Testbeam results of LHCb PicoCal R&D

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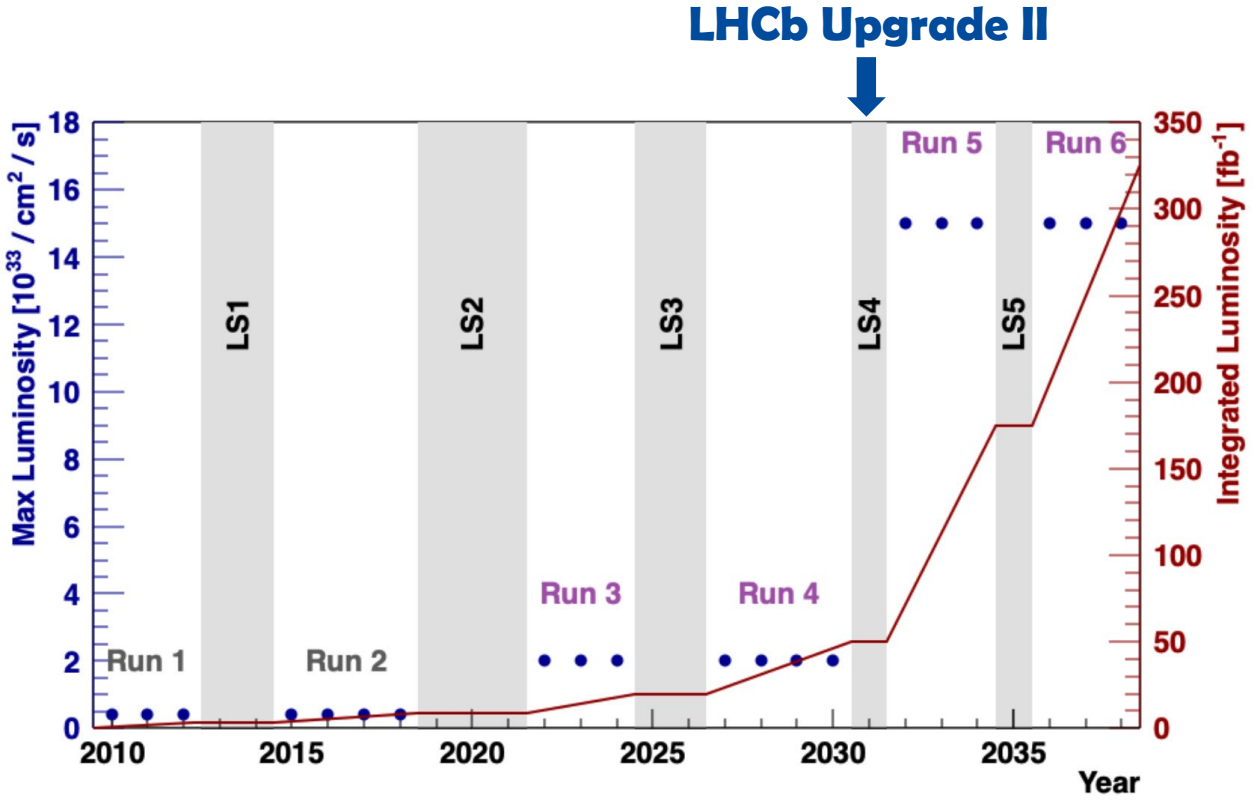
Introduction

- **Introduction**
- W-GAGG prototype assembly
- Latest testbeam result and simulation result
- Summary and outlook

Requirements on LHCb ECAL for Run5

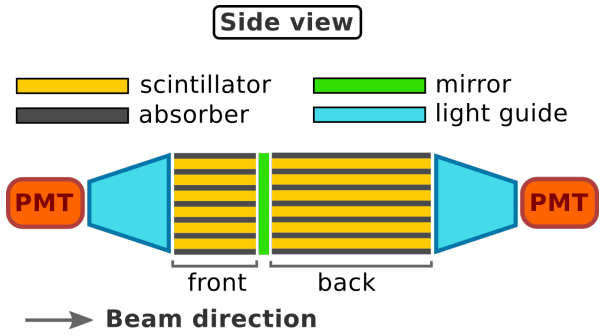


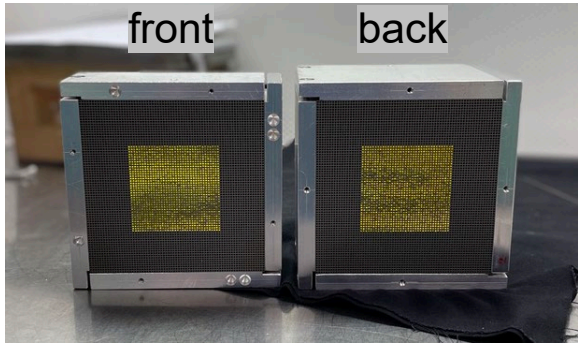
- Run5
  - Peak luminosity of $1.0 \sim 1.5 \times 10^{34}\ \mathrm{cm}^2/\mathrm{s}$ with pile up of $20 \sim 40$ (around five times more than Run 4)
  - Higher radiation dose
- Requirements on ECAL Upgrade
  - Sustain 1 MGy radiation dose
  - Energy resolution: $\sigma_E/E = 10\% \oplus 1\%$
  - Time resolution: $O(10\ \mathrm{ps})$

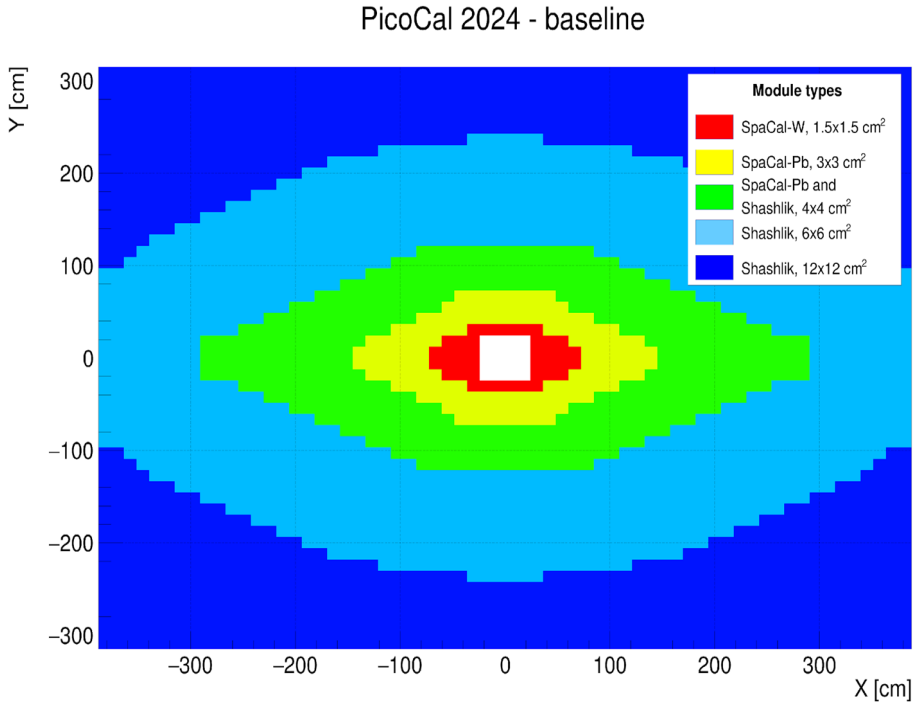
PicoCal

Design and Technology of PicoCal

- Technology:
  - Inner region(red, yellow, green): SpaCal + Shashlik
  - Outer region(light & dark blue): Shashlik
- Innermost modules:
  - SpaCal: Tungsten + GAGG fibers





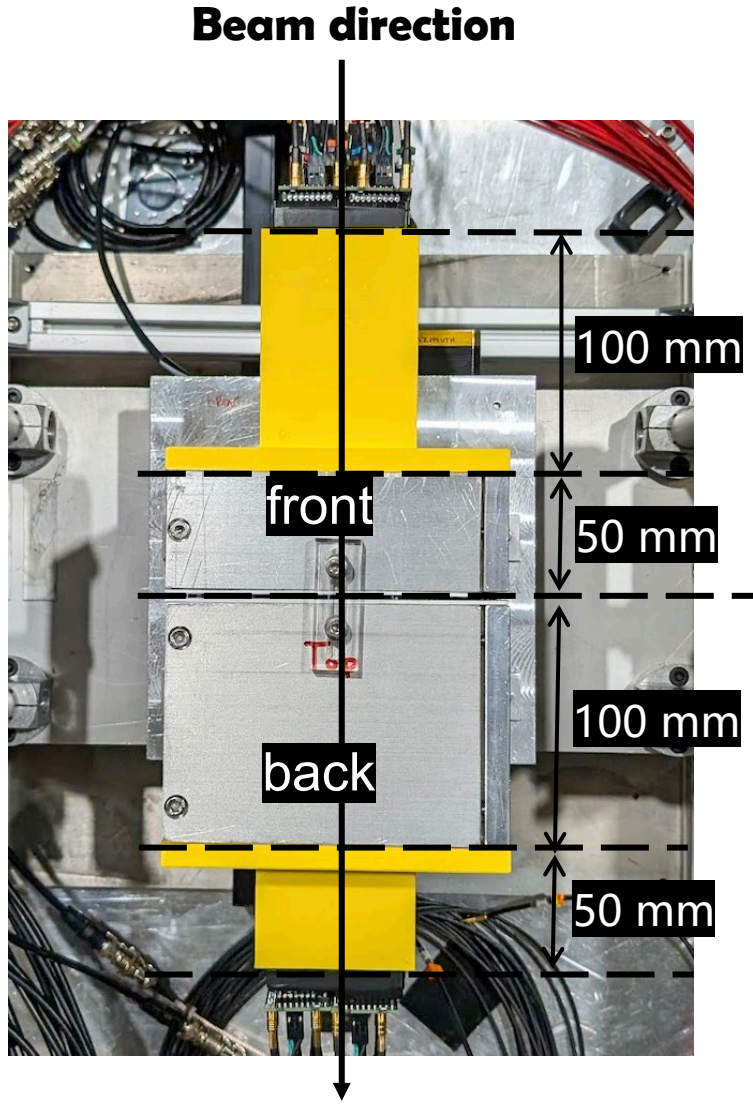


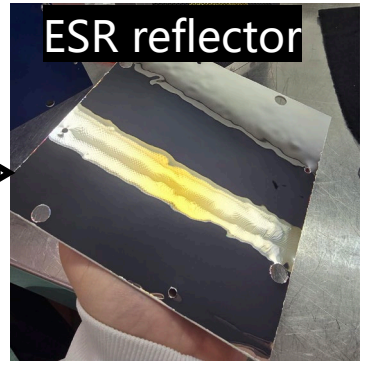
W-GAGG prototype assembly

- Introduction
- **W-GAGG prototype assembly and testbeam setup**
- Testbeam and simulation result
- Summary and outlook

Prototype design

- The size of prototype is $120.24 \times 120.24 \times 150\ \mathrm{mm}^3$
- Composed by two halves:
  - 50 mm for front part
  - 100 mm for back part
- Absorbers produced by LaserAdd
- Only 4×4 cells inserted with GAGG fibres produced by SIPAT (See report from Yuchong) :
  - 1296 GAGG fibers with $1.0 \times 1.0 \times 50\ \mathrm{mm}^3$
  - 1296 GAGG fibers with $1.0 \times 1.0 \times 100\ \mathrm{mm}^3$
- PMT and LGs provided by CERN:
  - 8 x Multi-anode PMT R7600U-00-M4
  - asymmetric LGs: square to square
  - double-side readout





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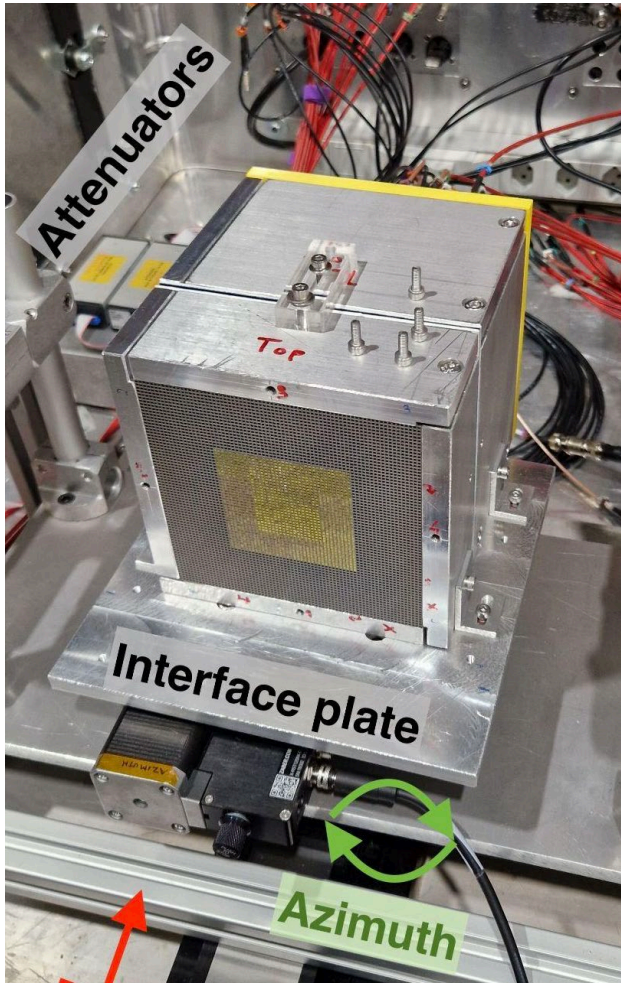

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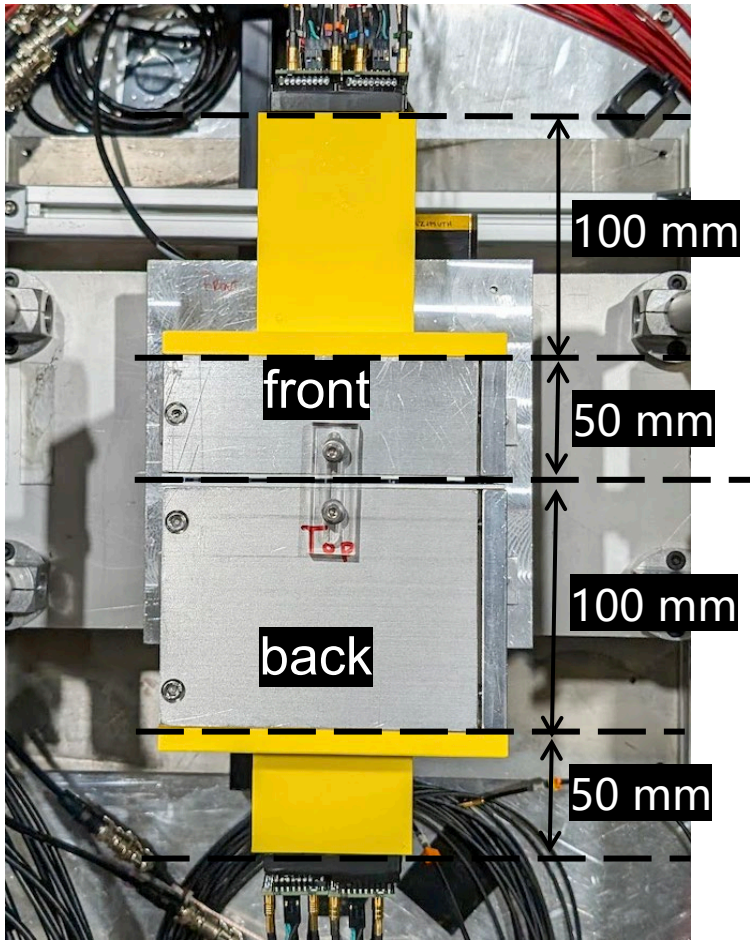
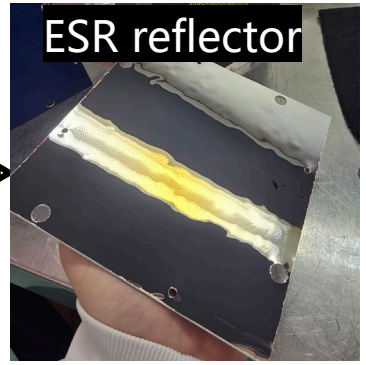
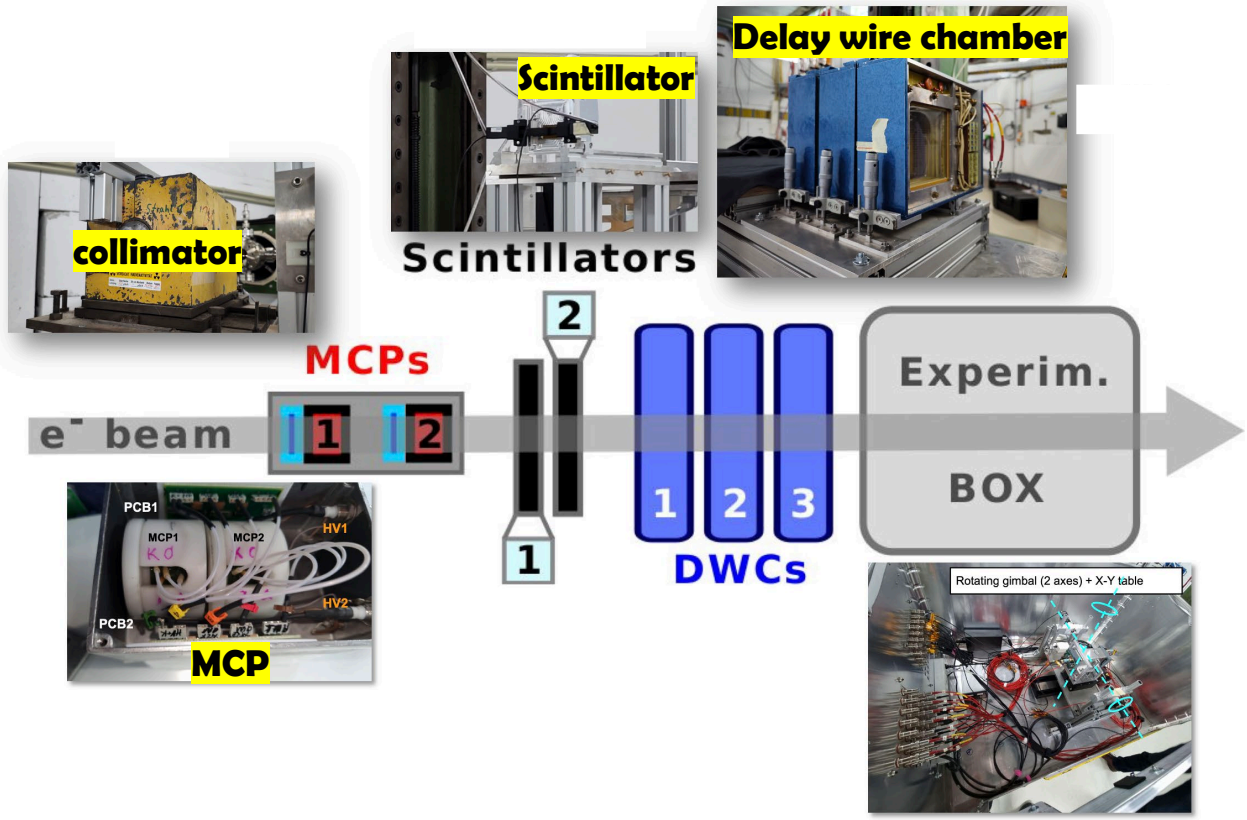




Testbeam setup

- **Electron beam**:
  - SPS: 20 – 100 GeV
  - DESY: 1 – 5 GeV (to be measured in November)
- **MCP** : Time reference
- **Scintillator** : Trigger
- **Delay wire chamber**: Position
- **Experimental Box**:
  - Stepper : Rotate module
  - X-Y table: Move box in x-y direction
- **Readout electronics**:
  - ADC (Energy), Digitizer (Time + Energy), etc.



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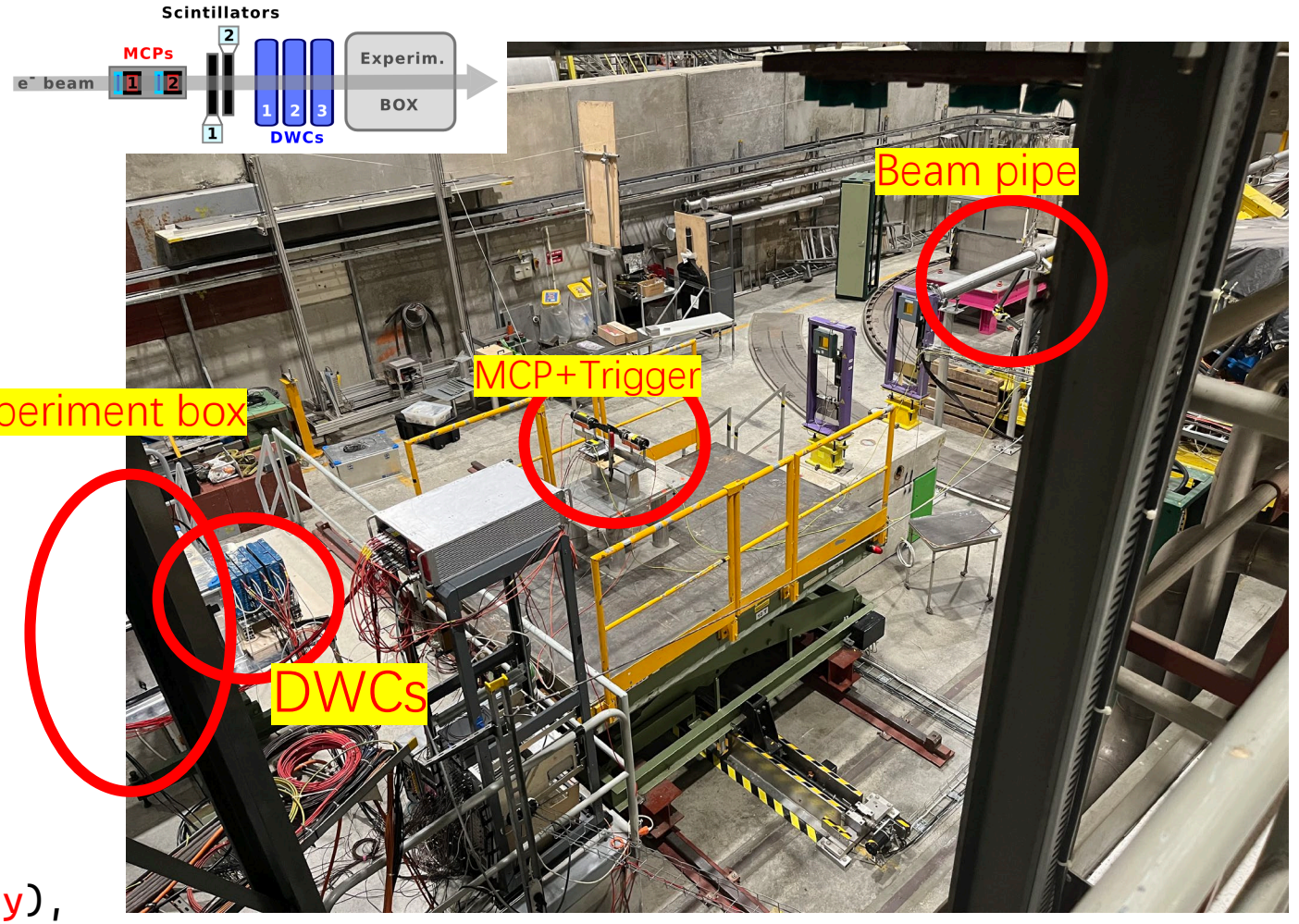

Latest testbeam result and simulation result

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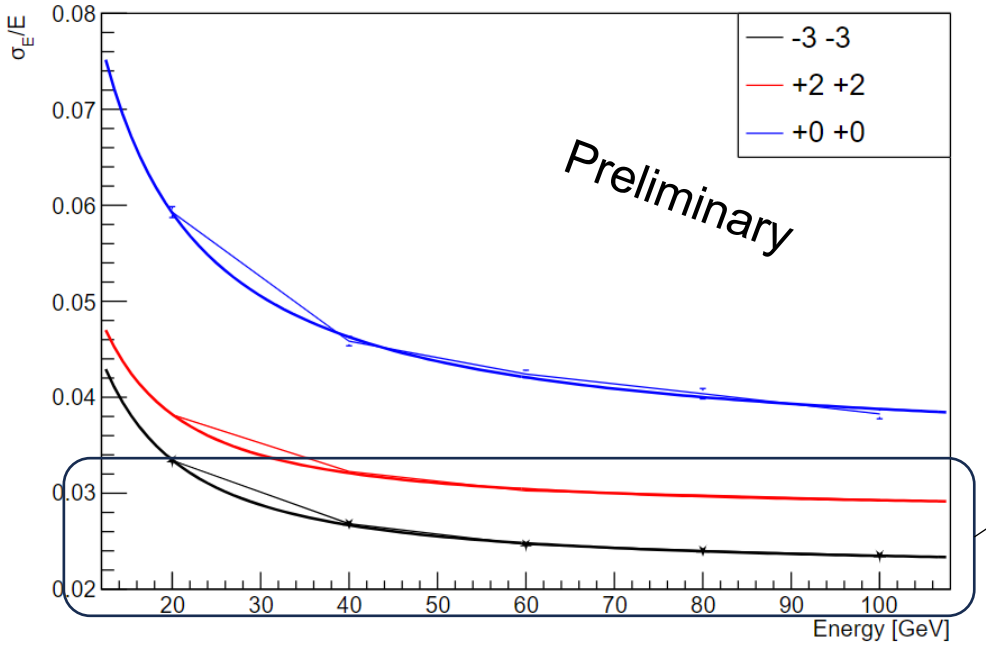
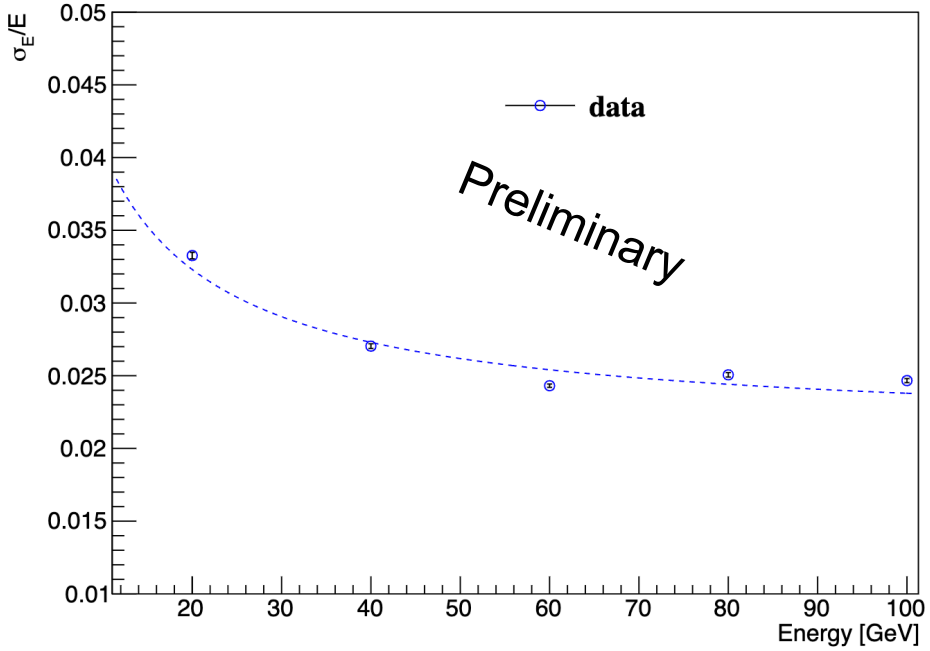
Energy resolution result (For cell in the center)

- **Fit with:** $\sigma/\mathrm{E} = \mathrm{a}/\sqrt{\mathrm{E}} \oplus \mathrm{b} \oplus \mathrm{c}/\mathrm{E}$





Angle scan for best energy resolution

Sampling term	a[%]	10.92 ± 0.17
Constant term	b[%]	2.11 ± 0.02
Noise term	c[%]	10.77

Improvement expected:
- Suitable PMT
- Tune the property of fibers
- etc.

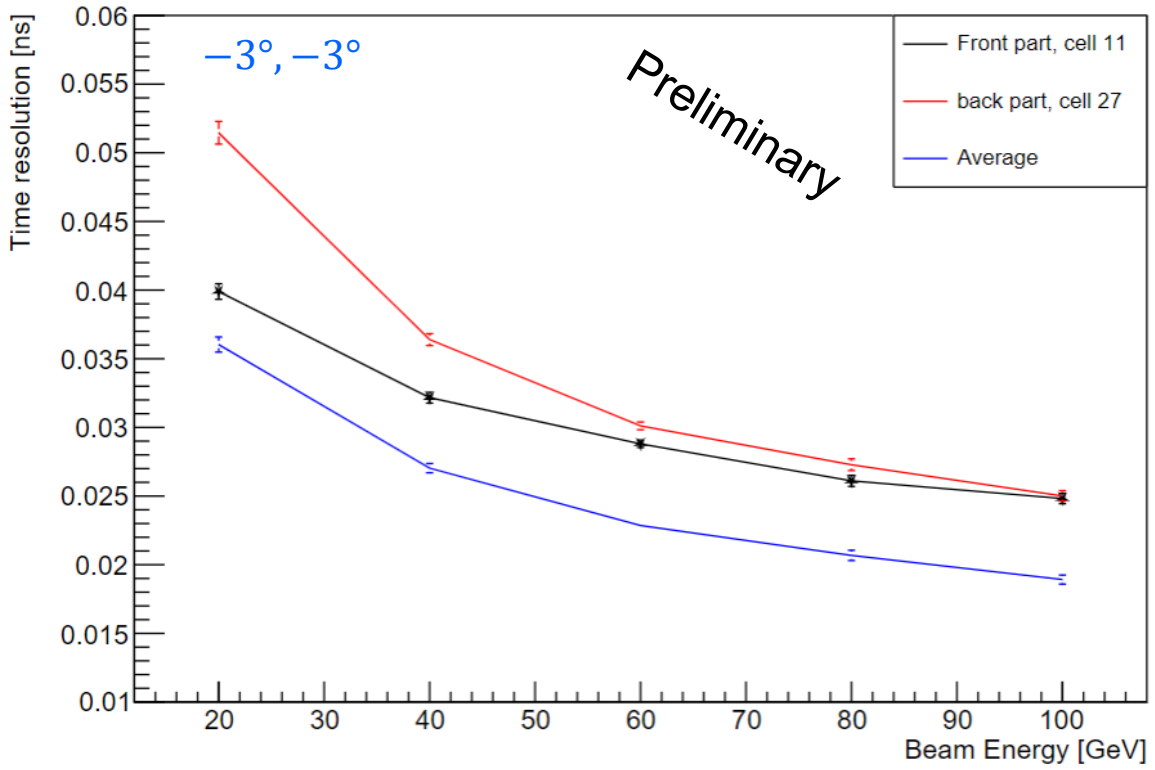
Time resolution results (For cell in the center)

Reference time (from MCP)

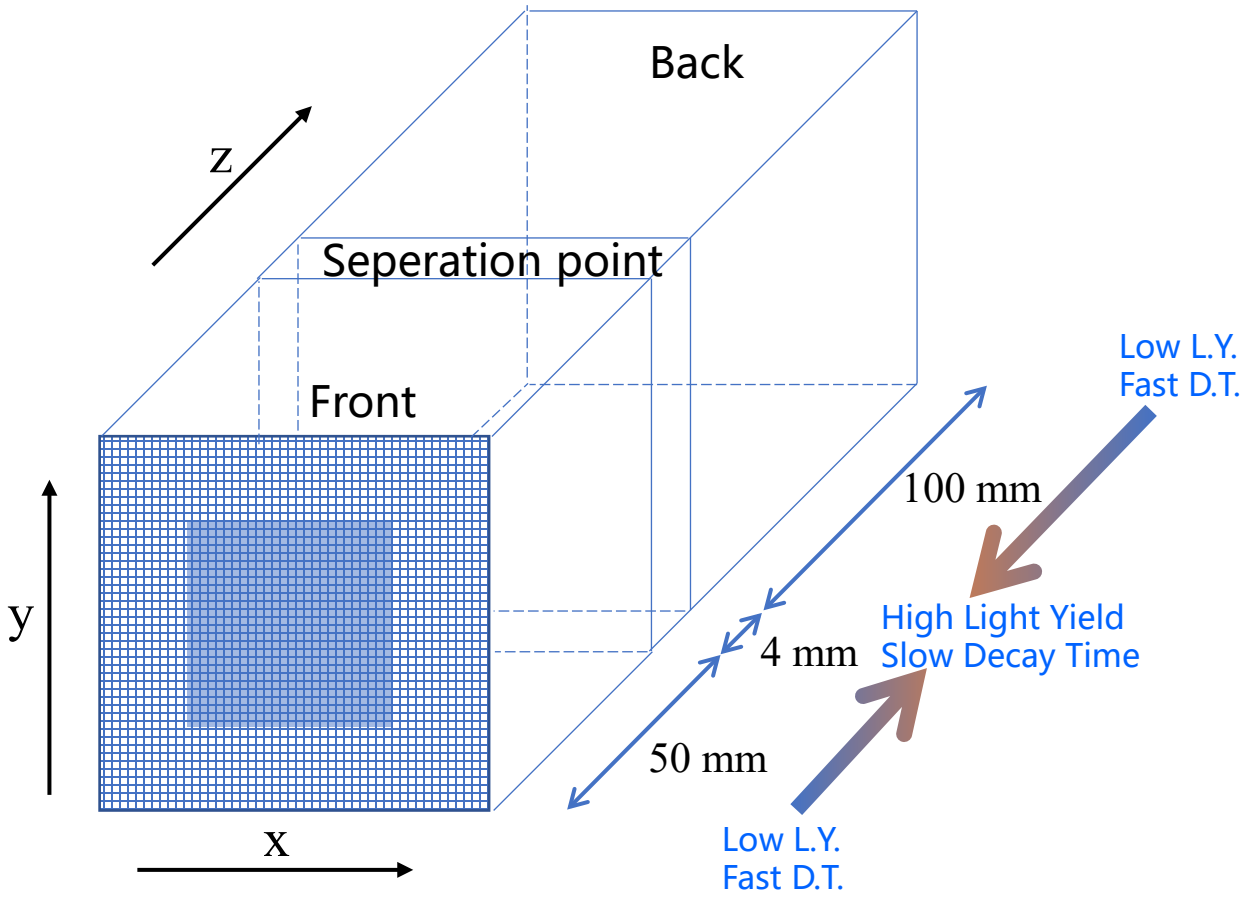
- **Weighted average method:**

$$t' = \left(\frac{t_f - \mu}{\sigma_f^2} + \frac{t_b - \mu}{\sigma_b^2} \right) / \left(\frac{1}{\sigma_f^2} + \frac{1}{\sigma_b^2} \right)$$

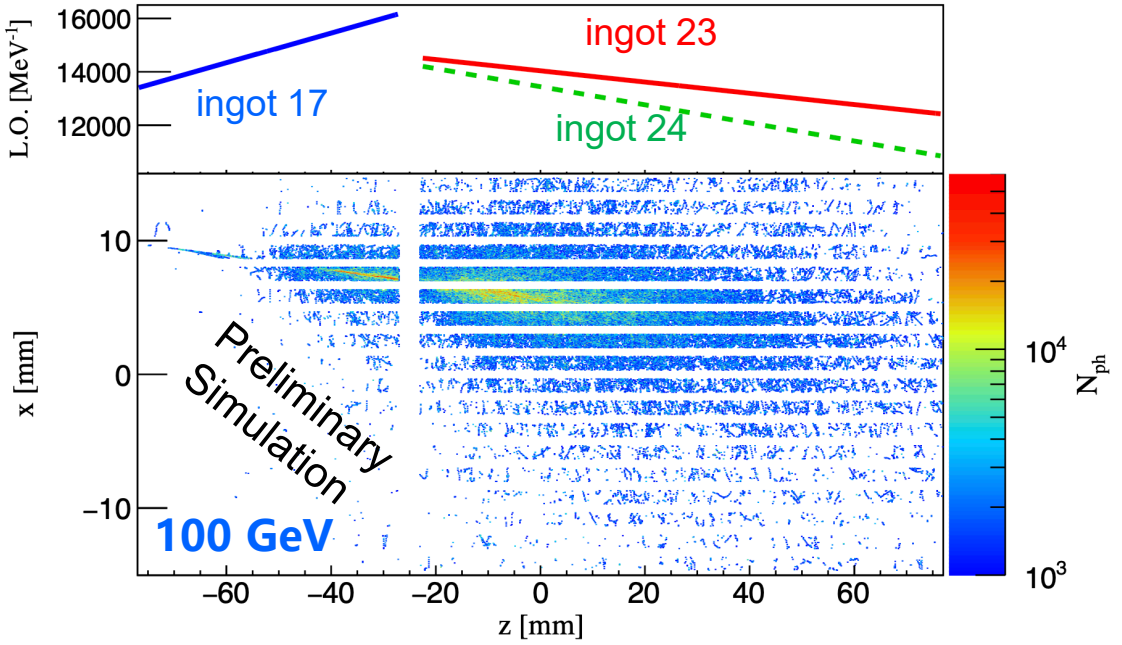
- **Time resolution of front part is better than that of back**
- **Time resolution above 20 GeV: better than 35 ps**
- **Time resolution at 100 GeV is 19 ps**



Simulation setup

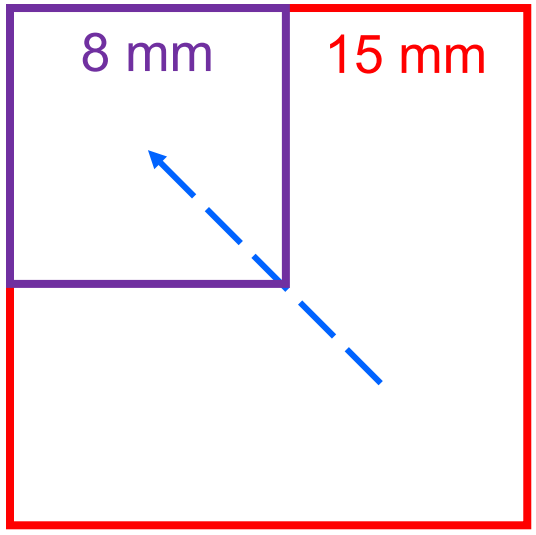


- Along the Z direction, the fiber light yield varies linearly in different parts of an ingot
- The fiber properties (light yield, etc.) have a 10% smearing.

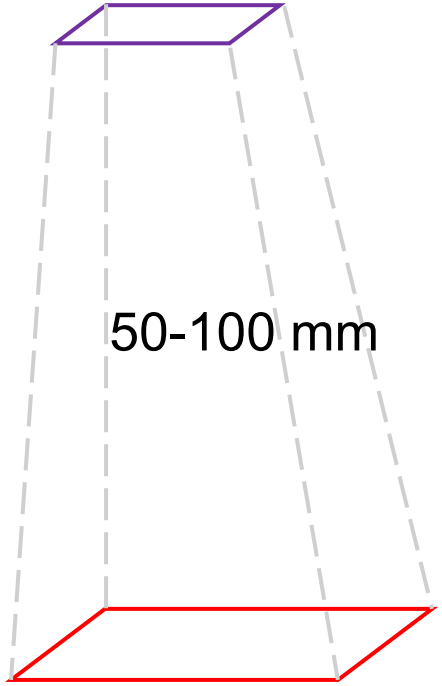


Simulation setup

- LGs responses map for 1 cell

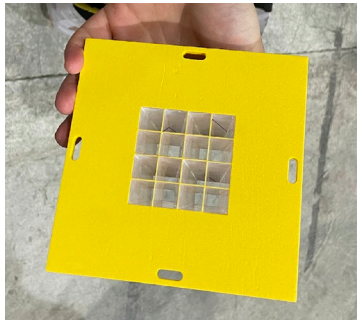


Top view



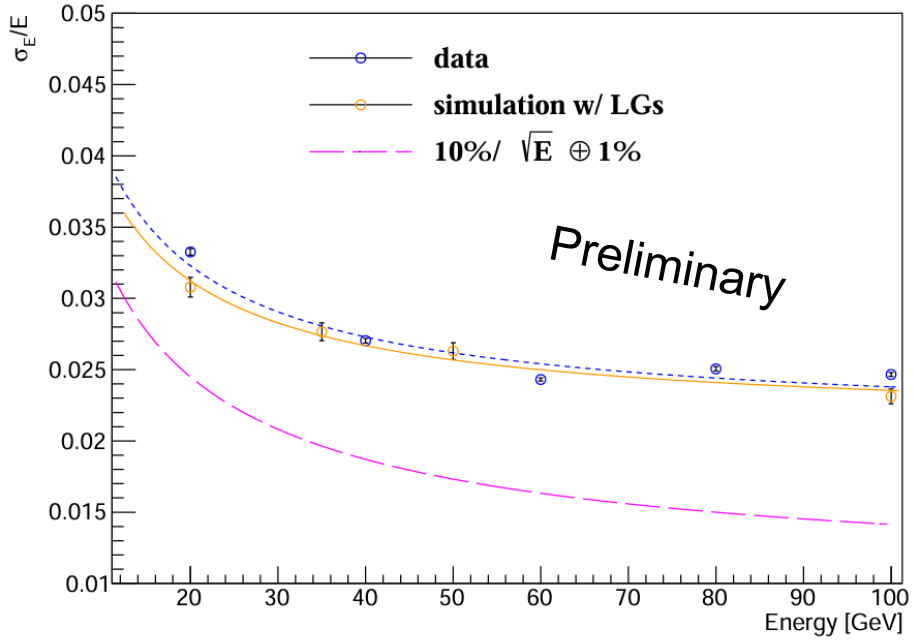
Side view

Light guide faces to crystal



Comparison between simulation and experiment

- **Energy resolution: Comparison between test beam data and simulation:**
  - **Fit with:** $\sigma/\mathrm{E} = \mathrm{a}/\sqrt{\mathrm{E}} \oplus \mathrm{b}$



	Test beam data	Simulation
a[%]	10.92 ± 0.17	10.25 ± 0.58
b[%]	2.11 ± 0.02	2.12 ± 0.07

Very good agreement between simulation and data

Summary and outlook

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- **Summary and outlook**

Summary and outlook

- HL-LHC sets high requirements on ECAL, SPACAL W-GAGG technology chosen for innermost region
- First prototype built for testbeam:
  - Energy resolution: $\sigma_E/E \approx 10.9\% \oplus 2.1\%$
  - Time resolution: 35 ps (20 GeV) to 19 ps (100 GeV)
  - Results are promising and improvements to be expected, results from 1-5 GeV expected in one month
- Simulation framework built:
  - Good consistency between testbeam result and simulation
- Outlook:
  - DESY result will be ready for further constraint on resolution curve
  - Improvements on PMT, light guide, fibers and so on are expected.

Thank you for listening

Energy resolution result (calibration)

Calibration

- **Procedure** :
- **Purpose** : Equalize the readout of each cell
  normalize the total readout to input energy

Test beam results of prototype Calibration procedure

➢Calibration procedure:

- **To adjust the ADC output to correspond with the energy deposited in the prototype.**
- **Runs without a plastic protection for GAGG fibers**
- **Scan performed with $40\ \mathrm{GeV}\ e^-$ beam at $-3°, -3°$**
- **Selected region: 4×4 cells ($60 \times 60\ \mathrm{mm}^2$)**

➢ **Only back part**
- calibrate the back part

$$F_{back} \sum_i c_{back,i}\ \mu_{back,i} = E$$

➢ **Both front and back part**
- calibrate the front part

$$F_{back} \sum_i c_{back,i}\ \mu_{back,i} + F_{front} \sum_i c_{front,i}\ \mu_{front,i} = E$$

fixed

➢ **Equalization of 16 cells (back only)**
- Fit the ADC output using Gaussian
- Equalize all μ to the same value

$$c_{back,i}\ \mu_i = \text{const} \rightarrow c_{back,i} = \text{const}/\mu_i$$

➢ **Normalization (back only)**
- Take one cell

$$F_{back} \times \sum_i c_{back,i}\mu_i = 40\ \text{GeV}$$

$$F_{back} = \frac{40\ \text{GeV}}{\sum_i c_{back,i}\mu_i}$$

➢ **Equalization of 16 cells (front)**
➢ **Normalization (front)**

Test beam results of prototype Calibration procedure

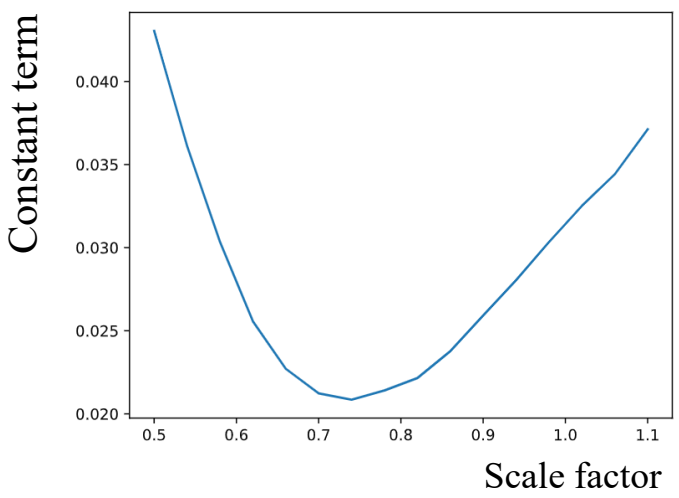
➢Extra procedure:

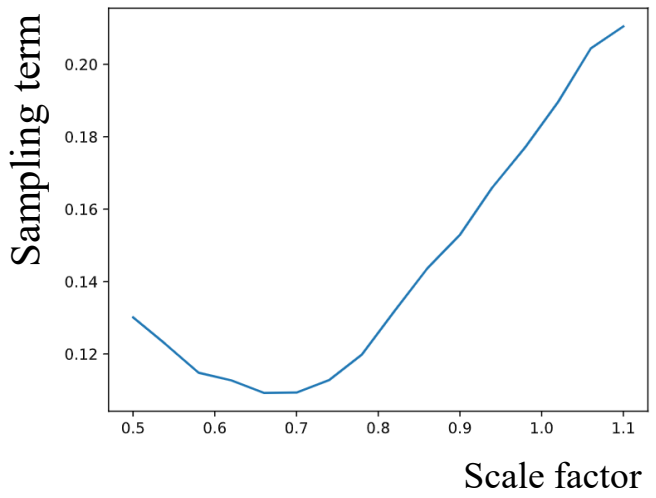
- **To improve energy resolution, cases such as overestimating reconstructed energy in the back or energy leakage must be considered.**

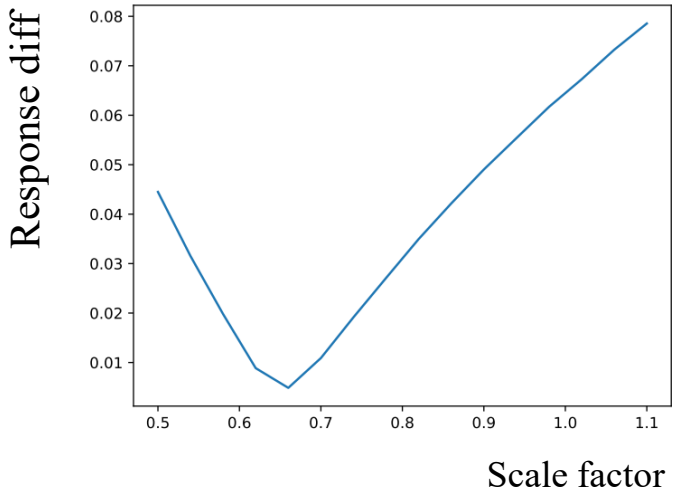
➢ **Scale coefficient for the back part is introduced:**

$$S \times F_{back} \sum_i c_{back,i}\, \mu_{back,i} + F_{front} \sum_i c_{front,i}\, \mu_{front,i} = E$$

Minimum all around 0.7







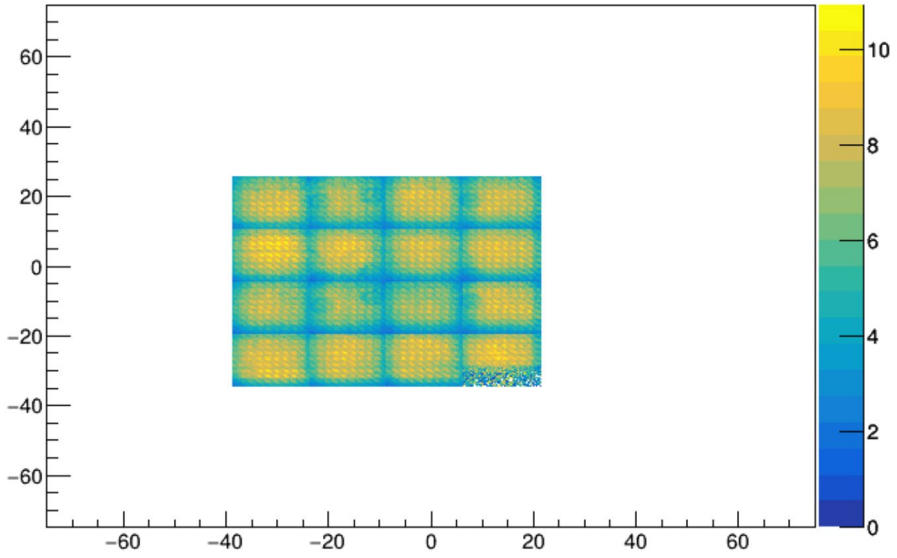
Energy resolution result (calibration)

Calibration

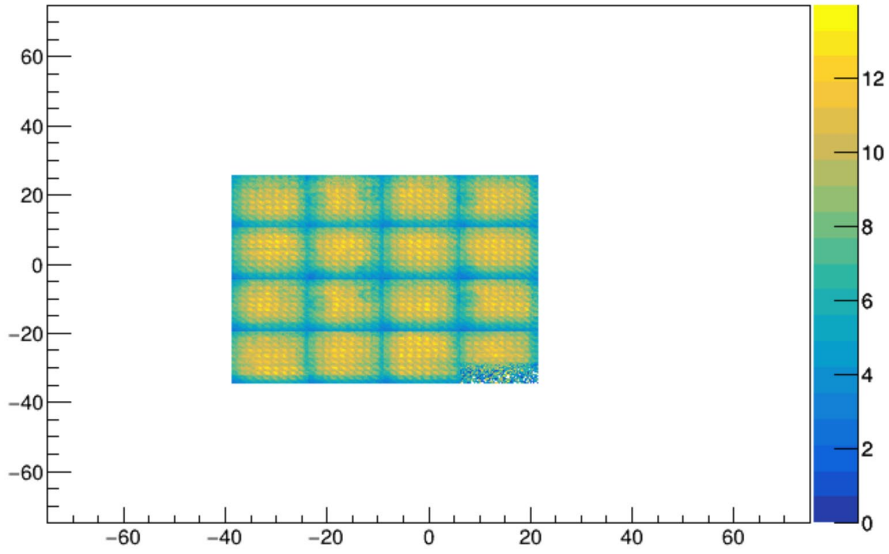
- **Procedure**: see back up slides

By shooting 40 GeV beam in each cell

- **Purpose** : Equalize the readout of each cell
  normalize the total readout to input energy



Before equalization



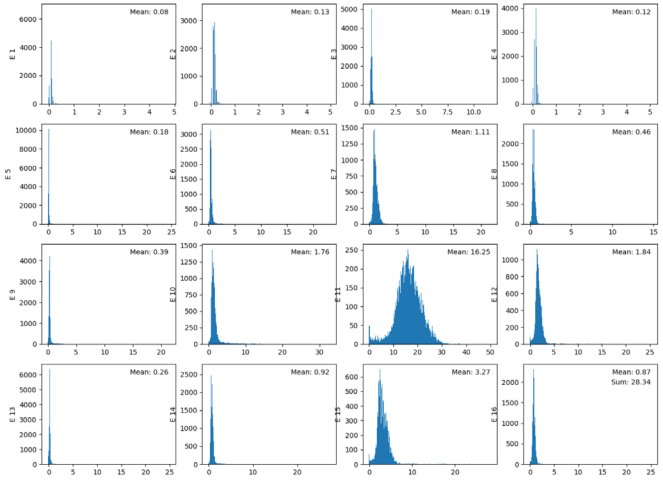
After equalization

Energy resolution result (calibration)

Calibration

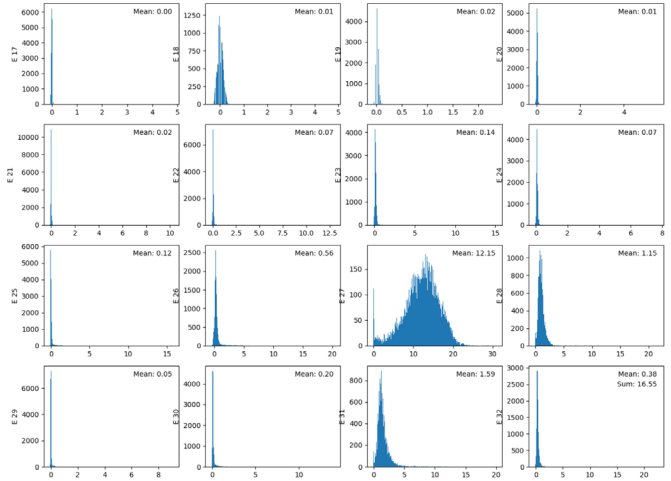
- **Procedure**: see back up slides
- **Purpose** : Equalize the readout of each cell
  normalize the total readout to input energy

By shooting 40 GeV in the center cell



Energy deposited in each cell (back part)

+



Energy deposited in each cell (front part)

= 40 GeV