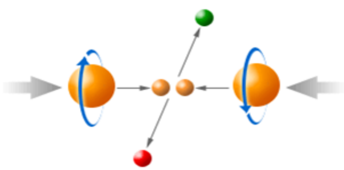

Status and Plan for the Polarized Hadron Collider at RHIC

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On behalf of RHIC Team

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Brookhaven National Laboratory, Upton, NY, USA

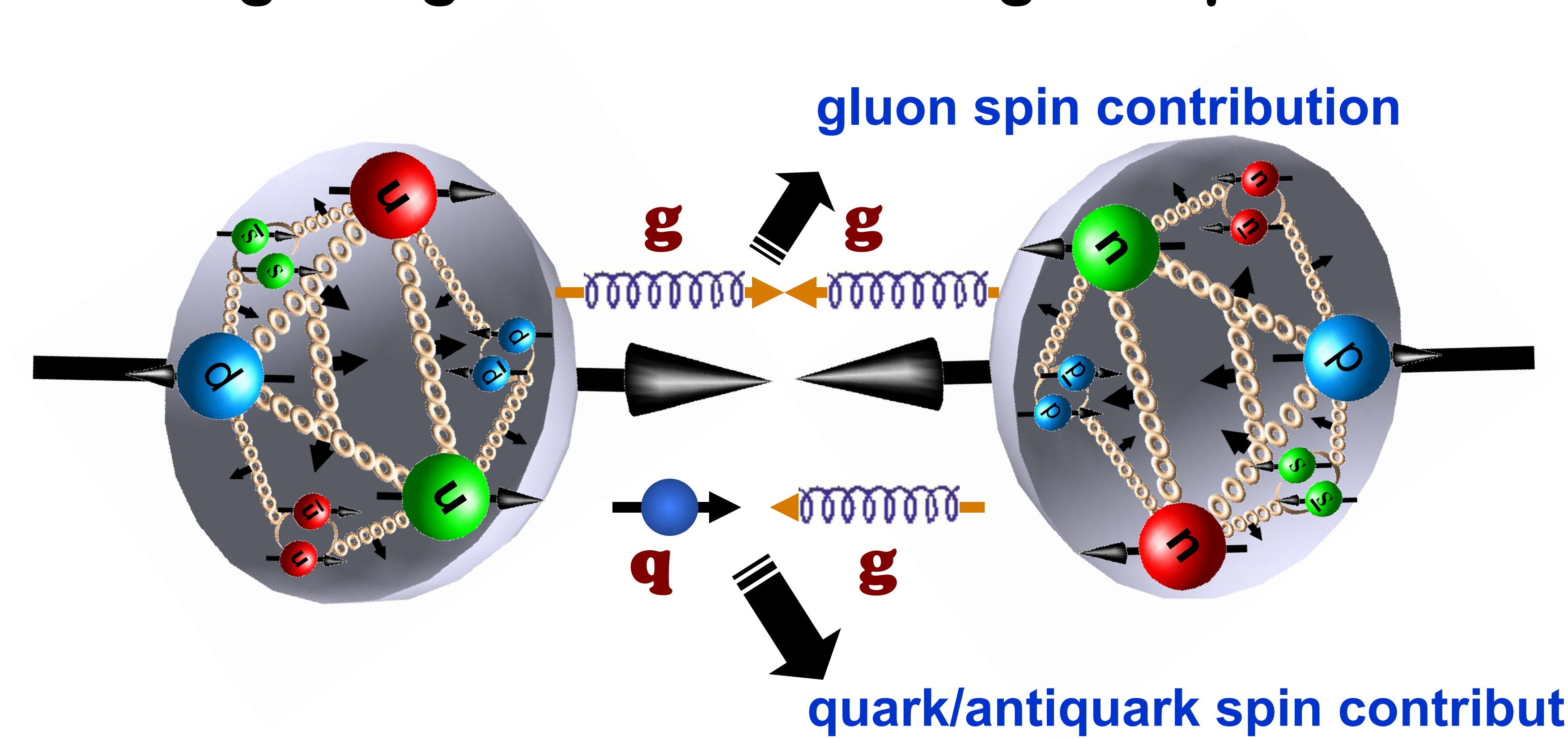
IPAC' 13, Shanghai, May 12-May 17, 2013

Outline

- Challenges in performance of high energy polarized proton collision at RHIC
  - Depolarizing mechanism in synchrotron
  - RHIC polarized proton configuration
- RHIC: current achieved performance
  - Latest major machine improvements
- Future plan
- Summary

Why high energy polarized protons?

High energy proton proton collisions:
gluon gluon collision and gluon quark collision



$$S = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L_q + L_g$$

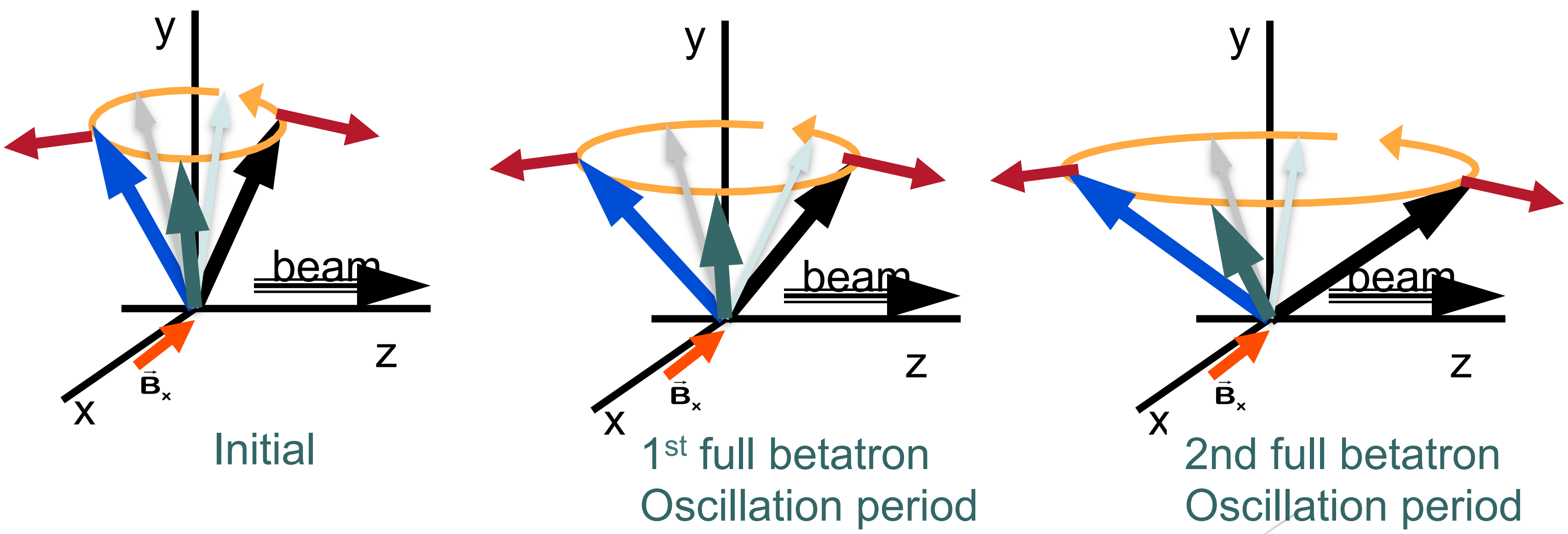
Spin motion in a circular accelerator

- Thomas BMT equation

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

Spin tune $Q_s = G\gamma$

- Non-vertical field kicks the spin vector away from vertical,
- depolarizing resonance



Depolarizing spin resonances

Imperfection resonance

- dipole errors, steering correctors and mis-aligned quadrupoles
- location: $G\gamma = k$
- resonance strength: ~ size of the vertical closed orbit distortion
- correction:
  - harmonic orbit correction
  - partial snake

Intrinsic resonance

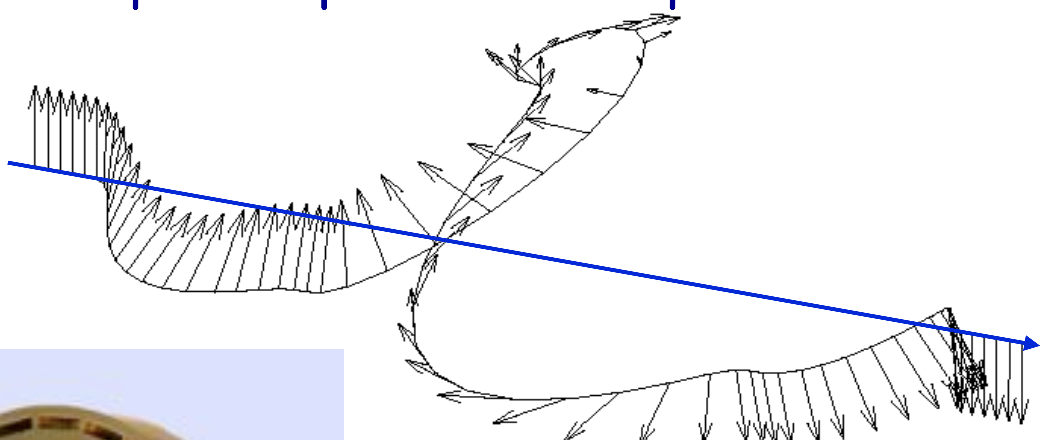
- focusing field due to vertical betatron oscillation
- location: $G\gamma = kP \pm Q_y$
- resonance strength: ~ size of the vertical betatron oscillation
- correction:
  - tune jump
  - RF dipole

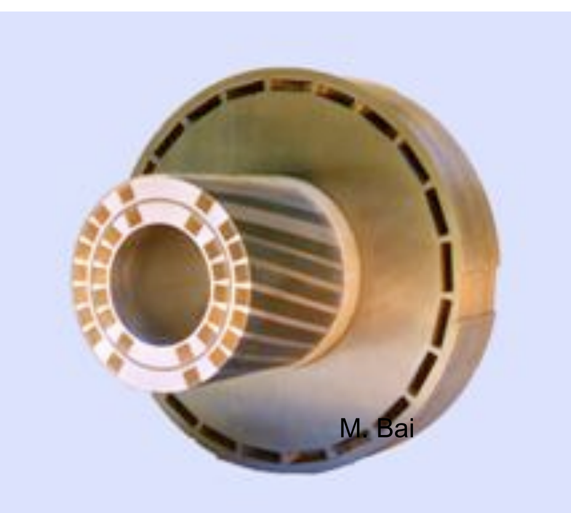
❖ **For protons, imperfection spin resonances are spaced by 523 MeV**

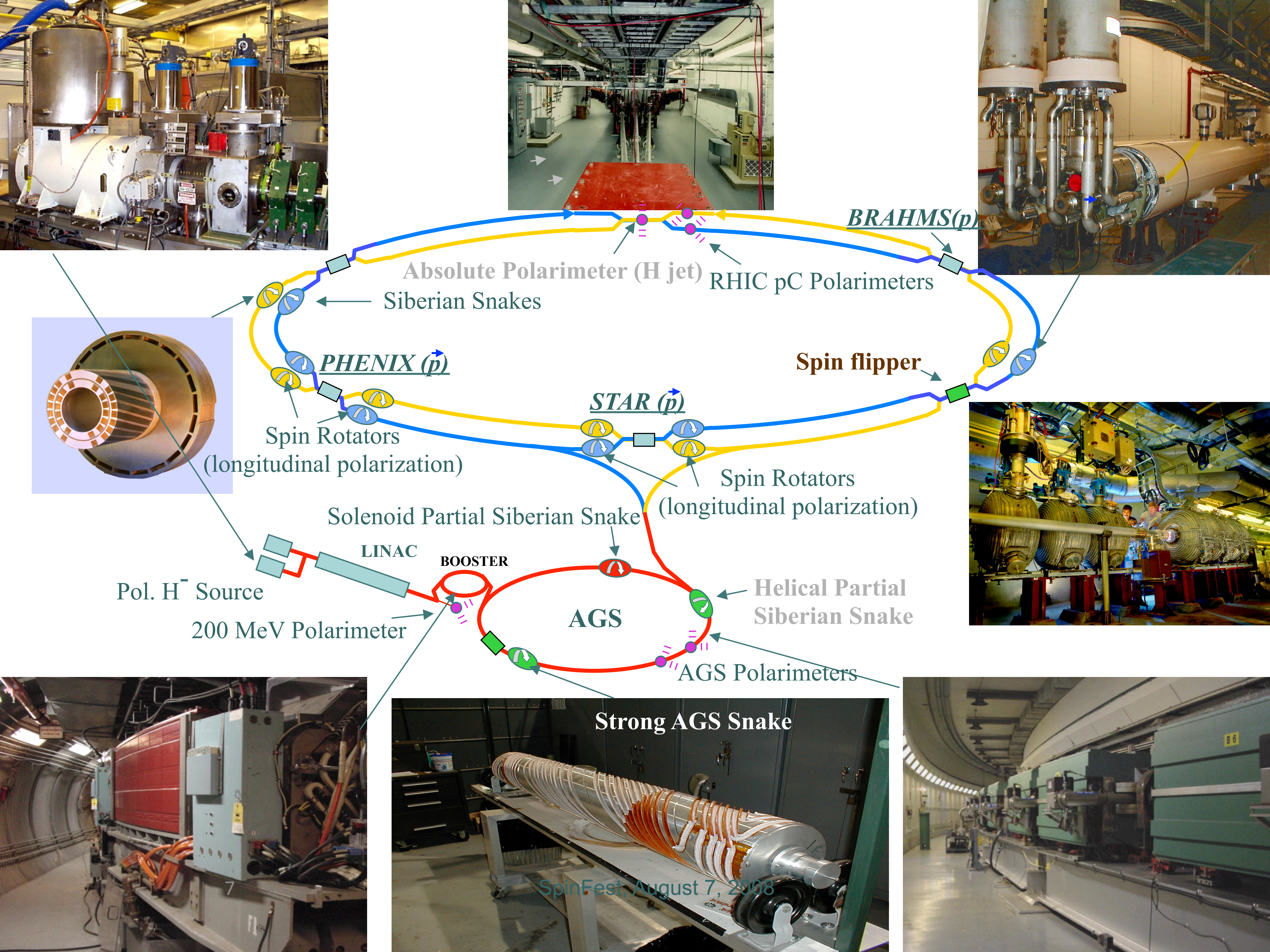
❖ **Between RHIC injection and 250 GeV, a total of 432 imperfection resonances**

Full Siberian Snake

- A magnetic device to rotate spin vector by 180^o
- Invented by Derbenev and Kondratanko in 1970s
- Keep the spin tune independent of energy

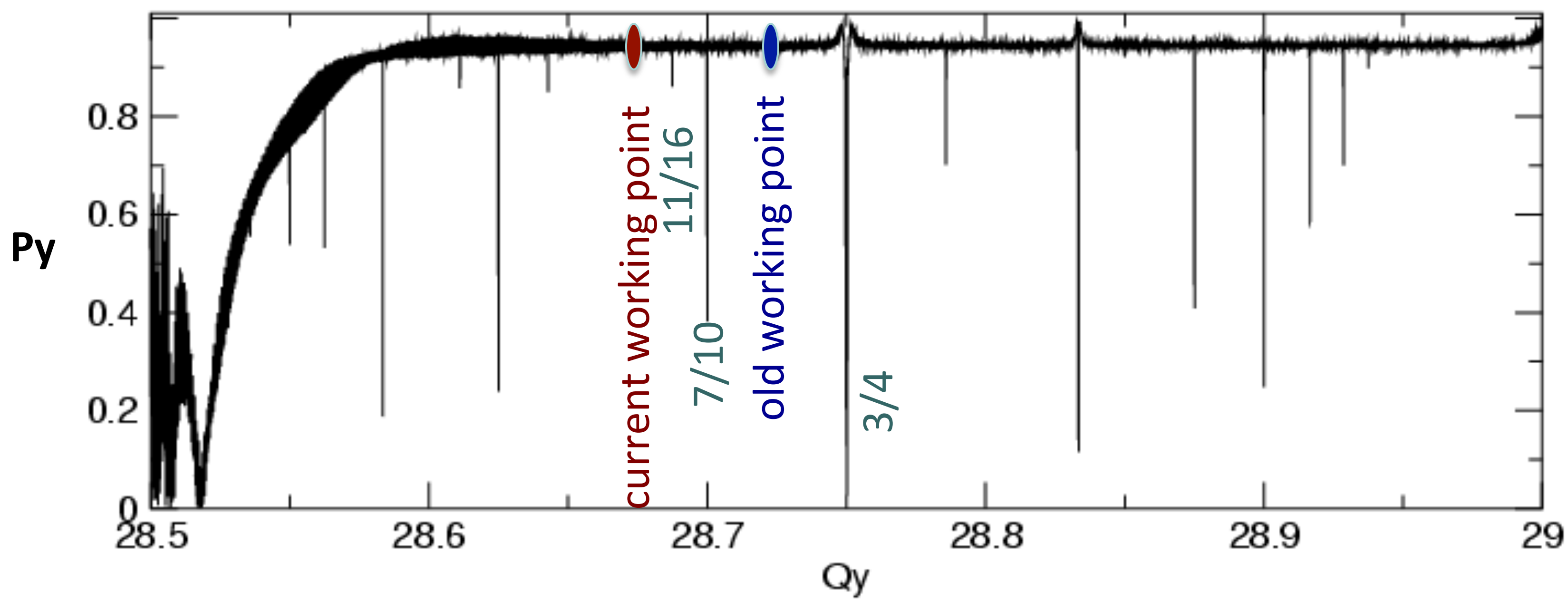





BRAHMS(p)
Absolute Polarimeter (H jet)
RHIC pC Polarimeters
Siberian Snakes
PHENIX (p)
Spin flipper
STAR (p)
Spin Rotators
(longitudinal polarization)
Spin Rotators
(longitudinal polarization)
Solenoid Partial Siberian Snake
LINAC
BOOSTER
Pol. H⁻ Source
200 MeV Polarimeter
AGS
Helical Partial
Siberian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

Snake Depolarization Resonance

- Condition $mQ_y = Q_s + k$
- even order resonance
  - 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



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

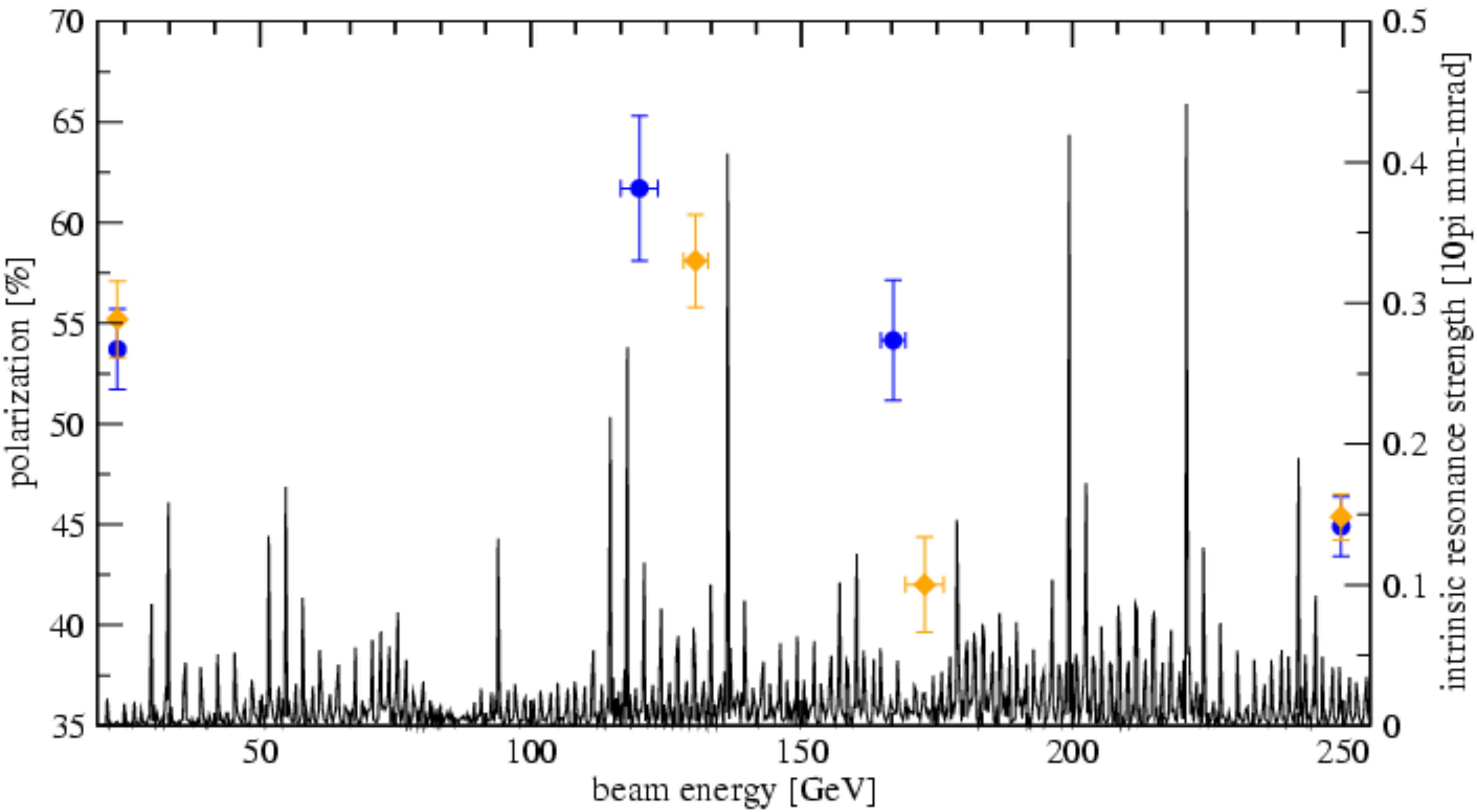
$$\Delta Q_s = \frac{|\Delta\phi|}{\pi} + (1+G\gamma)\frac{\Delta\theta}{\pi}$$

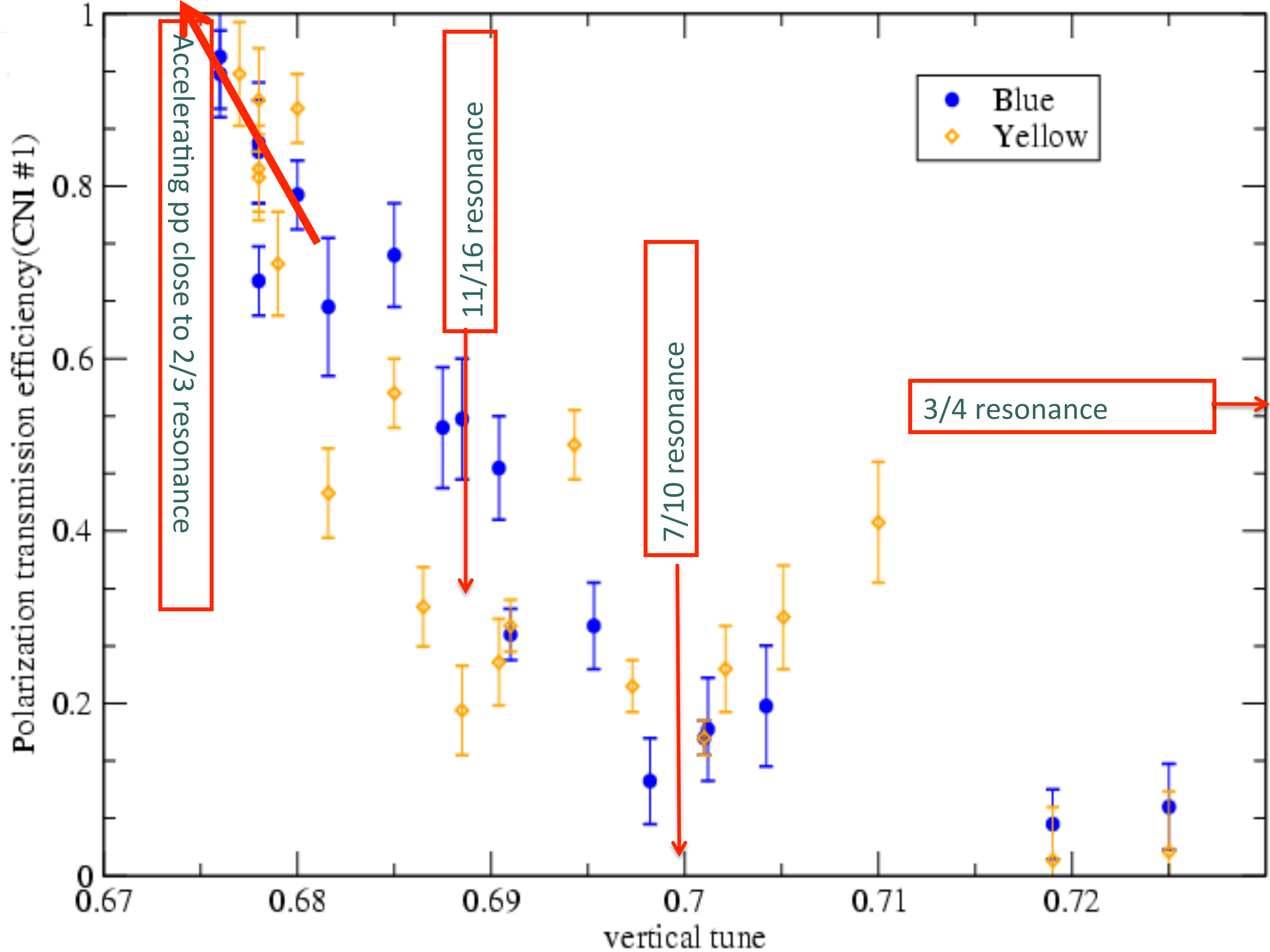
- Precise control of the vertical closed orbit

- 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 spin tune spread

Polarization Performance: 250 GeV

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

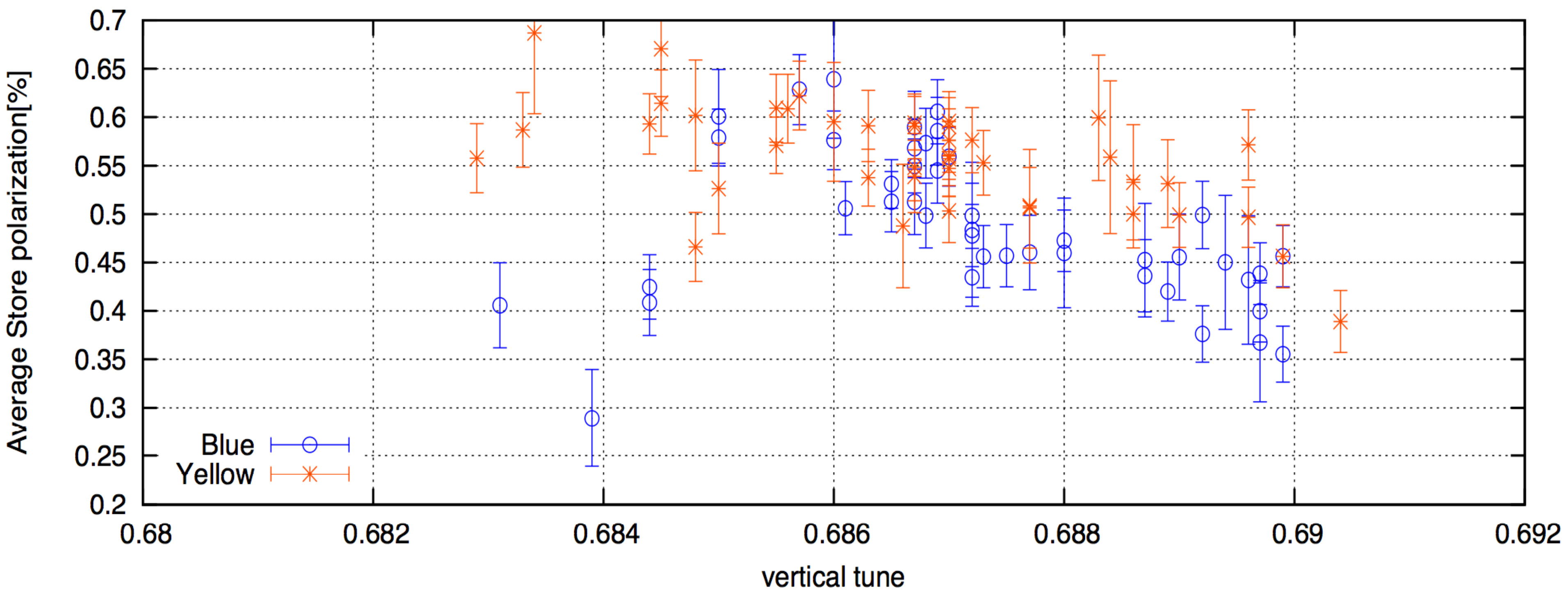




Polarization transmission efficiency(CNI #1)
vertical tune
0
0.2
0.4
0.6
0.8
1
0.67
0.68
0.69
0.7
0.71
0.72
Blue
Yellow
Accelerating pp close to 2/3 resonance
11/16 resonance
7/10 resonance
3/4 resonance

Average Store Polarization vs. Vertical Tune

- The closer the vertical tune towards 0.7, the lower the beam polarization
- The data also shows that the direct beam-beam contribution to polarization loss during store is weak



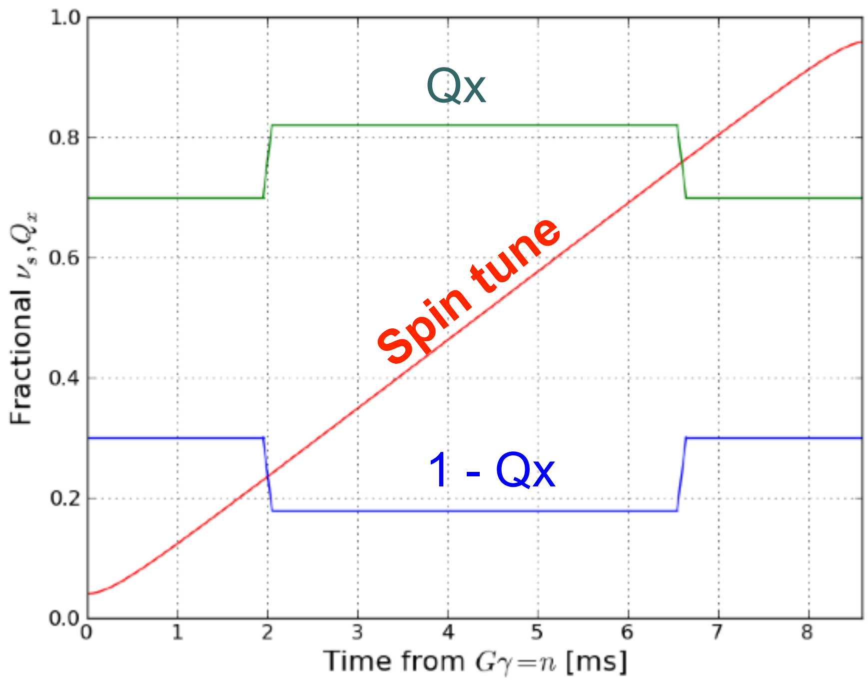
Polarization measured with H Jet polarimeter

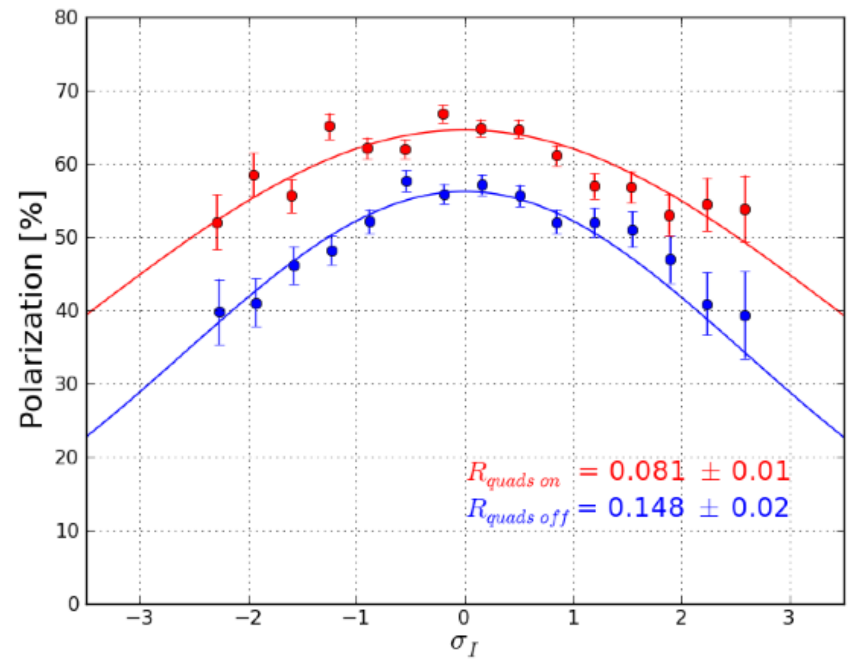
MAJOR MACHINE DEVELOPMENT IN RUN 2013

TUPF1084, V. H. Ranjbar et al, **RHIC POLARIZED PROTON OPERATION FOR 2013**

Major Machine Improvements

- AGS horizontal tune jump quadrupoles to overcome a total of 80 weak horizontal spin resonances during the acceleration



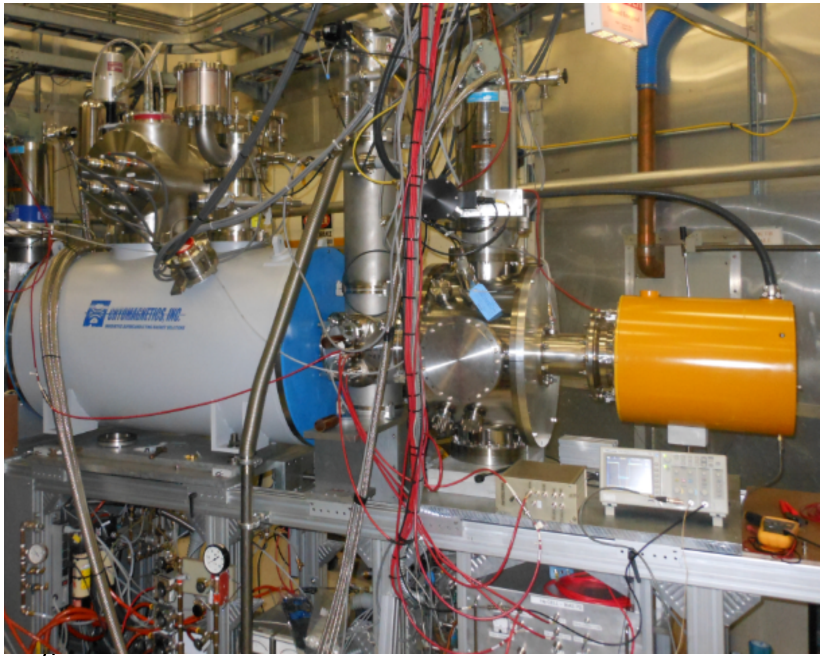


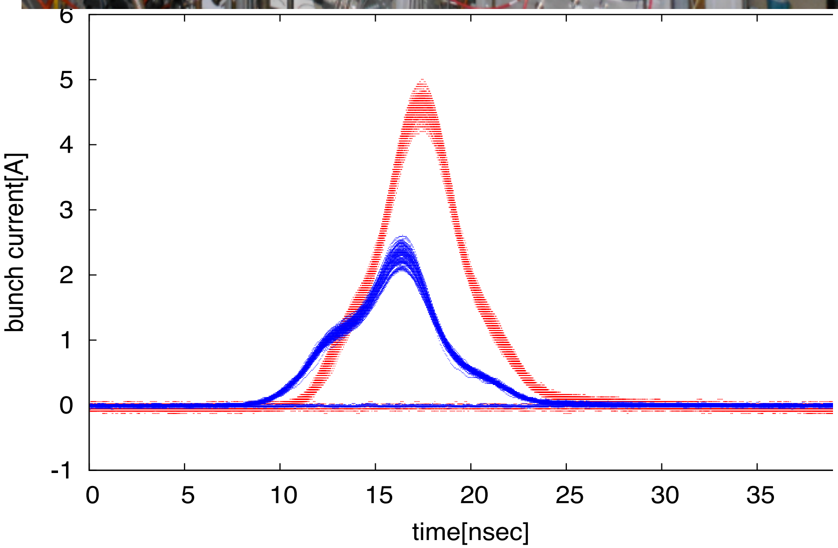
[1] V. Schoefer *et al,* INCREASINGTHEAGSBEAMPOLARIZATIONWITH80TUNEJUMPS, Proceedings of IPAC2012, New Orleans, Louisiana, USA

[2] F. Lin, et al., Phys. Rev. ST 10, 044001 (2007)

Major Machine Improvements

- **Optically Pumped Polarized Ion Source upgrade**
  - A high brightness external atomic H source from BINP replaced the traditional ECR source
  - Yields 3-4% higher polarization for 5×10^{11} ions/pulse. Reaches ~80% polarization for RHIC operation
- **Acceleration with 9MHZ cavity**
  - Provide better longitudinal match at injection to avoid the longitudinal emittance blowup
  - Longer bunch length during acceleration to reduce the peak bunch intensity
    - avoid transverse beam size blowup due to E-cloud
    - Allows higher bunch intensity

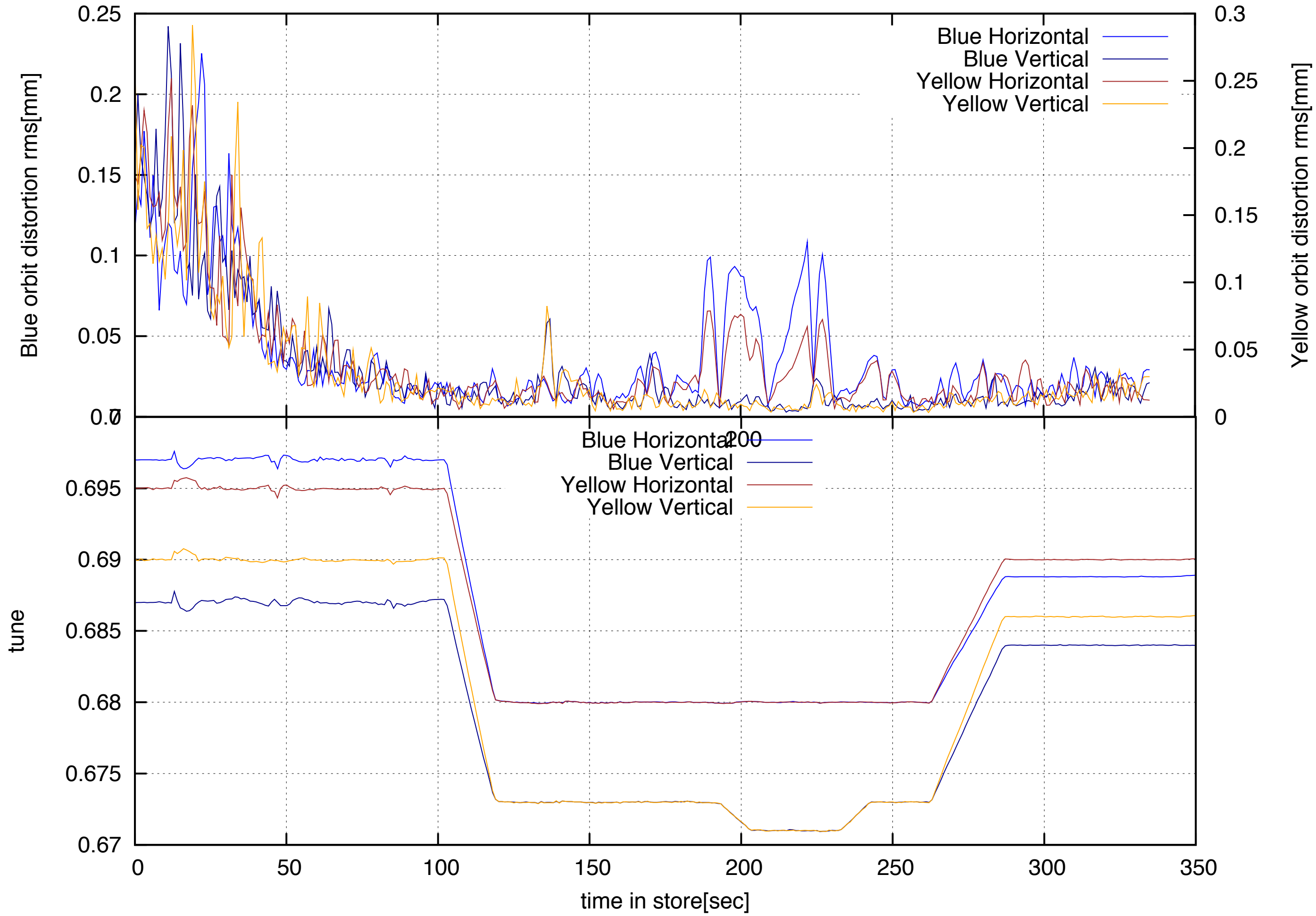




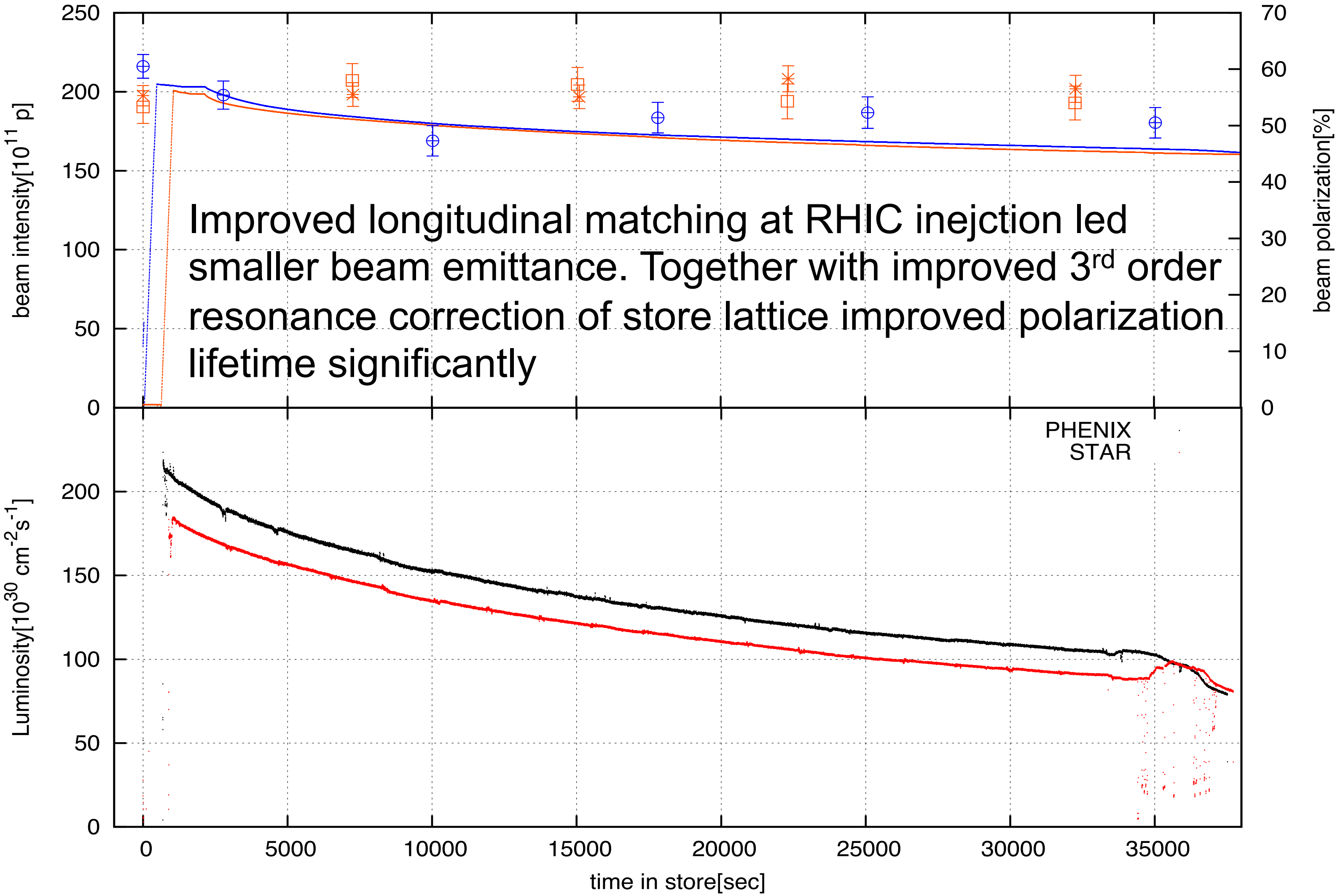
Precise Beam Control

Tune/coupling feedback system: acceleration close to 2/3 orbital resonance

Orbit feedback system: rms orbit distortion less than 0.1mm



The Golden Store of RUN 13



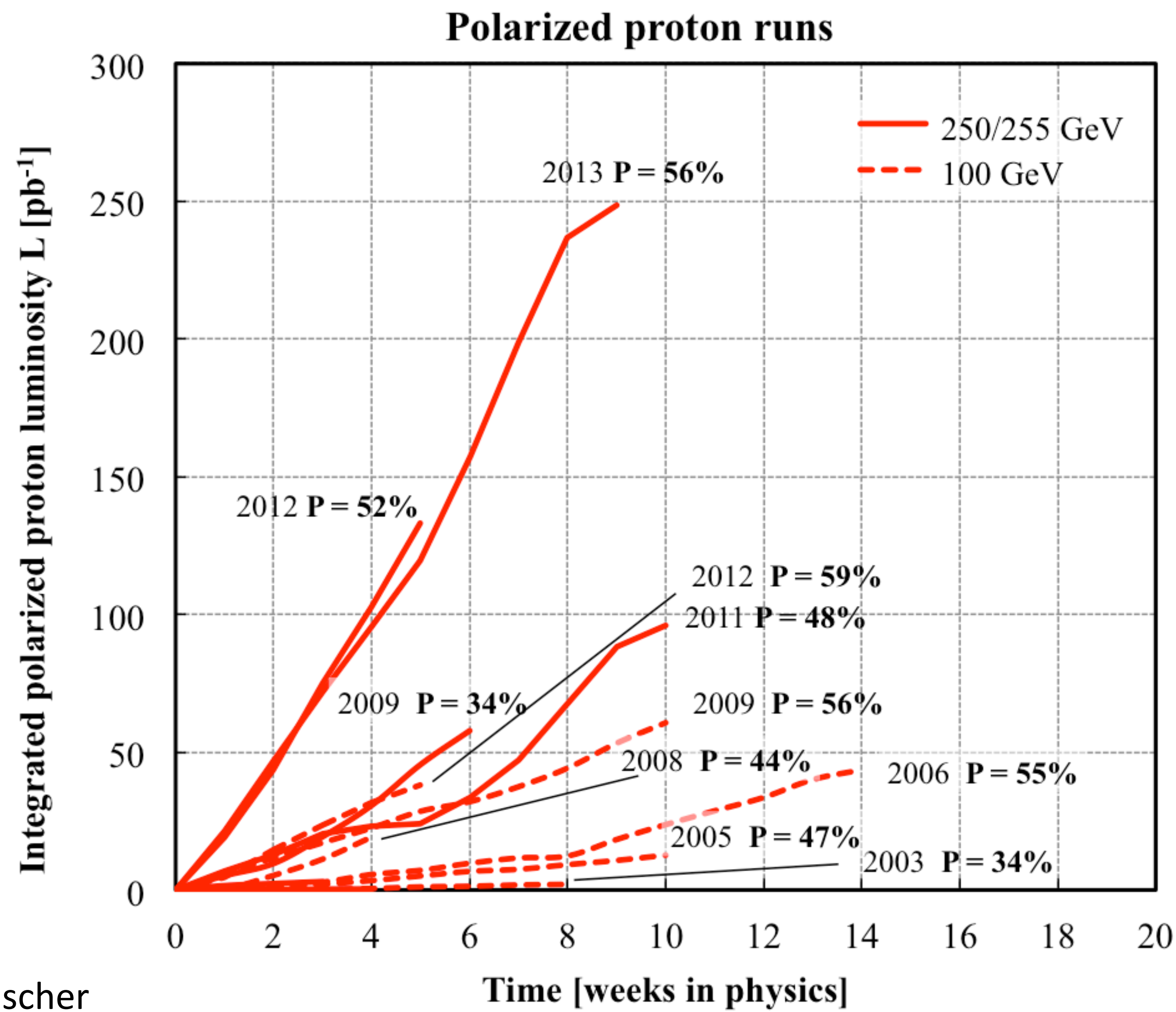
V. H. Ranjbar et al, **RHIC POLARIZED PROTON OPERATION FOR 2013, TUPF1084**

Achieved Performance and Projection

p↑- p↑ operation		2009	2012	2013	2014
Energy	GeV	100/250	100/255	255	100/255
No of collisions	…	107	107	107	107
Bunch intensity	10^{11}	1.3/1.1	1.3/1.8	1.85	2.0
Beta*	m	0.7	0.85/0.65	0.65	0.65
Peak L	$10^{30}cm^{-2}s^{-1}$	**50/85**	**46/165**	**210**	**65/280**
Average L	$10^{30}cm^{-2}s^{-1}$	**28/55**	**33/105**	**125**	**38/170**
Polarization P	%	**56/35**	**59/52**	**56**	**65/57**

Achieved (2009, 2012, 2013) **Projected** (2014)

Polarized Proton Luminosity Performance

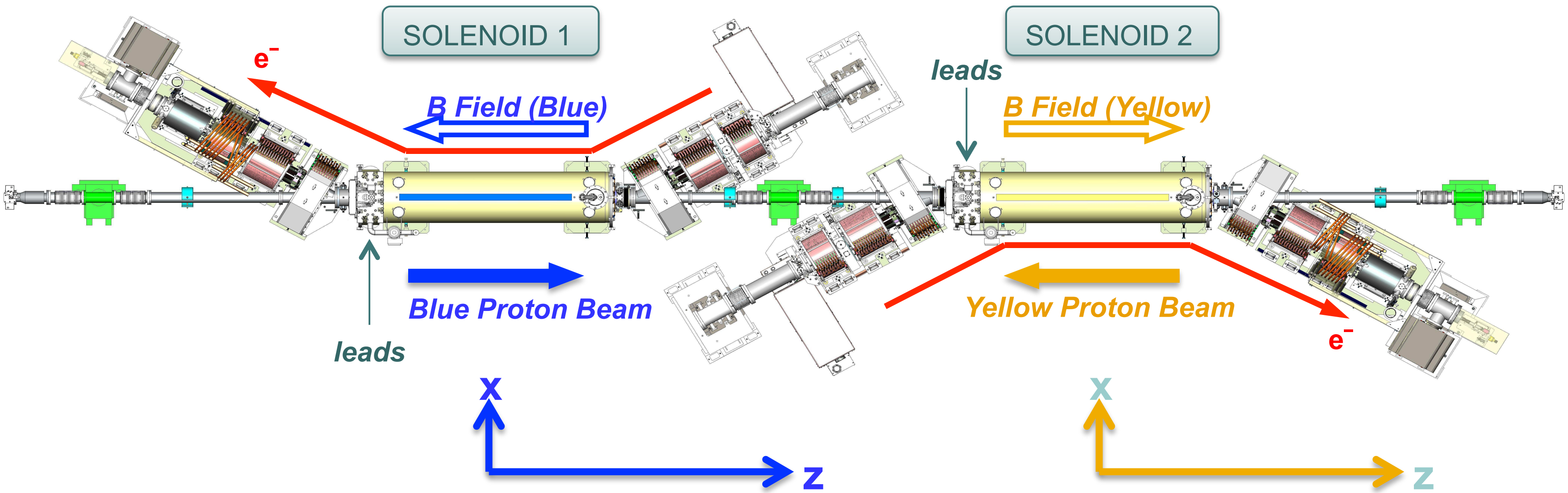


Courtesy of W. Fischer

FUTURE PLAN

Major Plans for luminosity improvement

- E-Lens: W. Fischer, Y. Luo, X. Gu and et al
  - Low energy electron beam to provide a focusing lens to compensate



- Non-linear chromaticity correctionMinimize chromatic tune spread
  - Reduce chromatic beta beat
- Further beta squeeze

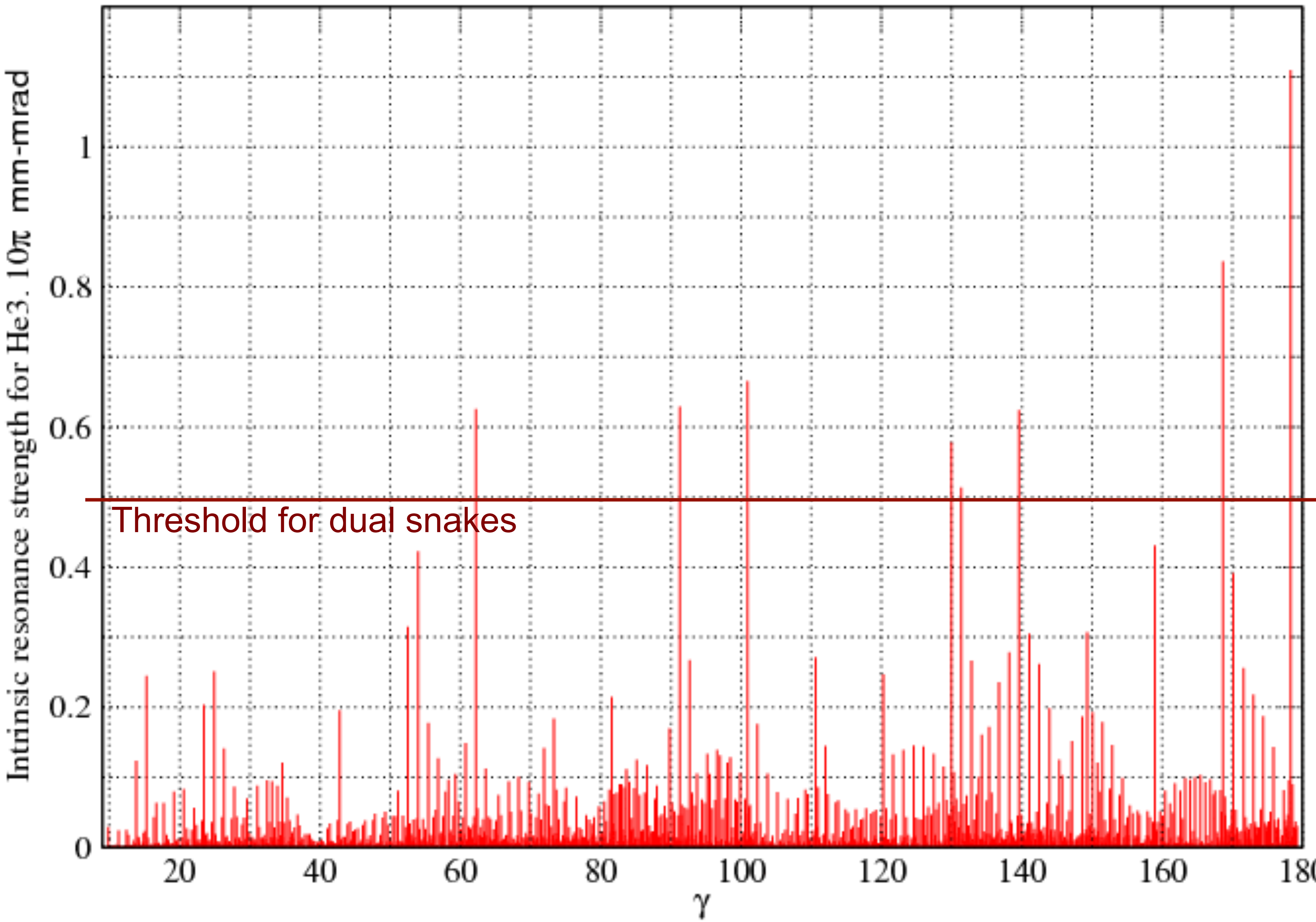
Accelerating Polarized Light Ions

Magnetic field strength for 180° spin rotation: $BL(\pi) = 10.48\frac{A}{ZG}$

species	g-2/2	Resonance spacing [GeV/u]	Snake strength [T-m]	source	Polarization Setup	
					AGS	RHIC
p	1.793	0.523	5.845	OPPIS	Dual partial snakes	Dual full snakes
d	-0.143	6.58	**147**	--	Harmonic correction + RF dipole	Difficult to construct full snake, as well as rotator for spin manipulation
He3	-4.191	0.218	3.751	ElectronBeamIonSource based*	Dual partial snakes	Dual snake +precise beam control

* R. Milner, J. Maxwell, C. Epstein *Development of a Polar- ized* 3He *Beam Source for RHIC using EBIS,* Proceedings of 20th International Spin Physics Symposium (SPIN2012), Dubna, Russia.

Intrinsic Spin Resonance of polarized He3 in RHIC

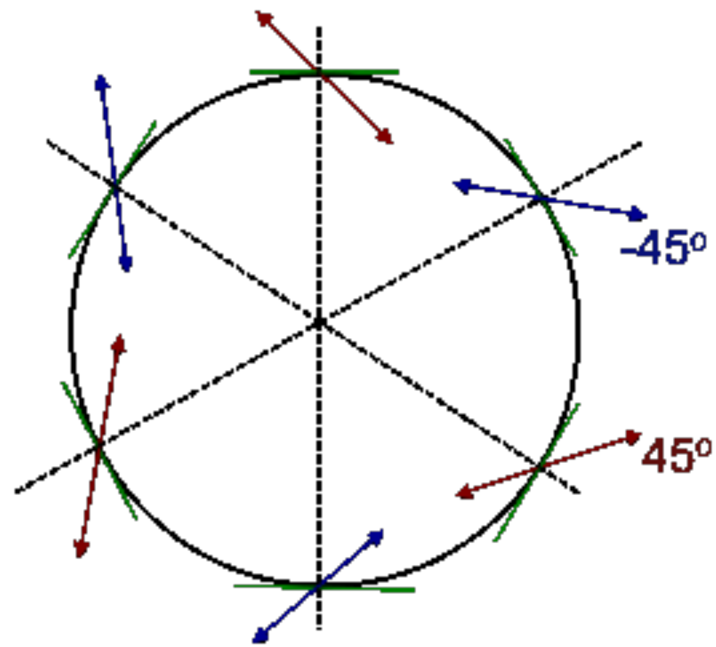


Accelerating Polarized He3 in RHIC

- Tolerance on beam parameters:

species	y_{rms} required	y_{rms} achieved	ΔQ_y required	ΔQ_y achieved
proton	0.5mm	0.1mm	0.003	0.005
He-3	0.15mm	N/A	0.001	N/A

- Six-snake scenario:
  - The spin rotation axis of each snake alternates between 45 degrees and −45 degrees with respect to beam direction for all six snakes. The plot below is the schematic layout of six snake configuration for RHIC.



Summary

- RHIC polarized proton performance has been improved significantly during the current operation.
  - AGS horizontal tune jump quadrupoles to overcome horizontal intrinsic spin resonances
  - Accelerating polarized protons in RHIC with 9MHz cavity
  - Upgrade with OPPIS with a fast high brightness atomic H source yielded 3-4% polarization increase for same ion bunch intensity
  - Excellent precise beam control to avoid snake resonances
- Future activities
  - Electron lenses commissioning to compensate head-on beam-beam effect to reach higher luminosity
  - Better beam control at store to avoid polarization deterioration
  - Explore acceleration of polarized He3 beam in RHIC complex

An Incredible Team

L. Ahrens, E.C. Aschenauer, G. Atoian J. Beebe-Wang, M. Blaskiewicz J.M. Brennan, K. Brown, D. Bruno, R. Connolly, K.O. Eyser T. D'Ottavio, K.A. Drees, Y. Dutheil, W. Fischer C. Gardner, J.W. Glenn, X. Gu, M. Harvey, T. Hayes, H. Huang, R. Hulsart, A. Kirleis J. Laster, C. Liu, Y. Luo, Y. Makdisi G. Marr A. Marusic, F. Meot, K. Mernick, R. Michnoff, M. Minty, C. Montag, J. Morris, S. Nemesure , P. Pile, A. Poblaguev, V. Ptitsyn, V. H. Ranjbar G. Robert-Demolaize, T. Roser,W. Schmidke, V. Schoefer, F. Severino, T. C. Shrey, D. Smirnov, K. Smith, D. Steski, S. Tepikian, D. Trbojevic, N. Tsoupas, J. Tuozzolo G. Wang, M. Wilinski, S. White, K. Yip, A. Zaltsman, A. Zelenski, K. Zeno, S.Y. Zhang

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An Incredible Team

THANK YOU!

謝謝

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