Challenges for Polarimetry at the ILC

Spin Tracking Studies

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DESY - FLC

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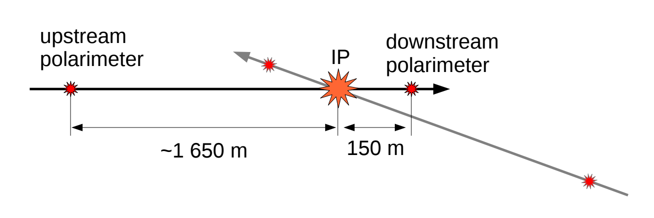
Deutsche Forschungsgemeinschaft
DFG

Introduction: Polarimetry at the ILC

- Two laser Compton polarimeters per beam in the beam delivery system (BDS)



- Polarimeters measure with 0.25 % systematic uncertainty (goal)
- **What happens between polarimeter and IP?**

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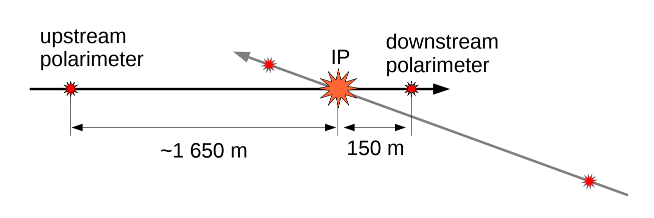
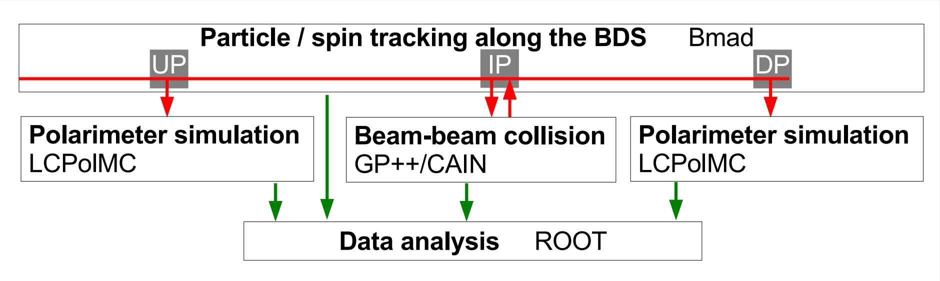


- Polarimeters measure with 0.25 % systematic uncertainty (goal)
- **What happens between polarimeter and IP?**
- In addition: calibration with average polarization from collision data (up to 0.1 %)
- **Must understand spin diffusion/depolarization to 0.1 %**

Introduction: Simulation Framework



UP/DP: up-/downstream polarimeter

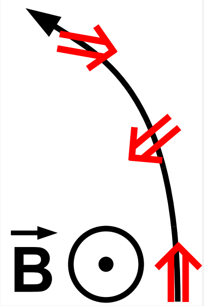
Framework could be used with different input also for other machines, e. g. CLIC

Introduction: Principles of Spin Propagation

- Spin propagation in electromagnetic fields is described by T-BMT equation (**semi-classical**)

- Approximation ($\vec{B}_\perp$ only) for illustration: spin precession

$$\theta_{\mathbf{spin}} = \underbrace{\left(\frac{\mathbf{g-2}}{\mathbf{2}} \cdot \frac{\mathbf{E}}{\mathbf{m}} + \mathbf{1}\right)}_{\approx \mathbf{568}} \cdot \theta_{\mathbf{orbit}}$$



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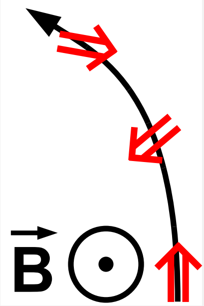

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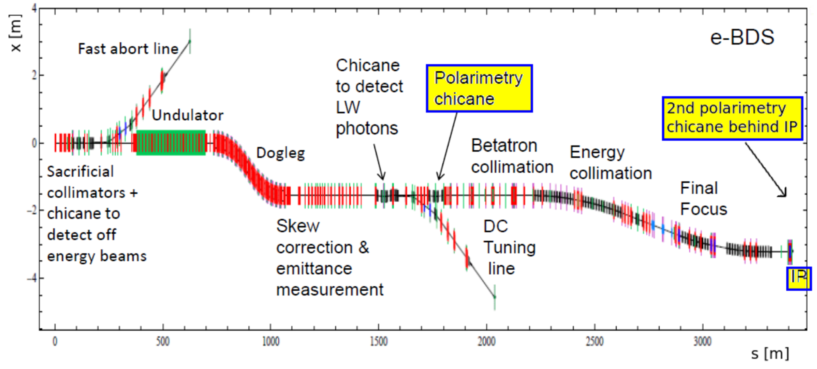
$$\theta_{\text{spin}} = \underbrace{\left(\frac{g-2}{2} \cdot \frac{E}{m} + 1\right)}_{\approx 568} \cdot \theta_{\text{orbit}}$$

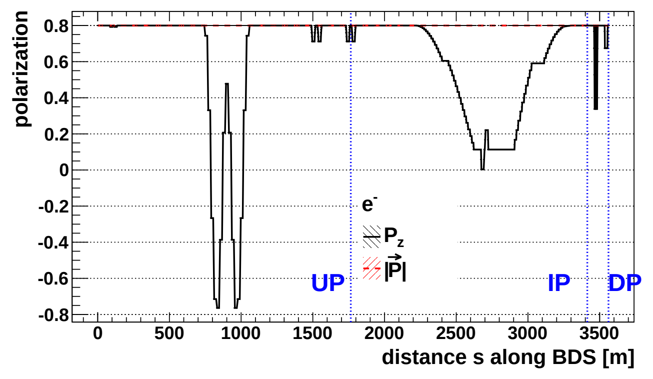
- Polarization vector $\vec{P} = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$ with polarization $\left|\vec{P}\right|$

Introduction: ILC Beam Delivery System



Latest available beamline design (SB2009_Nov10 lattice)

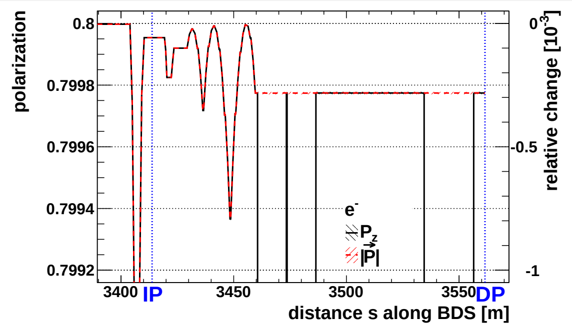
Spin Propagation through BDS (Idealized Lattice)



UP/DP: up-/downstream polarimeter

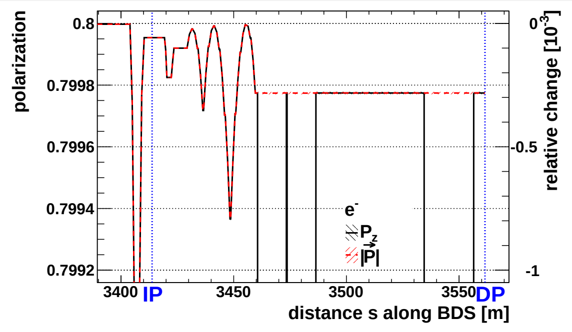
- 1000 runs with random bunches, 10 000 sim. particles each
- Drawn: median $\pm 1\sigma$
- Perfect magnet alignment, no collision effects

Spin Fan-Out



Only minor spin fan-out in quadrupoles

Spin Fan-Out



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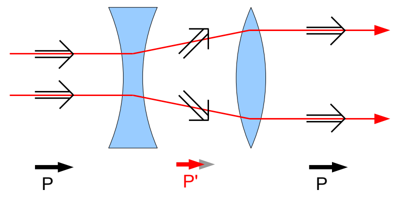
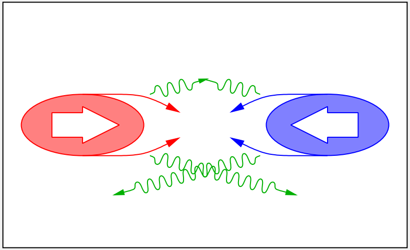


Collision Effects

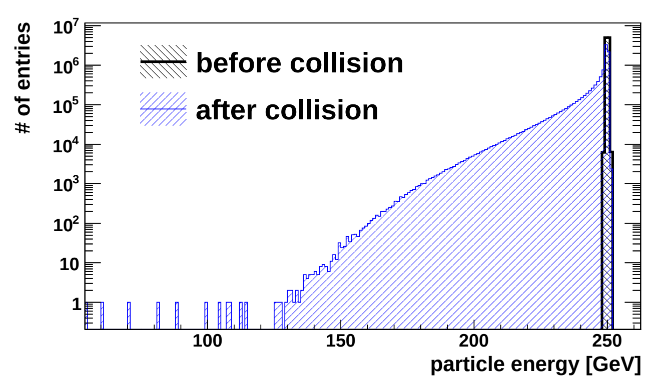
Simulation of Collision Effects (GP++):

- **T-BMT precession**: deflection from colliding bunch ($\sim 10^{-4}$ rad)
- Sokolov-Ternov: **spin flip** by emission of **beamstrahlung**



Collision Effects: Energy Loss

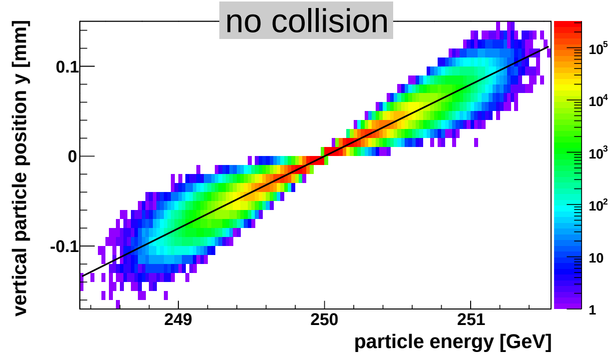
- Energy loss by beamstrahlung:



- Spin precession $\propto E$
  $\Rightarrow$ **Spin fan-out due to energy spread**

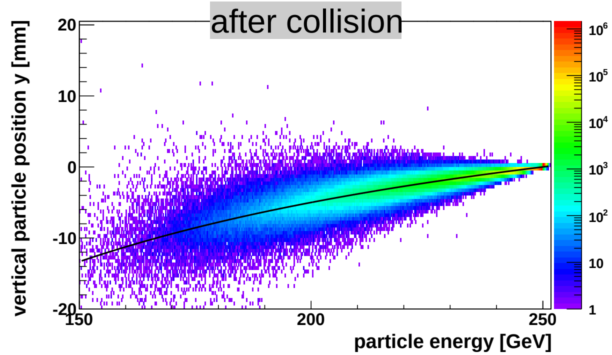
Collision Effects: Energy Loss vs. Laser-Spot

- **Laser-spot size** at Compton IP only $\sim$ **0.1 – 1 mm**
- chicane $\Rightarrow$ **dispersion** (black: reference particle)
- **Without collision:** 0.124 % beam energy spread
  Entire beam within laser-spot ✓



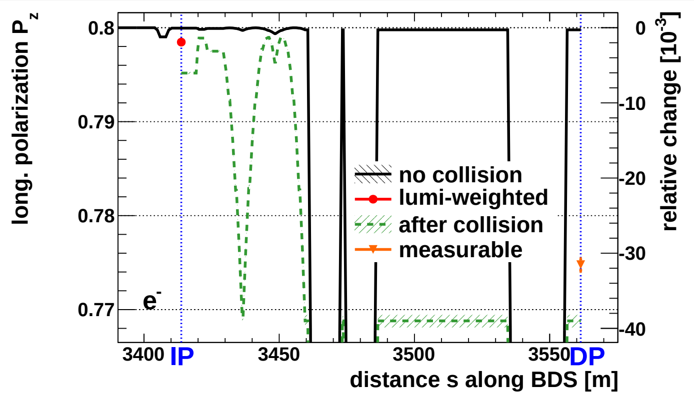
Collision Effects: Energy Loss vs. Laser-Spot

- **Laser-spot size** at Compton IP only $\sim \mathbf{0.1 - 1\,mm}$
- chicane ⇒ **dispersion** (black: reference particle)
- **After collision:** Off-energy particles evade laser-spot
- Downstream polarimeter needs detailed investigation (energy and polarization correlated!)



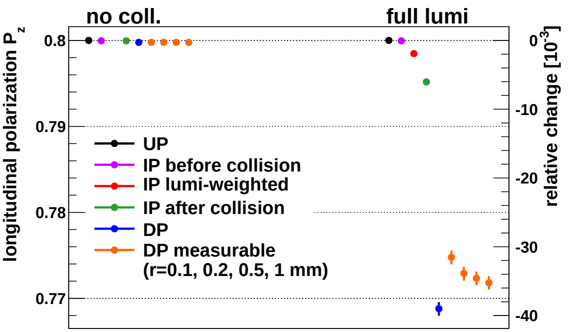
Collision Effects: Spin Propagation

- Collisions, but still perfect alignment
- Crossing angle 14 mrad, bunches crabbed



- Much stronger spin fan-out
- Polarization within 0.1 mm laser-spot different: "measureable"

Collision Effects: Spin Propagation



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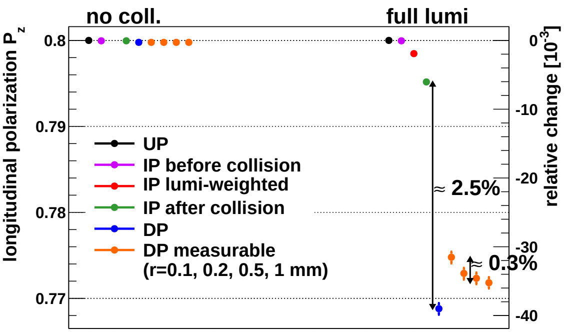
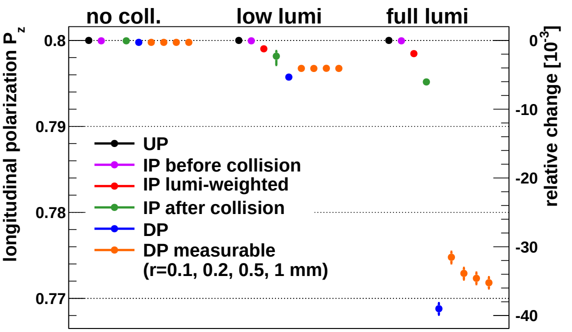


- **What does the measurement tell us about the polarization at the IP?? $\Delta P_z \sim 2.5\,\%$**
- Can we trust the simulation to calculate back?
  More details to come: detector magnets, misalignments
- Uncertainty in DP laser-spot size/position
  $\Rightarrow \Delta P_z = O(0.1\,\%)$

Collision Effects: Spin Propagation



Low luminosity sample (switched off bunch crabbing):

- Collision effects and also their consequences reduced
- Downstream measurement less affected by collision effects and less dependent on laser-spot size/position

Conclusion

- A spin tracking framework for high energy linear colliders including collision effects has been set up
- ILC: understanding of polarization to permille-level required
- Precision goals for upstream measurement seem achievable

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- **Downstream polarimeter struggles fiercely with collision effects**:
  - **High-precision simulation** including **all** effects required at high luminosities to obtain polarization at IP from data
  - Measurement highly sensitive to size/position of laser-spot
  - **Idea**: determine lumi-weighted polarization rather/also from upstream polarimeter and luminosity measurement?

Conclusion

- A spin tracking framework for high energy linear colliders including collision effects has been set up
- ILC: understanding of polarization to permille-level required
- Precision goals for upstream measurement seem achievable
- **Downstream polarimeter struggles fiercely with collision effects**:
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  - Measurement highly sensitive to size/position of laser-spot
  - **Idea**: determine lumi-weighted polarization rather/also from upstream polarimeter and luminosity measurement?
- **Downstream polarimeter needed nevertheless**:
  - Measure depolarization without collision effects / calibrate UP
  - Measure additional depolarization at low luminosities to test simulations

Thanks for your attention!

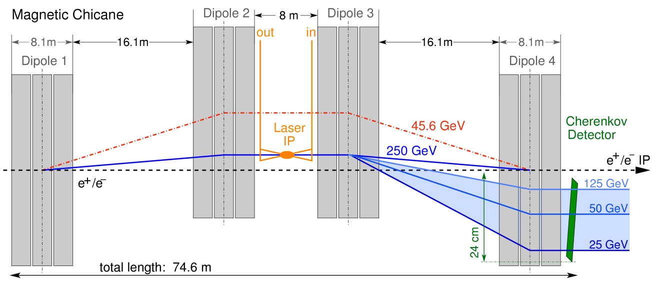
Thanks for support and useful discussions to:

- David Sagan (Cornell U.)
- Deepa Angal-Kalinin (Daresbury Lab.)
- Anthony Hartin, Mathias Vogt, Nick Walker (DESY)
- Andrei Seryi (JAI)
- Kenneth Moffeit, Yuri Nosochkov, Michael Woods (SLAC)
- Jeff Smith (formerly SLAC)
- und many others...

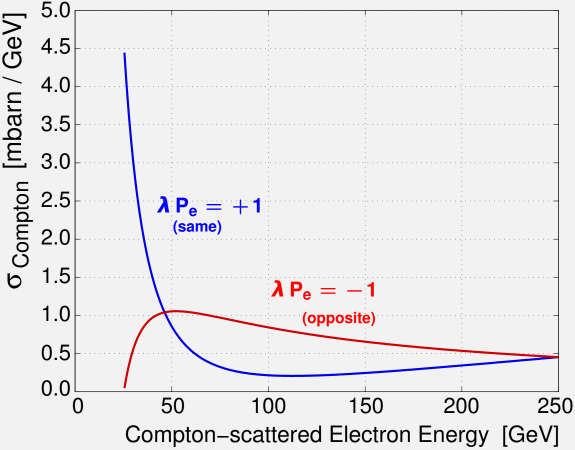
Backup slides

Compton Polarimeters: Principles

- **Compton scattering with polarized laser:**
  $\sim$ 1500 electrons per bunch
- **Measure energy spectrum of scattered electrons**
- Energy distribution $\rightarrow$ spatial distribution
- Cherenkov gas detector counts electrons per channel



Compton Polarimeters: Principles



- σ_{Compton} **depends on polarization** (laser × beam)
- Measure asymmetry and compare to analyzing power (predicted asymmetry for 100 % polarization)

Compton Polarimeters: Systematic Errors

Goal: relative systematic error on measurement $< 0.25\,\%$
(SLC polarimeter: $0.5\,\%$)

- Detector linearity: contribution of $\sim 0.1 - 0.2\,\%$ (goal)
  Prototype tests ongoing ...
- Laser polarization: $\sim 0.1\,\%$ ✓

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- Detector linearity: contribution of $\sim 0.1 - 0.2\,\%$ (goal)
  Prototype tests ongoing ...
- Laser polarization: $\sim 0.1\,\%$ ✓
- Analyzing power: $\sim 0.1\,\%$ (UP: ✓, DP: ?)
  - Detector alignment: can be determined from data (✓)
    0.5 mm precision sufficient
  - Alignment of magnets negligible compared to detector ✓
    Field inhomogeneities? to be investigated
  - Disrupted electron beam at downstream polarimeter:
    - Dependence on laser-spot size and position: ??
    - Beam energy spread no concern for small laser-spot sizes thanks to dispersion ✓

Misalignments

- Every element is shifted/rotated randomly in/about all directions/axes
- Gaussian-distributed random numbers, $\sigma = 10$ μm/μrad
- Static and time-dependent misalignments

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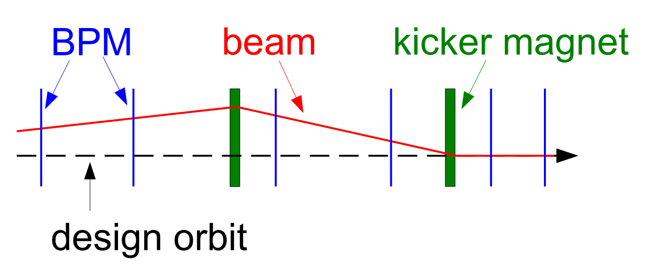
- Every element is shifted/rotated randomly in/about all directions/axes
- Gaussian-distributed random numbers, $\sigma = 10$ μm/μrad
- Static and time-dependent misalignments
- Simplified orbit correction with kicker magnets and fast feedback at IP

Misalignments: Correction with Kicker Magnets



- $\sim$ 40 kicker magnets and many more **B**eam **P**osition **M**onitors spread over BDS
- Calculate required kicks from measurements (SVD)
- **Automatic correction of spin alignment as well?**

Misalignments: Orbit Correction Strategy

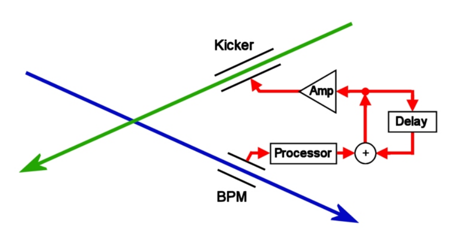
Strategy here:

- Interested in **effects of kicks on polarization**, not in sophisticated correction algorithm
- Get orbit corrected **somehow** with kickers such that
  - beam does no go lost
  - approximations (small coordinates) still hold

Misalignments: Orbit Correction Strategy

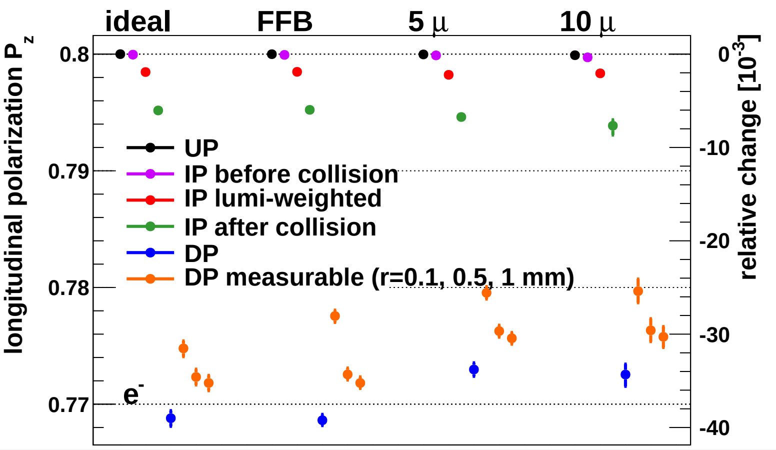
Strategy here:

- Interested in **effects of kicks on polarization**, not in sophisticated correction algorithm
- Get orbit corrected **somehow** with kickers such that
  - beam does no go lost
  - approximations (small coordinates) still hold
- Fake correction at IP: shift and rotate bunch coordinates to $0.1\,\sigma$ precision (goal), adjust beam size



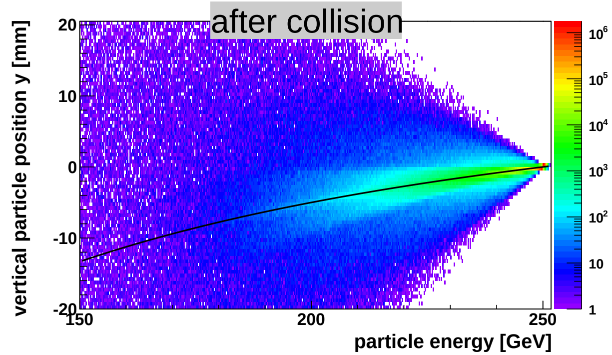
Misalignments: Spin Propagation

- Misalignments reduce luminosity ⇒ less collision effects
- Measured polarization depends on laser-spot size and position



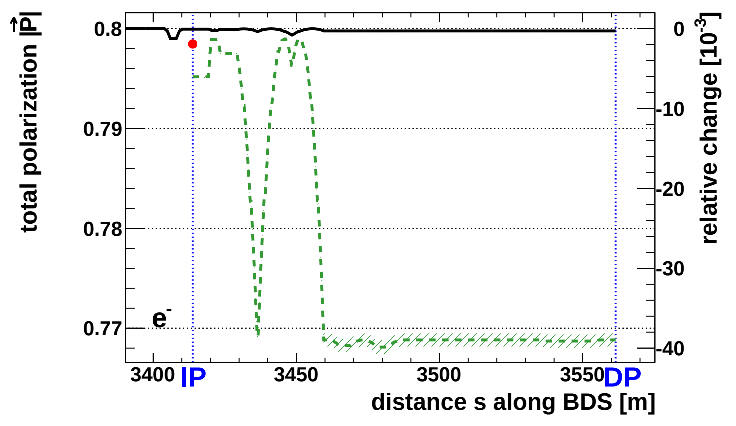
Collision Effects: Energy Loss vs. Laser-Spot

- **Laser-spot size** at Compton IP only $\sim$ **100** μm $-$ **1** mm
- chicane $\Rightarrow$ **dispersion** (black: reference particle)
- **After collision, bunch crabbing switched off**

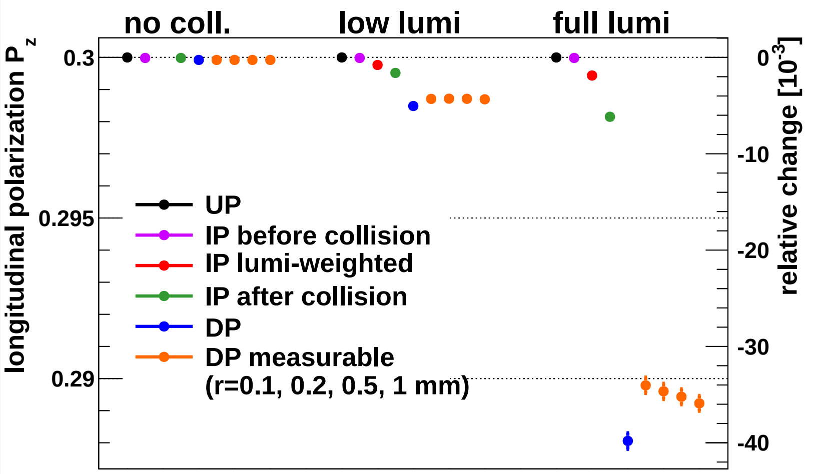


Collision Effects: Spin Propagation (Polarization)

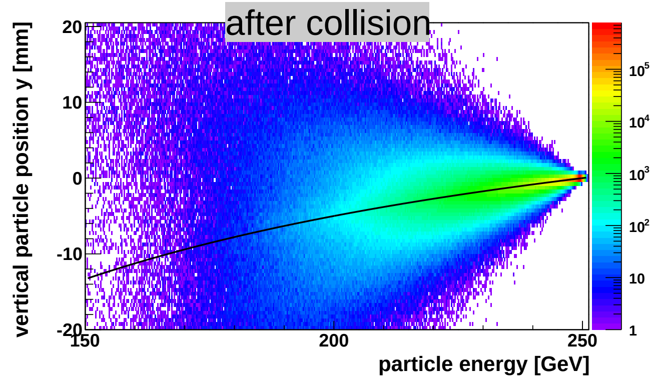
- Total polarization affected likewise
- Polarization decrease in chicanes: fan-out due to energy spread



Collision Effects: Spin Propagation (Positron Beam)

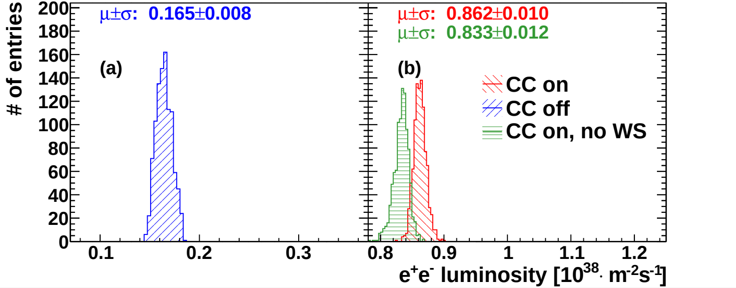


Collision & Misalignments: Downstream Polarimeter Measurement



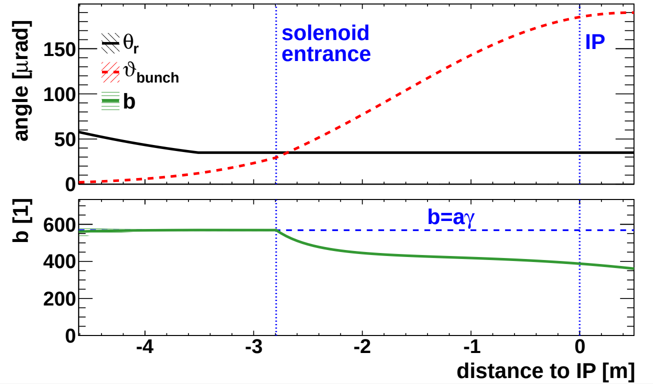
Luminosity

- Design values $1.8(1.5) \cdot 10^{38}\,\mathrm{m}^{-2}\mathrm{s}^{-1}$ (without waist shift)
- Need to improve tuning of grid parameters in GP++
- **Does not change statement of this talk** (effects might just get stronger for higher luminosities)



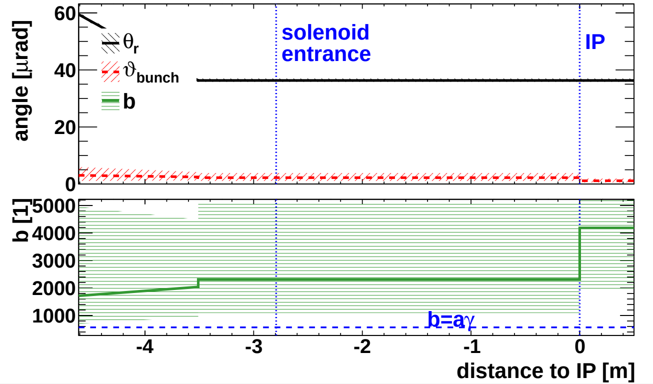
Polarization correction by angle measurement?

- Detector solenoid and anti-DID
- θ_r: angular spread within bunch
- Solenoid field invalidates "$B_\perp$ only" approximation
- Still sharp value for b ($\vartheta_{\text{pol}} = b \cdot \vartheta_{\text{bunch}}$) due to ideal conditions (no misalignments)



Polarization correction by angle measurement?

- This plot without detector magnets
- Small misalignments (2μm / 2μrad) make **correction for incident angle impossible**, since there is no more simple correlation between angles of bunch and polarization vector
- "Steps" due to correction kickers with zero length



Polarization

- Here: **longitudinal** polarization P_z (along beam axis)
- $P_z = p_R - p_L \in [-1, +1]$
- Beam with 90% R (and thus 10% L) $\rightarrow$ 80% longitudinal polarization
- More general: polarization vector $\vec{P} = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$ with polarization $\left|\vec{P}\right|$