PDE Measurement of SiPMs

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KIRCHHOFF-INSTITUTE FOR PHYSICS

CALICE Calorimeter for ILC

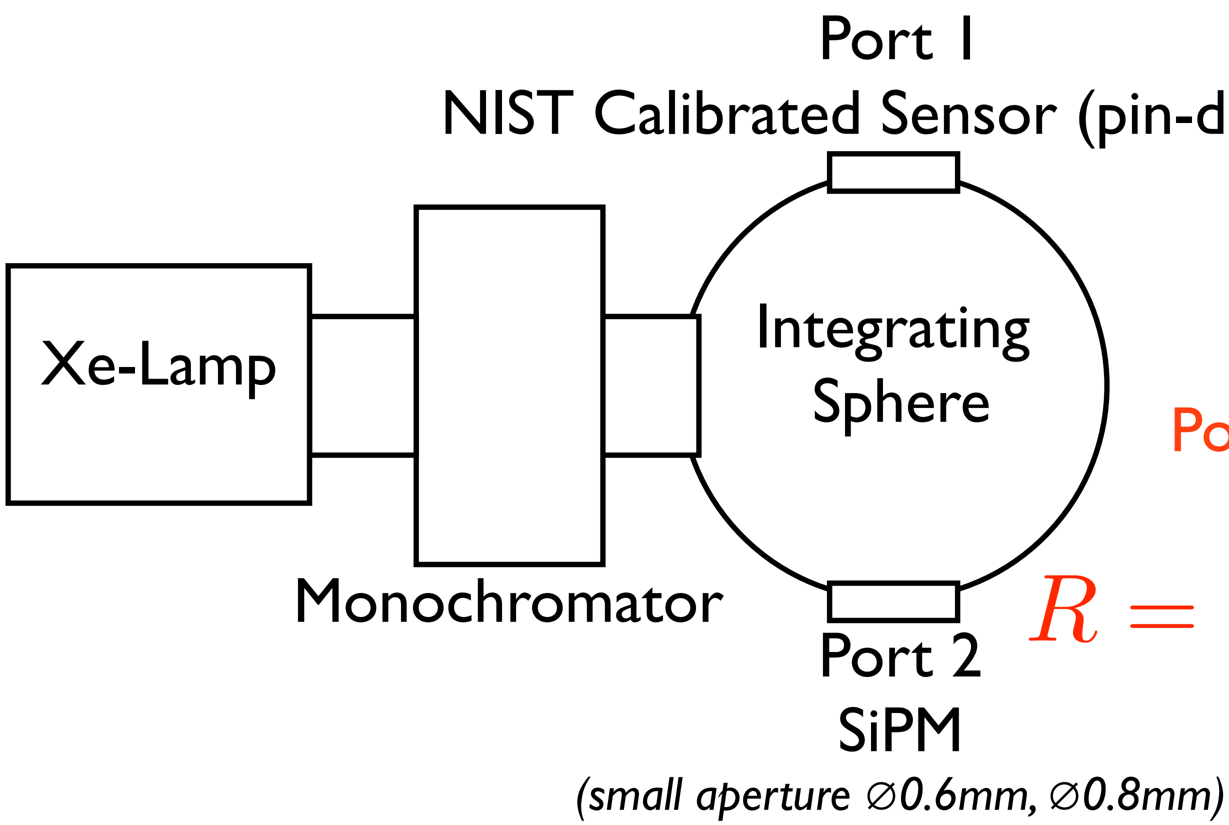
Bundesministerium für Bildung und Forschung

Characterisation of SiPMs

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

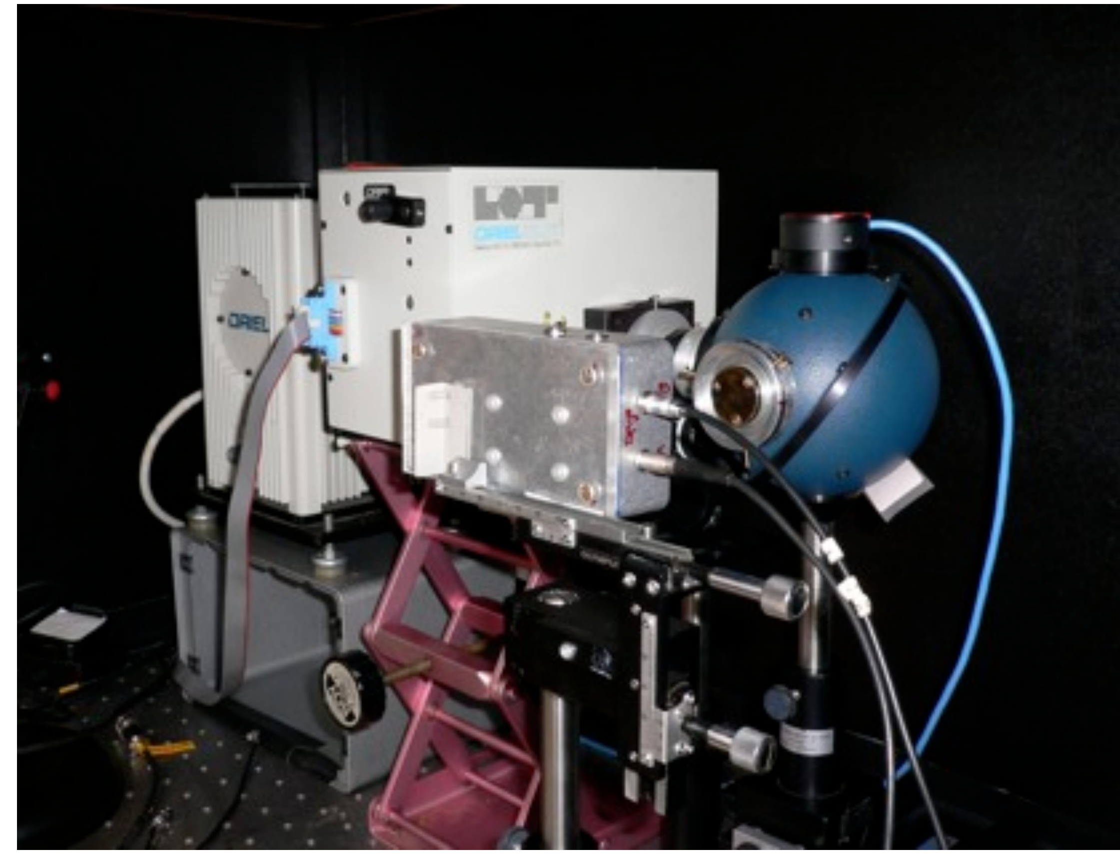
Test-Setup at Kirchhoff-Institute for Physics, University of Heidelberg

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

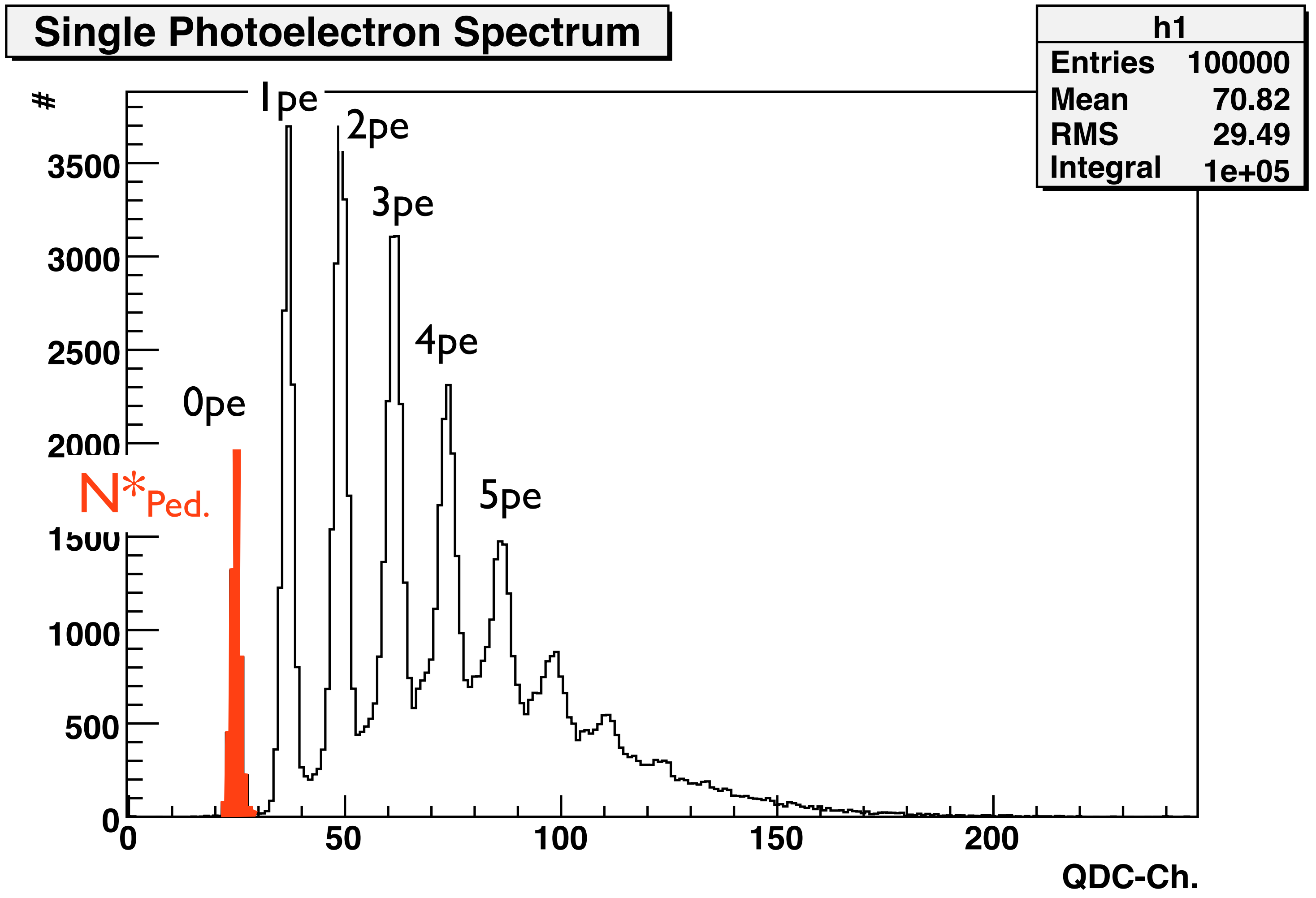
Photons, that arrive at the SiPM are Poisson-distributed:

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

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

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

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

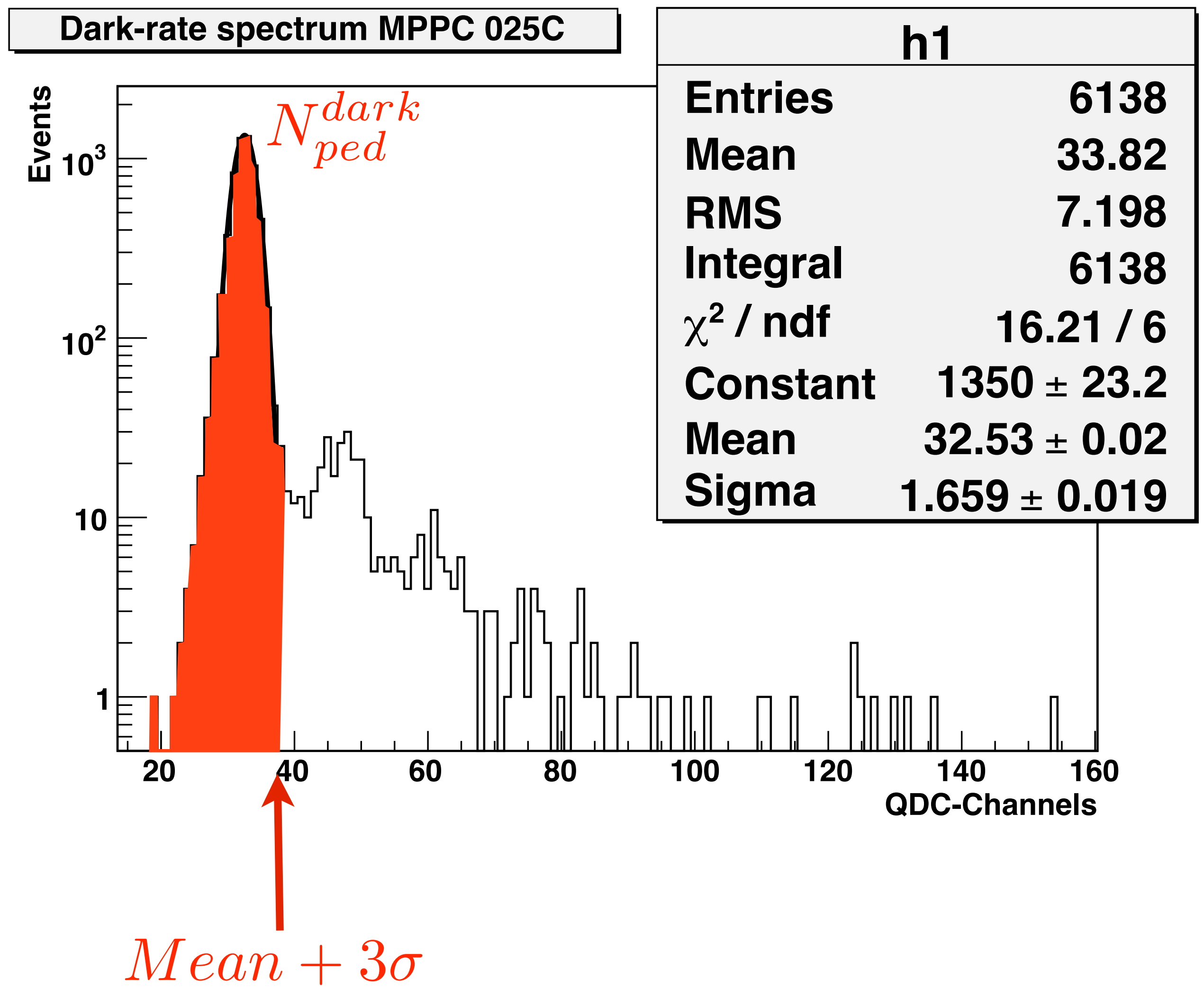


Dark-rate Correction

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

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

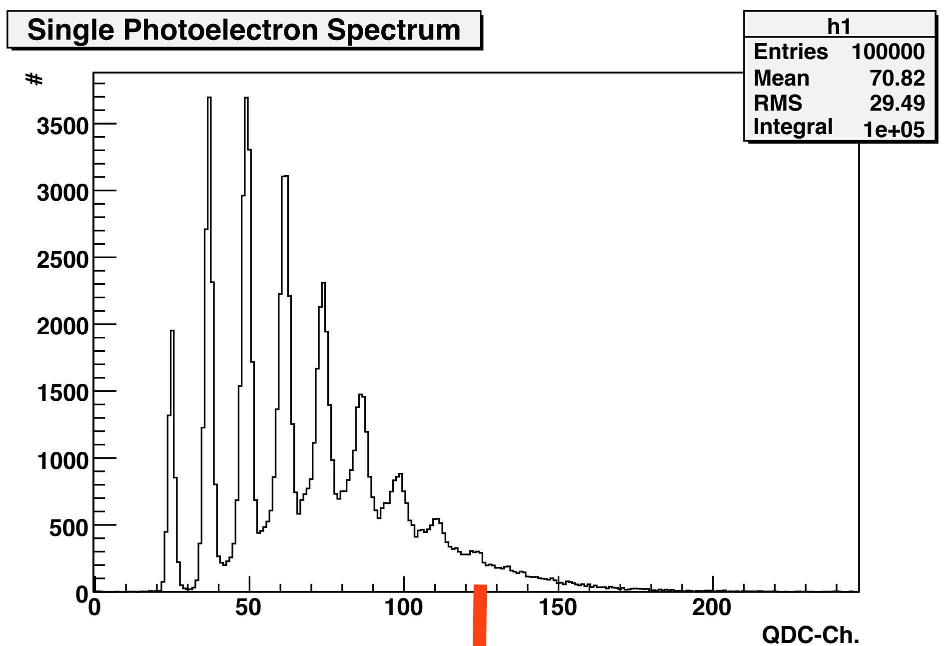
$$N_{Ped.} = \frac{N^*_{Ped.}}{1 - f}$$

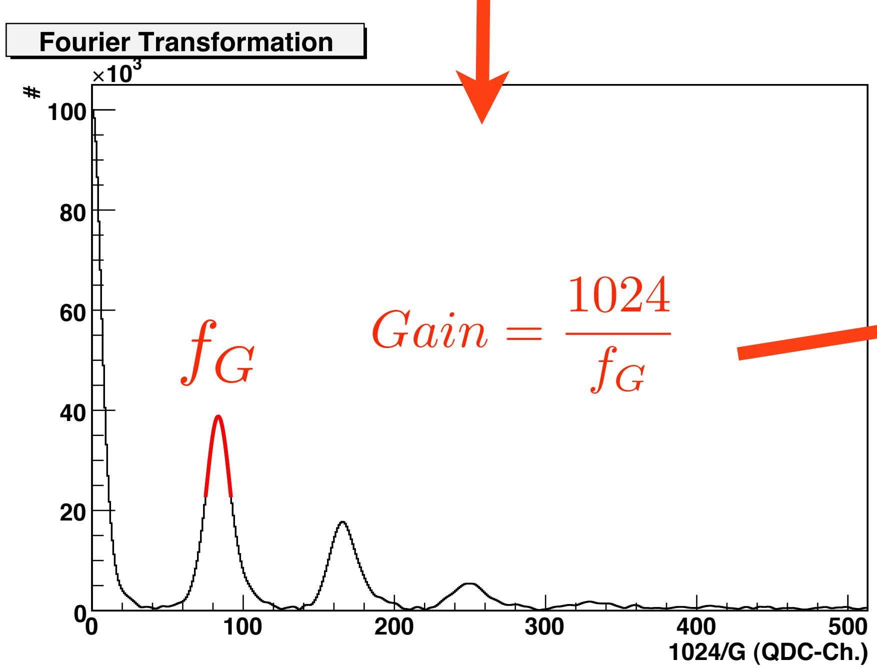


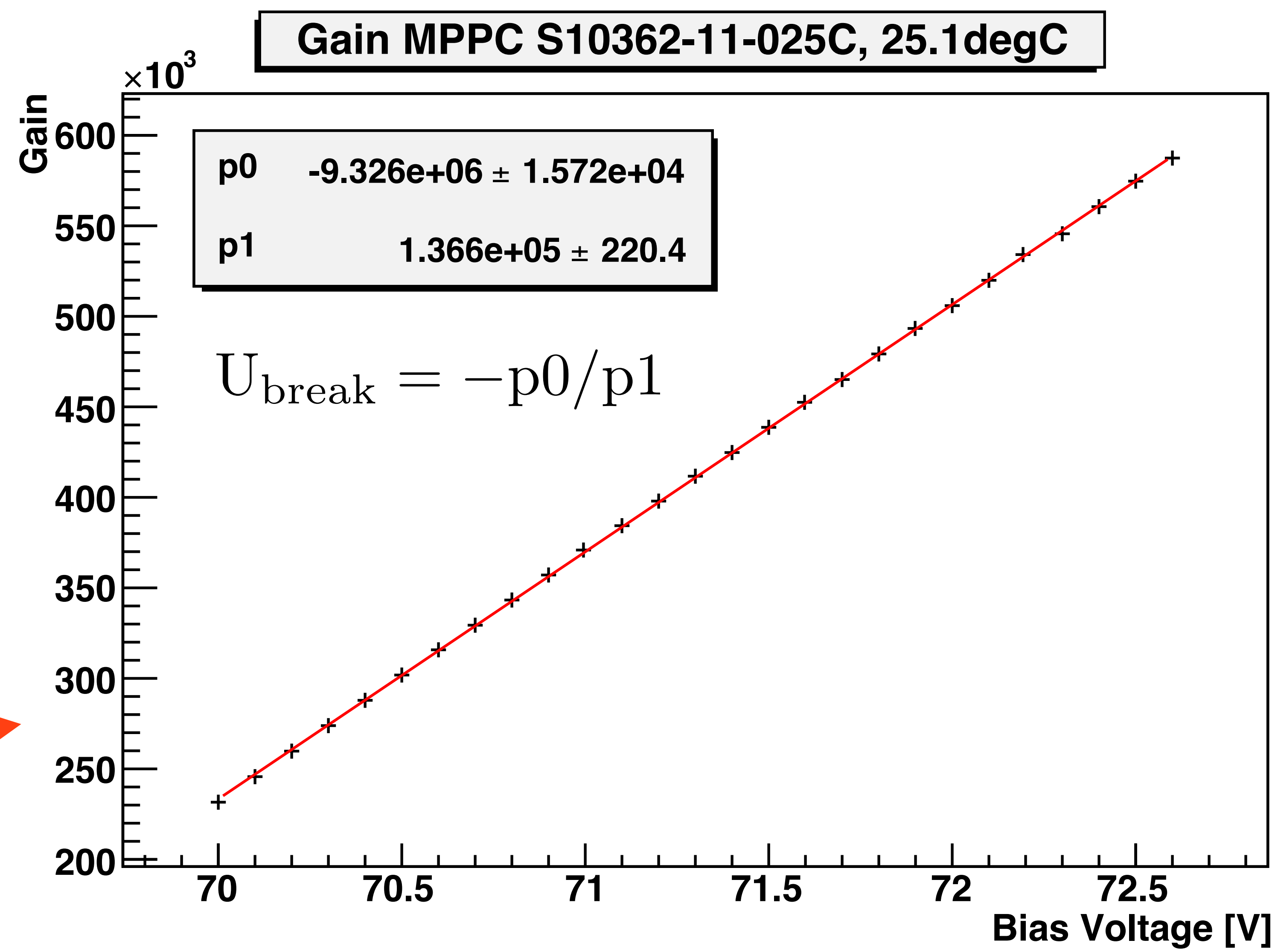
Gain Measurement

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

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







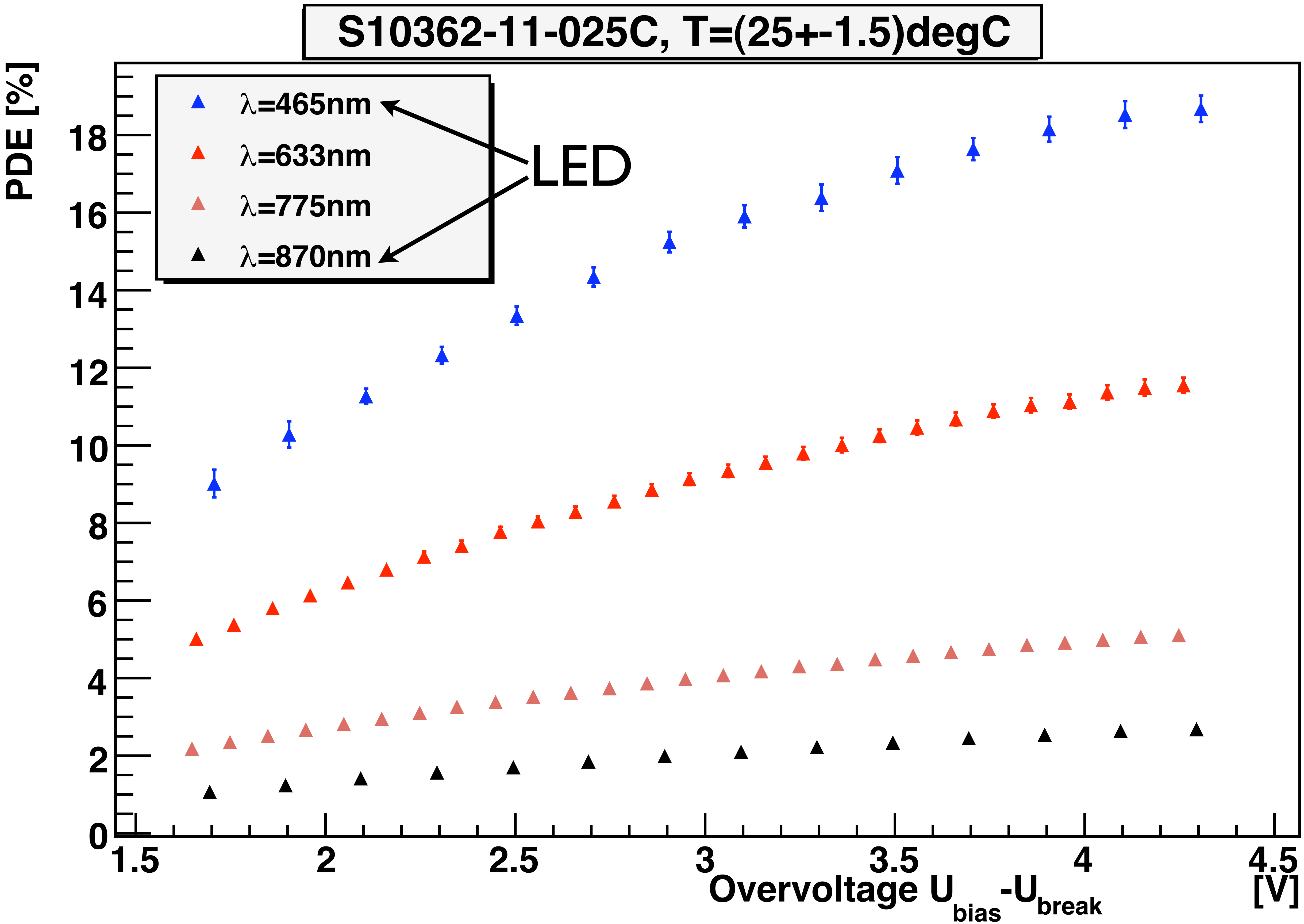
Automated Measurement
(LABVIEW)

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

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

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

Example: PDE MPPC 1600pix.

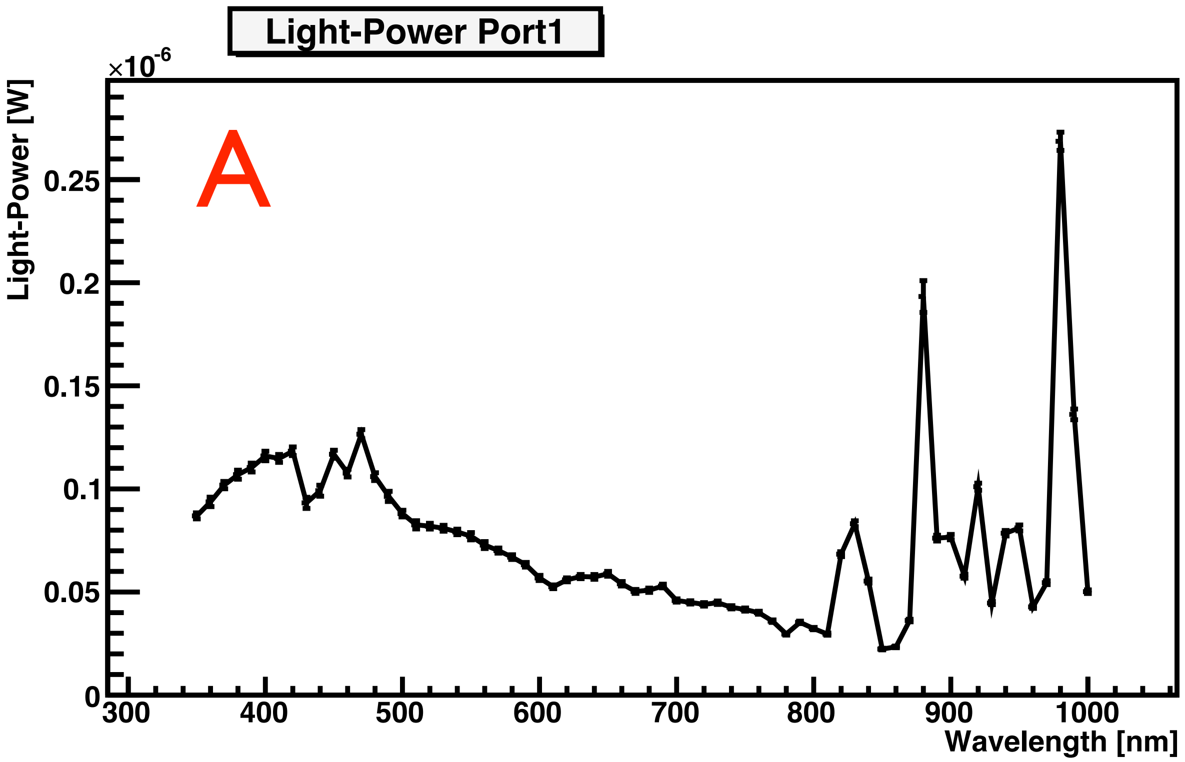


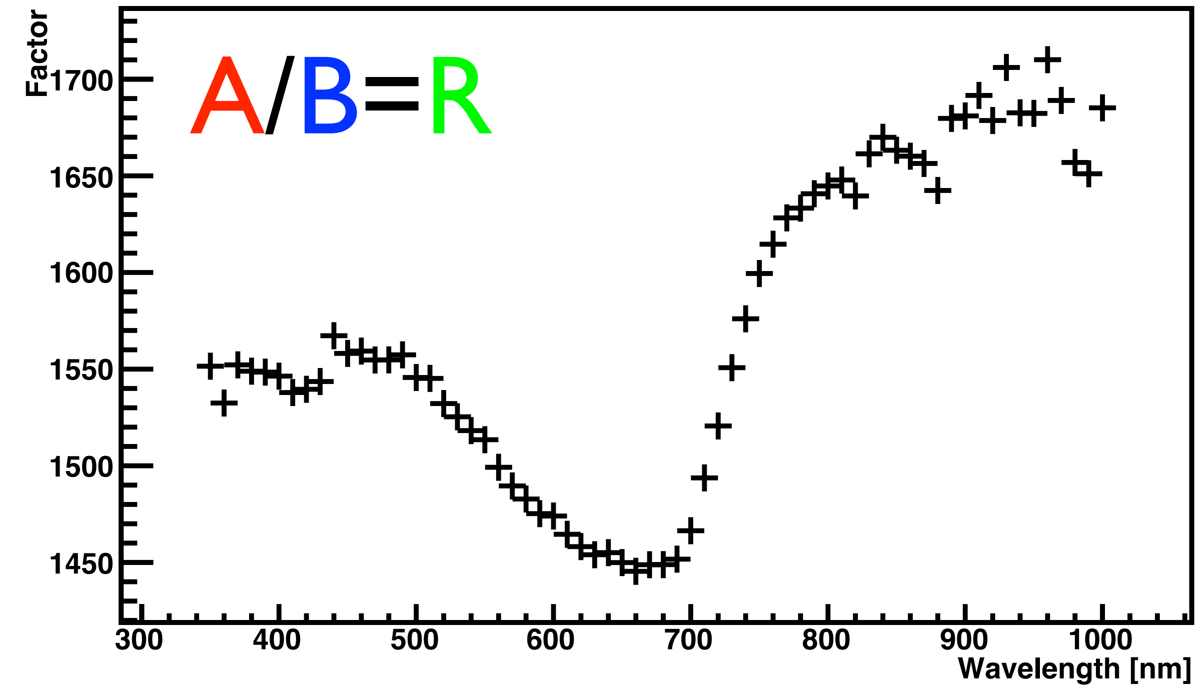
Relative Measurement

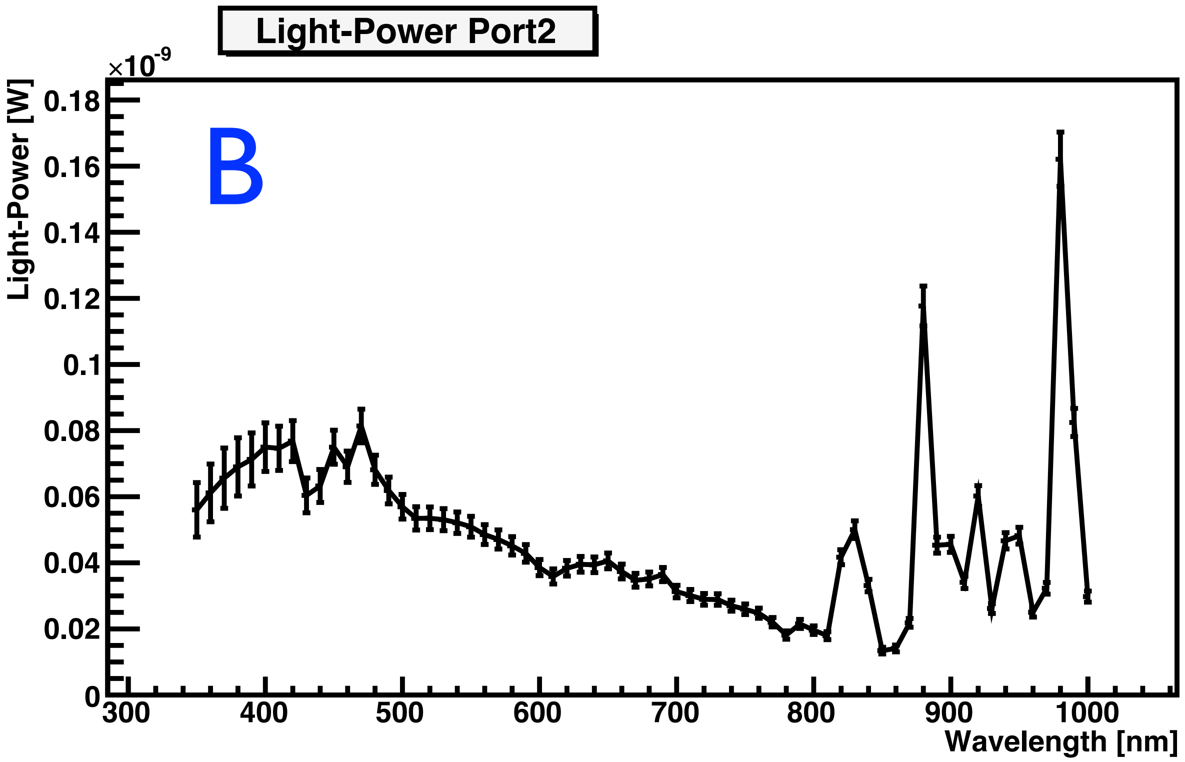
(350nm-1000nm)

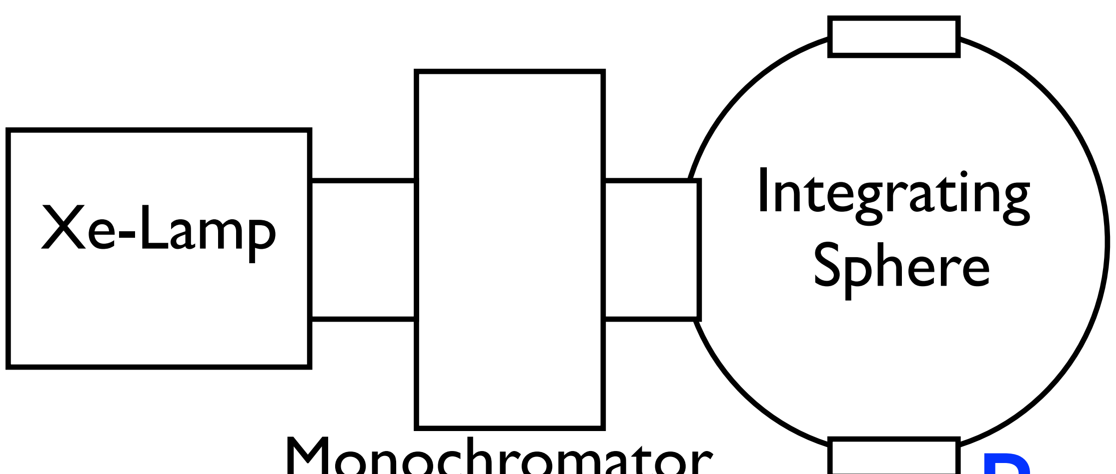
Setup Calibration (350-1000nm)
(∅=0.8mm aperture)

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



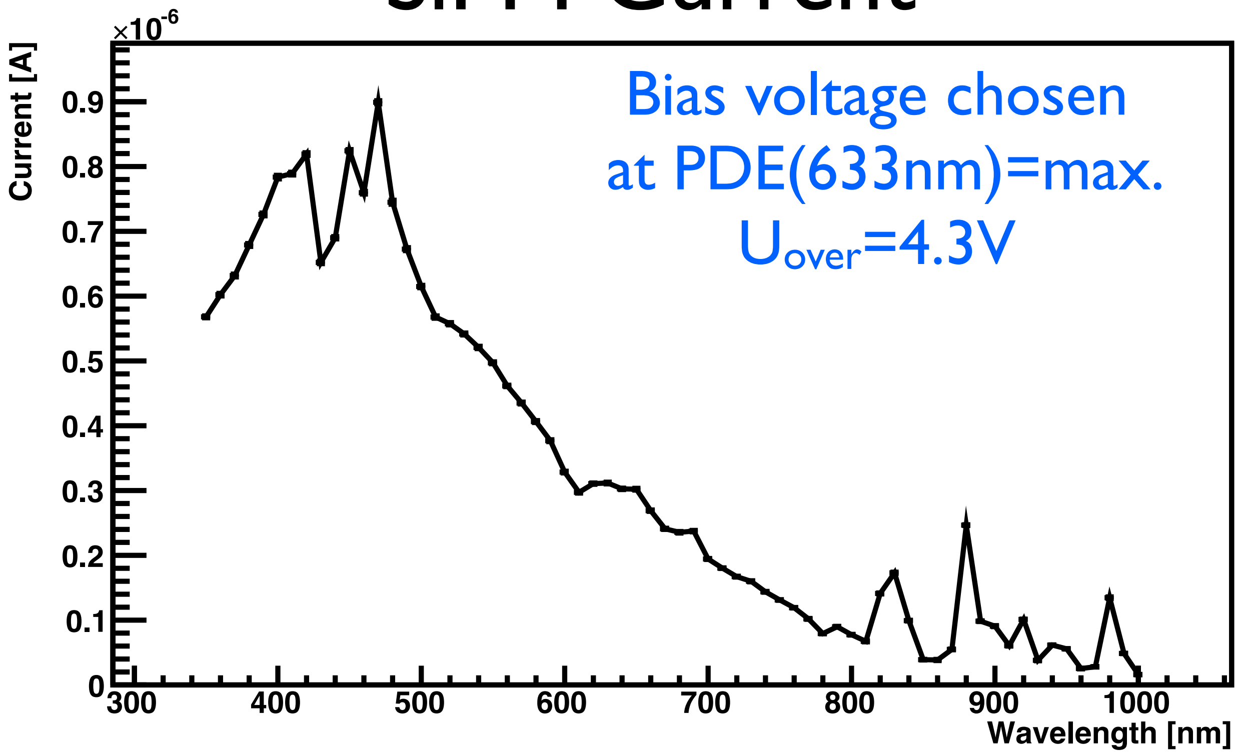




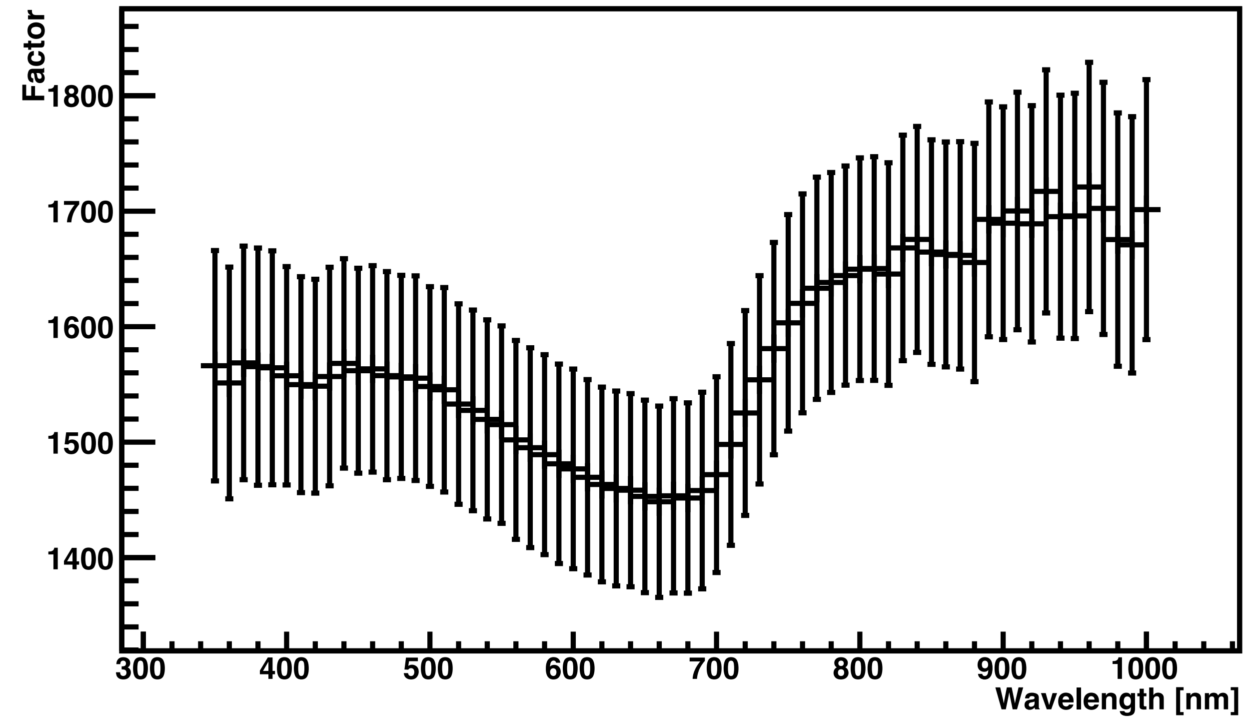


PDE Measurement (Relative)

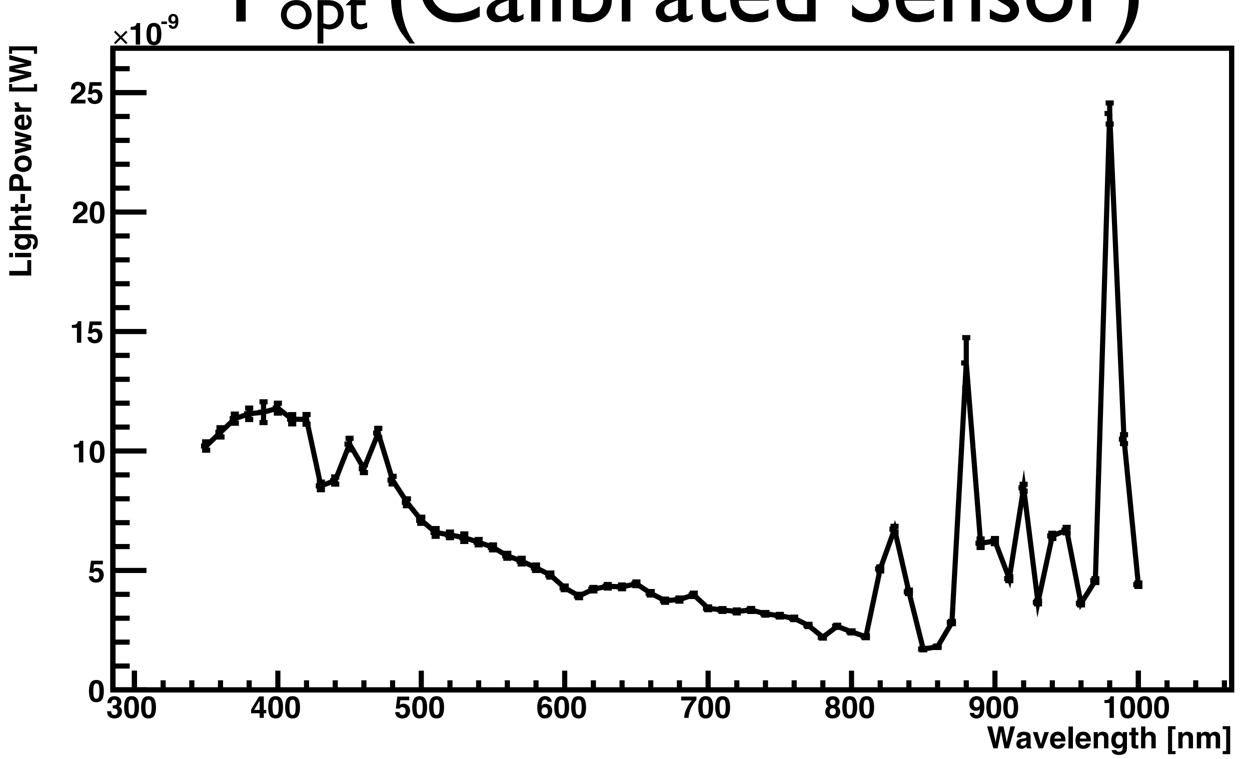
SiPM Current



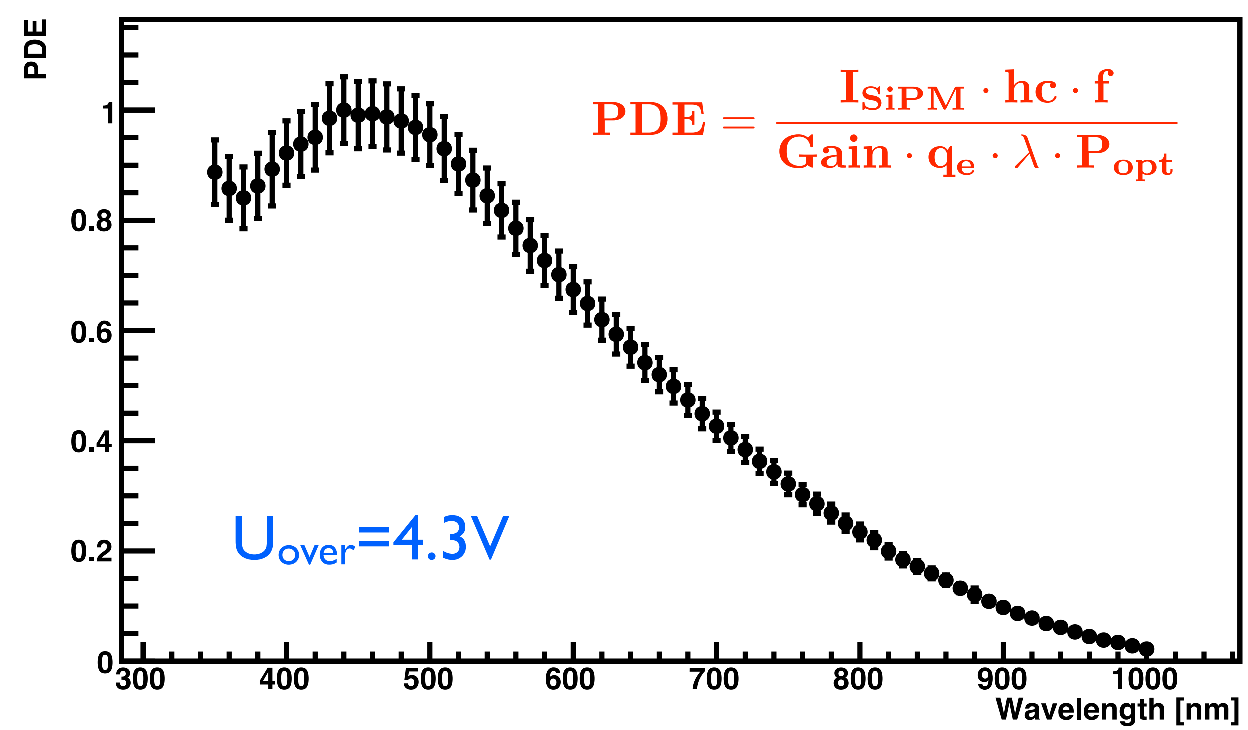
Power-ratio $R_{0.8mm}$



P_{opt} (Calibrated Sensor)



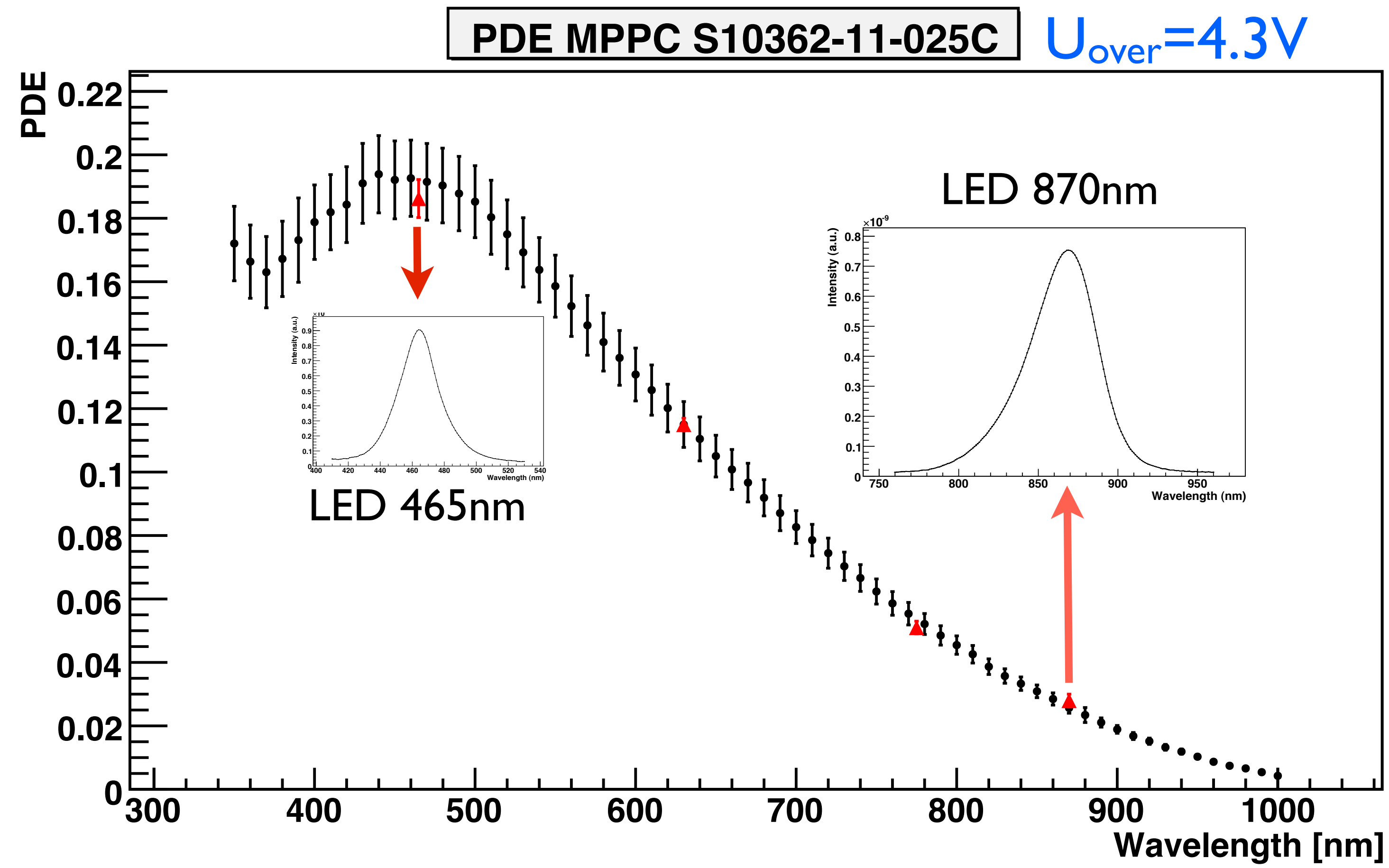
Relative PDE MPPC 025C

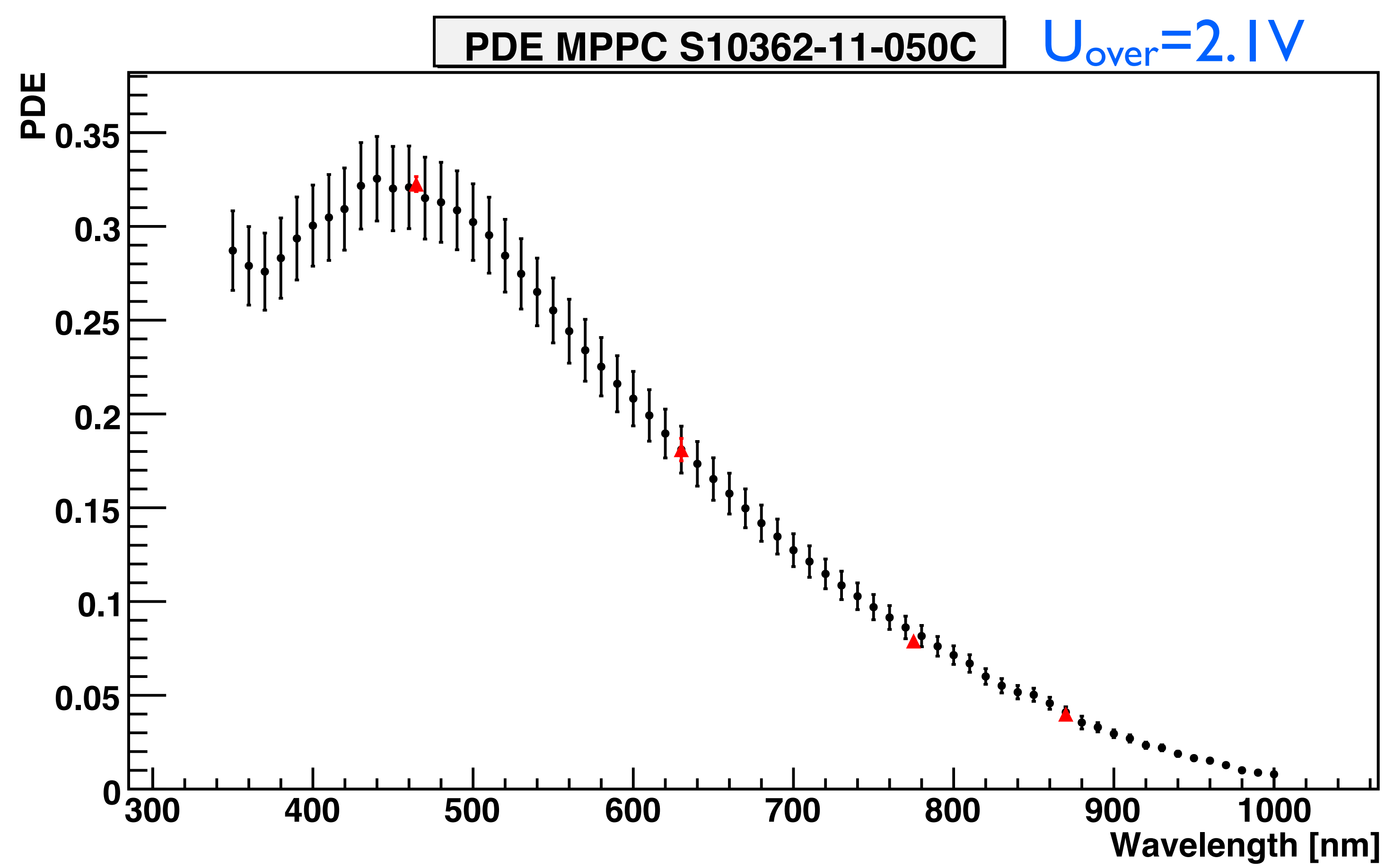


PDE Curve Scaling

- Curves are scaled to max. PDE value at 633nm
- Crosscheck: max. PDE-values at 465nm, 775nm and 870nm are shown.

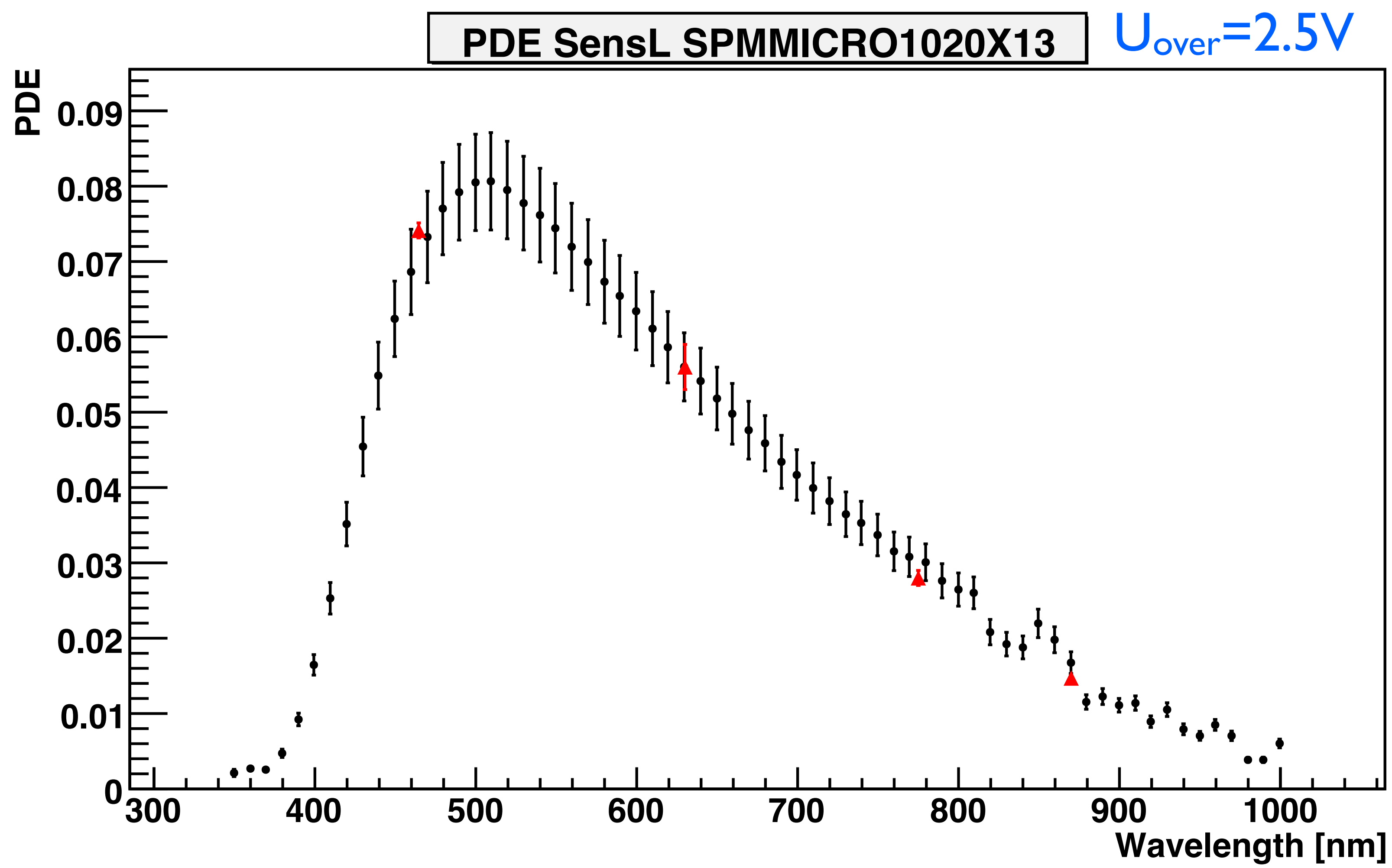
  ➡ Good agreement



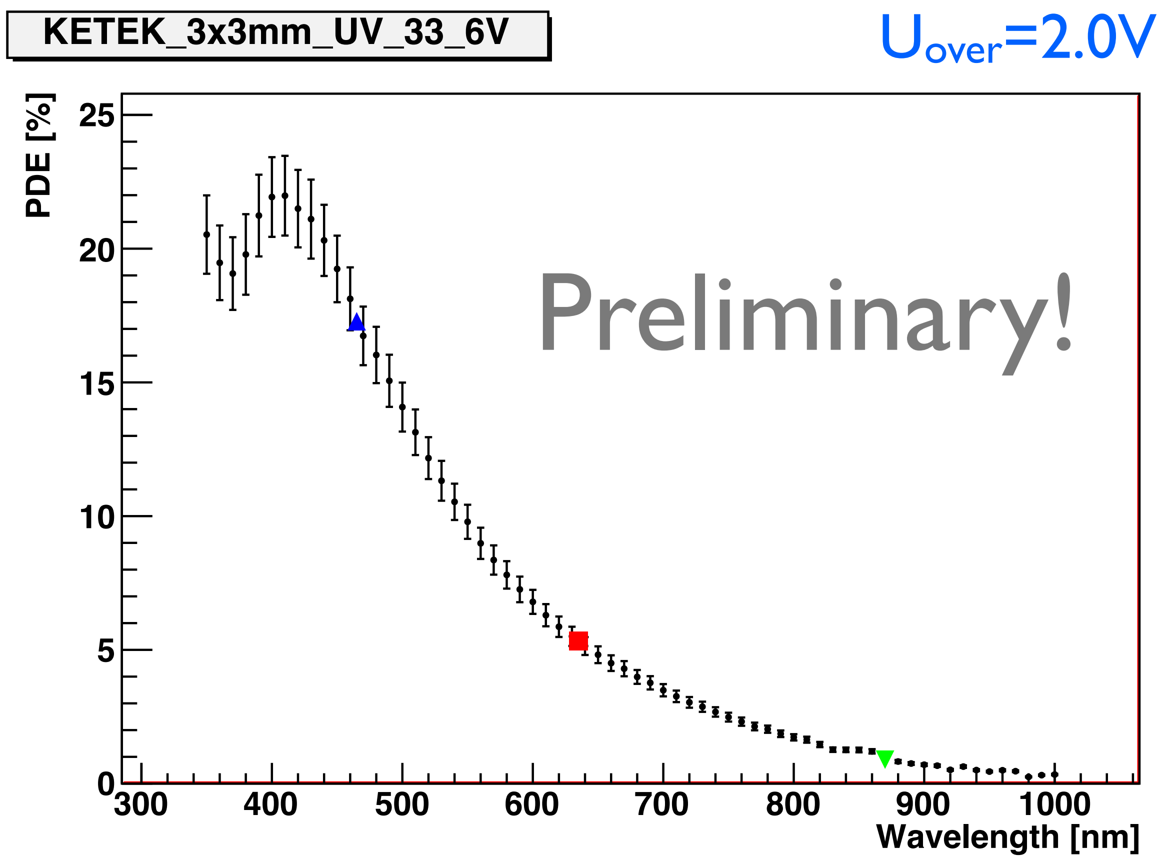


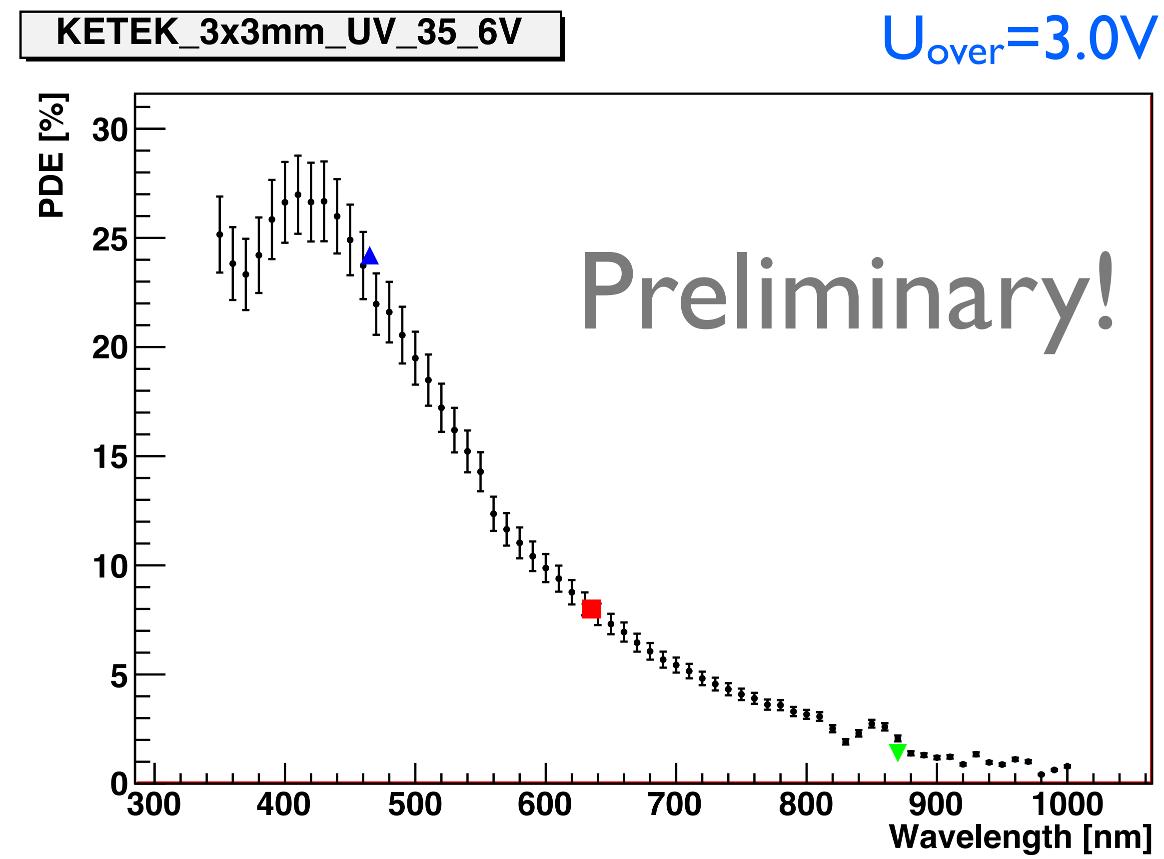
PDE Curve SensL SPMMICRO1020X13

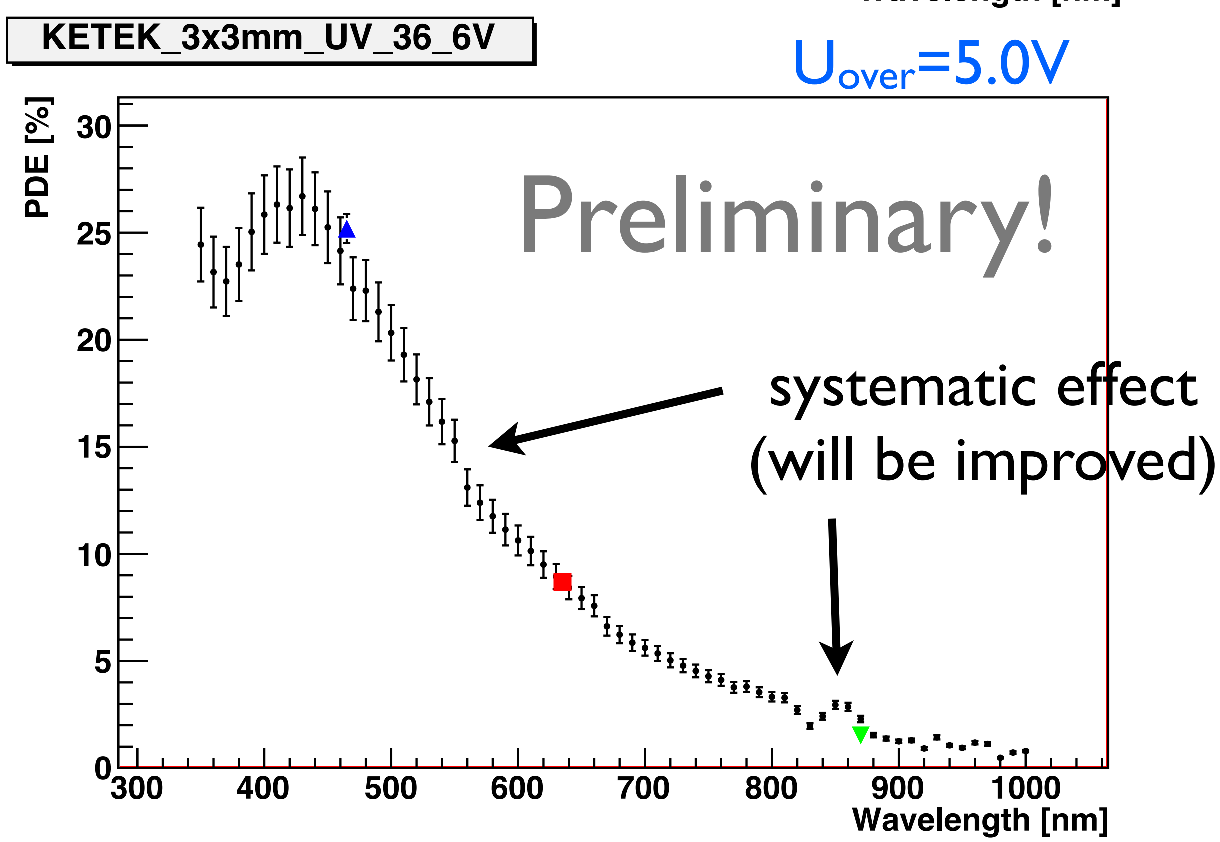
- Scaled to max. PDE value at 633nm.
- Highest PDE at ~500nm
- steep curve below 500nm



KETEK 3x3mm^2
(first look)



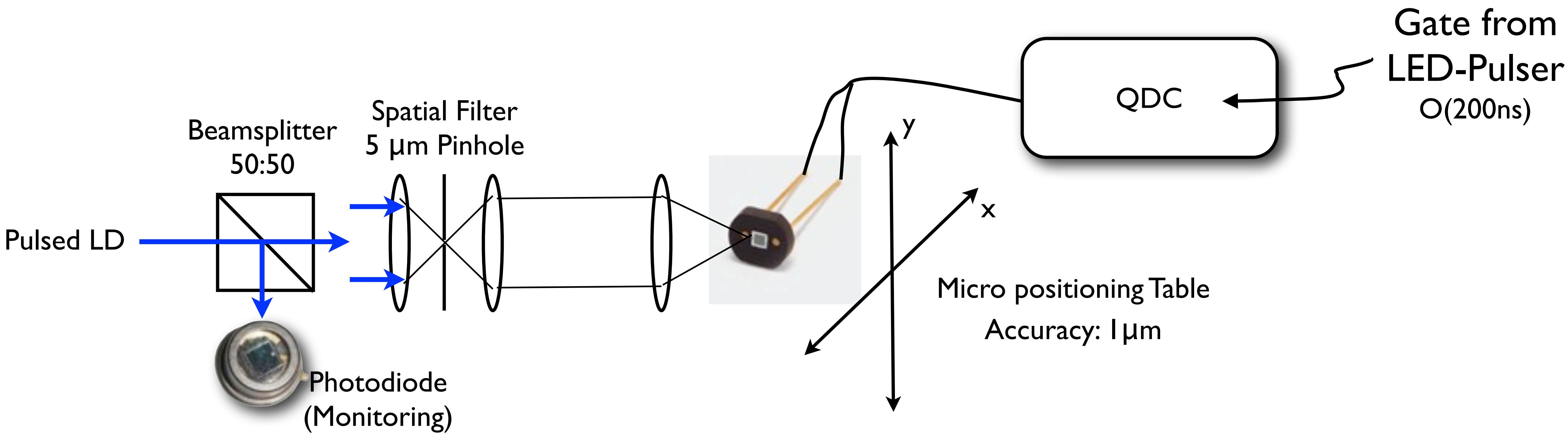




High PDE in the UV range

Uniformity Measurements

Setup for Uniformity-Scans

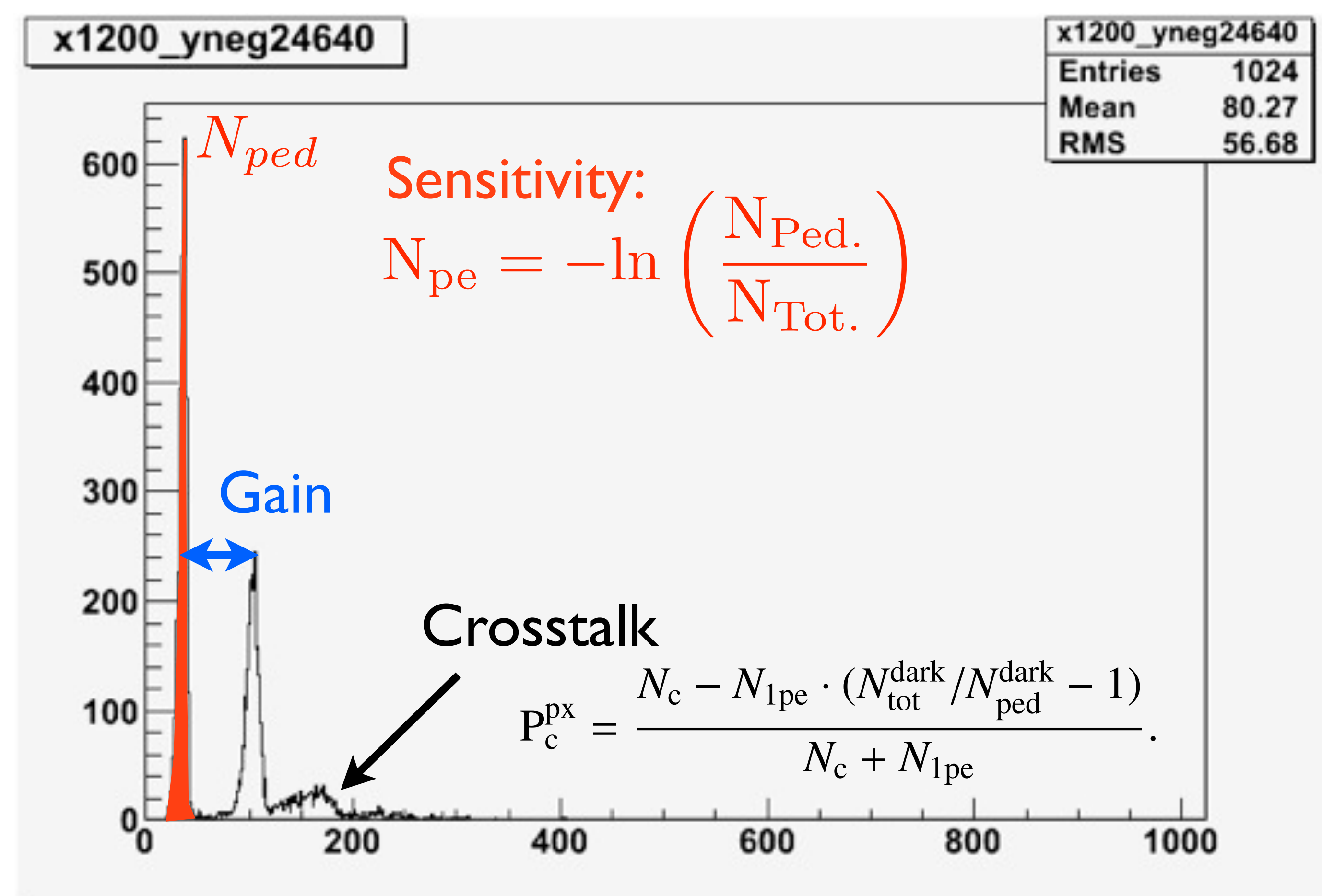


Scan Sensor with pulsed lightspot

(10,000 pulses per meas. point)

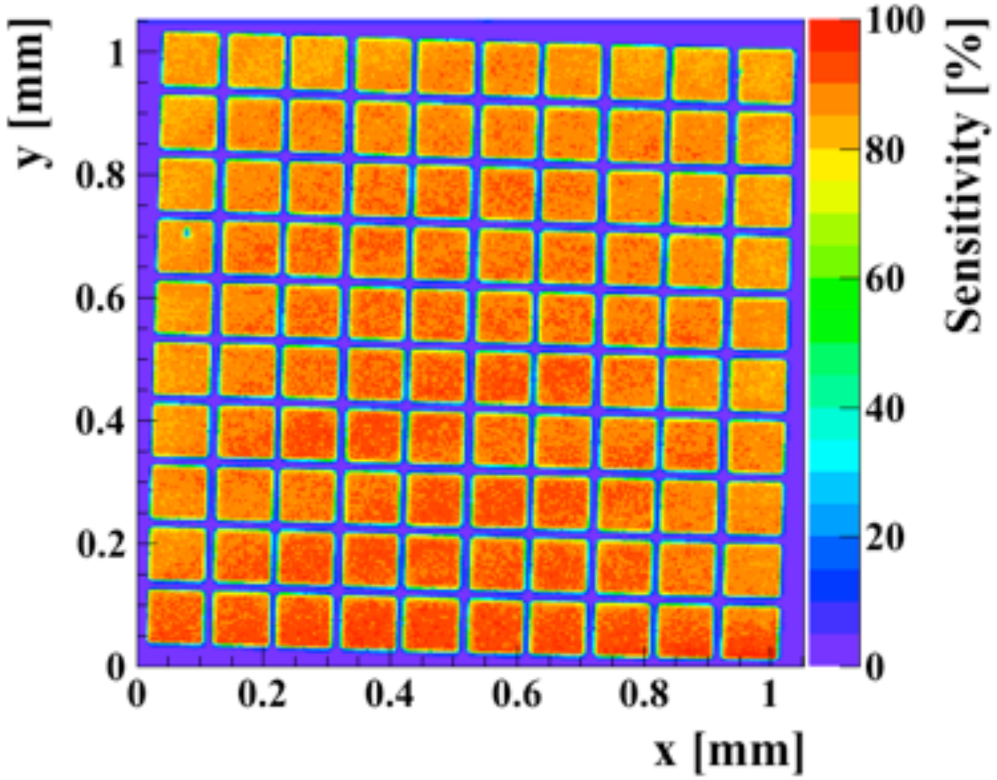
Versatile Analysis:

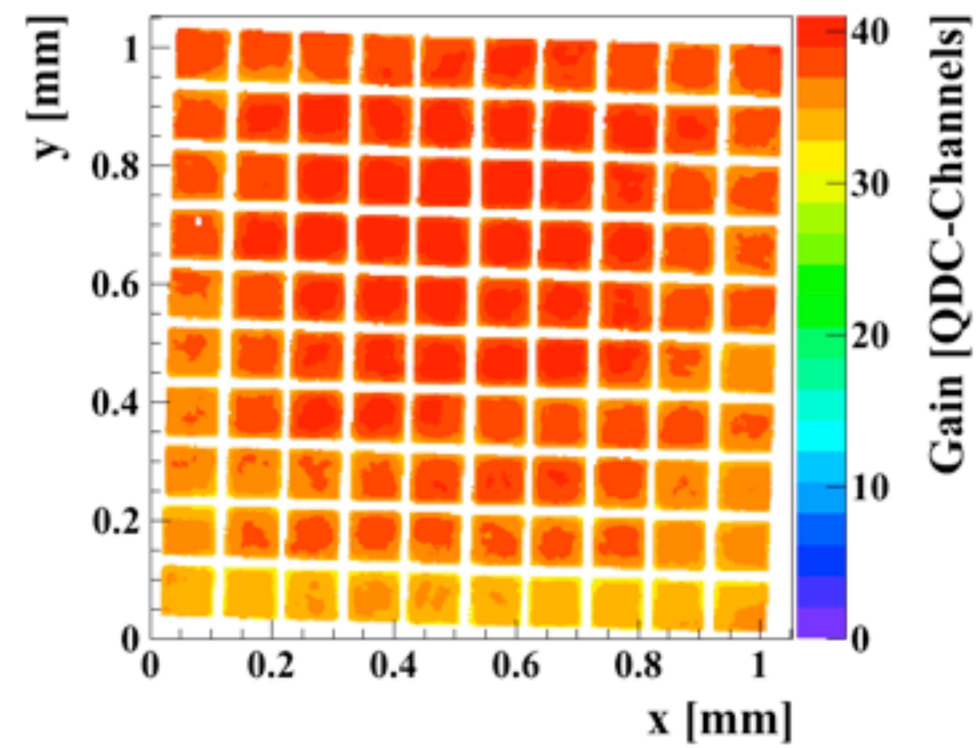
- Sensitivity Map $N_{pe}(x,y)$
- Gain Map G(x,y)
- Crosstalk Map C(x,y)

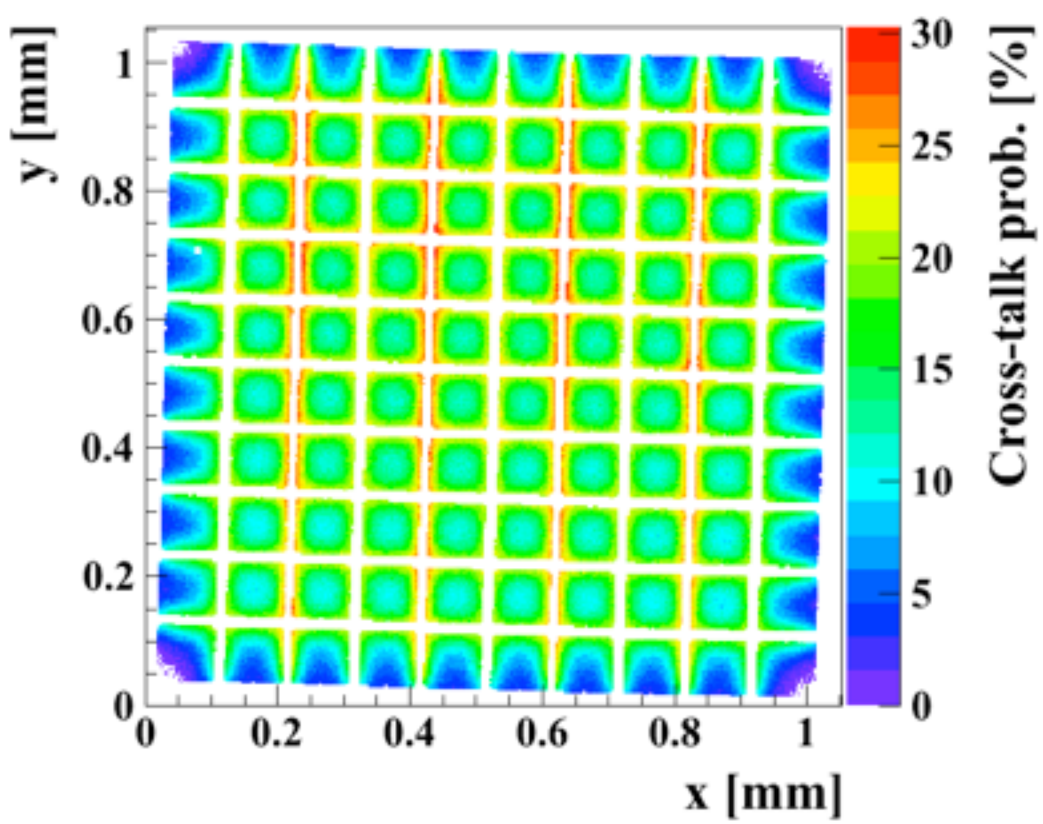


MPPC 10362-11-100C

U_{over} = 1.1V





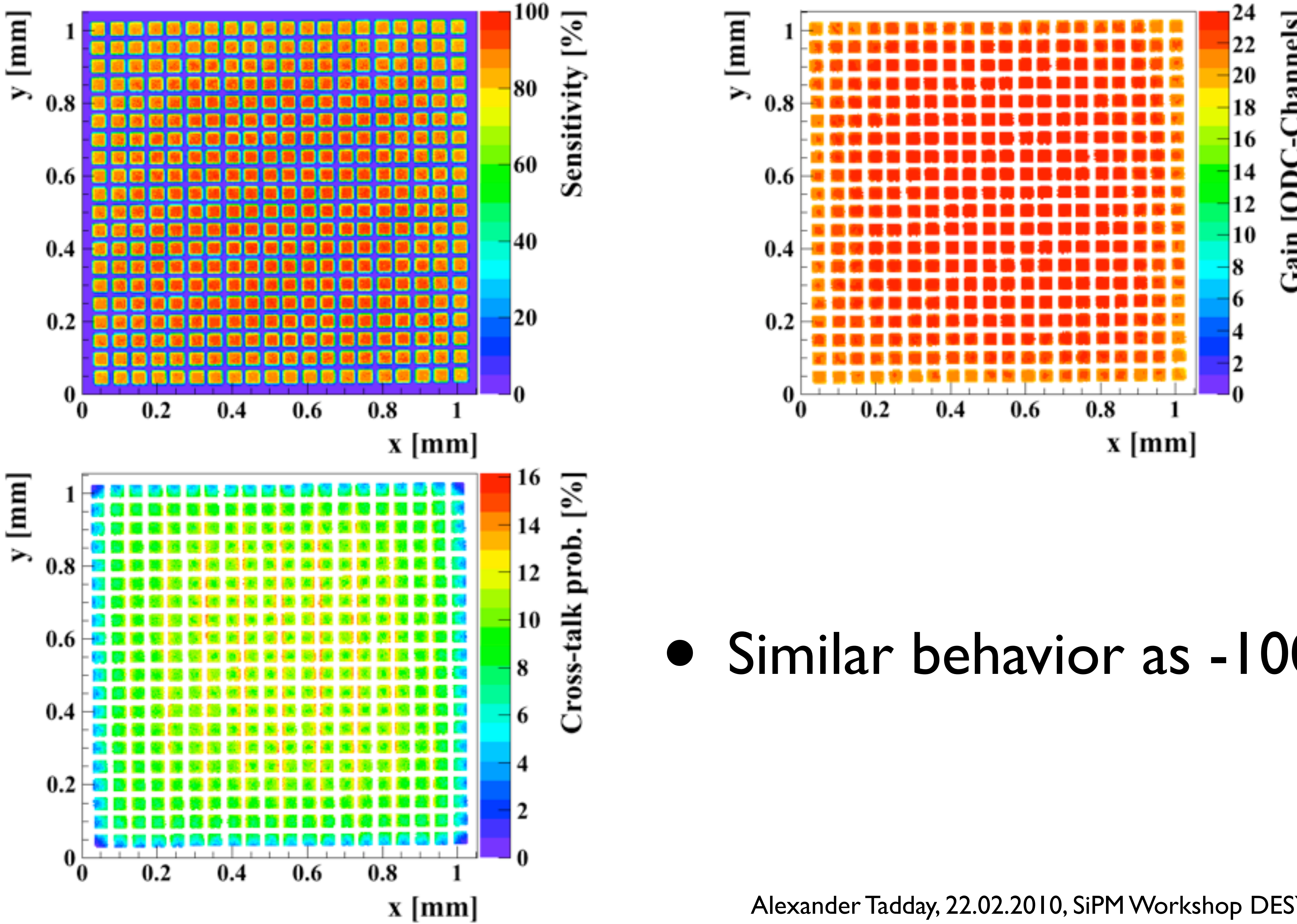


Sensitivity and gain quite uniform.

Cross-talk probability strongly depends on position!

MPPC 10362-11-050C

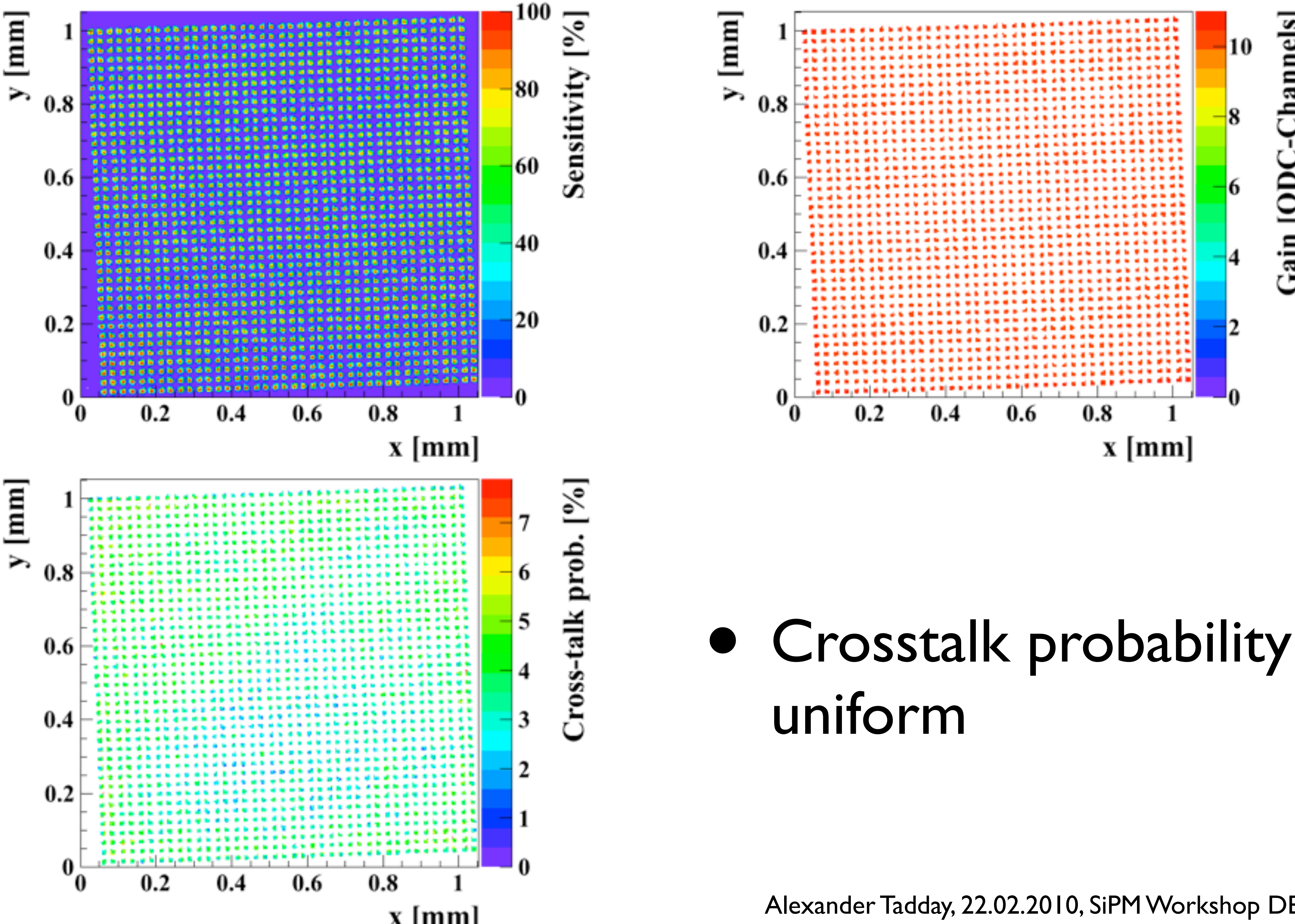
U_{over}=1.3V



- Similar behavior as -100C

MPPC S10362-11-025C

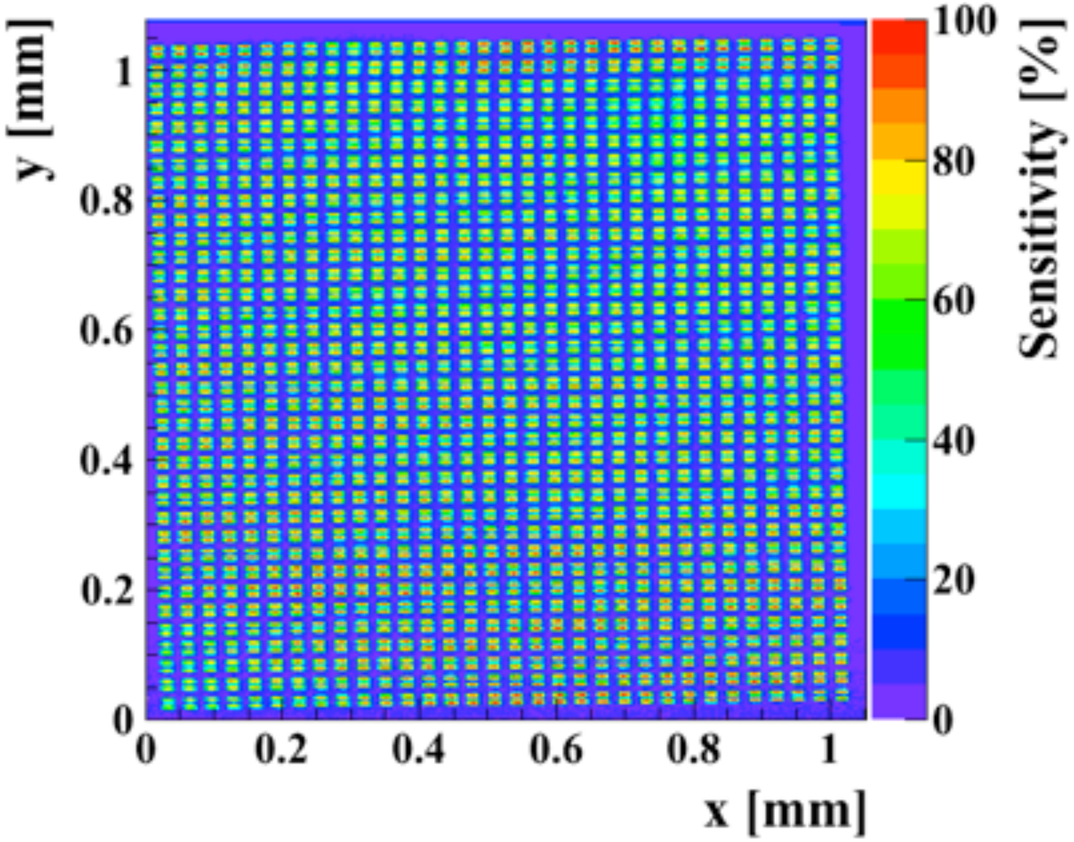
U_{over}=2.3V

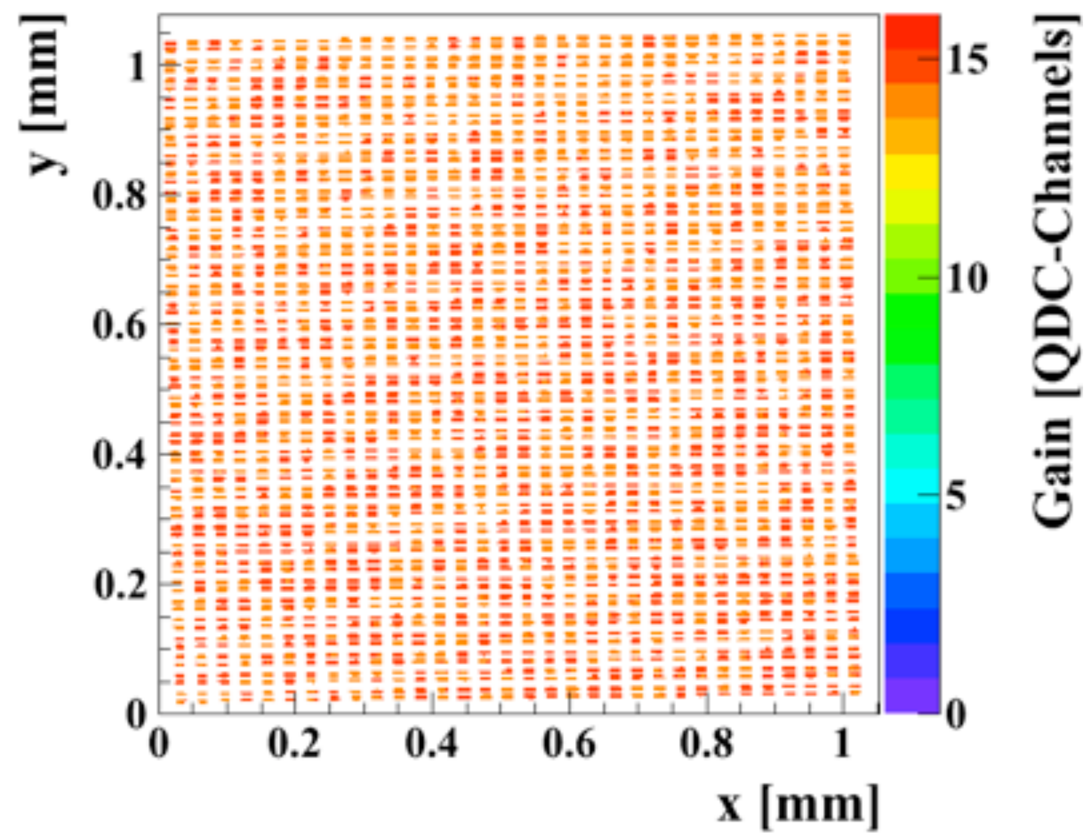


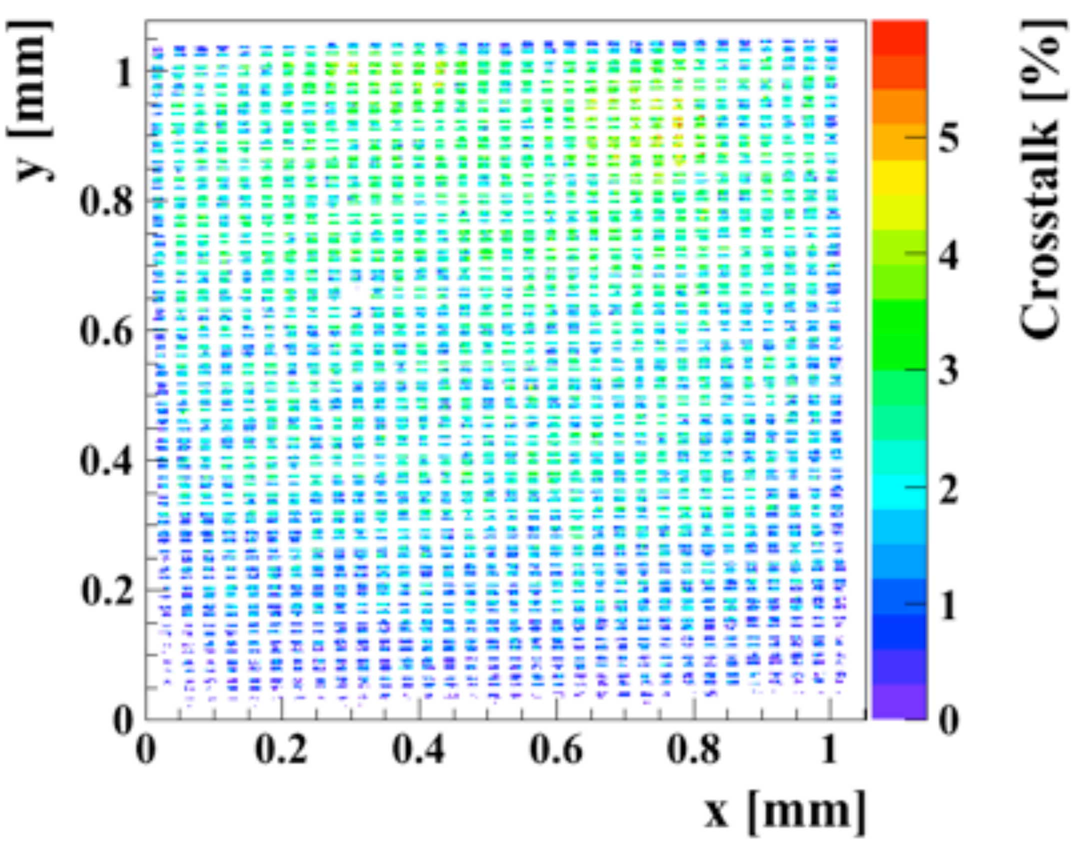
- Crosstalk probability is uniform

SensL SPMMICRO1020X13

U_{over}=1.6V







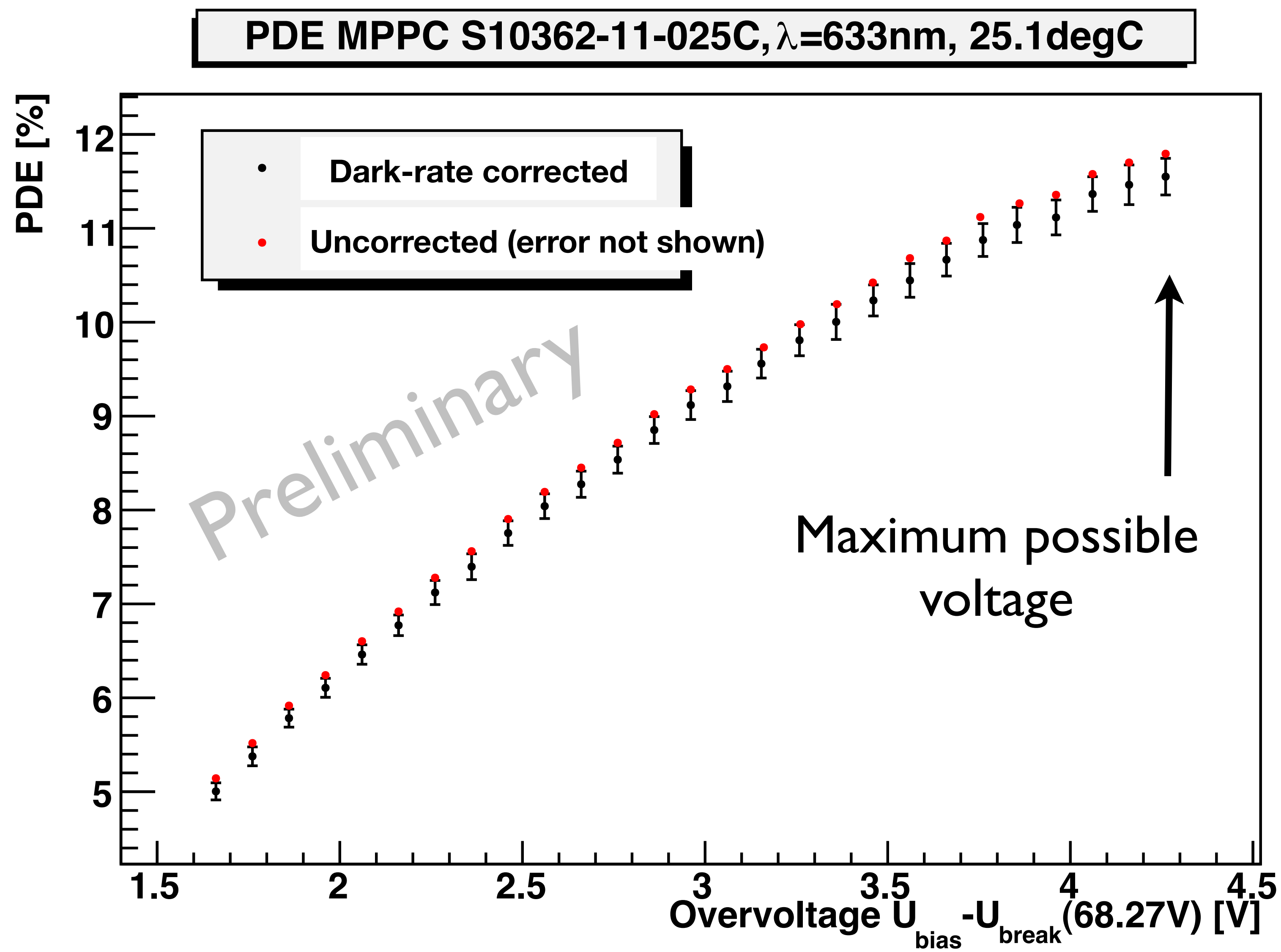
Conclusion

- Setup for SiPM characterization established
- Basic Characterisation
- Crosstalk and after-pulse measurements
- Temperature dependence
- Uniformity Scans (sensitivity, gain and crosstalk maps)
- PDE-measurement over wide spectral range (350-1000nm)

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



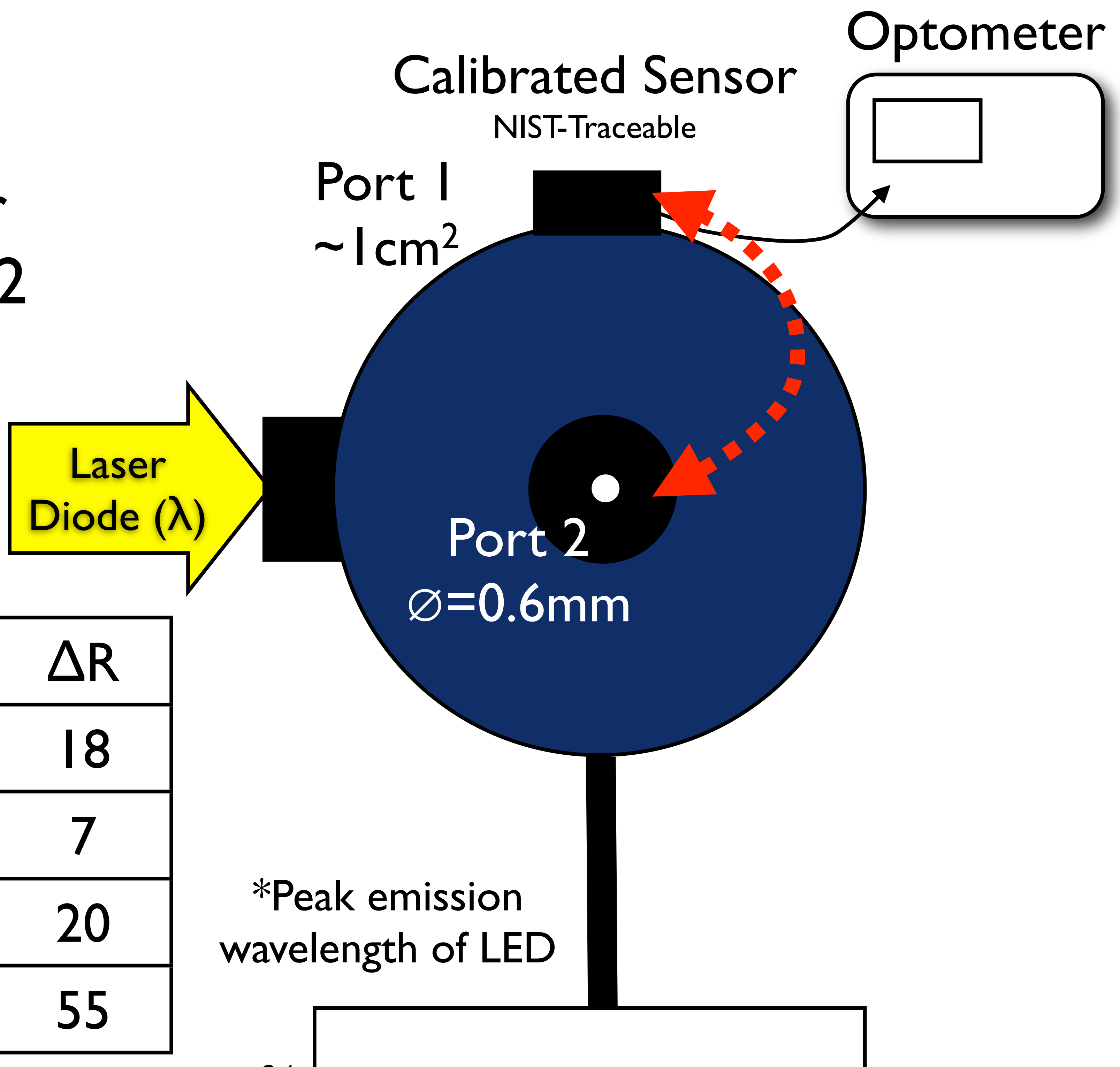
Measurement of Power-ratio R

(∅=0.6mm aperture)

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

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

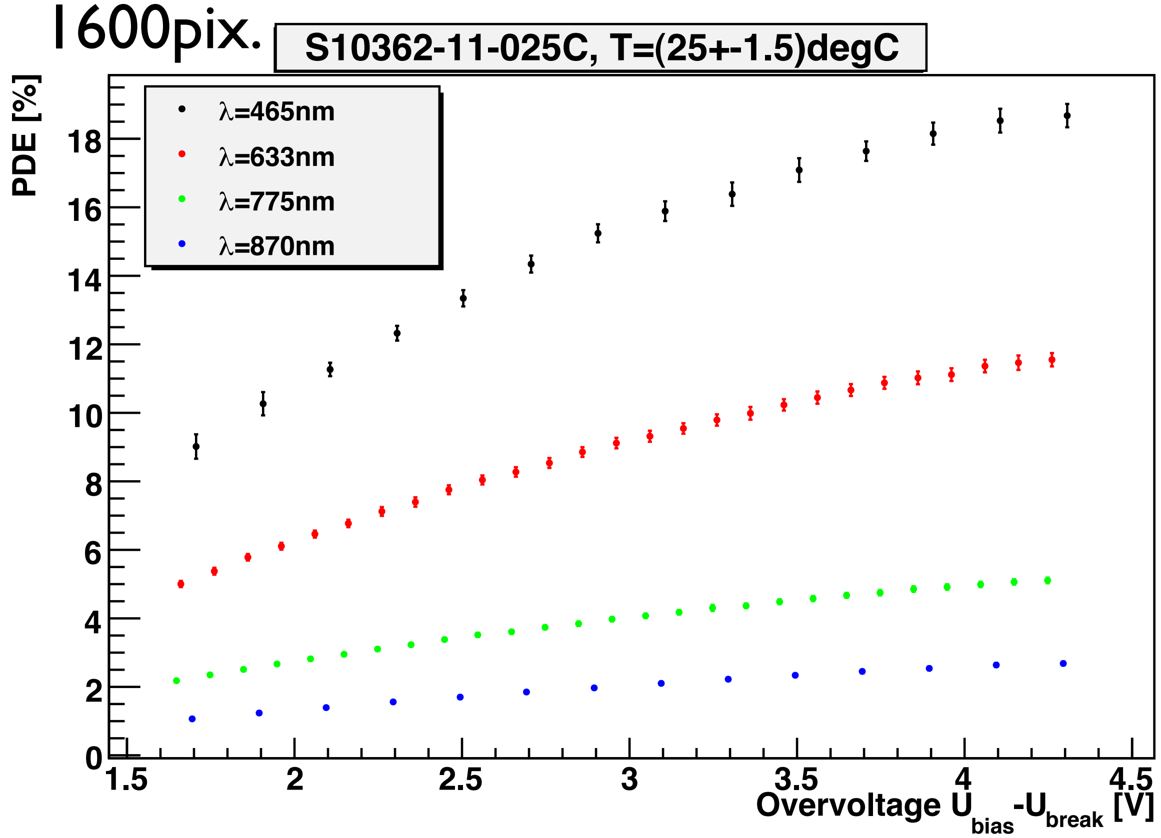
Type	λ [nm]	$R_{0.6mm}$	ΔR
Laserdiode	633	3852	18
Laserdiode	775	4328	7
LED	465*	4200	20
LED	870*	4625	55



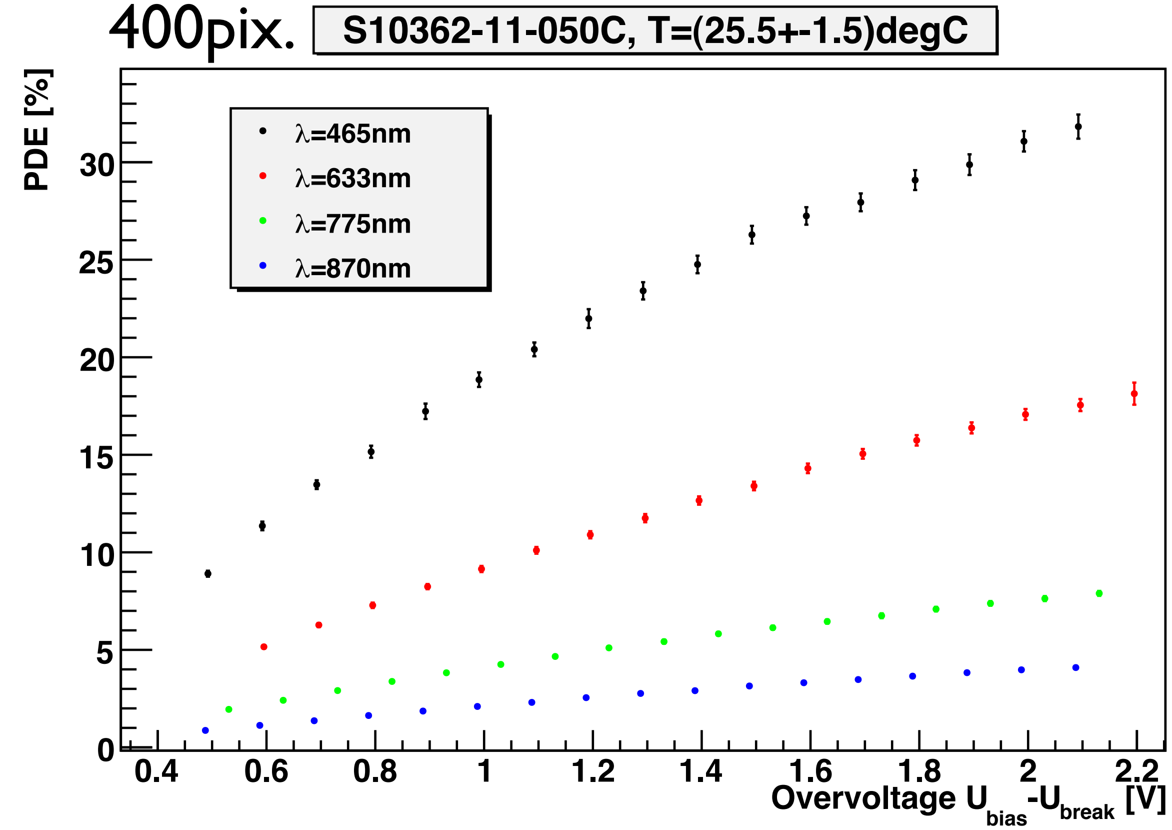
*Peak emission wavelength of LED

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

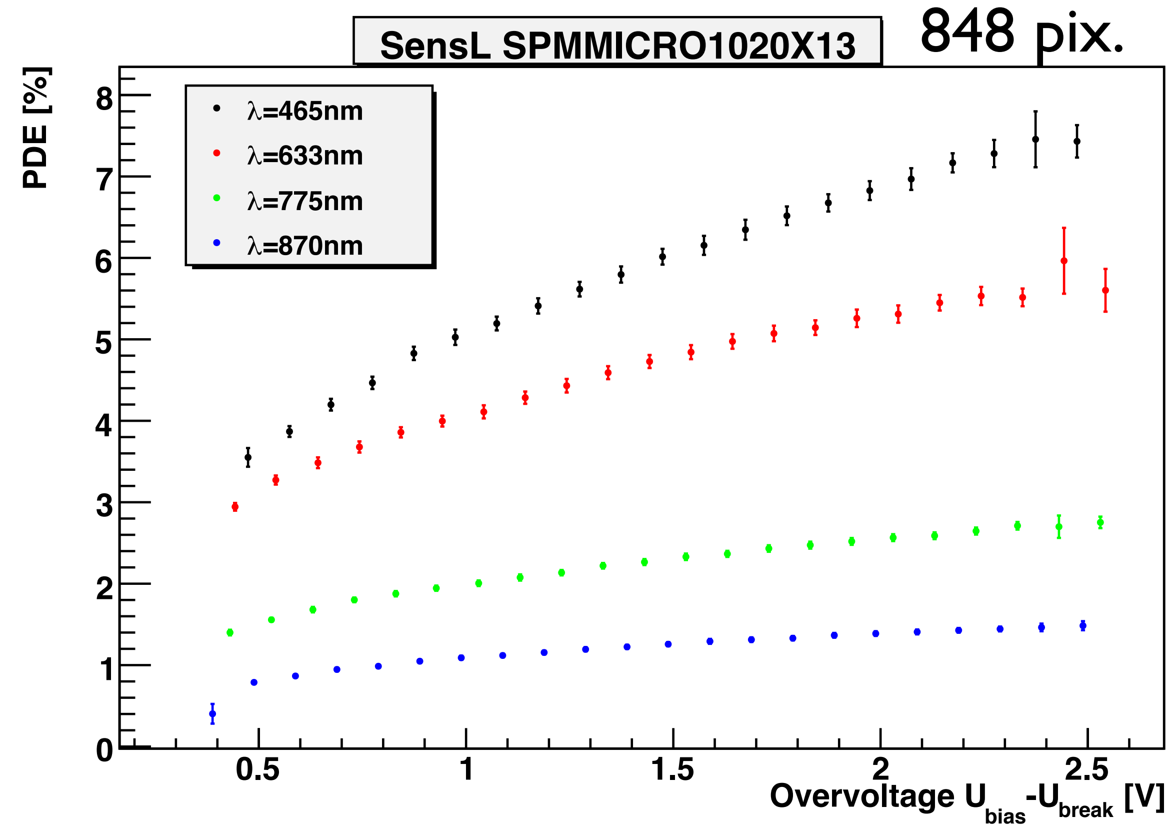
MPPC
1600pix.



MPPC
400pix.



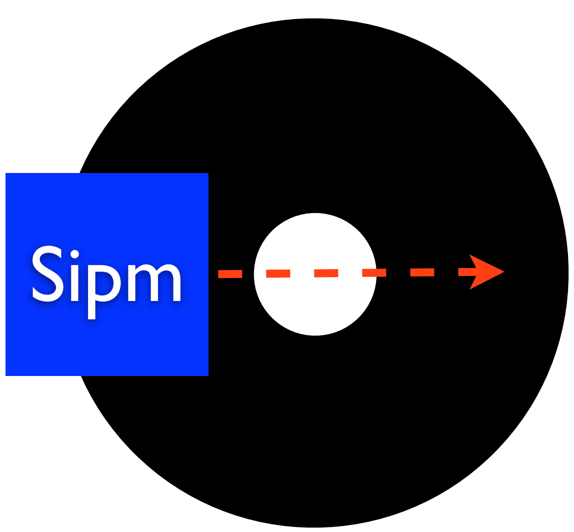
848 pix.

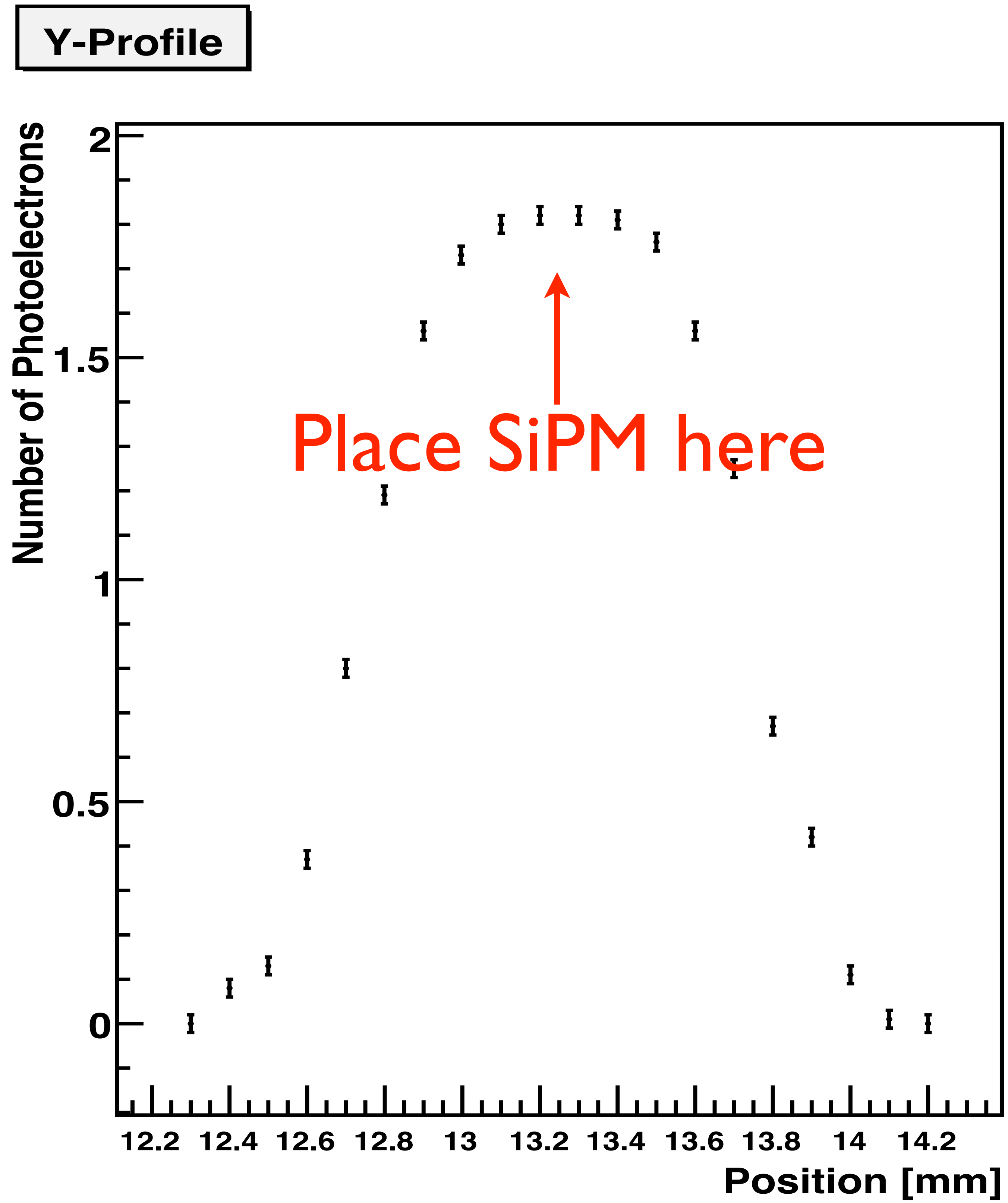


PDE was measured at four different wavelengths as a function of U_{over}

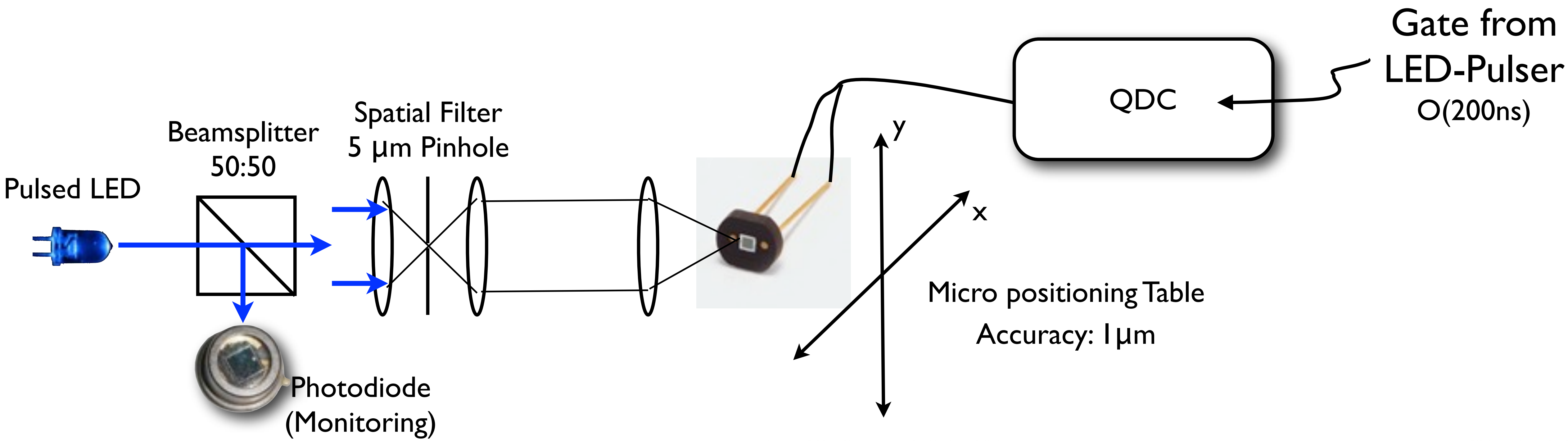
SiPM Positioning

- 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)