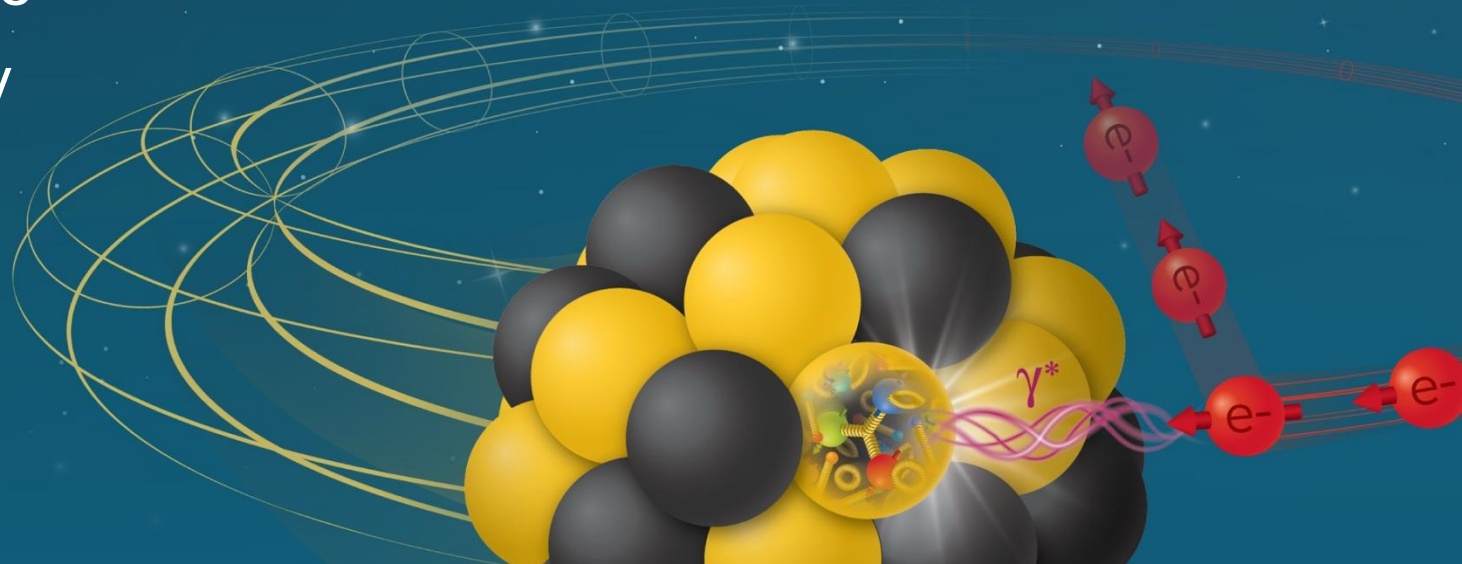
ESR Polarization

Matt Signorelli
Postdoctoral Research Associate
Brookhaven National Laboratory

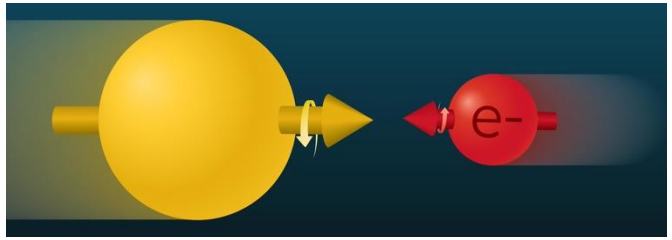
Increasing ESR Polarization Meeting
May 14th, 2026

Electron-Ion Collider

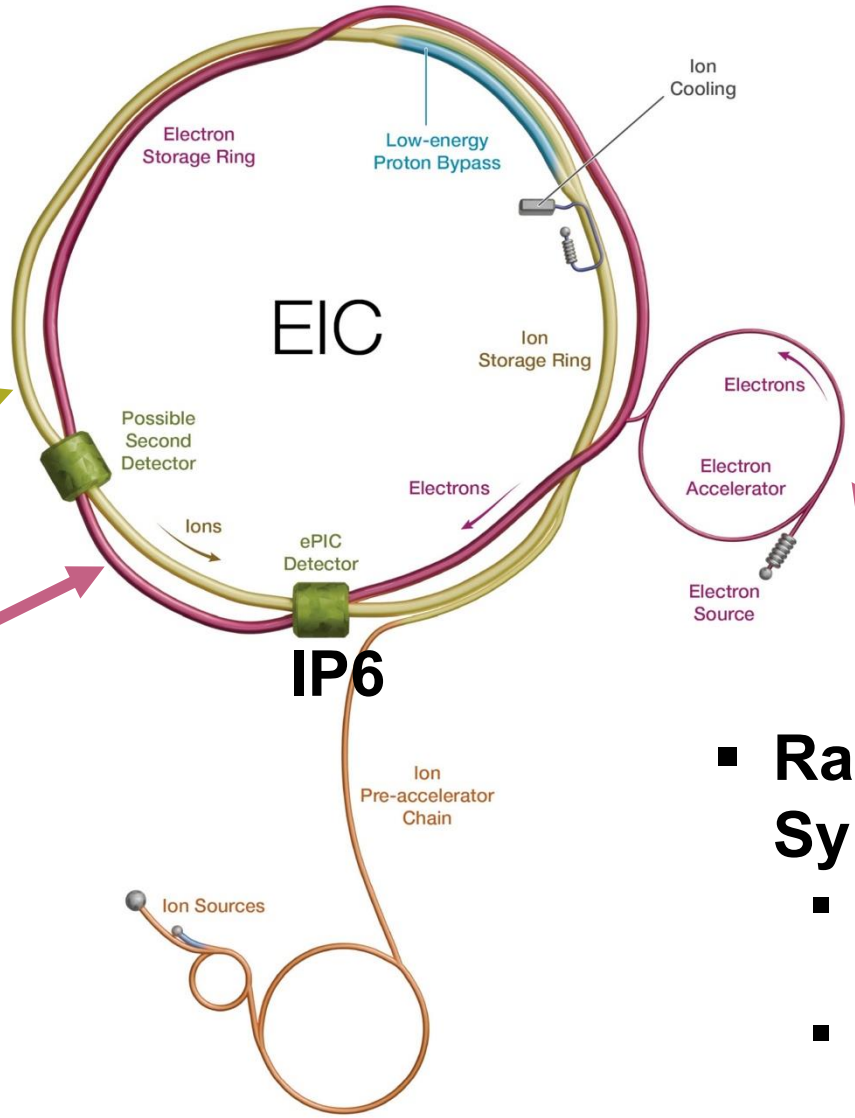


Overview

- **Electron-Ion Collider (EIC)**



- **Hadron Storage Ring (HSR)**
  - 41, 100, and 275 GeV
- **Electron Storage Ring (ESR)**
  - 5, 10, and 18 GeV

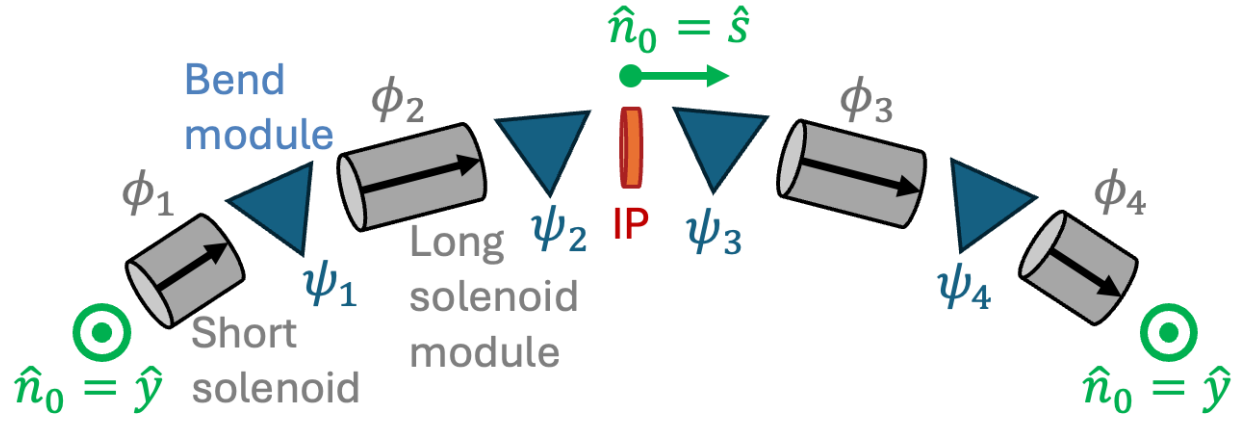


- **Rapid Cycling Synchrotron (RCS)**
  - Accelerates electrons from 750 MeV to 18(??) GeV
  - **The point of this meeting**

Matt Signorelli
msignorel@bnl.gov

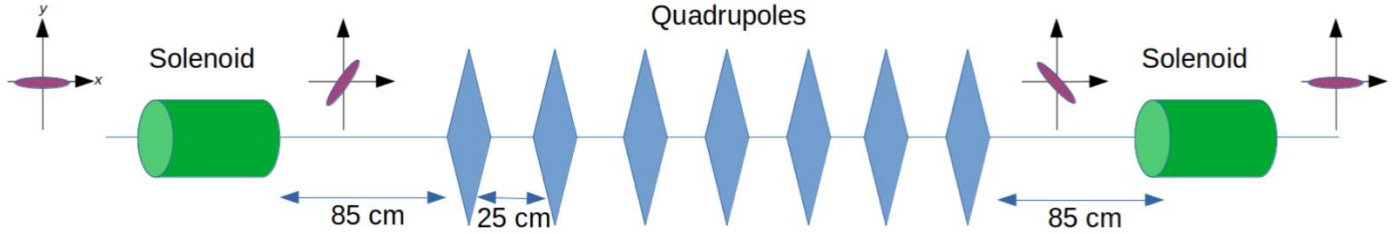
Spin Rotator

- Longitudinal spin at the IP for 5, 9, and 18 GeV
  - **Exact energy chosen for half integer ν_0**
- Symmetric arrangement of bends and “solenoid modules”
- “Solenoid module”
  - Two half solenoids
  - Quadrupoles for **spin matching** and **optics decoupling**



Bends: $\psi_1 = \psi_4,\ \psi_2 = \psi_3\ (= a\gamma_0\Delta\theta$, fixed by geometry and energy)

Solenoids: $\phi_1 = \phi_4,\ \ \phi_2 = \phi_3\ (= (1+a)K_sL\ )$



Matt Signorelli
msignorel@bnl.gov

Spin Configurations

1. **Sokolov-Ternov (ST) Effect:** polarizes anti-parallel to arc field, *unavoidable*
2. **Radiative Depolarization:** stochastic radiation reduces spin actions, *remedy via "spin matching"*

Both effects balance out to asymptotic P_∞

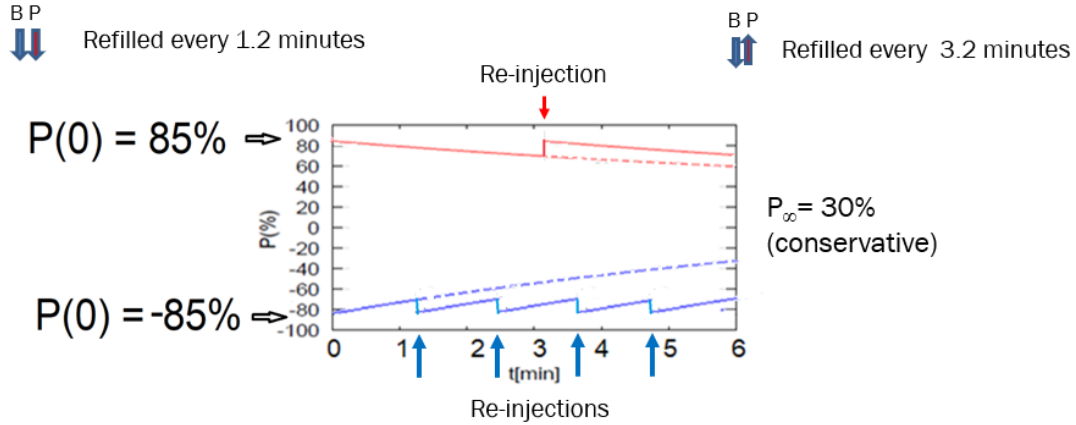
EIC-ESR: Collide bunches with both + and – helicities

- Half of bunches polarized parallel to arc (ST effect works against)
- Half of bunches polarized antiparallel to arc (ST effect works for)

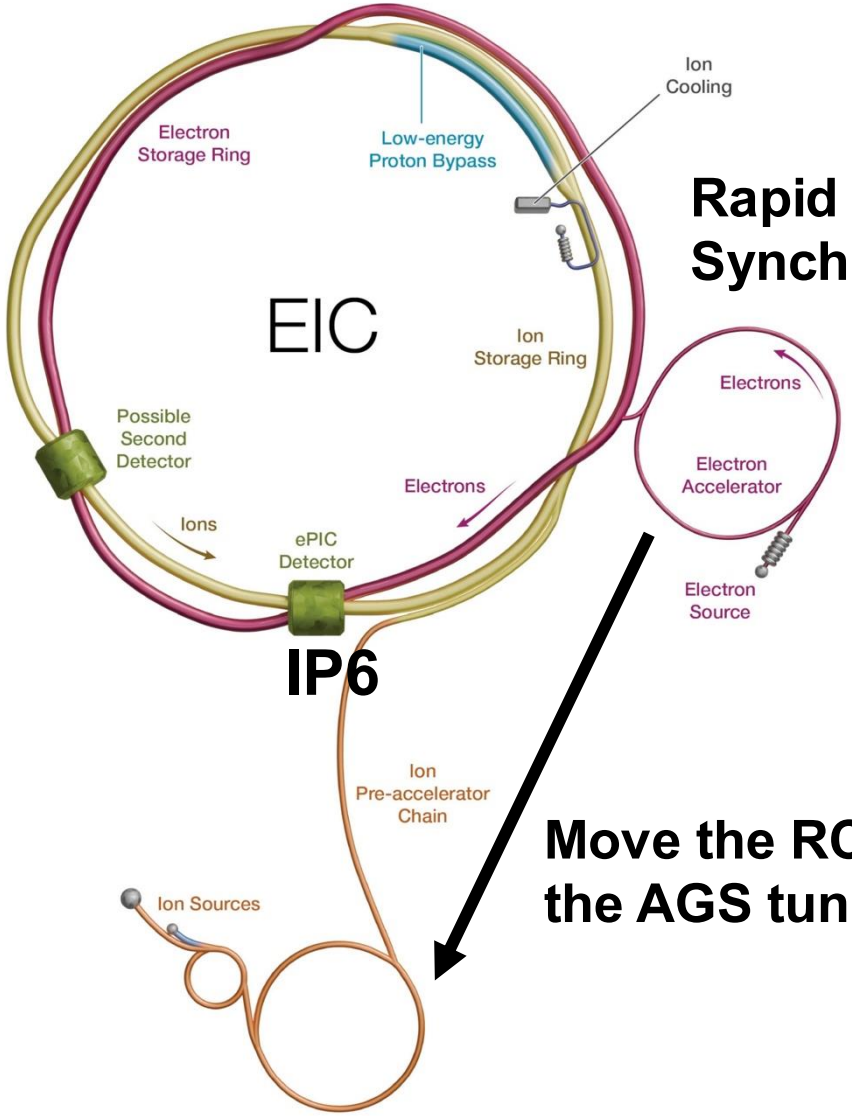
Swap-out injection: Replace bunch once depolarized

- Require $\langle P \rangle_t \geq 70\%$

- **Current plan is to store both at same time**



The Cost-Saving Idea



Rapid Cycling Synchrotron (RCS)

Move the RCS into the AGS tunnel

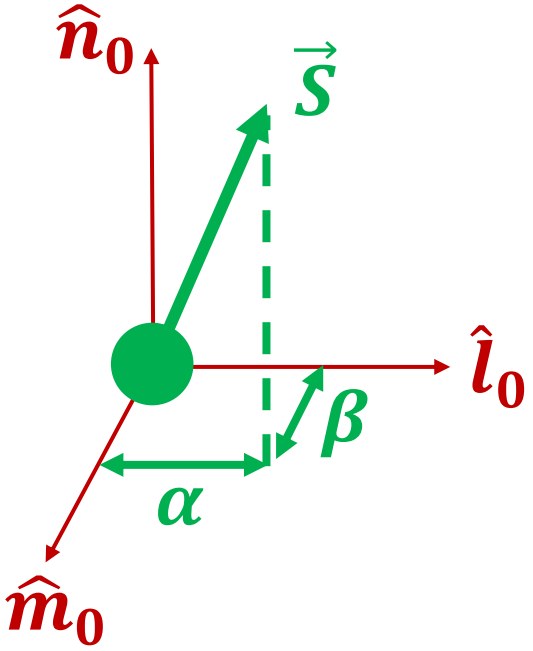
Pro:
- **Lots of money saved**

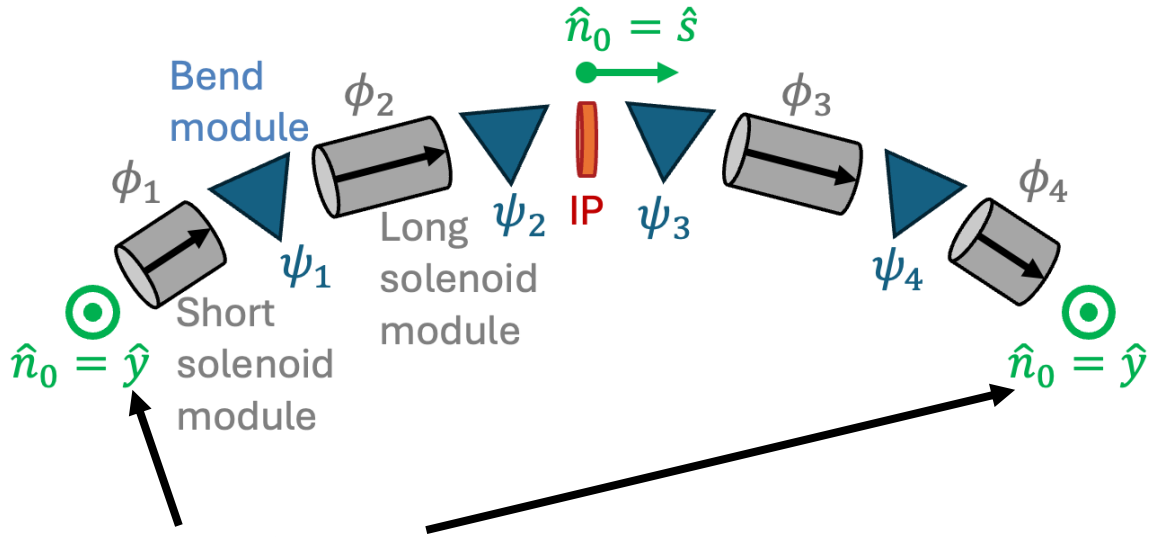
Con:
- **Can only ramp up to 9 GeV**

- Ramp from 9 to 18 GeV must then be in the ESR
- This will kill polarization, so…
- **Must achieve $P_\infty > 60\%$ in the ESR at 18 GeV to build up polarization after the ramp**
- **Must find a solution so both + and – helicities can be collided with minimal time between**

Matt Signorelli
msignorel@bnl.gov

What has been done?





From arc to arc:

$$\begin{pmatrix}\alpha\\ \beta\end{pmatrix}_f = \mathbf{G_x}\begin{pmatrix}x\\ p_x\end{pmatrix}_i + \mathbf{G_y}\begin{pmatrix}y\\ p_y\end{pmatrix}_i + \mathbf{G_z}\begin{pmatrix}z\\ p_z\end{pmatrix}_i + \mathbf{D}\begin{pmatrix}\alpha\\ \beta\end{pmatrix}_i$$

Horizontal

$0 \rightarrow$ achievable by setting solenoid module quads

Vertical

$0? \rightarrow$ Yes, when the vertical beam size is small…

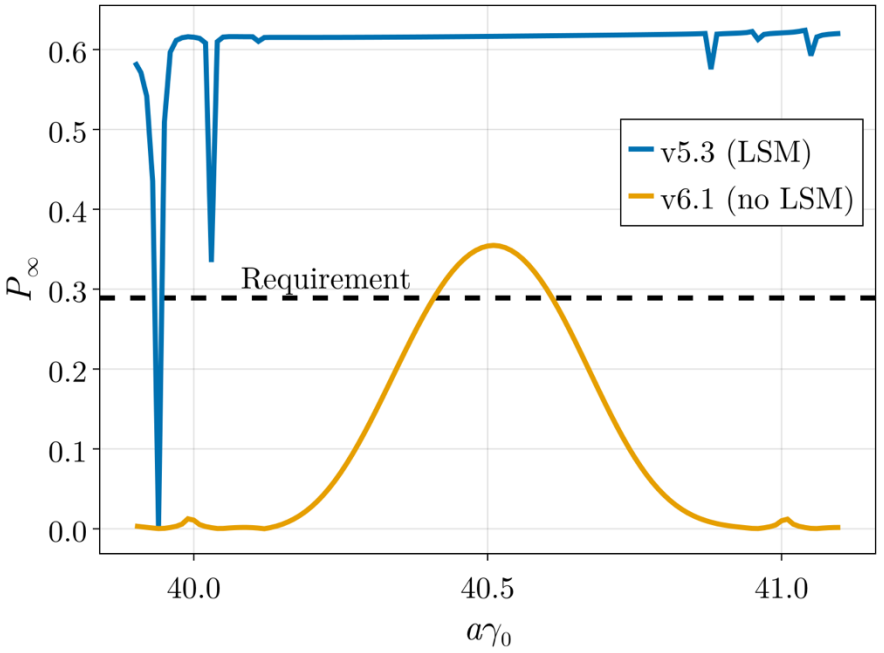
Longitudinal

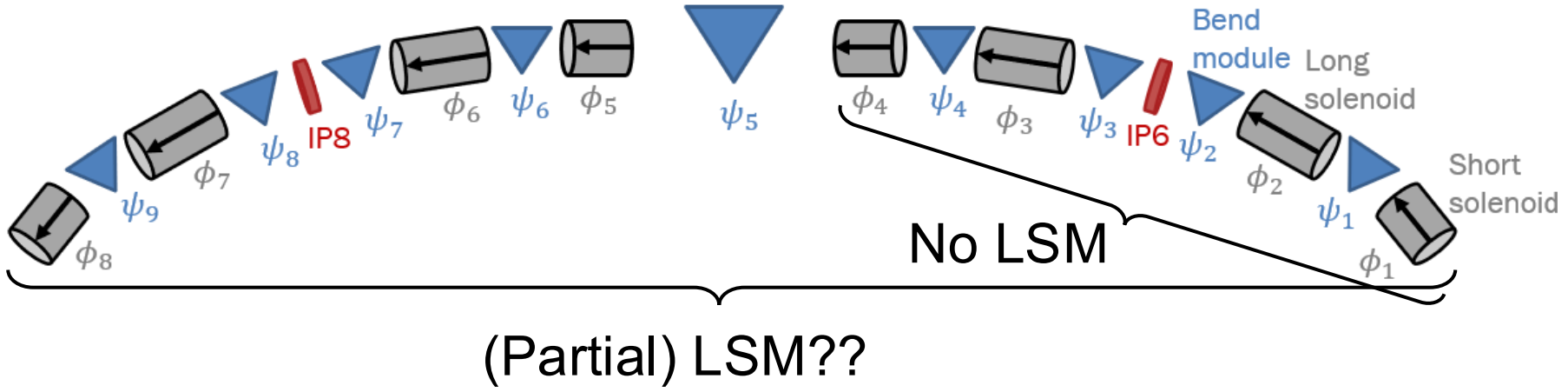
It's complicated…

Matt Signorelli
msignorel@bnl.gov

Longitudinal Spin Match

- 5, 9 GeV do not require longitudinal spin match (LSM)
- **At 18 GeV, the effect on polarization is *significant***
- But, would **need 11 Tesla solenoids. Not feasible**
- **Attempted "partial" LSM using 2nd IR:**

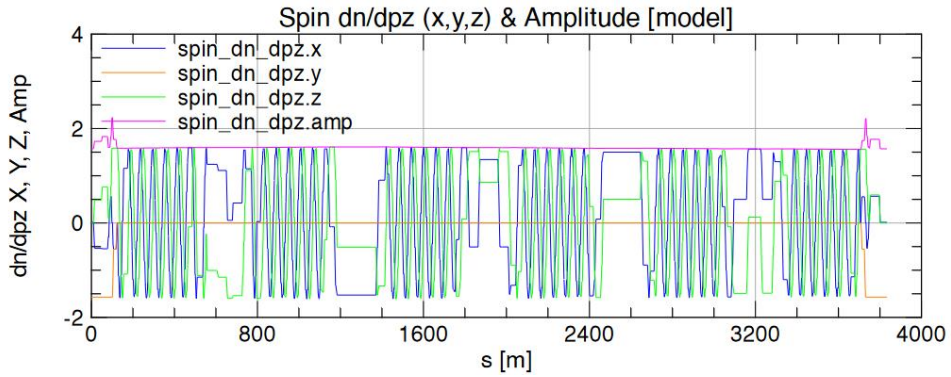




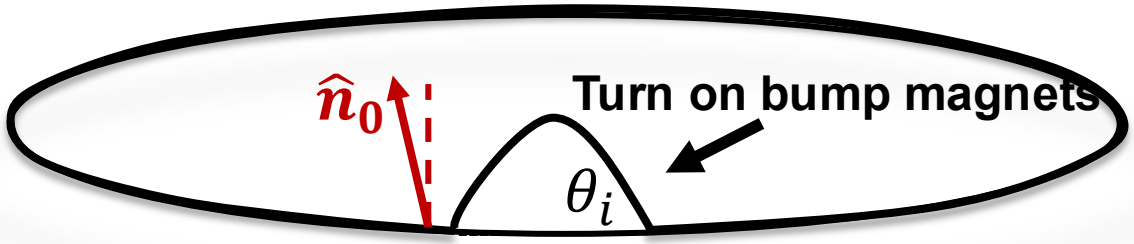
- **Marginal improvements, still insufficient**

Best Adjustment Groups for ELectron Spin

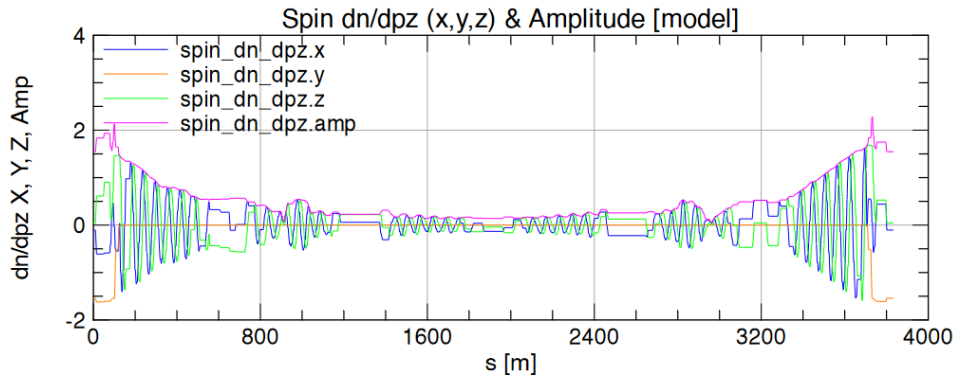
- $\vec{d} = \frac{\partial \hat{n}}{\partial \delta} =$ "spin−orbit coupling function" = **the bad thing!**
- Without a longitudinal spin match,



- **Vertical closed orbit bumps** tilt $\hat{n}_0$, causing small impacts on $\vec{d}$ around the ring:



4 BAGELS bumps

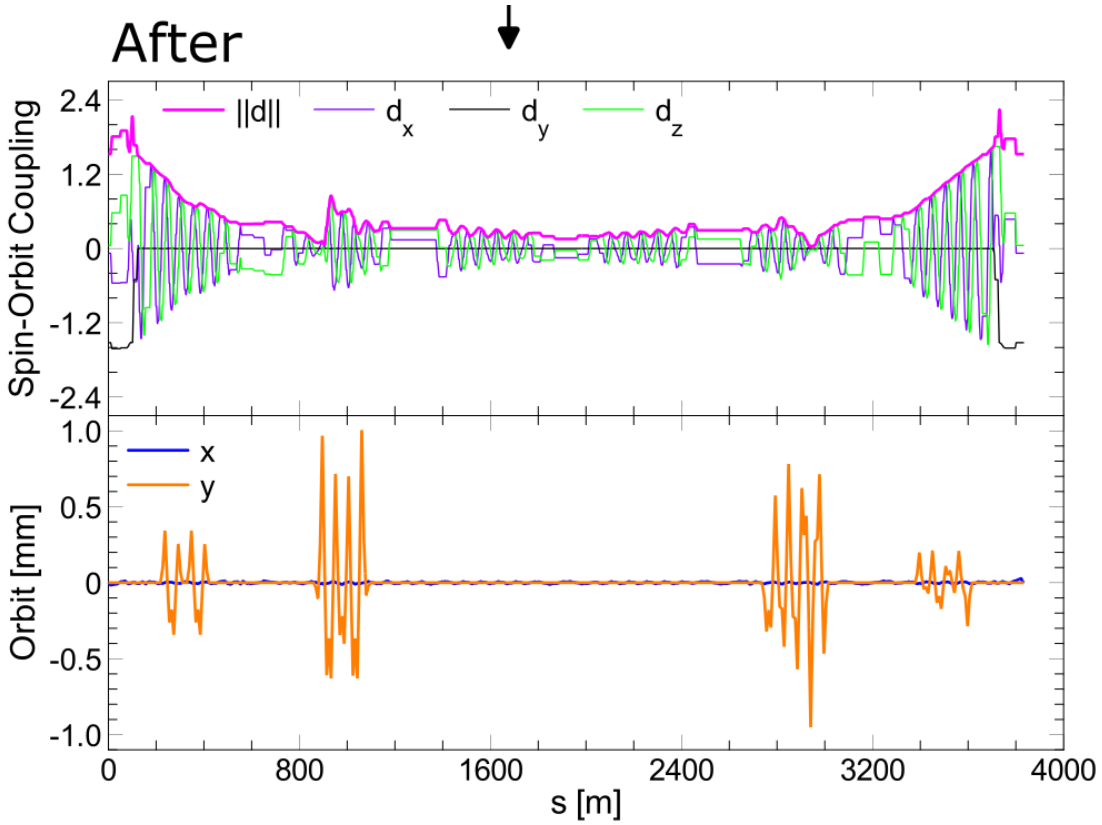


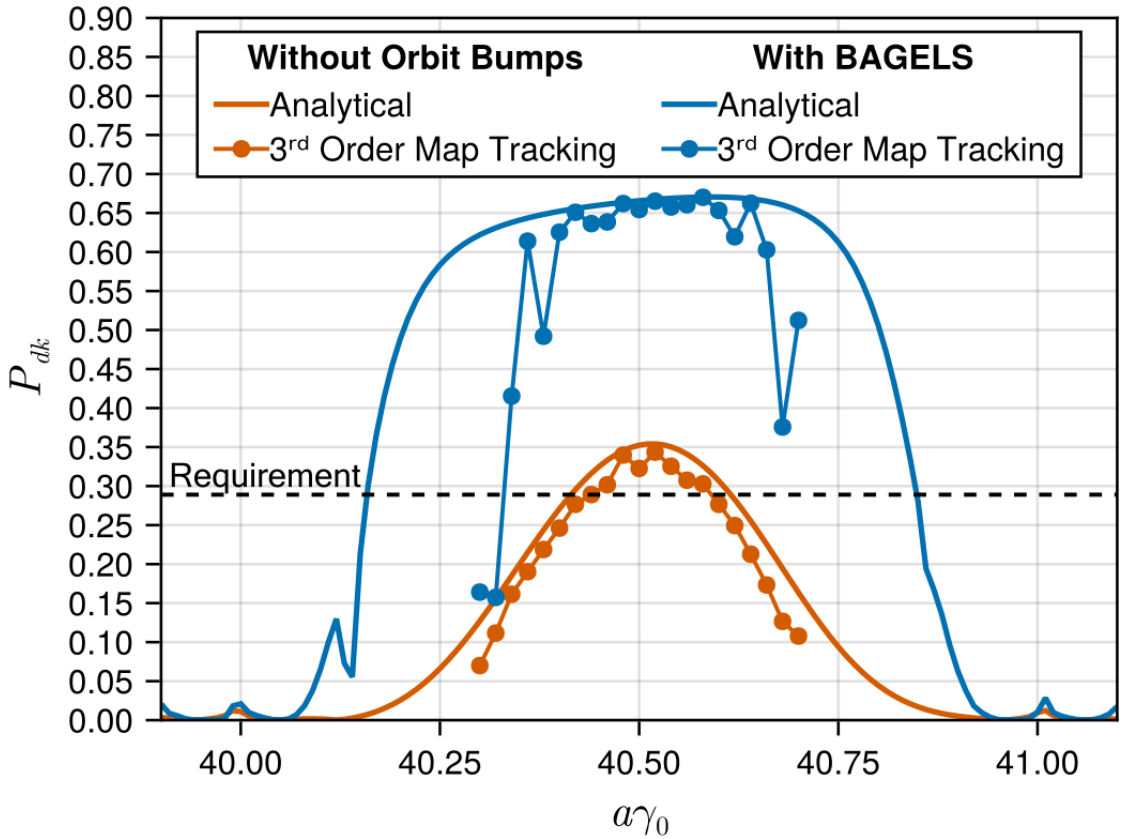
- **BAGELS is a procedure to compute the "best" bumps for minimizing $\vec{d}$**

Matt Signorelli
msignorel@bnl.gov

BAGELS in the 18 GeV ESR

- Turning **only 4 BAGELS knobs in the *ideal* 1-IP 18 GeV ESR:**
  - **"Analytical" =** first-order, **Map Tracking =** Monte Carlo simulation (nonlinear)





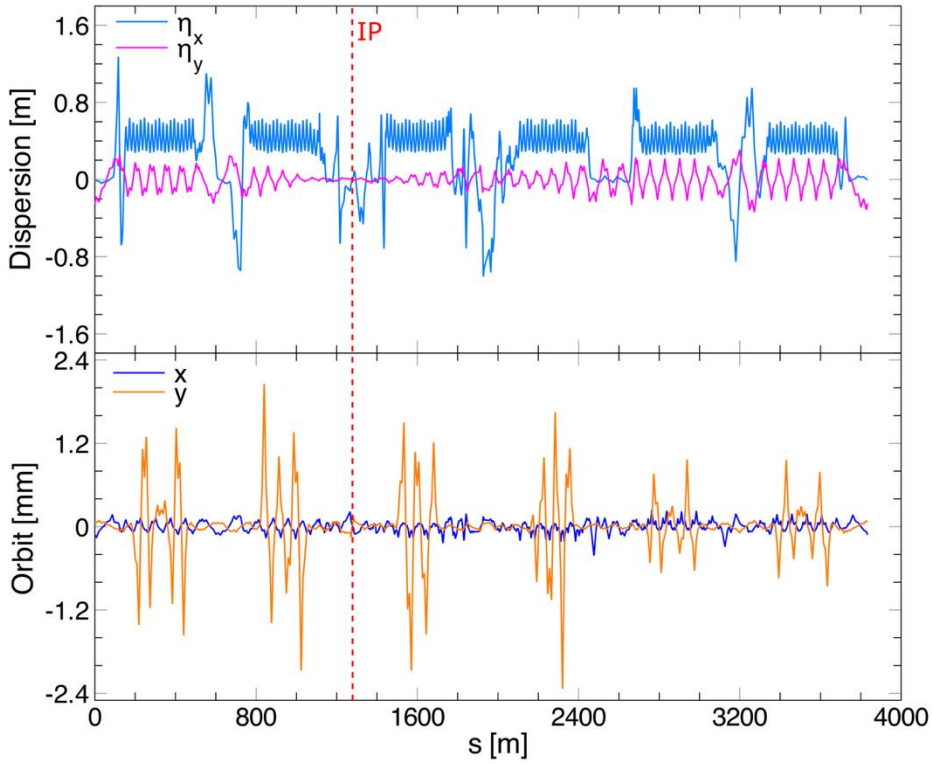
- **Good result in the ideal (no errors) lattice, $P_\infty \approx 65\%$**

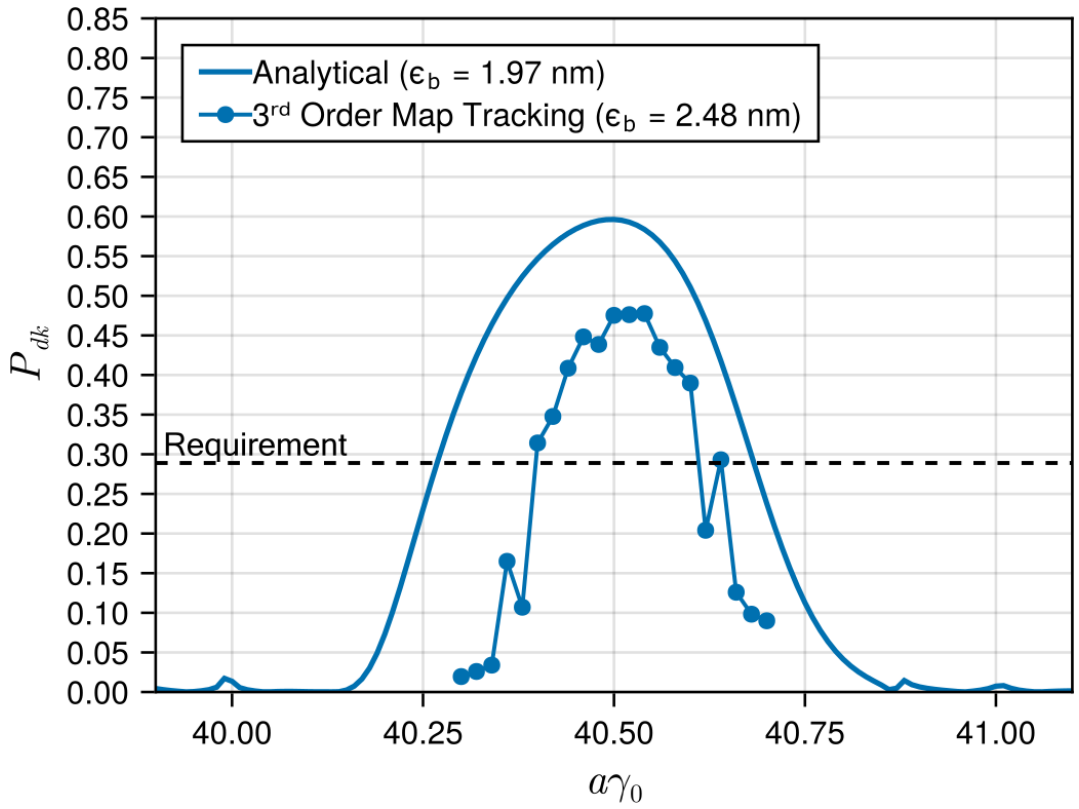
Matt Signorelli
msignorel@bnl.gov

However…

Need to intentionally create vertical emittance to match the hadron beam size

- In the **ideal 18 GeV** lattice with a special BAGELS vertical emittance bump:

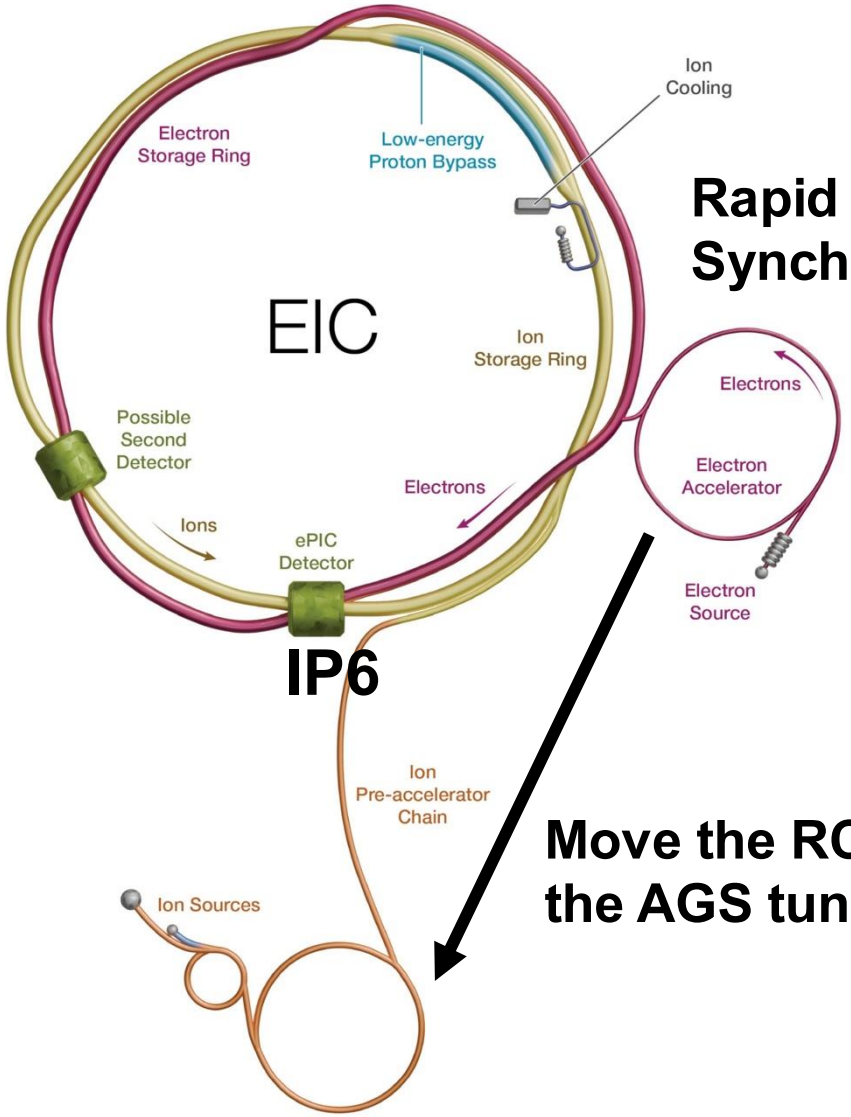




- $P_\infty \approx 48\%$ **in the ideal case! Add errors,** $\geq 60\%$ **is unlikely w/ BAGELS alone**

Matt Signorelli
msignorel@bnl.gov

Summary



Rapid Cycling Synchrotron (RCS)

IP6

Move the RCS into the AGS tunnel

- **Suppose RCS ramps only to 9 GeV**

Then:

- **ESR would ramp 9-18 GeV**
- **Must build up + store $P \geq 60\%$ at 18 GeV**
  - Including vertical emittance creation!
  - Also must be amenable to +, - helicities
- **BAGELS helps, but is not sufficient**
- **That's where you(!) come in**
- **Radical ideas may be on the table ☺**

Matt Signorelli
msignorel@bnl.gov