Depolarization between the upstream and downstream polarimeters

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- Spin tracking from upstream polarimeter to downstream polarimeter – so BDS and IP and extraction line depol
- BDS & extraction line spin tracking studies using BMAD – consider intertrain, intratrain and intrabunch
- CAIN can be used for IP depolarization, precision spin tracking with bunch field effects can be done using a more exact calculation

Motivation

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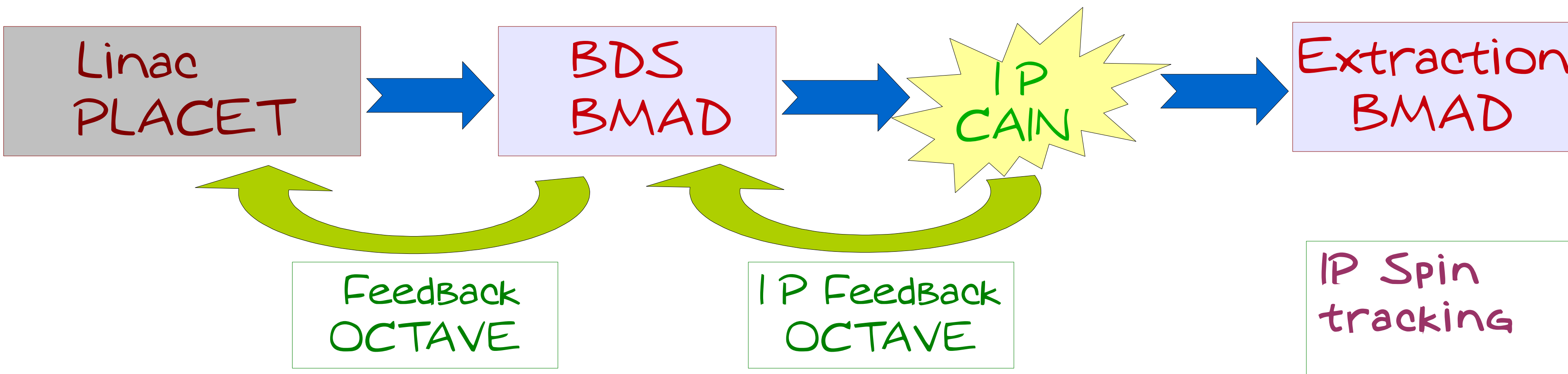
BDS: previous studies [Smith (BMAD) Malysheva (Slicktrack)] show that depol is small, but does it decline over time due to ground motion and on what scale? Mainly classical spin precession here

IP: significant depolarization due to beam-beam effects. Both classical precession and quantum spin flip. The spin-flip calculation assumes classical motion of electron, no beamstrahlung radiation angle. Discuss full calculation

Extraction: Propagate disrupted beam down extraction line and simulate polarization at downstream polarimeter

Time scales: Investigate depolarization within bunch, within train and train-train

Simulation components & flow



Placet sim of linac

- 1 micron random displacement
- 1:1 correction
- Dispersion free steering
- Deliver 100 Bunch trains of 300 Bunches

BMAD sim of BDS and Extraction

- Ground motion model applied
- Translate latest ILC MAD lattice
- Energy collimation key to depolarization

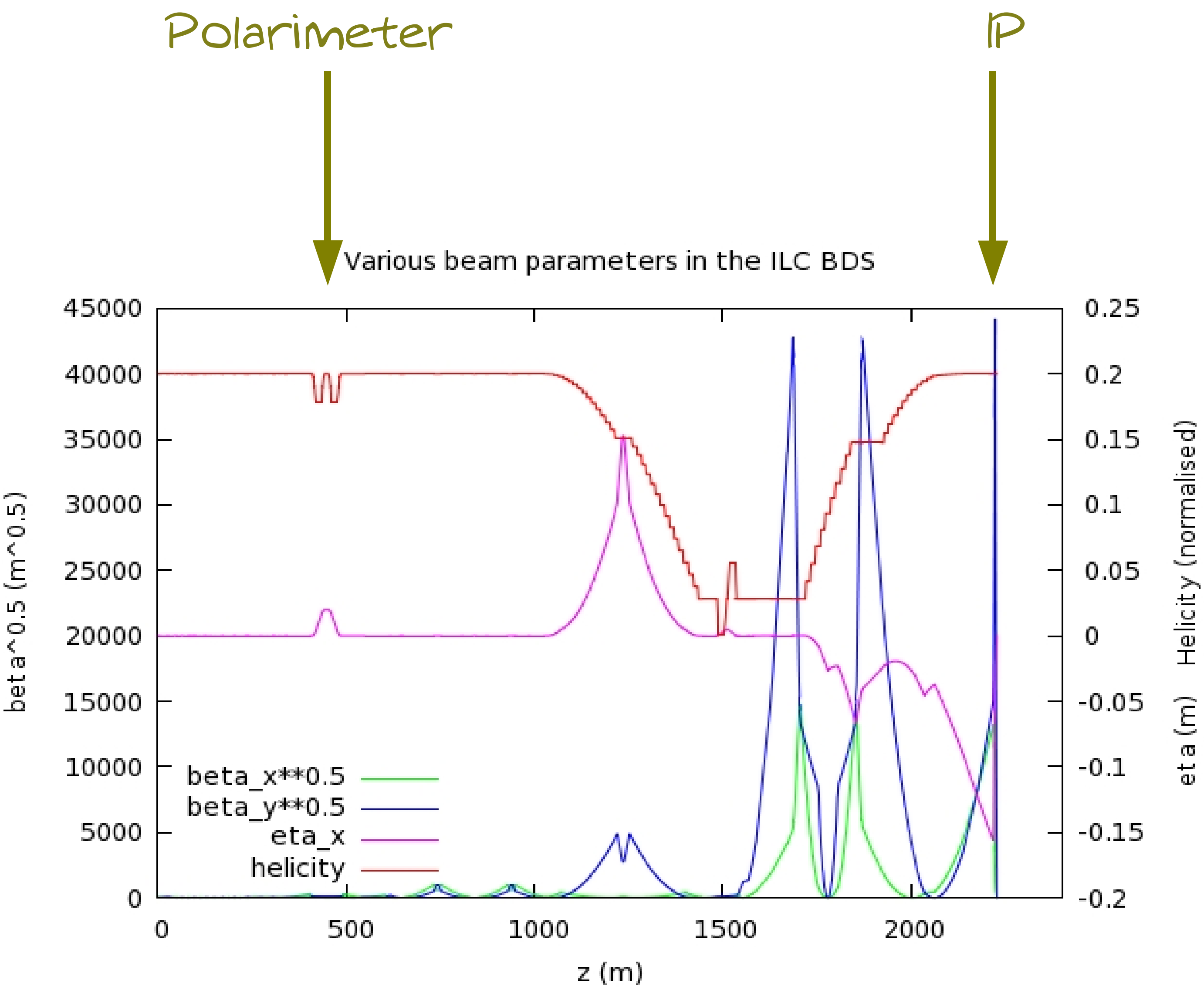
FEEDBACK LOOPS

- Alignment based on beam-beam kicks
- Simple PID controller implemented in Octave
- Bunch to bunch at IP

IP Spin tracking

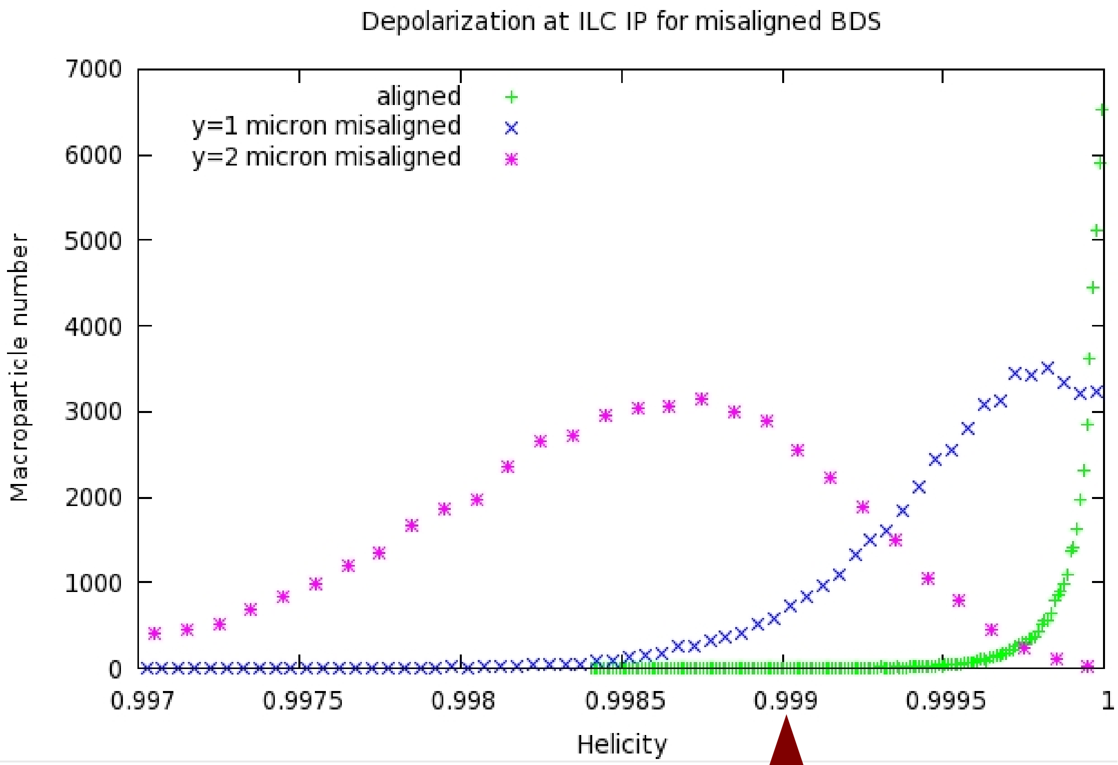
- Modified CAIN with full spin tracking
- Implemented spin tracking in all pair processes
- Full Beamstrahlung calculation (no approximations) investigated

BDS spin tracking



- Lattice translated from MADX to BMAD – checked dispersion and beta functions match TDR
- Helicity normalised to 0.2 for ease of viewing
- spin precesses in the latter part of the lattice returning (almost) to original helicity

BDS depolarization



0.1% Depolarization

- Starting with 100% longitudinal polarization
- Introduce misalignments into linac and make 1:1 correction with dispersion free steering
- Assume no depolarization in linac
- Make random misalignment of Bds elements in y

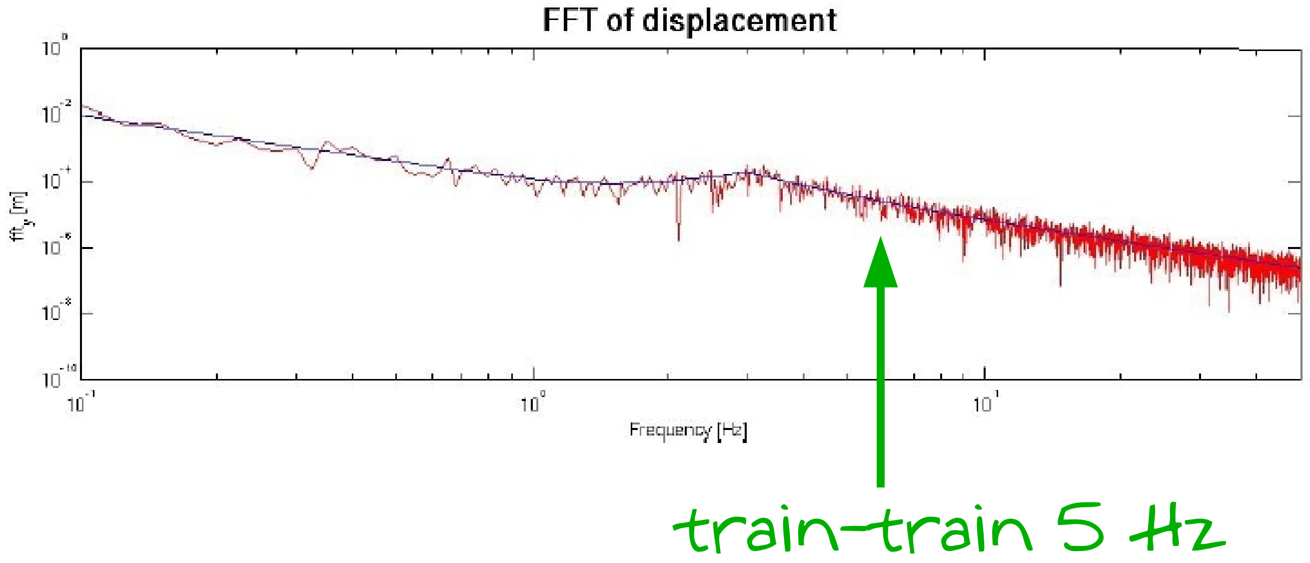
- To do:
  - Make realistic misalignments due to expected ground motion
  - Crab cavity is in the lattice only as a drift at present!
  - Examine depolarization along a realistic bunch with feedback on
  - Track in the extraction line to downstream polarimeter

Ground motion and misalignments

(Renier and Bambade CARE/ELAN-2007-004)

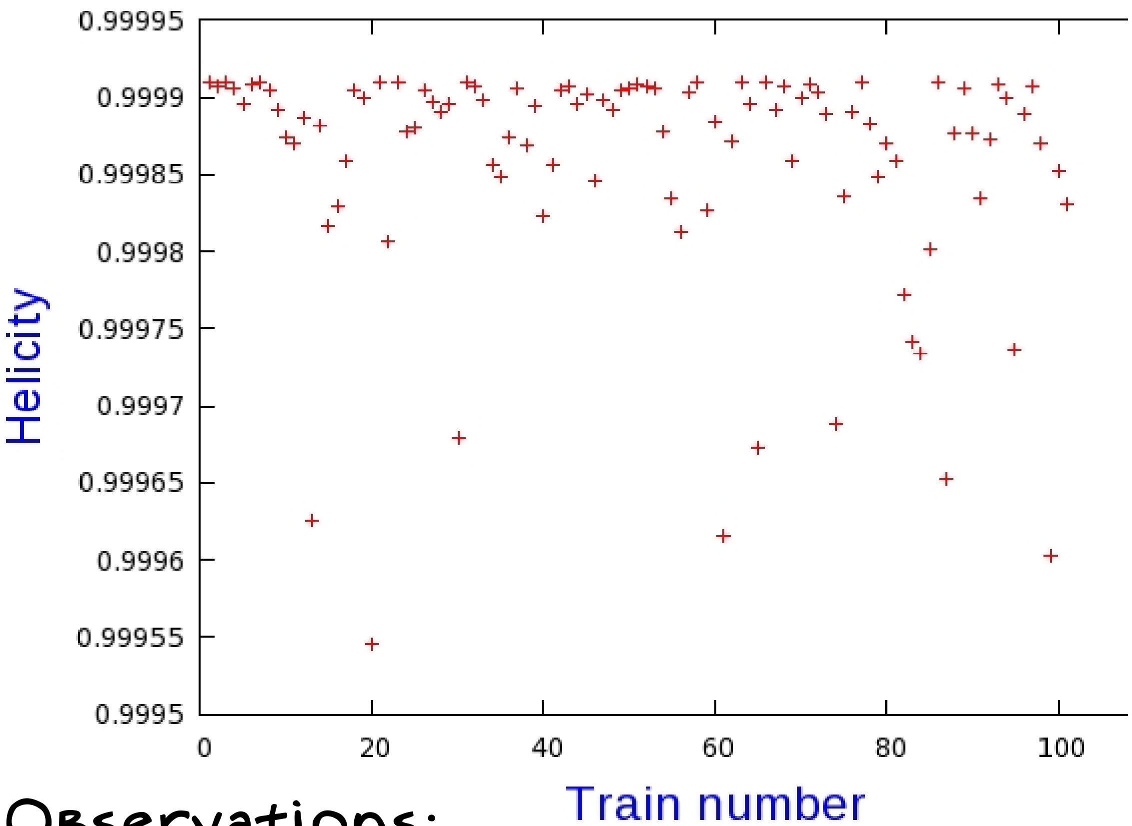
Schema:

- Real ground motion spectrum measured
- N random offsets generated and transformed into frequency domain
- Convolute random and measured spectra and invert transform back to time domain
- Apply coherency function so nearby elements move in a similar fashion



- Original paper applied 1-D transform for y-offsets
- We want 2-D x/y displacements and probably element roll

Depolarization growth train to train



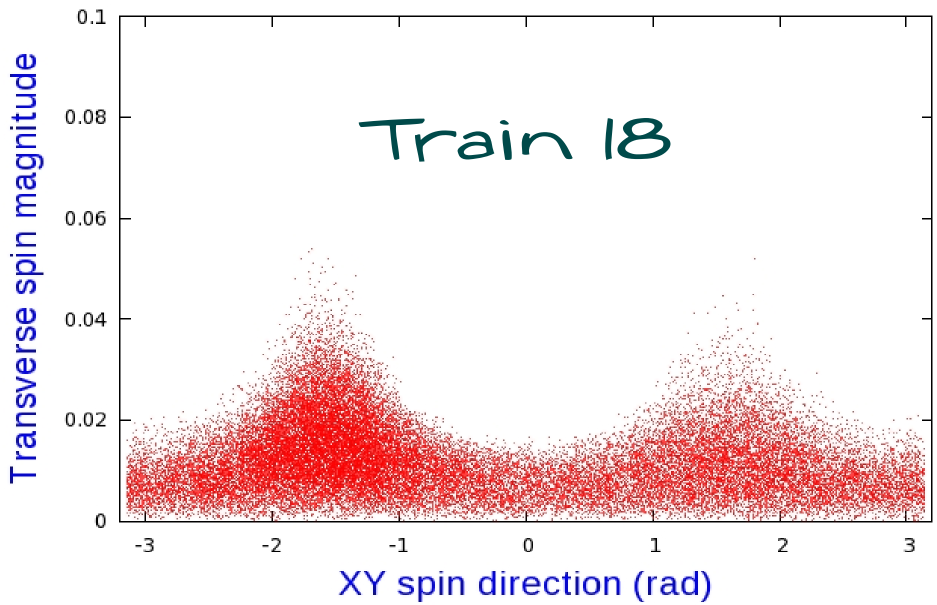
Model:

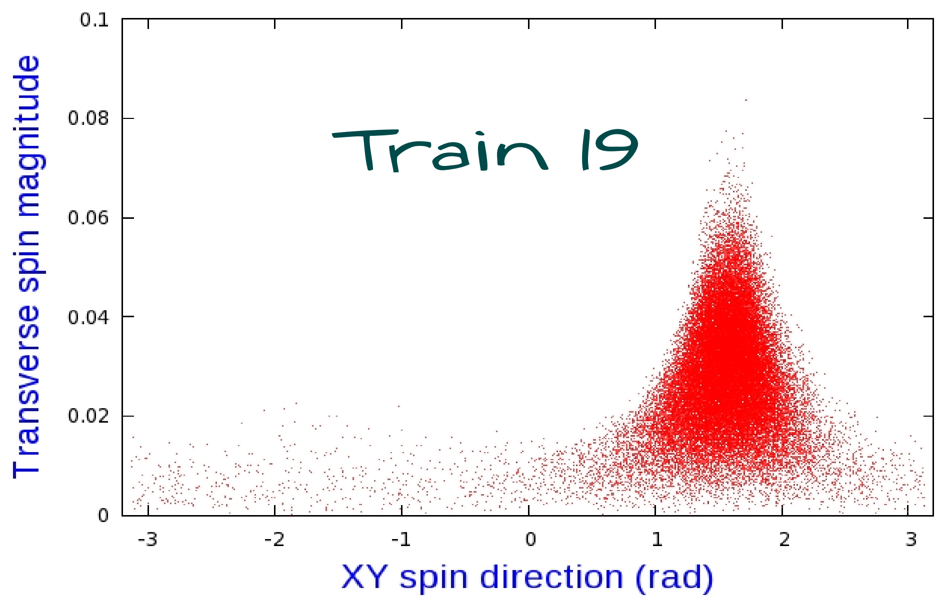
- Analysis based on leading bunch of train
- Assume no depolarization in linac, so normalize beam helicity at the end of the linac
- Start from perfect alignment and apply ground motion train to train in both linac and BDS
- Examine Helicity at IP

Observations:

- By train 10 significant growth in the uncertainty of the depolarization at a level of 0.05% - need to study in larger time scales
- No correlation with y_offset so probably no impact from train train feedback

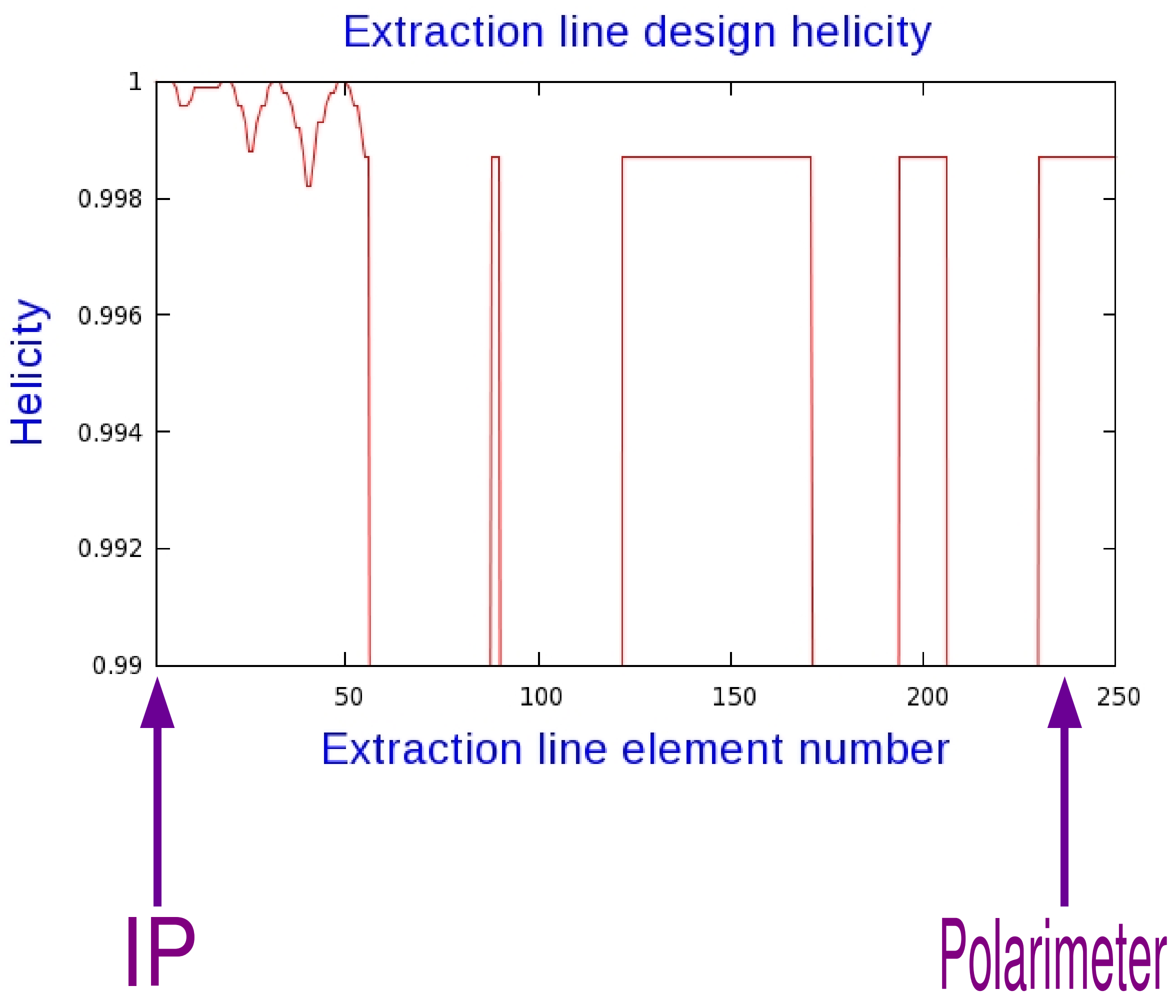
BDS depol - transverse polarization





- Transversely polarized beams can serve as a sensitive test of triple gauge couplings/CP violation
- Conversely, unplanned transverse polarization can be a false indicator,
- so... examine the transverse polarization of the depolarized bunches at IP
- Transverse polarization shows a preferred ±y direction which fluctuates train to train (and probably bunch to bunch)
- Need to understand the impact on physics

Depolarization – various issues



- 2006 lattice seems to indicate that the design helicity at the downstream polarimeter does not quite match the IP (0.15% depol)?
- Crab cavity is in the lattice as a drift, but can potentially rotate the spin vector by 7 mrad
- Depolarization can be sensitive to beam offsets – beam beam kick at IP so look for correlations
- minimum machine (undulator to end of linac and IP parameter changes) will mean redoing this analysis

Precision IP depolarization

There is depolarization (spin flip) due to the QED process of Beamsstrahlung, given by the Sokolov-Ternov equation

$$\frac{dW}{d\omega_f} = \frac{\alpha m}{\sqrt{3}\pi\gamma^2}\int_z^\infty K_{5/3}(z)\,dz + \frac{y^2}{1-y}K_{2/3}(z) \quad where \quad z=\frac{2}{3\Upsilon}\frac{y}{y-1}\ , \quad y=\frac{\omega_f}{\epsilon_i}$$

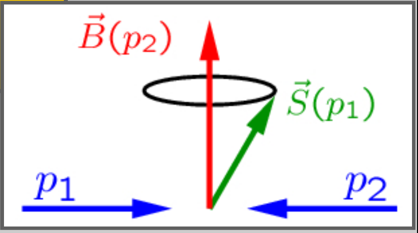
But calculation assumes that the fermion momentum is classical and that all particles colinear

The fermion spin can also precess in the bunch fields. Equation of motion of the spin given by the T-BMT equation

$$\frac{d\vec{S}}{dt} = -\frac{e}{m\gamma}\left[(\gamma a+1)\vec{B}_T+(a+1)\vec{B}_L-\gamma\left(a+\frac{1}{\gamma+1}\right)\frac{1}{c^2}\vec{v}\times\vec{E}\right]\times\vec{S}$$

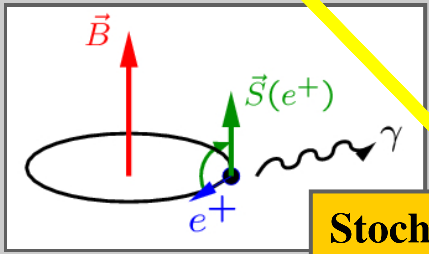
At the IP, the anomalous magnetic moment subject to radiative corrections in the presence of the bunch field

Classical spin precession in inhomogeneous external fields: T-BMT equation.



Depol sims with CLIC parameters (I Bailey) change in polarization vector magnitude

	CLIC-G	ILC nom	ILC (80/30%)
T-BMT	0.10%	0.17%	0.14%
Beamstr.	3.40%	0.05%	0.03%
incoherent	0.06%	0.00%	0.00%
coherent	1.30%	0.00%	0.00%
total	**4.80%**	**0.22%**	**0.17%**



Stochastic spin diffusion from photon emission: Sokolov-Ternov effect, etc.

Solution of Dirac equation in Beam field A^e

$$\left[(p-eA^e)^2-m^2-\frac{ie}{2}F^e_{\mu\nu}\sigma^{\mu\nu}\right]\psi_V(x,p)=0$$

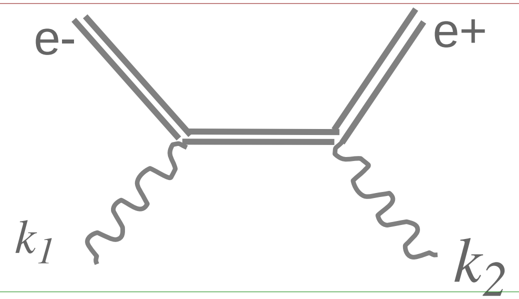
$$\psi_V(x,p)=u_s(p)F(\phi)$$

Substitution of the general solution for ψ_V yields a first order differential equation. whose solution can be expanded in powers of **k**,A^e

$$\psi_V(x,p)=\left[1+\frac{e}{2(kp)}\gamma^\mu k_\mu \gamma^\nu A^e_\nu\right]\exp[F(k,A^e)]\; e^{-ipx}u_s(p)$$

- make Fourier transform to get exponential of linear term in x
- n external field photons contribute
- Fermion momentum gains $\frac{\nu^2}{kp}k$
- Leads to fermion mass shift $m^2+\nu^2$
- F_2 are
  - Bessel functions for circular polarized A^e
  - Airy functions for constant crossed A^e

Usual solution in the absence of A^e



fermion solutions represented by double straight lines

Beamstrahlung in an external field (Sok-Ter) – Nikishov & Ritus (1964)

Calculation first performed in a linearly polarized field $A_\mu = a_\mu \cos(k.x)$

Volkov solutions introduce complicated functions B (l external field photons)

$$B_n(l,\alpha,\beta) = \frac{1}{2\pi}\int_{-\pi}^{\pi} \cos^n k.x\, e^{f(k.x)} \quad where \quad f(k.x) = i\alpha\sin(k.x) - i\beta\sin(2k.x) - il(k.x)$$

External field strength expressed by dimensionless parameter ν which has a direct relationship to field potential or strength and an inverse relationship to the field frequency ω

$$\nu = \frac{ea}{m} \propto \frac{B}{\omega}$$

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Constant field calculation performed for $\nu \to \infty$ ($\omega \to 0$)

Saddle point approximation used to write B_n as a function of Airy functions and the phase ψ of the slowly alternating external field

$$B_n \propto \frac{1}{\nu\sin\psi}\frac{Ai(y)}{\sqrt{y}} \quad \text{where} \quad y = \left(\frac{\nu}{\sin\psi}\right)^{2/3}$$

other approximations also made

Transformation to constant crossed field using solutions of a Schlömilch eqn

$$\text{if} \quad W(B) = \frac{2}{\pi}\int_0^{\pi/2} F(B\sin\psi)\,d\psi \quad \text{then} \quad F(B) = W(0) + B\int_0^{\pi/2} W'(B\sin\psi)\,d\psi$$

Clearly it would be better to do the calculation directly in the constant field, for arbitrary n and without approximations – work in progress

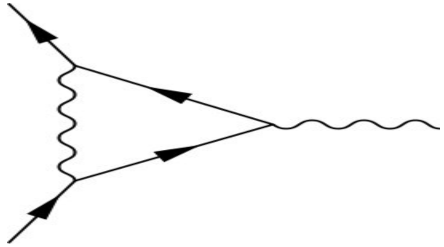
Anomalous magnetic moment in a strong field (IPPP - Durham)

Needed in T-BMT equation to calculate the rate of depolarization due to beam-beam effect

$$\vec{\Omega}=-\frac{e}{m\gamma}\left[\left(\gamma a+1\right)\vec{B}_T+\left(a+1\right)\vec{B}_L-\gamma\left(a+\frac{1}{\gamma+1}\right)\frac{\beta}{c}\vec{e}_v\times\vec{E}\right]$$

Main contrib^n from vertex diagram

$$a=\frac{\alpha}{2\pi}+O\left(\alpha^2\right)$$



when fermion is embedded in a strong external field characterised by $\Upsilon=\nu^2\frac{(k.p)}{m^2}$ the anomalous magnetic moment develops a dependence on Υ and is given by (Baier-Katk)

$$a(\Upsilon)=-\frac{\alpha}{\pi\Upsilon}\int_0^{\infty}\frac{x}{(1+x)^3}dx\int_0^{\infty}\sin\left[\frac{x}{\Upsilon}\left(t+\frac{1}{3}t^3\right)\right]dt$$

However...we can envisage

- recalculating the vertex diagram in BP with Volkov solutions replacing all fermion lines
- Making mass correction (including self-energies)

Summary & Future work

(1) We want to understand all sources of depolarization between upstream and downstream polarimeters, so look in BDS, IP and Extraction line

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(5) The spin flip process is significant at the IP and for a precision study use Volkov solutions for fermion lines without kinematic approximations. Modification of Anomalous mag moment in T-BMT can be analogously obtained

(6) Need to include Crab cavity, understand the impact of the undulator at the end of the linac, and the pair background effect on downstream polarimeter