Polarisation Measurement and Spin Tracking in the ILC BDS

Jenny List

Linear Collider Workshop 2015

Whistler, November 5, 2015

HELMHOLTZ | ASSOCIATION
ilc
Universität Hamburg DER FORSCHUNG | DER LEHRE | DER BILDUNG
DESY

Take-Home Messages of this Talk.

- The full exploitation of the ILC physics potential requires permille-level knowledge of the luminosity-weighted average polarisations at IP.
- This can only be achieved by the combination of upstream *and* downstream polarimeters with spin-tracking and collision data.
- Fast helicity reversal for *both* beams is essential for controlling systematic uncertainties

Introduction

Collision Data

Spin Tracking

Conclusions and Future Plans

Polarisation for Physics.

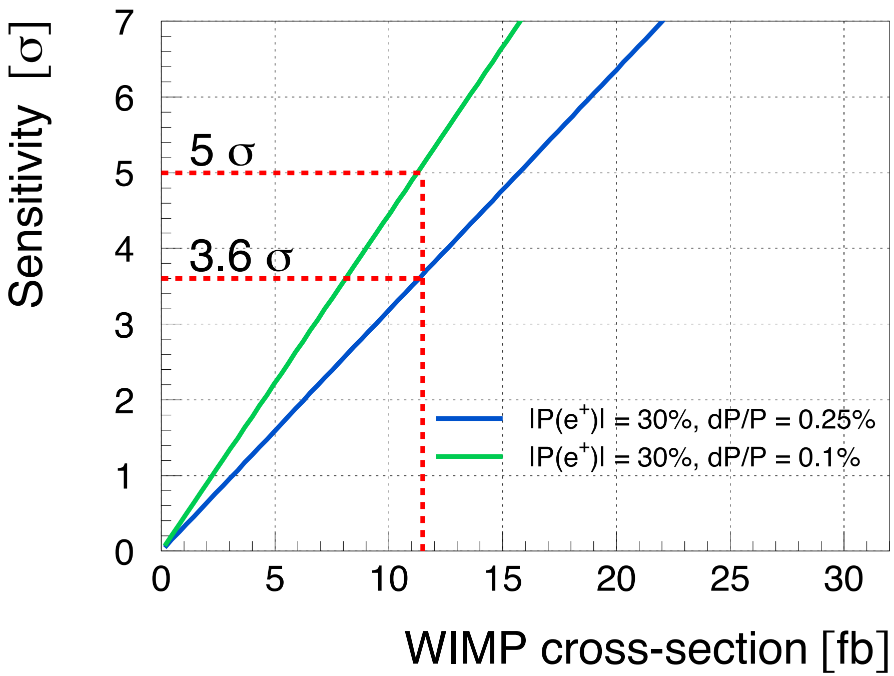
Longitudinal polarisation $P_z = \frac{N_R - N_L}{N_R + N_L}$
with $N_{R,L}$: number of right-/left-handed particles in bunch

- SM & BSM: left- and righthanded particles couple differently
  - polarised cross-sections are important observables carrying qualitatively new information!
  - beam polarisation can suppress background / enhance signal
- wanted for physics: luminosity weighted average polarisation at the IP, $\langle P_z \rangle_{IP} = \frac{\int P_z(t)\mathcal{L}(t)dt}{\int \mathcal{L}(t)dt}$
- Note: most physics studies sofar assume this average is known exactly and independently for e^- and e^+ beam.

$P \equiv P_z$ in the following.

Impact of Polarisation Uncertainty.

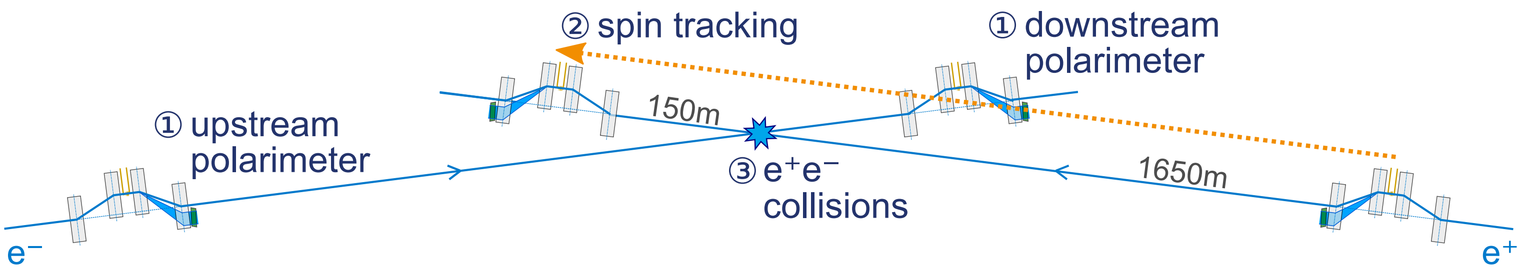
- SM precision measurements, eg. A_{LR} at Z pole will be limited by polarisation knowledge
  $\rightarrow$ simultaneous extraction of A_{LR} and $\langle P_{\text{eff}} \rangle_{IP}$
- BSM example: WIMP Dark Matter Search



- 500 fb^{-1} at 500 GeV, $|P(e^-, e^+)| = (0.8, 0.3)$
- ILD full simulation incl. systematics
- $dP/P = 0.25\%$ $\rightarrow$ “evidence for“
- $dP/P = 0.1\%$ $\rightarrow$ “discovery of“

Polarimetry concept for the ILC.

Goal for ILC polarimetry: per mille level precision by combining



① Compton polarimeter measurements upstream and downstream of the e^+e^- interaction point

② Spin tracking to relate these measurements to the polarization at the e^+e^- interaction point

③ Long-term average determined from e^+e^- collision data as absolute scale calibration

Introduction

Collision Data

Spin Tracking

Conclusions and Future Plans

Polarisation Average from Collision Data.

Direct extraction from collision data

- any abundant, well-known, polarisation dependent process:
- $\langle| P_{e^{\pm}} |\rangle_{IP} = \sqrt{\frac{(\sigma_{-+}+\sigma_{+-}-\sigma_{--}-\sigma_{++})(\pm\sigma_{-+}\mp\sigma_{+-}+\sigma_{--}-\sigma_{++})}{(\sigma_{-+}+\sigma_{+-}+\sigma_{--}+\sigma_{++})(\pm\sigma_{-+}\mp\sigma_{+-}-\sigma_{--}+\sigma_{++})}}$
- σ_{+-} is total cross-section for $P(e^-, e^+) = (+x\%, -y\%)$, etc.
- assumes $P_+(e^-) = -P_-(e^-)$ and $P_+(e^+) = -P_-(e^+)$

Methods studied so far

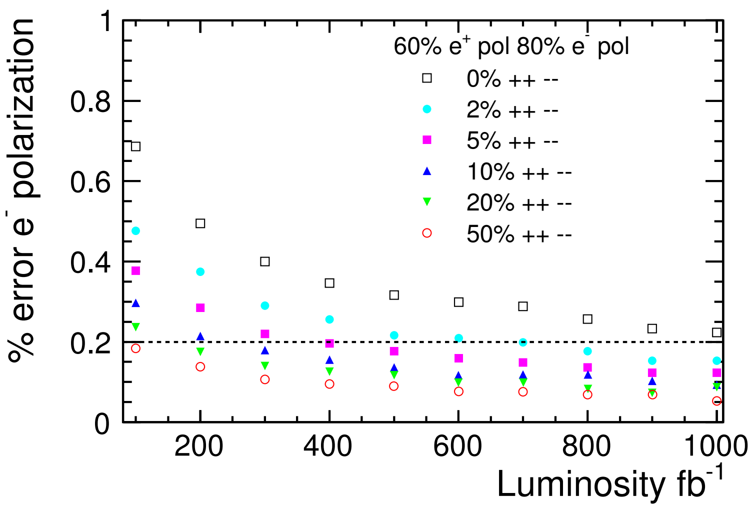
- total cross-sections: *WW* at 500 GeV and 1 TeV (ILD)
  single *W* etc at 3 TeV (CLIC)
- single-differential cross-sections: *WW* at 500 GeV & 1 TeV (ILD)
- double-differential cross-sections: *WW* at 1 TeV (SiD)

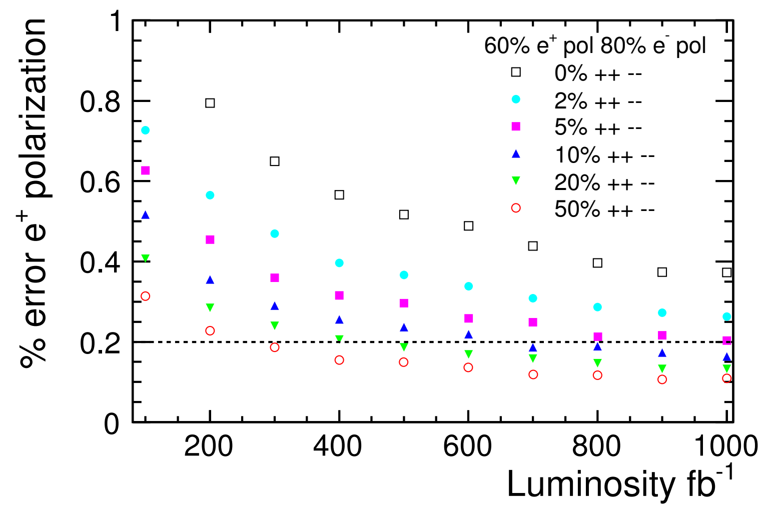
Luminosity Sharing.

How much running time needed for $++$ and $--$?

- like-sign combinations less interesting for SM phyics
- 10% to 20% like-sign lumi rather close to optimum (50%)
- even 2% halfs already total lumi needed for 0.2% precision

Example: *WW* at $\sqrt{s} = 500\,\text{GeV}$ (ILD)





Unequal Absolute Polarisation Values.

What happens if $P_+(e^-) \neq -P_-(e^-)$ and $P_+(e^+) \neq -P_-(e^+)$?

Measure enough cross-sections to determine all polarisations:

- eg single W,Z,γ with $++$, $--$, $+-$, $-+$, $+0$, -0, $0+$, $0-$
- precision significantly worse than for equal $|P|$ assumption

[cf. G. Wilson, LCWS 2012]

Assume $|P|$ equal up to $2\epsilon^{\pm}$ – measure $\epsilon^{\pm}$with polarimeters:

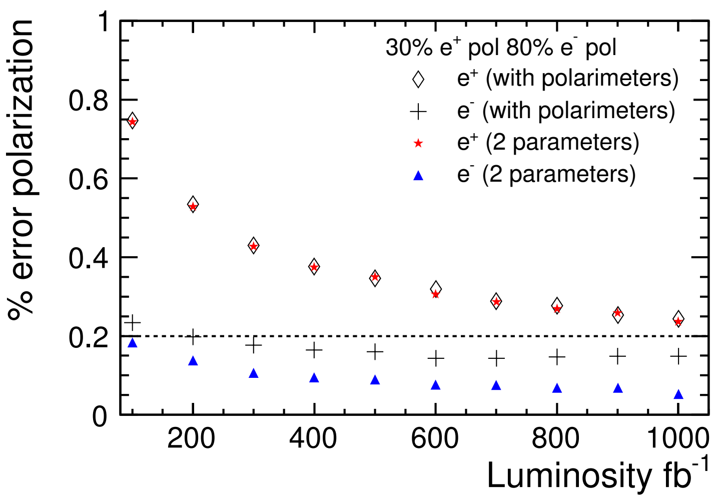
- $P_+(e^{\pm}) = P^{\pm} + \epsilon^{\pm}$ and $P_-(e^{\pm}) = P^{\pm} - \epsilon^{\pm}$
- $\delta P_+(e^{\pm})$ (or δA_{LR}) same order of magnitude as $\delta\epsilon^{\pm}$ and $\epsilon^{\pm}$

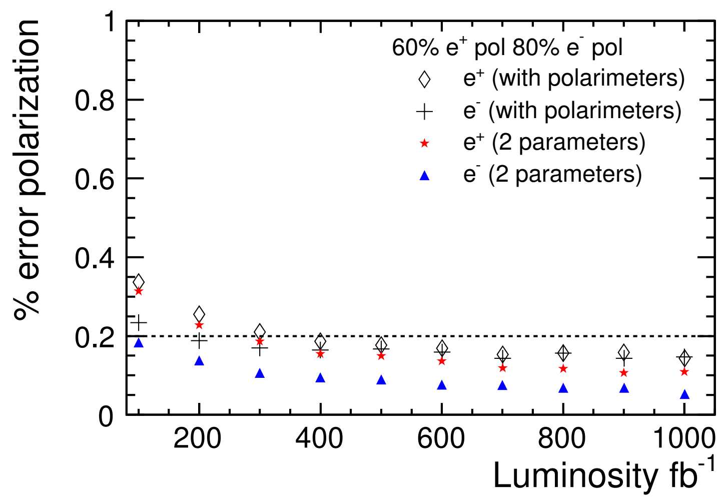
$\Rightarrow$ need to ensure that $\epsilon^{\pm}$ and $\delta\epsilon^{\pm}$ are small!

Impact of Polarimeter Precision.

Controlling $\delta\epsilon$

- let all P vary independently $\Rightarrow$ $\delta P/P$ in *percent* regime!
- this damages physics potential (e.g. Triple Gauge Couplings)
- better: correct difference by polarimeter measurements up to $\pm\delta P/P|_{pol} = 0.25\%$
- negligible impact on TGCs
- but: limits ultimate precision on $\langle P(e^-)\rangle_{IP}$!





Fast helicity reversal: Controlling ϵ.

... for both beams:

- collect data for all helicity configurations ”simultaneously”
- ensures similar polarisation (absolute) values for all data sets (small ϵ)
- enables cancellation of time dependent effects / systematic uncertainties for collider detector!

Counter example HERA:

- slow helicity reversal: weeks between flips
- differences in $\langle P_e \rangle_{IP}$: rely on polarimeters
- uncertainty $\sim 2\%$

Collisions	$P_e[\%]$	$\mathcal{L}[\mathrm{pb}^{-1}]$
e^+p	+32	98
e^+p	-38	82
e^-p	+37	46
e^-p	-26	103

Phys. Lett. B704 (2011) 388 [arxiv:1107.3716] (H1 Leptoquarks)

Fast helicity reversal: Controlling ϵ.

What does "fast" mean?

- much faster than typical period over which conditions are stable
- e.g. subdetector trips
- e.g. drifts of calibration
- e.g. changes in collision parameters, background levels

$\Rightarrow \simeq$ **train-by-train**

Solutions?

- two parallel spin rotation sections (c.f. release notes 2015a lattice)
- will they have identical field integrals etc? (ϵ!)
- alternative: could normal conducting magnets be fast enough?
- or: combining both???

Conclusions sofar.

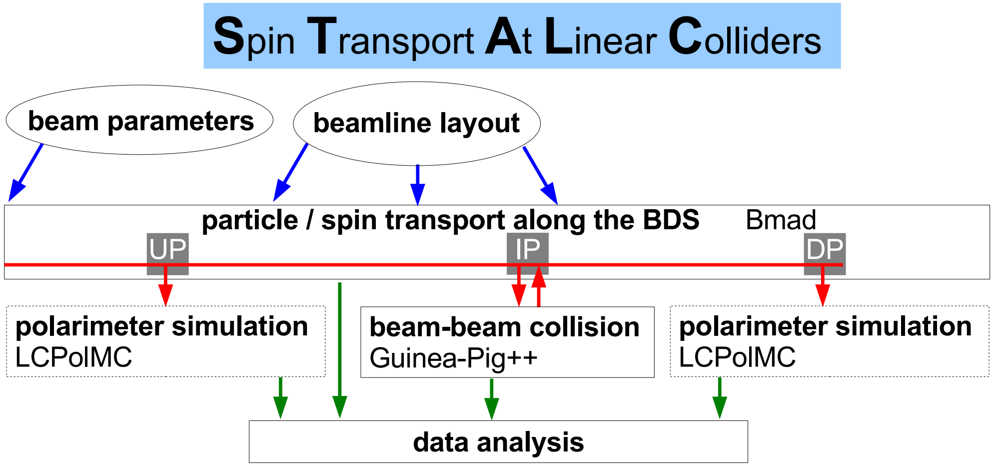
Polarisation Measurement from Collision Data:

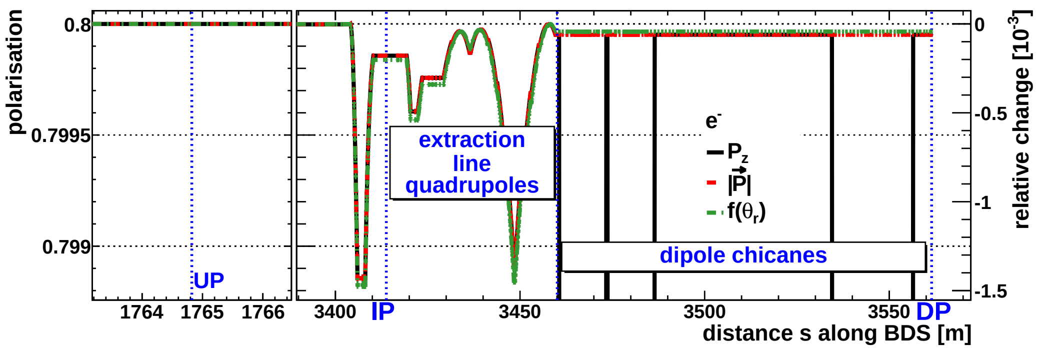
- important long-term scale calibration for $\langle P_z \rangle_{IP}$
- but relies on
  - **fast helicity reversal for both beams**
  - permille-level polarimetry to correct residual deviation from $|P_+(e^{\pm})| = |P_-(e^{\pm})|$
- for ultimate precision: 10% to 20% like-sign luminosity

Spin Tracking in BDS and Extraction Line.

Based on SB2009-Nov10 lattice (PhD Thesis M.Beckmann)

- developed simulation framework STaLC
- without collisions
  ⇒ cross-calibration of polarimeters
- with collisions
  ⇒ what does the downstream polarimeter measure?





Cross-calibration of Polarimeters.

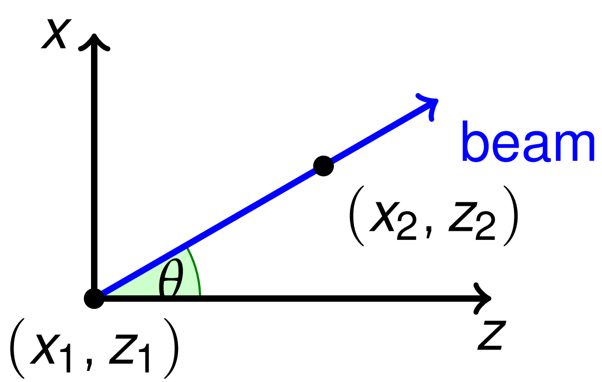
Without Collisions:
predict value at downstream location from upstream measurement

	effect on $P[10^{-3}]$
Beam and detector alignment at polarimeters ($\Delta\theta_{bunch} = 50\,\mu rad$, $\Delta\theta_{pol} = 25\,\mu rad$)	0.72
Variation in emittances	0.03
Crabbing	< 0.01
Detector magnets	0.01
Emission of synchrotron rad.	0.005
random misalignments (10 µm)	0.35
Total	0.80

Beam alignment.

Precision of Polarimeter Cross-Calibration

- is dominated by relative angle between beam directions at UP/DP $\Delta\theta_{bunch}$
- need *pairs* of BPMs at UP, IP and DP $\Rightarrow$ “local” angle
- $\Delta x = 7\,\mu$m, distance along $z =$ a few meters $\Rightarrow 1-2\,\mu$rad
- challenge: absolute reference over $\simeq 2$ km
  $\Rightarrow$ is 50 μrad a realistic number?



$$\theta \approx \frac{x_2 - x_1}{L}; \quad L := z_2 - z_1; \quad L = 8m$$

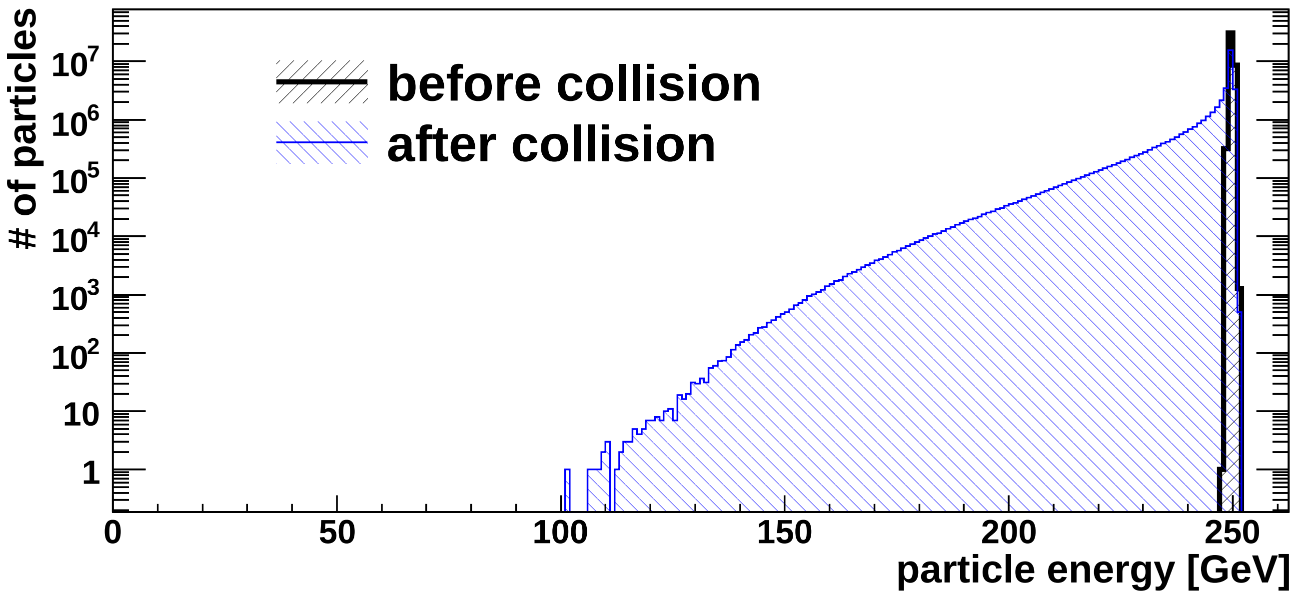
$$\Delta x_i = \Delta y_i = 7\,\mu m; \quad \Delta L \simeq 0$$

$$\Rightarrow \Delta\theta^2 \leq \underbrace{2\left(\frac{\Delta x_i}{L}\right)^2 + 2\left(\frac{\Delta y_i}{L}\right)^2}_{:=(\Delta\theta_{BPM})^2} + \underbrace{\left(\frac{\theta\Delta L}{L}\right)^2}_{:=(\Delta\theta_L)^2}$$

$$\Rightarrow \Delta\theta \simeq 1.7\mu rad$$

Beam Energy Spectrum with Collisions.

GuineaPig++, RDR nominal, $\sqrt{s} = 500\,\text{GeV}$

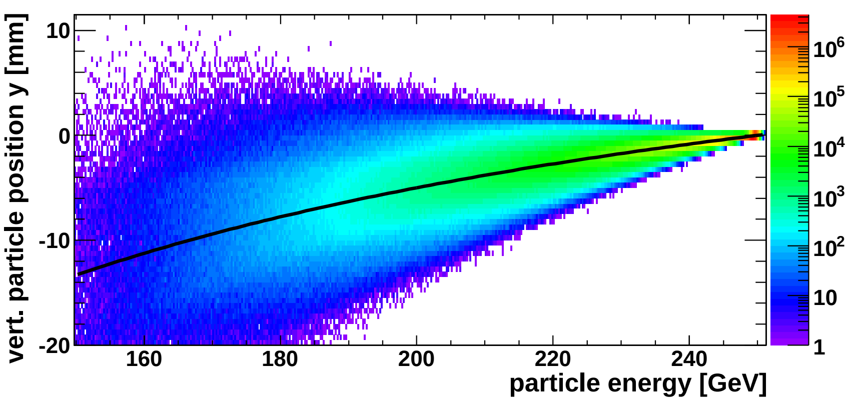


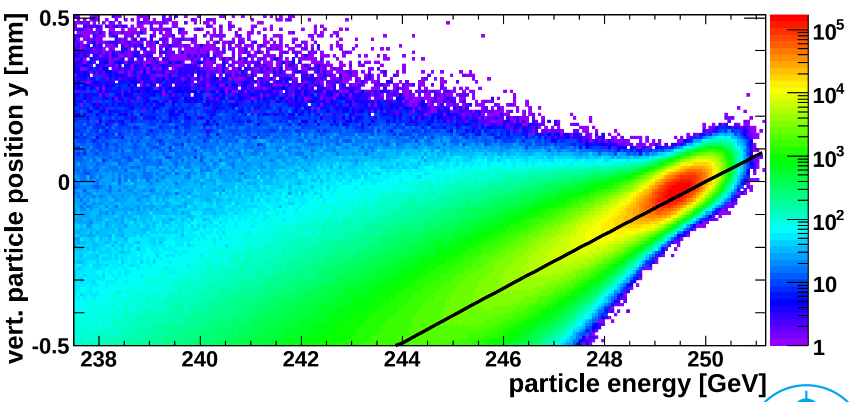
How will this influence the measurement at the downstream polarimeter?

y vs E at DP IP.

Particle Tracking through SB2009-Nov10 lattice (M.Beckmann)

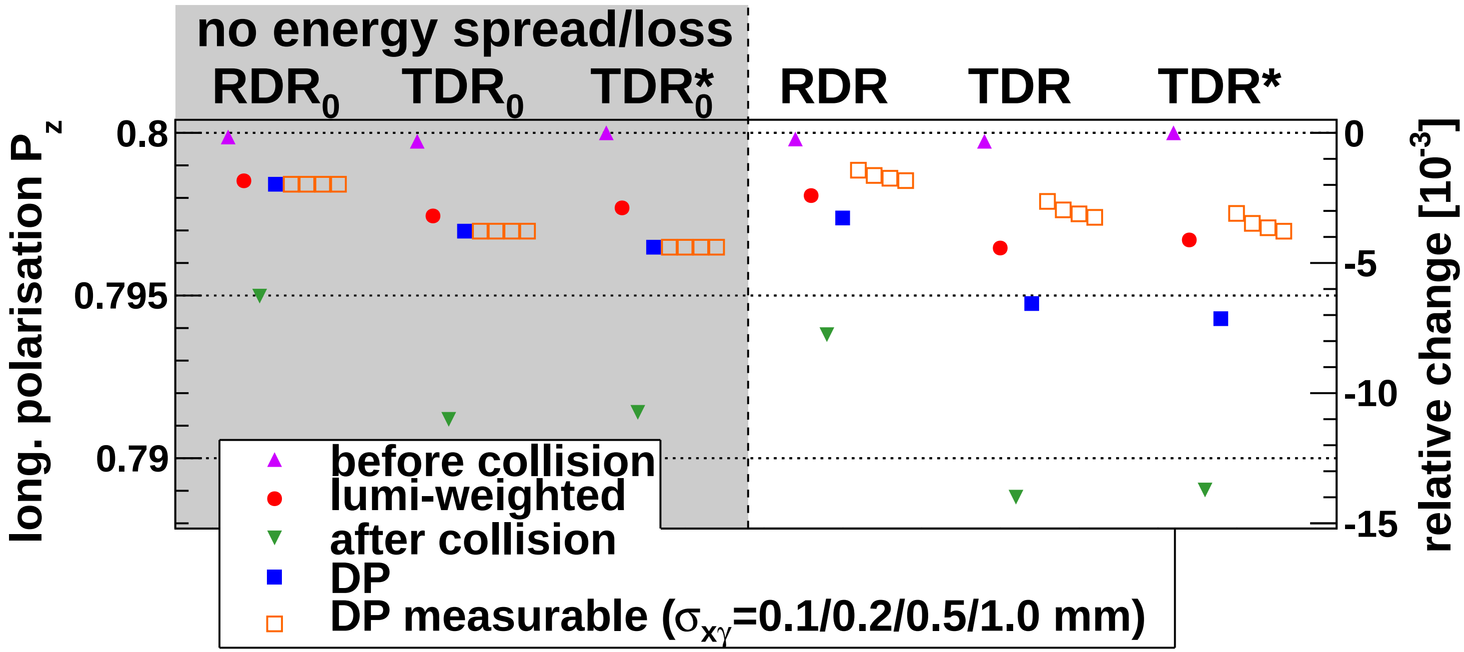
- vertical extension of spent beam at DP IP $\mathcal{O}$(cm)
- “core” size still $\simeq$ 0.5 mm
- sizable correlation of energy and position
- which part will the laser sample?
- expect dependence of measured polarisation on laser spot size and laser-beam alignment





Collision Effects & Downstream Polarimeter.

- Extraction line optics designed to retrieve $\langle P \rangle_{IP}$ at downstream polarimeter
- Confirmed by STaLC w/o beamstrahlung (energy loss, grey background)
- With beamstrahlung: few permille difference to $\langle P \rangle_{IP}$
- Measured polarisation depends on laser spot size (here: perfect centering!)
- Effect doubles from RDR $\to$ TDR parameters



Conclusions Spin Tracking.

In the presence of significant Beamstrahlung:

- Downstream polarimeter does *not* measure directly any more $\langle P \rangle_{IP}$
- difference DP measurement vs $\langle P \rangle_{IP}$ depends on
  - laser spot size & position
  - luminosity ($\simeq$ energy loss in collision)
- $\Rightarrow$ correcting for this requires
  - absolute reference from upstream polarimeter
  - luminosity & beam parameter monitoring
  - long-term scale of $\langle P \rangle_{IP}$ from collision data

Introduction

Collision Data

Spin Tracking

Conclusions and Future Plans

Conclusions.

Permille-level precision on lumi-weighted average polarisation at IP required by physics, needs combination of

- long-term scale calibration from e^+e^- collision data (fast helicity reversal!)
- upstream (UP) and downstream (DP) polarimeters
  - **UP**: time resolution, absolute reference
  - **DP**: collision effects
  - **combined**: cross-calibration, lumi-weighted polarisation @ IP
- spin tracking and understanding of collision effects

Compton Polarimeters:

- beam-detector alignment & detector linearity crucial
- R&D well underway, requirements $\simeq$ reached in prototypes
- cross-calibration without collisions: $\sim 0.1\%$ from alignment
  - esp. orbit and spin at UP and DP locations (2 km apart)

Next Steps (provided person power).

Polarisation from collision data:

- systematic evaluation of various approaches $\rightarrow$ combination?
- implementation of fast helicity reversal for positron beam?

Luminosity-weighted average polarisation:

- collision effects with TDR beam parameters and *new* lattice
- how to combine polarimeter measurements, luminosity measurement and collision data?

Realisation:

- site specific misalignments, ground motion etc
- revisit laser systems (site specific, new laser technologies...)
- BPMs, long-distance alignment?
- design chicane magnets and vacuum chamber (wide!)

More Details.

- E&P workshop Zeuthen 2008

  http://indico.desy.de/conferenceDisplay.py?confId=585

- its Executive Summary

  arXiv:0903.2959 [physics.acc-ph]

- downstream polarimeter 6-magnet chicane

  http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-12425.pdf

- publication on beam energy and polarisation measurements

  JINST **4** (2009) P10015, arXiv:0904.0122 [physics.ins-det]

- publications on polarimeter detector R&D:

  JINST **7** (2012) P01019, arXiv:1011.6314 [physics.ins-det]

  JINST **10** (2015) P05014, arXiv:1502.06955 [physics.ins-det]

  arXiv:1509.03178 [physics.ins-det], DESY-15-170

- publication on BDS spin tracking

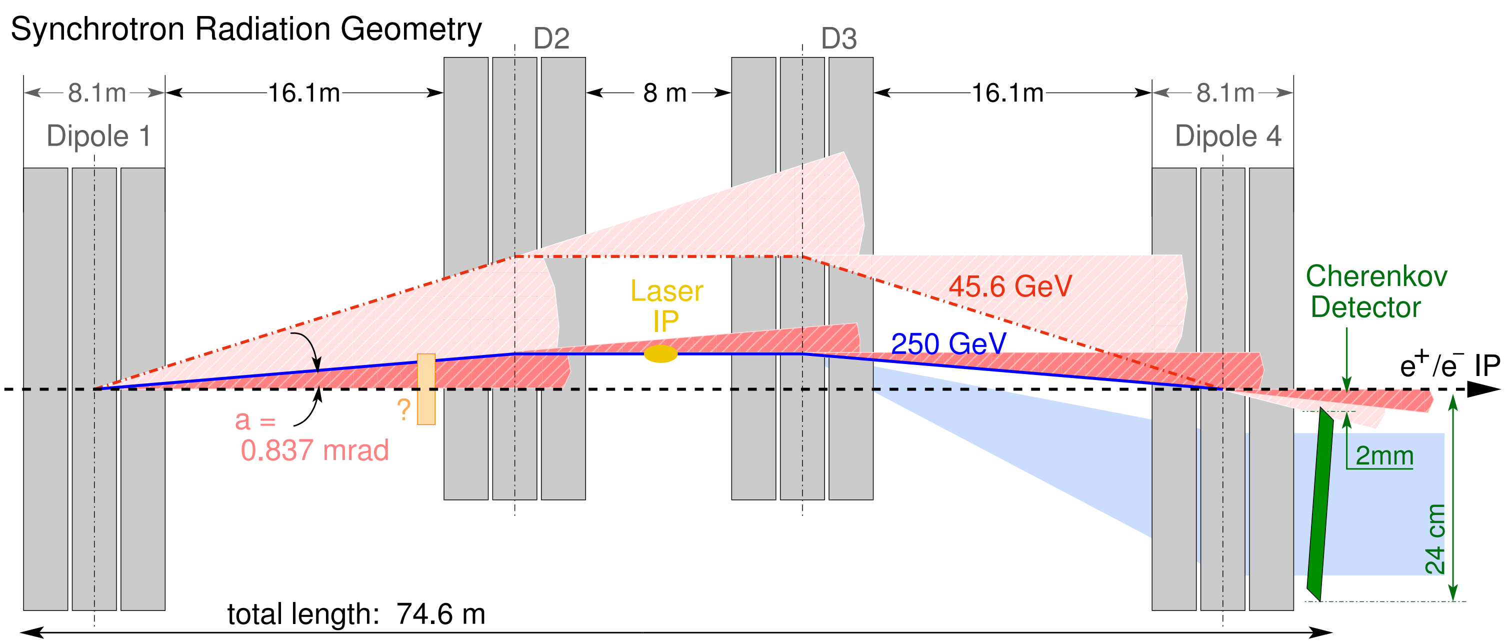
  JINST **9** (2014) P07003, arXiv:1405.2156 [physics.acc-ph]

Backup Slides .

For historic information: Recommendations to GDE and Research Director (2008).

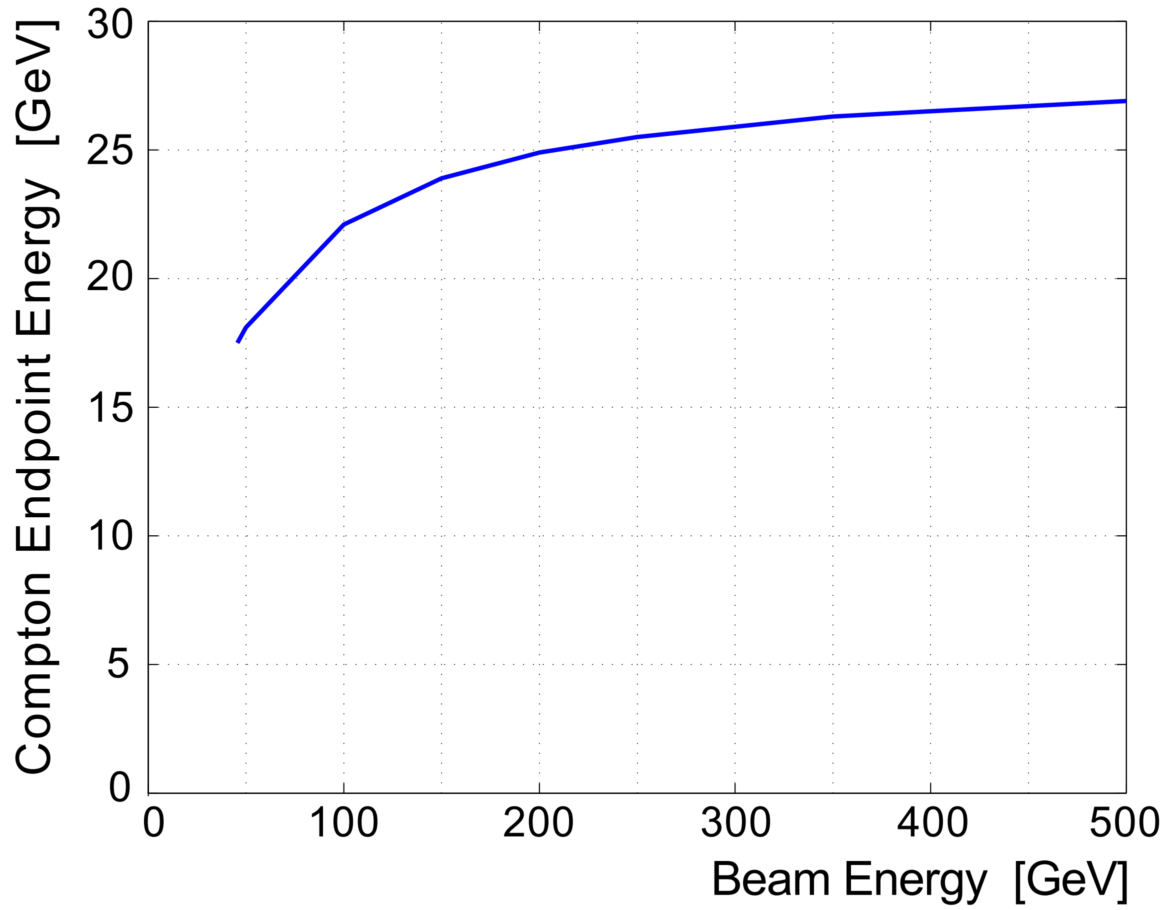
- Separate the functions of the upstream polarimeter chicane. Do not include an MPS energy collimator or laser-wire emittance diagnostics; use instead a separate setup for these two.
- Modify the extraction line polarimeter chicane from a 4-magnet chicane to a 6-magnet chicane to allow the Compton electrons to be deflected further from the disrupted beam line.
- Include precise polarisation and beam energy measurements for ***Z***-pole calibration runs into the baseline configuration.
- Keep an initial positron polarisation of 30-45% for physics, don't reduce to 22% .
- Implement parallel spin rotator beamlines with a kicker system before the damping ring to provide rapid helicity flipping of the positron spin.
- Move the pre-DR positron spin rotator system from 5 GeV to 400 MeV. This eliminates expensive superconducting magnets and reduces costs.
- Move the pre-DR electron spin rotator system to the source area. This eliminates expensive superconducting magnets and reduces costs.

Synchrotron Radiation.

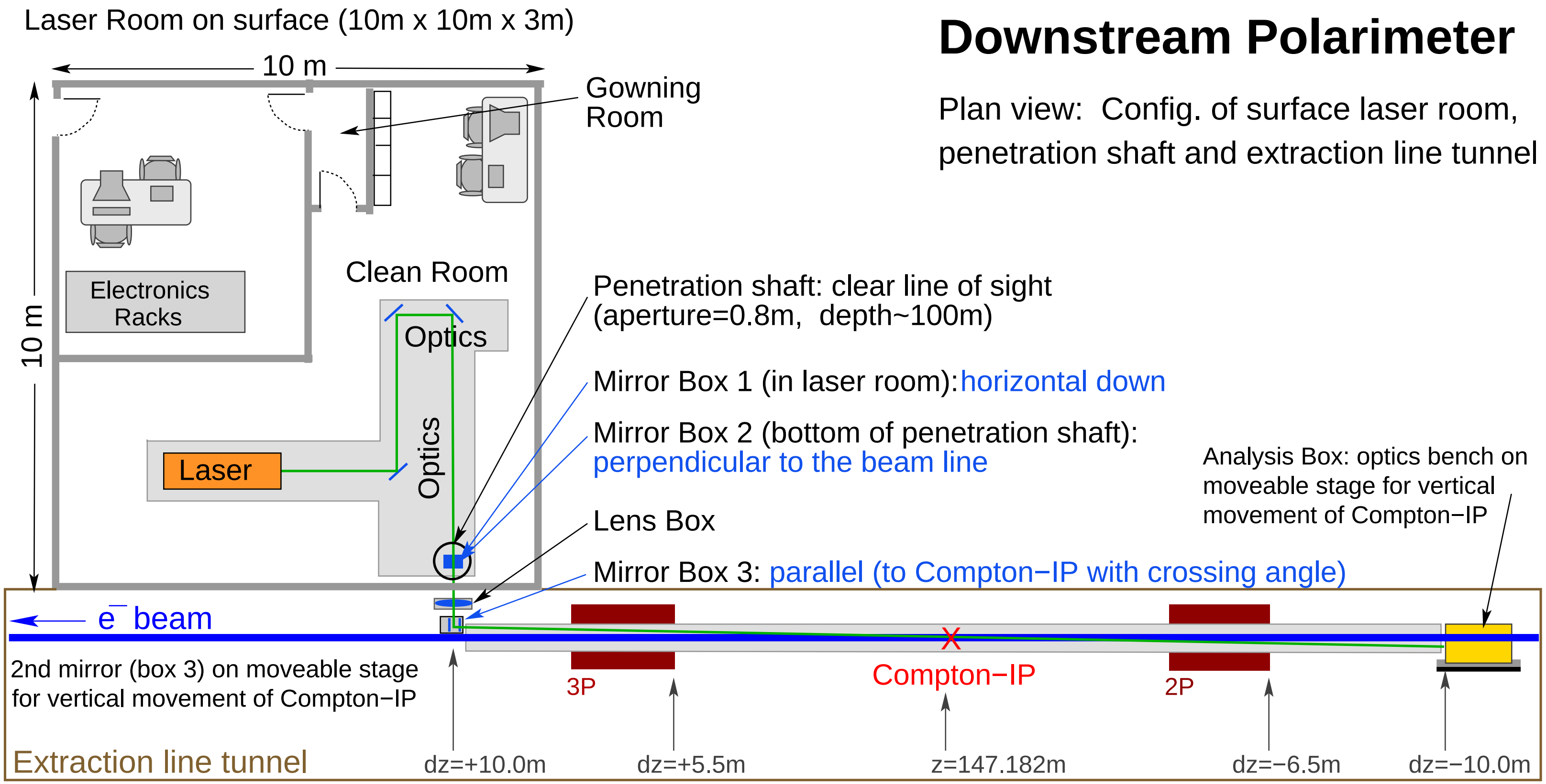


Compton edge.

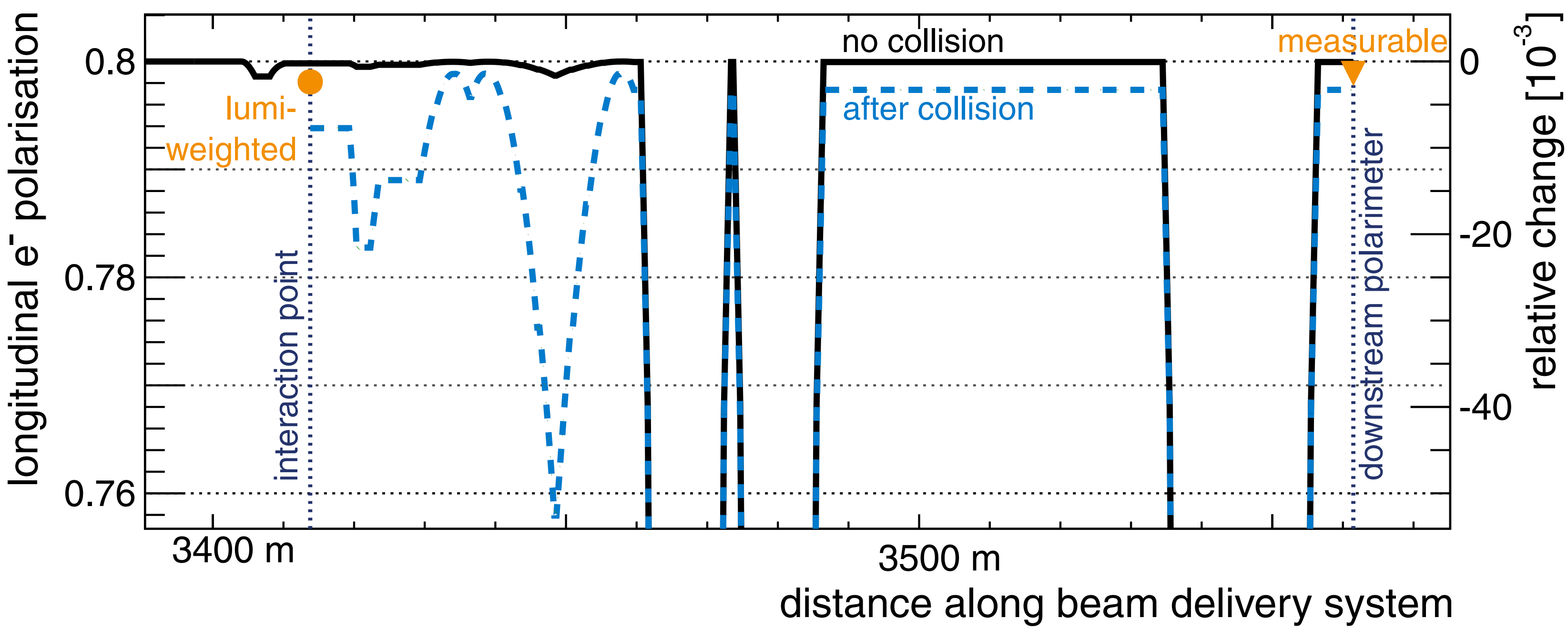
Compton edge position nearly independent of beam energy



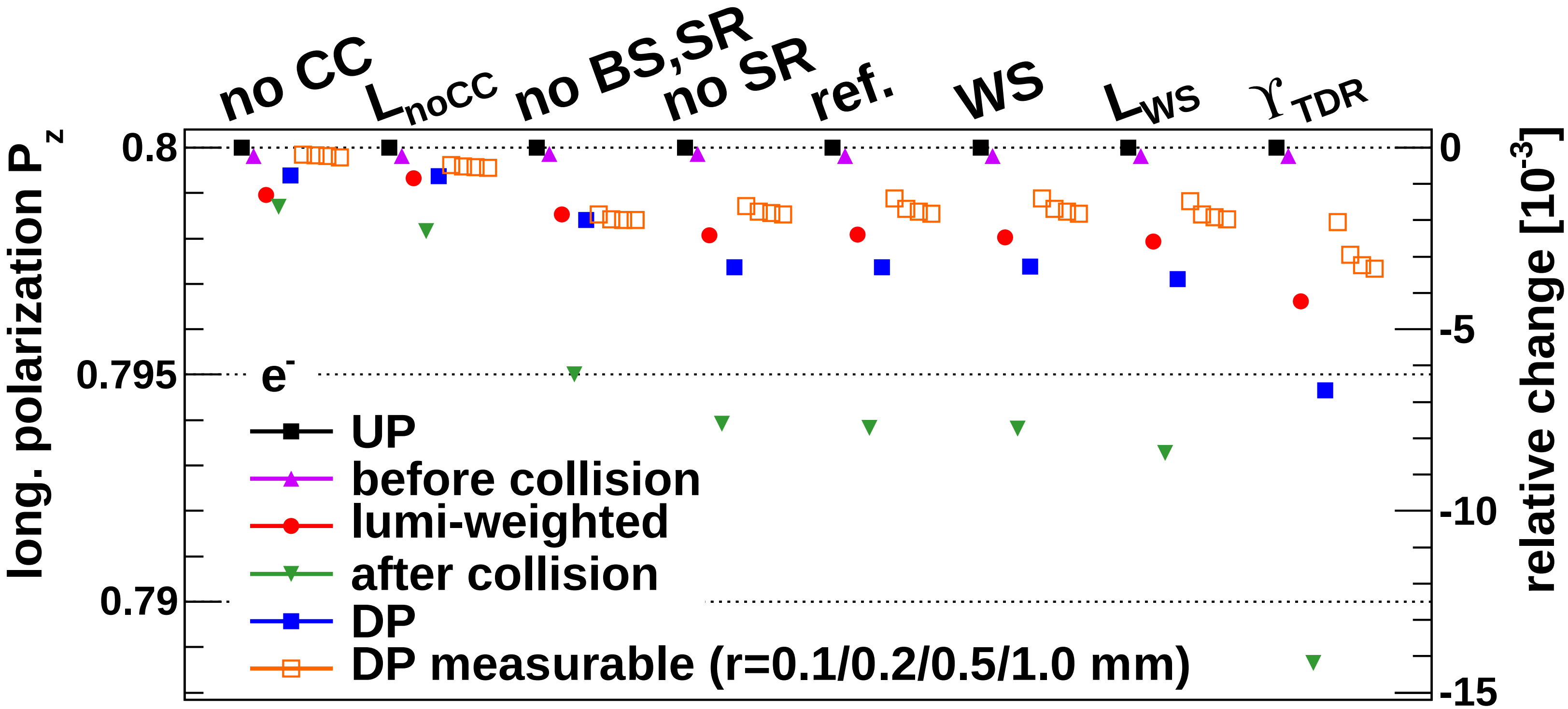
Laser Room.


Laser Room on surface (10m x 10m x 3m)
10 m
10 m
Gowning Room
Electronics Racks
Clean Room
Optics
Optics
Laser
Downstream Polarimeter
Plan view: Config. of surface laser room, penetration shaft and extraction line tunnel
Penetration shaft: clear line of sight (aperture=0.8m, depth~100m)
Mirror Box 1 (in laser room): horizontal down
Mirror Box 2 (bottom of penetration shaft): perpendicular to the beam line
Analysis Box: optics bench on moveable stage for vertical movement of Compton−IP
Lens Box
Mirror Box 3: parallel (to Compton−IP with crossing angle)
e⁻ beam
2nd mirror (box 3) on moveable stage for vertical movement of Compton−IP
3P
Compton−IP
2P
Extraction line tunnel
dz=+10.0m
dz=+5.5m
z=147.182m
dz=−6.5m
dz=−10.0m

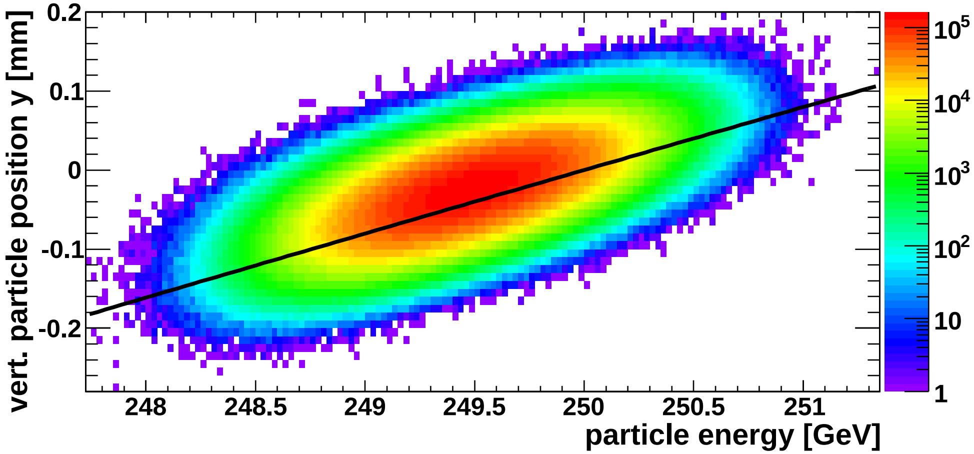
Spin transport.

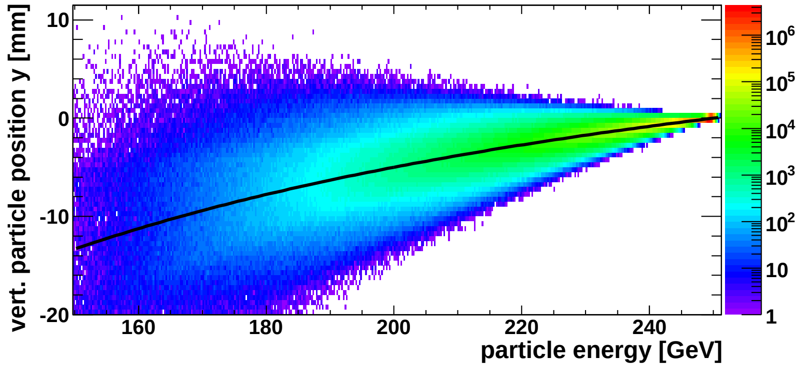


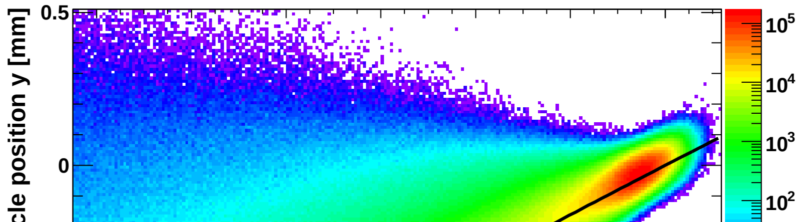
Spin tracking (more).



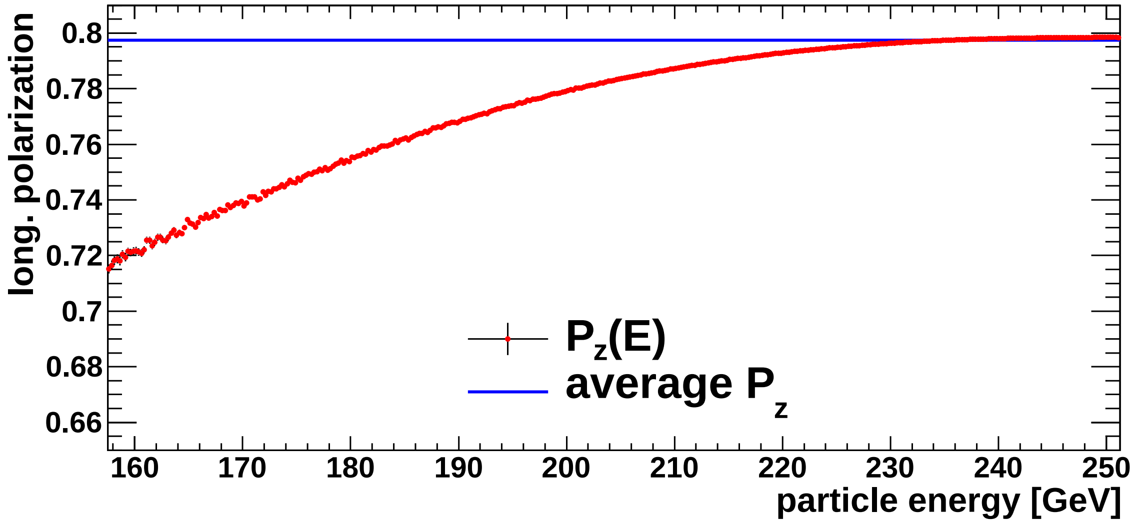
Downstream Polarimeter: y vs E.

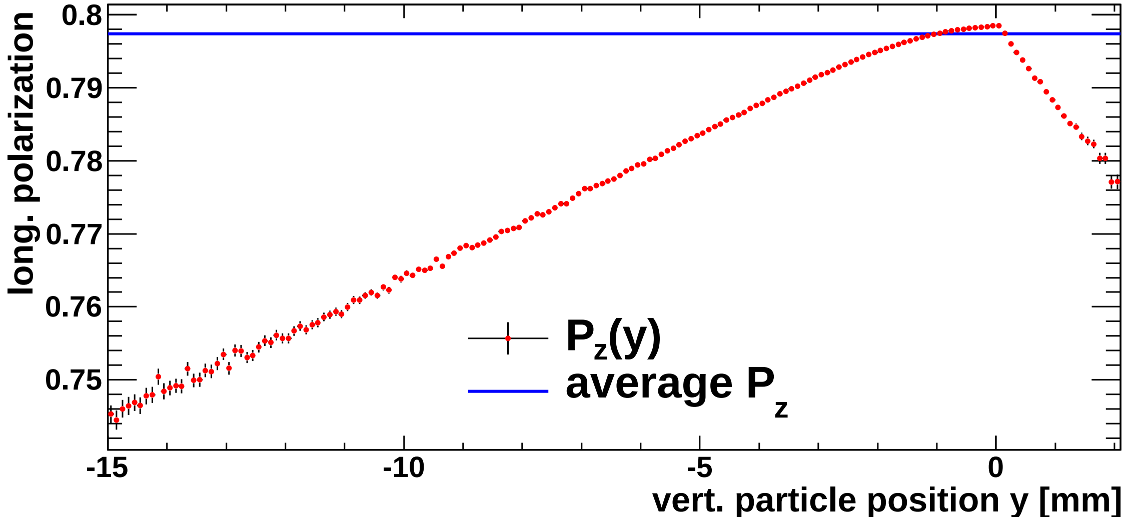




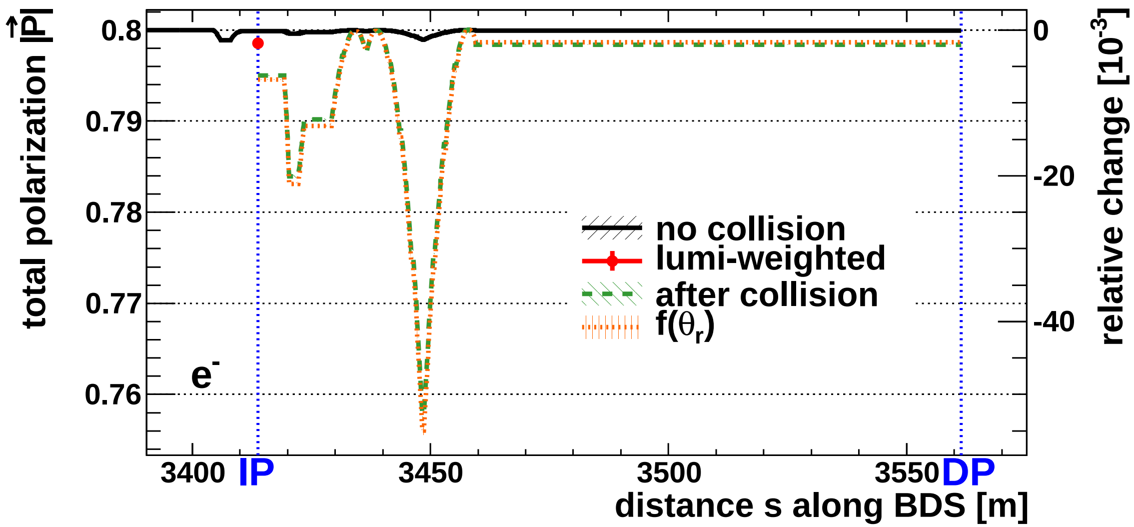


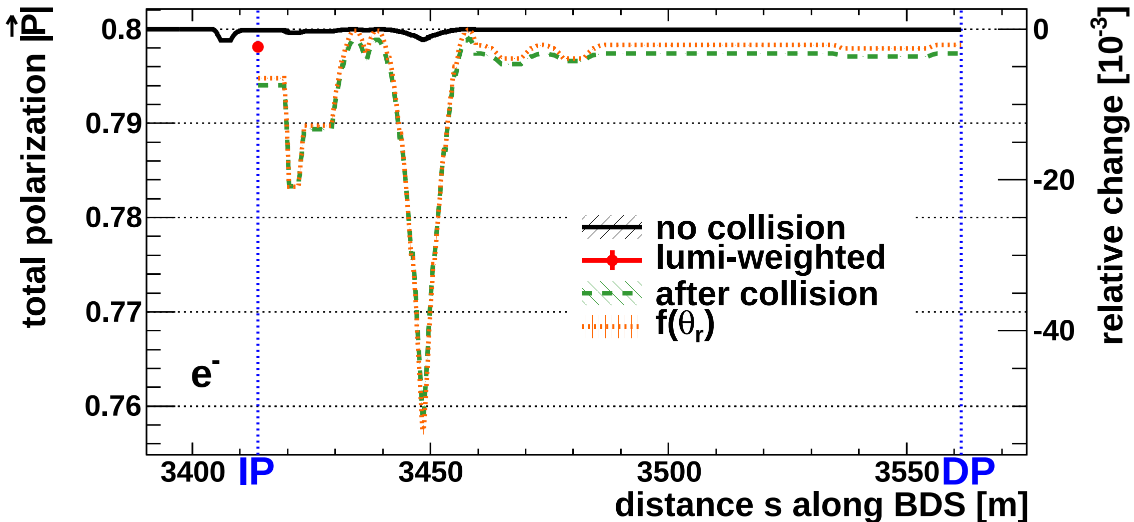
Downstream Polarimeter: P_Z vs E, P_Z vs y.





Total Polarisation IP → DP.





Polarised Cross-sections.

$$\sigma_{P_{e^-} P_{e^+}} = \frac{1}{4} \quad \{ \quad (1+P_{e^-})(1+P_{e^+})\sigma_{RR} + (1-P_{e^-})(1-P_{e^+})\sigma_{LL}$$
$$+ \quad (1+P_{e^-})(1-P_{e^+})\sigma_{RL} + (1-P_{e^-})(1+P_{e^+})\sigma_{LR}\}$$

processes with s-channel Z/γ exchange only:

- $\sigma_{RR} = \sigma_{LL} = 0$
- $4\sigma_{P_{e^-} P_{e^+}} = (1 - P_{e^-} P_{e^+})(\sigma_{LR} + \sigma_{RL})[1 - P^-_{\mathrm{eff}} A_{LR}]$
- with $P^-_{\mathrm{eff}} = 1 - \frac{P_{e^-} - P_{e^+}}{1 - P_{e^-} P_{e^+}}$ and $A_{LR} = \frac{\sigma_{LR} - \sigma_{RL}}{\sigma_{LR} + \sigma_{RL}}$

general case:

- $\sigma_{RR} \neq \sigma_{LL} \neq 0$
- $4\sigma_{P_{e^-} P_{e^+}} = (1 + P_{e^-} P_{e^+})(\sigma_{LL} + \sigma_{RR})[1 + P^+_{\mathrm{eff}} A_{LLRR}]$ + above
- with $P^+_{\mathrm{eff}} = 1 + \frac{P_{e^-} + P_{e^+}}{1 + P_{e^-} P_{e^+}}$ and $A_{LLRR} = \frac{\sigma_{LL} - \sigma_{RR}}{\sigma_{LL} + \sigma_{RR}}$

Polarisation Averages.

Absolute cross-section measurements require:

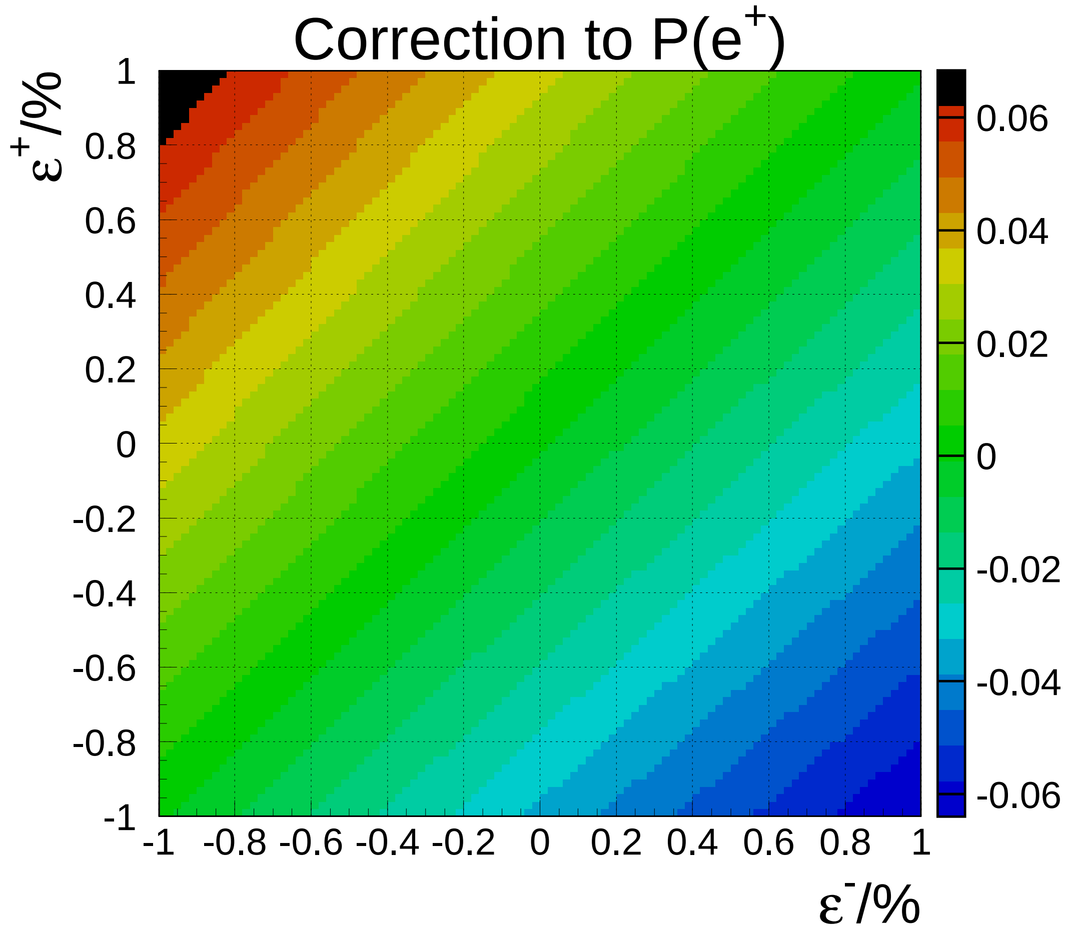
- $\langle P_{e^\pm} \rangle_{IP} = \frac{\int P_{e^\pm}(t)\mathcal{L}(t)dt}{\int \mathcal{L}(t)dt}$
- $\langle P_{e^-} P_{e^+} \rangle_{IP} = \frac{\int P_{e^-}(t)P_{e^+}(t)\mathcal{L}(t)dt}{\int \mathcal{L}(t)dt}$
- correlations between lumi and polarisation?!

Direct extraction from collision data

- any abundant, well-known, polarisation dependent process:
- $\langle | P_{e^\pm} | \rangle_{IP} = \sqrt{\frac{(\sigma_{-+} + \sigma_{+-} - \sigma_{--} - \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} + \sigma_{--} - \sigma_{++})}{(\sigma_{-+} + \sigma_{+-} + \sigma_{--} + \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} - \sigma_{--} + \sigma_{++})}}$
- σ_{+-} is total cross-section for $P(e^-, e^+) = (+x\%, -y\%)$, etc.
- assumes $P_+(e^-) = -P_-(e^-)$ and $P_+(e^+) = -P_-(e^+)$

Correction to modified Blondel scheme.

$$P_+(e^\pm) = P^\pm + \epsilon^\pm \text{ and } P_-(e^\pm) = P^\pm - \epsilon^\pm$$

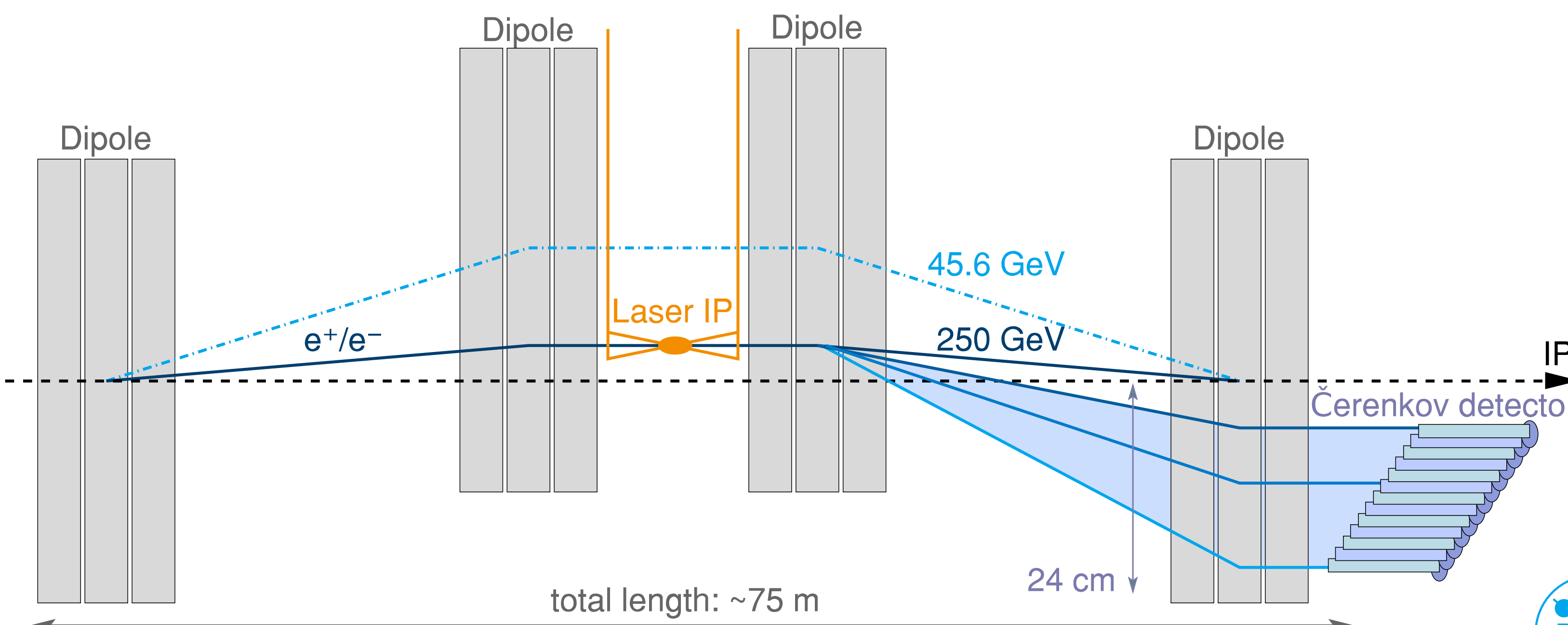


Compton Polarimeters

- Basics
- Upstream Polarimeter
- Downstream Polarimeter

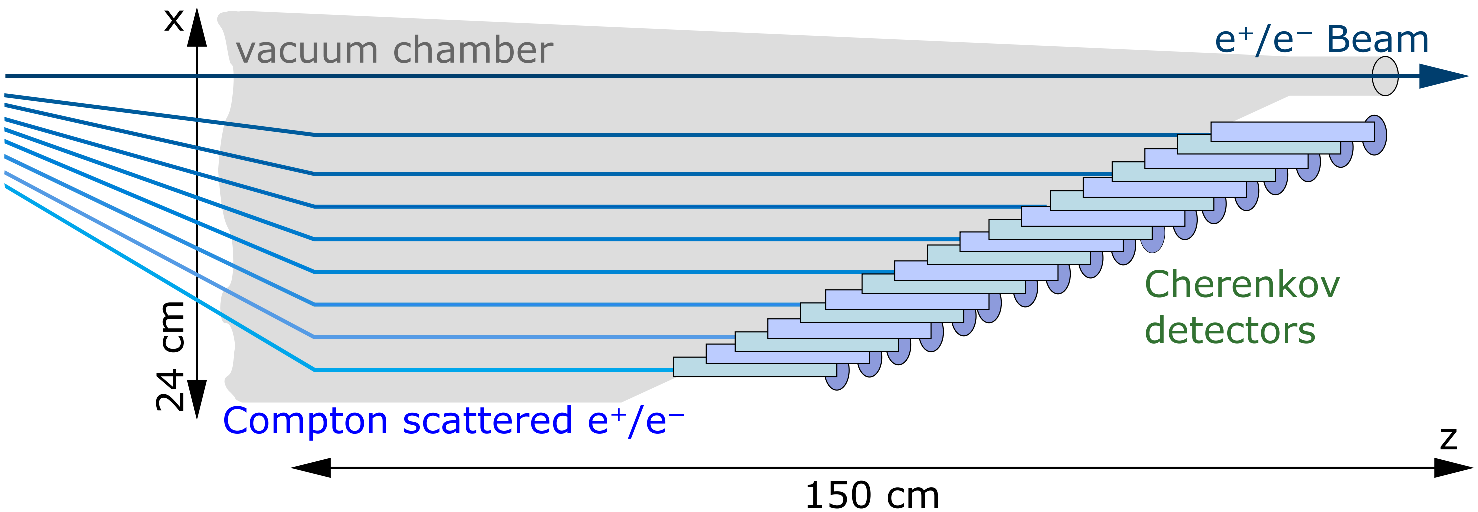
Compton polarimetry.

- fast measurement: $\mathcal{O}(10^3)$ Compton scatterings/bunch
- Energy spectrum of scattered e^+/e^- depends on product of lepton ($\mathcal{P}$) and laser (λ) polarisations
- Magnetic chicane: energy distibution $\rightarrow$ position distribution
- Measure number of e^+/e^- per detector channel



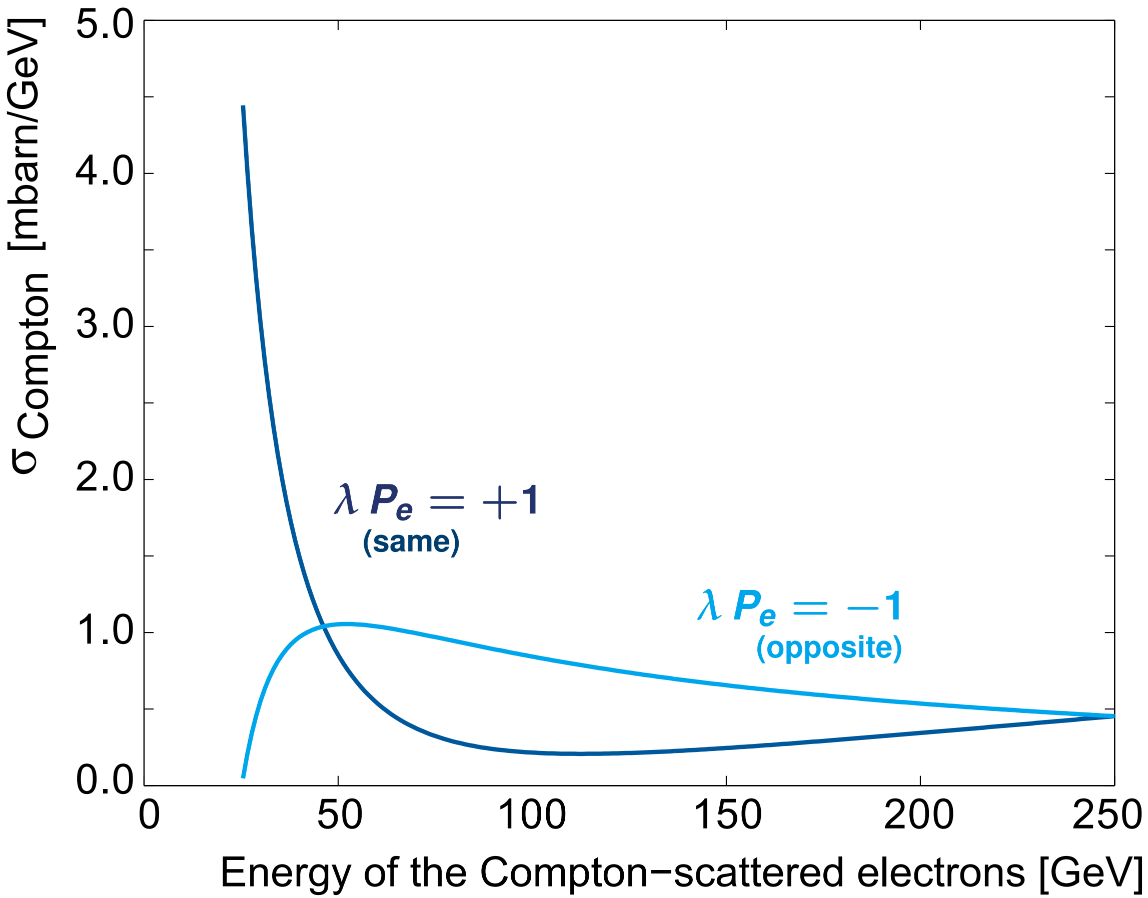
Compton polarimetry.

- fast measurement: $\mathcal{O}(10^3)$ Compton scatterings/bunch
- Energy spectrum of scattered e^+/e^- depends on product of lepton ($\mathcal{P}$) and laser (λ) polarisations
- Magnetic chicane: energy distibution $\rightarrow$ position distribution
- Measure number of e^+/e^- per detector channel



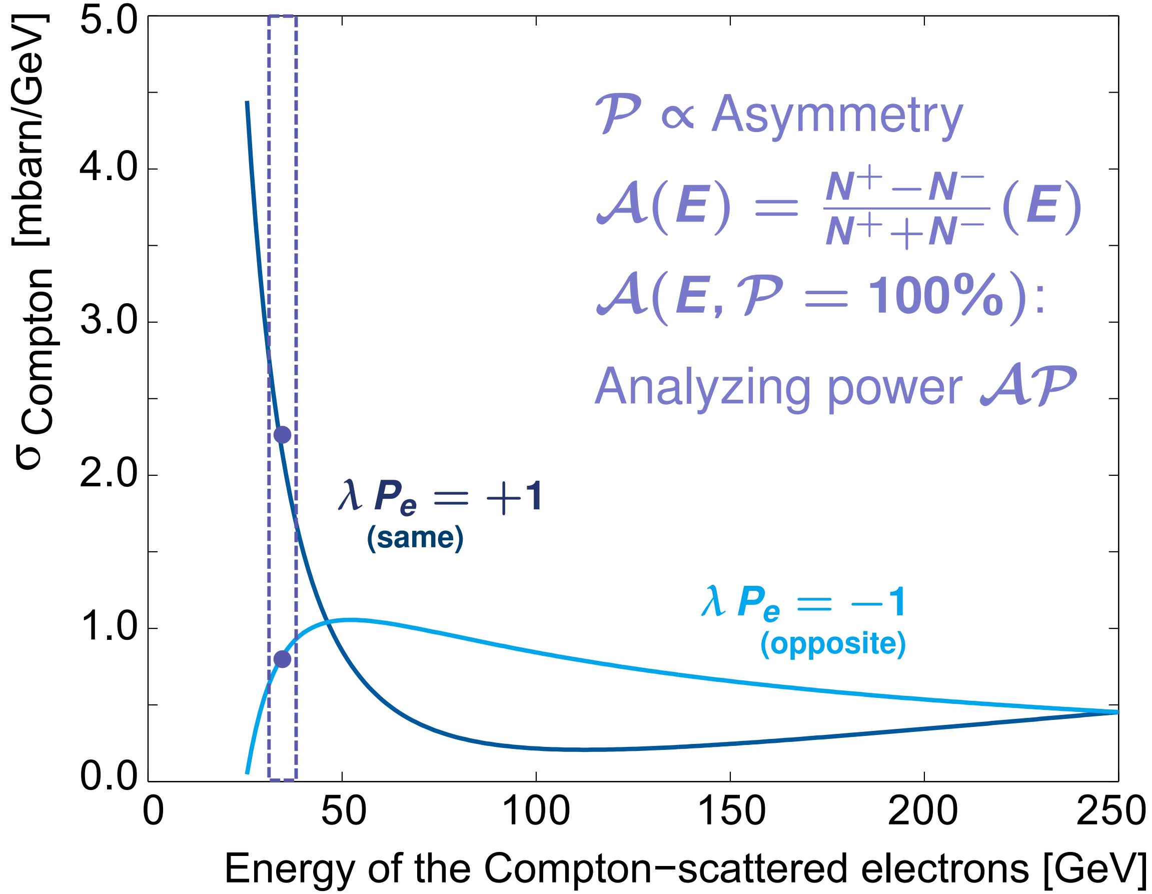
Measurement Principle.

Compton rate asymmetry is proportional to the beam polarisation:



Measurement Principle.

Compton rate asymmetry is proportional to the beam polarisation:



Measurement Precision.

ILC Goal: total uncertainty $\delta P / P \approx 0.25\,\%$ for $|P| \simeq 80\%$

source of uncertainty	$\delta P / P$	
	SLC achieved	ILC goals
laser polarisation	0.1%	0.1%
analyzing power	0.4%	0.15% – 0.2%
detector linearity	0.2%	0.1%
electronic noise and beam jitter	0.2%	0.05%
Total	0.5%	0.25%

- analysing power: prediction of count rate asymmetry per detector channel
  $\Rightarrow$ knowledge of beam parameters, design of chicane, beam-detector alignment, backgrounds
- detector linearity, electronic noise:
  $\Rightarrow$ detector design & calibration (not included this talk)
- beam jitter: much smaller at ILC due to luminosity requirements

Complementarity of Up- and Downstream.

Upstream Polarimeter

- 1.8 km upstream of IP
- rather clean environment
- begnin beam cond.
- samples every bunch
- stat. error 1% after few μs
- reference for control of collision effects

Downstream Polarimeter

- 140 m downstream of IP
- high backgrounds
- distrupted beam
- samples one bunch / train
- stat. error 1% after $\simeq$ 1 min
- access to depolarisation in collision

Combination

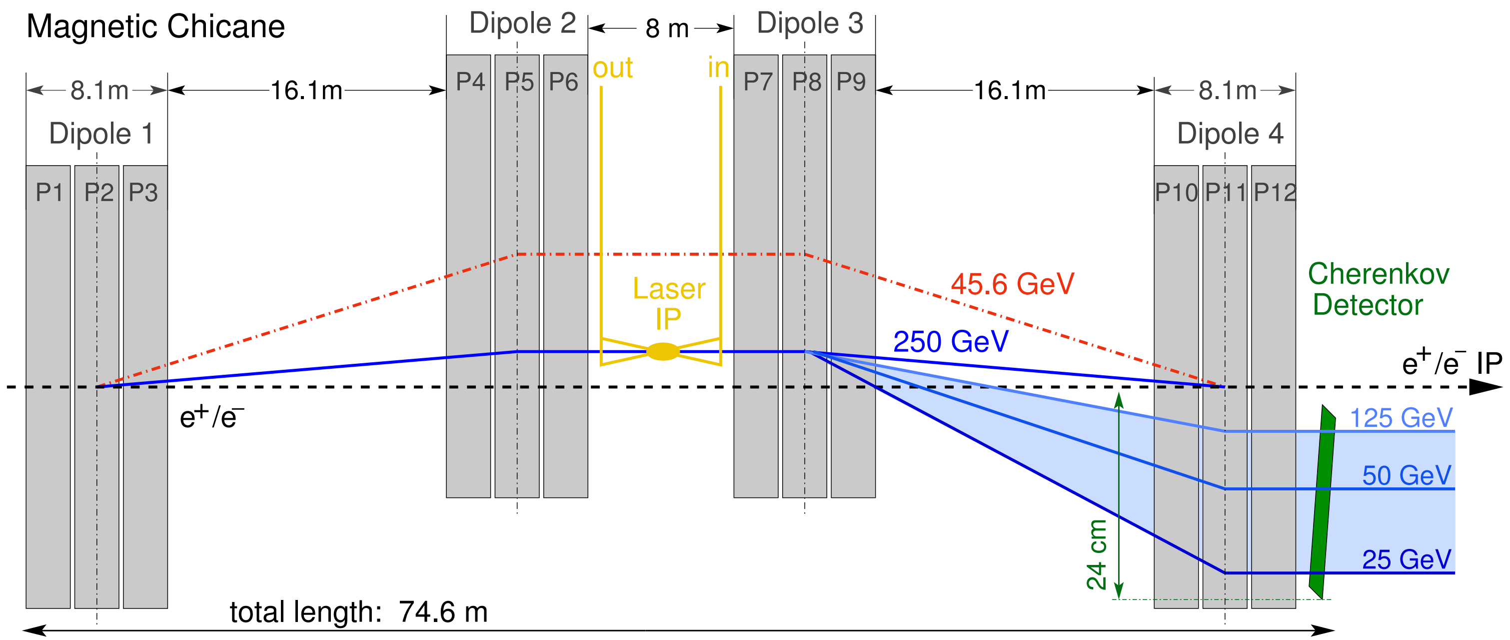
- without collisions: spin transport in Beam Delivery System and Extraction Line
- with collisions: depolarisation at IP
- **cross check each other!**

[c.f. "Spin Dance" Exp., Phys. Rev. ST Accel. Beams **7** 042802 (2004)]

Design of the Upstream Polarimeter Chicane.

Why a 4-Dipole-Chicane?

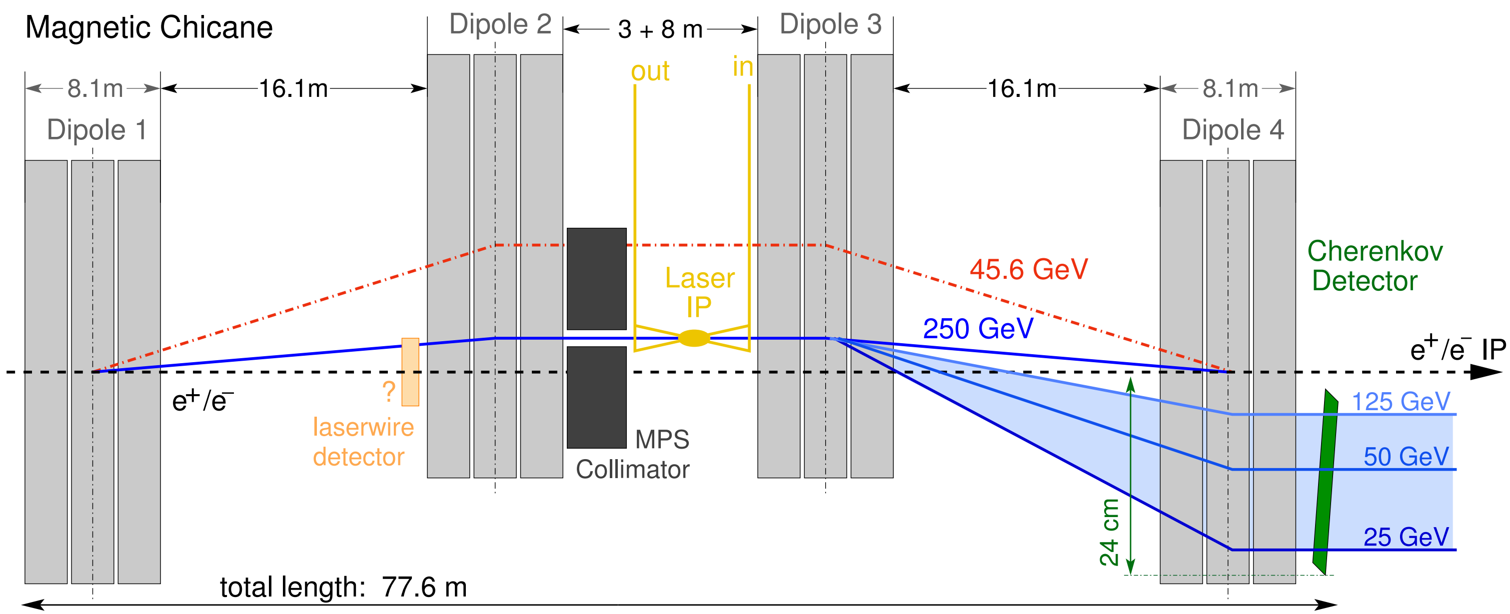
- Compton spectrum position at detector independent of E_{beam} if B-field constant
- price to pay: Compton IP moves laterally with E_{beam}



Design of the Upstream Polarimeter Chicane.

RDR Design:

- energy collimation and emittance diagnostics in same chicane
- $\Rightarrow$ laterally fixed Compton IP $\Rightarrow$ scaled field operation!
- collimator & laser-wire will create severe backgrounds

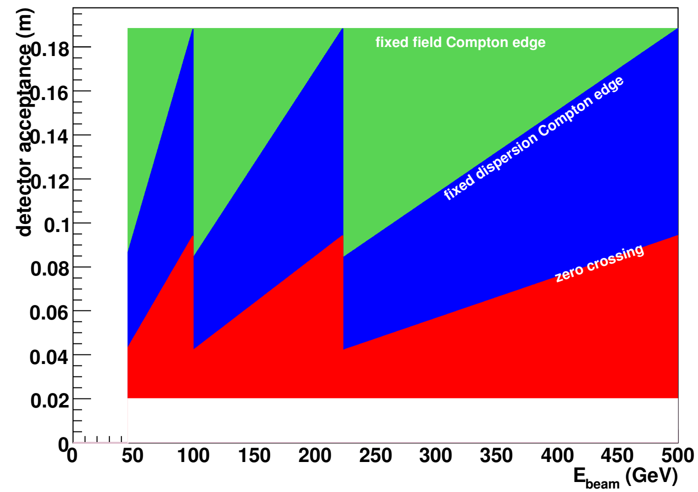


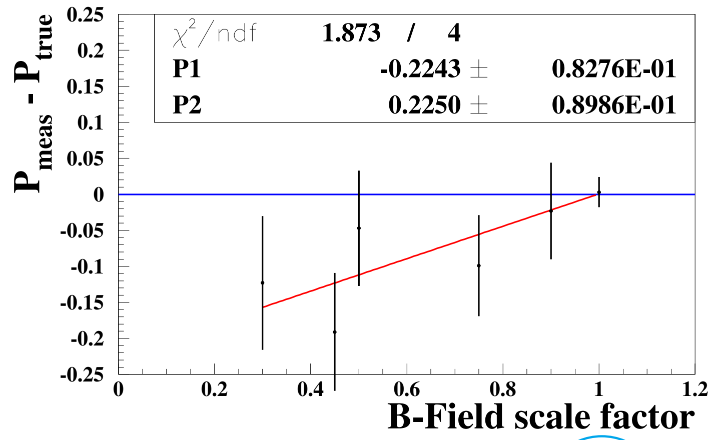
Scaled vs Fixed Field Operation.

Effects of scaled field on measurement:

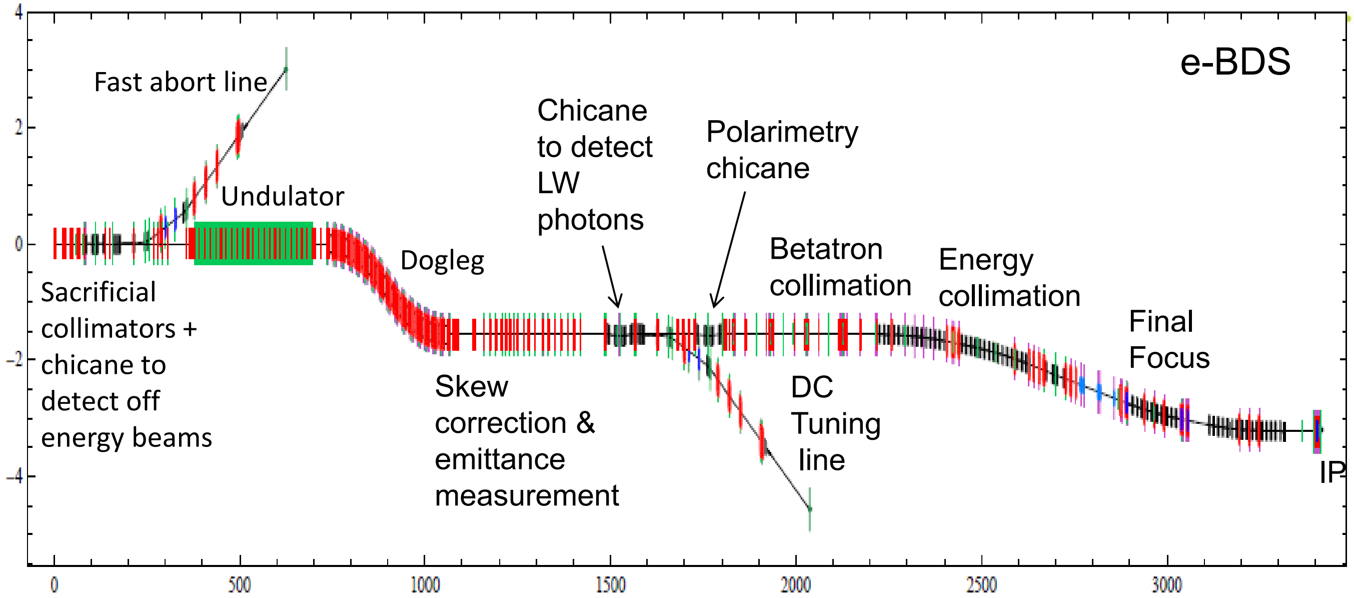
- acceptance: varies with E_{beam}
  $\Rightarrow$ inhomogeneous quality of polarisation measurement
- alignment: via Compton edge position w.r.t. main beam
  $\Rightarrow$ effect on $\delta\mathcal{P}/\mathcal{P}$ doubles
- systematic deviations for large scale factors

not compatible with extreme precision requirements c.f. ILC-NOTE-2008-047

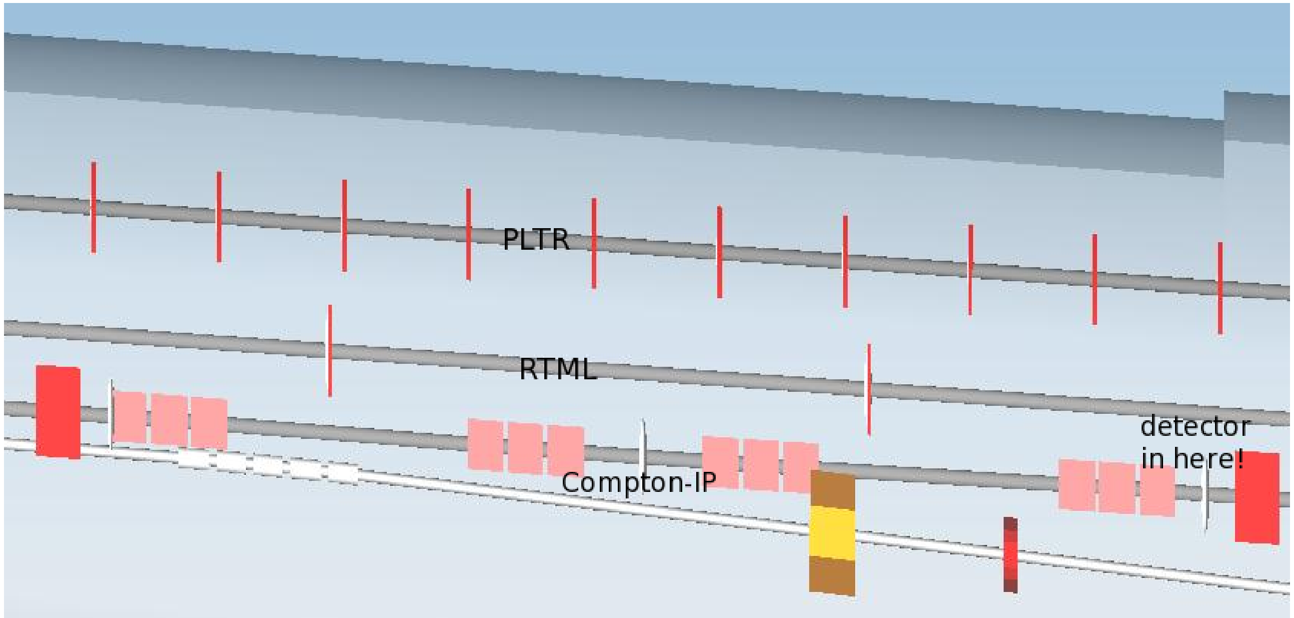




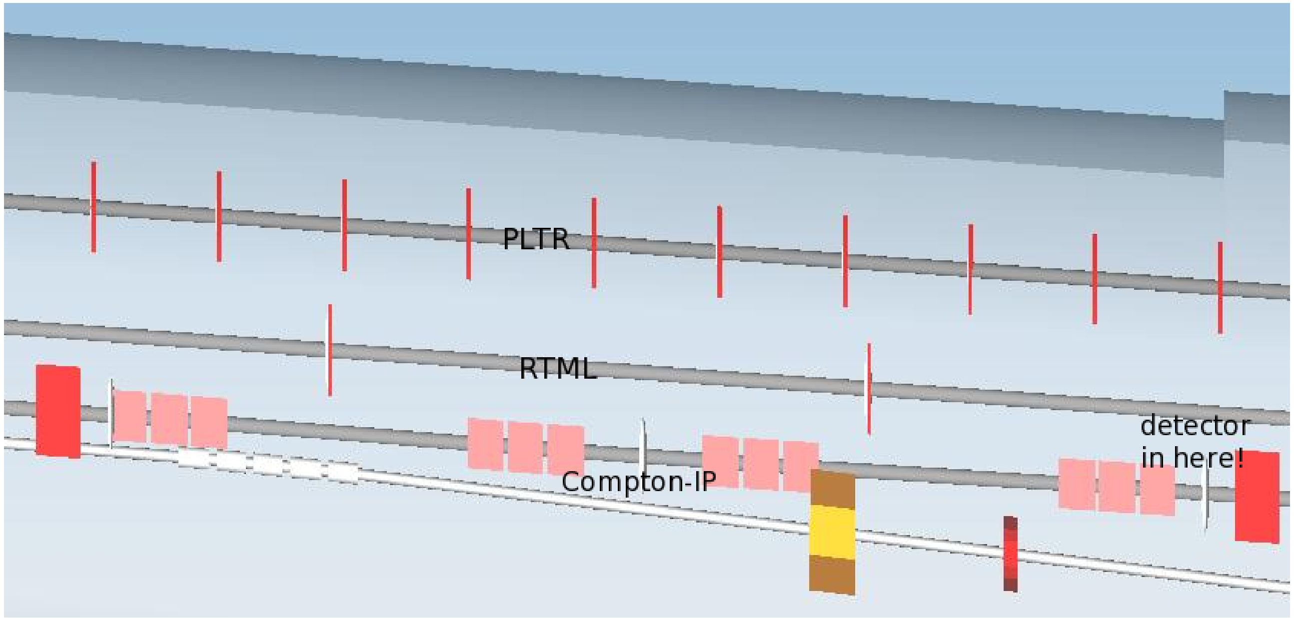
The Upstream Polarimeter in SB2009-Nov10 lattice.



The Upstream Polarimeter in SB2009-Nov10 lattice.



The Upstream Polarimeter in SB2009-Nov10 lattice.



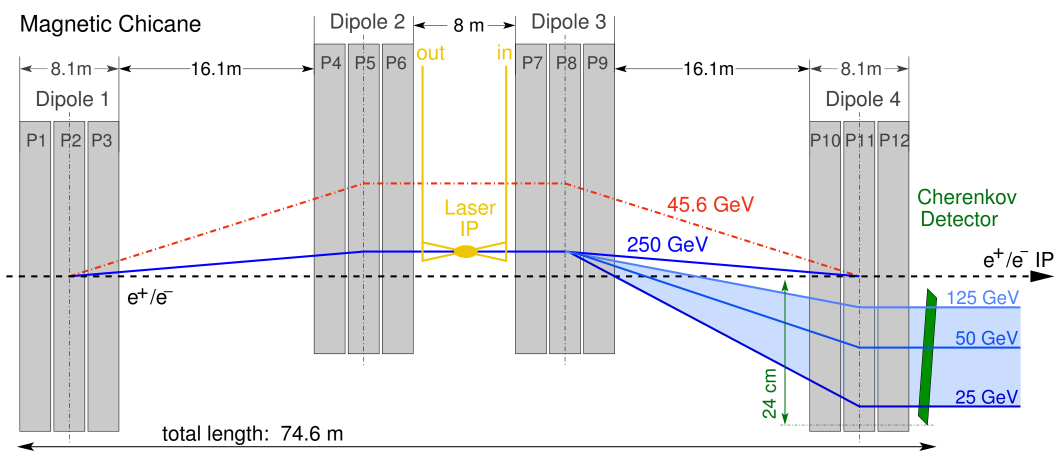
- distance Compton-IP to dump line ca 30 cm at 250 GeV
- down to ca 20 cm at lowest energies - enough?

[c.f. Baseline Technical Review Workshop 2011]

Vacuum Chamber in Chicane Region.

need special beam pipe through out whole chicane

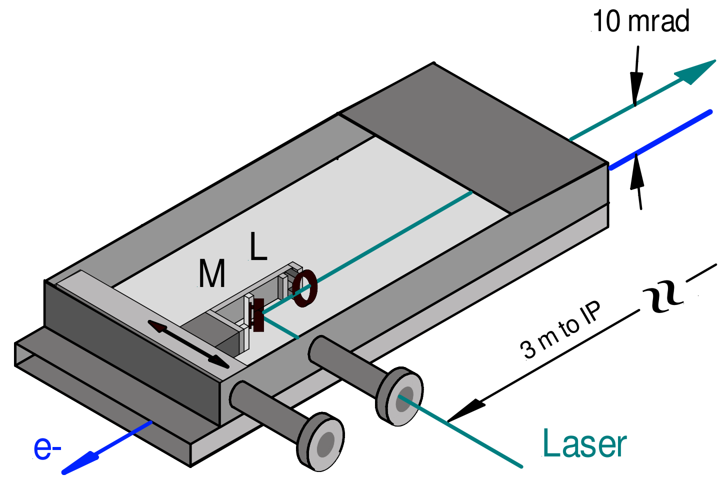
- to allow for varying bending angle
- to guide laser in and out
- to let fan of Compton scattered electrons pass
- to extract Compton fan to detector



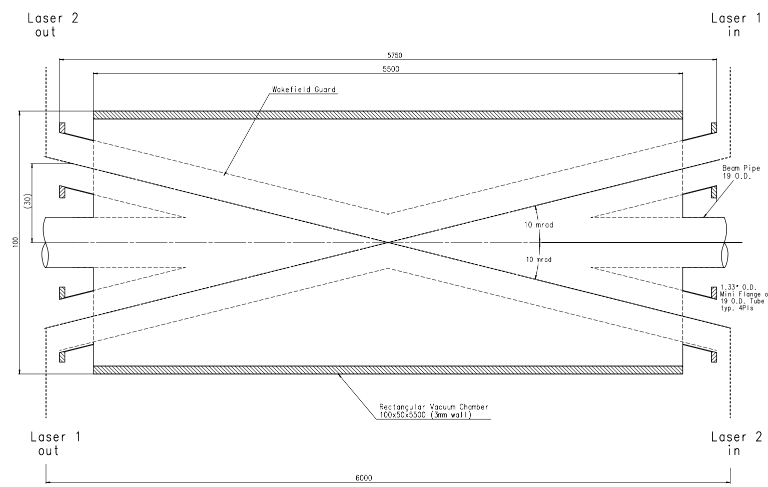
Attention: deflection of chicane the otherway round as on previous page!

Vacuum Chamber: Laser in / out.

- Laser enters chicane *horizontally* (far side from tune-up dump line!)
- final mirror / lens movable to adjust to e^{-} beam
- had been designed to some extent for TESLA (!) by N. Meyners, P. Schüler

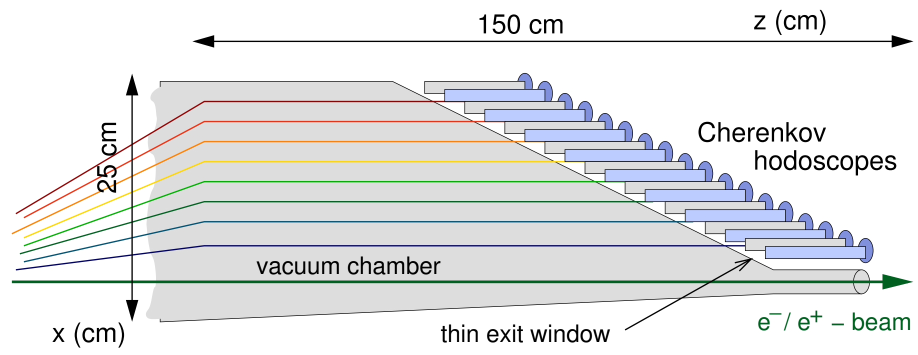


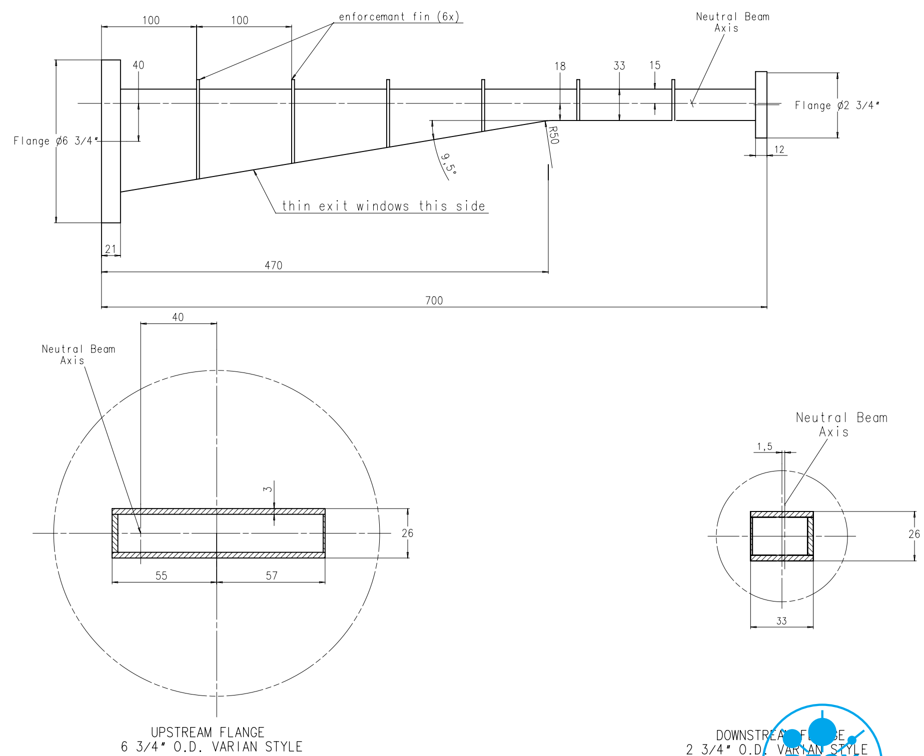
Movable Laser Beam



Vacuum Chamber: Compton fan exit.

- need tapered exit window to avoid wake fields
- again estimate from TESLA: $\simeq 10^\circ$ is fine (opinions?)
- need $\simeq$ 1.5 m for detector array, make it 2 m for shielding, accessability,...
- fine with SB2009-Nov10 lattice

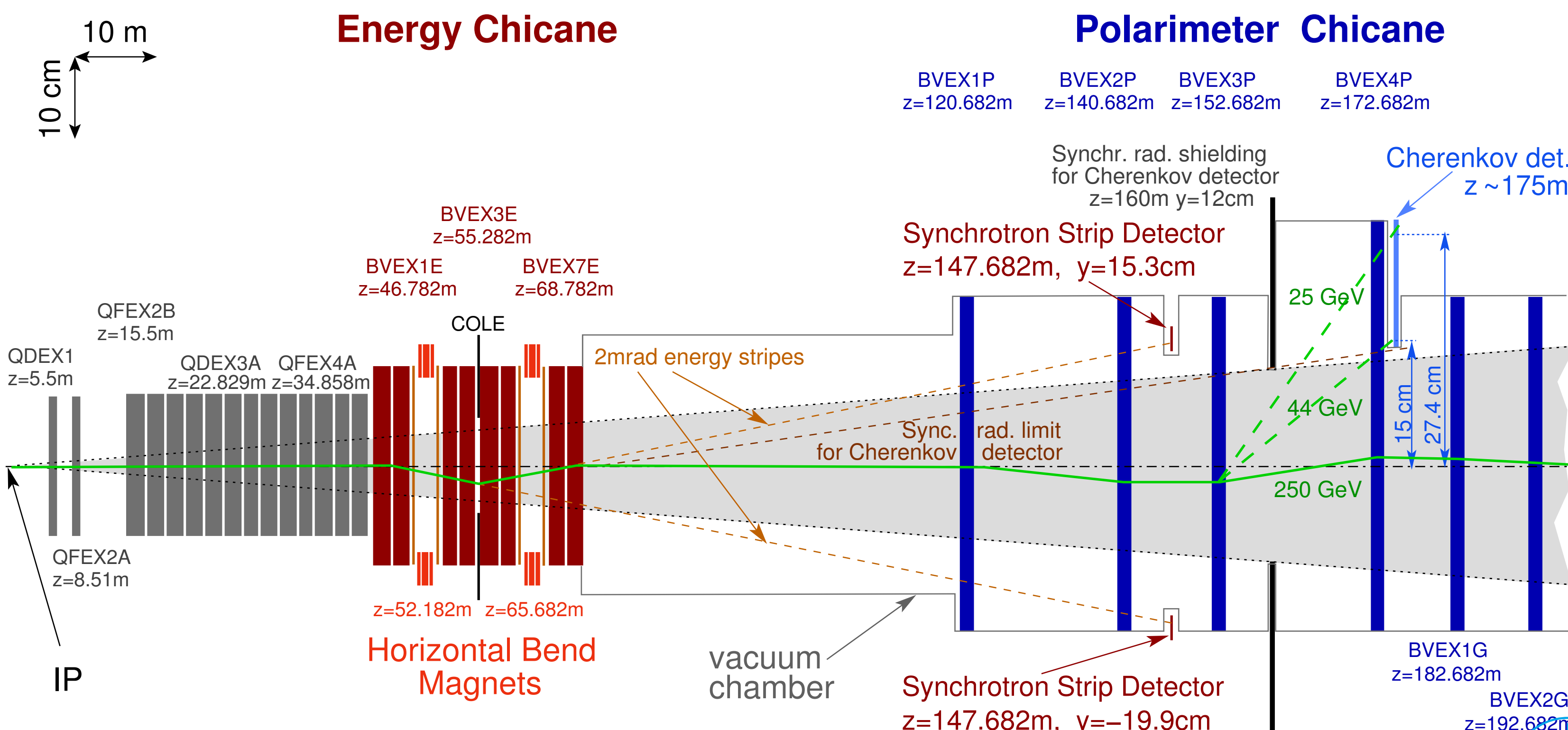




Downstream Polarimeter.

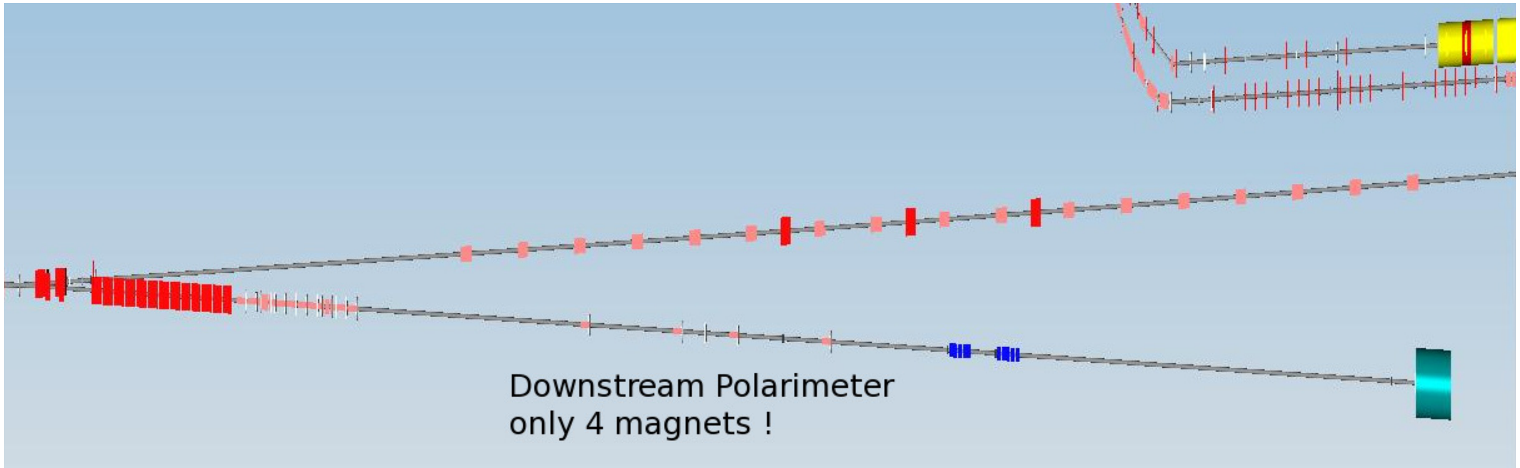
6-magnet chicane suggested in 2007 by Ken Moffeit et al:

- kick Compton e^- further out of the synchrotron radiation fan



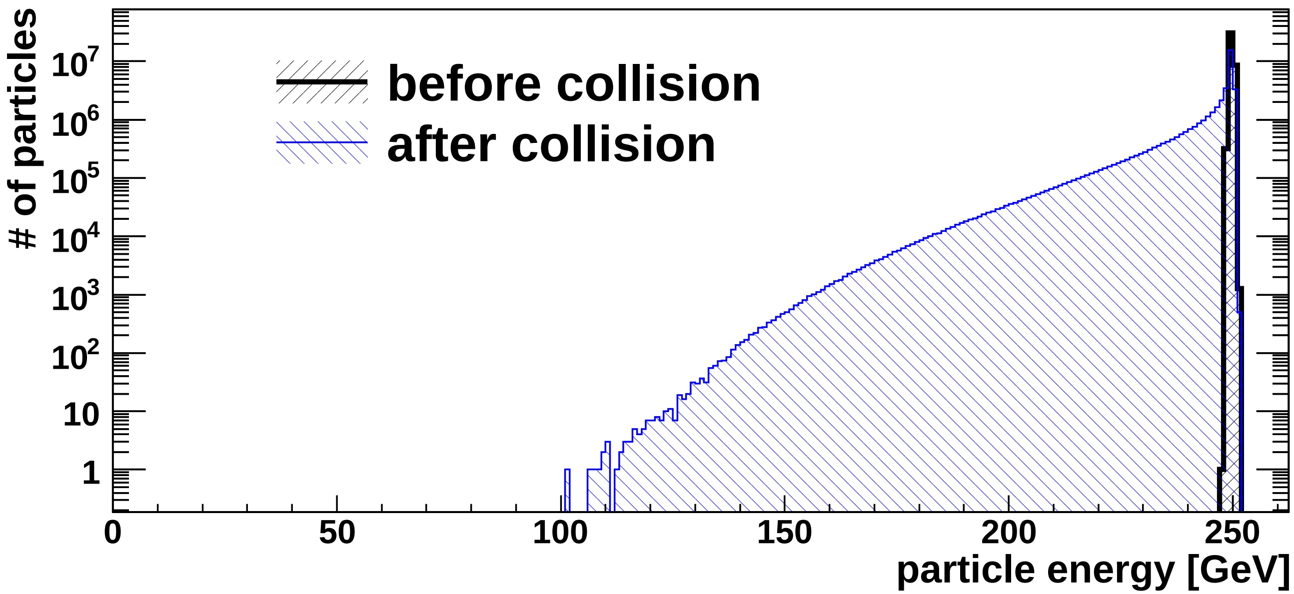
Downstream Polarimeter in SB2009-Nov10 lattice.

- still 4-magnet chicane - should be upgraded to 6-magnet design as propsed in SLAC-PUB-12425
- necessary due to push-pull related changes to the extraction SC quadrupoles
- at the same time gives better shielding of magnets due to additional collimators
- even more impact due to worse spent beam in low power configuration....



Beam Energy Spectrum with Collisions.

GuineaPig++, RDR nominal, $\sqrt{s} = 500\,\text{GeV}$

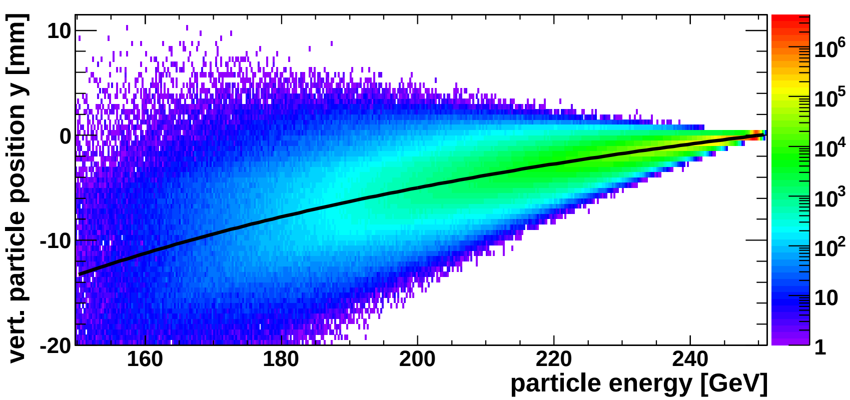


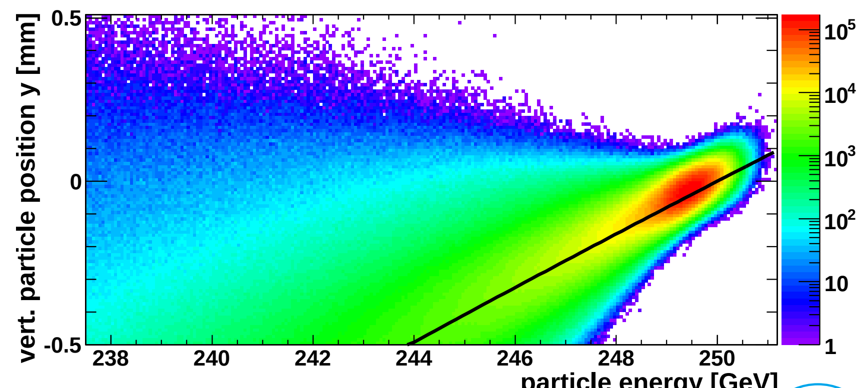
How will this influence the measurement at the downstream polarimeter?

y vs E at DP IP.

Particle Tracking through SB2009-Nov10 lattice (M.Beckmann)

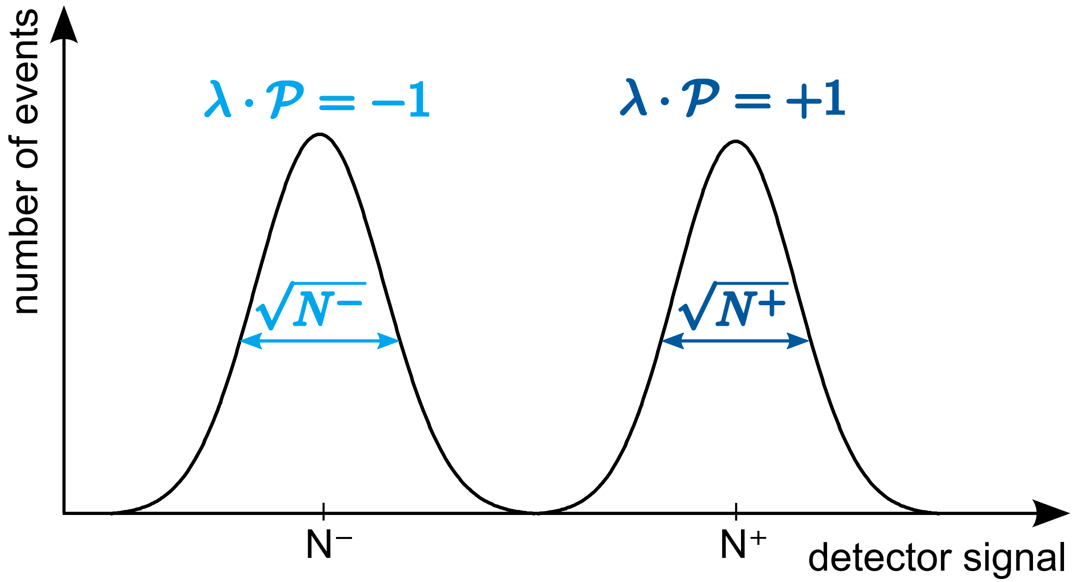
- vertical extension of spent beam at DP IP $\mathcal{O}$(cm)
- "core" size still $\simeq$ 0.5 mm
- sizable correlation of energy and position
- which part will the laser sample?
- expect dependence of measured polarisation on laser spot size and laser-beam alignment





Measurement principle.

Detector channel after measurements at both laser configurations:

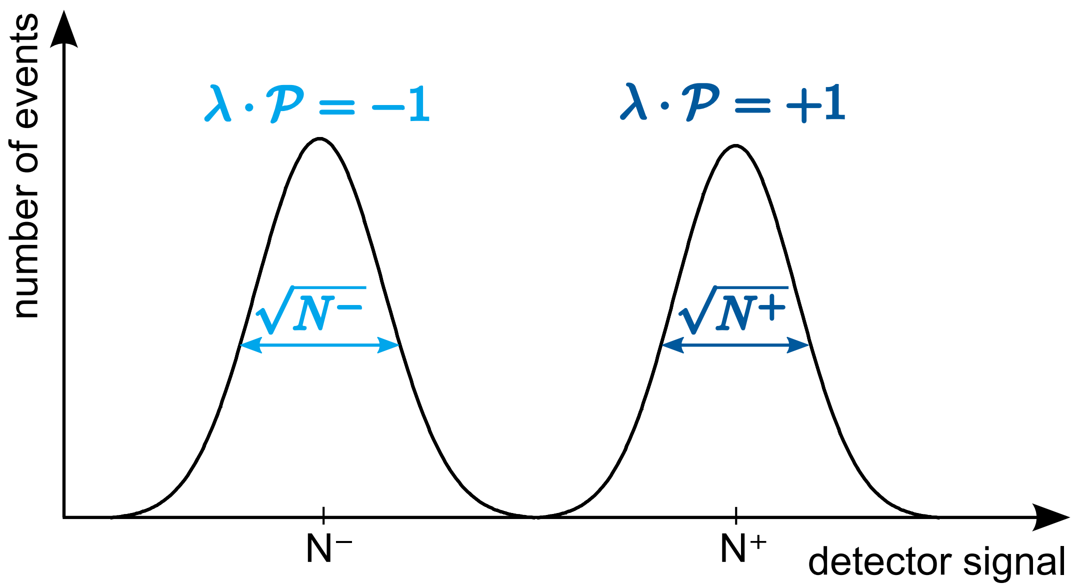


$\mathcal{P} \propto$ Asymmetry

$$\mathcal{A} = \frac{N^+ - N^-}{N^+ + N^-}$$

Measurement principle.

Detector channel after measurements at both laser configurations:



$\mathcal{P} \propto$ Asymmetry

$$\mathcal{A} = \frac{N^+ - N^-}{N^+ + N^-}$$

Goal: total uncertainty $\Delta P / P \approx 0.25\,\%$, of which

- laser: 0.1 %
- analysing power (i.e. asymmetry at $\mathcal{P} = 1$): 0.2 %
  $\Rightarrow$ Cherenkov detector design
- detector linearity: 0.1 % $\Rightarrow$ photodetector calibration

Detector Requirements.

Magnetic Chicane...

- transforms energy spectrum into spatial distribution
- behind chicane: $\sim$ 20 cm wide
- detect Compton electrons over this area

Detector requirements:

- Total ionising dose up to 100 Mrad / year
- read out signals of 1000-2000 Compton electrons (25-250 GeV) every bunch crossing
- either very linear response or “counting“ electrons
- alignment to $\sim$ 100 µm and $\sim$ 1 mrad
- suppression of background from low energetic particles

Detector Options.

Simple, robust, fast: Cherenkov detectors

- Cherenkov light emission proportional to number of electrons
- independent of electron energy (once relativistic)
- successfully used in best polarimeter sofar at SLC
- gas or quartz option for Cherenkov medium

Detector Options.

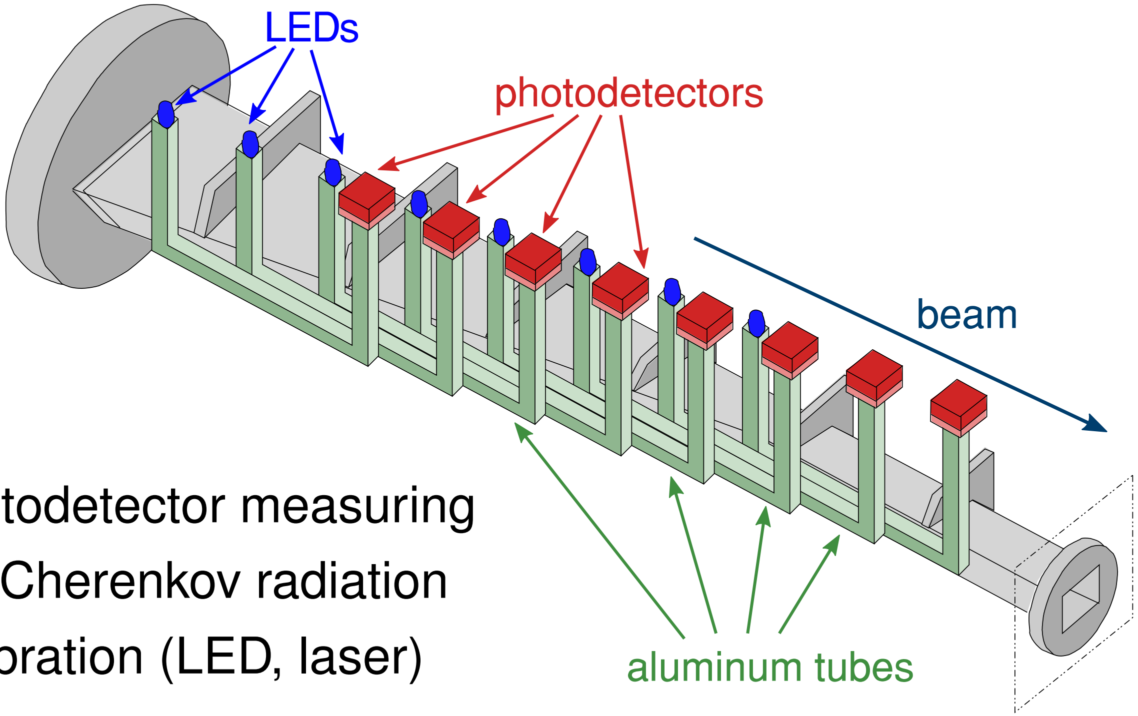
Simple, robust, fast: Cherenkov detectors

- Cherenkov light emission proportional to number of electrons
- independent of electron energy (once relativistic)
- successfully used in best polarimeter sofar at SLC
- gas or quartz option for Cherenkov medium

Goal: total uncertainty $\Delta P / P \approx 0.25\,\%$, of which

- laser: 0.1 %
- analysing power (i.e. asymmetry at $\mathcal{P} = 1$): 0.2 %
  $\Rightarrow$ Cherenkov detector design
- detector linearity: 0.1 % $\Rightarrow$ photodetector calibration

Gas Cherenkov detector.



- **hind U-leg:** photodetector measuring the Cherenkov radiation
- **front U-leg:** calibration (LED, laser)

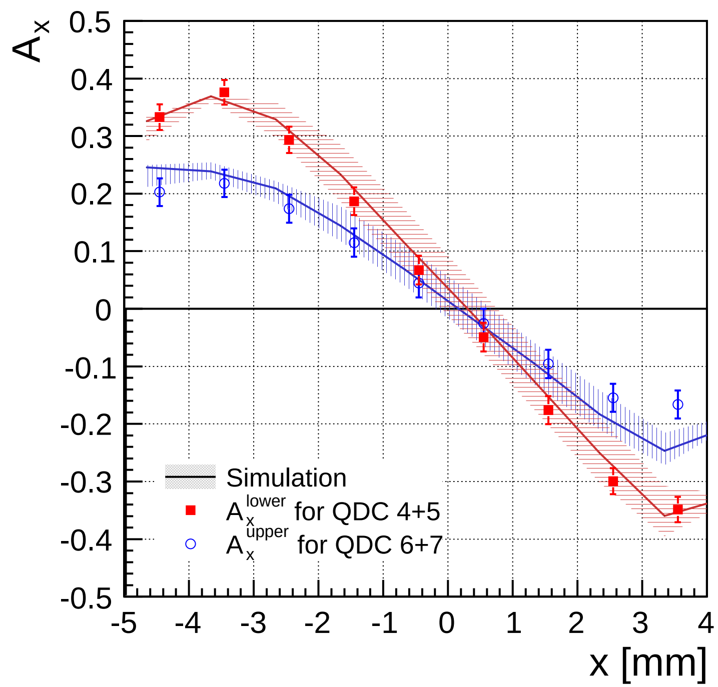
Alignment: locate Compton edge in the spectrometer
Segmented photodetectors: Tilt alignments via asymmetries

2-channel prototype tested at ELSA [JINST 7, P01019 (2012)]
$\Rightarrow$ tilt alignment of 0.1°, nearly fulfils alignment requirements

Gas Cherenkov detector: Alignment.

If the detector is tilted

- beam path through the detector varies $\Rightarrow$ different light path
- different light pattern on the photocathode
  $\Rightarrow$ alignment via spatial assymetries possible:

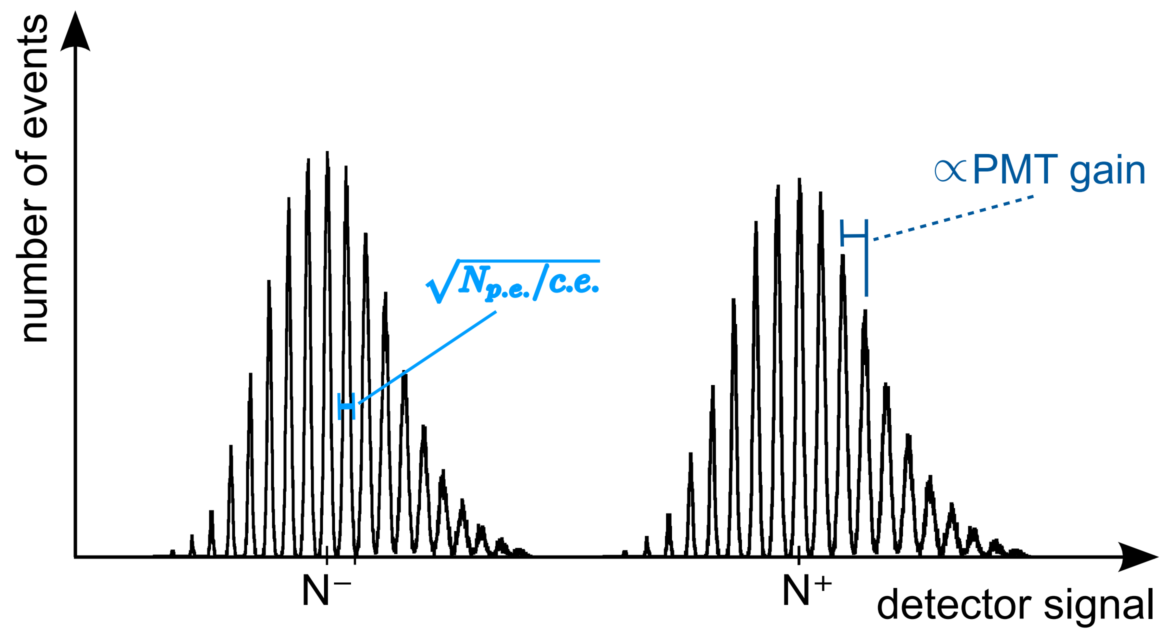


$\Rightarrow$ Reached a tilt alignment of 0.1°. [JINST 7, P01019 (2012)]

Quartz Cherenkov detector.

Alternative detector concept: quartz detector

- Higher refractive index $\rightarrow$ higher photon yield
- For enough photons per Compton e^-:
  $\rightarrow$ calibrate gain directly from the data

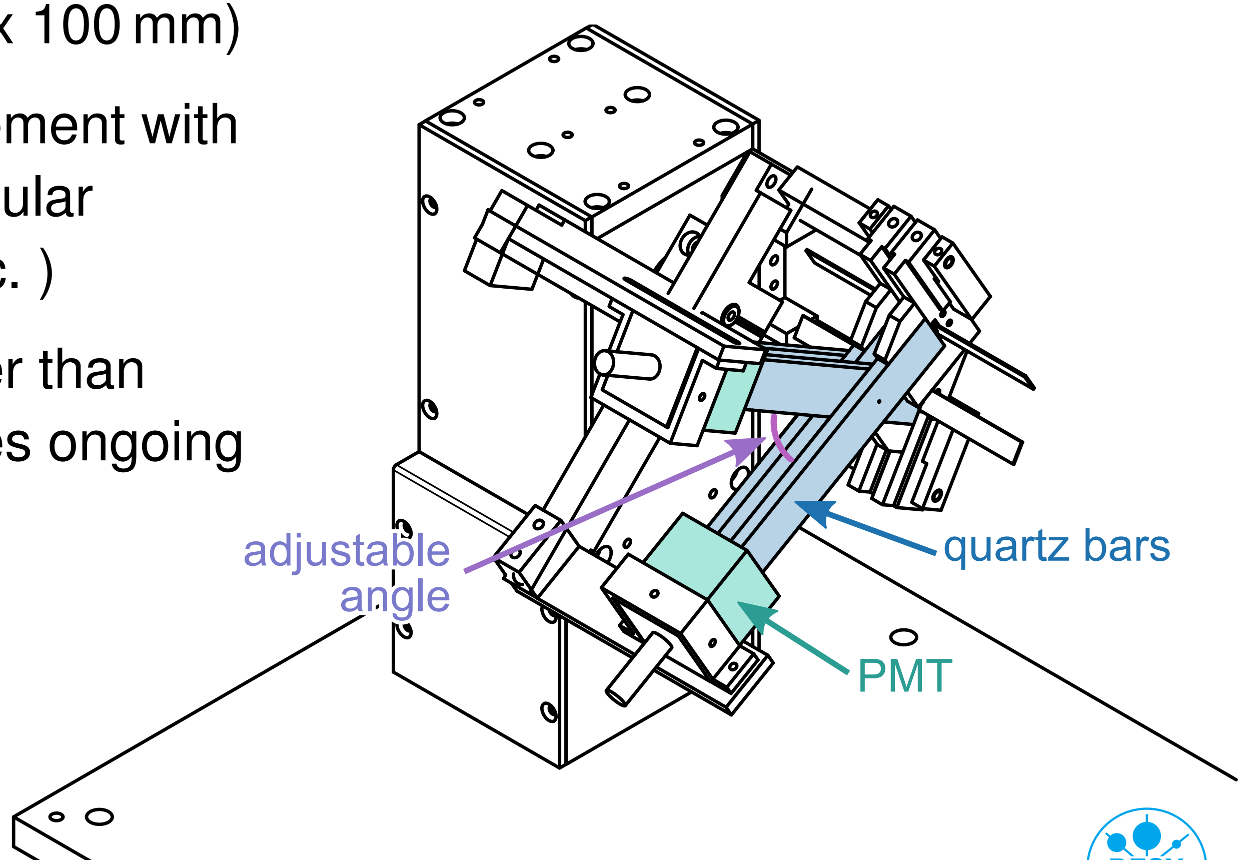


4-channel prototype operated at DESY II testbeam this year.

Quartz Cherenkov detector (2).

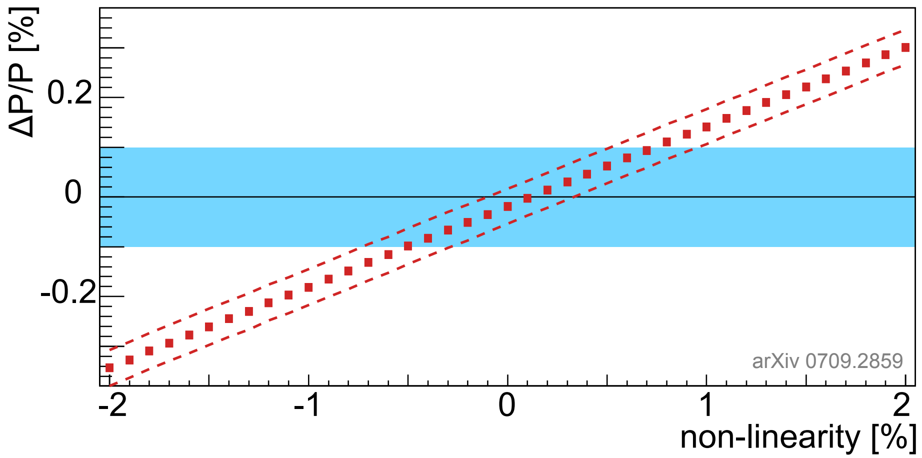
4-channel prototype operated at DESY II testbeam this year

- channels: quartz bars (5 mm x 18 mm x 100 mm)
- qualitative agreement with simulations (angular dependence, etc.)
- light yield smaller than predicted, studies ongoing



Calibration of detector non-linearity.

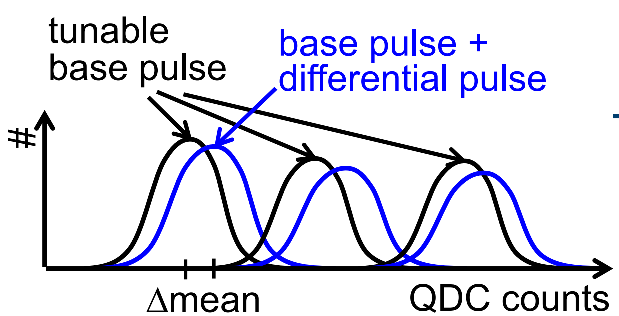
Goal: contribution to overall uncertainty $< 0.1\,\%$

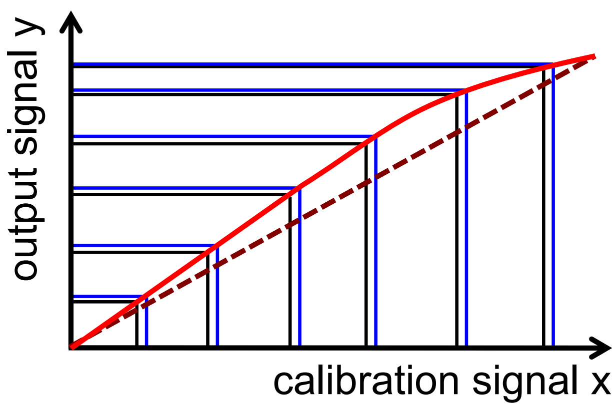


PMTs have to be calibrated to non-linearity $< 0.5\,\%$.

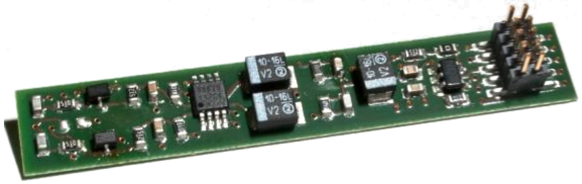
$\mathcal{P} \propto \frac{N^+ - N^-}{N^+ + N^-}$: no absolute calibration needed.

$\longrightarrow$ Differential calibration method using two LEDs:



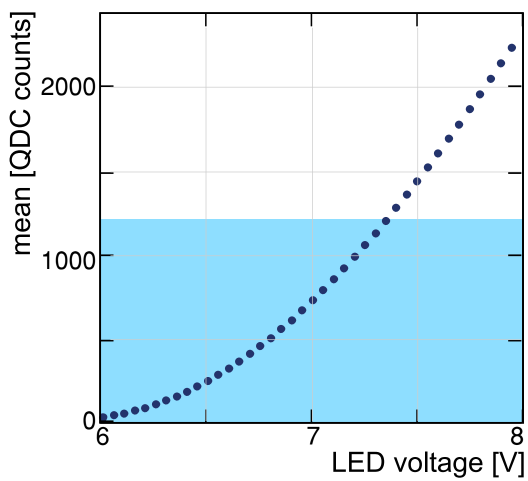


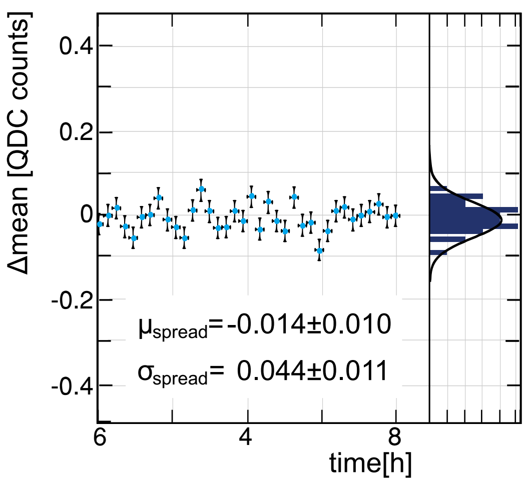
Calibration source requirements.



Requirements on the LED driver:

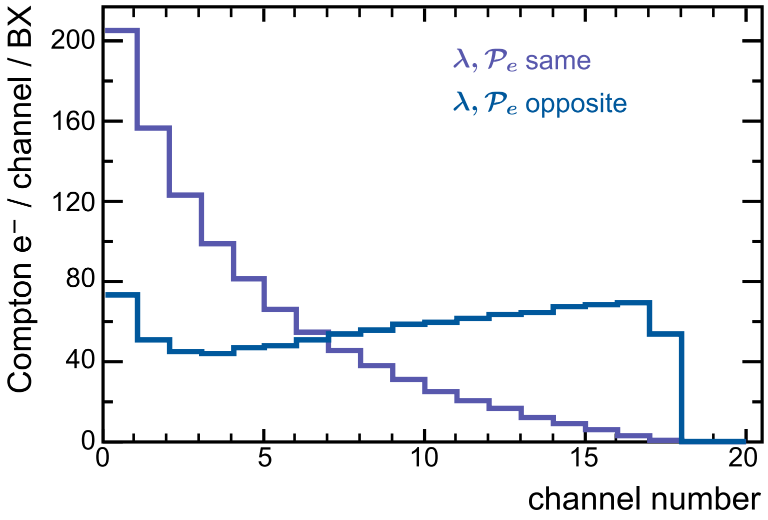
- wave length in UV range ($\lambda = 405\,\text{nm}$)
- applicable in detector design $\rightarrow$ small
- short light pulses ($< 10\,\text{ns}$)
- coverage of the whole dynamic range of the expected signal
- reproducable and stable light pulses

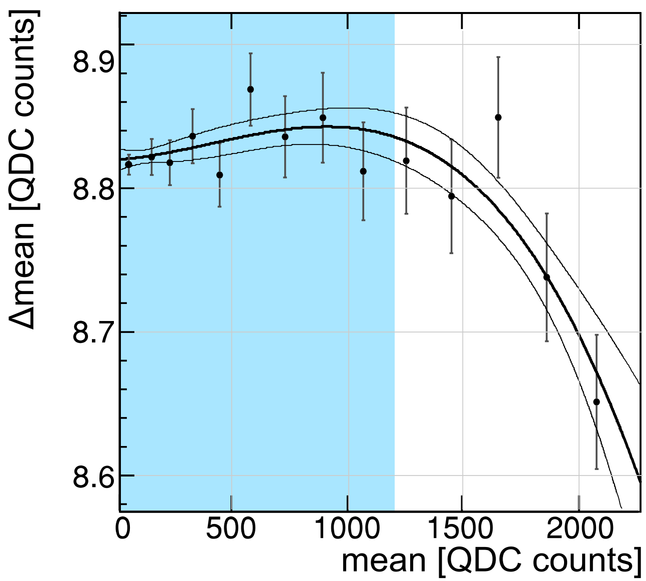


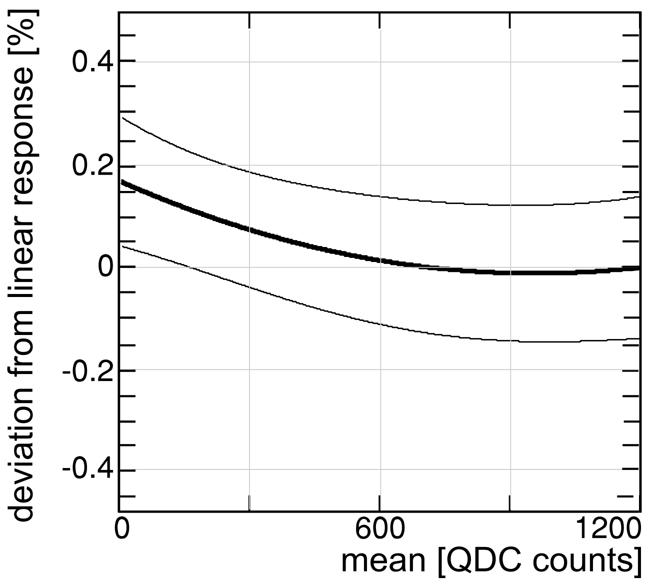


Non-linearity in extreme polarimeter channels.

- up to 210 Compton e^- ($\sim$ 1200 QDC counts)
- overall non-linearity already small in this range (max 0.2 %)
- in single channels even smaller

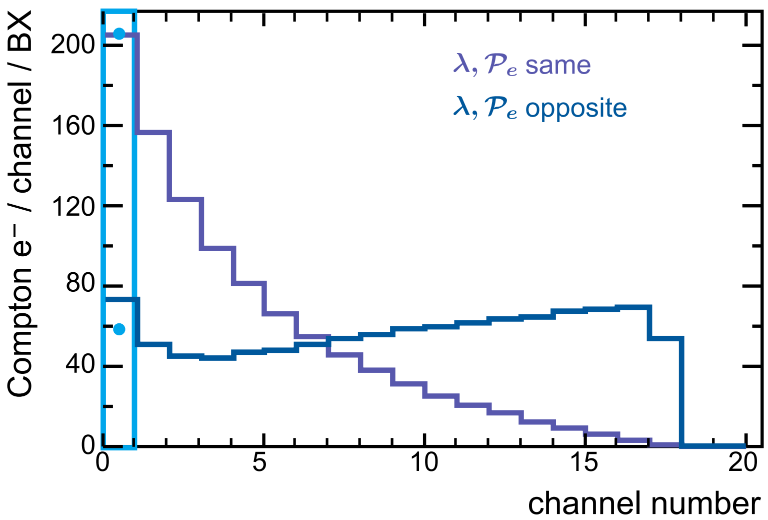


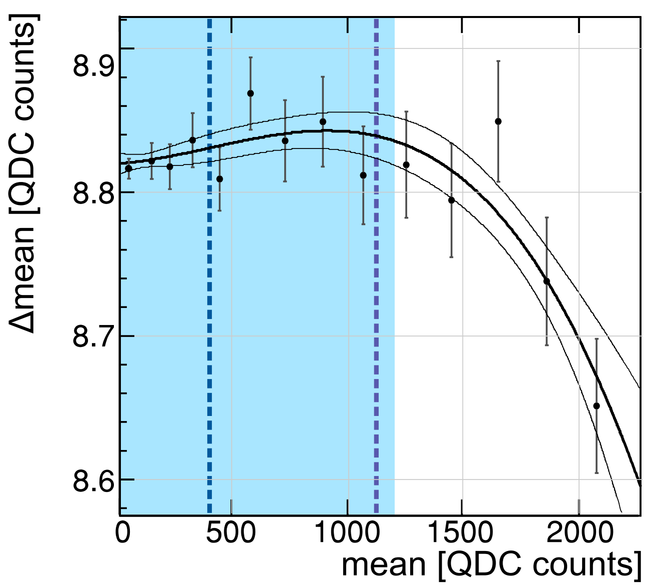


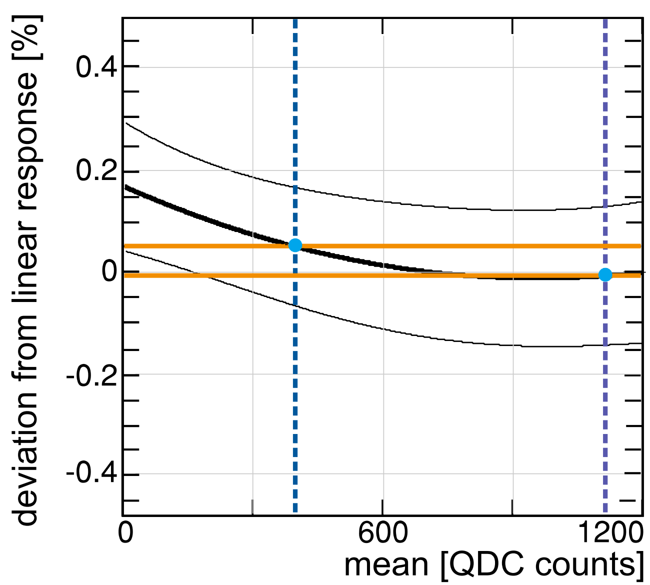


Non-linearity in extreme polarimeter channels.

- up to 210 Compton e^- ($\sim$ 1200 QDC counts)
- overall non-linearity already small in this range (max 0.2 %)
- in single channels even smaller







Non-linearity in extreme polarimeter channels.

- up to 210 Compton e^- (∼ 1200 QDC counts)
- overall non-linearity already small in this range (max 0.2 %)
- in single channels even smaller