Beam Polarisation

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Plan

- Self polarisation/depolarisation/spin matching
- Calculations at first order.
- Beam–beam/thick beams.
- The story so far.

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
  \+ spin–orbit coupling via 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 γ^{2N})

===> Trouble at high energy!

Spin–orbit resonances

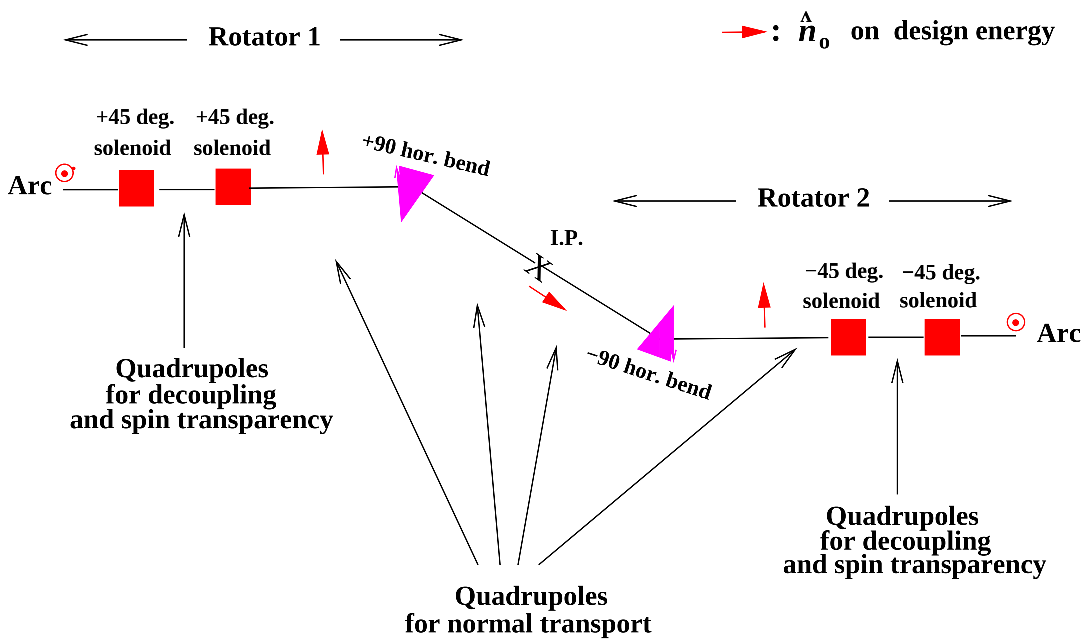
$$\nu_{\rm spin} \; = \; k + k_I \nu_I + k_{II} \nu_{II} + k_{III} \nu_{III}$$

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

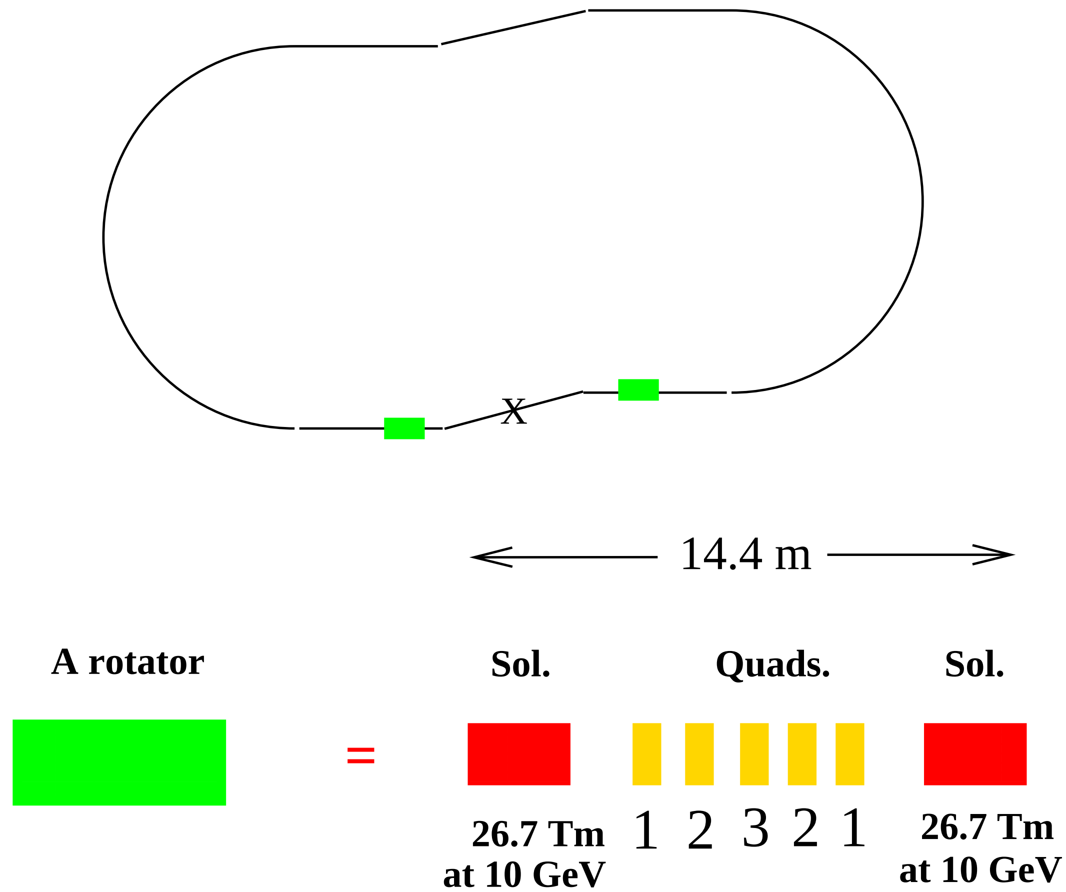
- Orbit "drives spins" ===> Resonant enhancement of spin diffusion.
- Resonance order: $|k_I| + |k_{II}| + |k_{III}|$
- First order: $|k_I| + |k_{II}| + |k_{III}| = 1$ e.g. SLIM like formalisms.
- Strongest beyond first order:
  synchrotron sidebands of first order parent betatron or synchrotron resonances

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

The solenoid spin rotators



The eRHIC basic geometry

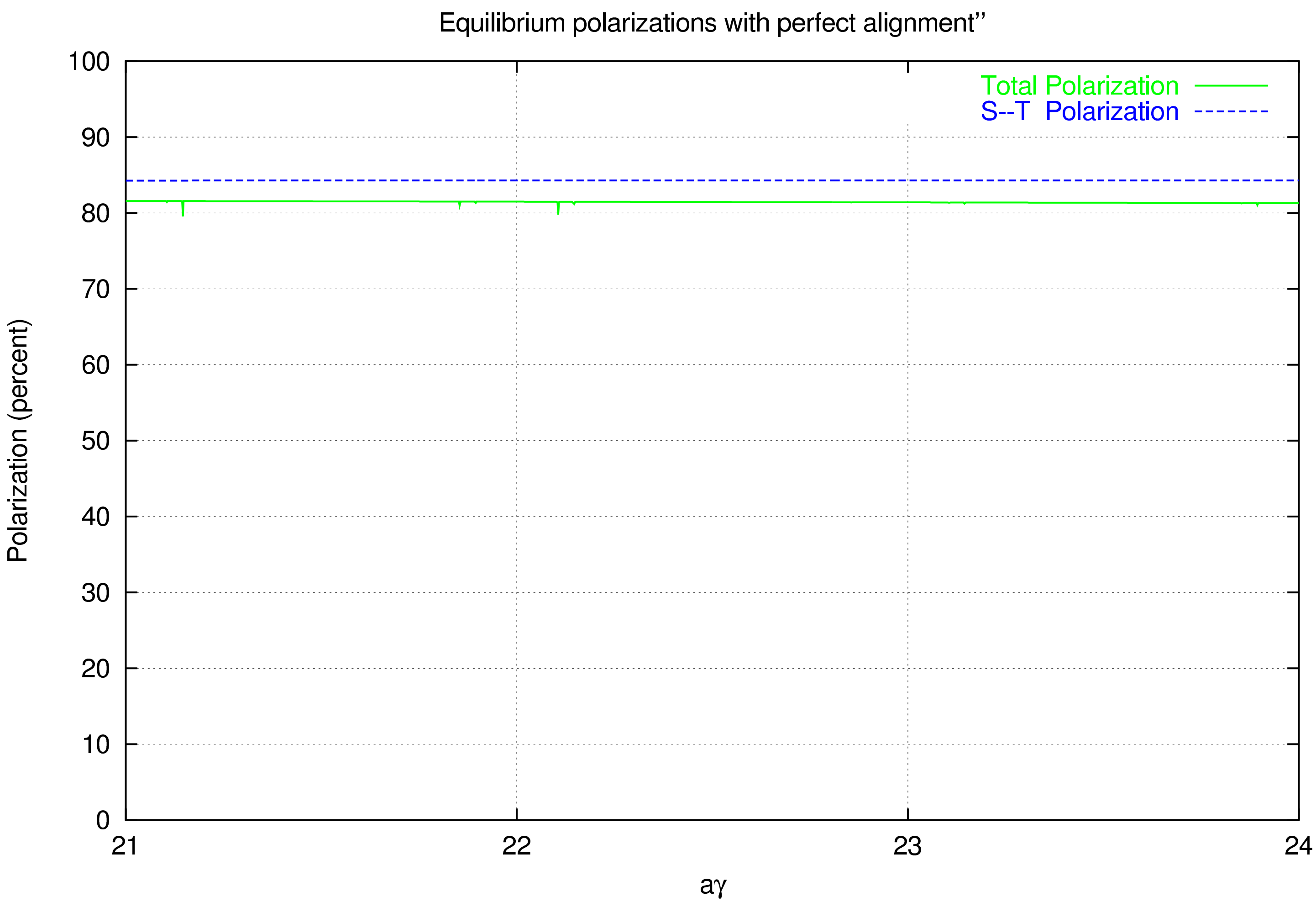


The 4×4 transfer matrix for the transverse motion through a pair of solenoids:

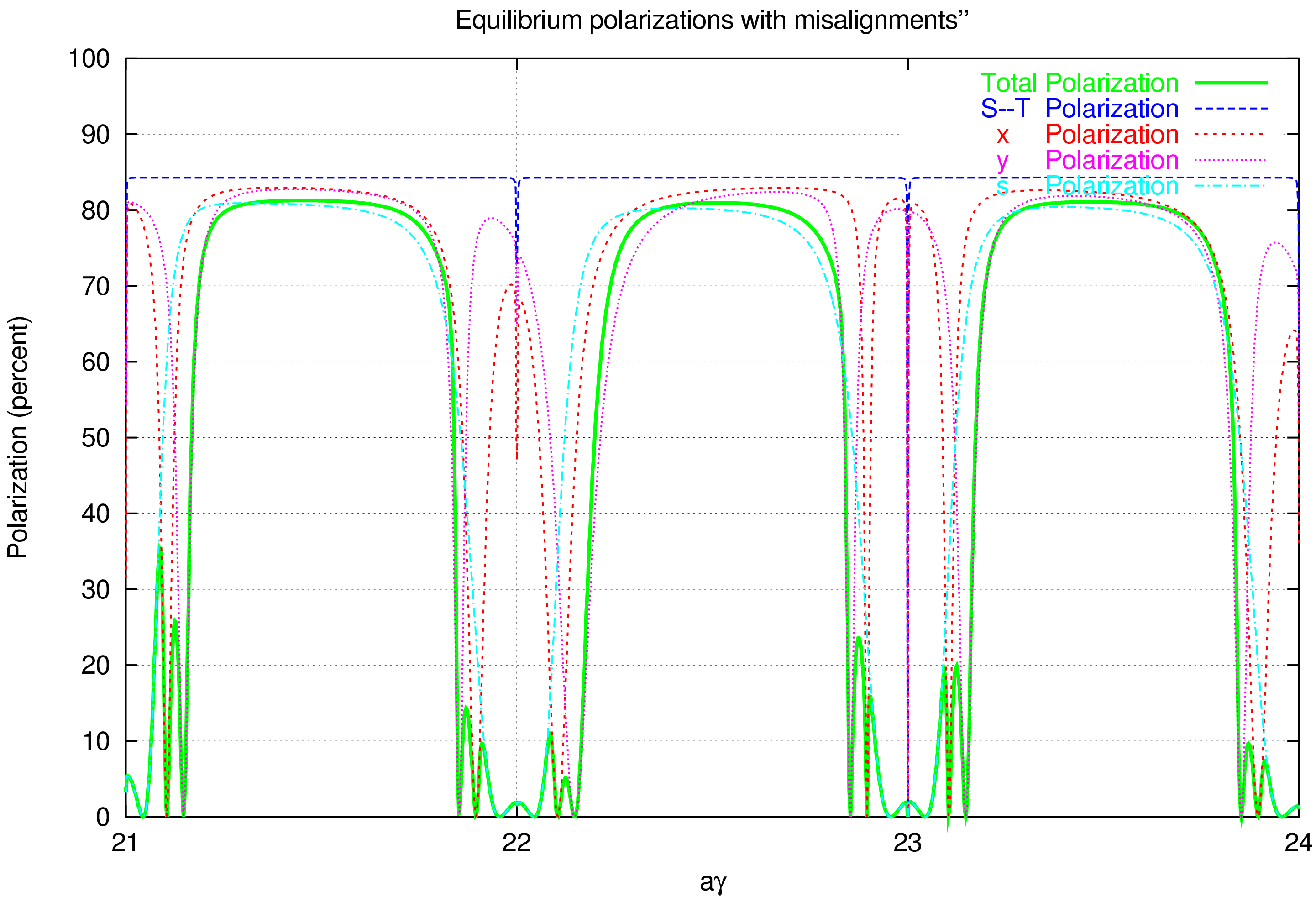
$$\begin{pmatrix} 0 & -2r & 0 & 0 \\ 1/2r & 0 & 0 & 0 \\ 0 & 0 & 0 & 2r \\ 0 & 0 & -1/2r & 0 \end{pmatrix}$$

where r is the radius of orbit curvature in the longitudinal field.

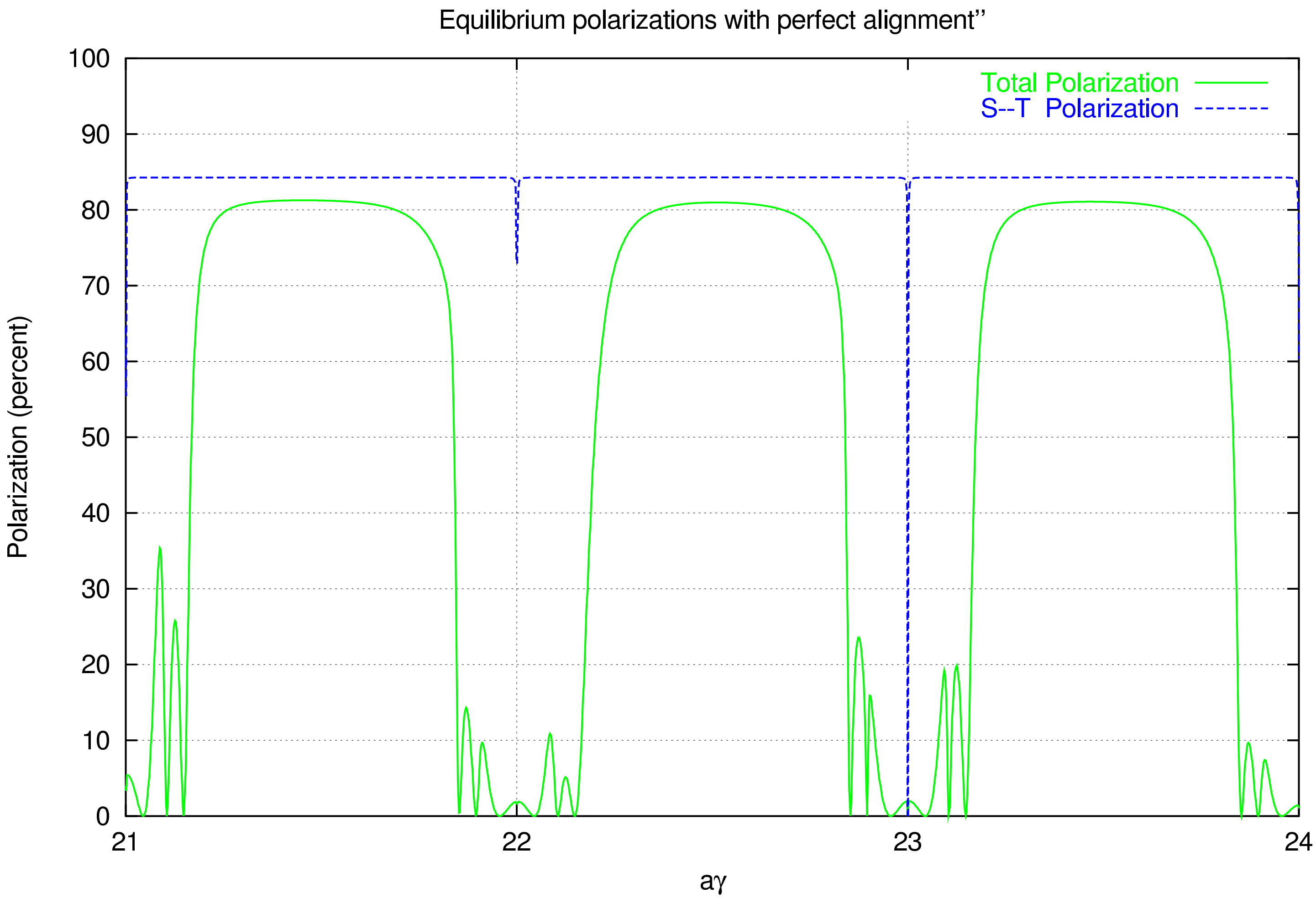
Use 5 back–to–back symmetric quadrupoles.


Equilibrium polarizations with perfect alignment''
Total Polarization
S--T Polarization
Polarization (percent)
aγ
100
90
80
70
60
50
40
30
20
10
0
21
22
23
24

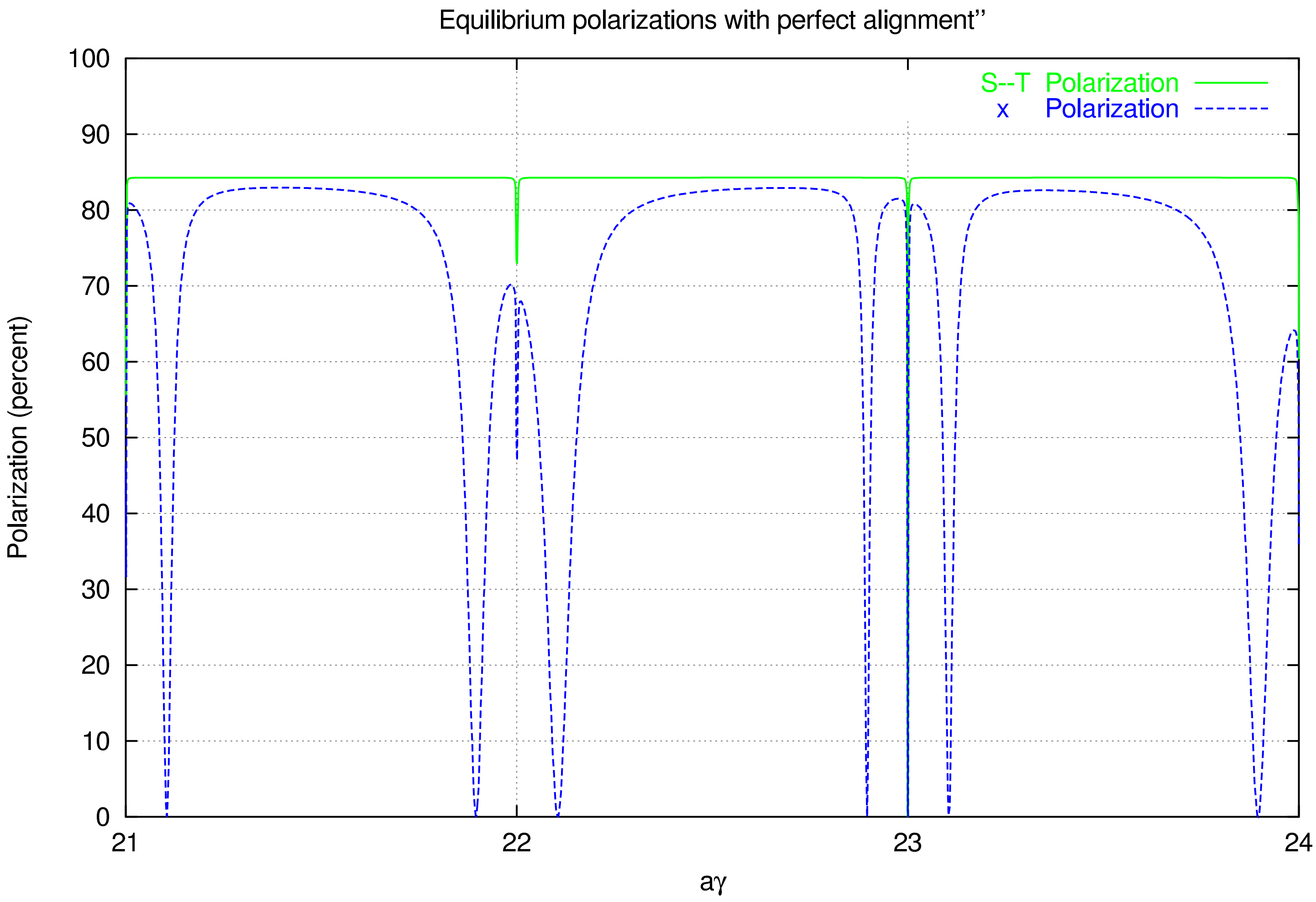
All monitors on



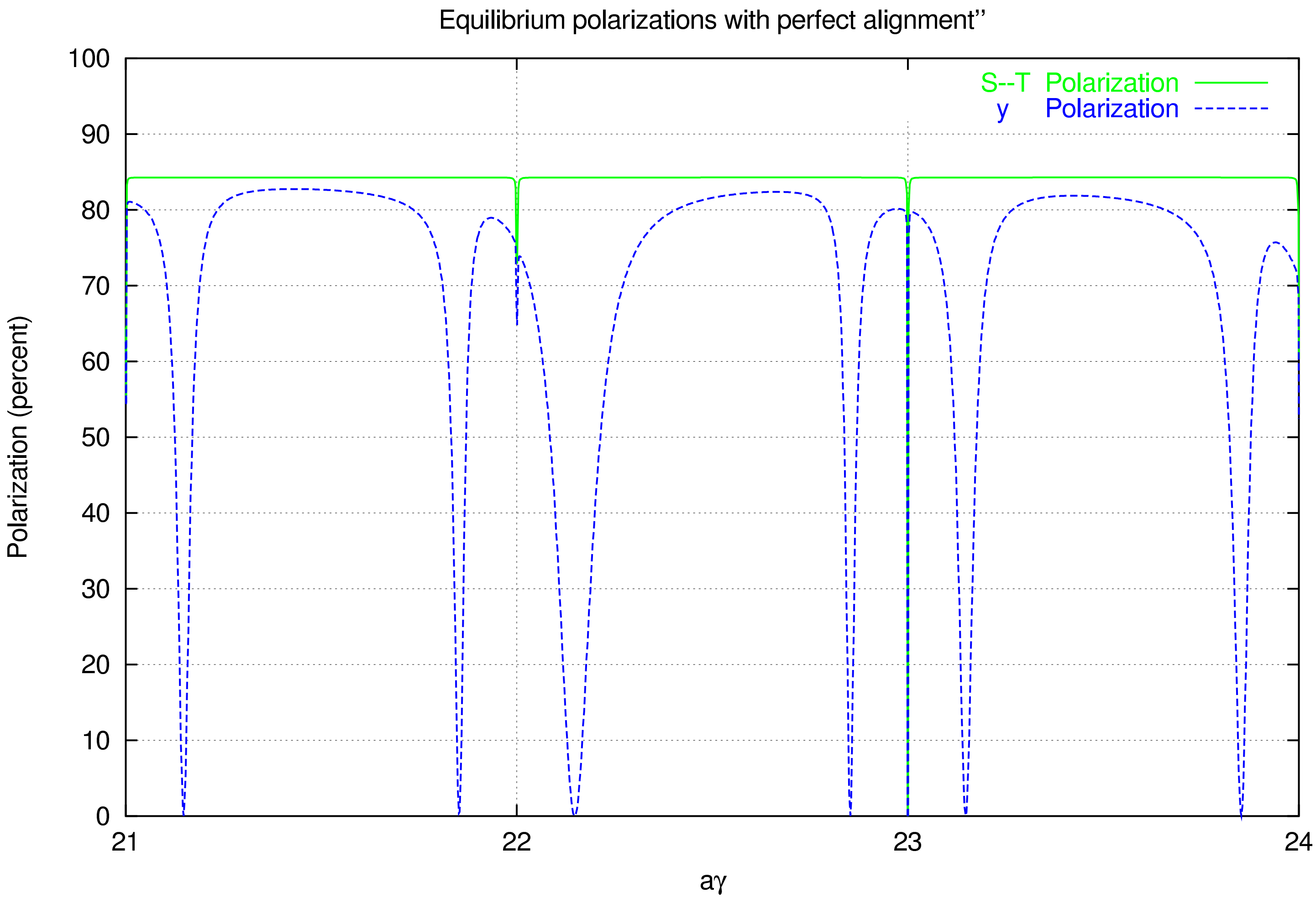
All monitors on



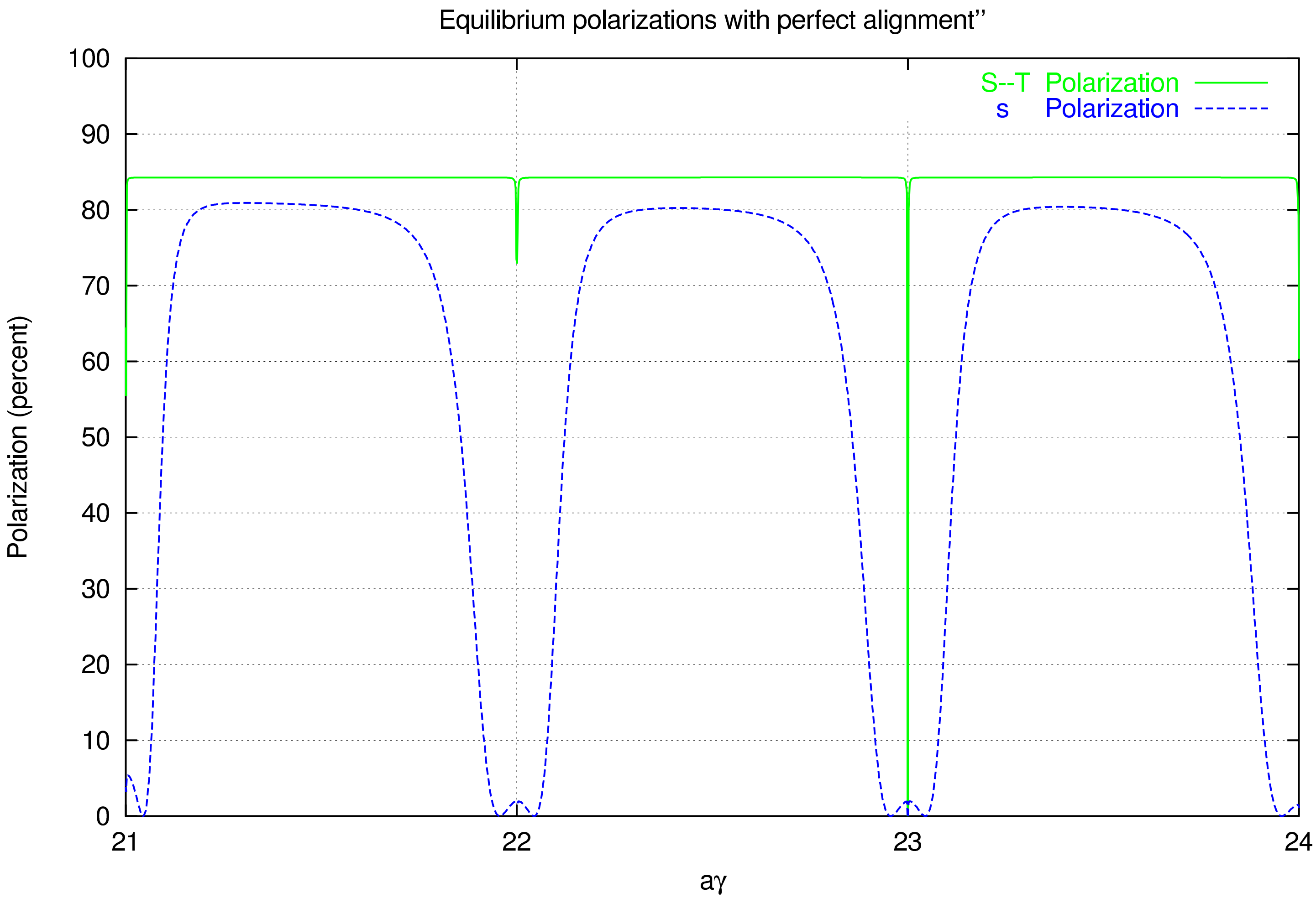
All monitors on



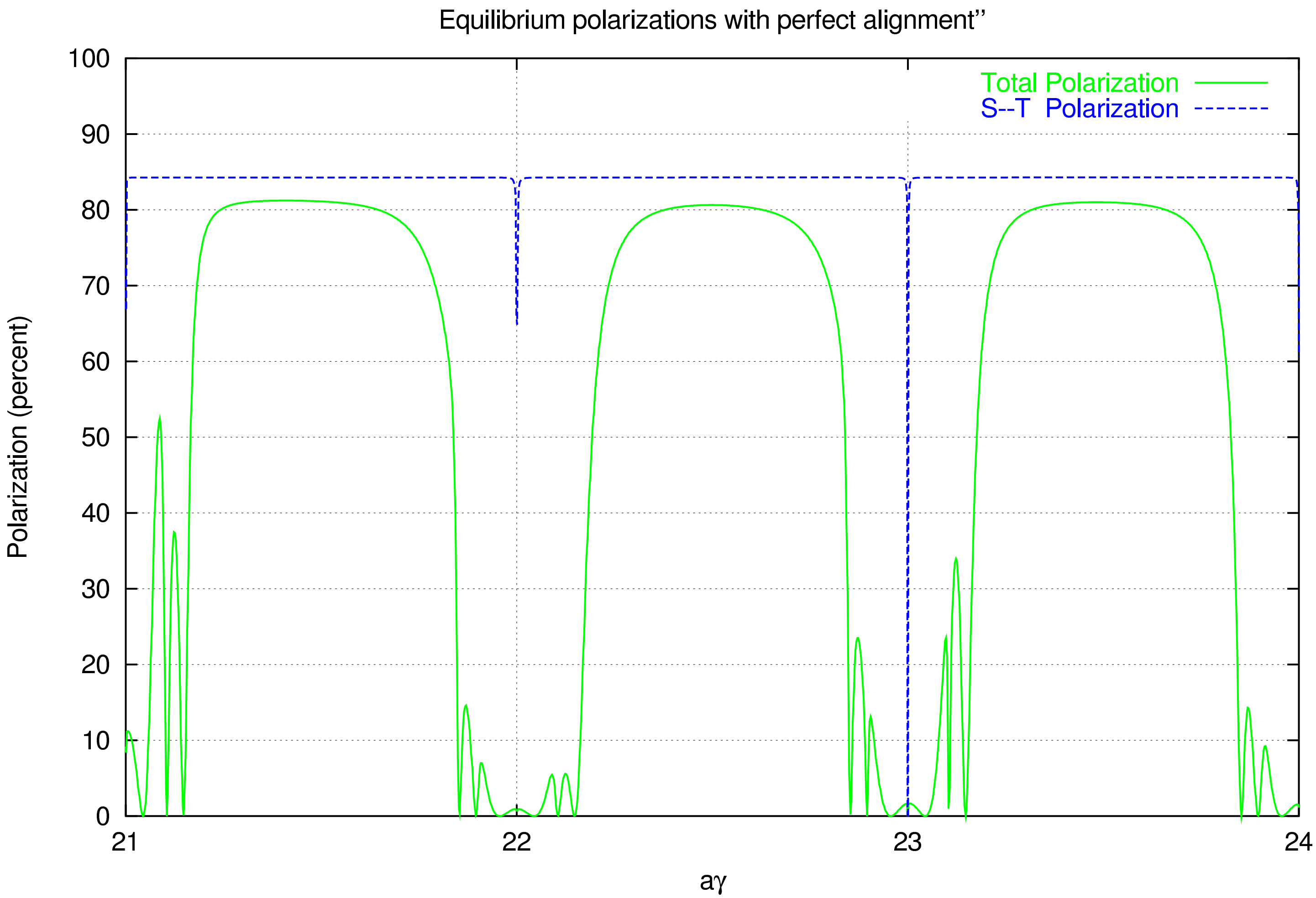
All monitors on



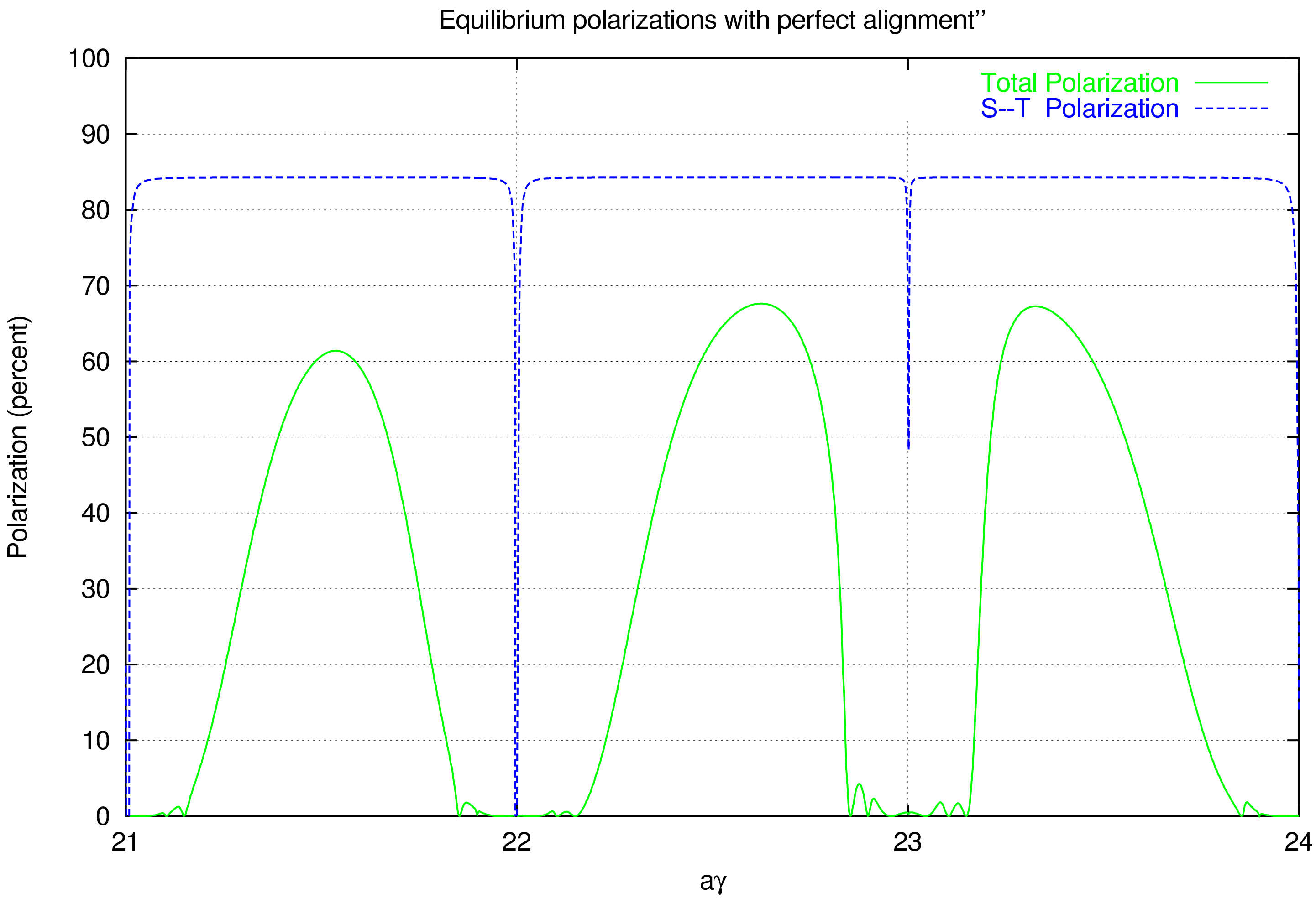
All monitors on

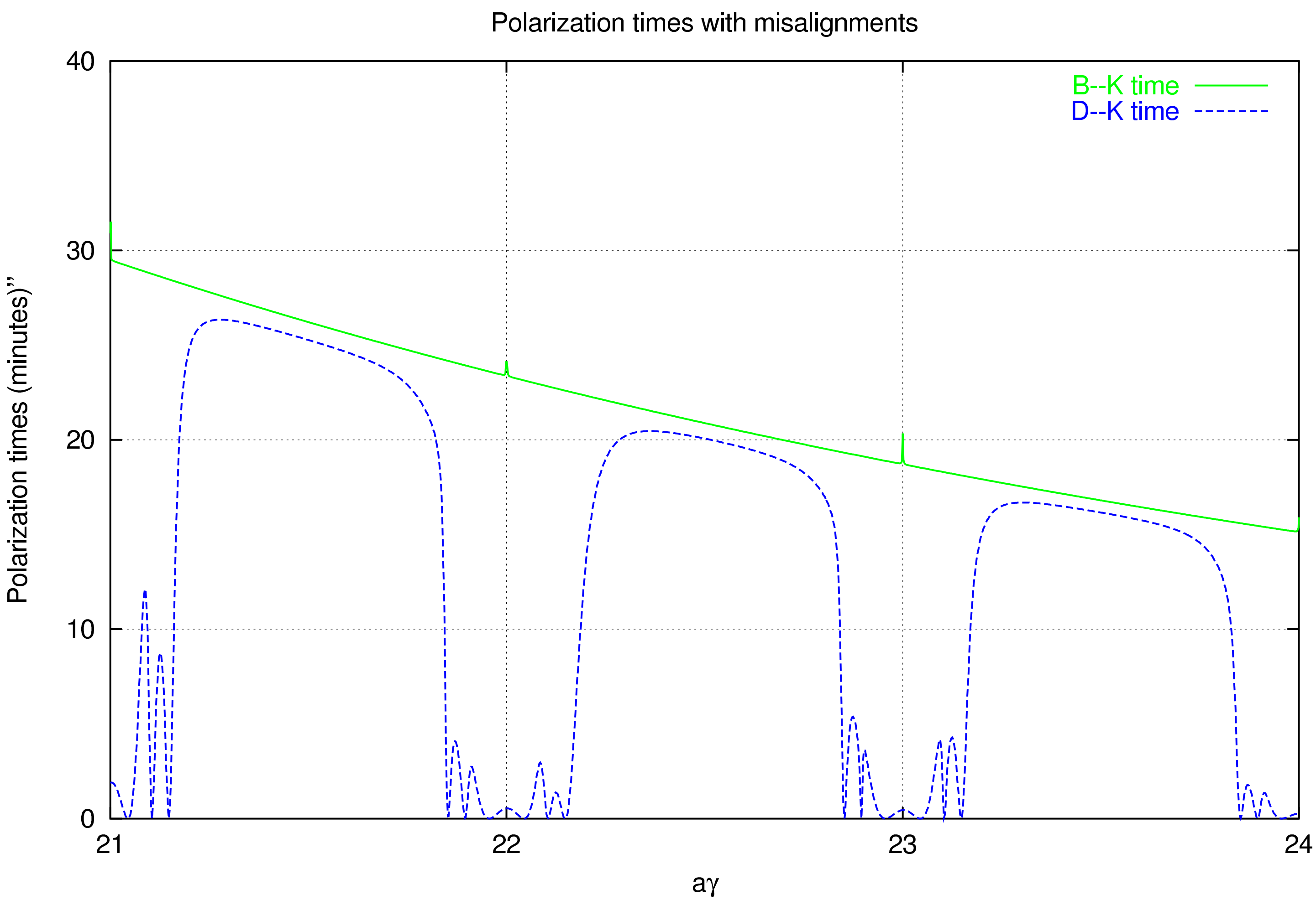


80 percent monitors on

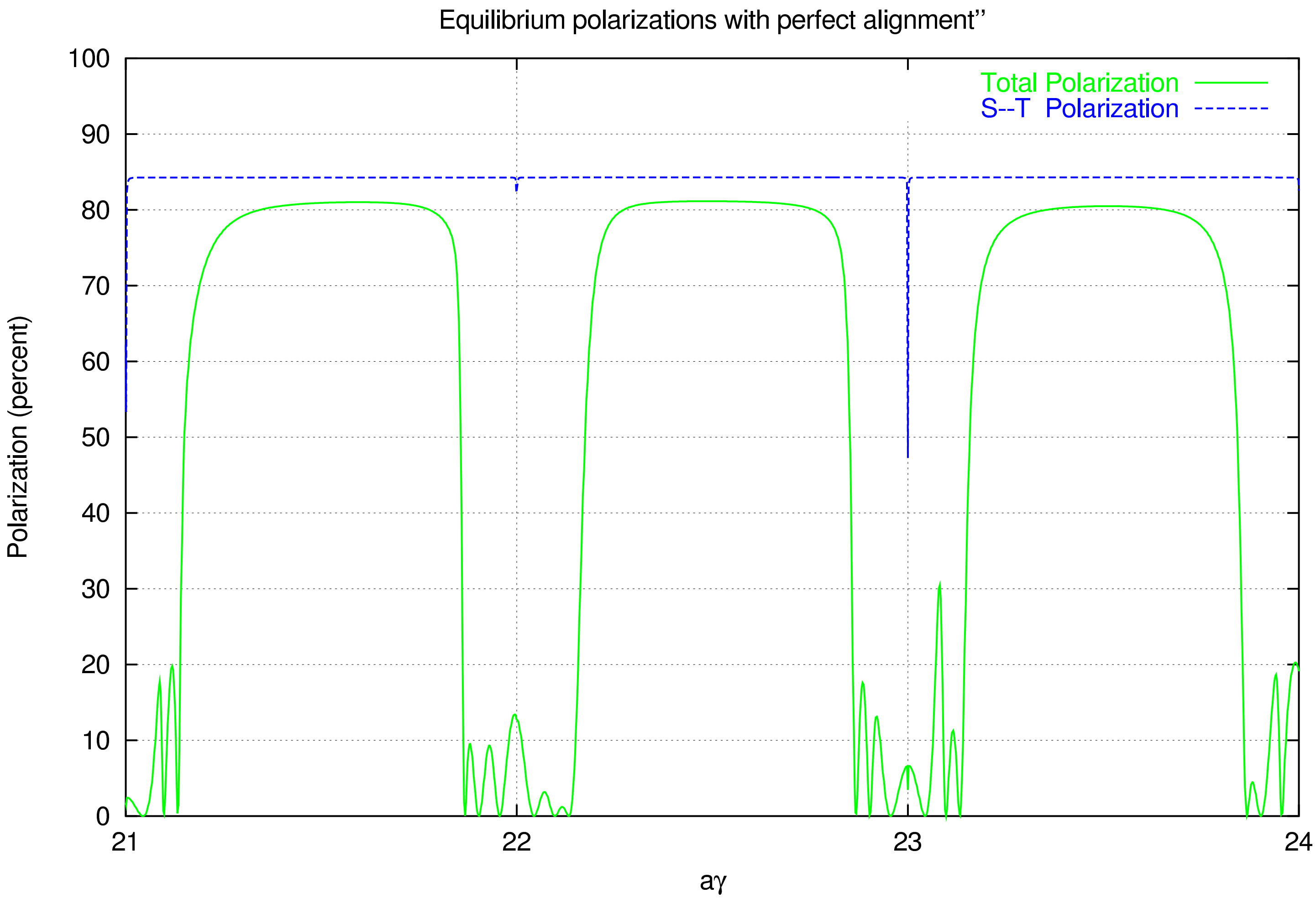


20 percent monitors on

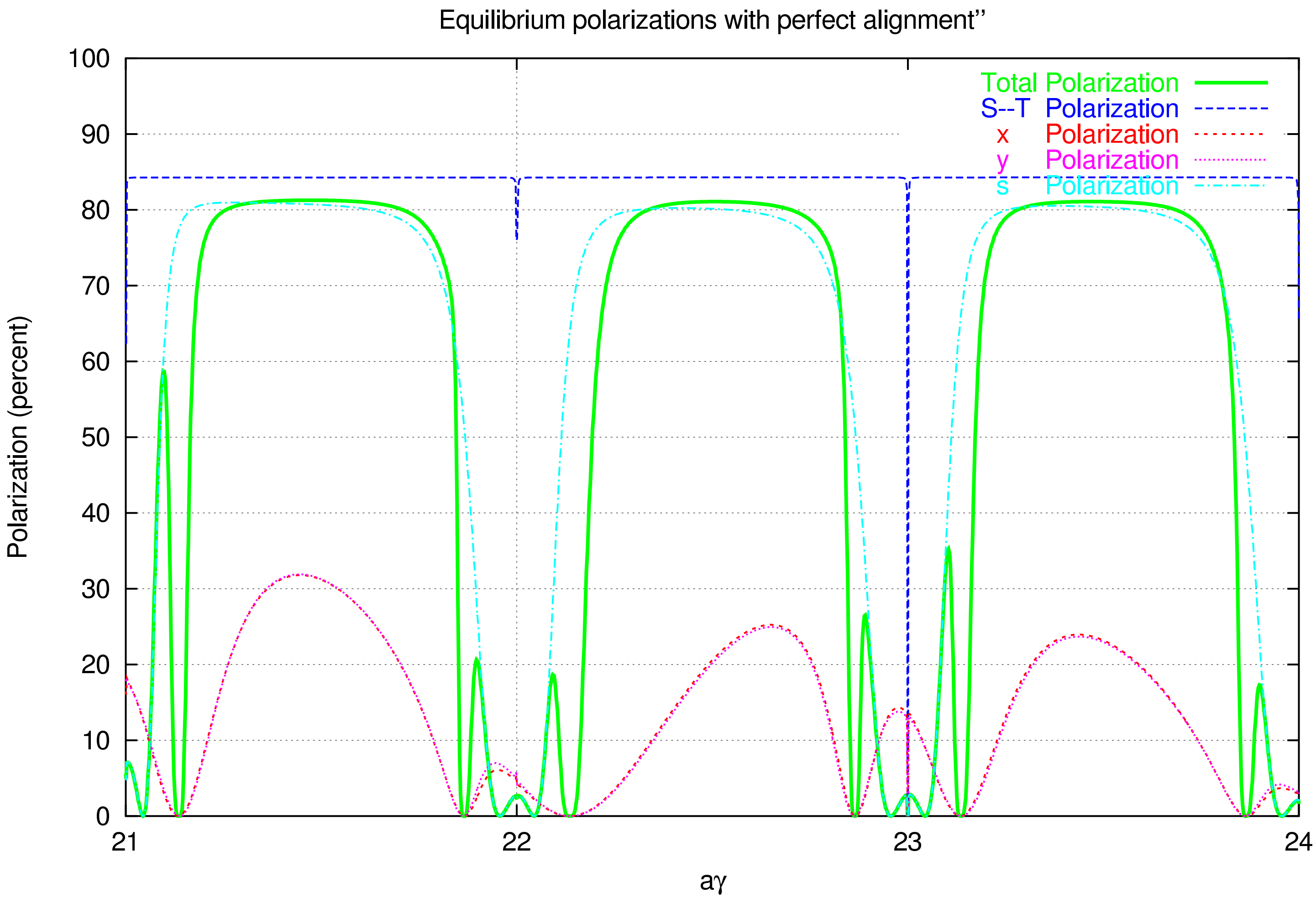



Polarization times with misalignments
B--K time
D--K time
Polarization times (minutes)"
aγ
0
10
20
30
40
21
22
23
24

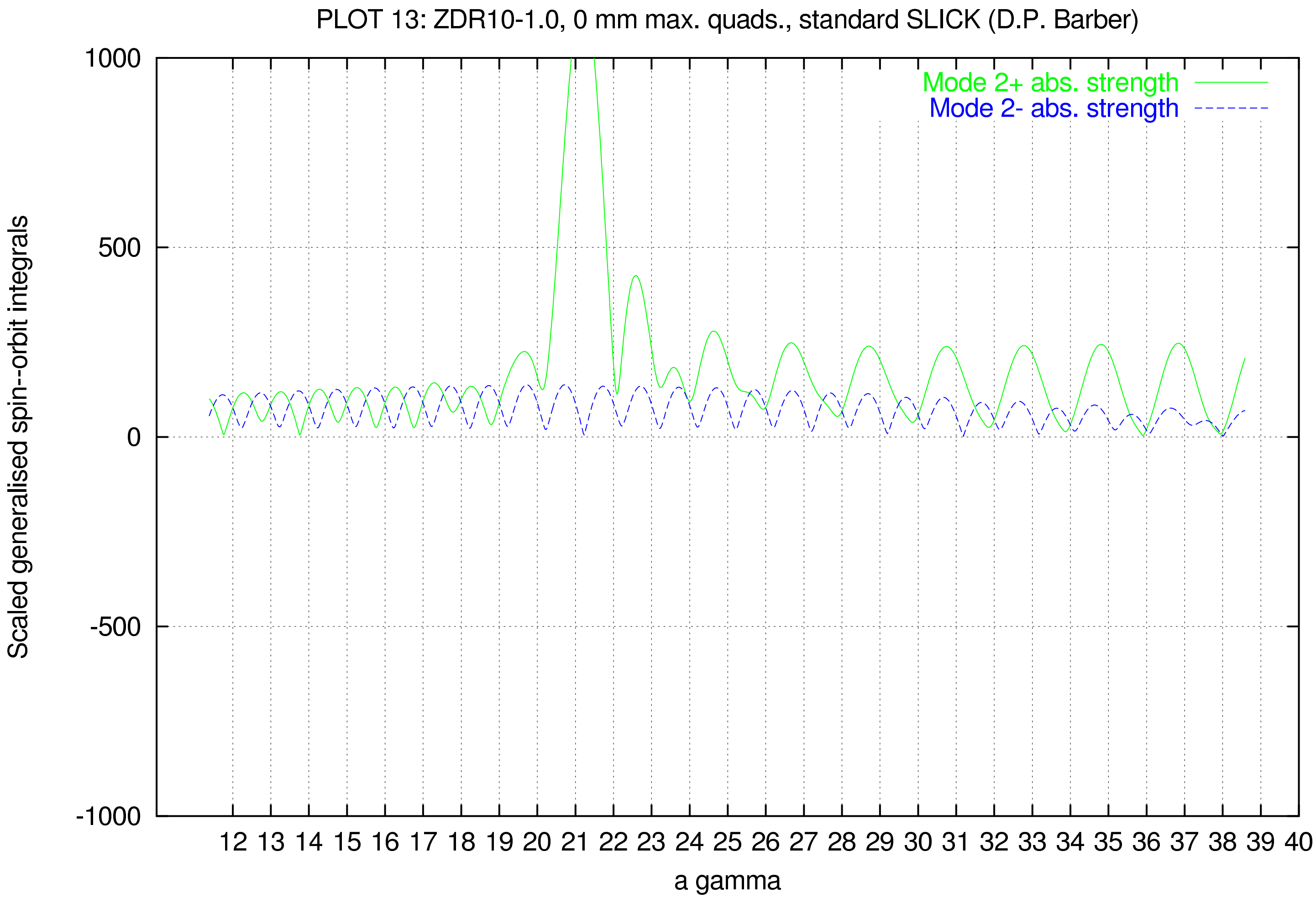
All monitors on and about half of the “b–b”



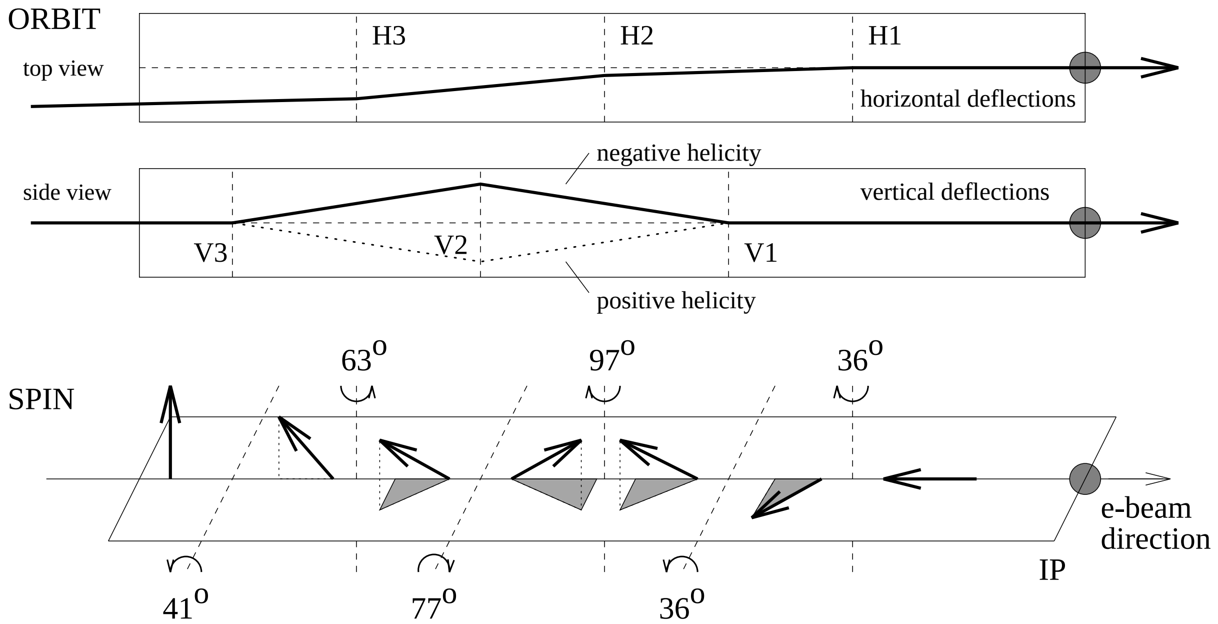
All monitors on, no “b–b”, near coupling resonance



Abs. spin integrals in the 90/90 optic



HERA MiniRotator: Buon + Steffen



56 m (“short”) → no quads.

27 – 39 GeV, both helicities, variable geometry

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:

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

  - 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 τ_{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.

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 ==> SLICKTRACK in future.

Diagnostics to understand what's going on.

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: Aaaaaaaaaaaaaaghhhhhhhhhhhhh!,
  - effects will become especially apparent if great care is taken with alignment – find a balance.

Thick beams/beam–beam

Existing spin match might take care of beam–beam depolarisation

Thick beams: very interesting!

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.**