Electron Ring Polarization

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Plan

- Phenomenology: Self polarisation/depolarisation – a reminder
- Spin rotators and spin matching
- Calculations at first order in spin: \(\rightarrow\) SLICK.
- Thick beams.
- Calculations with 3-D spin motion \(\rightarrow\) SLICKTRACK.
- Summary and plans.
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? $\implies$

  Stochastic/damped orbital motion due to synchrotron radiation
  + inhomogeneous fields
  + spin–orbit coupling via T–BMT

$\implies$ spin diffusion i.e. depolarisation!!

Self polarisation: Balance of poln. and depoln. $\implies$

$$P_\infty \approx P_{BK} \frac{1}{1 + \left(\frac{\tau_{dep}}{\tau_{BK}}\right)^{-1}} \quad \left(P_{ST} \to P_{BK}\right)$$

In any case:

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

$\implies$ Trouble at high energy!
Spin–orbit resonances

\[ \nu_{\text{spin}} = k + k_I \nu_I + k_{II} \nu_{II} + k_{III} \nu_{III} \]

\( \nu_{\text{spin}} \): amplitude dependent spin tune \( \approx \) closed orbit spin tune = precessions /turn on CO

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

\[ \nu_{\text{spin}} = k + k_i \nu_i + k_{III} \nu_{III}, \quad i = I, II \text{ or } III \]
The solenoid spin rotators

Rotator 1

Rotator 2

Arc

+45 deg. solenoid
+45 deg. solenoid

+90 hor. bend

I.P.

−45 deg. solenoid
−45 deg. solenoid

Quadrupoles for decoupling and spin transparency

Quadrupoles for normal transport

Quadrupoles for decoupling and spin transparency

$\hat{n}_o$ on design energy
The $4 \times 4$ 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.
All monitors on

Equilibrium polarizations with misalignment

Polarization (percent)
80 percent monitors on
20 percent monitors on
All monitors on, near coupling resonance
Calibrating the (first order) M-C software structure against SLICK

Polarisation and depolarisation times with misalignments

- S-T time
- Analytical depolarisation time
- M-C depolarisation time

Log₁₀(Δt)/t (minutes) vs. γ
Calibrating (first order) the M-C software structure against SLICK
Full 3–D spin motion
Summary so far

• First order calculations OK. Attention to alignment, monitoring and correction.

• New M-C code, SLICKTRACK, for HERA and eRHIC and damping rings etc., up and running and making sense.

• Then, initial indications that thick beams are OK at higher order.
Plans

• SLICKTRACK $\leftrightarrow$ HERA!!

• $\Rightarrow$ Careful study of the effects of beam–beam forces $\Rightarrow$ eRHIC.

• Include effects of detector fields.

• Apply SLICKTRACK to pre-accelerators.

We have longitudinal $e^\pm$ polarisation at 3 IPs in HERA at $3\times$ higher energy and with non-optimal C.O. control for spin!