Beam test results of fine-granularity tile/fiber EM calorimeter

The 7th ACFA workshop @ Taipei 2004/11/11

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Motivation

Requirements for the Linear Collider Calorimeter

- Fine longitudinal segmentation : *Energy resolution, compensation*
- Fine transverse granularity : *Position resolution, Jet separation*
- Required resolution for GLC calorimeter

  EM : $\sigma/\mathrm{E} = 15\%/\sqrt{\mathrm{E}} \oplus 1\%$

$\rightarrow$ Tile/fiber sampling structure calorimeter

In this report

We made a prototype of tile/fiber EM calorimeter module
and tested at KEK π2 test beam line in March-2004.
We report our calorimeter performance.

Beam test module setup

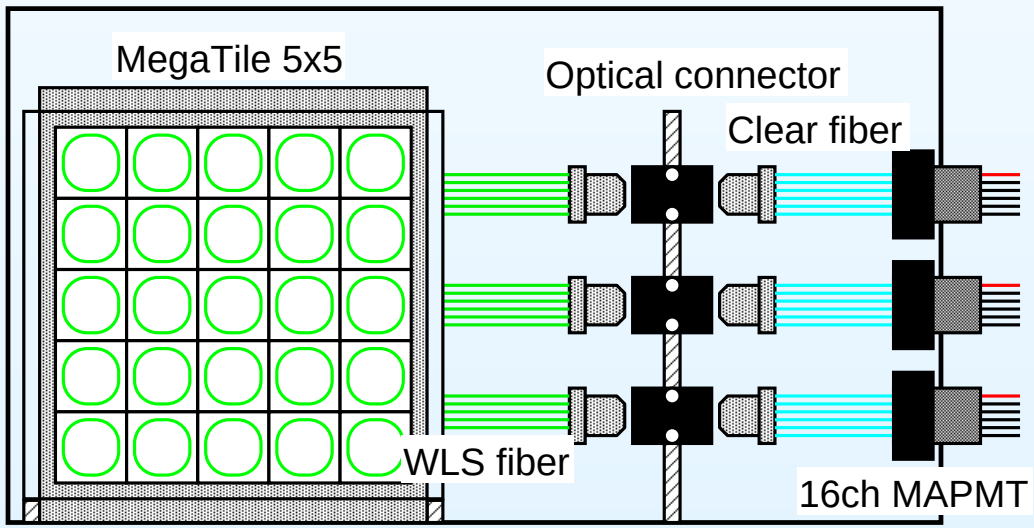
Tile size : 4cm×4cm×1mm with WLS fiber, 25 tiles in 1SL.

Sampling ratio : Pb / Scintillator = 4mm / 1mm (Hardware compensation)

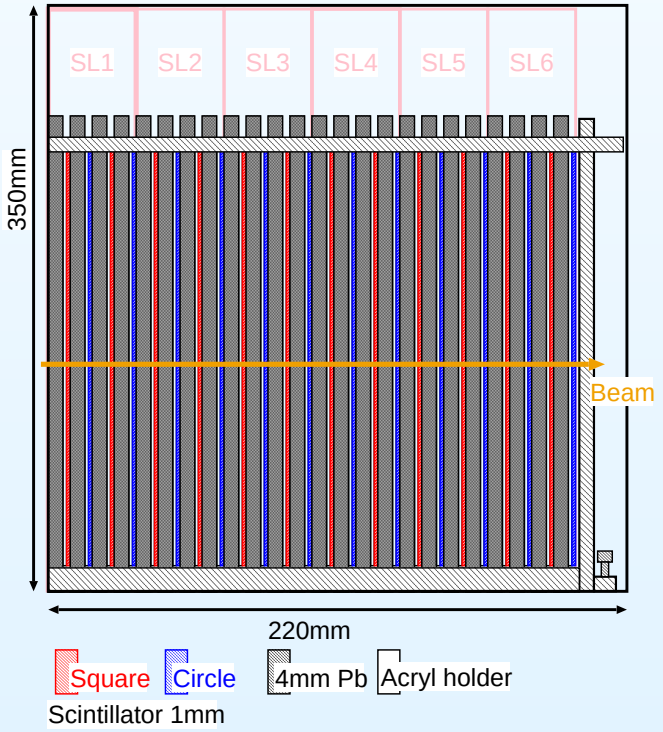
Number of Layers : 6 Super Layer (1 SL. = 4 layers) (17.1X_0)

Readout : 16ch Multi Anode PMT with WLS fiber

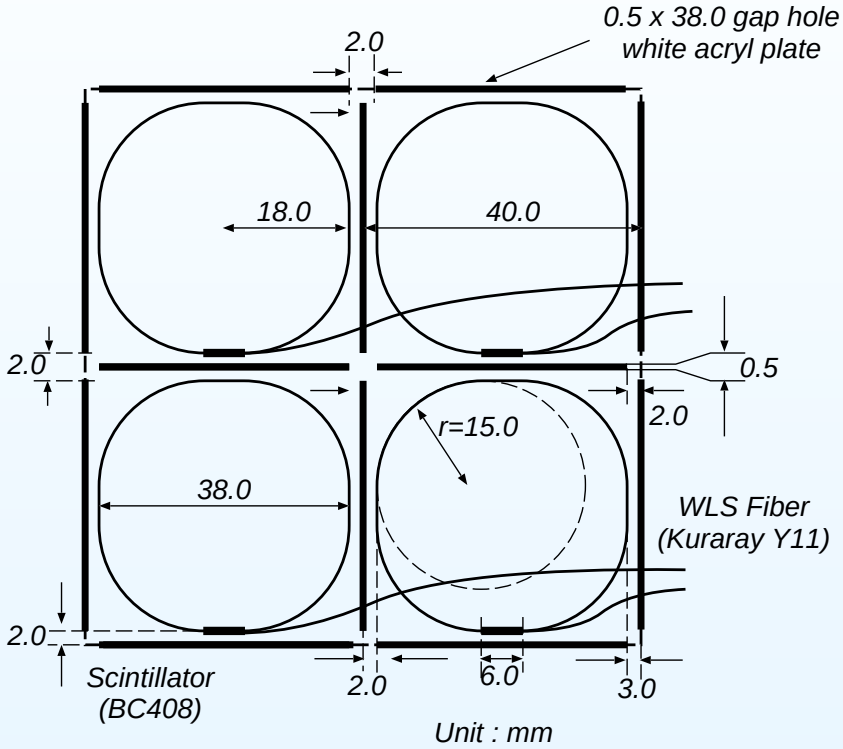
Module front view



Module side view



Mega-Tile structure layers

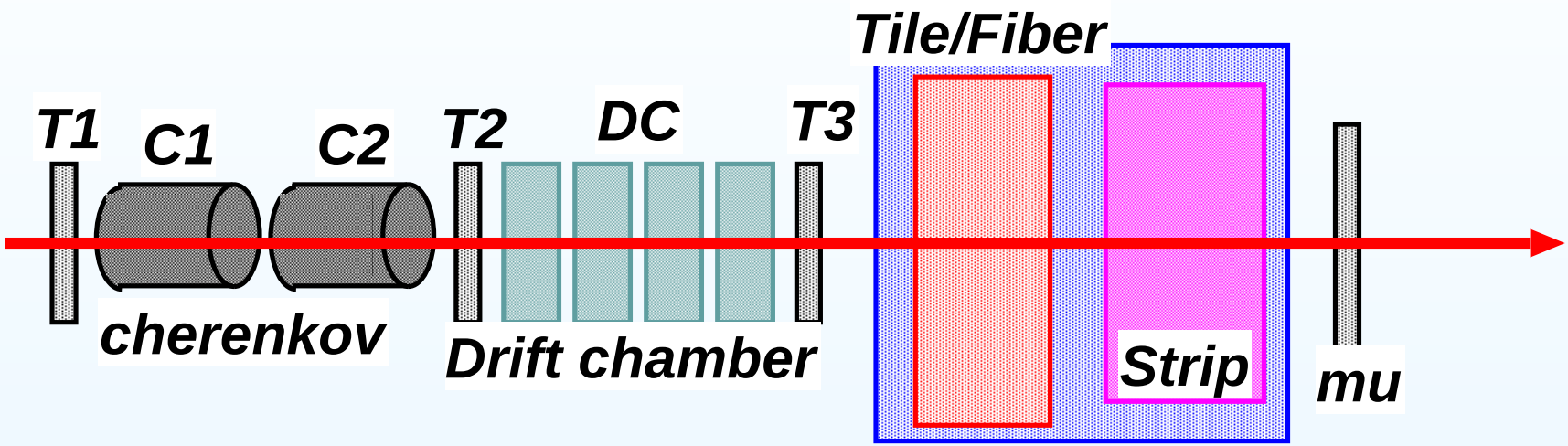


Scintillator : 1mm thickness tile with 0.8mmϕ fiber groove(Bicron BC40

WLS fiber : Y11 (Kuraray) 0.7mmϕ inserted to the groove

Mega-Tile matrix : 25 tiles (5$\times$5) per layer and connected on each corner.
Tiles are separated with white plastic strips.

Beam line setups (T545 Exp)



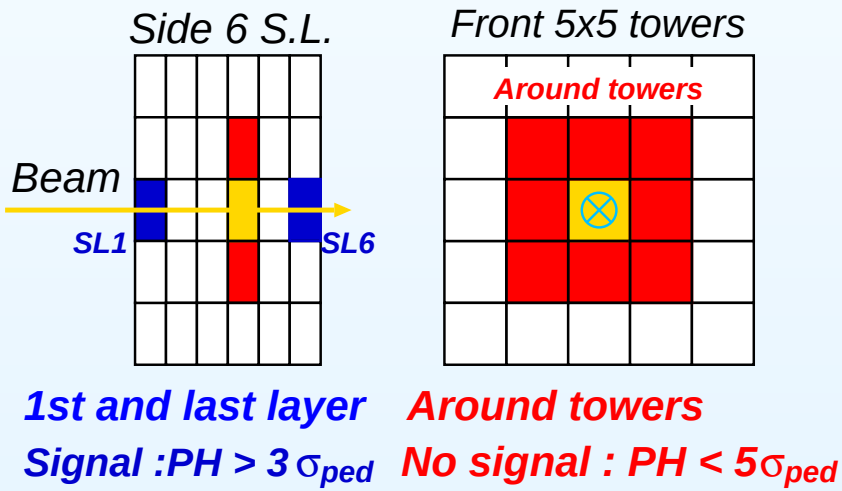
- Beam energy
  e,π,μ, 1GeV $\sim$ 4GeV
- Cherenkov counter
  e/π separation
- Drift chamber
  Tracking : $\sigma \sim$ 0.3mm

Results, Gain calibration scan

- Tile response for non-interacting pion(MIPs) were observed
- Fit function : Landau-Like function

$$f(x;p_0,p_1,p_2) = p_0 \exp\left(1 - \frac{x-p_1}{p_2} - \exp\left(-\frac{x-p_1}{p_2}\right)\right)$$

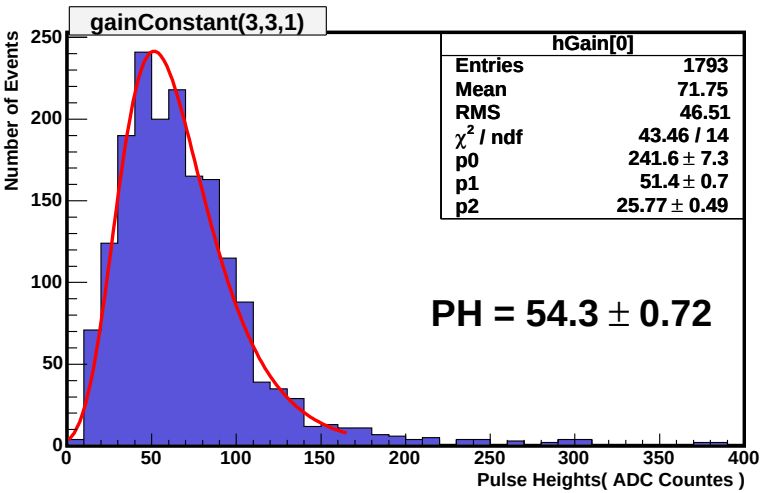
- Fitting range : peak - $3\sigma \sim$ peak + 5σ



1st and last layer ***Around towers***

Signal :PH > 3 σ_{ped} ***No signal : PH < 5σ_{ped}***

Typical signal



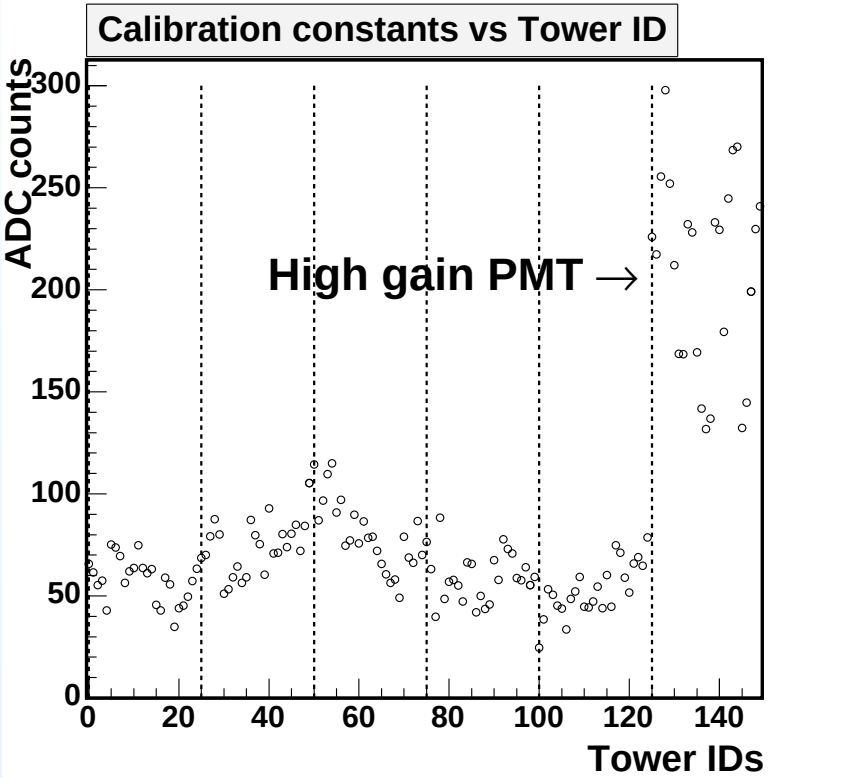
Required event selection

1st and last tower : Pulse Height $> 3\ \sigma_{\text{ped}}$

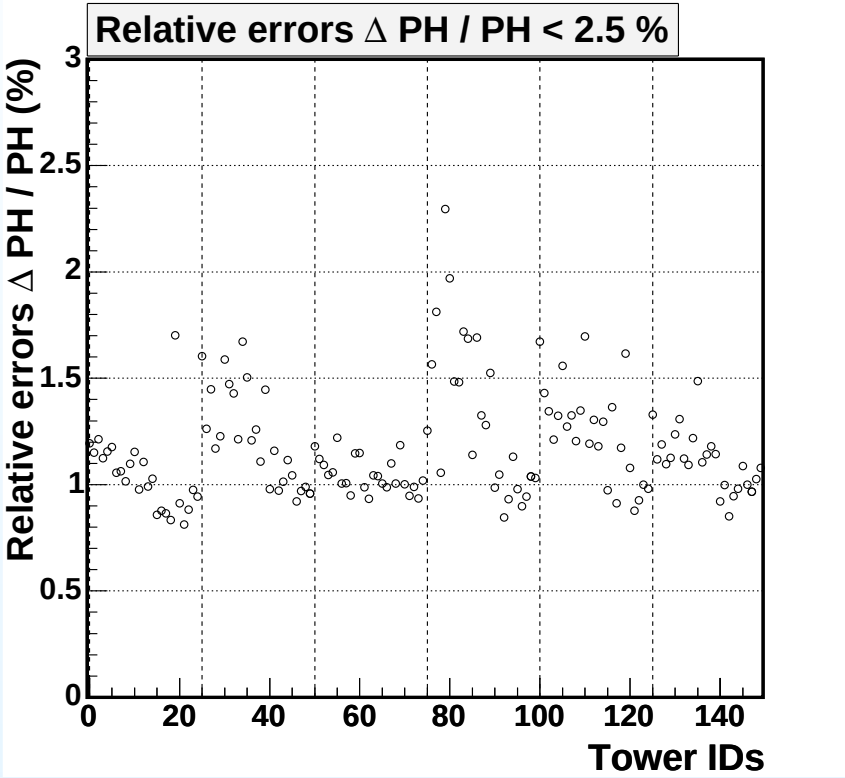
Around the hit tower : Pulse Height $< 5\ \sigma_{\text{ped}}$

Calibration constants and their Relative errors

Gain constants of all the towers



Relative errors

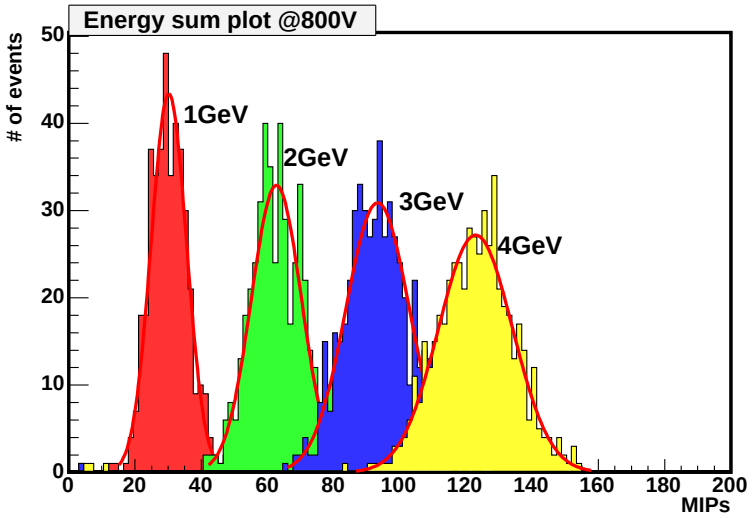


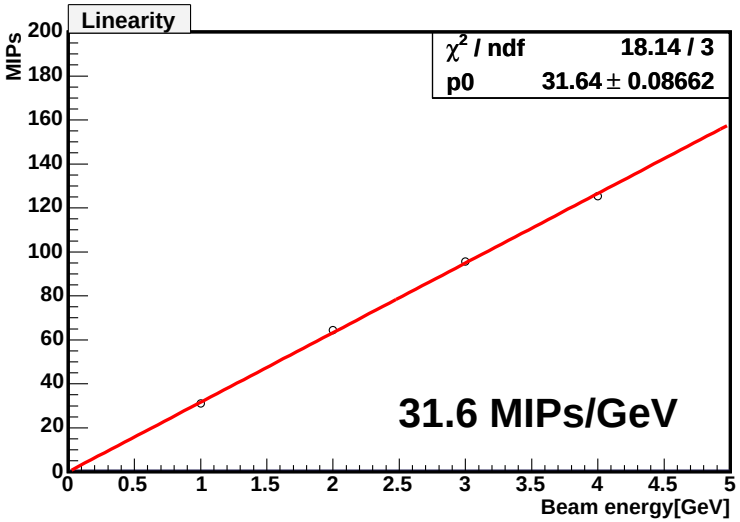
We used low gain PMT for SL.1 $\sim$ 5 and high gain PMT for SL.6

Relative errors : $\Delta PH/PH \sim 2.0\%$

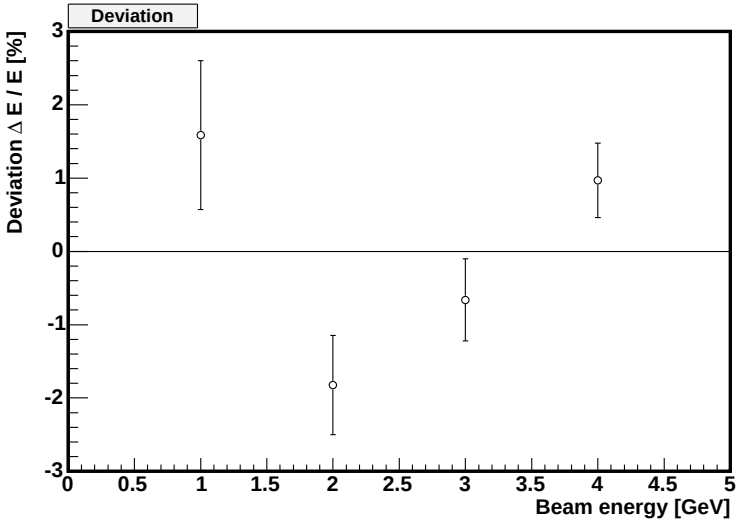
Energy response and Linearity for Electrons

PH distribution





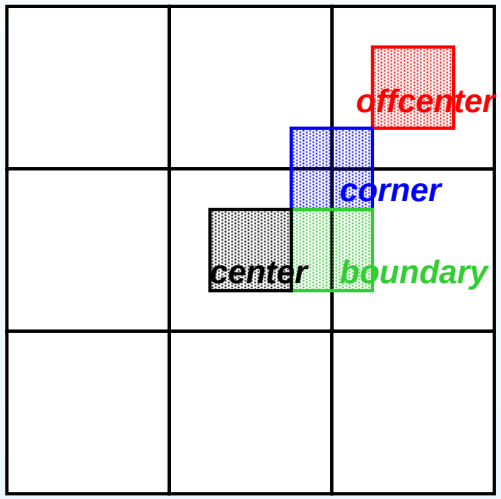
Deviation from streight line :
$\Delta E/E < 2\%$

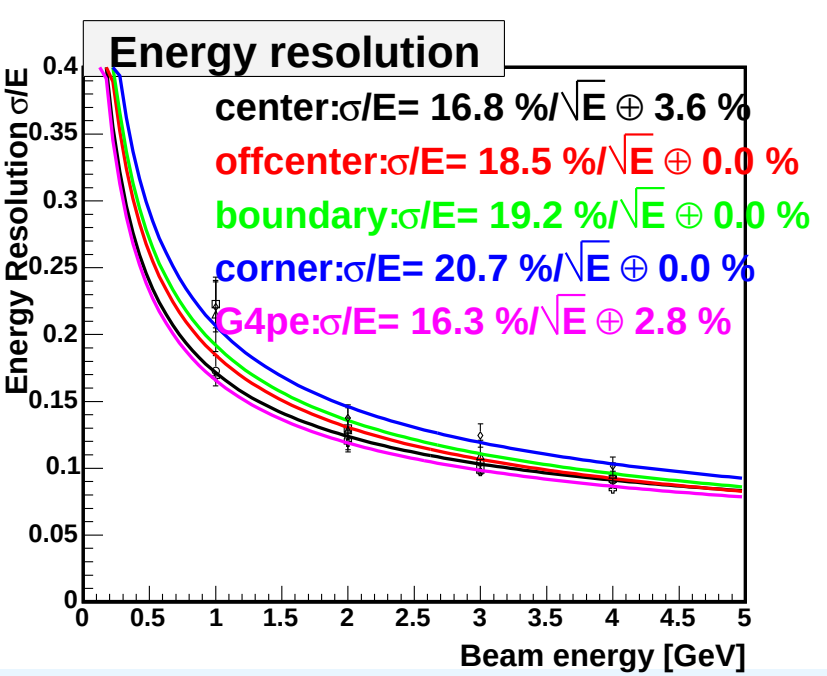


Energy resolution and Geant4 MC

$\sigma/\mathrm{E} = 16.8\%/\sqrt{\mathrm{E}} \oplus 3.6\%$ (center tile)

Beam hit positions





Geant4 MC including photo electron statistics

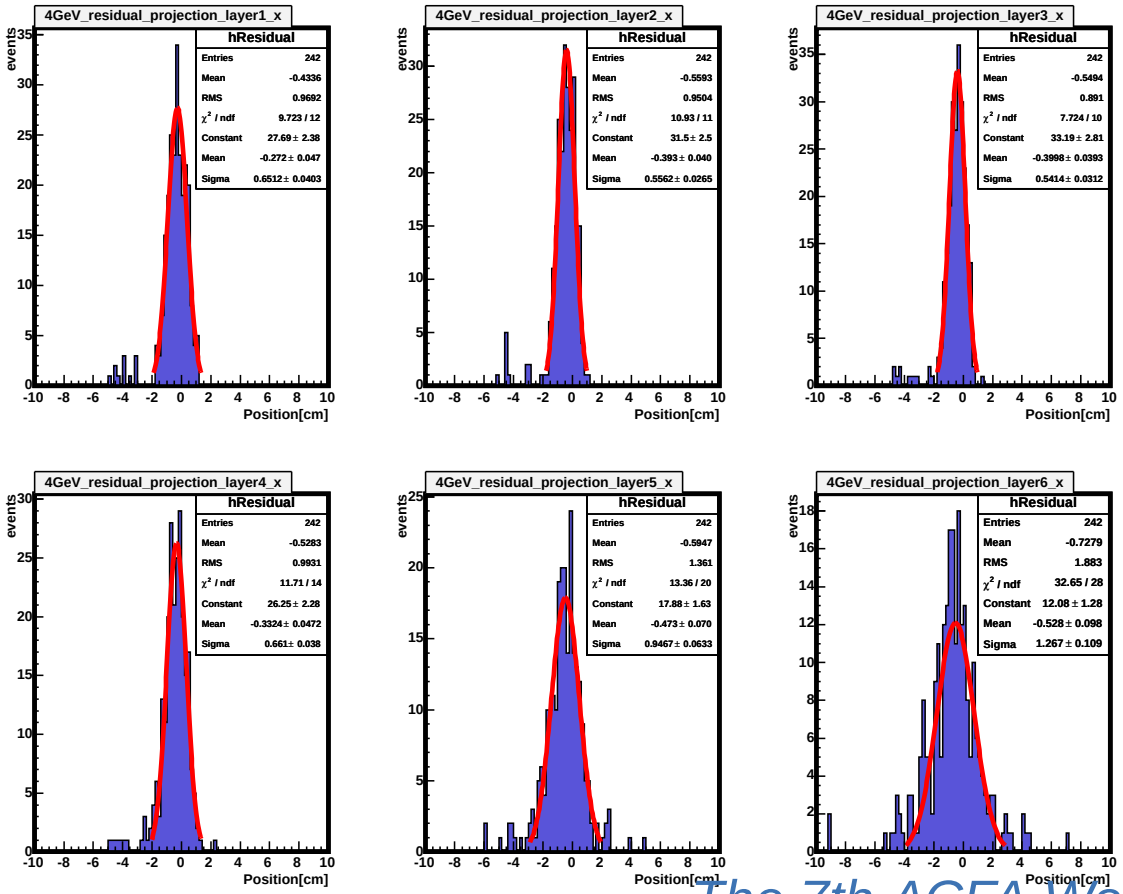
$(\sigma/\mathrm{E})_{\mathrm{MC}} = 16.3\%/\sqrt{\mathrm{E}} \oplus 2.8\%$

Beam test reslut was almost reproduced by Geant4 MC

Position resolution

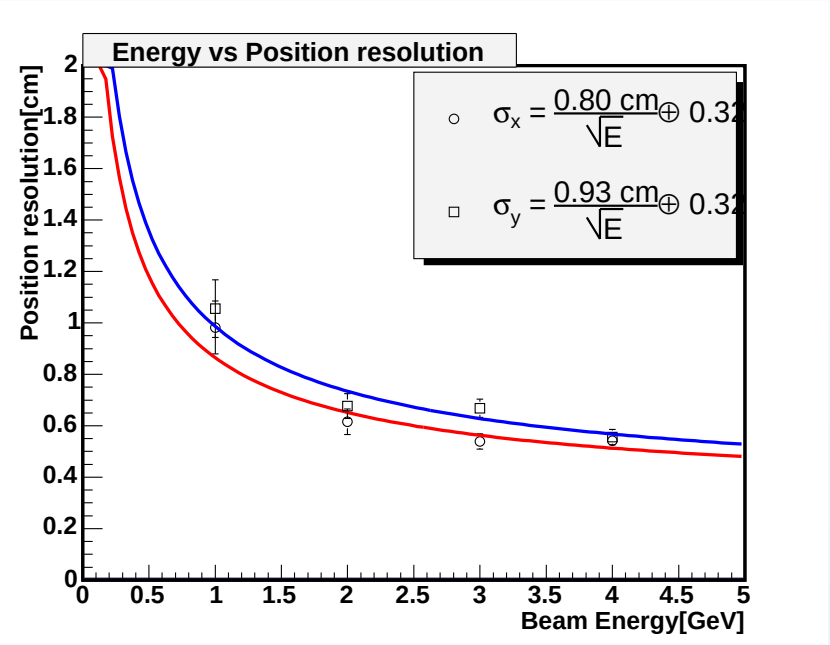
1. Get the Center of Mass position X_{CM} of the shower (signal projected to x or y direction)
2. Position resolution : σ of $X_{res} = X_{CM} - X_{DC}$ plot

Residual X_{res} distributions

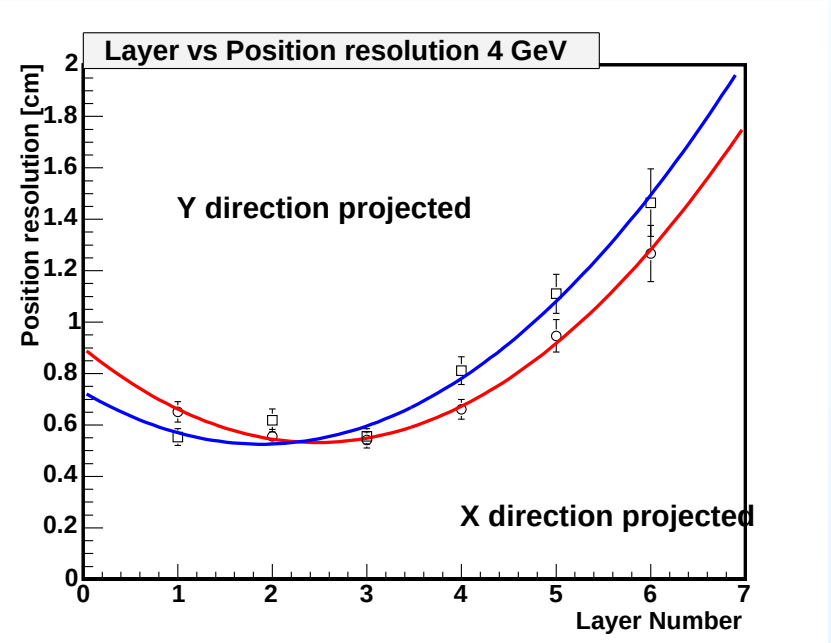


Position resolution vs Energy, SL. number

Position resolution vs Energy



1: Position resolution vs SL. number



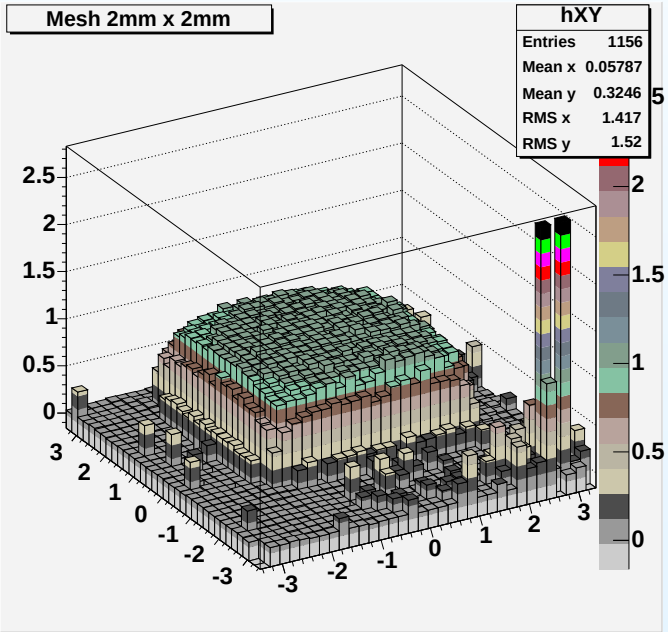
- $\sigma_x = 0.80\text{cm}/\sqrt{E} \oplus 0.32\text{cm}$ @ 3rd SL.
- $\sigma_y = 0.93\text{cm}/\sqrt{E} \oplus 0.32\text{cm}$ @ 3rd SL.
- Best position resolution achieved at shower maximum

Uniformity mapping analysis

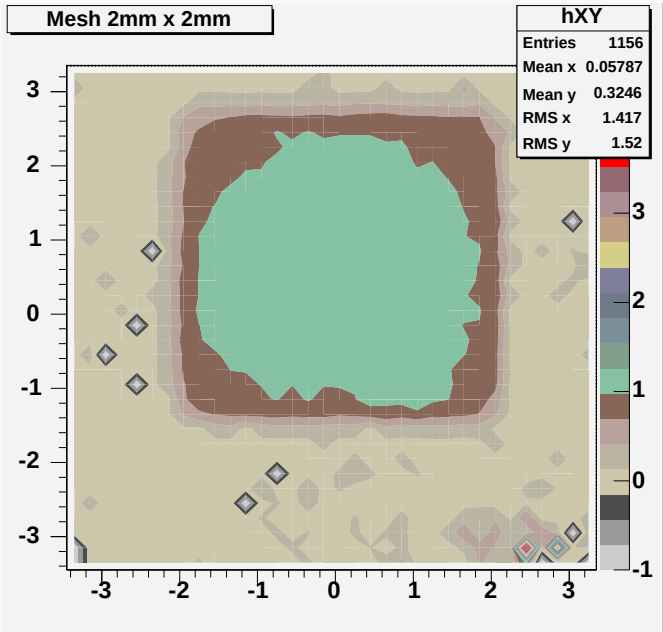
- Uniformity of Tile Light Output for MIP was maasured

Typical plots with 2mm × 2mm mesh

3D plot



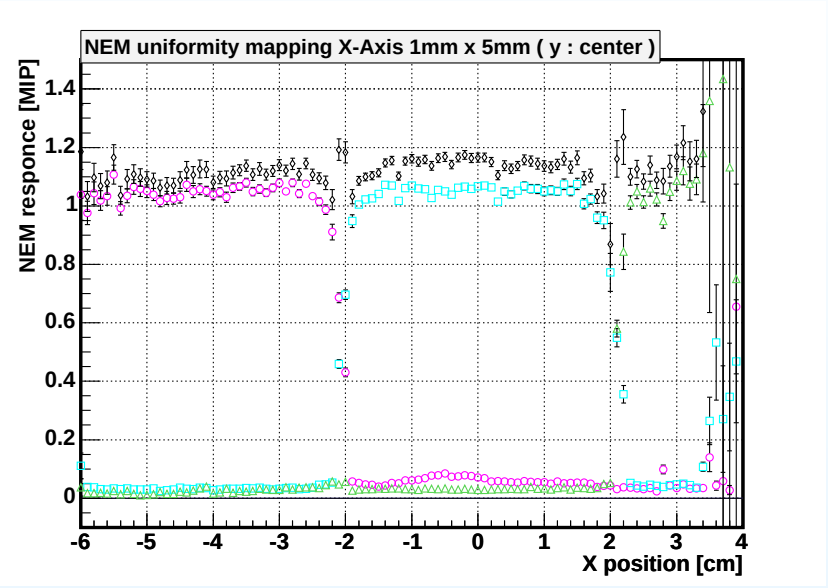
CONT plot



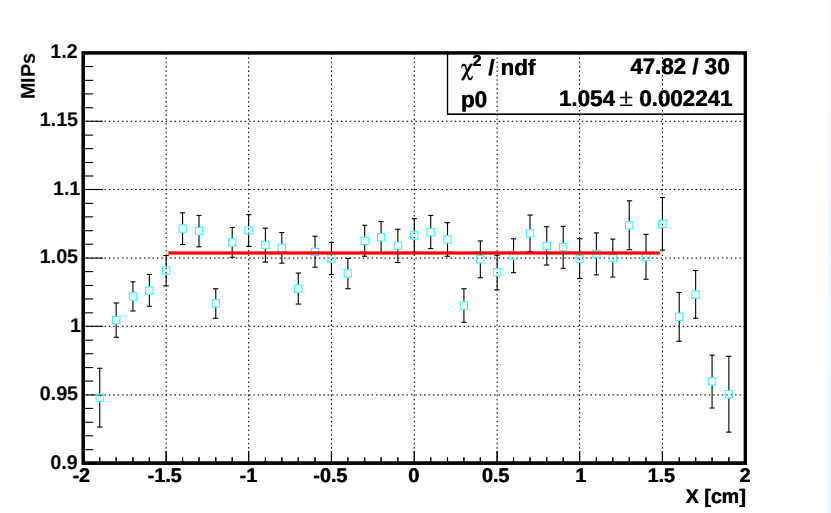
→ You can see the fiber groove position in the contour plot

X-axis transeverse scan

1mm(X) × 5mm(Y) mesh size

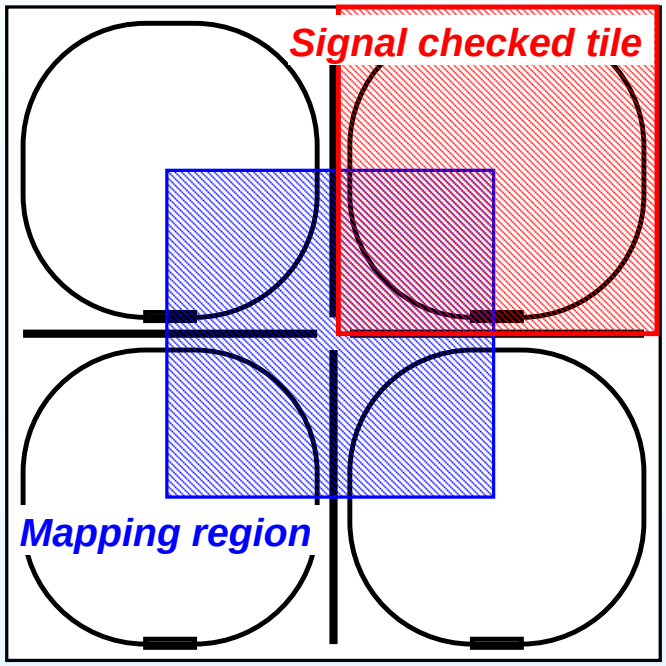


Zoom up of center tile

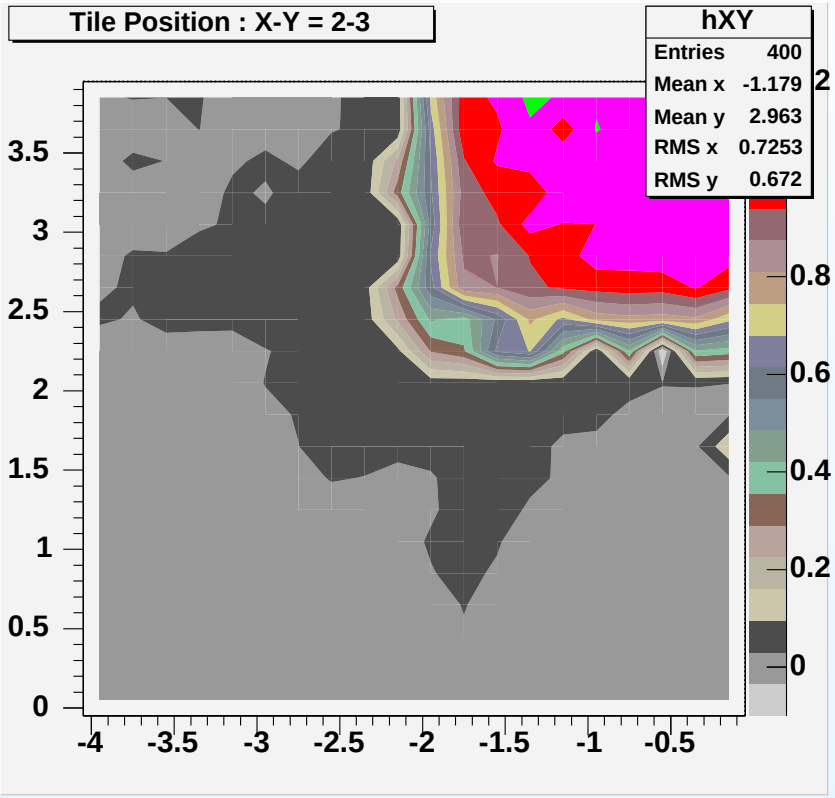


At the center tile in flat part (-1.5cm ∼ 1.5cm) : 1.05 MIPs
Uniformity : 1.47% (RMS)

Uniformity mapping at the Tile Corner



CONT plot of the mapping region



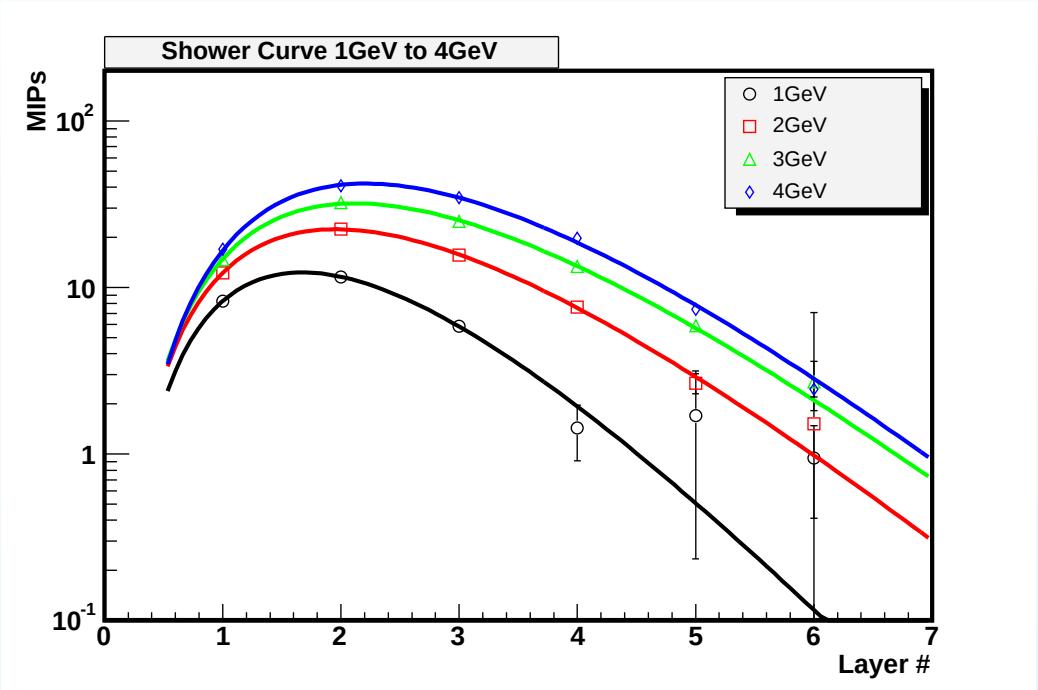
We can see the shape of fiber grooves.
This is due to that the light produced iniside of the fiber groove is absorbed in fiber.

Summary

- Energy resolution (at the center tile)
  Exp Resullt : $\sigma/\mathrm{E} = 16.8\%/\sqrt{\mathrm{E}} \oplus 3.6\%$
  Geant4 MC : $\sigma/\mathrm{E} = 16.3\%/\sqrt{\mathrm{E}} \oplus 2.8\%$
- Position resolution
  Energy vs position resolution at shower maximum
  $\sigma_{\mathrm{x}} = 0.80\mathrm{cm}/\sqrt{\mathrm{E}} \oplus 0.32\mathrm{cm}$
  $\sigma_{\mathrm{y}} = 0.93\mathrm{cm}/\sqrt{\mathrm{E}} \oplus 0.32\mathrm{cm}$
- Uniformity mapping
  Uniformity at the center tile : $< 1.47\%$(RMS)
  Good light containment inside of the fiber grooves.

Energy response and shower development

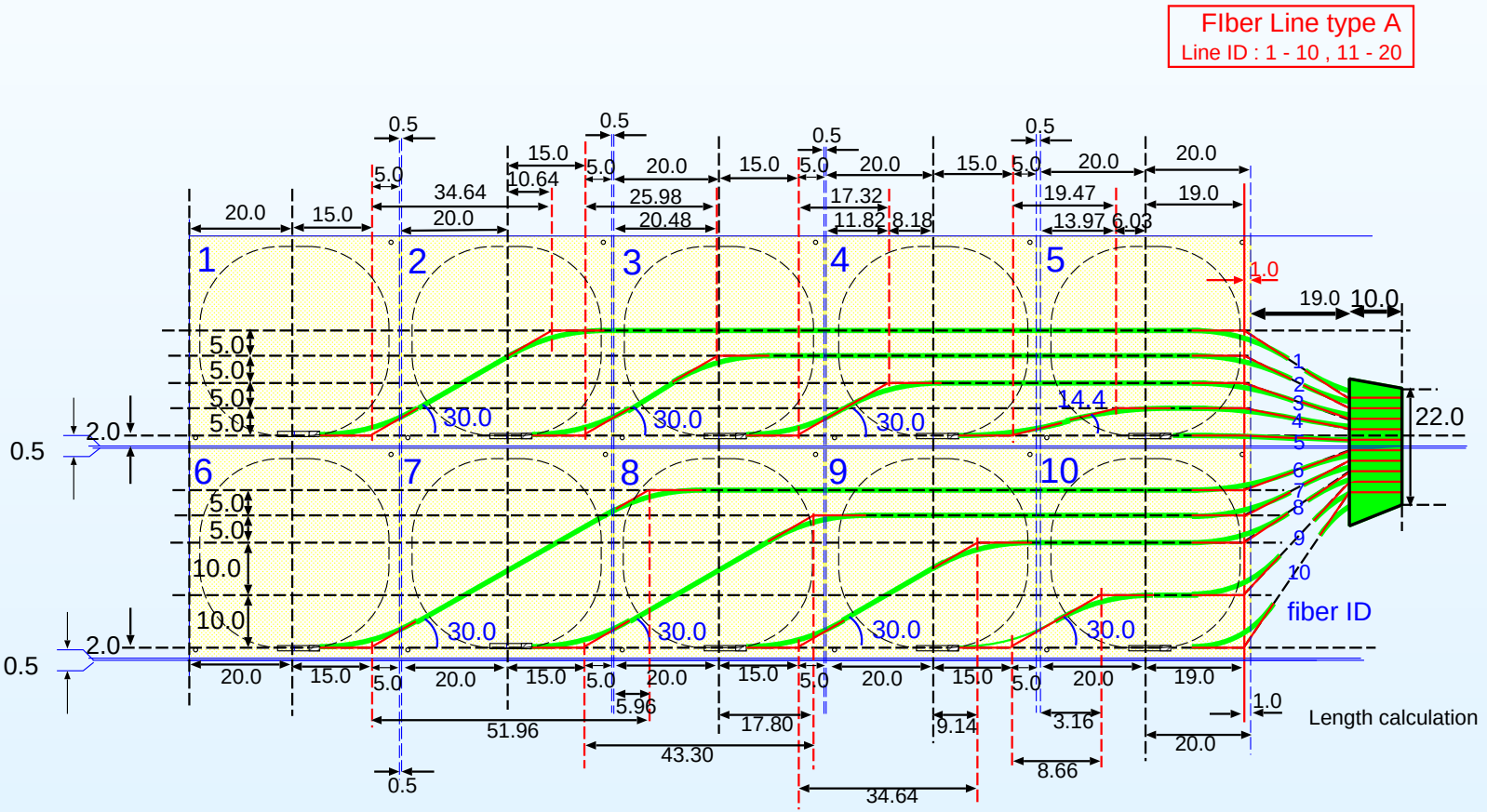
2: Shower profi le of logitudinal development



- Fitting function : $f(x, p_0, p_1, p_2) = p_0 x^{p1} e^{-p_2 x}$

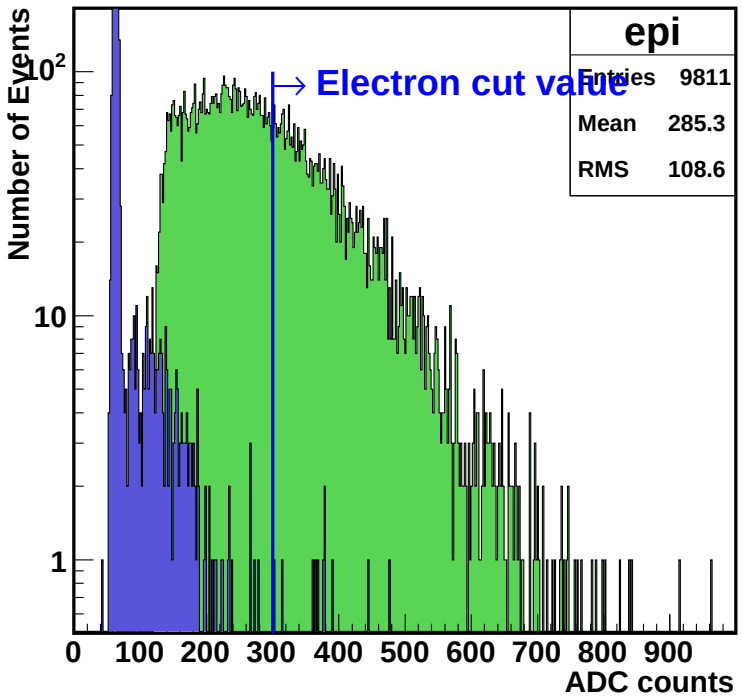
Fiber Lane light leakage

White acryl sheet : 0.2mm @fiber lane
→ Put the white teflon sheet into the fiber Lane.
Still light leak from fiber leans.



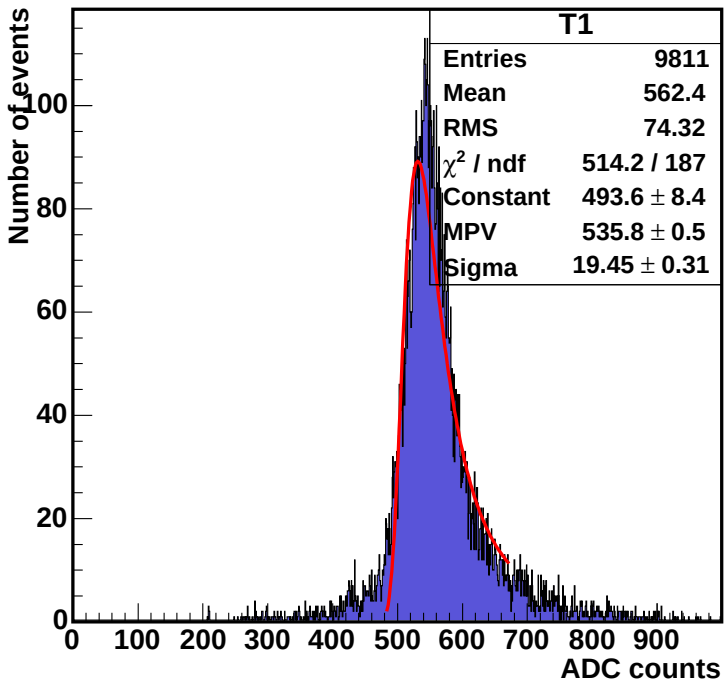
Cherenkov and Trigger cut

3: Chrenkov counter cut



Cherenkov ADC > 300

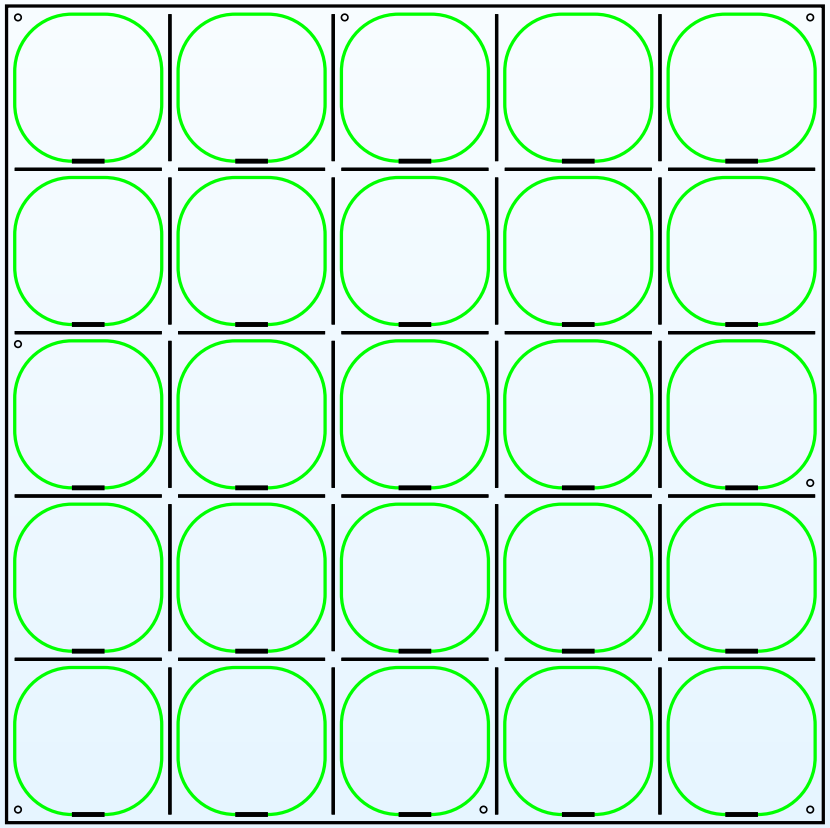
4: Trigger counter cut



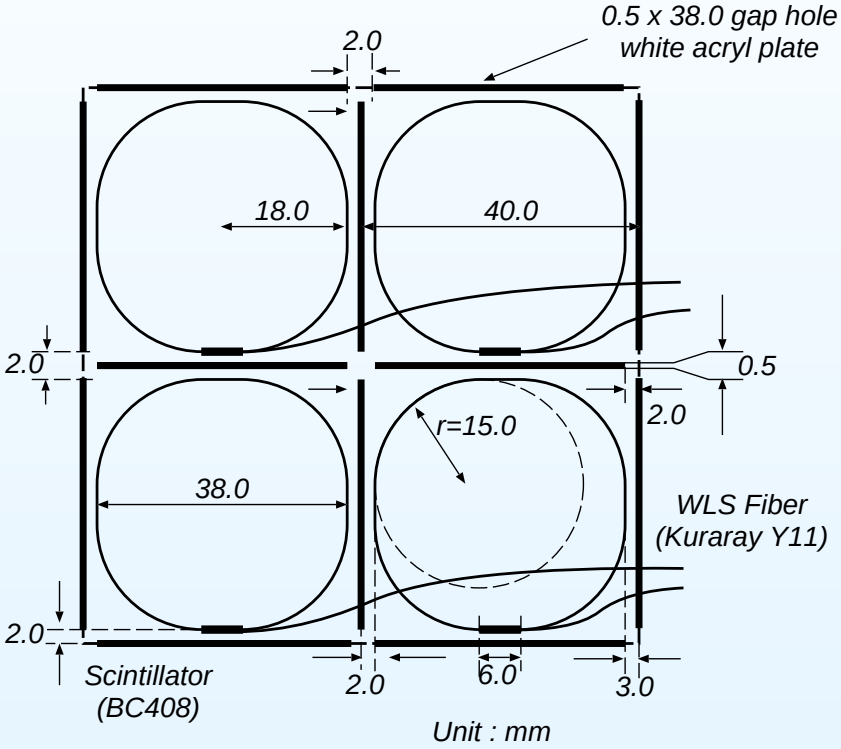
MPV-3σ < T1&T3 < MPV+8σ

Detail of mega-tile structure

5: 5x5 matrix megatile structure

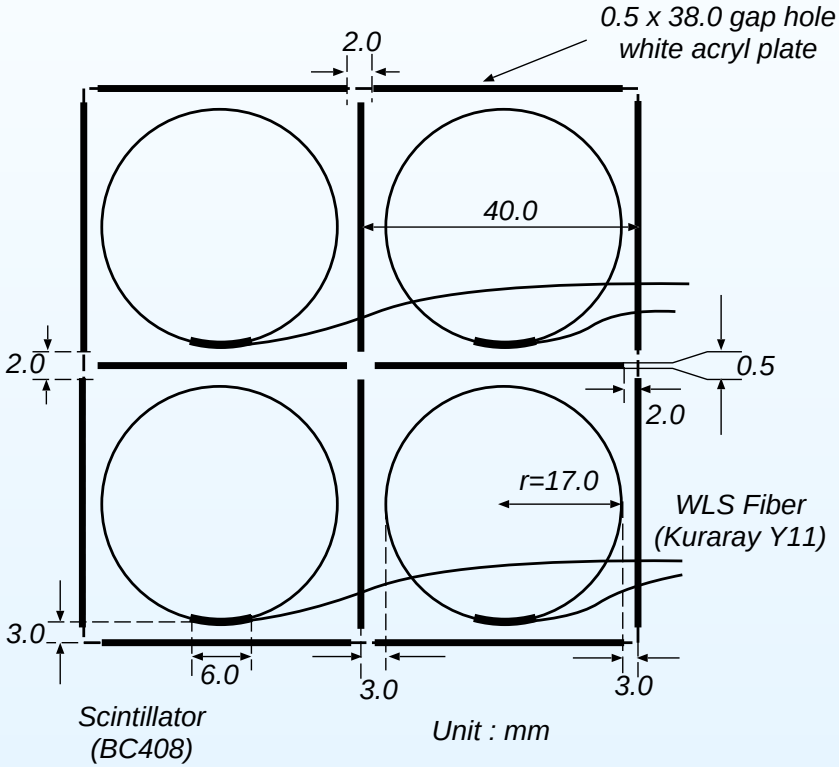


6: Zoom up of megatile structure

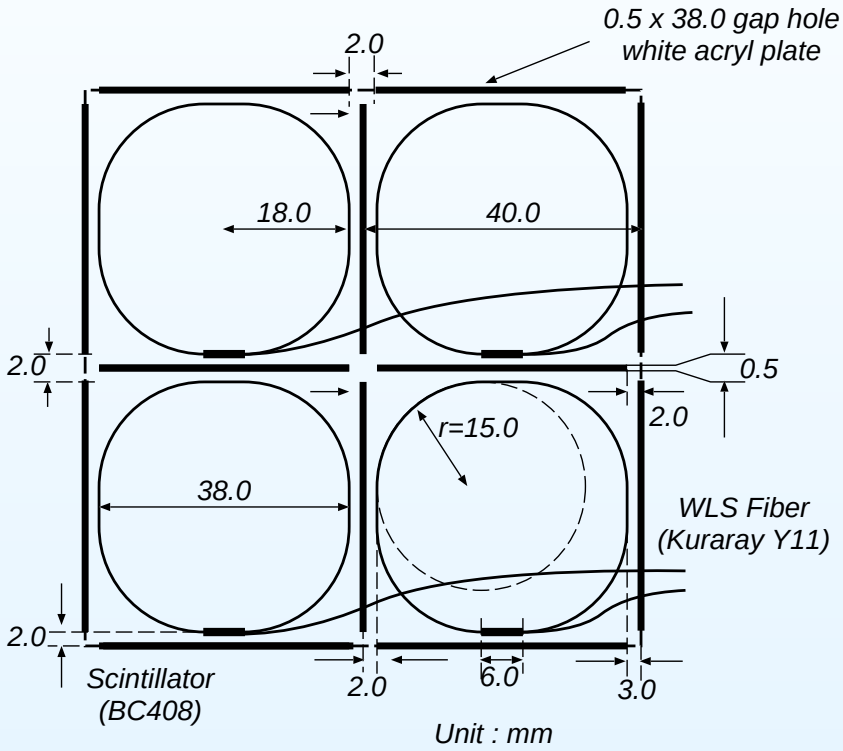


2 type fiber loops for staggering

7: Circle type fi ber groove



8: Square type fi ber groove



For better uniformity, we try to stagger the fiber loops.