Spin Polarization

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- 7 Presentations
  - Accelerating Polarized He3 Beam in eRHIC, M. Bai, BNL
  - Achieving Proton Polarization Goals for eRHIC, H. Huang, BNL
  - Ion Polarization Control in Figure-8 Rings Using Small Magnetic Field Integrals, A. Kondratenko, STL Zaryad
  - Development of Precise and Fast Spin-Orbit Tracking Codes, D. Abell, Tech-X
  - End-to-end, 9-D, Polarized Radiative Bunch Dynamics Simulations in eRHIC and LHeC FFAG ERL's, F. Meot, BNL
  - Electron Polarization Dynamics in eRHIC, V. Ptitsyn, BNL
  - Polarized Electron Beams in the MEIC Collider Ring at JLab, F. Lin, JLab

- Electron and proton phenomenology are very different except for the T-BMT eqn.
    - Electrons self-polarize
- But sync rad photons put noise into the trajectories and this together with the spin-orbit coupling of the T-BMT eqn and (for example) the non-uniform quad fields leads to spin diffusion --> depolarisation.
- Resonances, even in steady state
- Which wins? τ^{-1}_{dep} rises at least γ^2 faster than τ^{-1}_{pol}

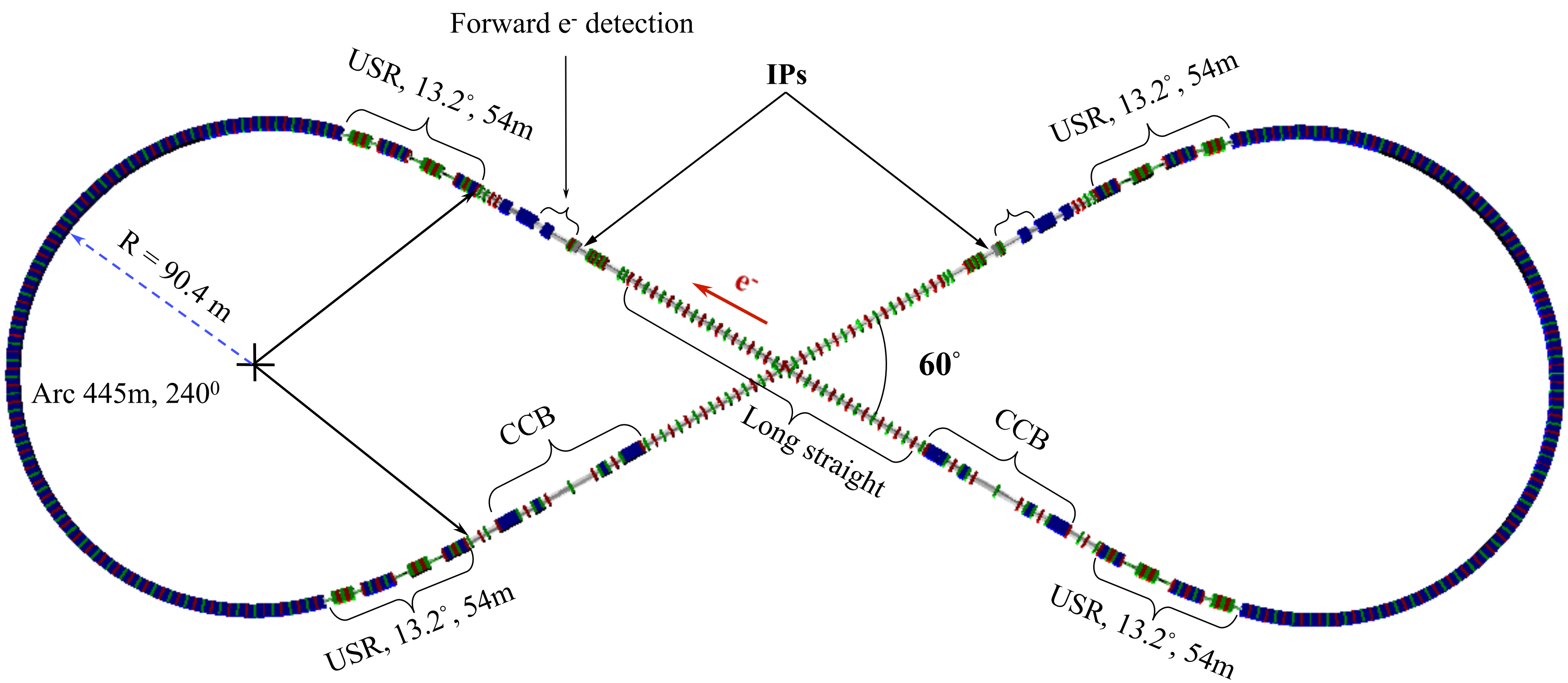
- Protons and ions must be pre-polarised at a source and then accelerated—resonances
- So very different approaches are needed.
- And this is reflected in the talks.
- Both want at least longitudinal poln.

MEIC (F. Lin)

- The shape of the electron ring is determined by the shape of the proton/ion ring.
- The Universal Spin Rotators provide vertical polarisation in the arcs and long pol at the IPs at all energies (3-11 GeV)
  - BUT they are not spin transparent.

Electron Collider Ring Layout

- The circumference of electron collider ring is ~1416m
- USR: Universal Spin Rotator
- CCB: Chromaticity Compensation Block
- Long straight (LS) will accommodate all required machine components



SLIM Algorithm and Spin Matching

- Obtaining expression for ${}^{\partial\hat{n}}/_{\partial\delta}$ in a linear approximation of orbit and spin motion. Therefore, $\hat{n}(\vec{u};s) = \hat{n}_0(s) + \alpha(\vec{u};s)\hat{m}(s) + \beta(\vec{u};s)\hat{l}(s)$.
  - The combined linear orbit and spin motion is propagated by an 8x8 transport matrix

$$\begin{pmatrix} x \\ x' \\ y \\ y' \\ \sigma \\ \delta \\ \alpha \\ \beta \end{pmatrix}(s_1) = \begin{pmatrix} M_{6\times6} & 0_{6\times2} \\ G_{2\times6} & D_{2\times2} \end{pmatrix}(s_1, s_0) \begin{pmatrix} x \\ x' \\ y \\ y' \\ \sigma \\ \delta \\ \alpha \\ \beta \end{pmatrix}(s_0)$$

Describe the coupling of spin variable to the orbit motion and is the target of "spin matching" by adjusting the optics to make some crucial region spin tansparent

- The code SLICK/SLICKTRACK, created and developed by Prof. A.W. Chao and Prof. D.P. Barber, calculates the equilibrium polarization and depolarization time using SLIM algorithm.

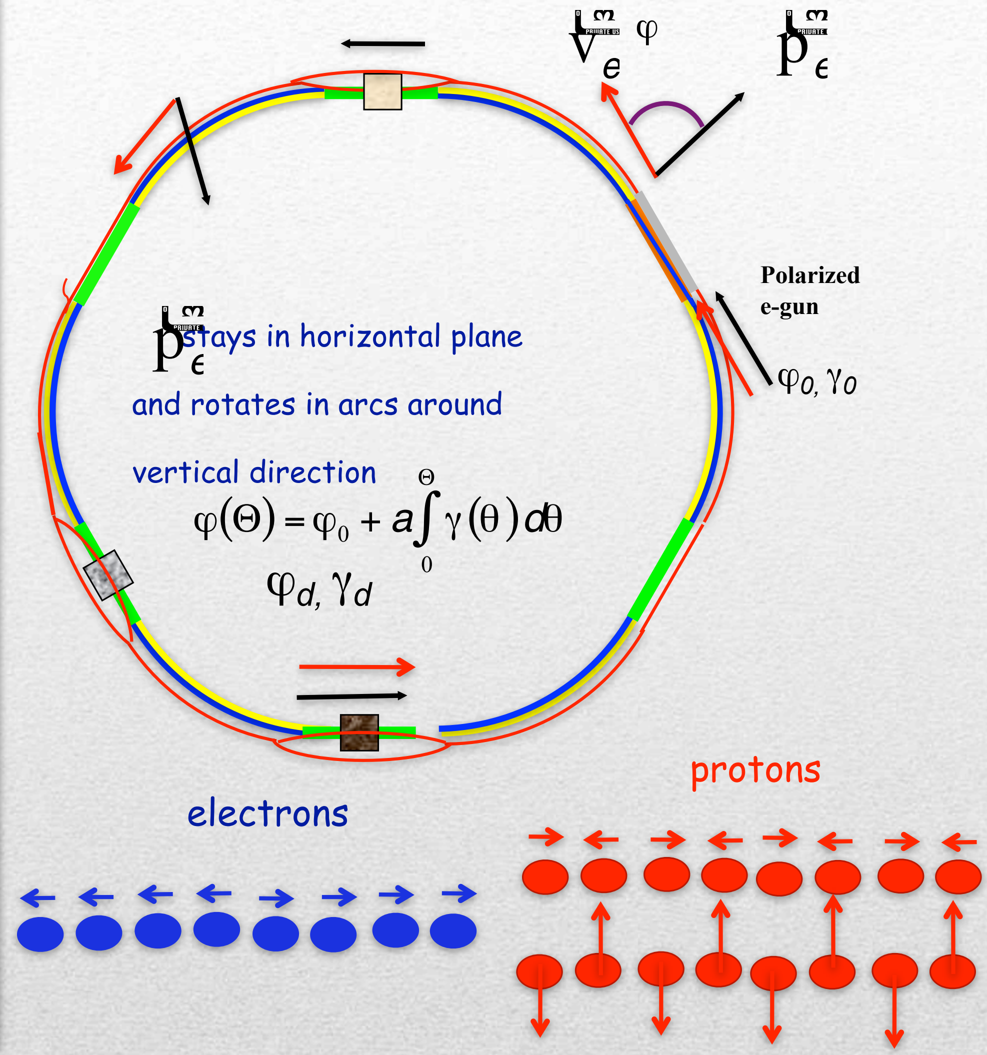
- Same-sign solenoids maintain S-T effect but cause nasty depolarisation.
  - Opposite-sign solenoids cancel one source of opacity but then S-T is then killed.
- So try to set up the optics so that there is spin transparency at all energies.
  - Or rely on S-T at low energy but abandon it at high energy and run with top-up with prepolarised beams from CEBAF.
- Investigations with SLICKTRACK to look at all this have started and have delivered the points just made.

eRHIC
Electrons (V. Ptitsyn)

- No storage, so no S-T. So accelerate a pre-polarised beam: linac and FFAG.
- Need a high current to get lumi -- Gatling gun—still needs development.

Electron Polarization in eRHIC

- 90% longitudinally polarized e-beam from DC gun with super-lattice GaAs-photocathode with polarization sign reversal by changing helicity of laser photons.
- 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
- To achieve 80% polarization up to 21.2 GeV harmonic cavities are used for the energy spread reduction

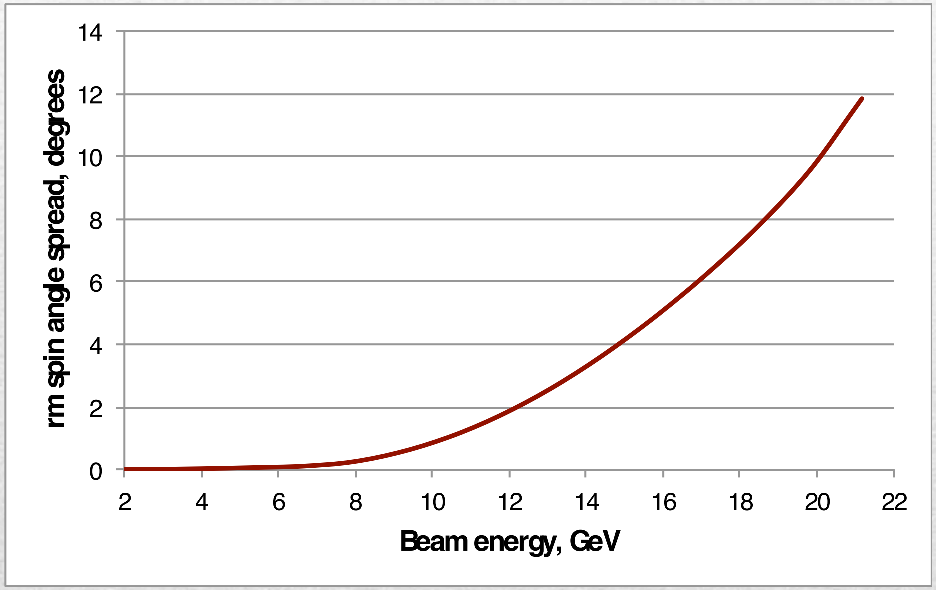


- Long poln at discrete final energies.
- Energy spread and stochastic photon emission can cause decoherence.
- So need to minimise the energy spread from the linac
- So far an analytical calc suggests that the loss of polarisation is small even at 21 GeV
  - BUT: what about resonances when the betatron phase advances match the spin phase advance in the dipole?
  - Recall the teething troubles in the arcs of the SLC for the SLD expt!
    - Need tracking simulations

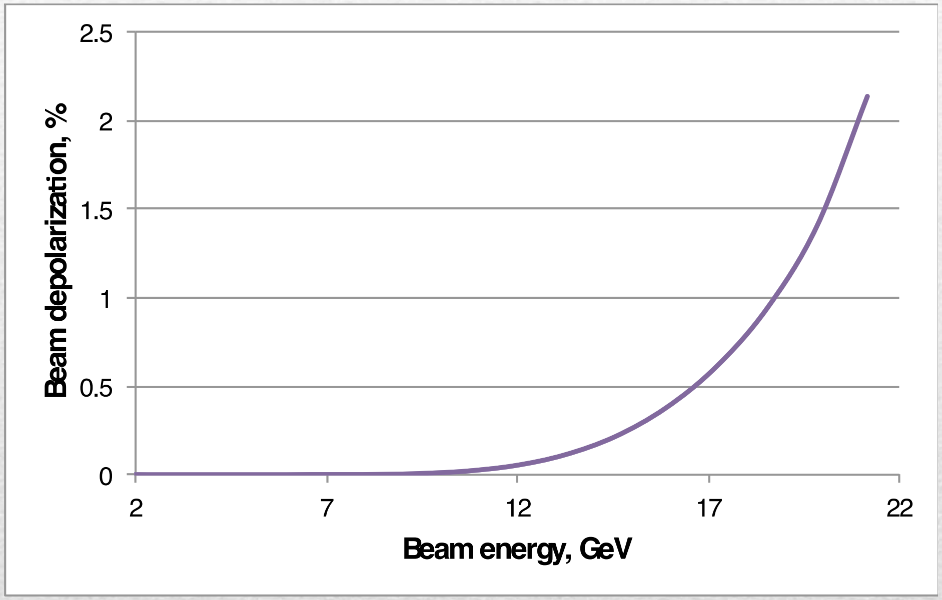
SR depolarization in eRHIC

Depolarization becomes noticeable at acceleration to 21 GeV.
Still the final polarization loss is at acceptable level.

rms spin angle spread



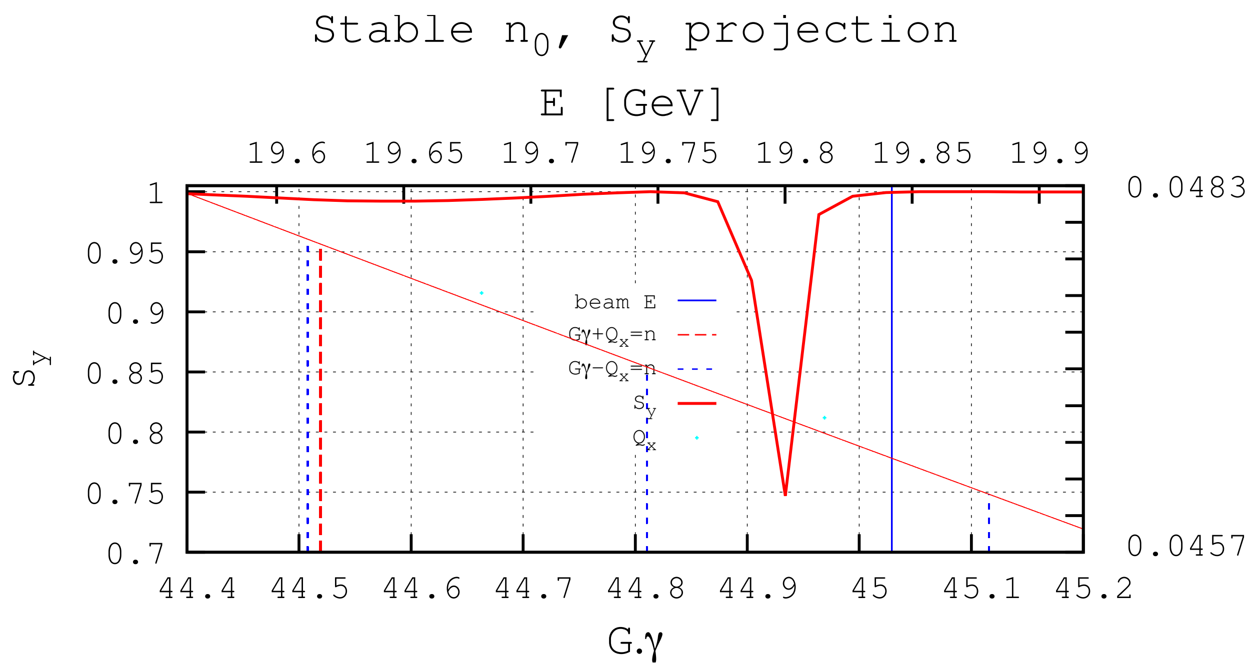
Beam polarization loss



Evolution of the quantities is shown on 21 turns of accelerating process (only arcs !)

Zgoubi Tracking Code (F. Meot)

- **A zoom on** $G\gamma = 45.0291$, $Q_y(G\gamma) = 0.0463$,



- **The resonance has a width,**
- **the beam too,**
  - **- in energy, dE/E**
  - **- and tune,** $\Delta Q = \xi \Delta E/E$

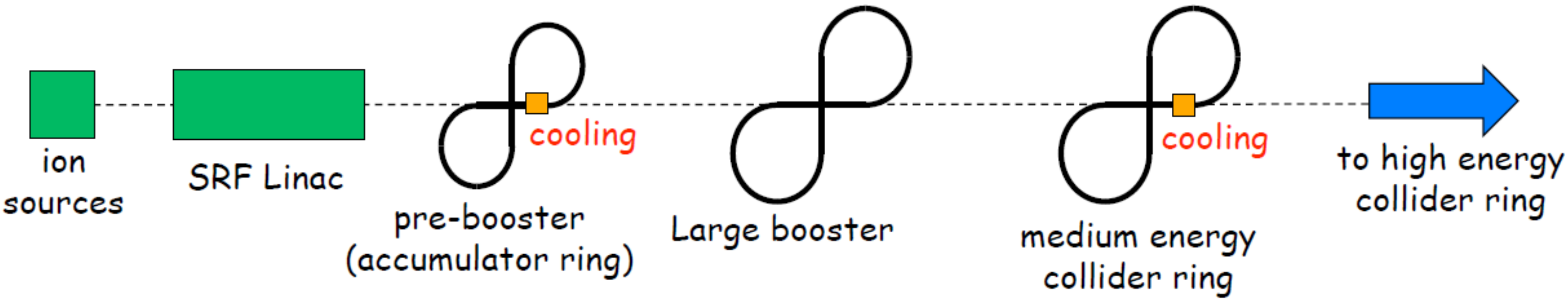
MEIC
Protons (A. Kondratenko)

- Acceleration of protons and ions in simple rings involves crossing spin-orbit resonances as the closed-orbit spin tune $\nu_0 = a \cdot \gamma$ crosses integers or orbital tunes:
  - $a \cdot \gamma = p \pm m\ \nu_x \pm n\ \nu_y \pm o\ \nu_s$
- The loss of polarisation is quantified by the Froissart-Stora formula for vertical spins and depends on the so-called resonance strengths and the rate of change of $a \cdot \gamma$.
  - large accn means that the spins don't notice that they've just been through a resonance. So no poln loss.
  - very small accn causes complete spin flip and preservation of the value of the poln --> partial snakes.

Deuterons

- with deuterons, the spin-orbit coupling is very small and snakes are not practicable
  - too large fields required.
  - And the F-S formula shows that neither non-flip nor complete flip can be arranged
  - So proposed the figure-8 rings to keep ν_0 independent of energy to avoid res. crossing. In fact, with perfect alignment it's zero!
- But then the axis of equil poln (so-called stable spin axis), n_0, is not unique and extra fields, e.g. solenoids must be installed to shift ν_0 away from zero to stabilise it. Nevertheless ν_0 only varies slowly with energy.
- Clever scheme but needs detailed evaluation with tracking

The major components of the MEIC ion complex



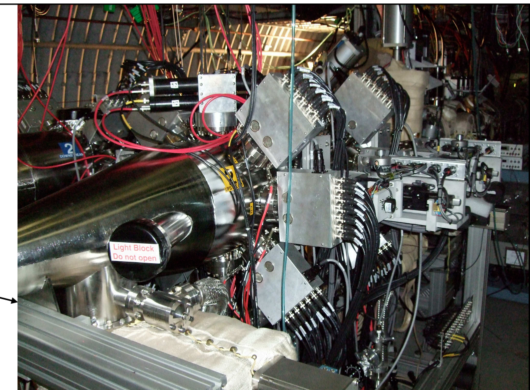
The MEIC ion beam polarization design requirements are:

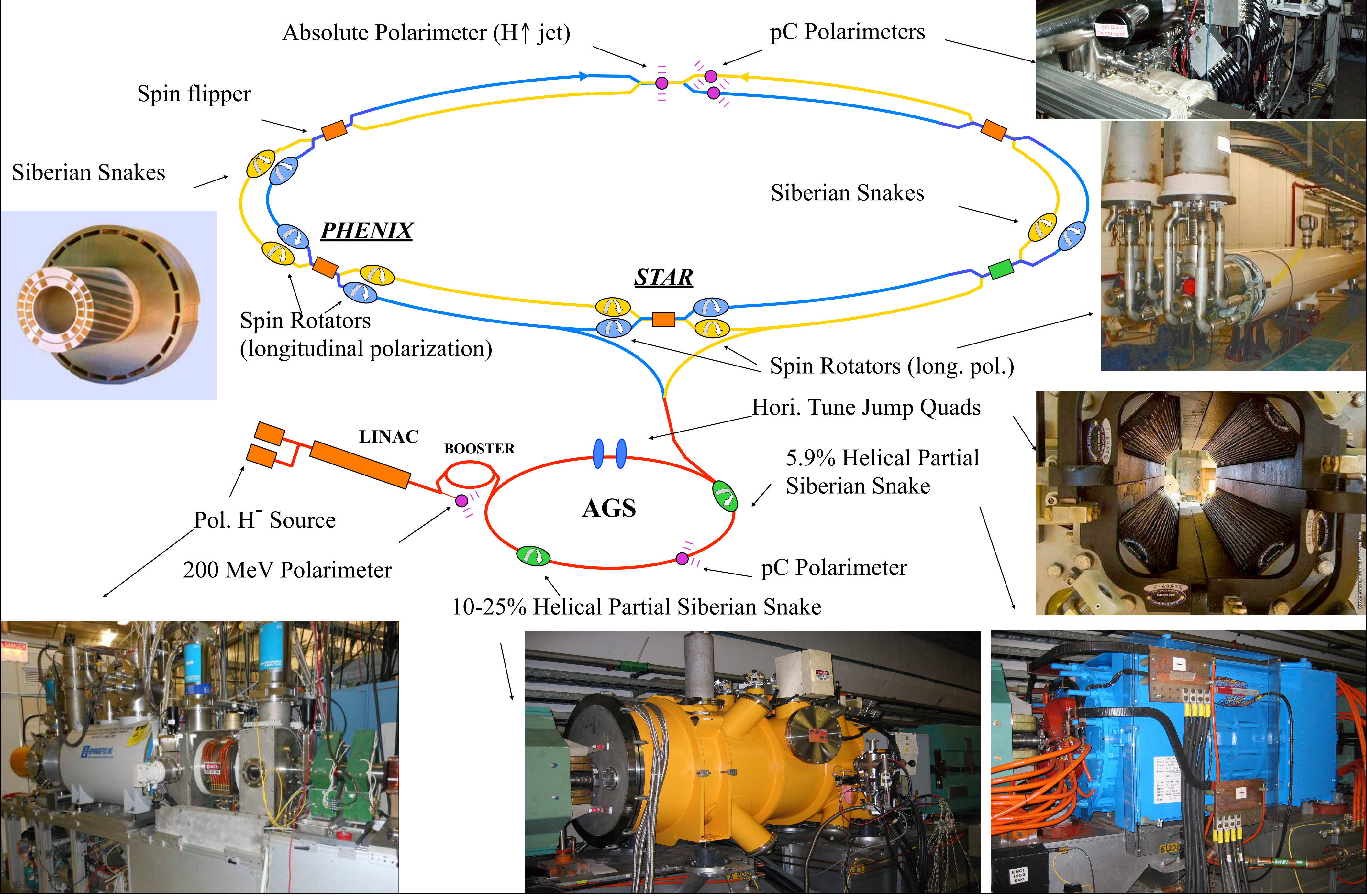
- High polarization (over 70%) for protons and light ions (**d**, 3He++, and possibly 6Li+++).
- Both longitudinal and transverse polarization at all IPs.
- Sufficiently large lifetime to maintain high beam polarization.
- Spin flipping at a high frequency.

Improving poln at full RHIC energy (H. Huang)

- Need to polish the existing techniques:
  - Careful choice of orbital tunes in the Booster and AGS
  - Partial snakes in the AGS
  - Control the emittances
  - Very careful control of orbital tunes on the RHIC ramp.
  - Avoid so-called ``snake resonances''
  - So far up to 58 percent at 255 GeV
  - In future smaller emittances
  - Six snakes? Preliminary indications of improvement but inclusion of machine distortions is ESSENTIAL.
  - Simulations continuing

RHIC–First Polarized Hadron Collider

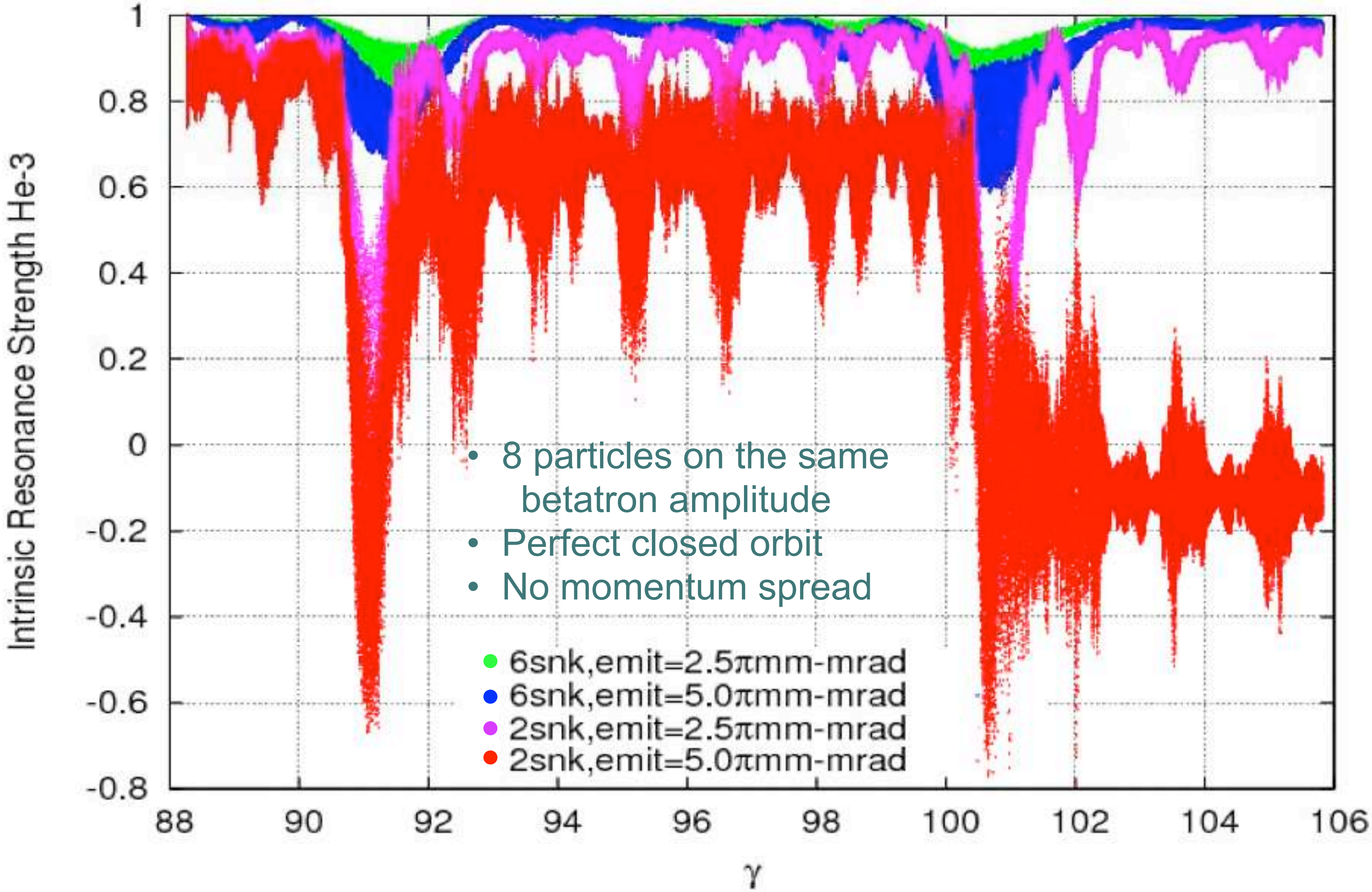




He-3 Polarization (M. Bai)

- Integer resonances every 523 MEV for protons, every 436 MeV for He-3
- Careful choice of tunes in booster and AGS etc.
- Careful choice of partial snake angles in the AGS
- Detailed simulations in progress (Yann Dutheil)
- Six snakes in RHIC?
- This problem was thoroughly studied in the 1990's with a filtering algorithm at DESY
  - Georg Hoffstatter's book: High Energy Polarized Proton Beams; A Modern View (Springer 2006)
  - Mathias Vogt's thesis: DESY-THESIS 2000-05

Accelerating He-3 in RHIC – spin tracking



A new fast s-o tracking code
(D. Abell)

- Spin-orbit tracking codes should describe particle motion with canonical (symplectic) transformations and transport spins with orthogonal rotation matrices
- The mathematics and typical algorithms have been well established for 30 years! E.g. Splitting algorithms to divide the Hamiltonian into pieces which allow easy exact integration! See Etienne Forest's book and Alex Dragt's book.
- Nevertheless, for spin improvements in speed while maintaining orthogonality are highly desirable.
- Dan Abell at colleagues at Tech-X have developed gpuSpinTrack for RHIC and any other takers

- It uses the Romberg algorithm to give enormous improvements in the precision of the quaternions that represent spin rotations —while maintaining speed. Can run on a laptop.
- This should be the code of choice for protons etc at the MEIC.
- For example the question about spin behaviour for protons etc in the figure-8 of the MEIC: Don't just talk about it—simulate it!
- Couple it with Forest's PTC and FPP for analysis.

Summary

Accurate spin tracking requires accurate orbital tracking.

Romberg quadratures applied to spins is an inexpensive “add-on” that speeds convergence of standard spin-tracking.

A gpu implementation of these algorithms–gpuSpinTrack–now enables us to compute an ISF for RHIC at 10^4 phase space locations using 10^3 turns in about an hour.

We look forward to applying these tools to new frontiers.

Further Thoughts

- We need consistent use of terminology. Don't mix proton and electron language for different kinds of phenomena
- Use proper mathematics with clear consistent use of symbols to avoid writing mathematical nonsense.
- We've progressed a long way since the confusions of the early 1980's so take advantage of that!
- My experience with b-b effect on electrons in the R-R version of eRHIC (up to 2005) is that we need to take a careful look at b-b effects. Nonlinear orbital motion can introduce a whole new zoo of s-o resonances!
- Does the figure-8 shape lead to suppression of sync.sideband resonances for the electrons? The sync modulation of the rate of spin precession is suppressed (NOT spin tune modulation).
- For protons: cooling and IBS are roughly analogous to radiation damping
- and stochastic photon emission for electrons. So is there spin diffusion for the protons?
- The mathematical objects needed to get a rough check on this at first order are already in SLIM/SLICK

You heard it here first!