Polarized protons in the RHIC .

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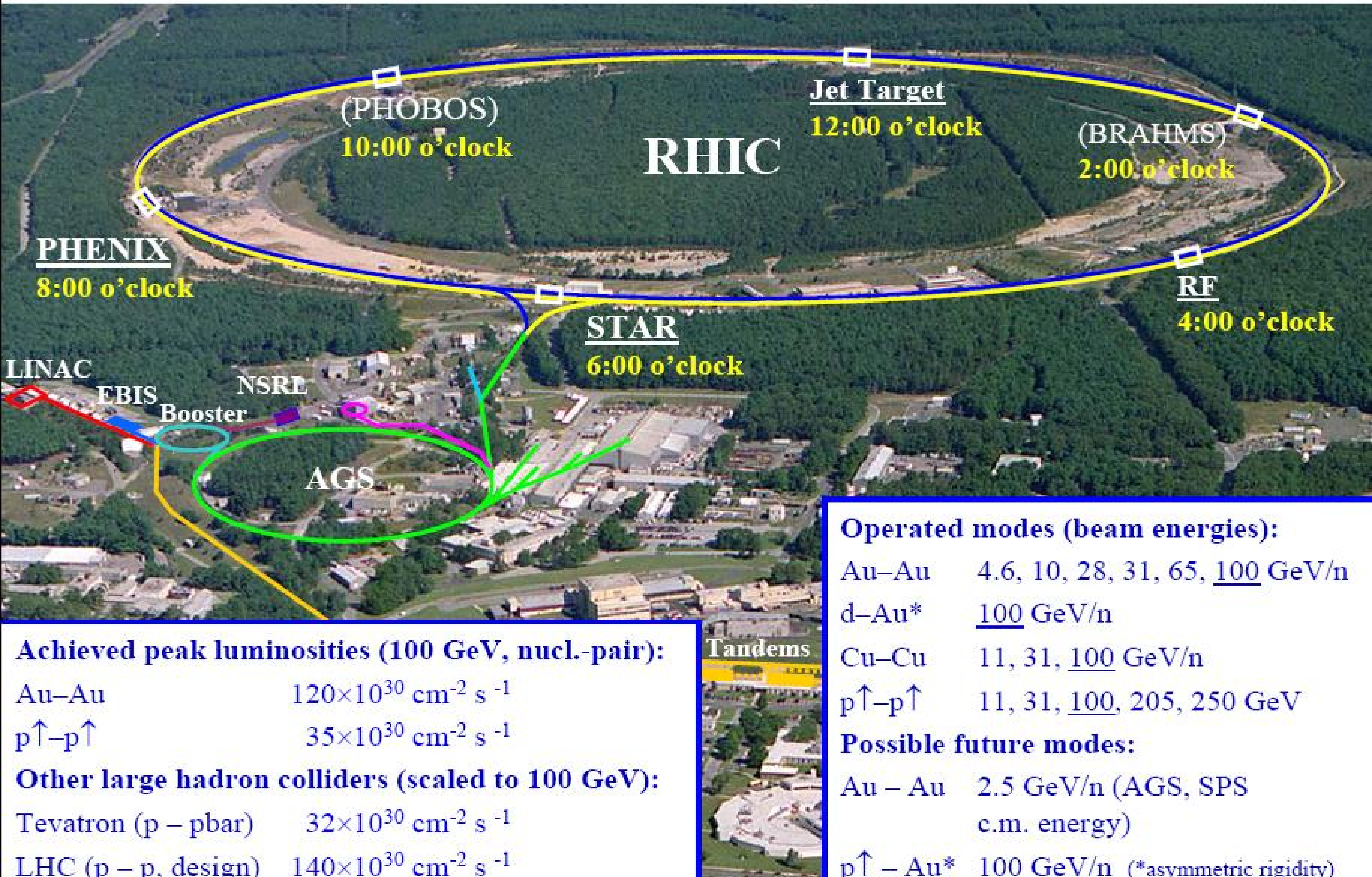
July 3, 2008 , Ferrara University.

RHIC – a High Luminosity (Polarized) Hadron Collider



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

Au–Au	120×10^{30} cm^{-2} s^{-1}
p↑–p↑	35×10^{30} cm^{-2} s^{-1}

Other large hadron colliders (scaled to 100 GeV):

Tevatron (p – pbar)	32×10^{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, 28, 31, 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>, 205, 250 GeV

Possible future modes:

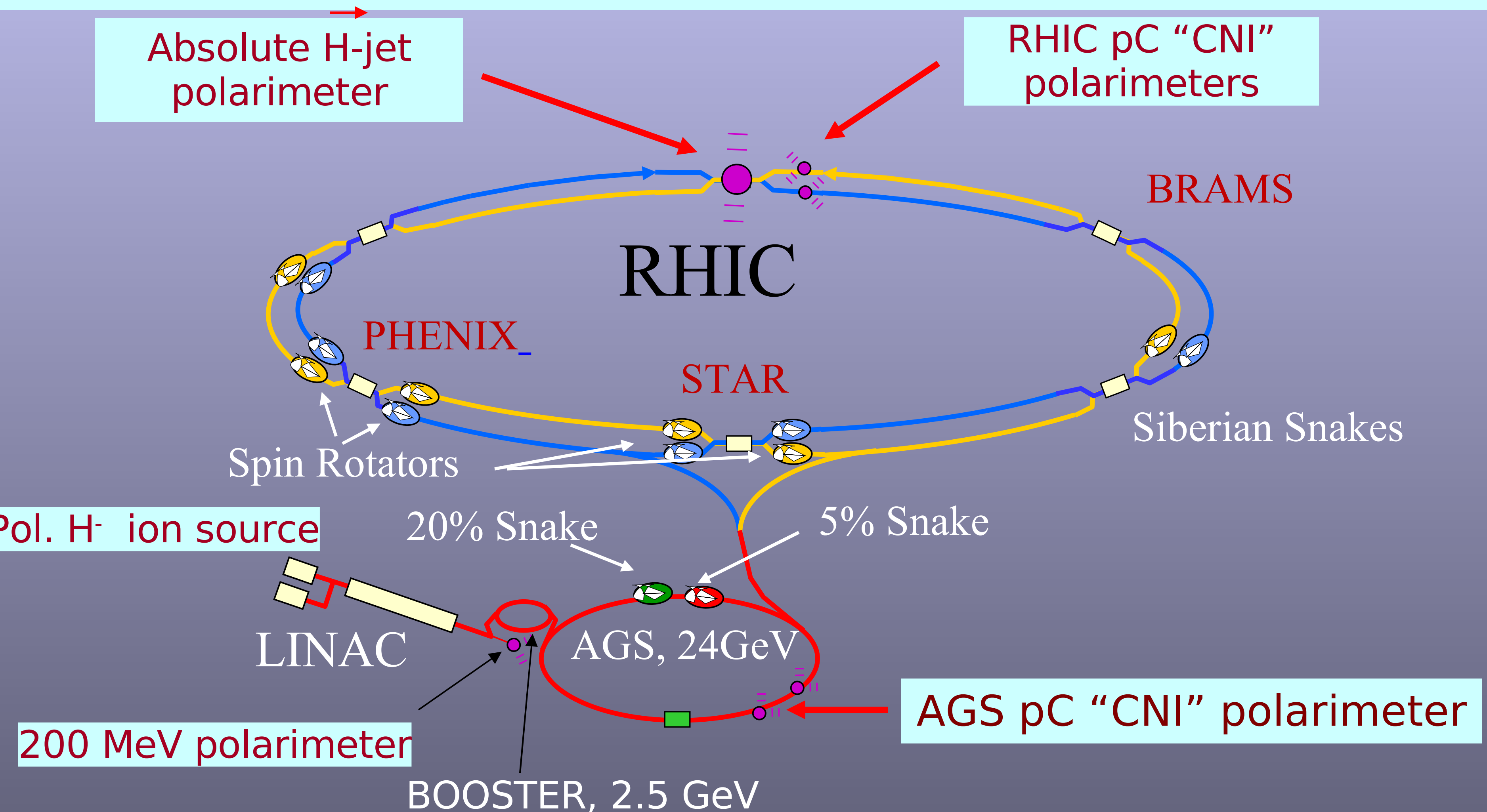
Au – Au	2.5 GeV/n (AGS, SPS c.m. energy)
p↑ – Au*	100 GeV/n (*asymmetric rigidity)

SPIN-PHYSICS at RHIC foundation.

- 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



Workshop on high –energy spin physics,

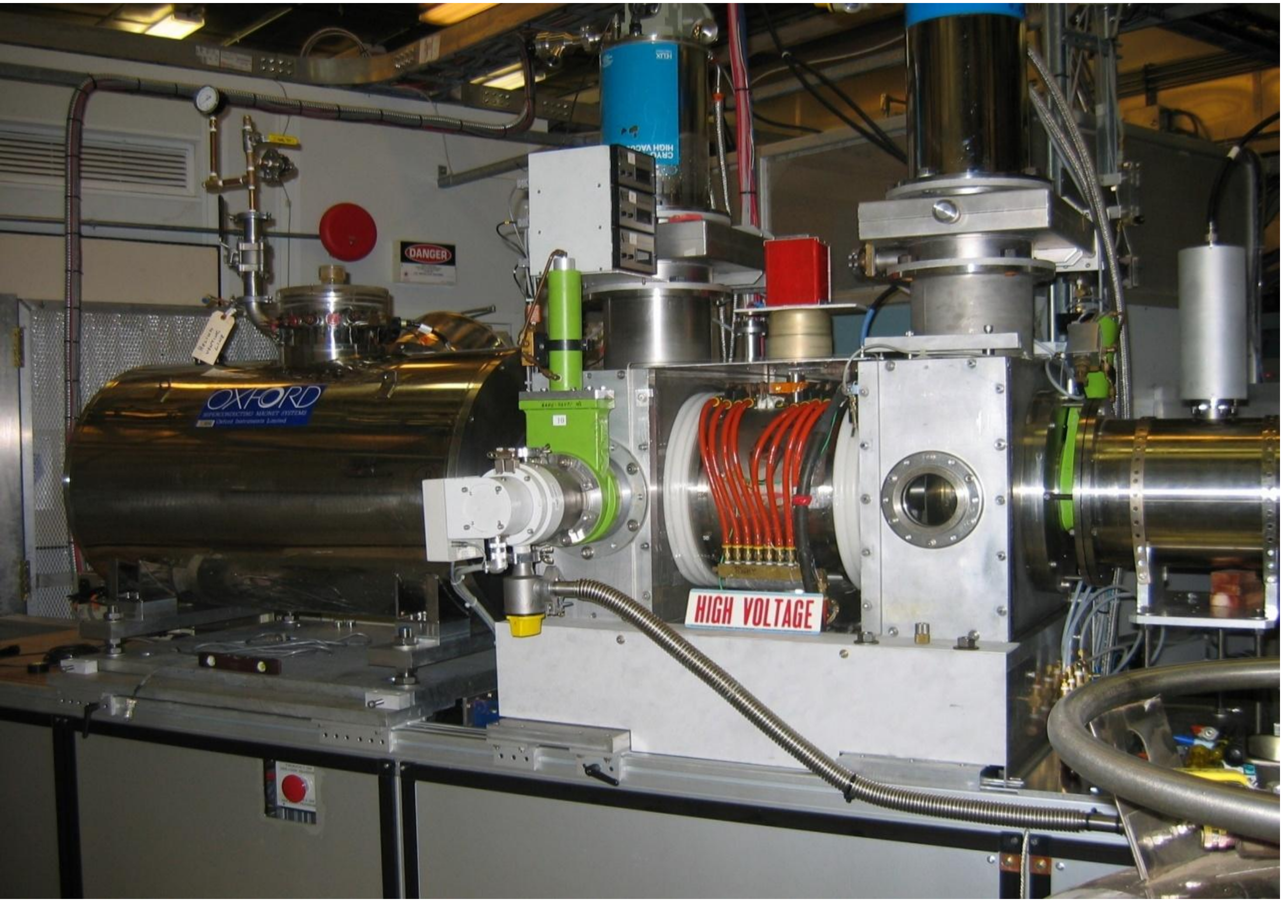
Protvino, IHEP, September,1983

Yaroslav Derbenev , (A.Kondratenko)-

“Siberian snake” proposal.

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

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



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%.

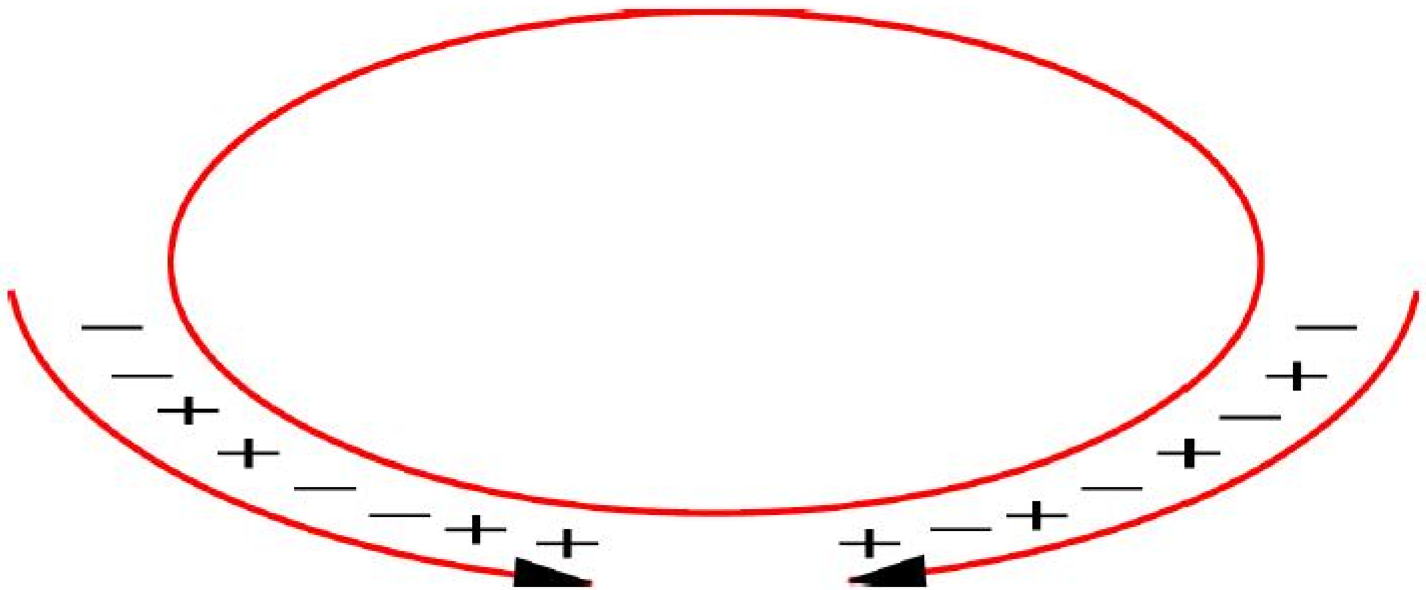
Beam intensity (ion/pulse) routine operation:

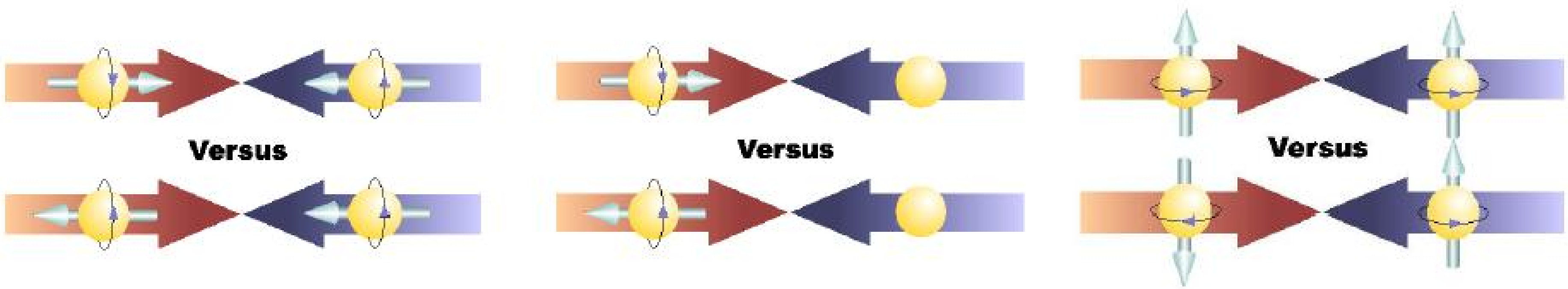
Source	- 10^{12} H^-/pulse
Linac (200MeV)	- $5 \cdot 10^{11}$
AGS	- $1.7 \cdot 10^{11}$
RHIC	- $1.4 \cdot 10^{11}$

(protons/bunch).

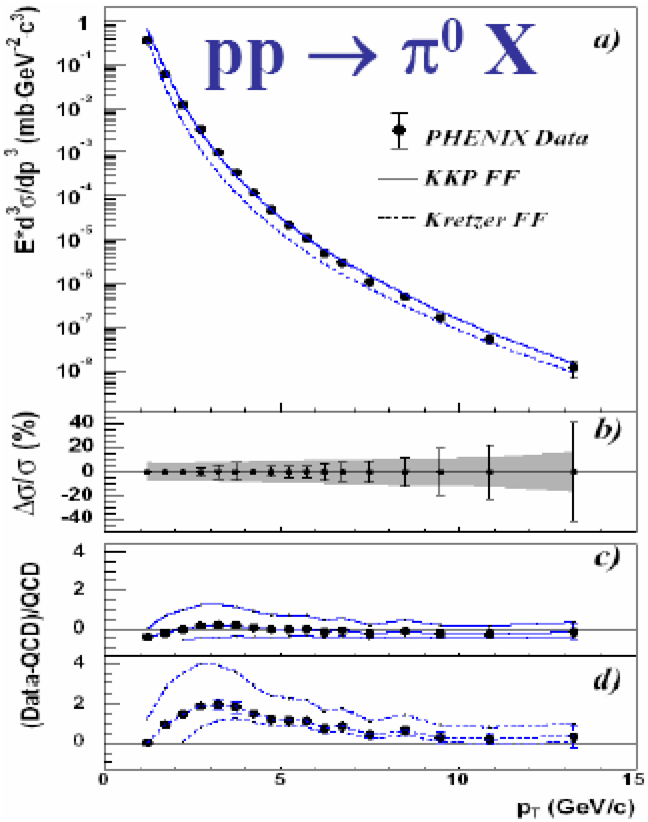
A beam intensity greatly exceeds RHIC limit, which allowed strong beam collimation in the Booster, to reduce longitudinal and transverse beam emittances.

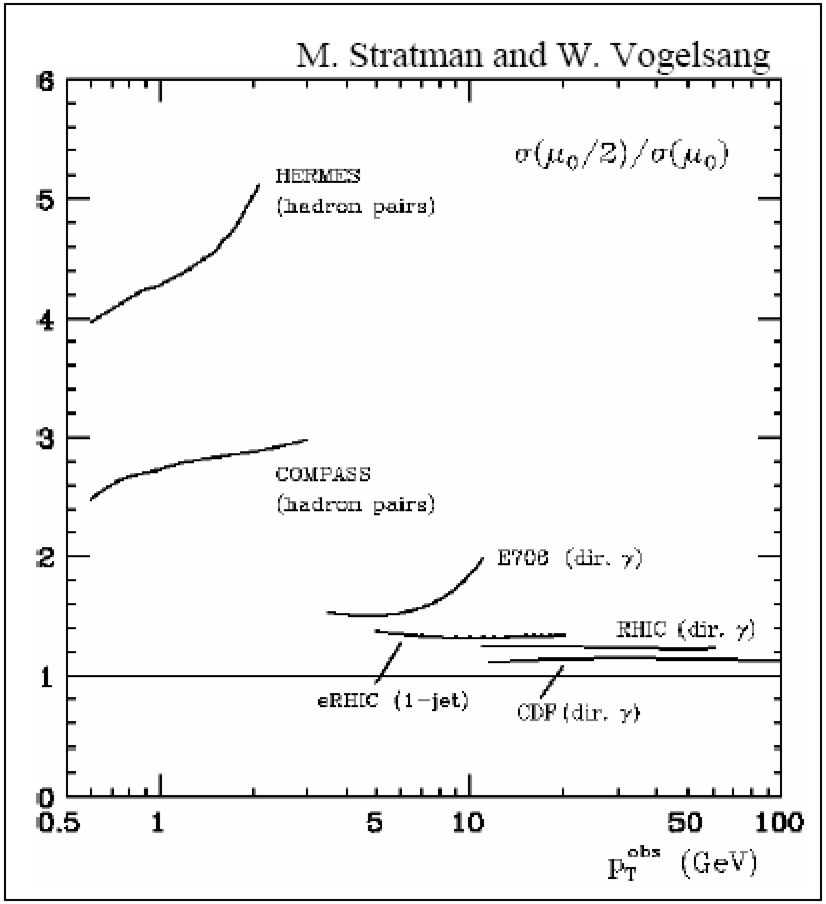
Exquisite Control of Systematics





Theory Under Control





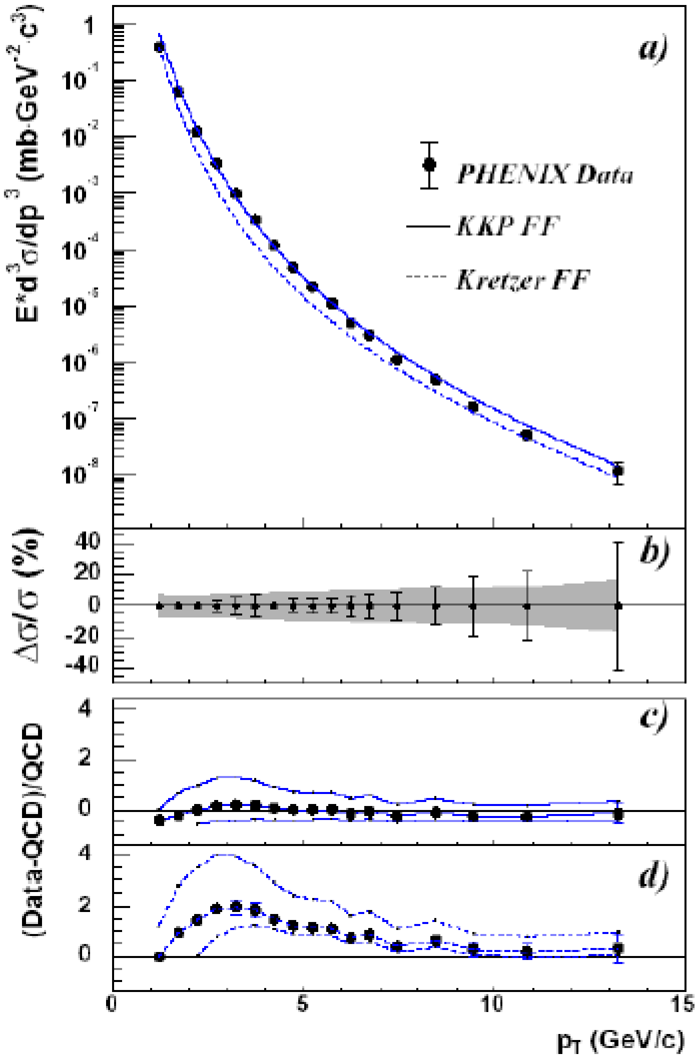
- Measured un-polarized cross section at √s=200 GeV well described by **NLO pQCD**
- non-identified charged hadrons, η also measured (and agree well w/ NLO)

$$d\Delta\sigma = \Delta f_{a/A}(x_a) \otimes \Delta f_{b/B}(x_b) \otimes d\Delta\hat{\sigma}^{ab\to cd} \otimes D_{h/c}(z_h)$$

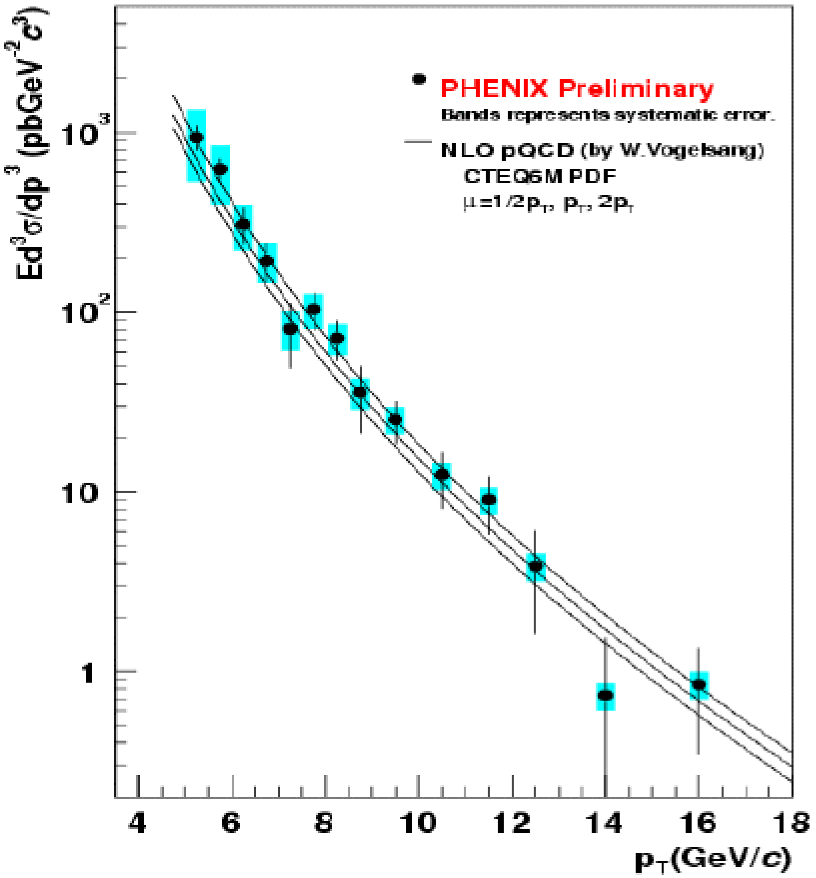
$$\Delta\sigma = \sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}$$

Cornerstone to the RHIC Spin program

$pp \rightarrow \pi X$



$pp \rightarrow \gamma X$



Unpolarized data are well described by NLO

Theoretical foundation

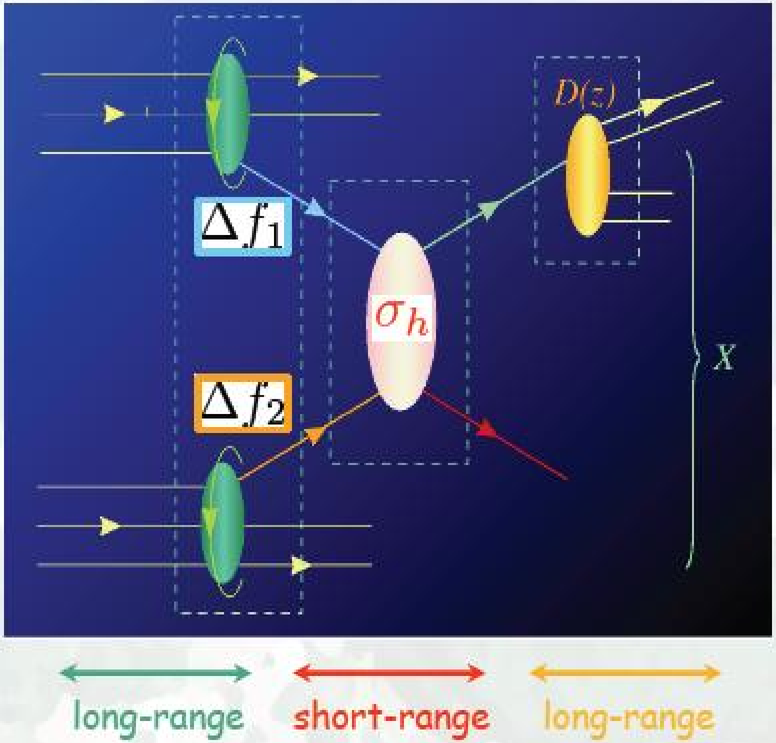
- Gluon polarization - Extraction

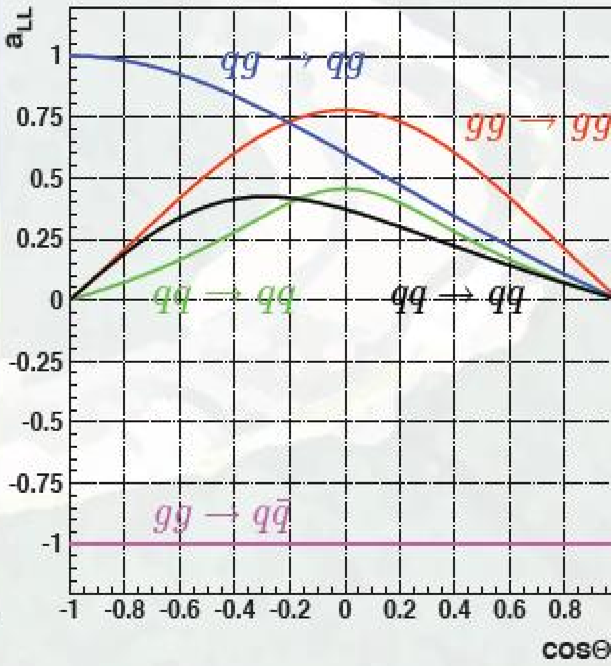
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx$$

Extract $\Delta g(x,Q^2)$ through

Global Fit (Higher Order

QCD analysis)!





$$a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}$$ } Input

$$A_{LL} = \frac{d\Delta\sigma}{d\sigma} \propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

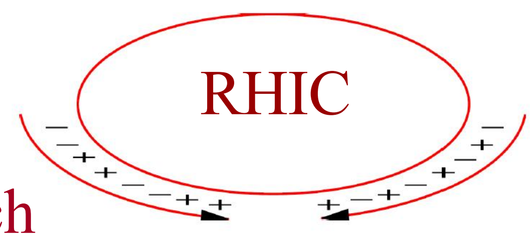
Polarized beams in RHIC.

OPPIS $10\cdot10^{11}$(maximum $40\cdot10^{11}$) polarized H^- /pulse.

LINAC $5\cdot10^{11}$ polarized H^- /pulse at 200 MeV, P=85-90%

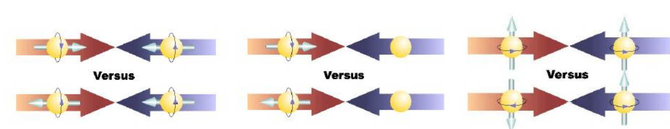
Booster $2\cdot10^{11}$ polarized protons /pulse at 2.3 GeV

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



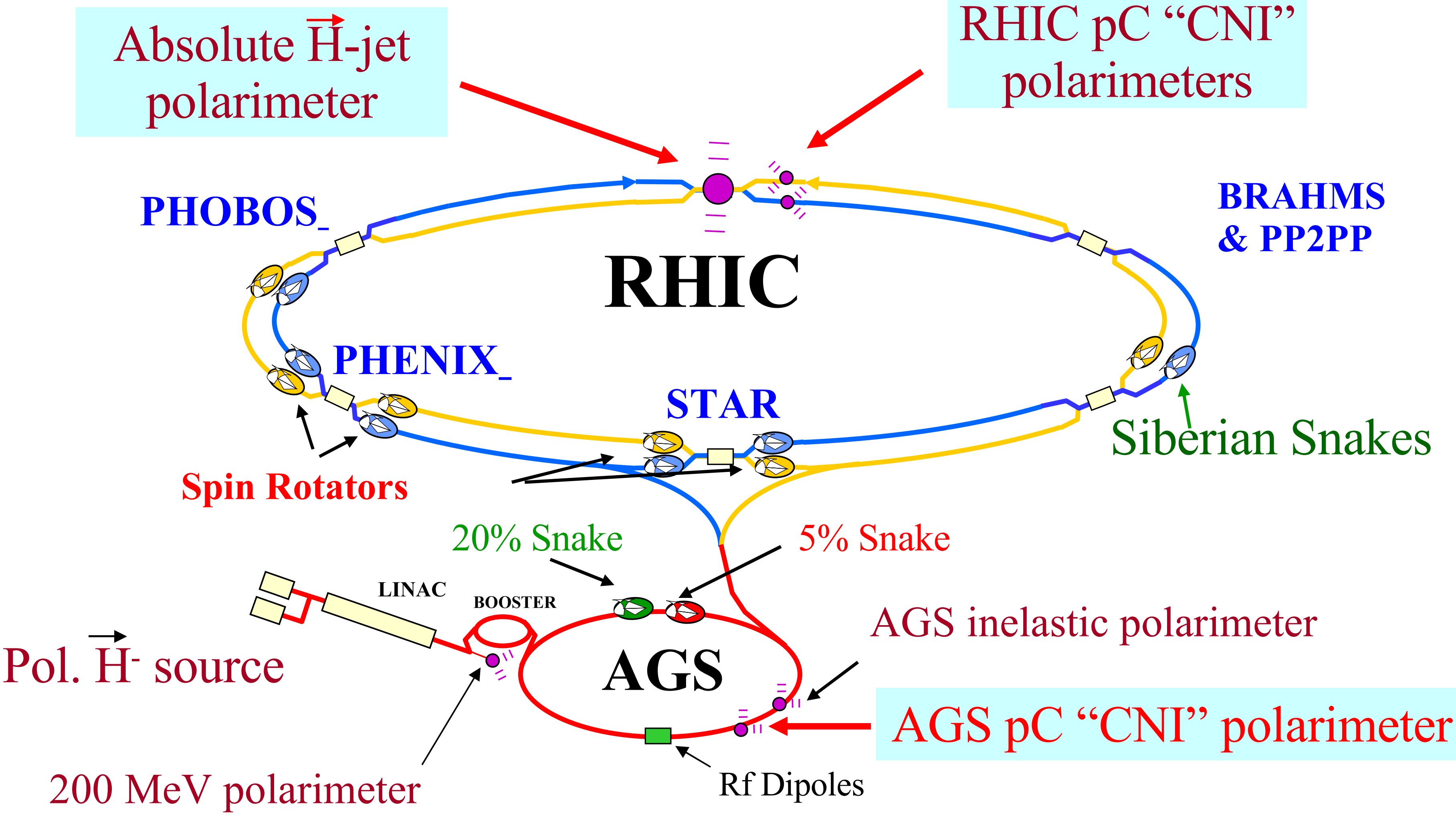
Maximum RHIC bunch intensity ~1.5 10^{11} p/bunch

Polarization -65%



Polarization facilities at RHIC.

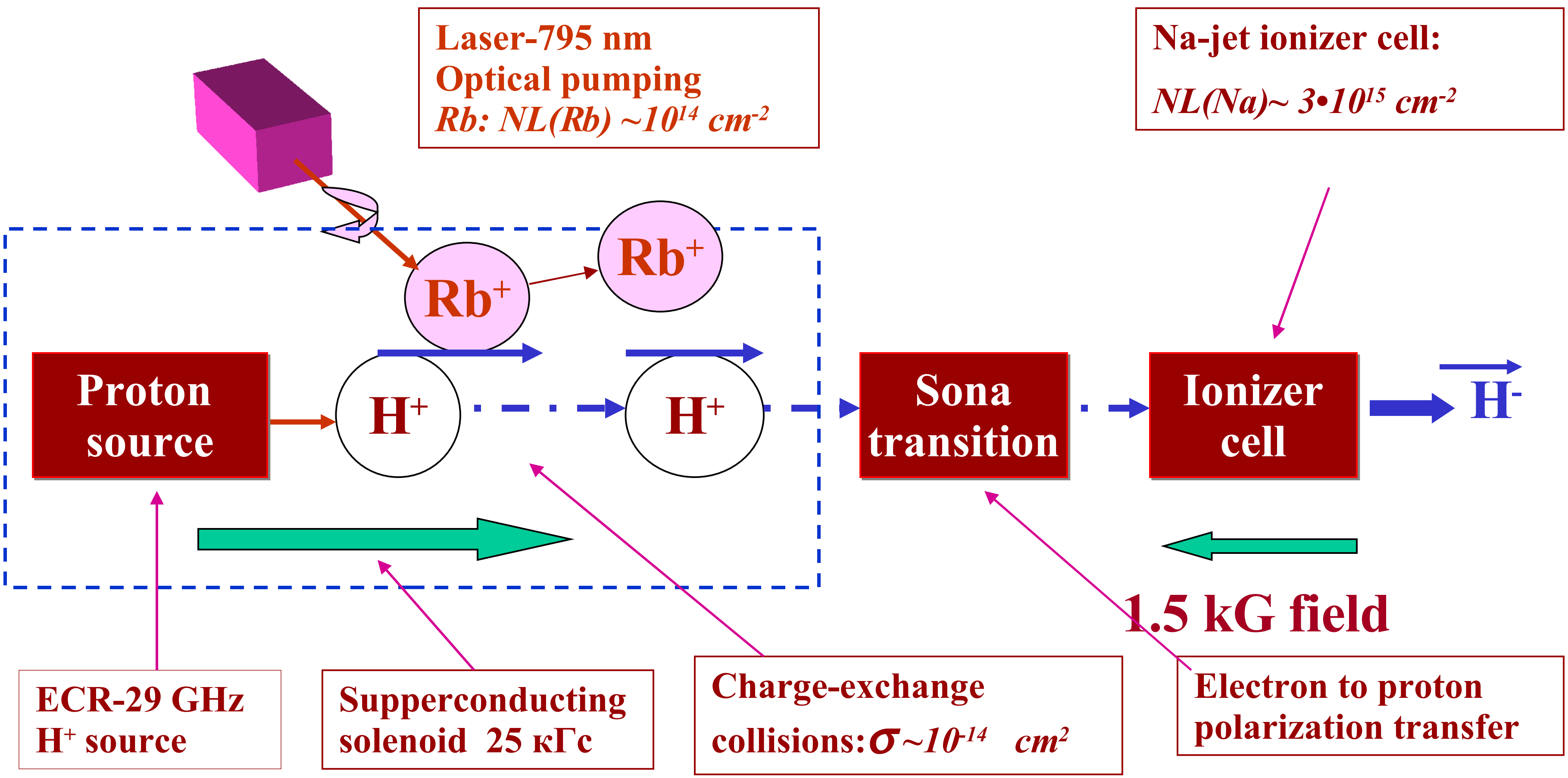
70% Polarization $L_{max} = 2 \times 10^{32}\ s^{-1}cm^{-2}$ $50 < \sqrt{s} < 500$ GeV



Polarized ion sources at RHIC.

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

SPIN -TRANSFER POLARIZATION IN PROTON-Rb COLLISIONS.

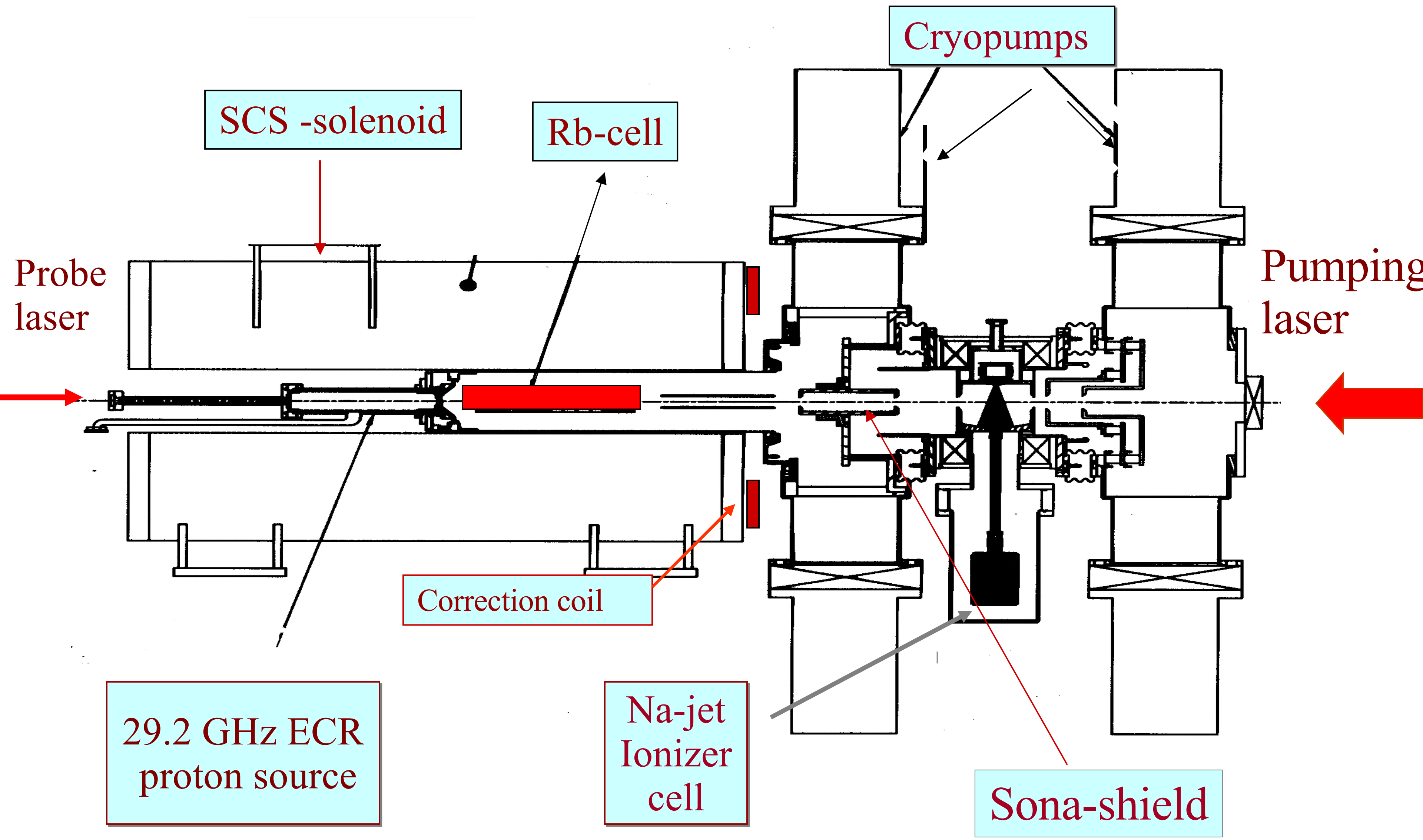


Laser beam is a primary source of angular momentum:

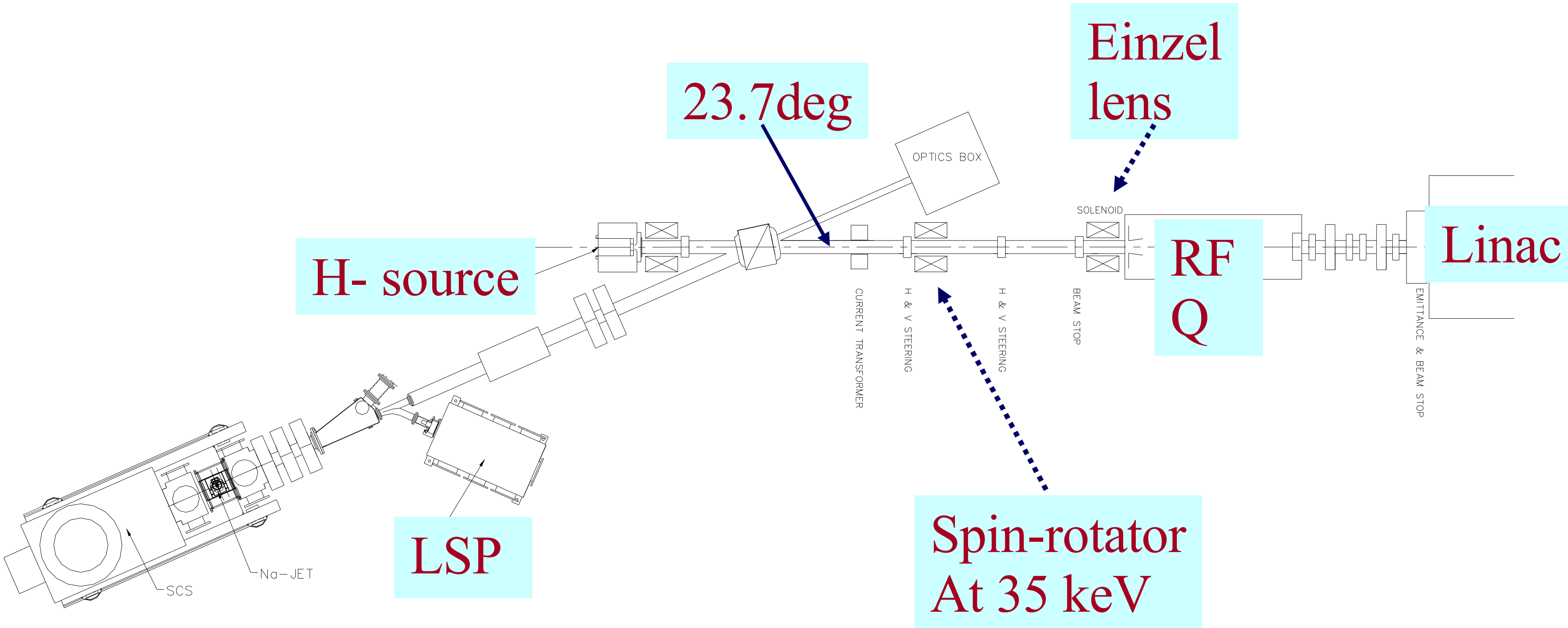
10 W (795 nm) ⇒ $4 \bullet 10^{19}$ hν/sec ⇒ $\vec{2}$ A, H^0

equivalent intensity.

SCHEMATIC LAYOUT OF THE RHIC OPPIS.



LEBT upgrade for 2009 Run.



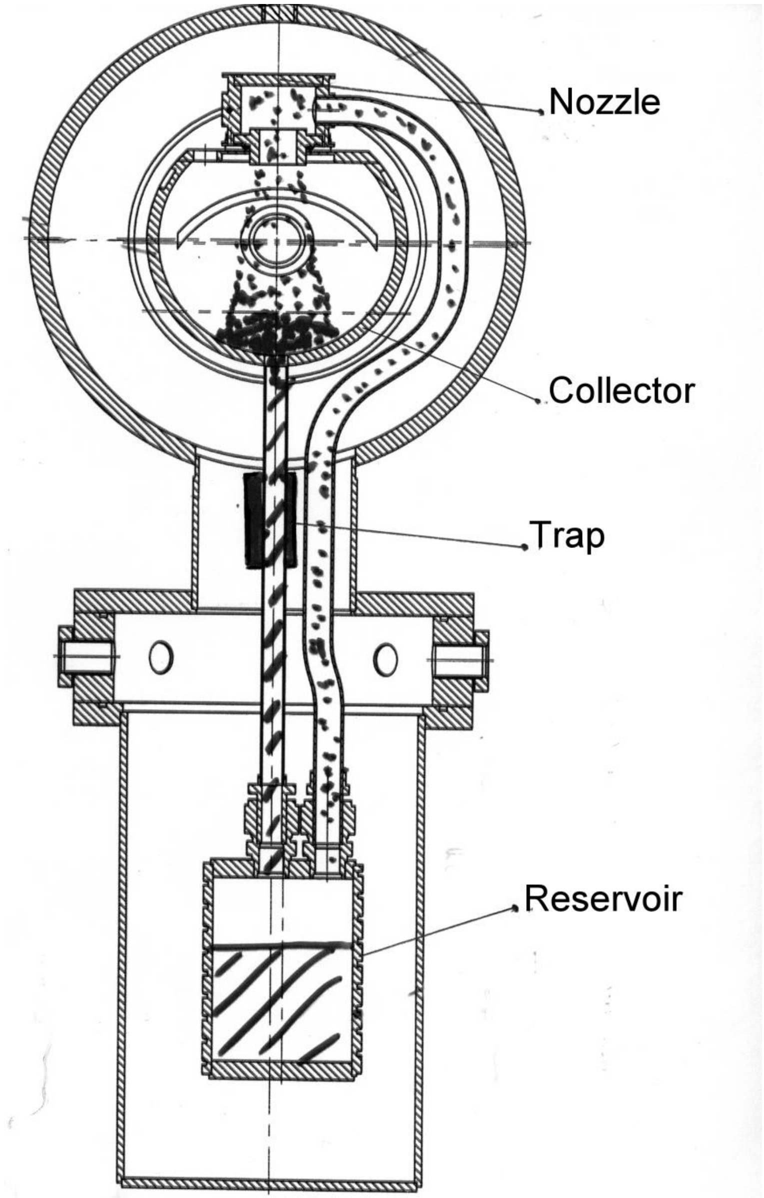
Spin-precession will be reduced to minimum required for vertical polarization direction in Linac. This should reduce the polarization profile generation in LEBT.

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

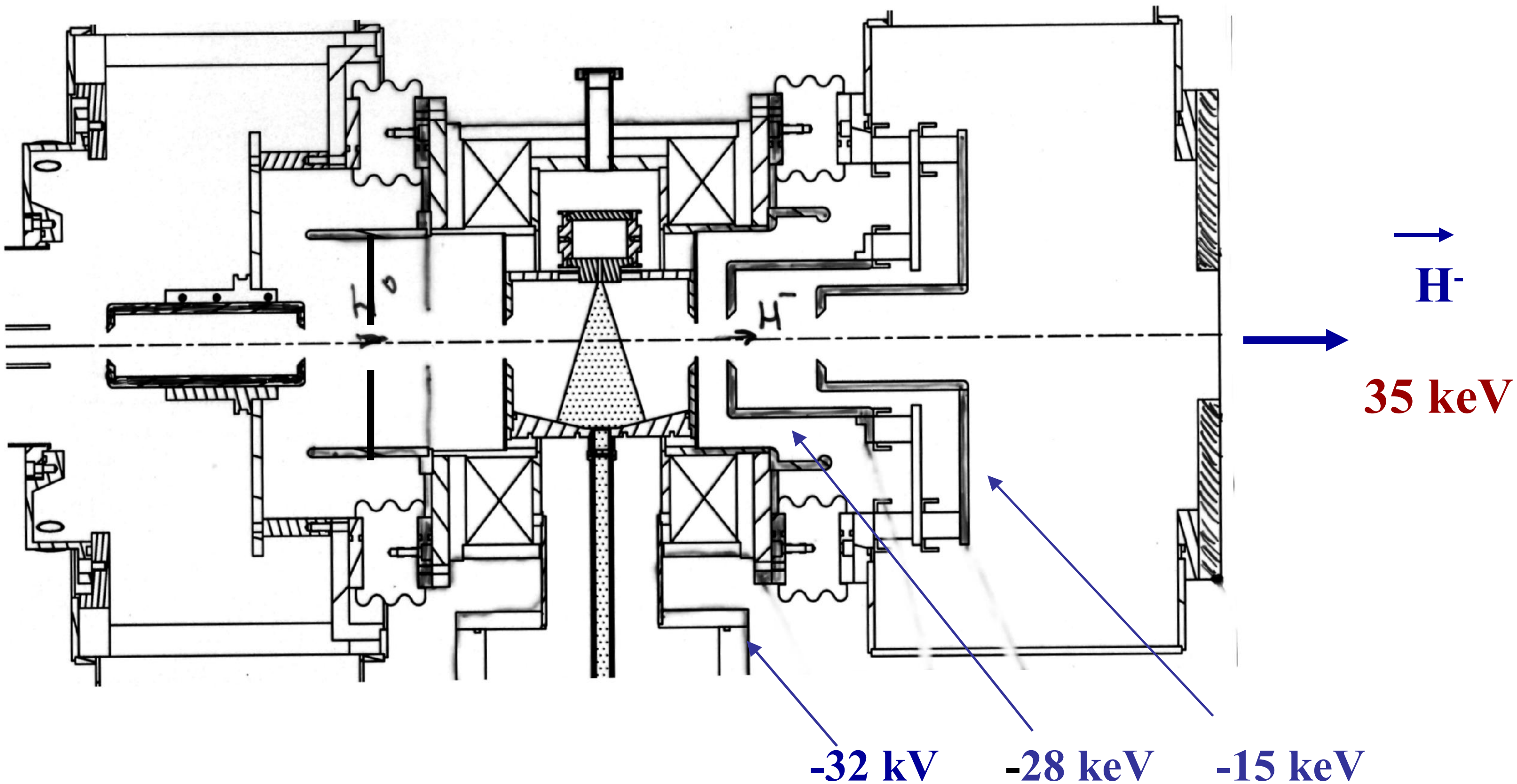
Sodium-jet ionizer cell.

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.



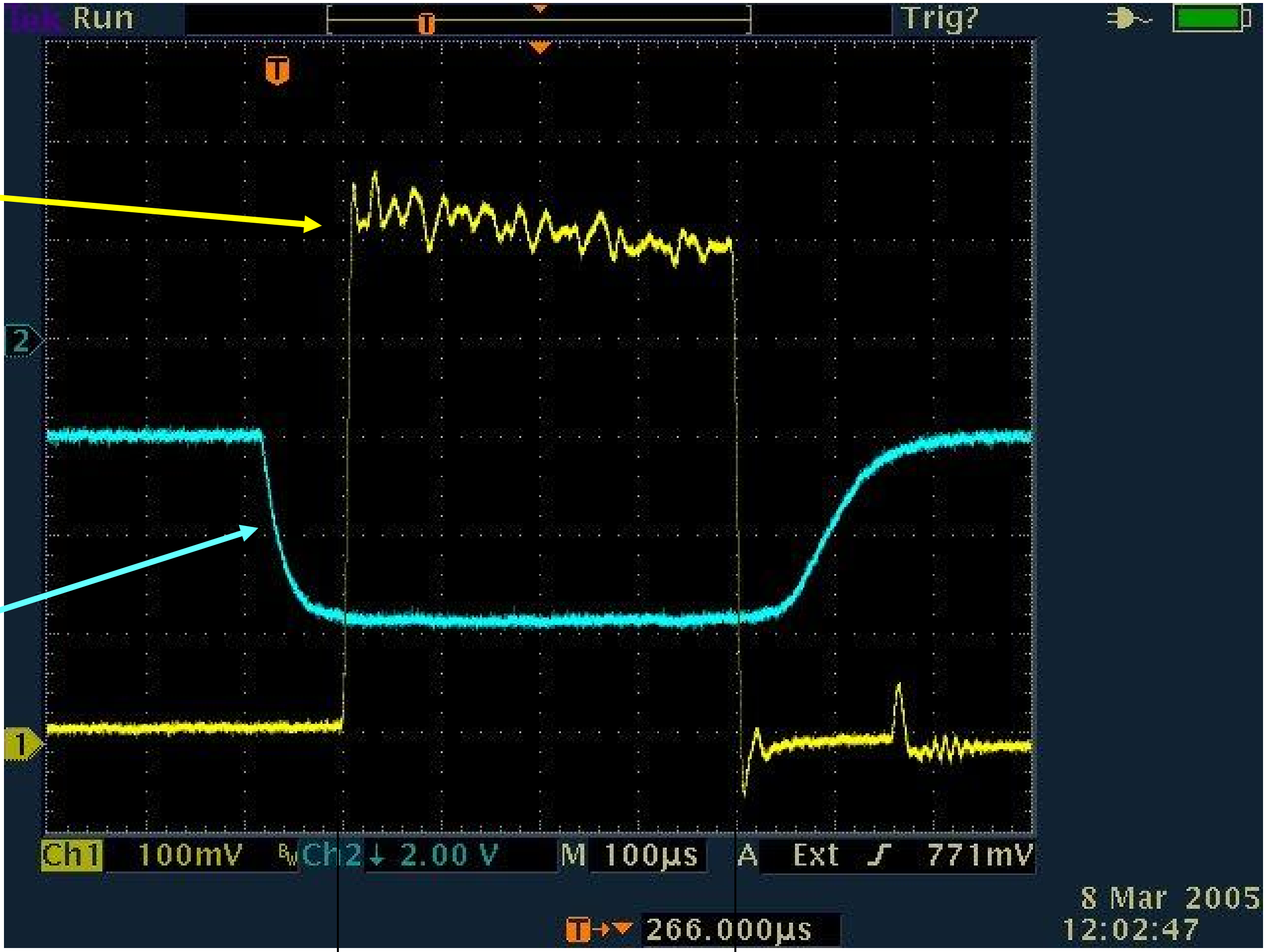
H⁻ beam acceleration to 35 keV at the exit of Na-jet ionizer cell.



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

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

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

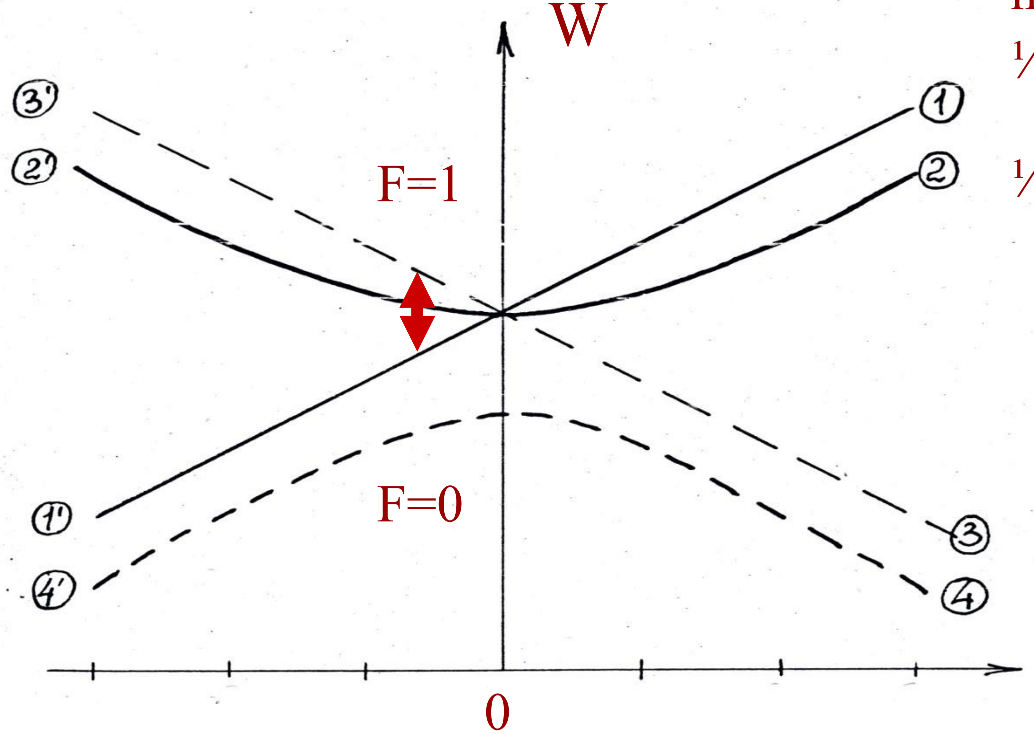


Faradey rotation polarization sinal.

400 uS

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

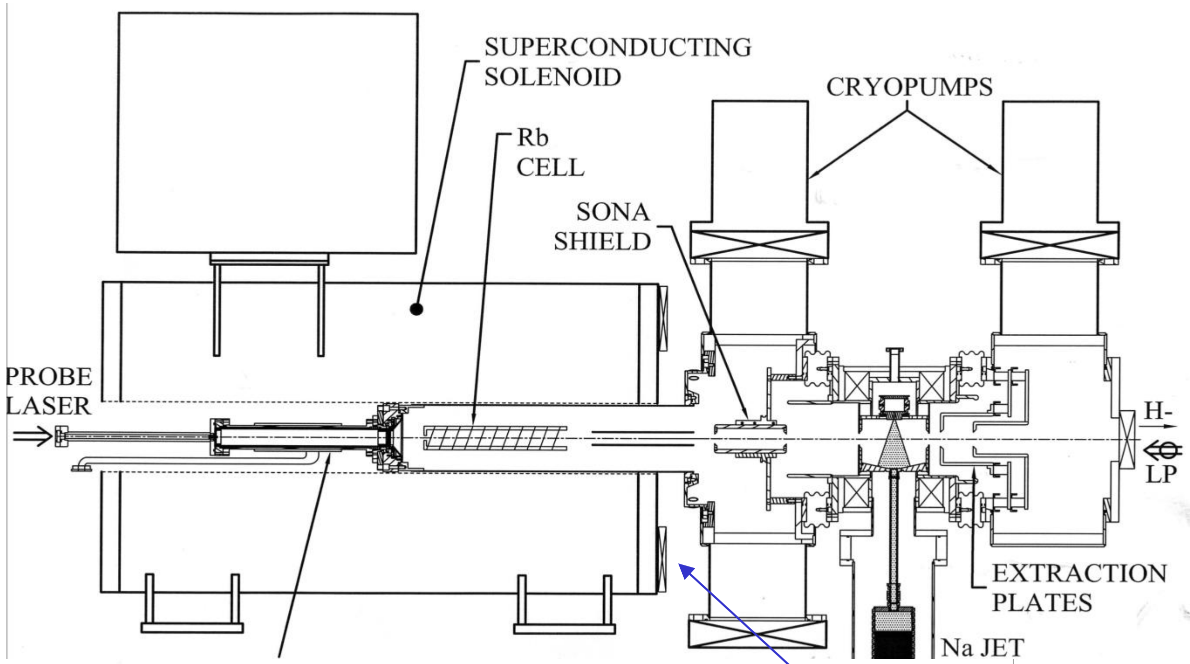
Sona-transition, P.G.Sona, Energia Nucleare, 1976



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

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

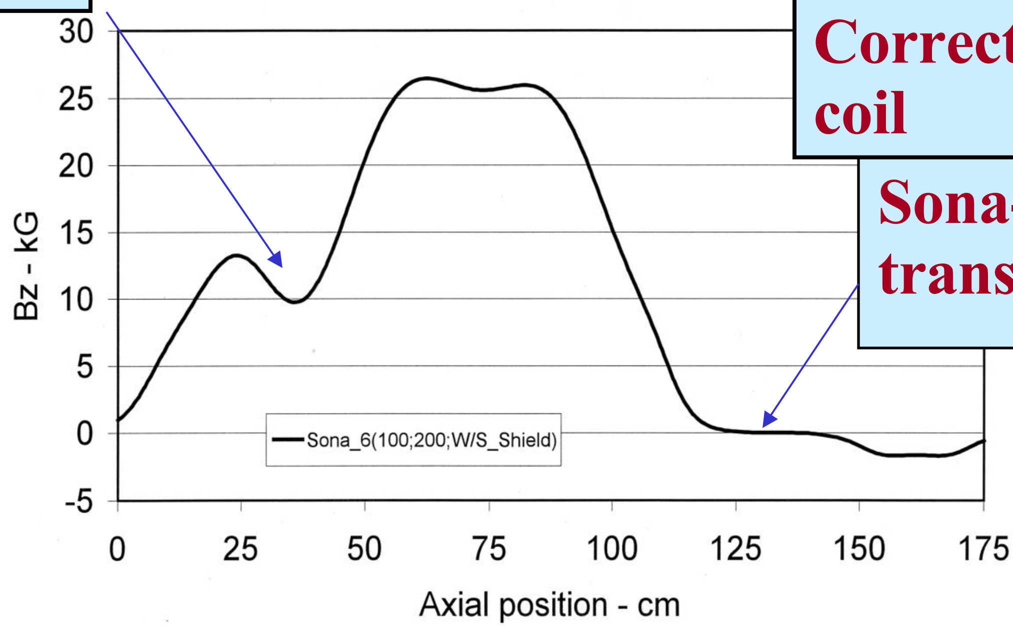
Sona-transition. Polarization transfer from electrons to protons.



ECR-zone

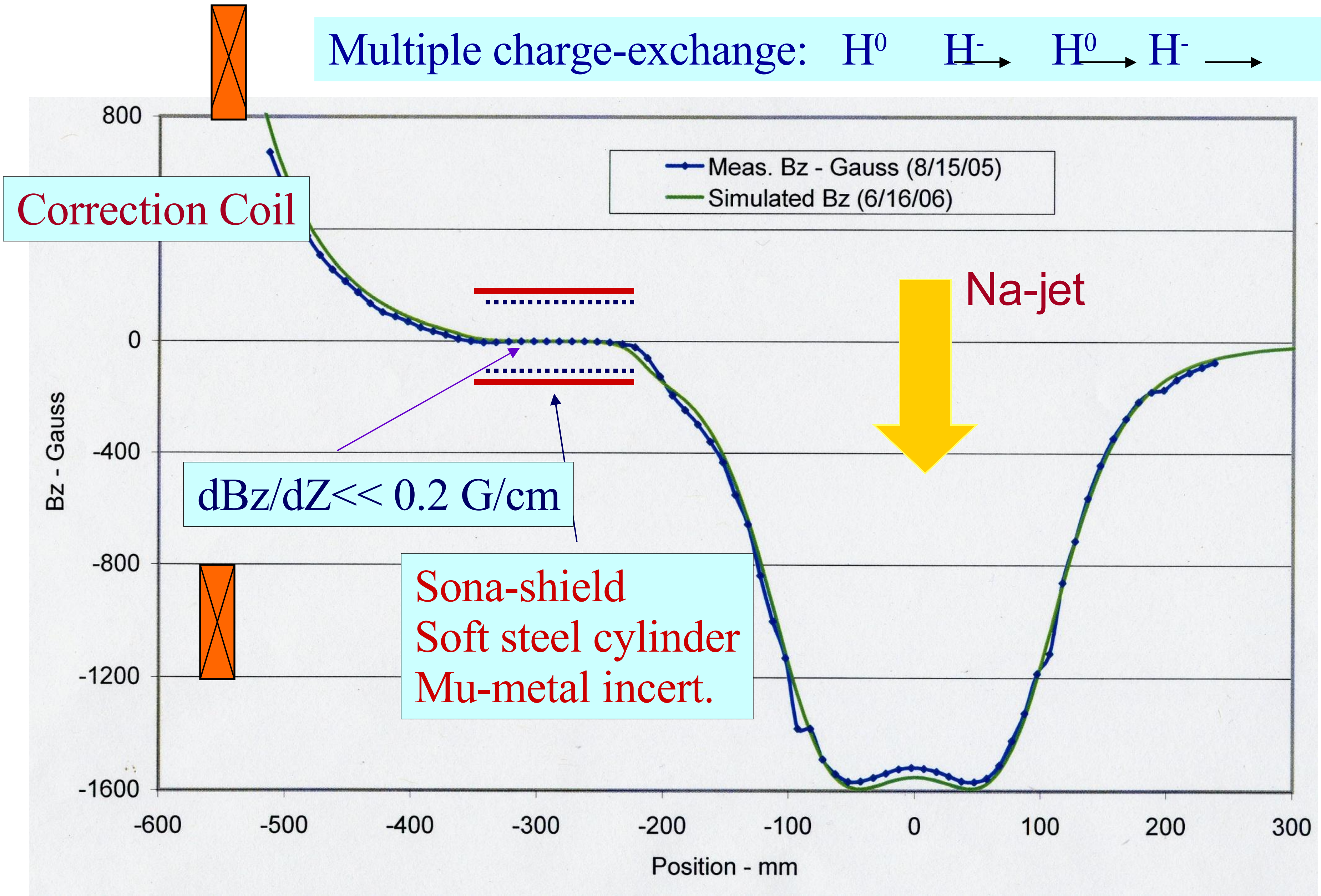
Correction coil

Sona-transition

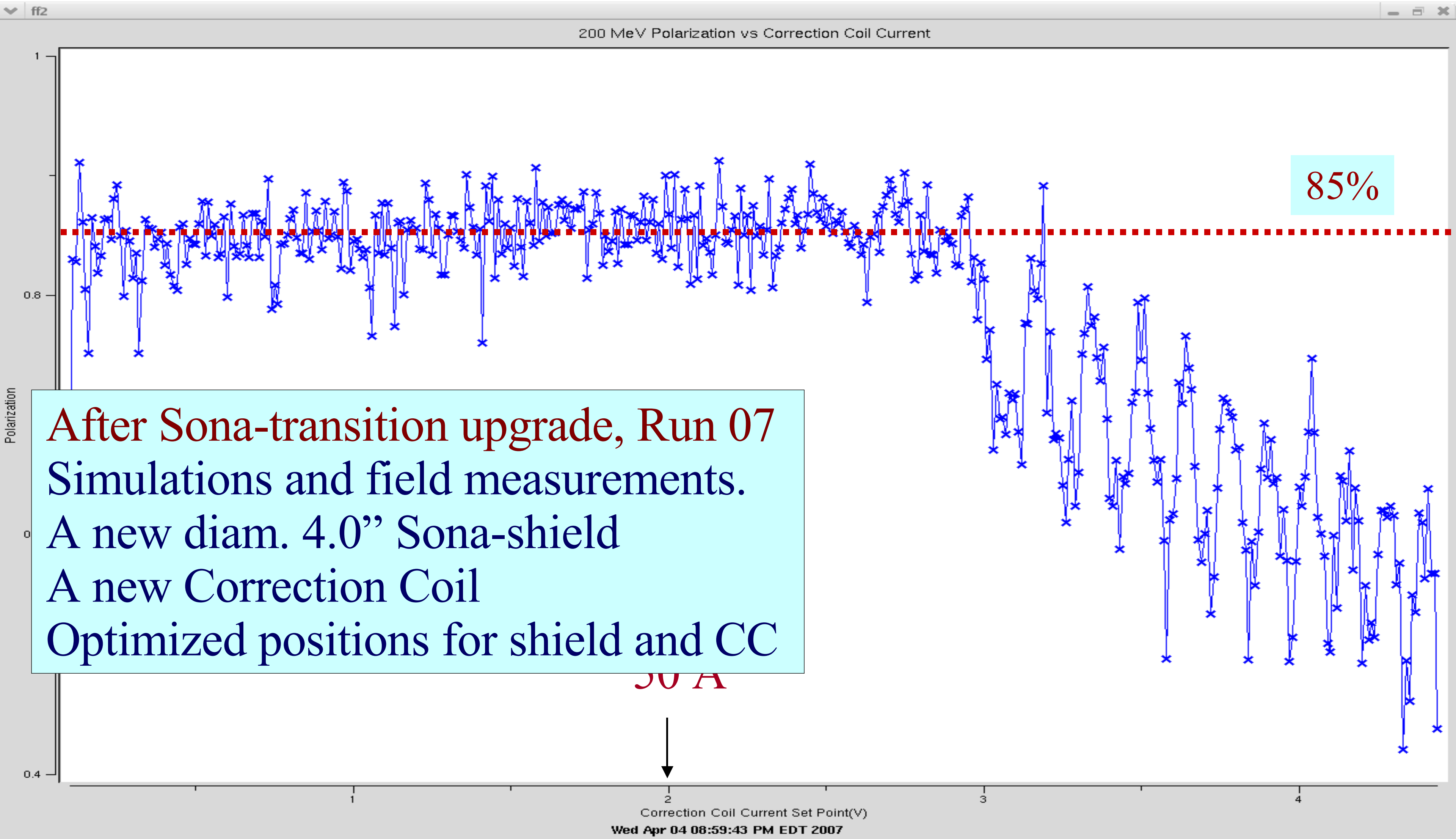


Bz-field component in the Sona-transition region.

Multiple charge-exchange: H^0 H^- → H^0 → H^- →



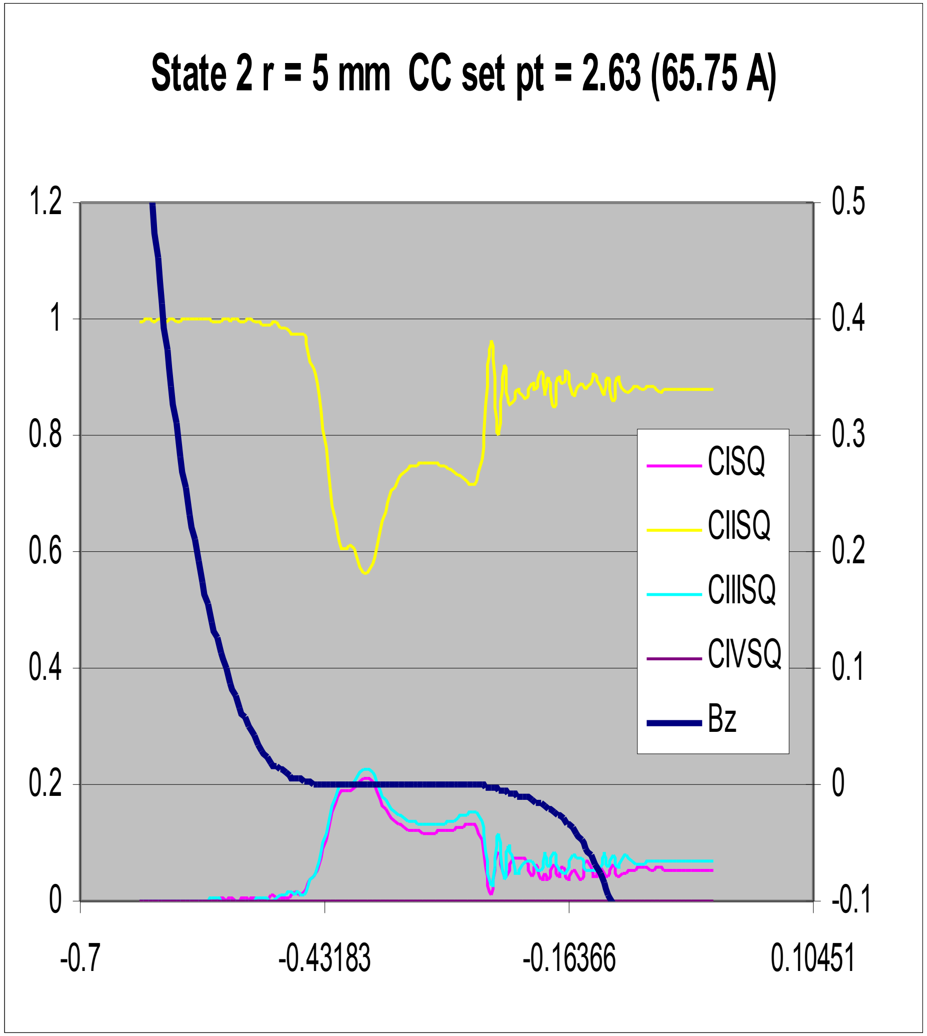
Polarization oscillations in the Sona-transition, Run - 07.



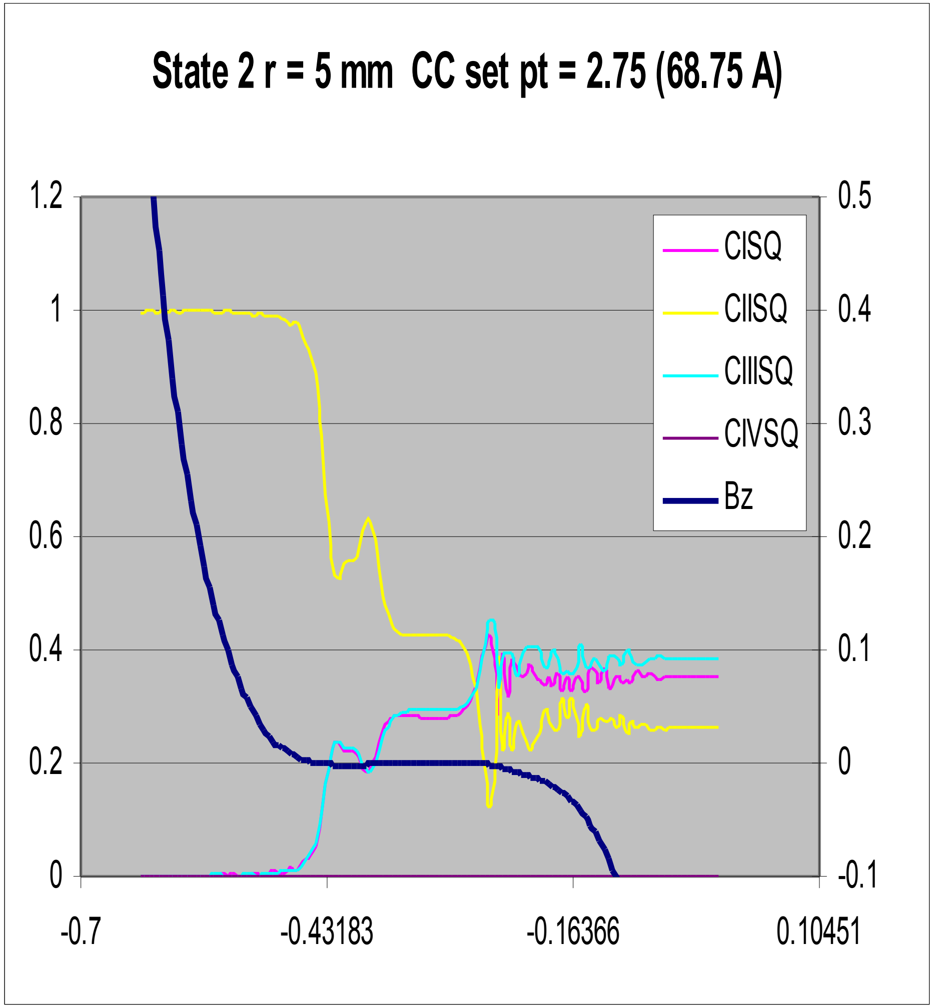
After Sona-transition upgrade, Run 07
Simulations and field measurements.
A new diam. 4.0” Sona-shield
A new Correction Coil
Optimized positions for shield and CC

Polarization at 200 MeV vs. Correction Coil current

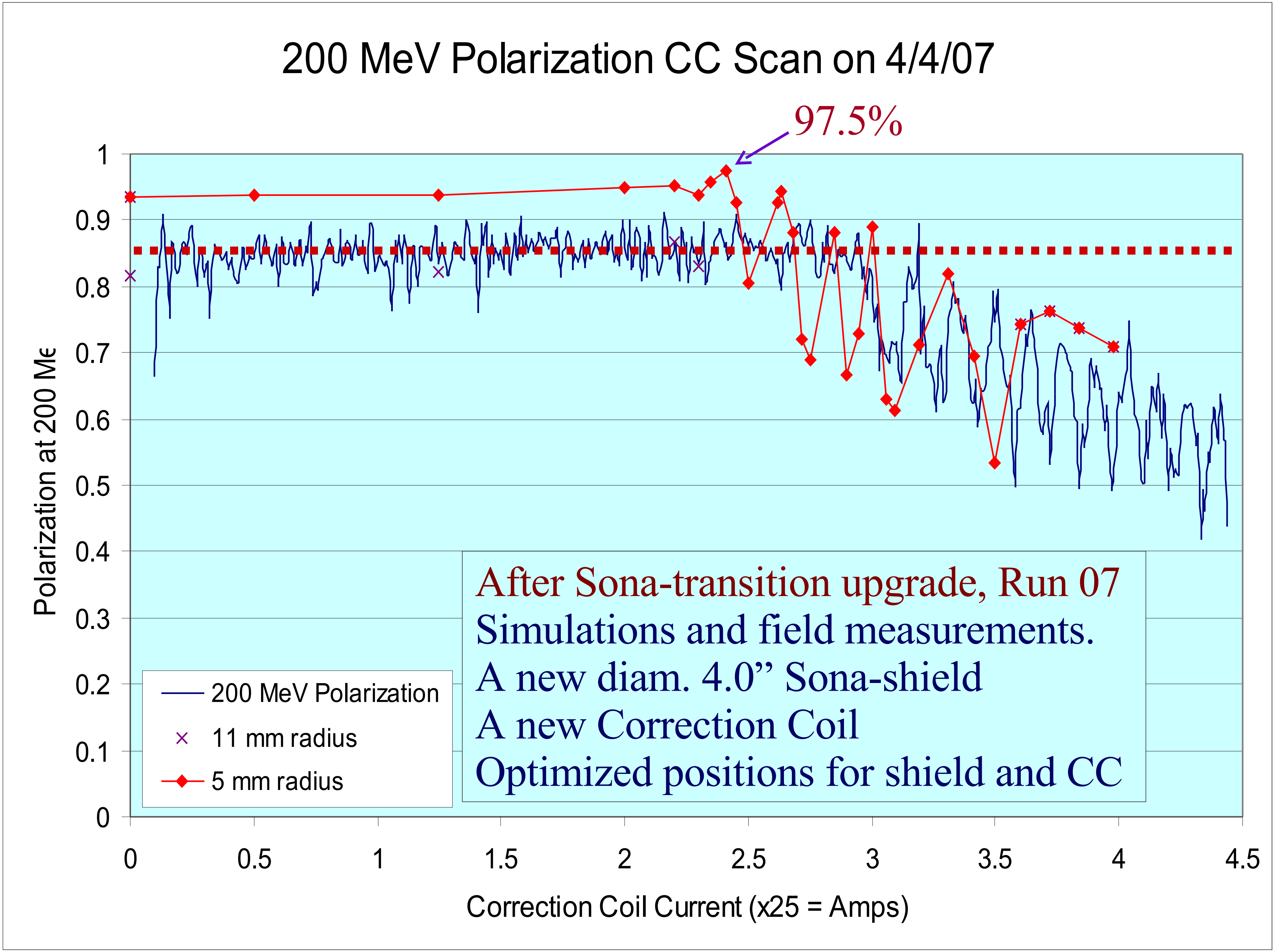
State 2 (r=5 mm)



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
Correction Coil Current (x25 = Amps)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
200 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%)

Expected

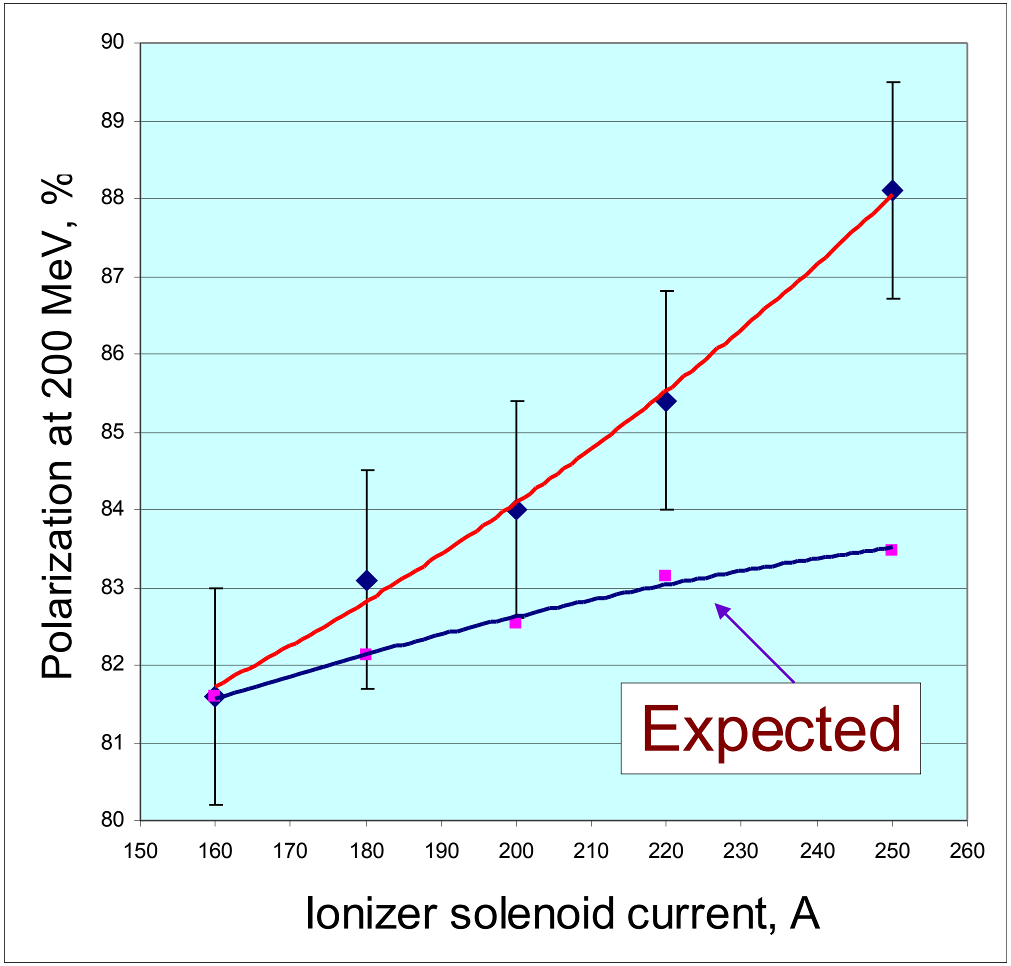
23 mm collimator.

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

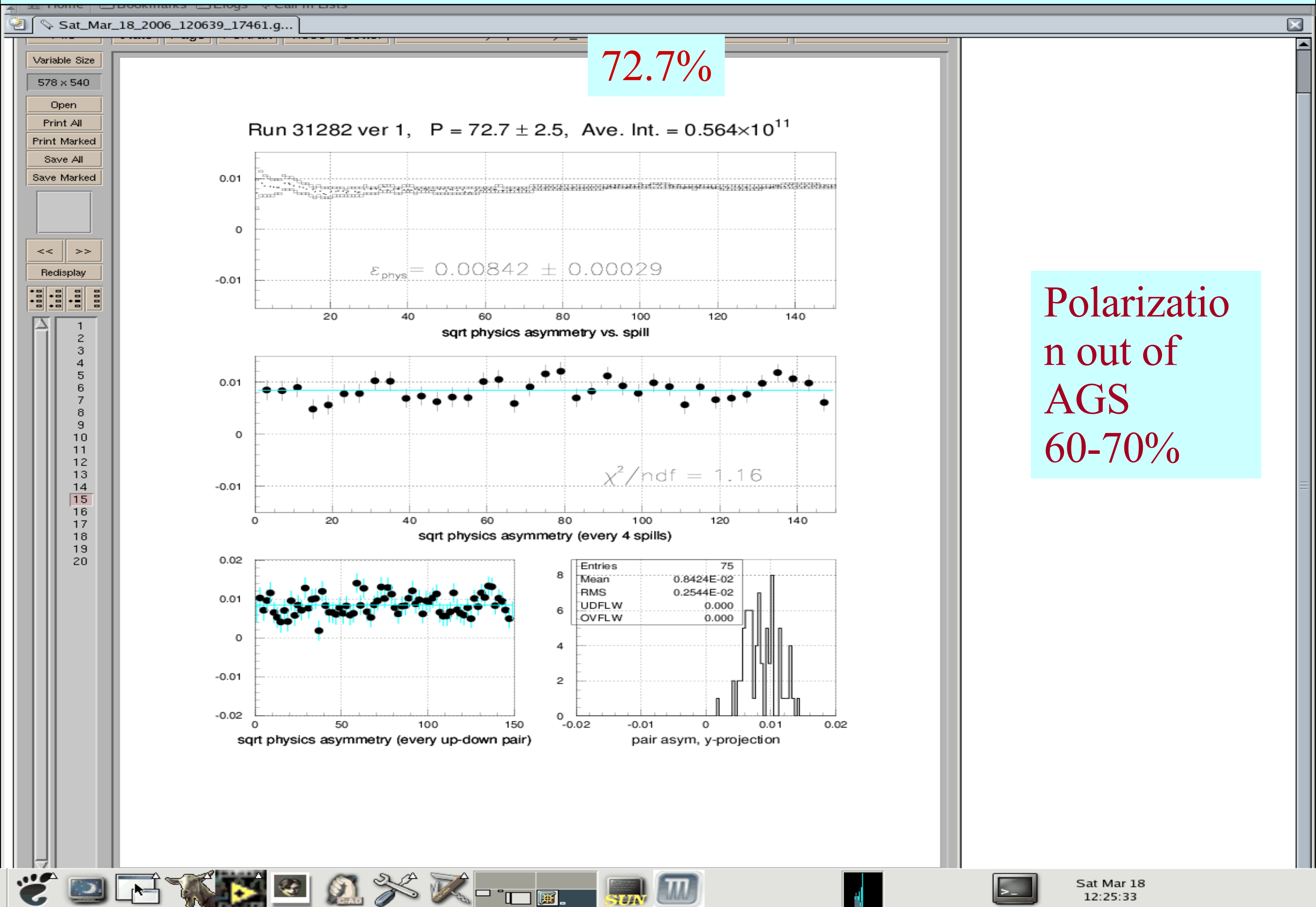
POLARIZATION (L/R) (P,dP): 0.856941 | 0.000236641

RESTART

Wed Apr 04 04:52:37 PM EDT 2007

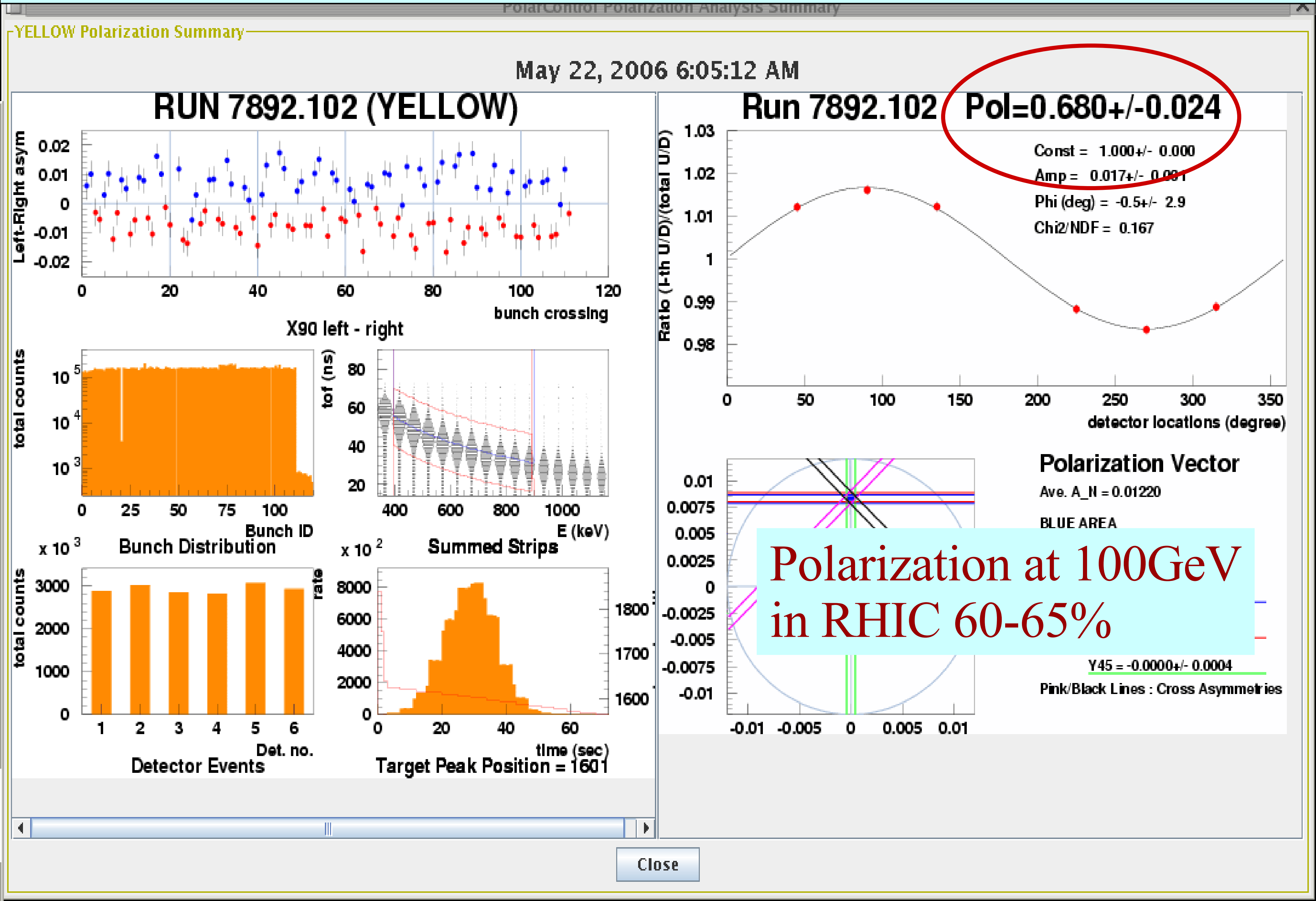
Polarization measurement in AGS at 24 GeV.

72.7%



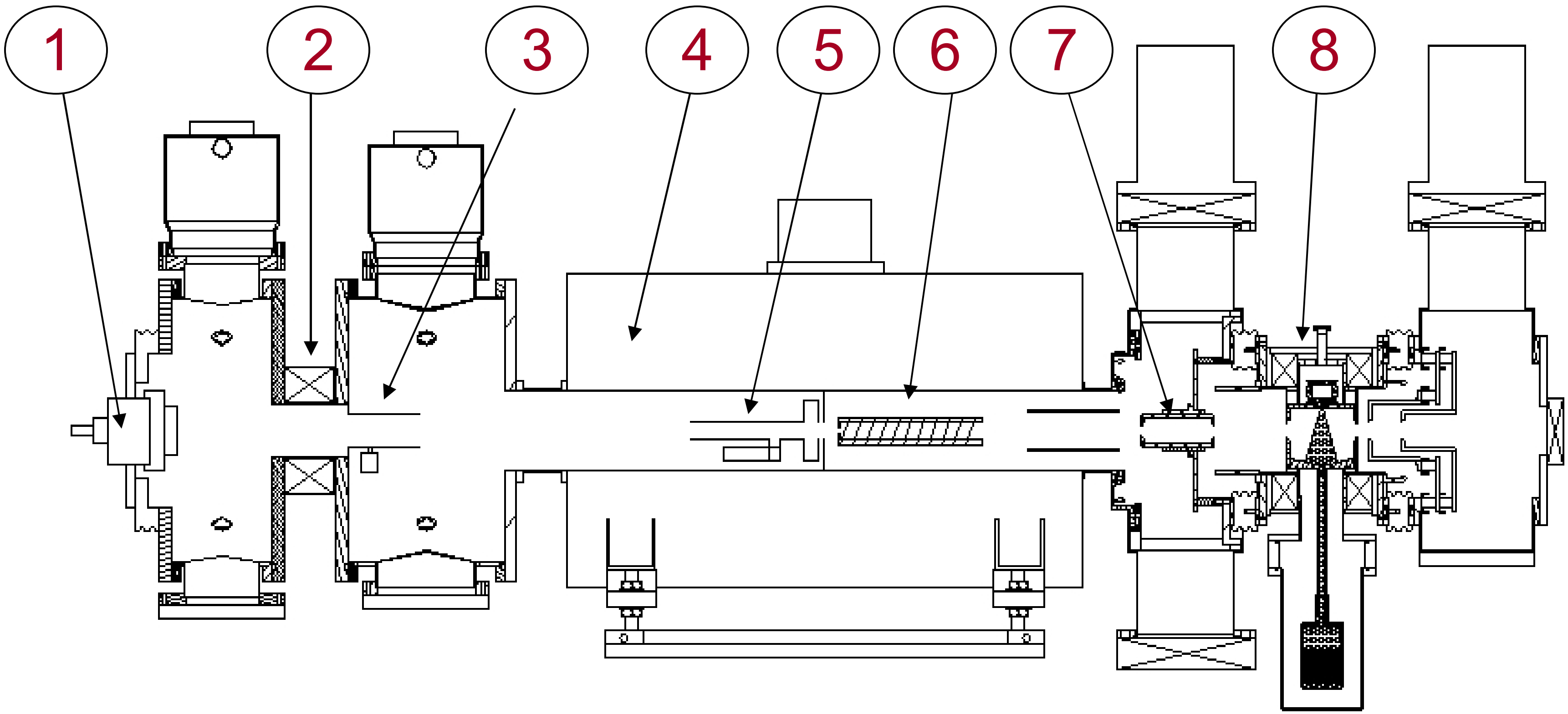
Polarization out of AGS 60-70%

Polarization measurements in RHIC at 100 GeV.



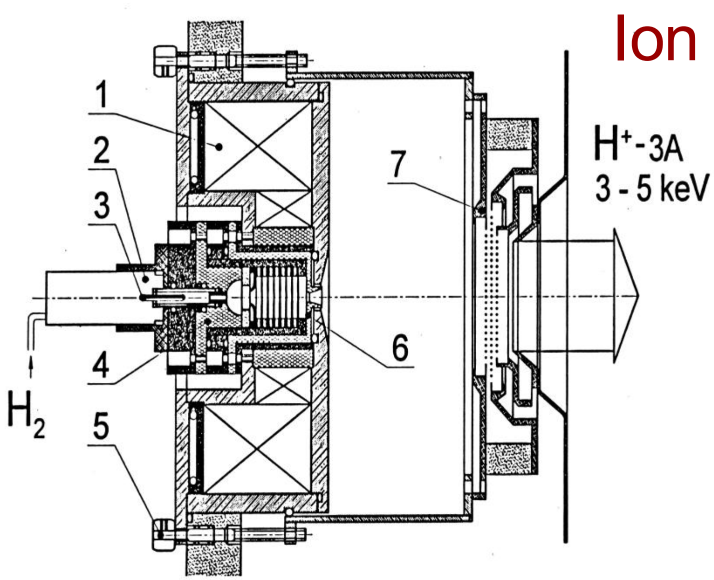
Polarization at 100GeV in RHIC 60-65%

OPPIS with Fast Atomic Beam Source

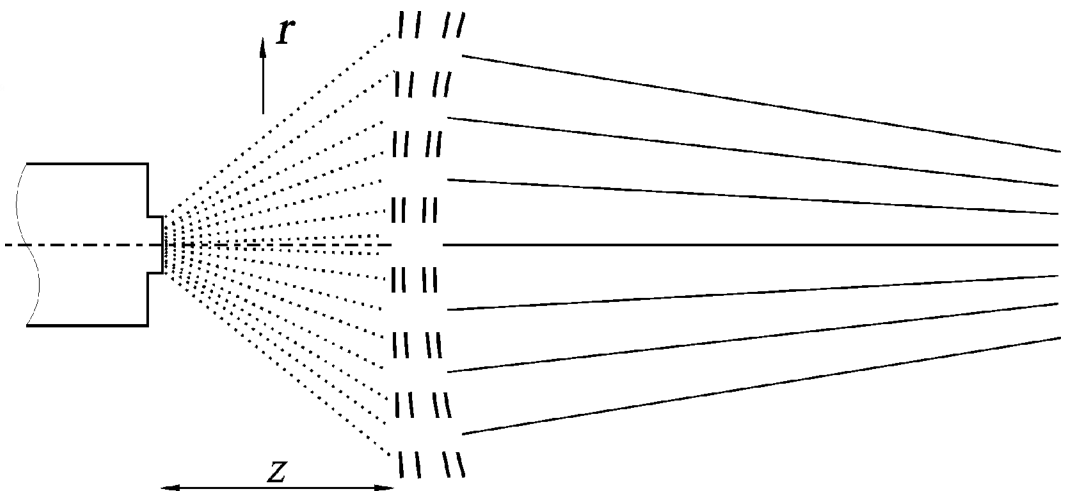


General layout: 1- high-brightness plasmatron proton source; 2 – focusing lens; 3- H2 neutralizer cell; 4-superconducting solenoid; 5-He ionizer cell; 6-Rb vapor cell; 7-Sona transition; 8- sodium-jet ionizer cell.

Proton "cannon" of the atomic H injector.

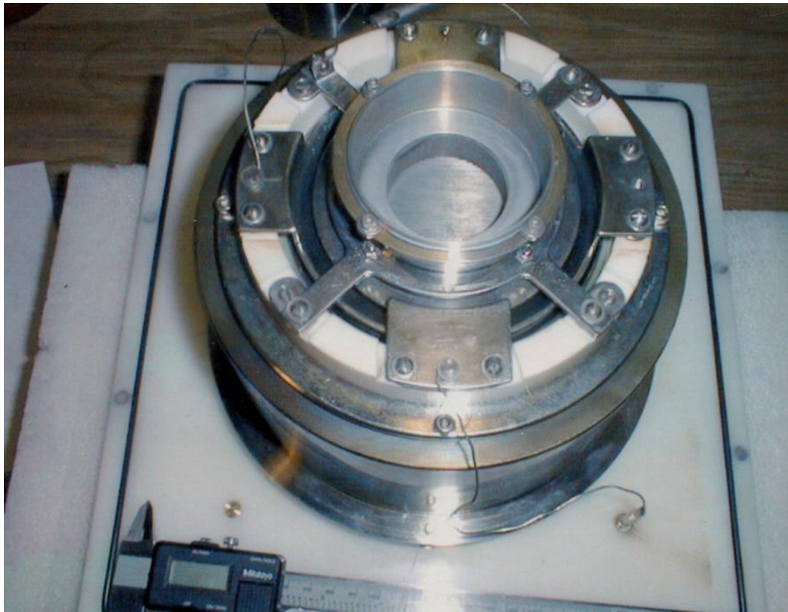


Ion Optical System with "geometrical focusing"

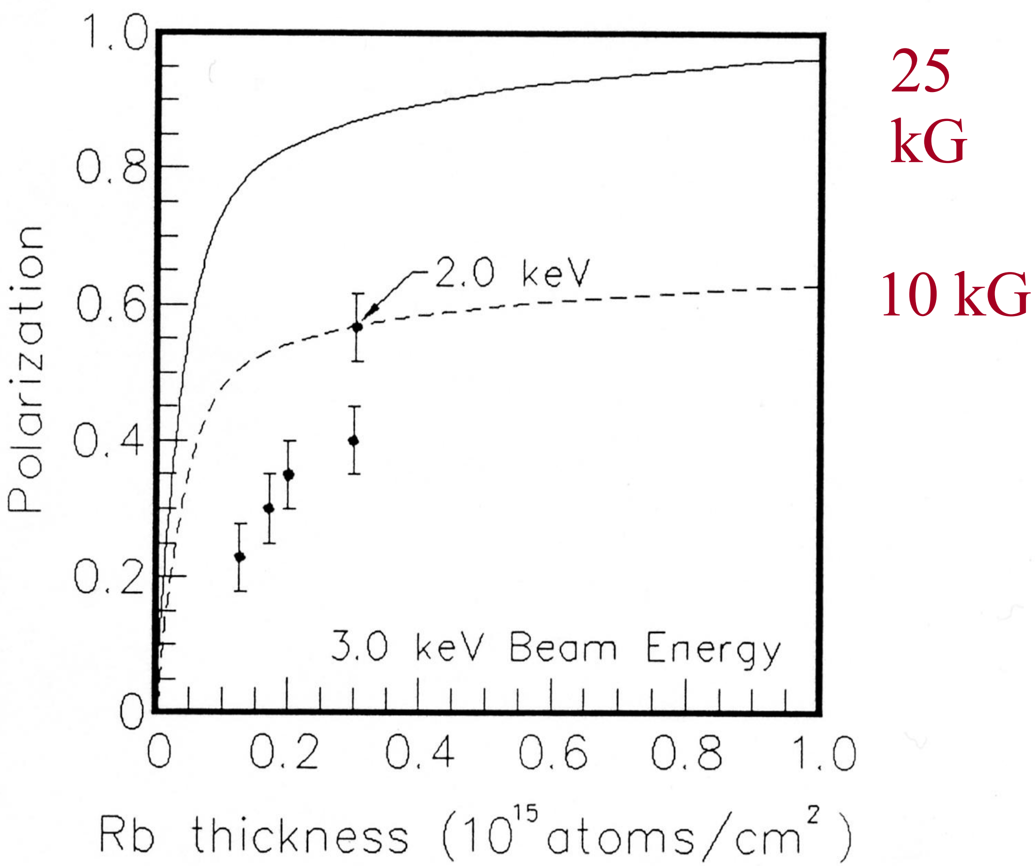


The source produced 3 A ! pulsed
proton current at 5.0 keV.

~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.



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.

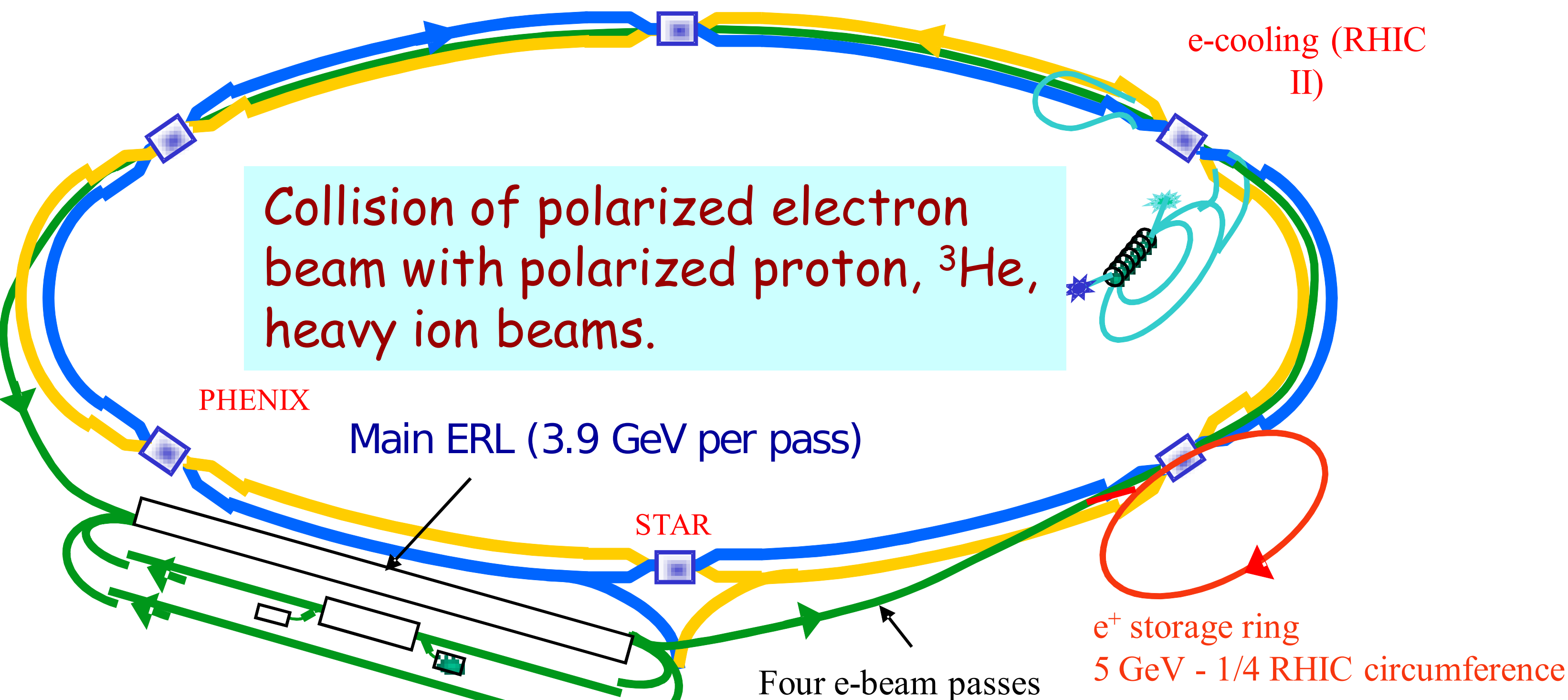
- All these factors combined will further increase polarization in the pulsed OPPIS to:

  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.

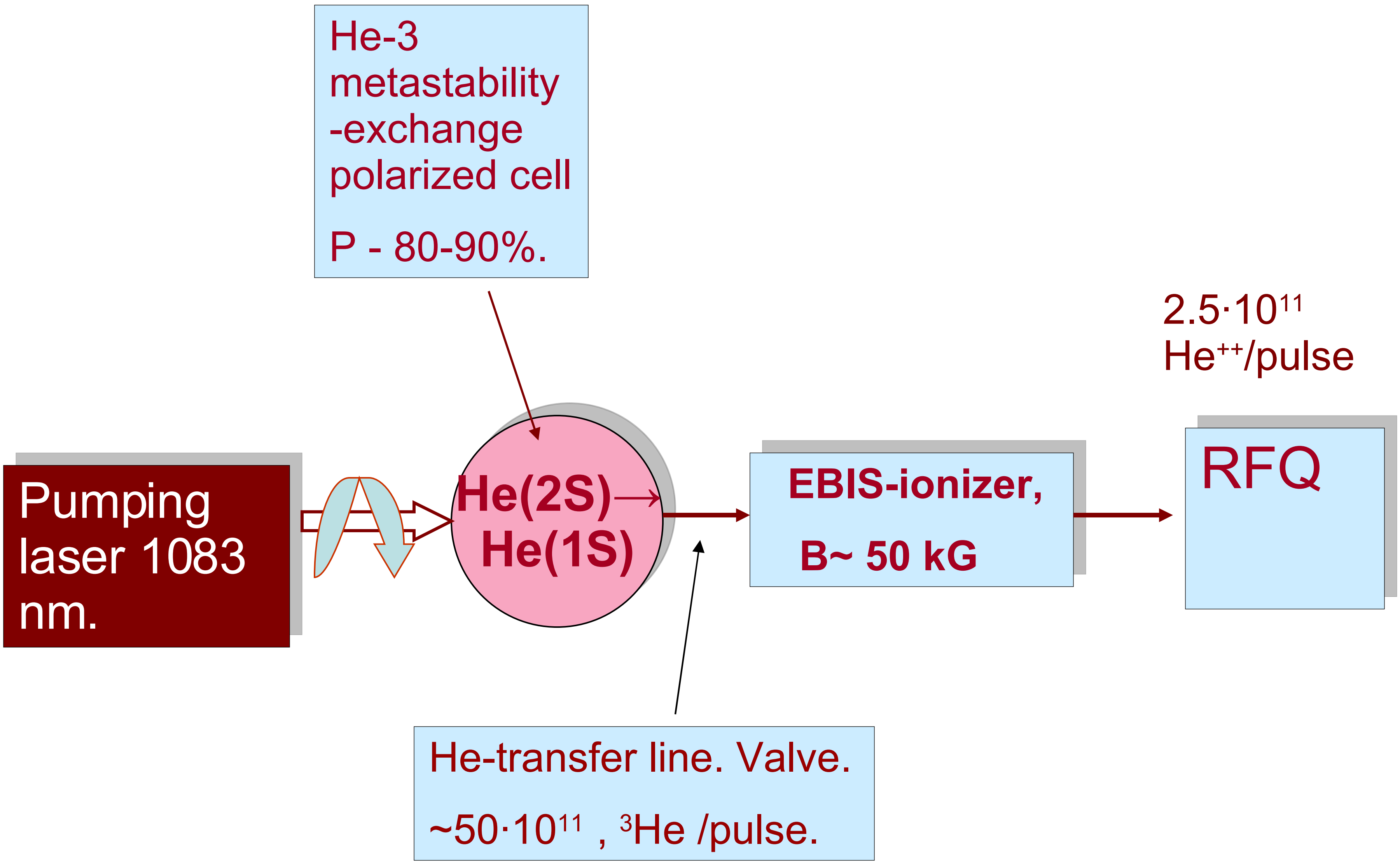
eRHIC-electron Ion Collider at BNL



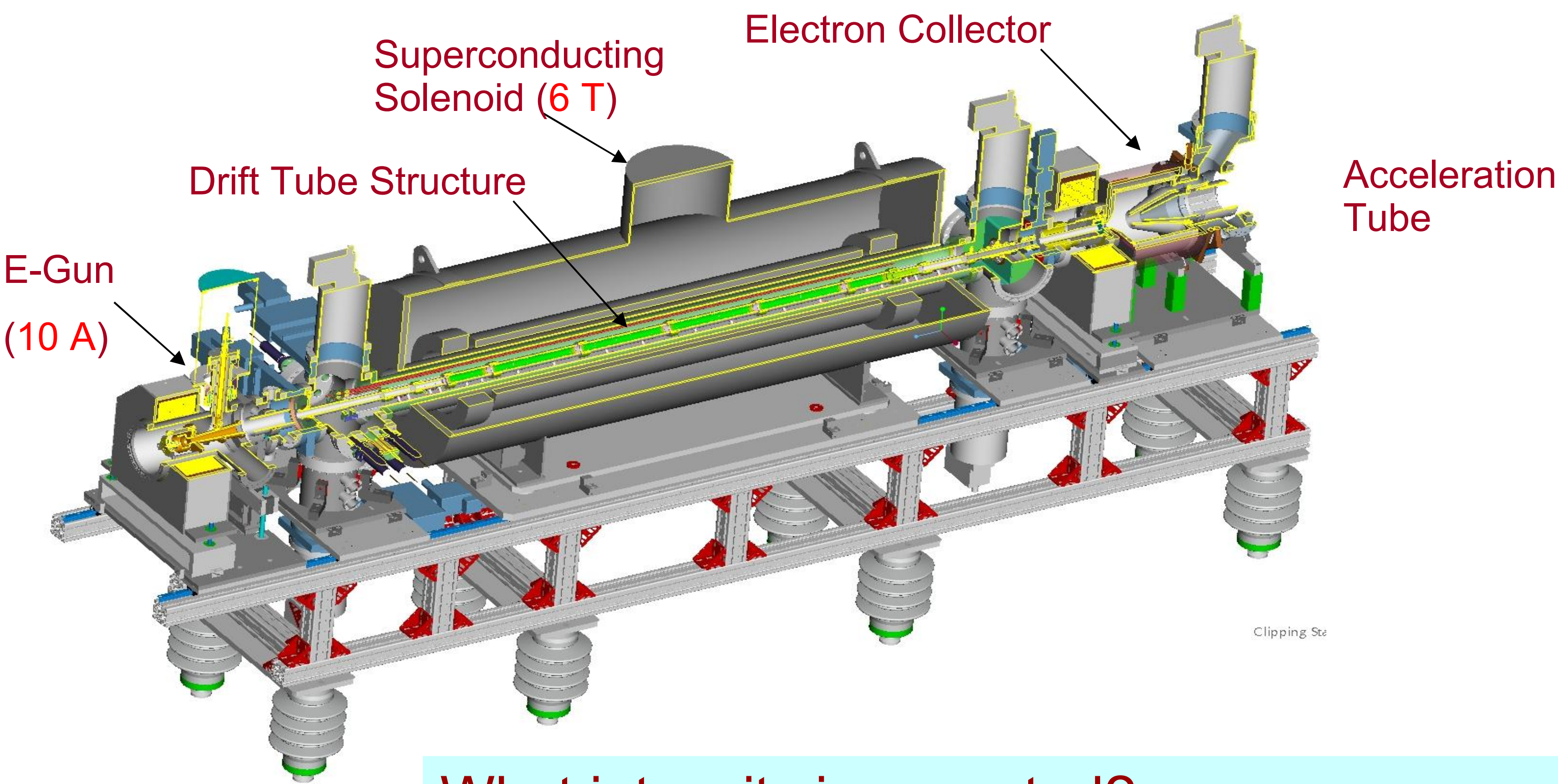
- Electron energy range from 3 to 20 GeV
- Peak luminosity of 2.6×10^{33} $cm^{-2}s^{-}$
- high electron beam polarization (~80%)
- full polarization transparency at all energies
- multiple electron-hadron interaction points

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

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



Electron Beam Ion Source at RHIC



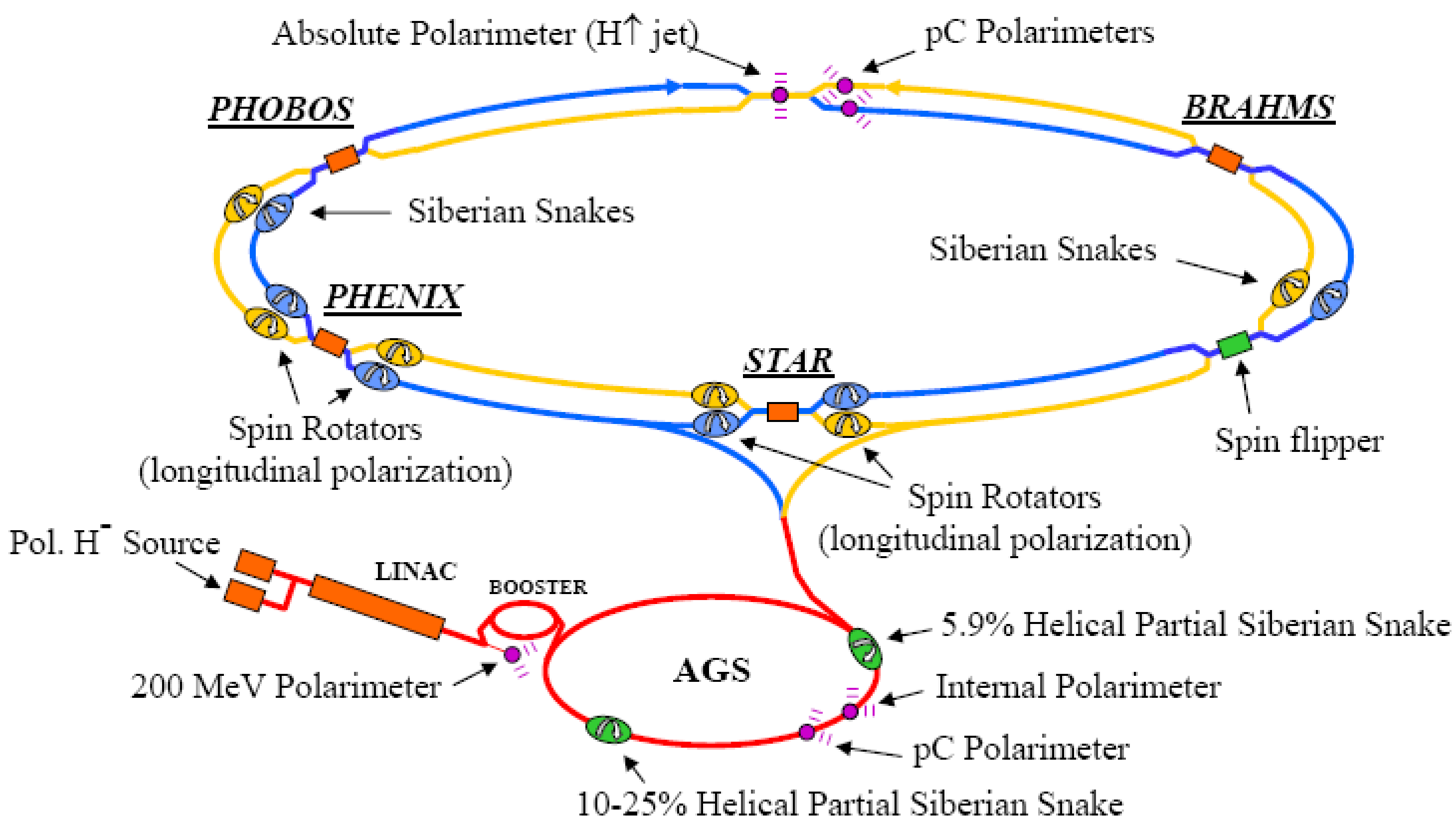
What intensity is expected?

Capacity will be 10^{12} charges/pulse

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

Polarized beam acceleration in AGS and RHIC.

RHIC – First Polarized Hadron Collider



Without Siberian snakes: $\nu_{sp} = G\gamma = 1.79\ E/m \rightarrow$ ~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

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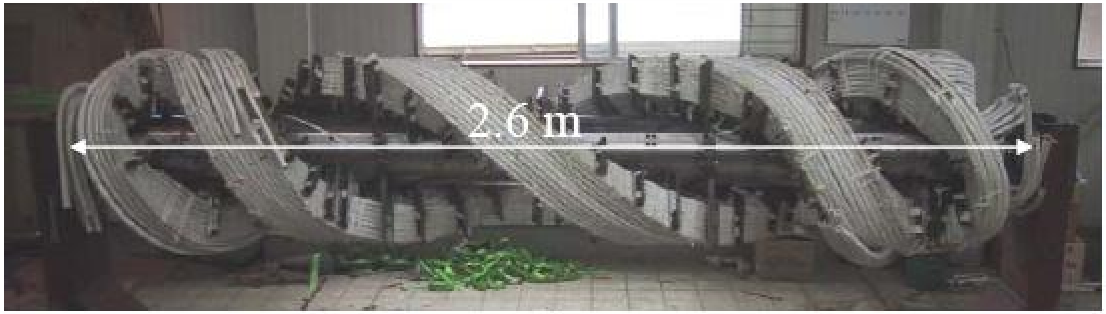
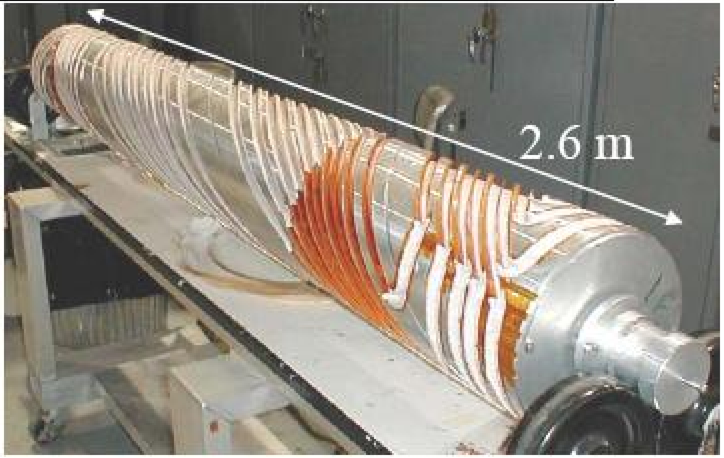
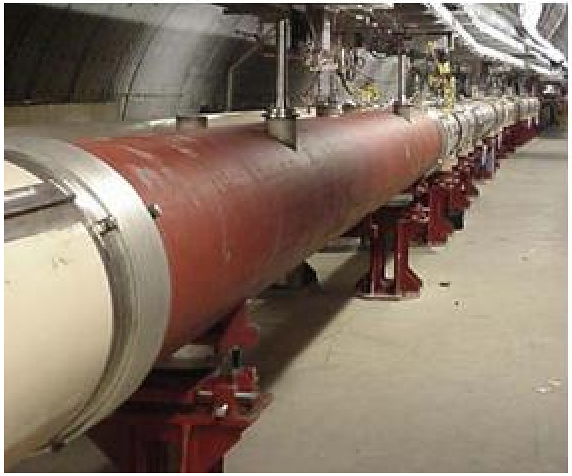
Siberian Snakes

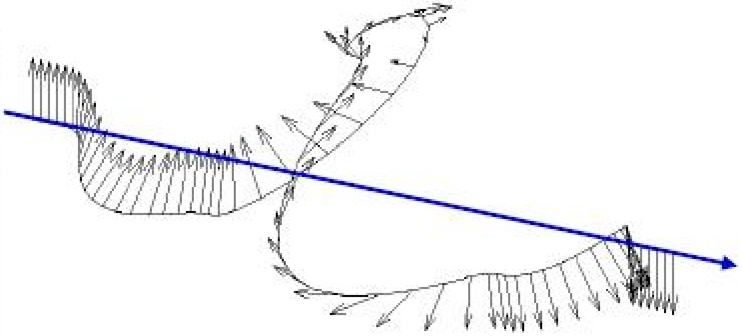


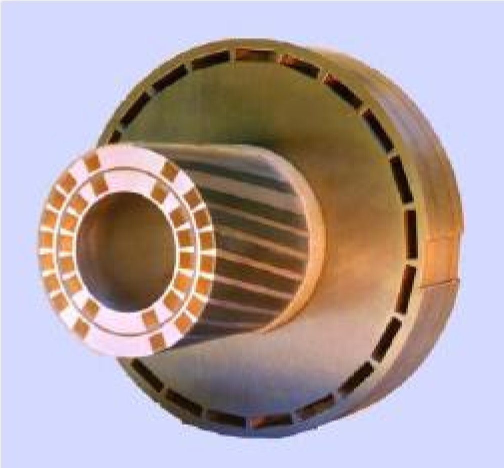


Major funding by RIKEN, Japan
RT helical dipole constructed at Tokano Ind., Japan
SC helical dipoles constructed at BNL

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

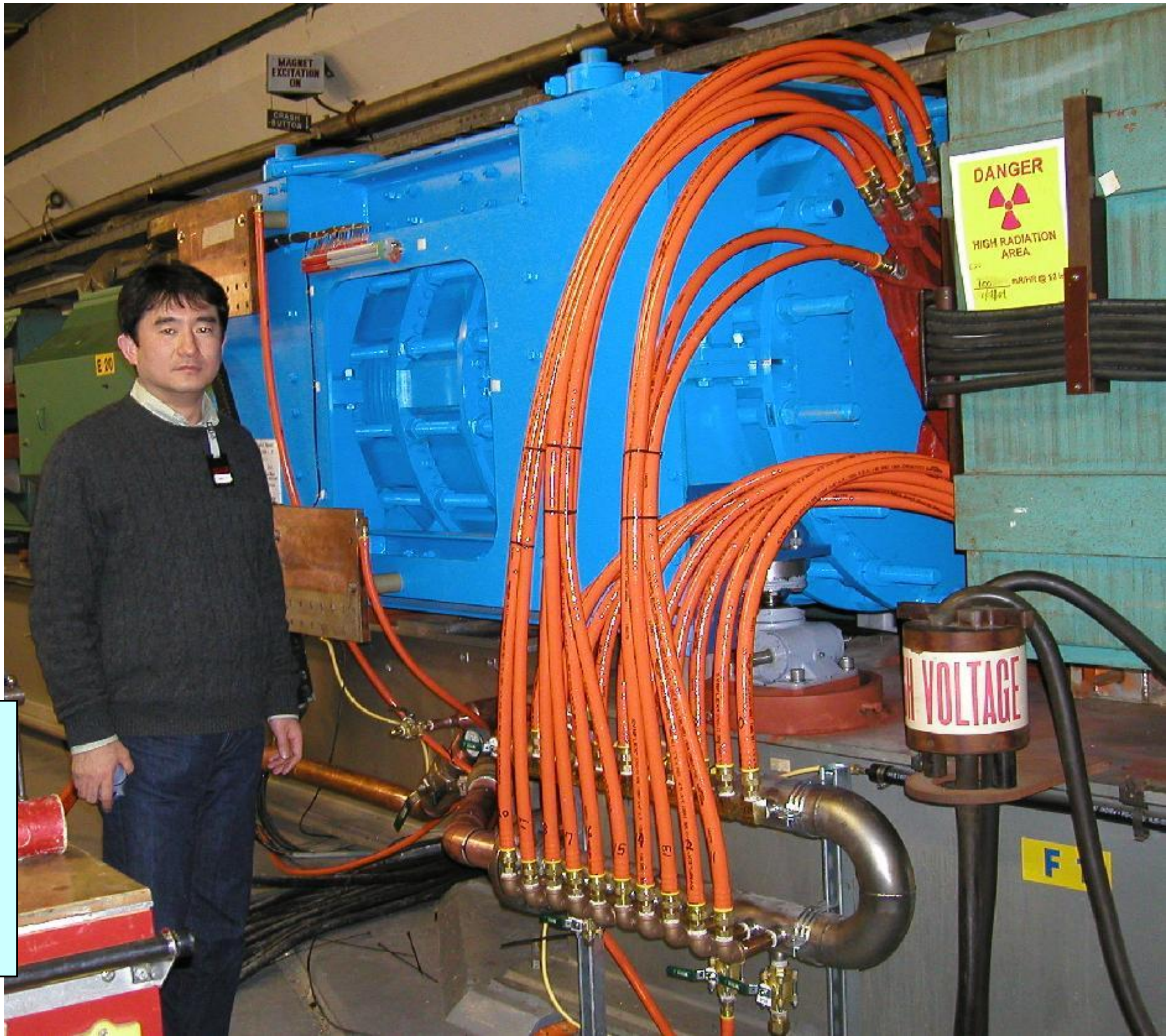






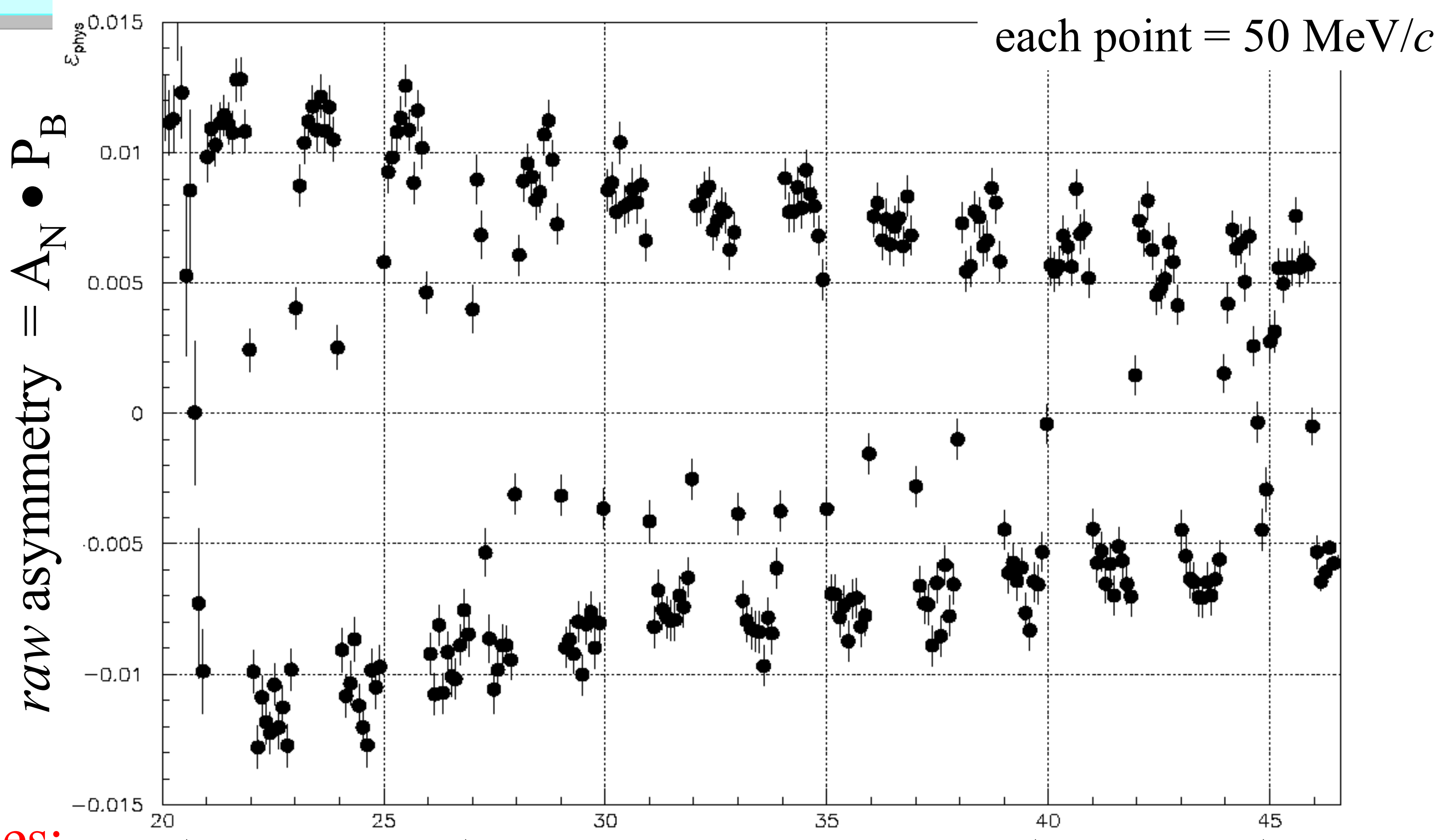
AGS Helical Warm Snake

- With the new warm snake, coupling between the two transverse motions are reduced.
- The commission of the new warm helical snake started March 5 with proton beam.
- Magnet has been run in the ring at 2700A.



Masahiro Okamura (RIKEN) designed and built a 5% helical snake for 2004 run.

AGS Polarization during acceleration (ramp).



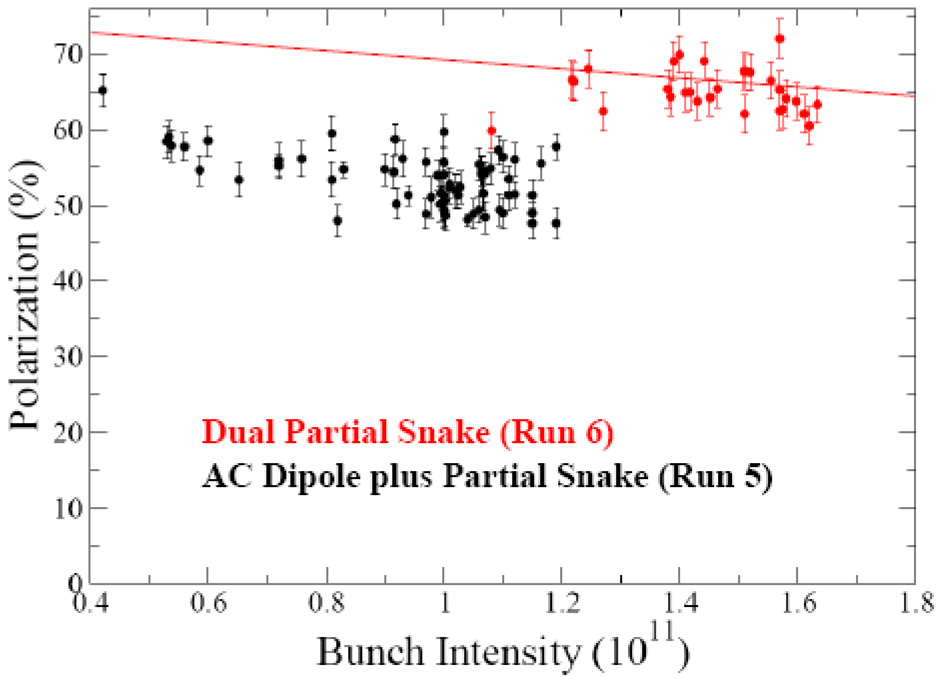
resonances:

intrinsic: $G\gamma$ = 12+ν 36-ν 48- ν 36+ν

$G\gamma = 1.91\ E_{beam}$

imperfection: $G\gamma = n$

AGS Polarization



- Dual Partial Snake in AGS avoided depolarization from all vertical depolarizing resonances. Strong partial snakes also drive weak horizontal depol. resonances. (~ 5-10% polarization loss)
- Plan to use tune jump for horizontal resonances

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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.

Local polarimeters at STAR and PHENIX.

A_N for Coulomb -Nuclear Interference.

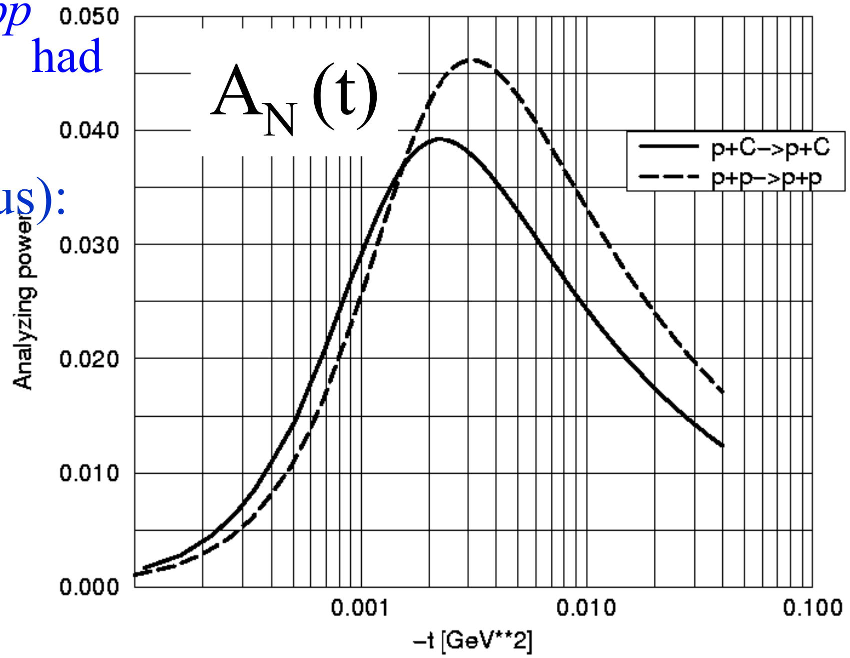
the left – right scattering asymmetry A_N arises from the interference of the spin non-flip amplitude with the spin flip amplitude (Schwinger)

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

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

in absence of hadronic spin – flip contributions A_N is exactly calculable (Kopeliovich & Lapidus):

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



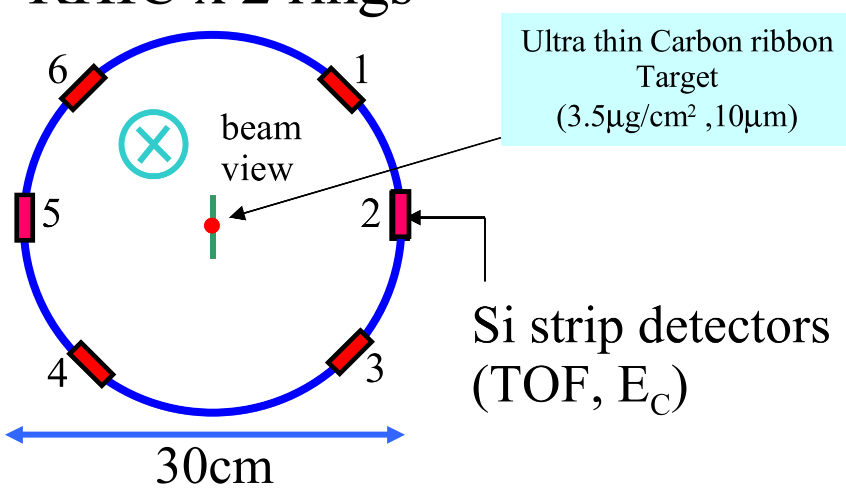
hadronic spin- flip modifies the QED "predictions"

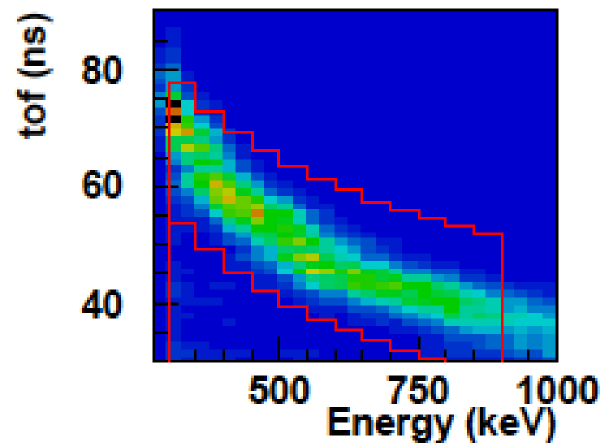
$$\frac{\mu_p - 1}{2} \rightarrow \frac{\mu_p - 1}{2} - I_5 + \left(\frac{\mu_p - 1}{2} I_2\right)$$

interpreted in terms of Pomeron spin – flip and parametrized as $\phi_5^{had} = \tau(s)\frac{\sqrt{-t}}{m_p}\phi_0^{had}$

Proton-Carbon CNI polarimeter in RHIC.

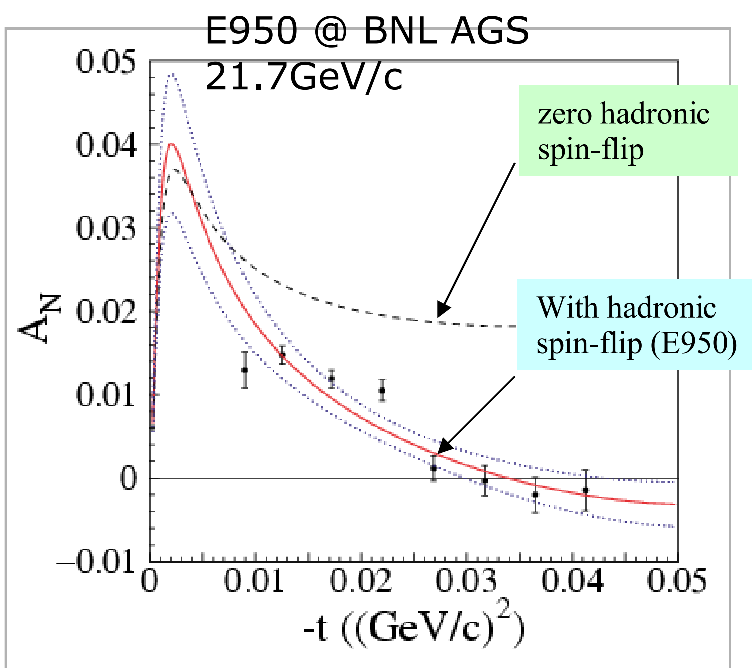
RHIC x 2 rings





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

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



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

$A_N \approx 0.015$ originates from anomalous magnetic moment of p

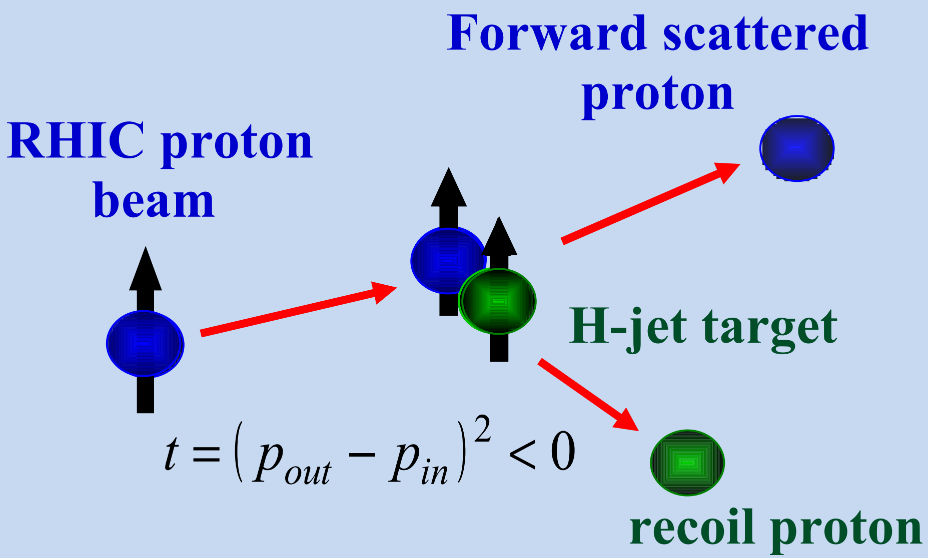
H-Jet polarimeter

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

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



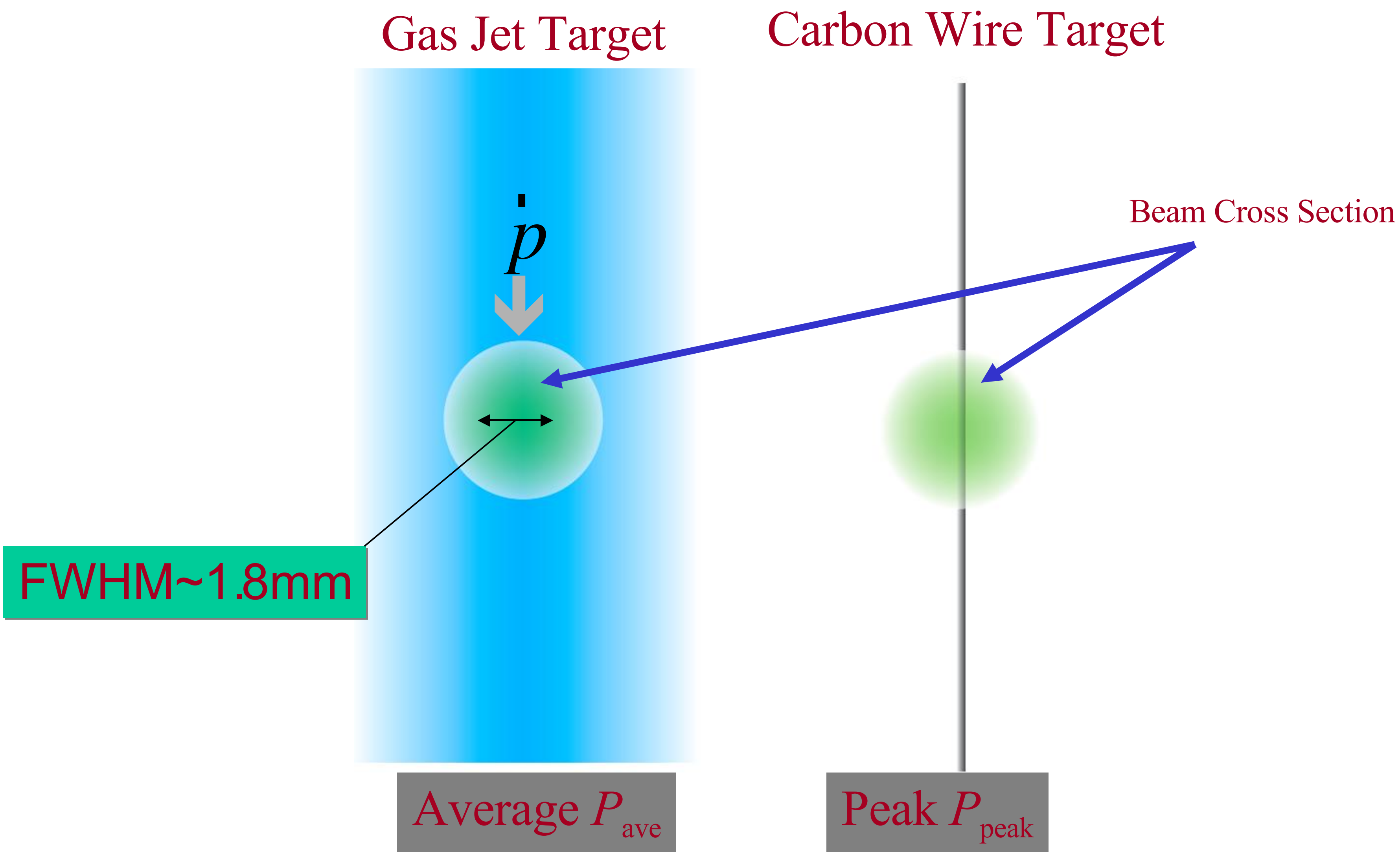
$$t = \left(p_{out} - p_{in}\right)^2 < 0$$

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

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

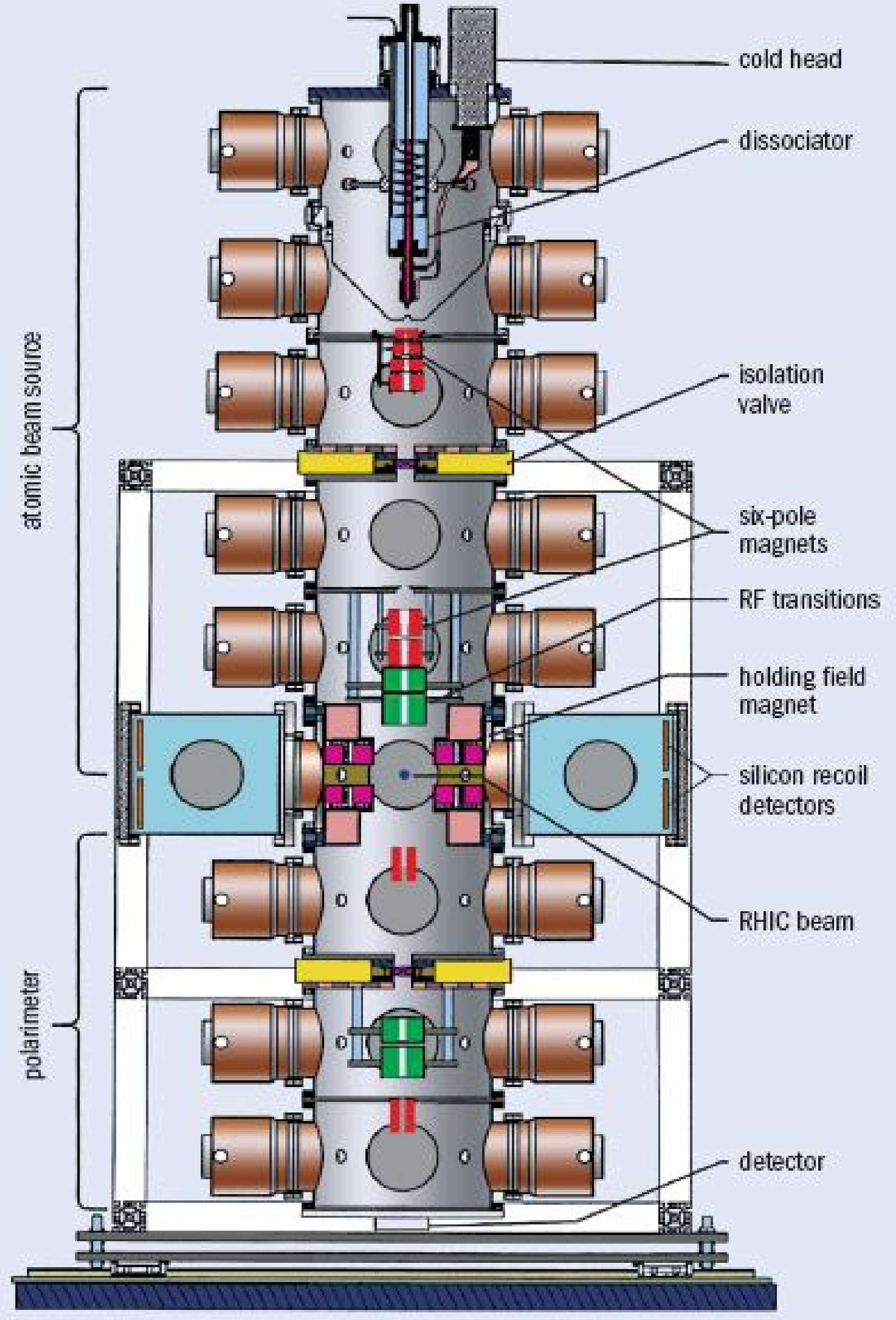
P_{target} is measured by Breit- Rabi Polarimeter

Hydrogen Gas Jet and Carbon Wire Targets.

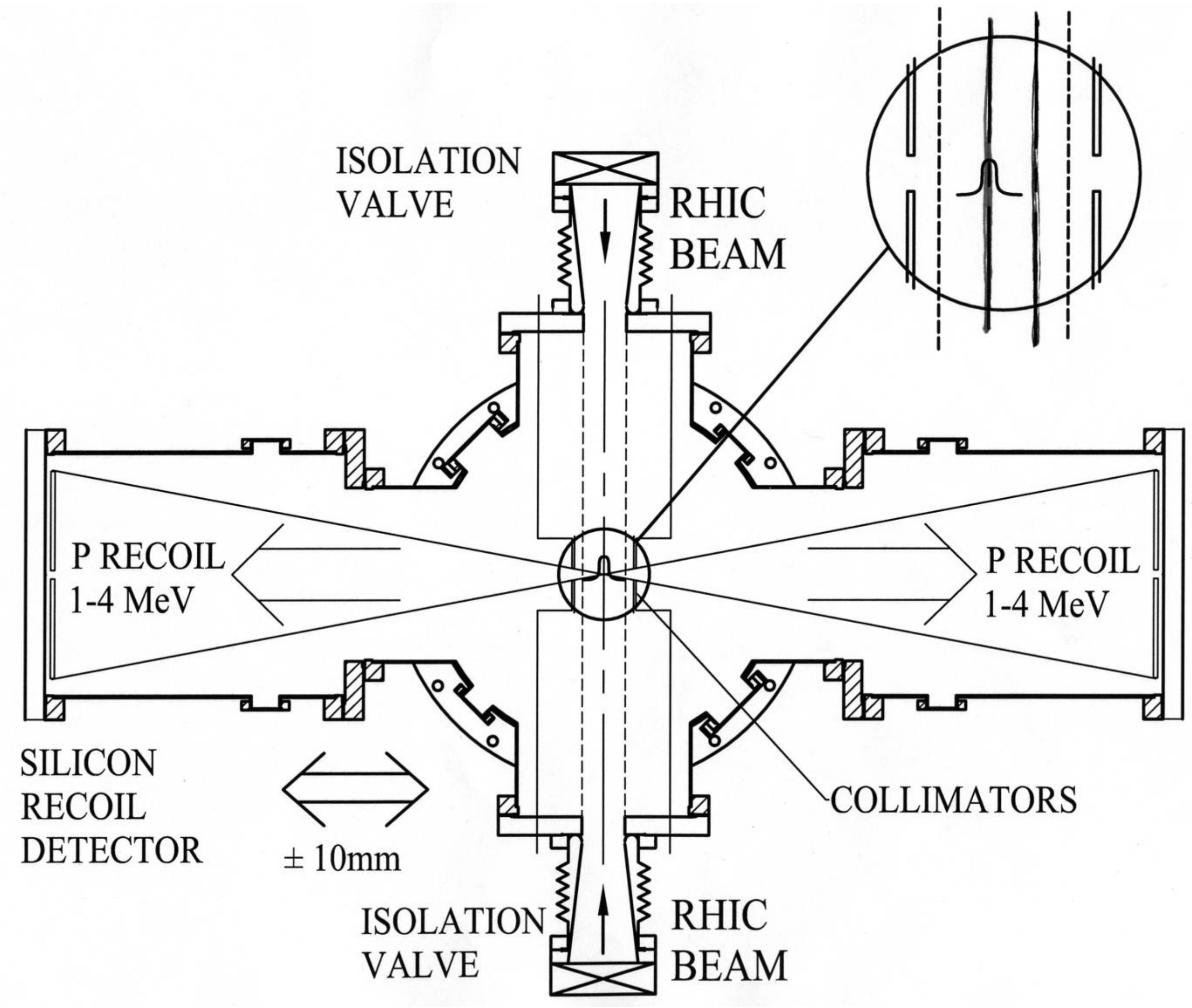


H-jet polarimeter.

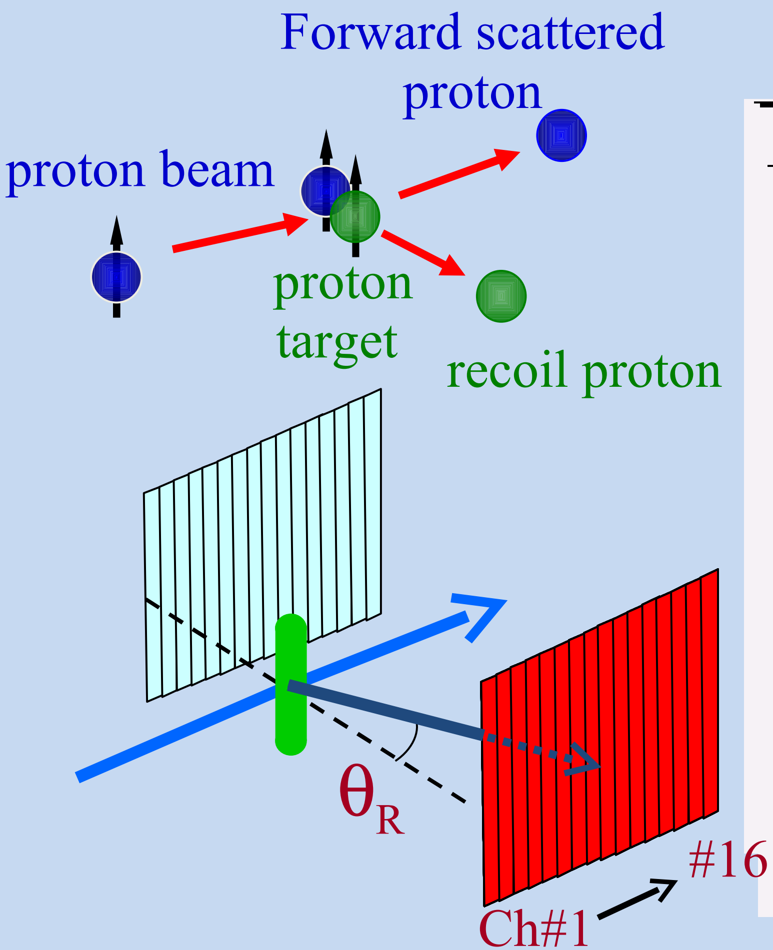
- The H-jet polarimeter includes three major parts: polarized Atomic Beam source (ABS), scattering chamber, and Breit-Rabi polarimeter.
- The polarimeter axis is vertical and the recoil protons are detected in the horizontal plane.
- The common vacuum system is assembled from nine identical vacuum chambers, 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 pumping ports.



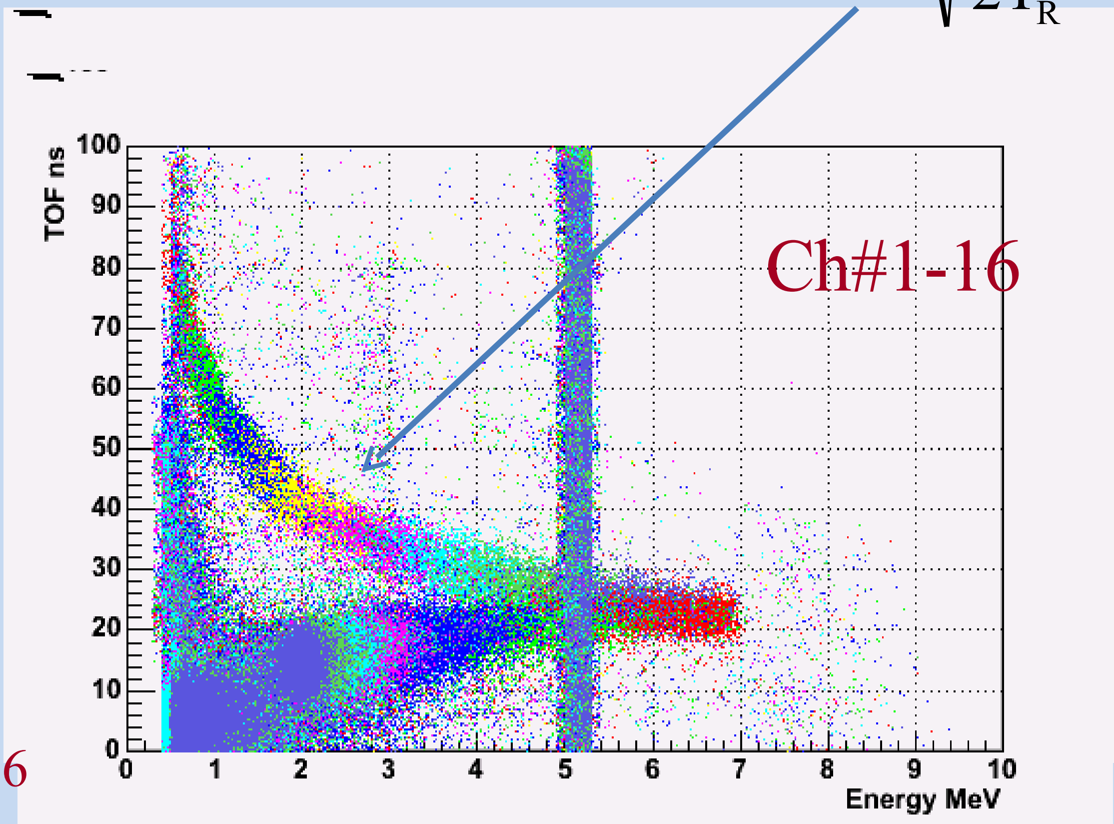
H-JET POLARIMETER SCATTERING CHAMBER.



H-Jet: Identification of Elastic Events



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

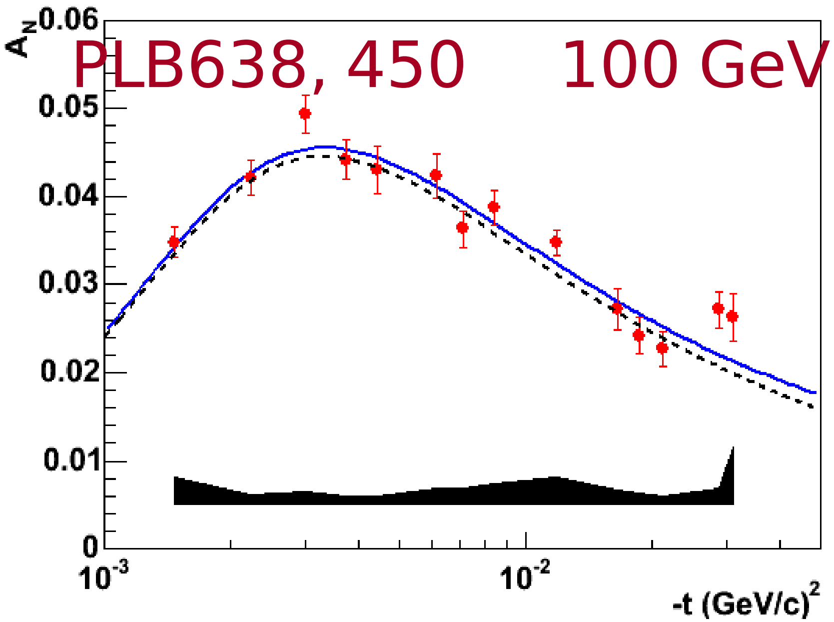


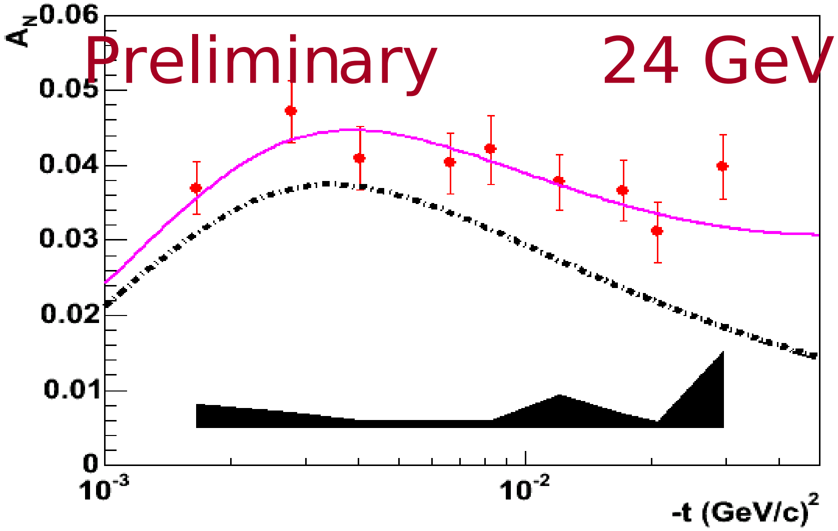
Array of Si detectors measures **T_R** & **ToF** of recoil proton.

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





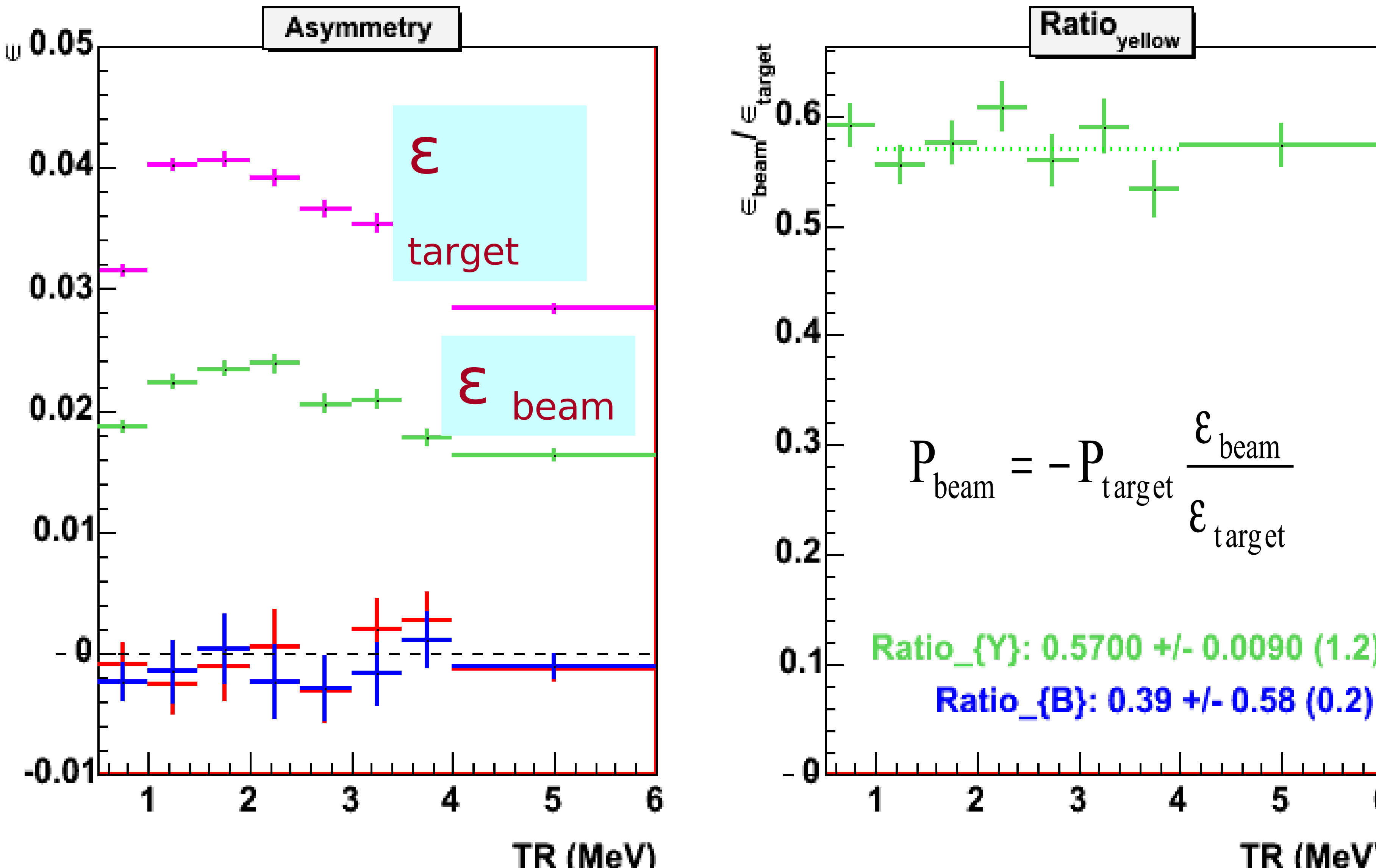
$$A_N \approx \mathrm{Im}\left(\phi_{SF}^{em}\phi_{NF}^{had} + \phi_{SF}^{had*}\phi_{NF}^{em}\right) \Big/ \left|\phi_{NF}^{had}\right|^2$$

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 Run
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)

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:

$$P_{beam} = (1/A) Beam_{asym} / Target_{asym}$$

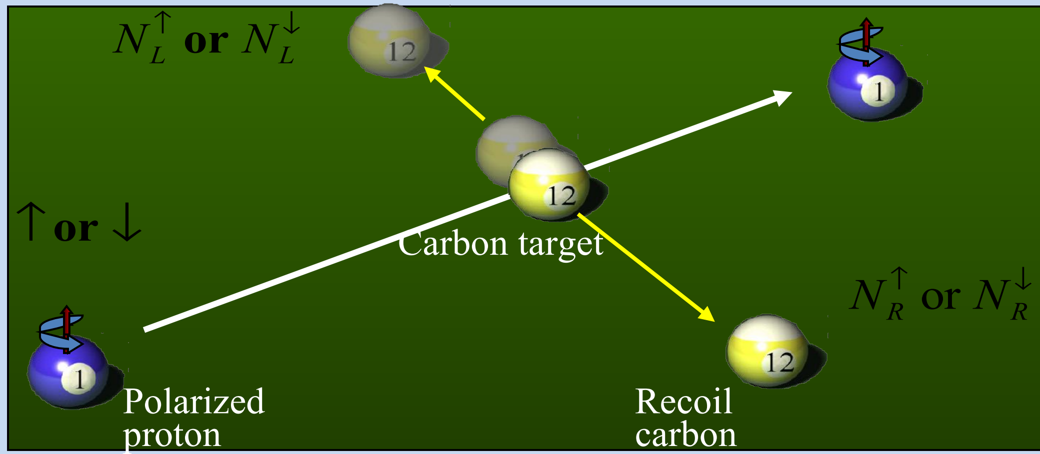
Problem.

Polarization dilution by H_2, H_2O and other residual gases.

Largest source of systematic error.

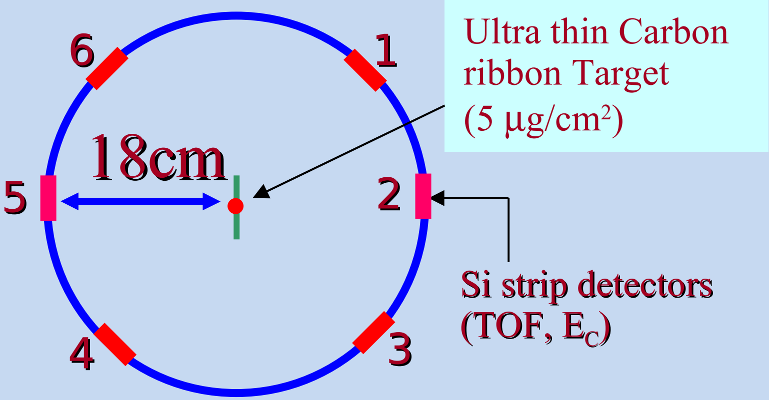
P-Carbon CNI polarimeter.

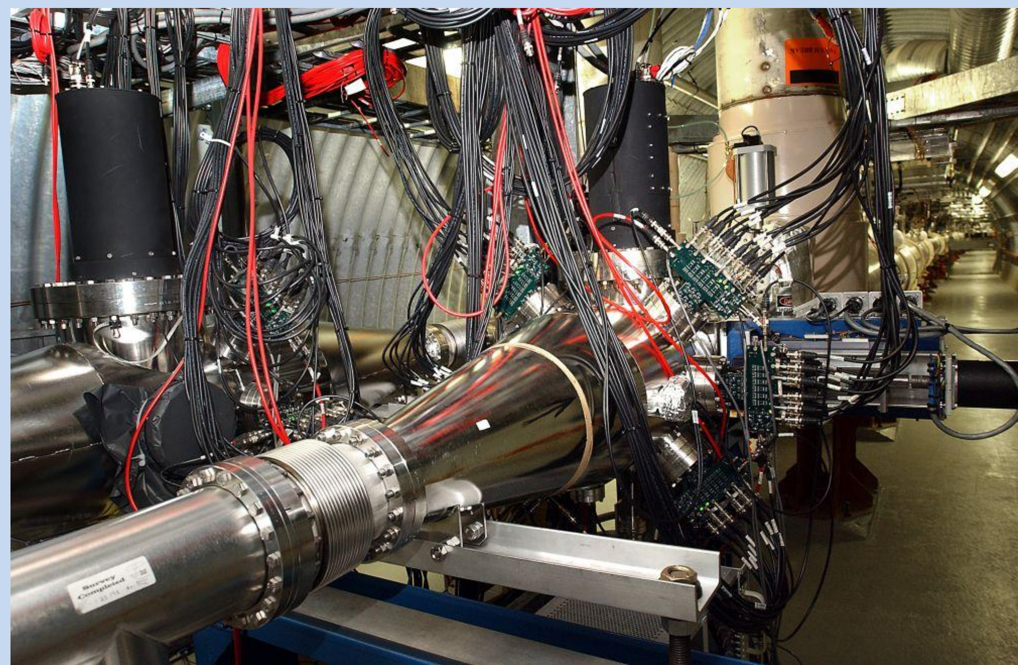
Elastic scattering: interference between electromagnetic and hadronic amplitudes in the Coulumb-Nuclear Interference (CNI) region



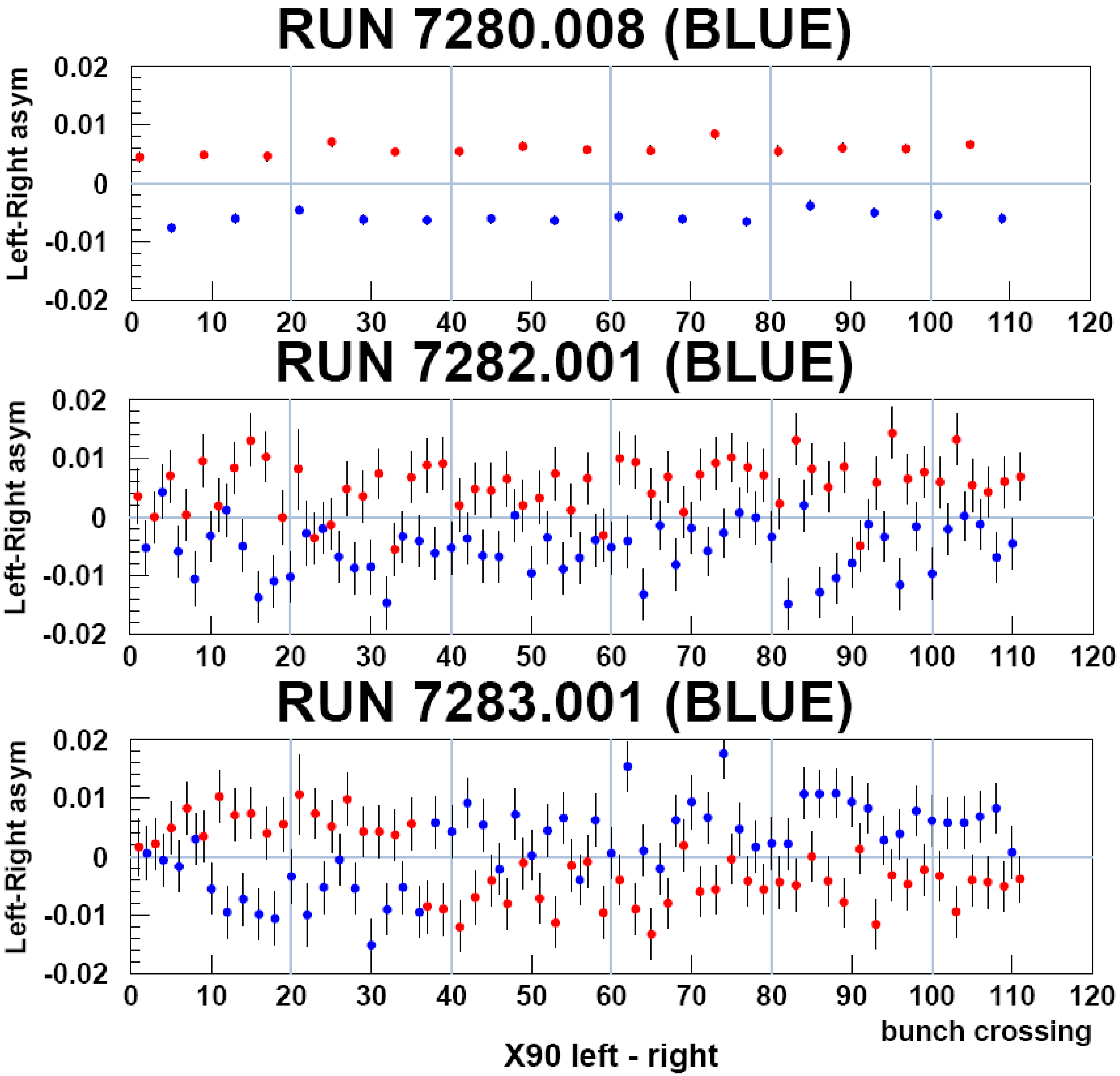
$$P_{beam} = -\frac{\varepsilon_N}{A_N^{pC}}$$

$$\varepsilon_N = \frac{N_L - N_R}{N_L + N_R}$$





Bunch by bunch polarization in RHIC.

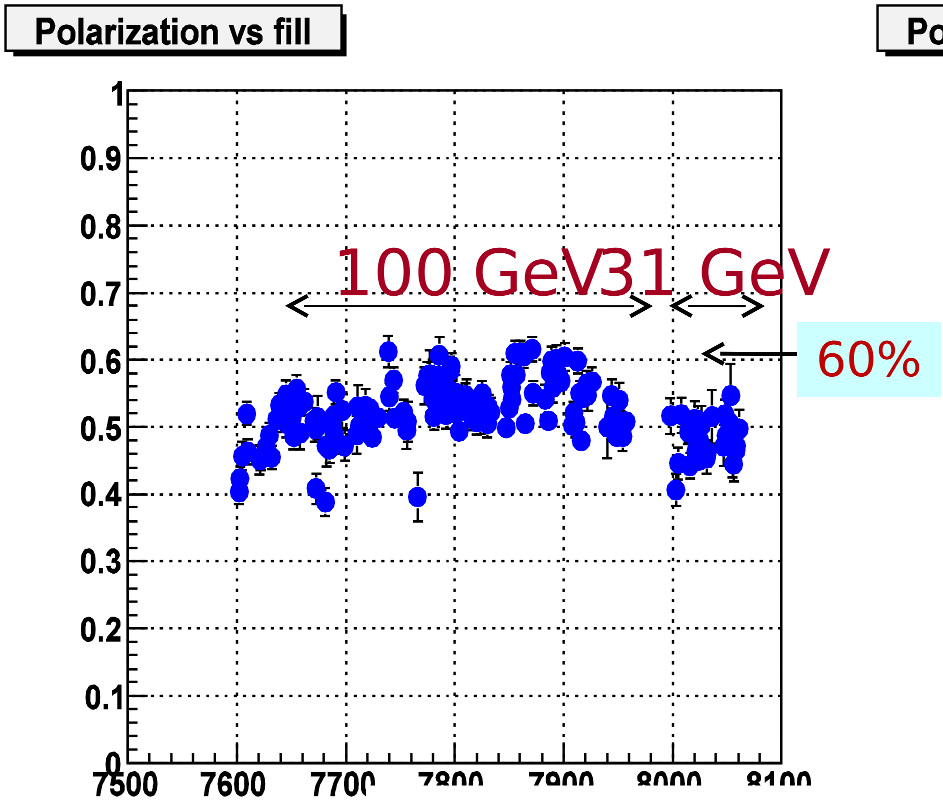


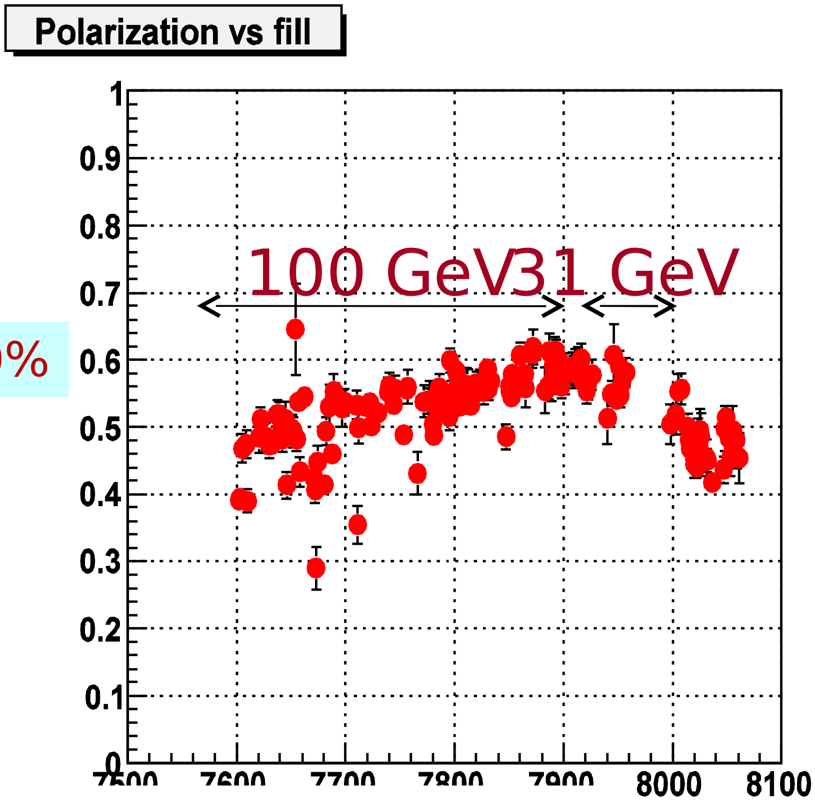
high statistics
28 bunches
@ injection

110 bunches
@ flattop
10^{11} p / bunch

110 bunches
@ flattop
with messed
spin pattern

pC: Polarization vs Fill #. Run 2006

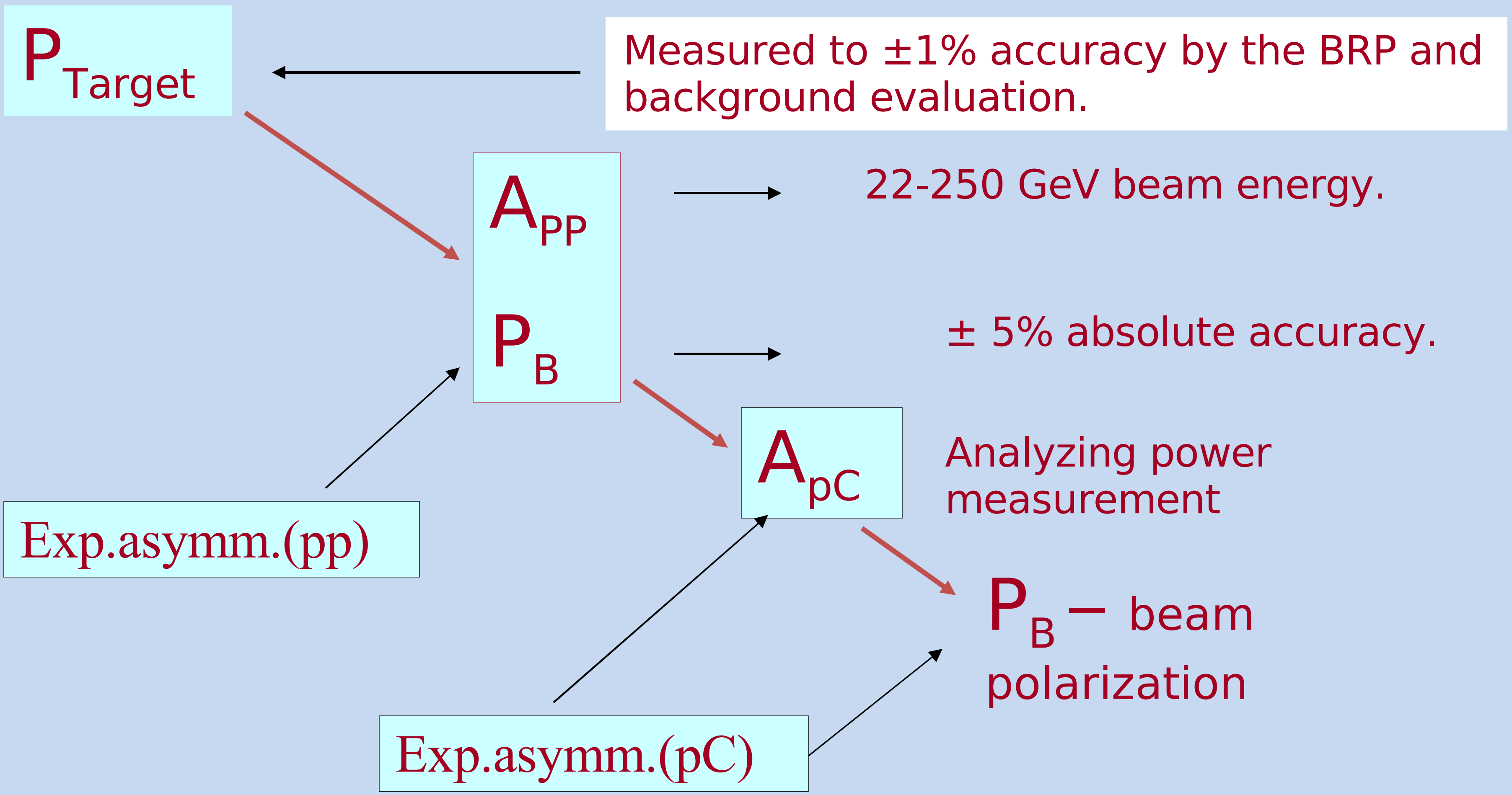




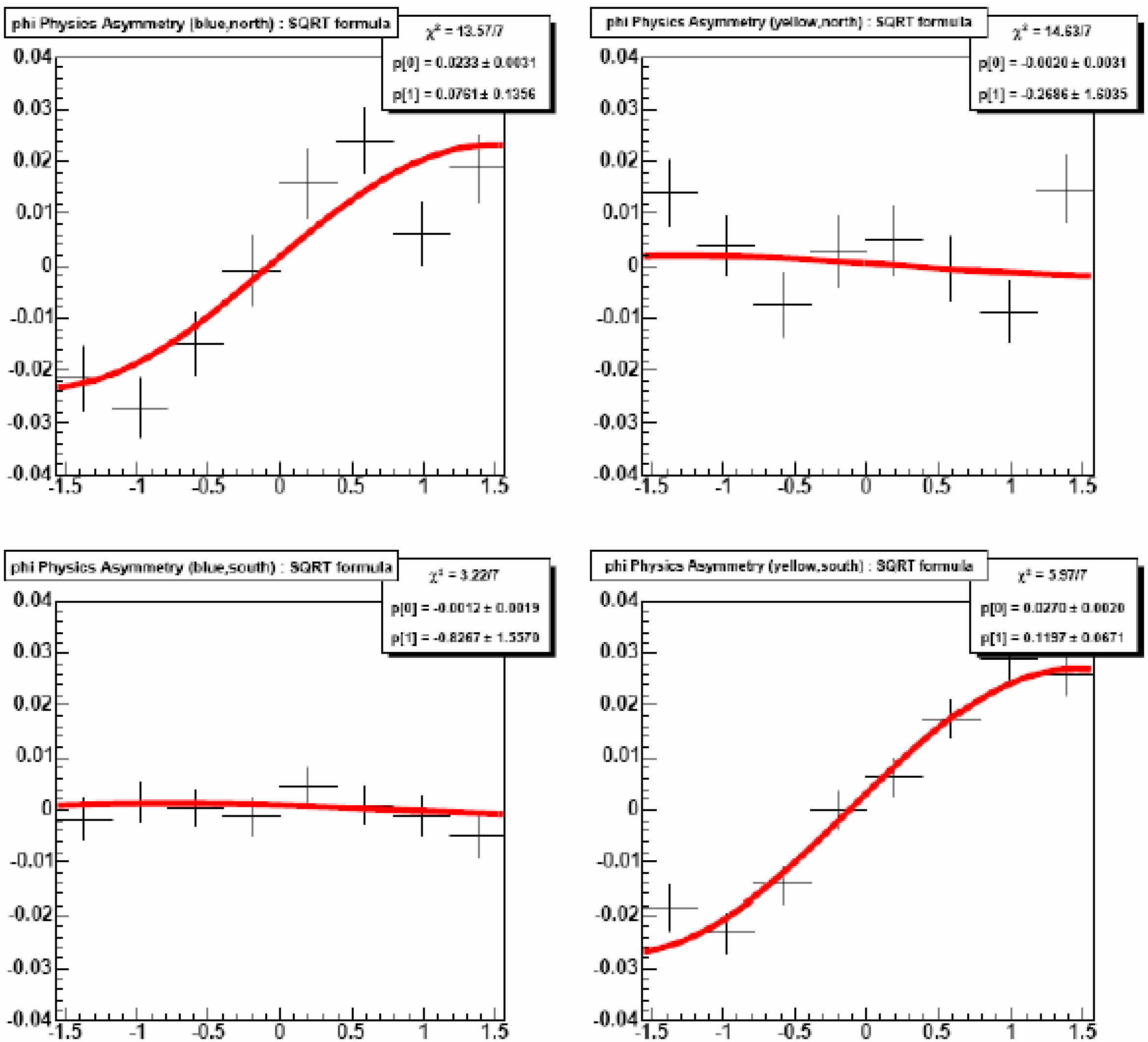
- ✓Normalized to Hjet
- ✓Corrected for polarization profile

$$\frac{\delta P_B}{P_B} = 4.7\% \qquad \frac{\delta P_Y}{P_Y} = 4.8\%$$

Polarization measurements in RHIC with the H-jet polarimeter.



410 GeV Transverse Polarization



M. Togawa

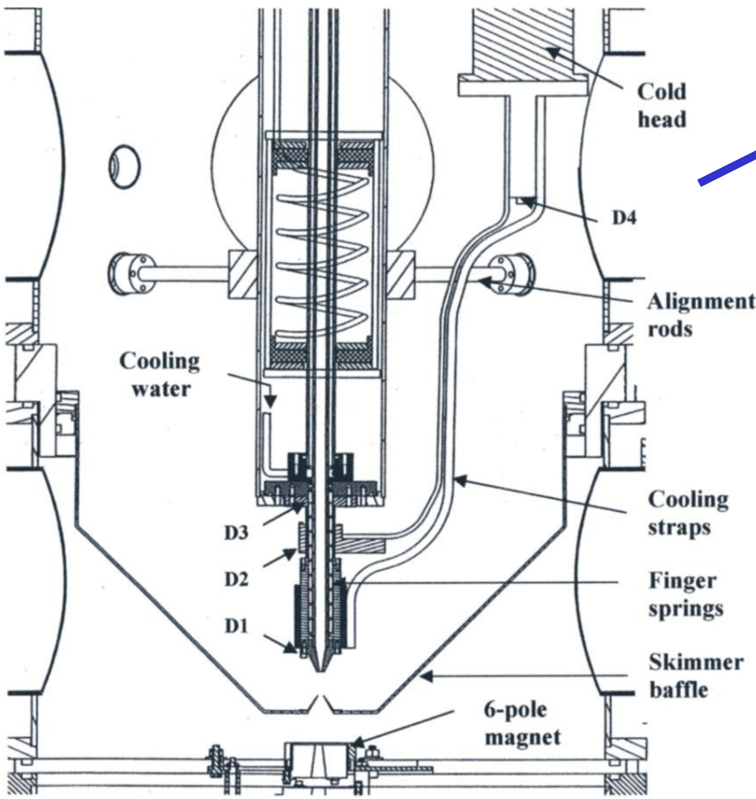
Polarization

blue : ~33%

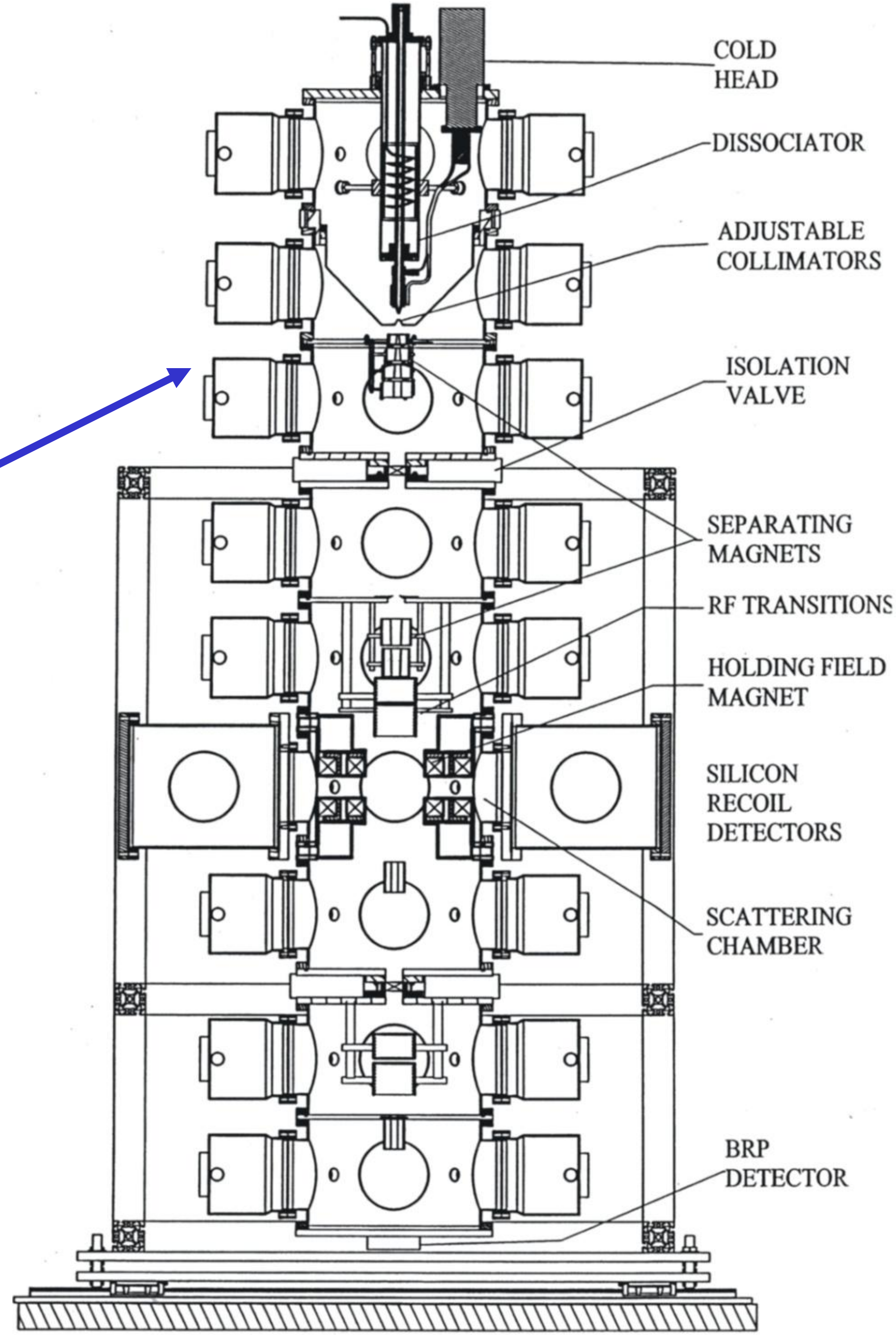
yellow : ~49%

- 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 $\sqrt{s}$

H - jet polarimeter.



Dissociator



Atomic beam intensity vs H_2 flow in dissociator.

AB intensity of

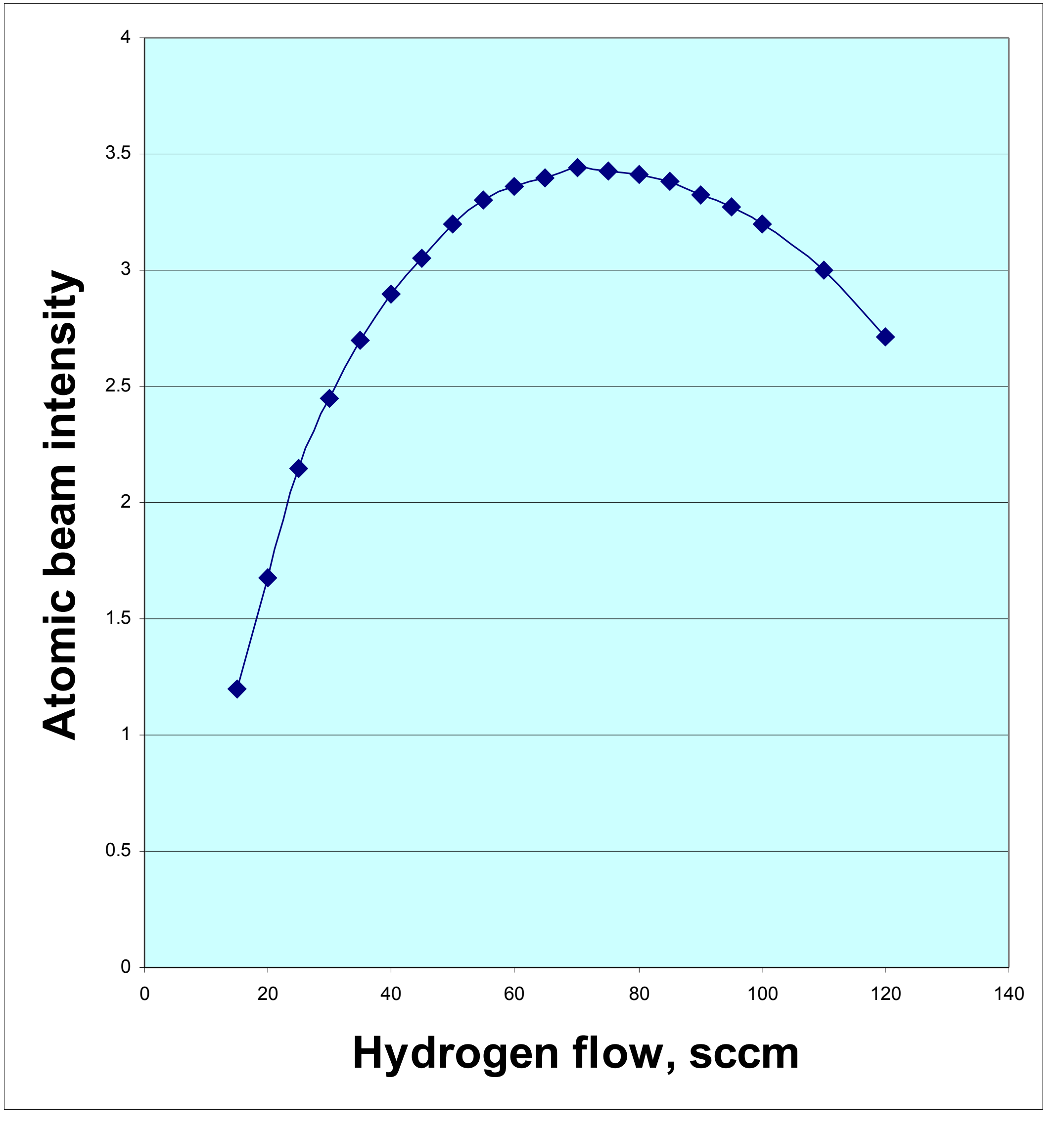
$12.5 \cdot 10^{16}$ at/s.

was measured at

70 scc/s H_2 flow.

250 W RF power

75 K nozzle temp.

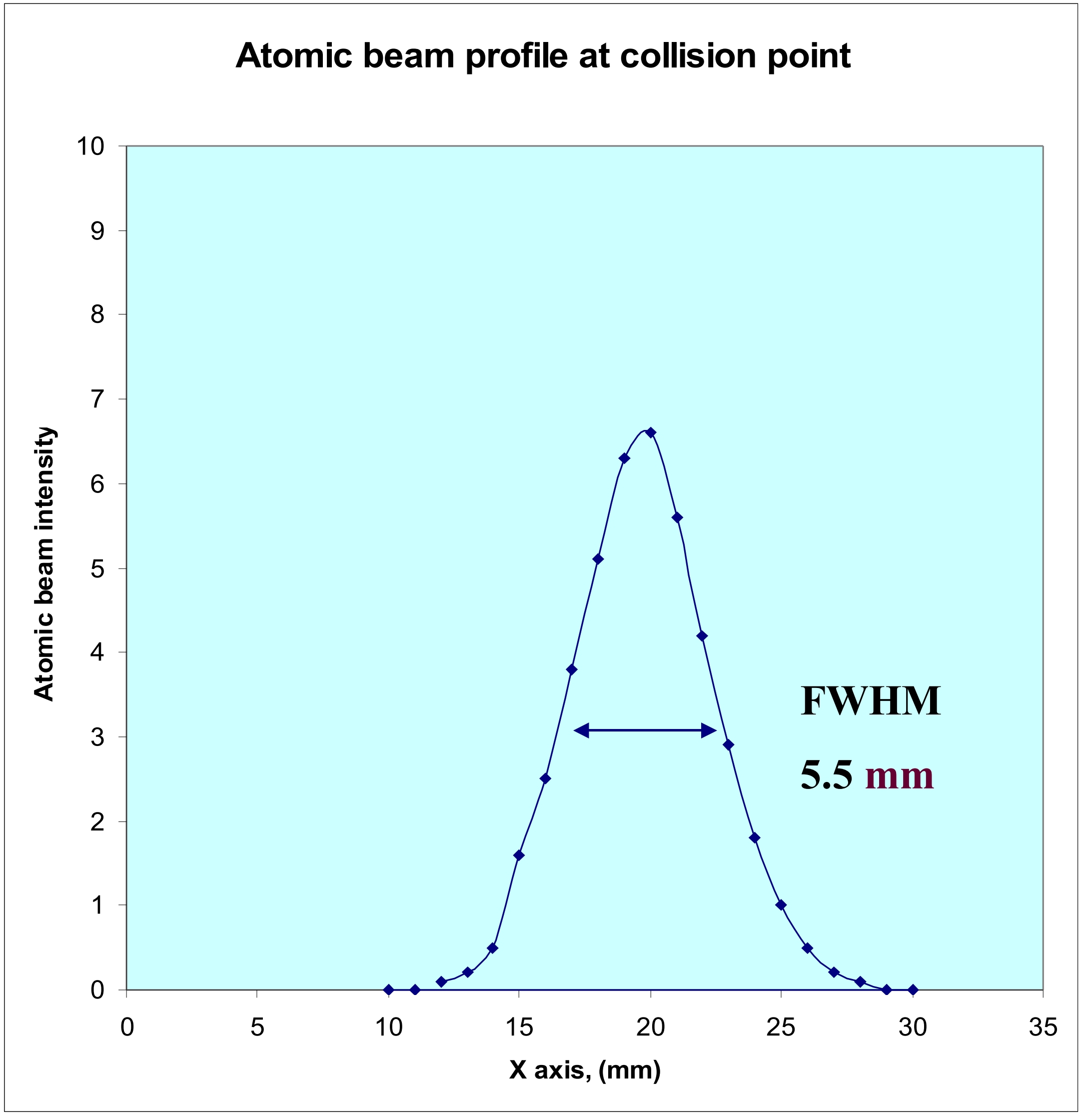


Atomic beam profile at the collision point.

- Atomic beam profile was measured with a 2.0 mm in diameter compression tube FWHM=5.5 mm

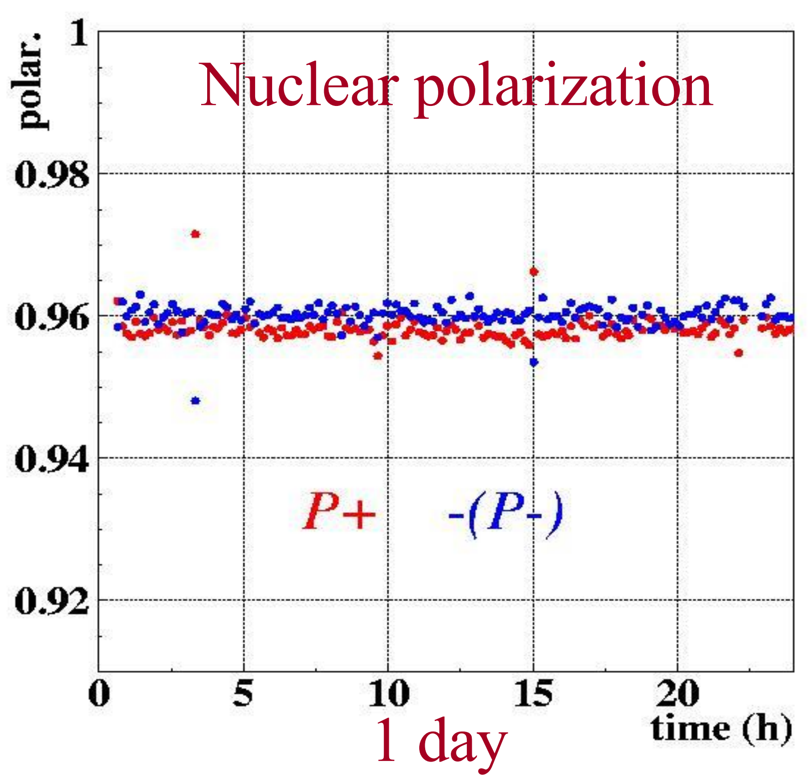
Atomic beam velocity ~1600m/s

- H - jet thickness at the collision point is about:
- $1.3 \cdot 10^{12}$ atoms/cm^2.



H-Jet: P_{target}

Source of normalization for polarization measurements at RHIC



Nuclear polarization of the atoms measured by BRP: 95.8% ± 0.1%

Correct for H_2, H_2O contamination.

P_{target} = 92.4% ± 1.8%

Polarization cycle:

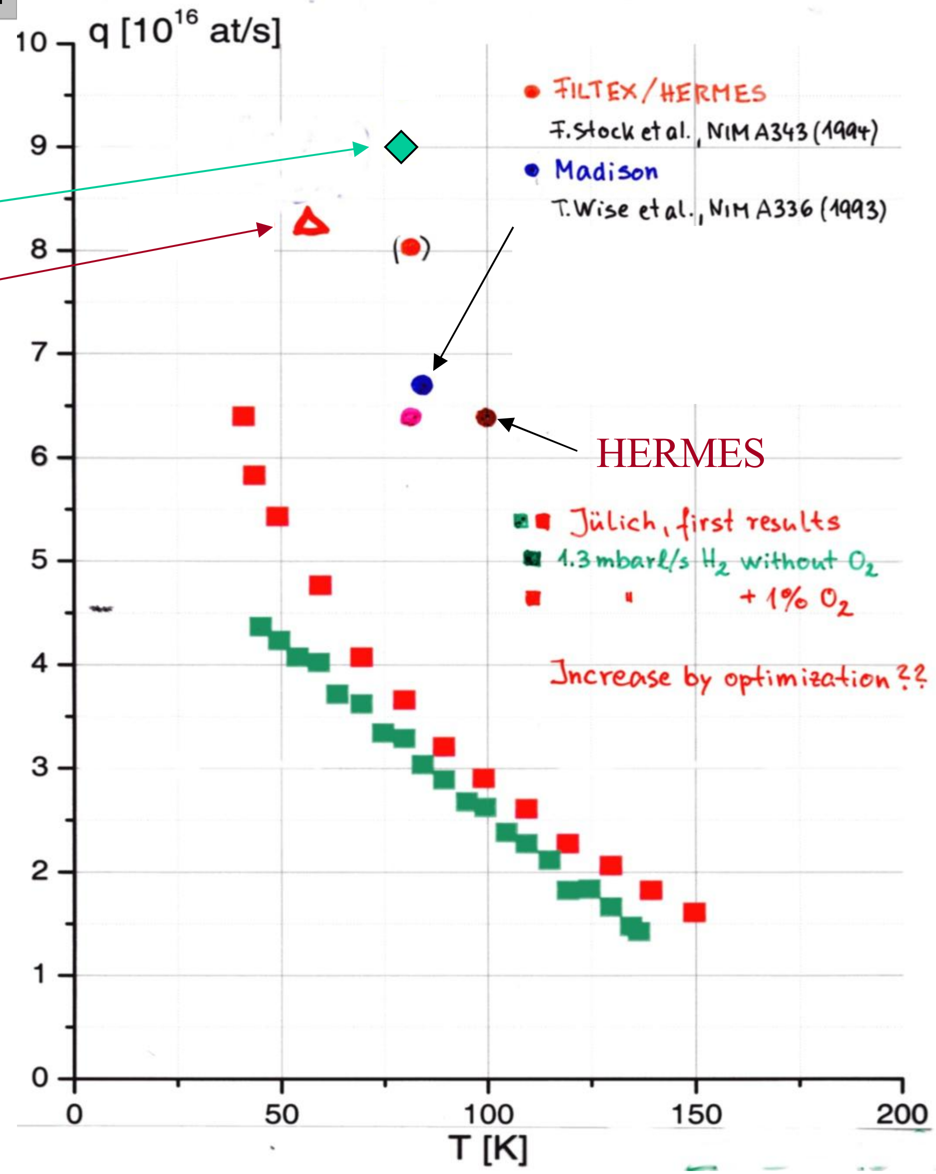
(+/ 0/ –) = (500/50/500) seconds

Very stable for entire run period !

Operational atomic beam sources intensities.

H-jet

$12.5 \cdot 10^{16}$ at/s



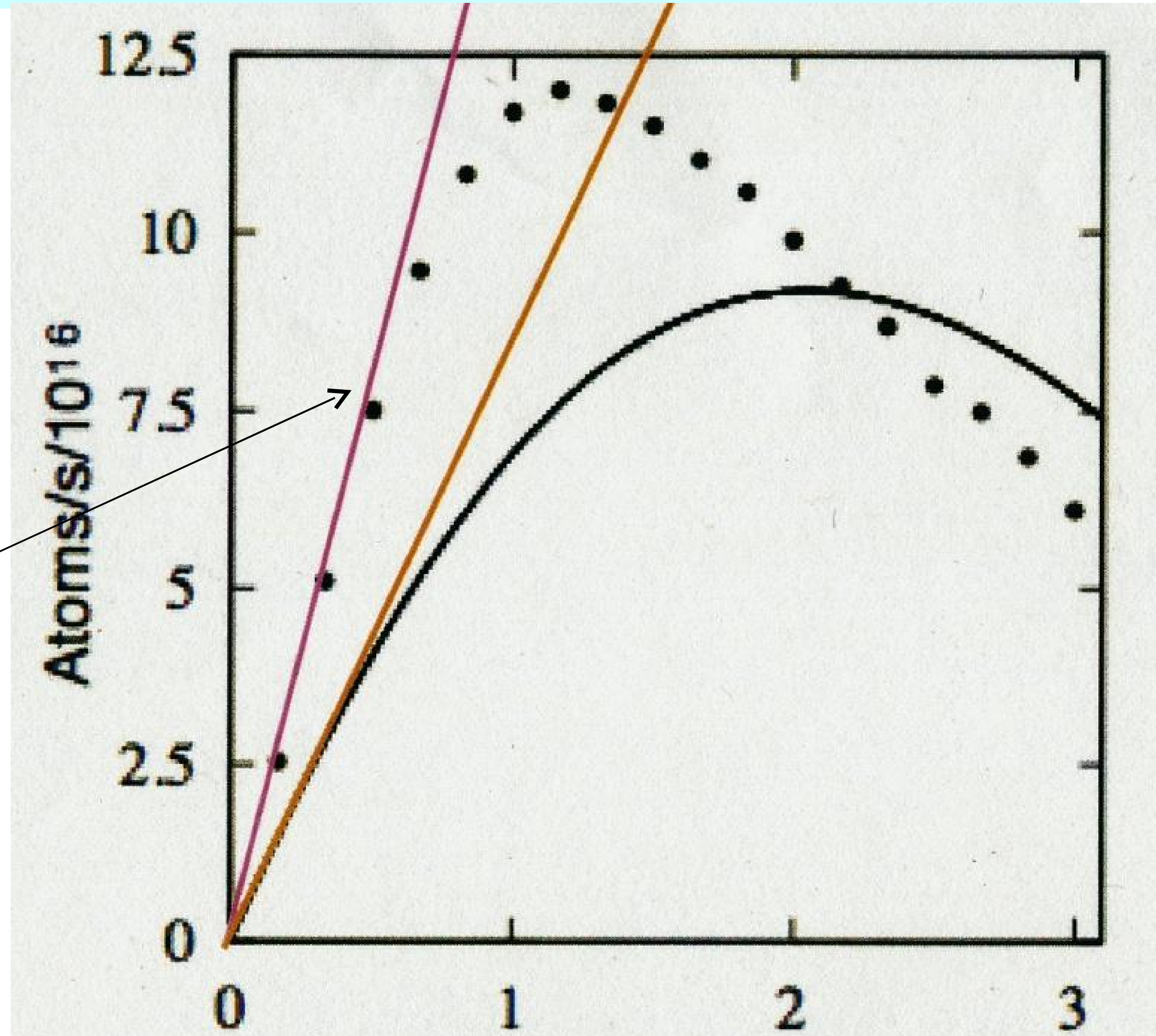
Maximum H-jet beam intensity is at T_{nozzle}~75 deg. K

Atomic beam intensity vs H_2 flow in dissociator.

RF-power was kept constant at 260 W

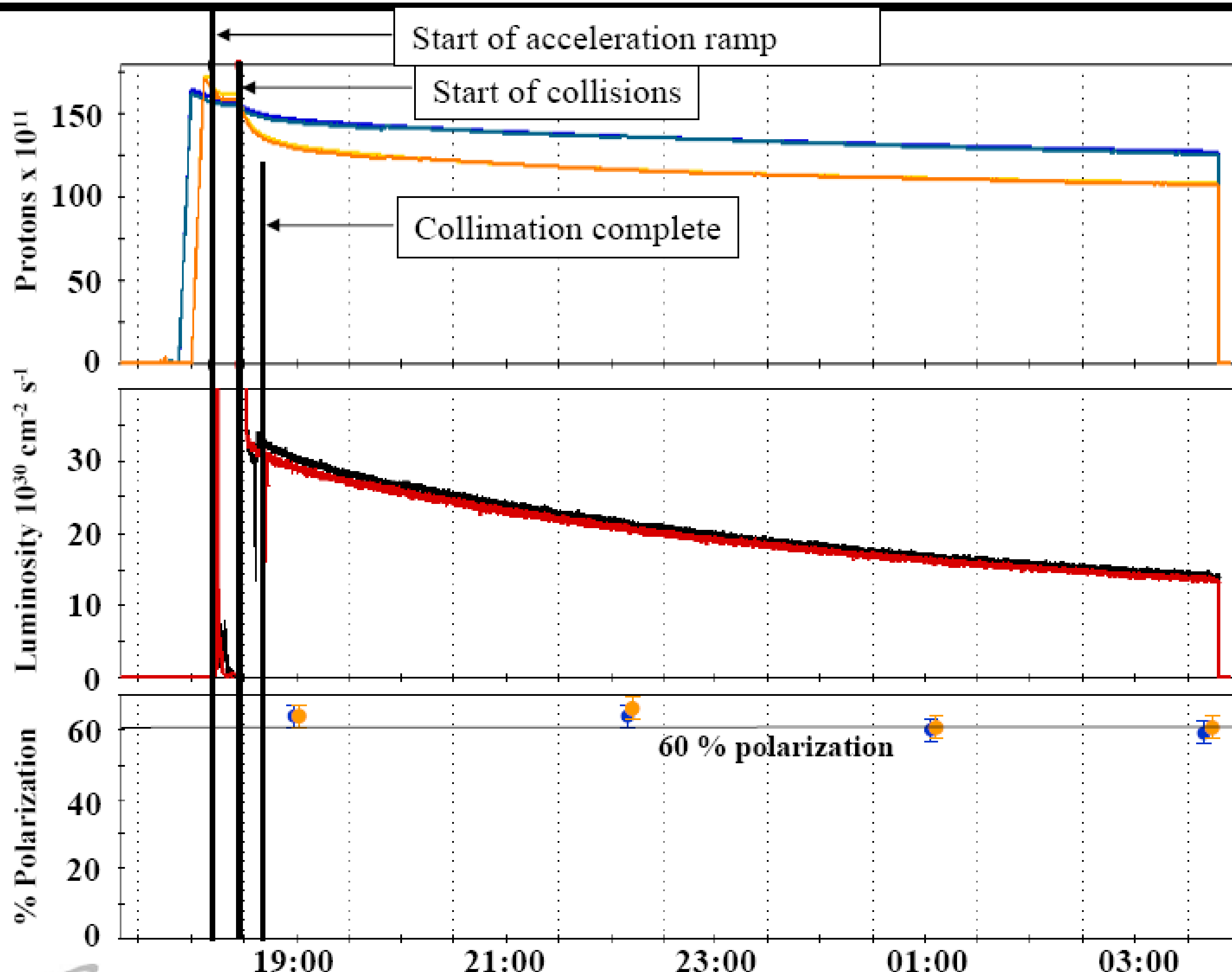
Nozzle temperature 75 K.

Slope is 1.75 steeper than simulations



H2 flow, cm3/s

Luminosity and Polarization Lifetimes in RHIC at 100 GeV



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45 % polarization on first acceleration to 250 GeV!

RHIC luminosity and polarization goals

Parameter	unit	**Achieved**	**Enhanced design**	**Next Lumi upgrade**
<u>Au-Au operation</u>		**(2007)**		**(~ 2011)**
Energy	GeV/nucleon	100	100	100
No of bunches	…	103	111	111
Bunch intensity	10^9	1.1	1.0	1.0
Average Luminosity	**$10^{26}cm^{-2}s^{-1}$**	**12**	**8**	**40**
<u>p↑- p↑ operation</u>		**(2006/08)**	**(~ 2010)**	**(~ 2012)**
Energy	GeV	100	100 (250)	250
No of bunches	…	111	111	111
Bunch intensity	10^{11}	1.5	2.0	2.0
Average Luminosity	**$10^{30}cm^{-2}s^{-1}$**	**23**	**60 (150)**	**300**
Polarization	**%**	**60**	**70**	**70**

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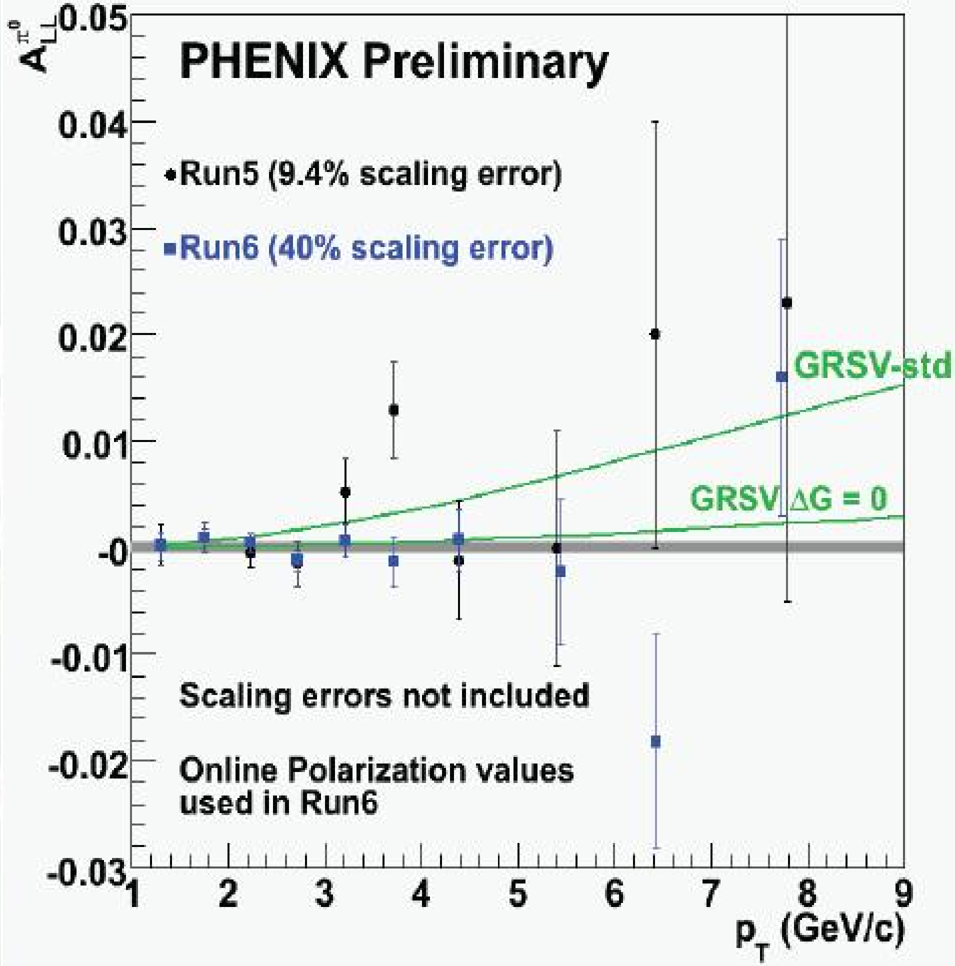
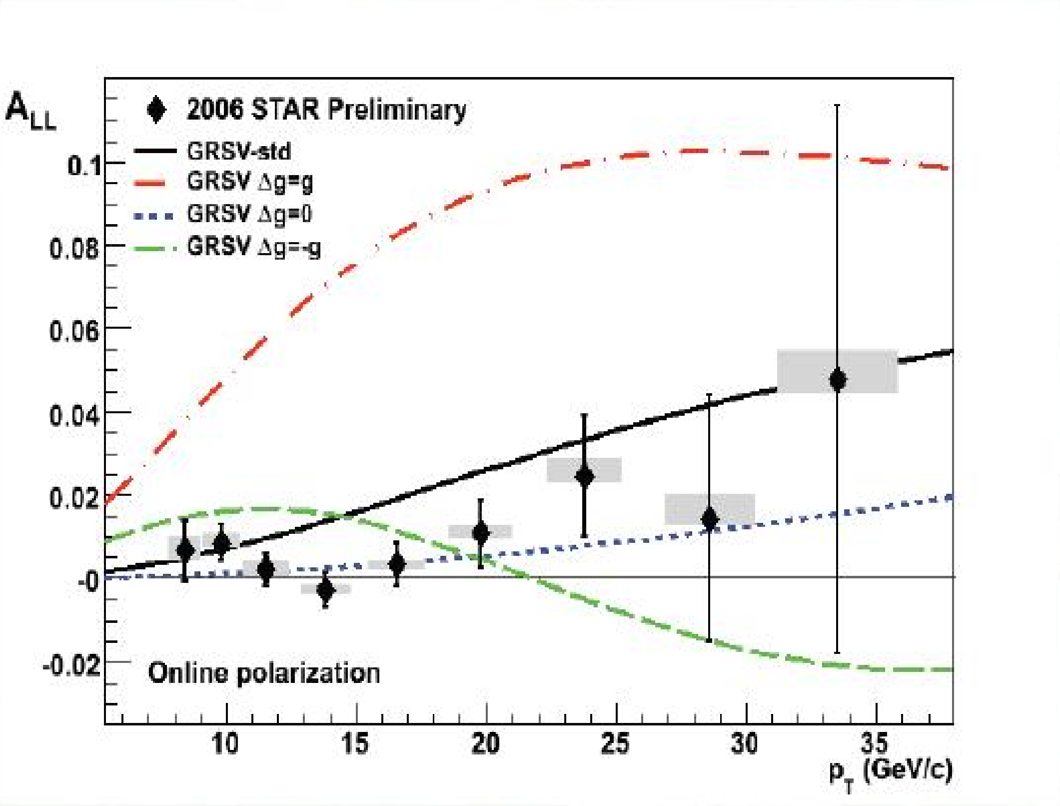
Highlights of recent results and achievements

- A_{LL} Results - Neutral pion production
  - Consistent RUN 5/6 results
  - RUN 6 results: A_{LL} result favor a gluon polarization in the measured x-region which falls in-between GRSV-STD and GRSV-ZERO



Highlights of recent results and achievements

- A_{LL} Results - Inclusive Jet Production

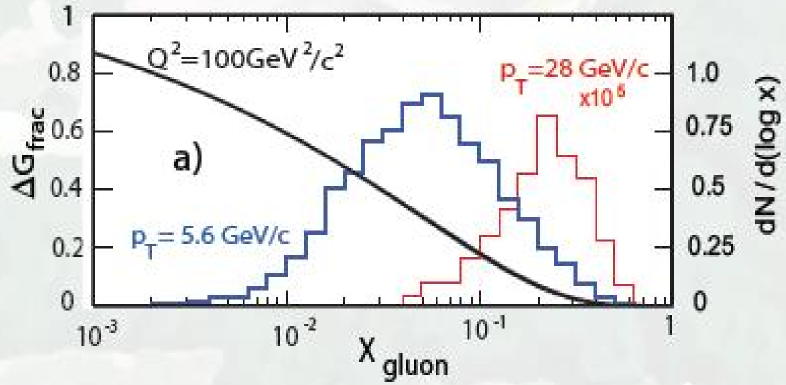


$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)\,dx$$

$$\Delta G(Q^2 = 1\,\mathrm{GeV}^2) \approx 1.8$$

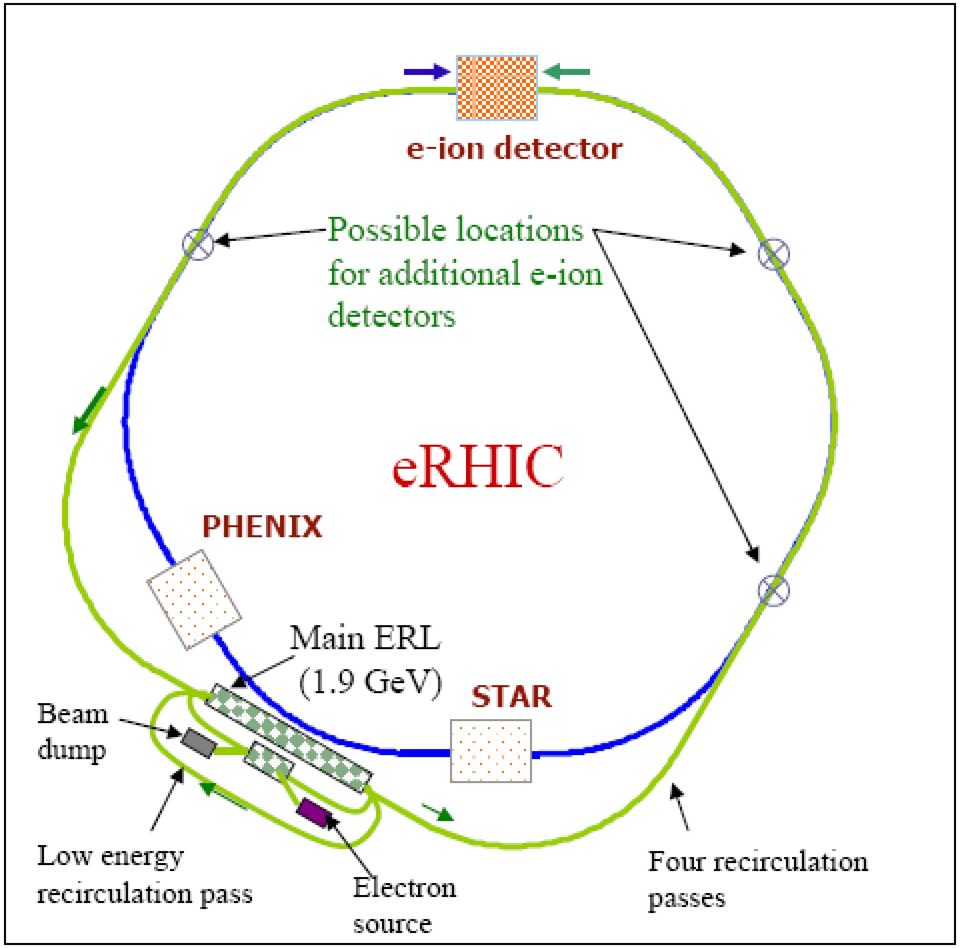
$$\Delta G(Q^2 = 1\,\mathrm{GeV}^2) \approx 0.4$$

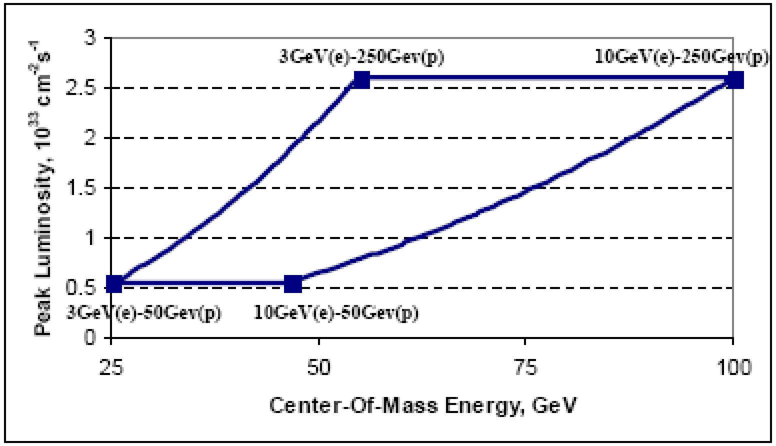
$$x_{\mathrm{parton}} \simeq 2p_T/\sqrt{s}$$



- RUN 6 results: GRSV-MAX / GRSV-MIN ruled out [illegible] favor a gluon polarization [illegible] measured x-region which falls in-between [illegible] GRSV-ZERO
- Consistent with RUN 5 result (Factor [illegible] improved statistical precision [illegible] 13GeV/c)

ERL – based eRHIC Design





- 10 GeV electron design energy. Possible upgrade to 20 GeV by doubling main linac length.
- 5 recirculation passes (4 of them in the RHIC tunnel)
- Multiple electron-hadron interaction points (IPs) and detectors;
- Full polarization transparency at all energies for the electron beam;
- Ability to take full advantage of transverse cooling of the hadron beams;
- Possible options to include polarized positrons: compact storage ring; Compton backscattering; undulator-based. All options at lower luminosity.

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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!