Response of MAPS ECAL from Testbeam

Hiroki Yokoyama
Nikhef/Utrecht University

CALICE collaboration meeting
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Digital Pixel Calorimeter

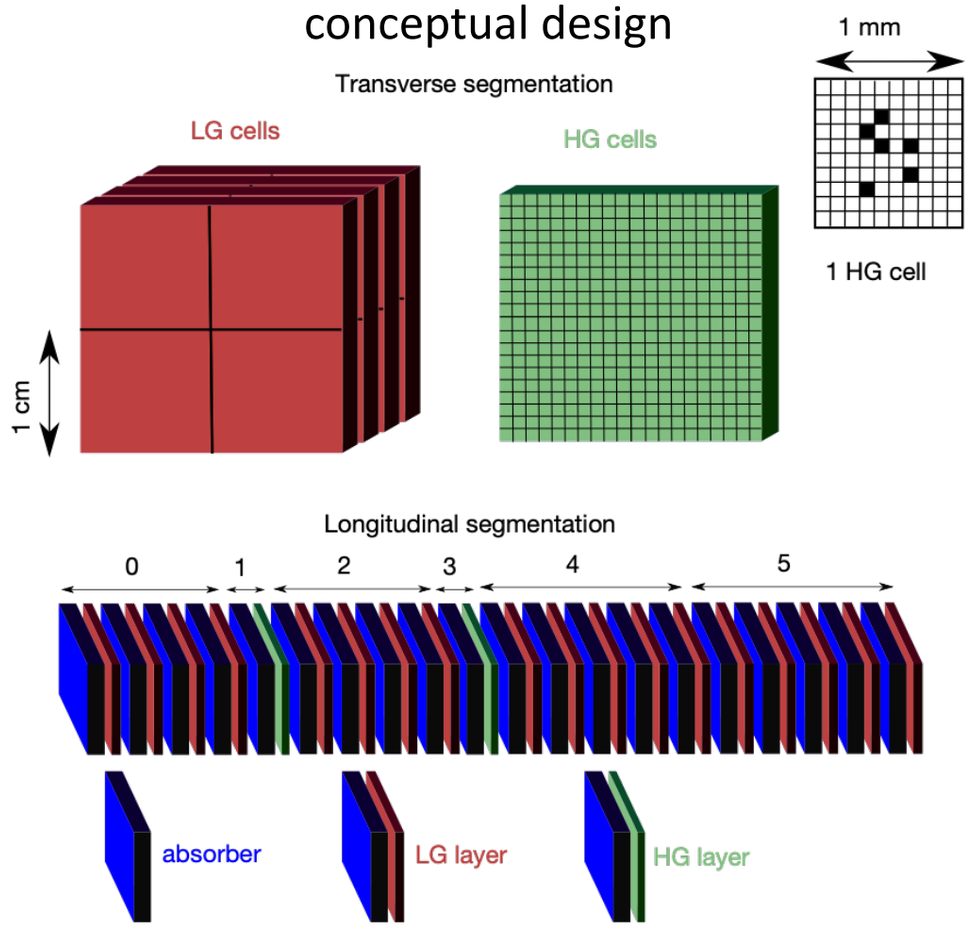
- **FoCal-E (Forward EM-Calorimeter) in ALICE**
  - W absorber (X_0~3.5 mm) + Si-sensors
  - **Low-granularity layers**
    - Si-pads (~1x1 cm²) energy measurement
  - **High-granularity layers**
    - CMOS MAPS (~30x30 μm²) two-shower separation

- **Digital Pixel Calorimeter**
  - all layers consist of high-granularity MAPS sensors
  - number of pixels above threshold in proportion to deposited energy
  - good position resolution
  - 3D shower shape measurement

digital calorimeter with very small pixels

- **discriminate π^0/γ at high energy**
  - separate photon pairs with < 5 mm
  - small Molière radius and high-granularity

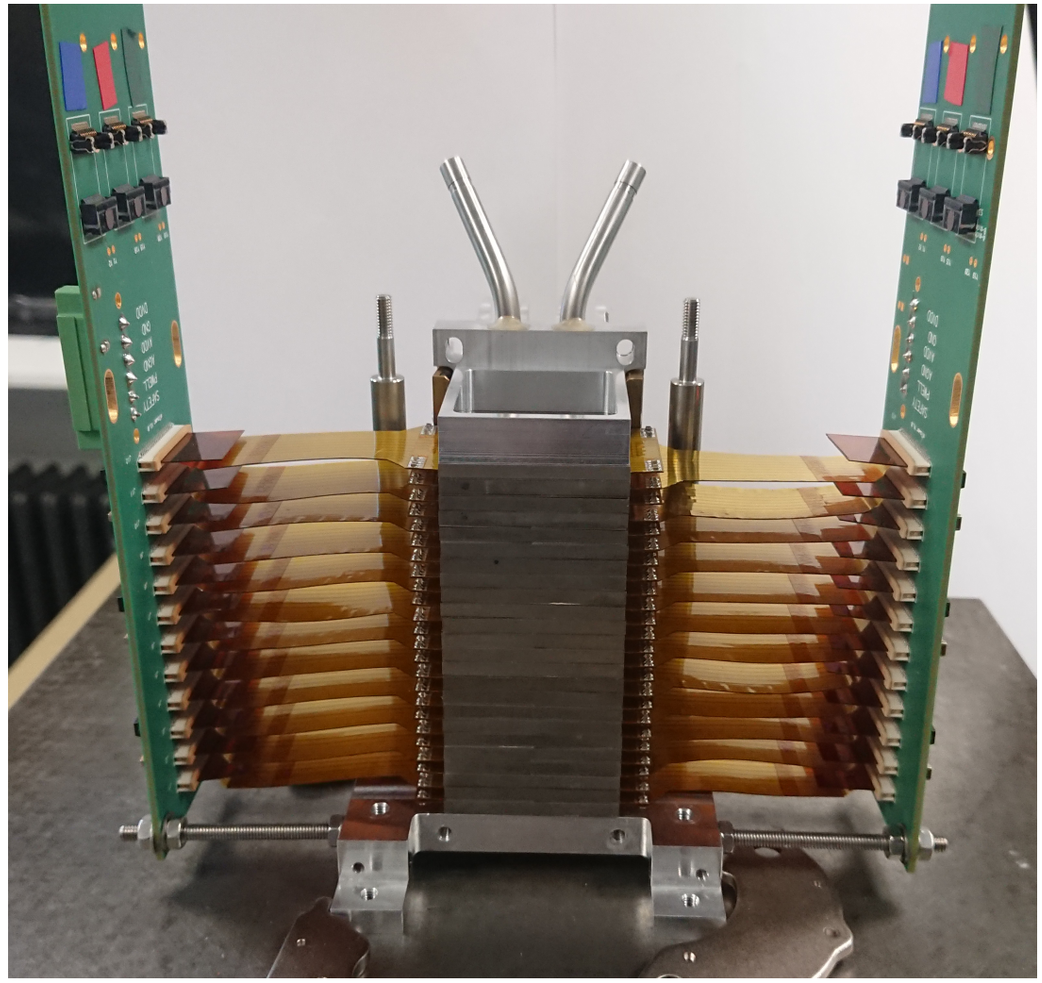
FoCal-E (electromagnetic) conceptual design

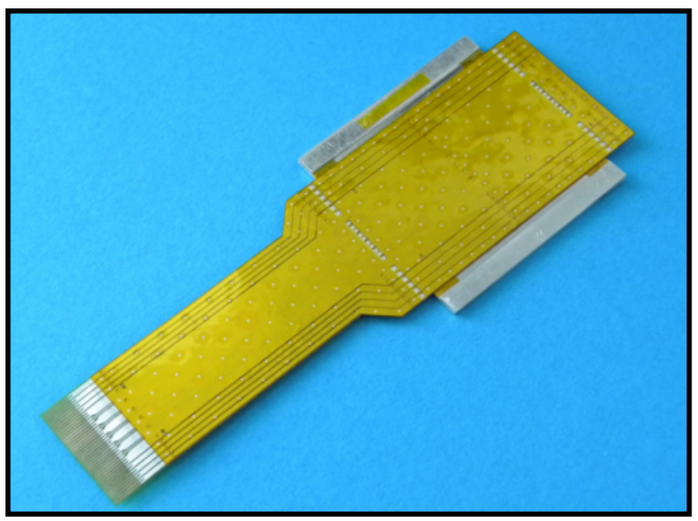


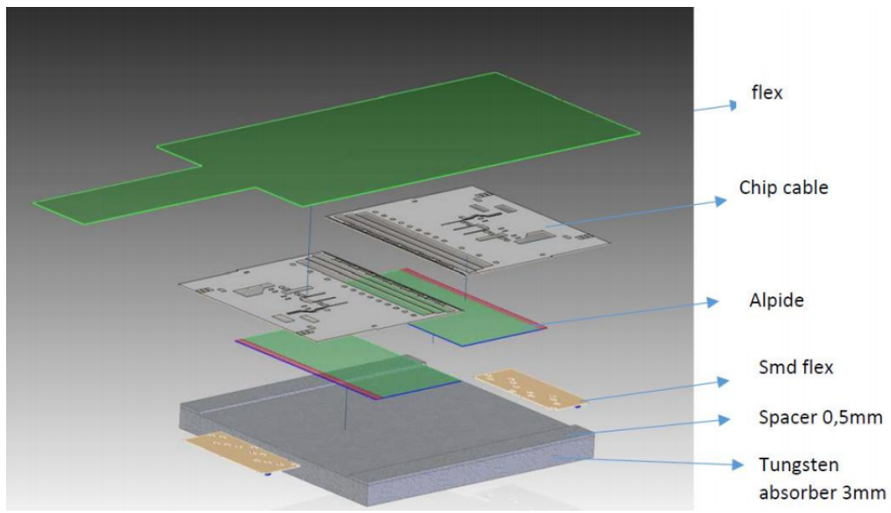
EPICAL-2 (Electromagnetic PIxel CALorimeter prototype-2)

- **New digital pixel calorimeter prototype**
  - small digital calorimeter (3x3 cm^2 cross section)
  - 24 layers with each
    - 2 ALPIDE CMOS MAPS
    - 3 mm W absorber

- **ALPIDE MAPS sensor**
  - developed for the new ALICE ITS
  - Chip size: 30 mm x 15 mm
  - Pixel matrix: 1024 x 512 (~500k pixels / chip)
  - Pixel size: 29.24 µm x 26.88 µm







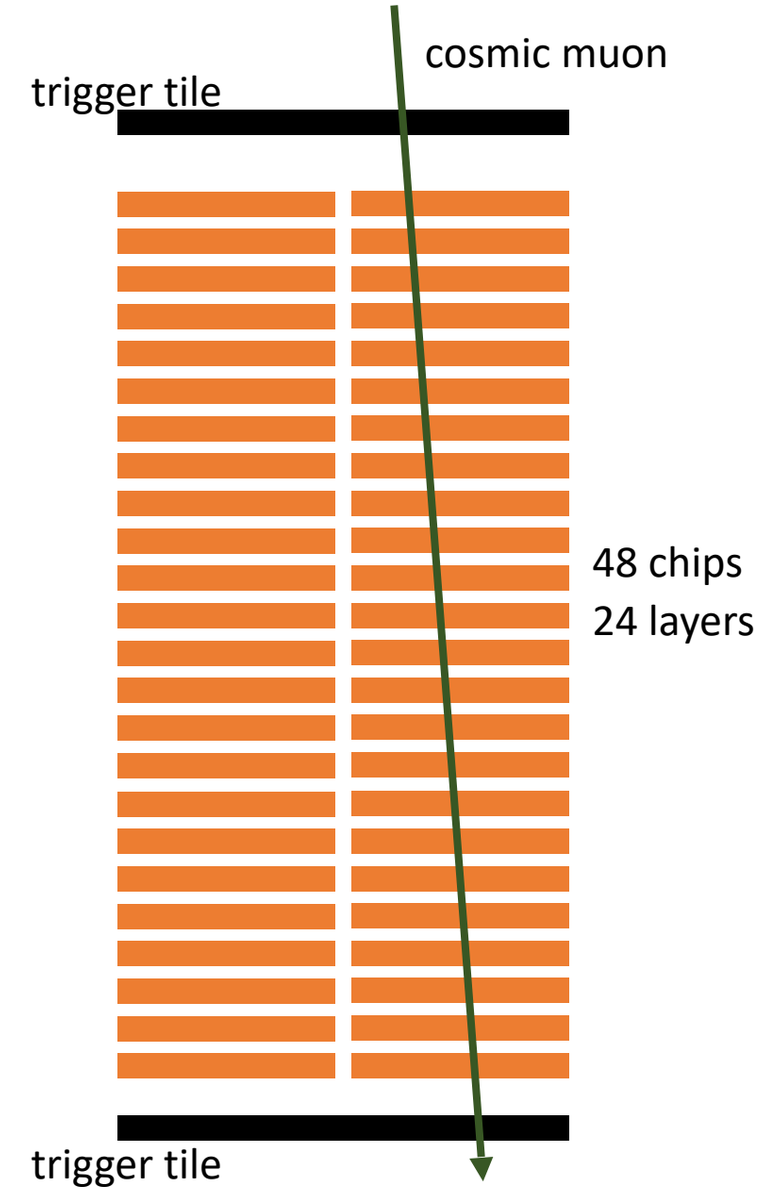
Data Taking Setup

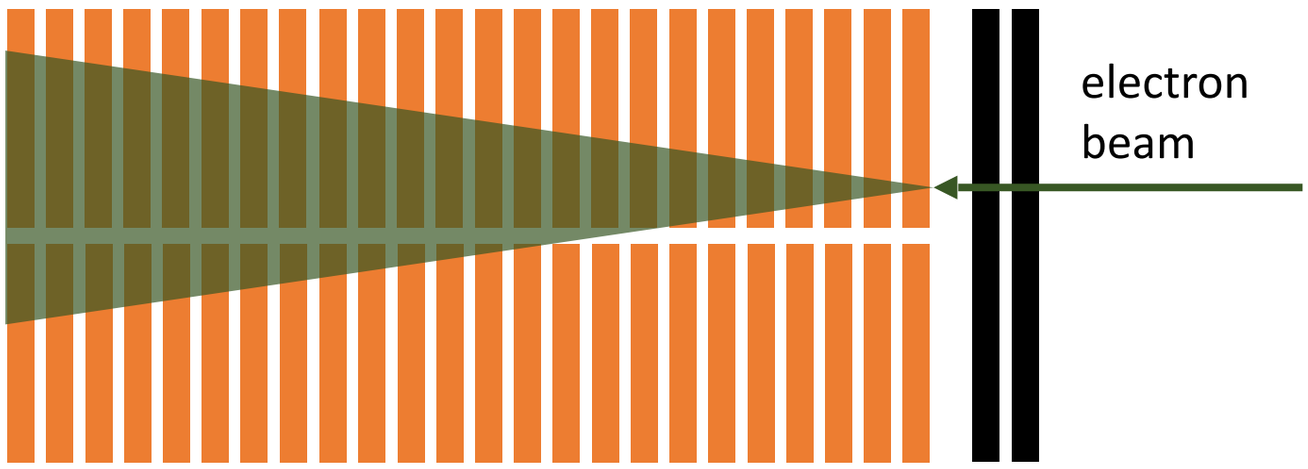
- ☑ **Cosmic muons**
  - ~6 months in 2020 at Utrecht University
  - non-showering, well-defined track
  - uniform energy deposition over all layers
  - total ~9000 events

  → **alignment, calibration**

- ☑ **Electron Test Beam**
  - February 2020 at DESY TB22
  - **electron** (positron) beam
  - beam energies:
    1.0, 2.0, 3.0, 4.0, 5.0 and 5.8 GeV
  - detector temperatures:
    20°C, 25°C and 30°C
  - total: ~44 million events

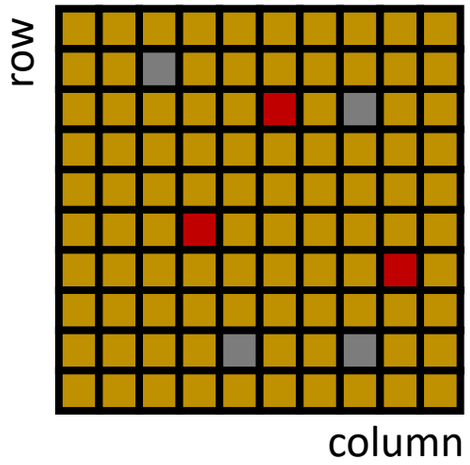
  → **energy linearity, energy resolution, shower profiles**



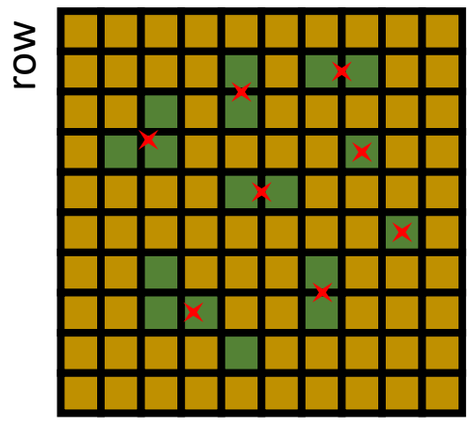


Analysis Setup

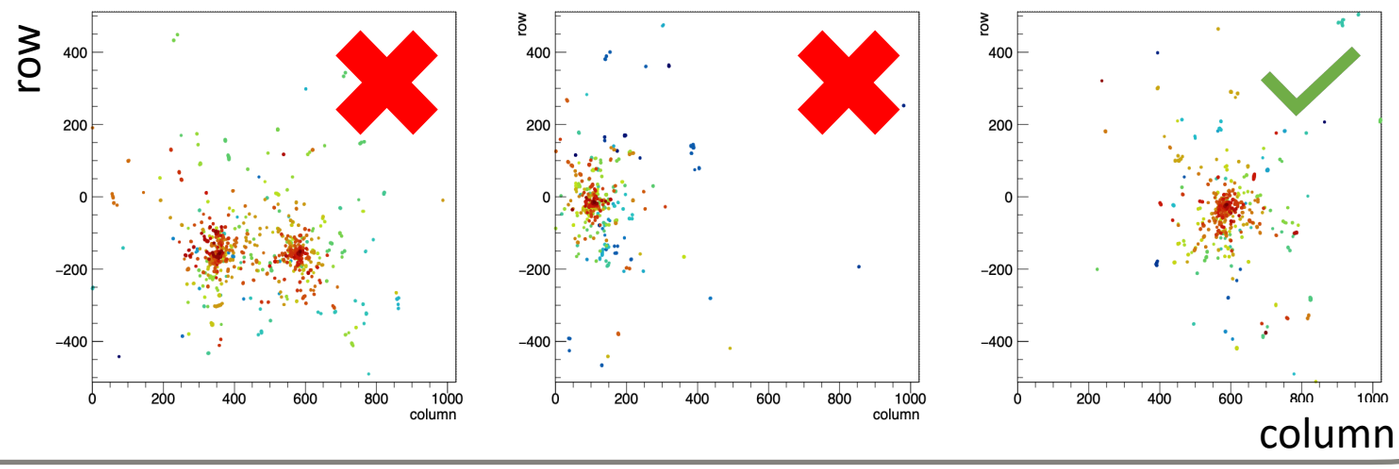
- **Pixel masking**
  - noisy and dead pixel removal
    - chip classification from serial testing
    - pedestal runs
    - beam runs



- **Clustering**
  - pixel hits -> cluster
  - DBSCAN algorithm
  - cluster comprised of adjacent hit pixels (eight neighbors)



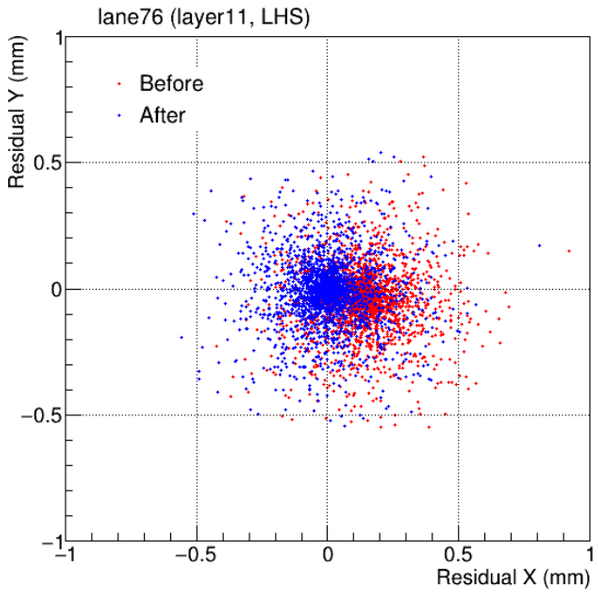
- **Event selection**
  - single particles
  - minimal lateral leakage

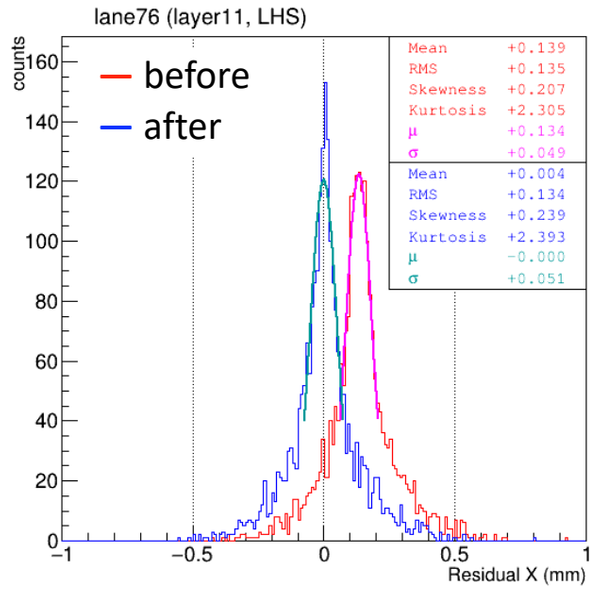


Chip Alignment

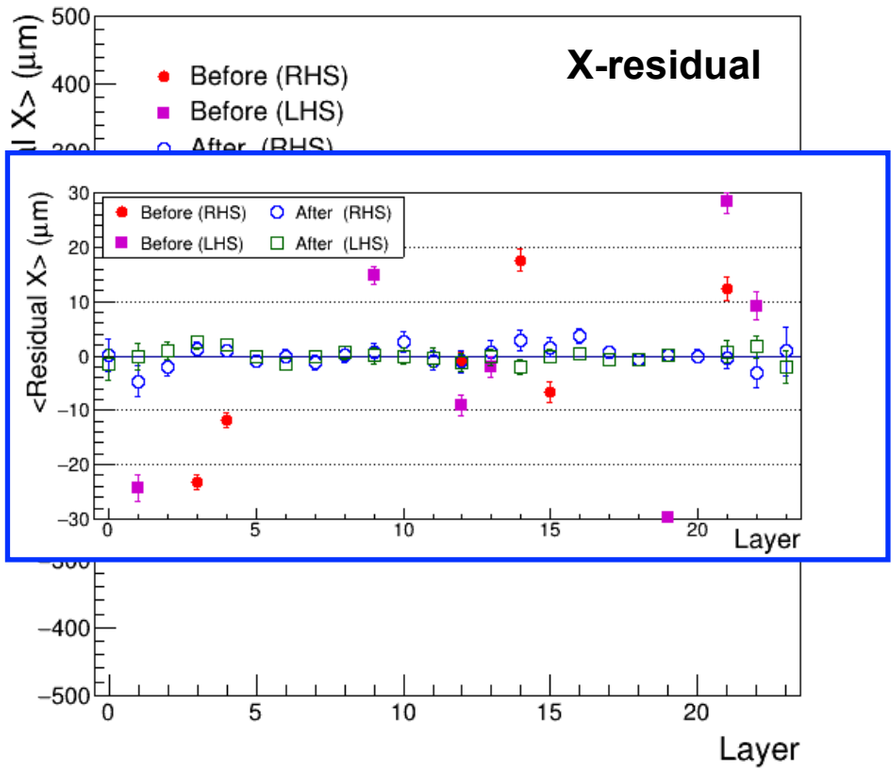
- ☑ longitudinal position fixed
- ☑ three parameters for lateral position
  - parallel shift: Δx, Δy
  - rotation around z-axis: Δθ
- ☑ 3D track fitting + χ^2 minimization approach

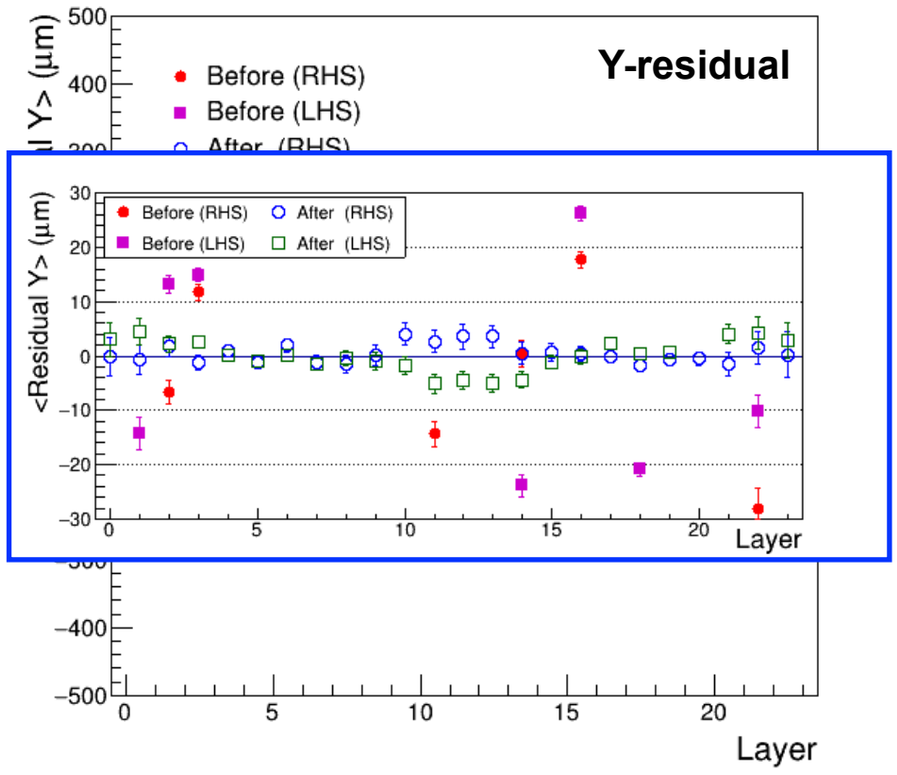
→ alignment precision better than 10 µm





LHS RHS
before
after

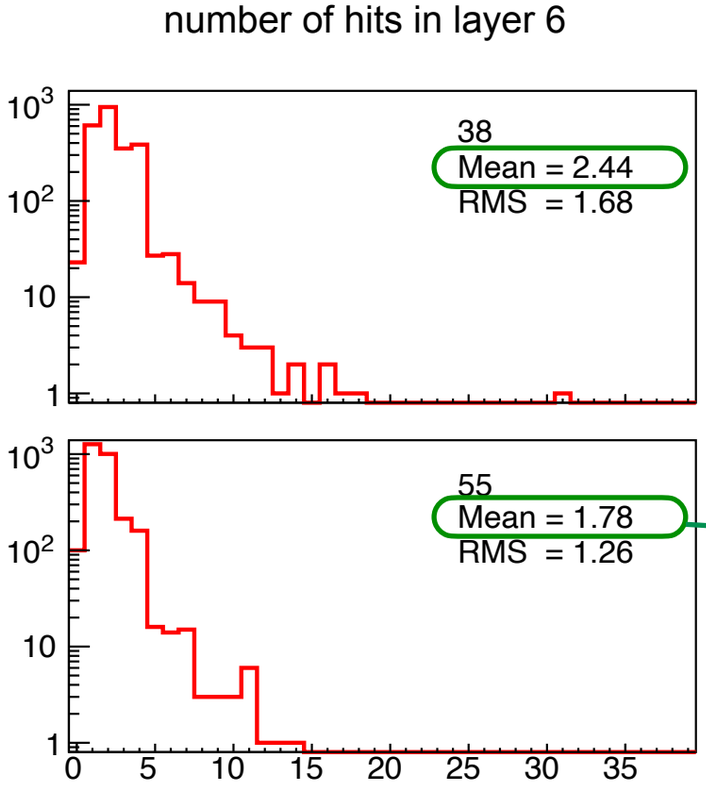


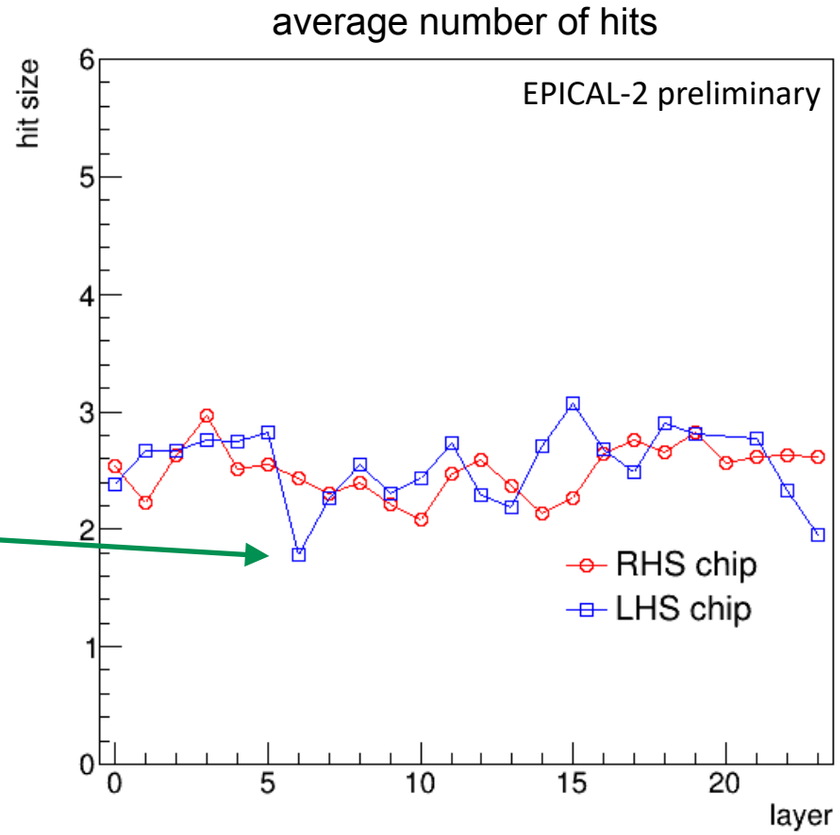


residual = cluster position - track fit

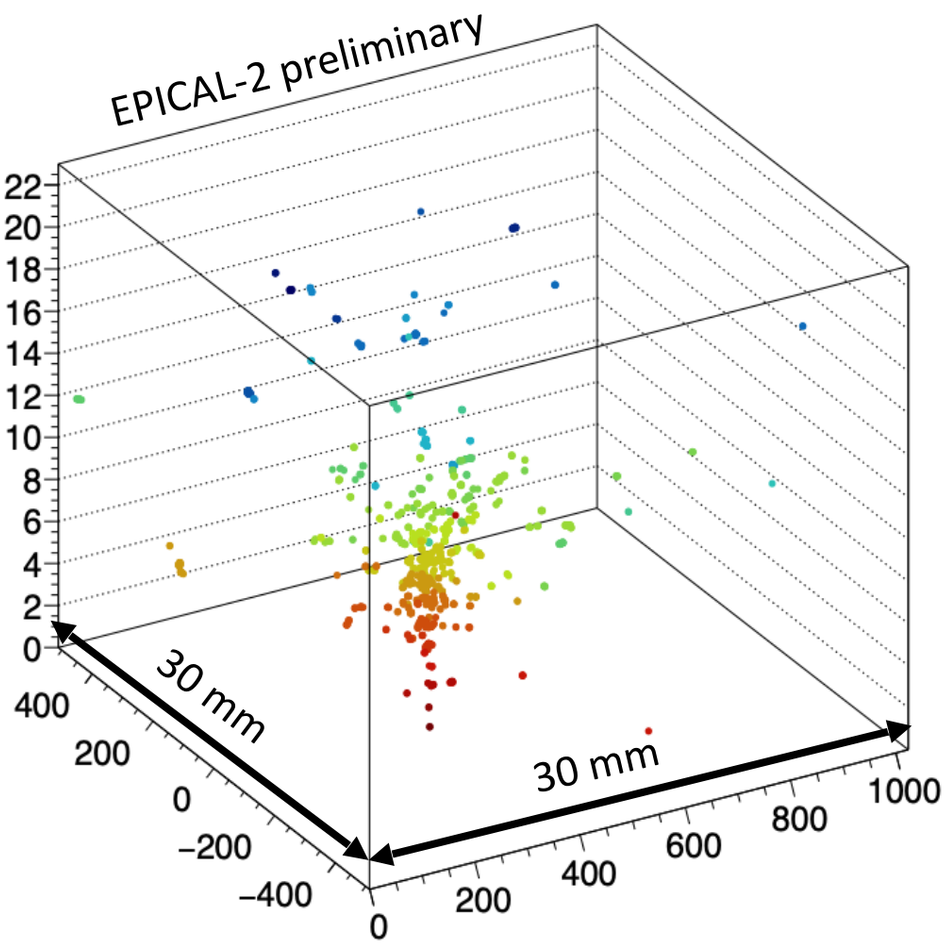
Energy Calibration

- assumption:
  - uniform energy deposition over all layers
- average number of hits per chip
  - calibration parameter of chip responses

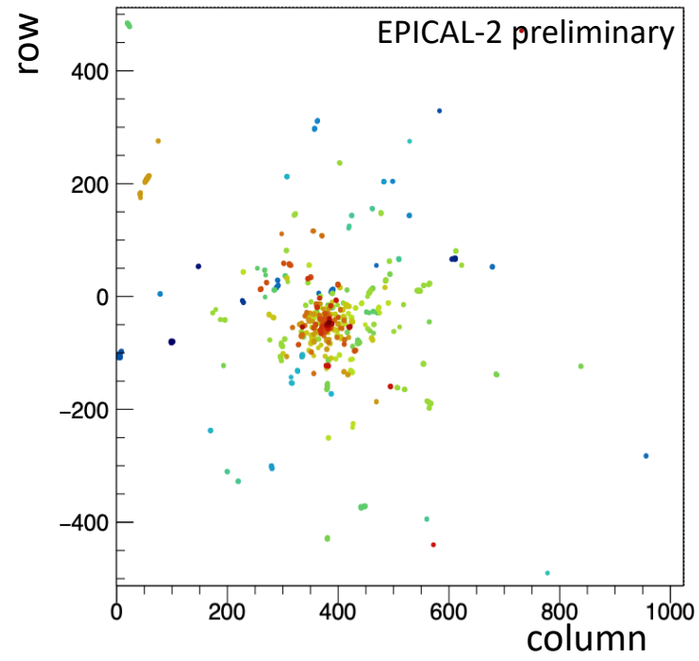


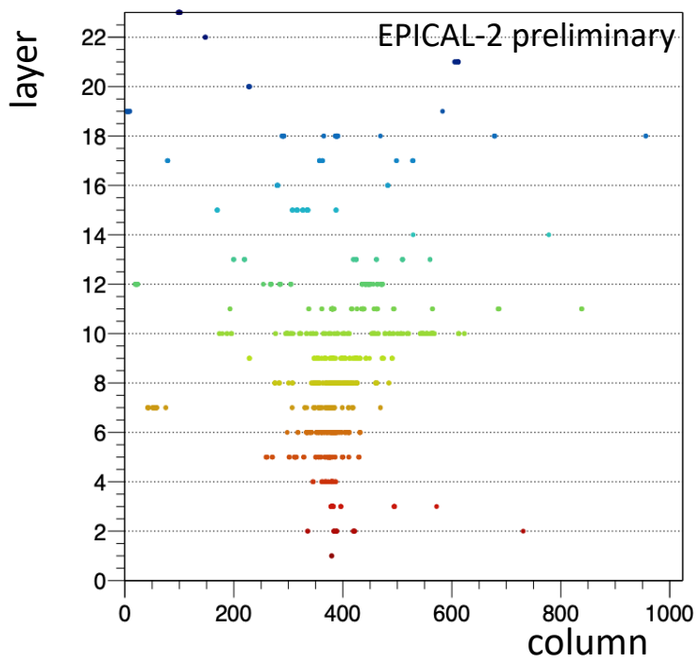


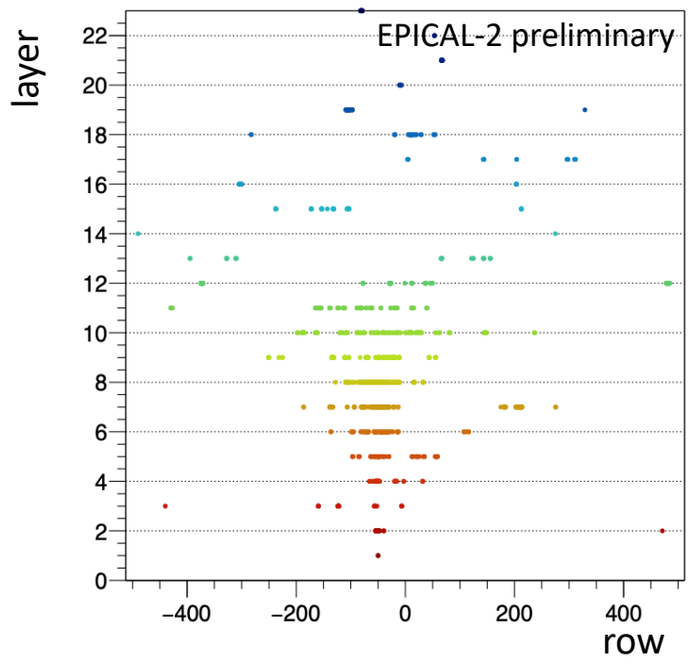
Event Display



one-electron event
5 GeV
raw data







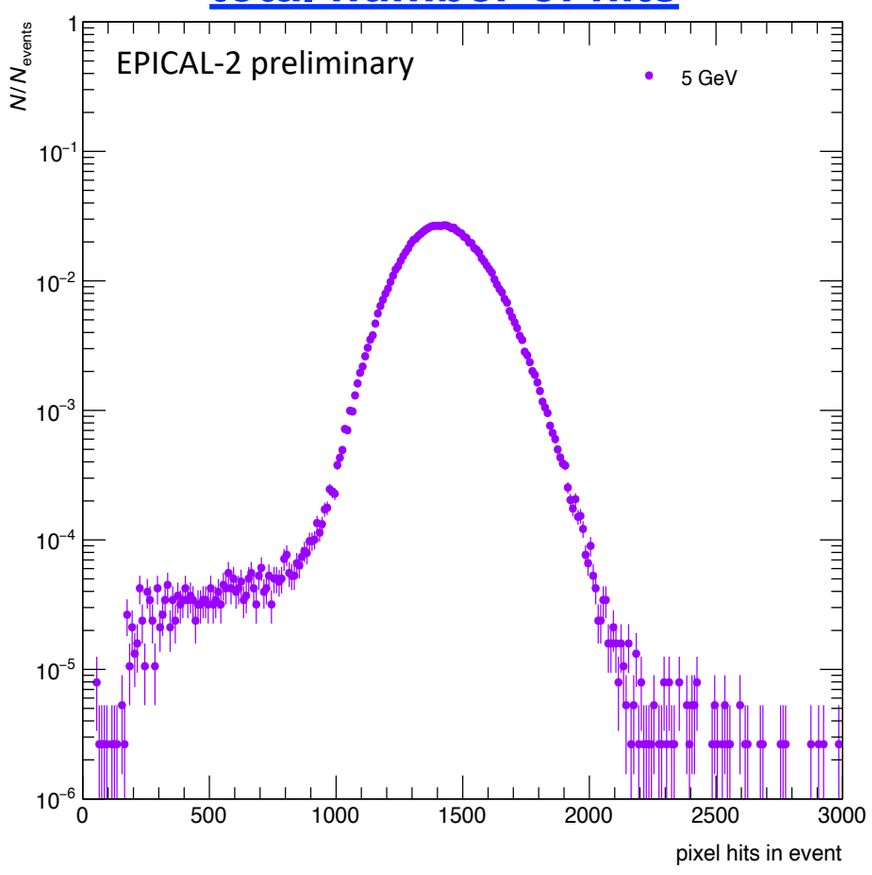
→ **detailed evolution of shower**

color coding: layers

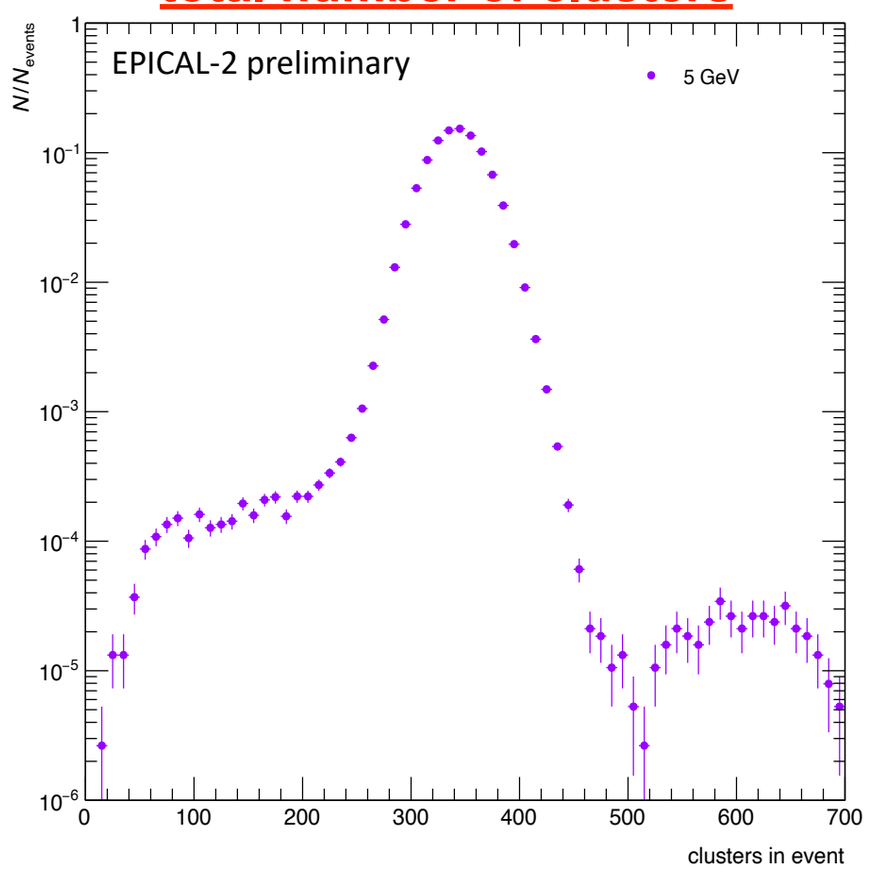
Energy measurement

- ☑ **Total number of hits(clusters) per event**
  - Gaussian shape with small asymmetry
  - smaller width for clusters
  - residual pileup at higher energy side
  - low-energy contamination of beam
- ☑ current study uses numerical mean and standard deviation

total number of hits



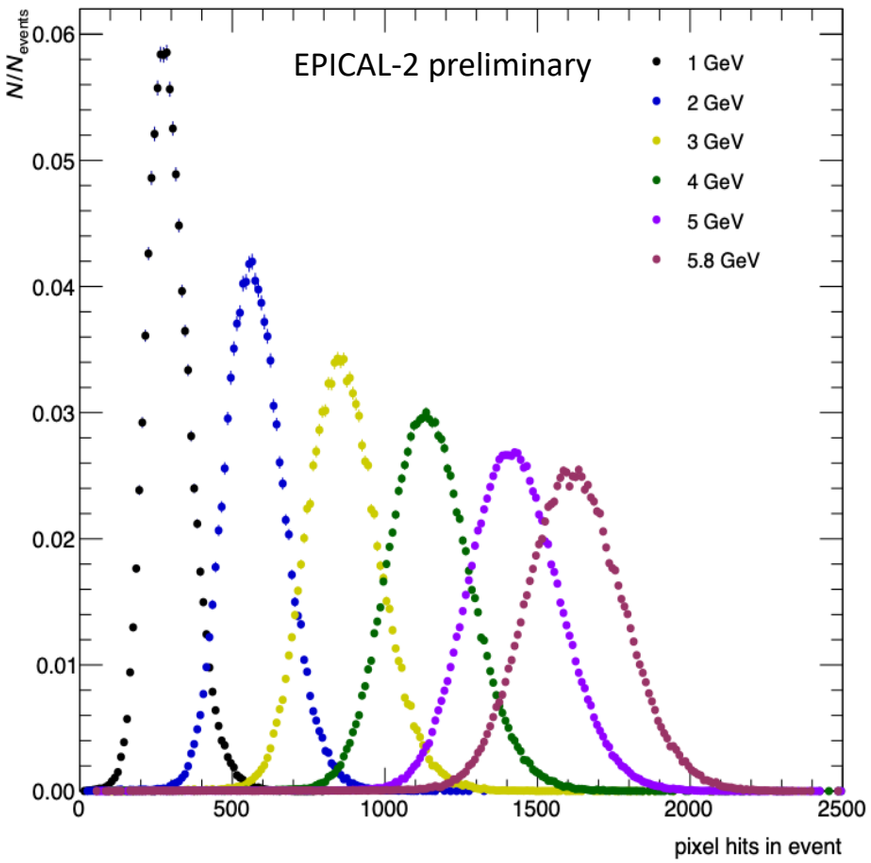
total number of clusters

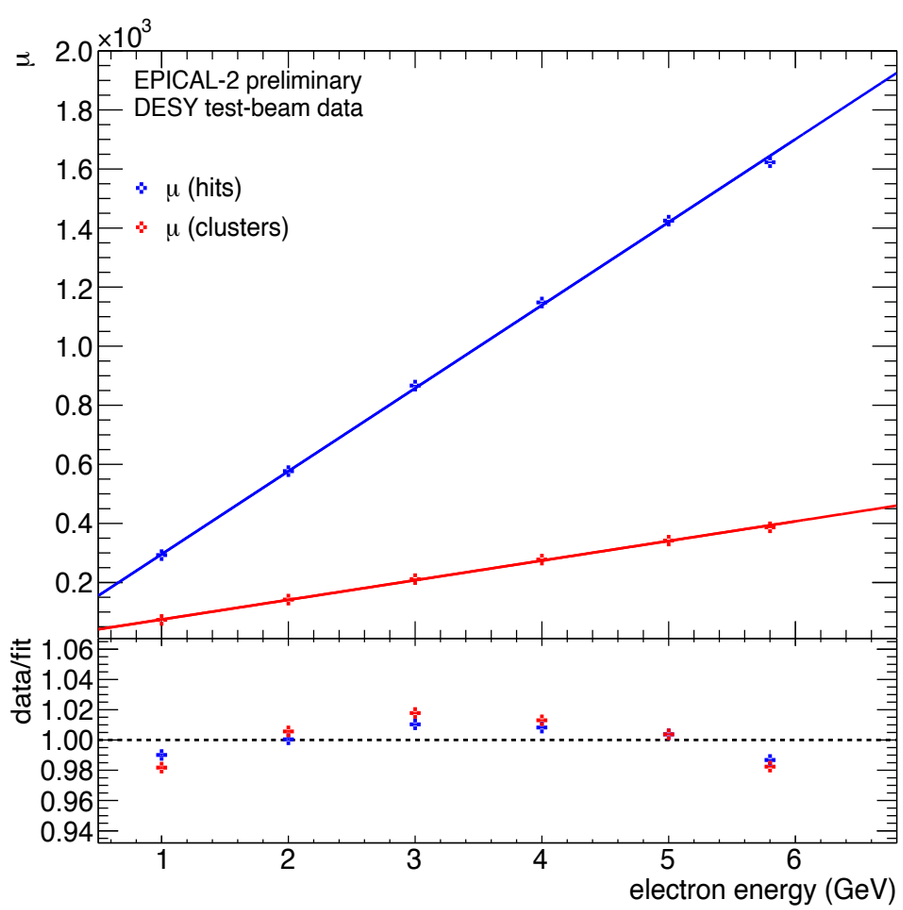


Energy Linearity

- ☑ numerical mean (μ) of total number of hits(clusters) distributions
  - **clear energy dependence**
  - similar performance between hits and clusters
  - **small deviation from linearity, possibly caused by**
    - energy leakage
    - cluster overlap
    - lower-energy contamination

under investigation

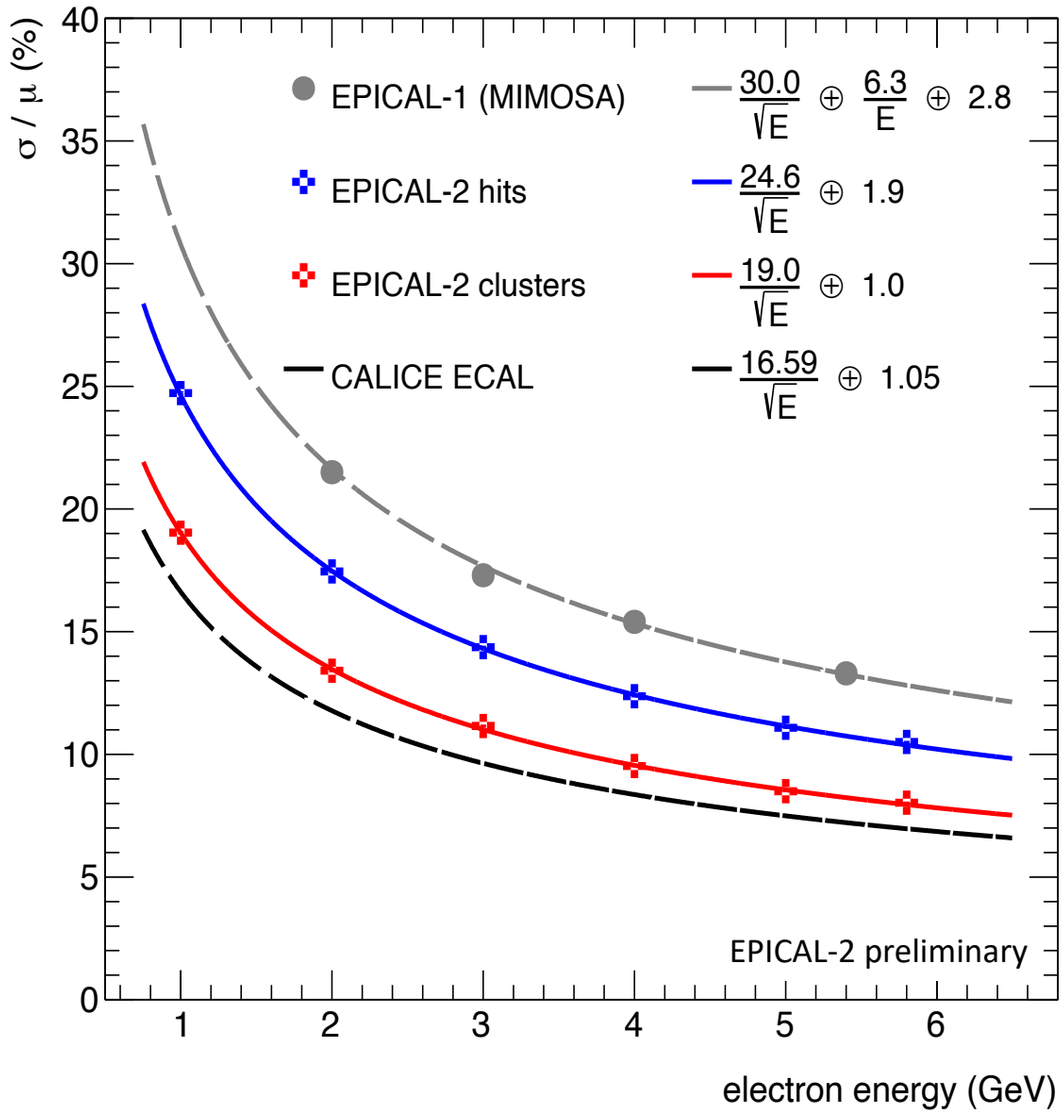




Energy Resolution

- ☑ standard deviation (σ) / mean (μ)
  - better than EPICAL-1 (MIMOSA)
    JINST 13 (2018) P01014
  - close to analog SiW ECAL (CALICE) physics prototype
    NIM A608 (2009) 372
  - **<u>better performance for clusters compared to hits</u>**
    - large cluster-size fluctuation
    - vertically directed tracks
    - (imperfect calibration)

    work in progress



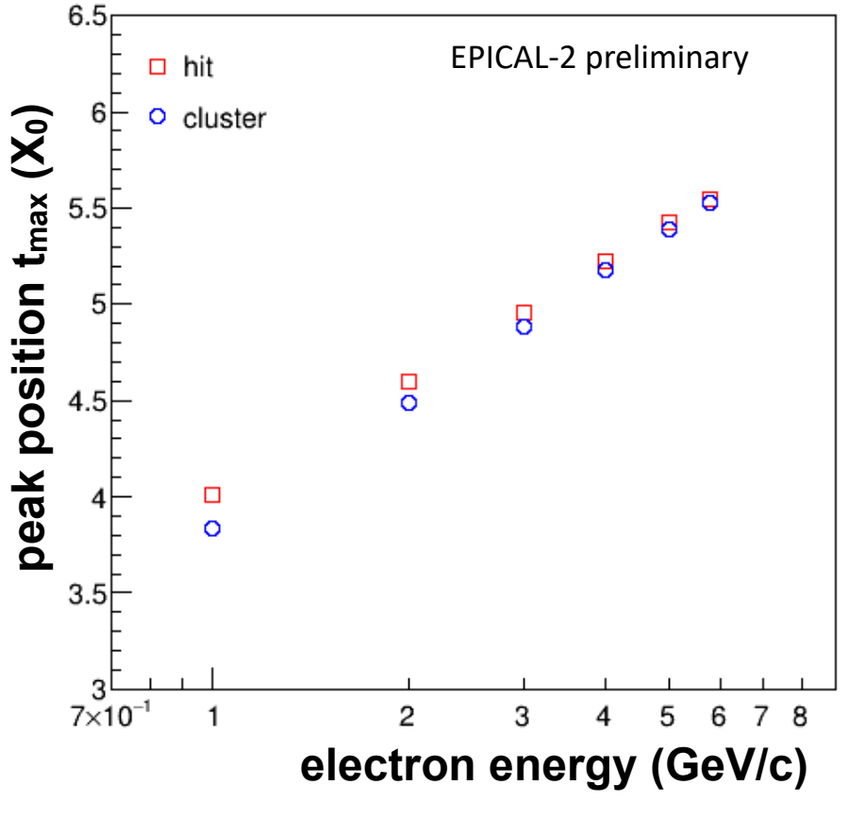
→ energy resolution superior to previous prototype

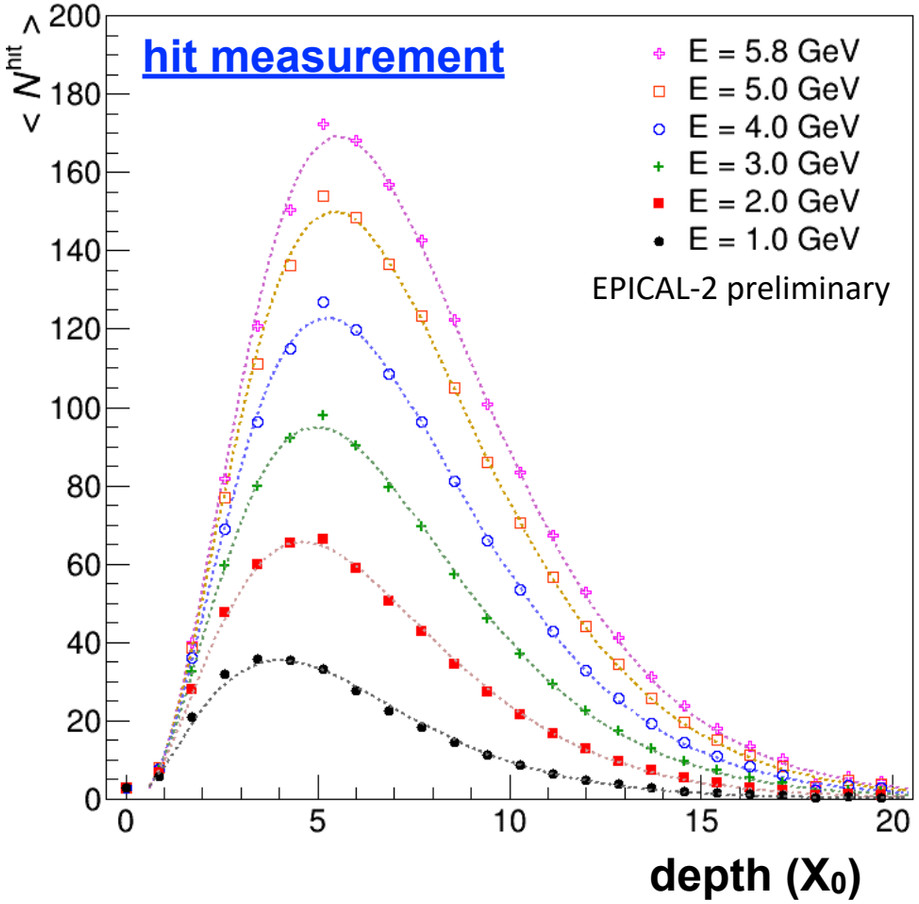
Longitudinal Profile

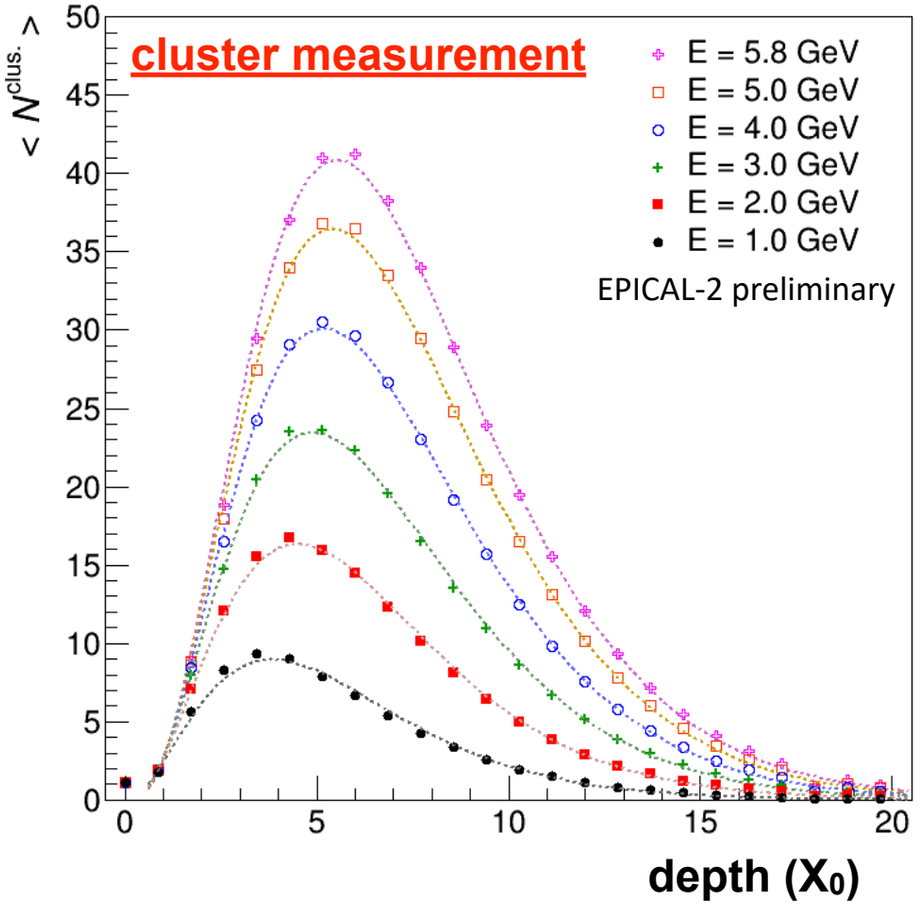
- ☑ **reasonable description by gamma distribution**
- ☑ peak position(t_{max}) proportional to log(E)
  - $t_{max}^{Hit} > t_{max}^{Cluster}$?
  - more accurate calibration for the conclusion

work in progress

→ first step in detailed shower shape analyses

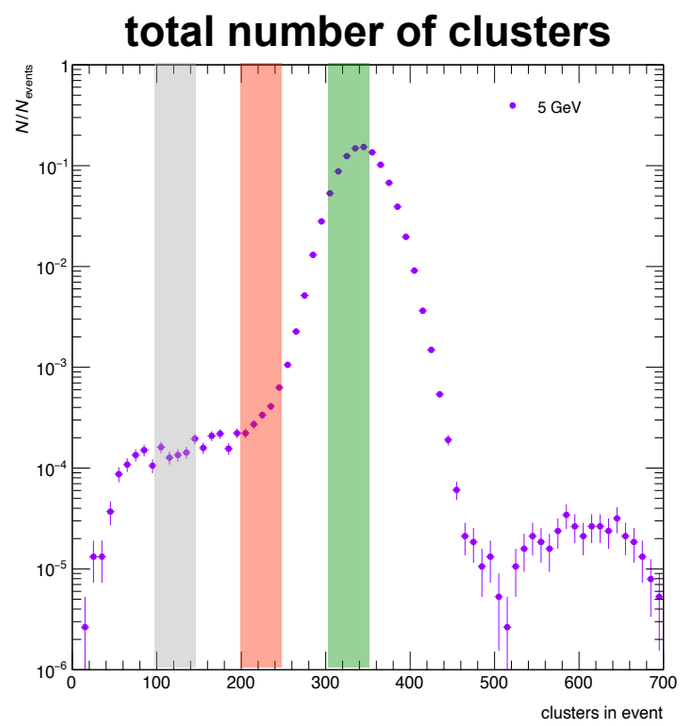


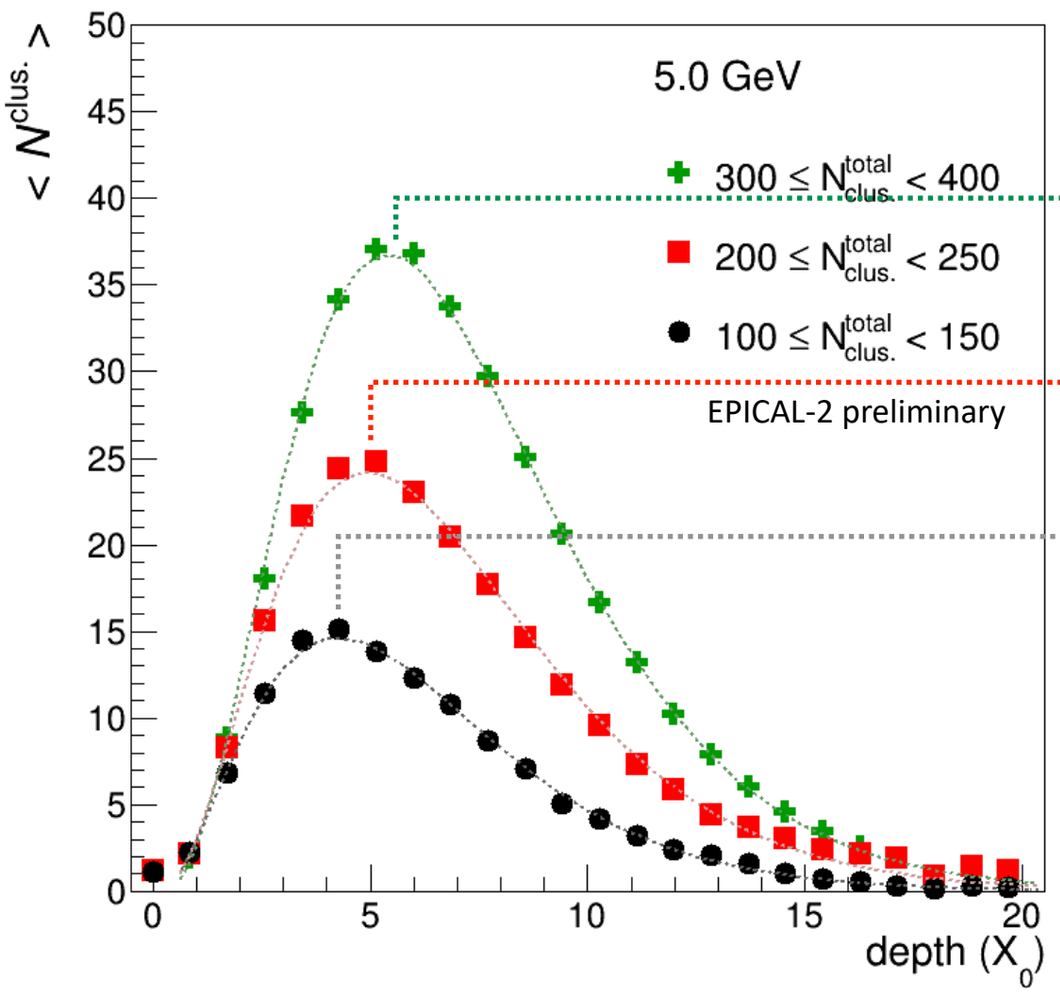


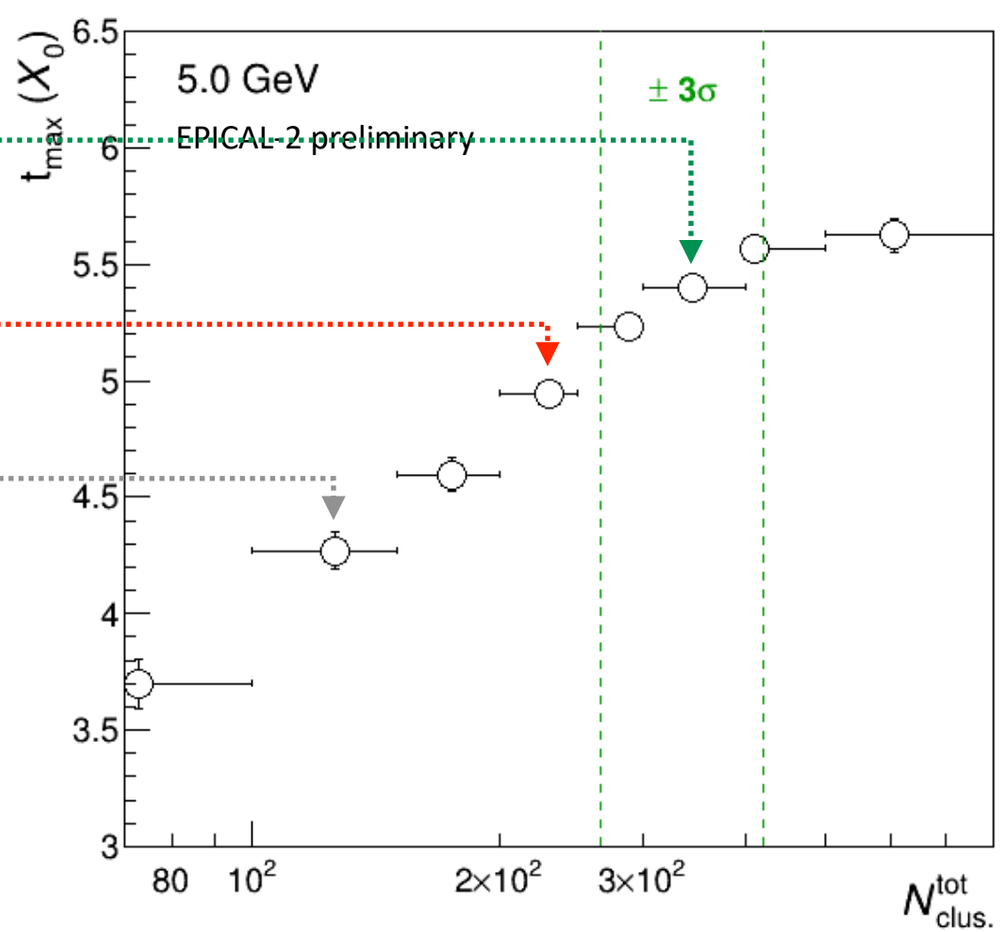


Tail at low energy side

- ☑ longitudinal profile from event subsamples
  - classified by total number of cluster
- ☑ the peak position (t_{max}) can be scaled by $log(N^{clus})$
  - low-energy tail is created by lower energy electrons







Summary

- ☑ **Successful test of full digital pixel calorimeter (EPICAL-2)**
  - test with cosmic muons and electron beam (1.0~5.8 GeV/c)
  - ALPIDE sensor (high granularity CMOS MAPS) suitable for calorimeter use

- ☑ **EPICAL-2 performance at DESY TB**
  - preliminary energy linearity check
  - energy resolution improved compared to EPICAL-1
  - reasonable longitudinal shower shape

- ☑ **Outlook**
  - detailed study of shower development
  - further studies of high-energy behaviour (simulation and SPS test beam)

EPICAL-2 Team

University of Bergen

Johan Alme
Viljar Eikeland
Ola Grøttvik
Dieter Röhrich
Emilie Solheim
Kjetil Ullaland

Goethe University Frankfurt

Henner Büsching
Johannes Keul
Fabian Pliquett
Tim Rogoschinski

University of Oslo

Qasim Malik
Ketil Røed

Utrecht University

Rene Barthel
Aart van Bochove
Erik Broeils
Naomi van der Kolk
Gert-Jan Nooren
Else Okkinga
Thomas Peitzmann
Sebastiaan van Rijk
Marcel Rossewij
Hiroki Yokoyama

University of Birmingham

Robert Bosley
Nigel Watson

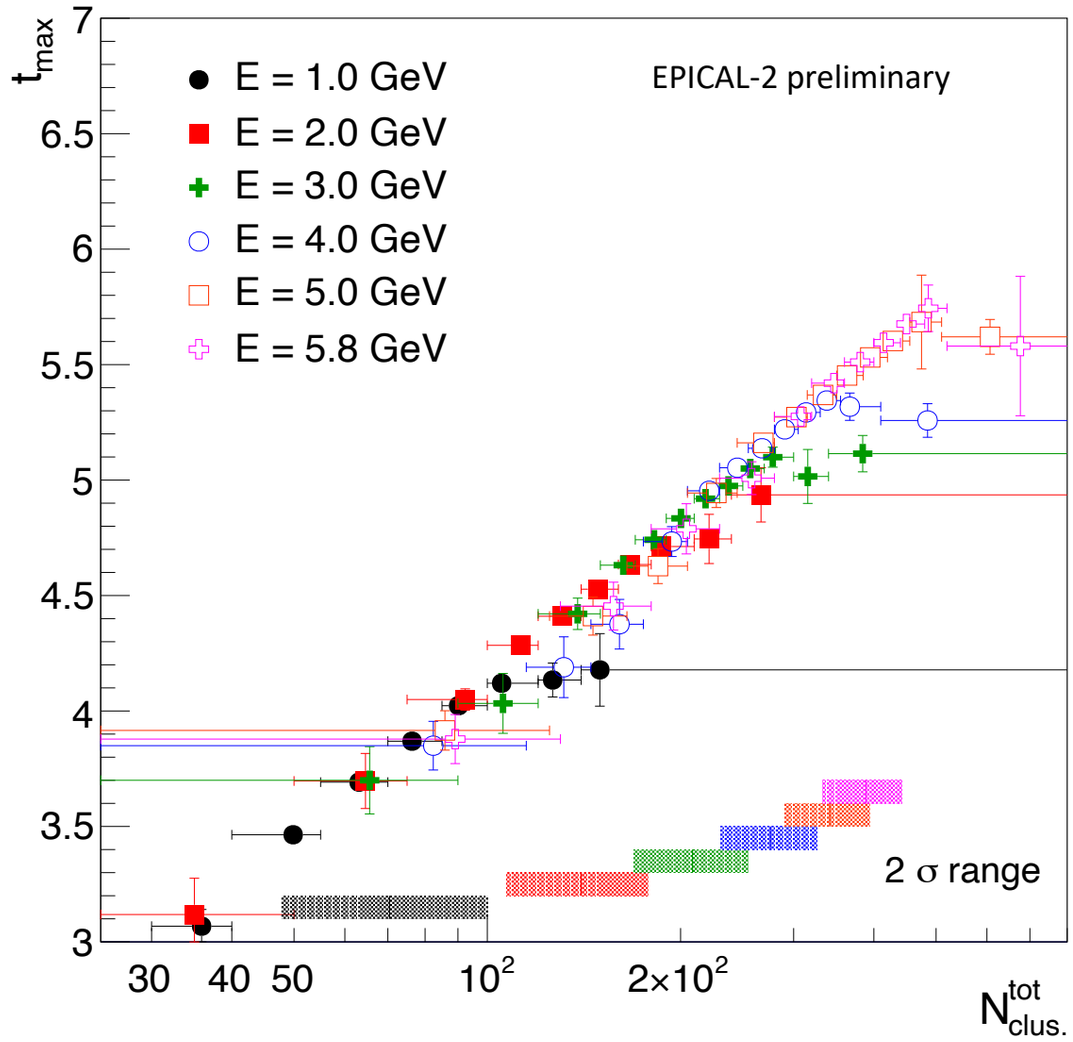
Research and Production Enterprise LTU Kharkiv Ukraine

Vyacheslav Borshchov
Ihor Tymchuk

backup

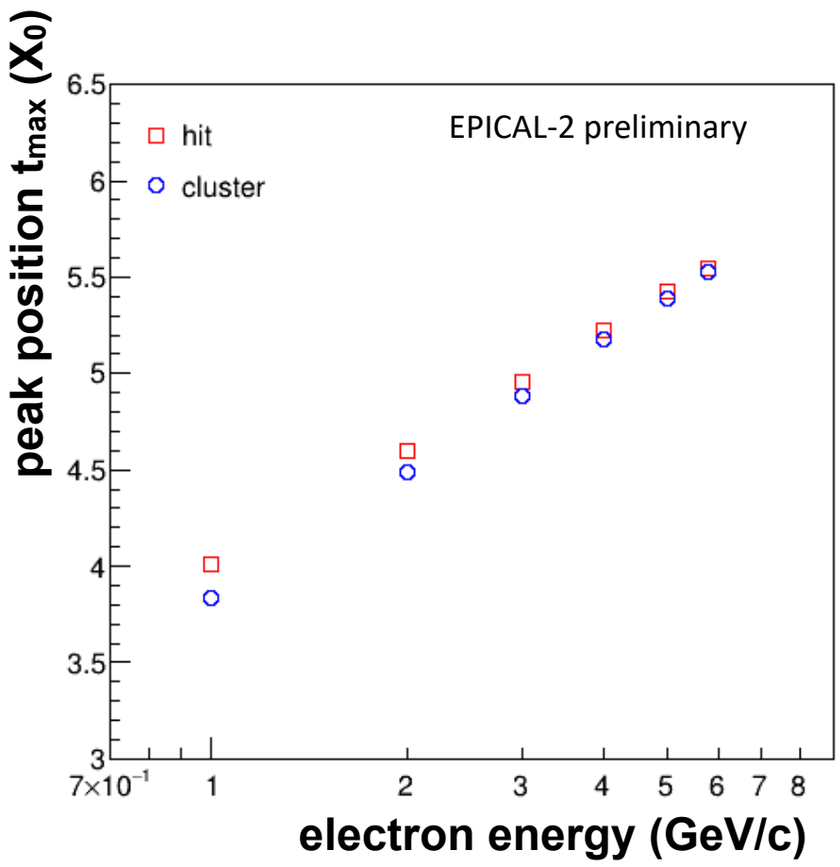
Tail at low energy side

- ☑ events classification by total number of cluster
- ☑ the peak position (t_{max}) can be scaled by $log(N^{clus})$
  - low-energy tail is created by lower energy electrons

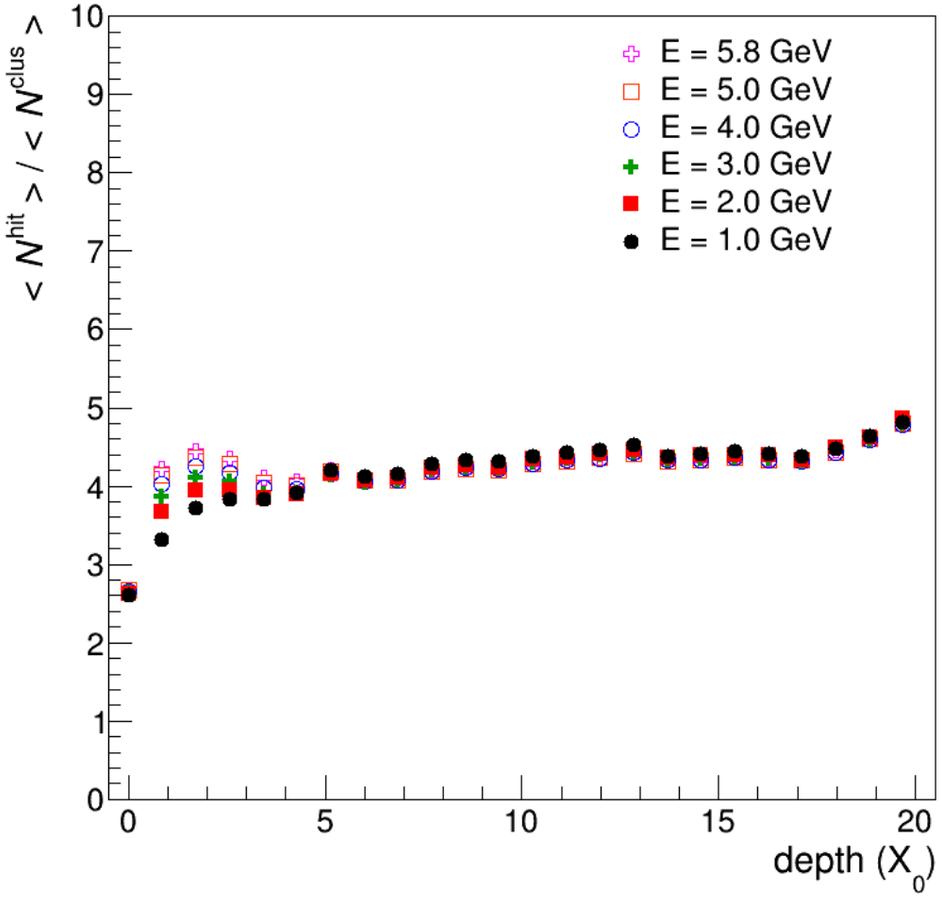


Longitudinal Profile, Hits v.s. Clusters

- ☑ peak position(t_{max}) proportional to log(E)
  - $t_{max}^{Hit} > t_{max}^{Cluster}$?
- ☑ cluster size is relatively small
  - for lower beam energy, at small depth

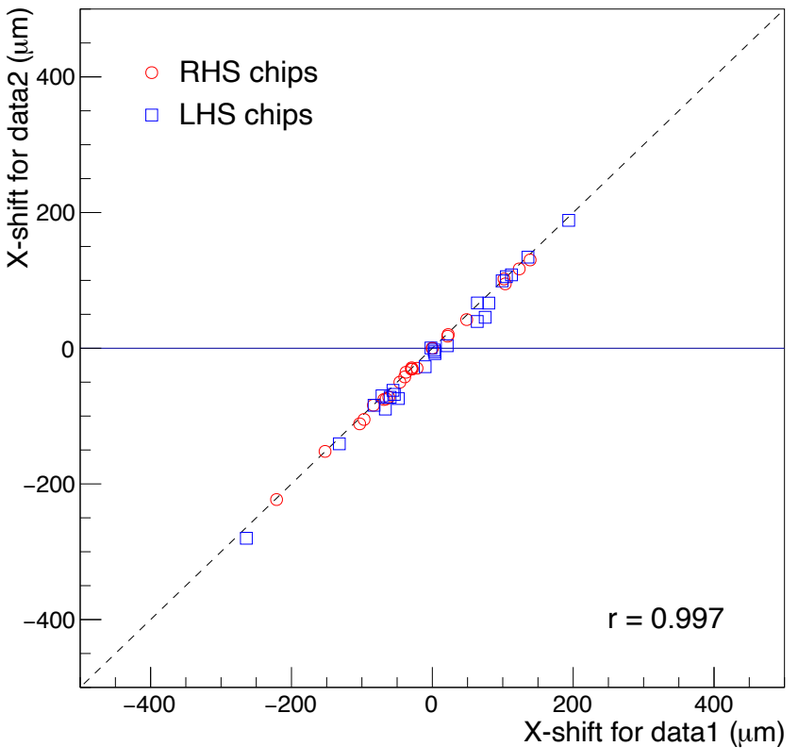


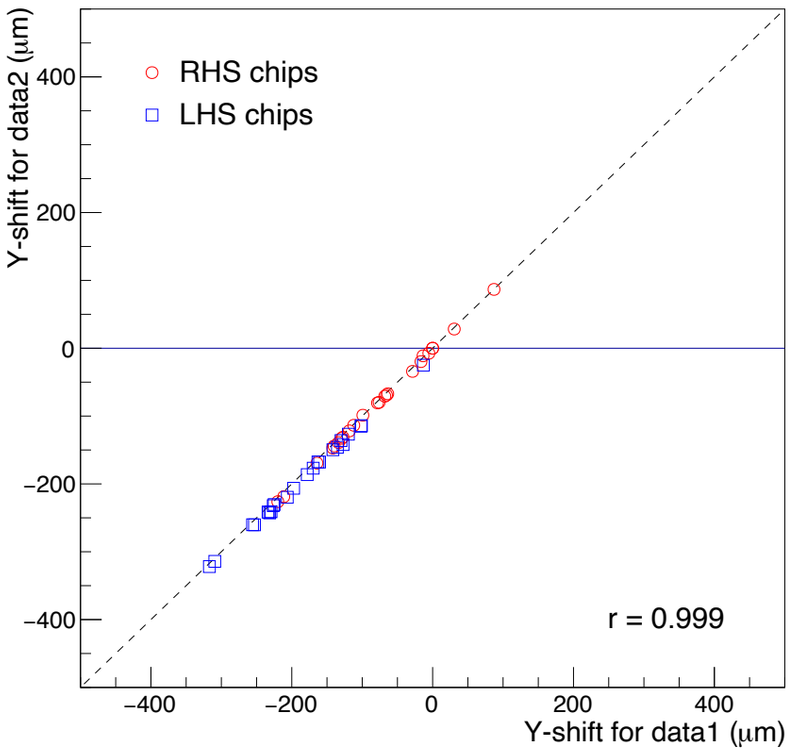
ratio: longitudinal profile

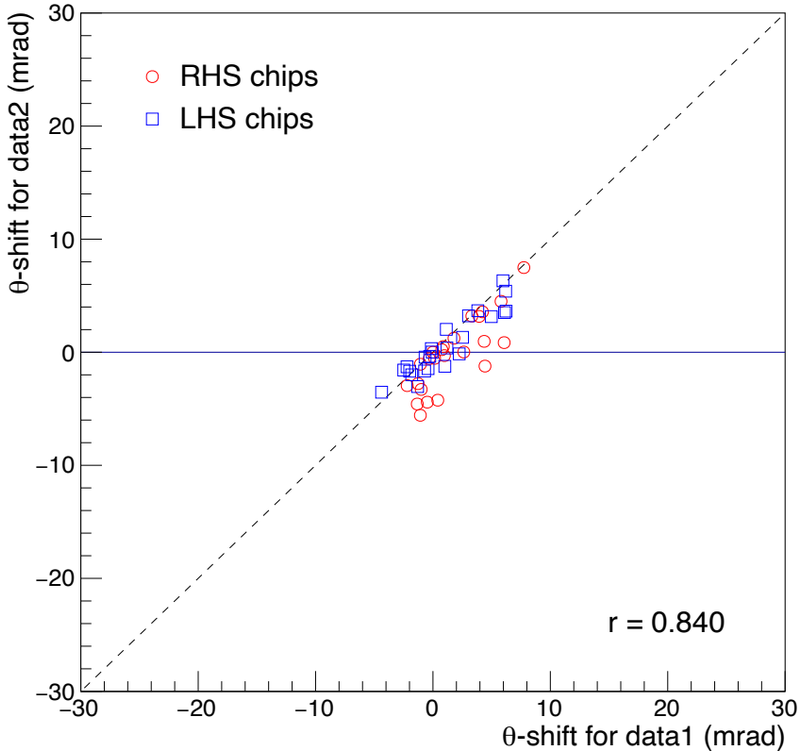


Alignment Verification

- ☑ alignment parameters from exclusive event subsets
  - good coincidence







Beam Inclination

- ☑ the chip positions are corrected by the alignment, except
  - x(y) shifts given by fixed chips
  - beam inclination with respect to the setup
- ☑ (x^{hit} - x^{beam}) vs. (y^{hit} - y^{beam})
  - cluster position in the first layer is taken as a beam position.
  - peak position deviates from (0,0) ⇒ inclination from beam axis
- ☑ clear beam inclination

- $f(x,y) = \frac{A}{r'} \cdot \exp\left(-r'/B\right)$
- $r' = \sqrt{C + (x - x0)^2 + (y - y0)^2}$
- 5 free parameters, A, B, C, x0 and y0

for different beam energies/runs