PDE Measurement of SiPMs

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KIRCHHOFF-INSTITUTE FOR PHYSICS

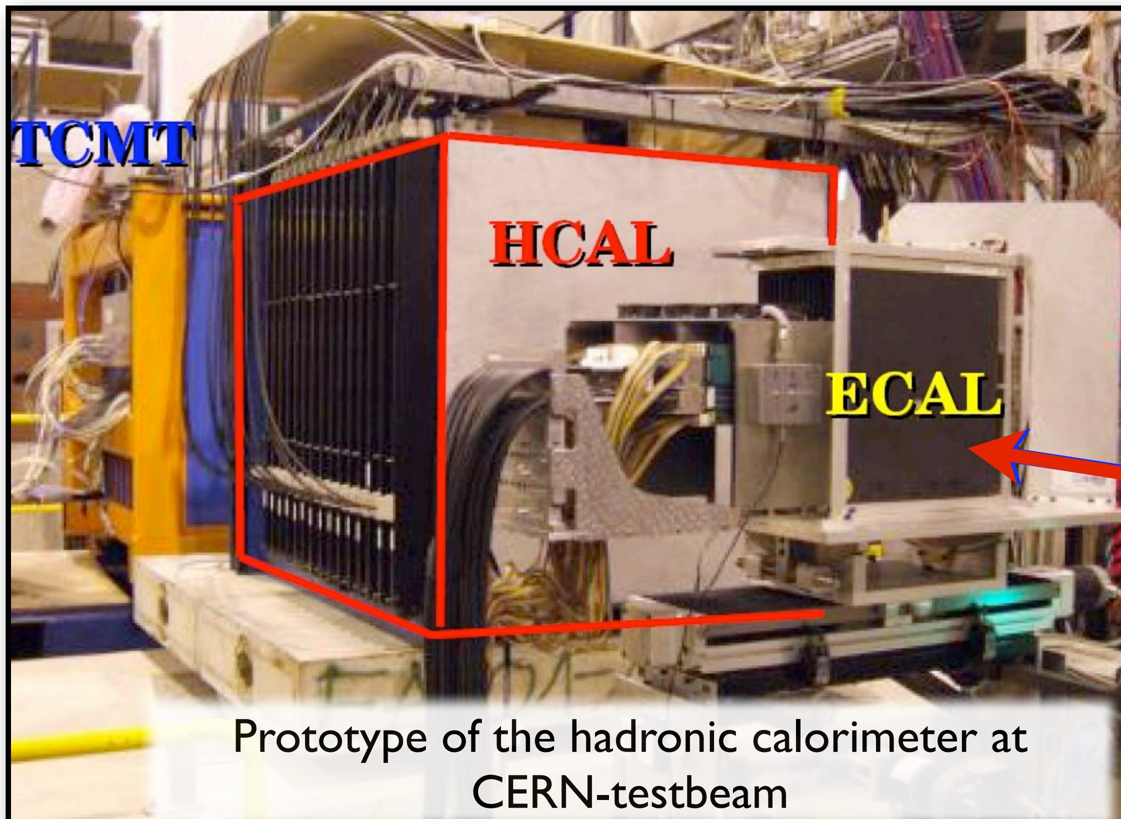
Calorimeter for ILC

Bundesministerium für Bildung und Forschung

Alexander Tadday, 17.07.2009, HCAL-Meeting DESY Hamburg

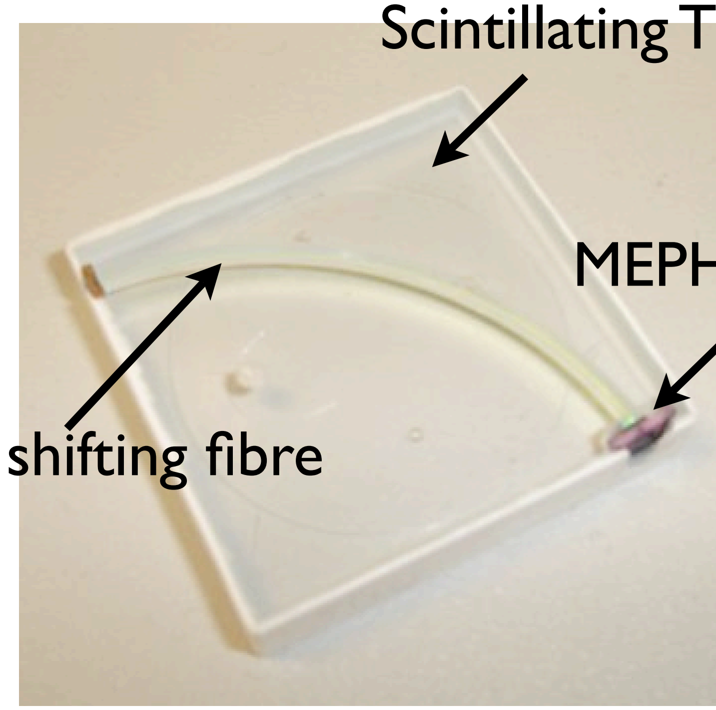
Highly Granular Hadronic Calorimeter

CALICE: Calorimeter for the Linear Collider Experiment



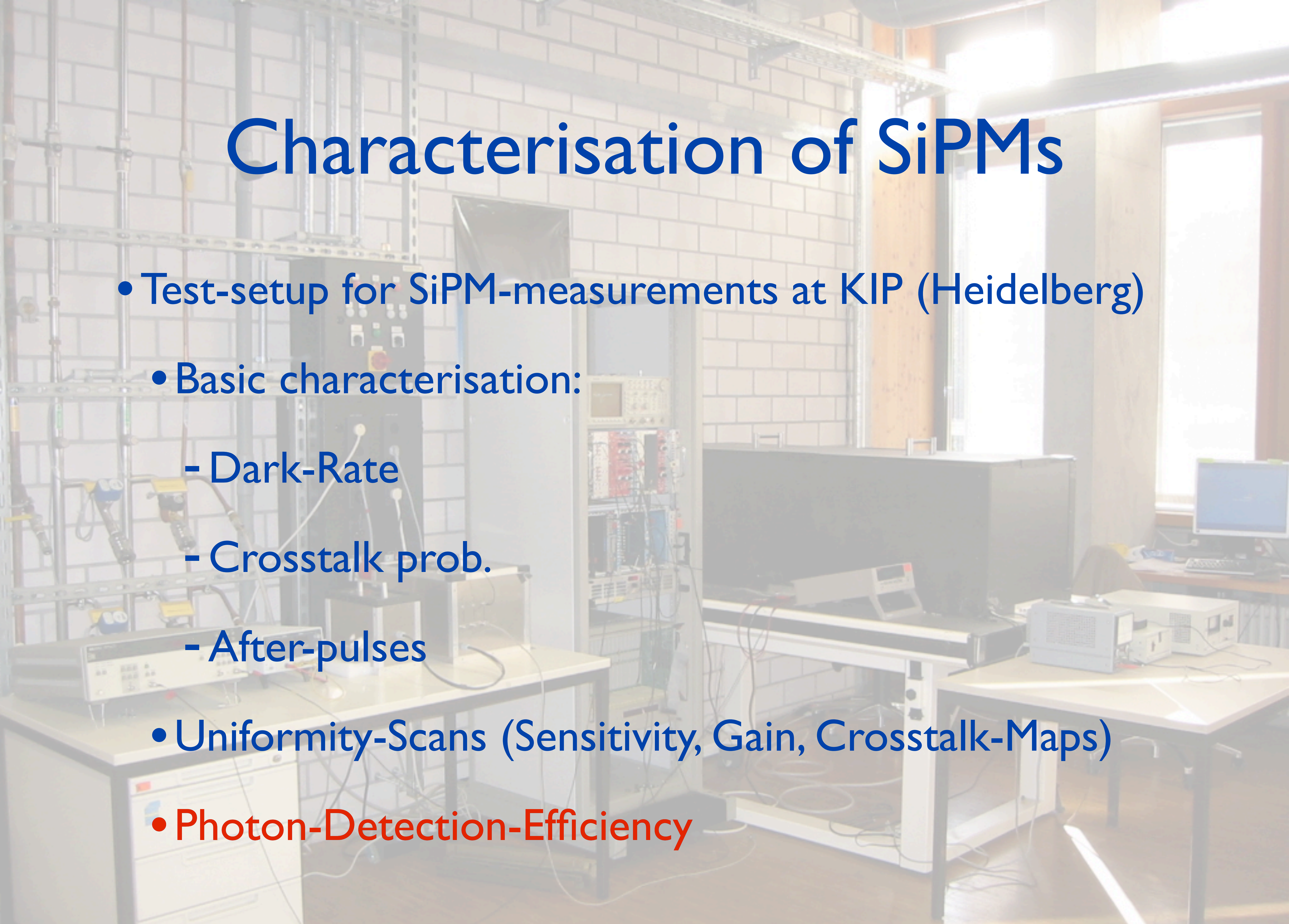
Prototype of the hadronic calorimeter at CERN-testbeam

~ 7600 SiPMs



Wavelength schifting fibre
blue ➔ green (highest sensitivity of sensor)
+ response uniformity

- Several producers/sensor types
- Which sensor ist best for the application?
- Characterisation is needed

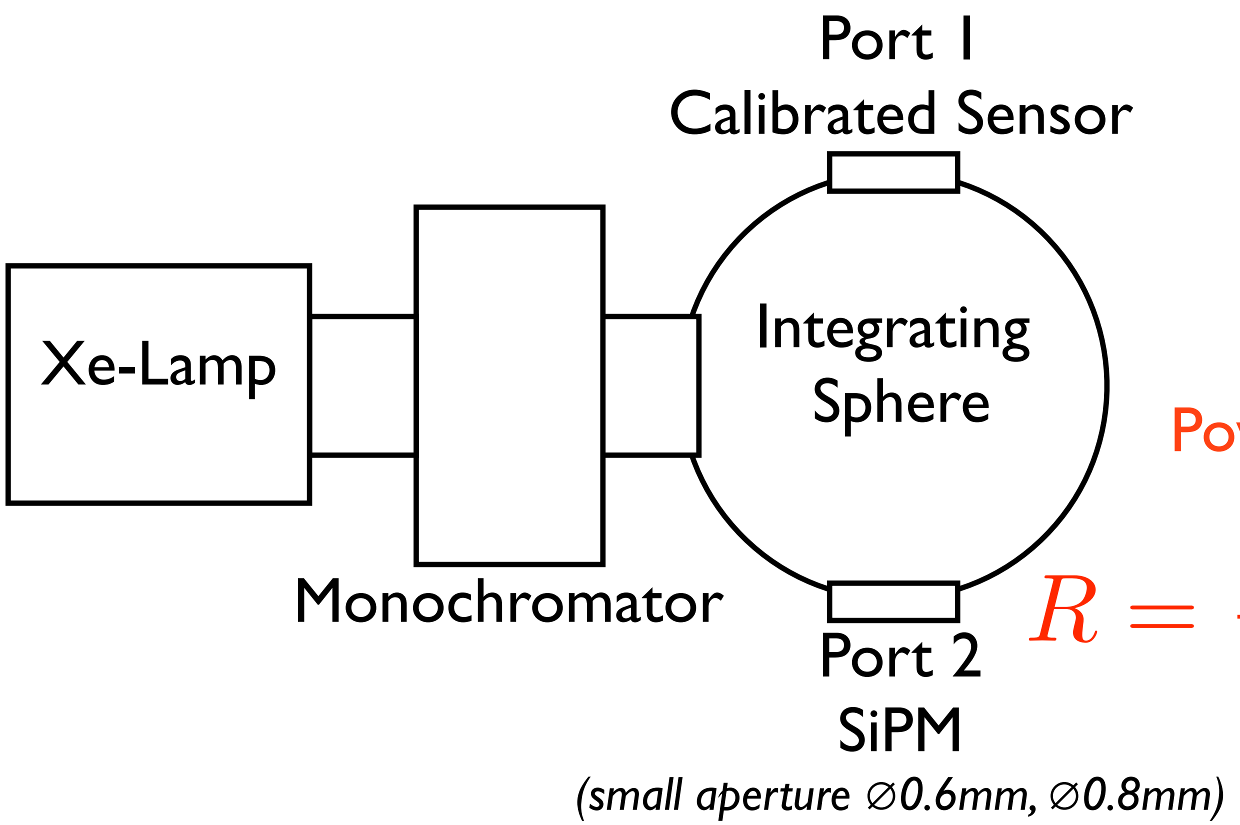


Characterisation of SiPMs

- Test-setup for SiPM-measurements at KIP (Heidelberg)
  - Basic characterisation:
    - Dark-Rate
    - Crosstalk prob.
    - After-pulses
  - Uniformity-Scans (Sensitivity, Gain, Crosstalk-Maps)
  - Photon-Detection-Efficiency

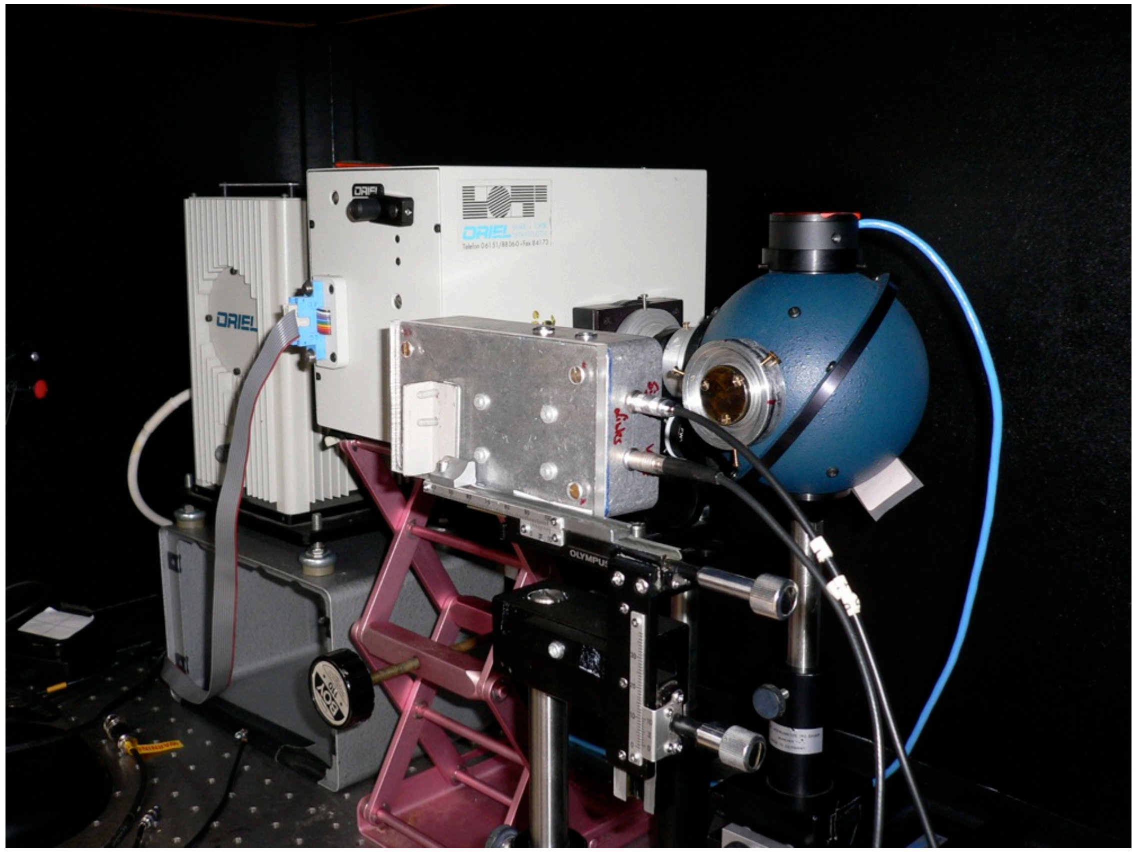
Test-Setup at Kirchhoff-Institute for Physics, University of Heidelberg

PDE Measurement Setup



Power-ratio:

$$R = \frac{P_{port1}}{P_{port2}}$$



- Power-ratio R *(partial compensation of different sensitivities SiPM/Cal. Sensor)*
- XE-Lamp + Monochromator *(350-1000nm)*
  Current-measurement (contains crosstalk and after-pulses)

  ➡ relative PDE
- Pulsed laserdiodes/LEDs *(465nm,633nm, 775nm, 870nm)*
  QDC-readout *(statistical analysis)*

  ➡ PDE without crosstalk and after-pulses

Measurement Principle

PDE without crosstalk and after-pulses

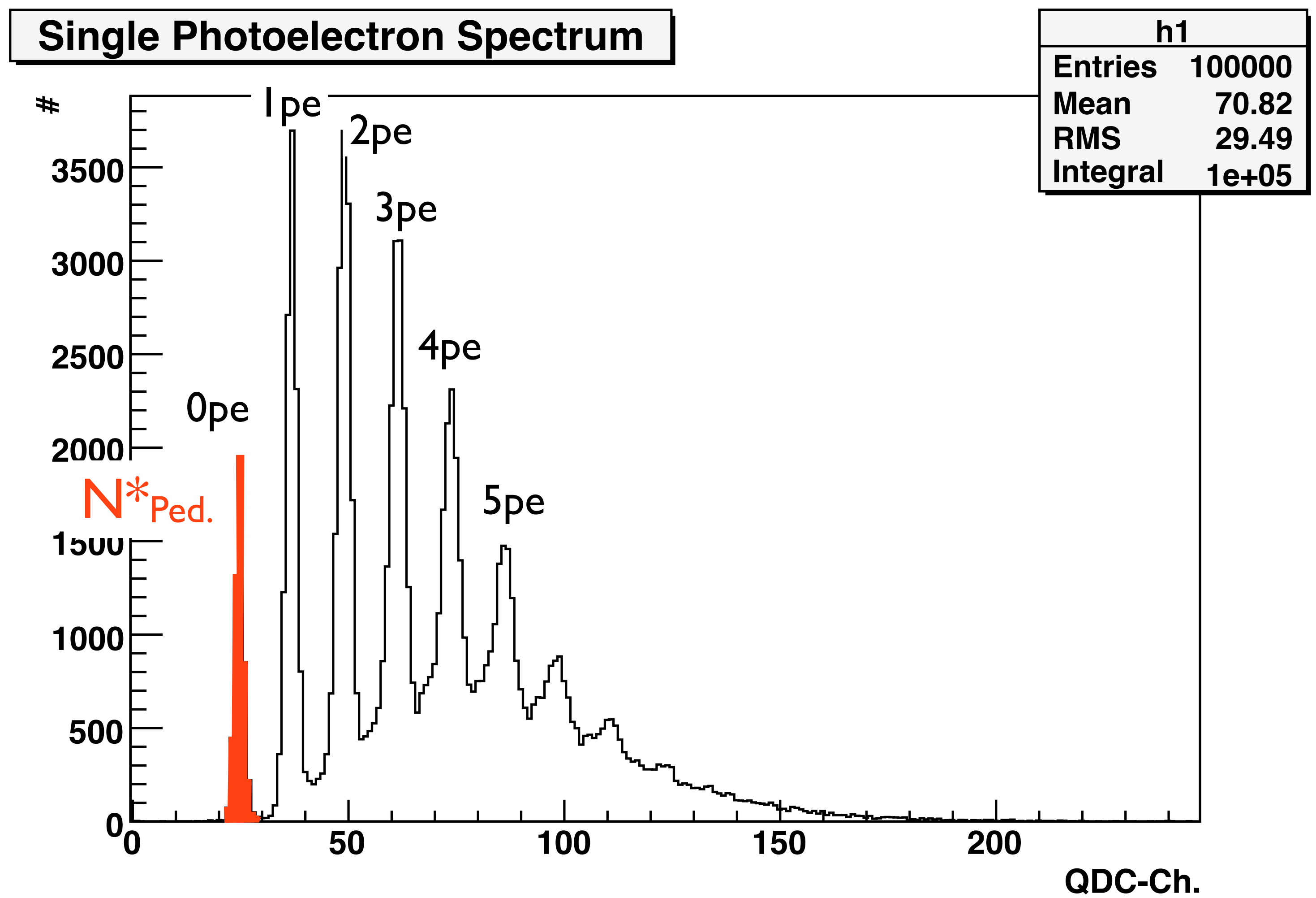
Photons, that arrive at the SiPM are Poisson-distributed:

$$\mathrm{P(n,\lambda)} = \frac{\lambda^{\mathrm{n}} \cdot \mathrm{e}^{-\lambda}}{\mathrm{n!}} \Rightarrow \mathrm{P(0,\lambda)} = \mathrm{e}^{-\lambda}$$

$$\Rightarrow \lambda = N_{pe} = -\ln\left(\frac{\mathrm{N_{Ped.}}}{\mathrm{N_{Tot.}}}\right)$$

N^*_{Ped} is not influenced by optical crosstalk and after-pulses, but needs to be corrected for dark-rate:

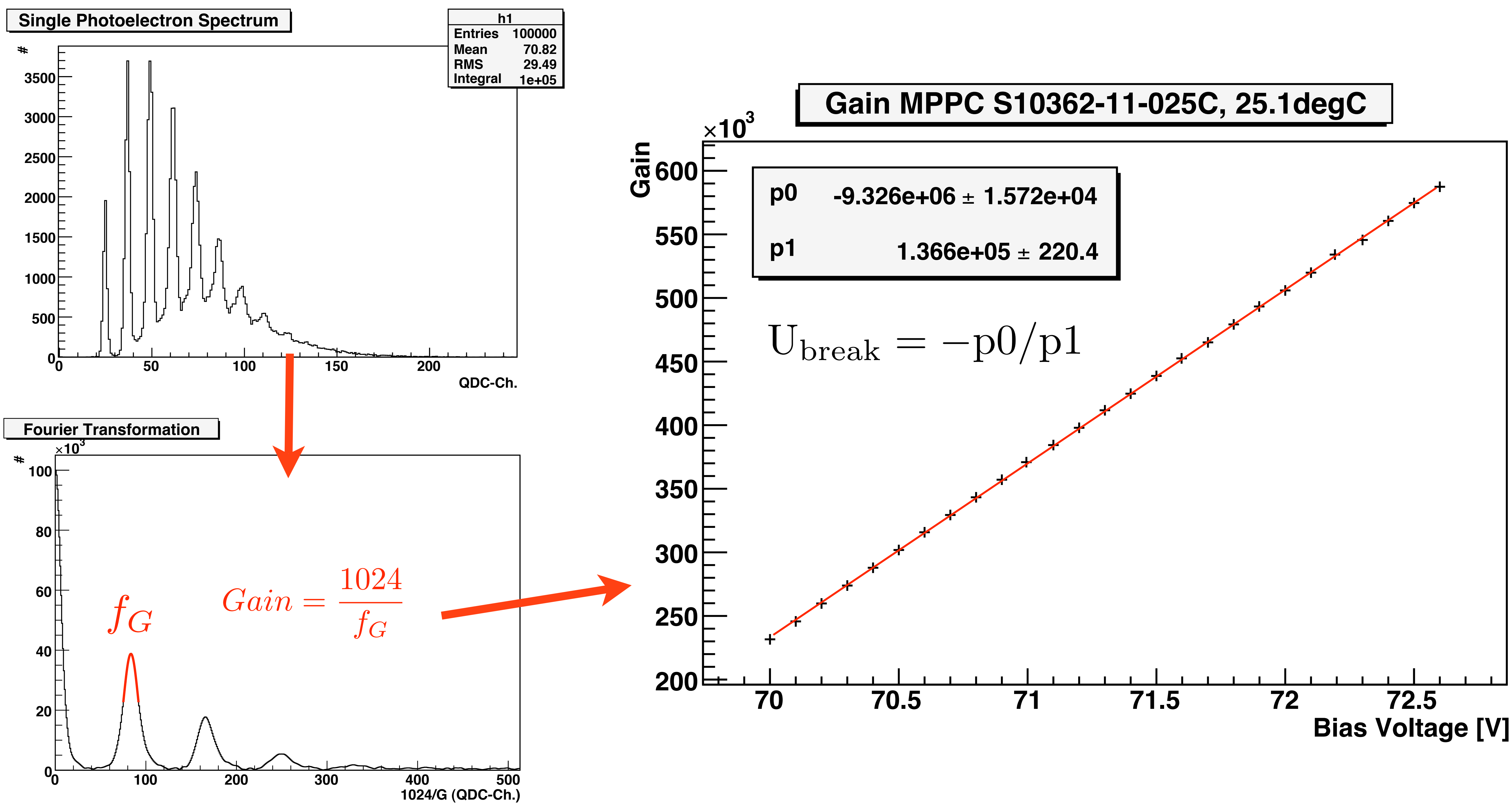
$$N^*_{Ped} = N_{ped} - N_{dark}$$



Gain Measurement

- PDE as a function of $U_{over} = U_{bias} - U_{break}$

  ➡ Calculate U_{break} *(from linear fit results)*



Automated Measurement
(LABVIEW)

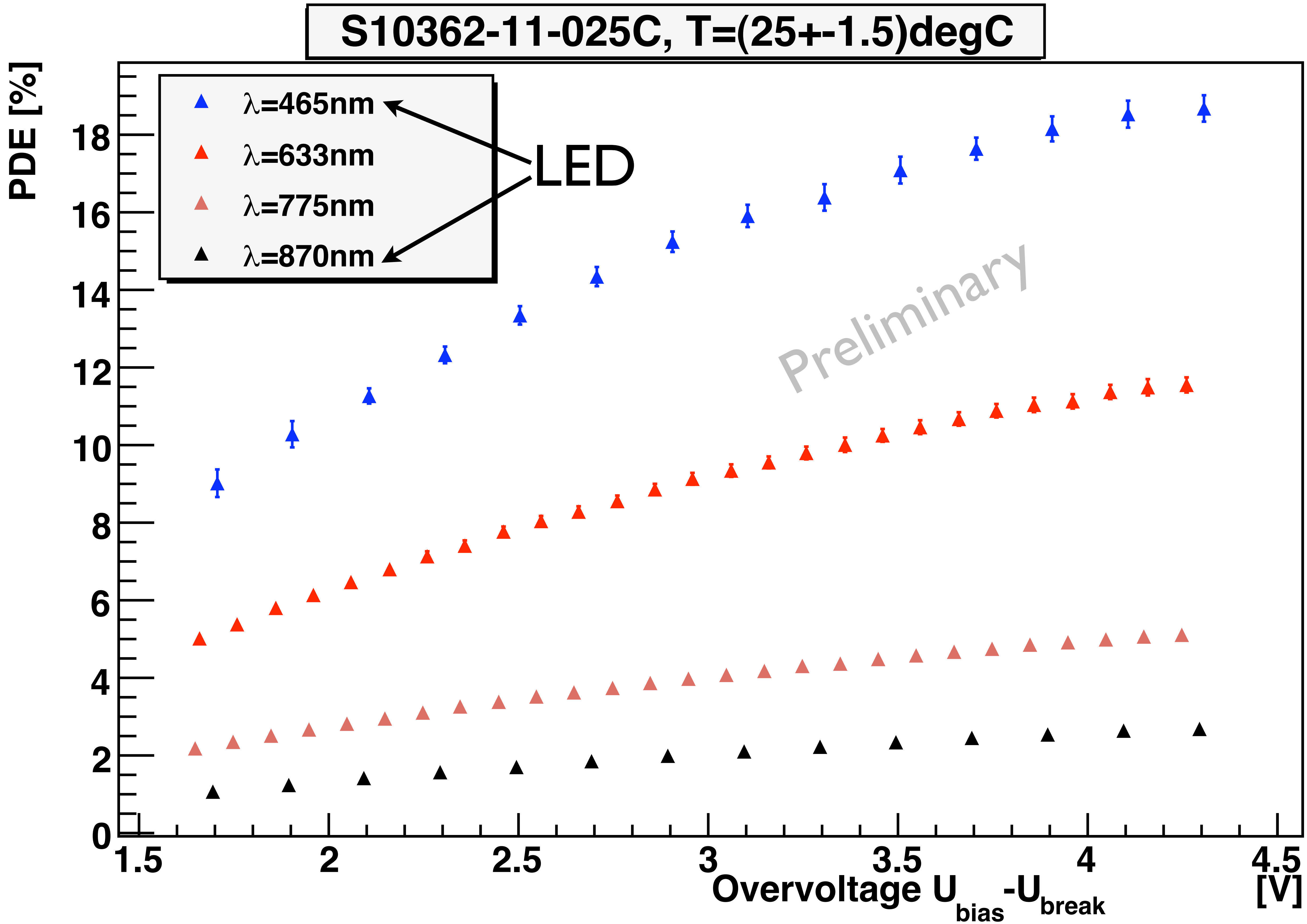
1) Record photoelectron spectrum
2) Switch off light and record dark-rate spectrum
3) Calculate gain and number of photoelectrons
4) Apply dark-rate correction ➔ PDE
5) Set new voltage
6) Start over at 1

$$PDE = \frac{n_{pe}}{n_{ph}} = \frac{N_{pe} \cdot R/T}{P_{opt}/(h \cdot \frac{c}{\lambda})}$$

$$\begin{aligned} N_{pe} &= Number\, of\, Photoelectrons/Pulse \\ R &= Power\, Ratio \\ T &= Period\, (30 \cdot 10^{-6} s) \\ P_{opt} &= Optical\, Power\, [W] \end{aligned}$$

NIST certified photodiode

Example: PDE MPPC 1600pix.



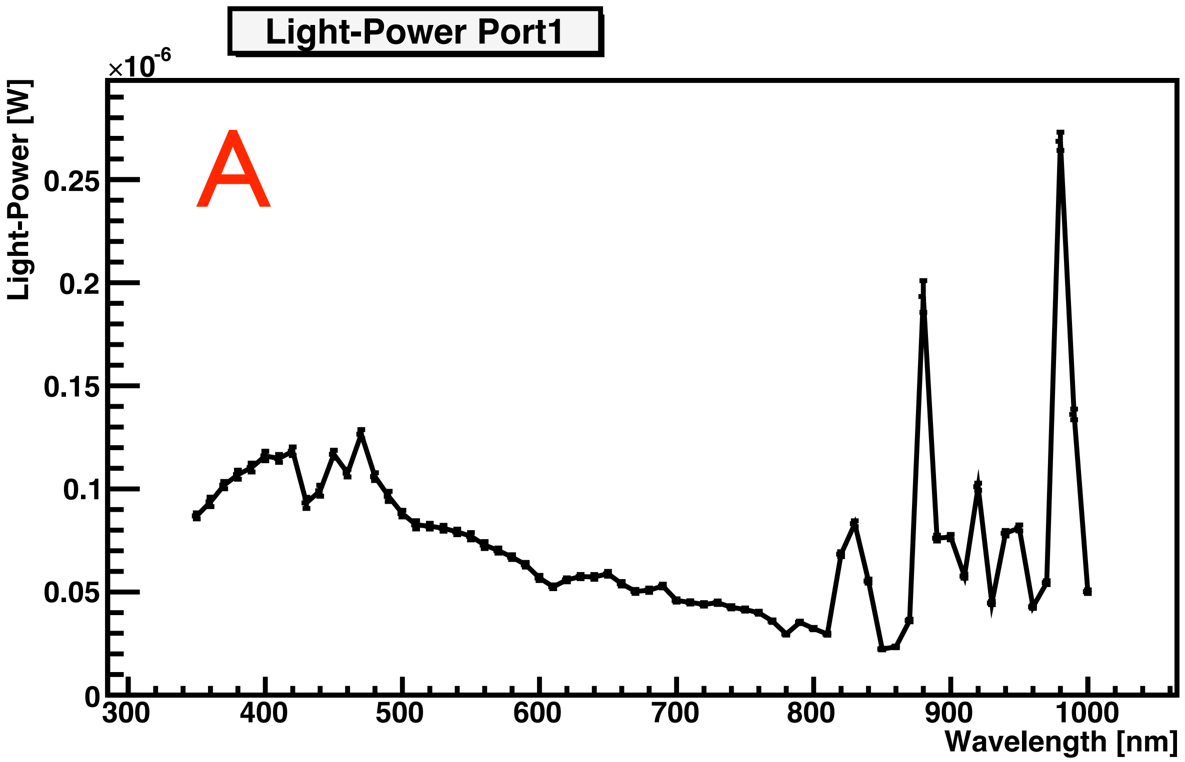
Relative Measurement

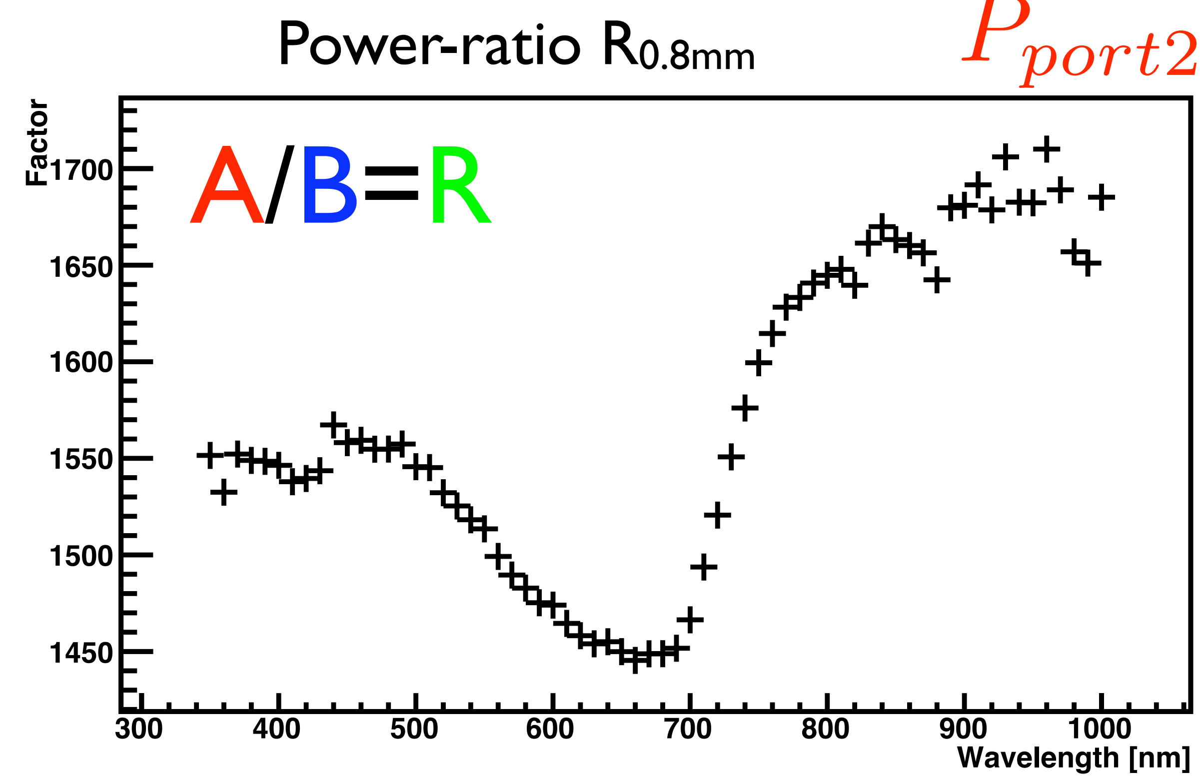
(350nm-1000nm)

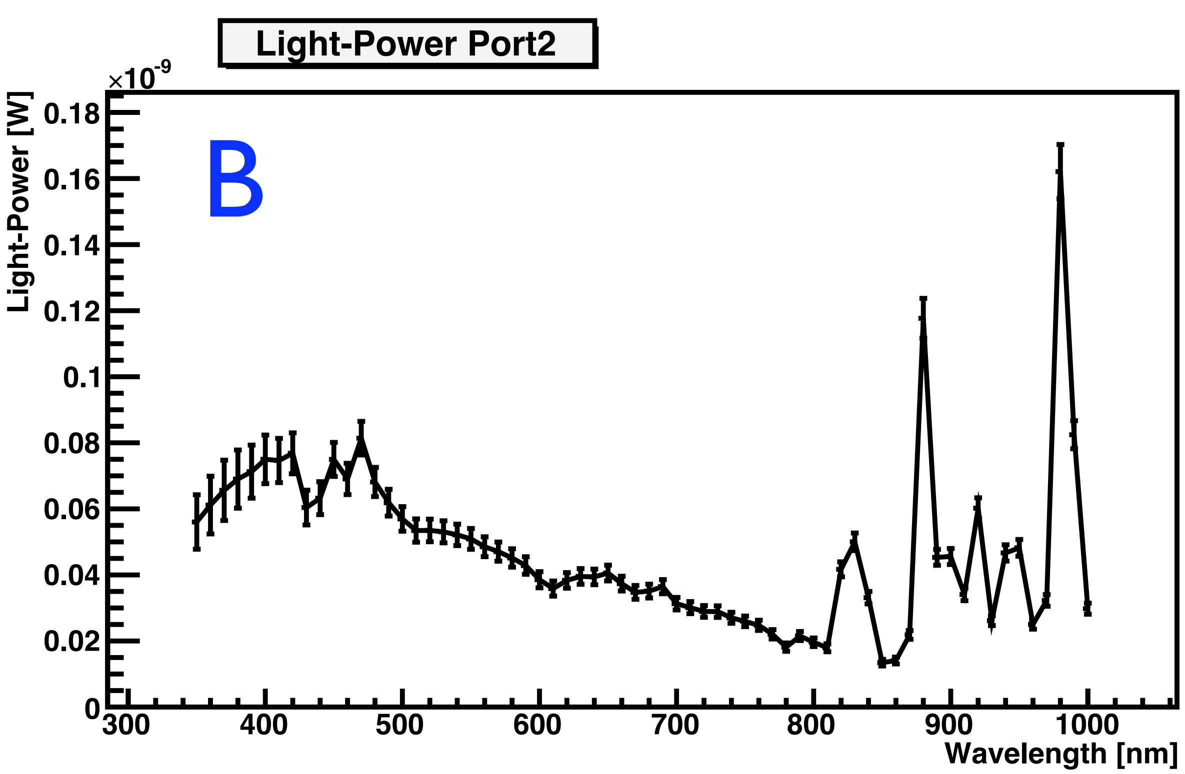
Setup Calibration (350-1000nm)

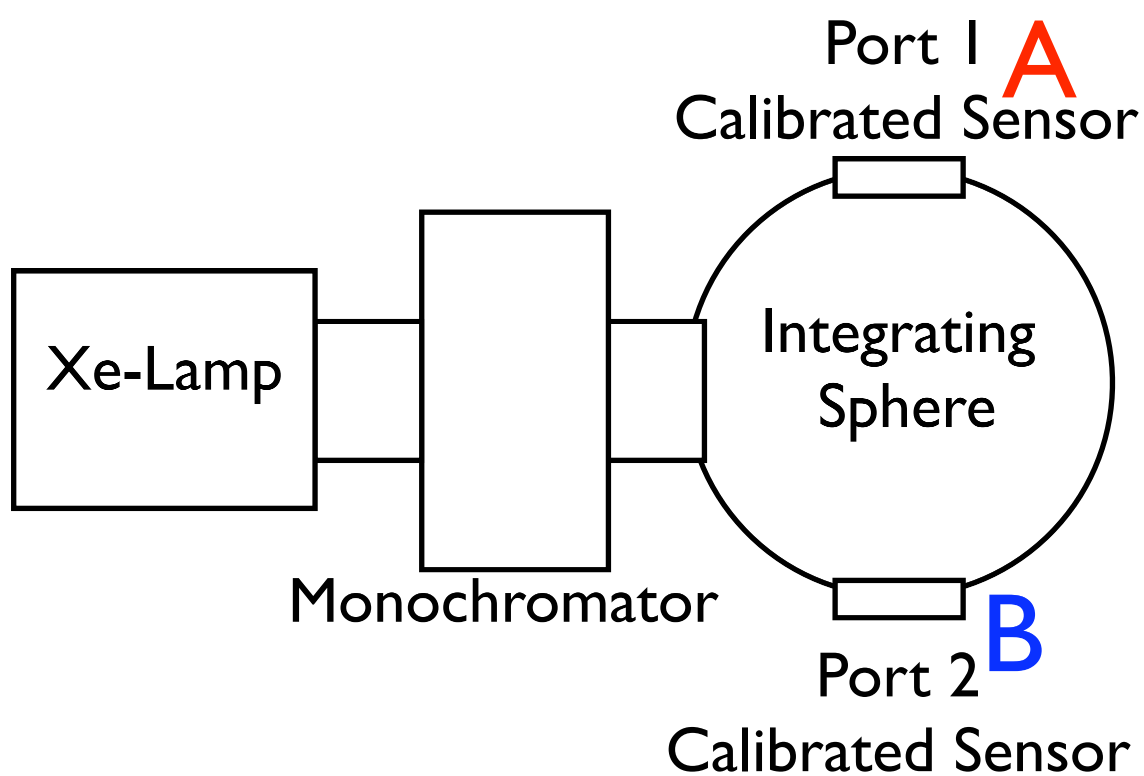
(∅=0.8mm aperture)

$$R = \frac{P_{port1}}{P_{port2}}$$



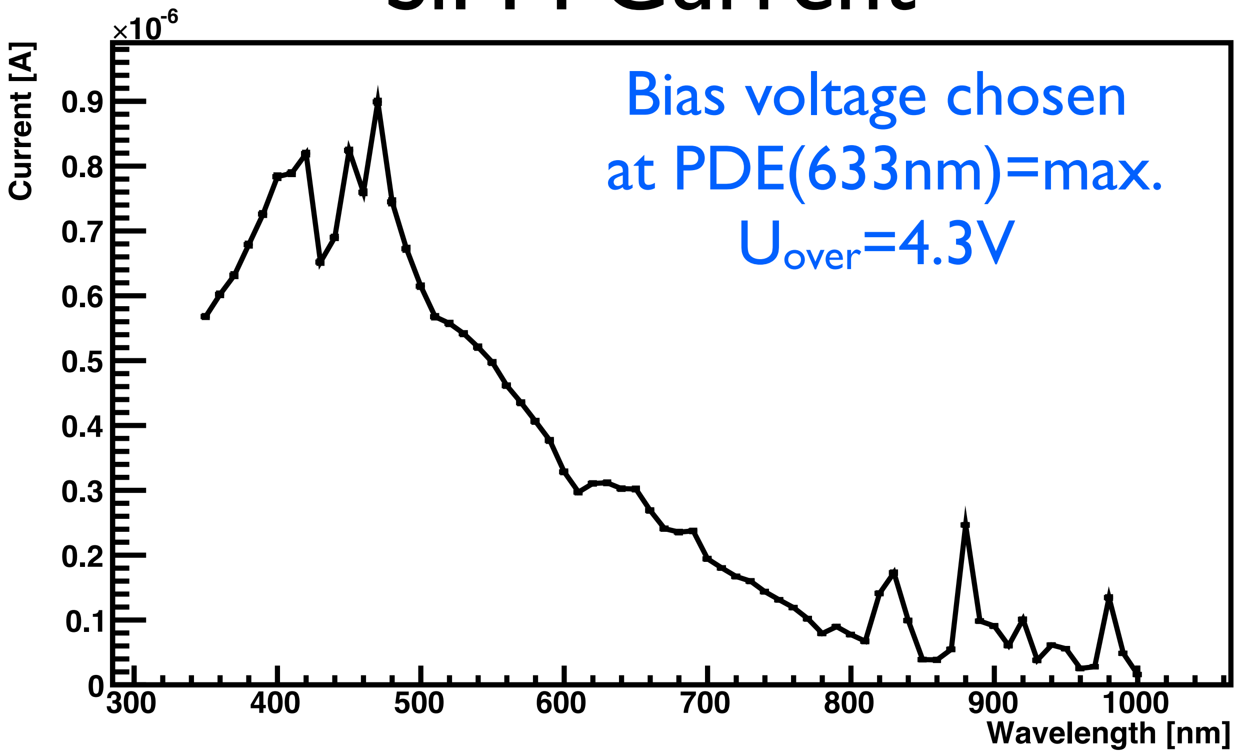




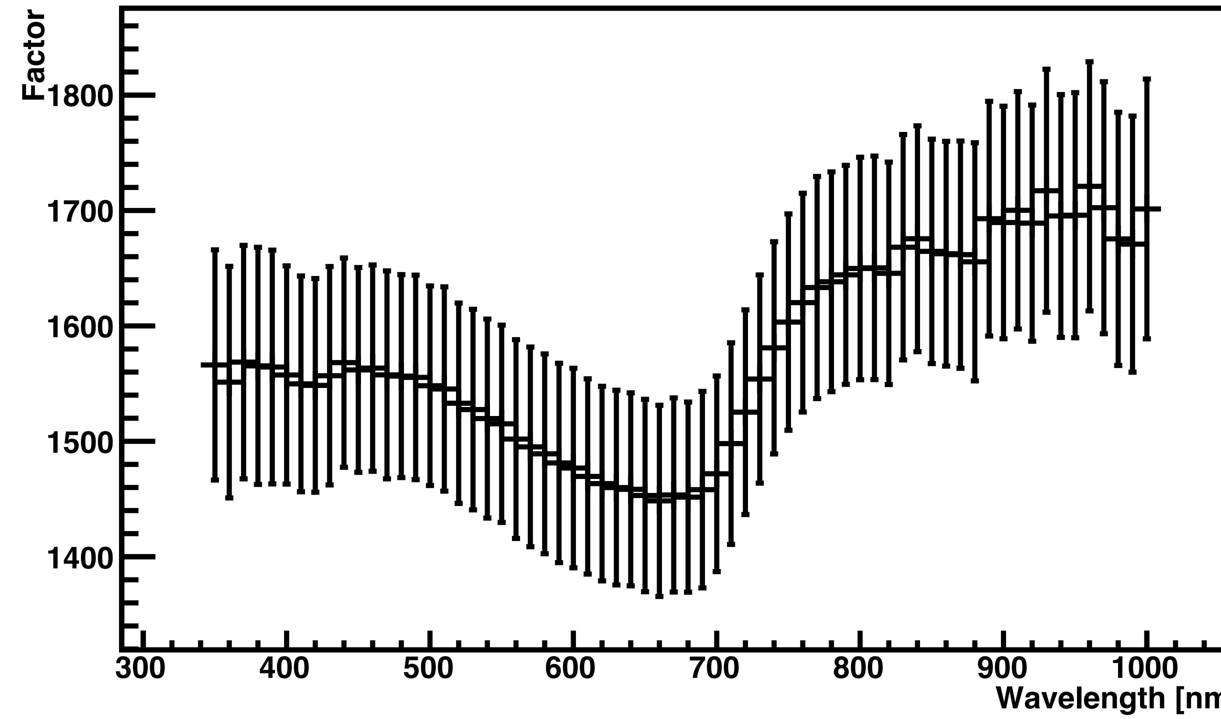


PDE Measurement (Relative)

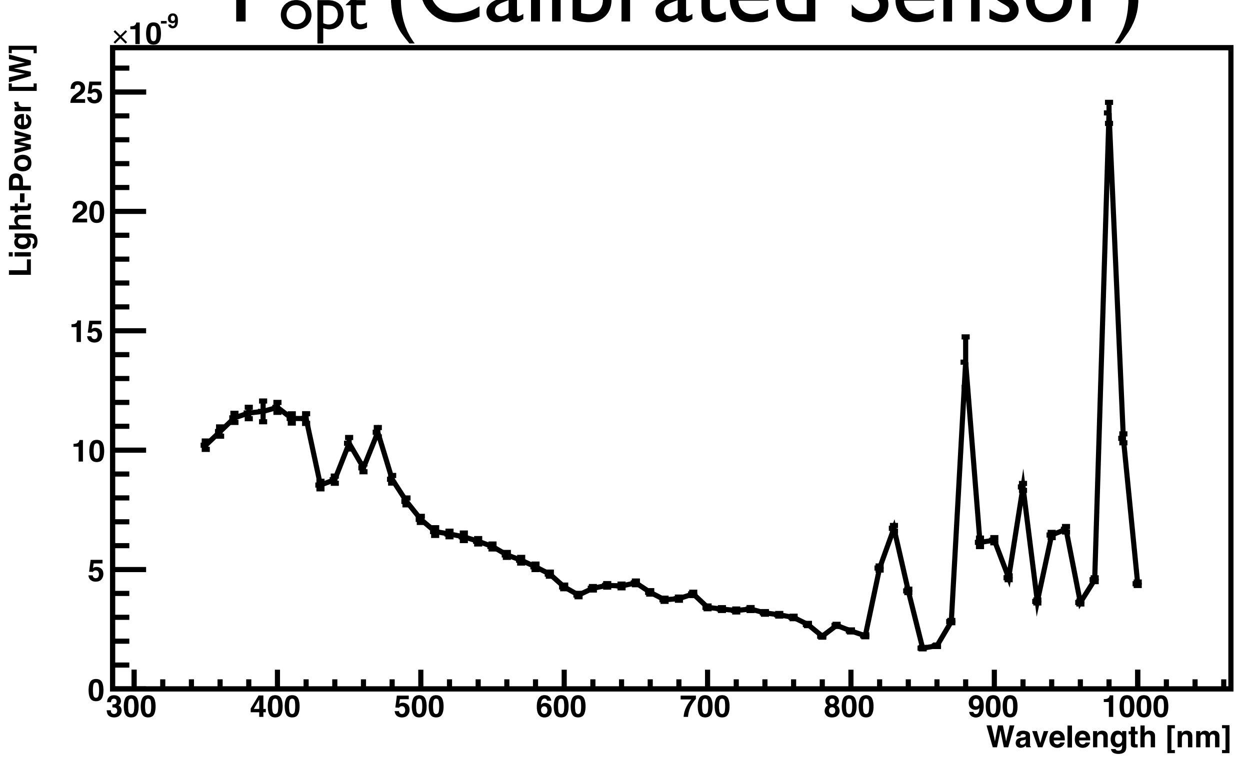
SiPM Current



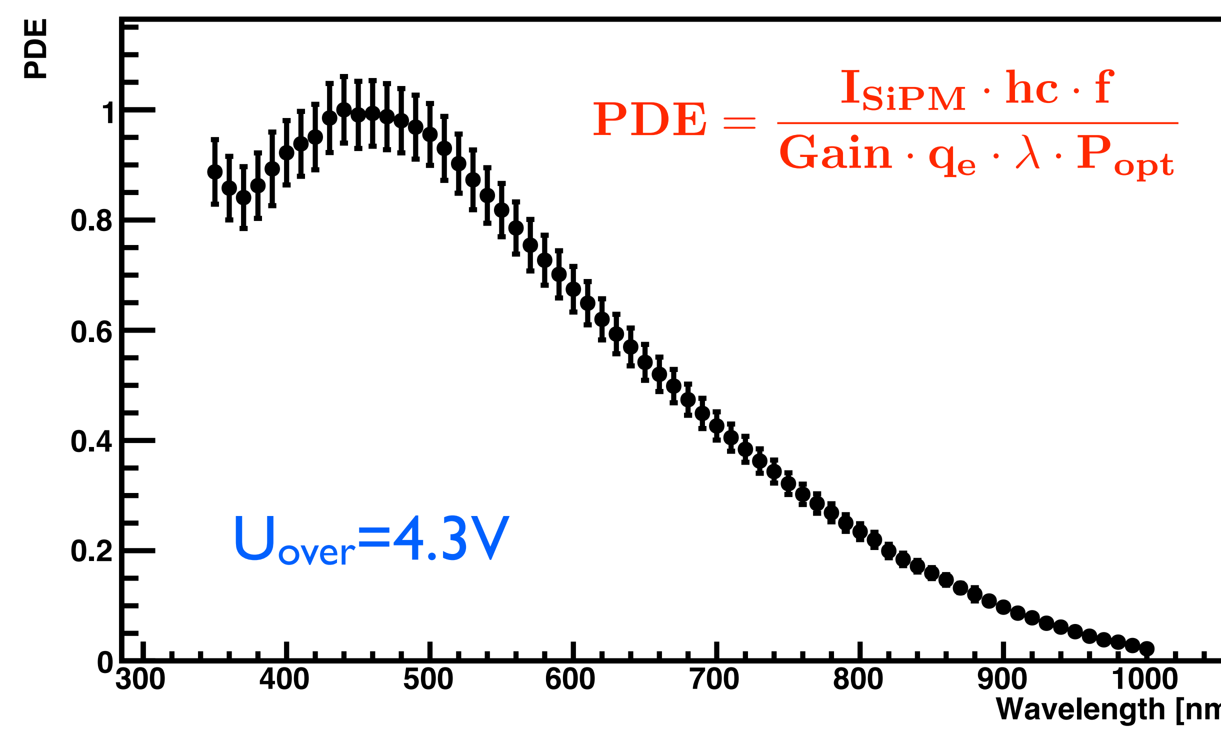
Power-ratio $R_{0.8mm}$



P_{opt} (Calibrated Sensor)

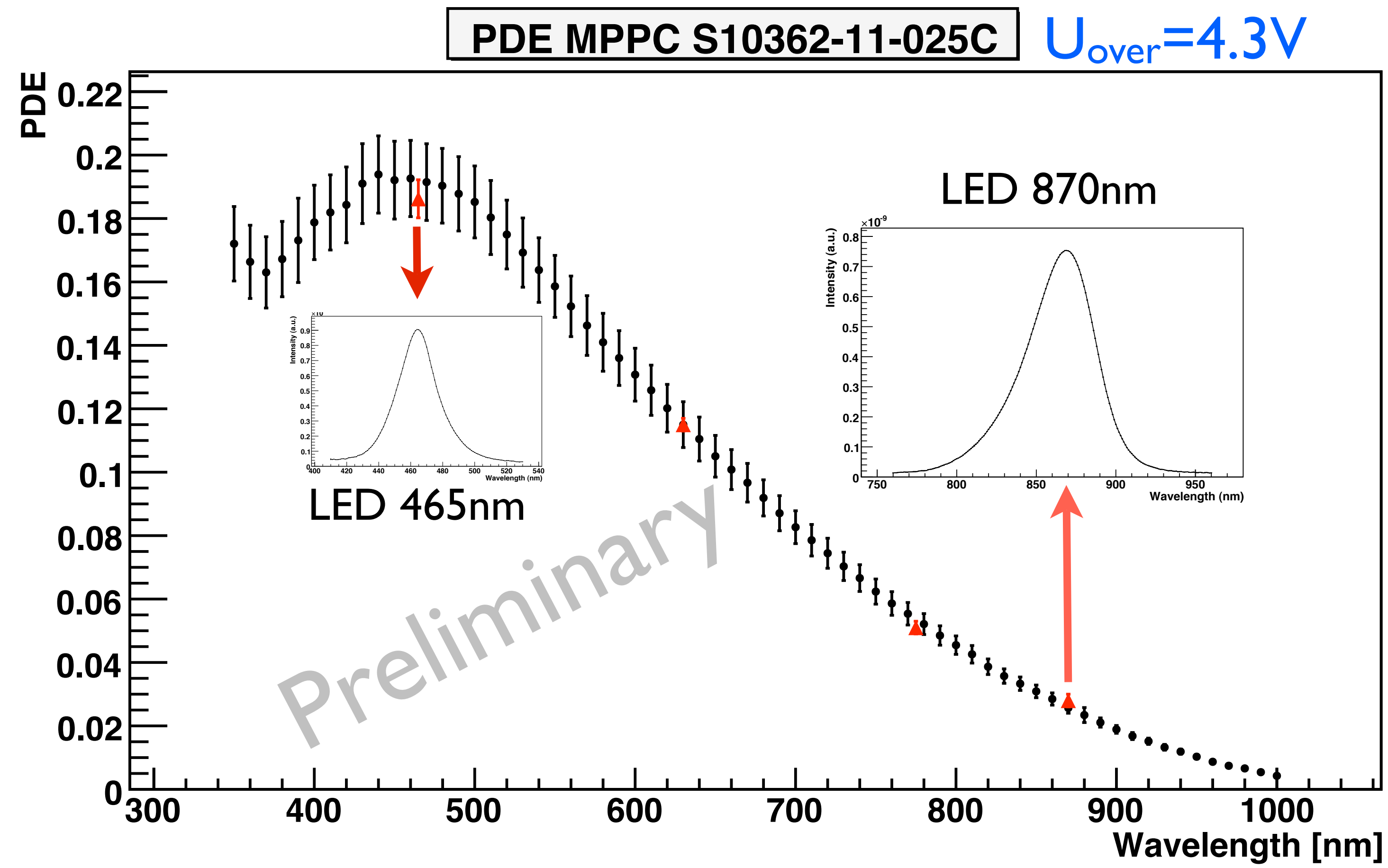


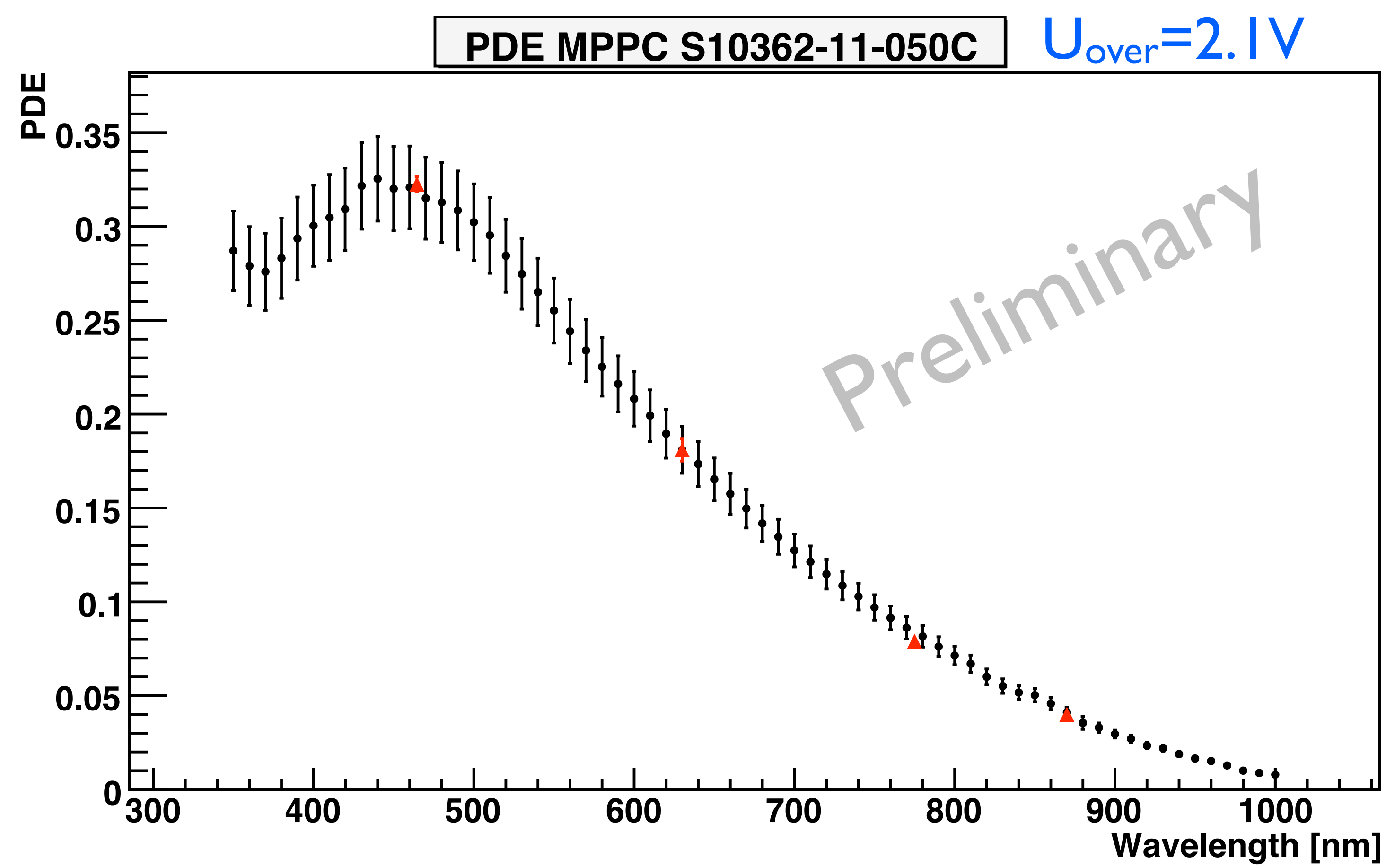
Relative PDE MPPC 025C



PDE Curve Scaling

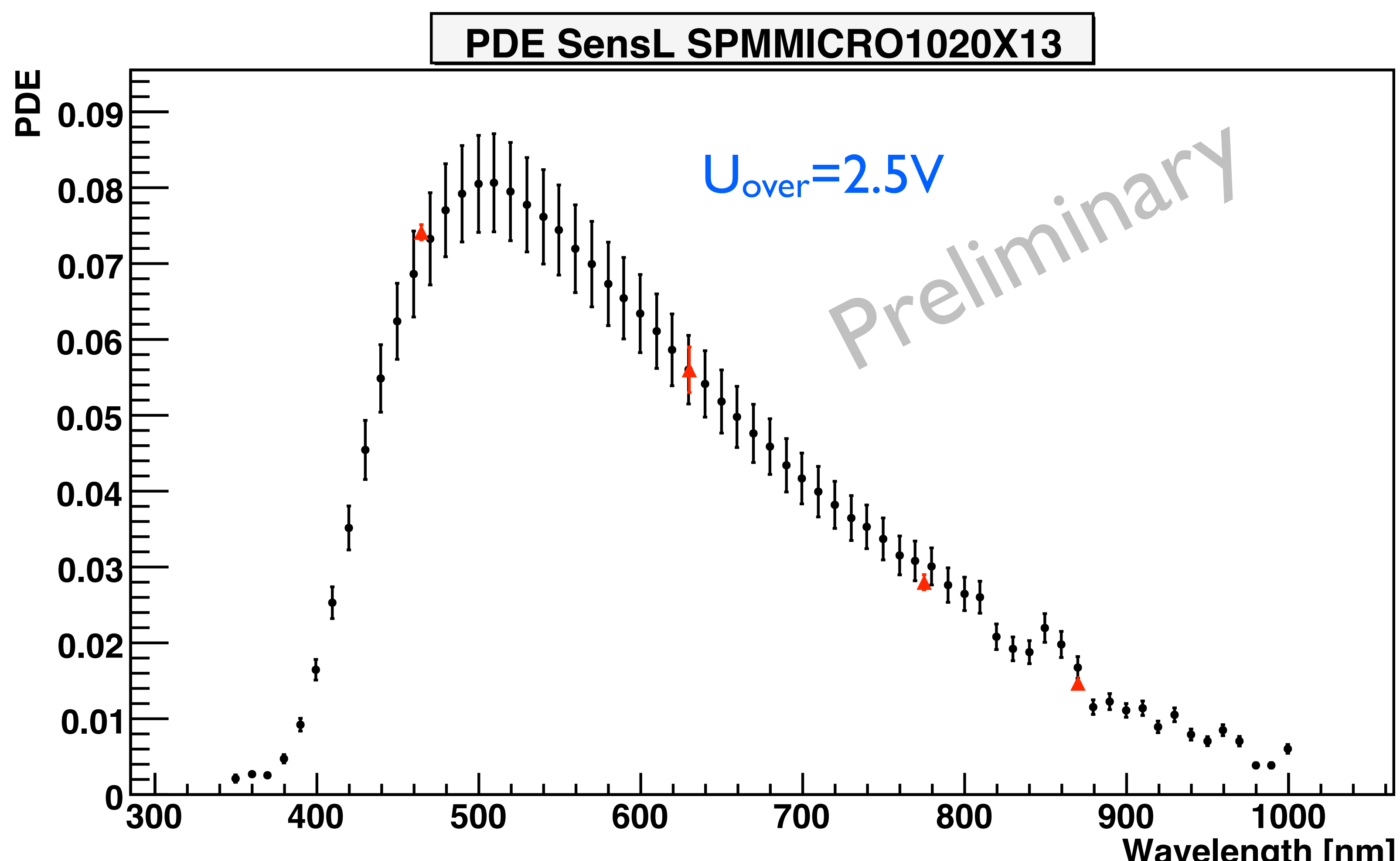
- Curves are scaled to max. PDE value at 633nm
- Crosscheck: max. PDE-values at 465nm, 775nm and 870nm are shown.
  - ➡ Good agreement
- Measurement at 832nm by factor 5 smaller than other measurements (feature of Laserdiode)
  - ‣ Has to be investigated





PDE Curve SensL SPMMICRO1020X13

- Scaled to max. PDE value at 633nm.
- Highest PDE at ~500nm
- steep curve below 500nm



(20µm, 848 microcells)

Conclusion

- Setup for SiPM characterization ready for testing
- Basic Characterisation
- Uniformity Scans (sensitivity, gain and crosstalk maps)
- New: PDE-measurement over wide spectral range (350-1000nm)
- Crosstalk and after-pulse measurement (Patrick Eckert)

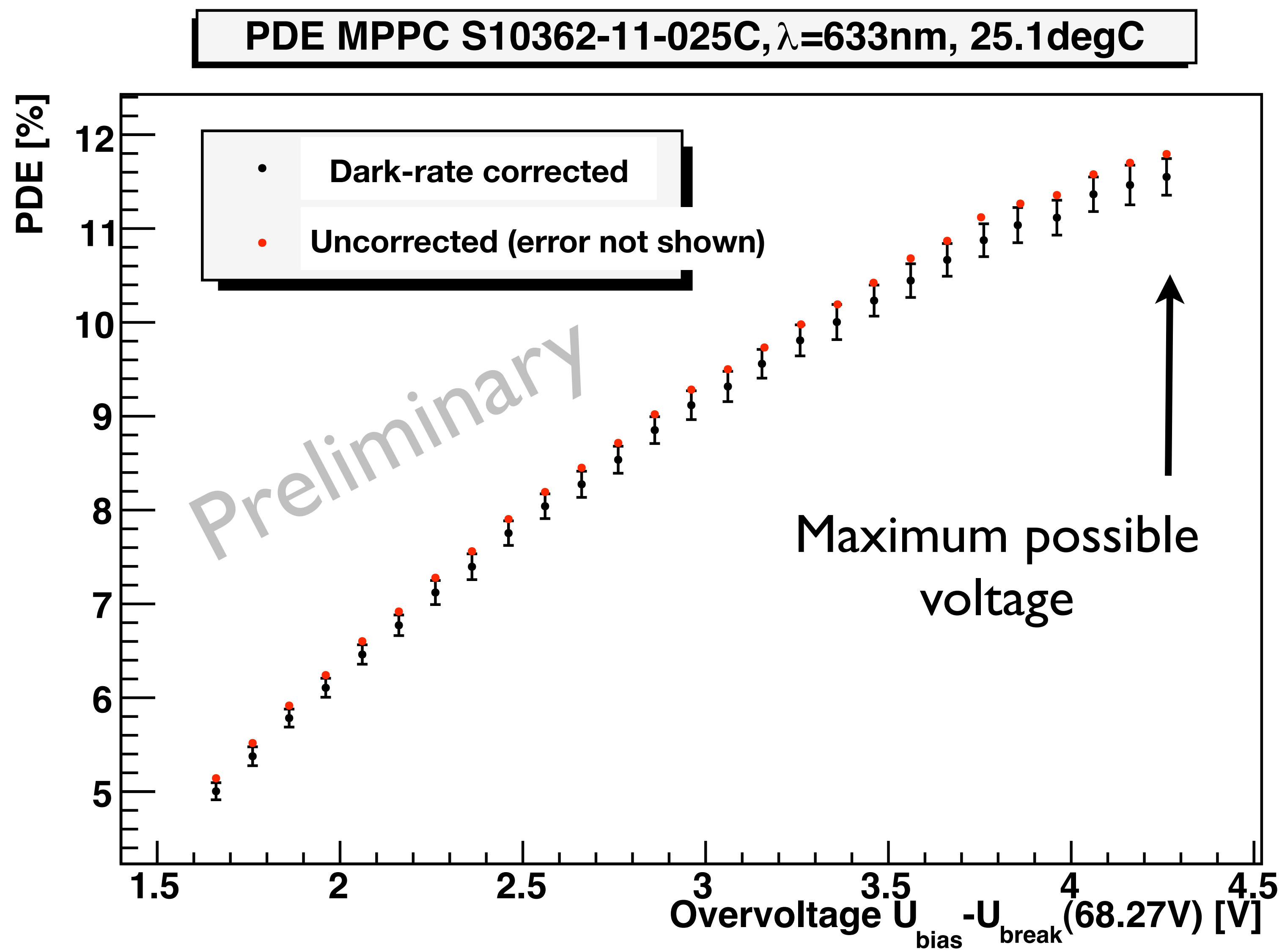
Further Projects (University of Heidelberg)

- Development of SiPM readout-chip (Wei Shen)
  (submission planned for summer/early fall)
  - HCAL channel (large dynamical range, low noise)
  - TOF-PET channel (good timing resolution)
- SiPM TDC readout development (Tobias Harion)
  - Further SiPM characterization measurements
  - For PET (in cooperation with DESY)

Backup Slides

PDE MPPC 1600 Pixels

- In the case of the MPPC with 1600 pixels the dark-rate correction is small (low dark-rate, short gate 50ns)
- In the following only corrected values are shown



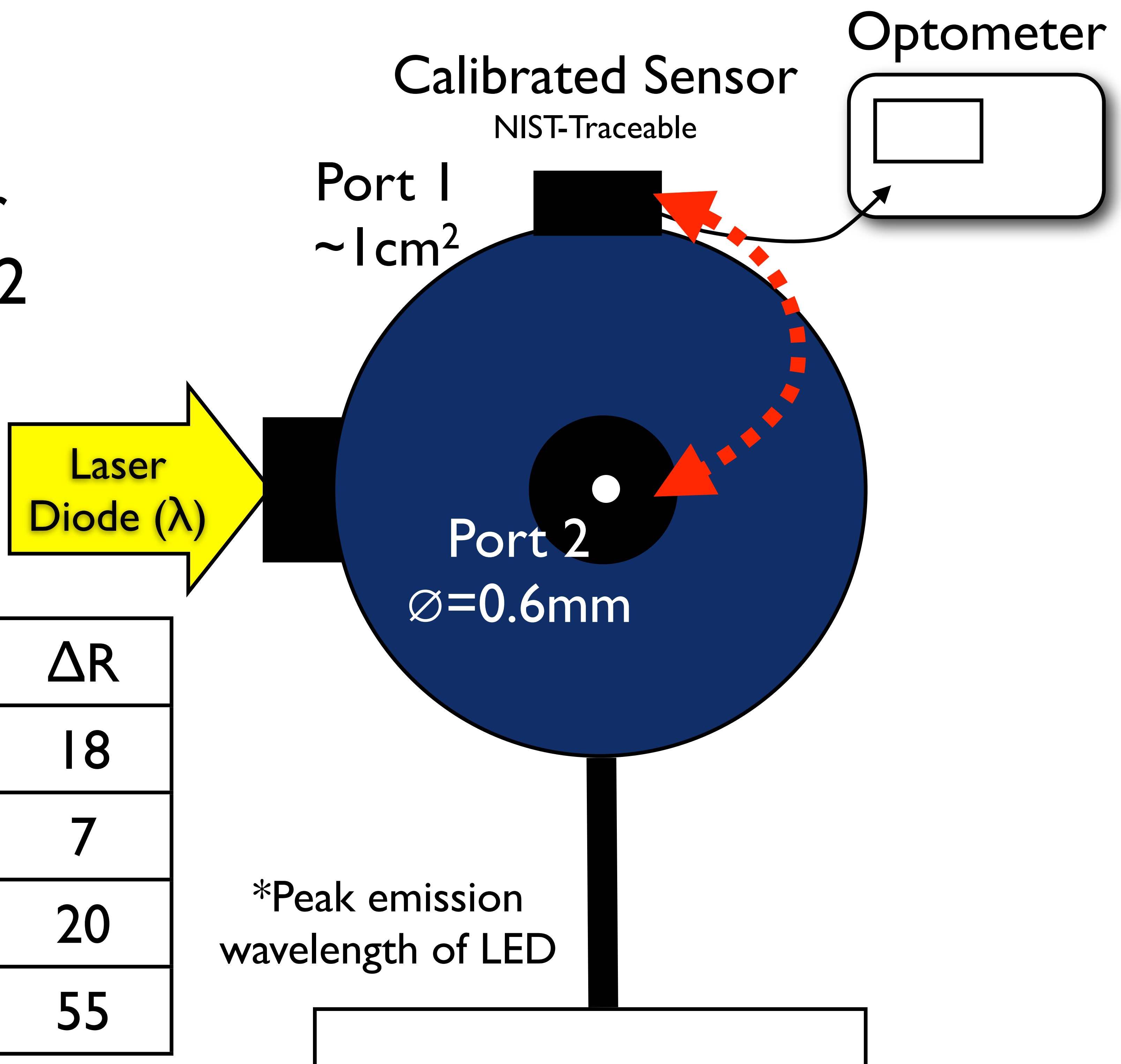
Measurement of Power-ratio R

(∅=0.6mm aperture)

The Power-ratio R is measured by moving the calibrated sensor from port 1 to port 2 and backwards.

$$R = \frac{P_{\mathrm{Port1}}}{P_{\mathrm{Port2}}}$$

Type	λ [nm]	$R_{0.6mm}$	ΔR
Laserdiode	633	3852	18
Laserdiode	775	4328	7
LED	465*	4200	20
LED	870*	4625	55



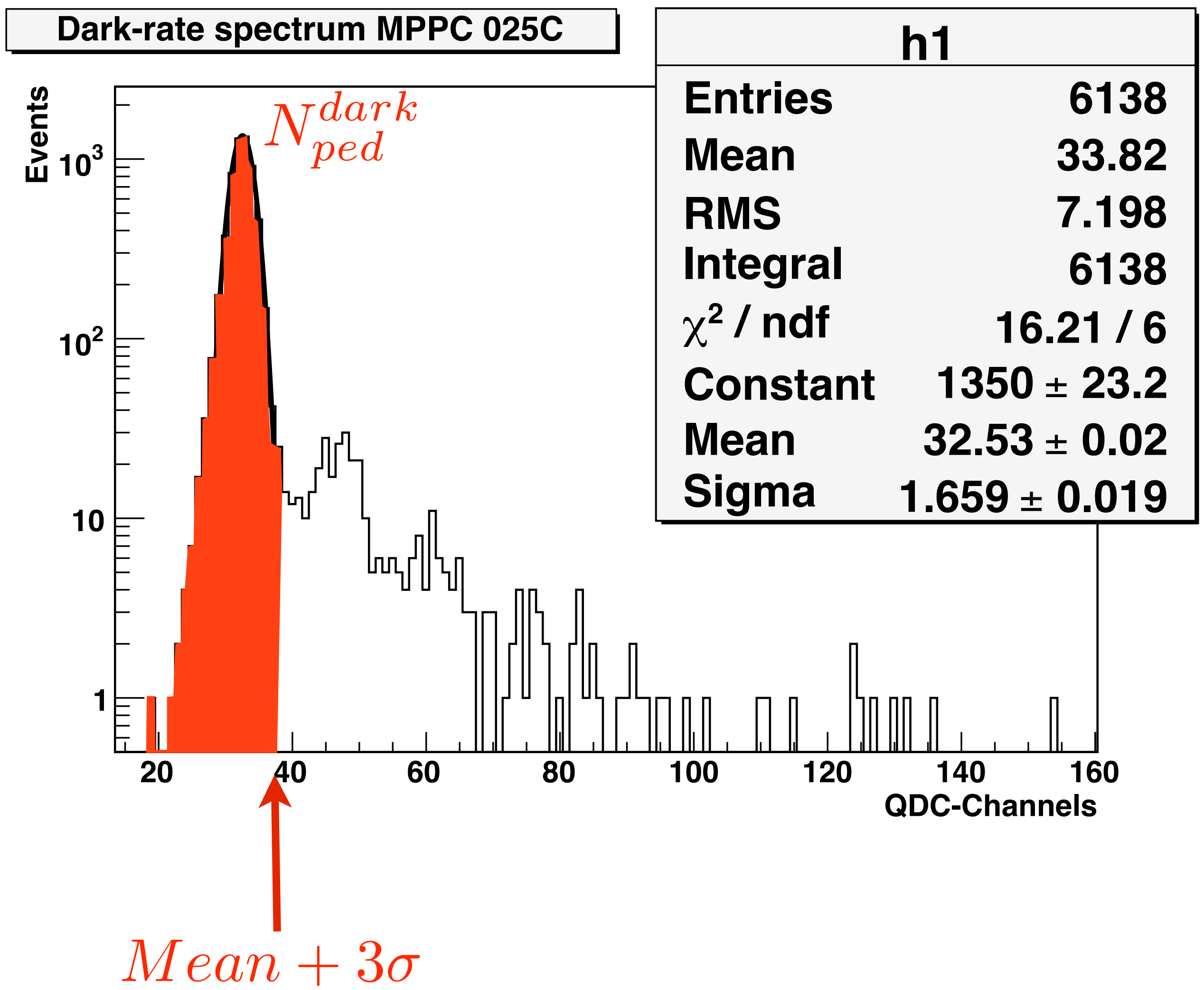
*Peak emission wavelength of LED

Dark-rate Correction

The pedestal events $N^*_{Ped.}$ need to be corrected for the dark-rate.
➔ Acquire dark-rate spectrum at each voltage value. Correction factor:

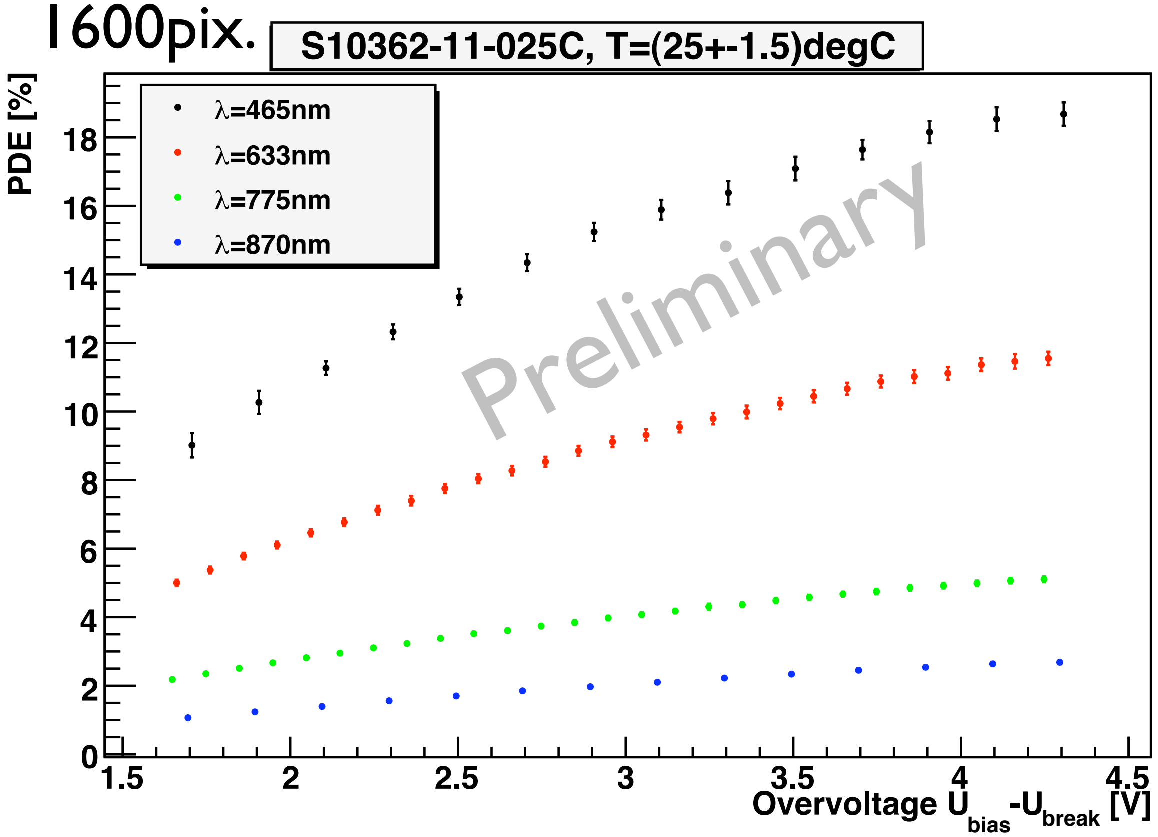
$$f = \frac{N^{dark}_{>ped.}}{N^{dark}_{tot}} = 1 - \frac{N^{dark}_{ped}}{N^{dark}_{tot}}$$

$$N_{Ped.} = \frac{N^*_{Ped.}}{1 - f}$$

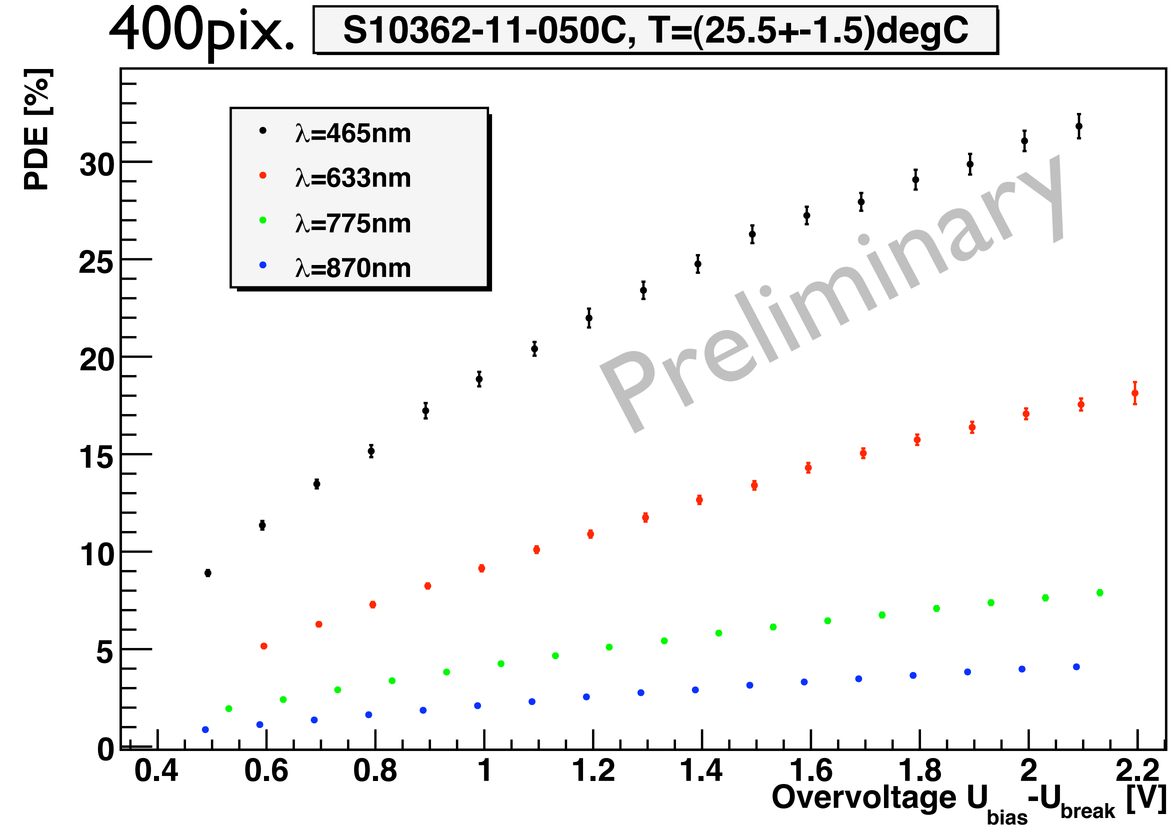


PDE (465nm, 633nm, 775nm, 870nm)

MPPC
1600pix.

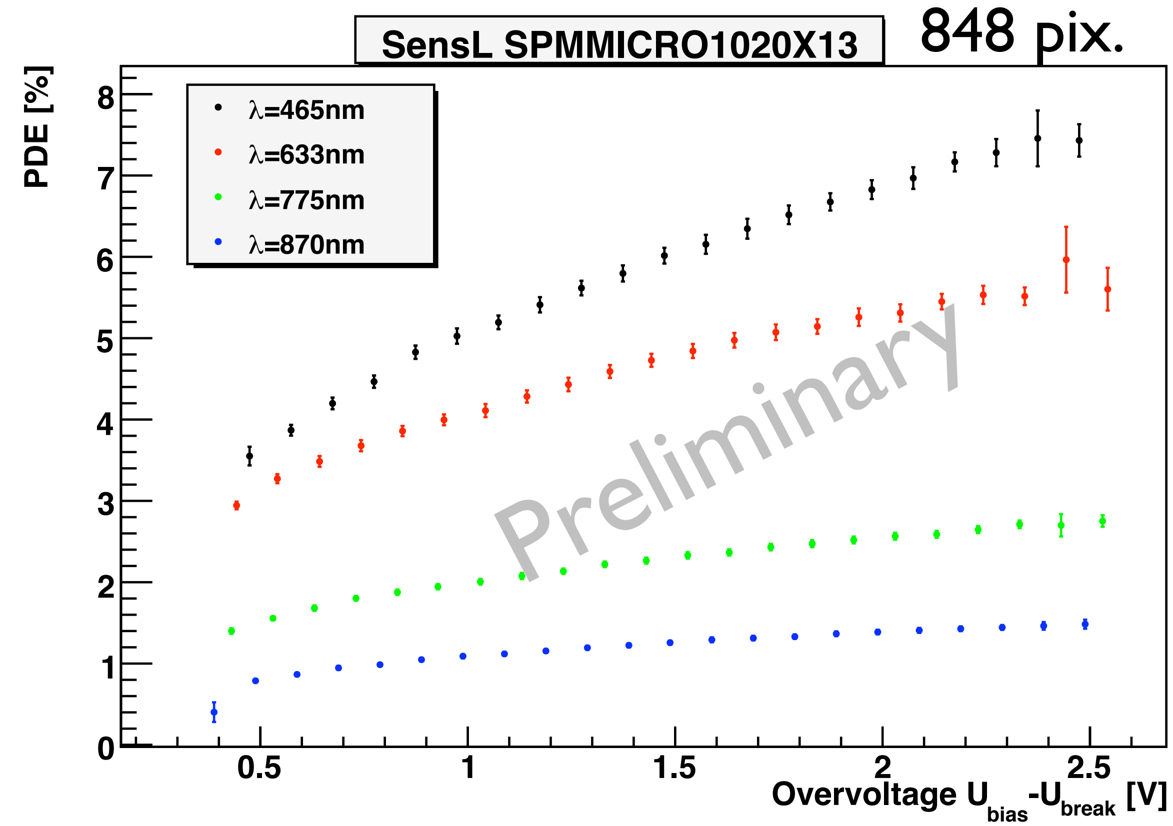


MPPC
400pix.



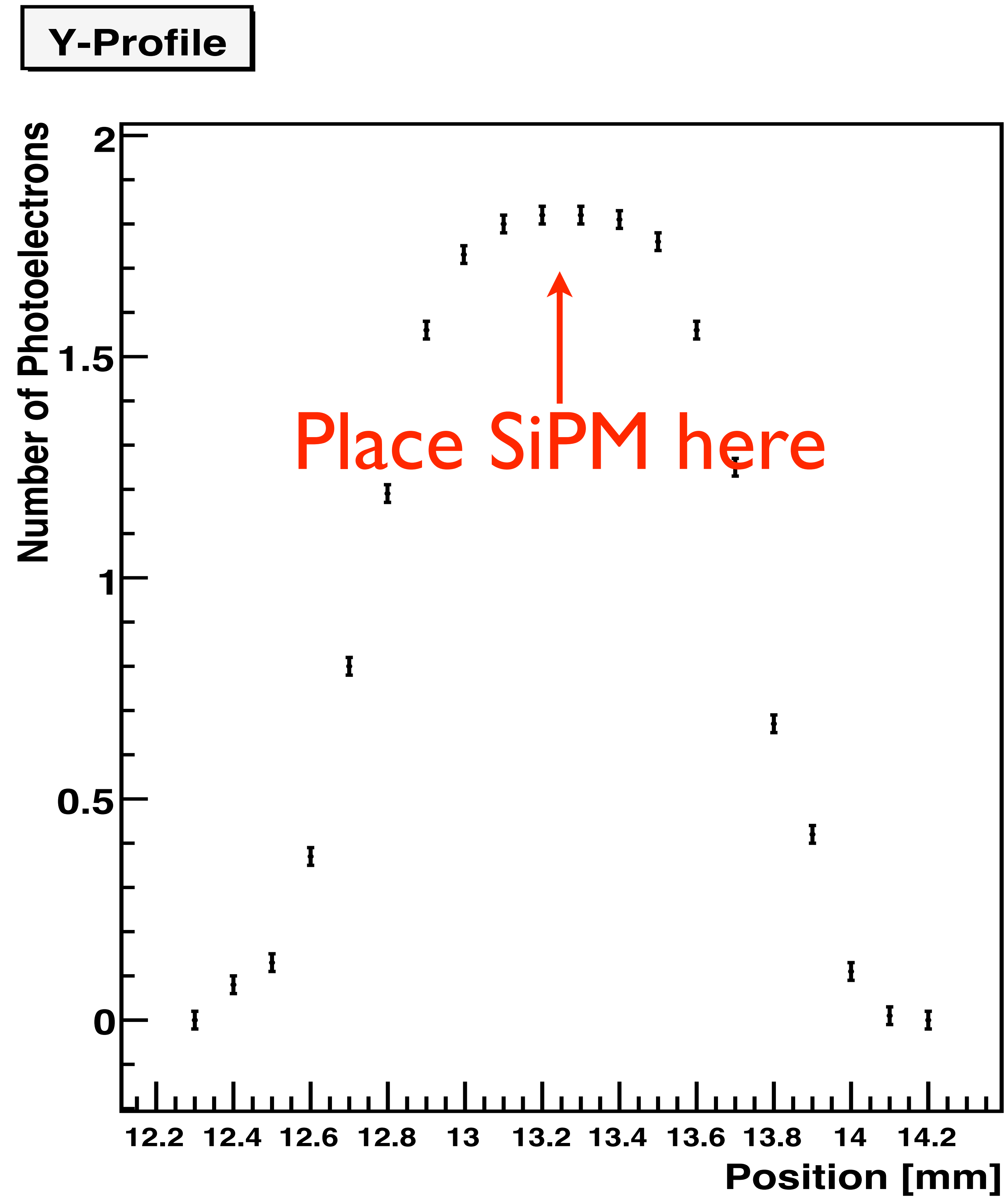
PDE was measured at four different wavelengths as a function of U_{over}

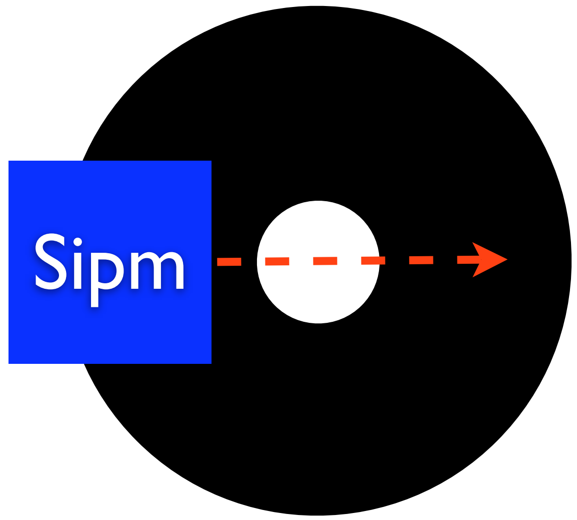
848 pix.



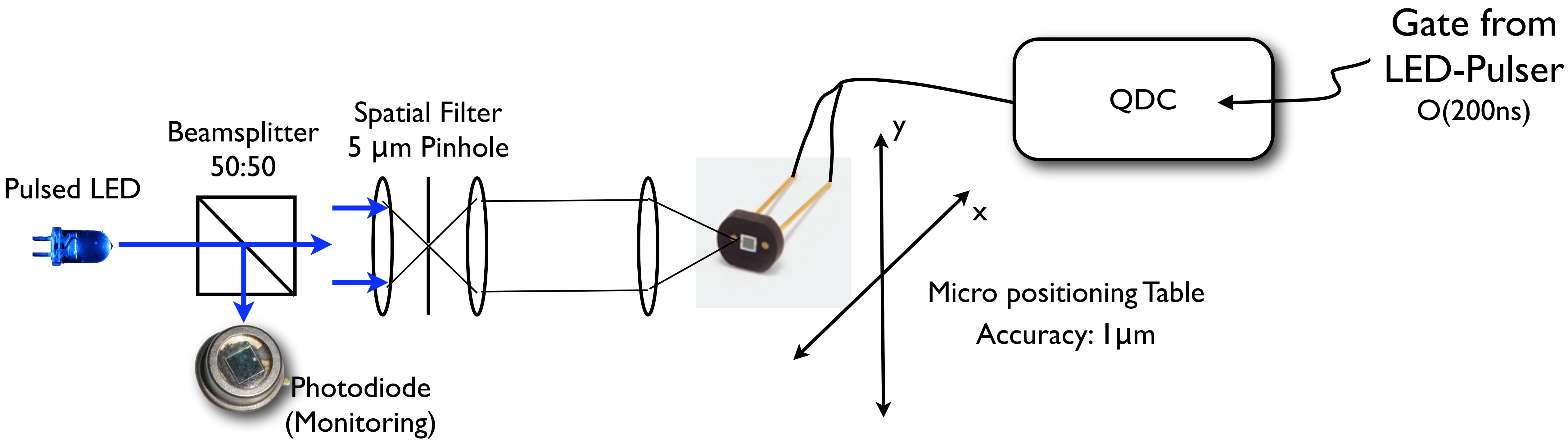
SiPM Positioning

- All light should hit the active SiPM-Surface.
- ∅=0.6mm aperture was used for measurements with pulsed laserdiodes.
- Plateau on top allows reproducible positioning at maximum.





Setup for Uniformity-Scans

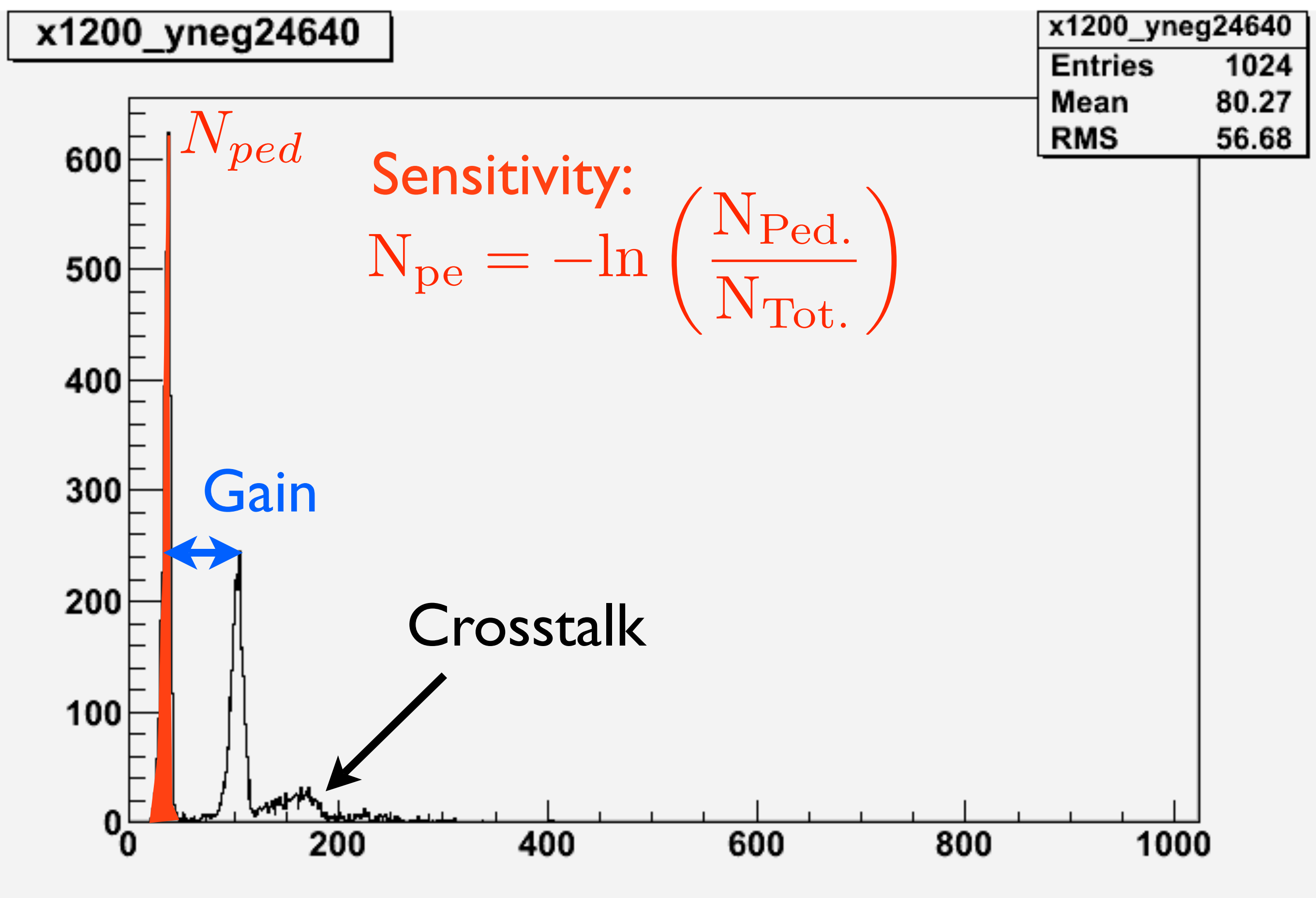


Scan Sensor with pulsed lightspot

(10000 pulses per meas. point)

Versatile Analysis:

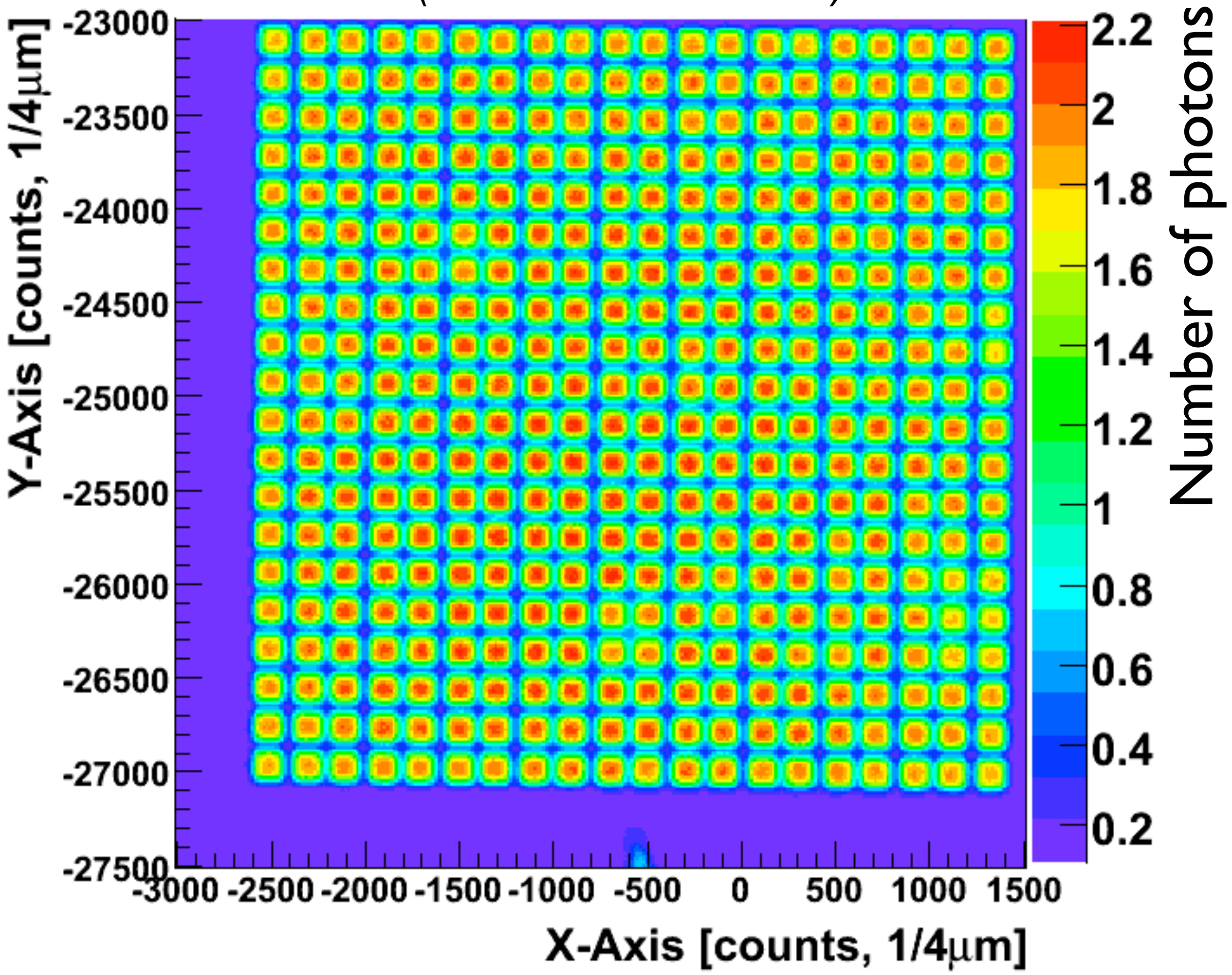
- Sensitivity Map $N_{pe}(x,y)$
- Gain Map G(x,y)
- Crosstalk Map C(x,y)



MPPC 50µm pitch (400 Pixels)

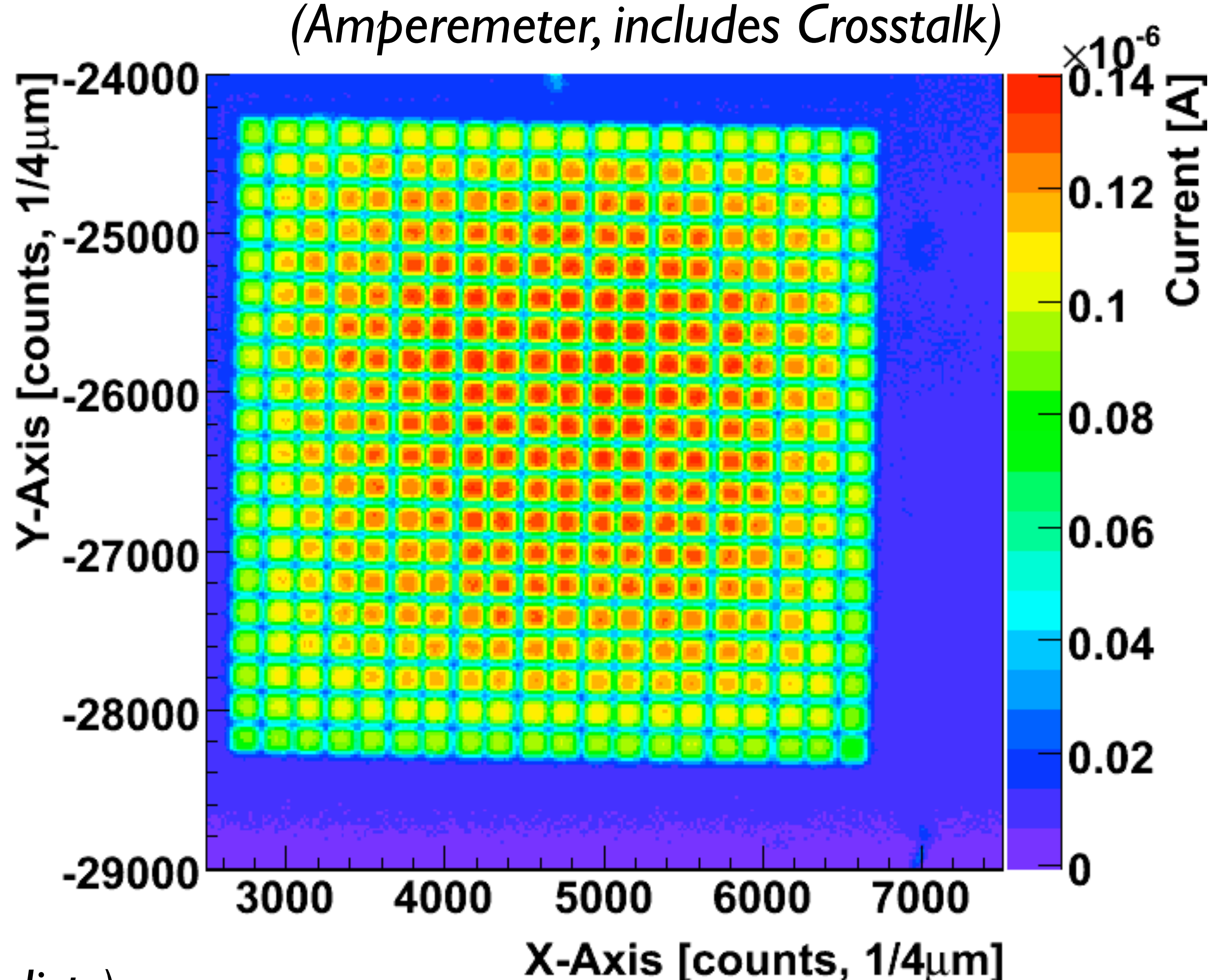
Sensitivity Map S(x,y)

(without Crosstalk)



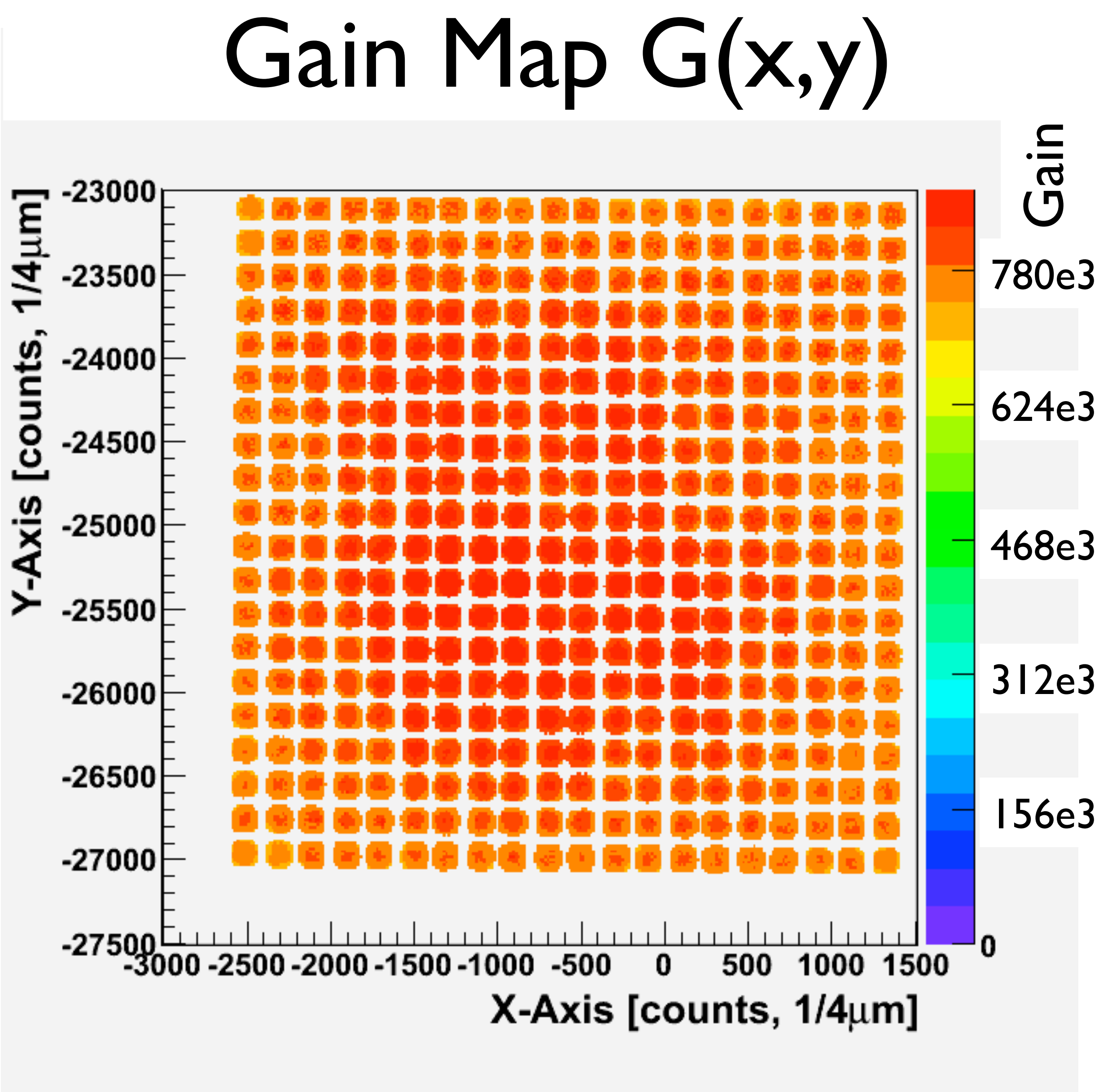
Current Measurement

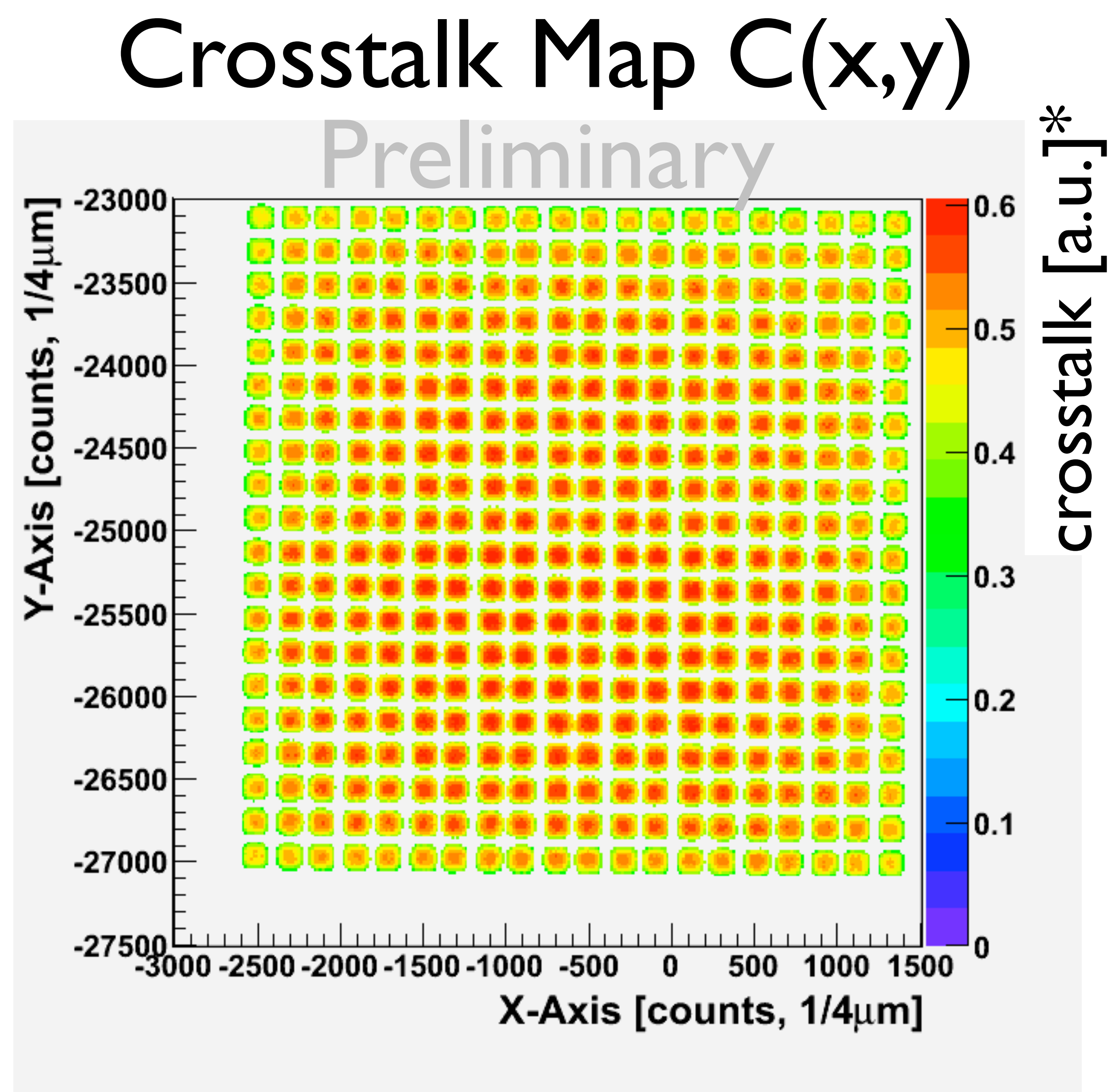
(Amperemeter, includes Crosstalk)



- Sensitivity Map *(statistical analysis of Poisson dist.)*
  - ➡ High uniformity
- Current Measurement:
  - ➡ Crosstalk-probability higher in the centre (more pixel neighbors)

Crosstalk and Gain Map





*so far only qualitative information about crosstalk possible.