# Polarisation issues for eRHIC

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## Plan

- Self polarisation/ depolarisation: some theory? — almost No!
- HERA: latest
- Approaches: self polarisation, injected polarisation.
- Optimisation: various forms of spin matching.
- Calculations/software.
- Rotators: the worst energy range.
- Experiment machine interface near IP.
- Superbends
- Round beams.
- Beam–beam.
- Terminology: recipes for confusion.
- Recommendations: again!.
- Deeply moving philosophy.

## Spin motions

- Protons: largely deterministic — unless IBS.
- Electrons/positrons:
  If a photon causes a spin flip, what are the other $\approx 10^{10}$ photons doing? ===>

  Stochastic/damped orbital motion due to synchrotron radiation
  \+ inhomogeneous fields
  \+ T–BMT
  ===> spin diffusion i.e. depolarisation!!!

  Self polarisation: Balance of poln. and depoln. ===>

  $$P_\infty \approx P_{BK} \, \frac{1}{1 \; + \; (\frac{\tau_{dep}}{\tau_{BK}})^{-1}} \qquad (P_{ST} \to P_{BK})$$

  In any case:

  $\tau_{dep}^{-1} \;\propto\; \gamma^{2N} \, \tau_{st}^{-1}$ (actually a polynomial in $\gamma^{2N}$)

  ===> Trouble at high energy!

## Spin–orbit resonances

$$\nu_{\rm spin} \;=\; k + k_I\nu_I + k_{II}\nu_{II} + k_{III}\nu_{III}$$

$\nu_{\rm spin}$ : amplitude dependent spin tune $\approx$ closed orbit spin tune = precessions /turn on CO

- Orbit "drives spins" ===> Resonant enhancement of spin diffusion.
- Resonance order: $|k_I| + |k_{II}| + |k_{III}|$
- First order: $|k_I| + |k_{II}| + |k_{III}| = 1$ e.g. SLIM like formalisms.
- Strongest beyond first order:
  synchrotron sidebands of first order parent betatron or synchrotron resonances

$$\nu_{\rm spin} \;=\; k + k_i\nu_i + k_{III}\nu_{III}, \quad i = I, II \text{ or } III$$

## HERA update

March 2003:

"Longitudinal positron spin polarisation has now been attained simultaneously at three experiments at HERA, the 6.3 km electron(positron)–proton ($e^{\pm} - p$) double storage ring collider at the Deutsches Elektronen-Synchrotron (DESY) laboratory in Hamburg, Germany HERA has been providing $e^{\pm} - p$ collisions since June 1992. The $e^{\pm}$ beam runs at about 27.5 GeV and the proton beam at 920 GeV . . . . . .

$$\vdots$$

The demonstration of the provision of high energy longitudinally spin polarised $e^{\pm}$ beams at HERA also increases confidence in the feasibility of the eRHIC project at Brookhaven National Laboratory, U.S.A., involving the provision of longitudinally polarised $e^{\pm}$ for collision with the high energy polarised protons in the Relativistic Heavy Ion Collider (RHIC)."

## Approaches: self polarisation, injected polarisation

- Self polarisation (e.g. at 10 GeV): Need high polarisation rate and low depolarisation rate.
  - Achieve by design: energy, small bending radius (super bends?), various spin matching.
- Injected prepolarised beam (e.g. at 5 GeV): Need low depolarisation rate:

$$\tau_{\mathrm{dep}} >> \tau_{\mathrm{beam}}$$

  - Achieve by design: large bending radius, spin matching probably not good enough for long storage (e.g. beam–beam).
    Snakes can be dangerous in electron rings!
  - Inject at full energy: little hope of accelerating through resonances.
  - Luminosity: Need to be sure that the (vertical) polarisation is not lost during stacking.
  - Luminosity: have discussed injecting small beams and ejecting after some damping times? Background? Stability?.....

**Can be difficult to combine everything in one ring.**

Booster for polarised positrons? Spin flipper?

## Optimisation to maximise $\tau_{\mathrm{dep}}$: various forms of spin matching

- Strong synchrobetatron spin matching for designing the basic optics, e.g. use SPINOR (matrix formalism), or SOM (C–S parameters).
- Harmonic closed orbit spin matching (after good initial alignment) for handling remaining effects of misalignments: harmonic bumps. Possible in eRHIC?
- Harmonic synchrobetatron spin matching, e.g. for coping with dispersion bumps.

All spin matching is based on first order perturbation theory.
It certainly helps but it is not the whole story:
higher order resonances, e.g. synch. sidebands,
but probably not too dangerous at these energies.

## HERA: SLIM polarisation:
## 3 rotator pairs, spin matched at 29.23 GeV, no distortions

## HERA: SLIM polarisation:
## 3 rotator pairs, spin match broken, no distortions

## Software

- Linearised spin–orbit motion: SLIM, SLICK, SITF, ASPIRRIN, SOM.
- Linearised orbit motion, full 3–D spin by pert. expn.: SMILE, thin lens
- Linearised orbit motion, full 3–D spin by 1–turn maps: SODOM I, storage needs.
- Linear + sext. orbit motion, full 3–D spin by ring section maps and Monte–Carlo radiative tracking; SITROS ==> SPRINT in future.

**Diagnostics** to understand what's going on.

## Rotators: solenoids

- Plus:
  - Elegant,
  - compact,
  - spin transparency across IR possible with careful design, (“vertical” spin match across arcs not needed), e.g. the Novosibirsk design.
  - loss of S–T can be avoided with long dipoles .
- Minus:
  - Solenoids alone are fairly spin–opaque,
  - the schemes for spin transparency are finely balanced — quad. tuning?.
  - especial care with the transparency of the detector region?
  - the closed orbit can go crazy inside: need internal correction.
  - pure longitudinal polarisation only at one energy – ask the users, and don’t choose that energy to be at an integer spin tune.

## Dipole Rotators: interleaved H–V dipoles

- Plus:
  - For a restricted energy range, pure longitudinal polarisation at all energies – with variable geometry, e.g HERA,
  - if short enough, can be automatically spin transparent (no internal quads),
  - then uncomplicated optics,
  - no problems with the closed orbit,
  - spin transparency possible with careful design (no internal quads).
- Minus:
  - Long – take a lot of lattice – but that's not too problematic if the straights are very long and the ring is designed for them at the start,
  - then loss of S–T unless the dipoles are long enough,
  - uncomfortable +/− vertical excursion at low energy,
  - is a design with a swing from 5 to 10 GeV possible?
  - spin match needed in the straight section and (vertically) in the arc.

**Examples of dipole rotators at www.desy.de/~mpybar/rotator.html**

**A lot more information on electron/positron polarisation in:**
**"Snowmass 2001" talk at: www.desy.de/~mpybar/rectalks.html**

## Experiment machine interface near IP

- Can perturb the best spin matching efforts of man and beast!,
  - Difficult to handle the messy fields (see M. Berglund thesis at www.desy.de/~mpybar/theses.html),
  - no space for anti–solenoids?,
  - want to avoid skew quads,
  - e.g. the HERA Upgrade: Aaaaaaaaaaaaaaghhhhhhhhhhhh!,
  - effects will become especially apparent if great care is taken with alignment – find a balance.

**Superbends?**

Initial calculations show a need for careful evaluation of their effect on the depolarisation in the presence of distortions.

## Round beams

How? Needed? beam–beam simulations!

Flat/round transformers? spin matching?

Vertical dispersion bumps? Harmonic synchrobetatron spin matching?

**Beam–beam effect**

We want to push to the limits: Very interesting! :-)

For some observations see:
"Snowmass 2001" talk at: www.desy.de/~mpybar/rectalks.html

## Terminology

- “Spin matching”, “transparency” to avoid spin diffusion (PEAS workshop, DESY 1982):
  don’t confuse with usage for the AGS–RHIC transfer line !
- “Imperfection resonances”: inappropriate language for spin diffusion:
  - There are no imperfection resonances in the depolarisation rate!
  - But there are strong, overlapping synchrotron depolarising resonances around integer (closed orbit) spin tune.
- Still use of $\hat{n}$ when $\hat{n}_0$ is meant and incorrect interpretation of the symbol
  $$\gamma\partial\hat{n}/\partial\gamma \qquad (\equiv \partial\hat{n}/\partial\delta)$$

**Wrong concepts, confusing terminology don’t help.**

## General recommendations for obtaining high self polarisation or large lifetime for stored injected polarisation

- Include polarisation in the design (lattice, rotators, optic, spin matching) from the start — it should not be an "add on".
- Pay particular attention to:
  - alignment control and beam position monitoring
  - $\longrightarrow$ deterministic harmonic C.O. spin matching?
  - facilities for beam–based monitor calibration.
  - careful solenoid compensation $\longrightarrow$ locally with anti–solenoids if possible.
- Use spin transfer matrix formalism for spin matching in exotic machines and understand the physics of the spin–orbit coupling of each section of the ring. Ensure that there are enough independent quadrupole circuits.
- There is plenty of software available for detailed numerical calculations of linearised spin motion. The theory for linear orbit motion is well established.
- Very interesting depolarisation effects due to beam–beam forces have been seen at HERA and LEP. For future high luminosity ring–ring colliders it will be very important to have a good understanding of these effects and to be able to carry out reliable simulations with tracking codes. This could become a high priority for running in the presence of intense proton beams.

/cont.

- Pay close attention to polarimetry: backgrounds!! $\longrightarrow$ build the machine around the polarimeter(s)! Fast precise polarimeters are essential for facilitating fast adjustment of the orbit or tunes. Build the machine around the polarimeter(s) so that bremsstrahlung and synchrotron radiation backgrounds are avoided
- Don't try to calibrate polarimeters during beam–beam collisions
  and when calibrating polarimeters be careful about the effects of kinetic polarisation if the ring is not flat.

## Philosophy

- **We have the opportunity, with a new machine, to get it right – or as good as possible – every step of the way.**
- **Polarisation is not an "add on", it's intrinic to the project.**
- **Initial calculations with initial eRHIC layouts have shown that the depolarisation can be much too strong even at these low energies.**
- **Base all decisions on numerical and analytical estimates of the polarisation achievable with the chosen layout/optic/proton beam.**