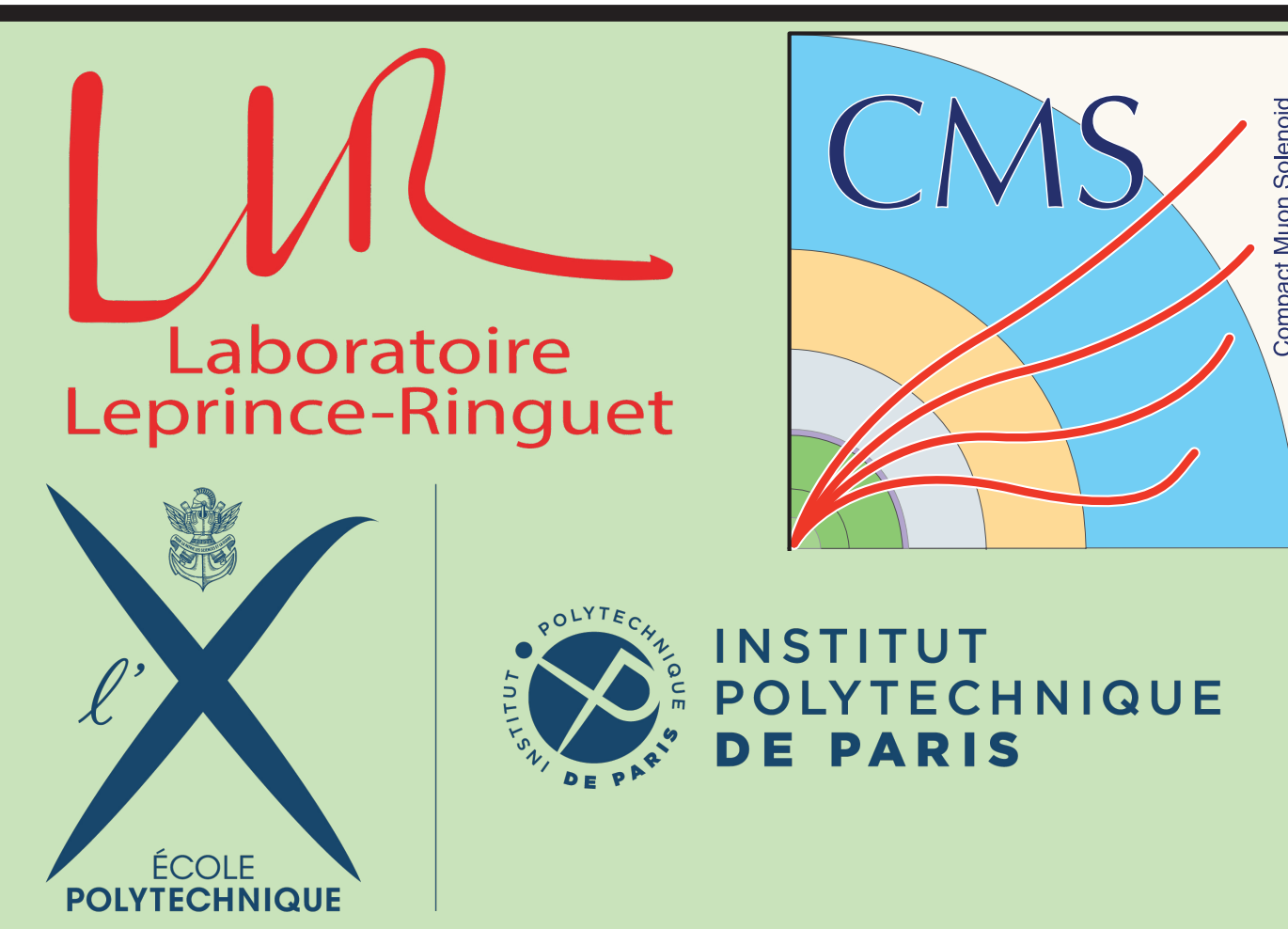# Performance study of CMS HGCAL's pattern recognition algorithm (CLUE3D) with test beam data
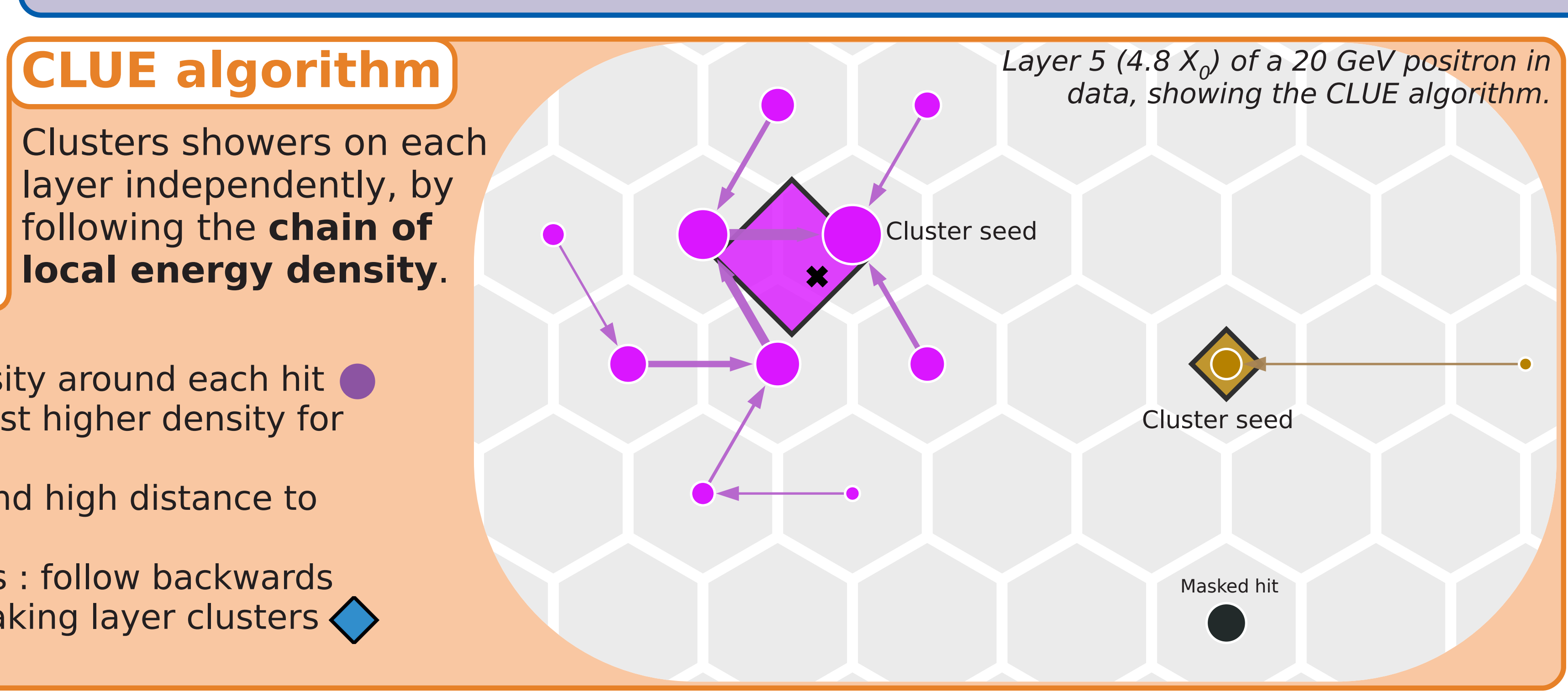
Théo Cuisset (LLR / École Polytechnique) on behalf of the CMS collaboration
theo.cuisset@polytechnique.edu

Reference : CMS DPS-23-

Context

In view of **HL-LHC**, the CMS endcap calorimeters will be replaced with the **High Granularity CALorimeter**. The electromagnetic section will consist of 26 layers of silicon sensors interspersed with copper absorbers. **Novel reconstruction algorithms** such as **CLUE** and **CLUE3D** will allow superior performance despite high pileup. Their performance has been assessed on simulation, but it is necessary to ascertain that their performance can translate equally well on data.
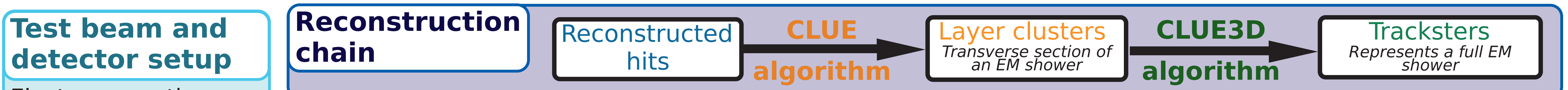
Test beam and detector setup

Electromagnetic calorimeter prototype with **28 layers**

October 2018 test beam campaign
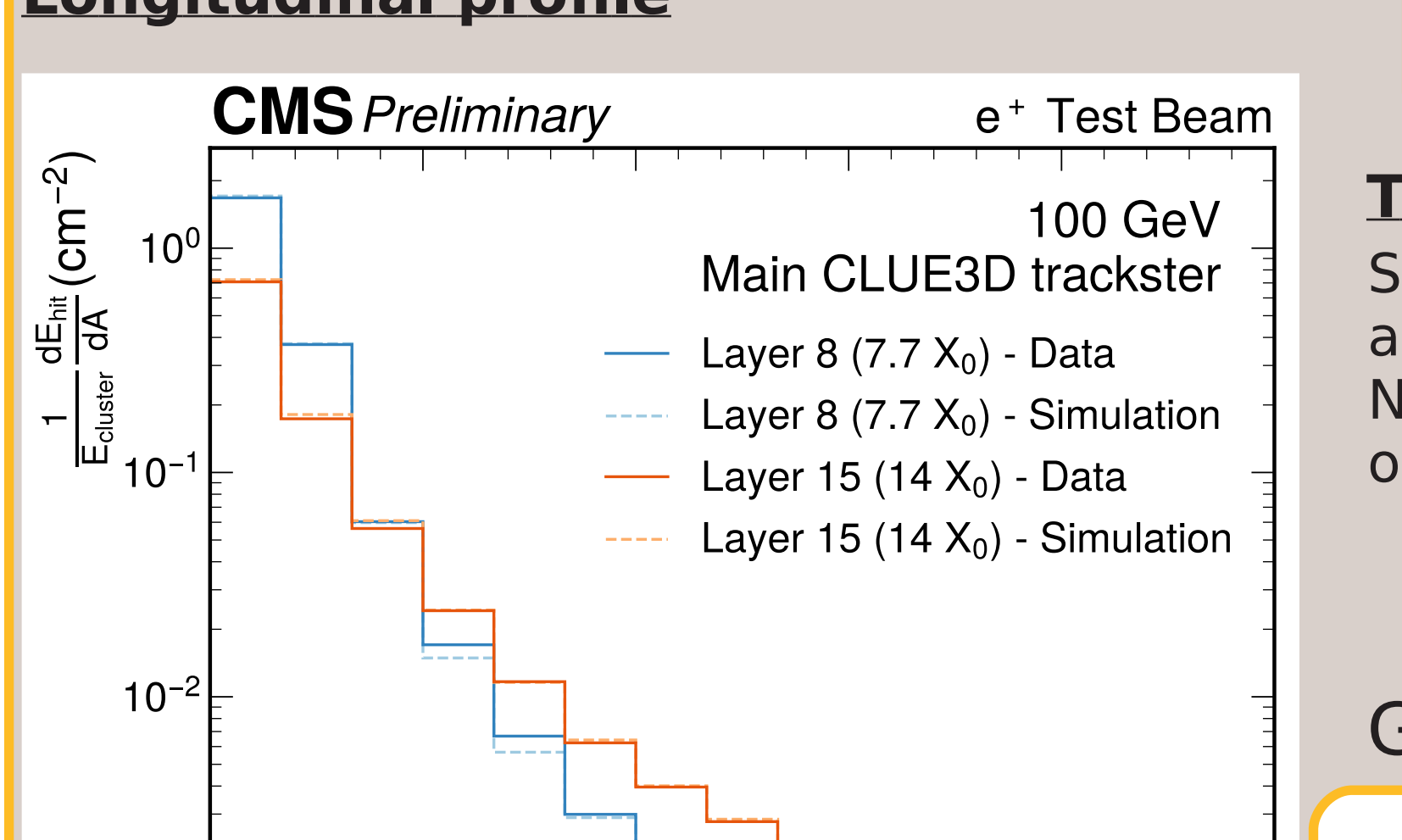
Positron beam **20 to 300 GeV**

Reconstruction chain

Reconstructed hits → **CLUE algorithm** → Layer clusters *Transverse section of an EM shower* → **CLUE3D algorithm** → Tracksters *Represents a full EM shower*

CLUE algorithm

Clusters showers on each layer independently, by following the **chain of local energy density**.

In each layer :
- Compute local energy density around each hit ●
- Compute distance to nearest higher density for each hit ➝
- Find seeds : high density and high distance to nearest higher
- Expand clusters from seeds : follow backwards chain of nearest higher, making layer clusters ◆
- Outliers : remaining hits ●

Layer 5 (4.8 X_0) of a 20 GeV positron in data, showing the CLUE algorithm.
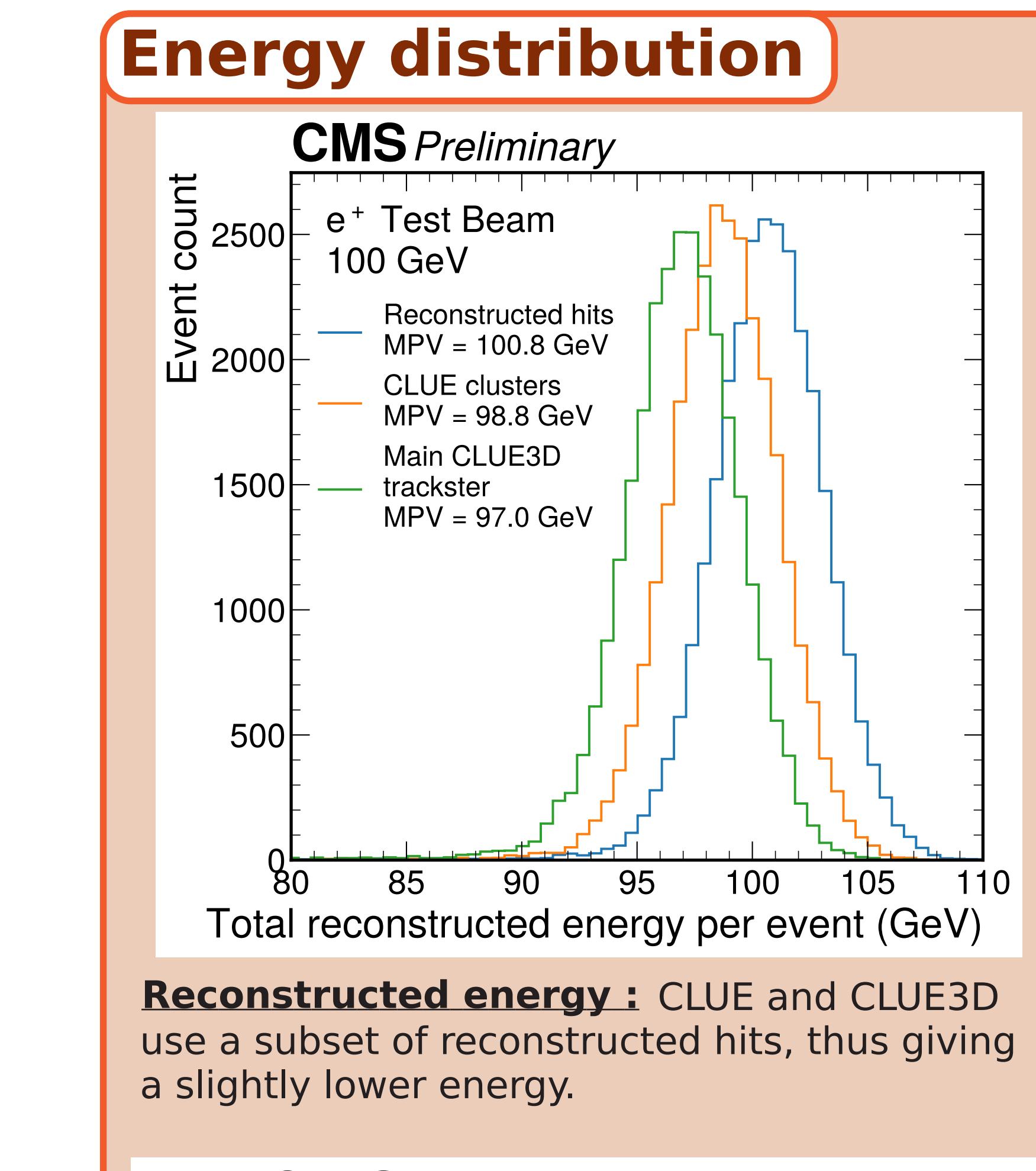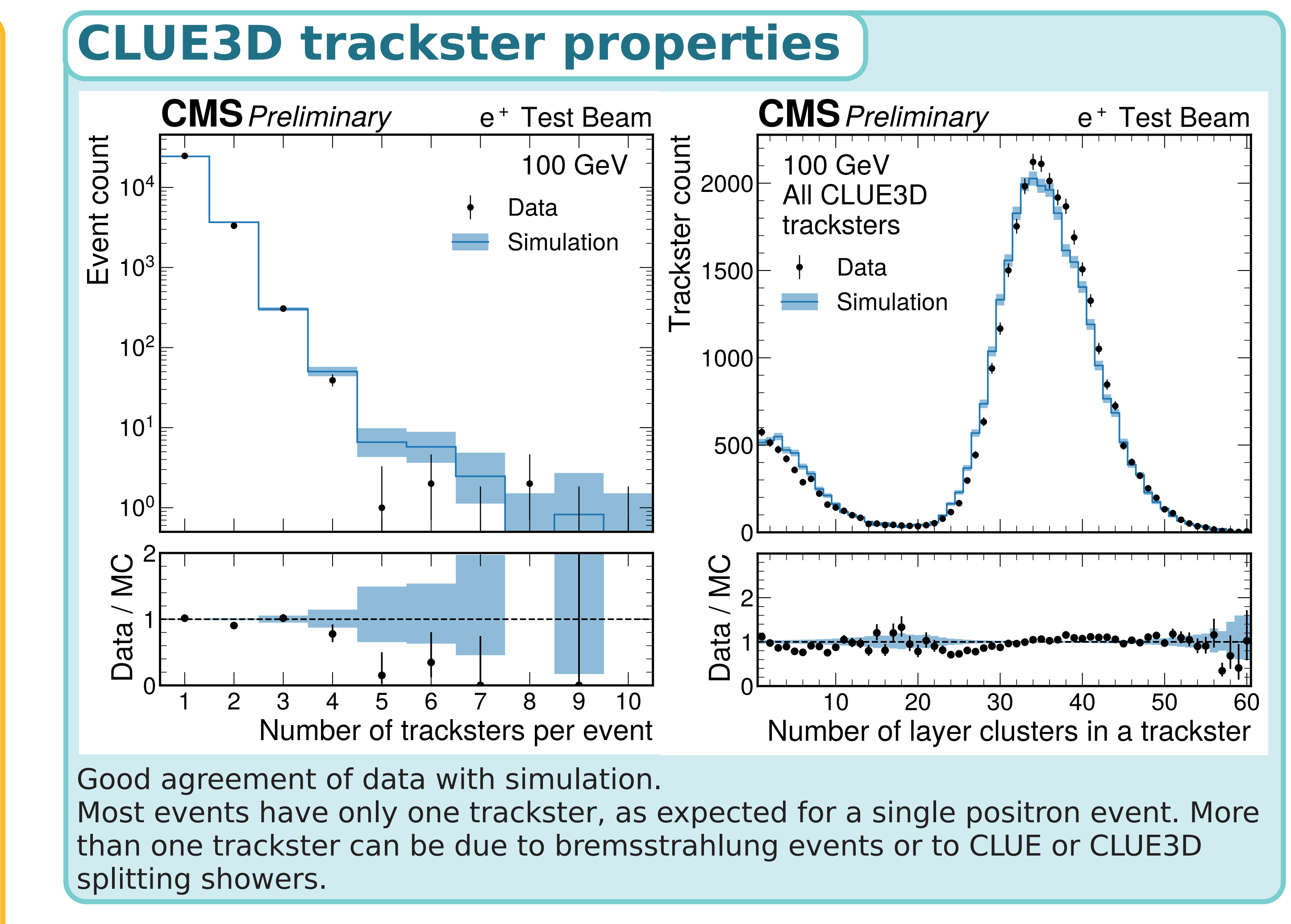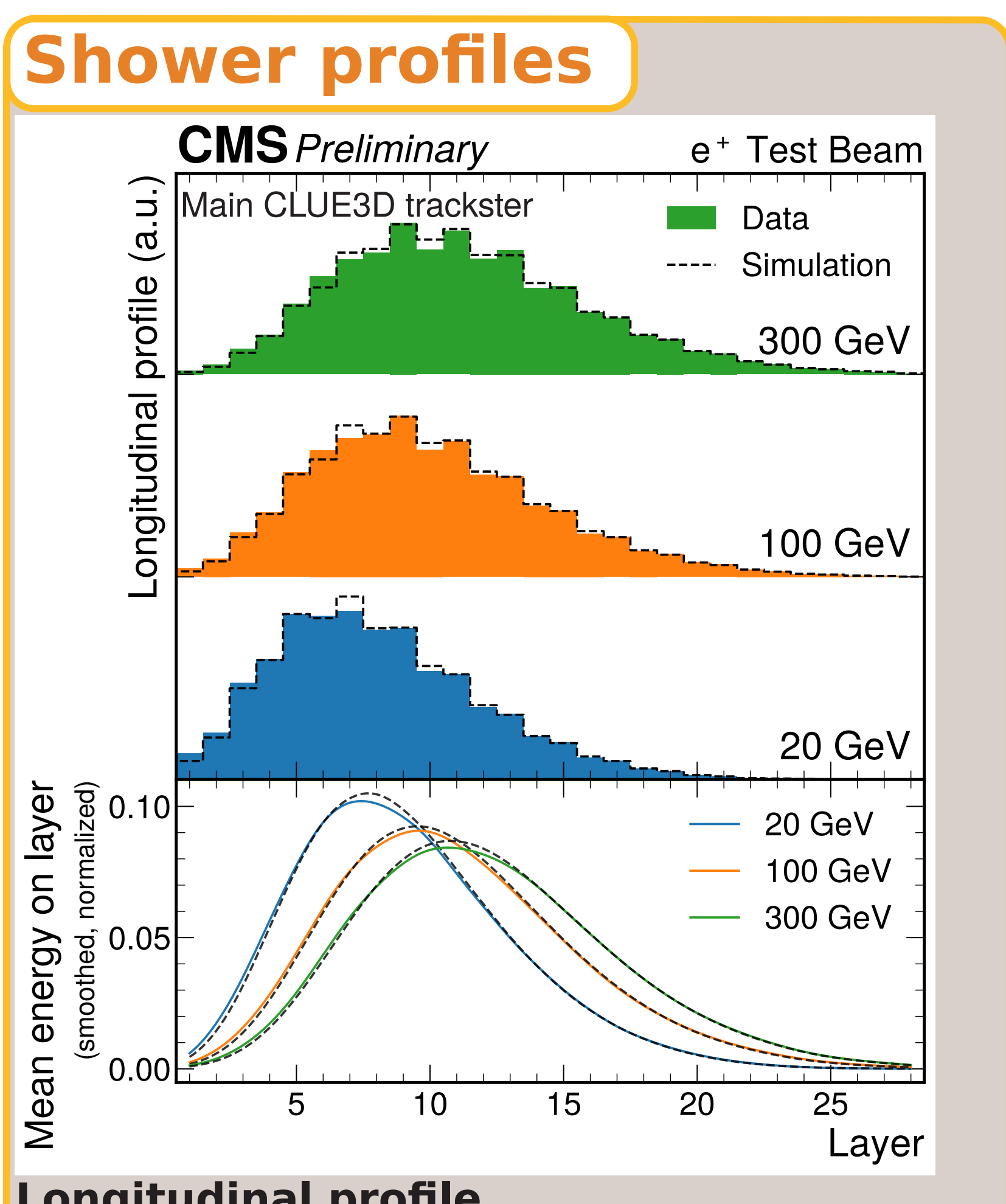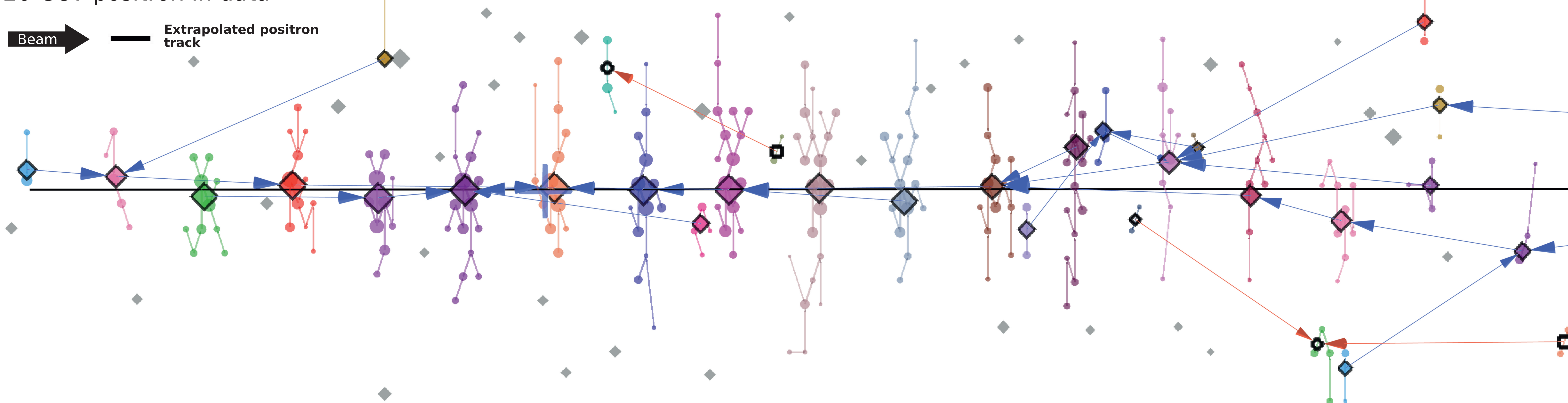
Cluster seed

Cluster seed

Masked hit

CLUE3D algorithm

CLUE3D is similar to CLUE, but uses layer clusters as inputs. Parameters are tuned to prefer clustering in the longitudinal direction.

➝ **Chain of nearest higher** color corresponds to trackster

✚ **Layer cluster outlier in CLUE3D**

✚ **Trackster**

The term "*Main CLUE3D trackster*" will refer, for each event, to the trackster with the highest energy.
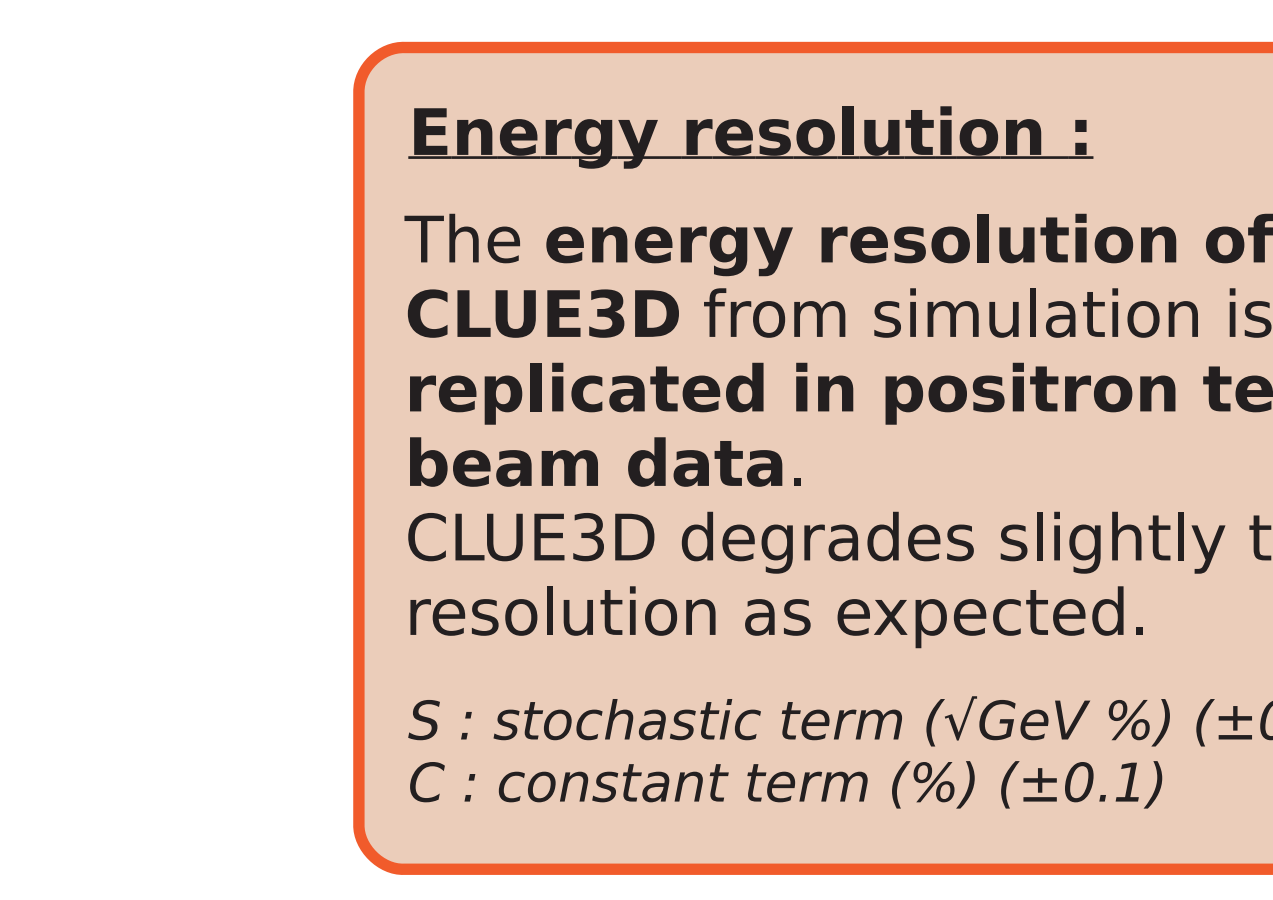
Event display

20 GeV positron in data

Beam ▶ ▬ **Extrapolated positron track**

Shower profiles

CMS *Preliminary*   e$^+$ Test Beam

Main CLUE3D trackster

Data / Simulation — 300 GeV / 100 GeV / 20 GeV

Longitudinal profile: Mean energy on layer (smoothed, normalized) vs Layer — 20 GeV, 100 GeV, 300 GeV

Longitudinal profile

CMS *Preliminary*   e$^+$ Test Beam

100 GeV Main CLUE3D trackster

$\frac{1}{E_{cluster}}\frac{dE_{tot}}{dA}$ (cm^{-2}) vs Distance to extrapolated impact point (cm)

Layer 8 (7.7 X_0) - Data
Layer 8 (7.7 X_0) - Simulation
Layer 15 (14 X_0) - Data
Layer 15 (14 X_0) - Simulation

CLUE3D trackster properties

CMS *Preliminary*   e$^+$ Test Beam

100 GeV — Event count vs Number of tracksters per event — Data / Simulation — Data / MC

CMS *Preliminary*   e$^+$ Test Beam

100 GeV All CLUE3D tracksters — Trackster count vs Number of layer clusters in a trackster — Data / Simulation — Data / MC

Good agreement of data with simulation.
Most events have only one trackster, as expected for a single positron event. More than one trackster can be due to bremsstrahlung events or to CLUE or CLUE3D splitting showers.

Transverse profile :
Sum the energy in annuli around the shower core. Normalize by area and energy on layer.

annulus — A_d — d — 0.3 mm — positron track extrapolation — Beam direction

Good agreement data/simulation.

Energy distribution

CMS *Preliminary*

e$^+$ Test Beam 100 GeV

Event count vs Total reconstructed energy per event (GeV)

Reconstructed hits MPV = 100.8 GeV
CLUE clusters MPV = 98.8 GeV
Main CLUE3D trackster MPV = 97.0 GeV

Reconstructed energy : CLUE and CLUE3D use a subset of reconstructed hits, thus giving a slightly lower energy.

Energy resolution :
The **energy resolution of CLUE3D** from simulation is **well replicated in positron test beam data**. CLUE3D degrades slightly the resolution as expected.

S : stochastic term (√GeV %) (±0.1)
C : constant term (%) (±0.1)

CMS *Preliminary*   e$^+$ Test Beam

Relative energy resolution (%) vs Incident beam energy (GeV)

Data   Simulation

Reconstructed hits
S=22.0, C=0.5 (data)
S=21.5, C=0.4 (sim)

Main CLUE3D trackster
S=23.5, C=0.3 (data)
S=23.1, C=0.3 (sim)

Fit function : $\frac{\hat{\sigma}}{\hat{\mu}} = \frac{S}{\sqrt{E^{incident}}} \oplus C$

Conclusion

The performance of the CLUE3D algorithm in positron test beam data is well modelled by simulation, in terms of energy resolution, longitudinal and transverse profiles. Future developments of reconstruction algorithms in HGCAL can thus proceed with reinforced confidence that their perfomance will translate well into data.