ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Dual Readout with capillary tubes

Test Beam Results

I. Vivarelli (on behalf of the Dual Readout collaboration) - 9/10/2023

Support notes

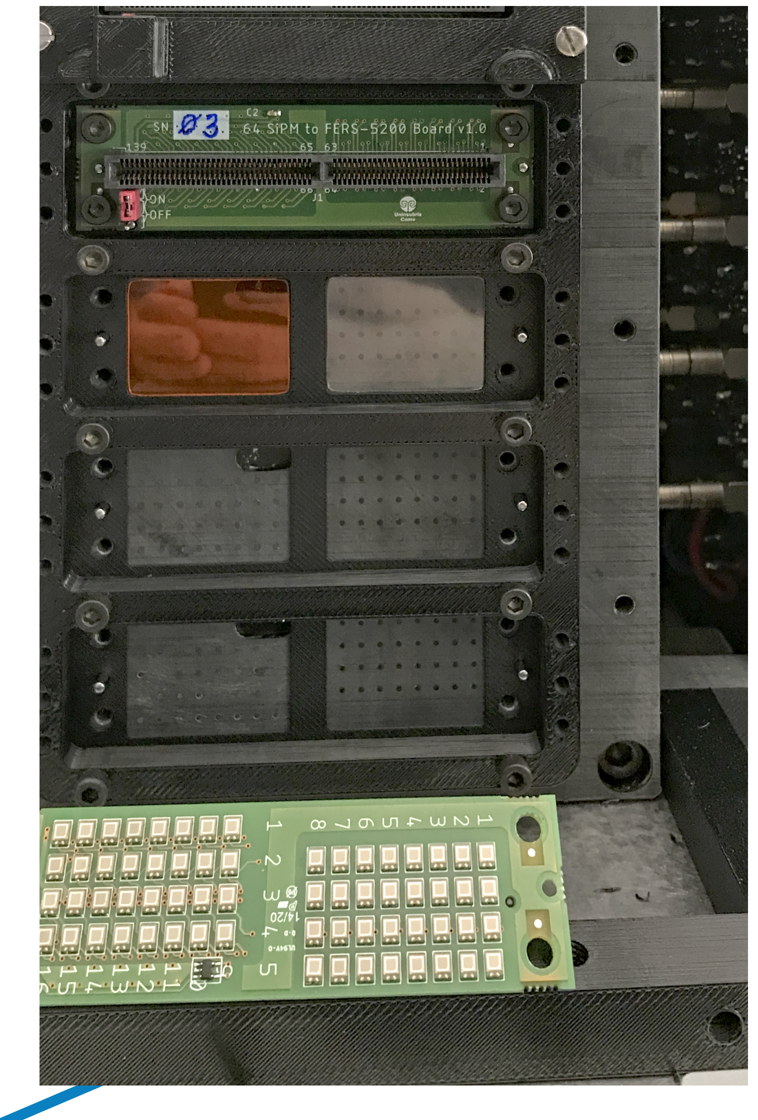
Five notes submitted for the mid-term review for the dual-readout IDEA calorimeter

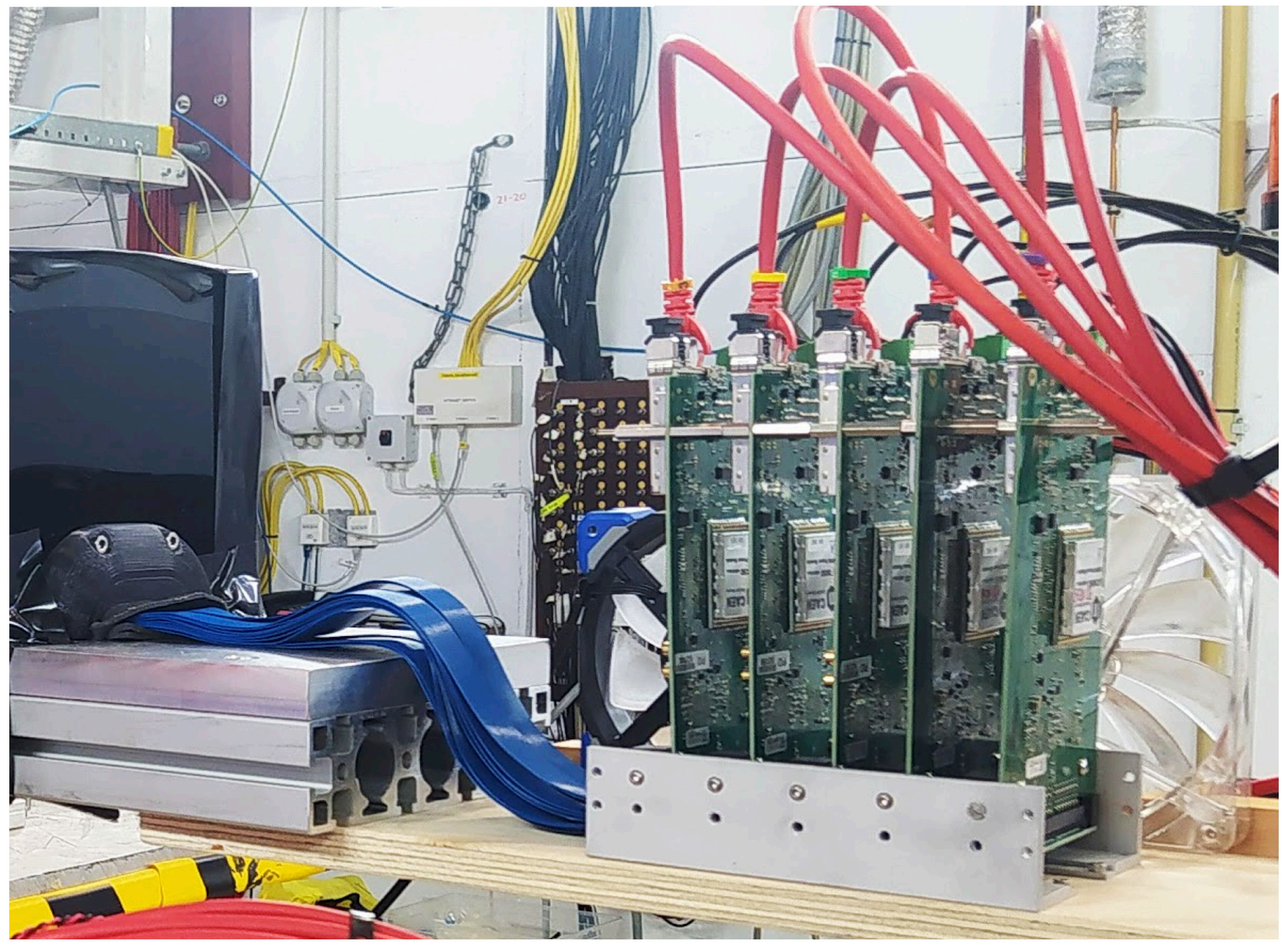
- Dual-Readout Calorimetry for Future Experiments Probing Fundamental Physics
- Exposing a fibre-based dual-readout calorimeter to a positron beam
- Particle flow with a hybrid segmented crystal and fiber dual-readout calorimeter
- New perspectives on segmented crystal calorimeters for future colliders
- Preliminary cost estimate of the IDEA dual-readout calorimeter system

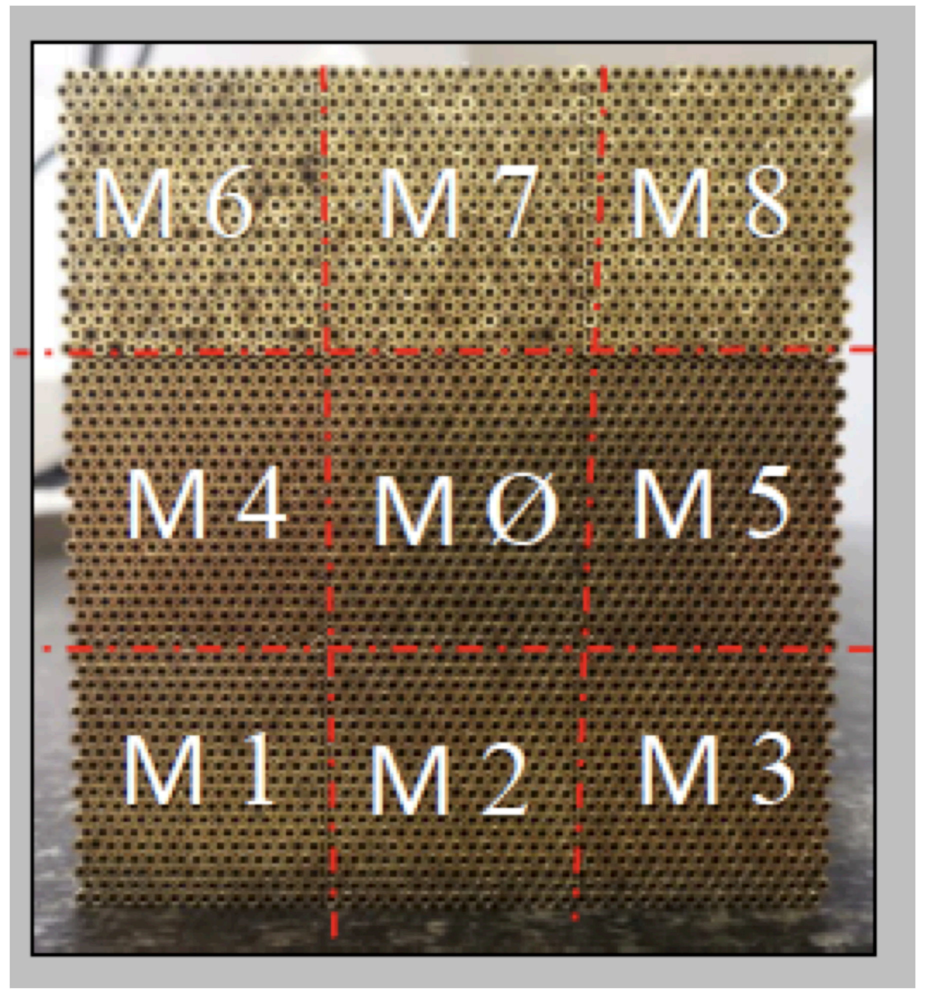
- Focus on **mechanical/readout option** for dual-readout construction:
  - Detector unit: **capillary tube with 2 mm external diameter** hosting an optical fibre, read by a **single SiPM**
    - Flexible/scalable option: modules are obtained by gluing tubes together
- **EM-containment-size prototype built in 2021** as a stepping stone for HiDRa (HAD-containment-size prototype)
- **Tested on beam in 2021** and again in 2023. Aim:
  - Assess response to EM showers, compare to simulation, exercise evolving DAQ and software tools
- Results published as N. Ampilogov et al 2023 JINST 18 P09021

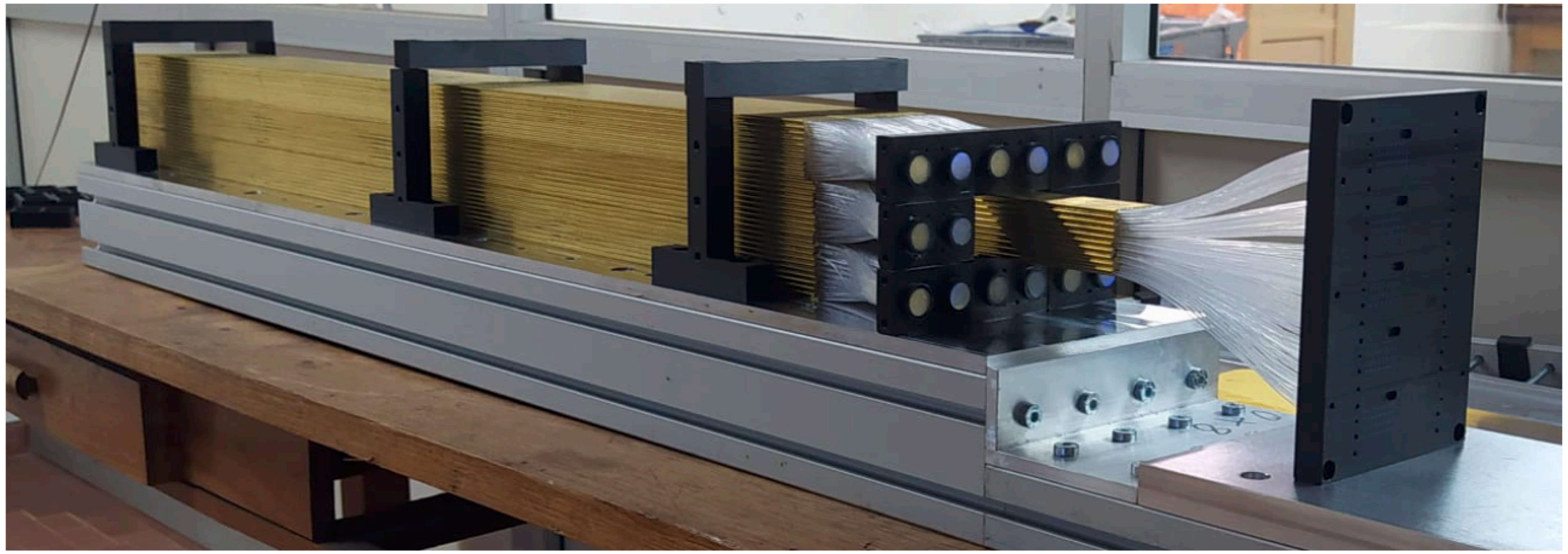
What was tested

- Dual readout (Cherenkov and scintillation signal) 10 x 10 x 100 cm^3.
- **9 towers**, each with 160 x 2 tubes/fibres
  - M1-8 fibres bundled and read by **2x8 PMTs** (2 readings per tower)
  - M0 fibres fan out and read by **2x160 SiPMs** (S14160-1315, 15 μm pitch)
    - **5 CAEN FERS-5200 boards** (64 channels each) provide bias voltage and sampling for SiPMs



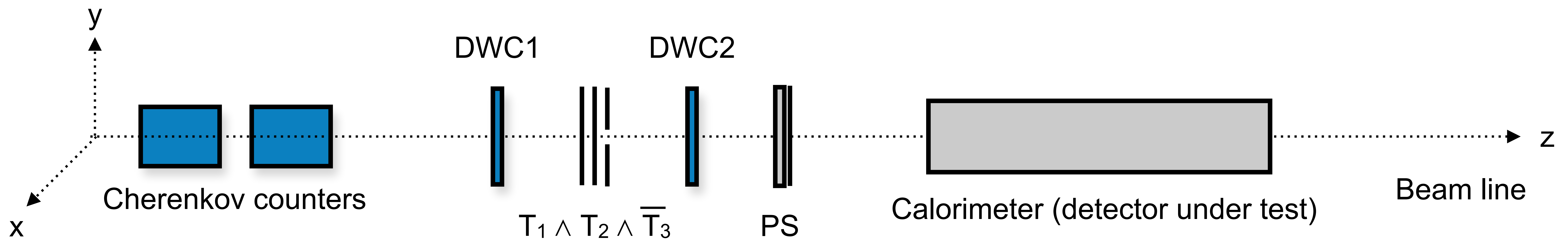






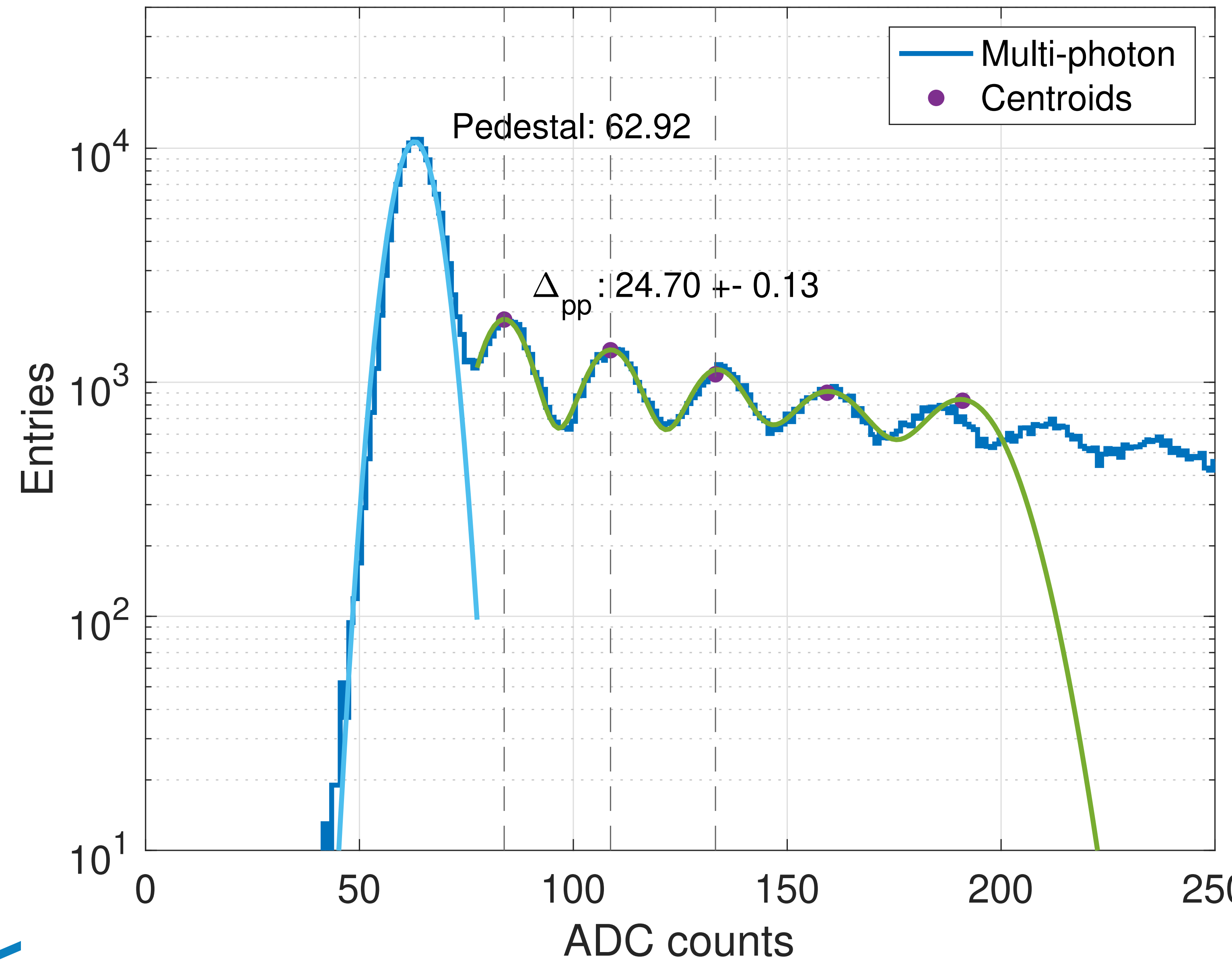
How it was tested

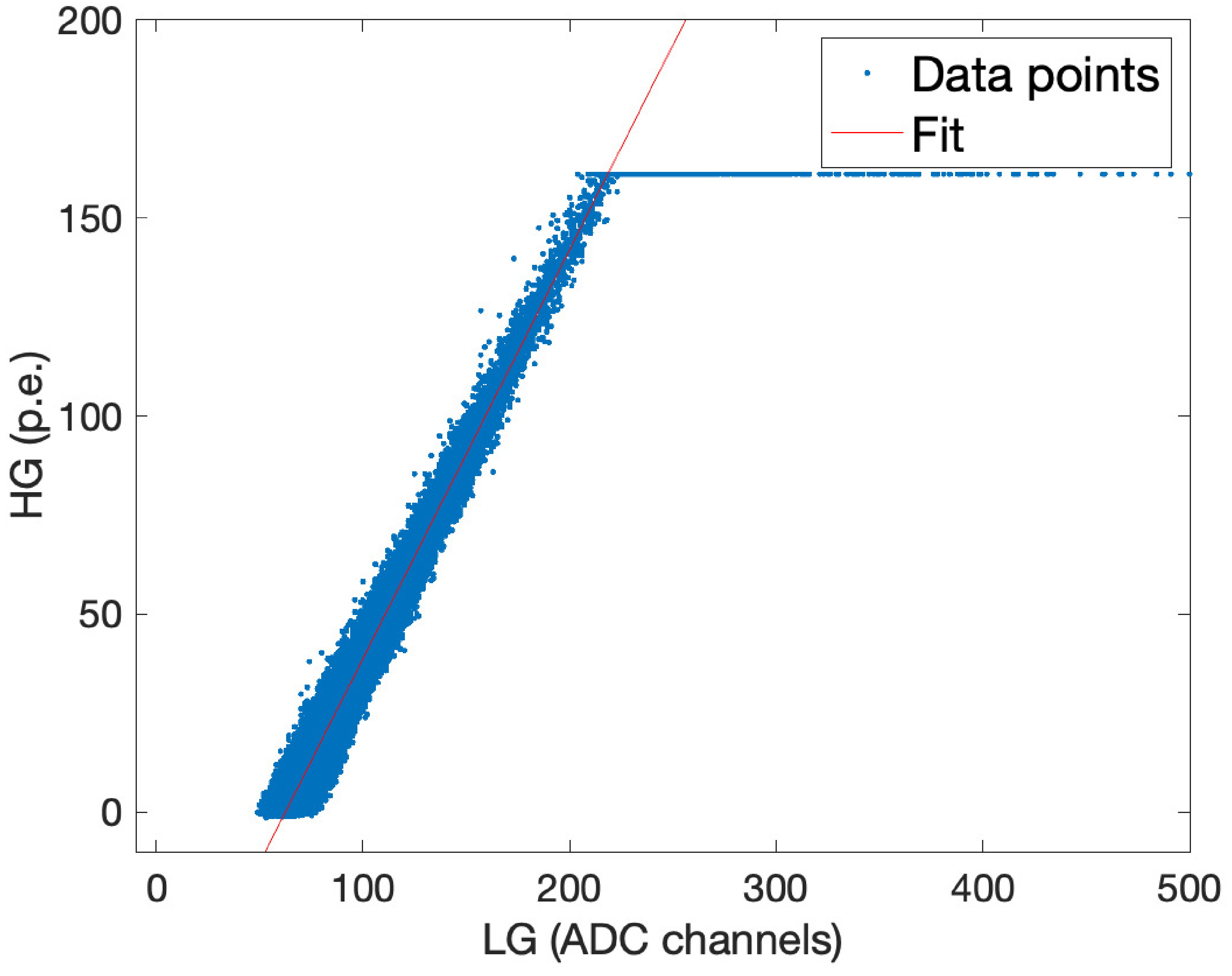
- SPS H8 beam line
  - …with a series of auxiliary detectors
    - **Cherenkov counters** filled with He, used to separate e from hadrons - good separation up to ~ 30 GeV
    - **DWCs** provide O(1 mm) resolution on particle position
    - Physics trigger provided by **3 thin scintillators ($T_{1\text{-}3}$)**
    - **Preshower**: 1 X_0 of lead glued to a plastic scintillator - useful to identify electrons at high energy

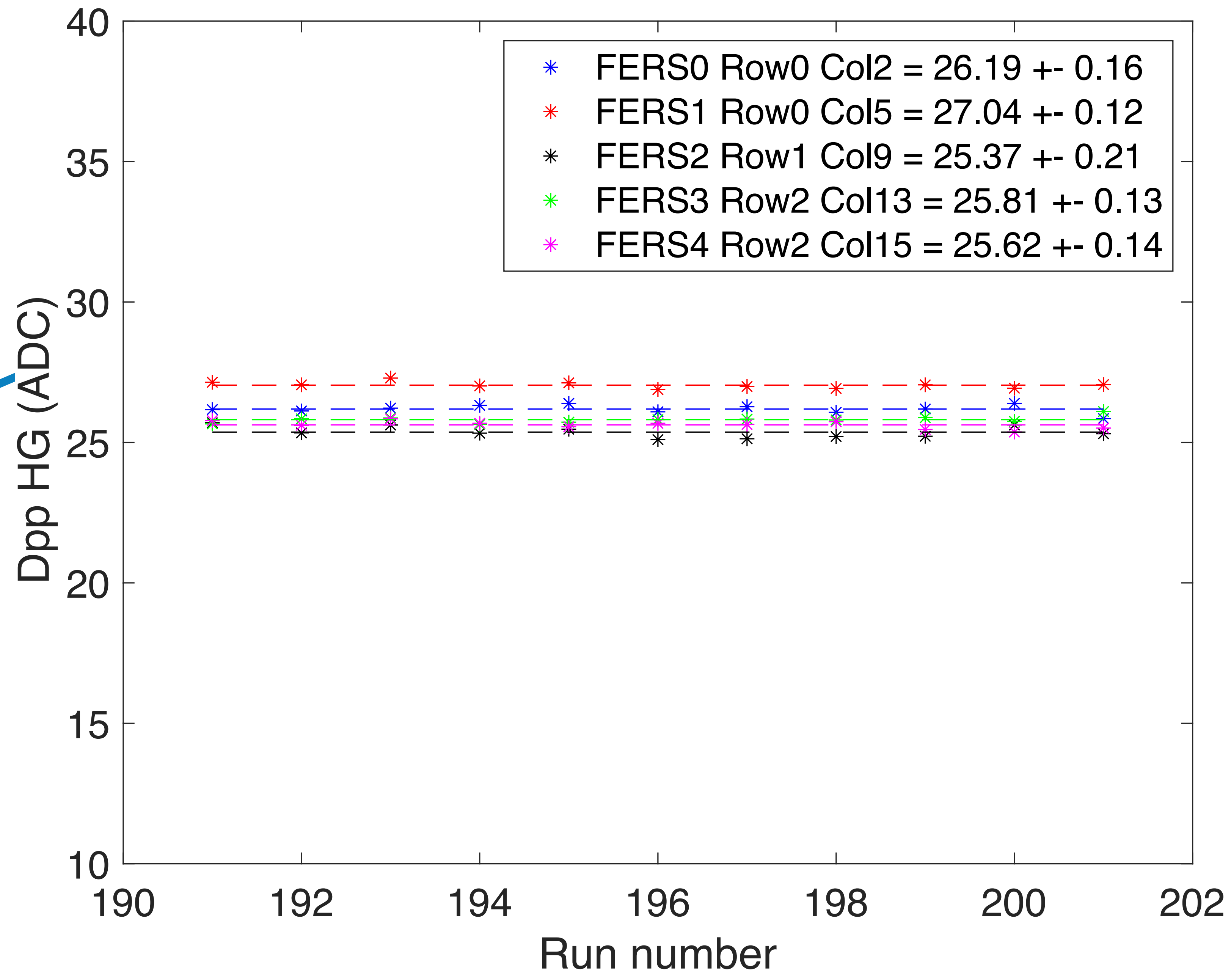


Calibration (1)

- FERS provide **double gain readout** for each SiPM
  - Gain ratio of about 10
- High Gain equalised by making use of **multiphoton spectrum**
- Low Gain scale set **exploiting correlation with High Gain**

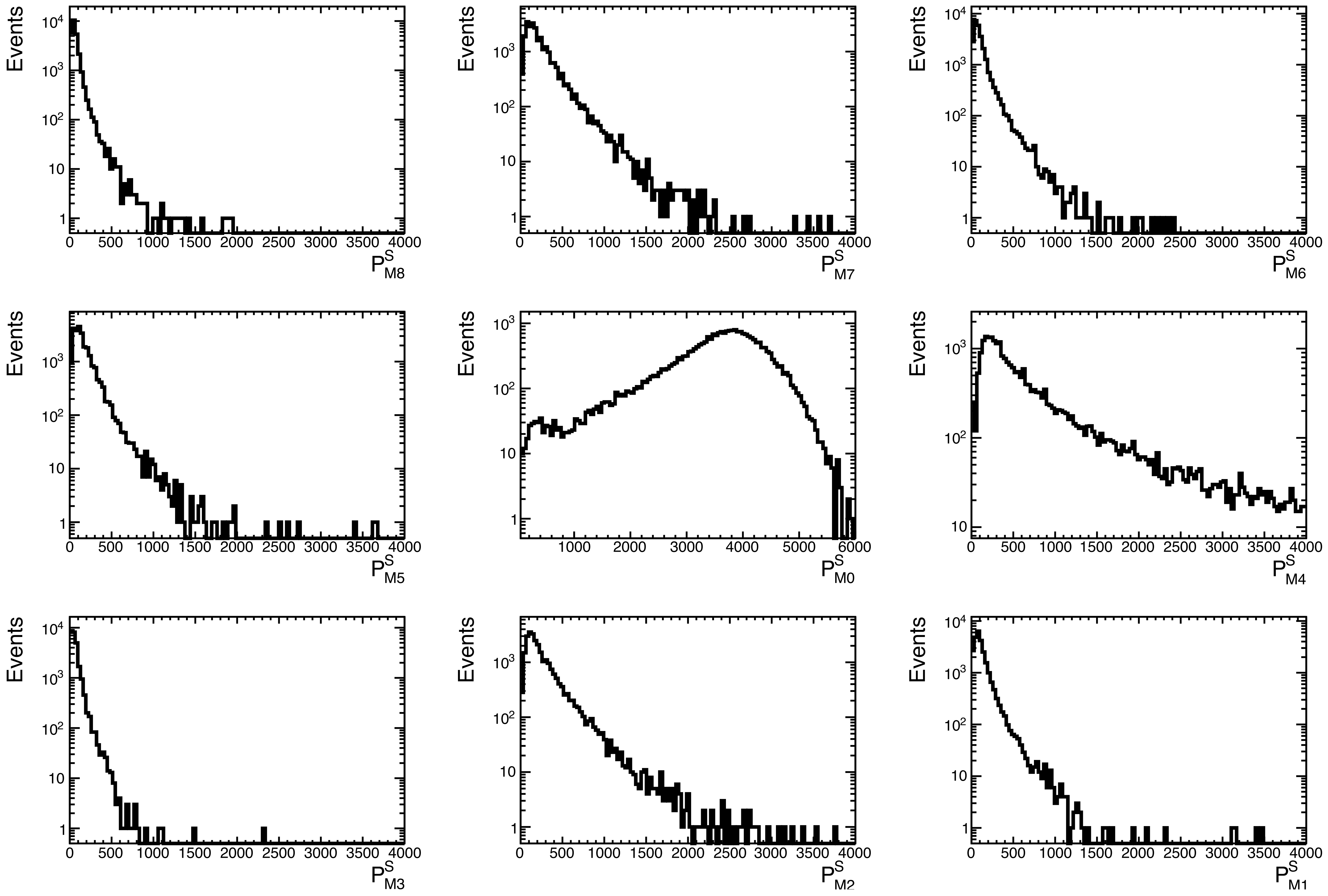






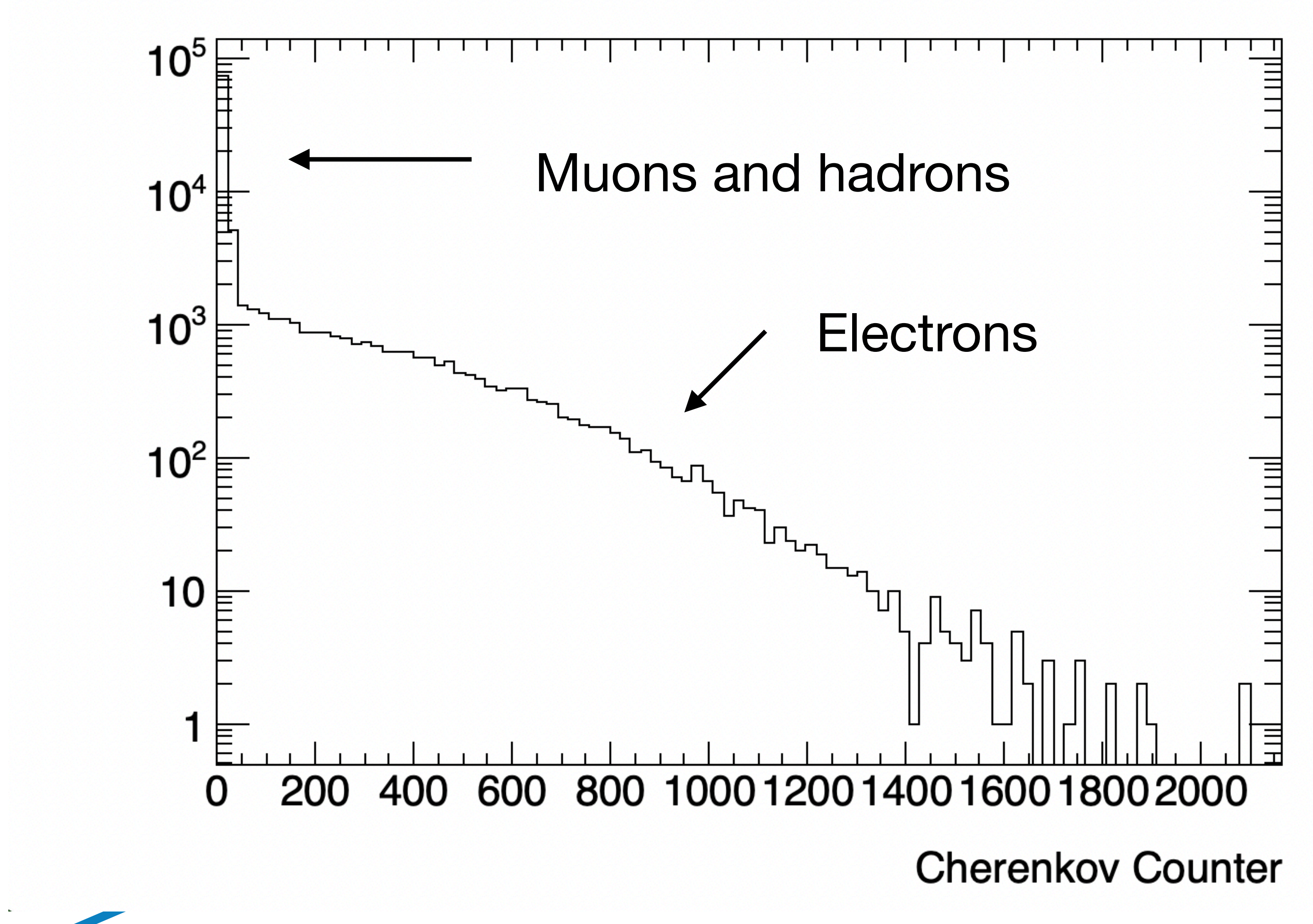
Calibration (2)

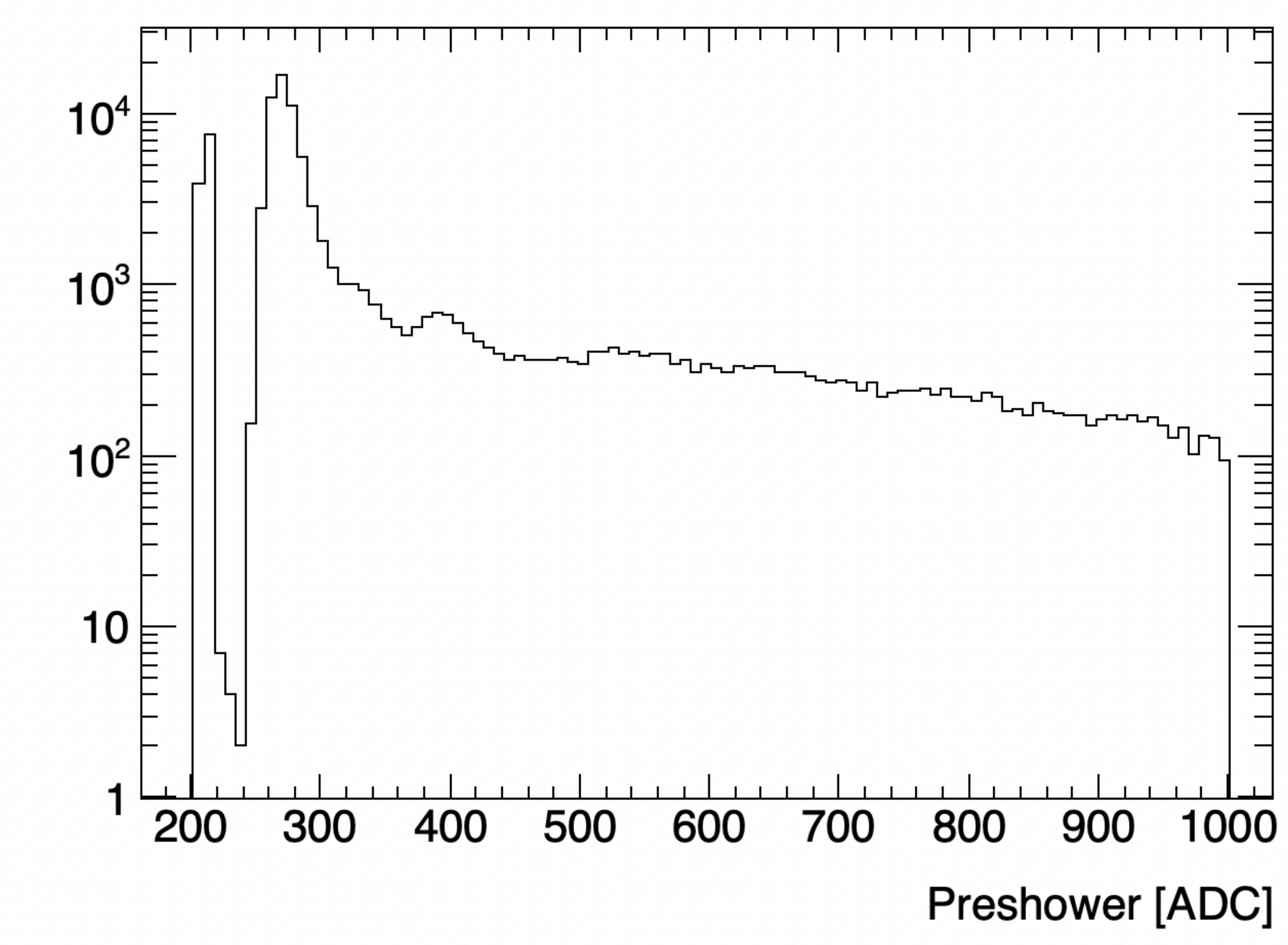
- SiPM gain made uniform by making use of **multiphoton spectrum**
- **M1-8 response equalised to that of tower M0** when aiming at the centre of each tower with a positron beam (20 GeV)
- Module calibration determined by setting the **response of the whole prototype** to 20 GeV

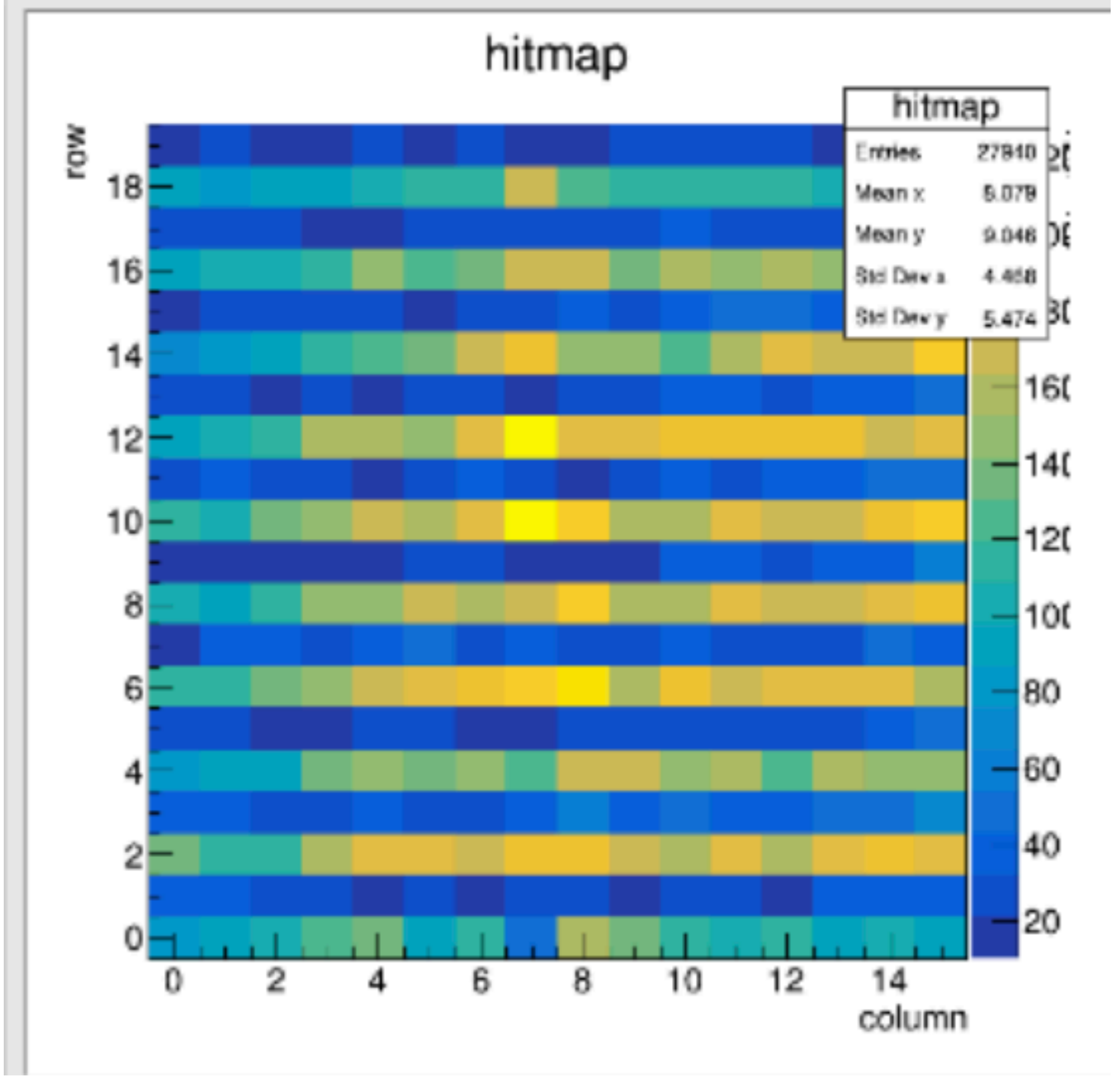


Electron selection

- DWCs used to select particles hitting a specific detector region
- Low energy ($E_{\mathrm{beam}} \leq 30\ \mathrm{GeV}$): use Cherenkov counters and reject particles in pedestals
- High energy ($E_{\mathrm{beam}} \geq 40\ \mathrm{GeV}$): use PS and reject single MIP peak







Issues with data taking

- Data taking was affected by:
  - **Very poor electron (actually positron) component** in the beam
    - < 5% at 50 GeV, ~ 1% above 80-100 GeV

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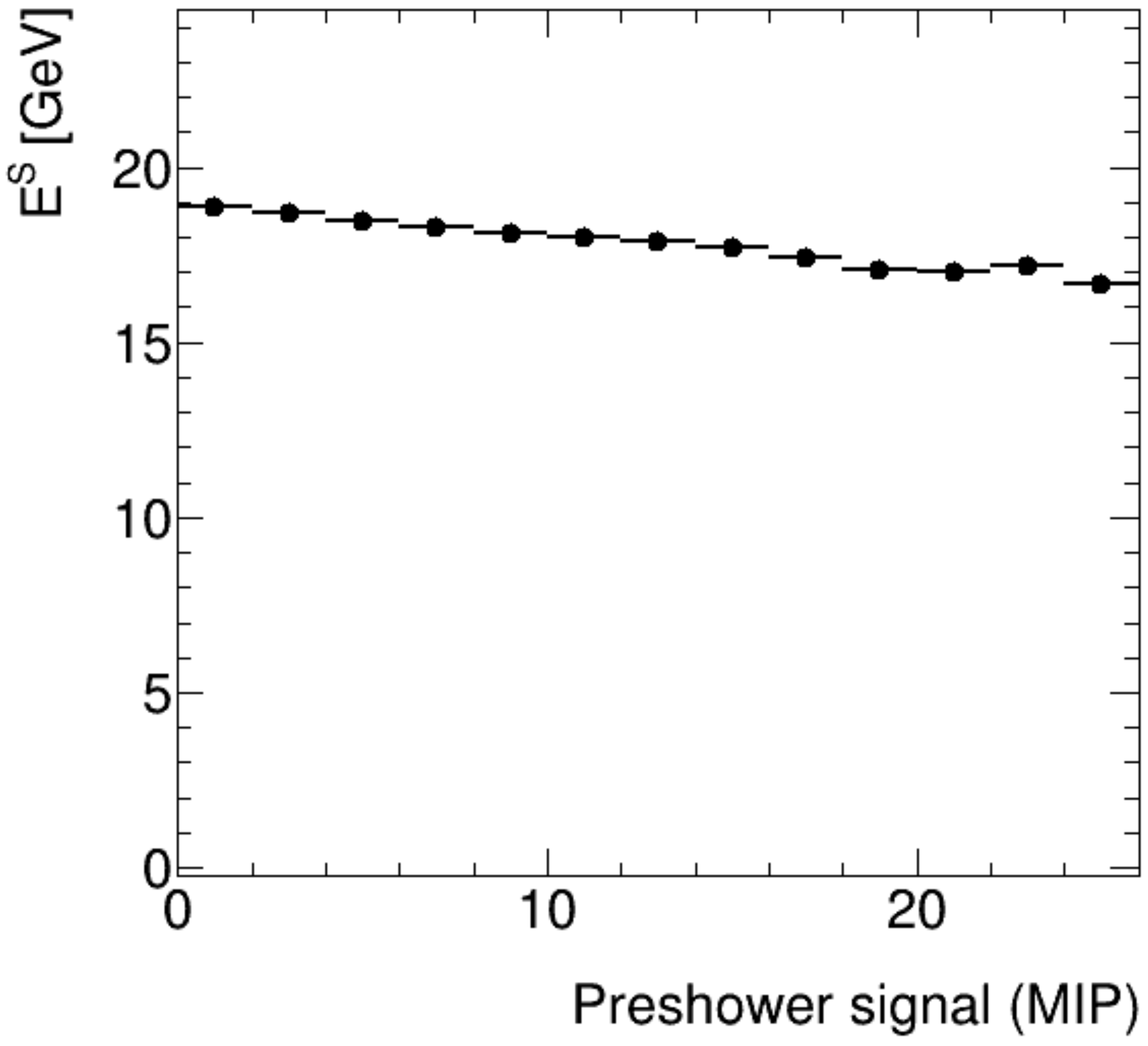
Preshower placement

- Distance between PS and calorimeter was about 2 m
- Lateral leakage induced **can be corrected on average** → linearity of the energy response unaffected
- Significant **worsening of resolution** observed
- Solution: **measure resolution at low energy** by requiring signal compatible with MIP at low energy ($E_{\mathrm{beam}} \leq 30$ GeV). **Extrapolate at higher energies** using simulation



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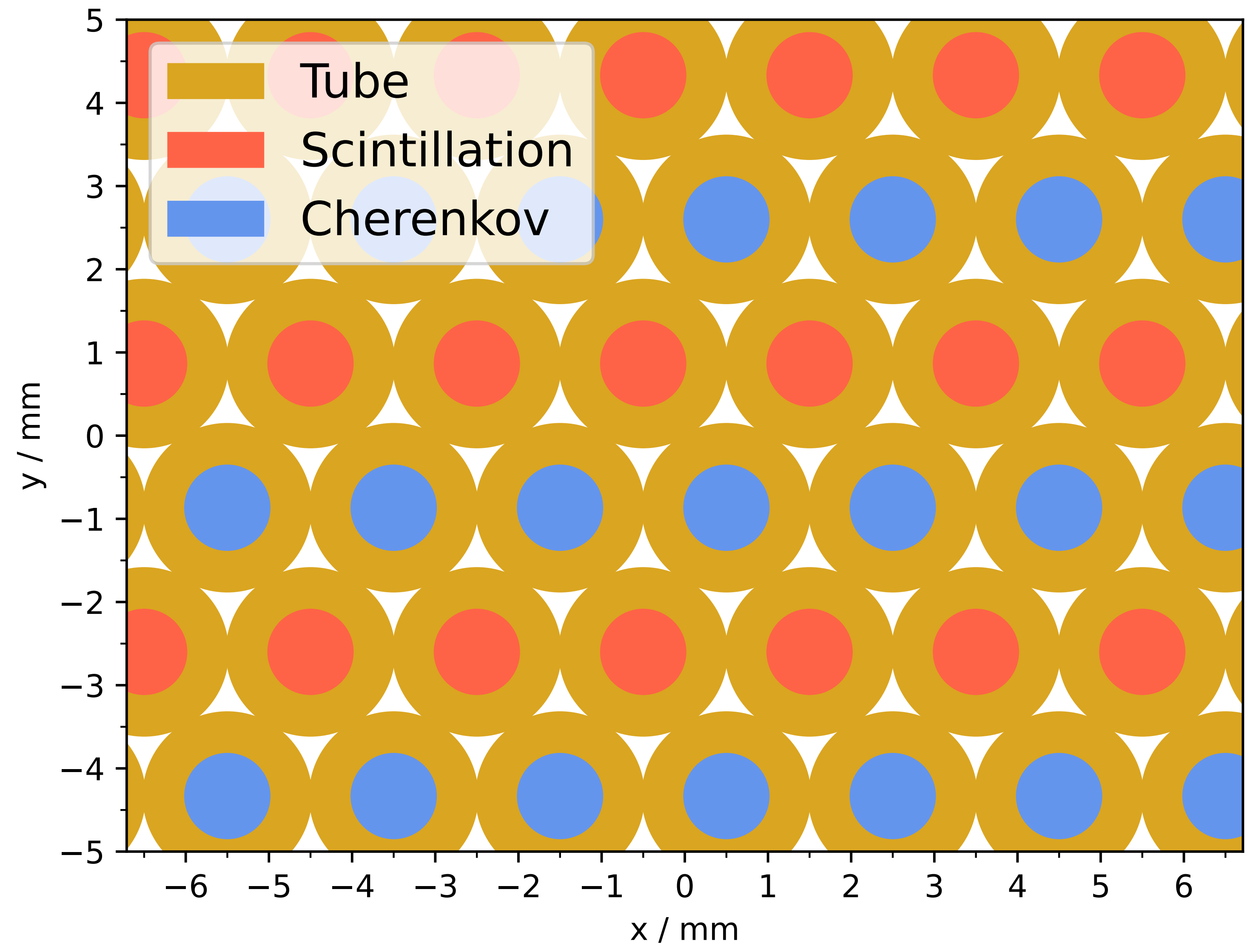
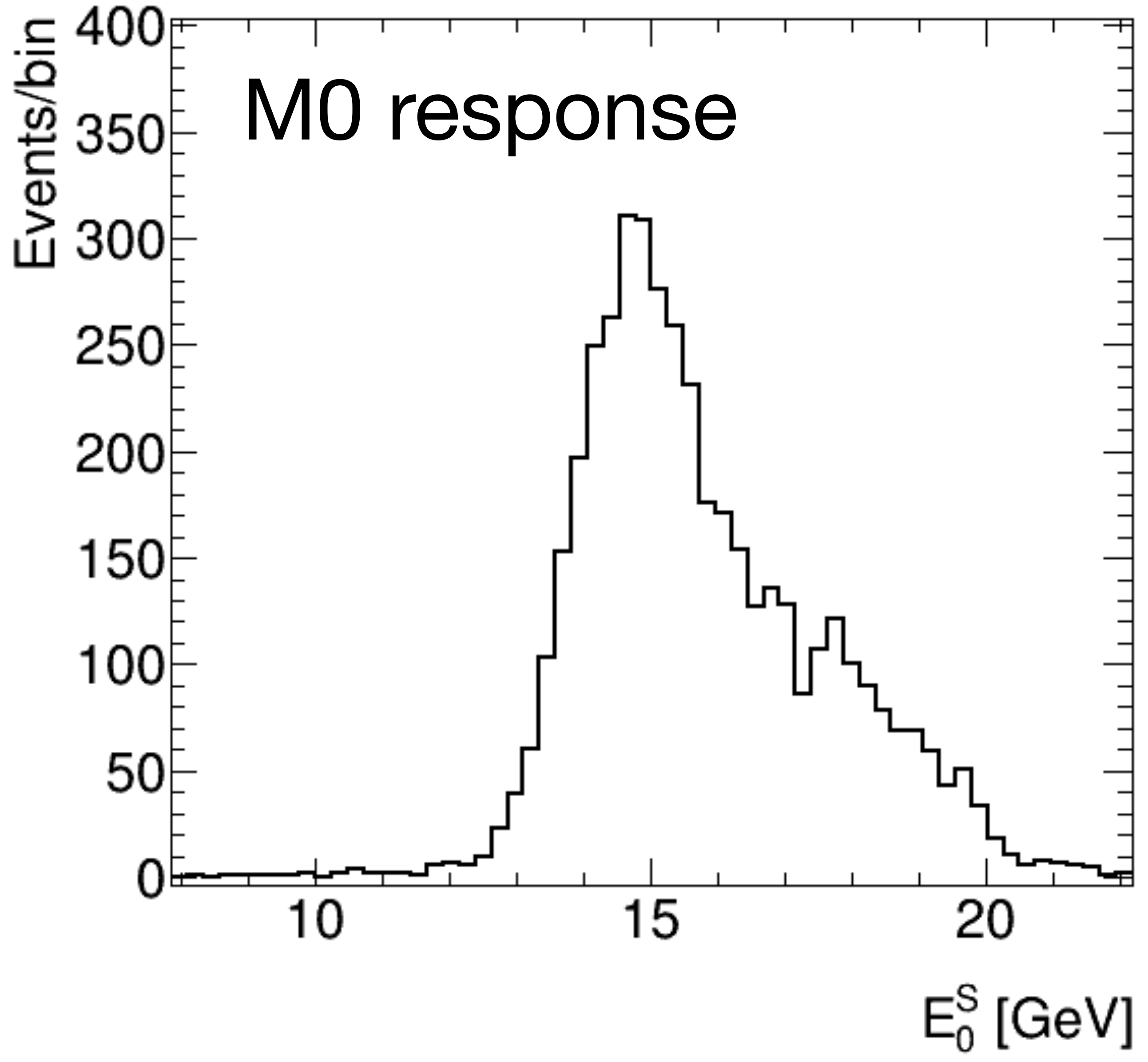
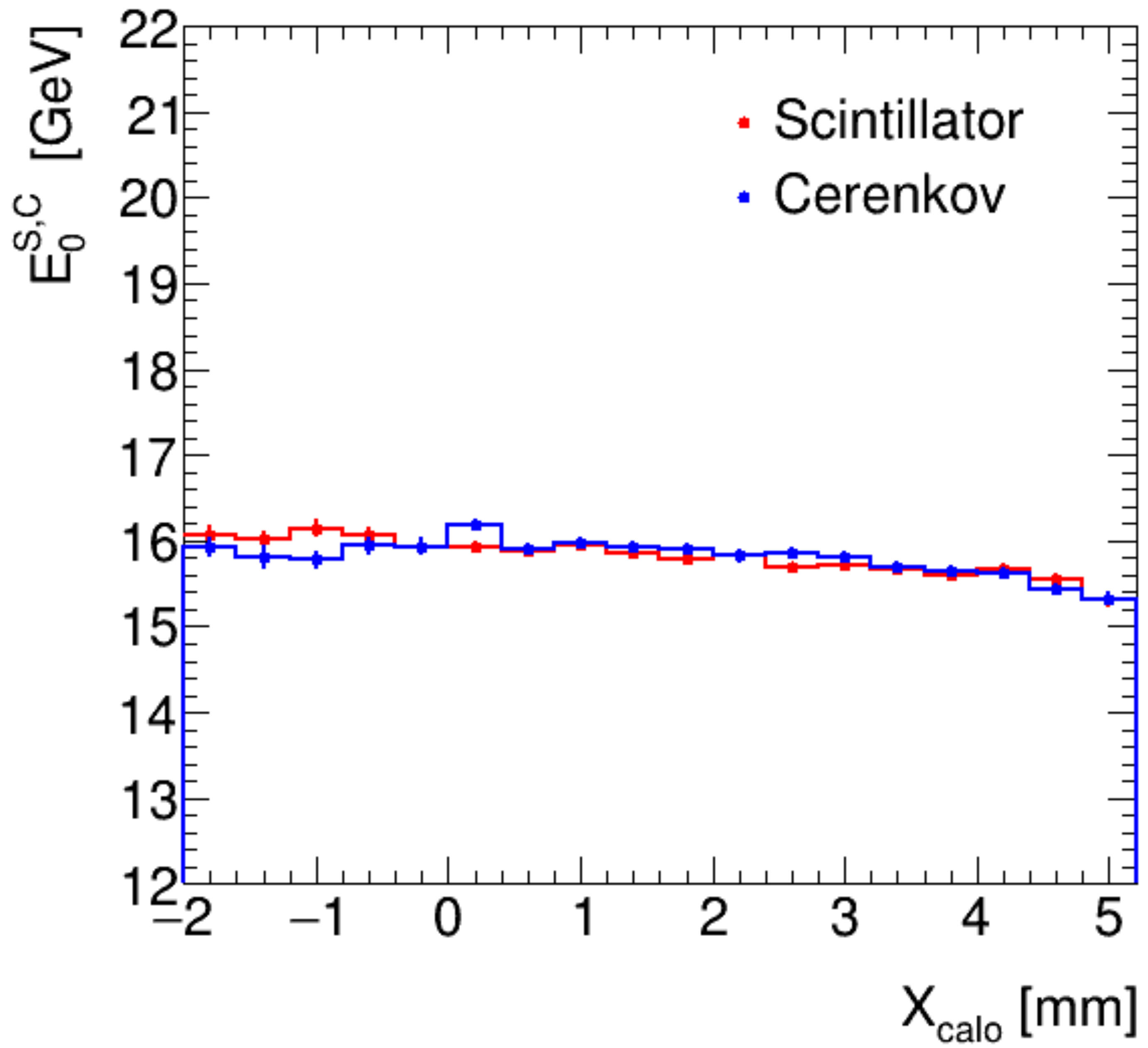
  - Slight tilt between fibers and beam needed (in Test Beam configuration). Correctly introduced in x, **but not introduced in y**

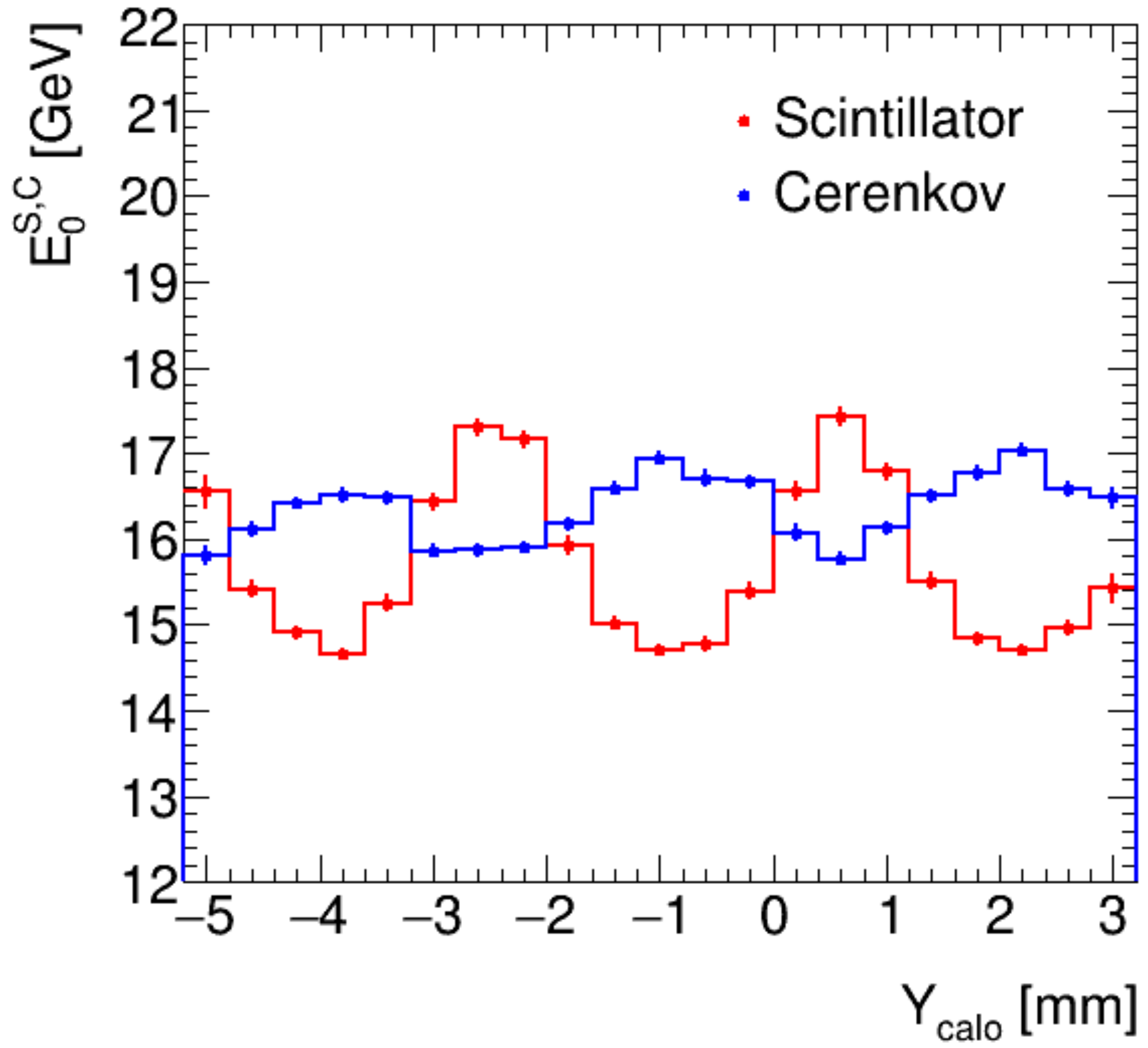
Electron response

- Raw electron energy measurement shows asymmetric response
  - The reason: **position dependence of the response** (absent when moving along x, well visible when moving along y)



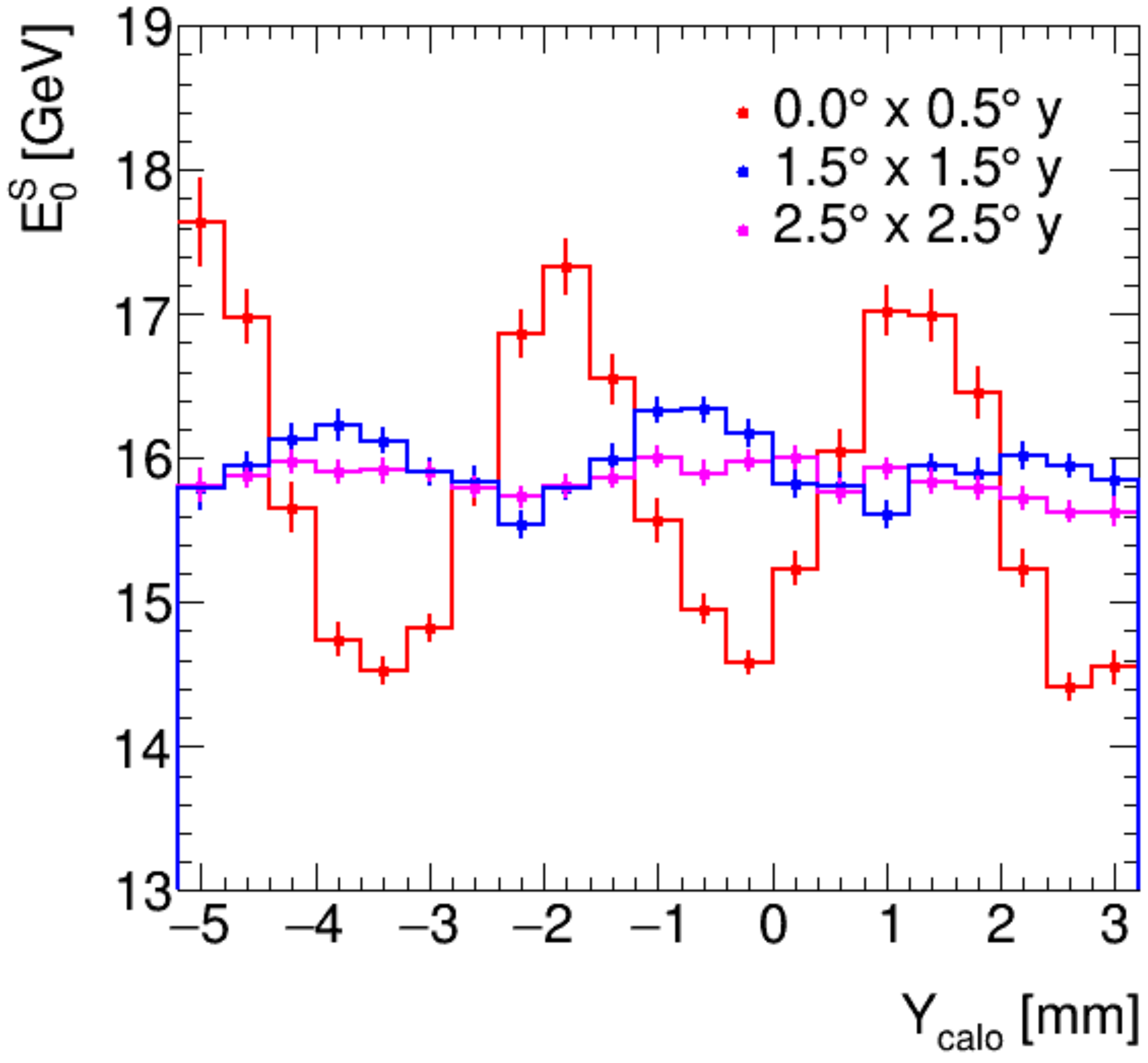






Electron response

- Raw electron energy measurement shows asymmetric response
  - The reason: **position dependence of the response** (absent when moving along x, well visible when moving along y)
- Simulation study: a 2.5º tilt in y-z plane would have avoided the issue completely.
  - Not an issue for IDEA (material in front of calorimeter + magnetic field)
- … but we **definitely need a strategy** to correct before assessing calorimeter performance



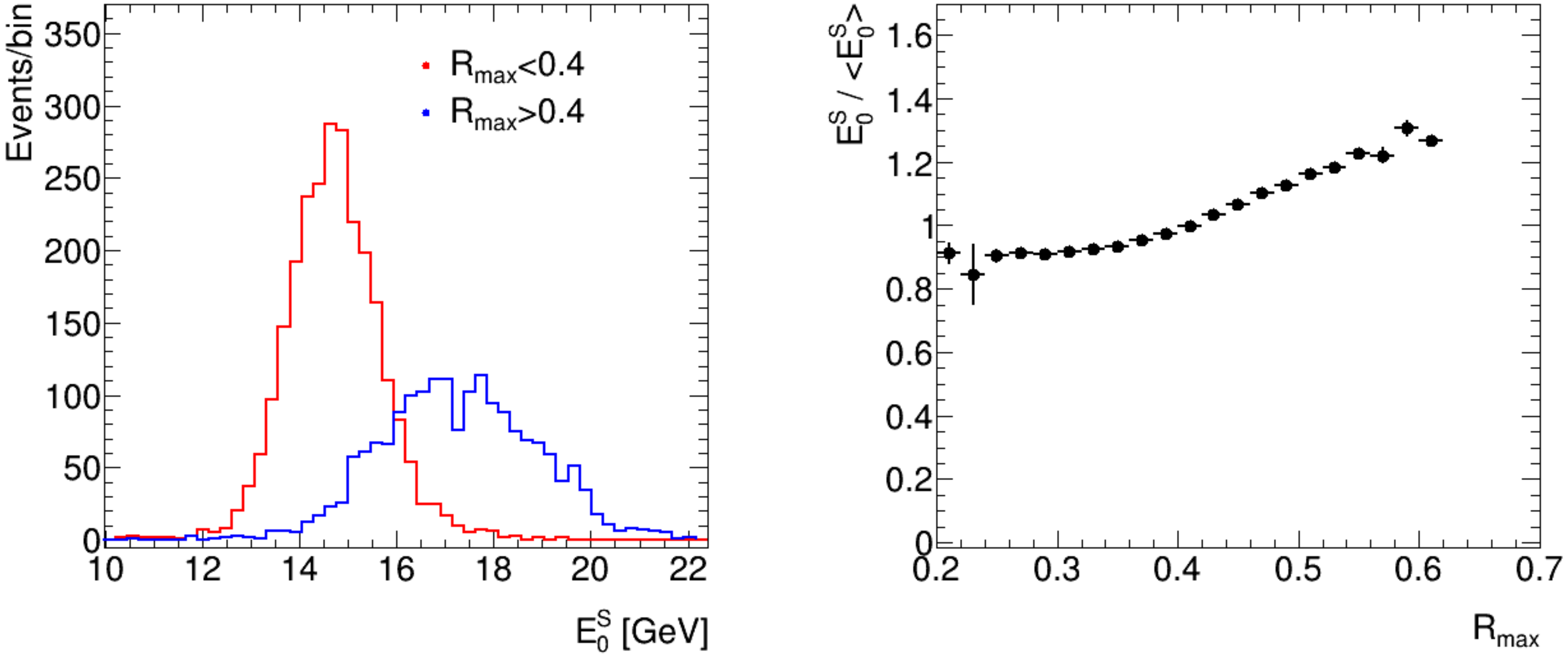
Correcting the position dependence

- Exploit the ~2 mm lateral shower granularity to correct for the position dependence

- Define $$R_{max} = \frac{\text{energy in most energetic scint row}}{\text{total energy in scint}}$$

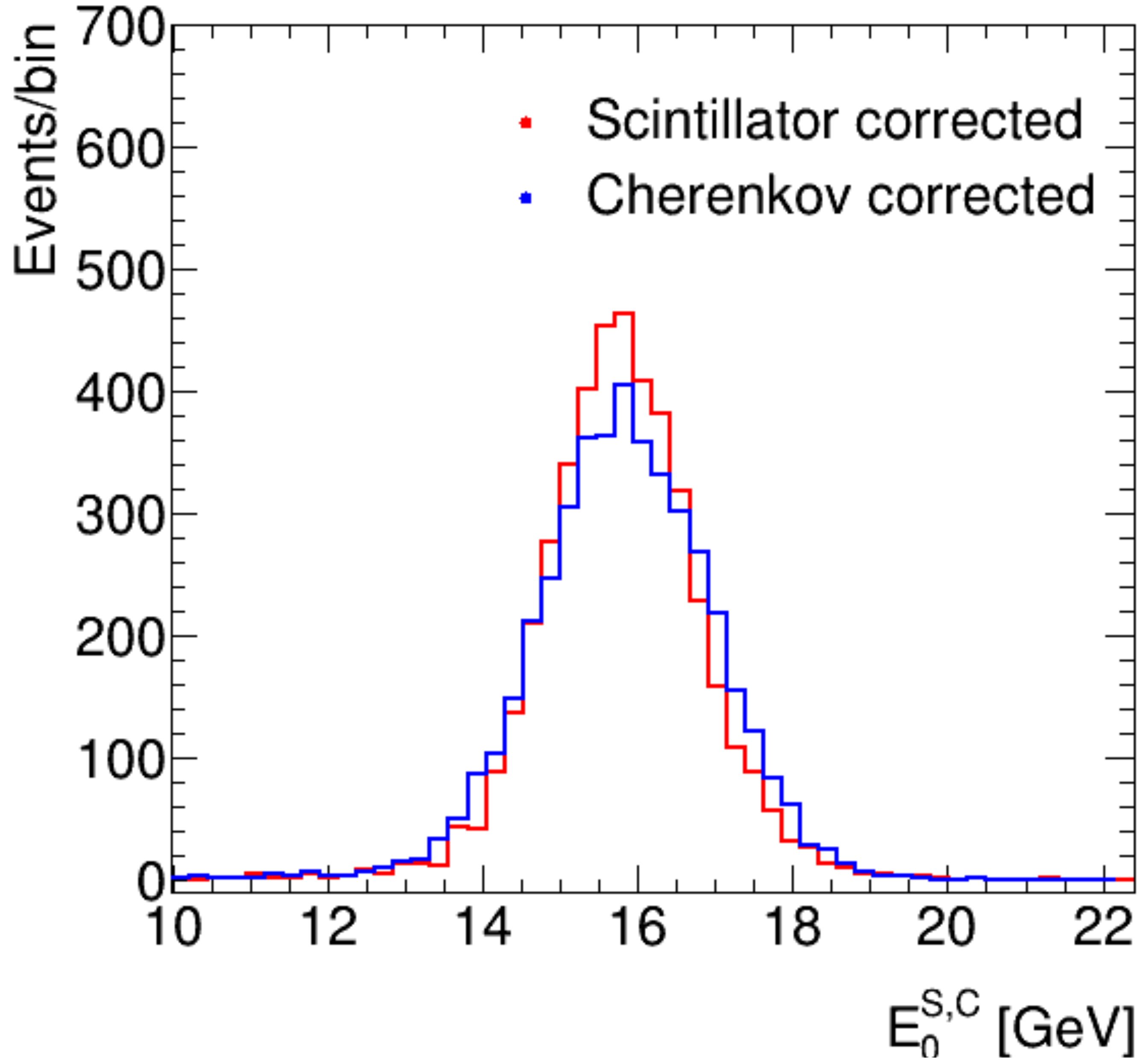
- Correlation with energy deposit through impact point position

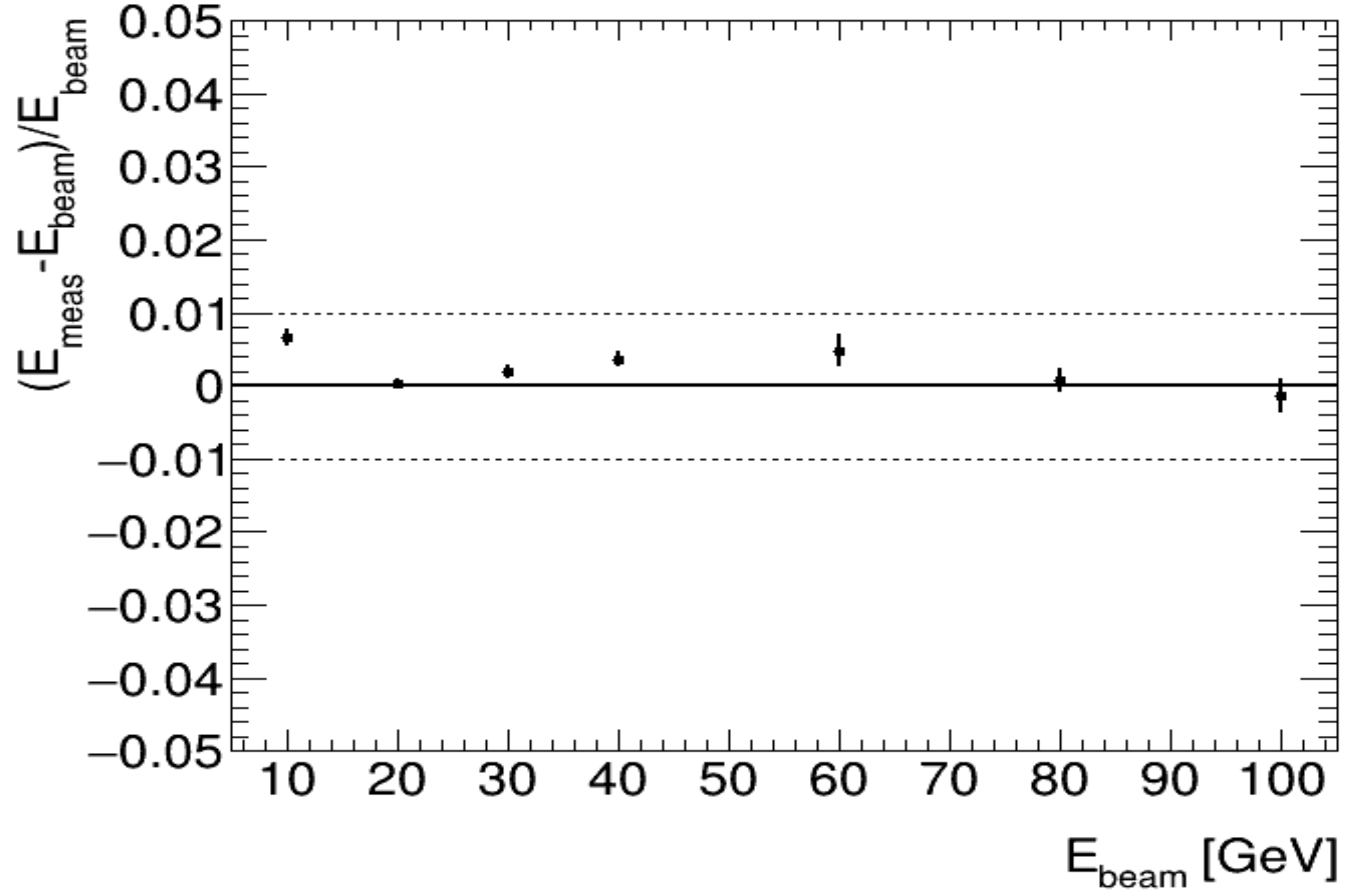
- Correct the response depending on R_{max}

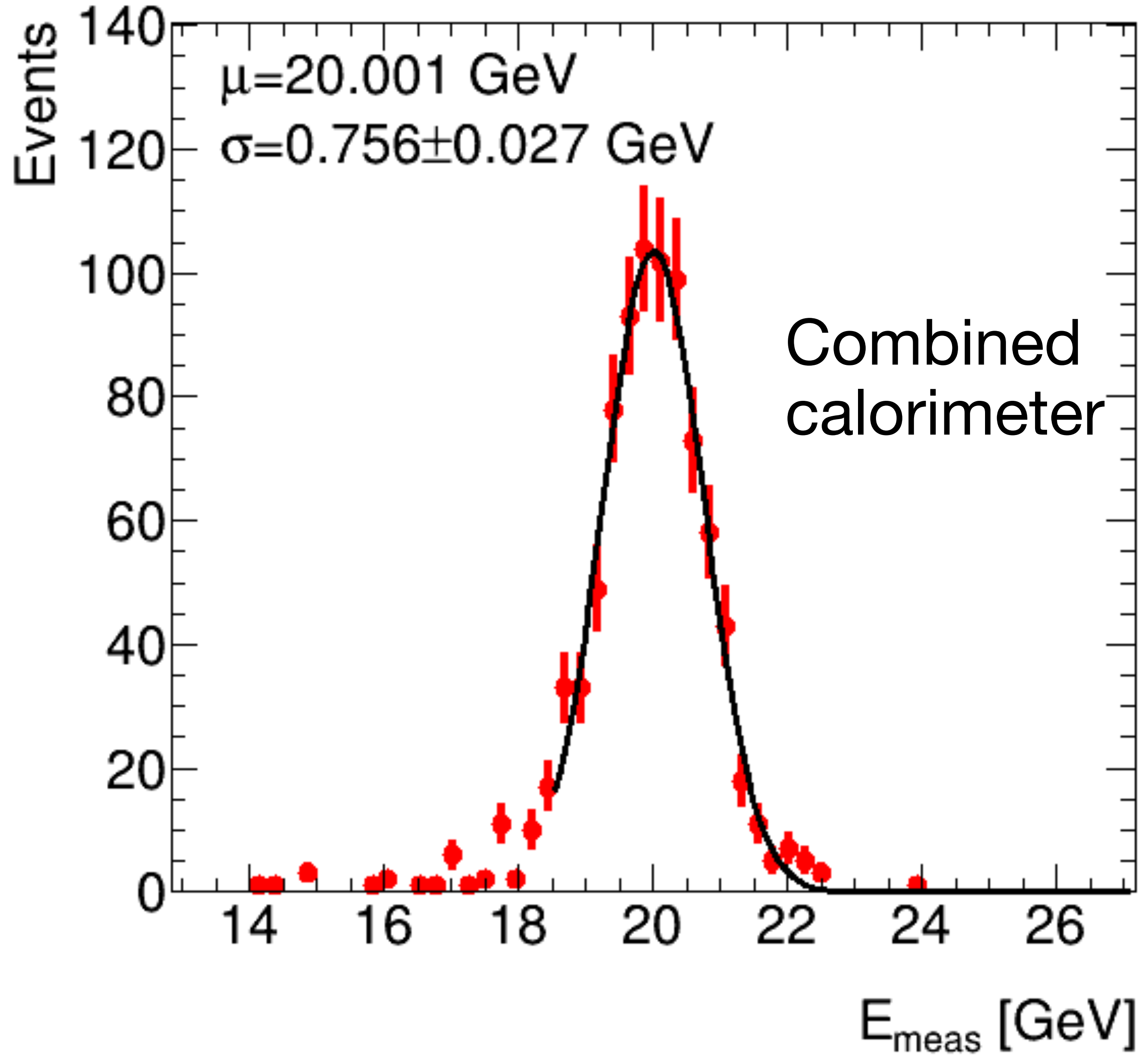


Response after corrections

- After correction, **symmetric response recovered**
- Combined response found to be **linear within 1%**

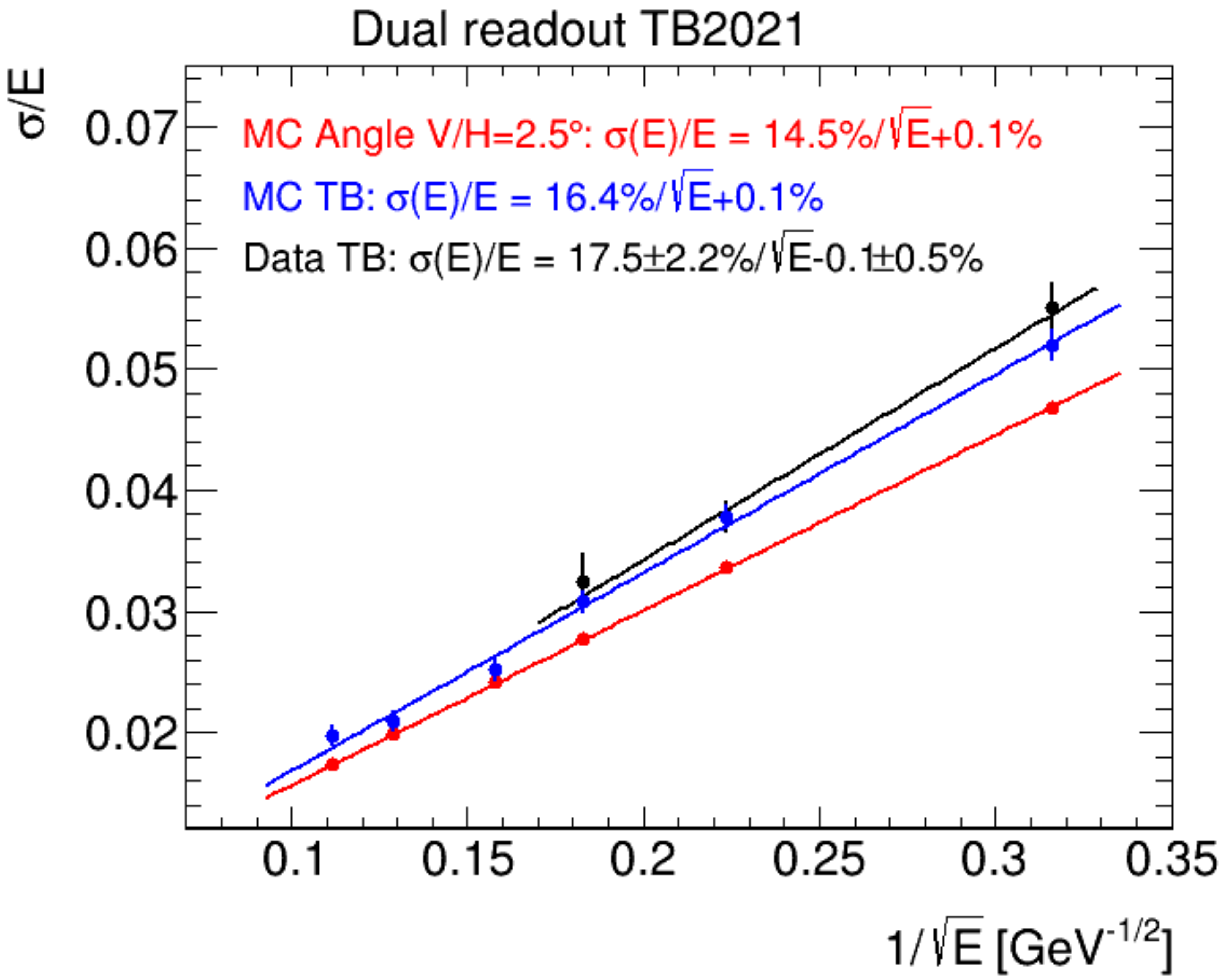






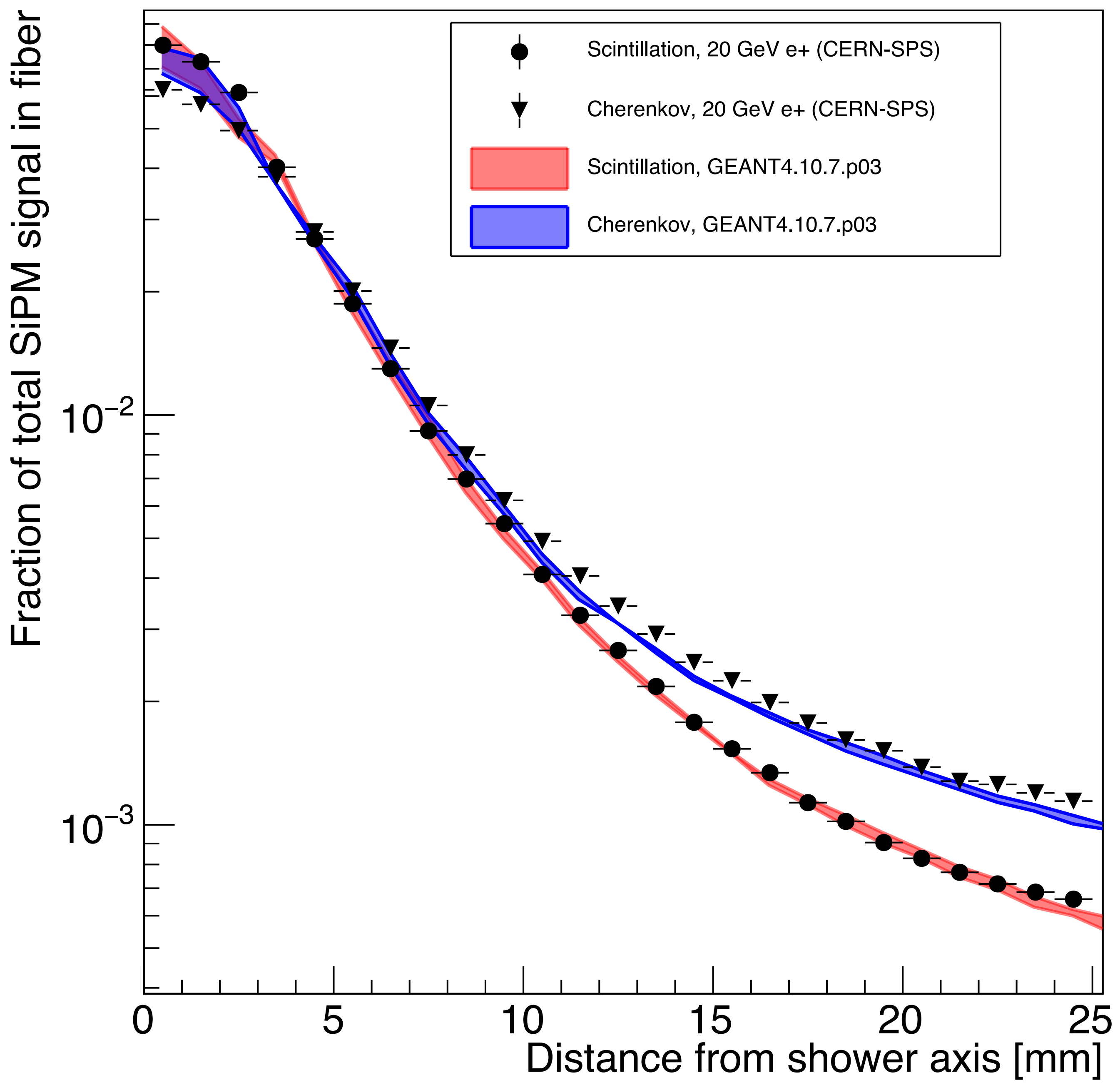
Electron energy resolution

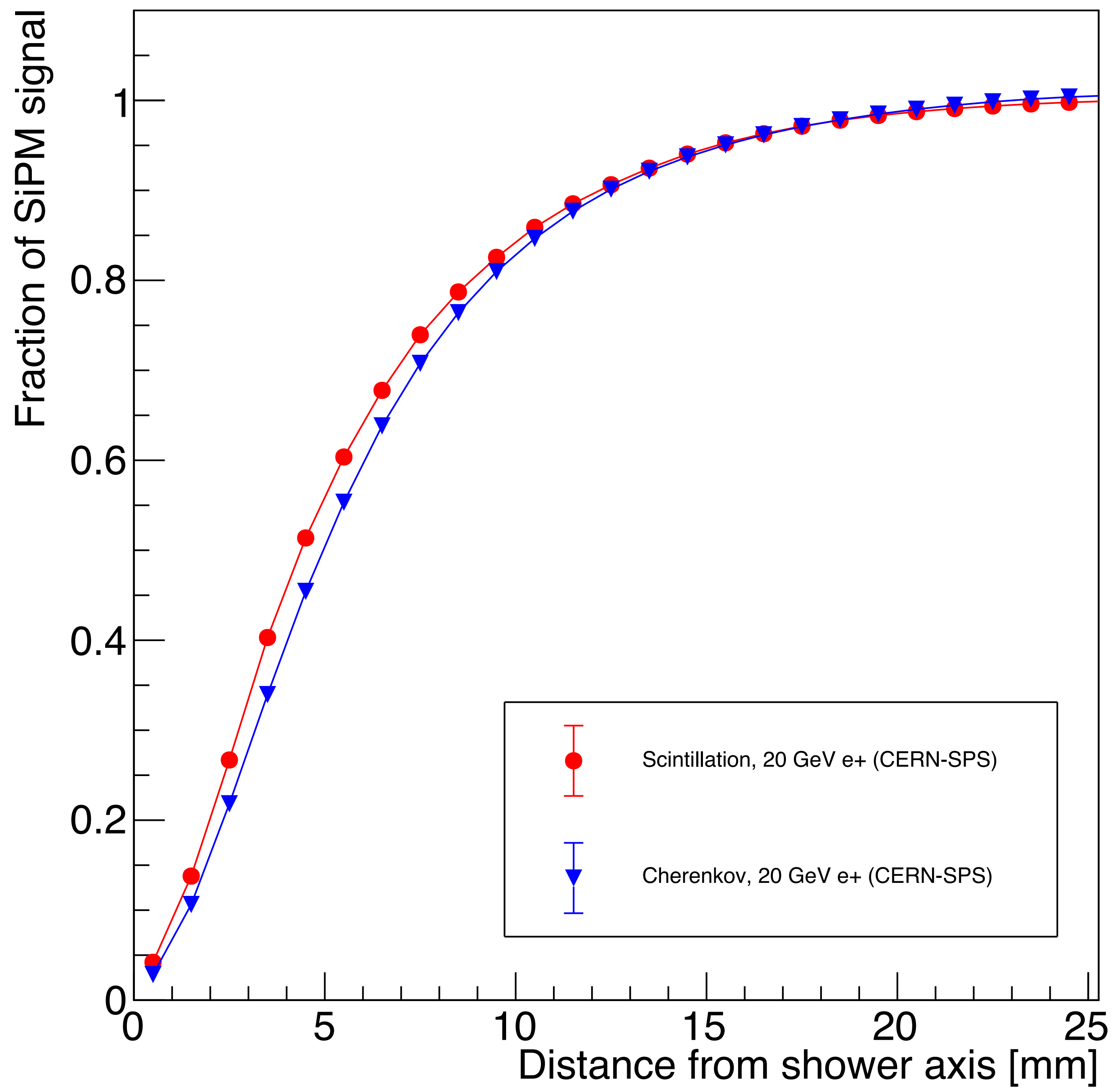
- Resolution to data at 10, 20 and 30 GeV **compatible to that obtained with the simulation** in same conditions (no tilt in the y-z plane)
- Simulation used to **assess electron performance in "ideal" conditions** (2.5º tilt in y-z)
- Resolution found comparable to that of **previously explored mechanical options**



Lateral shower shape

- Single-fibre readout allowed **high-precision measurement of the elecrton shower shape**
- Cherenkov view of the shower somewhat wider. **Very good agreement with G4 simulation**





Other activities

- Other **mechanical solutions and readouts** tested by colleagues from Korea in 2022 and 2023
- **New test beam** of the same capillary tube prototype took place in 2023. Analysis ongoing:
  - Much better **electron purity** in the SPS beam
  - Preshower **positioned at 15 cm from calorimeter**, data taken with different tilts in x-z and y-z planes
    - Plus muon and hadron runs, and runs with calorimeter at 90^{o}
- Construction of had size prototype (HiDRa) ongoing

Summary

- Capillary tube mechanical option for Dual Readout calorimetry **tested on beam in 2021** (and again in 2023)
- 2021 results recently published and summarised in this talk
- Despite harsh data taking conditions and a few oversights, we manage to show:
  - That **the response to electrons is linear** over a wide range of energies
  - That **the resolution in data is compatible to that in simulation**
  - That the **extrapolated simulation resolution is satisfactory** for construction of bigger prototypes
  - That **the simulation is reliable** even to reproduce **shower shapes** of the EM shower
- The capillary tube option for mechanical construction will be used for the construction of a prototype capable to contain hadronic showers