Presentation Title

Subtitle of Presentation

Name Surname
City, Date

Calibrating the Cherenkov Detector

Some thoughts

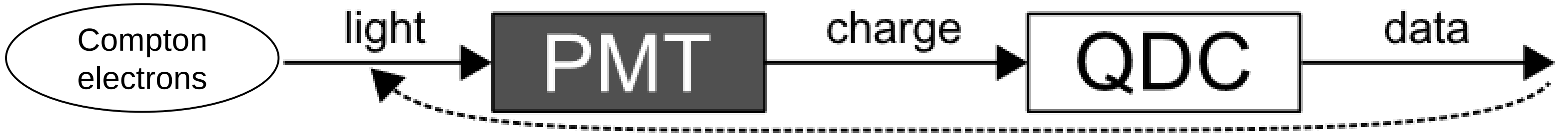
Ruth

LUXE technical meeting 22.06.23

HELMHOLTZ

DESY.

Non-linearities

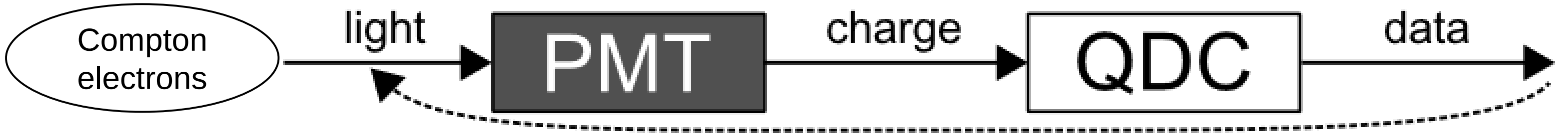


- Want to know the Number of Compton electrons in each detector channel but we actually get a digital electronic signal
- In an ideal world the relation between them is perfectly linear

  → would need only one measurement of Number of electrons and corresponding signal output to calibrate
- In real world measurement devices are not linear!

In addition to non-linearity there are also other effects (calibration differences between channels, time-dependent variations) etc., will discuss those later

Sources of Non-linearities



Sources of non-linearities for our detector:

1) SiPM response

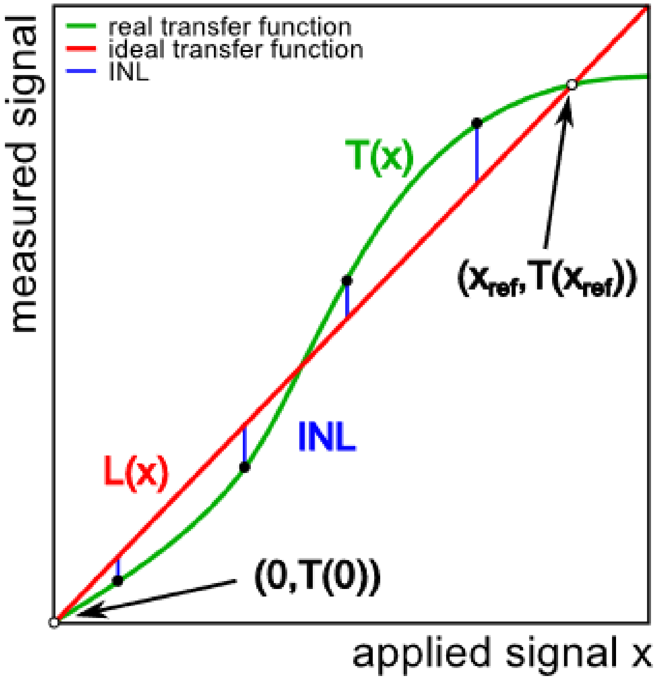
- at high photon densities, finite pixel number causes non-linearities
  (pixels have to recharge O(10ns) after each breakdown avalanche)
- thermal noise, afterpulses, cross-talk

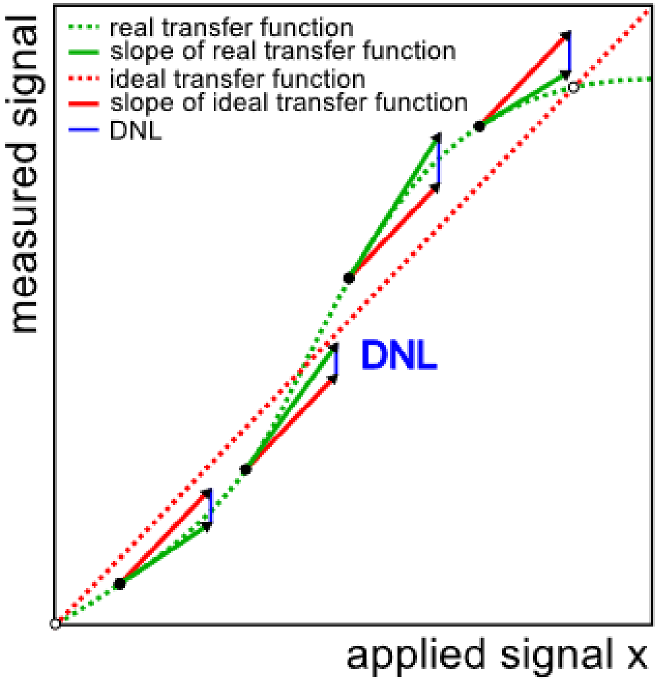
2) Readout non-linearities:

- unstable pedestal currents
- non-linearity in digitization step → depends on ADC implementation

Correct these by measuring non-linearity!

Non-linearities





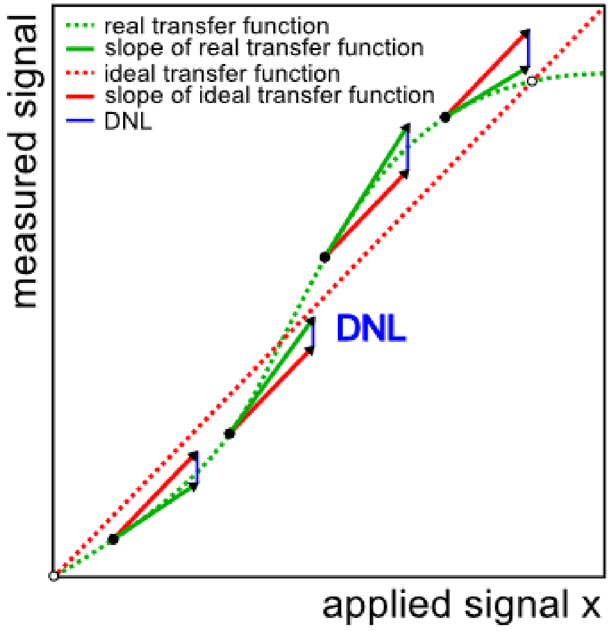
- Detector response: measured signal (e.g. ADC) versus applied signal (e.g. incoming electrons per channel
  → ideally: linear function $L(x) = A_0 + B_{x_{ref}} \cdot x$
  → in reality: non-linear function $T(x)$

- Two anchor points: $A_0 = \mathrm{T}(0)$ (Null measurement), $B_{x_{ref}} = \frac{T(x_{ref}) - T(0)}{x_{ref}}$ (reference measurement at x_{ref})

- Two ways to express non-linearity:
  - integrated (difference between ideal and real) $\mathrm{INL(x)} = T(x) - L(x)$
  - differential (difference in slope between ideal and real) $\mathrm{DNL(x)} = \frac{d}{dx}\big(T(x) - L(x)\big) = \frac{dT(x)}{dx} - B_{x_{ref}}$

INL: Getting a high-light-yield stable short UV LED pulse is complicated! (exect O(40%) intensity variation)

Differential non-linearity measurement



- Measuring DNL means measuring $\frac{dT(x)}{dx}$
- Approximate : $\frac{dT(x)}{dx} = \frac{T(x+\Delta x)-T(x)}{\Delta x}$

Technical meaning:

x: variable base signal (e.g. a variable LED pulse)
Δx: constant differential signal (e.g. second, constant low-intensity LED pulse)

$T(x+\Delta x)$: detector response with both signal at the same time
$T(x)$: detector response with just base signal

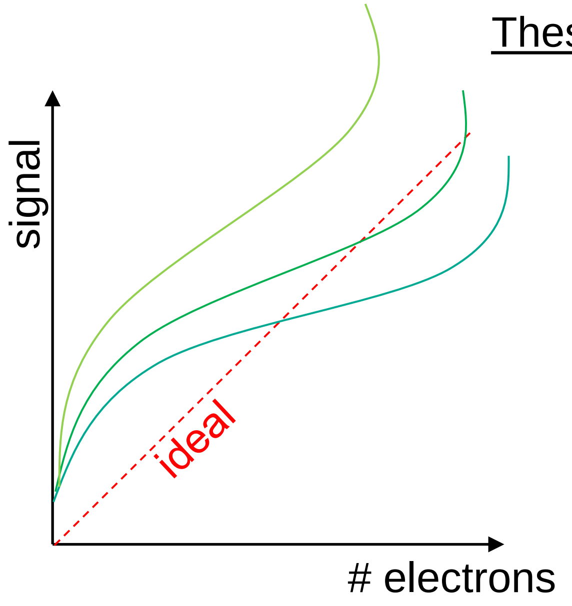
- Consequence of constant differential signal: $\frac{dT(x)}{dx} = \frac{\Delta T(x)}{c} \propto \Delta T(x)$, where c is constant
- Now measuring DNL(x) means measuring $\left(x_i, \frac{dT(x_i)}{dx}\right) \propto (x_i, \Delta T(x_i))$
- For small integrated non-linearities, assume: $x_i \propto T(x_i)$
- Extract information about non-linearity from $(T(x_i), \Delta T(x_i))$
  $\rightarrow$ no more dependence on absolute signal x!

Linearisation

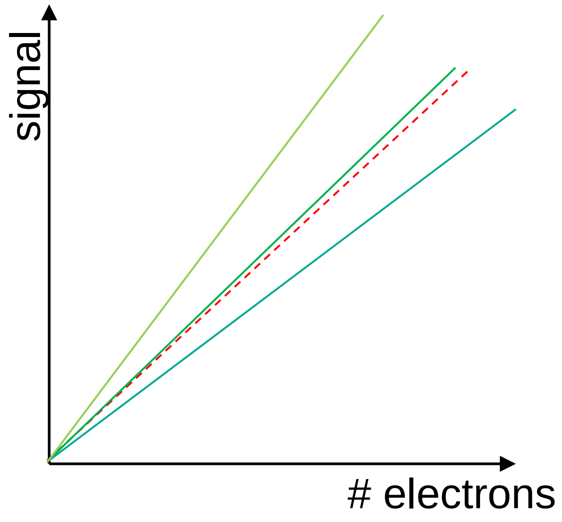
- Parametrize non-linearities in response: $T(x) = (B_{x_{ref}} + nl(x)) \cdot x$
- Express $\Delta T(x) = c \cdot \frac{dT(x)}{dx} = c \cdot (B_{x_{ref}} + nl(x) + nl'(x) \cdot x)$
- Solve for the non-linearity: $c \cdot nl(x) = \frac{1}{x} \int \ (\Delta T(x) - c \cdot \ B_{x_{ref}})\, \mathrm{dx}$
- Can show that: $\langle \Delta T(x) \rangle = c \cdot B_{x_{ref}}$
- And: $c \cdot nl(x) = \frac{1}{x} \int \ \Delta T(x)\, \mathrm{dx} - \langle \Delta T(x) \rangle$
- Linearisation correction factor: $Corr(x) = \frac{B_{x_{ref}}}{B_{x_{ref}} + nl(x)} = \frac{x \cdot \langle \Delta T(x) \rangle}{\int \Delta T(x) \mathrm{dx}}$

  → **Completely independent from absolute calibration scale!**

- Prescription:
  - take measurements of $(T(x_i), \Delta T(x_i))$
  - fit a polynomial function $\Delta T(x)$
  - calculate the correction factor using the integral and the average



BEFORE



AFTER

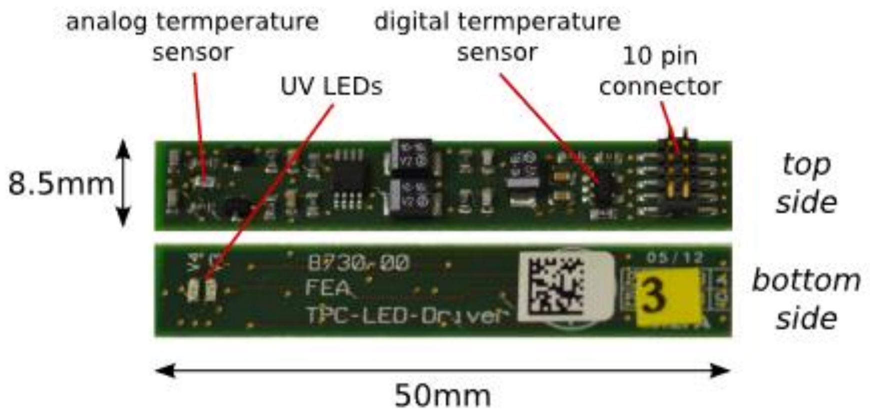
After this procedure, we know our detector response is linear, but we know the slope only to factor c!
→ Can correct using a complementary measurement (e.g. TB or in-situ calibration)

How to practically do the linearization?

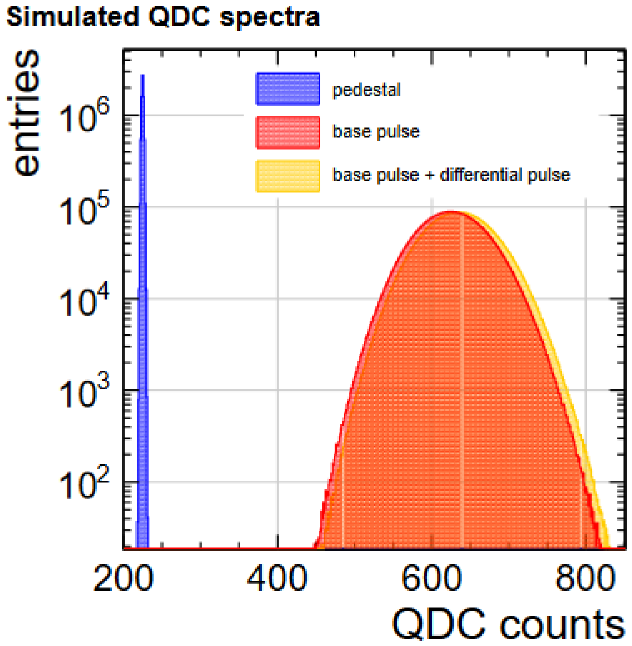
- There is already a LED board from the Polarimetry setup (based on CALICE) that can produce the base and differential signals
- Requirement: - choose Δx such that it is small compared to the calibration range of the photodetector and to the full-scale range of the readout ADC (e.g. comparable to LSB)
  - could be matching our requirements already?

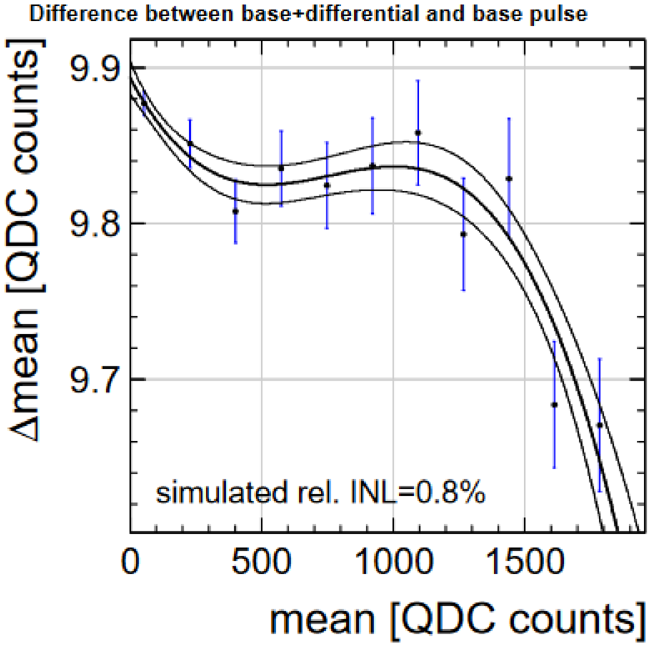
<u>Practical Procedure:</u>

- Measure QDC spectra with and without the differential signal for varying base LED signals
- Get the mean of the QDC, and difference between means for base only vs. base+ differential
- Fit polynomial function and proceed with linearization



(a)



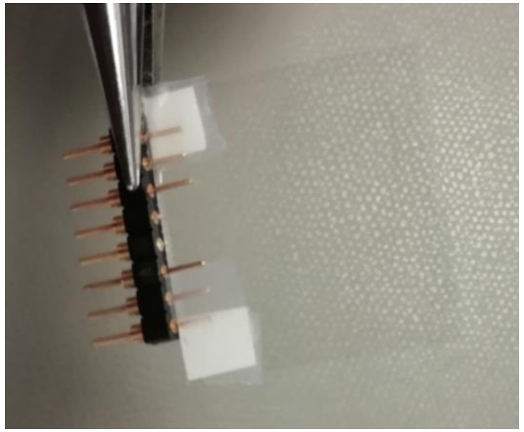


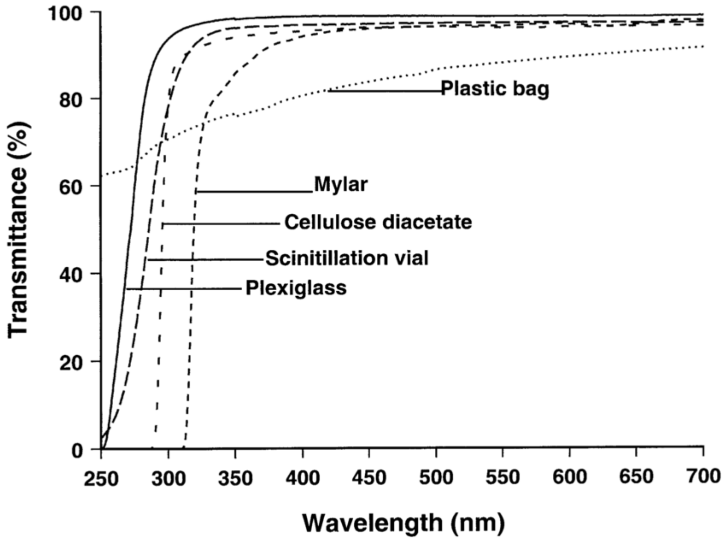
Linearization with Mylar foil?

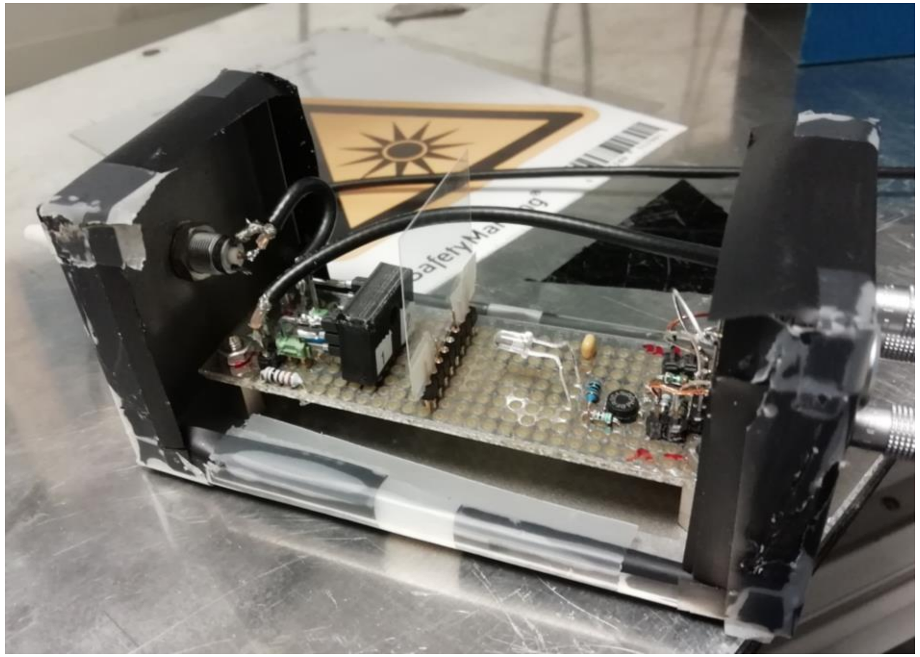
- Since LED boards did not work, fashioned a O(10%) attenuator from Mylar foil
- Requirement: - choose Δx such that it is small compared to the calibration range of the photodetector and to the full-scale range of the readout ADC (e.g. comparable to LSB)
  - could be matching our requirements already?

Practical Procedure:

- Measure QDC spectra with and without the Mylar attenuator varying base LED signals
- Get the mean of the QDC, and difference between means for base only vs. base+ differential
- **NOTE**: dT(x)/dx is proportional to T(x) (constant attenuation factor)

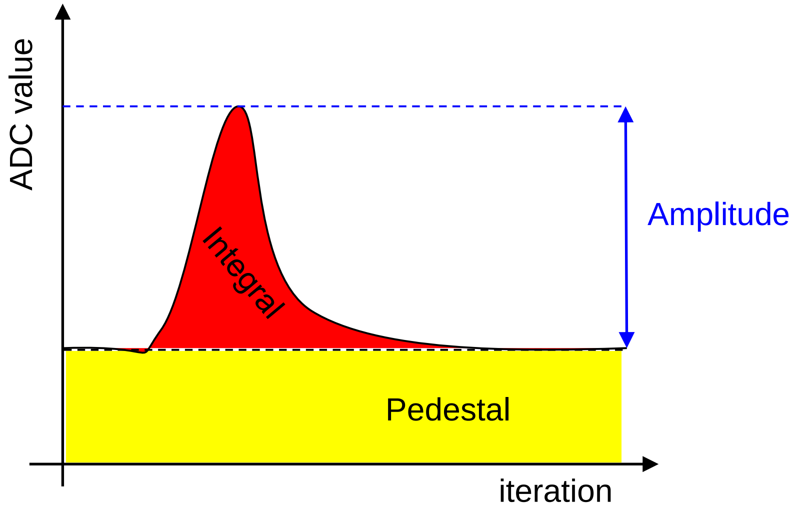




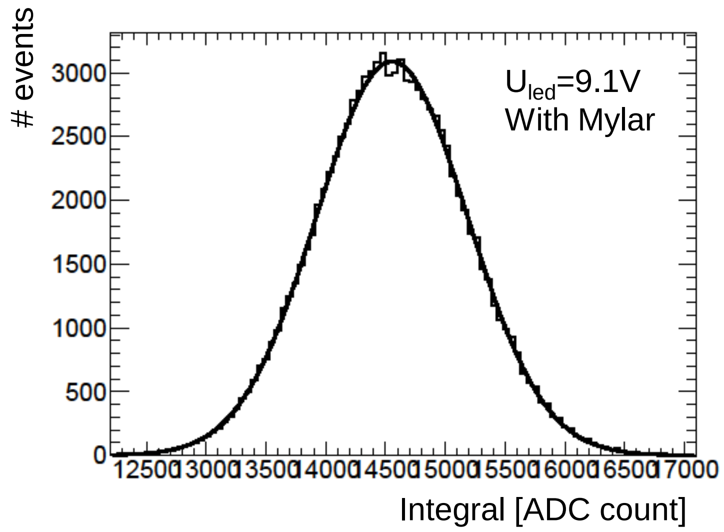


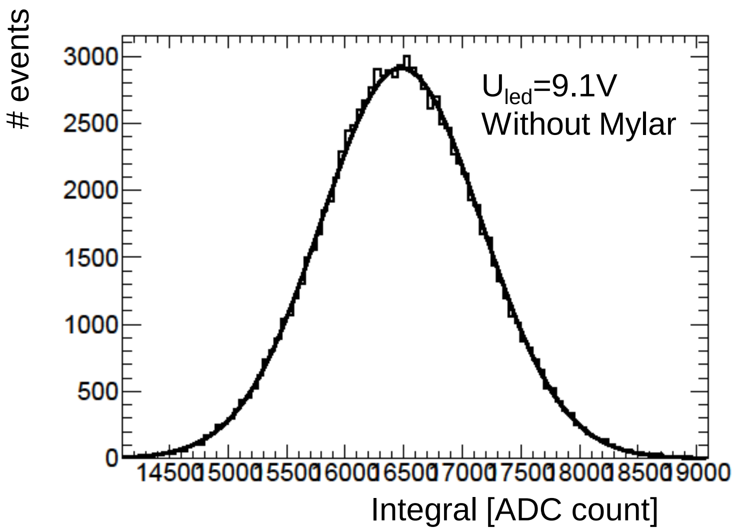
Linearization with Mylar foil

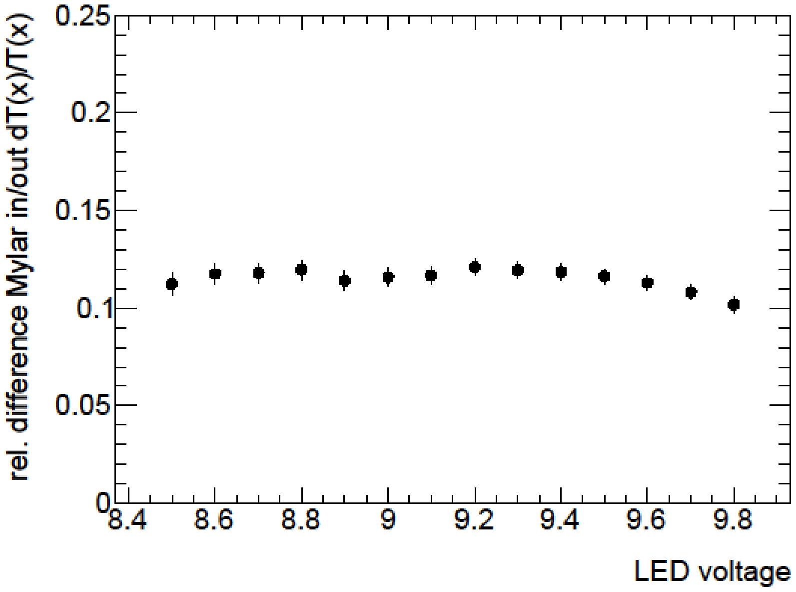
- **Step1:** Pedestal subtraction and digitizer pulse shape
  - Loop through iterations until there is a 5σ upwards deviation (pulse start)
  - average before pulse start: pedestal



- **Step2:** Get difference between Amplitude/Integral with and without Mylar foil at different LED voltages
  - fit Gaussian and take the difference
  - Uncertainties: Bootstrap method (fitting multiple subsets of samples)

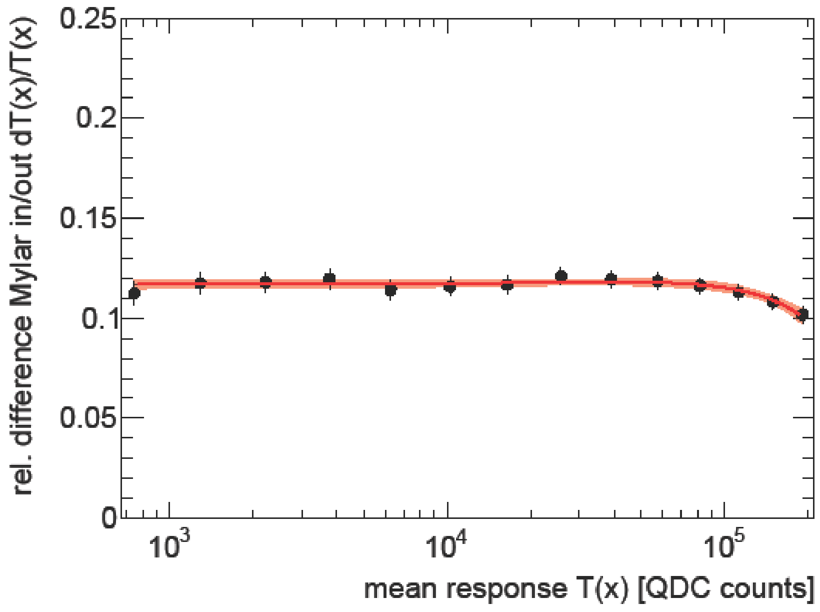






Linearization with Mylar foil

- **Step 3:** Plot relative difference of mean T(x) as function of mean T(x) and fit a polynomial (here: second order)

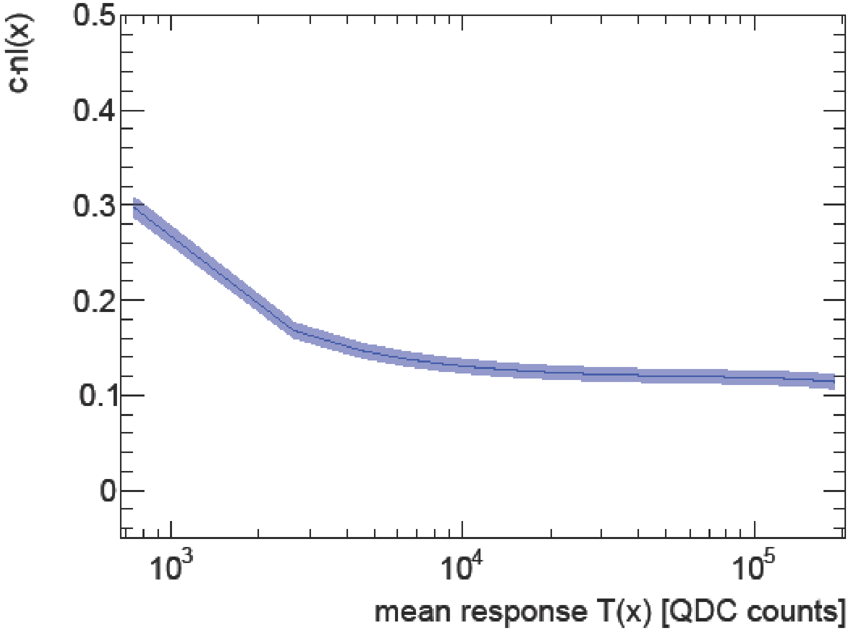


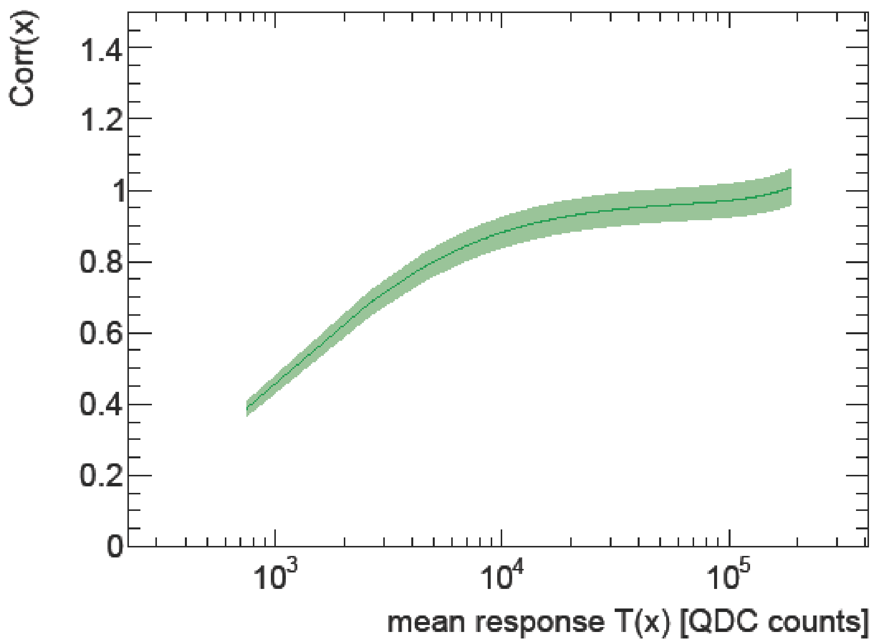
- **Step 4:** Solve integral equation for non-linearity using fitted function

$$c \cdot nl(x) = \frac{1}{x}\int \Delta T(x)\,\mathrm{dx} - \langle \Delta T(x) \rangle$$

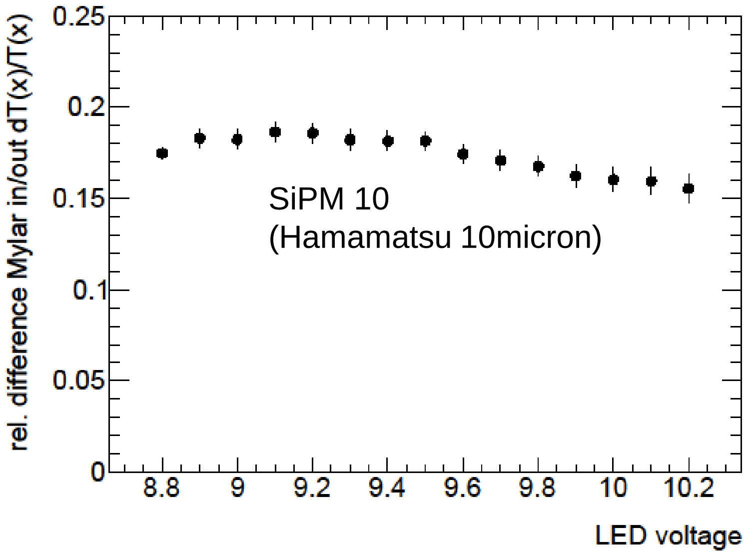
- **Step 5:** Calculate correction factor using result from Step 4

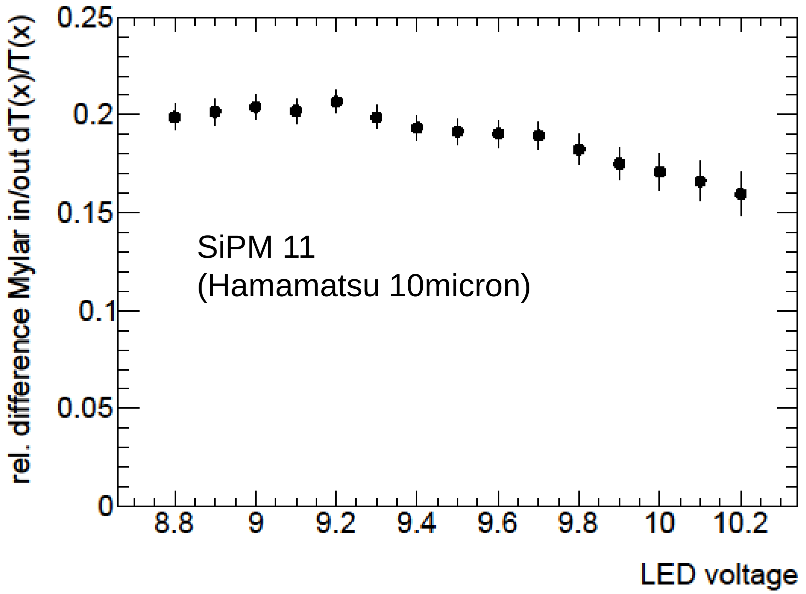
$$Corr(x) = \frac{B_{x_{ref}}}{B_{x_{ref}} + nl(x)} = \frac{x \cdot \langle \Delta T(x) \rangle}{\int \Delta T(x)\mathrm{dx}}$$

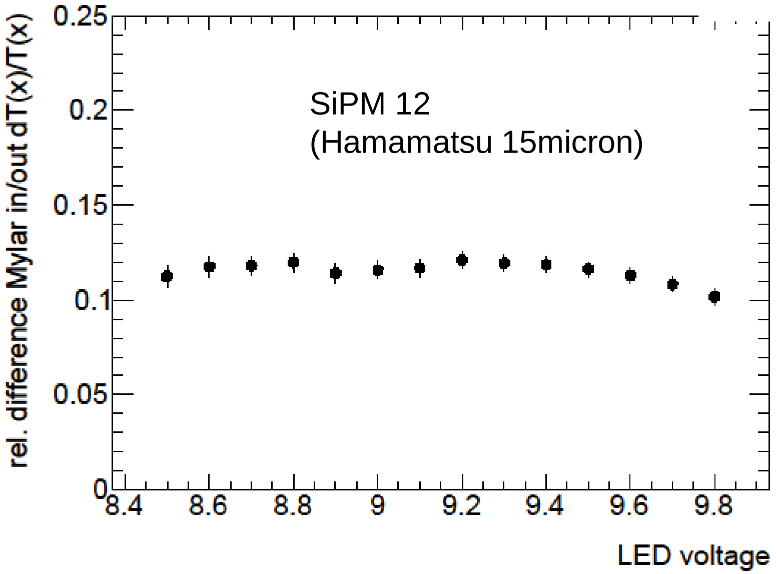




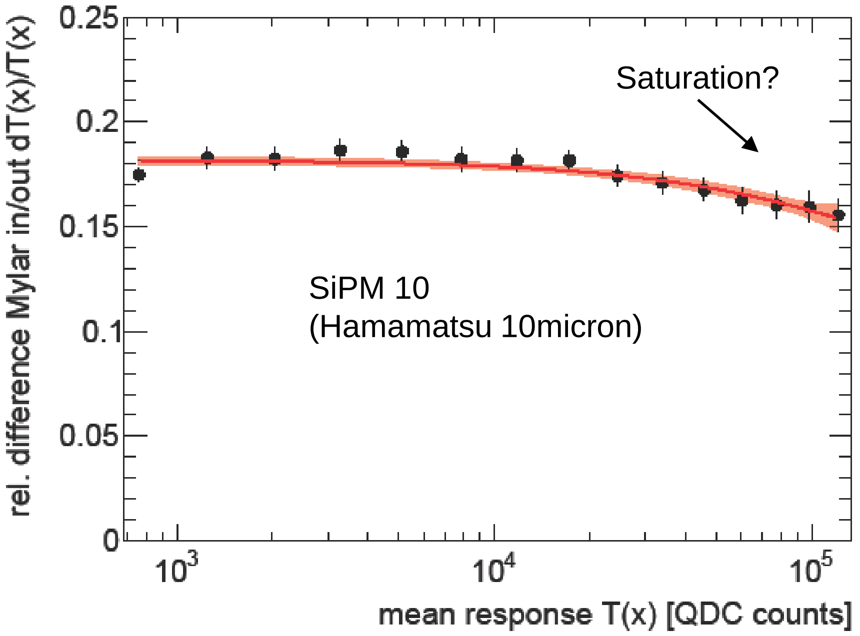
Photodetector comparison

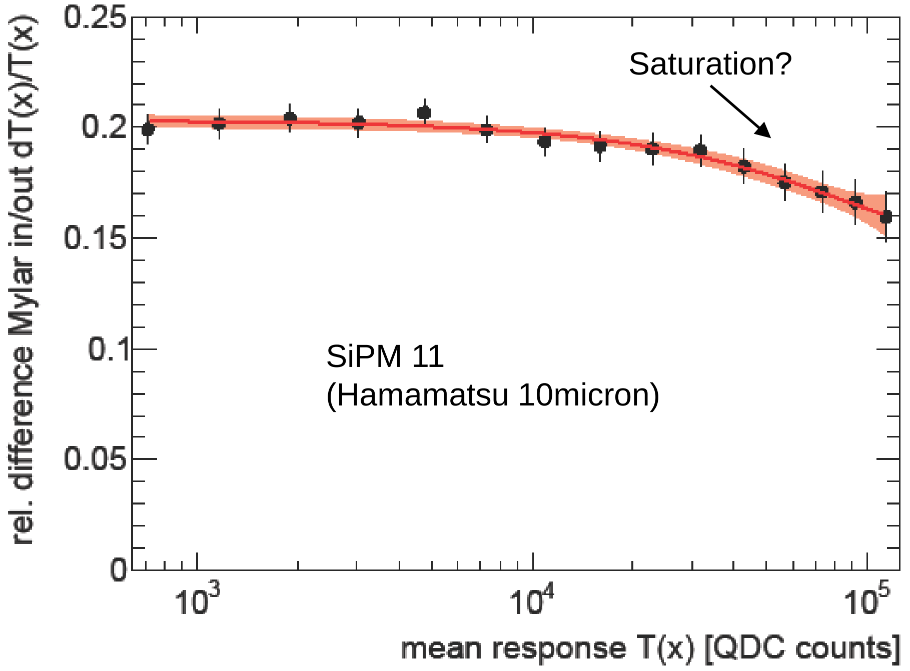


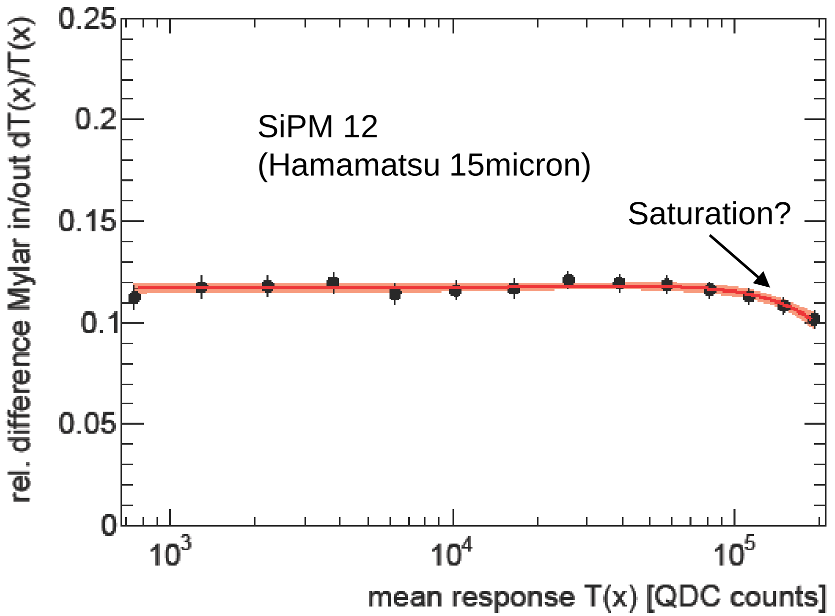




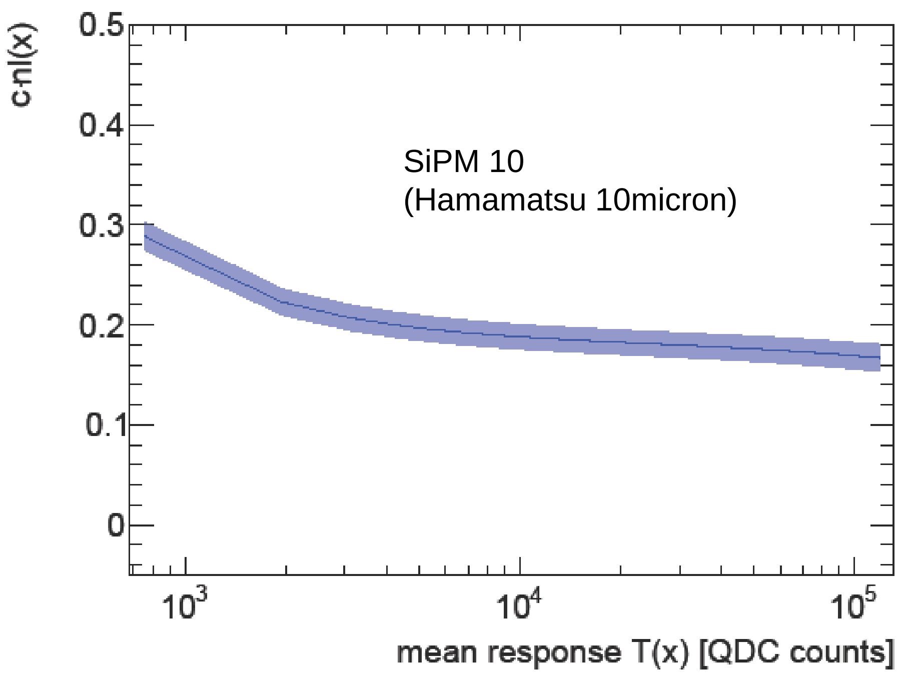
Photodetector comparison

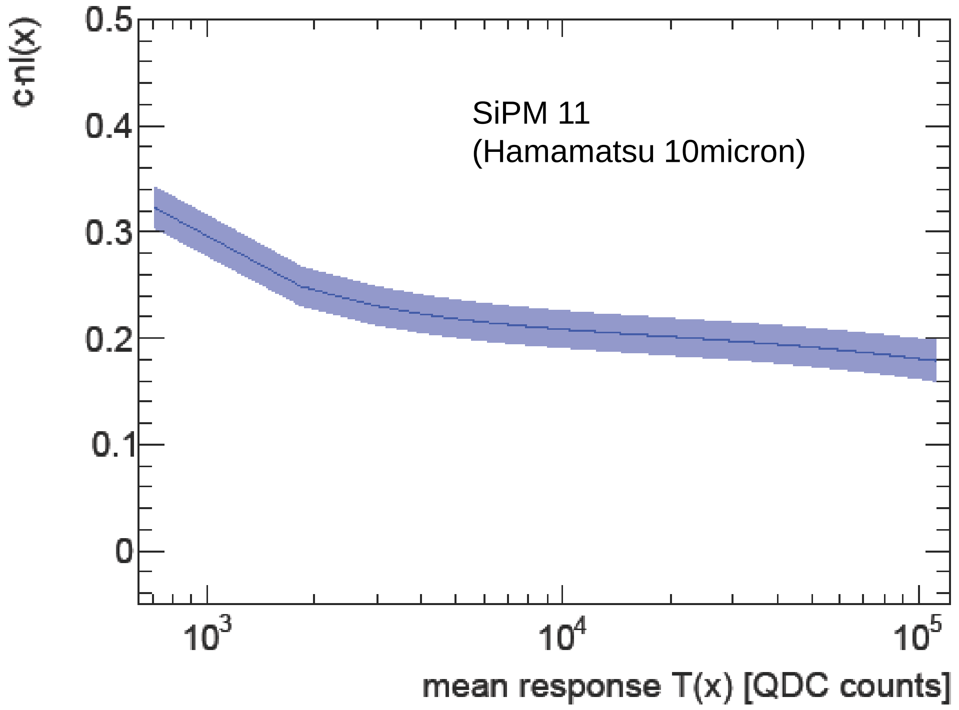


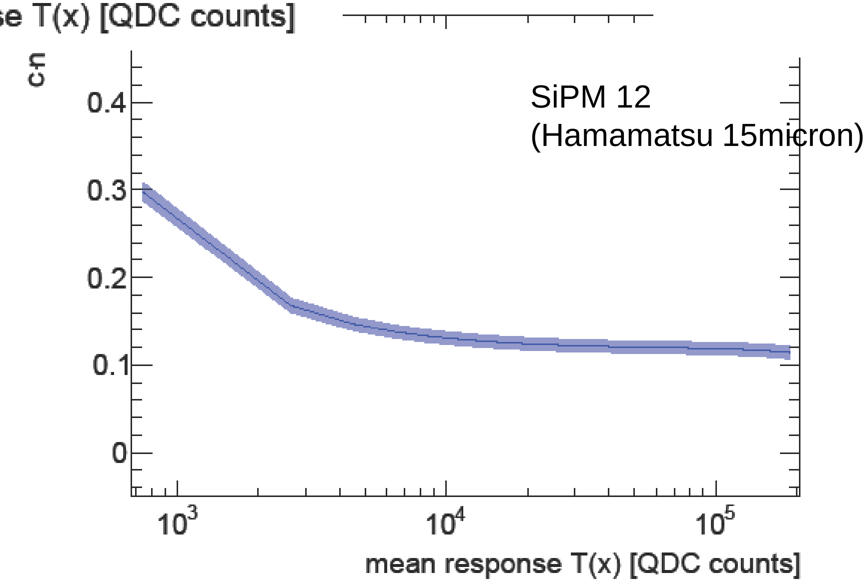




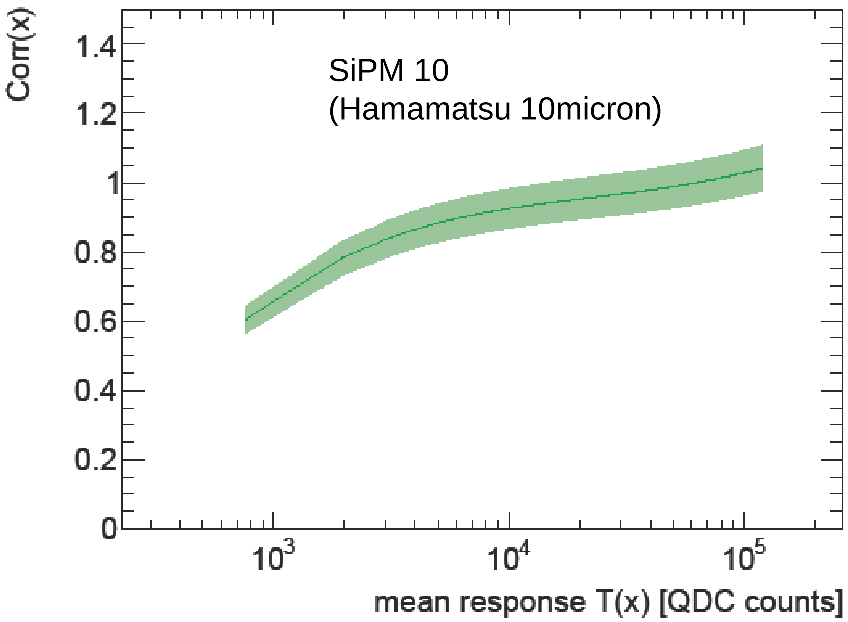
Photodetector comparison

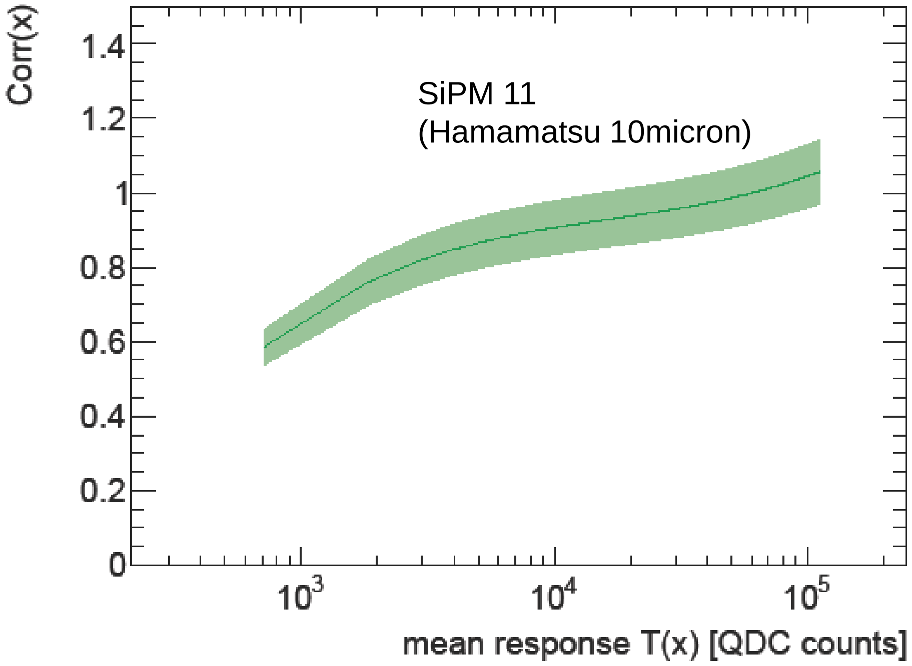


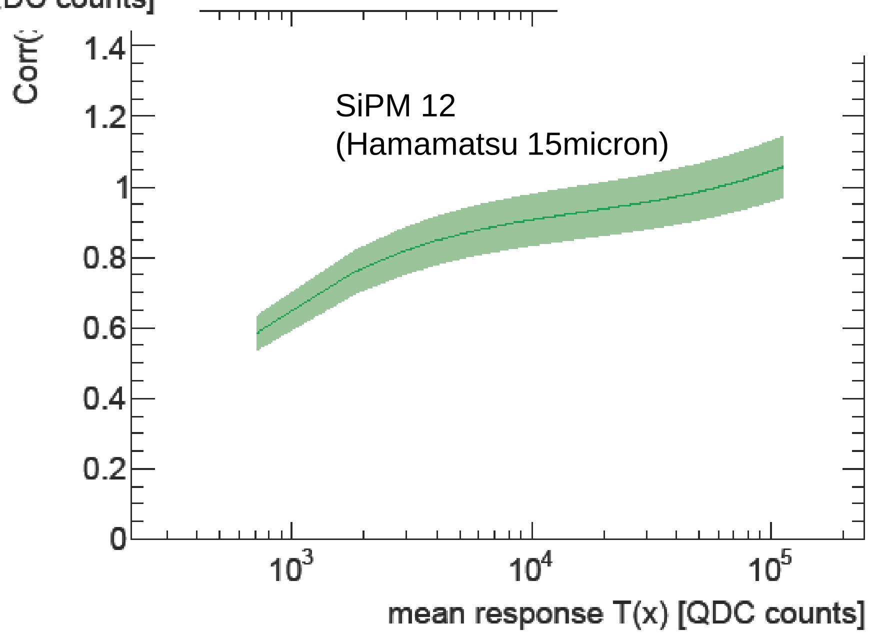




Photodetector comparison







Summary LED

- Linearization seems to work ok with Mylar foil
- Fast and easy way to characterize the different SiPM models with the digitizer over several orders of magnitude of signal
- Still some work to understand differences between SiPMs

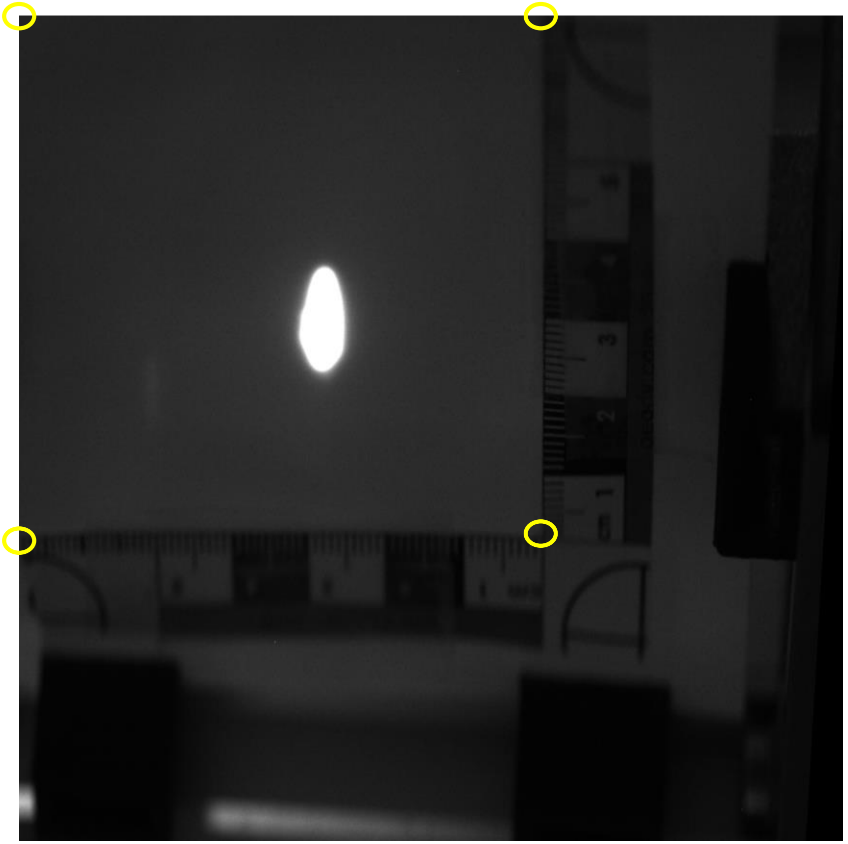
TODO:

- Anchor curves to signal observed in ARES Testbeam
- Possibly improve attenuator setup (properly frame and fix the Mylar foil?)
- Re-design of double-LED board? Components no longer available…
- Measure all our SiPMs, vary overvoltage operating points etc.

Bonus: Some fun with Scintillator pictures & openCV

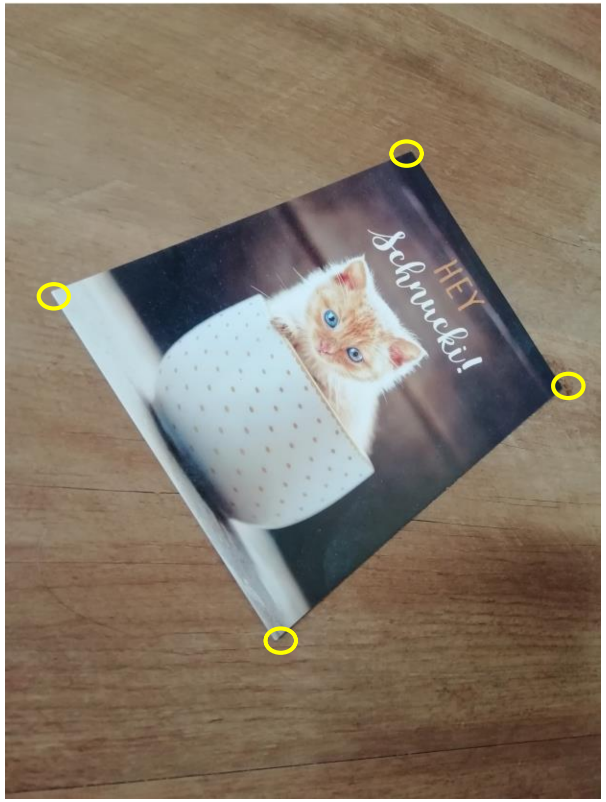
- We want to use the Scintillator screens to calibrate how much of the beam charge went into the straw
- Problem: Camera images taken from Scintillator screens are taken at an angle
  → perspective distorts beam spot
- Use openCV computer vision package to play with pictures: https://docs.opencv.org/3.4/index.html

Original

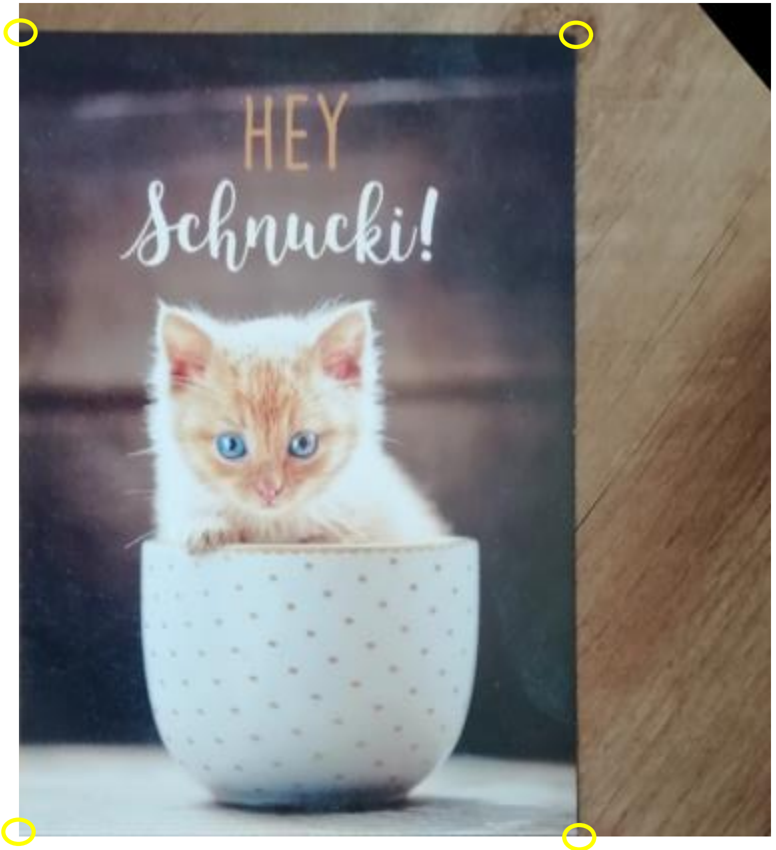


„Warped“

Bonus: Also works with kittens!



Original kitten



„Warped kitten“

- Next steps: try to interpolate between beamspots on first and second screen (without straws in between) to find beam profile in front of Cherenkov straws