Spin tracking at Future e^+e^- Colliders

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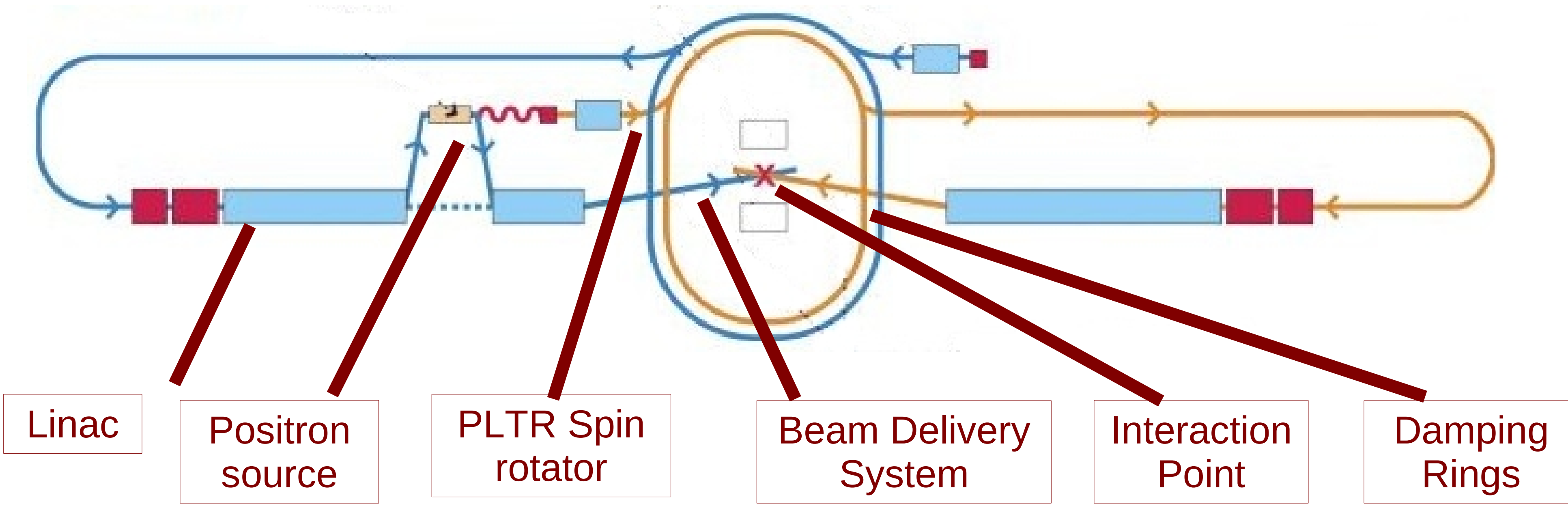
Synopsis

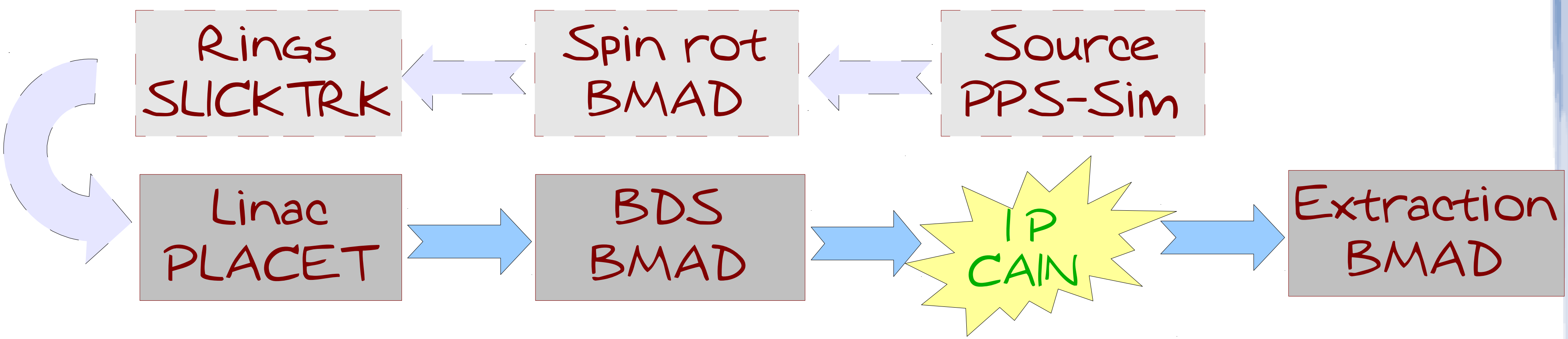
- Global "Source-to-IP" spin tracking
- Positron source, spin rotator, ring, linac/BDS, IP beam-beam
- Depolarisation due to ground motion, energy and emittance spread
- Strong field spin effects at the IP
- International Linear Collider (ILC) lattice, ILC/CLIC IP parameters

Source-to-IP spin tracking



- ILC is a precision machine – we need polarized beams (80% e^- /30% e^+)
  - We need to know how the polarization changes from source to IP
- $2X10^{10}$ particles per bunch, 2450 bunches per train, 4 trains per sec
  - Polarization P, Depolarization, ΔP and uncertainty $\delta\Delta P$
    - Ultimately we need to know $\delta\Delta P \leq 0.25\%$
      - ***SCOOP: Biggest*** $\delta\Delta P$ is at the IP

Integrated spin tracking simulation



Placet sim of linac

- 1 micron random displacement
- 1:1 correction
- Dispersion free steering
- Deliver multiple Bunch trains of 300 bunches

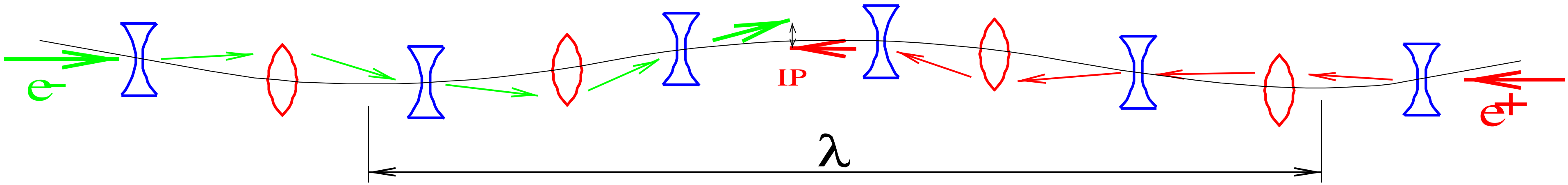
BMAD sim of BDS and Extraction

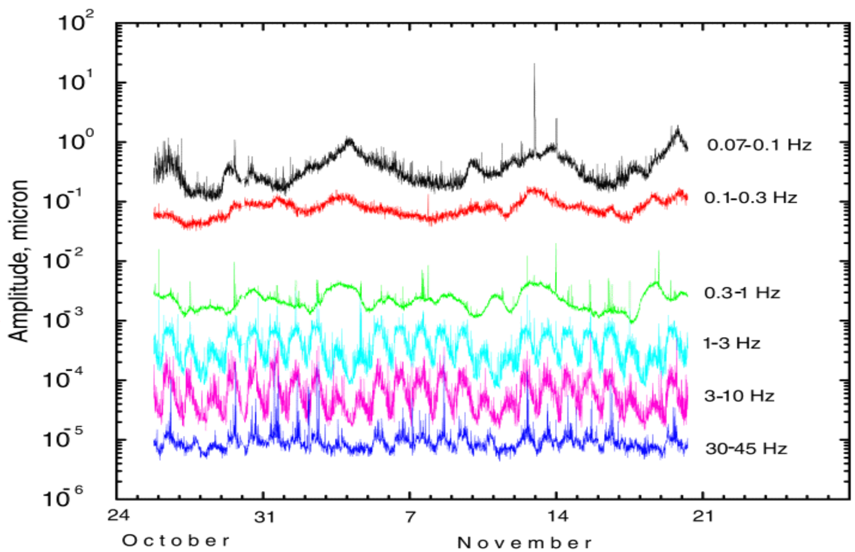
- Ground motion model B (moderate)
- Translate latest ILC MAD lattice
- Examine impact of orbit correction on the induced depolarisation

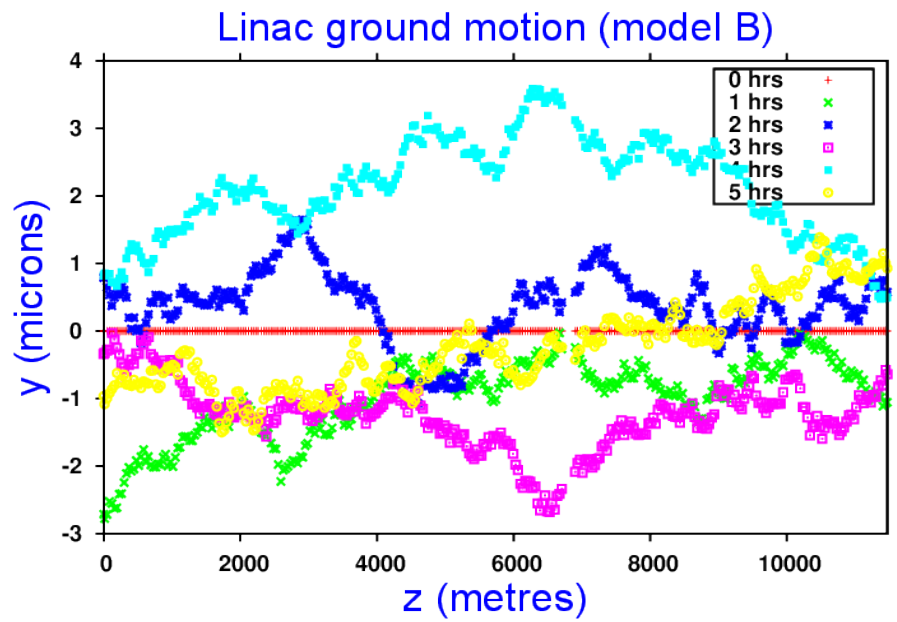
IP Spin tracking

- Modified CAIN with full spin components in 1st order processes
- Considered beam offsets, Energy and Polarisation spreads
- New program **Ipstrong** being developed for higher orders

Simulation of ground motion

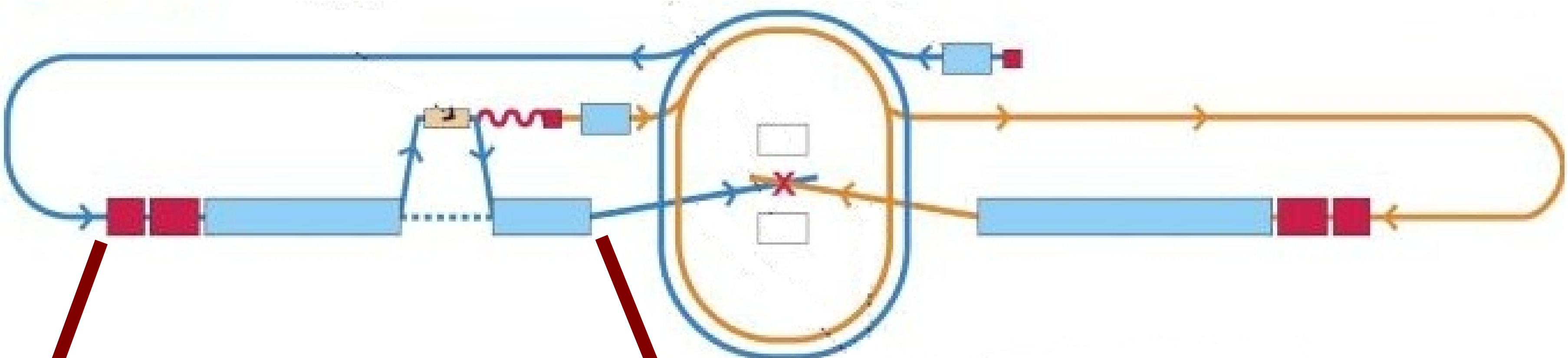


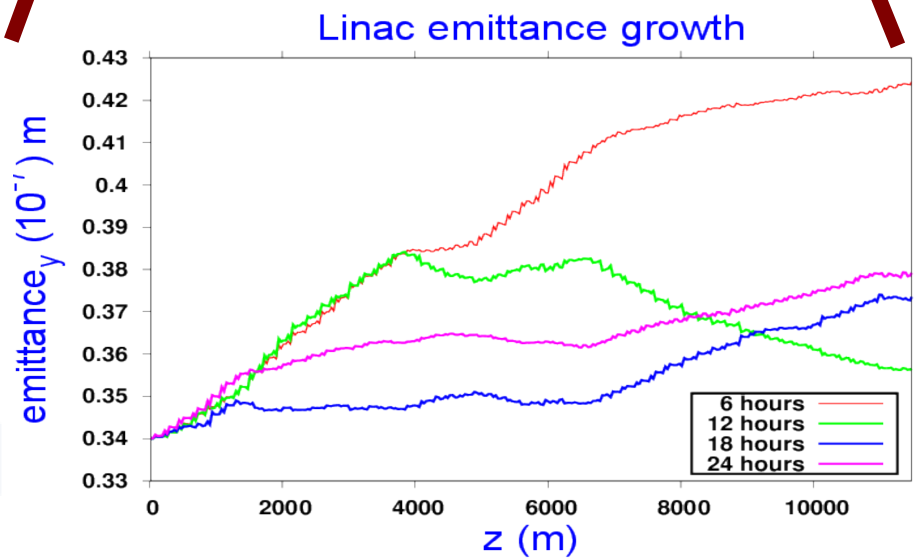




- Real spectra measured in environment
- generate random offsets generated and transformed into frequency domain
- Convolute random and measured spectra and invert transform back to time domain
- Apply coherency function so nearby elements move in a similar fashion

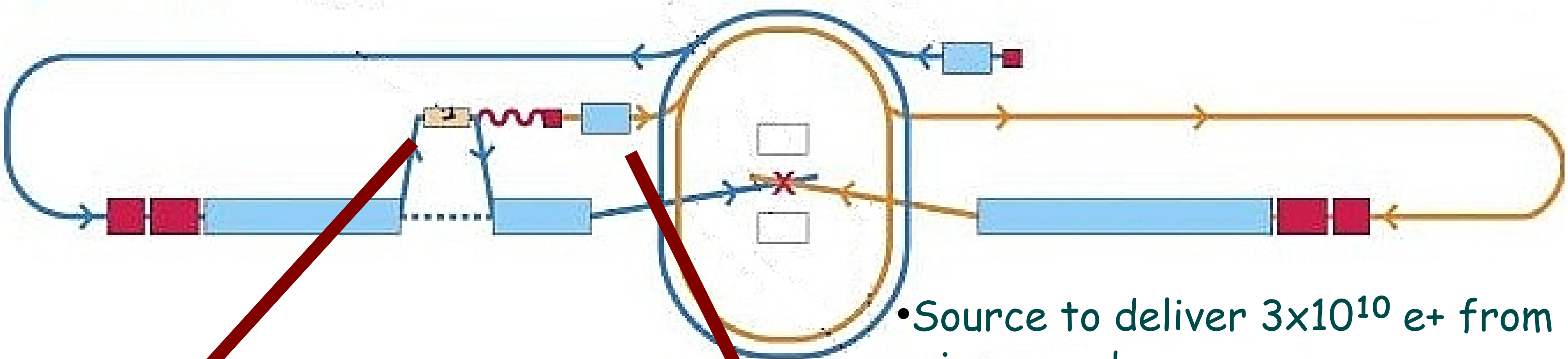
linac emittance growth

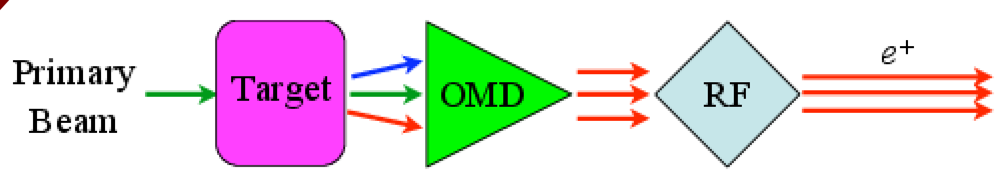


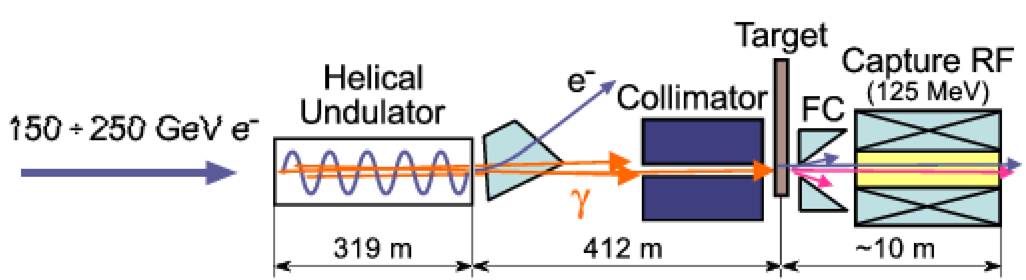


- Modelled in placet (no spin tracking)
- **Starting point:** 1 micron random beam jitter and an orbit correction (dispersion free steering + 1:1 correction)
- Emittance growth due to ground motion over several hours
- Previous studies estimate ΔP~0.001%, here we consider linac a "spin drift space"
- Feed beam into positron source

Positron Source



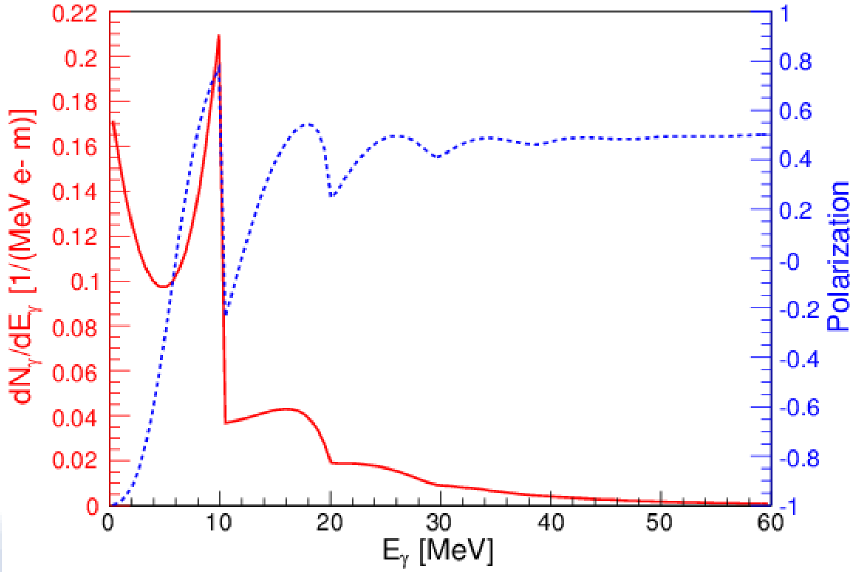




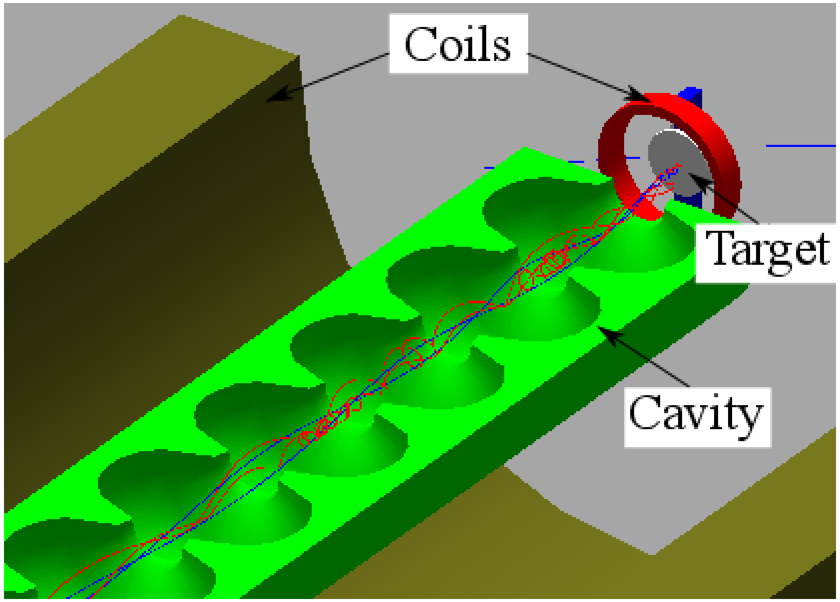
- Source to deliver 3×10^{10} e+ from primary e- beam
- Undulator converts Primary beam to photons
- Photon collimator improves polarization and reduces energy deposition in target
- Target is a solid wheel (Titanium, Tungsten) or liquid (Lead)
- OMD can be a quarter wave transformer RF cavities embedded in solenoid field

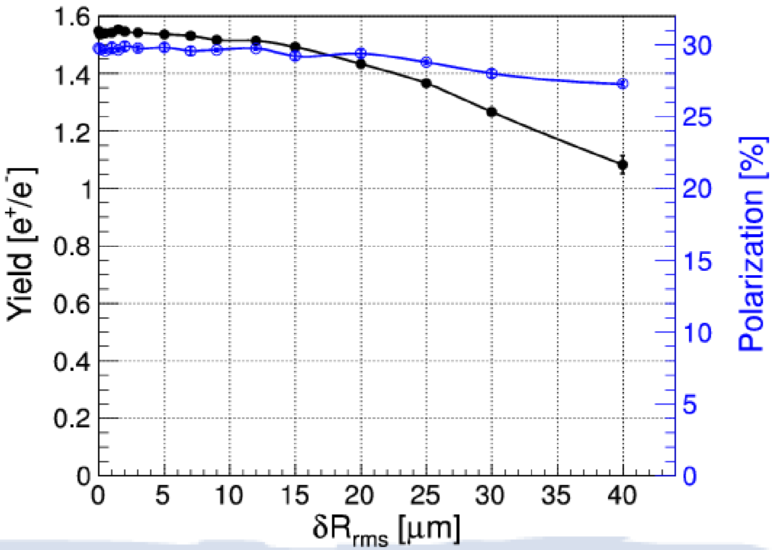
Positron Source Simulation

(Ushakov, Schaelike)

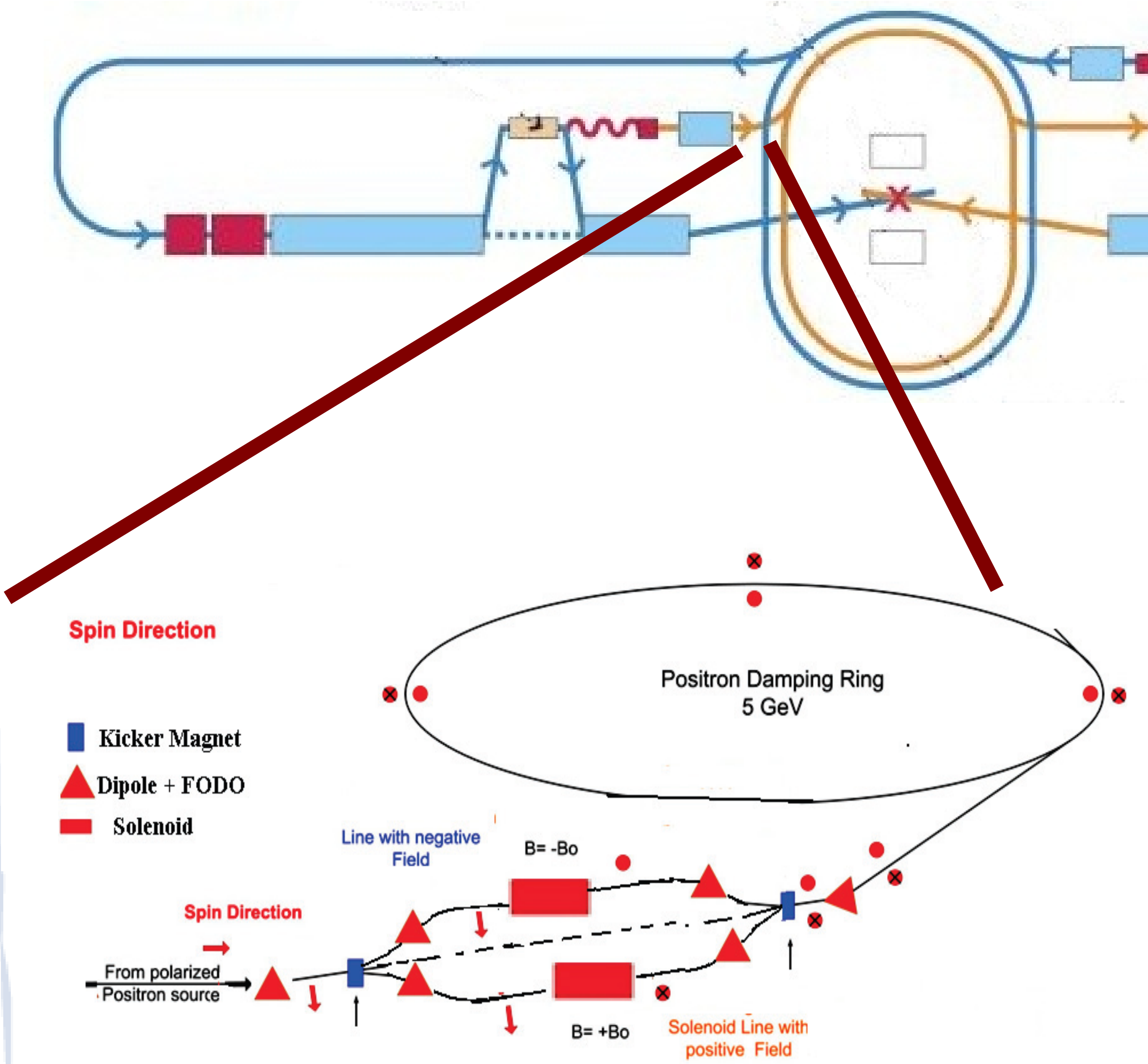


- Spin tracking with the Geant based PPS-Sim program – crosscheck with other codes
- PPS-Sim produces photon spectrum and polarization
- Visualization of OMD - electron and positron
- Random transverse beam offsets introduced to determine Δ**P**
- Assuming 1 micron beam jitter **$\delta\Delta$P~0.1%**





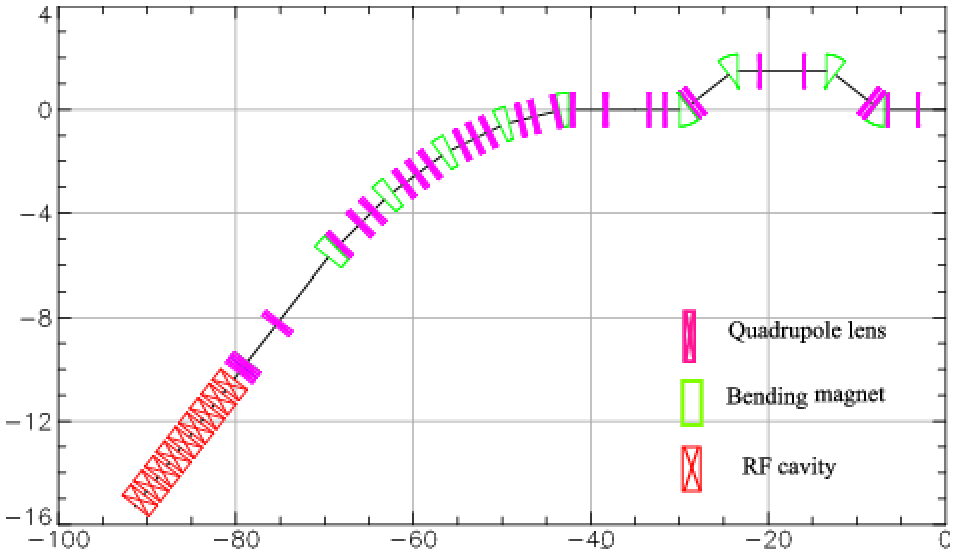
Spin Rotator

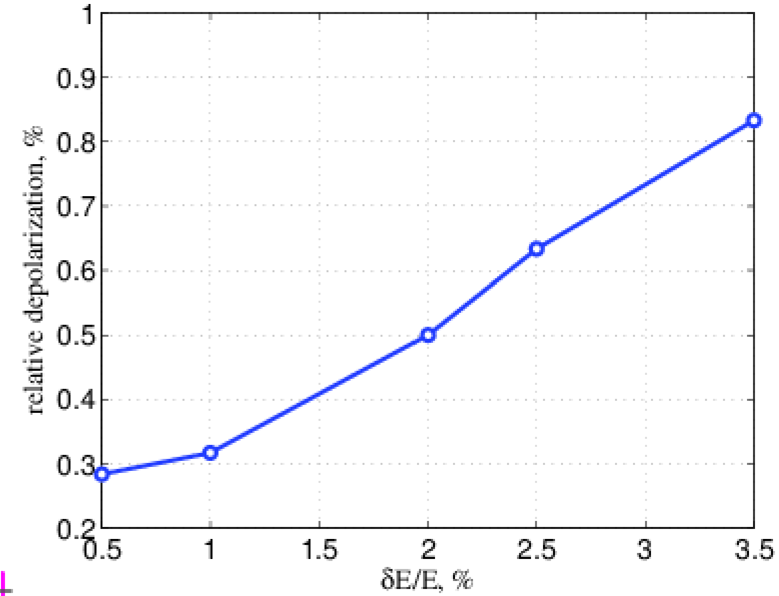


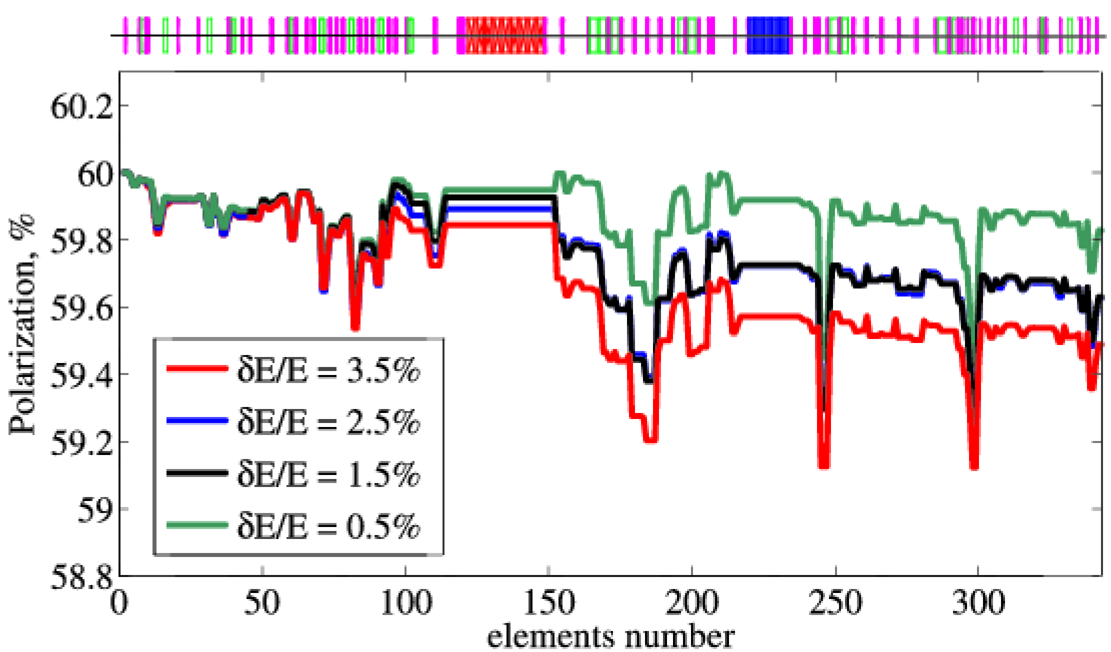
- Rotate polarization into and out of the vertical
- Requires fast helicity reversal via kicker and parallel lines
- Detailed lattice produced for the Positron Line To Ring (PLTR)
- Two FODO doglegs with a solenoid section in between

Spin Rotator Simulation

(Kovalenko, Malysheva)



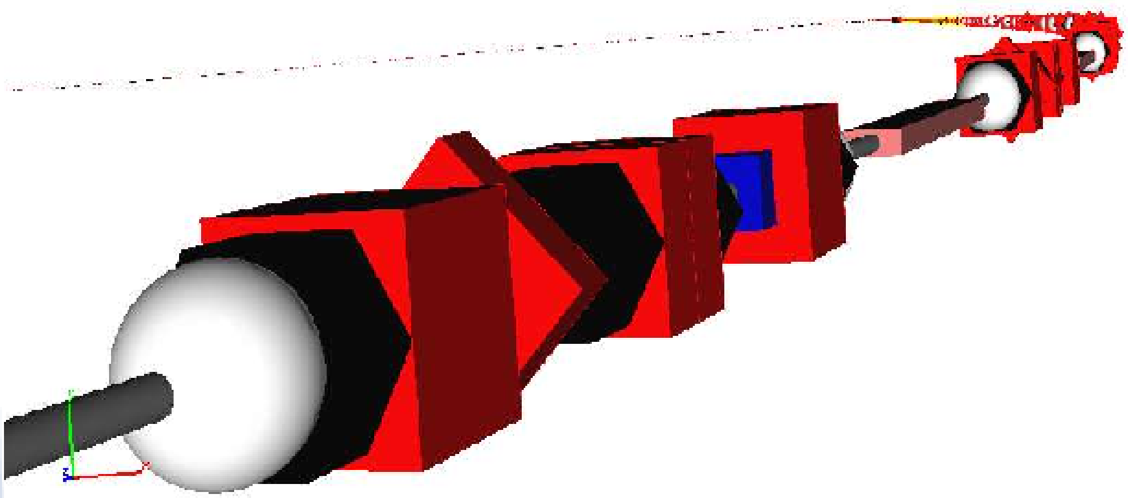


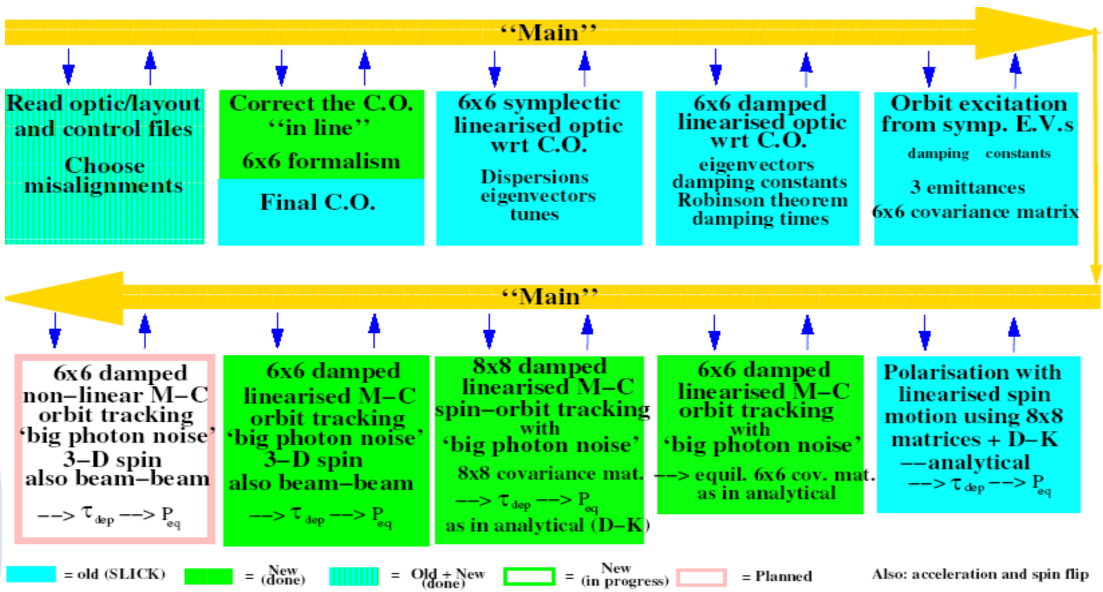


- *Modelled in BMAD*
- *No misalignments*
- *Initial random beam y offsets*
- *Polarization losses linked to beam energy spread*
- *RDR Design energy spread is 0.2%*
- *So* **ΔP=0.3%, δΔP=0.001%**

Damping Ring Depolarisation

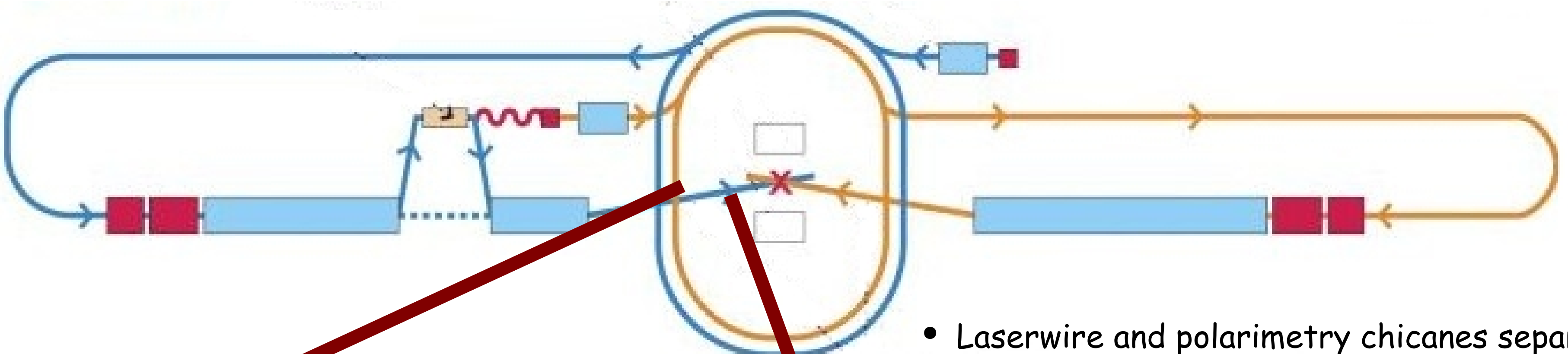
(Barber, Malysheva 2006)

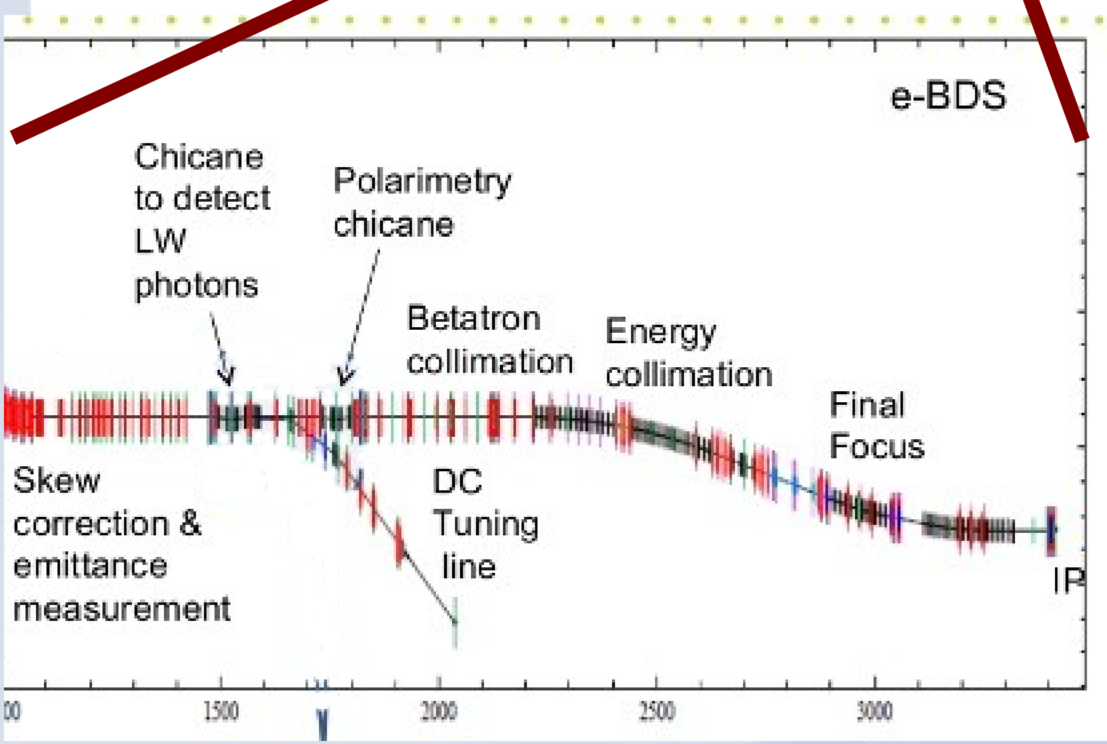




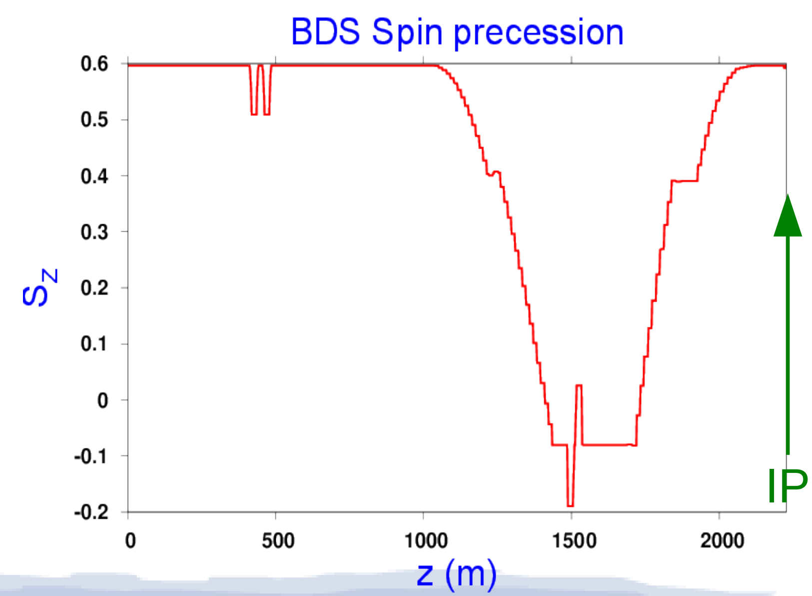
- Potential depolarisation via non-vertical spins (precession) and diffusion (spin flip)
- SLICKTRACK (SLICK + photon emission) simulation
- 1/3 mm misalignments, 1/3 mrad quadrupole roll
- Injection emittances -> 10*nominal
- Studied at 4.8 GeV (spin-orbit resonance) and 5 GeV (ILC)
- Different spin angles from vertical studied
- "Negligible depolarisation"

Beam Delivery System



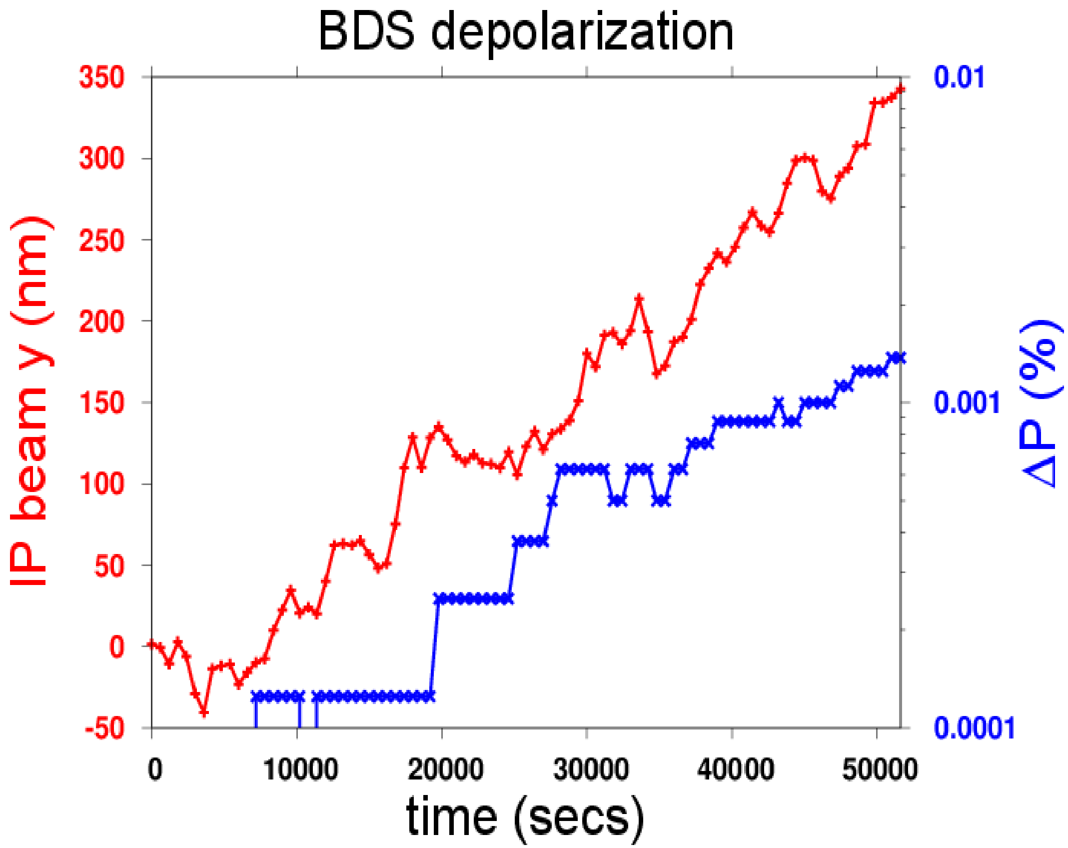


- Laserwire and polarimetry chicanes separated
- Spin precesses throughout BDS
- Final focus quadrupoles stabilised to 10^{-9} metre



BDS Depolarisation

(Hartin, Beckmann, List)

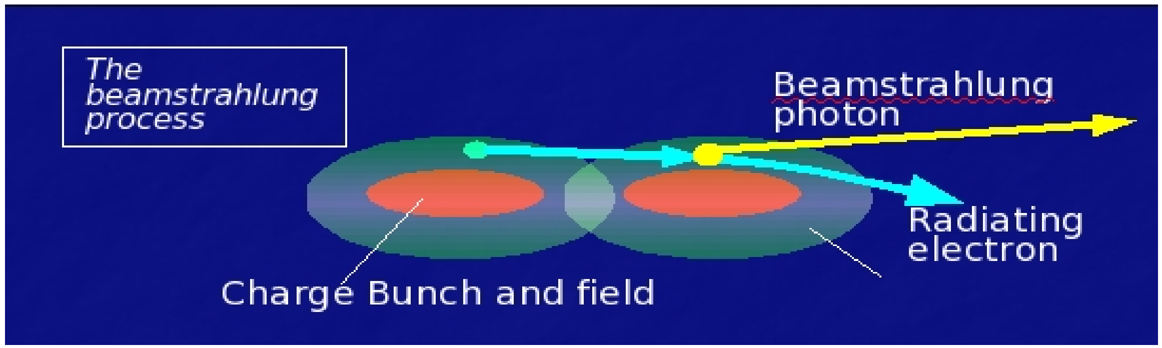


- *Analysis based on initially ideal bunch of 50,000 macroparticles*
- *ground motion in linac and orbit correction but assume no depolarization*
- *Apply realistic ground motion (model C) to BDS*
- *Examine beam y-profile and Depolarization at IP*

- *Within half a day depolarisation reaches 0.001% (small!)*
- *Long Before ΔP reaches 0.1% the orbit will be corrected*
- *See talk of J.List for more details + polarimetry studies*

Beam-beam processes

(processes which take place in the electromagnetic fields of both charge bunches)



Strong field 'Upsilon' parameter

Vector potential of beam field

particle momentum

$$\Upsilon = \frac{e\hbar|\boldsymbol{a}|}{mc^2 E_{\mathrm{cr}}}(k \cdot p_i)$$

particle mass

Schwinger critical field (10^{18} V/m)

momentum of beam field

Currently simulated processes

- Incoherent: Equiv Photon Approx,
  - Breit Wheeler, Bethe Heitler, Landau Lifshitz, Bremstrahlung
- Coherent: Strong field (Furry picture)
  - Beamstrahlung, pair production, AMM, higher orders
- Simulation tool: CAIN2.42 with full spin components

IP “1st order” depolarisation

(Hartin, Bailey, Pidcott)

Spin precession

Beam field strengths

Spin vector

$$\frac{d\mathbf{s}}{dt} = -\left[(a+\gamma^{-1})(\mathbf{B}-\mathbf{v}\times\mathbf{E}) - \mathbf{v}\frac{a\gamma}{\gamma+1}\mathbf{v}\cdot\mathbf{B}\right]\times\mathbf{s}$$

Anomalous magnetic moment in external field

Spin-flip process

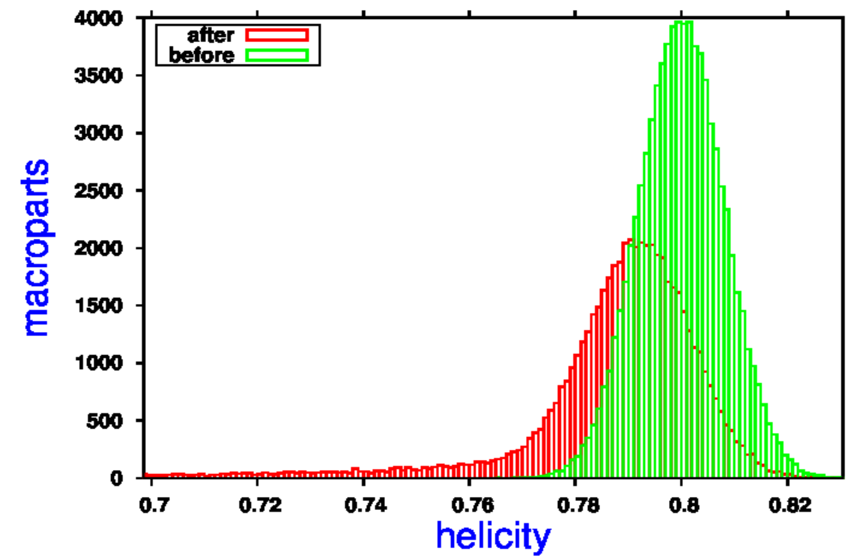
Constant crossed field – Airy functions

Spin vector

$$W(\Upsilon,\boldsymbol{\xi}) = \frac{\alpha m_e^2}{\pi\epsilon}\int_0^\infty \frac{du}{(1+u)^3}\left[\frac{e}{m^3}F^{*\mu\nu}p_\mu s_\nu \frac{z\mathrm{Ai}(z)}{1+u} - \mathrm{Ai}_1(z) - \frac{2+2u+u^2}{z\,(1+u)}\mathrm{Ai}'(z)\right]$$

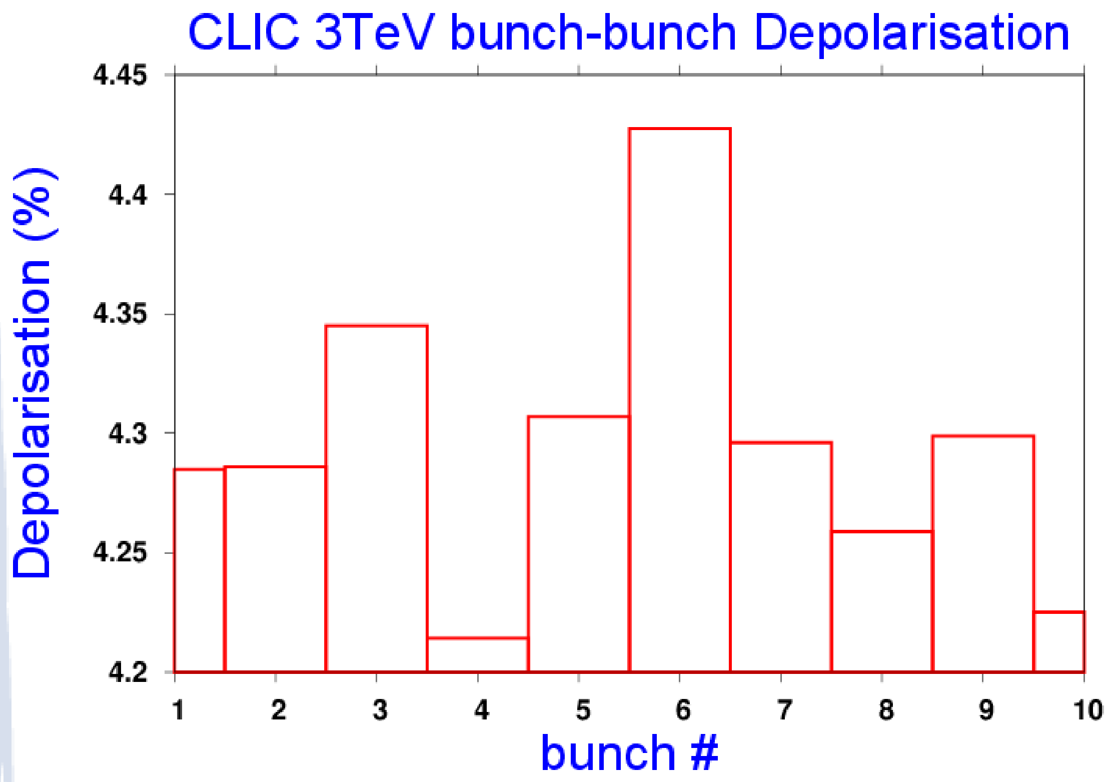
beam field tensor

CAIN simulation



Parameter Set	Υ	ΔP	Lumi weighted ΔP
ILC 1TeV	0.27	2.03%	0.55%
CLIC 3TeV	3.34	4.8%	1.31%

IP bunch-bunch depolarisation

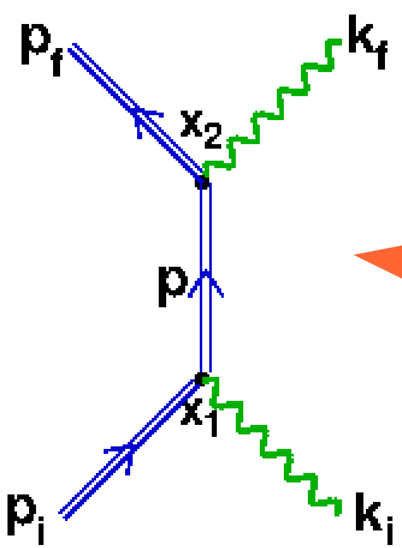


- Generate 10 CLIC 3 TeV e^+e^- bunches with design energy spread and initial 0.001% depolarisation
- Assume head-on collision
- Process the 10 bunch collisions in CAIN
- Uncertainty ~5% of ΔP

- CLIC 3TeV ΔP=4.3% and δΔP~0.2%
- ILC 1TeV ΔP=2.0% and δΔP~0.1%

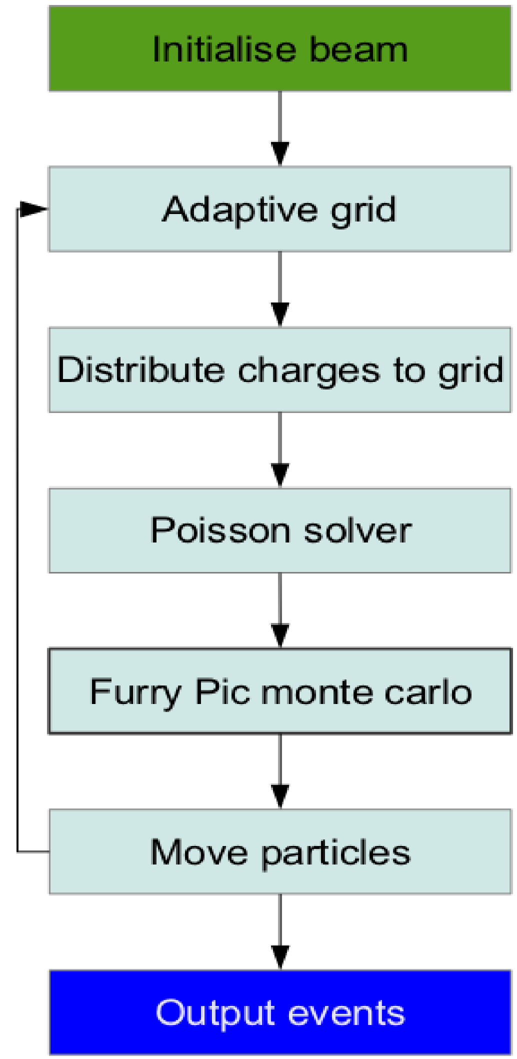
IP “higher order” depolarisation

(Hartin – see ICHEP12, Thur 5/7, 10.15am Track 12 talk)



Requires:

Theoretical calculations in the Furry Picture, a new Beam-Beam simulator and strong field Physics Event generator



Summary

- Integrated simulations of spin tracking reveal total Depolarisation ΔP and uncertainty $\delta\Delta P$
- Recent spin tracking studies of positron source, spin rotator, BDS and IP
- Biggest sources of Depolarisation (ΔP) at Source and IP
- Train-train uncertainty to be dealt with by polarimetry
- IP depolarisation due to both energy spread and theory and operates bunch-bunch
- In any case, we are within budget ($\delta\Delta P$=0.25%): **Total $\delta\Delta P$=0.183%**
- Remaining theoretical uncertainty being studied and simulated (**IPstrong**)

Component	ΔP	$\delta\Delta P$	Source of uncertainty	$\delta\Delta P$ timescale
linac	0.001%	0.001 %	Ground motion	train-train
Positron source	-	0.1 %	Emittance spread	train-train
Spin rotator	0.3%	0.001 %	Energy spread	train-train
BDS	0.001%	0.001 %	Ground motion	train-train
IP (ILC 1 TeV)	0.55%	0.03+? %	Energy spread+ theoretical	bunch-bunch
IP (CLIC 3TeV)	1.31%	0.05+? %	Energy spread+ theoretical	bunch-bunch