Direct Coupling of SiPMs to Scintillator Tiles: Timing and Uniformity

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Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Calorimeter for ILC

Excellence Cluster Universe

Outline

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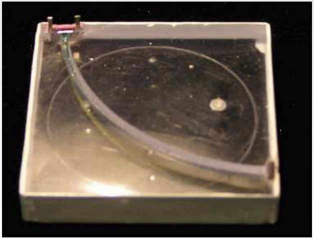
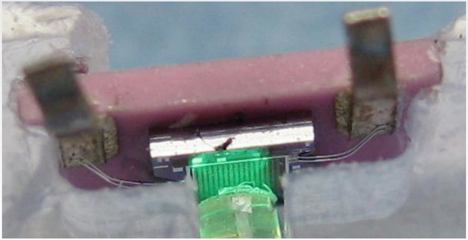
The CALICE Analog Hadron Calorimeter (AHCAL)

Development of blue sensitive SiPMs
allow for photon readout without wavelength shifting fiber:

- Advantage: Avoid machining of WLS into millions of tiles (ILD)
  Avoid difficult alignment of SiPM to WLS-end
  Improve timing of light collection
- Non-uniform cell readout: Measured energy deposition varies with the lateral position at which a particle traverses the tile
- Position dependence affects the performance of the HCAL.





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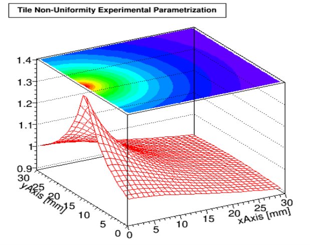

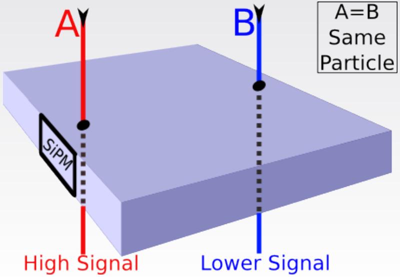

The Effect of Non-Uniform Cell Readout

Consequences: Subject of further investigations

Consequence 1

Distortion of the cell signal distribution
$\Rightarrow$ Effect on HCAL calibration

Consequence 2

Distortion of the energy sum distribution of showers
$\Rightarrow$ Effect on energy reconstruction process

Consequence 3

Deterioration of the energy resolution increasing with the particle energy

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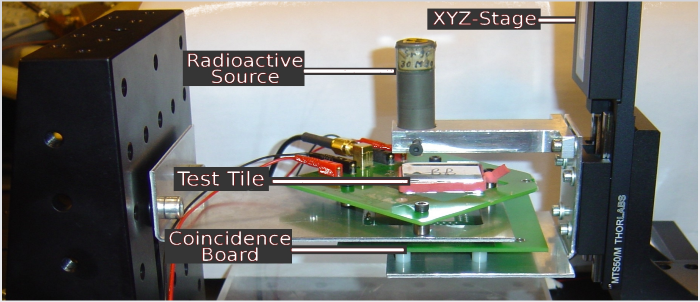
The Experimental Setup



Test Stand Properties

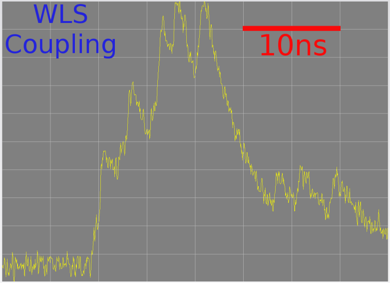
- Radioactive ^{90}Sr source: Beta decay ($E_{end\ point} = 2.27\,\mathrm{MeV}$)
- Movable stage: Translation in XY-direction over $3 \times 3\,\mathrm{cm}^2$ tile
- Active (Fan, Air Cond.) and Passive (Thermistor) T-control
- Select tile traversing electrons → Active coincidence trigger

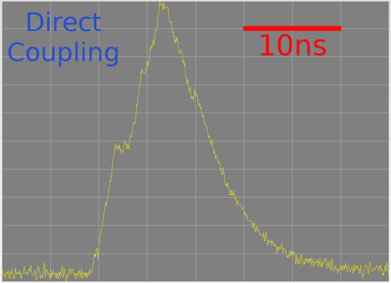
Outline

Time Resolved Measurements

Fast timing of HCAL implies fast light collection within tiles

- Aquire waveforms of SiPM Signal with 4 GHz Oscilloscope
- High sampling: Arrival of every single photon on SiPM can be identified

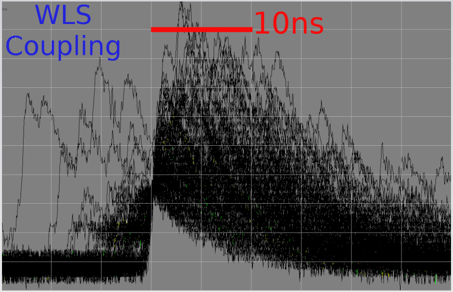


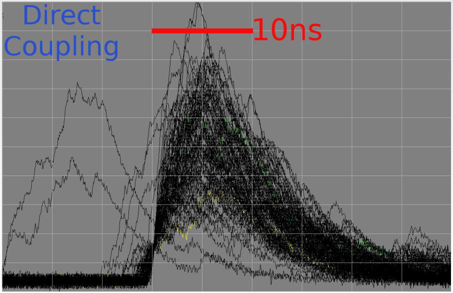


Direct Coupling

Signal from directly coupled tile significantly faster:
No delay due to absorption and reemission in WLS fiber

Time Resolved Measurements





CALICE 1st generation tile with WLS fiber

- Broad signal peak
- Long integration times needed

Directly Coupled Tile

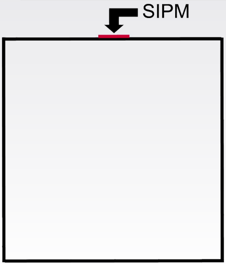
- Fast peaking signal, pronounced peak
- Short integration times sufficient

Outline

The Lateral Uniformity Scan

Scanning Sequence

- First test: Direct SiPM coupling to one side of a $3 \times 3\,\text{cm}^2$ tile
- Recording of 500 e^- signals at 60×60 XY-positions on the tile
  $\rightarrow$ Pixel Size: $0.5 \times 0.5\,\text{mm}^2$
- Determine mean signal height (MSH) from signal distribution
- MSH vs. XY-Position: Observe strong non-uniformity
- Modification of the tile geometry necessary to restore uniformity



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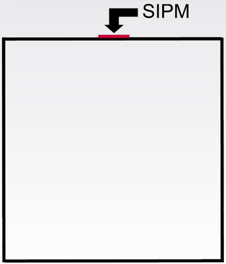

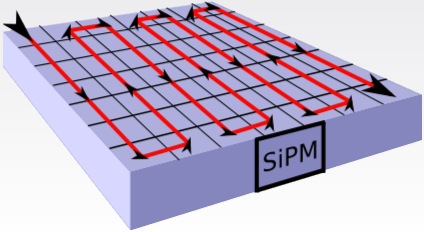

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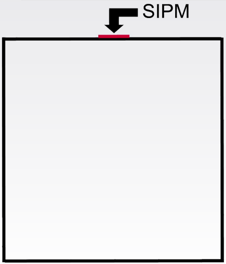

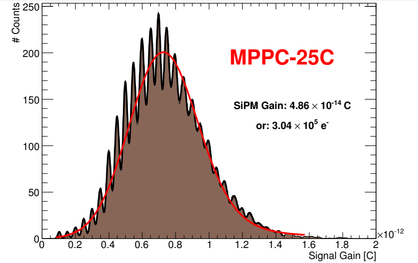

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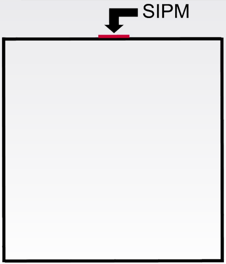

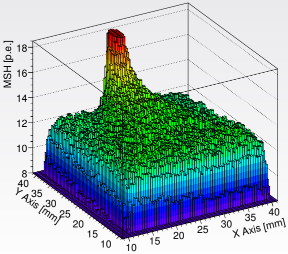

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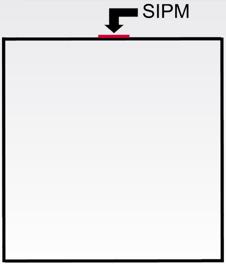
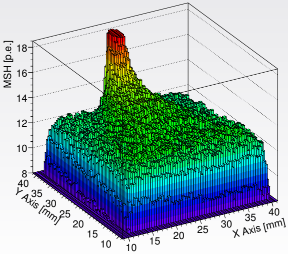
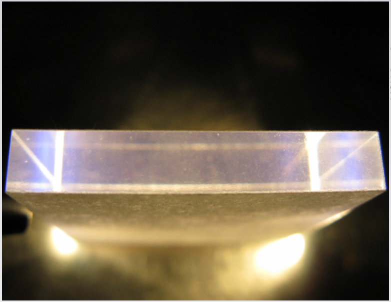
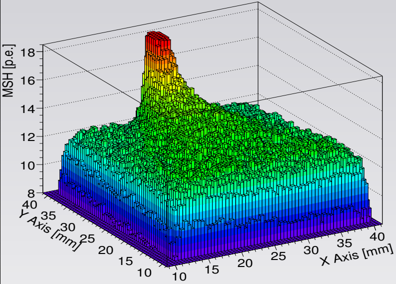




Outline

Towards an Optimal SiPM-Tile Entity





Tile Development

Simple Tile: SiPM coupled to the side

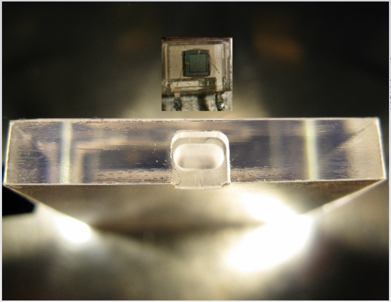
Highly non-uniform

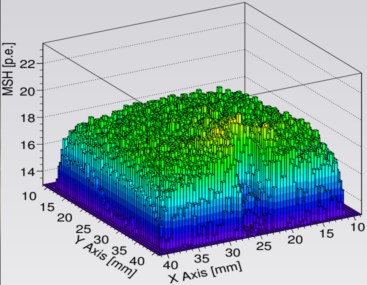
⇒ Solution: Reduce scintillating material close to SiPM

Overall mean of signal height: 13.0 p.e.

⇒ Solution: Integrate SiPM into the tile

Towards an Optimal SiPM-Tile Entity





Tile Development

Integrated Dimple: Height 1 mm, Width 4 mm, Depth 5.5 mm

⇒ Overall mean: 18.4 p.e. (Diffuse light refraction at dimple)

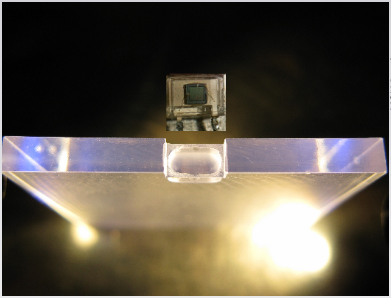
⇒ Good uniformity

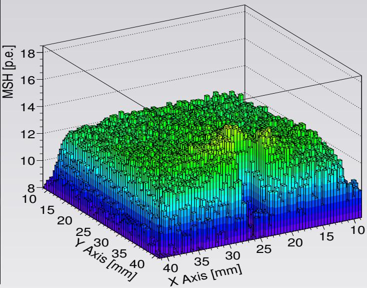
⇒ Signal at SiPM position not lower than 13 p.e.

⇒ Scalable solution for mass production

(arXiv:1001.4665 [physics.ins-det])

Towards an Optimal SiPM-Tile Entity





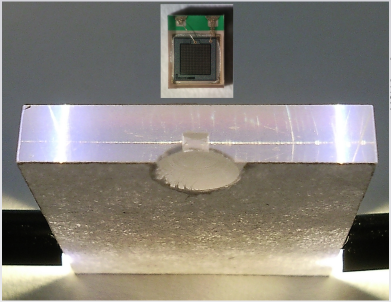
Tile Development

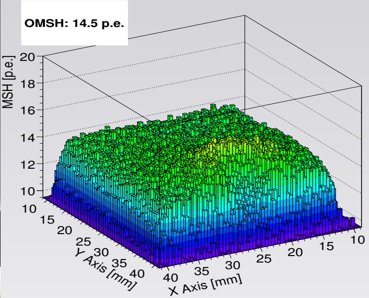
Transferable concept for the next generation prototype: 3mm Option:

⇒ Overall mean: 13.15 p.e.

⇒ Signal at Dimple not lower than 8 p.e.

Towards an Optimal SiPM-Tile Entity





Tile Development

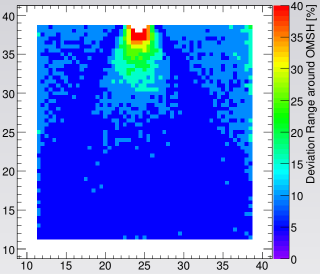
Very small packaging of new MPPCs
→ opens up the possibility for new tile geometries:
Aim: Avoid Signal Drop at SiPM Coupling Position
→ Very small integration hole
→ 2 mm deep bottom dimple(spherical drilling head with 5 mm radius)
Note: Only tested for 5 mm tiles, SiPM is SMD

High Precision Uniformity: Side Coupling vs. Integrated Dimple Concept

Side Coupling

Part of the Scintillator Tile	Deviation of overall mean: 13.0
98% (91%)	±20%
94% (81%)	±10%
69% (57%)	±5%

Unprecise → Cut Tile Edges!



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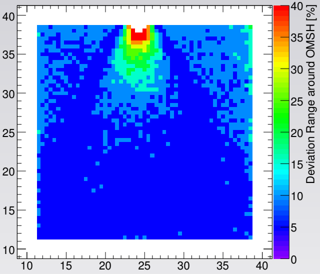
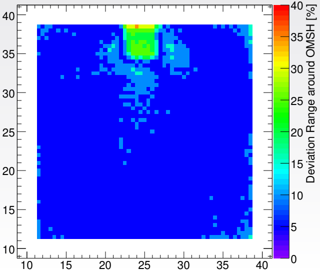
Side Dimple

Part of the Scintillator Tile	Deviation of overall mean: 18.4
99% (90%)	±20%
97% (84%)	±10%
88% (73%)	±5%





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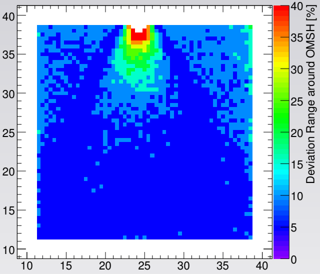
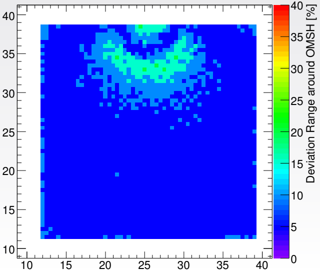
98% (91%)	±20%
94% (81%)	±10%
69% (57%)	±5%

Unprecise → Cut Tile Edges!

Bottom Dimple

Part of the Scintillator Tile	Deviation of overall mean: 14.5
99.8% (90%)	±15%
96% (82%)	±10%
83% (69%)	±5%





Outline

Summary and Outlook

Timing of the Tile Signal

Observe directly: Significantly faster tile signal for direct coupling

Tile Uniformity Study

- SiPM Integration: Tight cell mounting, higher light yield, easy SiPM alignment
- Side Dimple: High Uniformity, easy design, scalable for 5 mm and 3 mm tiles
- NEW: Bottom Dimple: Only possible with very small casing
  $\rightarrow$ MPPC P-Series available as SMD type
  Avoids signal drop at coupling pos while keeping light yield high
  $\rightarrow$ Potential for perfect uniformity
  Further improvements under investigation!
  Test concept for 3 mm tiles!

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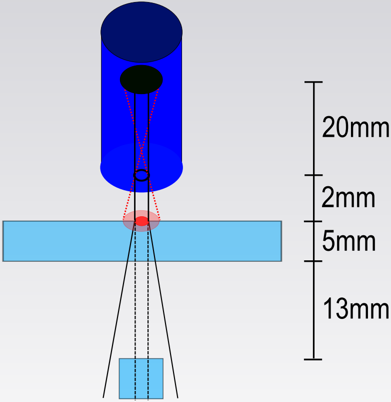
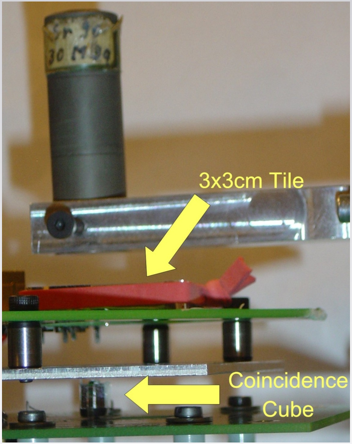
The Experimental Setup





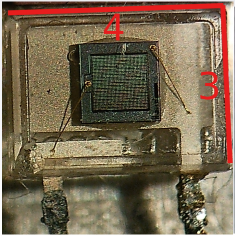
Trigger condition

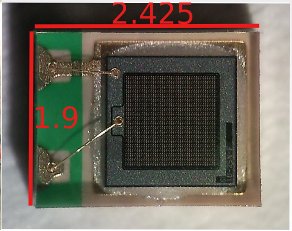
Signal of Tile & Coincidence Cube simultaneously $> 3\,$p.e.

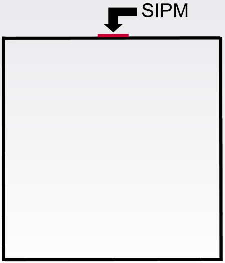
Tile Coupling

Coupling Properties

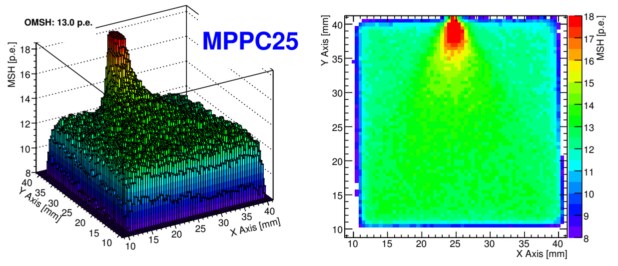
SiPM:	MPPC25, 1600 Pix, 2 plastic casings
Scintillator:	Saint Gobain BC-420
Tile Size:	$3 \times 3 \times 0.5$ and $3 \times 3 \times 0.3\,\mathrm{cm}^3$
Tile Surface:	Polished, completely enclosed by 3M mirror foil
SiPM Coupling:	Direct (Air Gap) fiberless coupling
Coupling Pos:	Center of one side face







Quantification of the Uniformity with Area Fractions



Determination of the Area Fractions

- Define the Tile Position (fixed to $3 \times 3\,\mathrm{cm}^2$):
  $\rightarrow$ Note: Measurement unprecise at tile edges
  Reason: Finite iris size of source casing $\rightarrow$ conelike e^- emission
- Determine OMSH: Mean value of all measurement points outside the extreme regions
- Determine Area Fractions: Fraction of all on-tile measurement points lying within a certain deviation region around the OMSH

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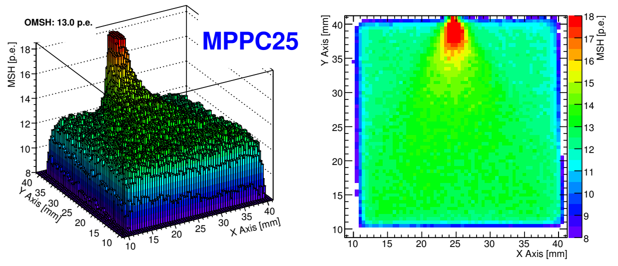

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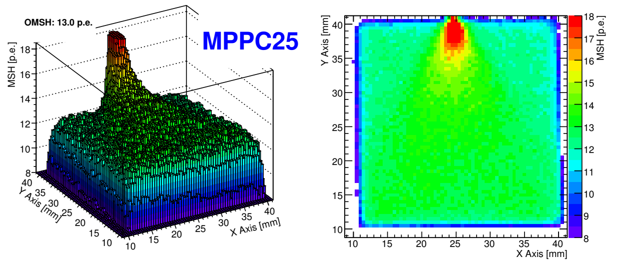

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