Polarized Proton at RHIC: Status and Future Plan

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Outline

- Introduction
  - What's involved in accelerating polarized proton?
  - RHIC polarized proton setup
- Achieved performance
  - Polarization
  - Luminosity
- Plans for improvement
- Summary

Spin motion in a 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

Magnetic field along the direction of the particle's velocity

Magnetic field perpendicular to the particle's velocity

- G is the anomoulous g- factor, for proton,
  G=1.7928474
- γ: Lorenz factor

Spin tune Q_s: number of precessions in one orbital revolution:

$$Q_s = G\gamma$$

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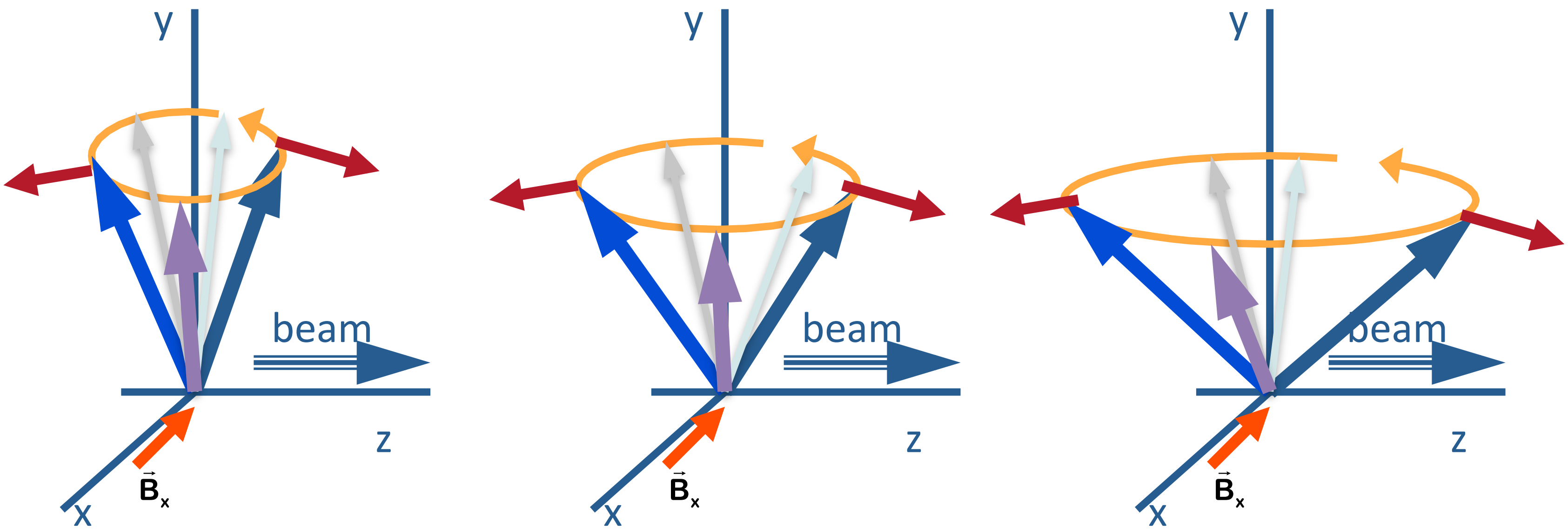
Depolarizing mechanism in a synchrotron

- **horizontal field kicks the spin vector away from its vertical direction, and can lead to polarization loss**
  - dipole errors, misaligned qadrupoles, imperfect orbits
  - betatron oscillations
  - other multipole magnetic fields
  - other sources



Initial

1st full betatron Oscillation period

2nd full betatron Oscillation period

Depolarizing Resonance

- **Intrinsic resonance: $G\gamma = kP \pm Qy$**
  - focusing field due to the intrinsic betatron oscillation
  - Location: $G\gamma = kP \pm Qy$; P: super periodicity of the accelerator,
    Qy: vertical betatron tune
  - Resonance strength:
    - Proportional to the size of the betatron oscillation

For protons, imperfection spin resonances are spaced by 523 MeV

- **Imperfection resonance:**
  - Source: dipole errors, quadrupole mialignments
  - Resonance location:

    $G\gamma = k$, k is an integer
  - Resonance strength:
    - Proportional to the size of the vertical closed orbit distortion

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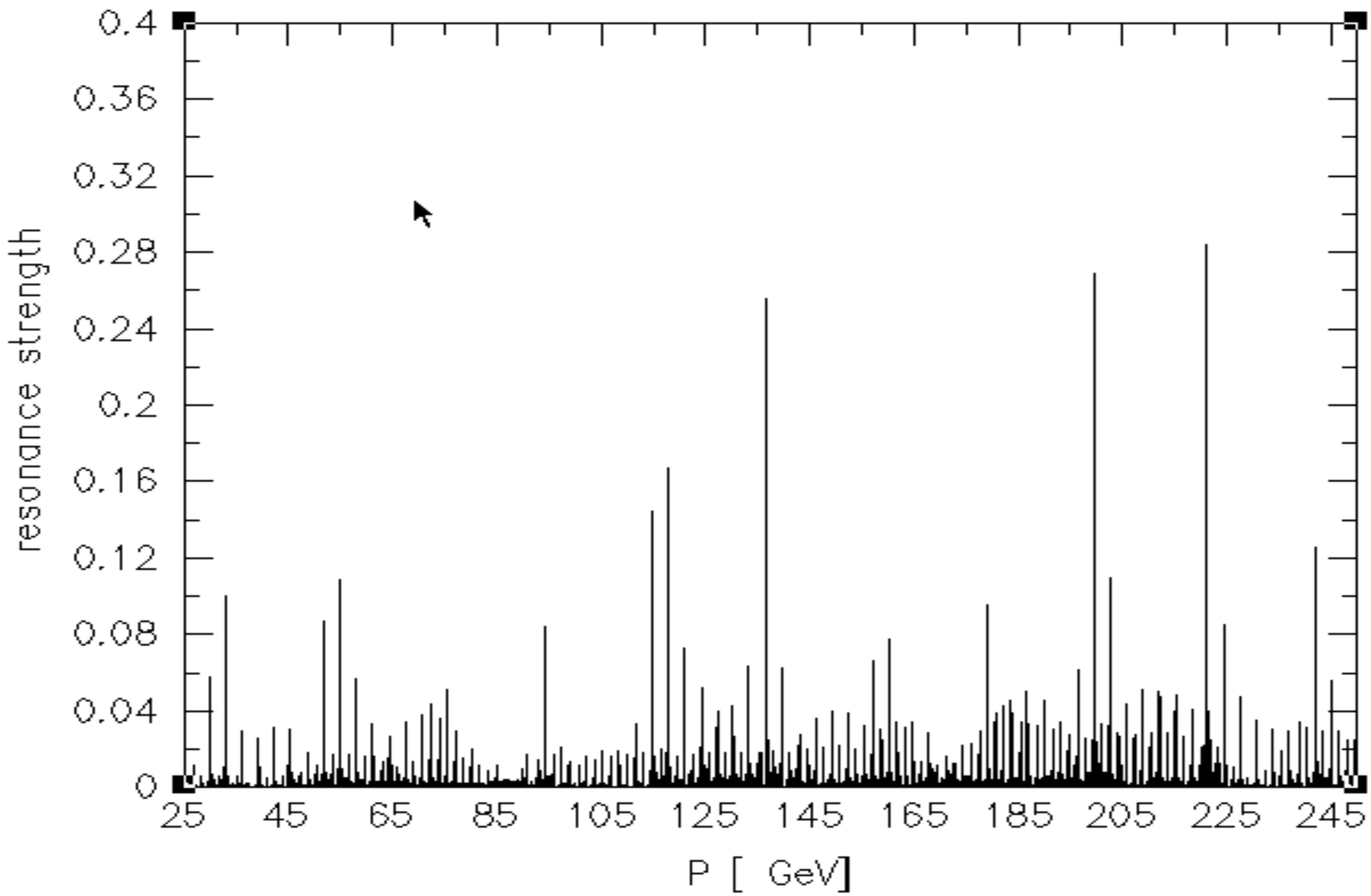
Spin depolarization resonance in RHIC



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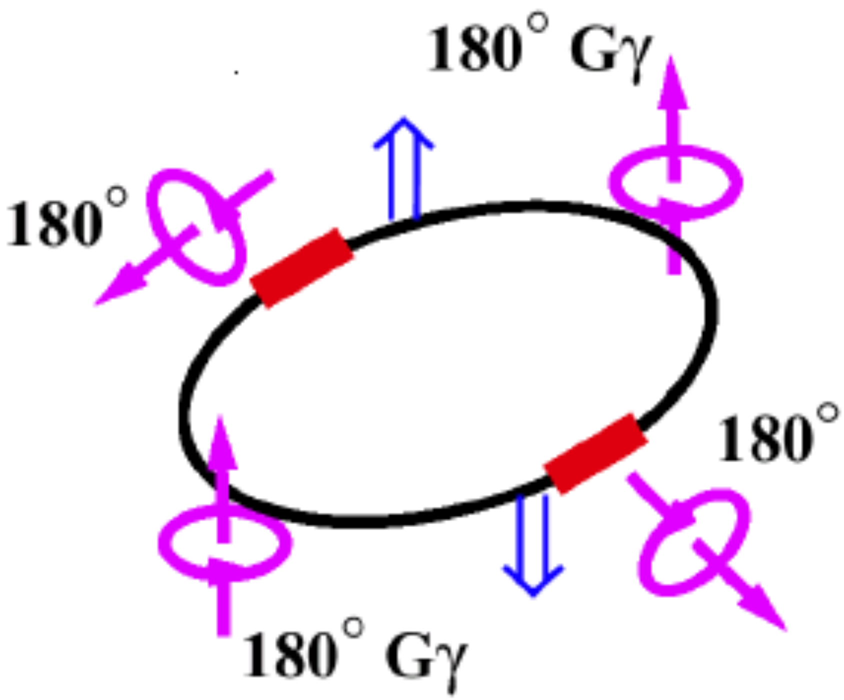
RHIC Polarized Proton Setup

- **Energy: 23.8 GeV ~ 250 GeV (maximum store energy)**
  - A total of 146 imperfection resonances and about 10 strong intrinsic resonances from injection to 100 GeV.
    - ***Two full Siberian snakes***



$$Q_s = \frac{1}{\pi}\left|\varphi_1 - \varphi_2\right|$$

$$\Rightarrow Q_s = \frac{1}{2}$$

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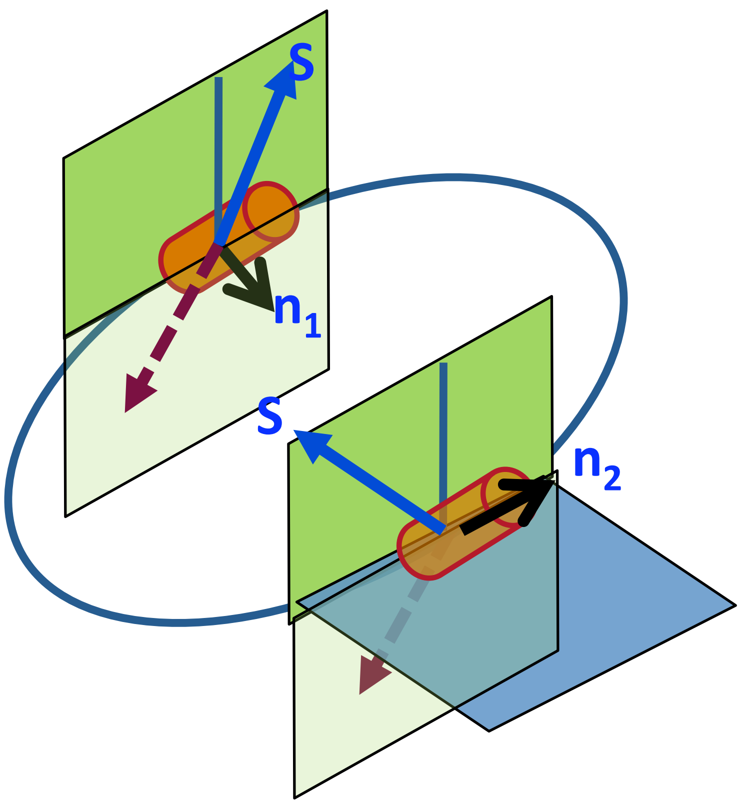
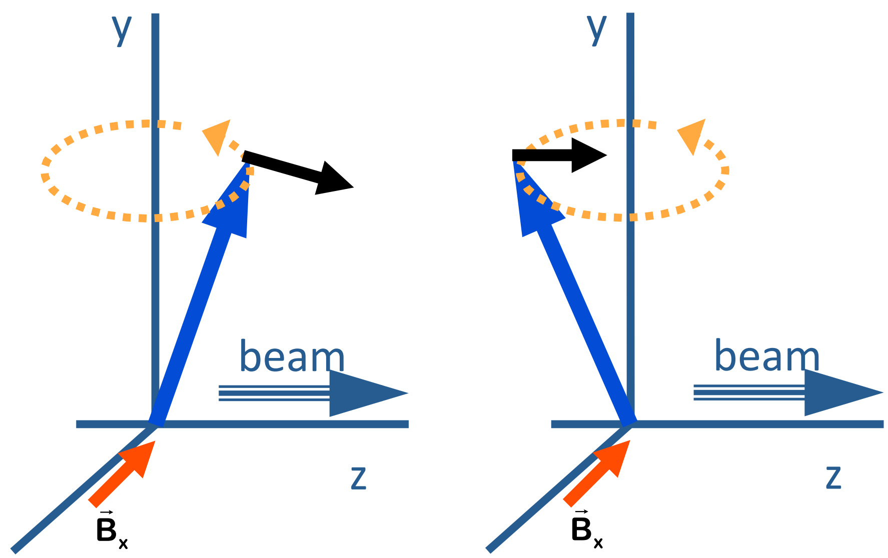
Why dual snake configuration works?

- 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



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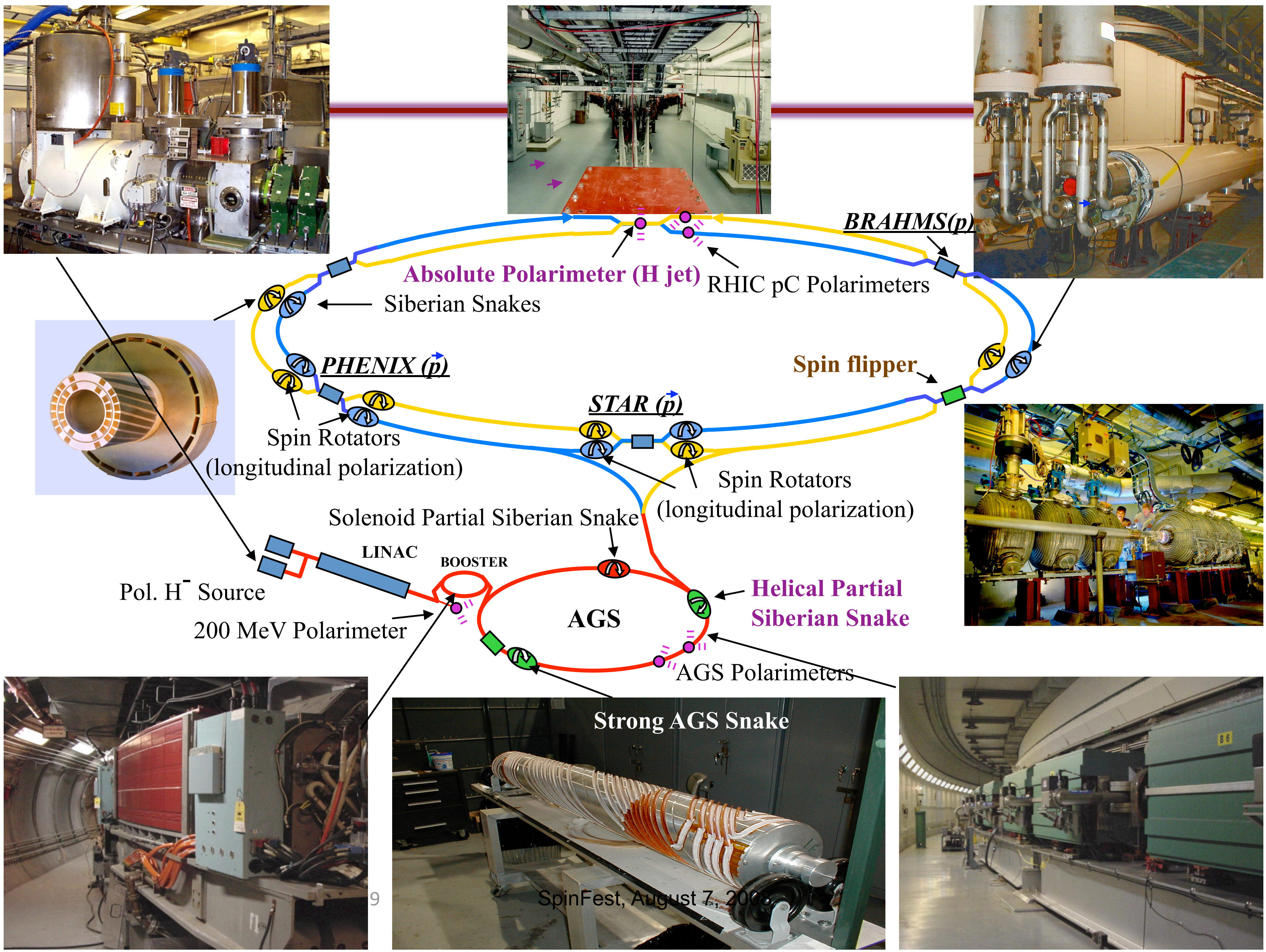
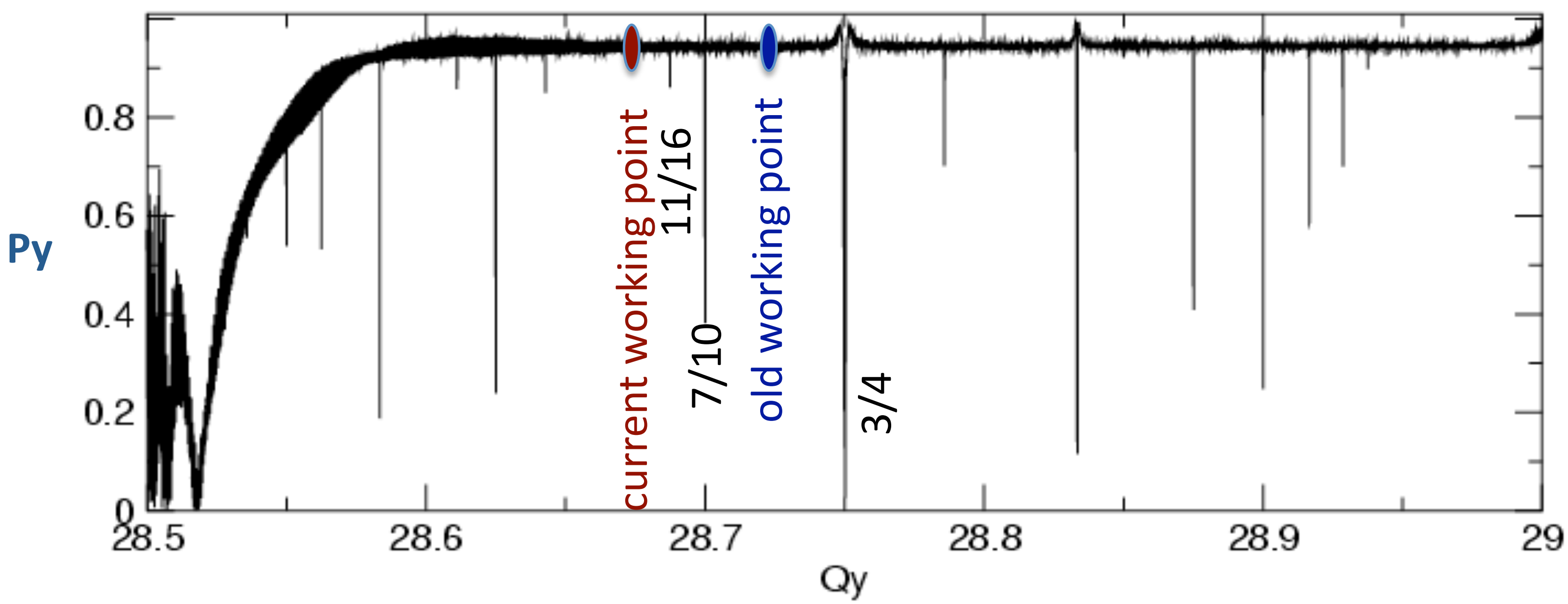

BRAHMS(p)
Absolute Polarimeter (H jet)
RHIC pC Polarimeters
Siberian Snakes
PHENIX (p)
Spin flipper
STAR (p)
Spin Rotators
(longitudinal polarization)
Spin Rotators
(longitudinal polarization)
Solenoid Partial Siberian Snake
LINAC
BOOSTER
Pol. H⁻ Source
200 MeV Polarimeter
AGS
Helical Partial
Siberian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

Snake depolarization resonance

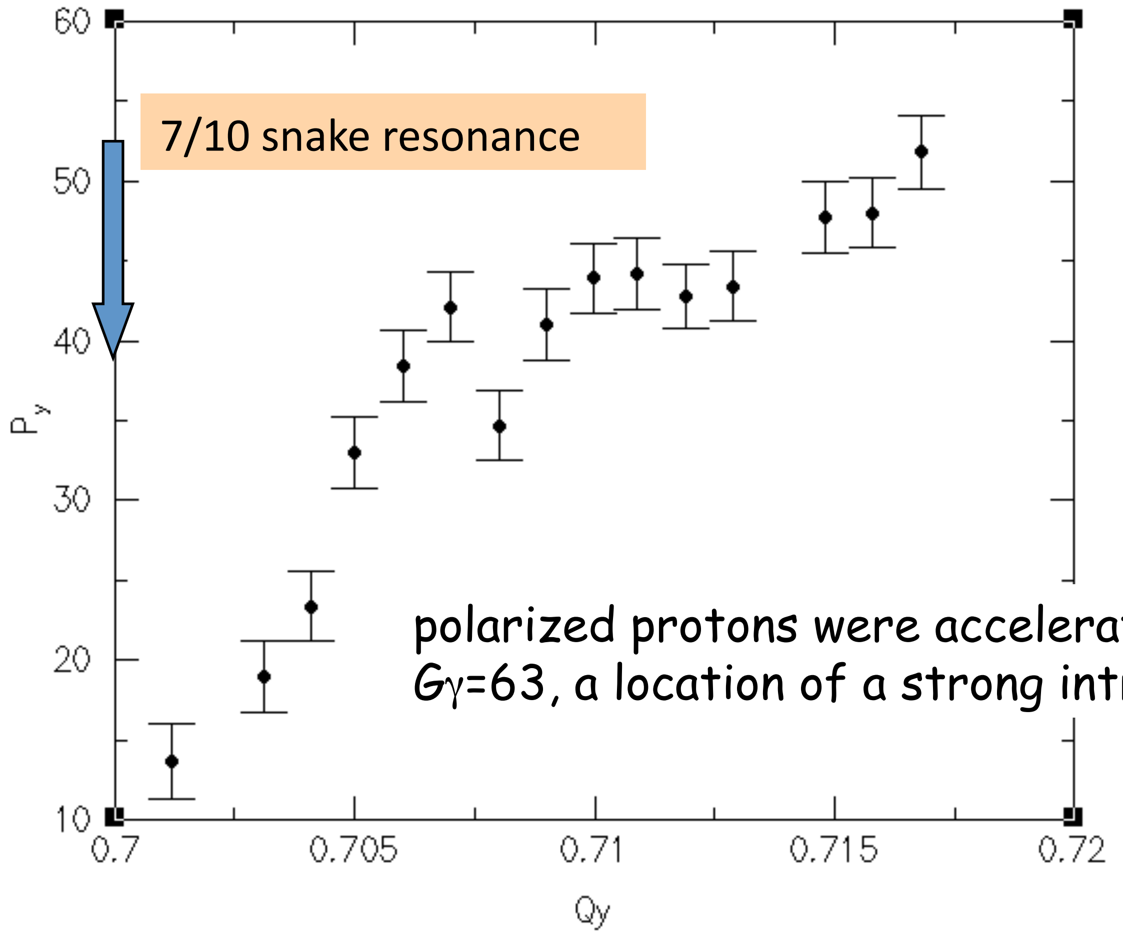
- Condition

$$mQ_y = Q_s + k$$

- even order resonance
  - Disappears in the two snake case if the closed orbit is perfect
- odd order resonance
  - Driven by the intrinsic spin resonances



Snake resonance observed in RHIC



polarized protons were accelerated to an energy of Gγ=63, a location of a strong intrinsic spin resonance

How to avoid a snake resonance

- ❑ Keep spin tune as close to 0.5 as possible
  - Snake current setting
  - Minimize horizontal orbital angle between two snakes
- ❑ Precise control of the vertical closed orbit
  - Minimize the vertical closed orbit distortion to reduce the strength of even order snake resonances
- ❑ Precise optics control
  - Proper working point at a location with no or negligible snake resonances
  - Minimize the linear coupling to avoid the resonance due to horizontal betatron oscillation
  - Minimize tune spread
    - Chromatic effect
    - Non-linear effects

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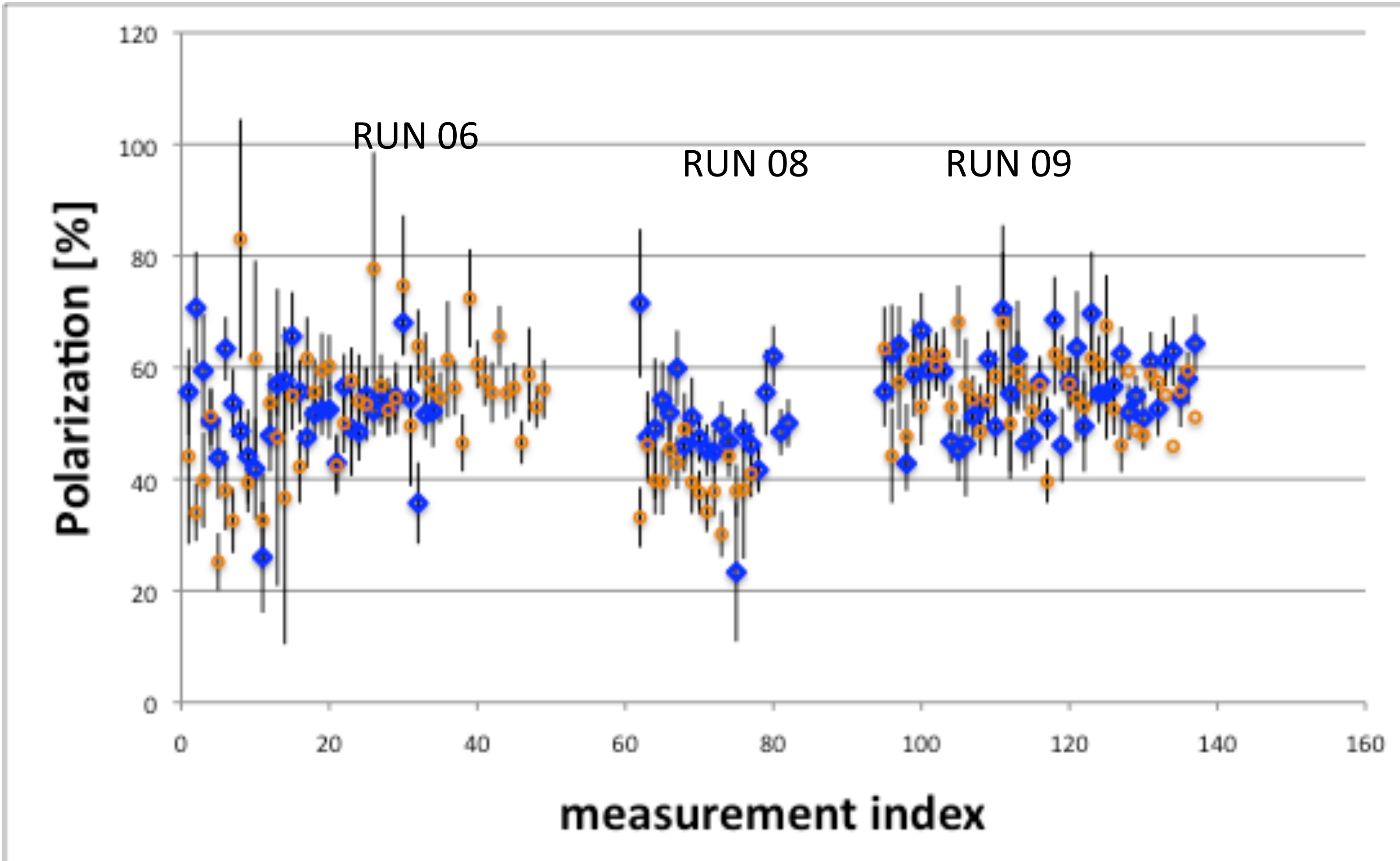
Polarization Performance: 100 GeV

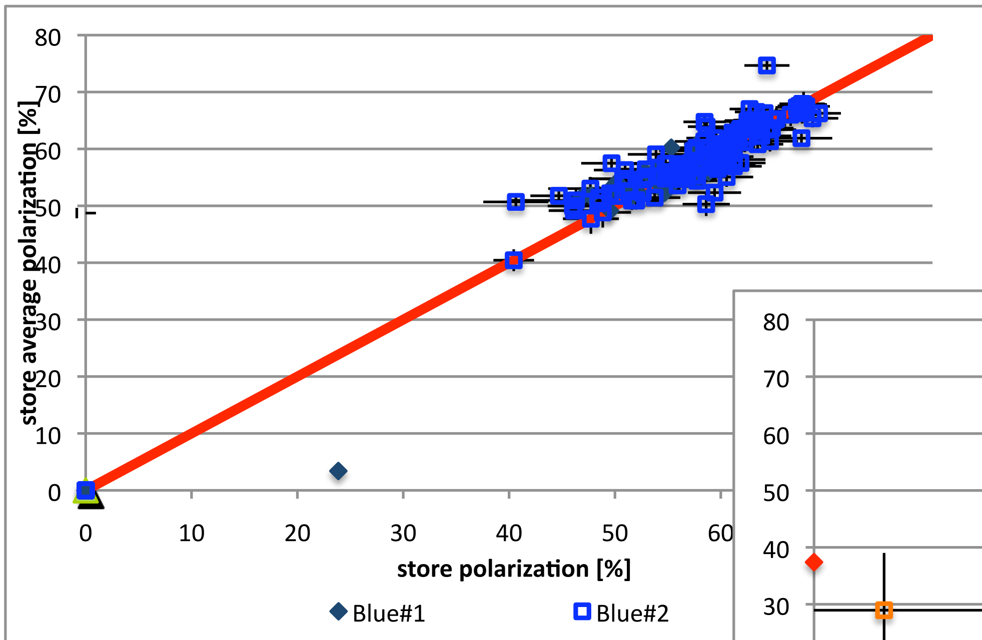
- Polarization transmission efficiency
  - negligible polarization loss during acceleration

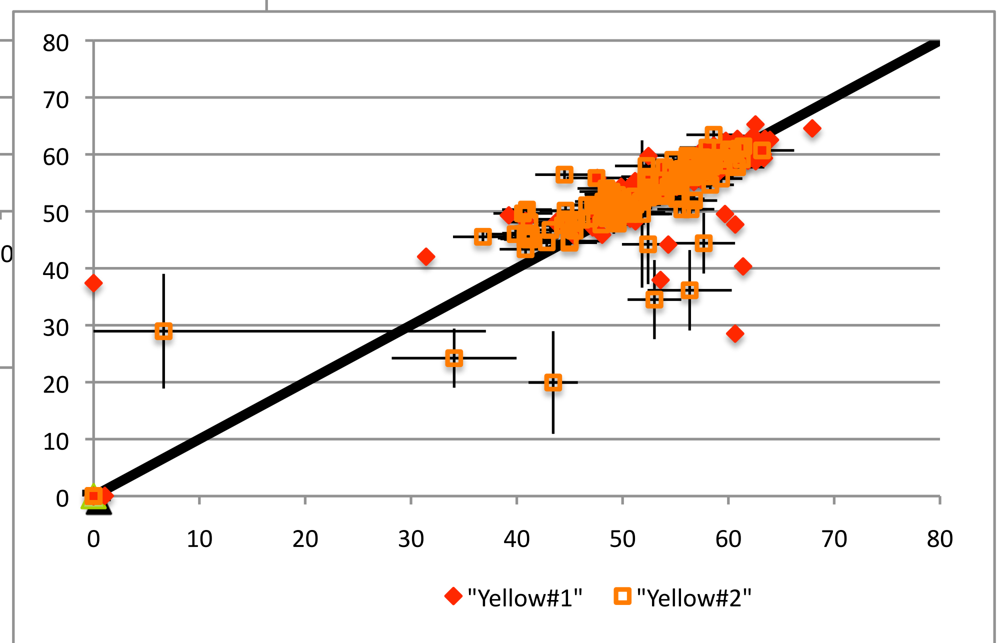


Polarization Performance: 100 GeV

❑ Polarization lifetime during store

- No deterioration during store w/w.o spin rotator





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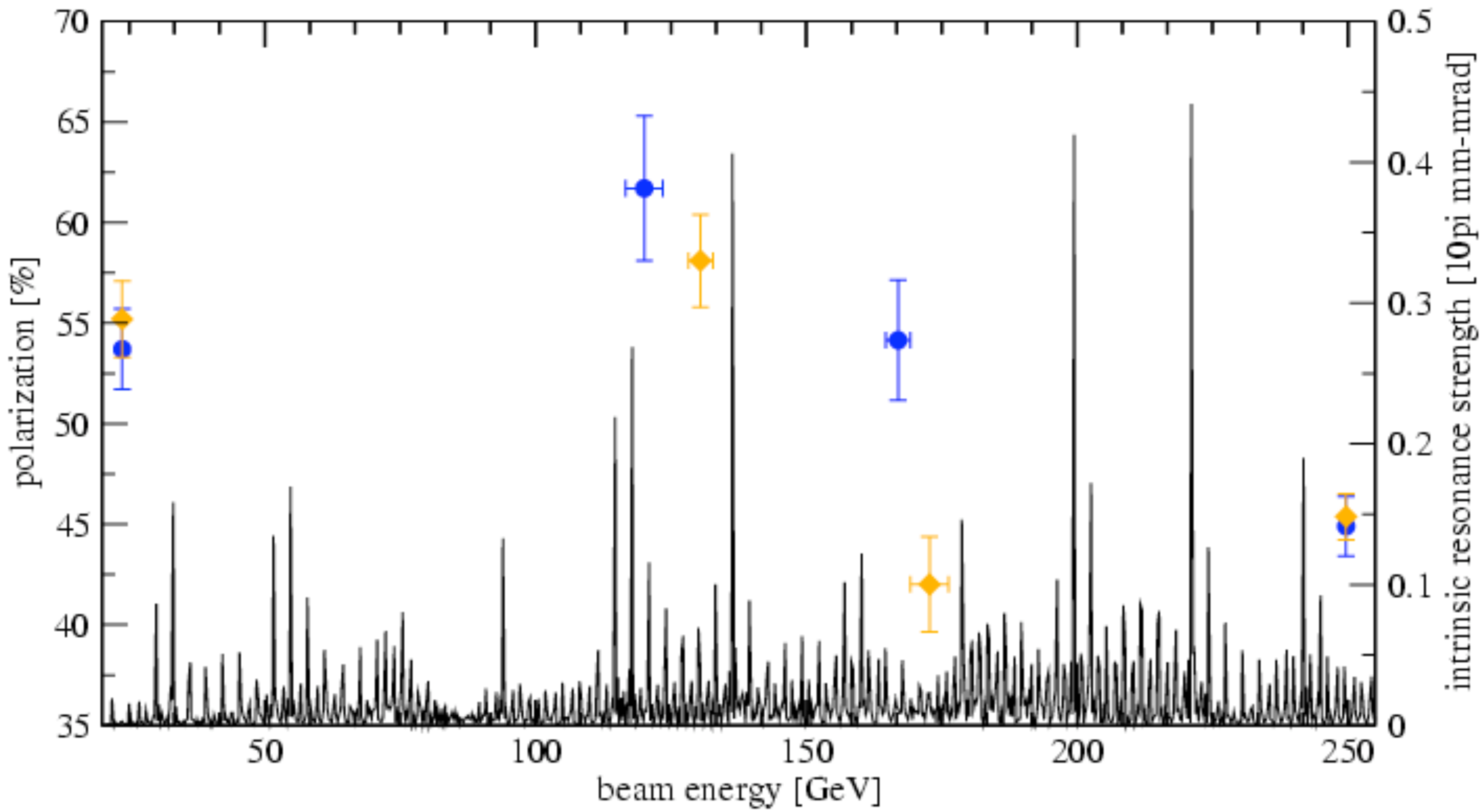
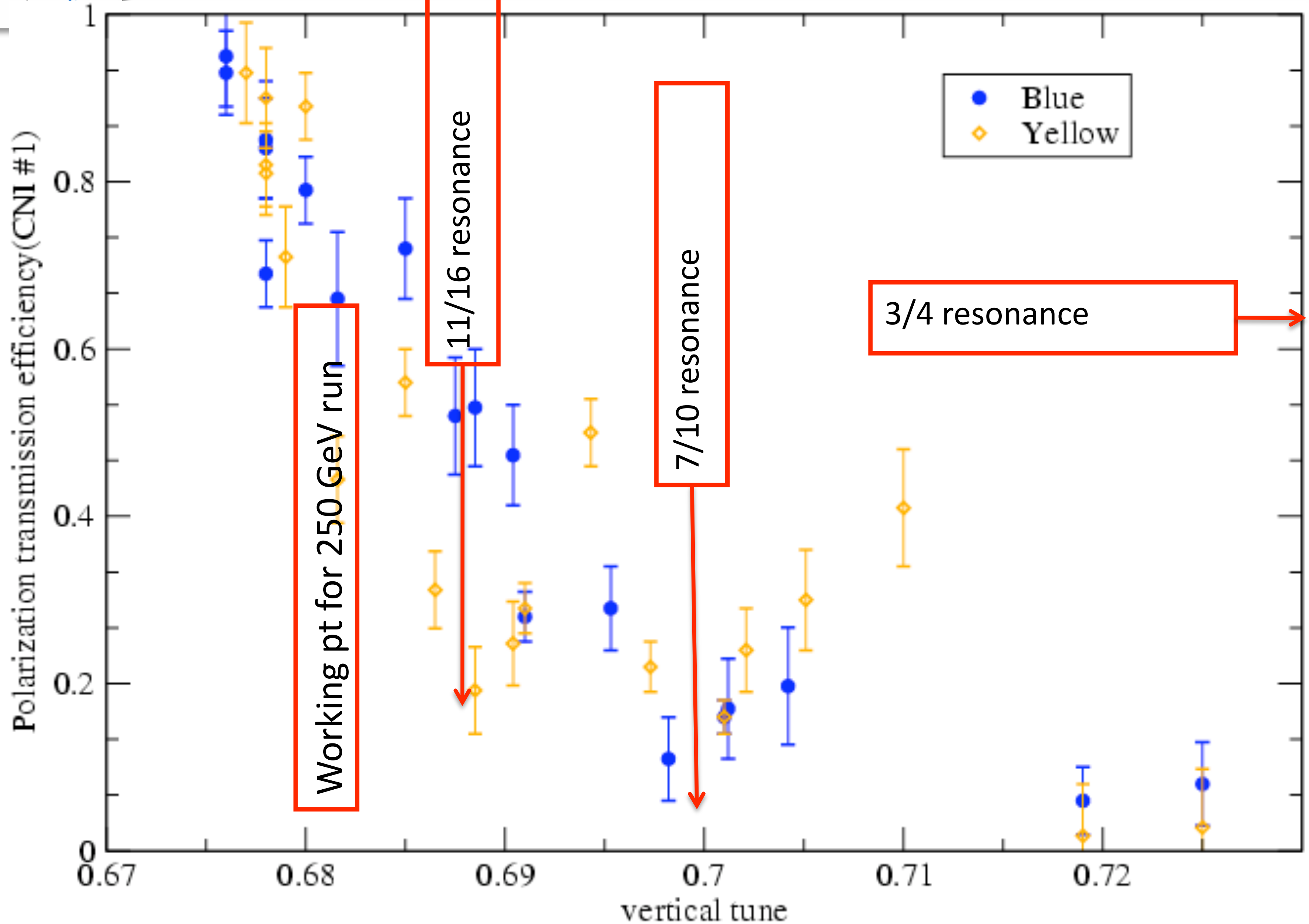
Polarization Performance: 250 GeV

- ❑ Polarization loss between 100 GeV and 250 GeV
  - – Measured with CNI polarimeter

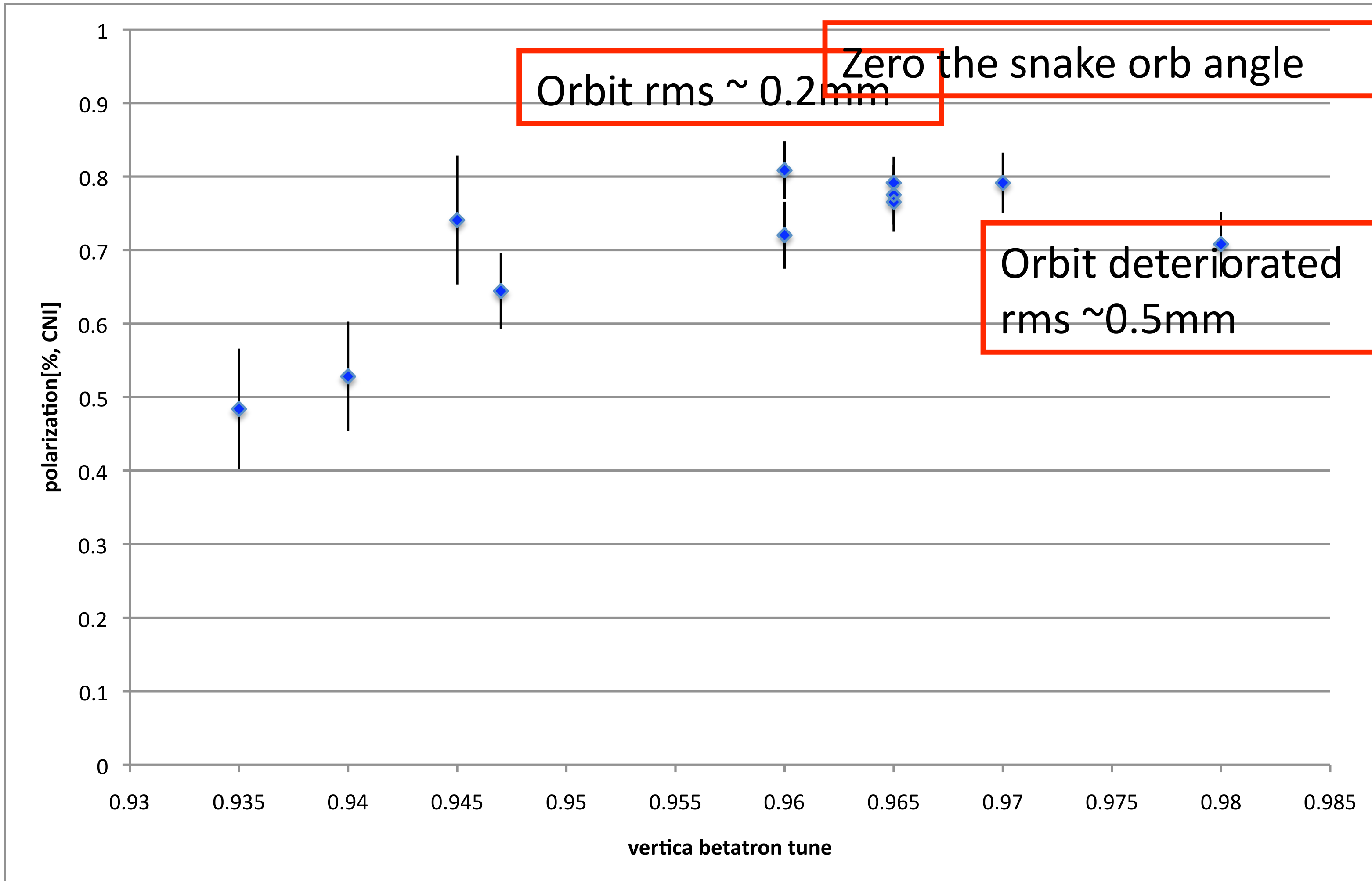


Polarization Tune Scan: 250 GeV acceleration



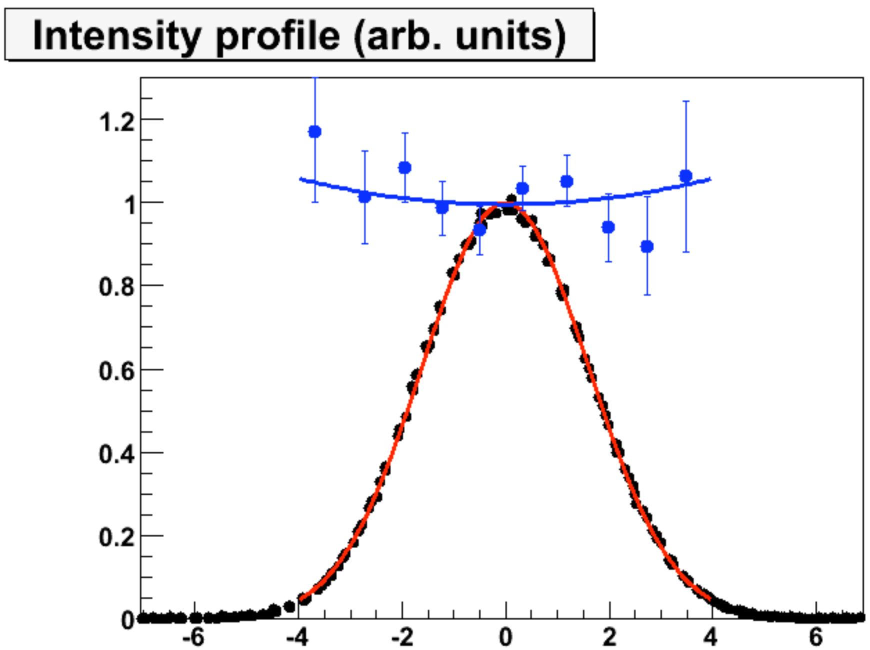
Polarization Tune Scan of 250 GeV Acceleration

- ❑ 250 GeV acceleration with Qy near integer

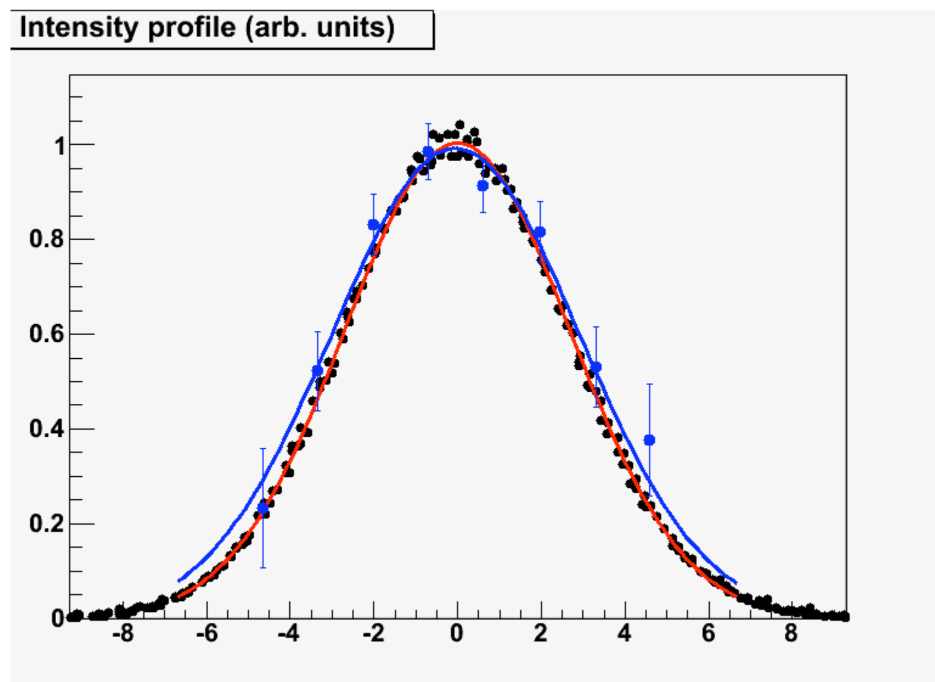


Polarization Profile

Fill 10753, Yellow2



Fill 10486, Yellow2



Courtesy of A. Bazilevsky

Sharper polarization profile for 250 GeV than for 100 GeV

How to Improve Polarization at 250 GeV?

- RHIC:
  - accelerate close to 0.675 between 100 GeV and 250 GeV
  - Tighter control of local orbit at rotators during store
  - CNI polarimeter improvement
- AGS:
  - Horizontal tune jump quad to avoid polarization losses at horizontal resonances
- Source:
  - Upgrade to achieve ~90% polarization

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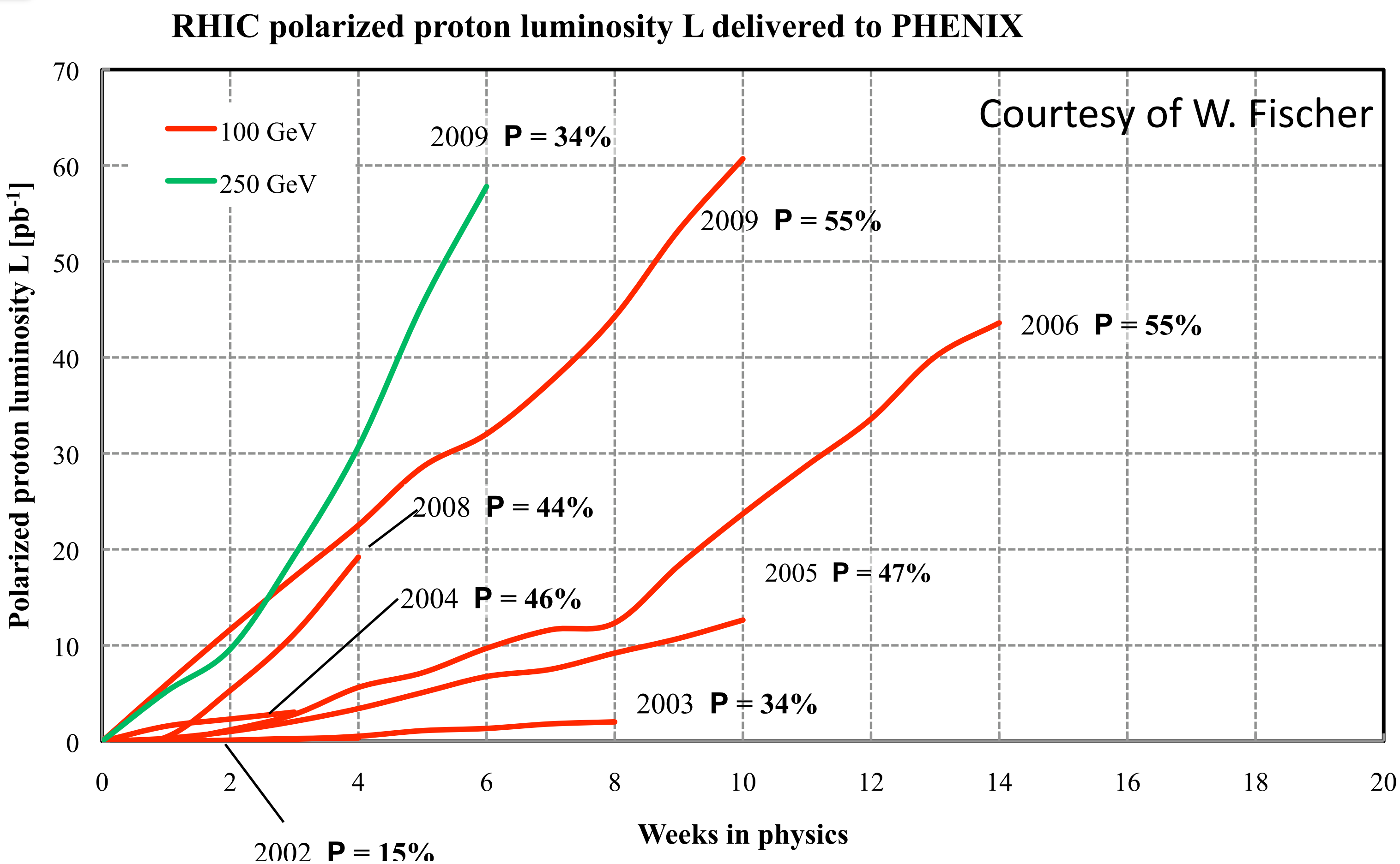
Luminosity Performance



Polarization as measured by H Jet target, average of the entire beam distribution. For 250 GeV, sharper polarization profile was observed and hence, effective polarization is ~ 20 % higher

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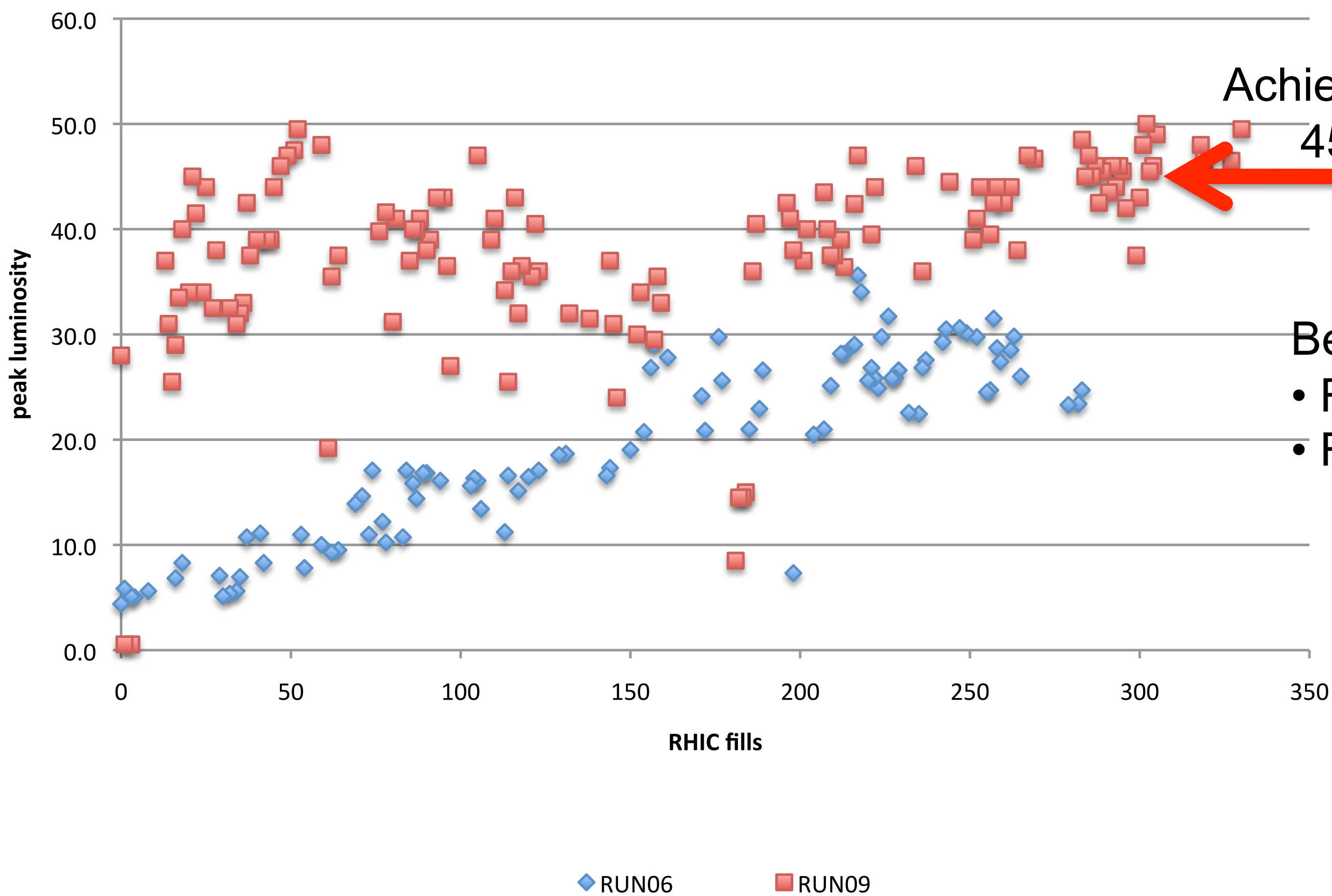
Luminosity Performance: Peak Luminosity



Achieved luminosity:
45x10^30 cm^-2 s^-1

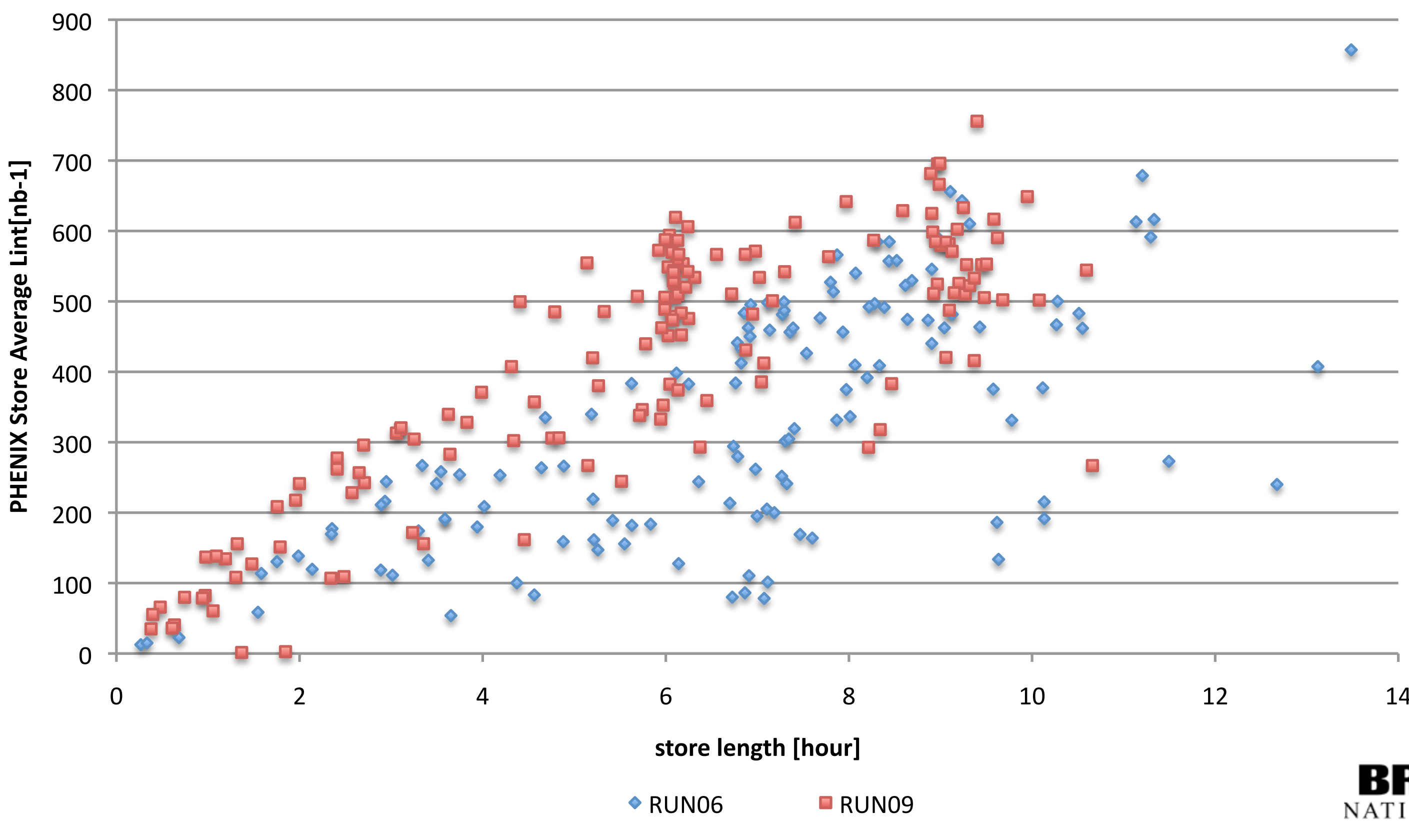
Beta*:

- RUN09 = 0.7m
- RUN06 = 1.0 m

Luminosity Performance: store average luminosity

- Not proportional to the achieved peak luminosity due to
  - Poor luminosity lifetime in RUN 09
  - Yellow bunch intensity was also limited by its poor transmission efficiency in RUN 09

➢ **0.7 m seems to be the limit of beta* at 100 GeV**



Beta*:
- RUN09 = 0.7m
- RUN06 = 1.0 m

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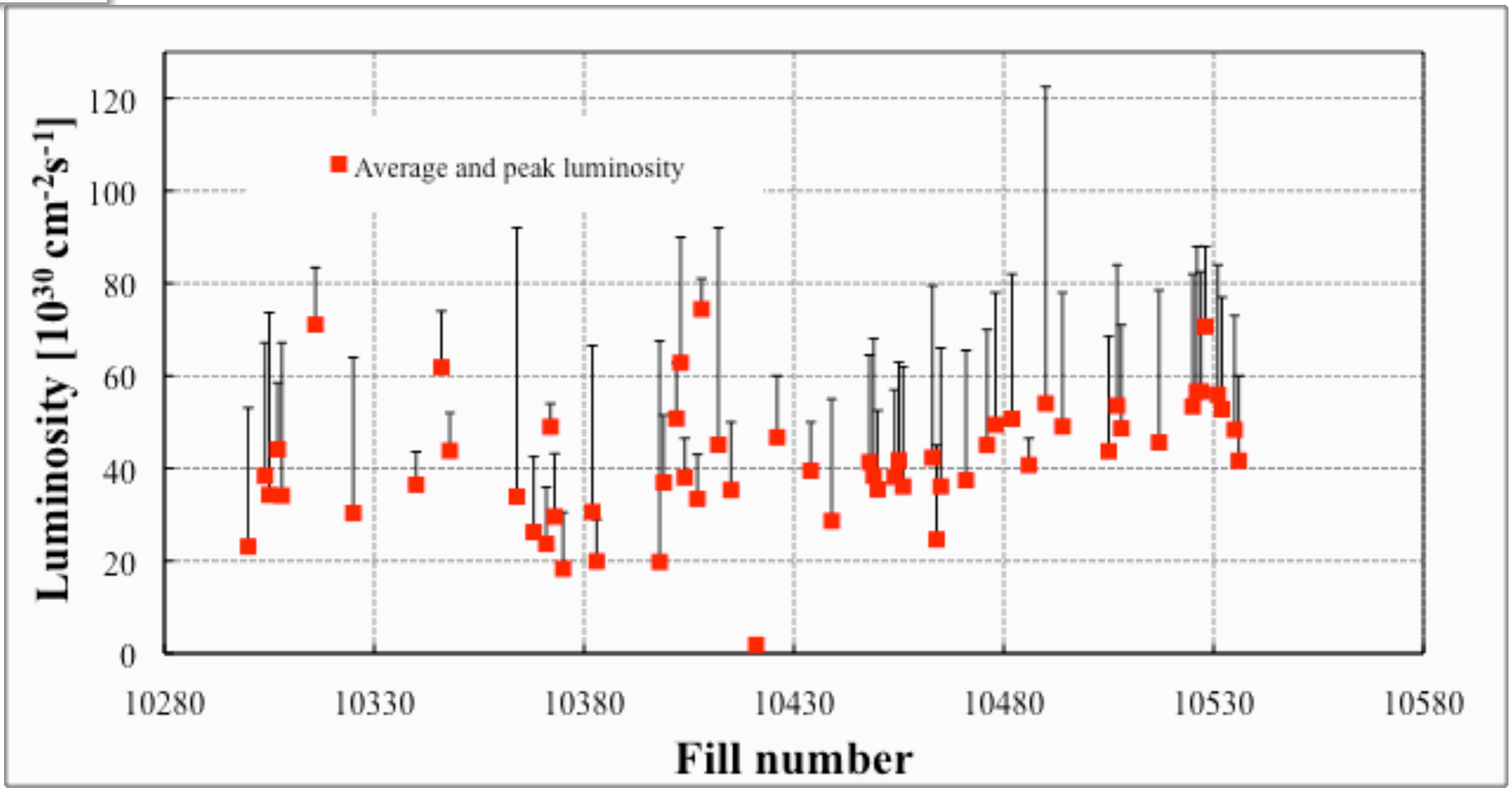
Luminosity Performance: 250 GeV



- beta*: 0.7m, # of bunches: 109
- Bunch intensity: 1.1x10^11 protons
- Peak luminosity: 85x10^30 cm^-2s^-1
- Average luminosity: 55x10^30 cm^-2s^-1

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Luminosity Improvement: 9MHz

- Dedicated 9MHz for acceleration: Mike Brenann and Blaskiewicz
  - Provide better longitudinal match at injection to avoid the longitudinal emittance blowup
  - Longer bunch length during acceleration to reduce the peak bunch intensity. Hence, minimize the electron cloud effect to avoid transverse beam size blowup
  - Adiabatic switch to existing 28MHz cavity results in a shorter bunch length. For a 1 ev-s beam, expected the bunch length rms ~ 1ns.

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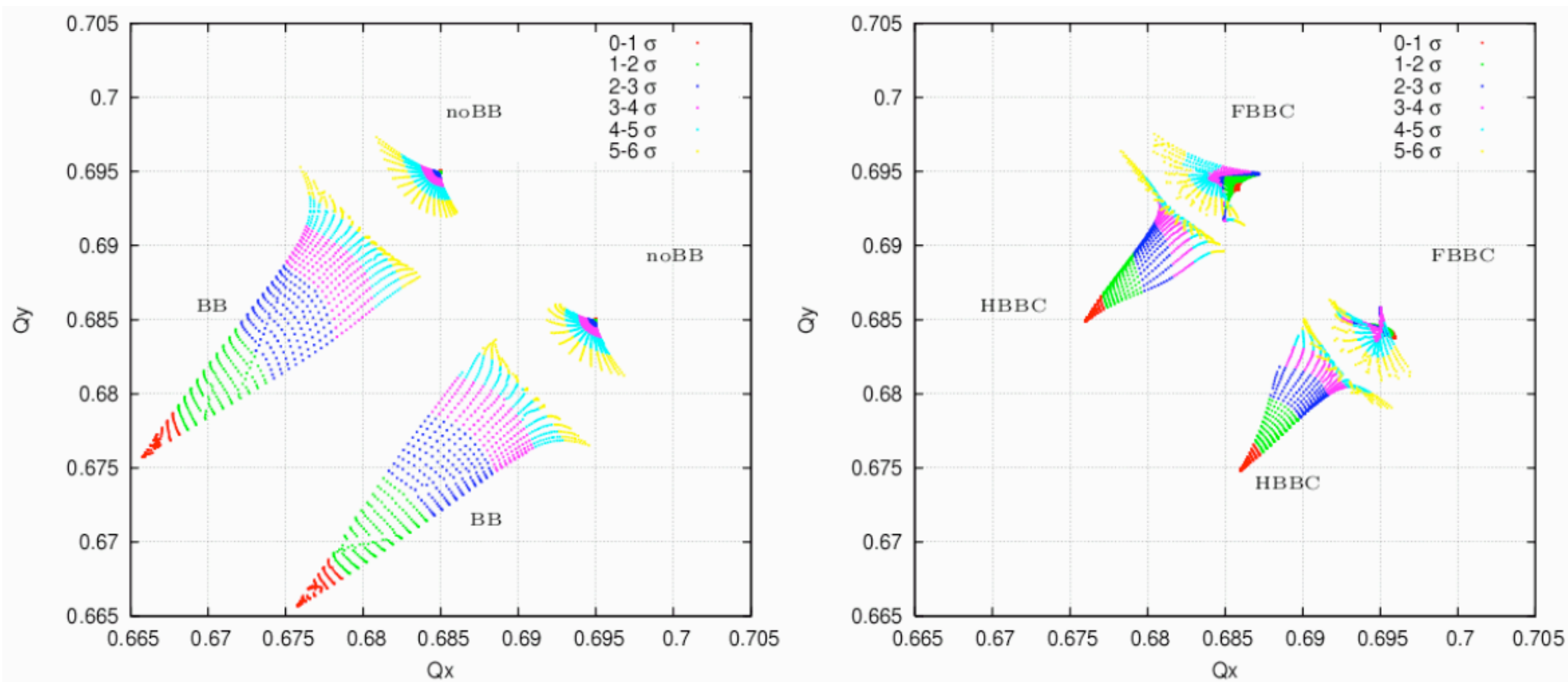
What learned from 9MHz test during Run 09

- Sensitive to the voltage glitches when the main magnets power supplies switch between the flat-bottom unit for injection&store and the unit for acceleration.
- High intensity beam became unstable at injection with 9MHz cavity.
- Longitudinal emittance blowup at injection when using Landau cavity to damp the instability

- Current efforts:
  - reduce the power supply glitch below the level that 9MHz cavity can tolerate
  - A dedicated damper to address the instability/emittance growth problem at injection

Luminosity Improvement: ELens

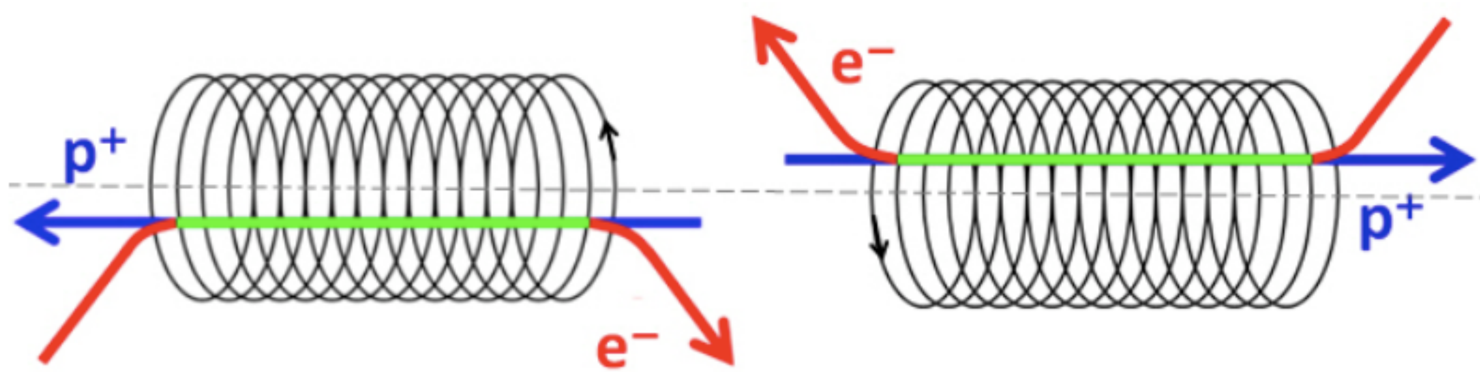
- Electron lens: W. Fischer, Y. Luo and et al
  - Low energy electron beam to provide a focusing len to compensate the beam-beam induced tune spread
  - Allows higher bunch intensity



  - Simulation by Y. Luo and et al

Luminosity Improvement: ELens

- RHIC Electron lens: W. Fischer, Y. Luo and et al
  - One 2.5m long 6 T super-conducting solenoid with field lines straight within ~ 0.2σ
  - Electron gun of current intensity 14A/cm^2
  - Received $4 million ARRA fund
  - Expect a factor of 2 gain in luminosity
  - Expect to commission in RUN 2012



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Luminosity Improvement for 250 GeV

- Increase bunch intensity
  - From 1.1x10^11 to 2.0x10^11 bunch intensity
- reducing beta* at 250 GeV
  - Run 09 shows 0.7 m beta* is the limit at 100 GeV. This is equivalent to a beta* of ~0.3 m at 250 GeV

Summary of Achieved Performance and Projection

p↑ - p↑ operation		2006	(2009)	(2011/12)	(2014)
Energy	GeV	100	100 / 250	100 / 250	250
No of collisions	…	109	107	107	107
Bunch intensity	10^{11}	1.3	1.3 / 1.1	1.3 / 1.5	2.0
Beta*	m	1.0	0.7	0.7/0.4	0.3
Average L	**$10^{30}cm^{-2}s^{-1}$**	**18**	**28 / 55**	**30 / 150**	**300**
Polarization P	**%**	**55**	**56 / 35**	**70**	**70**

Summary: Polarization

- First 250 GeV run achieved ~35% average store polarization measured by H-Jet. Polarization loss was located between 100 GeV and 250 GeV.
- Polarization studies show 90% or better polarization transmission efficiency can be preserved if pp can be accelerated at Qy close to 0.675
- Expect 50% and higher polarization with
  - H tune jump quads in the AGS
  - Source upgrade to yield 90% polarization
  - Accelerating pp with Qy close to 0.67 from 100 GeV to 250 GeV
- Currently invest efforts in spin simulation. Benchmark the spin simulation codes with the tune scan data taken in RUN09. Study the polarization study data during near integer working point development

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Summary: Luminosity

- Currently, pp@100 GeV luminosity is limited by beam-beam effect. The poor lifetime also shows the optimized beta* for 100 GeV is ~0.85m
- The glitches of the main magnets'power supplies limited the available bunch intensity for 250 GeV
- Expect luminosity improvement
  - Fix the power supply glitch
  - Raise both betatron tunes between 0.7 and 0.75 from injection to 100 GeV
  - 9 MHz cavity for acceleration
  - Electron lens
  - Reduce beta* to 0.3m at 250 GeV
  - Double the bunch intensity at 250 GeV

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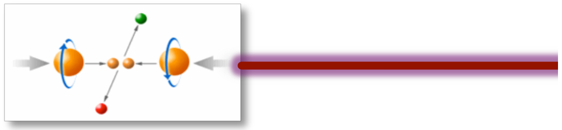

$$R = \frac{\sigma_I^2}{\sigma_P^2}$$

Sharper polarization profile for 250 GeV than for 100 GeV

Courtesy of A. Bazilevsky