

Performance of High Granularity Dual- Readout Fiber Calorimeter (HG-DREAM) with High Energy Particle Beams

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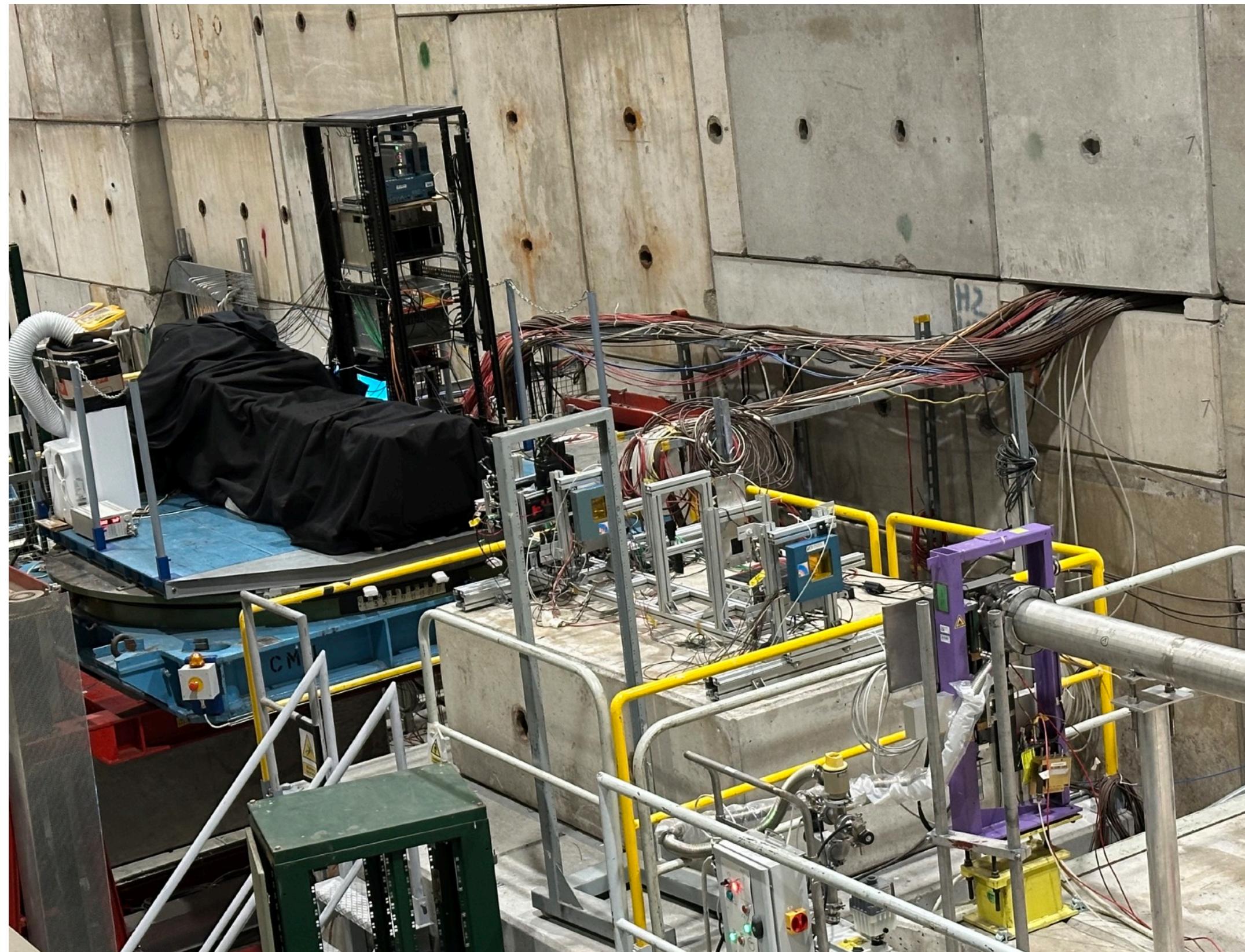
Texas Tech University

CPAD 2025, Philadelphia, PA

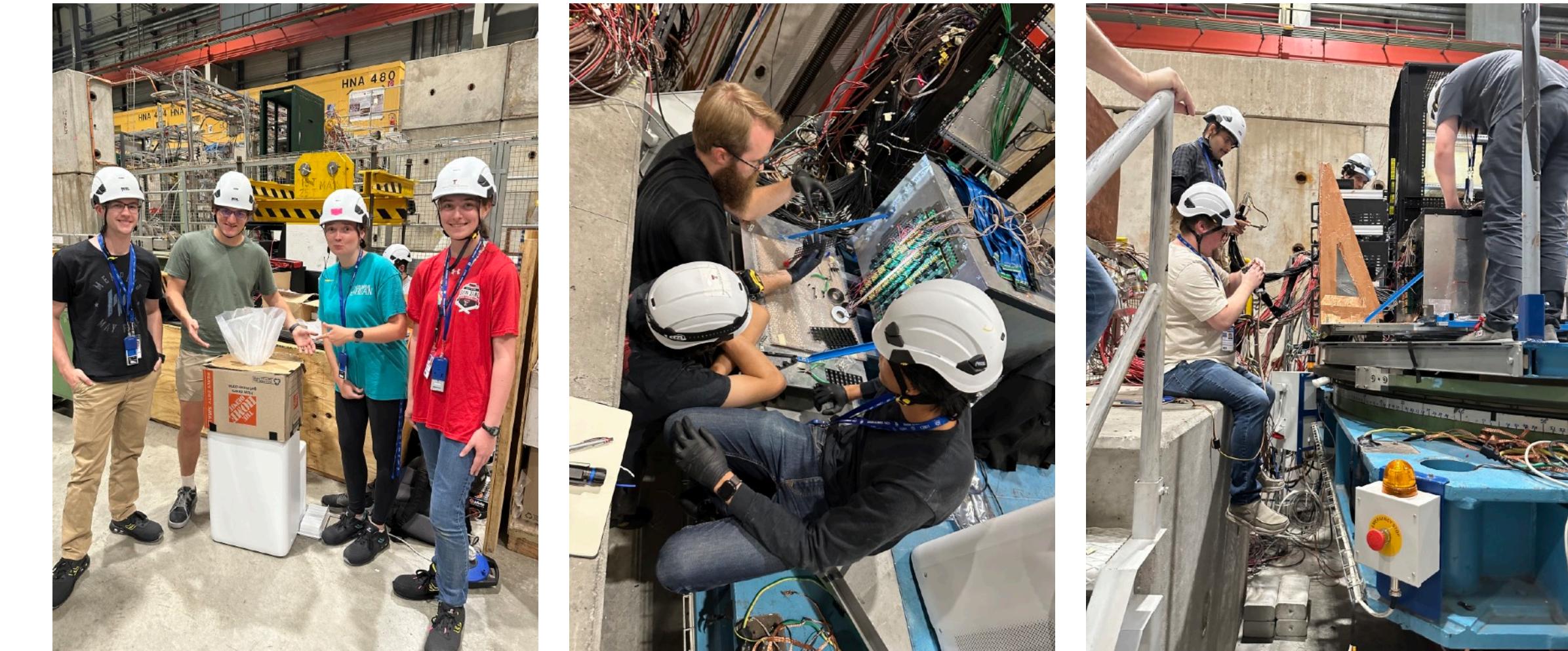
October 7th, 2025

Test beam at CERN SPS for HG-DREAM

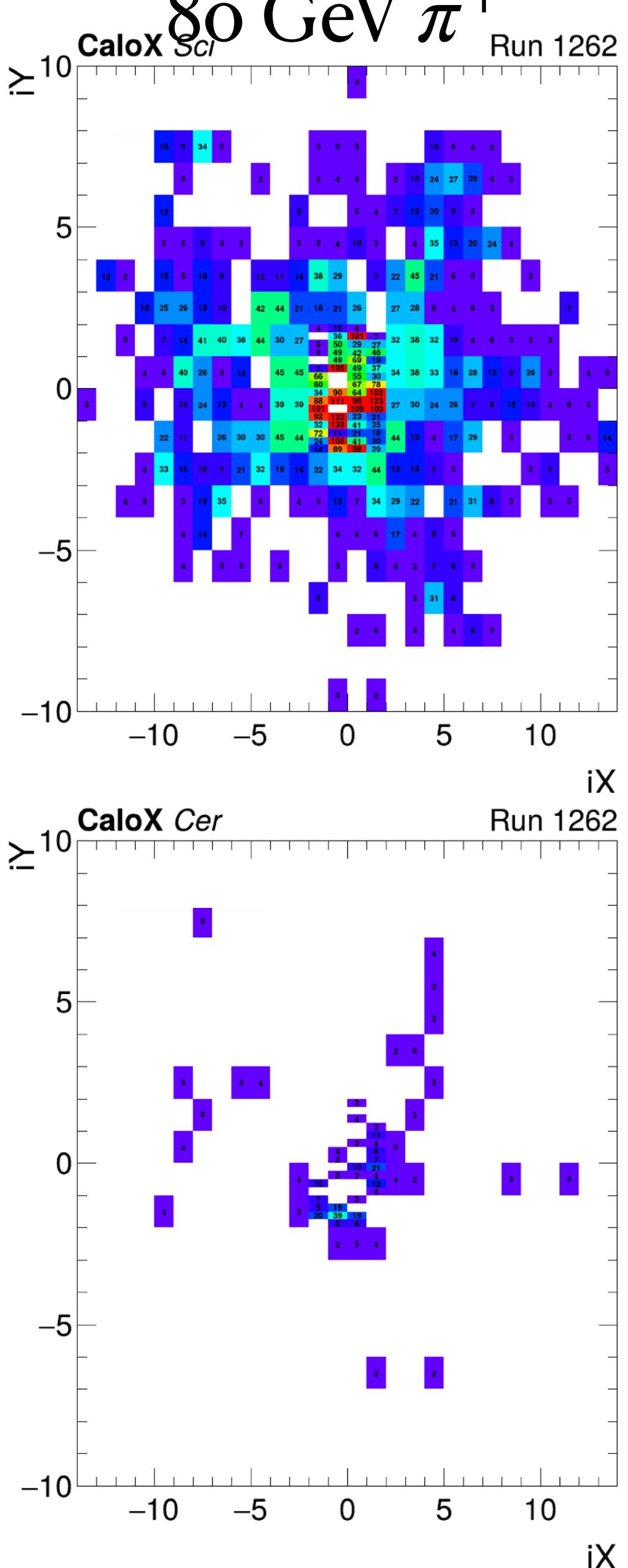
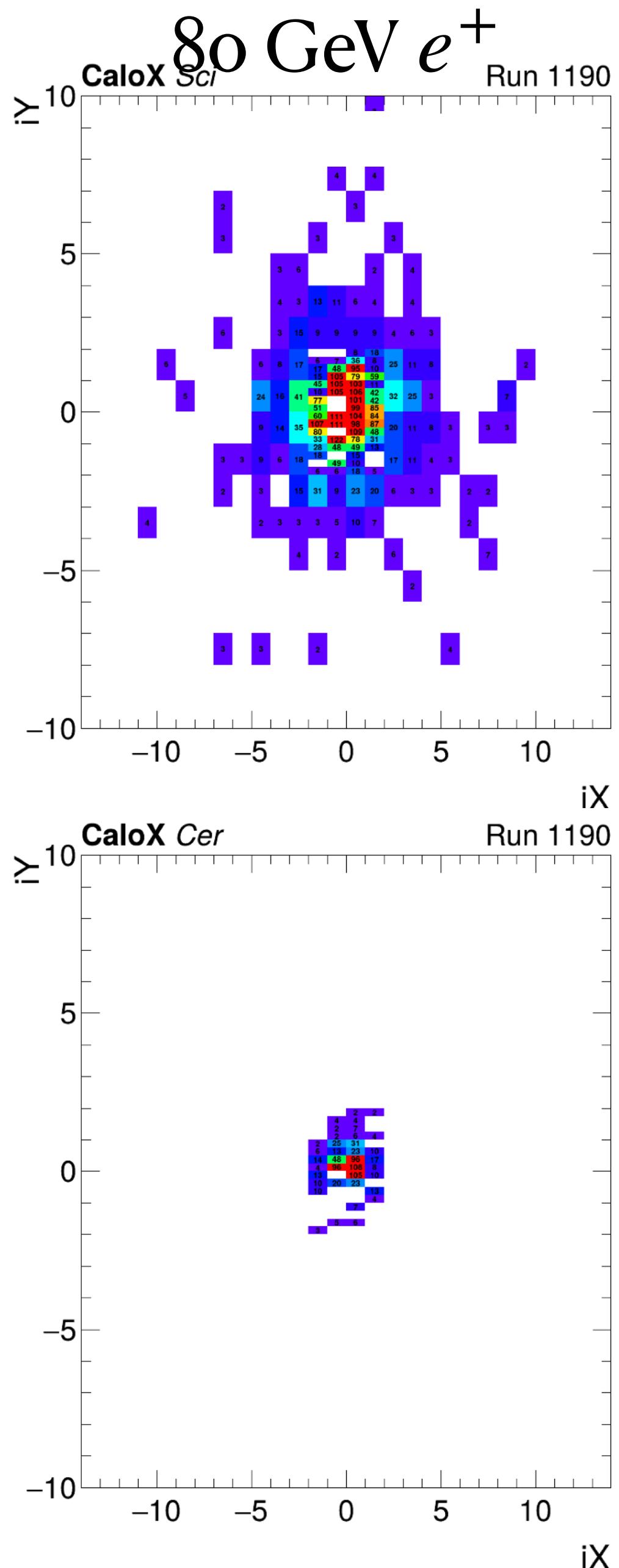
Two test beam experiments at CERN SPS in August and September 2025



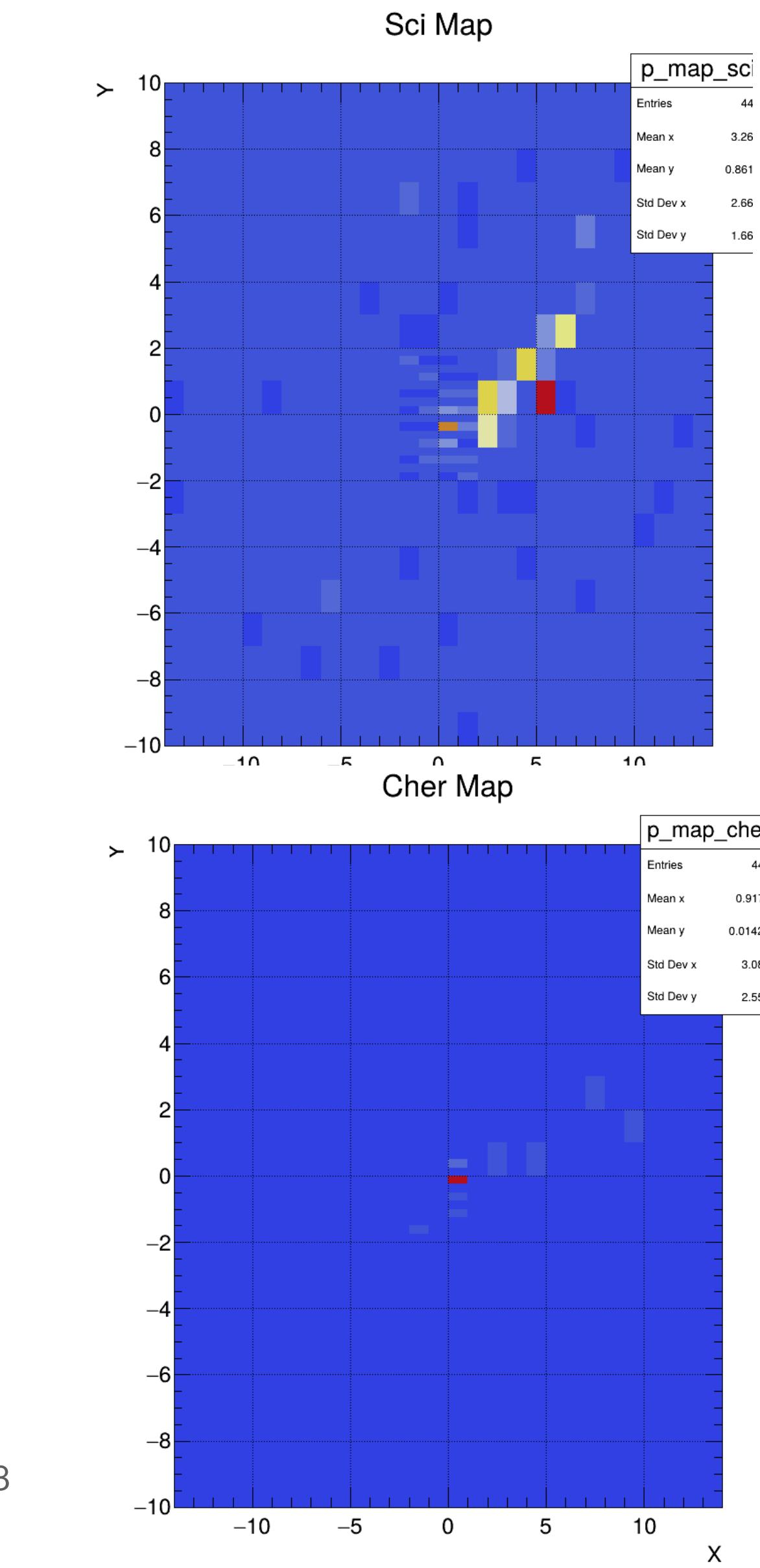
- Energy measurements of e^+ , π^+ and μ^+
 - Timing measurements with the calorimeter
- Resolve longitudinal shower shapes



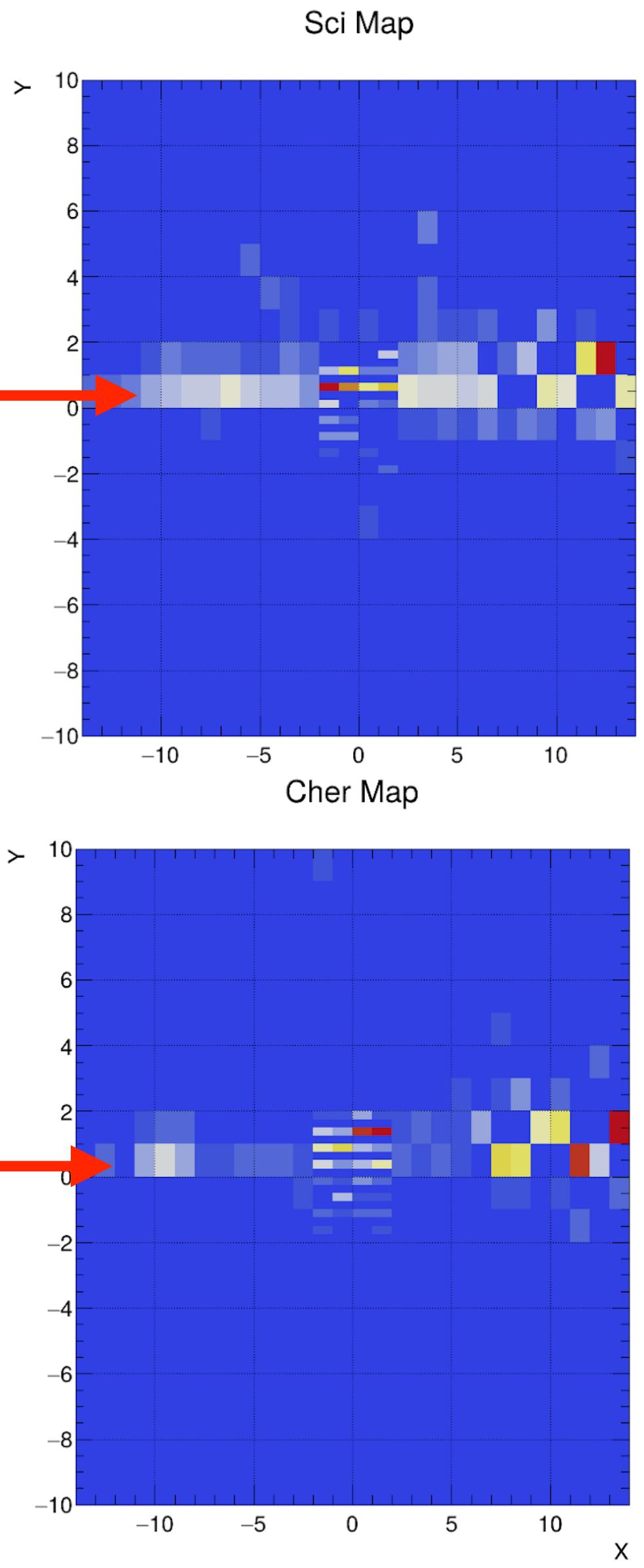
Events in the test beam



170 GeV μ^+ from front



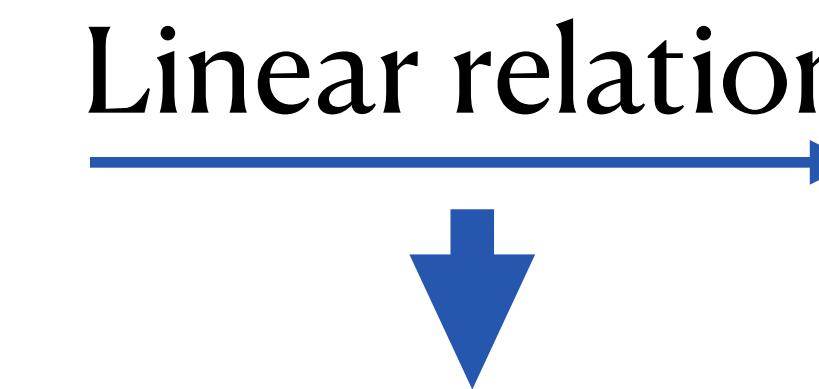
110 GeV μ^+ from side



Energy measurements

Per-channel calibration of energy measurement

Readout of a channel: **ADC counts**



What we want to know: **energy**

Derive the conversion factors: **conv._i** for channel ***i***

Use e^+ beams with known beam energy $E = 80$ GeV.

Scan the beam position in the detector

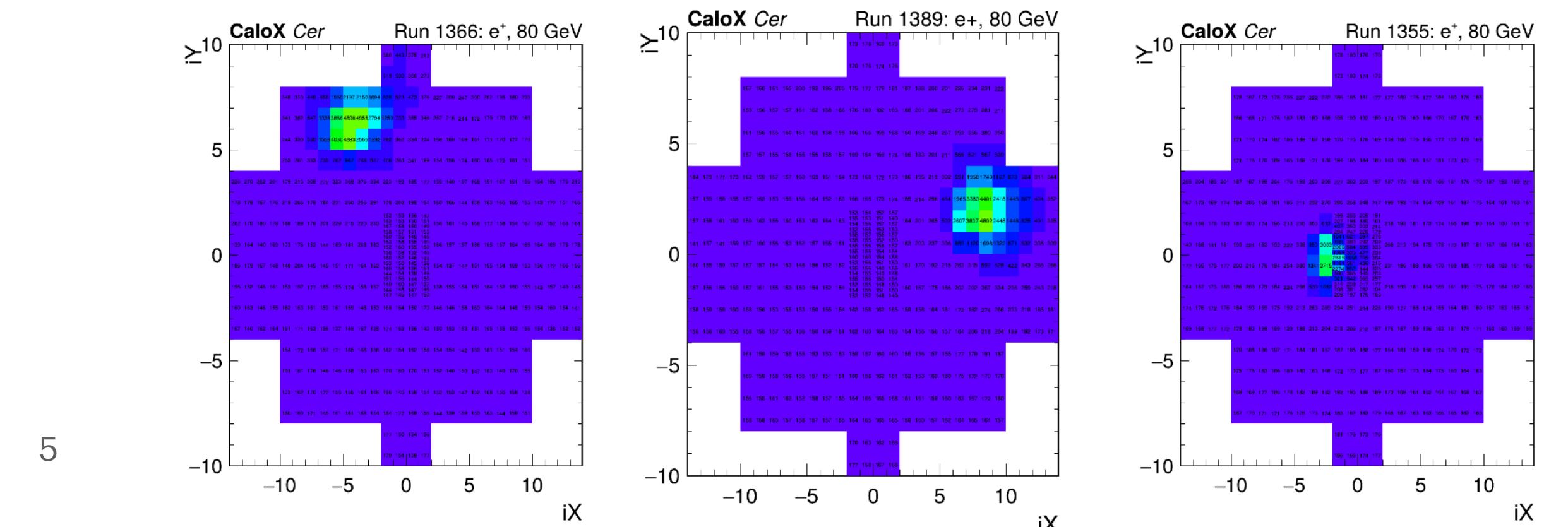
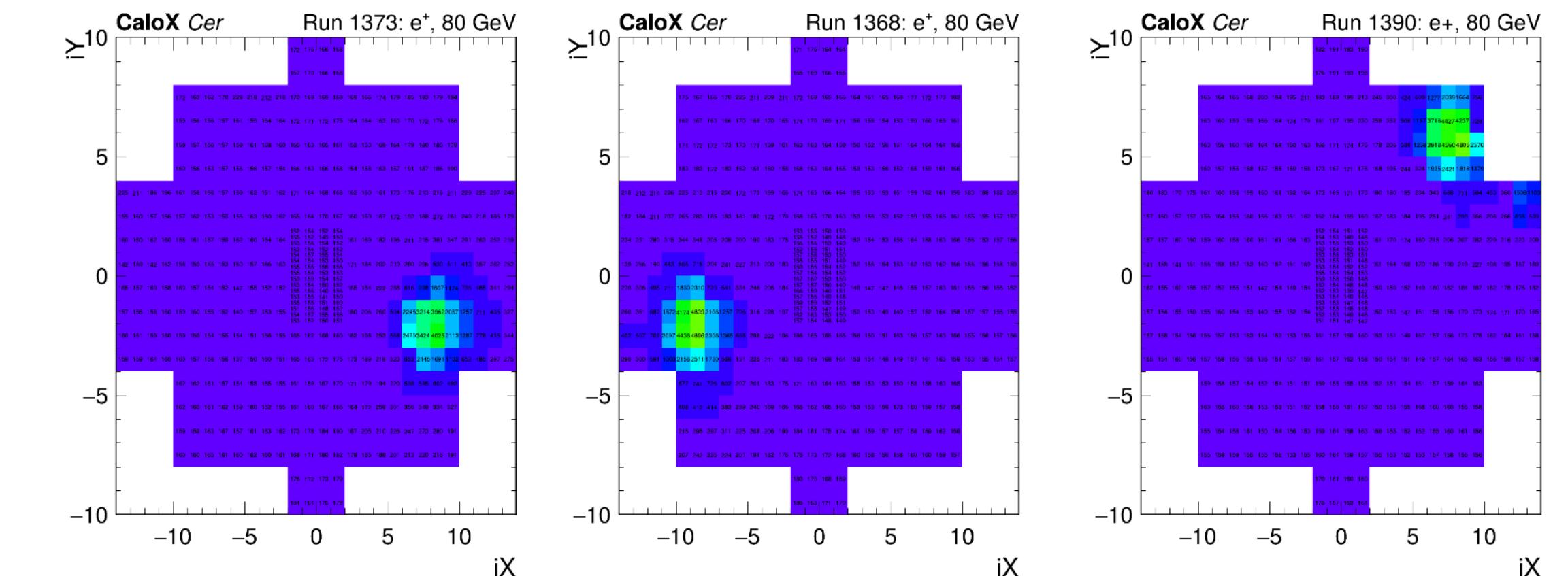
(~10k per position, 23 positions)

Channel i readout in event j : **ADC_{ji}**

Event j readout satisfies: $\sum_i \text{ADC}_{ji} \text{conv.}_i = E$

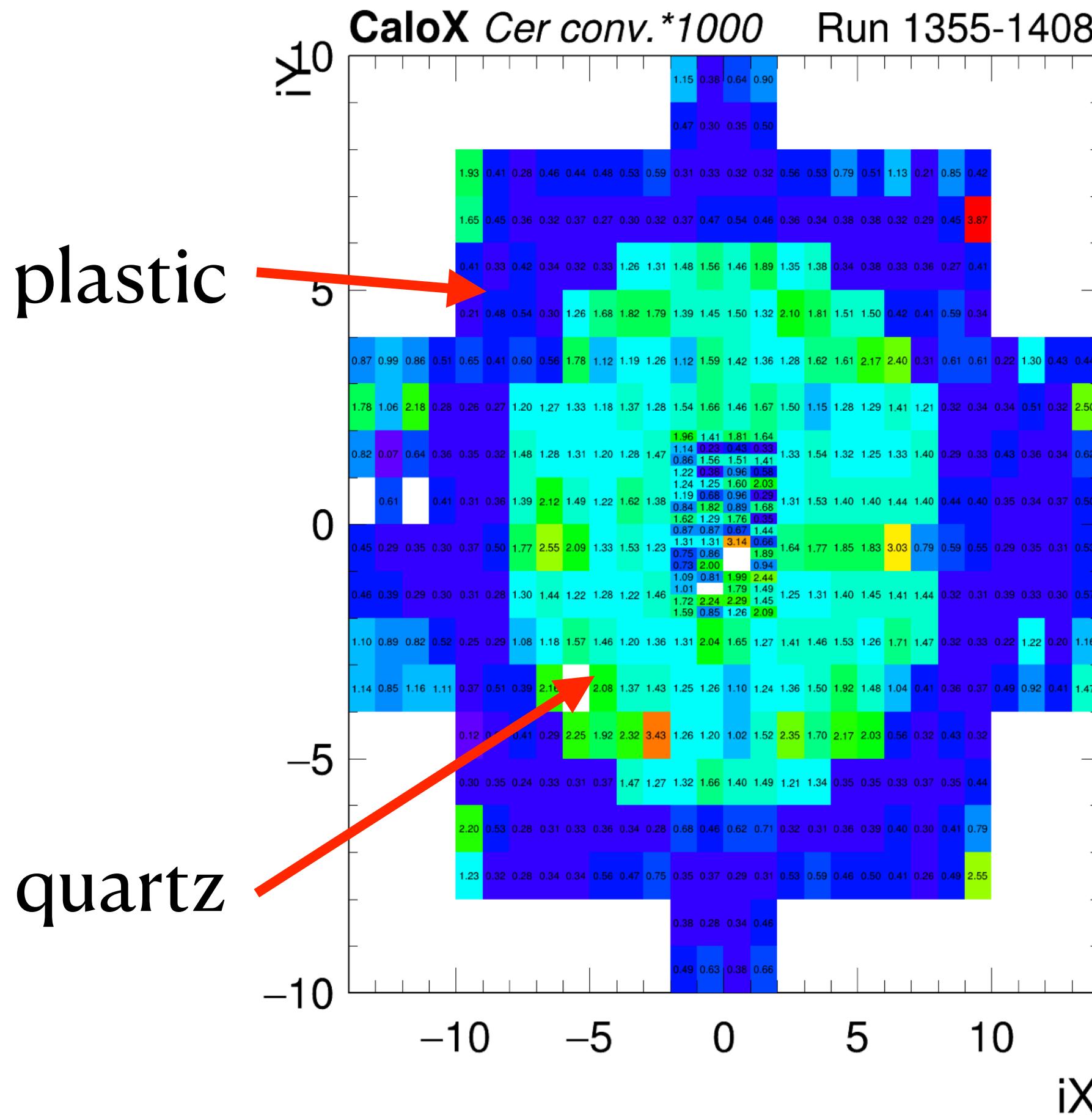
→ Linear regression on all events to solve **conv._i**

Mean readouts during the position scan

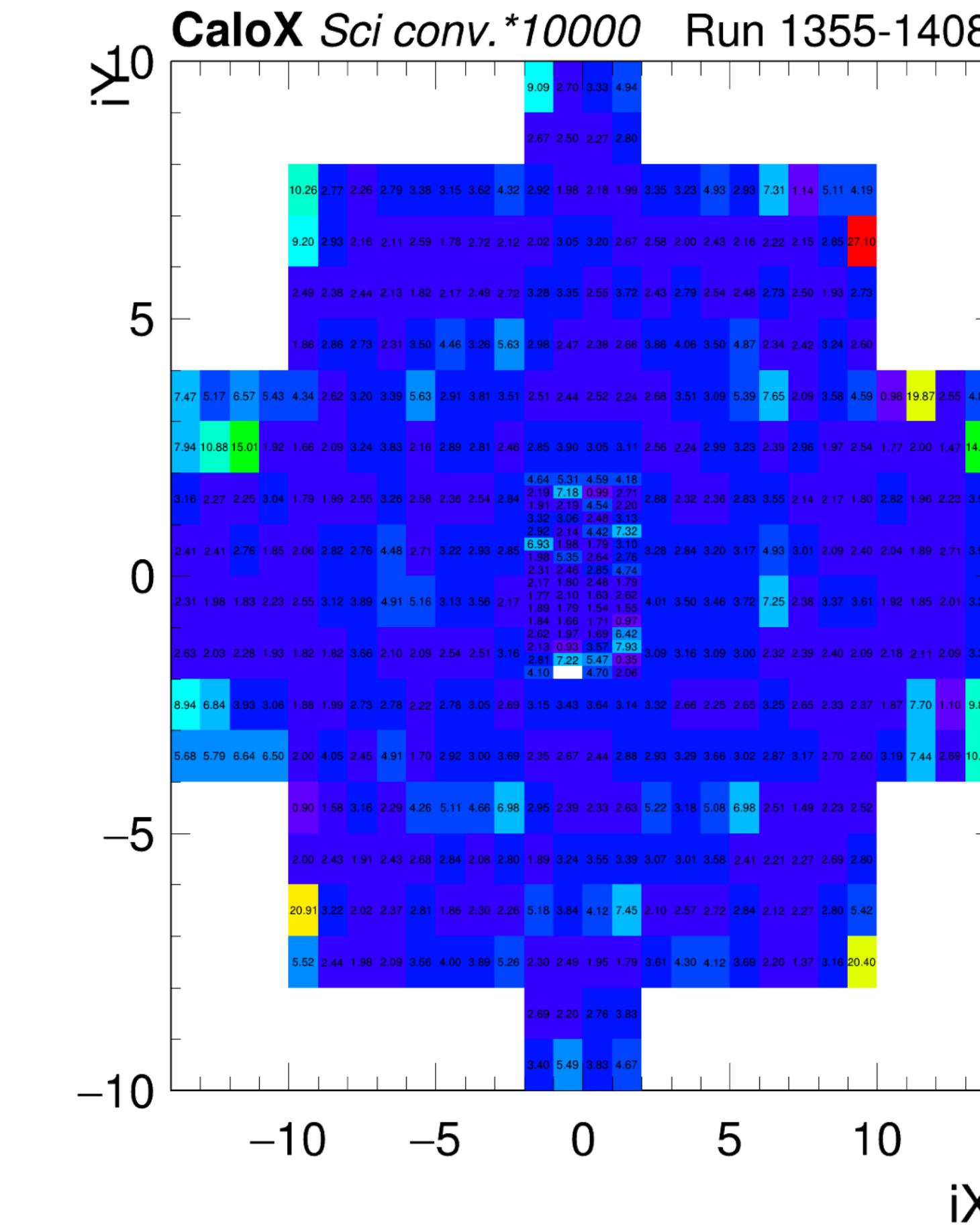


Calibration results

Map of conv. for Cherenkov channels



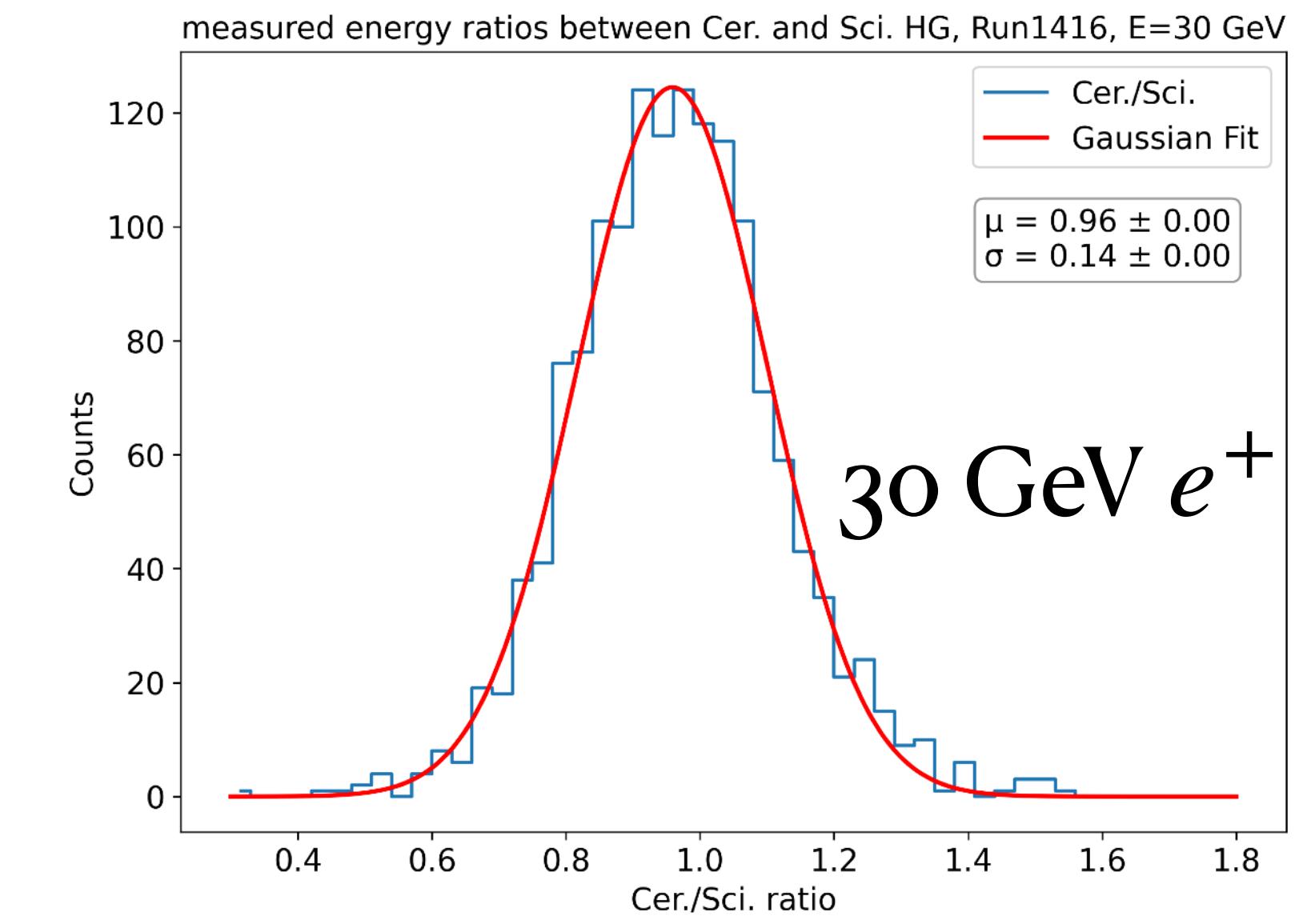
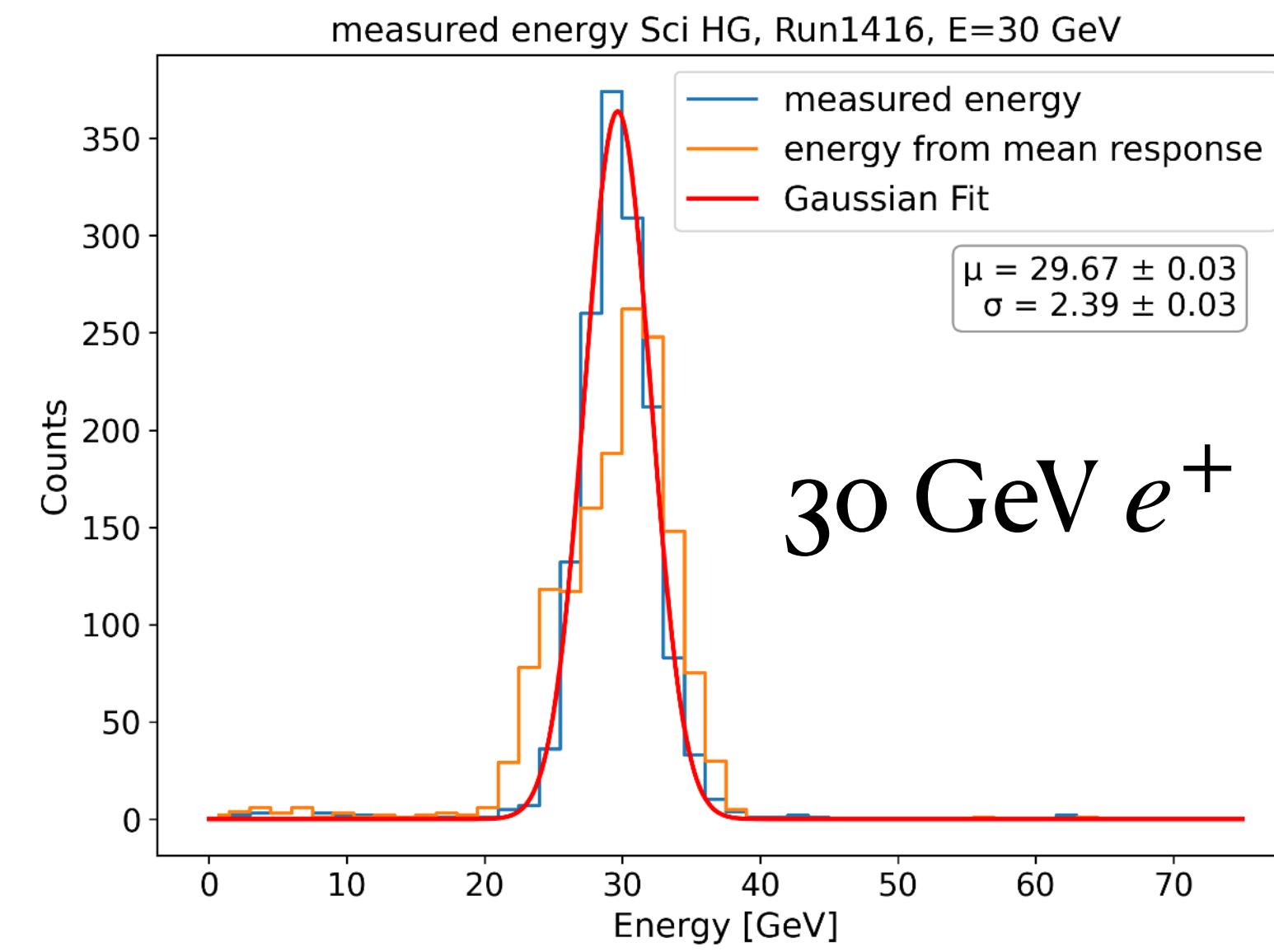
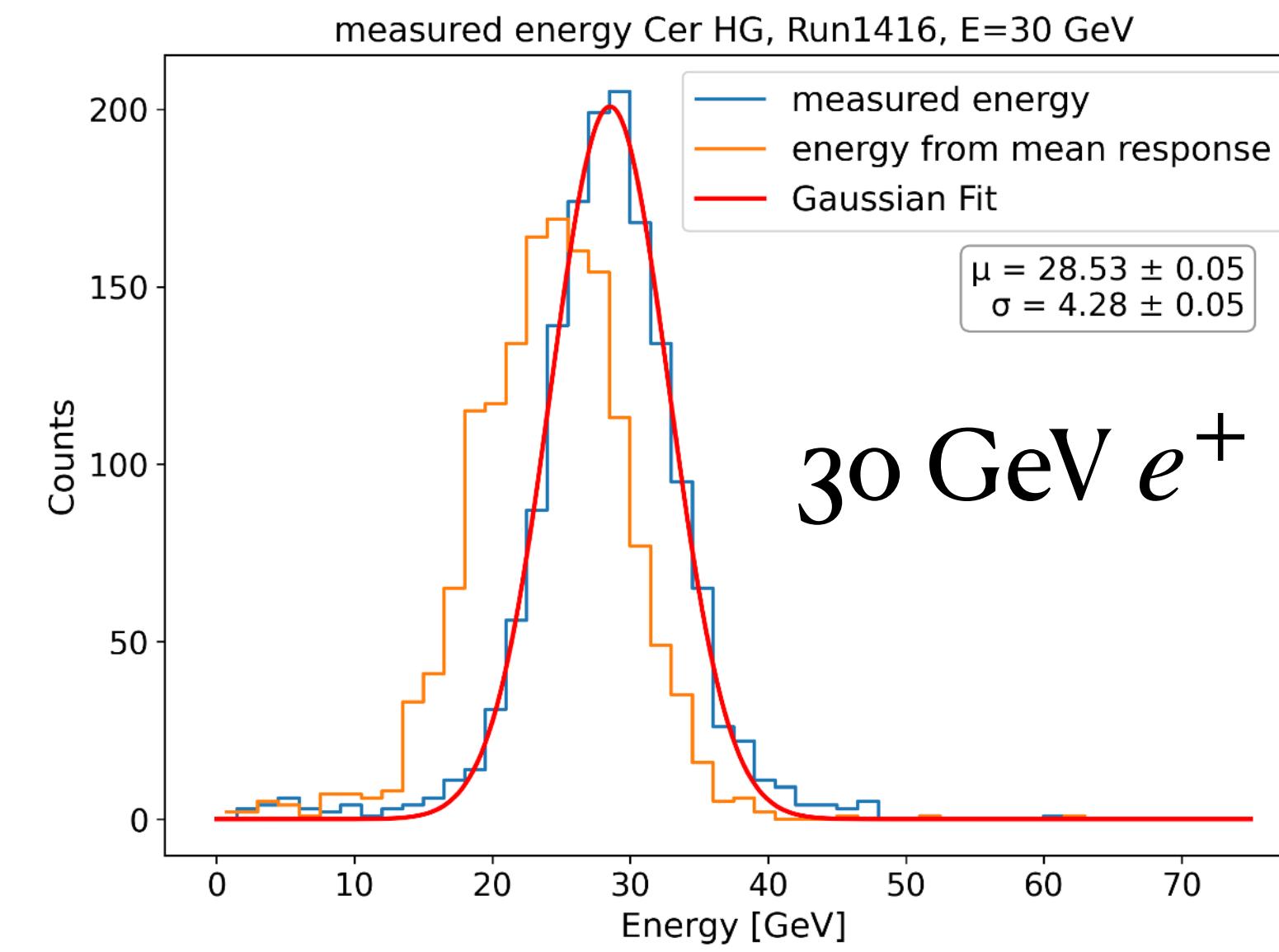
Map of conv. for Scintillation channels



Energy measurement of e^+

Test the energy calibration e^+ data with energy 10 – 100 GeV

preliminary



Measured energy from Cherenkov channels
Raw sum

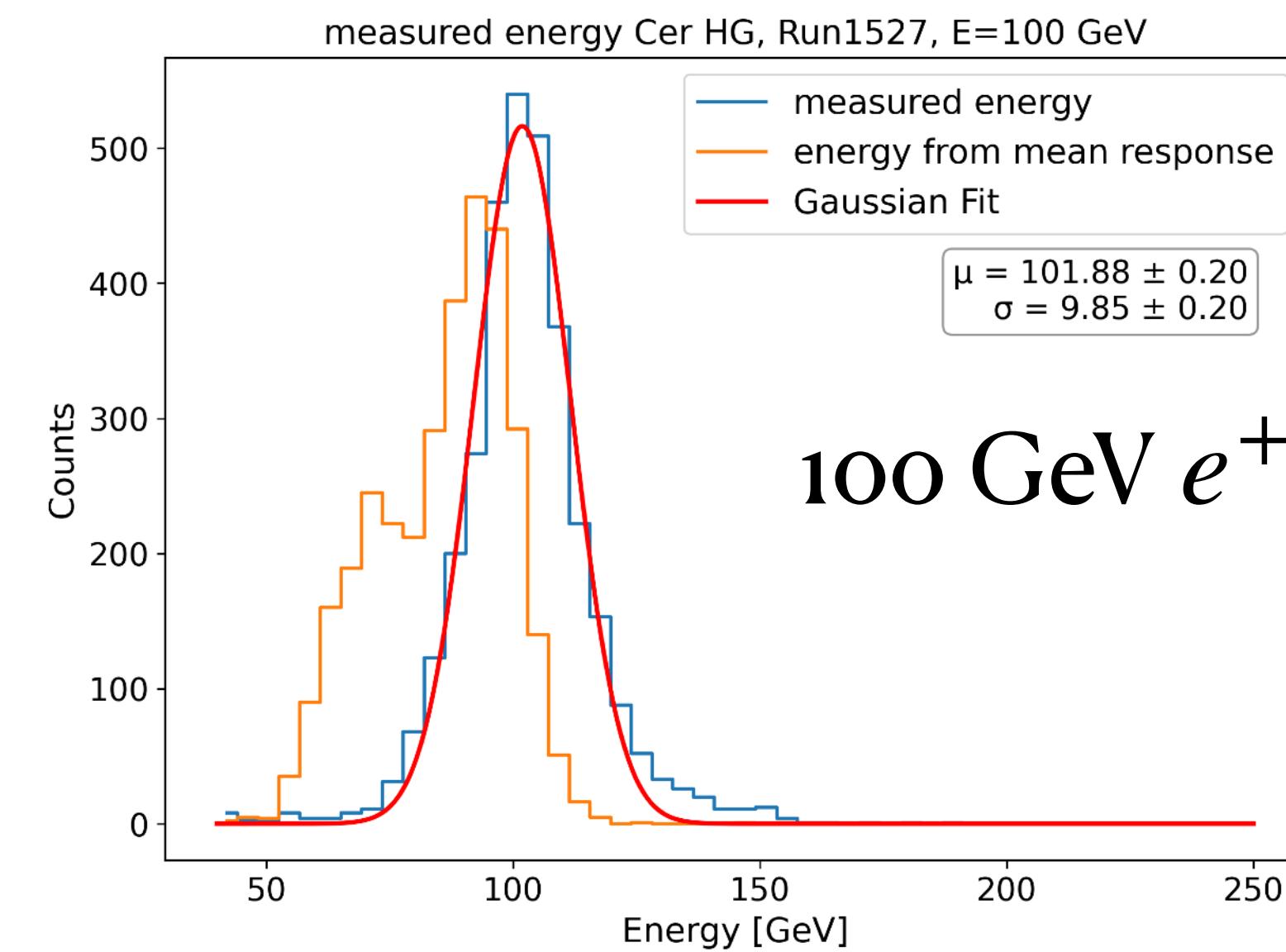
Measured energy from Scintillation channels
Raw sum

ratio of energy Cer./Sci.

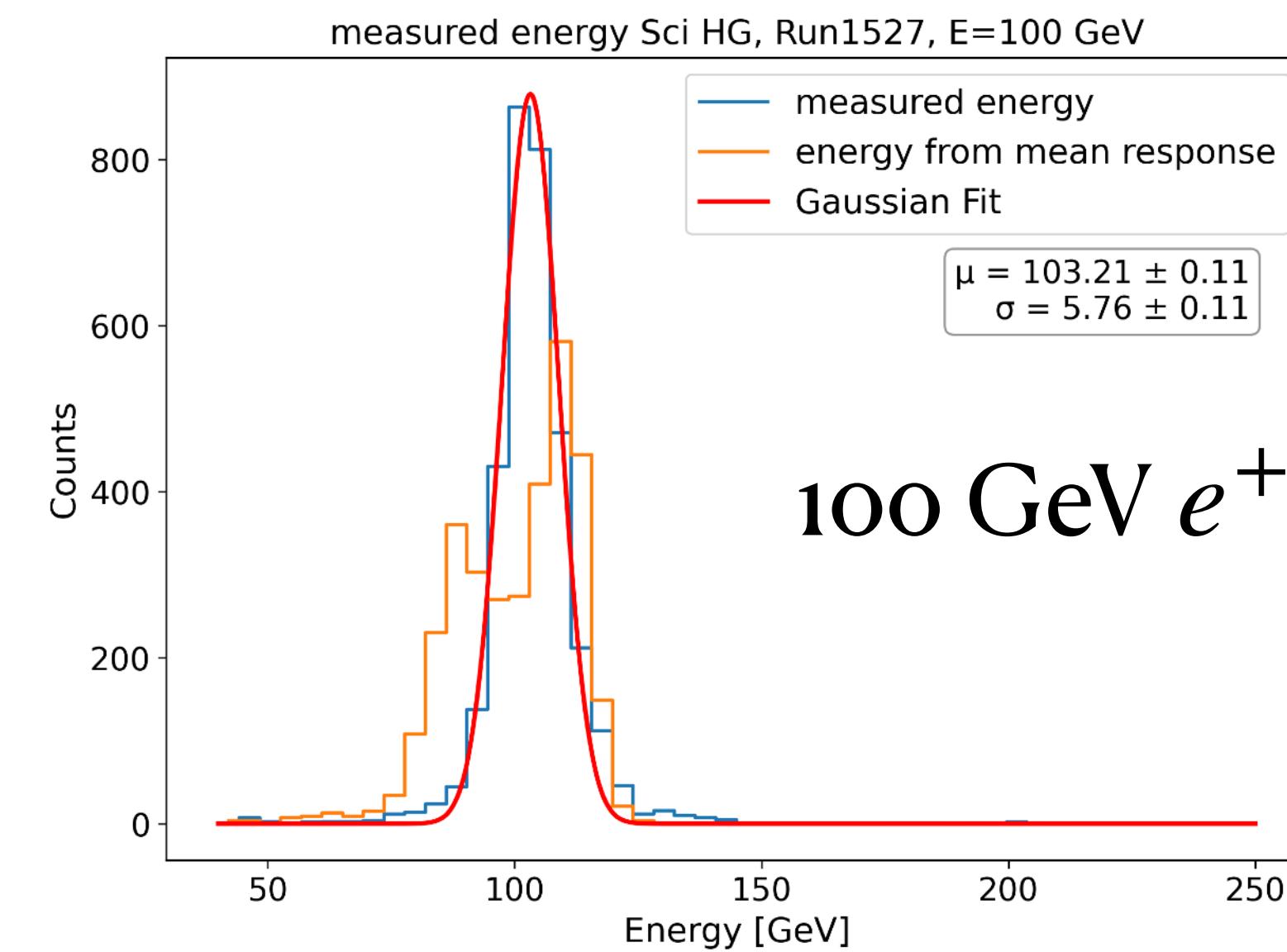
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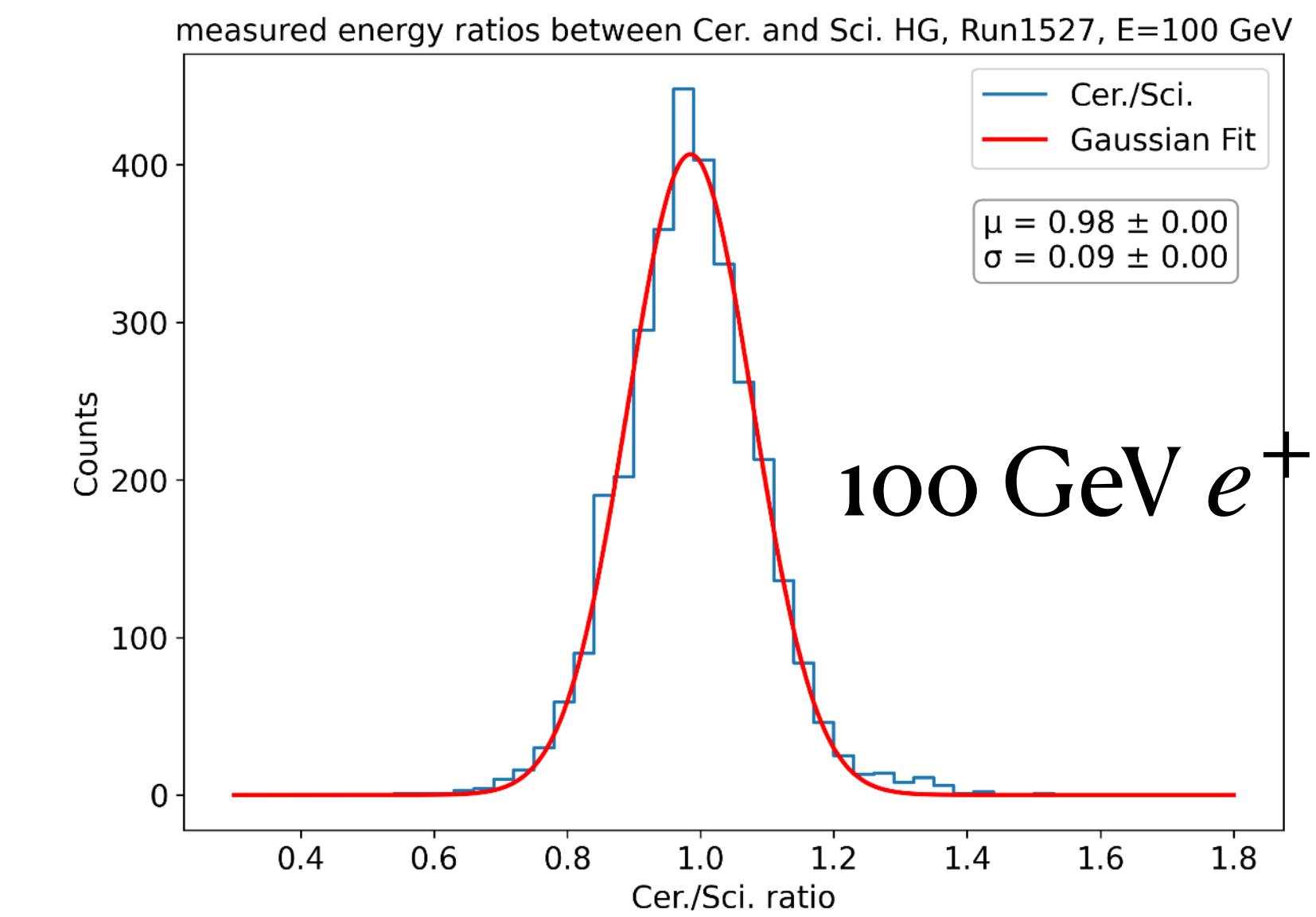
preliminary



Measured energy from Cherenkov channels
Raw sum



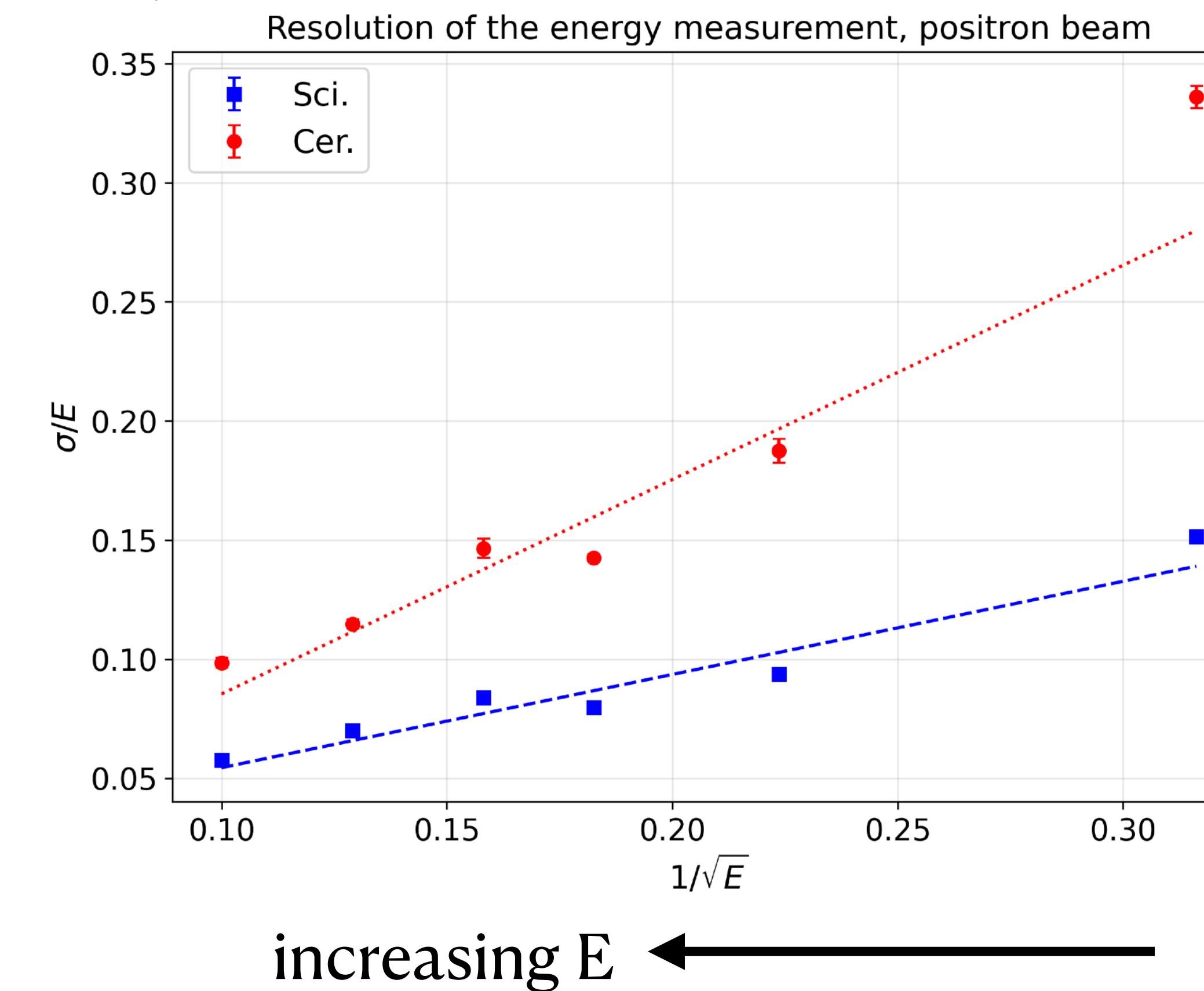
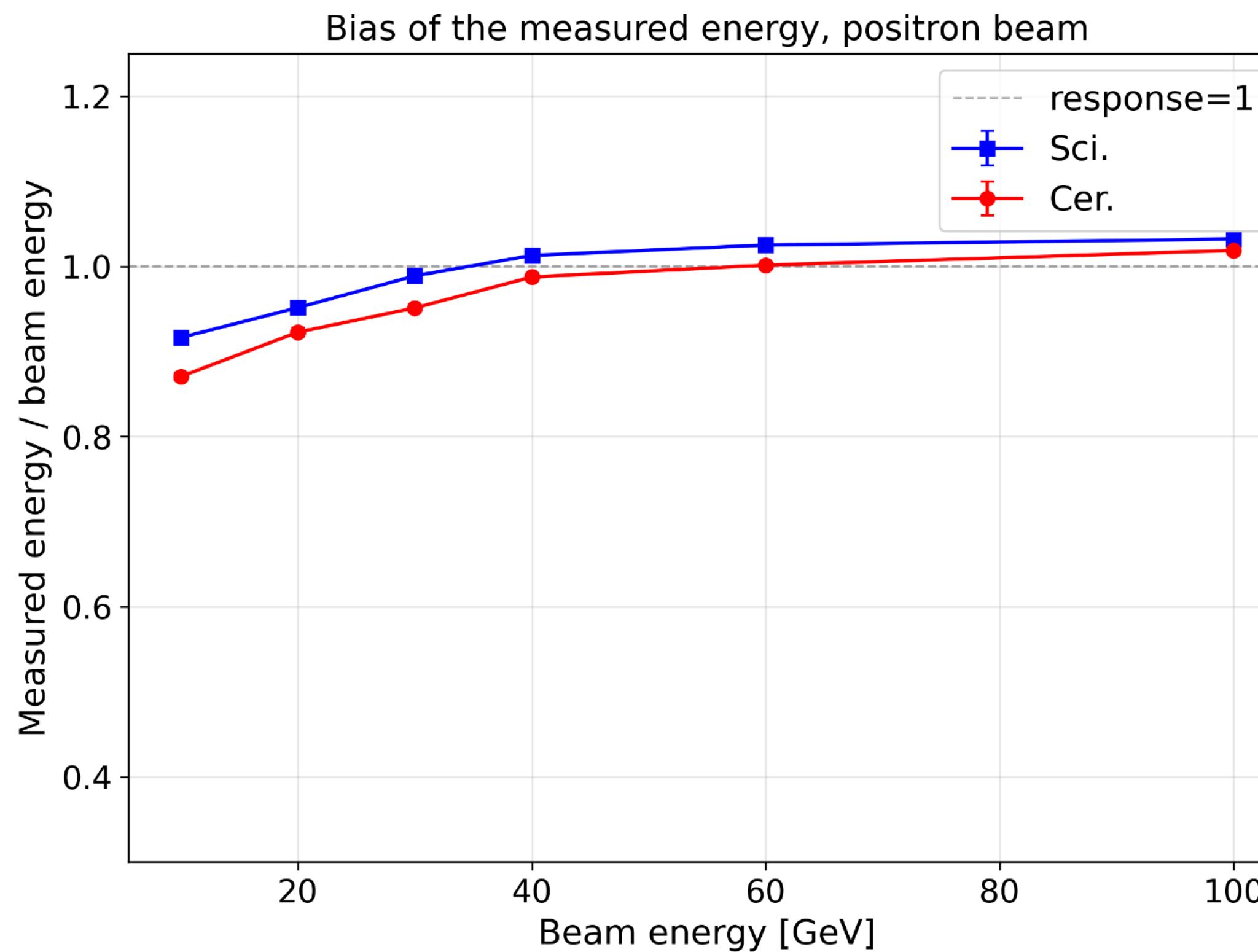
Measured energy from Scintillation channels
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ratio of energy Cer./Sci.

Energy measurement of e^+

preliminary

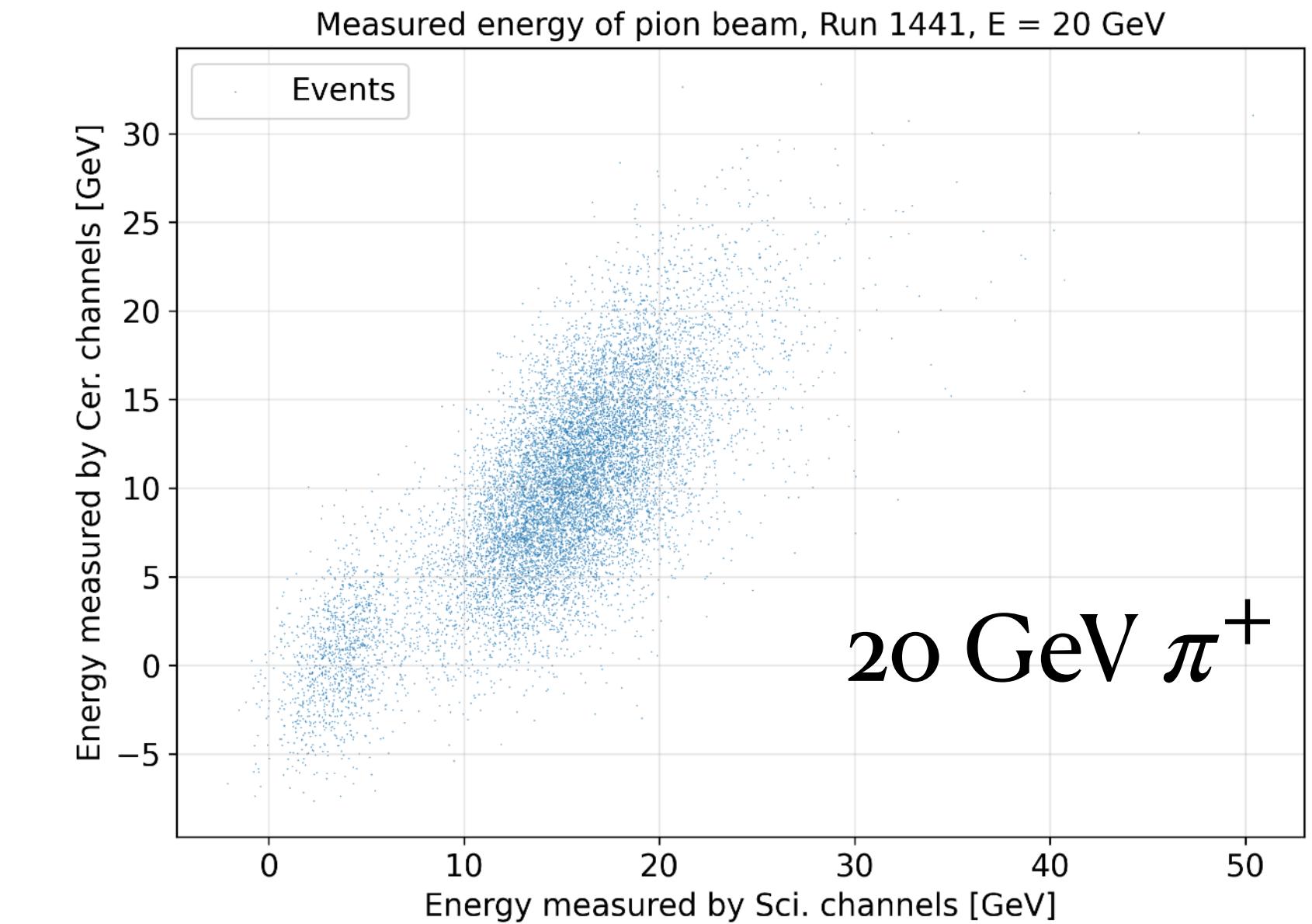
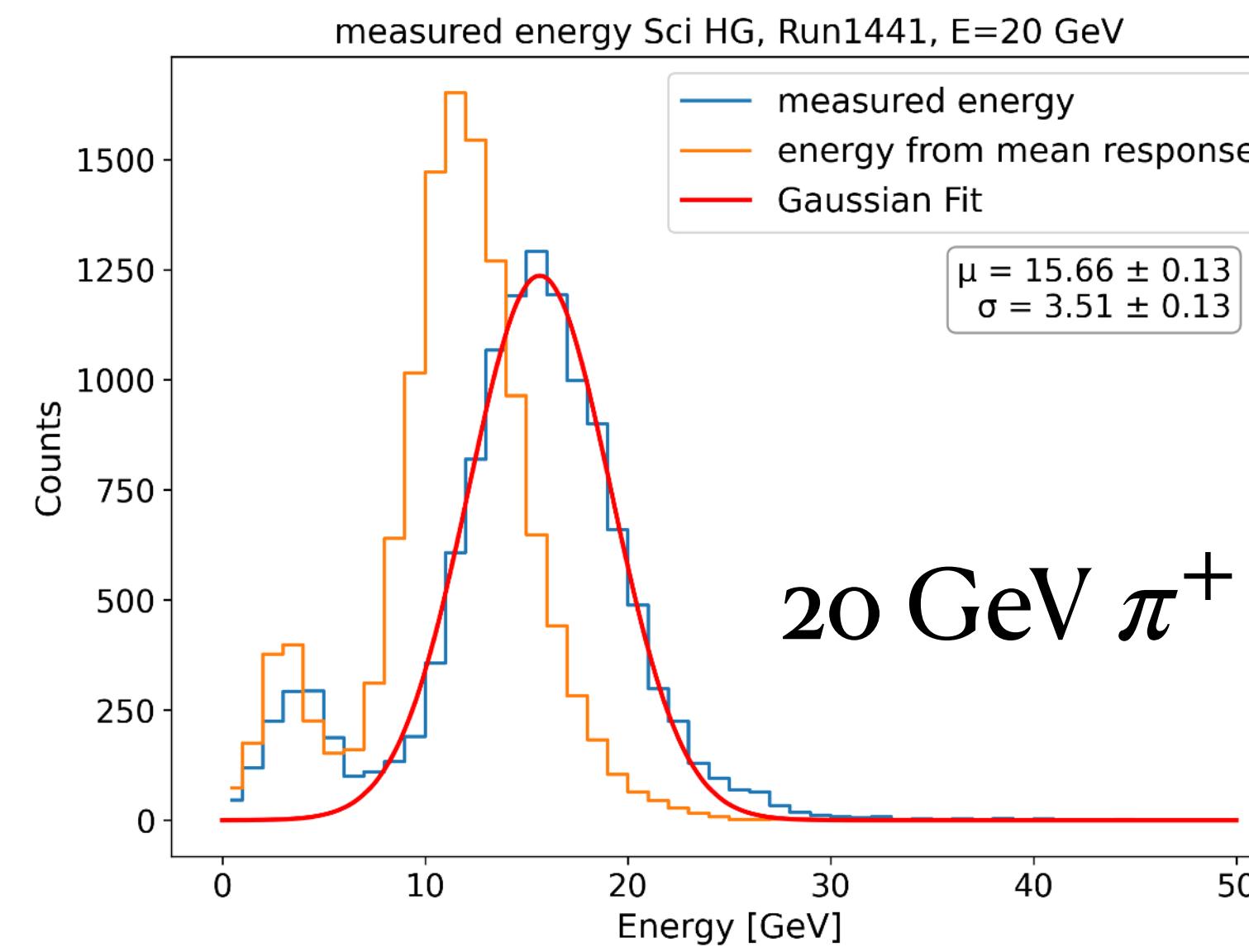
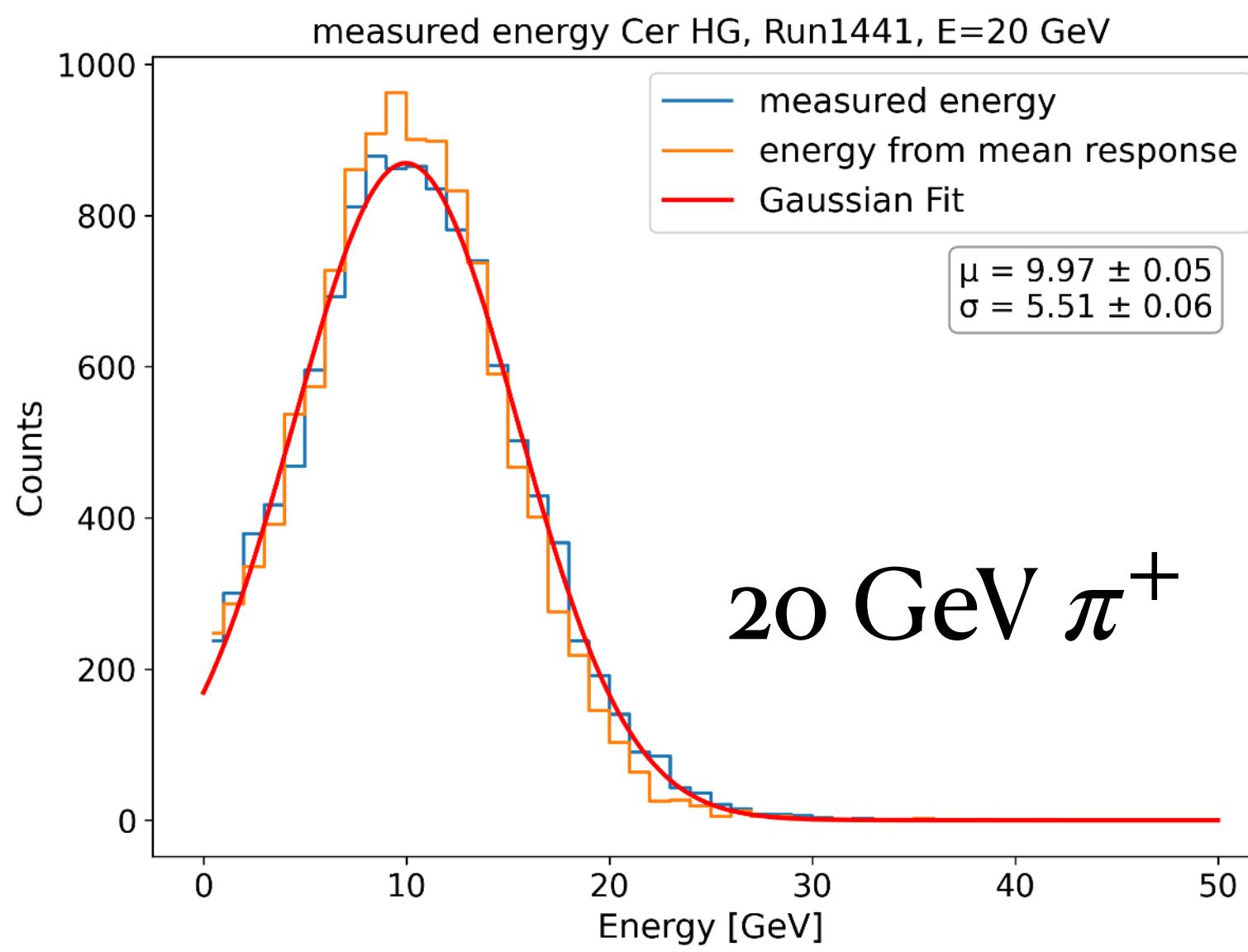


Response = measured E /beam E
versus E

Resolution = measured $\sigma(E)/E$
versus $1/\sqrt{E}$

Energy measurement of π^+

Apply the calibrated **conv.** on π^+ measurements with beam energy 10–160 GeV
preliminary



Measured energy from Cherenkov channels

Raw sum

Measured energy from Scintillation channels

Raw sum

Cer. v.s. Sci

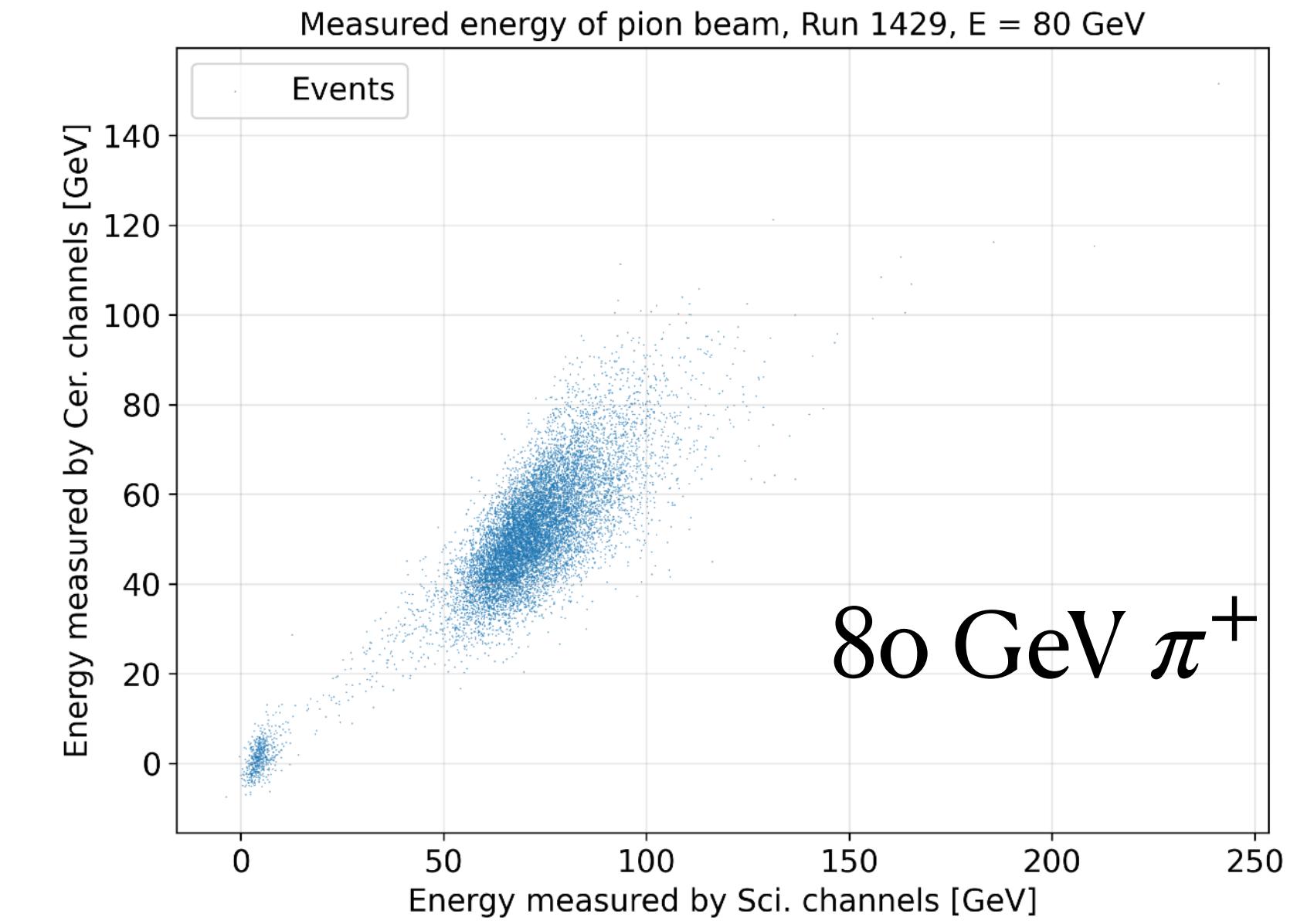
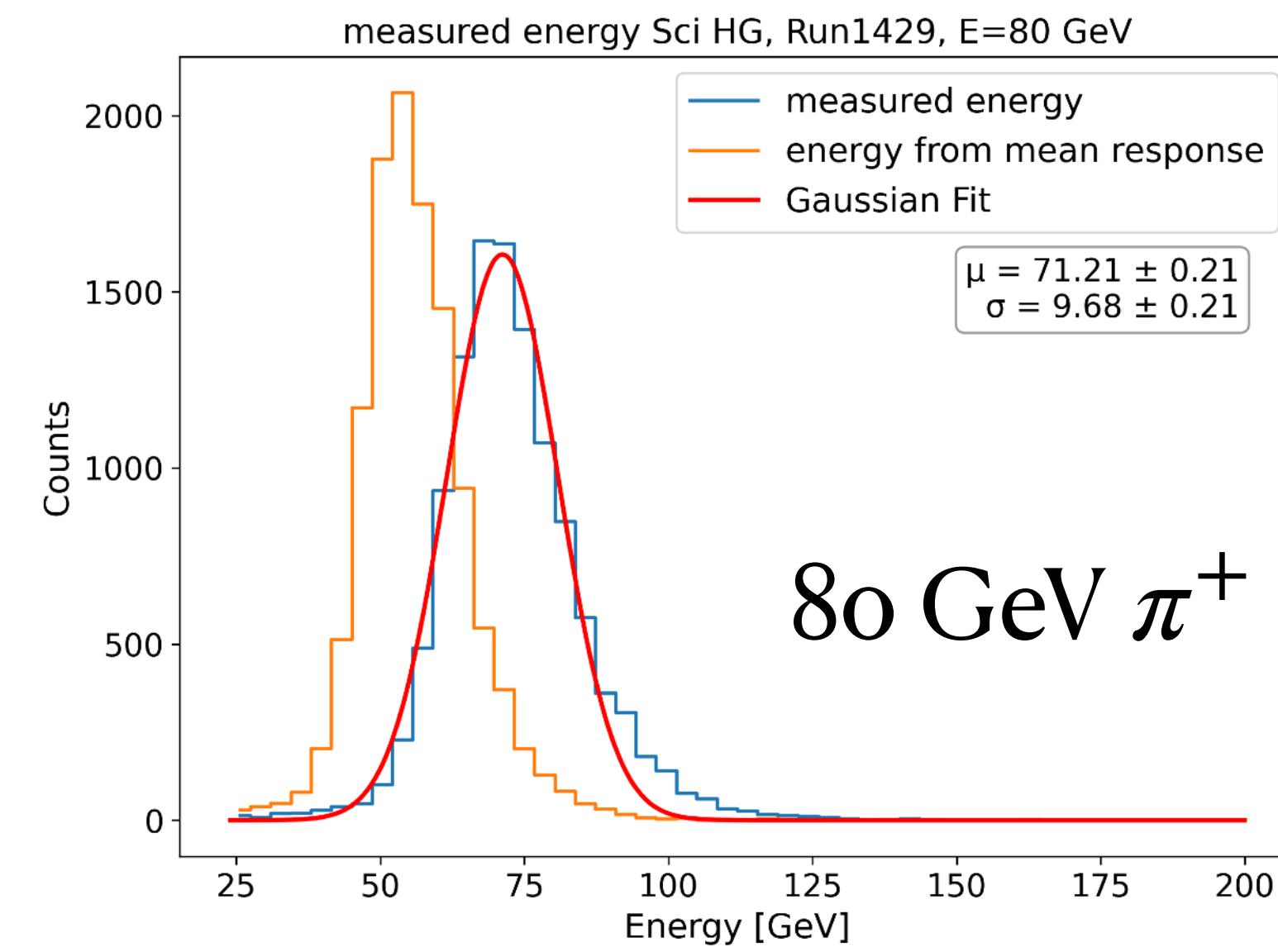
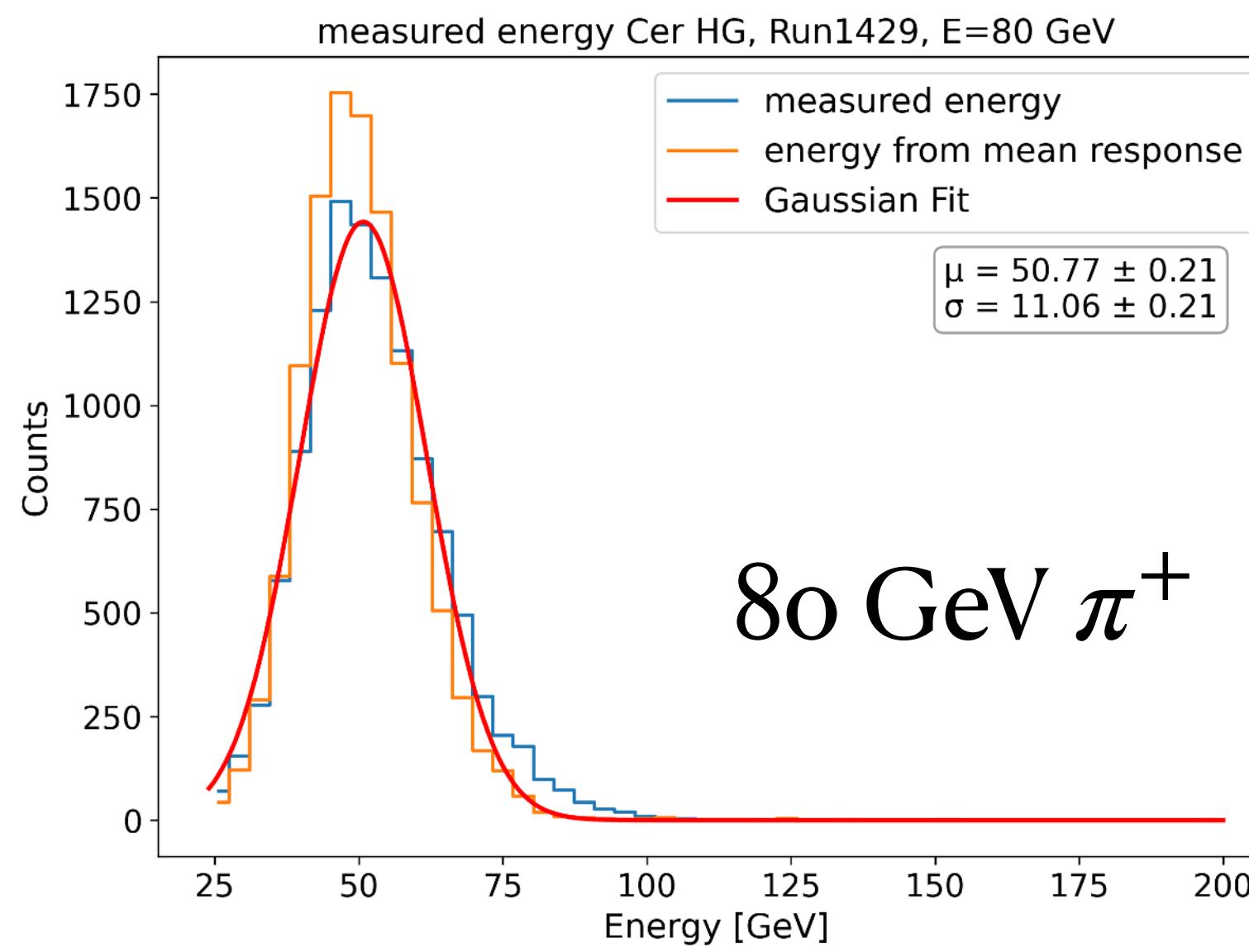
Correlations due to the same e.m. shower fraction per-event for Sci. and Cer. measurements

→ Dual-readout: linear combination of Sci. and Cer.

¹⁰ → Improved resolution compared to single Sci. or Cer. measurement

Energy measurement of π^+

Apply the calibrated **conv.** on π^+ measurements with beam energy 10–160 GeV



Measured energy from Cherenkov channels
Raw sum

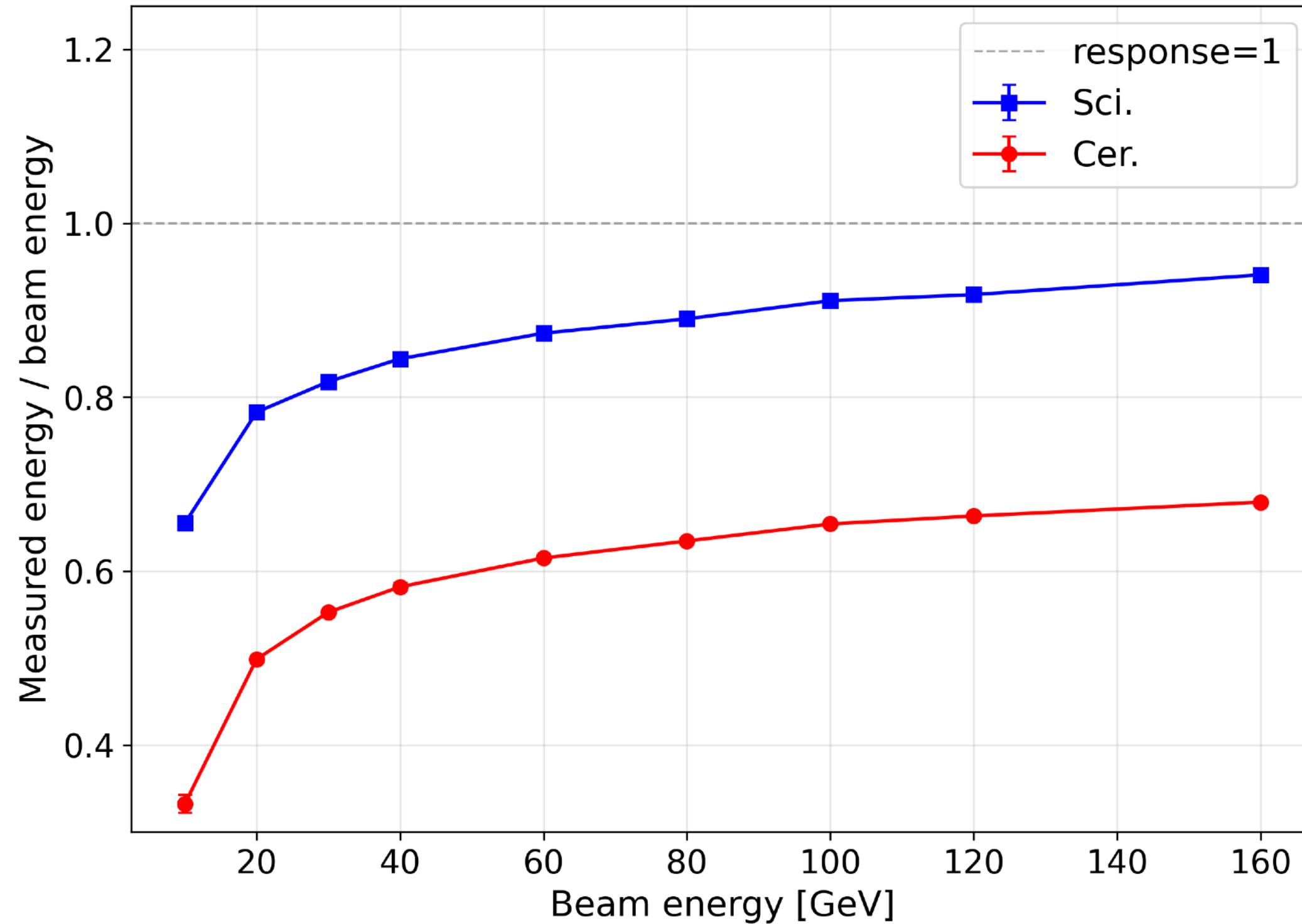
Meausured energy from Scintillation channels
Raw sum

Cer. v.s. Sci

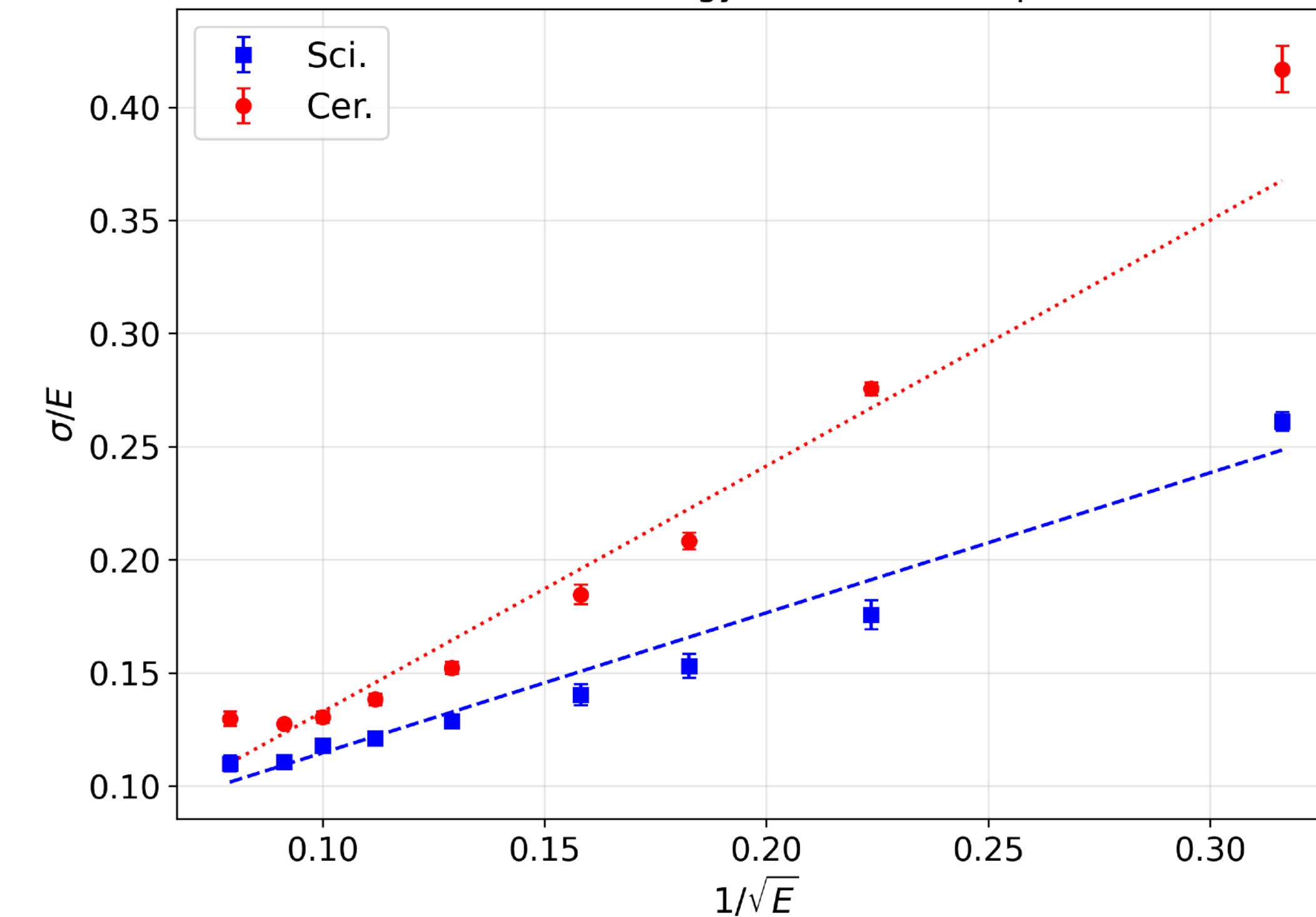
Energy measurement of π^+

preliminary

Bias of the measured energy, pion beam



Resolution of the energy measurement, pion beam



increasing E ←

Response = measured E /beam E
versus E

Resolution = measured $\sigma(E)/E$
versus $1/\sqrt{E}$

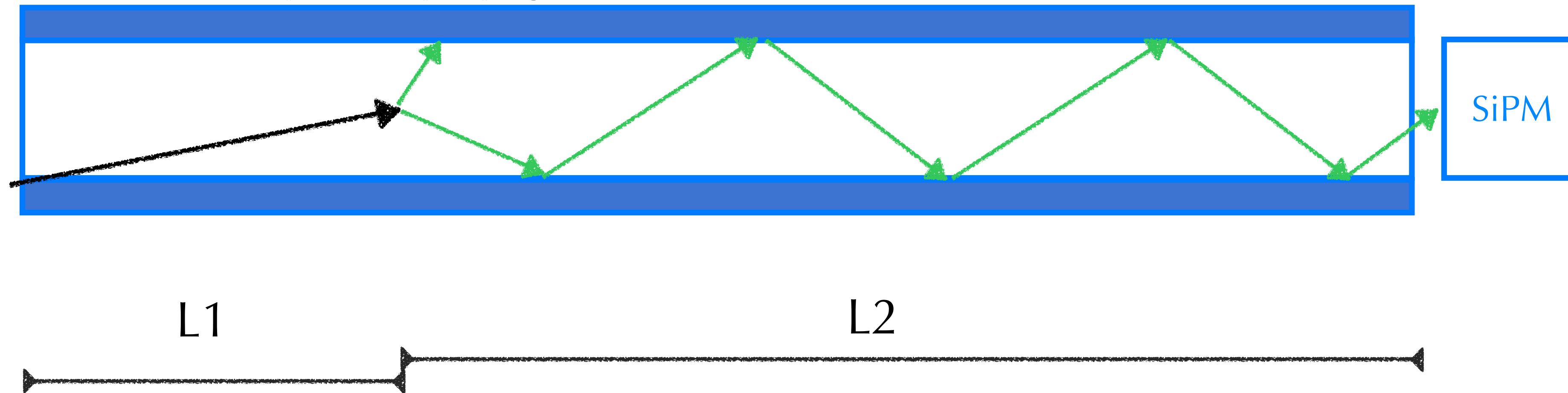
Timing measurements

Calorimeter with Timing Information

Detector layout does not give z- information by design

→ Actually, we can recover z from timing

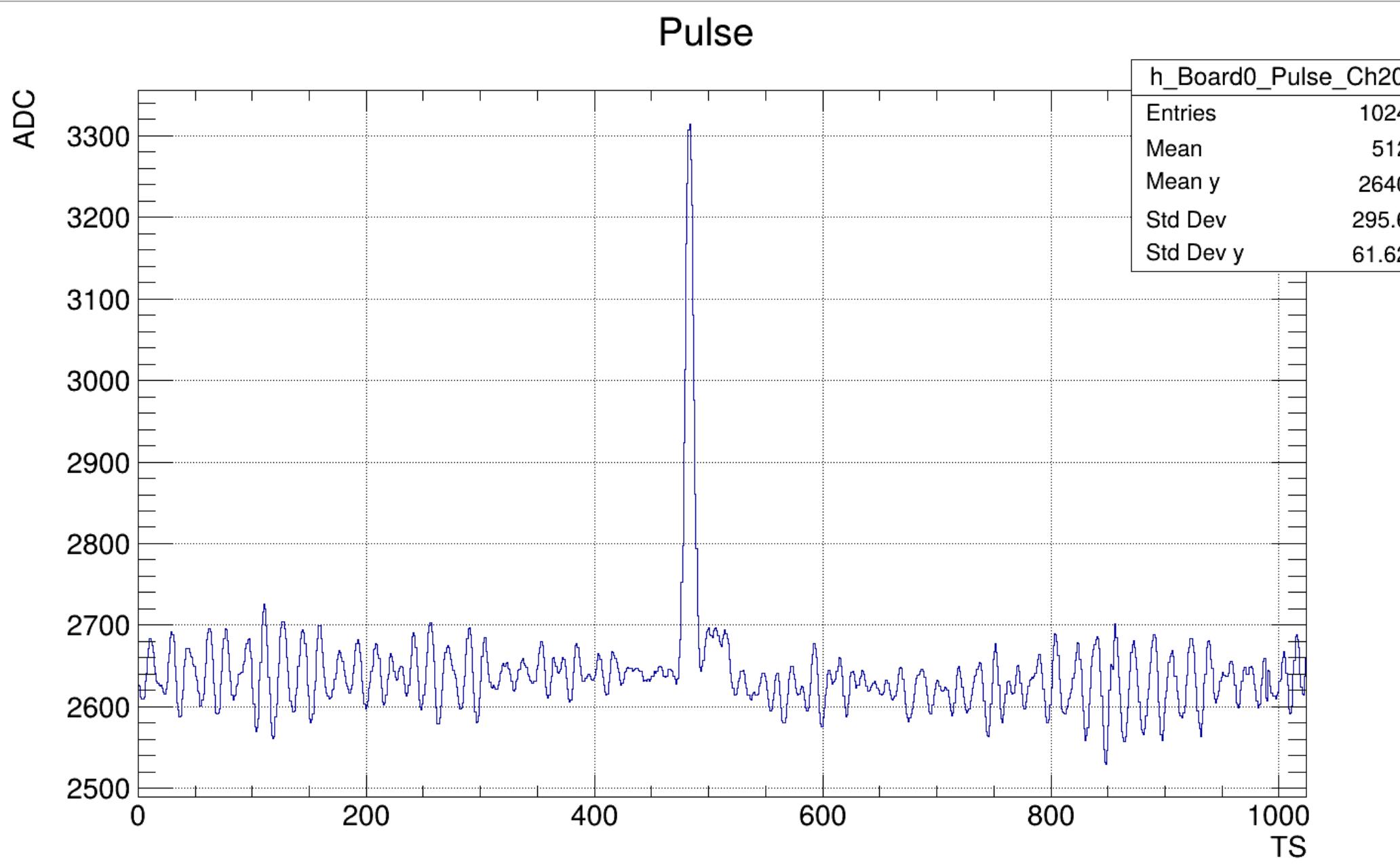
- Make use of the photon propagation in the fiber information



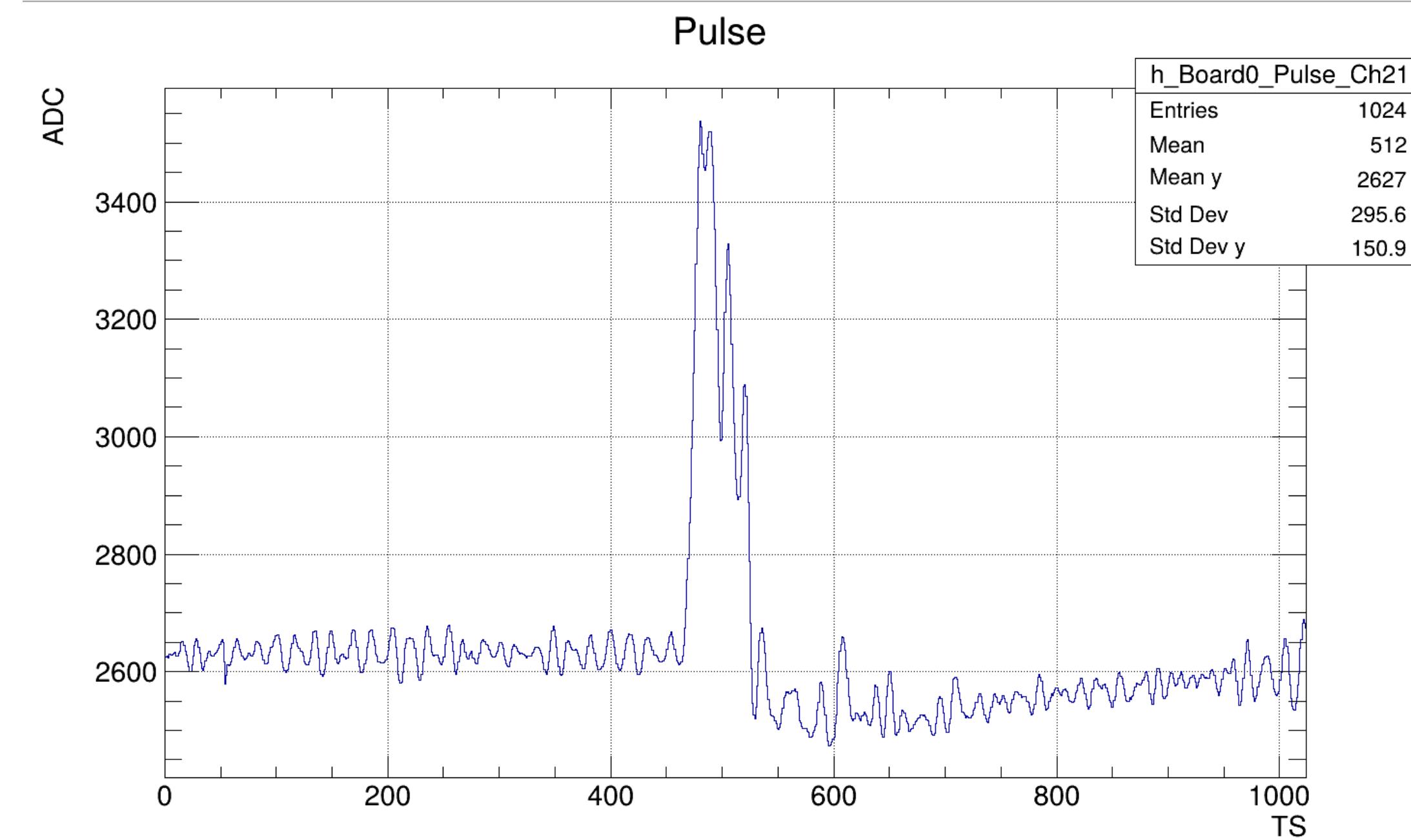
- Photon arriving time = $L1 / c + L2 / c * n$
- Can use photon arriving time to backtrack the energy deposit position, i.e., longitudinal shower information
 - ❖ Use time to reconstruct the longitudinal position
 - ❖ Particle traveling faster than the light; the deeper the shower, the earlier the time.

DRS Outputs (vs Time)

Cherenkov

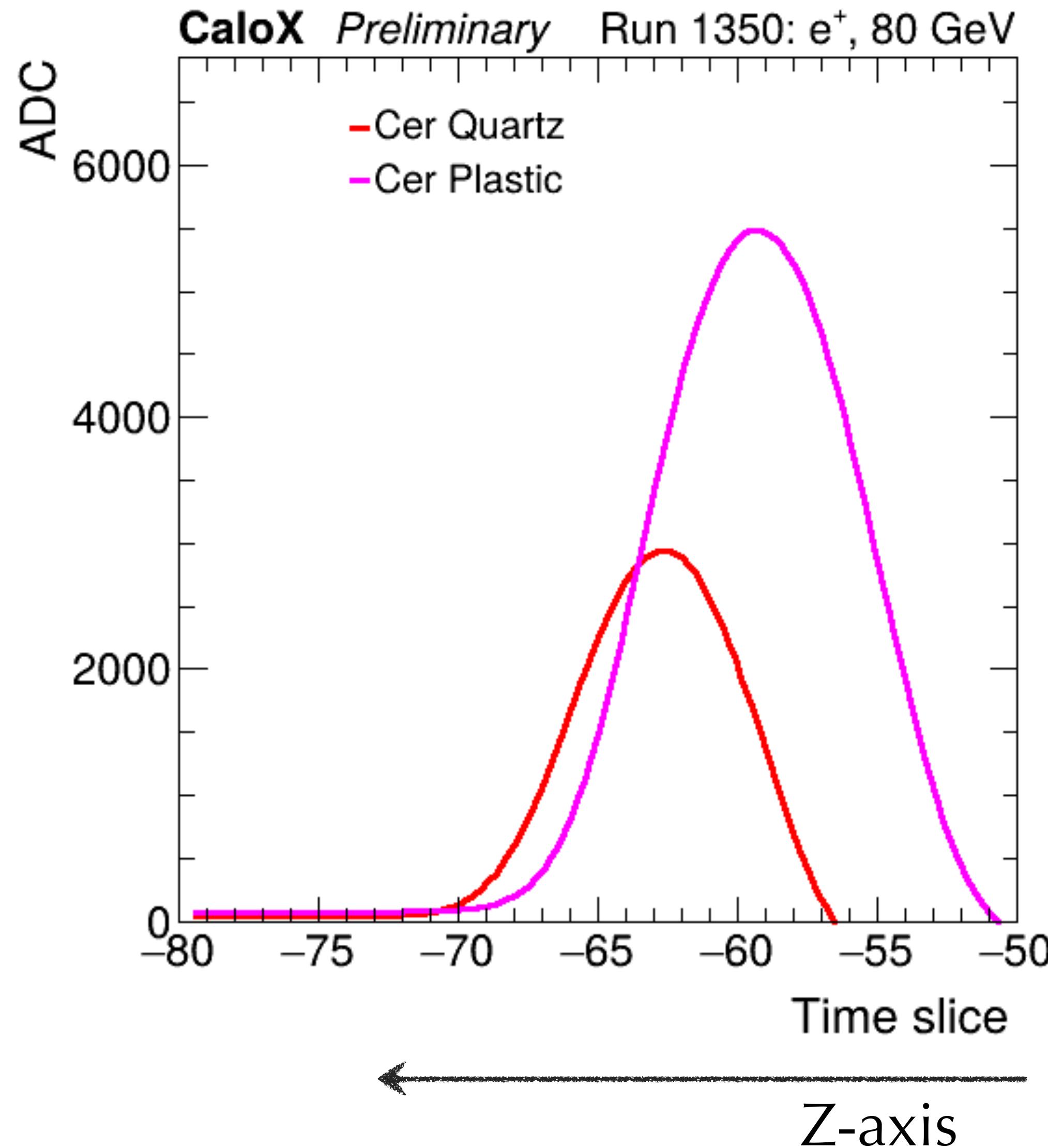


Scintillation



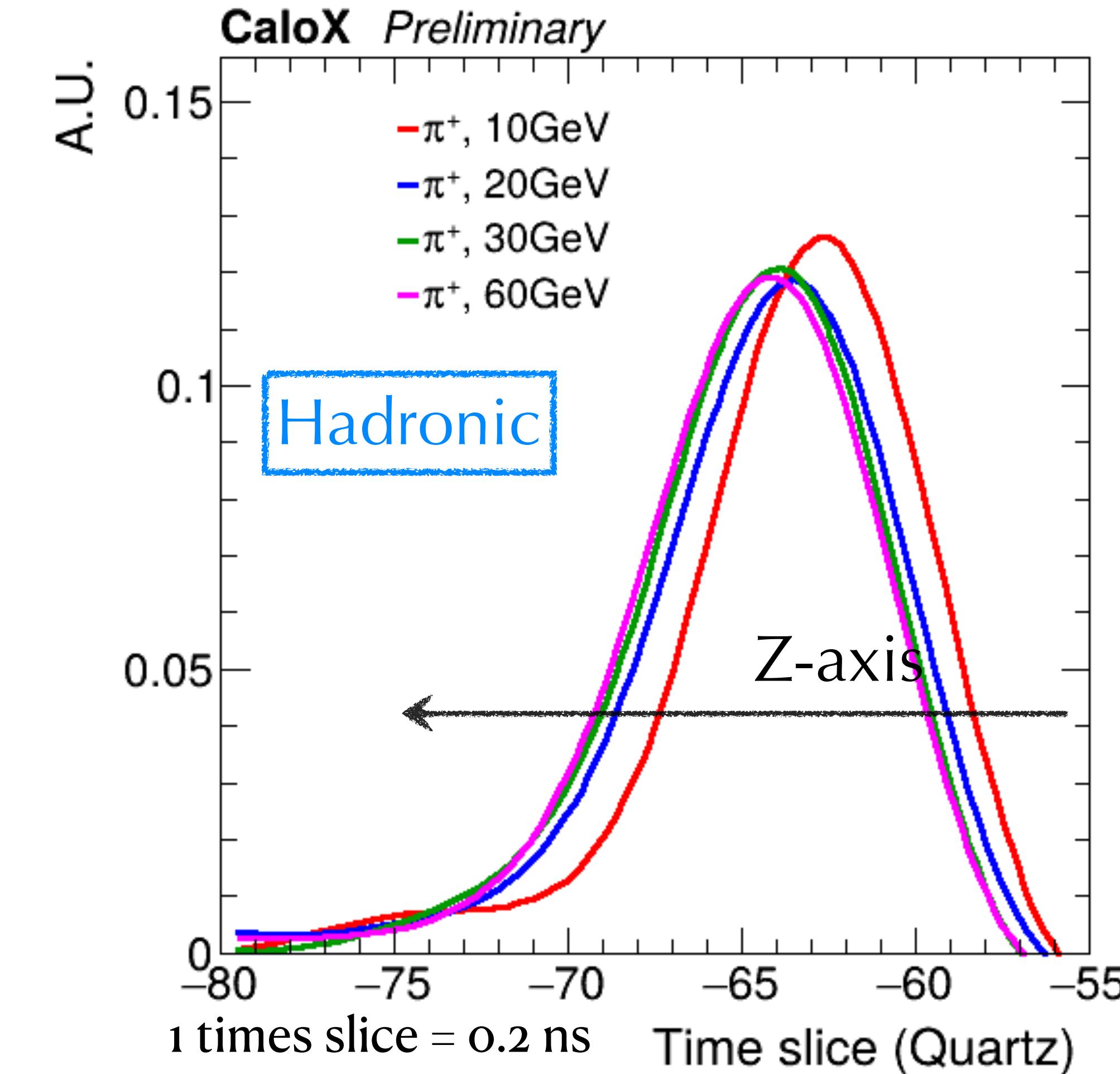
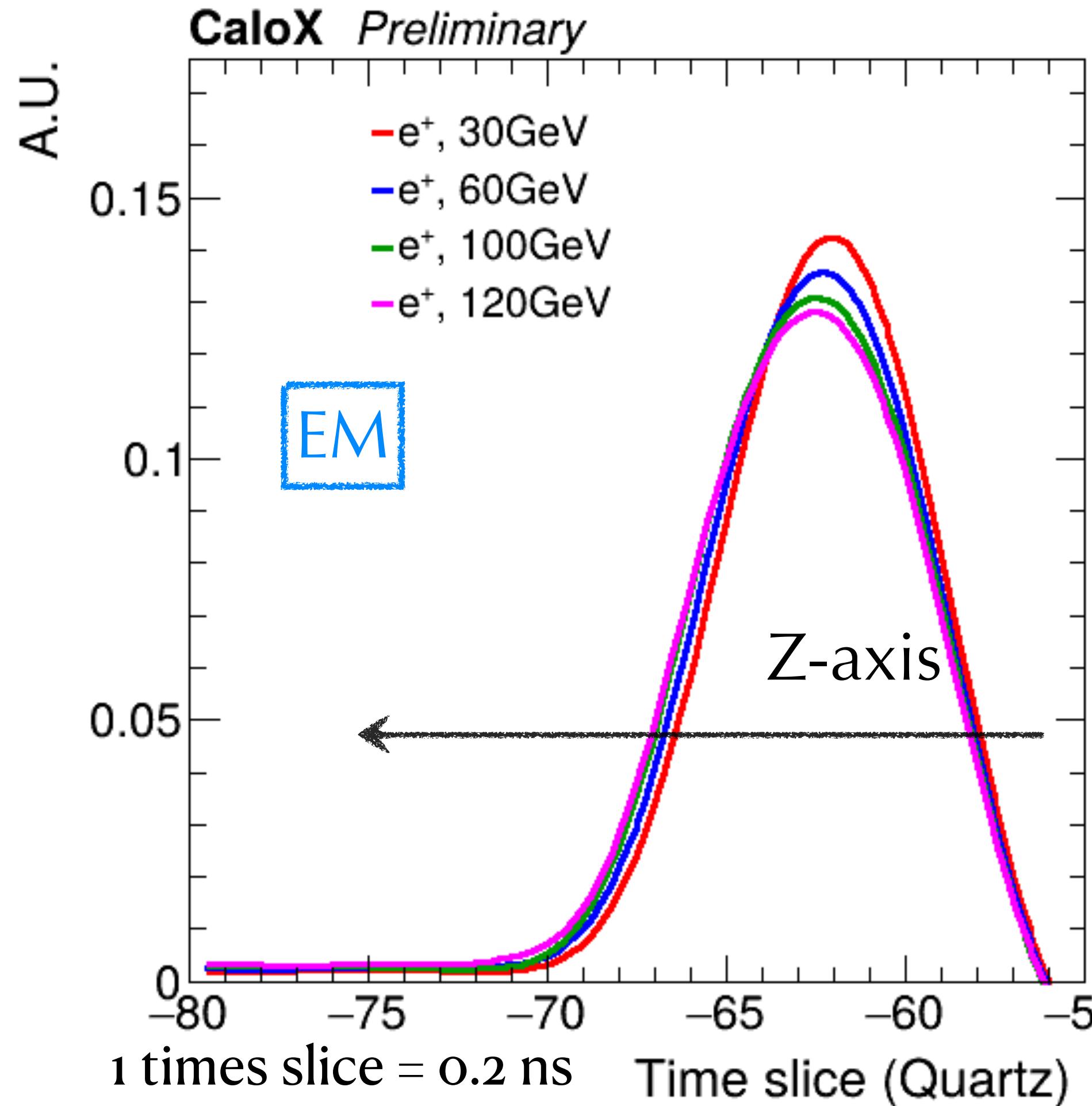
- Example outputs from the DRS channels, where one time slice corresponds to 200ps
- Calibrate and profile these pulse shapes to study “longitudinal” shower shapes

Cherenkov Signal vs Time (Positron)



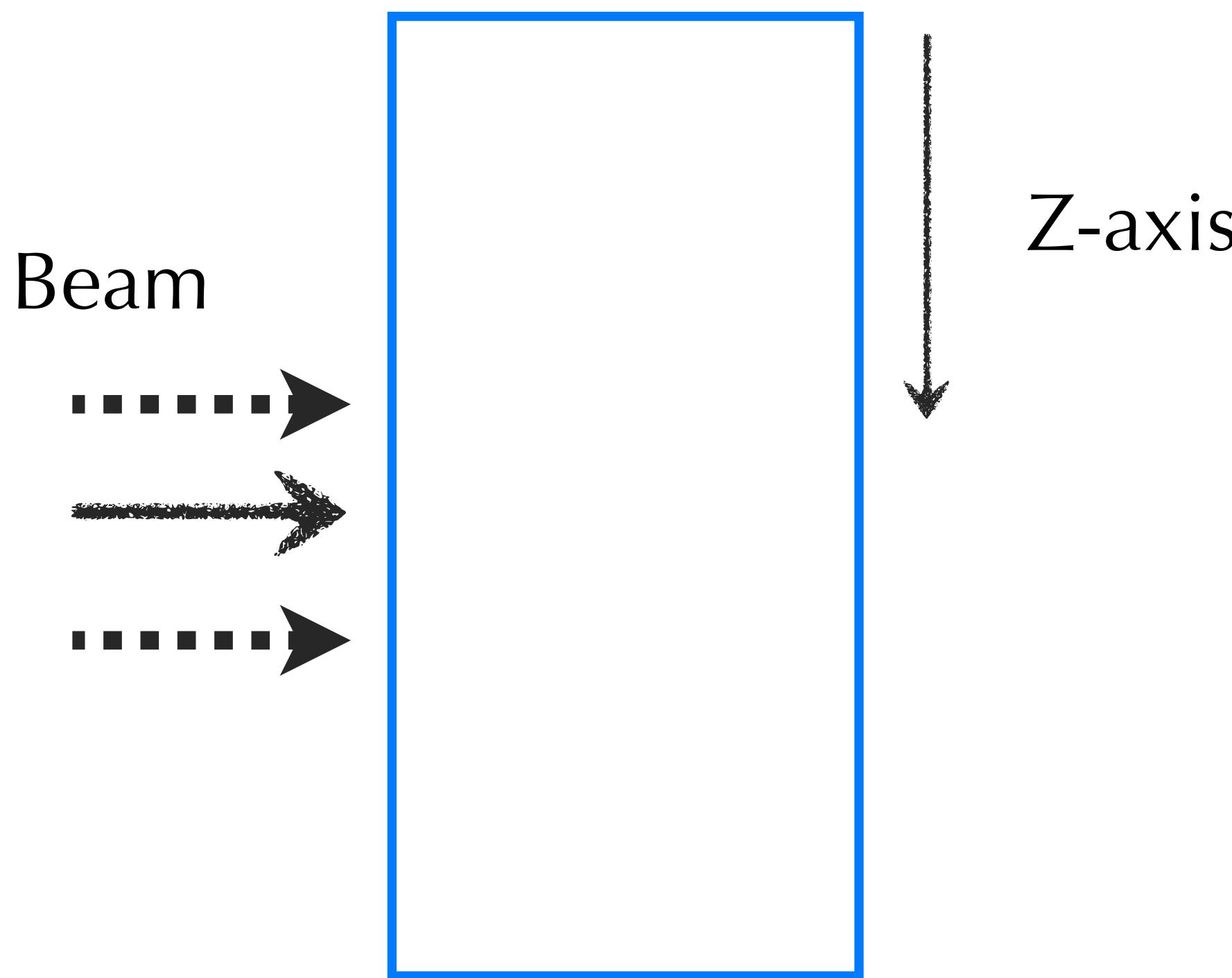
- Study the pulses as a function of time, in two different types of Cherenkov fibers (different refraction indices: 1.48 vs 1.62);
- Rightmost corresponds to the beginning of the shower, where the ΔT between the two fibers are maximal
- ΔT reduces as shower moves deeper and deeper
- **Successfully observed longitudinal shower shapes from the timing information**

“Longitudinal” shower profile (Different E)

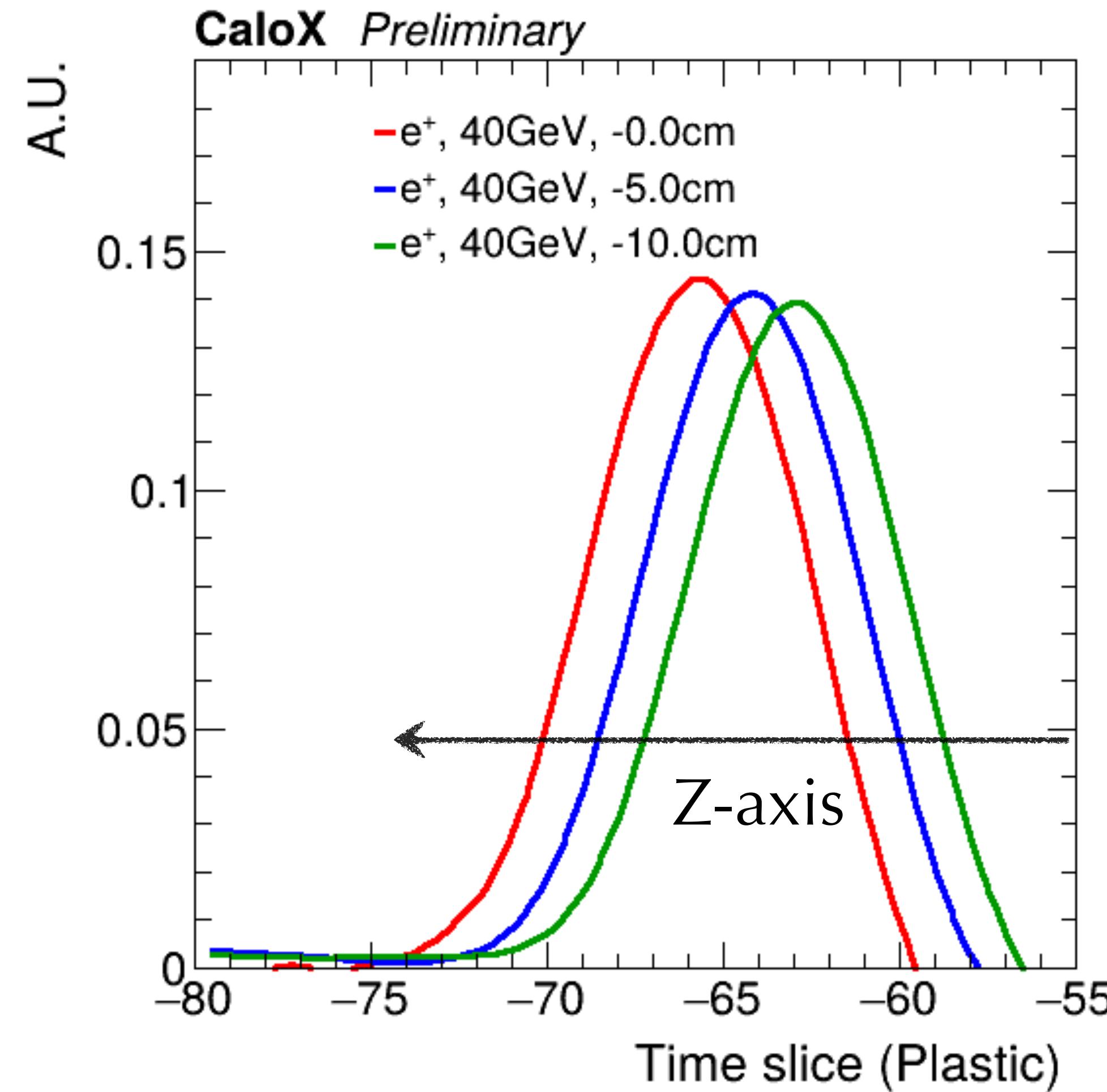


- As energy increases, shower goes deeper, for both EM showers (left) and hadronic showers (right)
- Hadronic shower goes deeper in z-axis into the detector, and has a longer tail at larger z.

Longitudinal Position Scans



- Rotate the detector by 90 degree; move the detector along the z-axis to check the shower shape change as a function of z
- **Observed the expected shower shape change along the z-axis, using timing information**



Summary

- We validated the performance of energy measurement with HG-DREAM test beam data.
- The timing measurement shows the longitudinal information of showers
- Data analysis is still on-going (1 week old). Results shown are preliminary. The full results will be public by December.



Back Up

Test beam layout

