Spin Tracking Studies for Polarimetry at the ILC

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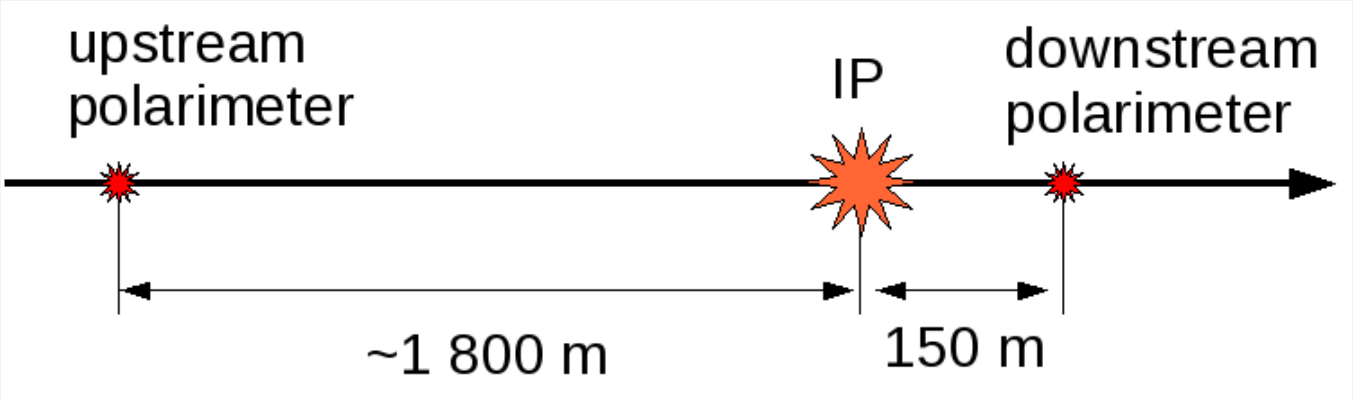
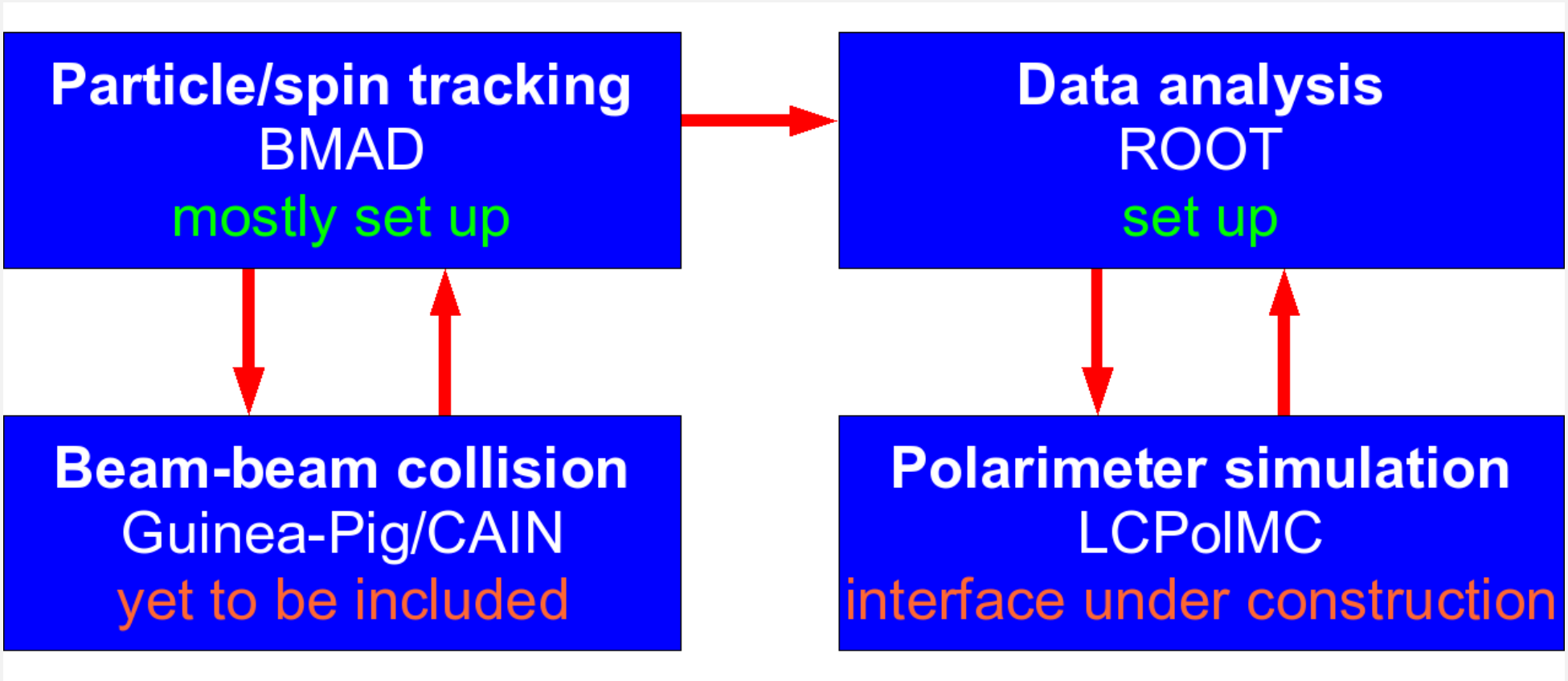
Introduction

- Polarization is planned to be measured at the ILC with 0.25 % uncertainty in the beam delivery system (BDS)
- Compton polarimeters, beam energy 45-500 GeV
- Longterm scale calibration of luminosity-averaged polarization at IP to 0.1% using e^+e^- collision data



- Spin diffusion / depolarization must be understood to 0.1% (further) spin tracking studies required

Simulation



- This study is performed for the ILC
- Could be used for other projects (e.g. CLIC) as well, if fed with corresponding lattice / parameters

Spin tracking

- Spin propagation in electromagnetic fields is described by T-BMT equation

$$\frac{d}{dt}\vec{s} = \vec{\Omega}\Big(\vec{E}(\vec{r},t),\ \vec{B}(\vec{r},t),\ \vec{p}\,,m\,,a\Big) \times \vec{s}$$

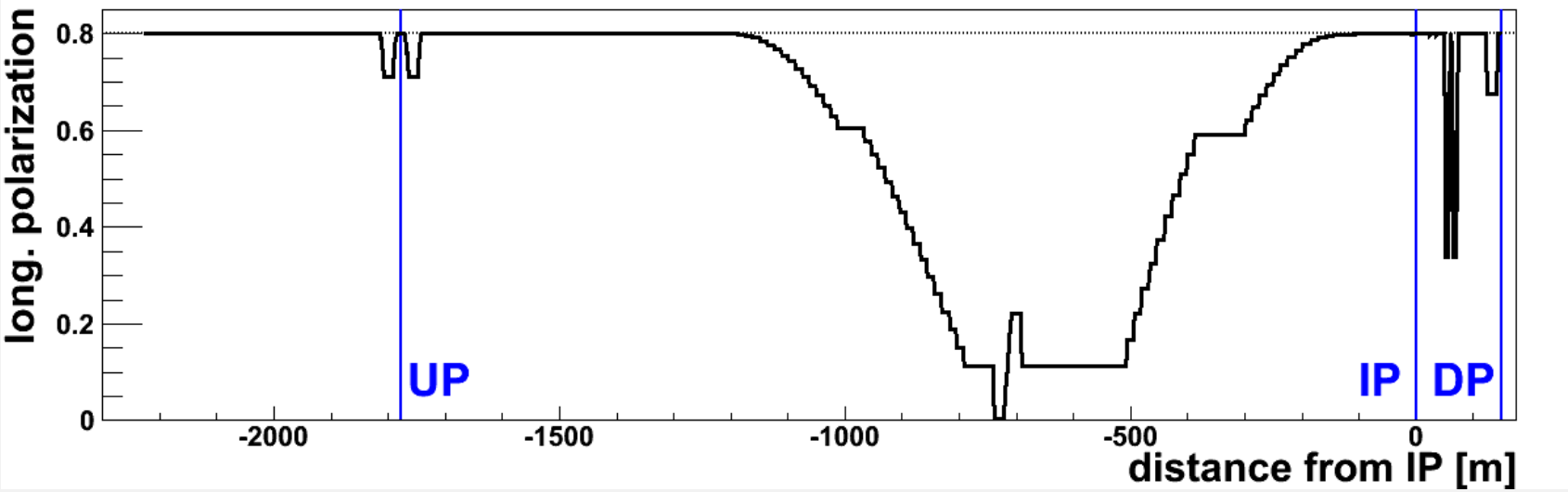
- Rough approximation ($\vec{E} = 0, \vec{B}_{\parallel} = 0$):
  Spin precession $\propto$ orbit bending in magnetic field:

$$\begin{aligned} \theta_{\text{spin}} &= a\gamma \cdot \theta_{\text{orbit}} \\ &\approx 567 \cdot \theta_{\text{orbit}} \quad \text{for electrons at 250 GeV} \end{aligned}$$

a: anomalous gyro-magnetic moment, a. k. a. $\frac{g-2}{2}$
$\gamma = \frac{E}{m}$

Idealized Lattice

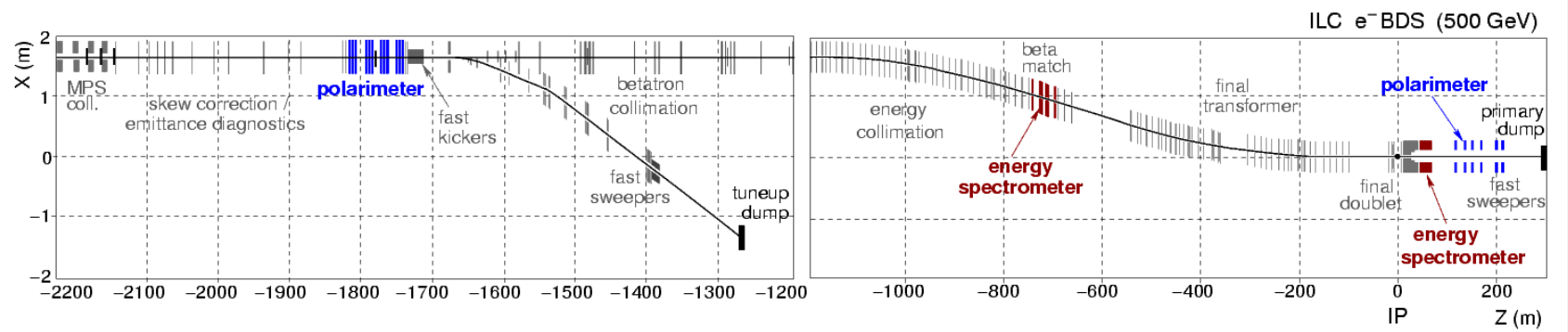
- Using latest available lattice (ILC2007b), beam parameters from Reference Design Report (2007)
- 10 000 particles, spins assumed $\propto \vec{e}_z$ at the end of the linac
- Perfect magnet alignment, no collision effects
- Plot: longitudinal polarization along BDS

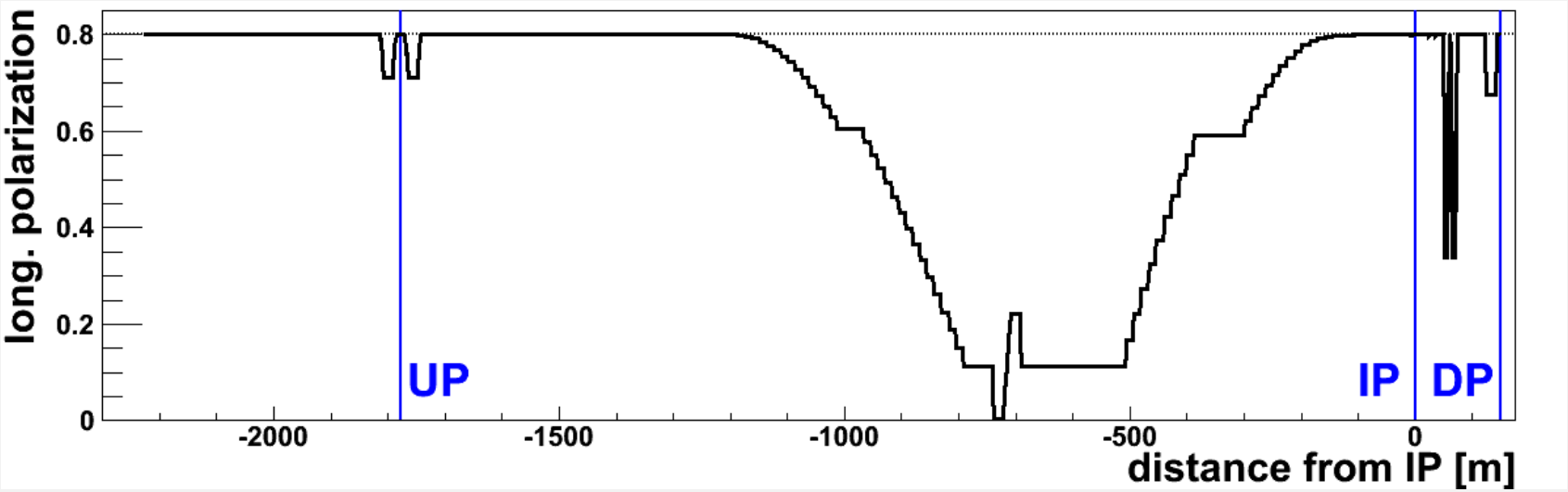


UP/DP: positions of up-/downstream polarimeters

- Dips due to dipoles: polarization vector rotates, but no significant depolarization

Idealized Lattice (cont'd)



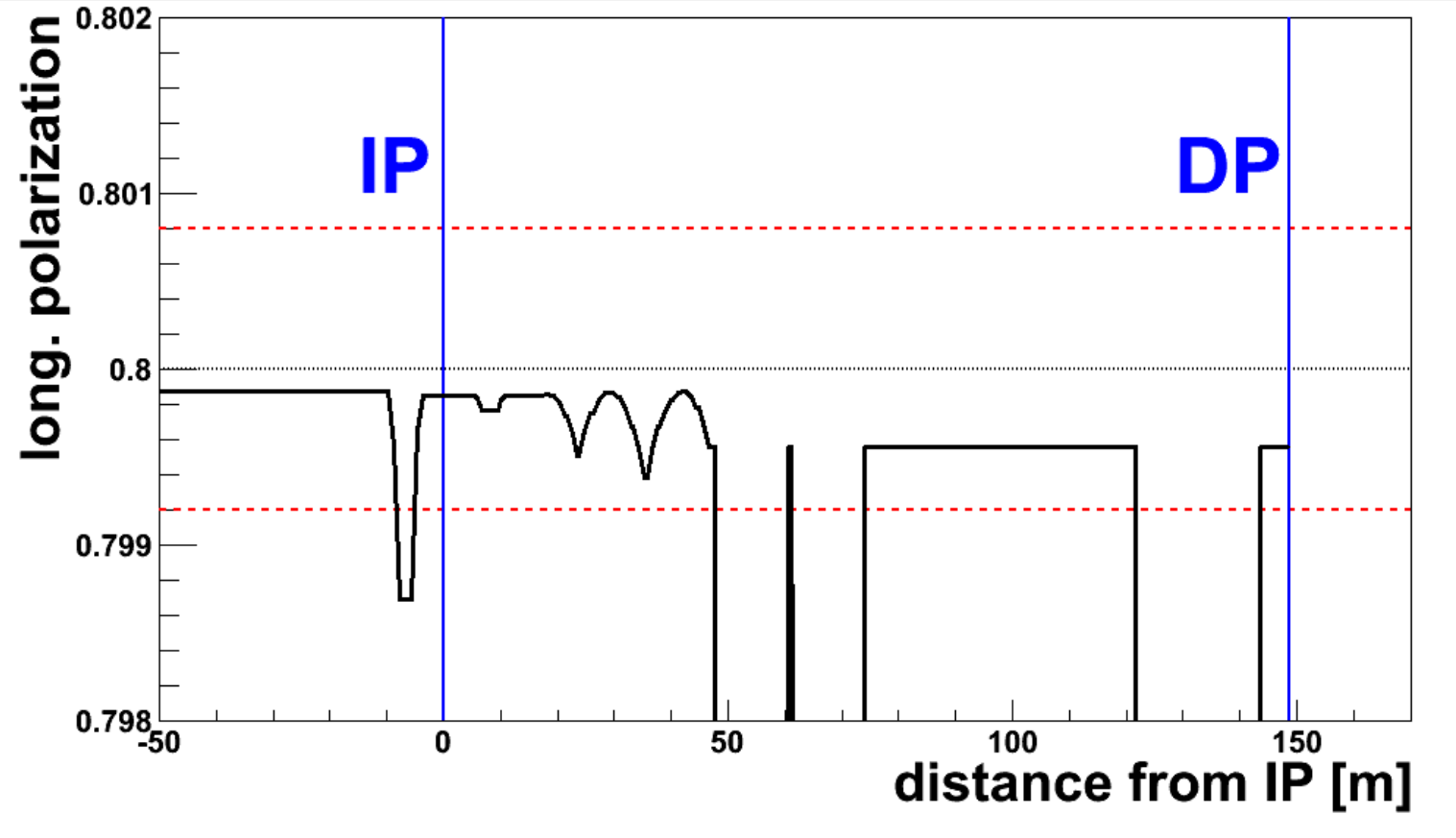


UP/DP: positions of up-/downstream polarimeters

Caution: scaling of x-axes varies

Idealized Lattice (Zoom)

- Spin fan-out due to lateral beam size in quadrupoles
- Red lines: $\pm 0.1\%$ (must know changes to this precision)



Special Issues in the Interaction Region

- Important elements are not yet included in lattice
  - Detector magnets
  - Crab cavities
    (give the bunch a transverse kick to compensate for beamline crossing angle)
  - Additional cavity or achromaticity for travelling focus scheme to achieve higher luminosity
- Effects of beam-beam collision have to be investigated
  - Disruption of beam ($\sim 10^{-4}$ rad)
  - Spin flips due to emission of beamstrahlung

Alignment / Ground Motion

- Magnet misalignments between polarimeters contribute to incomparability of measurements
- Need to investigate effect of static misalignments and ground motion:
  - Polarization vector rotation ($\theta_{\text{spin}} = a\gamma \cdot \theta_{\text{orbit}}$)
  - Spin fan-out due to poor focussing

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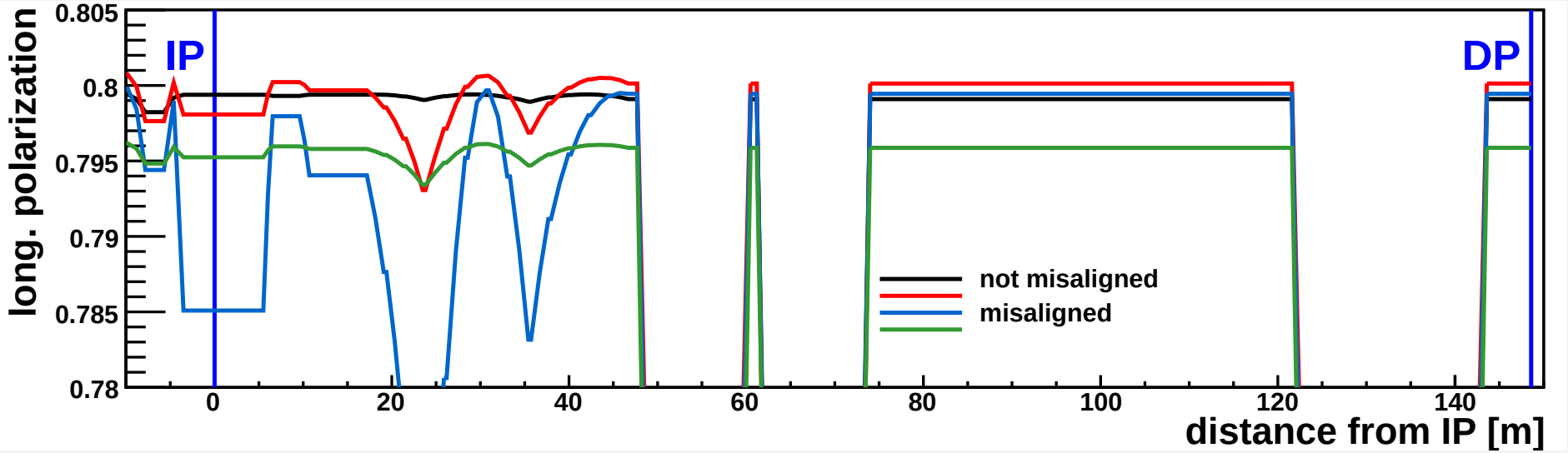
  - Polarization vector rotation ($\theta_{\text{spin}} = a\gamma \cdot \theta_{\text{orbit}}$)
  - Spin fan-out due to poor focussing
- Compensation by feed-back correctors?
  $\longrightarrow$ Requirements on alignment and BPM precision
  Need for additional correctors?

Static Misalignments

- Initial sample, each element randomly misaligned (Gaussian-distributed random numbers, $\sigma_{x,y} = 2\ \mu$m)
- $\sigma_{x,y} = 2$ nm in final focus region (0-50m in front of IP)
- Plots shows three **exemplary** samples



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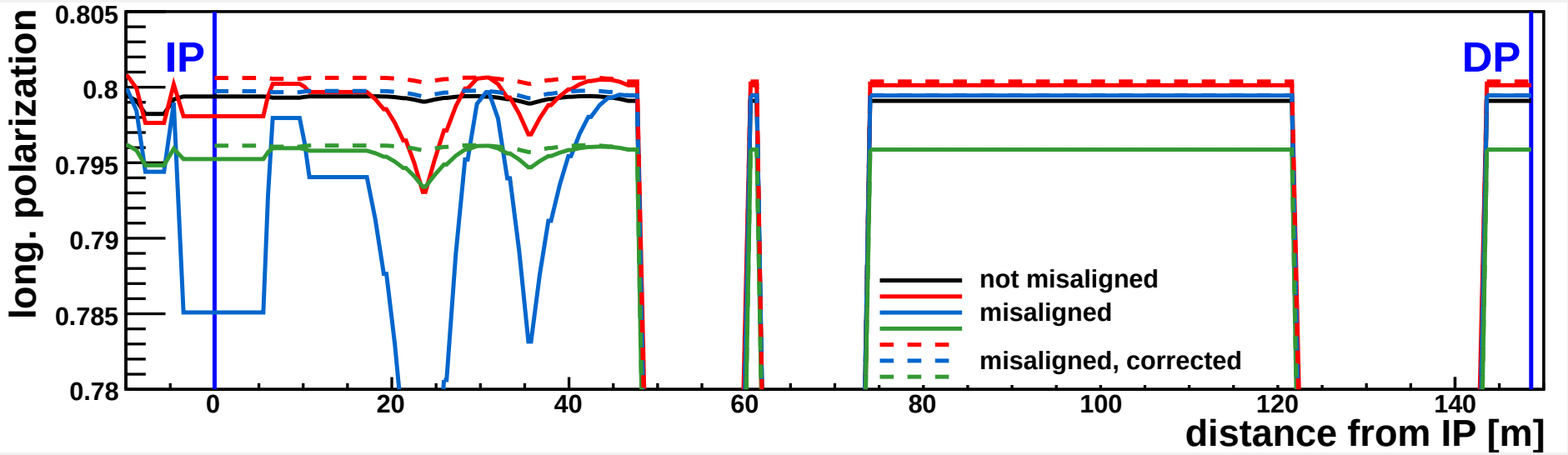
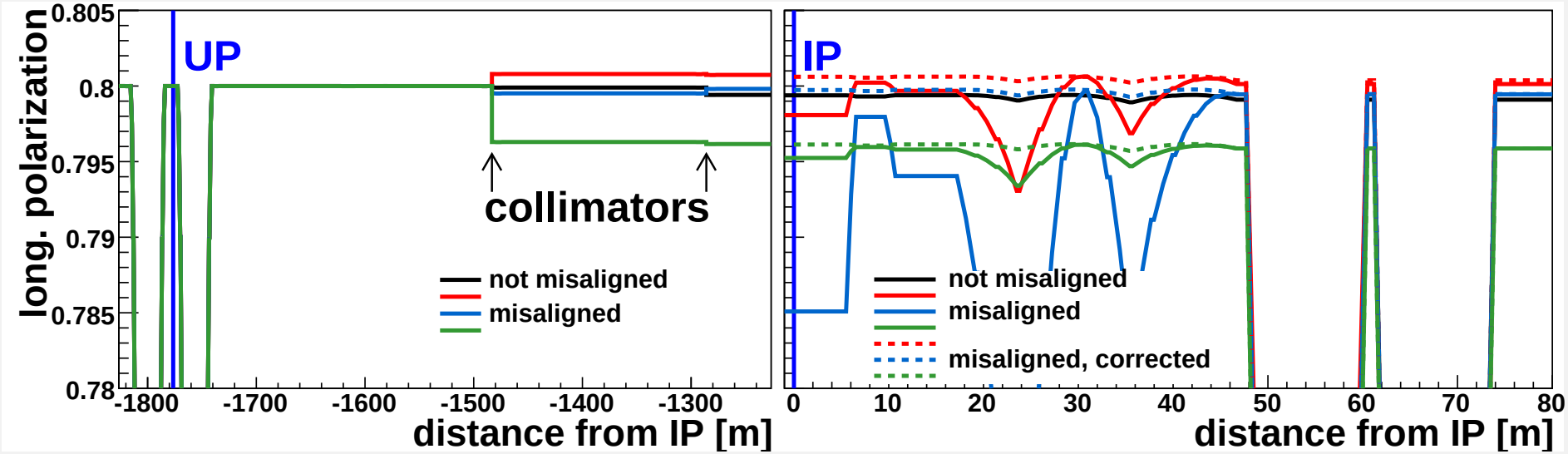
- Plots shows three **exemplary** samples
- No feed-back correctors implemented yet
- Dashed: after rotation of the momentum vectors at the IP such that $< p_t >= 0$; spins rotated accordingly ($a\gamma$)
- **Orbit correction at IP: $\frac{\Delta P_z}{P_z}$(IP,DP) $< 0.1\%$**

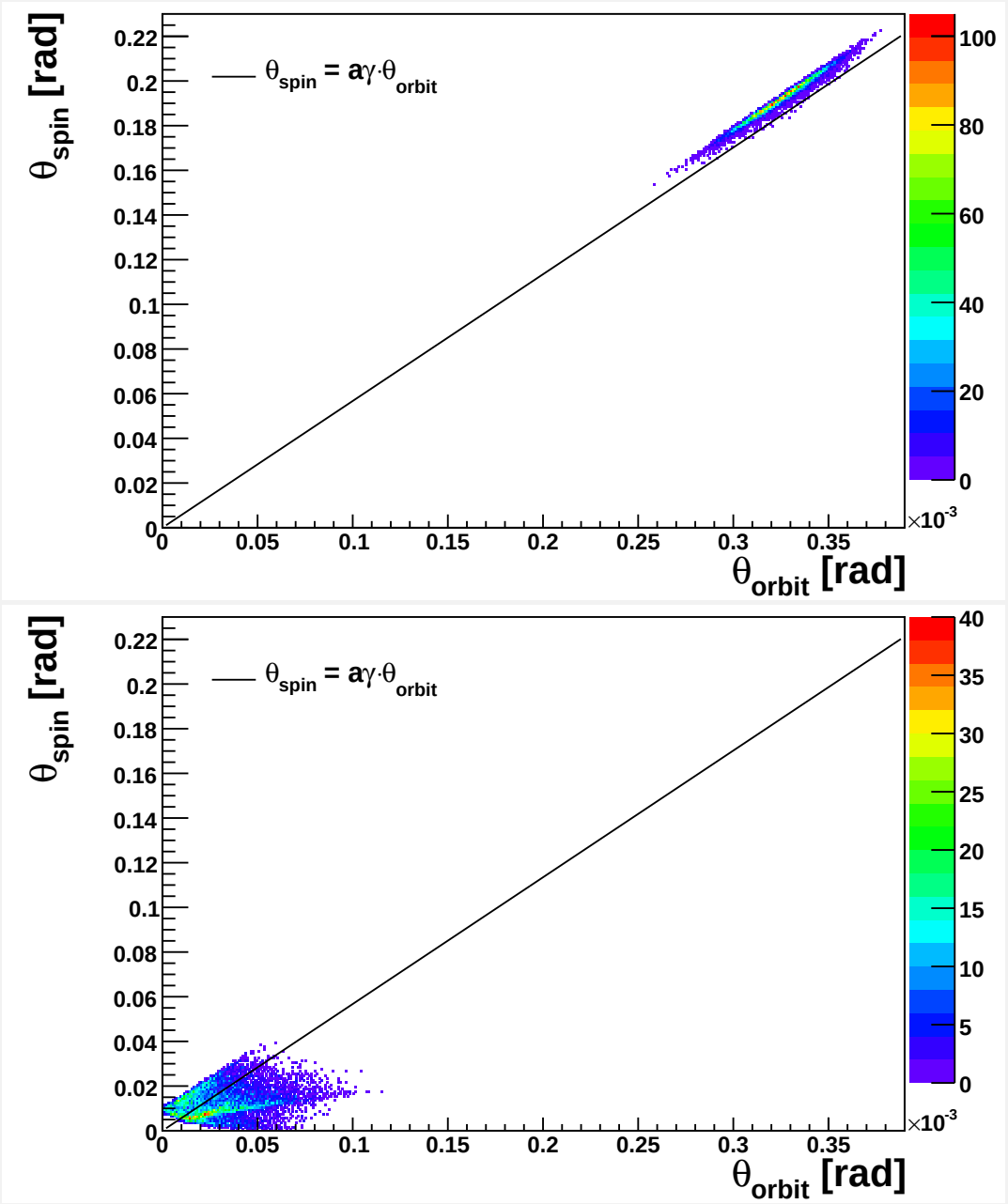


Static Misalignments (cont'd)

- Collimators in BDS absorb up to 1000 particles due to missing orbit correction (will be moved in front of upstream polarimeter according to SB-2009 proposal)
- Observed changes in polarization consistent with statistical effects ($\leq 2\sigma$)
- ΔP_z of corrected beams = ΔP_z from collimators
  $\Rightarrow$ **Orbit correction at IP: $\frac{\Delta P_z}{P_z}$(UP,IP) $< 0.1\%$**

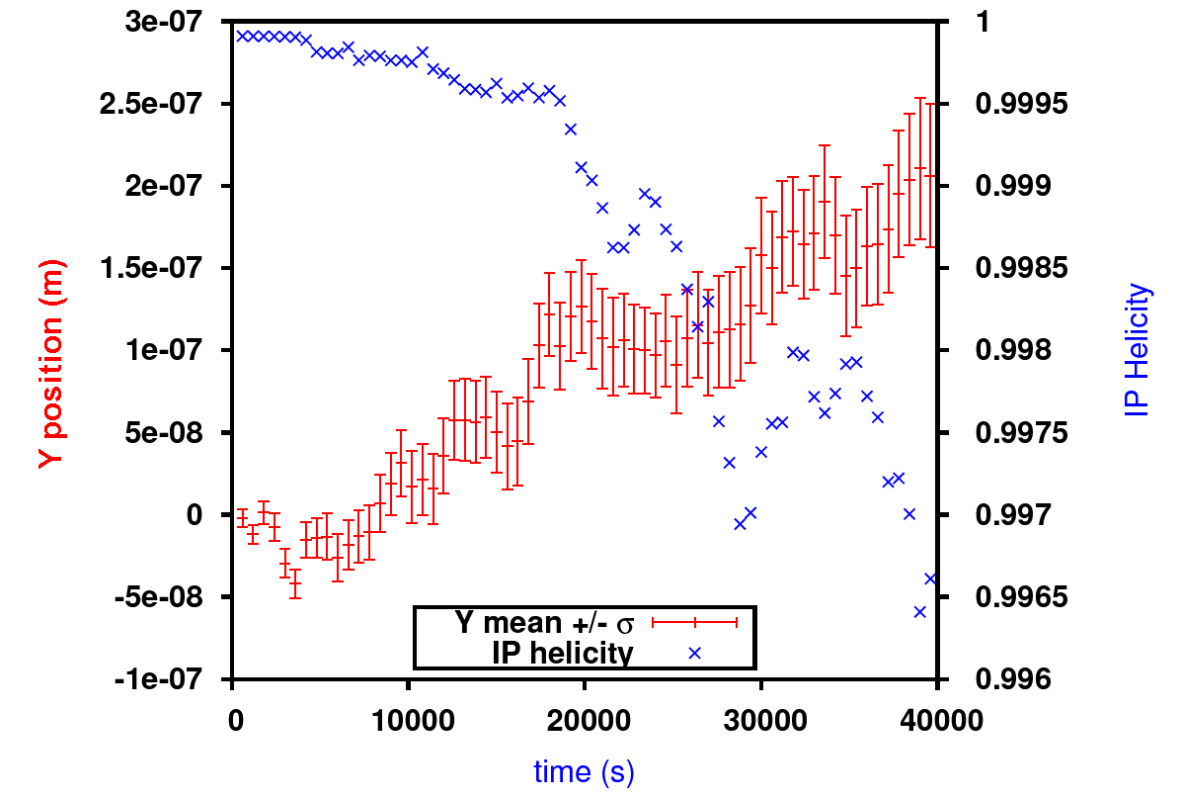


Static Misalignments: IP



- Orbit and helicity vector rotation are strongly correlated
- Provisional feed-back (lower plot) recovers longitudinal polarization
- Assumption: Spins $\propto \vec{e}_z$ at the end of the linac

Ground motion



A. Hartin, PST 2009

- Plot: IP beam y-position and helicity with ground motion model for "noisy" site without correction
- Nominal beam size σ_y at IP: 5.7 nm

Summary

- A spin tracking framework for high energy linear colliders has been set up
- First studies have been performed for the ILC, where an understanding of polarisation to the permille-level is required

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- A spin tracking framework for high energy linear colliders has been set up
- First studies have been performed for the ILC, where an understanding of polarisation to the permille-level is required

- Alignment in whole BDS is crucial, but causes mainly helicity vector rotation $\longrightarrow$ reversible
- Provisional orbit correction at the IP
  $\Rightarrow$ same P_z at polarimeters and IP w. r. t. tolerances

- Need to specify the polarization requirements on beam position monitors and alignment systems
  $\longrightarrow$ more investigations

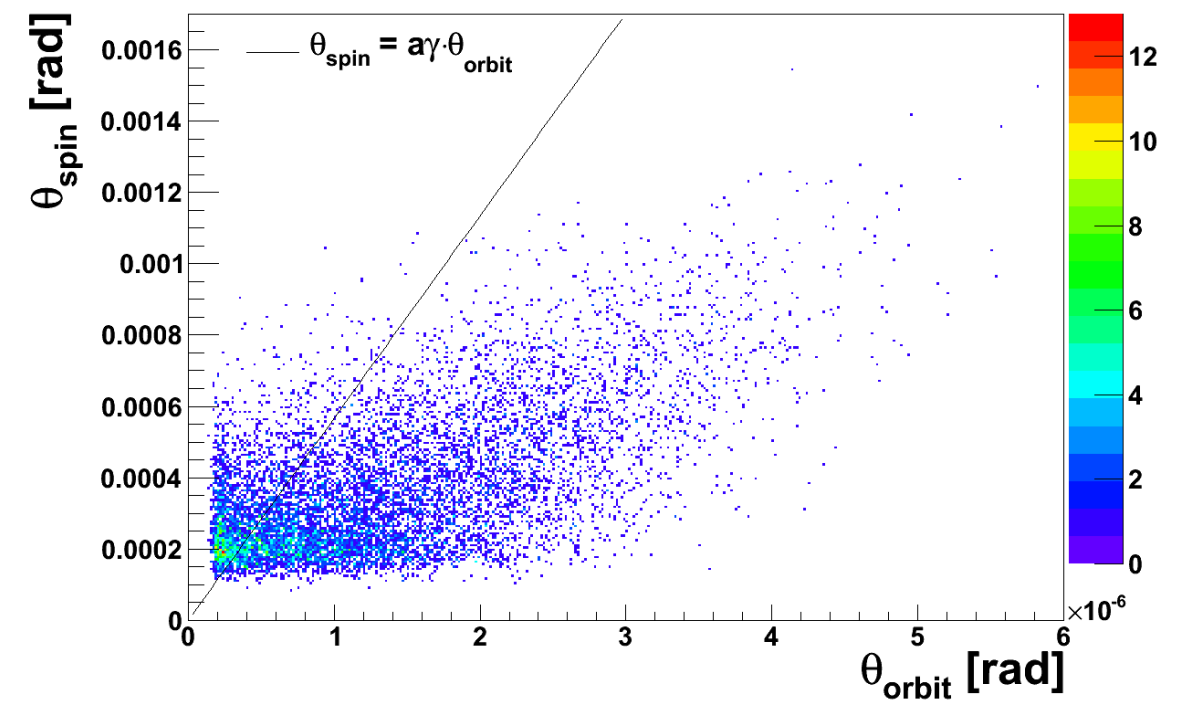
Outlook

- Include more details into the simulation
  - Detector magnets
  - Crab cavities
  - Travelling focus scheme
  - Collision effects
  - Ground motion
  - Feed-back systems in lattice
- Interface to polarimeter simulations
- Develop calibration strategies

Thanks for your attention!

Backup slides

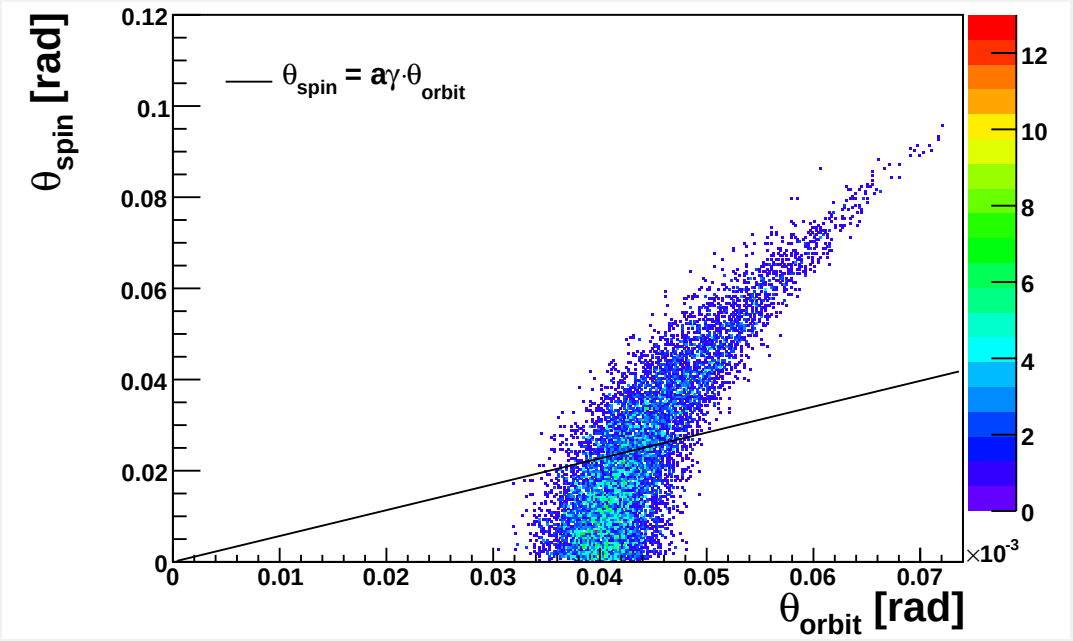
Static Misalignments: Upstream Polarimeter

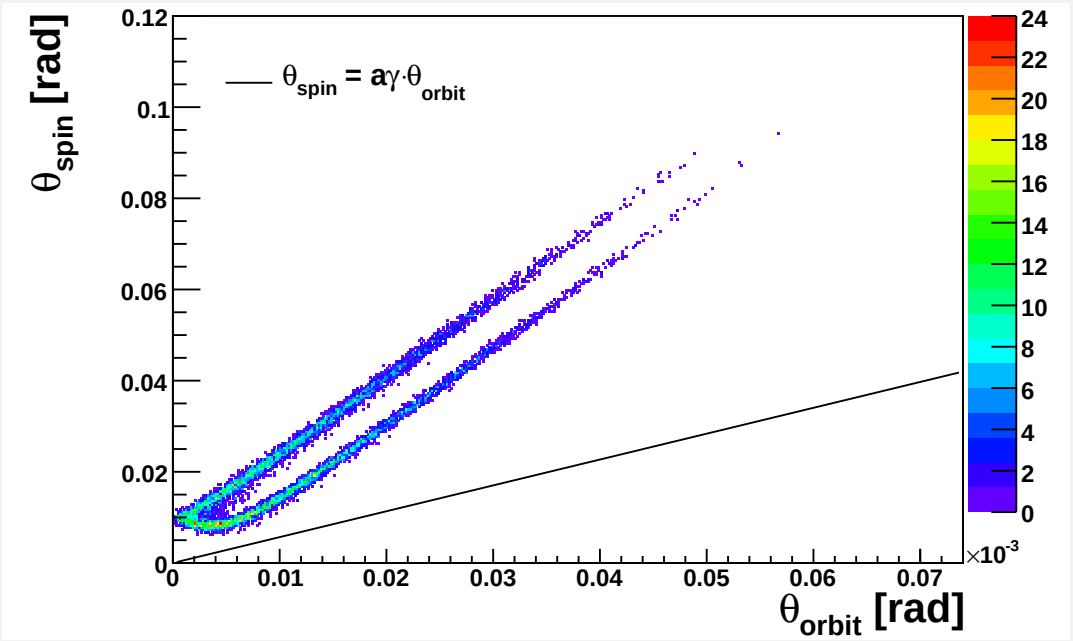


θ_{orbit}: angle between reference orbit and actual particle orbit

- Effects from misalignments are small, though visible (distribution offset from zero)
- Depolarization $\sim 10^{-7}$

Static Misalignments: Downstream Polarimeter

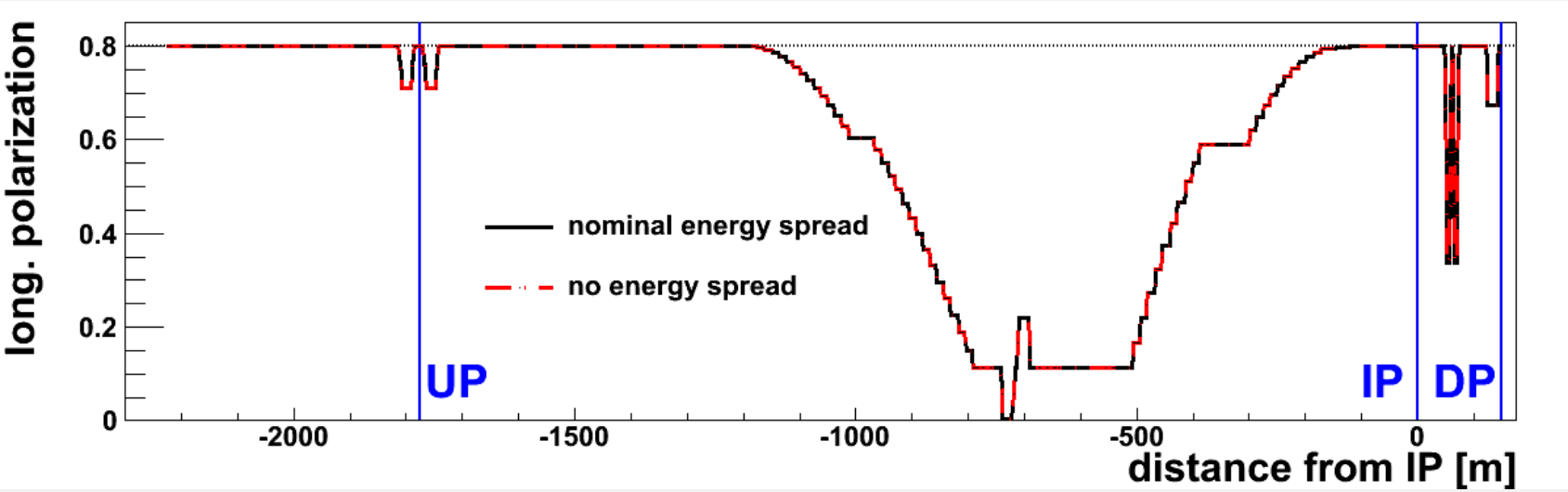




- Less correlation than at the IP, effect of extraction line quadrupoles?
- needs further investigation

Effects of Energy spread

- Sample as in the beginning, no misalignments
- No difference due to energy spread visible



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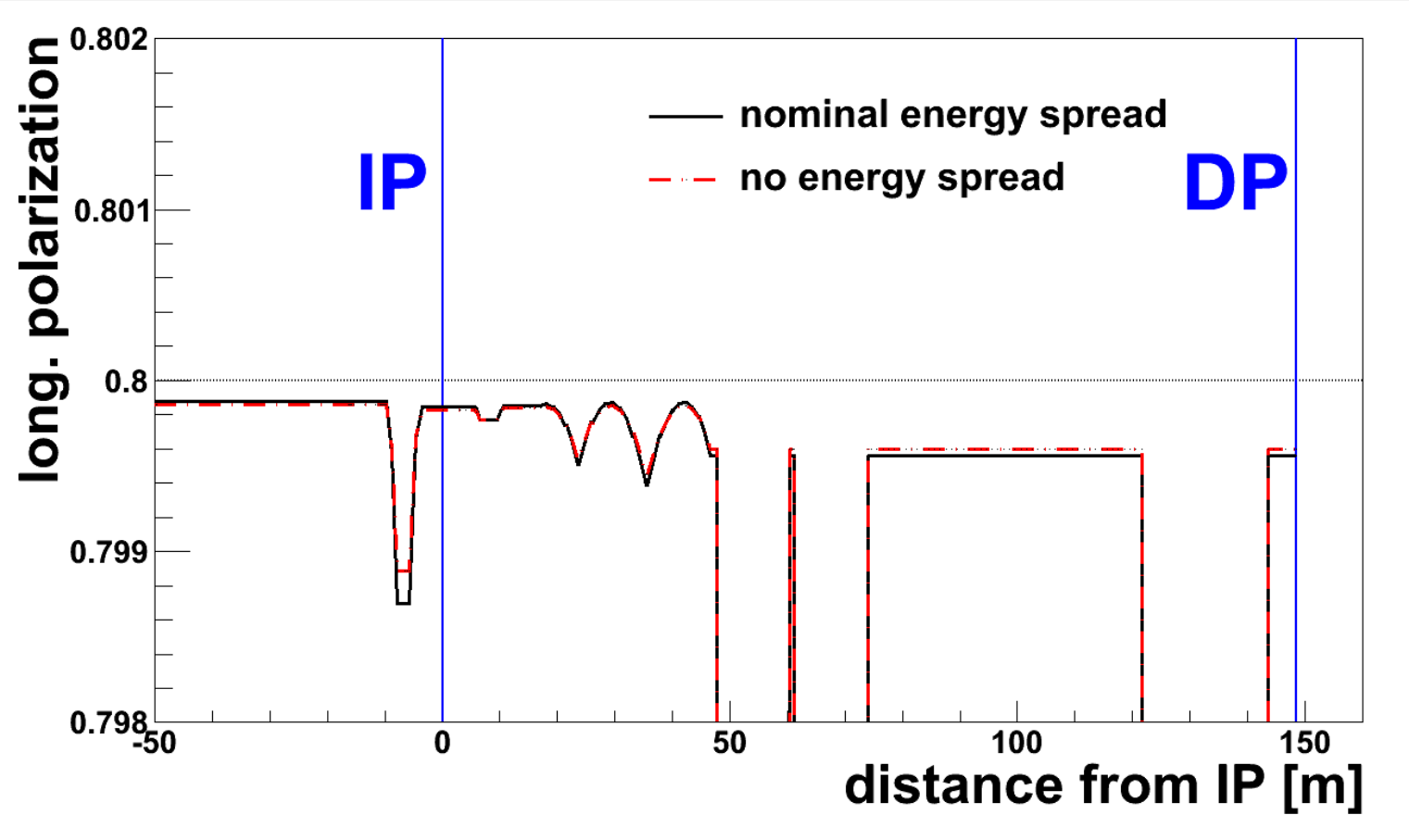
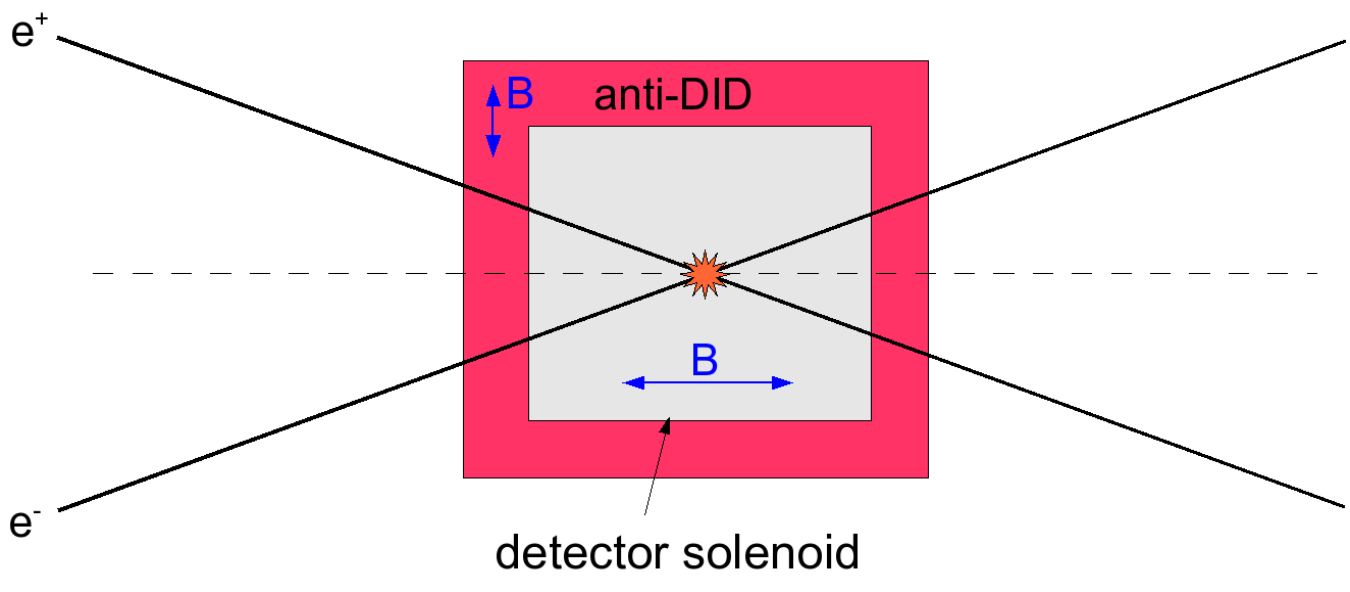


Detector magnets

- Detectors contain
  - solenoid for tracking devices
  - dipole (anti-DID) to compensate for (detector) effects of crossing angle



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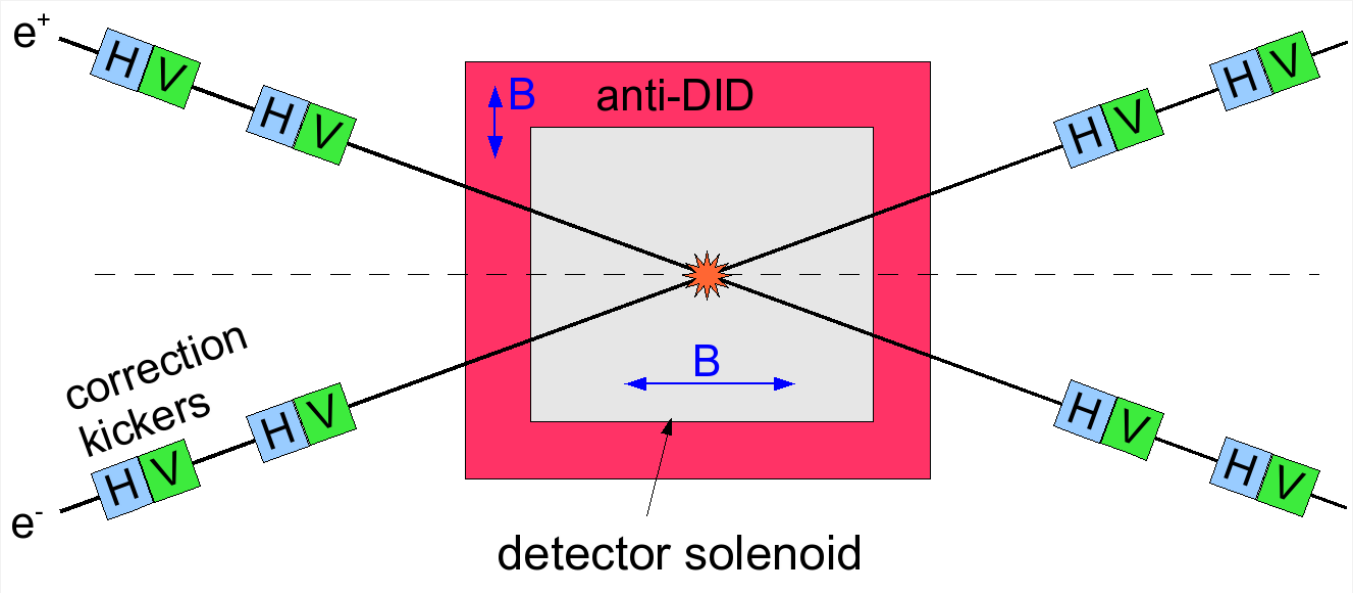
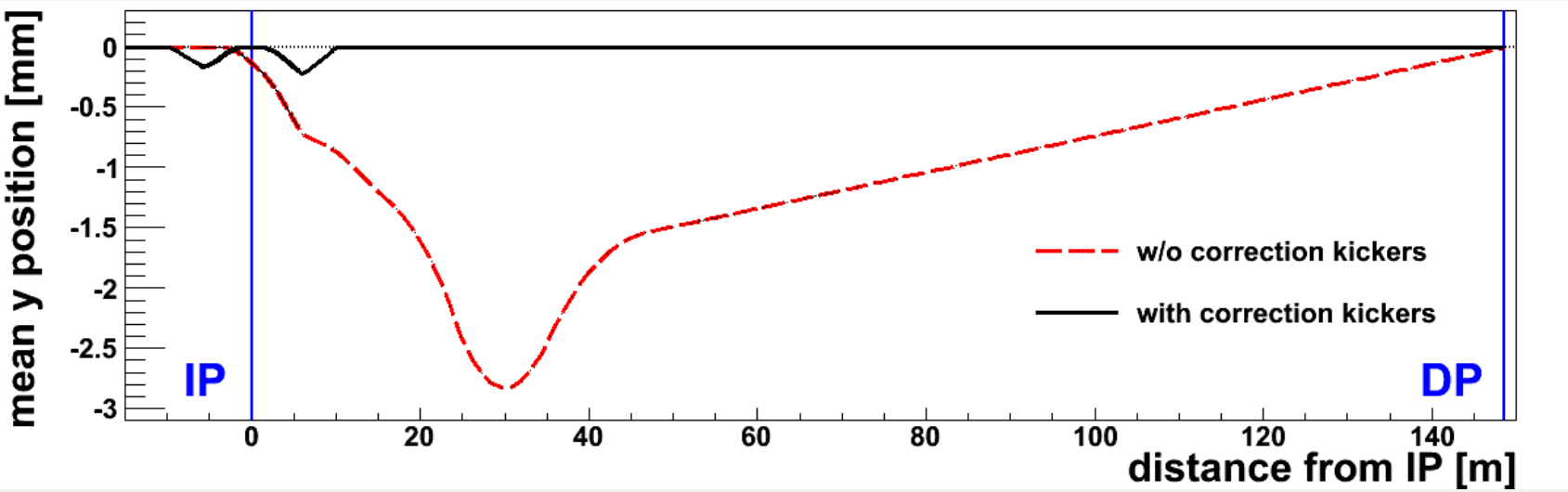


- Additional correction kickers required to align beam at IP and behind detector
- Parameters (solenoid field etc.) vary for different detector concepts

Detector magnets: Orbit Correction

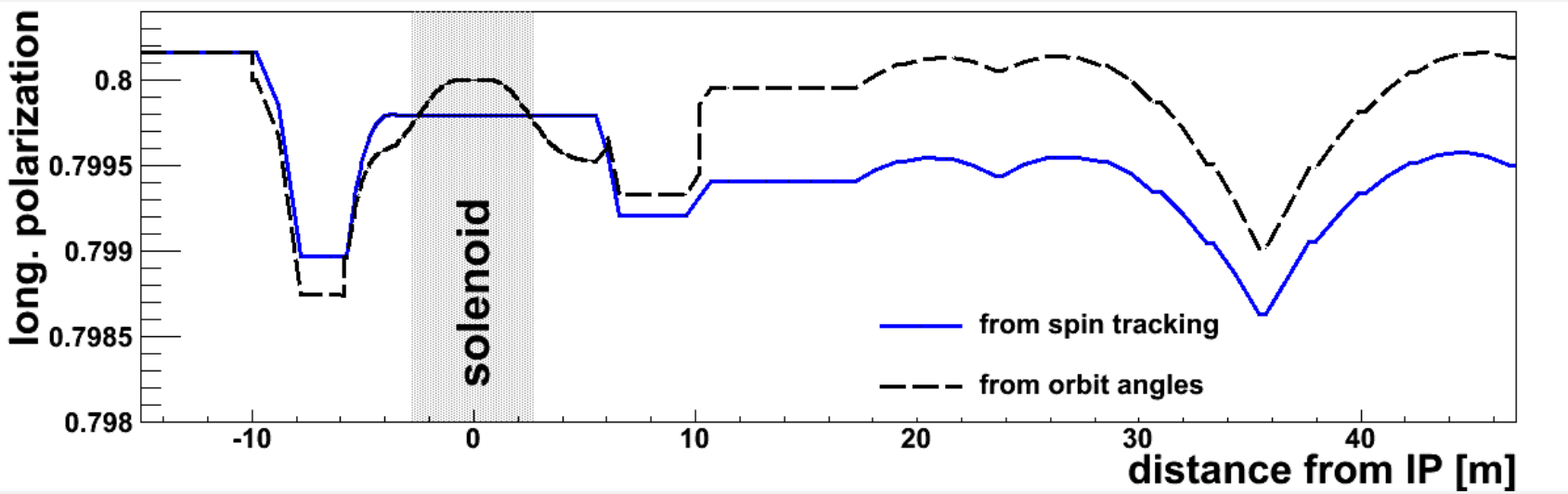
Simple model of SiD, first-order orbit correction



- Mean x position < 0.03 mm
- Plot for polarization not available due to technical problems

Detector magnets: Polarization

- Technical problem: Spin tracking through kickers not implemented yet
- Tracked spins: do not include kickers and anti-DID
- Orbit angles: approximation $\theta_{\text{spin}} = a\gamma \cdot \theta_{\text{orbit}}$ not valid in and around solenoid ($\vec{B}_{\parallel} \gg \vec{B}_{\perp}$)



- Tracked spins: visible effect from solenoid expected