Polarized proton beam at RHIC .

A. Zelenski, Brookhaven National Laboratory

PSTP 2009, Ferrara

Why study the proton (electron) spin?

- Spin (intrinsic angular momentum) is a fundamental quantum mechanical property of elementary particles (like mass, charge).

- Atoms and nuclei can not exist without the spin.

- "… without spin and associated with it statistics the whole universe would collapse".
- S.Tomonaga, "The Story of Spin".

PST 2007 will be hosted by Brookhaven National Laboratory (BNL), which has a long-standing tradition in spin physics. At PST 2007 we plan to have focused discussions on several selected topics, including:

- Polarized electron sources
- Polarized proton (deuteron) sources
- Polarized ^{3}He ion sources and targets
- Polarized internal hydrogen targets
- Polarized radioactive ion beams
- Polarized solid targets
- Polarimetry

The Workshop schedule will include round-table discussions of the basic limitations of various polarization techniques and possible paths for future progress. It is planned also to include a day of lectures for the wider community of BNL physicists, visiting graduate students and those attending local universities.

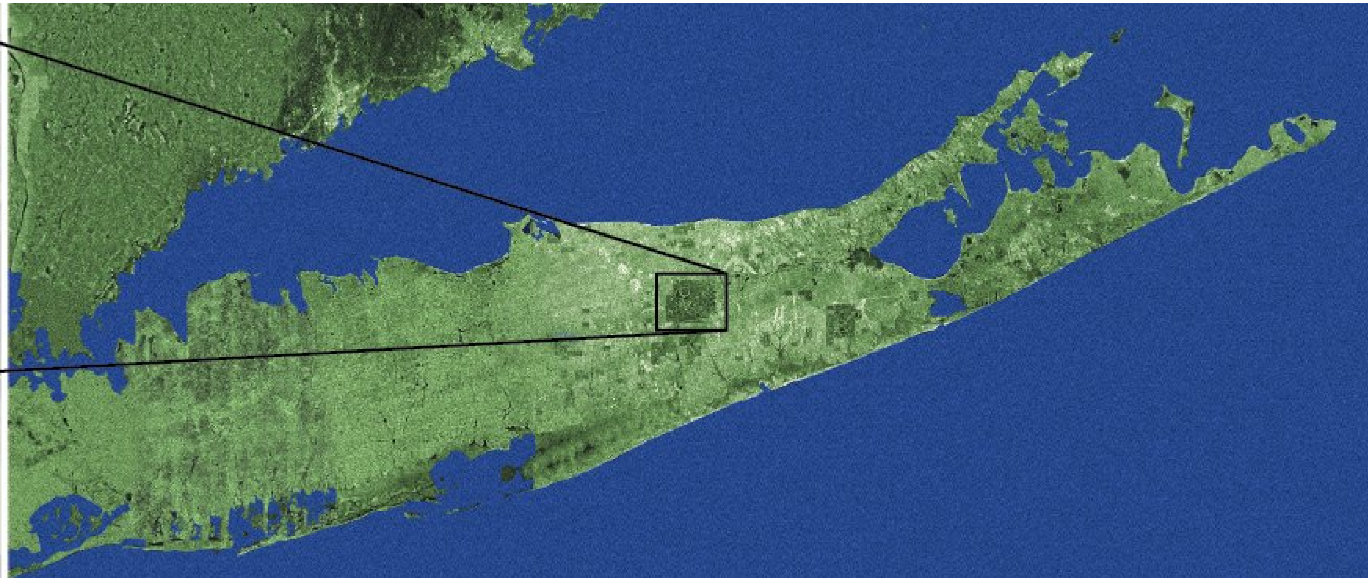
Deadlines

Abstracts Submissions
July 1, 2007

Workshop Registration
July 31, 2007

Local Organizing Committee

Anatoli Zelenski (Chairman)
Yousef Makdisi
Ahovi Kponou
Gerry Bunce
James Alessi



XII$^{\text{TH}}$ International Workshop on Polarized Sources, Targets & Polarimetry

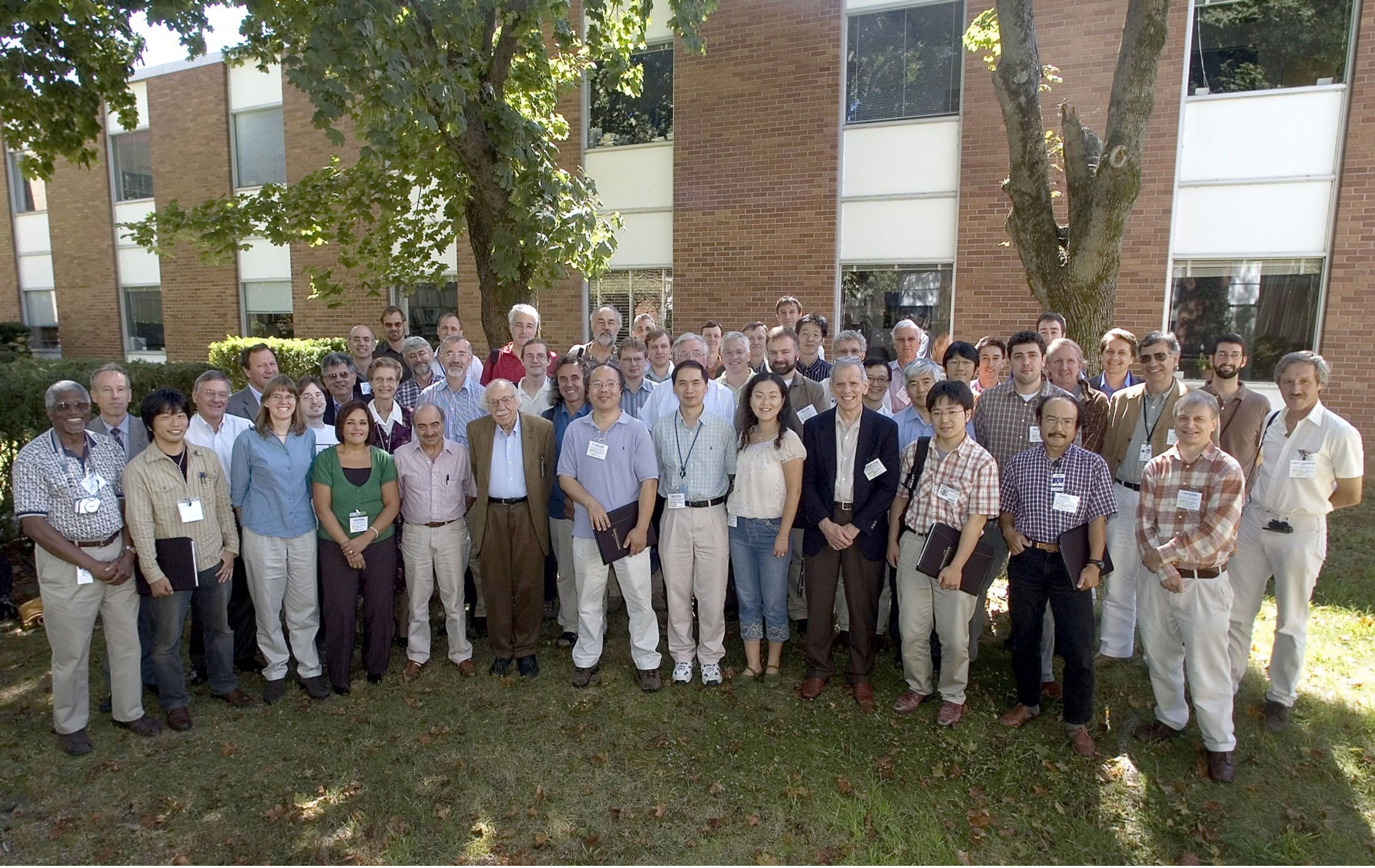
A forum to discuss new achievements and problems in polarization techniques.

September 10-14, 2007

Brookhaven National Laboratory (BNL)
Upton, Long Island, New York, USA

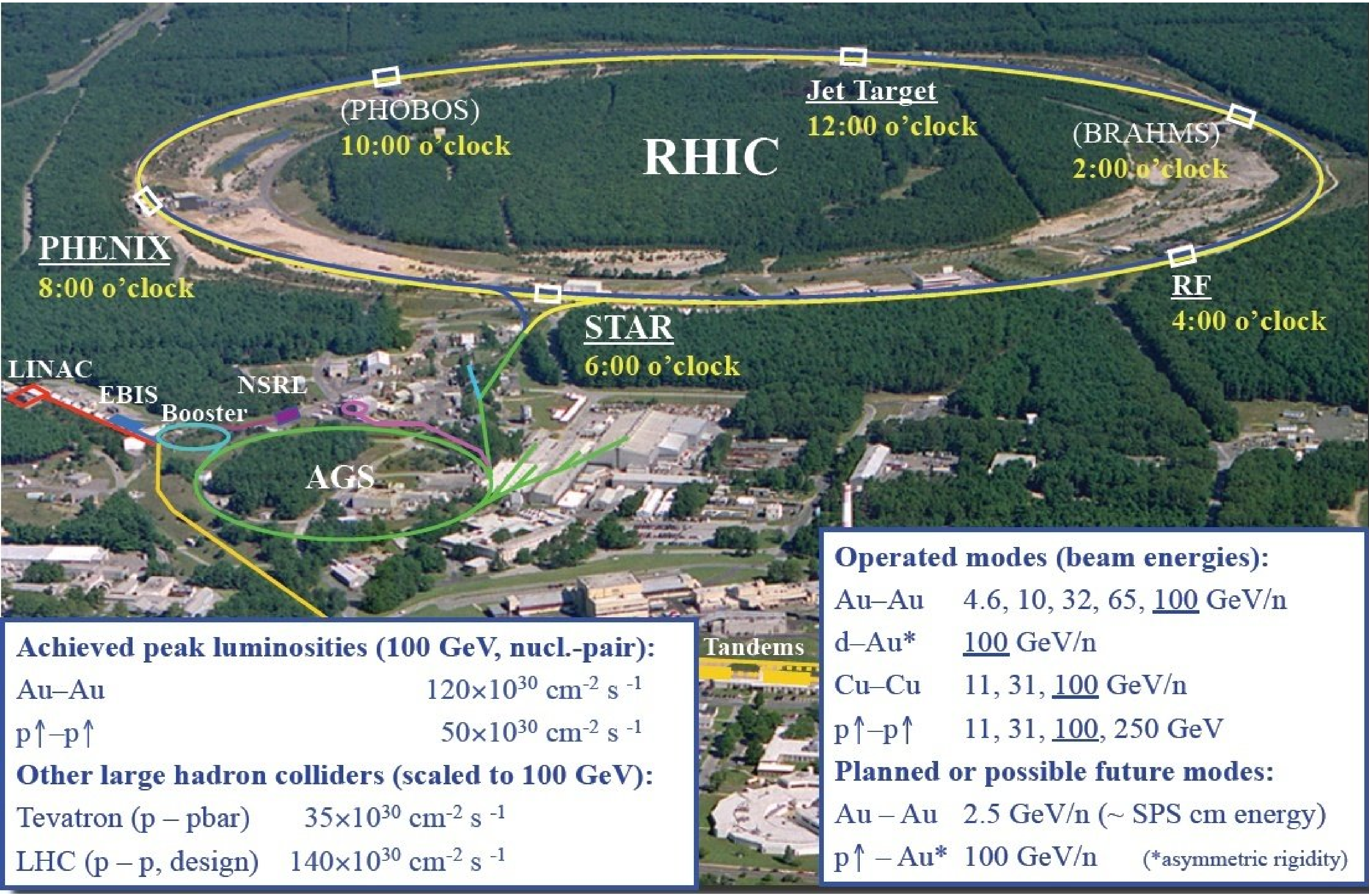
https://www.bnl.gov/PST2007

For additional information:
Contact the Event Coordinator, Sandy Asselta at PSTP2007@bnl.gov



35 participants, 52 talks. Published AIP Conf.Proc. No.980, 20

RHIC - High Luminosity (Polarized) Hadron Collider



Achieved peak luminosities (100 GeV, nucl.-pair):

Au–Au	120×10^{30} cm^{-2} s^{-1}
p↑–p↑	50×10^{30} cm^{-2} s^{-1}

Other large hadron colliders (scaled to 100 GeV):

Tevatron (p – pbar)	35×10^{30} cm^{-2} s^{-1}
LHC (p – p, design)	140×10^{30} cm^{-2} s^{-1}

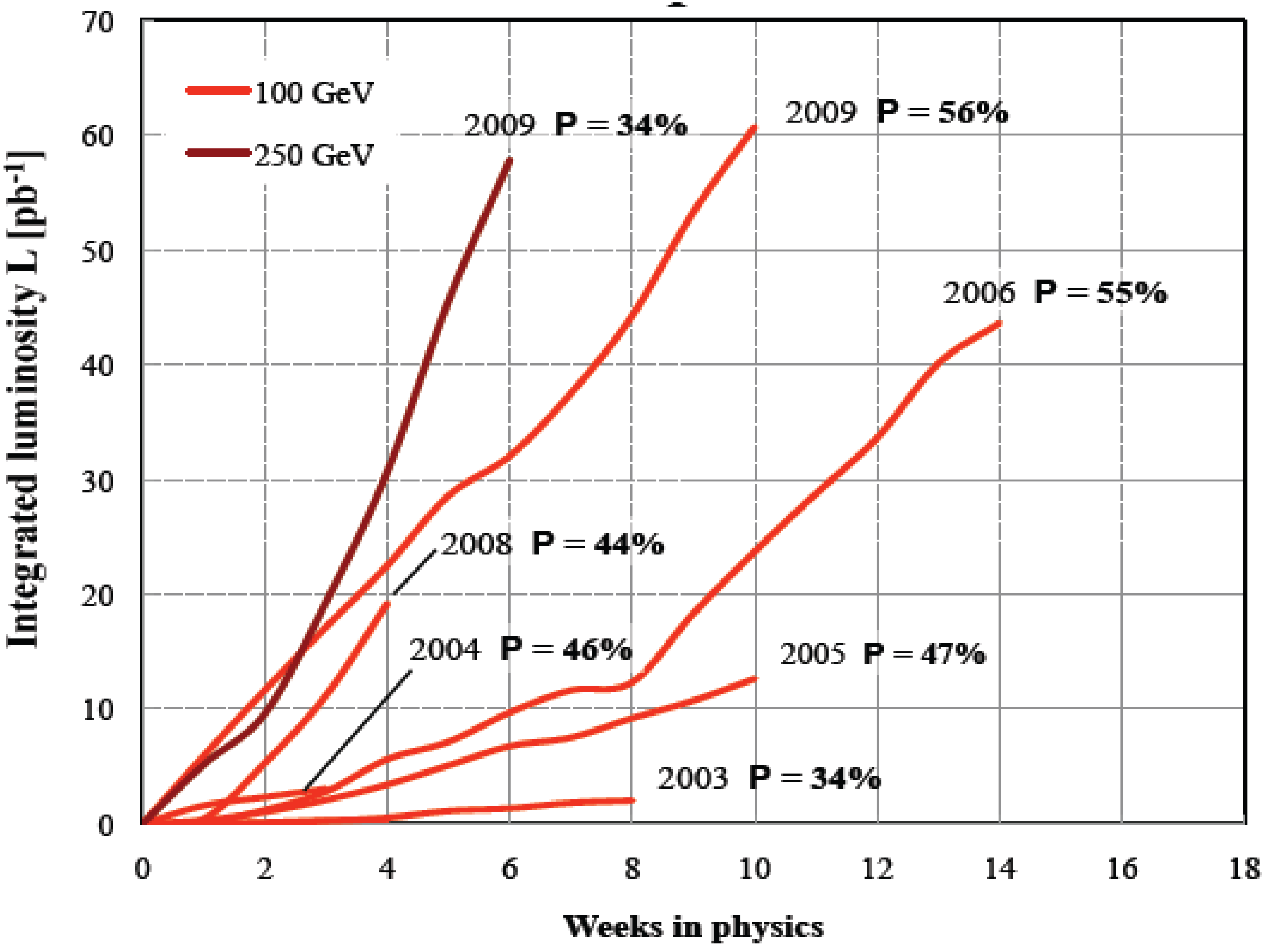
Operated modes (beam energies):

Au–Au	4.6, 10, 32, 65, <u>100</u> GeV/n
d–Au*	<u>100</u> GeV/n
Cu–Cu	11, 31, <u>100</u> GeV/n
p↑–p↑	11, 31, <u>100</u>, 250 GeV

Planned or possible future modes:

Au – Au	2.5 GeV/n (~ SPS cm energy)
p↑ – Au*	100 GeV/n (*asymmetric rigidity)

Integated luminosity for polarized proton collisions.

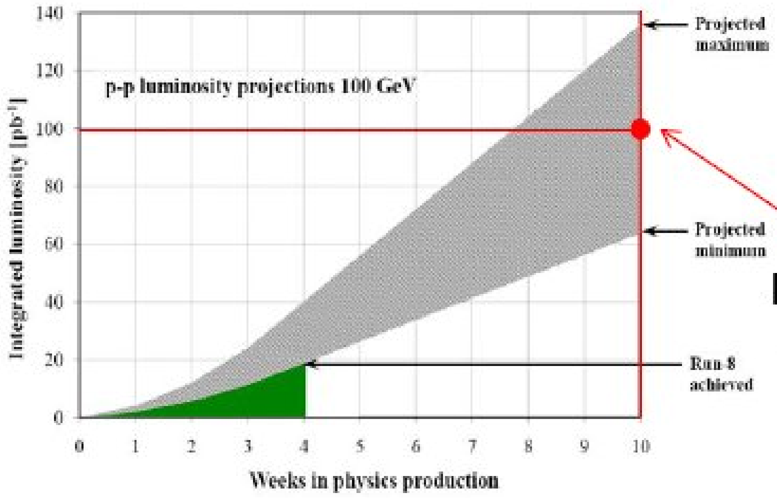


Executive Summary of STAR Goals for Run 9

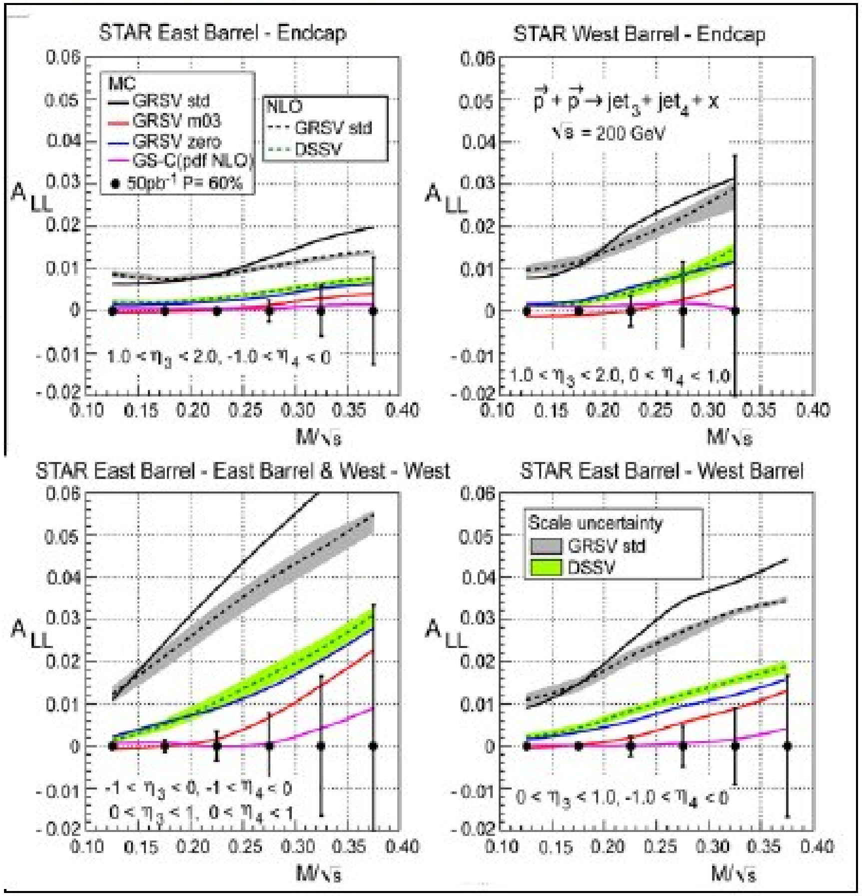
- Commission major detector upgrades (TPC, TOF, Trigger)
- Physics and preparation for the future at 500 GeV
  - Establish local polarimetery of transverse components
  - W cross-section
  - W A_L: 10 pb^{-1} sampled with Longitudinal polarization 50%
- pp2pp @ 200 GeV: ½ week for complete transverse program
- If the run is extended: highest priority 200 GeV p+p
  - BUR: 50 pb^{-1} sampled, 60% Polarization, FOM $P^4L = 6.5\ pb^{-1}$

STAR Run 9 200GeV program (Gluon polarization)

- Projected performance / assumptions - STAR 200GeV program



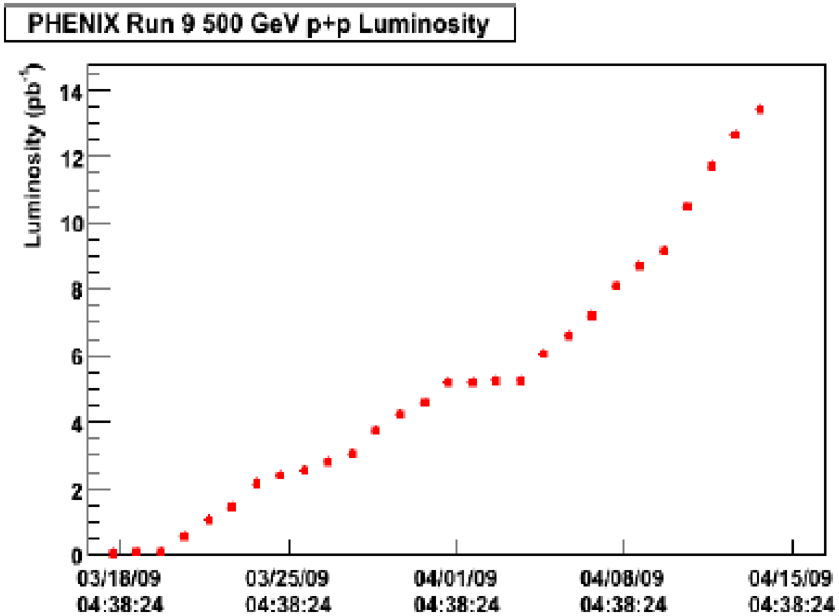
Reach BUR goal in 10 weeks!

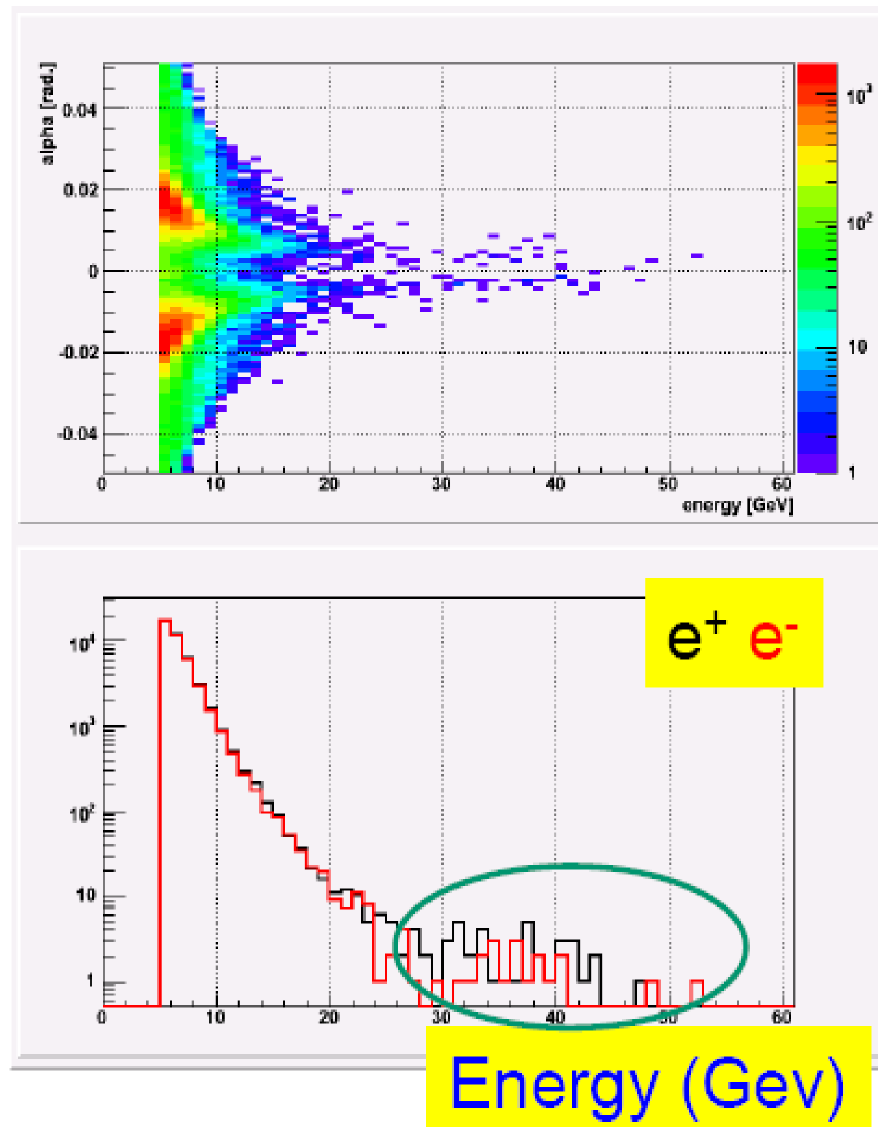


- Precision inclusive measurements, in particular inclusive jet production
- Di-Jet production - Probe x dependence of $\Delta g(x)$
- Substantial improvement of gluon polarization reflected in highest PAC recommendation!

Assumption: FOM = $P^4 L \sim 6.5 pb^{-1}$
$P \sim 0.6$, $L_{delivered} \sim 100 pb^{-1}$
$L_{recorded} \sim 50 pb^{-1}$
Need: 10 weeks

500 GeV pp so far





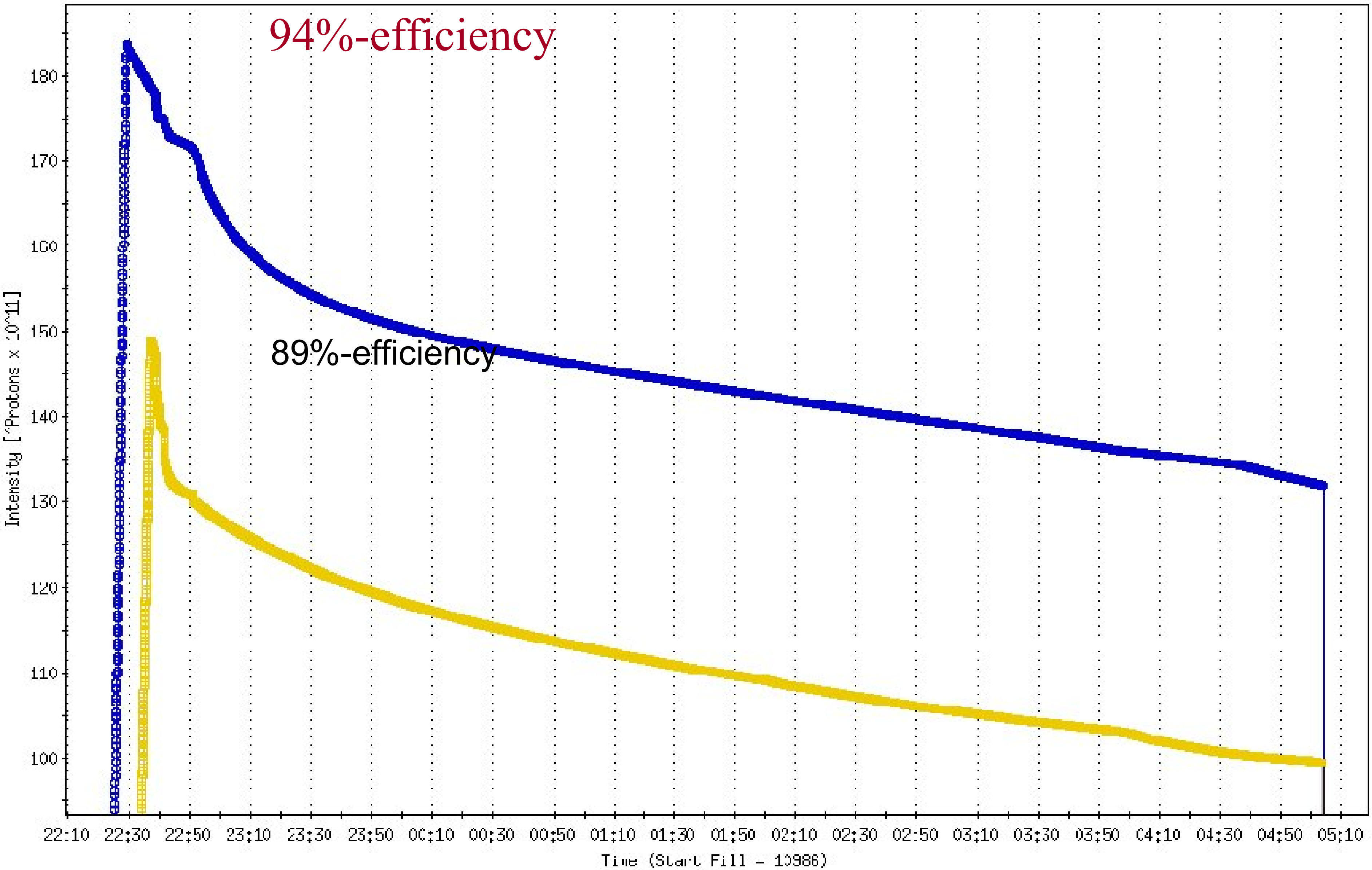
About 14 pb^{-1} recorded within vertex cut… Fastrak analysis shows evidence for $W \rightarrow e\nu$ in central arms

500 GeV pp beyond Run 9

- Spin plan calls for 300 pb^{-1} and 60% polarization
  - W program: $(300\ pb^{-1})(0.6)^2 = 108\ pb^{-1}$
  - ΔG: $(300\ pb^{-1})(0.6)^4 = 39\ pb^{-1}$ FOM goal
  - Run 9 W: $(14\ pb^{-1})(0.35)^2 = 1.7\ pb^{-1}$
- Polarization is very far from where we need to be; with 5 pb^{-1}/week, here's what we'd need to reach the FOM goal:

Polarization	Weeks for W	Weeks for ΔG
40%	135	304
50%	87	125
60%	60	60
70%	44	33

ne 24, FILL 10986, 6.18 hr, Int-0.623 pb^{-1}, <L> =$28.45 \cdot 10^{30}$

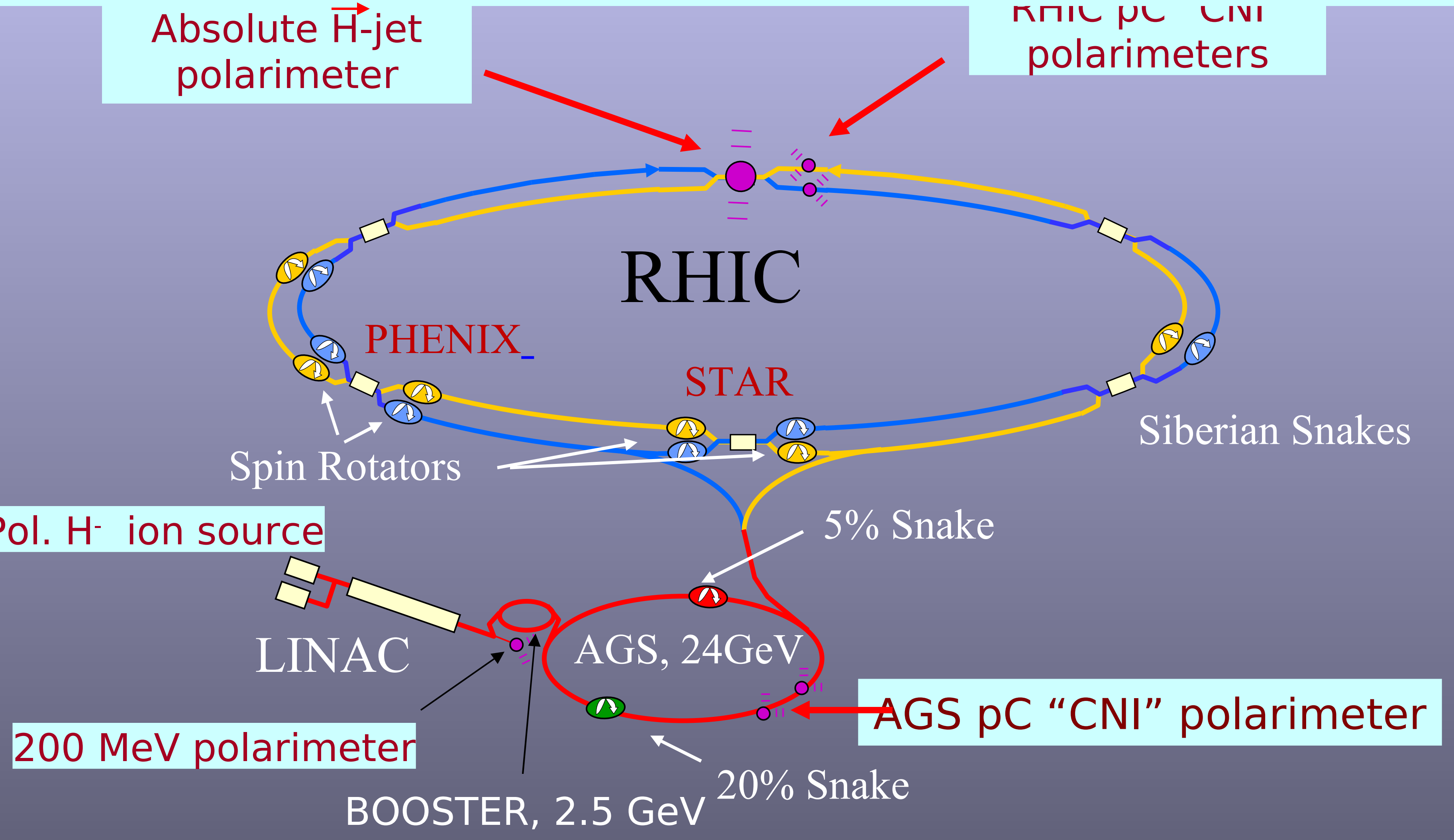


Foundations of the SPIN-PHYSICS at RHIC.

- High-intensity polarized proton source.
- “Siberian snakes” to preserve polarization.
- P-P and P-Carbon CNI polarimeters.
- Theoretical “tools”, QCD calculations.

Polarization facilities at RHIC.

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



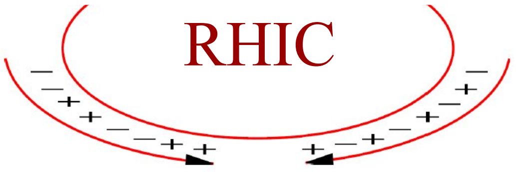
Polarized beams at RHIC.

OPPIS $10 \cdot 10^{11}$ (maximum $40 \cdot 10^{11}$) polarized H^- /pulse.

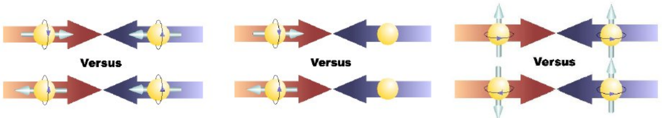
LINAC $5 \cdot 10^{11}$ polarized H^- /pulse at 200 MeV, P=85-

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

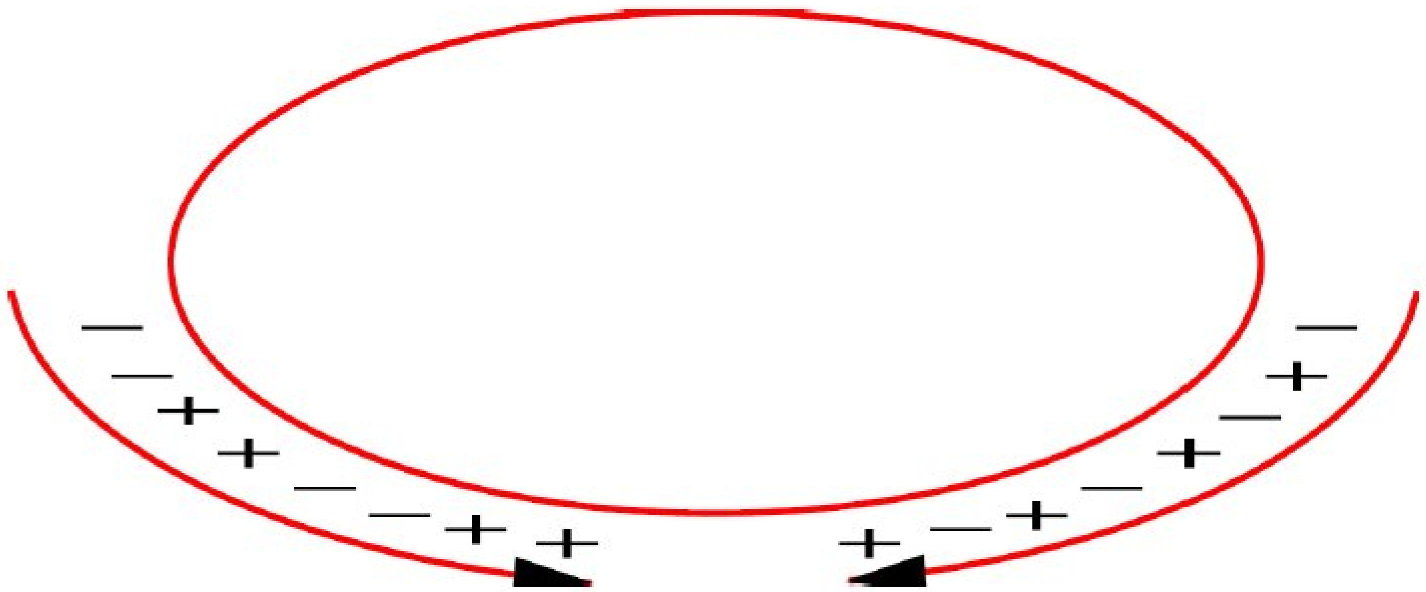
AGS 1.5-1.7 p/bunch, P ~65-70%

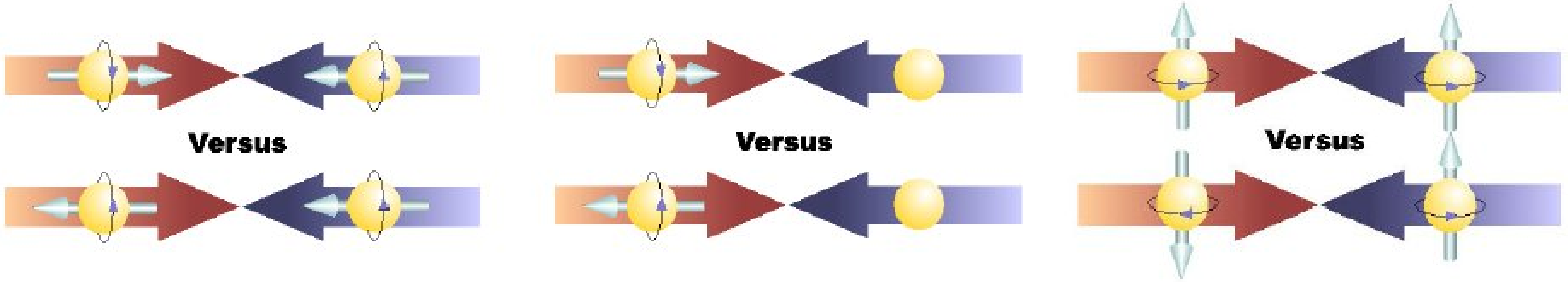


Maximum RHIC bunch intensity ~1.5 10^{11} p/bunch
Polarization -60-65% at 100 GeV



Exquisite Control of Systematics

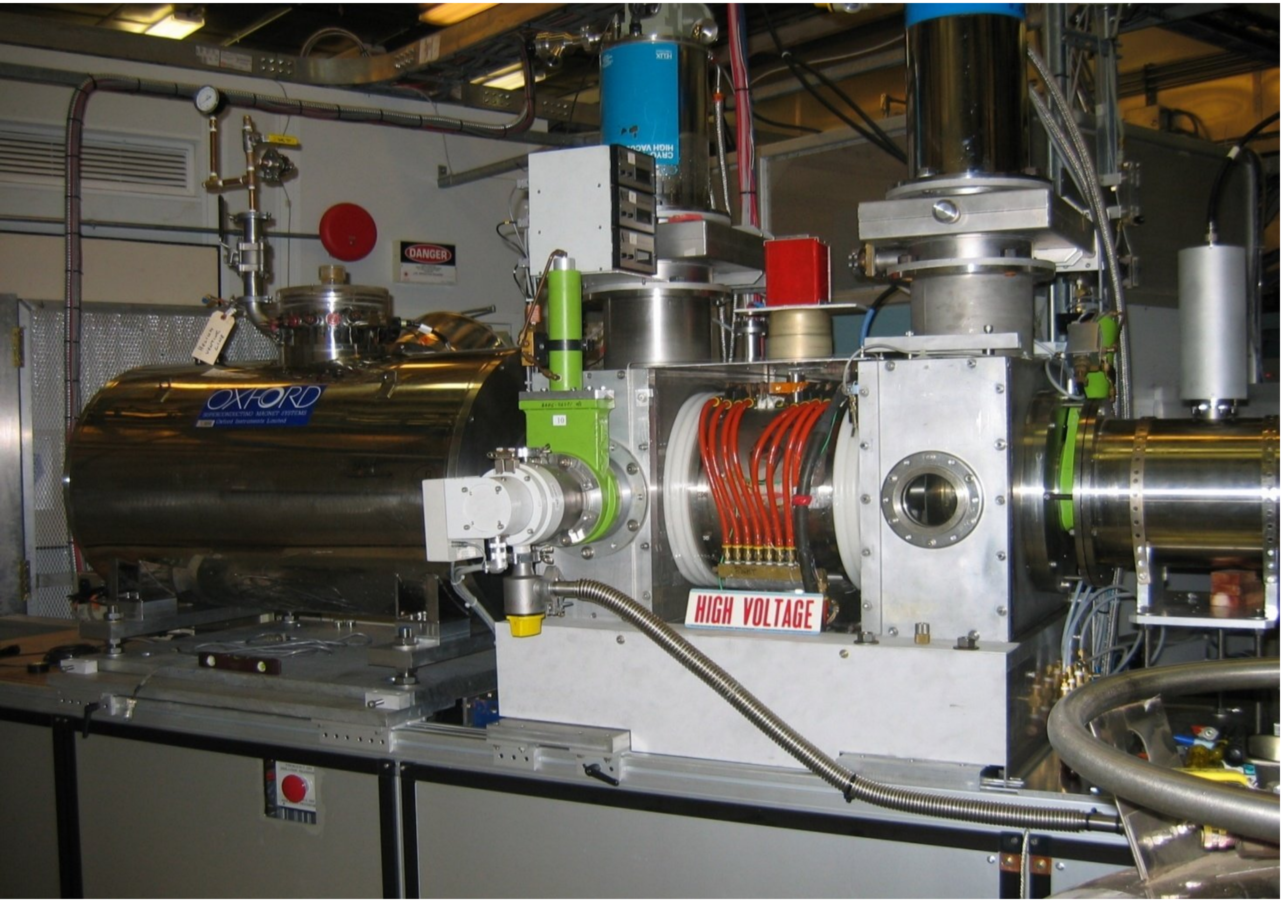




Polarized ion sources at RHIC.

- Optically-Pumped Polarized H^- Ion Source (OPPIS).
- Polarized D source for Deuteron EDM experiment (proposal).
- Polarized $^3He^{++}$ ion source on the base of EBIS for future eRHIC.

Optically-Pumped Polarized H^- Ion Source (OPPIS) at RHIC, (originally developed in collaboration between KEK, BNL, TRIUMF and INR Moscow).



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

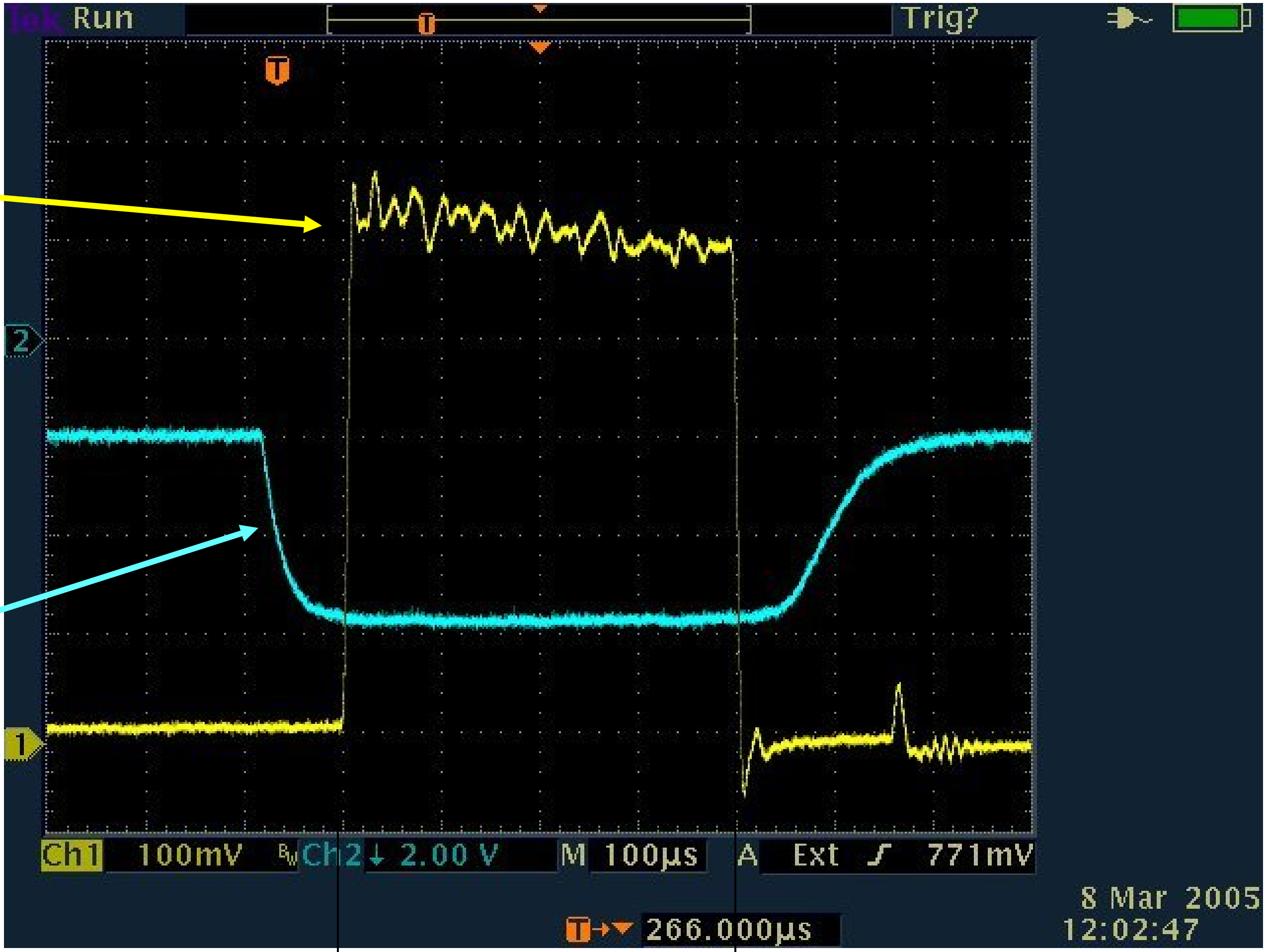
Linac (200MeV) - $5 \cdot 10^{11}$

AGS - $1.7 \cdot 10^{11}$

RHIC

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

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

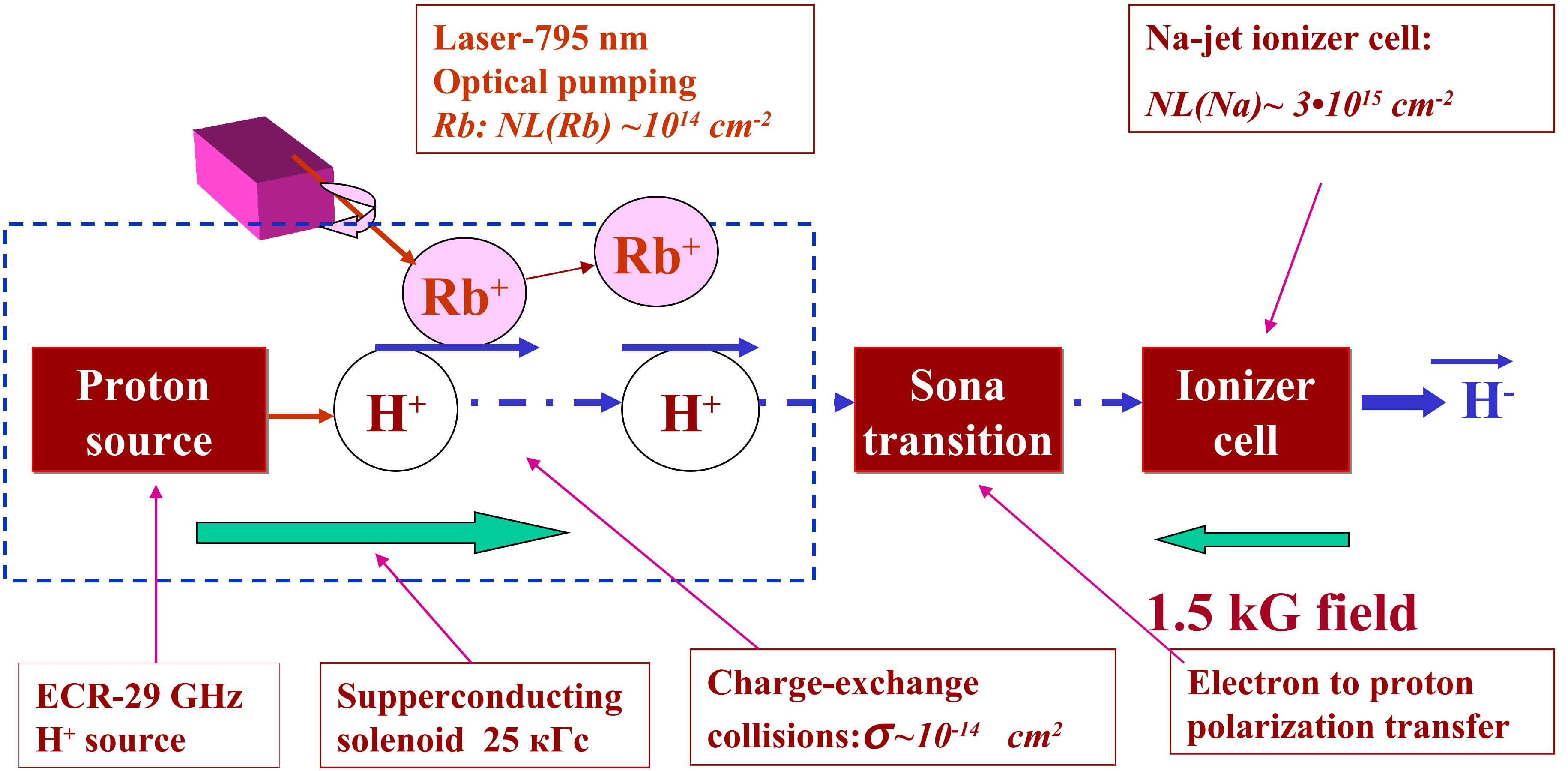


Faradey rotation polarization sinal.

400 uS

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

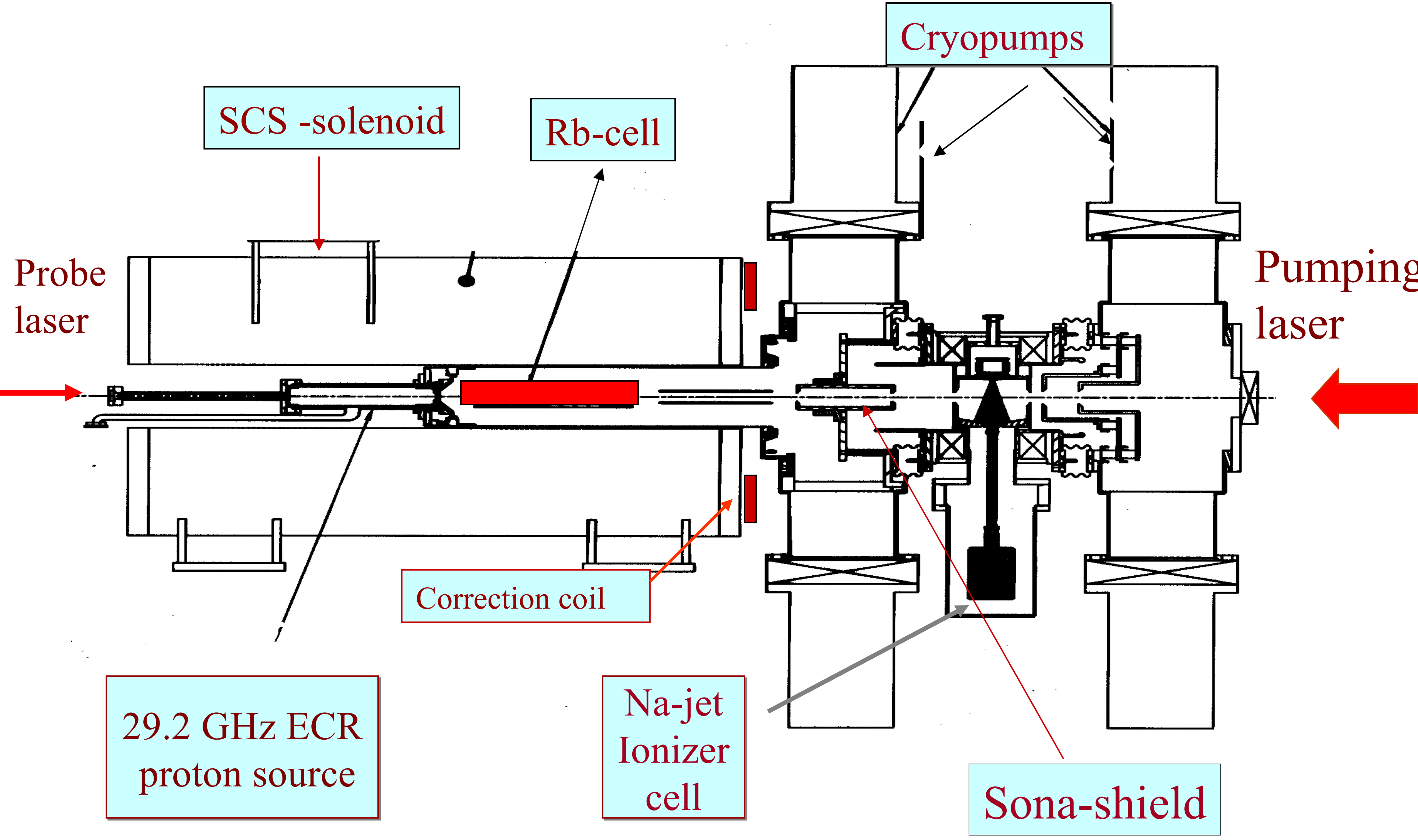
SPIN -TRANSFER POLARIZATION IN PROTON-Rb COLLISIONS.



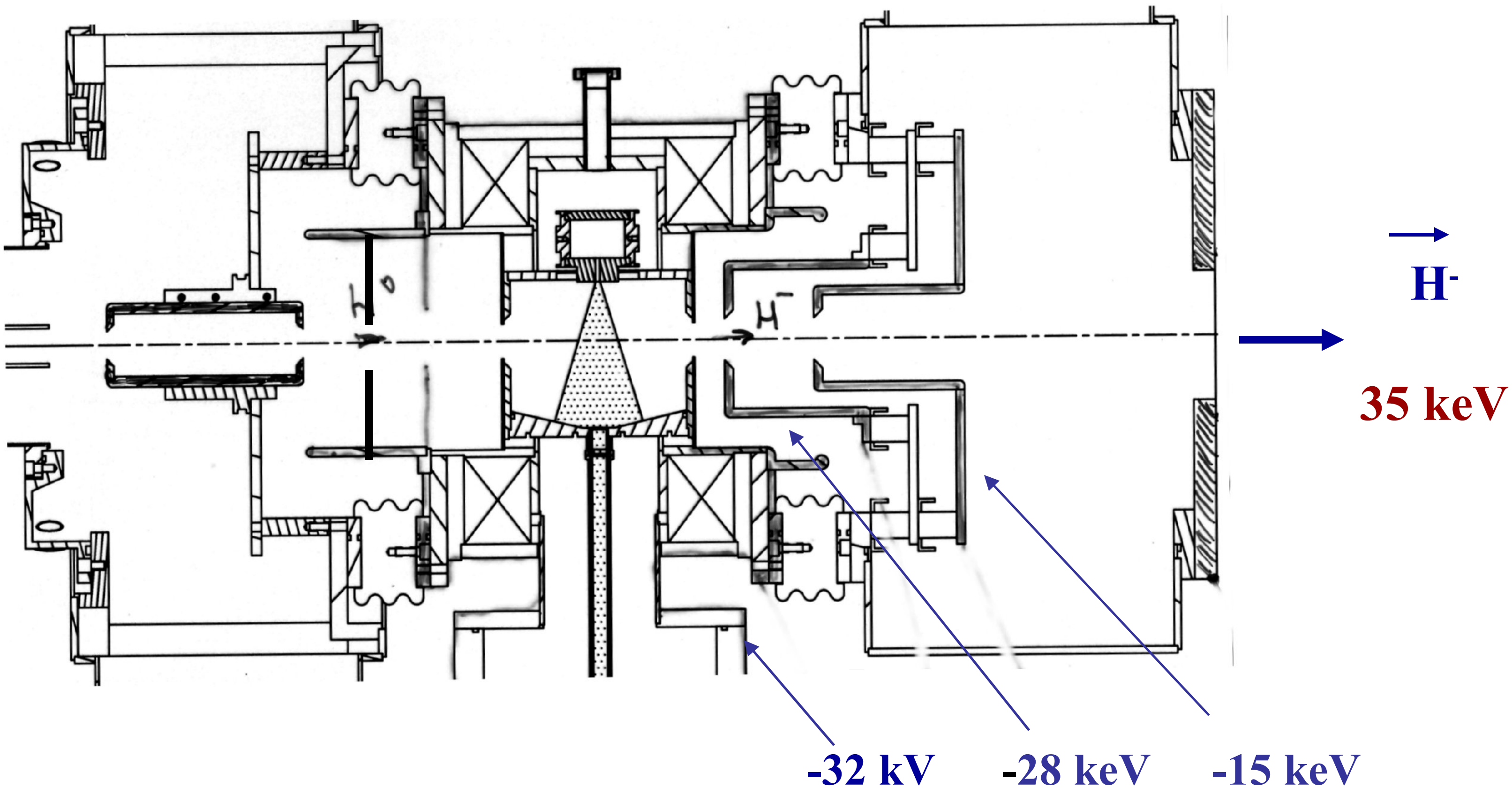
Laser beam is a primary source of angular momentum:

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

SCHEMATIC LAYOUT OF THE RHIC OPPIS.



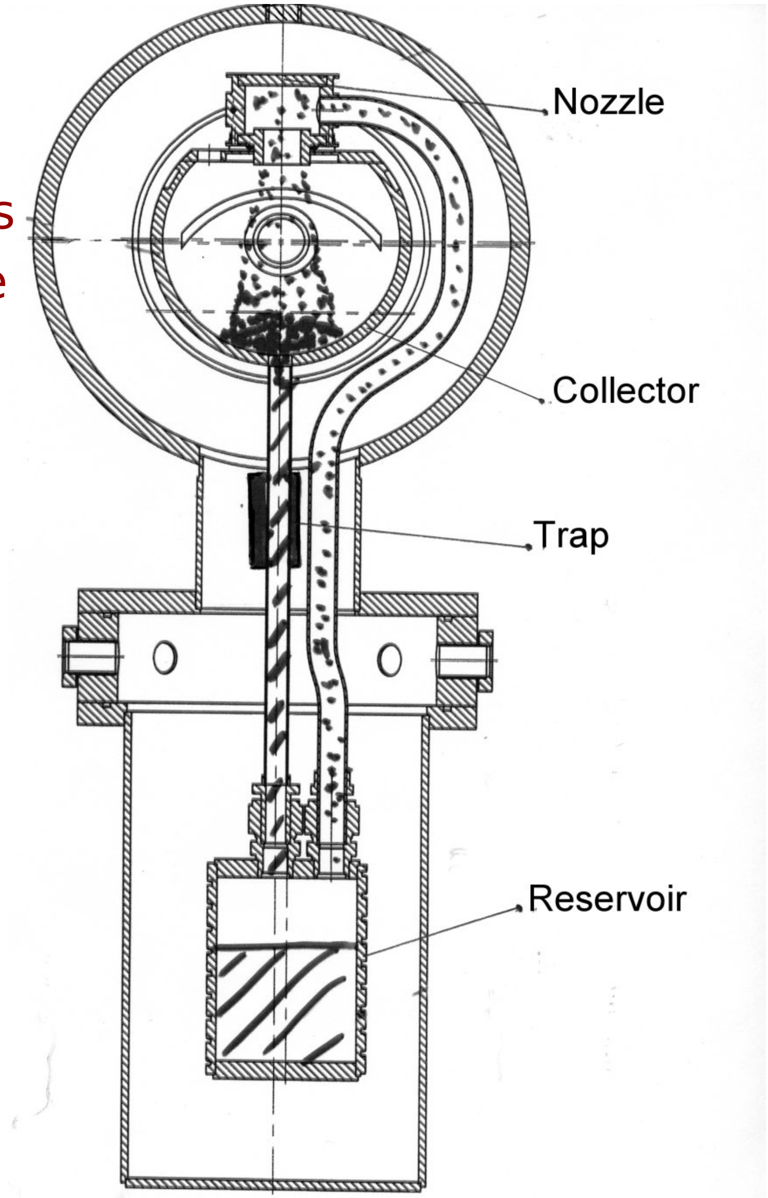
H^- beam acceleration to 35 keV at the exit of Na-jet ionizer cell.



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

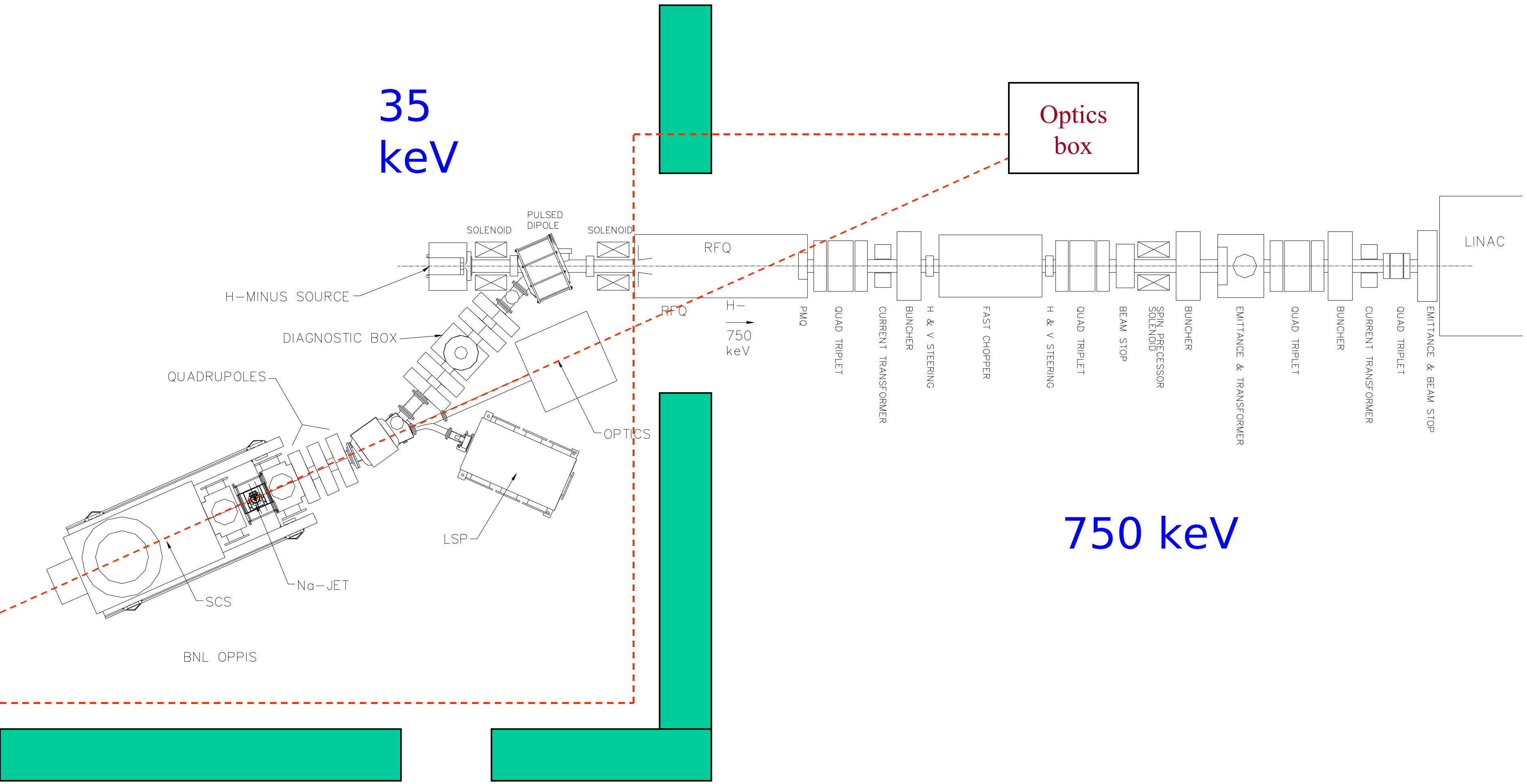
Sodium-jet ionizer cell.

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 .

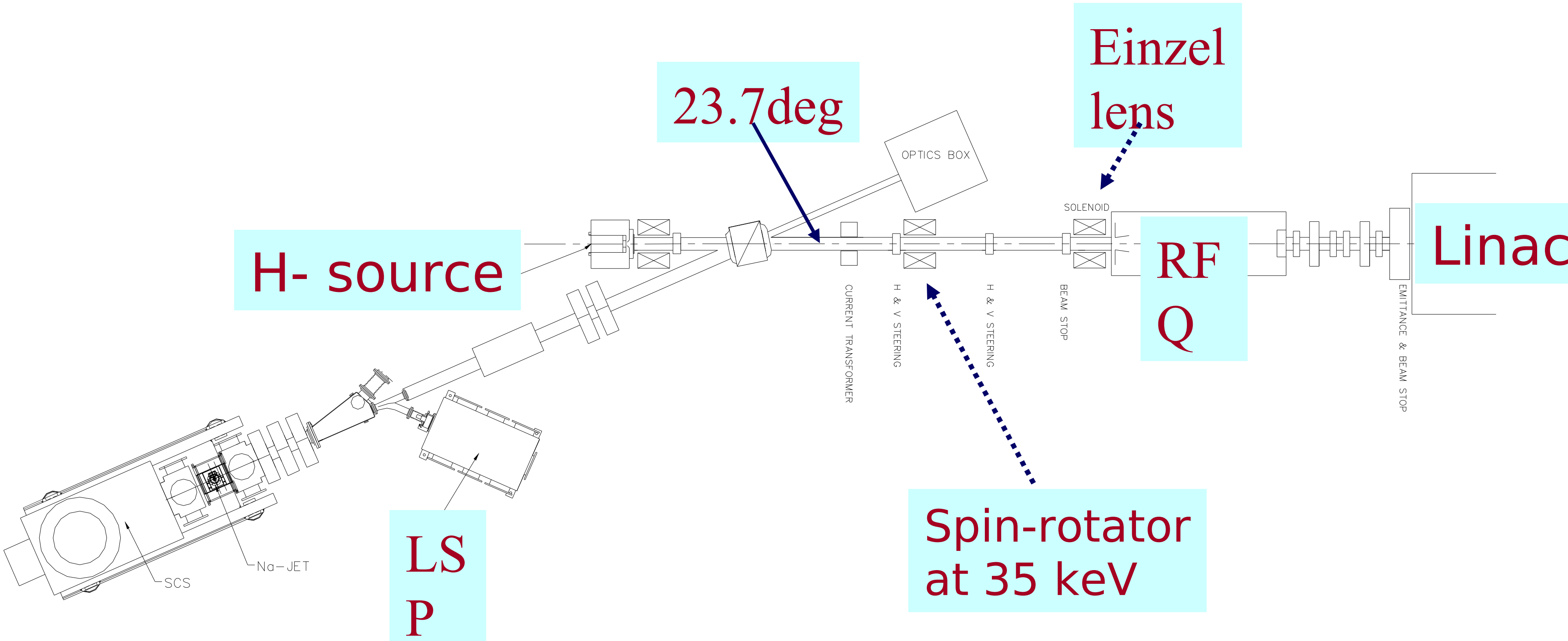


- Reservoir– operational temperature.
- Tres. ~500 ^{o}C.
- Nozzle– Tn ~500 ^{o}C.
- Collector- Na-vapor condensation: Tcoll.~120^{o}C
- Trap- return line. T ~ 120 – 180 ^{o}C.

Old LEBT & MEBT layout



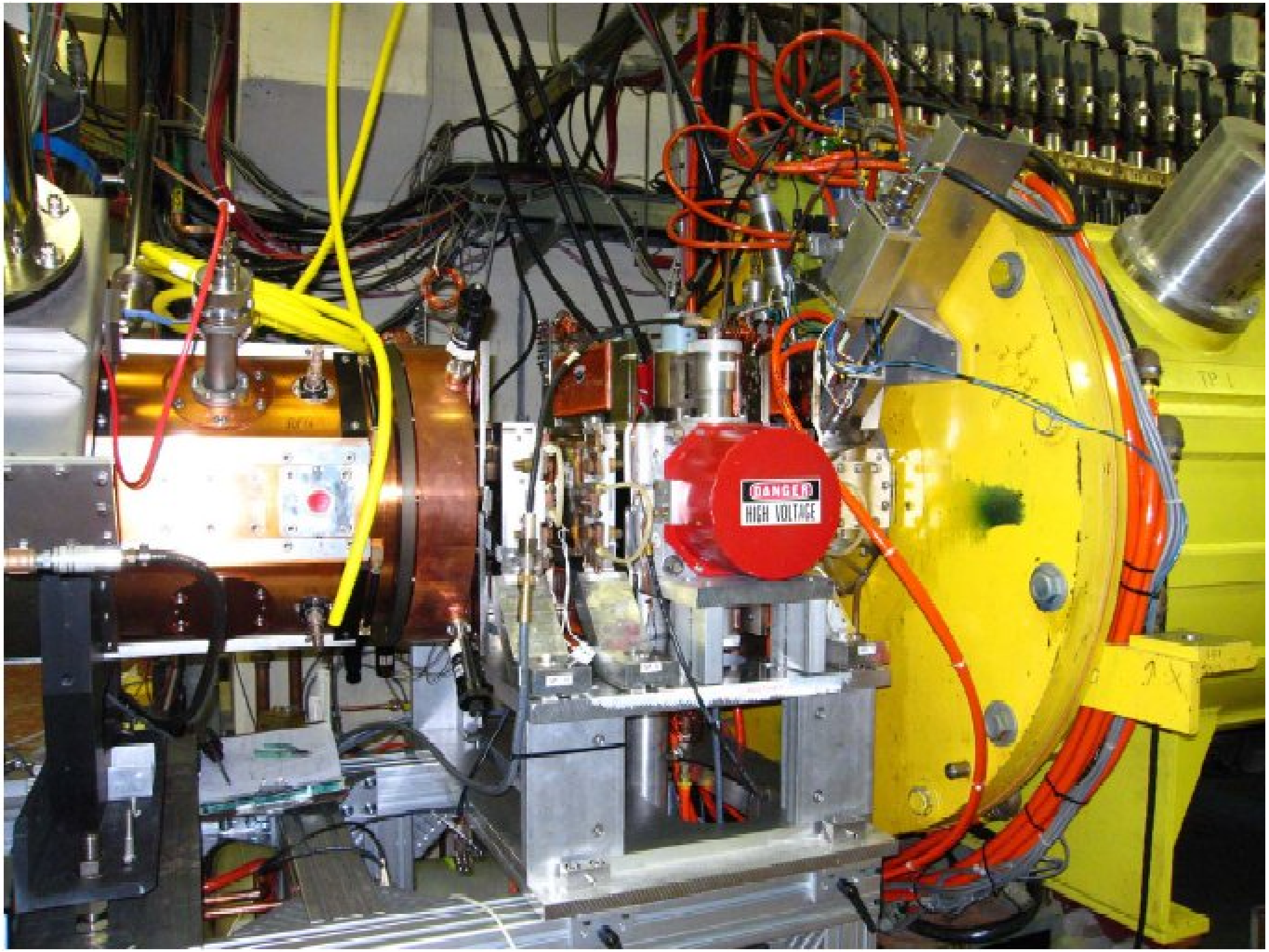
LEBT upgrade for 2009 Run.



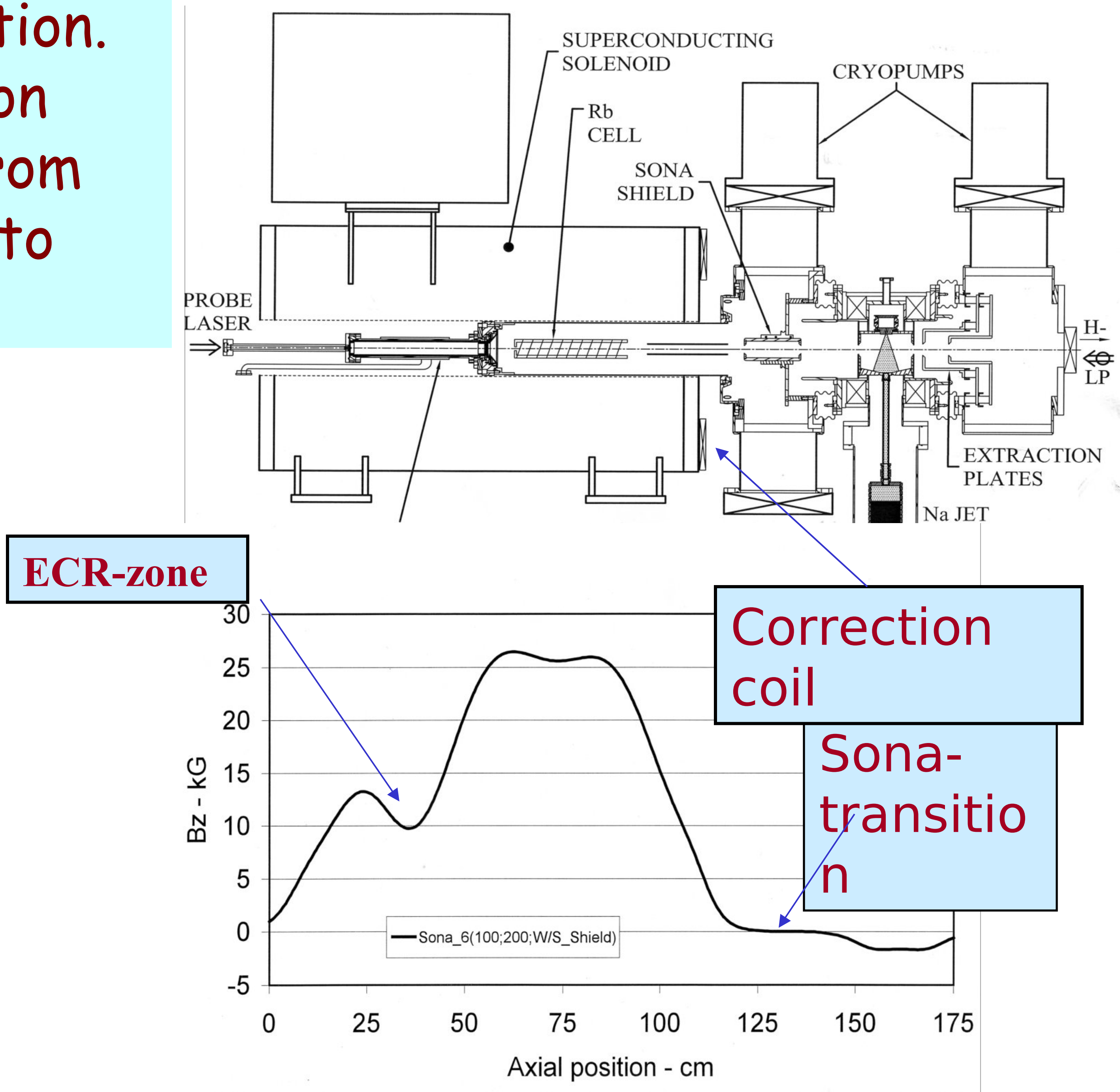
Spin-precession will be reduced to minimum required for vertical polarization direction in Linac. This should reduce the polarization profile generation in LEBT.

Significantly smaller beam emittance out of Linac is also expected due to improved matching between RFQ and Linac.

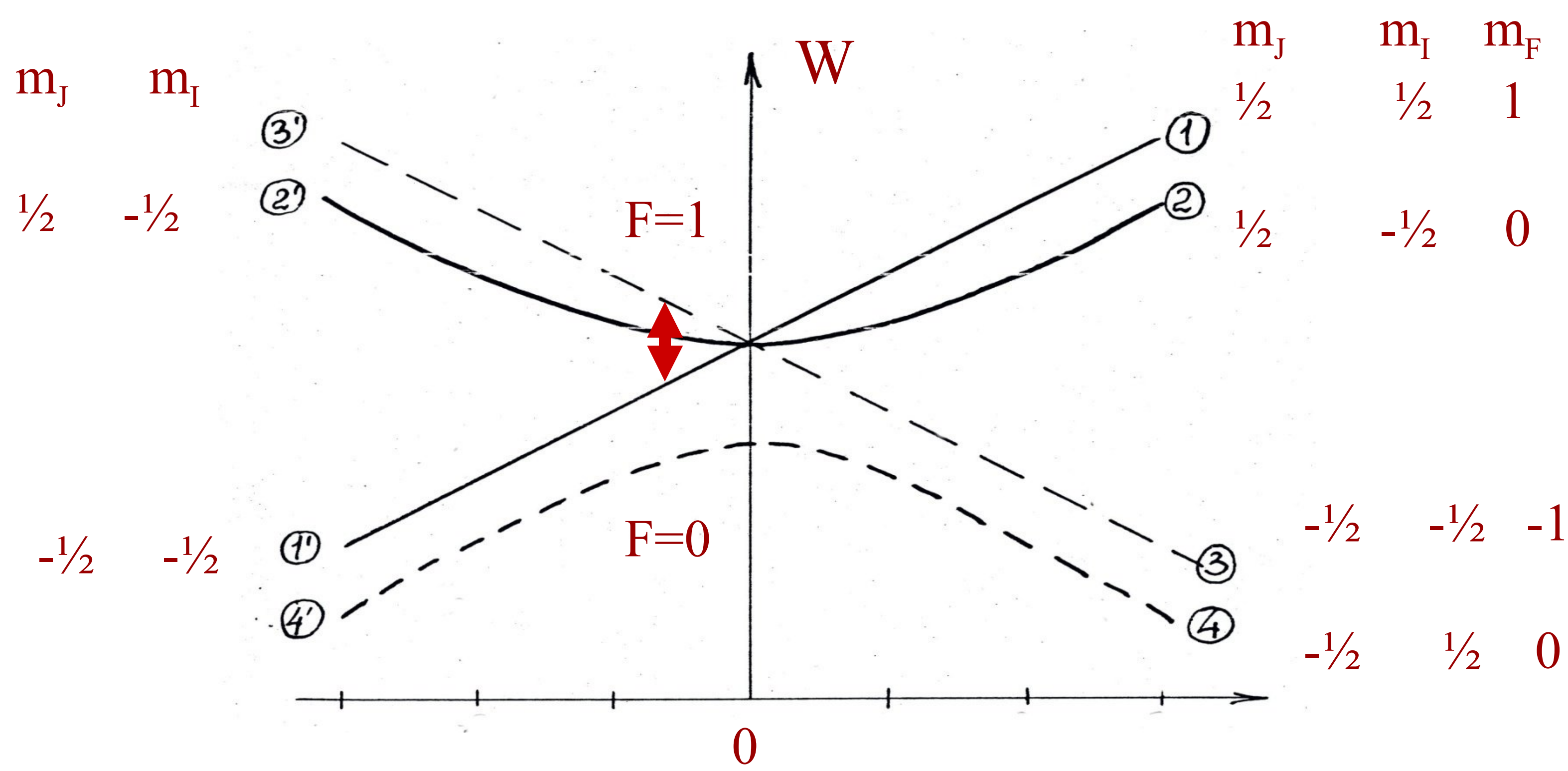
A new 750 keV MEBT line



Sona-transition. Polarization transfer from electrons to protons.



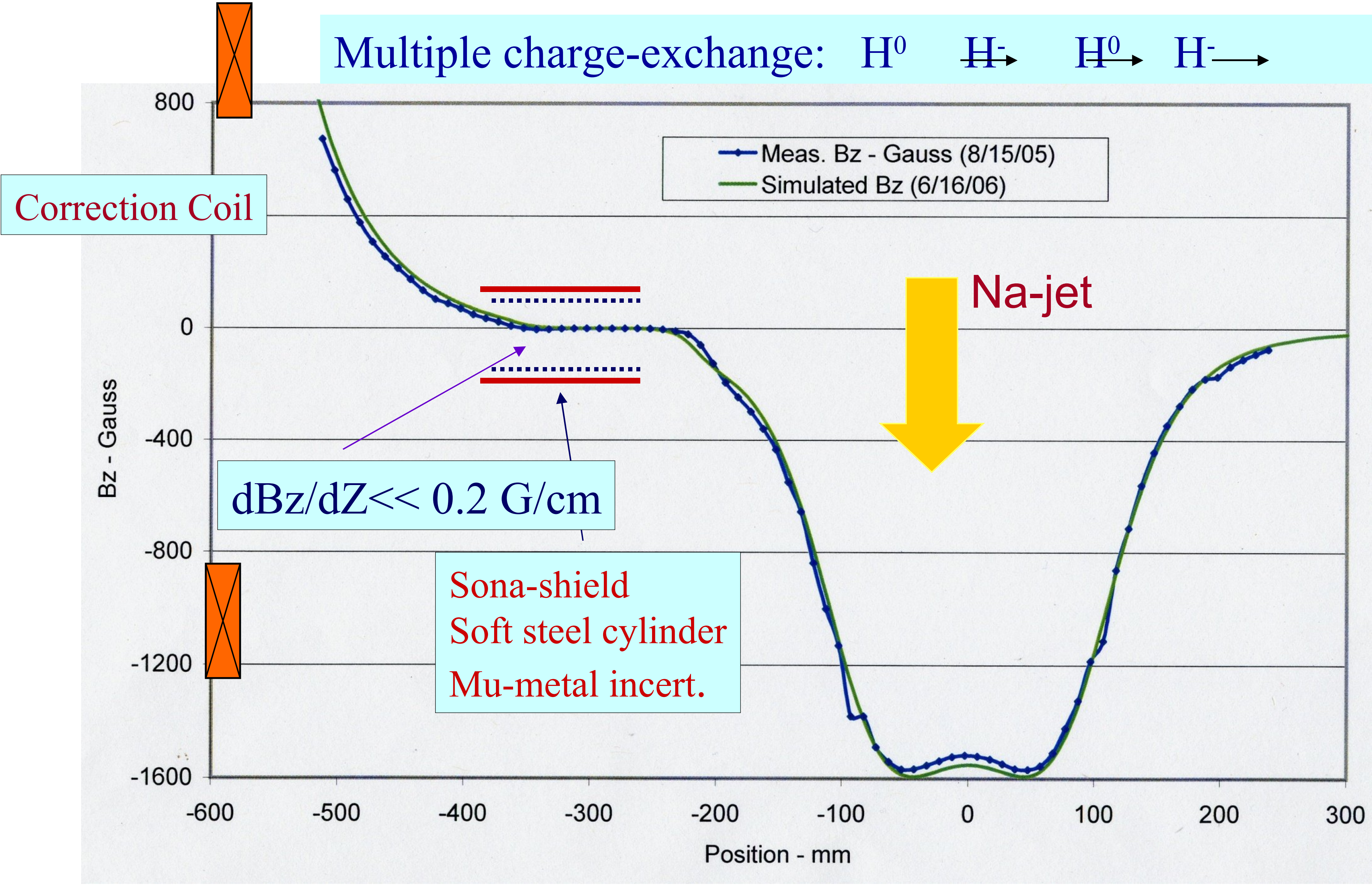
Sona-transition, P.G.Sona, Energia Nucleare, 1976



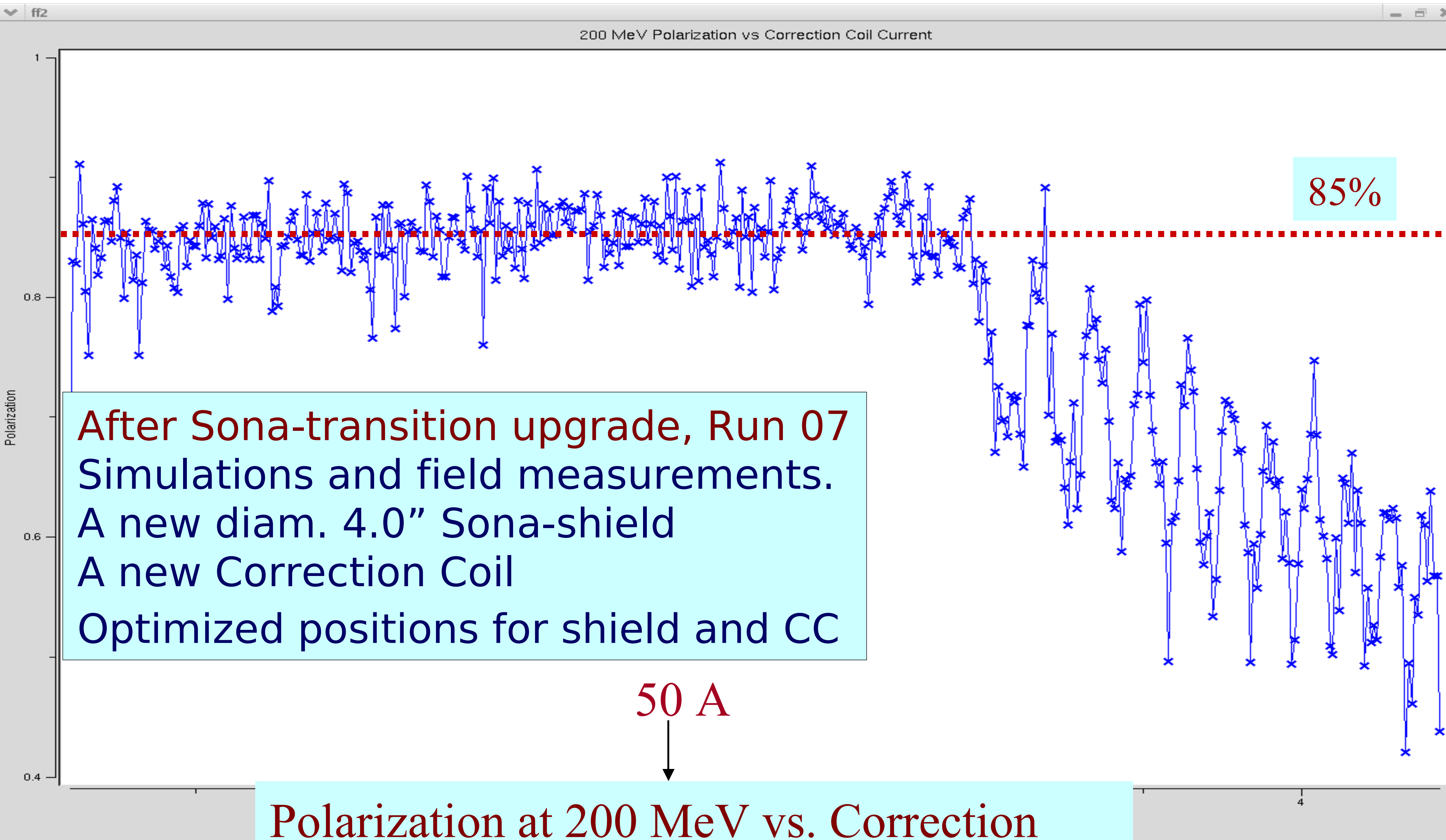
$Bs << B_R \sim R\ (dB/dZ)\ |_{B_Z=0} << 2$ G/cm – limitation on Bz gradient and beam size at the zero crossing point.

$\Delta m_F = +/-1$ – π- transitions, $\Delta m_F = 0$ – σ- transitions.

Bz-field component in the Sona-transition region.

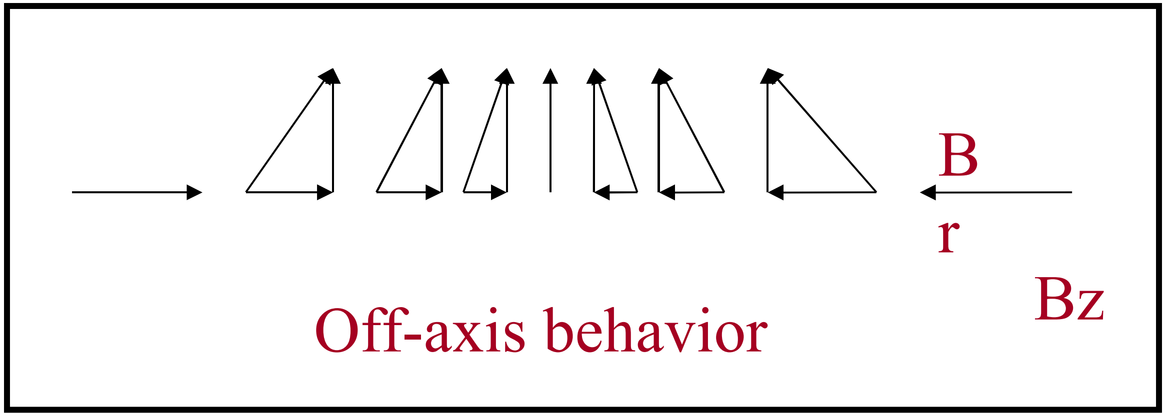


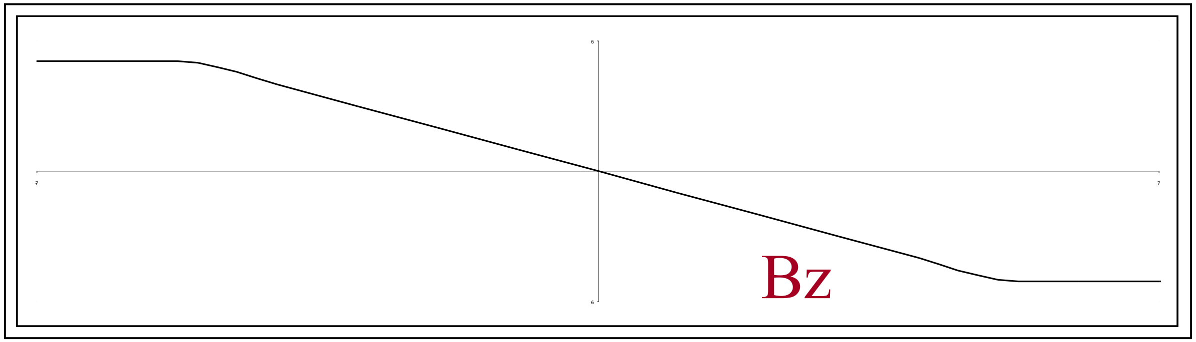
Polarization oscillations in the Sona-transition, Run - 07.



Polarization at 200 MeV vs. Correction Coil current

Sona-transition simulations, A.Kponou

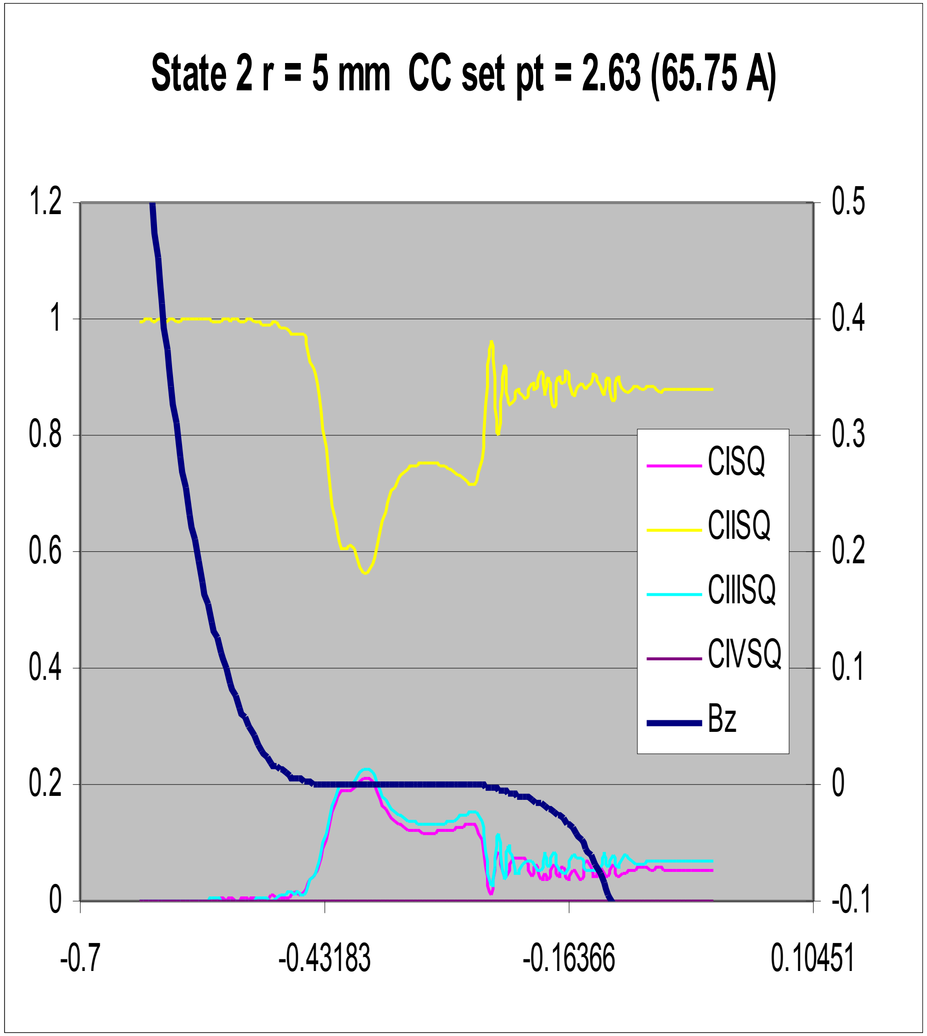




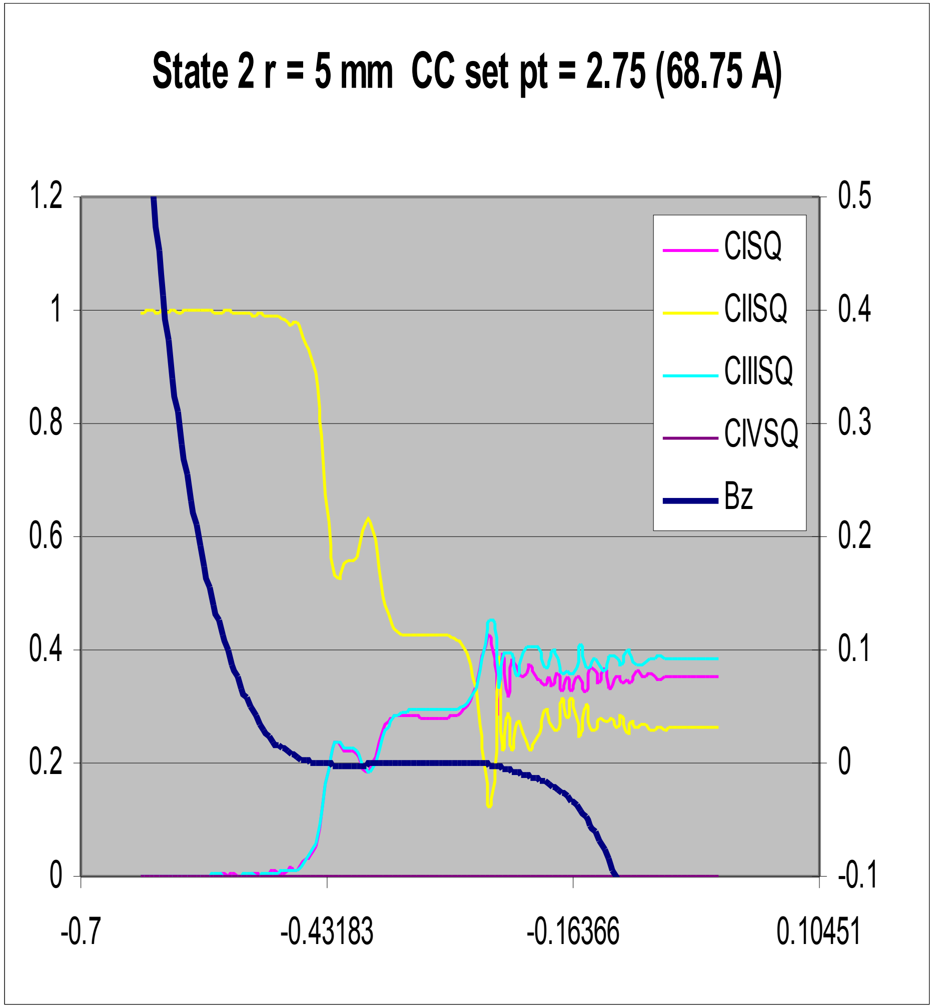
z

A.Belov , INR Moscow developed a computer code for calculation of hyperfine sublevels population in variable magnetic field.
This code was successfully aplied to the Sona-transition simulations in the RHIC OPPIS.

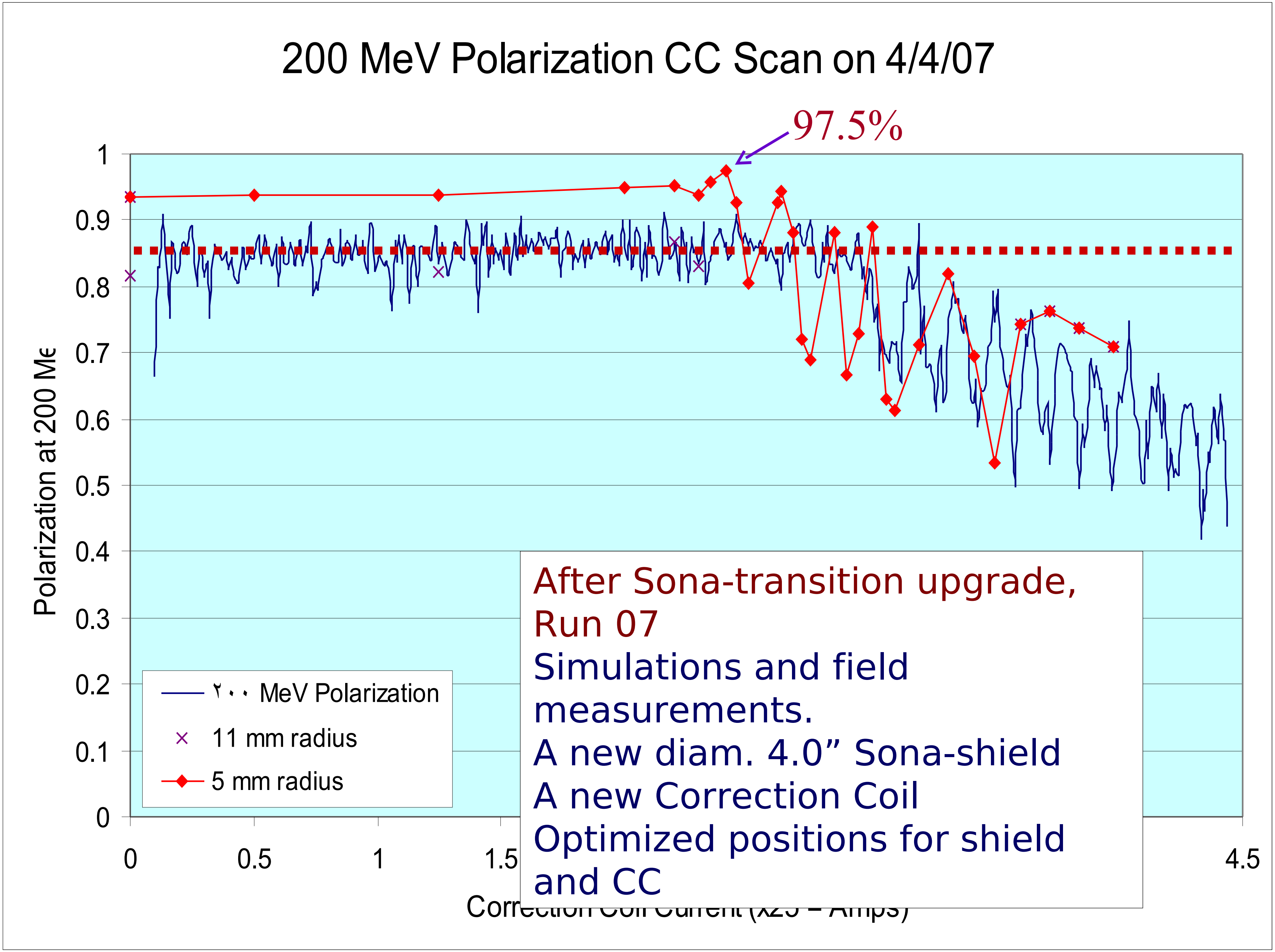
State 2 (r=5 mm)



State 2 r = 5 mm CC set pt = 2.63 (65.75 A)
1.2
1
0.8
0.6
0.4
0.2
0
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.7
-0.43183
-0.16366
0.10451
CISQ
CIISQ
CIIISQ
CIVSQ
Bz



State 2 r = 5 mm CC set pt = 2.75 (68.75 A)
1.2
1
0.8
0.6
0.4
0.2
0
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.7
-0.43183
-0.16366
0.10451
CISQ
CIISQ
CIIISQ
CIVSQ
Bz



200 MeV Polarization CC Scan on 4/4/07
97.5%
Polarization at 200 Me
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
4.5
٢٠٠ MeV Polarization
11 mm radius
5 mm radius
After Sona-transition upgrade, Run 07
Simulations and field measurements.
A new diam. 4.0” Sona-shield
A new Correction Coil
Optimized positions for shield and CC

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%)

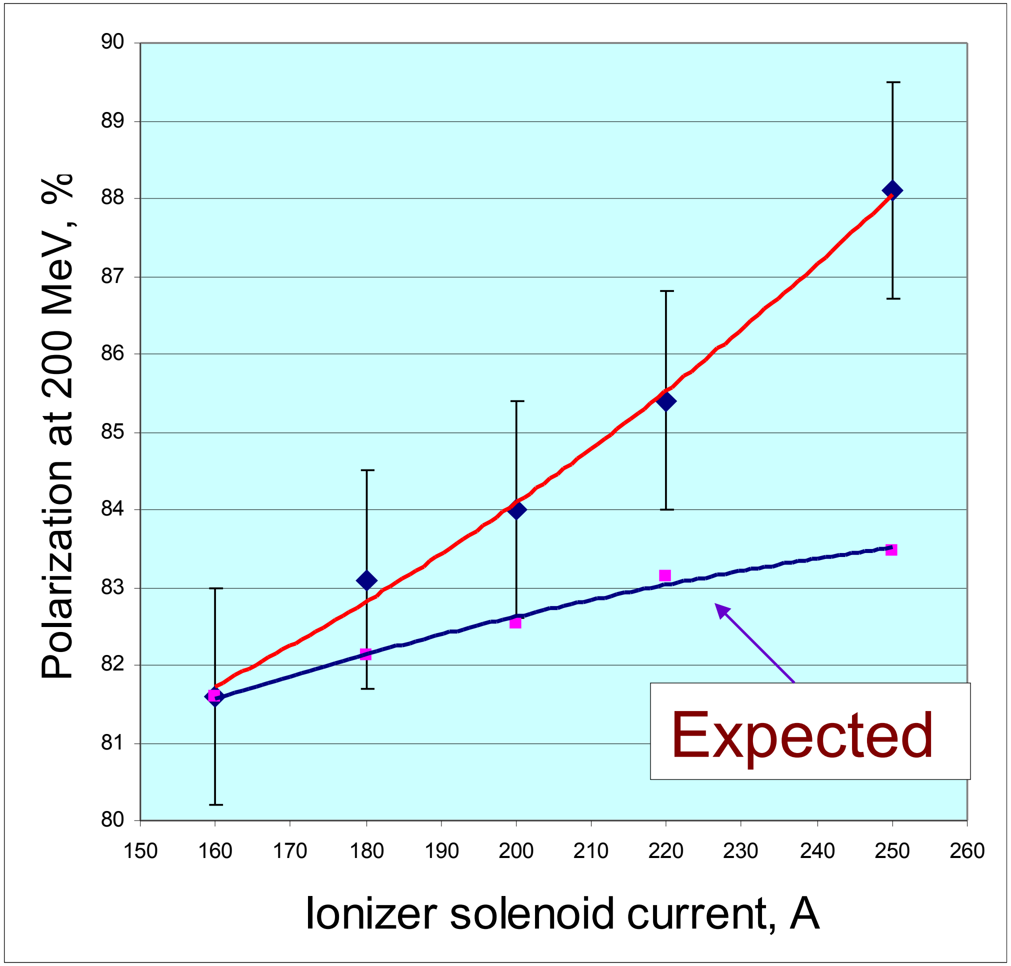
23 mm collimator.

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: ANALYZE | 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

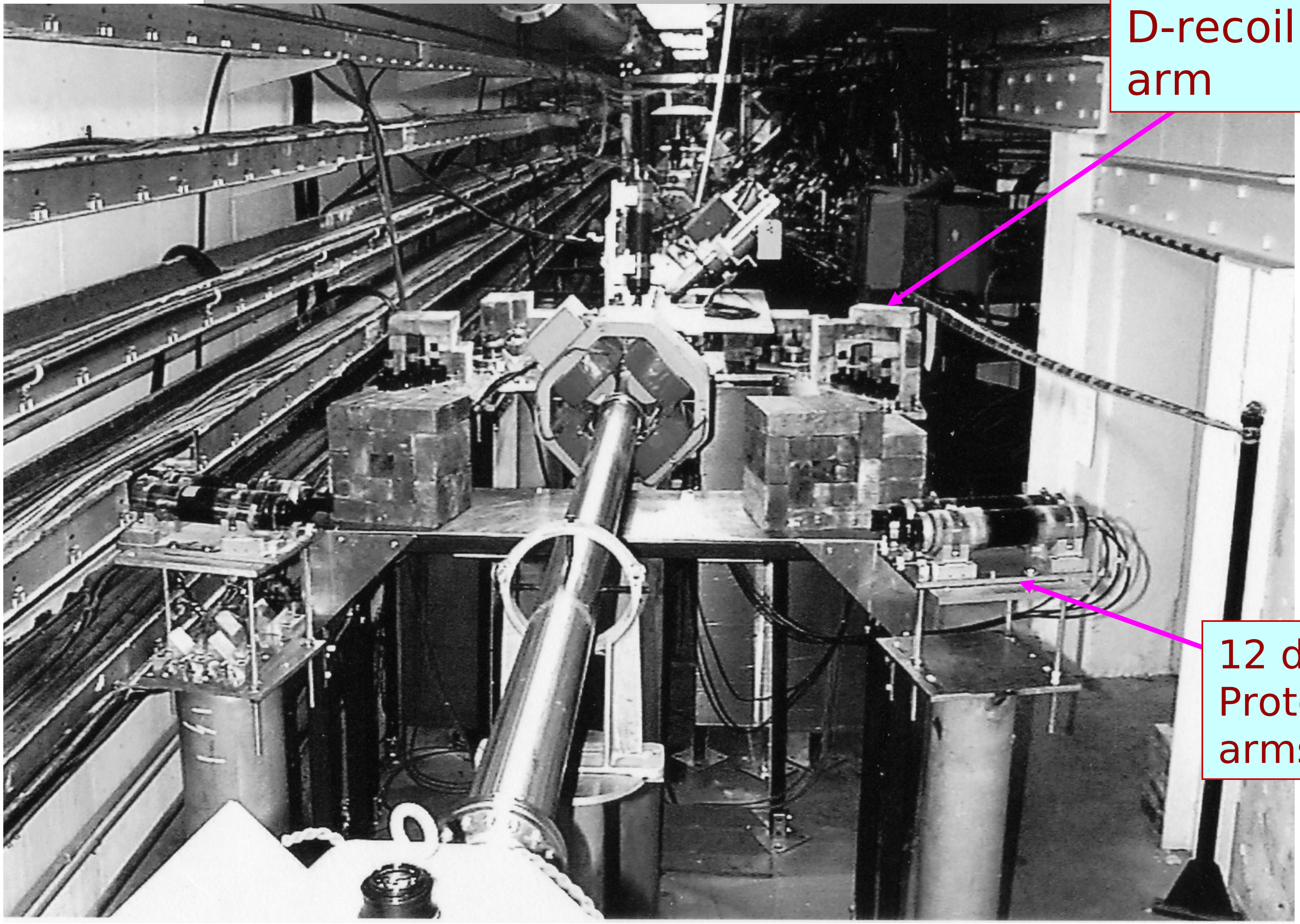
LEFT(SINGLE) POLARIZATION (P,dP): 0.85541 0.0207752 DOWN POLARIZATION: -0.877242

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

RESTART

Wed Apr 04 04:52:37 PM EDT 2007

200 MeV p-Carbon and p-D polarimeter.



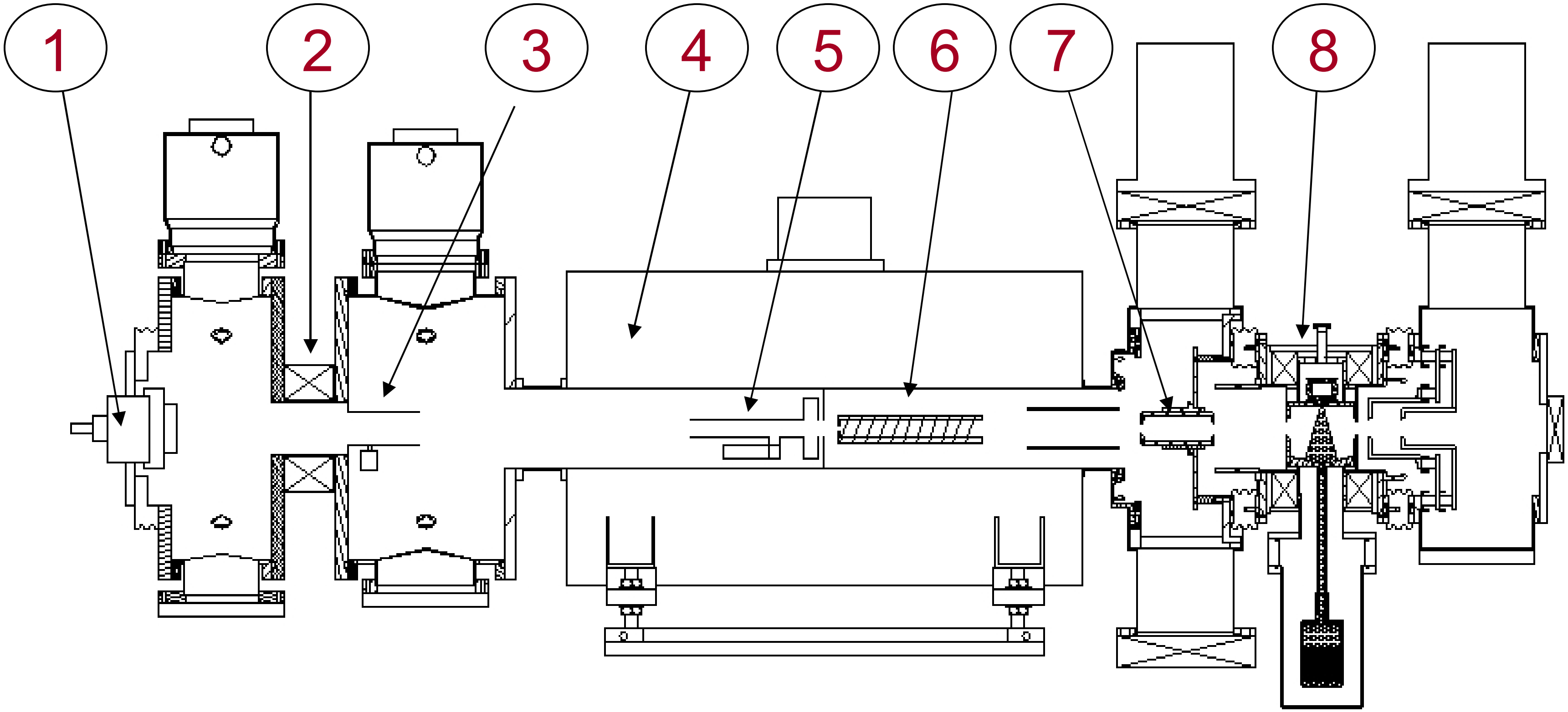
Polarimeter calibration, Run 2002-03, (after EL installation).

Run #	P, pD	P, pC	Ratio
158, April 7	78.6+/-6.5	73.0+/-0.2	1,07
159	79.5+/-4.5	72.8+/-0.2	1.09
160	74.7+/-6.8	72.9+/-0.2	1.03
161	85.6+/-3.7	73.0+/-0.2	1.17
162	79.2+/-3.4	74.0+/-0.2	1.07
169, April 9	78.6+/-5.0	72.5+/-1.5	1.08
174	76.7+/-5.1	73.0+/-1.0	1.05
191, Febr6,2003	90.7+/-7.6	75.5+/-1.5	1.20
197, Febr25, 2003	79.8+/-5.4	64.5+/-0.7	1.23
207, March2,2003	73.3+/-7.8	64.6+/-0.5	1,13

There is a plan to rebuilt proton-deuteron polarimeter and repeat calibration in 2010 Run.

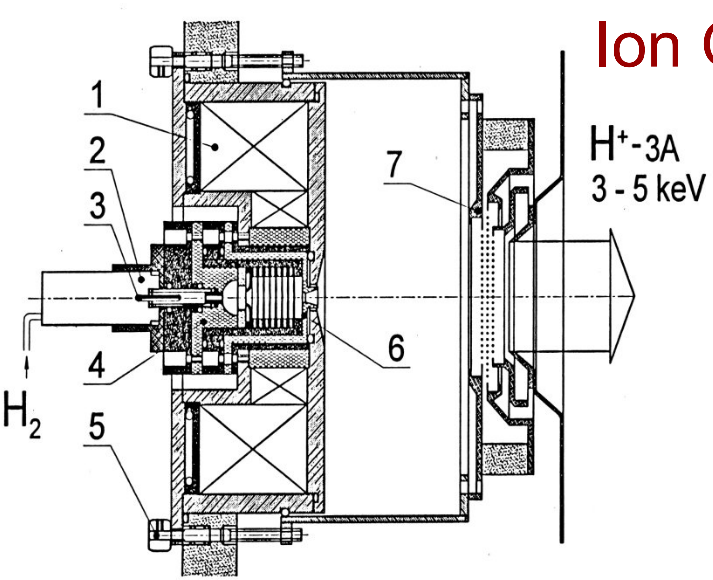
OPPIS with Fast Atomic Beam Source

The RHIC OPPIS upgrade with the "atomic H injector
is funded and will be implemented in 2010-12.

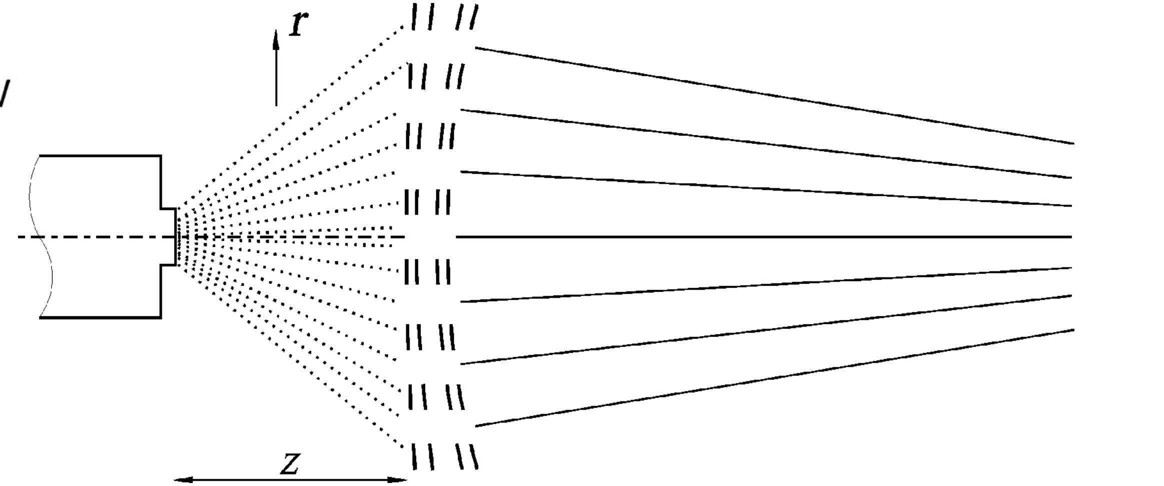


General layout: 1- high-brightness plasmatron proton source; 2 – focusing lens; 3- H2 neutralizer cell; 4-superconducting solenoid; 5-He ionizer cell; 6-Rb vapor cell; 7- Sona transition; 8- sodium-jet ionizer cell.

Proton "cannon" of the atomic H injector.

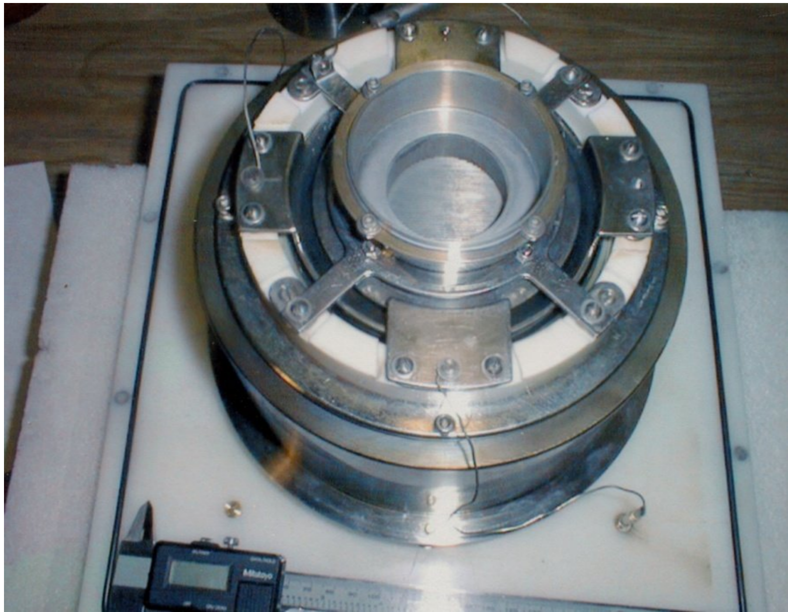


Ion Optical System with "geometrical focusing

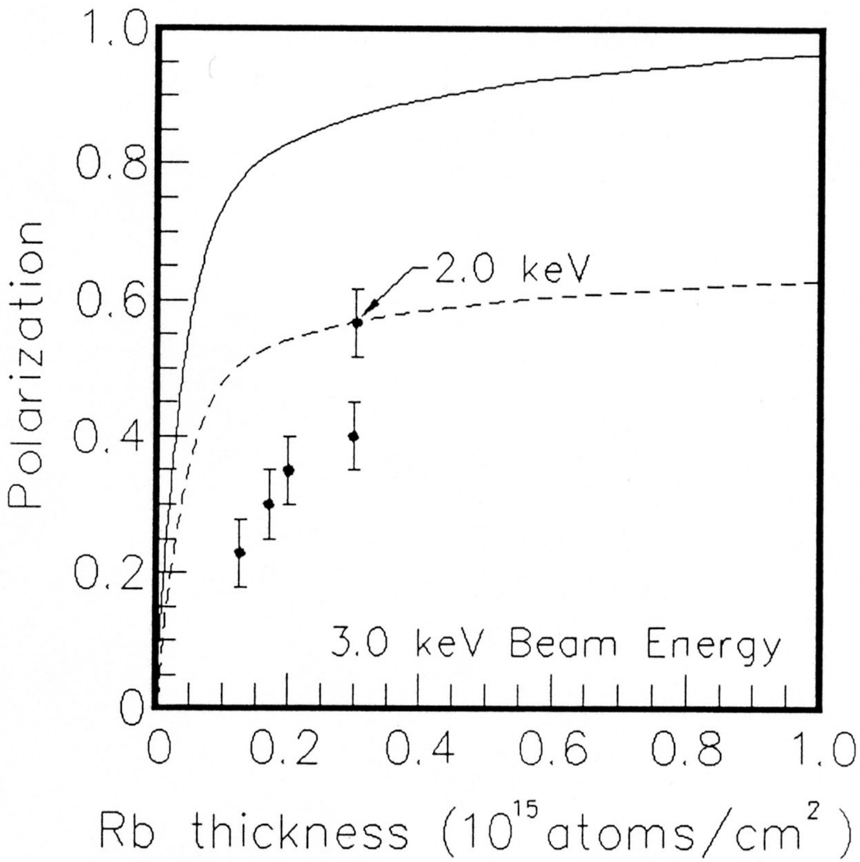


The source produced 3 A ! pulsed
proton current at 5.0 keV.

~20-50 mA H^- current. P=75-80%
~10 mA , P=85-90%.
~ 300 mA unpolarized H^- ion current.



Beam intensity and polarization in the pulsed OPPIS, TRIUMF 1999.



25 kG

10 kG

Beam energy, keV	2.0	3.0	4.0
H^- ion current, mA	5.0	8.0	14.0
Proton current, mA	16.0	50.0	
Polarization, %	55± 5	42± 5	30 ±5

OPPIS with the "Fast Atomic Hydrogen Source" *(Towards 100% polarization in OPPIS).*

- Higher polarization is also expected with the fast atomic beam source due to:

  a) elimination of neutralization in residual hydrogen;

  b) better Sona-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.

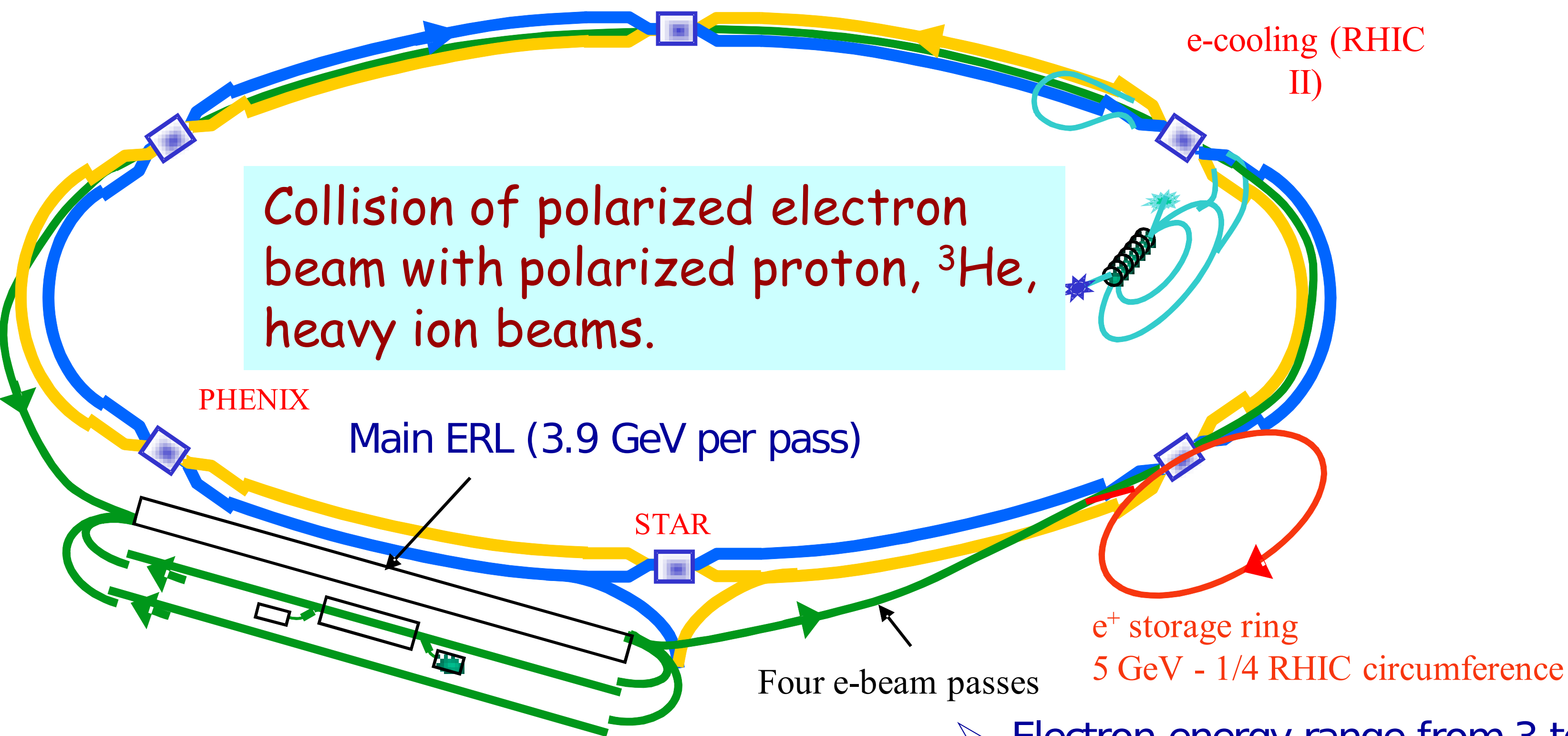
- All these factors combined will further increase polarization in the pulsed OPPIS to:

  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 and high polarization beam for polarized RHIC luminosity upgrade and for future eRHIC facilities.

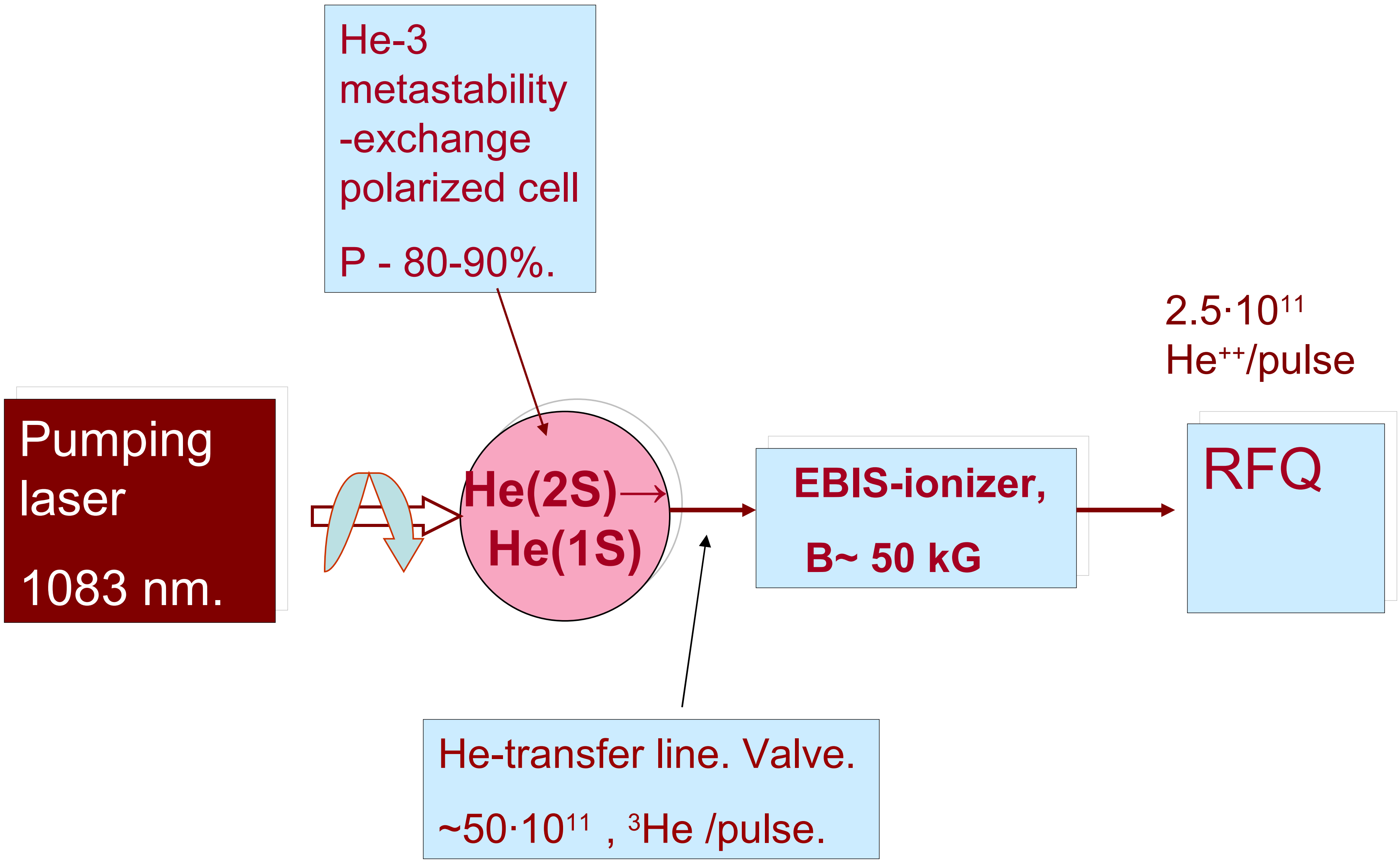
eRHIC-electron Ion Collider at BNL



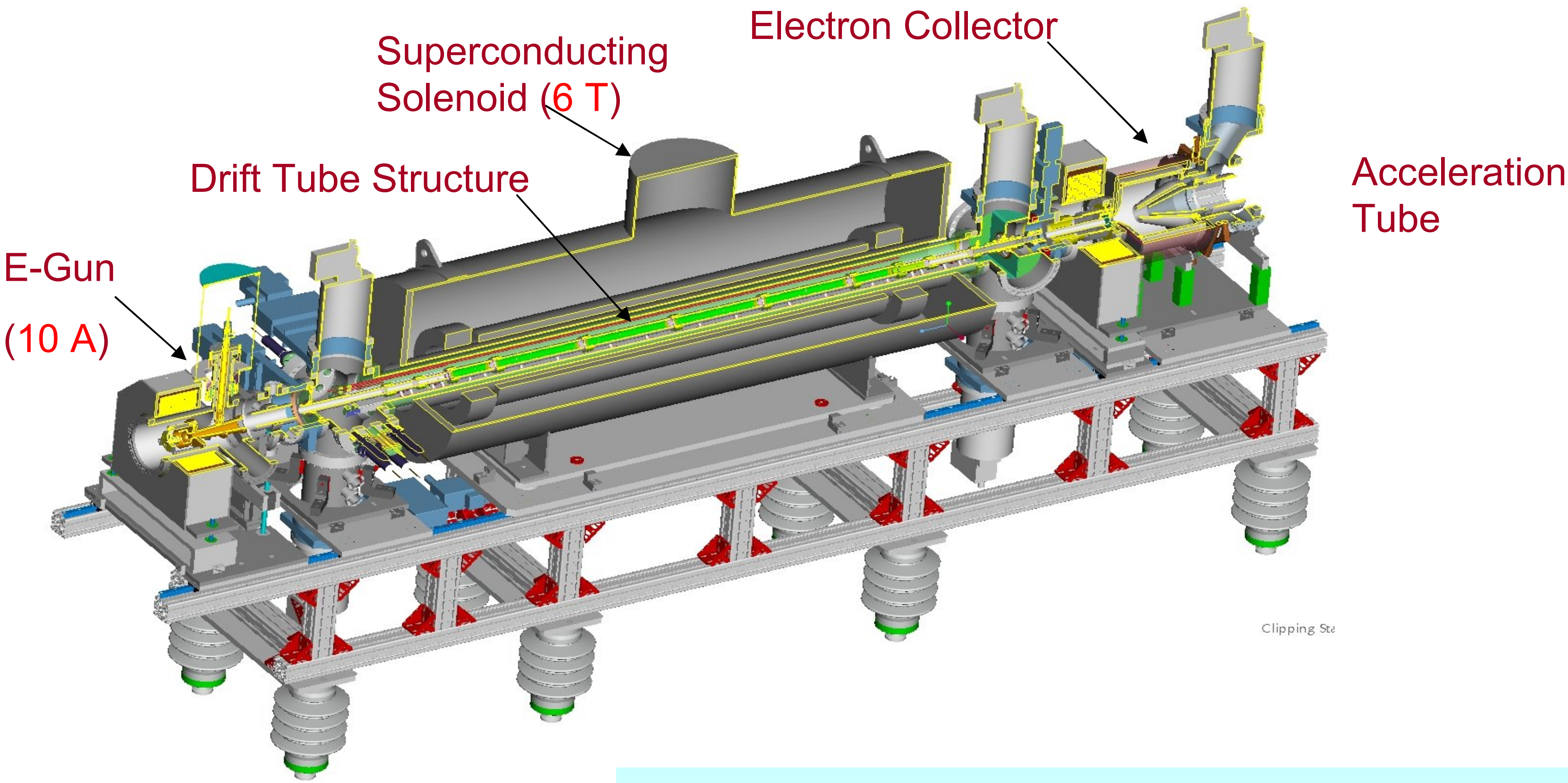
- Electron energy range from 3 to 20 GeV
- Peak luminosity of 2.6×10^{33} cm^{-2}s^{-}
- high electron beam polarization (~80%)
- full polarization transparency at all energies
- multiple electron-hadron interaction points

The AGS and RHIC "Siberian snakes" should preserve the $^3He^{++}$ beam polarization.

EBIS ionizer for polarized ^{3}He gas (proposal).



Electron Beam Ion Source at RHIC

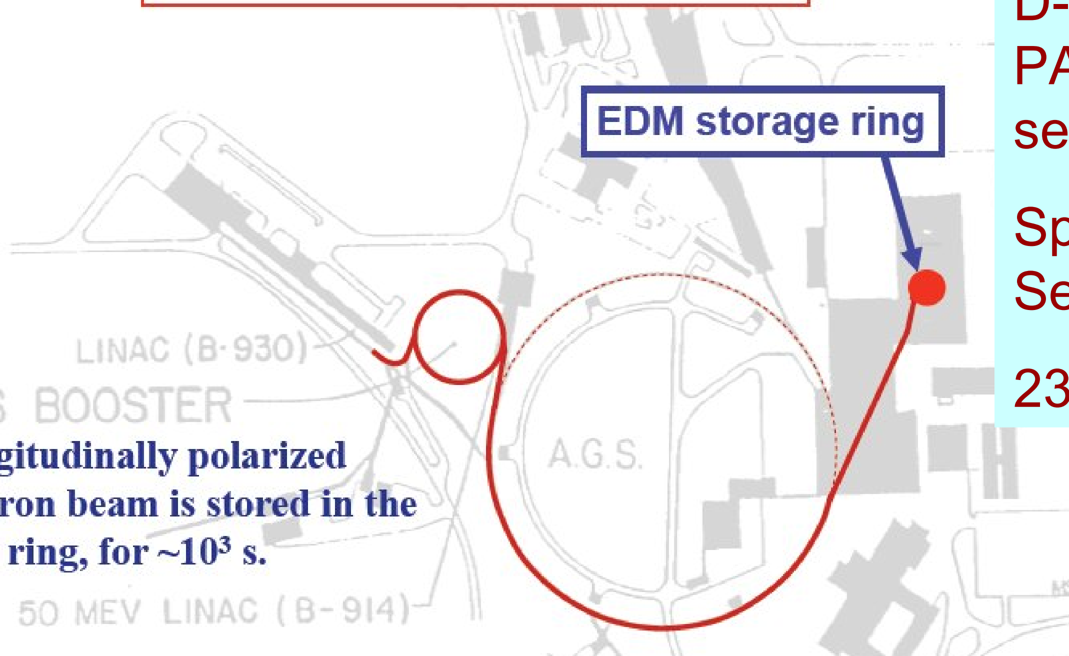


What intensity is expected?

Capacity will be 10^{12} charges/ pulse

→ ~ 2-3 x 10^{11} $^{3}He^{++}$ ions per

deuteron EDM search at BNL



A longitudinally polarized deuteron beam is stored in the EDM ring, for ~10^3 s.

The strong effective E*-field~V×B will precess the deuteron spin out of plane if it possesses a non-zero EDM

D-EDM exp't proposed to PAC in May 2008, with sensitivity goal of 10^{-29} e· cm

Spokesperson: Yannis Semertzidis (BNL)

23 collaborating institutions

System	Current limit [e·cm]	Future goal	Neutron equivalent
Neutron	$<1.6\times10^{-26}$	$\sim10^{-28}$	10^{-28}
199Hg atom	$<2\times10^{-28}$	$\sim2\times10^{-29}$	10^{-25}-10^{-26}
^{129}Xe atom	$<6\times10^{-27}$	$\sim10^{-30}$-10^{-33}	10^{-26}-10^{-29}
Deuteron nucleus		$\sim10^{-29}$	3×10^{-29}-5×10^{-31}

If nEDM is discovered at 10^{-28} e•cm level?

- If $\bar{\theta}$ is the source of the EDM, then

$$d_D(\bar{\theta})/d_n(\bar{\theta}) \approx 1/3 \Rightarrow d_D \approx 3\times10^{-29}\,\mathrm{e\cdot cm}$$

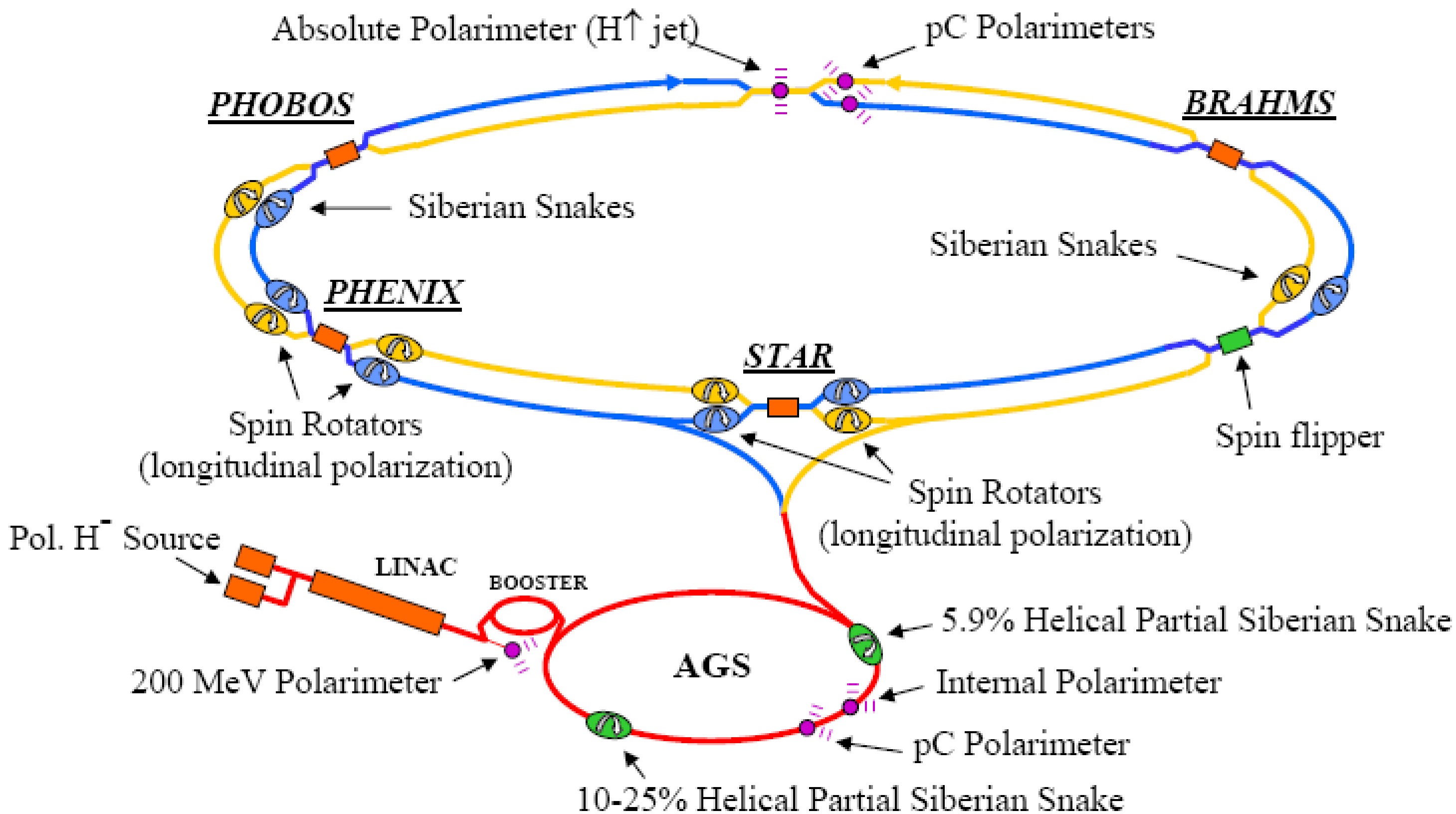
- If SUSY is the source of the EDM (isovector part of T-odd N-forces), then

$$d_D(\bar{\theta})/d_n(\bar{\theta}) \approx 20 \Rightarrow d_D \approx 2\times10^{-27}\,\mathrm{e\cdot cm}$$

The deuteron EDM is complementary to neutron and in fact has better sensitivity.

Polarized beam acceleration in AGS and RHIC.

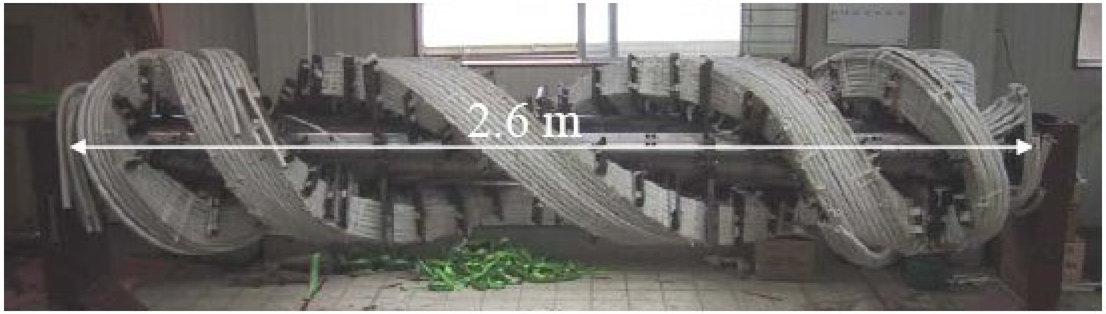
RHIC – First Polarized Hadron Collider

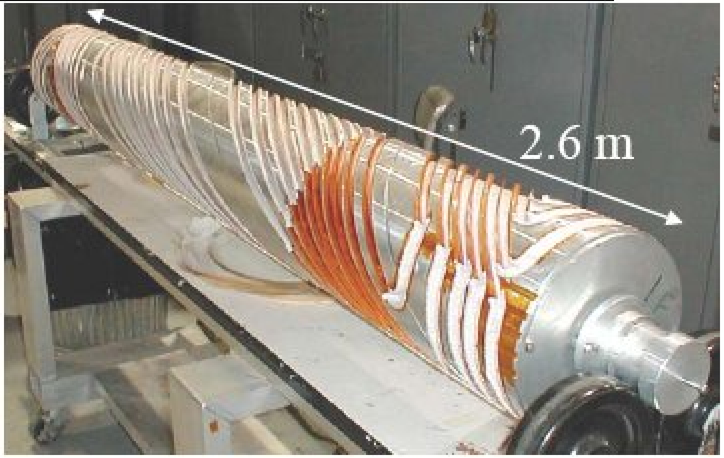


Without Siberian snakes: $\nu_{sp} = G\gamma = 1.79\ E/m \rightarrow \sim 1000$ depolarizing resonances
With Siberian snakes (local 180° spin rotators): $\nu_{sp} = ½ \rightarrow$ no first order resonances
Two partial Siberian snakes (11° and 27° spin rotators) in AGS

BROOKHAVEN NATIONAL LABORATORY

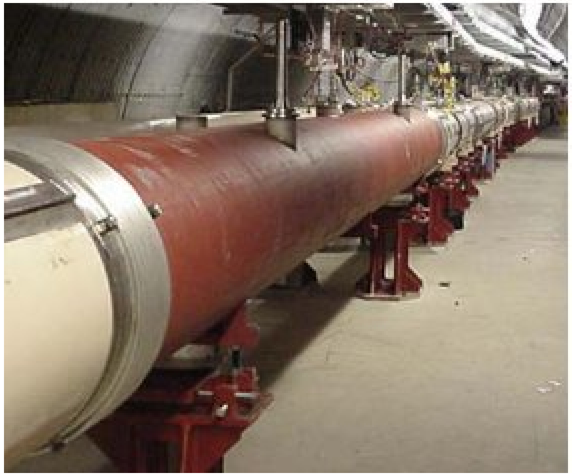
Siberian Snakes

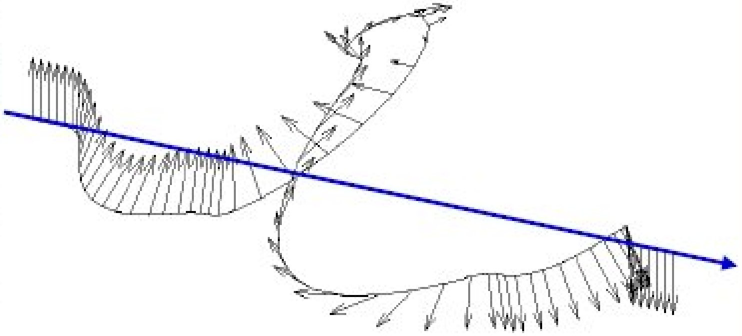


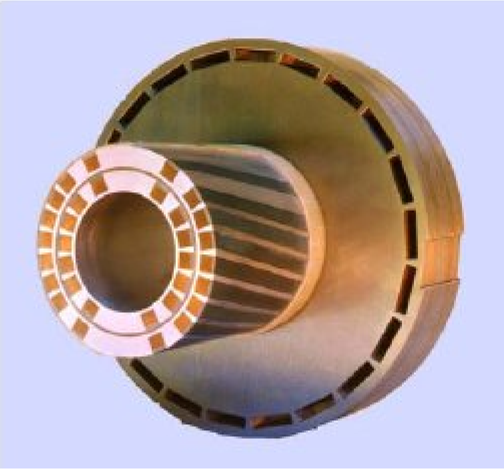


Major funding by RIKEN, Japan
RT helical dipole constructed at Tokano Ind., Japan
SC helical dipoles constructed at BNL

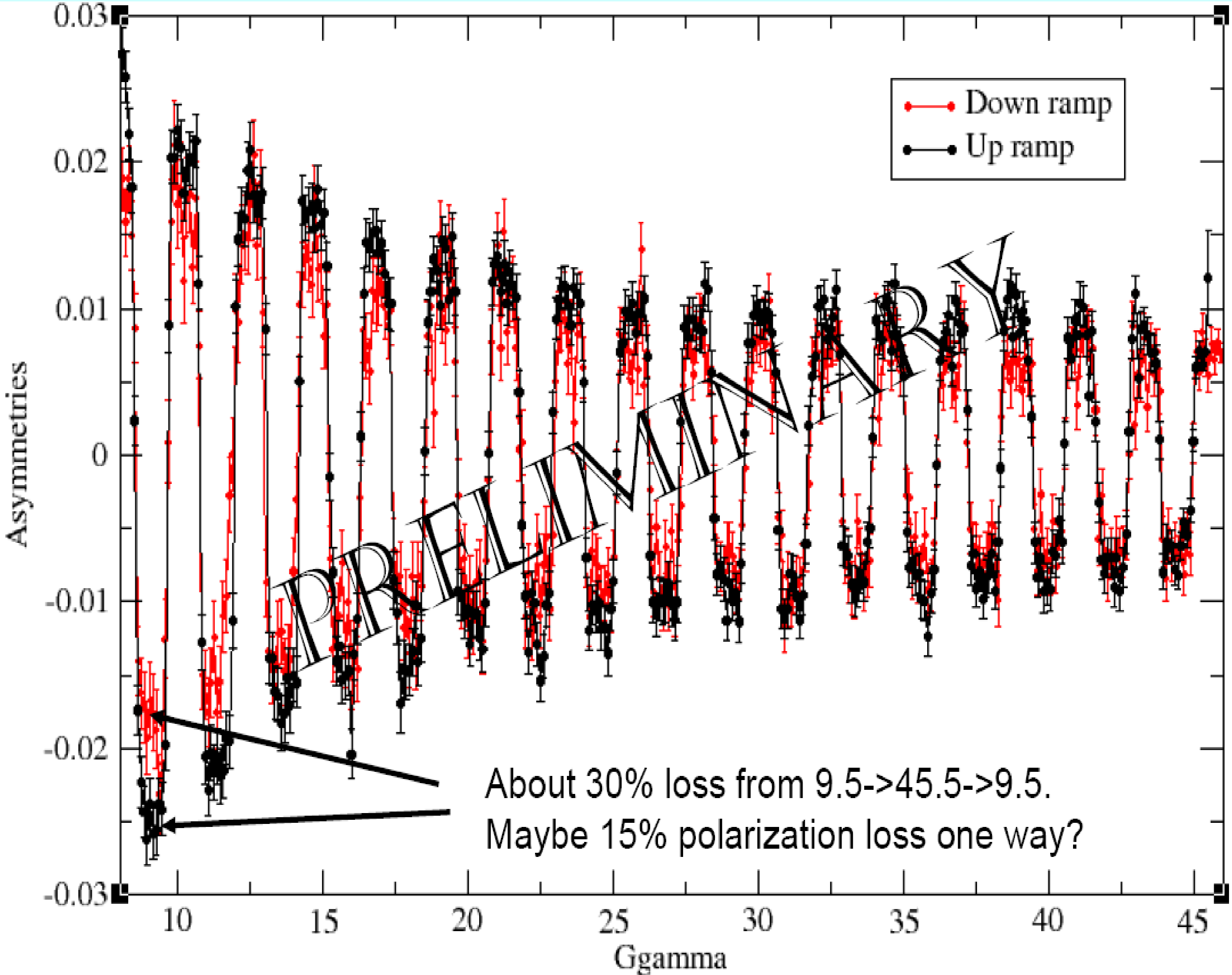
AGS Siberian Snakes: variable twist helical dipoles, 1.5 T (RT) and 3 T (SC), 2.6 m
RHIC Siberian Snakes: 4 SC helical dipoles, 4 T, each 2.4 m long and full 360° twist



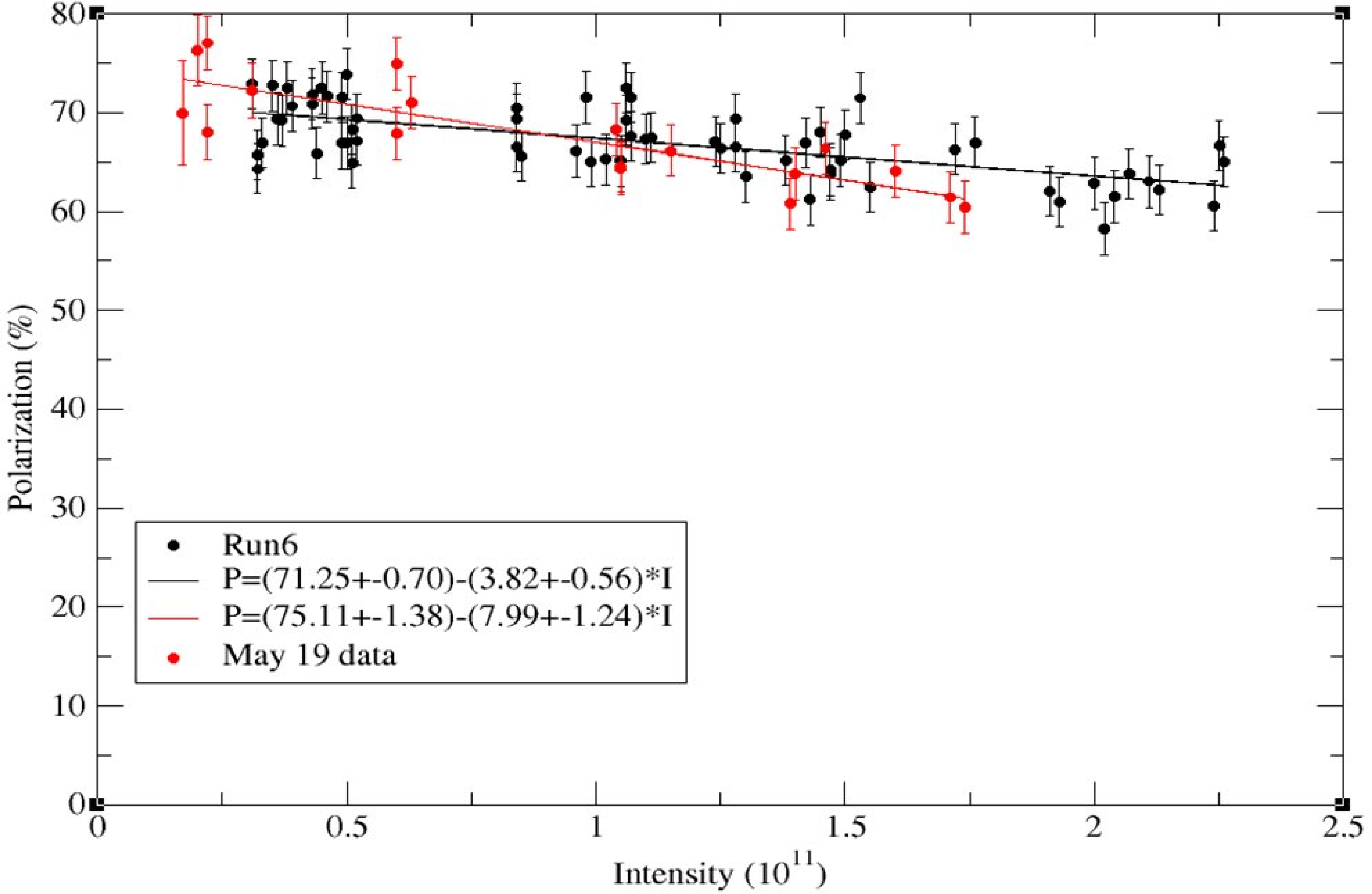




larization measurements during the energy ramp in



AGS polarization vs beam intensity



Pulsed Quads

motivation:

We lose (10-20)% of the (linac) 200MeV polarization by AGS extraction. Some of that loss occurs when the beam crosses the horizontal intrinsic resonances ($G\gamma$=M+/-Qh). This condition (different M's) is satisfied 82 times between ags injection $G\gamma$=4.5 and transfer to RHIC $G\gamma$=45.5. The polarization loss at each crossing is inversely proportional to the speed at which the resonance condition is crossed by the beam. Because the resonance condition depends on the horizontal tune, shifting the tune during the crossing changes the crossing speed and hence can reduce the polarization loss. The new pulsed quad system does this.

Leif Ahrens talk, at 2009 RHIC retreat

Polarimetry at RHIC.

Low energy polarimeters (Lamb-shift, 200 MeV).

P-P and P –Carbon CNI polarimeters in AGS and RHIC.

Absolute H-jet polarimeter. Y.Makdisi talk this afternoon.

Local polarimeters at STAR and PHENIX. M.Togawa talk this afternoon.

A_N for Coulomb -Nuclear Interference.

the left – right scattering asymmetry A_N arises from the interference of the spin non-flip amplitude with the spin flip amplitude (Schwinger)

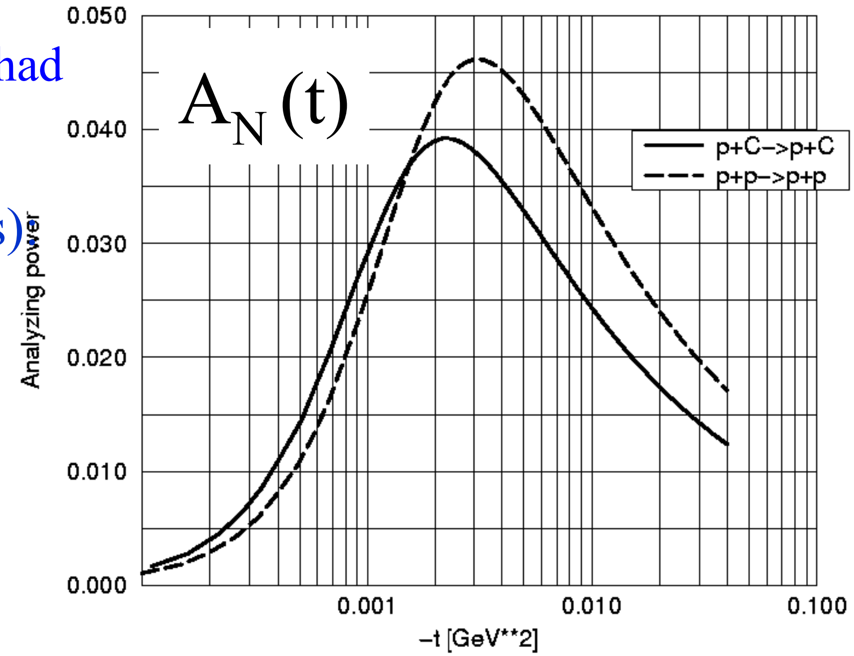
$$A_N = C_1 \,\mathrm{Im}(\phi^{em}_{flip}{}^{*}\phi^{had}_{non-flip}) + C_2 \,\mathrm{Im}(\phi^{had}_{flip}{}^{*}\phi^{had}_{non-flip})$$

$\propto (\mu - 1)_p$ $\propto \sqrt{\sigma^{pp}_{had}}$

in absence of hadronic spin – flip contributions

A_N is exactly calculable (Kopeliovich & Lapidus)

$$A_N = \sqrt{\frac{8\pi Z\alpha}{m_p^2 \sigma^{pA}_{tot}}} \frac{y^{3/2}}{1+y^2}(\mu - 1) \qquad y = \frac{\sigma^{pA}_{tot} t}{8\pi Z\alpha}$$



hadronic spin- flip modifies the QED "predictions"

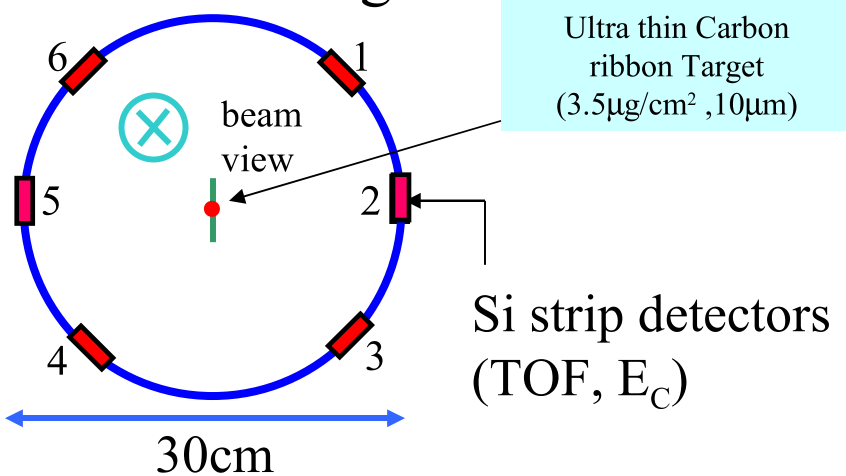
$$\frac{\mu_p - ١}{٢} \rightarrow \frac{\mu_p - ١}{٢} - I_٥ + \left(\frac{\mu_p - ١}{٢} I_٢\right)$$

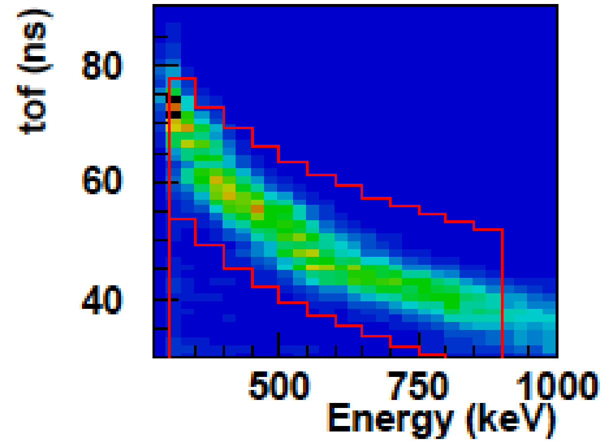
interpreted in terms of Pomeron spin – flip and parametrized as

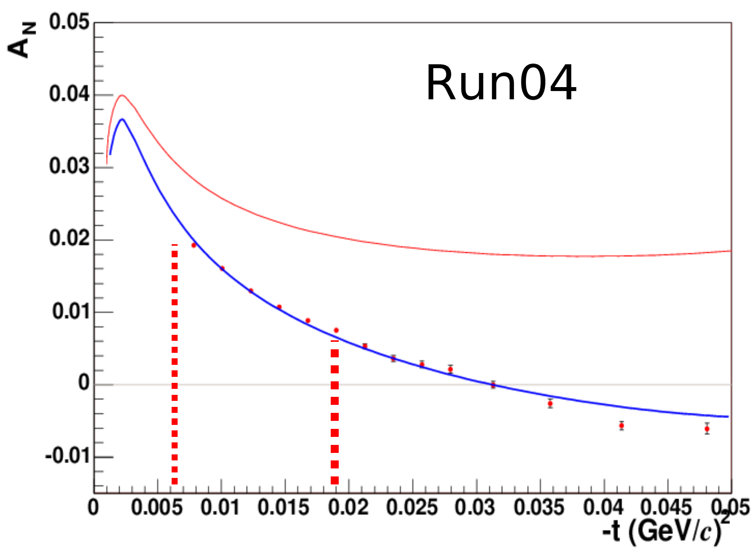
$$\phi^{had}_5 = \tau(s)\frac{\sqrt{-t}}{m_p}\phi^{had}_0$$

Proton-Carbon CNI polarimeter in RHIC.

RHIC x 2 rings







unpublished

$E_{beam} = 100$ GeV

- Measuring the recoil carbons from
- Carbon identification by kinematics cut (banana cut)

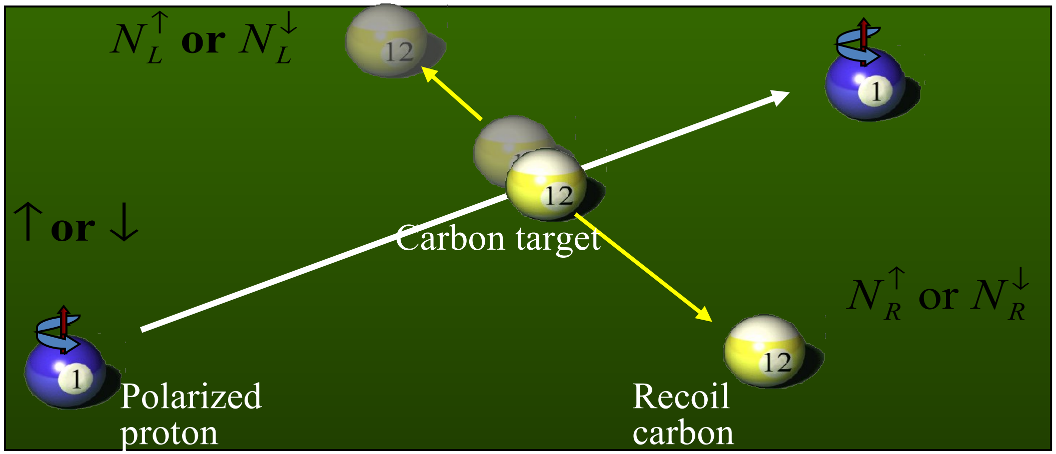
$$p^{\uparrow}C \rightarrow p^{\uparrow}C$$

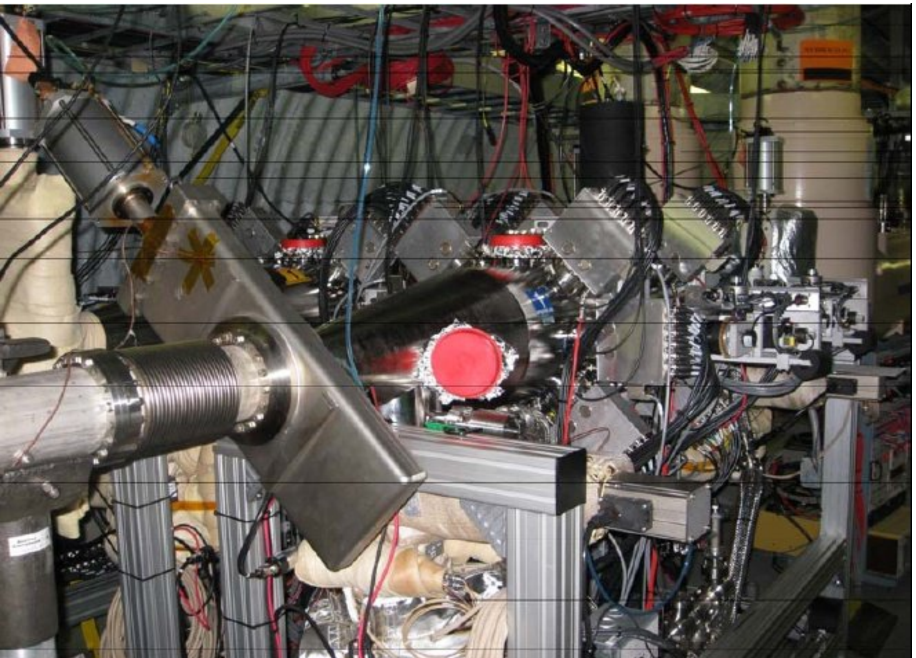
$$P_B = \frac{\varepsilon_{LR}}{A_N}, \quad \varepsilon_{LR} = \frac{N_L - N_R}{N_L + N_R}$$

$A_N \approx$ ٠.٠١٥ originates from anomalous magnetic moment of p

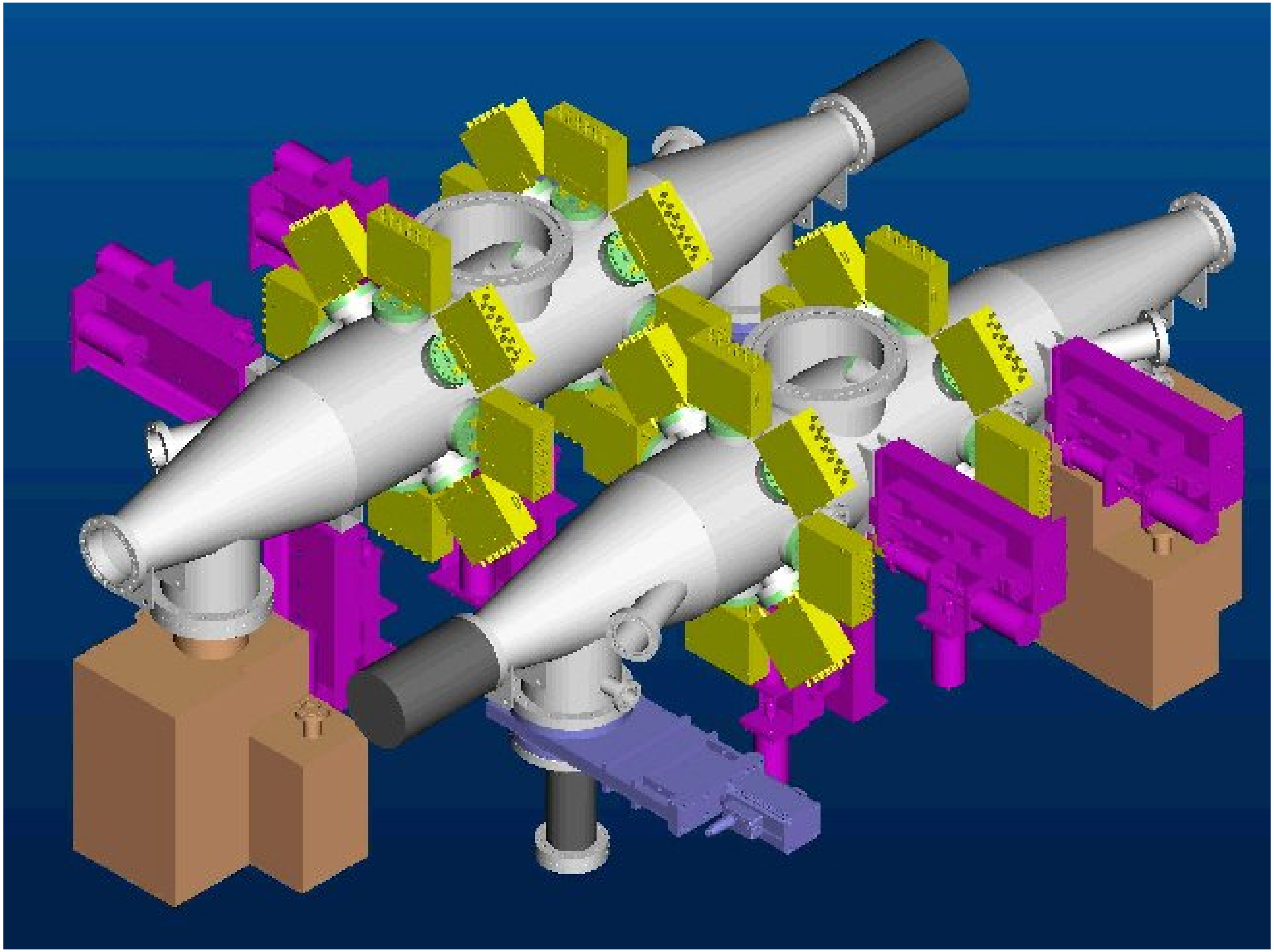
P-Carbon CNI polarimeter.

Elastic scattering: interference between electromagnetic and hadronic amplitudes in the Coulumb-Nuclear Interference (CNI) region





The RHIC p-Carbon CNI polarimeter upgrade for the beam polarization and intensity profile measurements (G.Mahler, S.Bugros)



The CNI polarimeter upgrade for the 2009 Run.

- Two identical target motion mechanisms and detectors assemblies were installed in new vacuum chambers in each ring.
- One polarimeter is used for the vertical polarization and intensity profile measurements and the other was used for the horizontal profile measurements (or vice versa).
- As a result the systematic polarization, polarization profiles and emittance measurements were obtained for both the vertical and horizontal planes (in previous Runs the measurements were limited to one plane, due to long target switching time).

- Additional set of detector ports had facilitated new detectors development, while keeping the established technique intact.

- Two sets of targets extended the period between target replacements and reduced the machine downtime.

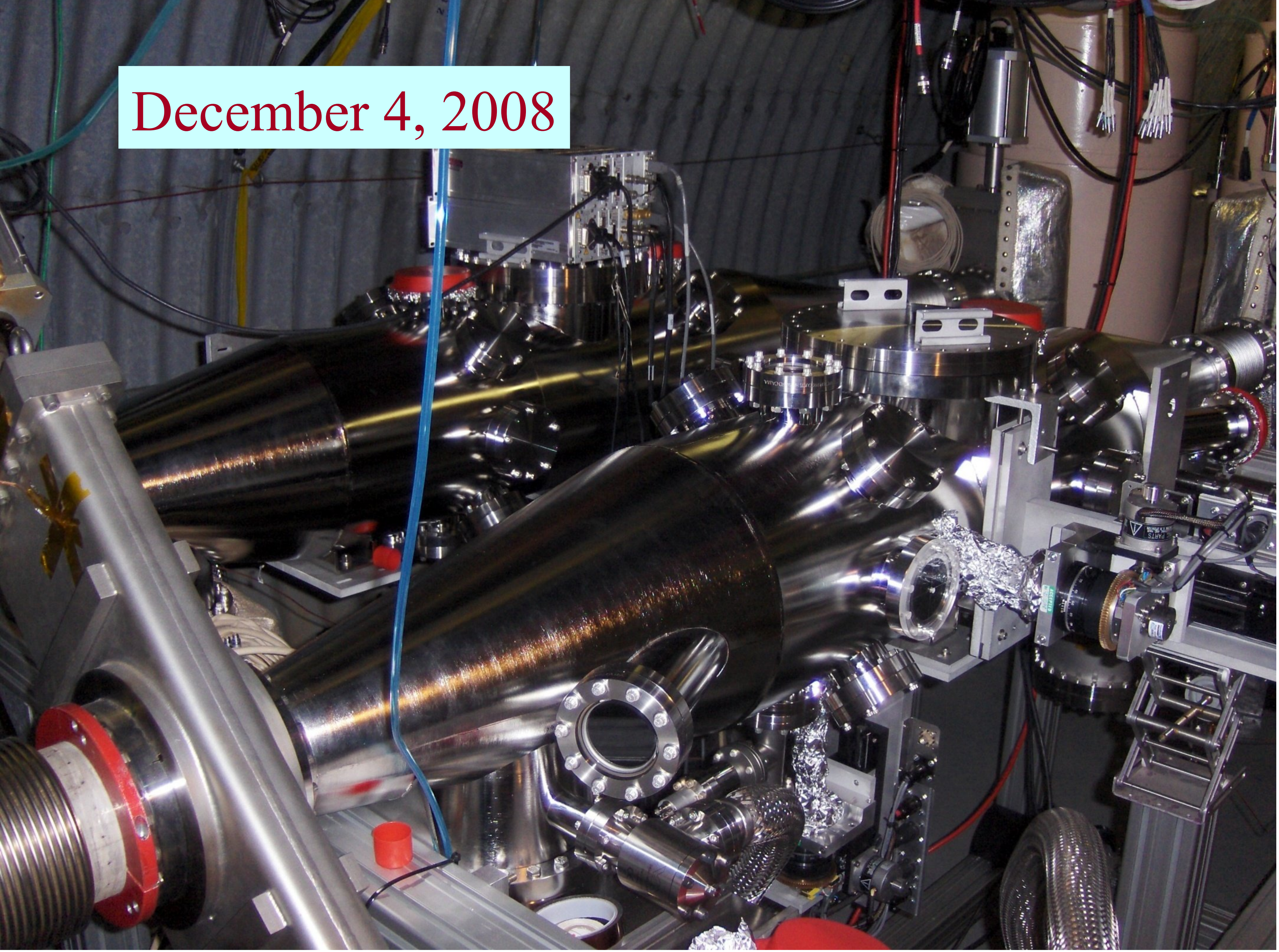
- Additional polarization and emittance measurements can be done with extra set of targets (polarization and emittance measurements during the energy ramp).

Measurements with p-Carbon CNI polarimeter

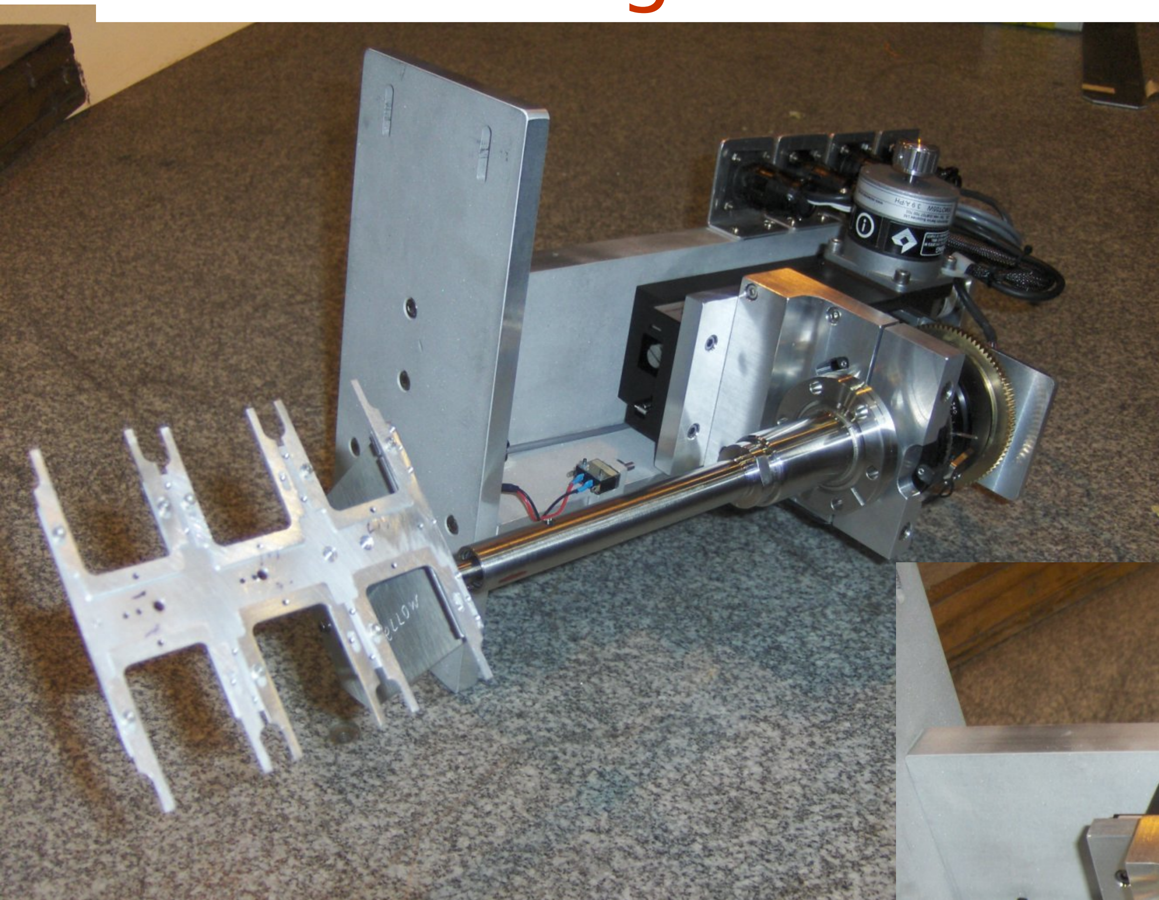
- Polarization, polarization profile measurements in the scanning mode.
- Polarization losses during acceleration and store.
- Polarization decay during store.

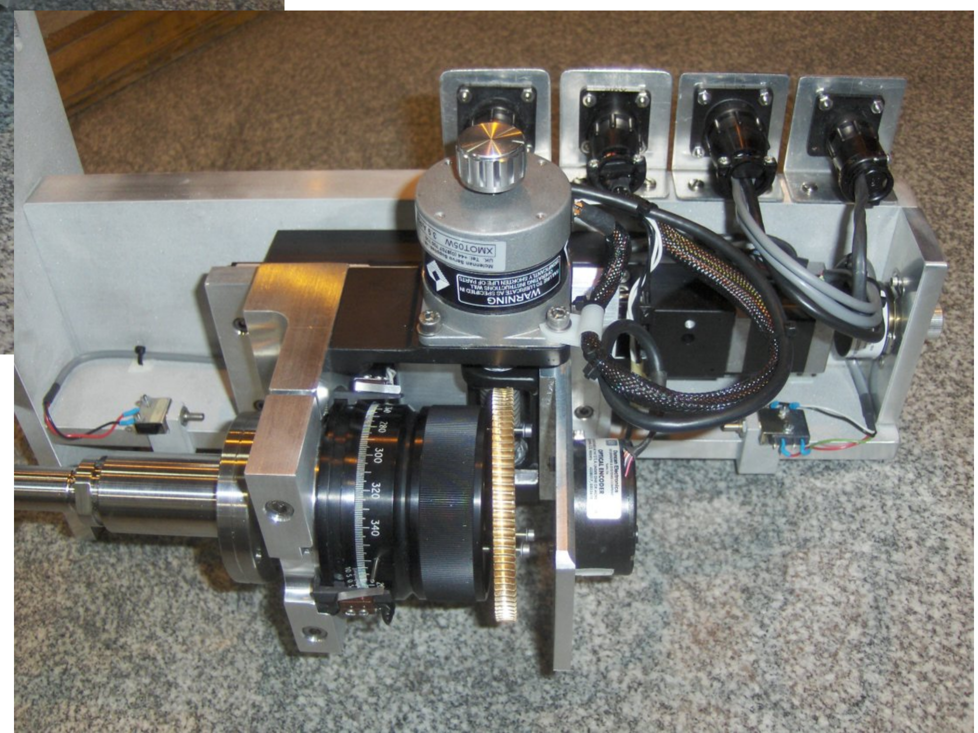
- Beam intensity profile (emttance) including bunch-by-bunch.
- Emittance measurements cross-calibrations.
- Emittance measurements on the ramp.

December 4, 2008

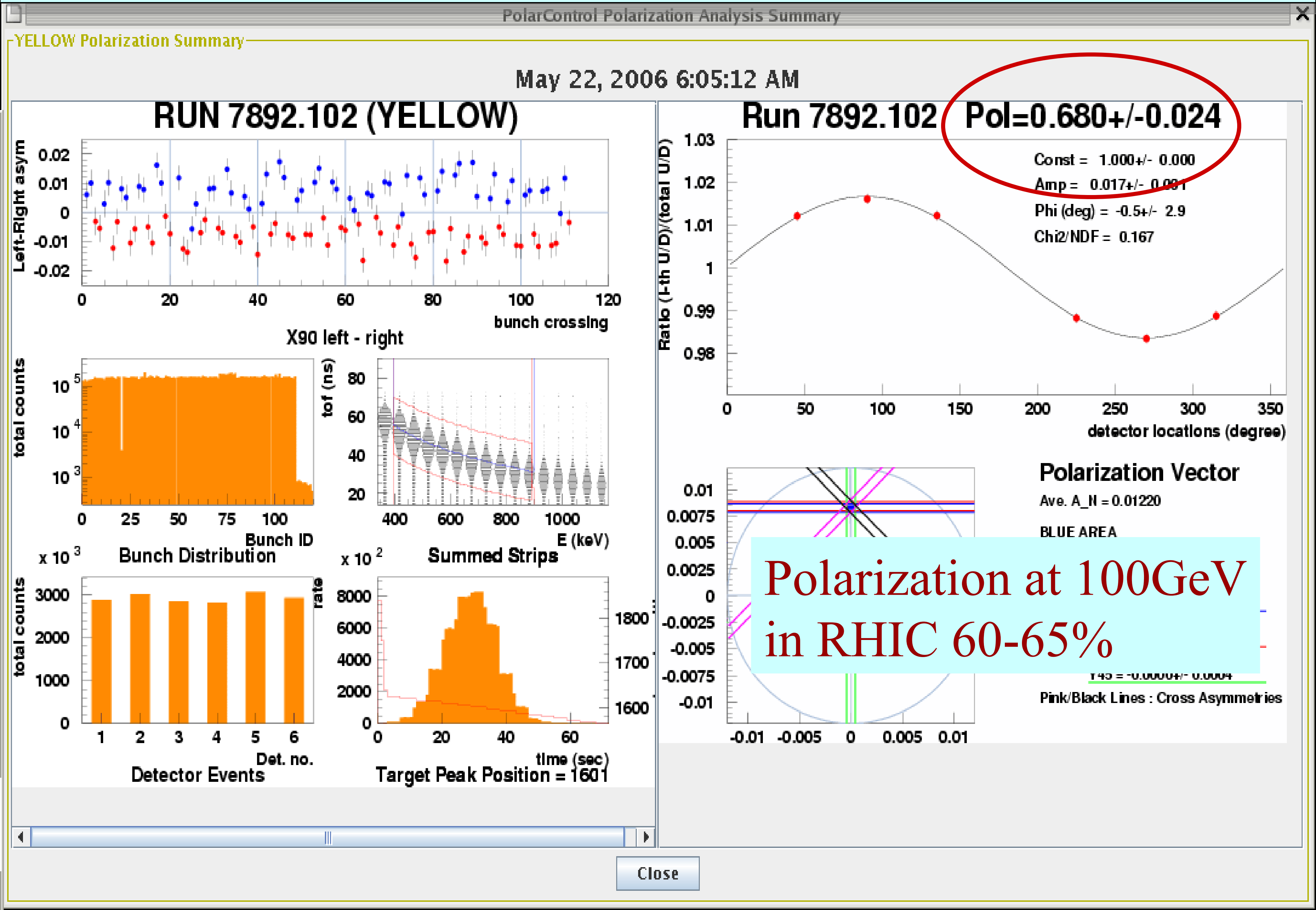


New target motion mechanism.





Polarization measurements in RHIC at 100 GeV.



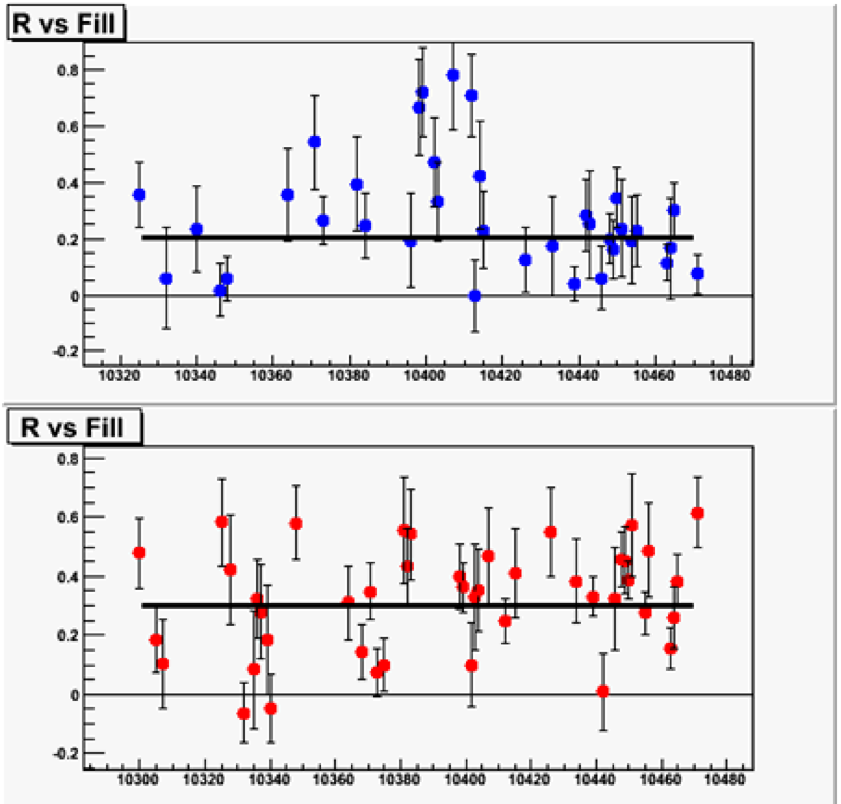
Polarization at 100GeV in RHIC 60-65%

First Look in Pol. Profile

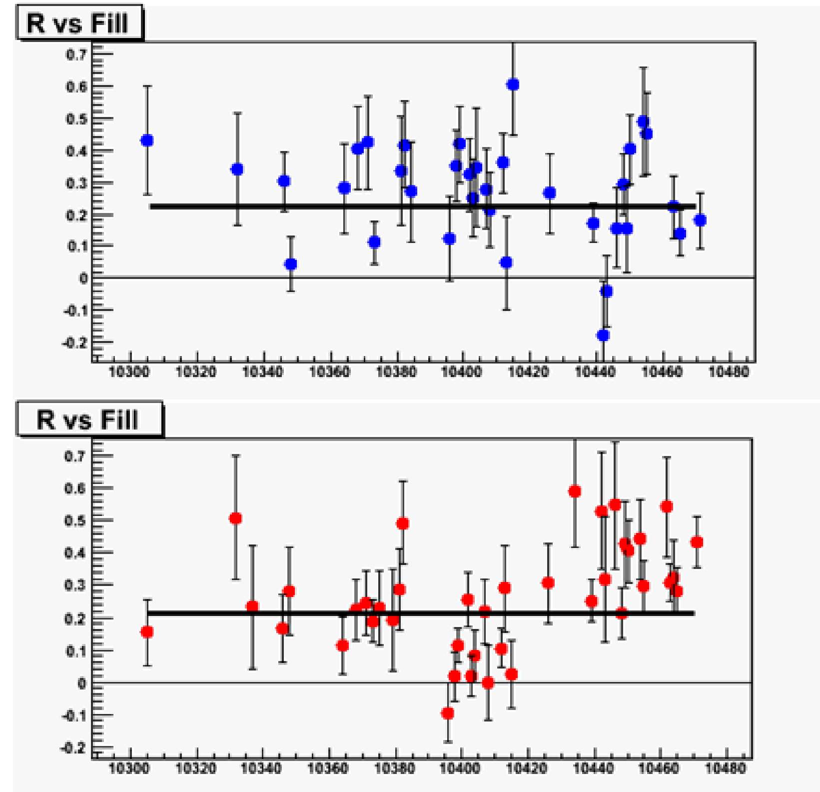
$$R = \frac{\sigma_I^2}{\sigma_P^2}$$

250 Gev

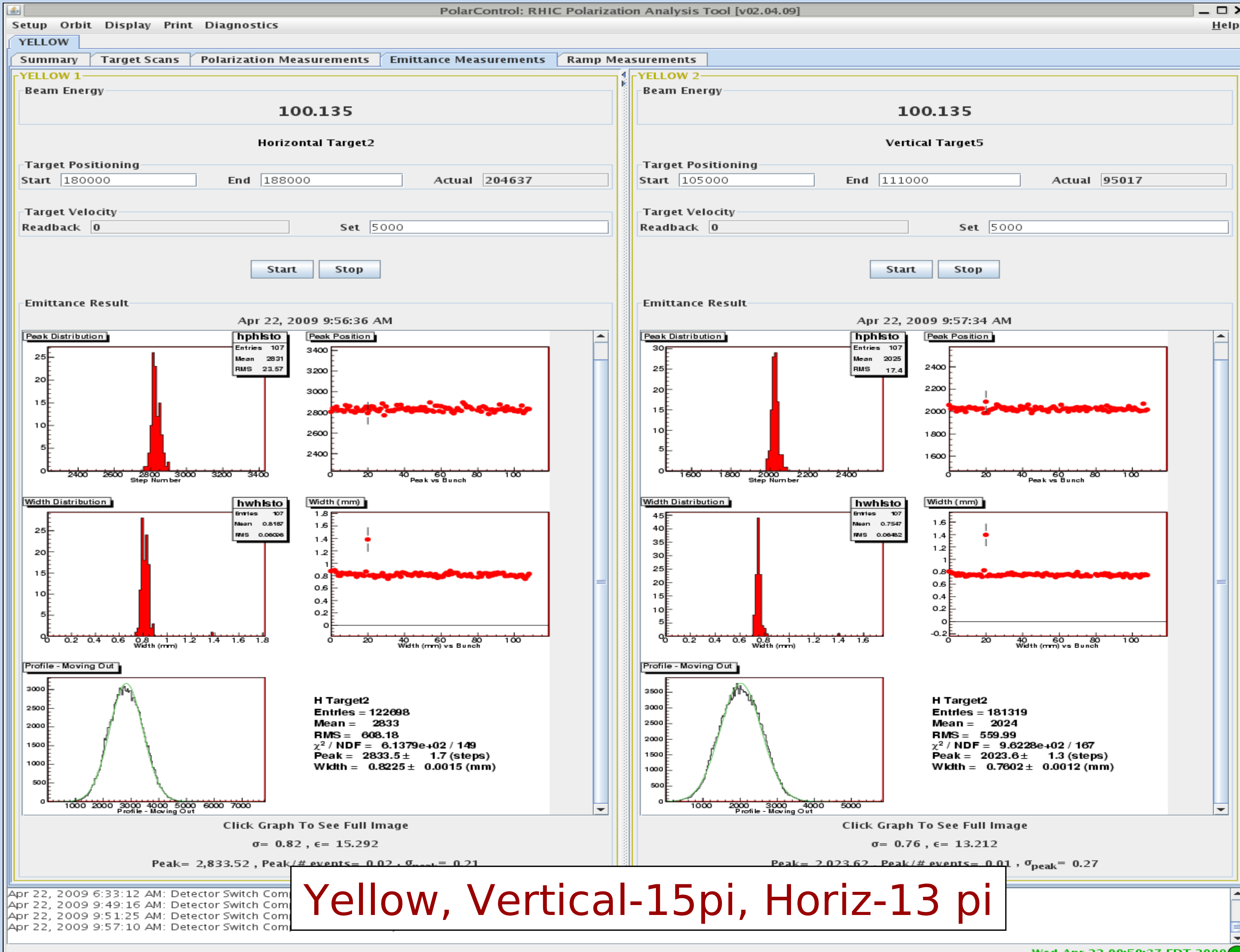
Polarimters 1



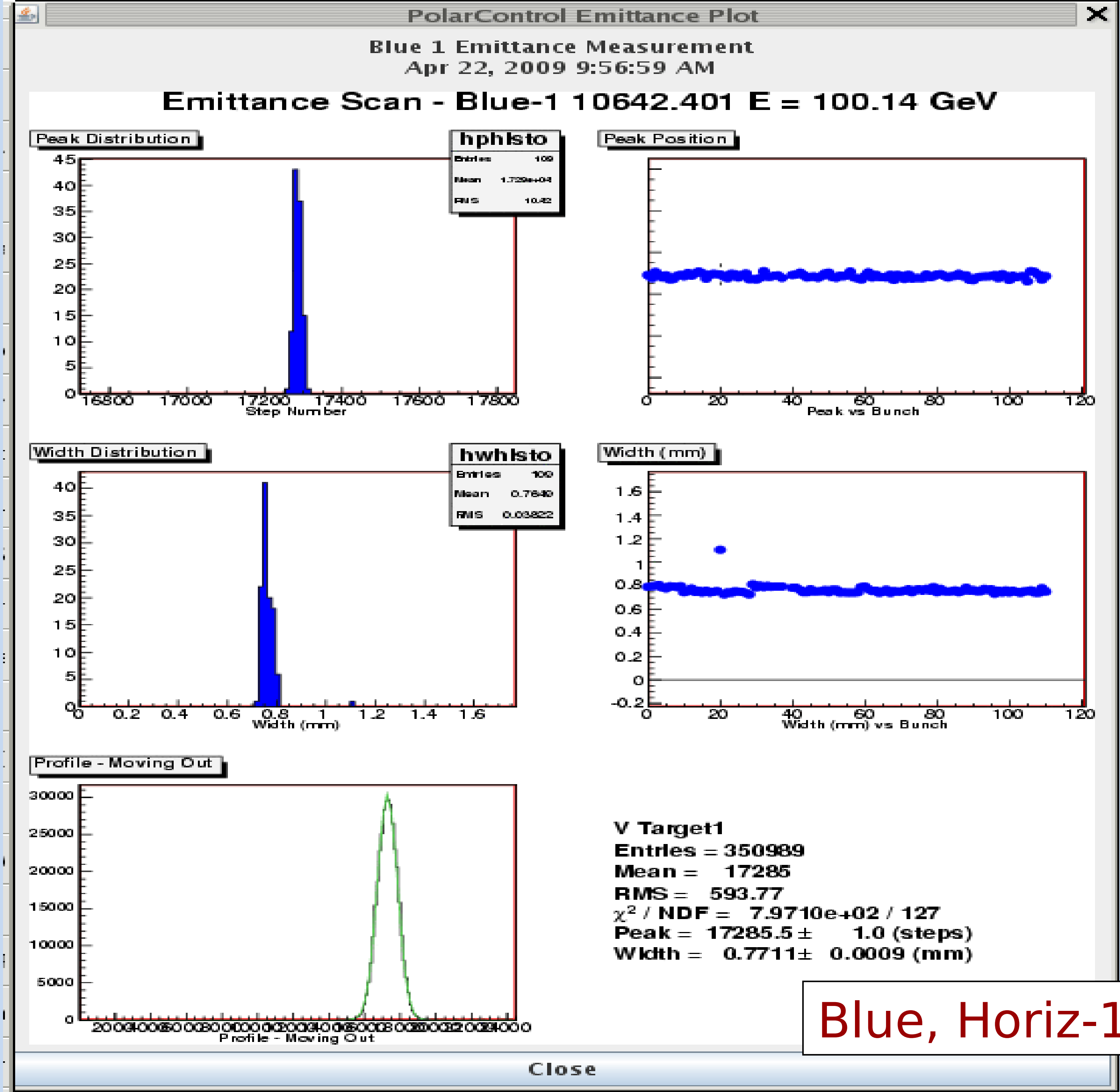
Polarimters 2



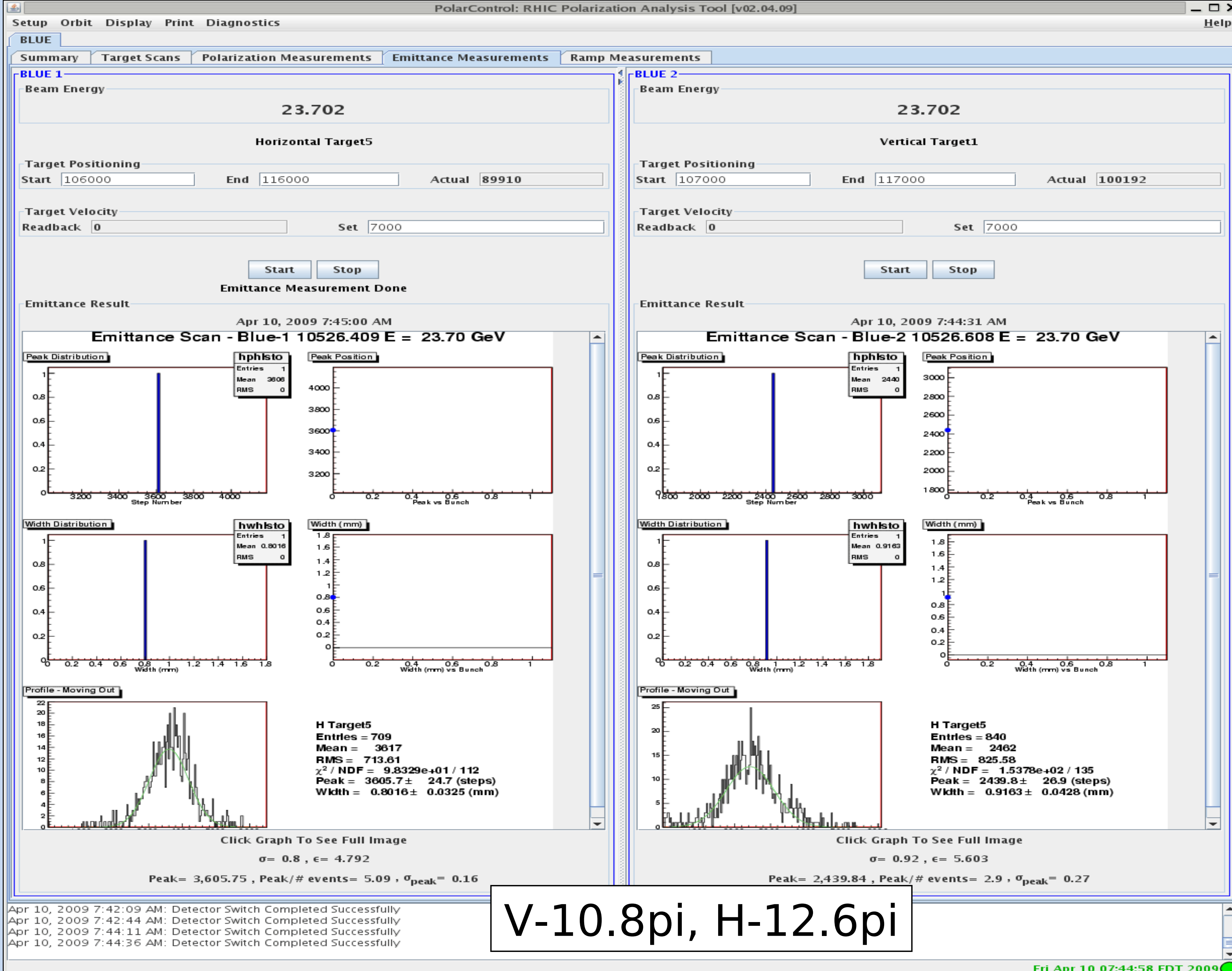
"Rate" effect may affect R measurement (not corrected yet)
Horizontal and Vertical profiles are plotted together
R≈0.15 in previous years (100 GeV beams)
R≈0.2 $\Rightarrow$ Experiments see 10% more polarization than Hjet



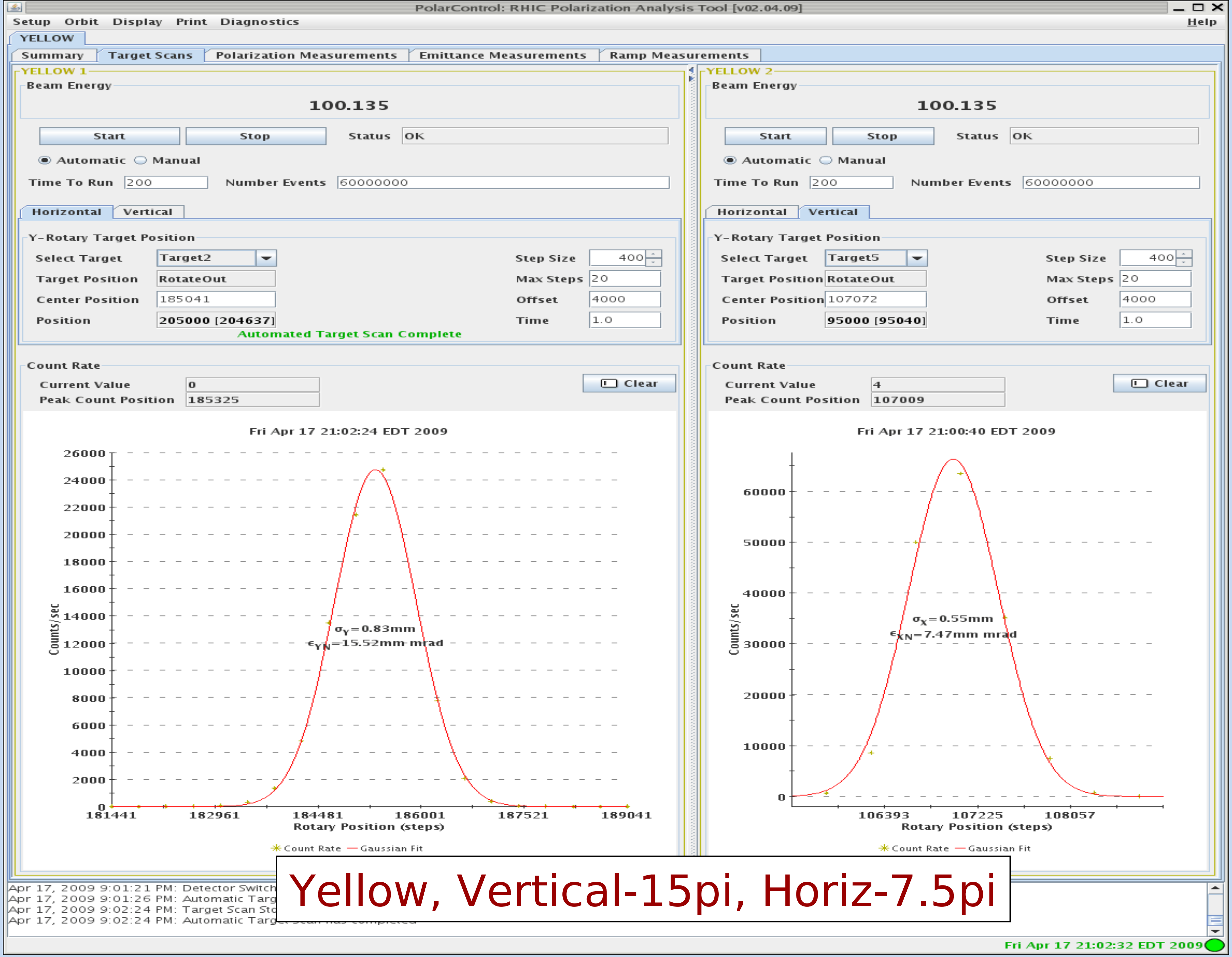
Yellow, Vertical-15pi, Horiz-13 pi



Blue, Horiz-13.7pi



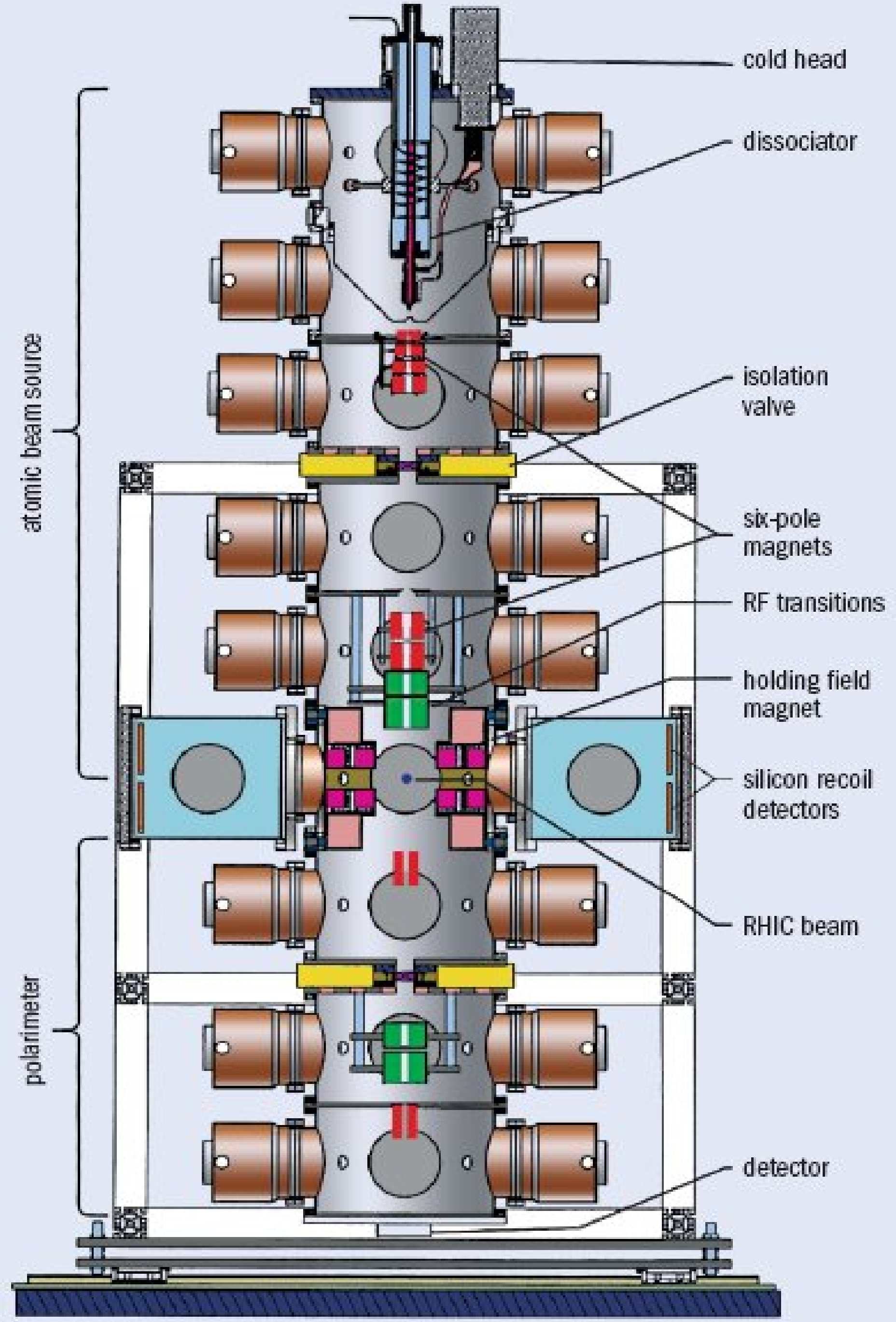
V-10.8pi, H-12.6pi



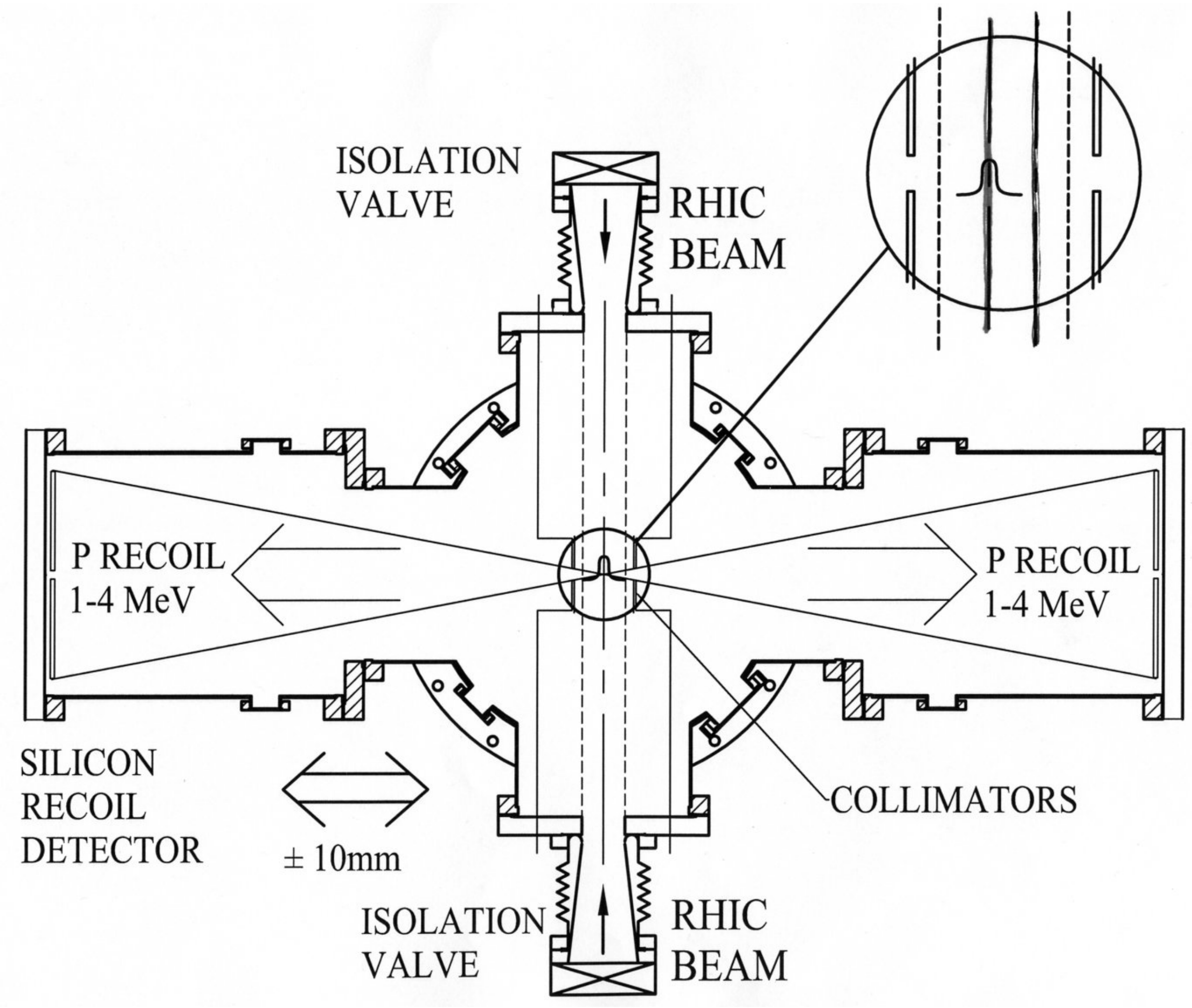
Yellow, Vertical-15pi, Horiz-7.5pi

H-jet polarimeter.

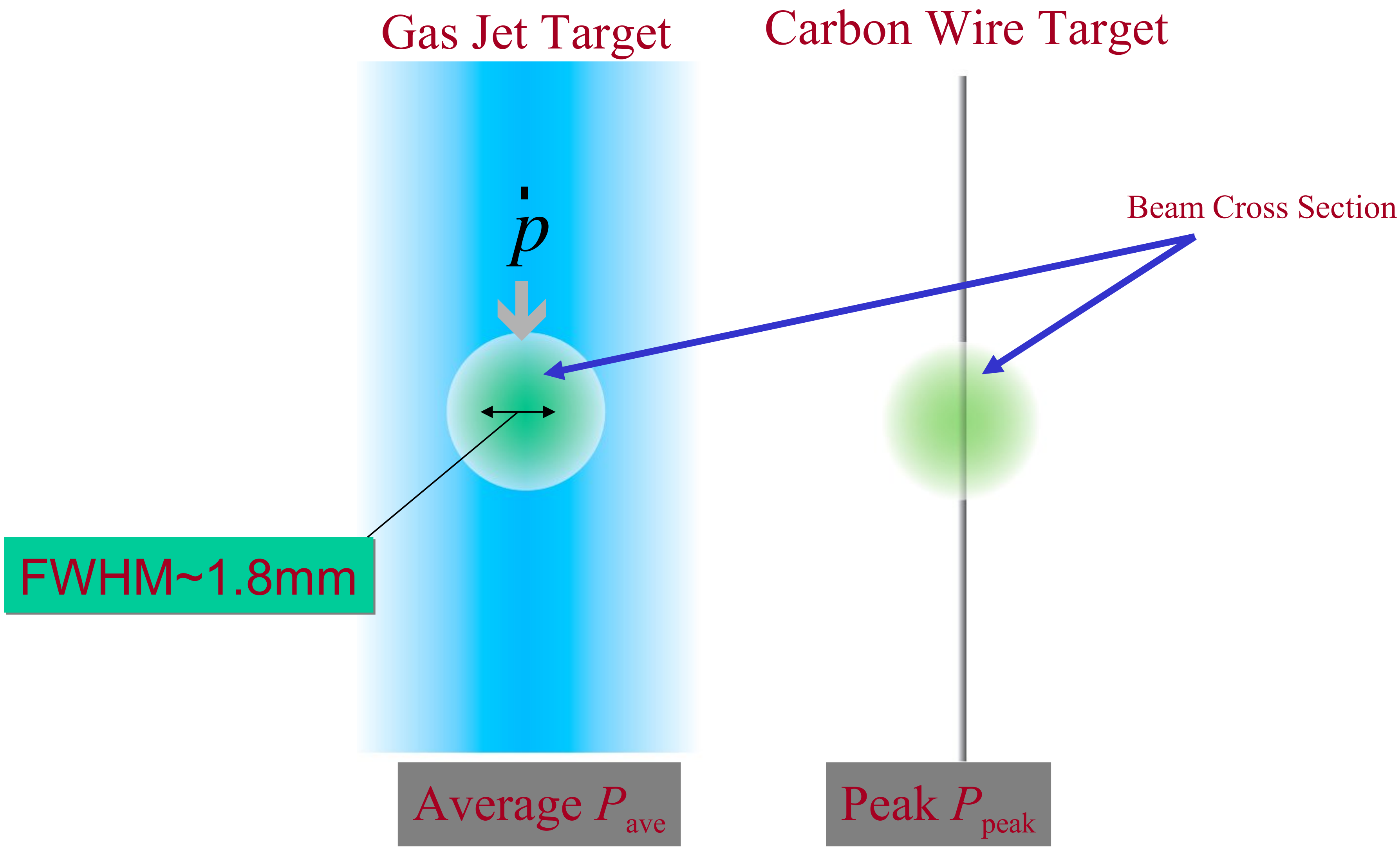
- The H-jet polarimeter includes three major parts: polarized Atomic Beam source (ABS), scattering chamber, and Breit-Rabi polarimeter.
- The polarimeter axis is vertical and the recoil protons are detected in the horizontal plane.
- The common vacuum system is assembled from nine identical vacuum chambers, which provide nine stages of differential pumping.
- The system building bloc k is a cylindrical vacuum chamber 50 cm in diameter and of 32 cm length with the four 20 cm (8.0”) ID



H-JET POLARIMETER SCATTERING CHAMBER.



Hydrogen Gas Jet and Carbon Wire Targets.



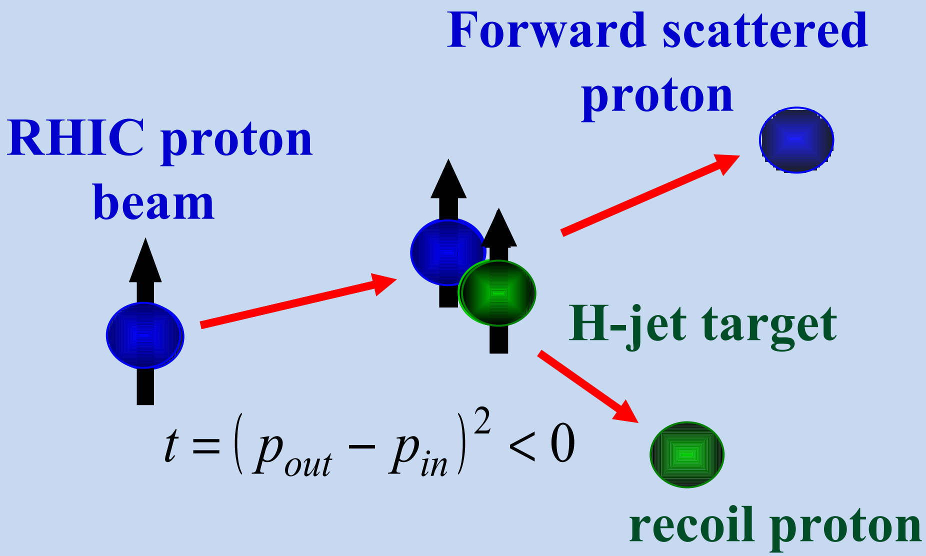
H-Jet polarimeter

Elastic scattering: Interference between electromagnetic and hadronic amplitudes in the Coulumb-Nuclear Interference (CNI) region

$$A_N \approx \mathrm{Im}\left(\phi_{SF}^{em}\phi_{NF}^{had} + \phi_{SF}^{had*}\phi_{NF}^{em}\right) \Big/ \left|\phi_{NF}^{had}\right|^2$$

Beam and target are both protons

$$A_N(t) = -\frac{\varepsilon_{\text{target}}}{P_{\text{target}}} = \frac{\varepsilon_{beam}}{P_{beam}}$$



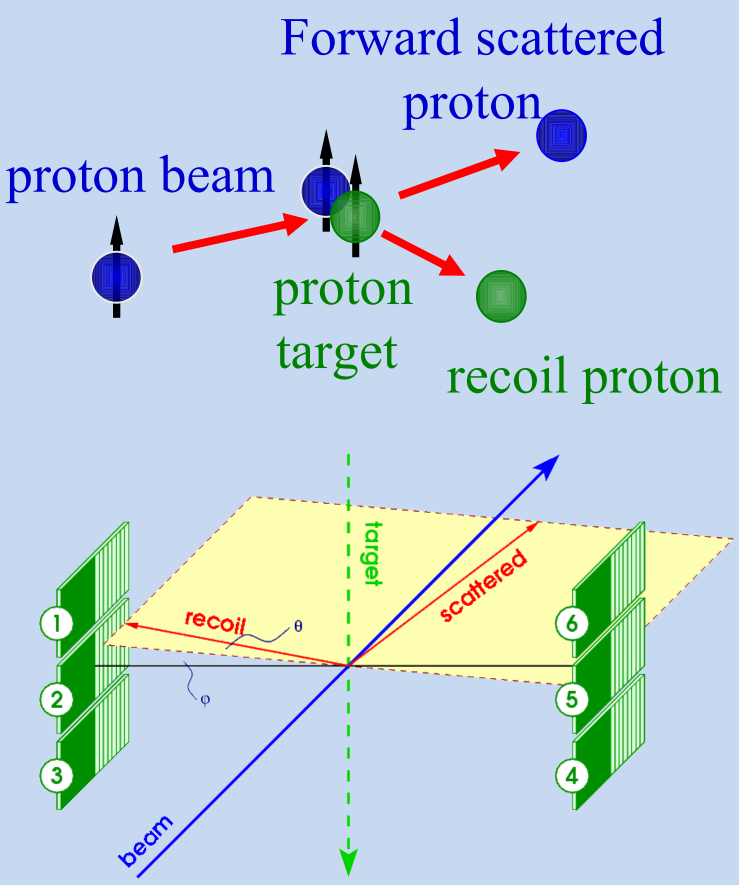
$$t = \left(p_{out} - p_{in}\right)^2 < 0$$

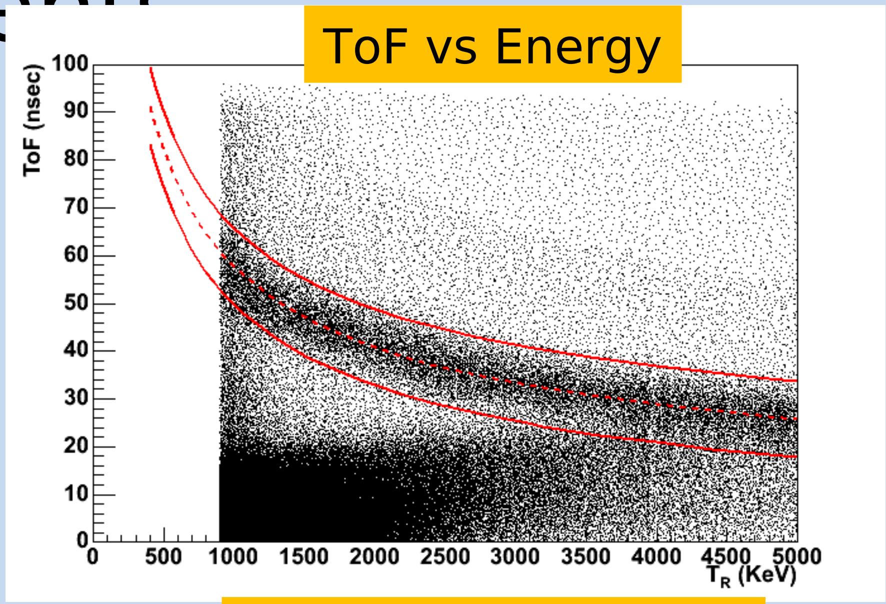
$$\mathrm{P}_{\text{beam}} = -\mathrm{P}_{\text{target}} \frac{\varepsilon_{\text{beam}}}{\varepsilon_{\text{target}}}$$

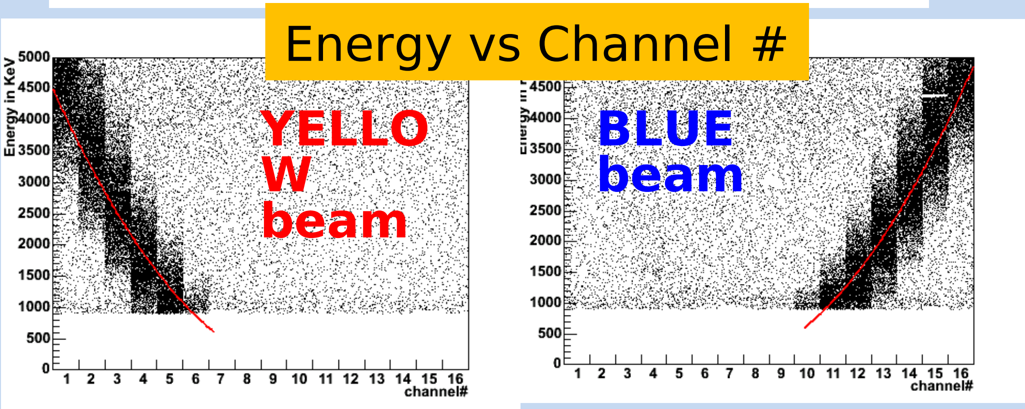
$$\frac{\Delta \mathrm{P}_{\text{beam}}}{\mathrm{P}_{\text{beam}}} \approx \frac{\Delta \mathrm{P}_{\text{target}}}{\mathrm{P}_{\text{target}}} \oplus \frac{\Delta\varepsilon_{\text{target}}}{\varepsilon_{\text{target}}} \oplus \frac{\Delta\varepsilon_{\text{beam}}}{\varepsilon_{\text{beam}}}$$ <5%

P_{target} is measured by Breit- Rabi Polarimeter

HJet: Identification of Elastic Events





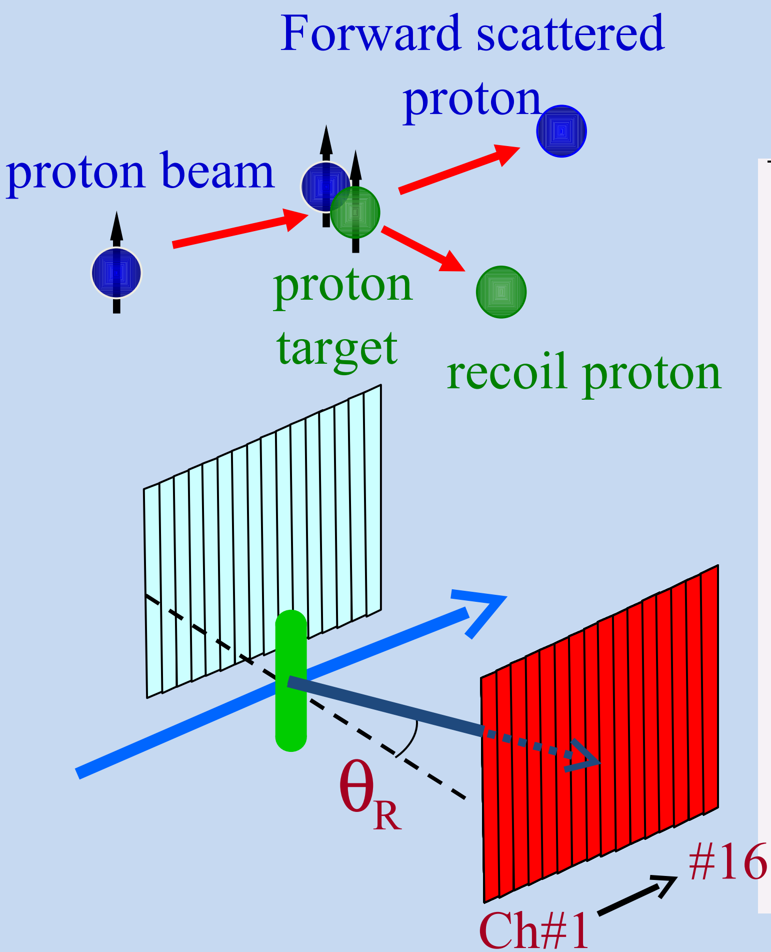


Array of Si detectors measures T_R & **ToF** of recoil proton.

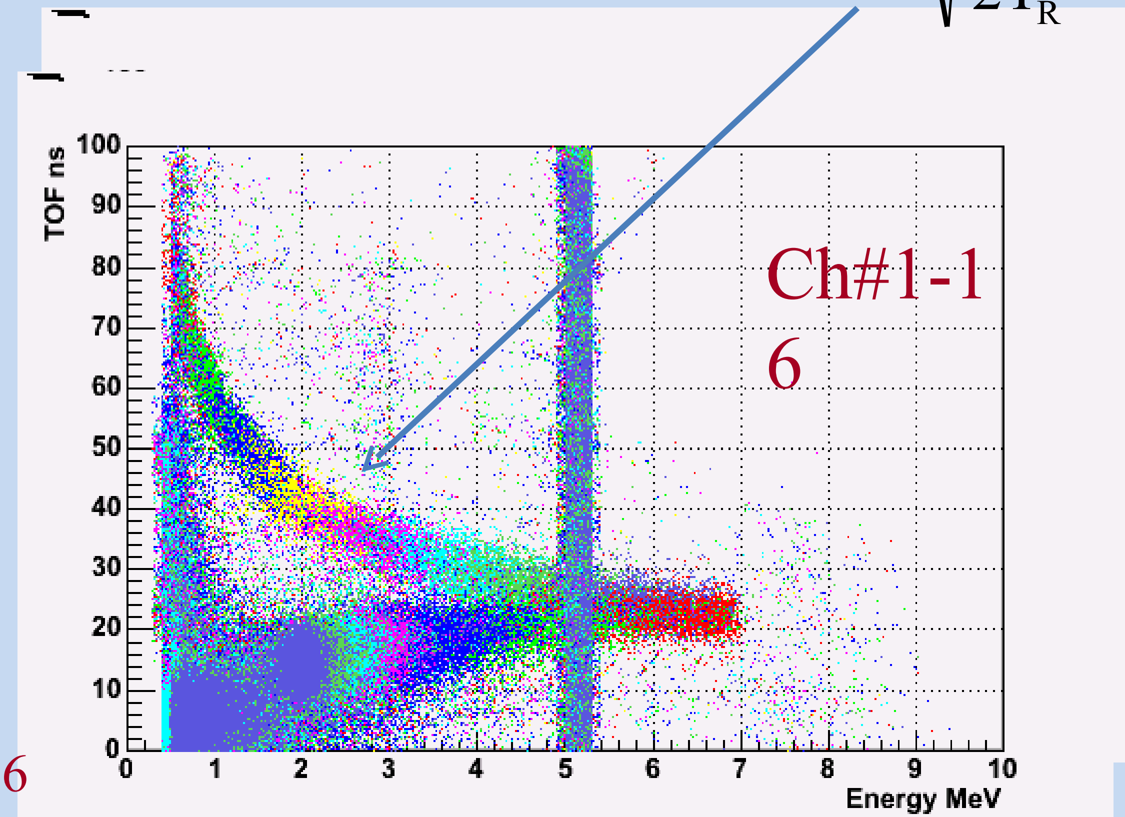
Channel # corresponds to recoil angle θ_R.

Correlations (T_R & ToF) and (T_R & θ_R) → the elastic process

H-Jet: Identification of Elastic Events



$$ToF_{cal.} \approx L\sqrt{\frac{m_p}{2T_R}}$$

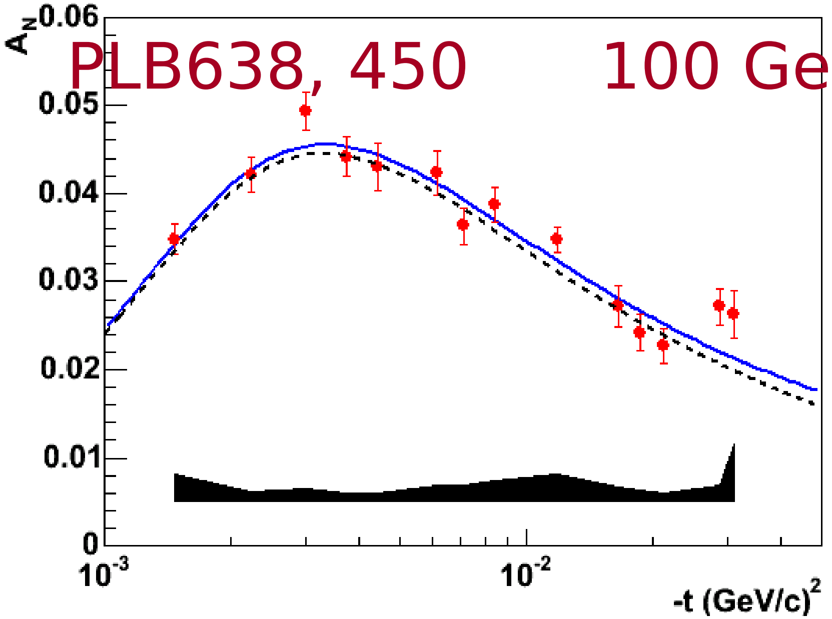


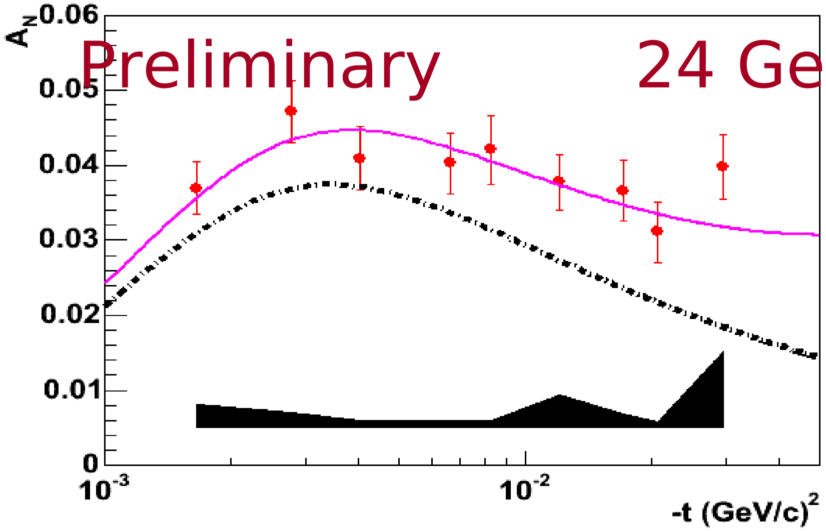
Array of Si detectors measures **T_R** & **ToF** of recoil proton.

Channel # corresponds to recoil angle **θ_R**.

Correlations (T_R & ToF) and (T_R & θ_R) → the elastic process

H-Jet polarimeter: A_N in pp





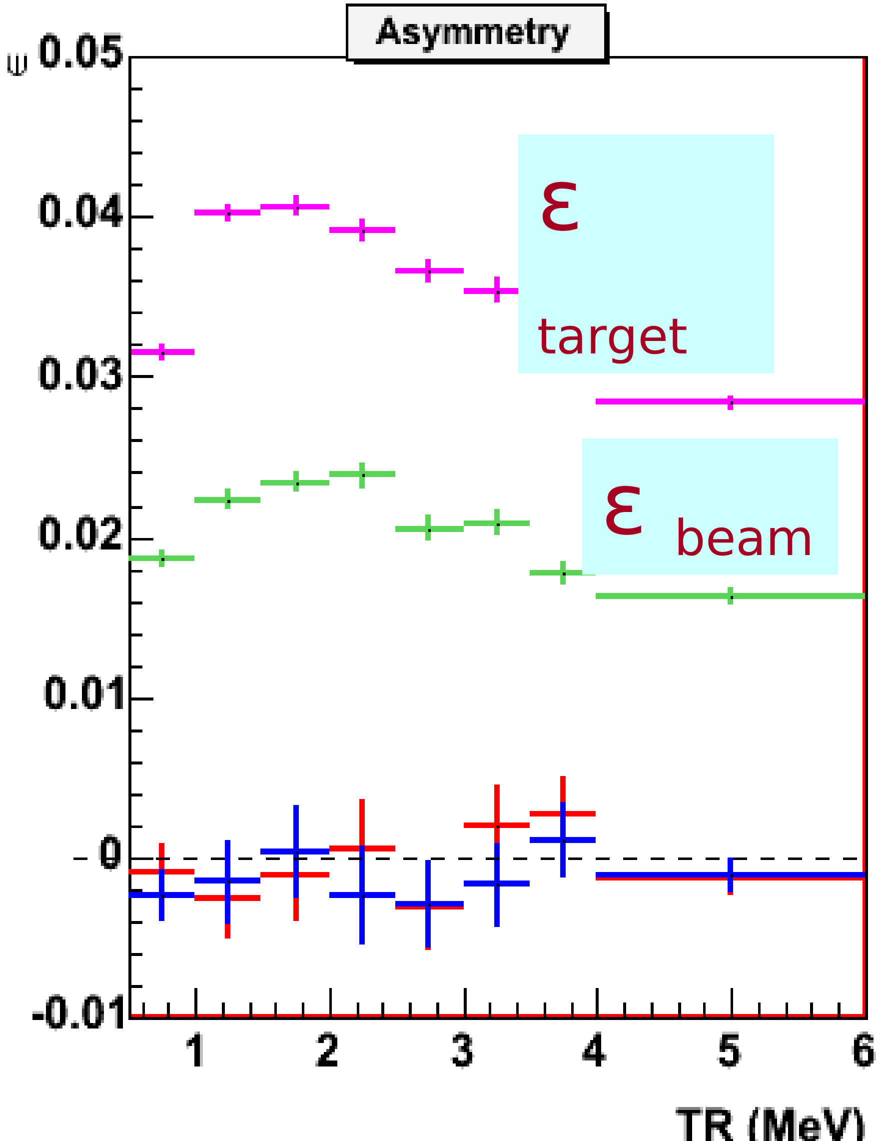
$$A_N \approx \mathrm{Im}\left(\phi_{SF}^{em}\phi_{NF}^{had} + \phi_{SF}^{had*}\phi_{NF}^{em}\right) \Big/ \left|\phi_{NF}^{had}\right|^2$$

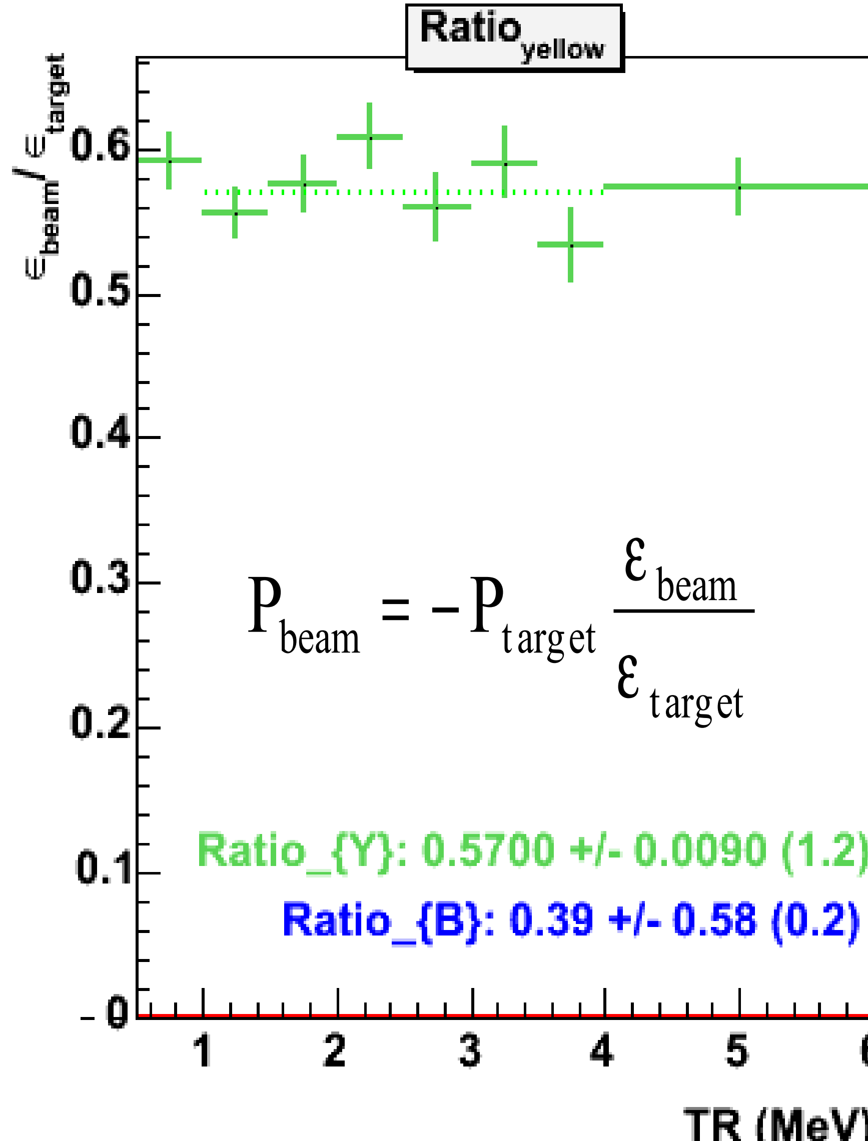
100 GeV: calculations with no hadronic spin flip amplitude contribution are consistent with data

24 GeV: calculations with no hadronic spin flip amplitude contribution are not consistent with data

More data to come:
24 GeV: take more data in Run9/10
31 GeV: finalize analysis of data from Rur
250 GeV: take data in Run9/10

$$A_N^{pp} = \frac{\varepsilon_{\mathrm{target}}}{P_{\mathrm{target}}}$$


Asymmetry
ε
0.05
0.04
0.03
0.02
0.01
0
-0.01
ε target
ε beam
1
2
3
4
5
6
TR (MeV)


Ratio_yellow
ε_beam/ε_target
0.6
0.5
0.4
0.3
0.2
0.1
0
$P_{beam} = -P_{target} \frac{\varepsilon_{beam}}{\varepsilon_{target}}$
Ratio_{Y}: 0.5700 +/- 0.0090 (1.2)
Ratio_{B}: 0.39 +/- 0.58 (0.2)
1
2
3
4
5
6
TR (MeV)

H-jet is an ideal polarimeter !

- High (~4.5%) analyzing power in a wide energy range (23-250 GeV).
- High event rate due to high intensity (~100 mA) circulated beam current in the storage ring (~6% statistical accuracy in one 8hrs. long fill). High polarized H-jet density in RHIC ABS.
- Non-destructive.
- No scattering for recoil protons.
- Clean elastic scattering event identification.
- Straightforward calibration with Breit-Rabi polarimeter.
- Most of the false asymmetries are cancelled out in the ratio:

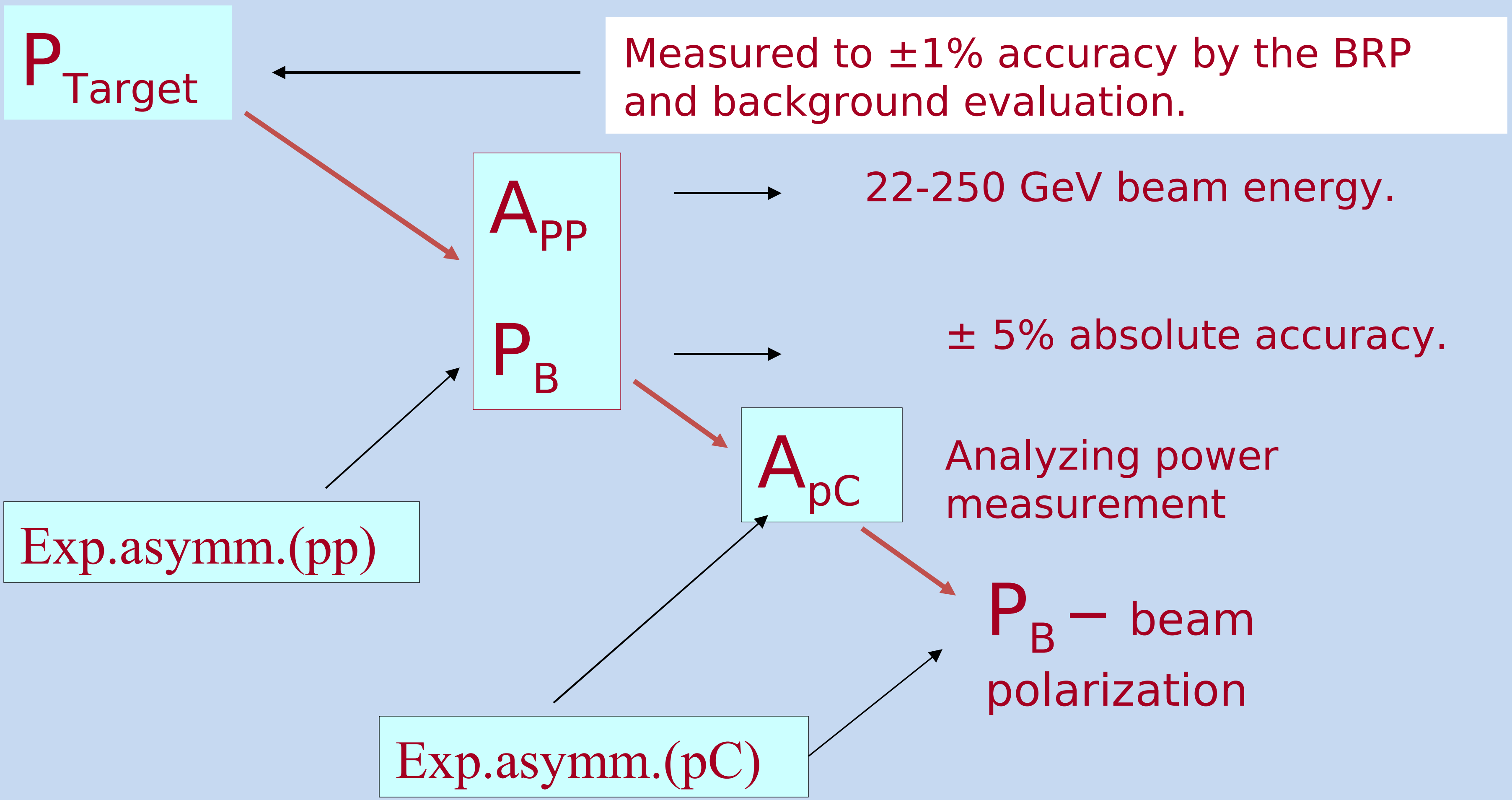
P (1/A)Beam / Target

Problem.

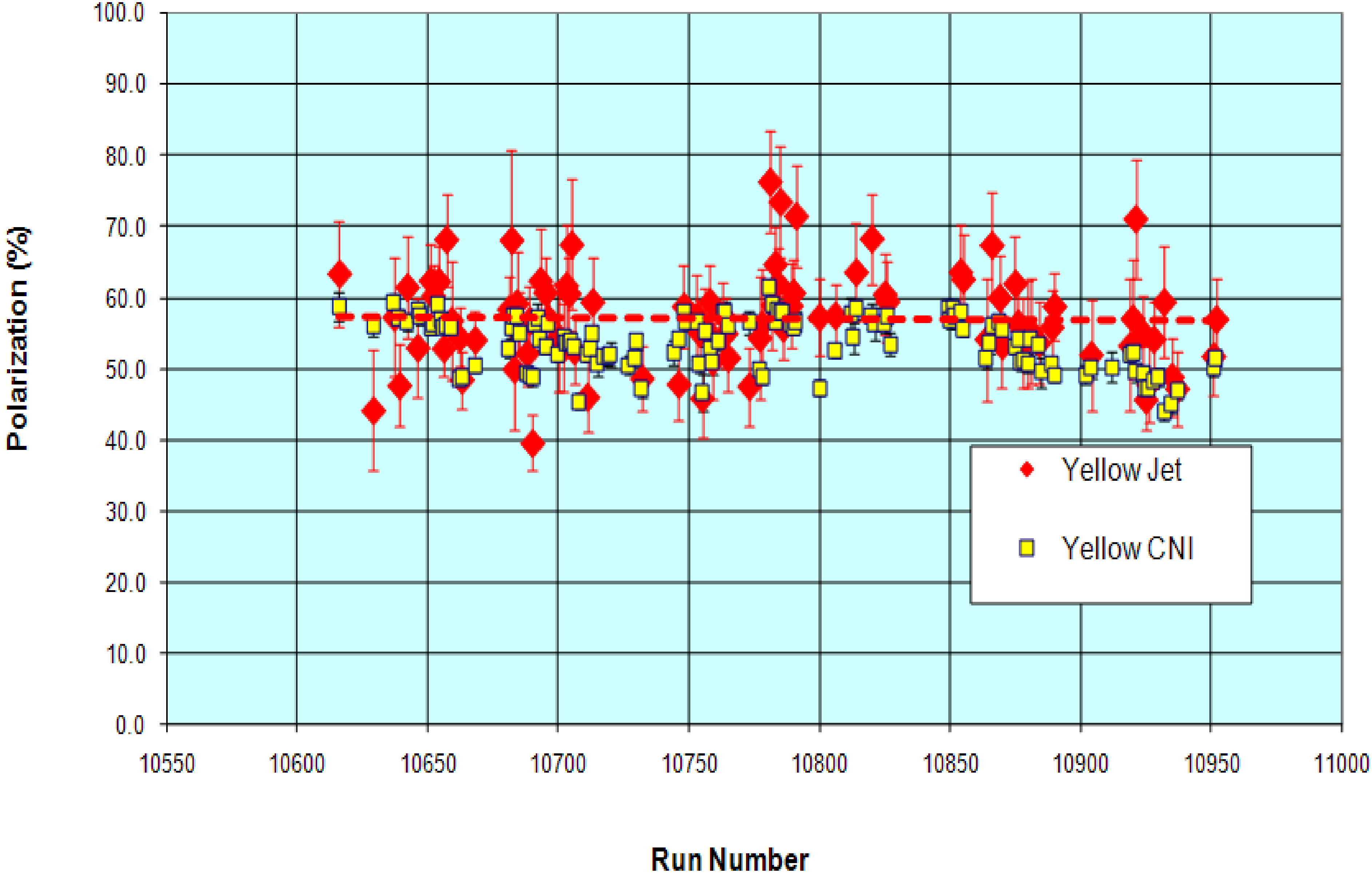
Polarization dilution by H_2, H_2O and other residual gases.

Largest source of systematic error.

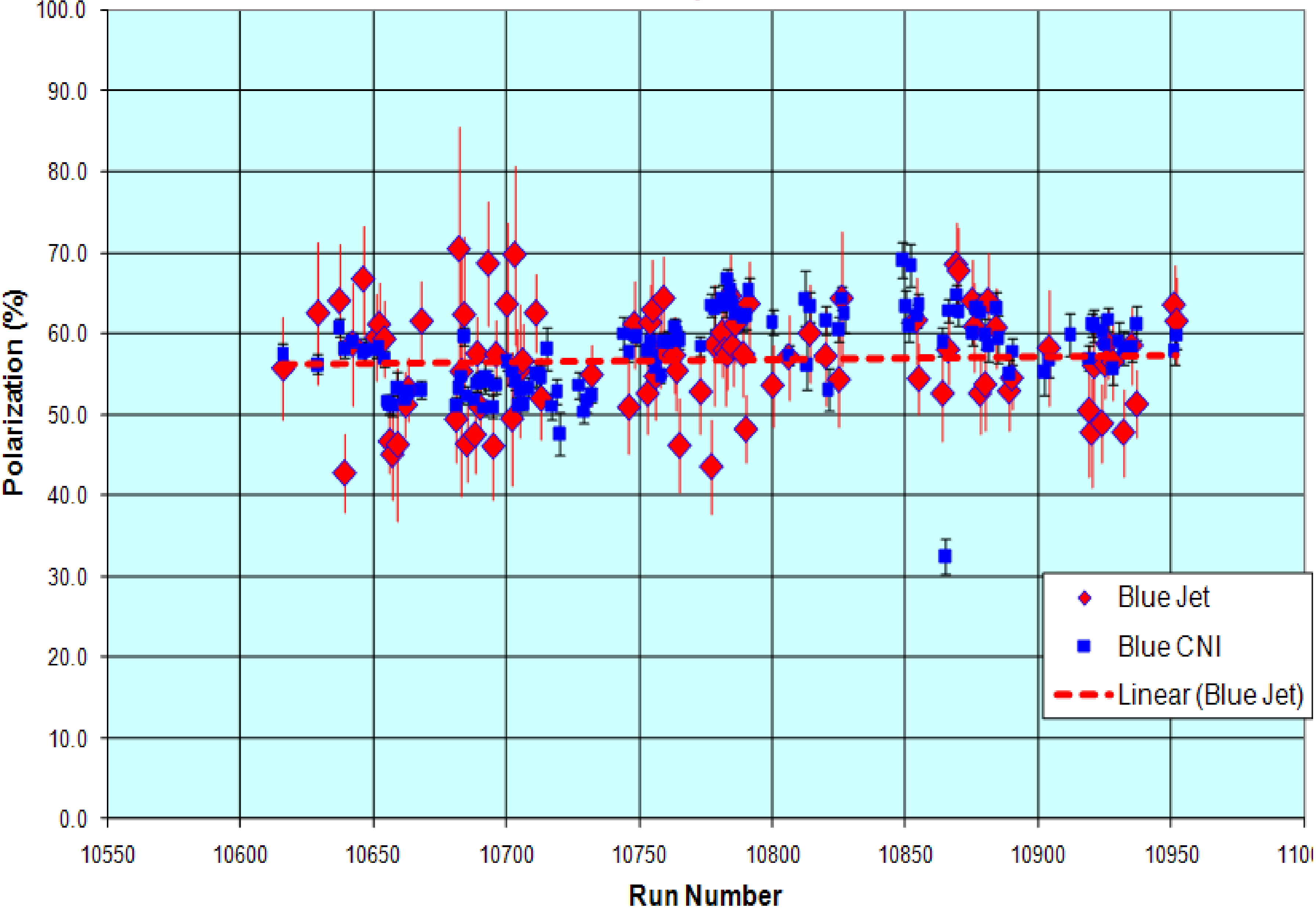
Polarization measurements in RHIC with the H-jet polarimeter.



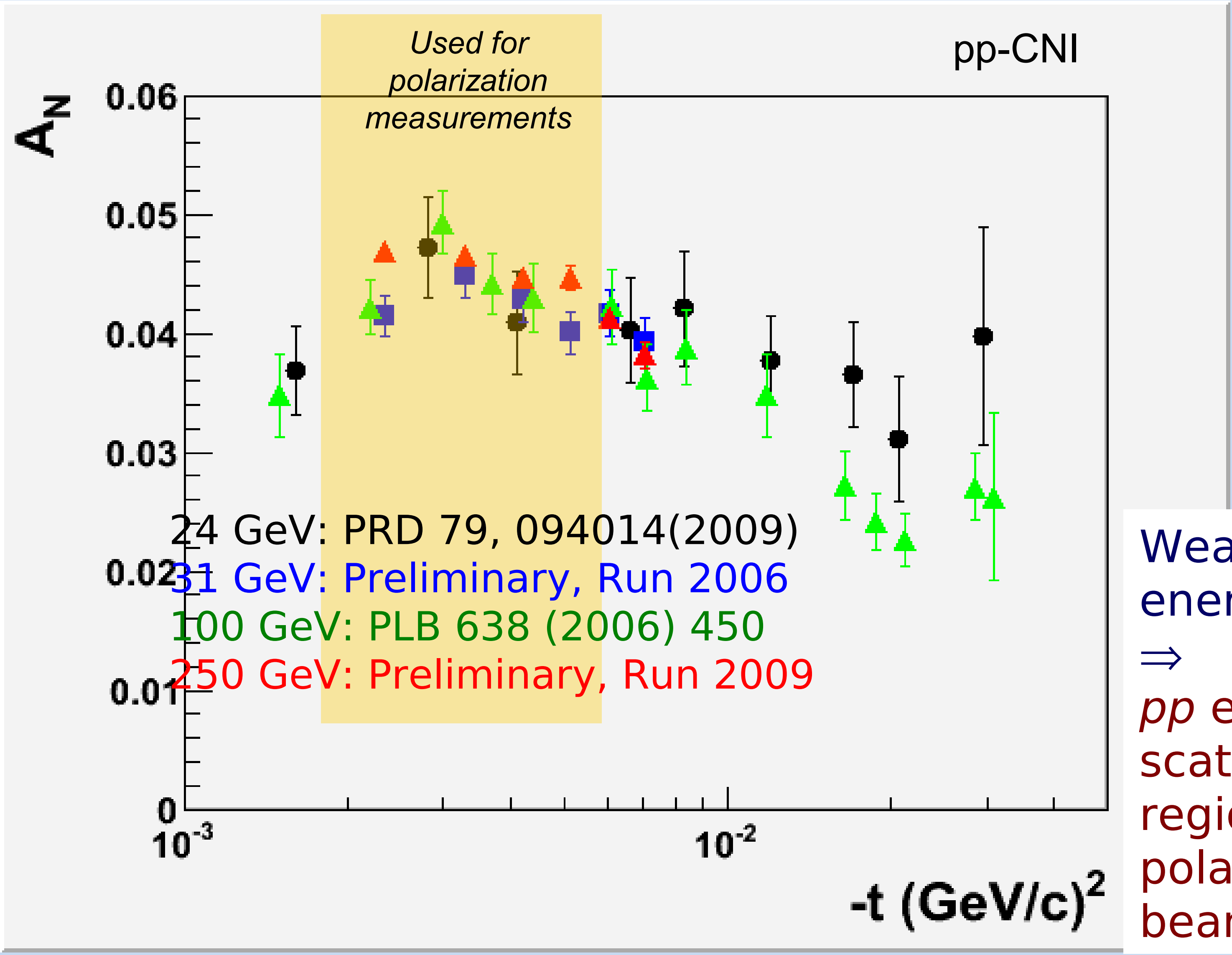
√S=200 GeV, 2009 Run. Polarization in Yellow Ring



√S=200 GeV, 2009 Run. Polarization in Blue Ring



Polarized H-Jet: A_N



Weak (if any) energy dependence
⇒
pp elastic scattering in CNI region is ideal for polarimetry in wide beam energy range

PHENIX local polarimeter, (M.Ogawa talk this afternoon).

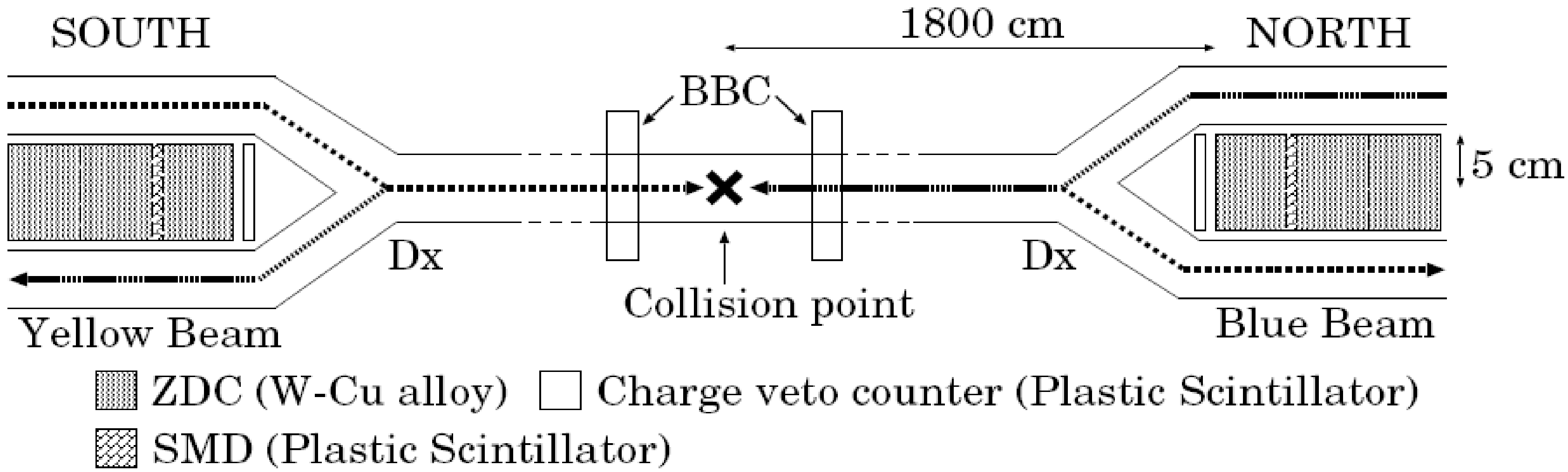
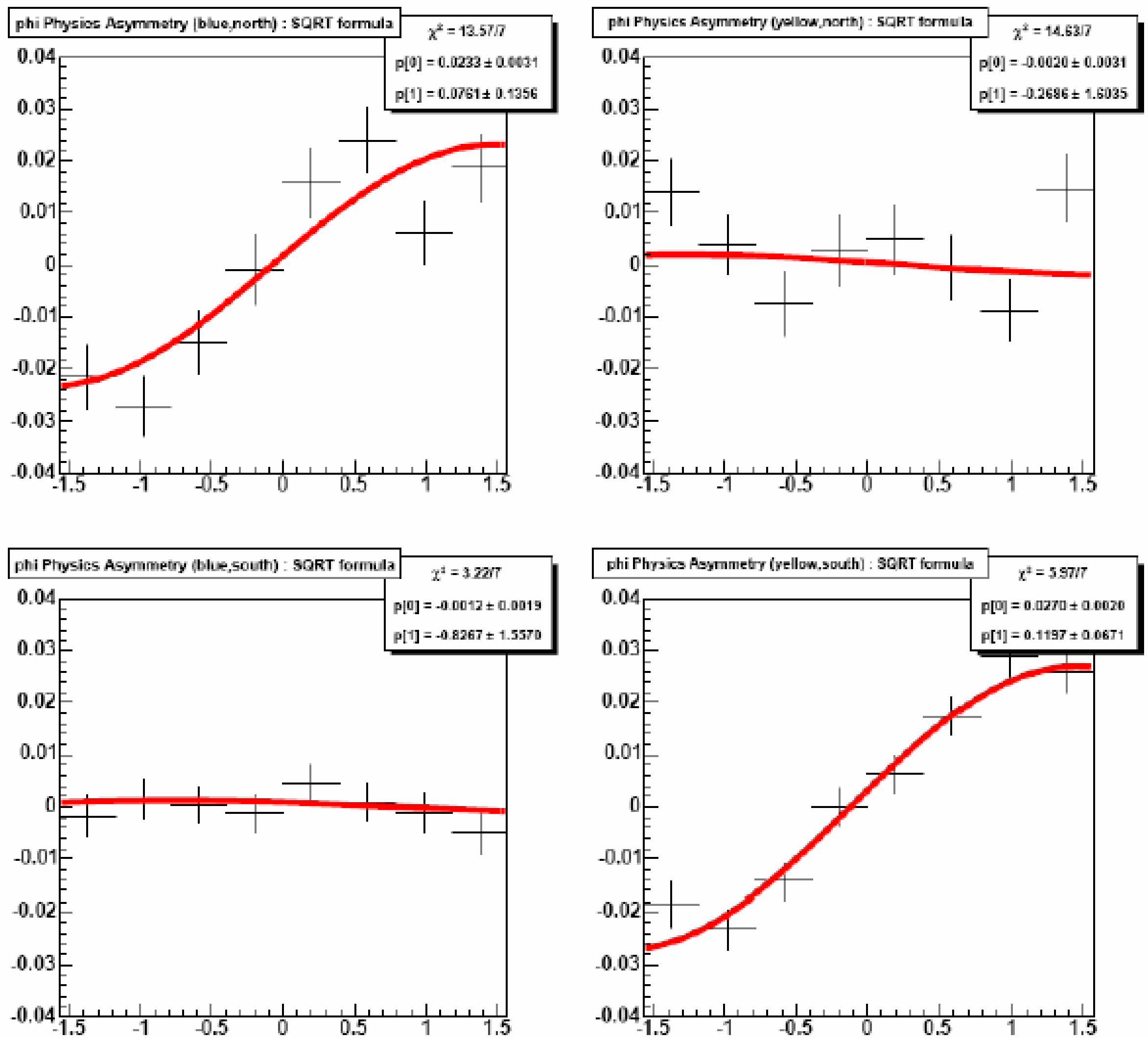


Figure 5.1: A plan view of the experimental setup at PHENIX, not to scale. Shown are the principle components for the leading neutron physics.

410 GeV Transverse Polarization



M. Togawa

Polarization

blue : ~33%

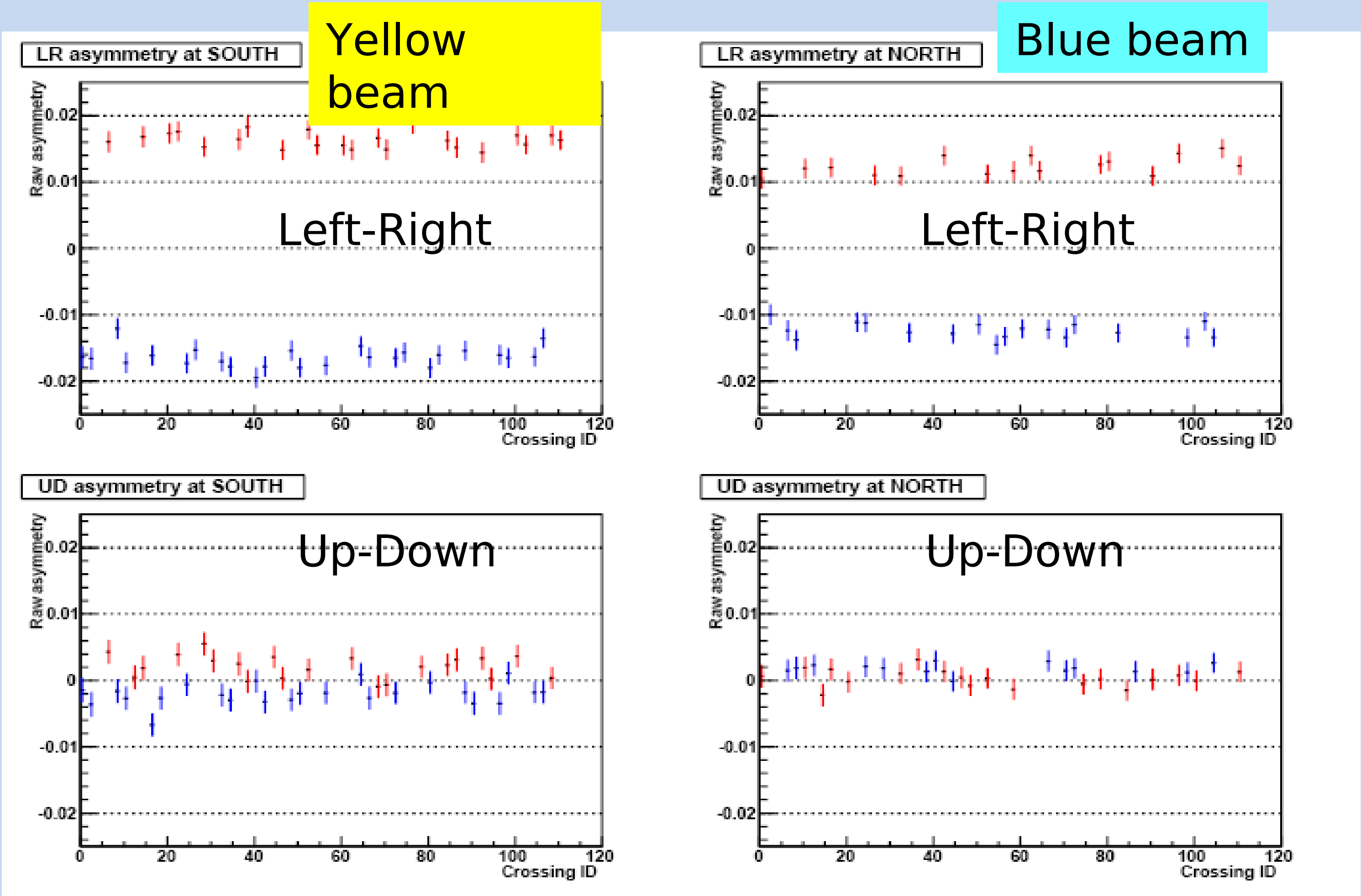
yellow : ~49%

- Analyzing power of PHENIX Local Polarimeter roughly the same despite doubling of energy
  - Local Polarimeter can be used at higher $\sqrt{s}$
- Demonstrates that RHIC is capable of accelerating to higher $\sqrt{s}$ without losing all polarization
- Will provide first look at A_N for higher $\sqrt{s}$

PHENIX Local Polarimeter, Run 2009

Asymmetry vs bunch #

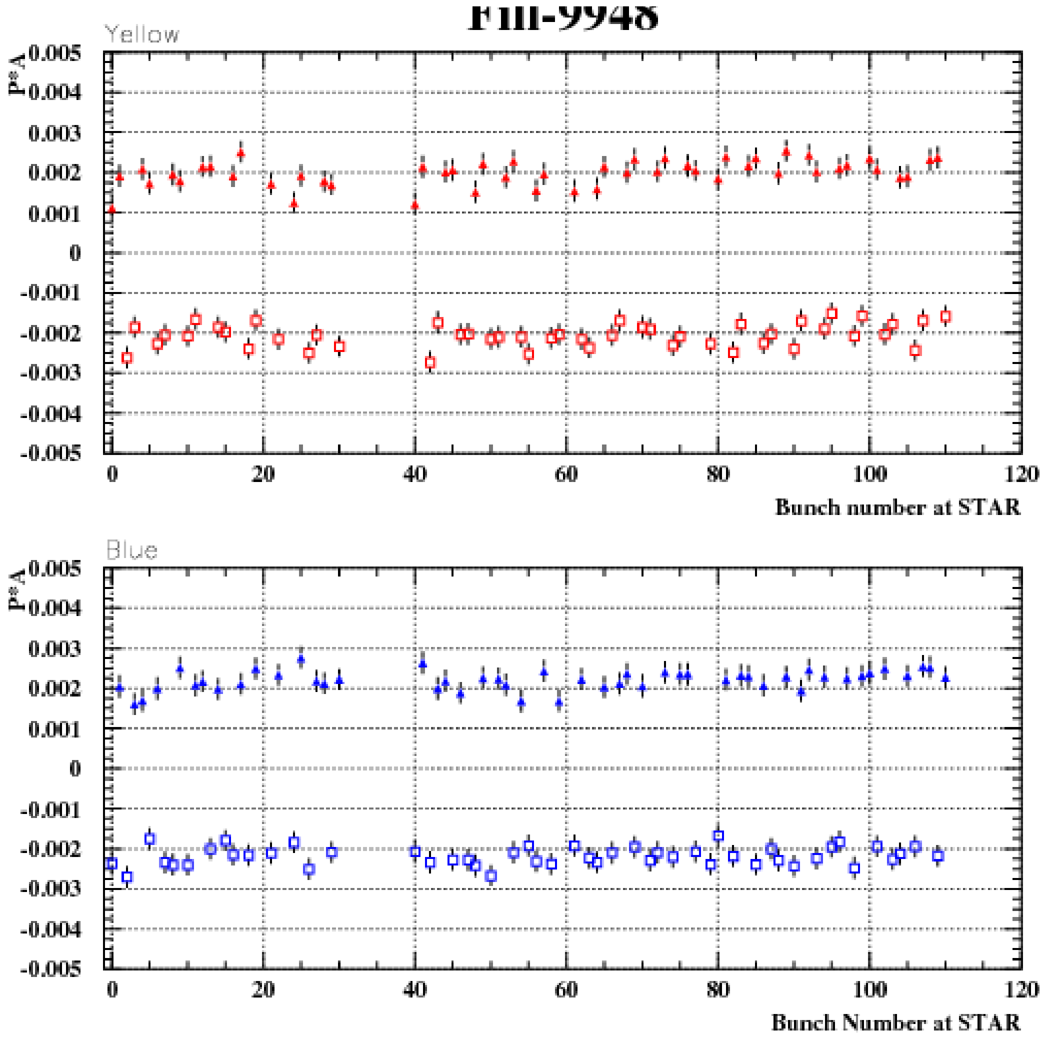
5 min data !
(in scaler mode)



Precisely monitor bunch-by-bunch polarization and polarization vs time in a fill (for transversely polarized beams)

STAR Local Polarimeter

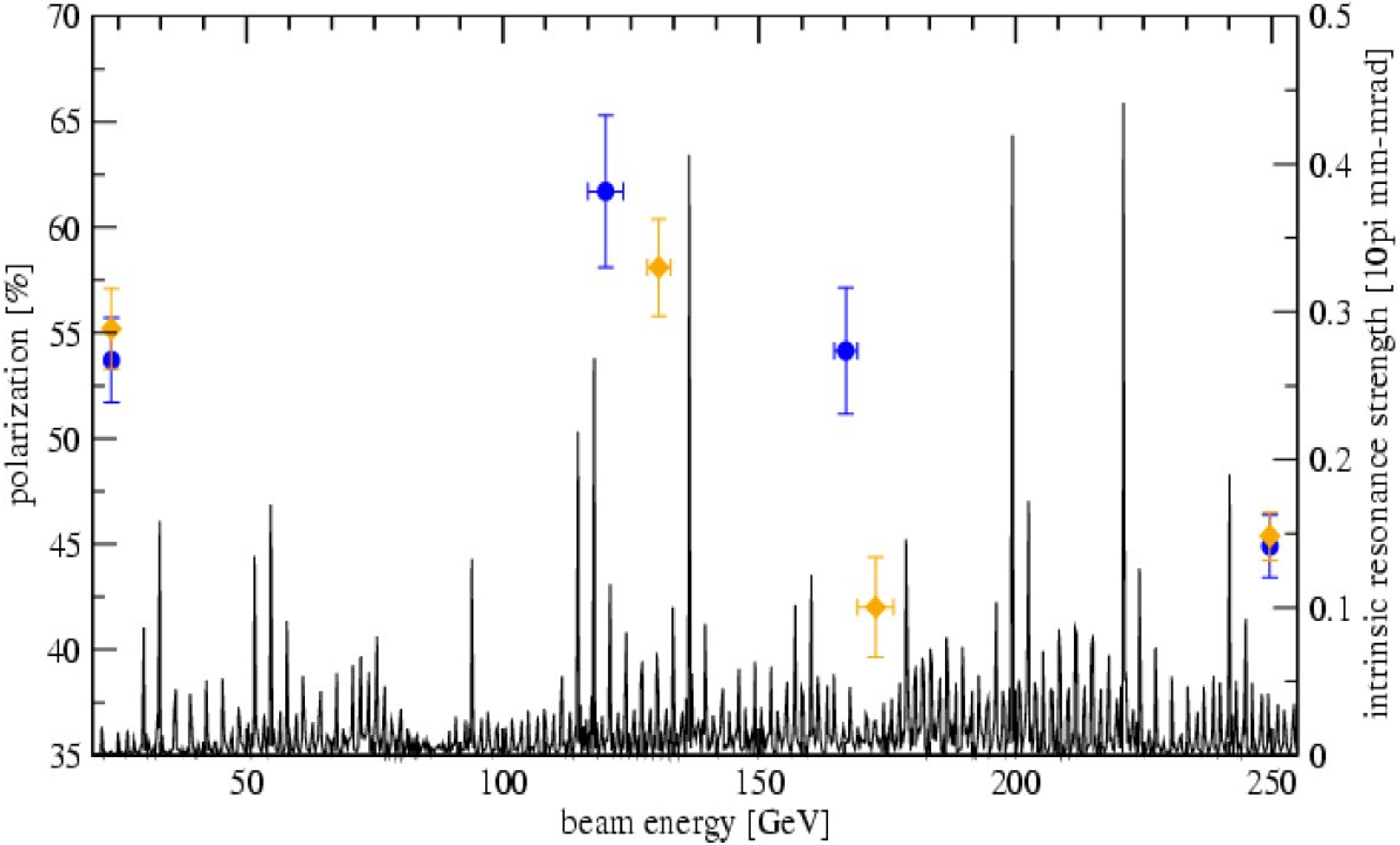
BBC: Asymmetry vs bunch



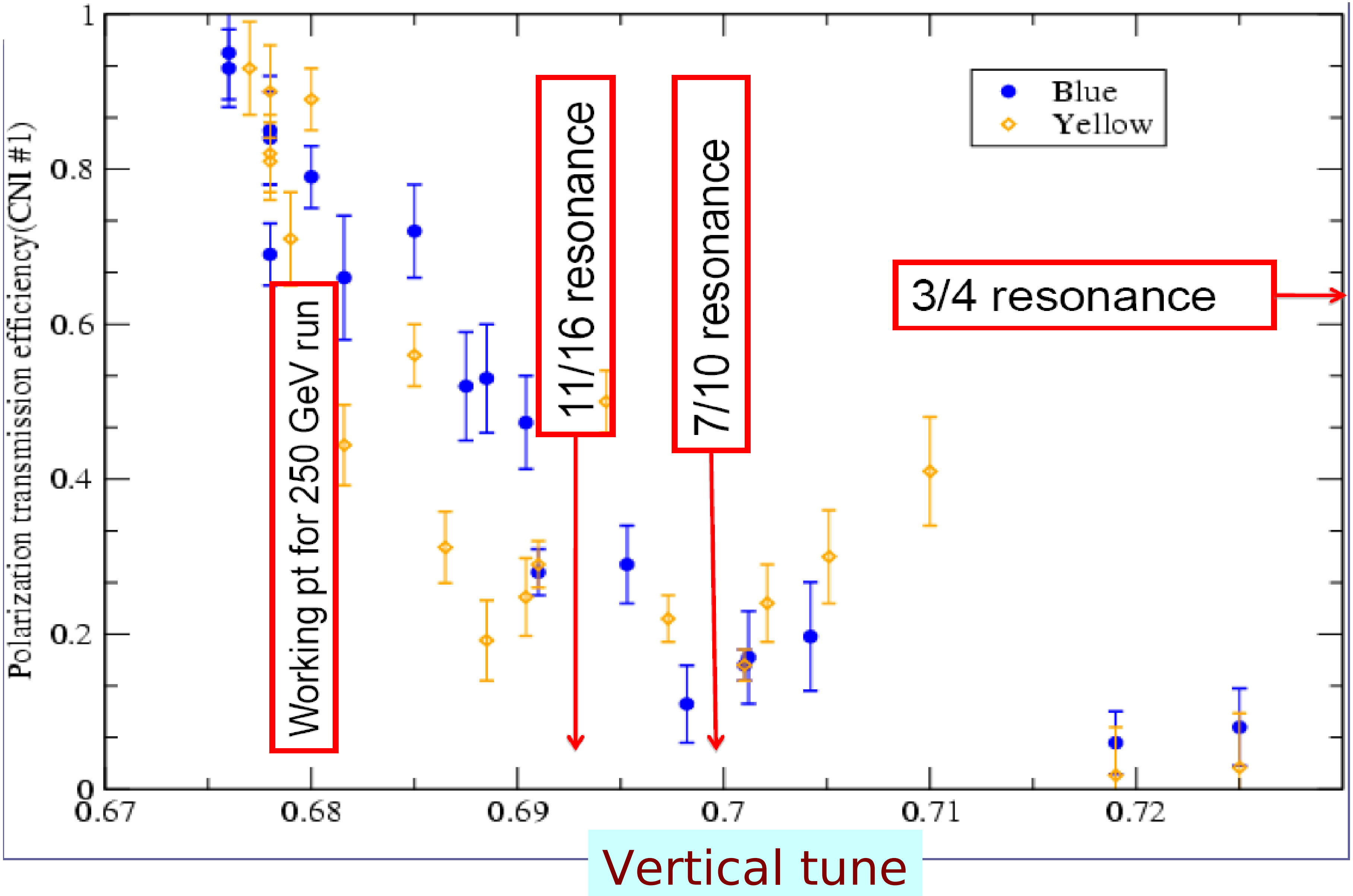
Monitors spin direction in STAR collision region

Capable to precisely monitor bunch-by-bunch polarization and polarization vs time in a fill

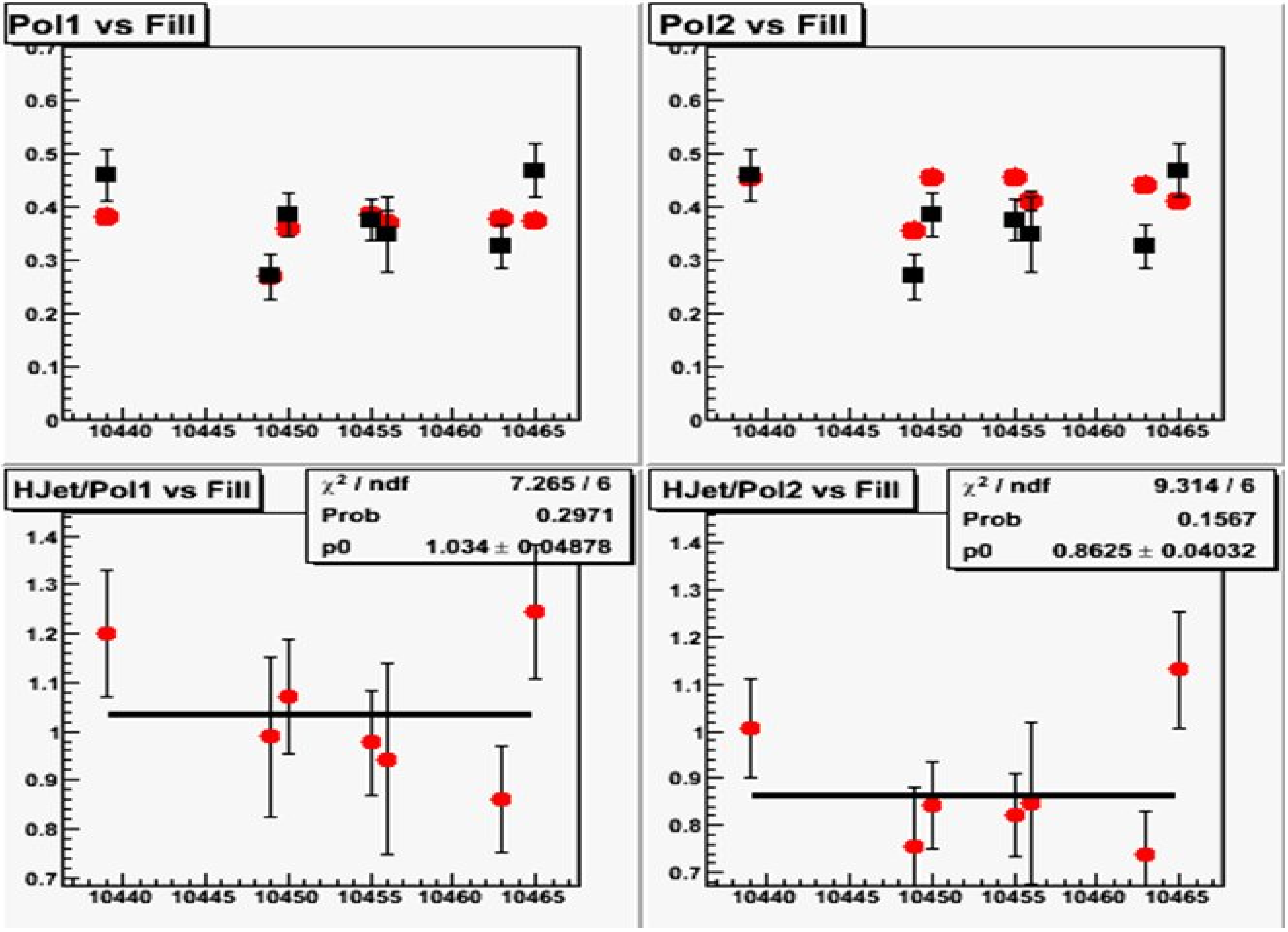
Polarization measurements on the energy ramp to 250 GeV.



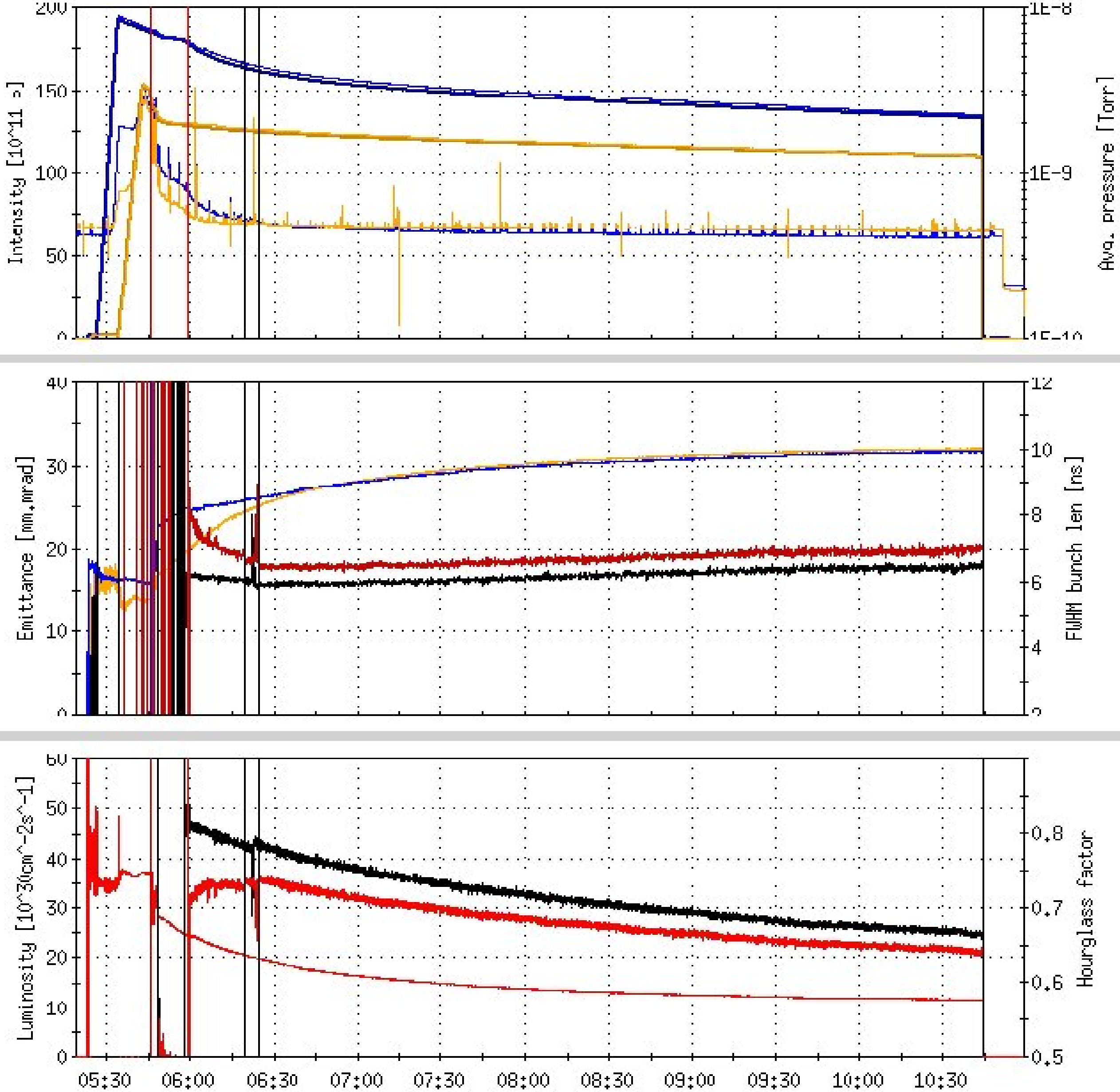
Vertical tune scan at 250 GeV.



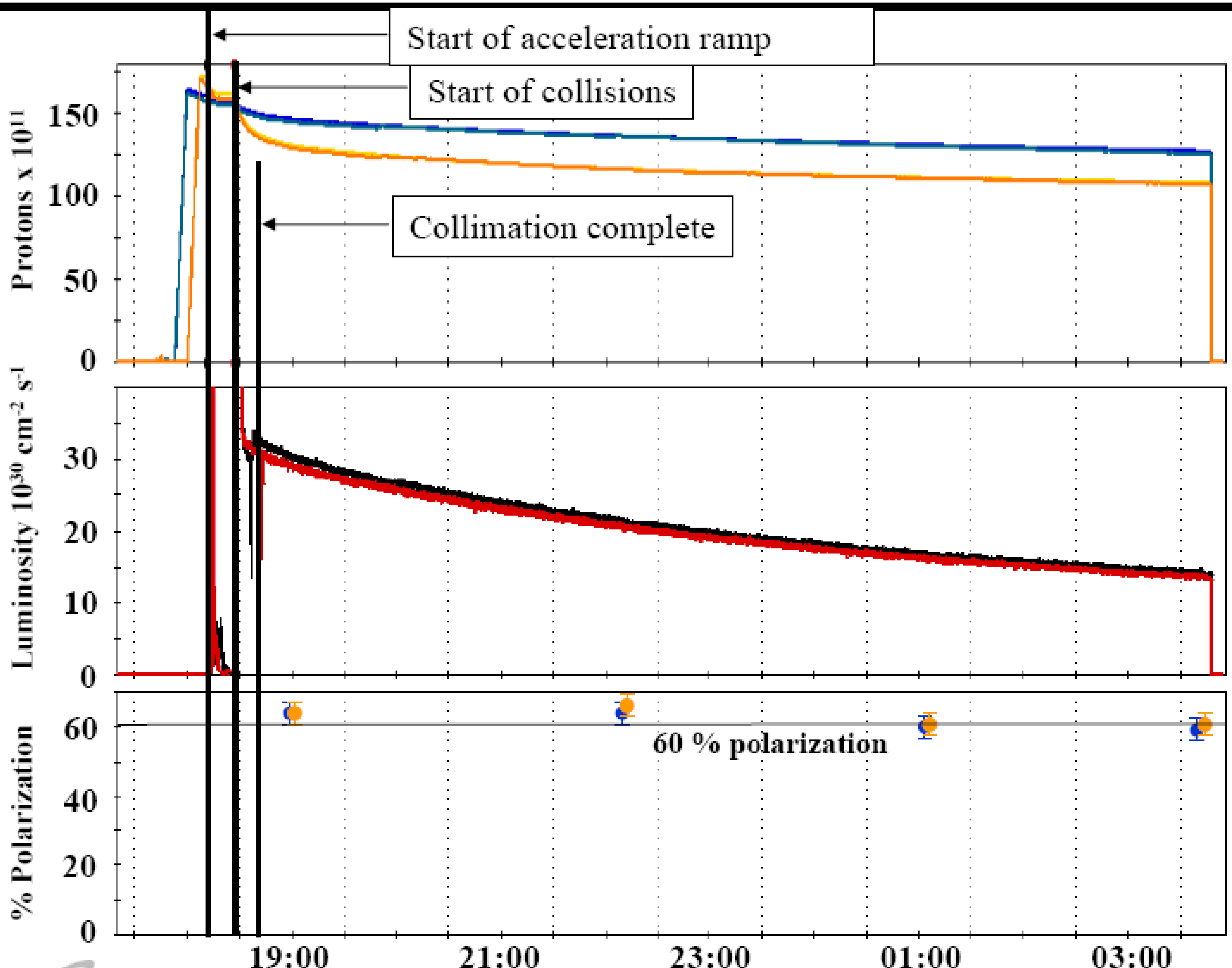
250 GeV, Yellow/H-Jet



June 24,2009, FILL 10987, 4.75 hr, Int-0.554 pb-1, <L> = $32.4 \cdot 10^{30}$ $1/cm^2$ s



Luminosity and Polarization Lifetimes in RHIC at 100 GeV



BROOKHAVEN NATIONAL LABORATORY

45 % polarization on first acceleration to 250 GeV!

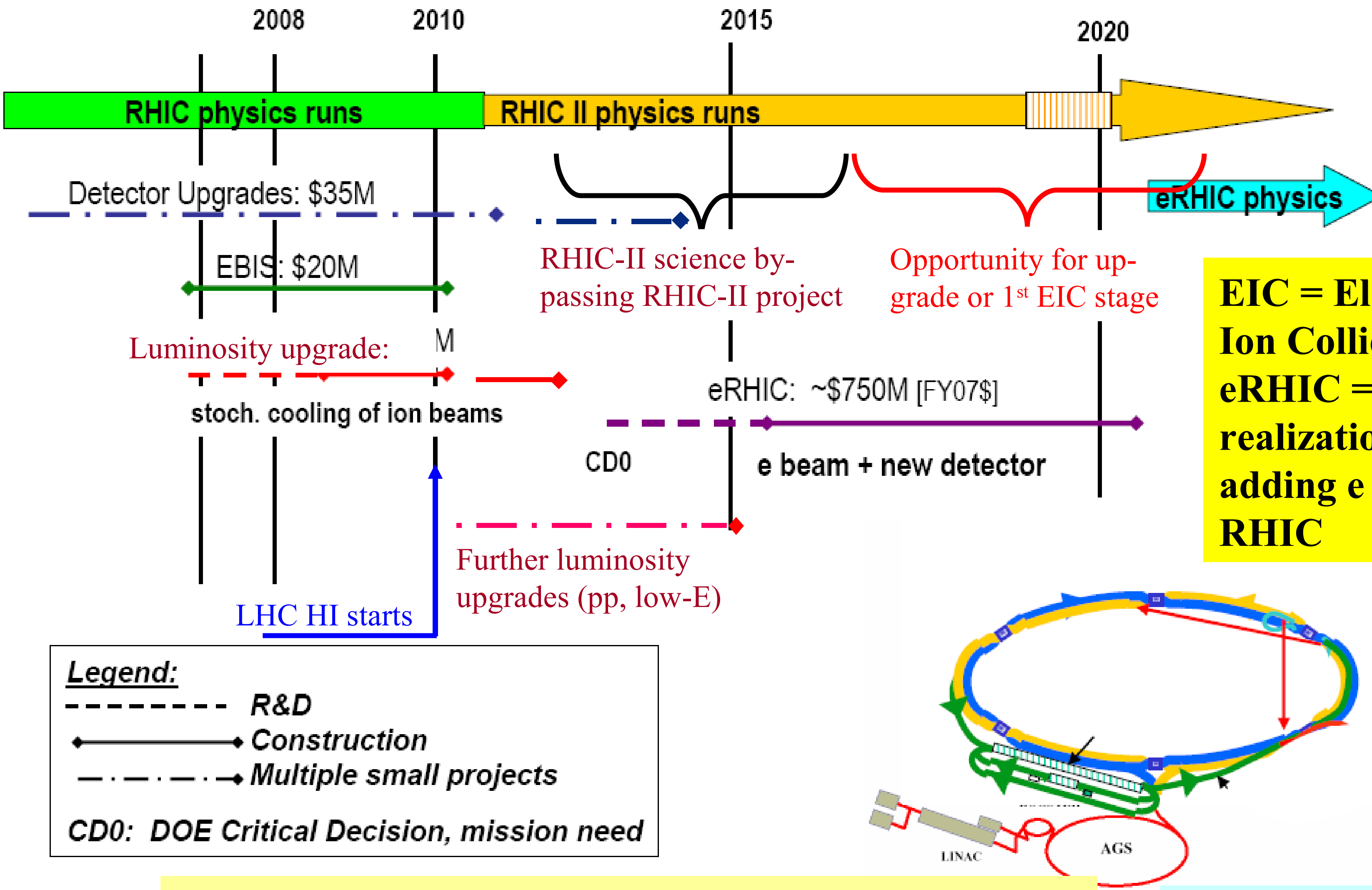
Summary and Outlook

- Summary
  - Three key elements:
    - Gluon polarization
    - Quark / Anti-Quark Polarization
    - Transverse spin dynamics
  - Critical:

Recorded Luminosity	Main physics Objective	Remarks
~50pb^{-1}	Gluon polarization using di-jets and precision inclusive measurements	200 GeV
~100pb^{-1}	W production (Important consistency check to DIS results - Phase I) Gluon polarization (Di-Jets / Photon-Jets)	500 GeV
~300pb^{-1}	W production (Constrain antiquark polarization - Phase II) Gluon polarization (Di-Jets / Photon-Jets)	500 GeV
~30pb^{-1}	Transverse spin gamma-jet	200 GeV
~250pb^{-1}	Transverse spin Drell-Yan (Long term)	200 GeV

- Beam polarization: 70% / Narrow vertex region / Spin flipper for high precision asymmetry measurements
- Critical: Sufficient running time!

A Long Term (Evolving) Strategic View for RHIC



EIC = Electron-Ion Collider; eRHIC = BNL realization by adding e beam to RHIC

RHIC, RHIC-II, LHC-HI and EIC science share a common

S.Vigdor