BDS Polarimetry & First Testbeam Results

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Basics
of Polarimetery

Requirements for the Polarimeters

Type of the measurement / precision:

- measurement of the longitudinal beam polarisation
  $\longrightarrow$ energy measurement $\leftrightarrow$ position measurement
- necessary precision: $\delta P/P \leqslant 0.2$ %
  2-times more precise than the SLD polarimeter (SLAC, Stanford)
- Compton-IP about 1700 m away from the e^+/e^- IP
- $\Rightarrow$ need a good understanding of the spin transport $\longrightarrow$ difficult
  . . . that's why we NEED precise measurements of the polarisation!
- Finally: cross check polarisation measurements, both: up- and downstream, with "real" physics from e^+/e^- IP (e.g. W-helicities) and among each other.

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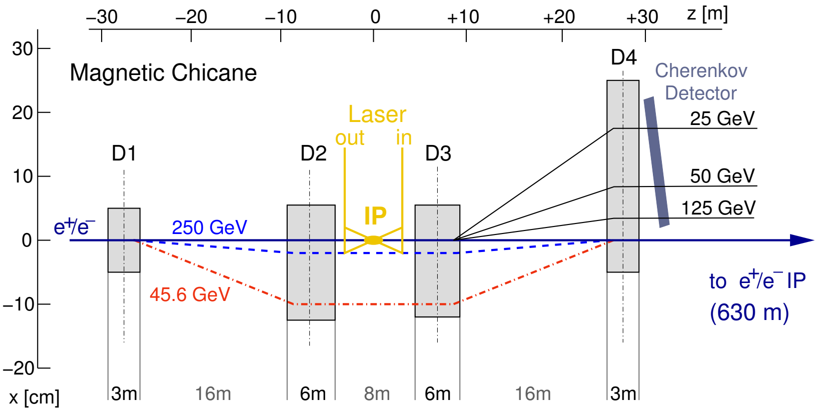
Measurement principle: Compton Polarimetry



The Compton-IP lies within the magnetic spectrometer (4 large dipoles)

→ Scattering of about 10^3 e^+/e^- per beam crossing

→ the Compton edge lies always at the same spot in the detector!

...then Detection of the scattered electrons via Cherenkov detectors

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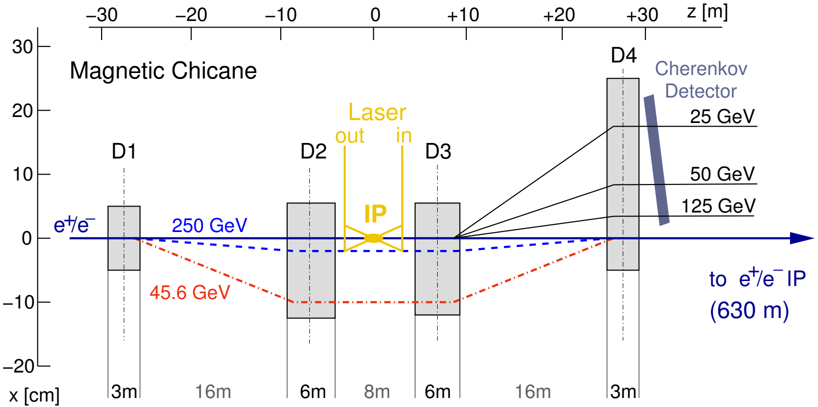

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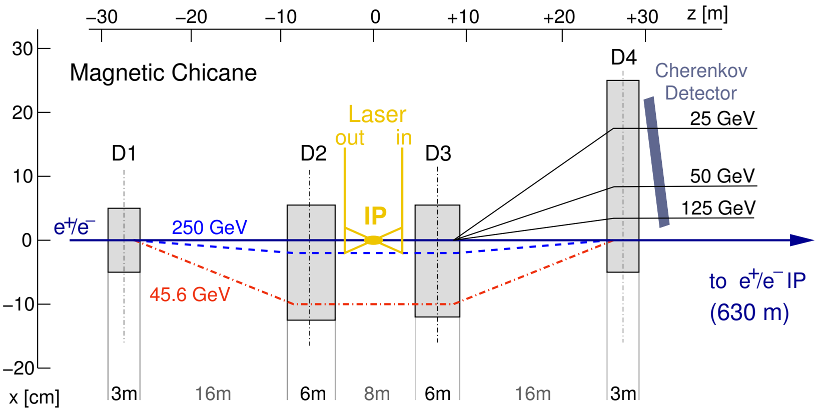

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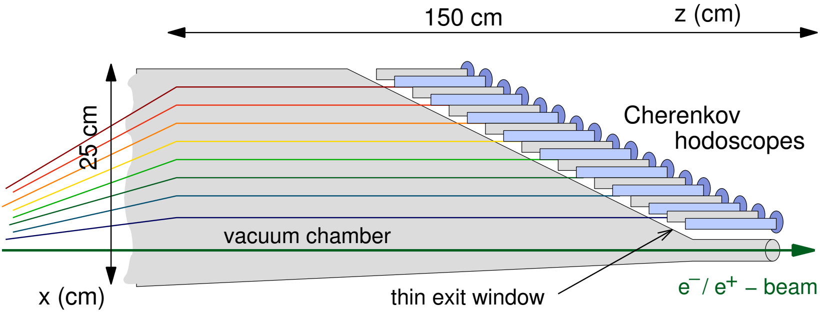

Measurement of the energy/position distribution via Cherenkov detectors:
Compton electrons $\rightarrow$ Cherenkov radiation $\rightarrow$ Photo electrons!

Cherenkov effect: $N_e^{Co} \rightarrow N_\gamma^{Ch}$: hodoscope length/refraction index
Photo electrons: $N_\gamma^{Ch} \rightarrow N_e^{Ph}$: type of photo detector!

Count photo electrons per channel $\rightarrow$ linearity extremely important!

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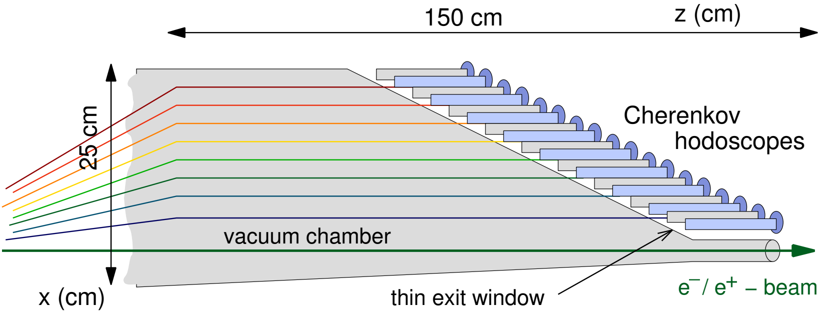

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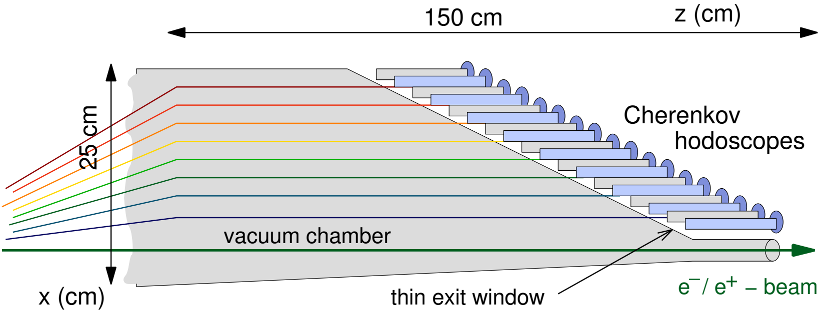

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Cherenkov detectors: but how exactly?

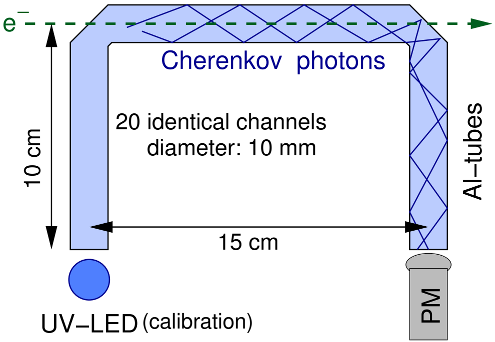
Diverse techniques usable & fast development (esp. with PMs)!

Layout 1: similar to the old SLD polarimeter with gas tubes + PMTs (conventional)

- gas?
- polishing?
- PM(T)s?

Layout 2: new!
quartz fibers + SiPMs

- sensitive area?
- dynamic range?



Detection method ⟷ necessary precision!

Quantum efficiency, sensitive area, light extraction, dynamic range (sensitive wavelength range) . . . all of them need to be optimised.

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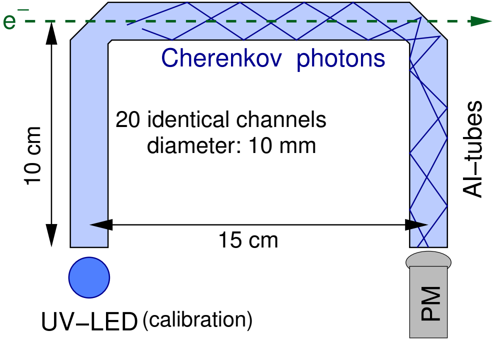

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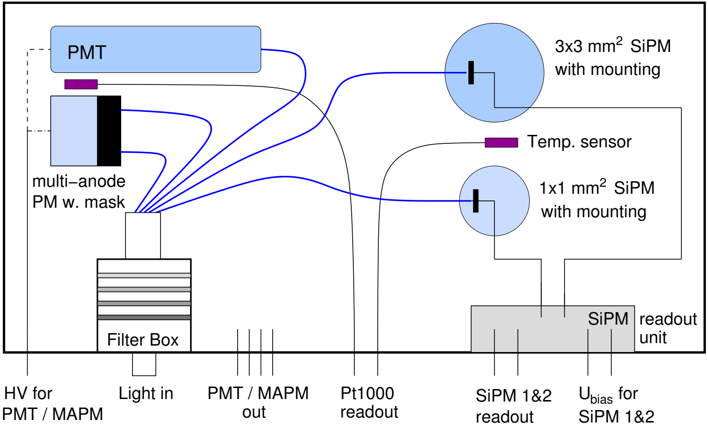
Photodetector Testbench

Testbench Setup & Measurements



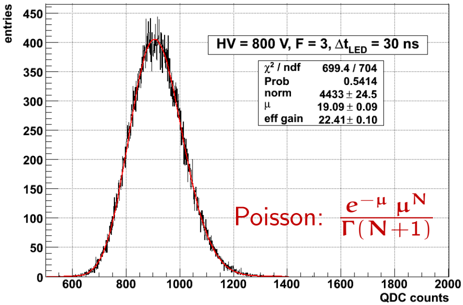
blue LED:
$\lambda \approx 470$ nm

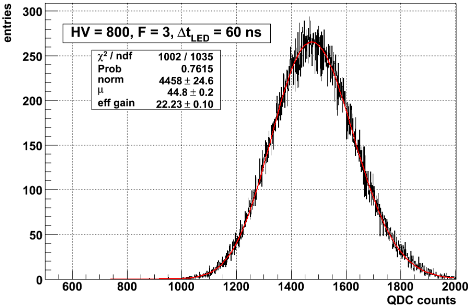
4 diff. filters
$\rightarrow$ 15 comb.

Linearity measurements - 2 methods:

- vary the length of the LED pulses (from 10 ns to 100 ns, every 5 ns)
- use optical filters to attenuate the LED light

Extracting N_e^{Ph} from the Spectra



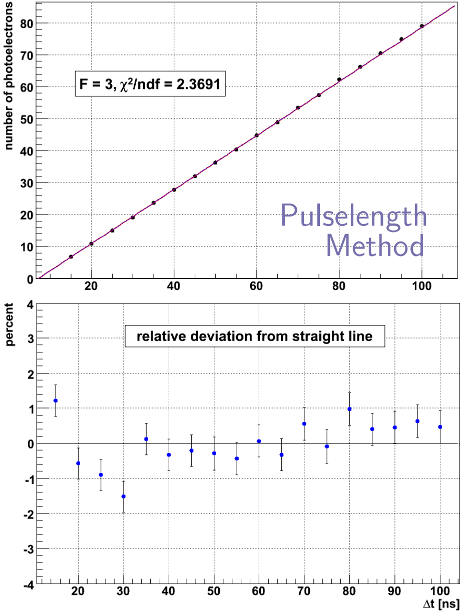


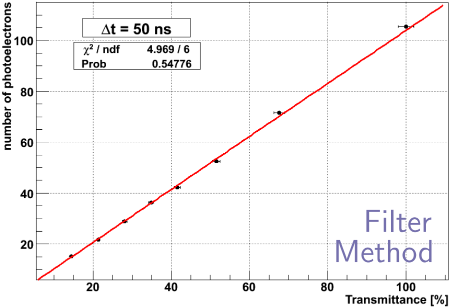
Measure PMT spectra for different LED pulse lengths: 20 ns to 100 ns and for different optical filters (15 combinations in total).

Poisson fits to the spectra yield the (effective) gain and the mean number of photoelectrons: N_e^{Ph}

The transmittance of the optical filters is not known with satisfying precision, but the measurements via variations of the LED pulse lengths gives good results.

Linearity: Pulslength vs. Filter Method





Pulse length variation:

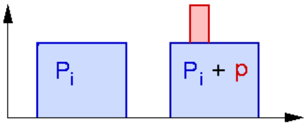
- less than 1% non-linearity
  (incl. possible electronics non-lin.)
- but: need more statistics for a reliable conclusion

Further Linearity Methods

- Double Pulse Method:

  use two LED-pulses: one wide pulse (P_i) and one narrow pulse ($p \ll P_i$)
  measure: P_i and $P_i + p$
  vary P_i, keep p const. $\rightarrow$ measure: P_i, $P_i + p$

  $\Rightarrow$ differential non-linearity



- Hole Mask Method:

  use mask with four holes on photodetector
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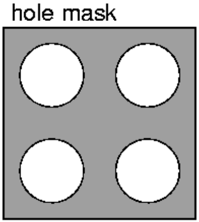
  DNL = (p1 + p2 + p3 + p4) / p0 - 1



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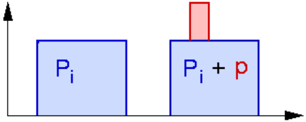

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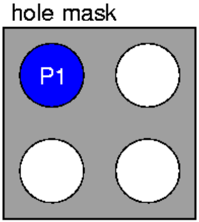

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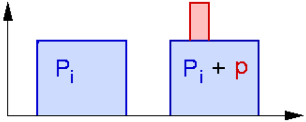

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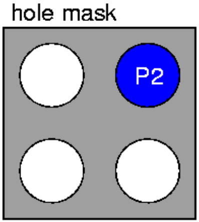

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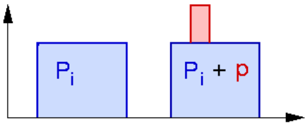

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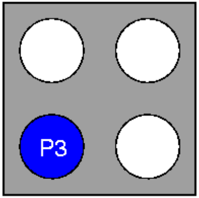

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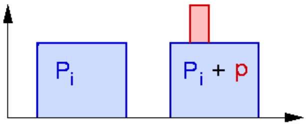

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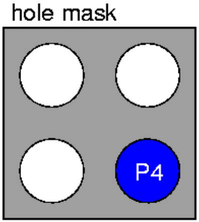

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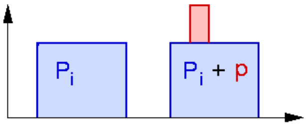

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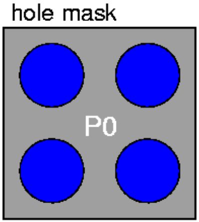
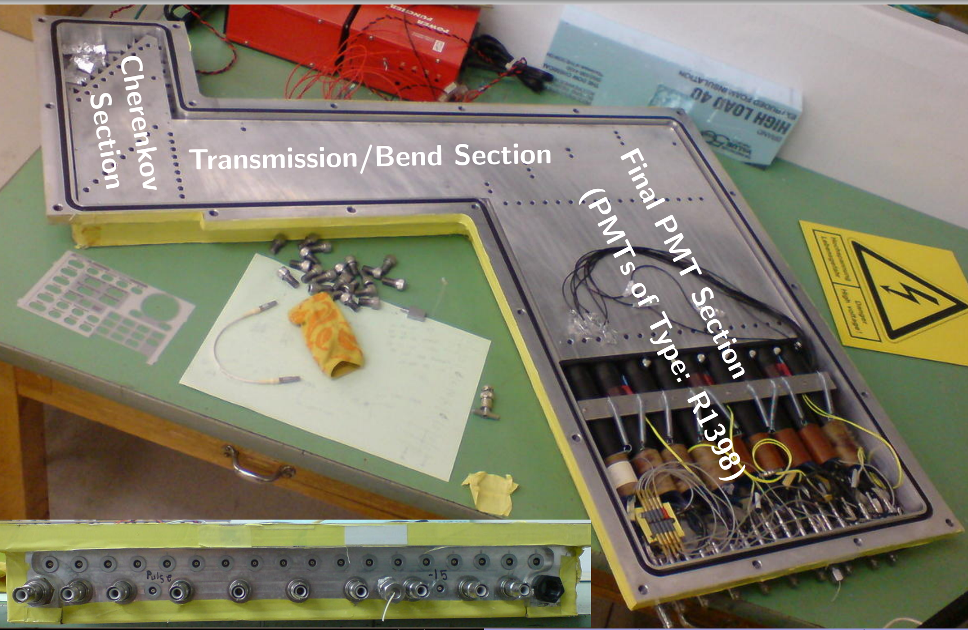
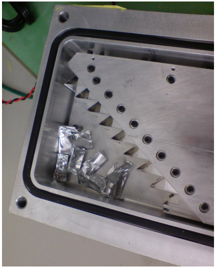


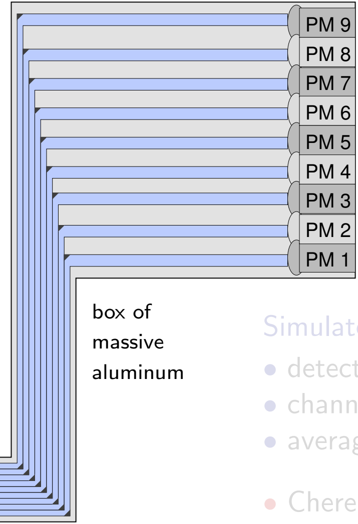
SLD Cherenkov Detector

The SLD Cherenkov detector I



The SLD Cherenkov detector II





readout with PMTs (R1398)

Optical Simulation:

Simulate 3 GeV e^- ($\sigma_x = 5$ mm)

- detector box walls: 5 mm wide
- channel walls: 500 µm wide
- average reflectivity: 92% (assumed)

- Cherenkov section: 20 cm long with: $\lambda \approx$ 200-650 nm $\rightarrow$ 30-40 γ's
- Quantum efficiency: $\langle q_{eff} \rangle = 20\%$

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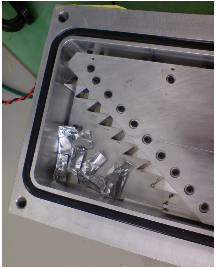

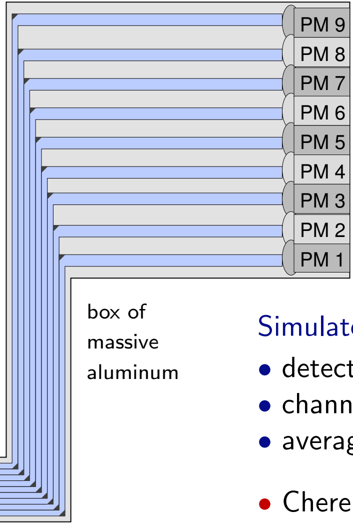

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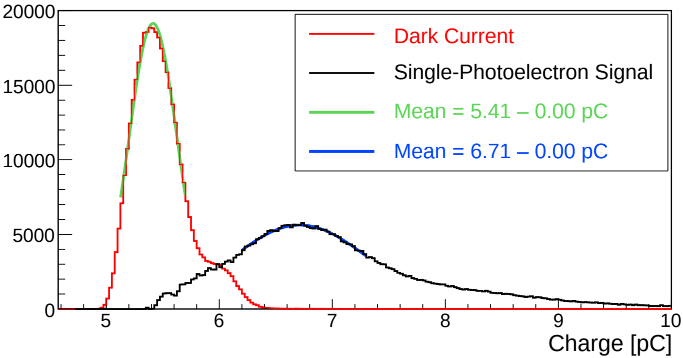
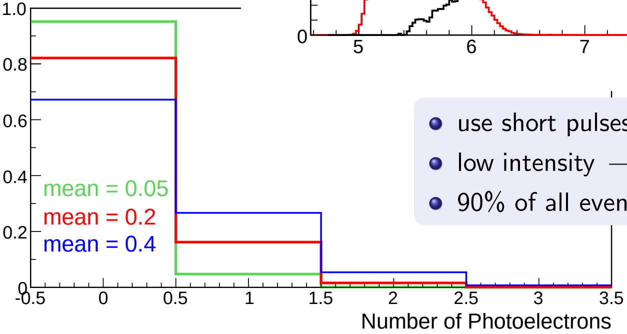
Determination of the PMT gain

$$g = \frac{Q_{1\,\mathrm{phe}} - Q_{\mathrm{dark}}}{e} \approx 8.1 \cdot 10^6$$



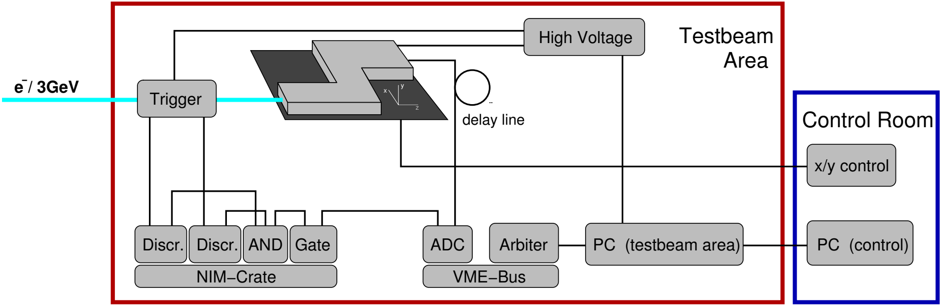


- use short pulses of blue LED light
- low intensity $\rightarrow$ 2-phe $\ll$ 1-phe Events
- 90% of all events are dark current only

SLD Detector
in the DESY testbeam

(November, 15 days)

Schematic drawing & Schedule



November 2007

15 days, incl. setup & first tests

- old PMTs
- channel 3 dead
- channels 1 & 2 bad

December 2007

4 days right before christmas

- some channels with SiPM and multi-anode PMTs
- channels 4 & 6 (SiPM) dead

SLD detector setup @ DESY testbeam 21

- detector mounted on moveable stage
- pressure gauge for monitoring purpose
- fast VME electronics for readout

What has been measured & how?

Preparatory steps:

- Position triggers exactly ("searching the beam", x/y-scans)
- y-Positioning of the SLD detector (channel height ≈ 1.7 cm)

First "real" measurements:

- Test all 8 channels (x-scan: 12 cm with 2 mm step size)
  (Ch. 3 PMT does not work → only 8 channels)
- Measurements without beam:
  without HV: electronics noise
  with HV: dark current rate

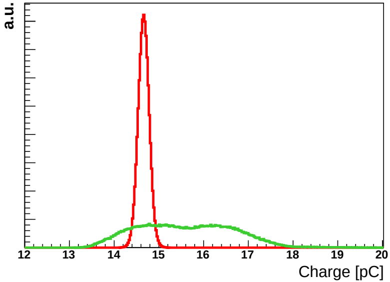
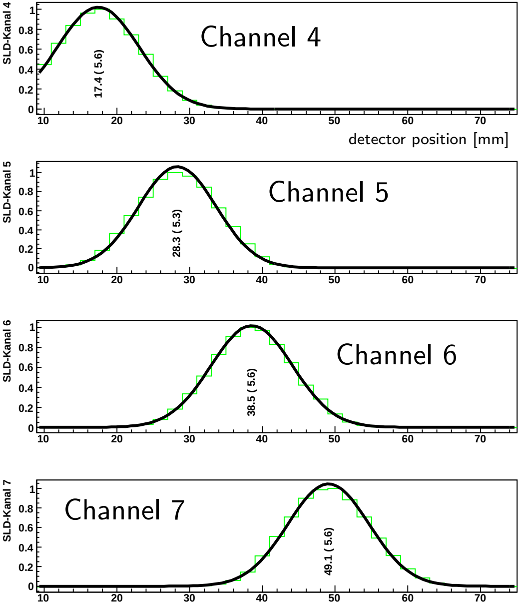
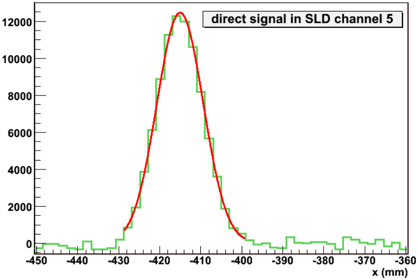


Table Scan





The channel width of 10 mm is folded with the beam spread and trigger xs, to find the accurate position of each ch.
→ for correct beam position!

Simulation yields:

$\sigma_{signal} \approx 5.3 - 5.6$ mm

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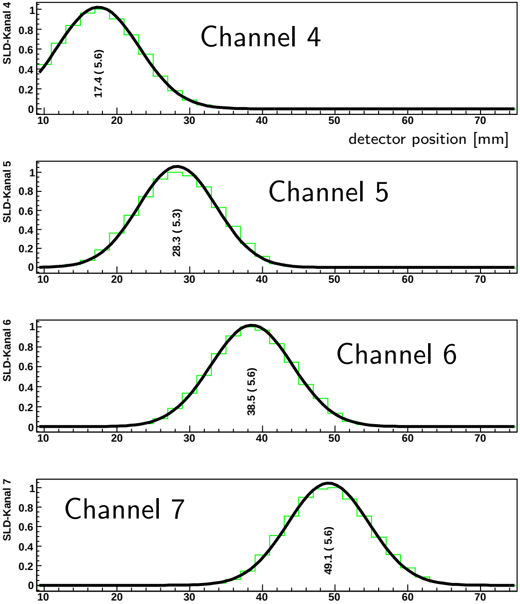

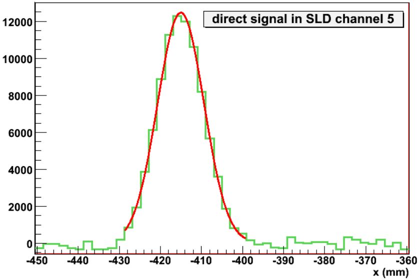

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Further Measurements

- Random triggers → variations in noise? time dependence?

- One measurement per channel each with 1 million events
(at x-mean of each channel)

- turn detector by about 5° in x-direction (tilt w.r.t. to the beam),
so that the electrons now hit the channels under a slight angle
(again a scan in x-direction)

- finally turn the detector by full 90° in x-direction
Long side → Cherenkov distance → Expectation: more light!?
(again a scan in x-direction)

- in between always 1-million reference measurements
on channel 5 (middle) to investigate the stability over time

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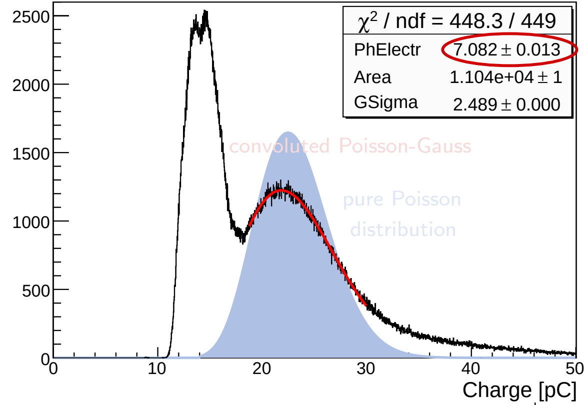
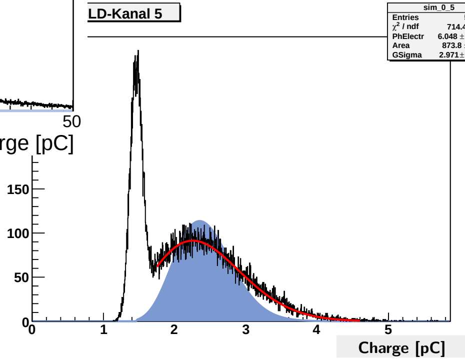
Signal Shape & Comparison with Simulation



From optical Simulation:

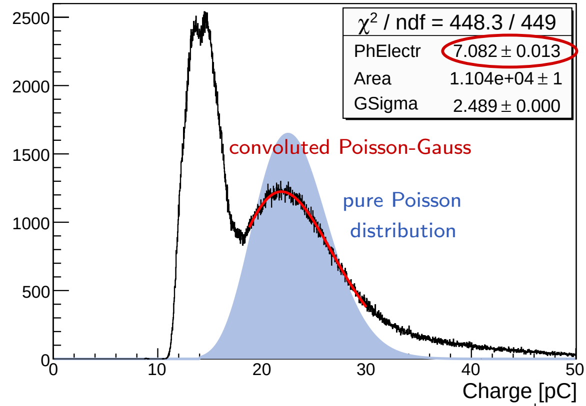
- photo electrons ($\approx$ 6)
- matches well with the observed data



Convoluted Poisson-Gauss

- effective gain
- pedestal
- photo electrons ($\approx$ 6-7)

Signal Shape & Comparison with Simulation



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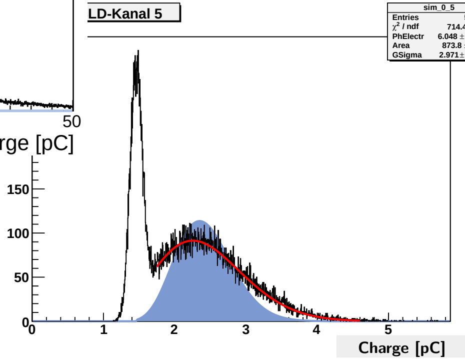


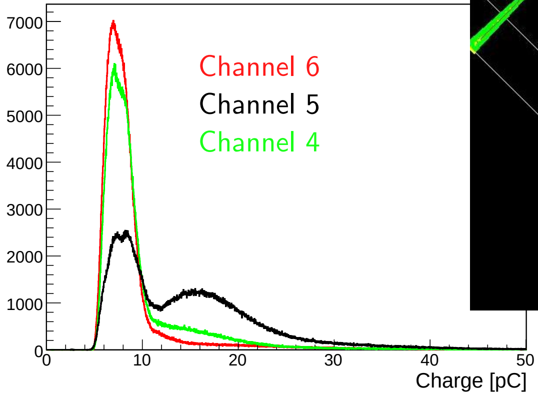
Convoluted Poisson-Gauss

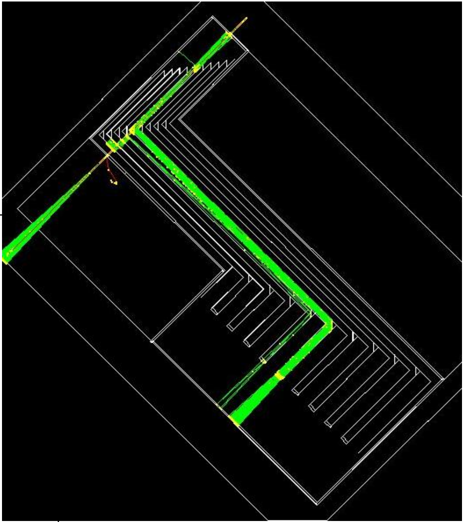
- effective gain
- pedestal
- photo electrons ($\approx$ 6-7)

Crosstalk: beam on channel 5

Crosstalk is asymmetric:

more in Channels to the left,
less in Channels to the right
of the one with beam on.

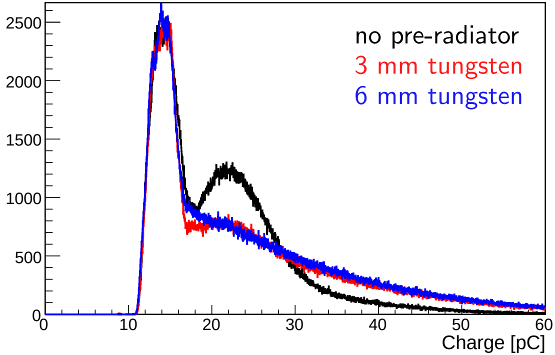




Trying to get more light out...

- Use pre-radiator (thin tungsten tiles) in front of the detector box
- Turn the detector such that the long side is the Cherenkov section

First try: tungsten pre-radiator (SLD: used 3 mm lead as pre-radiator)



Rad. length: $X_0 \approx 0.35$ cm
should lead to showering:
more e^- → more photons
→ larger signal

Dilutes spectra instead!
e^- with scattering angles above 4° cross two tubes.

→ **rad. length too large!**

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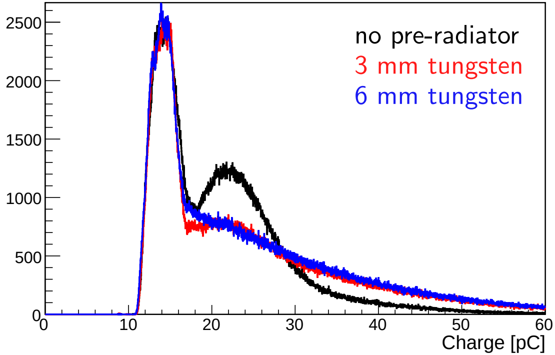

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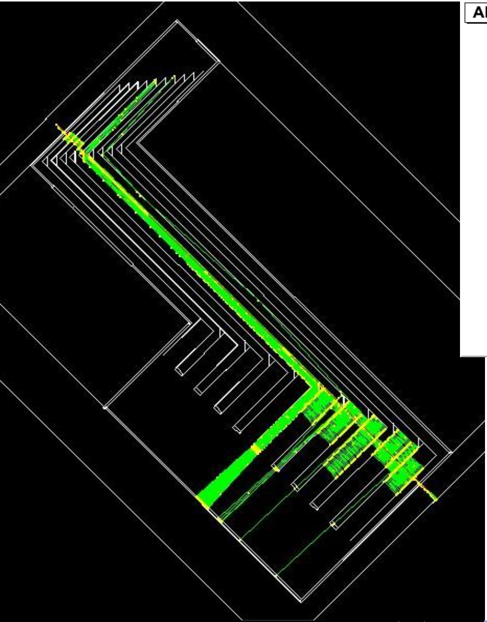
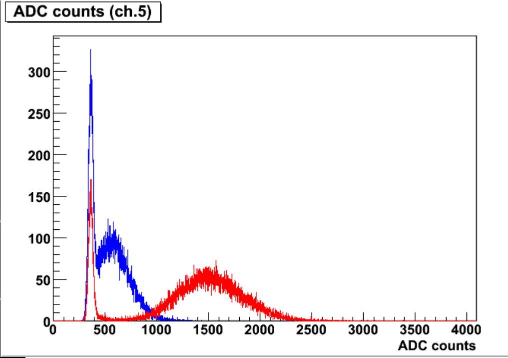
Second try: Rotated Detecor I



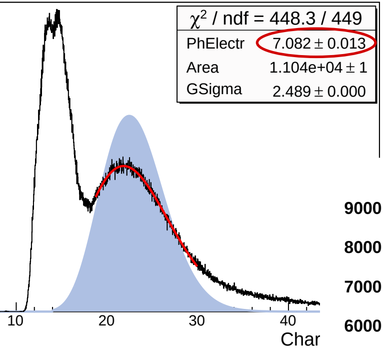


Transmission section: 40-80 cm long
$\longrightarrow$ increased photon yield

(Should provide a factor 2-4 larger signal.)

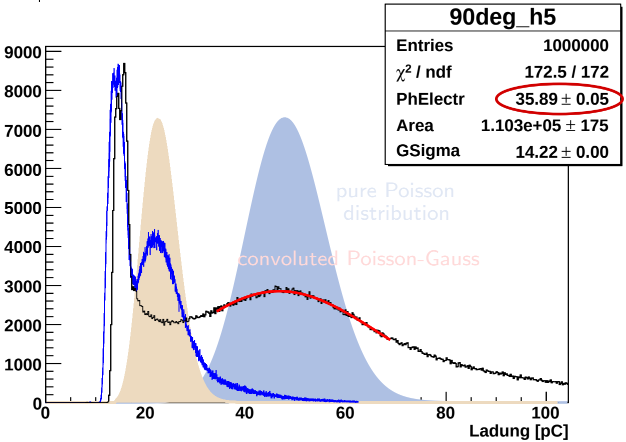
less reflections $\longrightarrow$ additional gain

Second try: Rotated Detecor II



Detector turned by 90°

→ longer Cherenkov section



Detector in normal position

dark current shifting. . .

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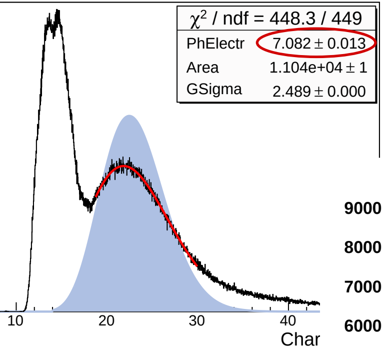

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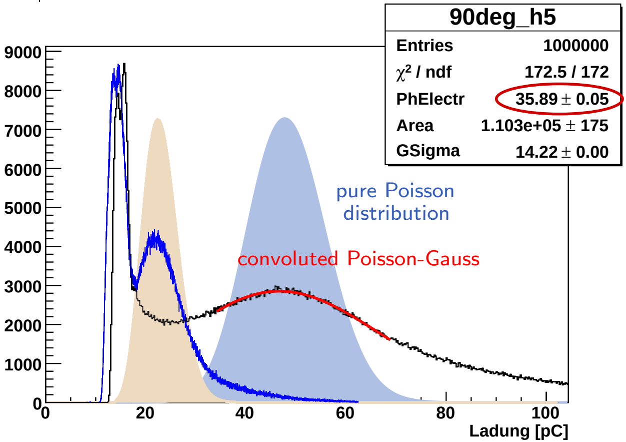
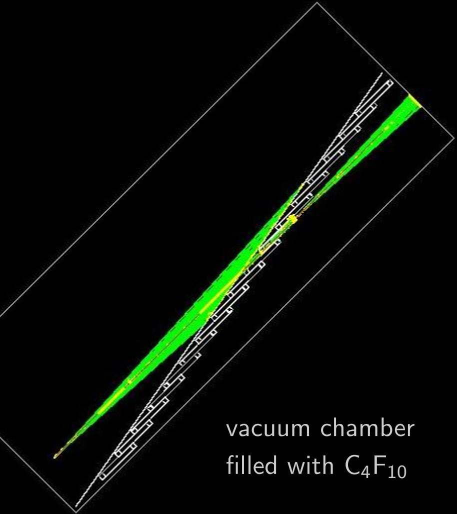
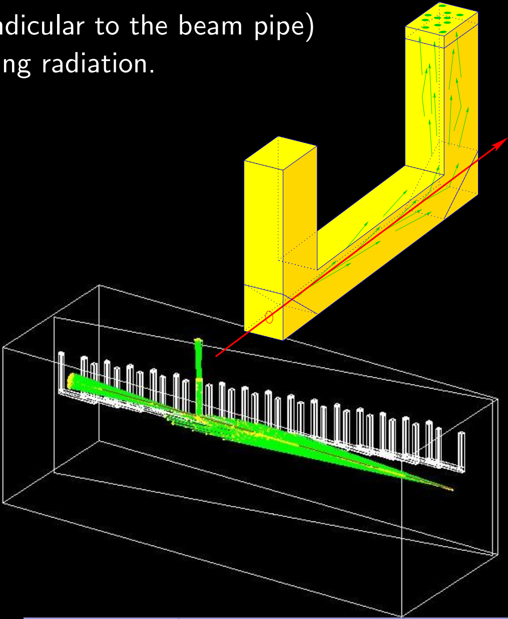


dark current shifting. . .

ILC Cherenkov Detector **prototype**

Go to third dimension (plane perpendicular to the beam pipe) to avoid synchrotron & beamstrahlung radiation.

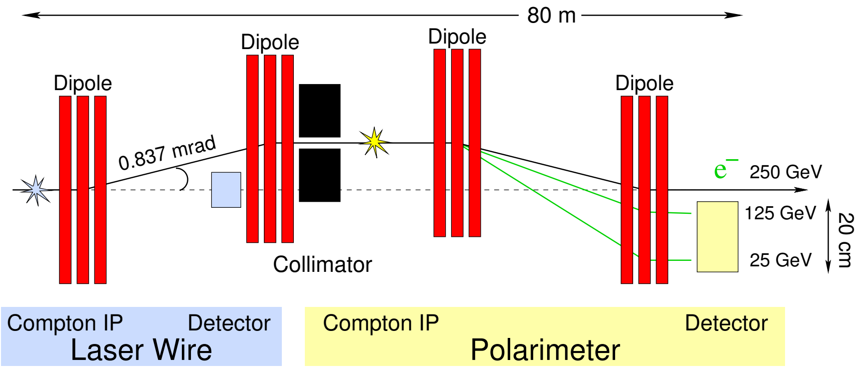




Chicane Issues

Fixed vs. Scaled Field
@ Fixed Dispersion

Fixed Field Chicane



- Compton edge is always at the same spot in the detector!
  → the Compton laser-IP & Collimator have to move
- Laser wire detector (emittance) very close to beam pipe @ 500 GeV (not operable anymore @ 1 TeV)

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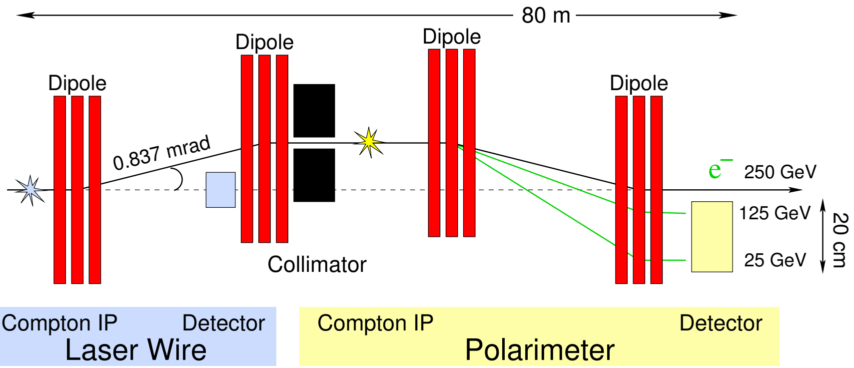

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Fixed vs. Scaled Magnetic Field?

Can three fixed dispersions cover everything, all CM-energies, from GigaZ up to 500 GeV ?

What happens to the 1 TeV upgrade option ?

Let's say for dispersions:

- 10 mm for 250 GeV to 500 GeV
- 30 mm for baseline parameter range: 100 GeV to 250 GeV
- 50 mm for GigaZ (45.6 GeV) to 100 GeV

Varying the Magnetic Chicane Layout

E [GeV]	B [mT]	disp.[mm]	E_{Comp} [GeV]
500.0	97.0	10.6	97.0
250.0	97.0	21.1	97.0
100.0	91.9	50.0	55.1
45.6	41.9	50.0	25.1

⇐ Fixed Field

Consider a design of the magnetic chicane with scaled field, and e.g. three "fixed field ranges", each with a fixed dispersion dep. on the range.

	1^{st} range		2^{nd} range		3^{rd} range	
E [GeV]	B [mT]	disp.[mm]	B [mT]	disp.[mm]	B [mT]	disp.[mm]
500.0	97.0	10.6	97.0	10.6	97.0	10.6
250.0	97.0	21.1	97.0	21.1	48.5	10.6
100.0	91.9	50.0	55.1	30.0	19.4	10.6
45.6	41.9	50.0	25.1	30.0	8.8	10.6

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E [GeV]	B [mT]	disp.[mm]	E_{Comp} [GeV]
500.0	97.0	10.6	97.0
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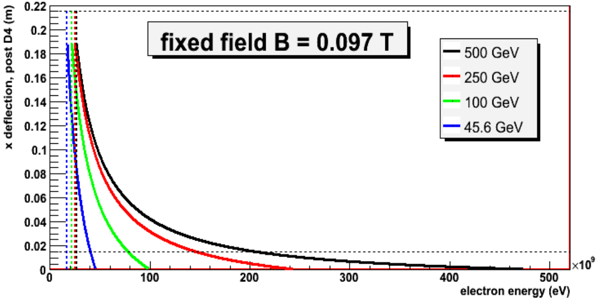
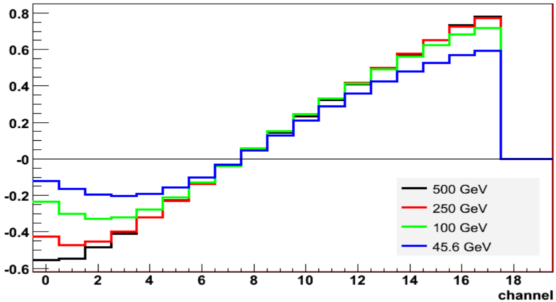
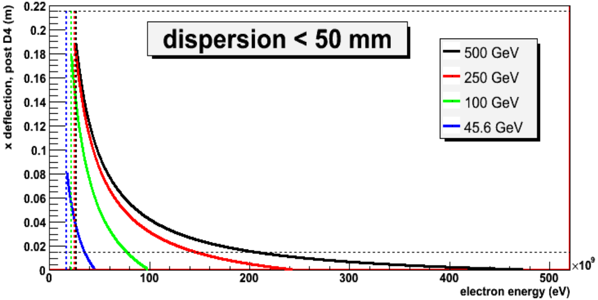
Fixed Field

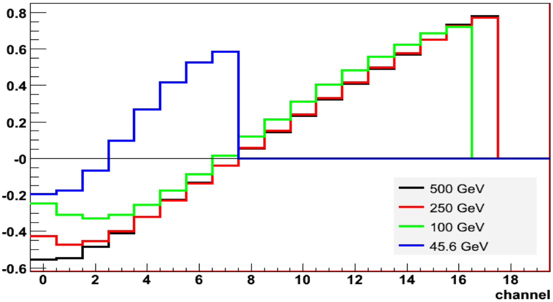


Only for fixed field:
Identical large detector coverage for all energies

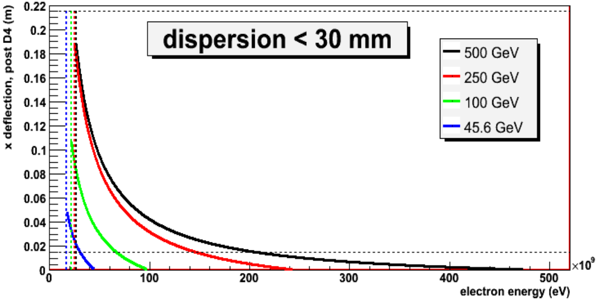


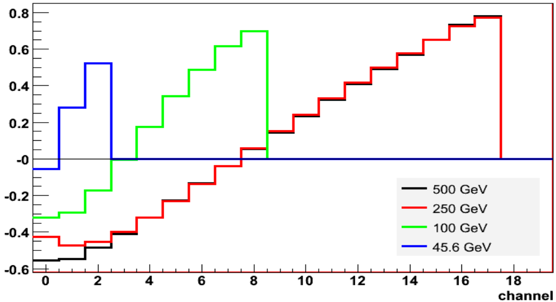
Scaled Field 1: Dispersion < 50 mm



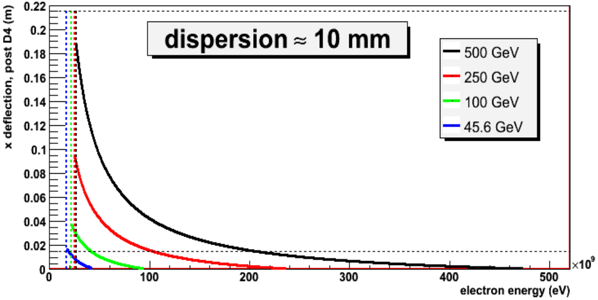


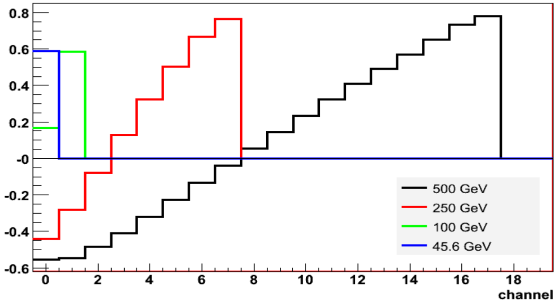
Scaled Field 2: Dispersion $<$ 30 mm





Scaled Field 3: Dispersion $\approx$ 10 mm

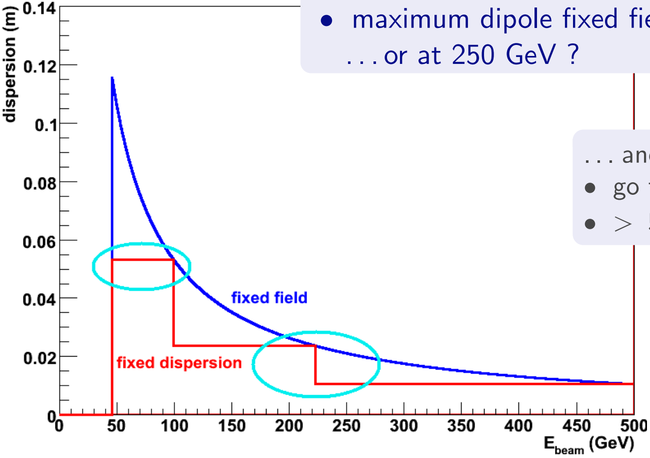




Fixed vs. Scaled Magnetic Field

What about . . .

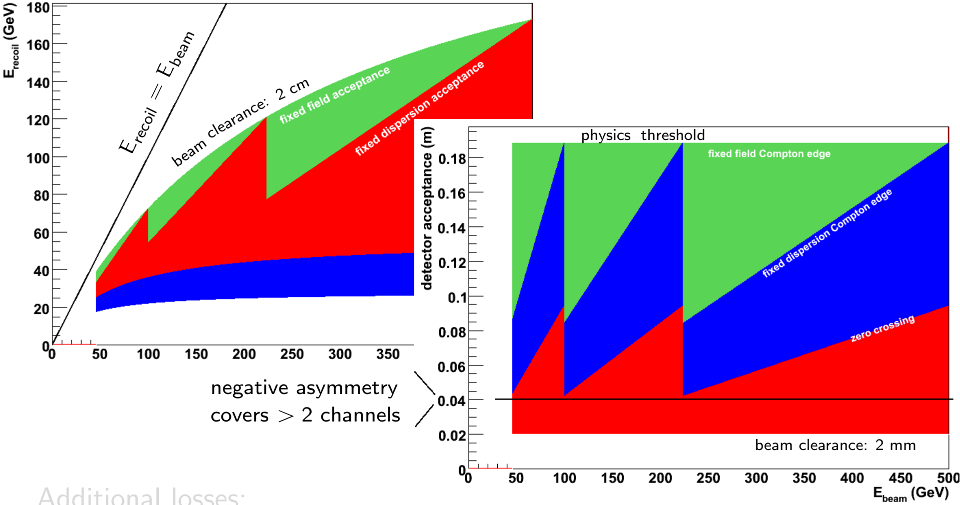
- overlap regions between dispersion ranges ?
- overall normalisation ?
- maximum dipole fixed field @ 500 GeV ?
  . . . or at 250 GeV ?



. . . and next:

- go to four dispersions?
- > 5 cm disp. @ GigaZ?

Energy & Detector Acceptance



Additional losses:

considerable asymmetry and reduced cross section due to a scaled field design of the chicane. (scaled field ↔ fixed dispersion)

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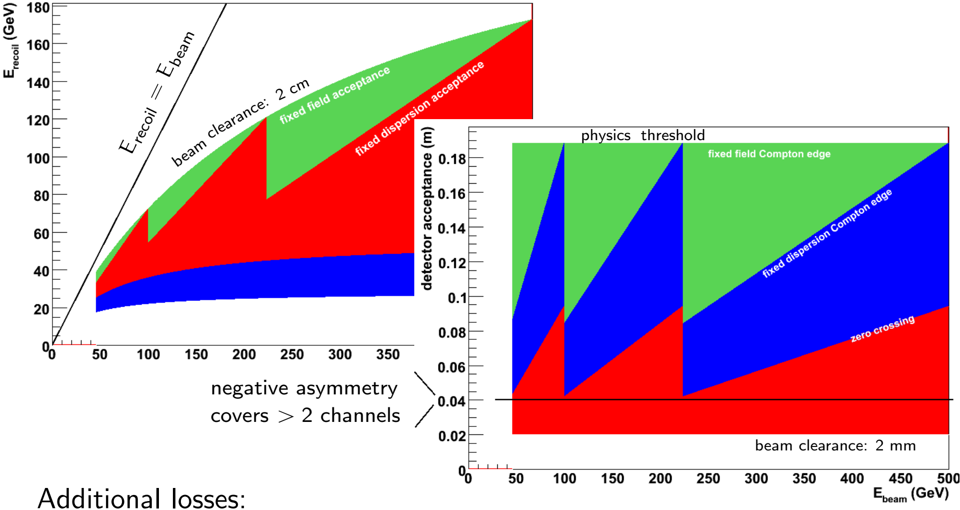

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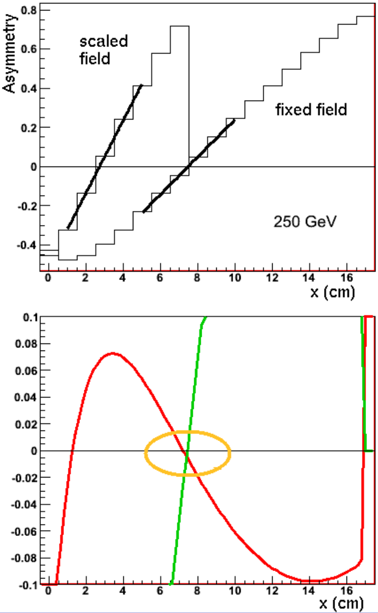
Asymmetry extracted from Data

Asymmetry:

fit straight line



For the Asymmetry:

Need to extract the positions of the Compton edge and zero crossing with high precision from data.

$\Rightarrow$ This defines the precision for the polarisation measurement !

Conclusion

Outlook

Conclusions & Outlook

- Photodetector testbench
  - ▷ different methods for measuring the linearity are developed
  - ▷ promising first results of detailed studies
  - ⇒ further tests ongoing → more results coming soon!

- Two successfull testbeam periods
  - ▷ operating & testing the SLD detector was very valuable
  - ▷ layout well understood → optical simulation has been tuned
  - ▷ analysis of latest testbeam data (new photodet.) ongoing
  - ⇒ simulate layout of the ILC prototype!

- Chicane issues: fixed vs scaled field
  - ▷ fixed field ensures high precision for all beam energies
  - ▷ need (at least) 3 channels covered by negative asymmetry to extract analyzing power / asymmetry from the spectra

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In Defence of...

Upstream Polarimetry

Up- vs Downstream: Backgrounds

- Backgrounds are THE BIGGEST operational difference:
  beam-beam effects are HUGE

  Downstream polarimetry only possible if:

  ▷ beam stay clear of at least ± 0.75 mrad

  ▷ crossing angle $\neq 0$

  ▷ magnetic chicane (to separate Compton-e^- from degraded beam-e^-)

- Upstream: no difficulties from backgrounds
  Only multi-scattered synchrotron photons appear (from the walls of the vacuum chamber), apart from external complications like e.g. photon- and/or MPS-collimators

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  only region close to Compton edge accesible . . .
  limiting effect @ SLD: determination of AP from data (i.e. calibration)

- Other issues depend on the technical realisation, e.g. like the beam-beam depolarisation (rather complicated)

- Two polarimeters per beam line: complementarity, redundancy and functionality due to different systematics, but comparable precision

- Cross checks between polarimeters

- Cross checks with physics results from e^+/e^- IP possible, but slow
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Upstream Polarimeter Strengths:

- high repetion rate possible → can sample all ILC bunches per train → fast polarisation measurements facilitating fast systematic checks and also calibration
- very low backgrounds (as pointed out before)
- very high confidence for a properly designed system to work well, making pol. measurements parasitic to delivered luminosity

Downstream Polarimeter Strengths:

- can measure polarization differences for collisions vs no collisions
- can measure effects from changing detector solenoid & DID (detector integrated dipole)

Need operational & functional redundancy! learned from HERA and SLC

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There is only ONE way to validate the results: simultaneous measurements with entirely independent polarimeters of comparable precision.

$\Rightarrow$ Systematic effects rule the game !

For precision physics we will need:

- a precise knowledge of all beam parameters: energy, polarisation . . .
- to combine the results $\rightarrow$ reduce total systematic uncertainty
- to precisely understand orbit & spin alignment at the e^+/e^- IP (two polarimeters spanning the IP are indispensable for this!)
  - ▷ spin rotator procedure for achieving longitudinal polarization
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Helicities are there in the SM → initial state should reflect this!

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"Beam energy and polarisation must be stable and measurable at a level of about 0.1%."

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Mini-Workshop on Spin Dynamics
Cockcroft Institute, Liverpool – March 27-28, 2008

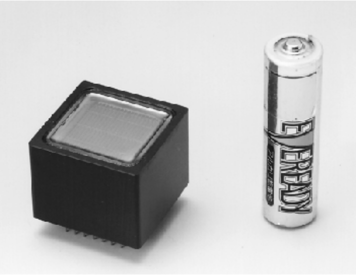
Positron Polarisation Workshop
DESY-Zeuthen, Berlin – April 9-11, 2008

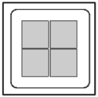
Both workshops are well suited to discuss more details and also cost reduction possibilities without deteriorating the physics goals of the ILC !

BACKUP

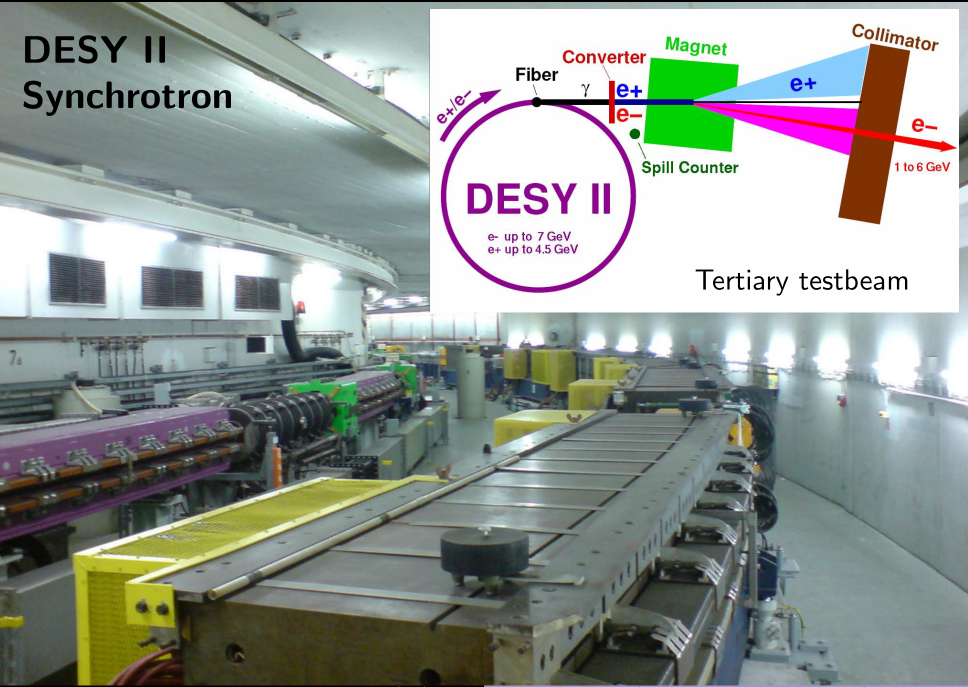
Multi-anode Photodetector

- fast
- compact
- fits the square gas tube cross sections optimally
- offers four anodes for separate readout
- but: need to study crosstalk ?!



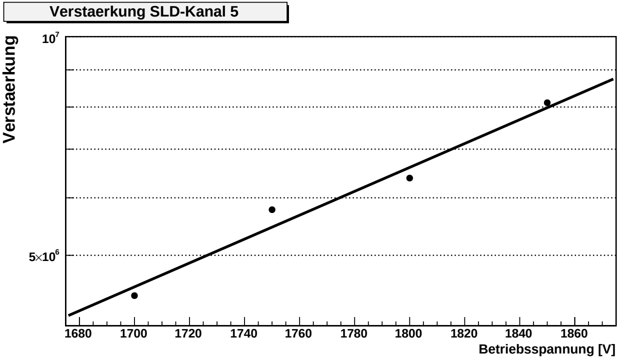
	4 Channel (2 × 2) Multianode
Anode Type	
Multianode PMT	R5900U-M4 Series
Multianode PMT Assembly (Built-in Voltage Divider Circuit)	—
Effective Area (per Channel)	8.9 mm × 8.9 mm
Anode Pulse Rise Time (per Channel)	1.2 ns
Cross-talk	2 %

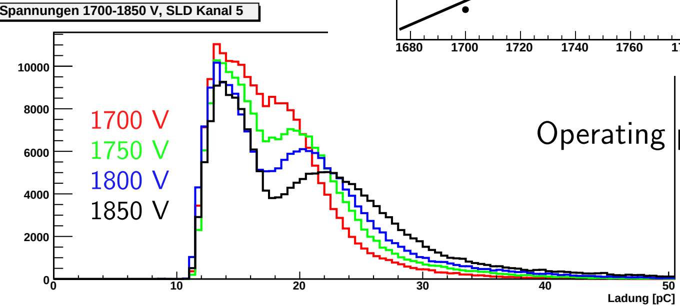
DESY II Synchrotron



Tertiary testbeam

Gain varies by a factor of two between channels (compare errors)



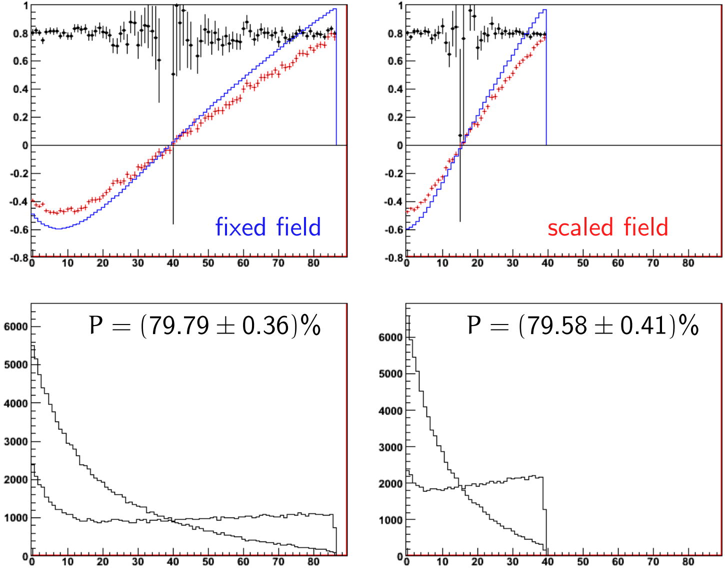


Operating point: 1850 V

Assume: perfect knowledge of Compton edge → AP

@ 250 GeV (11 cm dispersion) → ≈ 50% dipole strength

with a 90 channel detector (currently: ≈ 20 channels)



Synchrotron radiation of the primary and the deflected e^+/e^--beams

No Problems are expected with the originally planned configuration, neither for the dipole magnets, nor for the Cherenkoc detectors (incl. the PMs) . . .