Uniformity studies of scintillator tiles coupled with Surface Mounted SiPM

Yong Liu

CALICE Collab. Meeting, Annecy

Sep. 10, 2013

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

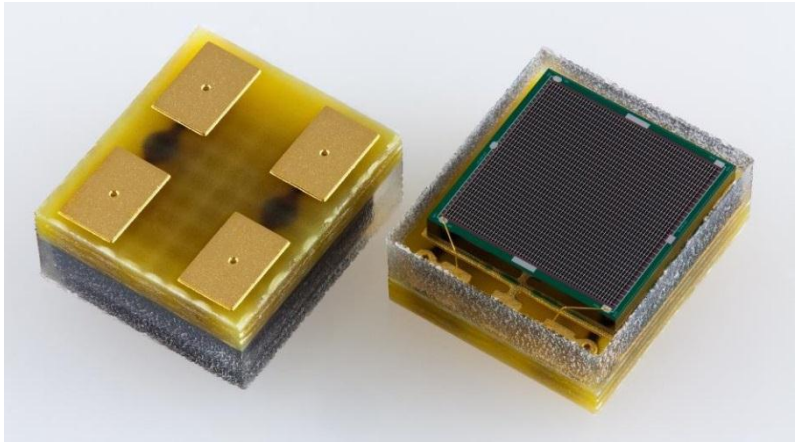
Outline

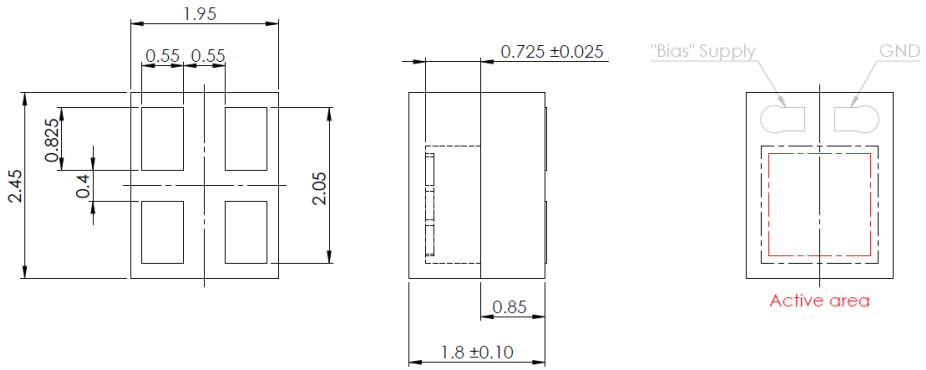
- Motivations
- Geant4 full simulation studies
- Uniformity measurements at MPI Physik, Munich
- Summary

Motivations

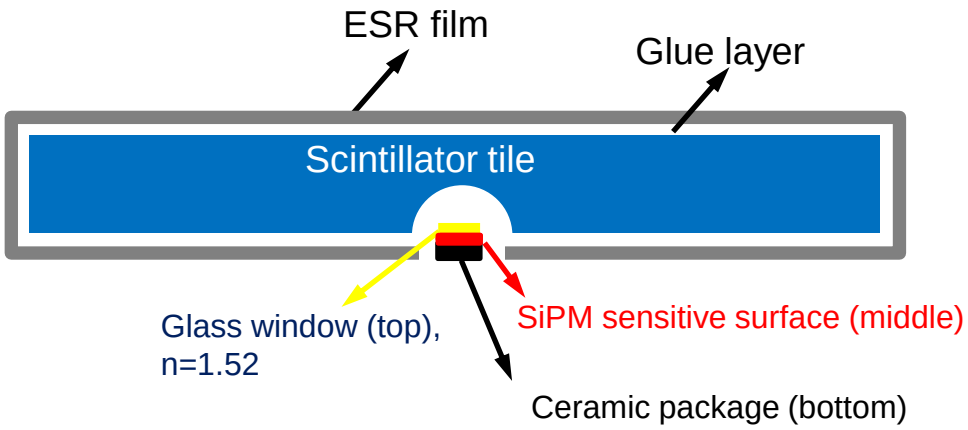
- Surface Mounted SiPM
  - No pins: more tolerance for alignment
  - Easier to solder on HBU boards automatically
    - Mass assembly by pick-and-place machine (talk by Phi Chau)

SMD SiPM module (KETEK)

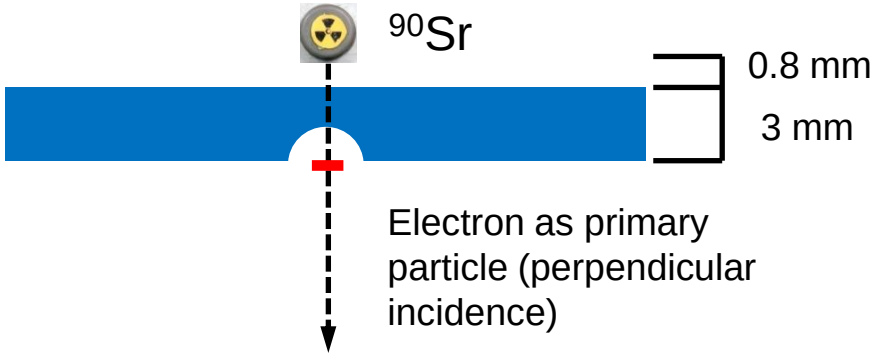




Simulation: setup for uniformity scan

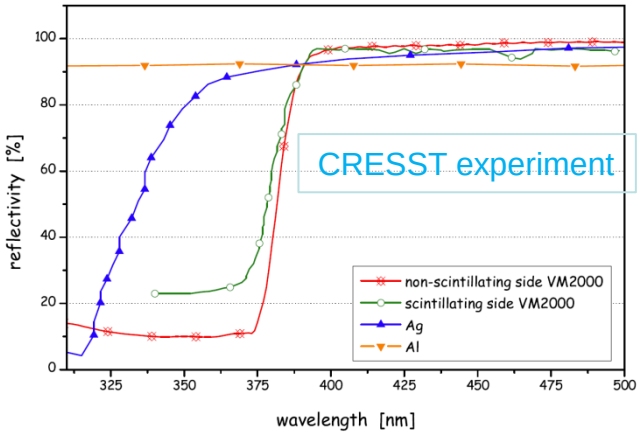


Scintillator tile: 30x30x3 mm³
KETEK SiPM: 1.2x1.2 mm²
Geant4 9.6.0.p01
Optical boundary model:
polished or ground (UNIFIED Model)



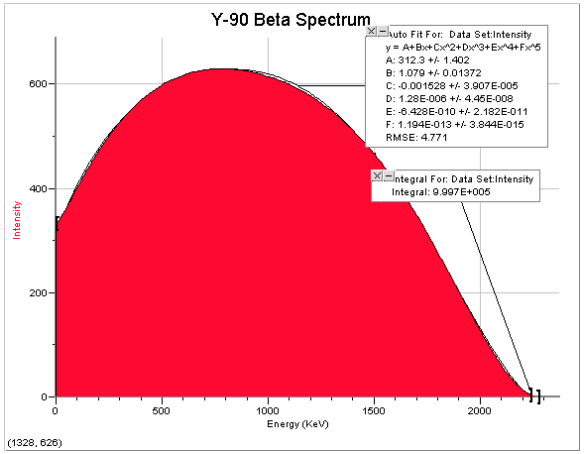
Scan step size: 1 mm
1 run: simulate 50 events at each position
30x30 positions to cover the whole tile area

Measured curve:
ESR reflectivity vs wavelength



Plot courtesy of Frank Simon

Simulation: details



^{90}Sr energy spectrum:

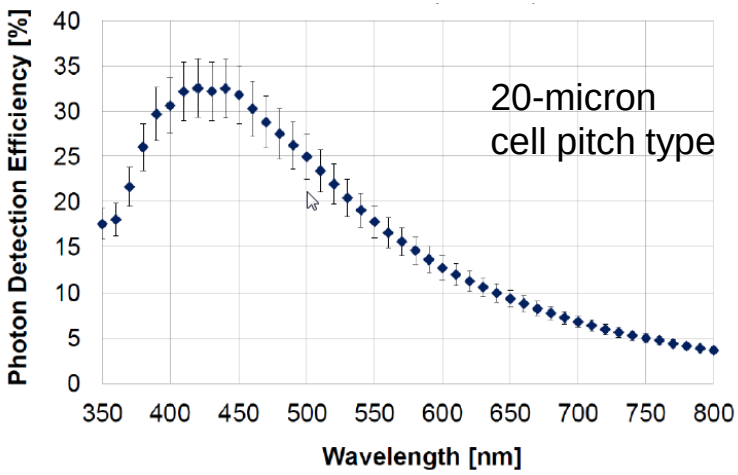
use normalized polymial fitting as p.d.f. to sample

$$^{90}Sr \rightarrow {}^{90}Y + e^- + \bar{\nu}$$

$$^{90}Y \rightarrow {}^{90}Zr + e^- + \bar{\nu}$$

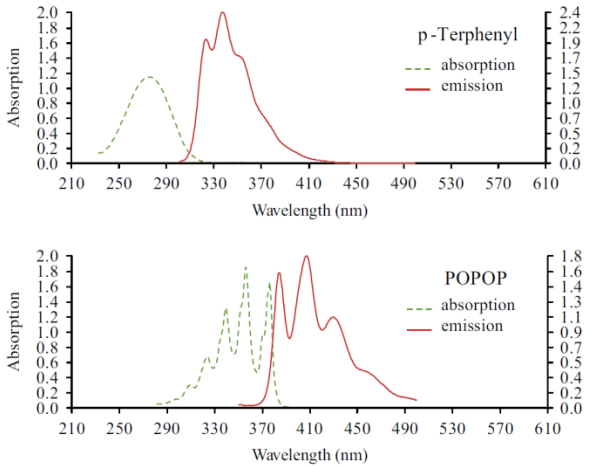
Ref 1: Silicon Strips and Pixel Technologies, Excellence in Detectors and Instrumentation Technologies 2011, CERN

KETEK PDE curve



Ref 2: SiPM Development at KETEK, CALICE Collaboration Meeting, March 2013 Hamburg

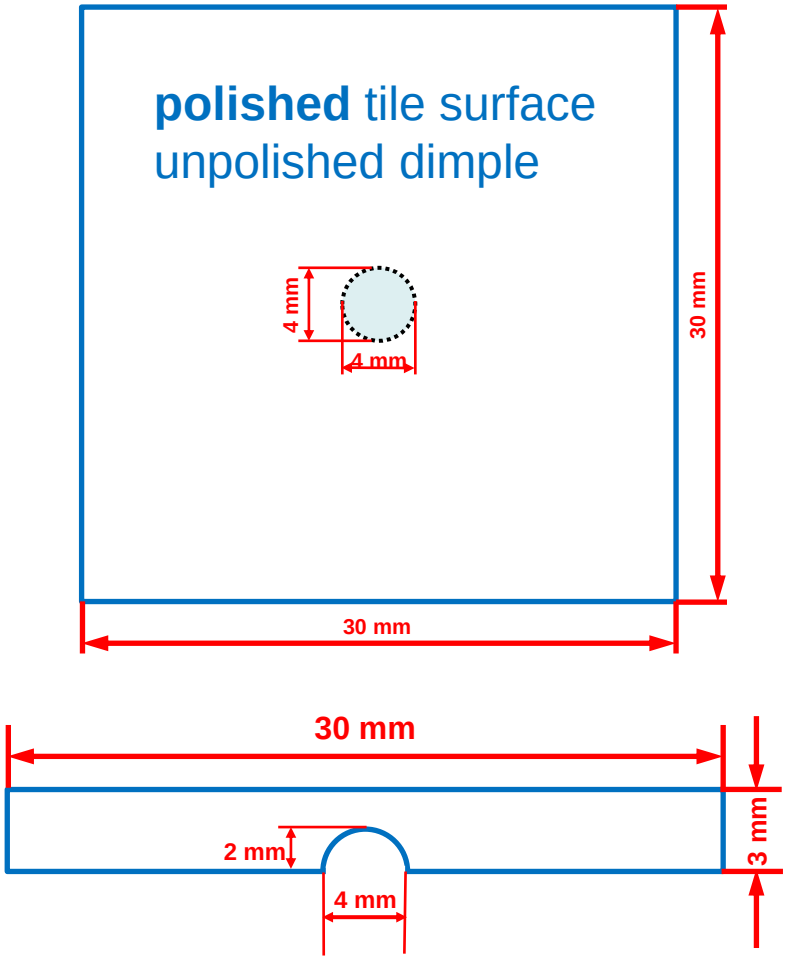
Scintillator emission spectra

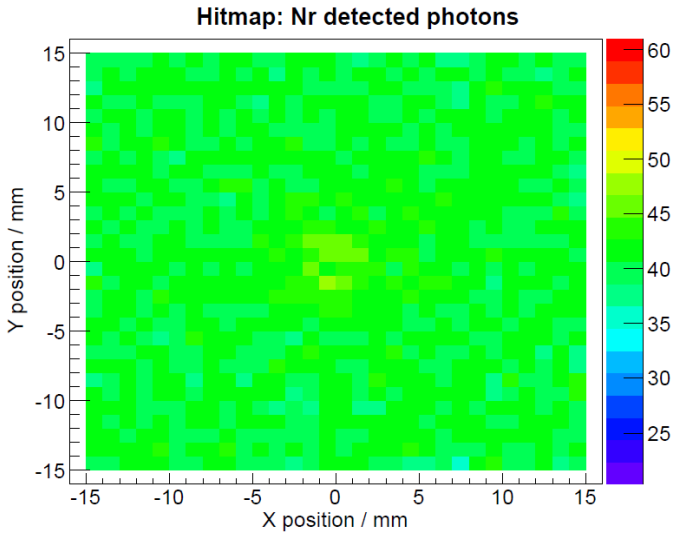


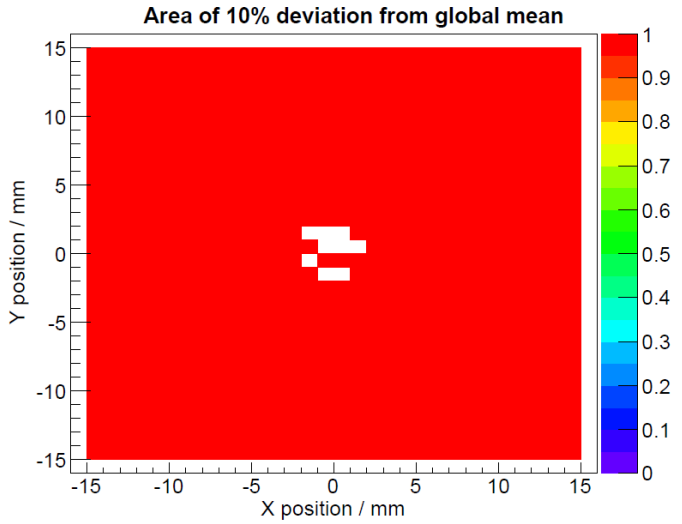
Scintillator from NA62, produced by IHEP (Protvino, Russia)

Ref 3: Nuclear Instruments and Methods in Physics Research A 577 (2007) 523

Simulation: hemisphere dimple (1)

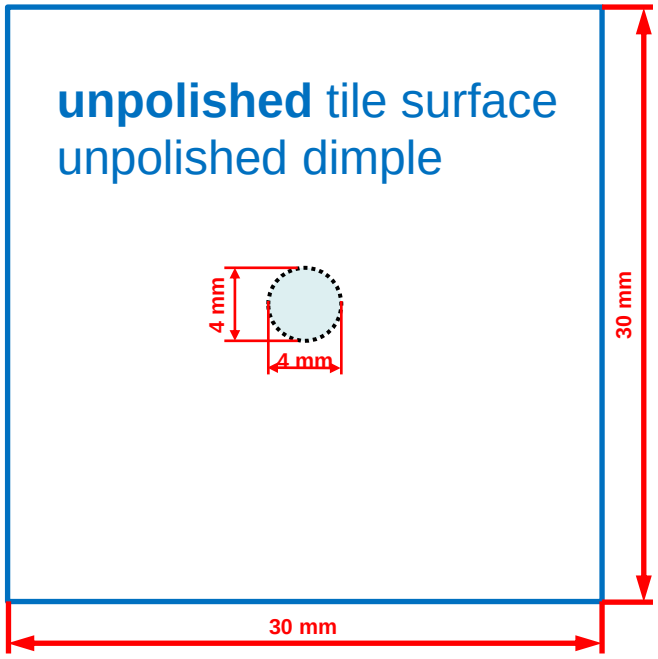


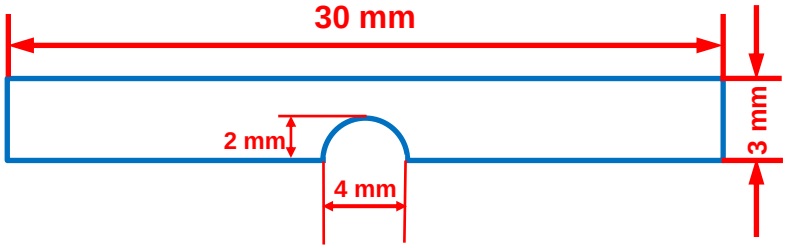


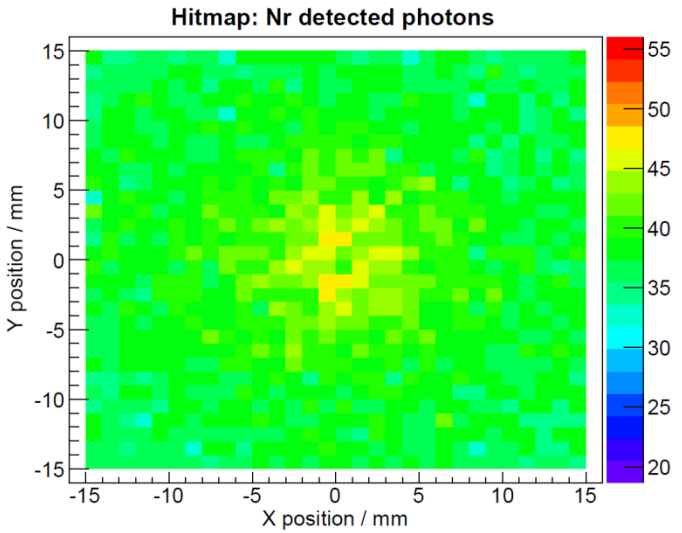


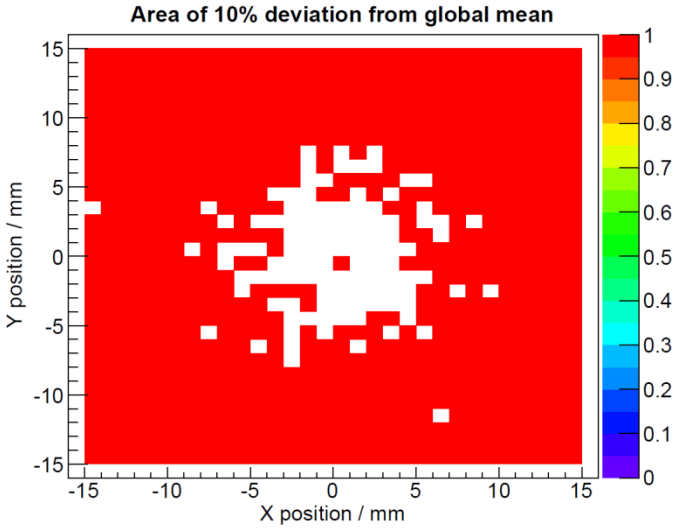
Average: 40.7 detected photons
10% deviation from average: 99.0 % area

Simulation: hemisphere dimple (2)



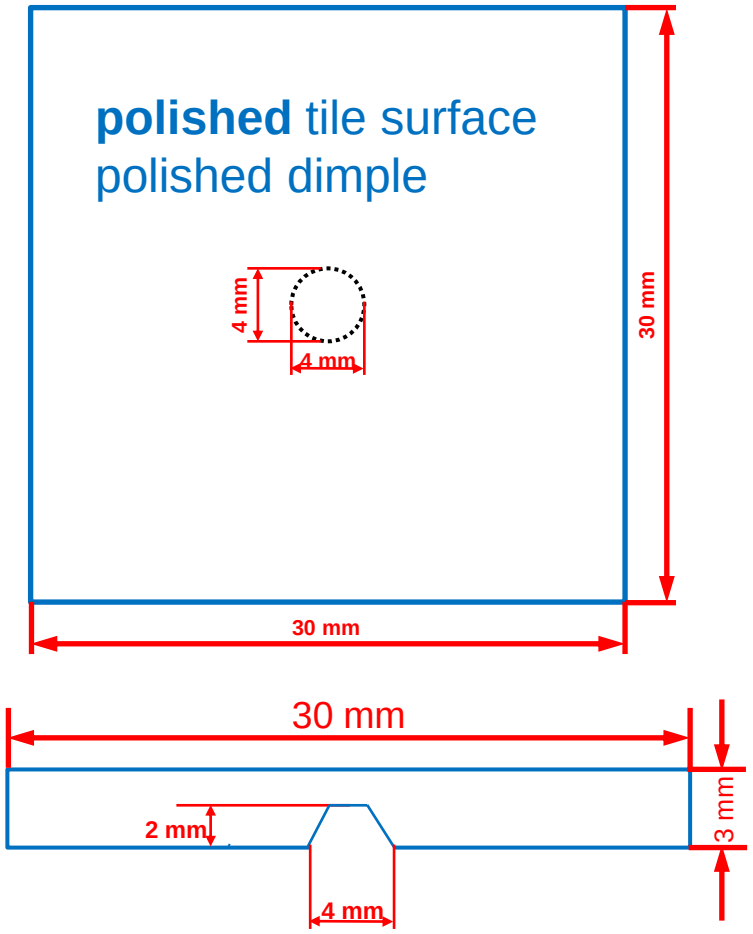




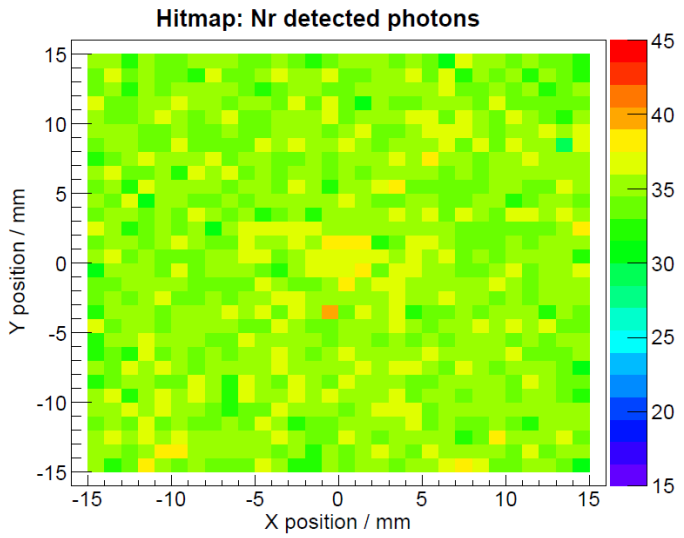


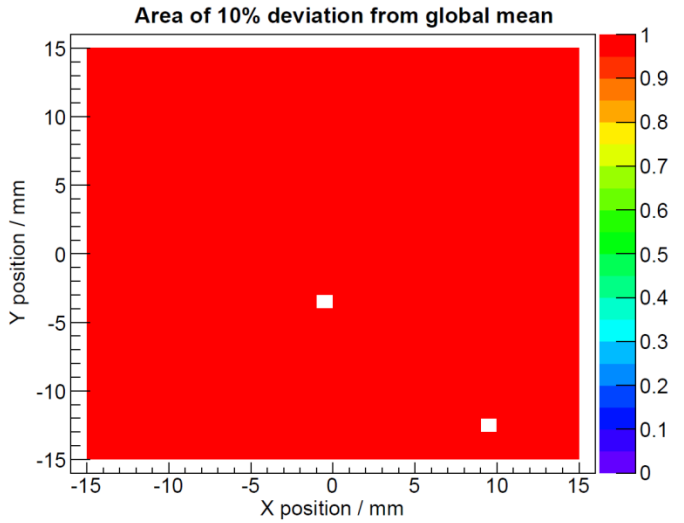
Average: 37.3 detected photons
10% deviation from average: 87.7 % area

Simulations: cone-like dimple (1)



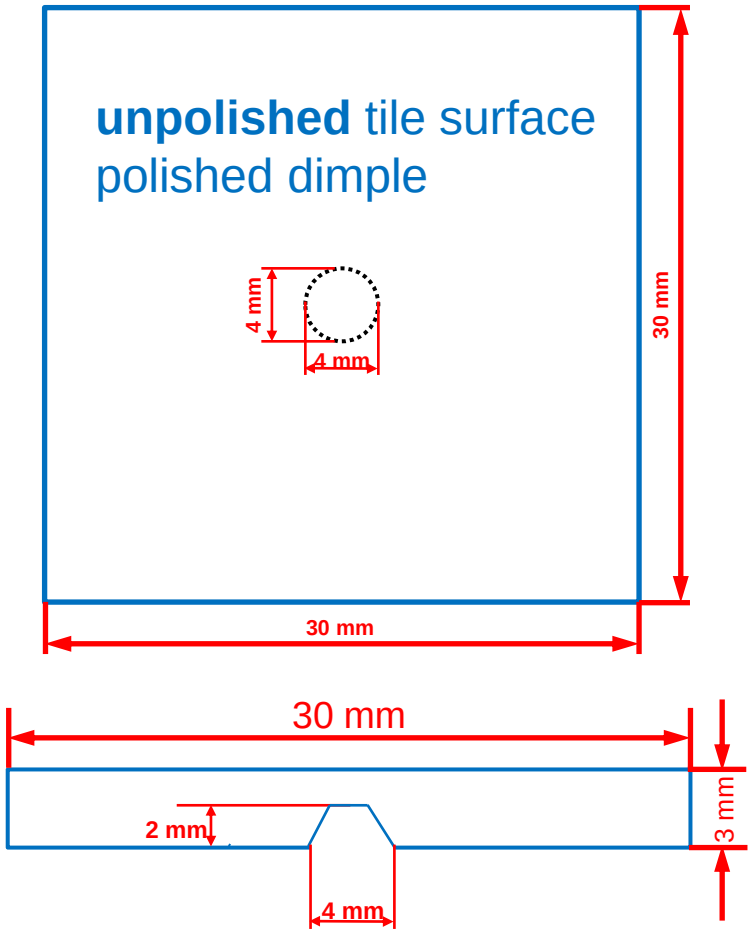
Different dimple shape if it is polished

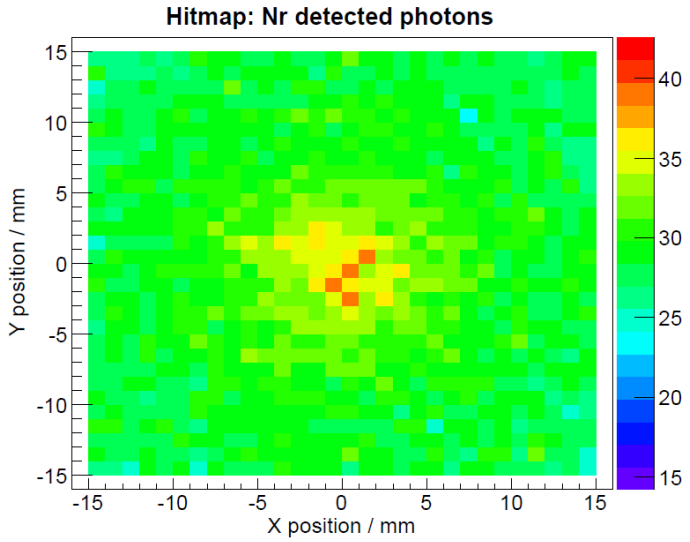


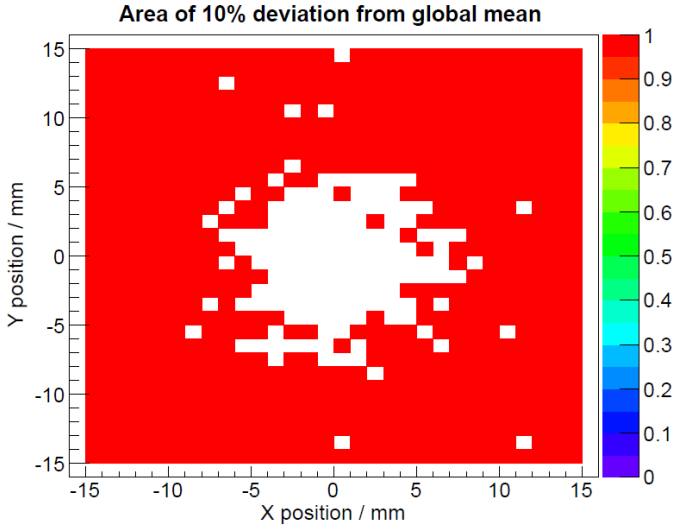


Average: 34.7 detected photons
10% deviation from average: 99.7 % area

Simulations: cone-like polished dimple (2)



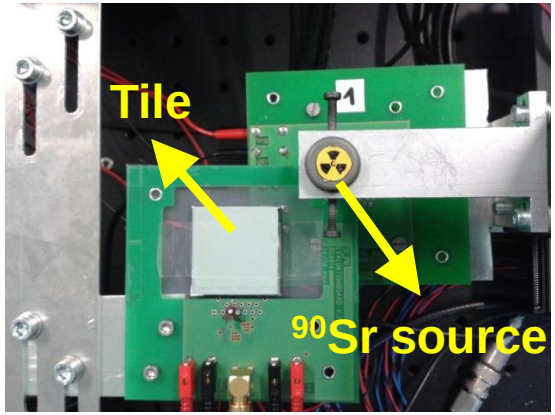


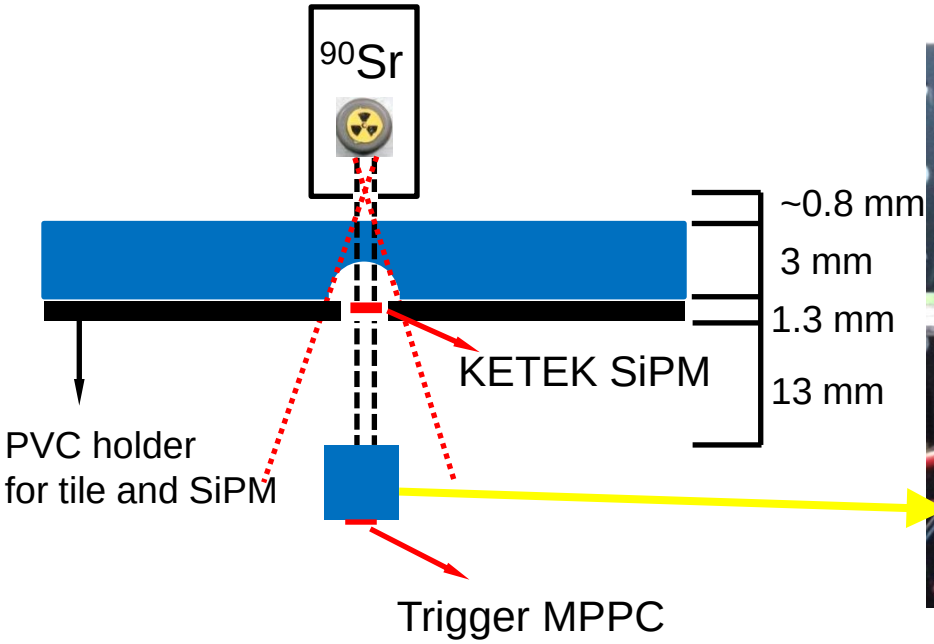


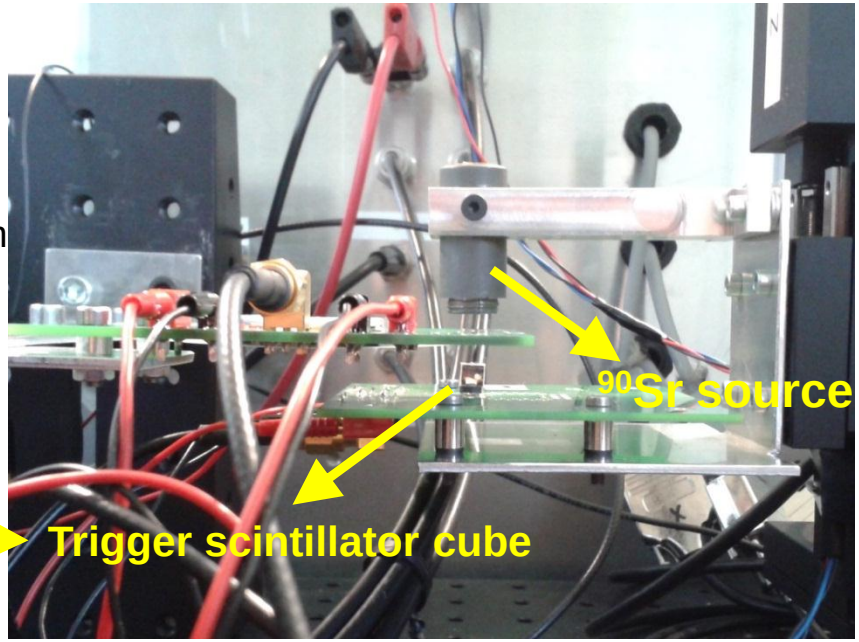
Average: 28.4 detected photons
10% deviation from average: 89.3 % area

Uniformity Measurements in MPI, Munich

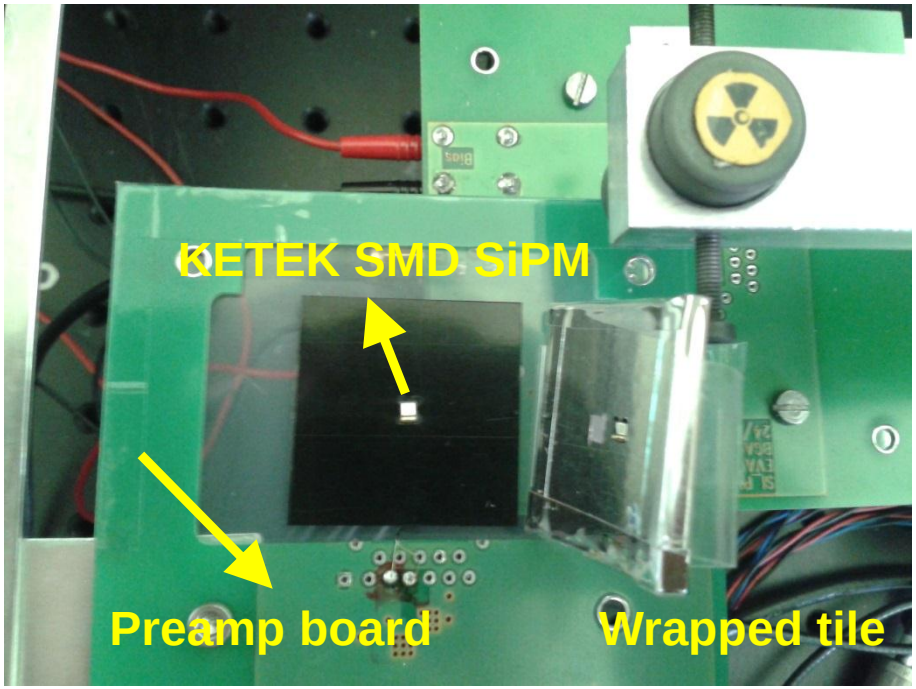
- Test setup (Aug, 2013)
  - Strontium 90 source
  - Air-coupled with KETEK SiPM
  - Glue-coupled with 3M foil (DESY)

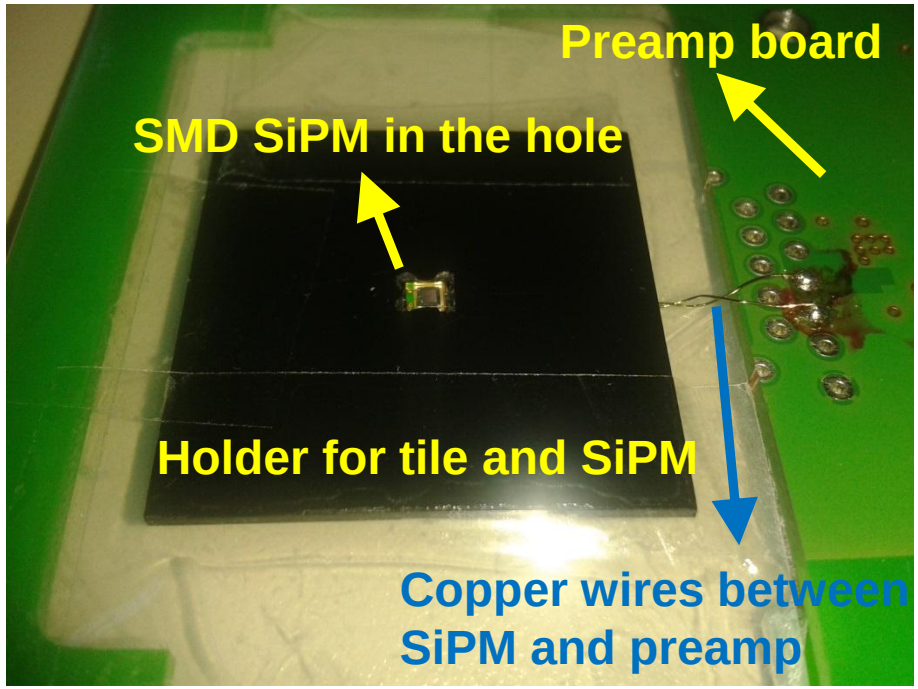






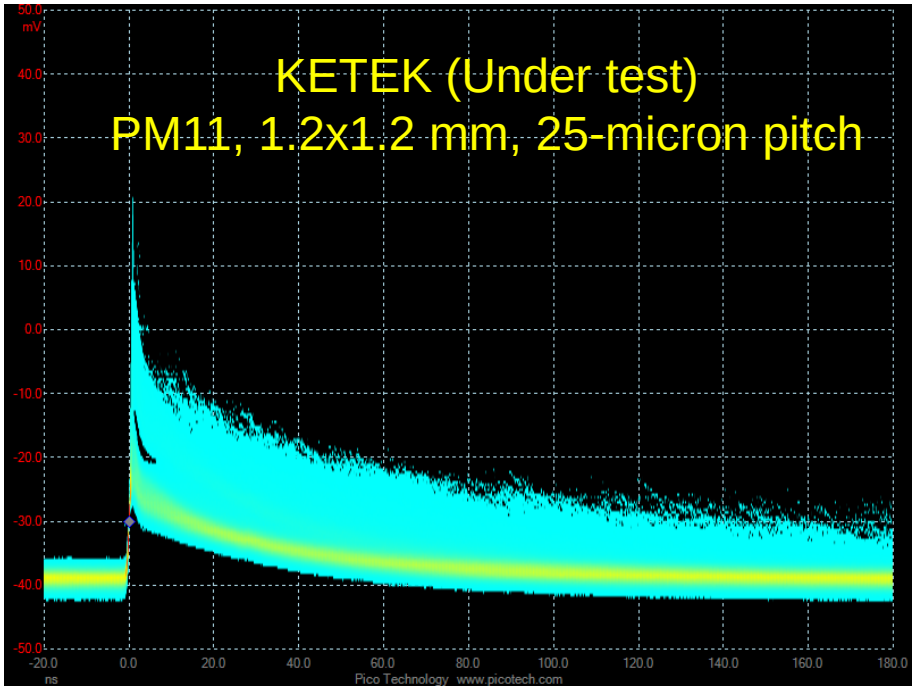
Wrapped tile and its mechanical support

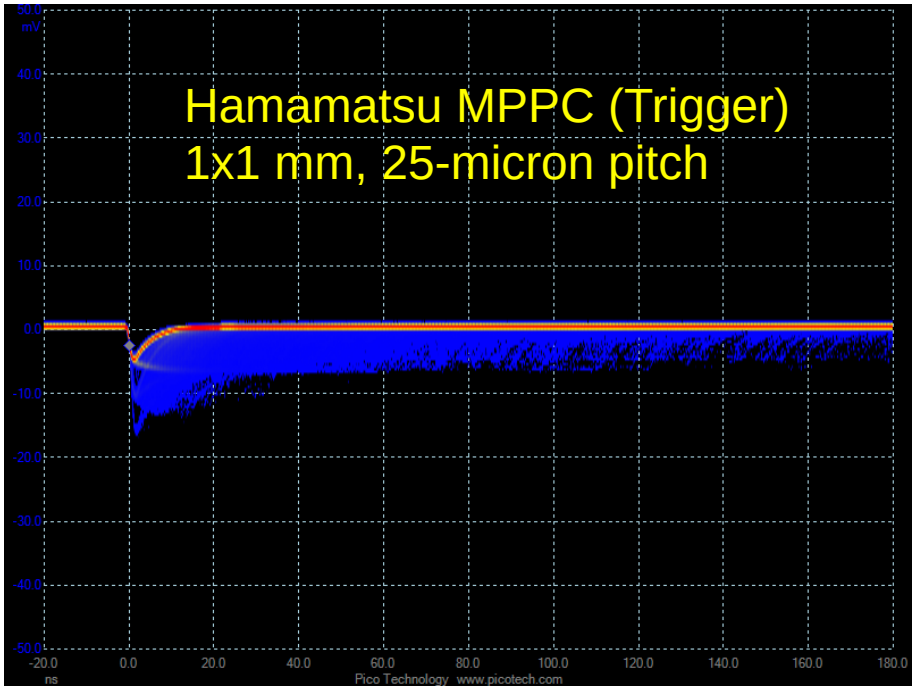




Note: it is difficult to make sure that SMD SiPM surface is horizontal and to evaluate its tilted angle.
This effect may cause an influerence on uniformity scan later on.

Single p.e. pulses: KETEK and Hamamatsu





Single p.e. pulse height: ~16 mV
Recovery time: ~100 ns
Threshold: 0.5 p.e.
Operational voltage: 32.4 V

Single p.e. pulse height: ~5 mV
Recovery time: ~10 ns
Threshold: 0.5 p.e.
Operational voltage: ~71 V

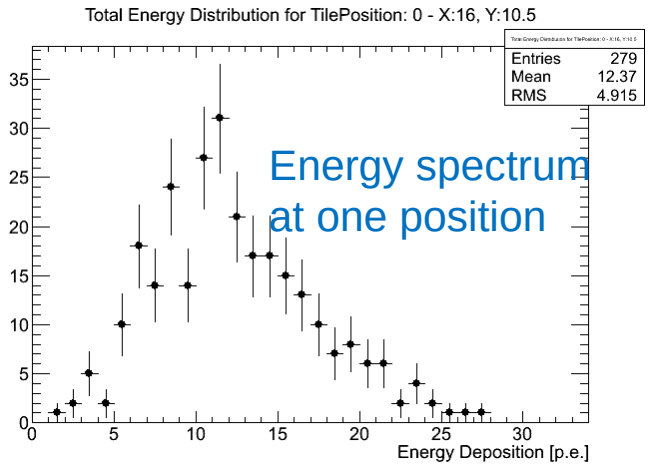
Run status

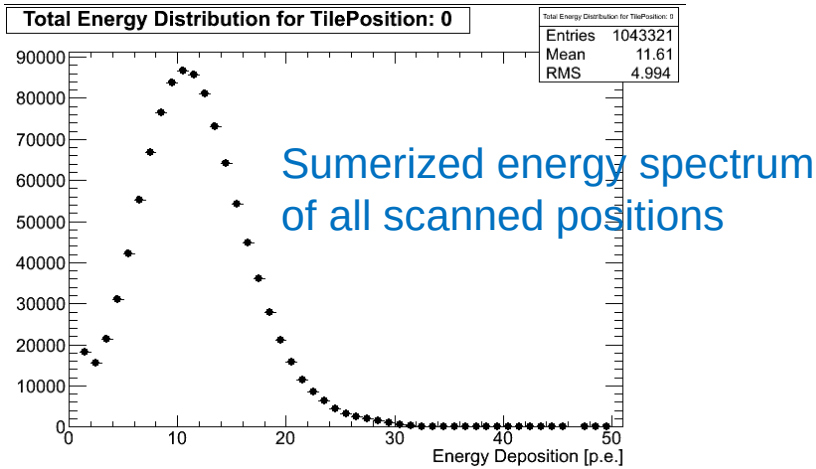
- Operations
  - KETEK SiPM: 32.4 V (20% overvoltage)
  - Trigger SiPM: threshold 7.5 p.e.
  - Time window for data taking: 640 ns

- Data taking (scan step size 0.5 mm)
  - 6 runs of full scanning
    - 3 shapes of dimples
    - 2 types of scintillator tile surfaces
      - polished, unpolished

Data analysis

- Time window cut: 9.6ns
  - SiPM after-pulse free
  - Similar technique to T3B analysis
- Energy spectrum (detected p.e.)
  - Get mean value of energy deposition at each position
  - Fill this mean into 2D histogram

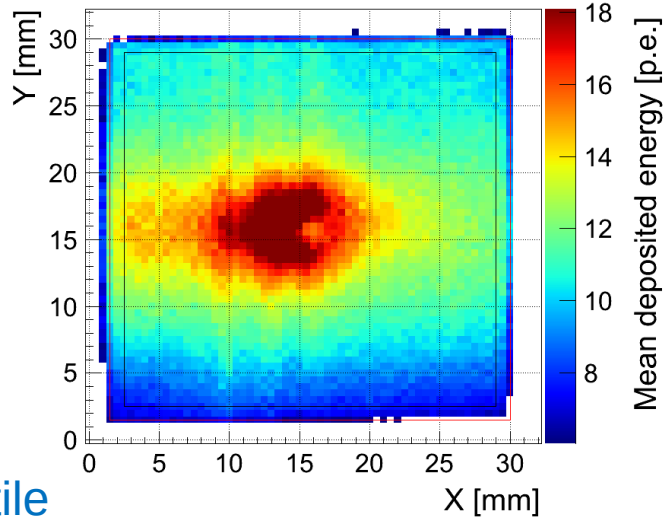


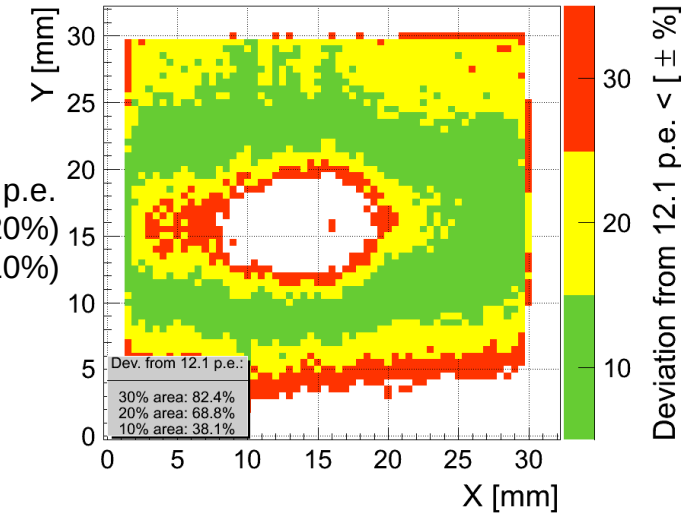


Polished dimple

Plots drawn in MPI T3B analysis framework

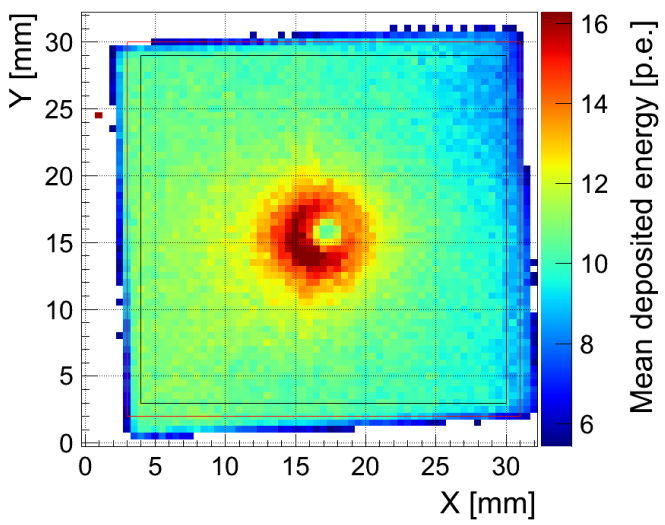
Polished tile surface

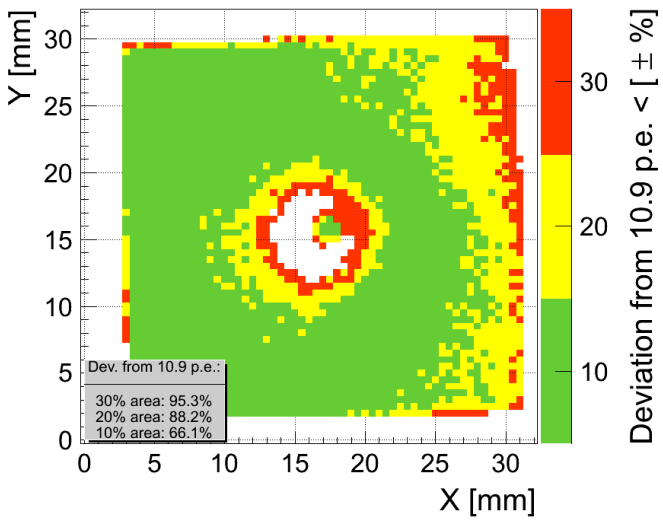




Dev. From 12 p.e.
68.8% area (20%)
38.1% area (10%)

Unpolished surface

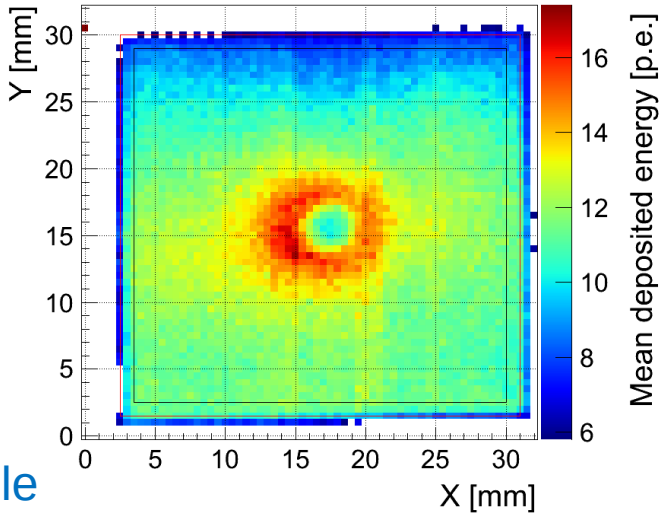


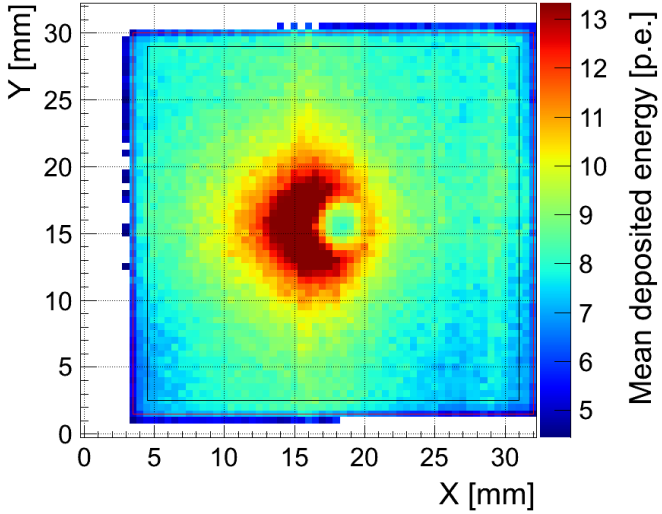


Dev. from 11 p.e.
88.8% area (20%)
66.1% area (10%)

Unpolished dimple

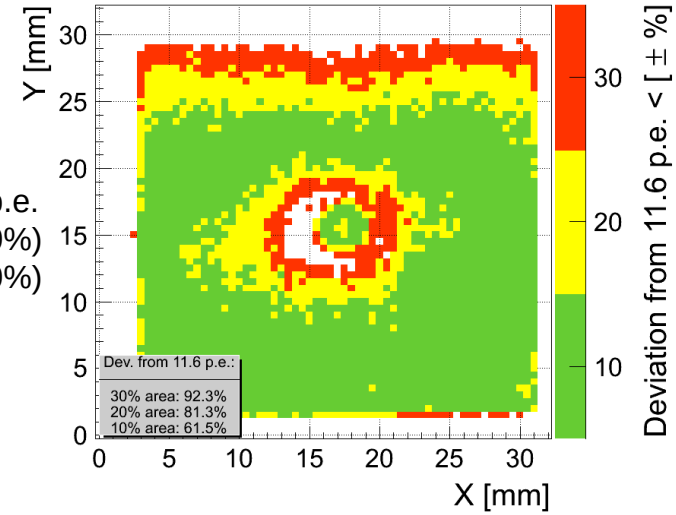
Plots drawn in MPI T3B analysis framework



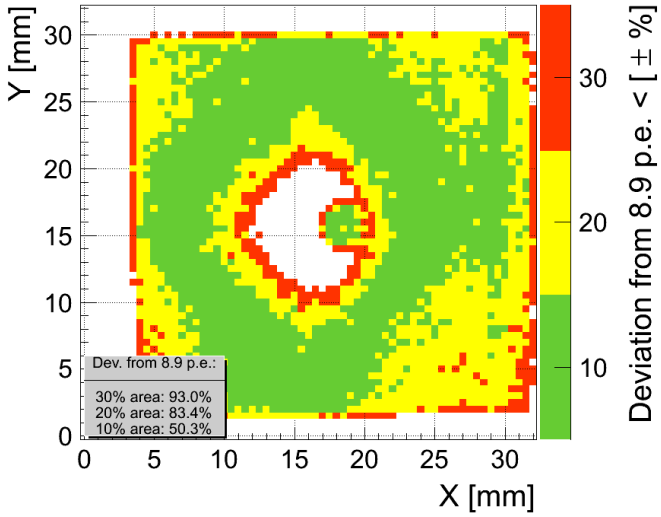


Polished tile surface

Unpolished surface



Dev. From 12 p.e.
81.3% area (20%)
61.5% area (10%)



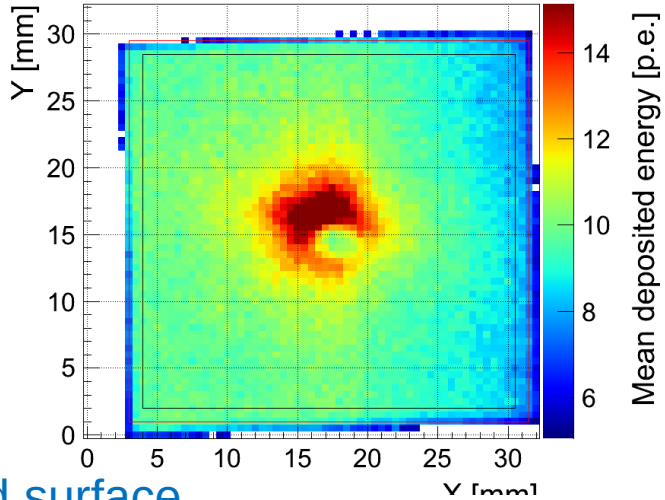
Dev. from 9 p.e.
83.4% area (20%)
50.3% area (10%)

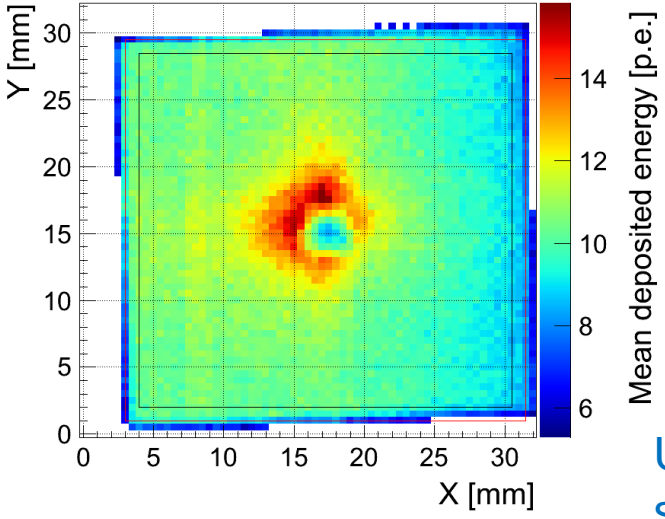
Unpolished dimple

Dome height: 0.5mm;
box depth: 1.0 mm

Plots drawn in MPI T3B analysis framework

Dome height: 0.5mm;
box depth: 1.5 mm

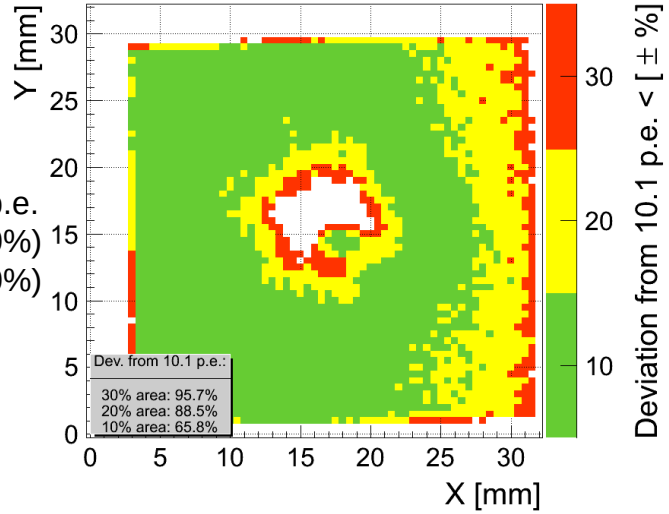


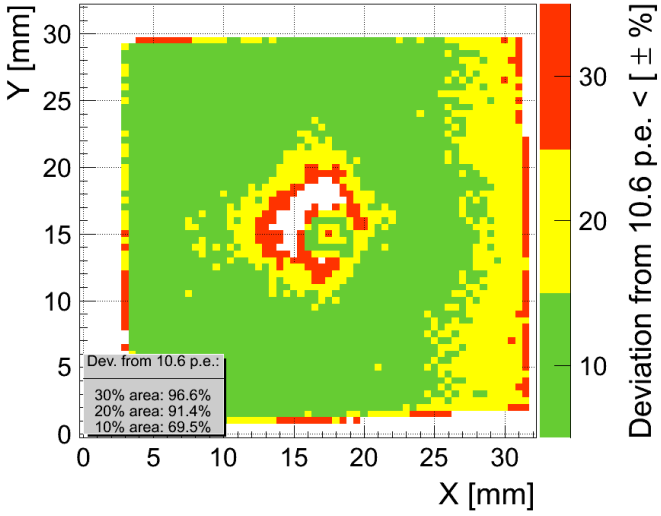


Unpolished surface

Unpolished surface

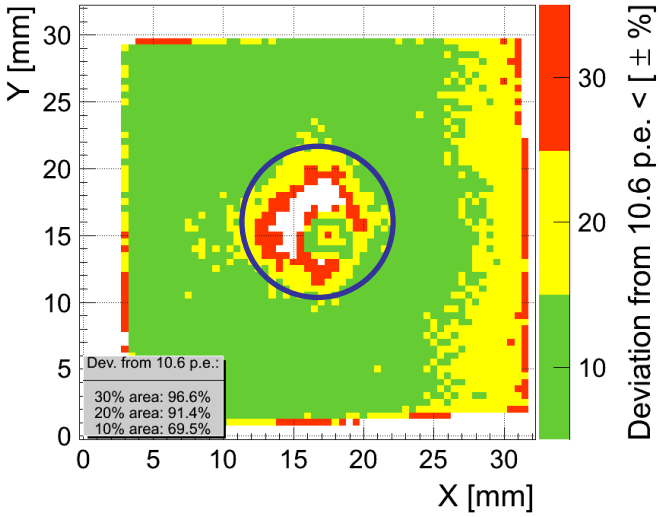
Dev. From 10 p.e.
88.5% area (20%)
65.8% area (10%)





Dev. from 11 p.e.
91.4% area (20%)
69.5% area (10%)

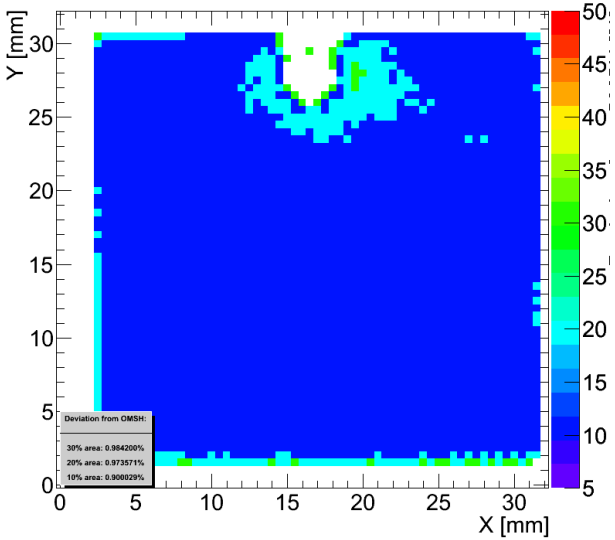
Comparison with uniformity of DESY tile



Overal mean: 11 p.e.

Deviation from mean	Tile area within this deviation
30 %	96.6 %
20 %	91.4 %
10 %	69.5 %

Non-uniformity introduced by dimple in circle is ~14% of tile
Area. Area within 10% dev. would be ~86%, close to the standard tile



Overall mean signal height: 28.4 p.e.

Deviation from OMSH	Tile area within this deviation
30 %	98.4 %
20 %	97.4 %
10 %	90 %

Ref: First results from ITEP Molded Tiles with Dimple, Christian Soldner, CALICE Collab. Meeting, Shinshu, 2012

Summary

- Simulation
  - Tiles coupled with SMD SiPM
  - Polished tiles suggest better uniformity and more p.e.s
- Uniformity measurements
  - Tiles with different dimples and surface treatment
  - ~86% of tile area can be within 10% deviation from average, if only non-uniformity from dimple area is taken into account
- Simulation and measurements are not well consistent now
  - More detected photons and better uniformity in MC

Outlook

- Uniformity measurements
  - Figure out better way to fix SMD SiPM
    - Horizontal sensitive surface, with no tilting
    - Precise center-positioned
  - Promising if shape is optimized further
  - ~86% of tile area within 10% dev. can be foreseen
- Simulation
  - Energy cut in spectrum of 90Sr source
    - Make sure electrons can pass through entire tile
  - Produce higher statistics of MC samples
    - Suppress statistical fluctuations
  - Optical boundary model for tile surface and foil

Thank you!
Especially thanks to
Frank Simon, Christian Soldner and Michal Tesař in MPI Munich for their great help!

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PRISMA

CALICE Calorimeter for ILC

Backup

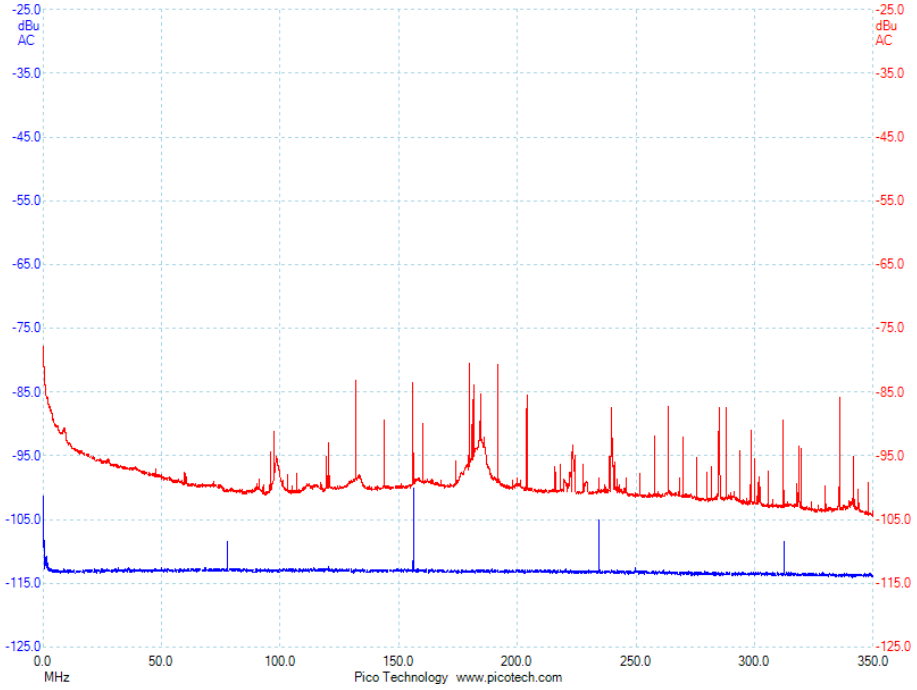
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

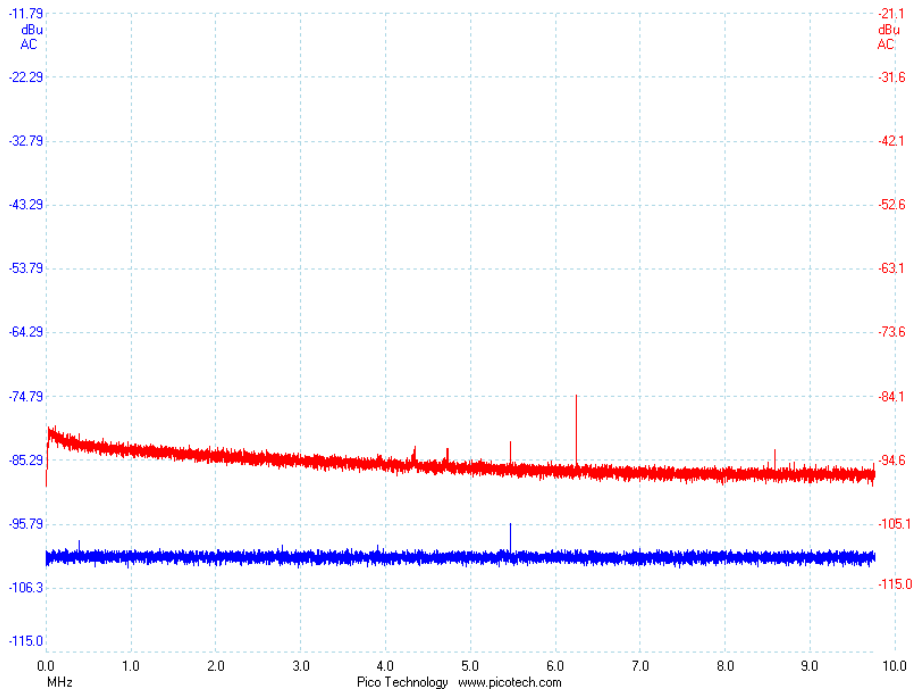
PRISMA

CALICE Calorimeter for ILC

SiPM noise: frequency spectra

Red: KETEK SMD SiPM PM11
Blue: Trigger SiPM (Hamamatsu MPPC, pinned)



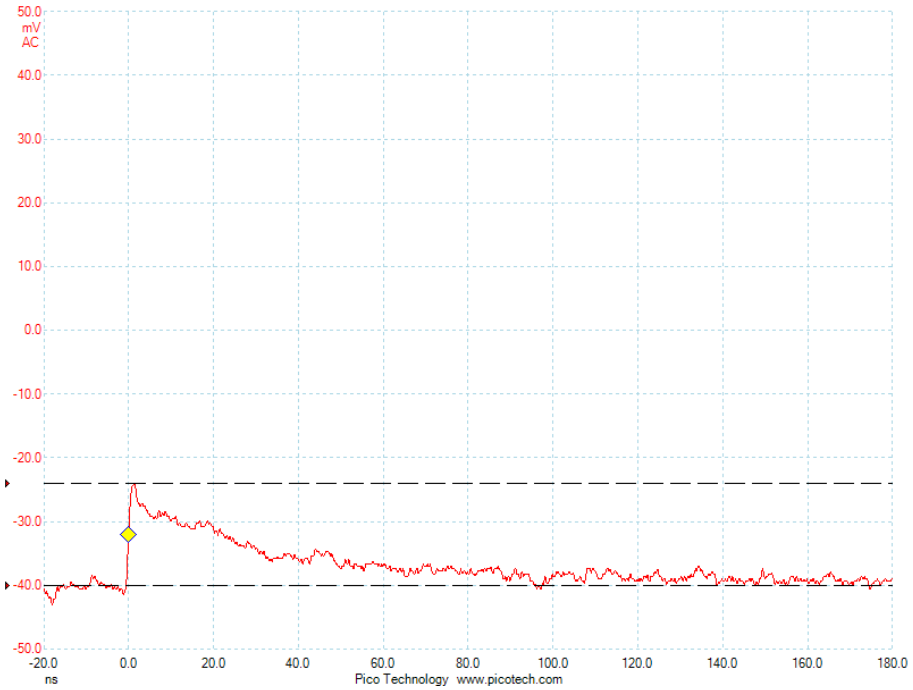


KETEK SiPM soldered with ~5 cm wires: pick up noises at different frequencies

KETEK SiPM soldered with ~1.5 cm Twisted wires: no spike noise observed

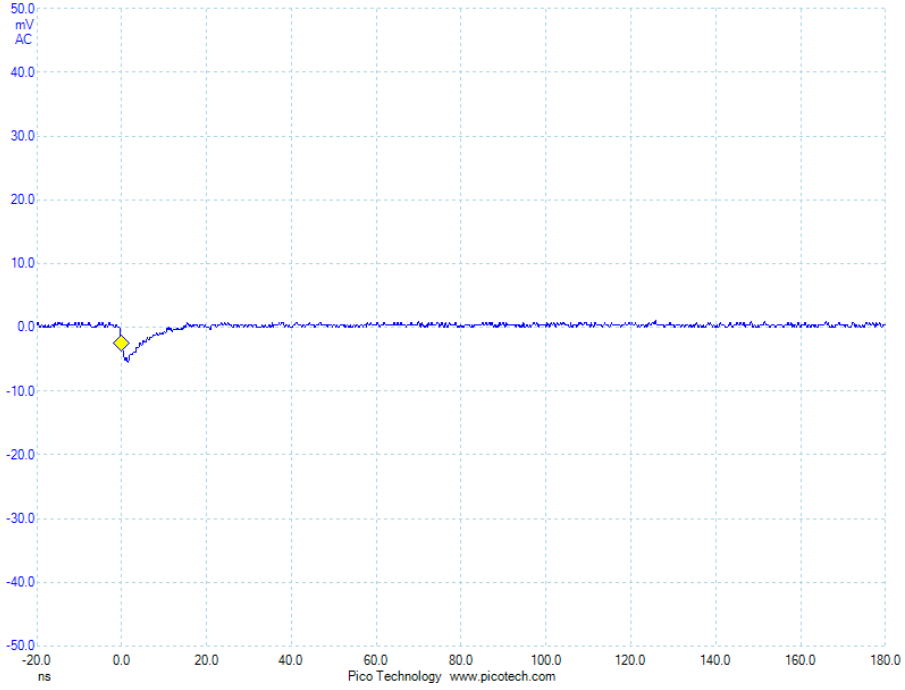
Single p.e. pulses: KETEK and Hamamatsu

KETEK (Under test)



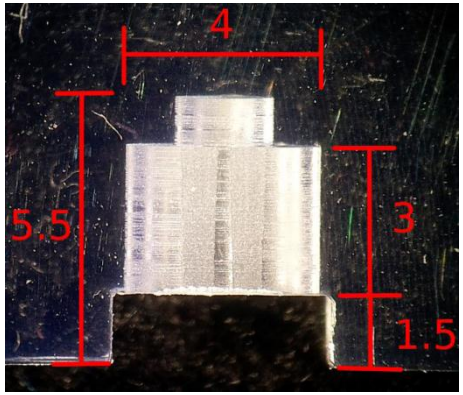
Single p.e. pulse height: ~16 mV
Recovery time: ~100 ns
Threshold: 0.5 p.e.
Operational voltage: 32.4 V

Hamamatsu (Trigger)

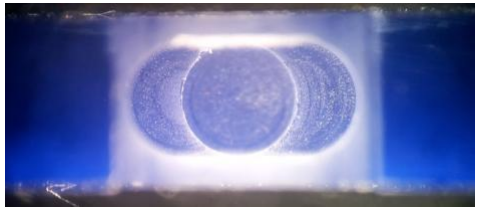


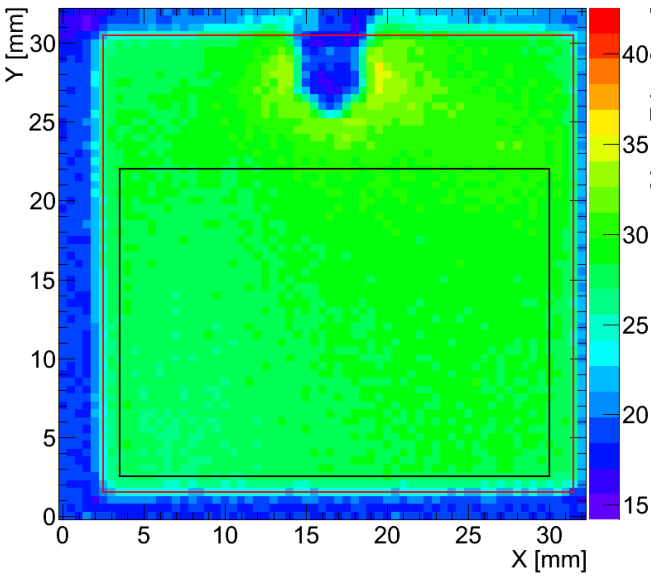
Single p.e. pulse height: ~5 mV
Recovery time: ~10 ns
Threshold: 0.5 p.e.
Operational voltage: 21.7 V

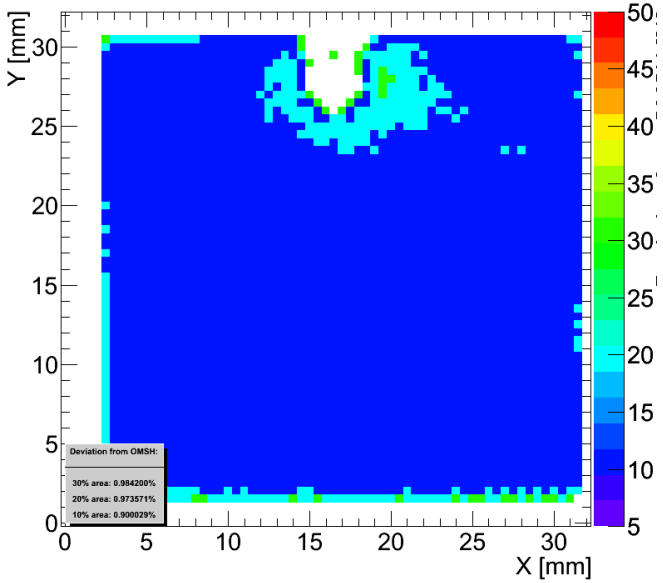
Uniformity of DESY tile with special dimple



First results from ITEP Molded Tiles with Dimple, Christian Soldner, CALICE Collab. Meeting, Shinshu, 2012



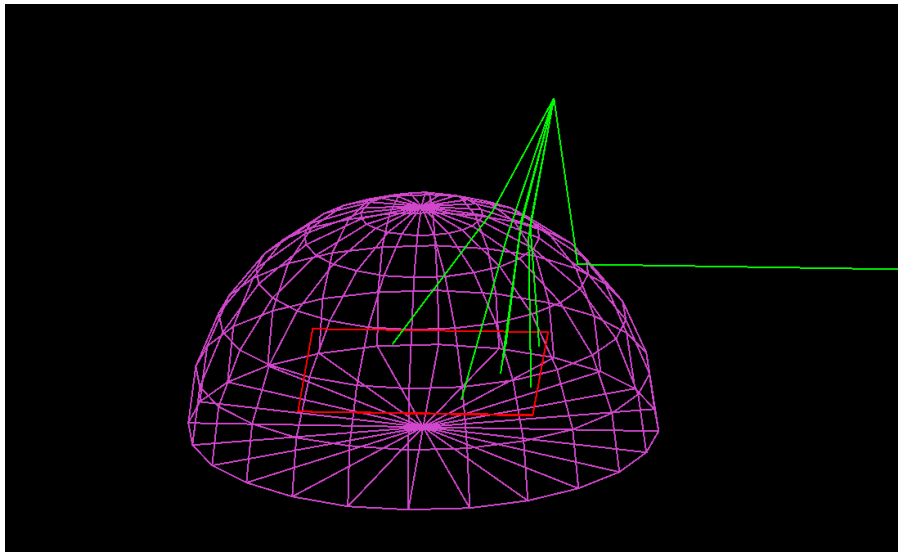


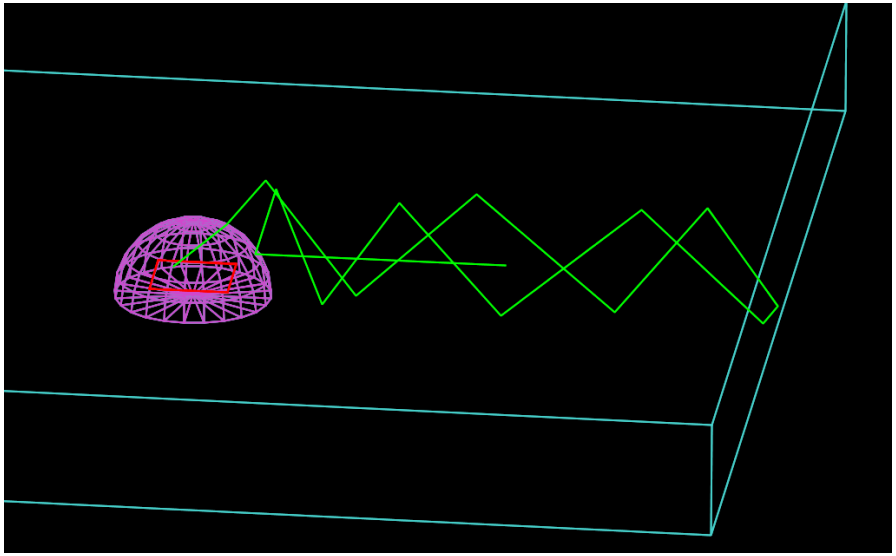


Overall mean signal height: 28.4 p.e.

Deviation from OMSH	Tile area within this deviation
30 %	98.4 %
20 %	97.4 %
10 %	90 %

Optical photons at hemisphere dimple in G4





Scintillator tile: 30x30x3 mm³
Dimple in the center of bottom surface

Starting position and momentum direction of optical photons

$$x = 8mm, y = 0mm, z = 0mm$$
$$\theta = 90°, \varphi = 180°$$

Optical surface:
etched tile air coupled with ESR

$$x = 8mm, y = 0mm, z = -0.3mm$$
$$\theta = 90°, \varphi = 180°$$

Critical angle of total reflection at dimple

$$\theta_c = \arcsin\left(\frac{1}{1.58}\right) = 39.3°$$