

Sensor-level simulation of MAPS ECAL test-beam data

2nd Allpix Squared User Workshop

17 – 19 August 2021

Tim Rogoschinski





ALICE

MAPS ECAL in context of: Forward Calorimeter (FoCal)

conceptual design

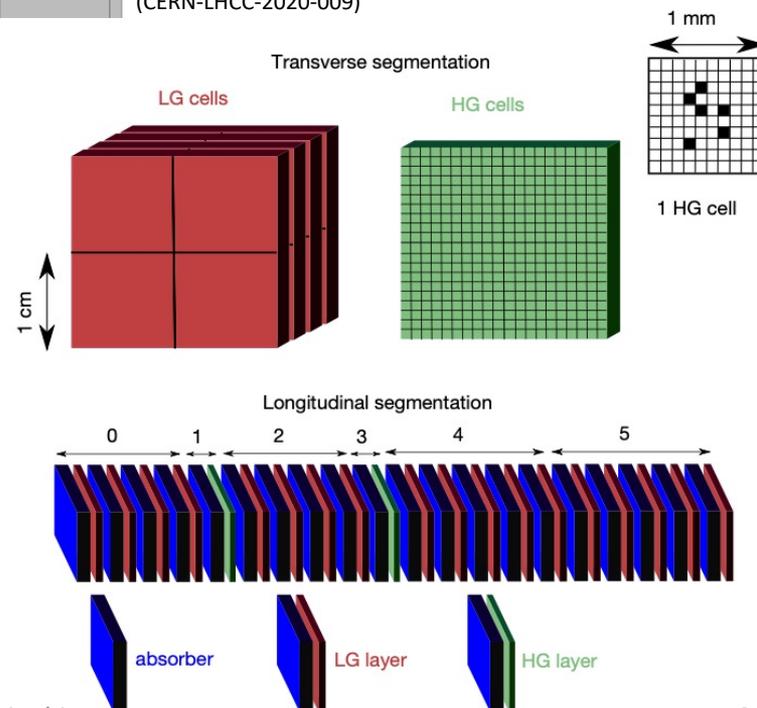
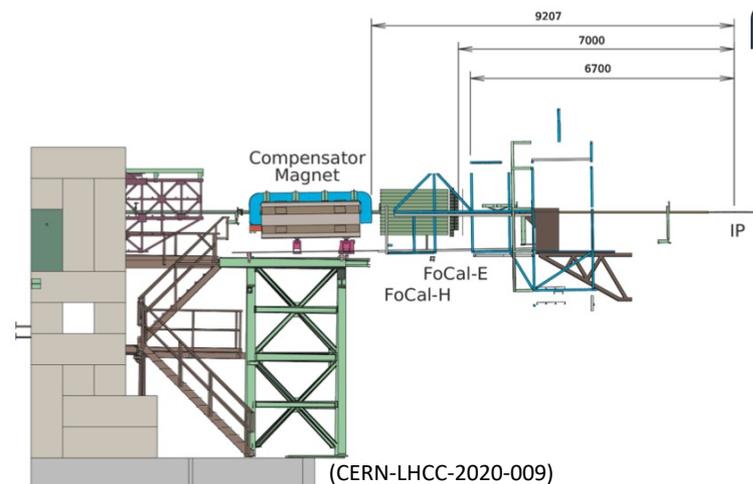
- upgrade of the LHC-ALICE experiment:
FoCal

- installation planned in ~2026
- SiW sandwich calorimeter
- $3.4 \leq \eta \leq 5.8, z = 7 \text{ m}$

- two components:

- 1) hadronic (FoCal-H) and
- 2) **electromagnetic calorimeter (FoCal-E)**

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



Electromagnetic Pixel Calorimeter 2 (EPICAL-2)

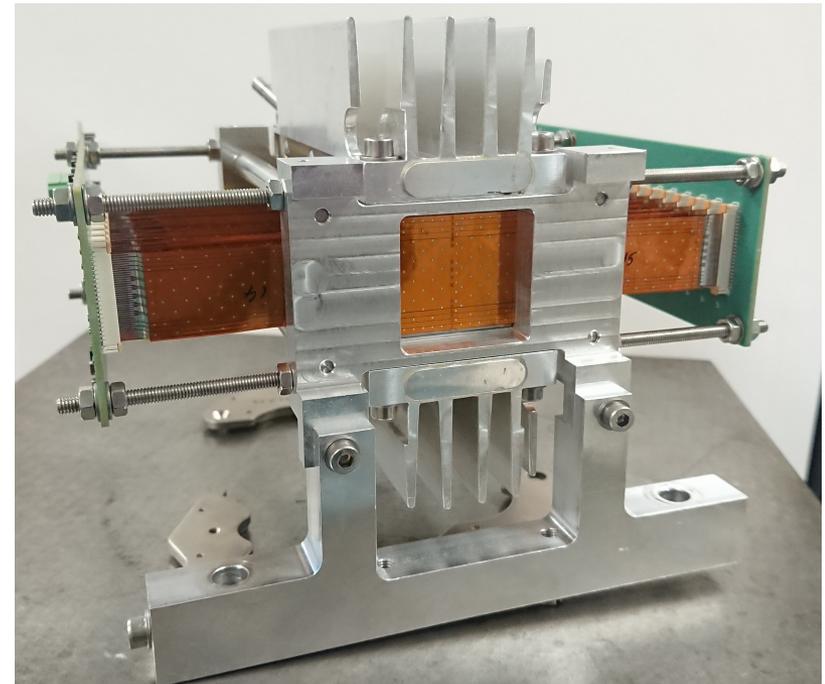
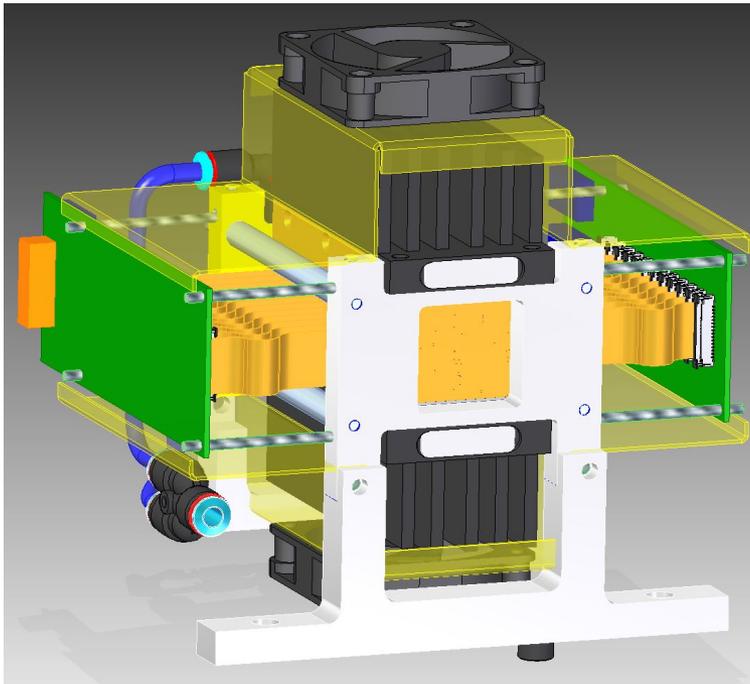
- **second MAPS ECAL prototype:**
 - related to Bergen pCT Collaboration
 - in context of R&D for planned LHC-ALICE FoCal upgrade in ~2026
 - **fully digital calorimeter** prototype

project goal:

demonstrate **suitability of ALPIDE** as solution for **FoCal high-granularity layers**

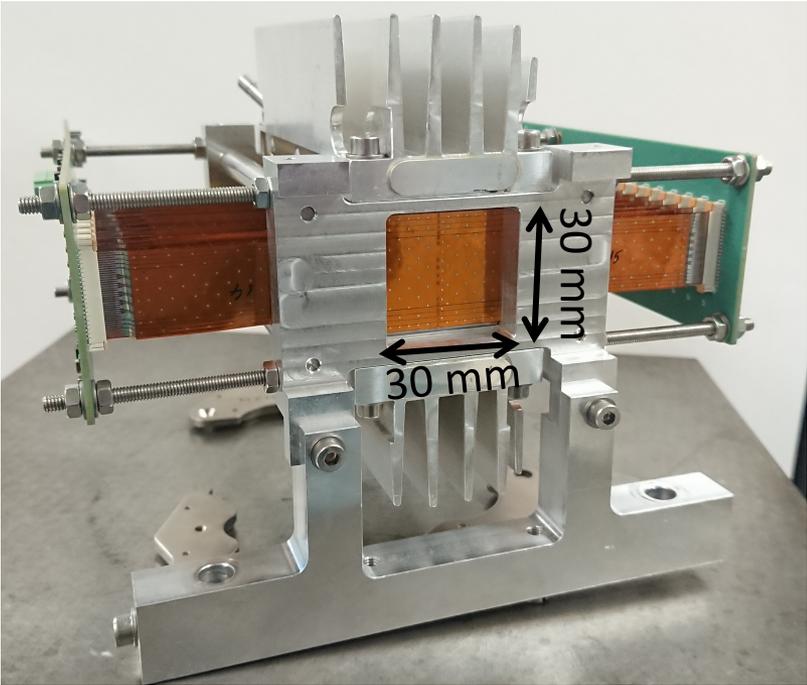
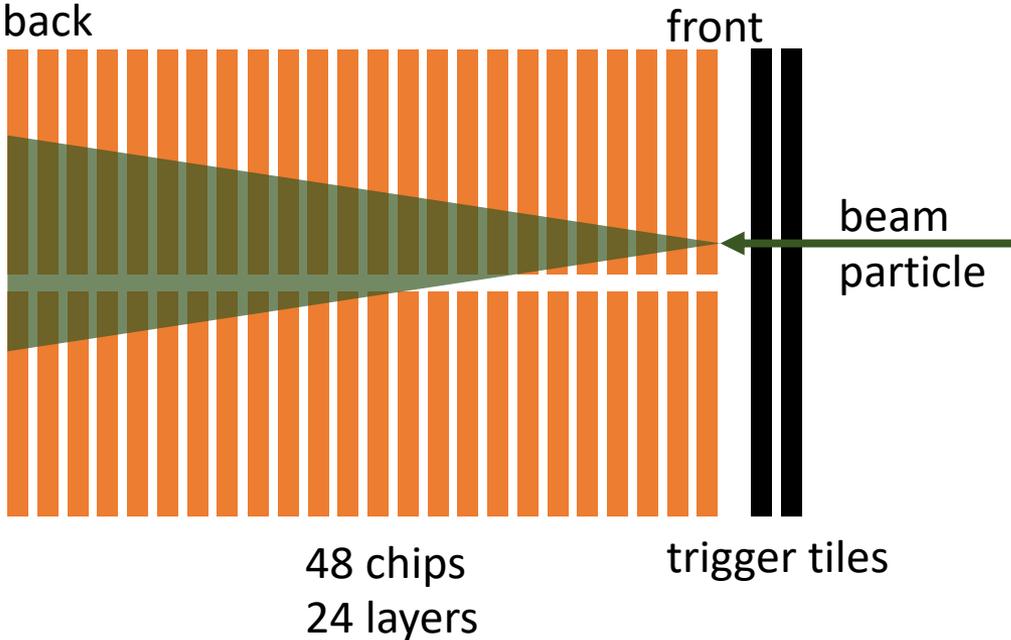
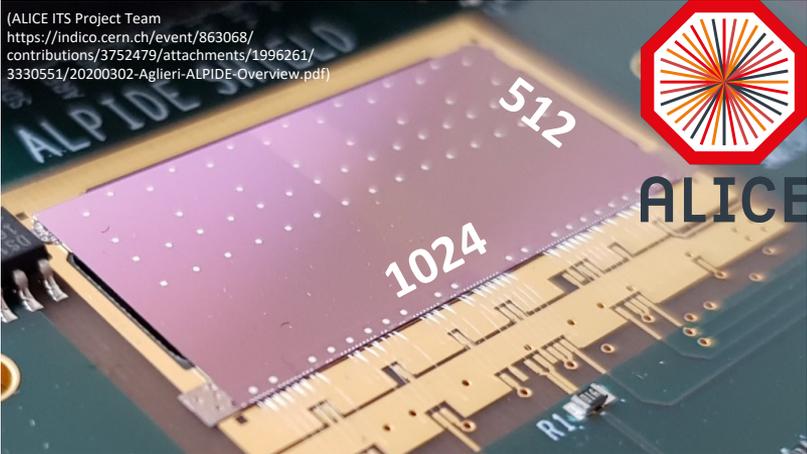
→ high particle density

→ two-shower separation



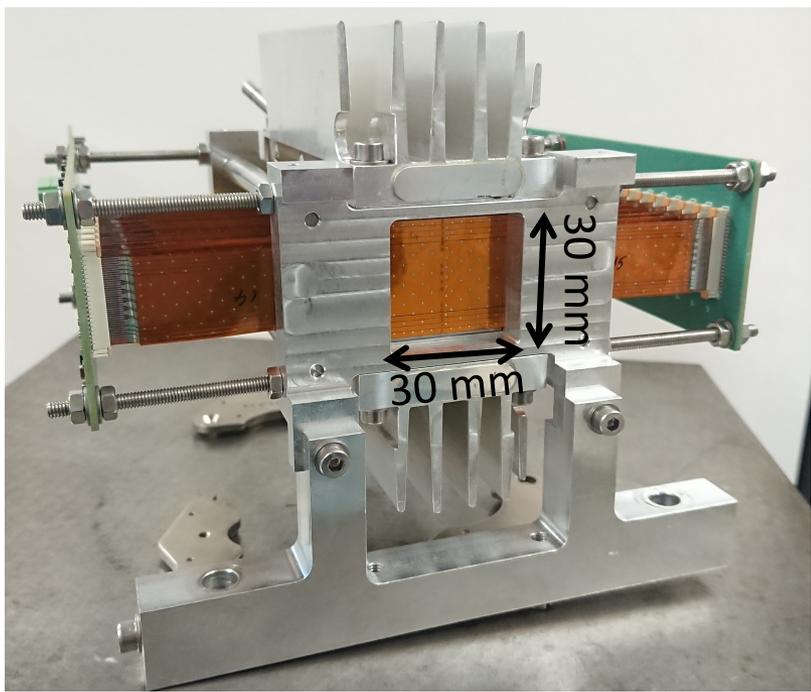
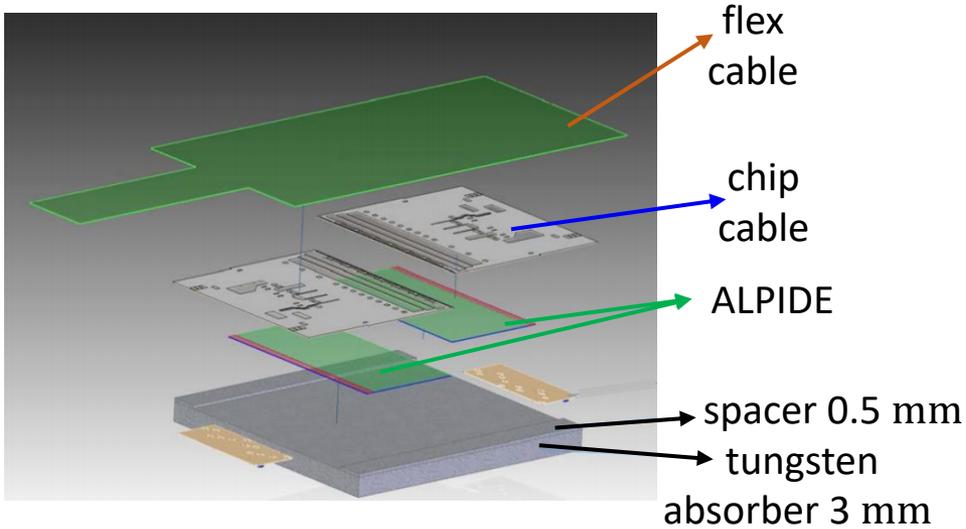
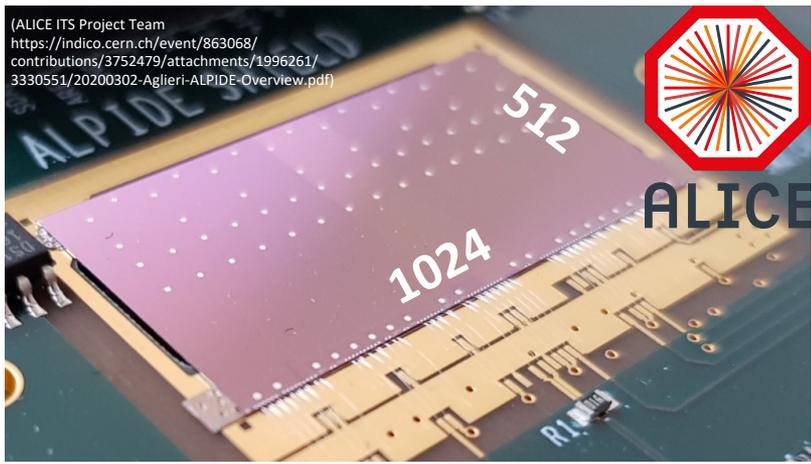
Electromagnetic Pixel Calorimeter 2 (EPICAL-2)

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 - 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



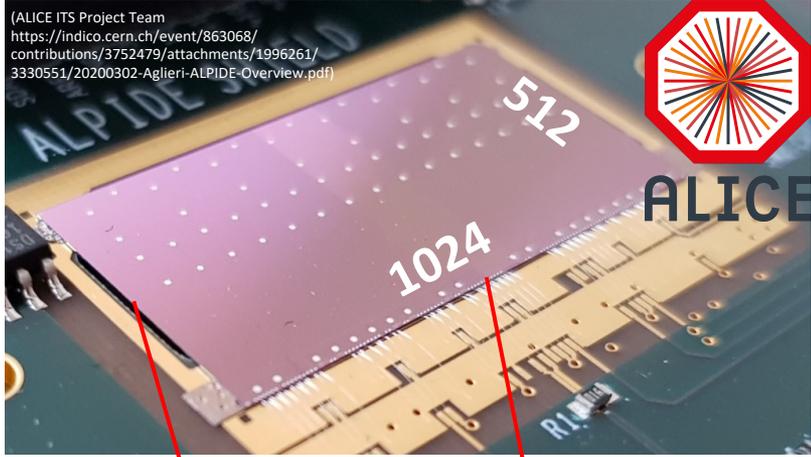
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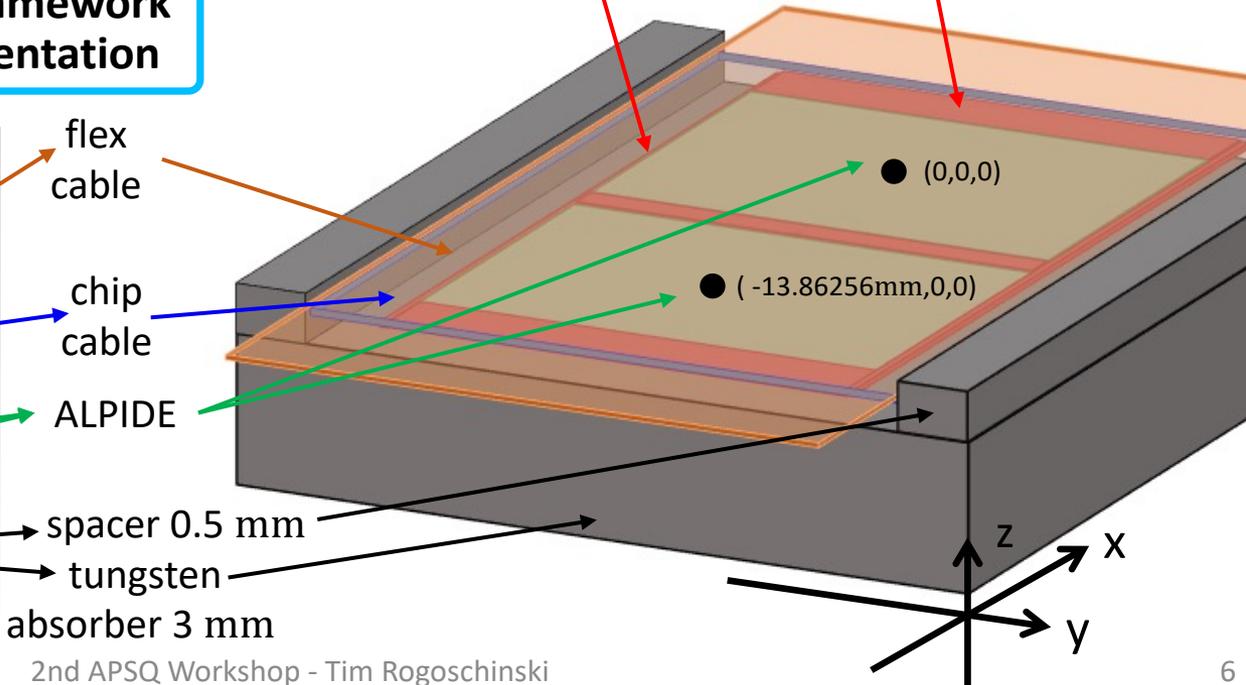
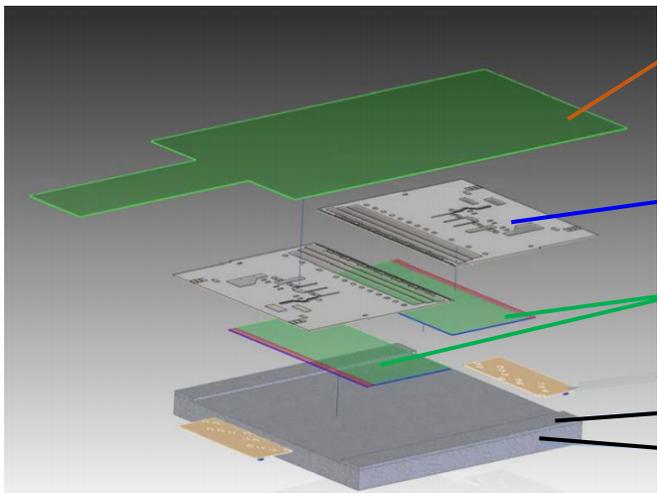


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- **simulation utilizing Allpix² framework**
 - **precise geometry implementation**

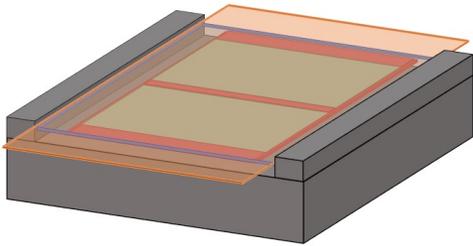


implemented as passive silicon



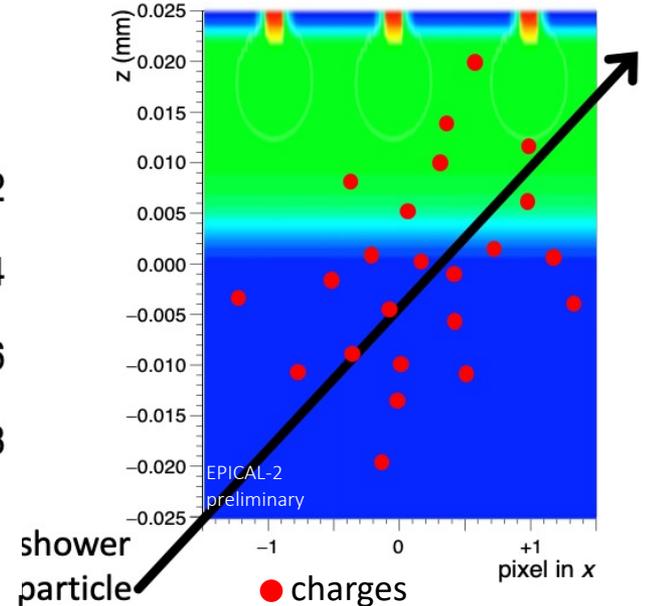
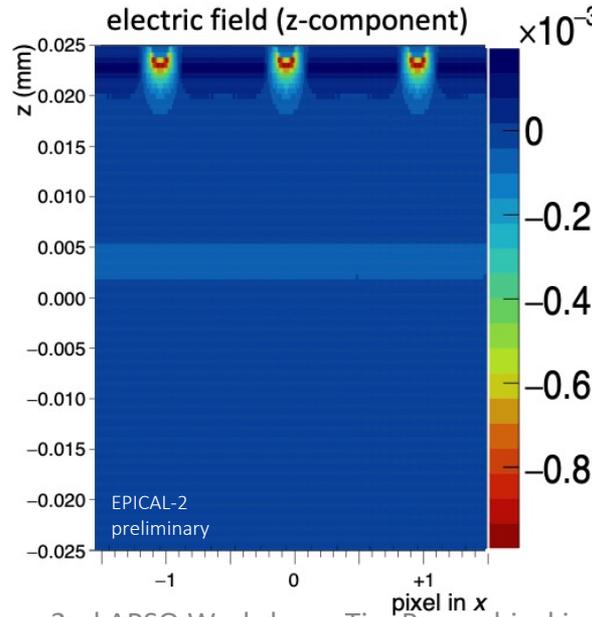
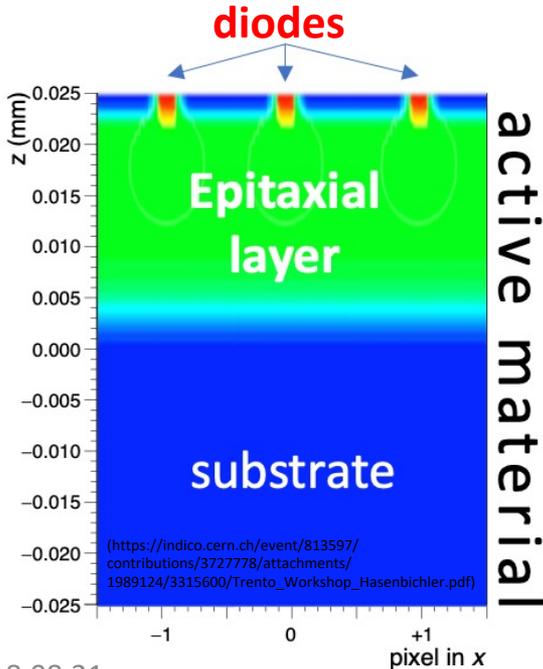
EPICAL-2 simulation utilizing Allpix²

simulation chain:



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

- **FTFP_BERT_EMZ**
- beam profiles via **GPS**



EPICAL-2 simulation utilizing Allpix²



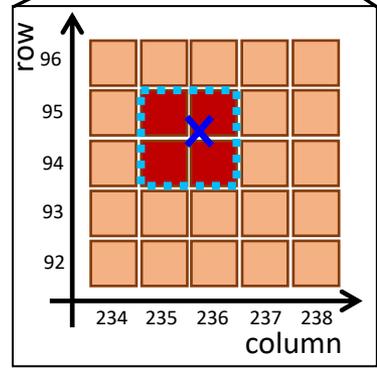
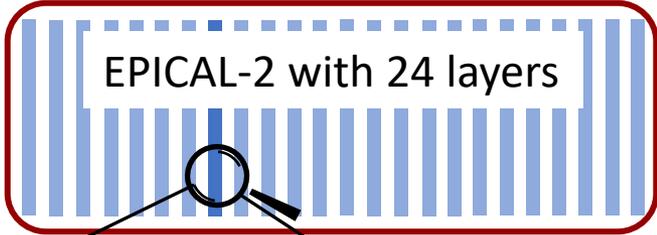
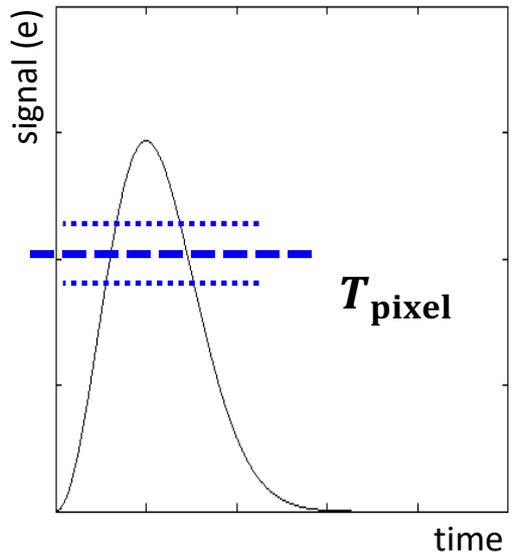
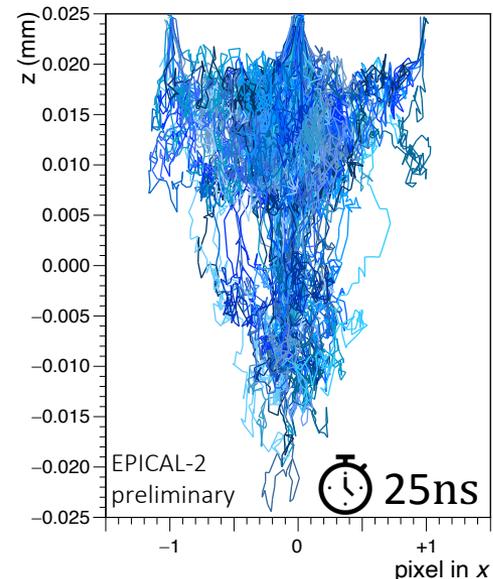
simulation chain:



- 50 charges per group
- integration time $t_{\text{int}} = 25 \text{ ns}$
- collection from implant

- electronic noise $\sigma_{\text{noise}} = 20 \text{ e}$
- pixel-threshold value and smearing $T_{\text{pixel}} = 82 \text{ e} \pm 20 \text{ e}$

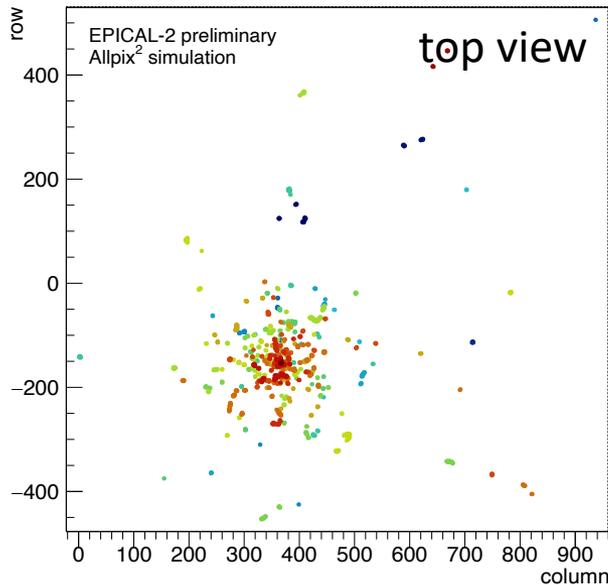
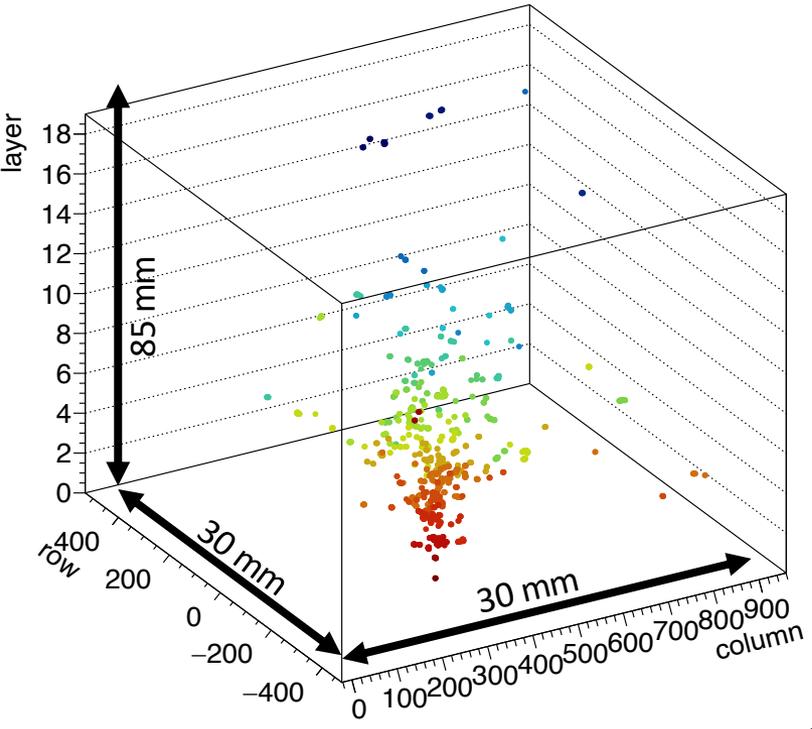
- 2D information of hits per layer \rightarrow column and row



“measurement”:
 \rightarrow number N_{hits} of pixel hits
 \rightarrow number N_{clusters} of clusters

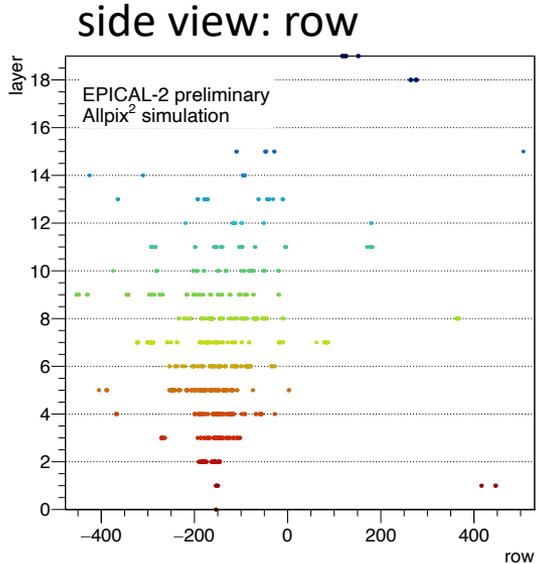
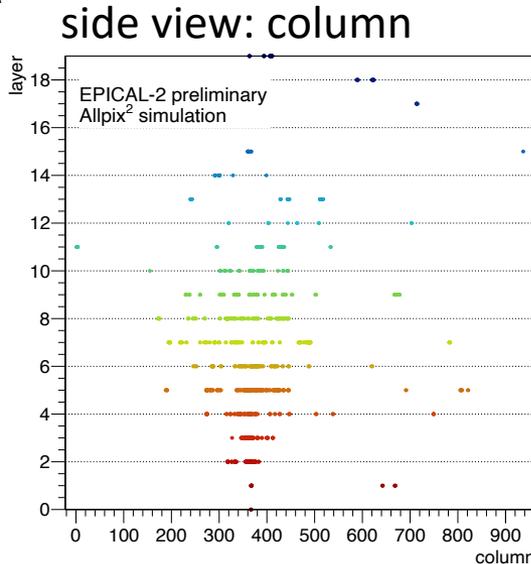
x shower particle ■ cluster
 ■ pixel with hit ■ pixel without hit

Event display: 5 GeV electron event



color code
 → layer 0 to 23

→ detailed evolution of shower

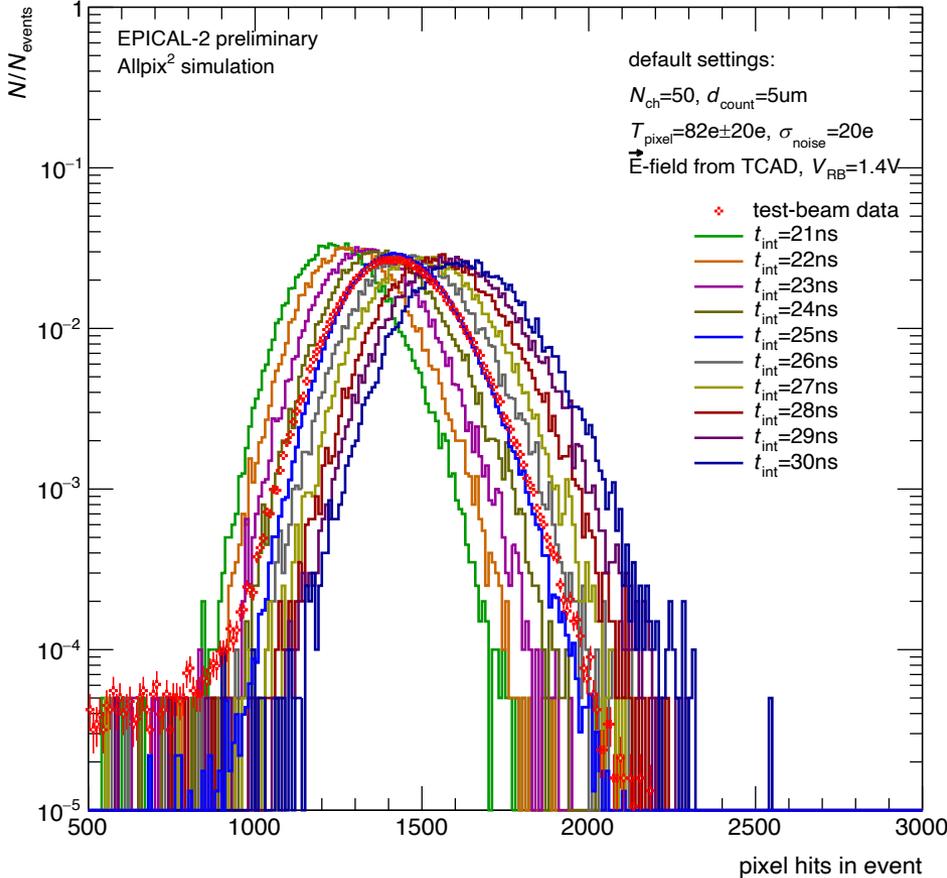


EPICAL-2 simulation validation I

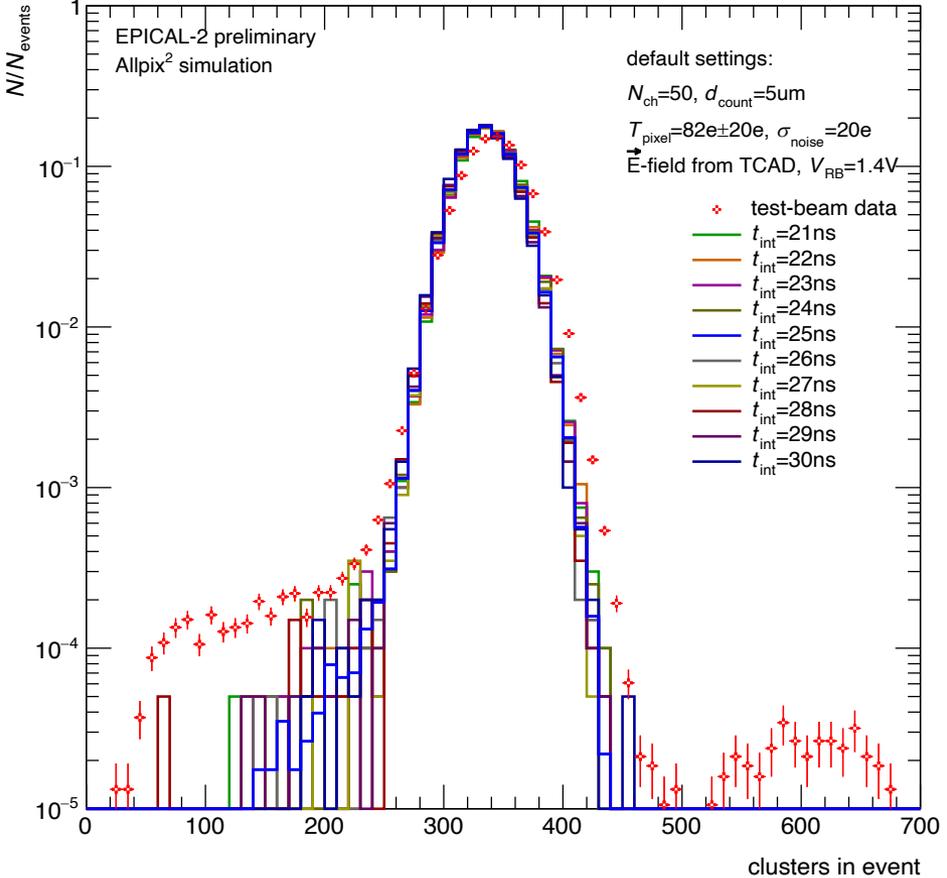
by means of 5 GeV electron test-beam data

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

number of pixel hits



number of clusters



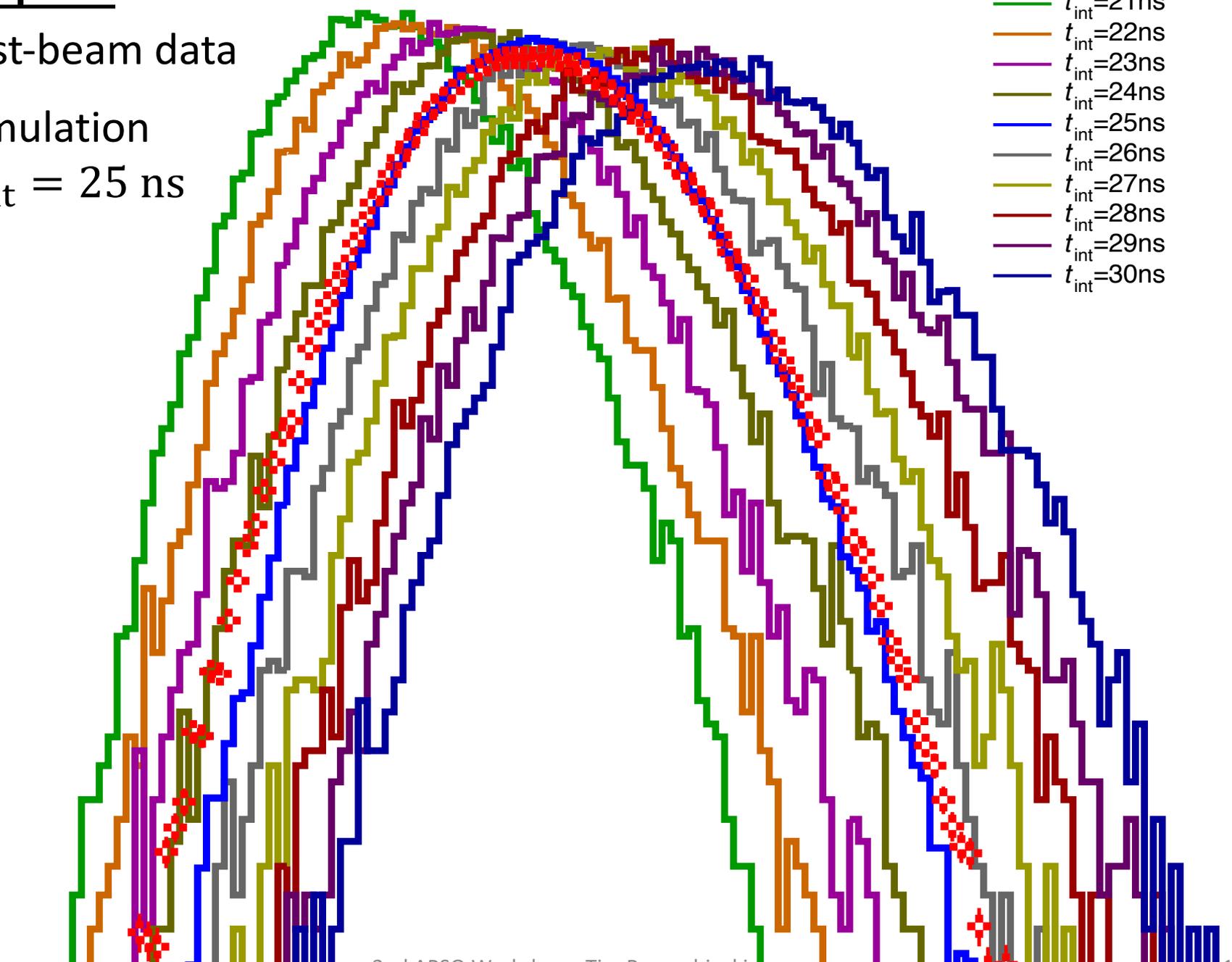
To compare:

 test-beam data

simulation

$t_{\text{int}} = 25 \text{ ns}$

-  test-beam data
-  $t_{\text{int}} = 21 \text{ ns}$
-  $t_{\text{int}} = 22 \text{ ns}$
-  $t_{\text{int}} = 23 \text{ ns}$
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-  $t_{\text{int}} = 28 \text{ ns}$
-  $t_{\text{int}} = 29 \text{ ns}$
-  $t_{\text{int}} = 30 \text{ ns}$

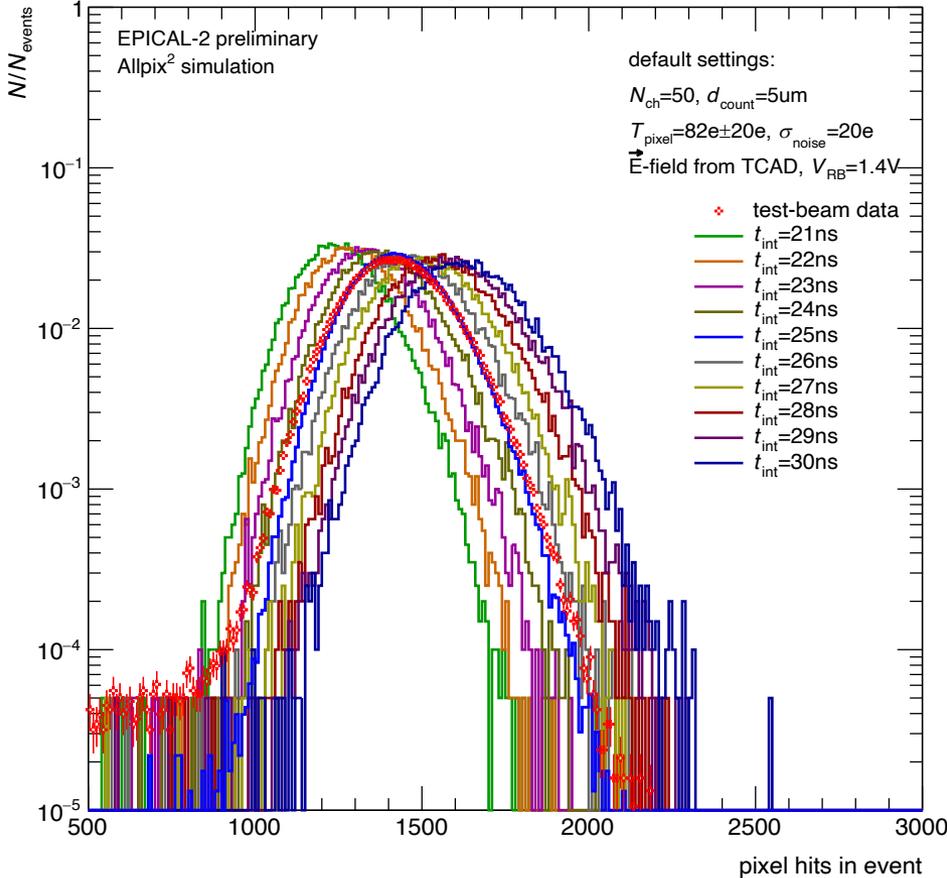


EPICAL-2 simulation validation I

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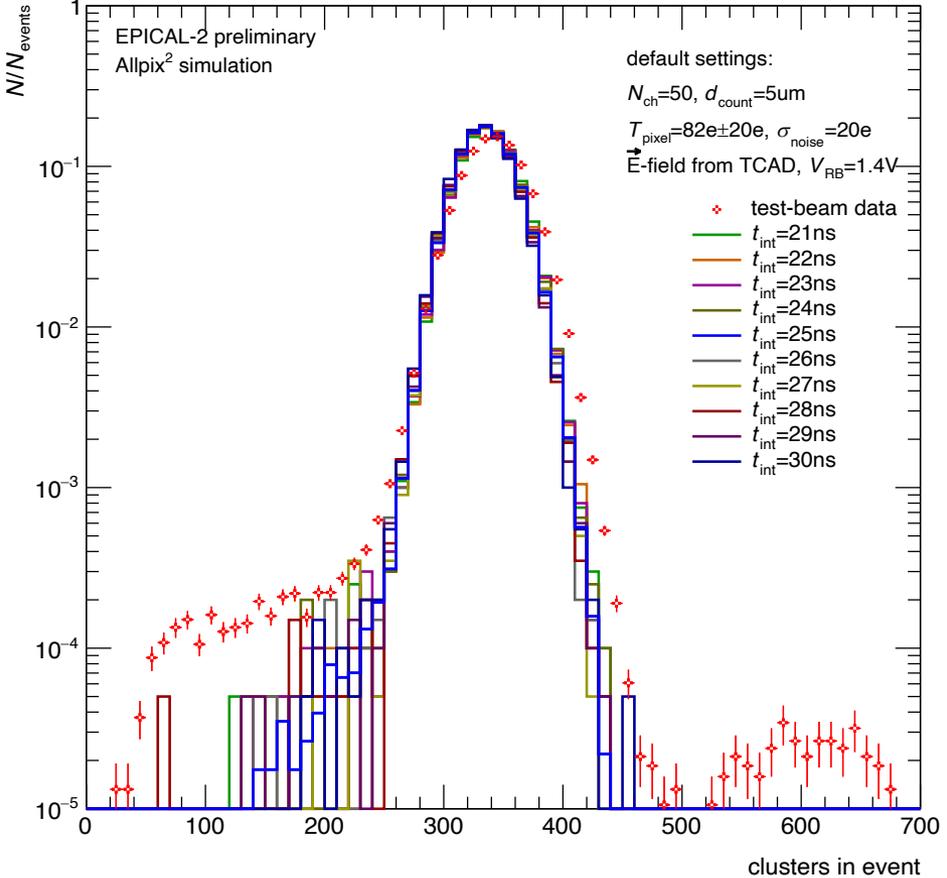
→ data taking at DESY Hamburg: similar data structure like simulation output

number of pixel hits



→ narrower tails in simulation

number of clusters



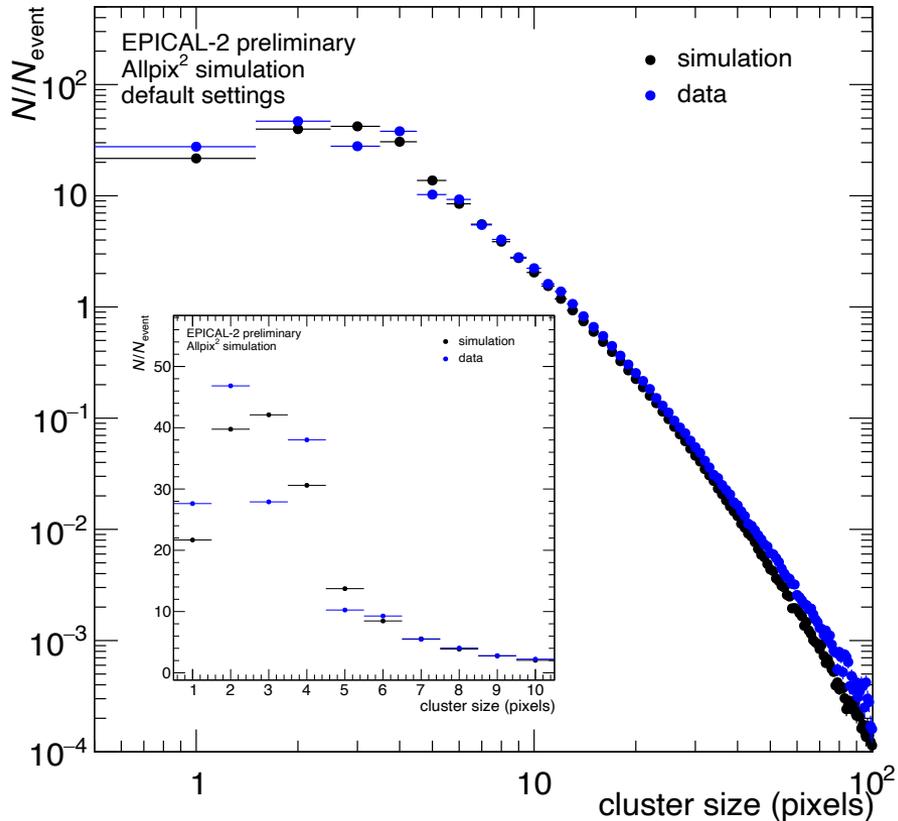
→ slightly lower mean values in simulation

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

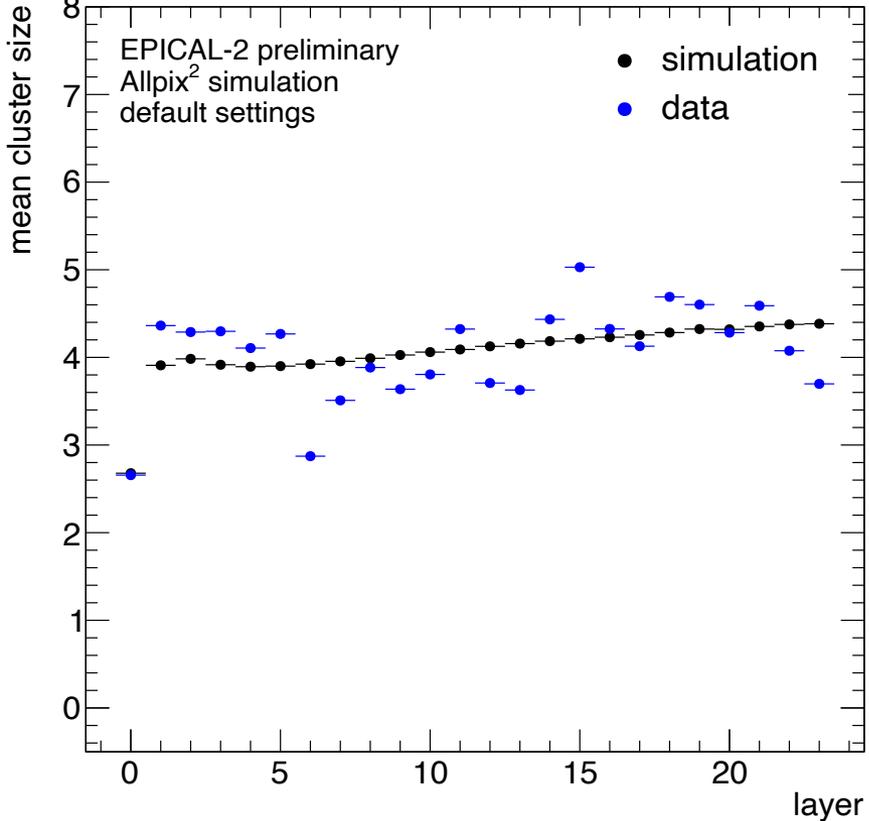
EPICAL-2 simulation validation II

by means of 5 GeV electron test-beam data

cluster-size distribution



mean cluster size



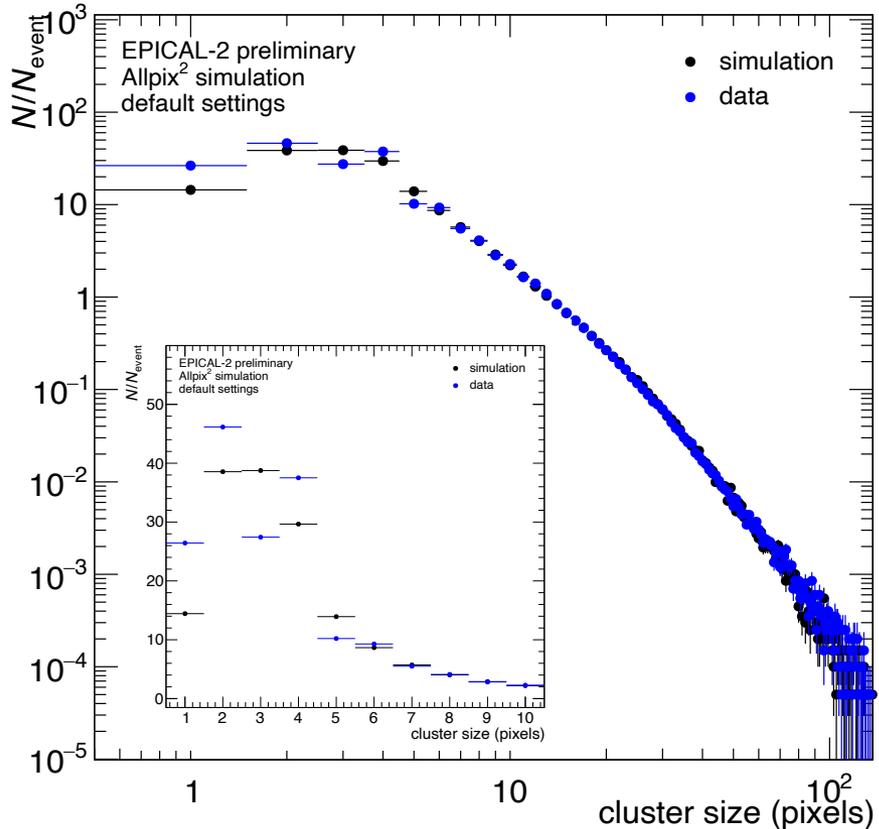
- small deviations for small clusters
- fewer large clusters in simulation

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

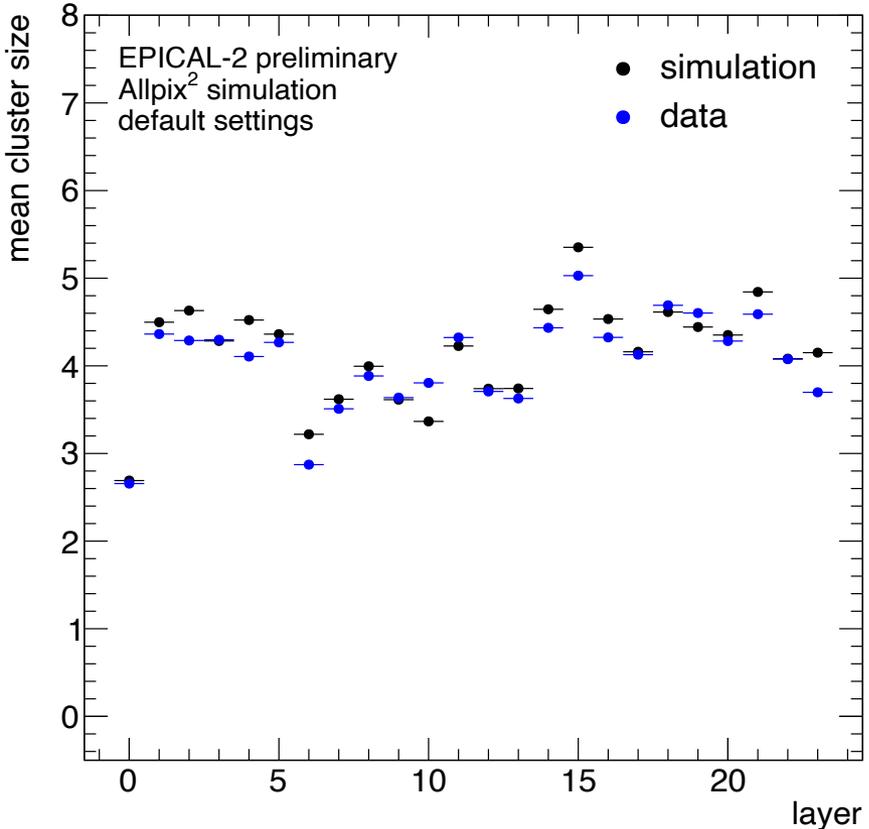
EPICAL-2 simulation validation II

by means of 5 GeV electron test-beam data

cluster-size distribution



mean cluster size



here: individual pixel threshold per chip according to test-beam setup

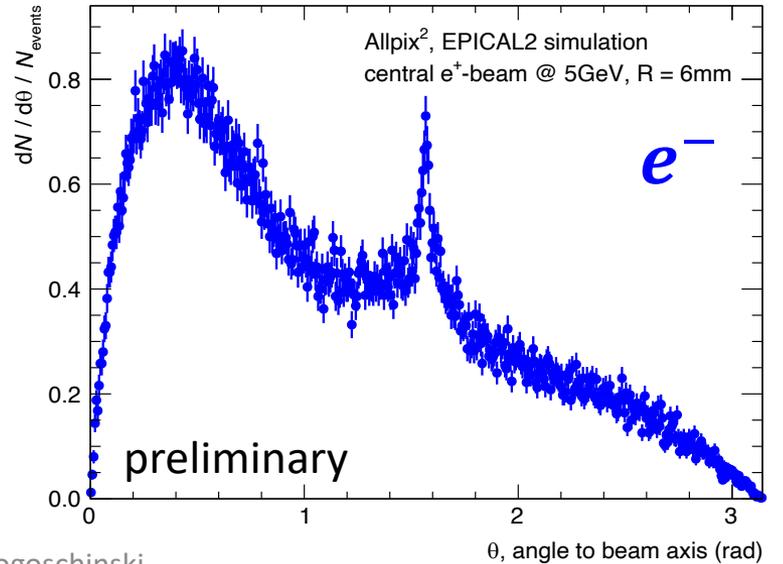
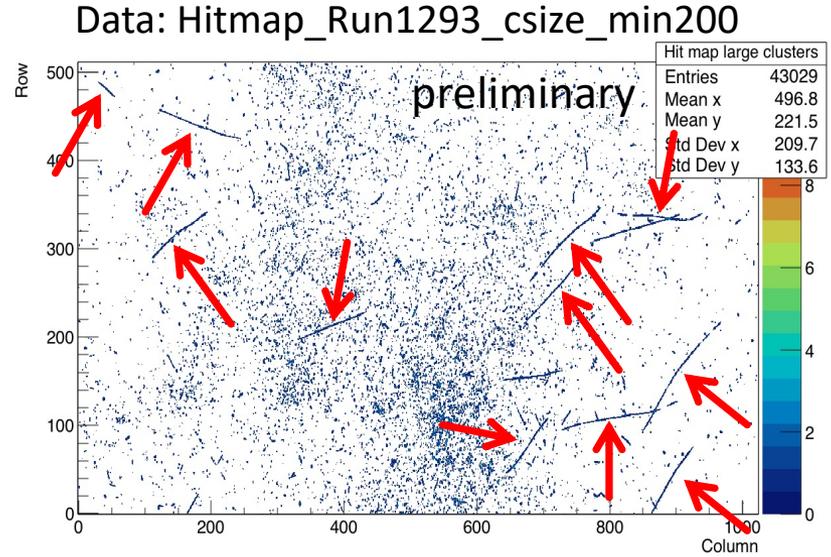
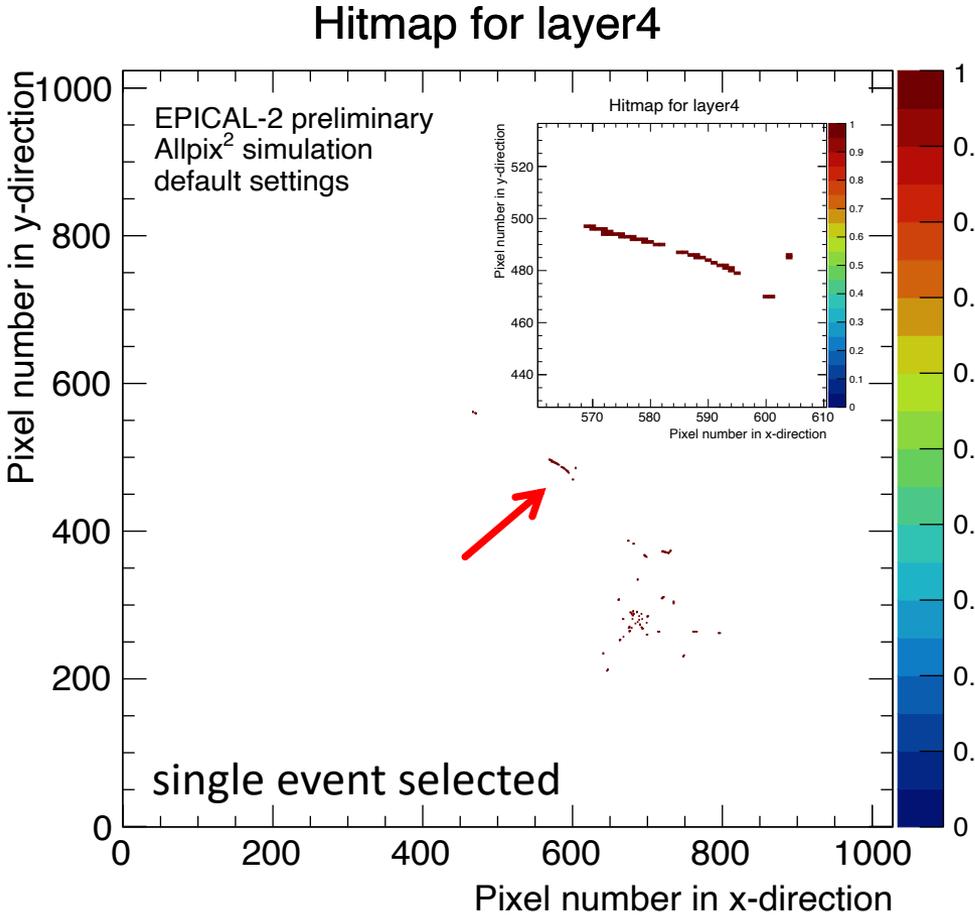
(only on this slide)

EPICAL-2 simulation validation |||

by means of 5 GeV electron test-beam data

track-like hit structures

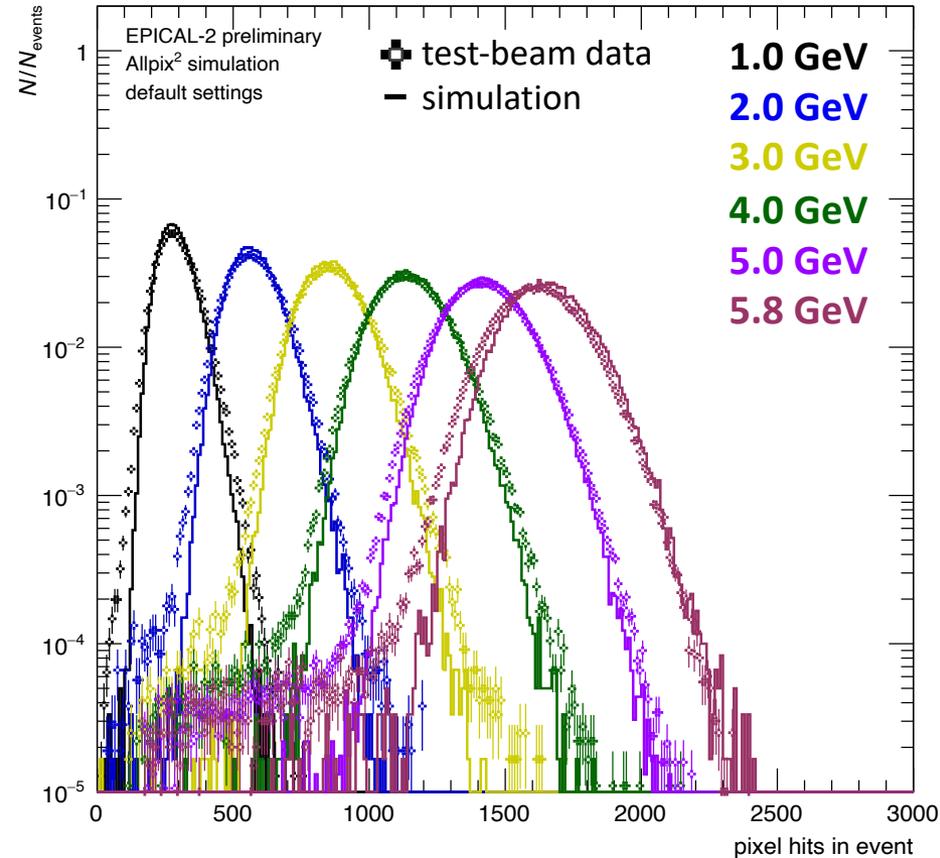
- very large clusters
- present in simulation - to be investigated



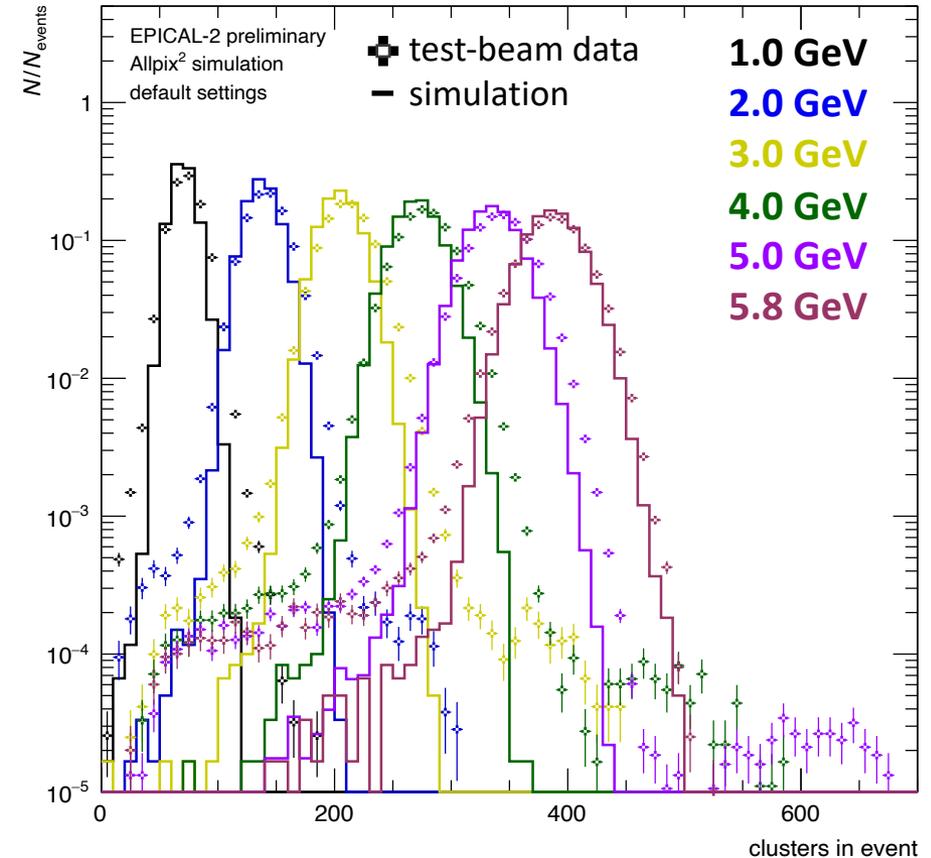
Number of hits and clusters

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

number of pixel hits



number of clusters

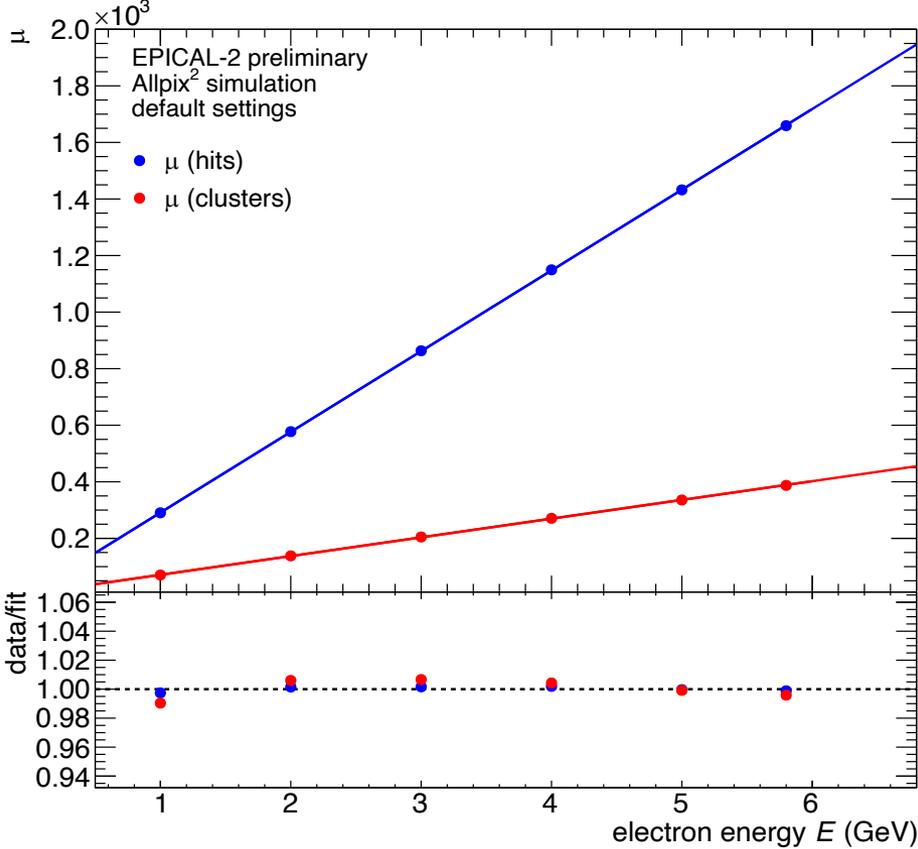


- simulation describes test-beam measurement
- essential for energy response and energy resolution
- extraction of mean μ and standard deviation σ from histograms

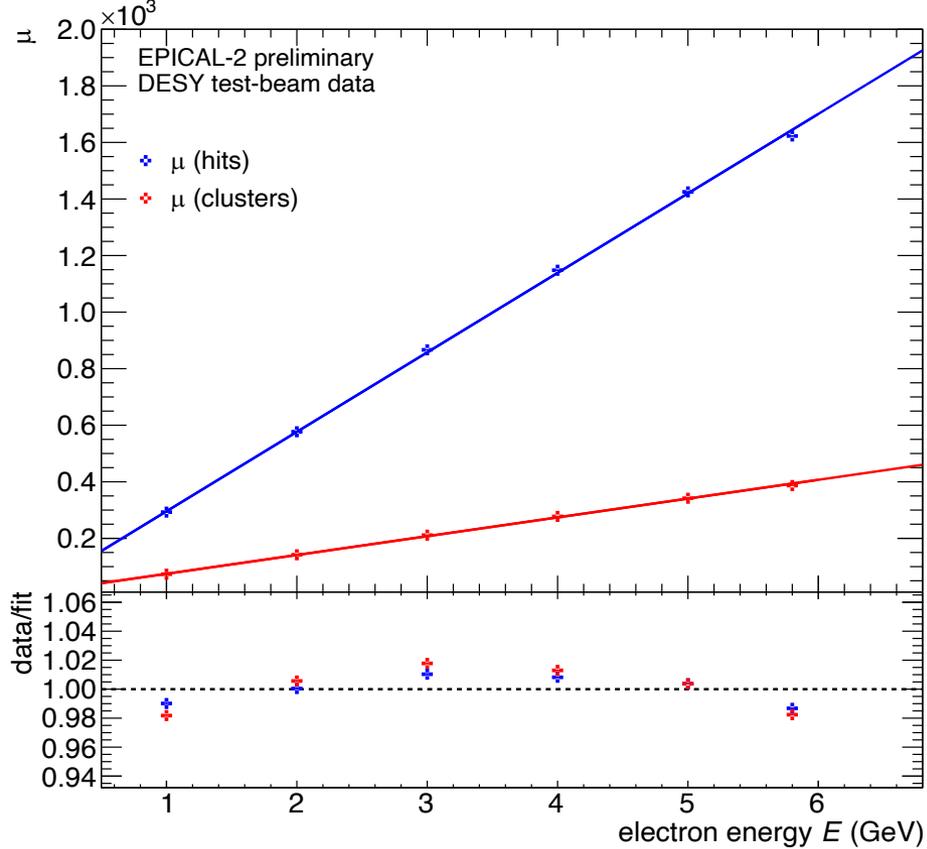
First attempt on energy response: linearity

derived from number of hits and clusters

simulation



test-beam data



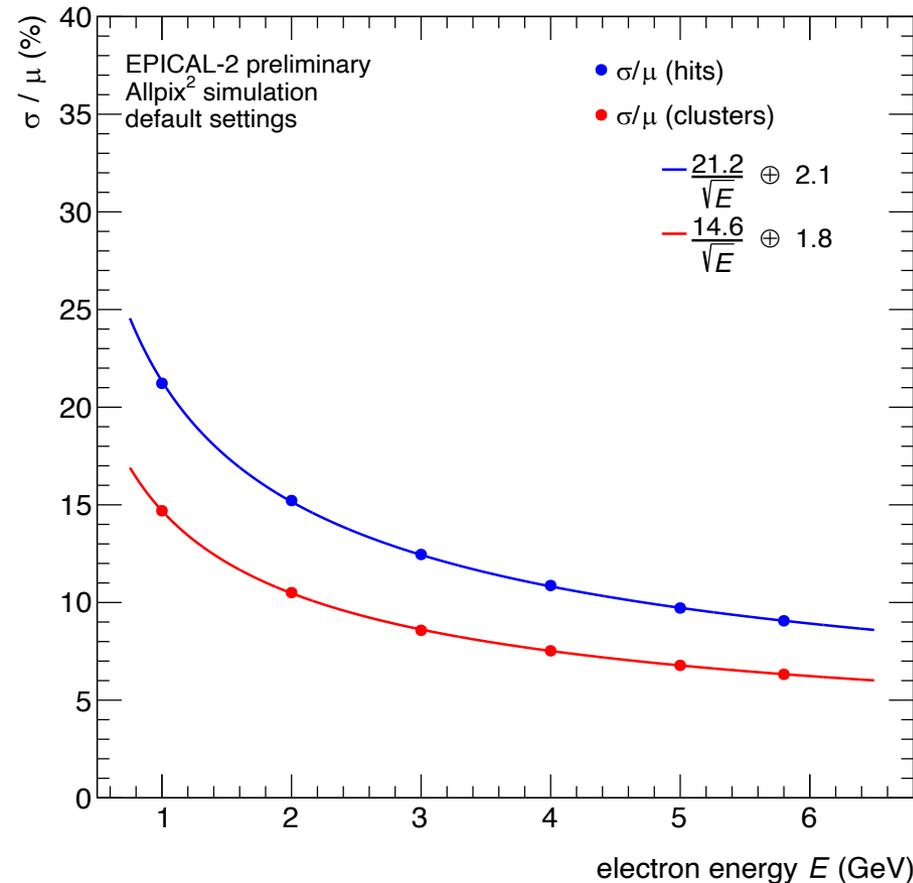
→ good linearity for mean value μ of hits in simulation

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

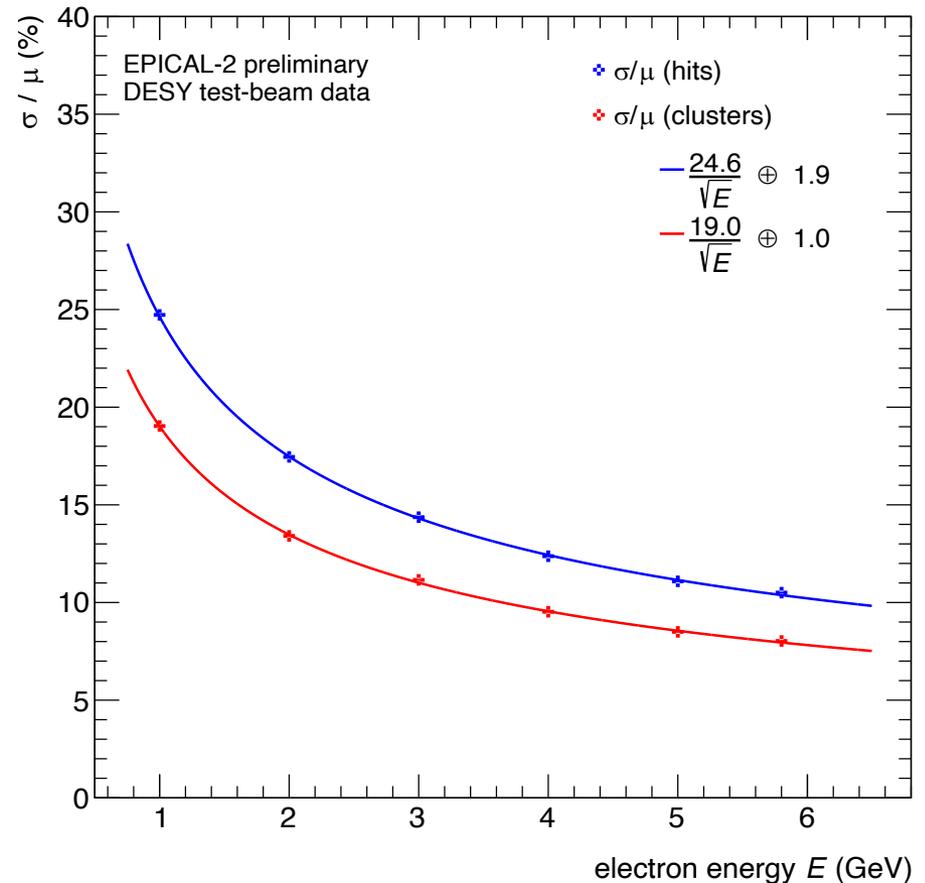
First attempt on energy resolution

derived from number of hits and clusters

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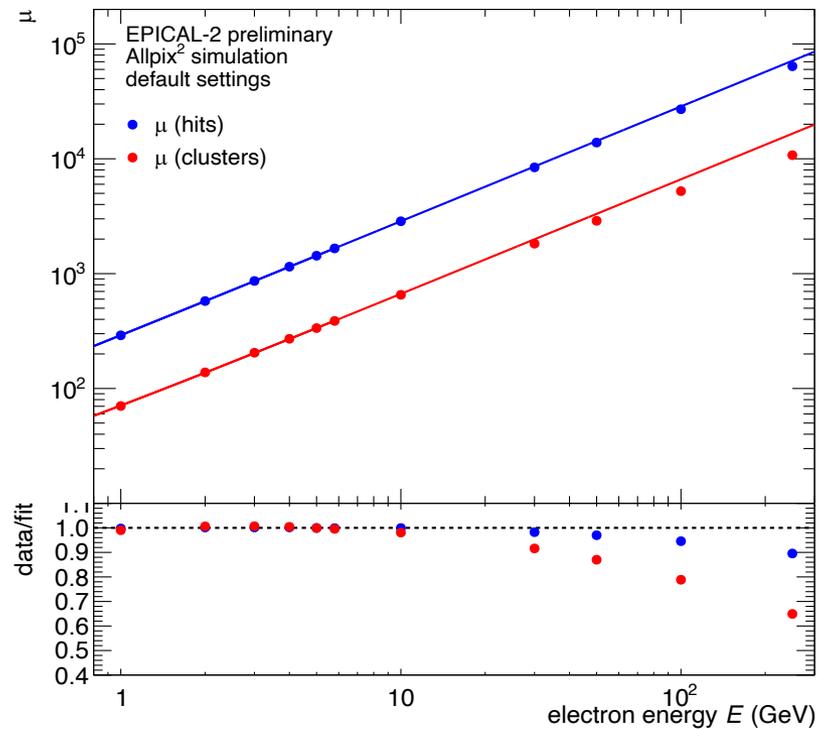
test-beam data



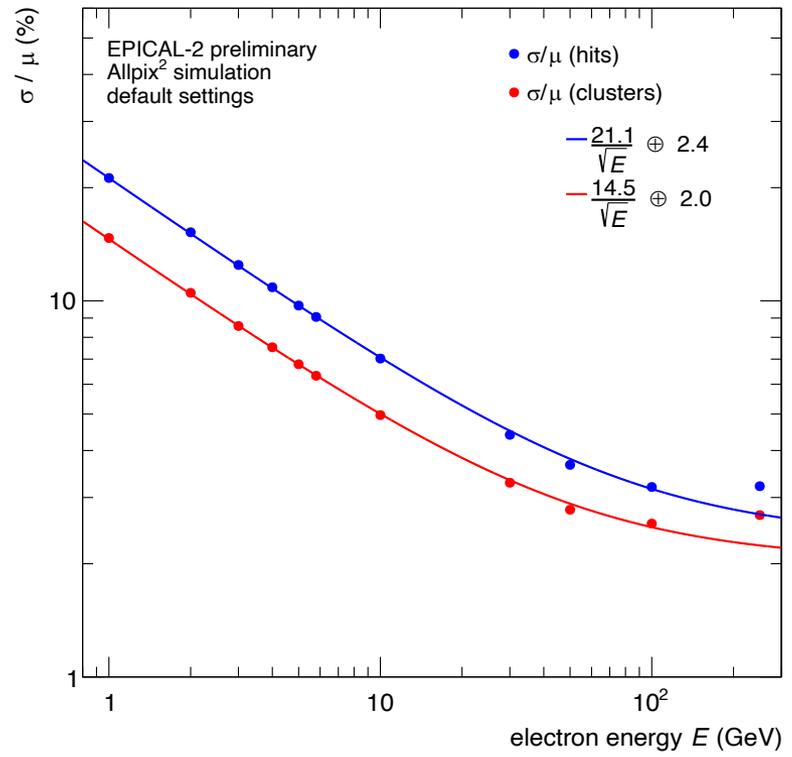
- test-beam resolution close to simulated values
- better energy resolution achieved for clusters than hits
- first analysis and comparison show very good performance: work in progress

Expectation for higher energies

energy response



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**
→ leakage and cluster overlap possible

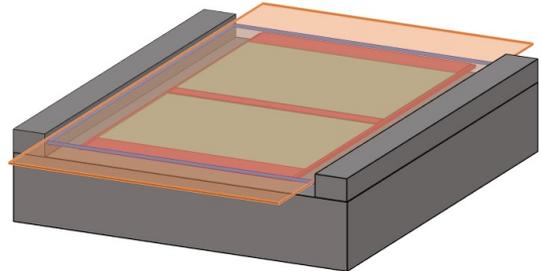
work in progress!

• preparation for EPICAL-2 test-beam measurement at CERN-SPS in September
→ modelling of high-energy performance utilizing Allpix²

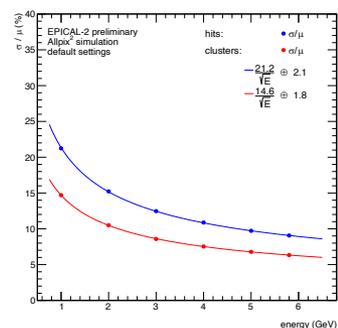
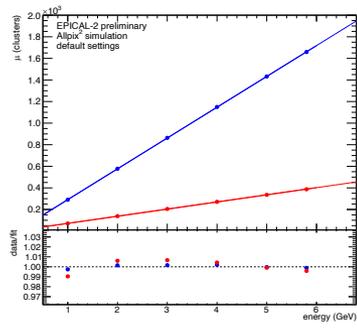
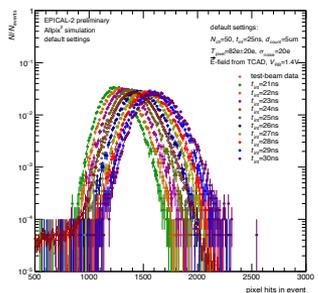


Summary

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

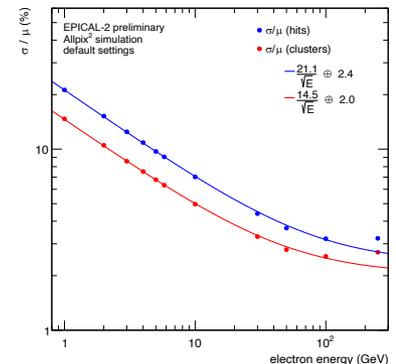


- **simulation validation** based on 5 GeV electron test-beam data
- investigation of **bulk properties** in EPICAL-2 simulation for test-beam energies
 - number of hits and clusters
 - energy resolution and linearity



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

- **first look at performance expectation for higher energies**



Contributors

**University of
Bergen**



**University of
Birmingham**



CERN



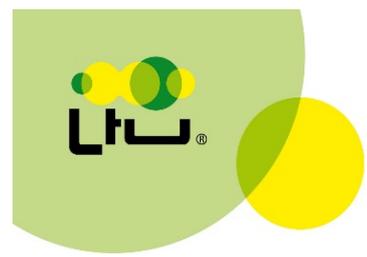
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Frankfurt**



University of Oslo



**Research and
Production Enterprise
LTU Kharkiv Ukraine**



**Utrecht
University/Nikhef**



Yonsei University

