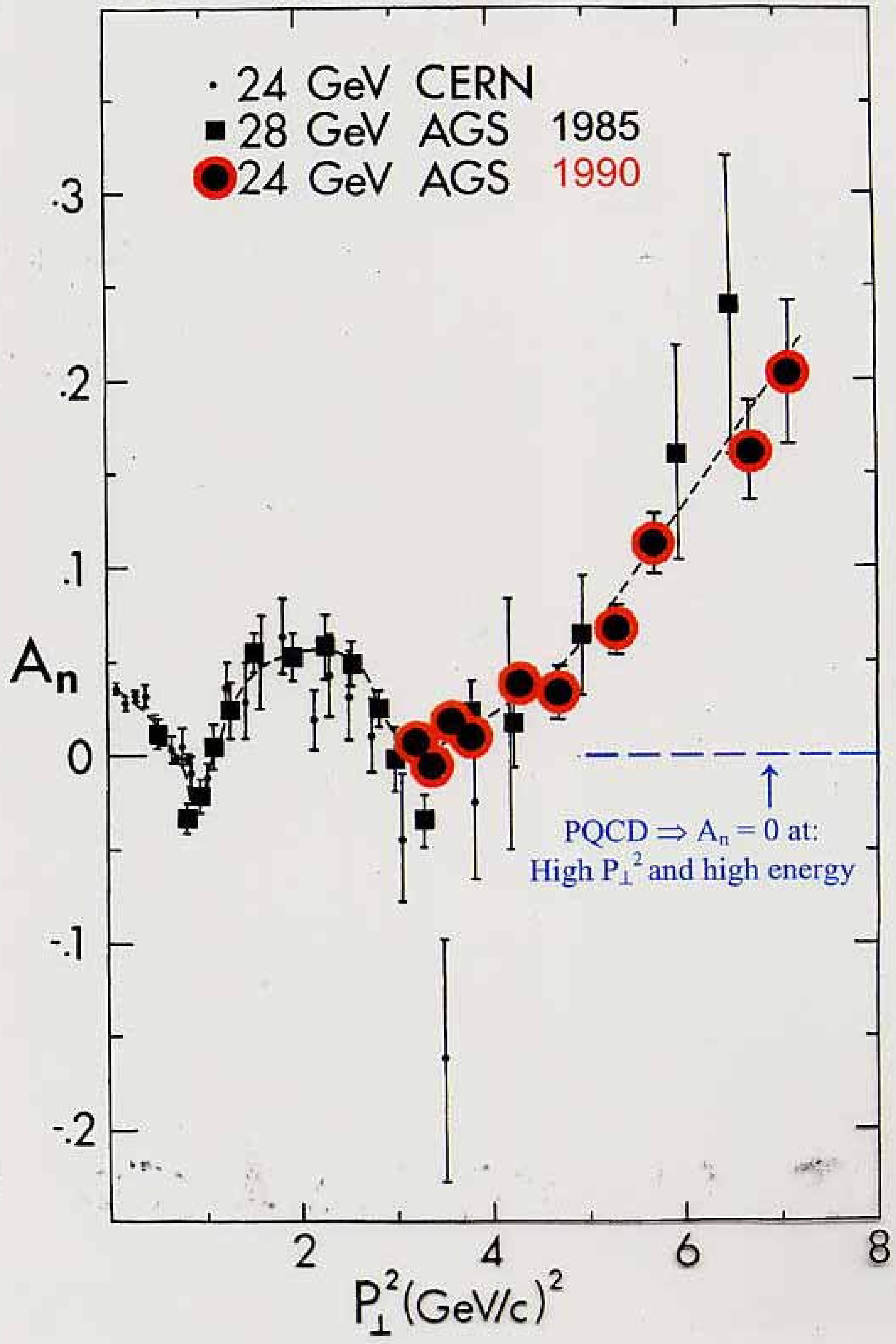


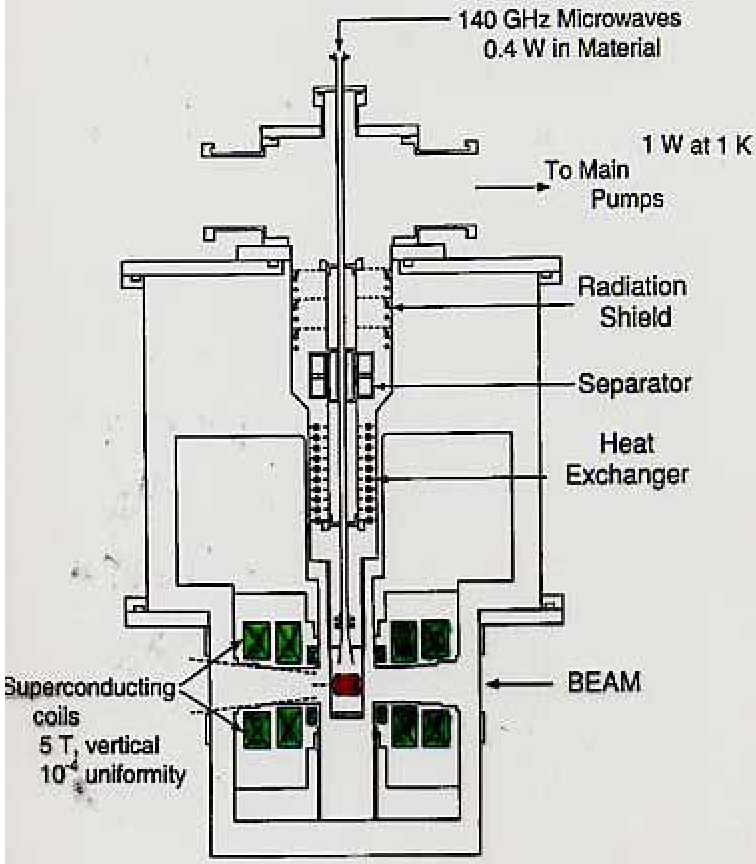
Proton-proton elastic cross-sections plotted against the scaled $P_{\perp}^2$ variable

Brookhaven AGS 1985 & 1990

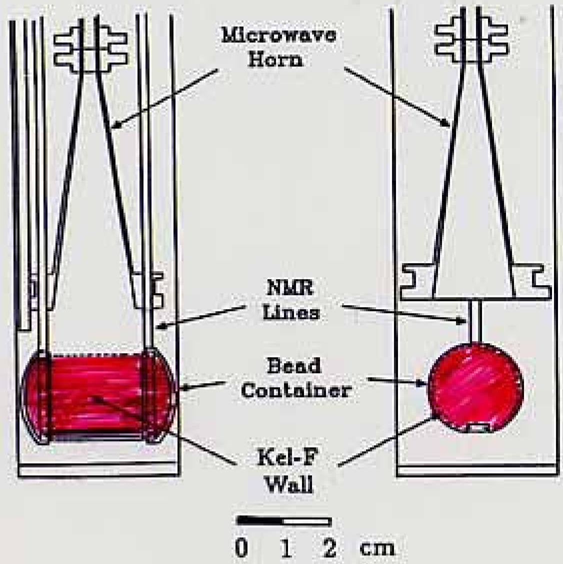
see August 1987 Scientific American



State-of-the-art Michigan Solid Polarized Proton Target

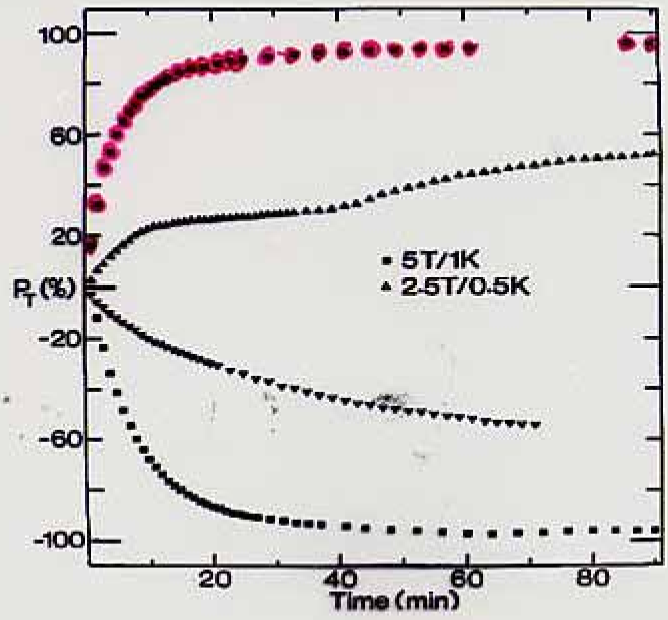


Expanded view of NH_3 cavity.



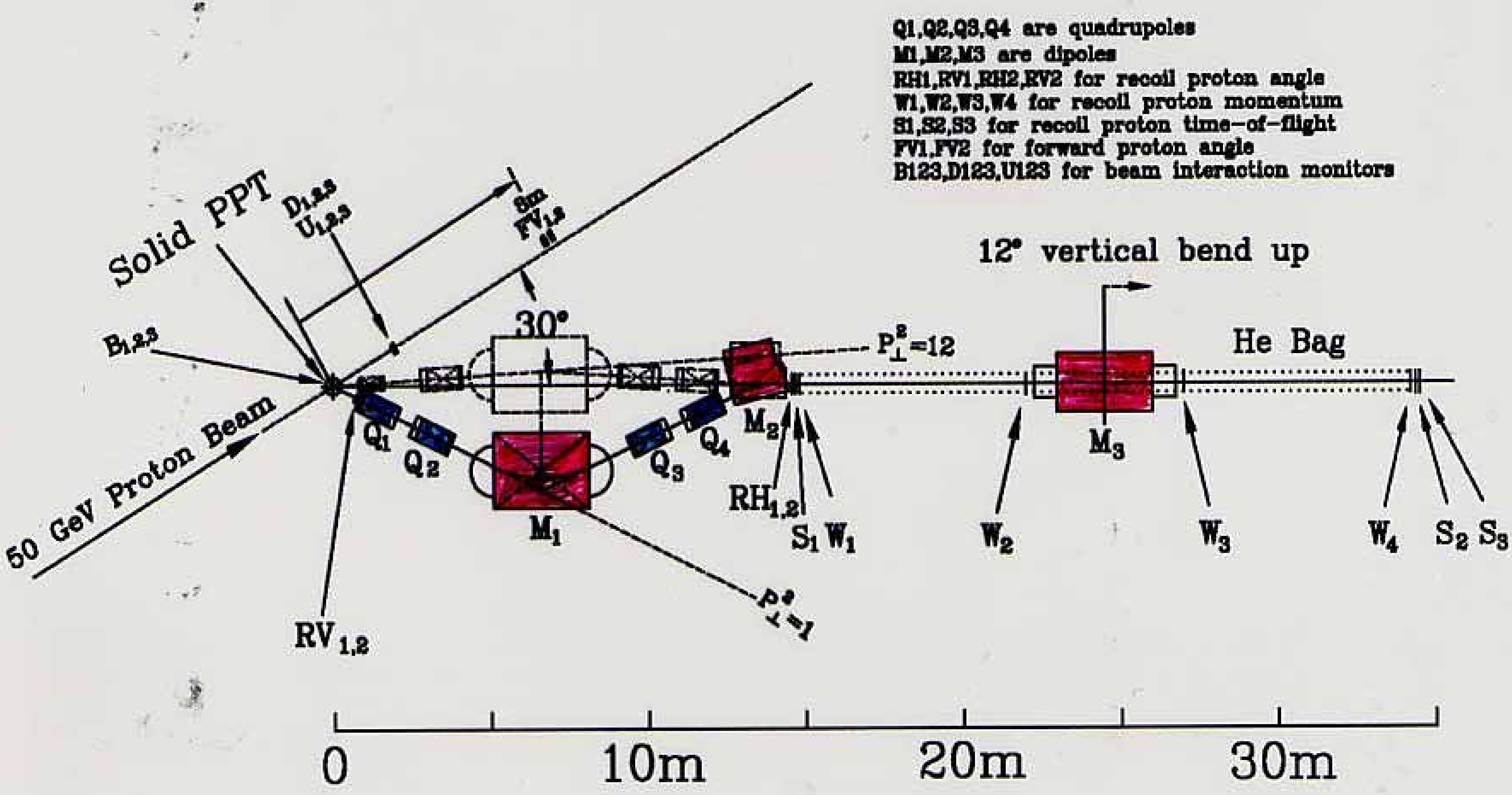
- **Superconducting magnet produces a highly uniform 5 T field;**
- **He^4 cryostat produces 0.9 W of cooling power at 1 K;**
- **Small target cavity filled with frozen radiation-doped ammonia (NH_3);**
- **Proton polarization in NH_3 reached 96%; average for 3-month AGS run = 85%**

Polarization of free protons in NH_3 plotted vs. time of 140 or 70 GHz microwaves irradiation at5 & 2.5 T



Possible 35-m-long Recoil Spectrometer in J-PARC extracted beam line

Large-$P_\perp^2$ elastic events would be detected using a focusing recoil spectrometer, similar to the SPIN@U-70 experiment, which was designed for 70 GeV proton-proton elastic scattering at IHEP-Protvino.



RECOIL ALMOST IDENTICAL

Angles & momenta of forward & recoil elastic protons & needed $\int B \cdot dl^{eff}$.

The $B \cdot dl^{eff}$ of each recoil spectrometer magnet needed for each $P_{\perp}^2$ setting was calculated from the below recoil proton's kinematics.

$P_{\perp}^2$	θ_F	P_F	θ_R	P_R	$\int B \cdot dl^{eff}$ PPT	θ_R'	$\int B \cdot dl^{eff}$ M1	$\int B \cdot dl^{eff}$ M2	$\int B \cdot dl^{eff}$ M3
$(GeV/c)^2$	degrees	GeV/c	degrees	GeV/c	T·m	degrees	T·m	T·m	T·m
1	1.16	49.5	61.2	1.14	0.445	54.7	3.15	-1.58	0.79
2	1.66	48.9	51.9	1.80	0.451	47.7	3.63	-1.81	1.25
3	2.05	48.4	45.8	2.42	0.456	42.7	3.57	-1.76	1.67
4	2.40	47.8	41.3	3.03	0.461	38.9	3.21	-1.57	2.09
5	2.72	47.2	37.8	3.65	0.467	35.8	2.64	-1.29	2.51
6	3.02	46.6	35.0	4.28	0.472	33.2	1.91	-0.94	2.93
7	3.30	45.9	32.6	4.92	-0.478	34.1	2.68	-1.31	3.35
8	3.58	45.3	30.5	5.58	-0.484	31.8	1.70	-0.83	3.78
9	3.86	44.6	28.7	6.26	-0.490	29.8	0.62	-0.30	4.22
10	4.13	43.9	27.0	6.96	-0.496	28.0	-0.57	0.28	4.67
12	4.68	42.4	24.2	8.45	-0.509	25.1	-3.21	1.57	5.59

Positive $\int B \cdot dl^{eff}$ bends to the right for PPT, M_1, and M_2 and bends up for M_3.
θ_R' is recoil angle after PPT magnet; it differs from θ_R by $\approx e\int B \cdot dl^{eff}{}_{PPT}/P_R$.

Recoil Spectrometer Magnet Parameters

Magnet	Length (m)	Diameter or Gap (cm)	B'_{max} (T/m)	B_{max} (T)
Q_1,Q_2,Q_3,Q_4	1.00	20	14.8	---
Q_1^{super} †	0.60	10x16	60.8	---
M_1	2.00	20	----	1.8
M_2	1.00	20	----	1.8
M_3	2.00 *	20	----	1.8

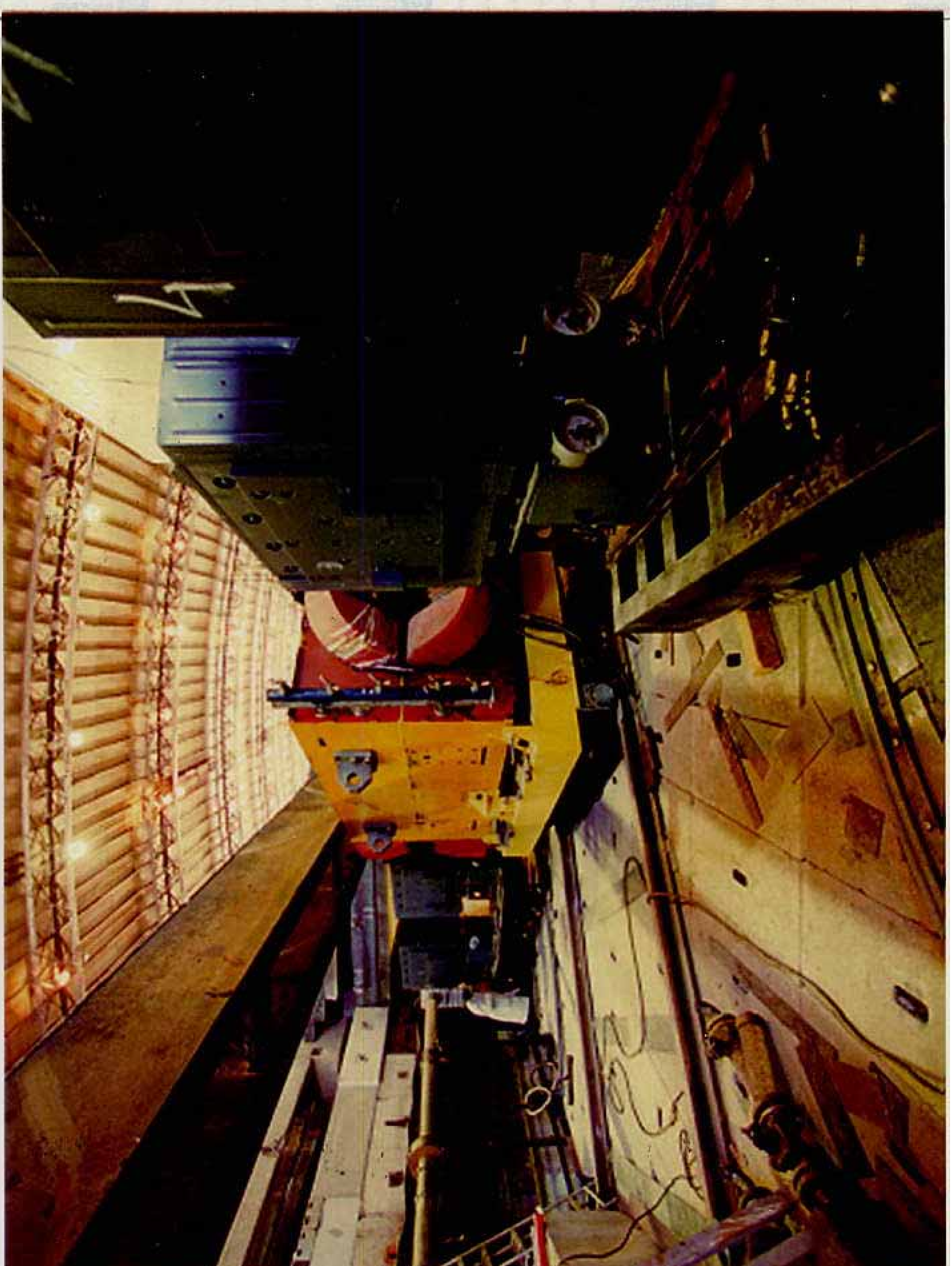
† Michigan will later provide Superconducting Q_1.

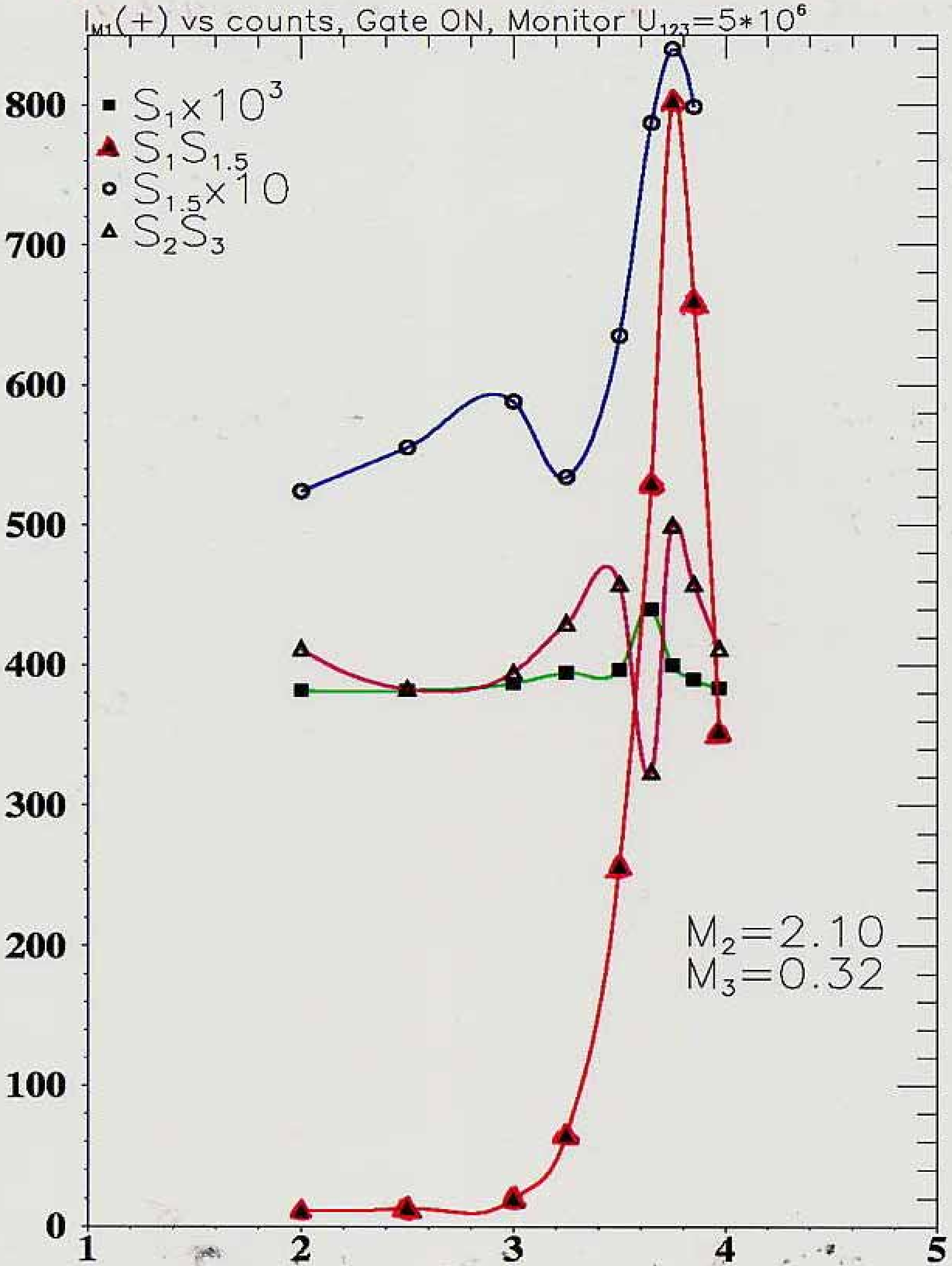
* May need extra 1 m of dipole for $P_\perp^2$ = 9-12 $(GeV/c)^2$ if background high.

SPIN@J-PARC Detectors

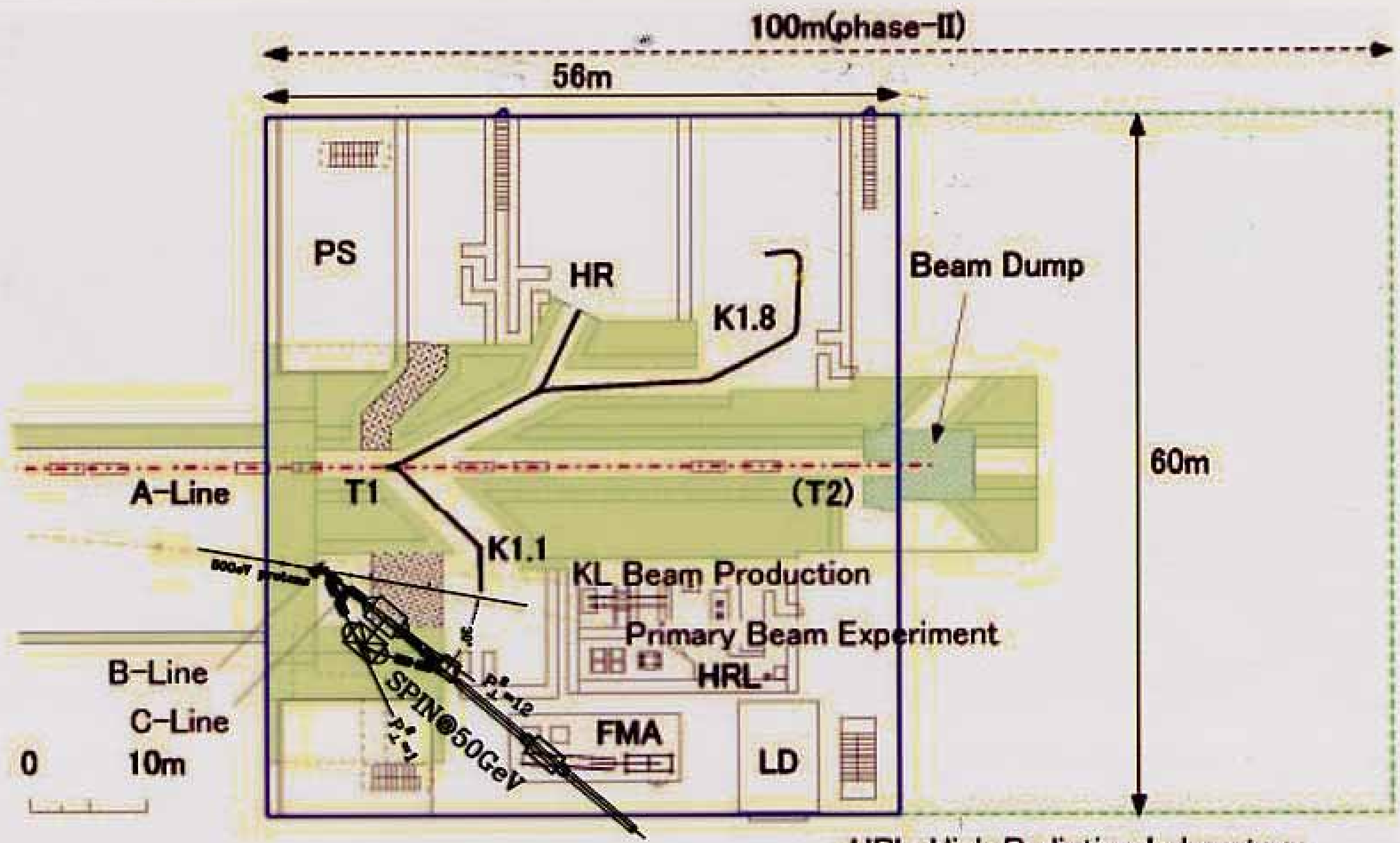
Detector Type	Location	Size(hxv) [mm]	Ch.	Resolution [mm]	Thickness [mm]
RV_1 Scintillator	R-0.8 m	60x160	8	10.7 V	10
RV_2 Scintillator	R-0.8 m	60x160	8	10.7 V	10
RH_1 Scintillator	R-14.2 m	200x200	8	13.3 H	10
RH_2 Scintillator	R-14.2 m	200x200	8	13.3 H	10
S_1 Scintillator	R-14.6 m	200x200	4	50 V	10
S_2 Scintillator	R-34.3 m	305x438	4	62.5 V	10
S_3 Scintillator	R-34.5 m	305x438	4	62.5 V	10
W_1 MWPC	R-15 m	200x200	192	1 V	20
W_2 Drift Chamber	R-22 m	300x500	2x32	1 V	20
W_3 Drift Chamber	R-26 m	300x500	2x32	1 V	20
W_4 Drift Chamber	R-33 m	300x500	2x32	1 V	20
FV_1 Scintillator	F-8 m	15x80*	8	1 V	10
FV_2 Scintillator	F-8 m	15x80*	8	1 V	10
U_{123} Scintillators	F-2 m 20°up	10 x10	3	--	32
D_{123} Scintillators	F-2 m 20°down	10x10	3	--	32
B_{123} Scintillators	1 m below	12x8.5	3	--	40

*The FV_{12} sizes are at $P_\perp^2 = 6\ (GeV/c)^2$;
we may use other sizes at other $P_\perp^2$ to match elastic kinematics.

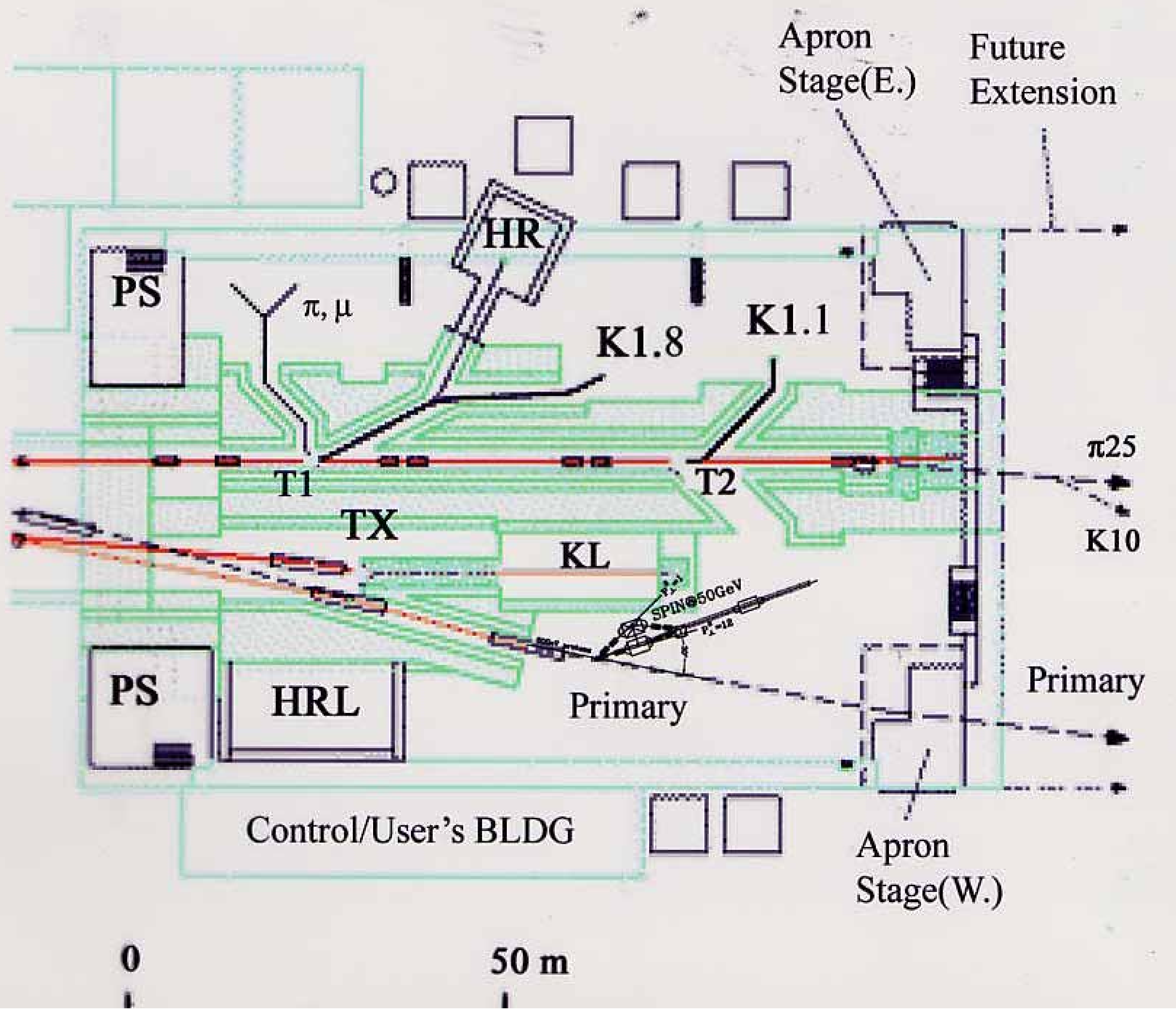




M1 Shunt Voltage
SPIN@U70 Recoil Spectrometer



HRL: High Radiation Laboratory
FMA: Field Measurement Area
LD: Loading Deck
PS: Power Supply Stage


Apron
Stage(E.)
Future
Extension
HR
PS
π, μ
K1.8
K1.1
π25
T1
T2
K10
TX
KL
SPIN@50GeV
PS
HRL
Primary
Primary
Control/User's BLDG
Apron
Stage(W.)
0
50 m

Event Rates & Errors in A_n

30 GeV
ALMOST IDENTICAL

PPT thickness:

$$T = N_0(\rho)t = 6.02\ 10^{23}\ gm^{-1}\ (0.1\ gm\ cm^{-3})\ 3.2\ cm$$
$$= 2\ 10^{23}\ \text{polarized protons}\ cm^{-2}$$

Time-averaged luminosity:

$$L = I_B \cdot T = 2\ 10^{34}\ s^{-1}\ cm^{-2}$$

$$\text{Events/hr} = L\ d\sigma/dt\ (\Delta t \cdot \Delta\phi / 2\pi)\ \varepsilon\ 3600\ s/hr$$
$$= 6\ d\sigma/dt\ [nb] \cdot (\Delta t \cdot \Delta\phi)[mr]$$

Elastic cross-sections $d\sigma/dt$ obtained from data compilation (Fig. 10).

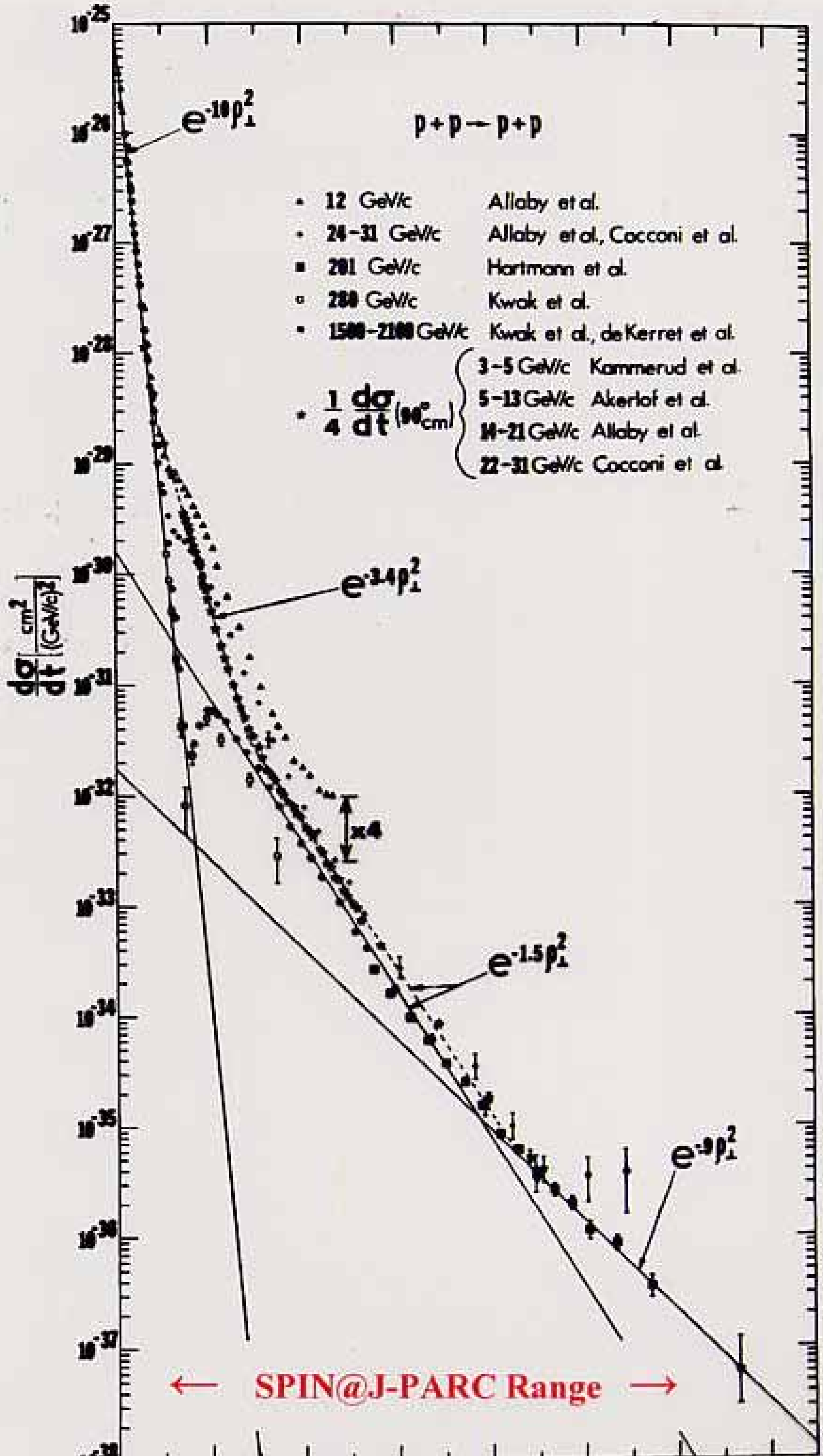
Efficiency factor ε conservatively estimated to be 50%.

$P_\perp^2$ $(GeV/c)^2$	Δt $(GeV/c)^2$	$\Delta\phi$ mr	$d\sigma/dt$ $nb/(GeV/c)^2$	Events per hour	Hours	Events	$\Delta A_n = [.85\sqrt{N}]^{-1}$ (%)	
1.0	0.06	159	4000	230000	100	$2.3\cdot10^7$	0.03	
2.0	0.09	177	90	8600	100	$8.6\cdot10^5$	0.1	
3.0	0.25	194	19	5500	100	$5.5\cdot10^5$	0.2	
4.0	0.35	210	4.0	1800	100	$1.8\cdot10^5$	0.3	
5.0	0.45	225	0.9	550	100	$5.5\cdot10^4$	0.5	
6.0	0.56	240	0.22	180	200	$3.6\cdot10^4$	0.6	
7.0	0.67	254	0.055	56	200	$1.1\cdot10^4$	1.1	Super Q_1
8.0	0.79	268	0.016	20	300	$6.0\cdot10^3$	1.5	"
9.0	0.92	282	0.0047	7.3	400	$2.9\cdot10^3$	2.2	"
10.0	1.06	296	0.0017	3.2	600	$1.9\cdot10^3$	2.7	"
12.0	1.25	324	0.0003	0.73	800	$4.4\cdot10^2$	4.9	"

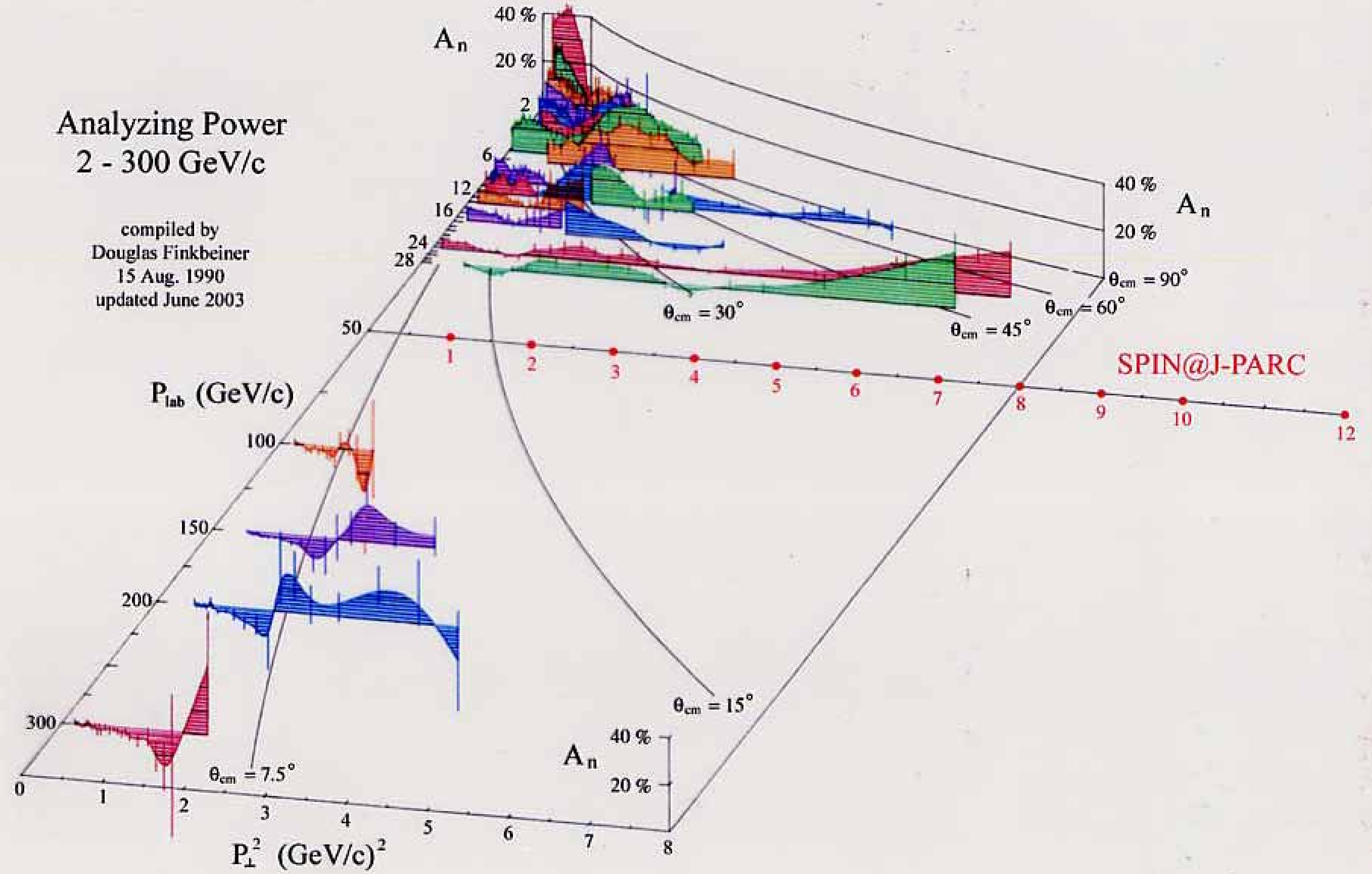
Total: 3000 hrs + 500 hrs (tune-up)
375 + 63 8-hr shifts

Status of Equipment

#	Item	Status	Suggested Action	Time Needed
1.	Solid PPT, NMR, Microwaves	At Michigan	Pack, ship, reassemble	9 months
2.	PPT pumps	Need	Acquire in Japan or US	1 year
3.	PPT stand + hardware	At Michigan	Modify and ship	3 months
4.	Quadrupoles Q_1, Q_2, Q_3, Q_4	J-PARC provide		2 years
5.	Dipoles M_1, M_2, M_3	J-PARC provide		2 years
6.	Stands for: Q_1,Q_2,Q_3,Q_4 Stands for: M_1,M_2,M_3	J-PARC provide		1 year
7.	Magnets' Power Supplies	J-PARC provide		1 year
8.	Scintillators: FV_1,FV_2,S_1,S_2,S_3 RH_1,RV_1,RH_2,RV_2	Some at Michigan	Make others at Michigan; then ship	6 months
9.	Wire Chambers: W_1,W_2 W_3, W_4	At Michigan Need	Pack, ship Make at Michigan	3 months 9 months
10.	Detector Stands	At Michigan	Pack, ship	3 months
11.	Cables, Connectors, Cable ends	Mostly at Michigan	Acquire the rest, pack, ship	3 months
12.	Electronics	Mostly at Michigan	Acquire the rest, pack, ship	3 months
13.	Computers	At Michigan	Pack, ship	3 months
14.	Monitors D_{123}, U_{123}, B_{123}	At Michigan	Check, pack, ship	3 months
15.	Beam Stabilizer System	J-PARC provide		1 year
16.	Rastering System	J-PARC provide		1 year
17.	Experiment Control Room	J-PARC provide ?		1 year
18.	Shielding blocks	J-PARC provide	Plan, rearrange	1 year
19.	Magnets' movement plates	J-PARC provide	Design, build at J-PARC	1 year
20.	Liquid Helium and Nitrogen	J-PARC provide	Purchase or Liquify	??
21.	Superconducting Q_1	J-PARC or Michigan	Will need later	2 years



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


Analyzing Power
2 - 300 GeV/c
compiled by
Douglas Finkbeiner
15 Aug. 1990
updated June 2003
A_n
40 %
20 %
2
6
12
16
24
28
50
100
150
200
300
P_{lab} (GeV/c)
θ_{cm} = 90°
θ_{cm} = 60°
θ_{cm} = 45°
θ_{cm} = 30°
θ_{cm} = 15°
θ_{cm} = 7.5°
SPIN@J-PARC
1 2 3 4 5 6 7 8 9 10 12
0 1 2 3 4 5 6 7 8
$P_\perp^2$ $(GeV/c)^2$

UM HE 99-05
June 24, 1999

UPDATE REPORT

Acceleration of Polarized Protons to 920 GeV at HERA*†

SPIN Collaboration
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JINR-Dubna, Moscow, INR-Moscow, BINP-Novosibirsk
KEK, TRIUMF

DESY Polarization Team
DESY, BINP, INR-Moscow

During January 1997 to June 1999, the SPIN Collaboration and the DESY Polarization Team have tried to extend and refine the 8 November 1996 Report on "Acceleration of Polarized Protons to 820 GeV/c at HERA" (UM-HE 96-20). The main areas of this new work are:

- increasing the accumulated polarized proton intensity,
- providing adequate spin stability with four (or more if absolutely necessary) Siberian snakes, probably by reducing HERA's emittance and rms orbit distortions during or after its Luminosity Upgrade.

As indicated in the 1996 Report all other problems appear to have straightforward solutions using existing techniques. The first Section of this Update Report summarizes the changes needed in each accelerator for polarized proton acceleration; it also contains a possible Schedule and Budget for the polarized proton beam project. The rest of the Report describes the new work on beam intensity and spin stability which might allow one to accelerate polarized protons and to perform polarized proton experiments at 920 GeV. *If some inexpensive way can be found to overcome HERA's rather strong depolarizing resonances with only 4 Siberian snakes*, then the total cost of the project should be about DM 24 Million.

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* Supported by research grants from DESY and the U.S. Department of Energy.
† Dedicated to the memory of Prof. Bjorn Wiik who supported this challenging and interesting study.

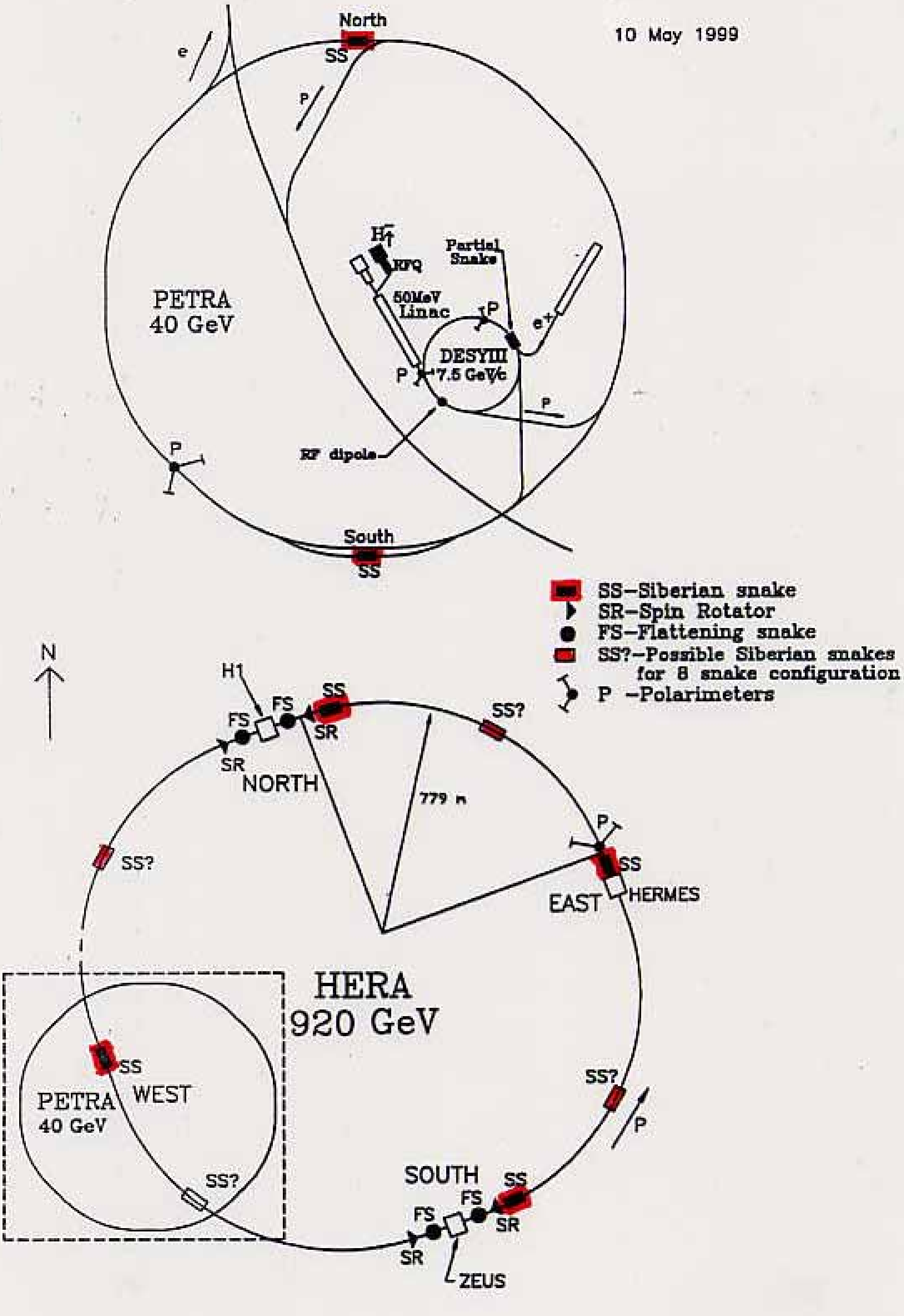

Figure 1.1: The proposed modifications for a 920 GeV polarized proton beam at DESY.

1c

23 June 1999

SPIN@HERA Collaboration

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1.2 Schedule

A possible schedule for commissioning the polarized proton beam is estimated in Fig. 1.2. This estimate assumes that the funding for this polarized proton beam project may become available in 2003 and that no other projects interfere with the commissioning.

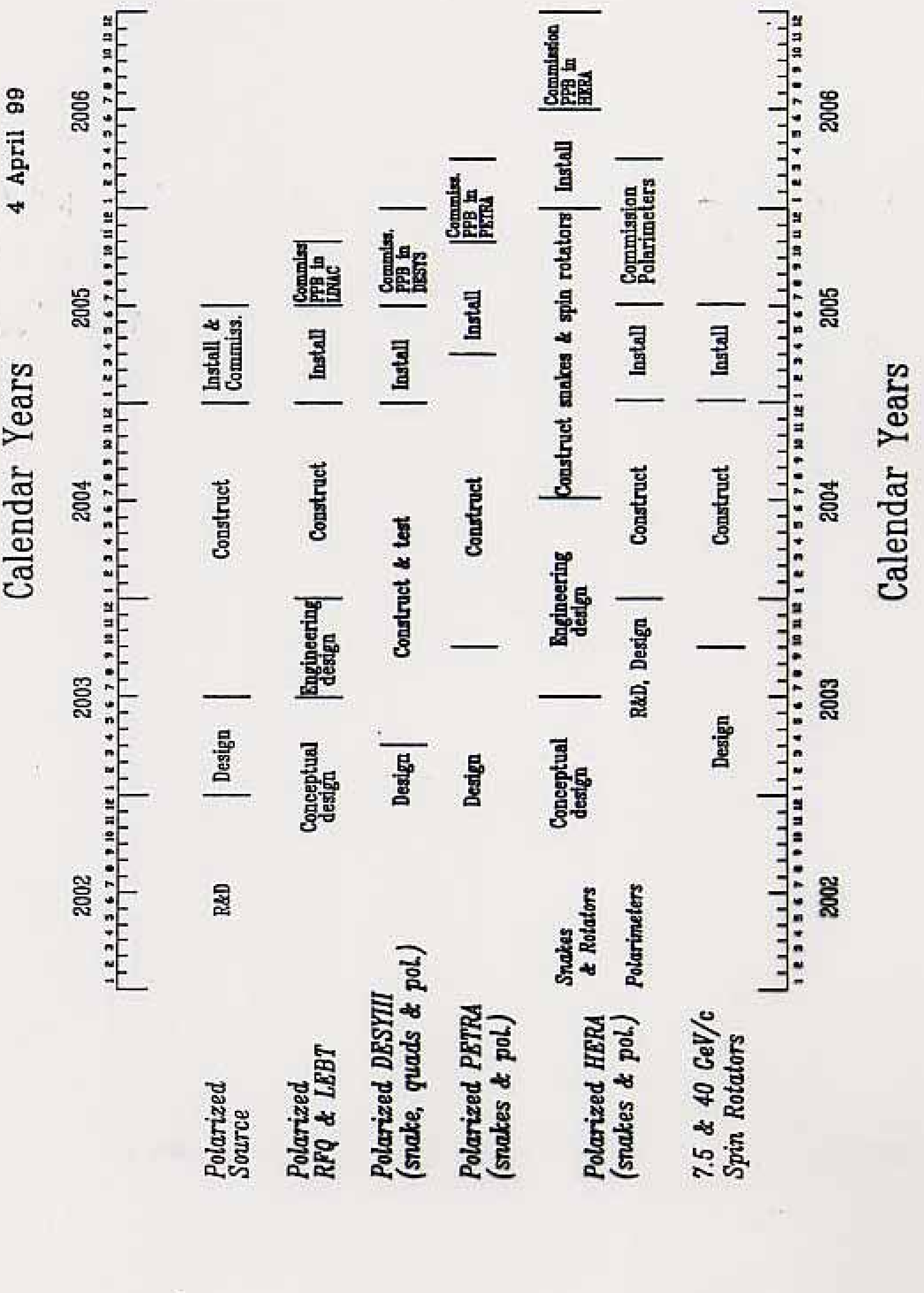


Figure 1.2: The schedule for commissioning a polarized proton beam in HERA.

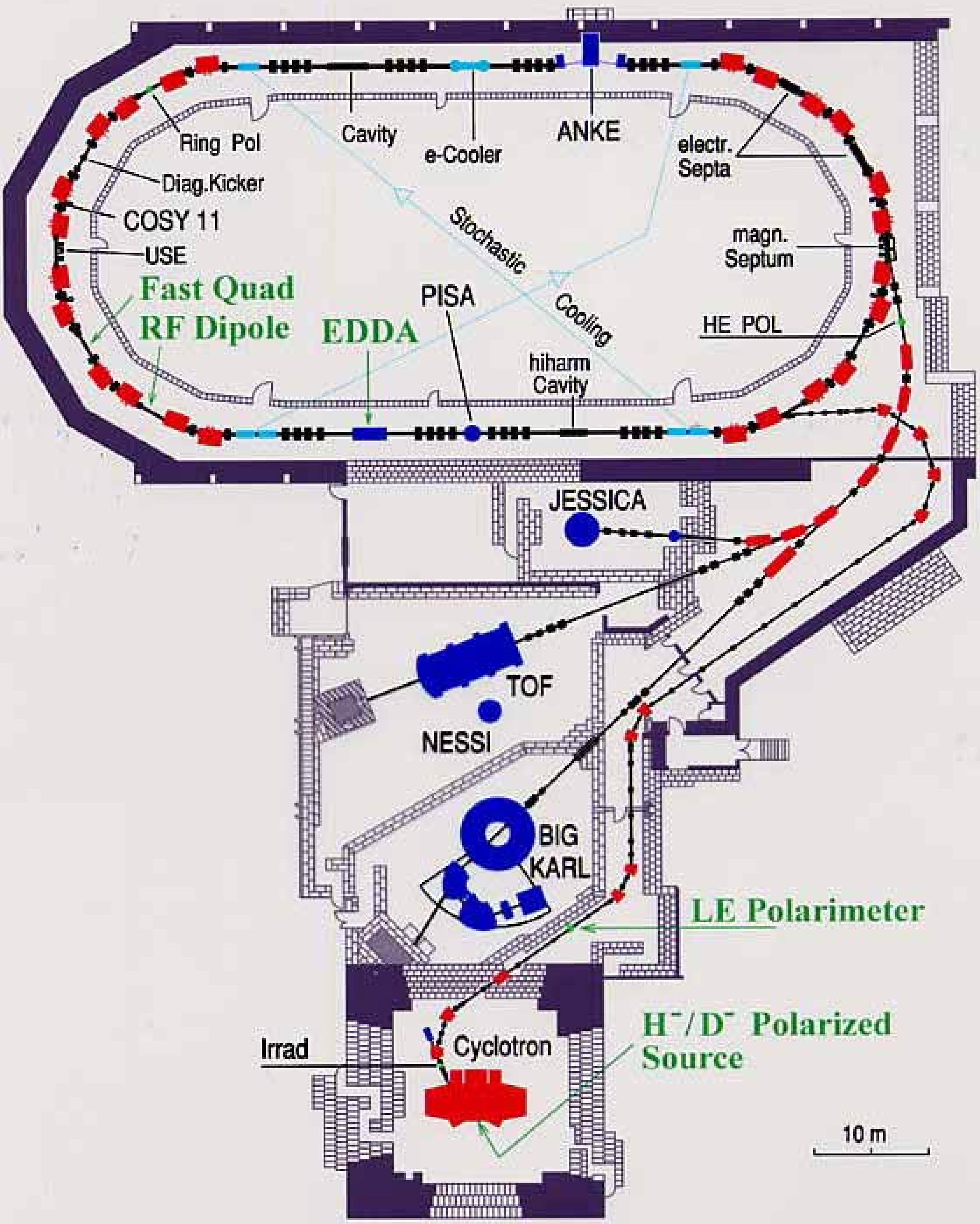
1.3 Budget

The estimated total cost to obtain an 920 GeV polarized proton beam capability at DESY is given in **1999** DM. Our estimate of about DM 24 Million seems a quite reasonable investment for the expected physics results. Moreover this cost might be considerably lower if the SPIN Collaboration fabricated some or all of the polarization hardware. *Note carefully that this estimate assumes that some inexpensive way is found to overcome the possible spin stability problem in HERA with only four Siberian snakes.*

Preaccelerator		**DM 4.7 M**
Polarized H^- ion source	DM 3.0 M	
RFQ and power supply (20 keV to 750 KeV)	DM 0.7 M	
Low energy beam transport, switching magnets, and vacuum system	DM 0.7 M	
Building change	DM 0.3 M	
50 MeV LINAC		**DM 0.2 M**
50 MeV polarimeter (p-Carbon)	DM 0.2 M	
7.5 GeV/c DESY III Booster		**DM 0.8 M**
Solenoid partial Siberian snake (ramped warm)	DM 0.3 M	
Pulsed quadrupoles, kicker or rf dipole with power supplies	DM 0.3 M	
7.5 GeV/c polarimeter (Relative)	DM 0.2 M	
40 GeV PETRA Ring		**DM 2.3 M**
Two warm Siberian snakes	DM 1.1 M	
Power supplies and connections	DM 0.3 M	
40 GeV polarimeters (CNI, Relative, and possibly Inclusive)	DM 0.9 M	
920 GeV HERA Ring		**DM 9.3 M**
4 Superconducting Siberian snakes	DM 2.2 M	
4 Superconducting flattening snakes	DM 2.2 M	
4 Superconducting spin rotators	DM 1.7 M	
Power supplies and cryogenic connections	DM 1.7 M	
920 GeV polarimeters (CNI, Inclusive, Relative, Elastic)	DM 1.2 M	
Spin Flippers	DM 0.3 M	
Miscellaneous		**DM 1.9 M**
Transfer line spin rotators	DM 0.6 M	
Computers, control modules, cables, and interface	DM 1.3 M	
ACCELERATOR SUBTOTAL		**DM 19.2 M**
Contingency (25%)		**DM 4.8 M**
ACCELERATOR TOTAL		**DM 24.0 M**

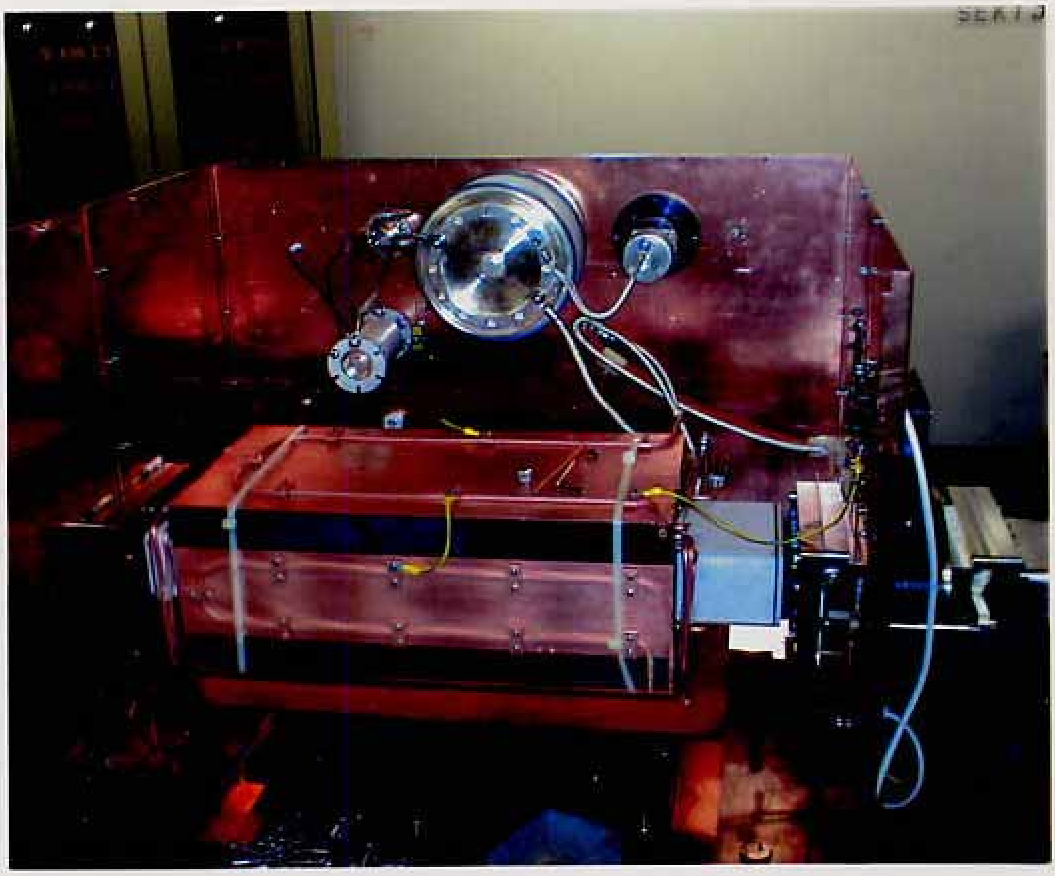
10 / 2·5 / 12. // ~ 7 Million ~ 10^9 ¥ FOR J-PAR

COSY



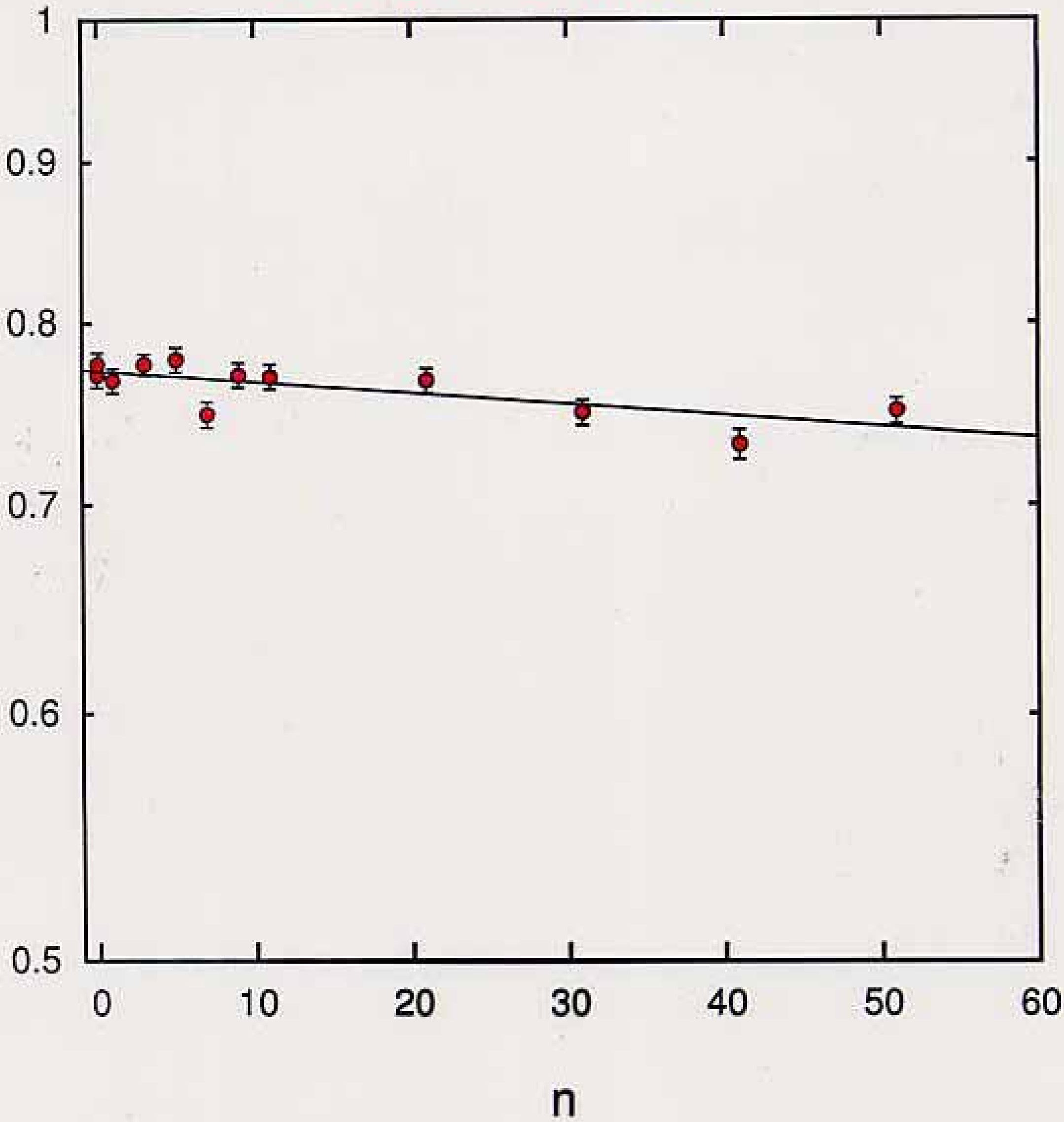
Ring Pol
Cavity
e-Cooler
ANKE
electr.
Septa
Diag.Kicker
COSY 11
USE
Stochastic
Cooling
magn.
Septum
Fast Quad
RF Dipole
EDDA
PISA
HE POL
hiharm
Cavity
JESSICA
TOF
NESSI
BIG
KARL
LE Polarimeter
Irrad
Cyclotron
H⁻/D⁻ Polarized
Source
10 m

WATER COOLED FERRITE RF DIPOLE



- installed around a ceramic vacuum pipe.
- $\int B_{rms} \cdot dl = 0.58\,T \cdot mm$ at $\sim$ 916 kHz.

SPIN@COSY APR 04 RUN 2.1 GeV/c protons
submitted to PRL



η = 99.92% ± 0.02%

Argonne ZGS 1978

1987 Scientific American