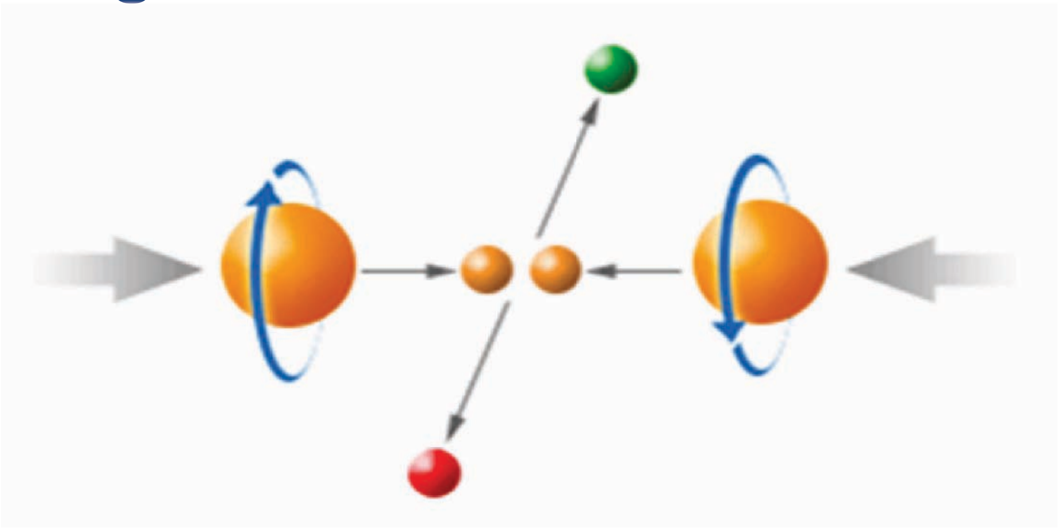
Accelerating Polarized Protons to 250 GeV



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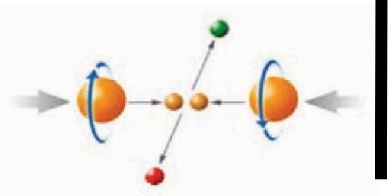
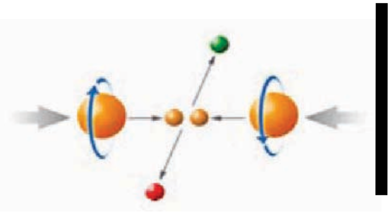


Outline

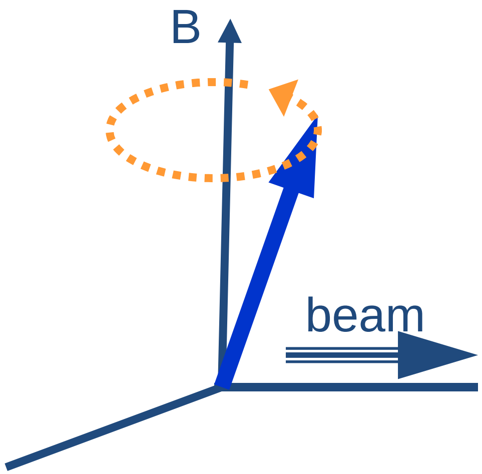
- ❖ Introduction of spin dynamics
- ❖ RHIC polarized proton 250GeV development
- ❖ Conclusion



Spin motion in circular accelerator: Thomas BMT Equation

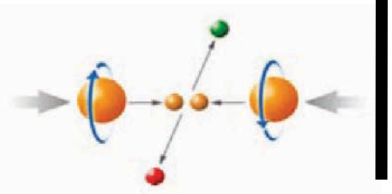
$$\frac{d\vec{S}}{dt} = \vec{\Omega}\times\vec{S} = -\frac{e}{\gamma m}[G\gamma\vec{B}_{\perp} + (1+G)\vec{B}_{//}]\times\vec{S}$$

Spin vector in particle's rest frame



- In a perfect accelerator, spin vector precesses around the bending dipole field direction: vertical
- Spin tune *Qs*: number of precessions in one orbital revolution. In general,

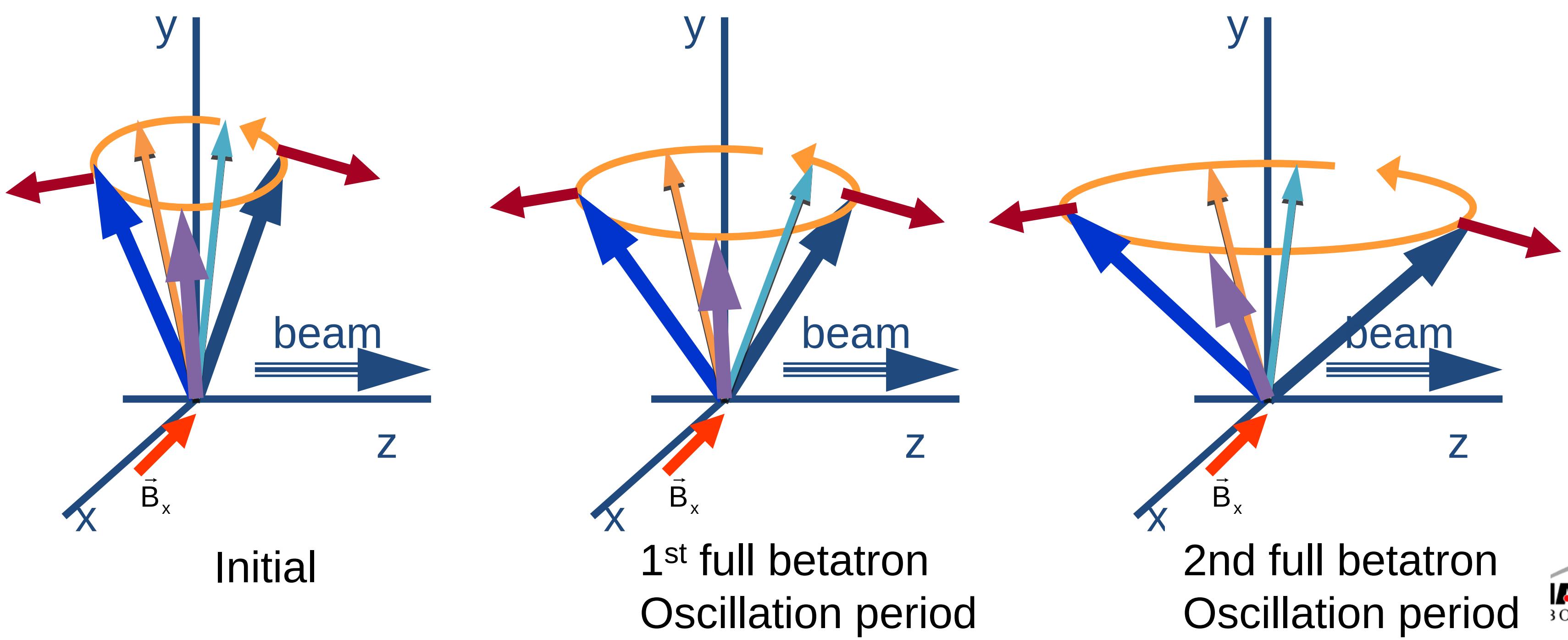
$$Q_s = G\gamma$$

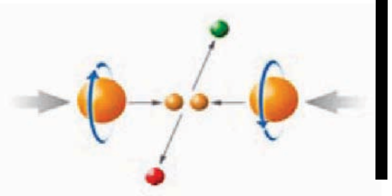


polarized proton acceleration challenges: preserve beam polarization

– Depolarization(polarization loss) mechanism

- Come from the horizontal magnetic field which kicks the spin vector away from its vertical direction
- Spin depolarizing resonance : coherent build-up of perturbations on the spin vector when the spin vector gets kicked at the same frequency as its precession frequency





spin depolarizing resonance

- Imperfection resonance
  - Source: dipole errors, quadrupole mis-alignments
  - Resonance location:

$$G\gamma = k$$

k is an integer

- Intrinsic resonance
  - Source: horizontal focusing field from betatron oscillation
  - Resonance location:

$$G\gamma = kP \pm Qy,$$

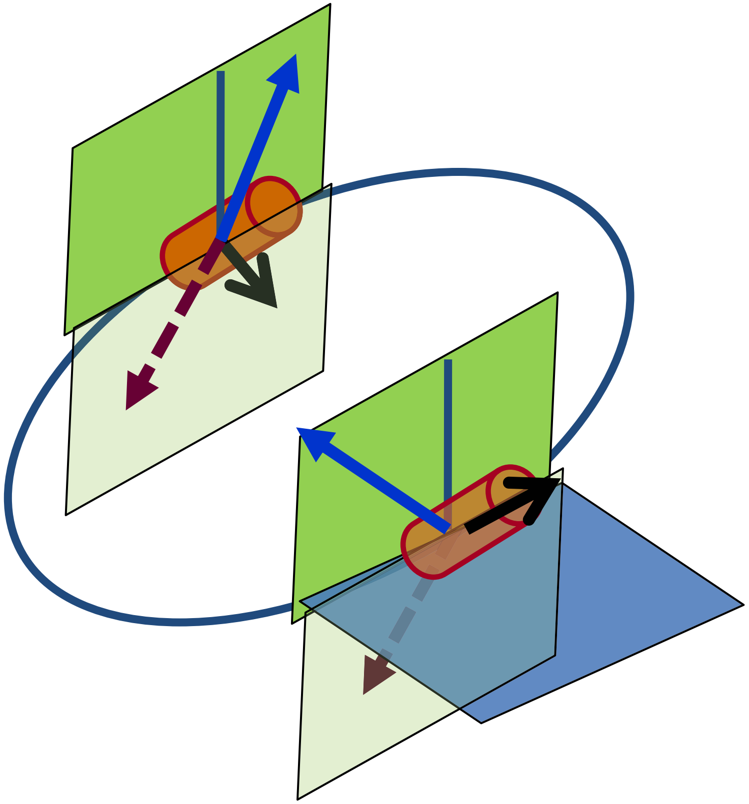
P is the periodicity of the accelerator,

Qy is the vertical betatron tune

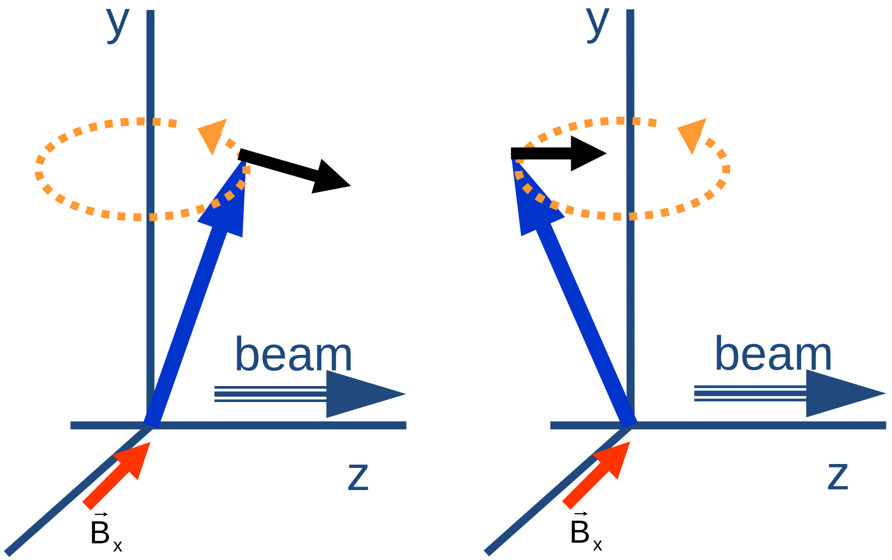
- **For protons, imperfection spin resonances are spaced by 523 MeV**
- **The higher energy, the stronger the depolarizing resonance**

preserve polarization: Siberian snake(s)

- Use one or a group of snakes to make the spin tune to be at ½

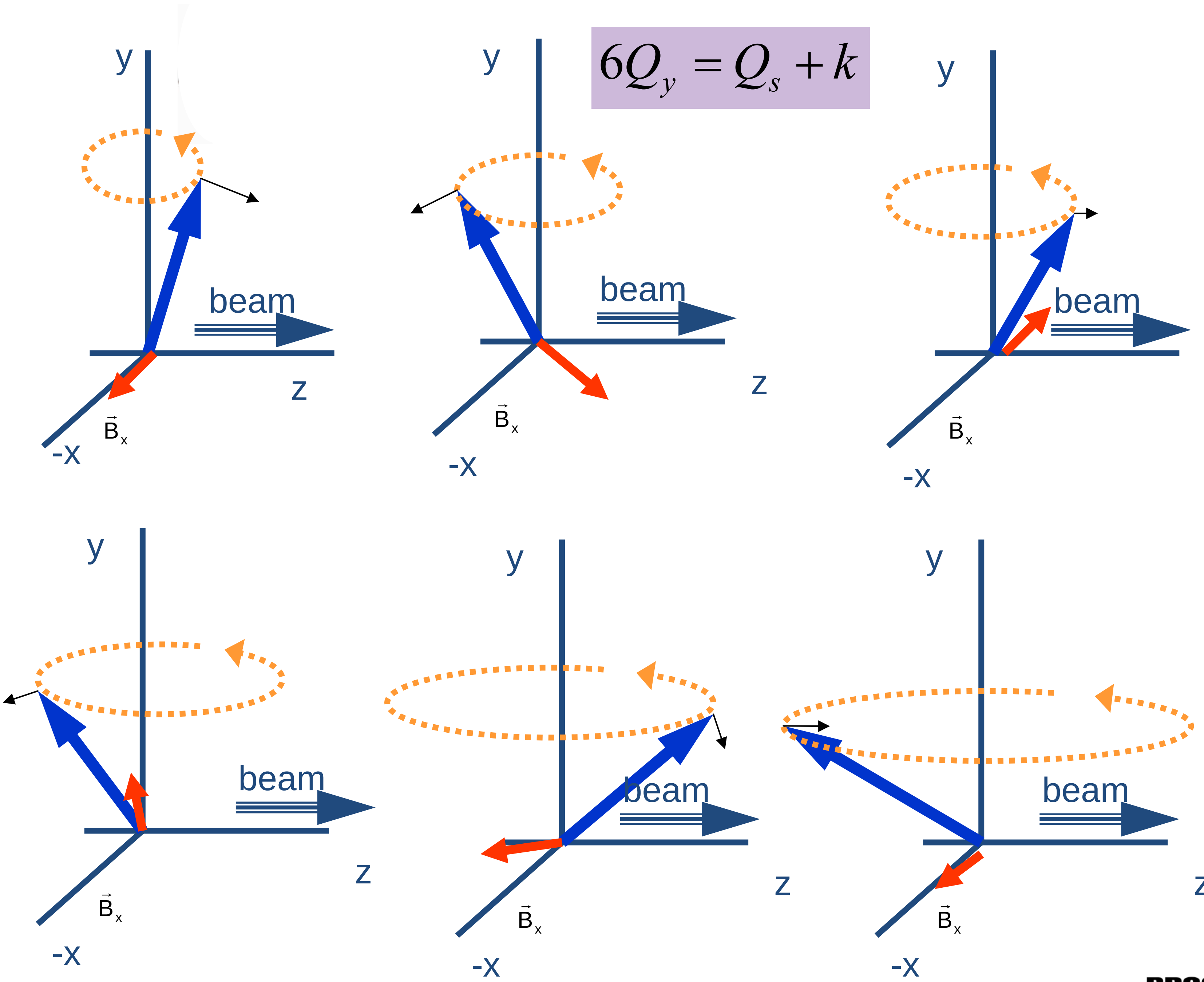


- Break the coherent build-up of the perturbations on the spin vector



However, …

$$6Q_y = Q_s + k$$



y
beam
z
$\vec{B}_x$
-x
y
beam
z
$\vec{B}_x$
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y
beam
z
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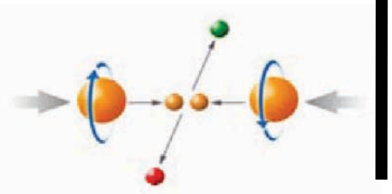
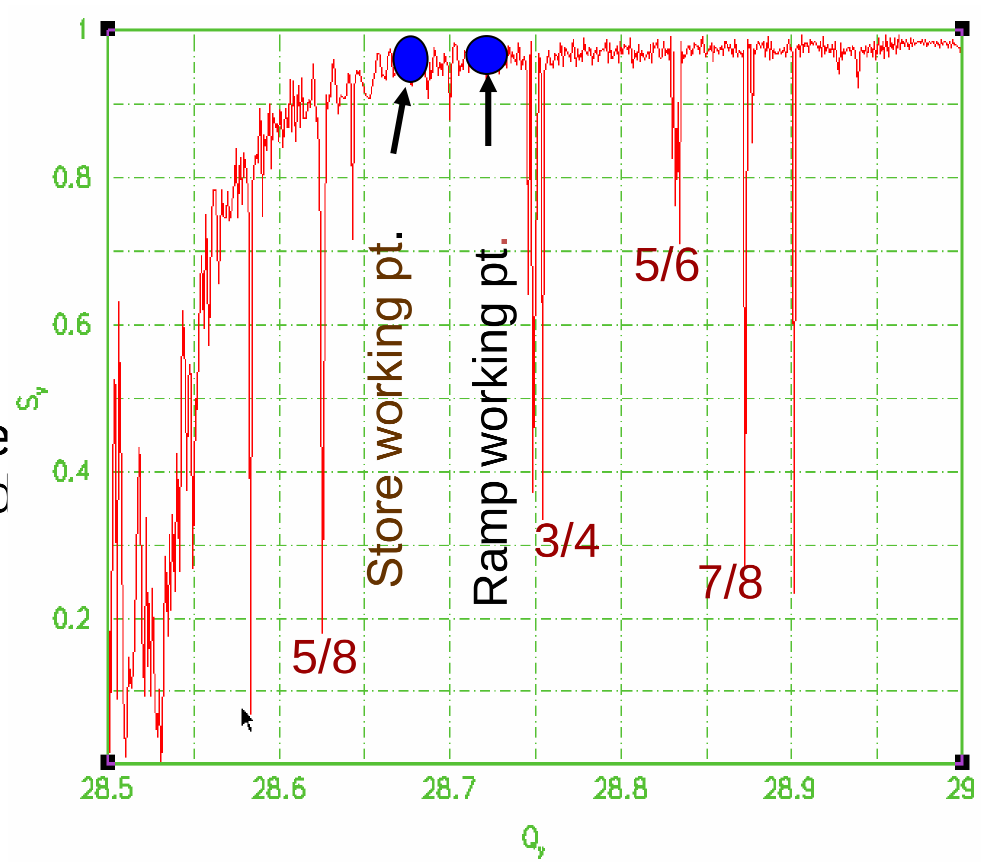


snake depolarization resonance

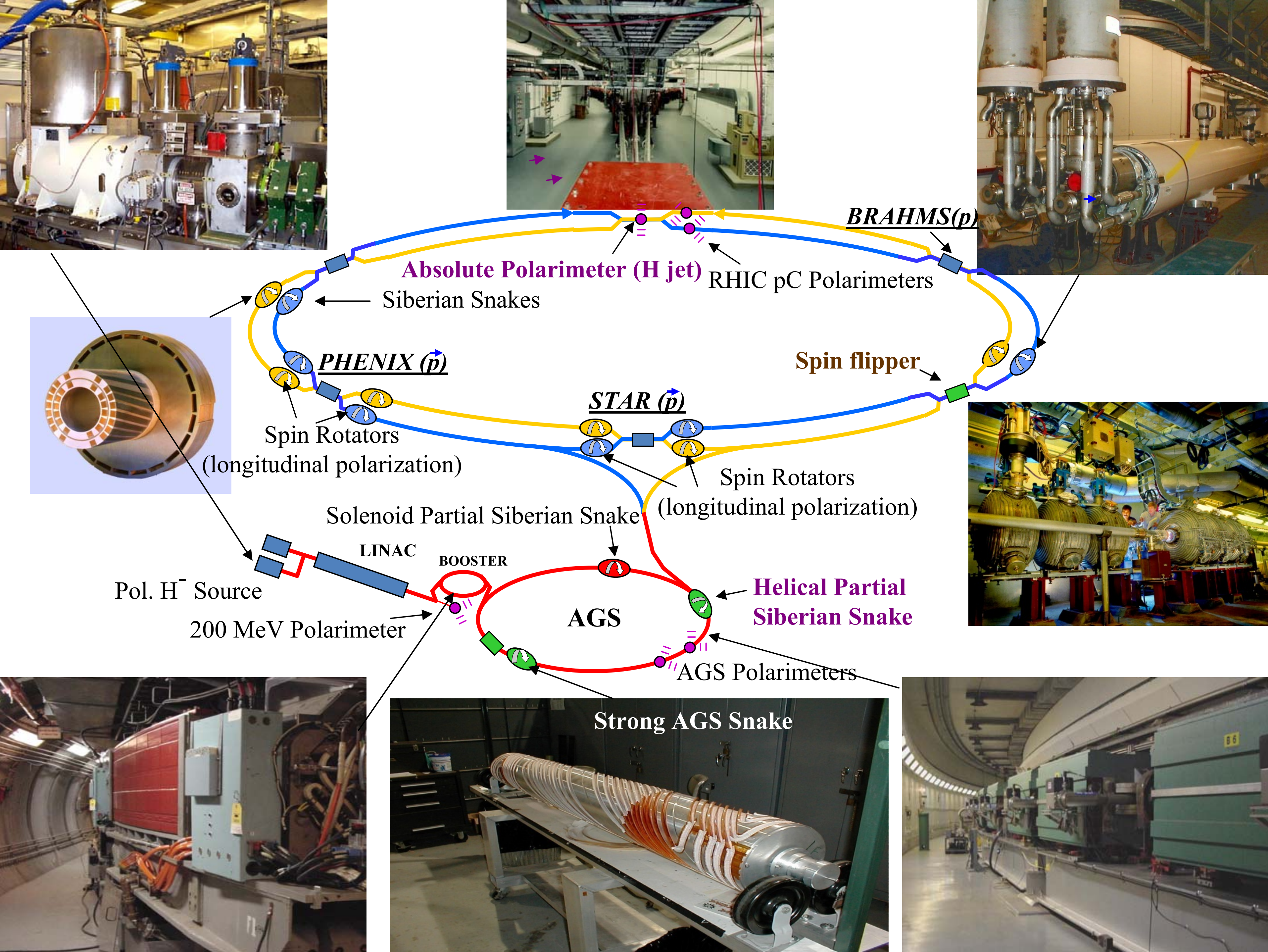
- Condition

$$mQ_y = Q_s + k$$

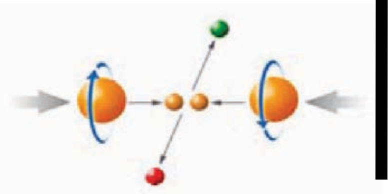
- even order resonance
  - When m is an even number
  - Disappears in the two snake case like RHIC if the closed orbit is perfect
- odd order resonance
  - When m is an odd number
  - Driven by the intrinsic spin resonances



Accelerate RHIC polarized protons to 250 GeV



BRAHMS(p)
Absolute Polarimeter (H jet)
RHIC pC Polarimeters
Siberian Snakes
PHENIX (p)
Spin flipper
STAR (p)
Spin Rotators
(longitudinal polarization)
Spin Rotators
(longitudinal polarization)
Solenoid Partial Siberian Snake
LINAC
BOOSTER
Pol. H⁻ Source
200 MeV Polarimeter
AGS
Helical Partial
Siberian Snake
AGS Polarimeters
Strong AGS Snake



RHIC pp design parameter

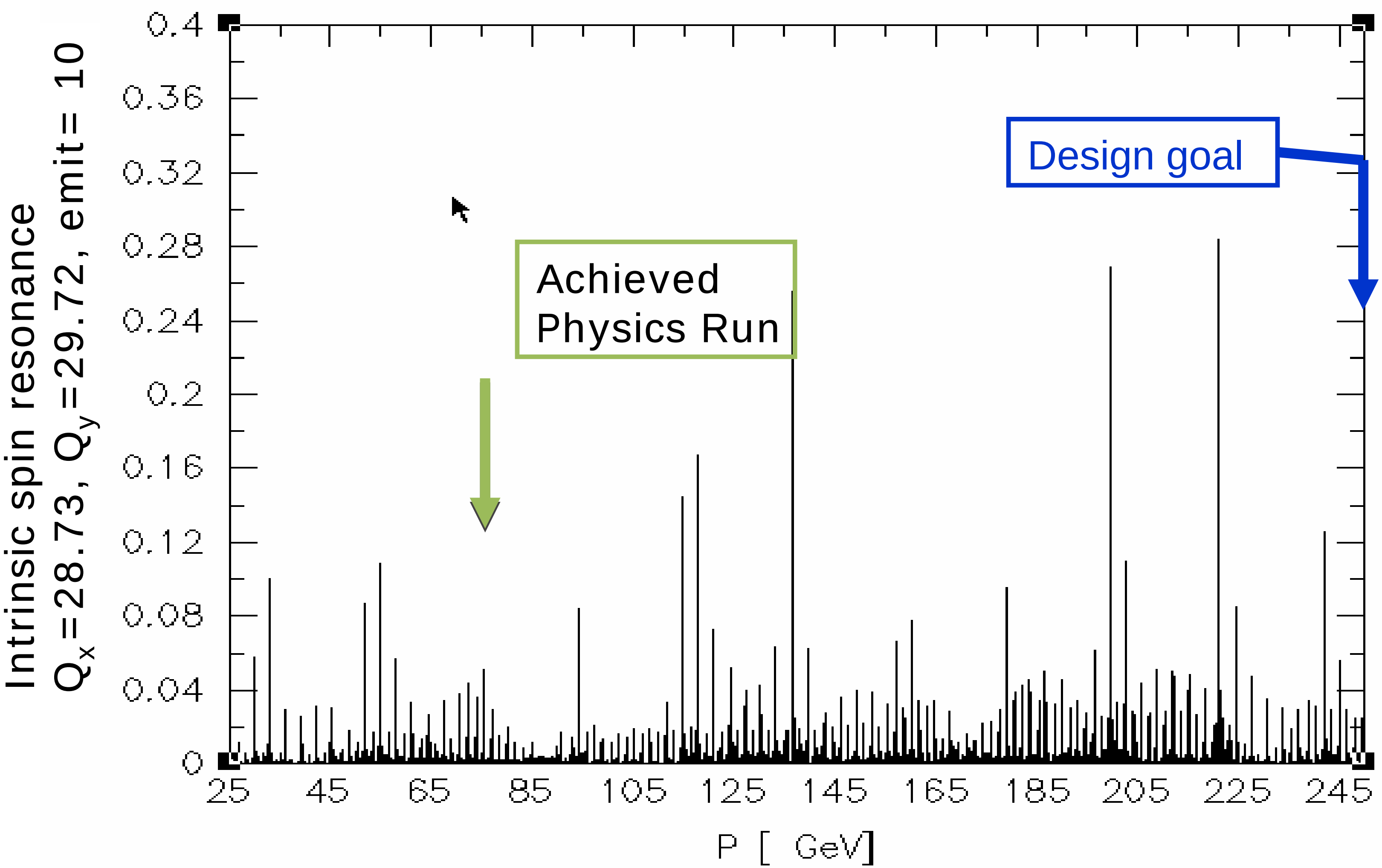
Achieved performance for physics runs

Parameter	Unit	p-p	p-p
relativistic γ, injection	…	25.9	25.9
relativistic γ, store	…	266.5	106.6
no of bunches, n_b	…	112	111
ions per bunch, N_b	10^{11}	2.0	1.3
emittance $e_{N\ x,y\ 95\%}$	mm-mrad	20	20
average luminosity	$10^{30}\ cm^{-2}s^{-1}$	150	20
polarization,store	%	70	60~65

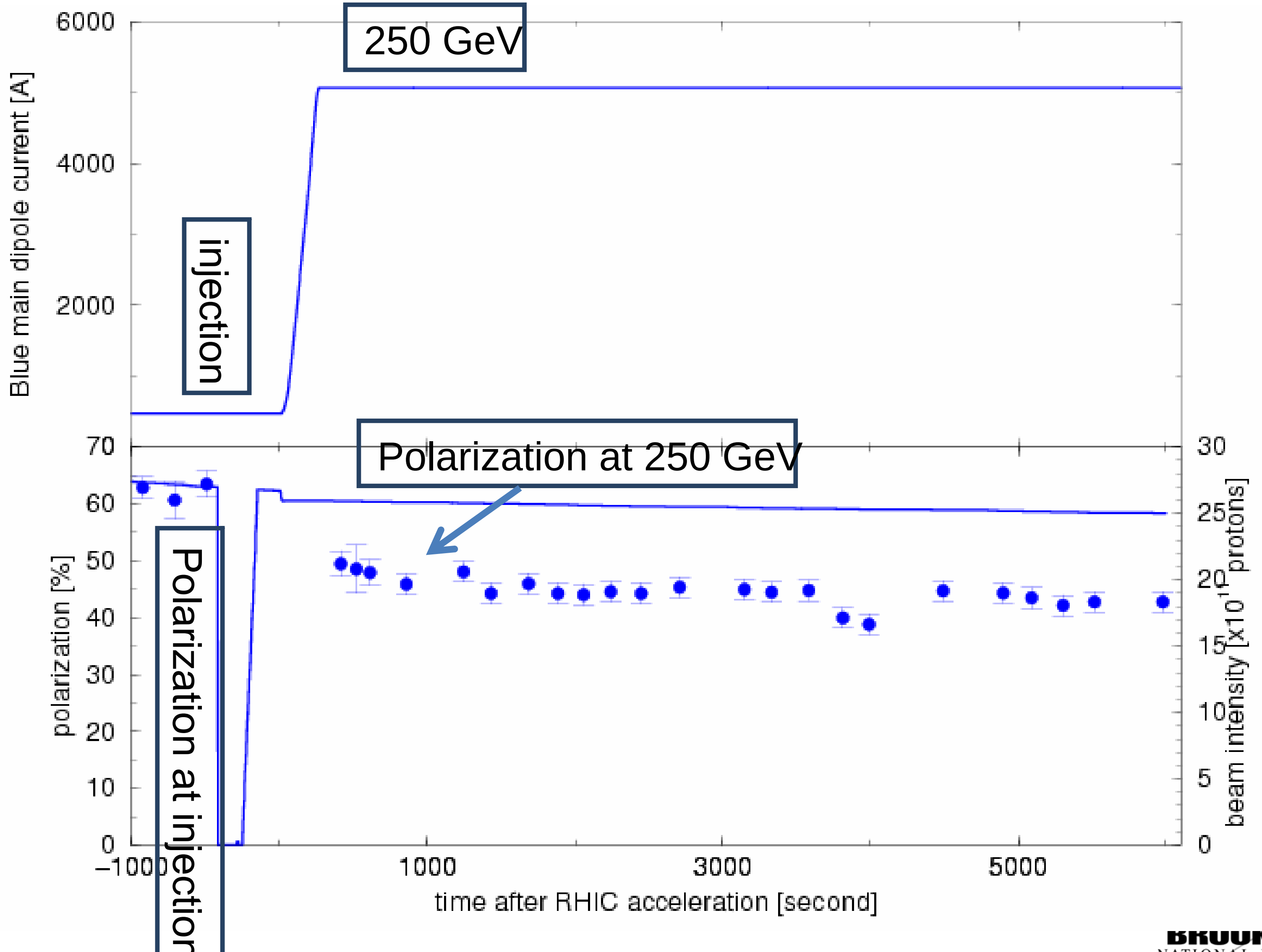
Preserving Polarization in RHIC

- Optimize the snake setting to have spin tune at 1/2
- Precise vertical closed orbit control
  - Minimize the vertical closed orbit distortion to reduce the strength of even order snake resonances
- Precise optics control
  - Minimize the linear coupling
  - Keep both horizontal and vertical tune with the window where no harmful snake resonances
- Avoid store the beam at an energy nearby a strong intrinsic spin resonance

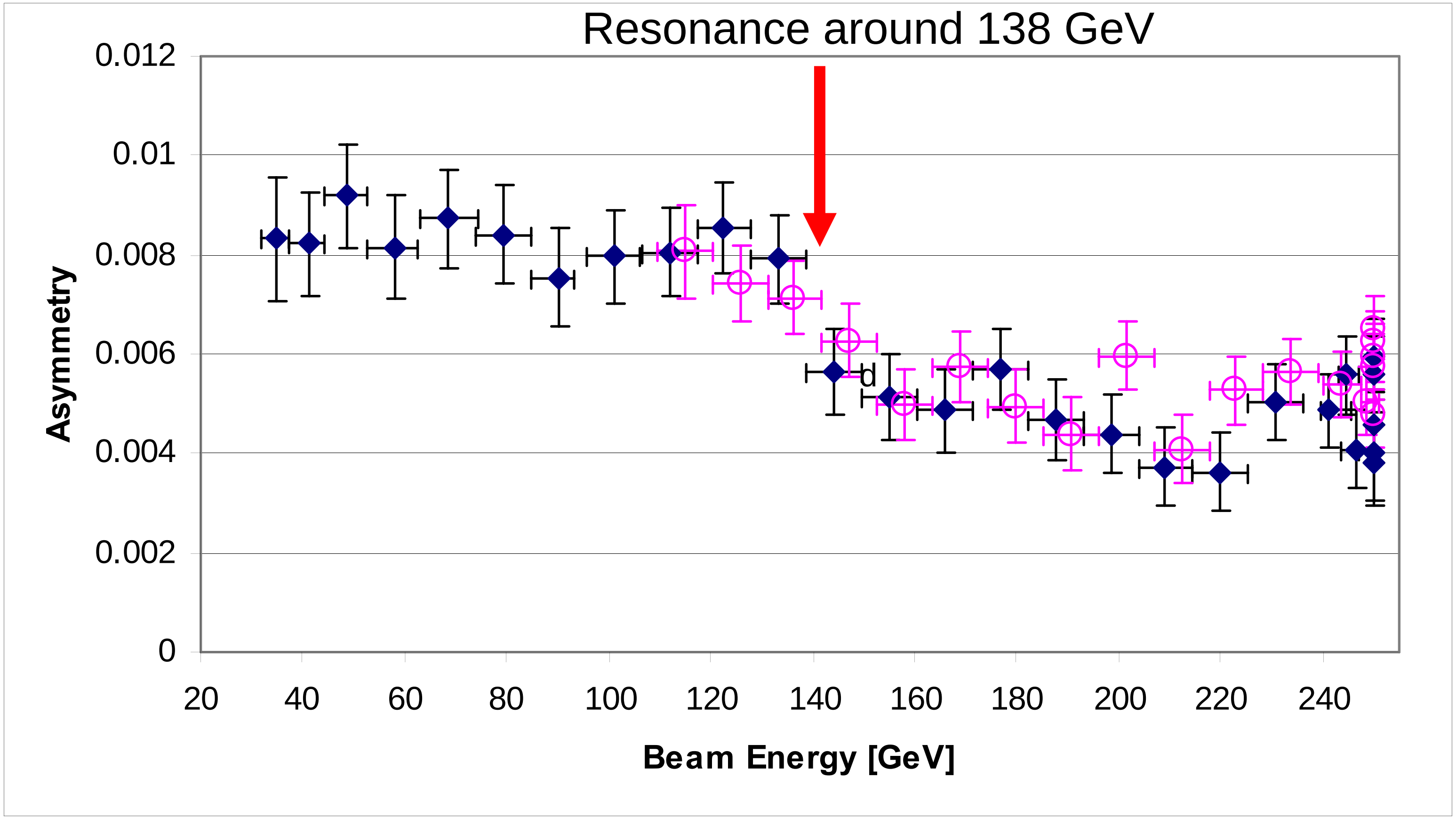
RHIC intrinsic resonance spectrum



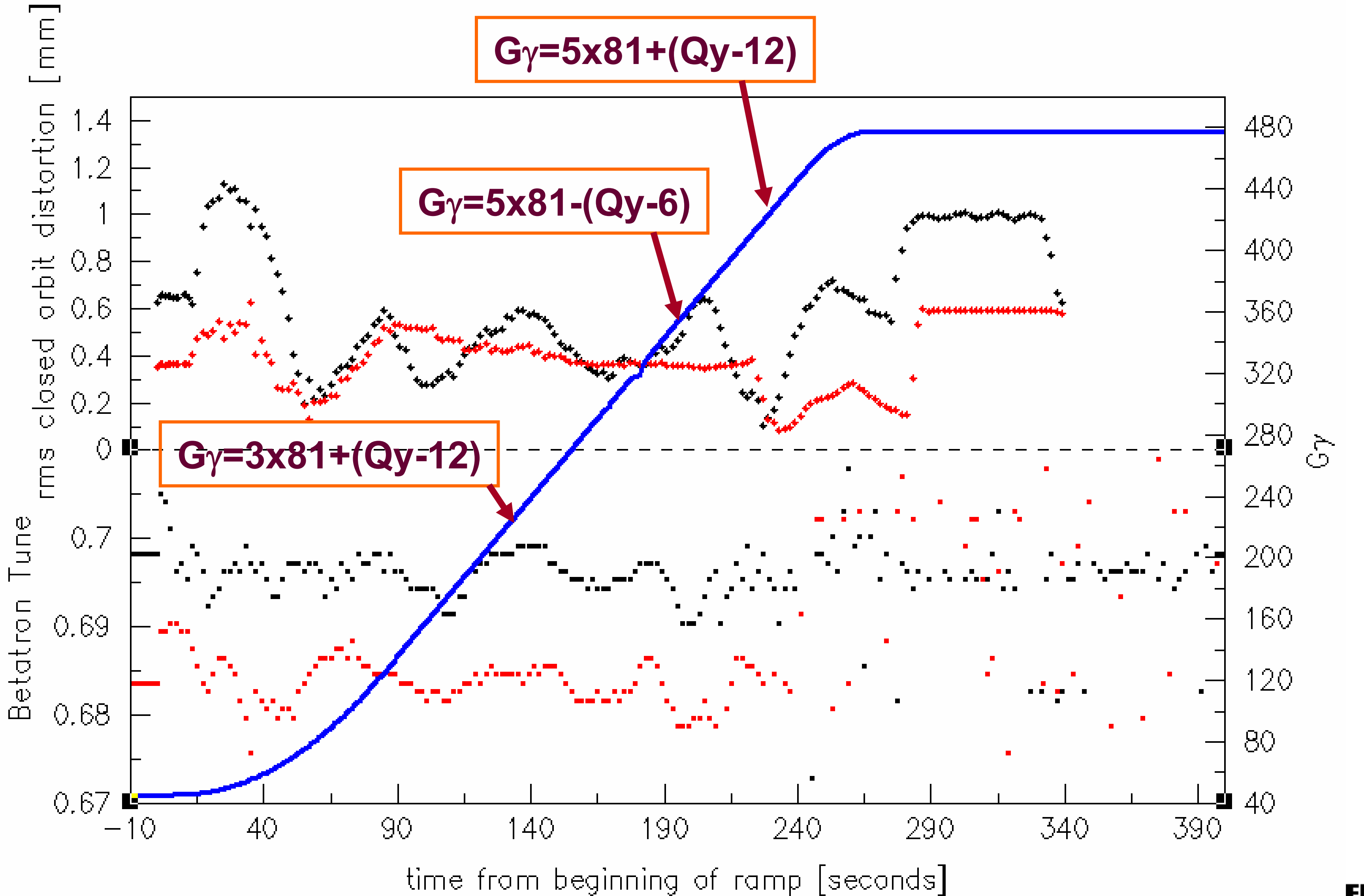
Polarized proton at 250 GeV



RHIC pp polarization ramp measurement



Orbit/Tunes during the 250 GeV acceleration



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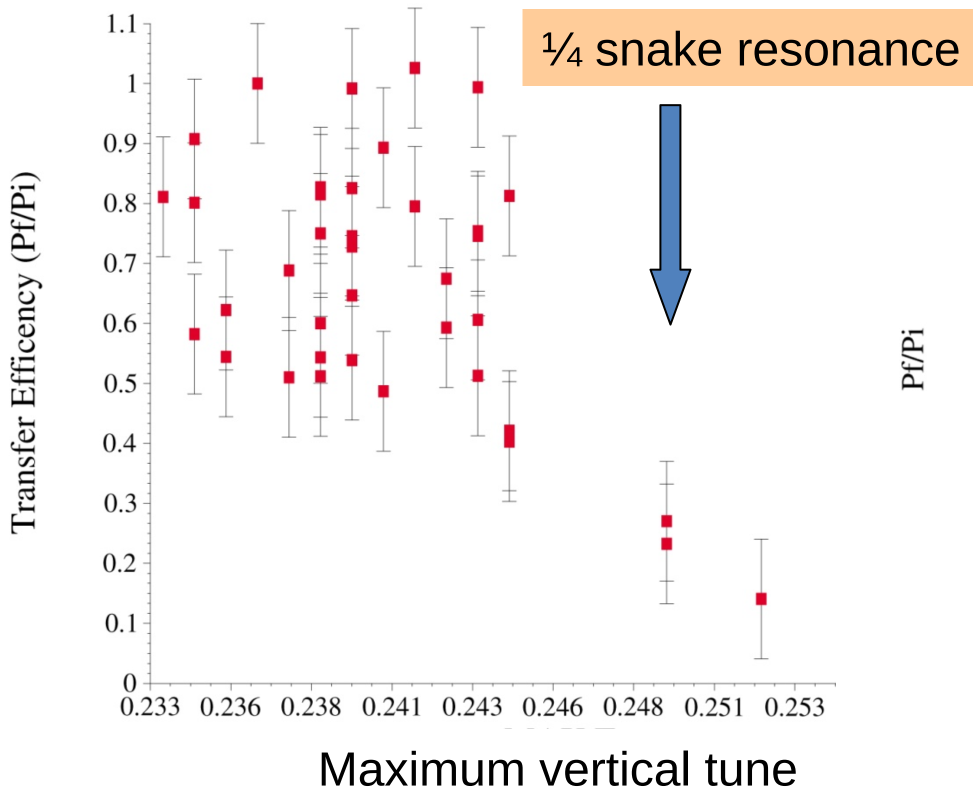
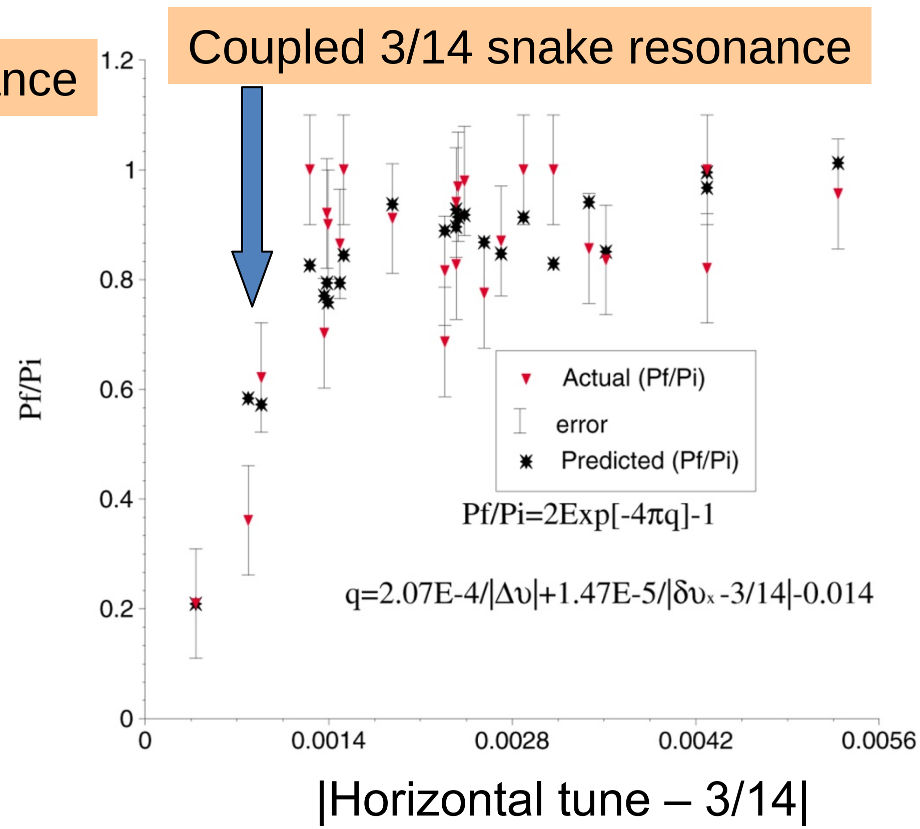
Snake resonance observed in RHIC





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Conclusion

- RHIC has achieved 100% polarization transmission efficiency at 100 GeV
- The first effort of accelerating polarized proton beam to 250 GeV yields a polarization of 46%
- The polarization as a function of beam energy during the acceleration shows the polarization loss at beam energy of 136 GeV, a strong resonance at $G\gamma=3\text{x}81+(Qy-12)$
- More time will be need to explore the polarization loss as a function of the betatron tune and orbit distortion at the three strong resonances.

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