A high-precision calibration system for the Compton polarimeters at the ILC.

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Overview

- Compton polarimetry at the ILC
- Calibration strategy
- Non-linearity measurement
- Conclusions & Outlook

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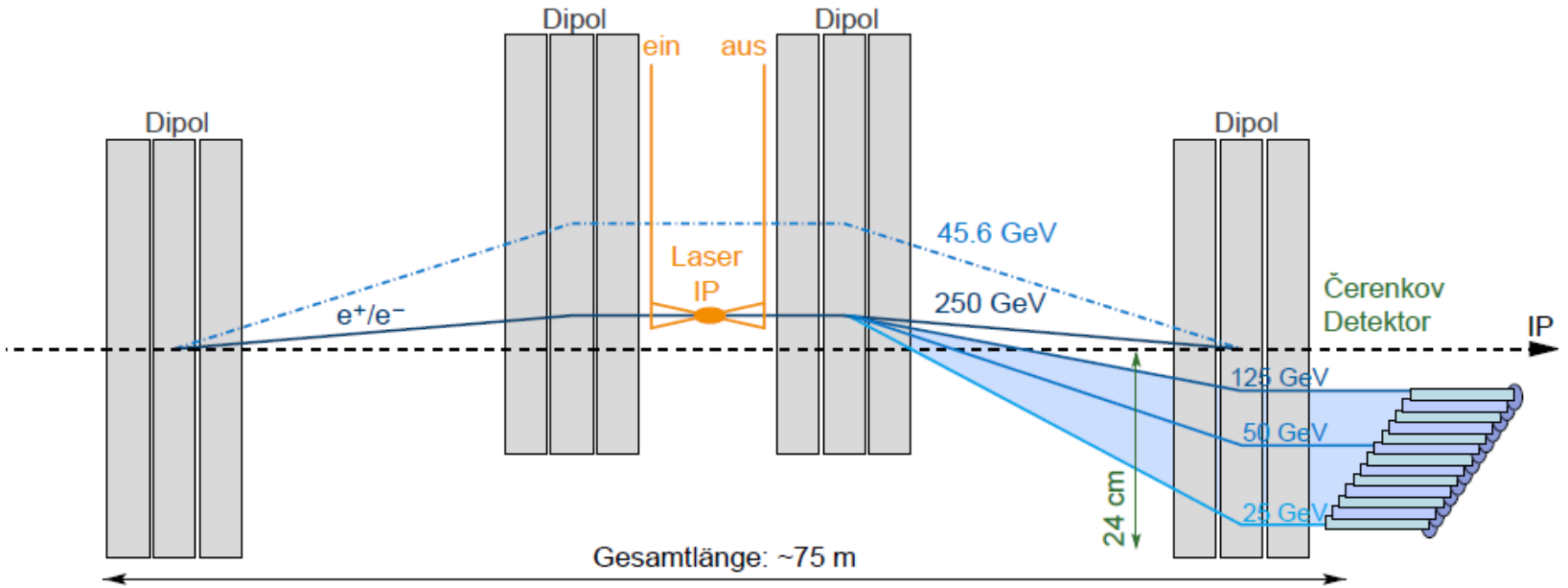
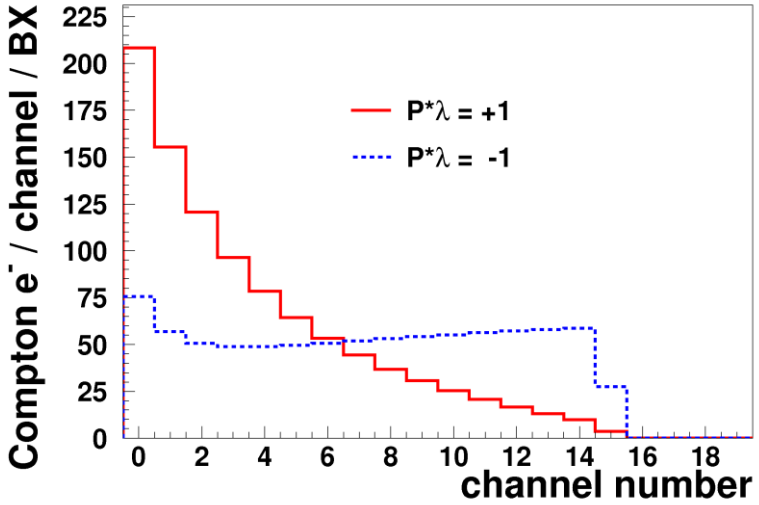
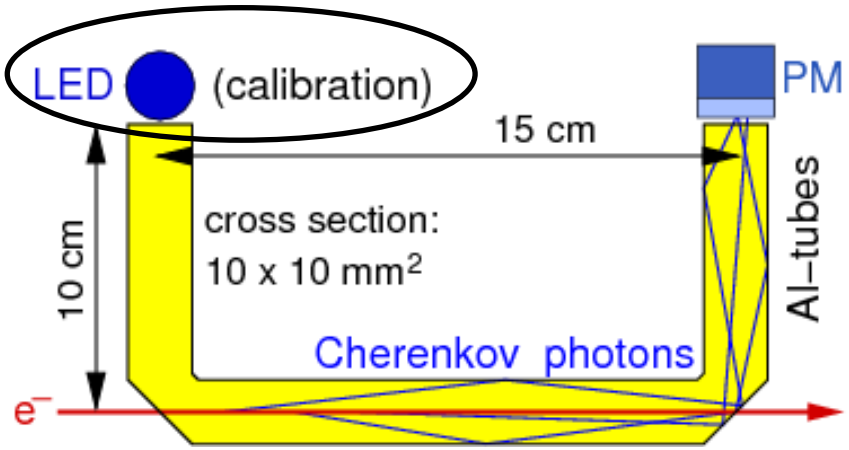
Polarization measurement



- Compton polarimeter: per beam one polarimeter before and after IP
- Compton energy spectrum dependent of **beam polarization P($e^{+/-}$) · laser helicity λ**
- magnetic chicane: energy spectrum translates into spatial distribution→ energy spectrometer
- classical solution for Compton electron measurement: Gas-Cherenkov detector

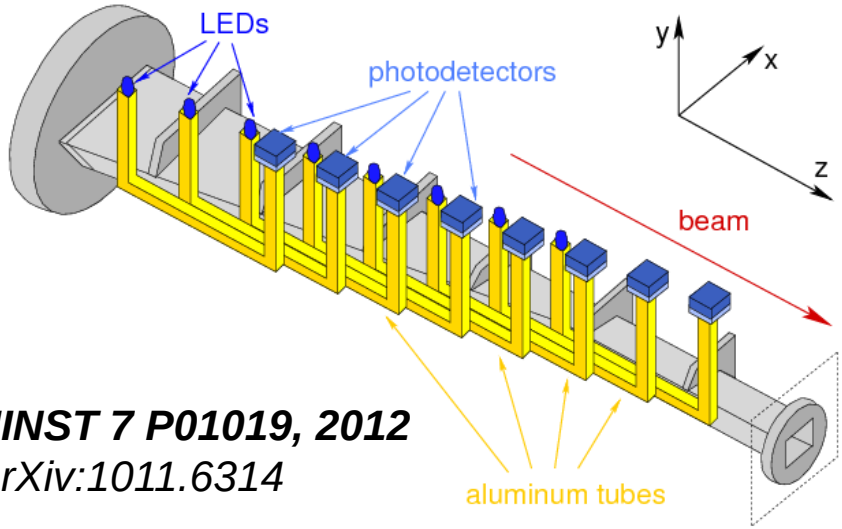


Gas Cherenkov detector prototype

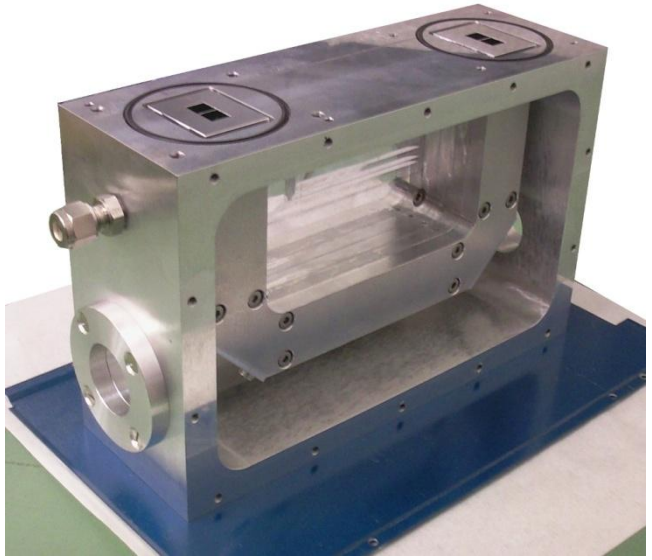


- gas-filled U-shaped tube (C_4F_{10} → n = 1,0014)
- 0-210 Compton electrons per channel
- channel width (10mm) defines energy resolution

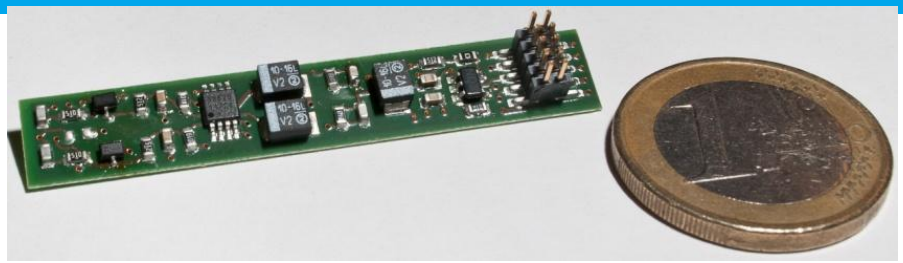
pro: known technology
con: has to be calibrated



JINST 7 P01019, 2012
arXiv:1011.6314

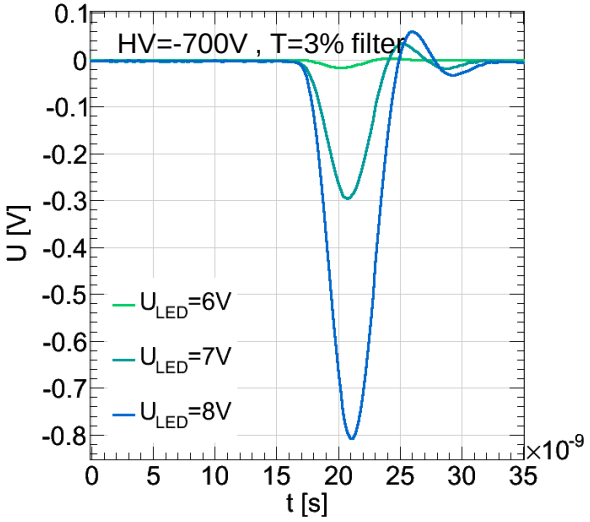


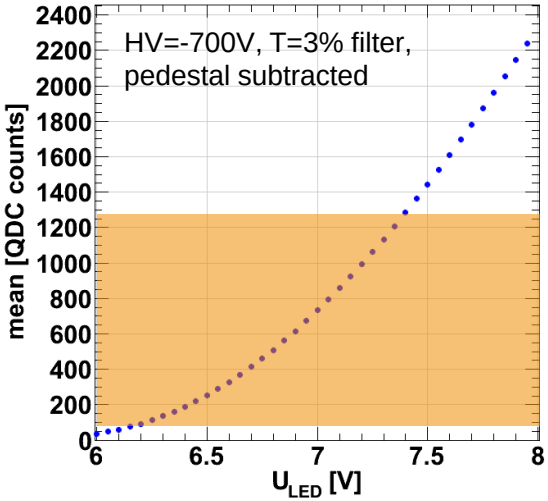
LED calibration source

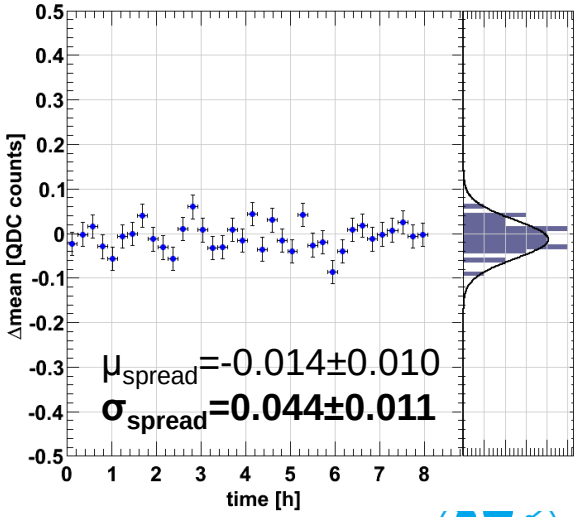


LED driver with two independent LEDs:

- **wave length** in UV range (λ=405nm)
- applicable in detector design → **small**
- **short light pulses** (<10ns)
- coverage of the **whole dynamic range** of the expected signal
- **reproducable** and **stable** light pulses







Contributions to uncertainty of polarization measurement

design aim: $\Delta P / P \approx 0.25\%$

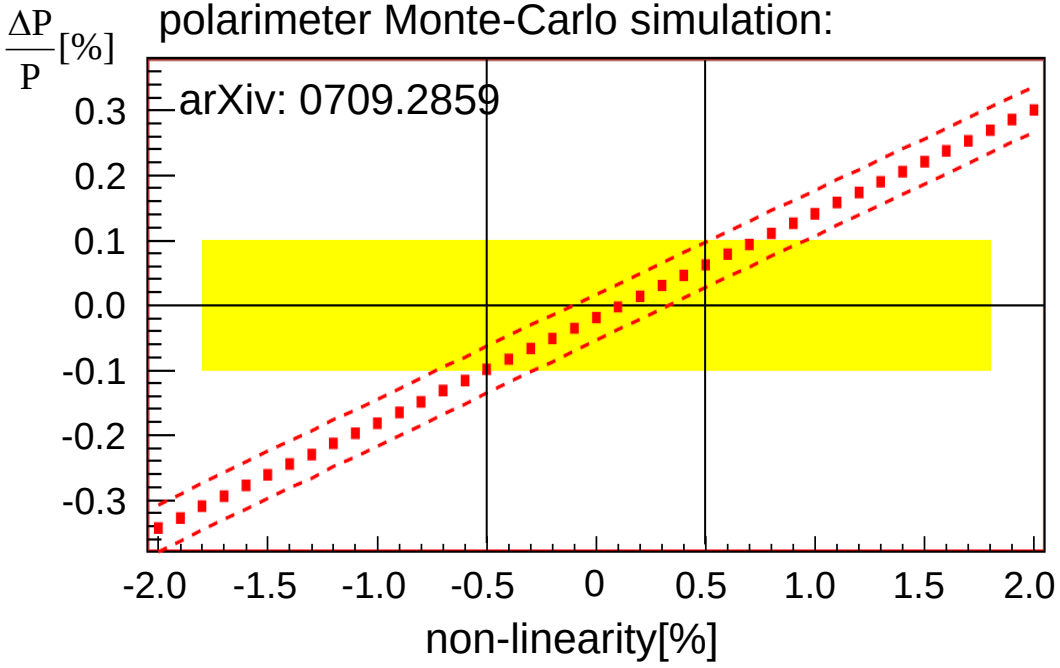
detector non-linearity

overall contribution to ΔP/P has to be less then 0.1%

detector alignment

laser helicity

polarimeter Monte-Carlo simulation:



→ non-linearity of detector < 0.5%

→ calibration of detectors/PMTs neccessary

- Compton polarimetry at the ILC
- **Calibration strategy**
- Non-linearity measurement
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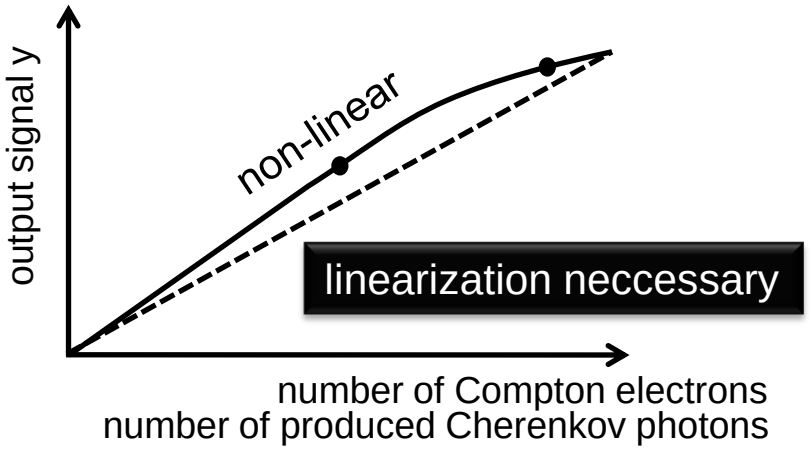
Polarization measurement

Measurement of number of Compton electrons for two helicity configurations of the laser in one detector channel (=energy interval):

$$P(e) \propto \mathcal{A} = \frac{N^+ - N^-}{N^+ + N^-}$$



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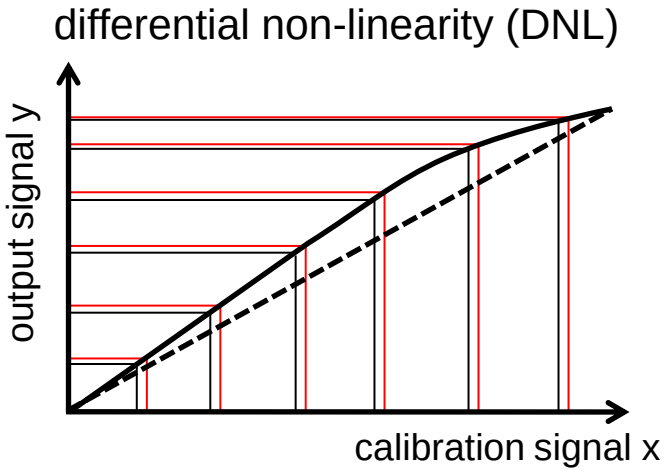

→ **light source doesn‘t need to be calibrated**
→ **measurement only of differences**
→ **NO absolute calibration**

Polarization measurement

Measurement of number of Compton electrons for two helicity configurations of the laser in one detector channel (=energy interval):

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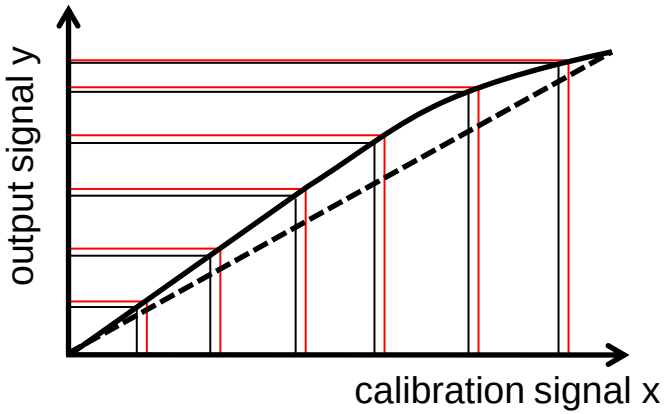
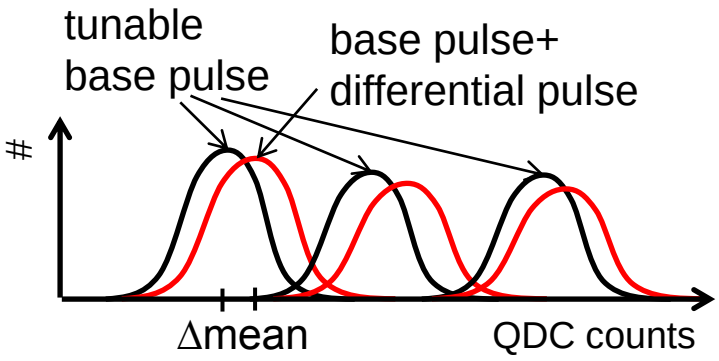
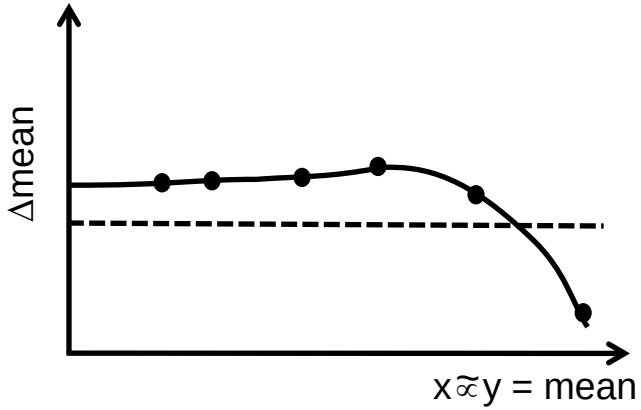
differential non-linearity (DNL)



double pulse method



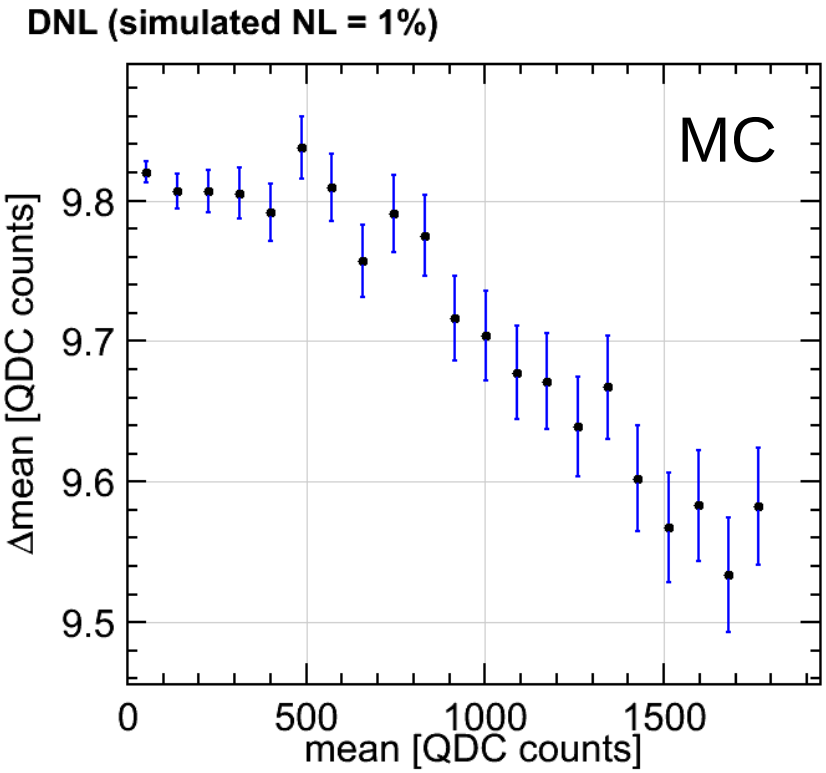


Linearization of data with measured DNL

Simulated non-linearity:

$$y = (c + A \cdot x^2) \cdot x$$

output signal (e.g. QDC counts) — input signal (e.g. light pulse)



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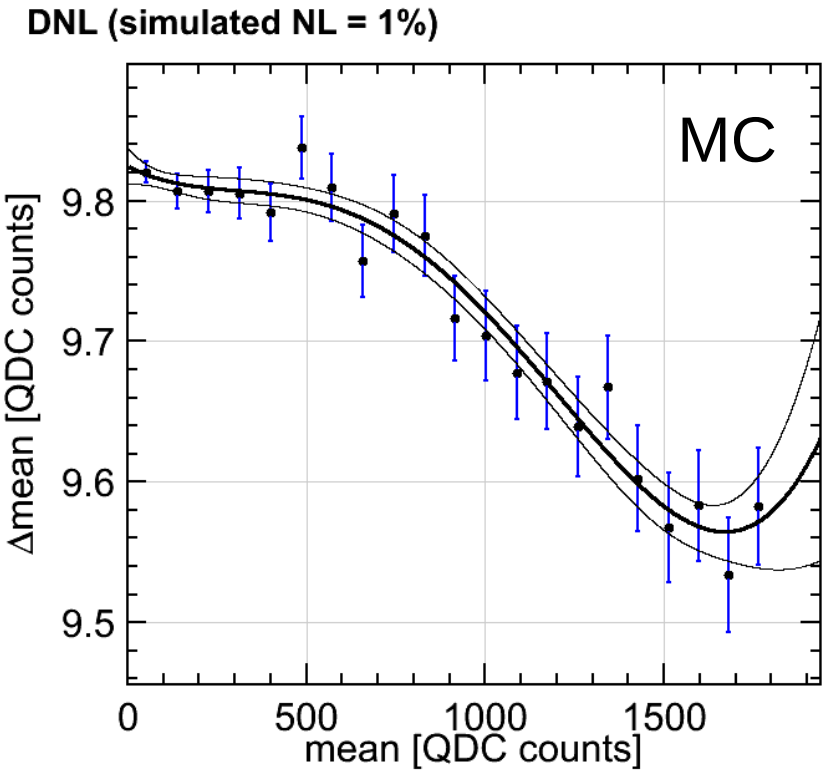

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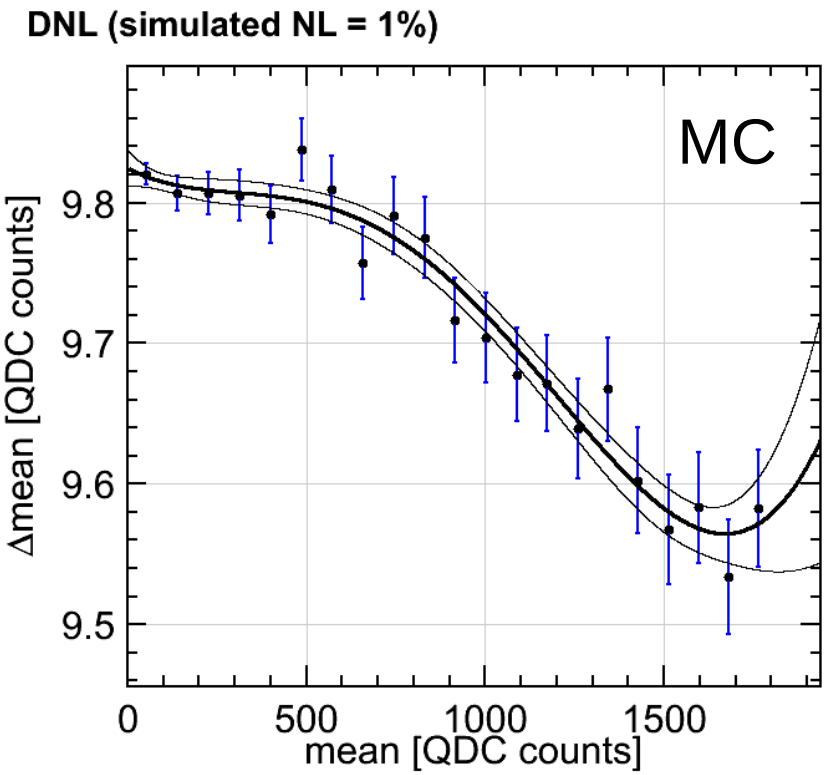

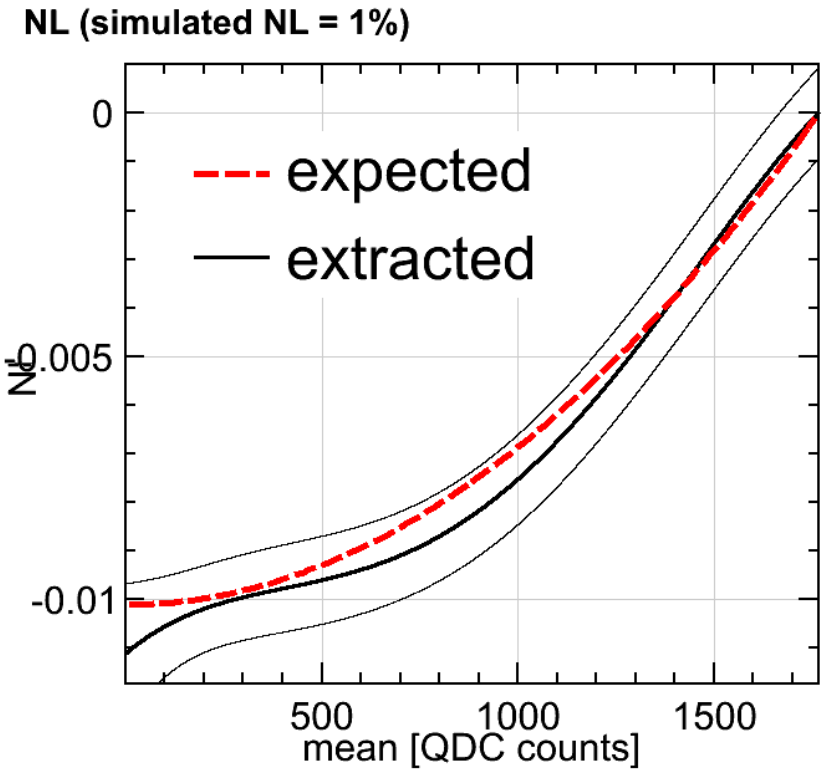

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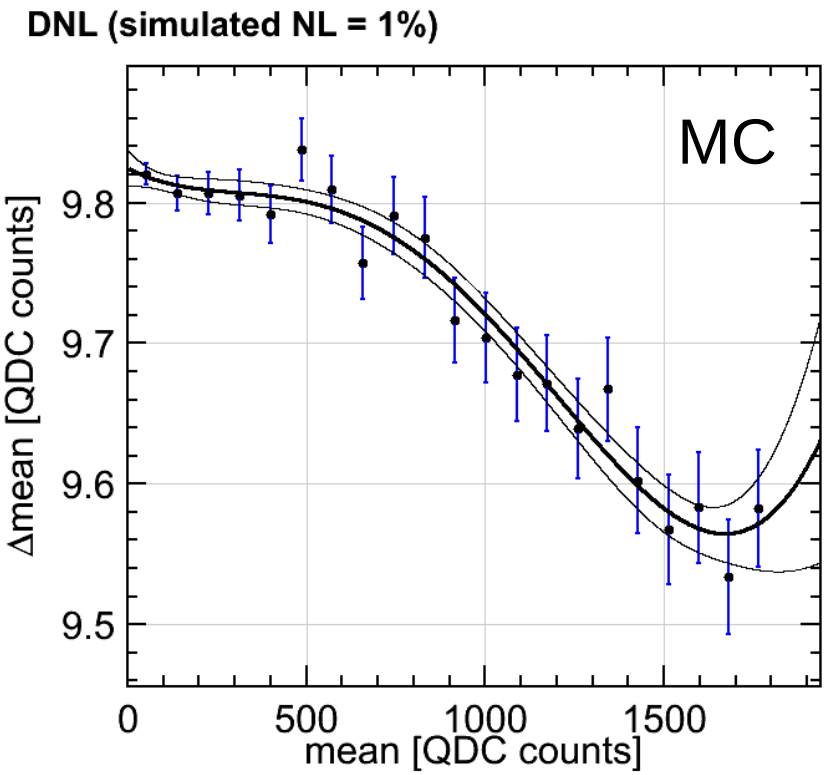
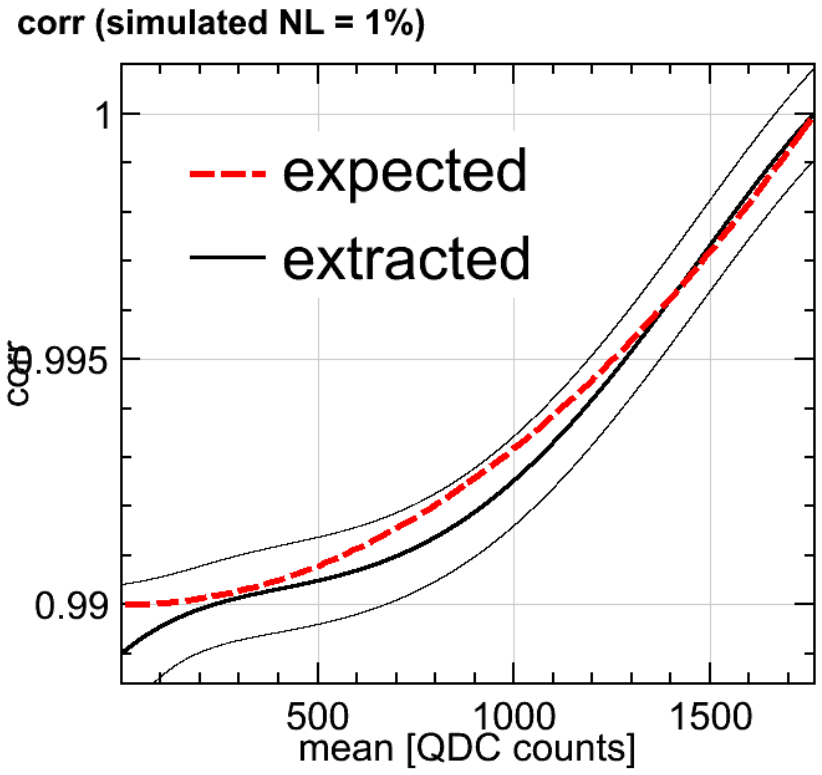
$$corr \propto \frac{1}{c + A \cdot x^2}$$





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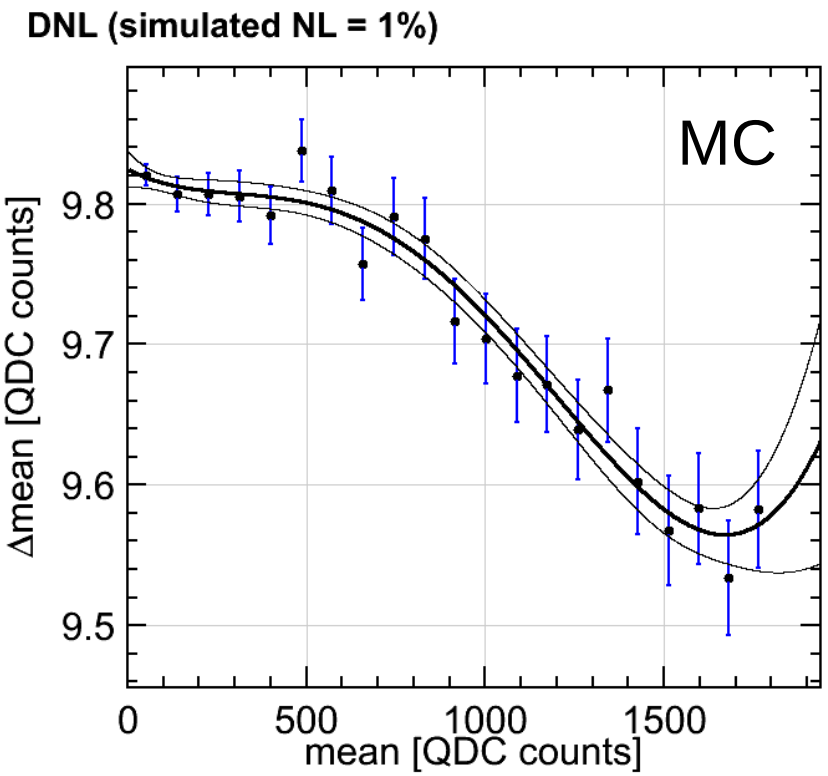
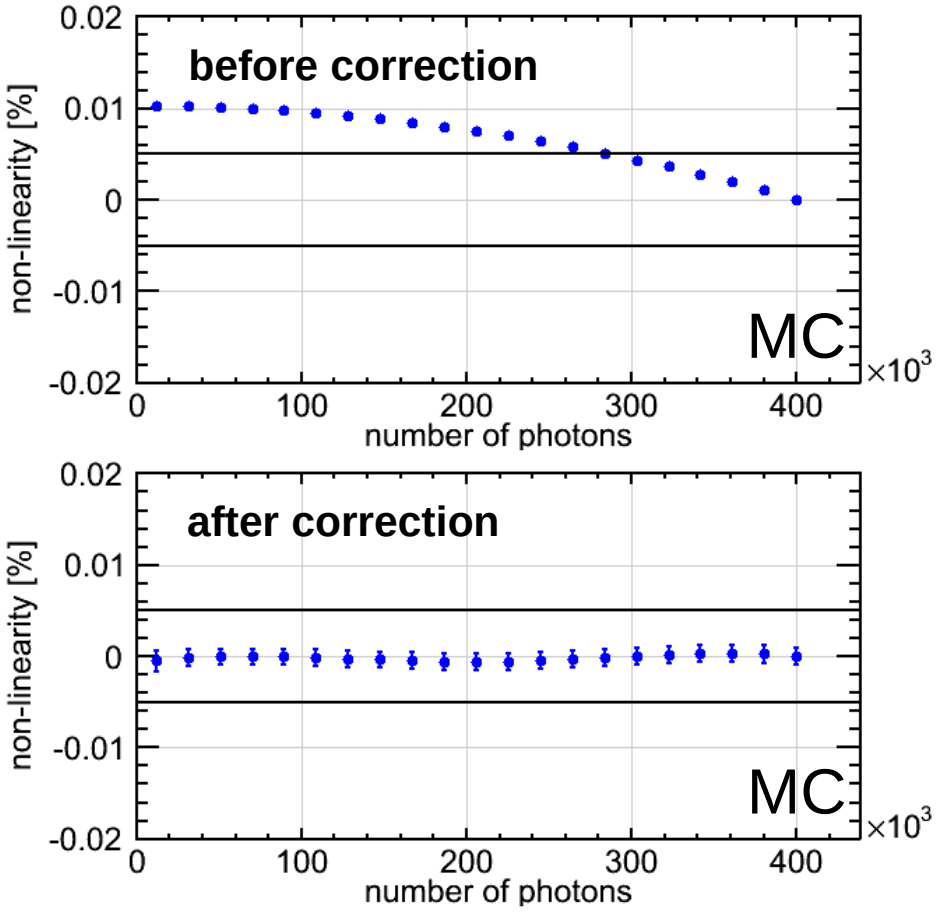
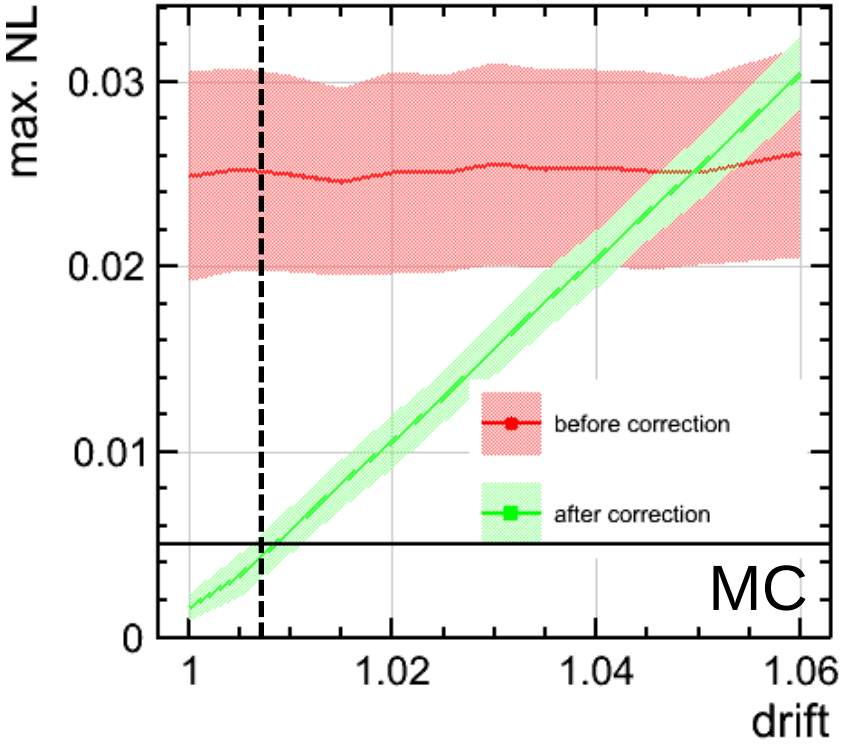




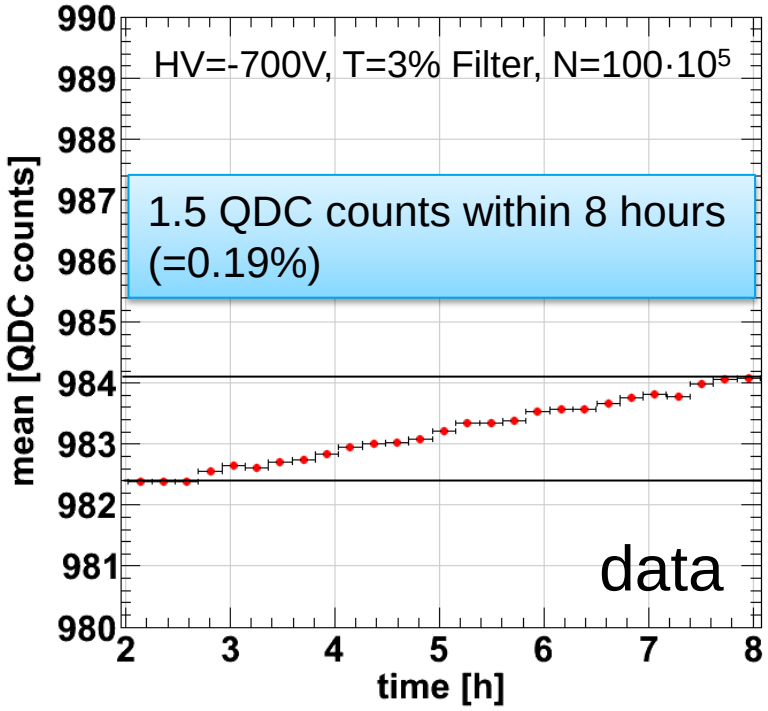
Effect of LED intensity drift

What is the maximum acceptable drift of LED intensity over one run?

effect of drift of LED-D on correction



measured drift of LED-D

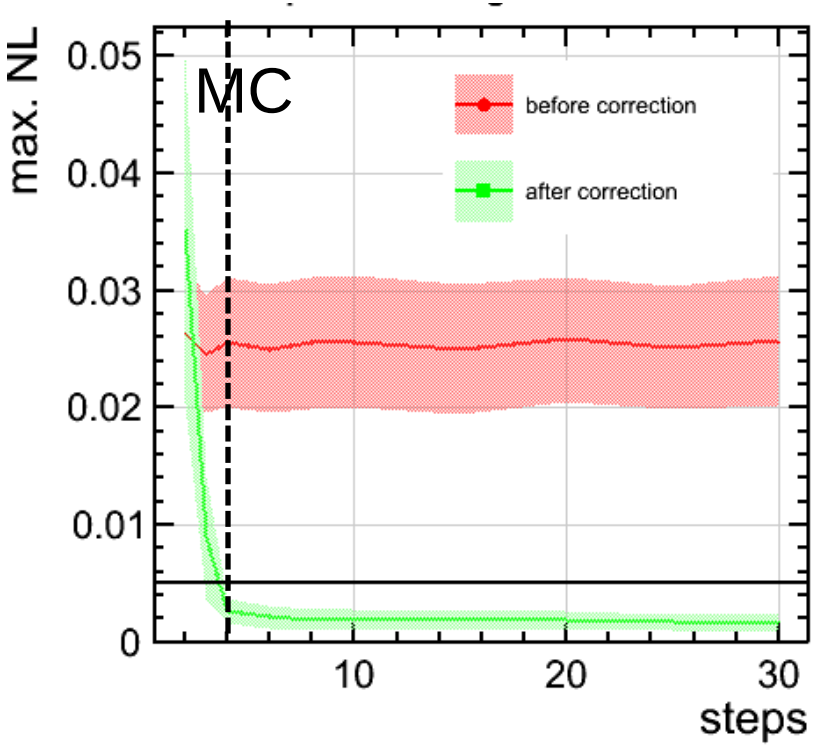


→ drift must be smaller then 0,5-1%

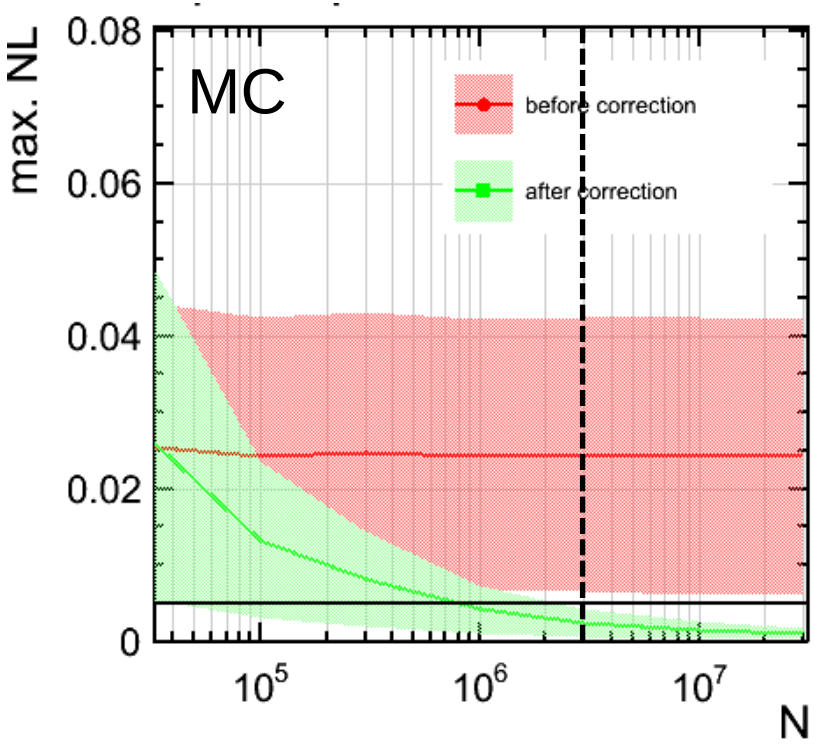
Required measurement parameters

What are the required DNL measurement parameters?

number of measurements within scan range



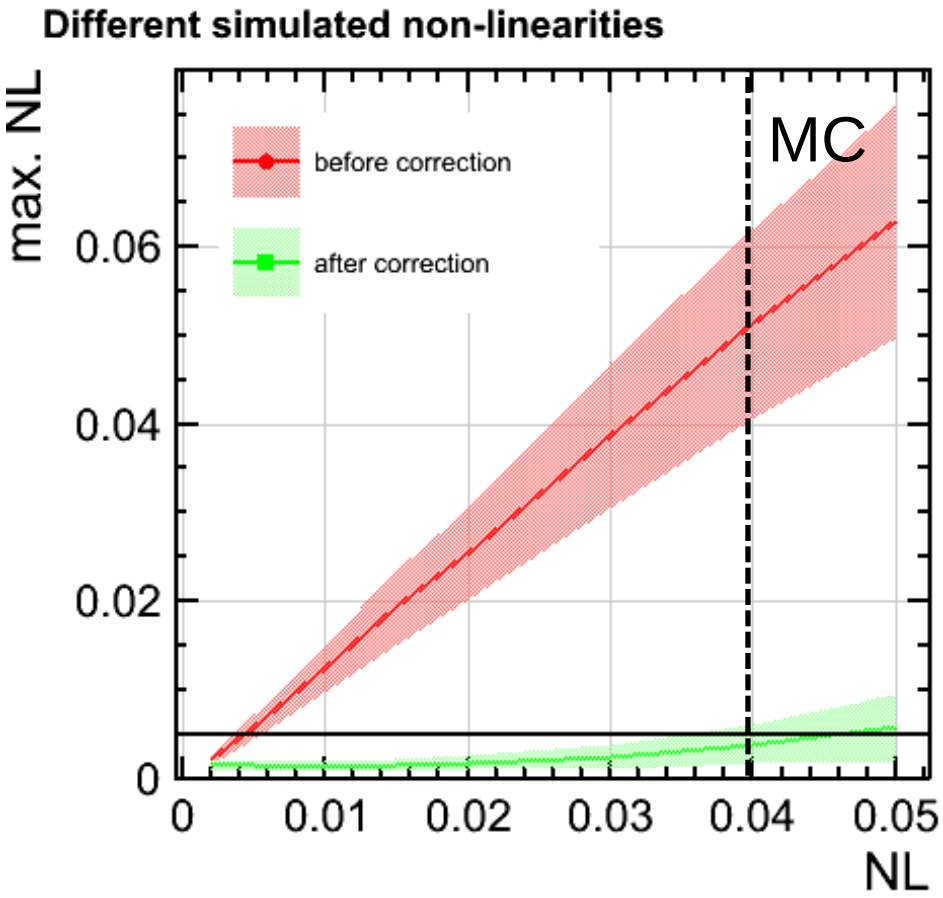
statistics per measurement



→ **at least 4 measurements within scan range**
→ **at least $2 \cdot 10^6$ events per measurement**

Limitation of linearization method

What is the maximum non-linearity, that can be corrected with this method?



→ corrections of non-linearities up to 4% possible

> Compton polarimetry at the ILC

> Calibration strategy

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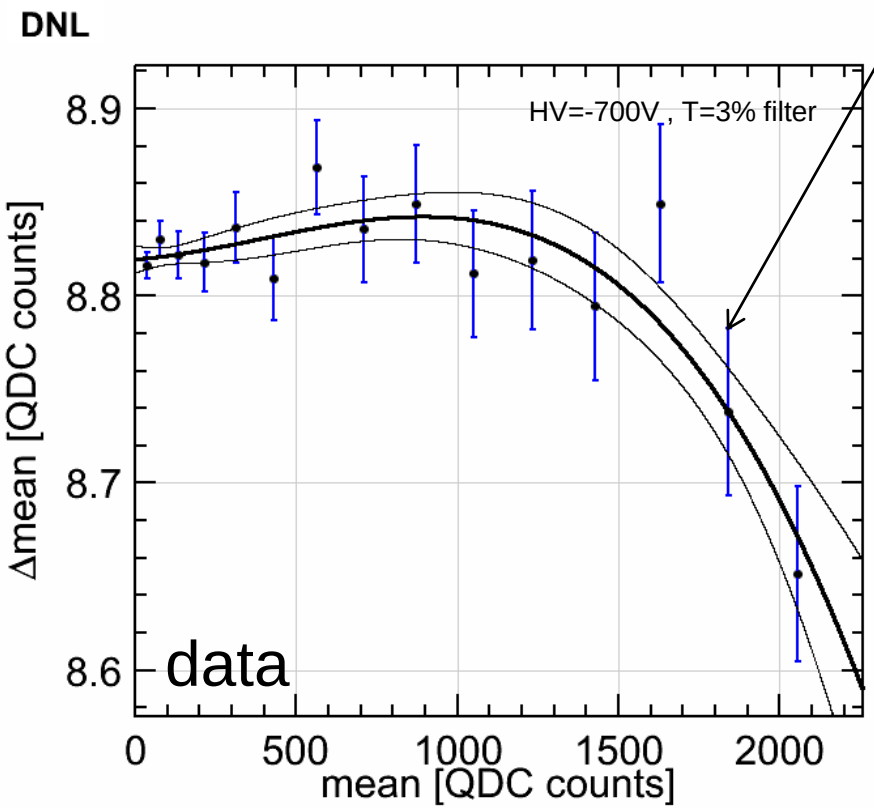
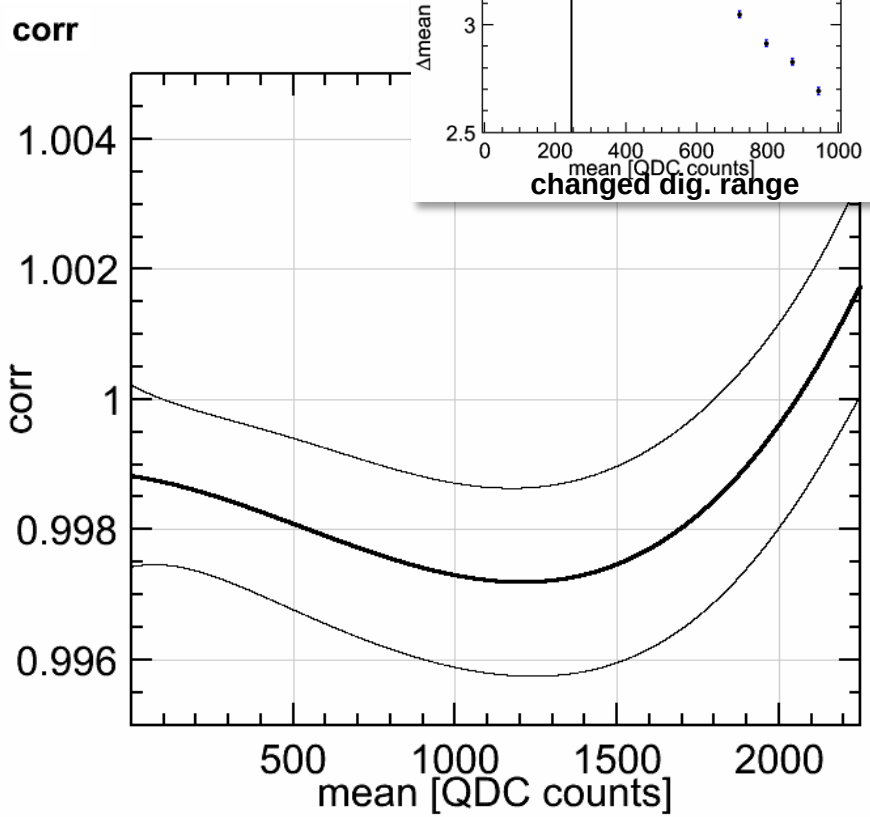
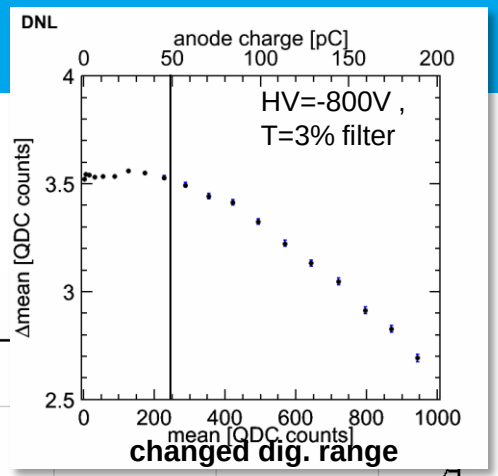
DNL measurement

Hamamatsu 5900-M4 PMT 2x2
→ *PMT used in gas-prototype*

PMT starts to saturate:





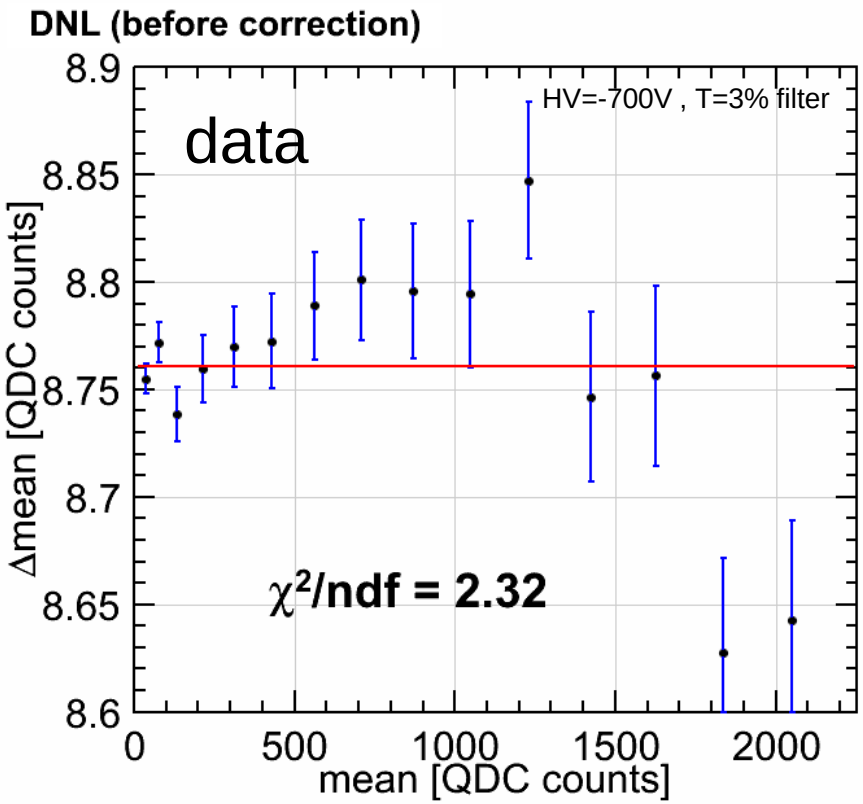


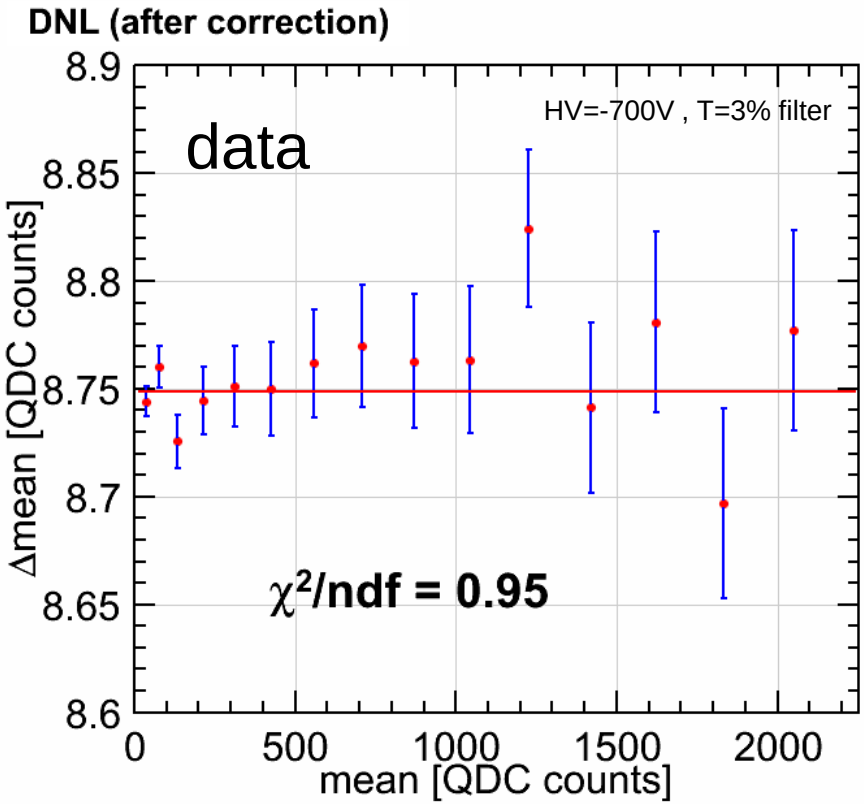
changed dig. range

→already very linear!
→non-linearity in the range of a few per mille

DNL measurement (correction)

- correction extracted from statistically independent dataset A (shown before)
- applied to datase B



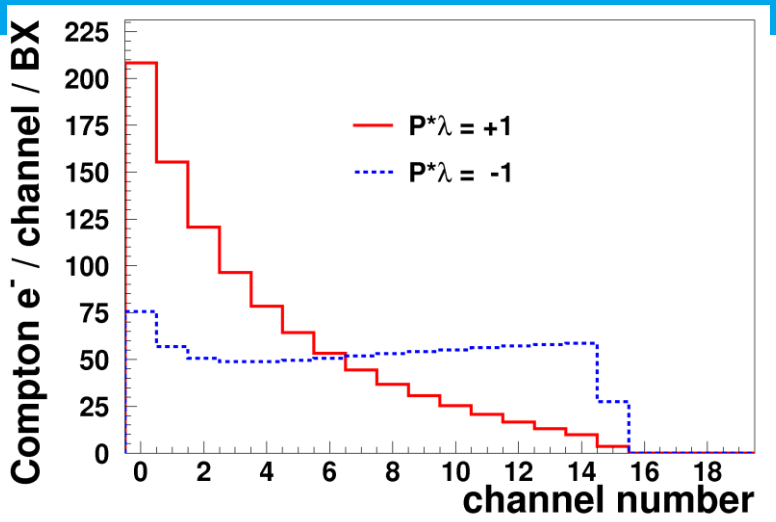


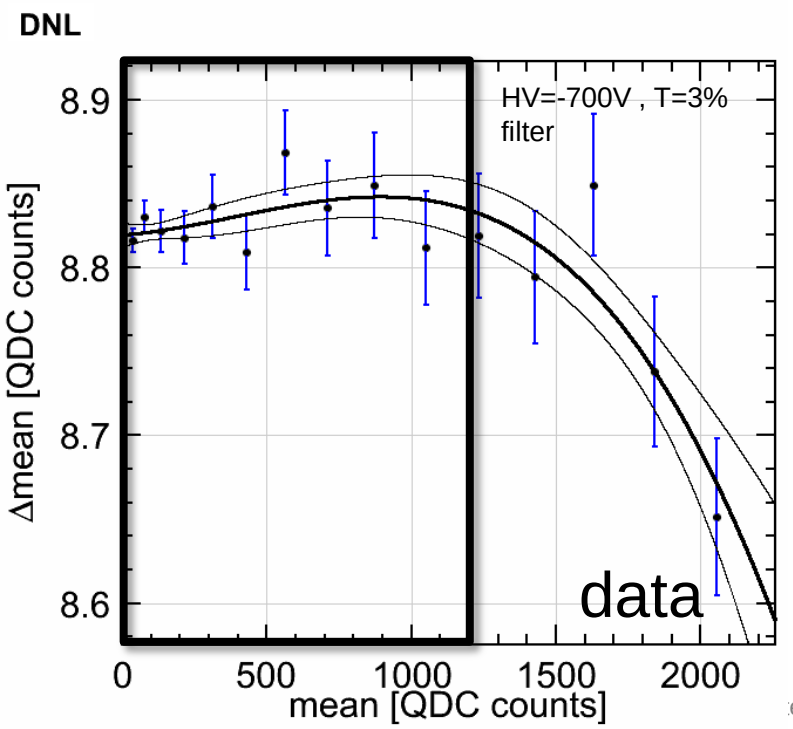
→correction linearizes dataset B

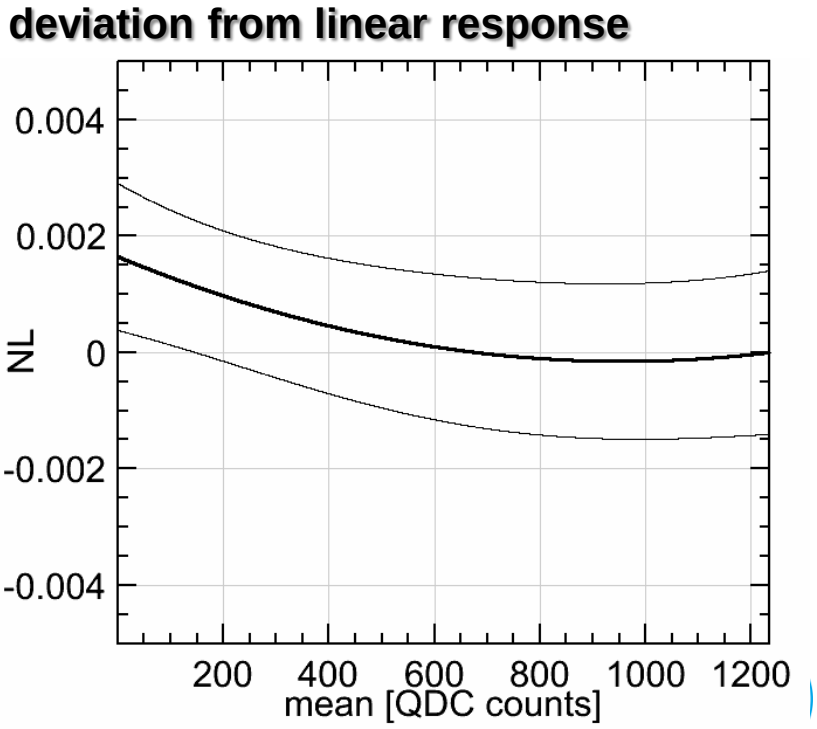
Non-linearity in polarimeter channels

- up to 210 Compton electron
  → 0-1200 QDC counts

- over all non-linearity already quite small in this range
  →max. NL 0.2%







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Non-linearity in extreme polarimeter channels

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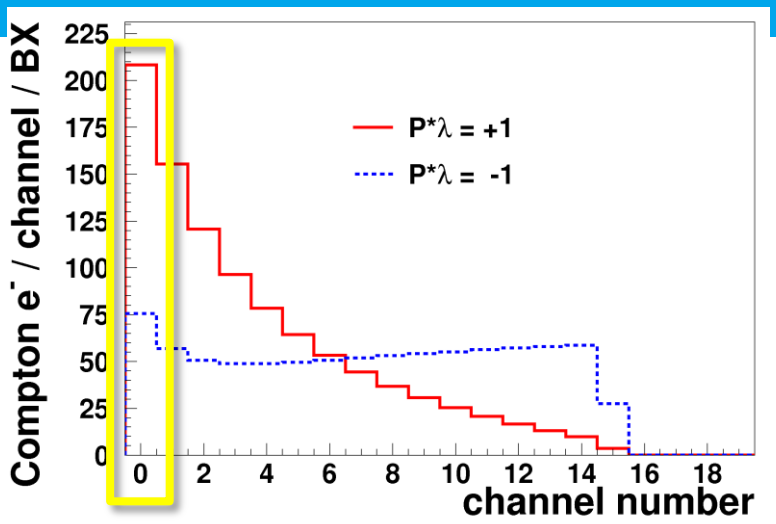
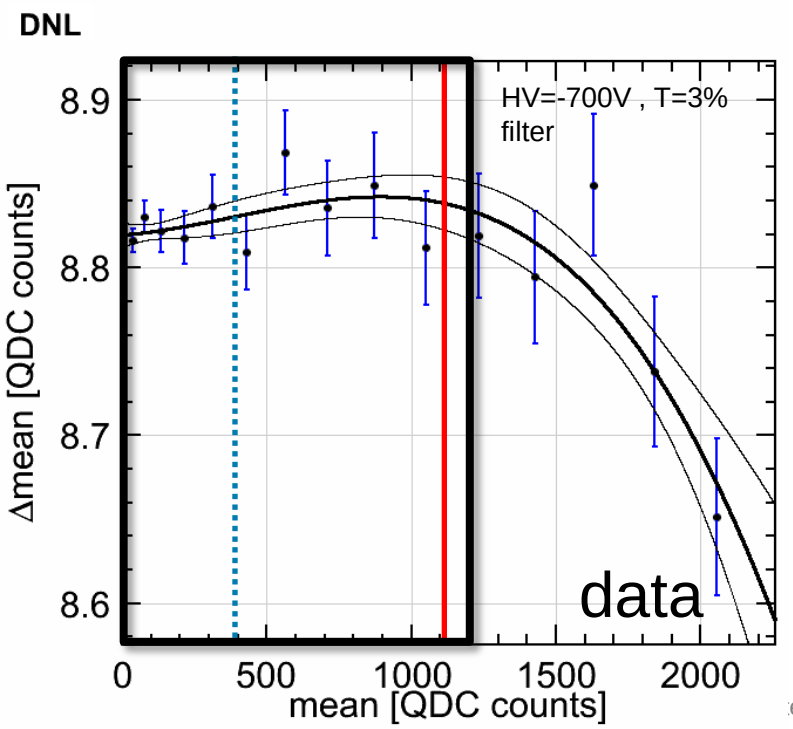
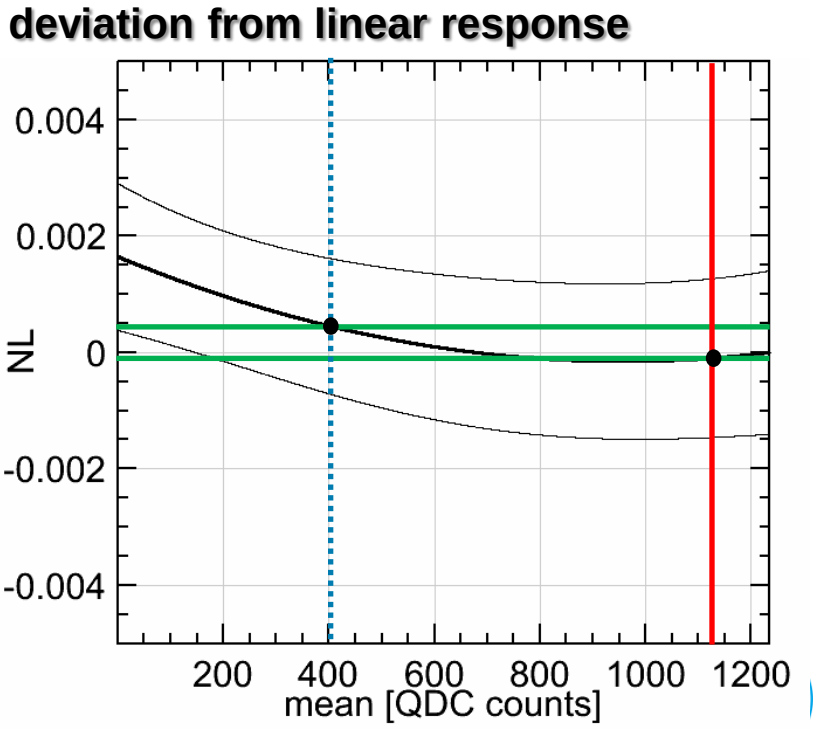
- in single channels even smaller







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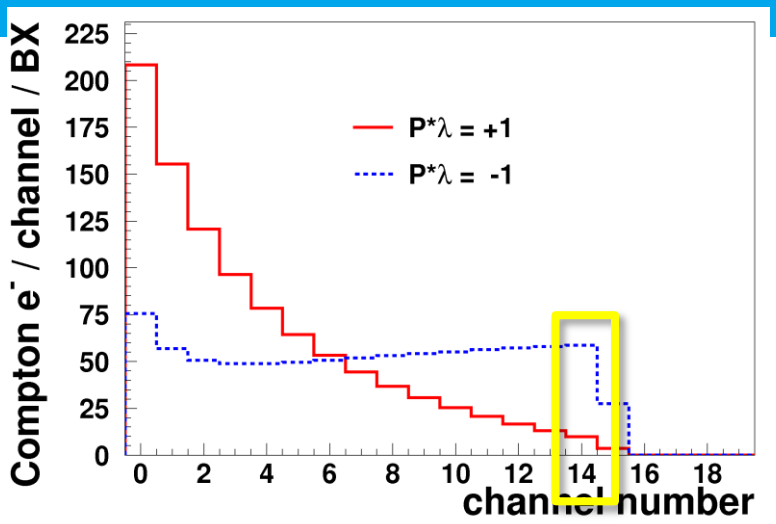

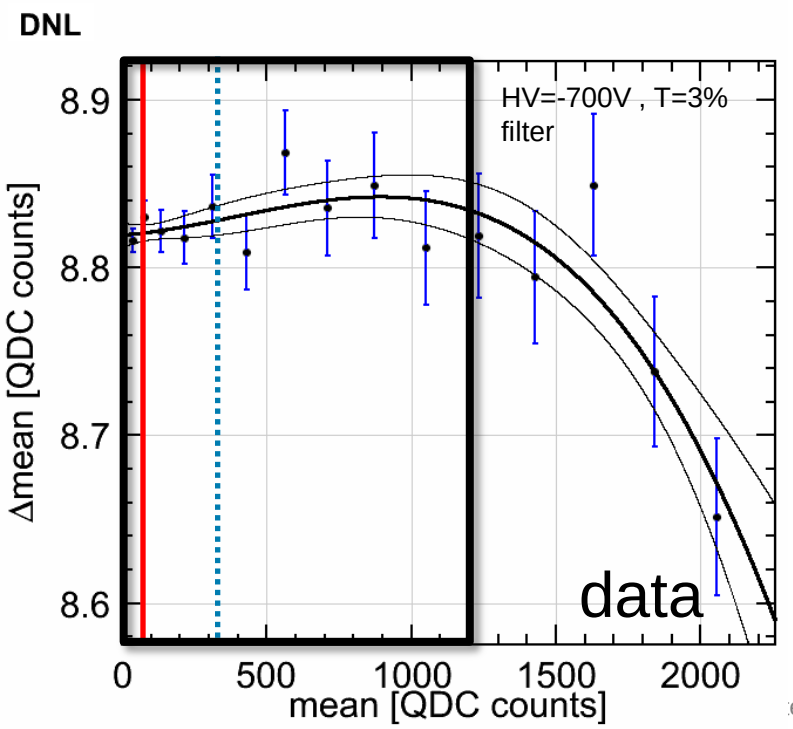

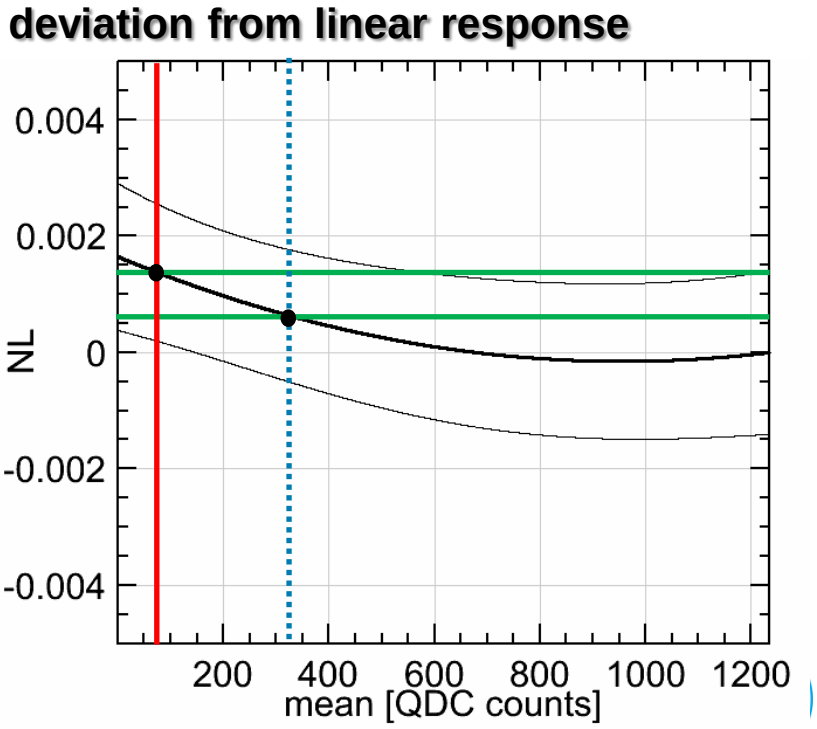

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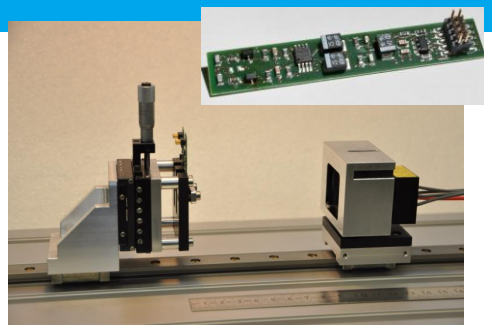
Conclusions & Outlook

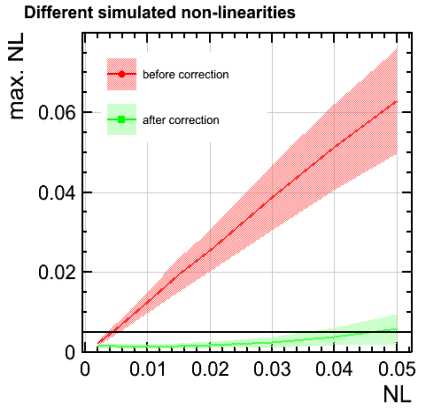


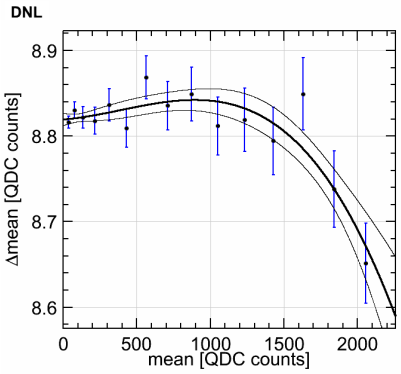
- **Developement of a LED driver** and test setup, which fulfills requirements to measure DNL of PMTs

- **Monte-Carlo simulation** set up to study DNL calibration method

- **DNL measurement of PMT** *Hamamatsu M5900 M4* showed NL < 0.2% in the expected dynamic range of the polarimeter

- next step: DNL measurement/ characterizing of **different PMTs**





Backup slides

Linearization of data with measured DNL

Mathematical description of non-linearity:

$$y = (c + nl(x)) \cdot x$$

output signal (e.g. QDC counts)

input signal (e.g. light pulse)

measurement proportional to

$$\frac{dy}{dx} = c + nl'(x) \cdot x + nl(x) \equiv M$$

For small non-linearities:

$$c + nl(x) = \frac{\int M \, \mathrm{d}x}{x} \approx \frac{\sum M \Delta y}{y}$$

$$corr \propto \frac{1}{c + nl}$$

→ correction factor independent of absolute value of x

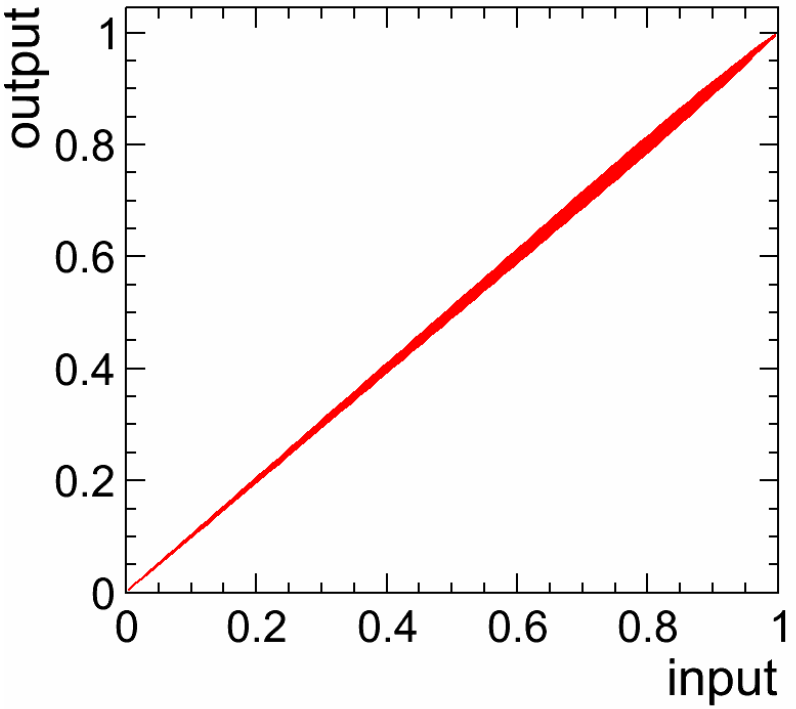
Monte Carlo Study

- generate randomly 200 different normalized transfer functions with

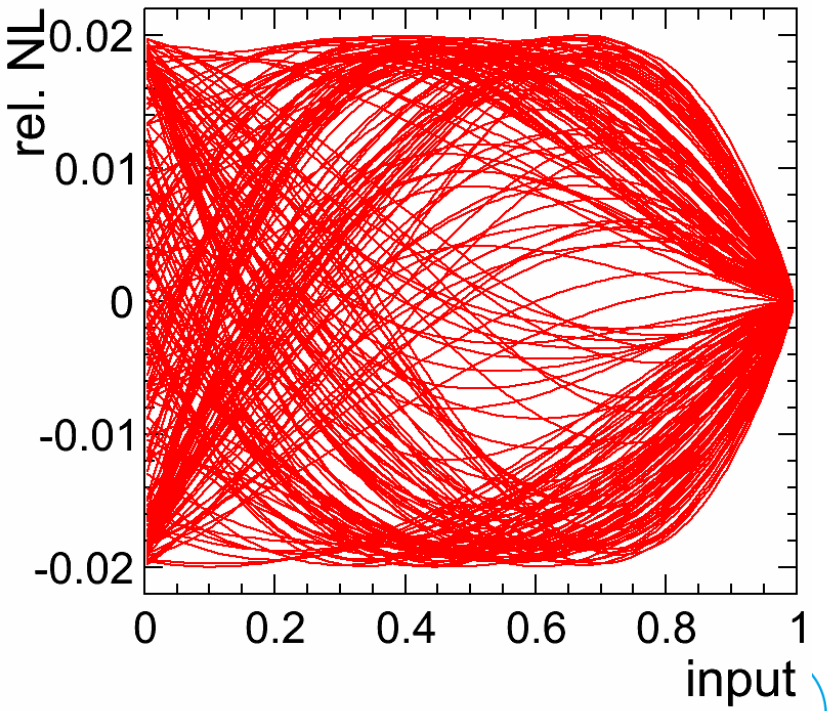
$$nl(x) = a + bx + cx^2 + dx^3$$

- simulate PMT/QDC response including resolution, noise etc. (tuned to data)
- extract correction function from dataset
- apply to another dataset generated with same nl(x)
- calculate remaining non-linearity after corretion

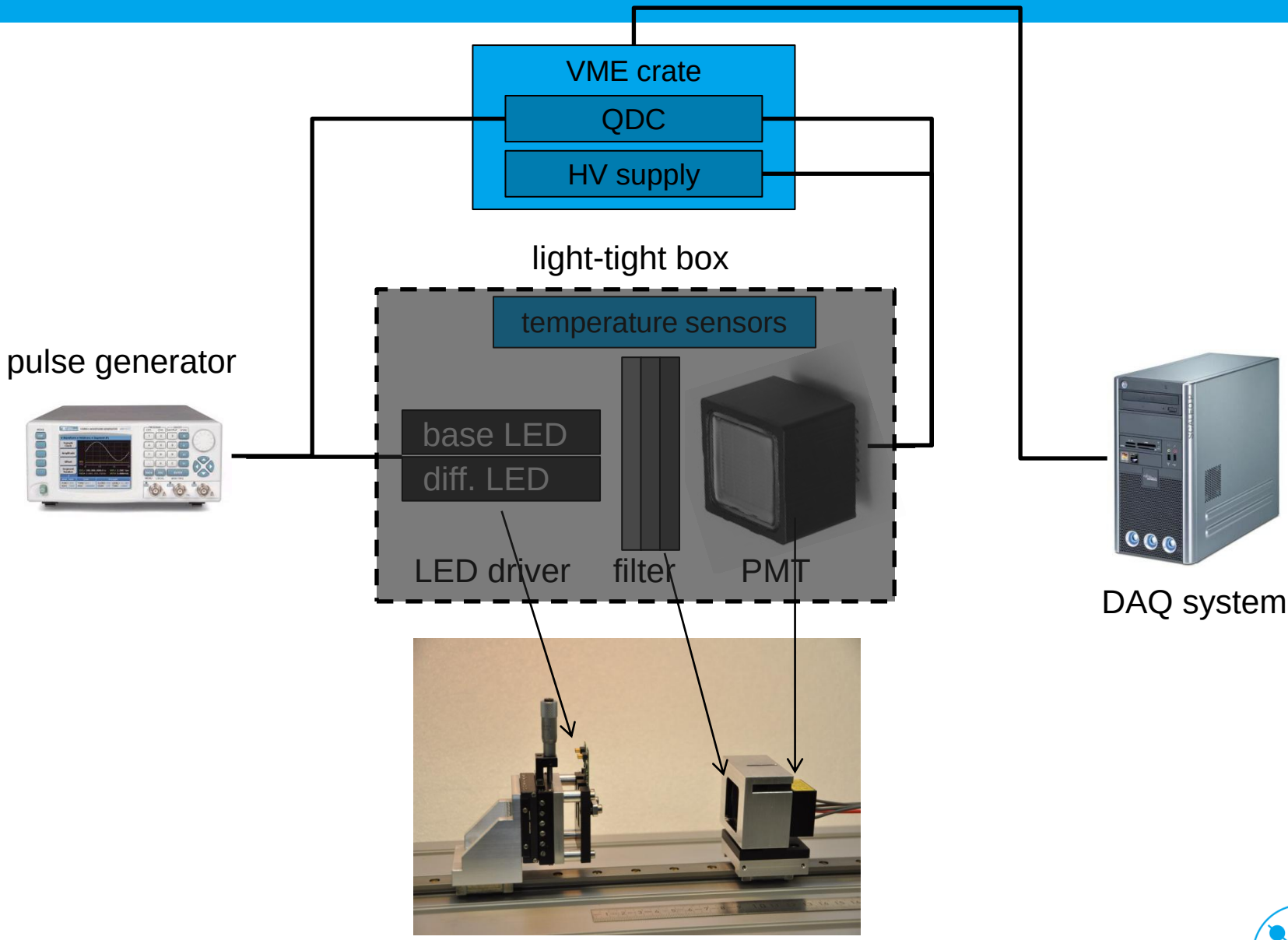
transfer function



relative non-linearity here: relative NL=2%



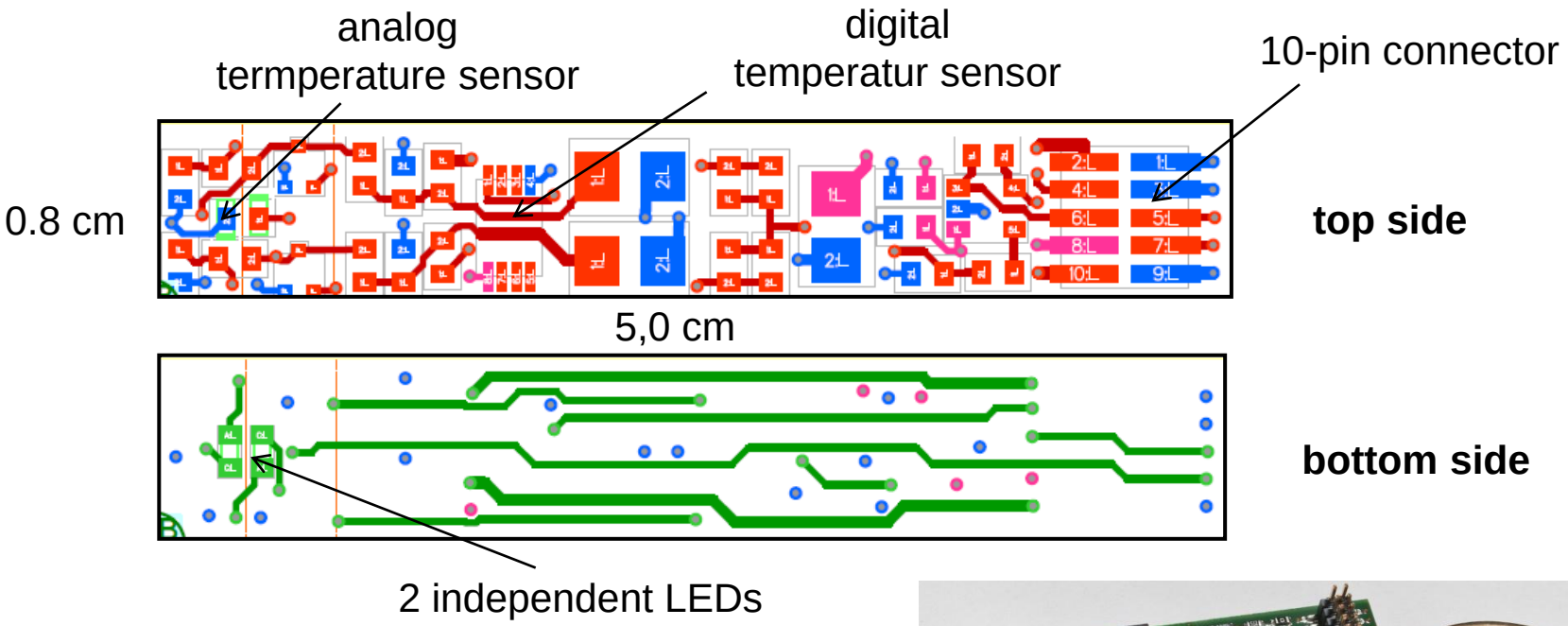
LED calibration system

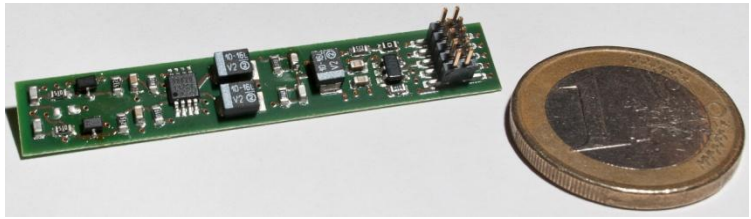


LED calibration system

Platine design

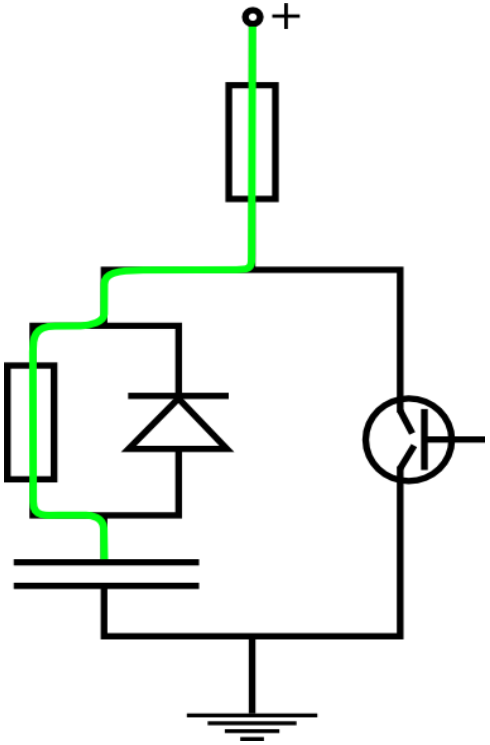
Developement of LED driver platine for polarimeter based on HCal LED driver (Mathias Reinecke)



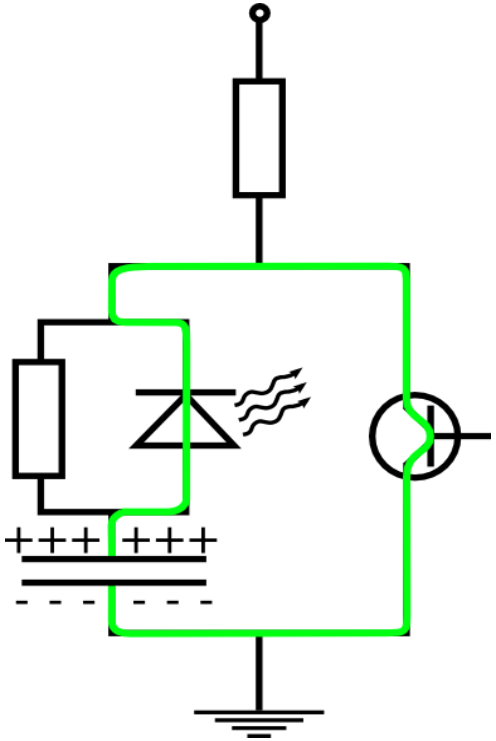


LED calibration system

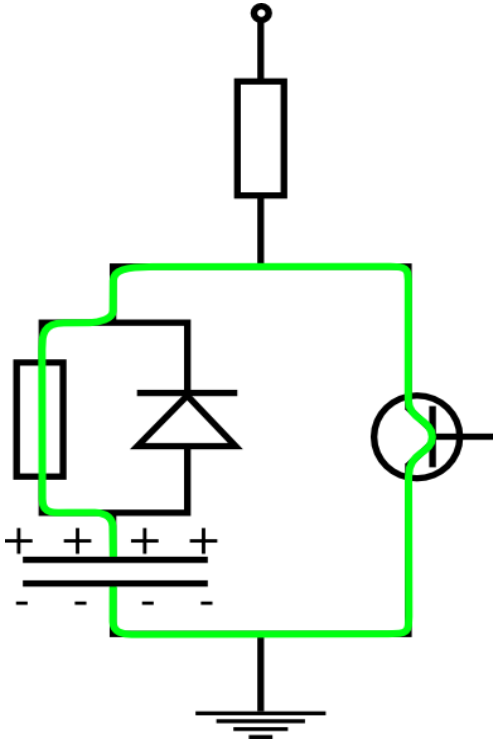
Creation of short light pulses



charging of capacitor
with U_{LED}



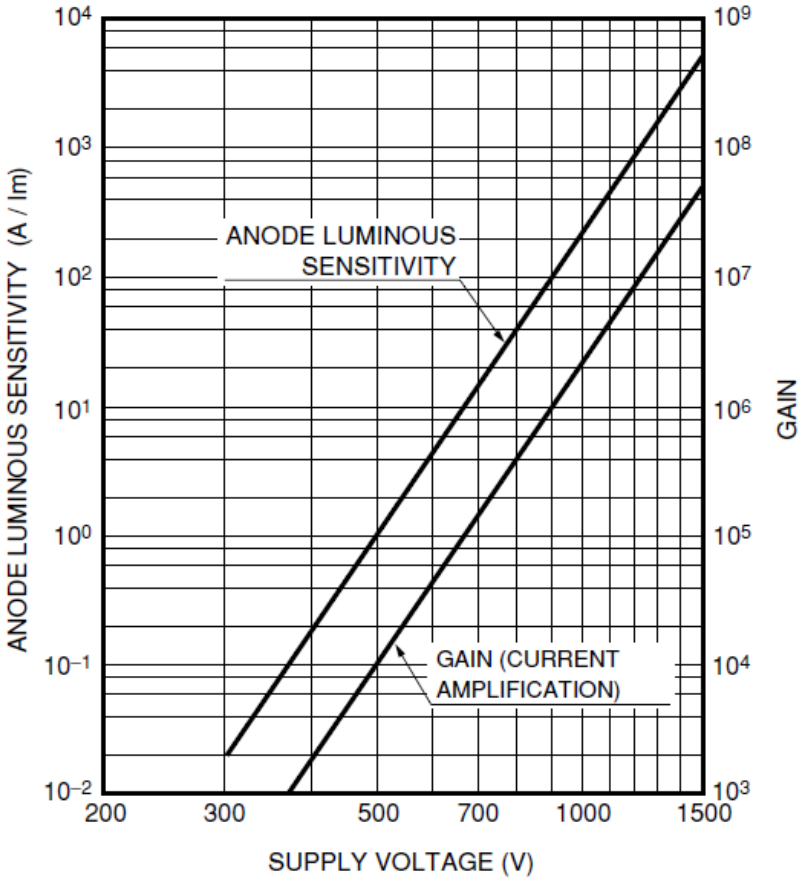
big voltage on capacitor:
$R_{LED}<R_{parallel}$



small voltage on capacitor:
$R_{LED}>R_{parallel}$

→ pulse length limited by quench resistor

Dynamic range



PMT gain for 700V: $g = 1{,}3 \cdot 10^5$

QDC resolution: LOW range: 200 fC/bin
HIGH range: 25 fC/bin

1 photo electron $= 1\ e_P = g \cdot e$
$= 1{,}3 \cdot 10^5 \cdot 1{,}6022 \cdot 10^{-19}\ C$
$= 20{,}8$ fC

1 Compton electron $= 1\ e_C = g_{Cherenkov} \cdot \eta_{QE} \cdot e_P$
$= 6{,}5 \cdot 20{,}8$ fC
$= 135{,}2$ fC

→ LOW range: 5,408 bins
→ HIGH range: 0,676 bins

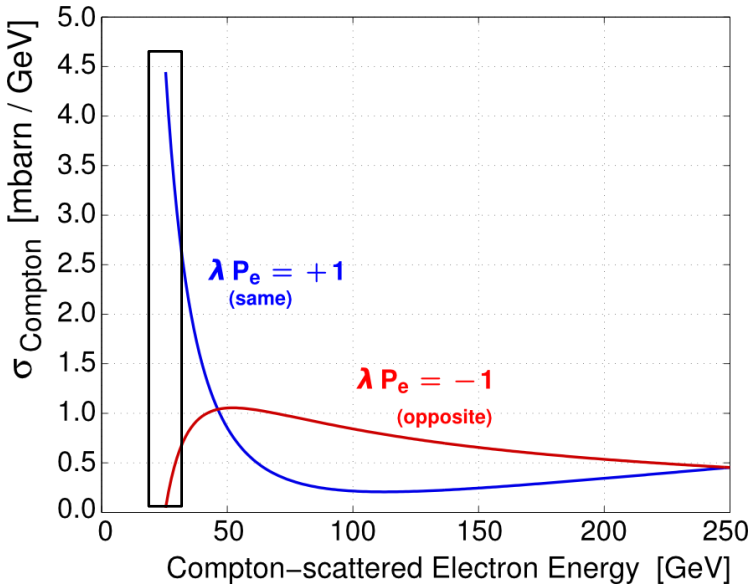
0 - 200 e_C
→ LOW range: 0-1200 bins
→ HIGH range: 0-150 bins

Dynamic range

Near the Compton edge:
~40-250 scattered Compton electrons per channel

↓ · **6.5** detected Cherenkov photons per Compton electron

~250-1625 detected photons (photo electrons) in PMT

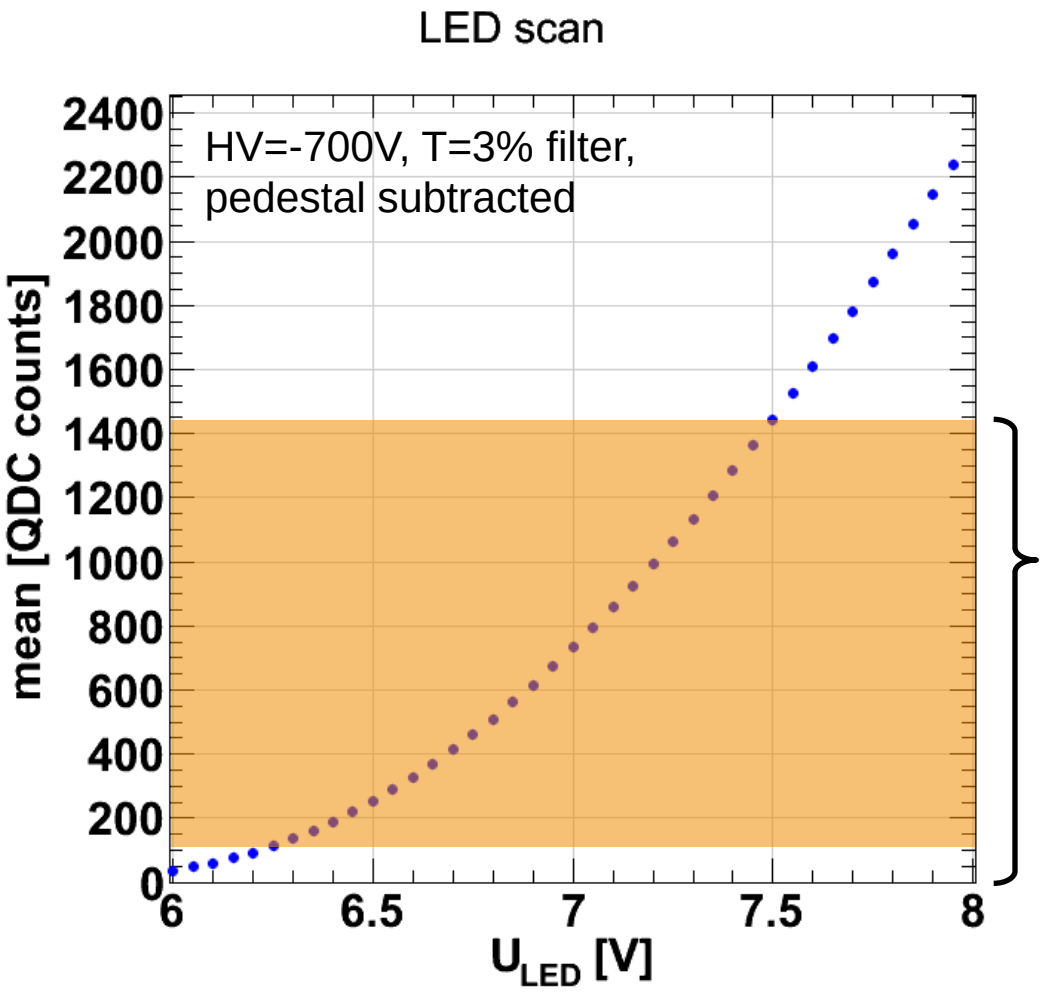


→ same dynamic range needed for measurement devices (PMT, QDC)

→ **same dynamic range needed for calibration source (LED driver)**

LED calibration system

Dynamic range

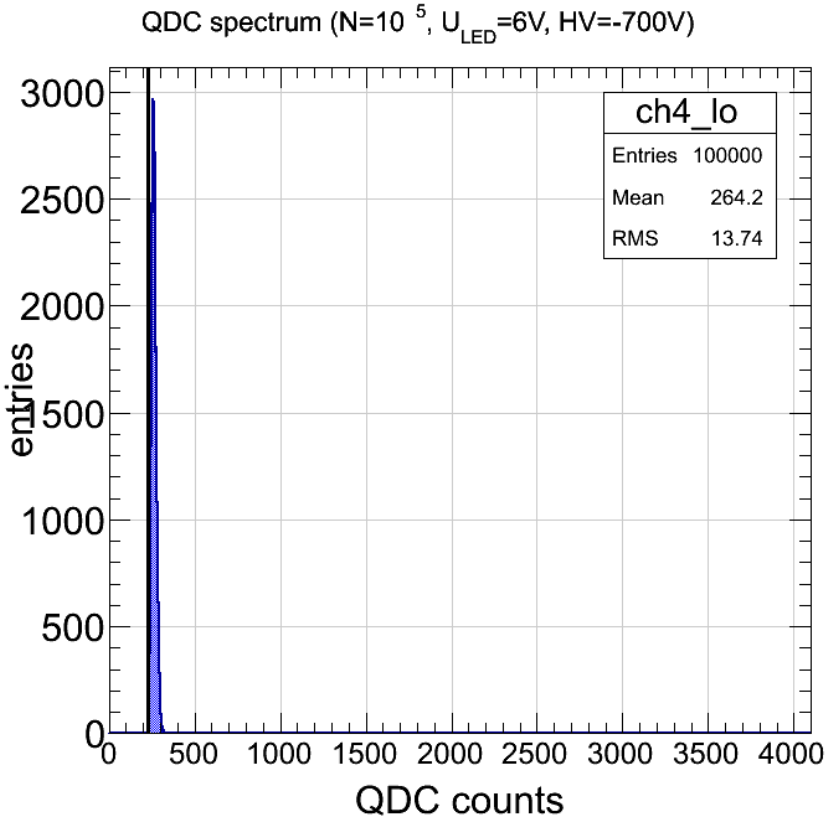


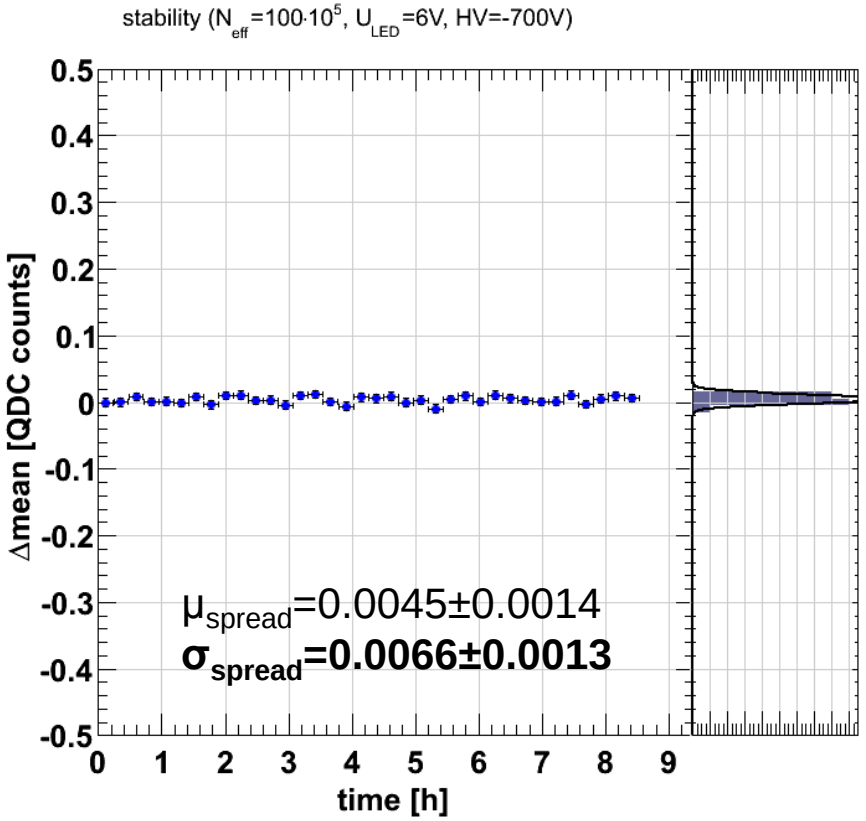
corresponding range for QDC signal

→ **range can be easily adjusted by neutral density filters**

LED calibration system

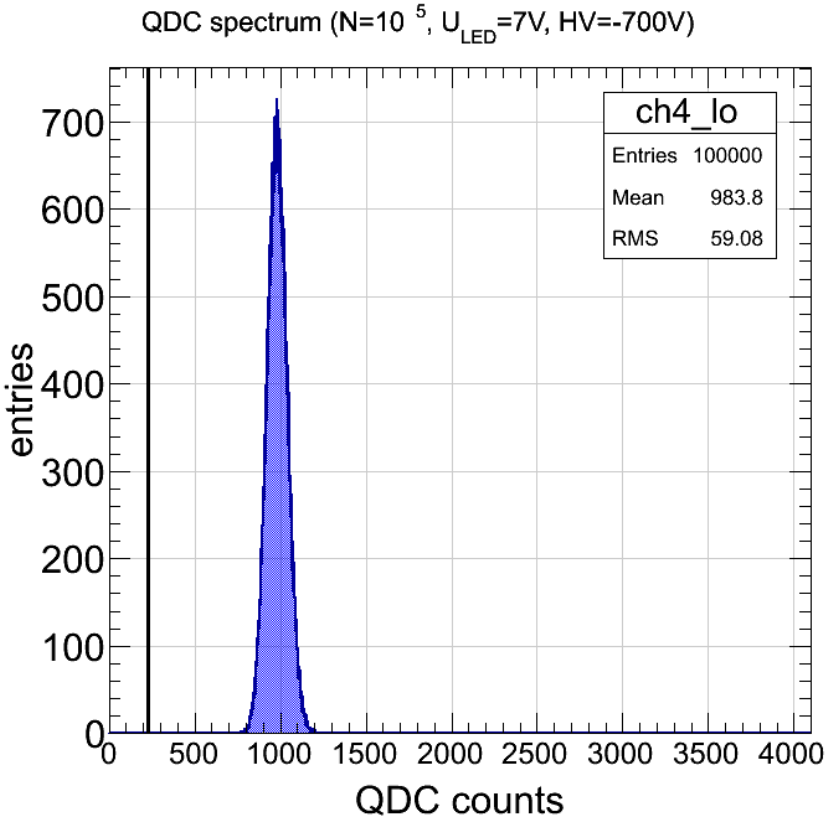
Pulse stability – reproducibility

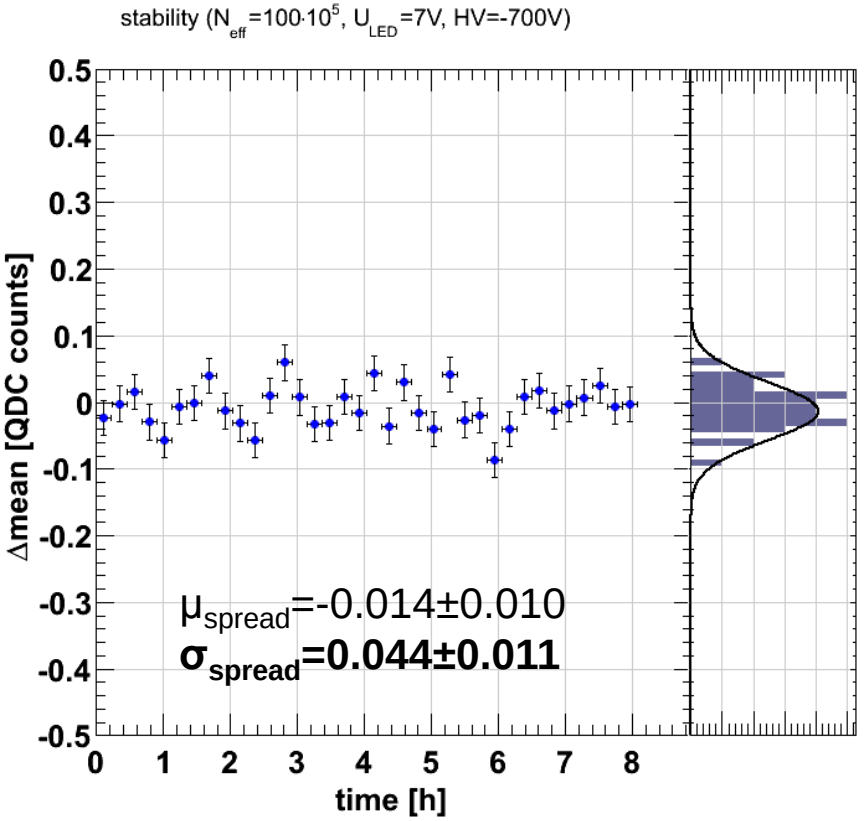




LED calibration system

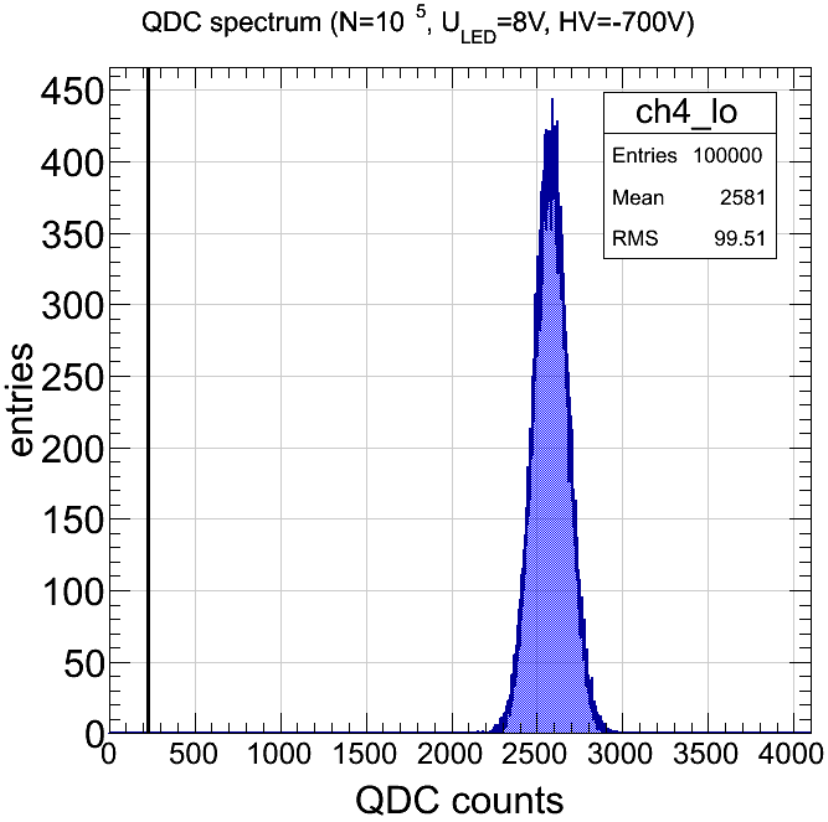
Pulse stability – reproducibility

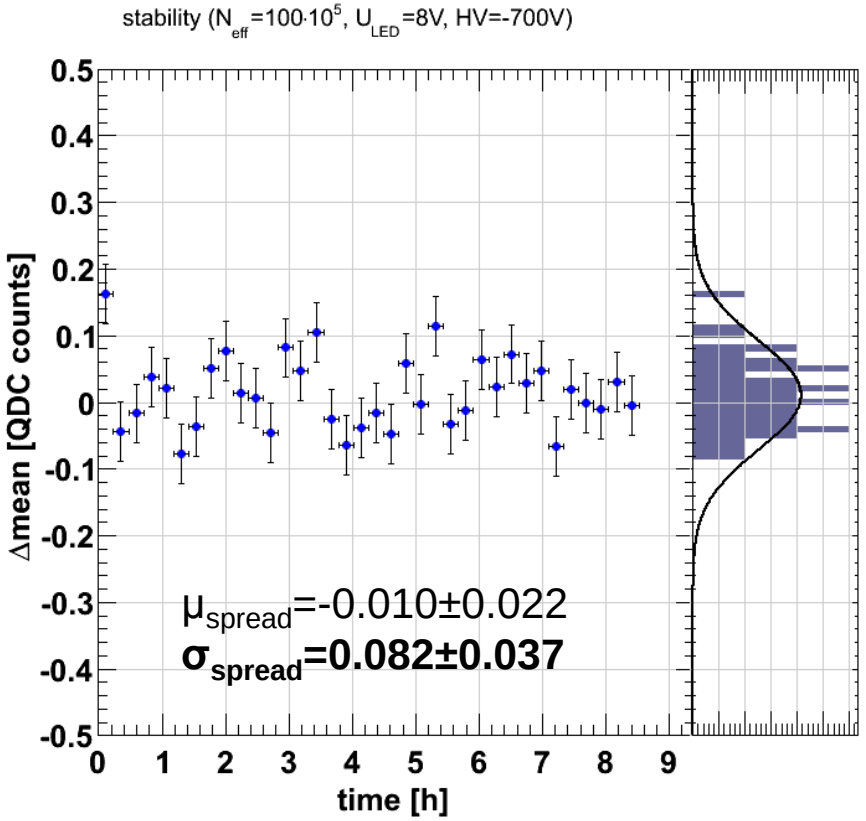




LED calibration system

Pulse stability – reproducibility





→ Kalibration von NL bis zu 0.5% kein Problem

LED calibration system

Pulse length