Accelerating and Colliding Polarized Protons in RHIC with Siberian Snakes

Spin dynamics and Siberian Snakes

Polarized proton acceleration in AGS and RHIC

High energy proton beam polarimetry

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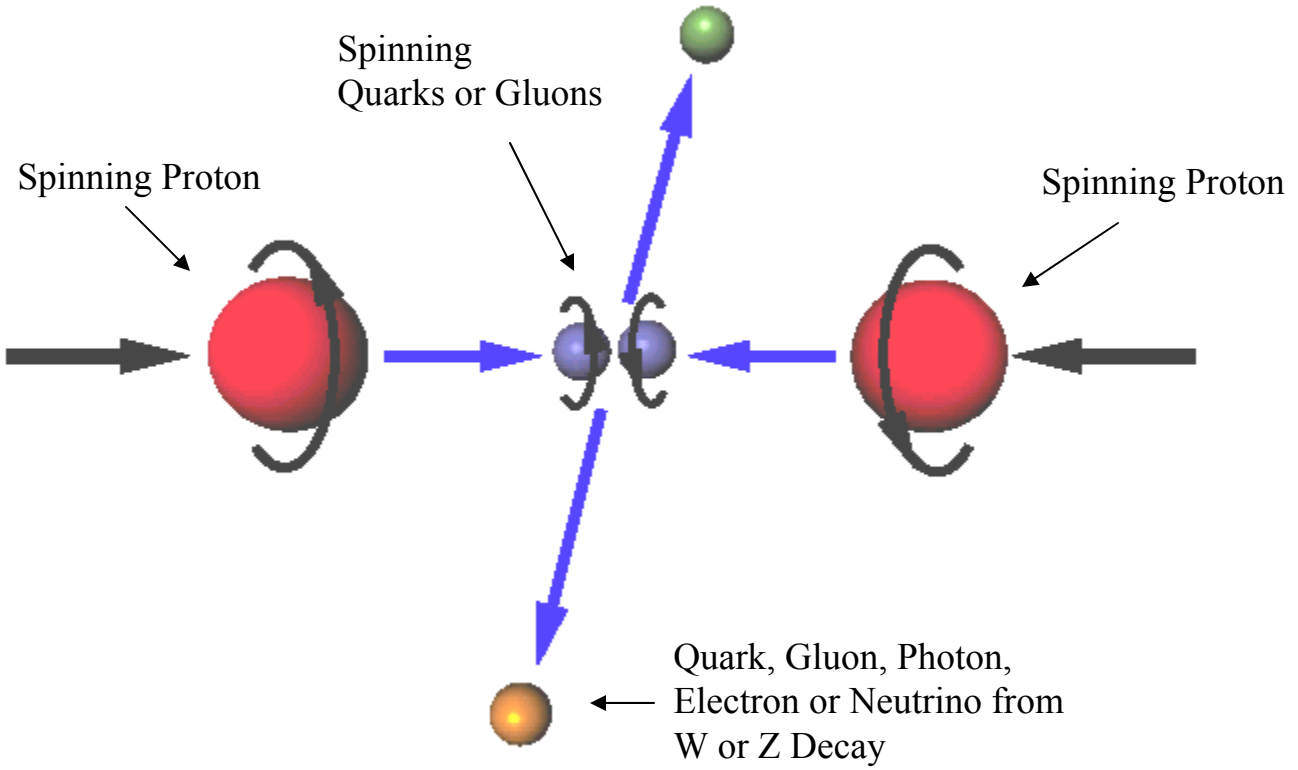
RHIC Spin Physics



- Spin structure functions of gluon and anti-quarks
- Parity violation in parton-parton scattering

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Spin Dynamics

Precession Equation in Laboratory Frame:
(Thomas [1927], Bargmann, Michel, Telegdi [1959])

$$d\mathbf{P}/dt = -(e/\gamma m)\,[G\gamma \mathbf{B}_{\perp} + (1+G)\,\mathbf{B}_{\parallel}] \times \mathbf{P}$$

Lorentz Force equation:

$$d\mathbf{v}/dt = -(e/\gamma m)\,[\ \mathbf{B}_{\perp}\ ] \times \mathbf{v}$$

- For pure vertical field:
  Spin rotates $G\gamma$ times faster than motion, $\nu_{sp} = G\gamma$
- For spin manipulation:
  At low energy, use longitudinal fields
  At high energy, use transverse fields

Depolarizing Spin Resonances

Spin tune: Number of 360 degree spin rotations per turn

Depolarizing resonance condition:

Number of spin rotations per turn = Number of spin kicks per turn

Imperfection resonance (magnet errors and misalignments):

$$G\gamma = \nu_{sp} = n$$

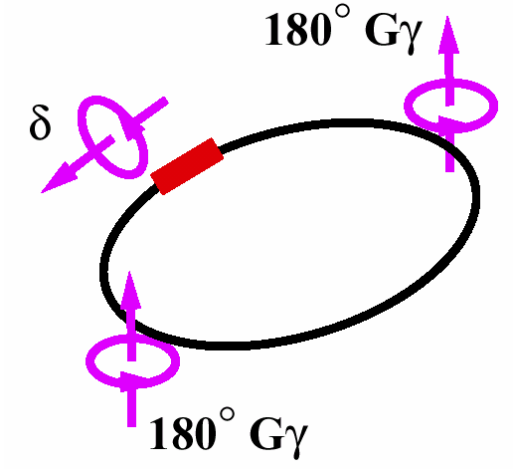
Intrinsic resonance (Vertical focusing fields):

$$G\gamma = \nu_{sp} = nP \pm \nu_y$$

P: Superperiodicity [AGS: 12, RHIC: 3]

ν_y: Betatron tune [AGS: 8.75, RHIC: 29.23]

Siberian Snakes (Local Spin Rotators)

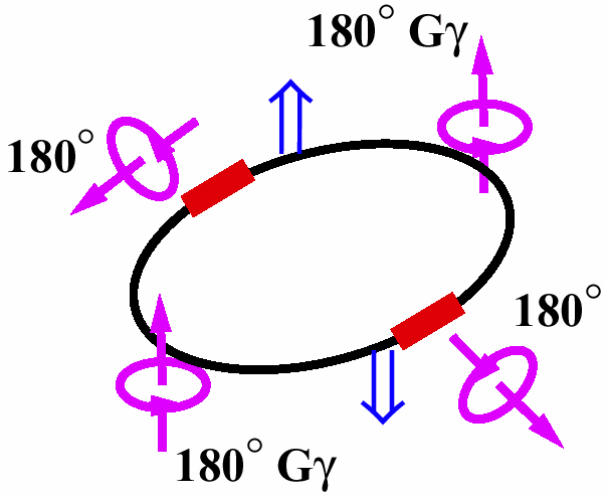


$$\cos(180^\circ \nu_{sp}) = \cos(\delta/2) \cdot \cos(180^\circ G\gamma)$$

$\delta \neq 0^\circ \rightarrow \nu_{sp} \neq n$

No imperfection resonances

Partial Siberian snake (AGS)



$\delta = 180^\circ \rightarrow \nu_{sp} = ½$

No imperfection resonances and

No Intrinsic resonances

Full Siberian Snake

Two Siberian Snakes in RHIC

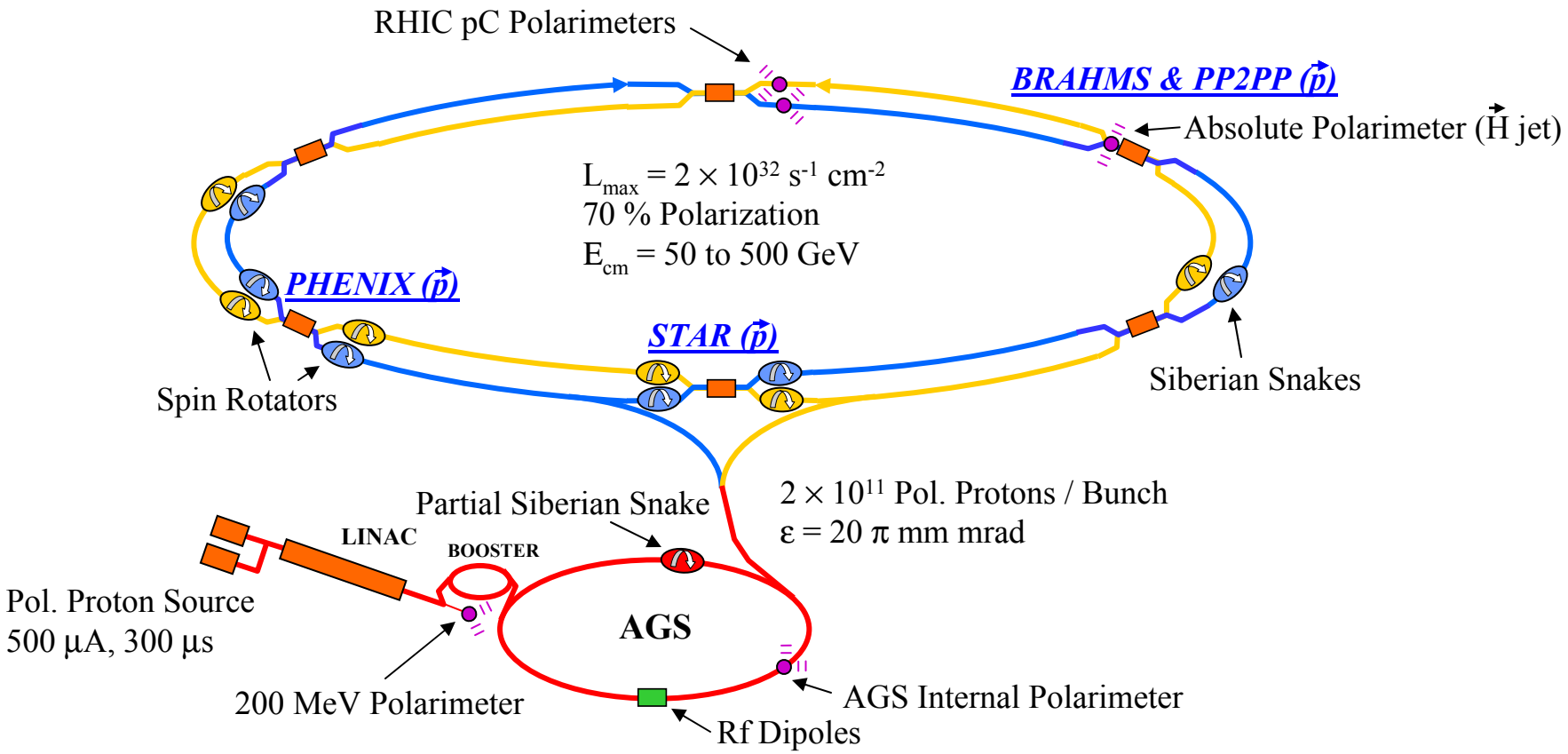
(Naïve) Limits for Siberian Snakes

Spin rotation of Siberian snake > Spin rotation of driving fields

Imperfection resonances	$\varepsilon \propto$ **Energy**
Intrinsic resonances	$\varepsilon \propto \sqrt{\text{Energy}}$
Partial Siberian snake (AGS, $\delta = 9°$)	$\varepsilon = \delta/360°$
One full snake	$\varepsilon = 1/2$
Two full snakes (RHIC)	$\varepsilon = 1$
N full snakes (HERA, LHC)	$\varepsilon = N/2$


PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP ($\vec{p}$)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX($\vec{p}$)
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
NASA - BAF
μ g-2
HEP/NP(p)
LINAC
BOOSTER
AGS
TANDEMS

Polarized Proton Collisions in RHIC



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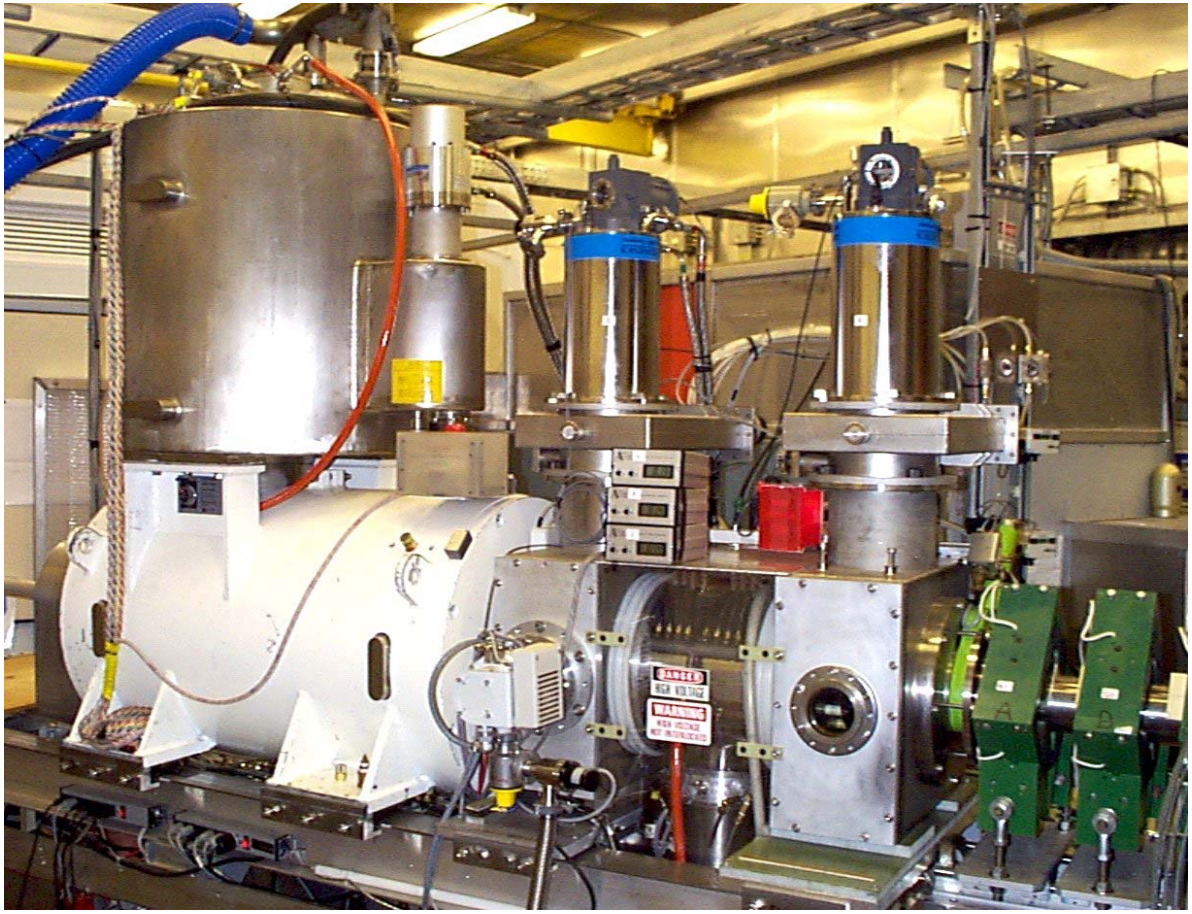
High intensity polarized H^- source



KEK OPPIS
upgraded at TRIUMF

70 - 80 % Polarization

15×10^{11} protons/pulse
at source

6×10^{11} protons/pulse
at end of LINAC

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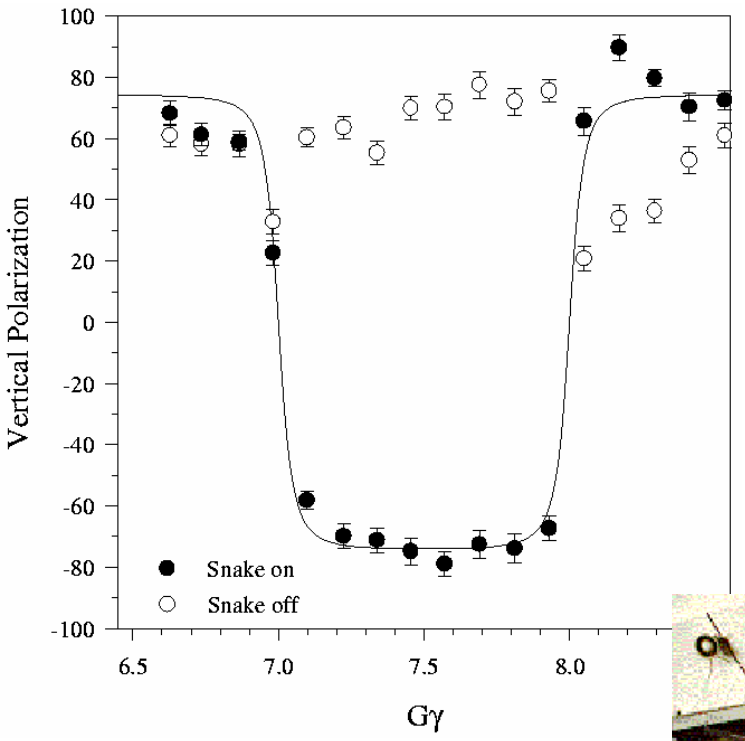
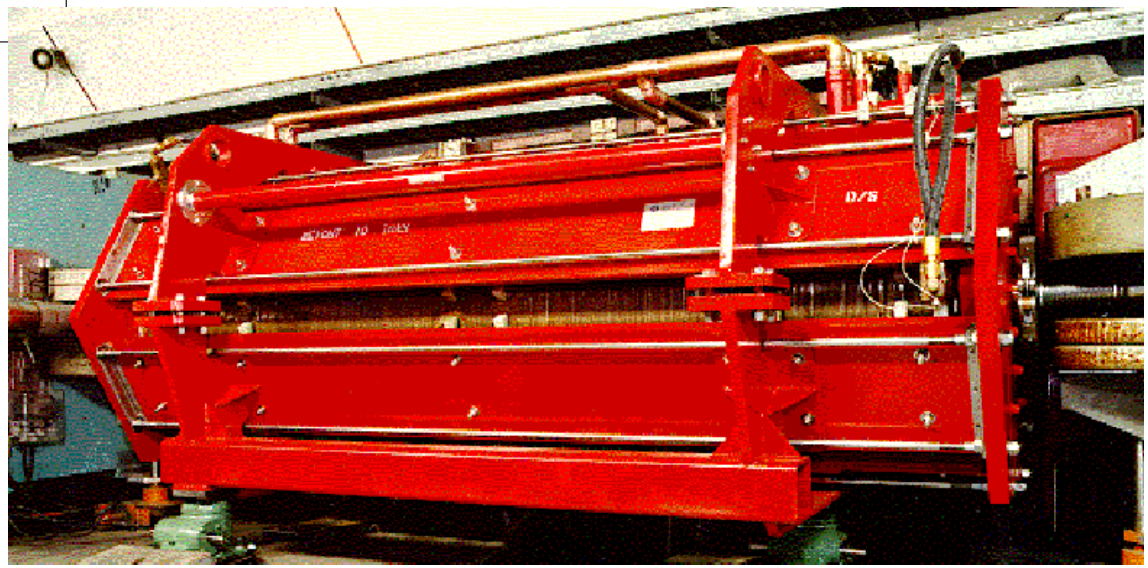
AGS Partial Siberian Snake Solenoid



- 4.7 Tm solenoid
- 9 degree spin rotation
- Reverses spin every 523 MeV without loss of polarization



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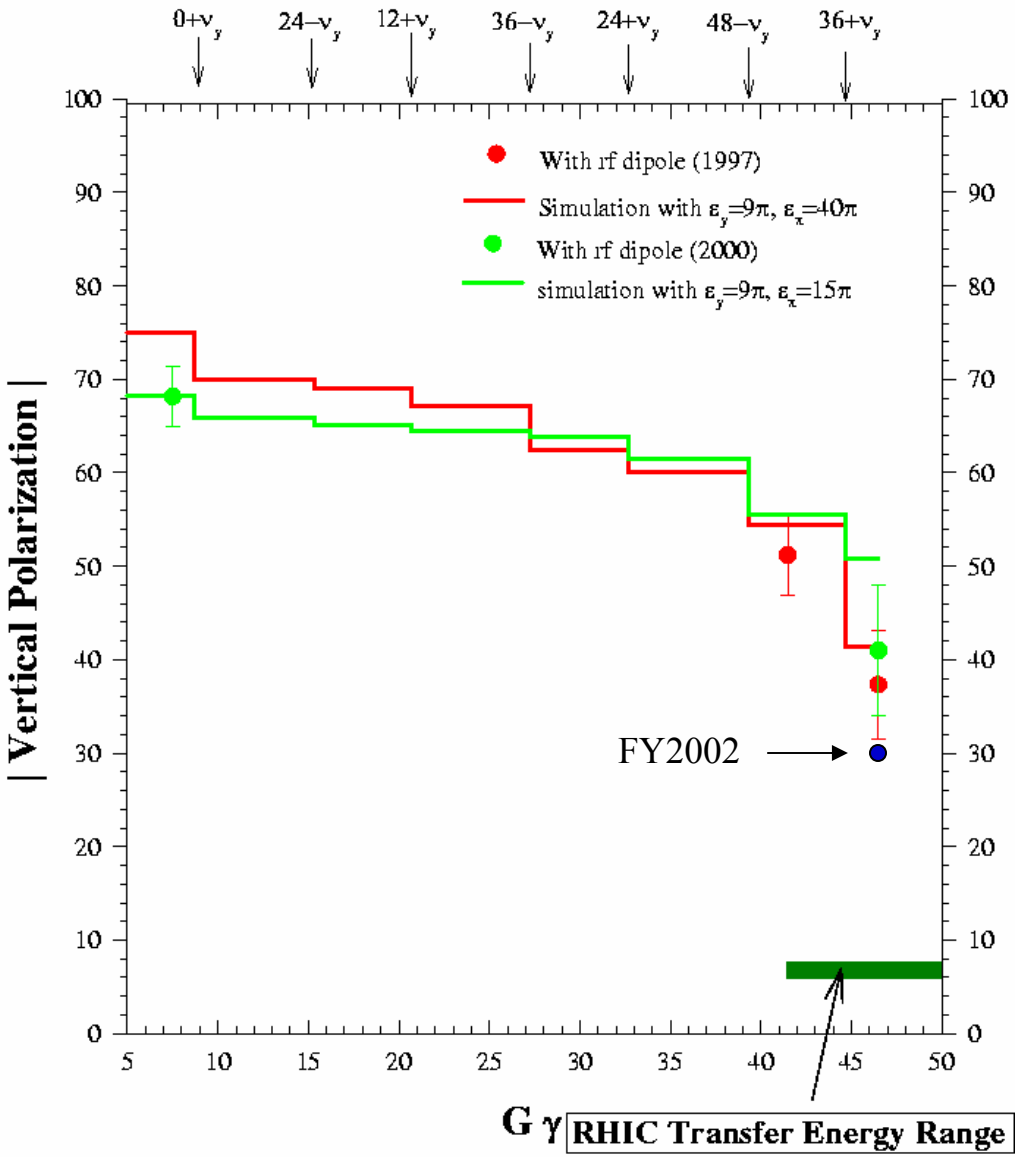
Proton polarization at the AGS

- Full spin flip at all imperfection resonances using partial Siberian snake
- Full spin flip at strong intrinsic resonances using rf dipole
- Remaining polarization loss from coupling and weak intrinsic resonances
- Larger polarization loss in RHIC RUN-2 due to lower ramp-rate AGS Main Magnet Power Supply



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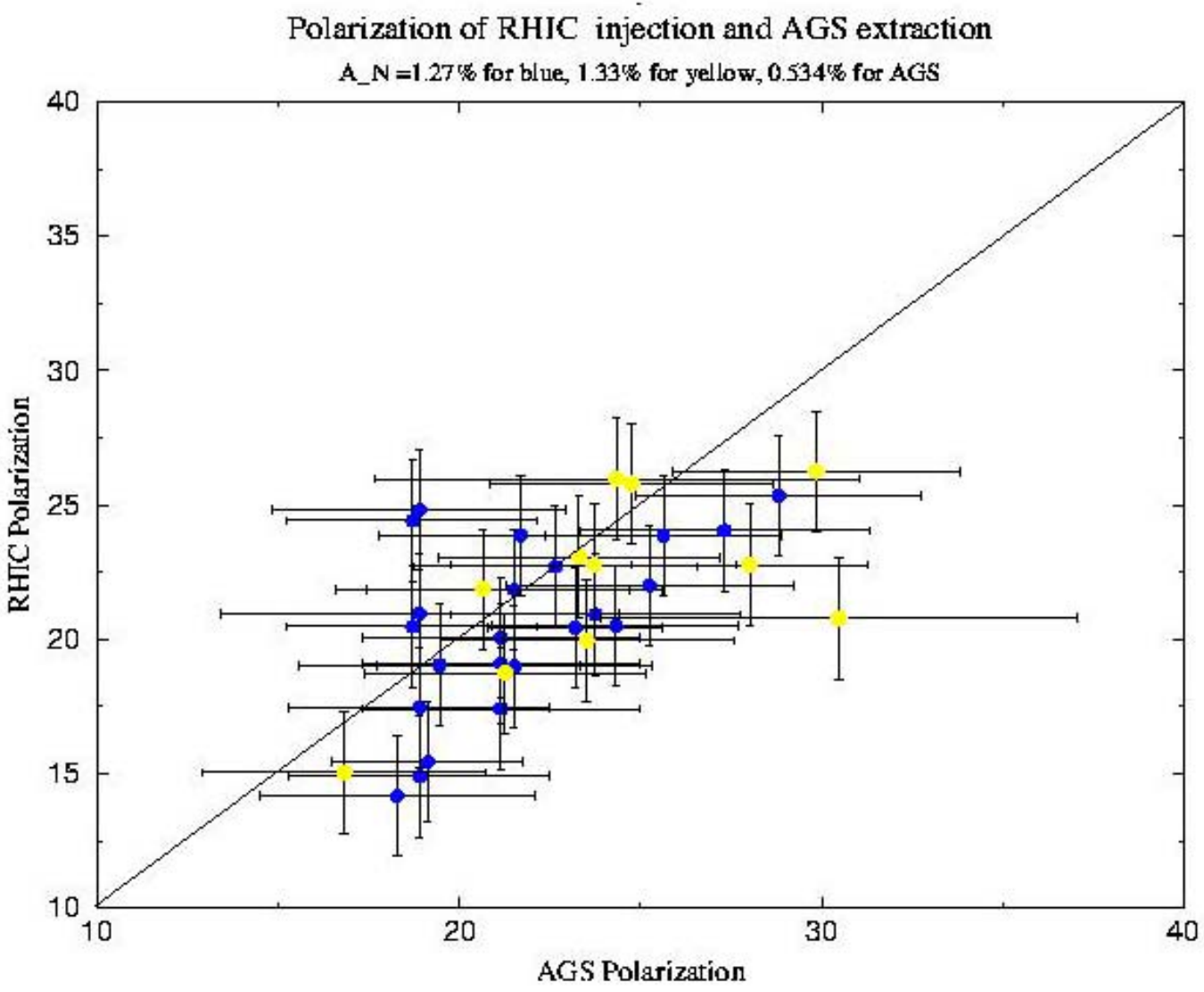
AGS-to-RHIC polarization transfer



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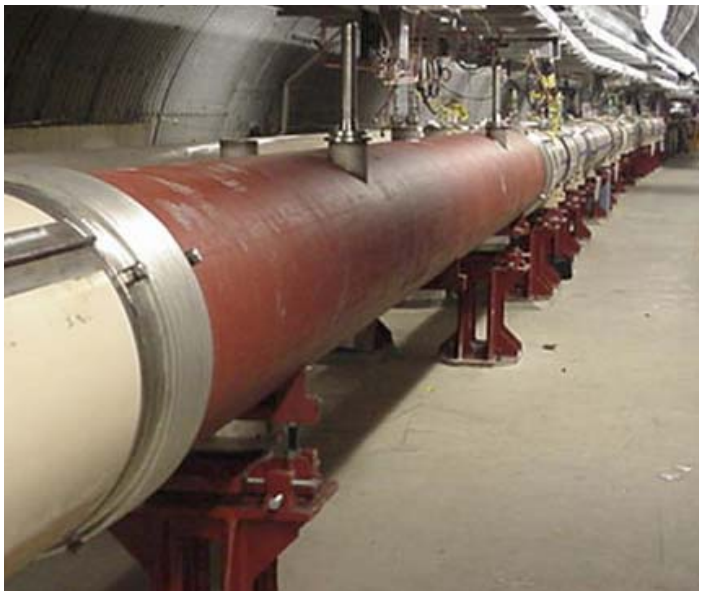
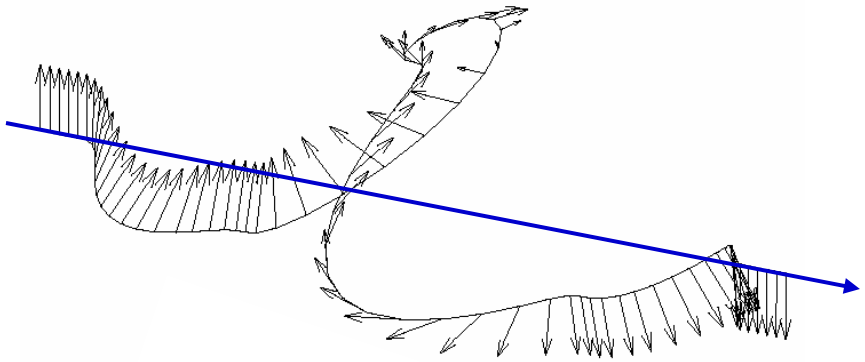
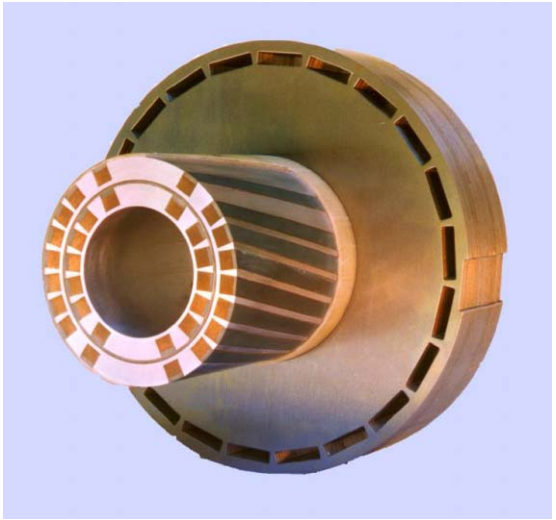
First Siberian Snake in RHIC Tunnel

Siberian Snake: 4 superconducting helical dipoles, 4Tesla,
2.4 m long with full 360° twist







Funded by RIKEN, Japan
Designed and constructed at BNL

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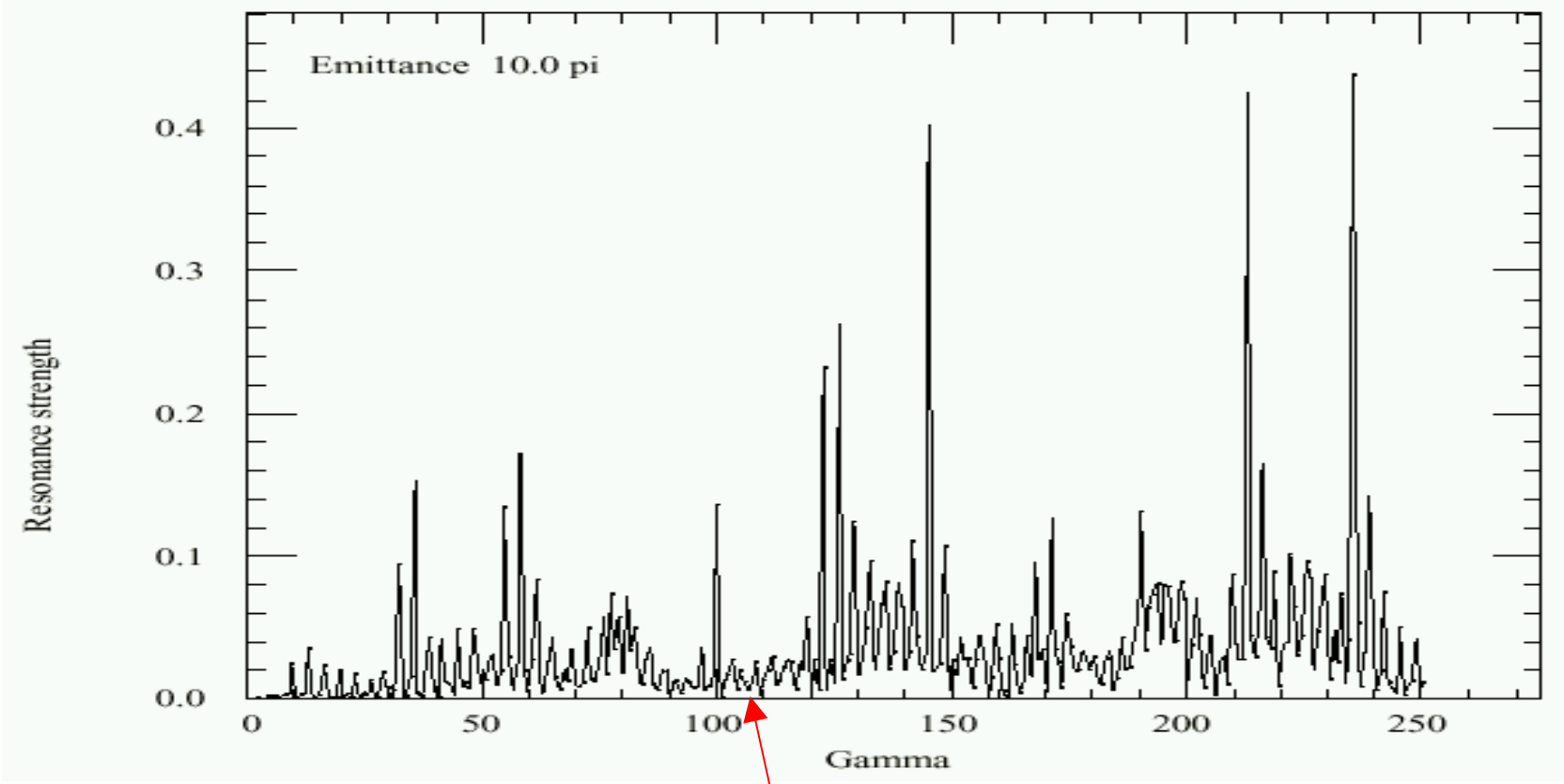
Intrinsic spin resonance strengths



Flattop energy for this run

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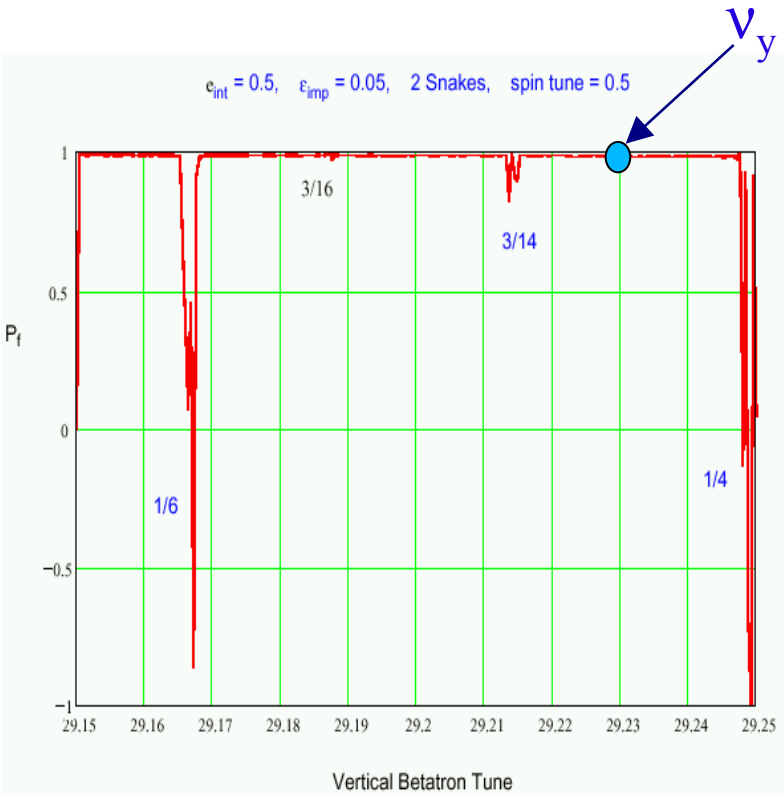
RHIC Polarization Set-up

Fract. vertical tune = 0.23, between 2 high-order spin resonances:

- 1/4 = 0.25 (depends on vertical orbit)
- 3/14 = 0.2143 (exists without orbit errors)

Flat vertical orbit with < 1 mm rms using measured misalignment data (3 years old).

Special attention to tunes and orbits at 4 strong intrinsic resonances



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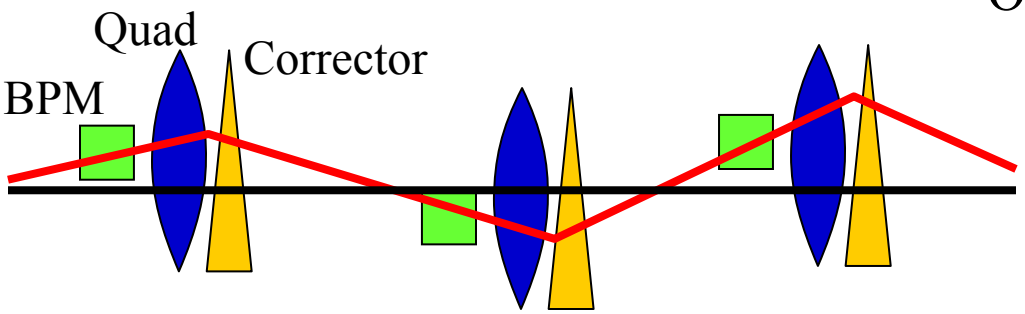
Ideal Orbit for Polarization

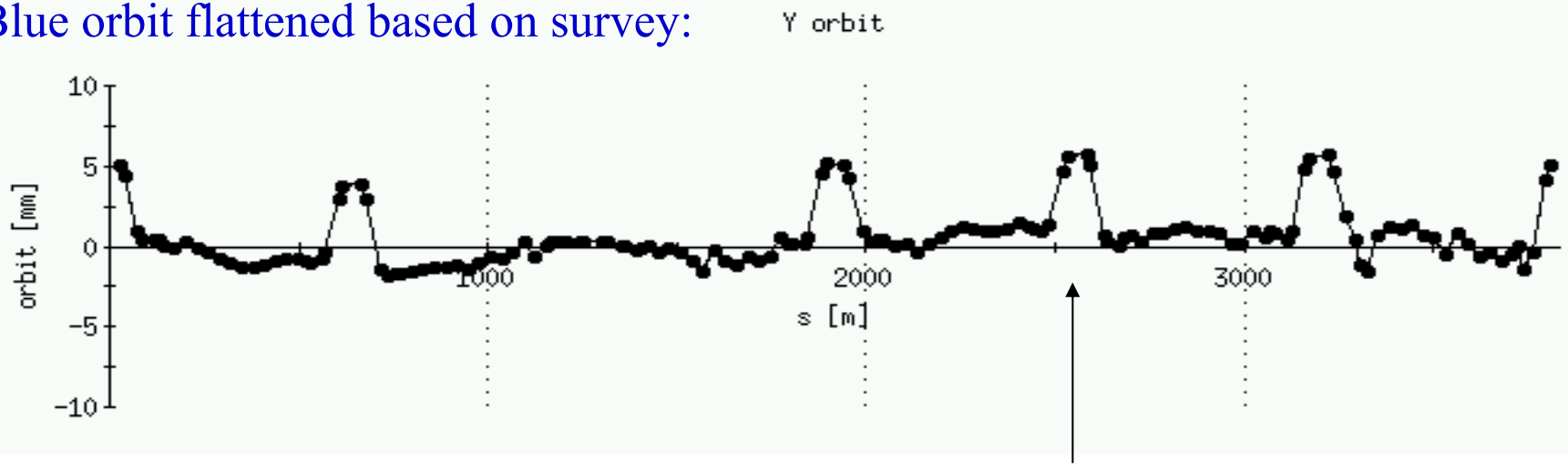
Correct orbit to minimize kicks:

Orbit going through center of BPM's

Orbit without kicks



Blue orbit flattened based on survey:



Vertical bumps to avoid collisions

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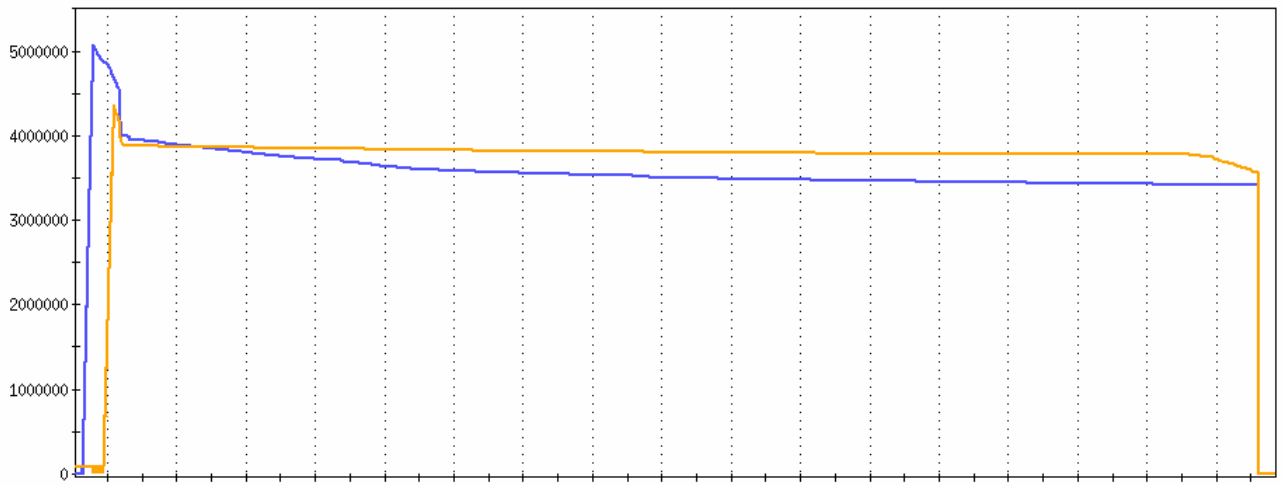
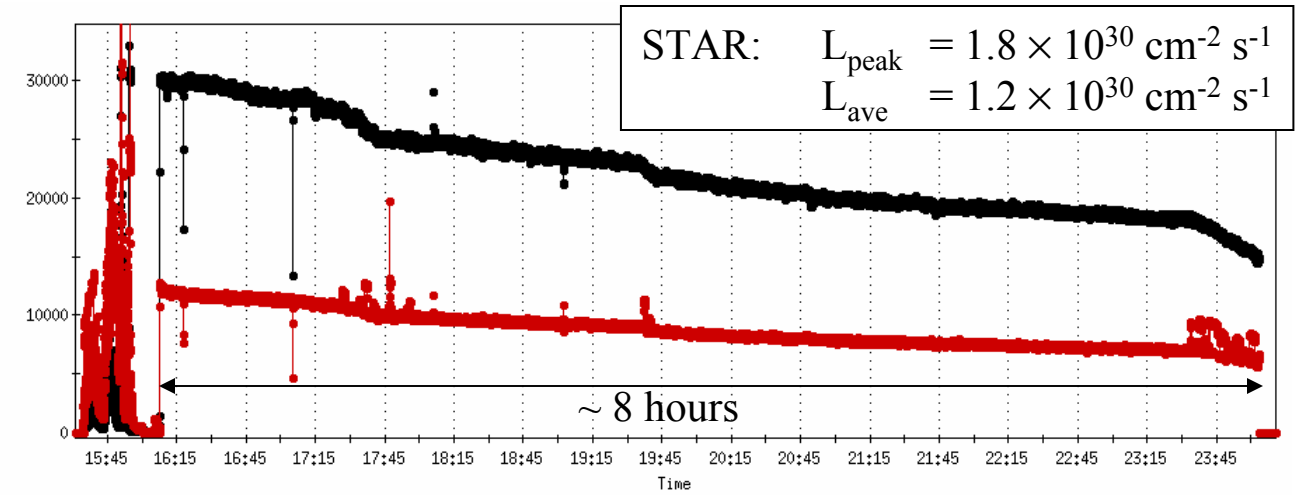
"Typical Store" # 2304

Beam currents [$\times 10^6$ ions]



Collision rate [Hz]



Vernier scans:
STAR: $10^4 \rightarrow 0.6 \times 10^{30}$ cm^{-2} s^{-1}
PHENIX: $10^4 \rightarrow 1.6 \times 10^{30}$ cm^{-2} s^{-1}

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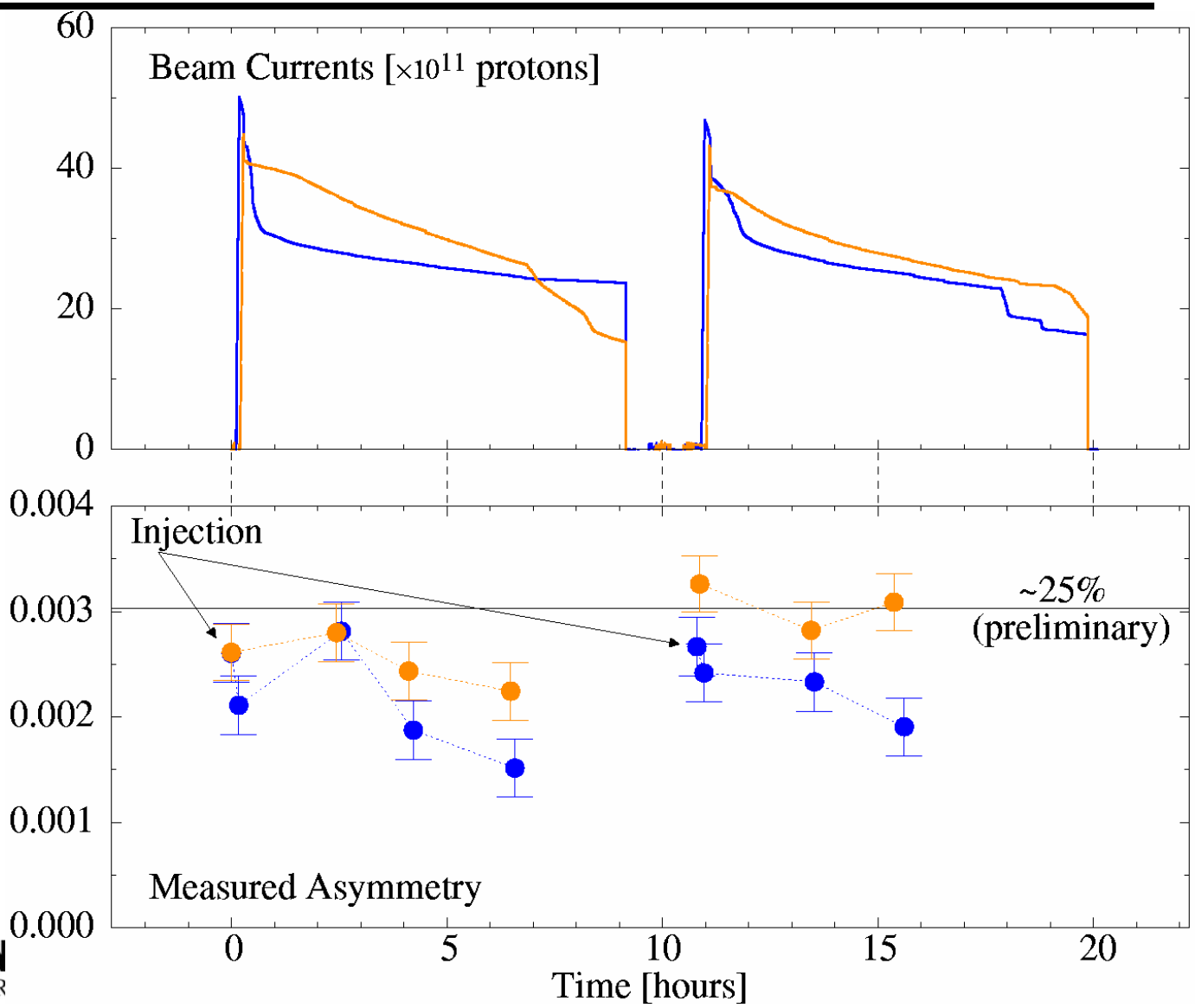
RHIC Beam Polarization



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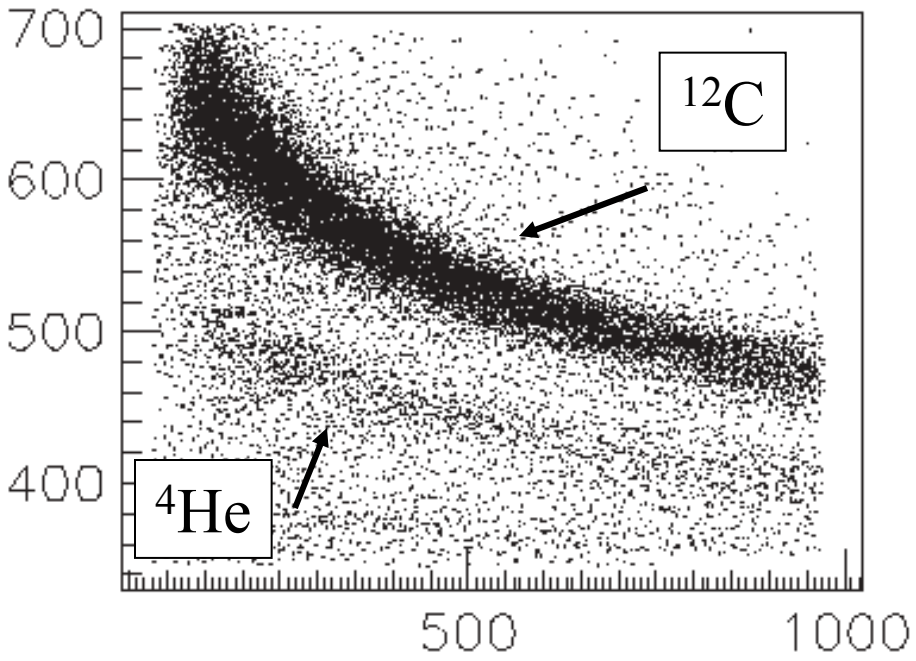
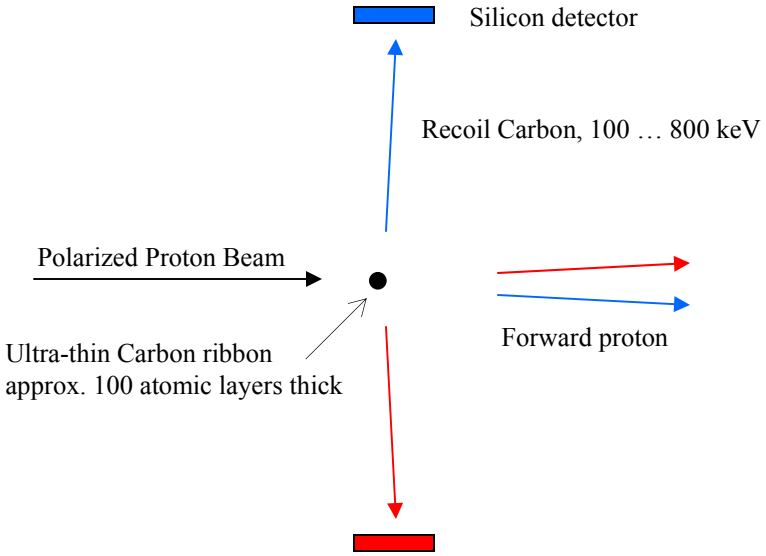
RHIC proton-carbon polarimeter



Energy vs. ToF spectrum



- ~ 1.2 % energy independent analyzing power for small-angle elastic scattering in the Coulomb-Nuclear Interference (CNI) region
- Slow recoil Carbon detected in between bunch crossings
- Fiber target allows for polarization profile measurement

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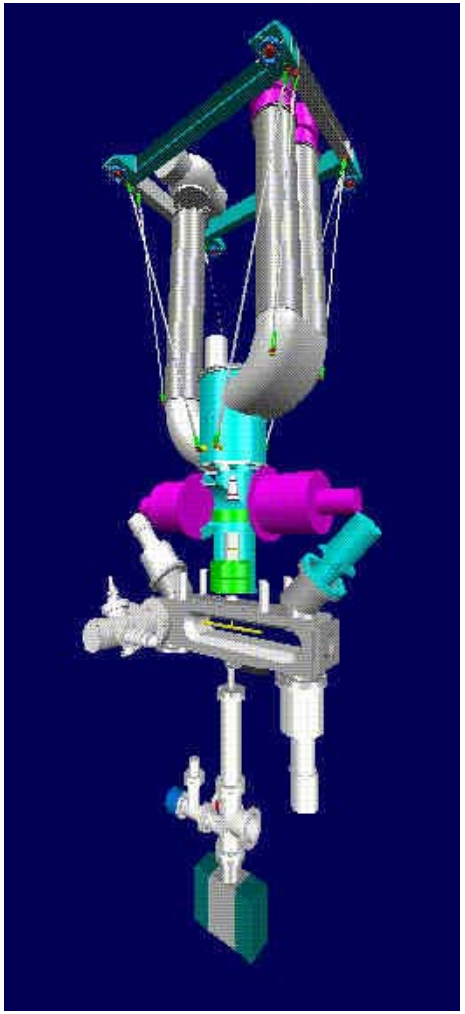
Polarized Hydrogen Jet Target

- pC polarimeter is used as fast relative polarization monitor and was calibrated in AGS at 22 GeV to about 15 %.
- Polarized hydrogen jet target allows for absolute beam polarization measurement:

$$P_{\text{Beam}} = P_{\text{Target}} \frac{N_{B\uparrow T\uparrow} - N_{B\downarrow T\downarrow} + N_{B\uparrow T\downarrow} - N_{B\downarrow T\uparrow}}{N_{B\uparrow T\uparrow} - N_{B\downarrow T\downarrow} - N_{B\uparrow T\downarrow} + N_{B\downarrow T\uparrow}}$$

- Jet target thickness of 3×10^{11} cm^{-2} achievable
- Jet polarization measurable to better than 3% using Stern-Gerlach method



Pol. H jet target at Bates from NIKHEF

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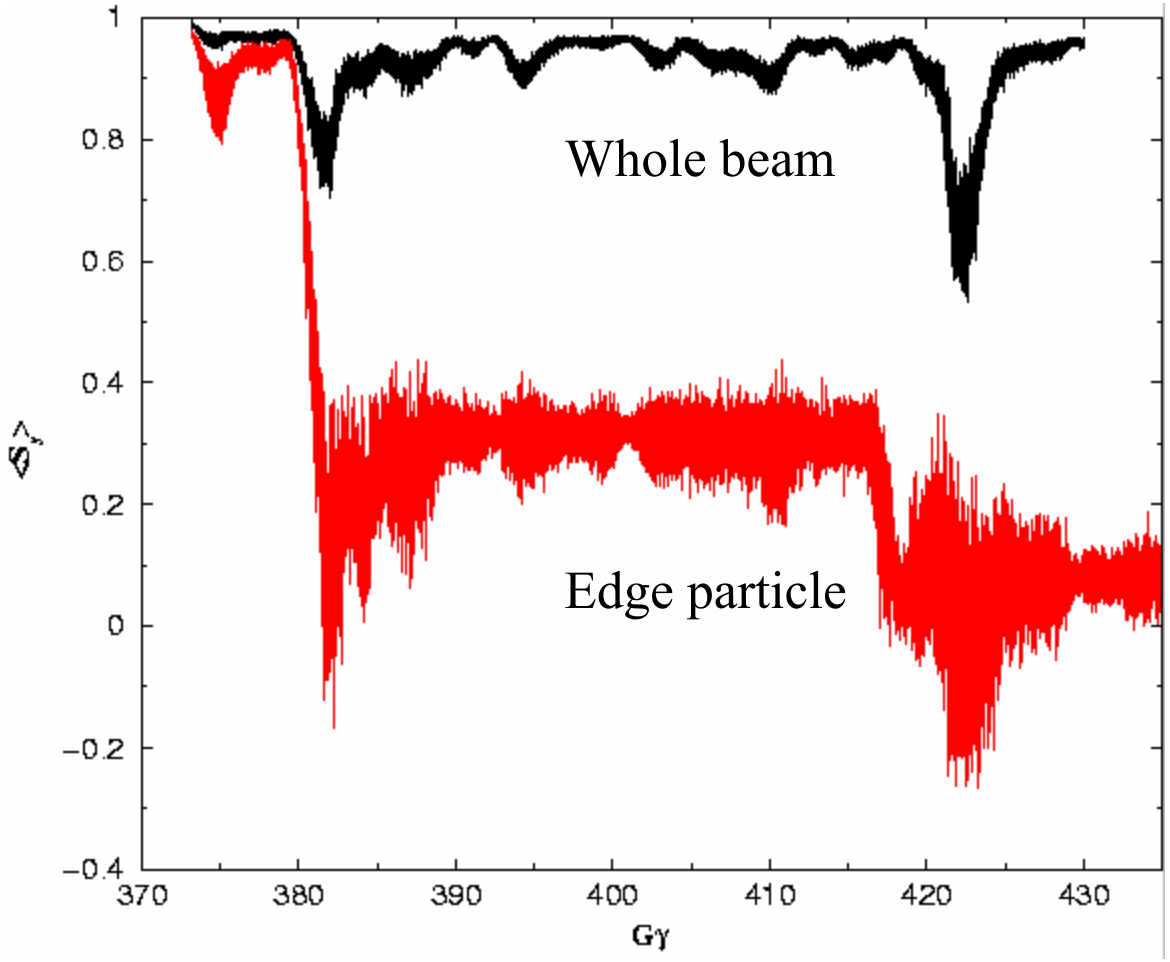
Accelerating polarized protons to 250 GeV



Spin tracking through strongest resonances:

- Two Siberian snakes
- 1 mm rms misalignment (Survey: < 0.5 mm)
- 0.2 mm rms closed orbit
- 20 π μm emittance (95%)

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Summary

- Very successful first RHIC spin commissioning and short data run
- 100 GeV on 100 GeV polarized proton collisions with ~ 25 % polarization and peak luminosity of 1.8×10^{30} cm^{-2} s^{-1}
- Little if any depolarization in RHIC during acceleration and store. **Siberian Snakes work !**
- RHIC Polarimeters commissioned and work reliably from injection to 100 GeV
- Collisions of polarized protons at center-of-mass energy of 500 GeV planned