Sensor-level simulation of MAPS ECAL testbeam data

CALICE collaboration meeting

25.03.2021

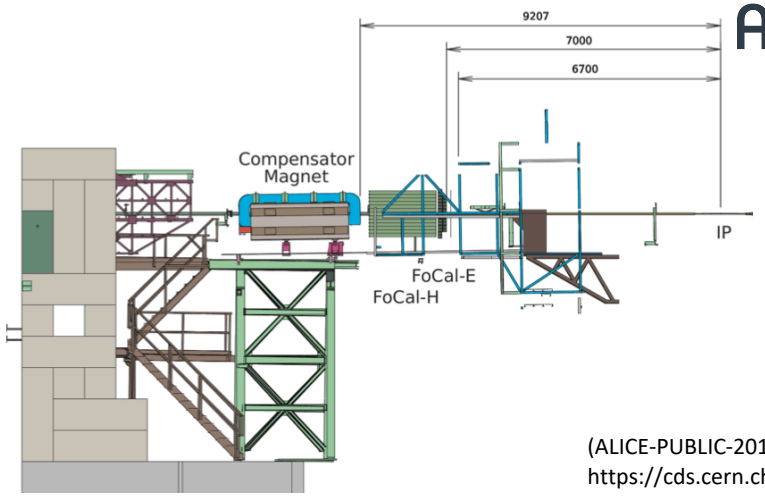
Tim Rogoschinski

Forward Calorimeter: FoCal
conceptual design

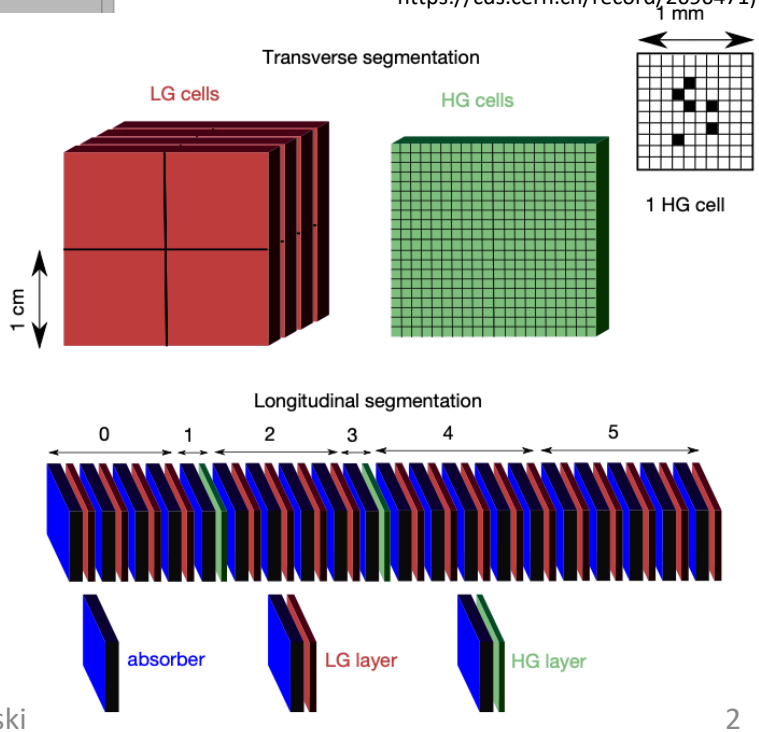
- upgrade of the LHC-ALICE experiment: **FoCal**
  → installation planned in ~2026
  → SiW sandwich calorimeter
  → $3.4 \leq \eta \leq 5.8$, z = 7 m

- two components:
  1) hadronic (FoCal-H) and
  2) electromagnetic calorimeter (FoCal-E)

  → low granularity cells (LG)
  pixel size ≈ $1\mathrm{cm}^2$
  energy and time measurements
  → high granularity cells (HG): **ALPIDE (CMOS MAPS)**
  pixel size ≈ $30 \times 30\ \mu\mathrm{m}^2$
  shower separation and position determination
  → **R&D directly applicable to whole electromagnetic calorimeter made of MAPS for linear collider**

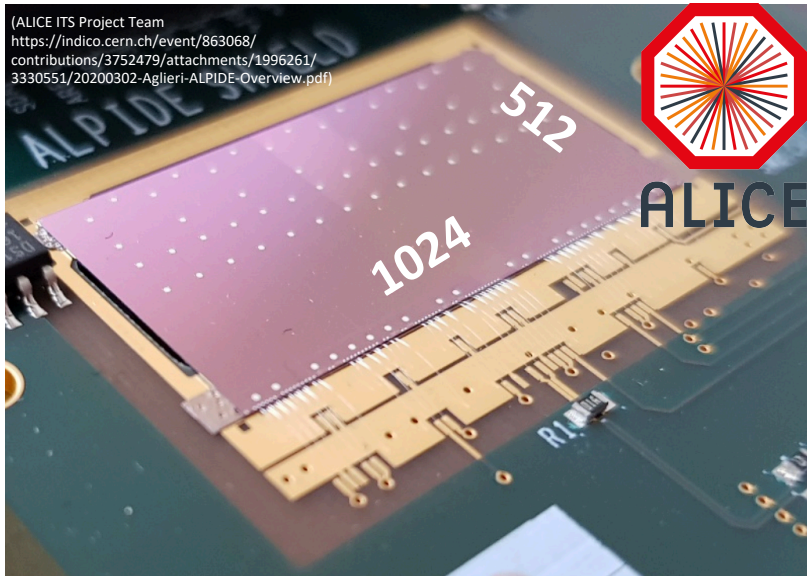


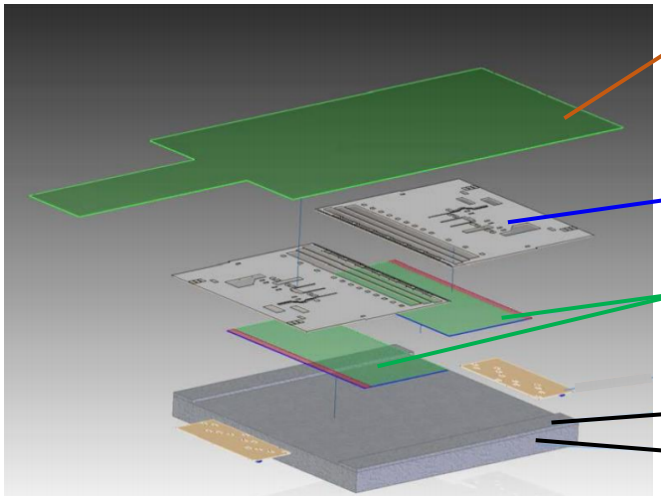
(ALICE-PUBLIC-2019-005
https://cds.cern.ch/record/2696471)

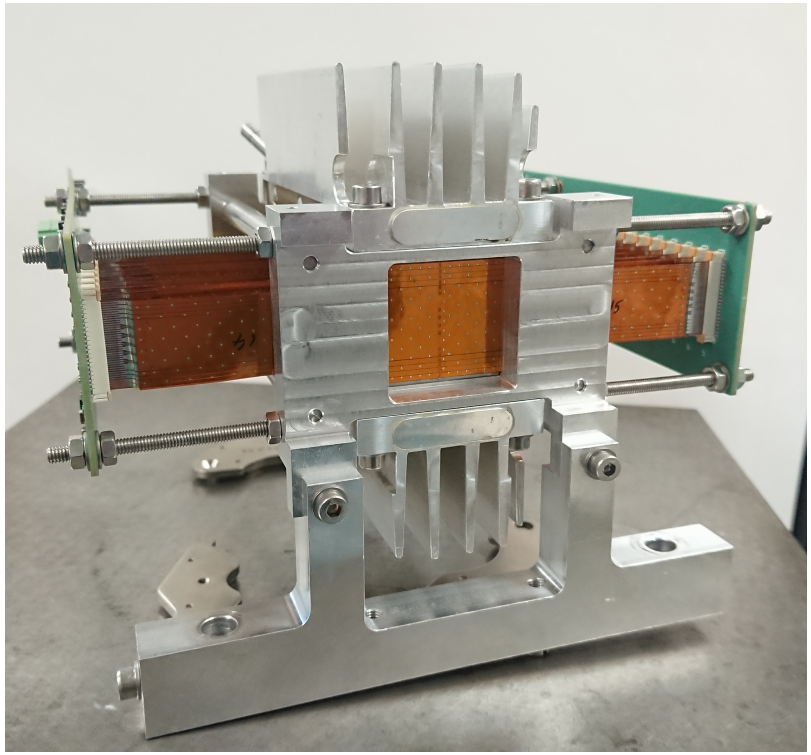


Electromagnetic Pixel Calorimeter 2 (EPICAL-2)

- **second prototype** in context of R&D for planned LHC-ALICE FoCal upgrade in ~2026
  → **fully digital calorimeter** prototype
- **24 layers** with **two ALPIDE chips each**
  → chip size: 30 mm x 15 mm
- **512 x 1024 pixels per chip**
  → pixel size: 26.88 µm x 29.24 µm







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- **24 layers** with **two ALPIDE chips each**
  → chip size: 30 mm x 15 mm
- **512 x 1024 pixels per chip**
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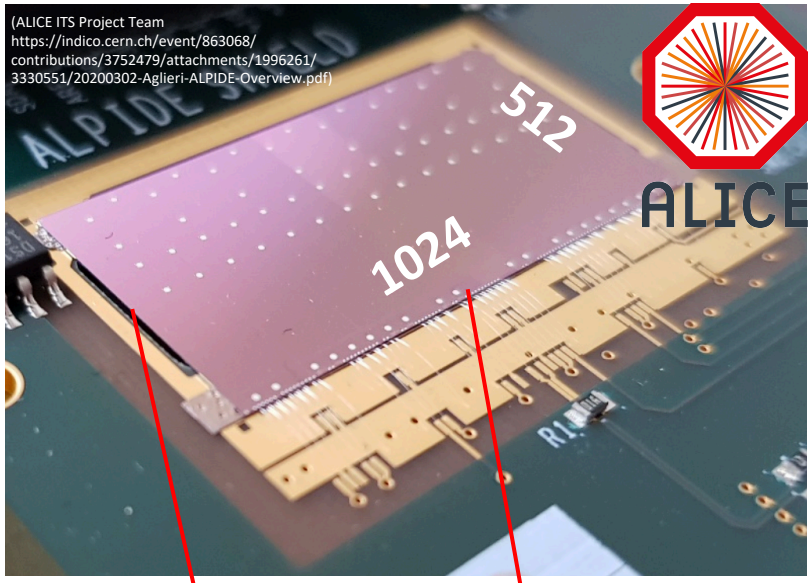
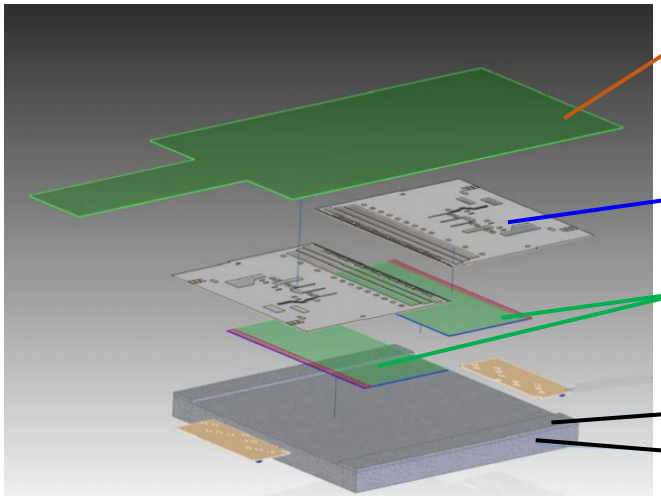
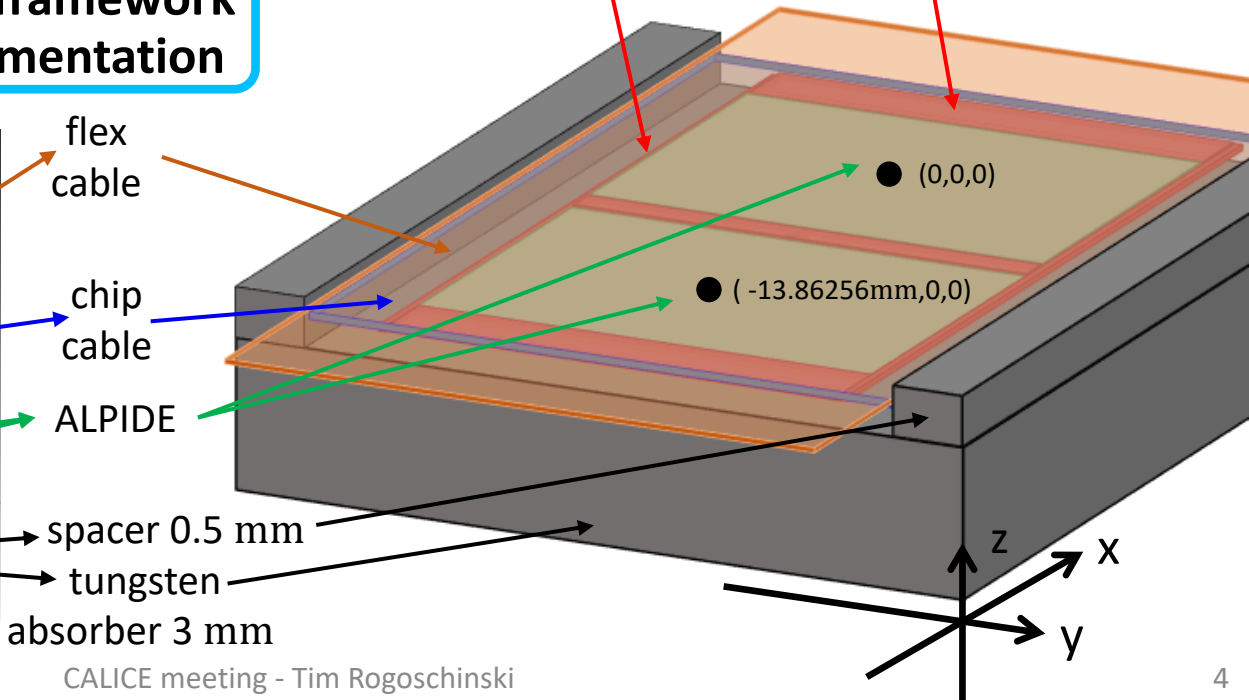
- **simulation** utilizing **Allpix² framework**
  → **precise geometry implementation**





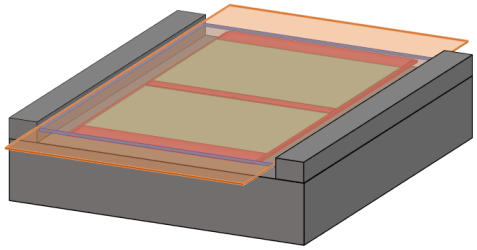


EPICAL-2 simulation utilizing Allpix² I

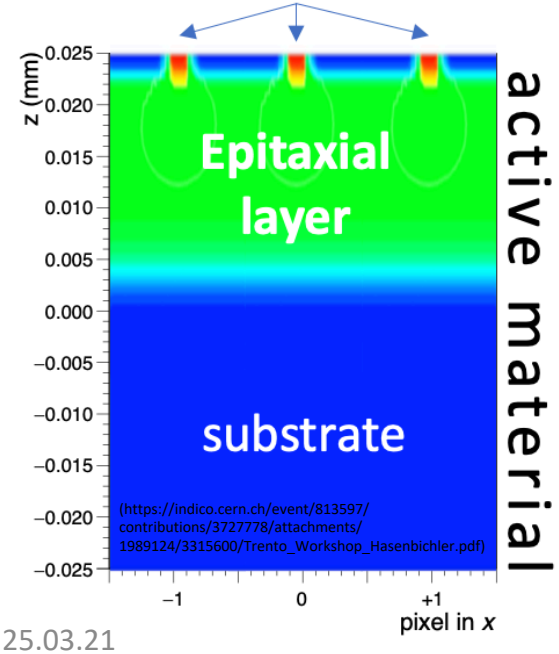
A Monte Carlo simulation tool for silicon pixel detectors
From incoming particle(s) to readout

simulation chain:

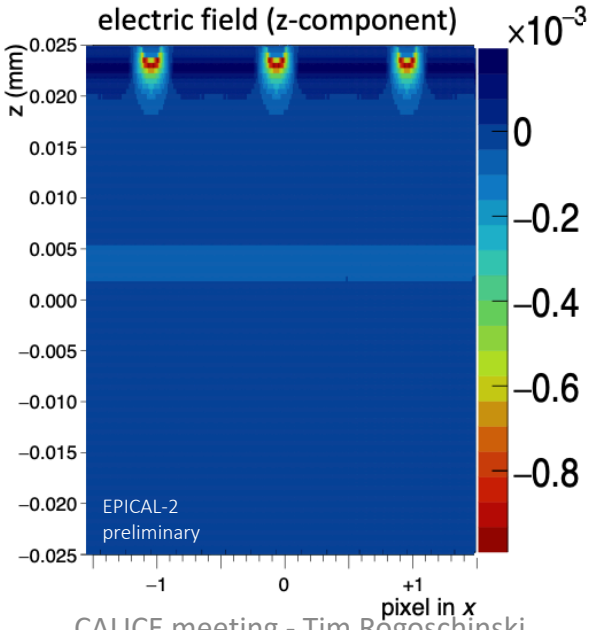
geometry builder → **electric field initialization** → **energy deposition**



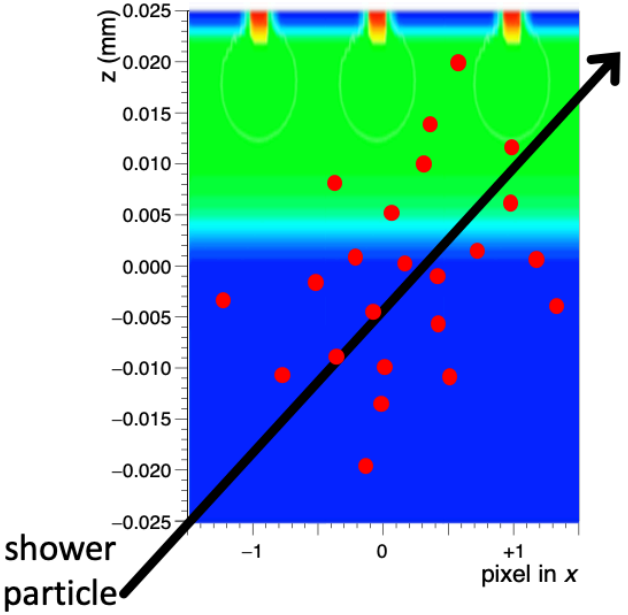
diodes



- electric field obtained from **TCAD** simulation by Jan Hasenbichler
- total reverse bias voltage of $V_{RB} = 1.4\ \mathrm{V}$



- particle transport and deposition of charges in active materials



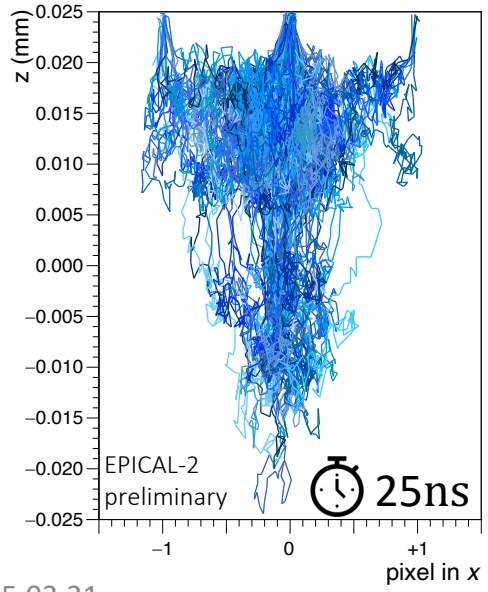
EPICAL-2 simulation utilizing Allpix² II

A Monte Carlo simulation tool for silicon pixel detectors
From incoming particle(s) to readout

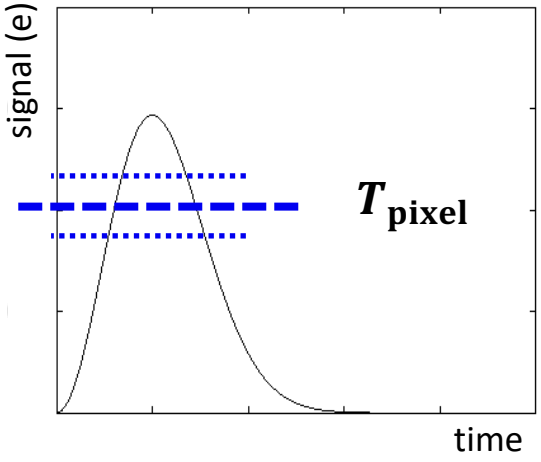
simulation chain:

propagation and transfer → **digitizer** → **output**

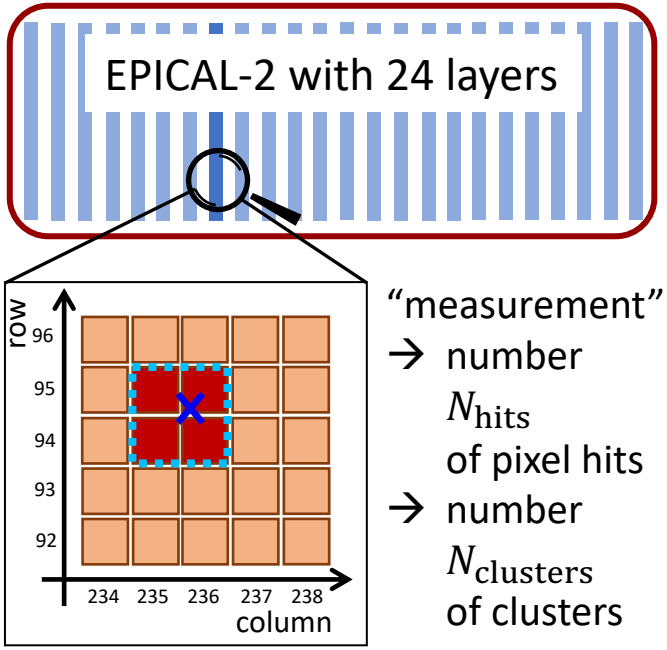
- propagation of charge carrier groups
  → set to **50 charges per group**
- diffusion and drift of groups within integration time t_{int}
  → set to $\boldsymbol{t_{\mathrm{int}} = 25\ \mathrm{ns}}$
- pixel assignment of charges



- noise added by Gaussian (width σ_{noise}) to each pixel
  → set to $\boldsymbol{\sigma_{\mathrm{noise}} = 20\ \mathrm{e}}$
- accept as hit: pixel charges surpassing threshold value T_{pixel}
  → set to $\boldsymbol{T_{\mathrm{pixel}} = 82\ \mathrm{e} \pm 20\ \mathrm{e}}$



- 2D information of hits per layer
  → column and row



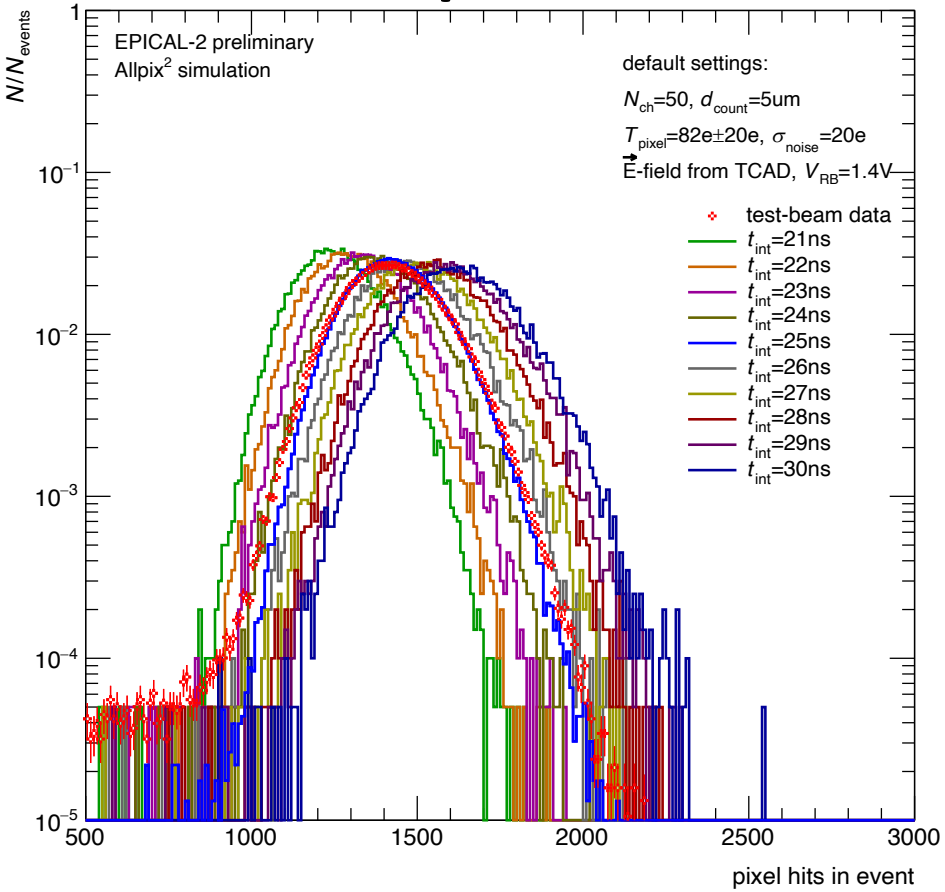
"measurement":
→ number N_{hits} of pixel hits
→ number N_{clusters} of clusters

EPICAL-2 simulation validation I

by means of 5 GeV **electron test beam data**

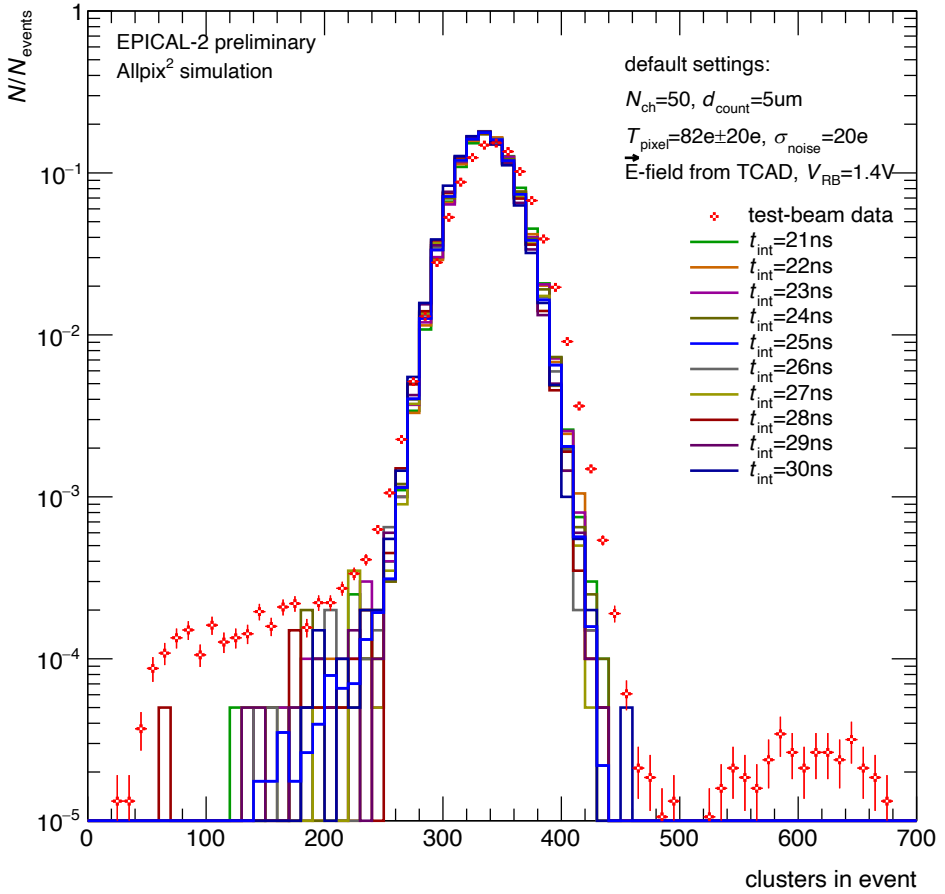
→ data taking at DESY Hamburg: similar data structure like simulation output

number of pixel hits



→ narrower tails in simulation

number of clusters



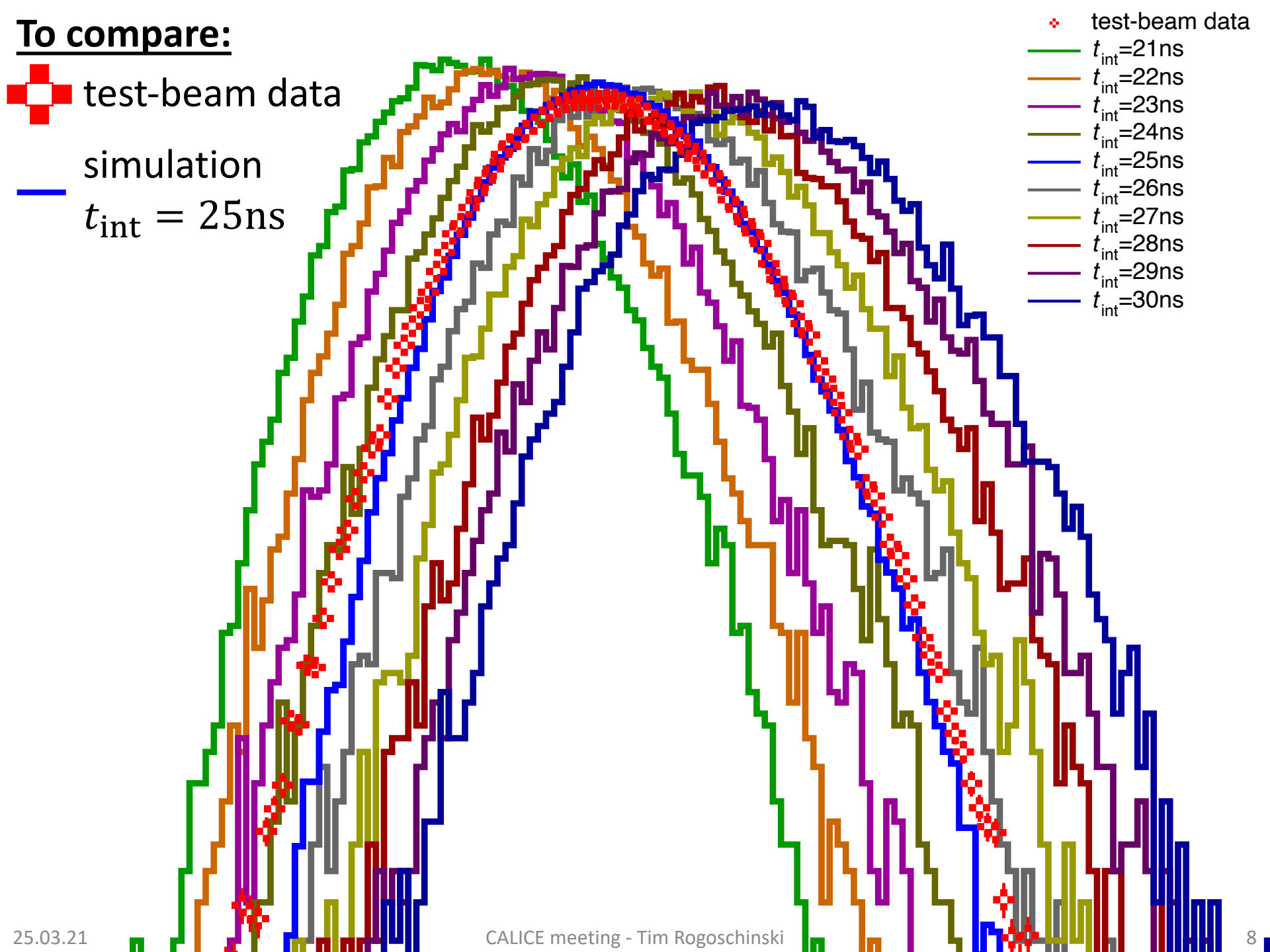
→ slightly lower mean values in simulation

→ **data and simulation essentially agree** for $t_{\mathrm{int}} = 25\mathrm{ns}$ → added to default settings

To compare:

test-beam data

simulation
$t_{\mathrm{int}} = 25\mathrm{ns}$



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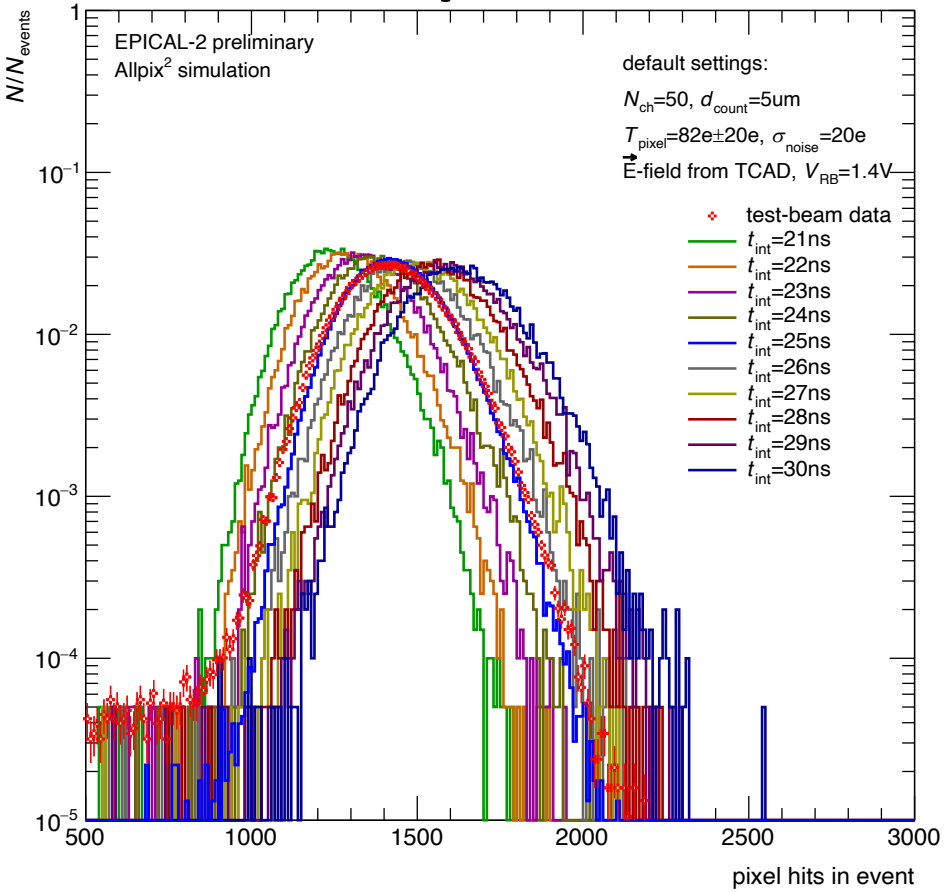

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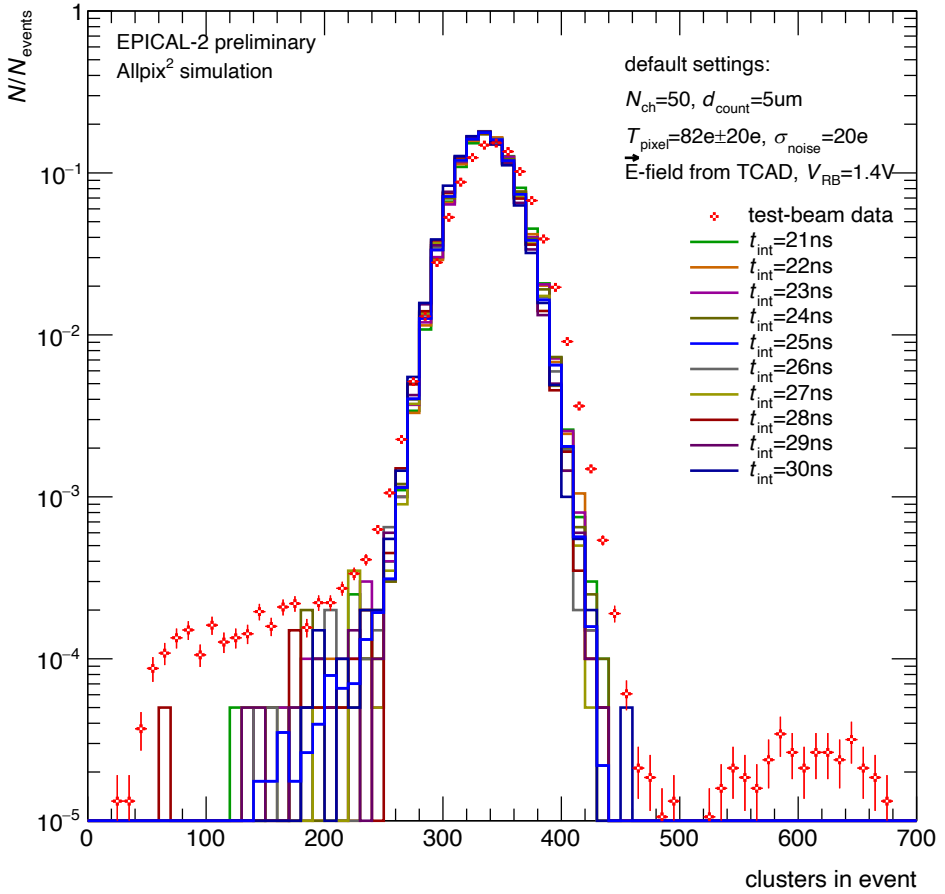

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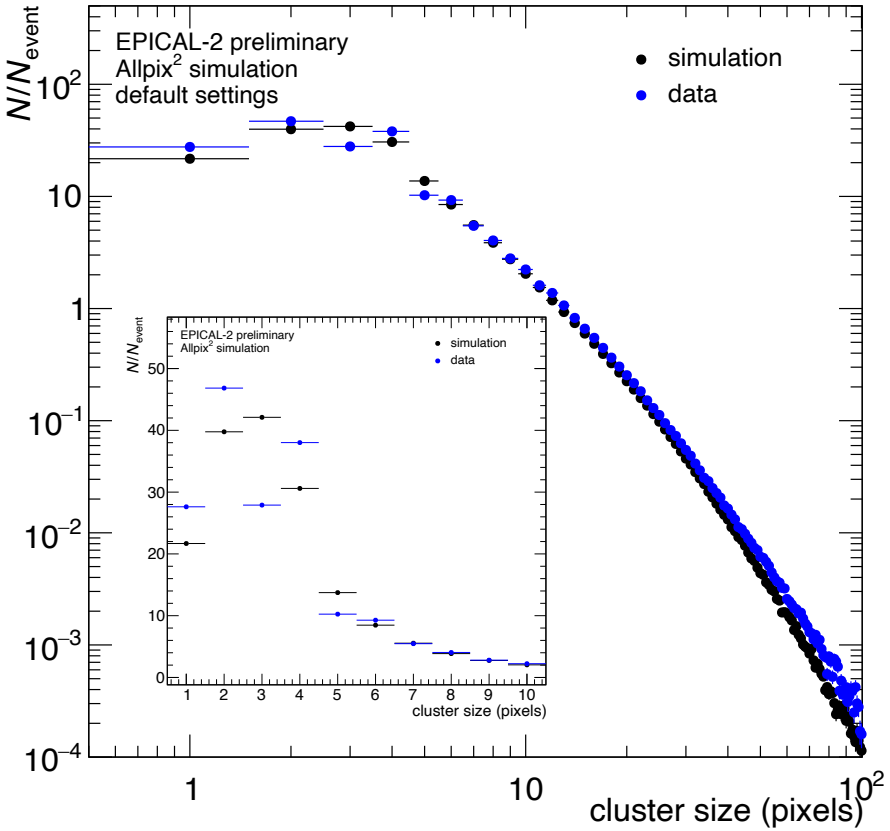
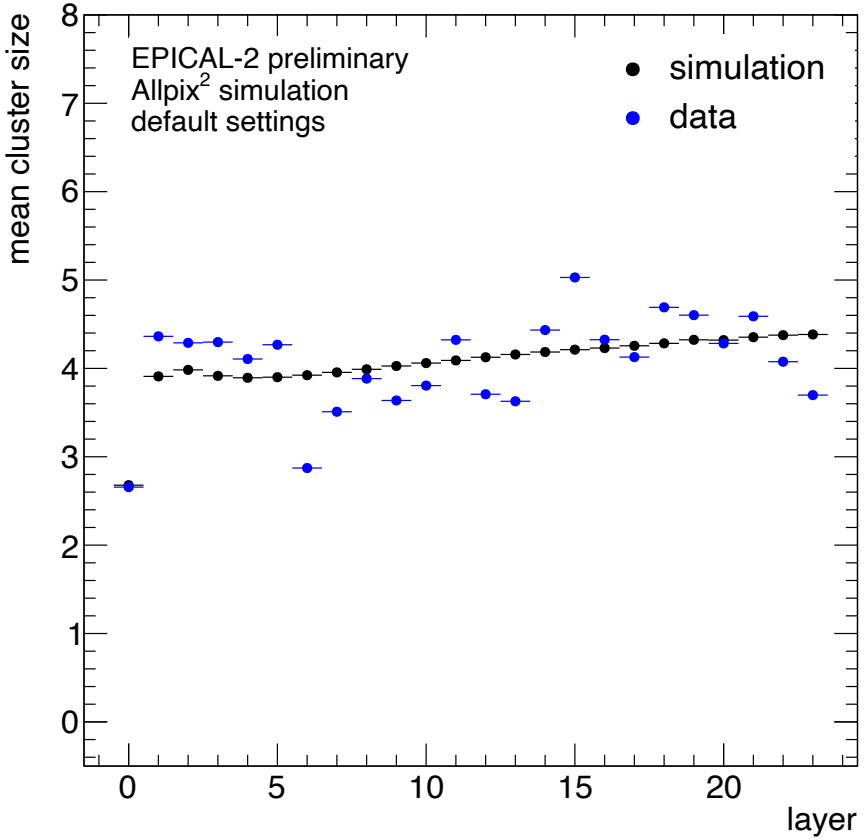
EPICAL-2 simulation validation II

by means of 5 GeV electron test beam data

cluster-size distribution



mean cluster size



→ small deviations for small clusters
→ marginal fewer large clusters in simulation

→ differences in sensitivity expected for data
→ will be corrected by calibration
→ simulation agrees rather well with data

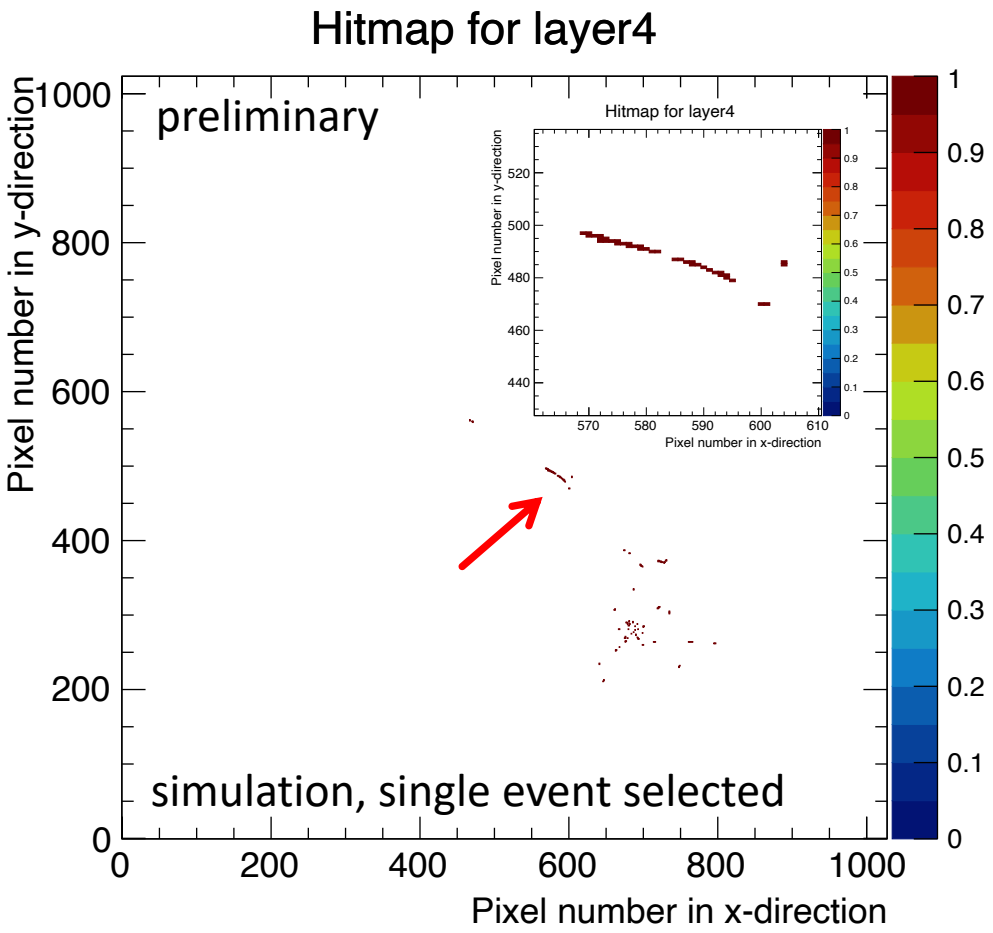
EPICAL-2 simulation validation III

by means of 5 GeV electron test beam data

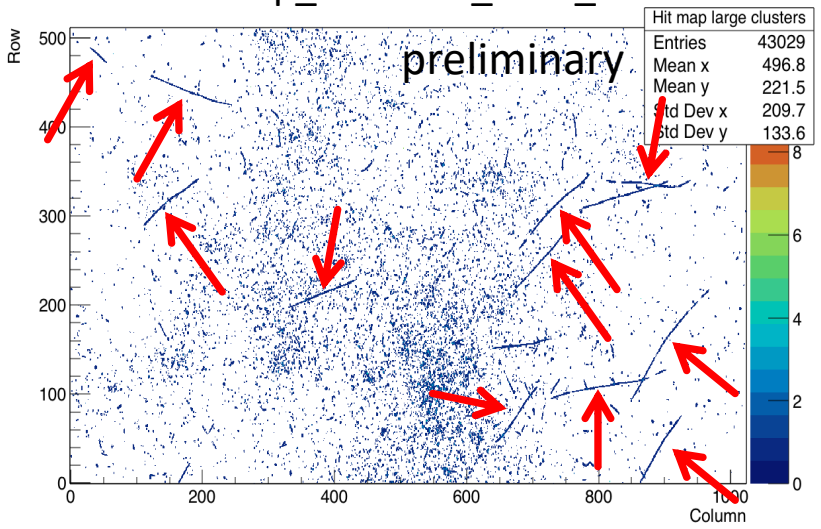
track-like hit structures

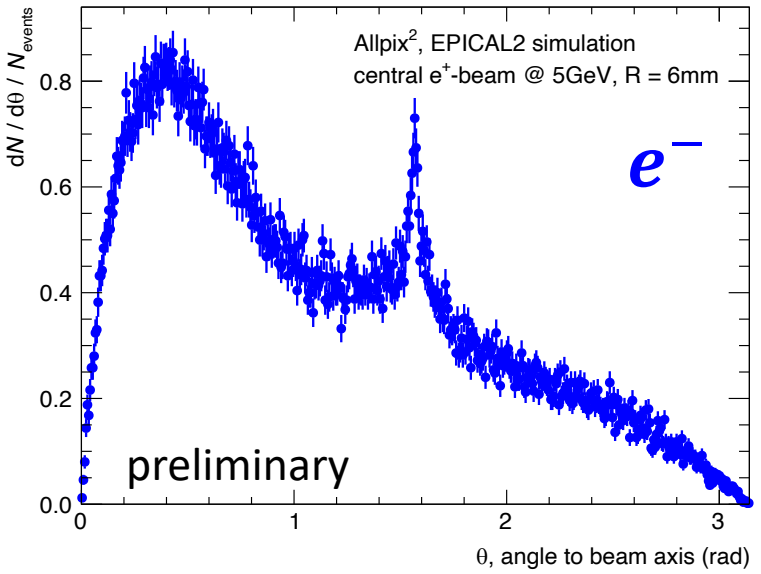
→ very large clusters

→ present in simulation - to be investigated



Data: Hitmap_Run1293_csize_min200

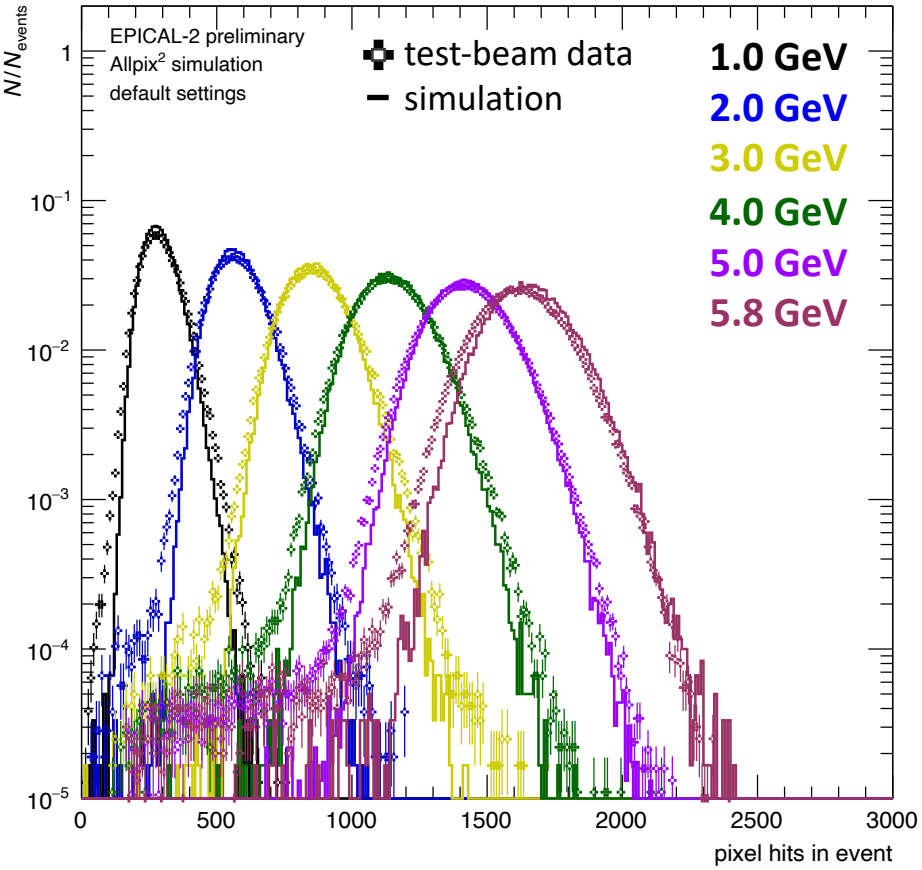




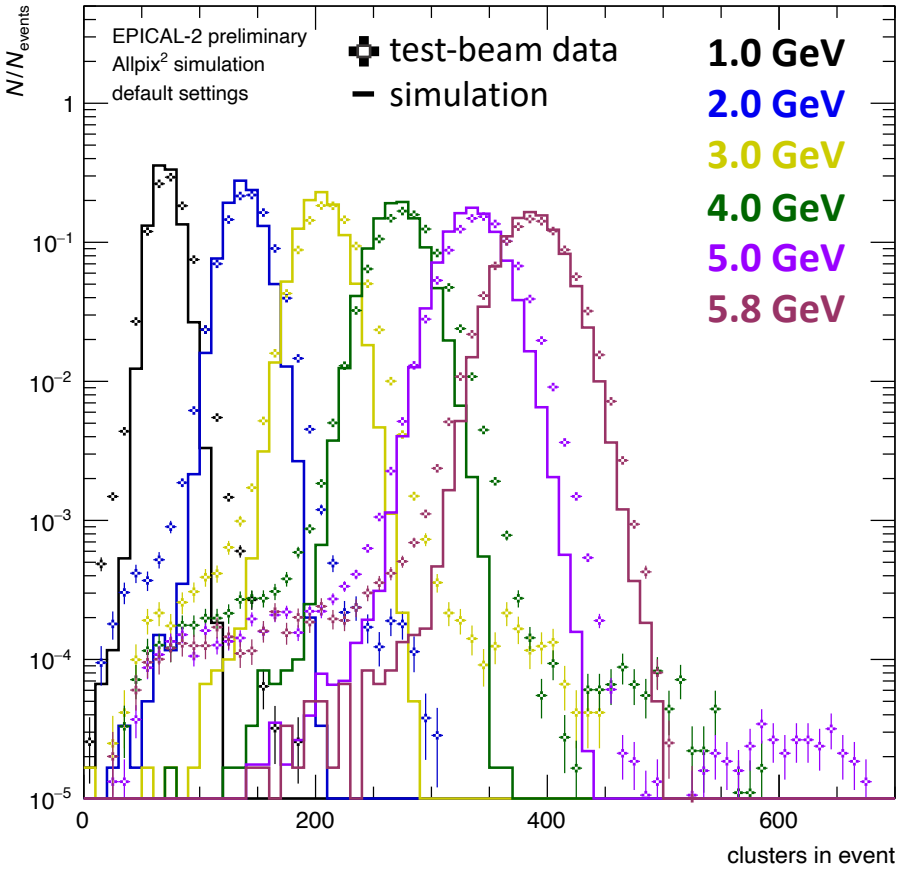
Number of hits and clusters

for DESY test-beam energies: 1 GeV to 5.8 GeV

number of pixel hits



number of clusters



→ simulation describes test-beam measurement

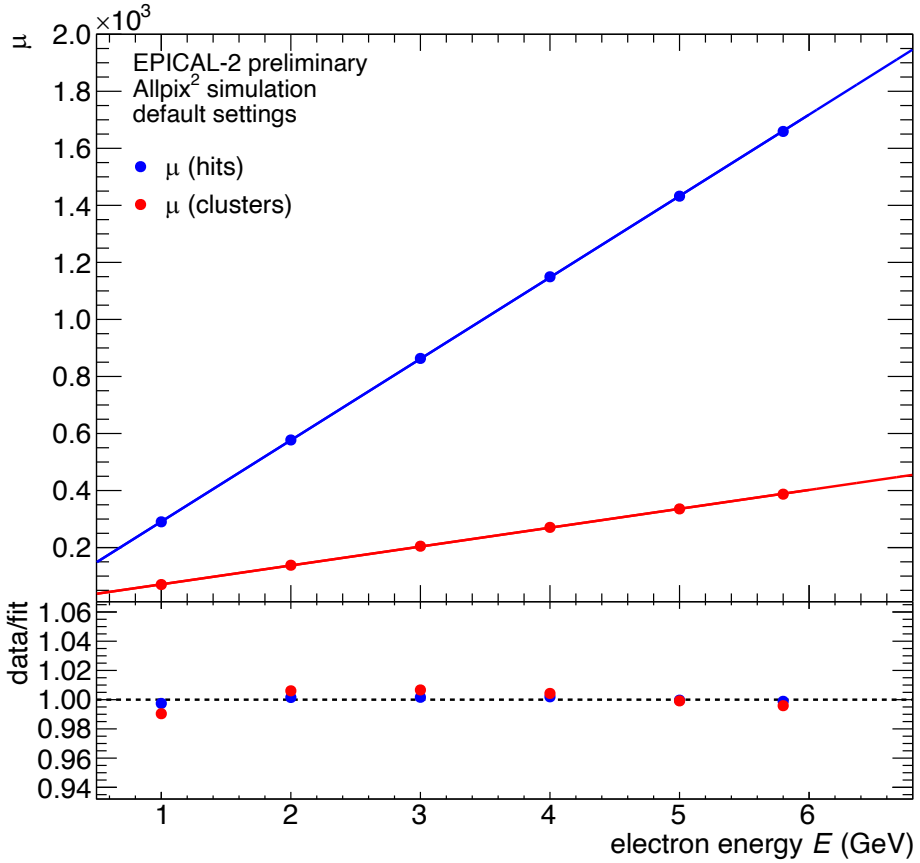
→ essential for energy response and energy resolution

→ extraction of mean μ and standard deviation σ from histograms

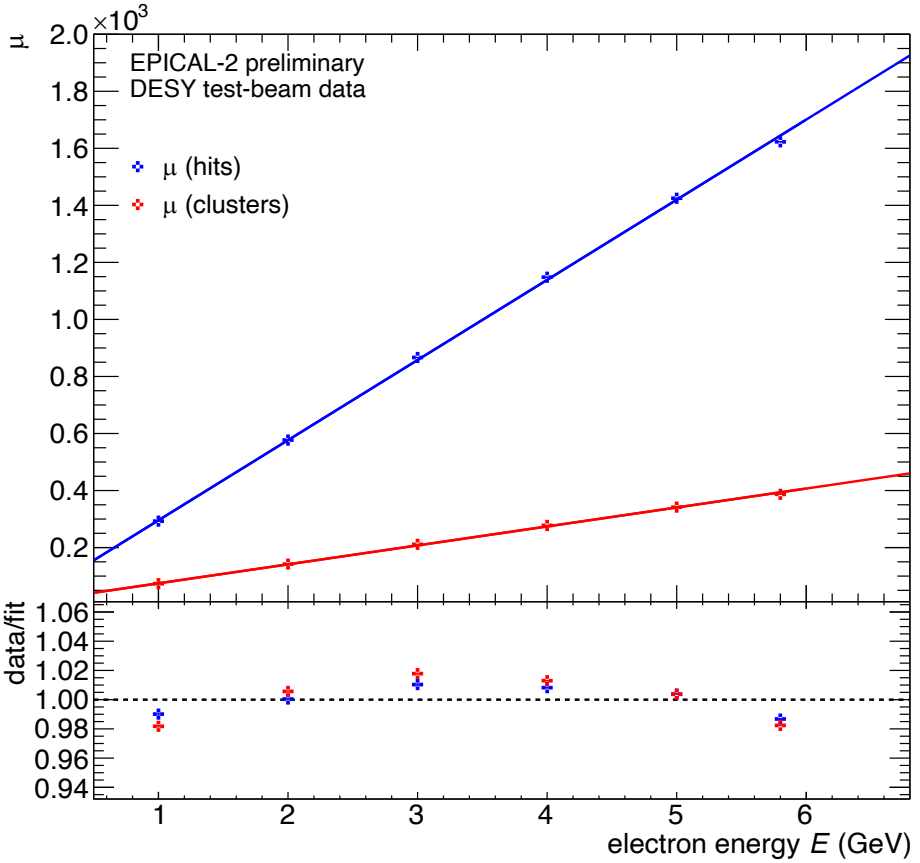
First attempt on **energy response: linearity**

derived from number of hits and clusters

simulation



test-beam data



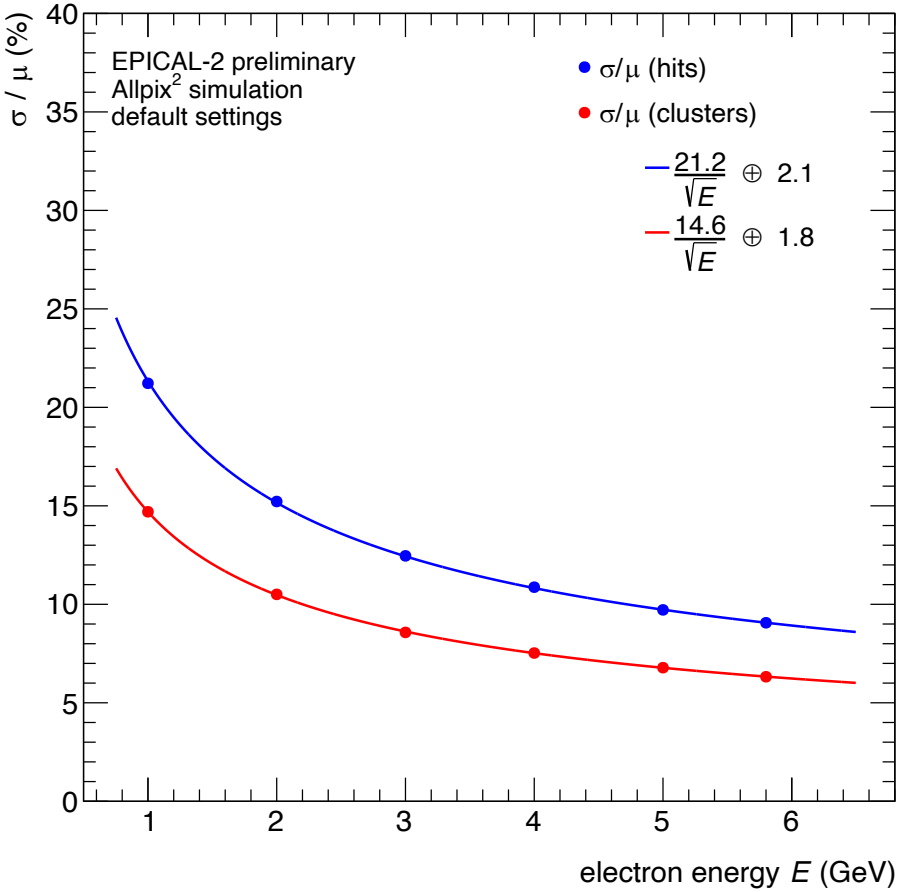
→ good linearity for mean value μ of hits in simulation

→ slightly greater deviation from linearity observed for test-beam data

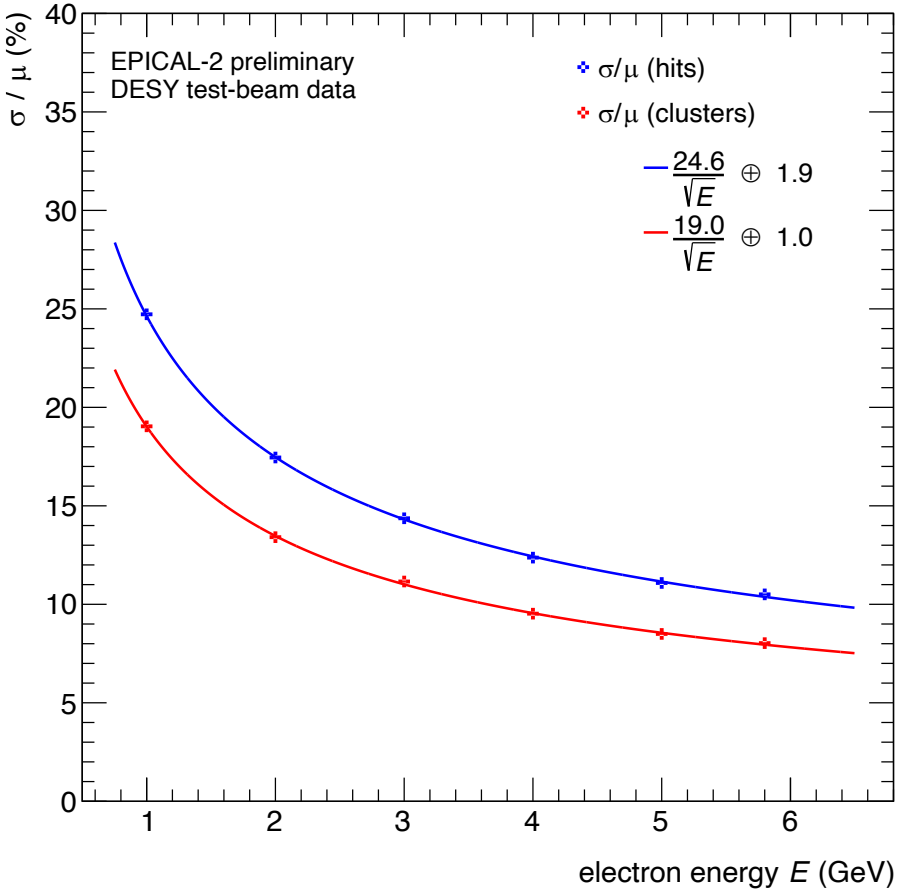
First attempt on **energy resolution**

derived from number of hits and clusters

simulation



test-beam data



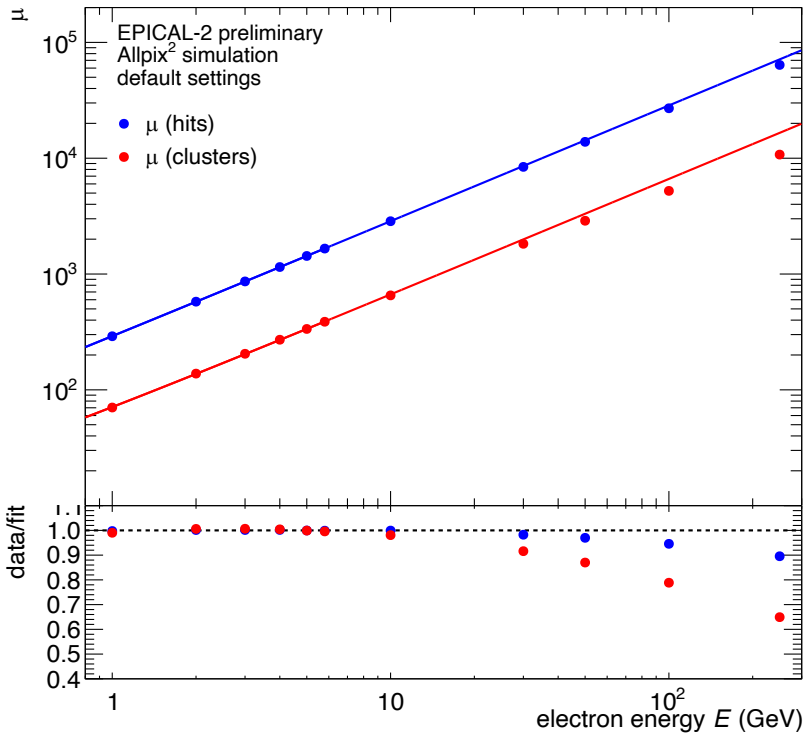
→ simulation and test-beam resolution in the same order of magnitude

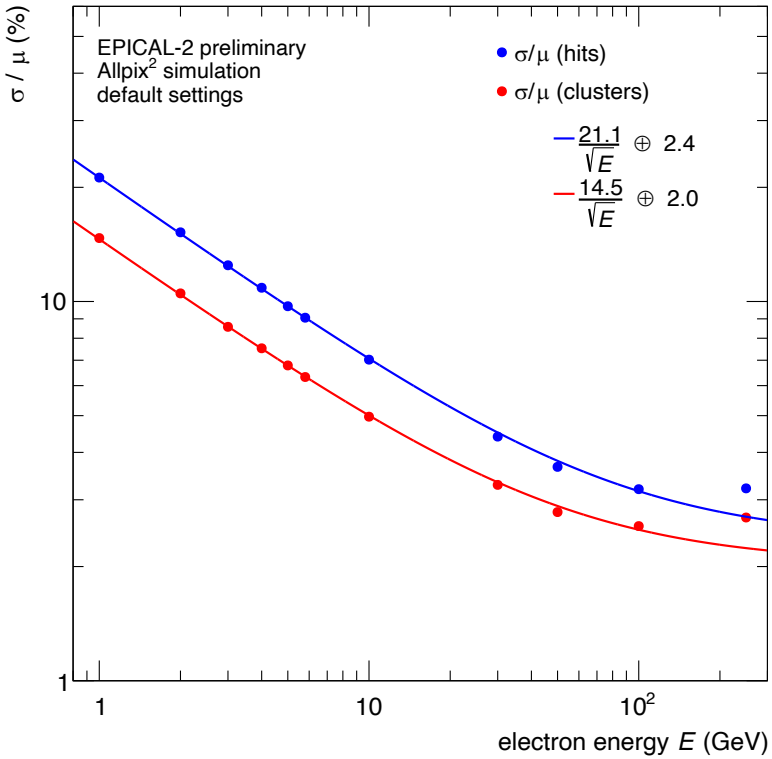
→ better energy resolution achieved for clusters than hits

→ first analysis and comparison show very good performance: work in progress

First look at higher energies

energy response and energy resolution





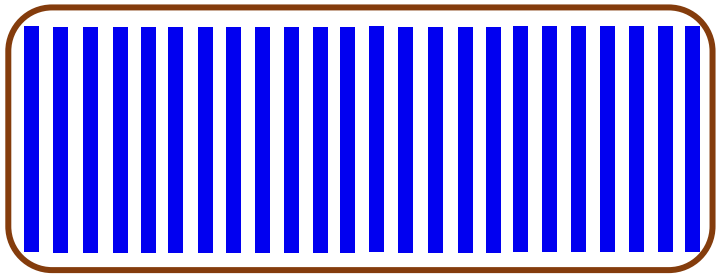
- **low energies: agreement** with **linearity** for hits and clusters, **promising energy resolution**
- **high energies: deviation** from **linearity** up to ~**10% for hits** and ~**35% for clusters, worsening of apparent energy resolution**
- resolution and linearity both affected by **leakage** for 20 X_0 detector, easy to overcome
- expect additional contribution from **cluster overlap**, possible corrections to be investigated
- note: ALPIDE sensor optimized for tracking
  → development of MAPS sensor with calorimeter-specific requirements could improve performance on timescale of any International Linear Collider use

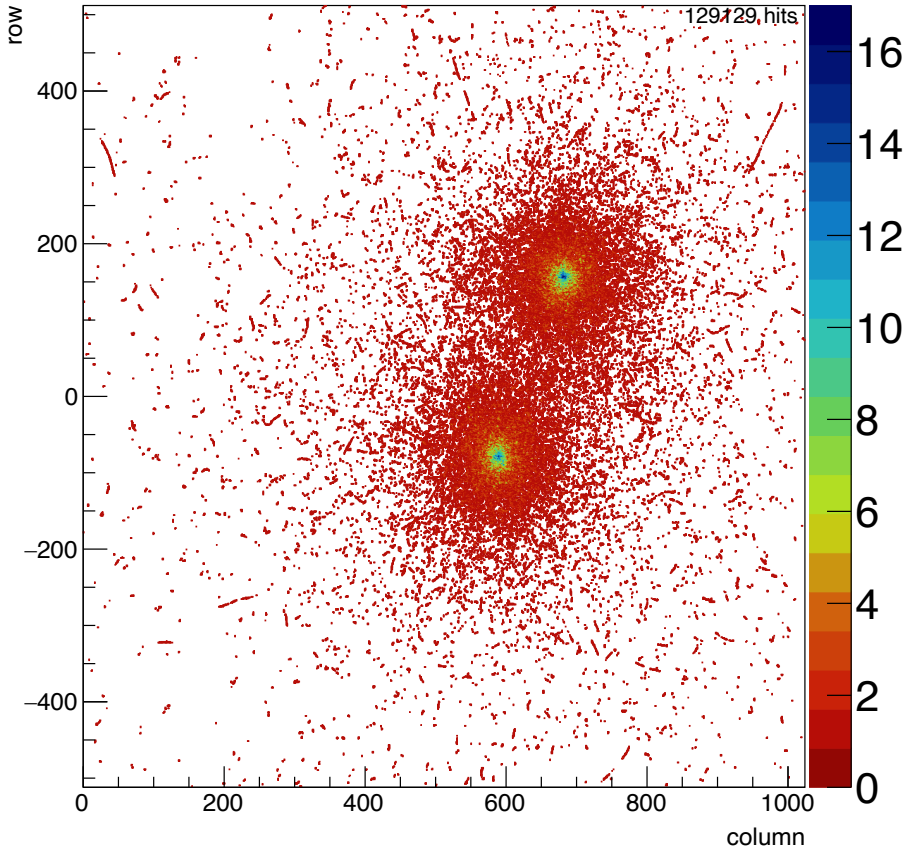
work in progress!

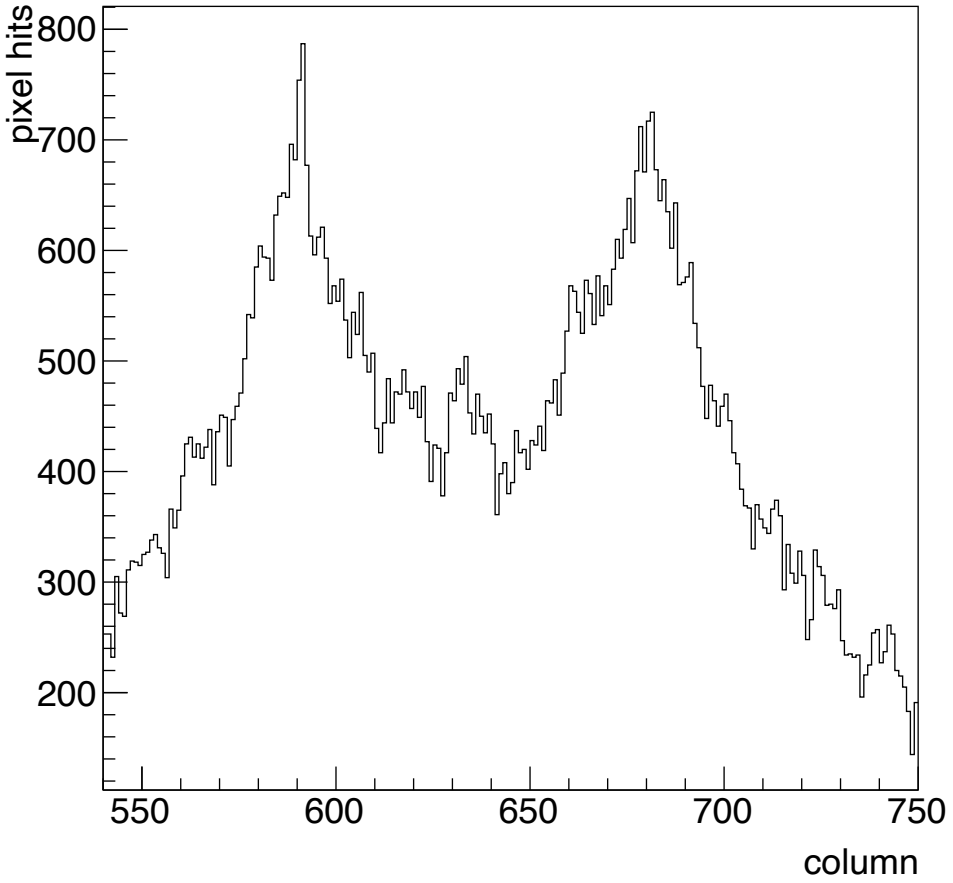
First look at higher energies

separation power

- same energy
- electrons separated by ~ 7.2 mm







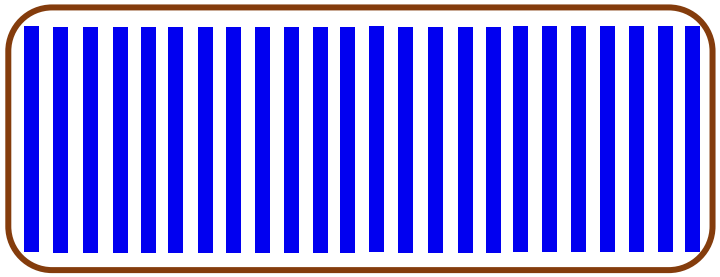
First look at higher energies

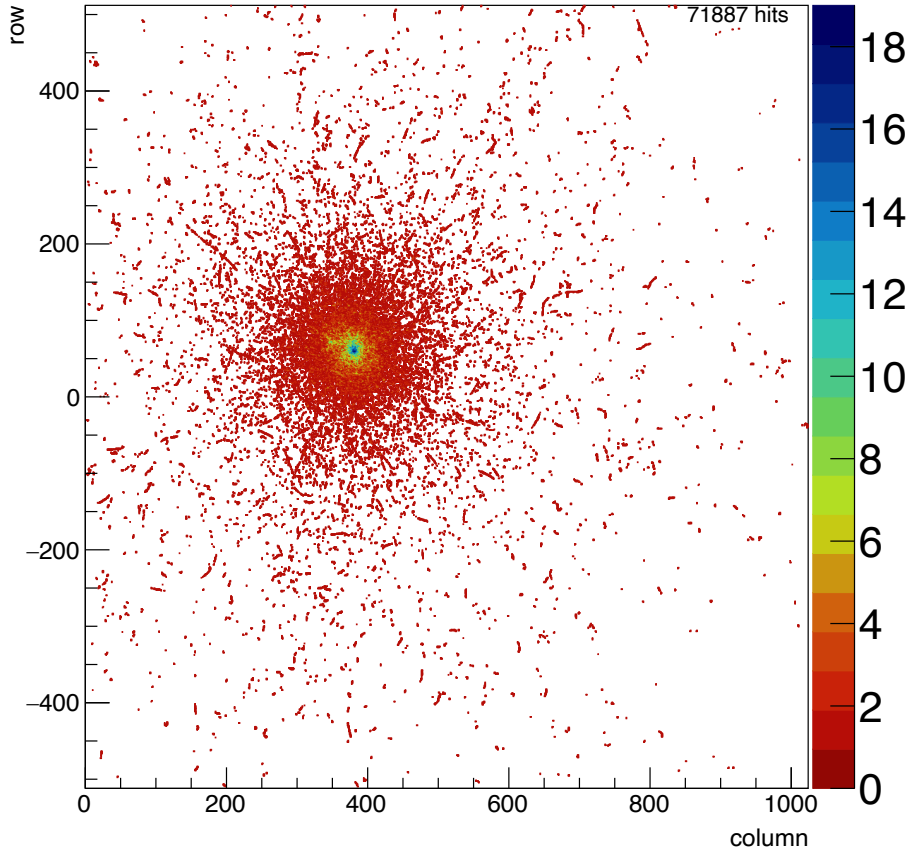
separation power

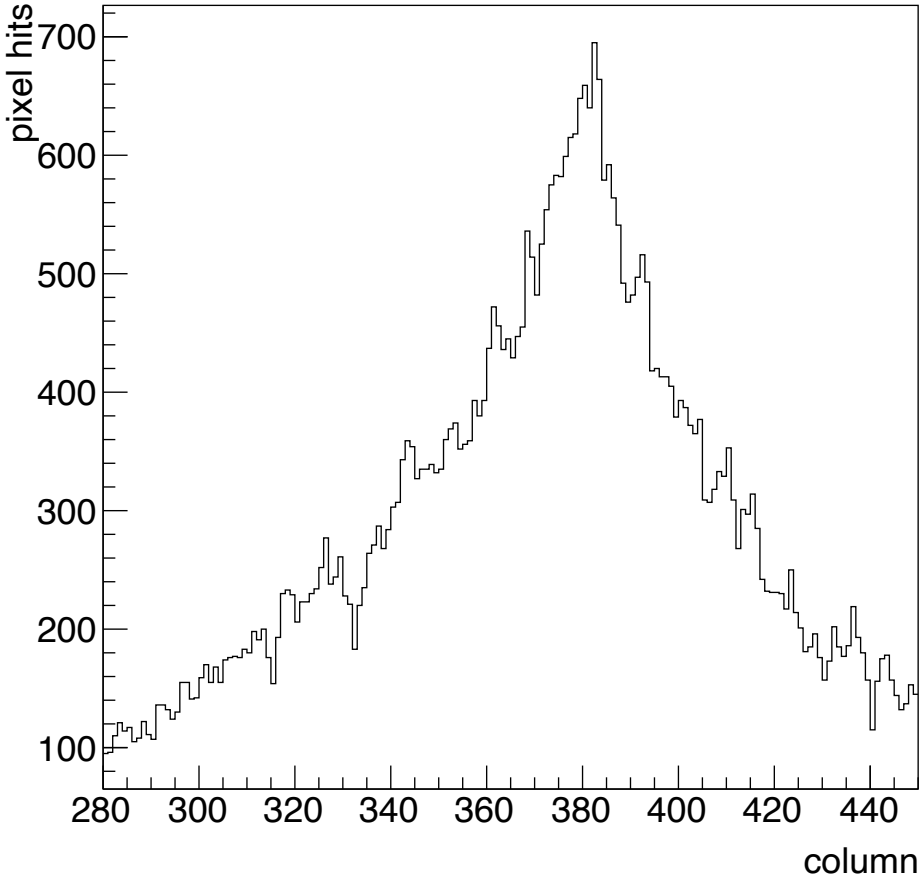
- large energy difference
- electrons close together

→ **provoking case**

250 GeV electron
30 GeV electron







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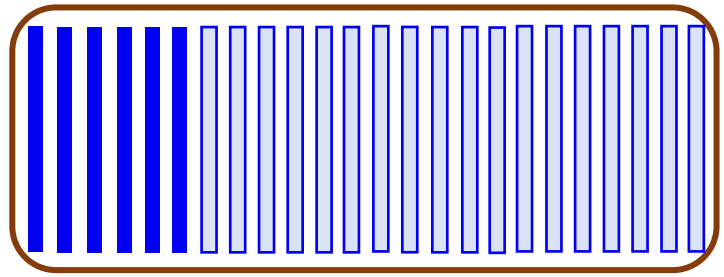
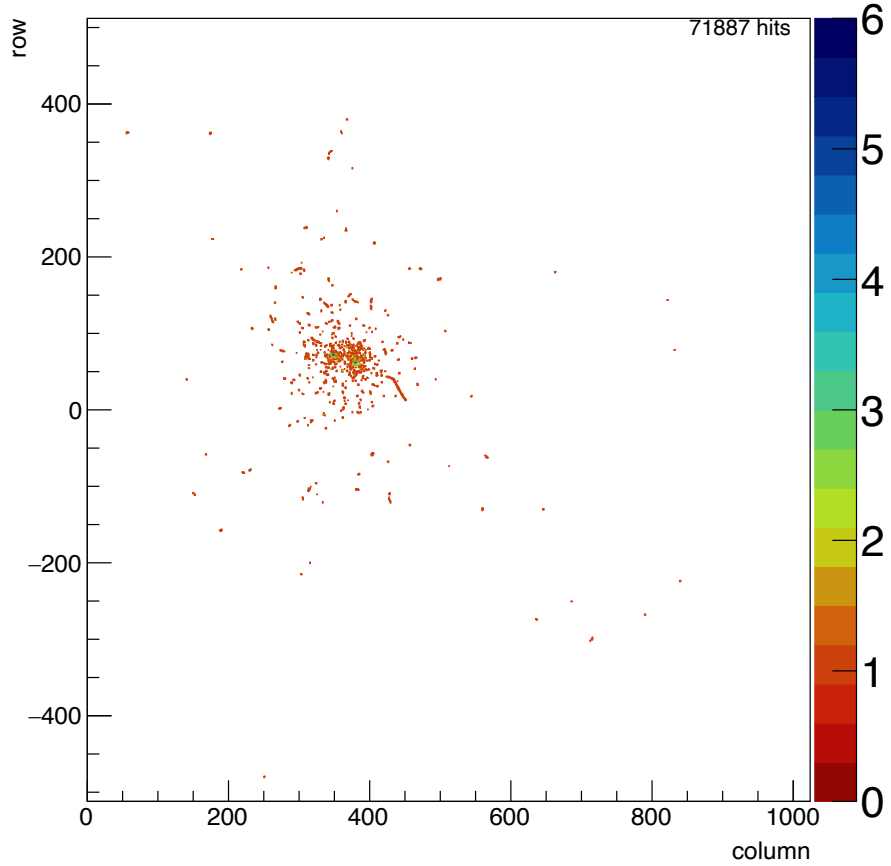
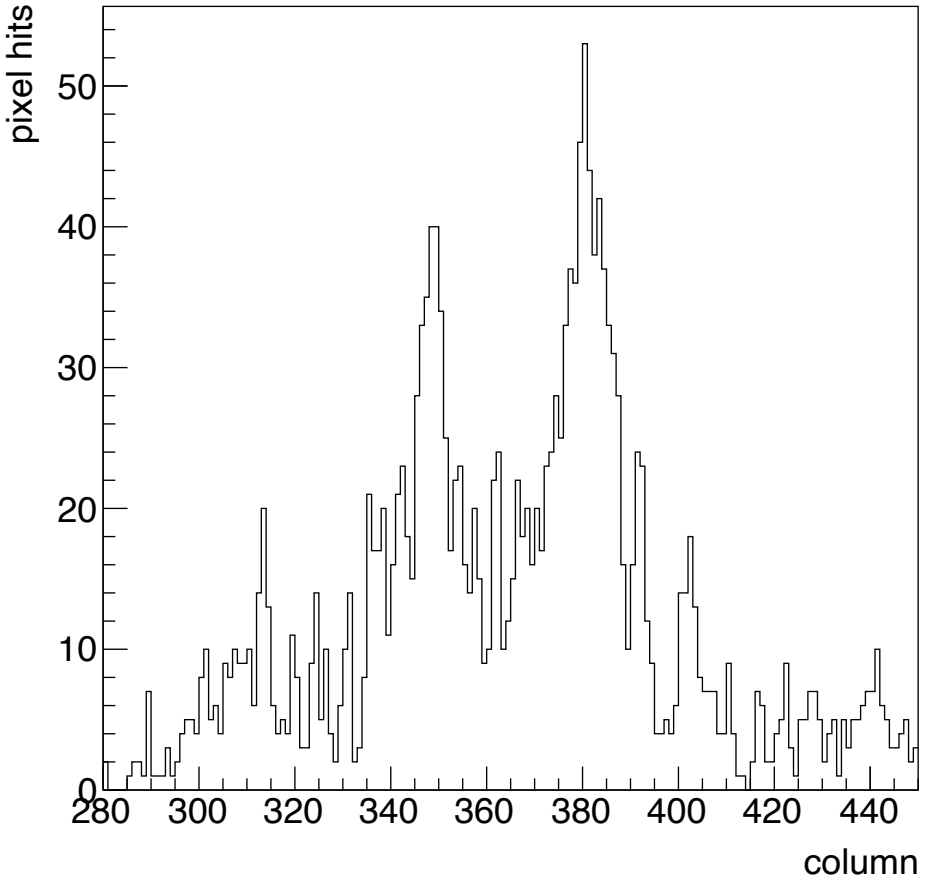


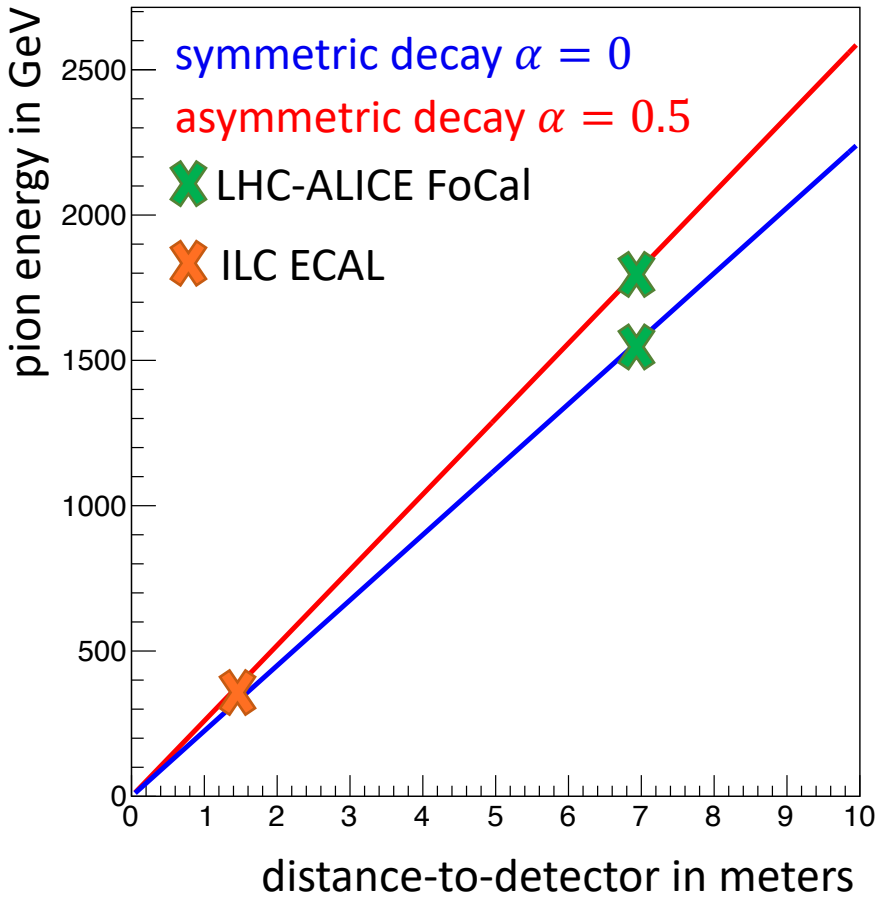


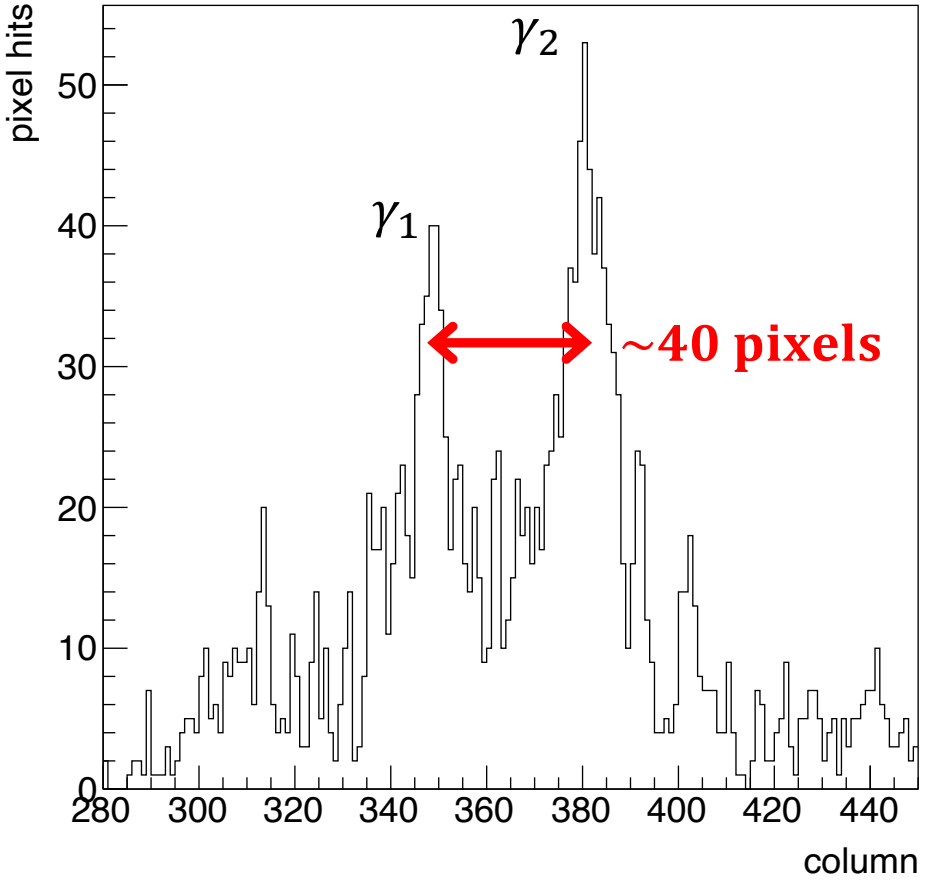


First look at higher energies

separation power …in terms of pion decay

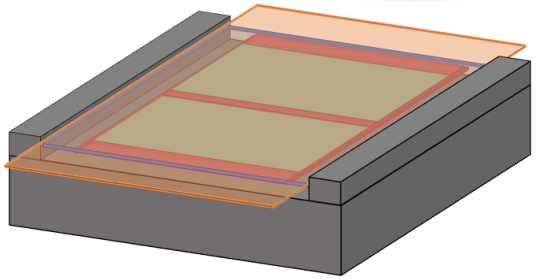
- assuming two showers emerge from photons γ_1 and γ_2 from a π^0 decay with separation $d \approx 40$ pixels $\cdot \frac{30\ \mu\text{m}}{\text{pixels}} = \mathbf{1.2\ mm}$ (conservative value)



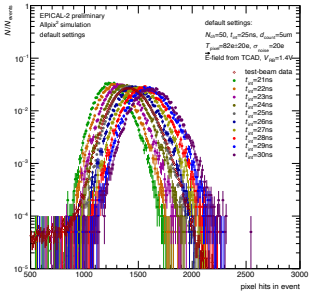


Summary

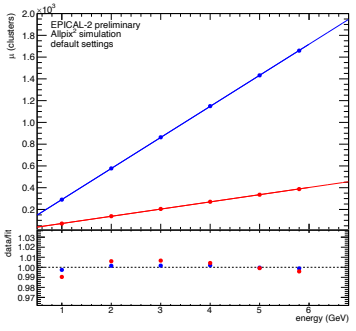
- first results obtained from **EPICAL-2 simulation utilizing Allpix²**
  → **detailed geometry** implemented
  → precise modeling of measurement process

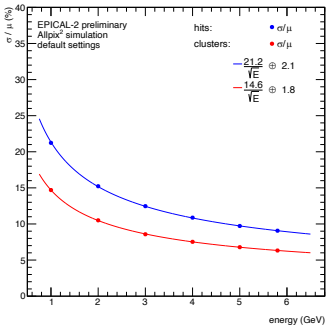


- **simulation validation** based on 5 GeV electron test-beam data



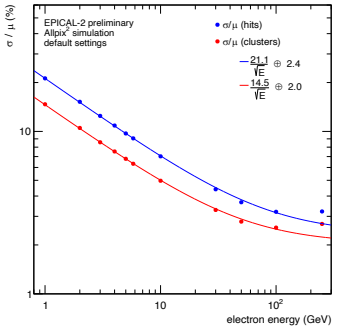
- investigation of **bulk properties** in EPICAL-2 simulation for test-beam energies
  → number of hits and clusters
  → energy resolution and linearity

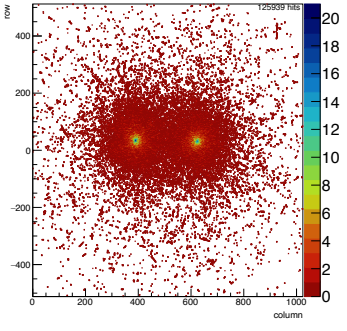




→ **EPICAL-2 simulation describes test-beam data**

- **first look at higher energies**
  → promising energy resolution
  → shower-separation capabilities





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