High granularity digital Si-W electromagnetic calorimeter for forward direct photon measurements at LHC

Hongkai Wang

for the ALICE-FoCal Collaboration

Utrecht University

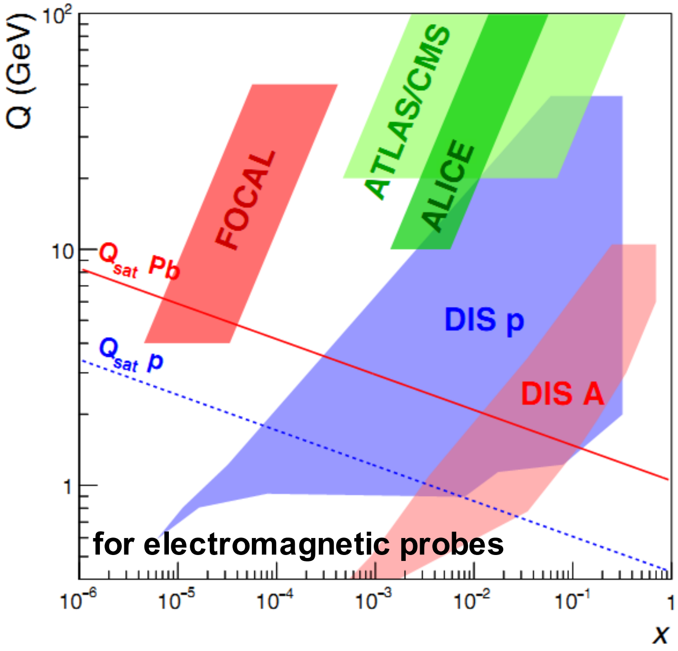
TIPP'2017, Beijing

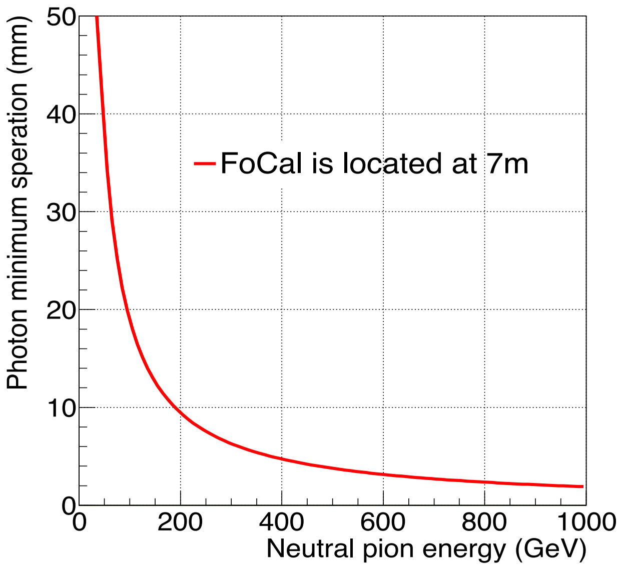
Physics Motivation

Motivation

- Gluon density increases with Q^2 and $1/x$ (Gluon Saturation)
- Direct photons promise to be a very clean probe
- LHC provides opportunity to access small-x

$$x_{min} \approx \frac{2p_T e^{-y}}{\sqrt{s_{NN}}}$$

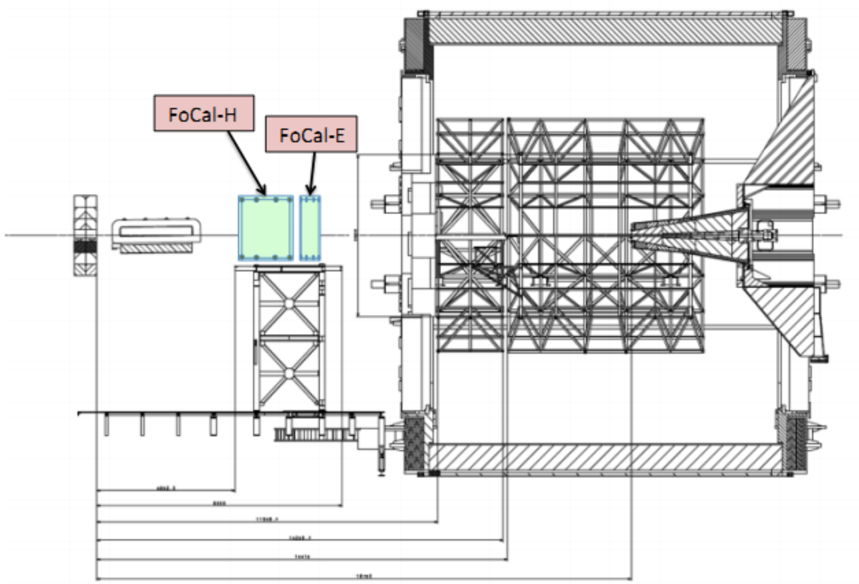


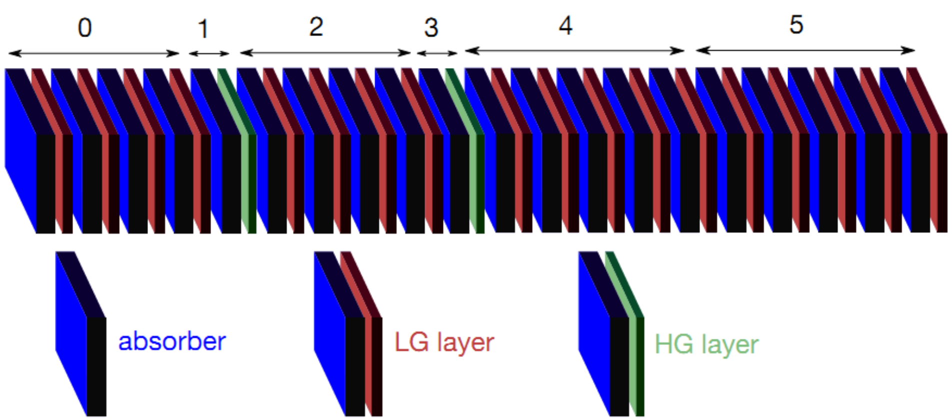


Probing small-x requires separation power in direct photon and decay photons from π^0

- High granularity detector
- Should allow 3D shower shape analysis and/or Particle Flow Algorithm

FoCal upgrade proposal





Proposed installation

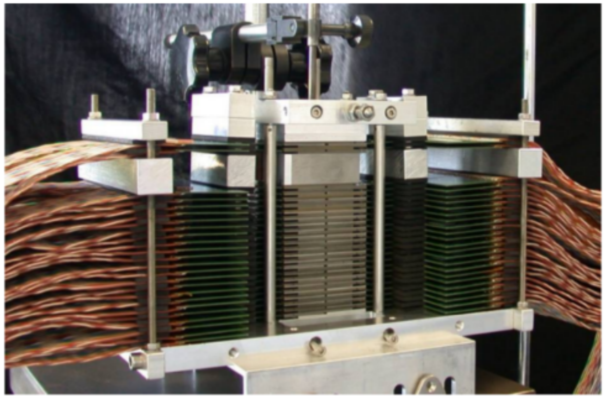
- Proposal discussed within ALICE
- In LHC long shutdown 3
- Outside the magnet of ALICE
- Focal-E + Focal-H
- Pseudorapidity : $3.5 < \eta < 5.3$
- ~7m away from interaction point

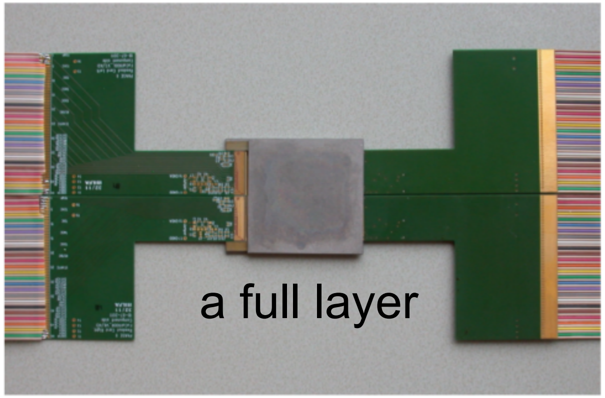
FoCal strawman design (FoCal-E)

- Hybrid layers
  - energy measurement+shower separation
  - LG : $1 \times 1\ cm^2$, HG : $30 \times 30 \mu m^2$
  - Pads + CMOS pixel sensors
- Analog + Digital readout
- Tungsten absorber (3.5mm ~ $1X_0$)

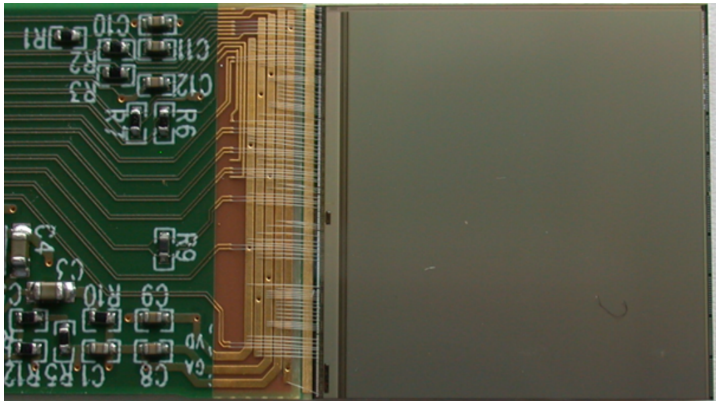
Prototype design

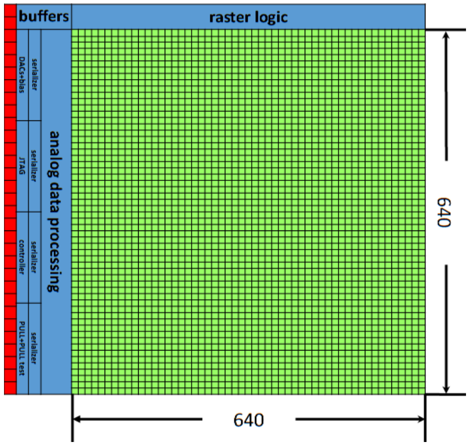
High granularity layers (HGL) need new technology, prototype built to perform generic R&D





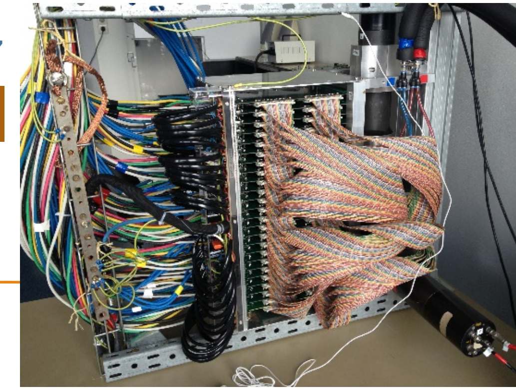
- 96 sensors
- 24 sampling layers
- 3 different types of sensors
- W : absorber + cooling
- 28 X_0 in total($0.97X_0$/layer)
- 11mm Molière radius





- MIMOSA-23 PHASE-2
- 640×640 pixels
- 1.92×1.92 cm^2
- 39M pixels in total
- 642μs readout time

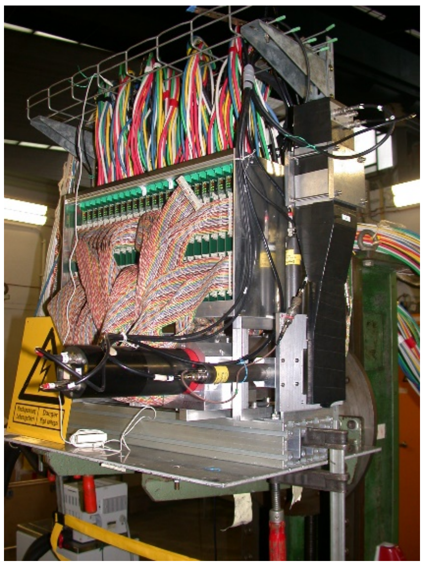
Beam tests



Utrecht 2014-2017

The Netherlands

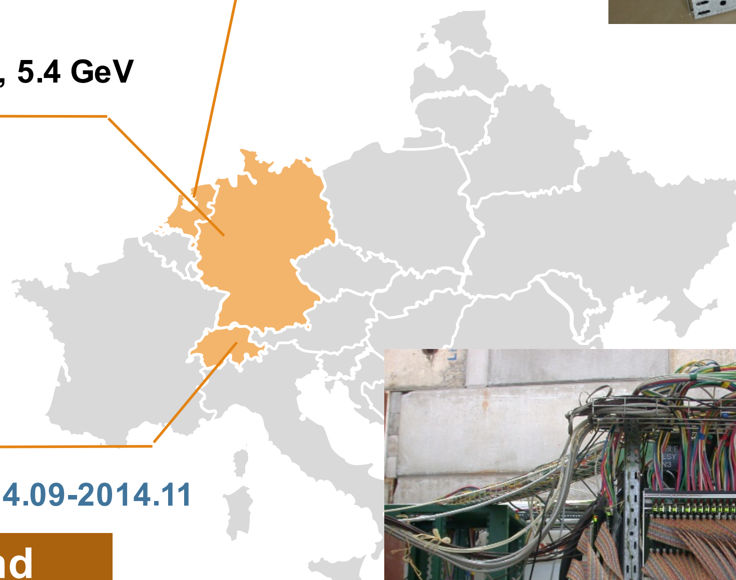
- μ
- Energy : continuous



DESY 2014.02-2014.03

Germany

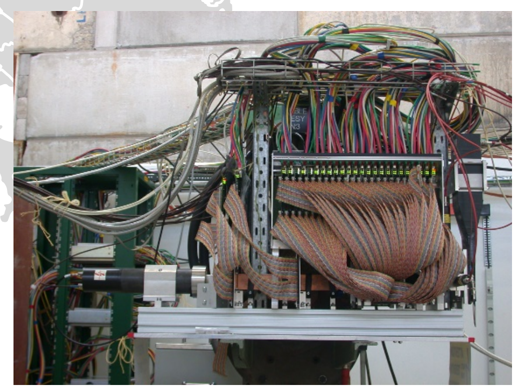
- e
- Energy : 2, 3, 4, 5.4 GeV



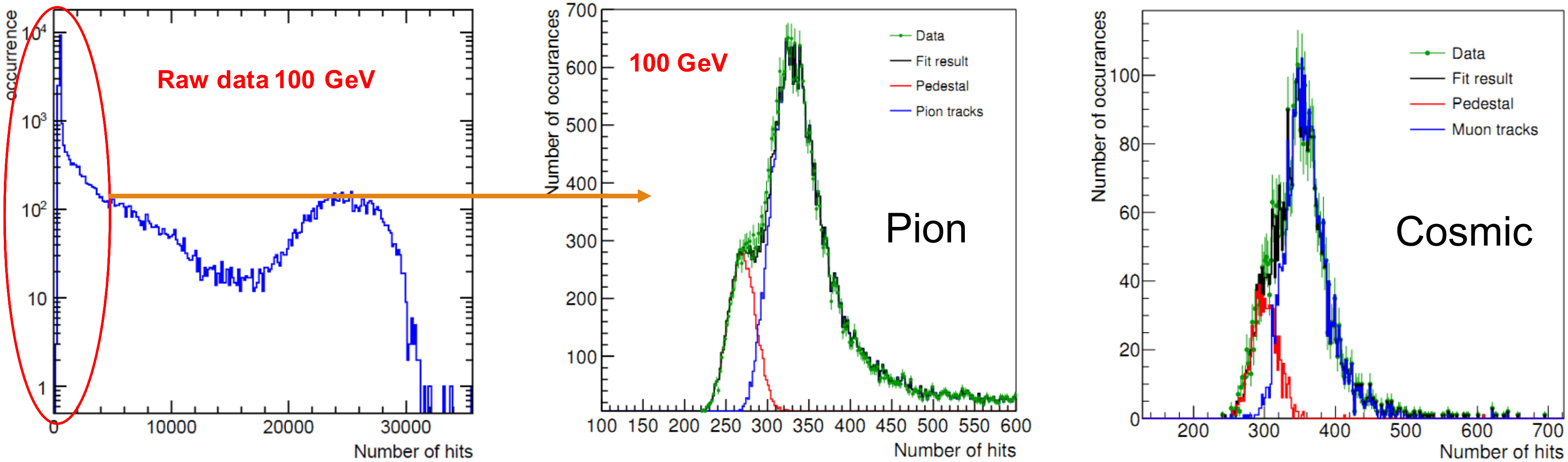
CERN 2014.09-2014.11

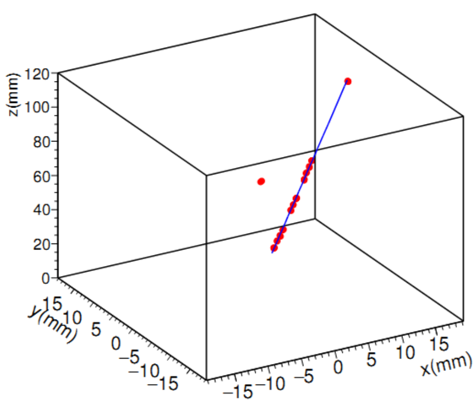
Switzerland

- e, π (Mixed)
- Energy : 30, 50, 100, 244 GeV

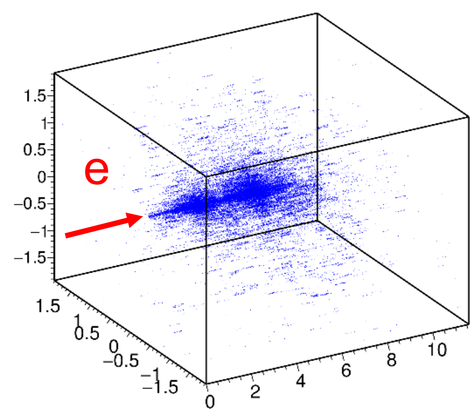


Event reconstruction and tracking





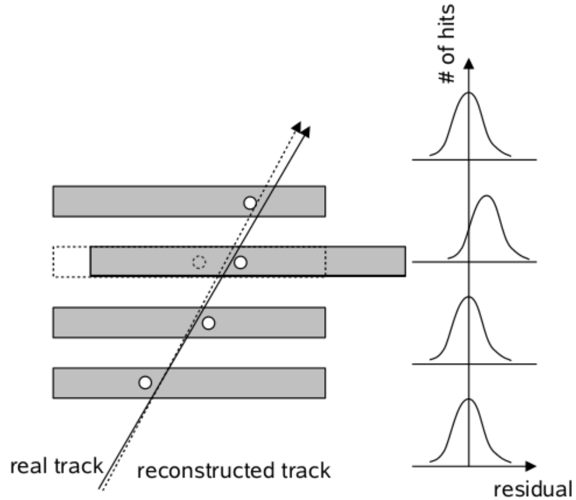
muon example



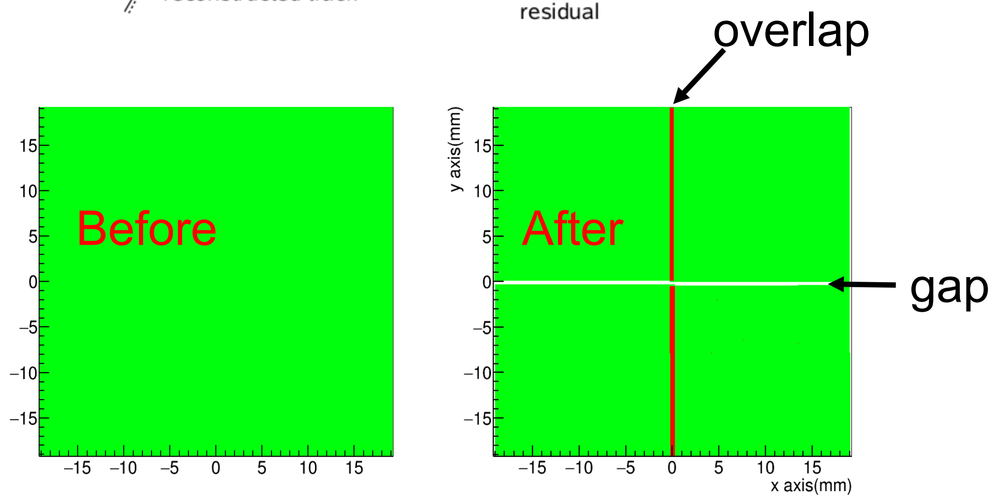
electron example

- Full 3D shower reconstruction
- Straight line model for MIP tracking
- MIP tracking efficiency up to 95%
  - Important for alignment
  - Beam inclination correction

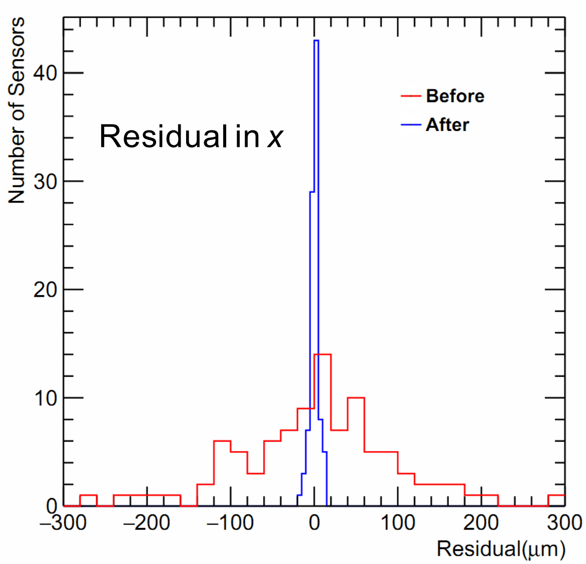
Alignment



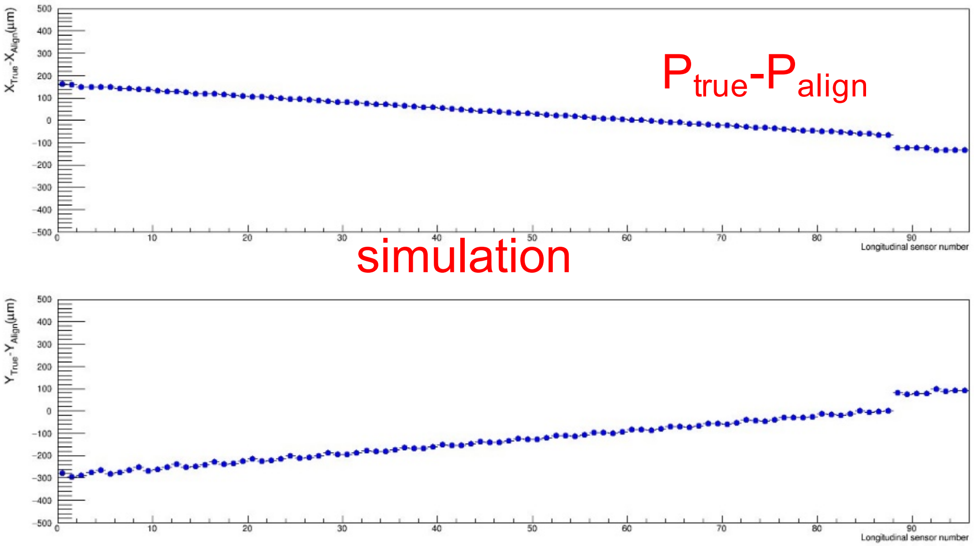
- alignment based on cosmic muon
- every sensor : 3 DoFs needs to be determined
- constrain weakly defined DoFs
- total DoFs : (3-1)×96 -2 = 283
- use π tracks as validation

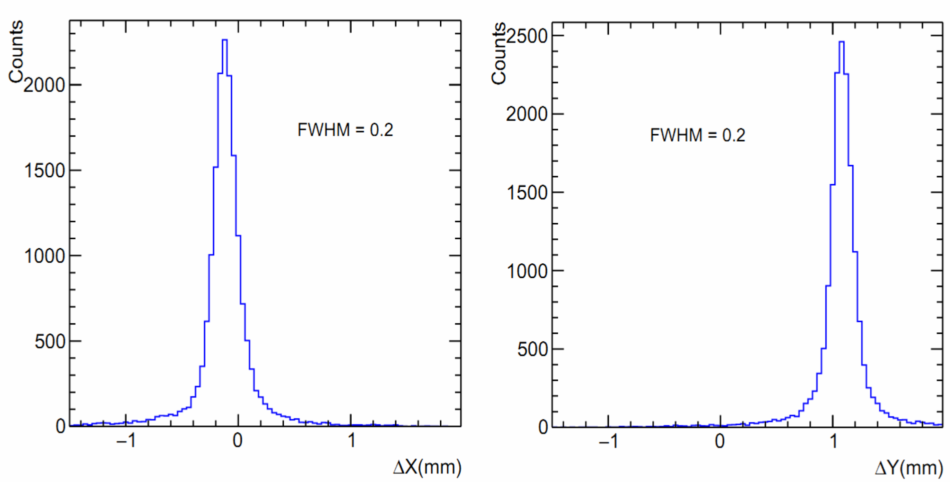


layer geometry



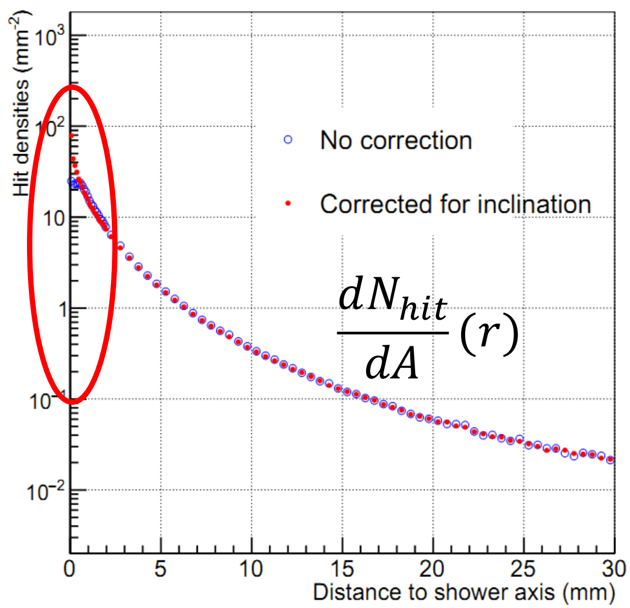
Inclination correction





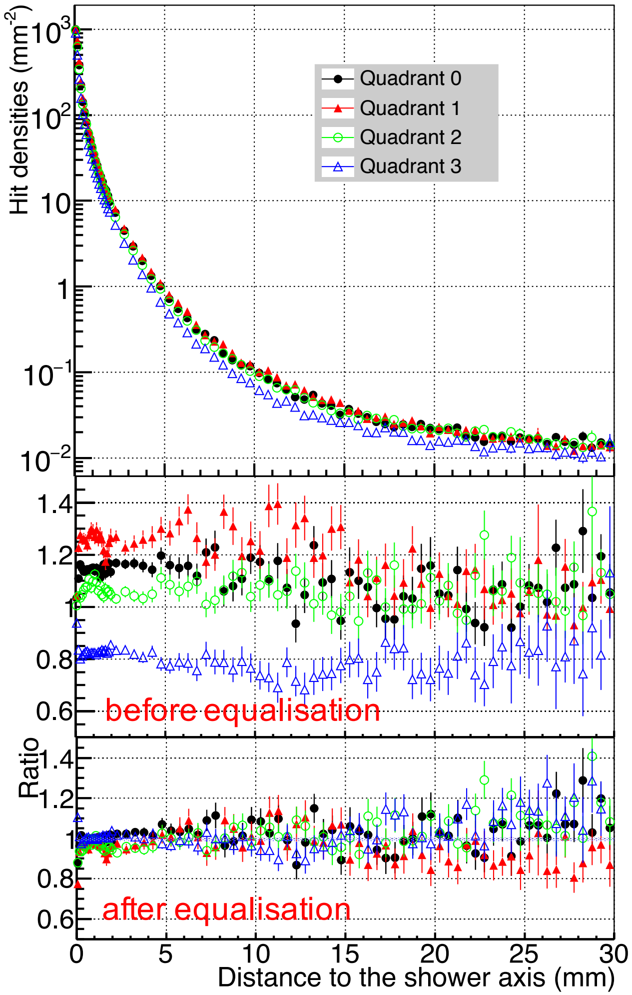
Apparent transverse shift of sensors with linear dependence on longitudinal position: most likely explained by relative inclination of the beam direction.

- Related to weakly defined DoF from alignment(no constrain on orientation of z direction).

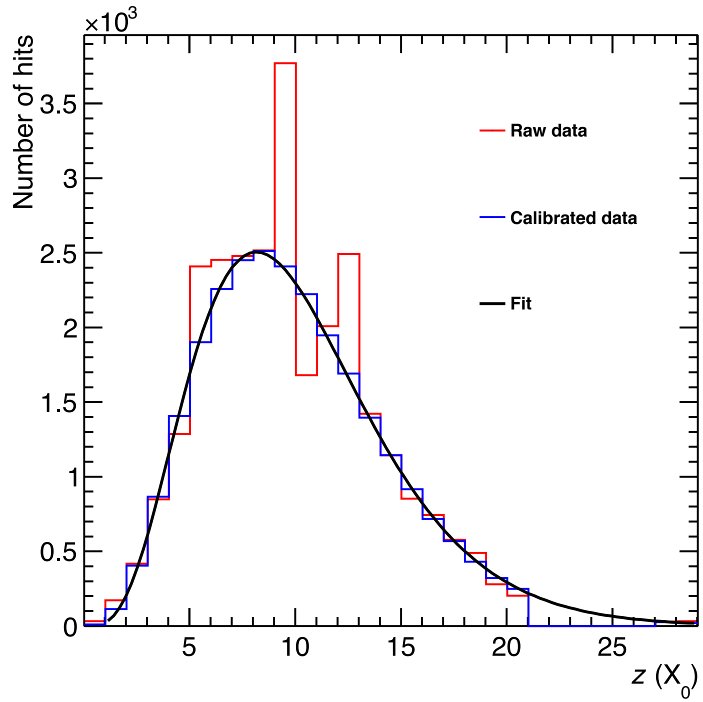


Calibration

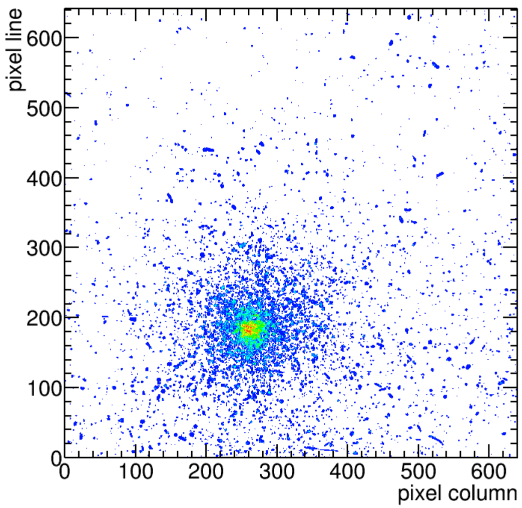
- calculate hit density in rings around shower center
- equalize response of the 4 sensors in each layer
- relative layer-to-layer calibration with gamma distribution

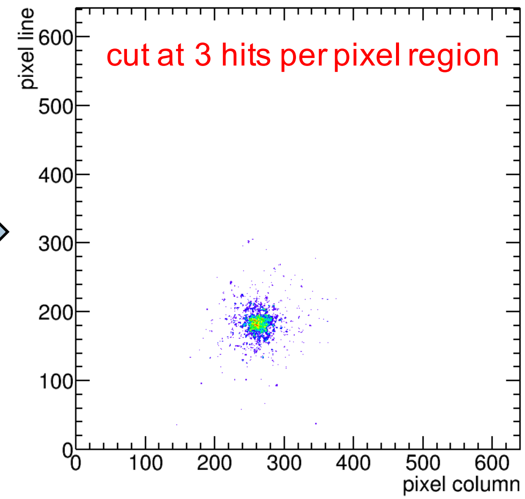


$$N(t) = N_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)} \; (t = x/X_0)$$



Shower center determination





$$X_c = \frac{\sum_i w_i^n x_i}{\sum_i w_i^n}$$

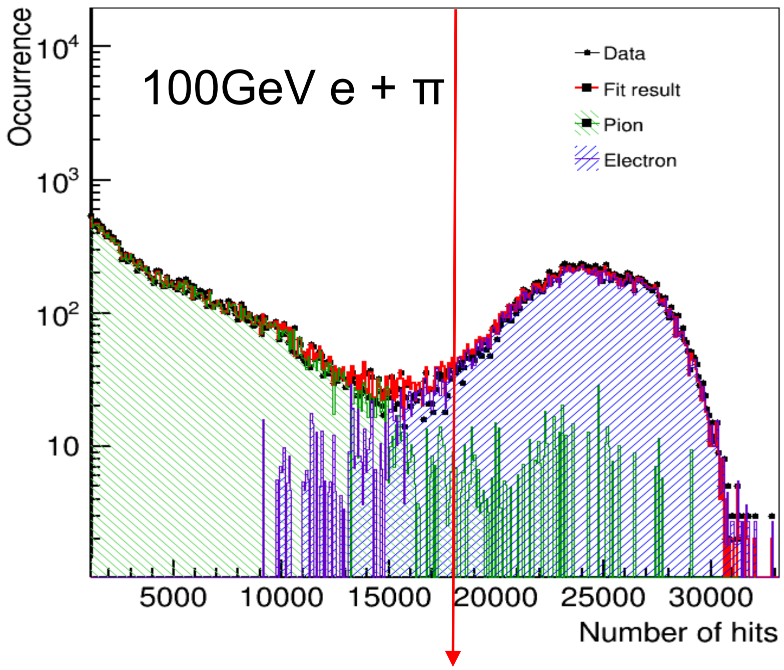
$$w_i = \sum_L R_{l,i}$$

$$(R_{l,i} = 0 \; or \; 1)$$

- Use information of all good layers to reconstruct the shower center.
- Refine the shower core region by setting cut on amplitude in pixel region.
- Use power law weight to make shower core region more significant.

Event selection and pion contamination

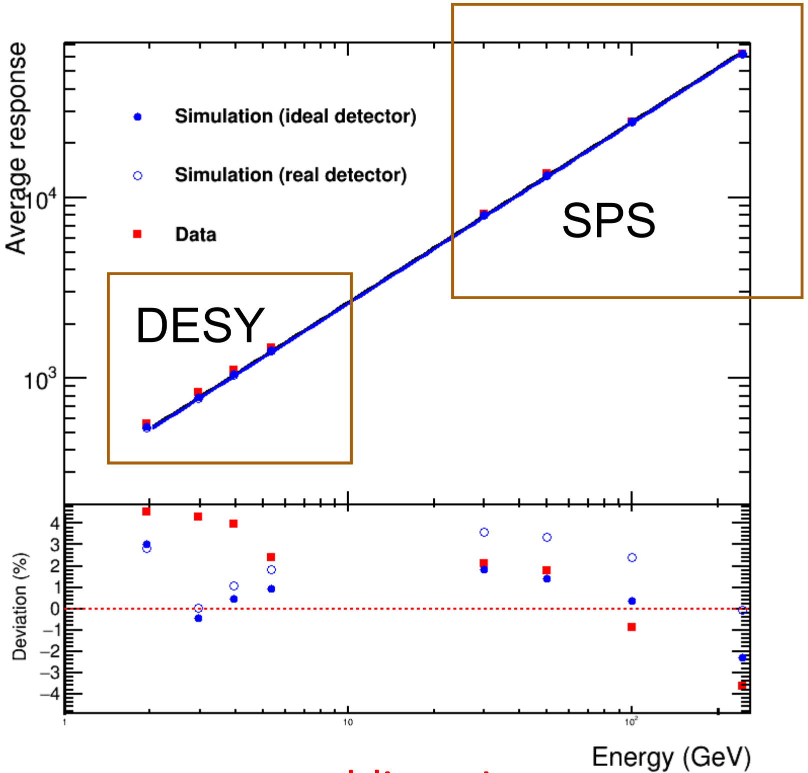
- Electron event selection
  - Shower center selection
    - $-1.5 < x_c, y_c < 1.5$ cm
  - Cut on number of hits (reject pions)
    - Contamination negligible in test beam data(~1%)
  - Exclude gap and overlap
- e/π separation power of FoCal (Simulation)
  - Pion rejection better than 90% in broad range of energy
    - Using cut on shower start point
  - Considering other separation methods (lateral information) to achieve higher separation power

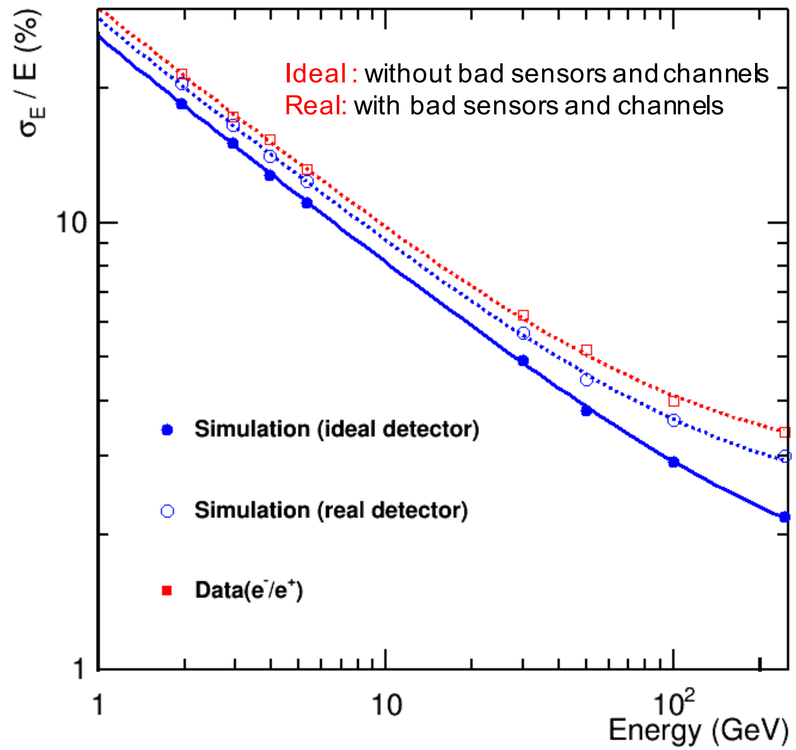


electron cut at 18000, pion contamination 1%~2%

Results

Linearity & Energy Resolution





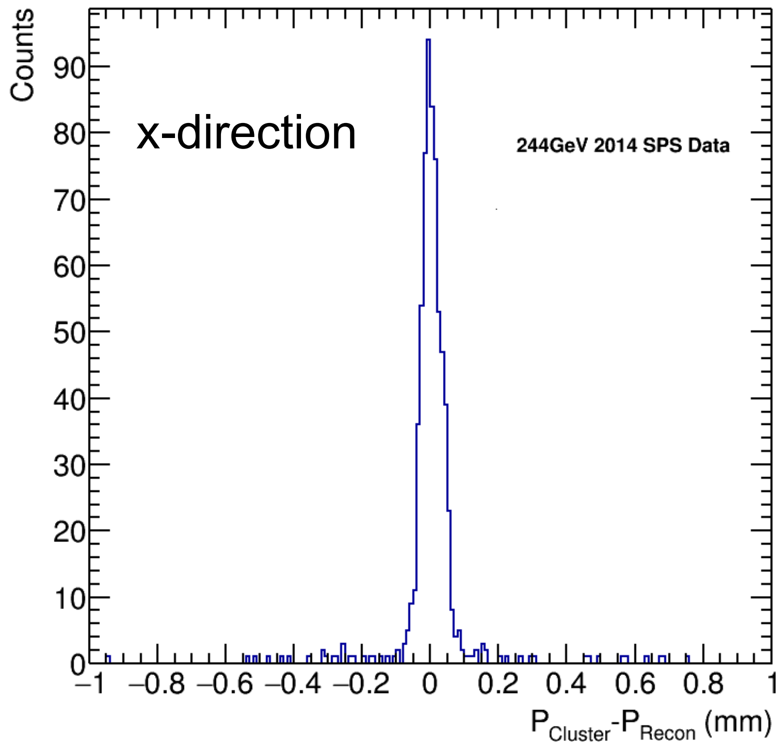
good linearity

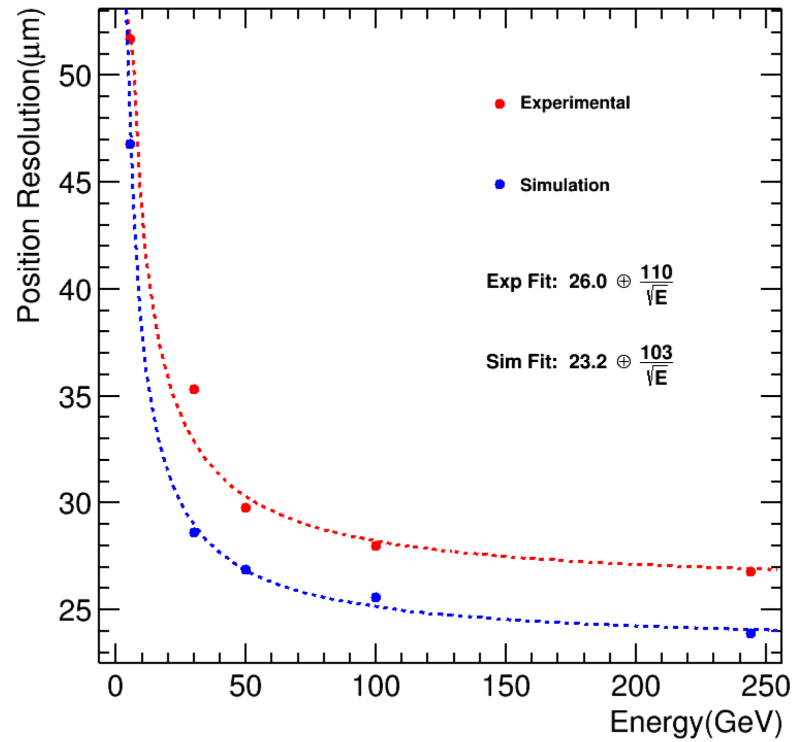
Note: different settings of detector for DESY and SPS data sets

reasonably good energy resolution (within 0.5% discrepancy between Data and MC)

Results

Position Resolution



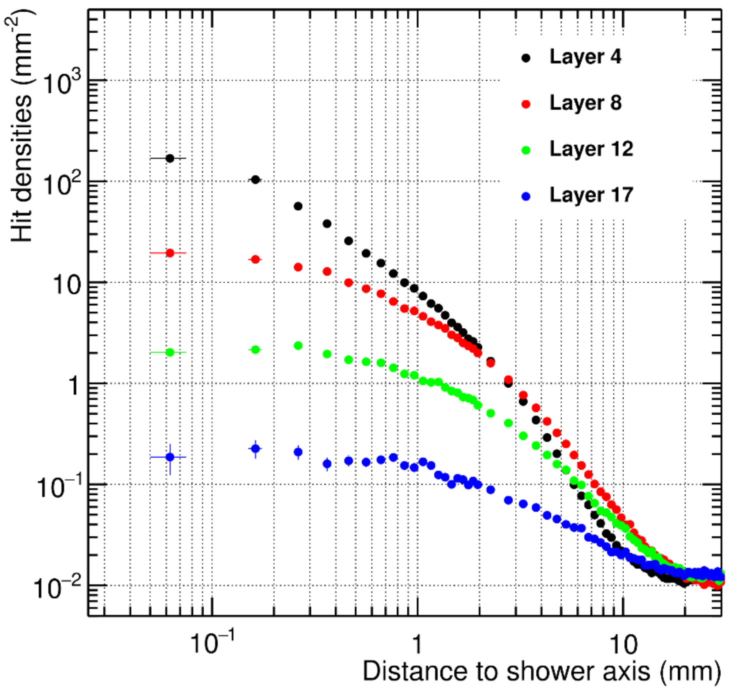


- Use clusters in layer 0 as true position.
- Sigma of the distribution is the shower position resolution.

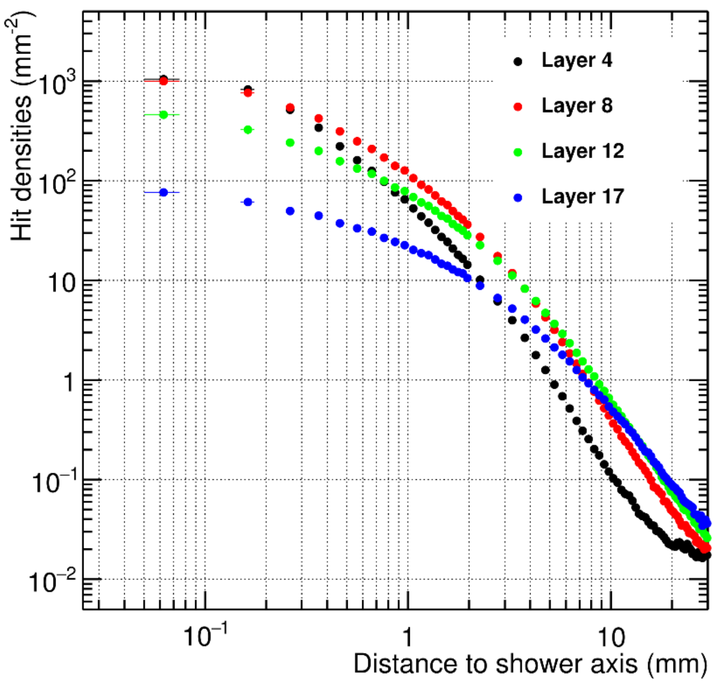
Results

Lateral Profile

5GeV



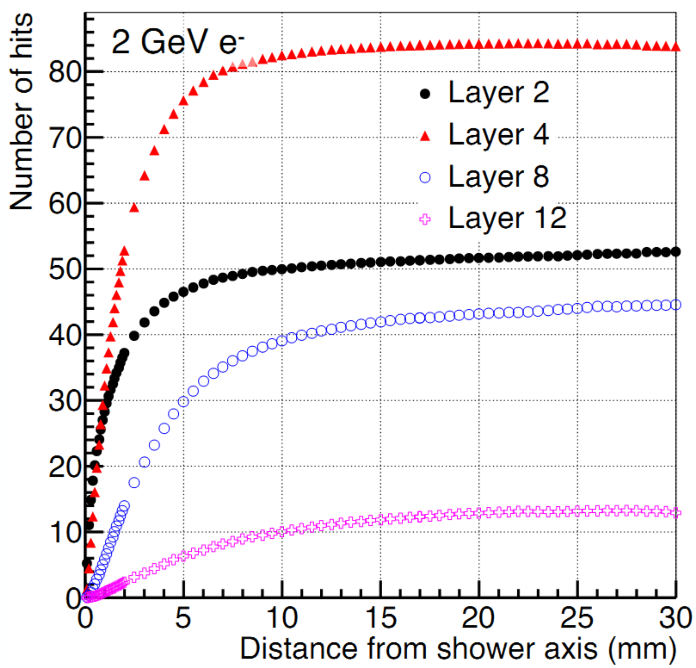
100GeV

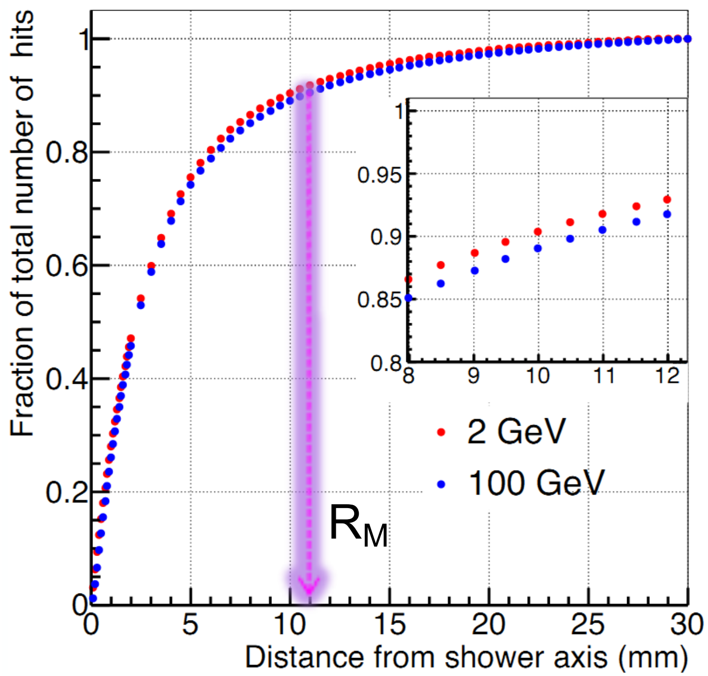


- Average hits densities as a function of distance to shower center.
- Shows unprecedented detail of shower profile
  - — Unique feature of the detector

Results

Measured Moliere Radius from Cumulative Distributions

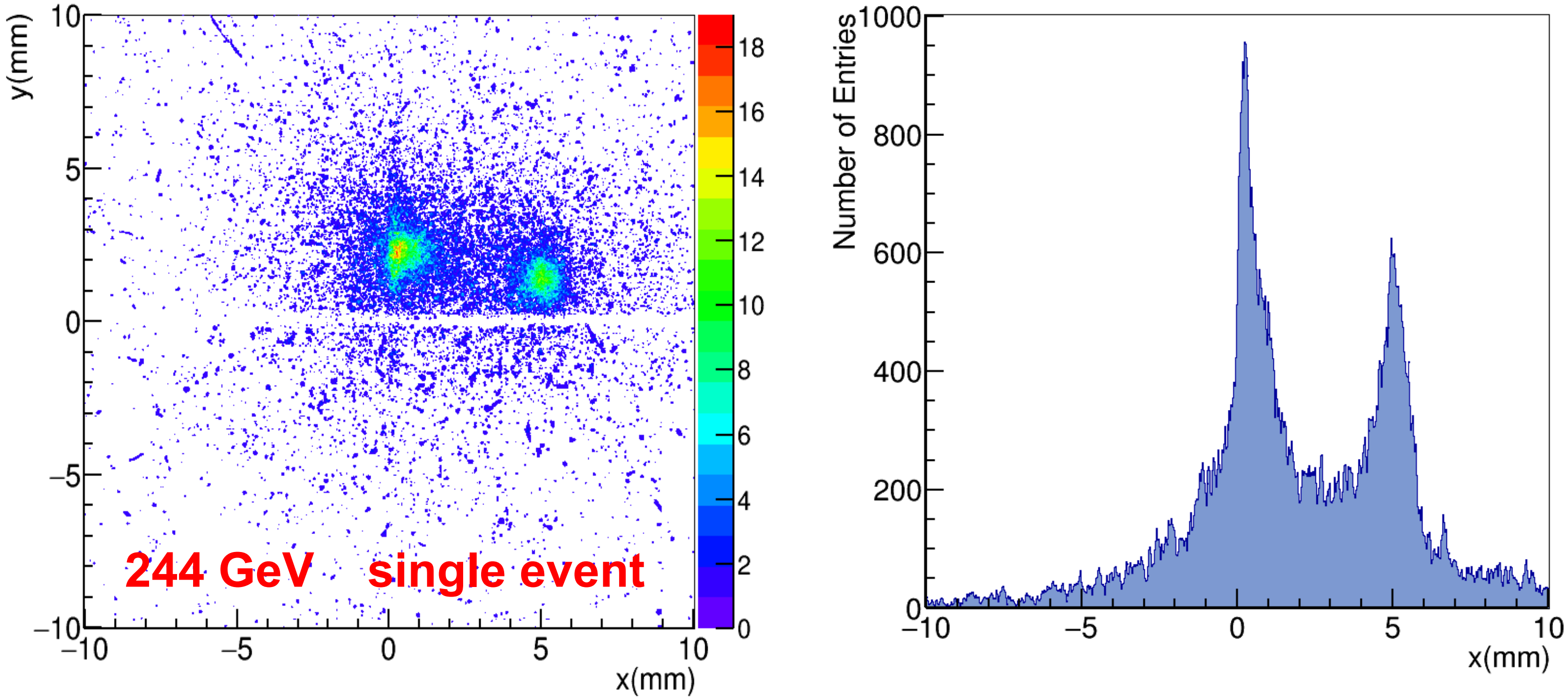




- Integral of the lateral profile
- Measured Molière radius is around 11 mm.

Results

Two-Shower Separation



- Good separation power of two close showers down to few mm

Conclusion

Successful proof of principle of particle counting calorimetry.

- A high granularity digital Si-W calorimeter prototype for FoCal has been built and tested.
- Good linearity and reasonable energy resolution have been achieved.
- Provide capability of e/π separation in broad range of energies.

Extremely high granularity allows unique measurements.

- Small Molière radius (11mm).
- Lateral shower profiles down to few percent Molière radius have been obtained.
- Down to the pixel level(~µm) position resolution was reached.
- Excellent two-shower separation power.

Thank you

Back-up

Analysis overview

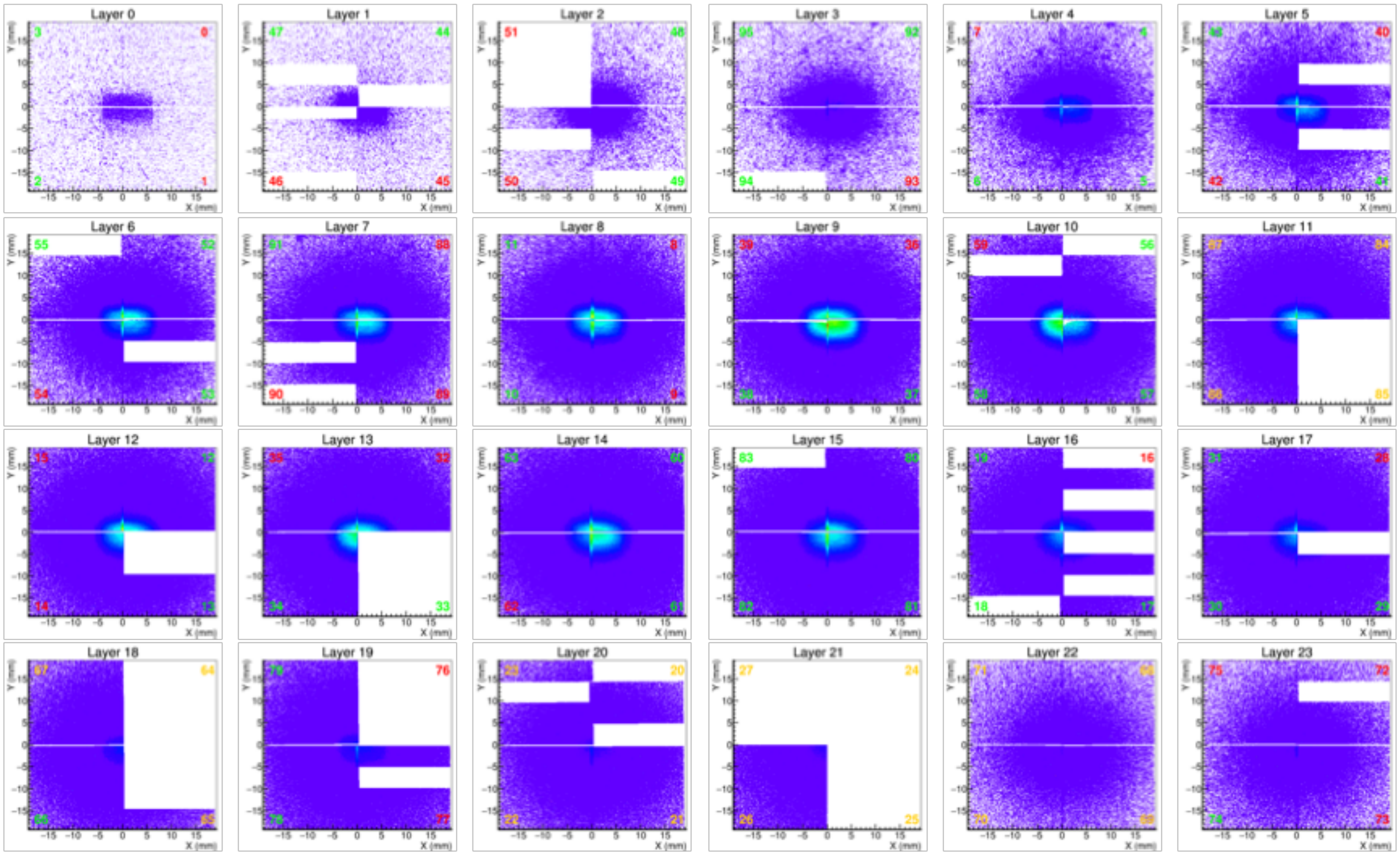
Track data(muon + pion)

- Particle tracking(muon, pion)
- Alignment based on track residual
- Inclination correction
- MIP calibration (not in this presentation)

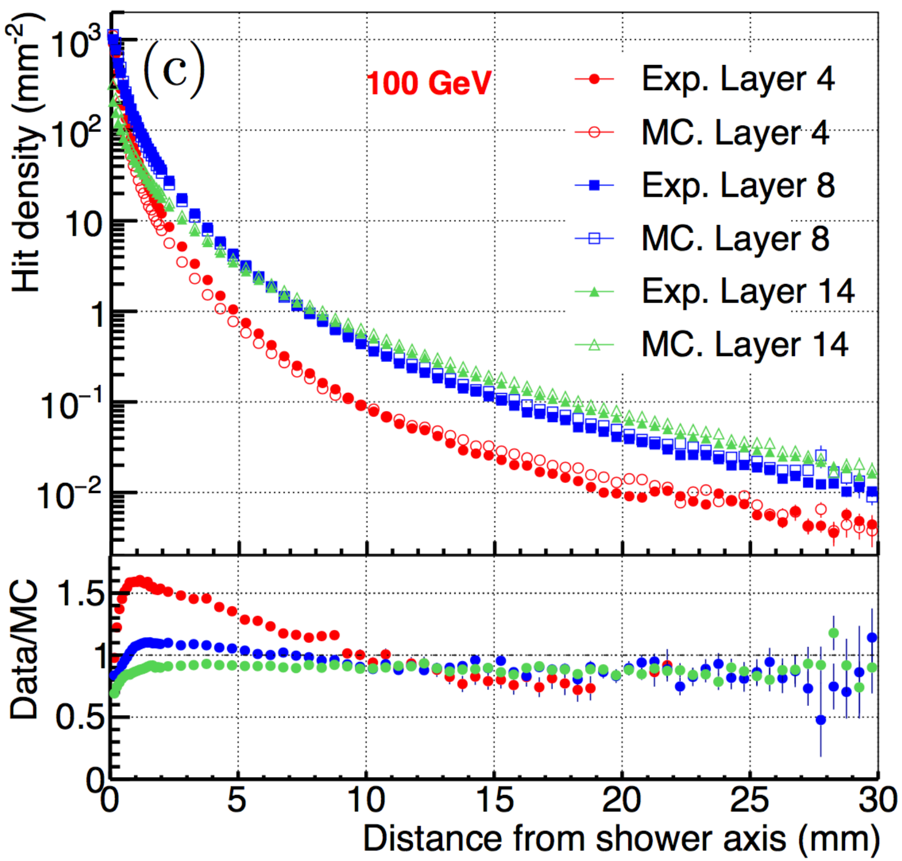
Electron data

- Shower reconstruction
- Shower center determination
- Sensor sensitivity calibration
- Detector performance results

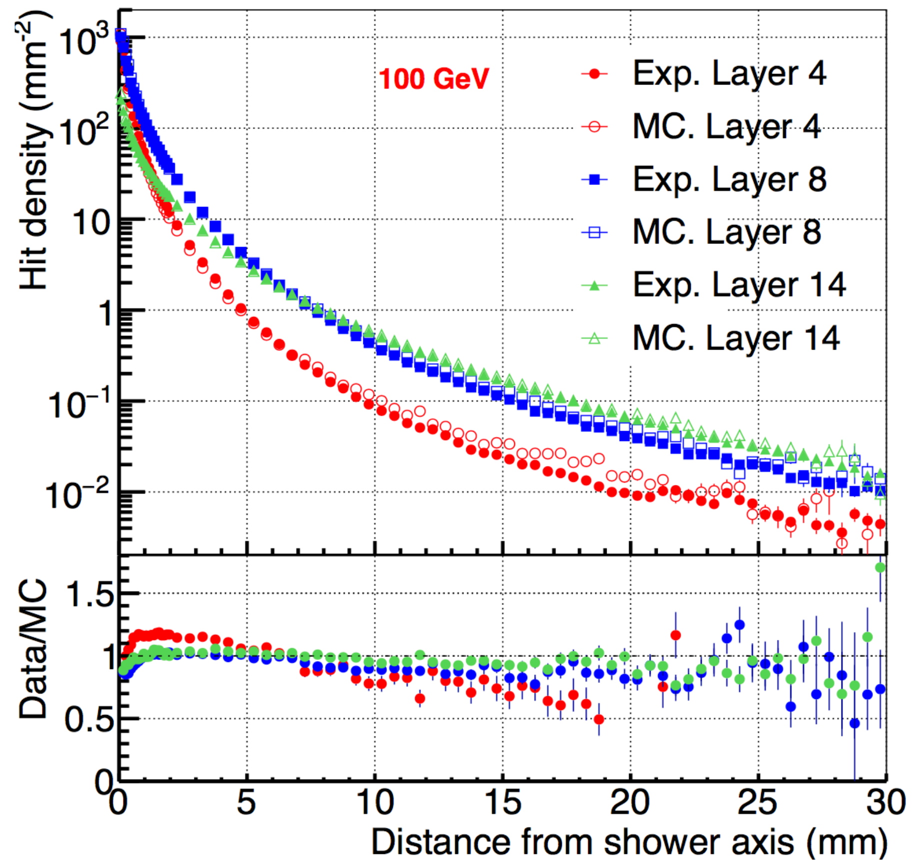
Transverse hits distribution for 244 GeV



Data vs MC



Discrepancy : up to 20%



Add 2mm W in front(= 0.7X_0)