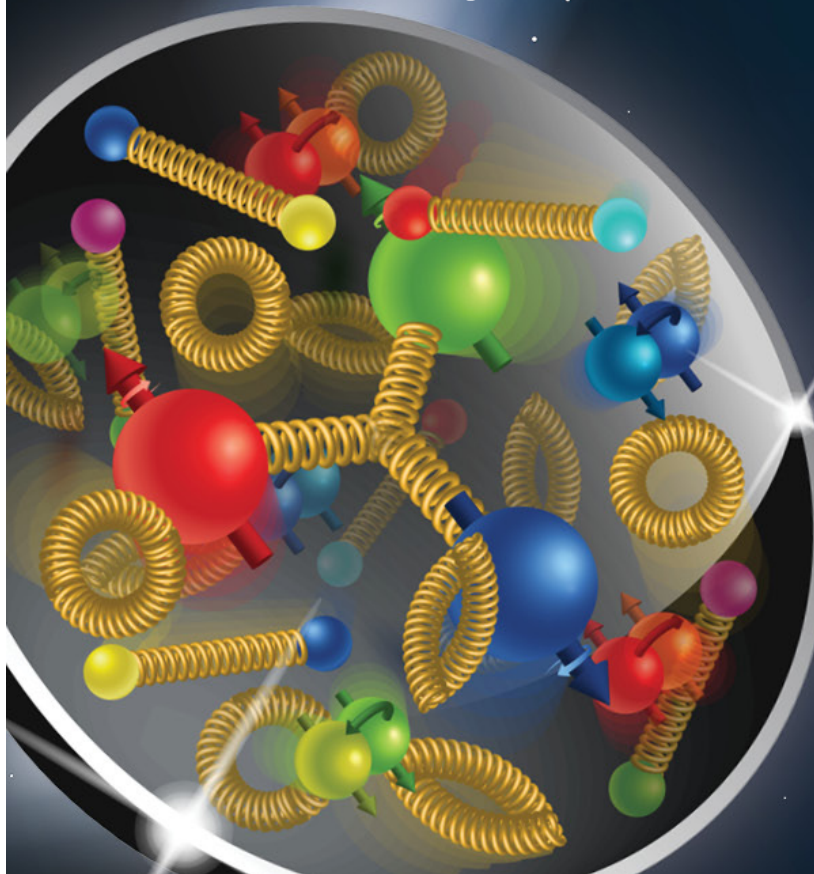# Hadron Polarization for EIC

Haixin Huang, Kiel Hock, Vadim Ptitsyn, Vahid Ranjbar, Vincent Schoefer
(BNL)

20th International Workshop on Polarized Source, Target and Polarimetry at Newport News, VA

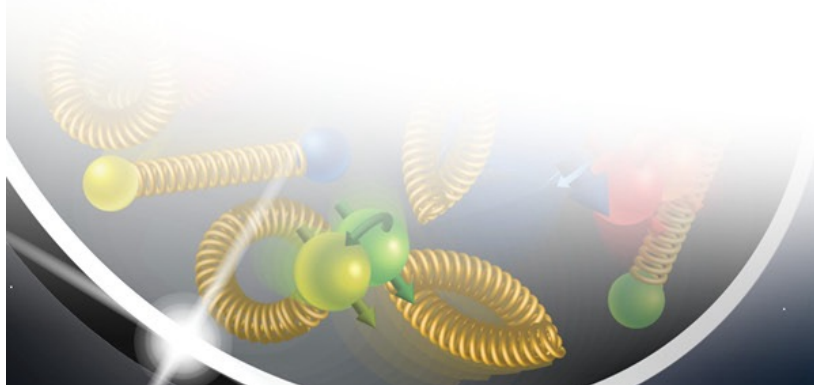Sept. 24, 2024

Electron-Ion Collider

BROOKHAVEN
NATIONAL LABORATORY

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Proton polarization in EIC as Baseline
- He-3 polarization in EIC and Snake upgrade
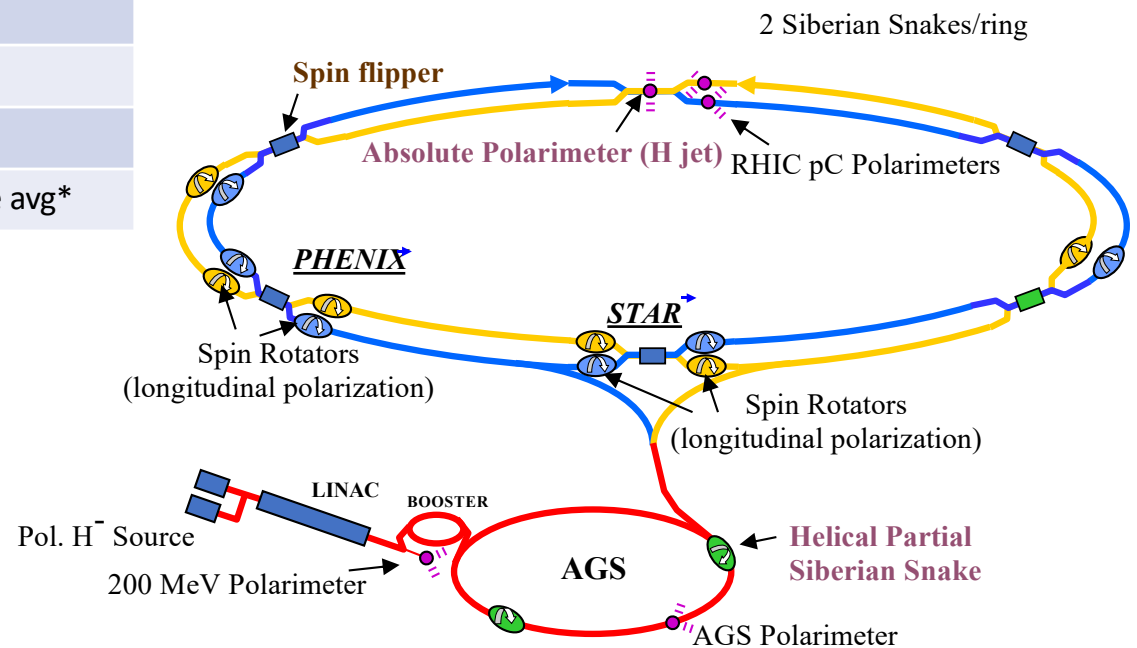- Potential for polarized deuterons
- Conclusion

RHIC Polarized Beam Complex

	Max Energy [GeV]	Pol. At Max Energy [%]	
Source+Linac	1.1	82-84	
Booster	2.5	82-84	
AGS	23.8	67-70	p-Carbon
RHIC	255	55-60	Jet, full store avg*

* Includes both ramp loss and store decay

|	Relative Ramp Polarization Loss (Run 17, full run avg)	
AGS	~17 %	
RHIC	~10 %	

With pulsed skew quads in the AGS (they are under commissioning in run24), the polarization loss in the AGS from horizontal resonances will be mostly fixed.
With precooler at injection and six snakes, it is expected that polarization will be preserved in Hadron Storage Ring (HSR) in EIC.

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Understand Polarization Loss in RHIC

- There are about 10-15% polarization loss in RHIC when beam is accelerated to 255GeV. Recent simulations show that the root cause is the vertical orbit errors.

- Bottomline: Two snakes are not enough for polarization preservation with rms emittance of 2.5μm and vertical orbit error >0.2mm.

- The reproduction of RHIC polarization loss gives us confidence of the simulation tool.

RHIC. Polarization loss vs rms vertical orbit. 2 snakes
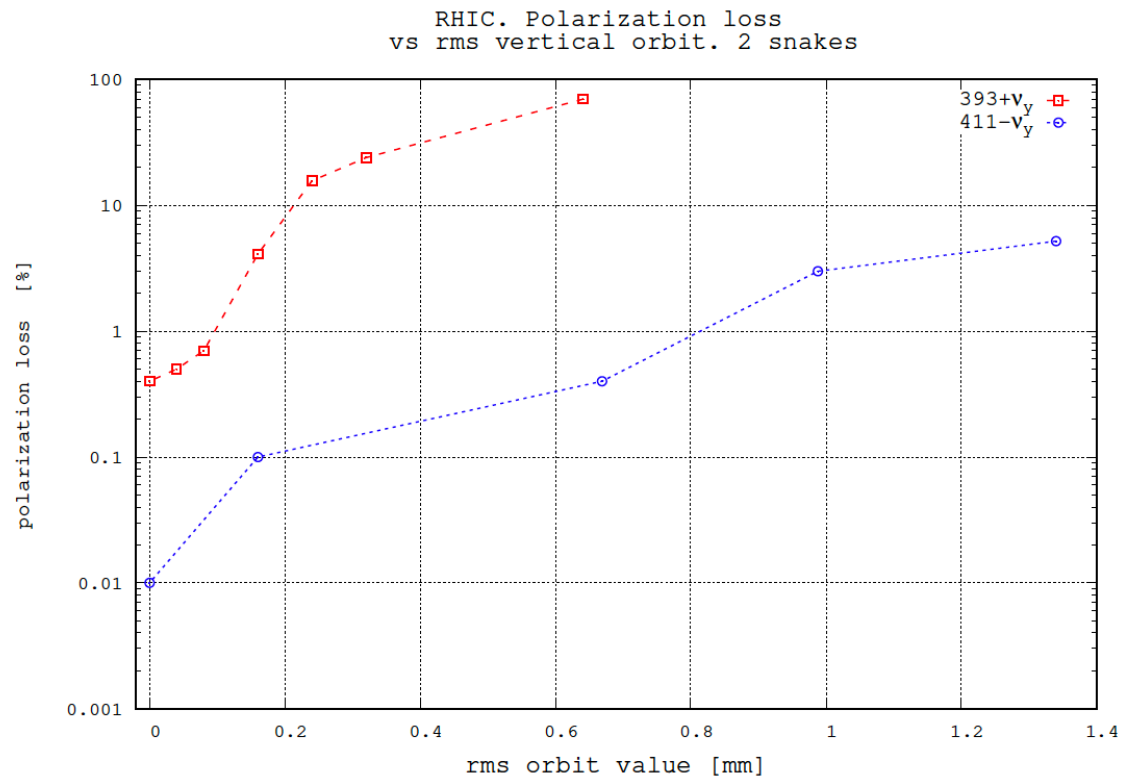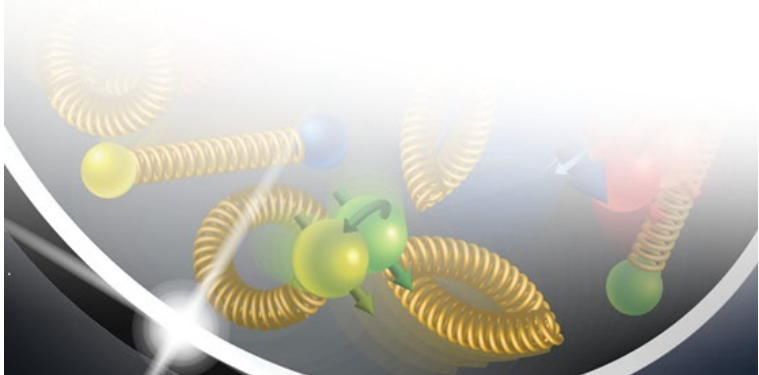
Depolarizing Resonance Strength Comparison
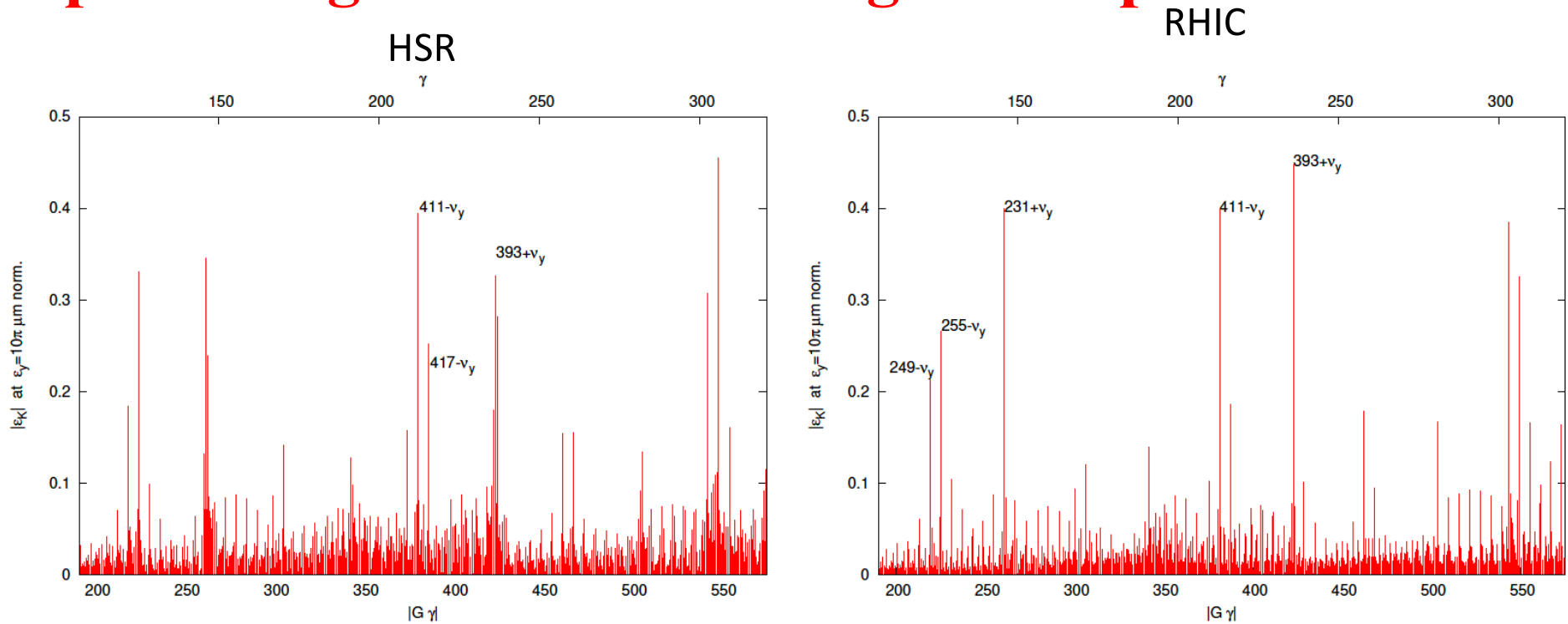

Systematic resonances, located at 393+Qy, 411-Qy, 231+Qy, 255-Qy, appear weaker in HSR, compared to RHIC, the reverse occurs for non-systematic resonances, the latter effect is an indication that the 3-periodicity of former RHIC lattice is in jeopardy in its HSR evolution.
A potential adverse configuration which results regarding resonance crossing, is the presence of wide non-systematic resonances in the direct vicinity of systematic resonances.

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Crossing of Strongest Spin Resonance in EIC

- EIC will have pre-cooling at injection. Vertical emittance is expected to be cooled down to 0.5-1mm-mrad.

- Simulations show that two snakes preserve proton polarization with cooled rms emittance of 1 mm-mrad (no orbit error)

A 1,000 particle bunch is tracked across 393+ν using ZGOUBI*

$\varepsilon_x = \varepsilon_y = 1\mu m$, norm., $\sigma_{dp/p} = 0.7e-3$
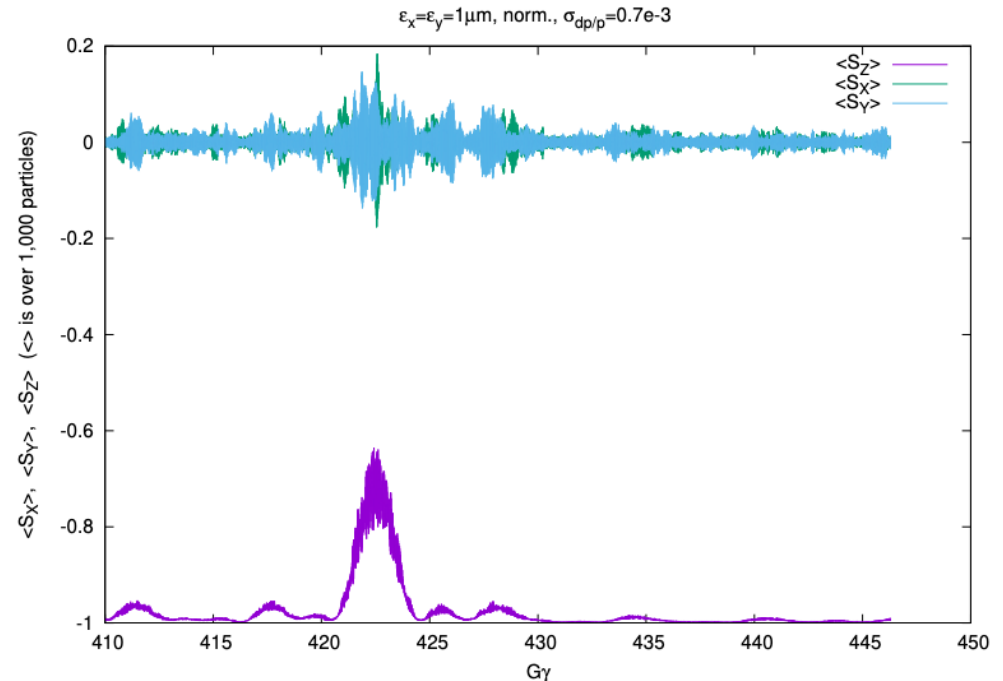
* F. Méot, H. Huang, V. Ptitsyn, V. Ranjbar, G. Robert-Demolaize, V. Schoefer, and V. Morozov, RHIC optics and spin dynamics with snakes and rotators, Phys. Rev. Accel. Beams 25, 121002 (2022).
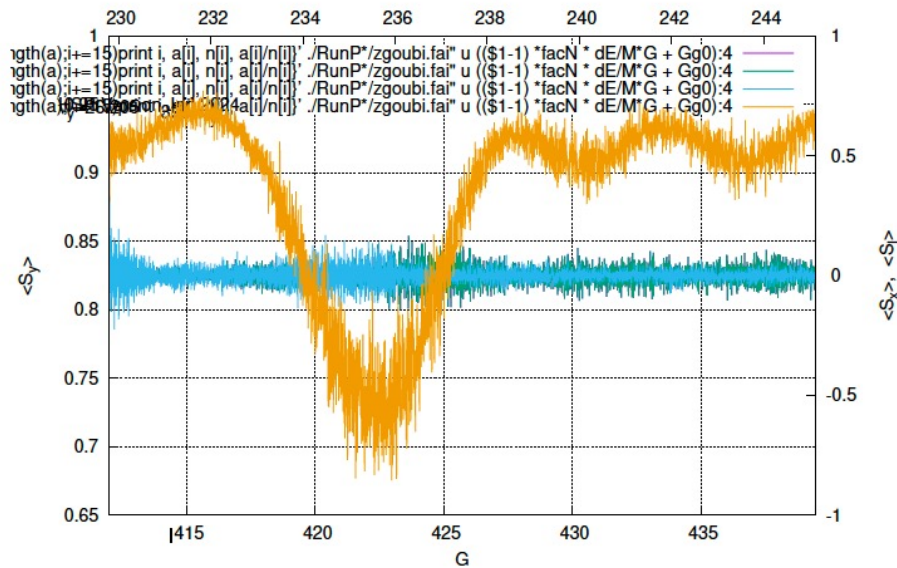
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With Vertical Orbit Error Included

Case of 395+Qy= 421.2

Case of 410-Qy = 383.8

VKIC .1, $\sigma_y = 0.65$ mm
$P_i = 0.945$ $P_f = 0.935$ $P_f/P_i = 0.989$

VKIC 0.025, $\sigma_y = 0.178$ mm, 100 protons
$P_i = 0.983$ $P_f =$ $P_f/P_i = 0.992$

100 protons
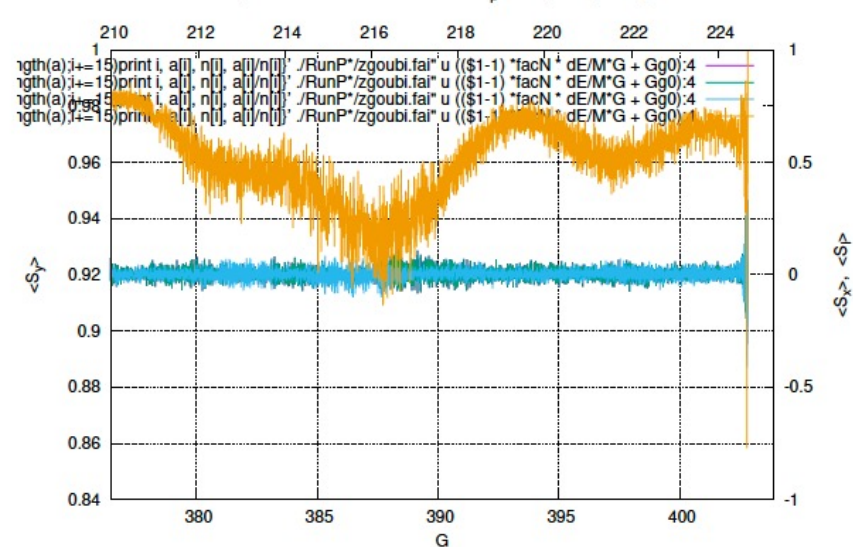
Under condition of emittance as 2.5mm-mrad in both planes (no pre-cooling), the simulations were done with vertical orbit errors. The rms orbit error is expected to be at the 0.2mm level. Six snakes can preserve polarization for protons in the presence of rms errors.

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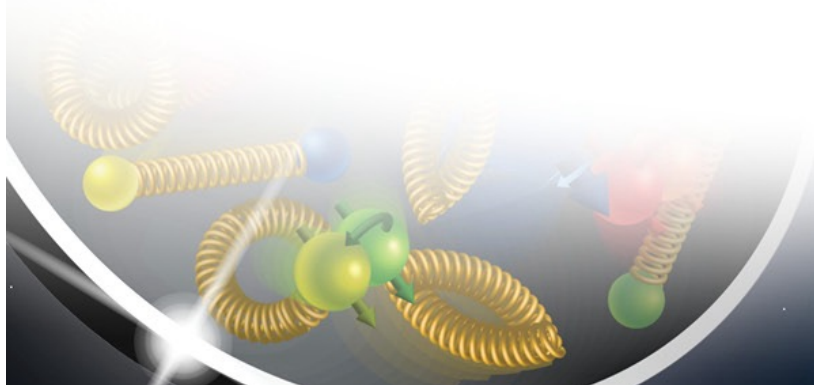
Polarized He-3 Before EIC

- From new EBIS source, intensity ~ $2 \cdot 10^{11}$ $3He^{++}$ ions in 10 μs pulse . Maximum polarization > 80%. Polarized He3 source is expected to be ready in 2026.

- An AC dipole has been installed in the Booster to overcome intrinsic resonances.

- Simulations show that the imperfection resonances up to $|G\gamma|=10$ can be corrected by existing orbit correctors (25A maximum current).

- AGS will run with two partial snakes, 25%+14% (due to larger $|G|$ value, same B field gives stronger partial snake) and both betatron tunes will be put into spin tune gap($\nu_x = 8.95, \nu_y = 8.98$).

- Tracking with 8 particles on the ellipse of 3*2.5 μm emittance for 25%+14% partial snakes. Polarization is good before 60-ν_y.

With the source available in 2026, polarized He-3 development is possible in the AGS during EIC construction.
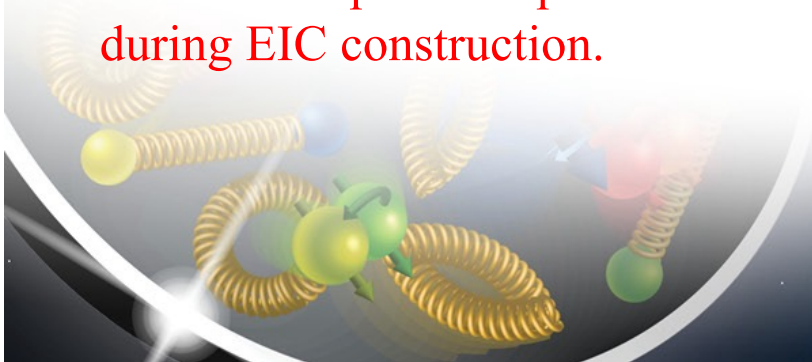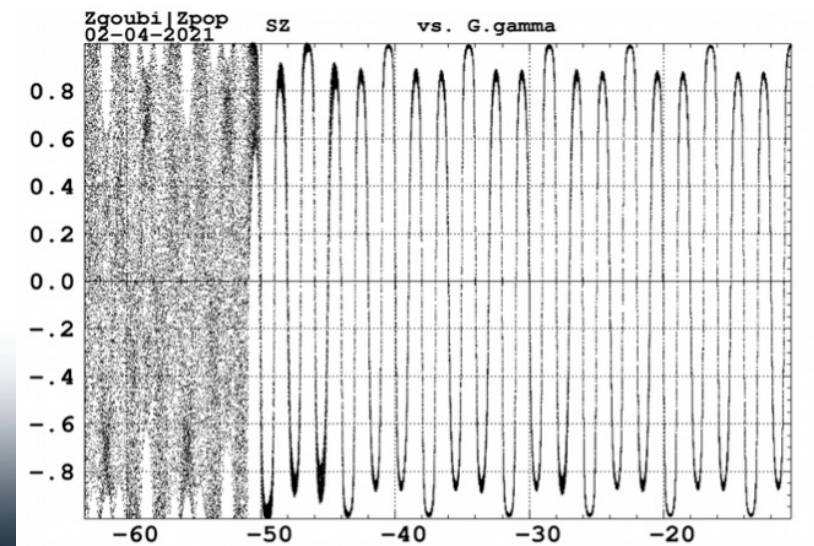
Polarized ³He in Present RHIC

- Existing Siberian snakes and spin rotators for ³He in RHIC
- Much stronger resonance strength requires more snakes.
- The snakes and spin rotators from the 2nd RHIC ring can be reconfigured as additional snakes.

	p	³He⁺²
m, GeV	0.938	2.808
G	1.79	-4.18
E/u, GeV	24-275	11-183
$|G\gamma|$	46.5-525.5	47.5-819.4
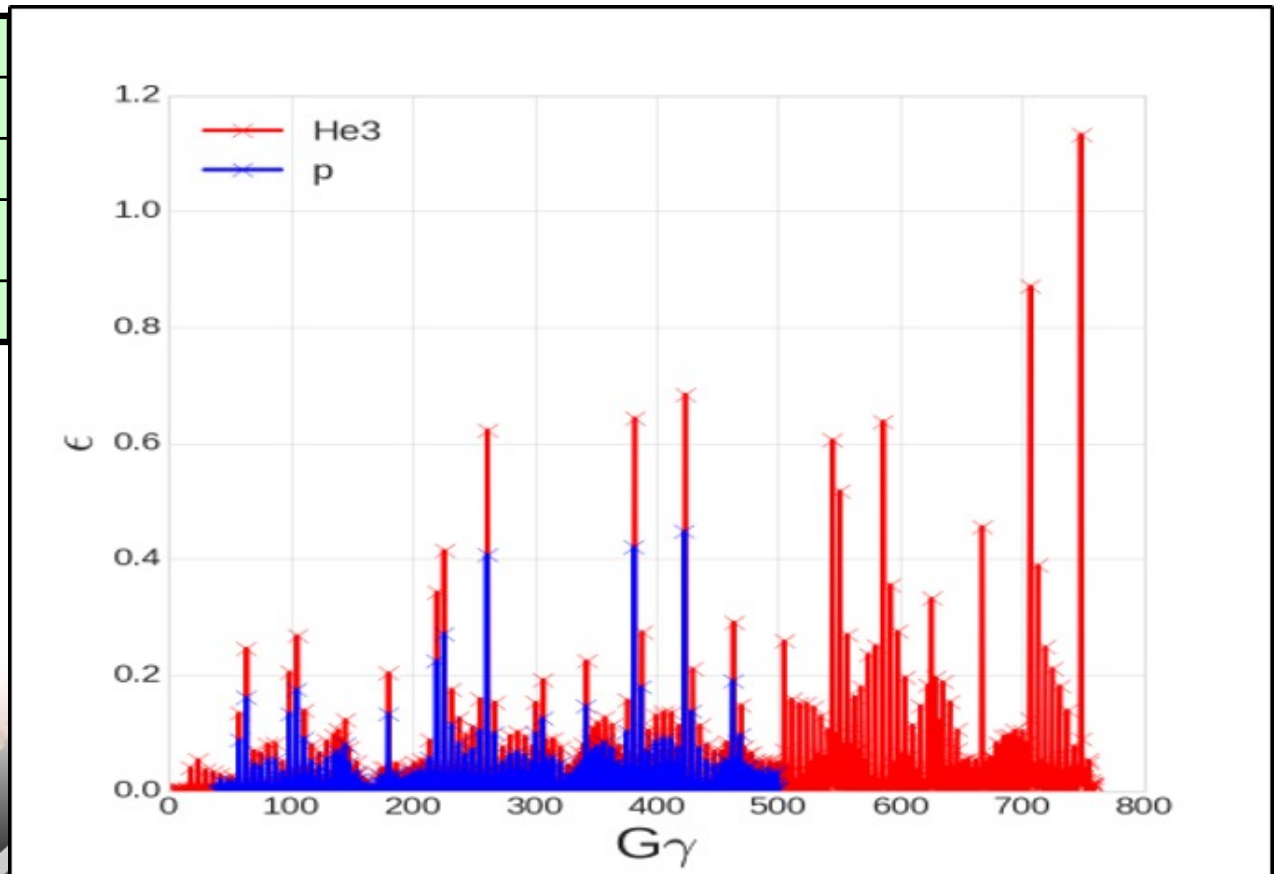
³He Simulation Results

Simulations through the strongest depolarizing resonances for ^{3}He at $763-Qy$ and $681 + Qy$ in EIC lattice. The simulation was done for 1000 particles with Gaussian distributions in 6D phase space. Realistic acceleration rate is used. The betatron tunes are $Qy = 26.21$ and $Qx = 28.228$. The rms normalized emittance for uncooled beam is $\varepsilon = 2.5$ μm in both planes. The rms normalized emittance for uncooled beam is $\varepsilon = 2.5$ μm in both planes and is 0.5 μm in vertical plane for pre-cooled beam.
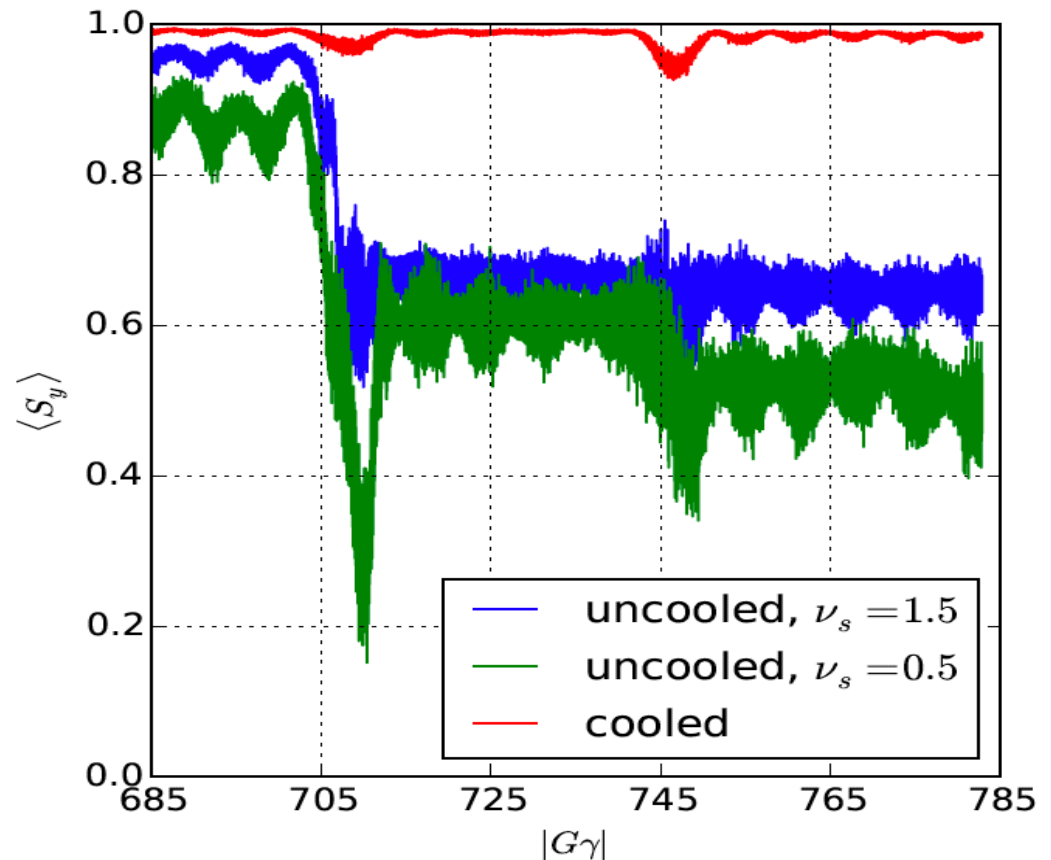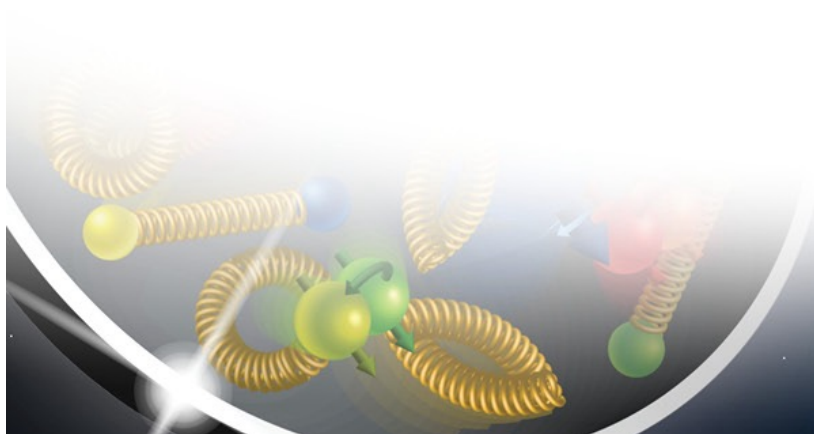

Figure 5: Resonances crossing simulations of the $|G\gamma| = 681+\nu_y$ and $763-\nu_y$ using 1,000 particles with a comparison of transmission of cooled and uncooled emittances.

Pre-cooling is necessary even with six snakes.

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Polarized Deuterons in EIC

- Unpolarized deuteron beam has been used in RHIC during ion physics program.
- Present EIC physics program does not include polarized deuterons.

In EIC hadron ring

	p	³He⁺²	d
m, GeV	0.938	2.808	1.876
G	1.79	-4.18	-0.143
E/u, GeV	24-275	11-183	12-137
$|G\gamma|$	45.5-525.5	47.5-818	1.6-20.9

Small deuteron G:
- Much higher magnetic field required for spin rotation
(Siberian Snakes not feasible)
- But:
  - Weaker resonances
  - Small number of resonances
(makes it possible to deal with individual resonances)

H. Huang, F. Méot, V. Ptitsyn, V. Ranjbar, and T. Roser, Polarization preservation of polarized deuteron beams in the electron ion collider at Brookhaven National Laboratory, Phys. Rev. Accel. Beams 23, 021001(2020).

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Polarized Deuterons in EIC Hadron Ring

- Gγ range: -1.6 to -20.9. 19 imperfection resonances. With rms orbit error of 0.3mm, the strongest resonance strength is less than 0.0015. From the nominal ramp rate in RHIC d-Au run, the ramp rate is about dγ/dt=90/220s=>resonance crossing rate α=1.2E-7.

- A partial snake can be used to overcome these resonances. The required partial snake snake strength is 0.22%. The existing snake is not strong enough. Adding a solenoid is a solution. 15Tm warm solenoid (0.45% partial snake) should work. AGS Solenoid: 4.7Tm and 2.4m long.

- There are 38 intrinsic resonances in the energy range. They can be overcome by a modest vertical tune jump system (0.03 unit in 50 turns). For the strongest one, full spin flip can be achieved (2μm rms emittance assumed).

Haixin Huang

Polarization after Each Intrinsic Resonance

At the strongest resonance, normal ramp is better than tune jump.

Polarization After Each Resonance

γ

Normal ramp, 2π, $\nu_y = .673$
tune jump 0.03 in 50 turns
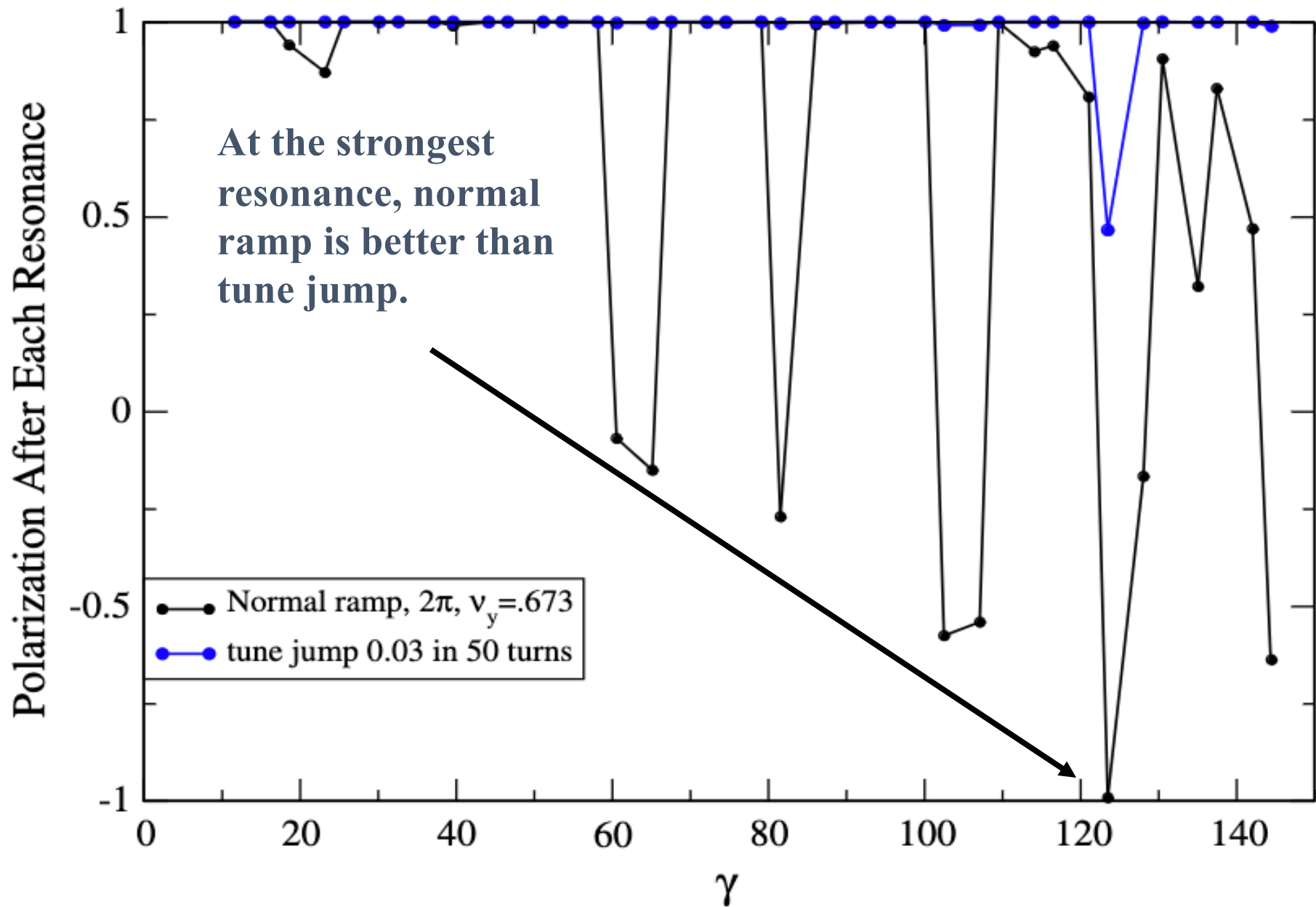
Summary

- Currently, RHIC proton ring can deliver 60% polarization at 255GeV for collisions with $1.8*10^{11}$ bunch intensity.

- For the planned various EIC operation scenarios, AGS can deliver 67-70% polarization. Additional polarization gain would come from the newly installed pulsed skew quads system.

- Extensive simulations have been done for protons in HSR with six snakes. Polarization can be preserved.

- Polarized $^3He^{+2}$ development is expected in about two years when the source is available. Simulations show that the polarization can be preserved with six snakes for pre-cooled beam without orbit errors. With orbit errors, other optimization schemes are needed.

- Polarized deuteron possibility has been explored. The imperfection resonances can be overcome by a solenoid partial snake. The intrinsic resonance can be overcome with modest tune jump.

Haixin Huang