Characterising SiPMs for the Analogue Hadronic Calorimeter for the ILC

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CALICE
Calorimeter for ILC

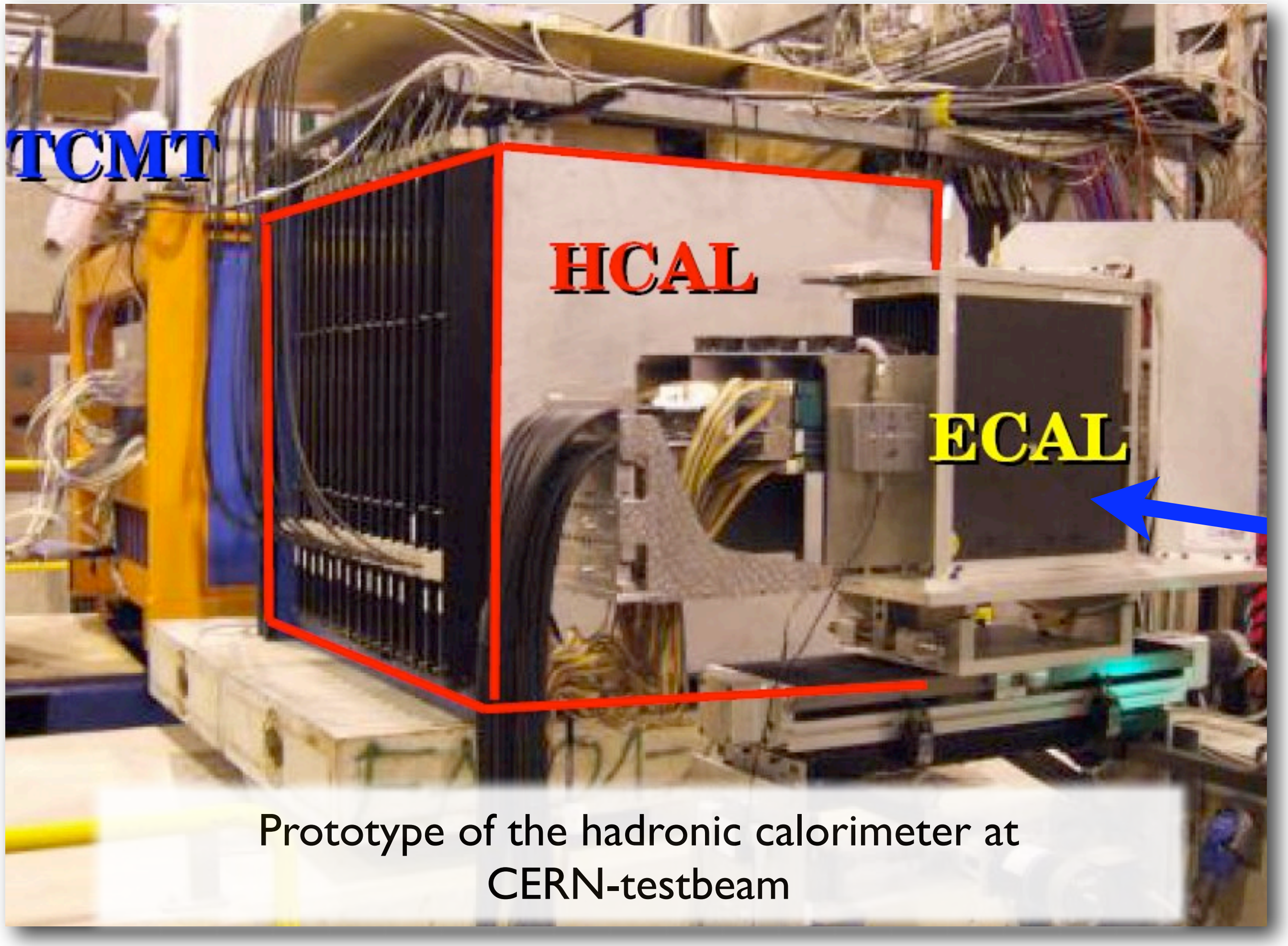
10 years
KIRCHHOFF-
INSTITUTE
FOR PHYSICS

Outline

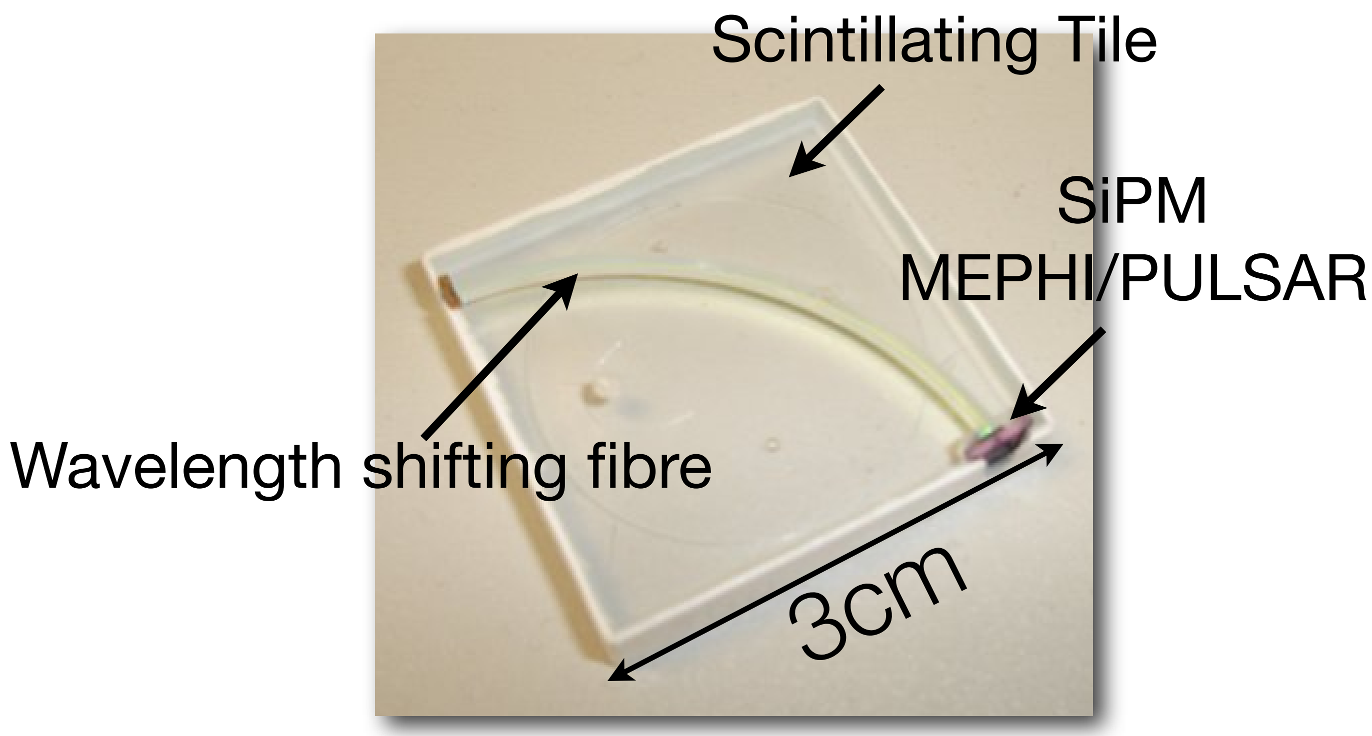
- **Analogue Hadronic Calorimeter (AHCAL) for the ILC**
- **Silicon Photomultiplier (SiPM) Introduction**
- **Essential SiPM Characterisation**
    - Photon Detection Efficiency
- **SiPM Readout Chip**
- **Tile Coupling Studies**
- **Development of Embedded LED Calibration System**

Highly Granular Hadronic Calorimeter

- Sandwich Calorimeter 38 Layers Steel / Plastic Scintillator Tiles
- ≈ 7600 Tiles with SiPM readout
- Several SiPM producers and sensor types on the market
- Future: Different Tile geometrics and readout schemes possible
- Which ones are suitable?
  - ➡ Characterisation studies necessary

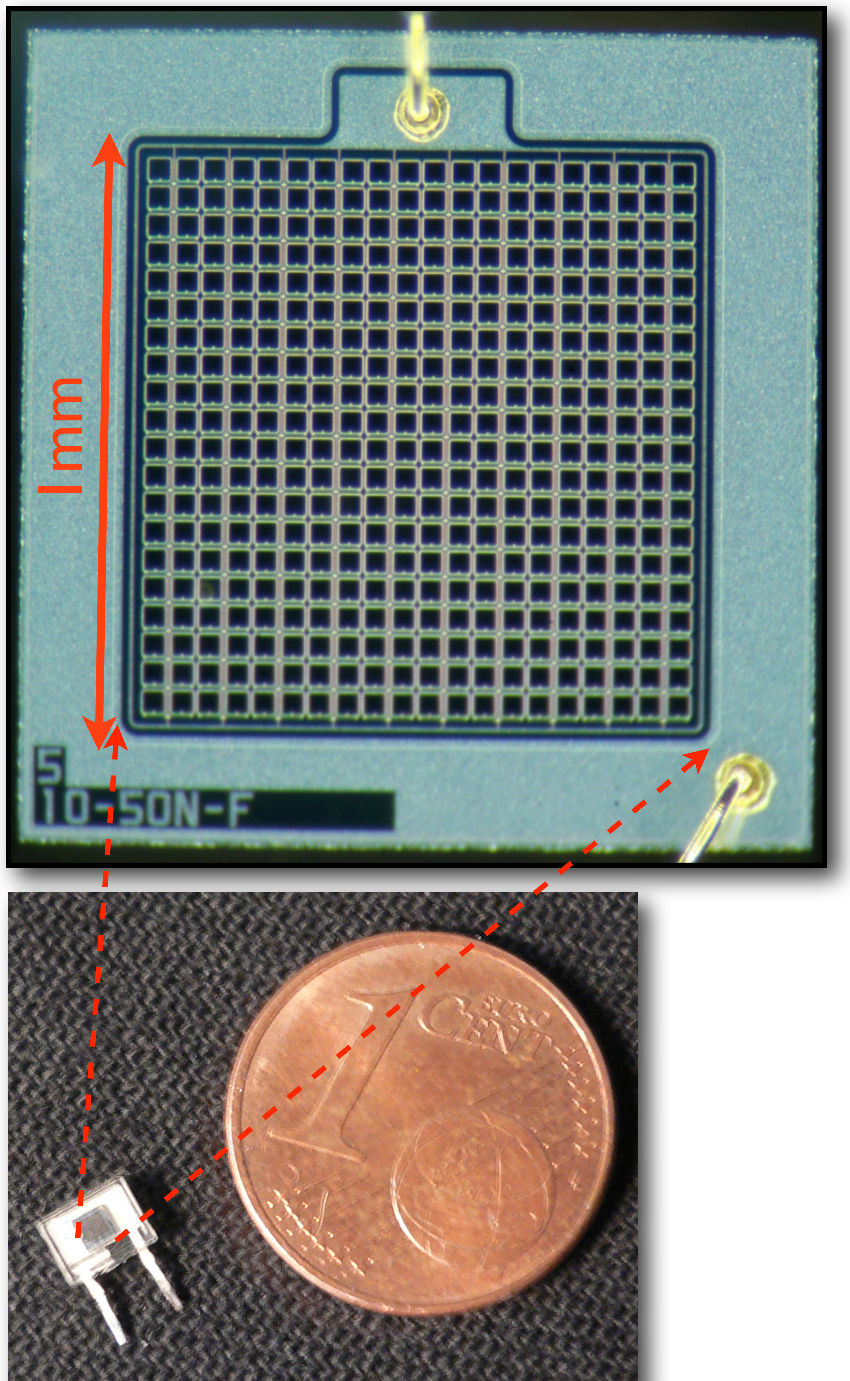


Prototype of the hadronic calorimeter at CERN-testbeam



Silicon Photomultiplier (SiPM)

Geiger-Mode Avalanche-Photodiode GAPD, Pixelised Photon Detector PPD,
Multi Pixel Photon Conter MPPC (HAMAMATSU)



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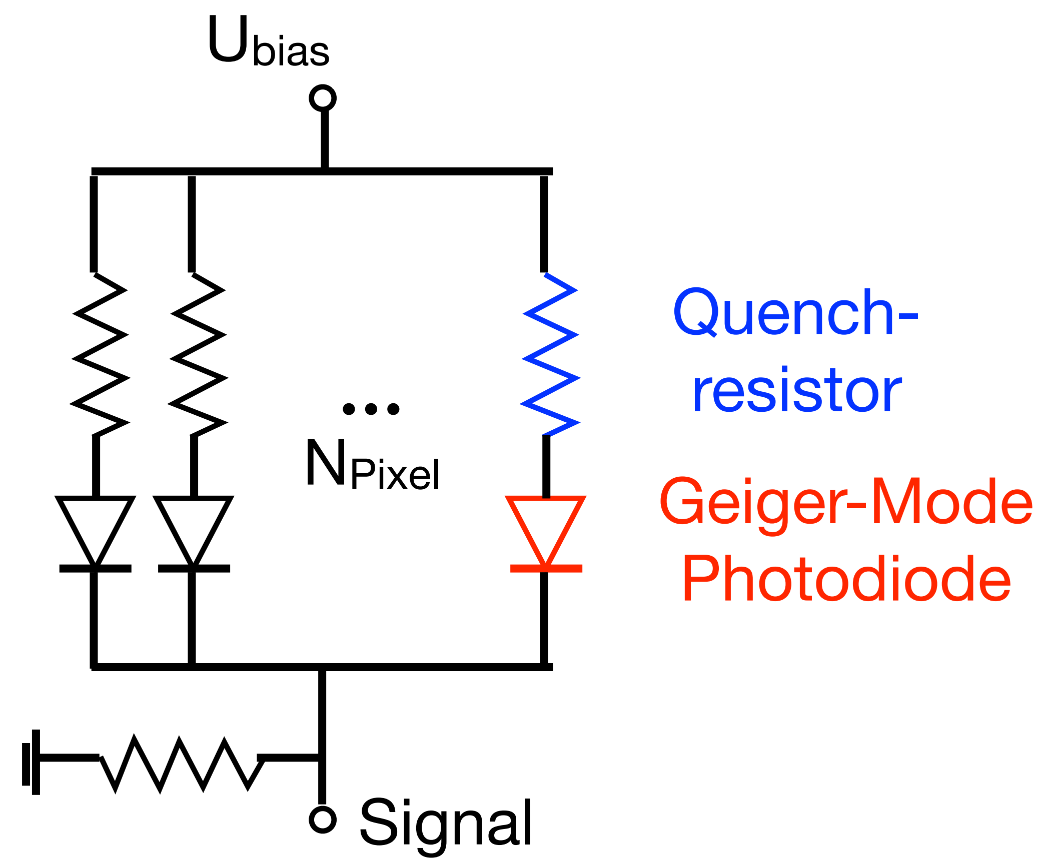


- Geiger Mode ($U_{bias} > U_{break}$) ➟ Binary device!
- Pixels signals are summed up ➟ Linear response if $N_{photon} << N_{pixel}$

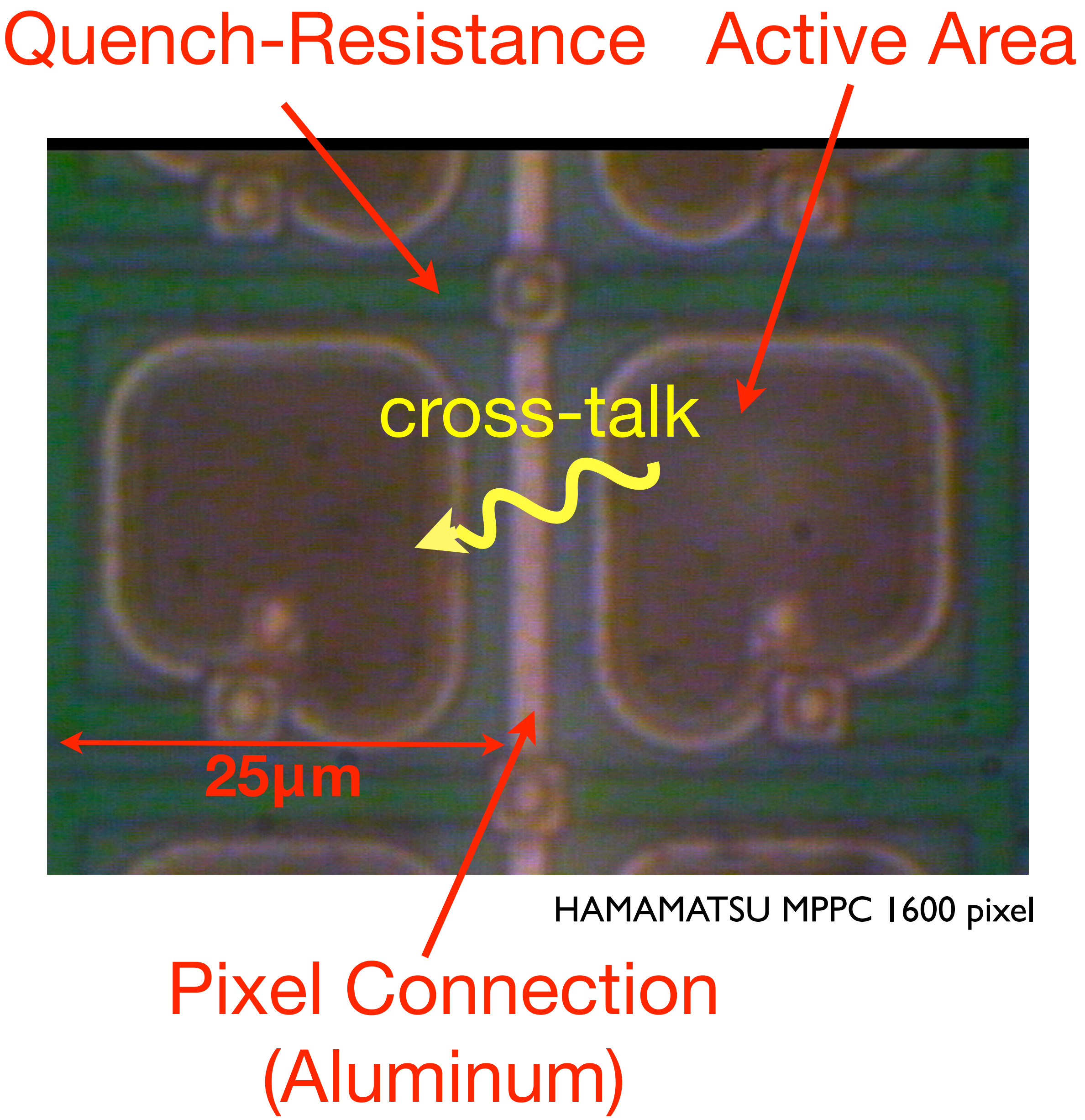
SiPM Properties

- **High Gain O(10^6)**
- **Low operating voltage (<100V)**
- **Compact (few mm)**
- **Magnetic field insensitive**

- But there are also **drawbacks**:

- **Optical cross-talk (CT)**
  $3x10^{-5}$ photons per charge carrier traversing the junction
  $G=10^6$ ➠ 30 photons (E>1.14eV)

- **After-pulses (AP)**
  Delayed Avalanche caused by trapped electrons

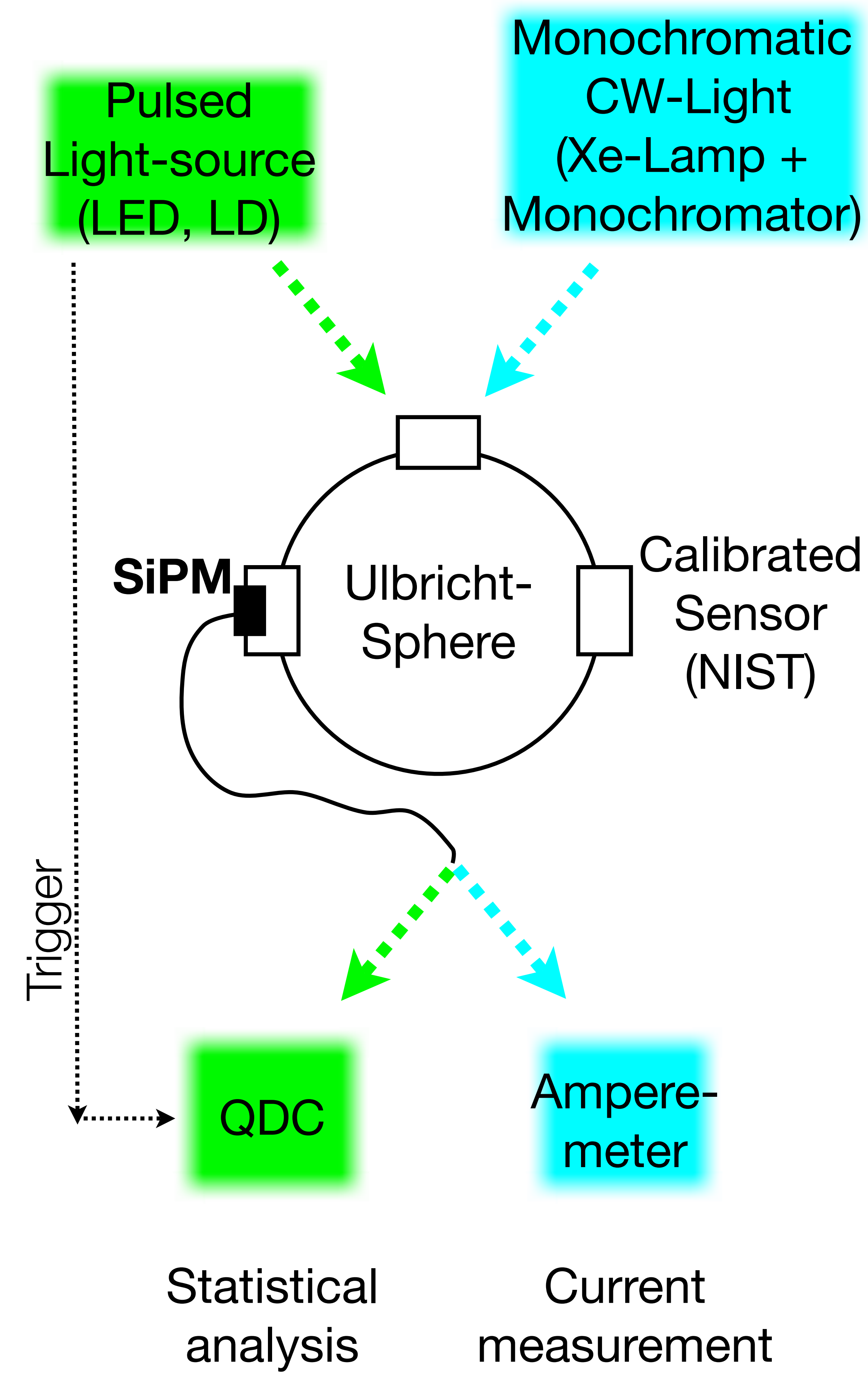


HAMAMATSU MPPC 1600 pixel

PDE Measurement

(KIP Heidelberg)

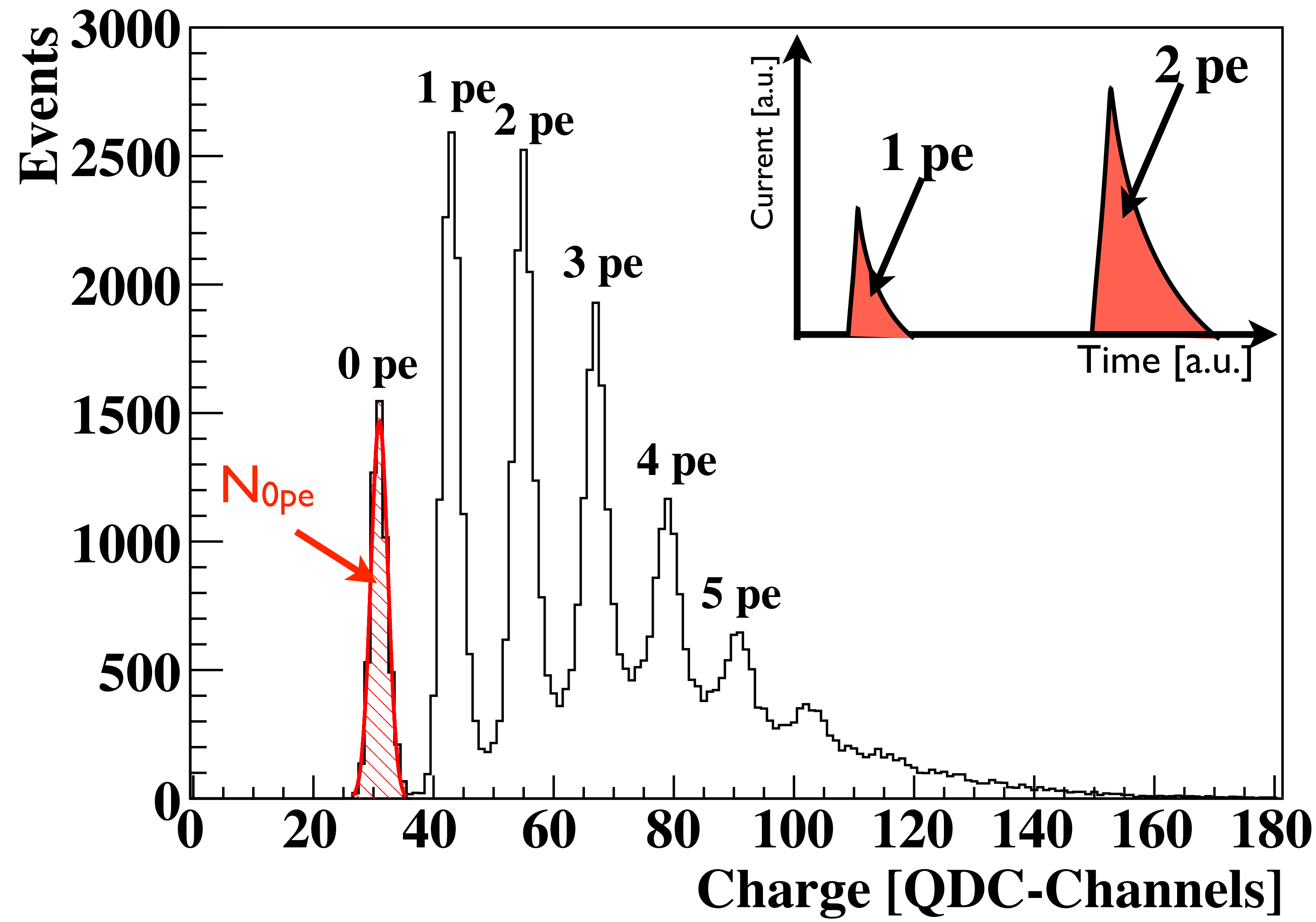
- Problem: Cross-talk and after-pulses cannot be separated from the photon induced signal
- **Statistical analysis method** allows to measure **absolute PDE** without CT and AP, but only for **individual λ** (i.e 465, 635, 775, 870nm)
- **Current measurement** allows to measure **relative PDE** over wide spectral range **(350-1000nm)**, but contains CT and AP
- **Idea: Scaling of relative PDE**



Absolute PDE (Statistical Analysis)

- QDC readout is triggered independent from SiPM signal
- By measuring the number of times no photon was detected $\mathbf{N_{0pe}}$, the average number of detected photons $\mathbf{n_{pe}}$ can be calculated (poisson dist.)
- Since $\mathbf{N_{0pe}}$ is not influenced by **CT** and **AP** (no pixel is firing), $\mathbf{n_{pe}}$ can be used to calculate the **absolute PDE**

QDC Spectrum



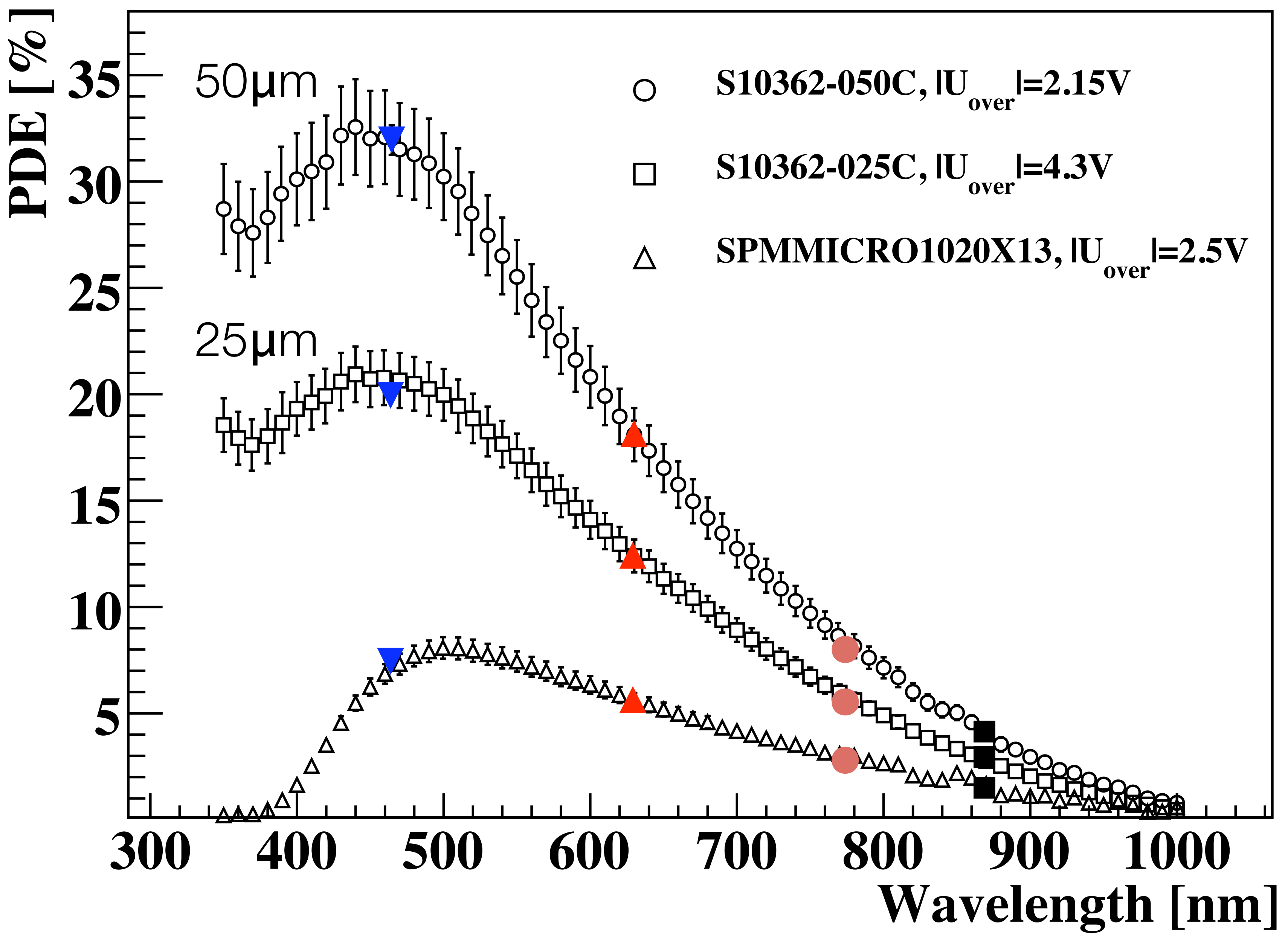
Poisson distribution:

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

$$\Rightarrow n_{pe} = -\ln\left(\frac{N_{0pe}}{N_{Tot.}}\right)$$

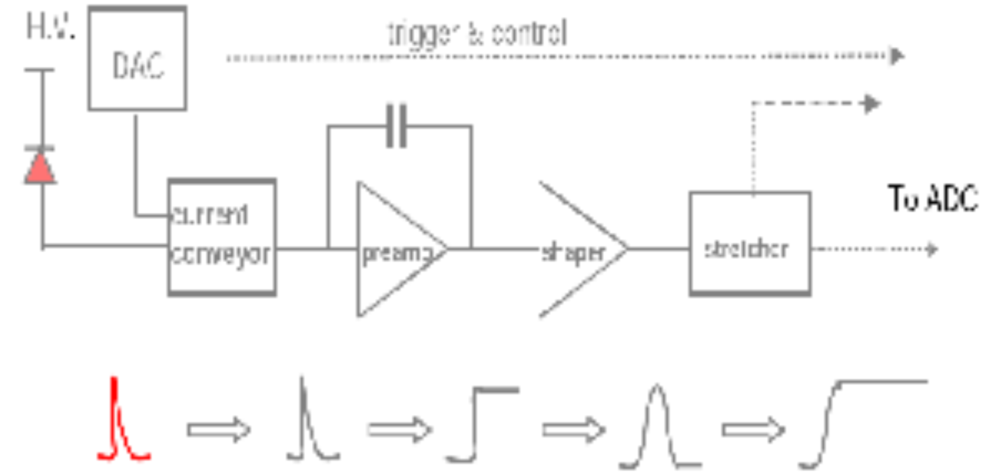
PDE: Wavelength dependent

- Relative PDE curves have been scaled to the highest absolute PDE at 633nm.
- PDE values at 465, 775 and 870nm are in good agreement
  ➠ Consistency check
- MPPC: high PDE in blue region
- SensL SPM: more green sensitive



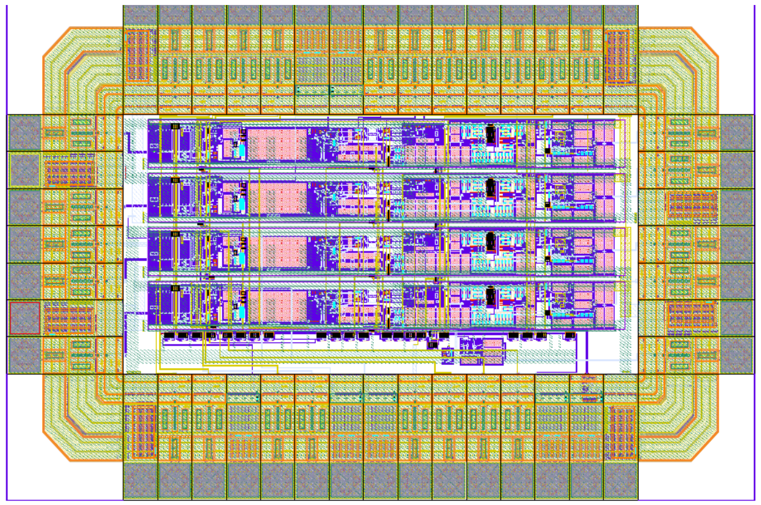
SiPM Readout Chip

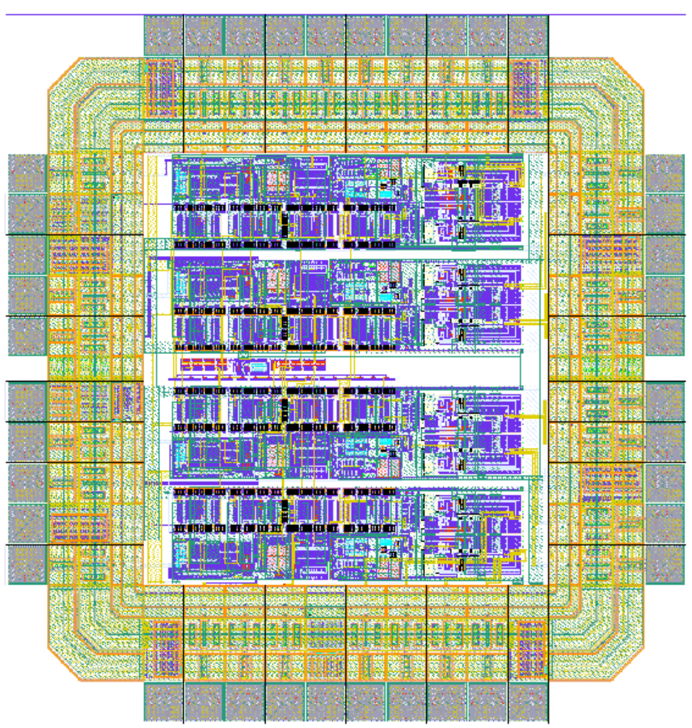
(KIP Heidelberg)

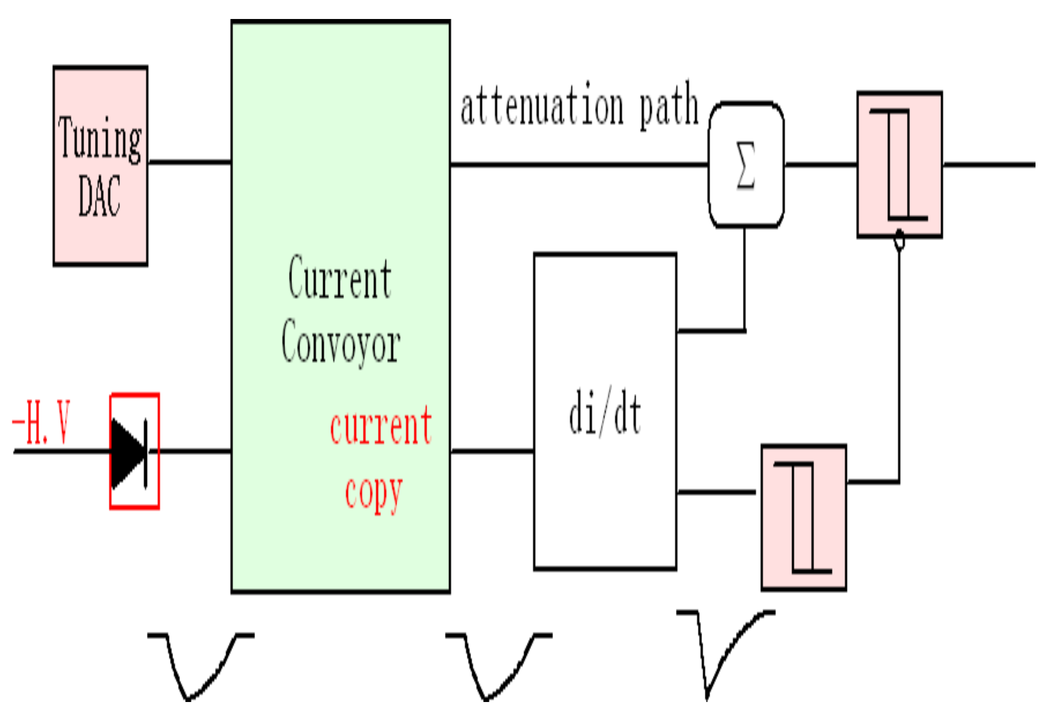


SiPM charge sensitive readout

- tunable Sensor bias
- high signal to noise ratio (>10 for SiPM gain = 2.5×10^5)
- fast trigger available for discrimination
- test chip with 4 channels
- Submitted in Oct. 2009
- AMS 0.35 um CMOS







Fast Timing readout Chip

LVDS output

Leading edge & CF triggering

Time walk for 10:1 signal 80ps

Time jitter ~ 15ps

Power < 10 mW / channel

4 channels

Submitted in Oct. 2009

AMS 0.35um CMOS

Tile Coupling Study
(DESY Hamburg)

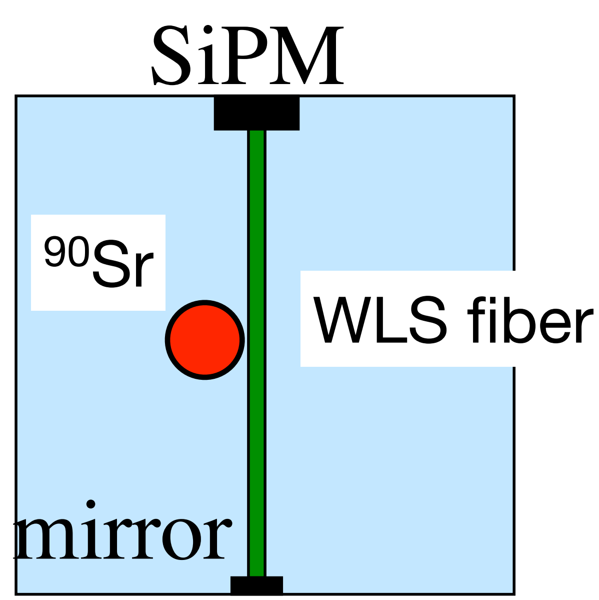
- Wavelength shifting fiber vs. direct coupling (simpler assembly, cheaper)
- Source for Minimum ionizing particles (mips): ^{90}Sr
- Second tile with PMT readout used for trigger
- mip spectra recorded for different Tile-SiPM configurations
  -> Most probable value (MPV)

MPPCs used in study

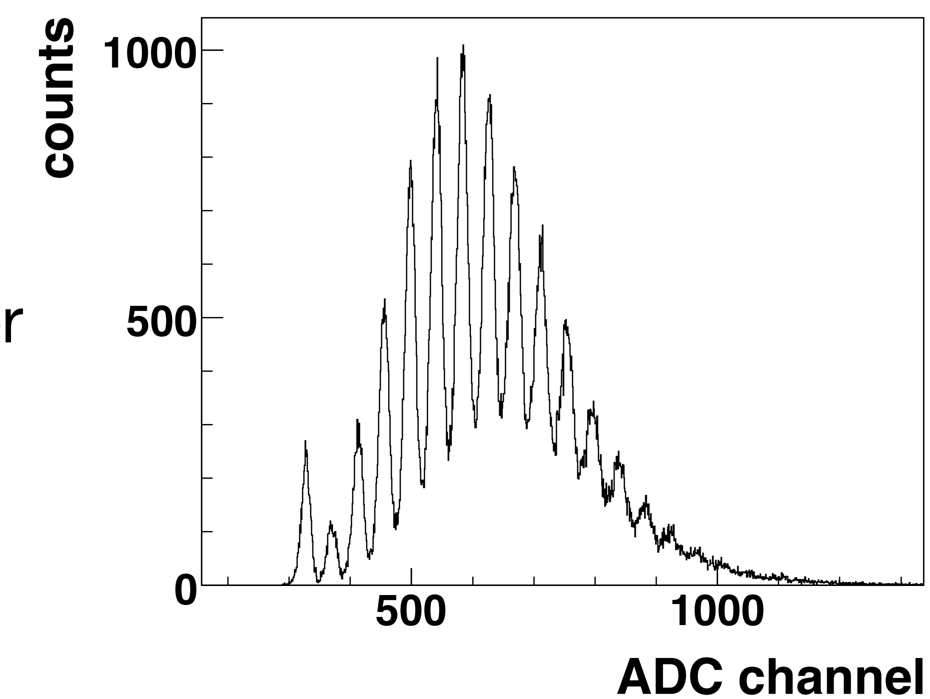
# Pixels (size [mm^2])	Bias [V]	Dark Rate (0.5 p.e. threshold)	Pixel Size [μm^2]	Gain (10^5)	PDE [%]
1600 (1x1)	70.4	200	25x25	2.5	25
3136 (1.4x1.4)	71.8	550 (200 kHz/mm^2)	25x25	2.5	25
400 (1x1)	69.4	600	50x50	7.5	50
676 (1.3x1.3)	70.5	900 (530 kHz/mm^2)	50x50	7.5	50

Contains CT and AP

3x3x0.3cm^3 Tile



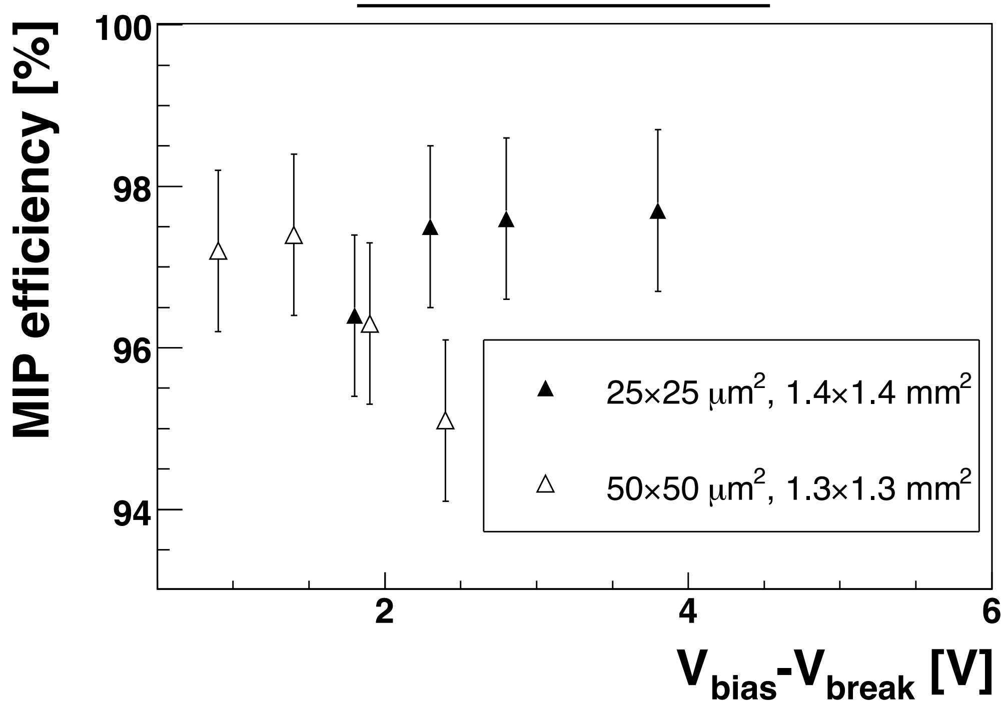
Typical mip spectrum



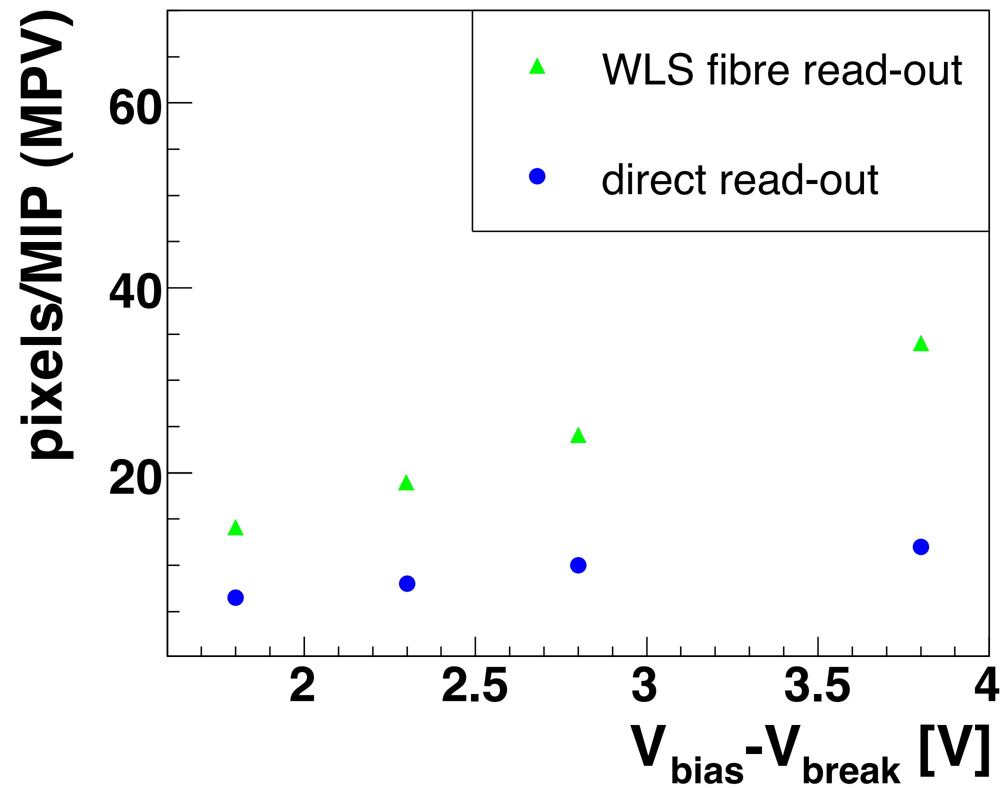
Tile Coupling: Results

- 25µm and 50µm Devices well suited
- Higher MPV for WLS fibre readout, but direct readout results also sufficient
- Mip detection efficiency higher than 95% for all configurations

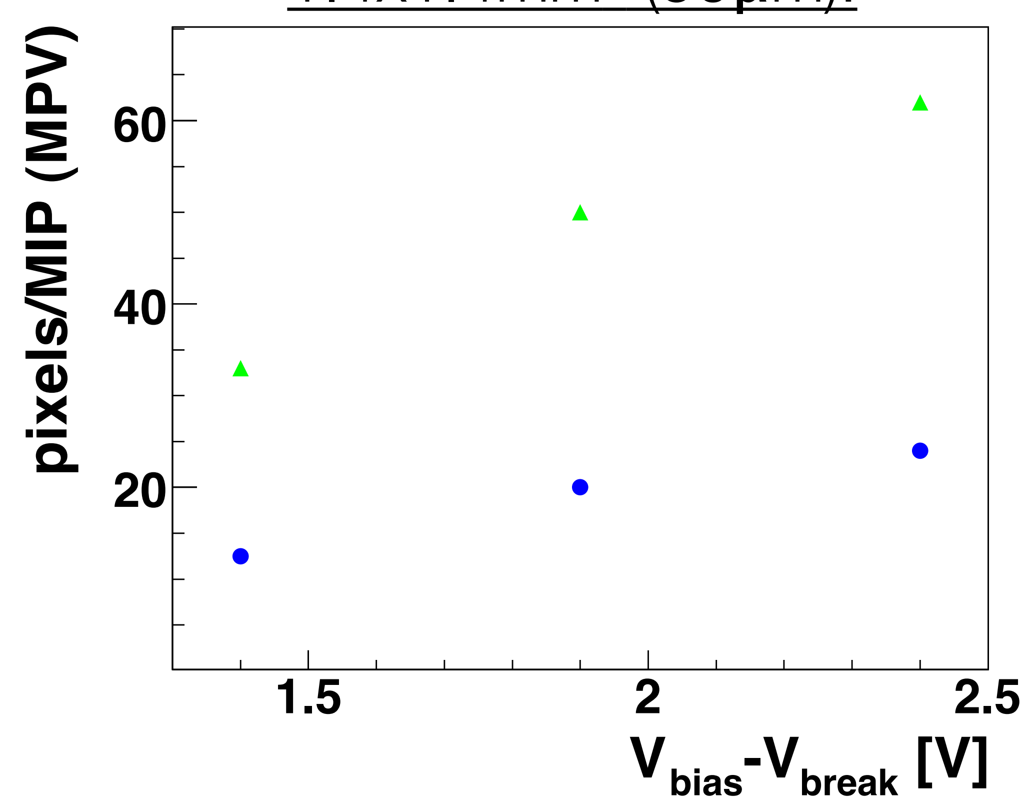
Direct read-out



1.3x1.3mm² (25µm):



1.4x1.4mm² (50µm):



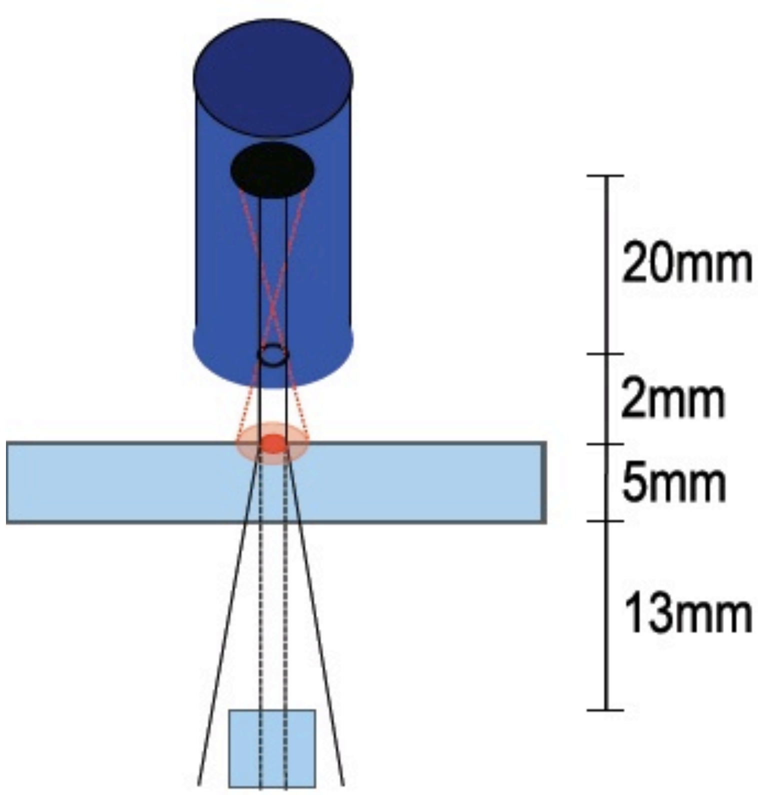
Fiberless Readout of Scintillator Tiles

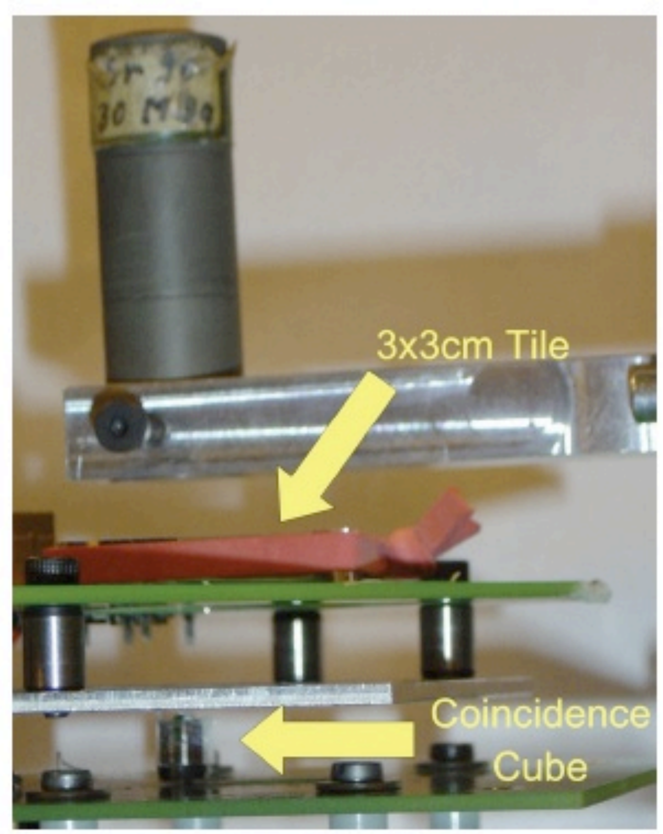
(MPI for Physics & Excellence Cluster 'Universe', Munich)

Blue sensitive SiPMs do not require a WLS fiber for readout

- Advantages:
  - Simplified mechanics, alignment of SiPM
  - Faster response: No spreading of pulse due to WLS absorption and reemission
- Drawback:
  - WLS fiber collects light and guides it to the SiPM: improves uniformity!

➯ Optimize tile geometry to improve uniformity

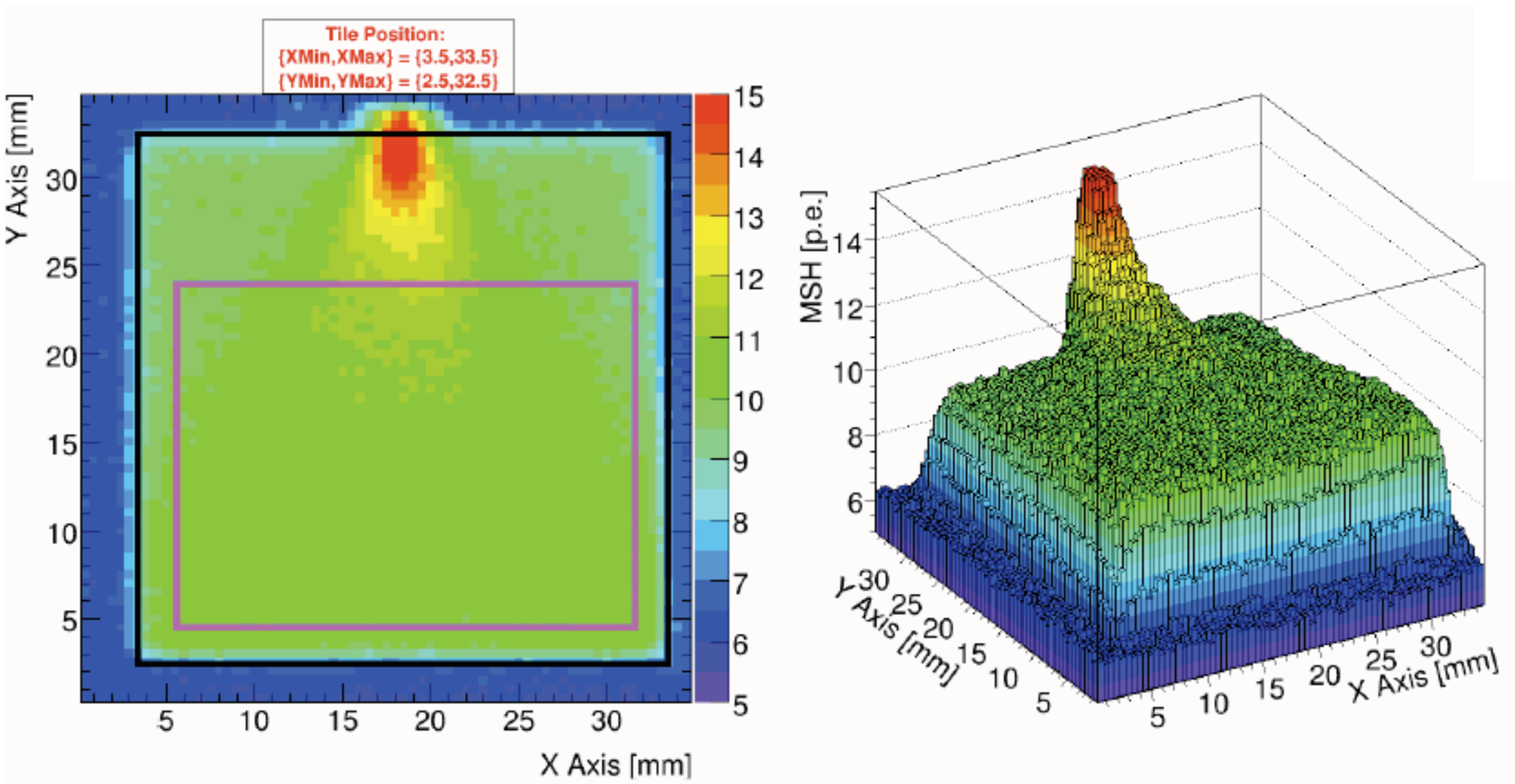




A scanning setup with a ^{90}Sr source and a coincidence trigger for detailed mapping of the response of scintillator tiles has been constructed at MPI Munich

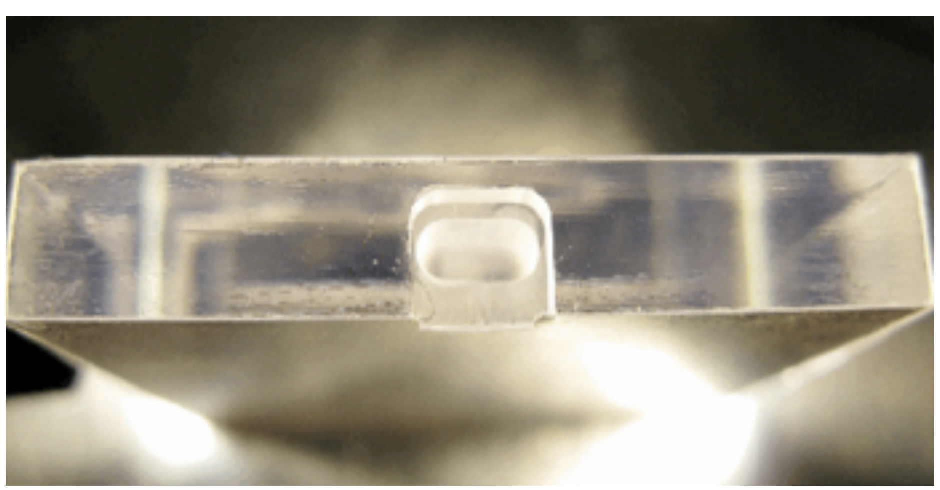
About 50 different tile geometries have been investigated

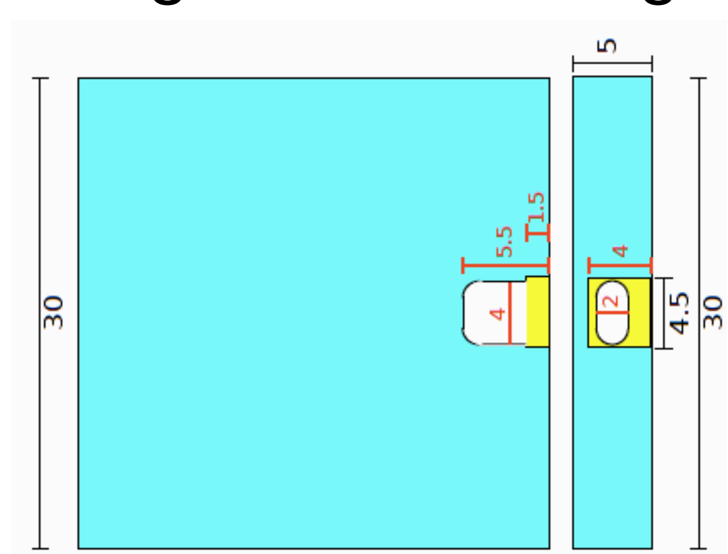
Direct Coupling: Non-Uniformity



Strong non-uniformity, significantly increased response close to SiPM coupling position

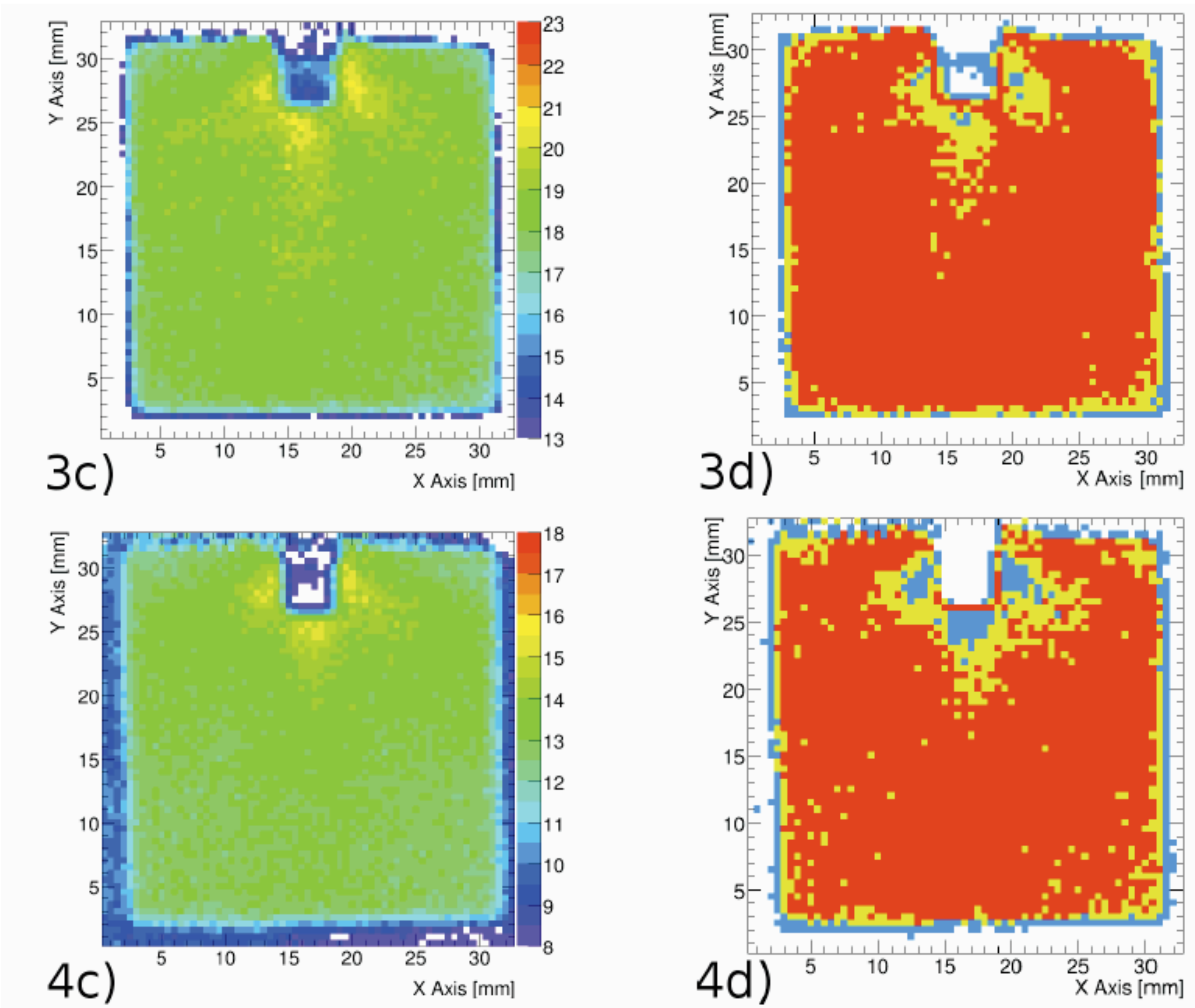
➯ The strategy: reduce material close to coupling position, improve light collection through embedding of SiPM and light diffusion





Add a “dimple” at the SiPM coupling position: Drilled into the tile

Improved Uniformity



4 x 2 mm^2 slit,
4 mm deep, SiPM embedded
(1.5 mm deep)
mean signal 18.4 pe

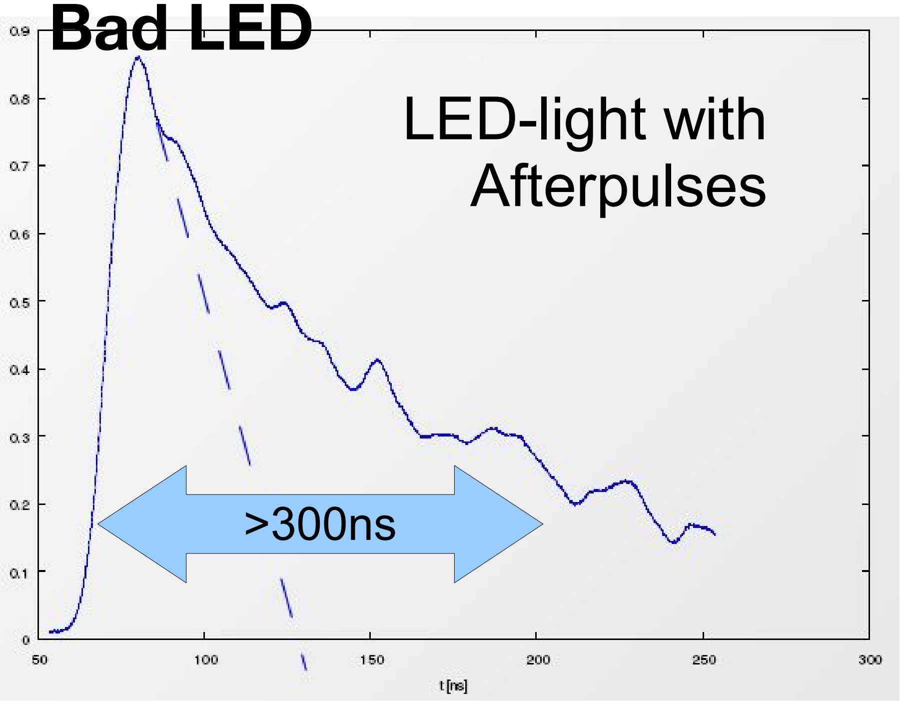
Typically
5%: ~72%
10%: ~84%

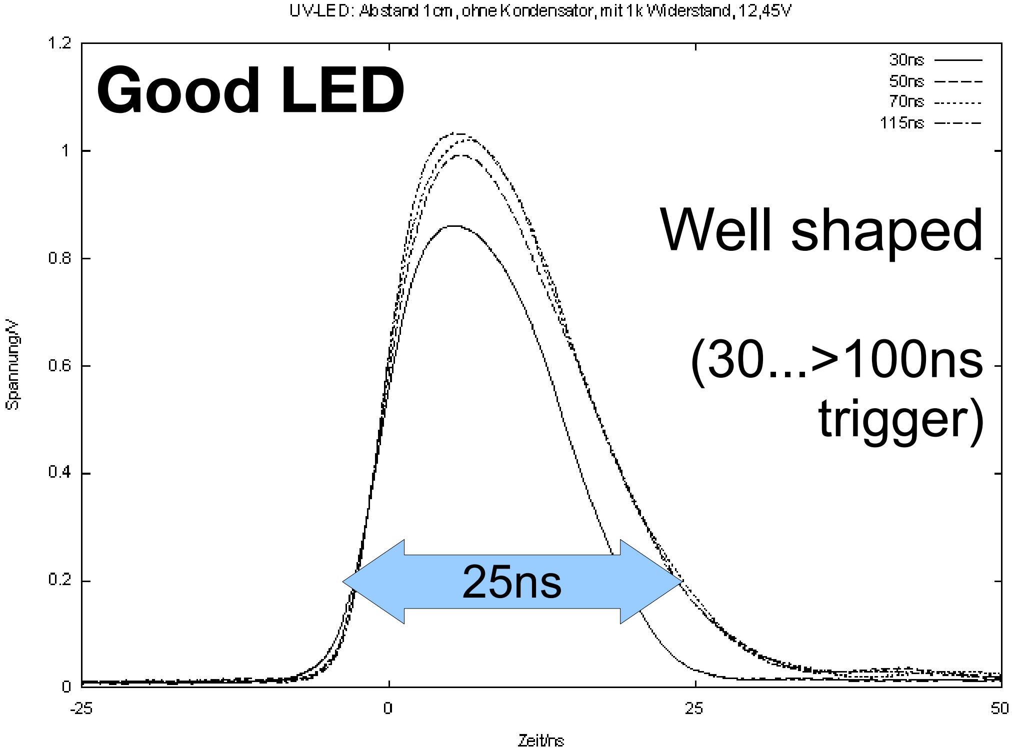
3 mm thick tile!
4 x 2 mm^2 slit,
4 mm deep, SiPM embedded
(1.5 mm deep)
mean signal 13.2 pe

Embedded LED calibration system

(Uni Wuppertal)

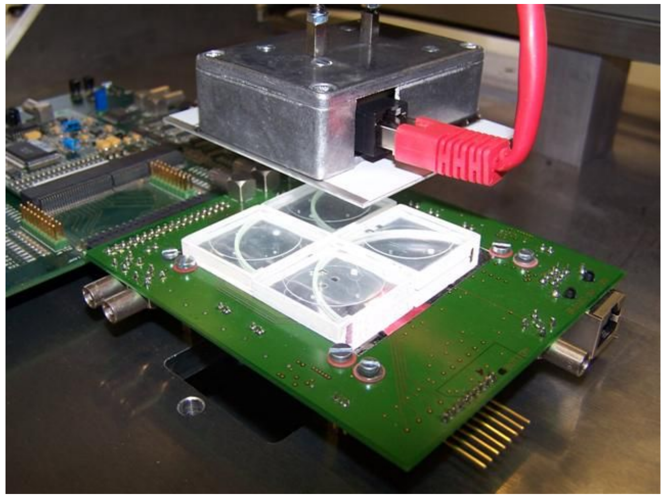
- One LED plus driver placed over each AHCAL tile, triggered by dedicated signal
- Driving circuit has been optimized to match needs of single photon spectra
  - Sharp, well shaped light pulse
  - Independence of trigger signal length
- Several LEDs of different type, color and manufacturer tested
- Most suitable, some show undesirable behaviour (afterpulsing)
  - **Blue LEDs work fine!**

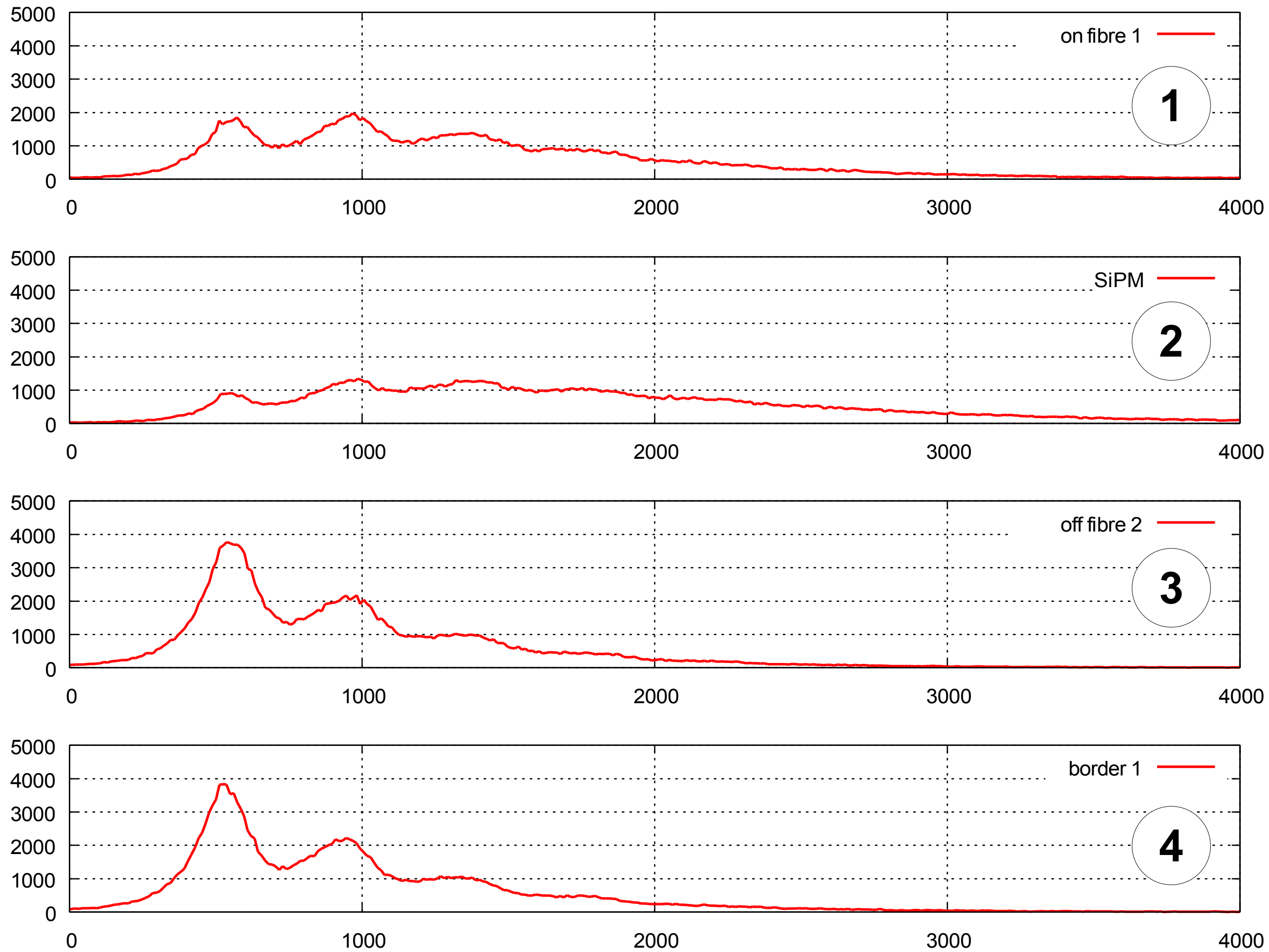


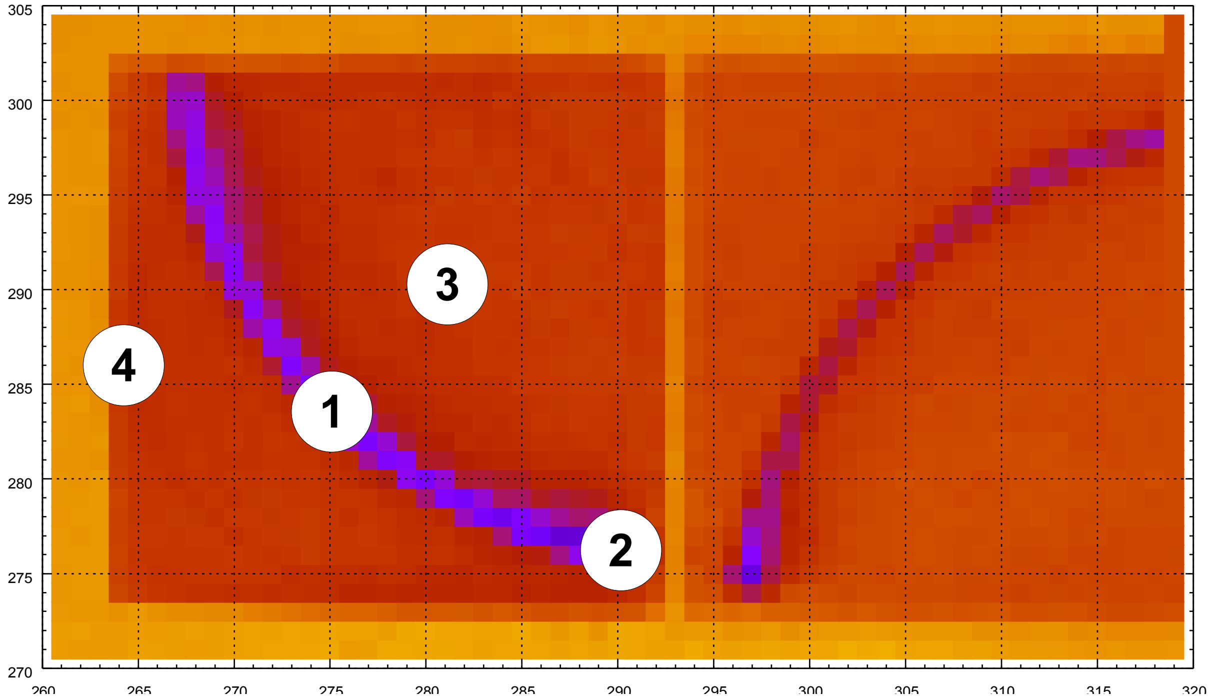


LED Position

- XY stage to place LED on HCAL tiles
- Quickly exchangable LED&Driver PCB
- Surface scan shows structure of tiles
- Fiber shows gain of ~2 in SiPM-signal, but also more noise
  (LED over SiPM: ~3)
- In the future: scans with Sr90







Conclusion

- Test stand for essential SiPM characterisation
  ➠ PDE, Cross-talk, After-pulse probabilities ...

- SiPM readout chip submitted in october

- Detailed tile coupling studies covering SiPM selection and tile geometry have been performed

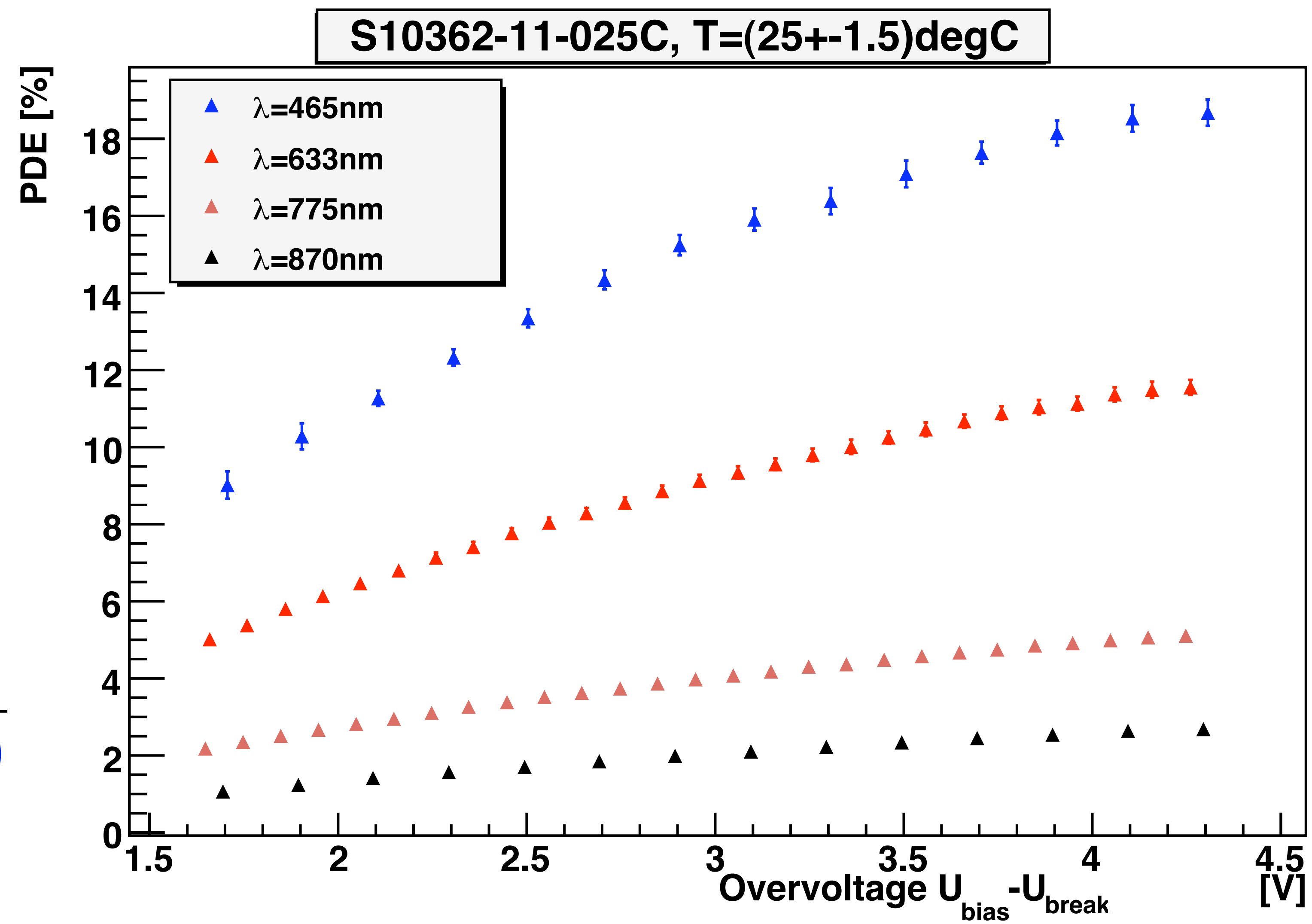
- First results on embedded LED calibration system

Backup Slides

PDE: Voltage Dependent

- QDC spectra recorded and evaluated for a range of bias voltages
- Highest PDE value at 635nm is used in the next step scaling.

Example: HAMAMATSU MPPC 25µm



$$\mathrm{PDE} = \frac{N_{\mathrm{SiPM}}}{N_{\mathrm{Photon}}} = \frac{n_{\mathrm{pe}}}{P_{\mathrm{opt}} \cdot T / (R_{0.6} \cdot h \cdot \frac{c}{\lambda})}$$

n_{pe}: Photoelectrons per light-pulse
T: Light-pulse period
$R_{0.6}$: Power-ratio of sphere (Port1/Port2)
P_{opt}: Optical power measured by calibrated sensor

Temperature dependency

- XY-stage placed in temperature controlled environment
- Studies of temperature dependencies over wide range possible

- Gain 0...38°C:
  - Measure peak distance
  - Almost linear as expected (8.9 counts/K → 2.1%/K)