Beam Polarization Aspects of eRHIC

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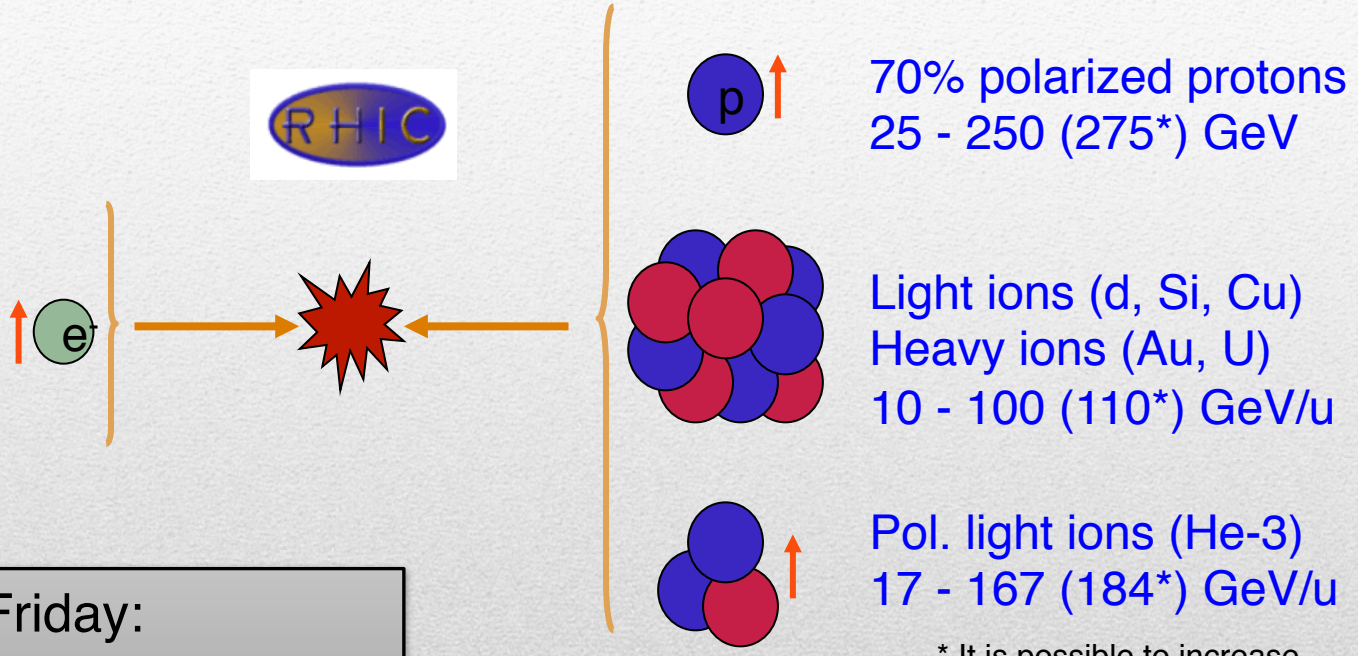
Center-of-mass energy range: 30 – 145 GeV
Any polarization direction in electron-hadron collisions



70% polarized protons
25 - 250 (275*) GeV

80% polarized electrons:
5 – 21.2 GeV

Light ions (d, Si, Cu)
Heavy ions (Au, U)
10 - 100 (110*) GeV/u

Pol. light ions (He-3)
17 - 167 (184*) GeV/u

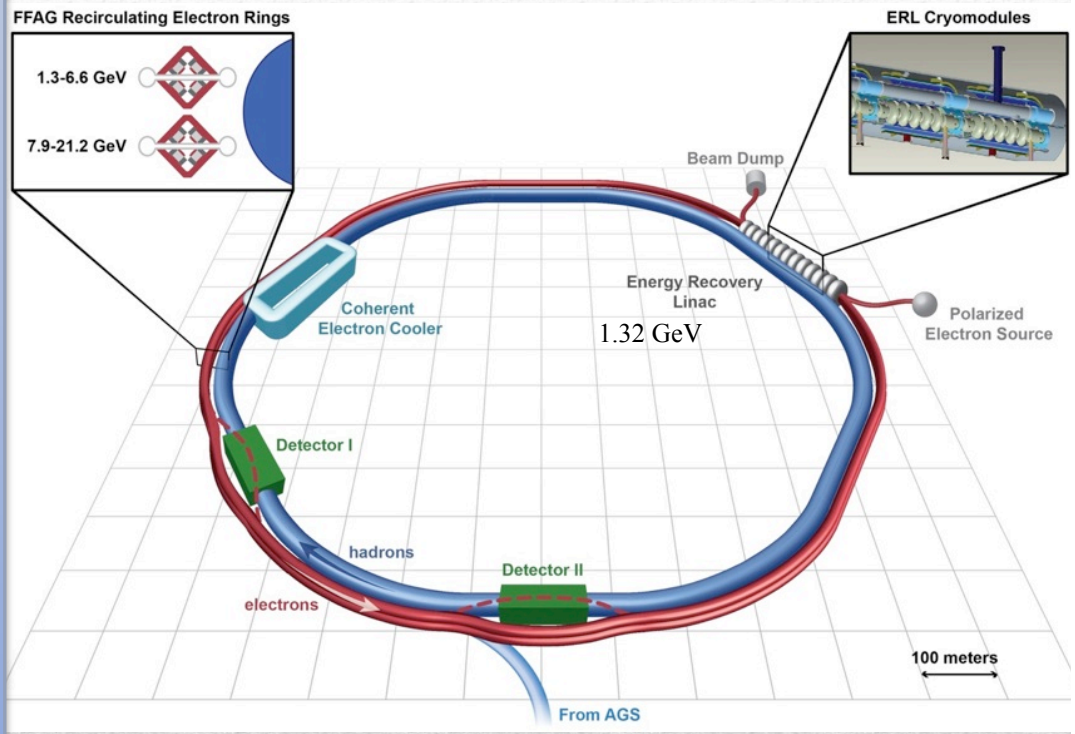
* It is possible to increase RHIC ring energy by 10%

Talks about EICs on Friday:
- *M.Bai: "EIC in the US"*
- *X.Chen: "EIC/HIAF in China"*

eRHIC: QCD Facility at BNL

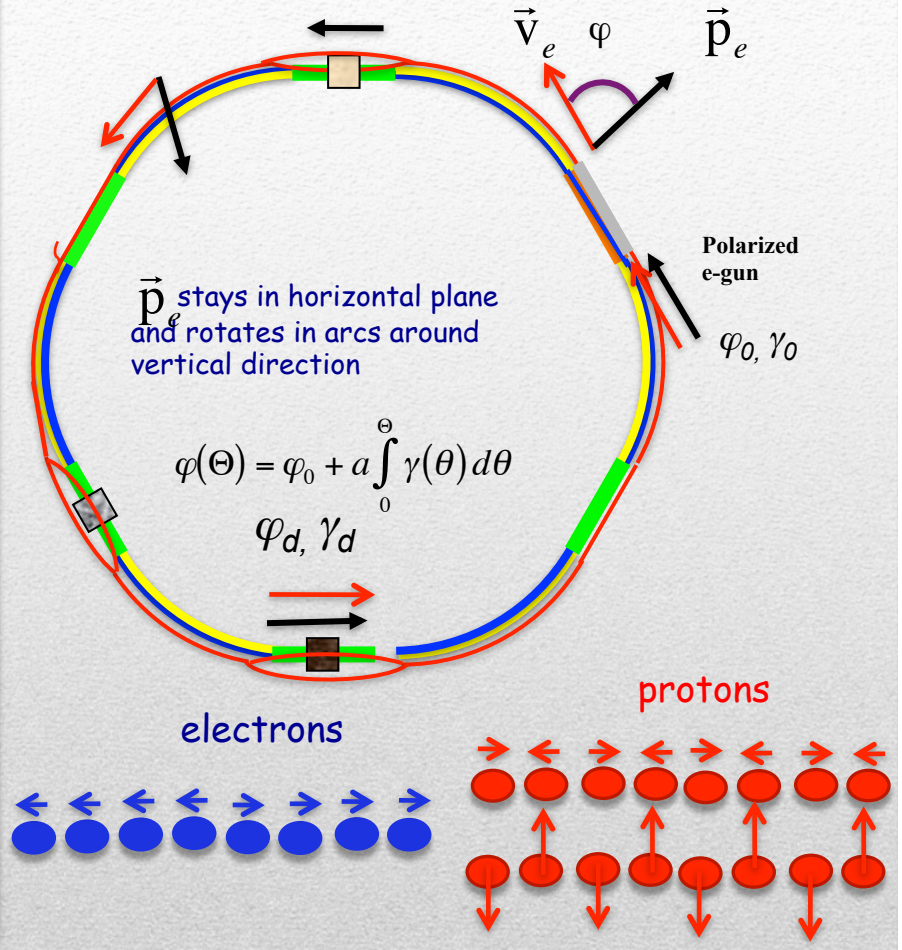
FFAG eRHIC Design

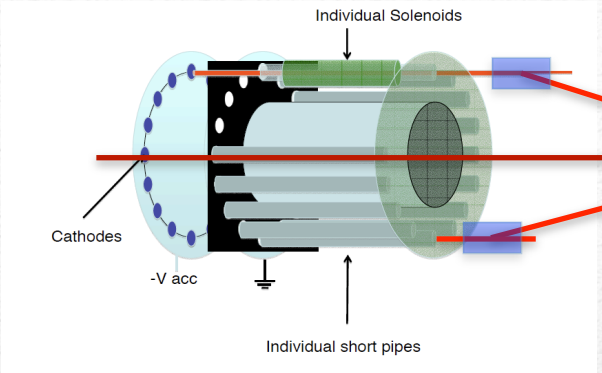
- Up to 21.2 GeV electron beam accelerated with Energy Recovery Linac (ERL) inside existing RHIC tunnel collides with existing 250 GeV polarized protons and 100 GeV/n HI RHIC beams
- Single collision of each electron bunch allows for large disruption, giving high luminosity and full electron polarization transparency
- Use 2 FFAG magnet strings in RHIC tunnel to transport up to 16 beams
- Considered permanent magnet design for FFAG lattice magnets
- Cool hadron beam 10-fold in all directions using coherent electron cooling (CeC) at reduced intensity of hadron beam
- IR design with $\beta^* = 5$ cm using SC magnet technology and crab-crossing scheme
- Average polarized electron current of 50 mA

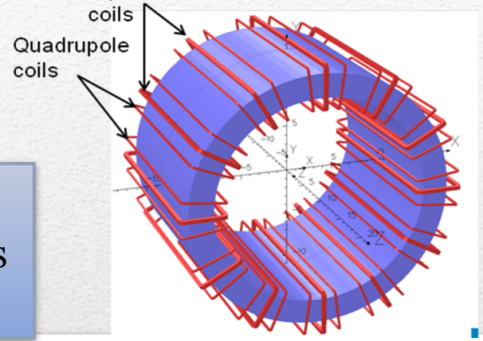


Electron Polarization in eRHIC

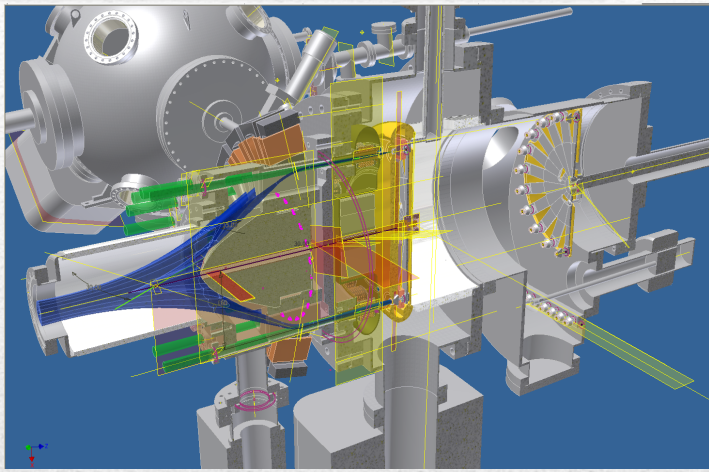
- 90% longitudinally polarized e-beam from DC gun with super-lattice GaAs-photocathode.
- Only longitudinal polarization is needed in the IPs.
- eRHIC avoids lengthy spin rotator insertions. Cost saving.
- Integer number of 180-degrees spin rotations between the gun and IPs
- With the linac energy of 1.322 GeV the polarization is longitudinal at both experimental IPs.
- Wien filter in the injector for small polarization direction adjustments.
- To achieve 80% polarization up to 21.2 GeV harmonic cavities are used for the energy spread reduction







BNL Gatling Gun R&D:
the current from multiple cathodes is merged

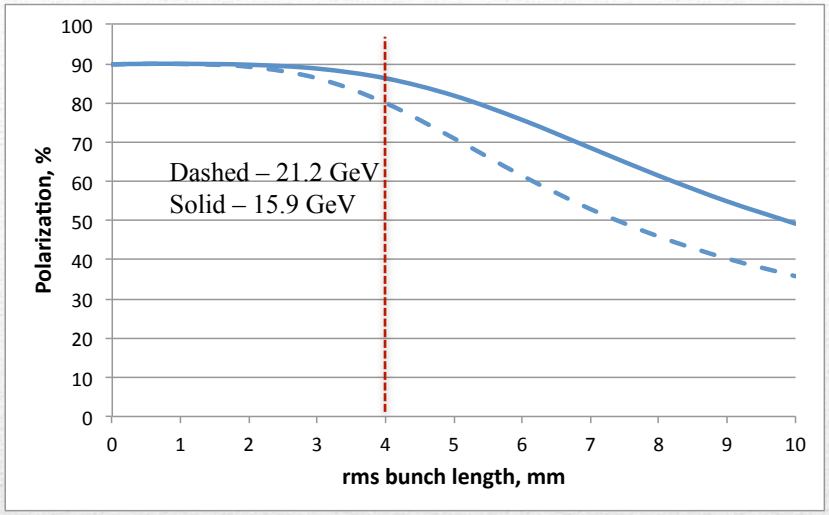


Talk on Friday:
I.Ben-Zvi, "High current electron guns for eRHIC"

- Prototype with 20 potential cathodes has been built
- Photo current from two cathodes during first test at Stangenes Industries (CA)
- End of 2014: test with two cathodes in Stony Brook

In parallel another R&D, for a large cathode gun, is underway in MIT. (E.Tsentalovich)

50 mA polarized electron source R&D



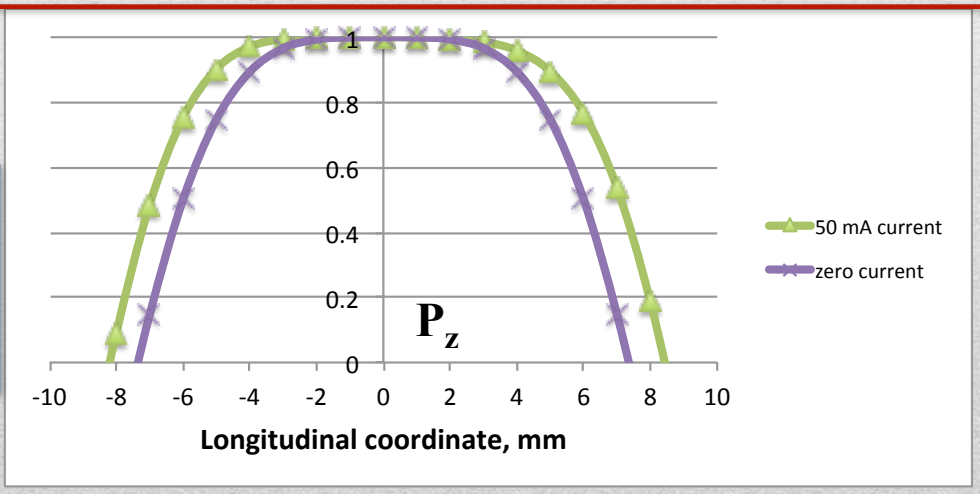
Shown is the averaged polarization: for two top energies

$$P = \left\langle \cos\left(\Delta\varphi_{sp}\right) \right\rangle$$

To reduce energy spread and achieve acceptable polarization transmission 5th harmonic cavity system will be used : 2.1 MHz; 45 MeV

Longitudinal polarization profile along the bunch

The energy spread created by the beam interaction with the beam pipe resistive wall and with the linac cavity wakes reduces spin de-coherence effect



Polarization Loss due to Decoherence

Spin Diffusion due to Synchrotron Radiation

Well known effect from the electron storage rings:
Quantum nature of the synchrotron radiation leads to depolarization

One can consider to apply a Fokker-Plank method approach developed for studies of the spin decoherence in storage rings (K.Heinemann, DESY Report 97-166) for the recirculating linac case.

Diffusion equations for second moments of the energy deviation-spin angle distribution:

$$\overline{\Delta E^2}' = \omega$$

$$\overline{\Delta E \Delta \phi}' = \alpha \overline{\Delta E^2}$$

$$\overline{\Delta \phi^2}' = 2\alpha \overline{\Delta E \Delta \phi}$$

$$\omega = \frac{C}{\rho^3} \lambda\!\!\!^{-}_c r_e \gamma_0^5 E_0^2 \qquad C = \frac{110\sqrt{3}}{144}$$

$$\alpha = \frac{1}{\rho E_{r1}} \qquad E_{r1} = 0.441\,\mathrm{GeV}$$

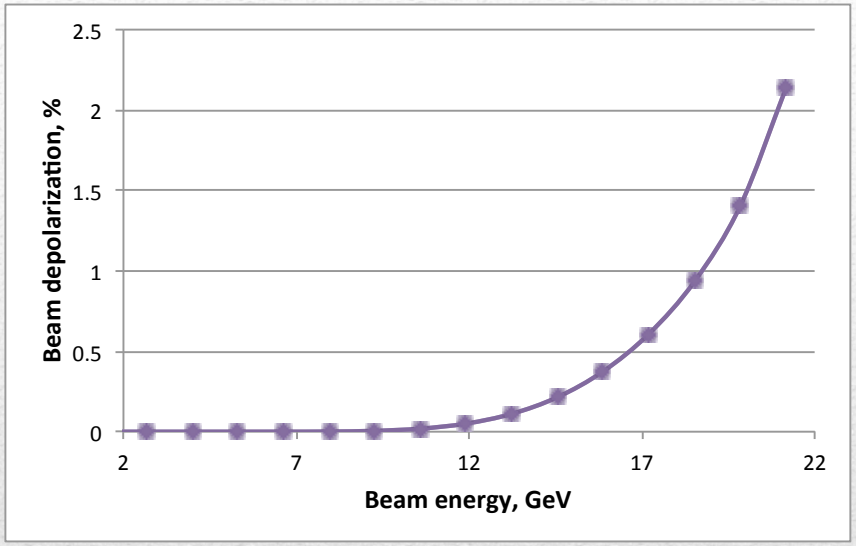
Solution of spin diffusion equations

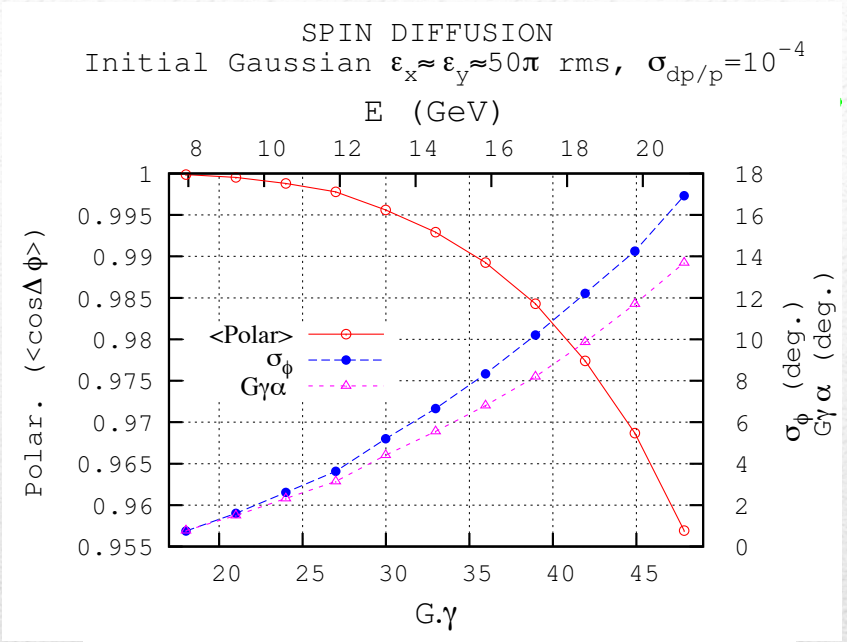
Solution in a constant field region is:

$$\begin{pmatrix} \overline{\Delta E^2} \\ \overline{\Delta E \Delta\phi} \\ \overline{\Delta\phi^2} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ \alpha s & 1 & 0 \\ \alpha^2 s^2 & 2\alpha s & 1 \end{pmatrix} \begin{pmatrix} \overline{\Delta E^2} \\ \overline{\Delta E \Delta\phi} \\ \overline{\Delta\phi^2} \end{pmatrix}_0 + \omega \begin{pmatrix} s \\ (\alpha s^2)/2 \\ (\alpha^2 s^3)/3 \end{pmatrix}$$

- One can find the corresponding transformation matrices for magnets, cells, and individual recirculating passes at given beam energy.
- Doing then pass-by-pass propagation of second order momenta one can find their values at the interaction point(s)

Analytical calculations were used to benchmark the simulation code ZGOUBI





ZGOUBI simulation (F. Meot)

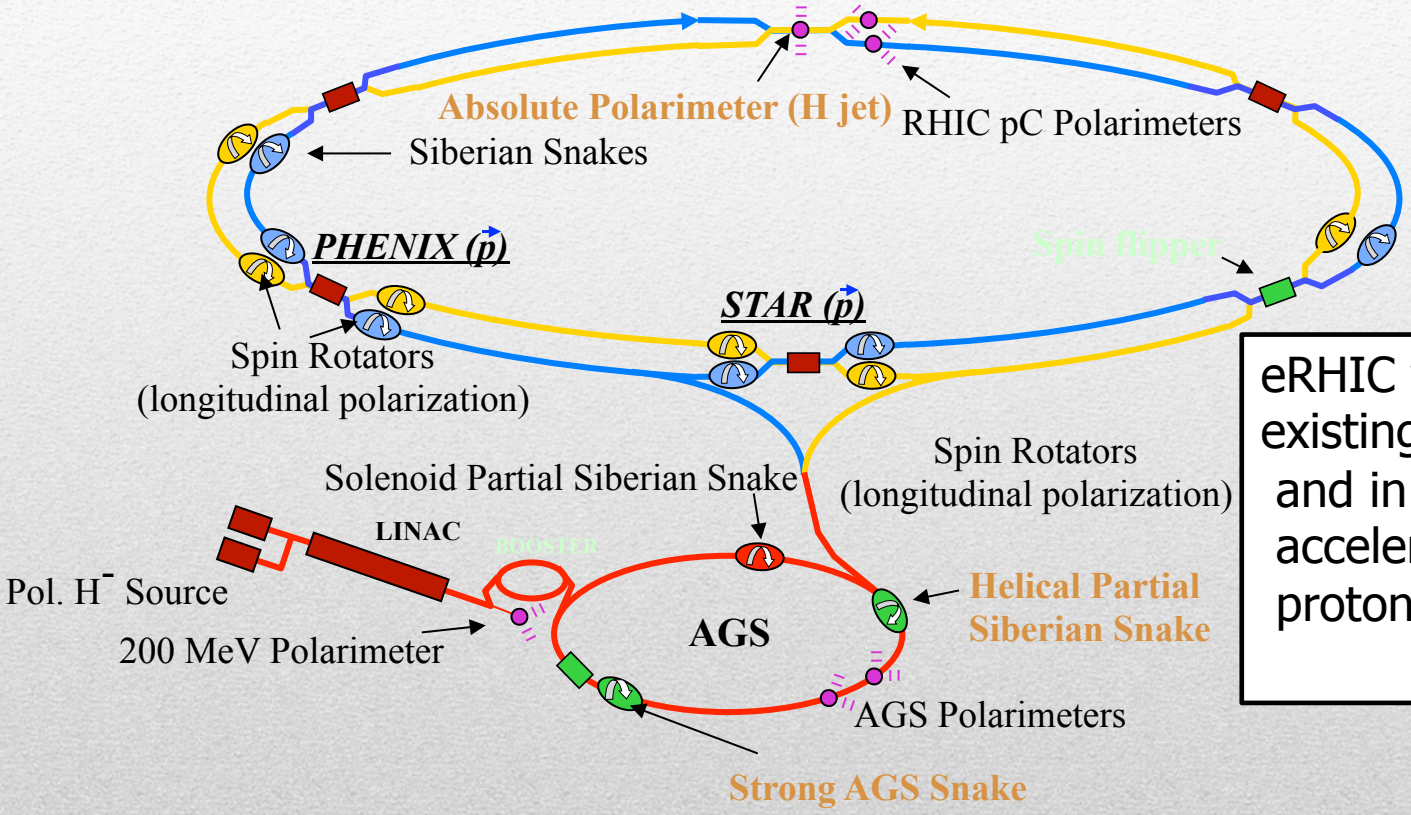
Depolarization becomes noticeable at acceleration to 21 GeV.
Still the final polarization loss is at acceptable level.
Further ZGOUBY simulations are underway (exploring accelerator imperfections)

SR depolarization in eRHIC

RHIC :
- only polarized proton collider in the world

-very successful Run-13: fully completed physics program at 255 GeV

-achieved beam polarization at 255 GeV 57-58% (H-jet polarimeter)



eRHIC will take favor of existing hardware in RHIC and in its injector chain to accelerate polarized protons up to 255 GeV.

eRHIC: polarized protons

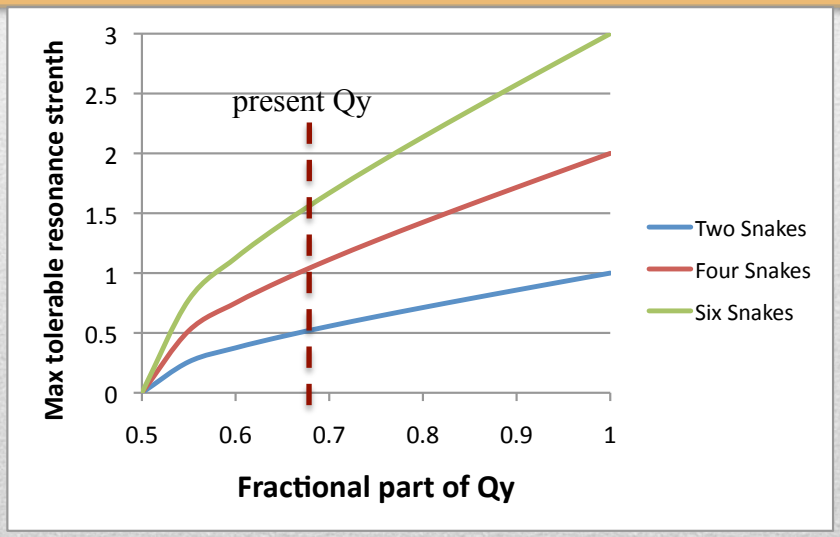
Proton polarization for eRHIC

A pathway to 70% proton polarization :

- Using smaller beam transverse emittances.

  Beam scraping in Booster taking advantage of upgraded intensity of the polarized source.

- Higher polarization from the source (85% or more)
- Increased number of Siberian Snakes (to 6 per ring)

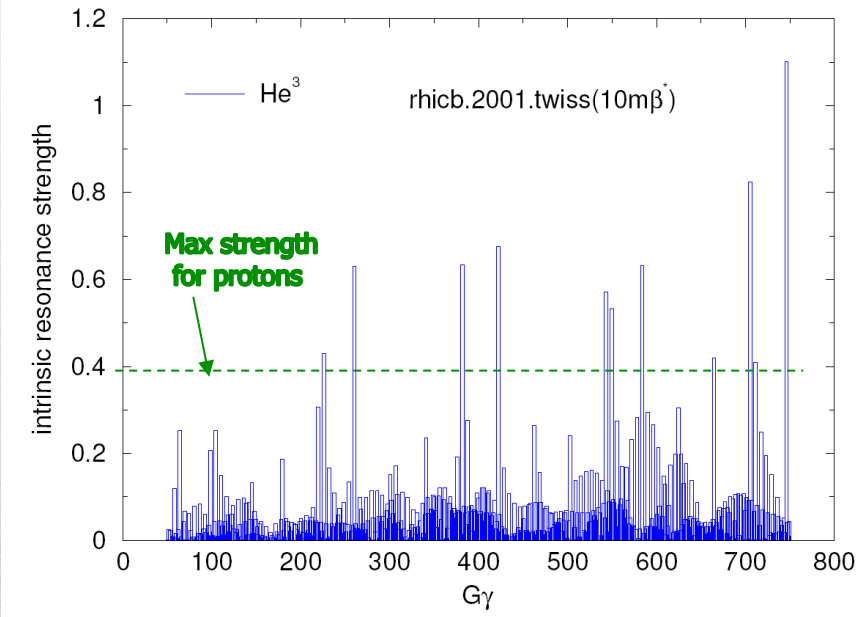


To provide the longitudinal polarization in eRHIC detectors the present set of helical magnet RHIC spin rotators will be used.

Polarized $^3He^{+2}$ and deutrons for eRHIC

Polarized $^3He^{+2}$:

- Source development .
  (J.Maxwell's talk on Wednesday)
- More spin resonances. Larger resonance strength.
  6 snakes are planned to address it.
- Polarimetry.



	p	*$^3He^{+2}$*	*d*
G	*1.79*	*-4.18*	*-0.14*
E/n, GeV	*24-250*	*16-167*	*12-125*
|Gγ|	*46.5-478*	*72.5-744*	*1.9-19.1*

Deutrons were not planned initially.
Presently polarized 2H+ feasibility is being evaluated:

- Snakes can be used only as partial Snakes.

With proper configuration of 6 Snakes: few percent strength. Enough for overcoming imperfection resonances.

- For intrinsic resonances: tune jump similar to those employed in AGS.
- Longitudinal polarization in experiments:
  - near $G\gamma = int$ (with partial Snakes)
  - or using strong enough RF flipper ($|w| >> \Delta\nu_{sp}$)

Summary points

- Polarized beams of electrons, protons and light ions are essential for the physics program of future collider eRHIC
- Important R&D is underway for high current polarized electron gun
- Electron polarization: system to reduce spin decoherence (caused by the beam energy spread) have to be accommodated by the accelerator design
- For polarized protons: the pathway to 70% polarization is based on higher number of Snakes and smaller beam emittance