energy linearity and resolution from measurements at DESY

EPICAL-2 project

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CALICE collaboration meeting

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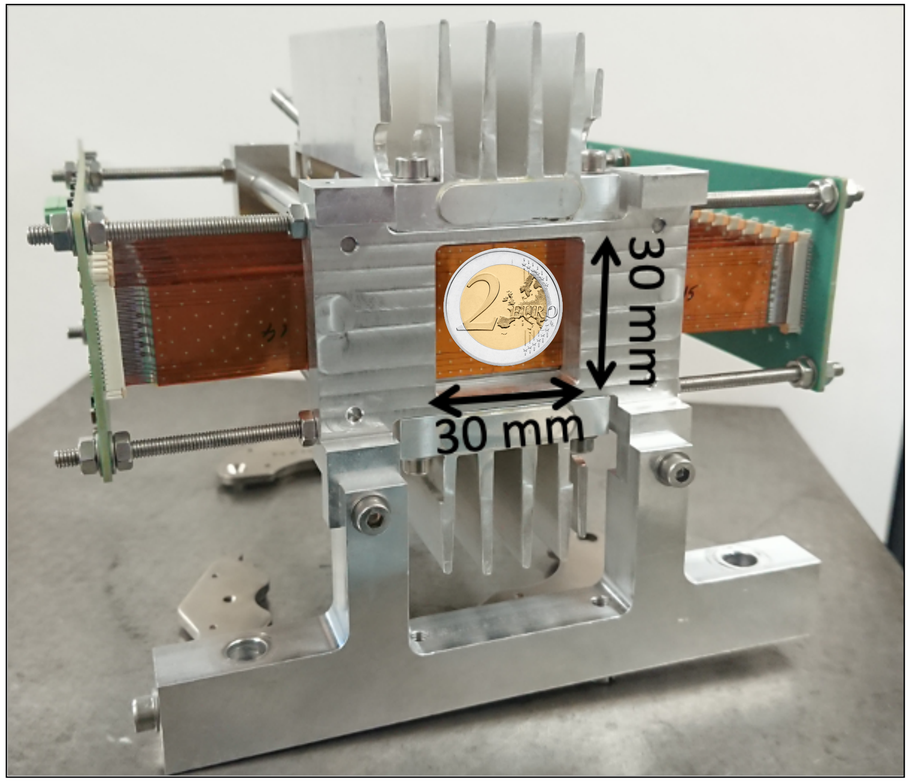
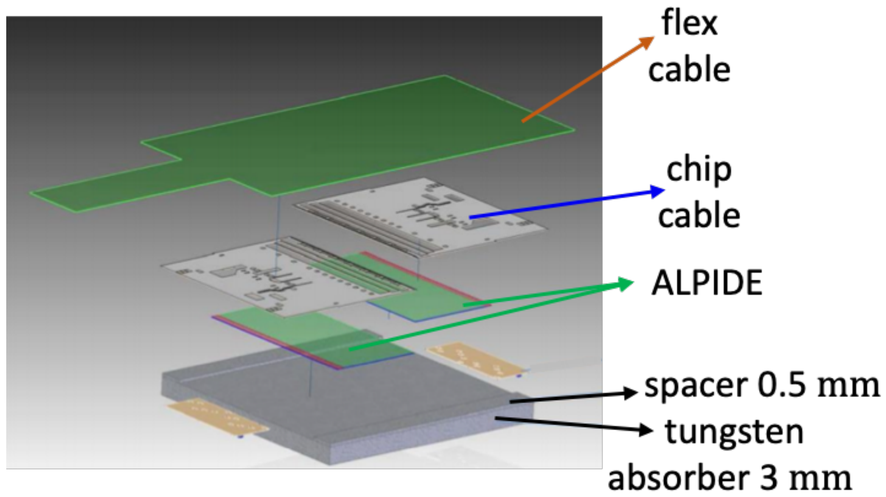
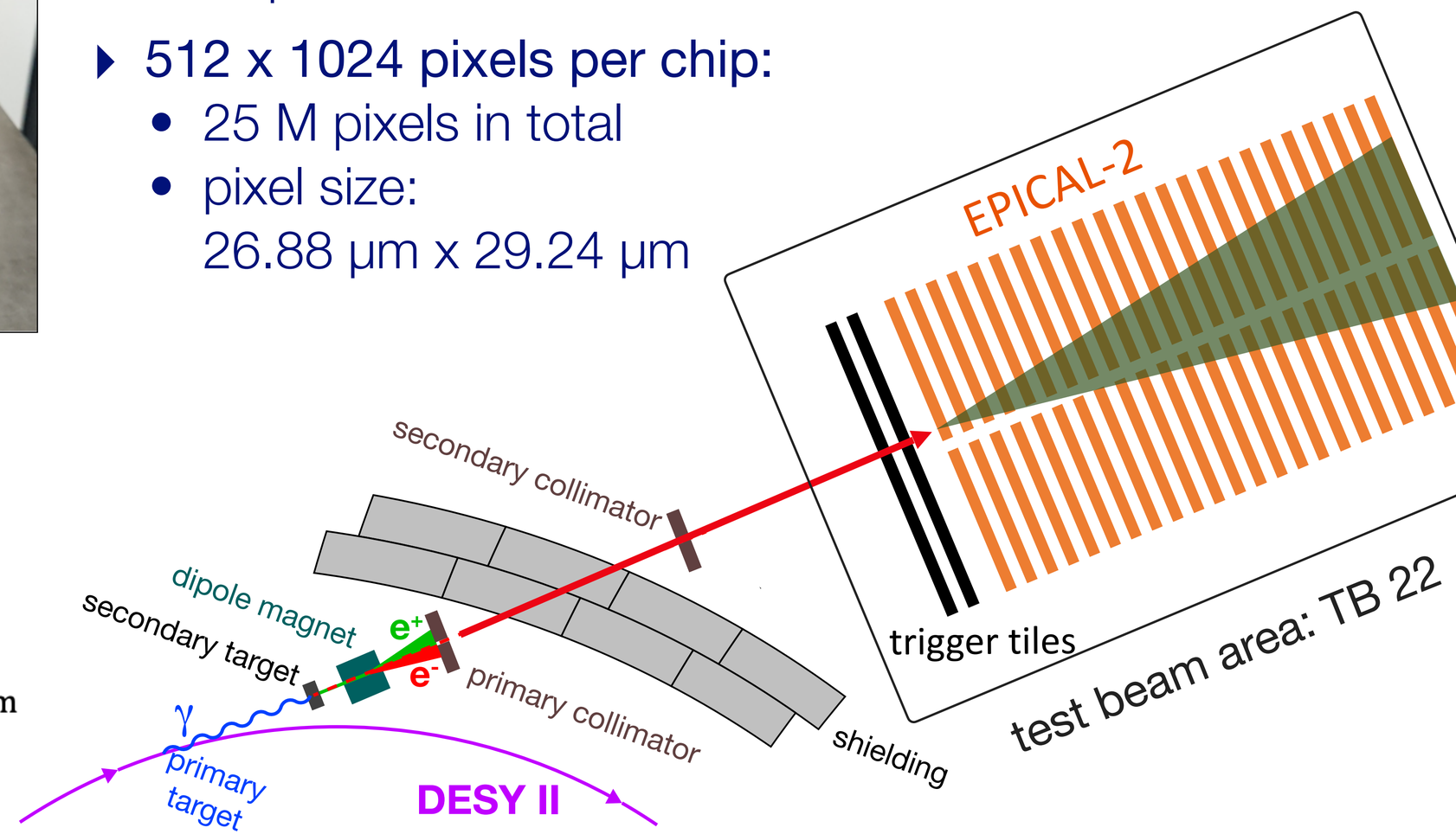
reminder: EPICAL-2 test-beam measurement at DESY

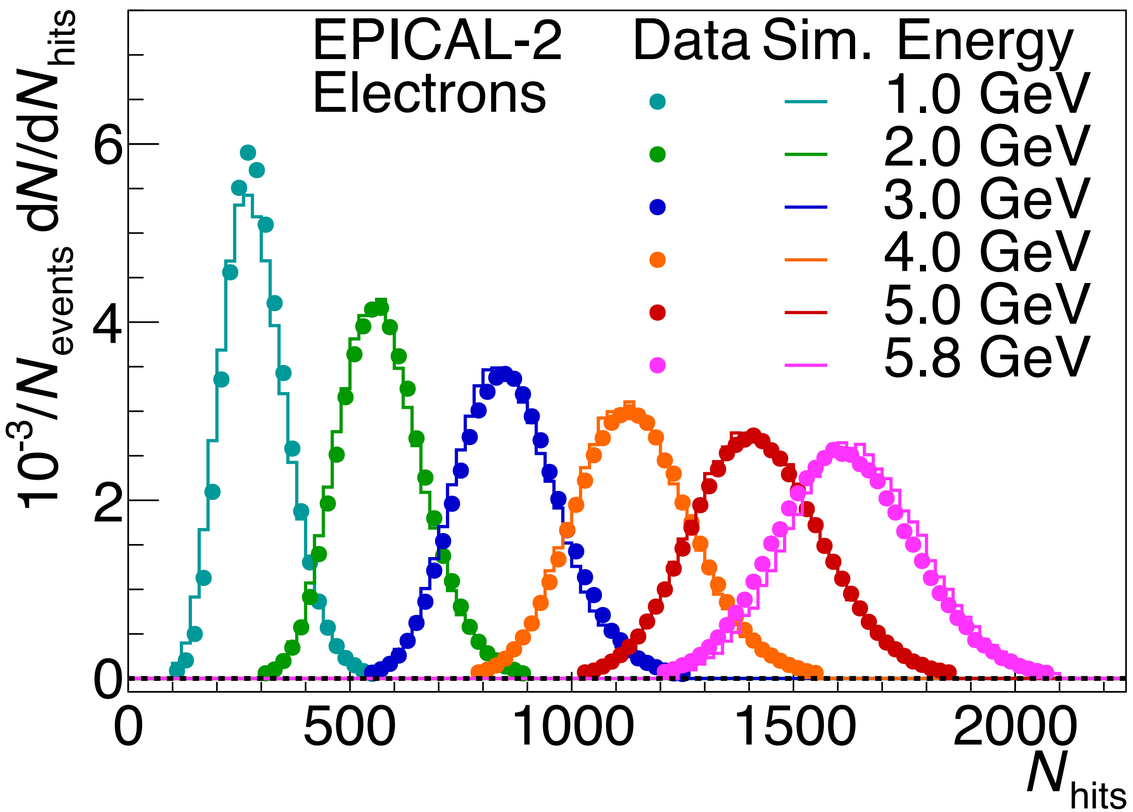


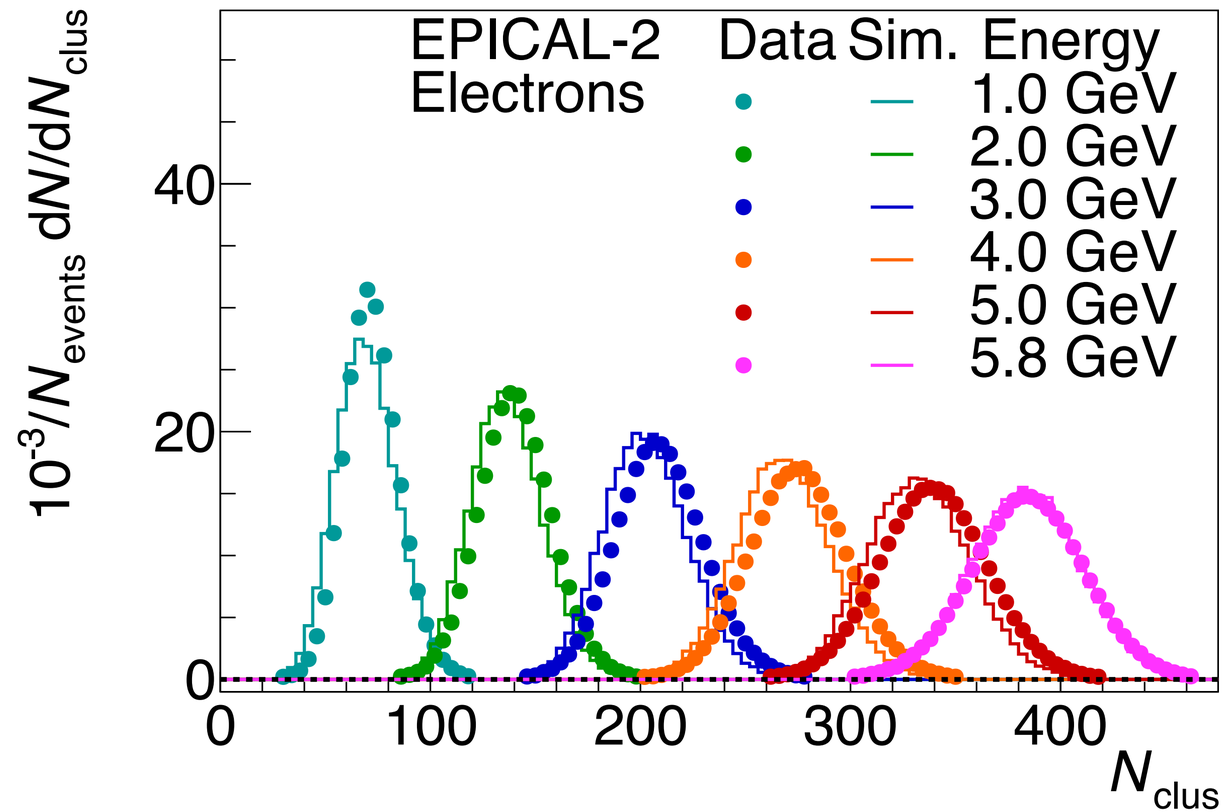
- fully digital pixel calorimeter prototype utilising only high-granularity MAPS sensors
- 24 layers with 3 mm tungsten and two ALPIDE chips each
  - chip size 30 mm x 15 mm
- 512 x 1024 pixels per chip:
  - 25 M pixels in total
  - pixel size: 26.88 μm x 29.24 μm





EPICAL-2 signal distribution

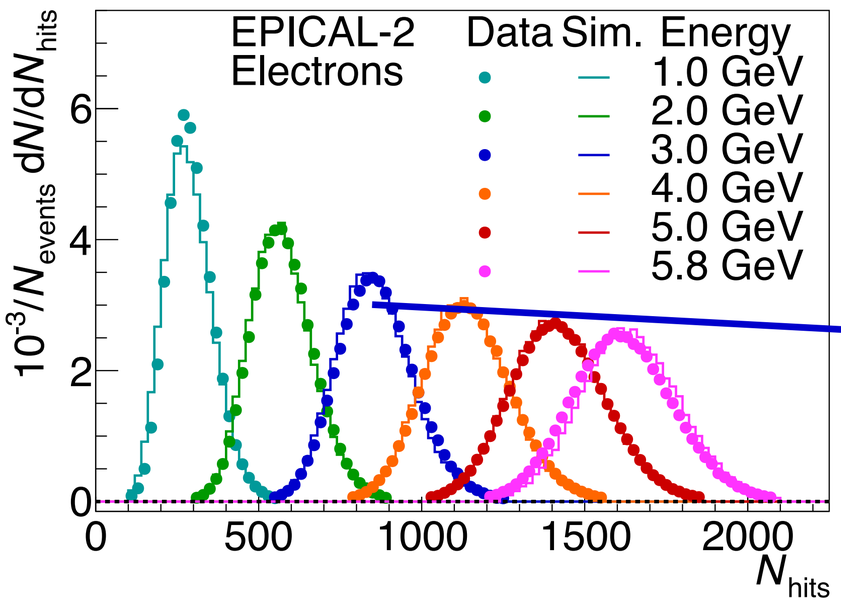


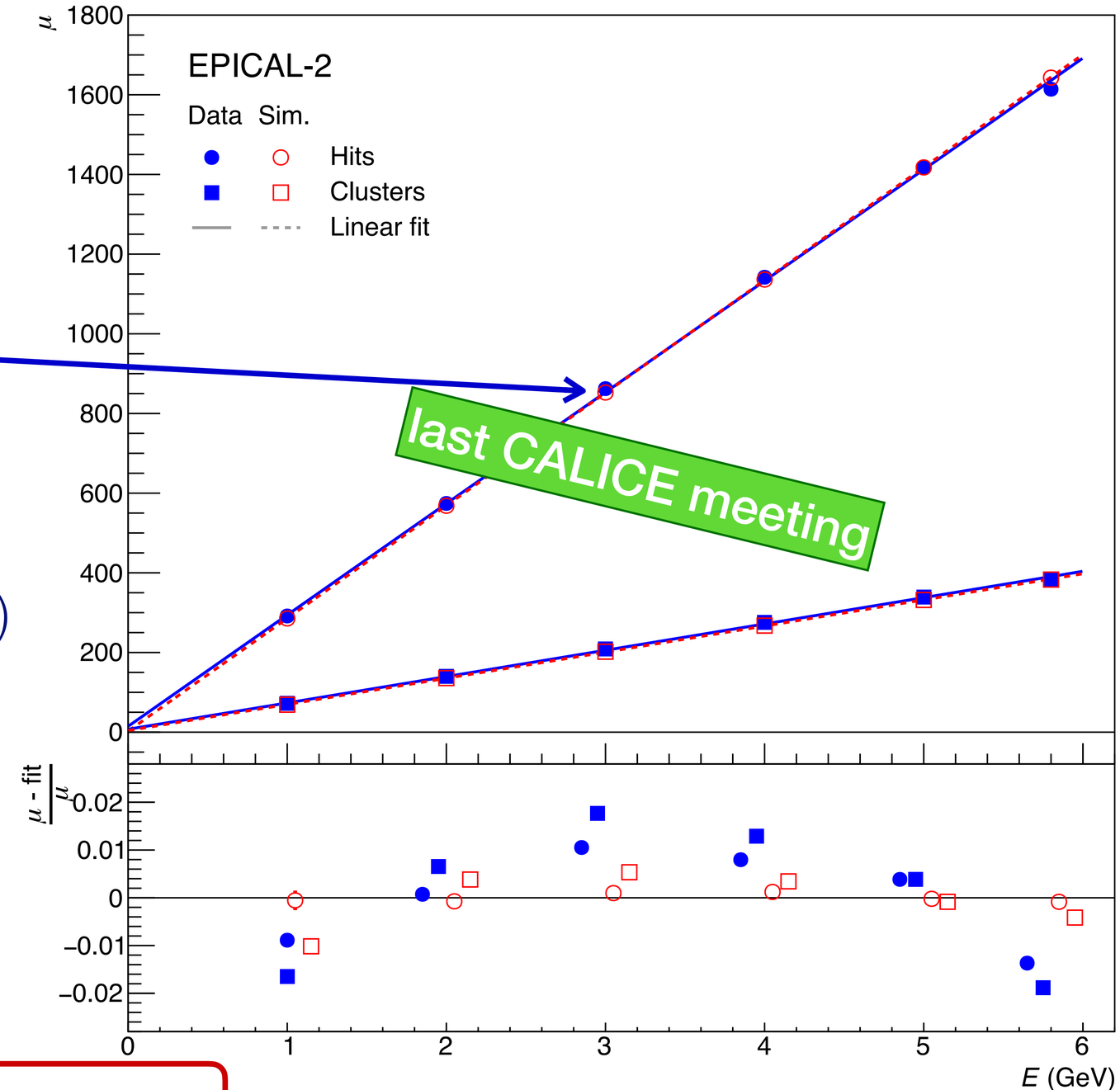


- Gaussian shape (small asymmetry)
- residual pile-up at higher N_{hits} / N_{clus} side
- low-energy contamination of electron beam
- good agreement with simulation

extraction of arithmetic mean and standard deviation of distribution

energy response: linearity check





arithmetic mean (μ) and standard deviation (σ) of hit and cluster distributions

- dependence of mean on test-beam energy
- similar performance for hits and clusters
- simulation describes the trend in data

observation: small additional non-linearity in data

energy linearity studies

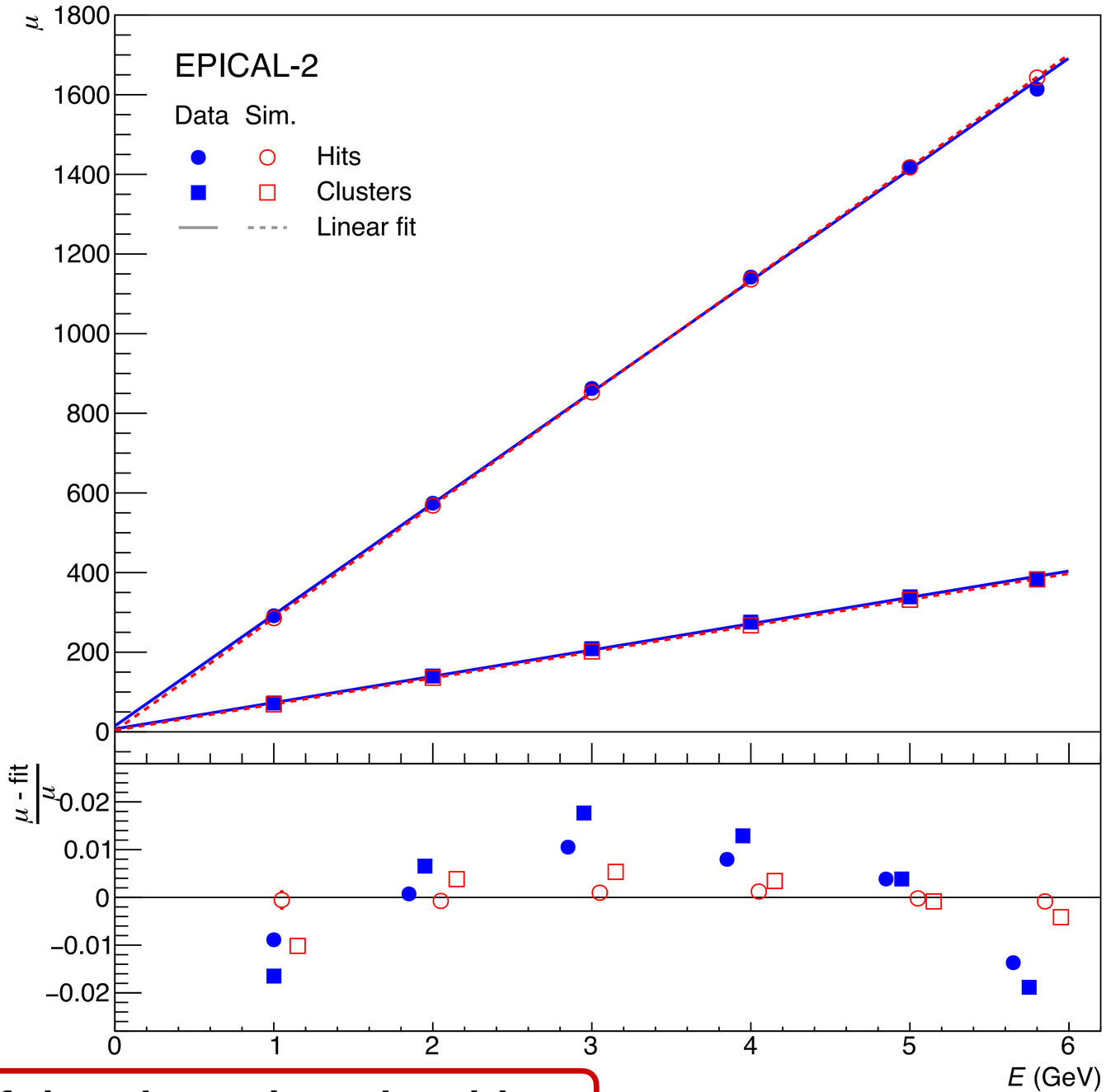
Linear fit:

$$\mu(E) = m \cdot E + b$$

- ***b*** usually associated with noise that one would see in pedestals

y - intercept (values for parameter b):

	hits	clusters
data	14.7 +- 0.2	7.3 +- 0.03
sim.	2.6 +- 0.4	4.1 +- 0.07



part of the non-linearity is a side-effect of the clustering algorithm

energy linearity studies

Linear fit:

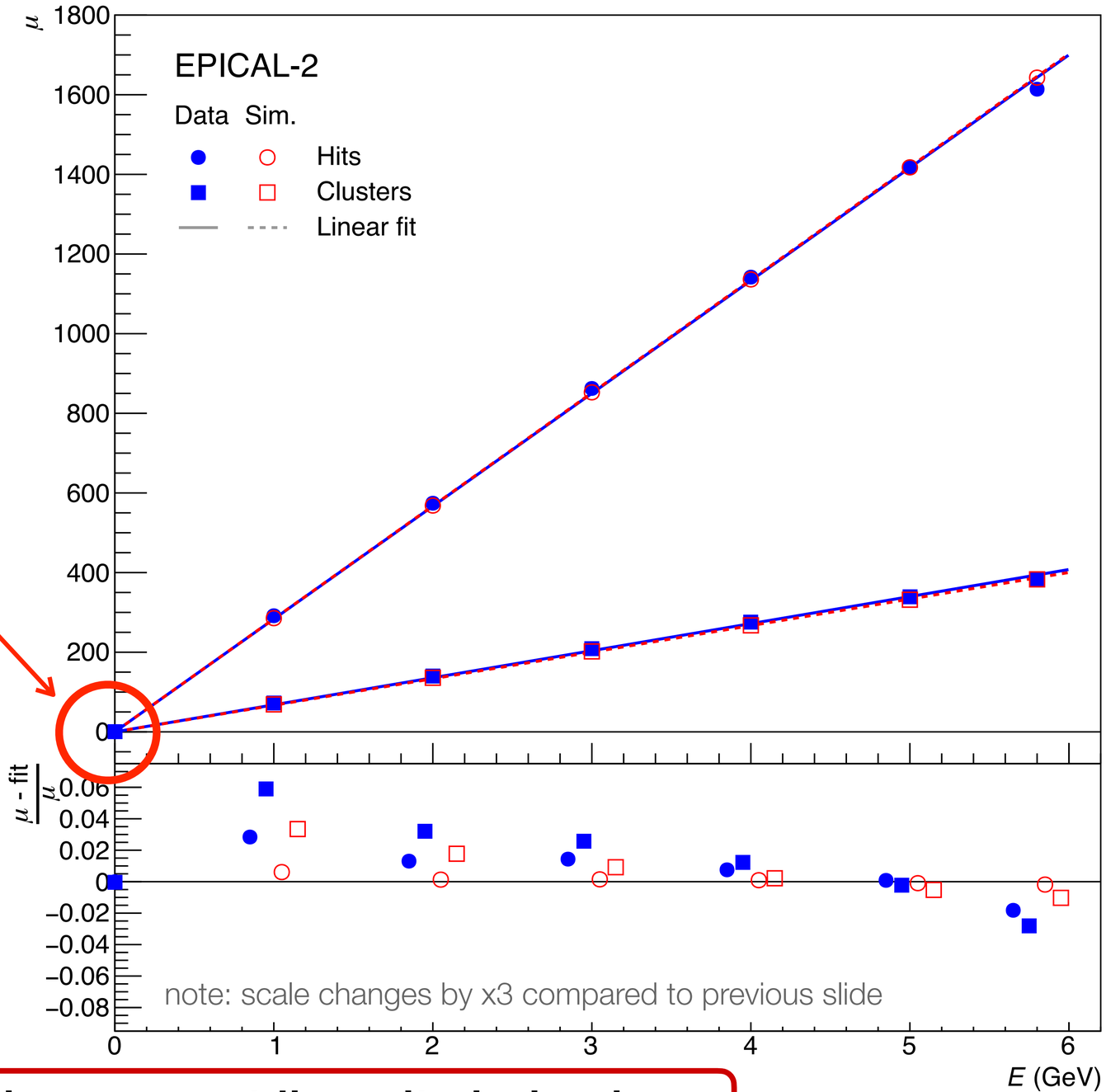
$$\mu(E) = m \cdot E + b$$

including noise estimate from pedestals:

$2.91 \times 10^{-3} \pm 9.2 \times 10^{-6}$

y - intercept (values for parameter b):

	hits	clusters
data	2.91×10^{-3}	2.91×10^{-3}
sim.	0	0



including noise estimate causes change in apparent linearity behaviour

looking for mechanisms causing the apparent non-linearity:
DESY beam energy uncertainty

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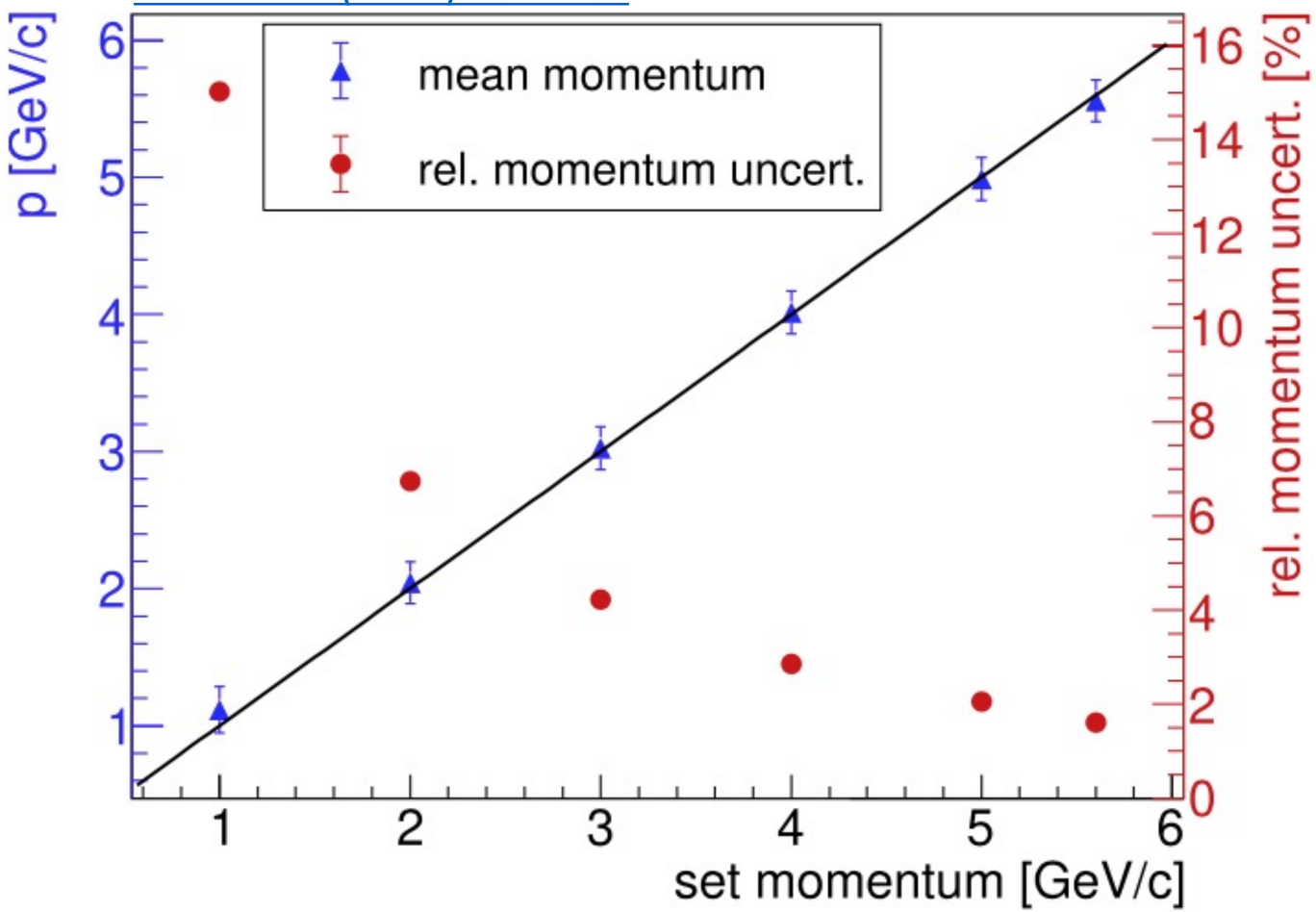


deviation as estimate for test beam momentum uncertainty

DESY test beam paper:

- mean momentum and momentum spread measurement
- set momentum via magnet currents
- expectation values as diagonal (black line)
- constant momentum spread: (158 ± 6) MeV
- deviation from expectation values:

p_0 (GeV/c)	p_{eff} (GeV/c)	Δp (GeV/c)
1.0000	1.1214	0.1214
2.0000	2.0475	0.0475
3.0000	3.0301	0.0301
4.0000	4.0246	0.0246
5.0000	4.9951	- 0.0049
5.6000	5.5659	- 0.0341

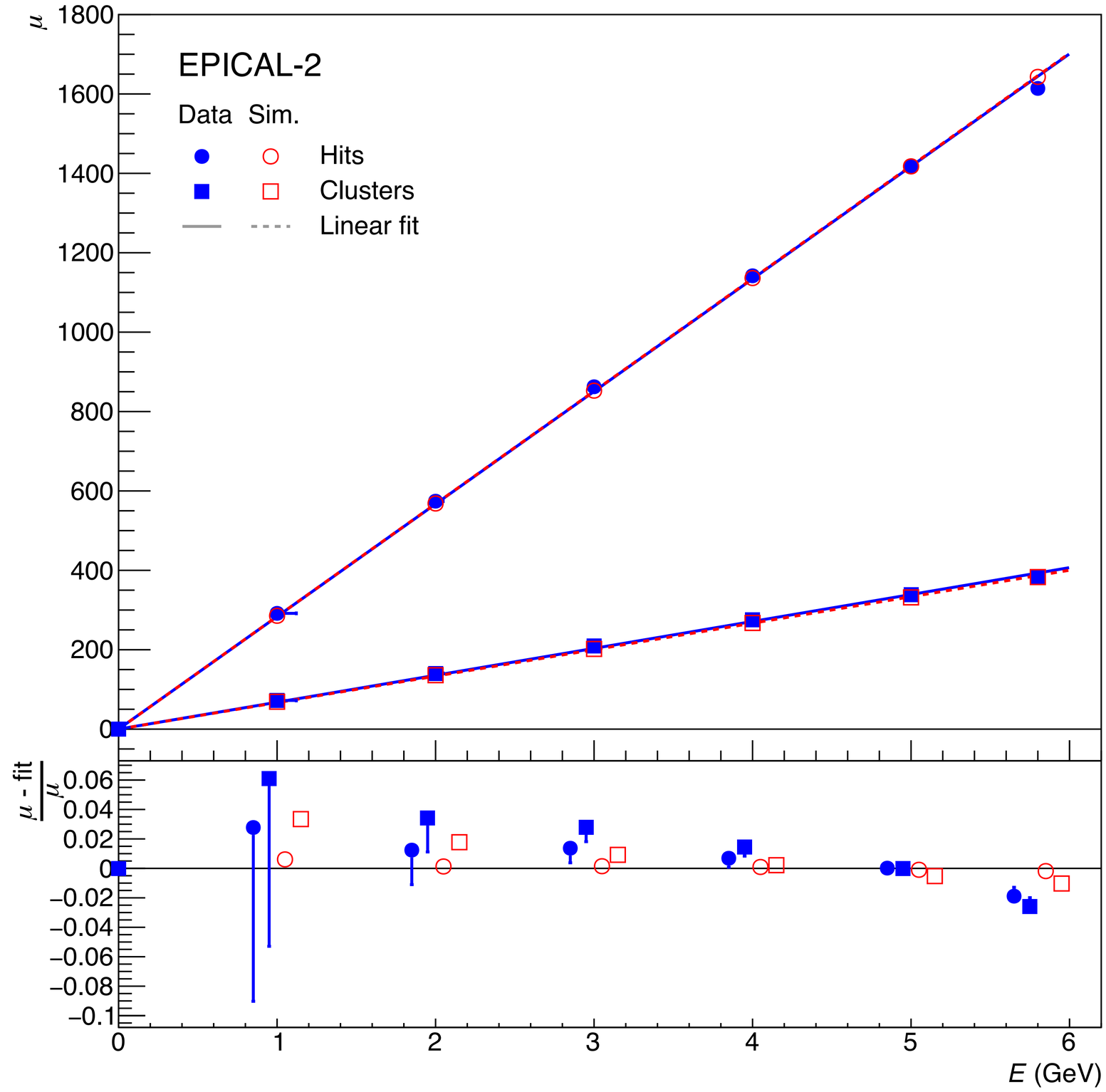
energy linearity

data:

- additional point
  with noise level at E = 0 GeV
- asymm. syst. unc. on energy
  from DESY paper
  (unc. on 5.8 GeV approximated
  by 5.6 GeV value)
- unc. on energy converted to
  unc. on residuals by calculating
  maximally possible shift
- data points displaced for better
  visibility

simulation:

- parameter *b* fixed to *b* = 0



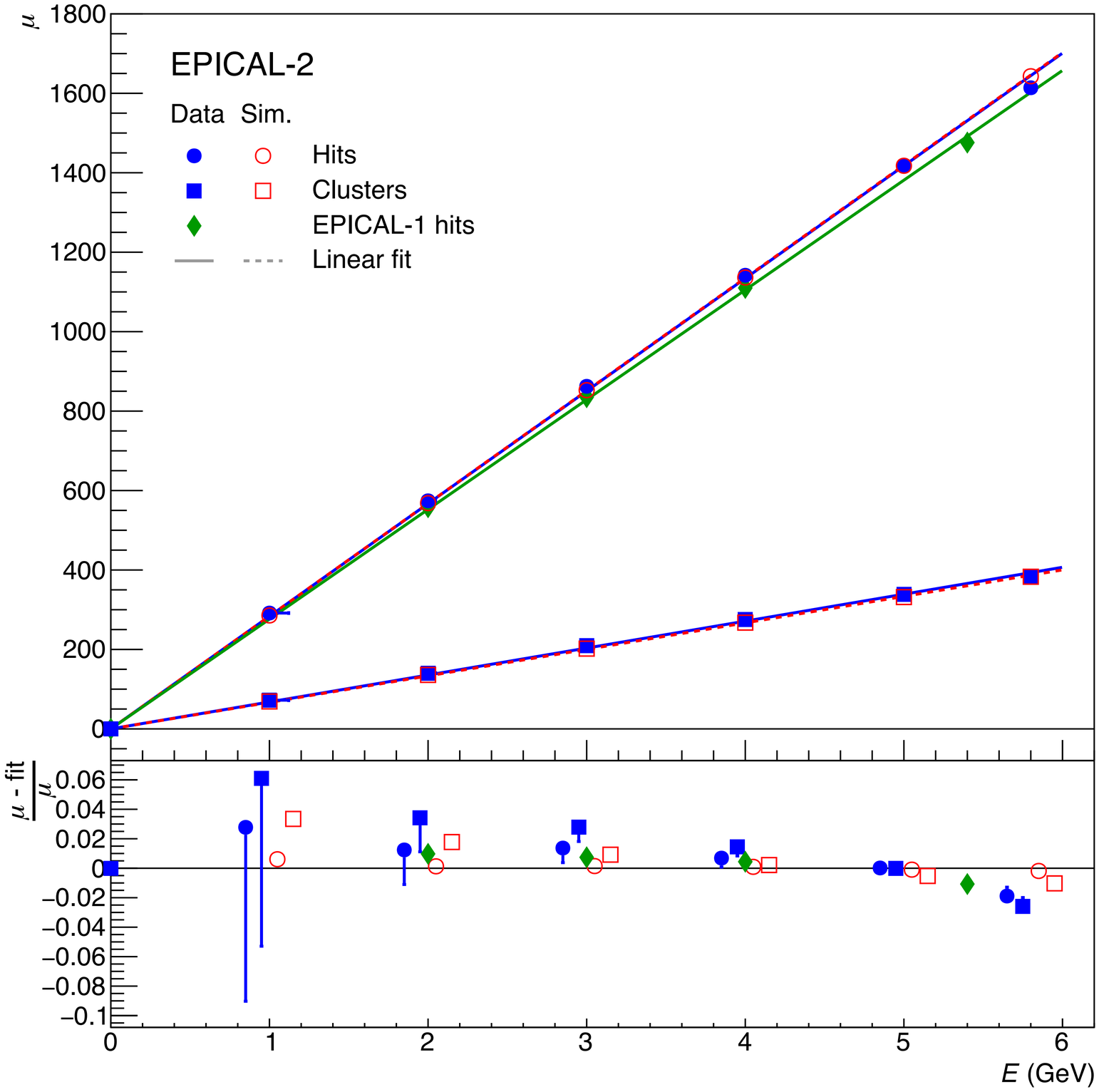
energy linearity

EPICAL-1 data points added:

- same detection principle
- similar pixel size as EPICAL-2

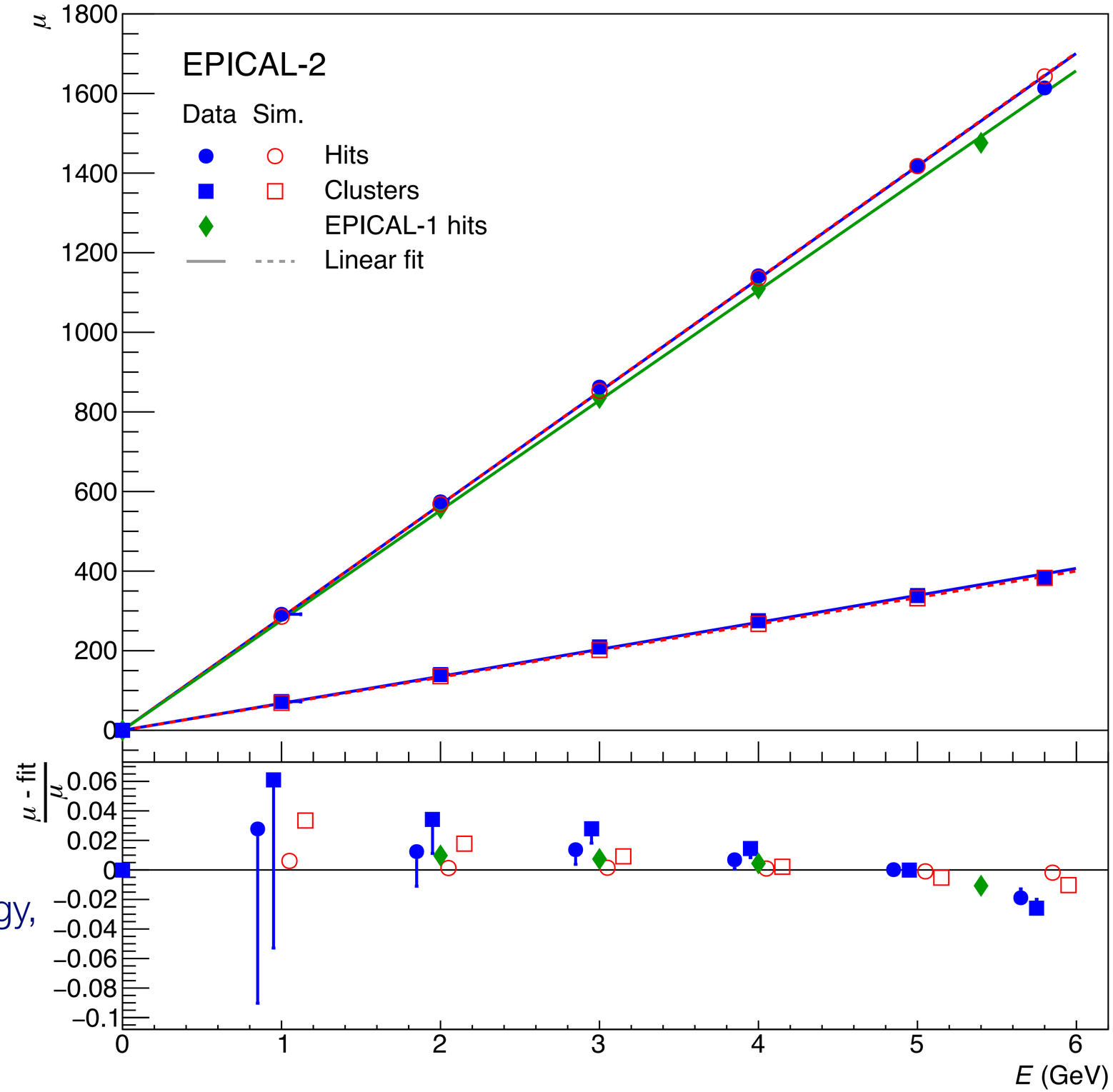
comparison btw.
EPICAL-1 and EPICAL-2:

- similar non-linear trend (probably also related to DESY beam momentum uncertainty)

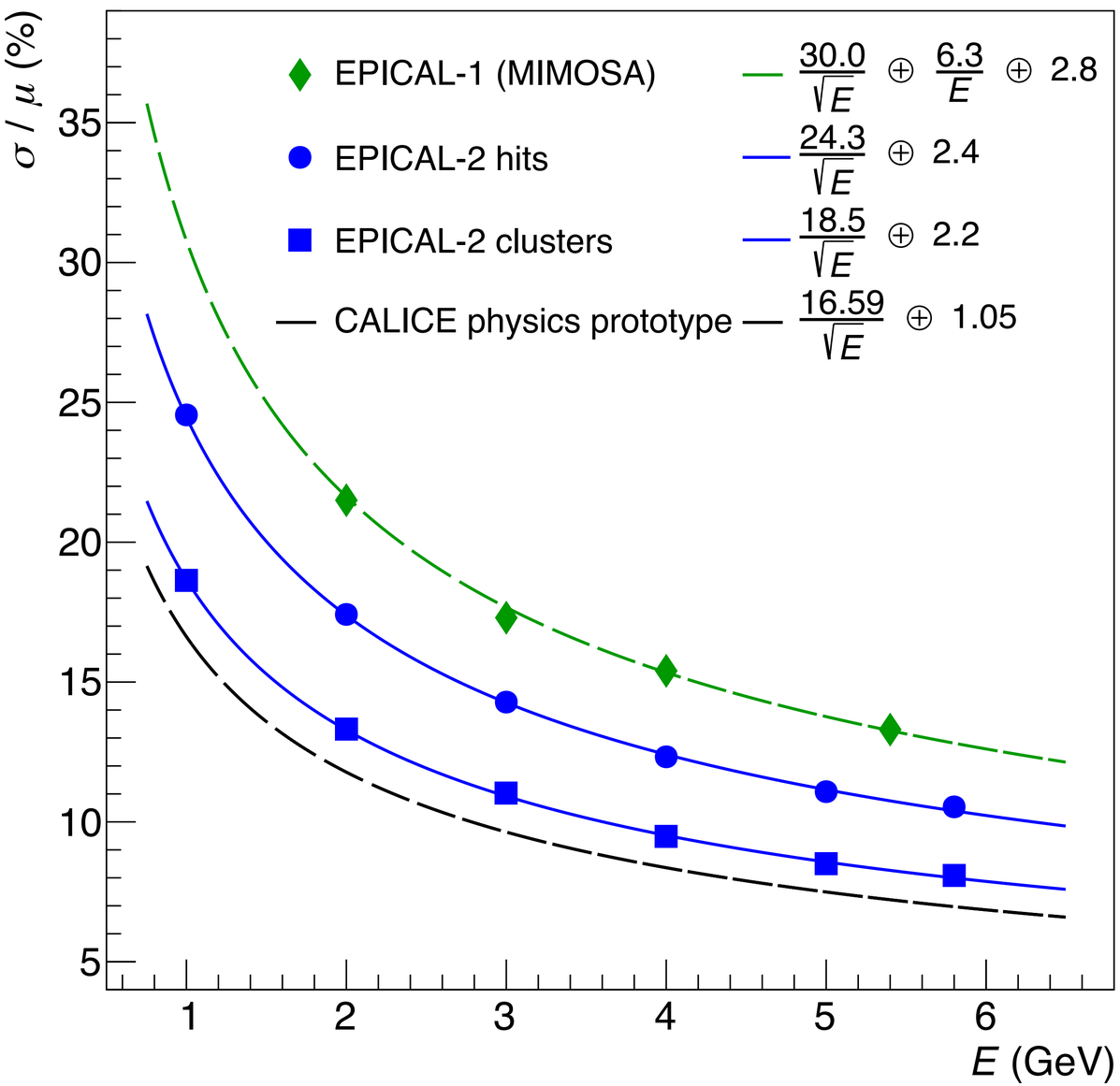


effectively fixing offset in response function to 0 justified?

- consistent with observed extremely low noise
- number of hits in simulation very close to ideal linearity
- significant non-linearity in number of clusters in simulation
- difference between hits and clusters similar for data and simulation
- number of hits from EPICAL-1 agree with EPICAL-2
- deviation of data from simulation consistent with energy non-linearity in DESY test beam
- additional deviation for highest energy, related to phase-space limit of accelerator?



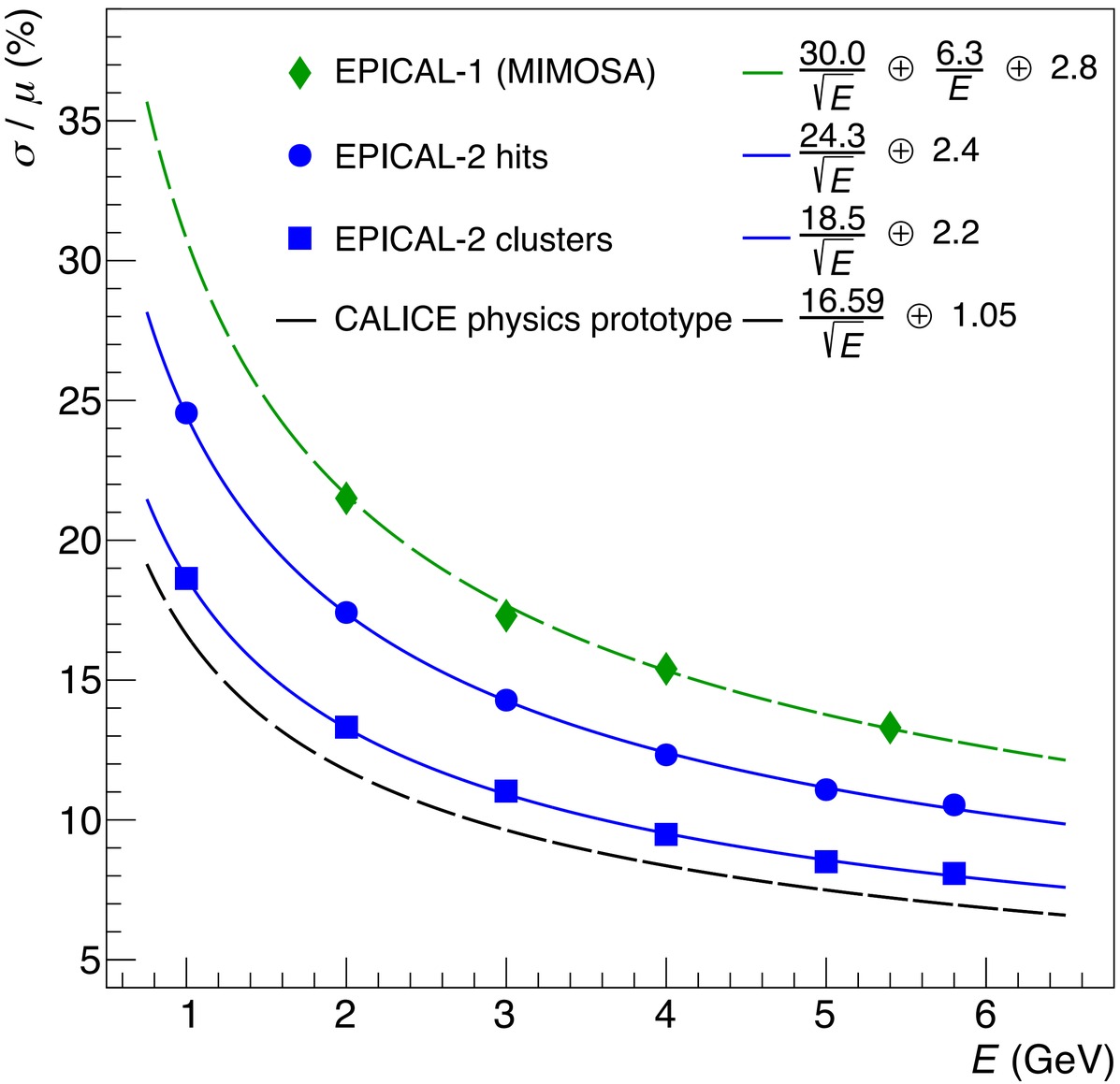
energy resolution: comparison to other prototypes



arithmetic mean (μ) and standard deviation (σ) from corresponding distributions:

- noise term negligible
- better performance for clusters
  - large cluster-size fluctuation
  - calibration can be improved

energy resolution: comparison to other prototypes

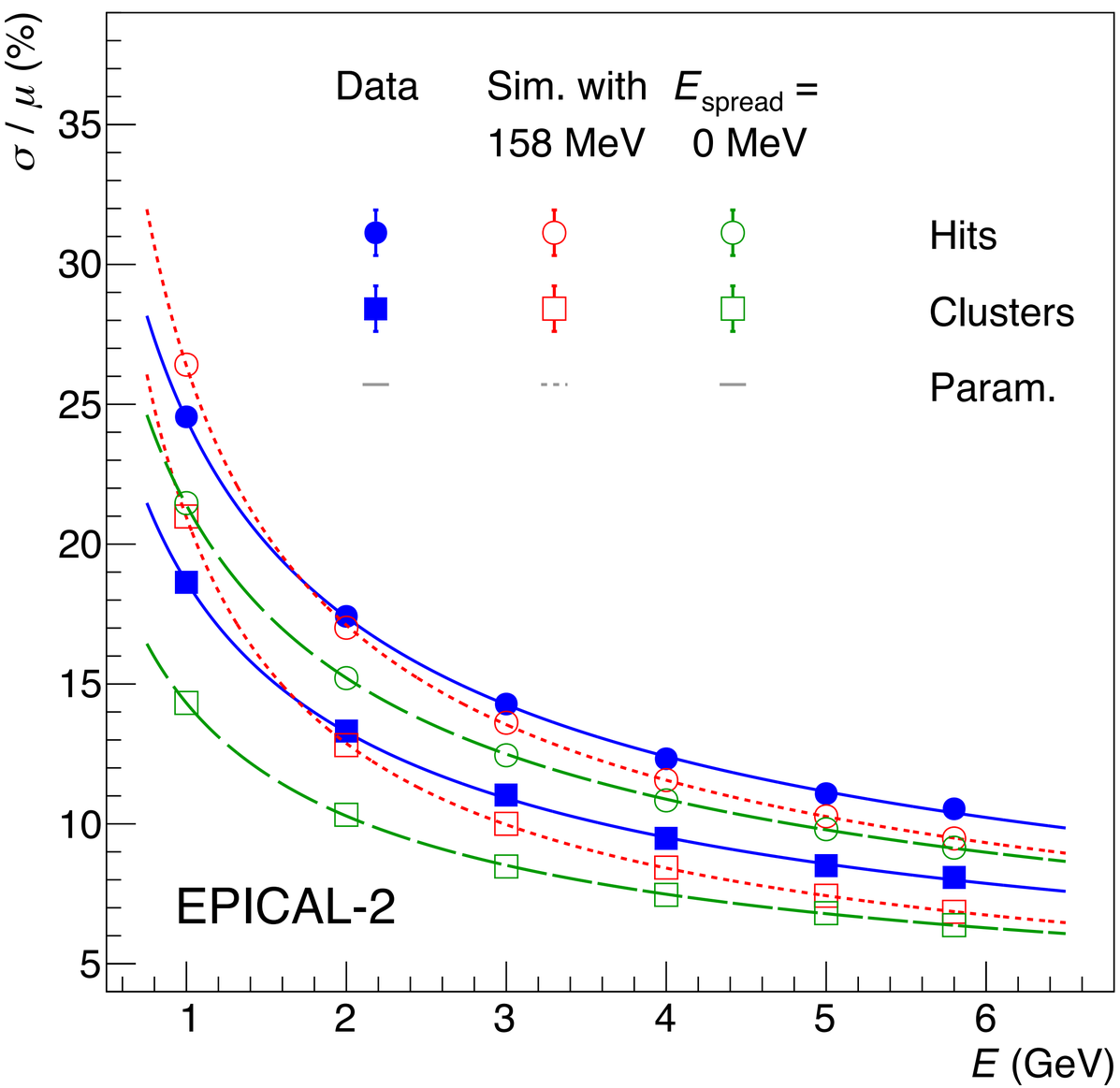


arithmetic mean (μ) and standard deviation (σ) from corresponding distributions:

- noise term negligible
- better performance for clusters
  - large cluster-size fluctuation
  - calibration can be improved
- improvement since EPICAL-1 (MIMOSA)
  JINST 13 (2018) P01014
- close to analog SiW ECAL (CALICE) physics prototype
  NIM A608 (2009) 372

energy resolution superior to previous prototype

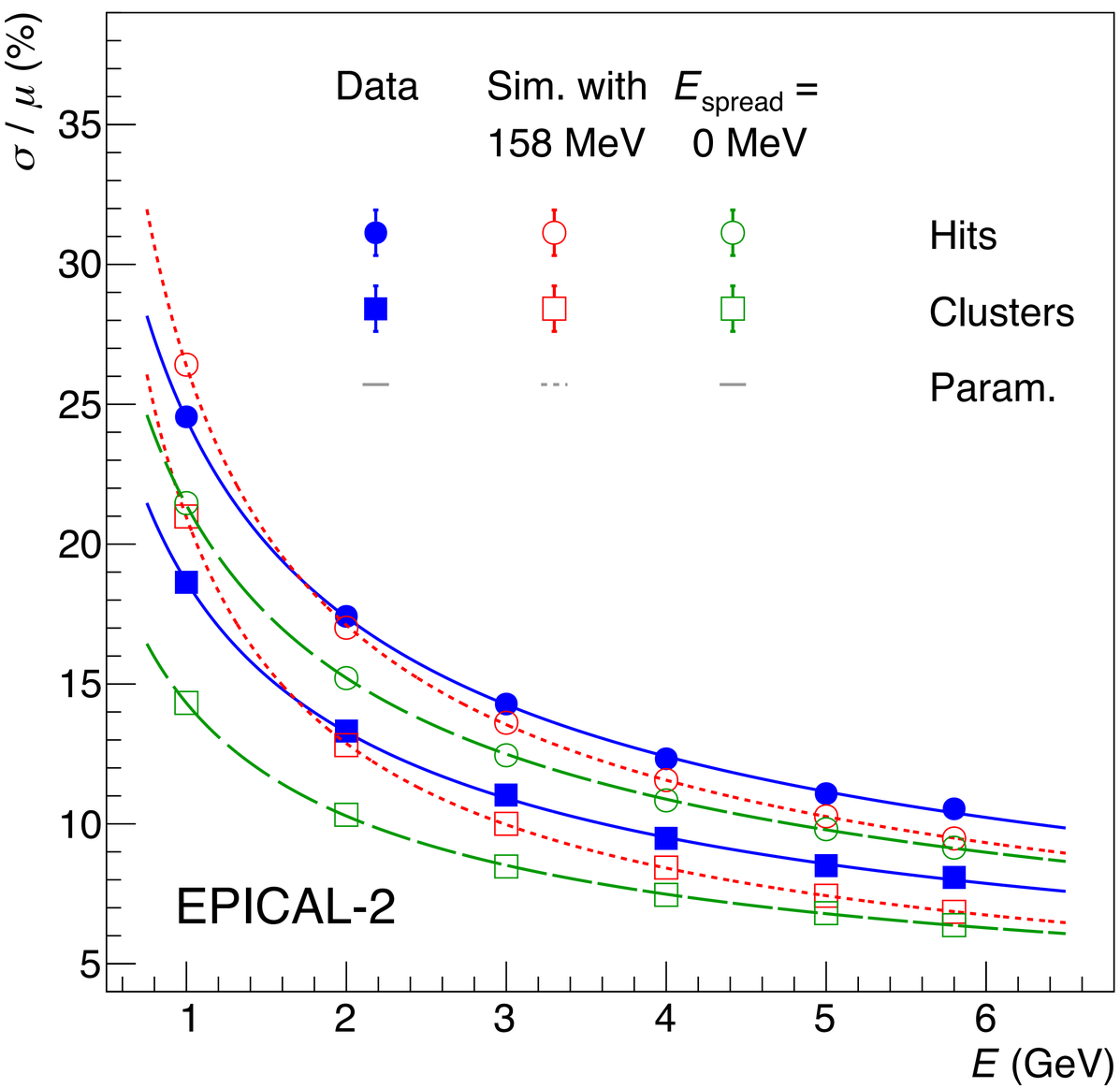
energy resolution: comparison to simulation



two simulation scenarios:

- ideal simulation - - -
  no beam energy spread
  - better energy resolution w.r.t. data
- simulation with constant absolute value of the beam energy spread (158 MeV) - - -
  NIM A 922 (2019) 265—286
  - below data at high energy
  - above data at low energy

energy resolution: comparison to simulation



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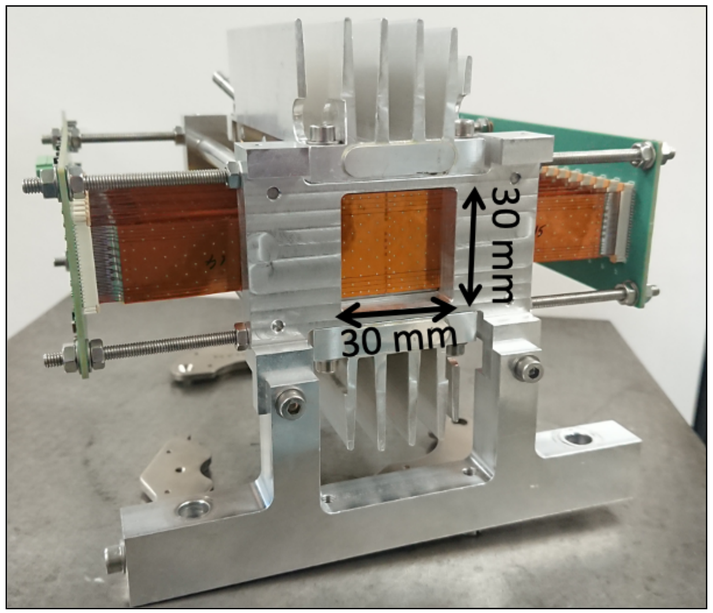
  NIM A 922 (2019) 265—286
  - below data at high energy
  - above data at low energy
- experimental data contain some energy spread from the beam

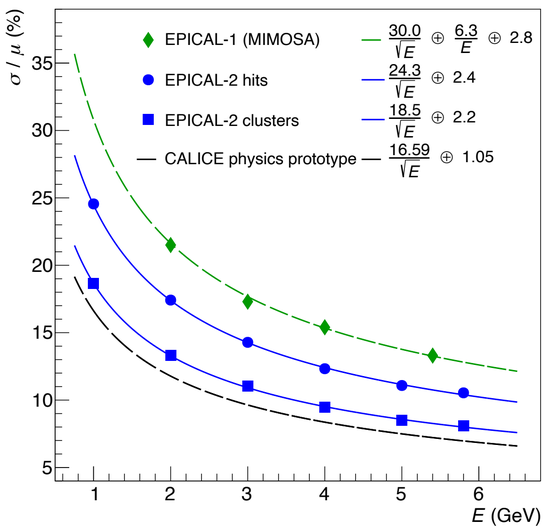
measured values are upper limits of the energy resolution

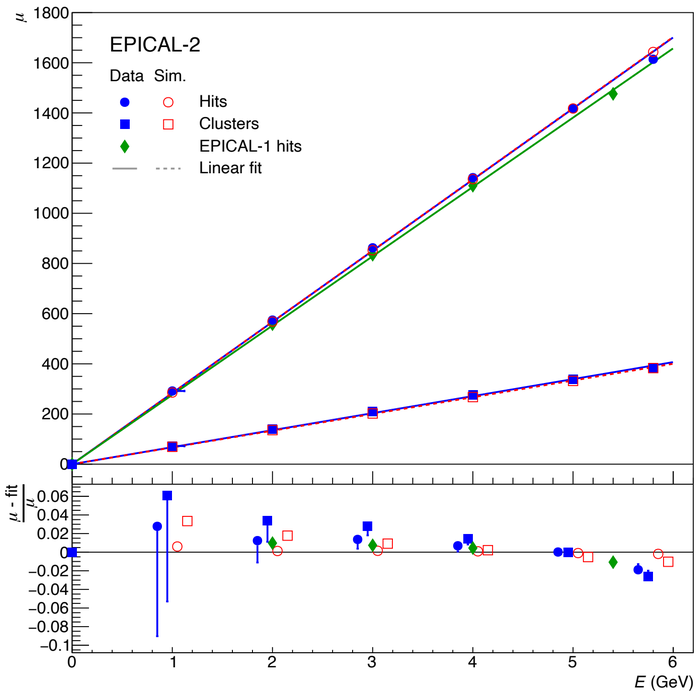
summary

EPICAL-2 measurement at DESY TB

- good understanding of the measurement
- energy resolution superior to previous EPICAL-1 (MIMOSA)
- cluster measurement provides better resolution but is worse for energy linearity (find improved clustering algorithm)
- significant impact of DESY test beam properties for precision results
- overall good agreement between data and simulation







outlook

- preparing publication