Towards 100% polarization in the Optically-Pumped Polarized Ion Source at RHIC.

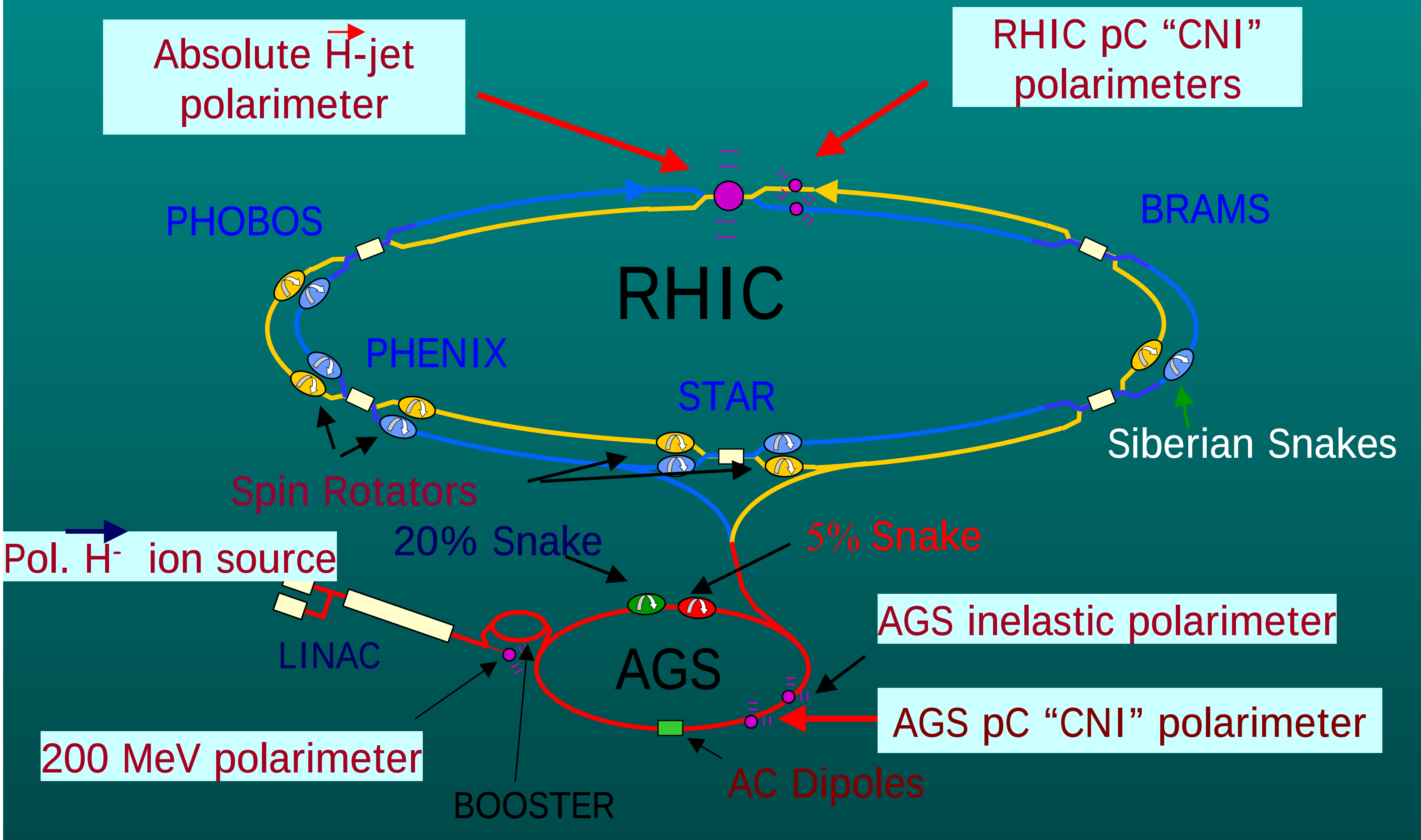
Anatoli Zelenski, BNL

- The OPPIS polarization technique.
- Polarization losses in a multi-step spin- transfer process.
- OPPIS performance in 2006-07 Runs.
- Polarized Sources and Targets Workshop PST-2007 at BNL.

PAC 2007, Albuquerque, June 29, 2007

Polarization facilities at RHIC.

Design goal - 70% Polarization, $L_{max} = 1.6 \times 10^{32}\ s^{-1}cm^{-2}$, $50 < \sqrt{s} < 500$ GeV



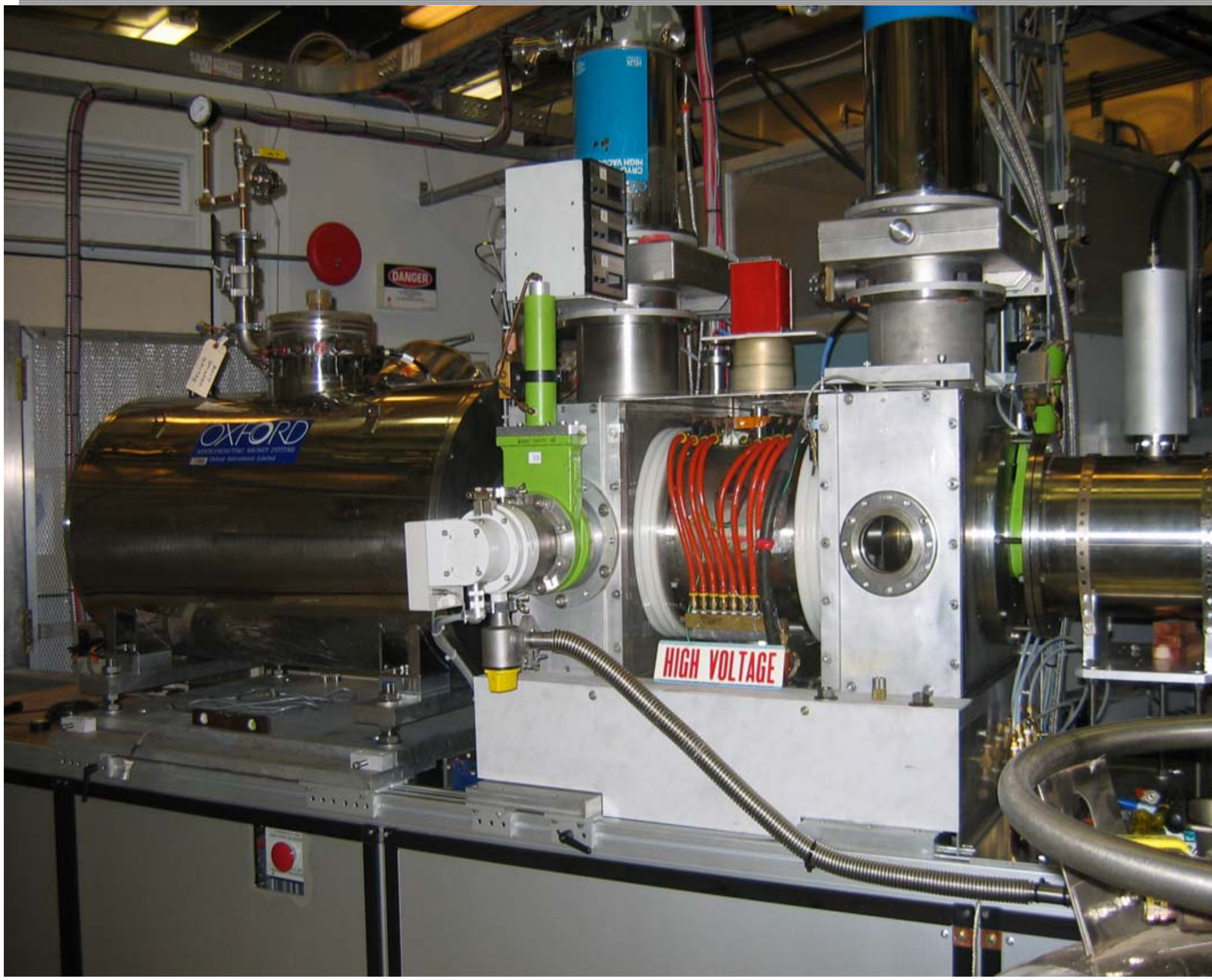
Workshop on high –energy spin physics,

Protvino, IHEP, September,1983

Yaroslav Derbenev
“Siberian snake” proposal.

Anatoli Zelenski
A new polarized source technique.
Equal intensity for polarized and unpolarized proton beams.

Optically-Pumped Polarized H^- Ion Source at RHIC.



A beam intensity greatly exceeds RHIC limit, which allowed strong beam collimation in the Booster, to reduce longitudinal and transverse beam emittances.

RHIC OPPIS produces reliably 0.5-1.0mA (maximum 1.6 mA) polarized H^- ion current.

Pulse duration 400 us.

Polarization at 200 MeV

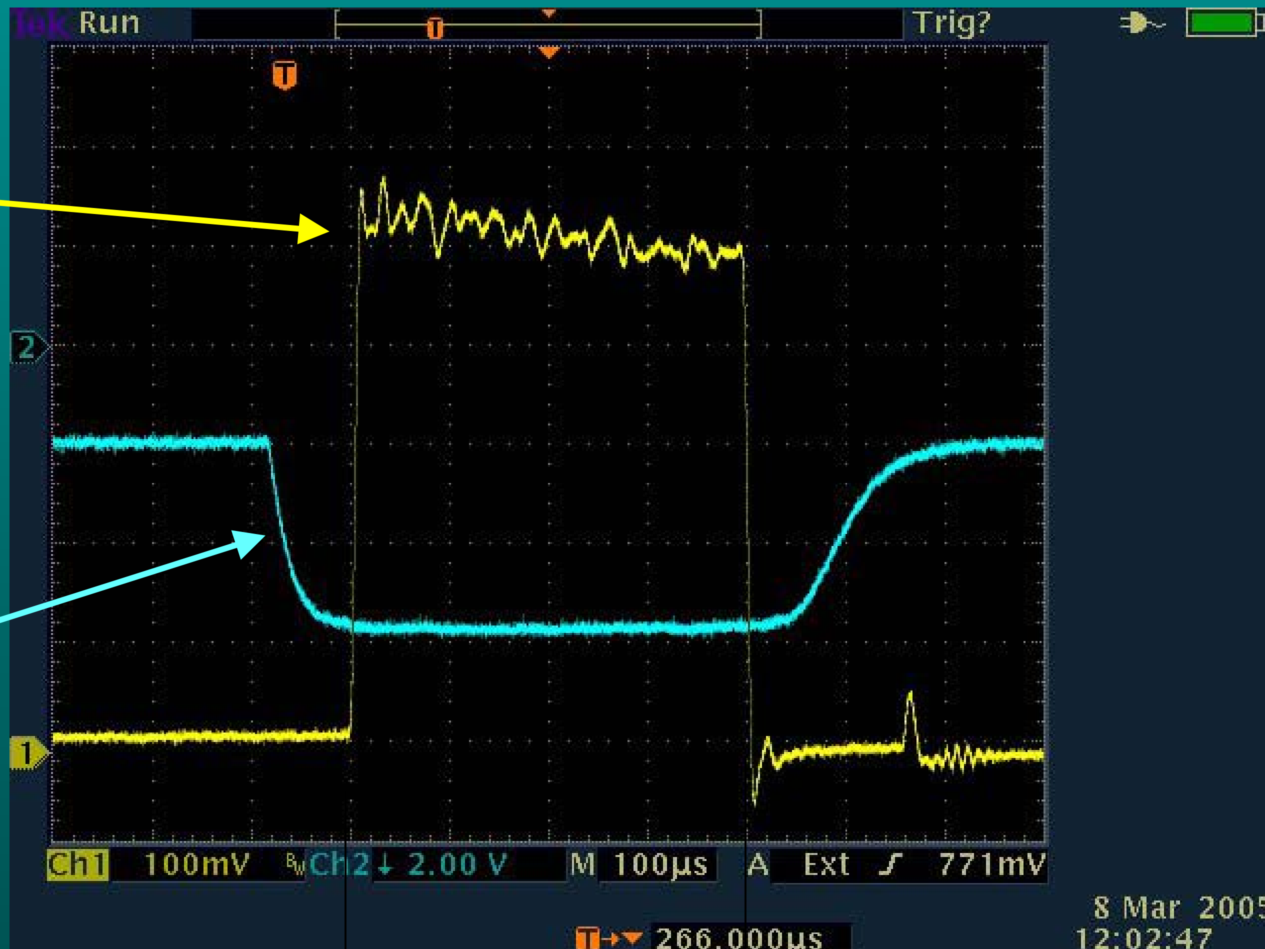
P = 85-90 %.

Beam intensity (ion/pulse) routine operation:

Source	- 10^{12} H^-/pulse
Linac (200MeV)	- $5 \cdot 10^{11}$
Booster	- $2 \cdot 10^{11}$, 50% - scraping.
AGS	- $1.7 \cdot 10^{11}$
RHIC	- $1.5 \cdot 10^{11}$ (p/bunch).

Polarized H^- ion current pulse out of 200 MeV linac.

500 uA cuurent At 200 MeV. 85-hole ECR Source for the maximum polarization.

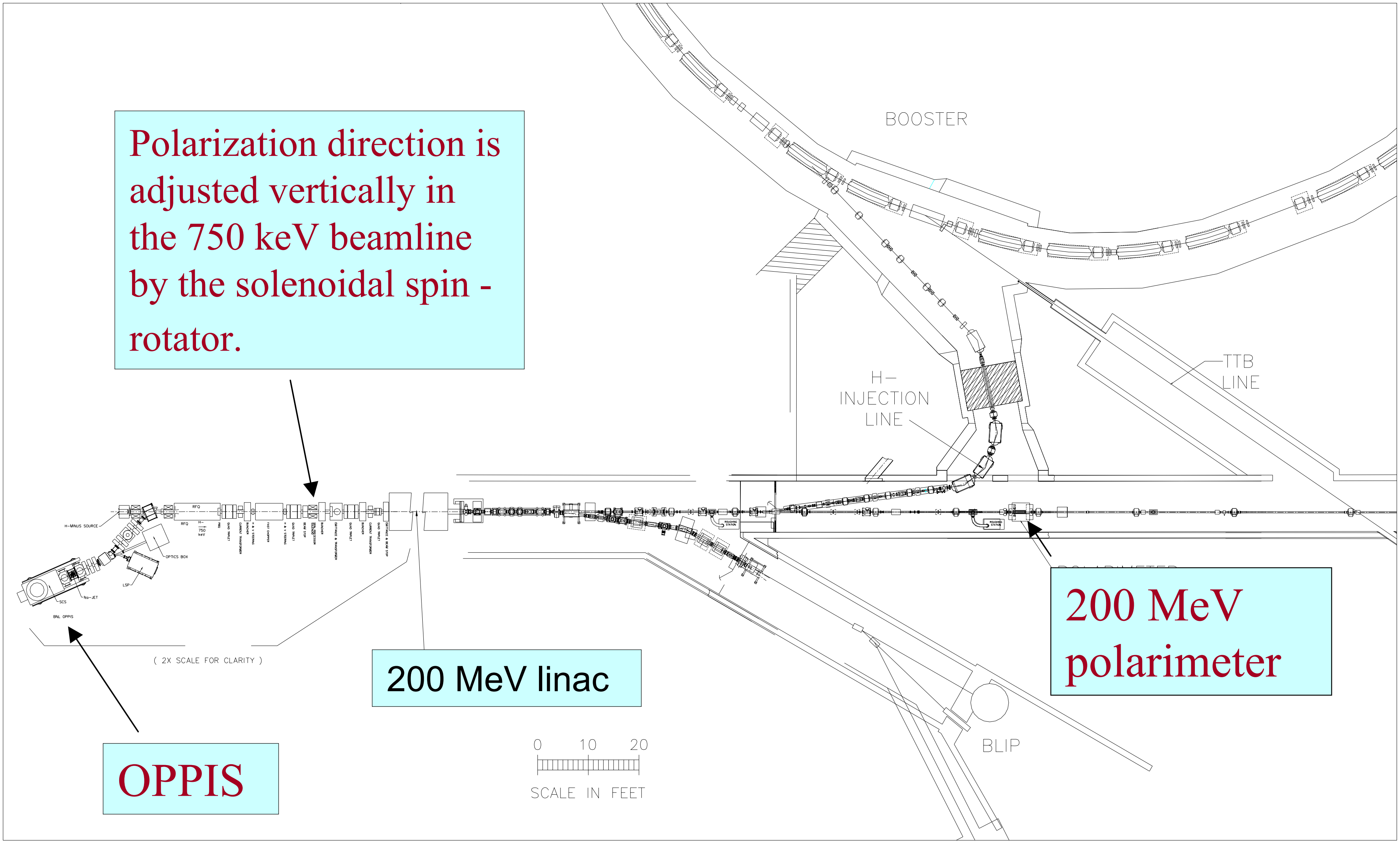


Faradey rotation polarization sinal.

400 uS

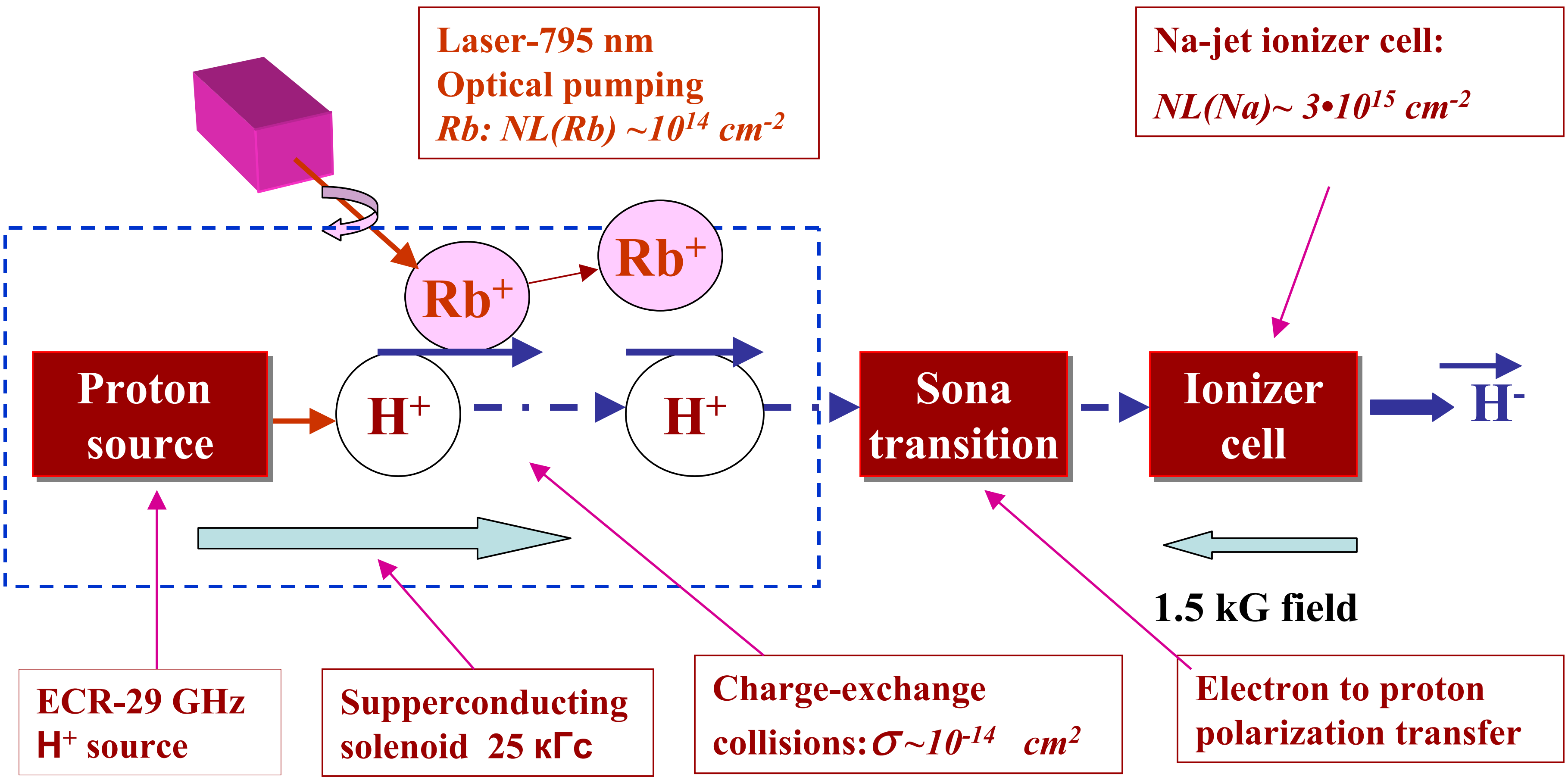
$12 \cdot 10^{11}$ -polarized H^- /pulse.

Polarized injector, 200 MeV linac and injection lines.



SPIN -TRANSFER POLARIZATION IN PROTON-Rb COLLISIONS.

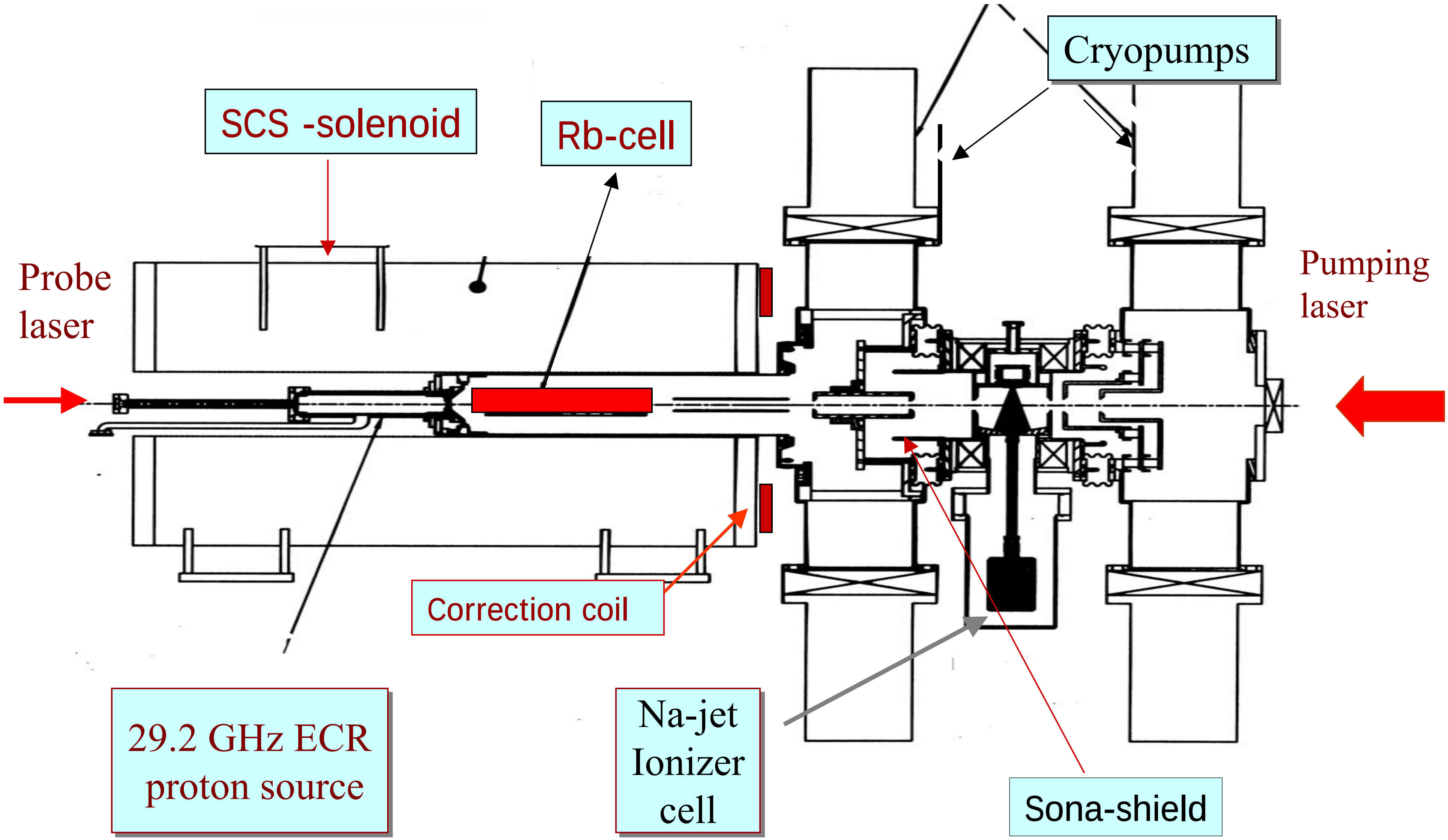
PROTON-Rb COLLISIONS.



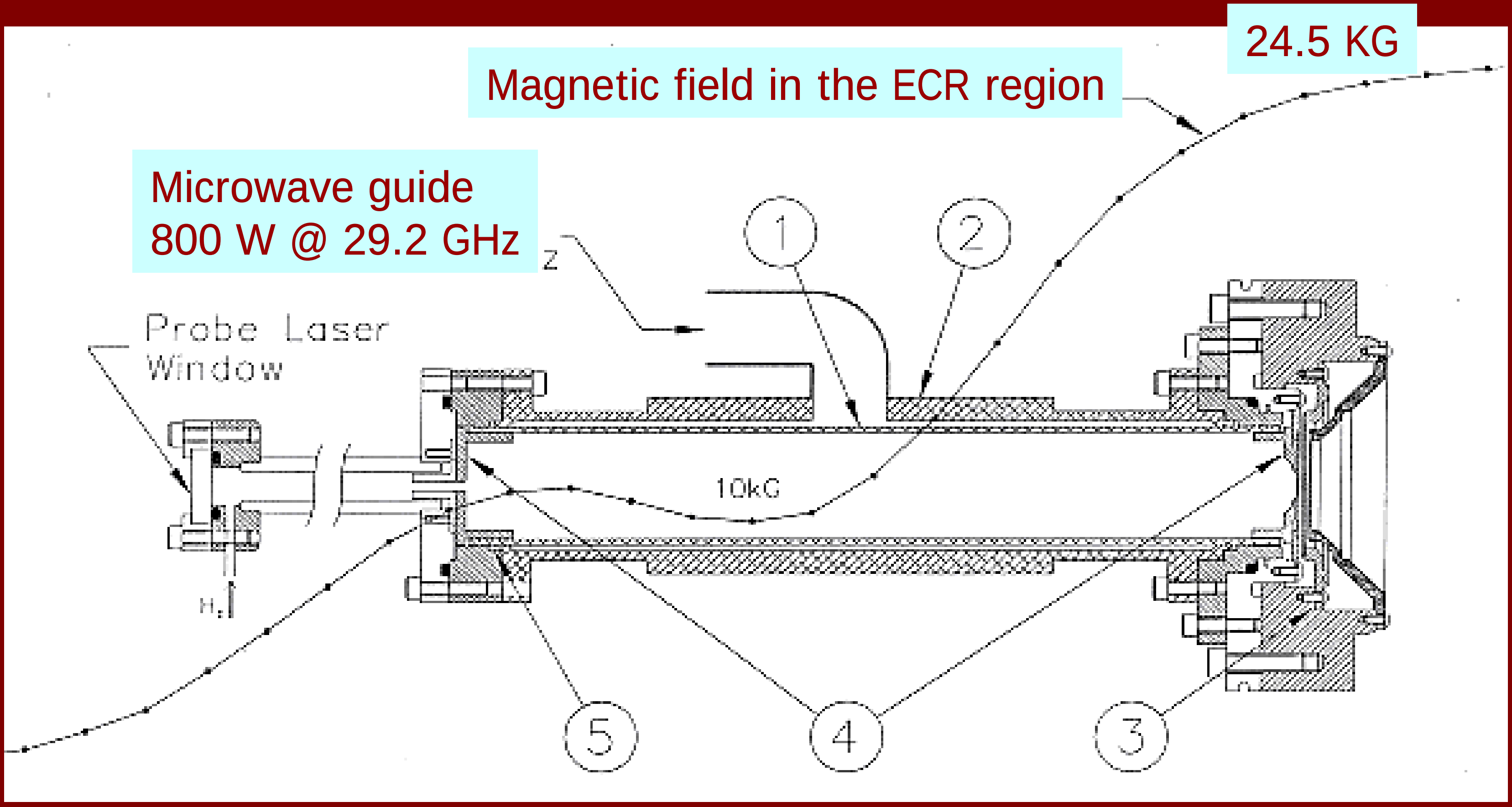
Laser beam is a primary source of angular momentum:

10 W (795 nm) ⇨ $4 \cdot 10^{19}$ hν/sec ⇨ 2 A, $\vec{H}^0$ equivalent intensity.

SCHEMATIC LAYOUT OF THE RHIC OPPIS.

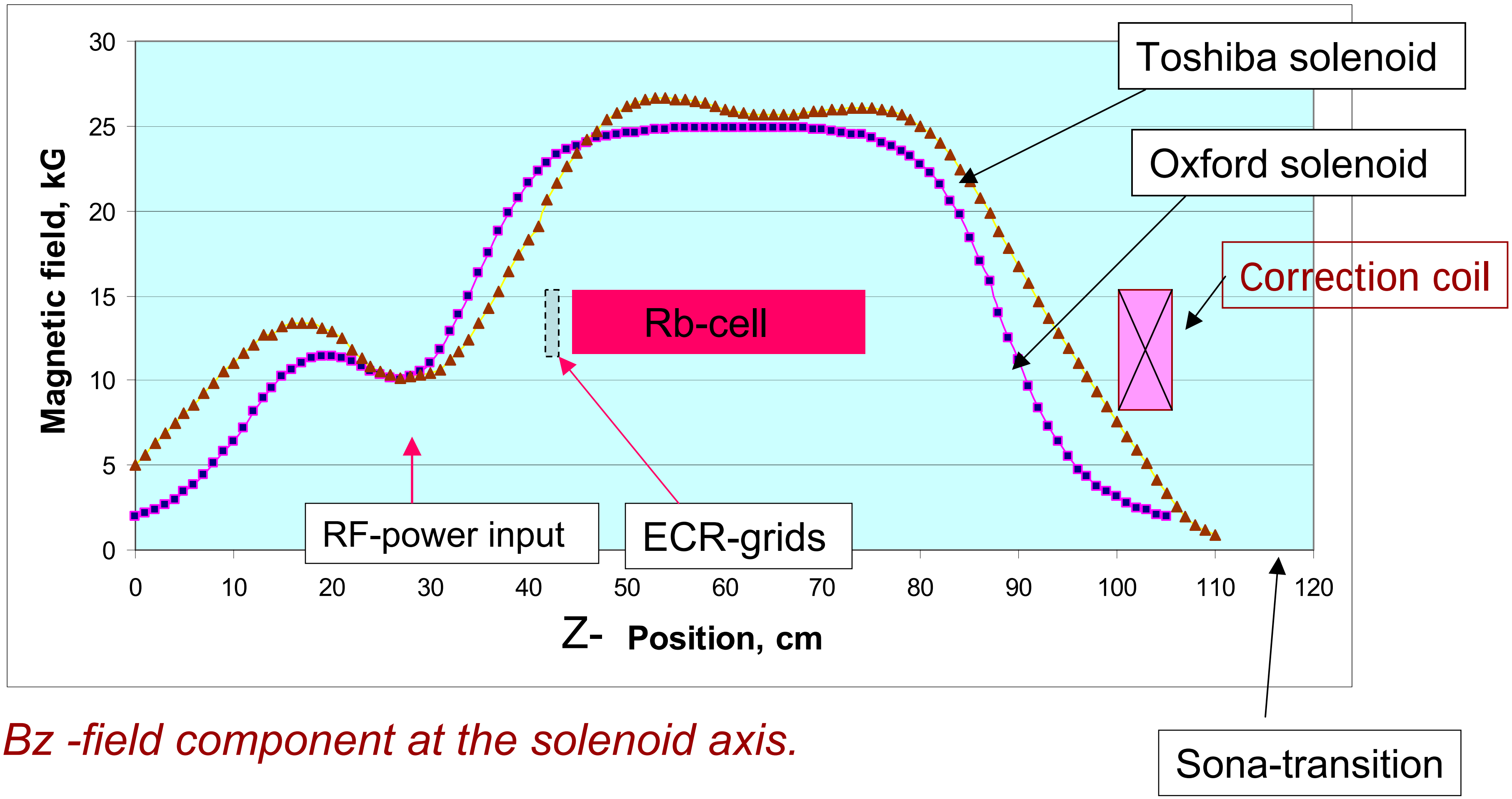


ECR - primary proton source.



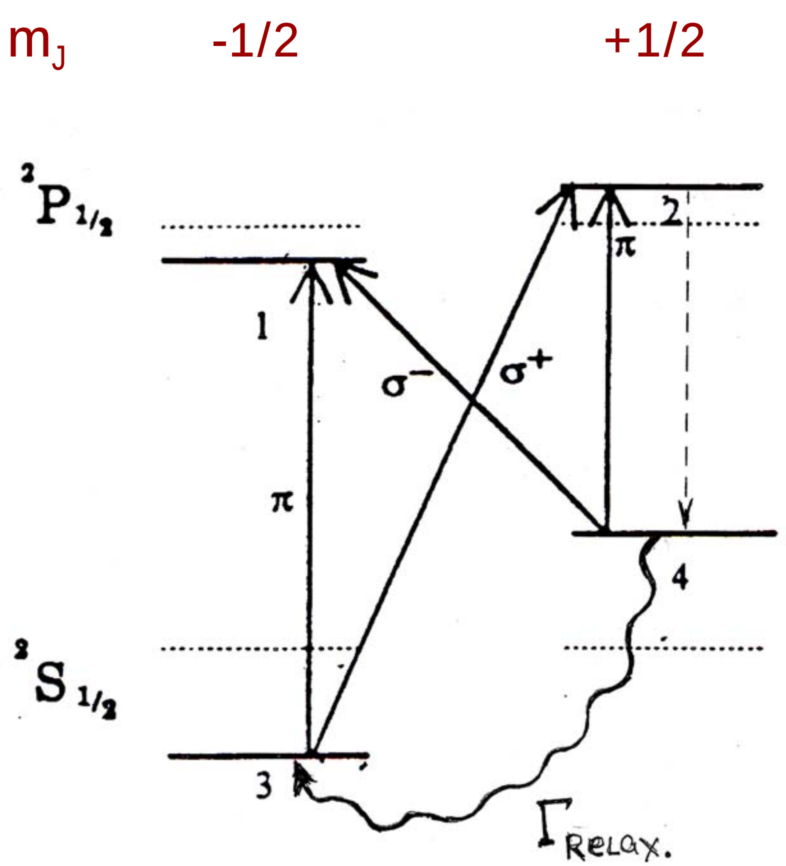
1-quartz liner Ø40 MM; 2- ECR-cavity; 3-three-grid multihole proton extraction system; 4- boron-nitride cups; 5-"Kalrez" O-rings. Longitudinal magnetic field distribution for optimal OPPIS operation.

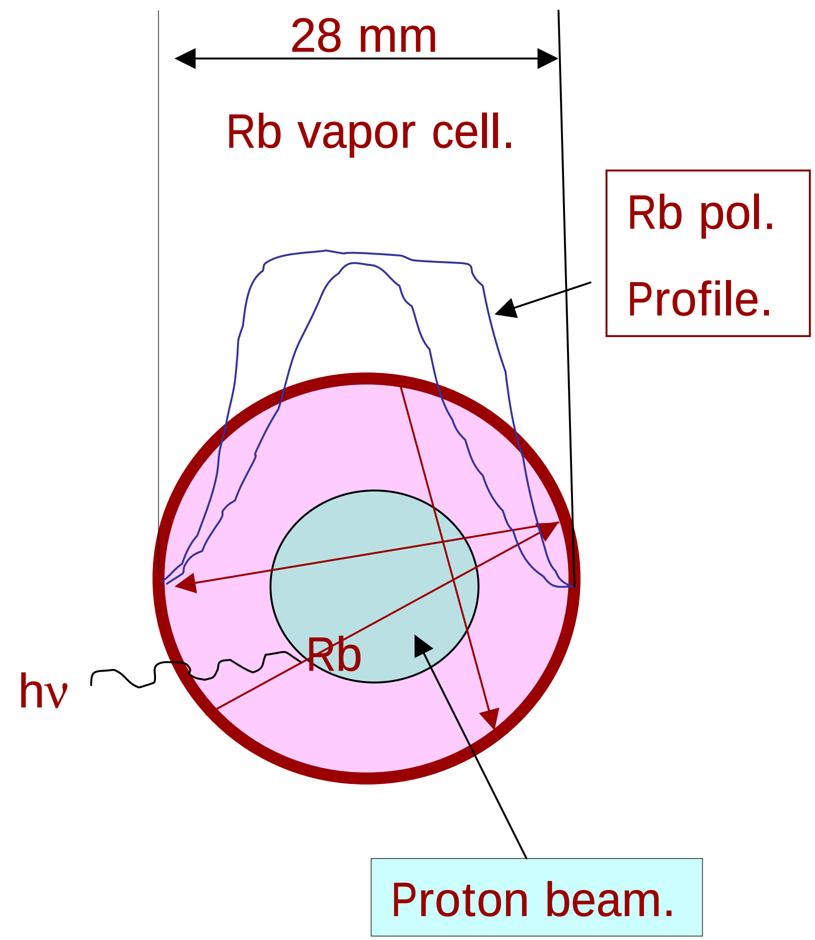
Magnetic field maps for Oxford Instr. and Toshiba solenoids.



Bz -field component at the solenoid axis.

Optical pumping of Rb charge-exchange vapor cell.

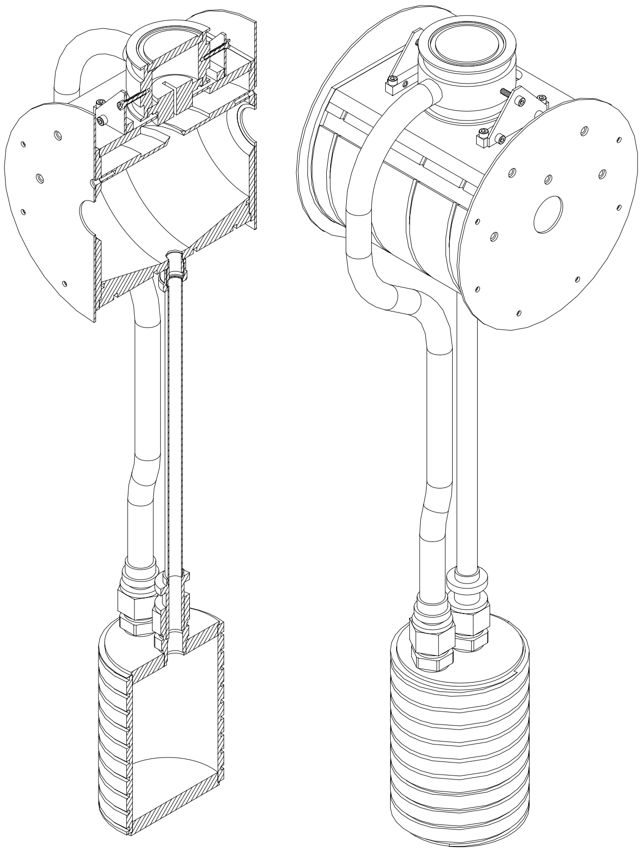


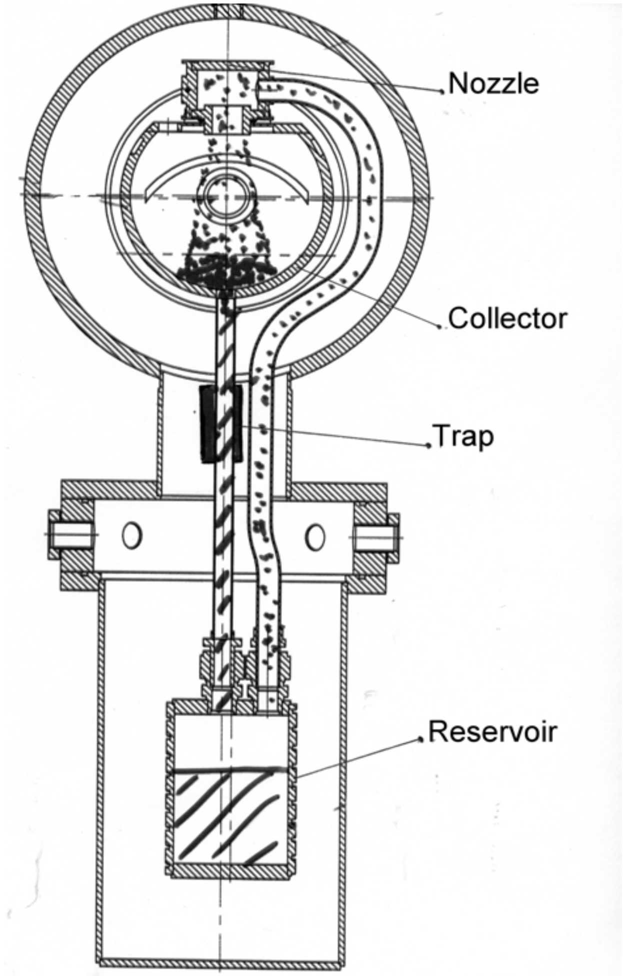


Optical pumping by σ+: $\Delta m_J=1$
Spontaneous radiation: $\Delta m_J=0$, 1.

Sodium-jet ionizer cell.

Transversal vapor flow in the N-jet cell. Reduces sodium vapor losses for 3-4 orders of magnitude, which allow the cell aperture increase up to 3.0 cm .





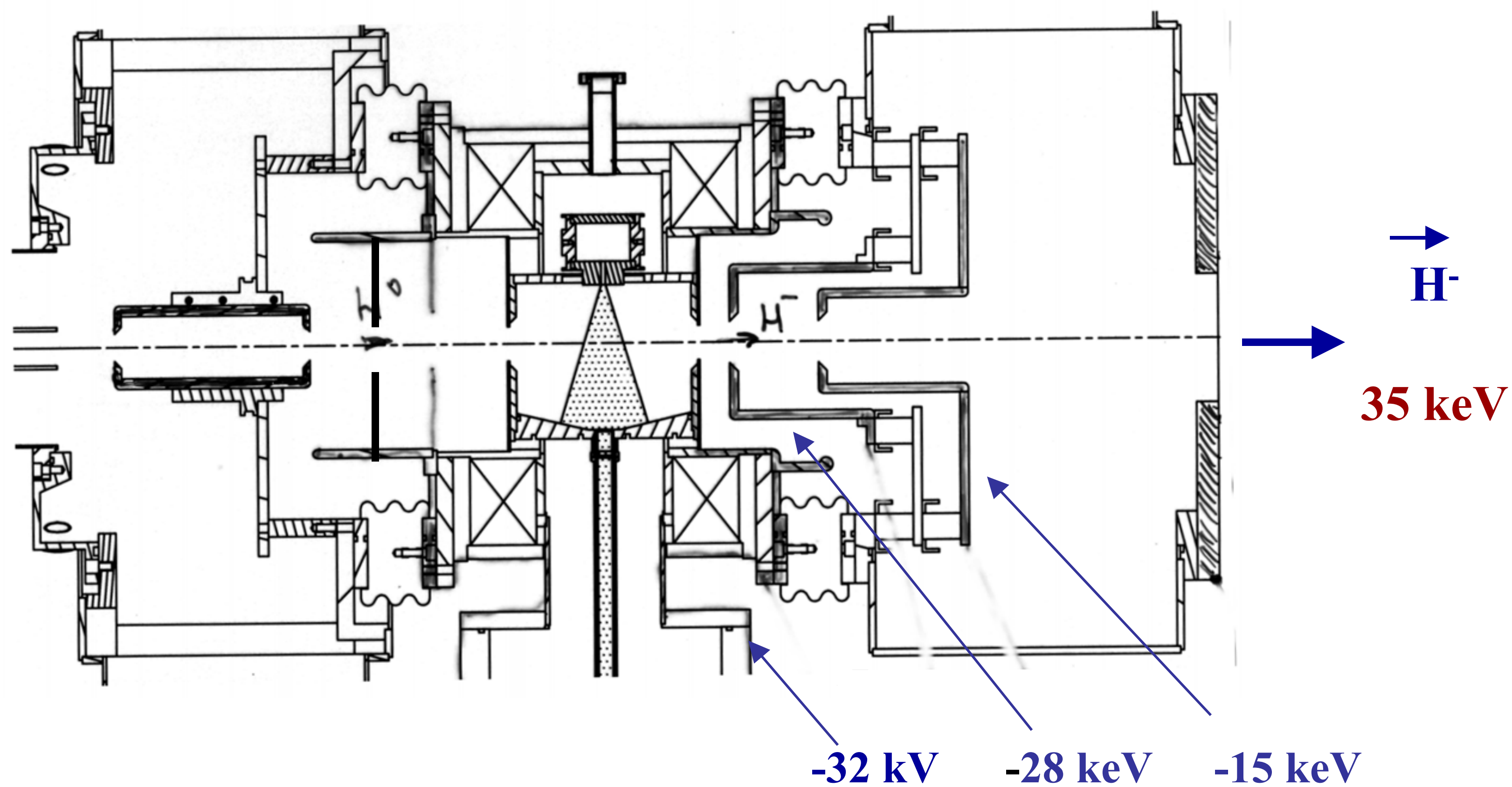
Reservoir– operational temperature. Tres. ~500 ^{o}C.

Nozzle– Tn ~500 ^{o}C.

Collector- Na-vapor condensation: Tcoll.~120^{o}C

Trap- return line. T ~ 120 – 180 ^{o}C.

H^- beam acceleration to 35 keV at the exit of Na-jet ionizer cell.



Na-jet cell is isolated and biased to – 32 keV. The H^- beam is accelerated in a two-stage acceleration system.

Depolarization factors in the OPPIS.

Depol. Factor	Process	Estimate
P_{Rb}	Rb polarization	0.98 - 0.99
S	Rb polarization spatial distribution	0.97 - 0.98
B_{H2}	Proton neutralization in residual gas.	0.94 - 0.97
E_{LS}	Depolarization due to spin-orbital interaction.	0.98 - 0.98
E_S	Sona-transition efficiency	0.96 - 0.99
$E_{ioniz.}$	Incomplete hyperfine interaction breaking in the ionizer magnetic field.	0.95 - 0.98
X	Polarization dilution by molecular hydrogen ions in the ECR source.	1.00 –1.00

$(0.9/0.8)^4$ ~1.6

Total: 0.82 - 0.90

OPPIS operation in Run-2006

- BNL OPPIS reliably delivered polarized H^- ion beam (P= 82-86%) in the 2006 run for the RHIC spin program.
- A beam intensity greatly exceeds RHIC bunch intensity limit, which allowed strong beam collimation in the Booster, to reduce longitudinal and transverse beam emittances.

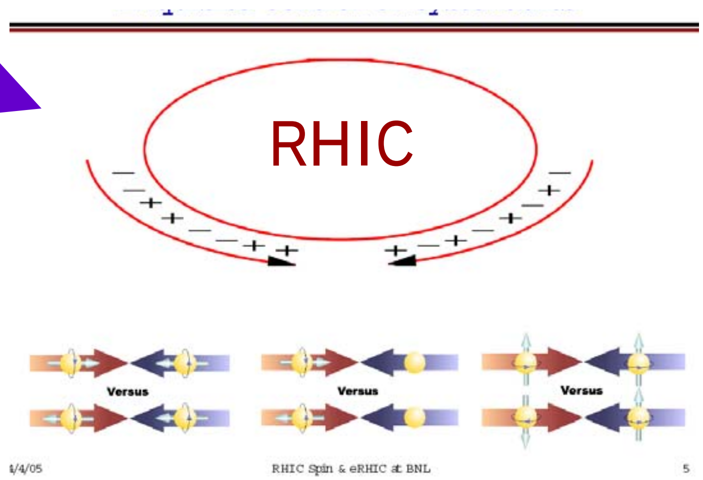
Polarized beams in RHIC.

OPPIS — $10 \cdot 10^{11}$ (maximum $40 \cdot 10^{11}$) polarized H^- /pulse, P =85%

LINAC — $5 \cdot 10^{11}$ polarized H^- /pulse at 200 MeV, P=85%

Booster — $2 \cdot 10^{11}$ polarized protons /pulse at 2.3 GeV

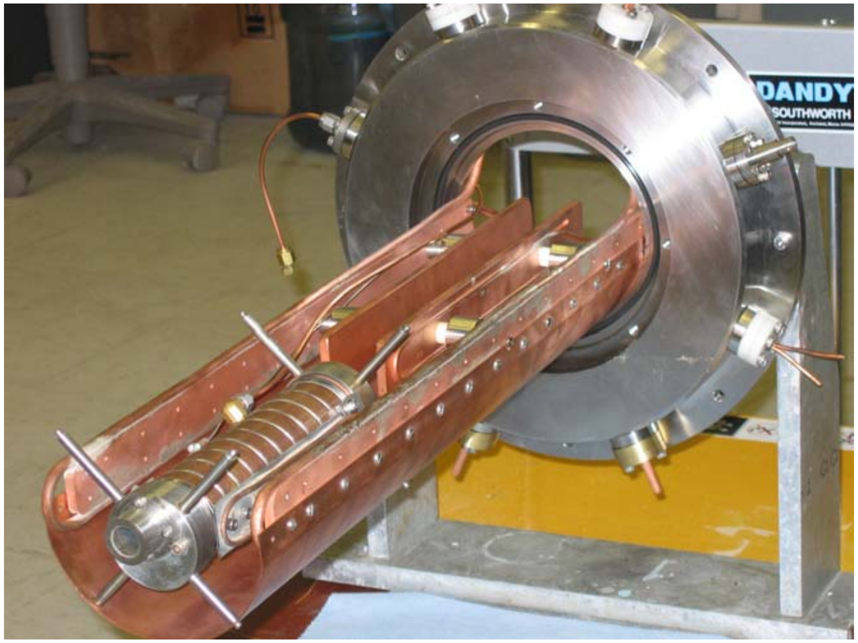
AGS — 1.5-1.7 p/bunch, P ~65-70%

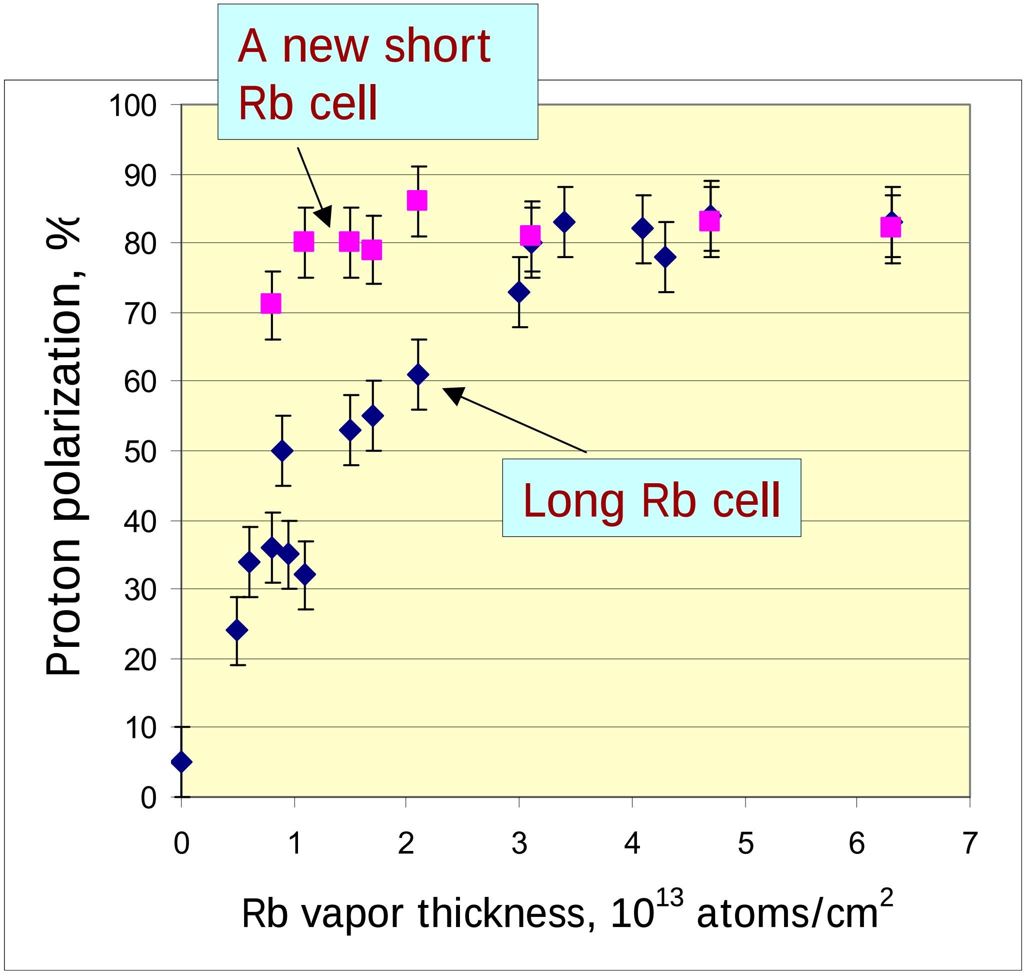


Maximum RHIC bunch intensity ~1.5 10^{11} p/bunch

Polarization -65%

Proton polarization vs. Rb vapor thickness.





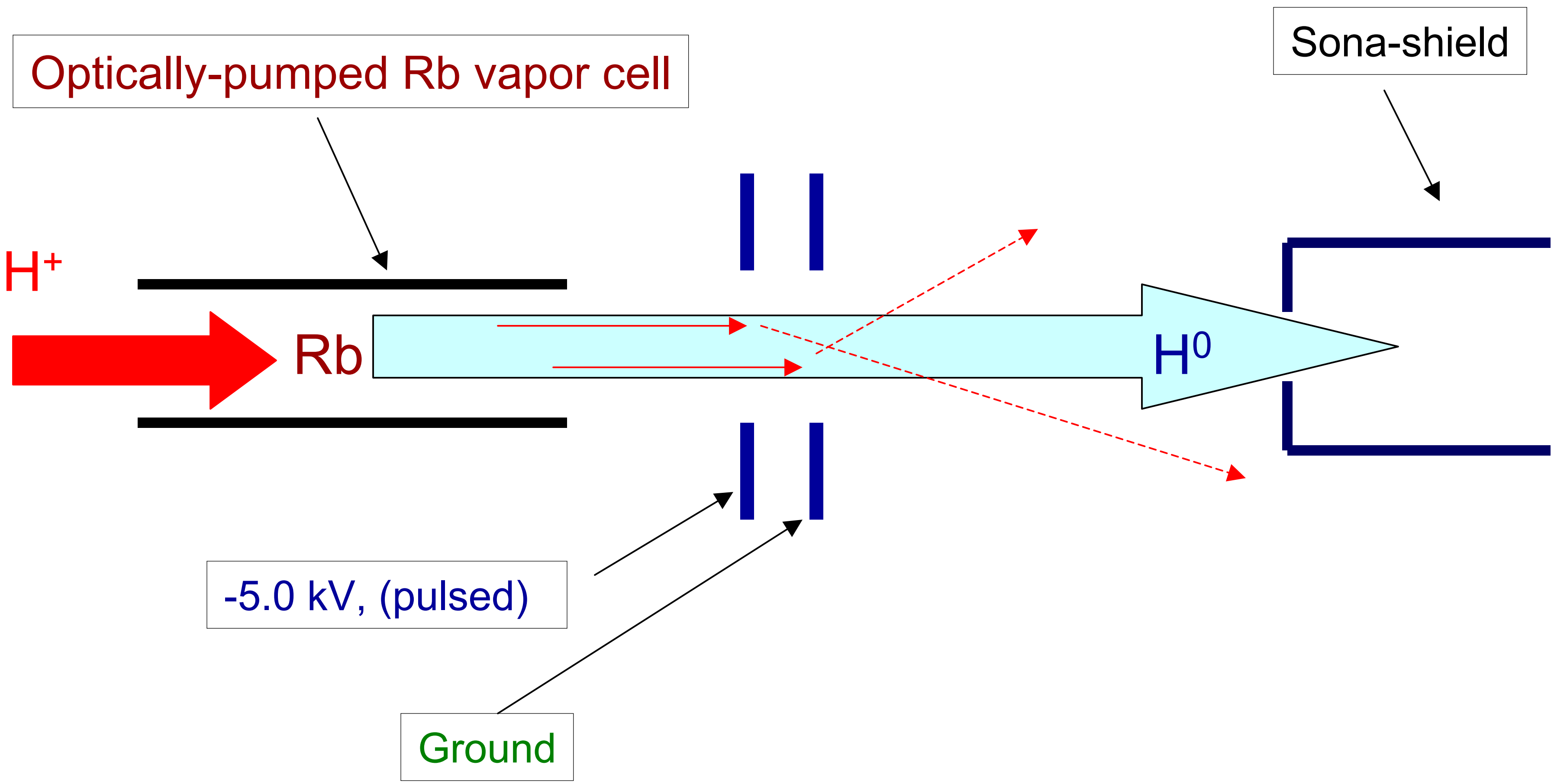
Rb cell upgrades:

A new vacuum chamber.

A new cooling system.

A new deflecting plates.

Longitudinal “deflecting” plates.



Polarization measurement in 200 MeV polarimeter.

	Pol	(%)	dPol	mean_lu	dmean	mean_ru	dmean	mean_ld	dmean	mean_rd	dmean	good_pts
All......:	86.42	+/-	5.47	99.47	8.45	32.79	6.09	31.74	5.45	114.53	9.38	19
4SigmaCut:	86.42	+/-	5.47	99.47	8.45	32.79	6.09	31.74	5.45	114.53	9.38	19
3SigmaCut:	86.42	+/-	5.47	99.47	8.45	32.79	6.09	31.74	5.45	114.53	9.38	19
2SigmaCut:	86.70	+/-	5.60	98.12	7.33	32.24	5.62	31.59	5.76	114.71	9.90	17
1SigmaCut:	86.02	+/-	4.46	97.60	6.88	31.20	4.27	32.40	3.91	111.80	3.63	5

86.7%

32	121.0	30.0	1335.0	0.0	0.9293	2.0	0.0
33	36.0	115.0	0.0	1335.0		1.0	1.0
34	107.0	28.0	1335.0	0.0	0.9078	1	1
35	25.0	120.0	0.0	1336.0		0	
36	90.0	43.0	1335.0	0.0	0.8357	1	
37	33.0	111.0	0.0	1335.0		0	
38	104.0	45.0	1336.0	0.0	0.7581	1	
39	29.0	148.0	0.0	1335.0		0	

200 μA× 400 μs pulse at 200 MeV

~ $4.8 \cdot 10^{11}$ H^-/pulse

AVERAGING INTERVAL — 5

HISTOGRAM — GET HISTOGRAM

ANALYSIS — ANALYZE

86.4%

Left arm events (+,-):	1922 - 32	608 - 5	96.1 - 1.6	32.0 - 0.2632
Right arm events(+,-):	624 - 1	2183 - 7	31.2 - 0.05	114.9 - 0.3684

POLARIZATION (P,dP): 0.8643 0.01874 AVE POL(LAST 100) (P,dP): 0.865 0.08891

RIGHT(SINGLE) POLARIZATION (P,dP): -0.8958 0.02207

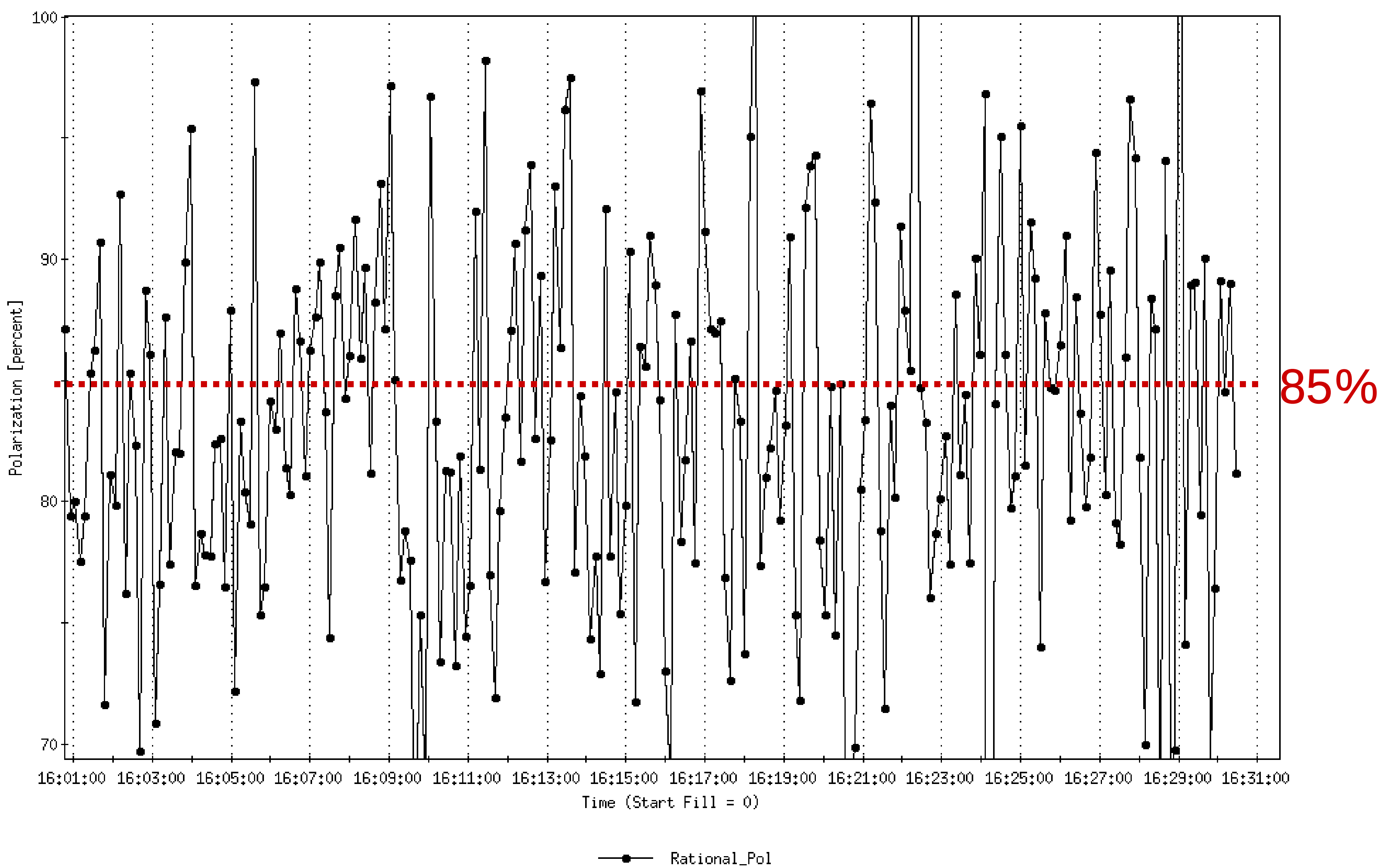
LEFT(SINGLE) POLARIZATION (P,dP): 0.8377 0.01316

POLARIZATION (L/R) (P,dP): 0.8326 0.0003489

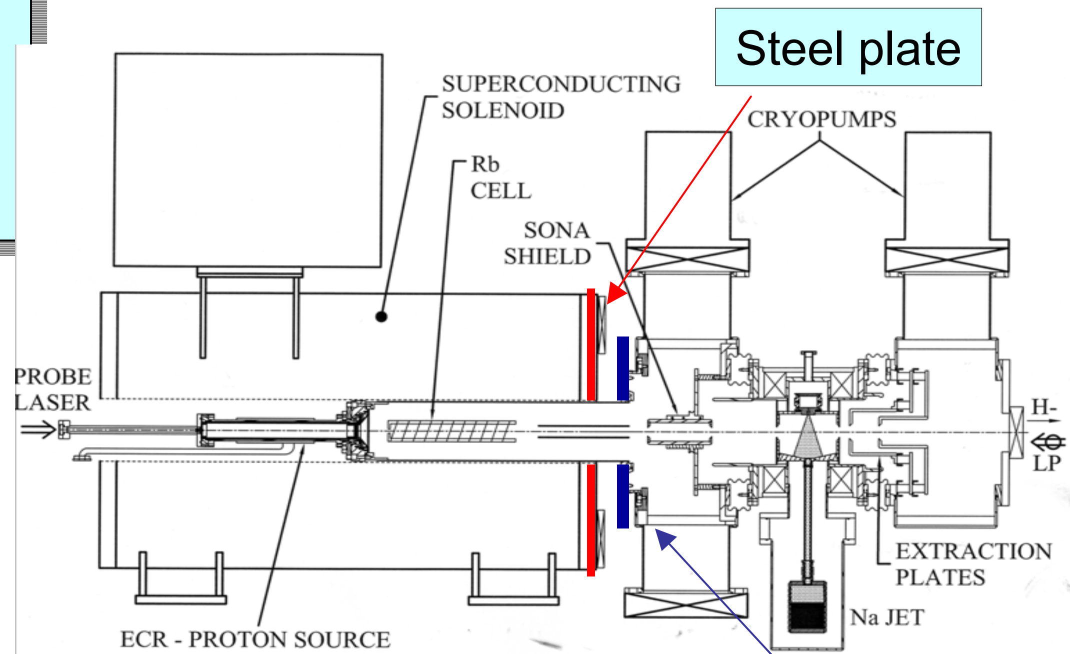
RESTART

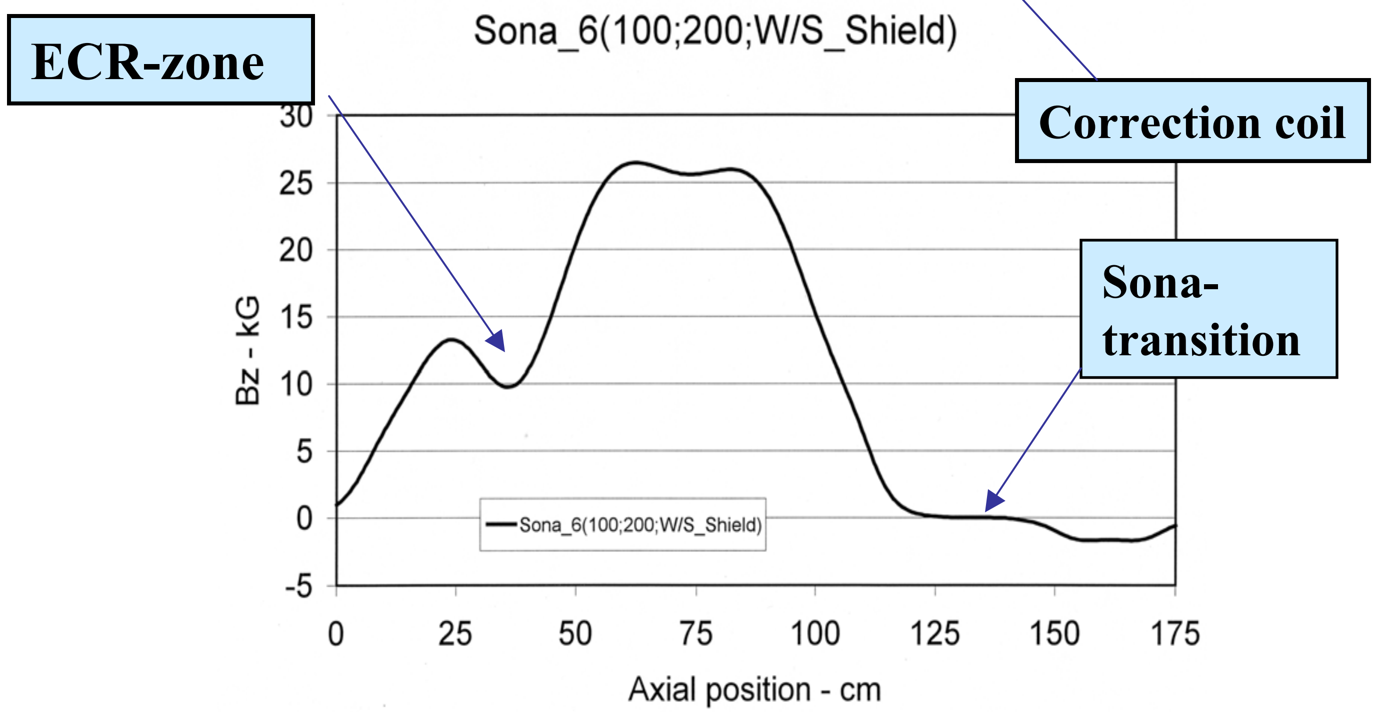
Thu Mar 02 12:28:38 PM EST 2006

Polarization measurements in 200 MeV polarimeter.



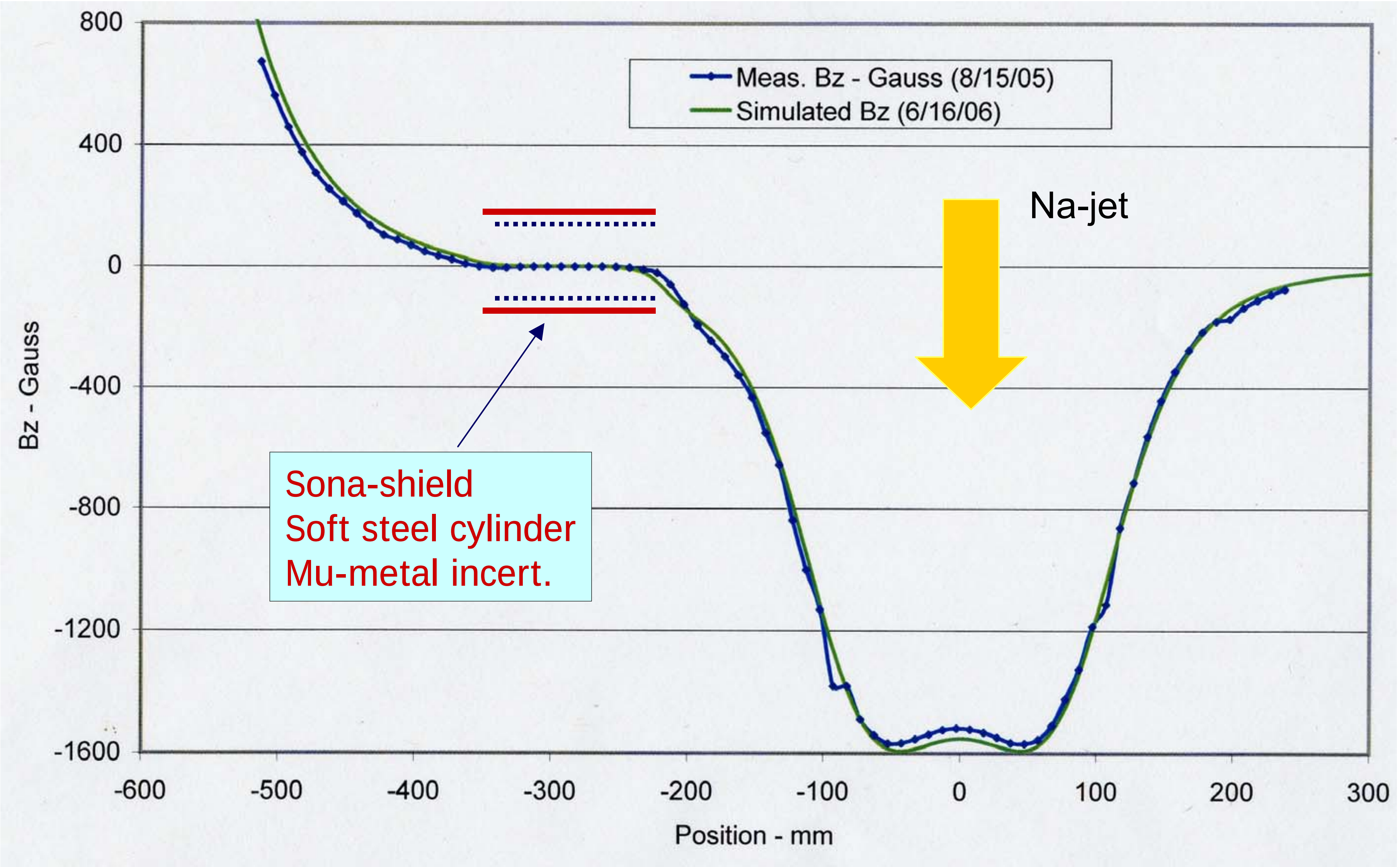
Polarization transfer from electrons to protons.



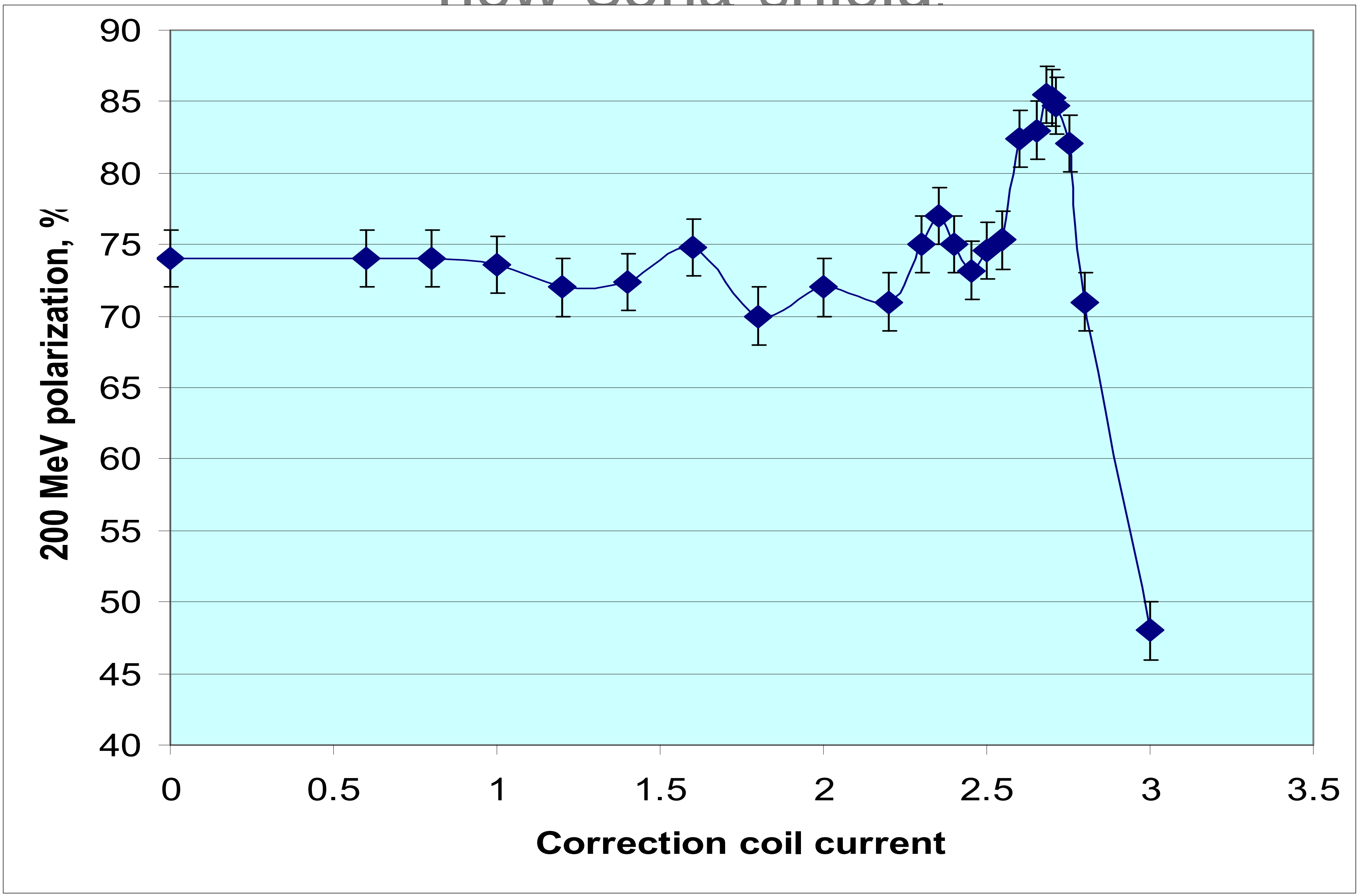


Bz-field component in the Sona-transition region.

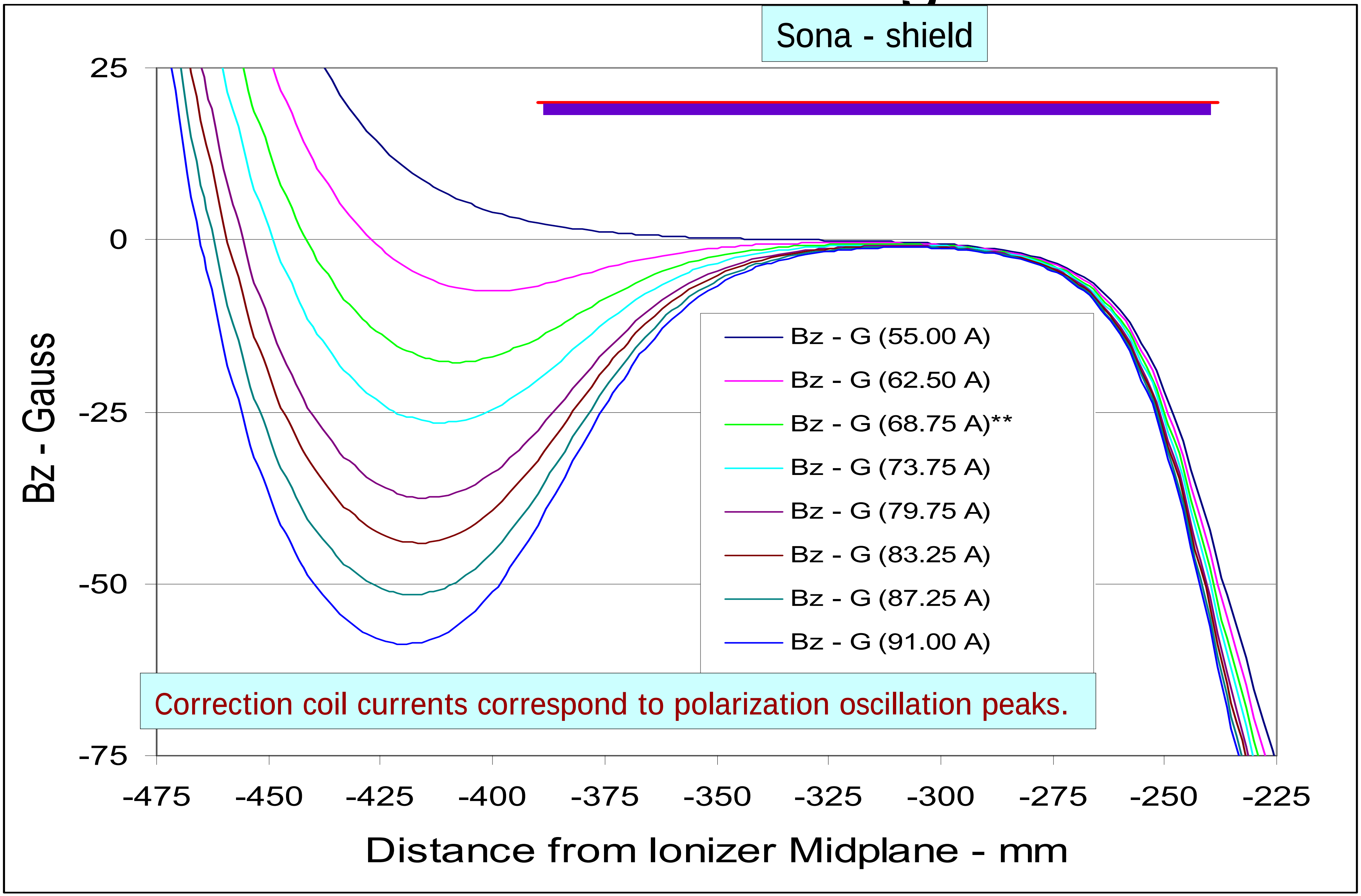
Multiple charge-exchange: $H^0 \rightarrow H^- \rightarrow H^0 \rightarrow H^-$



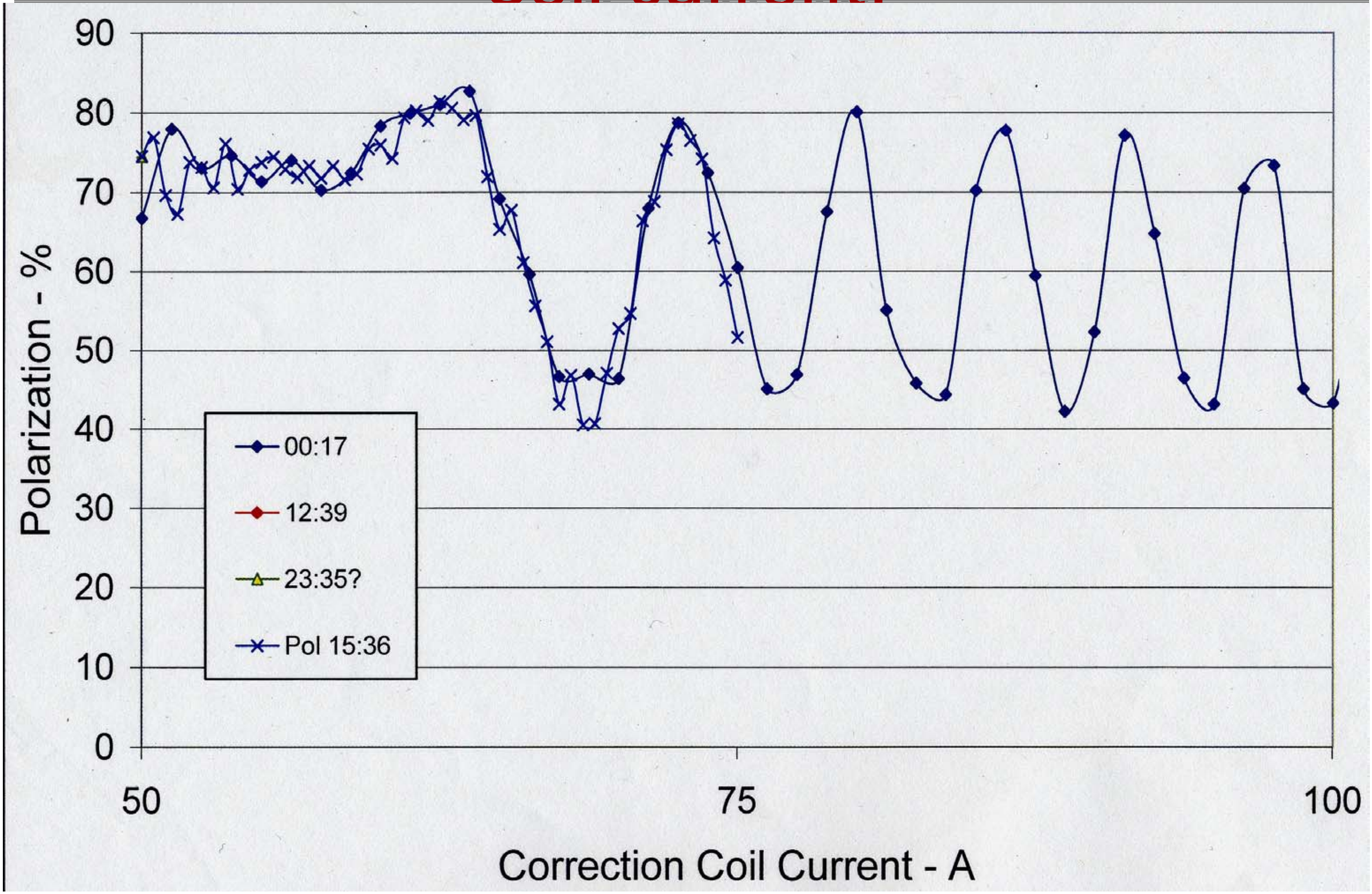
Polarization vs Correction Coil current with a new Sona-shield.



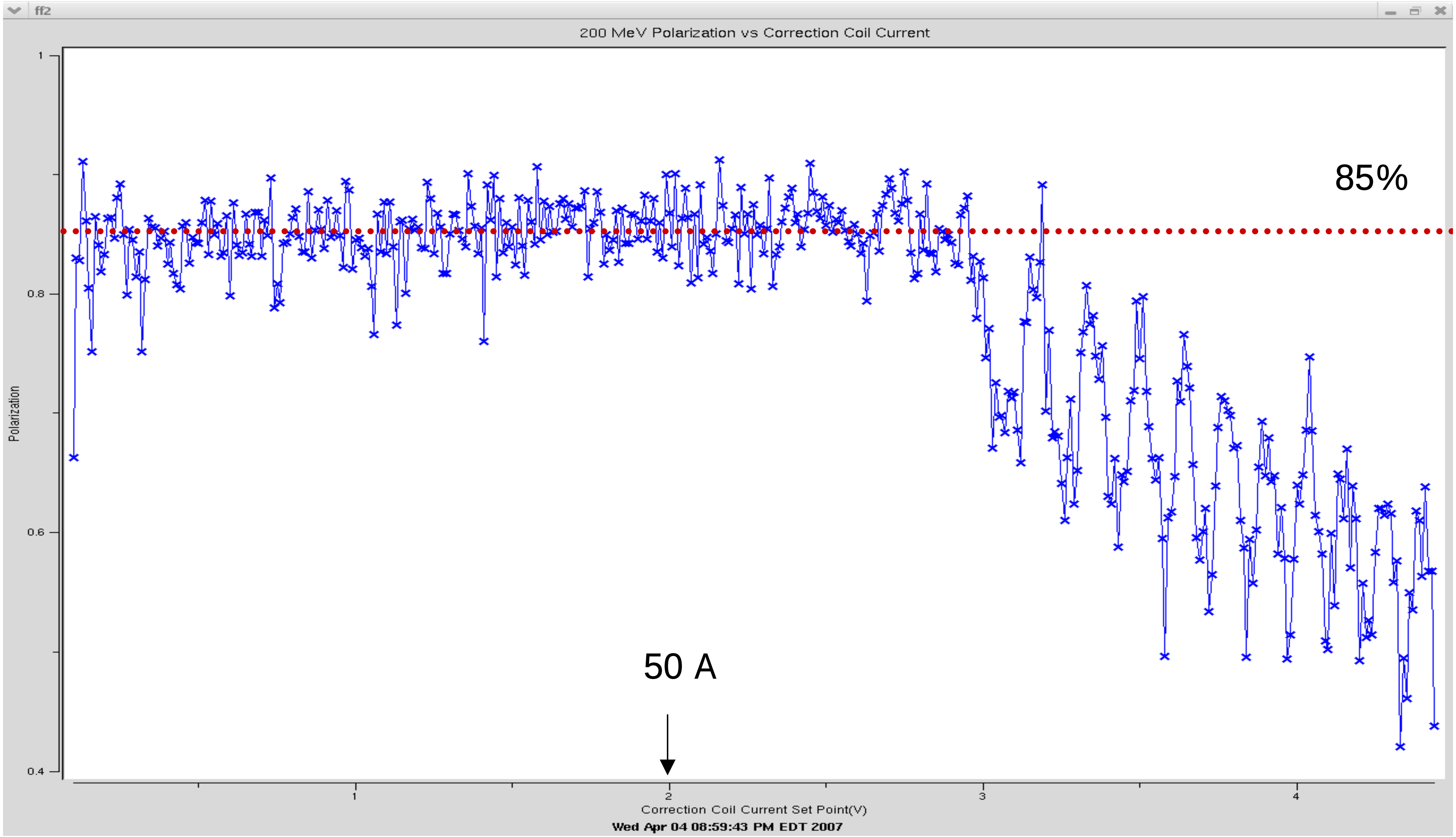
Calculated magnetic field profiles in the Sona transition region.



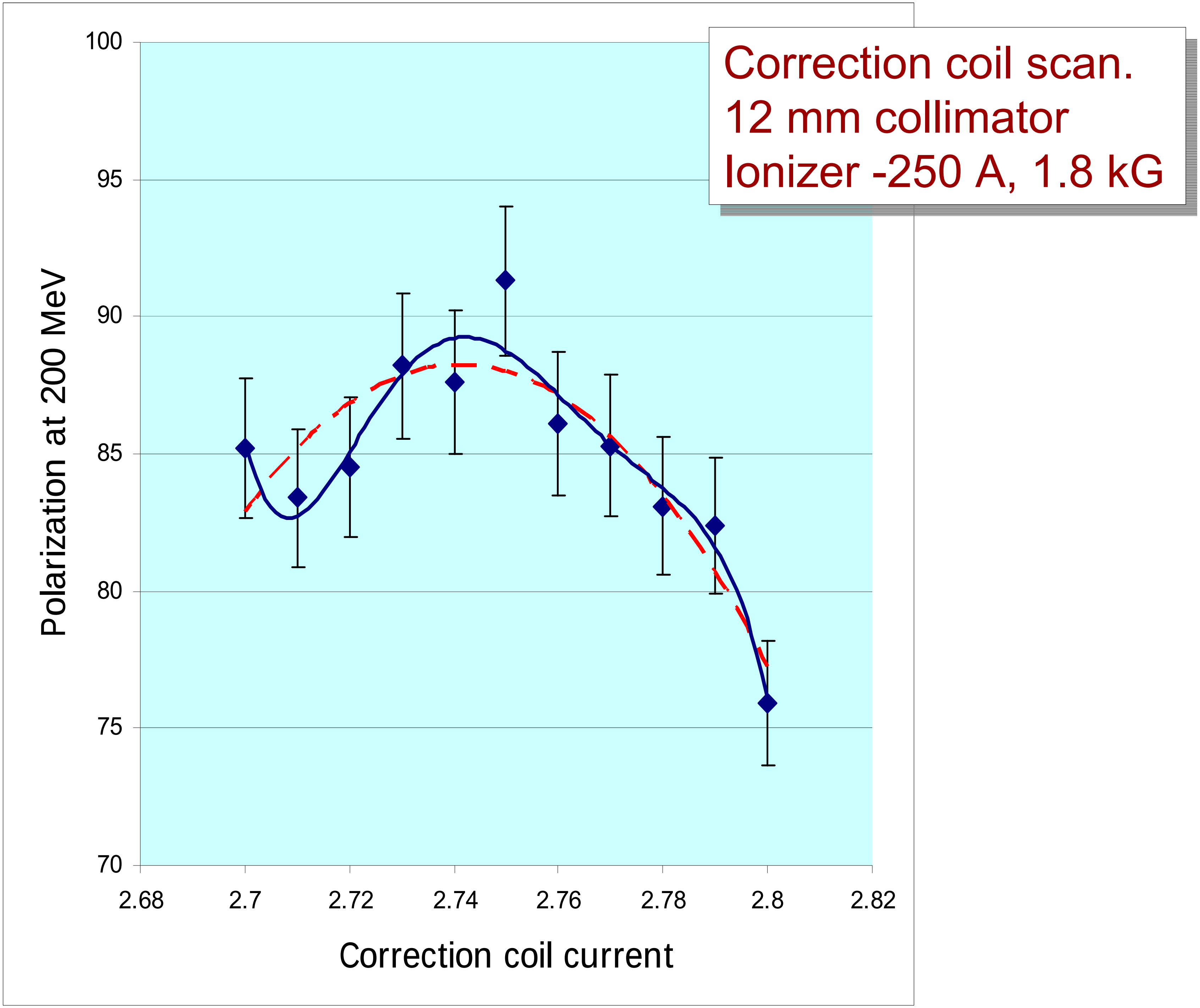
Polarization oscillations vs. Correction Coil current.



Polarization oscillations in the Sona-transition.



Polarization at 200 MeV vs. Correction Coil current



Correction coil scan.
12 mm collimator
Ionizer -250 A, 1.8 kG
Polarization at 200 MeV
100
95
90
85
80
75
70
2.68
2.7
2.72
2.74
2.76
2.78
2.8
2.82
Correction coil current

Polarization vs. ionizer solenoid current with the 12mm collimator.

Maximum polarization from the correction coil scans, collim. -12 mm.

160 A ↔1.16 kG, 81.6% (95.9%)

200 A ↔1.45 kG, 84.9% (97.0%)

250 A ↔1.81 kG , 88.1% (98.1%)

Theoretical limit

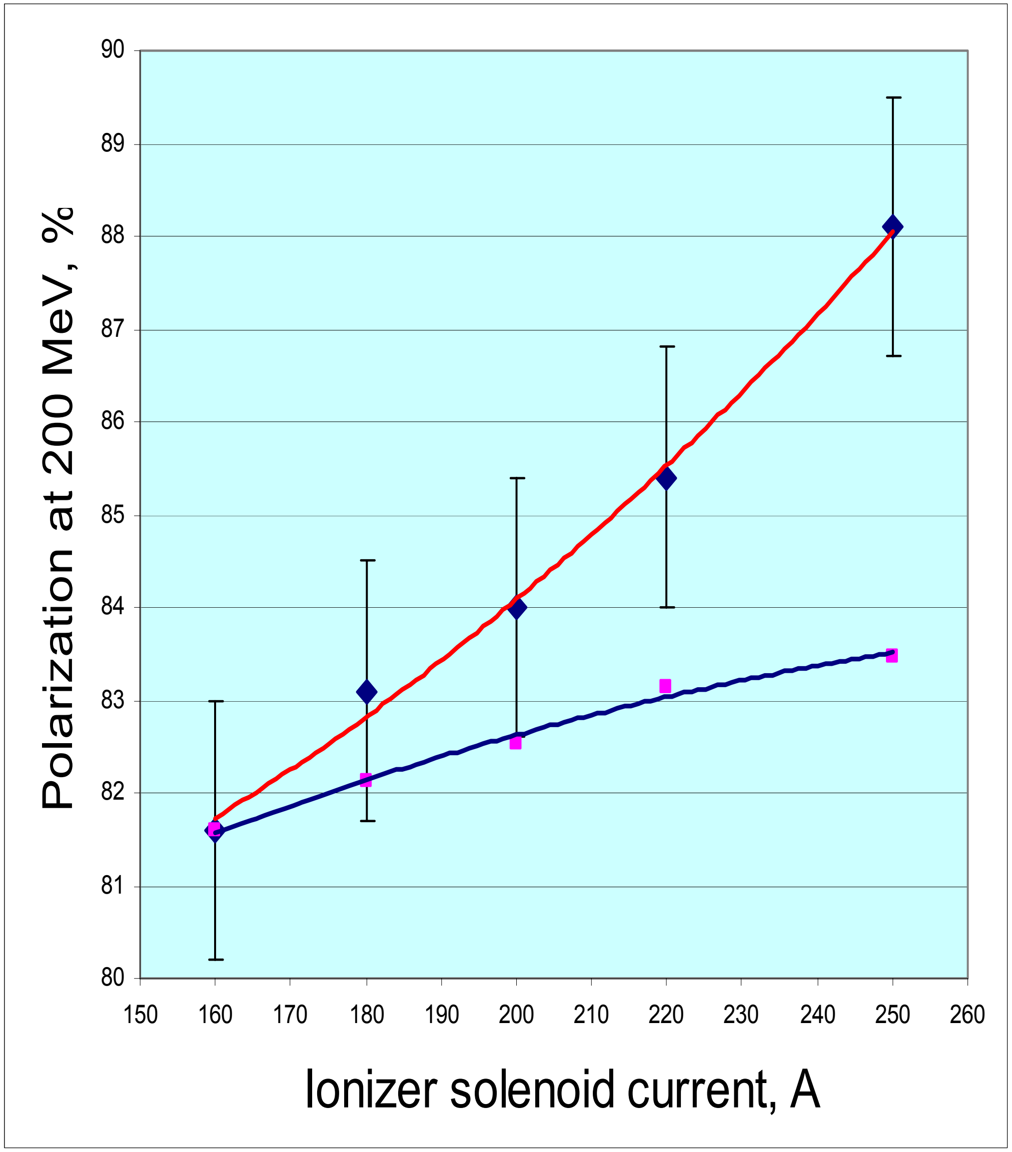
23 mm collimator.

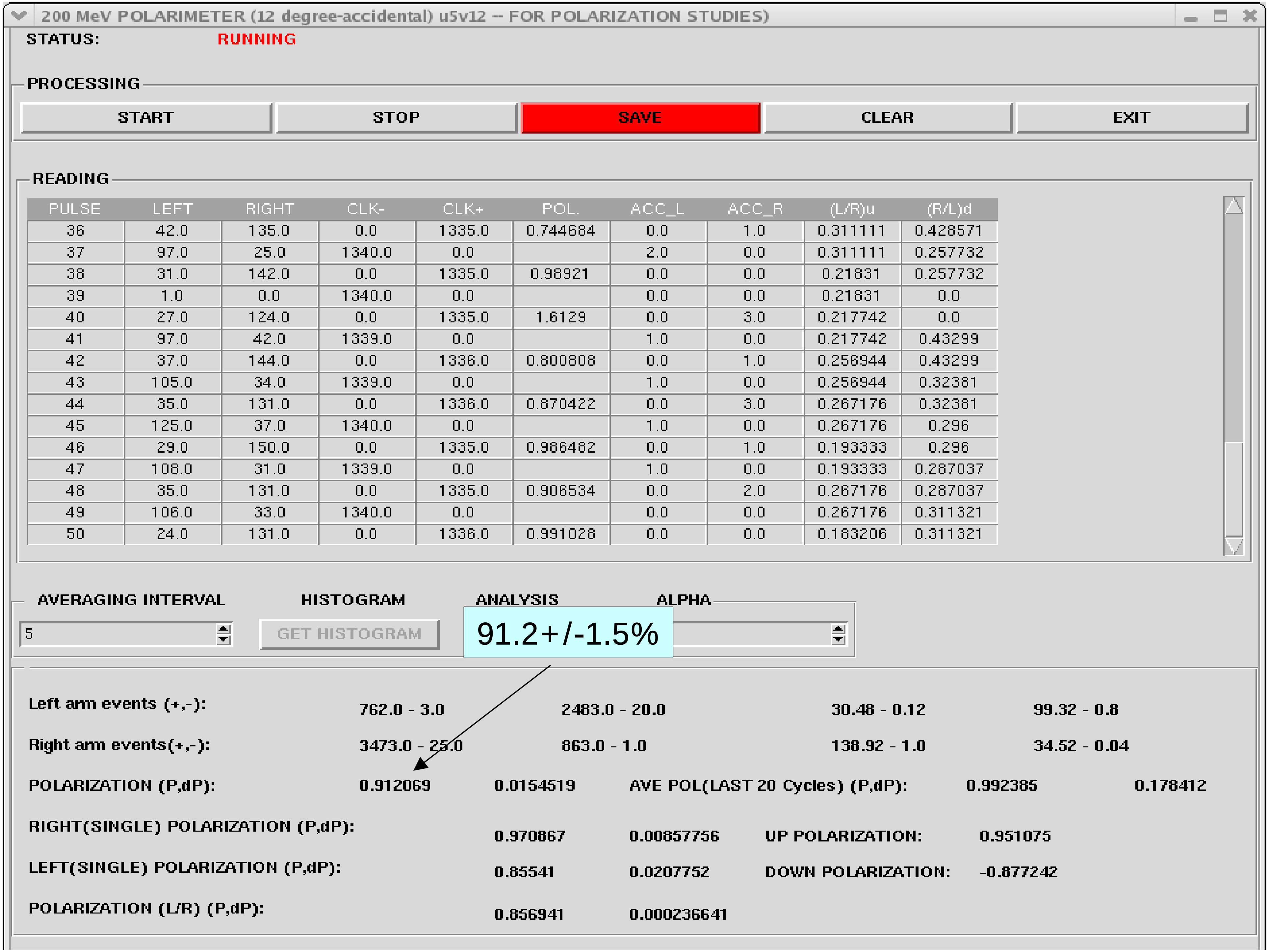
200 A ↔1.45 kG, 82.5% (97.0%)

250 A ↔1.81 kG , 84.5% (98.1%)

A new ionizer solenoid:

250 A ↔1.98 kG , 90.0% (98.4%)





200 MeV POLARIMETER (12 degree-accidental) u5v12 -- FOR POLARIZATION STUDIES)

STATUS: RUNNING

PROCESSING

START | STOP | SAVE | CLEAR | EXIT

READING

PULSE	LEFT	RIGHT	CLK-	CLK+	POL.	ACC_L	ACC_R	(L/R)u	(R/L)d
36	42.0	135.0	0.0	1335.0	0.744684	0.0	1.0	0.311111	0.428571
37	97.0	25.0	1340.0	0.0		2.0	0.0	0.311111	0.257732
38	31.0	142.0	0.0	1335.0	0.98921	0.0	0.0	0.21831	0.257732
39	1.0	0.0	1340.0	0.0		0.0	0.0	0.21831	0.0
40	27.0	124.0	0.0	1335.0	1.6129	0.0	3.0	0.217742	0.0
41	97.0	42.0	1339.0	0.0		1.0	0.0	0.217742	0.43299
42	37.0	144.0	0.0	1336.0	0.800808	0.0	1.0	0.256944	0.43299
43	105.0	34.0	1339.0	0.0		1.0	0.0	0.256944	0.32381
44	35.0	131.0	0.0	1336.0	0.870422	0.0	3.0	0.267176	0.32381
45	125.0	37.0	1340.0	0.0		1.0	0.0	0.267176	0.296
46	29.0	150.0	0.0	1335.0	0.986482	0.0	1.0	0.193333	0.296
47	108.0	31.0	1339.0	0.0		1.0	0.0	0.193333	0.287037
48	35.0	131.0	0.0	1335.0	0.906534	0.0	2.0	0.267176	0.287037
49	106.0	33.0	1340.0	0.0		0.0	0.0	0.267176	0.311321
50	24.0	131.0	0.0	1336.0	0.991028	0.0	0.0	0.183206	0.311321

AVERAGING INTERVAL: 5

HISTOGRAM: GET HISTOGRAM

ANALYSIS

ALPHA

91.2+/-1.5%

Left arm events (+,-): 762.0 - 3.0 | 2483.0 - 20.0 | 30.48 - 0.12 | 99.32 - 0.8

Right arm events(+,-): 3473.0 - 25.0 | 863.0 - 1.0 | 138.92 - 1.0 | 34.52 - 0.04

POLARIZATION (P,dP): 0.912069 | 0.0154519

AVE POL(LAST 20 Cycles) (P,dP): 0.992385 | 0.178412

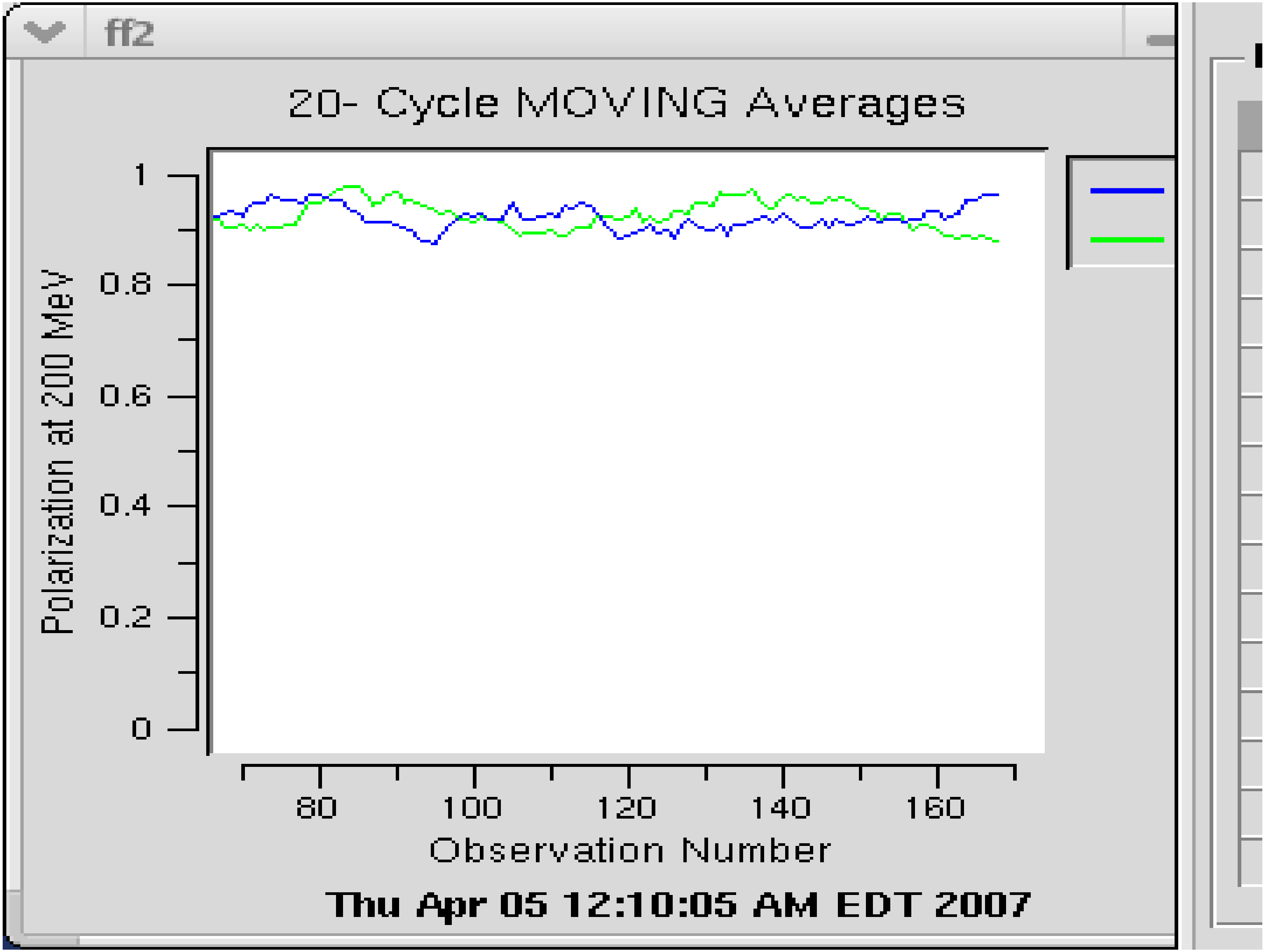
RIGHT(SINGLE) POLARIZATION (P,dP): 0.970867 | 0.00857756

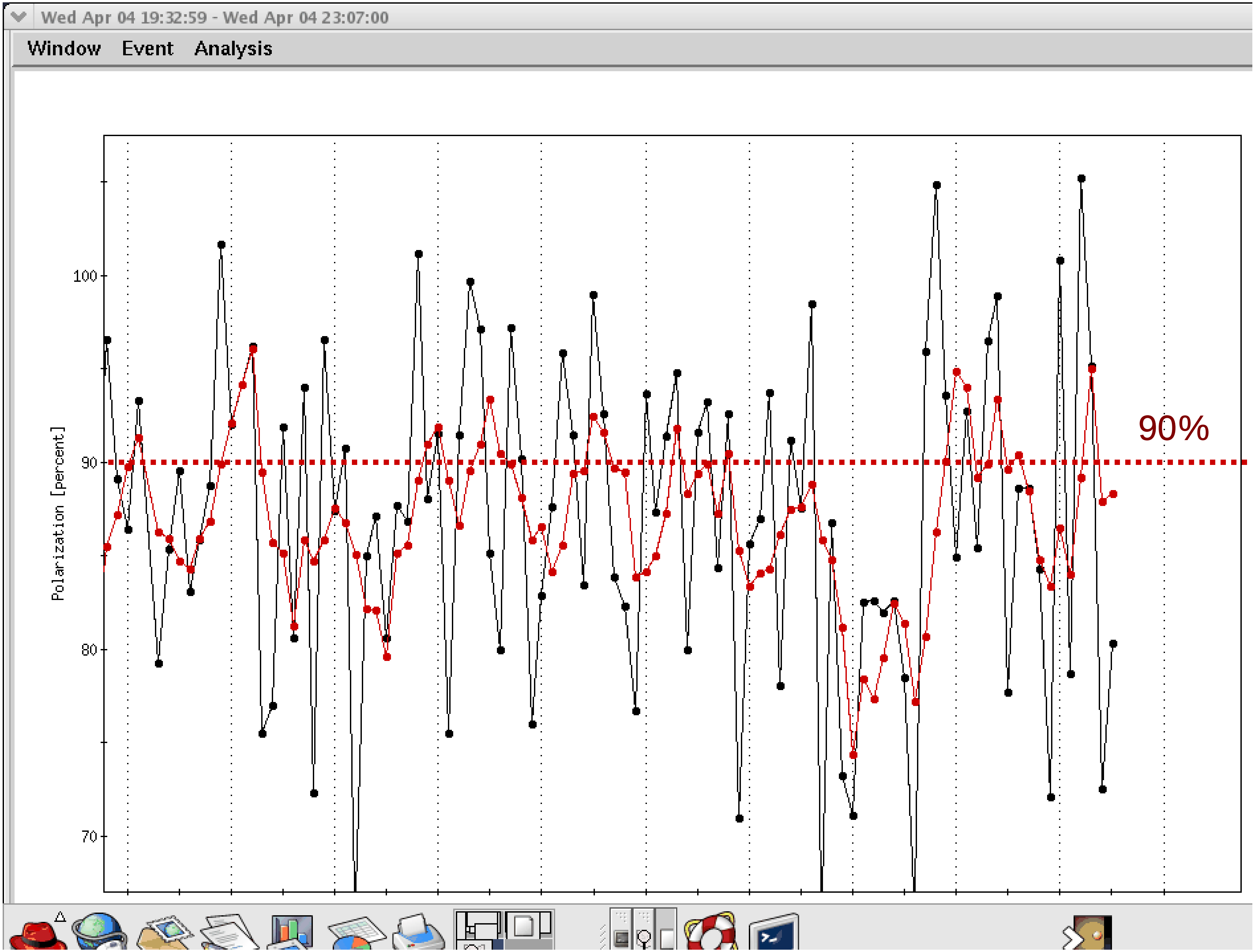
UP POLARIZATION: 0.951075

LEFT(SINGLE) POLARIZATION (P,dP): 0.85541 | 0.0207752

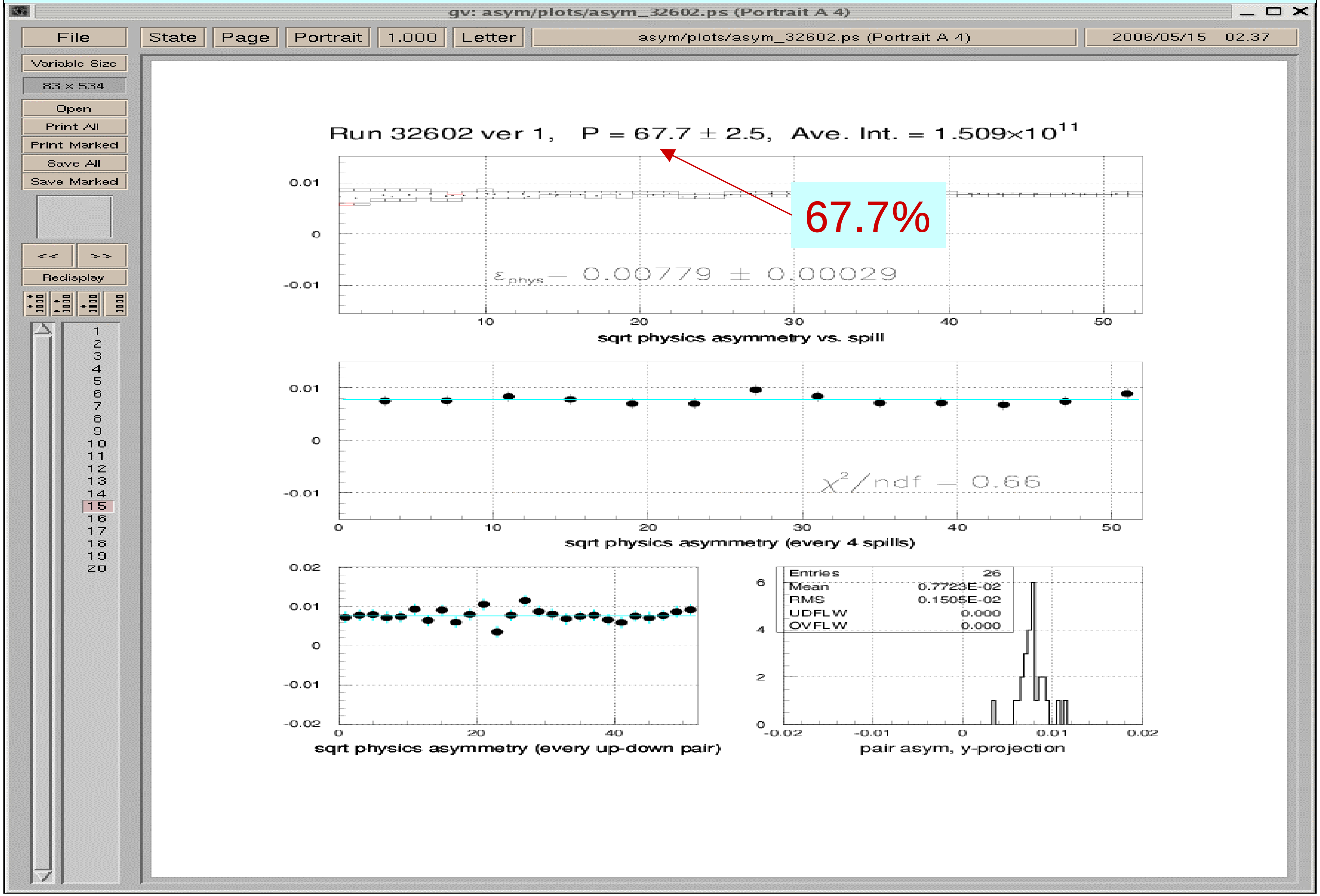
DOWN POLARIZATION: -0.877242

POLARIZATION (L/R) (P,dP): 0.856941 | 0.000236641

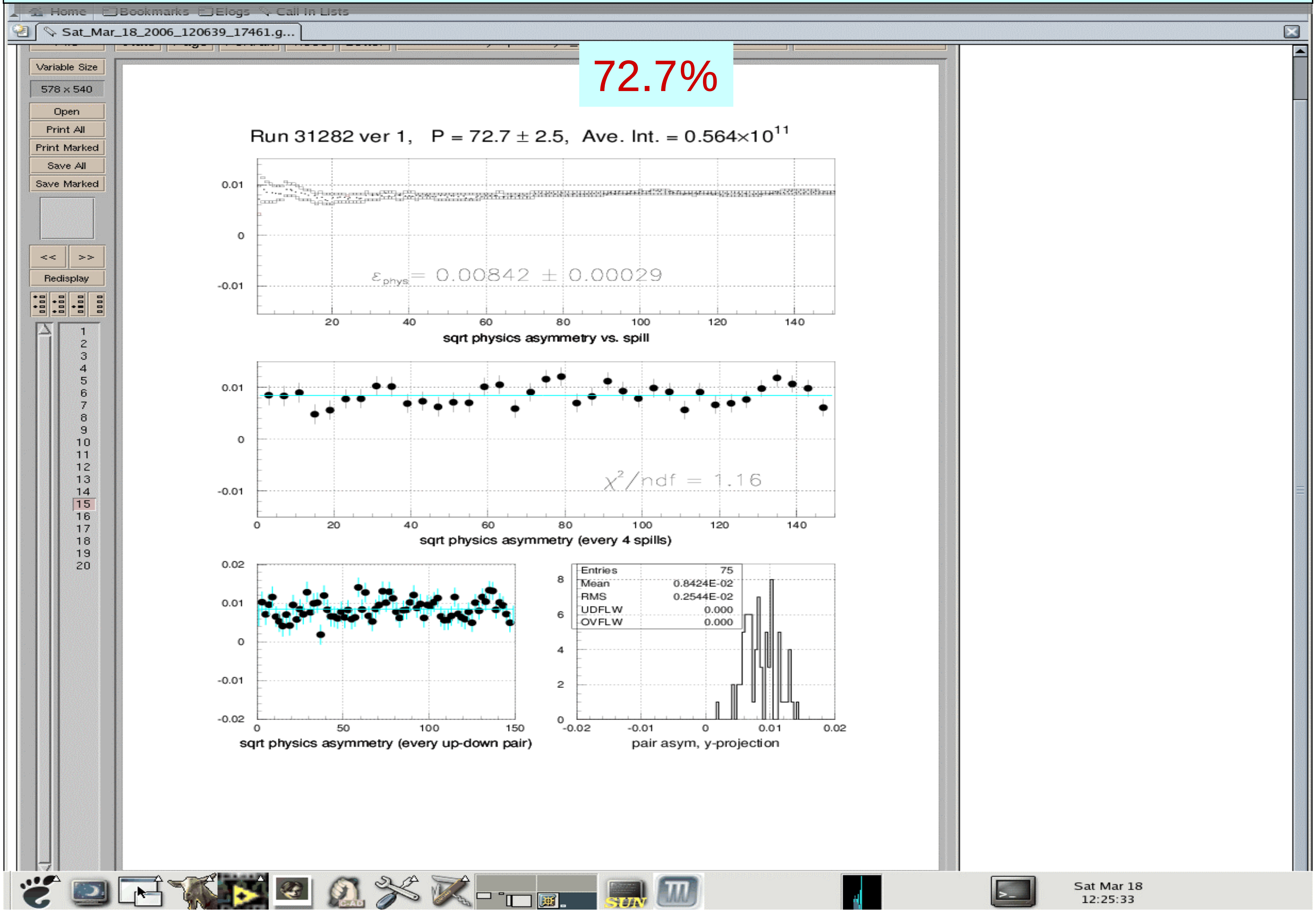

ff2
20- Cycle MOVING Averages
Polarization at 200 MeV
1
0.8
0.6
0.4
0.2
0
80
100
120
140
160
Observation Number
Thu Apr 05 12:10:05 AM EDT 2007


Wed Apr 04 19:32:59 - Wed Apr 04 23:07:00
Window
Event
Analysis
Polarization [percent]
100
90
80
70
90%

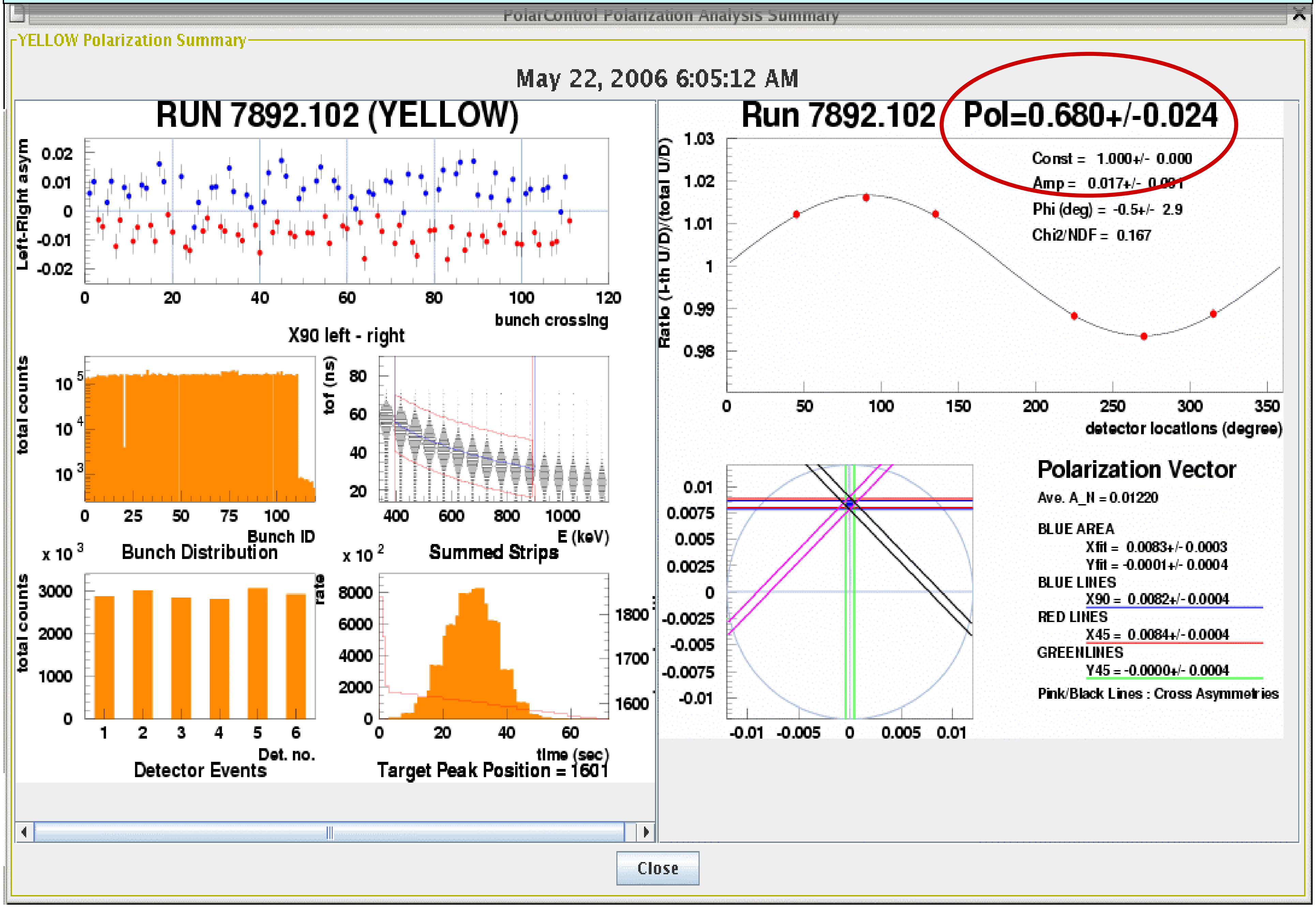
Polarization measurement in AGS, Run 06.



Polarization measurement in AGS at 24 GeV, Run 06.



Polarization measurements in RHIC at 100 GeV.



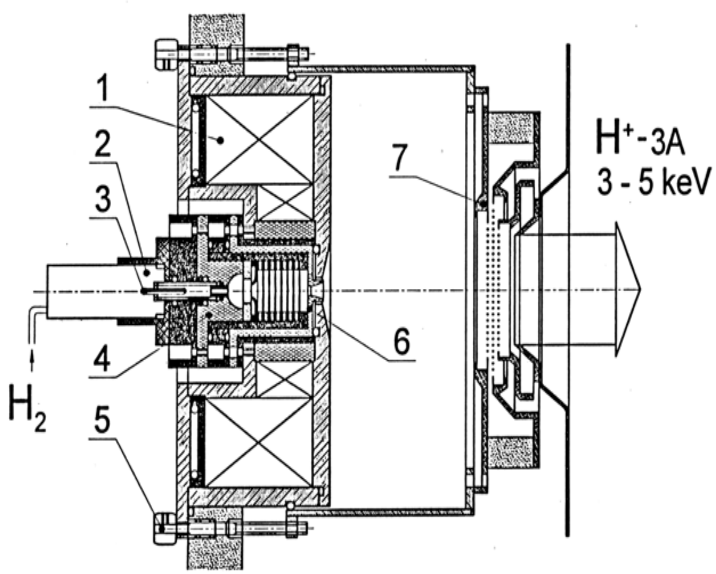
OPPIS with the "Fast Atomic Hydrogen Source"

- The ECR source has a comparatively low emission current density and high beam divergence. This limits further current increase and gives rise to inefficient use of the available laser power for optical pumping.

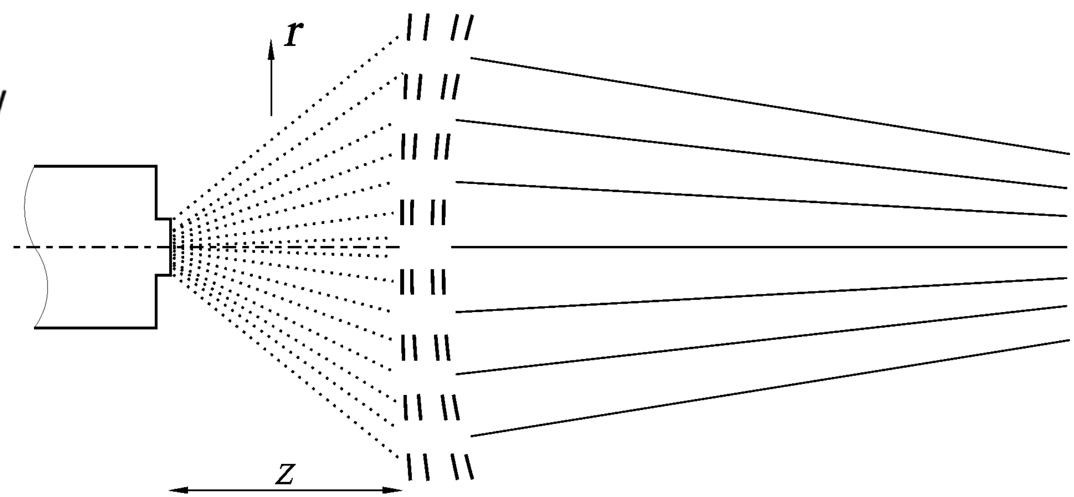
- In pulsed operation, suitable for application at high-energy accelerators and colliders, the ECR source limitations can be overcome by using instead a high brightness proton source outside the magnetic field.

- Atomic hydrogen beam current densities greater than 100 mA/cm^2 can be obtained at the Na jet ionizer location (about 180 cm from the source) by using a very high brightness fast atomic beam source developed at BINP, Novosibirsk, and tested in experiments at TRIUMF, where more than 10 mA polarized H^- and 50 mA proton beam intensity was demonstrated.

Proton “cannon” of the atomic H injector.

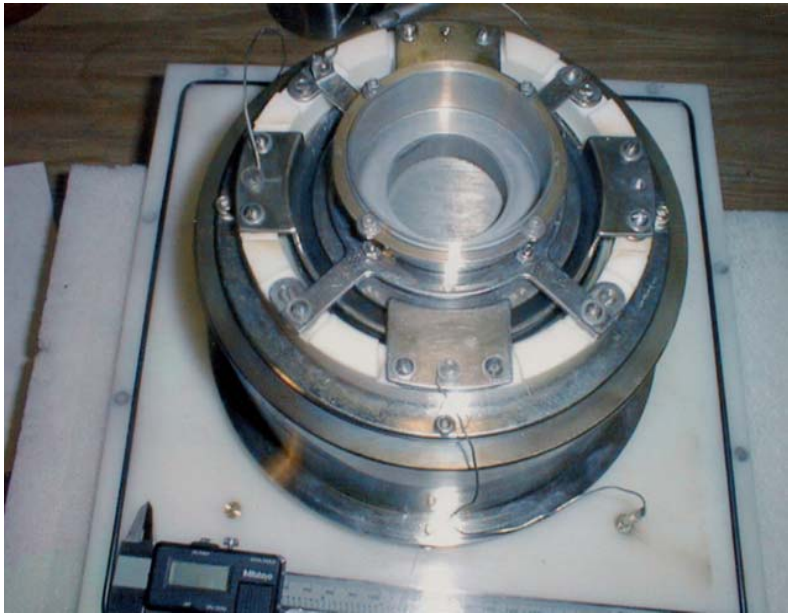


Ion Optical System with “geometrical focusing”.

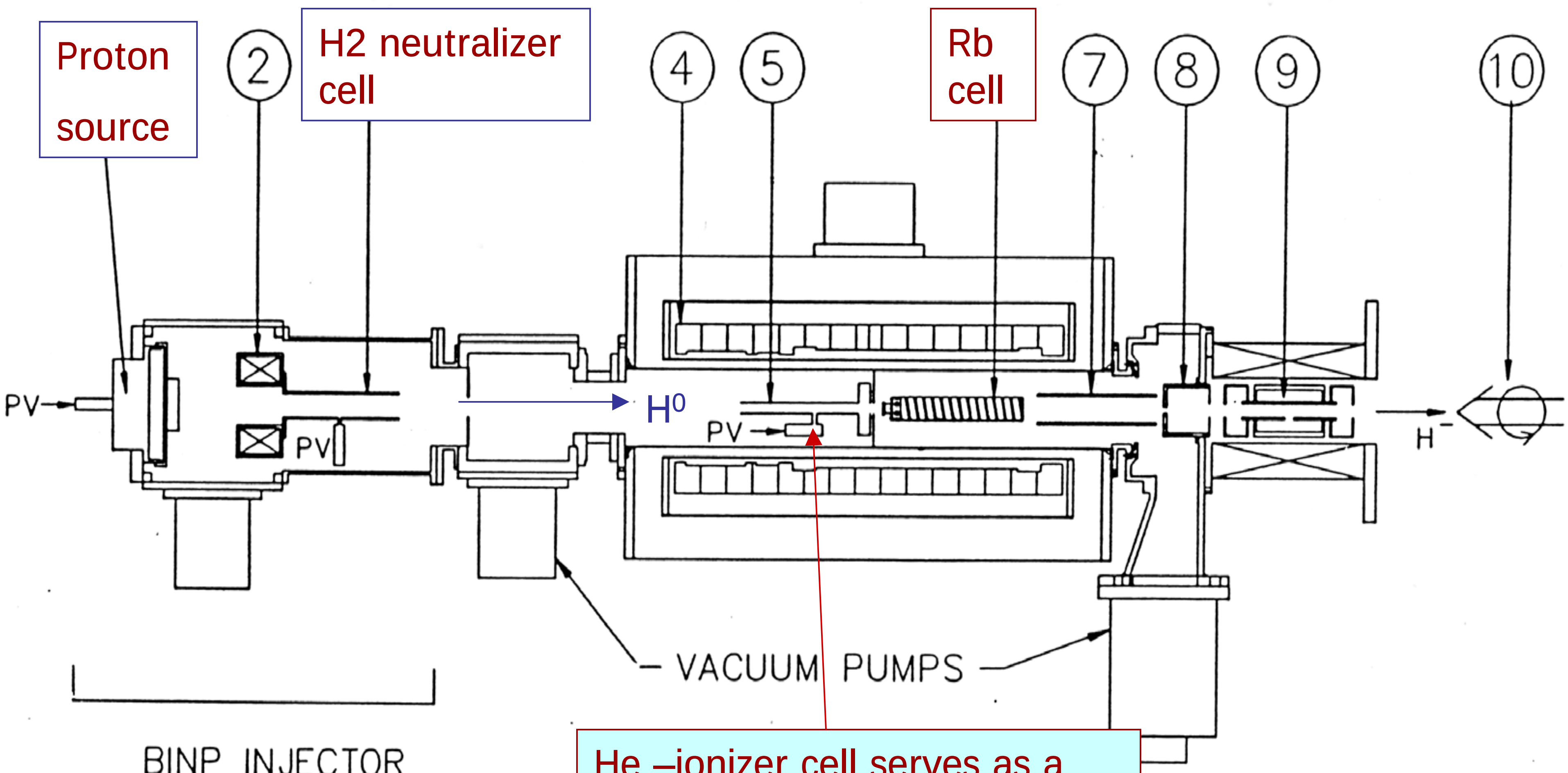


The source produced 3 A ! pulsed proton current at 5.0 keV.

~20-50 mA H^- current. P=75-80%
~10 mA , P ≥ 90%.
~ 300 mA unpolarized H^- ion current.

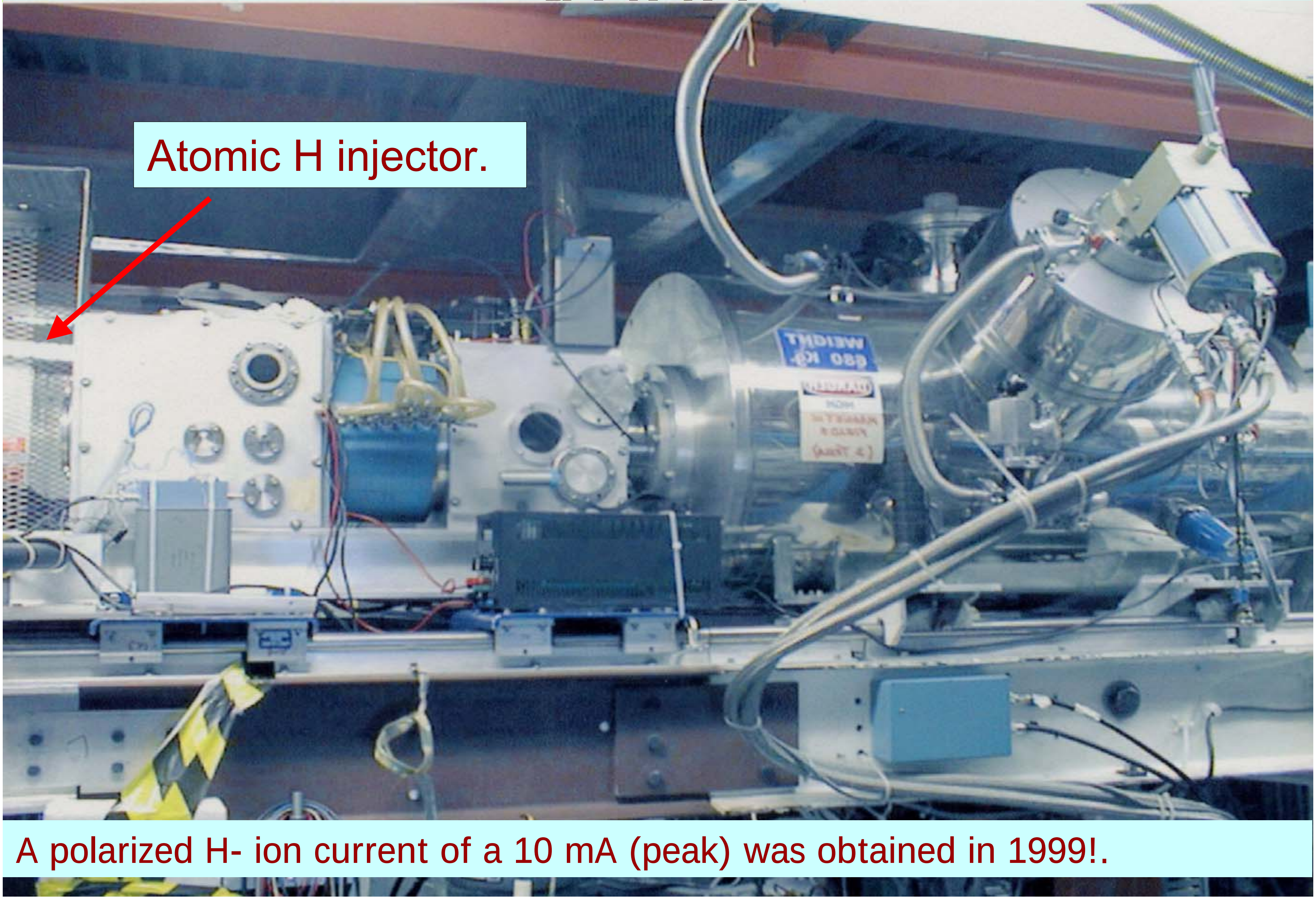


OPPIS with the "Fast Atomic Beam Source" layout.



He –ionizer cell serves as a proton source in the high magnetic field.

Pulsed OPPIS at TRIUMF, 1999



A polarized H- ion current of a 10 mA (peak) was obtained in 1999!.

OPPIS with the “Fast Atomic Hydrogen Source”.

- Higher polarization is also expected with the fast atomic beam source due to: a) elimination of neutralization in residual hydrogen; b) better Sona-still transition efficiency for the smaller ~ 1.5 cm diameter beam; c) use of higher ionizer field (up to 3.0 kG), while still keeping the beam emittance below 2.0 π mm·mrad, because of the smaller beam – 1.5 cm diameter.

- All these factors combined will further increase polarization in the pulsed OPPIS to:

  over 90% and the source intensity to over 10 mA.

  A new superconducting solenoid is required.

- The ECR-source replacement with an atomic hydrogen injector will provide the high intensity beam for polarized RHIC luminosity upgrade and for future eRHIC facilities.

Polarized Sources and Targets PST 2007 Workshop.

- Date: September 10-14, 2007
- Brookhaven National Laboratory
- Focussed discussions on:
- *Polarized Ion, Electron and He-3 polarized sources.*
- *Polarized internal targets.*
- *Polarimetry.*
- Invited speakers. Round – table discussions.
- Posters on status and summary talks.
- One day – lectures for students and BNL staff at BNL.
- Expected number of participants ~80 (~20 students).
- Publication in AIP Proceedings.

OPPIS upgrade with the atomic H injector.

- Atomic H injector produces an order of magnitude higher brightness beams than ECR proton source.
- A 5-10 mA H^- ion current can be easily obtained with the smaller, about 12 mm in diameter beam. This reduces most of possible polarization losses and produce smaller emittance polarized beam.
- Neutralization in the residual gas is much smaller too.
- All these factors combined will increase polarization to over 90%.

Major purchase will be a new superconducting solenoid ~$150 k.