Studies of Scintillator Tile Geometries for direct SiPM Readout of Imaging Calorimeters

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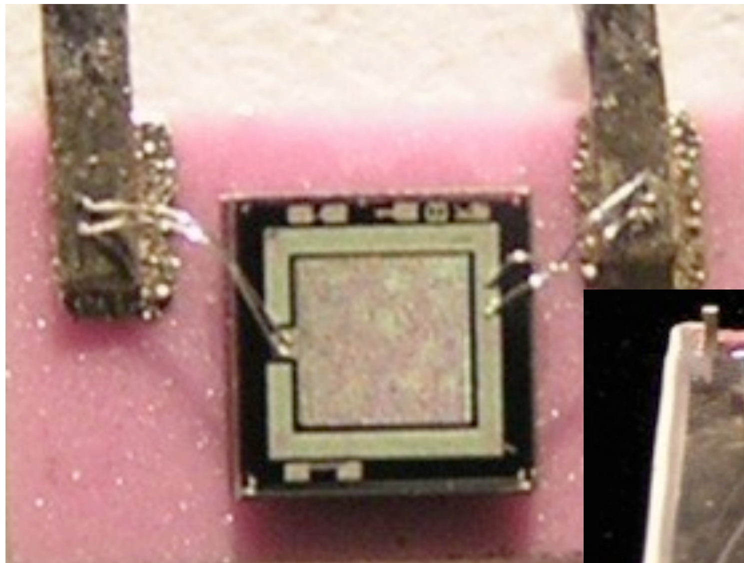
CALICE
Calorimeter for ILC

TUM
LMU
Excellence Cluster
Universe

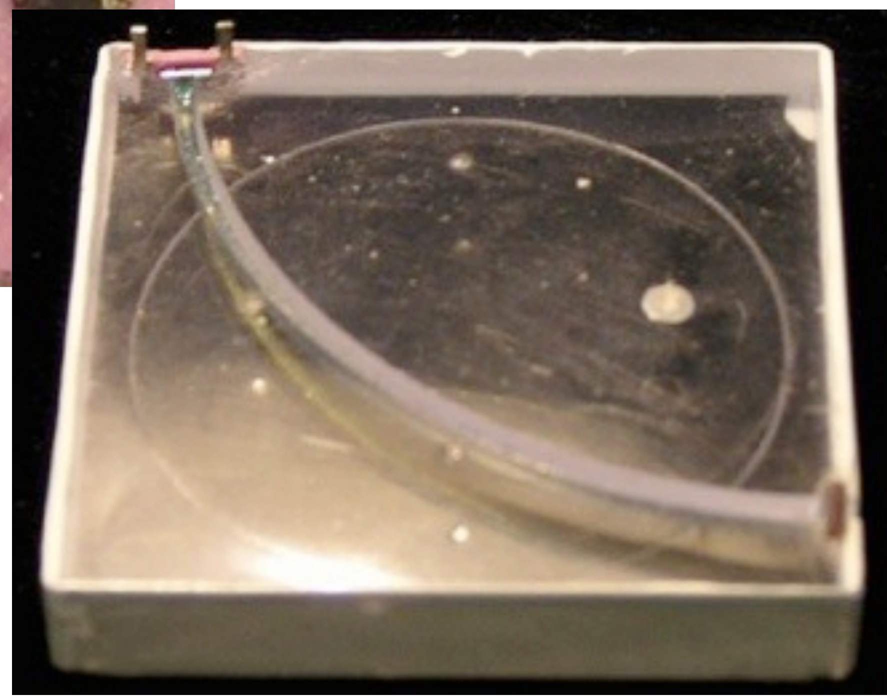
Outline

- The Analog HCAL Physics Prototype
- Scintillator Tiles for the 2nd Generation Prototype
- Direct Coupling of SiPMs to Scintillator Tiles
  - Geometry Variations
  - Molded Scintillator
- Summary

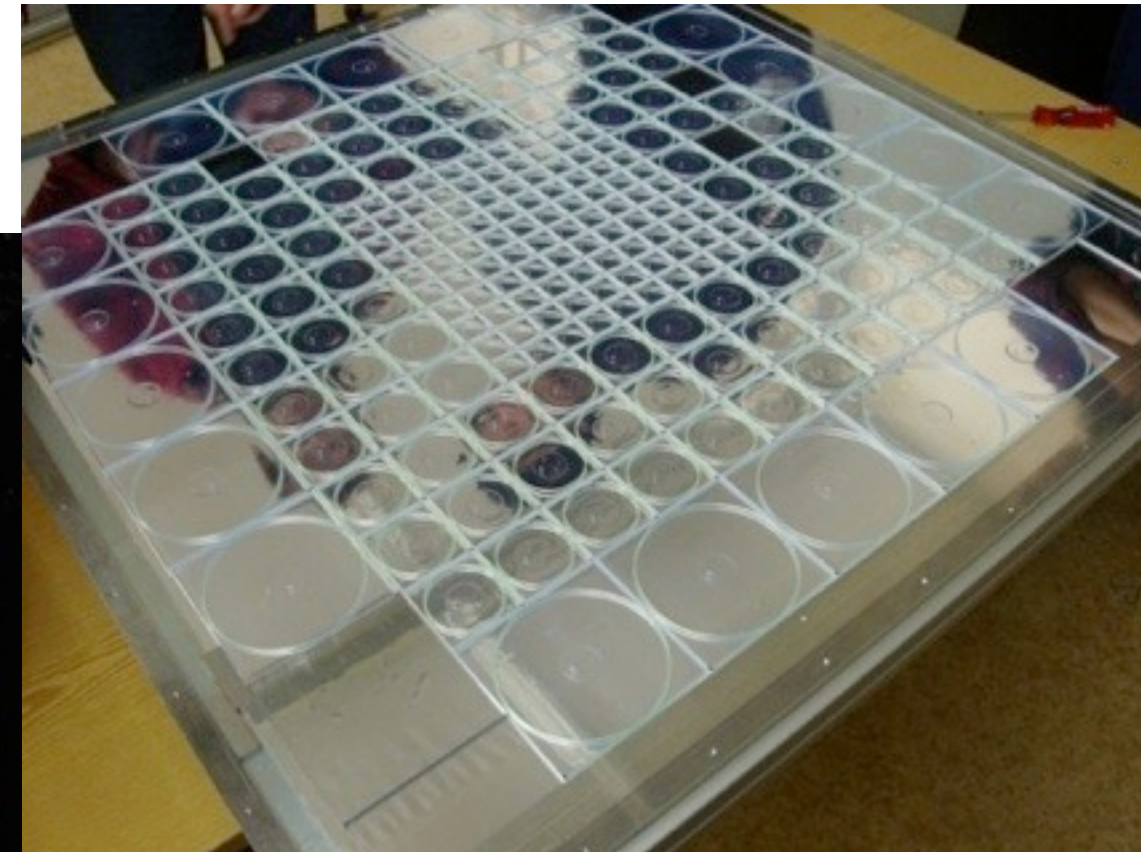
The Analog HCAL Physics Prototype



SiPM



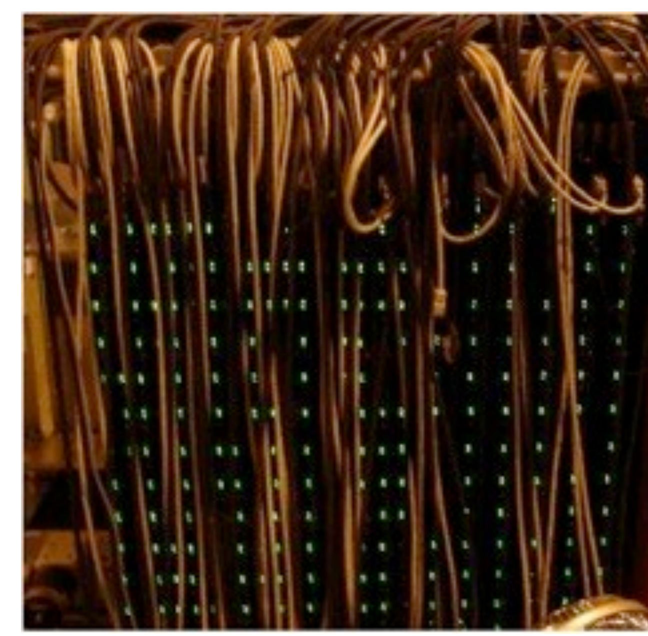
3 x 3 cm^2 plastic scintillator tile with embedded WLS fiber



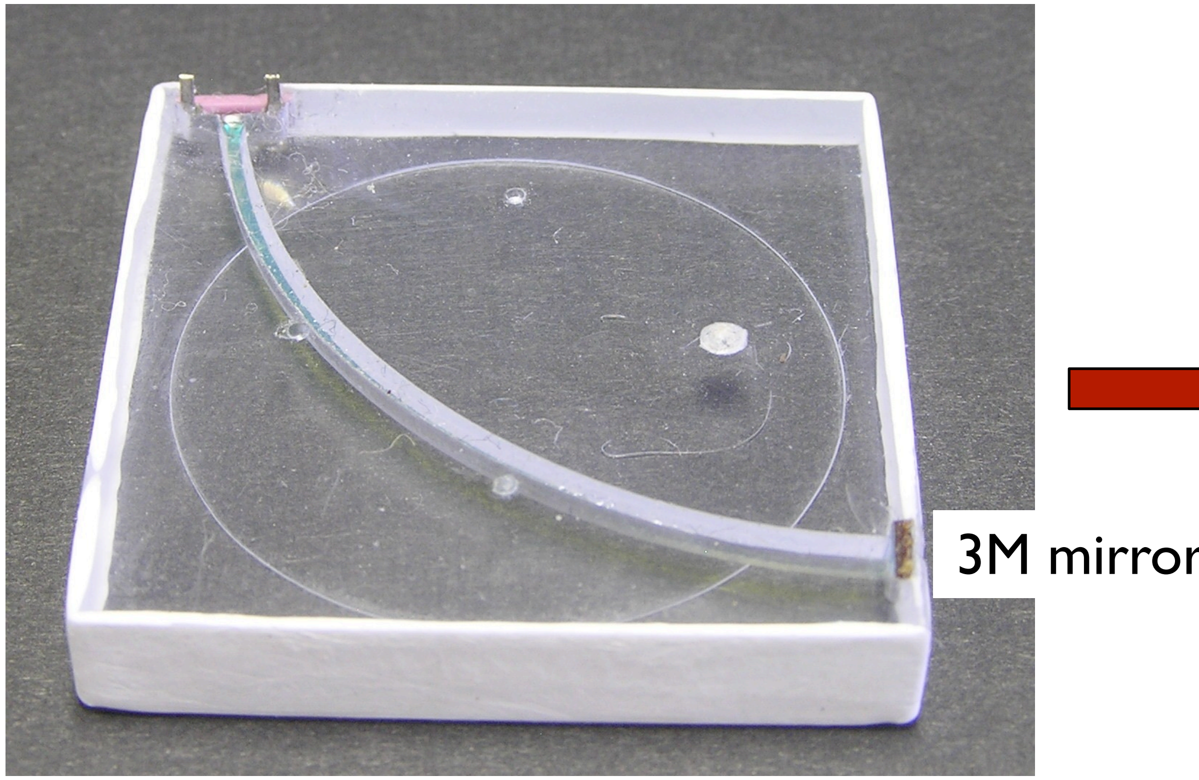
Calorimeter layer: 212 tiles, varying size

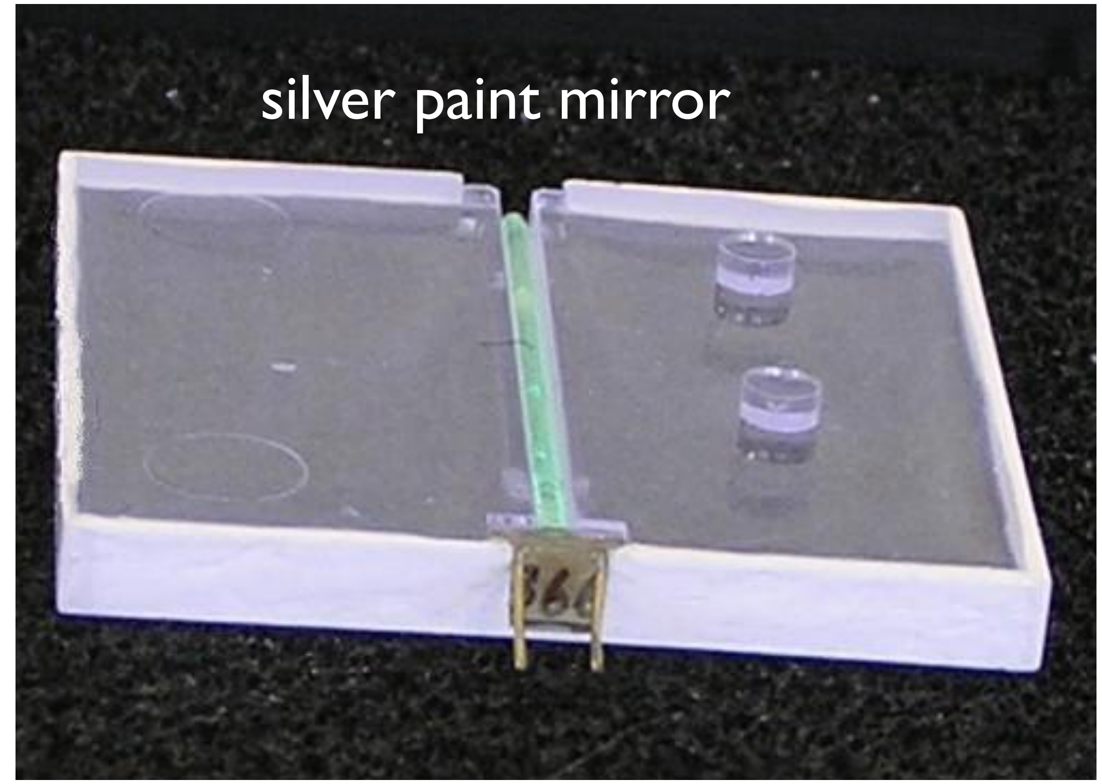
- Successful operation in various test beams since 2006

Analog HCAL:
38 layers
7608 channels total



Scintillator Tiles & SiPMs for the 2nd Generation

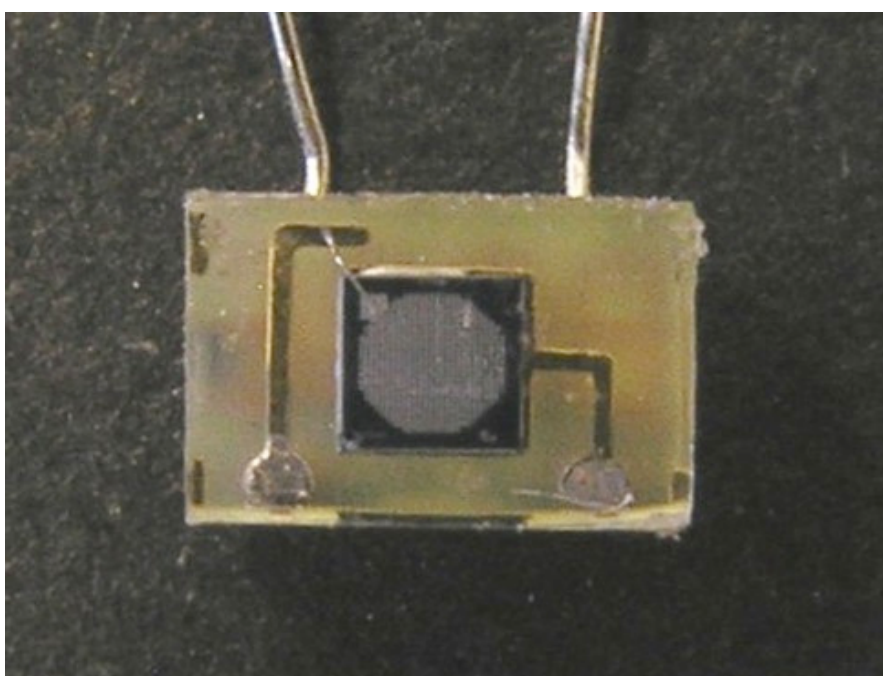




5 mm thickness

3 mm thickness

“Lego” alignment pins



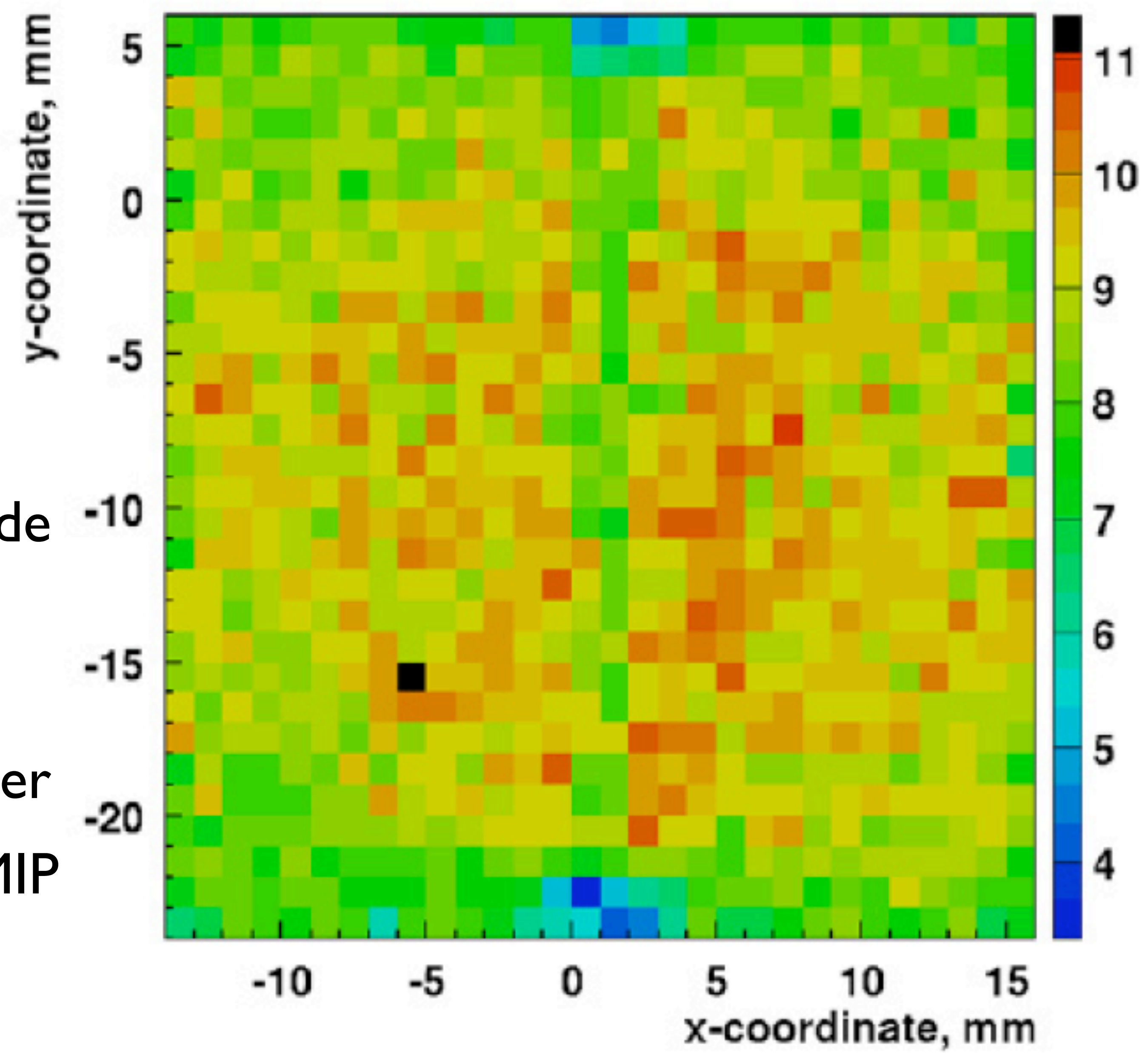
- Improved SiPMs: 556 pixels, now moving to 796 pixels, active area adapted to fiber coupling
- Tile can be cut without design changes: Different layer sizes can easily be accomodated

New Tiles: Uniformity of Response

- Moderate requirement on uniformity:
  - Large number of cells in any given hadronic shower reduces influence of non-uniformity on energy resolution
  - Strong non-uniformities compromise calibration with MIPs

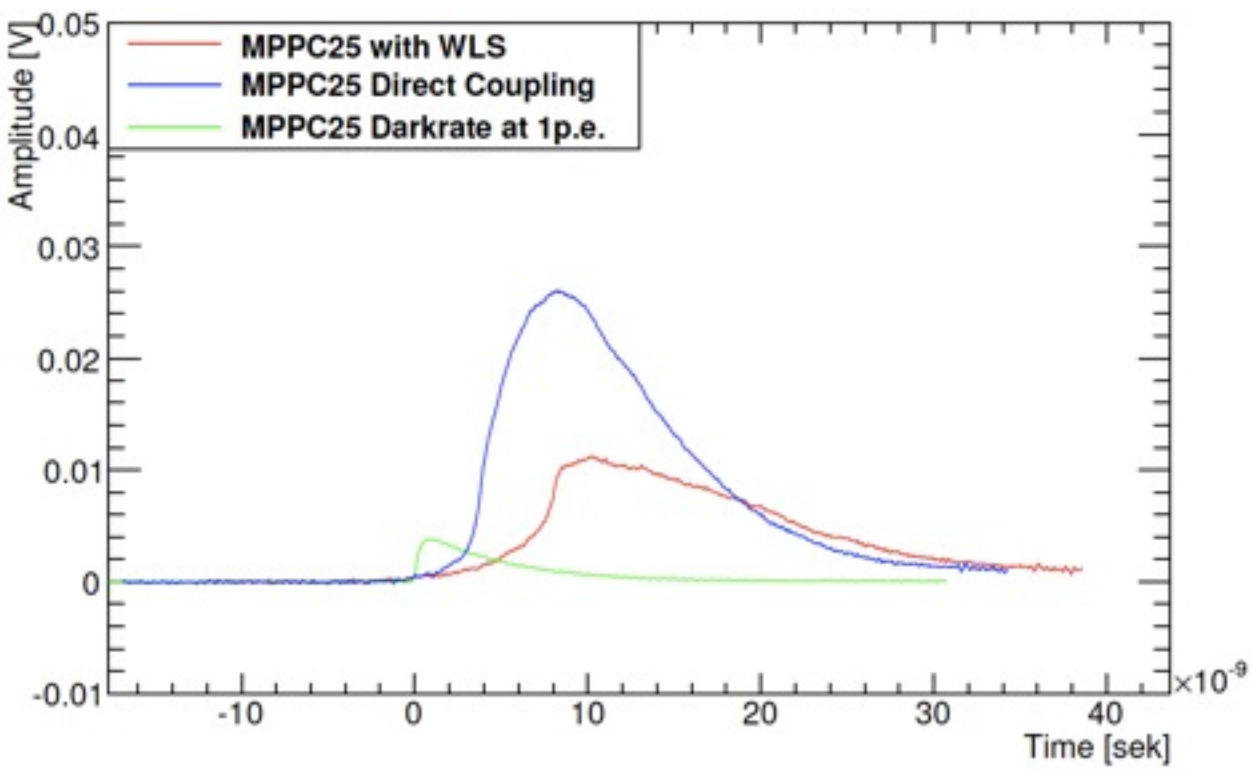
- New scintillator tiles with WLS fiber provide very good uniformity and completely adequate signal amplitude
  - ~ 20% signal loss in the region of the fiber
  - Tiles will be operated at about 10 p.e./MIP to provide large dynamic range and an efficiency of ~96% at 0.4 MIP threshold

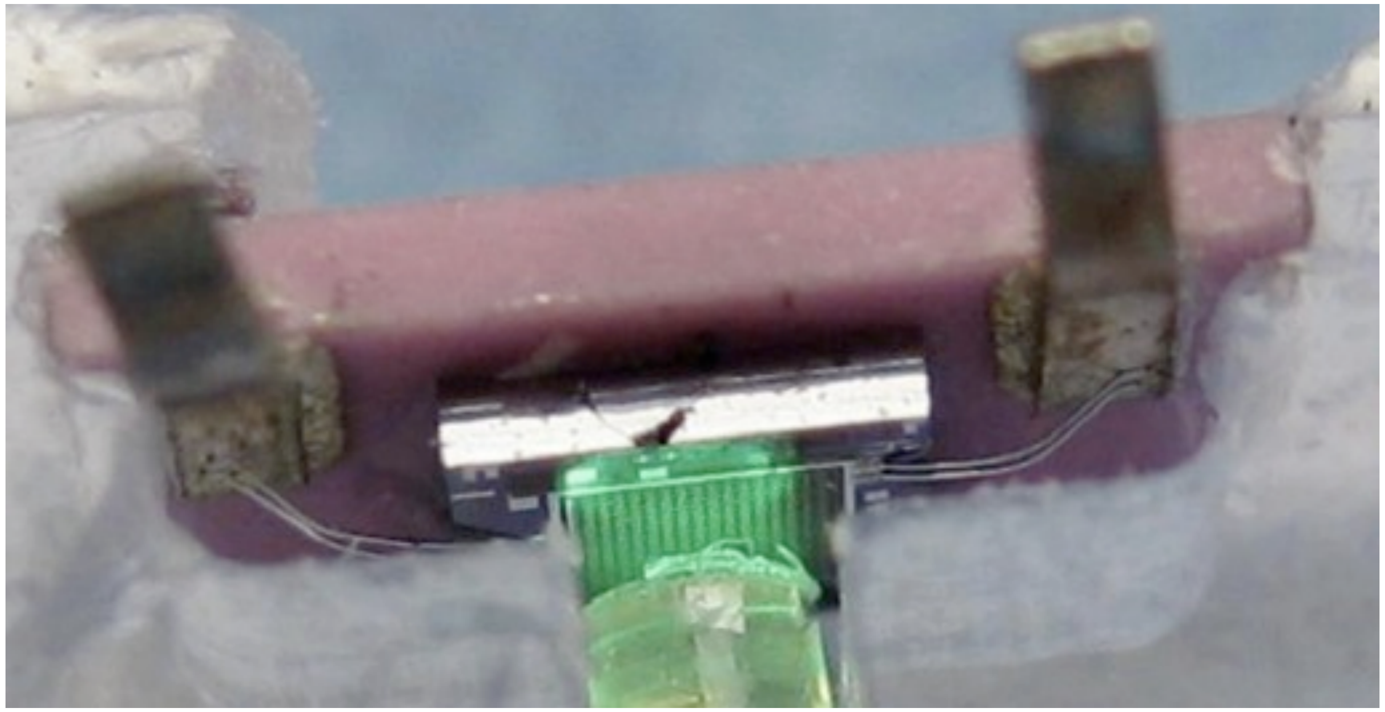
Measurement performed with protons from ITEP synchroton



New Developments: Direct Coupling of SiPMs to Tiles

- Modern SiPMs are blue sensitive: Well matched to emission spectrum of scintillator
  - WLS fiber not necessary for wavelength matching
  - Simplification of scintillator tile production, relaxed mechanical tolerances for SiPM installation and alignment
  - Faster response: No additional time constant from WLS

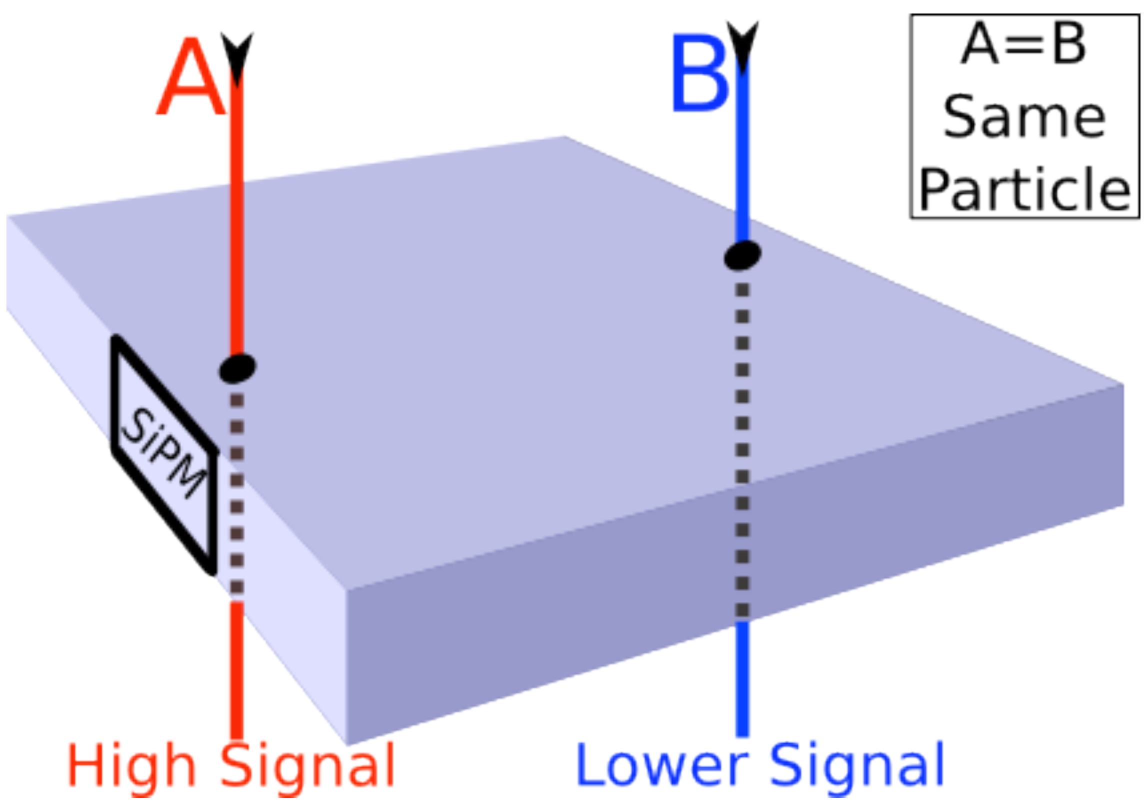


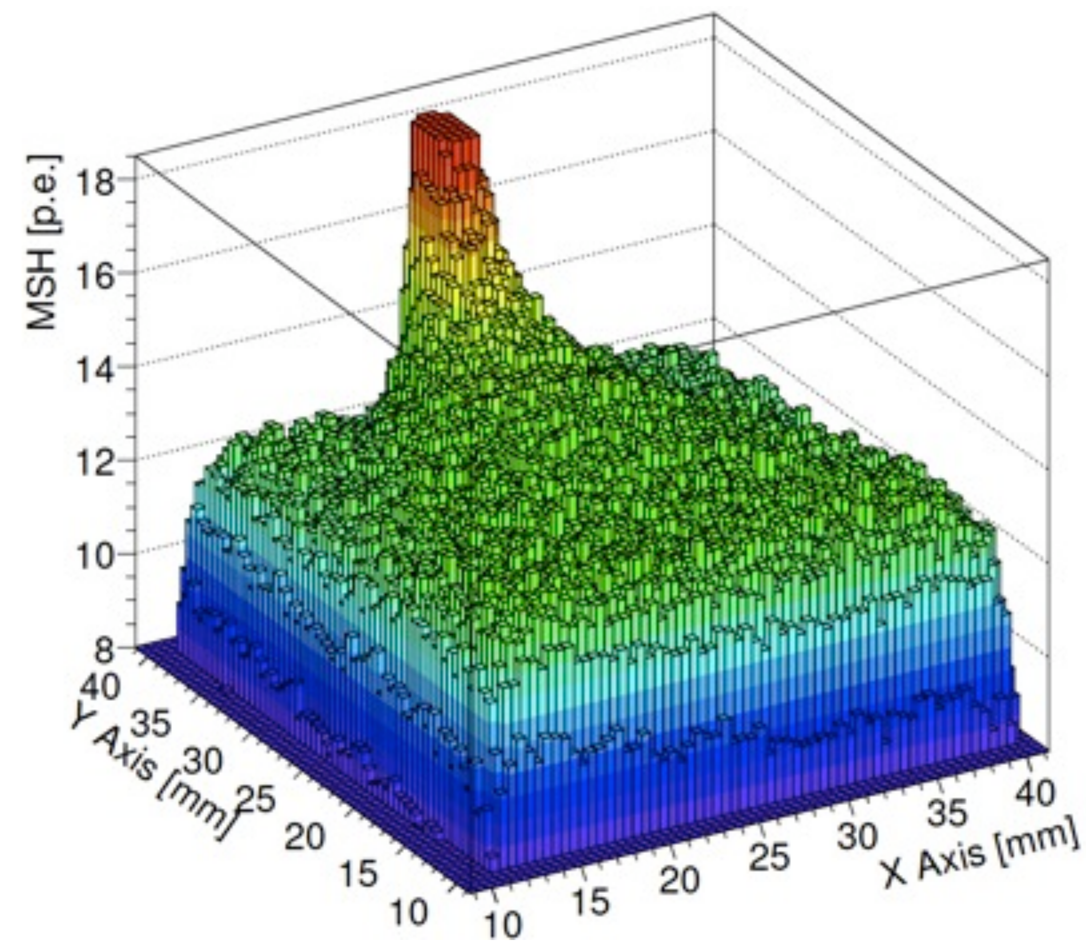


Direct Coupling: Drawbacks

- A WLS fiber helps to improve the uniformity of the scintillator tile response: It collects light and guides it to the SiPM

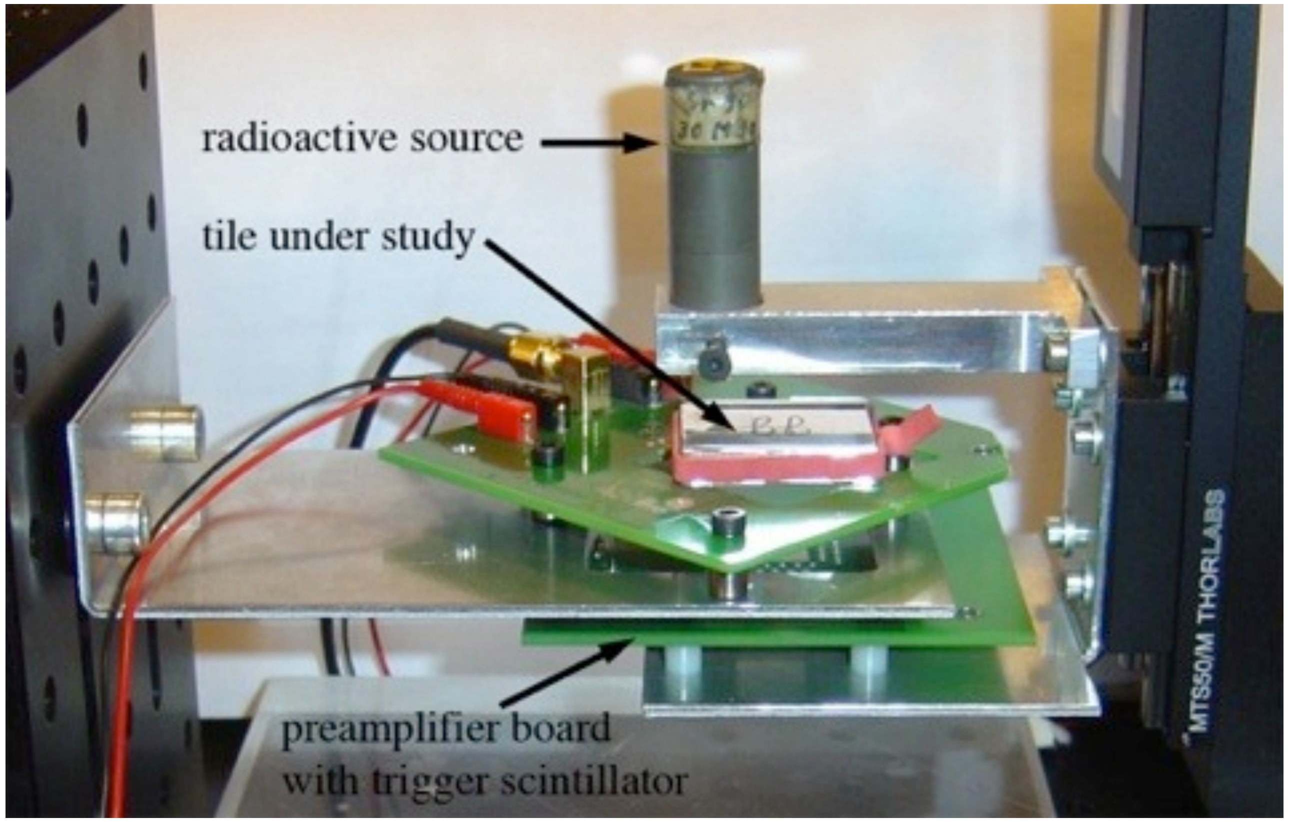
- Naive direct coupling: Just stick a SiPM to the side of a scintillator tile



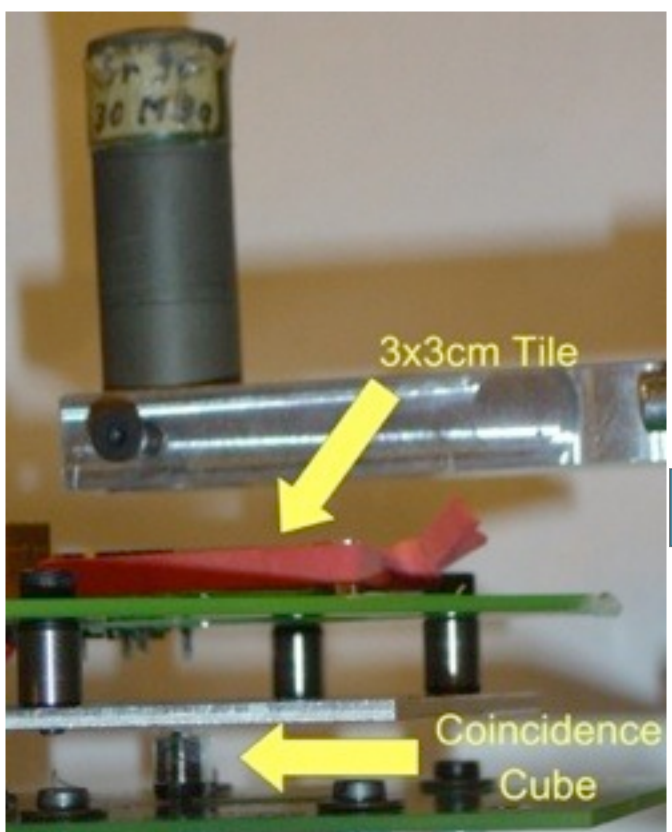


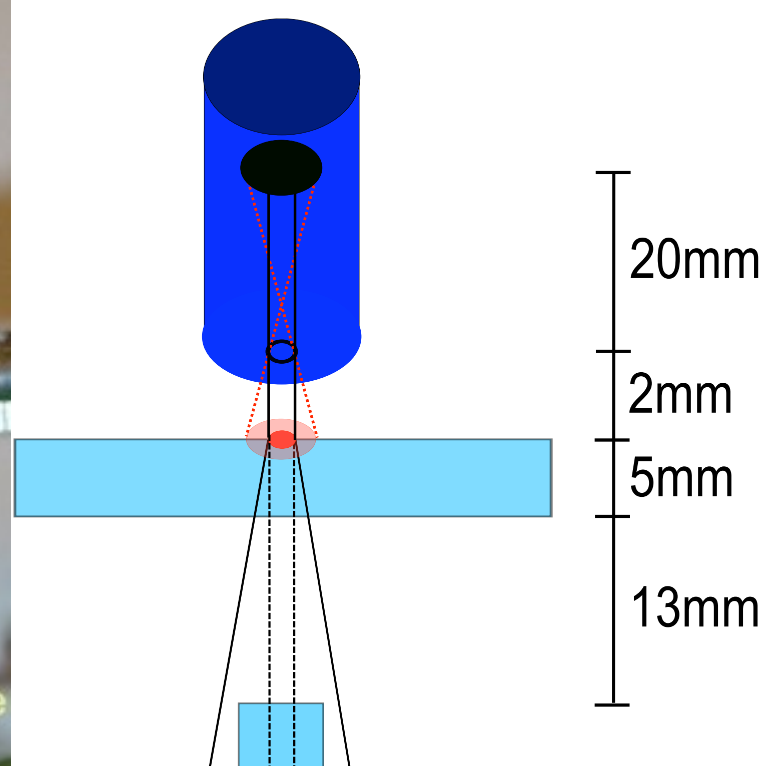
➩ Significant non-uniformity of response in simple direct coupling!

Experimental Setup to study Tile Response



- Readout of SiPMs (using MPPC-25P) with fast Oscilloscope
- Scanning of radioactive source (^{90}Sr) across surface
- Trigger for penetrating electrons provided by a (5 mm)^3 trigger scintillator that moves with source

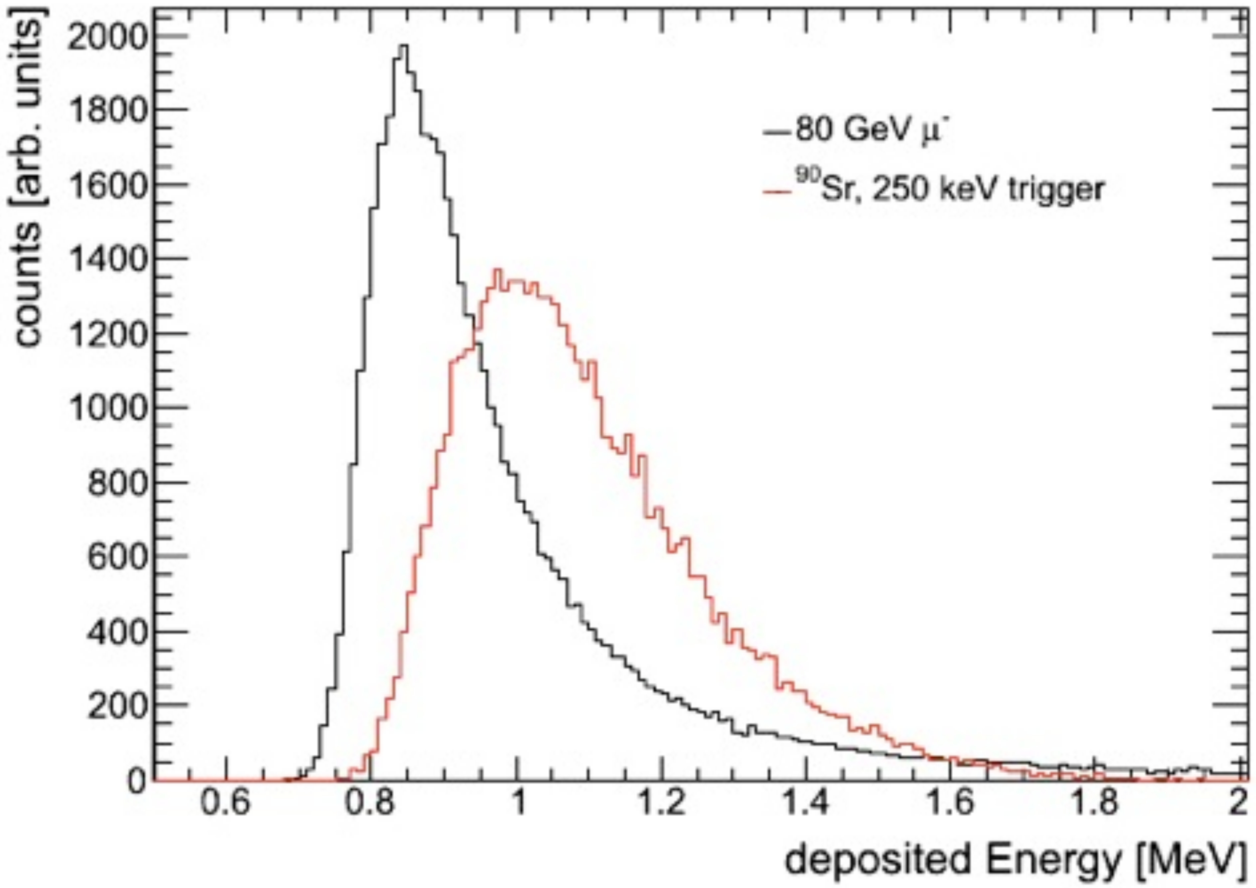




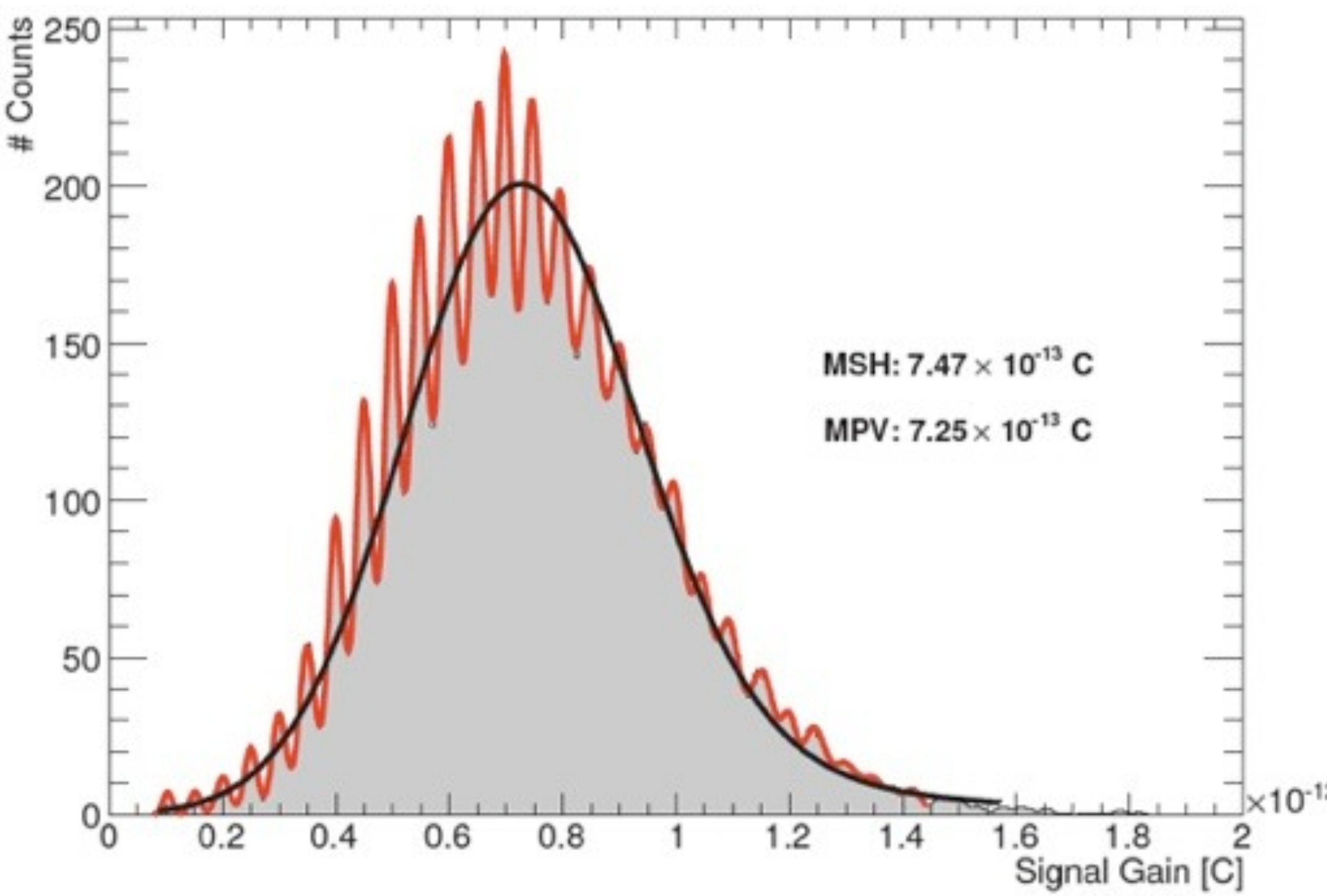
- Limitations: Inclined electrons and scattering lead to "edge effects"
  ➩ Lower signal from electrons that leave the tile early

Signal in Scintillator

GEANT4 simulations, 5 mm scintillator

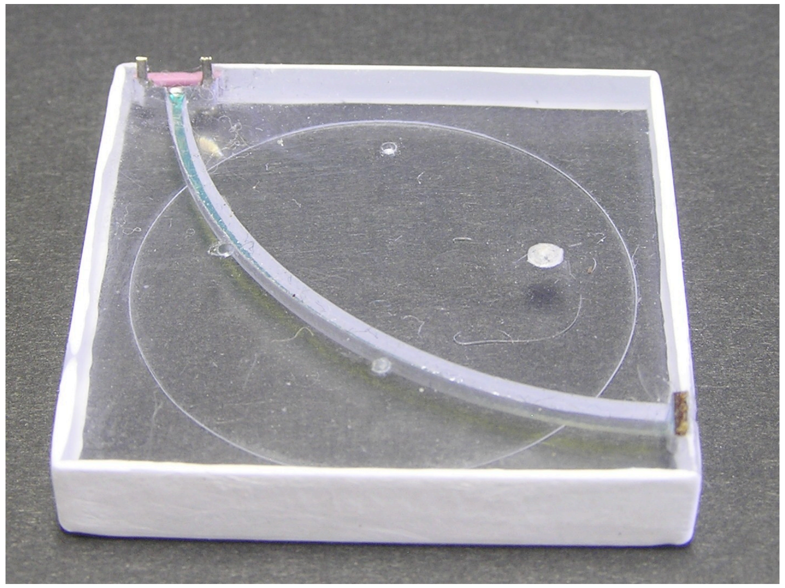


- Electrons from ^{90}Sr source are not quite MIPs:
  - ~15% higher most probable energy loss than 80 GeV μ
  - Less pronounced "Landau-Tail"

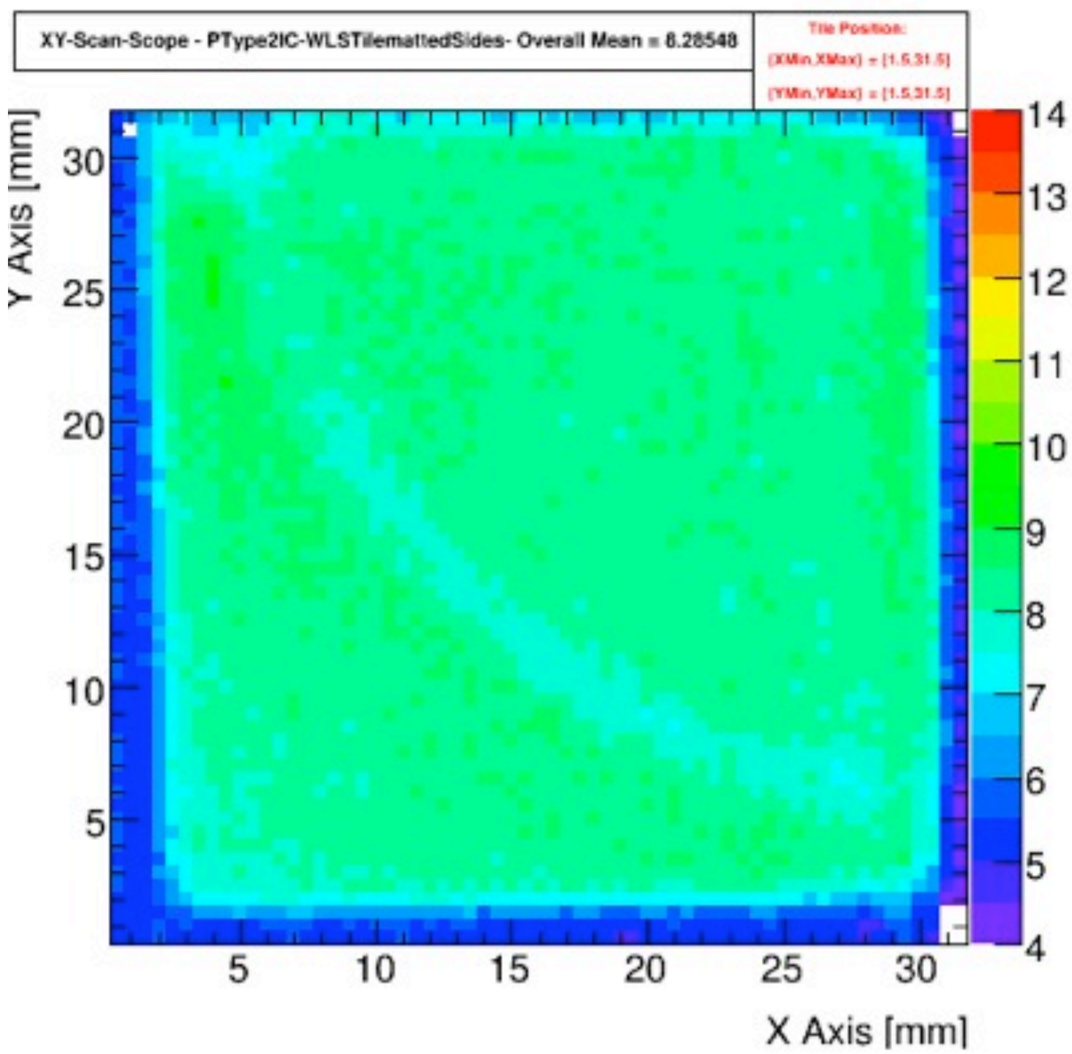


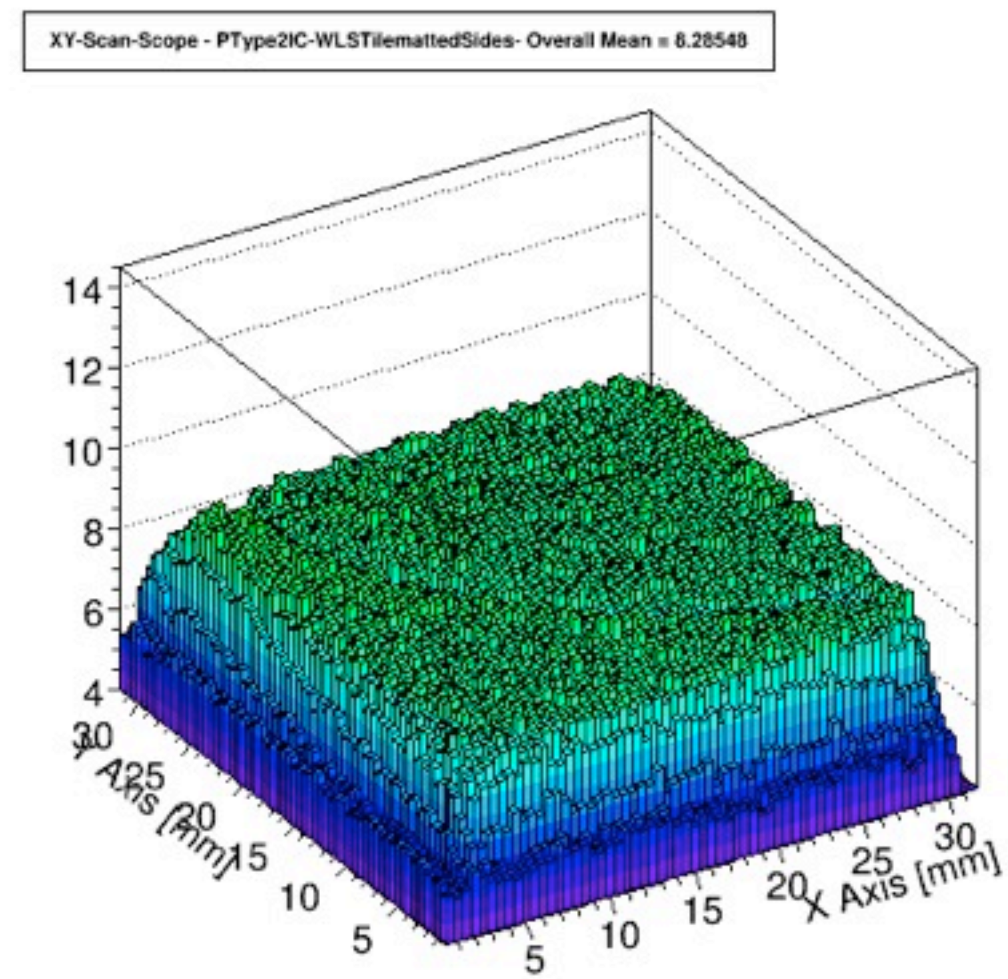
- Signal for a 5 mm thick scintillator tile:
  - Resolution of individual detected photons possible!

A Quick Look at the Old Tiles



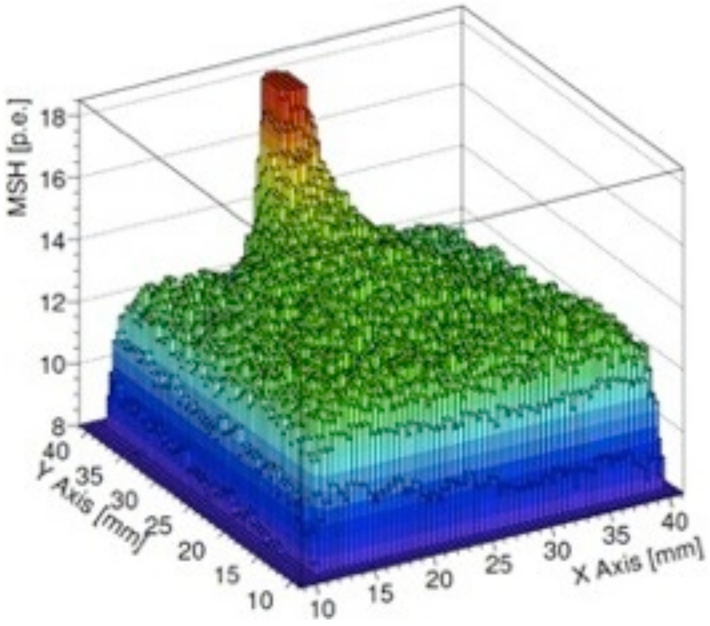
- Tile from 1st generation prototype with WLS fiber, read out with MPPC25P
  - Reduced signal amplitude (mean: 8.3 p.e.): sensitivity of MPPC not matched to fiber emission
  - Excellent uniformity: 78% within 5% of mean, 88% within 10% (not corrected for edge effects)





Improving Uniformity

- The strategy:
  - Reduce material close to SiPM to eliminate signal overshoot
  - Improve overall signal by integration of SiPM into tile
- Here: Design compatible with 2nd generation tiles previously: SiPM at bottom of tile [NIM A605, 277 (2009)]



Improving Uniformity

- The strategy:
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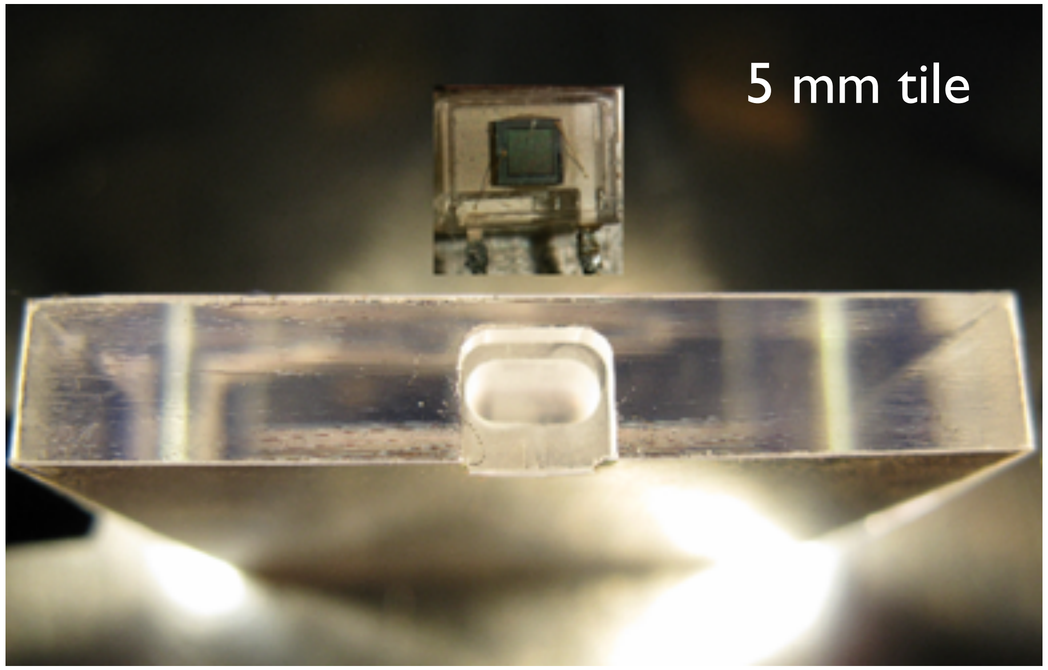
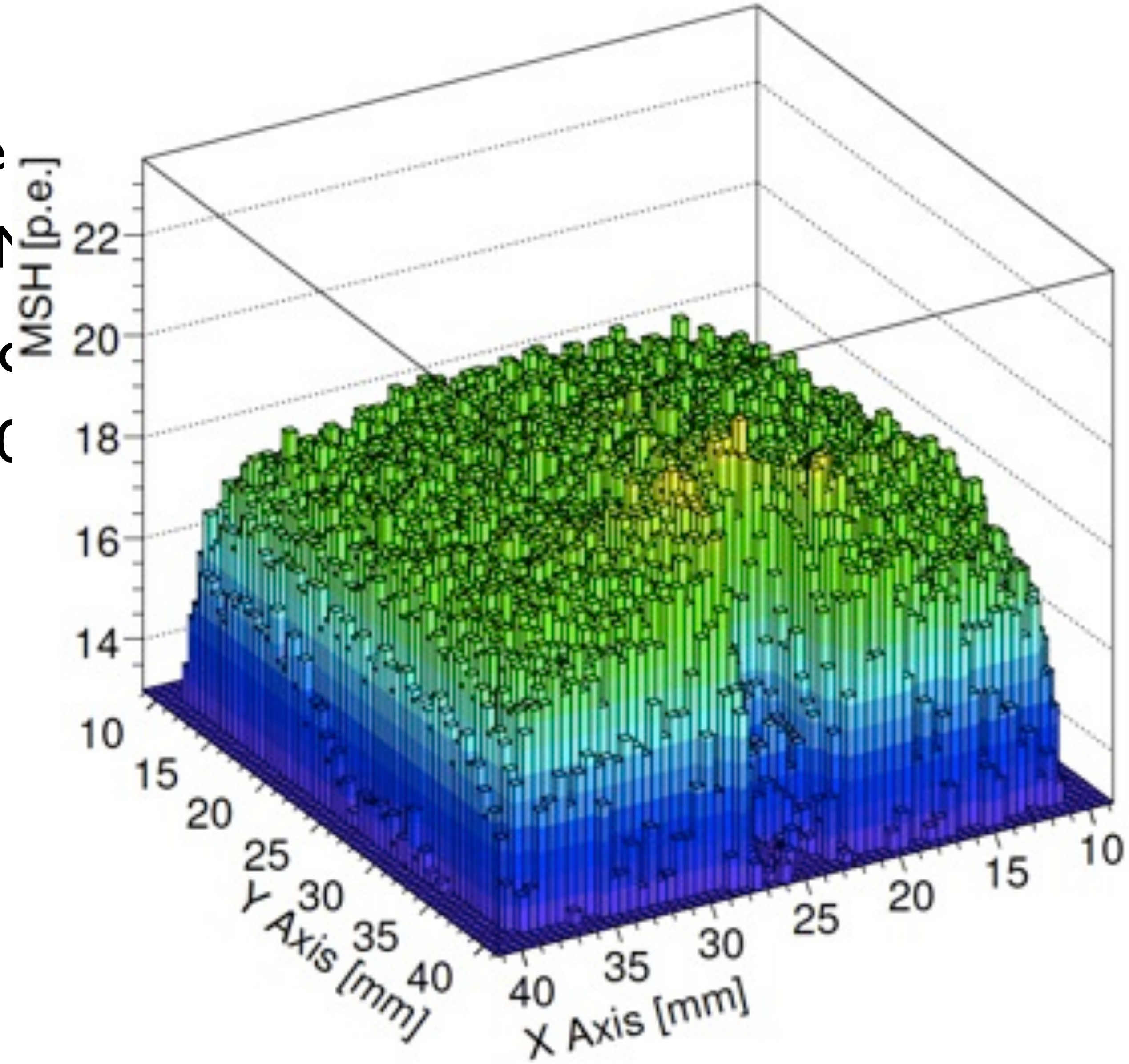


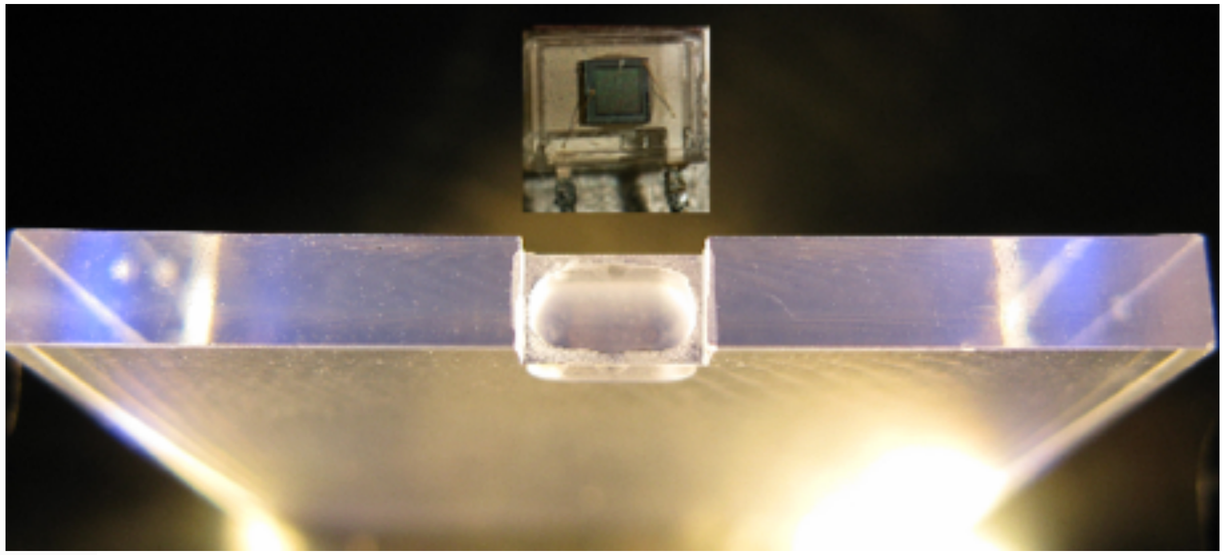
- Slit for SiPM integration
- Dimple to reduce scintillation material close to sensor, diffuse light
- Tile covered in reflective foil

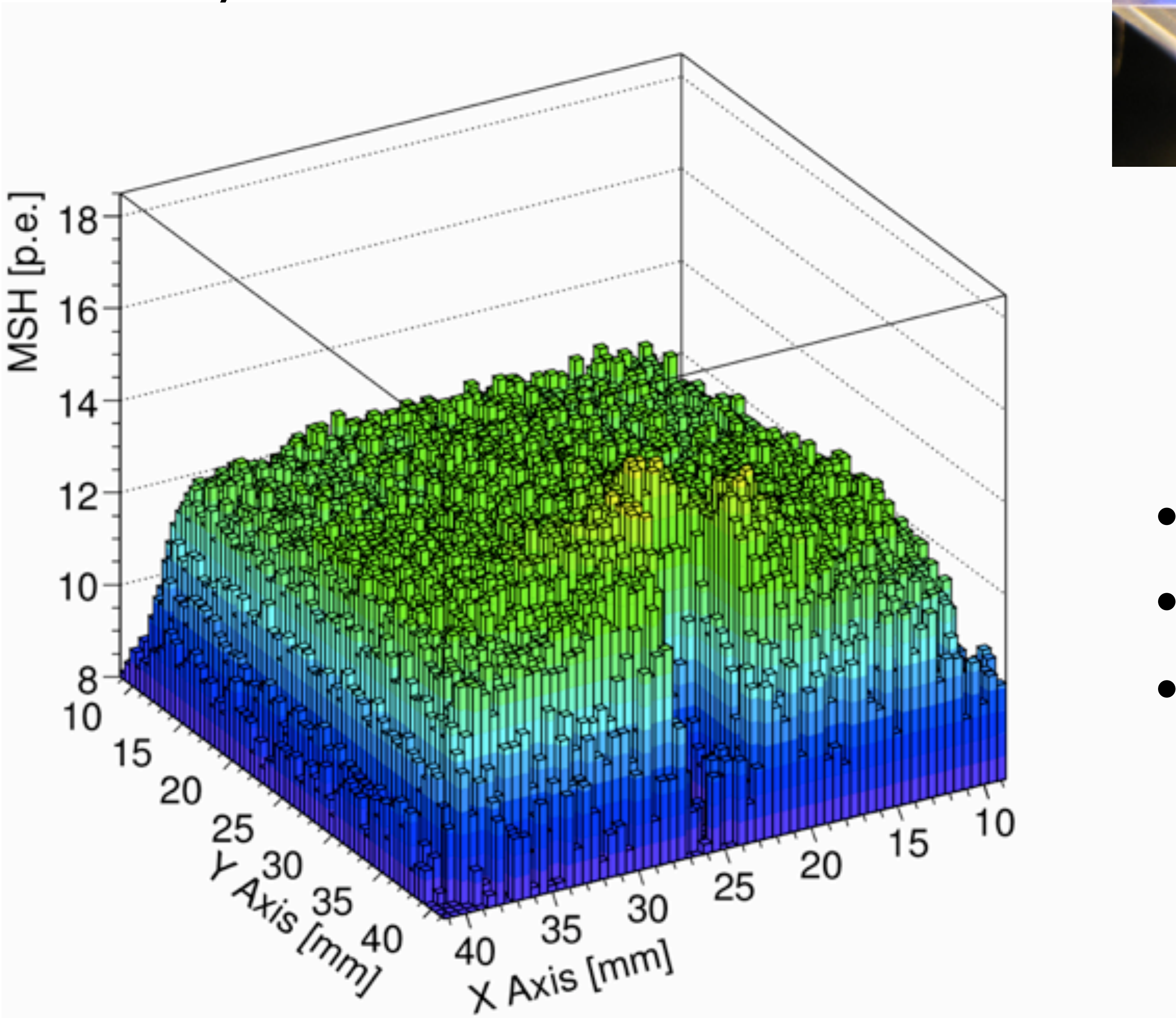


- Good uniformity
- Increased signal: Mean amplitude ~18 p.e. (+50% compared to simple direct coupling)

Tiles for Mass Production

- 3 mm thick tiles for 2nd generation
- "Ideal" tile: BC-420 scintillator
  - fully enclosed in 3M reflective foil

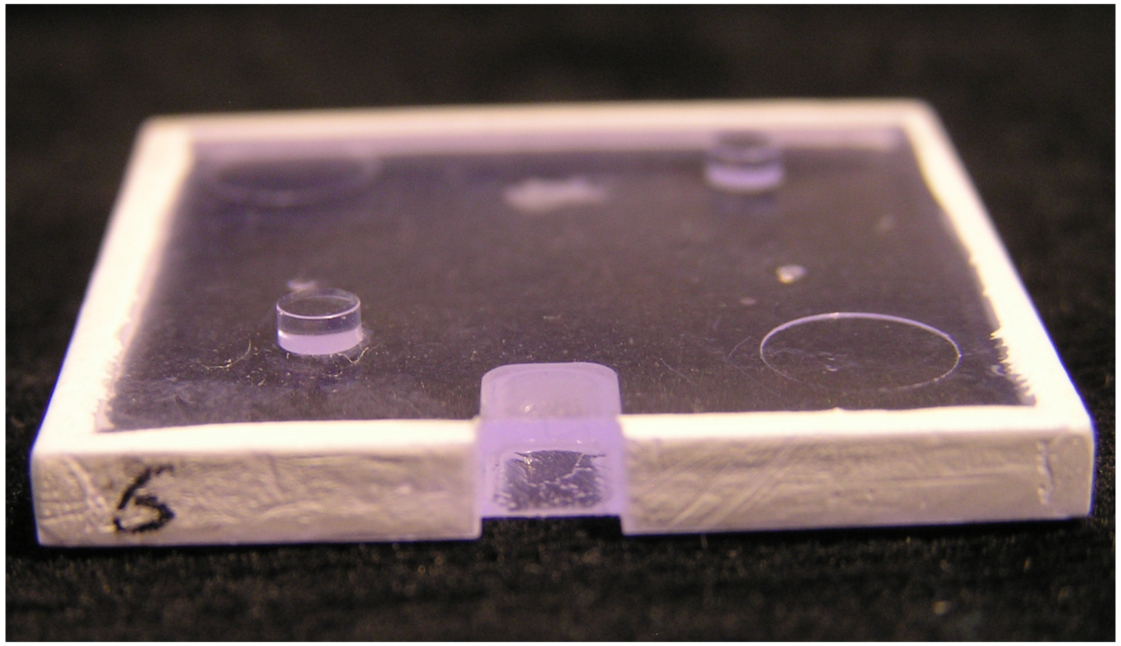


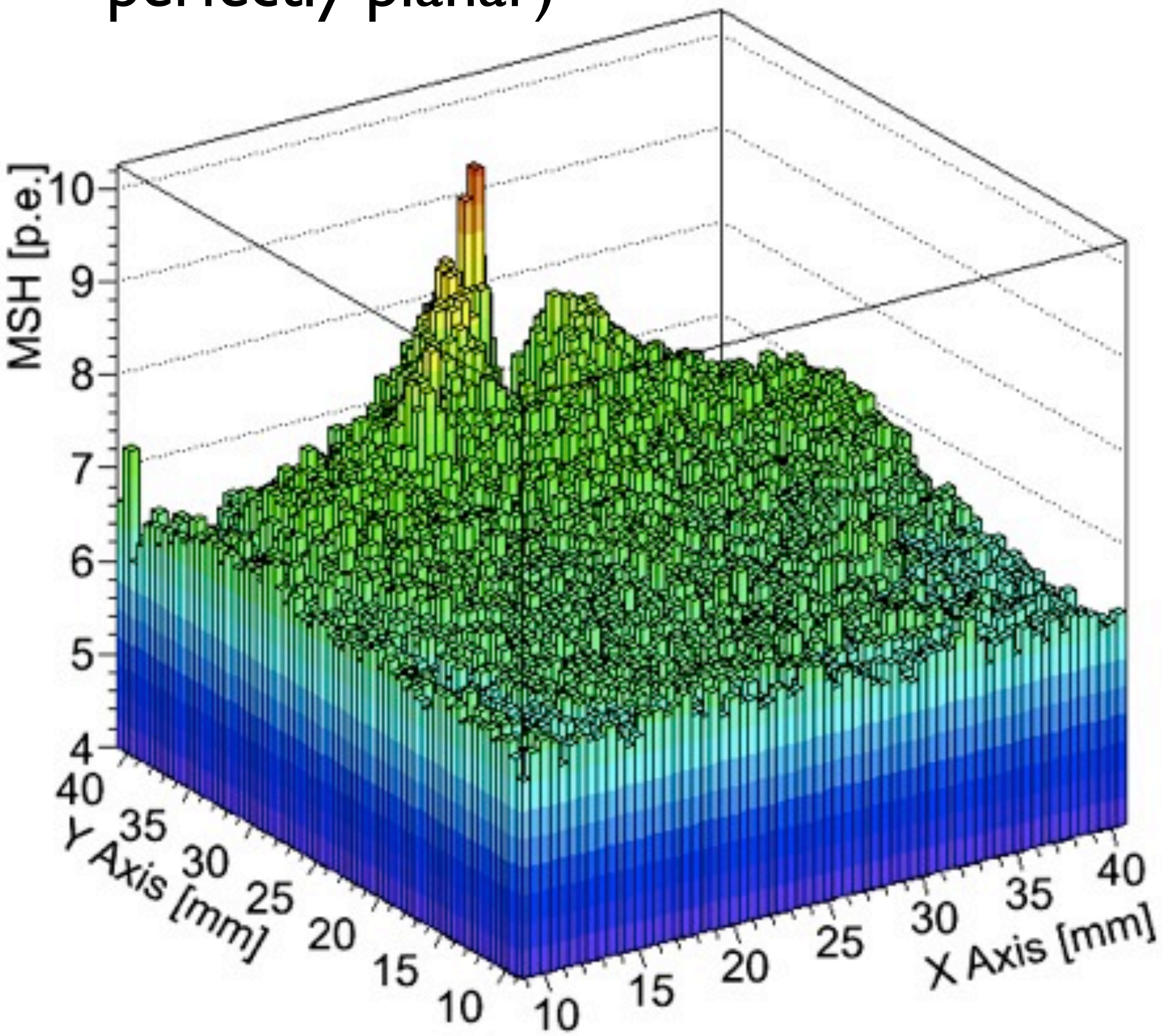


- Excellent uniformity
- High signal amplitude: mean 13 p.e.
- loss of signal at SiPM position

Tiles for Mass Production

- 3 mm thick tiles for 2nd generation
- Molded tile, produced by Uniplast (Vladimir, Russia), dimple was machined after molding
  - sides chemically matted, top and bottom enclosed in 3M foil, imperfect covering (tile not perfectly planar)



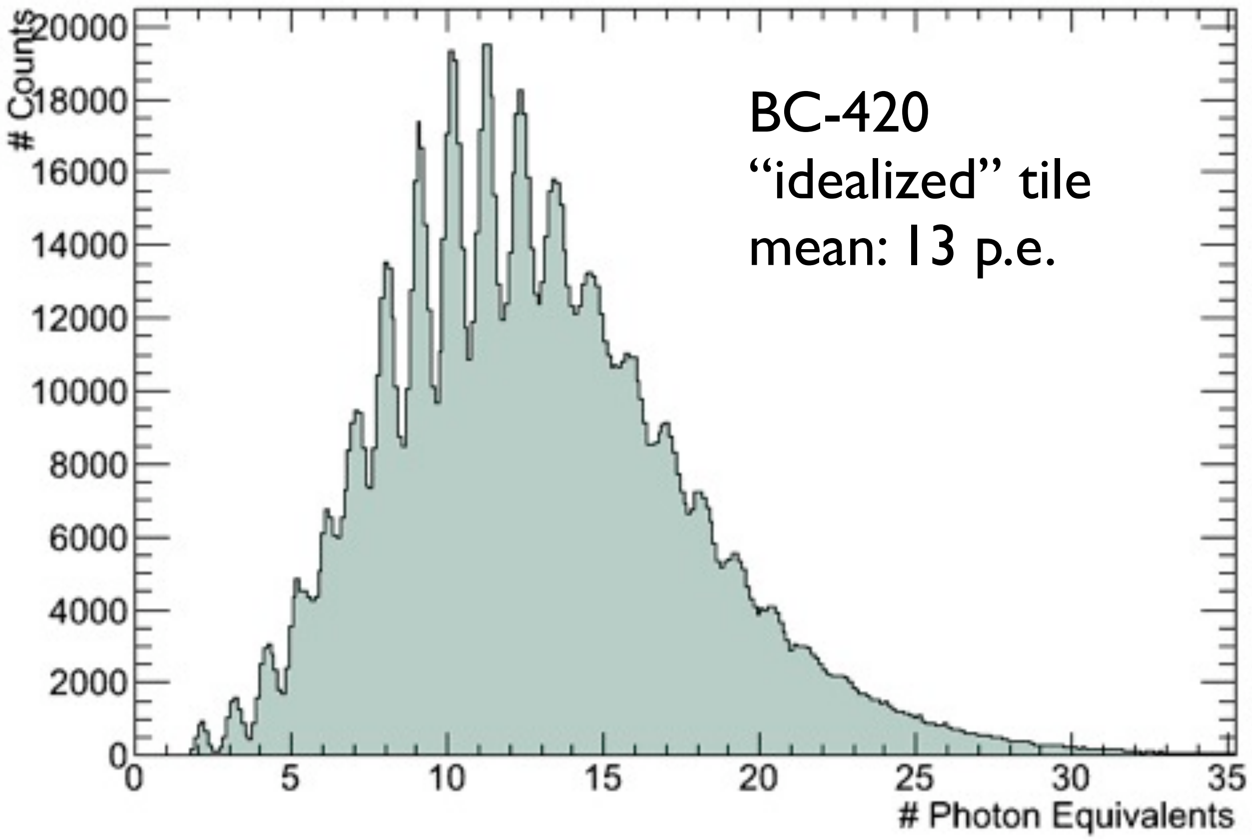


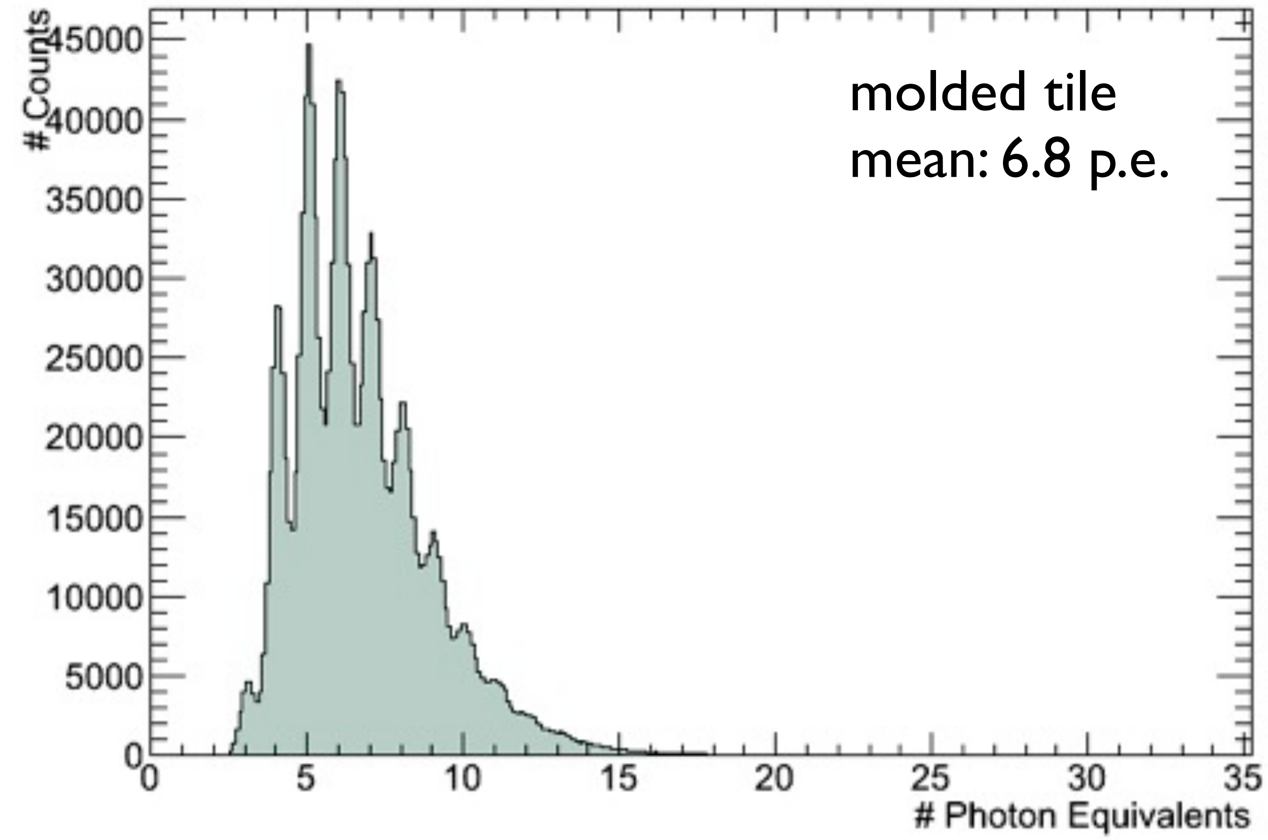
- Good uniformity
- Low signal amplitude: mean 6.8 p.e.
- Large signal spike close to SiPM: Potentially a coupling problem

Idealized Tile vs Mass Production

- Slight deterioration of uniformity
- Significant reduction of light output

Matting of tile edges, reduced light yield of molded scintillator





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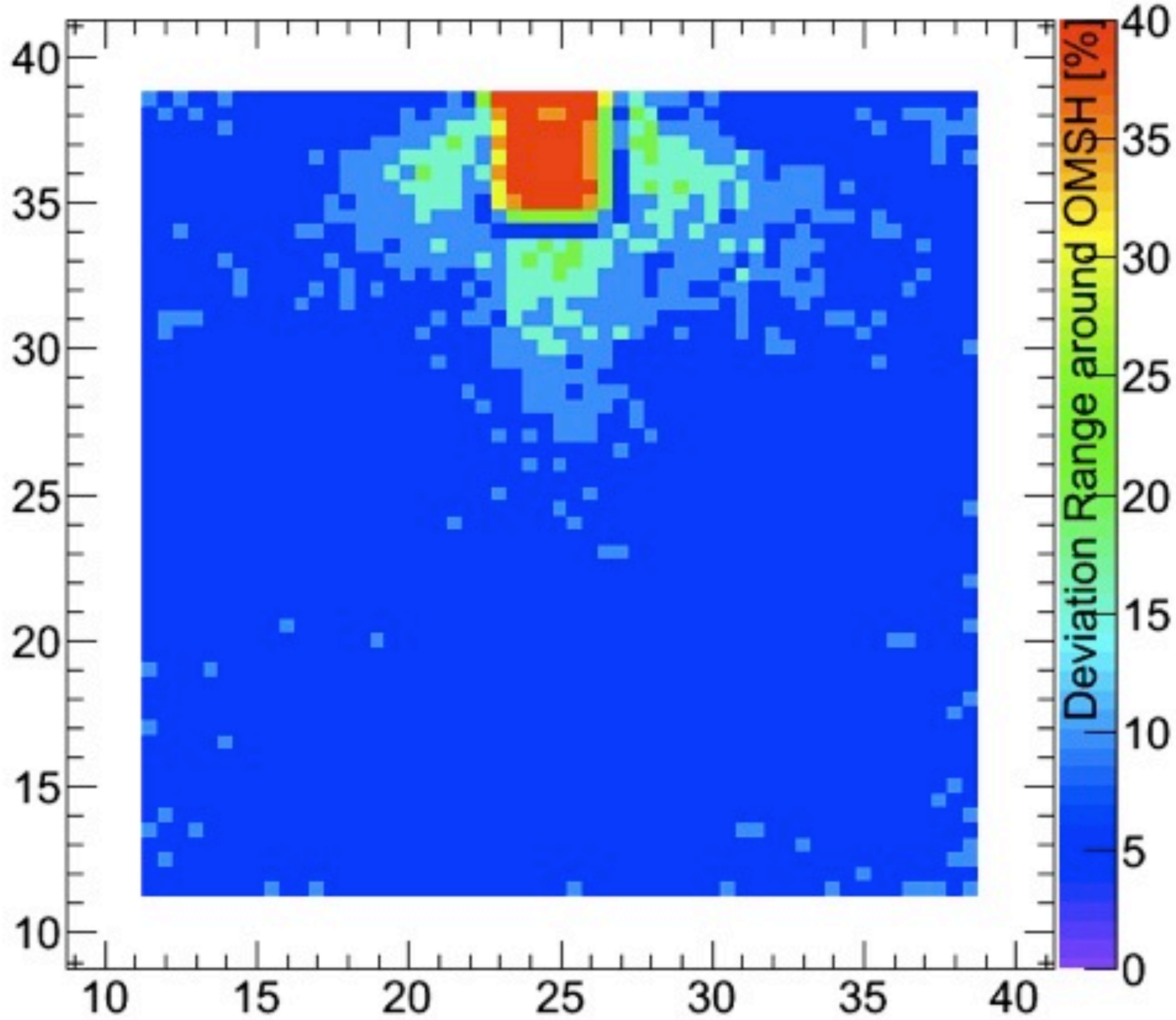
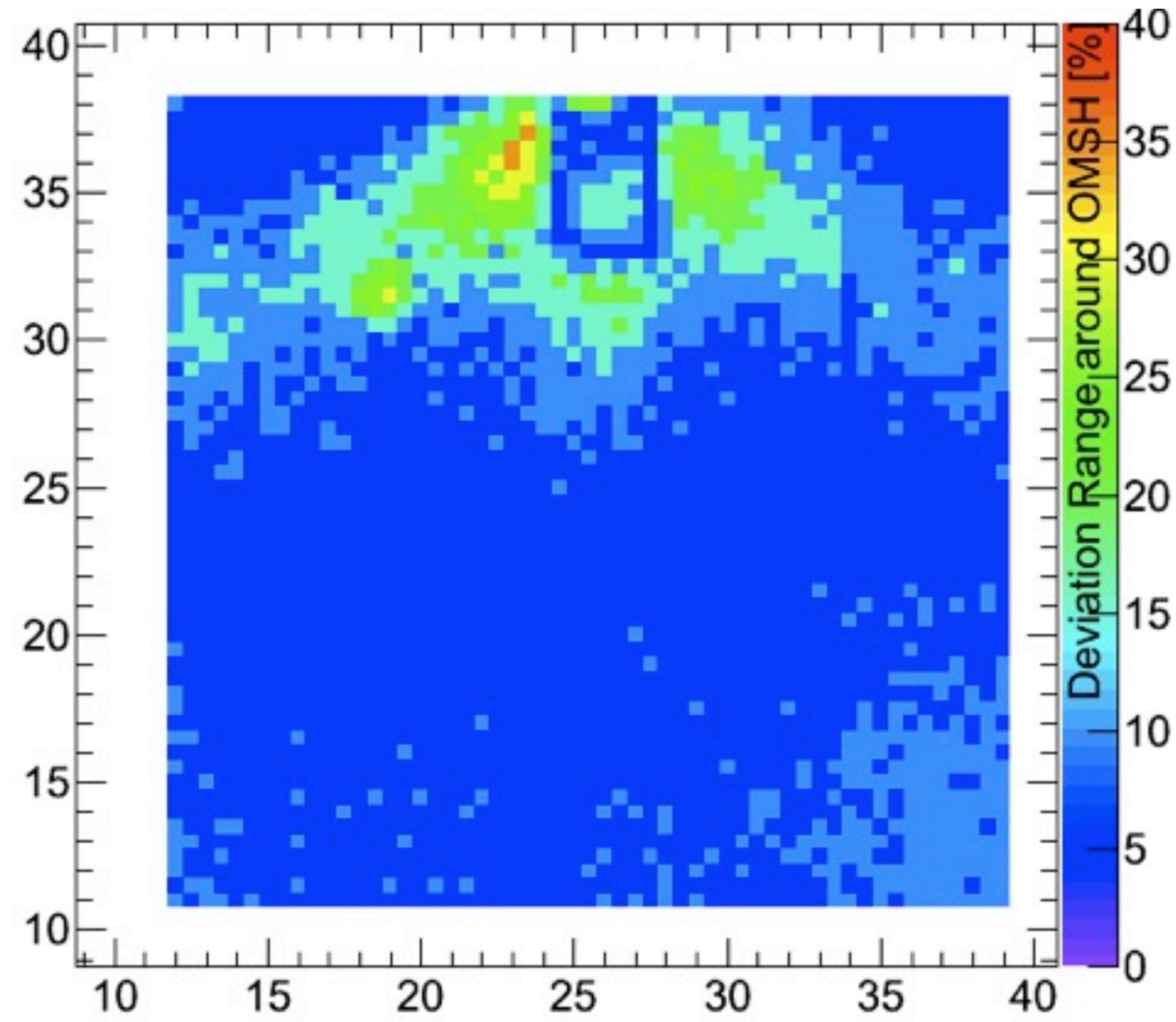
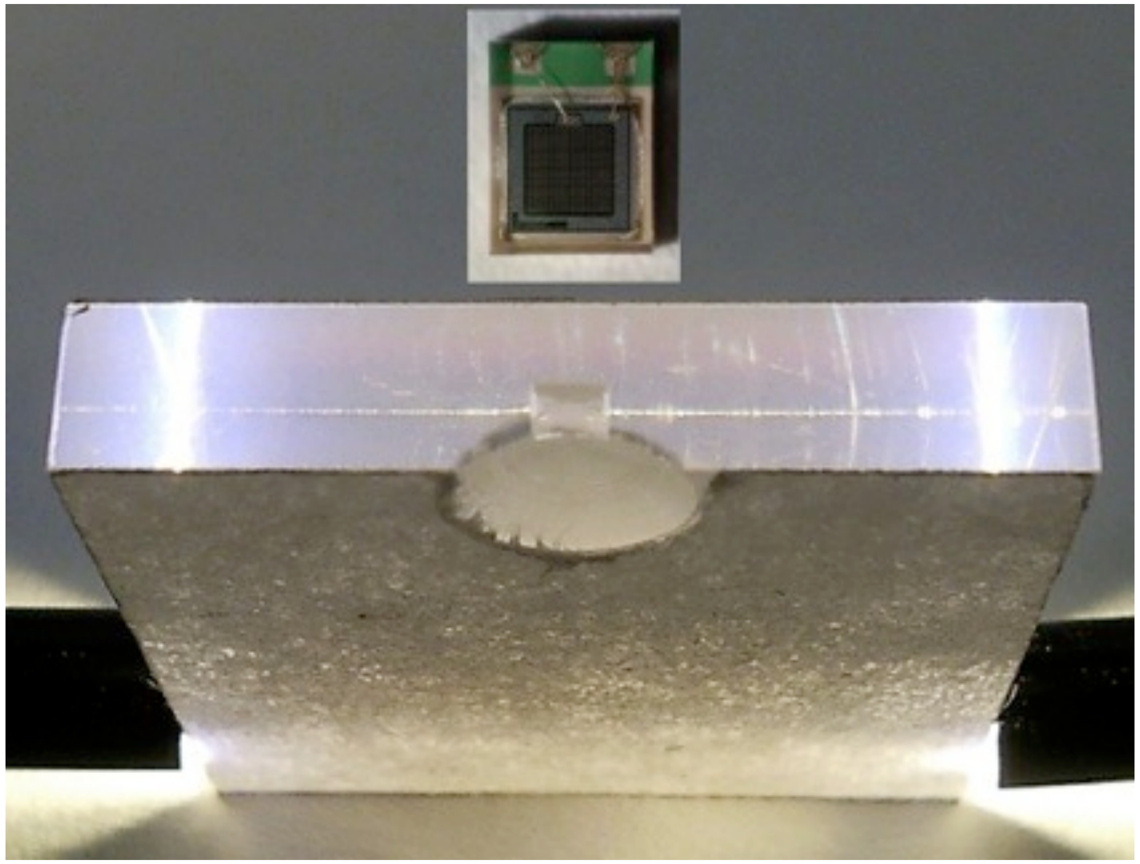


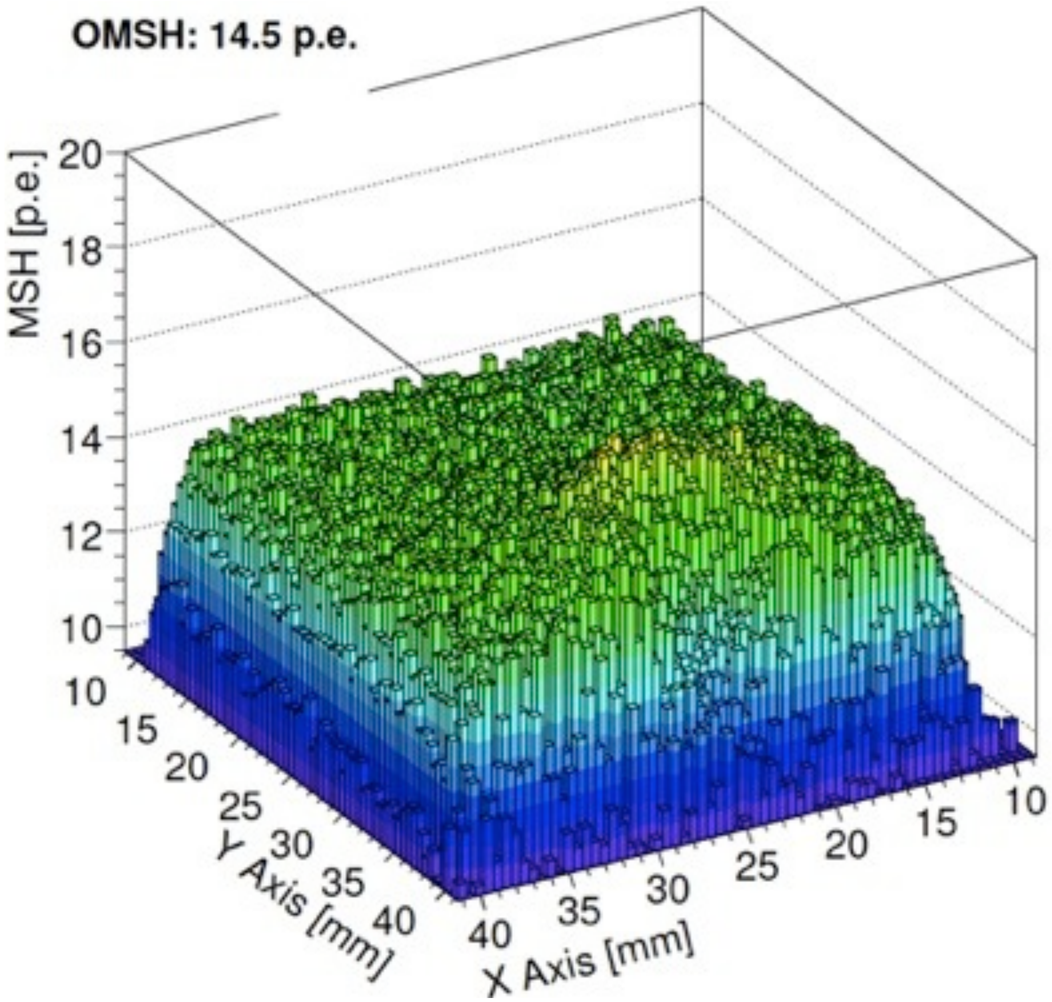


➩ Explore improved shaping and coupling, use other SiPMs with higher photon detection (larger pixels, larger active area)

Further Studies

- Attempt to avoid the signal drop at the SiPM coupling position
- Allow easier molding





- Achieved with a spherical hole, 5 mm radius, and a small SMD MPPC (for 5 mm thick tiles)
  - Needs to be adapted for 3 mm thick tiles
  - Likely also signal yield issues with molded scintillator: Use different SiPMs

Summary

- Scintillator tiles & SiPMs under development for the 2^{nd} generation prototype of the CALICE Analog HCAL
  - Building on the success of the physics prototype: WLS fiber embedded in the tile

- Blue sensitive SiPMs allow direct (fiberless) coupling of SiPM to scintillator
  - Easier production, relaxed assembly tolerances, faster signal
  - Signal amplitude and uniformity challenging
  - ▸ Special geometries at the SiPM position: recover uniformity, increase signal yield

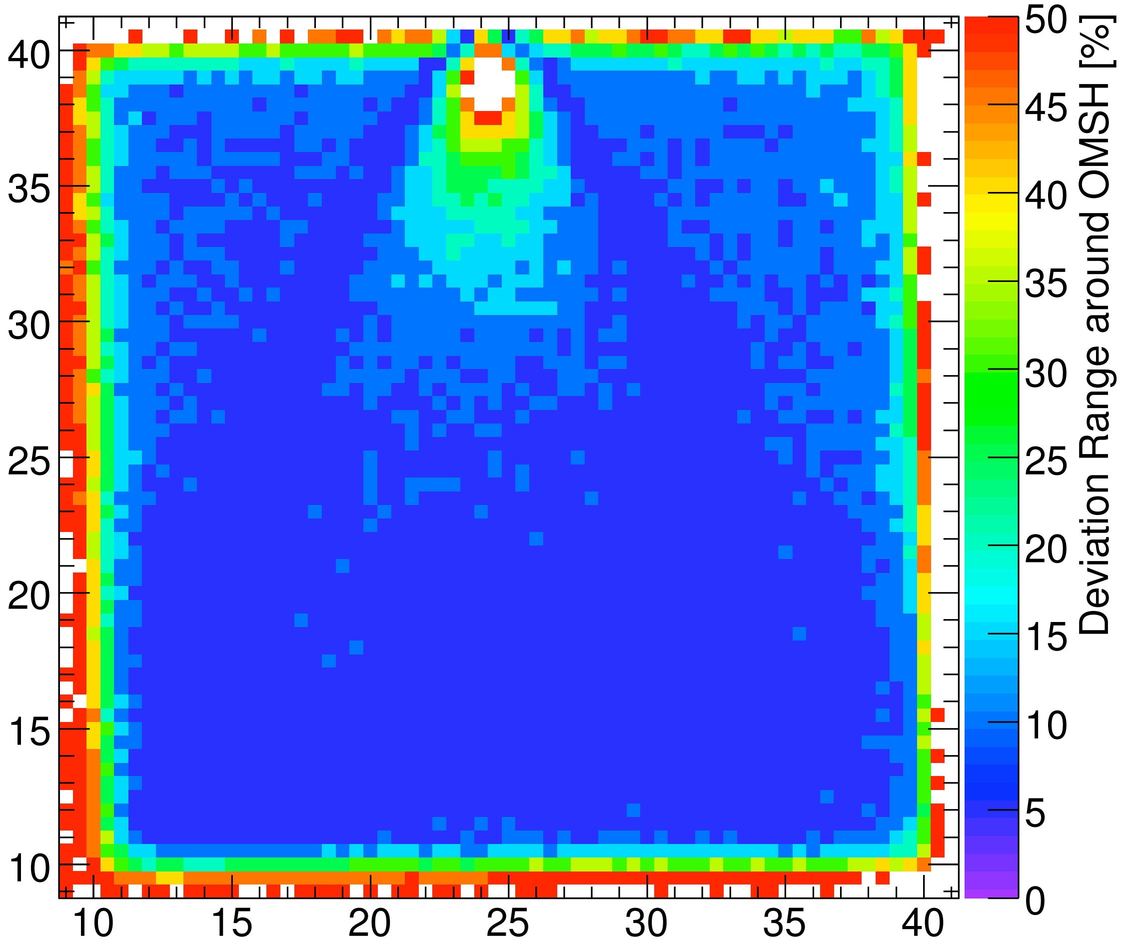
- First studies of molded tiles for direct coupling: Promising results
  - Larger SiPMs might be needed to obtain satisfactory signal amplitudes

- Potential for further simplification of tile geometry is being investigated

Backup

Quantifying the non-uniformity

simple coupling



81% within ±10%

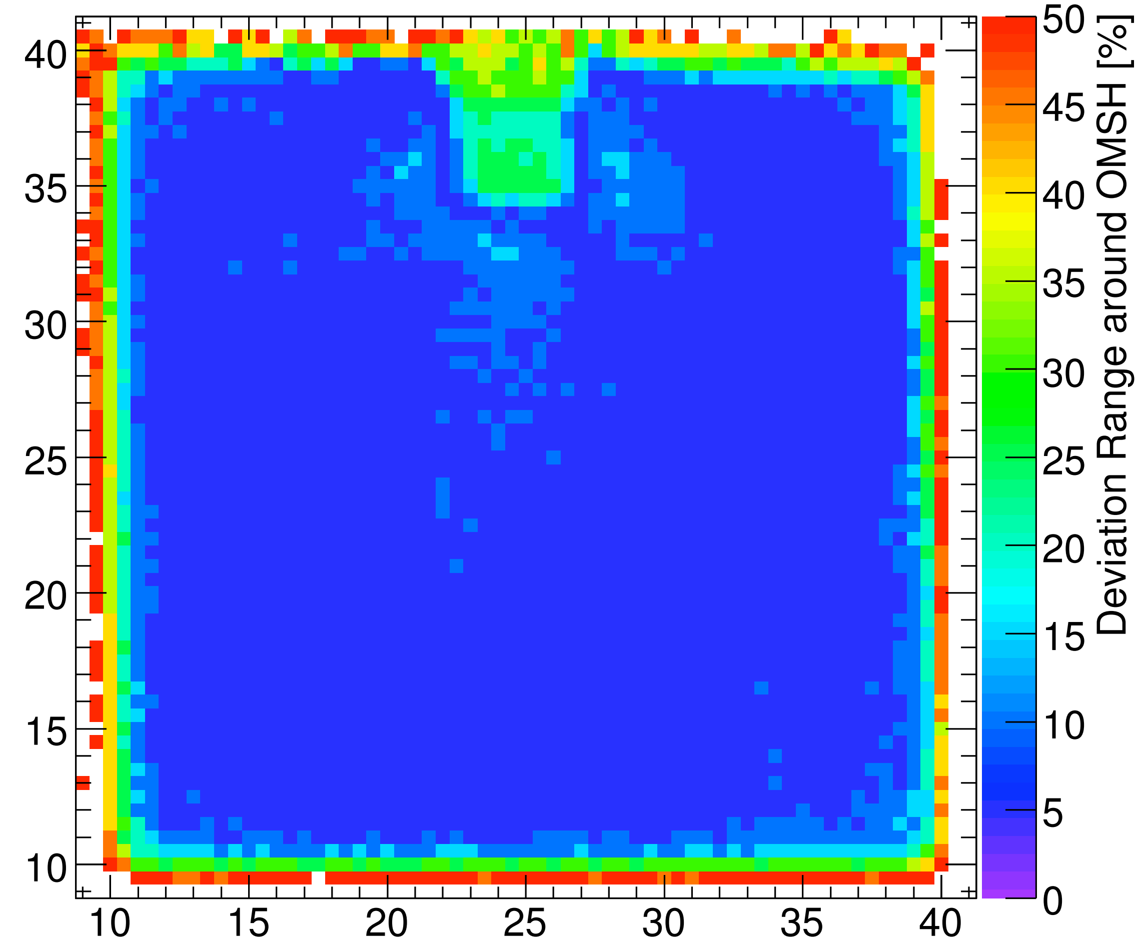
57% within ±5%

without edge region (1.5 mm wide rim):

94% within ±10%

69% within ±5%

side dimple



84% within ±10%

73% within ±5%

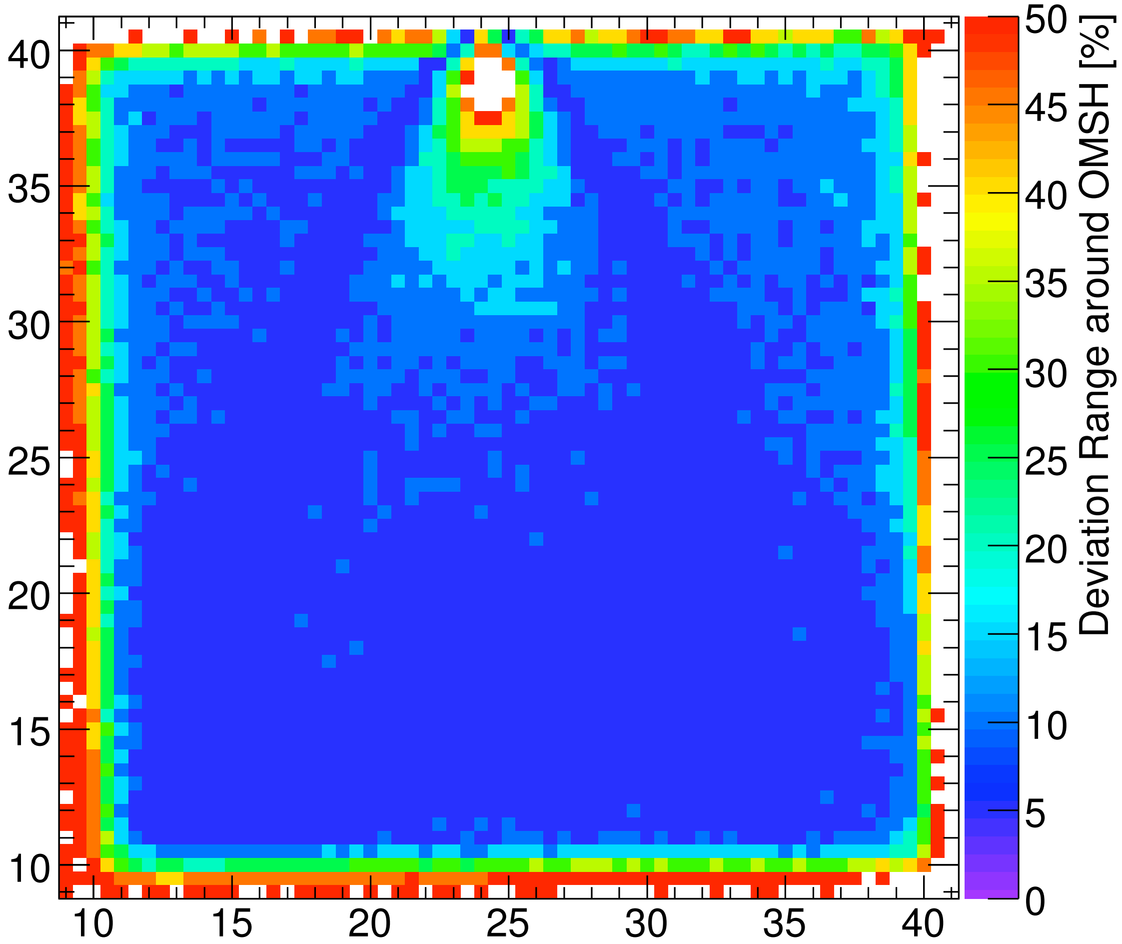
without edge region (1.5 mm wide rim):

97% within ±10%

88% within ±5%

Quantifying the non-uniformity

simple coupling



81% within ±10%

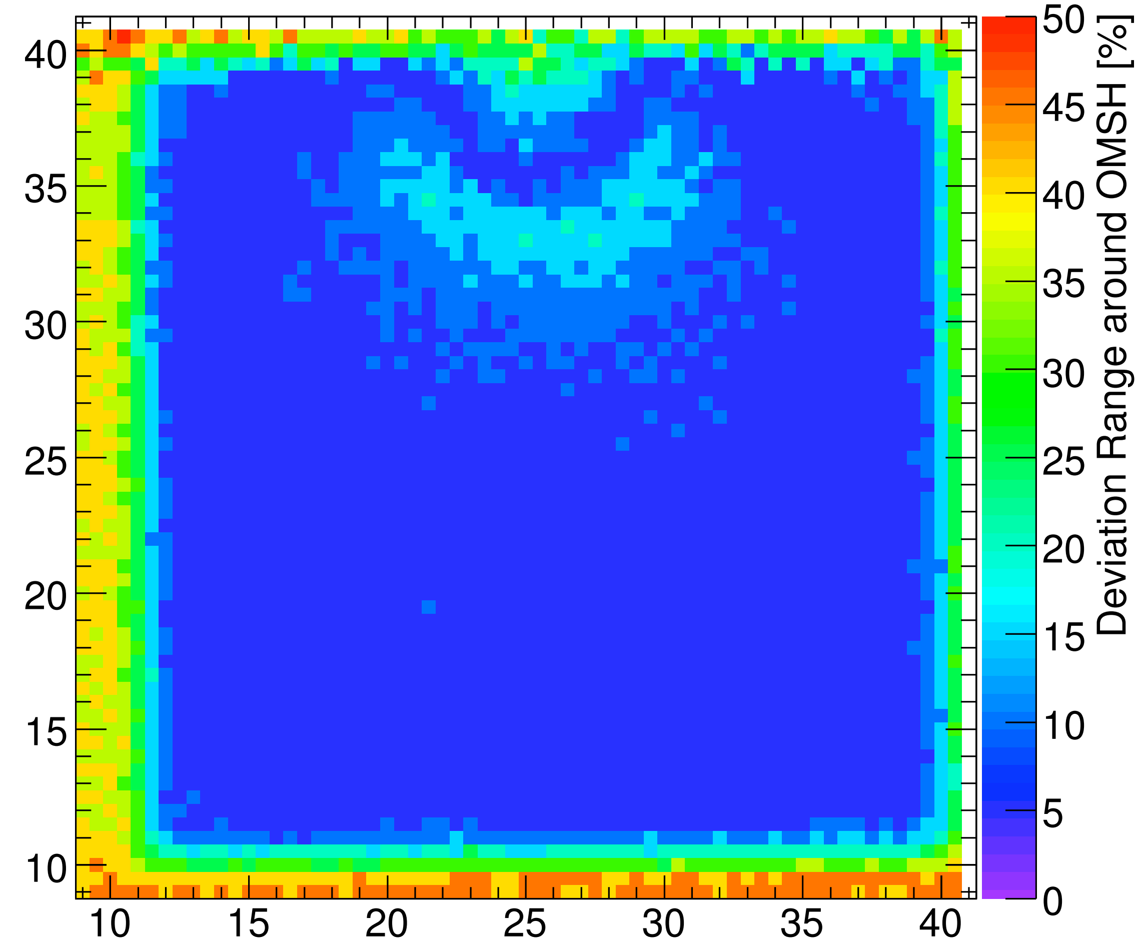
57% within ±5%

without edge region (1.5 mm wide rim):

94% within ±10%

69% within ±5%

large circular hole



82% within ±10%

69% within ±5%

without edge region (1.5 mm wide rim):

96% within ±10%

83% within ±5%