# Acceleration of polarized ion beams at HIAF and EicC

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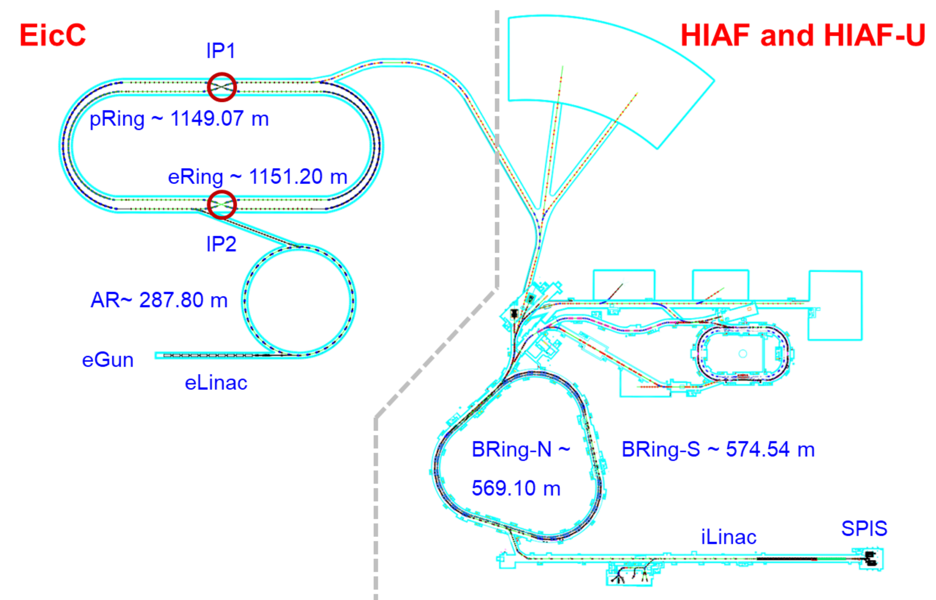
## Introduction

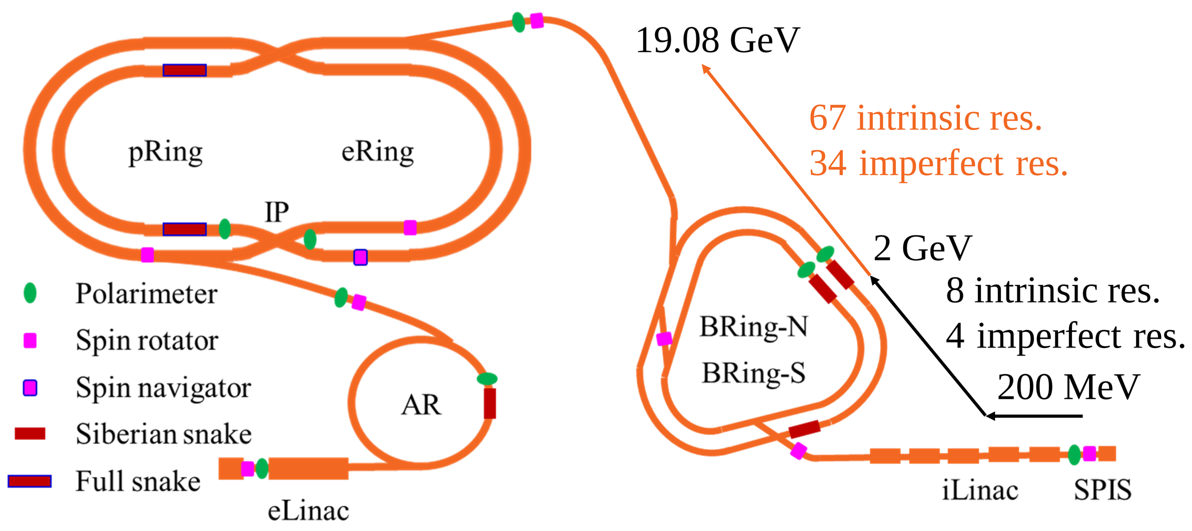



- **Study of polarized beam acceleration at the High Intensity heavy ion Accelerator Facility (HIAF) and the Electron-Ion Collider in China (EicC).**
- **Design of a constant field solenoid Siberian snake for rapid cycling acceleration.**

## Accelerator complex

The Electron-Ion Collider in China (EicC), proposed by the Institute of Modern Physics, Chinese Academy of Sciences, aims to study nucleon structure in the sea quark energy region using **15-20 GeV center-of-mass energy with 80% electron and 70% proton polarization**. Proton beams are accelerated **from 200 MeV to 2 GeV in the BRing-N and then to 19.08 GeV in the BRing-S**. To maintain high beam polarization, **a constant-field solenoid Siberian snake and a helical snake** are employed.

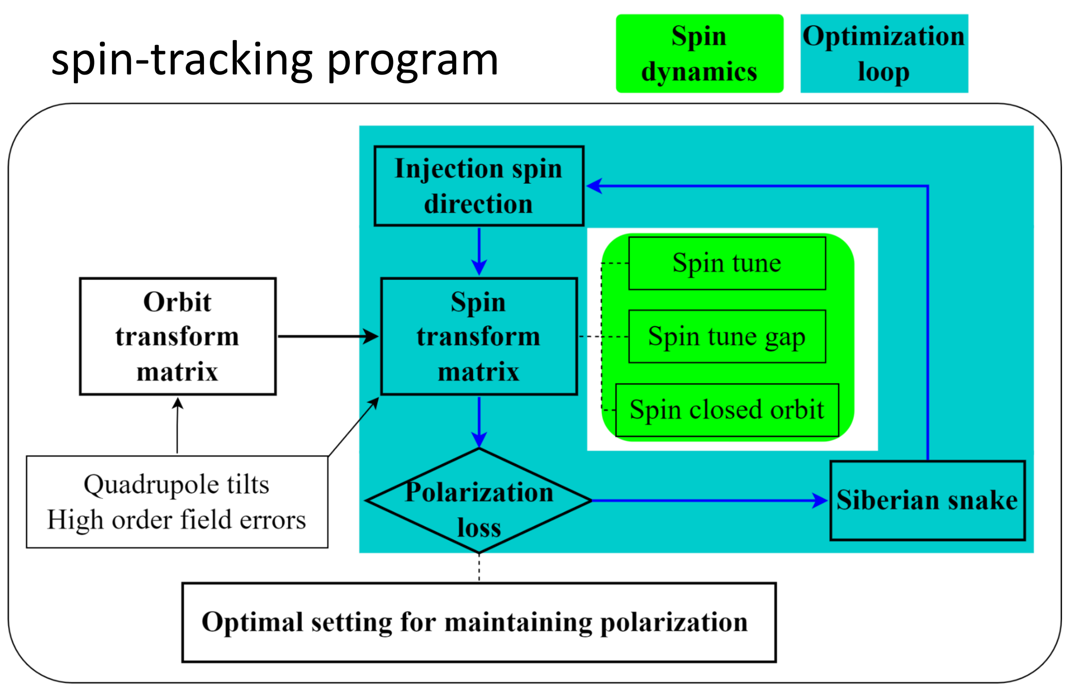
| Designs | High luminosity mode | |
|---|---|---|
| Particle | e | p |
| Circumference(m) | 1151.20 | 1149.07 |
| Kinetic energy (GeV) | 3.5 | 19.08 |
| Momentum (GeV) | 3.5 | 20 |
| Total energy (GeV) | 3.5 | 20.02 |
| CM energy (GeV) | 16.76 | |
| $f_{collision}$ (MHz) | 100 | |
| Polarization | 80% | 70% |
| $B\rho$ (T·m) | 11.7 | 67.2 |
| Bunch intensity($\times 10^{11}$) | 1.7 | 1.05 |
| $\varepsilon_x/\varepsilon_y$ (nm·rad, rms) | 50/15 | 100/50 |
| $\beta_x^*/\beta_y^*$ (cm) | 10/4 | 5/1.2 |
| RMS divergence (mrad) | | 1.4/2.0 |
| 10×RMS size @ BpF2 (cm) | | 15.5/7.7 |
| Bunch length (cm, rms) | 0.75 | 8 |
| BB parameter $\xi_x/\xi_y$ | 0.102/0.118 | 0.0144/0.01 |
| Laslett tune shift | - | 0.066/0.105 |
| Crossing angle (mrad) | 50 | |
| Luminosity ($cm^{-2}\cdot s^{-1}$) | $4.25\times 10^{33}$ (H=0.52) | |

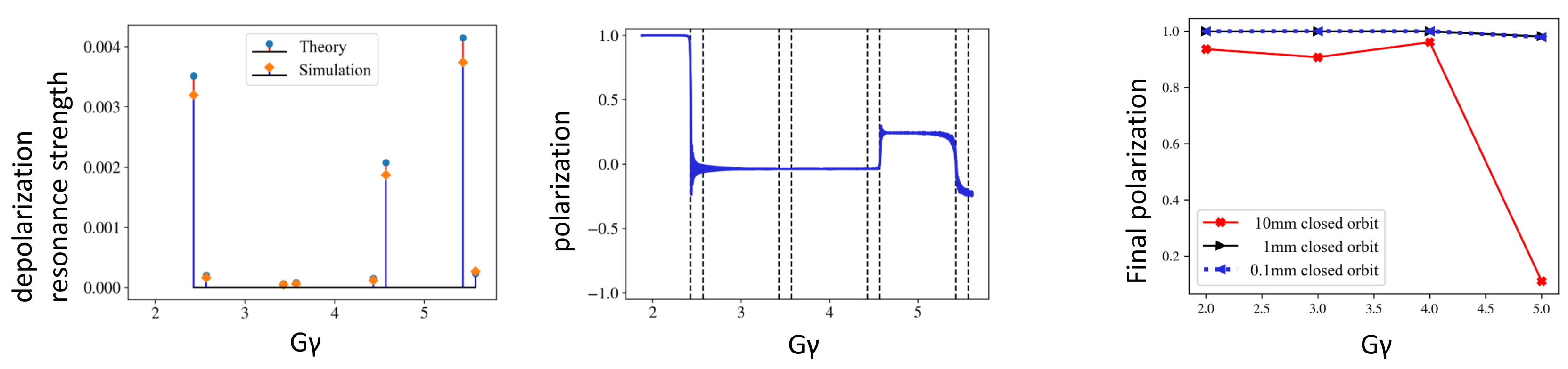



**This constant-field snake** has been simulation-verified and demonstrates **high hardware feasibility,** accommodating **rapid dipole ramping at 12 T/s** in the BRing-N.

## Depolarization Resonances at BRing-N

The BRing-N accelerator faces **significant polarization loss due to intrinsic and imperfection depolarization resonances** during proton beam acceleration, **necessitating a polarization-maintaining device like the Siberian snake.**

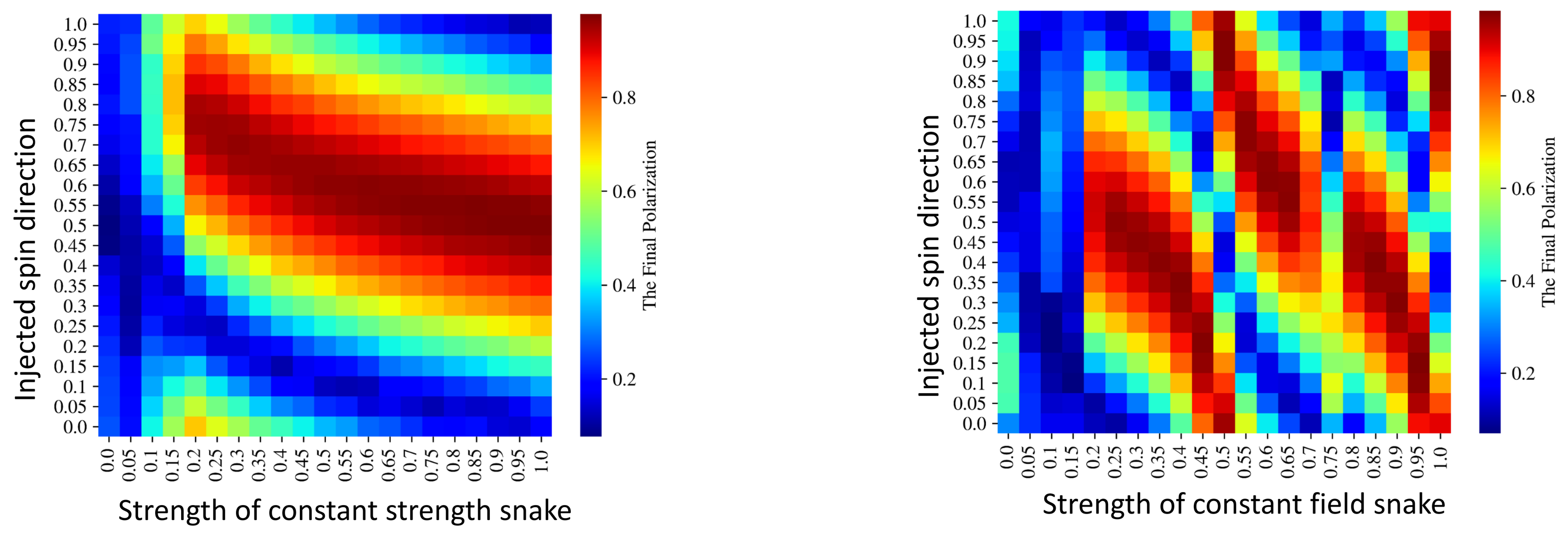


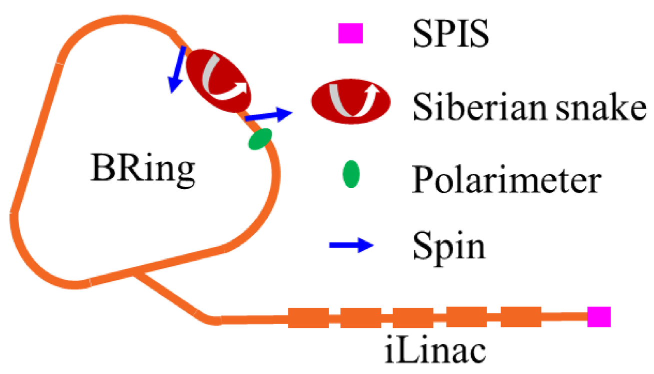



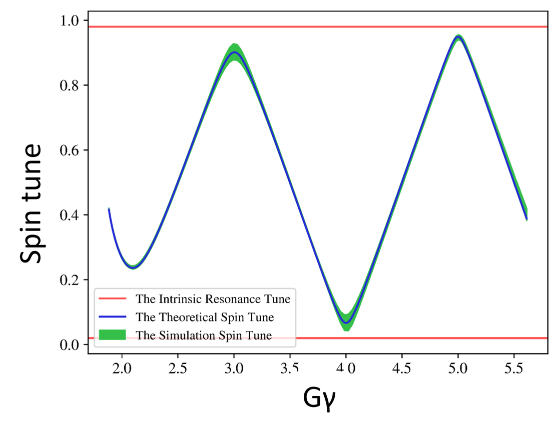

- Three strong **intrinsic depolarization resonances** found by multi-particle spin-tracking simulation and theoretical calculation, causing severe polarization loss (up to 70%) without snakes.
- **Imperfection depolarization resonances** are minimized by controlling the closed orbit amplitude to below 1 mm.

## Constant Field Solenoid Siberian Snake

The **constant field solenoid Siberian snake** is proposed as a practical solution to suppress polarization loss. Simulations show that a **20% strength** snake **with vertical tune 9.98 controls polarization loss below 10%,** matching the EicC's requirement for 70% beam polarization.

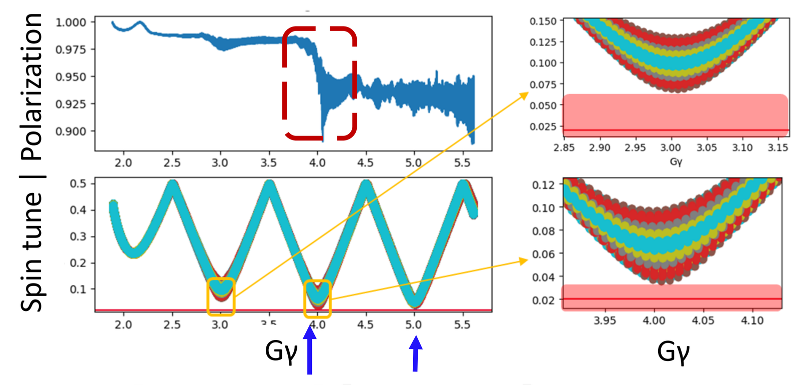



- By installing **a solenoid with an integral field of 0.942 Tm** in the electron cooling section, the spin tune gap is adjusted to avoid intrinsic resonances.

| type | constant strength | constant field |
|---|---|---|
| $L_s(m)$ | 2 | 2 |
| $K_s(/m)$ | 0.1125 | 0.4610<br>0.0503 |
| $B_s(T)$ | 0.1149<br>1.0524 | 0.4708 |
| $\frac{dB_s}{dt}/\frac{dB_D}{dt}$ | 2.4185 | 0.0 |

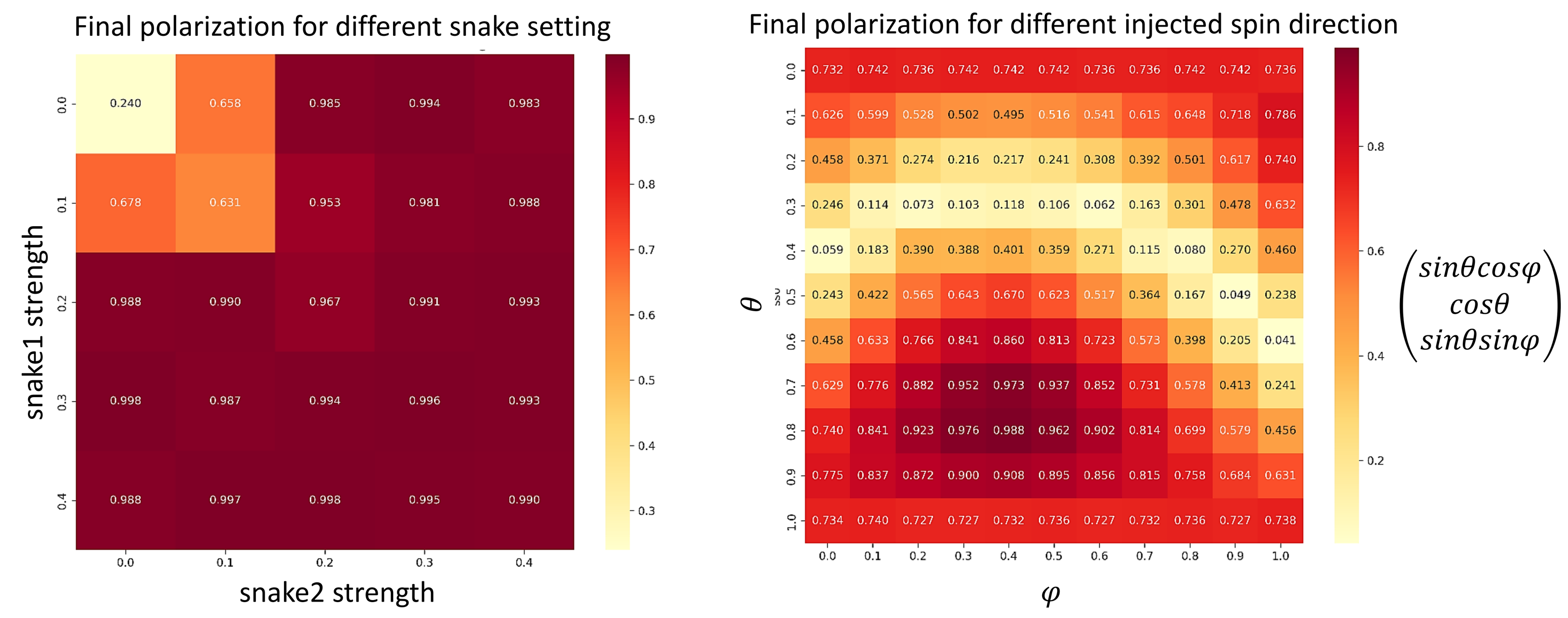



[0, **0.038**] [0, **0.042**]

- Unlike constant strength snakes (requiring rapid magnetic field ramping up to **29 T/s**), a constant field snake maintains **a static magnetic field, simplifying hardware requirements.**
- This scheme also accounts for **snake resonances, quadrupole tilts, and the nonlinear effects of high-order field errors**. Polarization loss occurs due to **second-order Siberian snake resonance** $\nu_{spin} = 0.04$, as shown in the red box.

## Polarization maintenance at BRing-S

Solenoid Siberian snakes with constant fields can avoid depolarization resonances in limited energy ranges, but are confined to low-energy operations. Due to wide energy range and high magnetic rigidity **at BRing-S, helical snakes will be adopted**. Beam emittance comparison by electron cooling (8.47/4.24 μm → 2.22/1.11 μm) reduces depolarization resonance effects significantly, allowing lower snake field strength and fewer helical snakes.




- **A 20% field strength helical snake** can limit polarization loss below 10% with optimized injection spin direction. While its design is progressing, further optimization of spin matching throughout beam transport is required.

## Future Plan

- **Polarization maintenance scheme for high-energy proton beams and the helical snake design.**
- **Acceleration of polarized helium-3 beams and polarized deuteron beams (both vector and tensor-polarized).**
- **Spin direction control based on spin-transparent ring concepts.**