Polarized Proton and He-3 in Run-22 and Beyond

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RHIC Retreat

OPPIS Preparation for Run-21

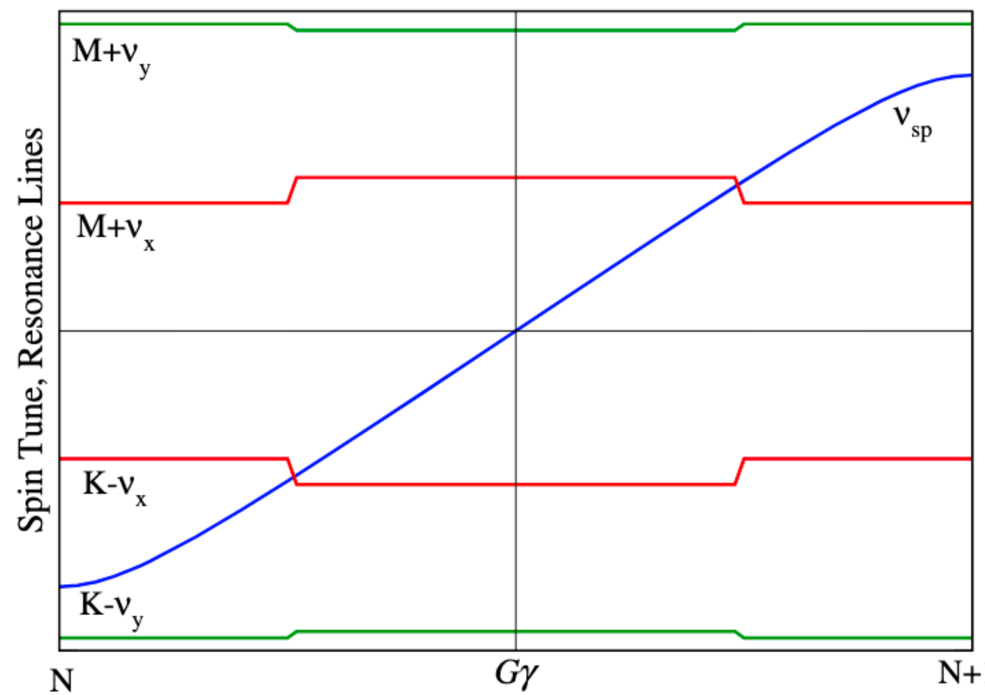
Polarized Protons have not been run for three years. Next Jan., we are going to run polarized protons in the AGS before RHIC operation starts.

- Complete vacuum system refurbishment
- LEBT upgrade for three source operation
- New Laser beam transport and optics box
- Atomic hydrogen injector upgrades
- Control and interlock systems upgrades
- OPPIS system testing and polarization optimization
- 200 MeV polarimeter preparation for the Run.

Horizontal Resonances in the AGS

The stable spin direction is not vertical in the presence of partial snakes. Particles undergoing horizontal betatron oscillations encounter vertical field deviations at the horizontal oscillation frequency. The resonances with the spin tune are driven by the horizontal betatron oscillations and will occur whenever the spin tune satisfies $\nu_{sp} = N \pm \nu_x$. A modest tune jump has been used to mitigate these weak resonances.

On the other hand, betatron coupling can cause so-called coupling resonances at the same condition: $\nu_{sp} = N \pm \nu_x$. The horizontal resonance from the partial snakes can be compensated by introducing coupling resonances with equal strength but opposite phase.



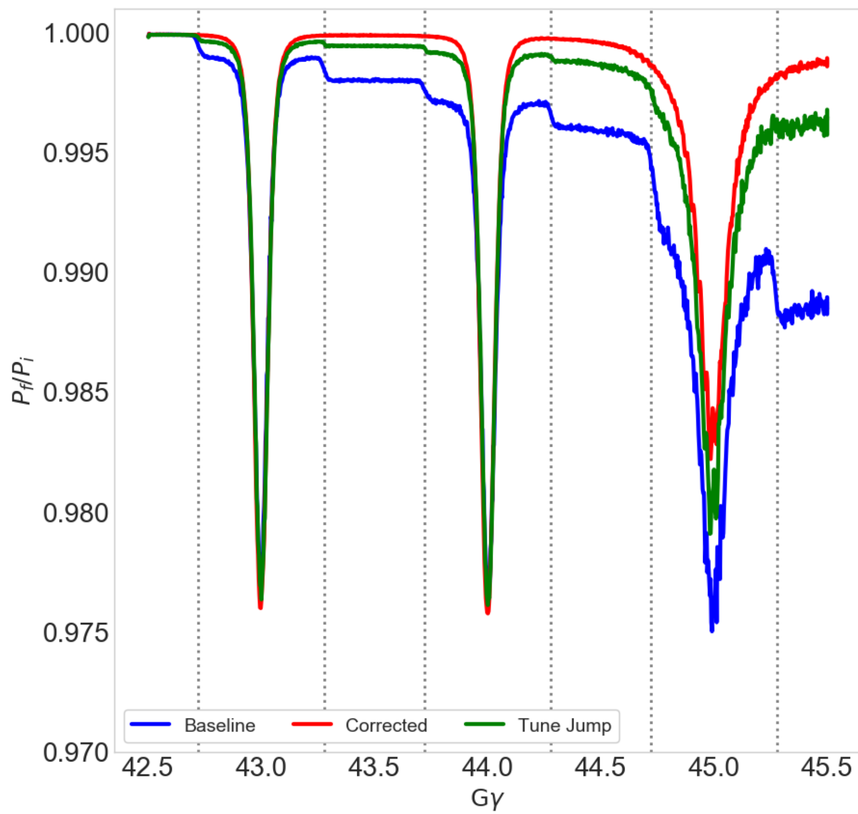
Horizontal Resonance Suppression with Betatron Coupling

- Both horizontal resonance due to partial snakes and resonance from betatron coupling occur at

$$\nu_{\mathrm{sp}} = N \pm \nu_x$$

- Introduce skew quads to excite coupling spin resonance to cancel snake drive term
- Benefits:
    - Possibility of full resonance correction (tune jump is limited by the jump amplitude of 0.04)
    - Tune jump is sensitive to timing at the 100 μs level. The determination of jump timing is a pain in the neck. Skew quad is on for a full millisecond around the resonance. The timing accuracy is relaxed to ms level.
- Design challenges:
    - Phasing changes a lot from resonance to resonance, requires fast ramping skew quads
    - ν_y is near integer, additional constraints to limit optics distortion

Vincent is leading the effort.

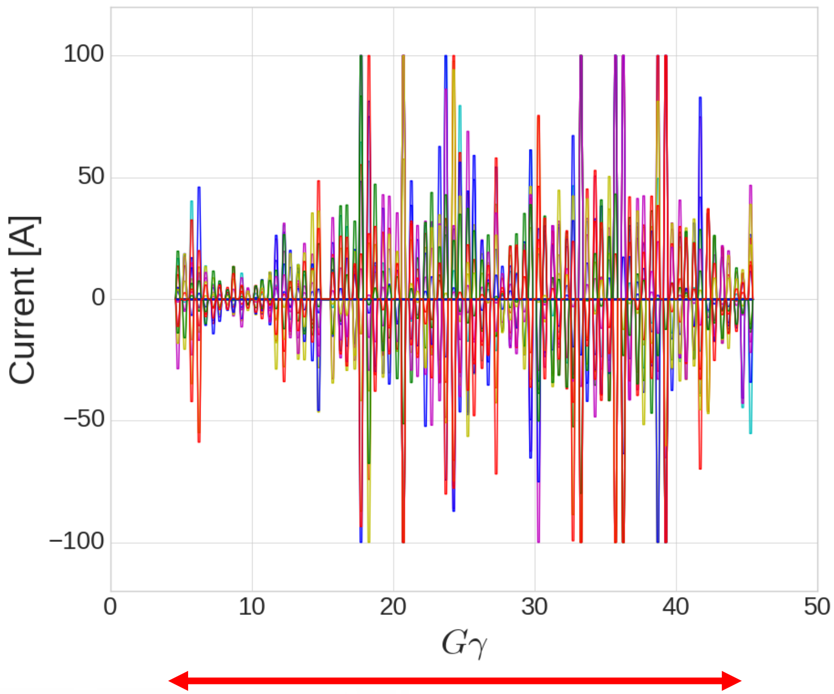


Correction with 15 skew quadrupoles

Skew Quad Current Functions

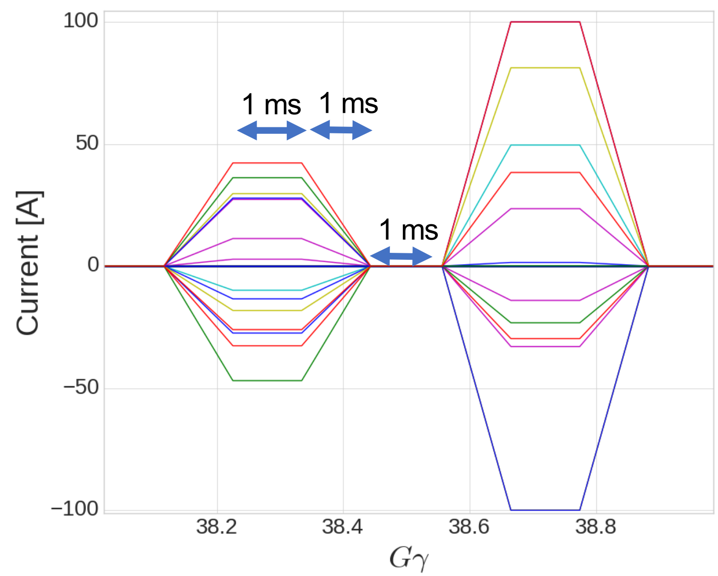
Following results Use 15 quads with 0.35m length.
Current assuming the transfer function of the 'thin' quads for cold snake compensation
1 ms ramp up, 1 ms hold, 1 ms ramp down. : rms current is ~25 A

Corrector currents



400 ms

100 A = 0.07 Tesla pole-tip field



The power supply required for these quads are large due to the short length. We are looking for solutions to make the magnets longer and power supply smaller based on available space in the AGS ring. Schedule is tight for the system to be ready by Run-22.

Emittance Preservation in AGS

Demonstrated in Run 17: Peak current-driven emittance growth at AGS injection

Addition of defocusing RF voltage:

- 20% reduction in peak current
- 15% reduction in vertical emittance

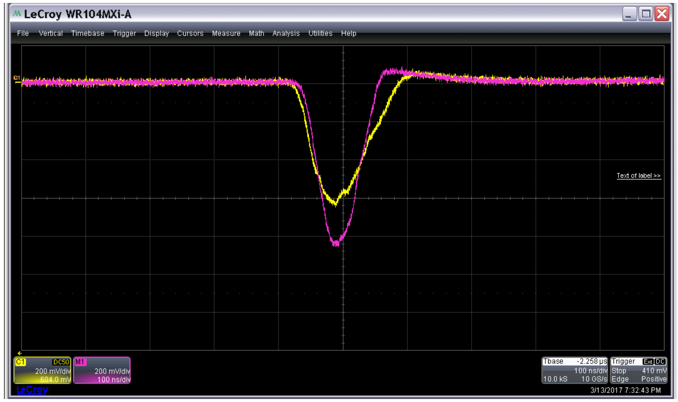
AGS has large injection space charge tune shifts

$\Delta Q_{sc}(x,y) = -0.17, -0.25$

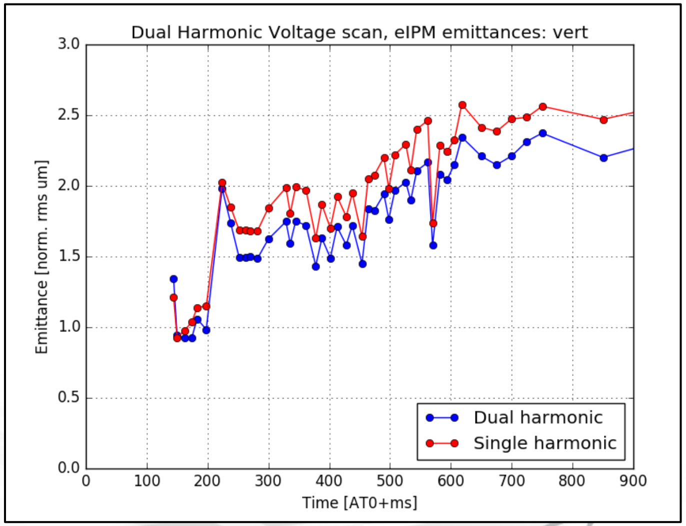
Two further mitigation strategies

1. Raise the Booster to AGS transfer energy. It is possible now with AC dipole to overcome intrinsic resonances in the Booster. But this at least requires upgrading Booster extraction(F3, F6), AGS injection(L20,A5) from ~9-9.5Tm to 10.8Tm(for He-3 at $|G\gamma|$=10.5) or 12.8Tm(for proton at $G\gamma$=7.5).
2. Bunch splitting/merging

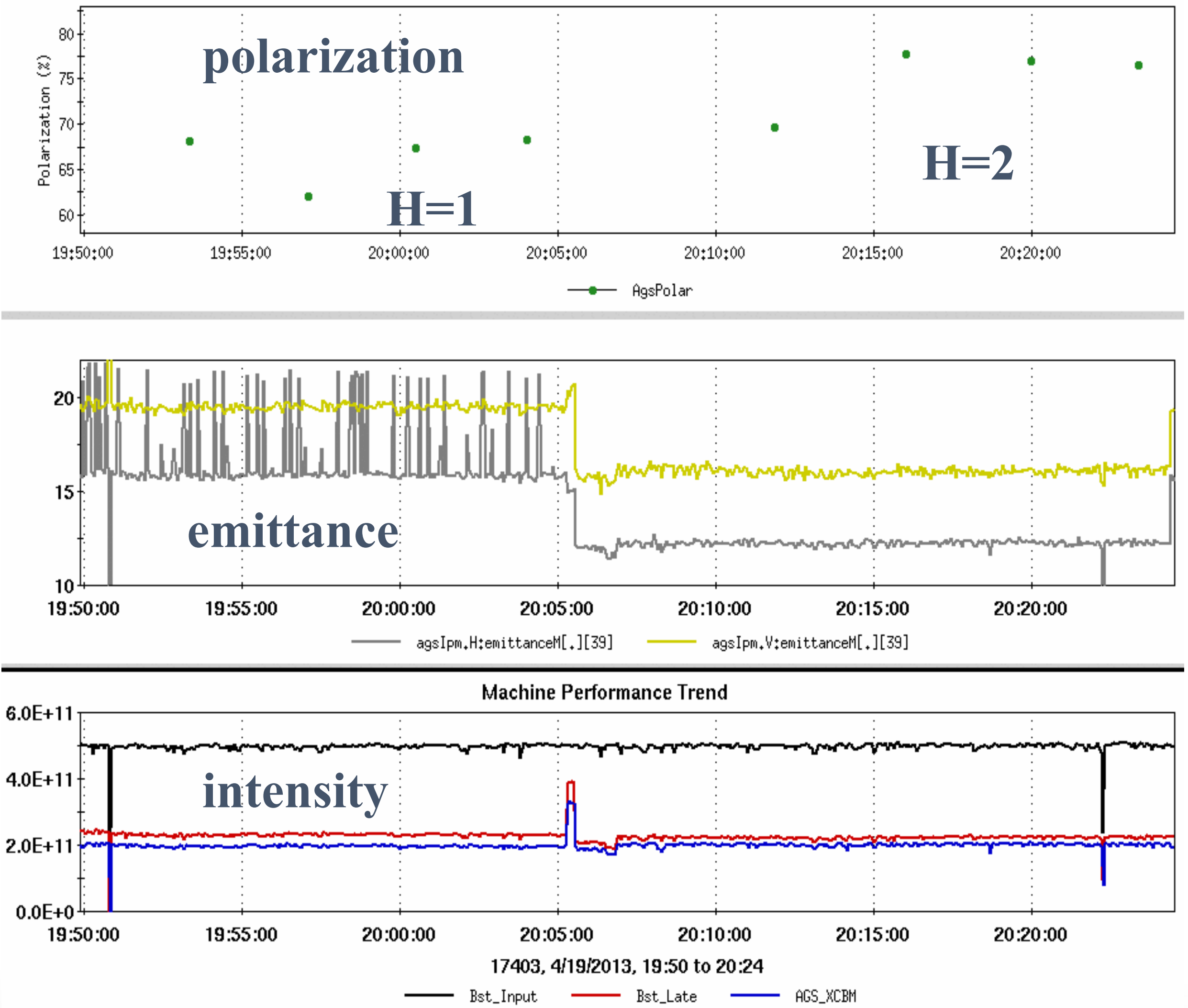
AGS Longitudinal distribution



AGS Vertical Emittance



Booster H=2 and H=1 Comparison (Done in 2013)



1. The emittance growth in AGS is larger for higher bunch intensity.
2. With intensity dependent emittance growth at the AGS injection and ramp, a bunch merge at high energy may lead to smaller emittance for high intensity beam.
3. The better polarization with h=2 seems consistent with this argument.
4. However, capture with h=2 at Booster injection prevents dual harmonic to mitigate the space charge effect. Need other approach for full benefit.

4/19/2013	B	B_{input}	B_{late}	A_{CBM}	$MW006_H$	$MW006_V$	AGS_H	AGS_V	$P_{ave.}$
	h	10^{11}	10^{11}	10^{11}	$\pi\mu m$	$\pi\mu m$	$\pi\mu m$	$\pi\mu m$	%
19:53 - 20:04	1	5.0	2.30	2.00	10.5	3.49	16.0	19.8	66.5
20:11 - 20:23	2	5.0	2.25	2.02	11.9	3.13	12.3	16.1	75.2

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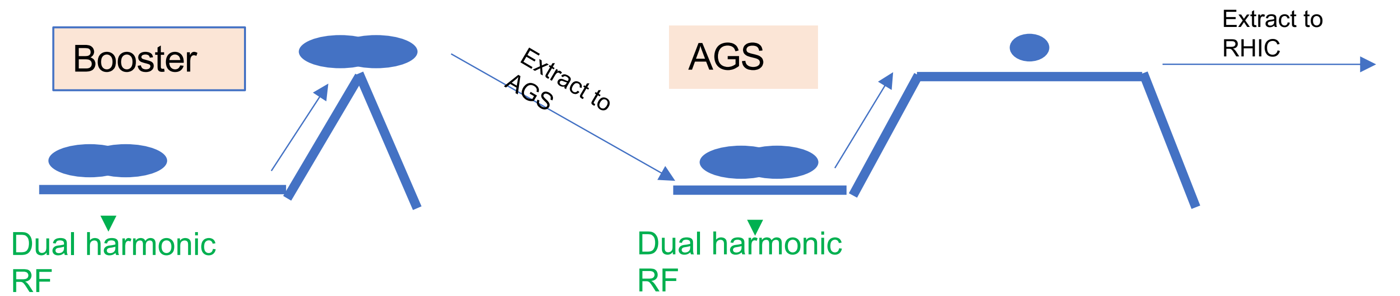
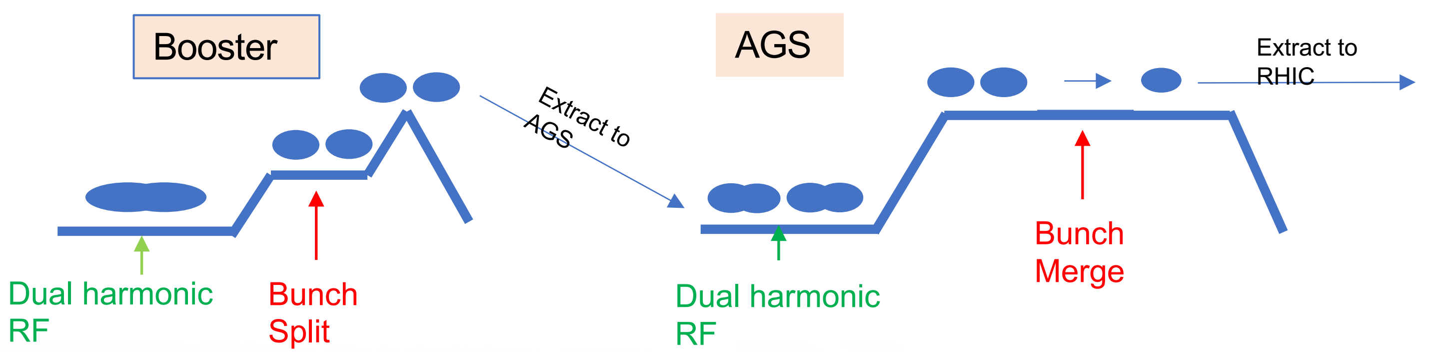
Splitting and Merging Polarized Protons

Present scheme: Single bunch from source to RHIC, dual harmonic RF at Booster and AGS injection

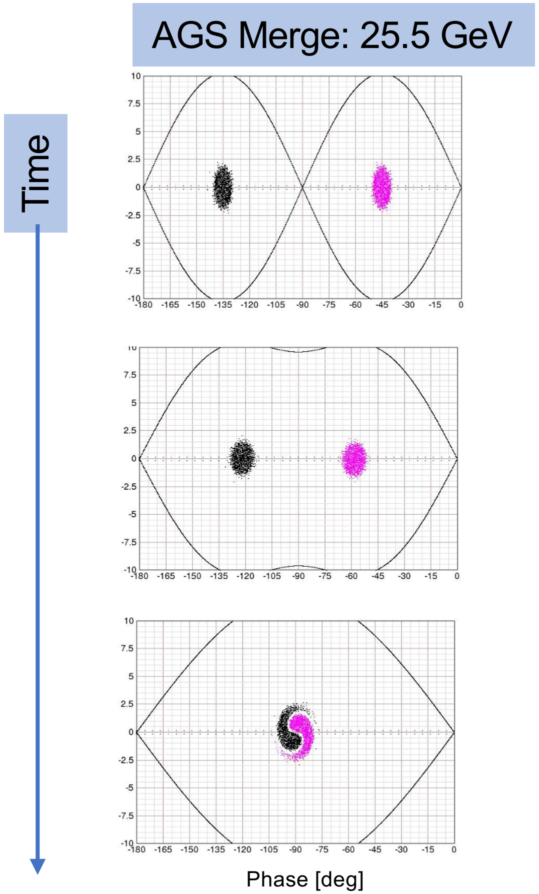


Proposed scheme: Add a longitudinal split in Booster and merge in AGS at 25.5 GeV



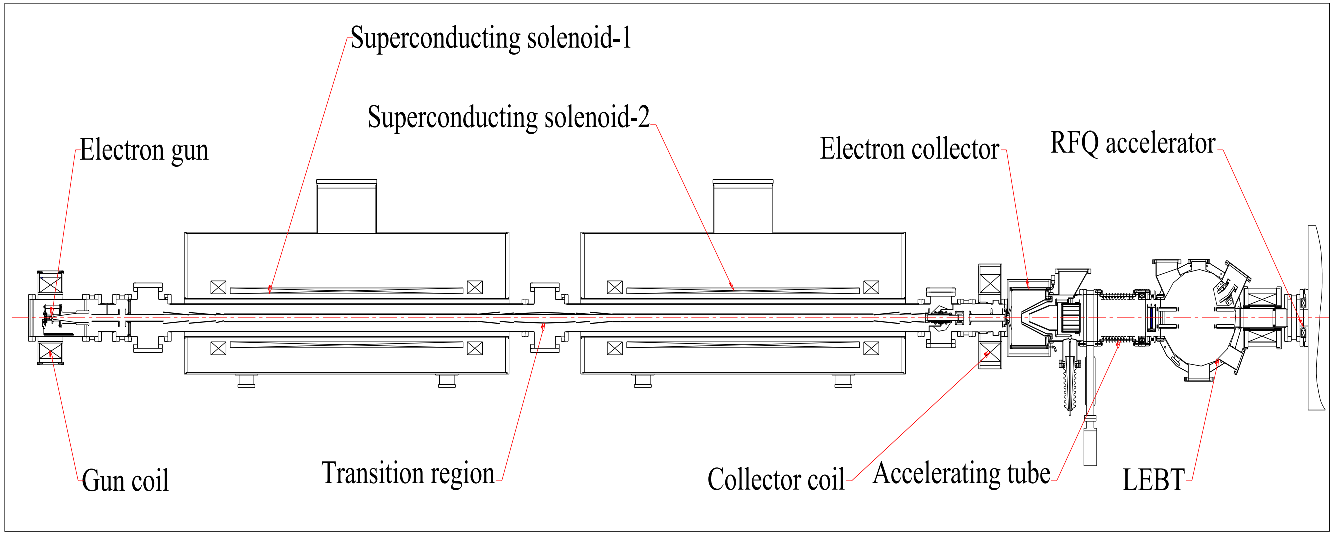
Splitting and Merging Polarized Protons

- Split bunches at AGS injection have
  - ½ intensity
  - ½ longitudinal emittance
  - 30% reduced peak current (and peak space charge)
- Longitudinal bunch merges are common in Booster and AGS for heavy ions BUT
- Possible challenges:
  - What are the spin and beam dynamics constraints to the energy of the 'split porch' in the Booster?
  - Synchrotron period at AGS extraction energy is ~12 ms, a reasonable merge takes ~500 ms in simulation
    - Longitudinal emittance growth, dipole noise over a long period etc.



If time allows, the bunch merge will be tested next January before RHIC setup.

Polarized He-3 source and Extended EBIS



Extended EBIS

- The He3 source is presently being realized as a part of an extension of existing EBIS ion source
- Additional solenoid extends the trap length leading to 40-50% heavy ion intensity increase

- Developed by **BNL-MIT collaboration**
- He-3 is polarized using Metastability Exchange Optical Pumping (MEOP) mechanism
- Ionized in the ionization cell using electron beam (up to 10A)
- High magnetic field (5T solenoid)

- Intensity ~ $2 \cdot 10^{11}$ $3He^{++}$ ions in 10 μs pulse
- Maximum polarization > 80%
- Polarized He3 in RHIC in 2023

Polarized He-3 beam at EBIS

- Optical pumping studies of He-3 in high magnetic field is in progress
- Cryogenic He-3 gas delivery system provided required gas purity.
- He-3 cell and laser system for the optical pumping is near completed
- Pneumatic gas filling valve was successfully tested.
- Pulsed electromagnetic valve developed for the polarized gas injection to the EBIS.
- Polarized He-3 cell development for installation to the extended EBIS is in progress
- He-3 Spin-rotator and absolute polarimeter (based on He3-He4 elastic scattering) is in progress.

Booster AC Dipole

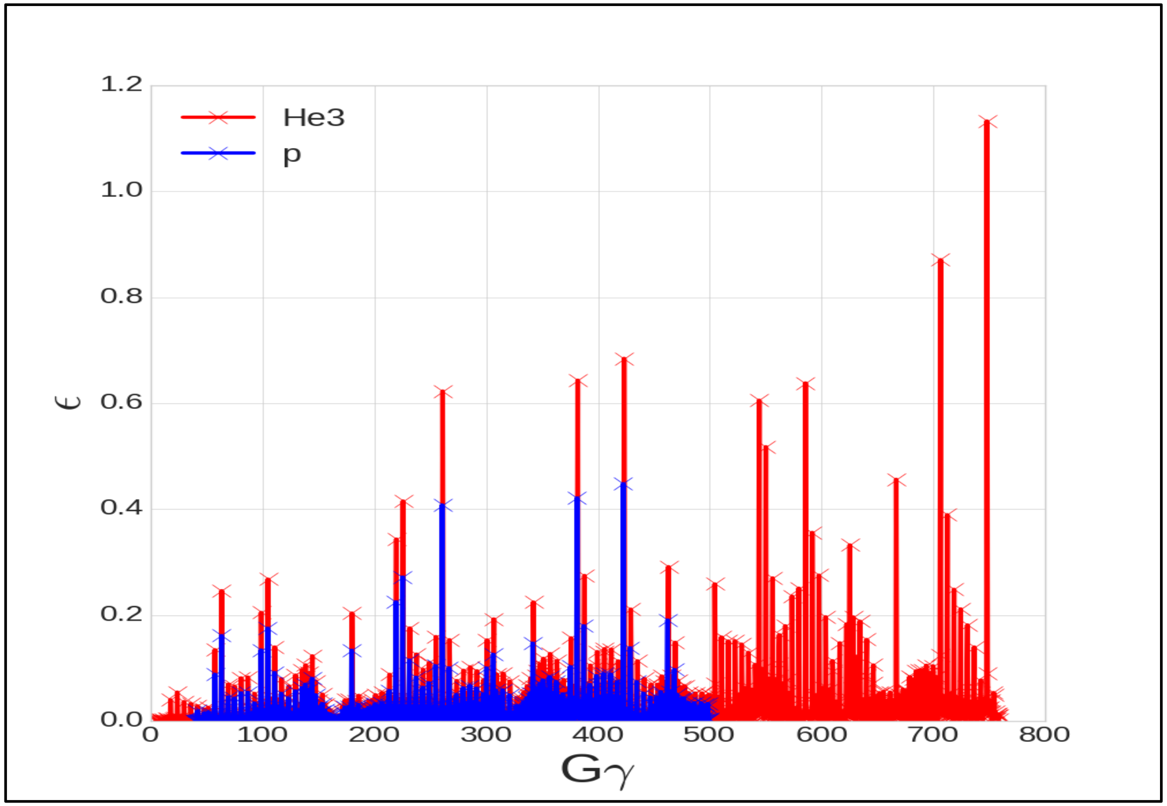
- The Booster AC dipole design strength is 25Gm. We don't have the required power amplifier yet. The one taken from RHIC AC dipole has shown 17Gm which is enough for the proton test. This strength is also enough for 12- ν_y , which is needed for $|G\gamma|$=7.5. For $|G\gamma|$=10.5, a stronger 6+ ν_y requires stronger AC dipole.
- The plan is to do beam test during NSRL operation.
- There are 3 parts of the commissioning:
  - Drive large amplitude oscillations and confirm measured Y_{coh} matches expectations (through use of BPMs).
  - Drive large amplitude oscillations and confirm there is no emittance growth (using scrapers in the Booster).
  - Cross $G\gamma = 0 + \nu_y$ with polarized protons and confirm measured polarization matches expectations for correlated $B_m l$ and δ_m values.
- Items 1 and 2 can be performed without polarized protons. Beam test with unpolarized protons has started Oct. 14.
- Polarized protons is needed for item #3 and is scheduled for the coming Jan. AGS polarimeter will be needed at injection.

Polarized He-3 in Booster and AGS

- Two options for Booster extraction: extraction at either $|G\gamma|$=7.5 or 10.5. $|G\gamma|$= 7.5 is similar to Bρ of proton case. $|G\gamma|$= 10.5 would require upgrade of Booster extraction and AGS injection magnets. No constraint for $|G\gamma|$=7.5 injection case.
- 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 about same strength, 15% (due to larger $|G|$ value, same B field gives stronger partial snake) and both betatron tunes will be put into spin tune gap.
- With polarized He-3 source available in 2023 and longer stores in RHIC are expected, polarized He-3 development can start in the AGS behind RHIC stores (although coexisting with NSRL is an issue). The carbon polarimeter has been tested in 2012 at AGS extraction energy with unpolarized beam. The asymmetry may be diluted due to inelastic scattering (He-3 breakup). Ramping beam down to initial energy can be used to determine polarization level before calibration with polarized He-3 target.

Polarized He-3 in RHIC

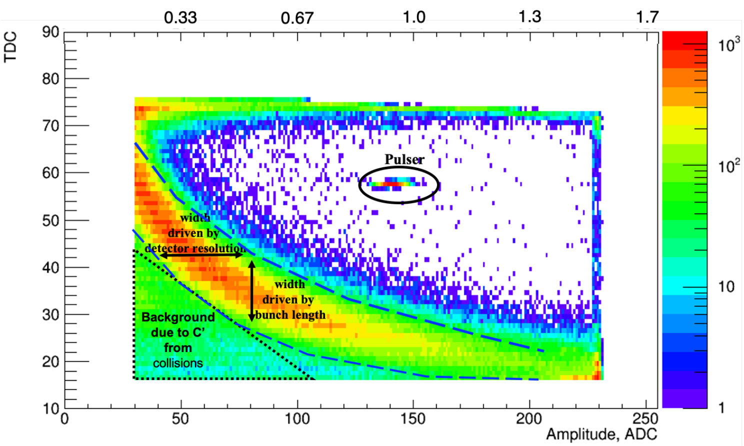
	p	$^3He^{+2}$
m, GeV	*0.938*	*2.808*
G	*1.79*	*-4.18*
E/u, GeV	*24-275*	*16-183*
$\vert G\gamma \vert$	*46.5-525.5*	*72.6-819.4*



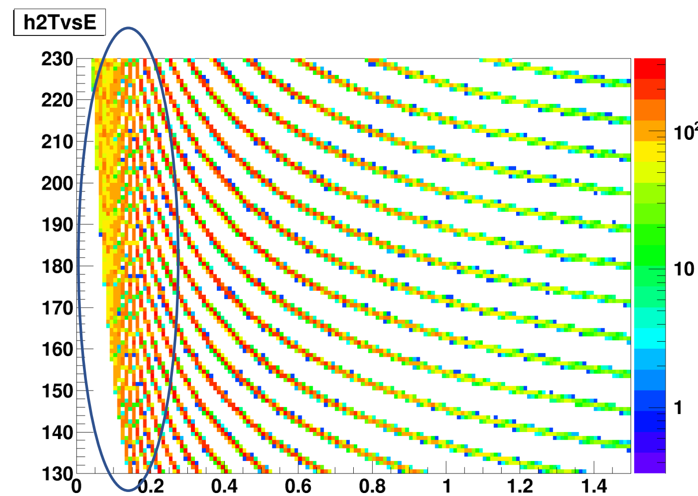
- For He-3, existing RHIC Siberian snakes and spin rotators can be used for the spin control, with less orbit excursions than with protons.
- 2 Snakes can preserve He-3 polarization up to about 60GeV. If polarization is needed for polarimetry test, this is the highest energy we can provide polarized He-3 beam in RHIC.
- Before polarized He-3 jet is available, ramping down with beam can be an option to find analyzing power at higher energy.

EIC Polarimetry Challenges

In RHIC precise polarization measurement includes Energy-TOF correlation analysis to cut background



In EIC the bunch spacing is reduced by factor 12 (to 9ns) creating problem with background separation



Challenges for EIC: 1% systematic uncertainty requirement, bunches closer in time, background not yet totally understood, heating of pC polarimeter targets.

Heating due to Beam Energy-loss

Assumptions used for the temperature estimates

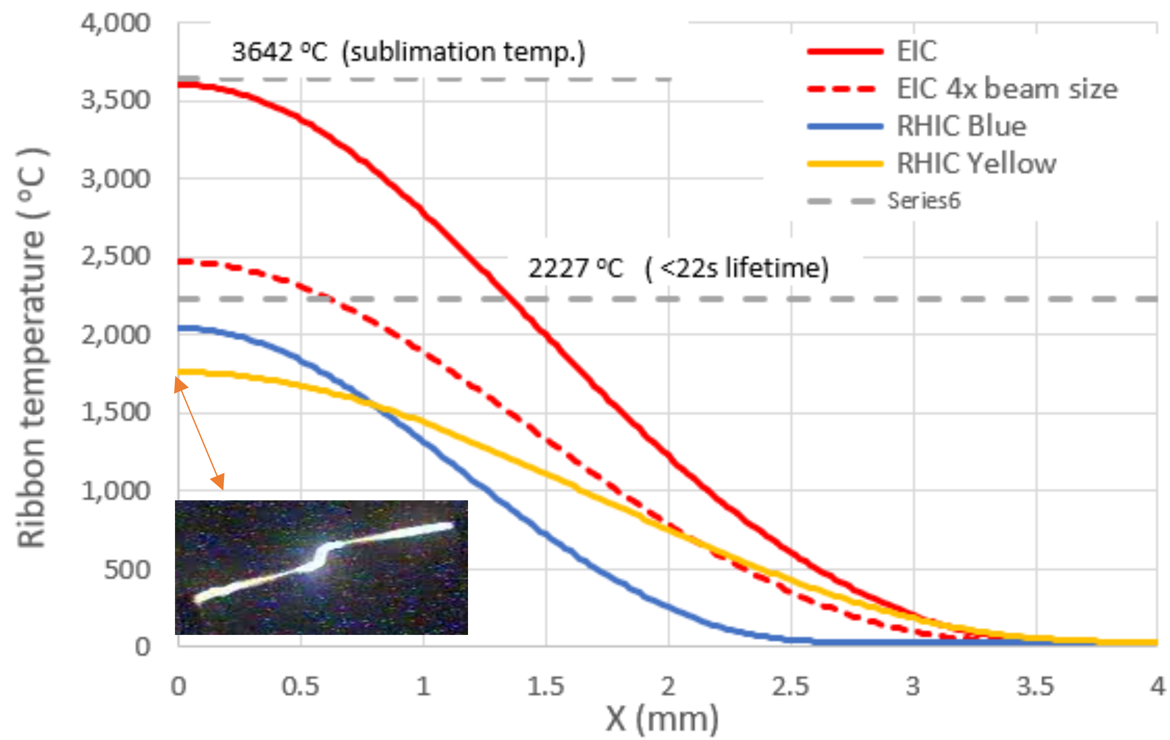
dE/dx = 1.8 keV cm^2/mg
(close to minimum ionizing)

16 eV proton energy loss

Emissivity = 0.7

Only radiative cooling is significant.

Constant emissivity is used because graphite emissivity data at these temperatures is not available.



- ➢ Solid targets for proton polarimetry will not survive in EIC operating at design intensities.
- ➢ Cluster jet targets may be an attractive solution for EIC by providing fixed targets.

Polarimeter Related Tests

- A test on the RHIC polarimeters, using a second layer of silicon strips, is planned for 2022, to understand the feasibility of vetoing prompts.
- Recent PHENIX experiment results show large asymmetry in p-Au collision. It is believed due to high Z effect. Using gold as target material could be problematic due to its low melting point. Tungsten is considered and we are in contact with CFN for the target material development. If it is available in the right form, it will be put into RHIC for testing. The gaseous xenon target material will also be explored.
- For He-3 polarimeter, basic functioning of the carbon and jet polarimeters need to be checked. For example, He-3 breakup needs to be studied. The plan is to add ZDC (spare PHENIX) 18 m away from H jet (outside vacuum) to study it. A harder one is to add scintillators inside the beam pipe, downstream of jet target, to tag target and beam breakup. All of above require He-3 beam in RHIC.

Summary

- Booster AC dipole is needed for polarized He-3. It also overcomes all intrinsic resonances and allows higher rigidity for AGS injection (p and He-3). Next Jan., it will be tested with polarized proton beams (polarization will be checked at AGS injection). In addition, bunch merge at AGS flattop will be studied.
- 250/255GeV polarized proton operation is requested by STAR for FY22.
- A skew quad system to compensate polarization losses from horizontal resonances in the AGS is under development. We need to work very hard to make it available for Run-22.
- Polarized He-3 source would be ready in 2023. Polarized He-3 study can start in 2023.
- Polarimetry for EIC requires beam test. This will be carried out during proton operation in 2022 and future years.
- As RHIC history showed, polarization requires development time. Unlike RHIC, EIC requires polarization in almost all physics programs, which makes the development time during RHIC operation critical. We need to plan the polarization development before RHIC shutdown.

Backup Slides

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Raising AGS Injection Energy

Actually driven by helium-3 spin considerations

Raising injection of He3 from $|G_{He}\gamma| = 7.5 \rightarrow 10.5$ reduce the optical distortion induced by partial snakes and avoids a major AGS resonance crossing

This would also allow higher energy transfer of protons.

$$|G_{proton}\gamma| = 4.5 \rightarrow 6.5$$

Protons injected at the higher rigidity would have space charge tune shift reduced by 70%

Challenges:

- Additional spin resonance crossing in the Booster and AGS need to be considered (and avoided)
- Spin transparency of the transfer line is energy dependent (-3% pol for $G_{proton}\gamma = 6.5$)
- Expensive: Booster main dipoles and quads, Booster RF, transfer line dipoles and pulsed power need upgrades