MegaTile studies:
with a focus on simulation

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CALICE Collaboration Meeting at UT Arlington

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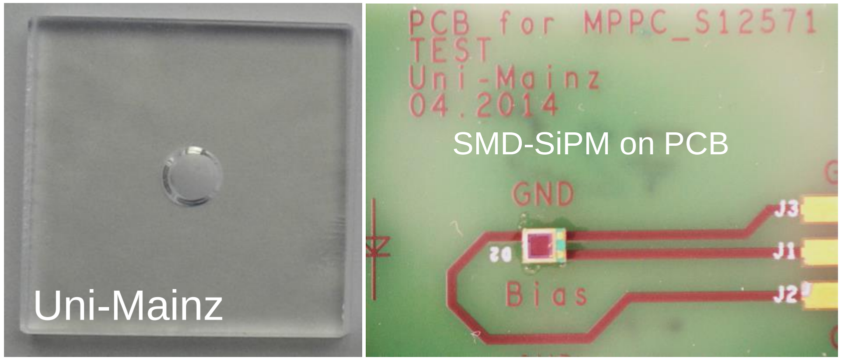
PRISMA DETECTOR LAB

Bundesministerium für Bildung und Forschung

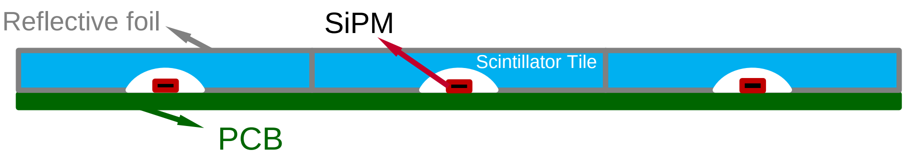
CALICE

Scintillator HCAL: towards mass assembly

Surface-mounted Design



HCAL detector unit: a scintillator tile (30×30×3 mm³) with a SiPM



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  - Optimized with Geant4 full simulation

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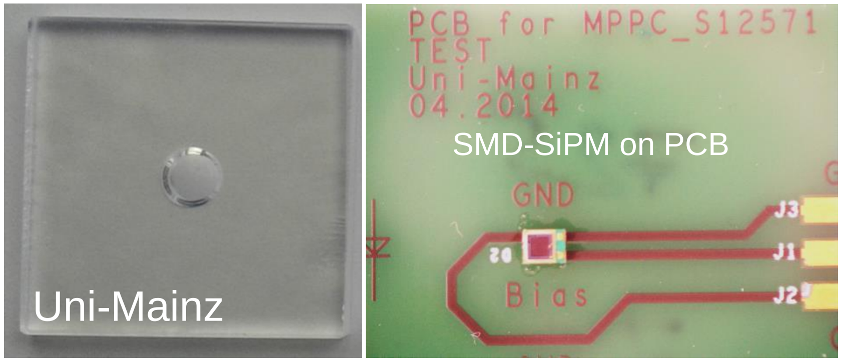

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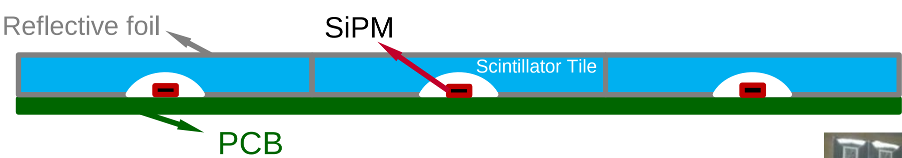
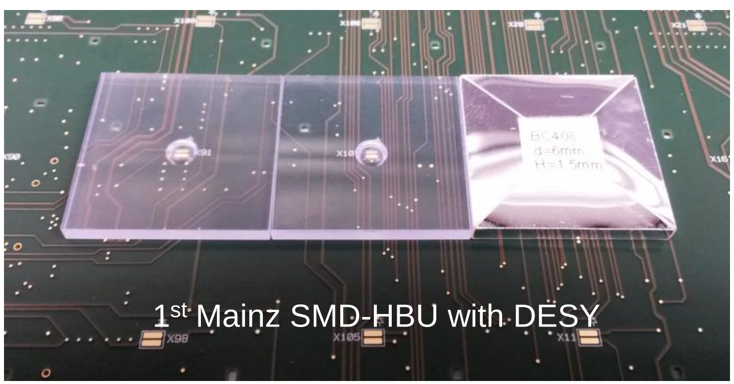
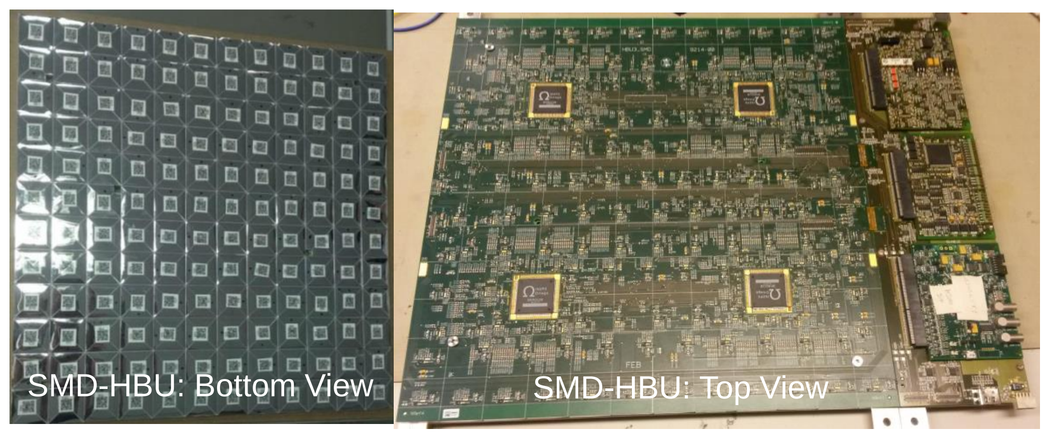


- Surface-mount tile design
  - Optimized with Geant4 full simulation
  - 1st board built successfully in 2014





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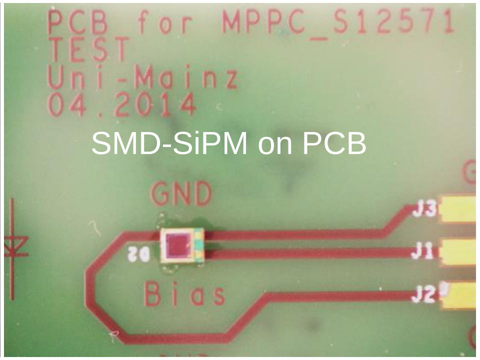

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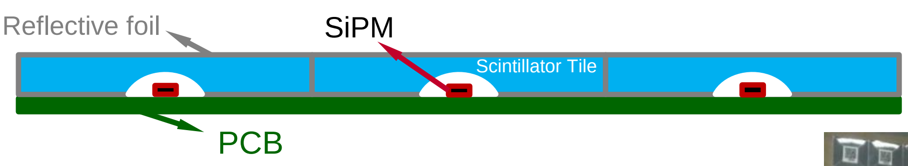
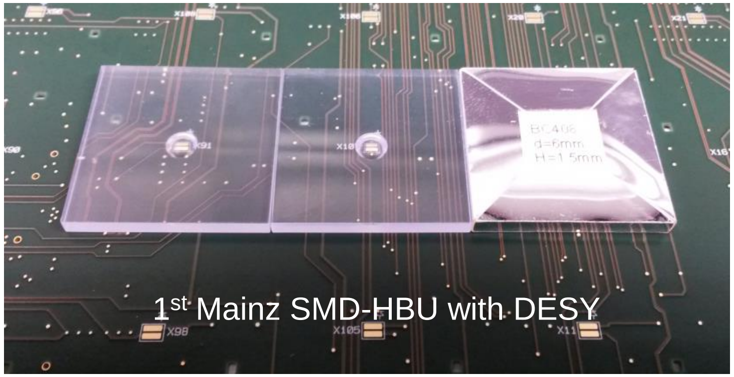
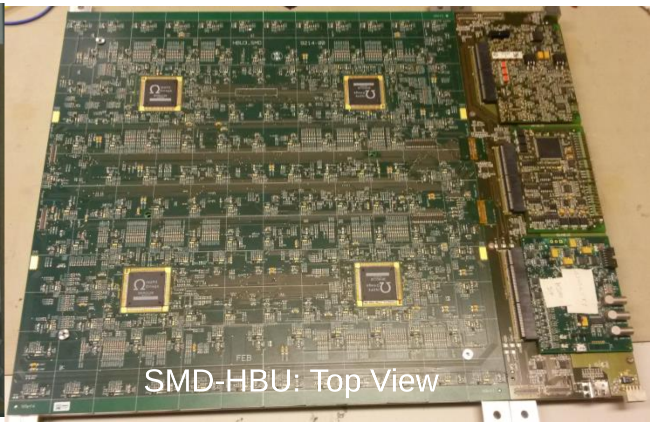


- Surface-mount tile design
  - Optimized with Geant4 full simulation
  - 1st board built successfully in 2014
  - Adopted as a baseline design for the tech. prototype (2015-2018)
  - 6 new SMD-HBUs fully assembled
    - New SiPMs and updated tile design
    - Tile assembly at Mainz

Details in talks from Katja and Phi

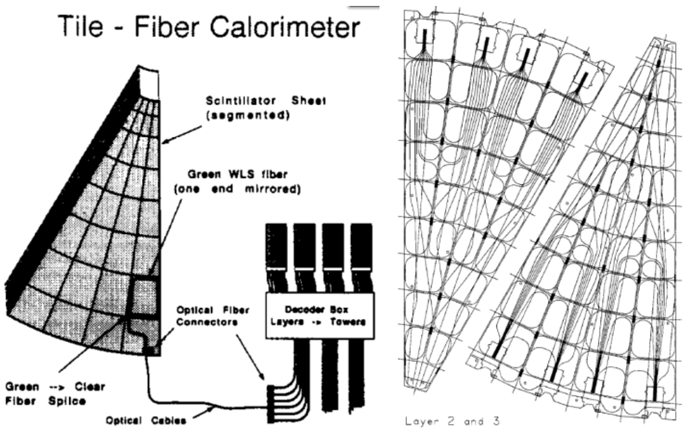




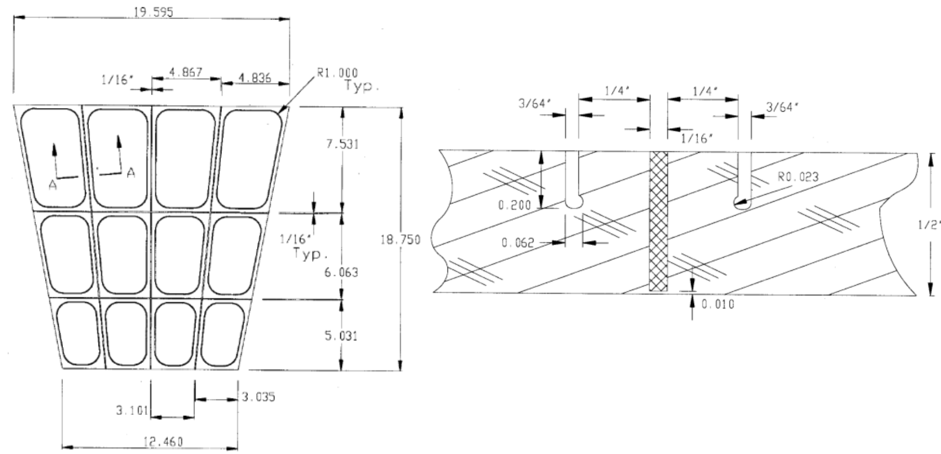
Can we further simplify the design for more efficient mass assembly?

Megatile: applications in the past and at present

CDF End Plug Upgrade HCAL (1994)



D0 Run II Inter Cryostat Detector (1999)



Note: this list is not meant to be exhaustive; the year corresponds to the earliest one appearing in the documents at hand

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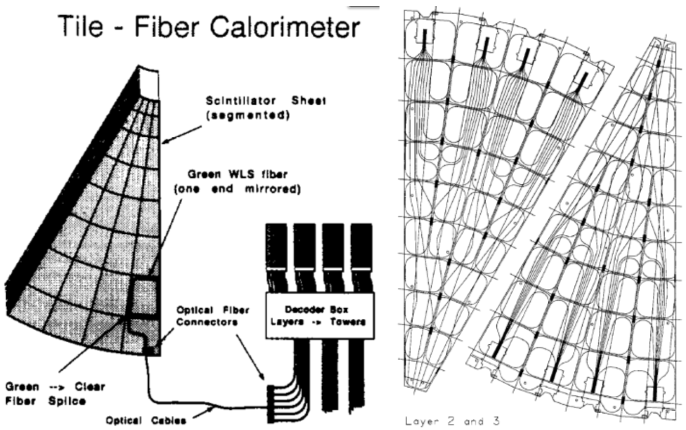

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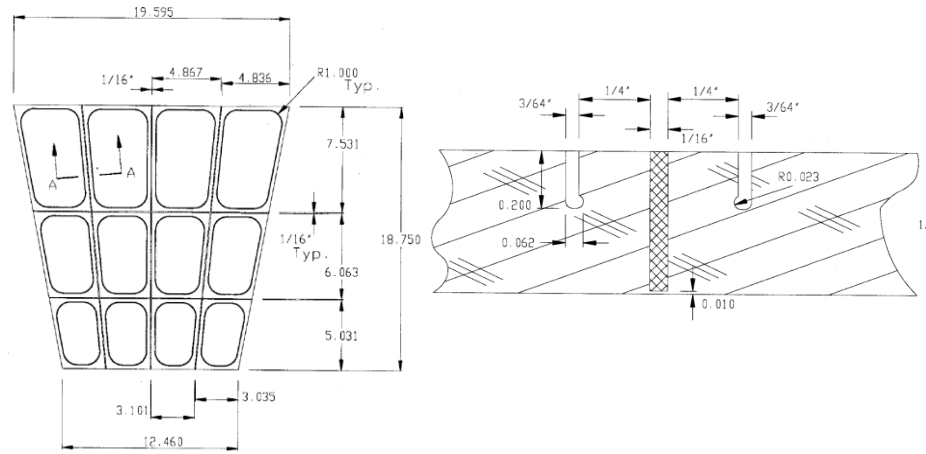
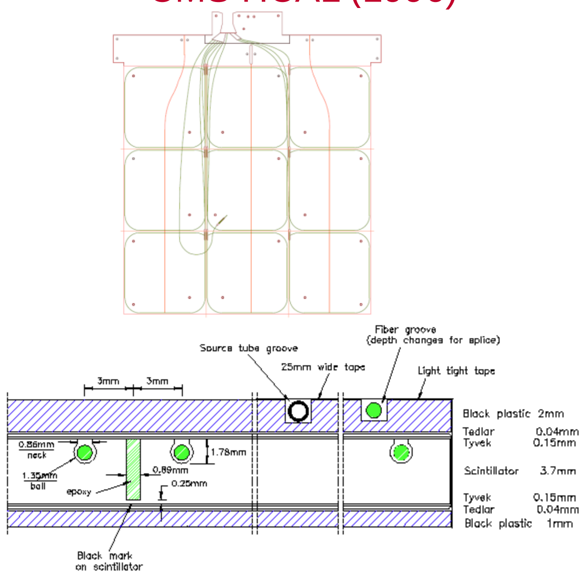


CMS HCAL (1996)



STAR Barrel EMC (2002)

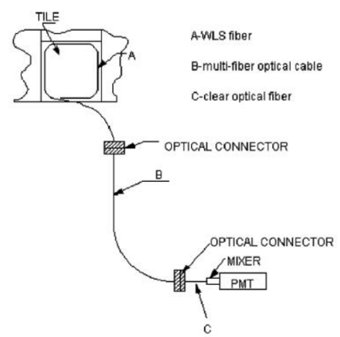
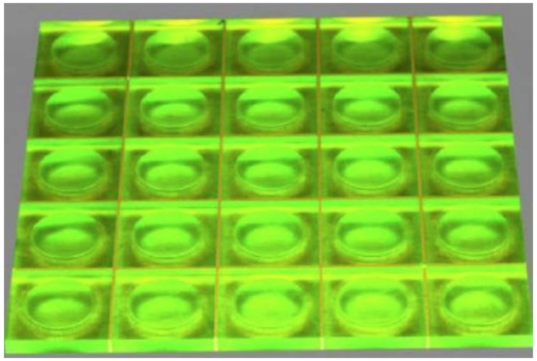


Fig. 5. Schematic diagram of the BEMC optical system illustrated for a single tile.

NIU Integrated Readout Layer (2009)



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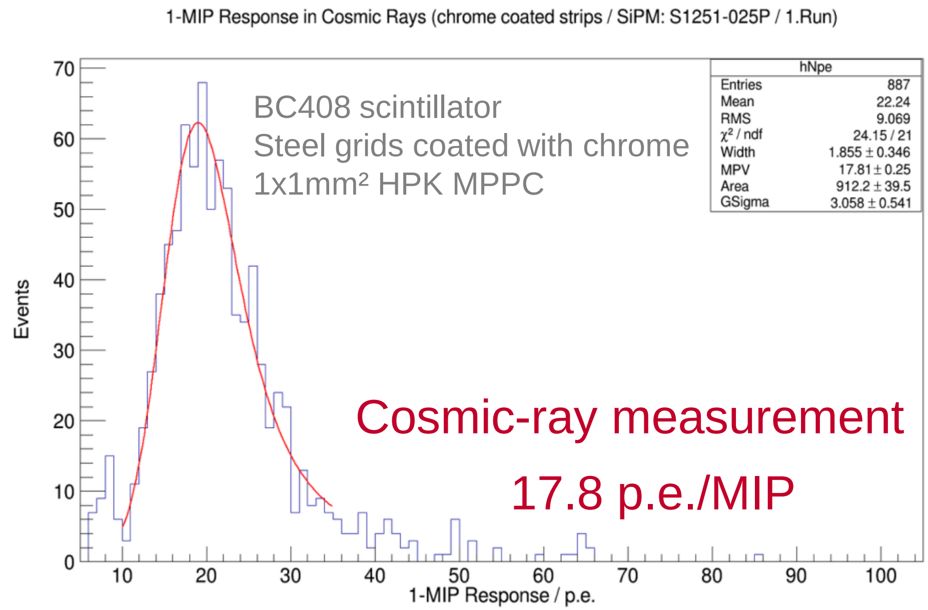
Efforts of MegaTile development at Mainz (1)

- MegaTile with steel grids

Prototype with metal grids and individual tiles



  - Idea: quickly produce metal grids
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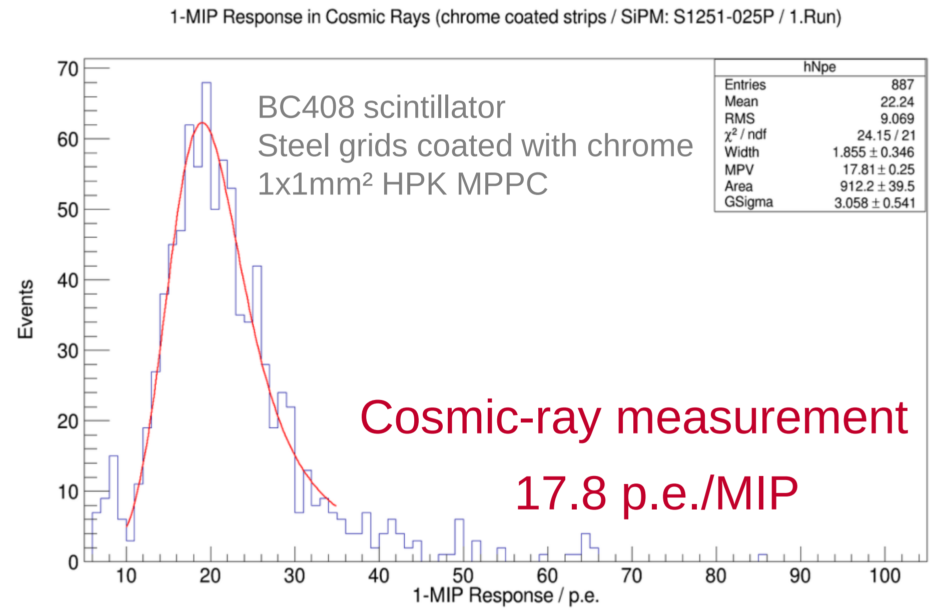
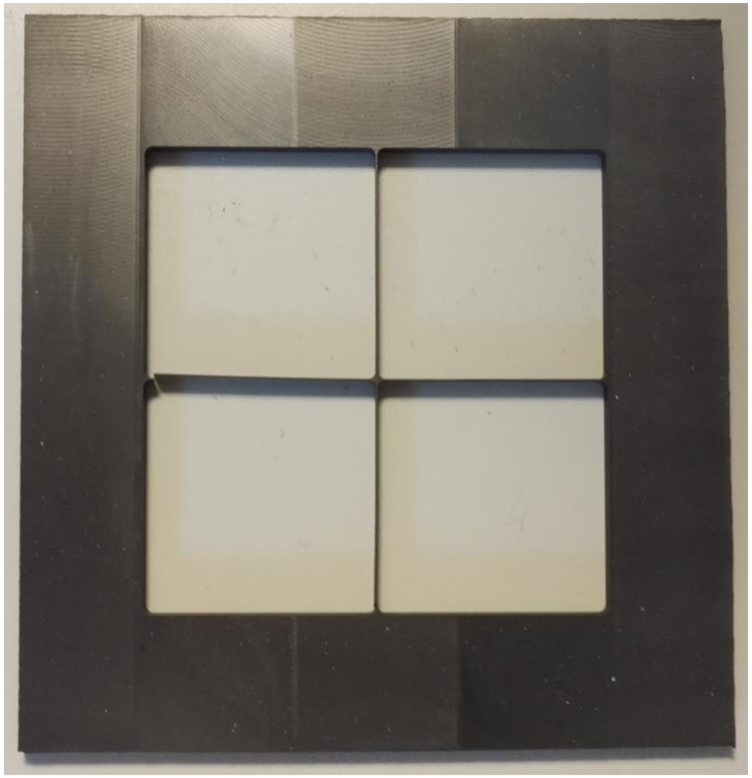


- Idea: quickly produce metal grids
- A first prototype worked well with steel strips and individually machined tiles
- Many manufacturers tried, but could not produce the steel grids with sub-mm thickness at the size ~ 36x36 cm^2

Efforts of MegaTile development at Mainz (2)

- MegaTile with carbon-fiber
  - Built a prototype of grids
    - Carbon-fiber: many thin layers glued together
    - Mechanically fragile



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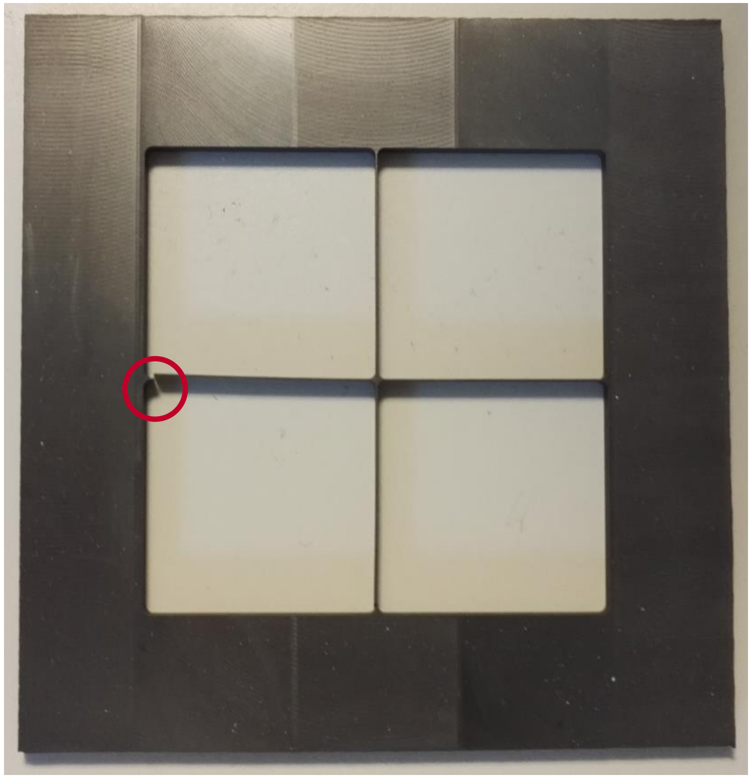
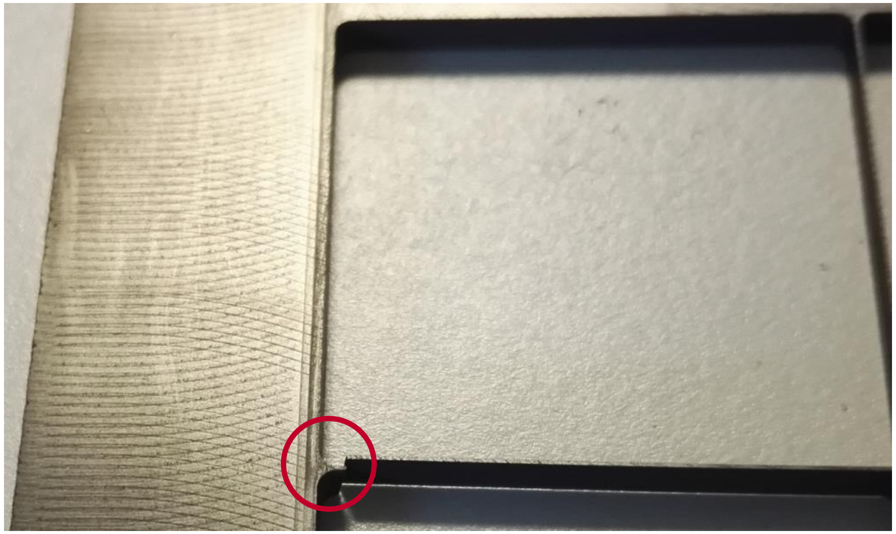




A small part fractured

Revisit MegaTile designs

- How to proceed?
  - Create trench arrays
    - either by cutting (for prototyping), or injection molding (mass production)
  - Fill in the trenches with white paints

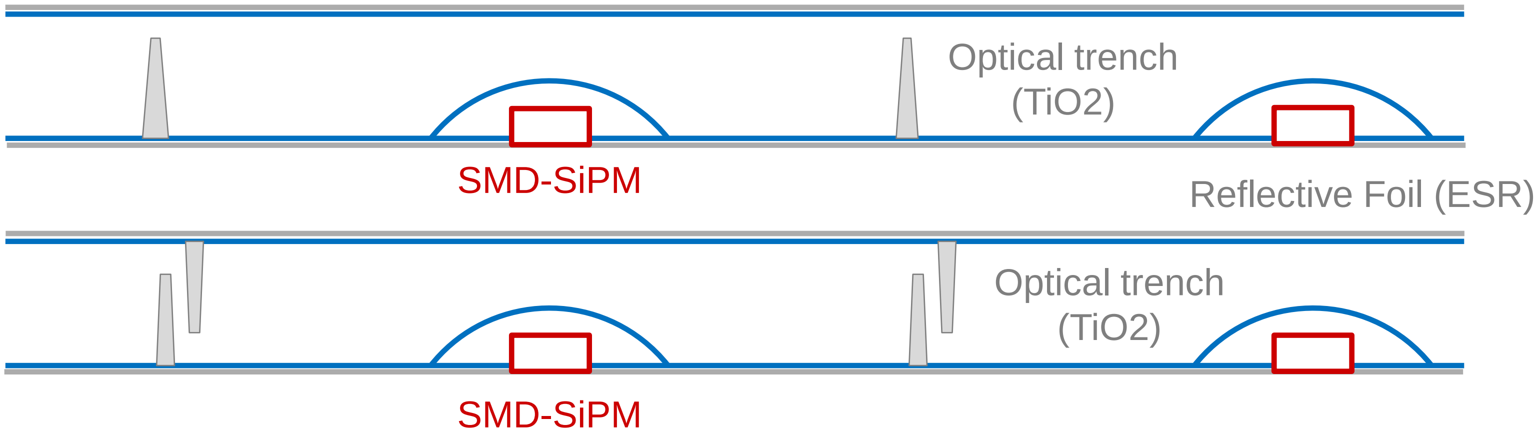
Revisit MegaTile designs

- How to proceed?
  - Create trench arrays
    - <u>either</u> by cutting (for prototyping), <u>or</u> injection molding (mass production)
  - Fill in the trenches with white paints
- Designs
  - Trench arrays: single vs double
  - Trench free variables: shapes, depth, width(s)
    - Double trenches: position offset of top and bottom trenches

Trench schematics (side view): not in scale

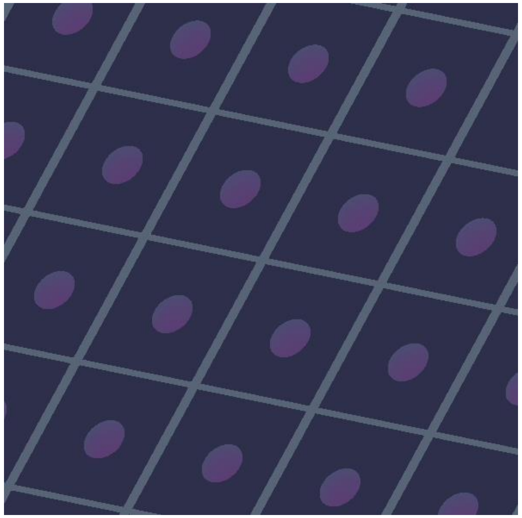
Single trench arrays

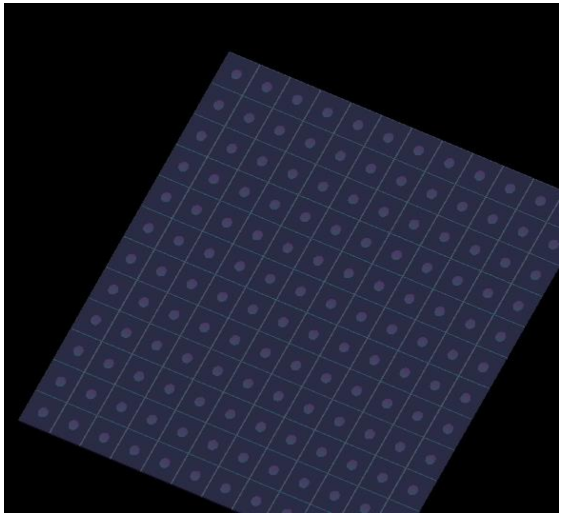
Double trench arrays



Geant4 simulation of MegaTile: overview

- A scintillator plate (BC408) segmented for 12×12 cells
  - Cells separated by trenches, filled in with white paints
  - Each cell individually read out by an SMD-SiPM

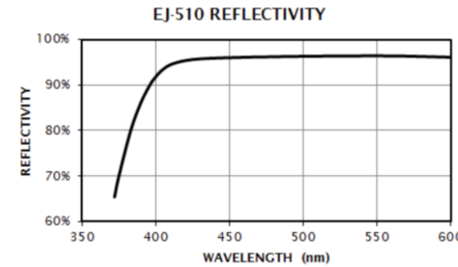


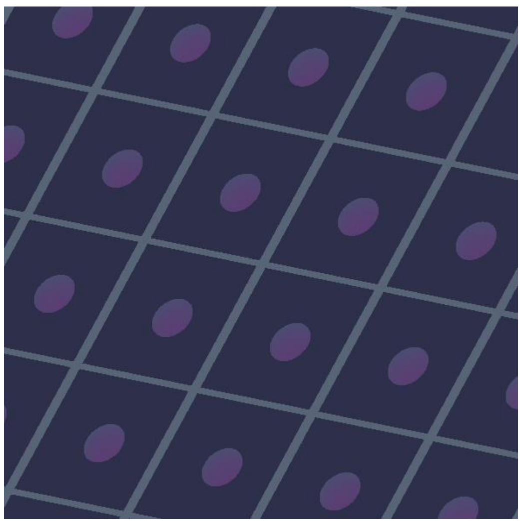


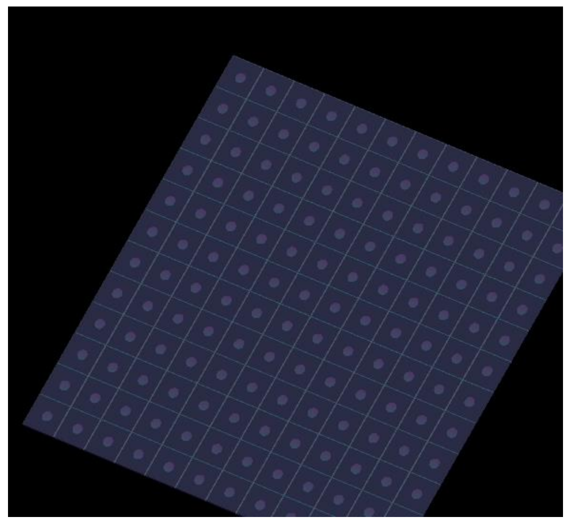
Geant4 simulation of MegaTile: overview

- A scintillator plate (BC408) segmented for 12×12 cells
  - Cells separated by trenches, filled in with white paints
  - Each cell individually read out by an SMD-SiPM
  - Top/bottom surfaces covered with ESR foil
  - Muons pass through the central cell perpendicularly

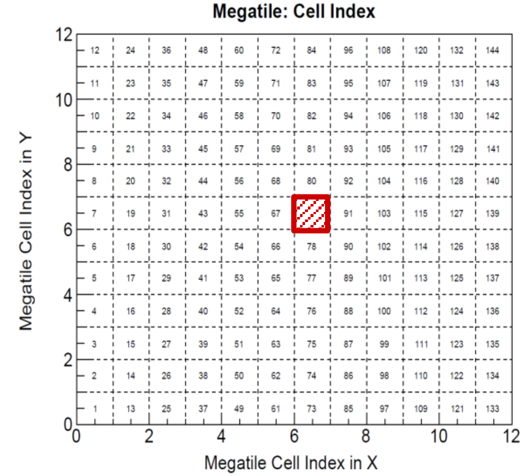
Trenches filled in with TiO2, presumed to be ideally diffuse

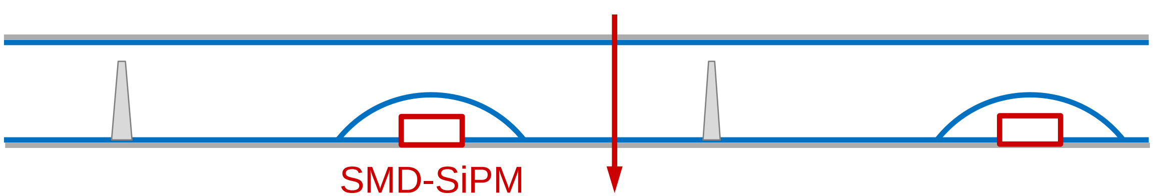






12×12 cells

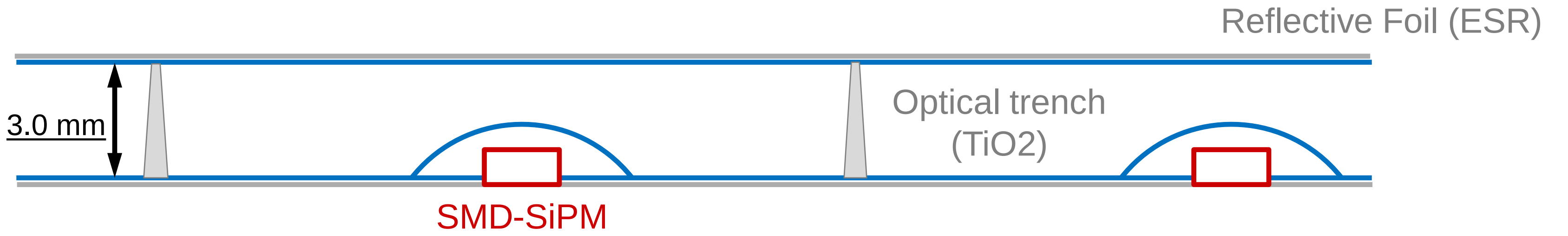




Muons: hit positions

Response of each SiPM is read out and averaged by the number of events

MegaTile simulation: a simple start



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- Mostly similar to individually wrapped tiles (current SMD-HBUs)

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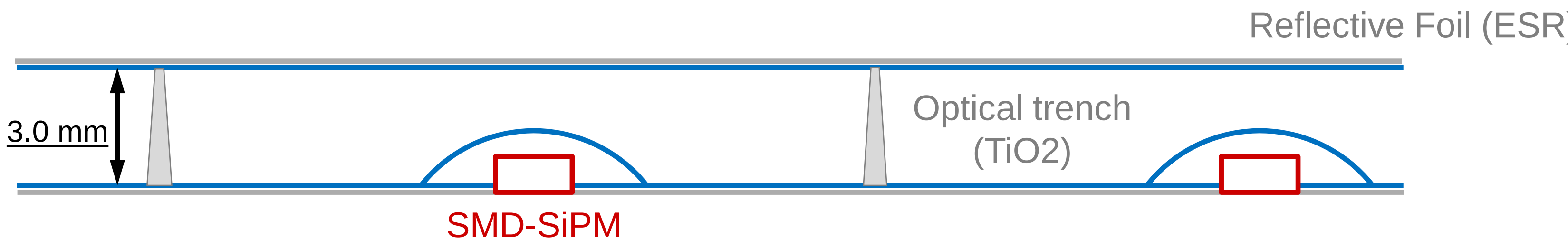

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- Mostly similar to individually wrapped tiles (current SMD-HBUs)
- Minor differences
  - Air gaps between top/bottom foil and MegaTile (assumed small; focus on trench)
  - Reflective properties of side surfaces
    - ~95% diffuse in MegaTile vs ~98% specular in individual tiles (ESR foil) (37.3 p.e./MIP)

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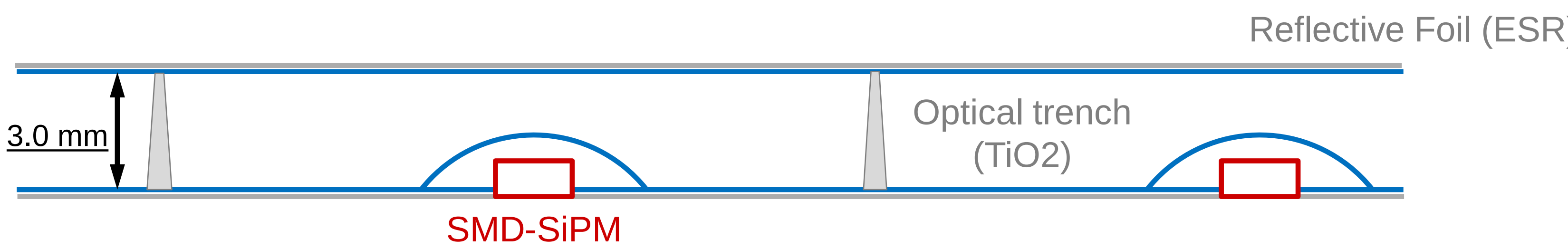

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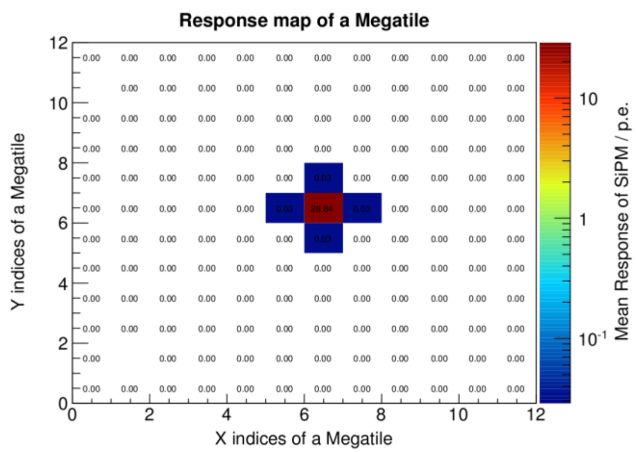
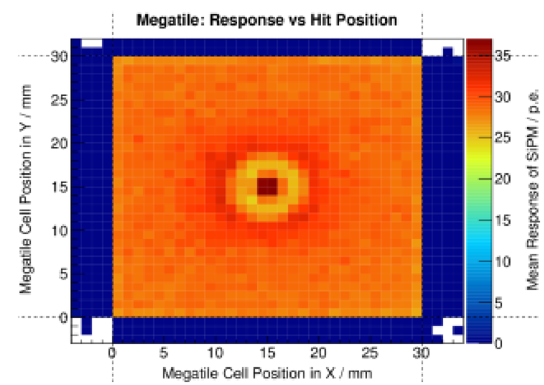
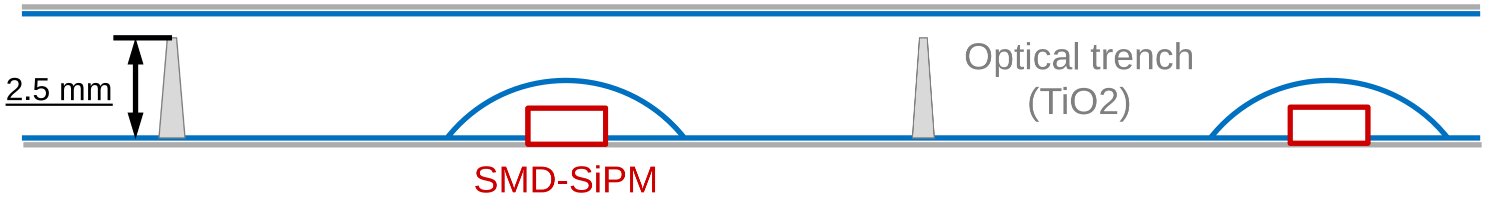


2-cell crosstalk:
0.03 p.e./ 28.84 p.e
= 0.1 %



Central cell details:
similar uniformity map

Single trench arrays: simulation of 2.5 mm depth



- Single trenches
  - 2.5 mm depth
  - Quite deep already
- Bridges between cells
  - 0.5 mm thick

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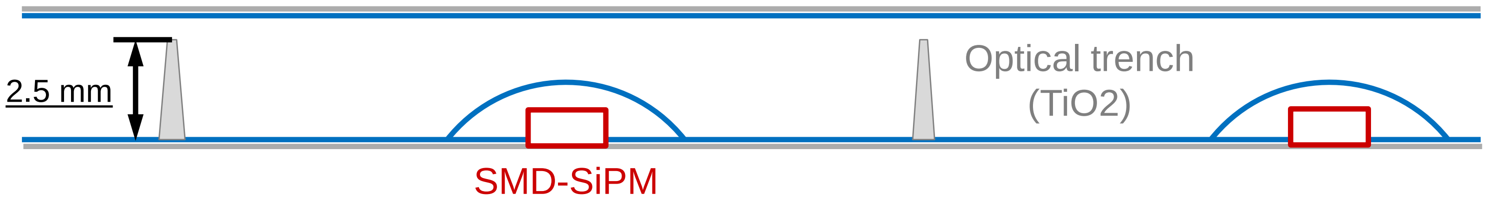

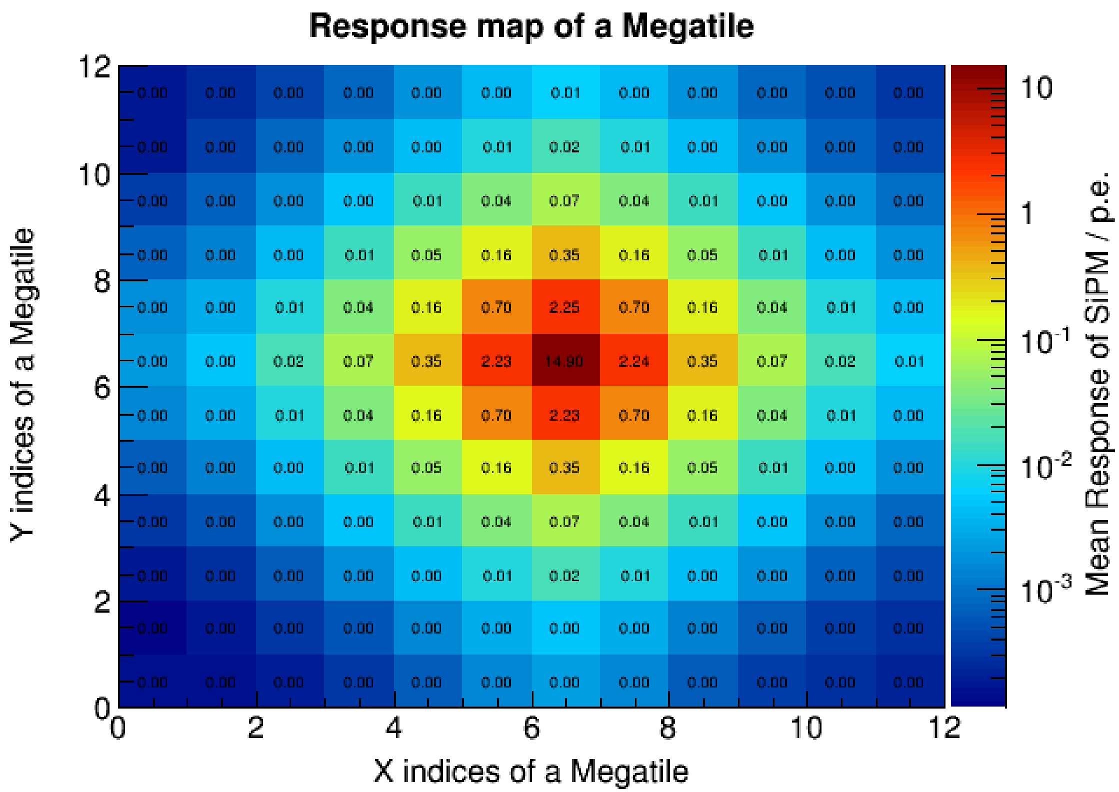

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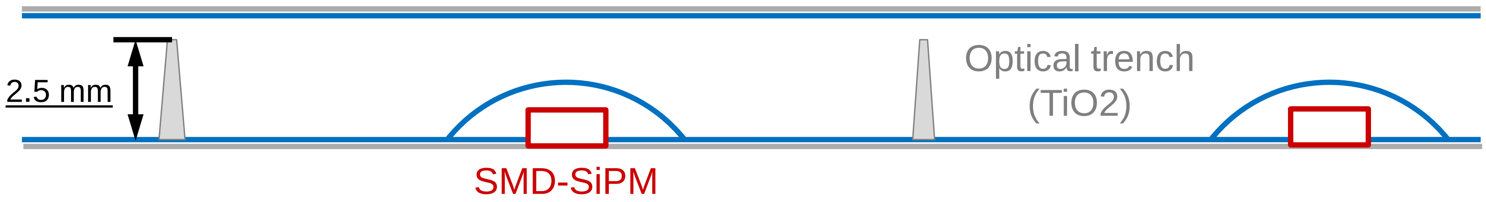
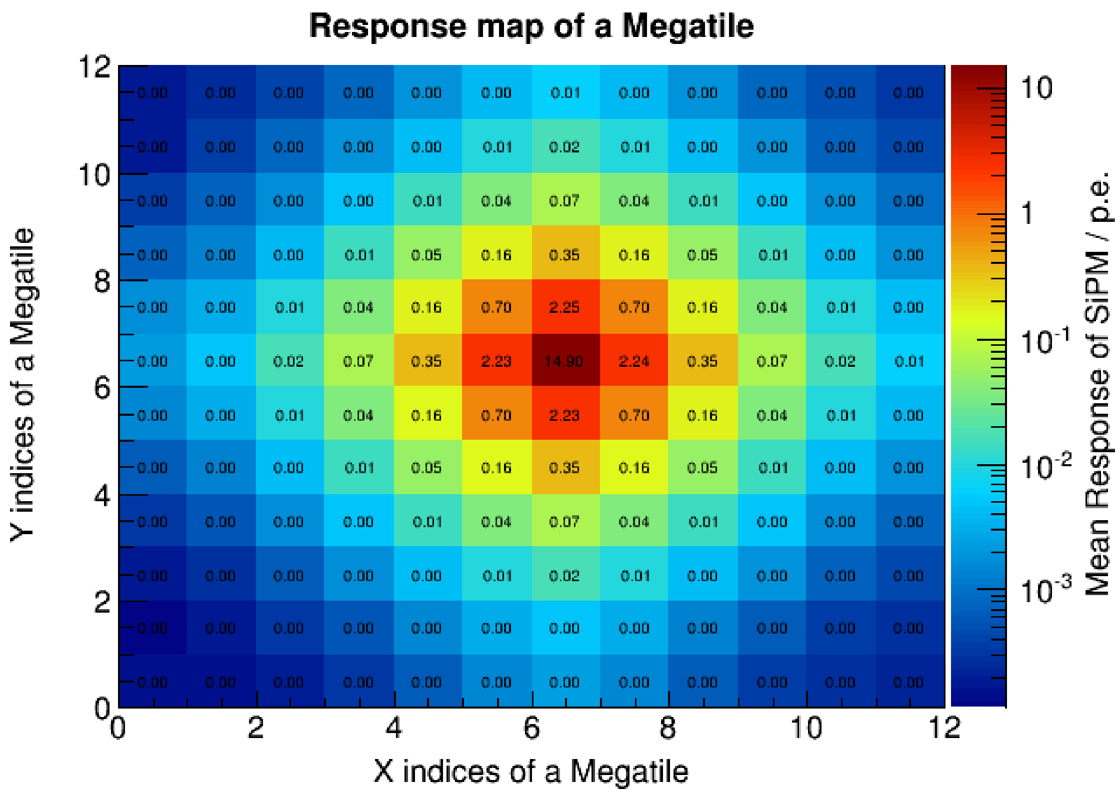
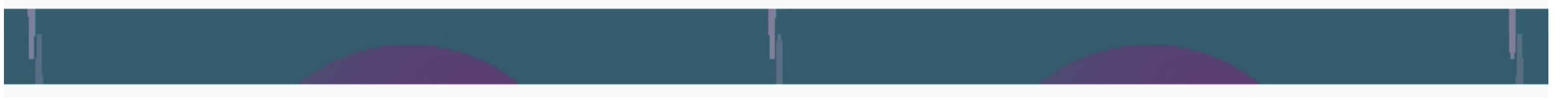




2-cell crosstalk: 15.1 %

- Single trenches
  - 2.5 mm depth
  - Quite deep already
- Bridges between cells
  - 0.5 mm thick
- 2-cell crosstalk
  - 15.1% between the central cell and one of its neighbors (max.)
- Central cell
  - 1-MIP Response: 14.9 p.e.
  - Compared to scenario of 3mm depth: 28.8 p.e.

MegaTile: double trenches



Rendered by G4RayTracer

- Top and bottom trenches
  - Different trench depths, widths, offset between top and bottom
  - Only show results of one design
    - 2.0 mm deep, 200 µm and 300µm wide (trapezoid), 300µm offset

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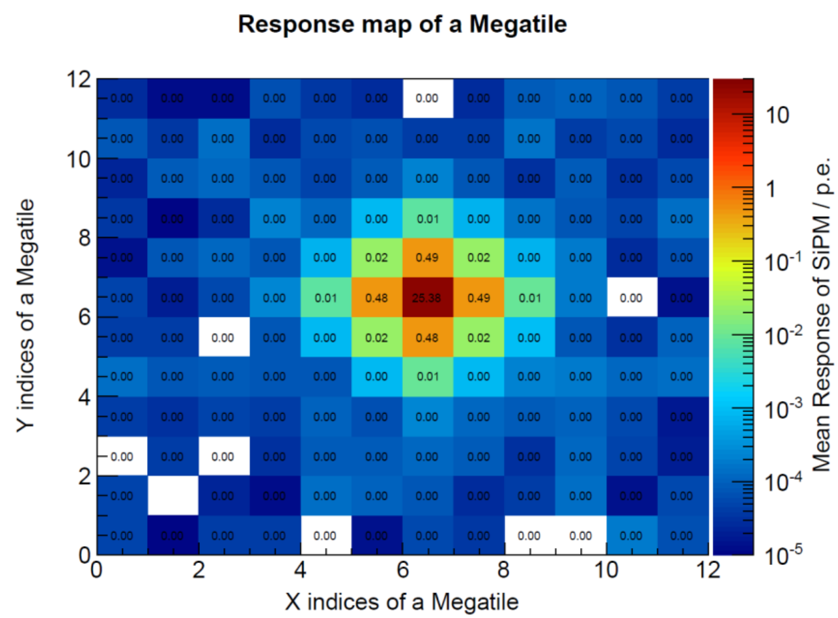
    - 2.0 mm deep, 200 µm and 300µm wide (trapezoid), 300µm offset

- Geant4 results
  - 2-cell crosstalk: 1.9 %
    - Central cell: 25.4 p.e./MIP
    - Neighboring cell: 0.49 p.e./MIP
    - Boundary effects removed
      - Cut away hit positions within 2 mm from cell boundary

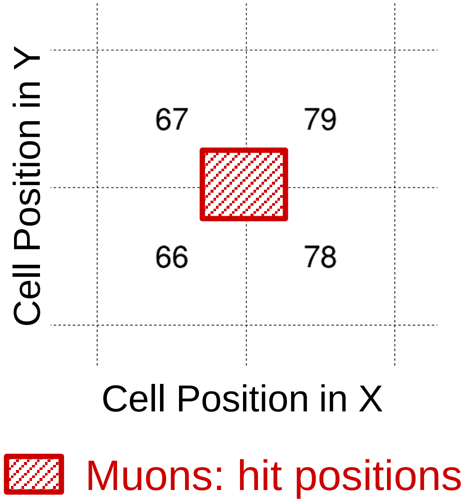


2-cell crosstalk: 1.9 %

Also interesting to see what are boundary effects (next page)

Double trenches: boundary effects

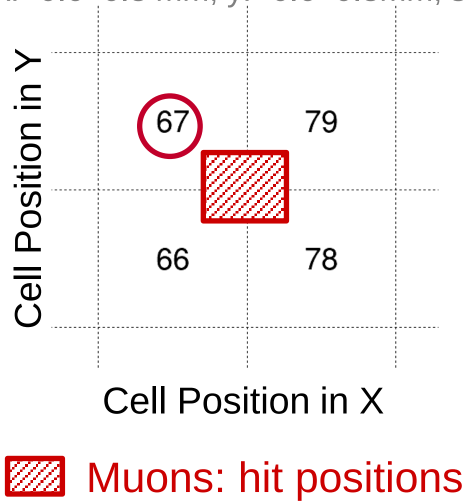
- Special MC runs: muons only hit the shared corner of 4 cells



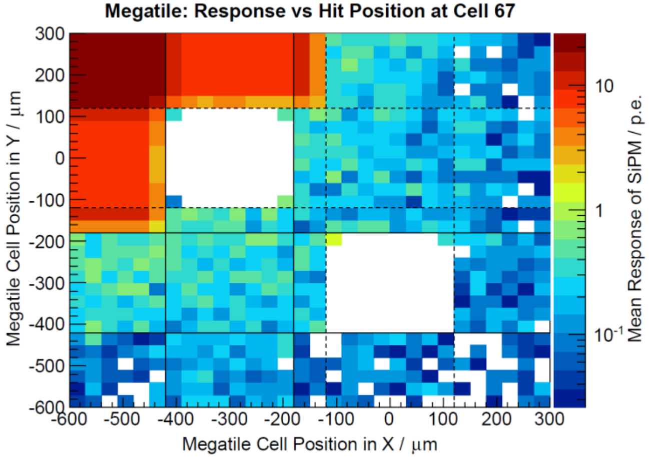
Double trenches: boundary effects

- Special MC runs: muons only hit the shared corner of 4 cells

x: -0.6~0.3 mm; y: -0.6~0.3mm; step size: 30 µm



Cell 67



Solid and dashed lines indicate top and bottom trenches (borders)

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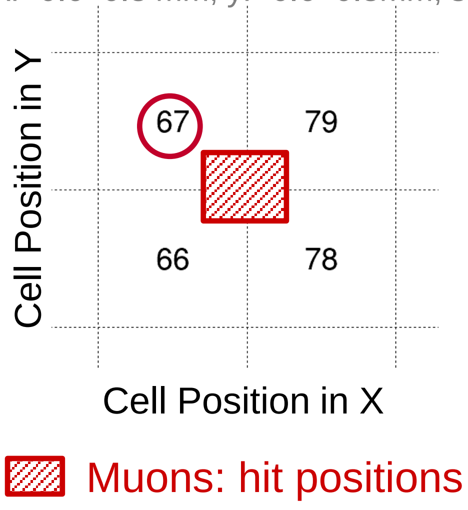

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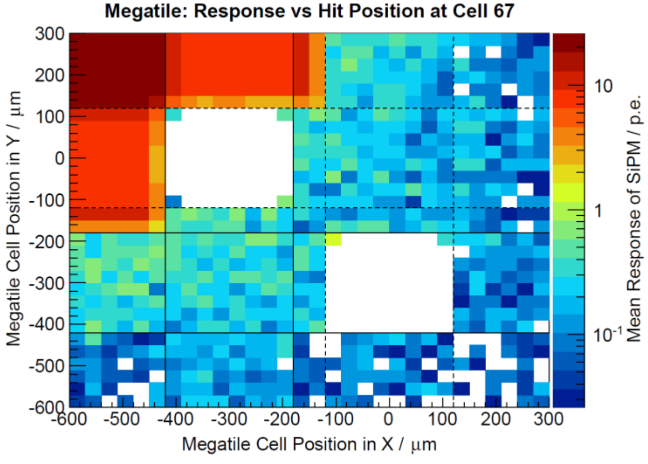
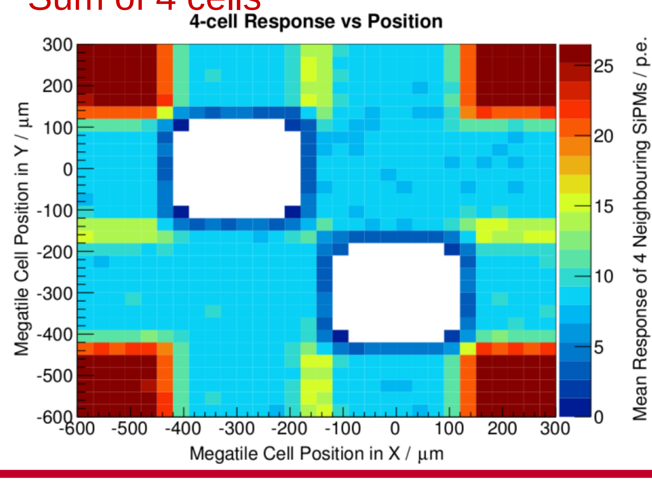


Sum of 4 cells



Solid and dashed lines indicate top and bottom trenches (borders)

Boundary areas: ~ 8 p.e./MIP

~ 30% of each cell response (~32.4 mm² per cell)

Geometric effect:
1mm thick scintillator in these regions

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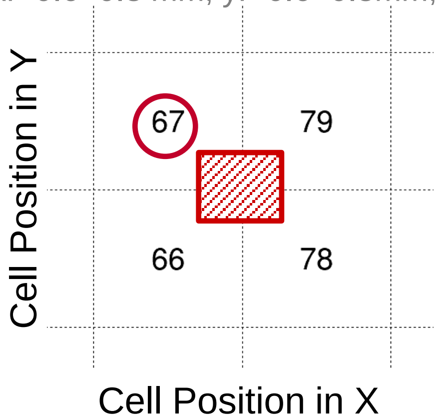
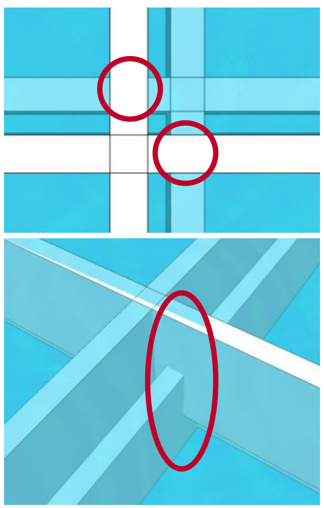


Muons: hit positions



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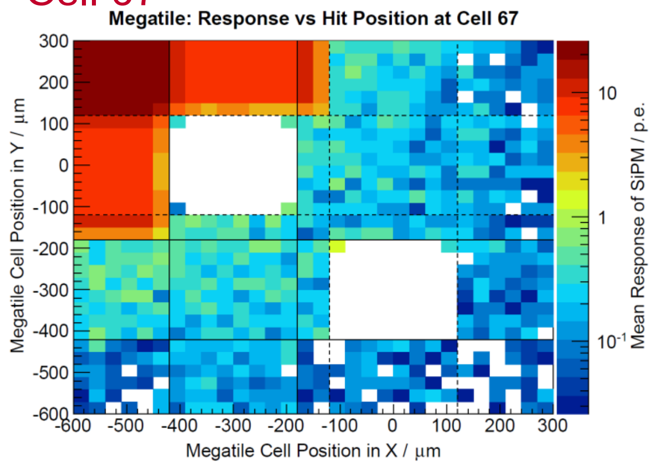

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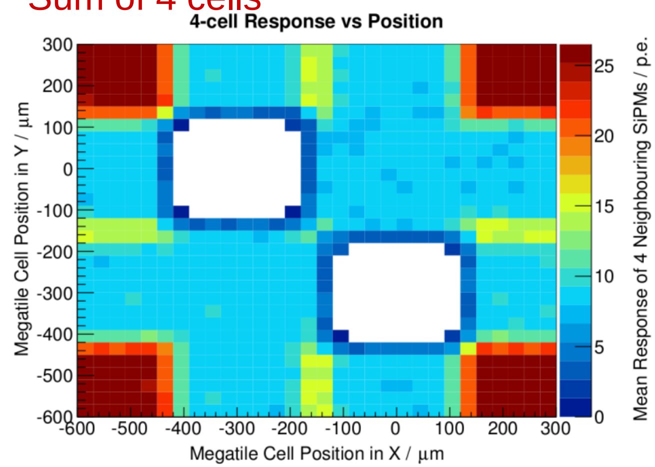

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Geometric effect:
1mm thick scintillator in these regions

Dead areas: 0.12 mm² per cell (overlapping of top and bottom trenches)

Current tile size: 29.6 × 29.6 mm²
dead area per tile: 23.84 mm²
(~ 2.6% of a tile)

MegaTile: tilted (double) trenches

- Straight double trenches
  - Boundary area: mostly active, less response (~30%)
    - Geometry effect: 1mm scintillator material left in the area
  - Dead areas (small): 0.12 mm^2 per cell
    - Depend on trench width
- Tilt trenches by some angle
  - Increase response of boundary areas

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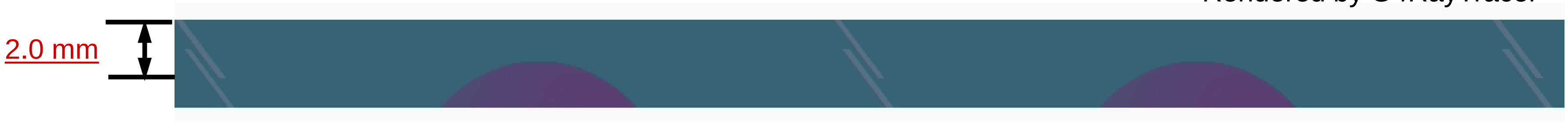
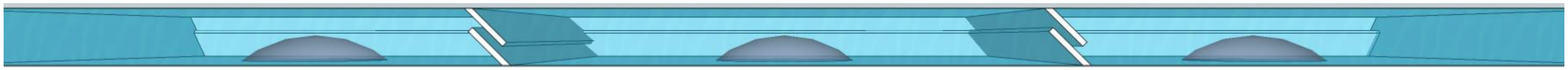
    - Depend on trench width
- Tilt trenches by some angle
  - Increase response of boundary areas
- Tilted trenches: only one design shown
  - Tilted 45°, 2mm depth (vertical projection)

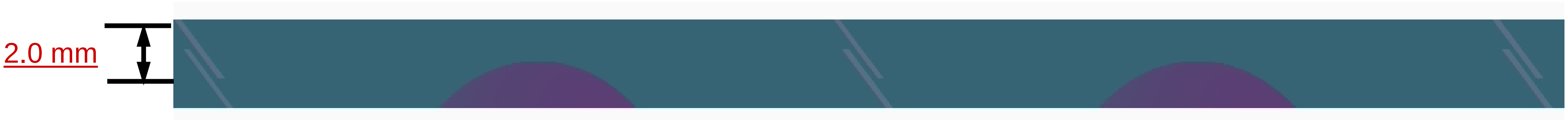
Rendered by G4RayTracer



Constructed in SU



Simulation of tilted trenches: crosstalk



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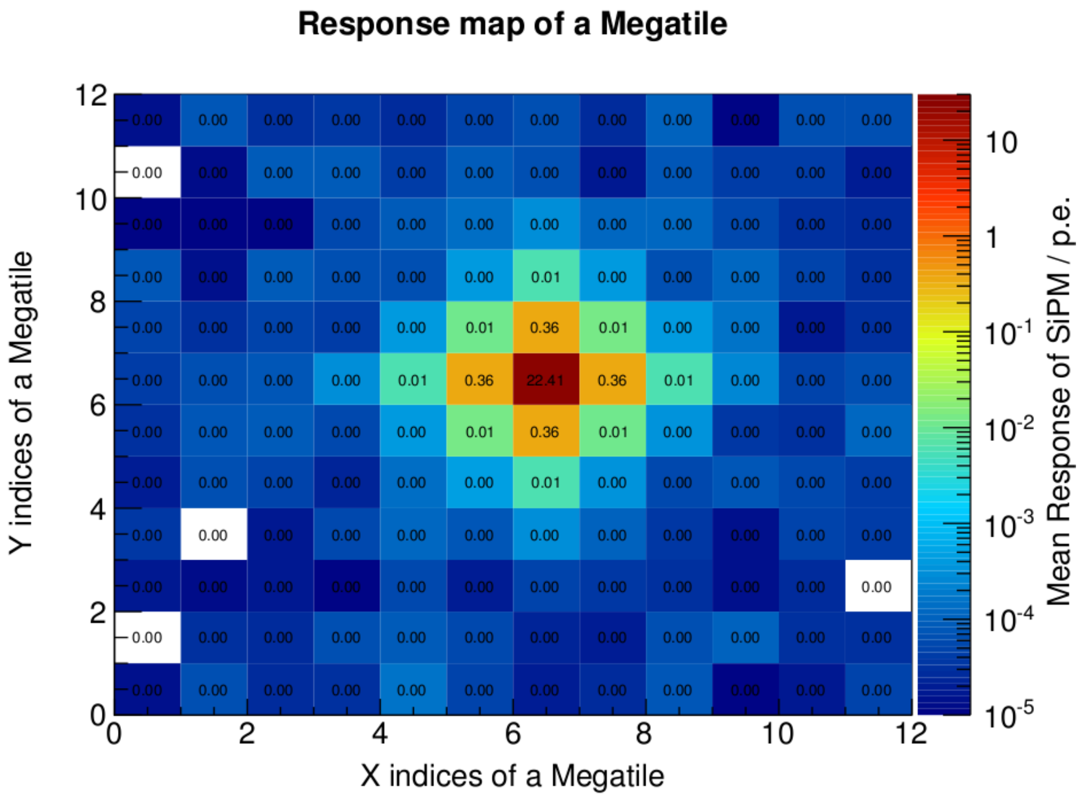
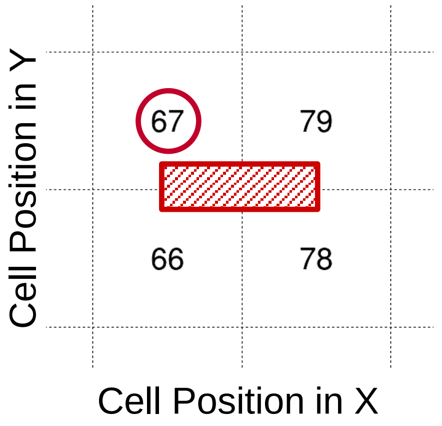


- Crosstalk
  - 2-cell crosstalk 1.9 %
  - Same as straight trenches
- Central cell
  - 22.4 p.e./MIP
  - Lower response than straight trenches (25.4 p.e.)

2-cell crosstalk: 1.9 %

MC suggests promising low crosstalk level and moderate MIP response

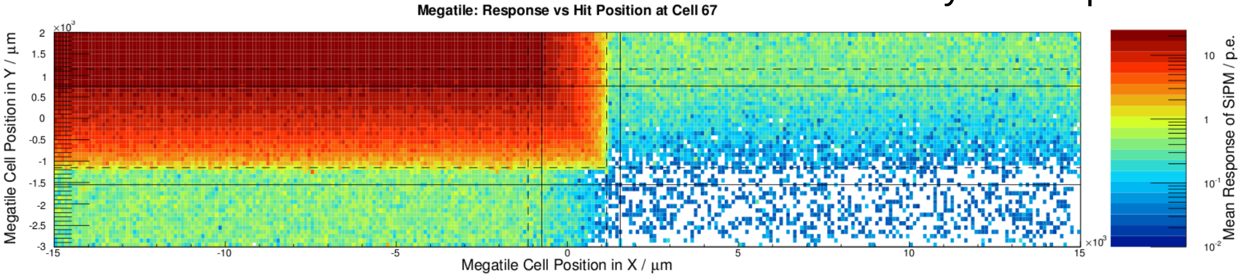
Simulation of tilted trenches: boundary areas



Muons: hit positions

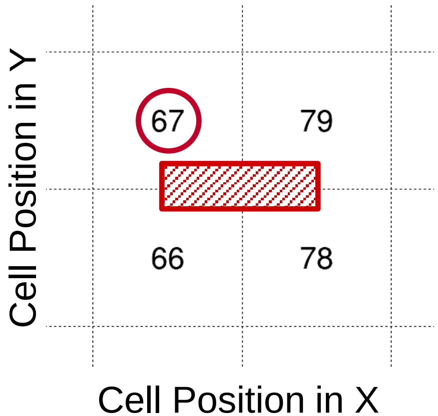
Cell 67

Cell boundary well separated



x: -15~15mm; y: -3~2mm; step size: 100 µm

Simulation of tilted trenches: boundary areas



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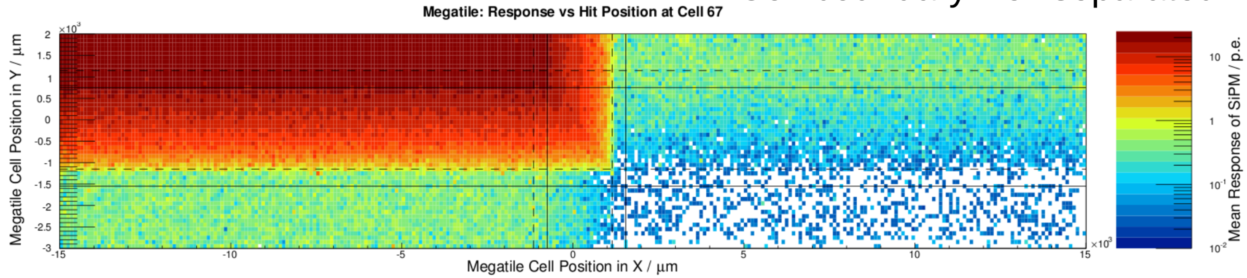

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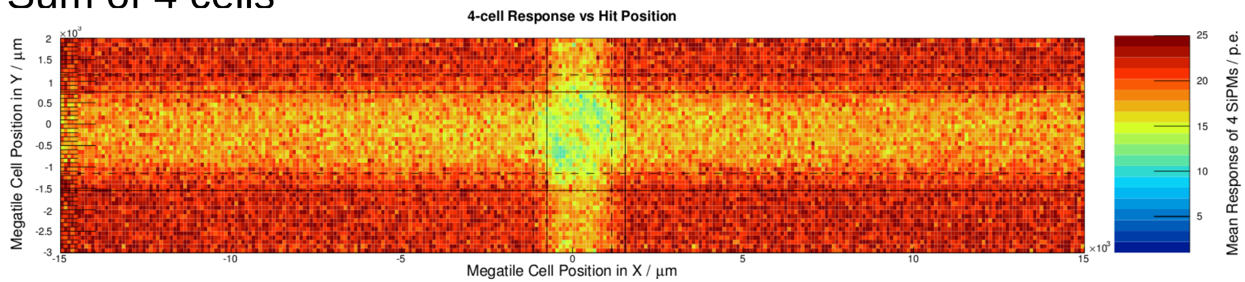
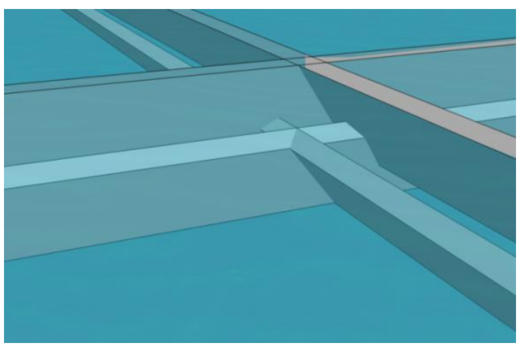
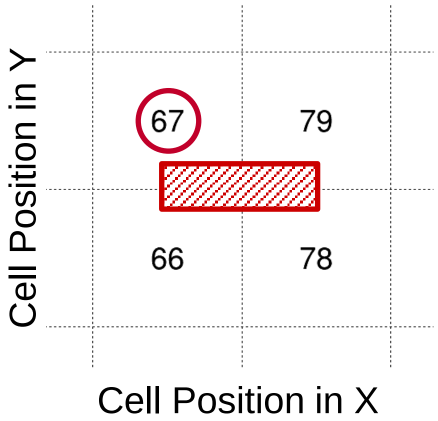
Sum of 4 cells





Solid and dashed lines indicate top and bottom trenches (projection to x-y plane)

Simulation of tilted trenches: boundary areas



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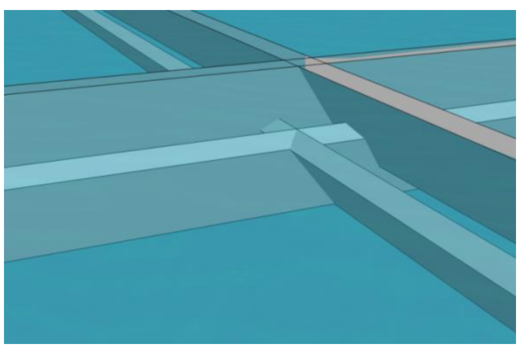

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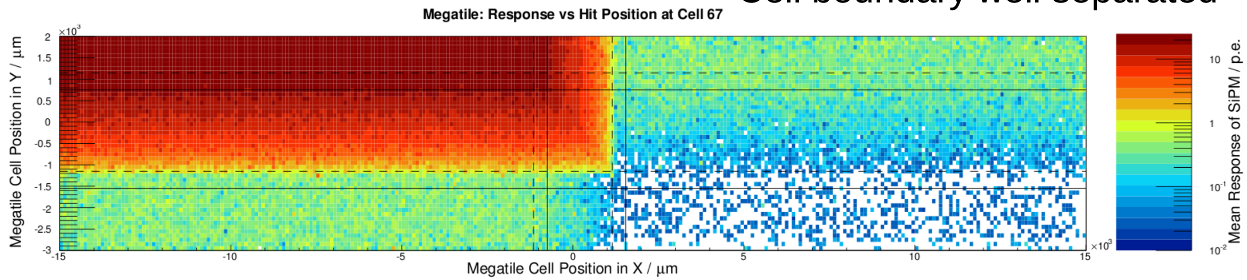

x: -15~15mm; y: -3~2mm; step size: 100 µm

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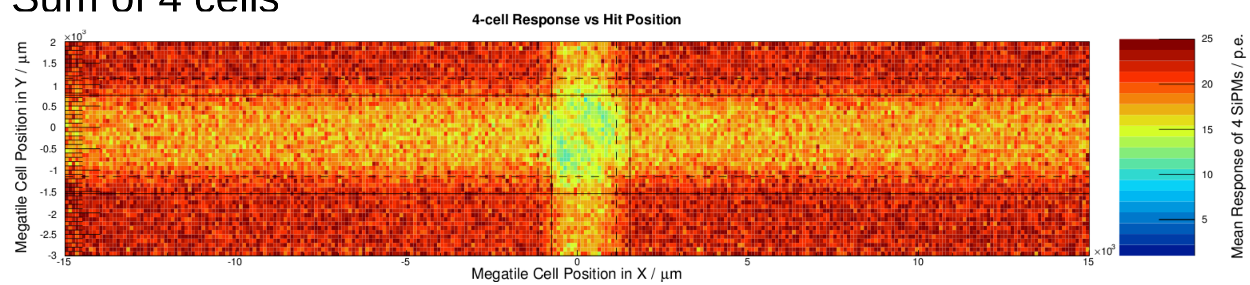
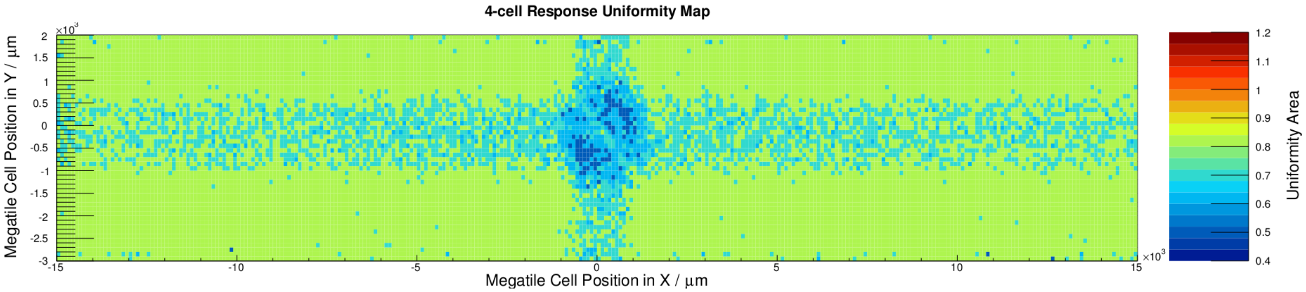


- Boundary areas: also high response
- Impact from particle incidence angle
  - Perpendicular: no dead area (as shown)
  - Oblique: very small dead area foreseen
    - Only ~ 45° incident tracks, but these tracks also lead to higher energy depositions in the scintillator

Simulation of tilted trenches: uniformity map

x: -15~15mm; y: -3~2mm; step size: 100 µm

Compared to cell mean response: 22.4 p.e.



99.3% area: uniformity 60%

96.1% area: uniformity 70%

79.1% area: uniformity 80%

51.7% area: uniformity 90%

Simulation of tilted trenches: uniformity map

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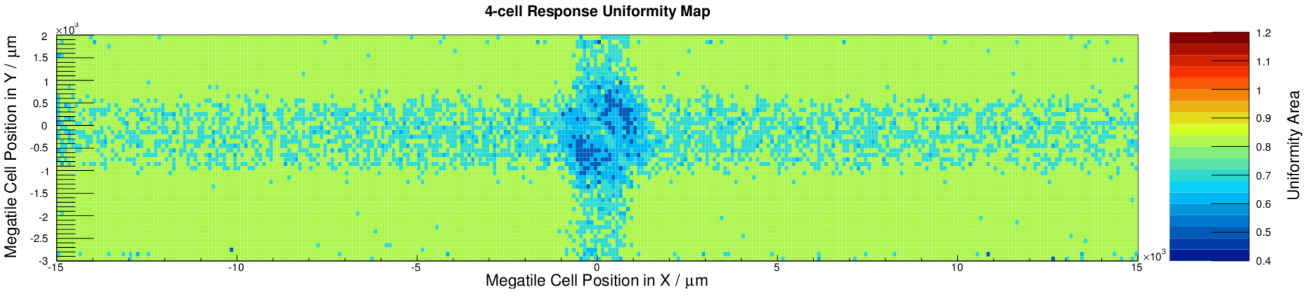

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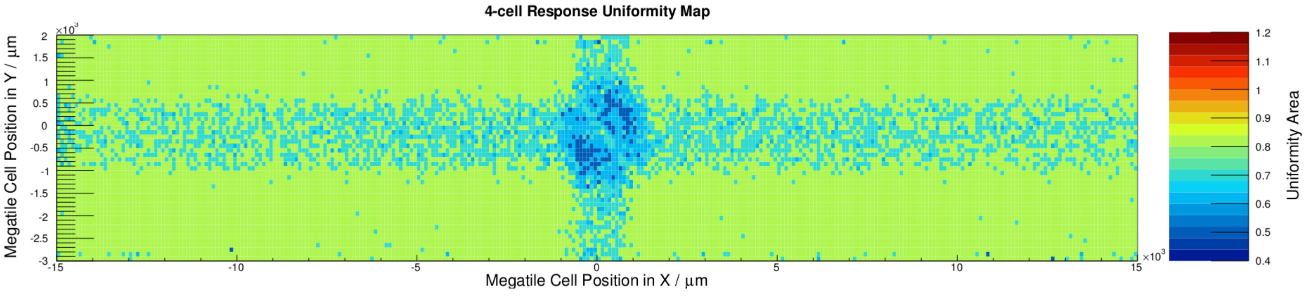

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- All boundary area is active and most (>96%) has >70% response
- Comparison with current tile design
  - Nominal size: 30.0 ×30.0 mm²
  - Current tile size: 29.6 × 29.6 mm²
  - Dead area per tile: 23.84 mm² (~ 2.6%)

Improved size also exists: 29.7 × 29.7 mm²;
Dead area per tile 17.91 mm² (~ 2.0%)

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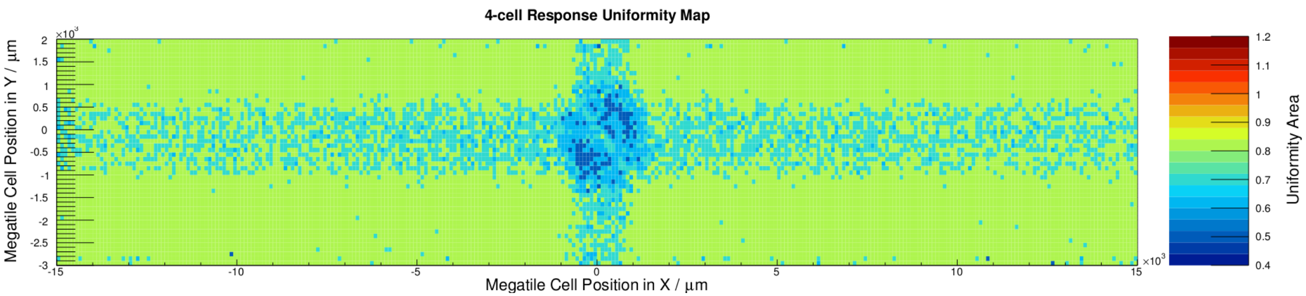

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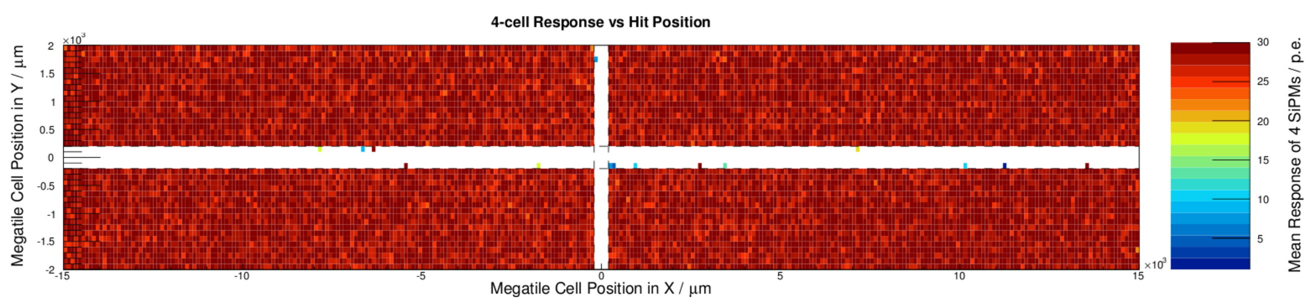
Non-sensitive area: 400µm between each cell (simulation)

x: -15~15mm; y: -3~2mm; step size: 100 µm



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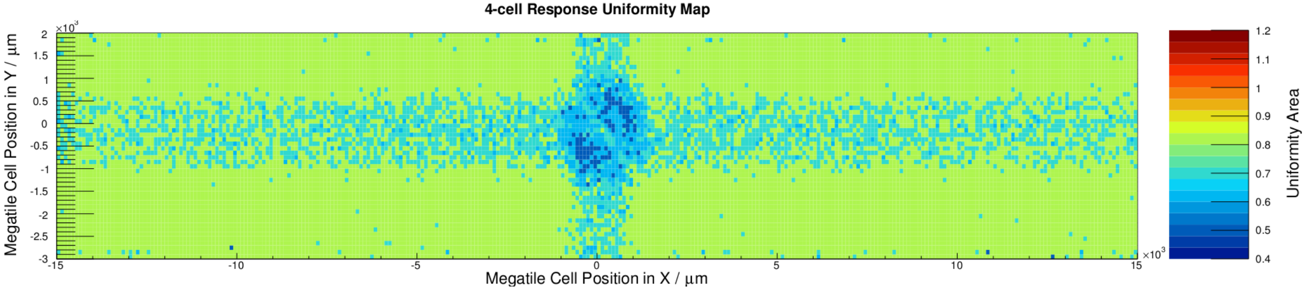

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Megatile has such a potential of almost zero dead area

Improved size also exists: 29.7 × 29.7 mm²;
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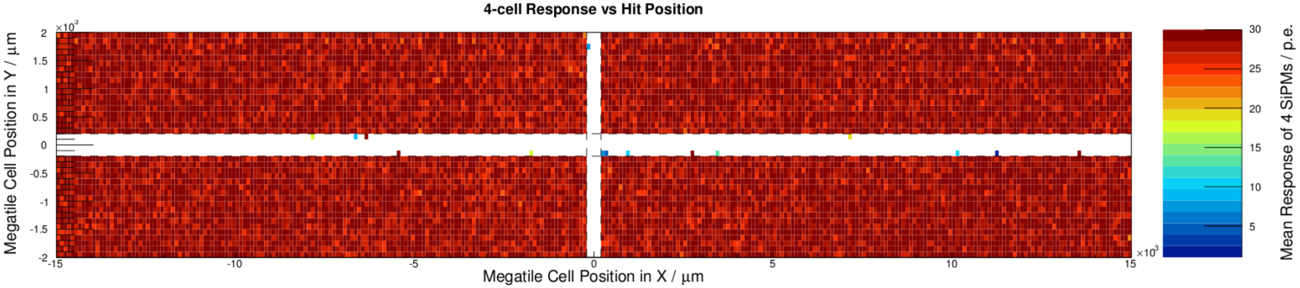
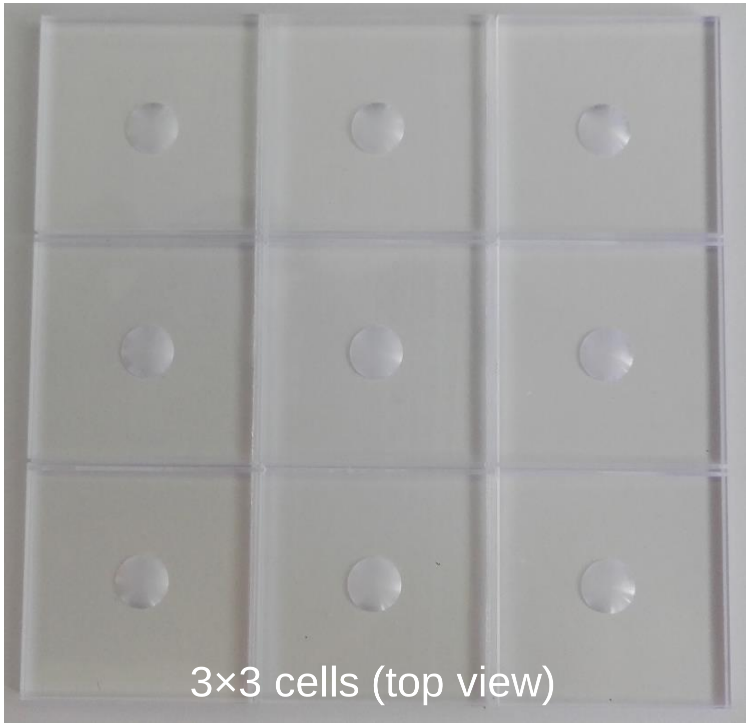
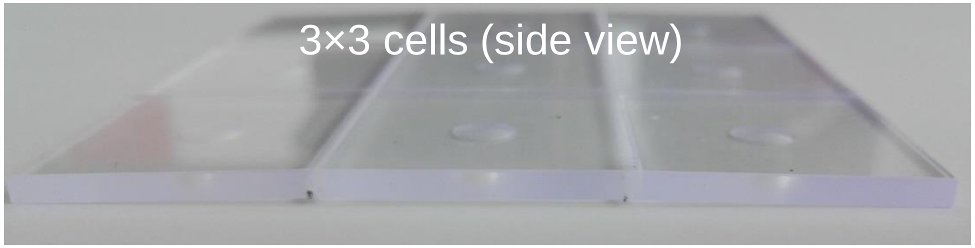


MegaTile: a first new prototype (1)

- Double trenches (straight), 3×3 cells
  - Scintillator: NE110 (comparable to BC408)
    - Difficult to polish perfectly; cracks seen
    - Fabricated by machine: cutting, polishing …

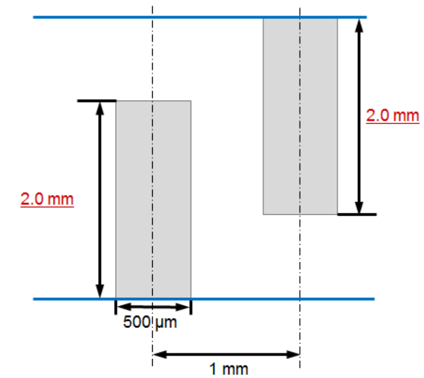

3×3 cells (top view)

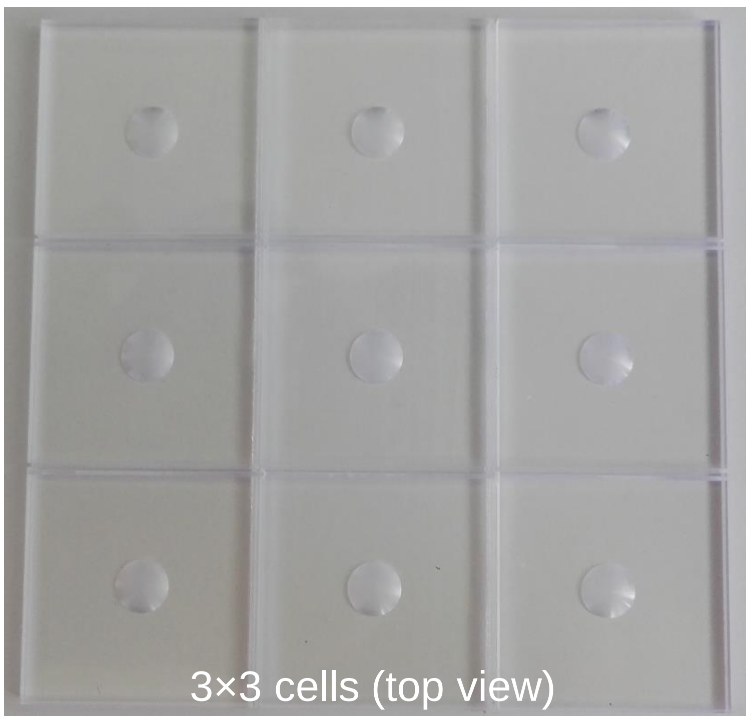

3×3 cells (side view)


Megatile and its foil wrapping

MegaTile: a first new prototype (1)

- Double trenches (straight), 3×3 cells
  - Scintillator: NE110 (comparable to BC408)
    - Difficult to polish perfectly; cracks seen
    - Fabricated by machine: cutting, polishing …
  - Depth 2.0 mm, width 0.5 mm, offset 1.0 mm
    - Previous simulation: width <u>0.3mm</u>, offset <u>0.3mm</u> (same depth 2mm)

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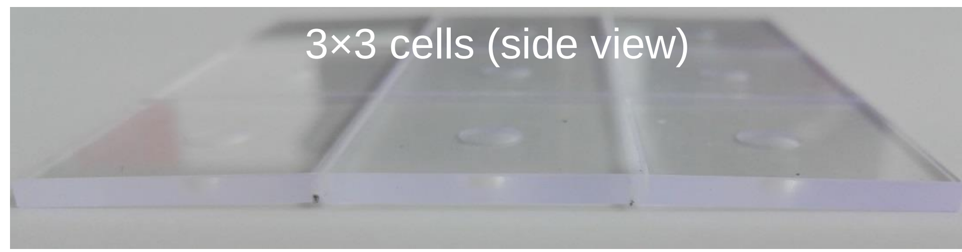
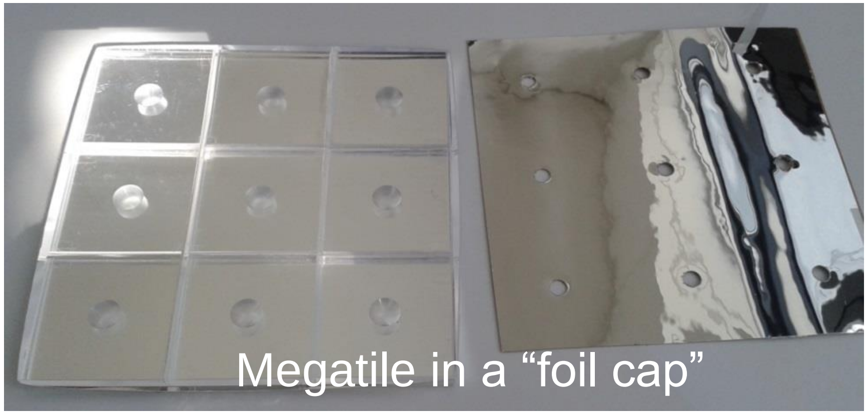

3×3 cells (side view)


Megatile and its foil wrapping

MegaTile: a first new prototype (2)

- Megatile all 6 surfaces covered by foil
  - 3M DF2000MA
- Foil strips were put inside trenches
  - High reflectivity (>98 %)
  - Next step: white paints (~95%)



Megatile in a “foil cap”

Foil strips for trenches

MegaTile: a first new prototype (2)

- Megatile all 6 surfaces covered by foil
  - 3M DF2000MA
- Foil strips were put inside trenches
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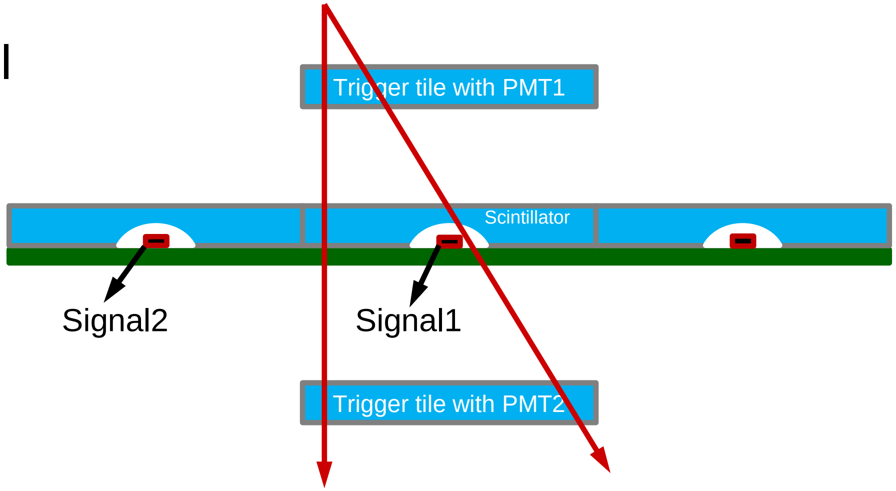
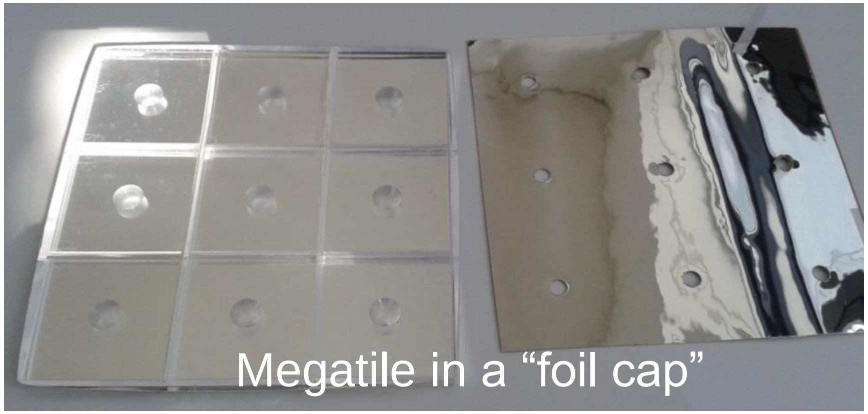
  - Next step: white paints (~95%)
- Cosmic-ray test stand
  - Trigger the central cell
  - Read out the central cell and its left cell
  - Include tracks passing cell boundaries



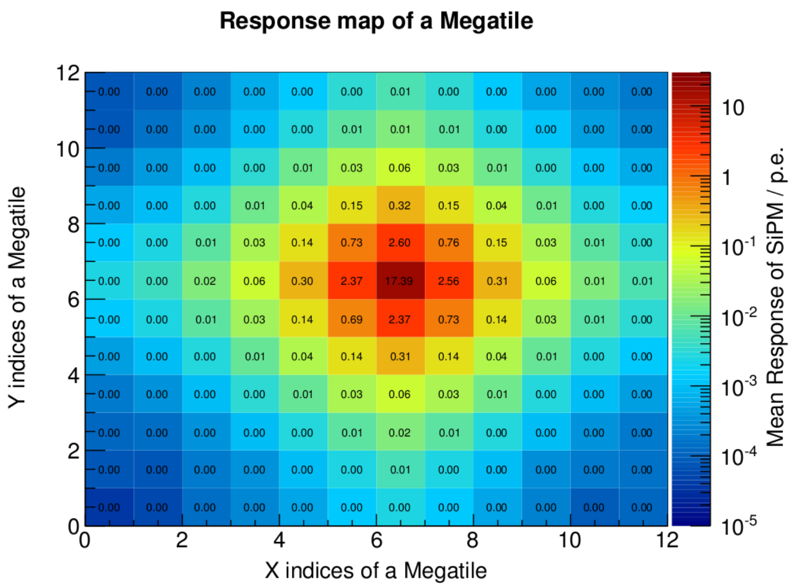
A first quick test:
prototype finished just some days ago


Megatile in a “foil cap”


Foil strips for trenches

Megatile prototype: check what its simulation says

- Wider trenches and wider top/bottom offset in prototype (3×3 cells)
  - Simulation still for 12×12 cells: not exact the same geometry
  - Due to wider trenches and wider offset
    - Higher crosstalk: ~15%; lower response (central cell): 17.4 p.e./MIP
  - No cut on the muon track positions
    - Kept the same as cosmic-ray test stand



2-cell crosstalk: ~15%

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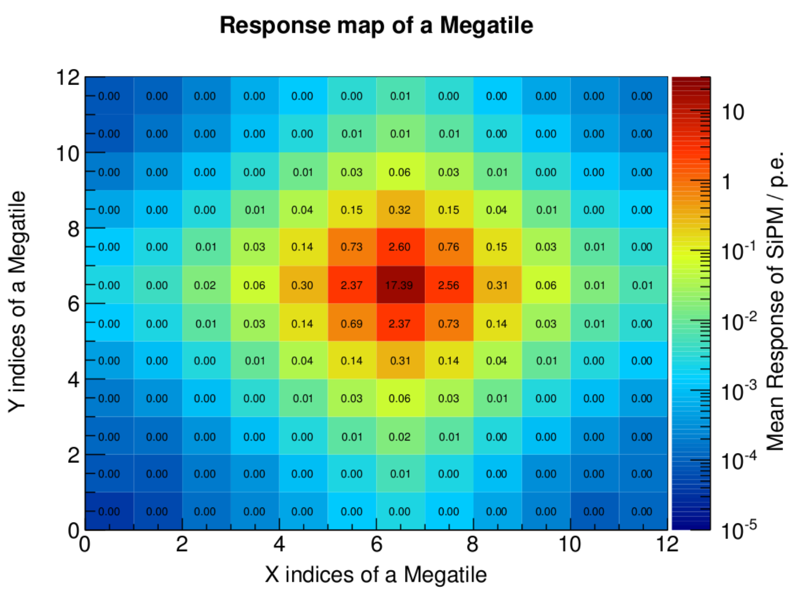

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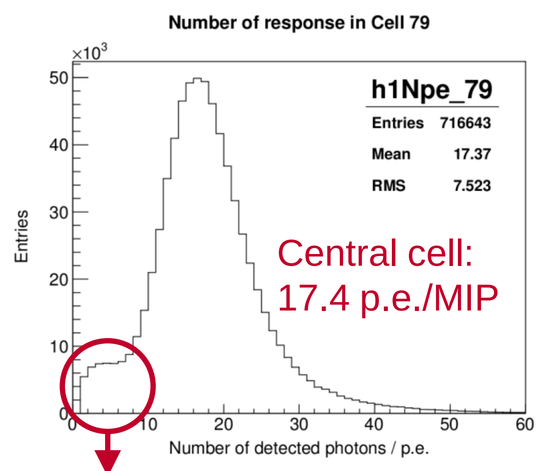
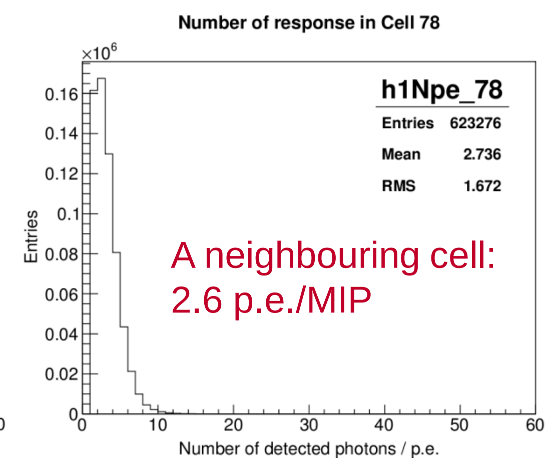




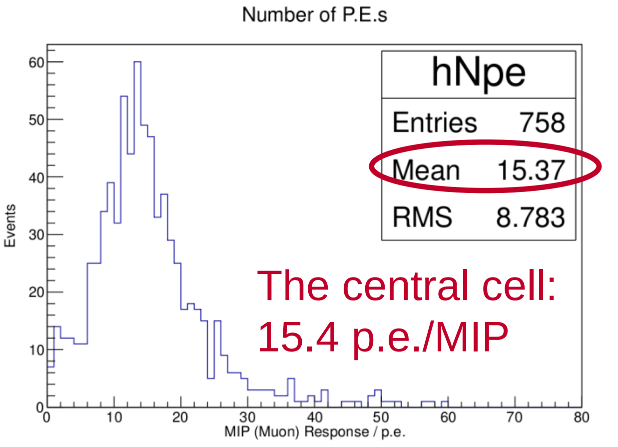
Tracks passing through boundary

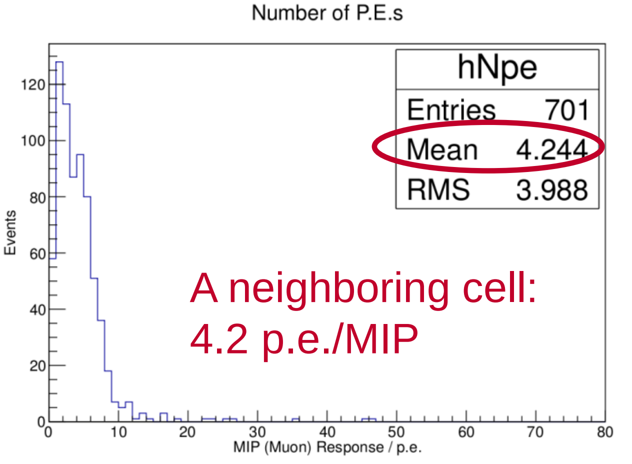
Entries with 0 p.e. exist (no noises), just not plotted;
Response averaged by number of events (i.e. 720k),
entries of 0 p.e. also included

Megatile 1st prototype: cosmic-ray tests

- First results
  - The central cell: 15.4 p.e./MIP (mean)
  - A neighboring cell: 4.1 p.e. /MIP (mean)
  - 2-cell crosstalk: 27 %

Mean values are used in the simulation studies; keep this the same to treat measurements





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  - 2-cell crosstalk: 15 %

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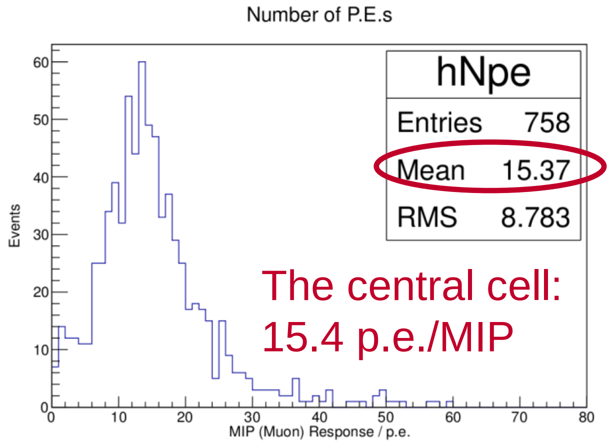

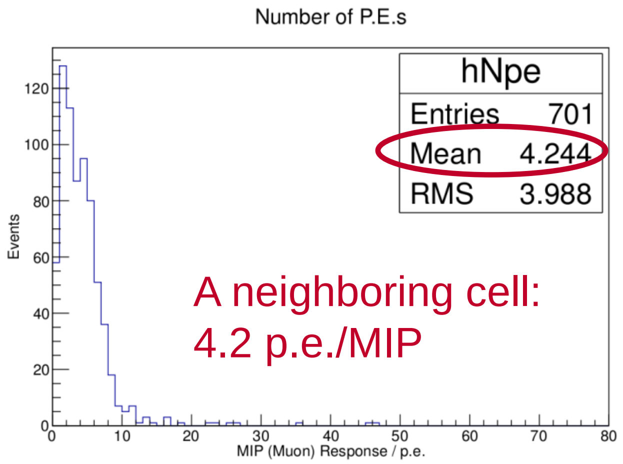

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  - Simulation done for 12×12 cells: underestimate the crosstalk level for 3×3 cells
  - Simulation assumed a very thin air gap between top/bottom surface and foil (ideal)
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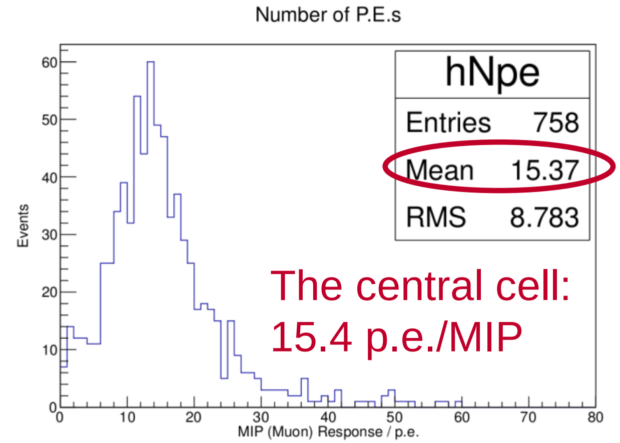

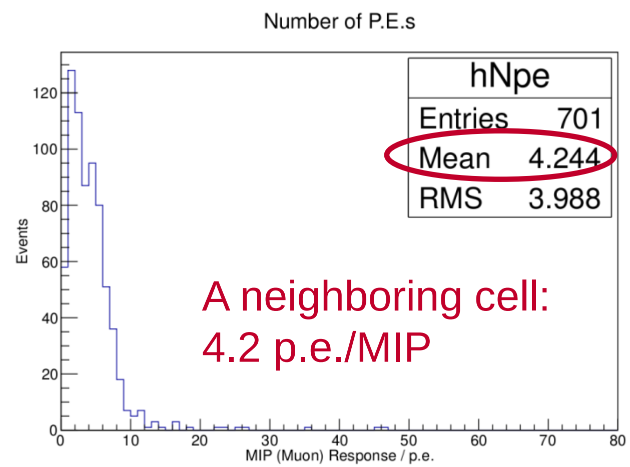

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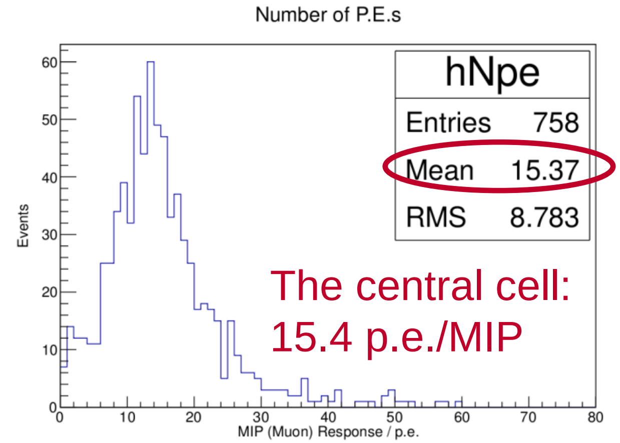

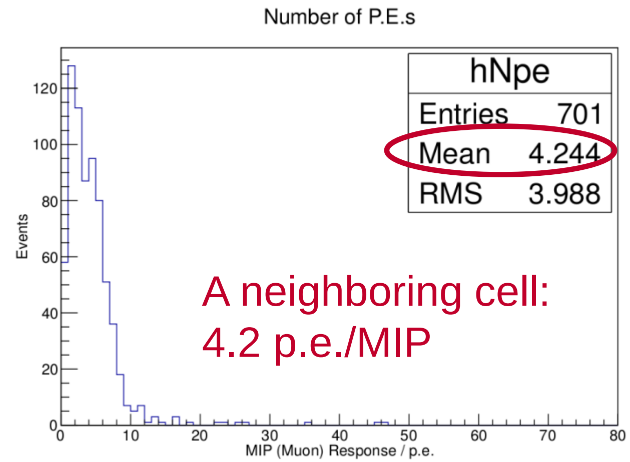

This prototype still has wider trenches and wider offset than designs; still promising if optimal designs can be realized

Summary and outlook

- Megatile can be a major simplification
  - for the mass assembly of scintillator HCAL
- Detailed simulation studies on megatile based on Geant4
  - Promising performance suggested
  - High response (>20 p.e./MIP) and low cell-to-cell crosstalk (~2%)
  - Almost no dead area, most (>96%) boundary area with >70% response
    - Current tile design: 2~2.6% dead area

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  - Almost no dead area, most (>96%) boundary area with >70% response
    - Current tile design: 2~2.6% dead area

- Efforts of megatile development ongoing
  - A first megatile prototype has been produced and measured
  - Will build more prototypes with optimized geometry
    - Try to be close to design values in simulation
  - Study mechanical stability and performance at a larger scale (12×12 cells)
  - Test other ways to enhance mechanical stability (e.g. glue+TiO2 pigments)

Thank you!

Backup

Crosstalk: different definitions

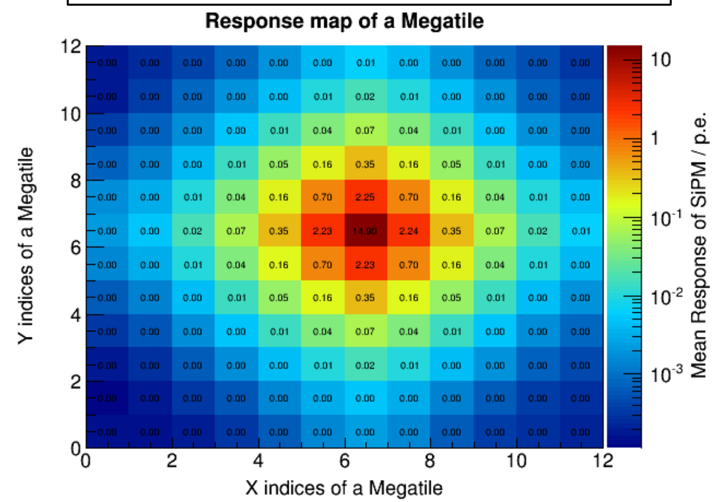
- Crosstalk can be defined by response ratio
  - between the central cell and one of neighbours (ε)
  - or between the central cell and all 3×3 cells ($\varepsilon_{3\times3}$)

$2\varepsilon^2 N_1$	εN_1	$2\varepsilon^2 N_1$
εN_1	N_1	εN_1
$2\varepsilon^2 N_1$	εN_1	$2\varepsilon^2 N_1$

Only consider crosstalk between cells which share one side

ε is the 2-cell crosstalk probability;
N_1 is the response in the central cell

Single trench arrays, 2.5mm deep



2-cell crosstalk: 15.1 %

3x3 cells crosstalk: $\frac{14.90}{14.90+8.95+2.80} = 55.9\%$

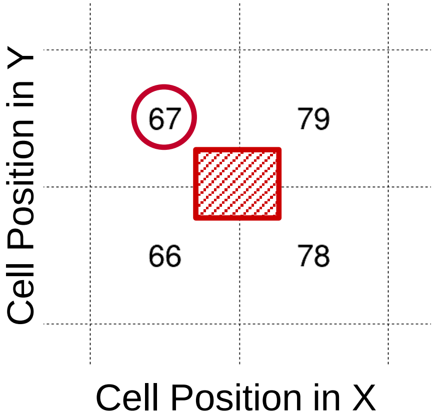
$$\varepsilon_{3\times3} = \frac{N_1}{N_1+4\varepsilon N_1+8\varepsilon^2 N_1} = \frac{1}{1+4\varepsilon+8\varepsilon^2}$$

For $\varepsilon = 15.1\%$, $\varepsilon_{3\times3} = 56.0\%$

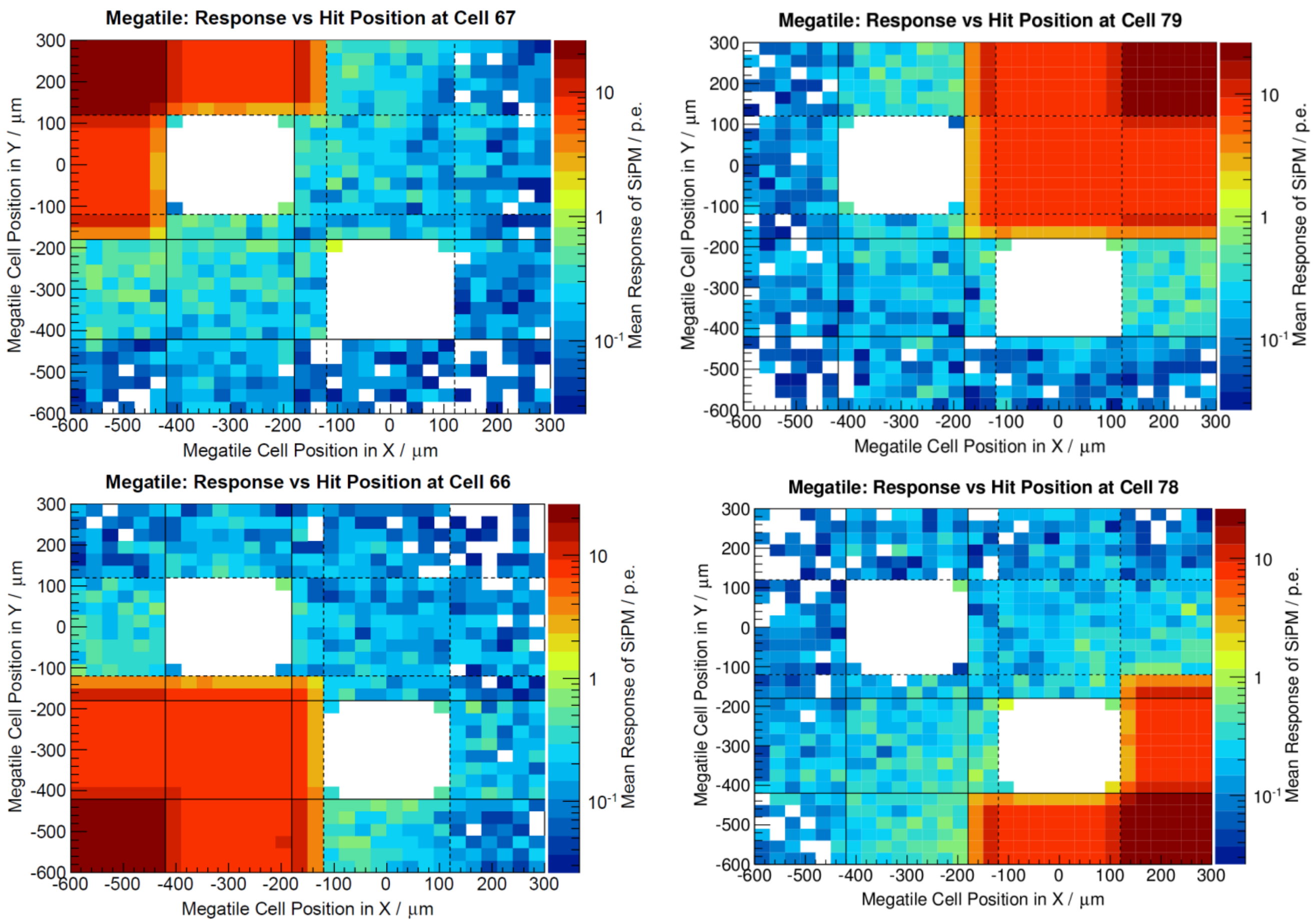
2 definitions are equivalent

Simulation of double trenches: details of boundary areas

- Special MC runs: positions of all muons closer to corners of 4 cells
  - Read out relavant 4 SiPMs, respectively (4 response maps)

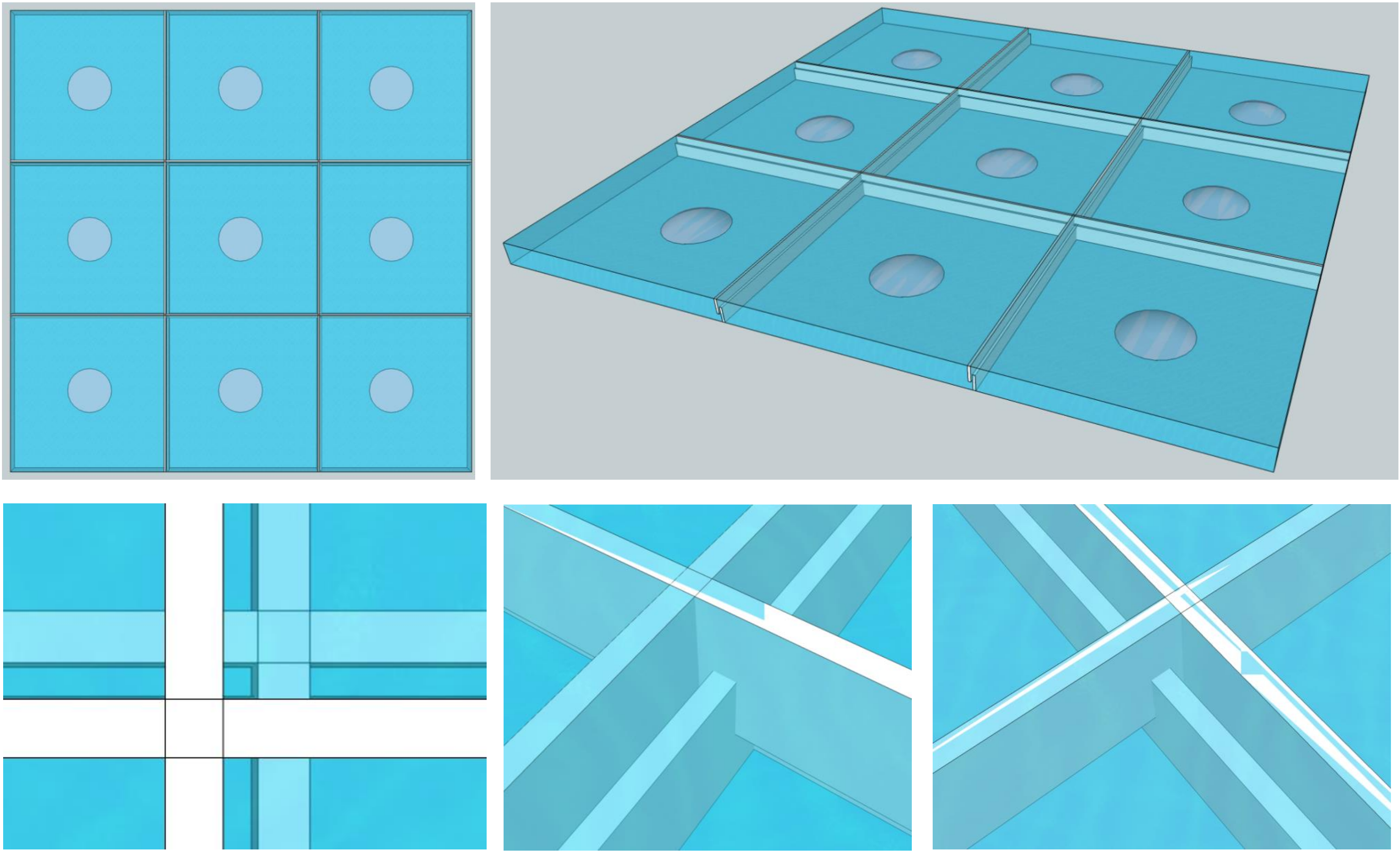


Muons: hit positions



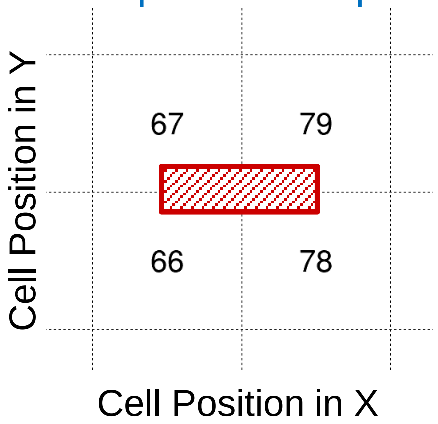
Solid and dashed lines indicate top and bottom trenches (borders)

Details of straight trenches



Simulation of tilted trenches: details of boundary areas

Step size: 125 µm

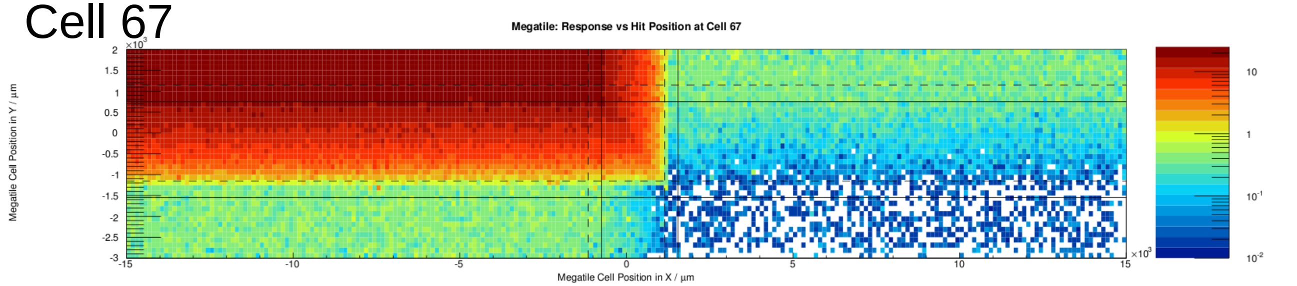


Muons: hit positions

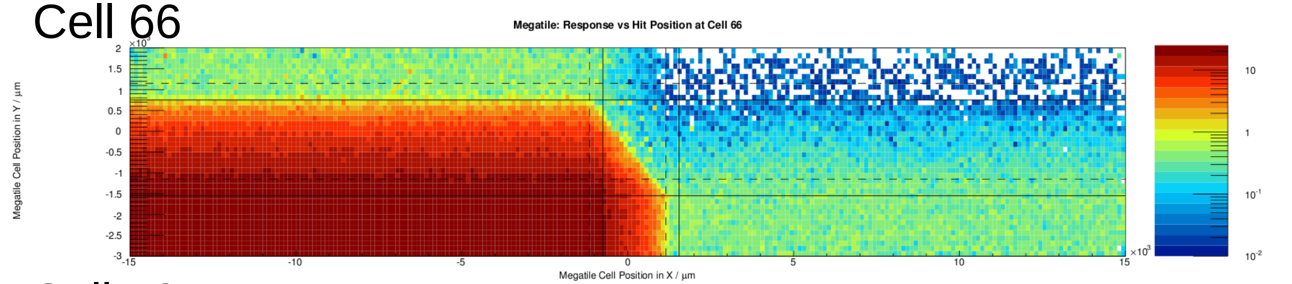
Cell boundary well separated

Solid and dashed lines indicate top and bottom trenches (projection to x-y plane)

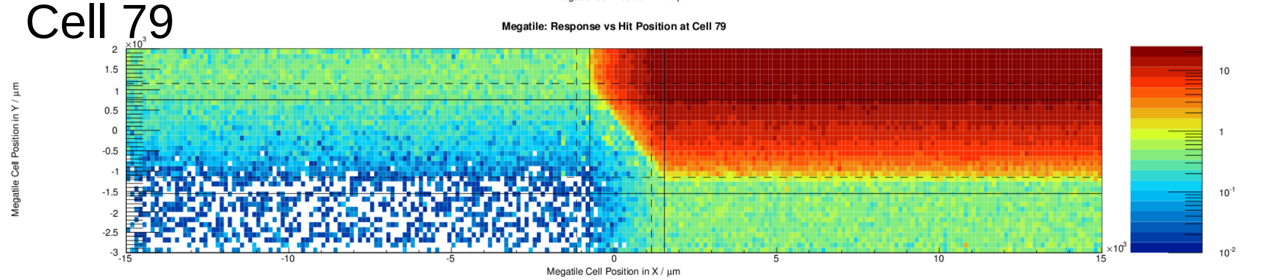
Cell 67



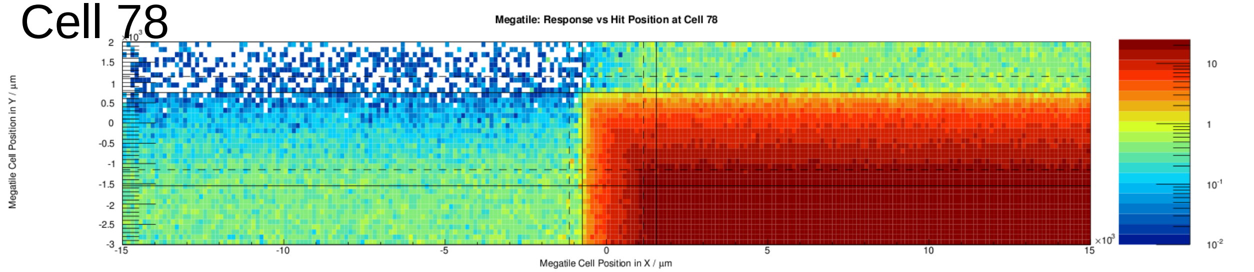
Cell 66



Cell 79



Cell 78



Details of tilted trenches