Megatile Studies

Yong Liu
Johannes Gutenberg Universität Mainz

CALICE AHCAL Main Meeting
Dec. 16, 2016, DESY Hamburg

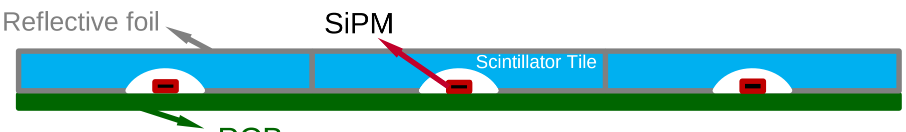
Volker Büscher, Phi Chau, Reinhold Degele, Karl-Heinz Geib, Sascha Krause,
Lucia Masetti, Ulrich Schäfer, Stefan Tapprogge, Rainer Wanke

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

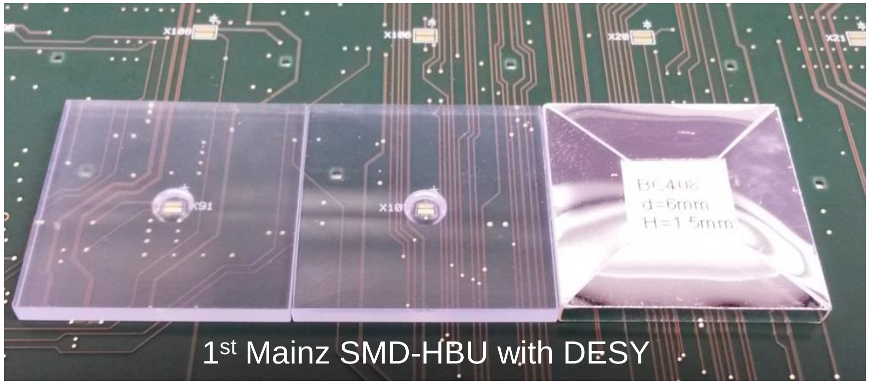
PRISMA DETECTOR LAB

Bundesministerium für Bildung und Forschung

AHCAL: towards mass assembly



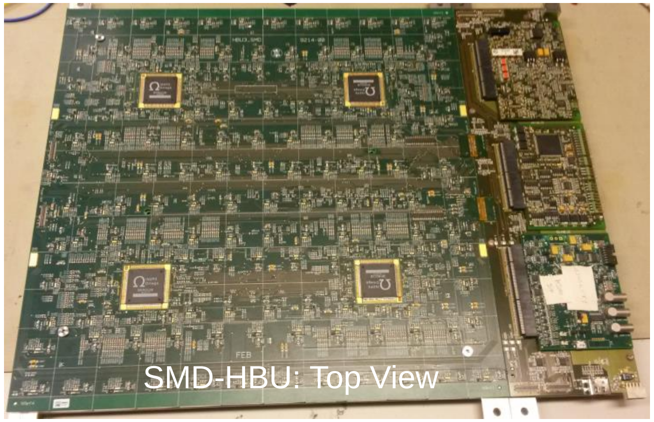
Detector unit: a scintillator tile (30×30×3 mm³) with a SiPM



1st Mainz SMD-HBU with DESY

- Surface-mount tile design (Uni-Mainz)
  - Suitable for mass assembly
  - Optimized with Geant4 full simulation for response uniformity
  - 1st board built successfully in 2014
  - Adopted as a baseline design for the tech. prototype (2015-2018)
  - 6 new SMD-HBUs fully assembled

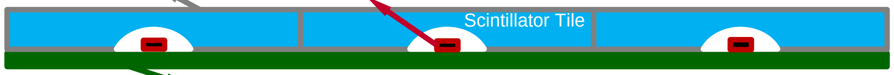
SMD-HBU: Bottom View



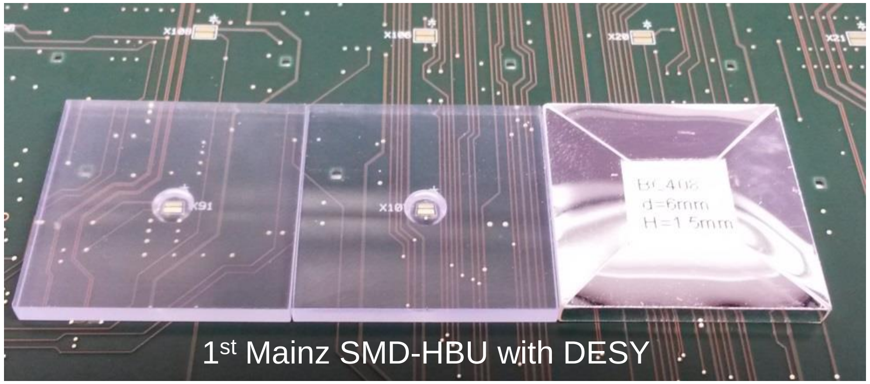
SMD-HBU: Top View

Y. Liu et al, IEEE NSS 2014
DOI: 10.1109/NSSMIC.2014.7431118

AHCAL: towards mass assembly



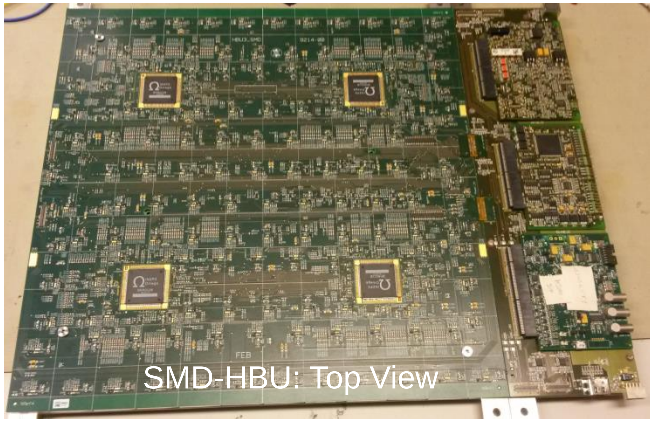
Detector unit: a scintillator tile (30×30×3 mm³) with a SiPM



1st Mainz SMD-HBU with DESY

- Surface-mount tile design (Uni-Mainz)
  - Suitable for mass assembly
  - Optimized with Geant4 full simulation for response uniformity
  - 1st board built successfully in 2014
  - Adopted as a baseline design for the tech. prototype (2015-2018)
  - 6 new SMD-HBUs fully assembled

SMD-HBU: Bottom View



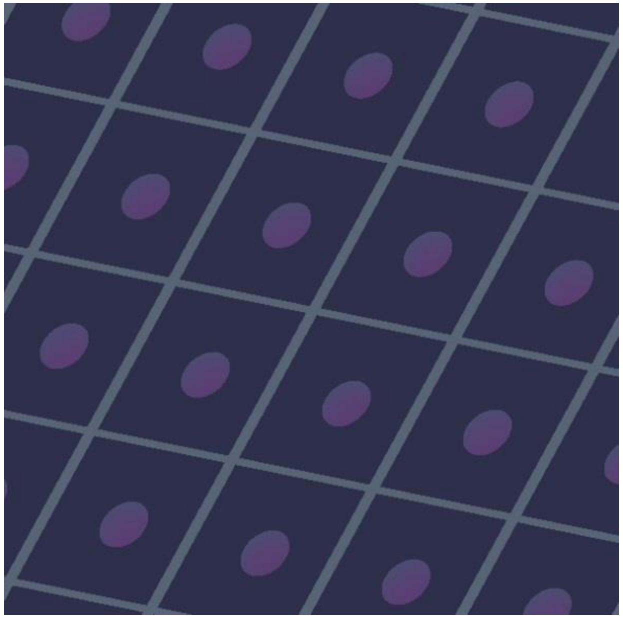
SMD-HBU: Top View

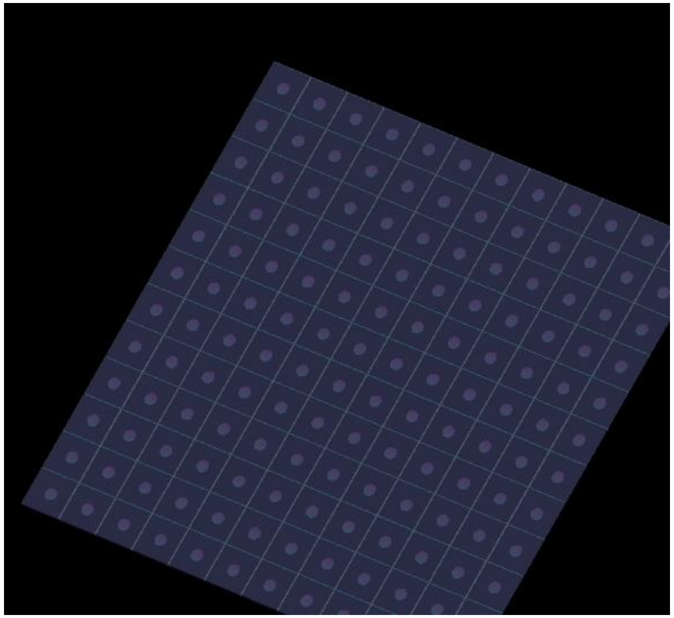
Further simplify mass assembly?

Y. Liu et al, IEEE NSS 2014
DOI: 10.1109/NSSMIC.2014.7431118

Overview: megatile

- Further simplify mass assembly
  - Scintillator plates with embedded structures
  - Optically isolated for individual readout
- Optimize structure by Geant4 simulation

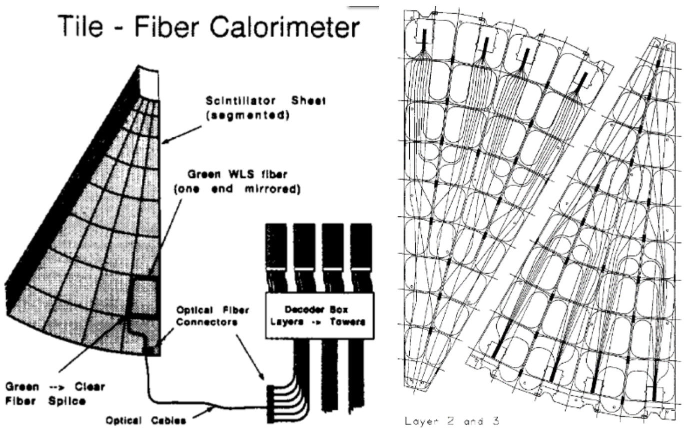




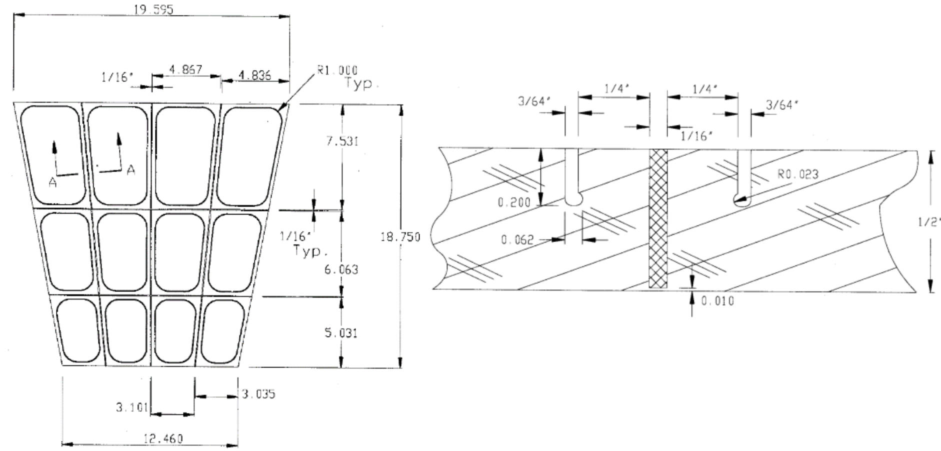
- Successful applications in the past

Megatile: applications in the past and at present

CDF End Plug Upgrade HCAL (1994)



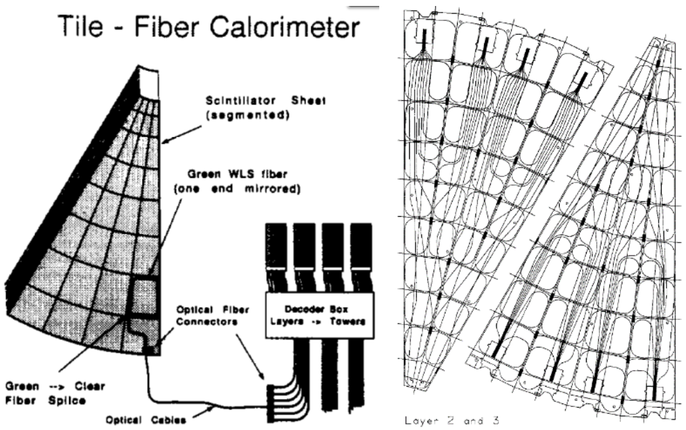
D0 Run II Inter Cryostat Detector (1999)



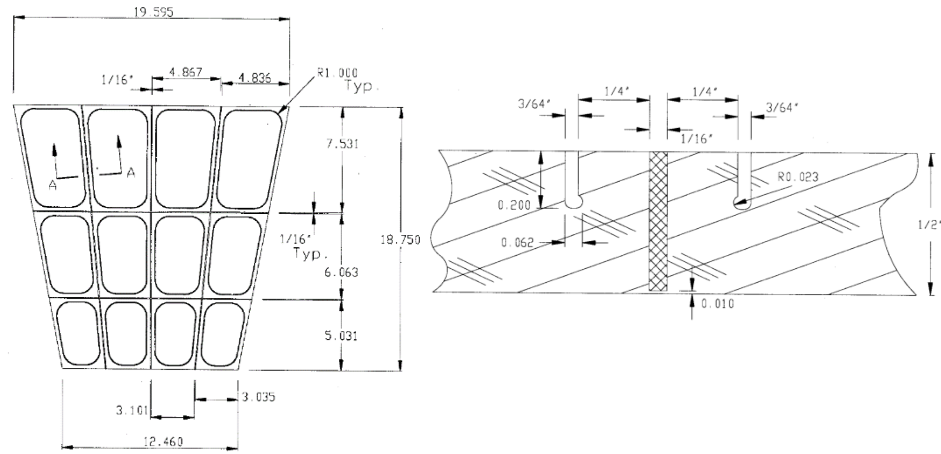
Note: this list is not meant to be exhaustive; the year corresponds to the earliest one appearing in the documents at hand

Megatile: applications in the past and at present

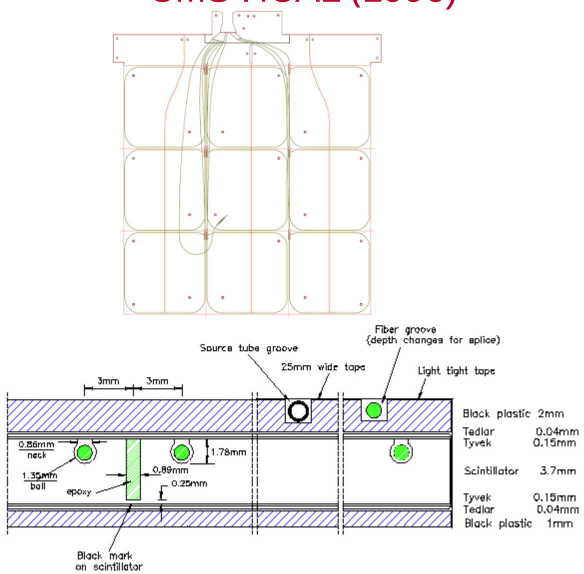
CDF End Plug Upgrade HCAL (1994)



D0 Run II Inter Cryostat Detector (1999)



CMS HCAL (1996)



STAR Barrel EMC (2002)

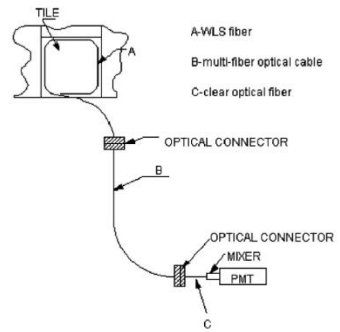
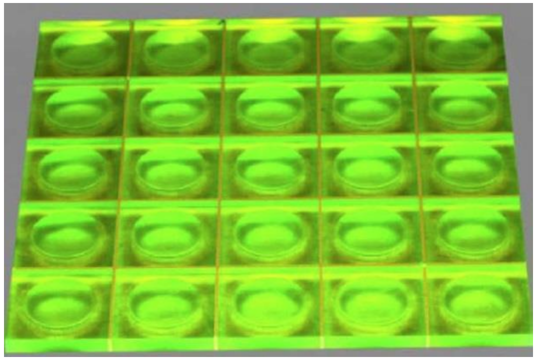


Fig. 5. Schematic diagram of the BEMC optical system illustrated for a single tile.

NIU Integrated Readout Layer (2009)



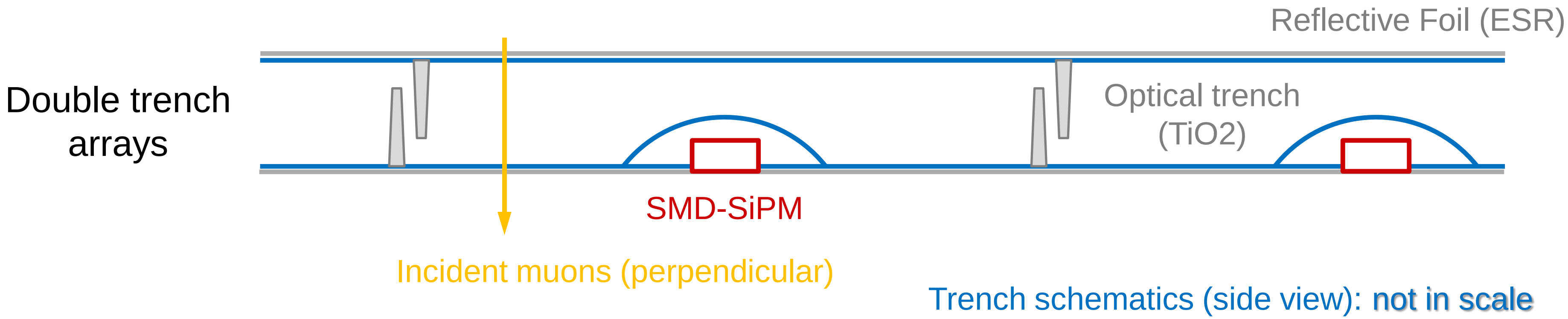
Note: this list is not meant to be exhaustive; the year corresponds to the earliest one appearing in the documents at hand

MegaTile design

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

MegaTile design

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

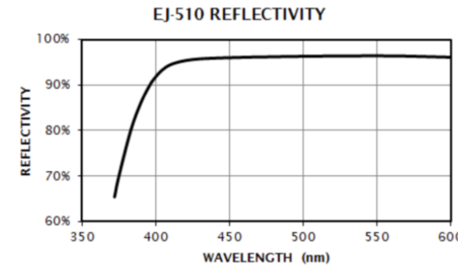


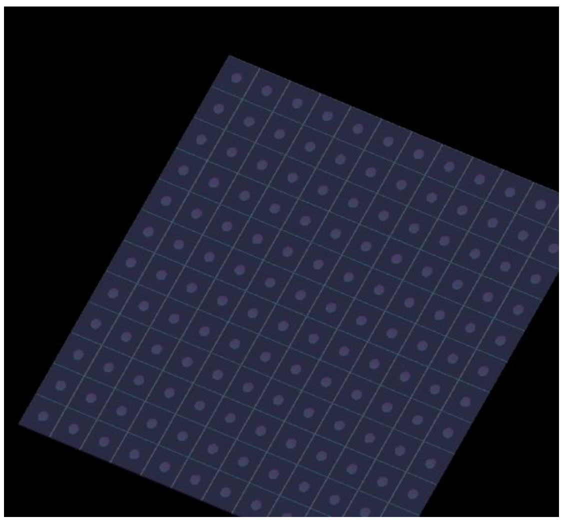
Predicted performance: MIP response, cell-to-cell crosstalk?

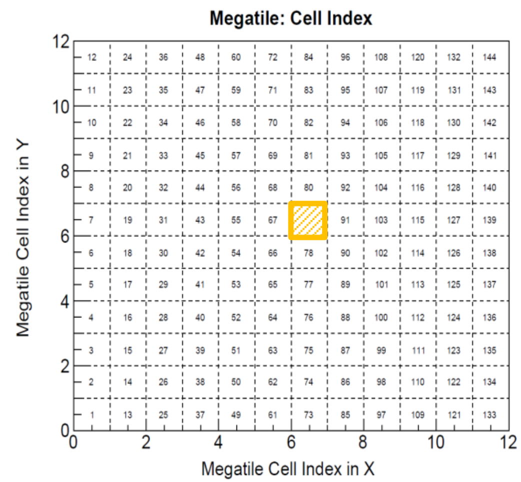
Megatile full simulation: overview

- 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

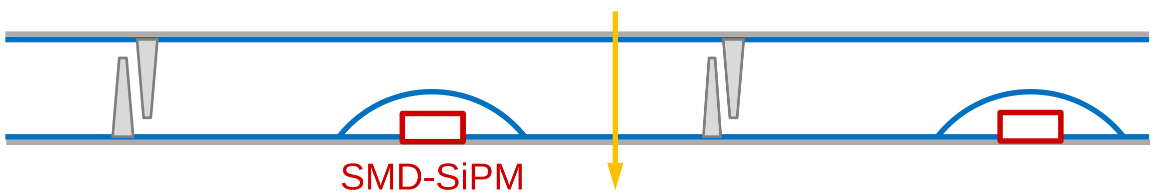






12×12 cells

Muons: hit positions



SMD-SiPM

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

Simulation: straight trenches

Rendered by G4RayTracer

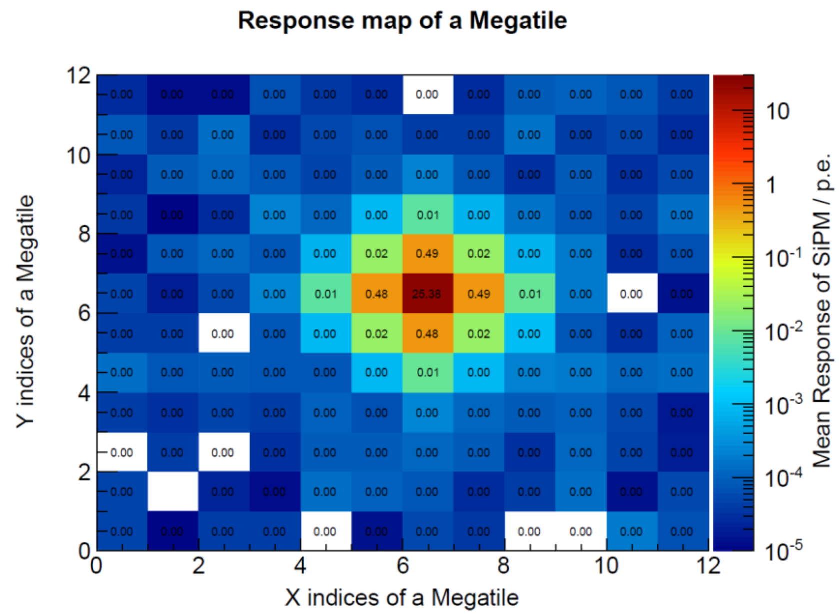
- Top and bottom trenches
  - Different trench depths, widths, offset between top and bottom
  - Including technical constraints
    - 2.0 mm deep, 200 µm and 300µm wide (trapezoid), 300µm offset

Simulation: straight trenches

Rendered by G4RayTracer

- Top and bottom trenches
  - Different trench depths, widths, offset between top and bottom
  - Including technical constraints
    - 2.0 mm deep, 200 µm and 300µm wide (trapezoid), 300µm offset

- Geant4 simulation results
  - Central cell: 25.4 p.e./MIP
  - Neighboring cell: 0.49 p.e./MIP
  - 2-cell crosstalk: 1.9 %
    - Same in 4 direct neighboring cells:



2-cell crosstalk: 1.9 %

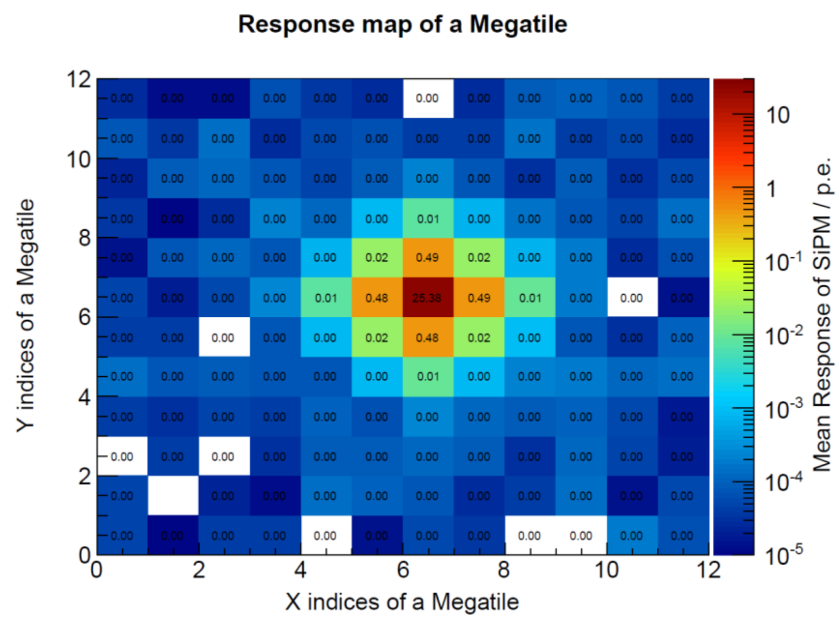
Simulation: straight trenches

Rendered by G4RayTracer

- Top and bottom trenches
  - Different trench depths, widths, offset between top and bottom
  - Including technical constraints
    - 2.0 mm deep, 200 µm and 300µm wide (trapezoid), 300µm offset

- Geant4 simulation results
  - Central cell: 25.4 p.e./MIP
  - Neighboring cell: 0.49 p.e./MIP
  - 2-cell crosstalk: 1.9 %
    - Same in 4 direct neighboring cells:

No cell boundary effects (cut off hit positions within 2 mm from cell boundary)



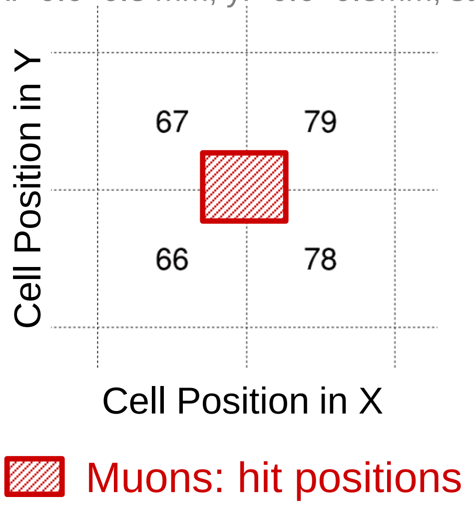
2-cell crosstalk: 1.9 %

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

Straight trenches: boundary effects

- Special MC runs: muons only hit corners of 4 cells

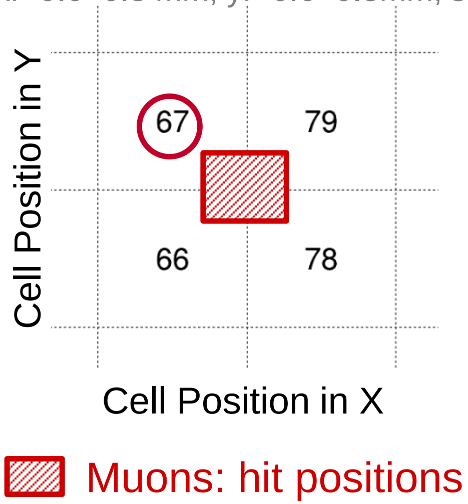
x: -0.6~0.3 mm; y: -0.6~0.3mm; step size: 30 µm



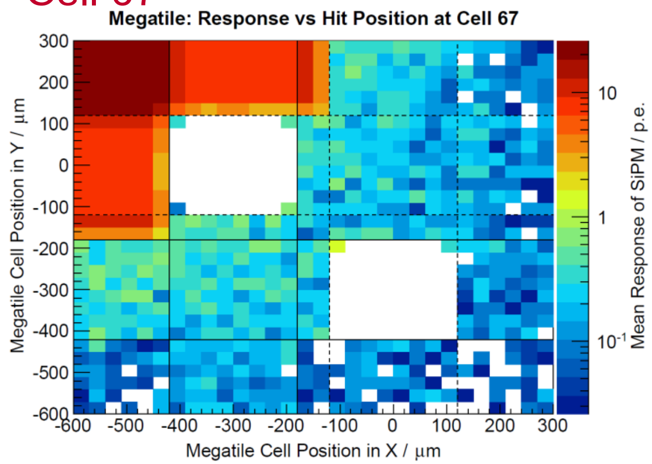
Straight trenches: boundary effects

- Special MC runs: muons only hit corners 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)

Boundary area: 3.6 % of a cell

Lower response: ~ 8 p.e./MIP

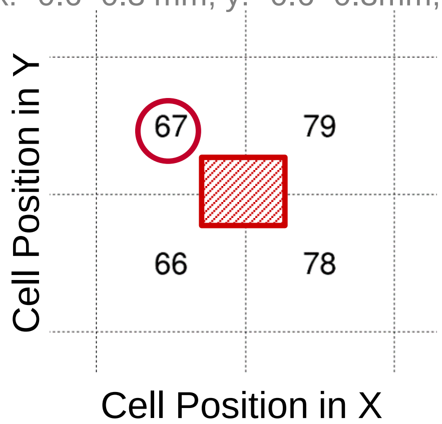
~ 30% of each cell response

Due to trench geometry:
only 1mm thick scintillator in these regions, not nominal 3mm

Straight trenches: boundary effects

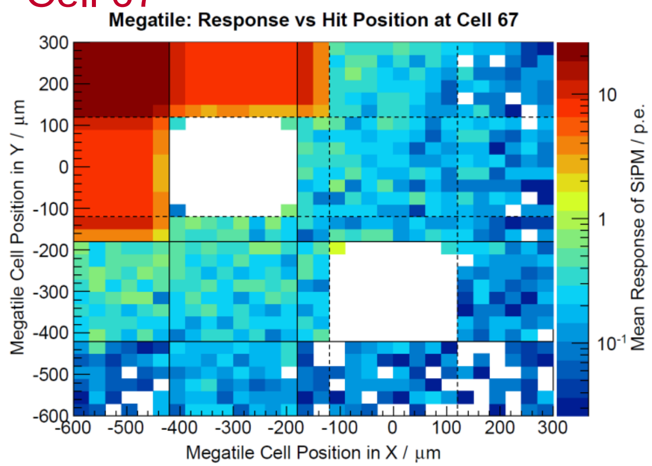
- Special MC runs: muons only hit corners of 4 cells

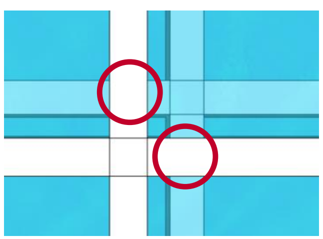
x: -0.6~0.3 mm; y: -0.6~0.3mm; step size: 30 µm

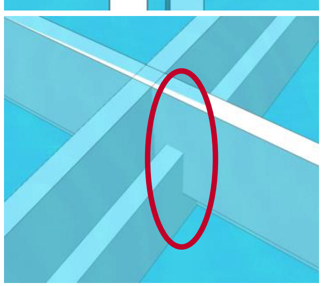


Muons: hit positions

Cell 67







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

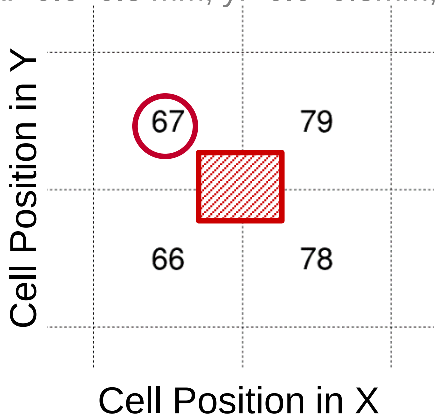
Boundary area: 3.6 % of a cell
Lower response: ~ 8 p.e./MIP
~ 30% of each cell response

Due to trench geometry:
only 1mm thick scintillator in these regions, not nominal 3mm

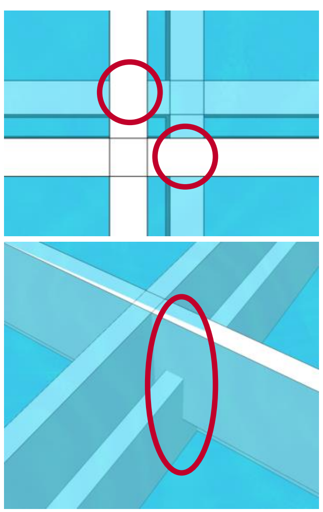
Straight trenches: boundary effects

- Special MC runs: muons only hit corners of 4 cells

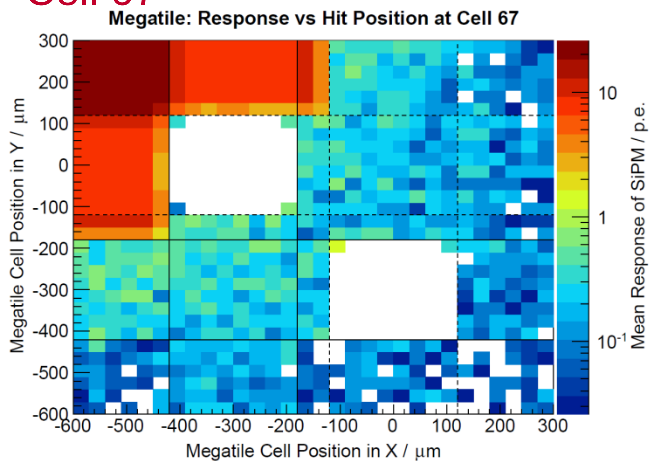
x: -0.6~0.3 mm; y: -0.6~0.3mm; step size: 30 µm



Muons: hit positions



Cell 67

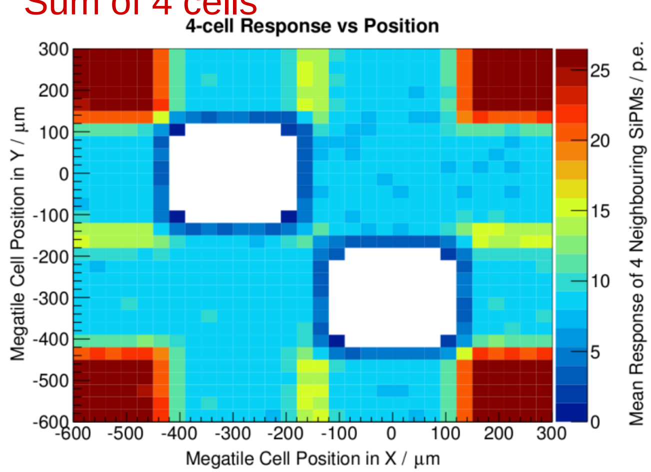


Solid and dashed lines indicate top and bottom trenches (borders)

Boundary area: 3.6 % of a cell
Lower response: ~ 8 p.e./MIP
~ 30% of each cell response

Due to trench geometry:
only 1mm thick scintillator in these regions, not nominal 3mm

Sum of 4 cells



Small dead area: 0.01% of a cell (overlapping of top and bottom trenches)

Individually wrapped tiles

Tile size: 29.6 × 29.6 mm²

Dead area per tile: 2.6% (23.84mm²)

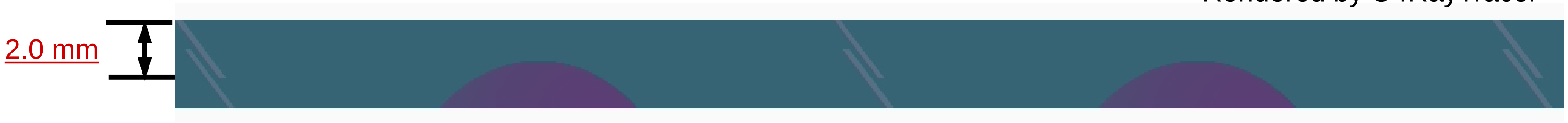
A megatile design: tilted trenches

- Straight double trenches
  - Boundary area: 3.6 % per cell
    - Active, but with lower response (only ~30% of center area)
    - Geometry effect: 1 mm scintillator material left in the area
  - Dead areas (small): 0.01% per cell
    - Depend on trench width
- Trenches tilted by some angle
  - To increase response of boundary areas

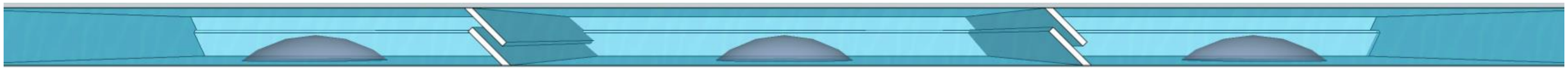
A megatile design: tilted trenches

- Straight double trenches
  - Boundary area: 3.6 % per cell
    - Active, but with lower response (only ~30% of center area)
    - Geometry effect: 1 mm scintillator material left in the area
  - Dead areas (small): 0.01% per cell
    - Depend on trench width
- Trenches tilted by some angle
  - To increase response of boundary areas
- Tilted trenches: only one design shown
  - Tilted 45°, 2mm depth (vertical projection)

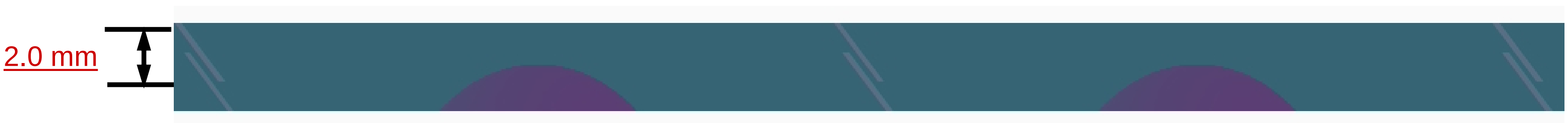
Rendered by G4RayTracer



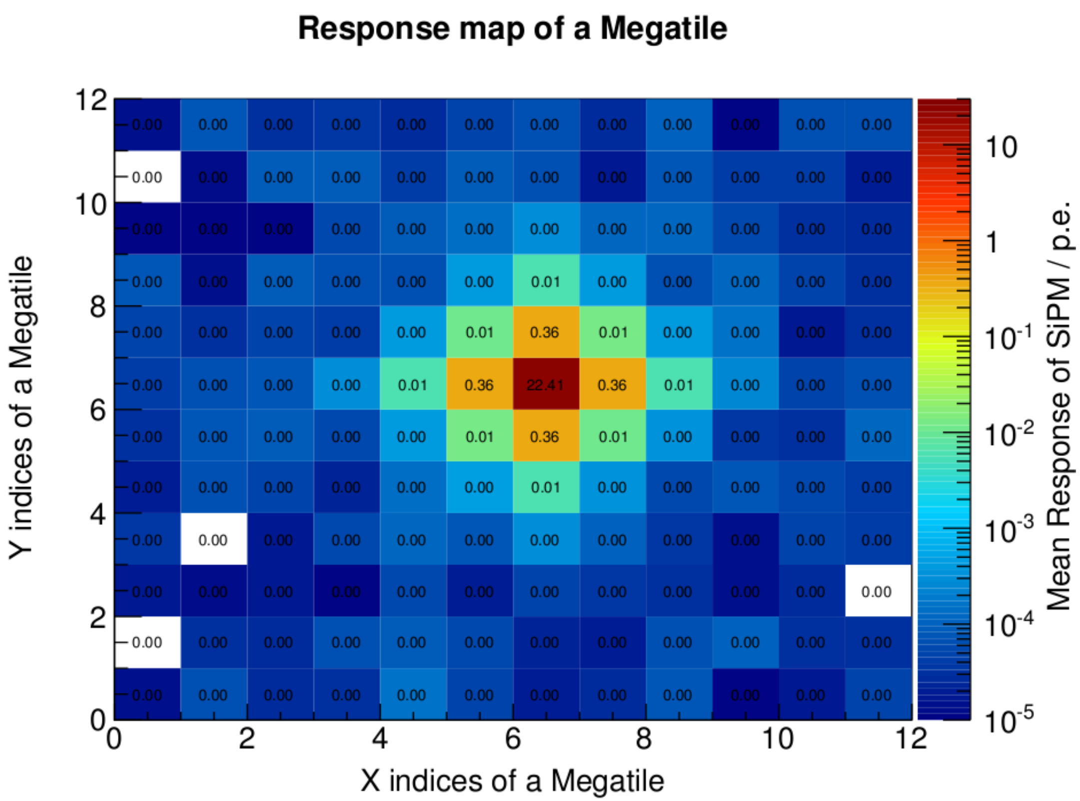
Constructed in SU



Simulation: tilted trenches



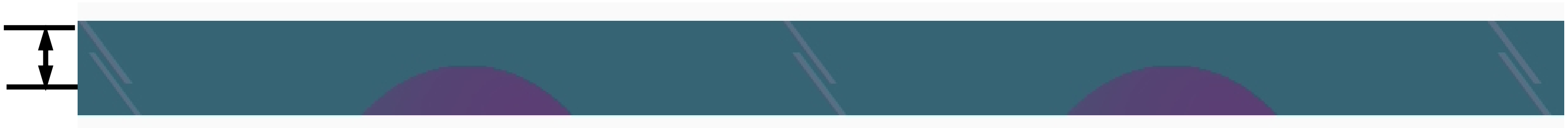
Rendered by G4RayTracer



2-cell crosstalk: 1.9 %

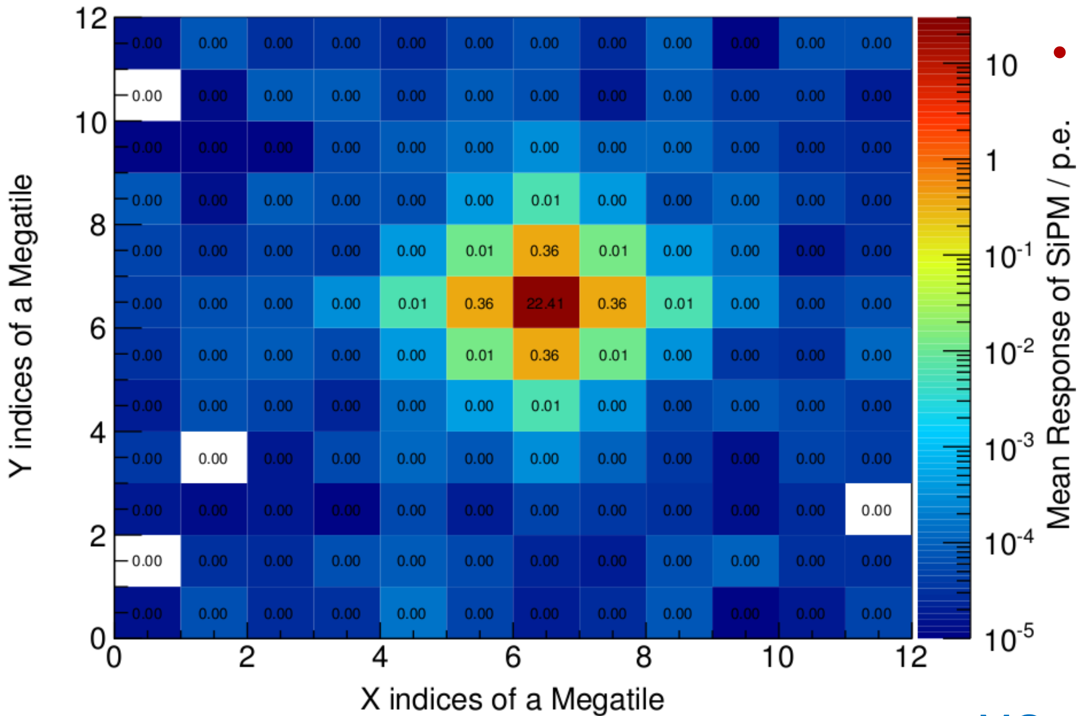
Simulation: tilted trenches

2.0 mm



Rendered by G4RayTracer

Response map of a Megatile



2-cell crosstalk: 1.9 %

- Geant4 simulation results
  - Central cell: 22.4 p.e./MIP
  - Neighboring cell: 0.36 p.e./MIP
  - 2-cell crosstalk: 1.9 % in all 4 neighboring cells

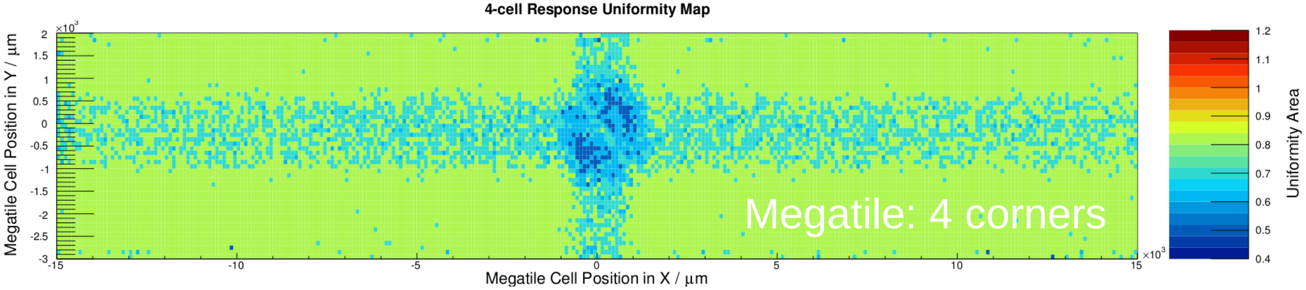
No boundary effects (cut off hit positions within 2 mm from cell boundary)

MC suggests promising low crosstalk level and moderate MIP response

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.

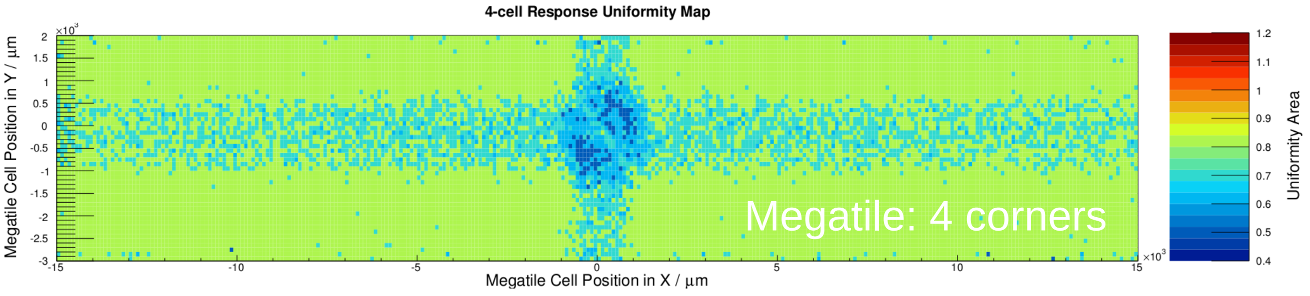


99.3% area: uniformity 60%
96.1% area: uniformity 70%
79.1% area: uniformity 80%
51.7% area: uniformity 90%

Simulation of tilted trenches: uniformity map

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%

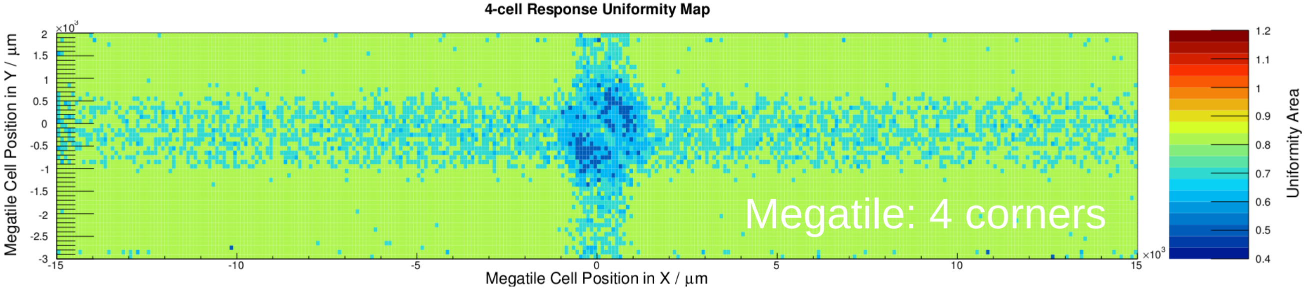
51.7% area: uniformity 90%

- All boundary area is <u>active</u> and most (>96%) has <u>>70% response</u>

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%

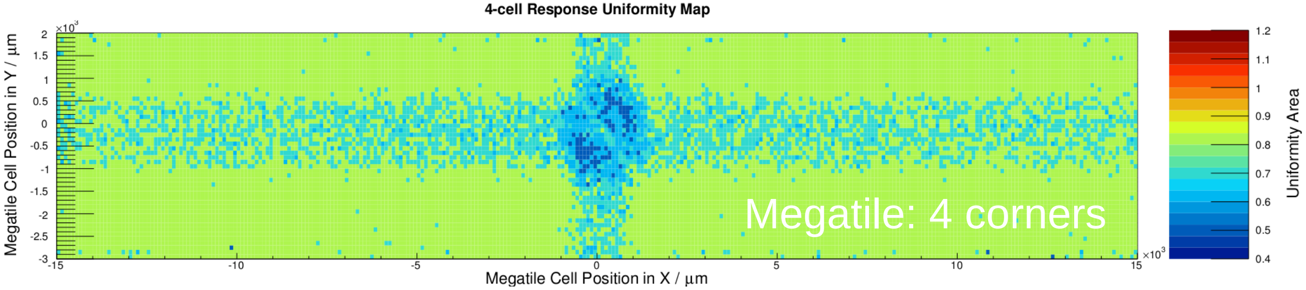
- All boundary area is active and most (>96%) has >70% response
- Comparison with current tile design
  - Nominal size: 30.0 ×30.0 mm²
  - Current tile size: 29.6 × 29.6 mm²
  - Dead area per tile: 23.84 mm² (~ 2.6%)

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

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.



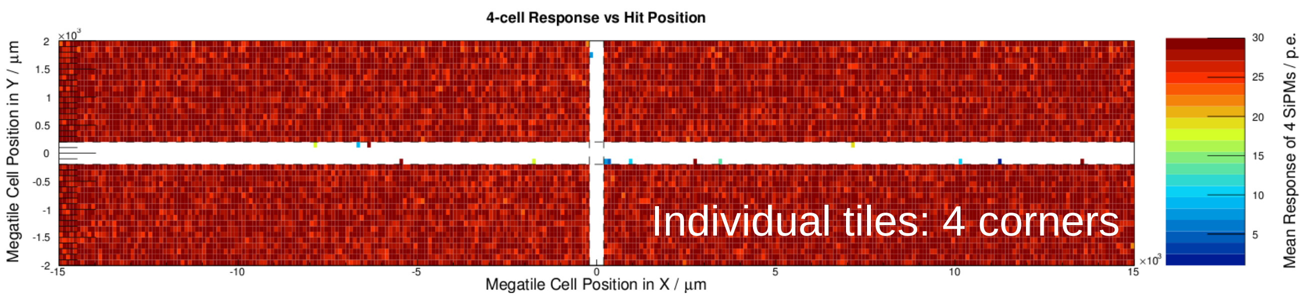
99.3% area: uniformity 60%
96.1% area: uniformity 70%
79.1% area: uniformity 80%
51.7% area: uniformity 90%

- 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%)

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)

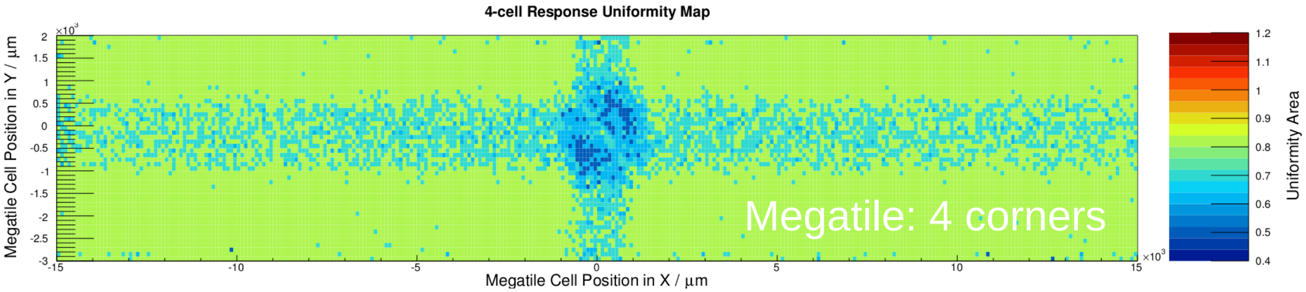
x: -15~15mm; y: -3~2mm; step size: 100 µm



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%

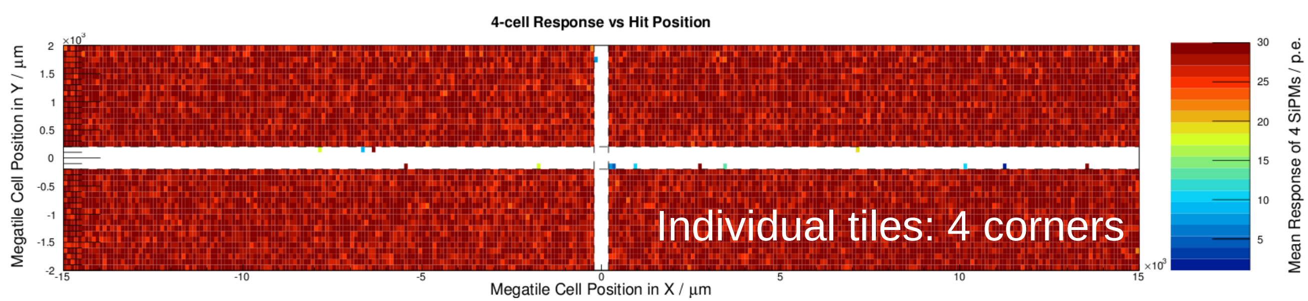
- All boundary area is active and most (>96%) has >70% response
- Comparison with current tile design
  - Nominal size: 30.0 ×30.0 mm²
  - Current tile size: 29.6 × 29.6 mm²
  - Dead area per tile: 23.84 mm² (~ 2.6%)

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%)

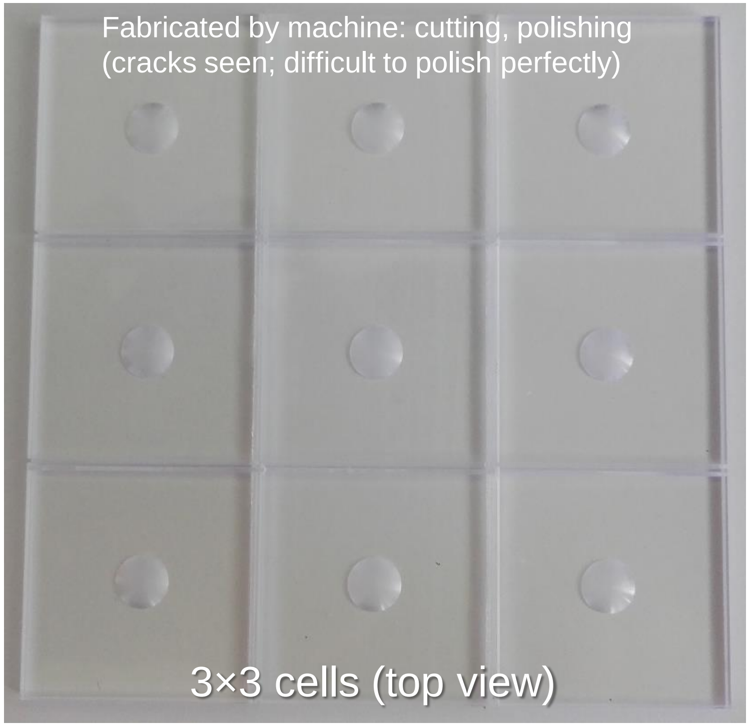
Non-sensitive area: 400µm between each cell (simulation)

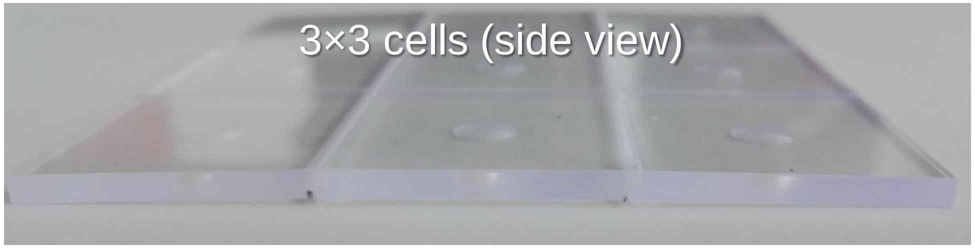
x: -15~15mm; y: -3~2mm; step size: 100 µm



Megatile: a first prototype

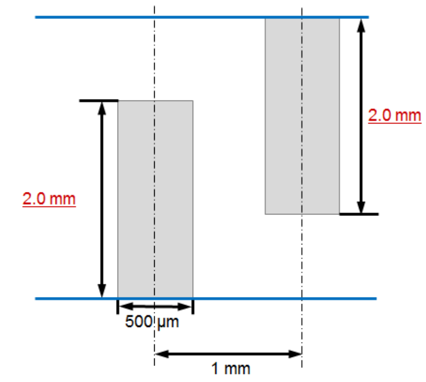
- Double trenches (straight), 3×3 cells
  - Scintillator: NE110 (comparable to BC408)

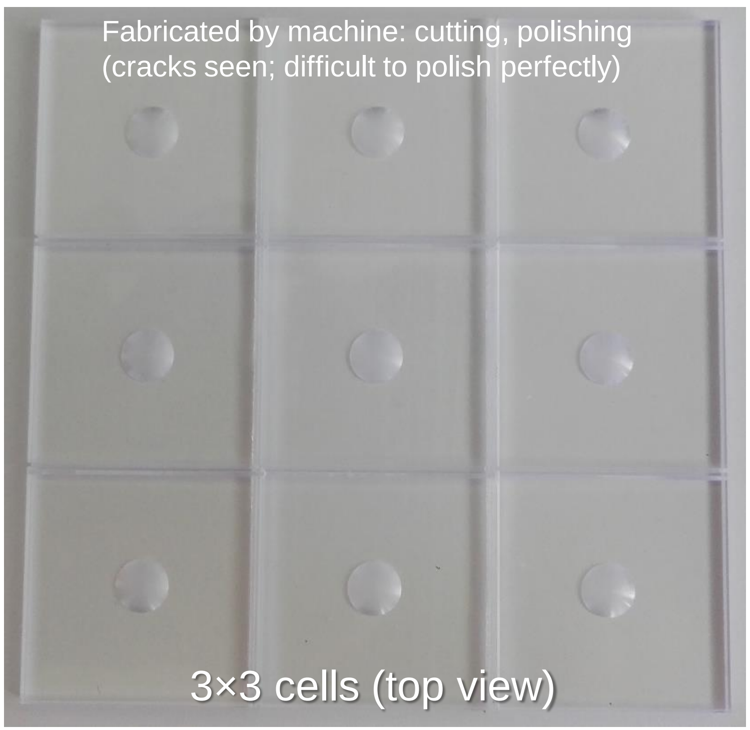


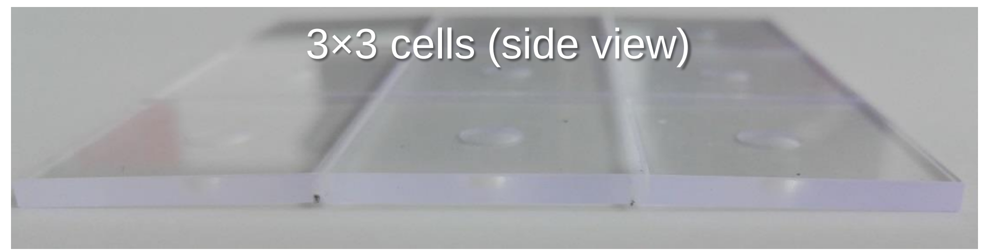


Megatile: a first prototype

- Double trenches (straight), 3×3 cells
  - Scintillator: NE110 (comparable to BC408)
  - Depth 2.0 mm, width 0.5 mm, offset 1.0 mm
    - Less challenging parameters, only for the first prototyping
    - Worse performance than previous simulation expectation
  - Still could verify simulation by adapting new parameters

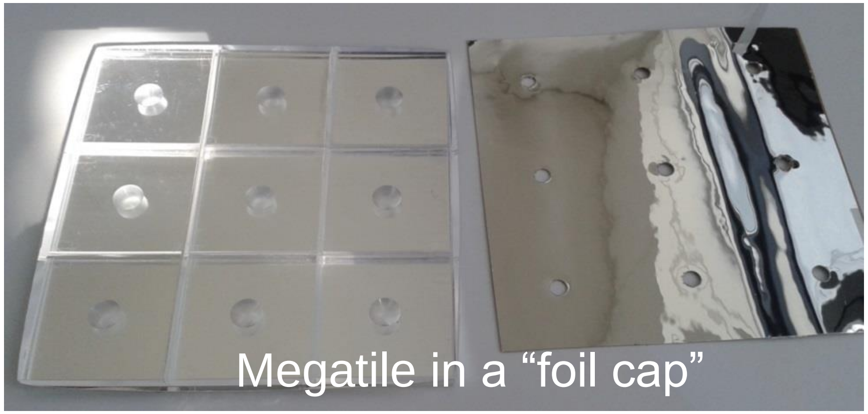






Megatile prototype: cosmic-ray tests

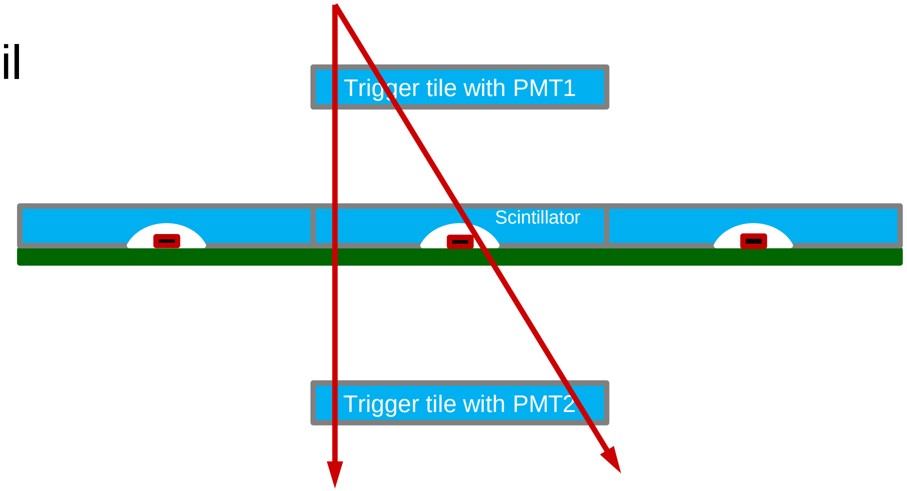
- Megatile all 6 surfaces covered by foil
  - 3M DF2000MA
- Foil strips inside trenches
  - High reflectivity (>98 %)
  - Specular reflector

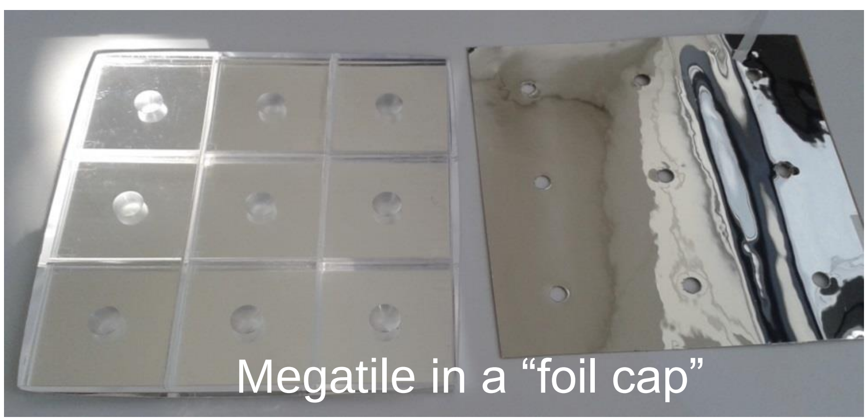


Megatile in a “foil cap”

Megatile prototype: cosmic-ray tests

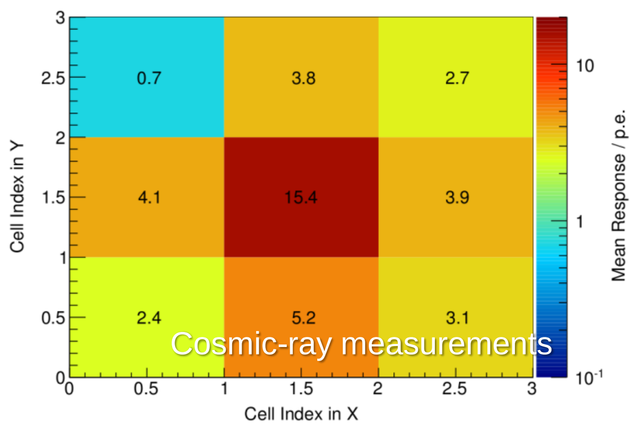
- Megatile all 6 surfaces covered by foil
  - 3M DF2000MA
- Foil strips inside trenches
  - High reflectivity (>98 %)
  - Specular reflector
- Cosmic-ray test stand
  - Trigger the central cell
  - Include tracks passing cell boundaries





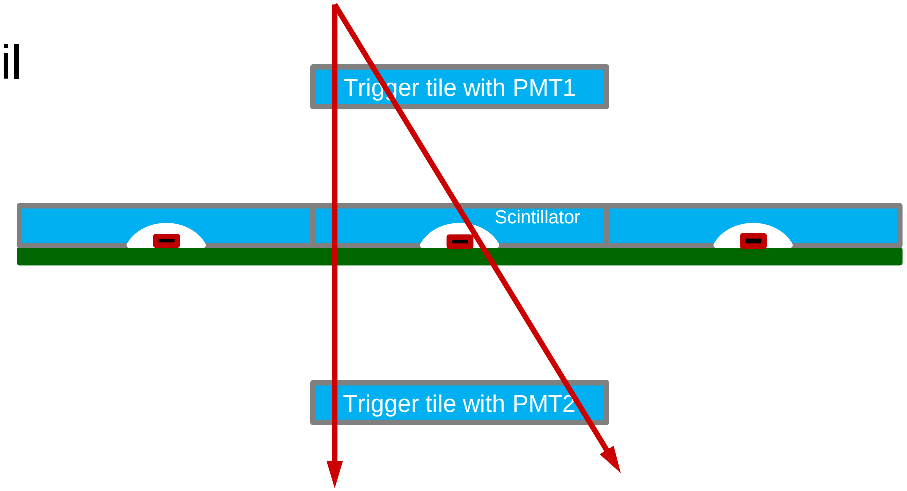
Megatile in a “foil cap”

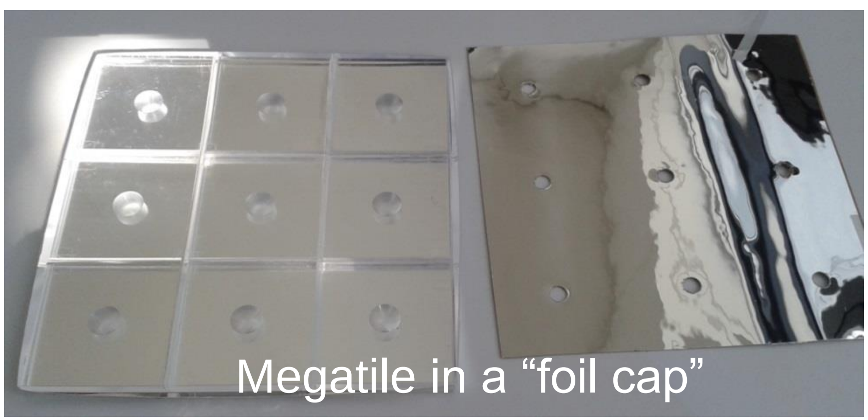
Mean response in cosmic rays



Megatile prototype: cosmic-ray tests

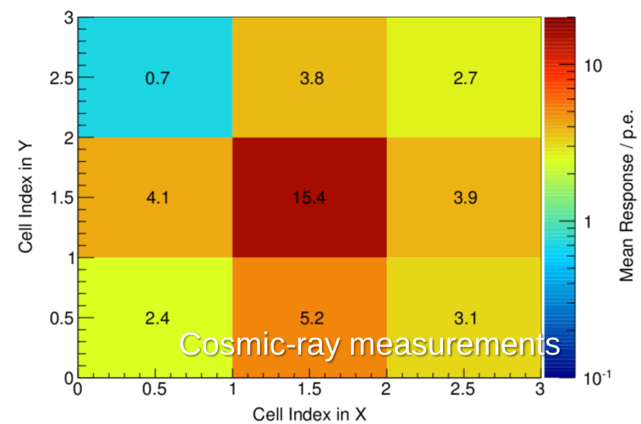
- Megatile all 6 surfaces covered by foil
  - 3M DF2000MA
- Foil strips inside trenches
  - High reflectivity (>98 %)
  - Specular reflector
- Cosmic-ray test stand
  - Trigger the central cell
  - Include tracks passing cell boundaries





Megatile in a “foil cap”

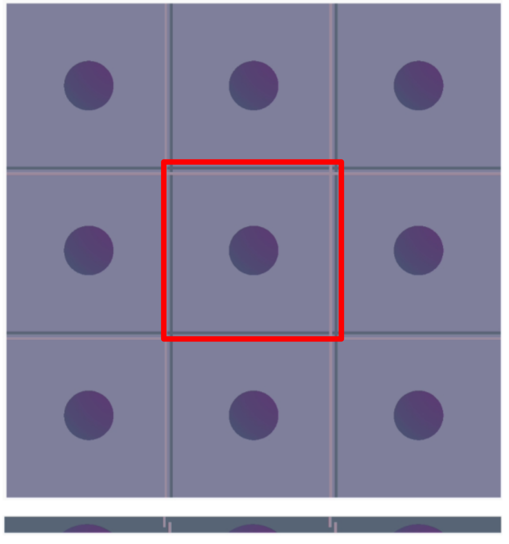
Mean response in cosmic rays



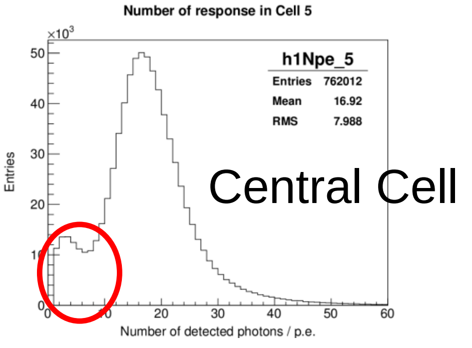
Central cell: 15.4 p.e./MIP
2-cell crosstalk: 24~34 %

1st prototype versus its custom simulation

Geant4 simulation

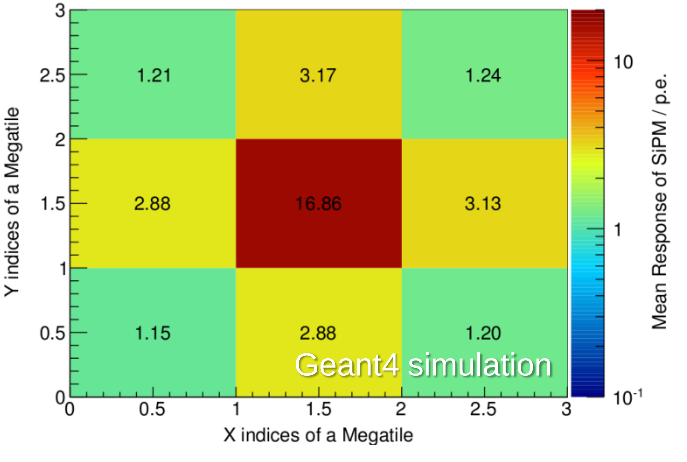


Bright: top trenches
Dark: bottom trenches



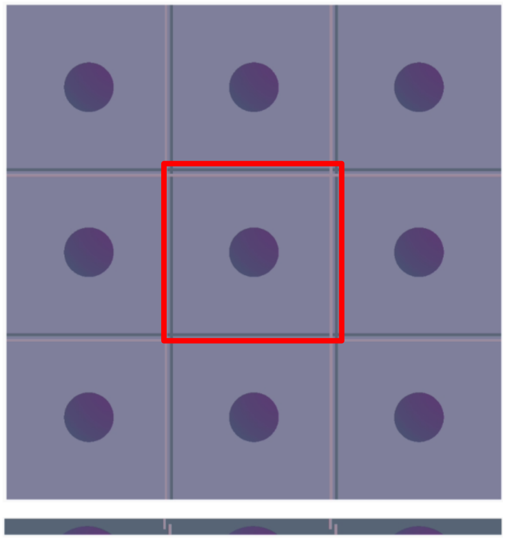
Muons hitting boundary regions

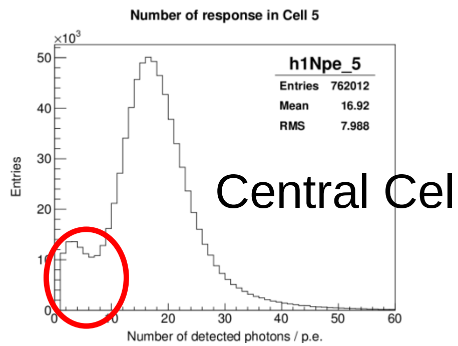
Response Map (MC)



1st prototype versus its custom simulation

Geant4 simulation



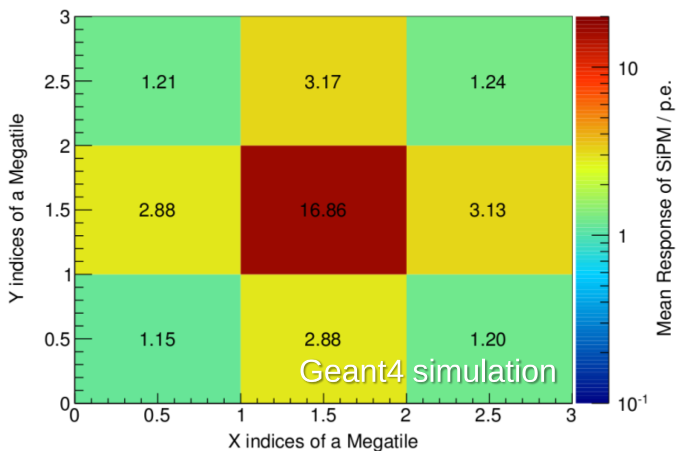


Muons hitting boundary regions

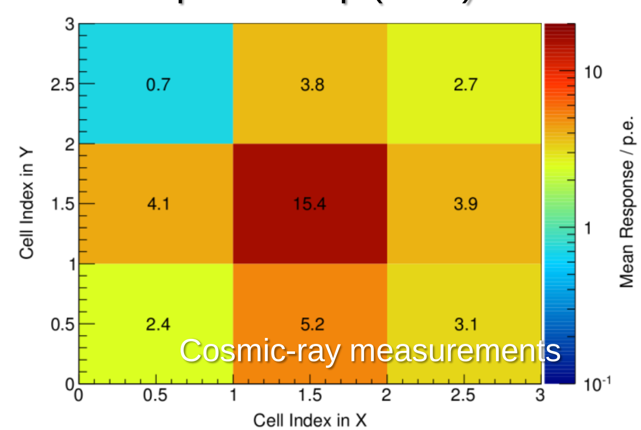
- Comparisons
  - Similar MIP response in central cell in data and MC
  - MC also predicts similar crosstalk
  - Worse uniformity of crosstalk seen in prototype measurements
  - Simulation assumed perfect quality of trench cutting

Bright: top trenches
Dark: bottom trenches

Response Map (MC)

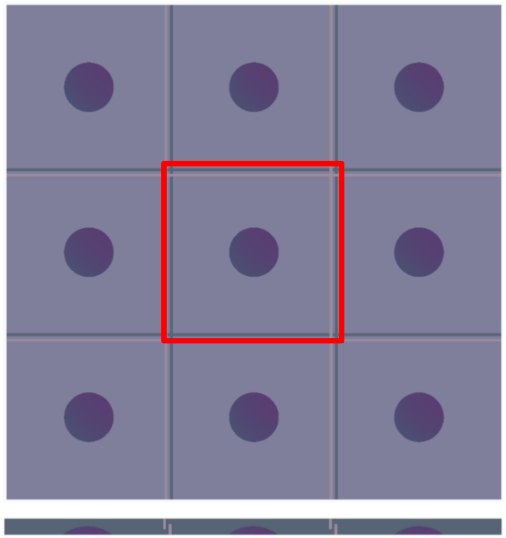


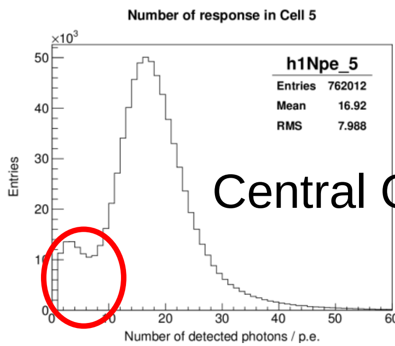
Response Map (Data)



1st prototype versus its custom simulation

Geant4 simulation



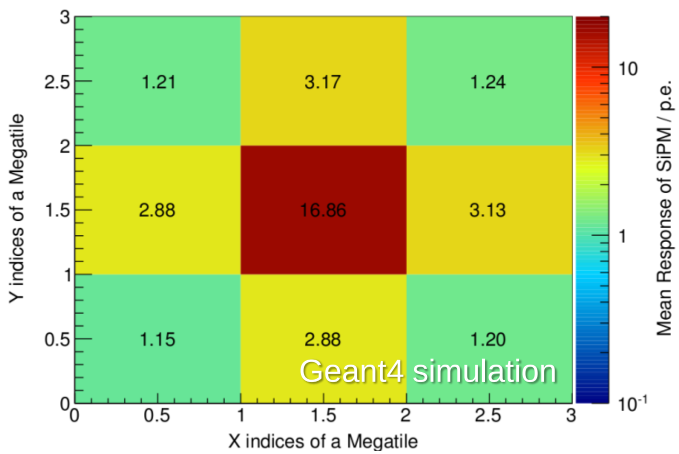


Muons hitting boundary regions

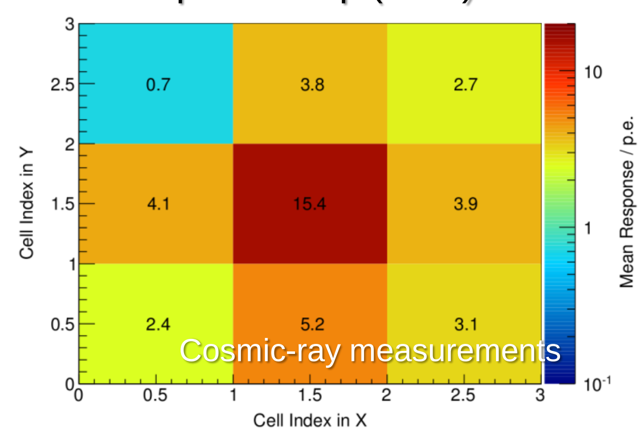
- Comparisons
  - Similar MIP response in central cell in data and MC
  - MC also predicts similar crosstalk
  - Worse uniformity of crosstalk seen in prototype measurements
  - Simulation assumed perfect quality of trench cutting

Bright: top trenches
Dark: bottom trenches

Response Map (MC)



Response Map (Data)



This first prototype still different from optimized design; promising performance if optimal designs can be realized

Summary and plans

- Megatile R&D: to further simplify mass assembly
  - Various designs tried out in simulation
  - Optimized designs foresee promising performance (also with considering practical tech. constraints)
  - A small prototype built to verify simulation

Summary and plans

- Megatile R&D: to further simplify mass assembly
  - Various designs tried out in simulation
  - Optimized designs foresee promising performance (also with considering practical tech. constraints)
  - A small prototype built to verify simulation

- Status
  - Ingredients ready for white paints (transparent epoxy, TiO_2 powder, etc.)

- Plans
  - Full-size prototypes (12×12 cells) under development
  - Test mixing epoxy and TiO_2 (curing time, mechanical stability)

Summary and plans

- Megatile R&D: to further simplify mass assembly
  - Various designs tried out in simulation
  - Optimized designs foresee promising performance (also with considering practical tech. constraints)
  - A small prototype built to verify simulation

- Status
  - Ingredients ready for white paints (transparent epoxy, TiO_2 powder, etc.)

- Plans
  - Full-size prototypes (12×12 cells) under development
  - Test mixing epoxy and TiO_2 (curing time, mechanical stability)

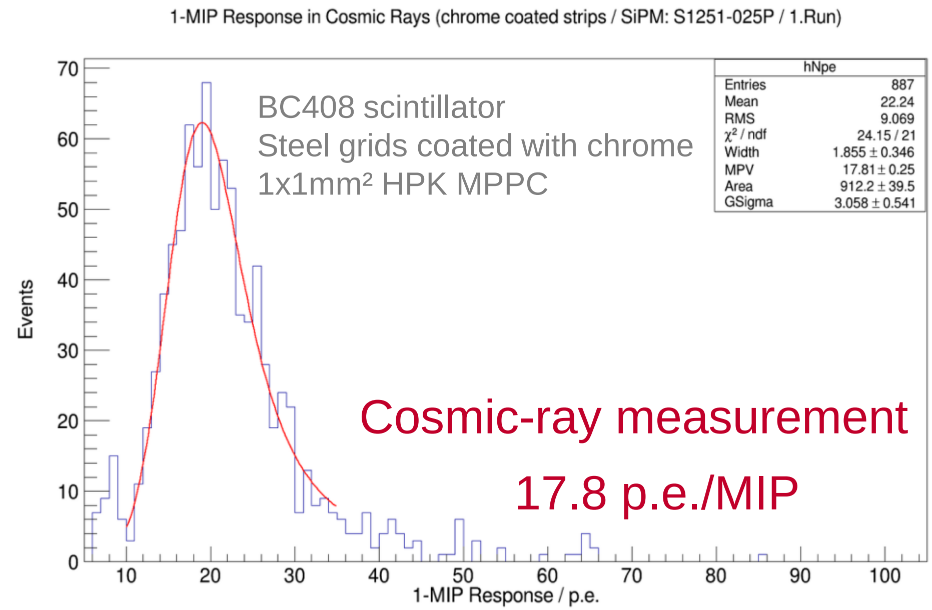
Thank you!

Backup

Efforts of MegaTile development at Mainz (1)

- MegaTile with steel grids

Prototype with metal grids and individual tiles

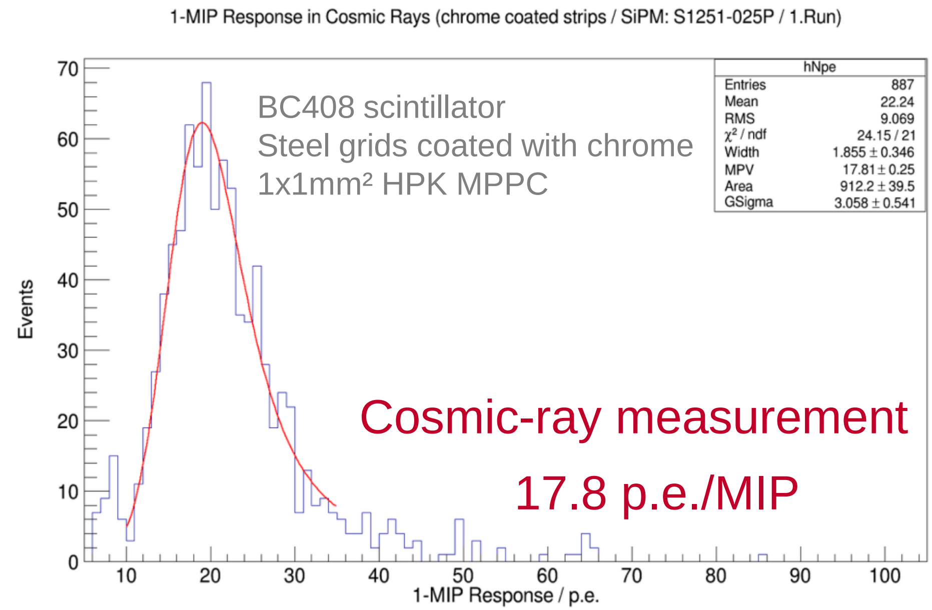


– Idea: quickly produce metal grids
– A first prototype worked well with steel strips and individually machined tiles

Efforts of MegaTile development at Mainz (1)

- MegaTile with steel grids

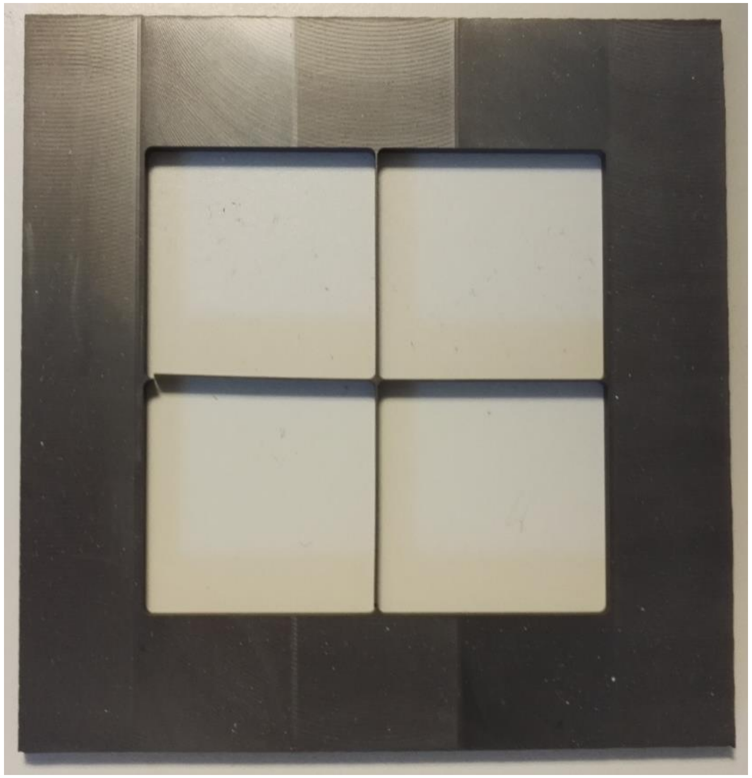
Prototype with metal grids and individual tiles



- 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

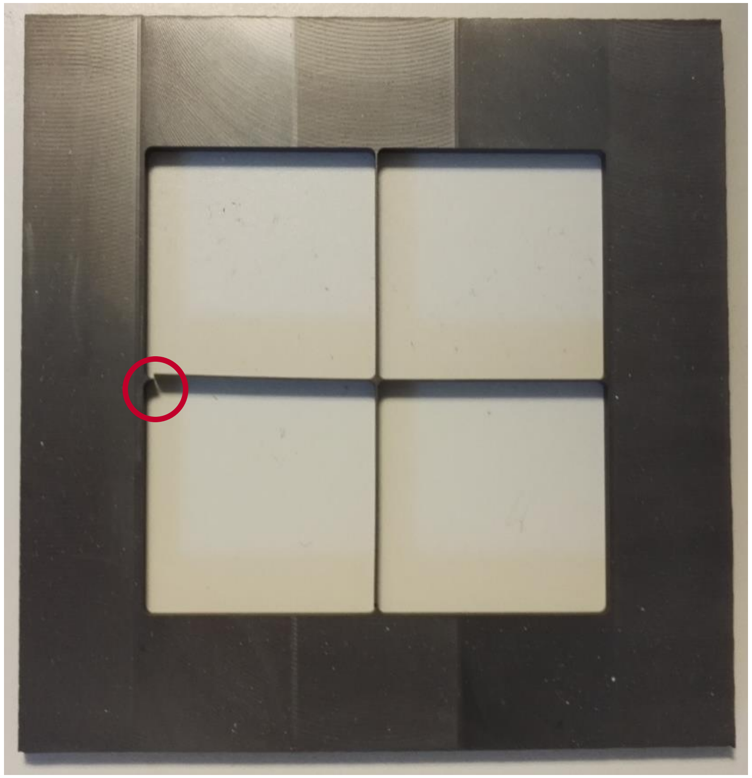
Efforts of MegaTile development at Mainz (2)

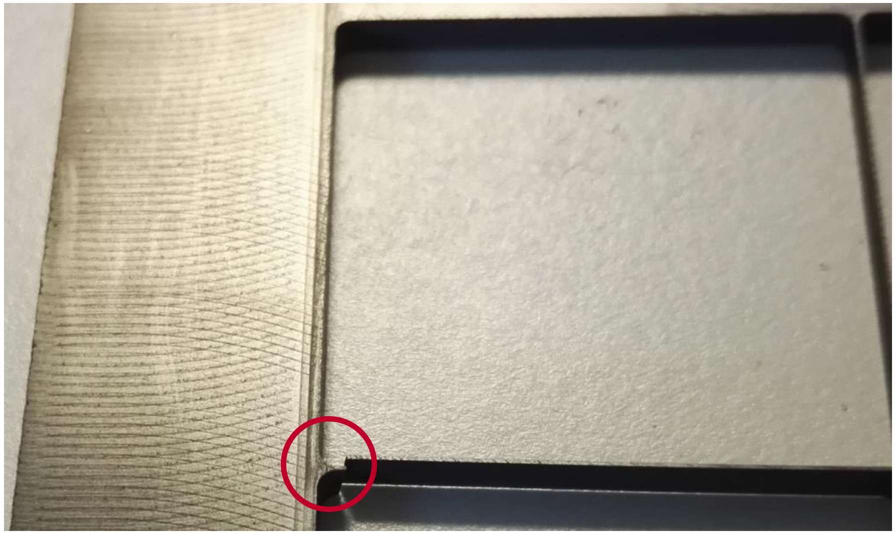
- MegaTile with carbon-fiber
  - Built a prototype of grids
    - Carbon-fiber: many thin layers glued together
    - Mechanically fragile



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