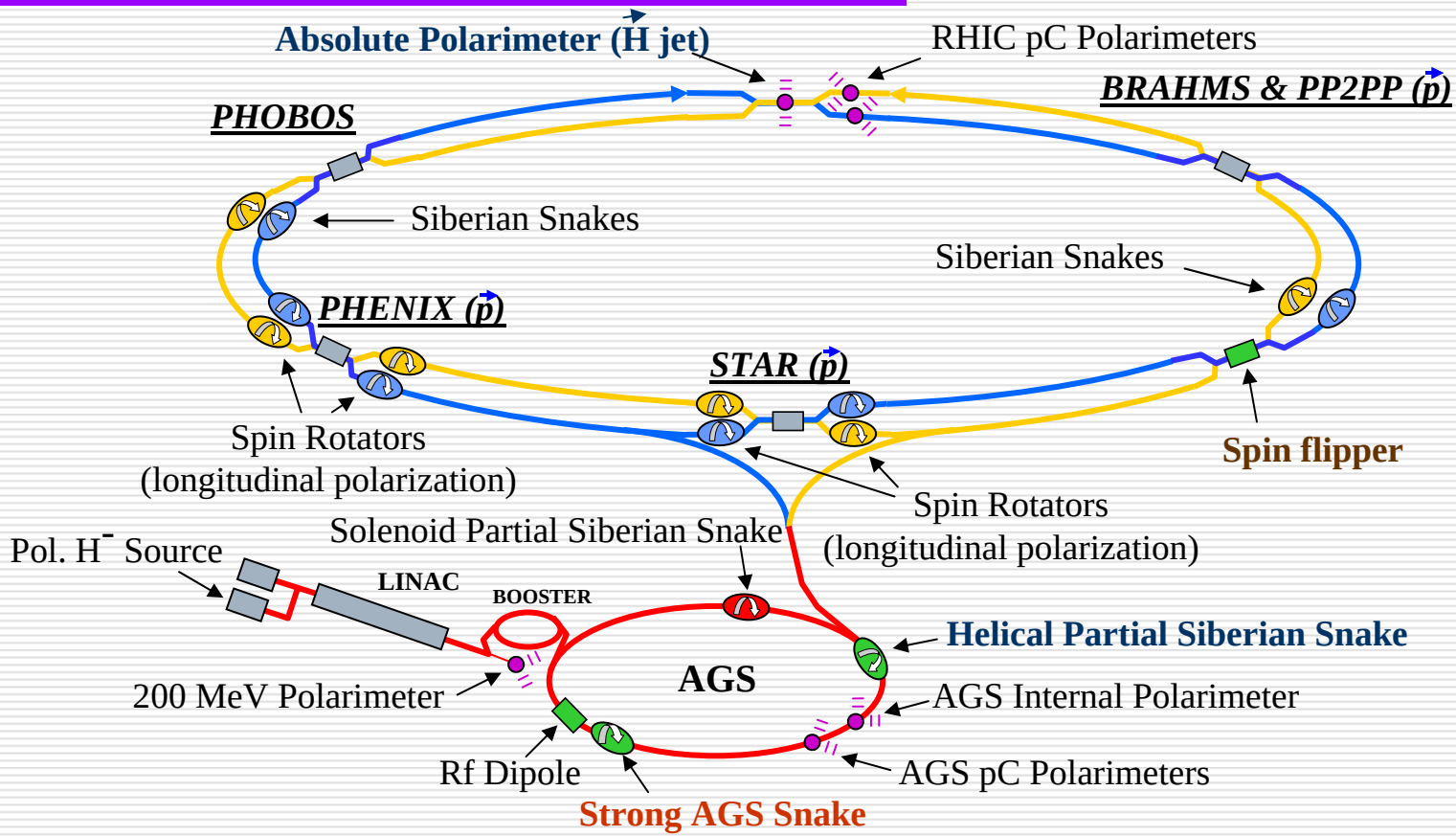
Polarized Proton Operations in AGS and RHIC

Mei Bai
Brookhaven National Laboratory

Outline

- Layout of polarized proton acceleration complex
  - Milestones of RHIC polarized proton program
- Spin Dynamics
  - Spin depolarization resonances
- Status
  - AGS capability
  - RHIC capability
- Challenges and Future Plans
  - Machine developments for the future

Polarized Proton Acceleration Complex Layout



- Installed and commissioned during FY04 run
- Plan to be commissioned during FY05 run
- Plan to be installed and commissioned during FY05 run

Milestones of RHIC Spin Program

	Milestone
FY00	New polarized proton source (OPPIS) commissioned One snake was installed in the sector 9 in Blue ring By slowly turning on this snake after the pp was injected, a radial polarization was measured and demonstrated that the snake was working as expected CNI polarimeter in Blue installed and commissioned
FY02	All snakes for both rings installed and commissioned CNI polarimeter in Yellow installed and commissioned
FY03	Spin rotators installed and commissioned provided longitudinal polarizations at STAR and PHENIX for physics data taking
FY04	RHIC new working point commissioned RHIC absolute polarimeter using Hydrogen Jet target installed and commissioned AGS 5% helical warm snake installed and commissioned

Goal for the Polarized Proton in RHIC

- Polarization
  - 70% beam polarization at RHIC store energy 250 GeV/c
- Luminosity
  - bunch intensity: 2×10^{11} protons per bunch
  - 112 bunch per ring
  - with a normalized beam emittance of 20π mm-mrad, a luminosity of
    - 60×10^{30} $cm^{-2}s^{-1}$ is expected at 100 GeV/c
    - 150×10^{30} $cm^{-2}s^{-1}$ is expected at 250 GeV/c

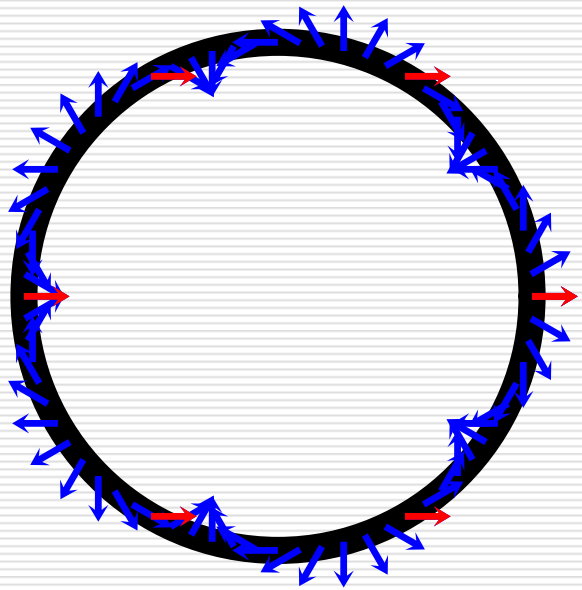
Spin Dynamics

- Spin precession in a planar circular accelerator

$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S} = -\frac{e}{\gamma m}[(1+G\gamma)\vec{B}_{\perp} + (1+G)\vec{B}_{//}] \times \vec{S}$$

- Orbital motion

$$\frac{d\vec{P}}{dt} = \vec{\Omega}_{rev} \times \vec{P} = -\frac{e}{\gamma m}[\vec{B}_{\perp} \qquad] \times \vec{P}$$



- Spin tune

$$\nu_s = \frac{\Omega - \Omega_{rev}}{\Omega_{rev}} = G\gamma$$

In the frame which moves with the particle

Spin Depolarization resonances

- First order spin depolarization resonance
  - Imperfection resonance
    - Due to the additional kick on the spin vector by the dipole field from the correctors or magnet misalignments

$$\nu_s = n$$

  - Intrinsic resonance
    - Due to the additional kicks from the quadrupole fields particle experiences during the betatron oscillation

$$\nu_s = m \pm \nu_y$$

    - For a machine with P super-periodicity

$$\nu_s = Pn \pm \nu_y$$

Overcome Spin Depolarization resonances

- Siberian Snake:
  - Rotates spin vector by 180°

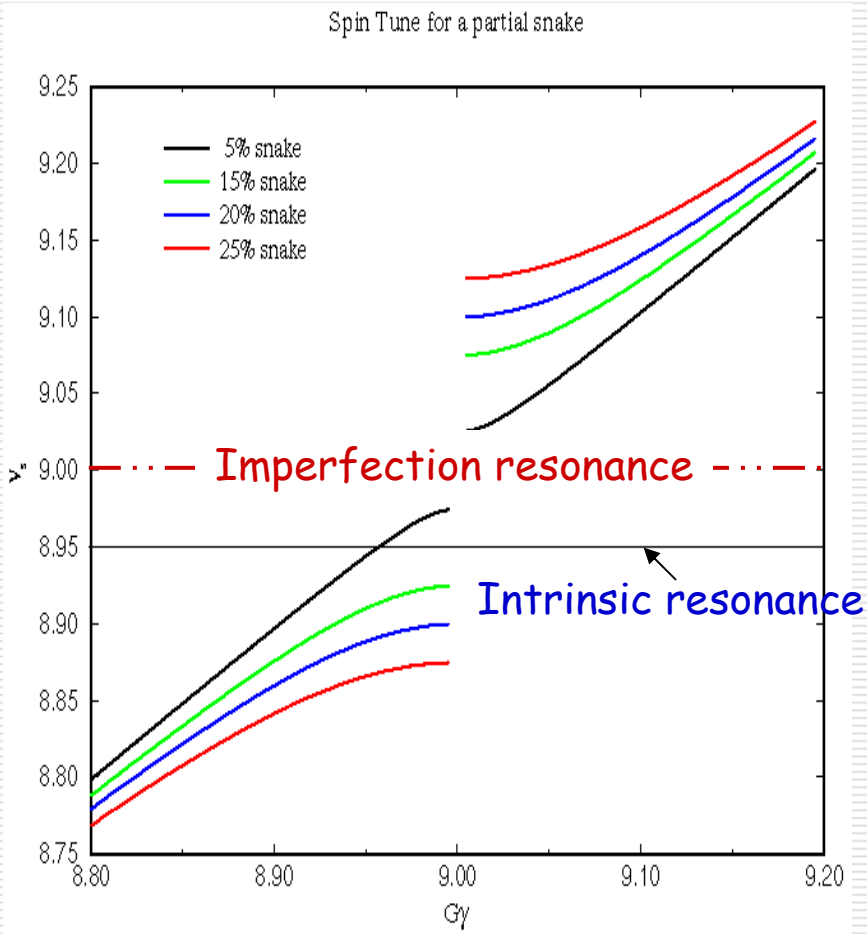
$$\nu_s = \frac{1}{2}$$

- Partial Snake

$$\nu_s = \frac{1}{\pi}\cos^{-1}\left(\cos(\delta/2)\cos(\pi G\gamma)\right)$$

Rotation angle of the spin vector from the partial snake

- AC dipole
  - Provide large coherent oscillation at a intrinsic spin resonance to achieve a full spin flip at normal acceleration speed.



Current AGS Setup

- Machine parameters
  - Lattice
    - 12 fold superperiodicity, 5 FODO cells per super-period
  - Energy:
    - Injection: 2.2 GeV
    - Extraction: 24.3 GeV
- Spin depolarization resonances
  - Imperfection spin resonance
    - A total of 42 resonances at $G\gamma$ = integer
    - Overcome by helical 5% partial snake
  - Intrinsic spin resonance
    - A total of 7 significant intrinsic resonances
    - 4 strong ones at $G\gamma$ = 0+Qy, 12+Qy and 36±Qy are overcome by the AC dipole
    - 3 weak ones at $G\gamma$ = 24±Qy and 48-Qy are crossed without any corrections

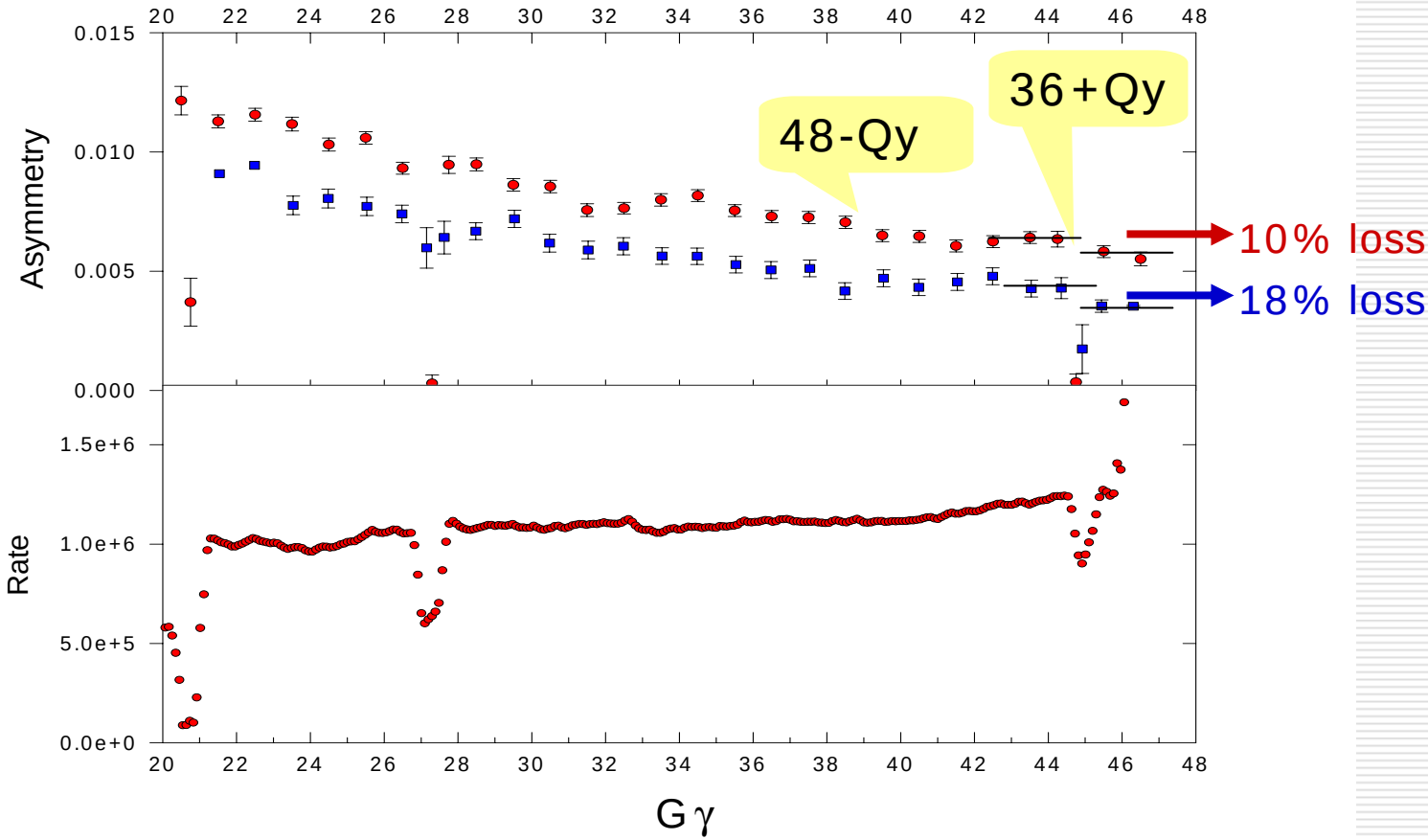
AGS Current Capability

- routinely provide a beam of 0.7×10^{11} bunch intensity with 50% polarization at RHIC injection energy

- Demonstrated the capability of providing 1.0×10^{11} bunch intensity with 50% polarization at RHIC injection energy

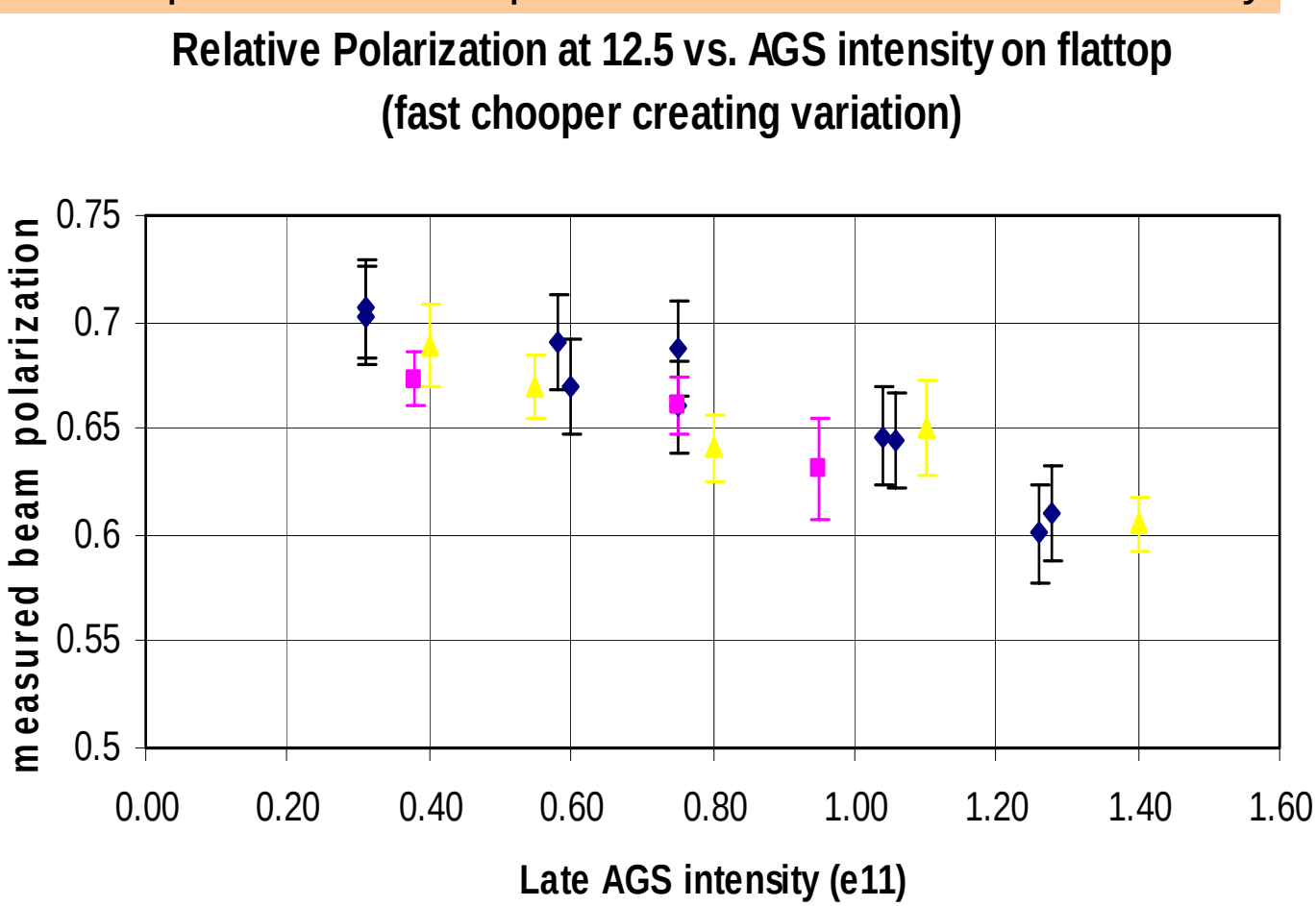
Challenges of reaching > 70% at the AGS extraction

- Polarization losses due to weak intrinsic resonance
- polarization losses due to coupling resonance



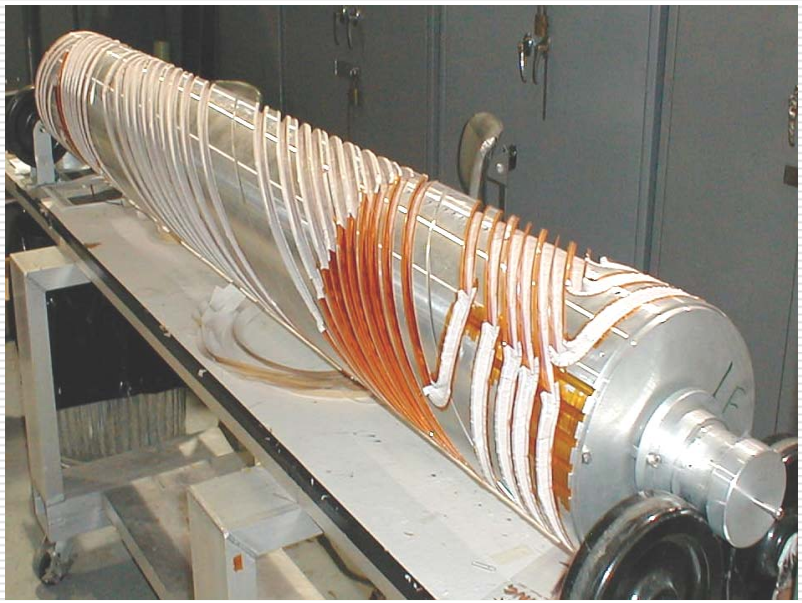
Other Challenges of Improving AGS Performance

- Beam polarization dependance on the bunch intensity

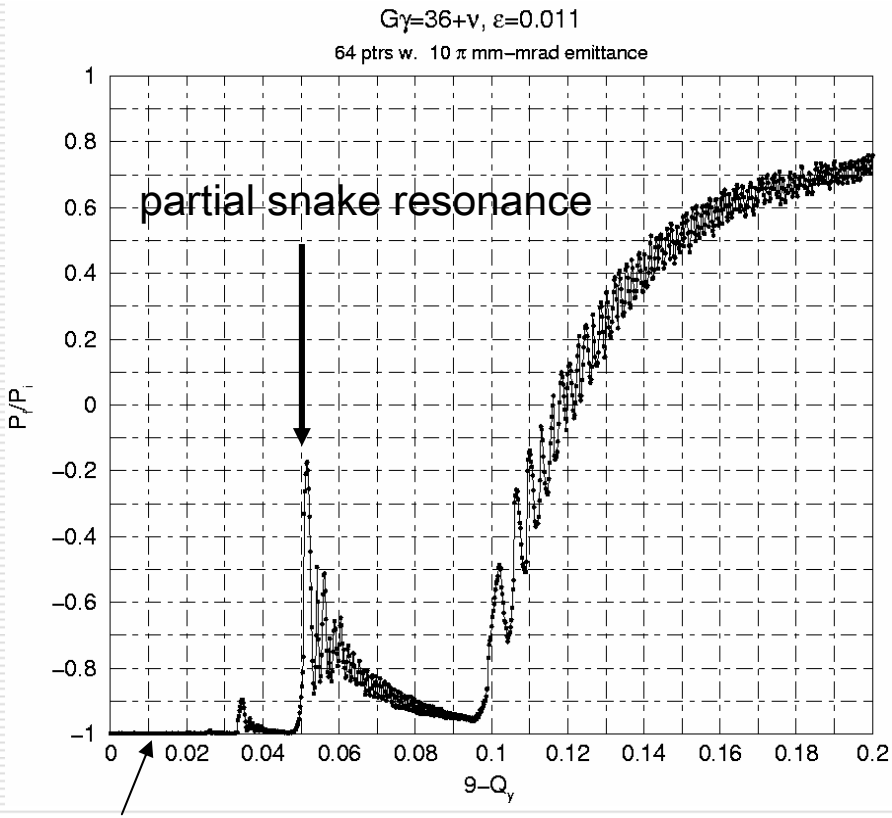


Solution I: a strong partial snake

- AGS strong cold snake, funded by DOE, is expected to yield 100% polarization transmission efficiency from AGS injection energy to extraction energy. The expected absolute polarization is 70%.

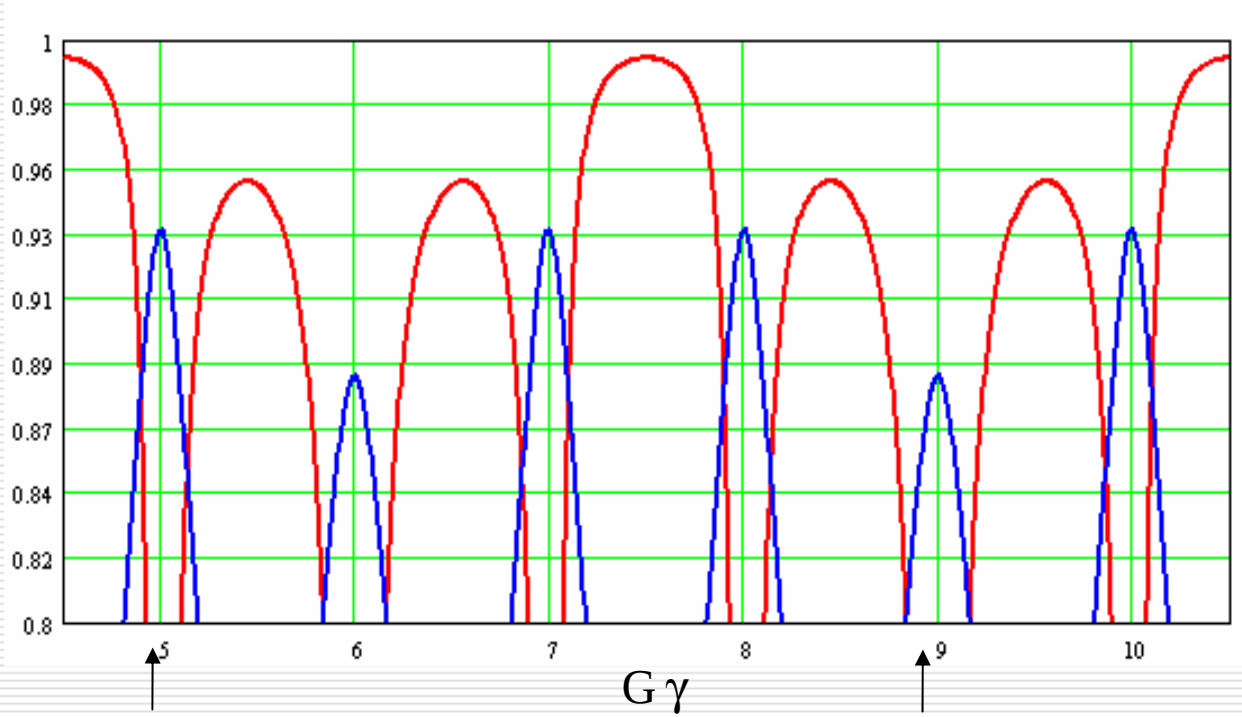


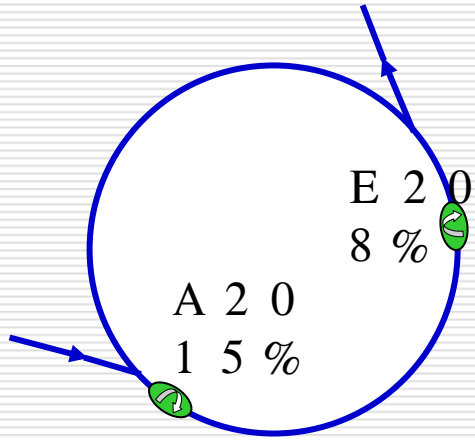
30% s.c. helical snake build at SMD (AIP)



desired vertical betatron tune to avoid depolarization

Solution II: two snakes





Injection

First intrinsic resonance (0+Qy)

Vertical component of stable spin direction

Spin tune

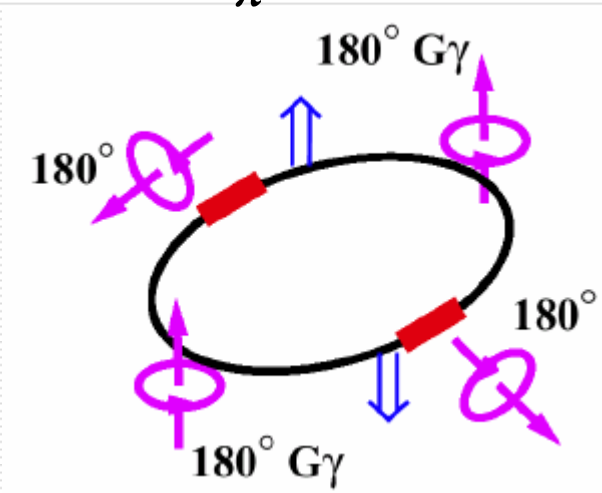
AGS Plan for Run 5

- operational: warm helical partial snake + AC dipole (the same setup as RHIC pp FY04 Run)
- commission the two snake solution (cold helical snake at 2.5Tesla field + warm helical snake at 1.5 Tesla field)

RHIC pp Setup

- Two full Siberian snakes per ring. The two snakes are located 180º apart with their precession axes perpendicular to each other

$$\nu_s = \frac{1}{\pi}\left|\phi_1 - \phi_2\right|$$

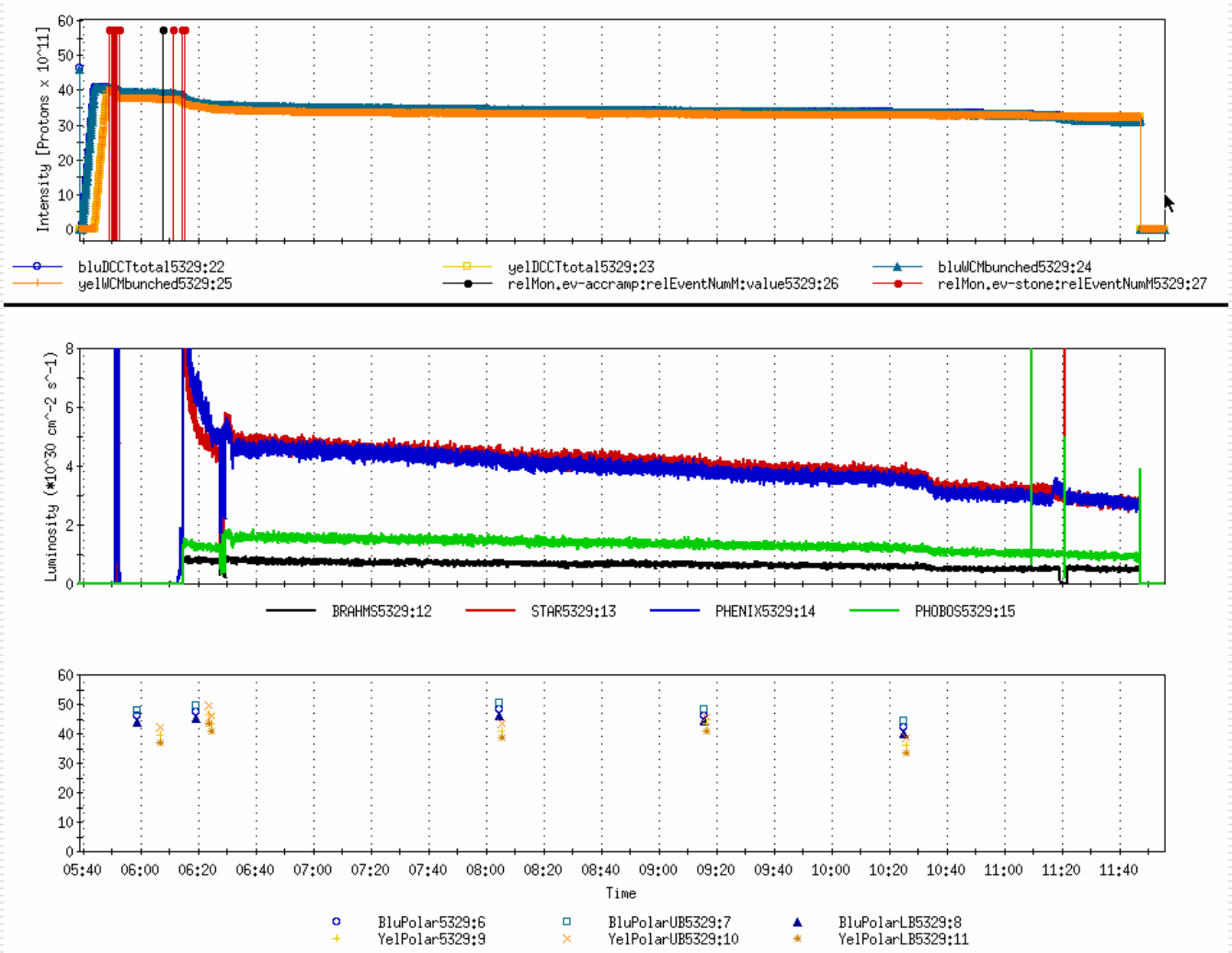


Energy at injection	24.3	GeV/u
Energy at Store	100.2	GeV/c
Interaction points	6 8 10 12 2 4	clock
β* at injection	10 10 10 10 10 10	m
β* at store	1 1 10 10 10 10	m
Working points	Inj & ramp: (28.73, 28.72) Store: (28.69, 29.68)	
Snakes current	DC	
Spin rotator current	Ramp up after store	
Experimental magnets	STAR, PHENIX: on DC from inj. to top	
RF accelerating cavities	At injection: 100 kV ramp: 300 kV At store: 300 kV	
RF storage cavities	No rebucketing	

RHIC Achieved Performance

	bunch intensity $[10^{11}]$	# of bunch	$\mathcal{L}_{peak}$ $[10^{30}]$ $cm^{-2}s^{-1}$	$\mathcal{L}_{store\ average}$ $[10^{30}]$ $cm^{-2}s^{-1}$	$\mathcal{L}_{per\ week}$ $[pb^{-1}]$	polarization at store
FY04	0.70	56	5.4	4.0	1.0	40-45%
FY04 Unpolarized proton	1.70	28	10.0	--	--	--

A typical store



Challenges in RHIC

- Improve the luminosity performance
  - Goal:
    - 60×10^{30} $cm^{-2}s^{-1}$ is expected at 100 GeV/c
    - 150×10^{30} $cm^{-2}s^{-1}$ is expected at 250 GeV/c
- Achieve > 70% beam polarization at 100 GeV/c as well as 250 GeV/c

Challenges in RHIC -- Luminosity

- Beam-beam effect on the luminosity lifetime
  - Beam emittance blowup
  - beam lifetime dominated by the beam-beam driven resonances

Treatment: proper working point

- Total beam intensity limit due to the dynamic pressure rise

Treatment: NEG coating the warm beam pipes

Polarization challenges in RHIC: snake resonances

- Snake resonance

$$\nu_s = m\nu_y + k \xrightarrow{\nu_s = \frac{1}{2}} \nu_y = \frac{2k+1}{2m}$$ K, m are integers

  - even order resonance: m is even, driven by overlapping imperfection and intrinsic resonance. The stronger the two resonances, the stronger the snake resonance
  - odd order resonance: m is odd, driven by intrinsic resonance

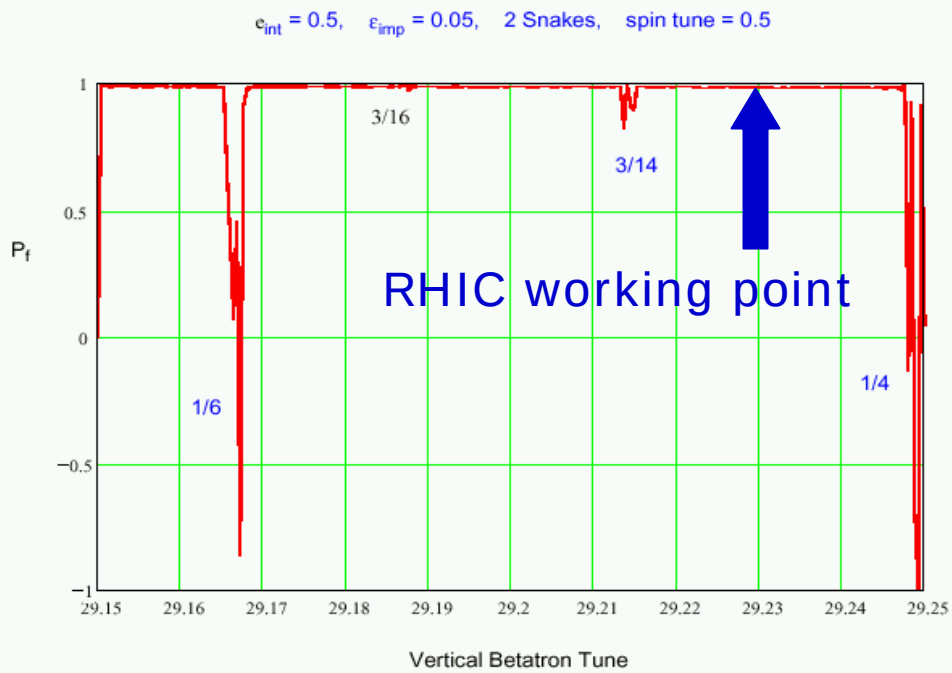
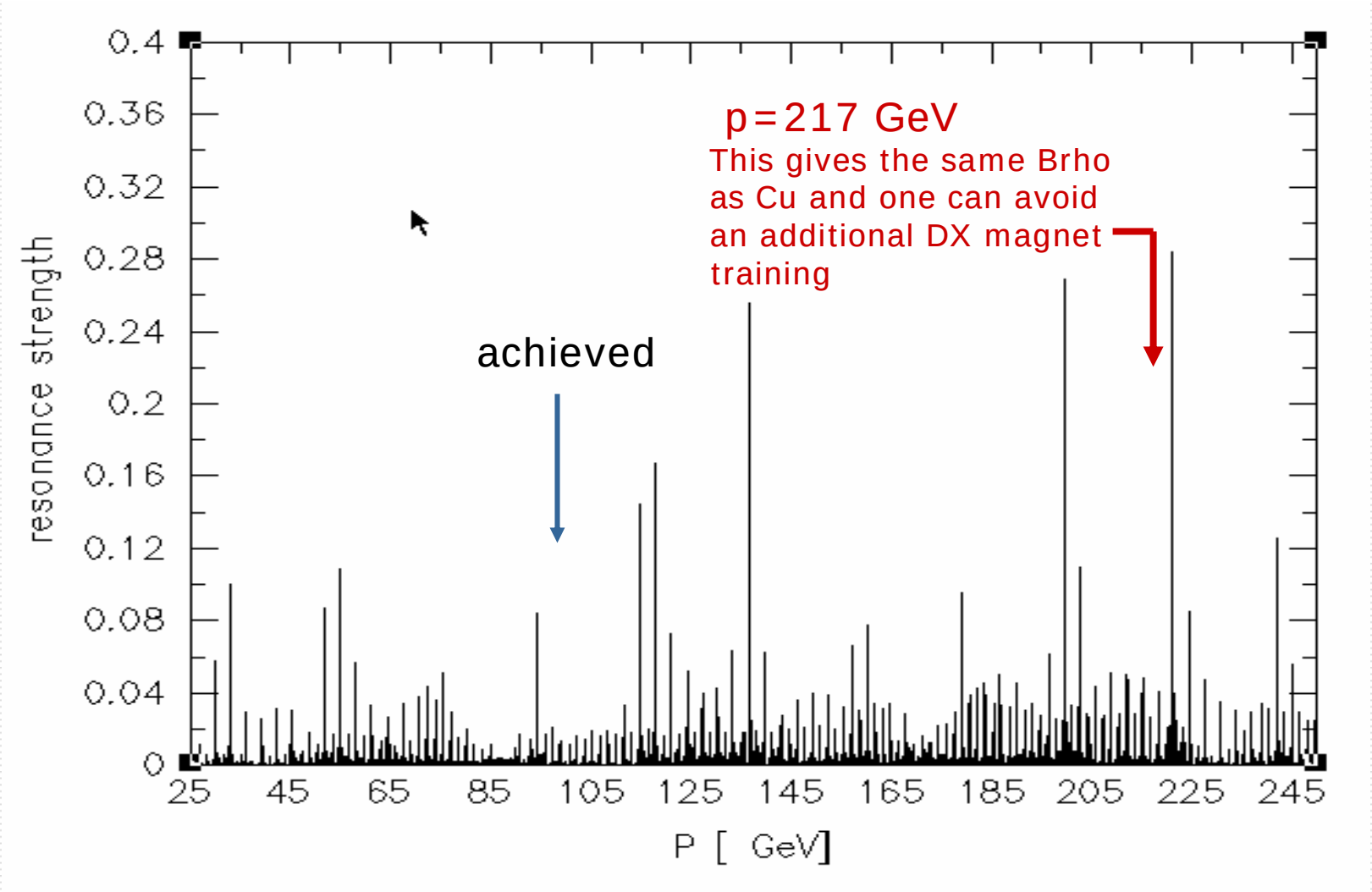


Figure 5.3: Vertical component of the polarization after acceleration through a strong intrinsic resonance and a moderate imperfection resonance shown as a function of the vertical betatron tune.

See V. Ptitsyn's talk

RHIC Intrinsic spin resonance spectrum



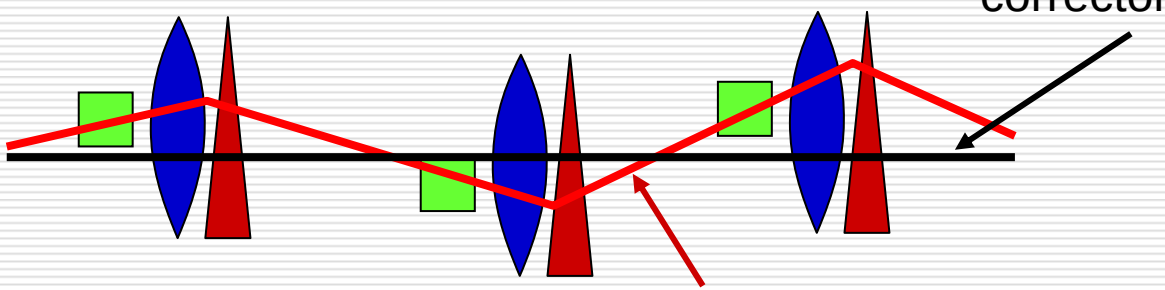
Solution I: precise orbit control

Details in V. Ptitsyn's talk

Flat orbit:

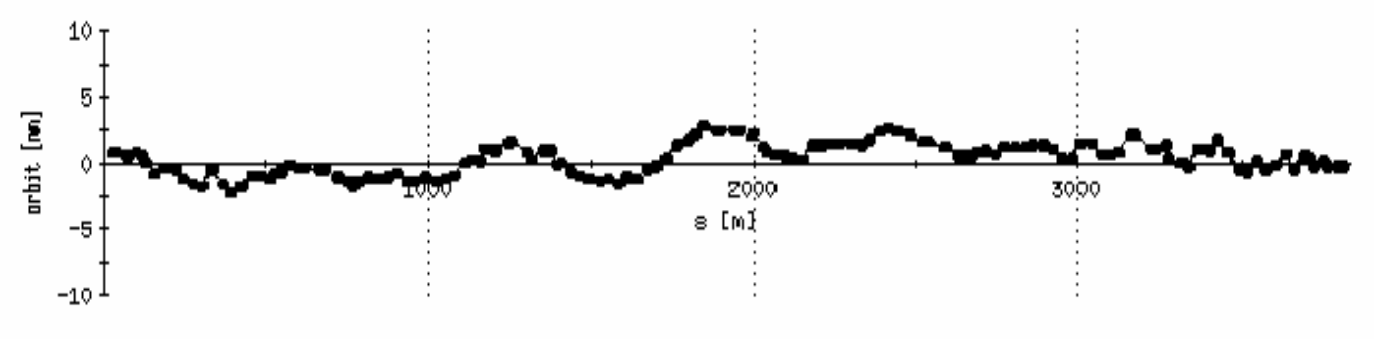
Sum of kicks on the spin vector from quads as well as the dipole correctors = 0

Goal: rms orbit distortion < 0.3mm

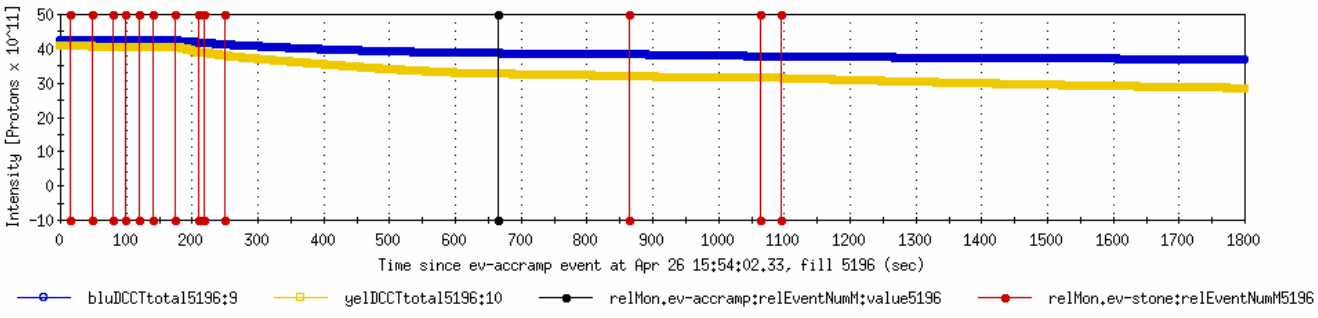


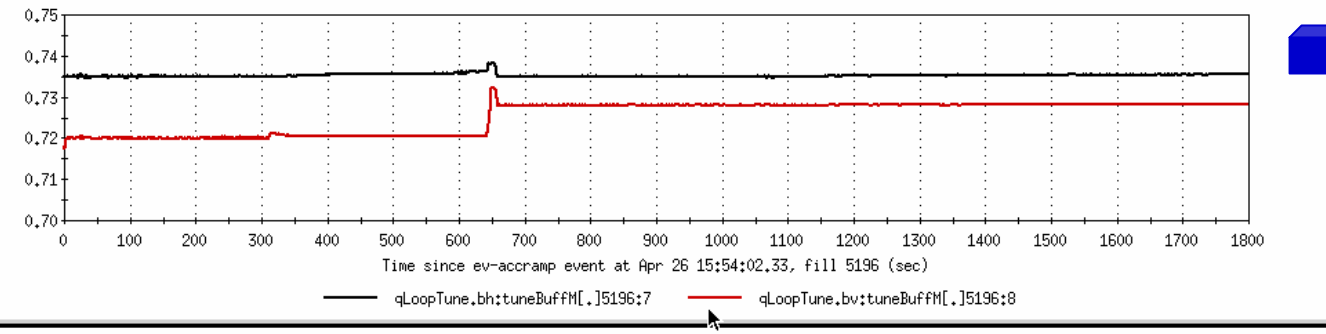
Orbit through the center of bpms

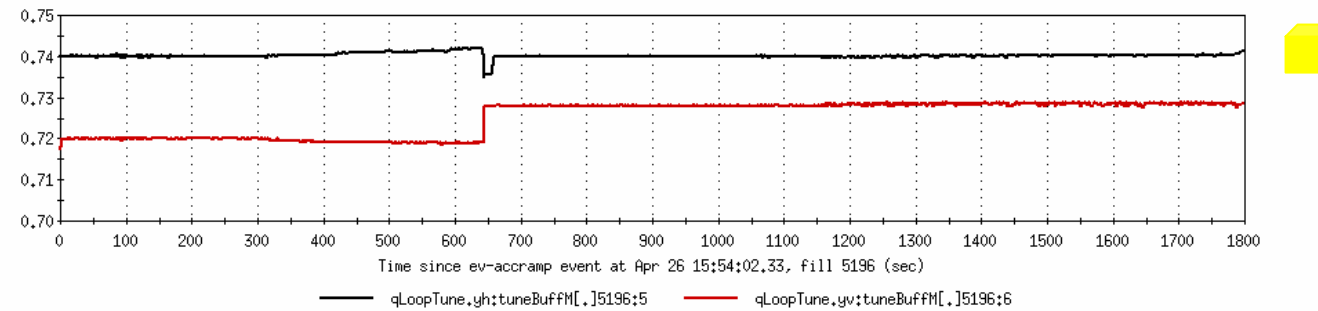
golden orbit using the latest survey



Solution 2: precise tune control







The tune feedback system has been demonstrated during the RHIC PP FY04 Run

RHIC Plan for Reaching the Machine Goal

- During the summer shut-down
  - Resurvey and re-alignment of IP12
  - BPM system upgrade
- Plan for Machine development
  - Polarimeter development: H. Huang's talks
  - Spin tune measurement: H. Huang's talks
    - This will allow us to check the snake current settings at top energy
  - **Explore pp acceleration beyond 100 GeV towards 250 GeV**

If time permits

  - Spin flipping commissioning
  - Establish injection with both snake and spin rotators on at full field
    - This will allow us to save ~7 minutes per store.

Summary

- Source performance: measured at the end of LINAC
  - Achieved: Average polarization 80% with 3~5x10^{11} protons per pulse
  - Expect: Average polarization 85% with >5x10^{11} protons per pulse
- AGS performance: 50% polarization with 0.7~1.0x10^{11} bunch intensity
- RHIC performance: 40~45% polarization with average 1 pb^{-1}/week luminosity

FY05	survey and realignment IP12 BPM(Beam Position Monitor) system uprade AGS cold snake commissioning NEG coating 250m warm beam pipes acceleration beyond 100 GeV better solenoid for the polarized proton source OPPIS
FY06	realignment more areas AGS cold snake operational more NEG coating more luminosity improvement