Position sensitive SiPM detector for Cherenkov applications

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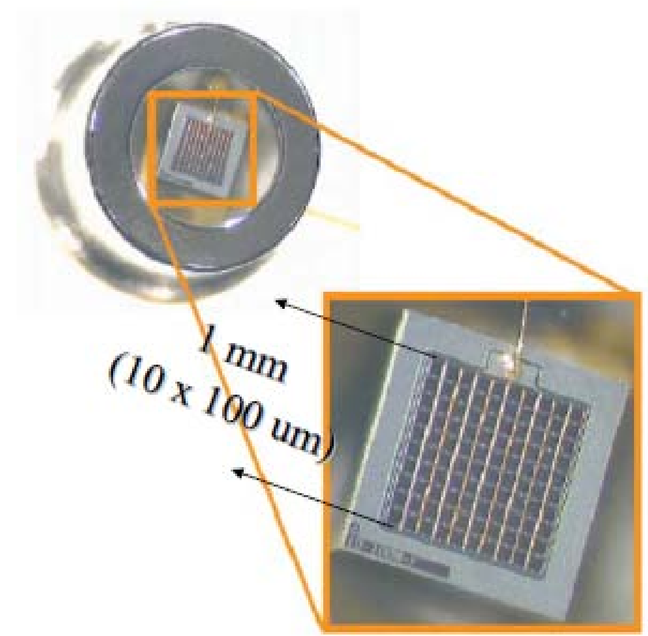
Silicon Photomultipliers (SiPMs)

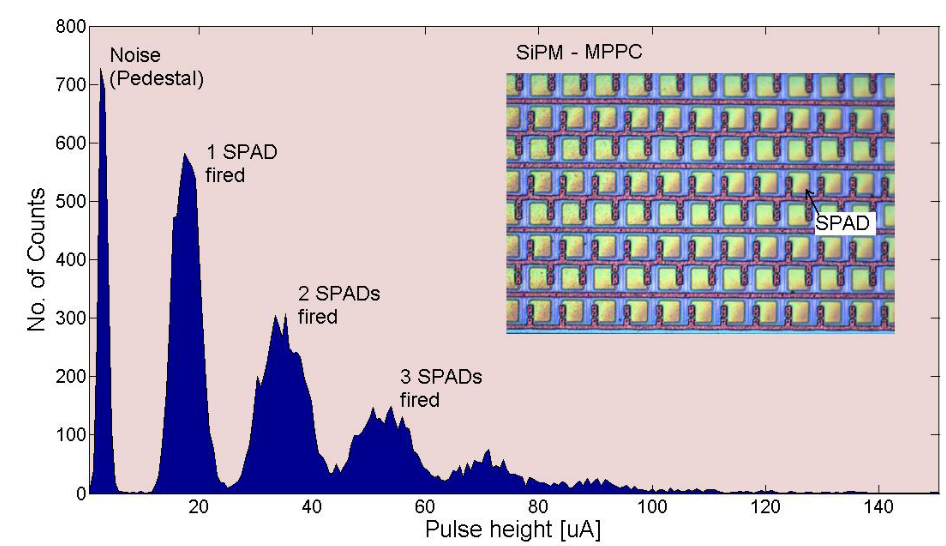
		PMT	MCP-PMT	SiPM
PDE	Blue	20%	20%	50%
	Green - Yellow	40%	40%	40%
	Red	≤ 6 %	6%	30%
Time precision		100 ps	≤ 100 ps	130 ps
Gain		10^6	10^6	10^5 - 10^6
Threshold sensitivity		1 p.e.	1 p.e.	1 p.e.
Dark count rate		Hz - kHz	Hz/cm²	MHz/cm²
Operation in magnetic fields		< 10^{-3} T	< 2 T	Yes
Operation voltage		1 kV	3 kV	< 100 V



Hamamatsu S10362-11-100U

- Other advantages:
  - low costs
  - low power consumption
  - compact size and robustness
  - excellent photon counting capability
  - long life time

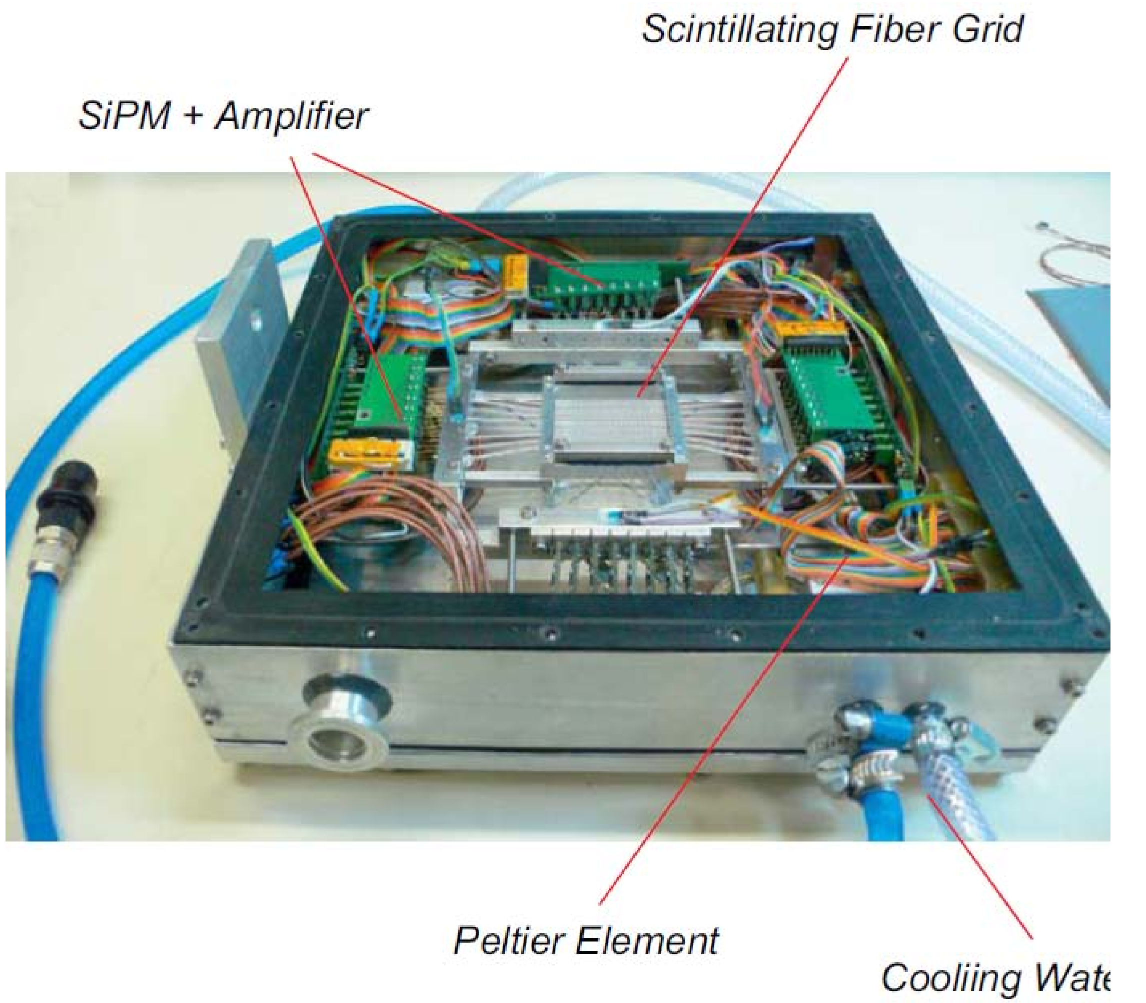
photon counting with SiPMs



Applications of SiPMs at SMI

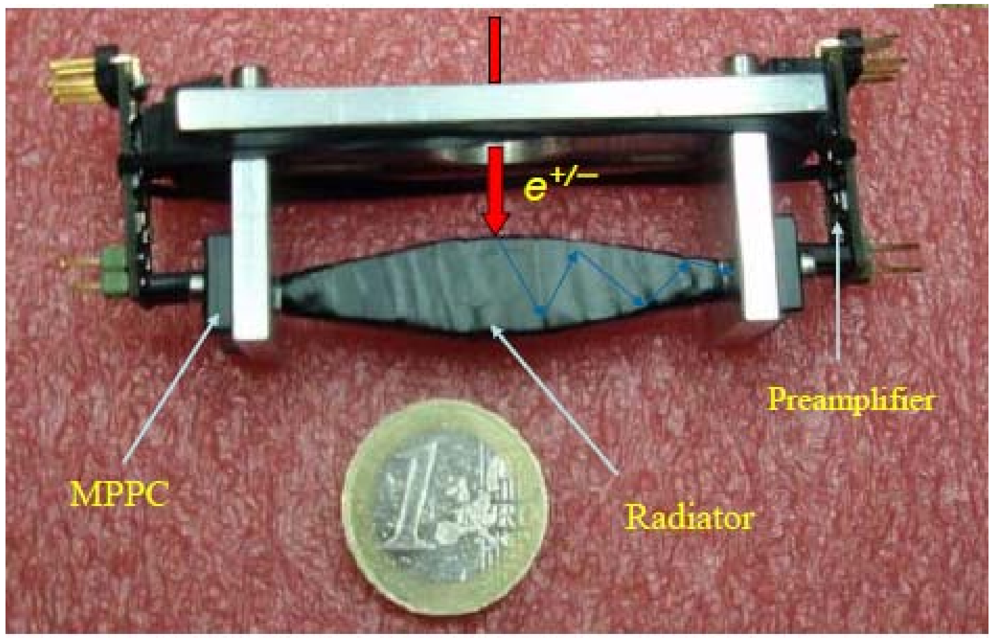
- Scintillating fiber detector
  beam profile monitor for FOPI

K. Suzuki et al., NIMA 610 (2009) 75



- Timing Cherenkov detector

G.S.M Ahmed et al., NIMA628 (2011) 393



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Position sensitive photo detector

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- We are developing a position sensitive photo detector based on an array of SiPMs which can be used as a photon counter in various applications.
- The readout of promptly emitted Cherenkov light with fast responding SiPMs is a promising option for TOF applications.
- Alternative to position sensitive Photomultipliers like Multi-Anode type MCP-PMTs
- Advantages:
  - fast response
  - high photon detection efficiency
  - compact size
  - low costs
  - insensitivity to magnetic fields
  - long life time
- Applications:
  - RICH and DIRC detectors (e.g. PANDA)
  - medical applications

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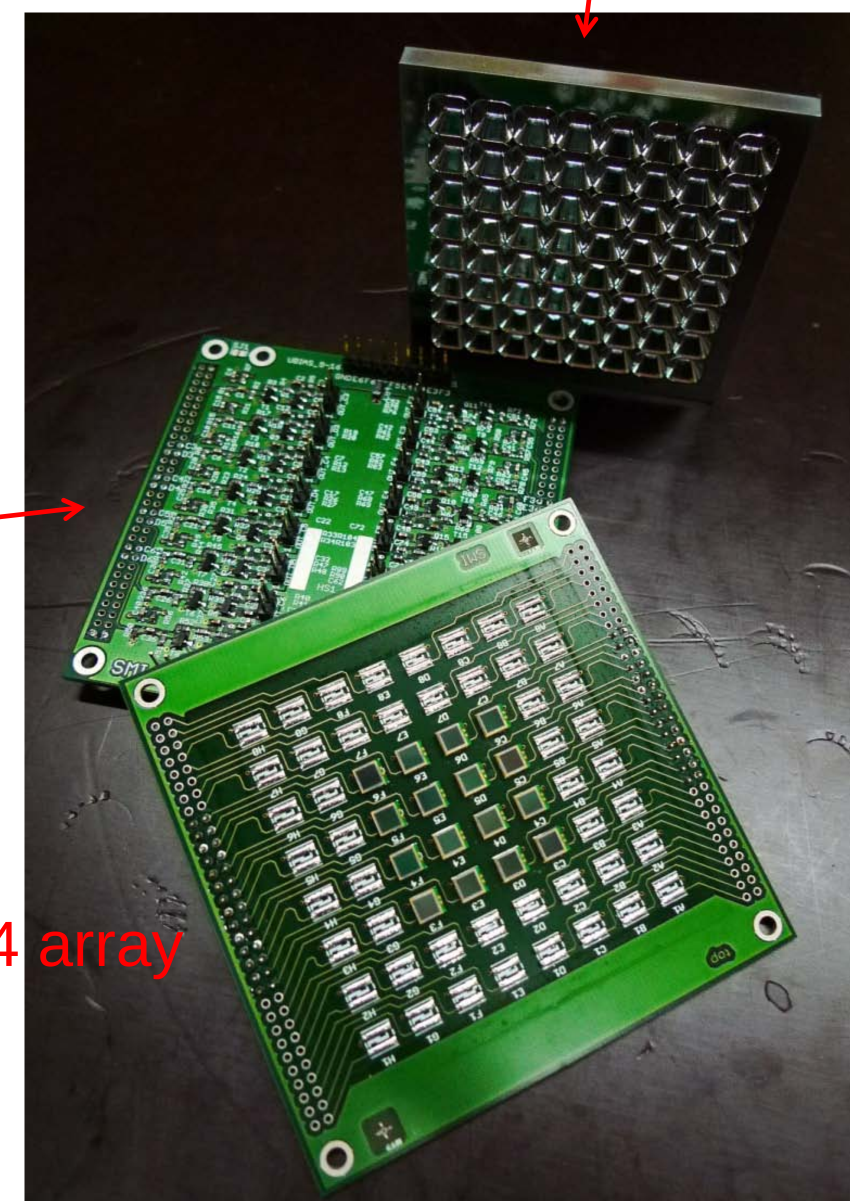
SiPM module

- The prototype photo detector consists of 64 3x3 mm² Hamamatsu SiPMs (MPPC S10931-100P) arranged in a 8x8 array with suitable light guides on top.

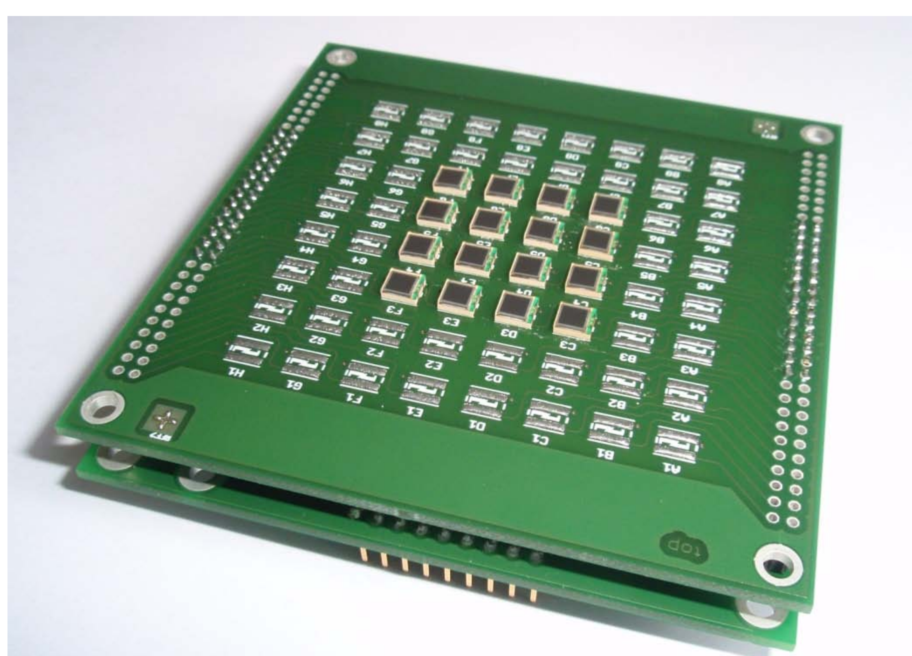
- Each detector is readout separately
  → 64 readout channels

- First, an array of 4x4 SiPMs is tested.

- The photo sensors are readout by a 16 channel preamplifier board.



4x4 array



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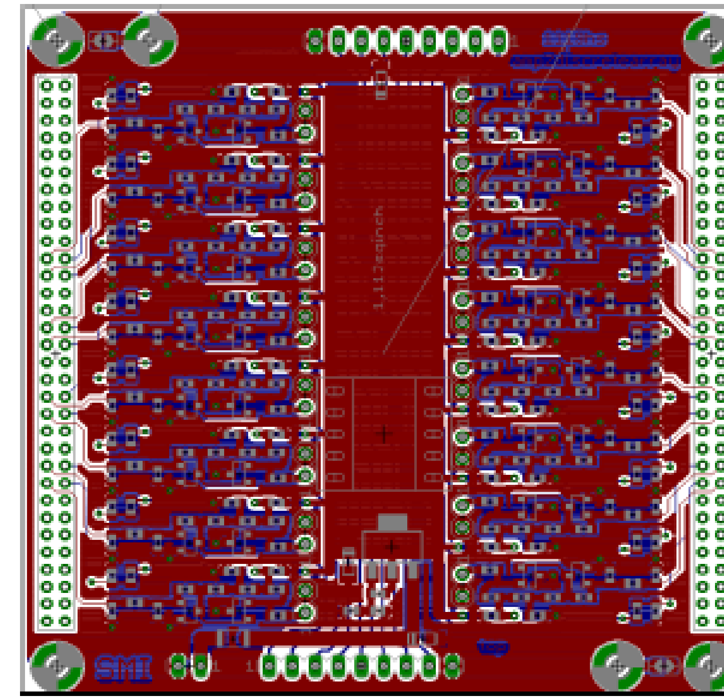
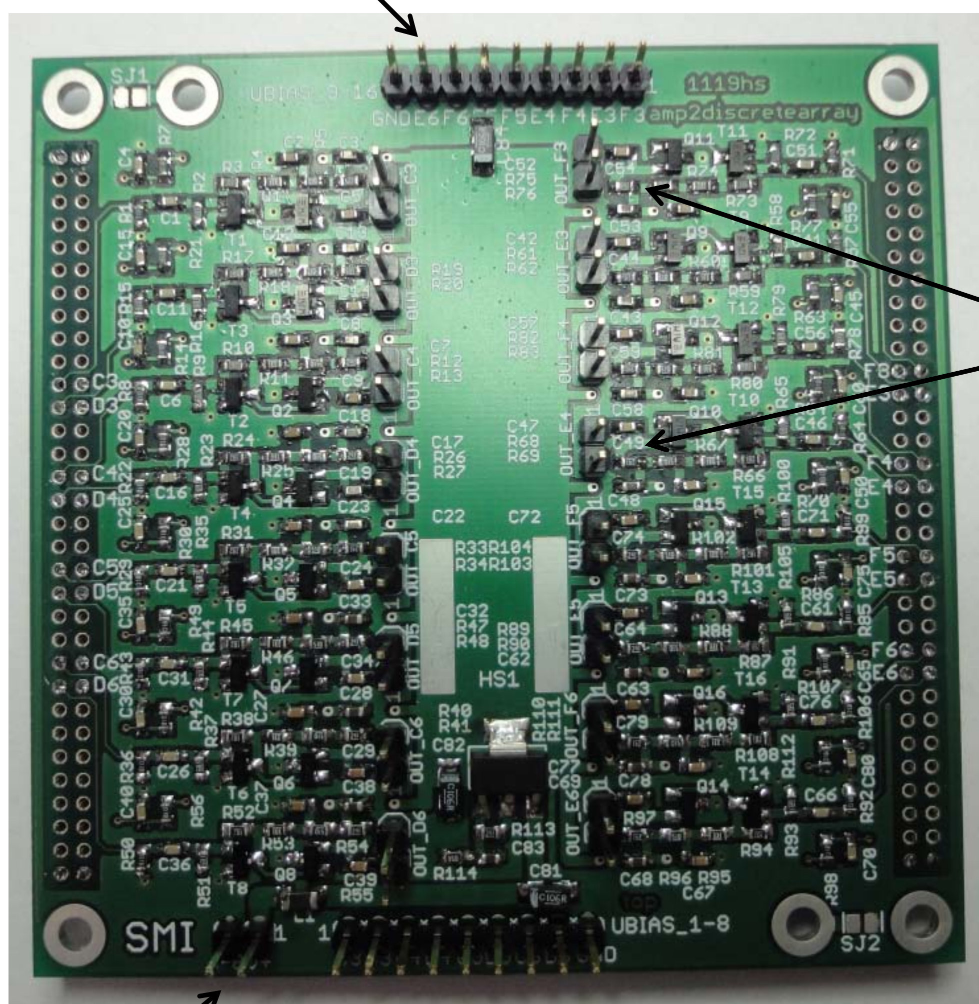
16 channel Preamplifier board

- The SiPM module is readout by a 16 channel preamplifier board, developed at SMI



SiPM bias



Signal out

Preamp supply

The preamplifier is basically a copy of Photonique AMP_0611

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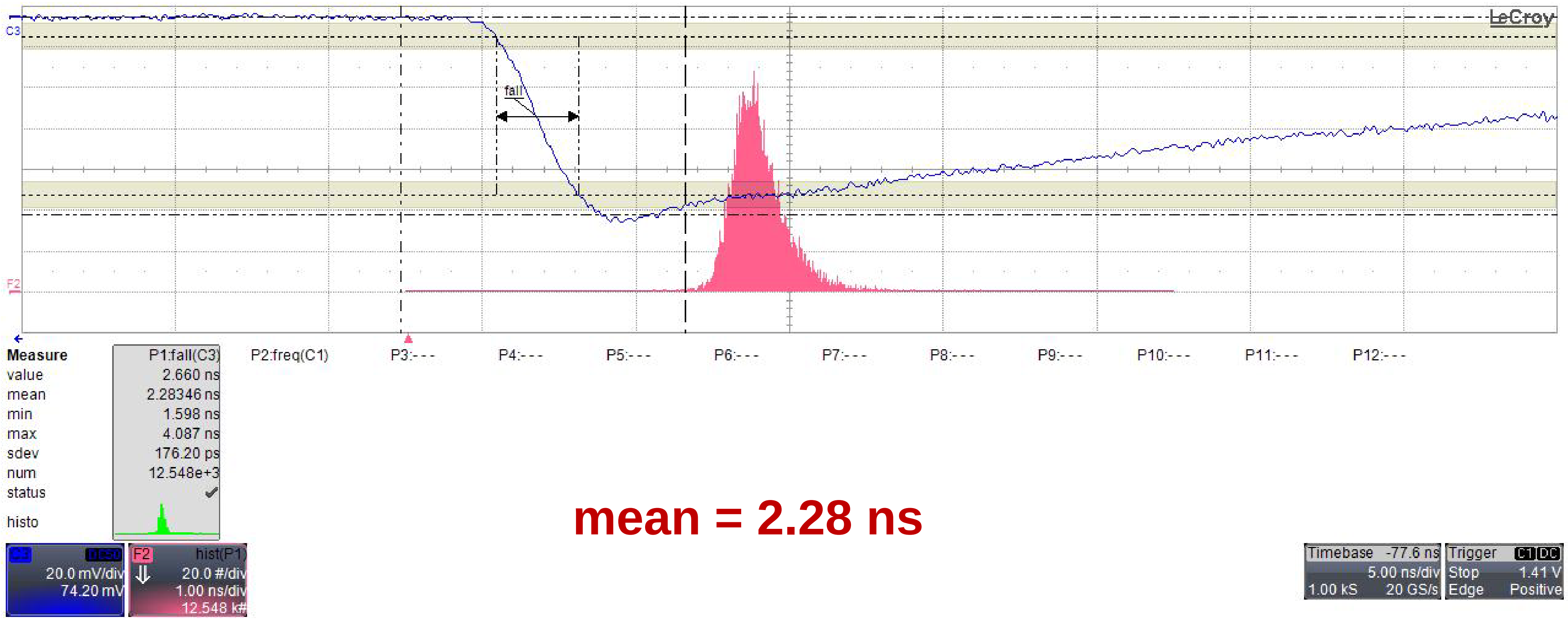
Preamplifier board

Rise time and gain

- Rise time



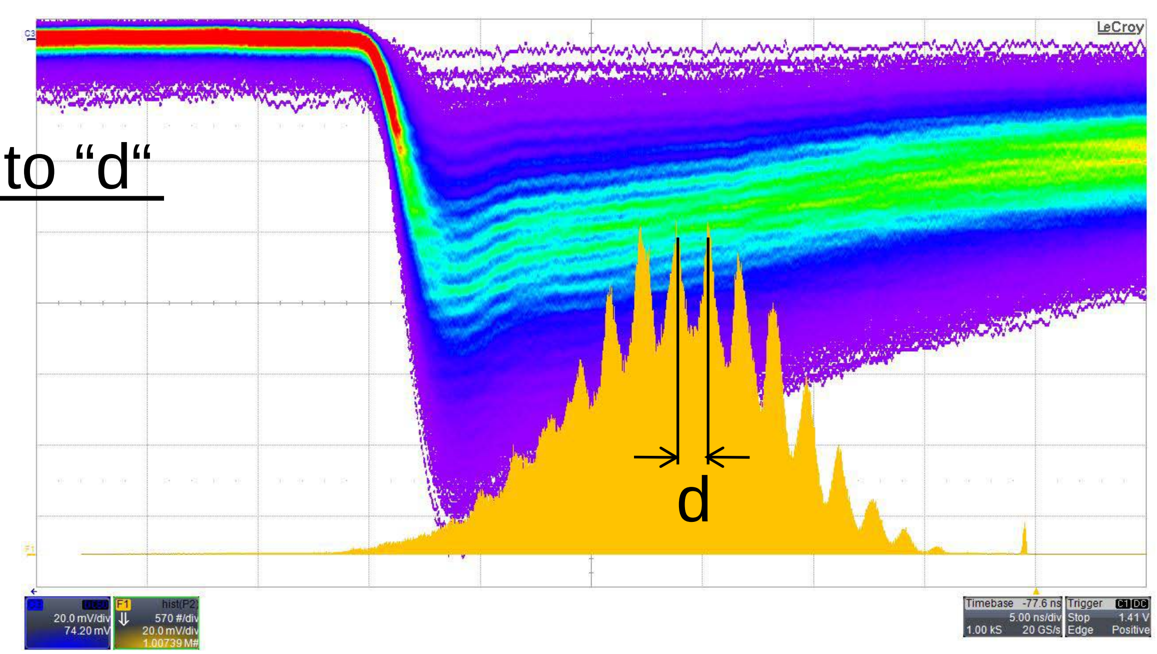
mean = 2.28 ns

- Gain

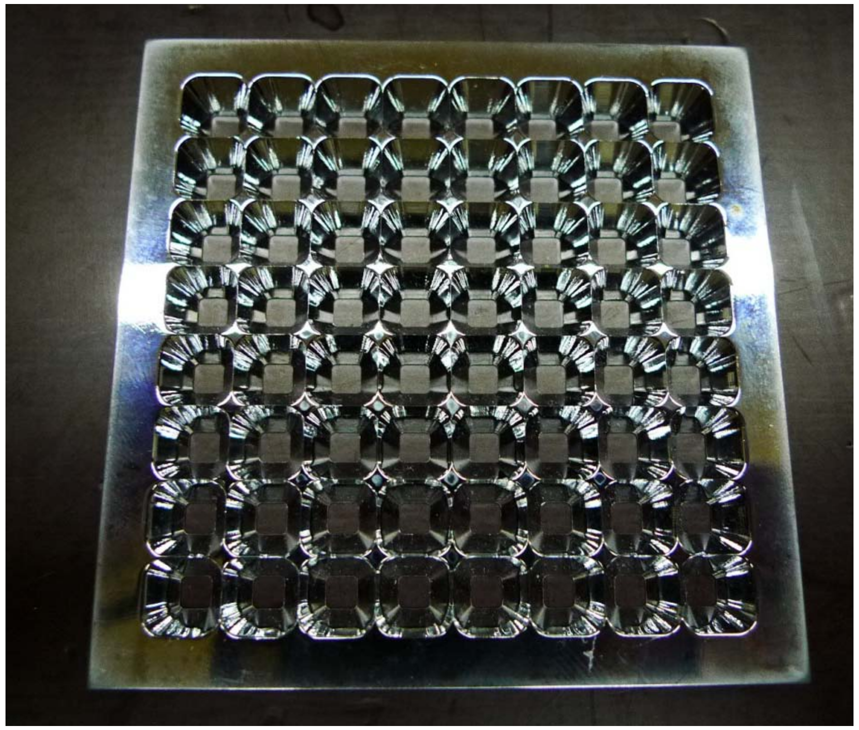
$$\text{Gain} = \frac{\text{Charge corresponding to “d“}}{\text{electron charge}}$$

$\sim 12 \times 10^6$

→ gain (preamp) ~ 5



Light concentrator

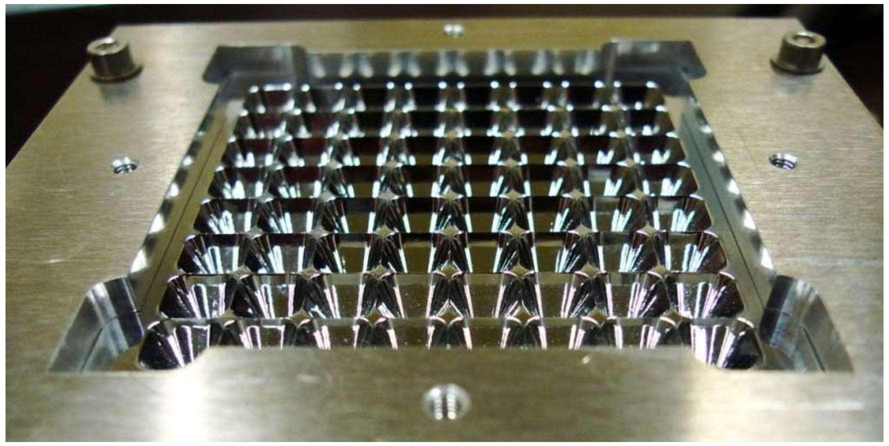


- An array of suitable light guides placed on top of the detectors leads to
  → increased geometric acceptance
  → increased signal to noise ratio
  (dark count not affected by light guides)

- The light concentrator is made out of brass, the funnels were produced by electro-erosion. Then the plate has been chrome-plated.

- It consists of 64 regularly arranged pyramid-shaped funnels with round edges and has been designed to be used with an array of 3x3 mm² SiPMs.

- The dimensions are:
  Total: 65 mm x 65 mm x 4.5 mm
  Entrance window: 7 mm x 7 mm
  Exit aperture: 3 mm x 3mm



- Simple geometry, robust, easy to fabricate

Light concentrator performance

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Monte Carlo Studies

- In order to estimate the collection efficiency ε_{col} of the light concentrator and to study its dependence on the funnel length and incident angle Monte Carlo simulations were carried out.

$$\epsilon_{col} = \frac{n_d/N_{phot}}{(3/7)^2}$$

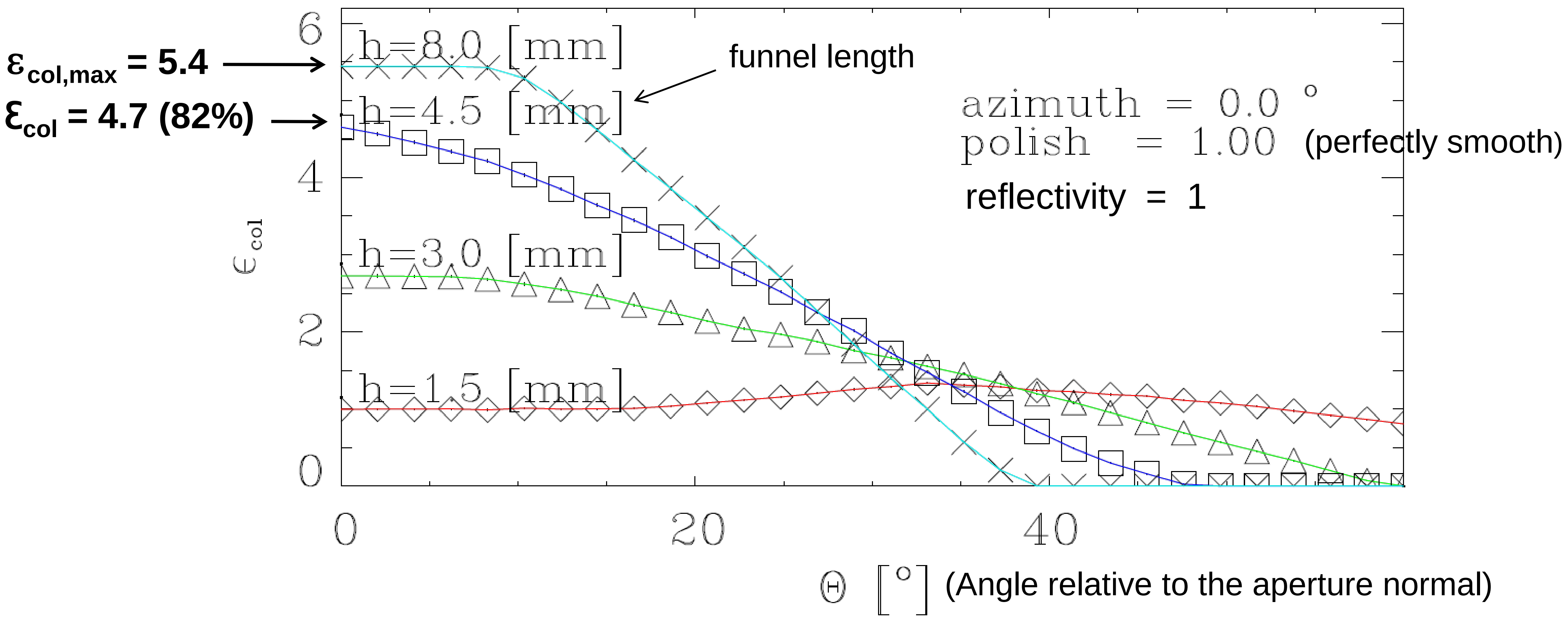
n_d ………. number of photons reaching the exit window
N_{phot} .... total number of photons hitting the light guide

$\varepsilon_{col,max}$ (N_{phot} = n_d) = $(7/3)^2$ ~ 5.4 (100% efficiency)

Measurements

- In order to study the performance and properties of the light concentrator and the SiPM array several measurements are done. In a first step, the array is scanned with a small laser spot.

Efficiency simulations

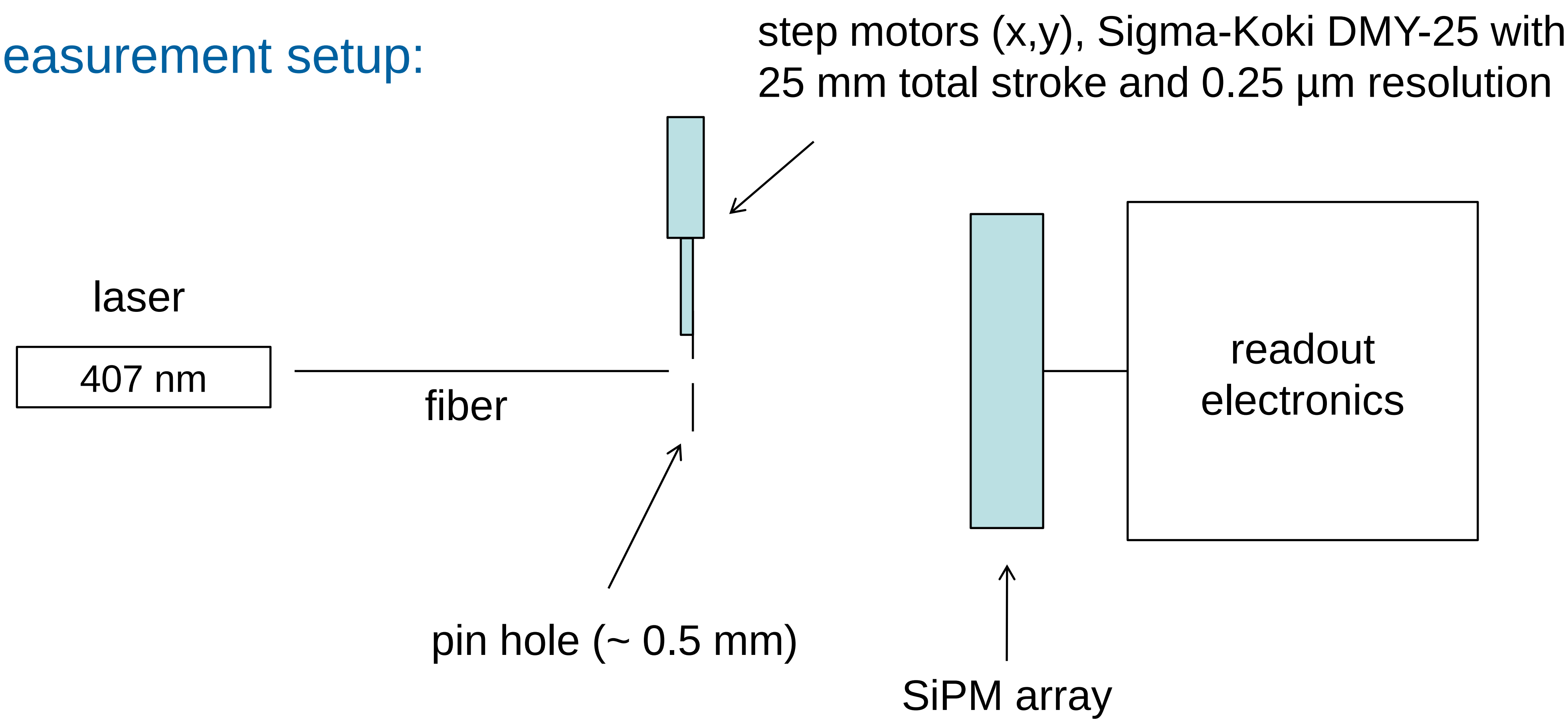


- It was decided to go to h = 4.5 mm funnel length
- At a reflection coefficient of 0.55 and for a reasonable surface roughness (polish < 1), we find an average light collection efficiency of 2.8 (52%) for 4.5 mm funnel length and Θ = 0°.

G.S.M Ahmed et al., NIMA (2010) , submitted, arXiv:1008.5266v1

Efficiency measurements

- Measurement setup:



- The measurements were done inside a dark box
- Laser light was coupled into an optical fiber as a first collimator (single mode, 3.2 µm core diameter, angular acceptance ± 7°)
- We used an additional pin hole collimator to restrict the angle further
- The fiber and collimator can be moved in 2 dimensions in order to scan the light concentrator
- The distance between fiber and detector is ~ 15 mm
- The beam diameter at the detector is ~ 1 mm
- The setup was kept at a stable temperature of 15°C

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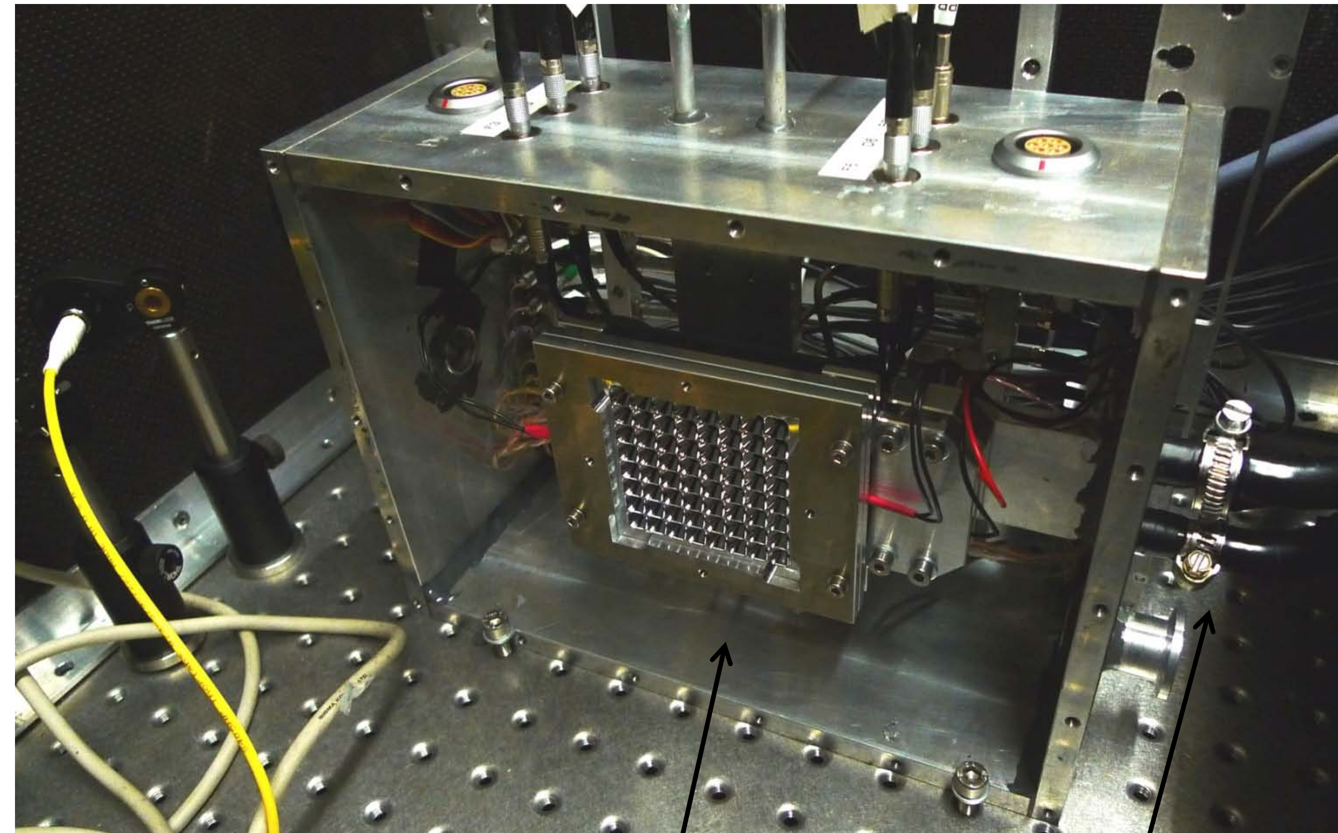
Measurement setup

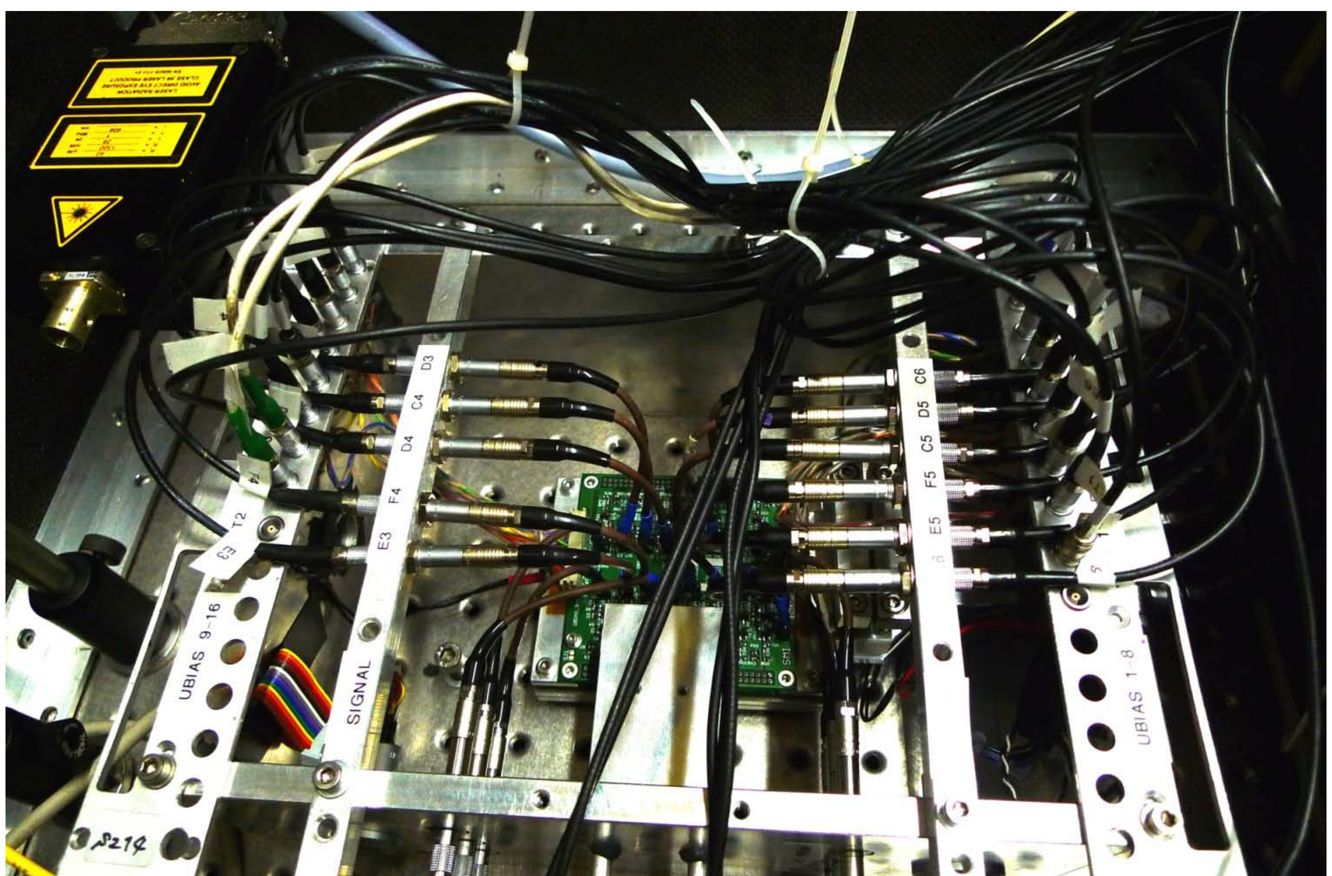


optical fiber (moved outside)

laser

SiPM array

water cooling



backside view

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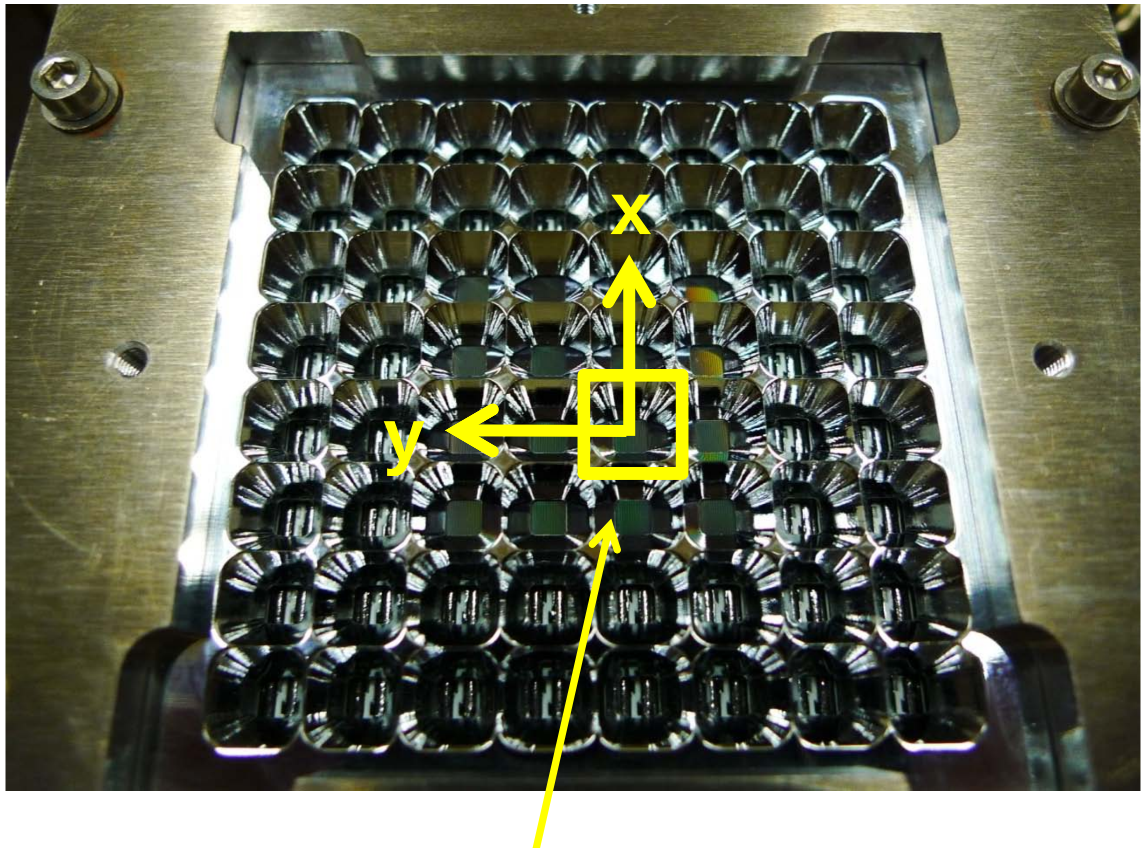
Measurements

1st step



- As a starting point we scanned one cell of the SiPM array in x and y direction.
- The size of the laser beam was approx. 1 mm. The incident angle Θ (angle relative to the aperture normal) is 0°.
- We scanned a total area of 8x8 mm² in steps of 500 µm.
- We measured the average light intensity for each pixel.
- The results are compared with the simulations.

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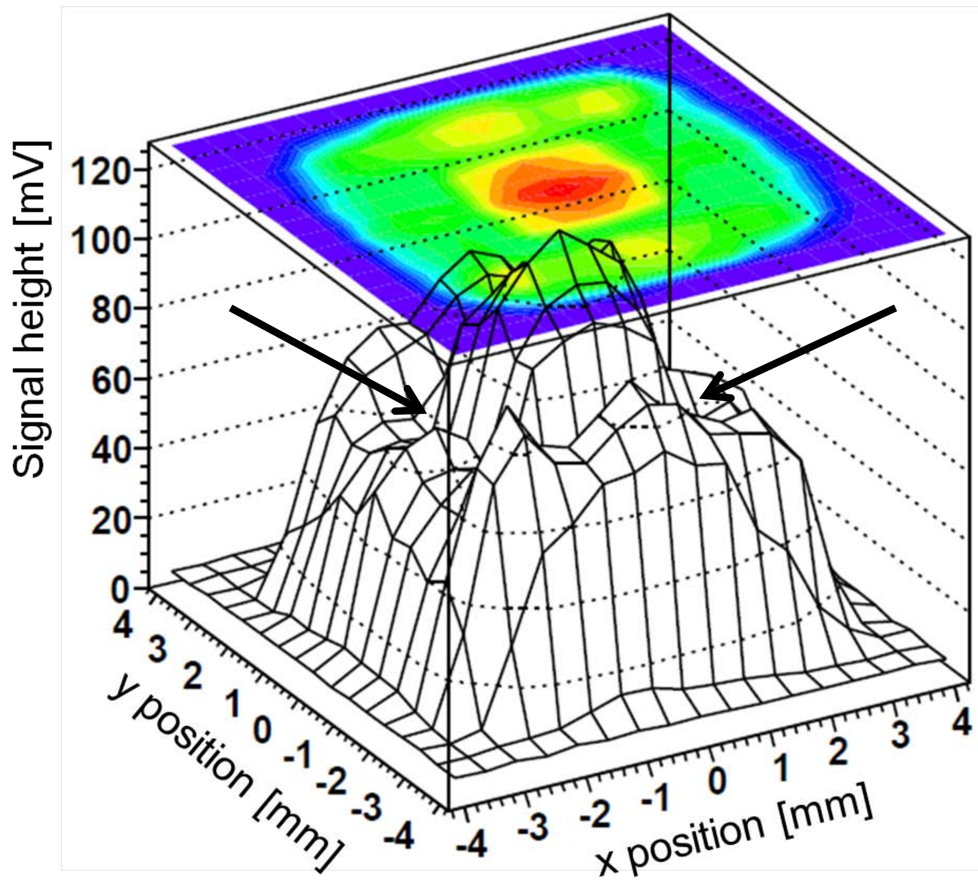
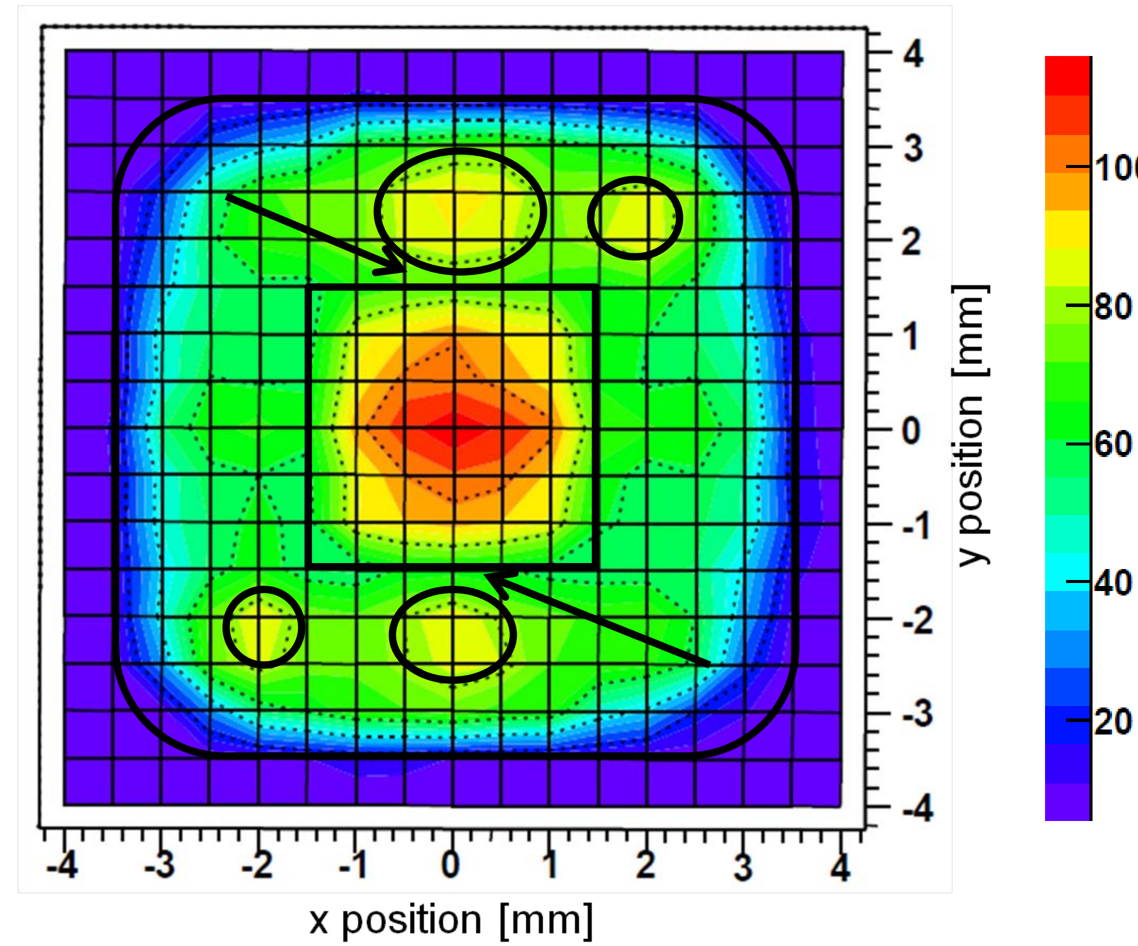
Results

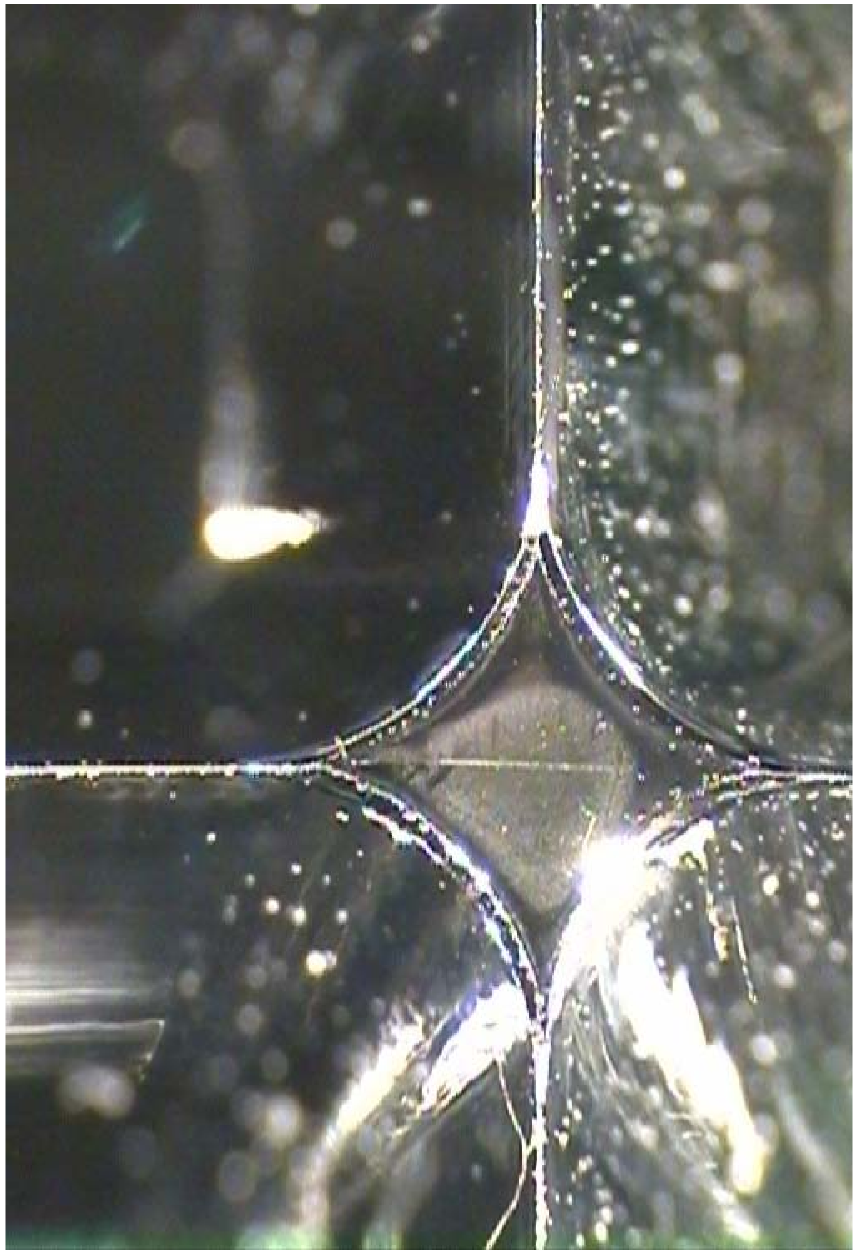


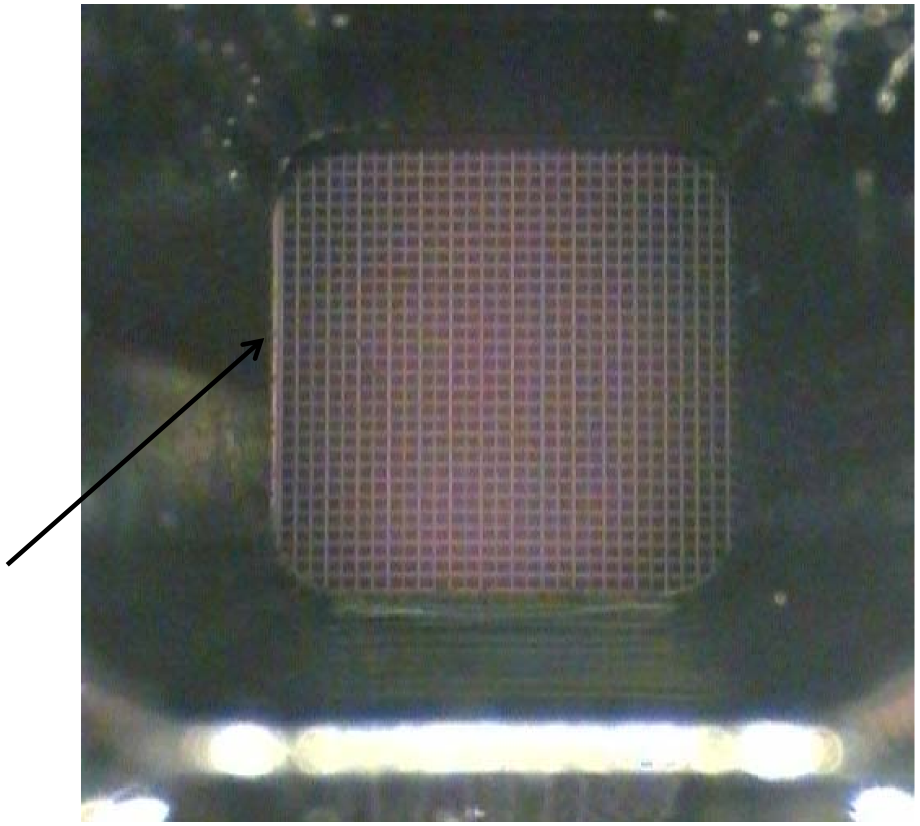


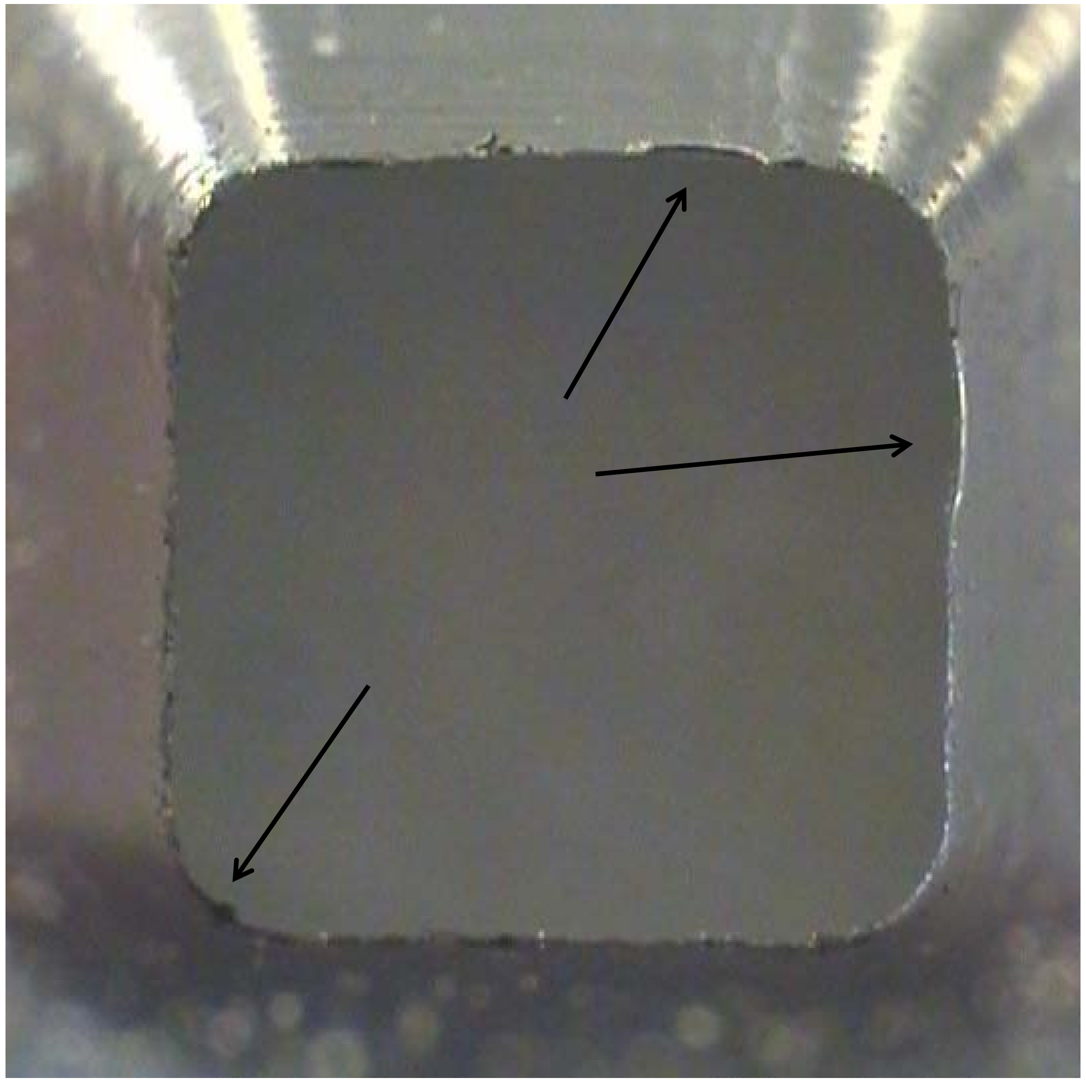
- The light concentrator is working very well
- It clearly increases the acceptance
- One can clearly identify the dimensions of light concentrator and SiPM

- There are some "hot spots": fabrication, inhomogeneous surface quality
- Inefficient bands at the edge of the funnel (transitions from light concentrator to SiPM), not expected, confirmed optically with microscope
- No real plateau in the center: beam size
- More measurements are necessary

Some pictures







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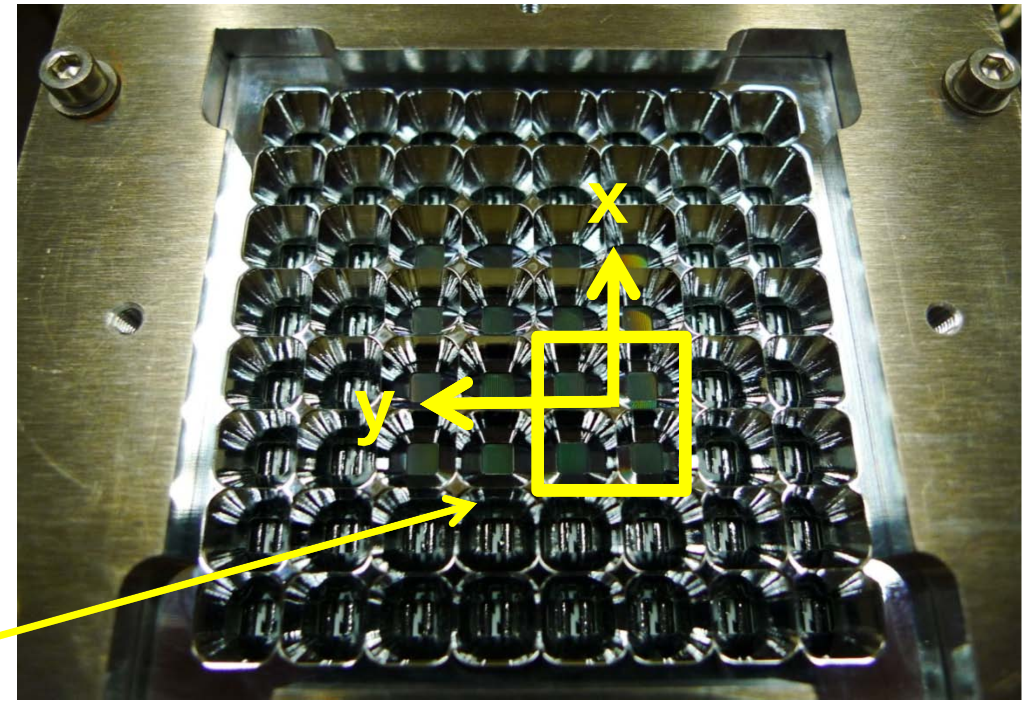
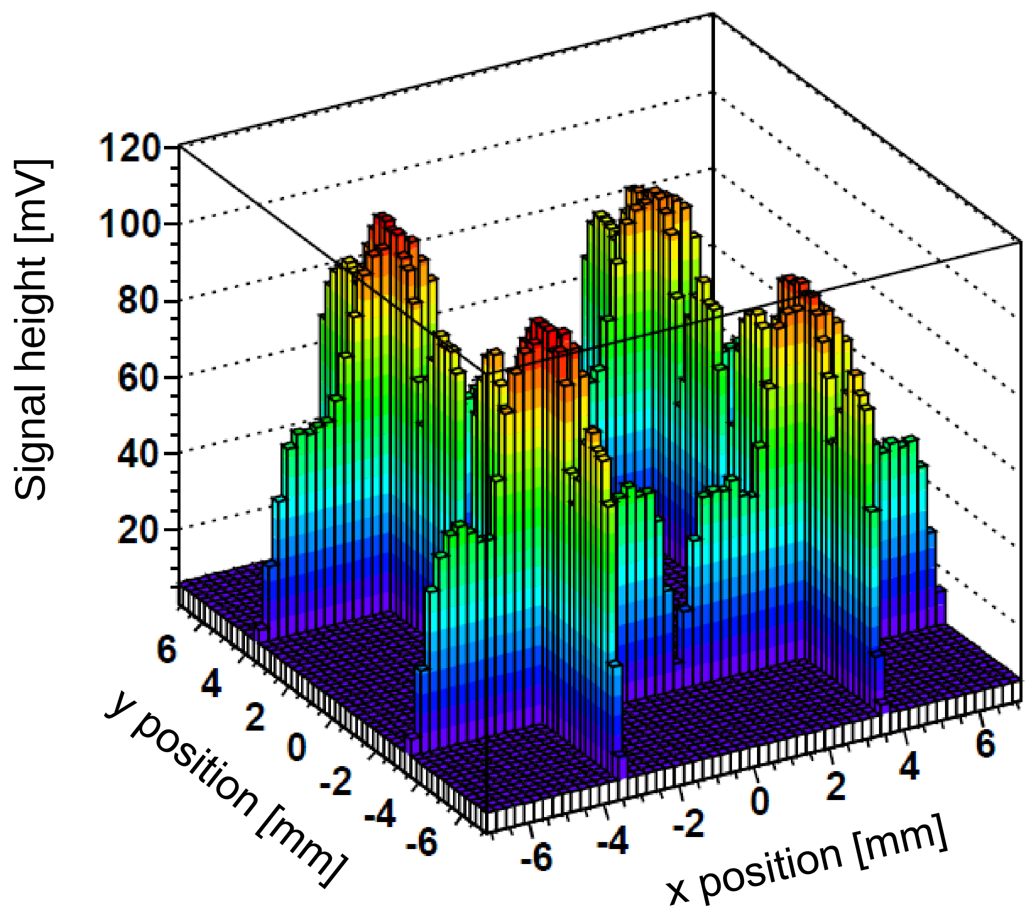
Measurements

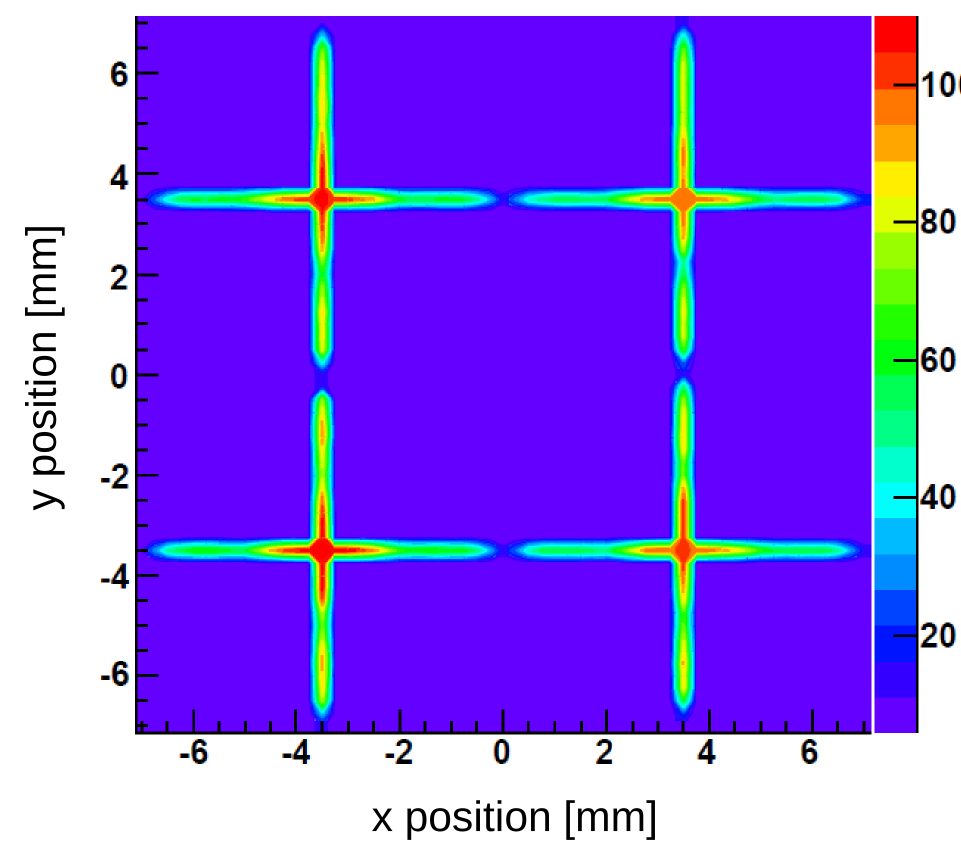
2nd step



- As a next step, we measured other cells to check if they behave in a similar way.

- We scanned four neighboring cells in x and y direction at fixed y and x positions and measured the average signal heights.





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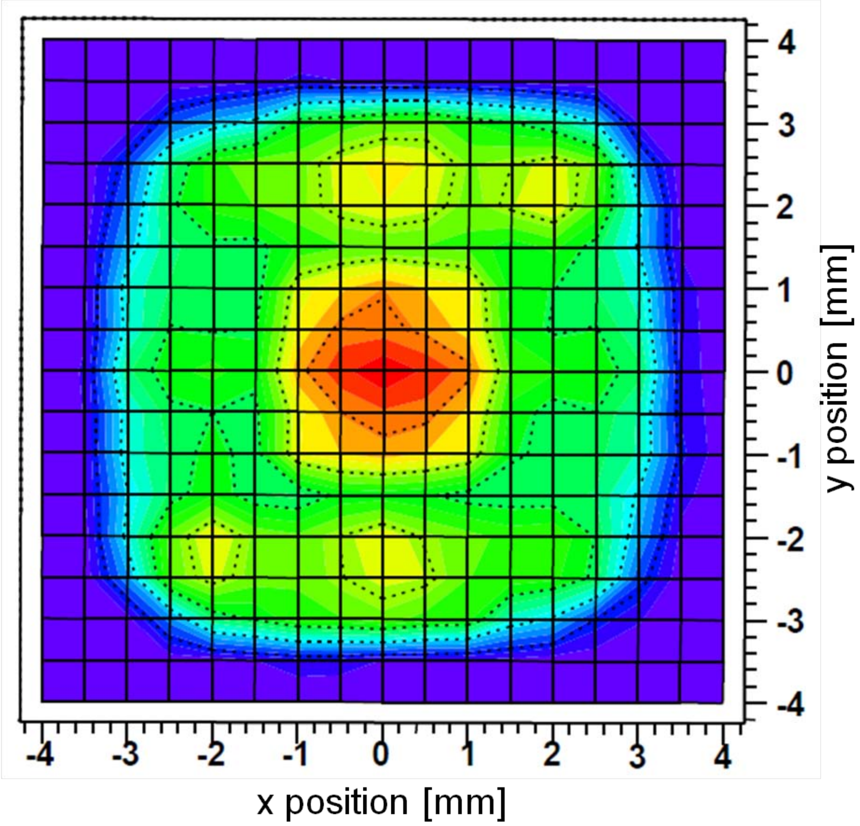
Conclusions from measurements

- Basically the SiPM array is working very well
- The light concentrator is behaving more or less as expected

- Explanations for unexpected behavior:
  - no plateau: beam size (1 mm)
  - "hot spots": fabrication defects, inhomogeneous surface, oval beam profile (asymmetry of "hot spots")
  - minima at transitions: defects, oxidation or dust at the edges, no perfect matching between light guide and SiPM, incident angles not exactly 0°

- Comparison with simulations:
  From the measurements we find an average light collection efficiency of 3.1 (57%), which is in very good agreement with the simulated value of 2.8 (52%).
  This is a first and rough estimation but shows that the light concentrator is working very well.



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Summary

- A prototype of a position sensitive photo detector with SiPM readout has been built and tested.
- The detector module consists of an array of 4x4 SiPMs (Hamamatsu 3x3 mm^2), an array of suitable light guides (light concentrator) and an in-house built 16 channel preamplifier board.
- First measurements showed that the prototype detector is working very well. The light concentrator clearly increases the acceptance of the detector.
- The light concentrator itself partly shows inhomogeneous behavior due to fabrication defects and inhomogeneous surface quality.
- It was shown that the measurements are in good agreement with the simulations.

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Next steps

- Scan the whole 4x4 array to see if all channels are behaving in a similar way
- Better collimation of the laser light → better resolution
- Study the behavior for different incident angles
- Aluminum coated light concentrator → better performance expected
- Go to an array of 8x8 SiPMs → 64 channels
- Use existing ASIC chips for readout
- Test beam measurements in GSI (June) and CERN (July)