Study of detection efficiency distribution and areal homogeneity of SiPMs

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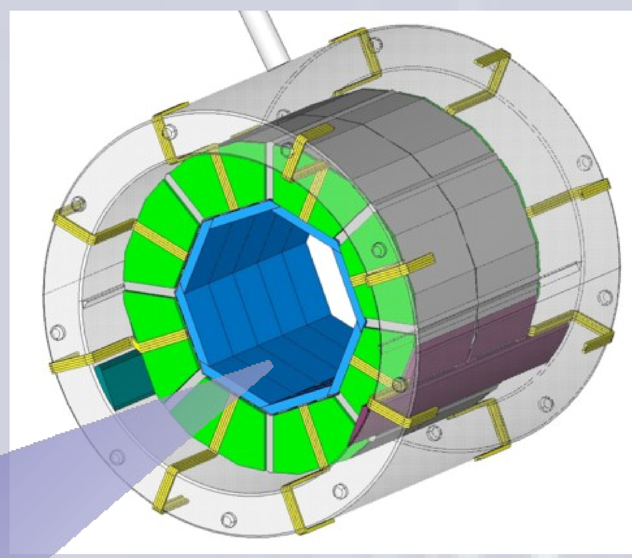
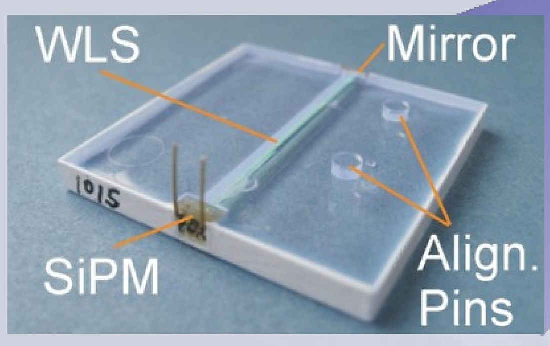
Highly granular calorimeters for future colliders

- particle flow algorithms for optimized jet energy reconstruction meet requirements for precision physics studies
- ➔ needs highly granular calorimeter systems

An Analog Imaging Hadron Calorimeter

- 10 millions channels
- fully integrated electronics
- small photon sensor embedded in each $3\times3\times0.3$ cm^3 scintillator tile
- ➔ possible with SiPMs


ILD analog HCAL.



Scintillator tile for the CALICE analog HCAL prototype.

- requires large-scale SiPM production
- detailed understanding of SiPM devices crucial

➔ need to develop a tool for precise study of SiPMs on microscopic level to be able to compare different devices

Measurement capabilities

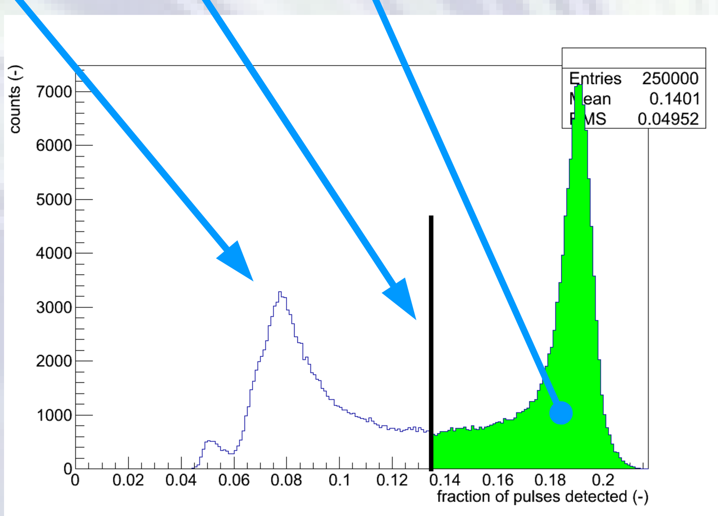
Sensitivity maps measured at 0.5 and 1.5 p.e. threshold.

Analysis example:

- sensitivity distributions over large area to set thresholds to determine active/non-active area
- extraction of parameters of interest
- noise subtraction
- calculate fill-factor from overall distribution
  - for whole scanned area
  - for each single pixel individually

Extracted quantities:

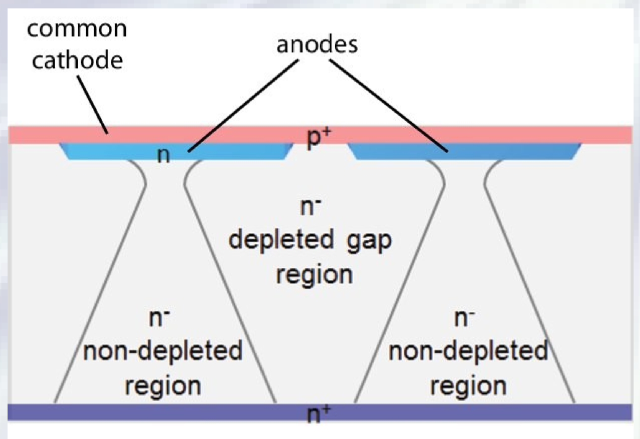
- relative photon detection efficiency (PDE) map
- crosstalk probability map
- pure 1 p.e. signal map
- overall geometrical fill-factor
- dark count



Distribution of fraction of detected pulses over ¼ of Hamamatsu MPPC (50 µm pixel pitch).

Study of SiMPl prototypes

- SiMPl (Silicon MultiPixel light detector) is a SiPM prototype developed in the Semiconductor Lab of the Max-Planck-Institute in Munich
- uses the silicon bulk as a quenching resistor instead of a polysilicon structure on the top of the detector



Cross-section of a SiMPl prototype.

Advantages:

- simple fabrication process
- no obstacles in entrance window
- possible high geometrical fill-factor
- possibility of antireflective coating

Disadvantages:

- silicon wafer thickness 30-70 µm required
- the quenching resistor acts like JFET
- ➔ 3-4× longer recovery times compared to conventional SiPMs

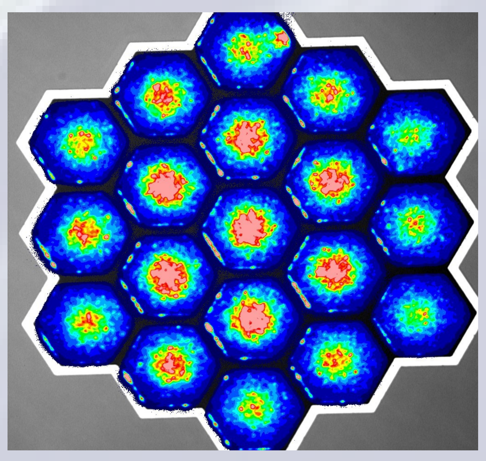
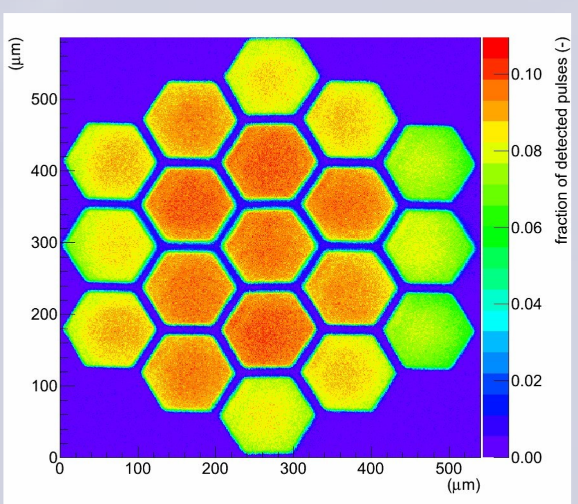


Photo-emission image of a SiMPl prototype.



Scan map of a SiMPl prototype.

Room temperature measurement is not the best option for these prototypes. This performance issue will be eliminated in the next production series.

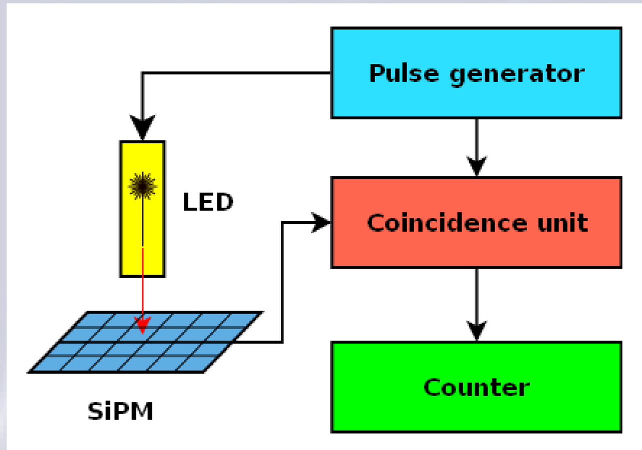
A talk about SiMPls: SiPM session, June 13, 2:20 PM.

A test setup for SiPM areal sensitivity scanning

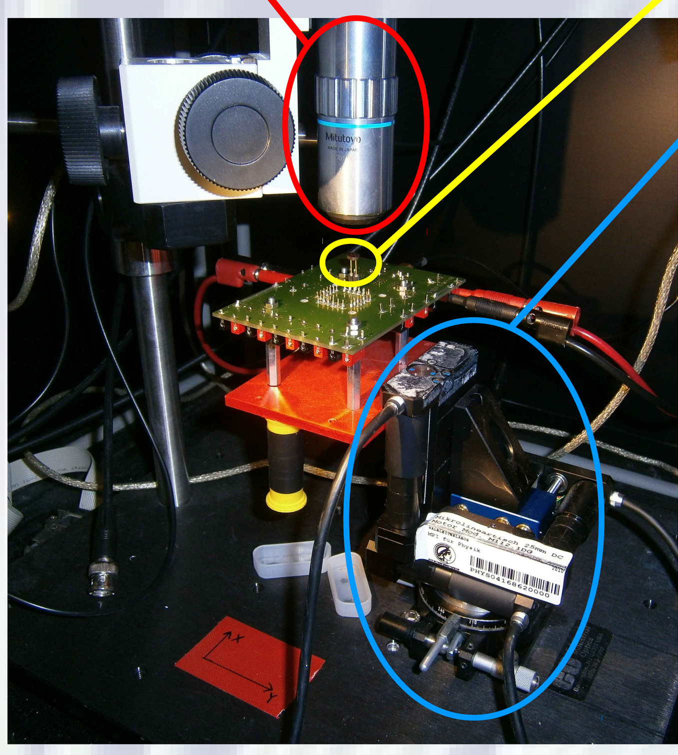
Measurement goal: high resolution sensitivity maps of SiPMs
➔ scanning of SiPM surface with highly focused pulsed light source

Measurement parameters:

- step size ~ 1 µm
- light spot diameter ~ 1 µm
- LED steering pulse length 10 ns
- number of shots per step 20 000
- scan time of a typical 1×1 mm^2 ~ 40 hours



Simplified block scheme of the setup.



SiPM sensitivity scan setup.

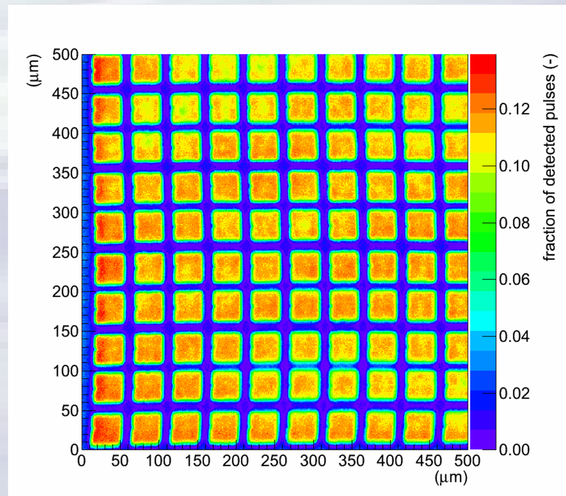
Measurement methodology:

- initial alignment of device using three reference points to ensure optimal focusing over full sensor surface
- scanning with 3D micropositioning stage in 1µm steps on SiPM surface
- two simultaneous measurements of SiPM response at two thresholds provide information on cross-talk

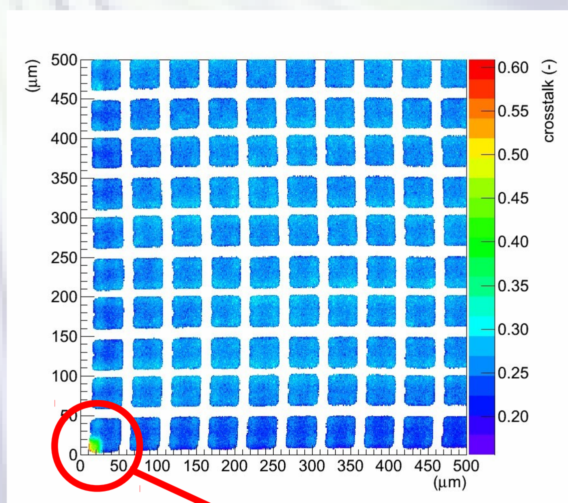
Study of a Hamamatsu MPPC

Hamamatsu MPPC (50 µm pitch):

- used in CALICE-T3B experiment to study the time structure of hadronic showers
- ➔ detailed investigation of properties of the device are of interest
- in addition to response properties, possible variations of these quantities with over-bias voltage were investigated



Relative PDE map recorded at discrimination threshold of 0.5 p.e.



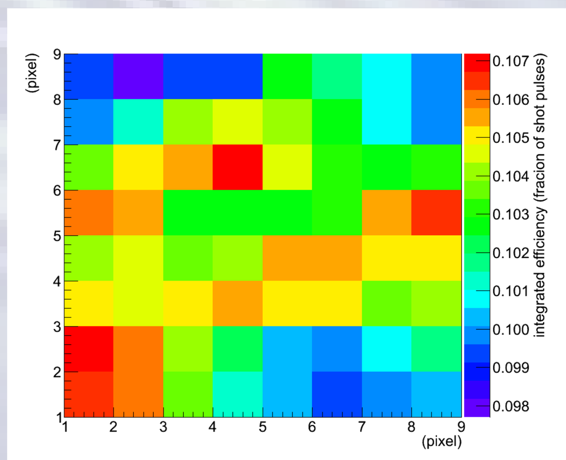
Crosstalk probability map.

Study results:

- detection efficiency patterns do not show significant voltage dependence
- geometrical fill-factor does not show significant voltage dependence
- edge breakdown observed, disappears with increasing over-bias voltage

Analysis of (integrated) efficiency and fill-factor of each pixel:

- study of homogeneity of device at microcell level



Integrated efficiency map. Each square represents one microcell.

Homogeneity fluctuations are characterized by:

- PDE spread between the most and least sensitive pixel
- spread of geometrical fill-factor between pixel with the largest and the smallest sensitive area

quantity	value
PDE spread	8%
Fill-factor spread	11%
Crosstalk probability*	18%
Geometrical fill-factor	55%

Study results.

* measured in a black box without any explicit illumination

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PhotoDet, Orsay, France, June 2012