MegaTile studies: with a focus on simulation

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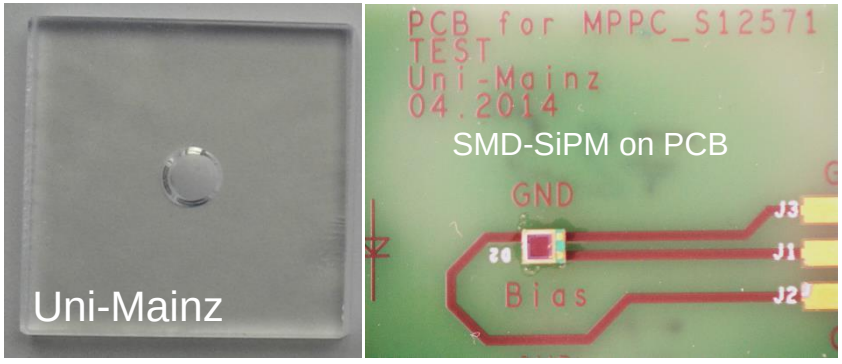
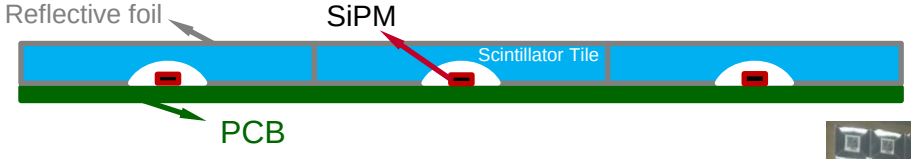
CALICE

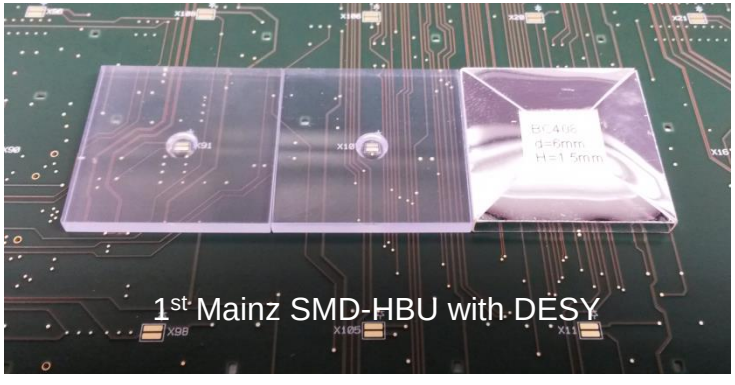
Scintillator HCAL: towards mass assembly

Surface-mounted Design



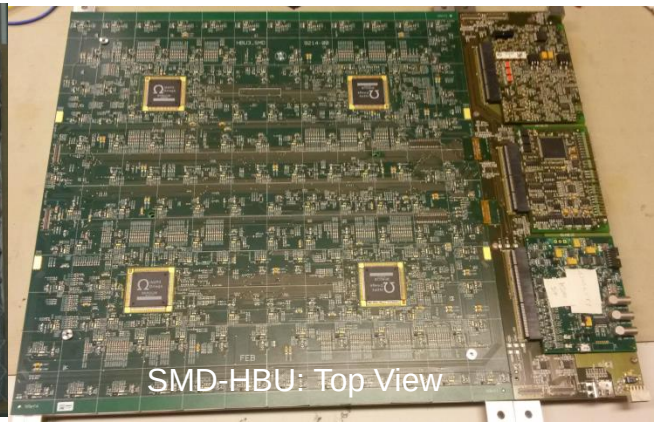
HCAL detector unit: a scintillator tile (30×30×3 mm³) with a SiPM





- 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

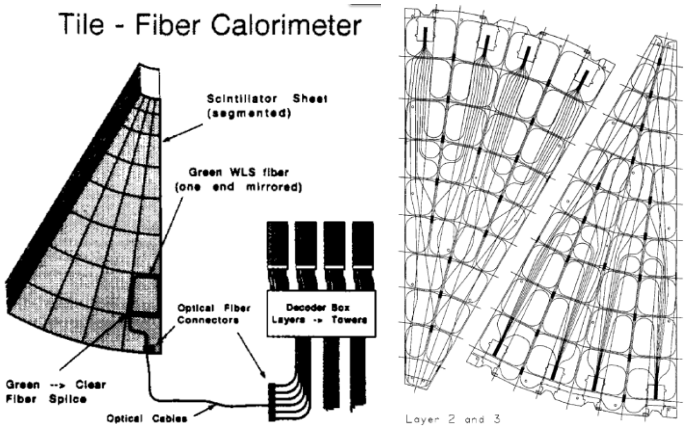
Details in talks from Katja and Phi



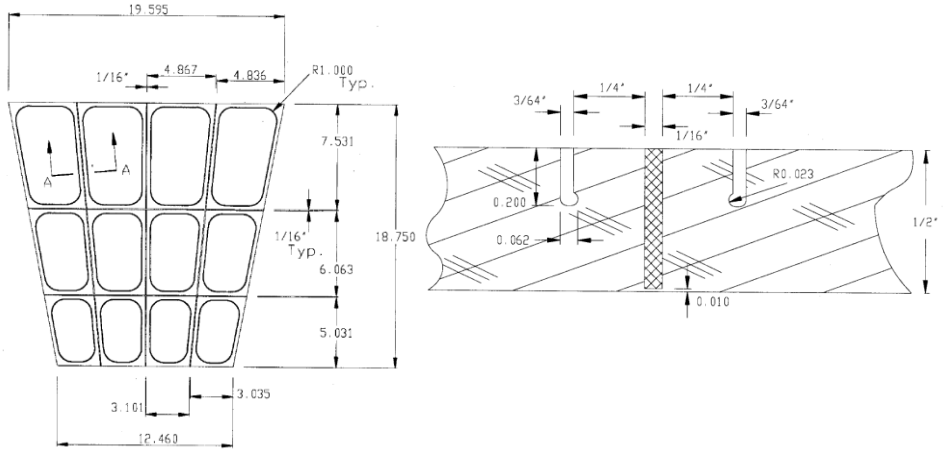
Can we further simplify the design for more efficient mass assembly?

Megatile: applications in the past and at present

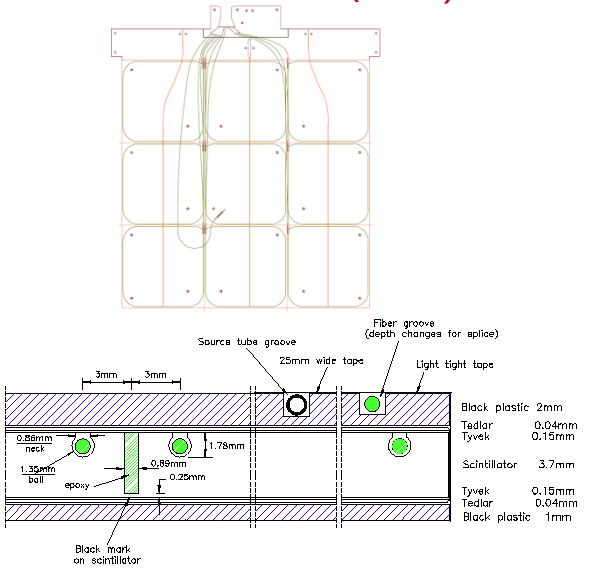
CDF End Plug Upgrade HCAL (1994)



D0 Run II Inter Cryostat Detector (1999)



CMS HCAL (1996)



STAR Barrel EMC (2002)

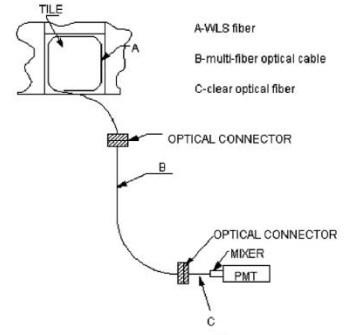
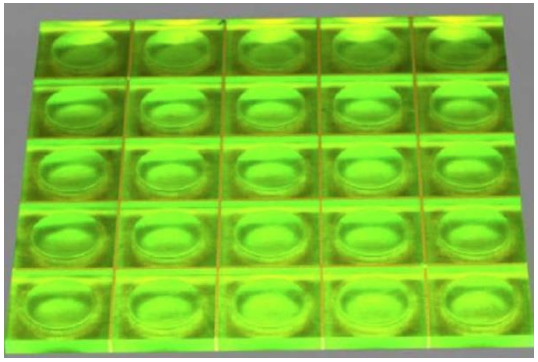


Fig. 5. Schematic diagram of the BEMC optical system illustrated for a single tile.

NIU Integrated Readout Layer (2009)

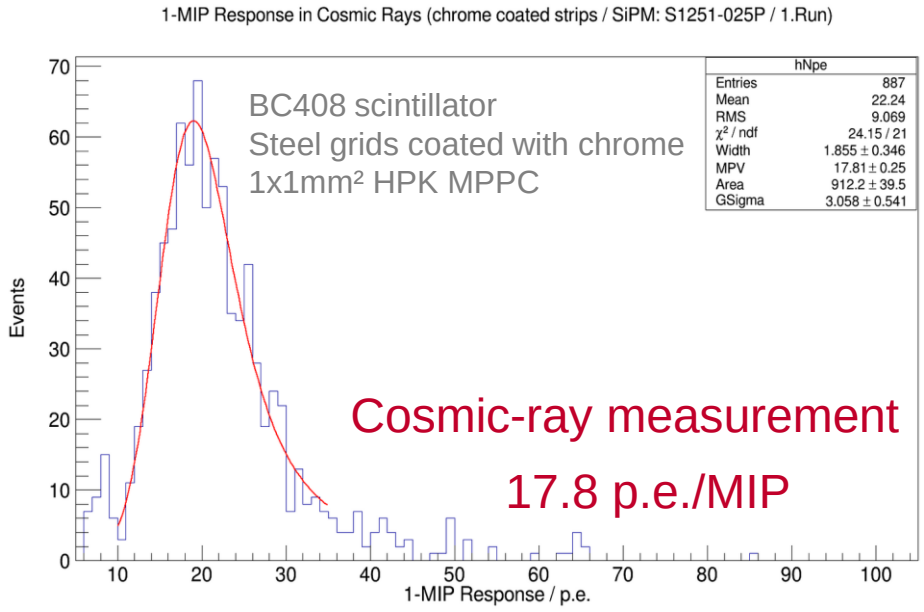


Note: this list is not meant to be exhaustive; the year corresponds to the earliest one appearing in the documents at hand

Efforts of MegaTile development at Mainz (1)

- MegaTile with steel grids

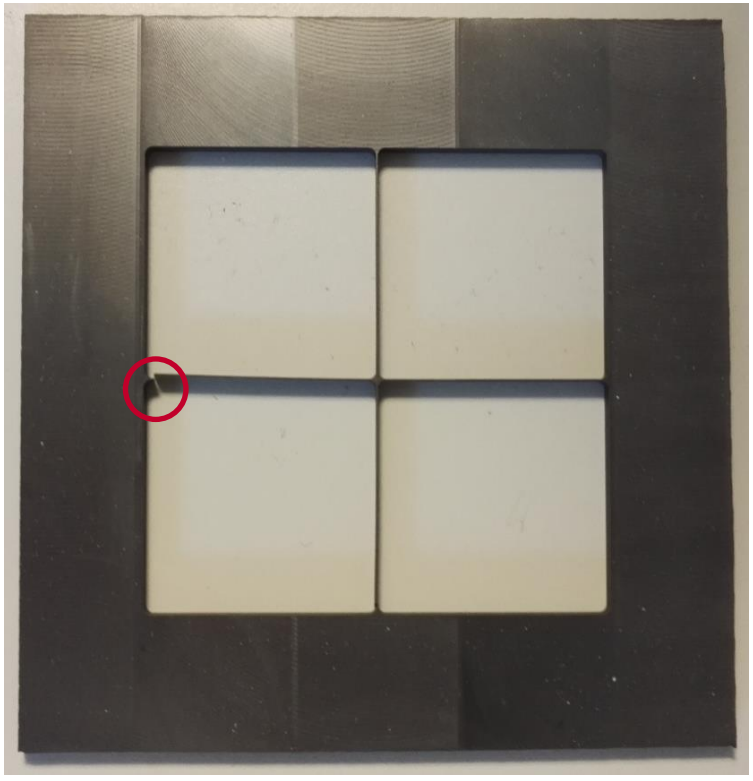
Prototype with metal grids and individual tiles

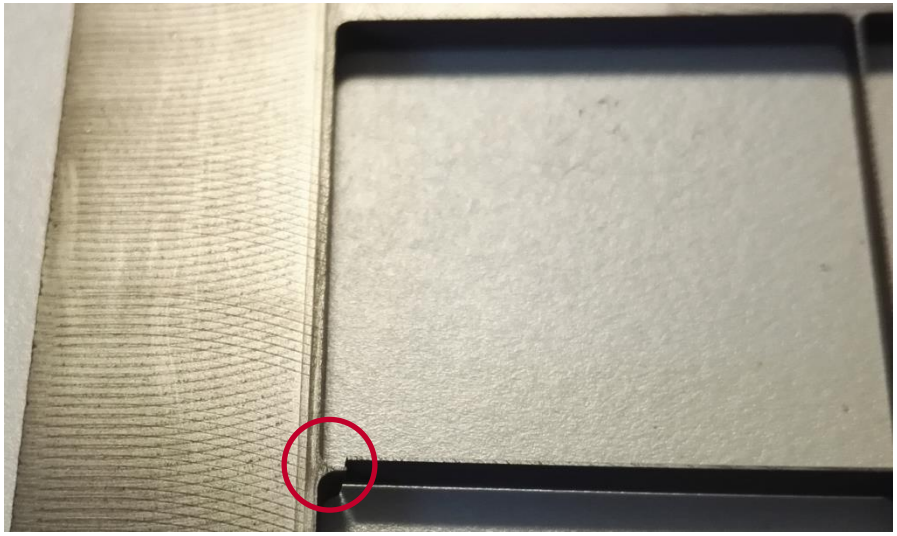


- Idea: quickly produce metal grids
- A first prototype worked well with steel strips and individually machined tiles
- Many manufacturers tried, but could not produce the steel grids with sub-mm thickness at the size ~ 36x36 cm²

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



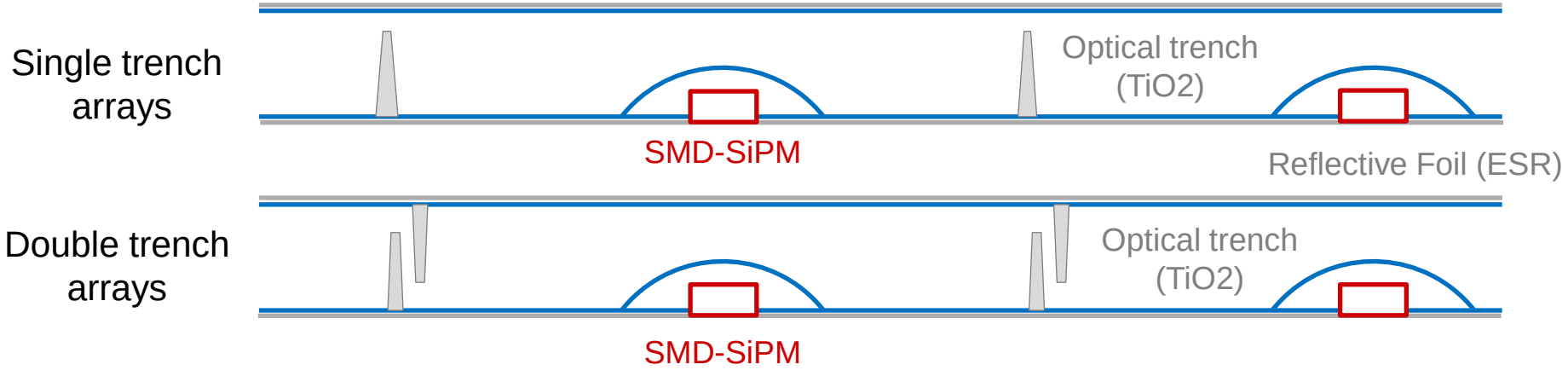


A small part fractured

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
- Designs
  - Trench arrays: single vs double
  - Trench free variables: shapes, depth, width(s)
    - Double trenches: position offset of top and bottom trenches

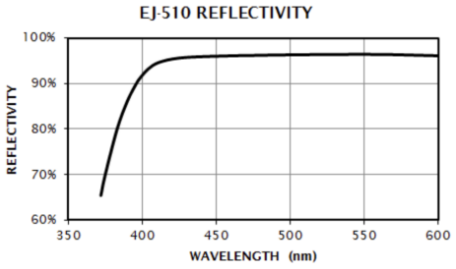
Trench schematics (side view): not in scale

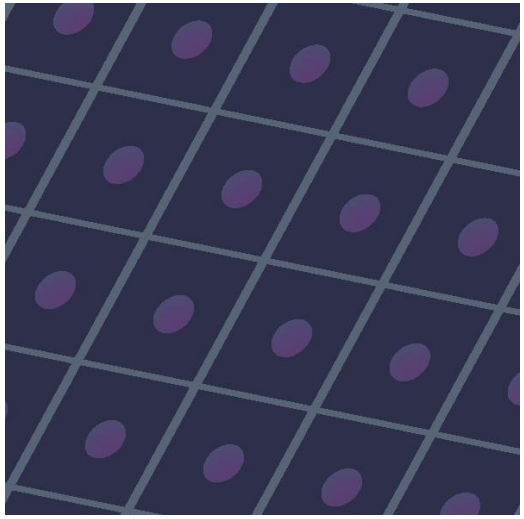


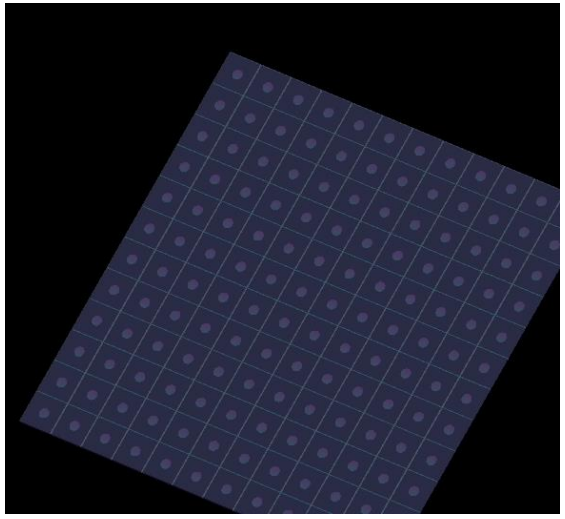
Geant4 simulation of MegaTile: overview

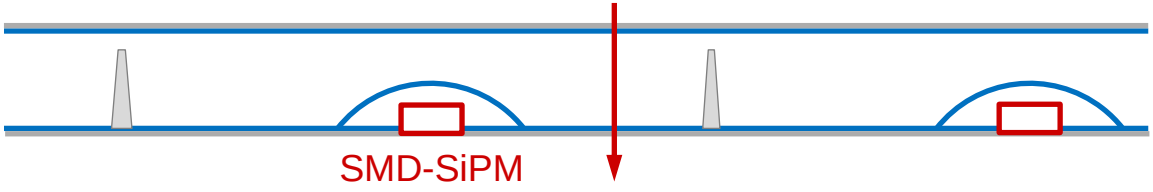
- A scintillator plate (BC408) segmented for 12×12 cells
  - Cells separated by trenches, filled in with white paints
  - Each cell individually read out by an SMD-SiPM
  - Top/bottom surfaces covered with ESR foil
  - Muons pass through the central cell perpendicularly

Trenches filled in with TiO2, presumed to be ideally diffuse



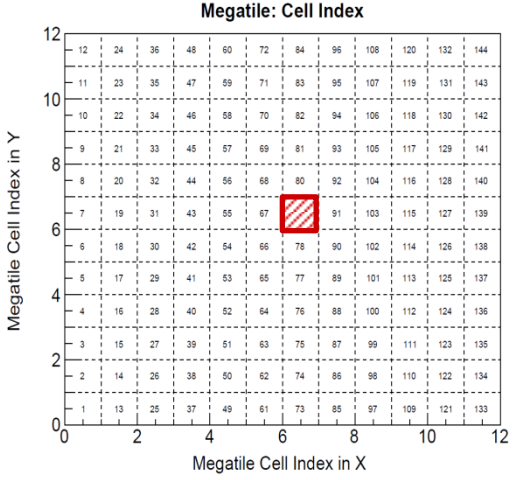






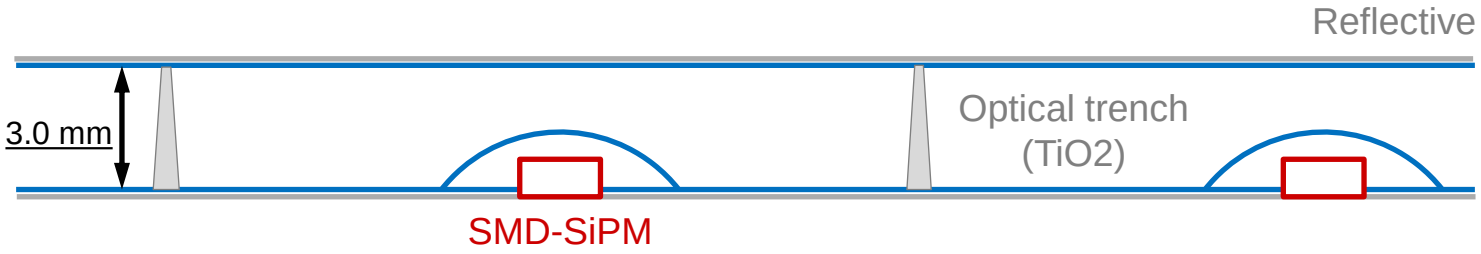
Response of each SiPM is read out and averaged by the number of events

12×12 cells



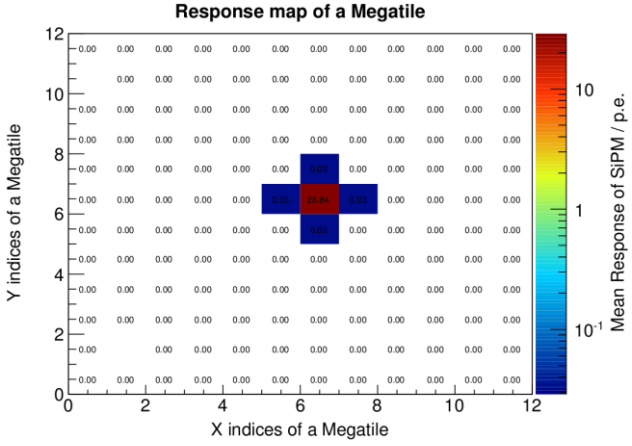
Muons: hit positions

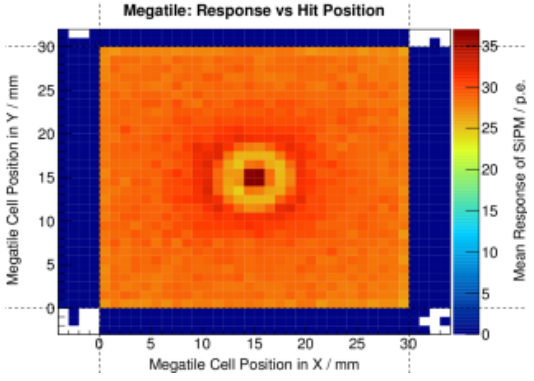
MegaTile simulation: a simple start



- Trench depth: 3mm
- 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)

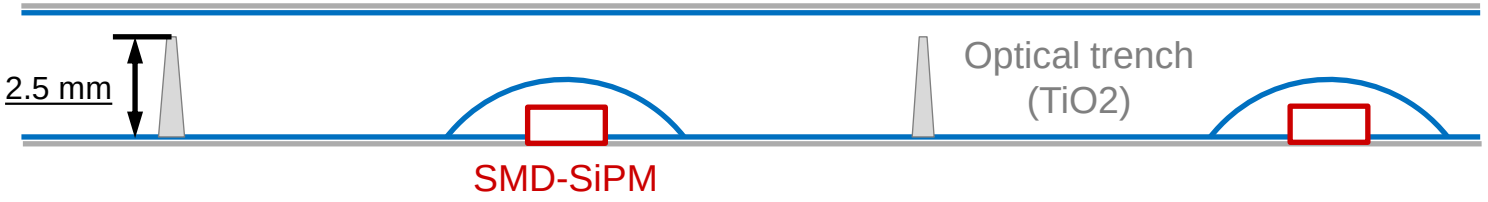
2-cell crosstalk:
0.03 p.e./ 28.84 p.e
= 0.1 %

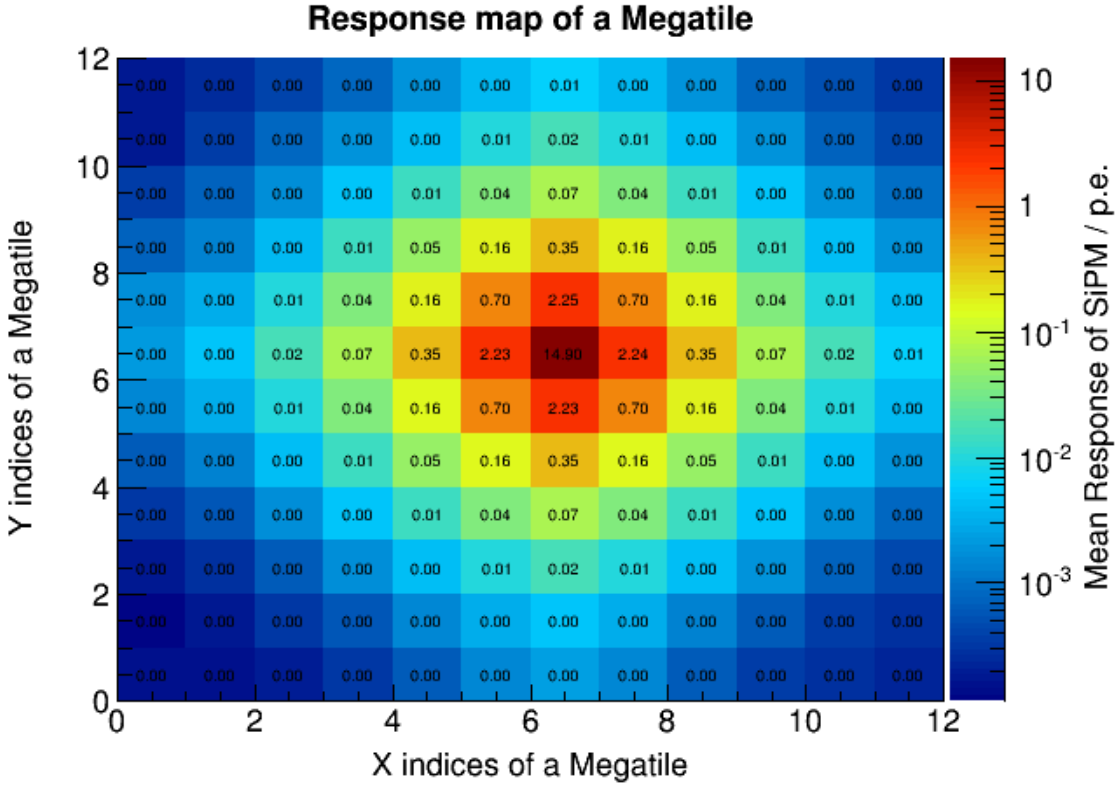




Central cell details:
similar uniformity map

Single trench arrays: simulation of 2.5 mm depth





2-cell crosstalk: 15.1 %

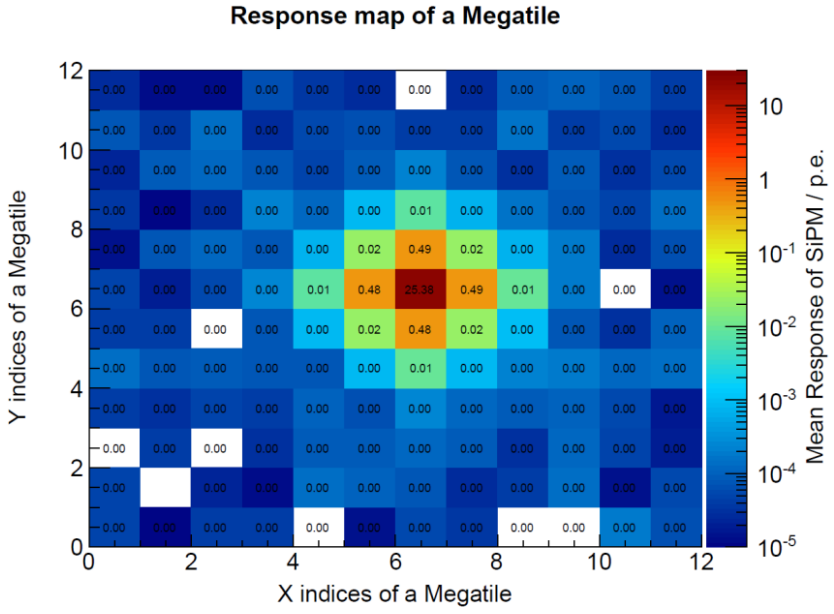
- Single trenches
  - 2.5 mm depth
  - Quite deep already
- Bridges between cells
  - 0.5 mm thick
- 2-cell crosstalk
  - 15.1% between the central cell and one of its neighbors (max.)
- Central cell
  - 1-MIP Response: 14.9 p.e.
  - Compared to scenario of 3mm depth: 28.8 p.e.

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

- 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



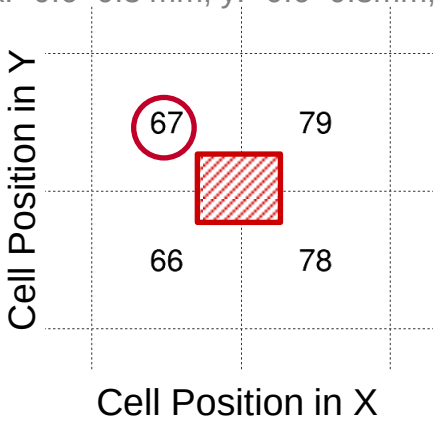
2-cell crosstalk: 1.9 %

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

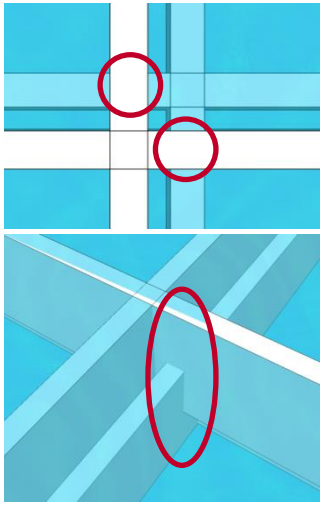
Double trenches: boundary effects

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

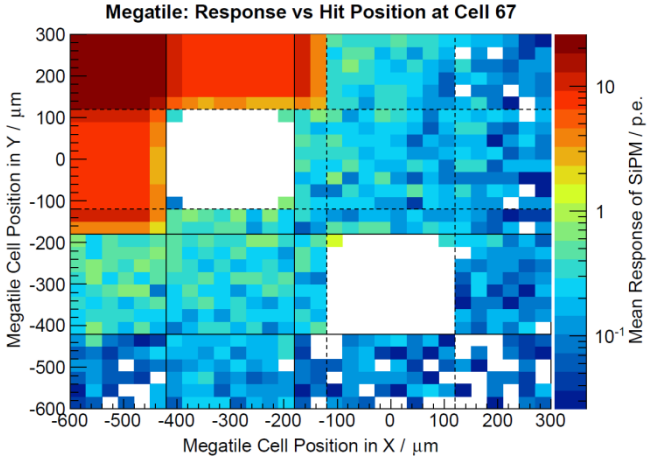
x: -0.6~0.3 mm; y: -0.6~0.3mm; step size: 30 µm



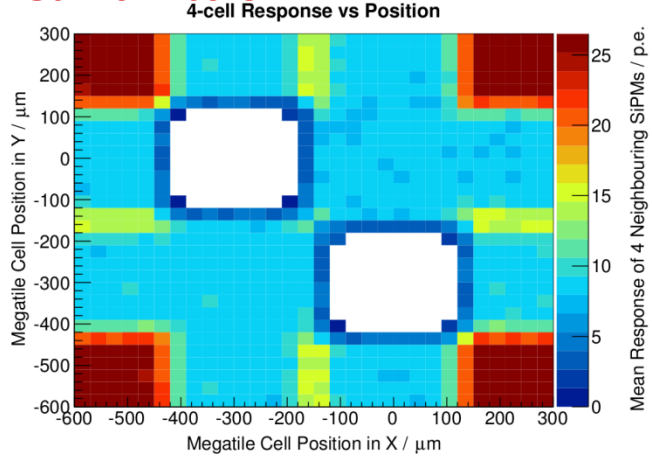
Muons: hit positions



Cell 67



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

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

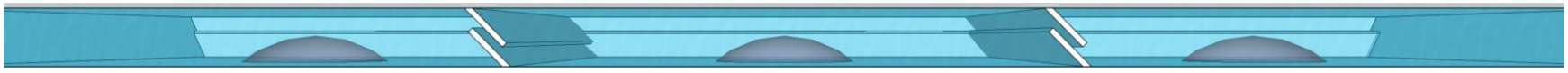
Current tile size: 29.6 × 29.6 mm²
dead area per tile: 23.84 mm²
(~ 2.6% of a tile)

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 mm² per cell
    - 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)

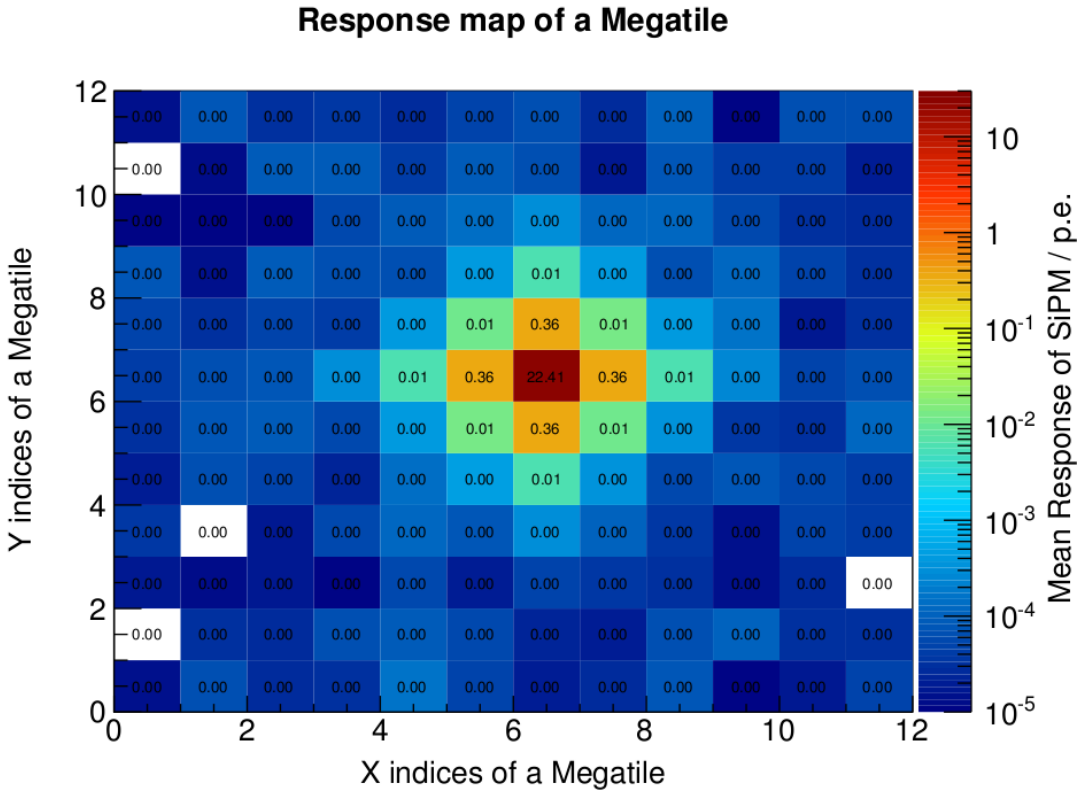
Rendered by G4RayTracer

Constructed in SU



Simulation of tilted trenches: crosstalk

Rendered by G4RayTracer

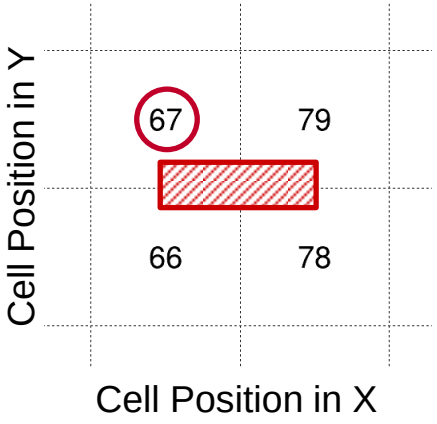


- Crosstalk
  - 2-cell crosstalk 1.9 %
  - Same as straight trenches
- Central cell
  - 22.4 p.e./MIP
  - Lower response than straight trenches (25.4 p.e.)

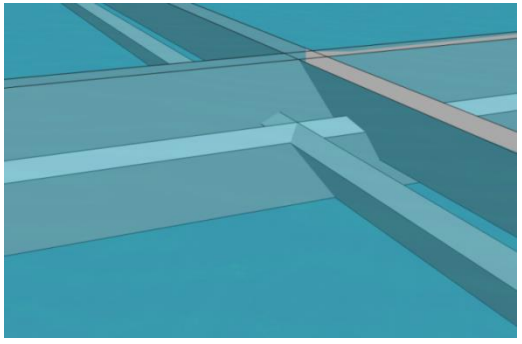
2-cell crosstalk: 1.9 %

MC suggests promising low crosstalk level and moderate MIP response

Simulation of tilted trenches: boundary areas



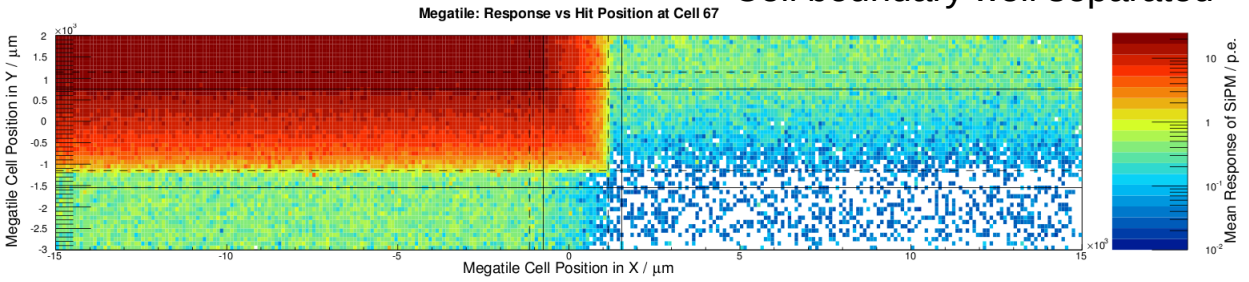
Muons: hit positions



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

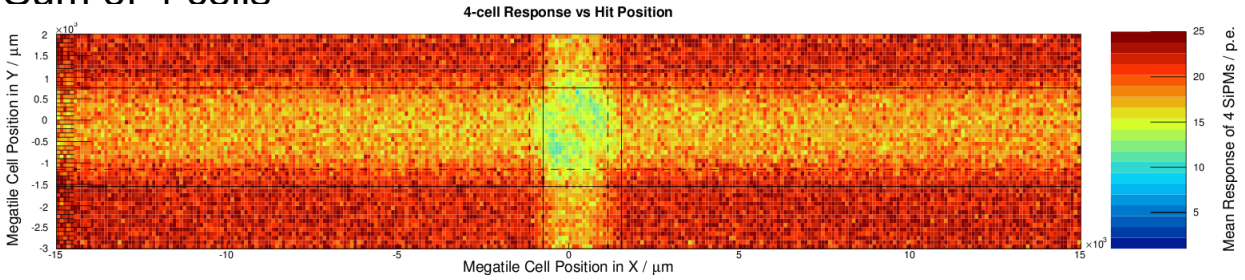
Cell 67

Cell boundary well separated



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

Sum of 4 cells

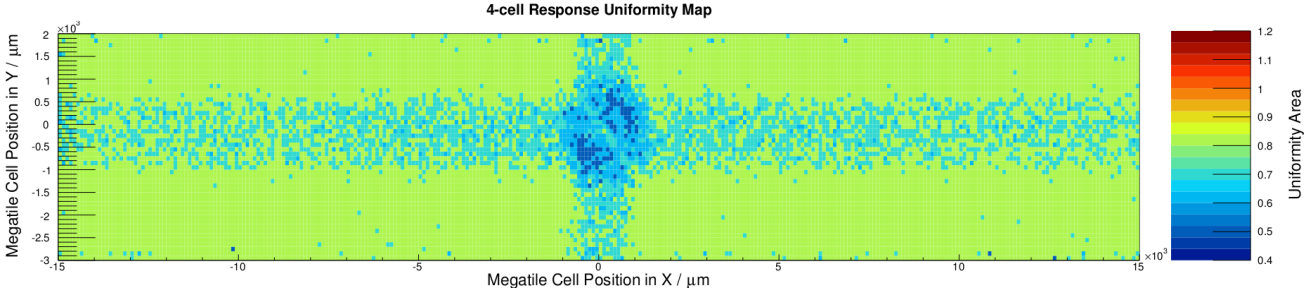


- Boundary areas: also high response
- Impact from particle incidence angle
  - Perpendicular: no dead area (as shown)
  - Oblique: very small dead area foreseen
    - Only ~ 45° incident tracks, but these tracks also lead to higher energy depositions in the scintillator

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%

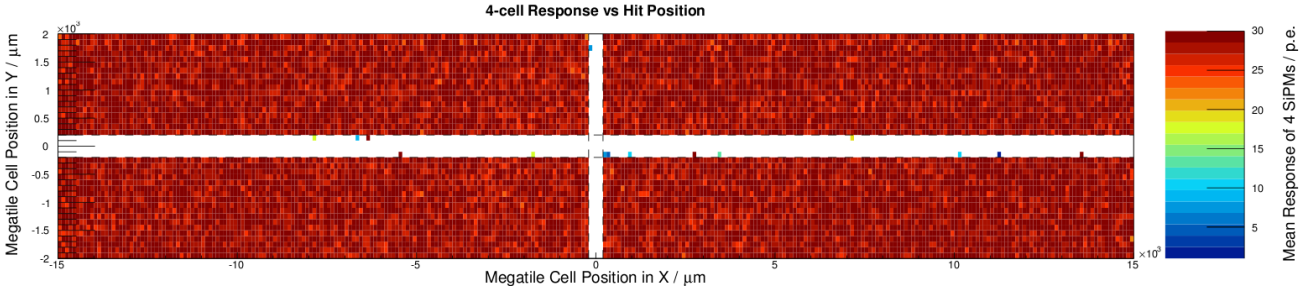
- All boundary area is active and most (>96%) has >70% response
- Comparison with current tile design
  - Nominal size: 30.0 ×30.0 mm²
  - Current tile size: 29.6 × 29.6 mm²
  - Dead area per tile: 23.84 mm² (~ 2.6%)

Megatile has such a potential of almost zero dead area

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

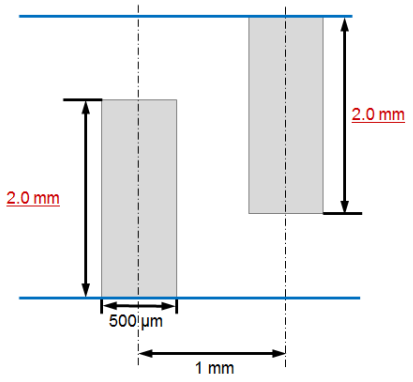
Non-sensitive area: 400µm between each cell (simulation)

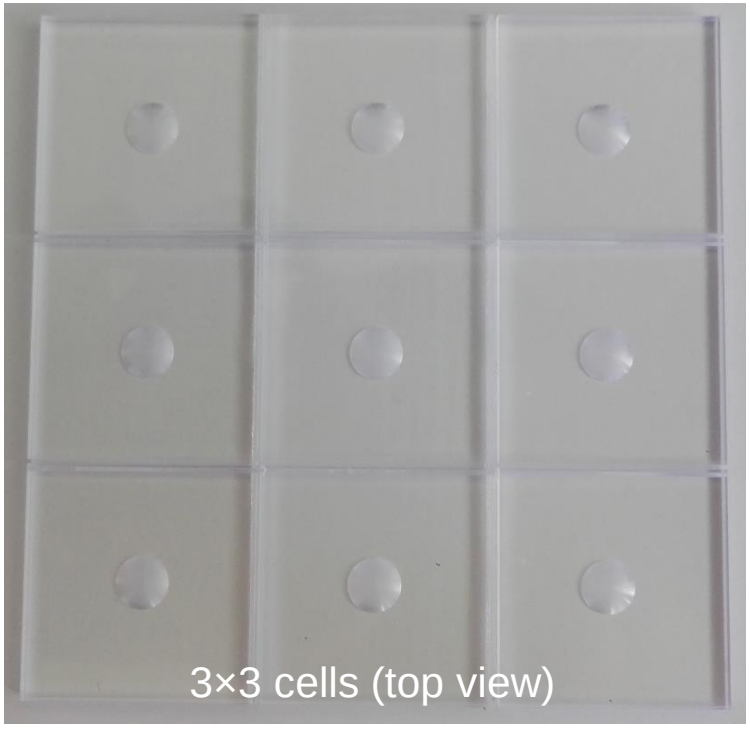
x: -15~15mm; y: -3~2mm;
step size: 100 µm

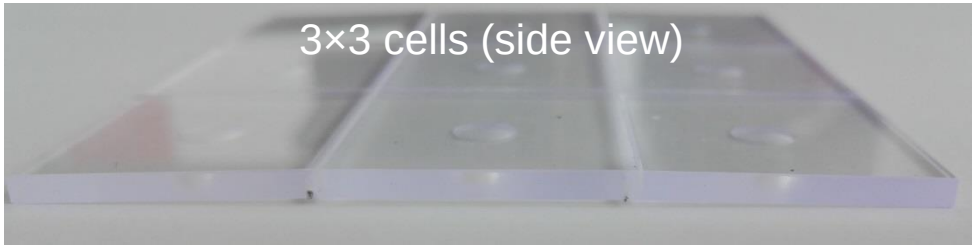


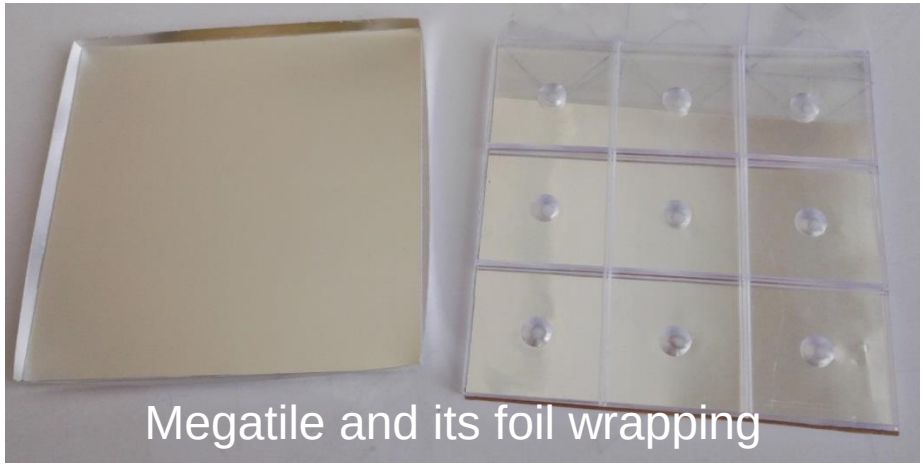
MegaTile: a first new prototype (1)

- 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 0.3mm, offset 0.3mm (same depth 2mm)



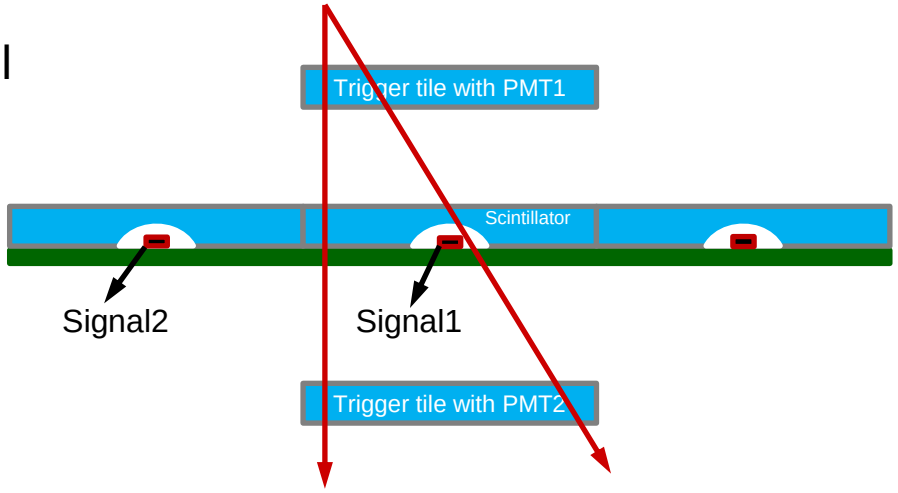

3×3 cells (top view)


3×3 cells (side view)

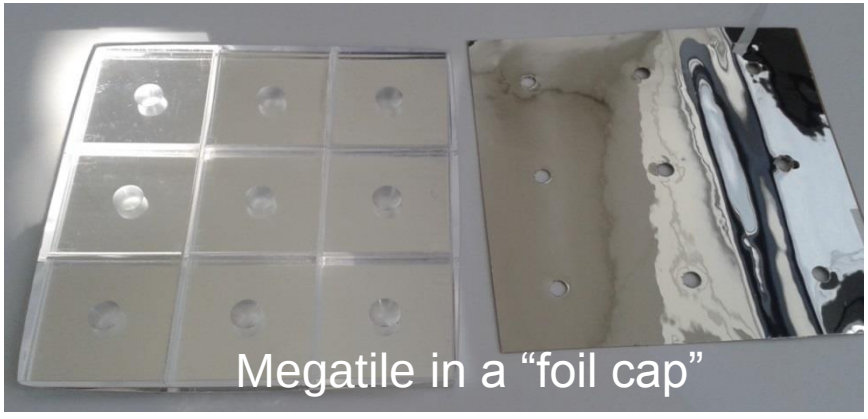

Megatile and its foil wrapping

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%)
- Cosmic-ray test stand
  - Trigger the central cell
  - Read out the central cell and its left cell
  - Include tracks passing cell boundaries



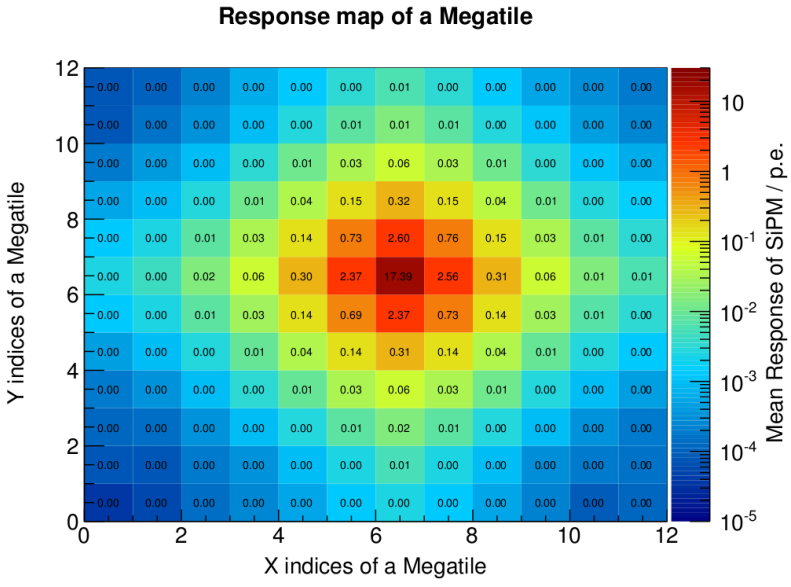
A first quick test:
prototype finished just some days ago


Megatile in a “foil cap”

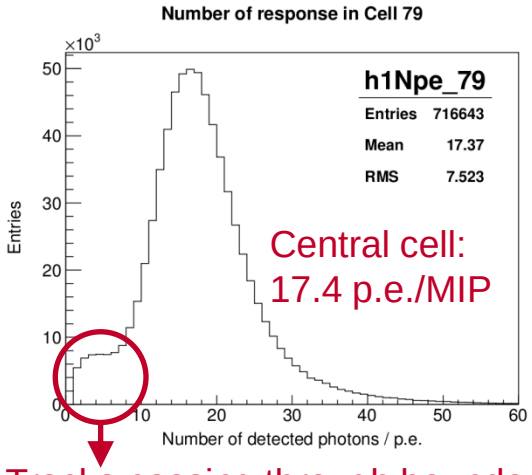

Foil strips for trenches

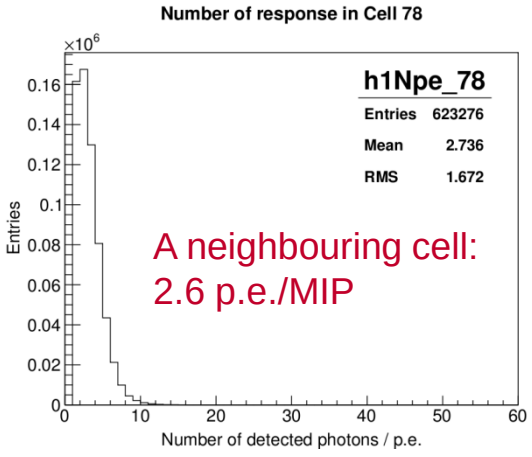
Megatile prototype: check what its simulation says

- 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%





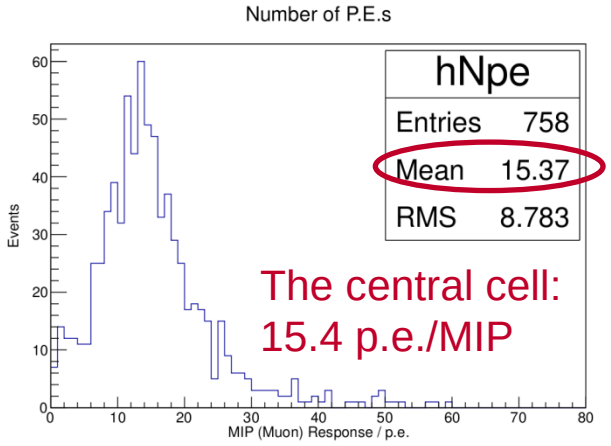
Tracks passing through boundary

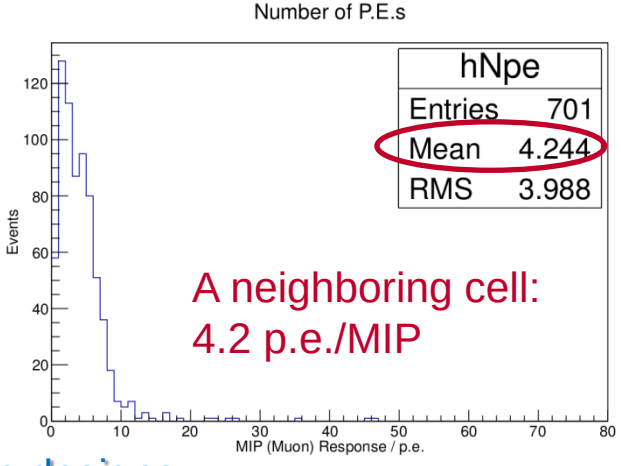
Entries with 0 p.e. exist (no noises), just not plotted;
Response averaged by number of events (i.e. 720k), entries of 0 p.e. also included

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 %
- Simulation for this prototype
  - Central cell 17.4 p.e./MIP
  - A neighboring cell: 2.6 p.e./MIP
  - 2-cell crosstalk: 15 %
- Possible reasons
  - 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)
  - Alignment between megatile and trigger tiles
  - Foil strips in trenches: trenches too wide (0.5mm), strips (0.14mm thick) can be tilted

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





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

- 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	$2\varepsilon^2 N_1$

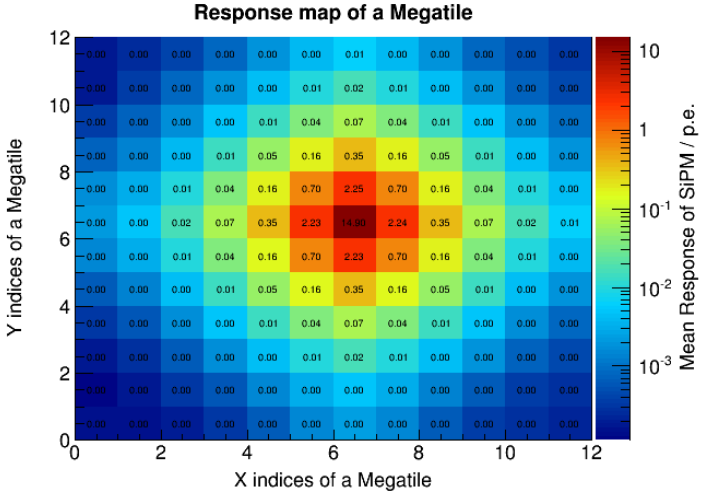
Only consider crosstalk between cells which share one side

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

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

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

Single trench arrays, 2.5mm deep



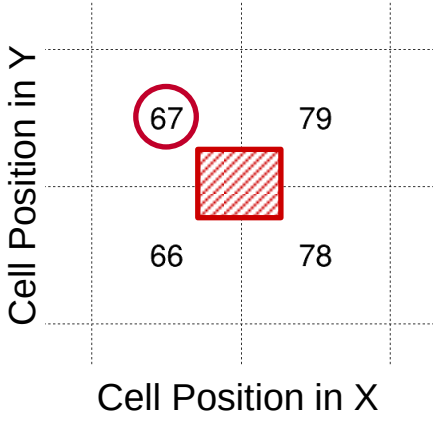
2-cell crosstalk: 15.1 %

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

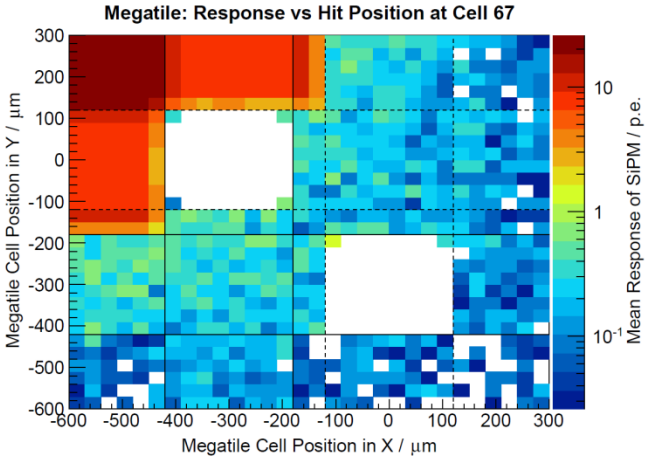
2 definitions are equivalent

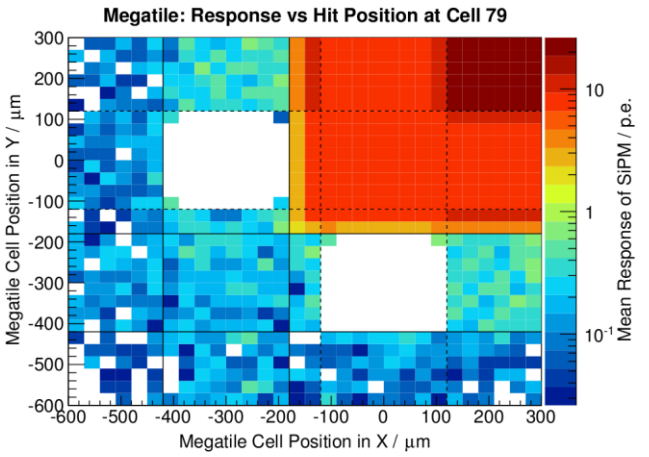
Simulation of double trenches: details of boundary areas

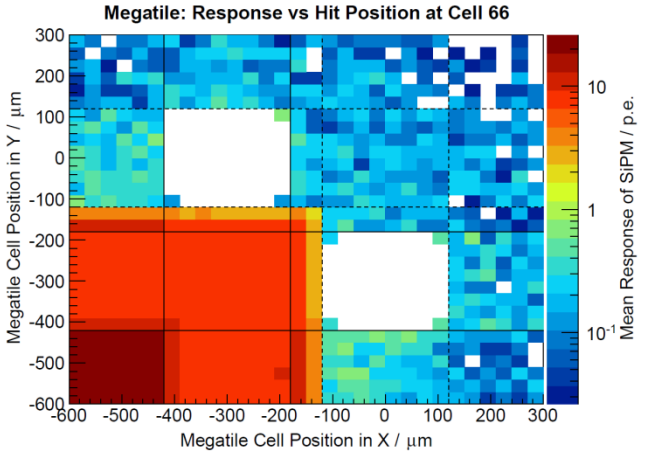
- Special MC runs: positions of all muons closer to corners of 4 cells
  - Read out relavant 4 SiPMs, respectively (4 response maps)

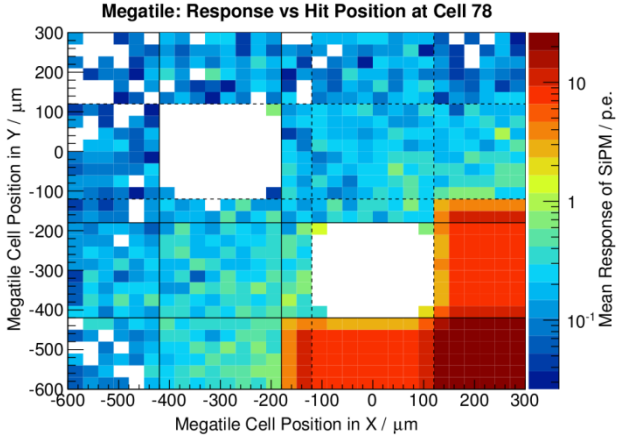


Muons: hit positions



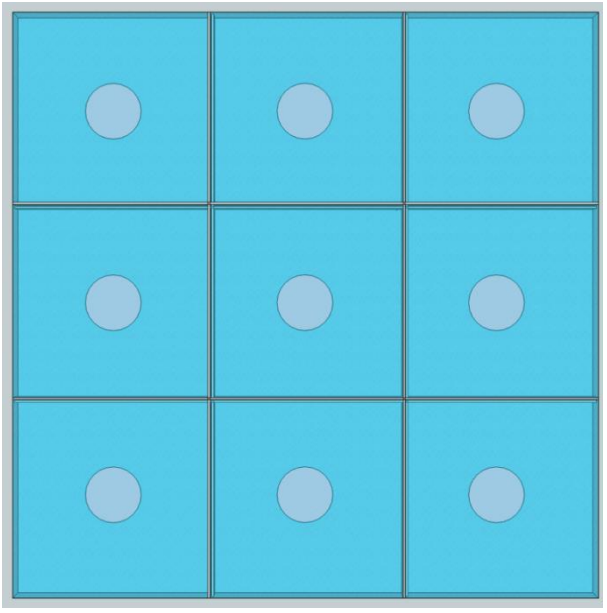


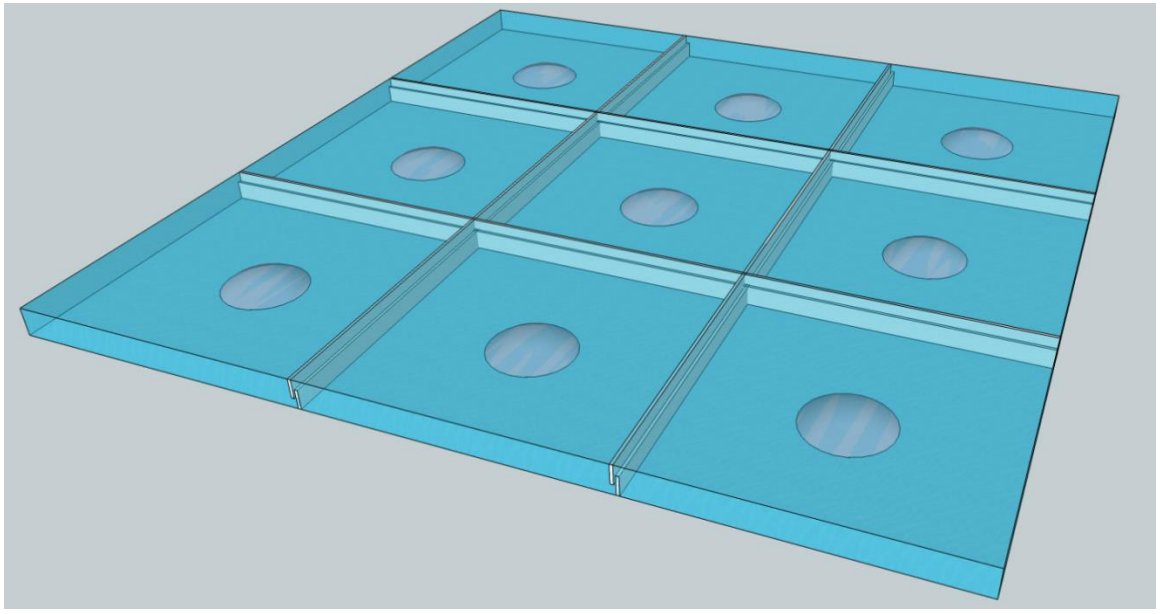


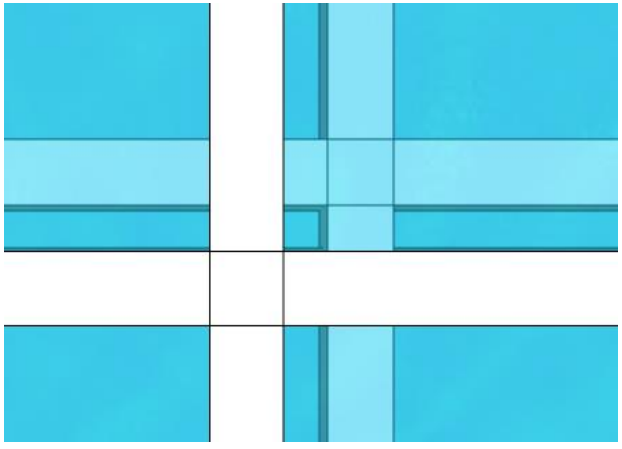


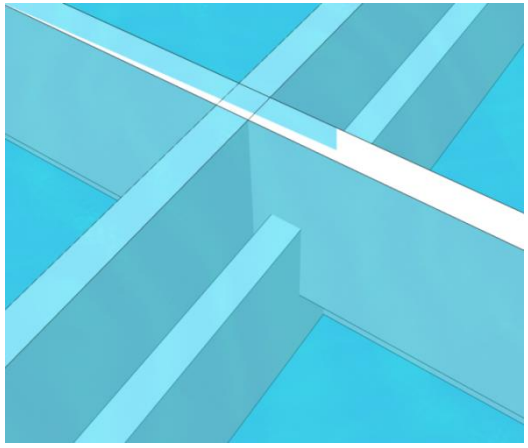
Solid and dashed lines indicate top and bottom trenches (borders)

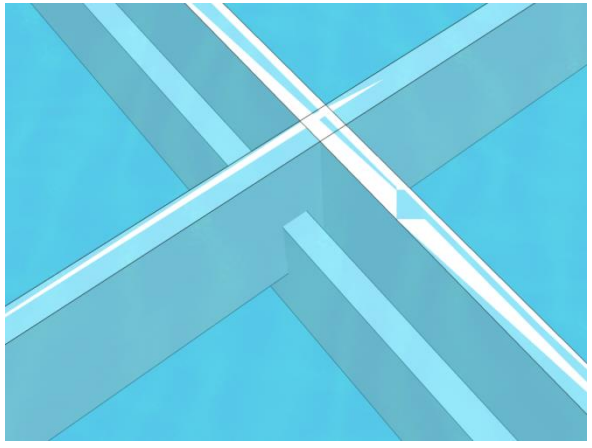
Details of straight trenches





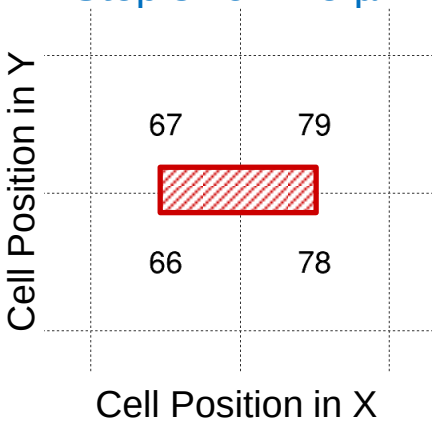






Simulation of tilted trenches: details of boundary areas

Step size: 125 µm

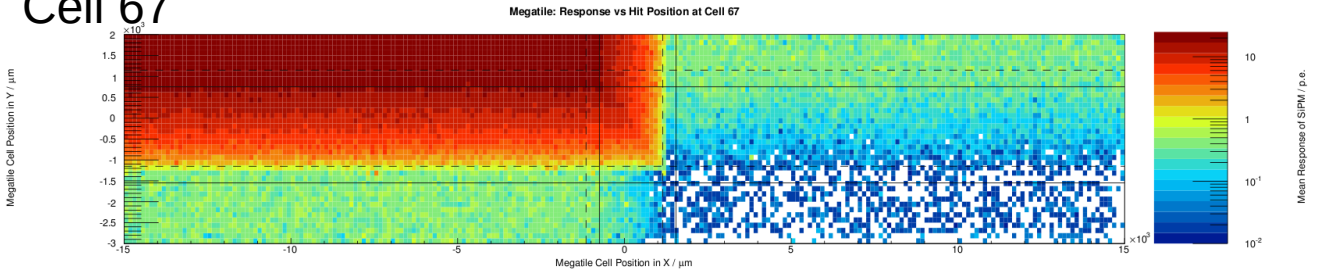


Muons: hit positions

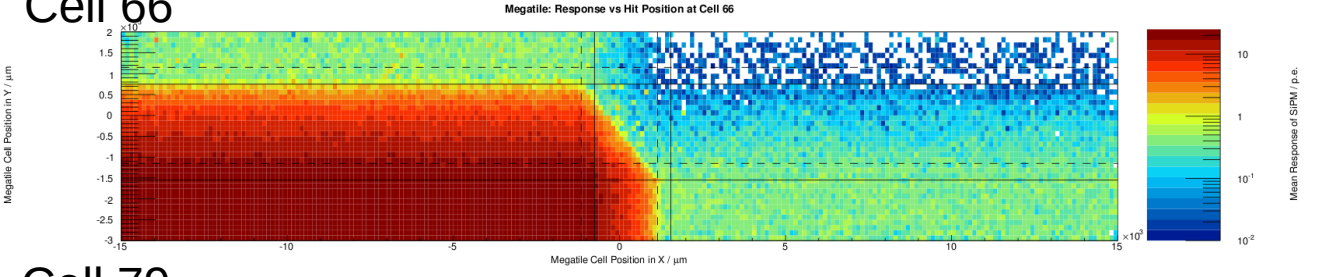
Cell boundary well separated

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

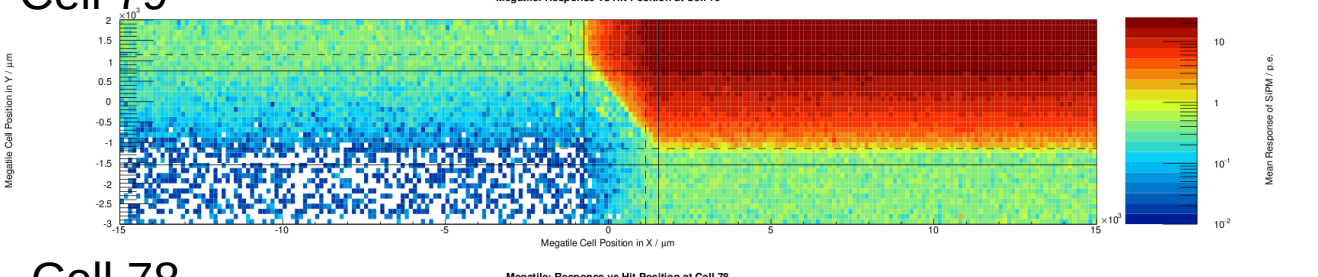
Cell 67



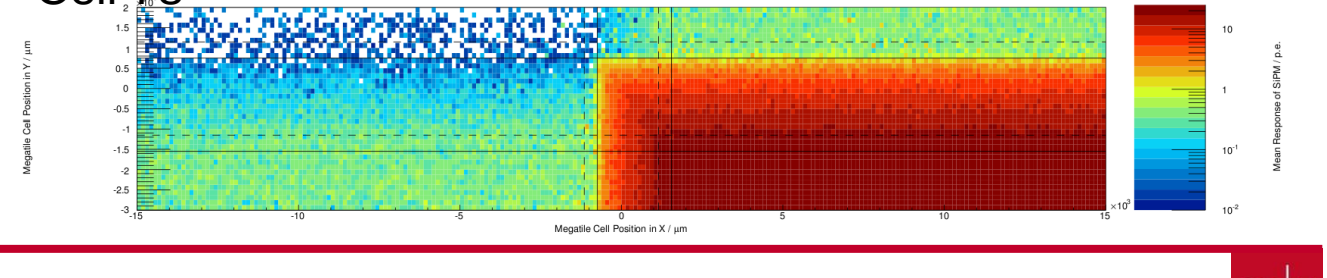
Cell 66



Cell 79



Cell 78



Details of tilted trenches