AGS Booster for eRHIC

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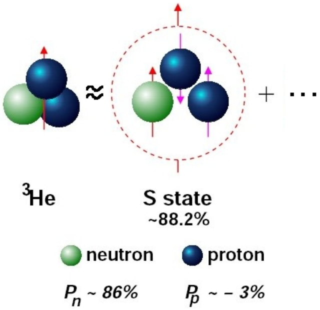
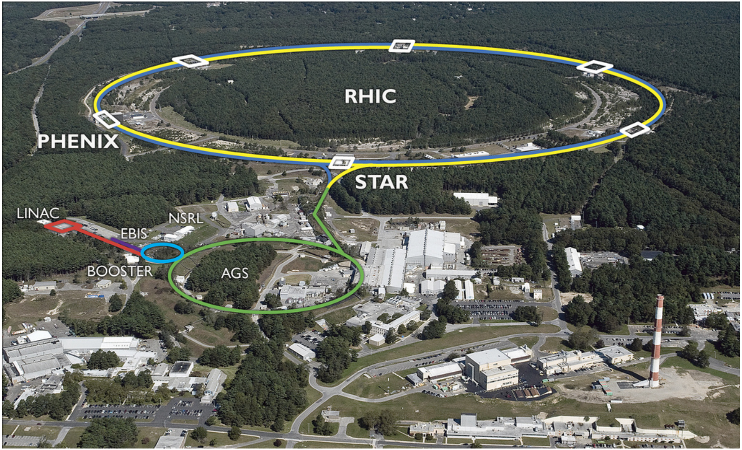
Introduction

Why He3?

- Neutrons are difficult to accelerate due to zero charge.
- Polarization scheme of ^{3}He provides polarized neutrons paired with two unpolarized protons, q=2.
- Collisions of polarized ^{3}He with polarized e is part of eRHIC's physics program.

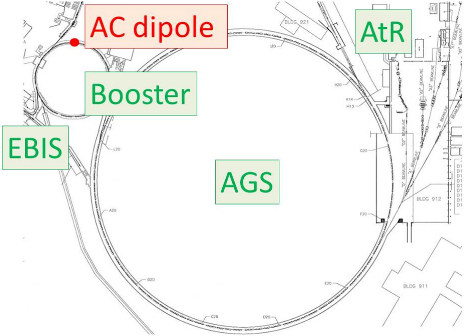


RHIC Accelerator Complex



AGS Booster

- Injector to the AGS.
- Receives particles from the sources:
  - Polarized protons from the OPPIS and unpolarized protons from the H- source via LINAC.
  - Receives ions from EBIS and TANDEM.
- Will receive polarized ^{3}He from the upgraded EBIS source.



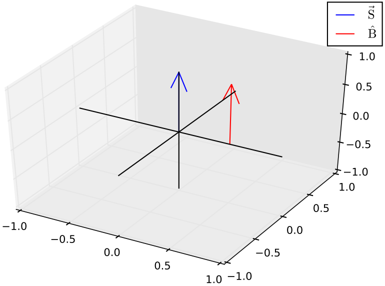
The relationship between magnetic field and a particles momentum is defined as the rigidity,

$$B\rho = p/q$$

Spin Interacting with Magnetic Fields

Torque on the magnetic moment from a magnetic field: $\Gamma = \vec{\mu} \times \vec{B}$

- No torque if the two are parallel
- Maximum if the two are orthogonal



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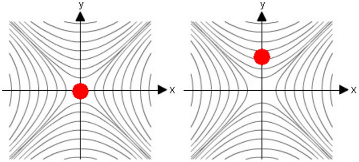

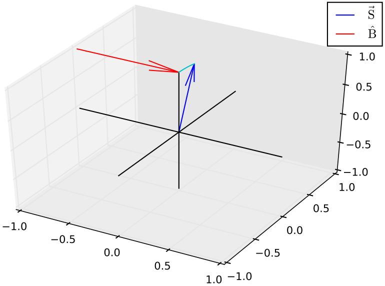

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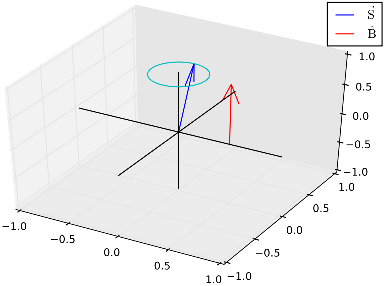


Number of rotations the spin vector undergoes in one turn is known as the spin tune:

$\nu_{\mathrm{s}} = \mathrm{G}\gamma$

Depolarizing Resonances

Resonance strength is defined as [1]: Imperfection resonances:

Occur when Gγ=n and is the result of non-zero vertical closed orbit.

Intrinsic resonances:

Occur when Gγ=$\mathrm{nP} \pm \nu_{\mathrm{y}}$ and is the result of non-zero betatron motion. The intrinsic resonance strength is defined as:

$$\epsilon_k = \frac{1+G\gamma}{2\pi}\sqrt{\frac{\varepsilon_N}{\pi\gamma}}\int \frac{\frac{dB_z}{dx}}{B\rho}\sqrt{\beta_z(s)}cos(\nu_z\phi_z(s)+\xi)e^{iK\theta}ds \qquad (1)$$

[1] S. Y. Lee. Spin Dynamics and Snakes in Synchrotrons. World Scientific 1997.

Spin Resonances in the AGS Booster

What about polarized protons?

$\mathrm{G_p}$=1.79, $|\mathrm{G}\gamma_{\mathrm{extr}}| = 4.5 < 0 + \nu_{\mathrm{y}}$ (ν_{y} >4.7)

Polarized ^{3}He spins faster than protons=more spin resonances

$\mathrm{G_h}$=-4.18, $|\mathrm{G}\gamma_{\mathrm{extr}}| = 10.5$

^{3}He will cross $\mathrm{G}\gamma = 12 - \nu_{\mathrm{y}},\ 6 + \nu_{\mathrm{y}}$ spin resonances

$\mathrm{G}\gamma = 0 + \nu_{\mathrm{y}}$ for ^{3}He is avoided by injecting at $\mathrm{G}\gamma = 4.193$ with $\nu_{\mathrm{y,inj}} \sim 4.1$

ac dipole

Preserves polarization by forcing all particles to undergo large amplitude oscillations in ring [2]:

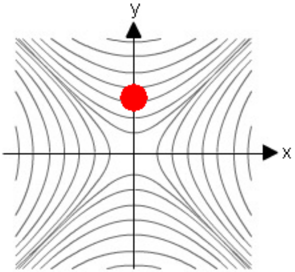
$$\mathrm{Y_{coh}} = \frac{\mathrm{B_m l}}{4\pi \mathrm{B}\rho\delta_\mathrm{m}}\beta_\mathrm{yk} = \frac{\beta_\mathrm{yk}\theta_\mathrm{k}}{4\pi\delta_\mathrm{m}}$$

The ac dipole does this with a sinusoidally oscillating magnetic field in close phase with the betatron oscillations. The separation of the ac dipole tune and betatron tune is

$$\delta_m = \nu_y - (k - \nu_m)$$

with the ac dipole tune defined as

$$\nu_\mathrm{m} = \mathrm{f_m}/\mathrm{f_{rev}}$$



[2] M. Bai, S. Y. Lee, H. Huang, T. Roser, M. Syphers. Overcoming the Intrinsic Spin Resonance using Resonance Island created by RF Dipole. AGS/RHIC/SN no 055 May 5, 1997.

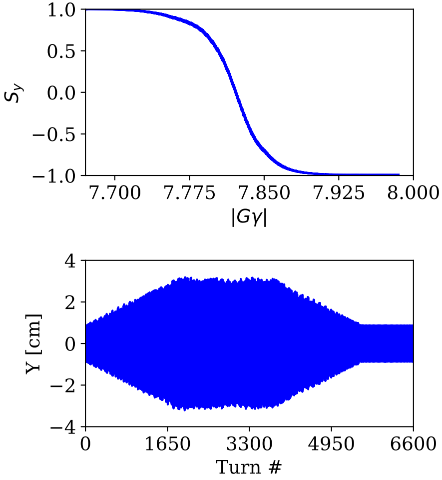
ac dipole - Simulations

Simulations have been performed with ^{3}He crossing the $\mathrm{G}\gamma = 12 - \nu_\mathrm{y}$, $\mathrm{G}\gamma = 6 + \nu_\mathrm{y}$, and protons crossing the $\mathrm{G}\gamma = 0 + \nu_\mathrm{y}$.

Simulation used to determine field requirements of ac dipole.

A fixed ac dipole frequency, f_m=250 kHz, will constrain the betatron tune as a result of $\delta_\mathrm{m} \sim 0.01$.

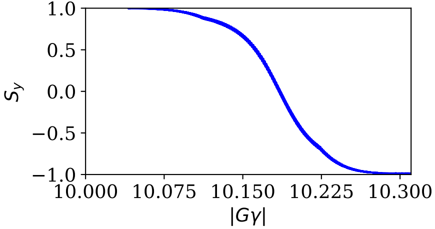
$\mathrm{G}\gamma = 12 - \nu_\mathrm{y}$

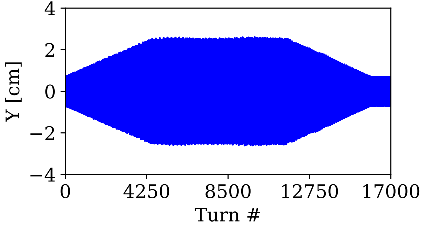


Simulations performed with 1,000 particles using the zgoubi ray tracing code.

Parameter	Value
$B_m \cdot l$	$16.5\ \mathrm{G \cdot m}$
ν_y	4.192
$G\gamma$	7.808

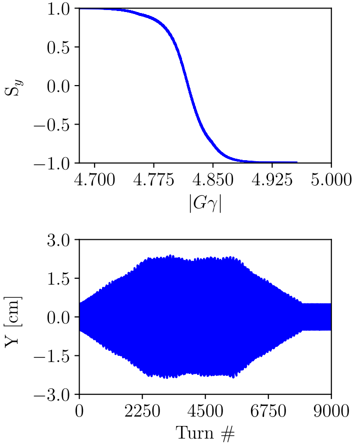
$G\gamma = 6 + \nu_y$





Parameter	Value
$B_m \cdot l$	$20.5\ \mathrm{G \cdot m}$
ν_y	4.174
$G\gamma$	10.174

Polarized protons crossing the $\mathrm{G}\gamma = 0 + \nu_\mathrm{y}$



- It is possible to cross $\mathrm{G}\gamma = 0 + \nu_\mathrm{y}$ resonance with protons if $\mathrm{G}\gamma_\mathrm{extr} > \nu_\mathrm{y}$.
- Extraction to AGS at $\mathrm{G}\gamma = 4.9$

Parameter	Value
$B_m \cdot l$	15.5 $\mathrm{G} \cdot \mathrm{m}$
ν_y	4.809
$G\gamma$	4.809

Conclusion

- The ac dipole has demonstrated ability of preserving polarization through intrinsic resonances via spin flip.
- Simulations show the ac dipole is able to preserve polarization of ^{3}He in the Booster.
- Protons crossing $\mathrm{G}\gamma = 0 + \nu_\mathrm{y}$ resonance is possible and similar to ^{3}He crossing the $\mathrm{G}\gamma = 12 - \nu_\mathrm{y}$.

Questions

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