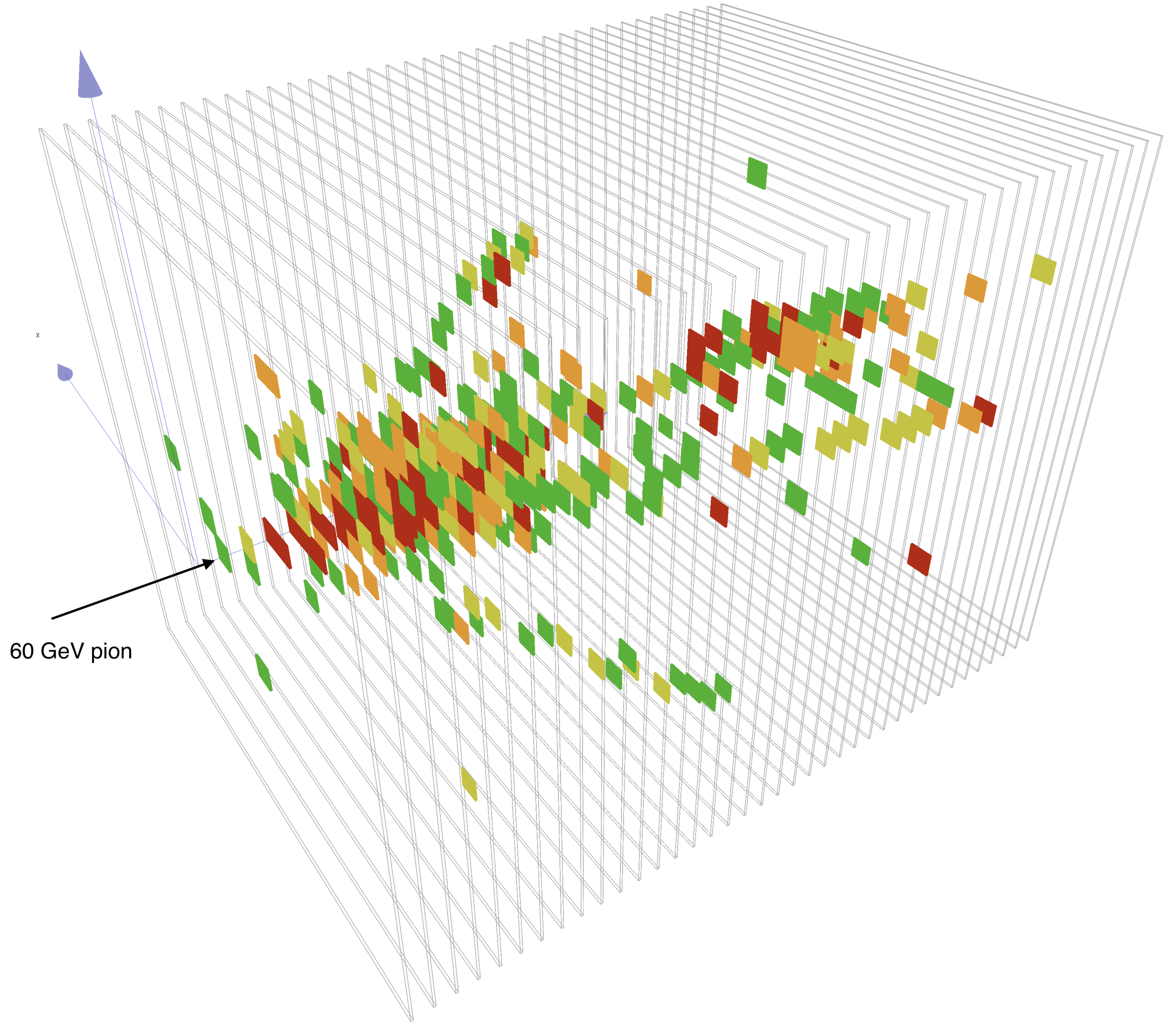
Analysis of testbeam data recorded with the large CALICE AHCAL technological prototype

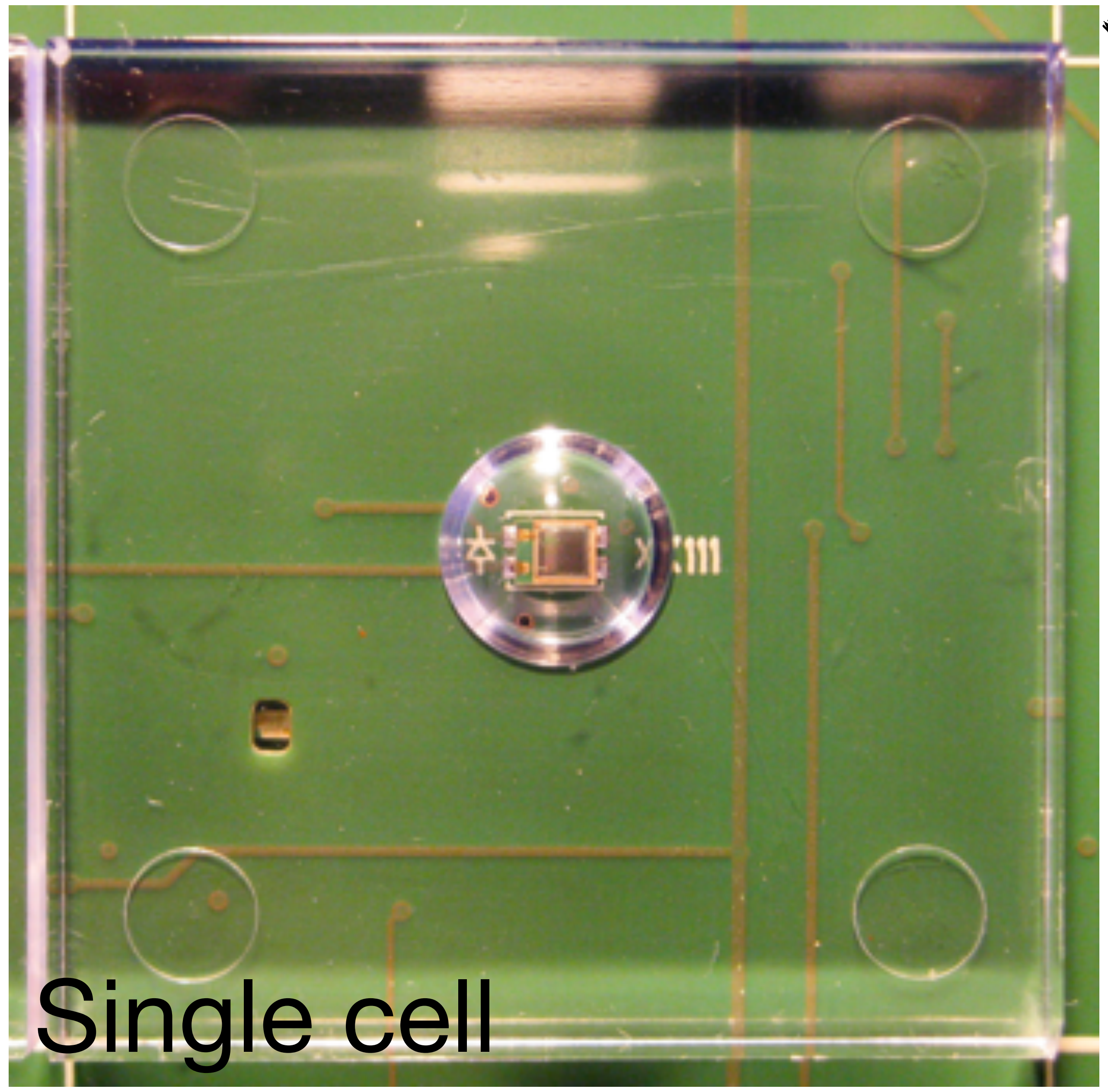
Lorenz Emberger, for the CALICE Collaboration

LCWS - 18. March 2021



MAX-PLANCK-INSTITUT FÜR PHYSIK

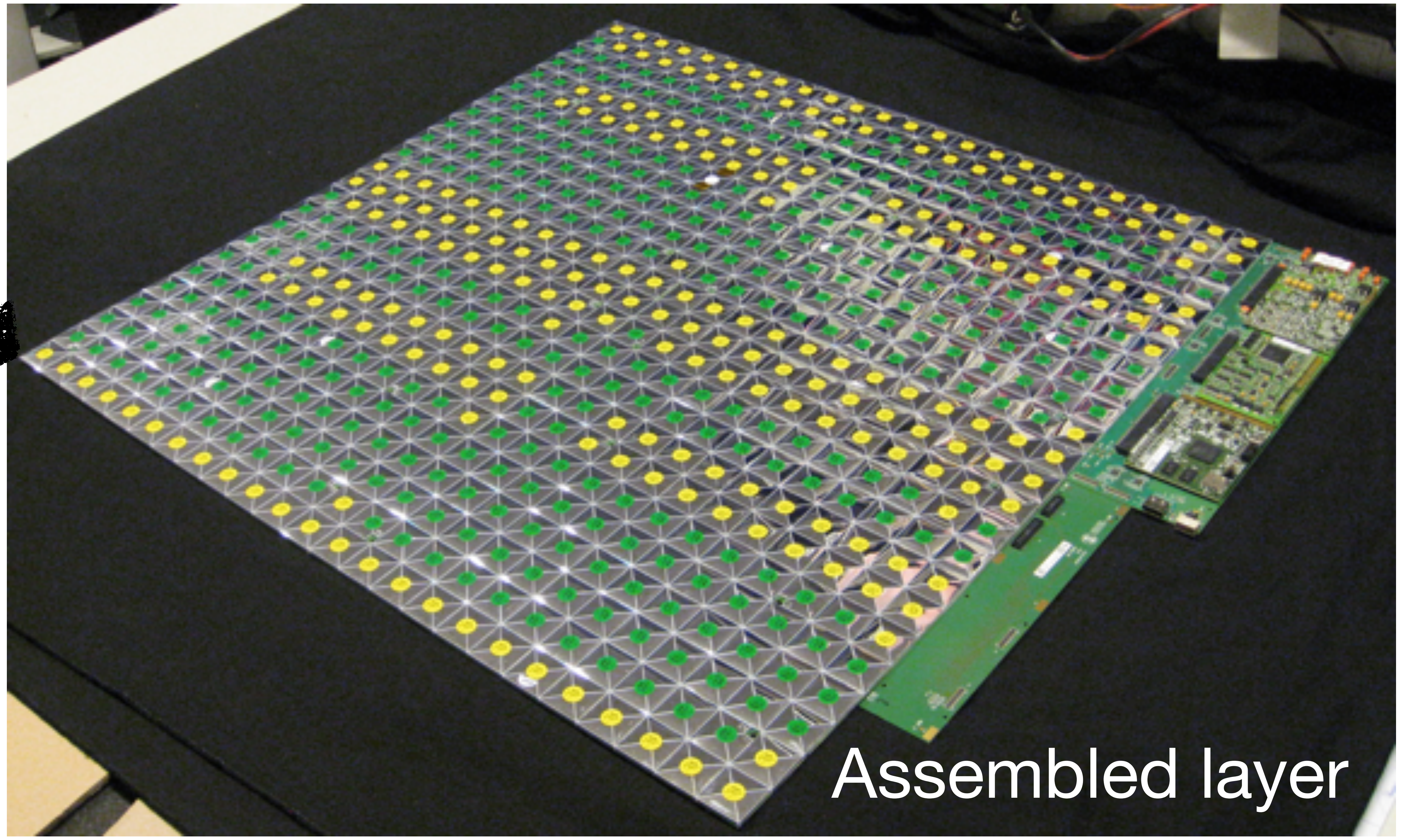
AHCAL Technological Prototype



automated wrapping and gluing

Hadronic sampling calorimeter (constructed 2017/18):

- 17mm steel absorber
- 3mm thick plastic scintillator



3x3cm2 scintillator tiles:

- Individual SiPM readout
- Optically separated by reflective foil
- Placed directly on the pcb

AHCAL Technological Prototype

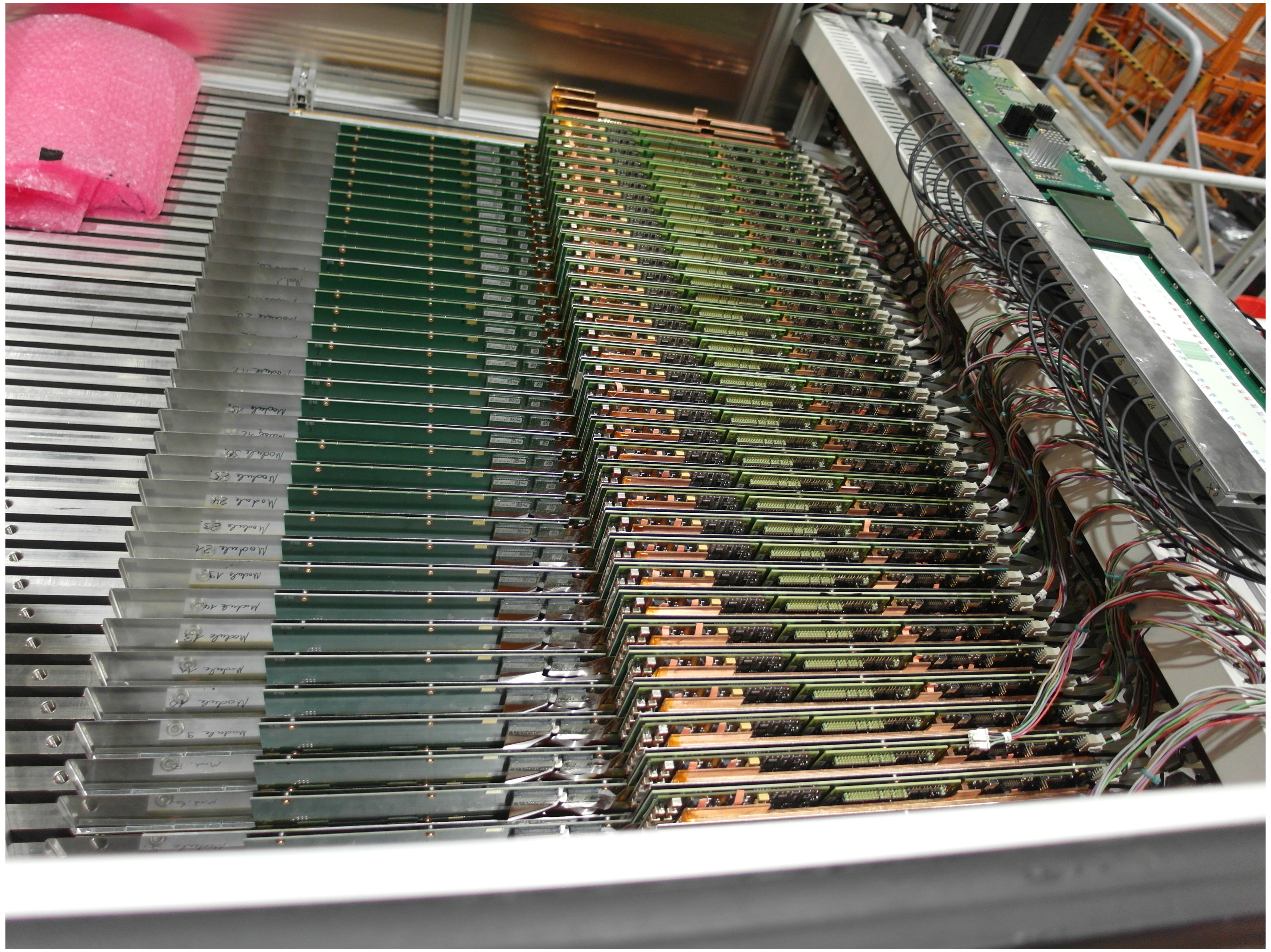
39 fully assembled layers:

- ~4λ, 38X0
- ~22000 channels
- Active front face area of 72x72cm²

Features:

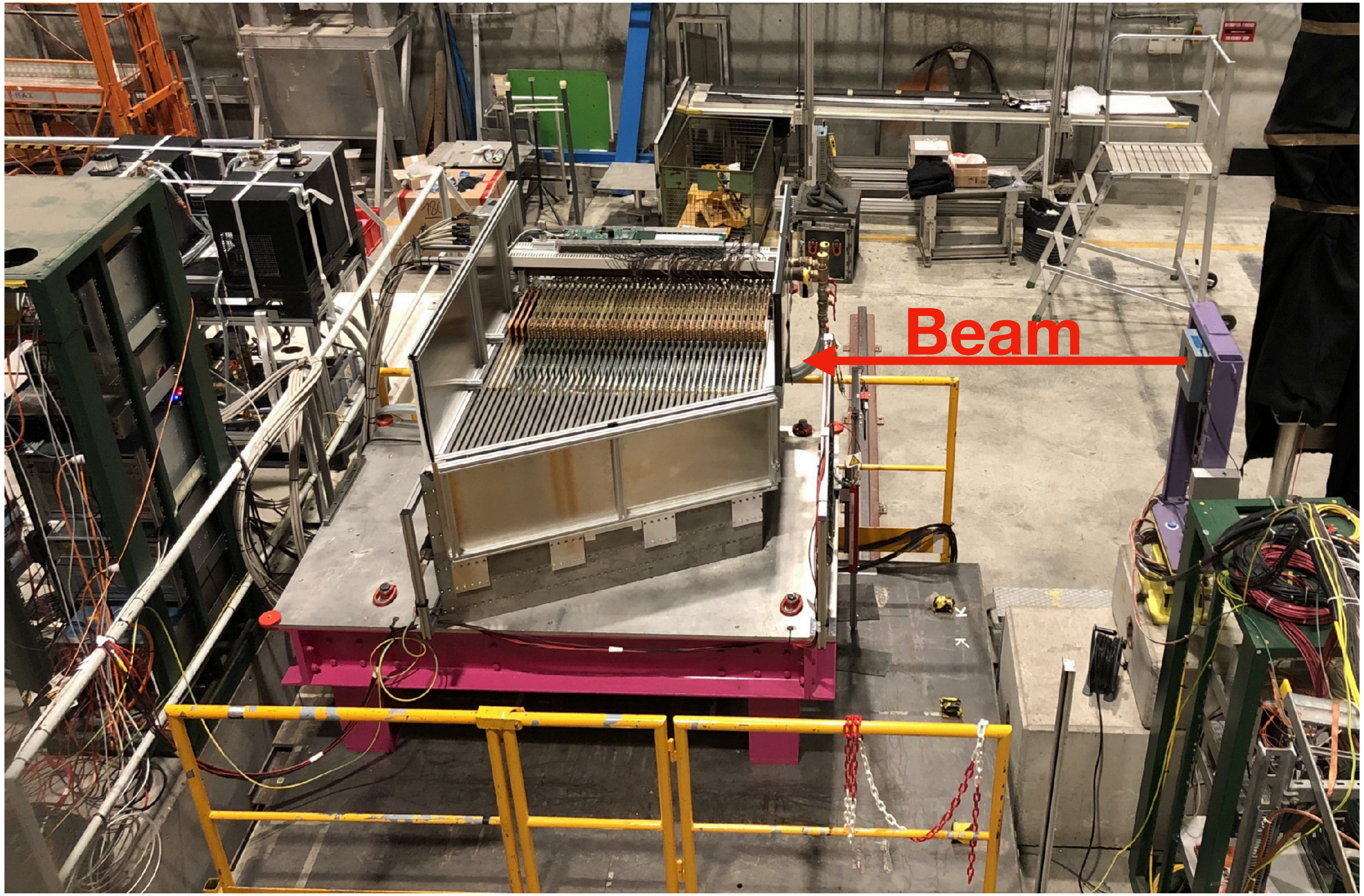
- High spatial segmentation
- Single channel energy and time measurement
- Temperature compensation for SiPM bias
- Power pulsing operation

Technological Prototype



Data Taking at the SPS

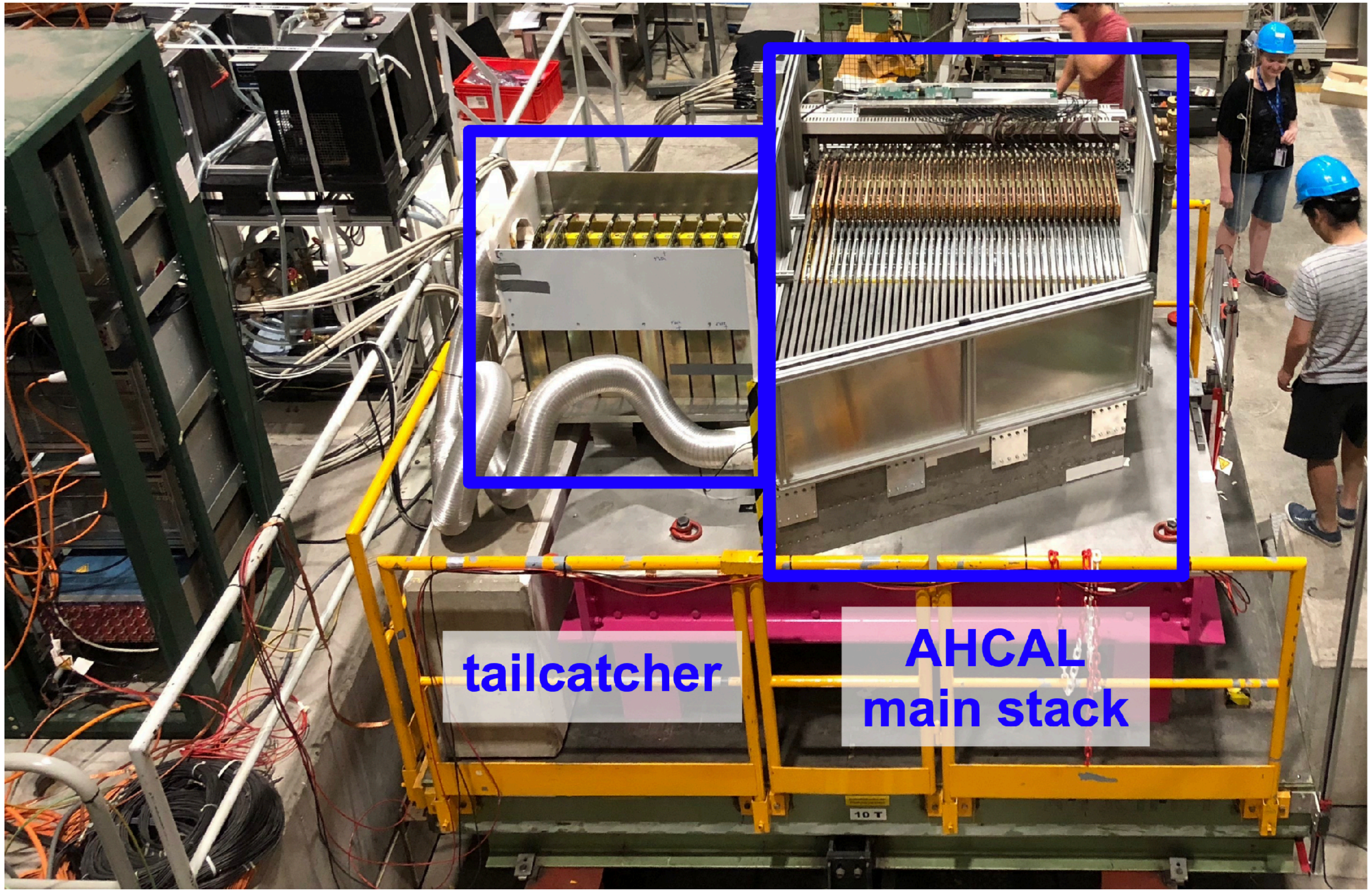
May 2018



- First beam test of the fully assembled prototype
- Wire chambers for particle track reconstruction
- Moveable stage for position scans

Data Taking at the SPS

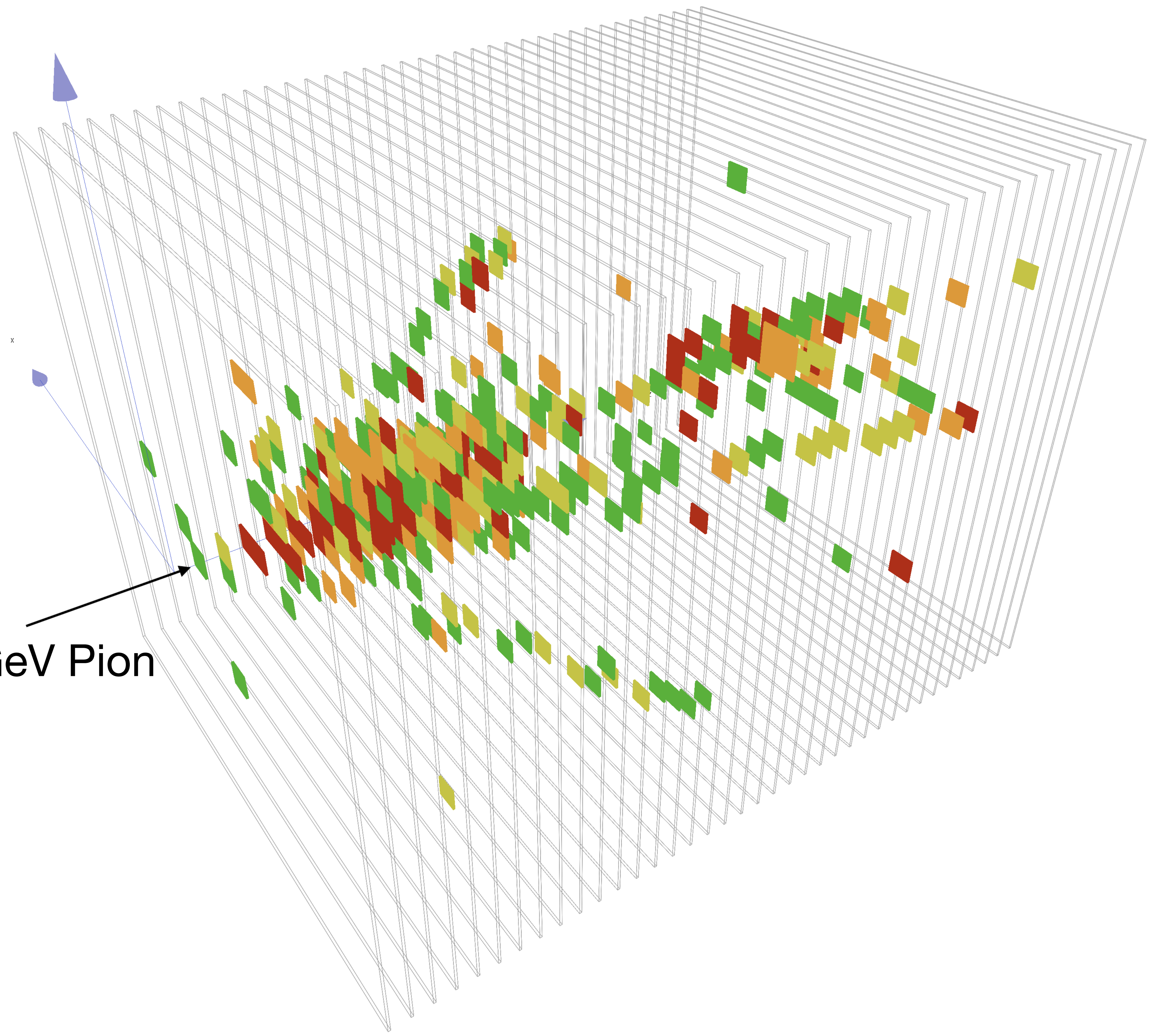
June/July 2018



- Pre shower detector to identify upstream showering
- One module with 6x6cm^2 tiles
- 12 layers of tail catcher with 7.4 cm steel absorber

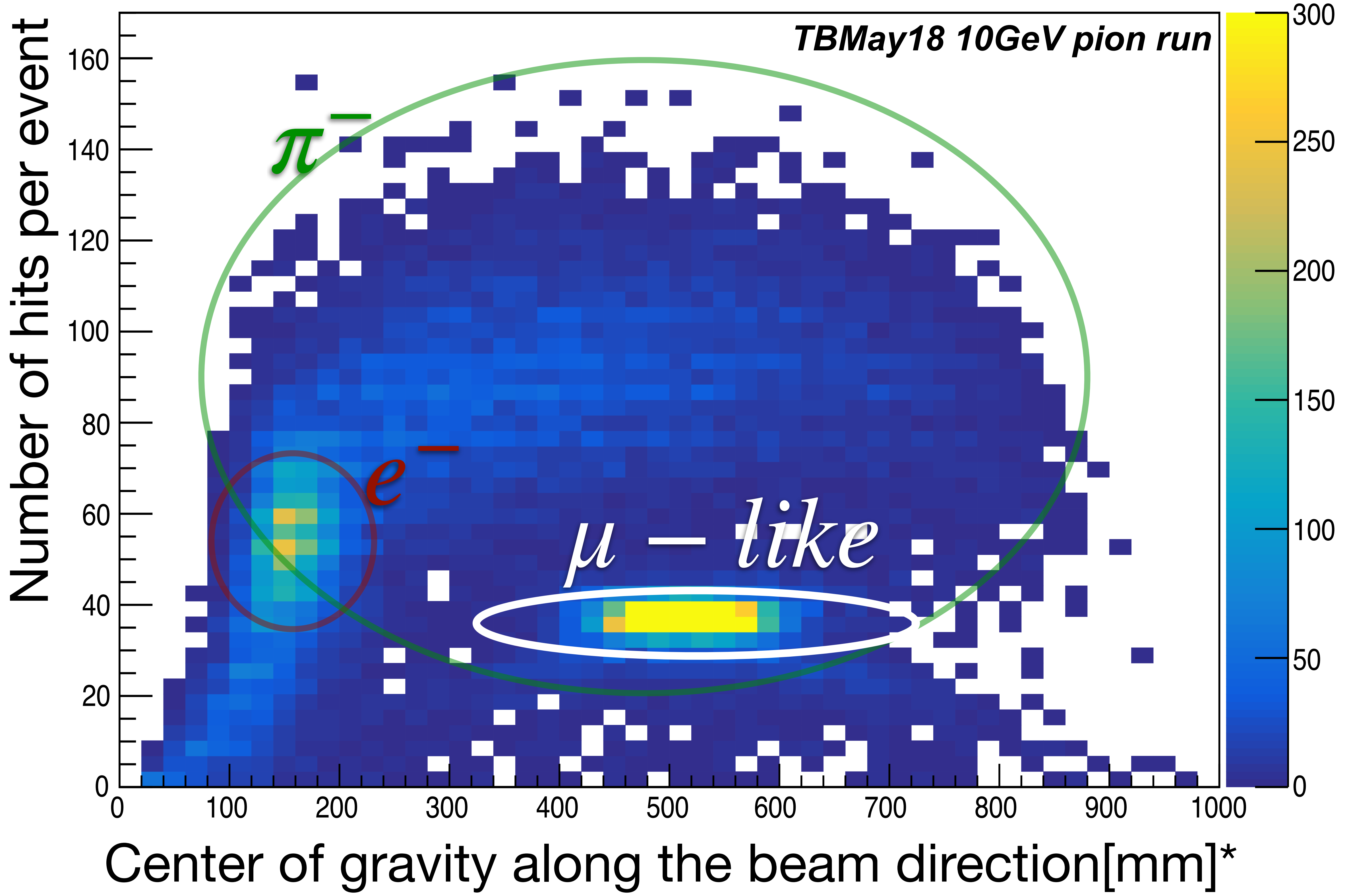
Dataset

- Muon scan of the full volume for calibration
- Position and energy scan with electrons:
  - 10, 20, 30, 40, 50, 60, 80, 100 GeV with and without power pulsing
  - 200,000 to 400,000 events per energy
- Position and energy scan with pions:
  - 10, 15, 20, 30, 40, 50, 60, 80, 100, 120, 160, 200 GeV with and without power pulsing
  - 400,000 to 600,000 events per energy



Conduct particle identification, particle separation, shower shape and timing analyses

By Vladimir Bocharnikov



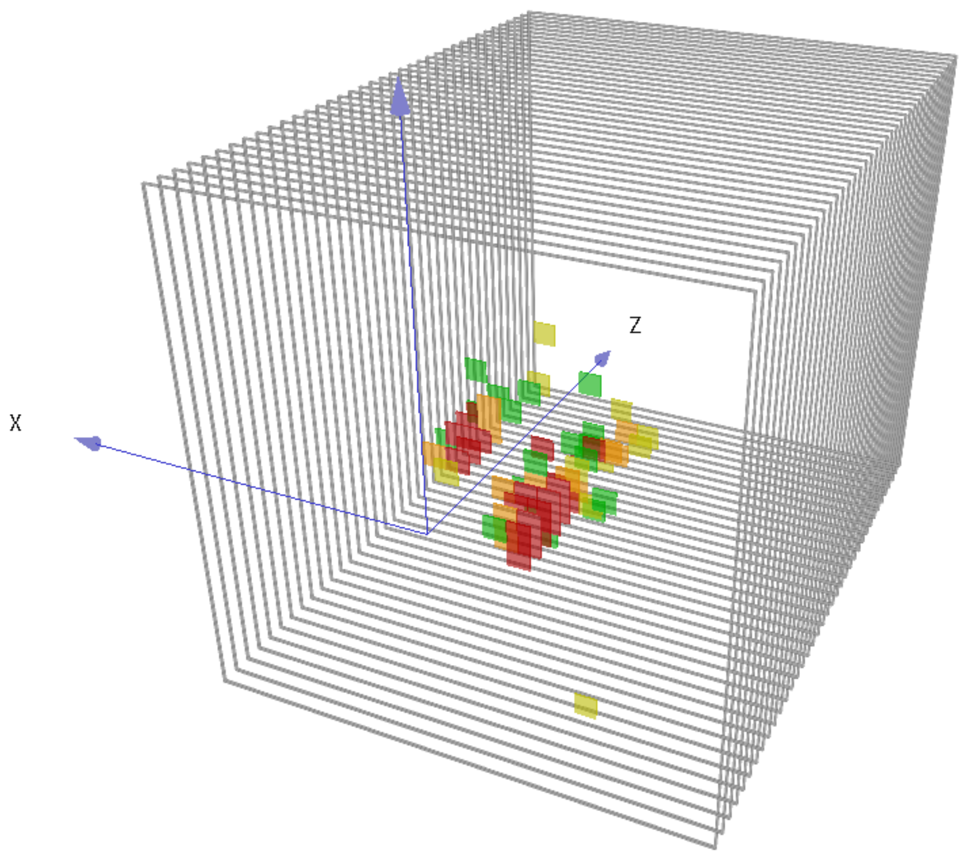
$$* \, z_{CoG} = \frac{\sum_{i=1}^{N_{hits}} z_i \cdot E_i}{E_{sum}}$$

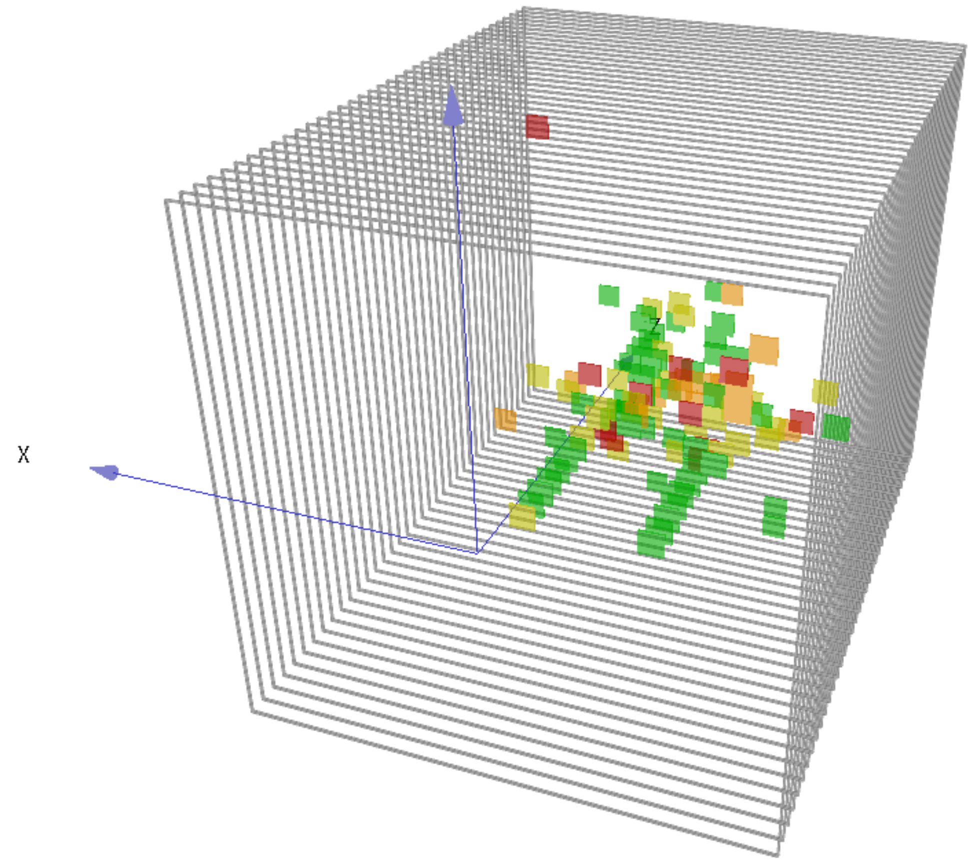
Goals:

- Identify contamination in test beam datasets
- Learn discriminative variables

Data preparation:

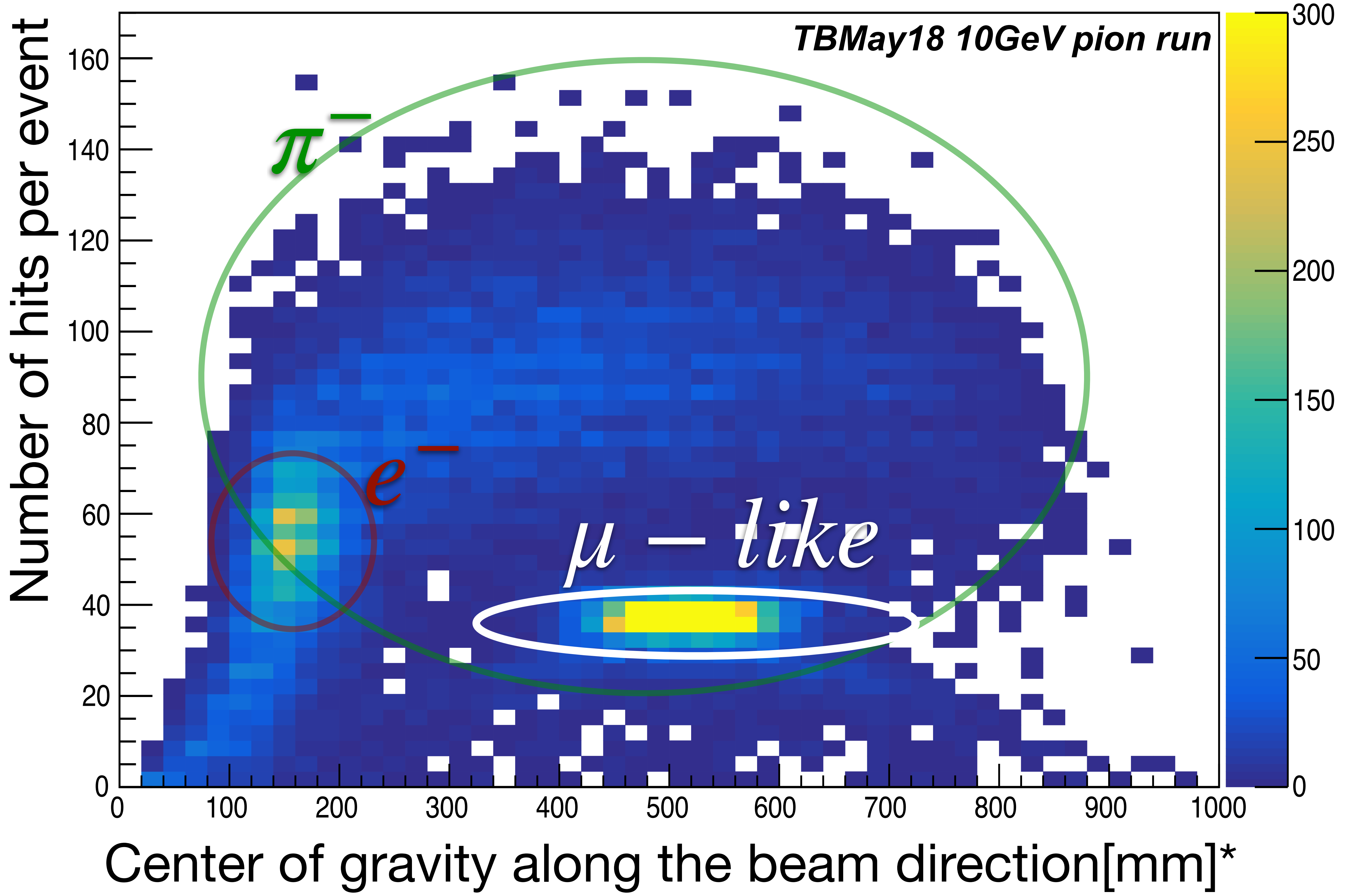
- Clustering and track finding for double particle rejection





Particle Identification

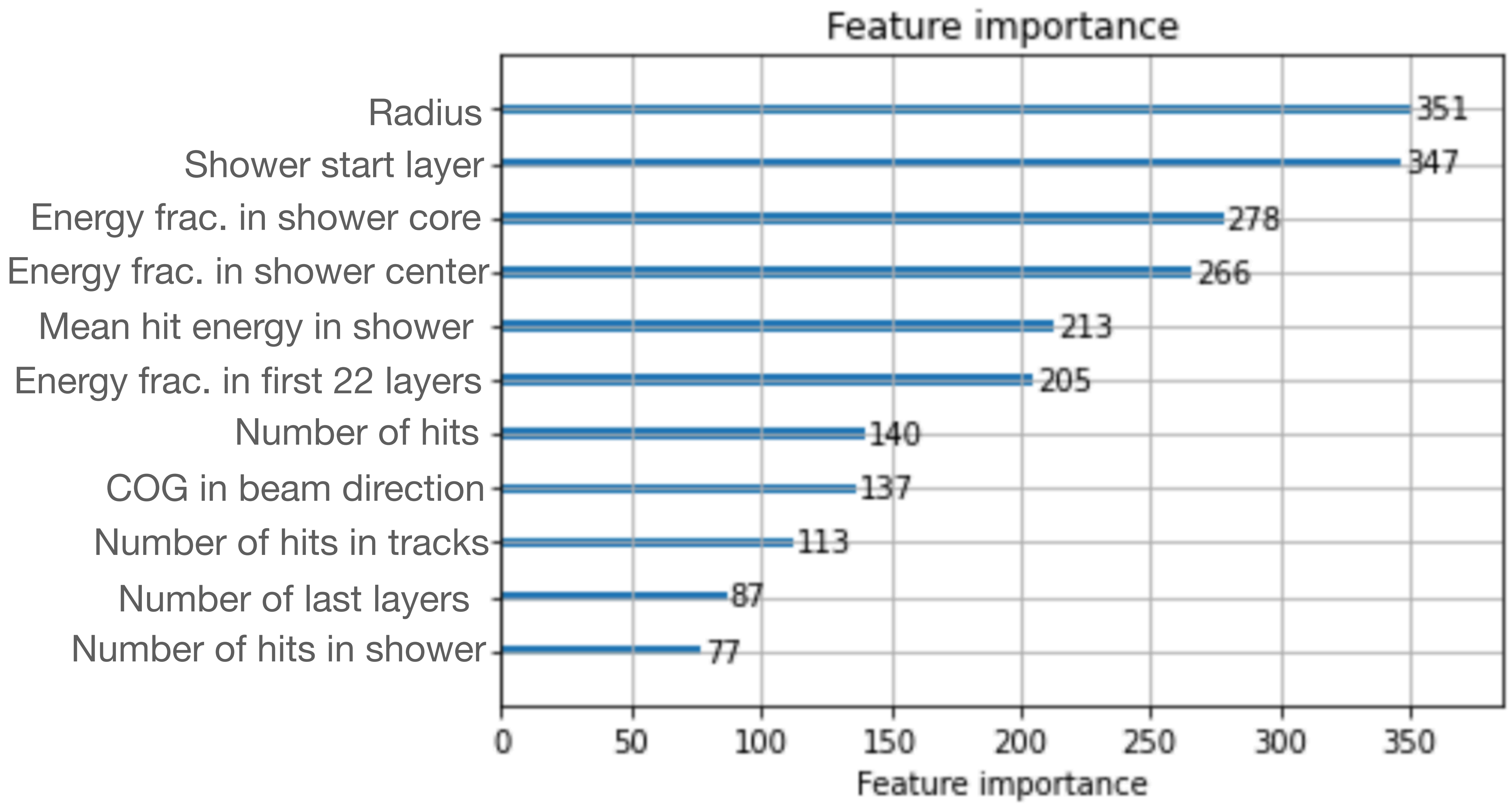
By Vladimir Bocharnikov



$$* \, z_{CoG} = \frac{\sum_{i=1}^{N_{hits}} z_i \cdot E_i}{E_{sum}}$$

Boosted decision tree setup:

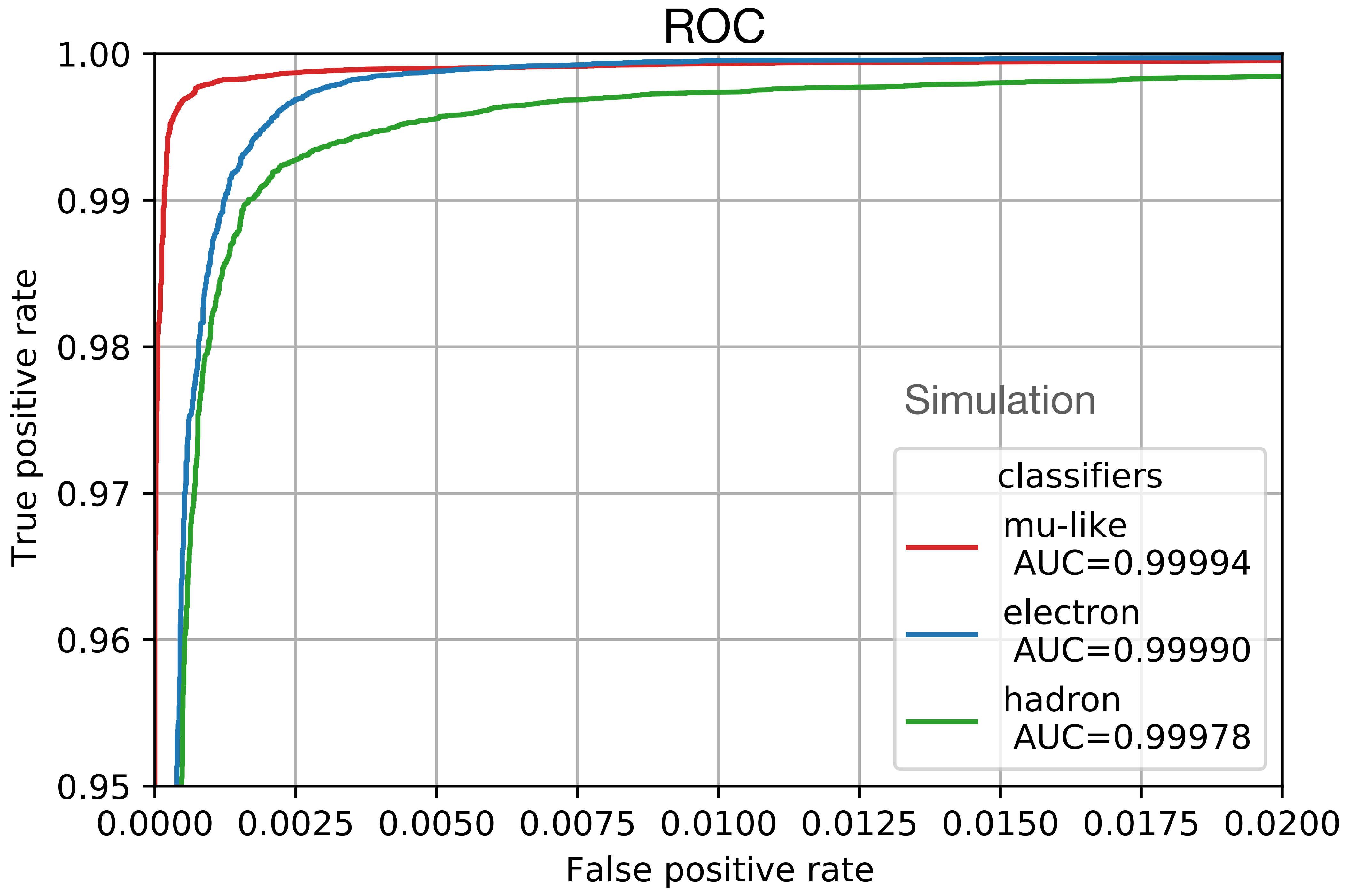
- MC generated electrons, muons and pions from 10 to 200GeV
- 50/50 ratio of train/test
- One classifier per particle type

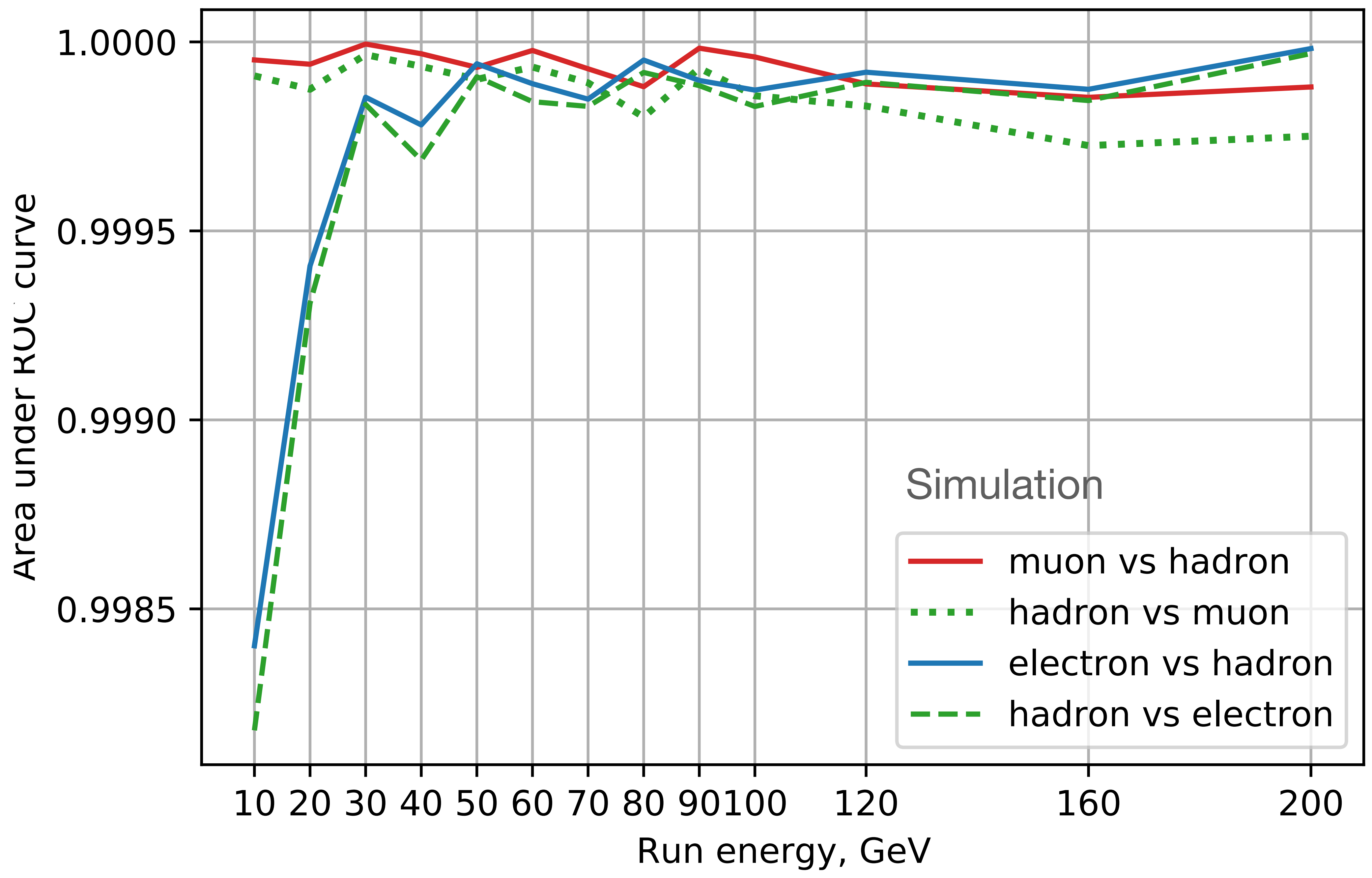


By Vladimir Bocharnikov

BDT identification performance on labeled simulation data

$$TruePositiveRate = \frac{TP}{TP + FN}, \quad FalsePositiveRate = \frac{FP}{FP + TN}$$



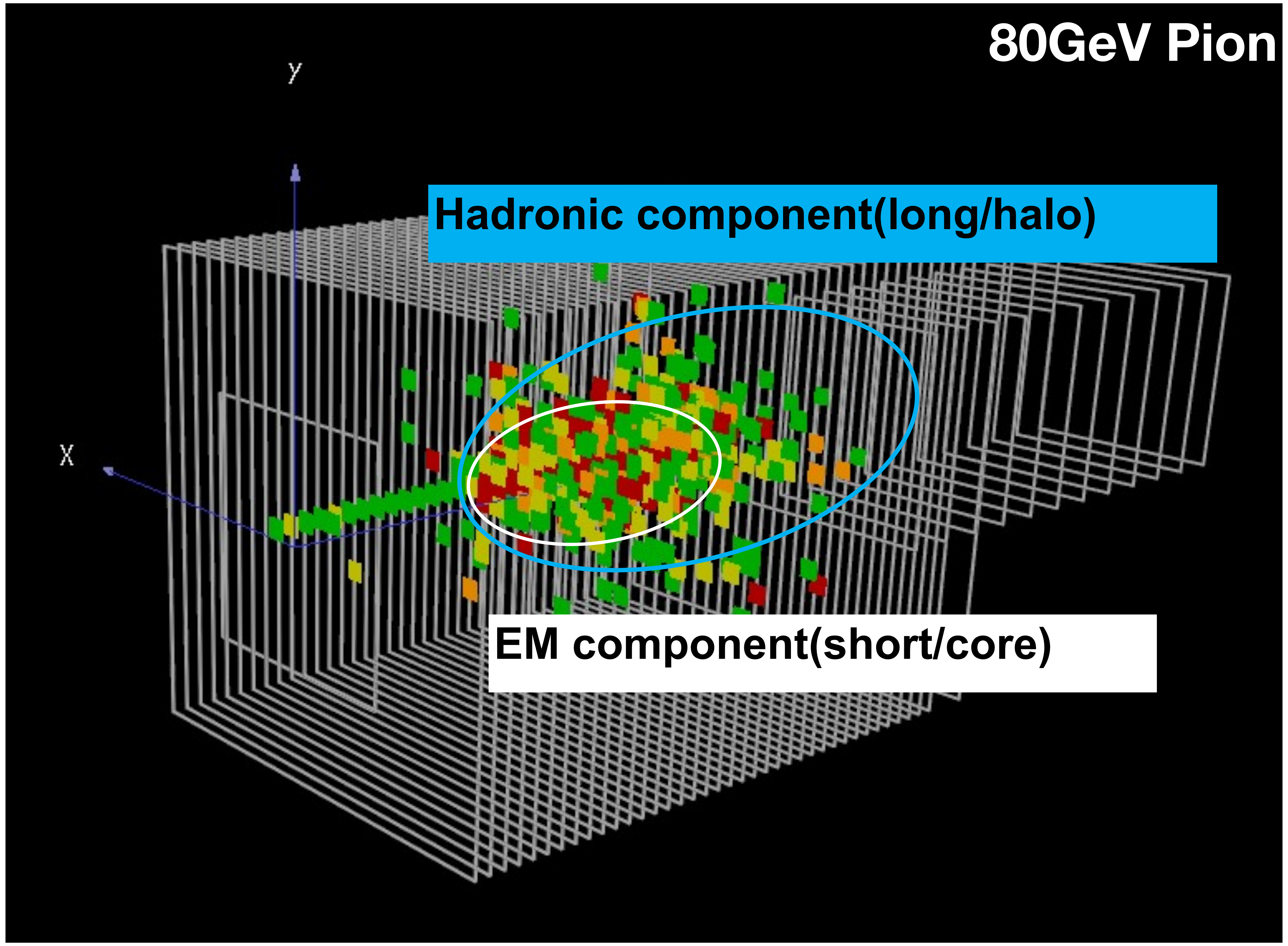


Very high identification power over full energy range

Shower Shapes

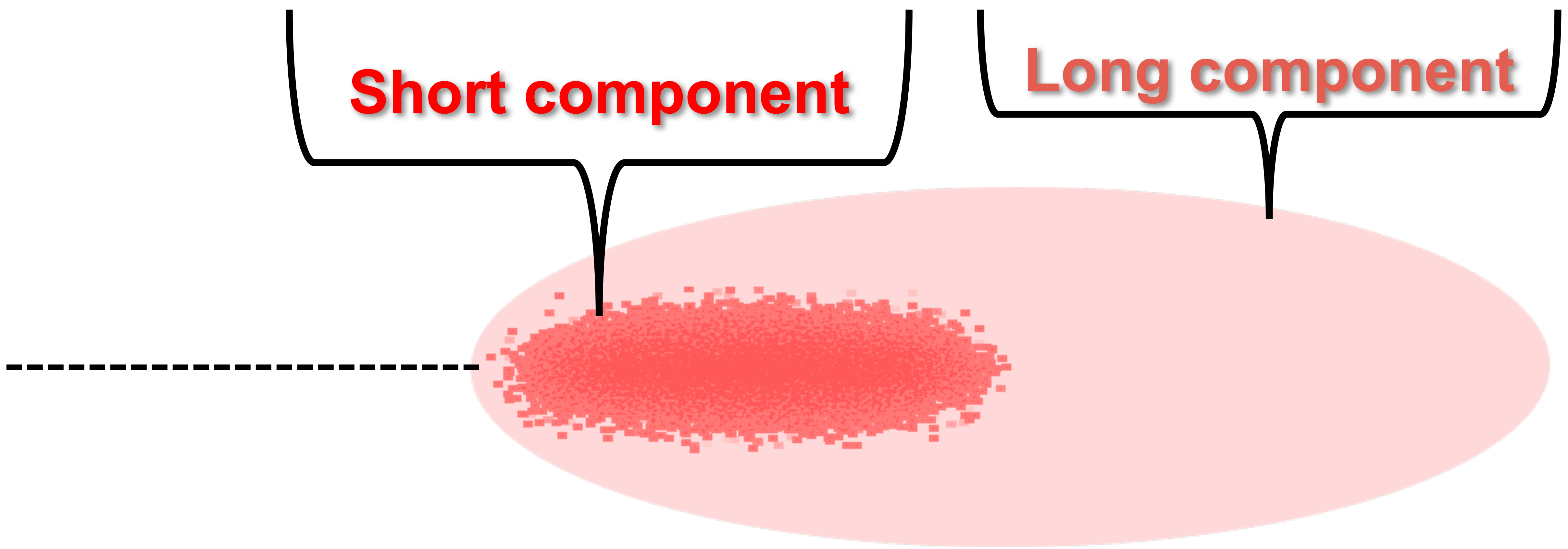
By Olin Pinto

- Exploitation of shower shapes allows an estimation of **h/e signal ratio.**



Parameterize longitudinal energy density by sum of gamma functions:

$$\Delta E(z) = E \cdot \left\{ \frac{f}{\Gamma(\alpha_s)} \cdot \left(\frac{Z[X_0]}{\beta_s}\right)^{\alpha_s - 1} \cdot \frac{e^{\frac{-Z[X_0]}{\beta_s}}}{\beta_s} + \frac{1-f}{\Gamma(\alpha_l)} \cdot \left(\frac{Z[\lambda_I]}{\beta_l}\right)^{\alpha_l - 1} \cdot \frac{e^{\frac{-Z[\lambda_I]}{\beta_l}}}{\beta_l} \right\}$$



f: fraction of short component,

α: shape parameters, β: slope parameters

First studied in: JINST 11 (2016) P06013

Shower Shapes

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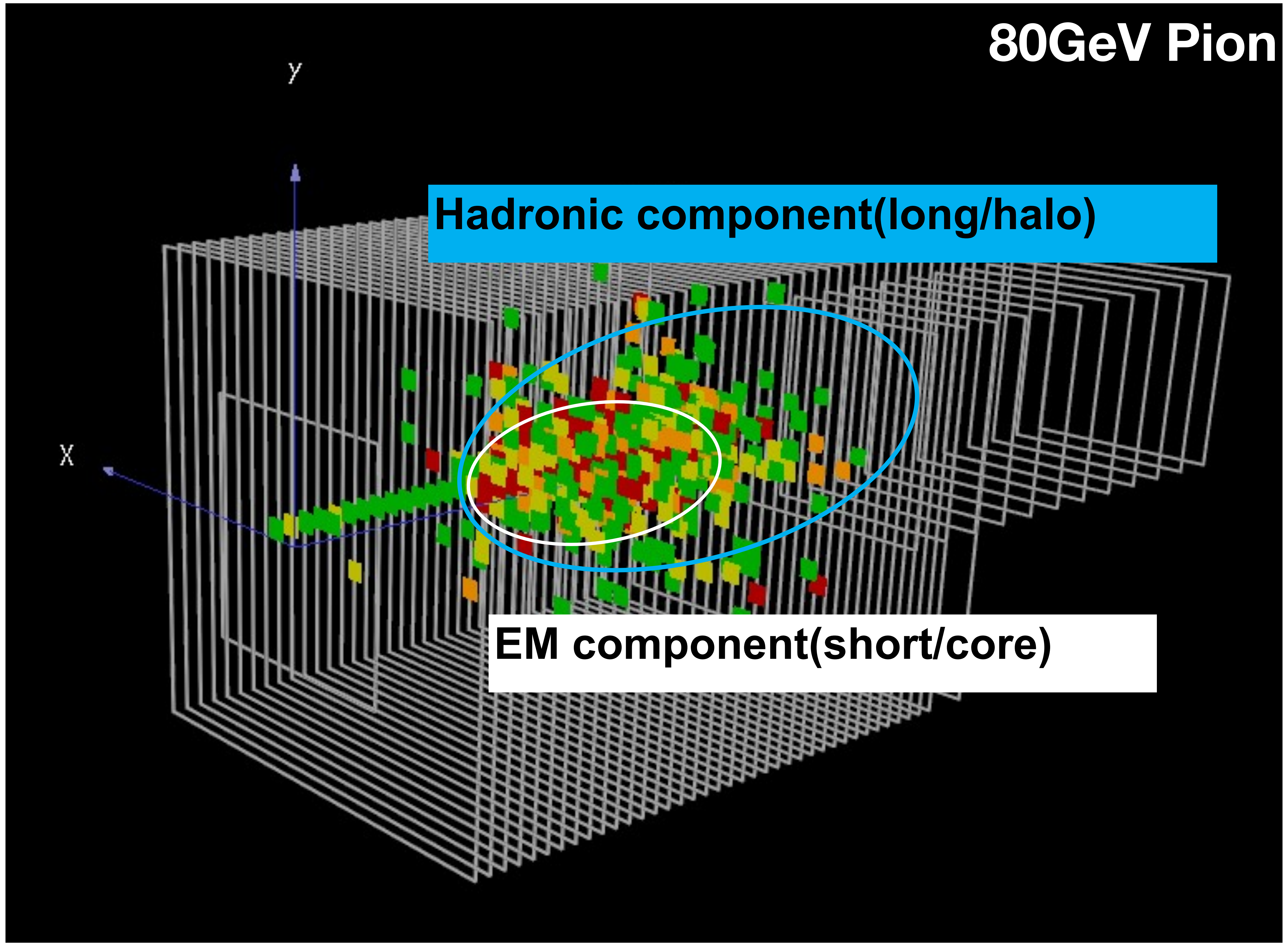

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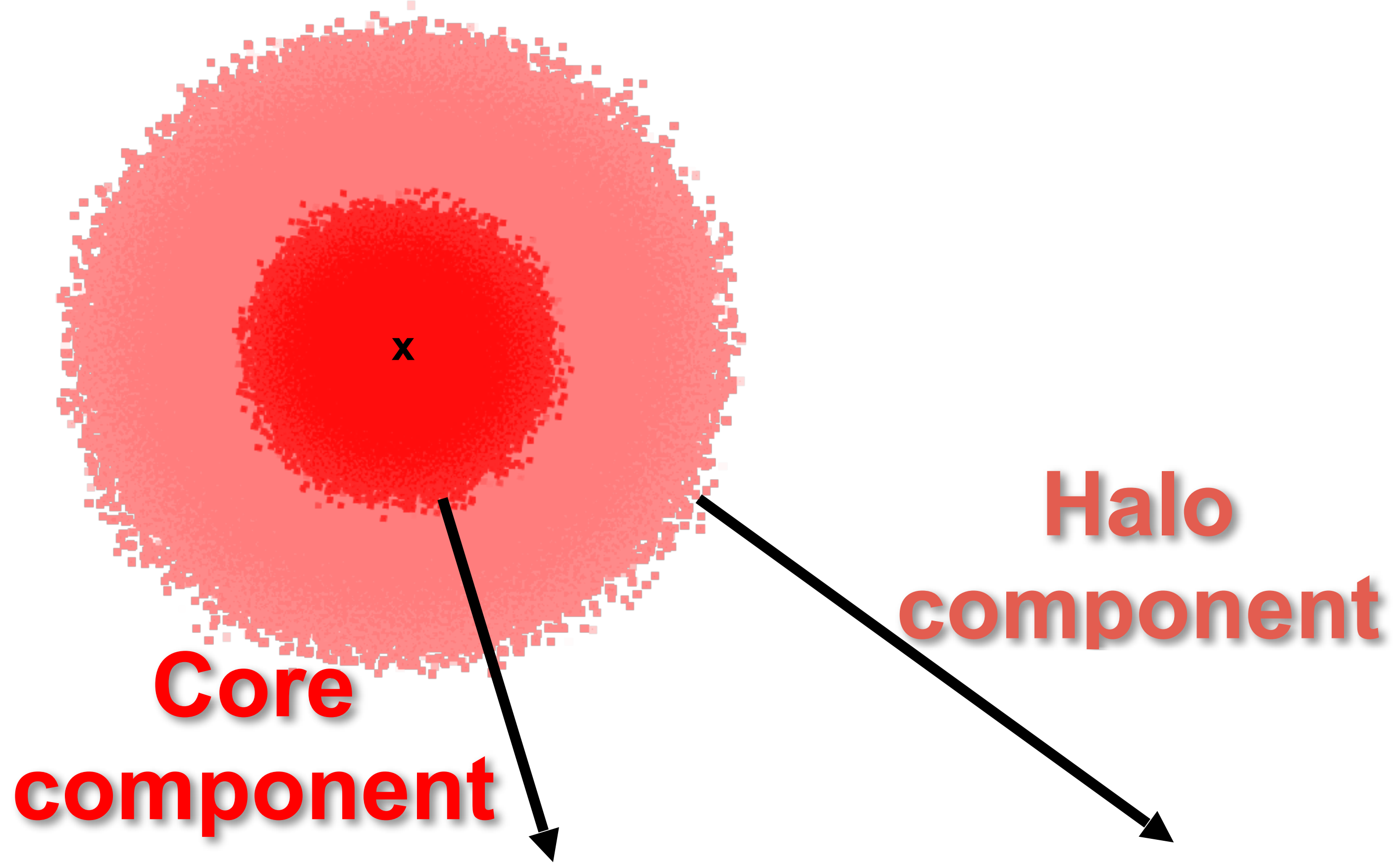
Parameterize radial energy density by sum of exponential decays:

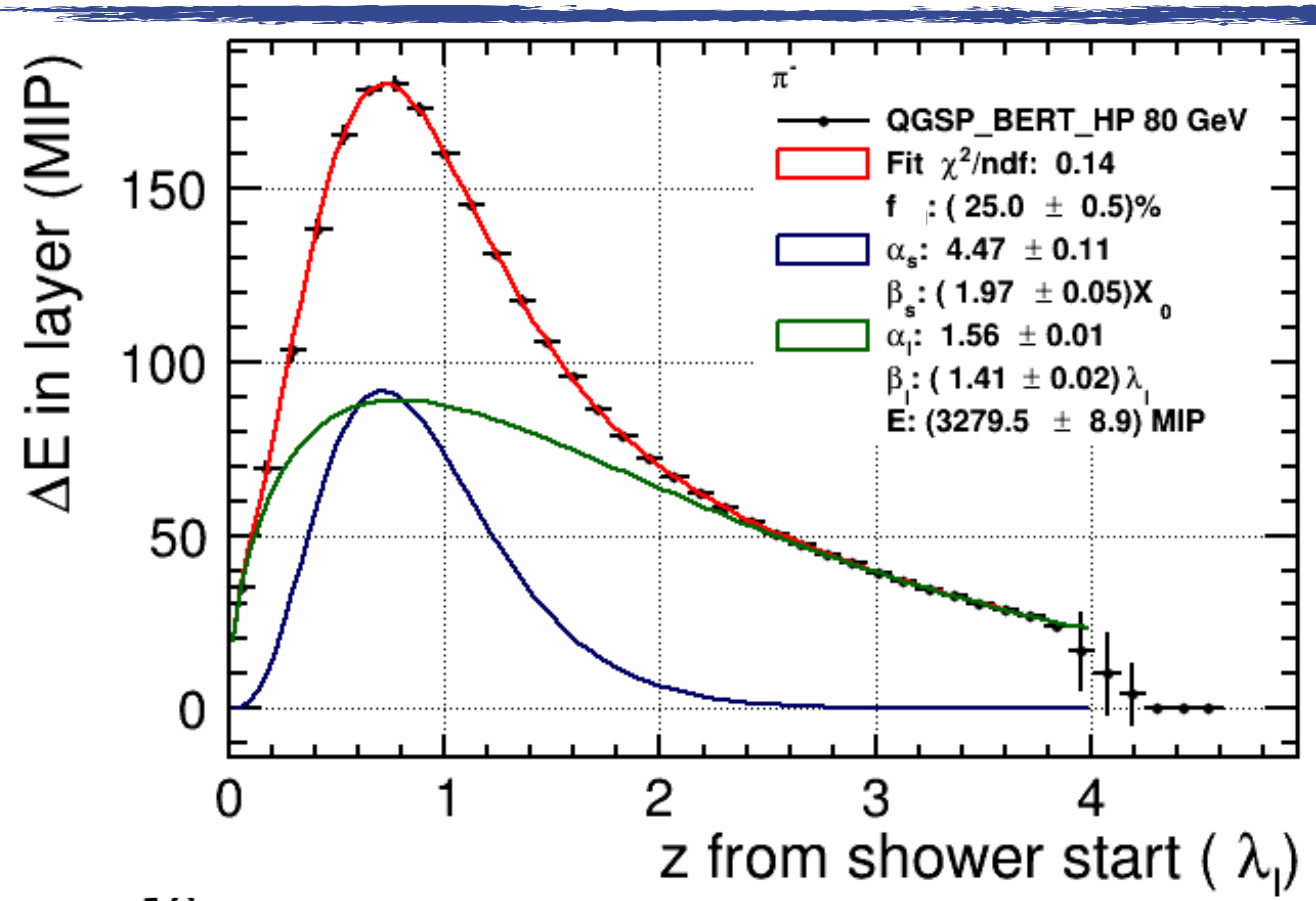


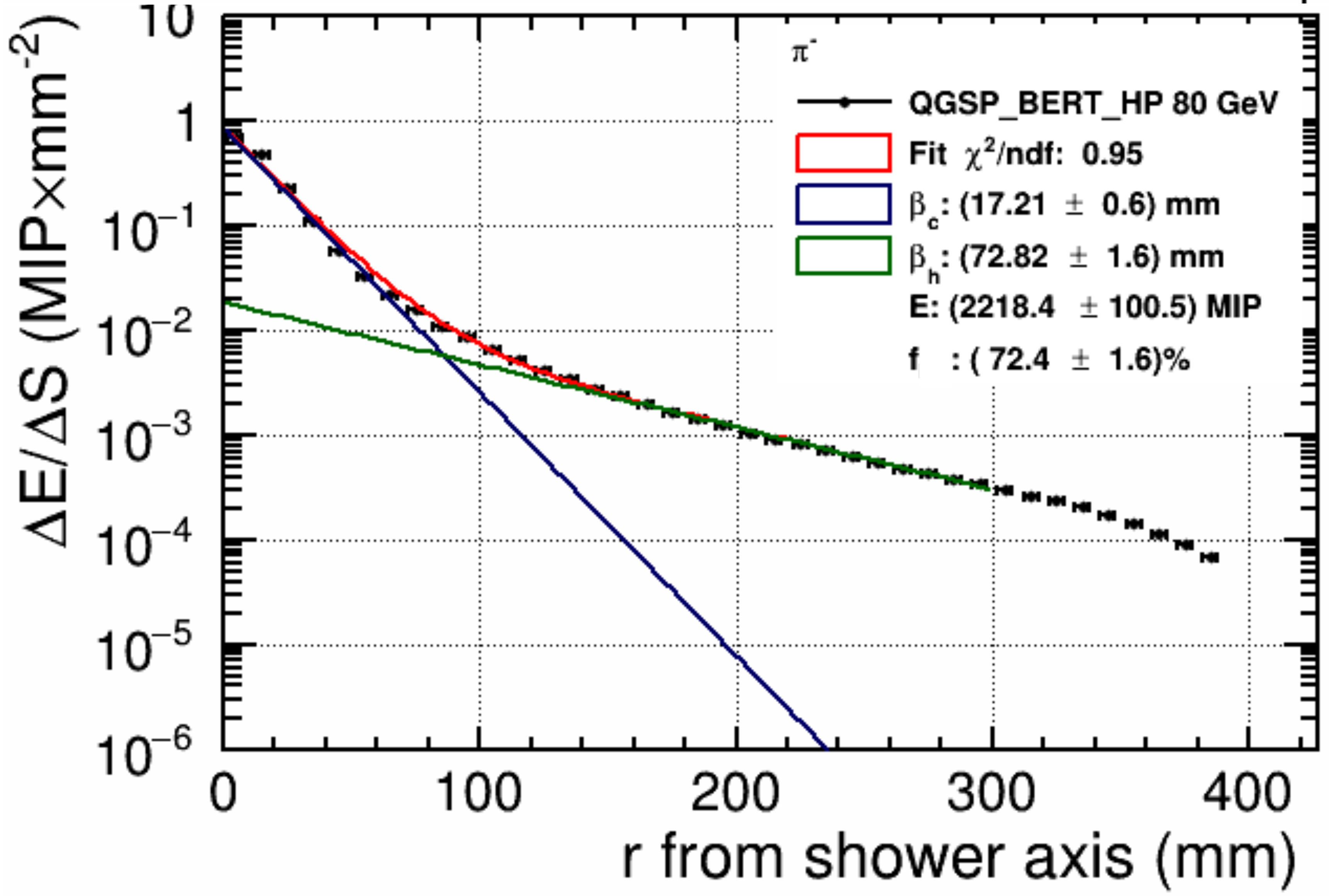
$$\frac{\Delta E}{\Delta S}(r) = \frac{E}{2\pi} \cdot \left\{ f \cdot \frac{e^{\frac{-r}{\beta_c}}}{\beta_c^2} + (1-f) \cdot \frac{e^{\frac{-r}{\beta_h}}}{\beta_h^2} \right\}$$

$\Delta S = 2\pi r \Delta r$ is the area of a ring of width Δr at a distance r from the shower axis

Shower Shapes In Simulation

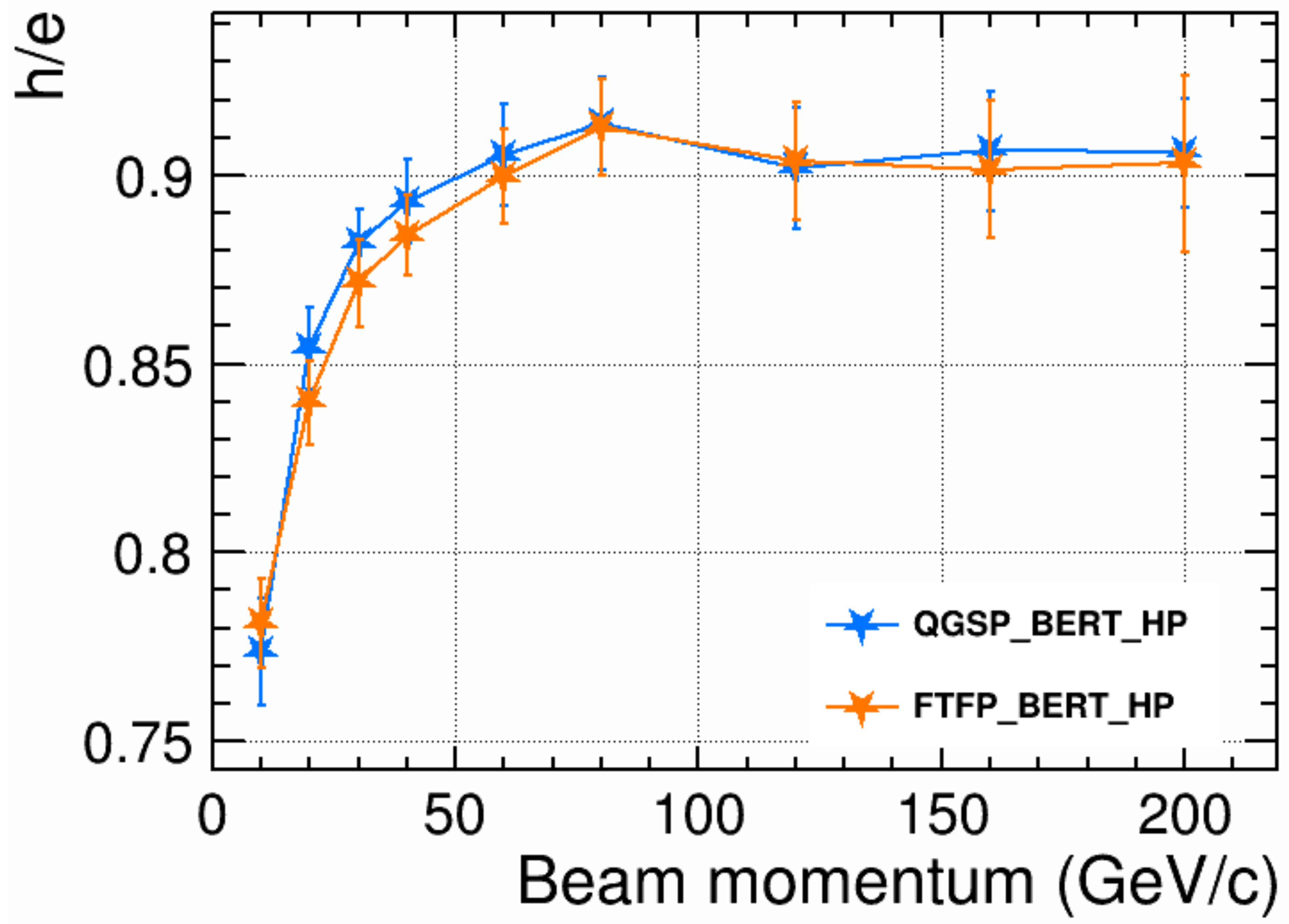
By Olin Pinto





$$E_{em}^{fit} = E_{reco} \cdot f \cdot C_{em} \qquad E_{Had}^{fit} = E_{reco} \cdot \left(1 - f\right) \cdot C_{em}$$

$$\frac{h}{e} = \frac{E_{Had}^{fit}}{E_{beam} - E_{em}^{fit}} \qquad C_{em} = EMcalibration$$



Shower Shapes In Simulation

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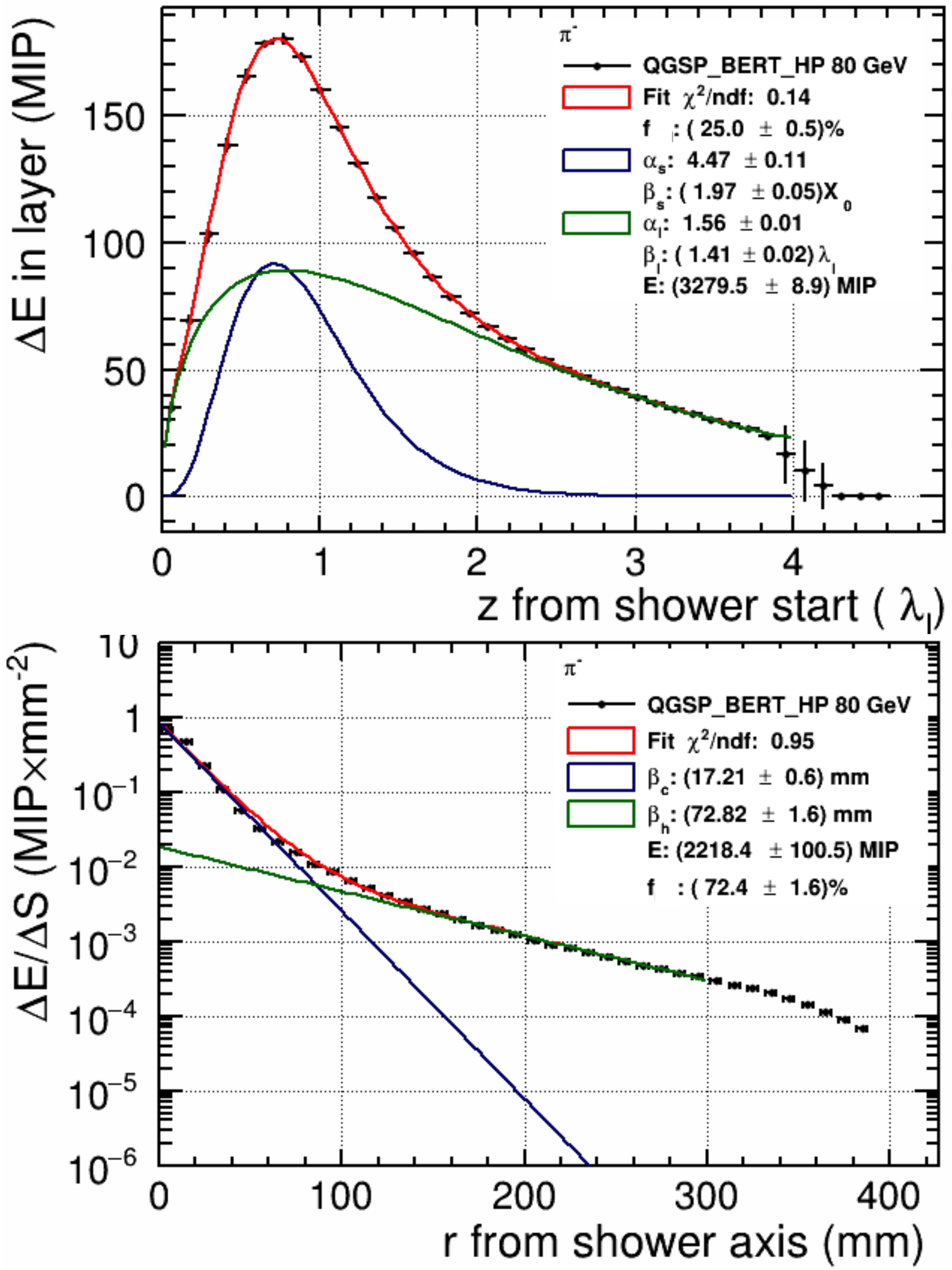


First studied in JINST 11 (2016) P06013 with physics prototype

Repeat study with large technological prototype to exploit:

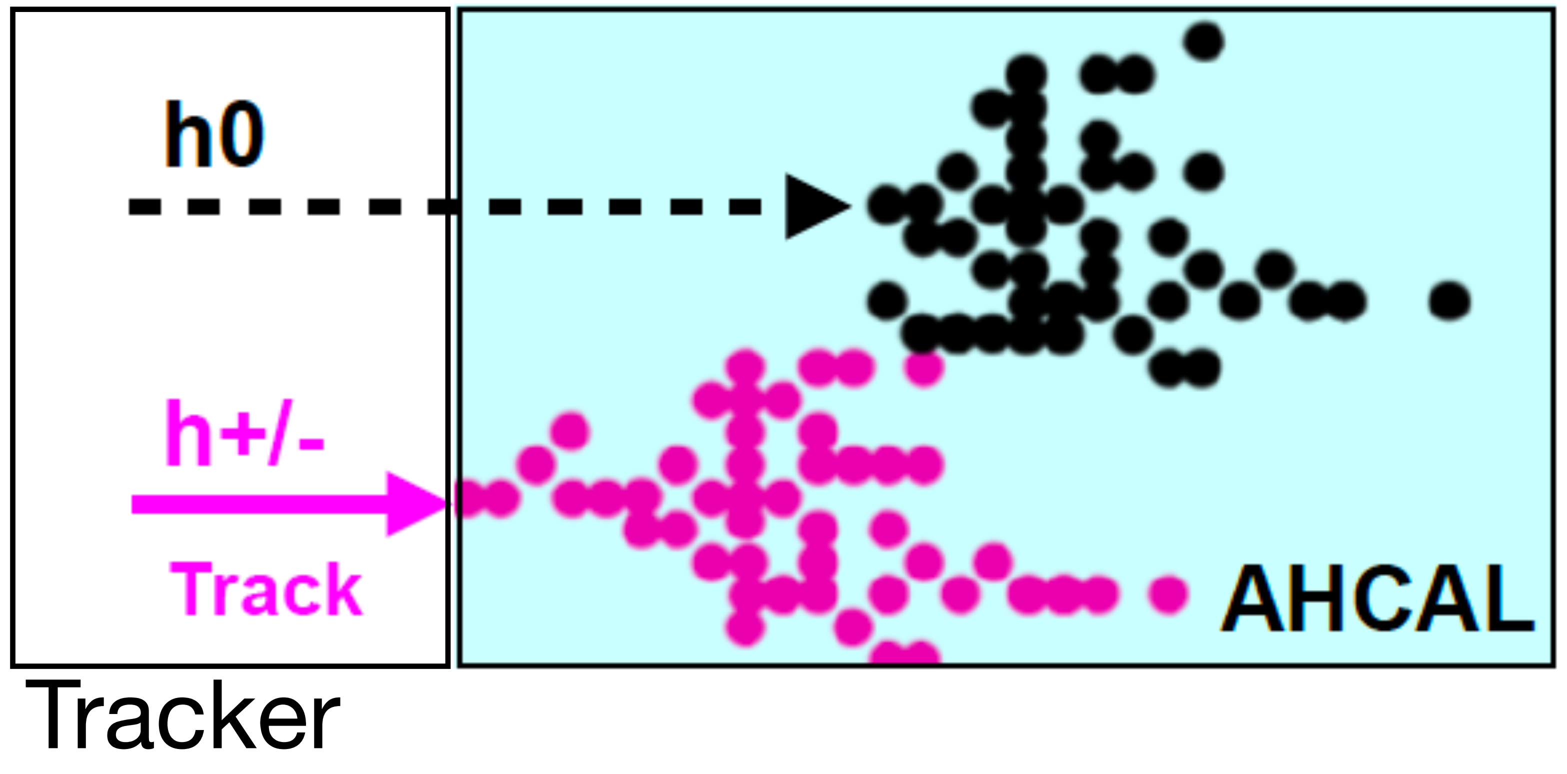
- higher spatial granularity
- noise free detector
- slightly finer longitudinal sampling

High spatial granularity enables efficient particle separation:

- Track to cluster assignment for particle flow calorimetry
- Separation and reconstruction of neutral and charged hadron showers

Ongoing study using Pandora PFA:

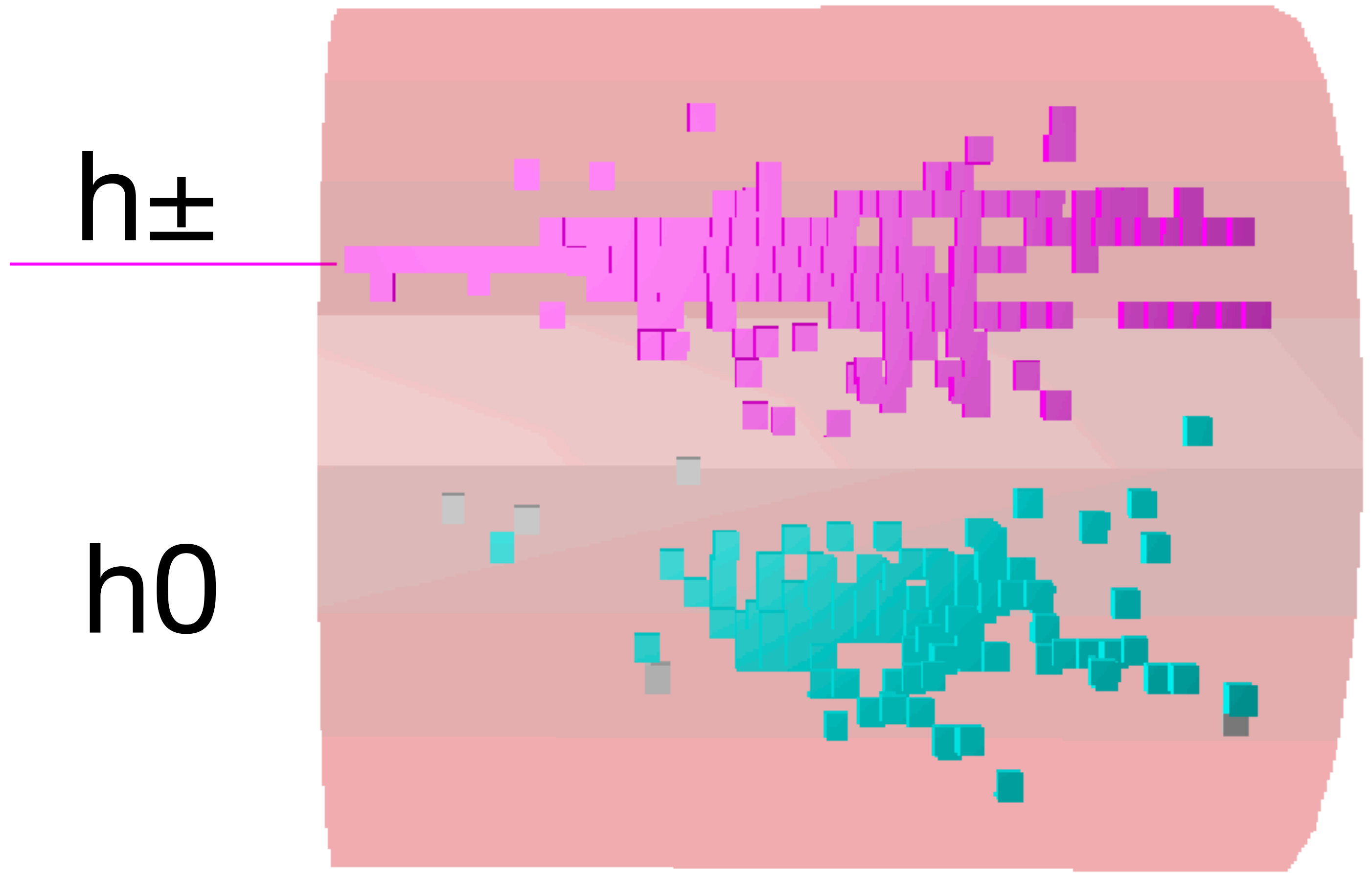
- Fake neutral hadron event by primary track removal
- Overlay with charged hadron event
- Study different shower distance and energies



By Daniel Heuchel

Particle Flow

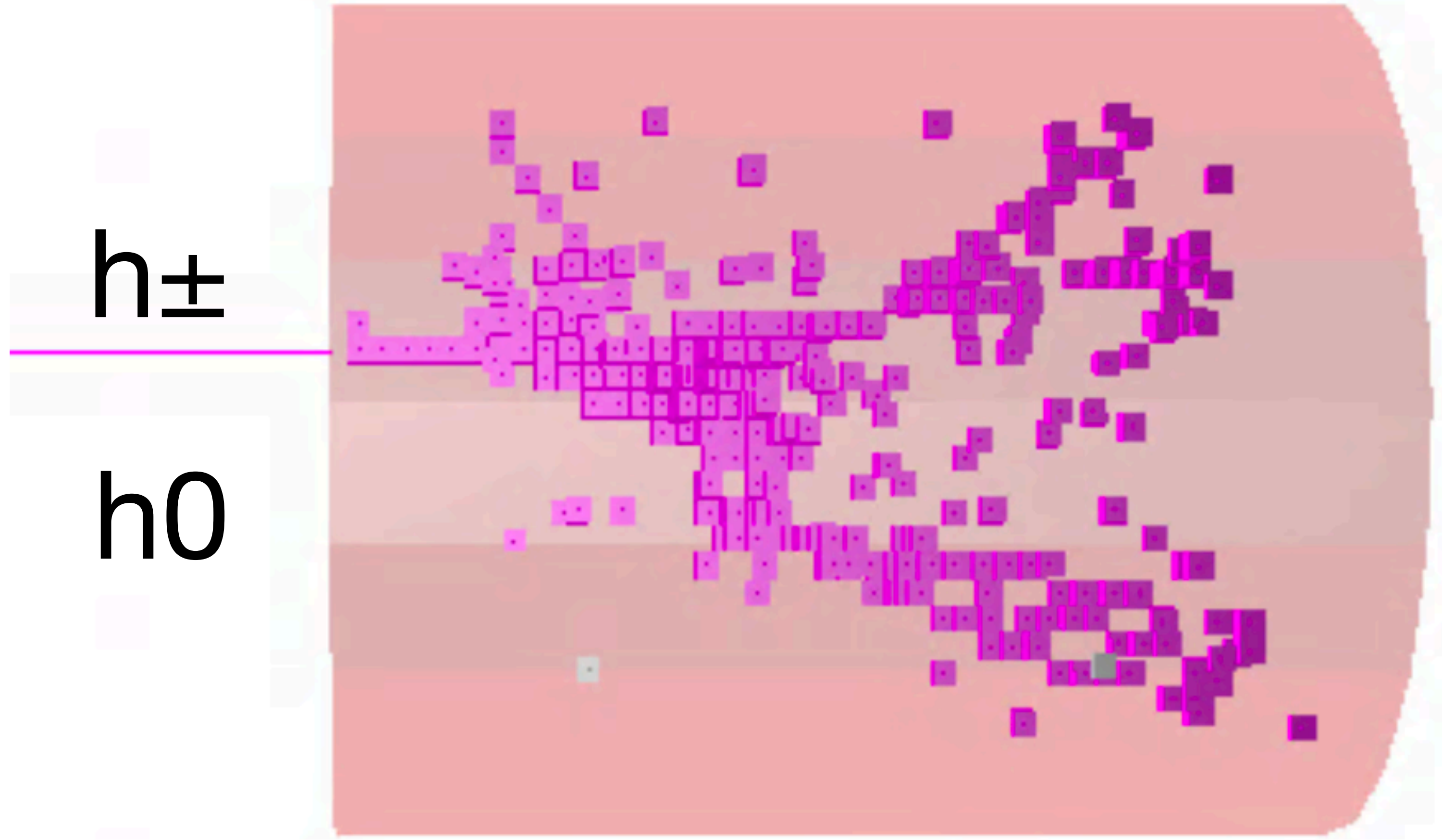
Good (majority)



10GeV h0 + 10GeV h±, 300mm distance:

- 2 separate PF objects
- Good agreement of calorimeter and PF energy
- <u>Majority of events</u>

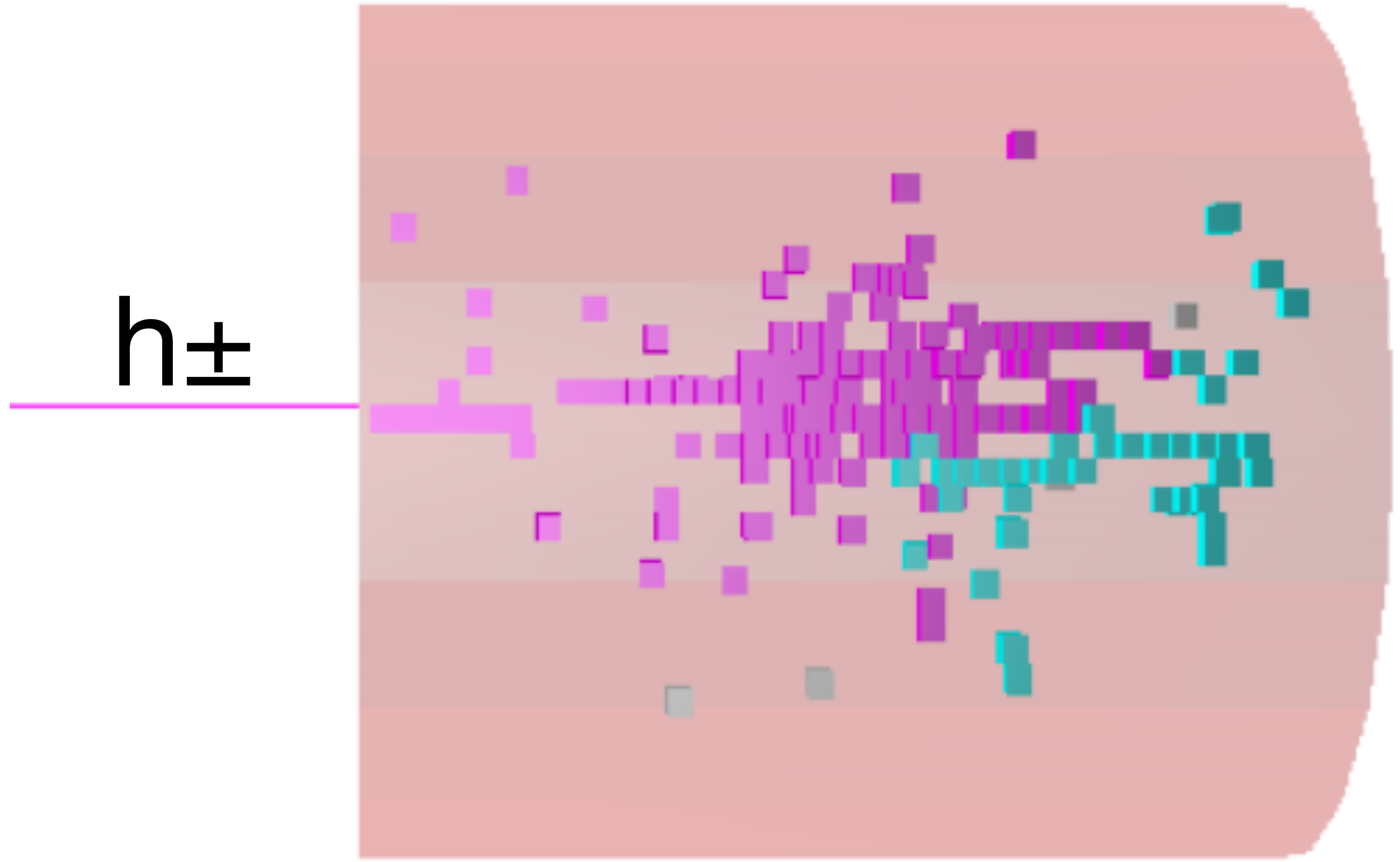
Confusion - neutral deficit



10GeV h0 + 10GeV h±, 300mm distance:

- Neutral cluster merged to charged cluster

Confusion - neutral excess



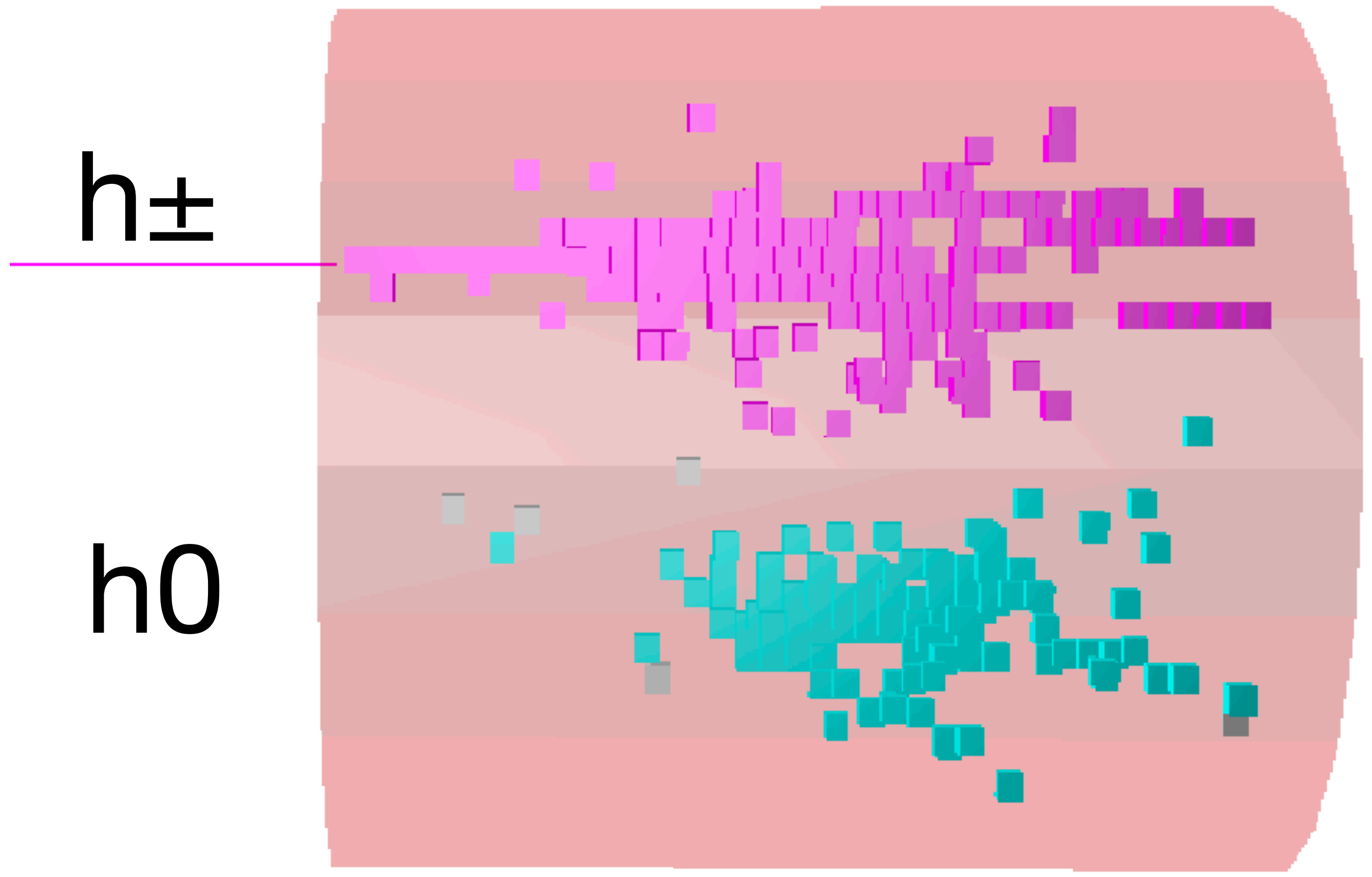
Single 30GeV h±:

- Charged track identified
- Parts of the charged cluster misidentified as neutral

By Daniel Heuchel

Particle Flow

Good (majority)



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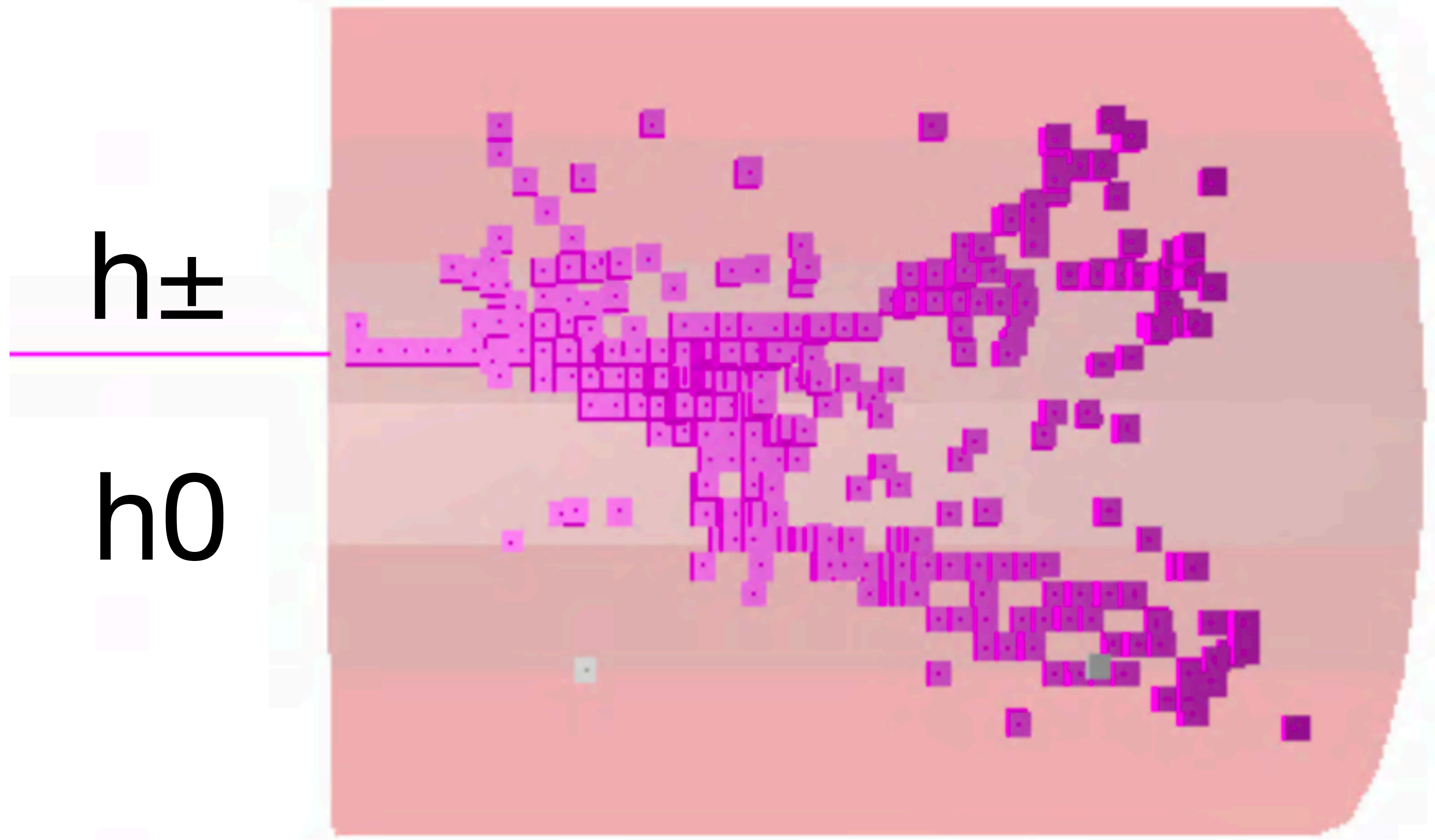

10GeV h0 + 10GeV h±, 300mm distance:

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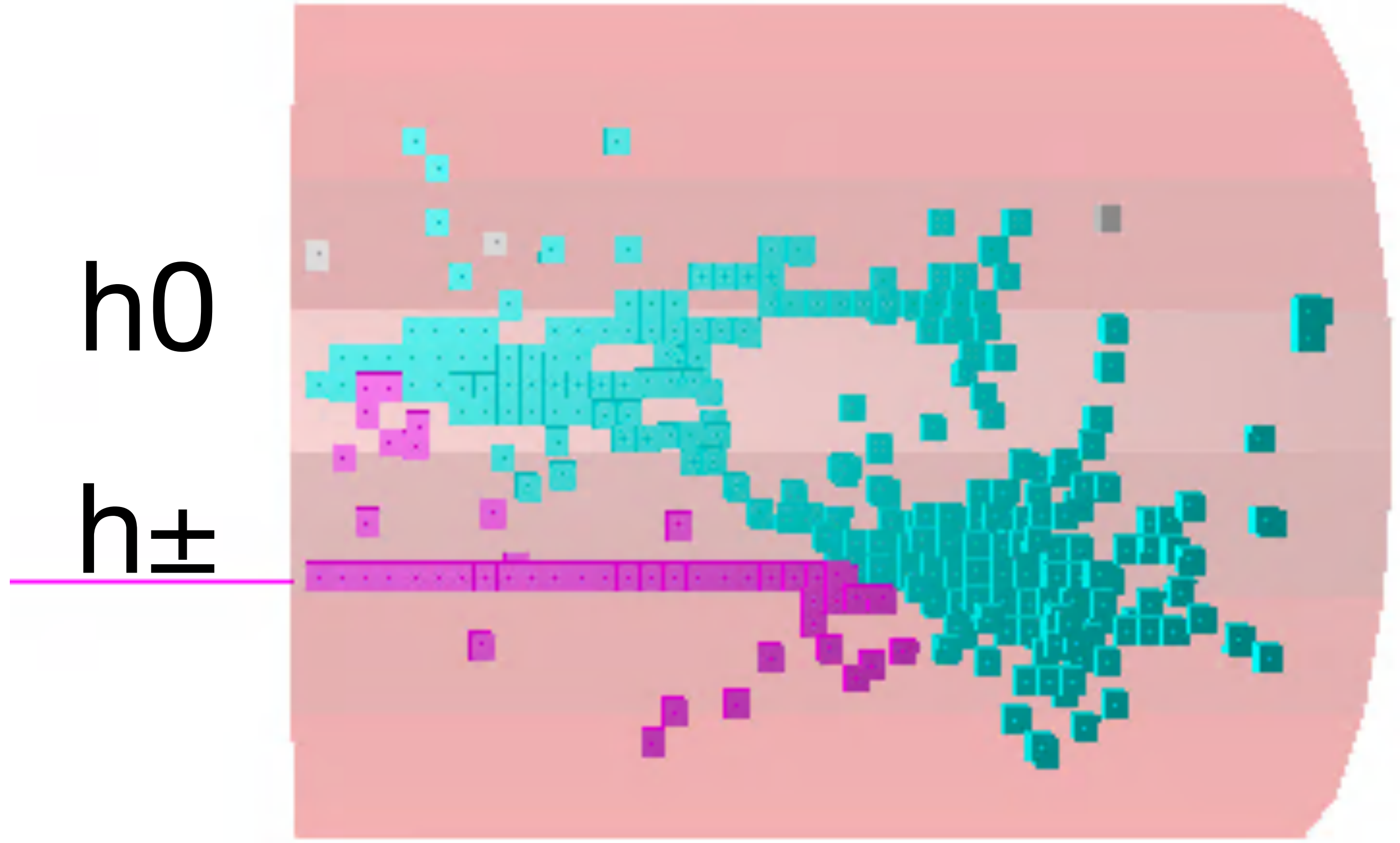

10GeV h0 + 30GeV h±, 300mm distance:

- Charged track identified
- charged cluster merged to neutral cluster
- Currently under study

By Daniel Heuchel

Timing Studies

Design goal of the technological prototype at ≦1ns for individual channels

Dedicated dataset taken at the DESY TB in 2019:

- 5 AHCAL Layers without absorber
- MIP tracks for time calibration
- Only events with chip occupancy =1

Timing Studies

Design goal of the technological prototype at ≦1ns for individual channels

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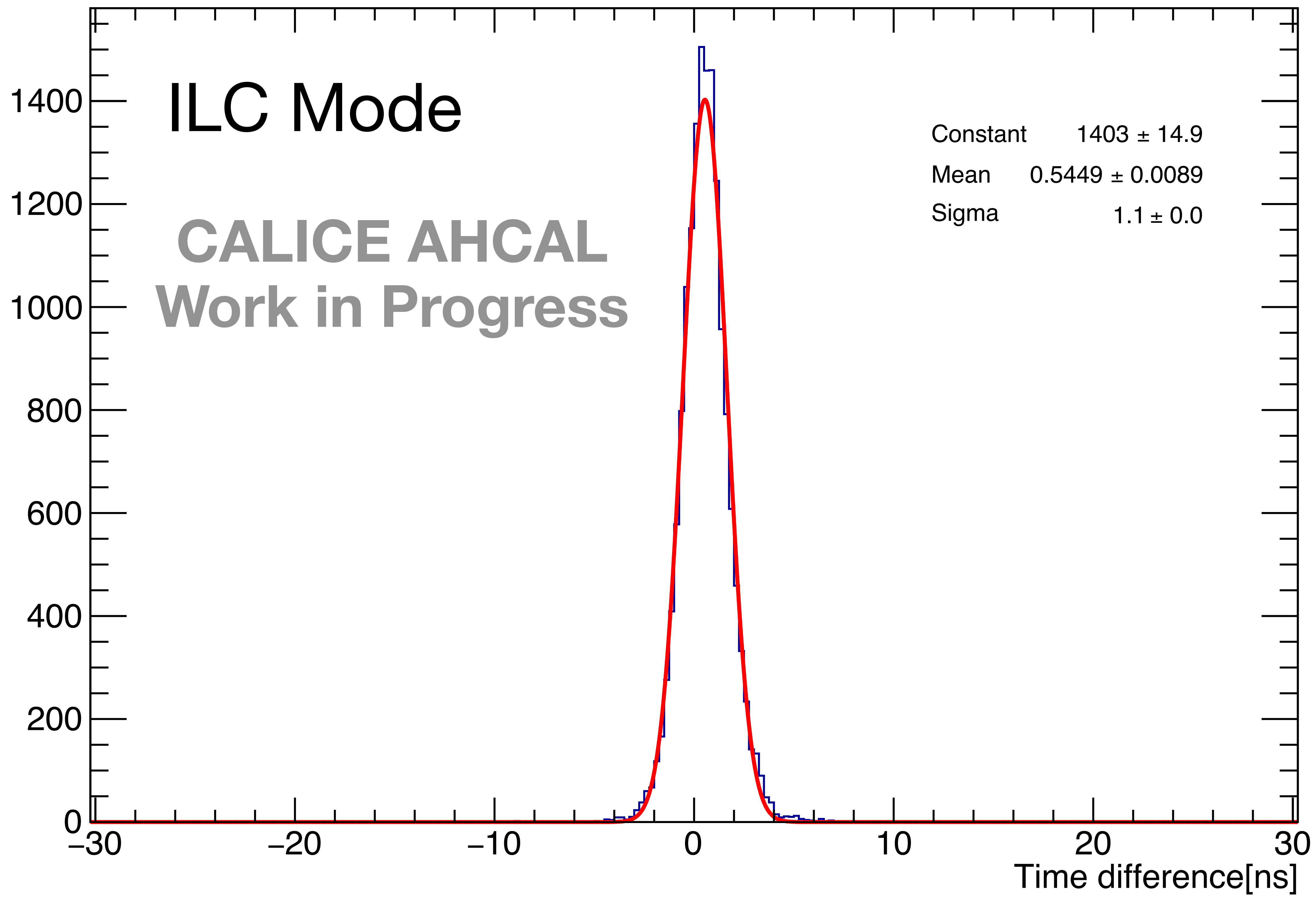
- 5 AHCAL Layers without absorber
- MIP tracks for time calibration
- Only events with chip occupancy =1

Time difference of adjacent layers to suppress trigger resolution



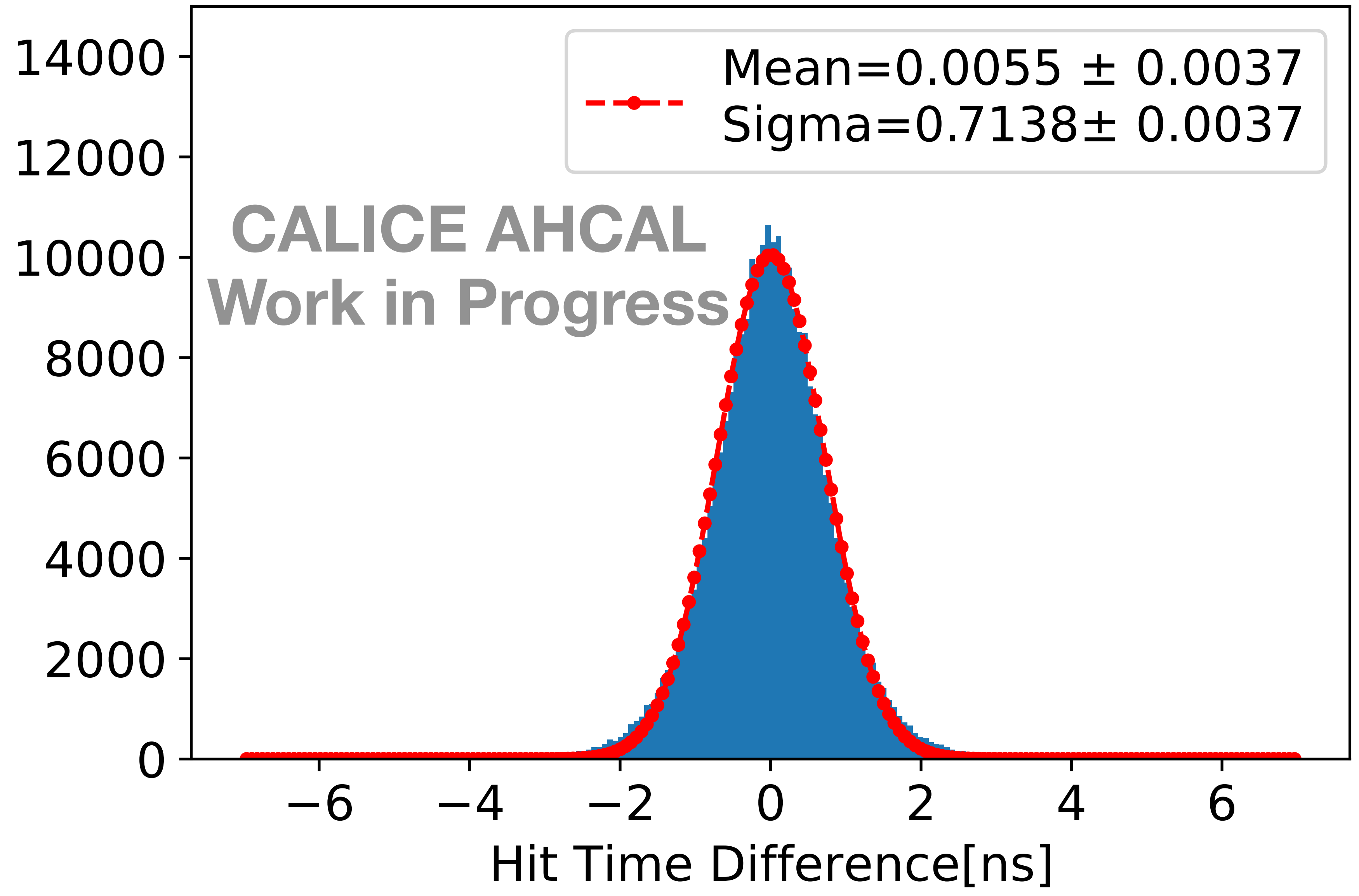
Single channel resolution: 1.1/√2 = 0.78ns

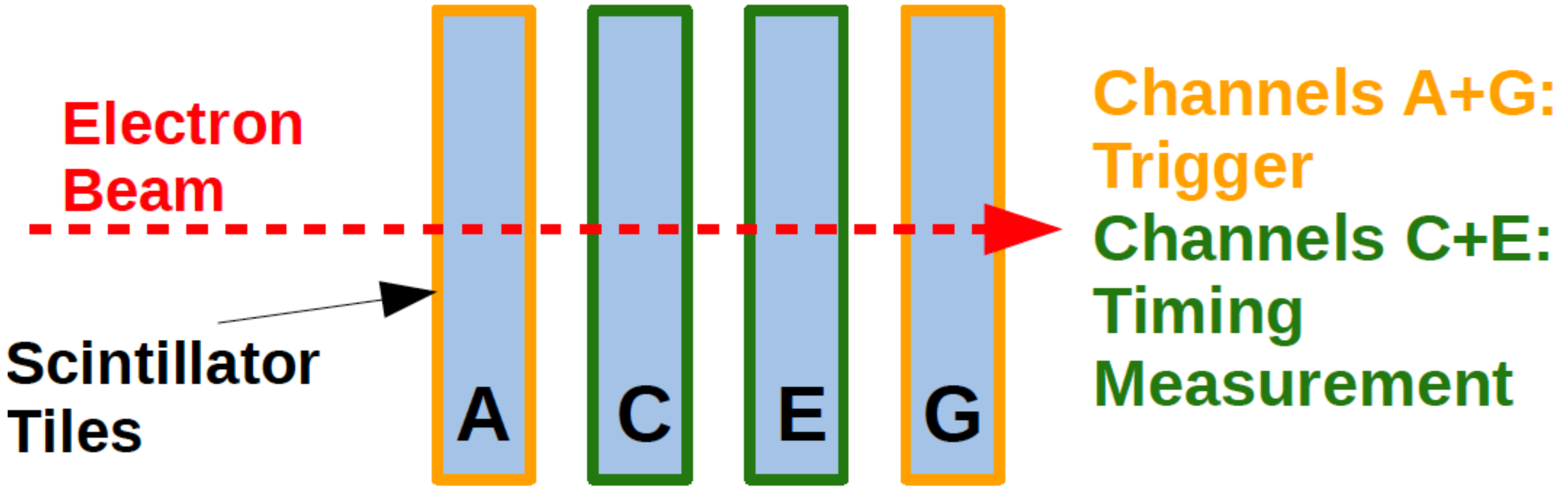
The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

Timing Studies

Separate dedicated beam test in 2020 at DESY:

- Beam telescope-like setup, 2.5GHz sampling
- Study intrinsic time resolution of SiPM-on-Tile
- Same SiPM but independent of AHCAL front end





Time resolution=0.714/sqrt(2)=0.507ns

- Interpret as intrinsic time resolution of SiPM-on-Tile

Compared to 0.780ns of the AHCAL:

- AHCAL front-end contributes ~0.6ns

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

Conclusion and Outlook

Very smooth and successful data taking in 2018 at the SPS

High level analyses in full swing:

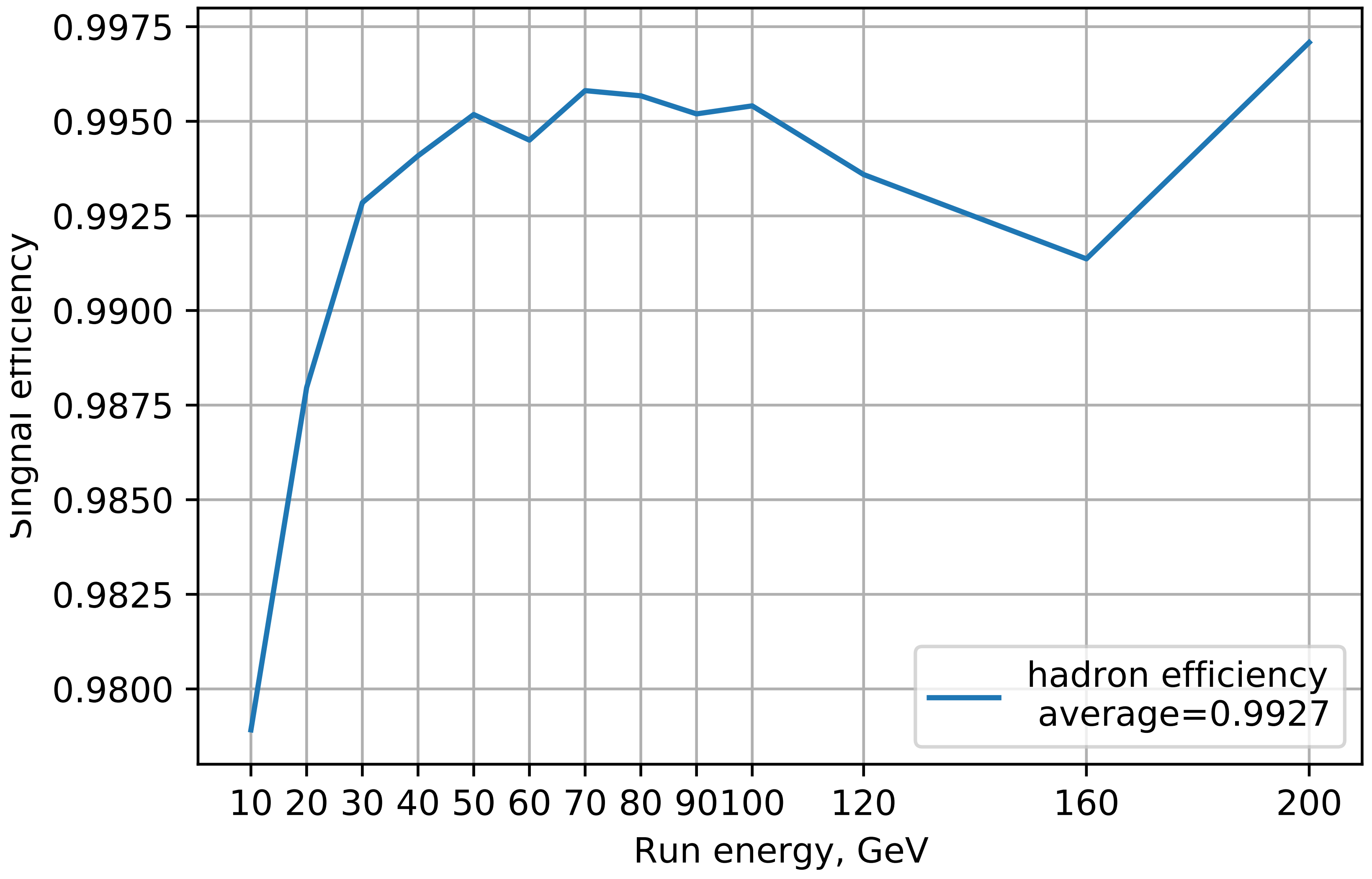
- Very good particle identification with Boosted Decision Tree
- Hadronic shower decomposition in core and halo:
    - Redo analysis from previous prototype, exploit features of technological prototype
- Particle separation with Pandora PFA ongoing:
    - Particle separation possible, problematic cases identified

Reached the design time resolution of ≦1ns*

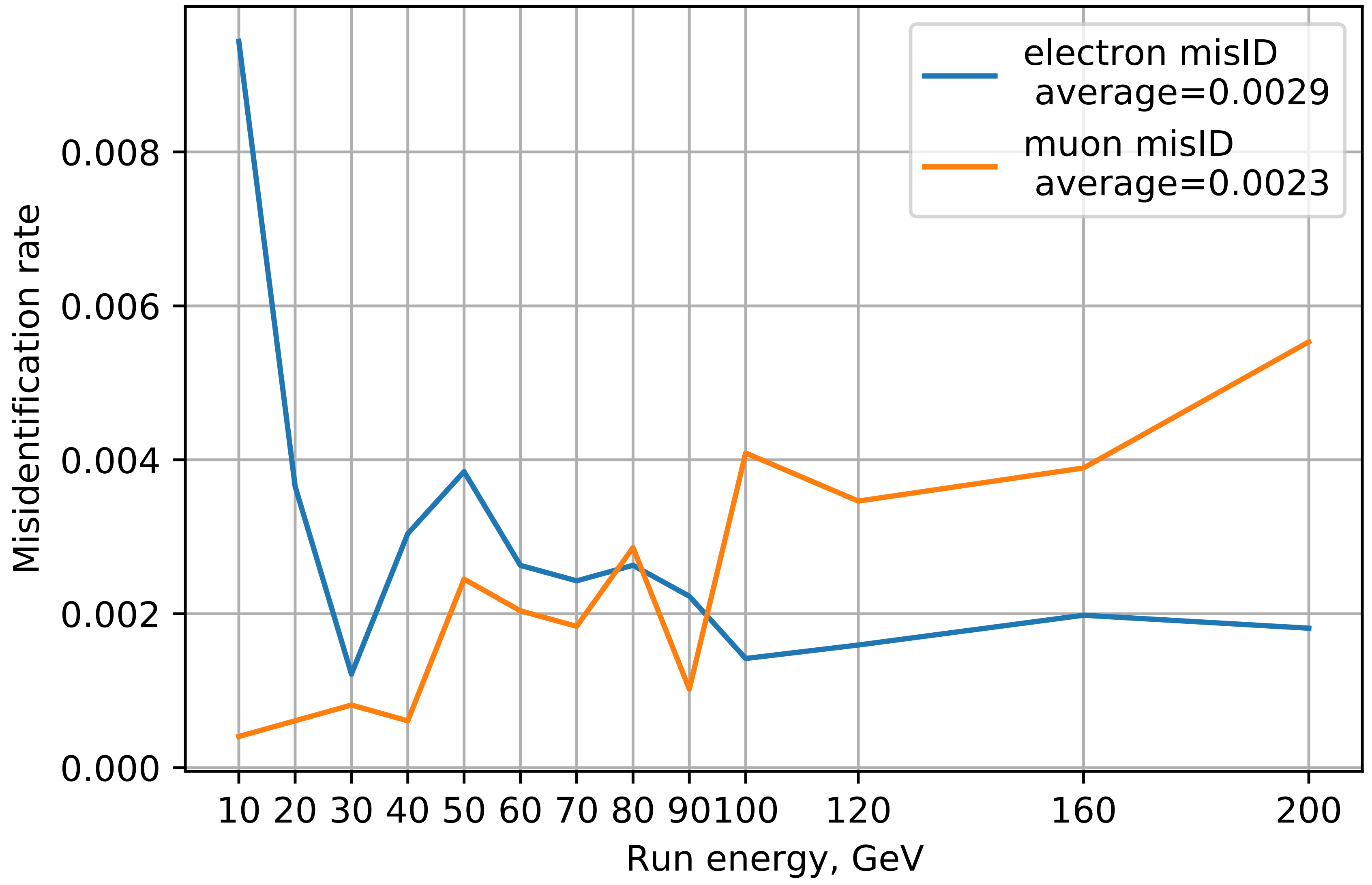
**The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)*

Backup

PID

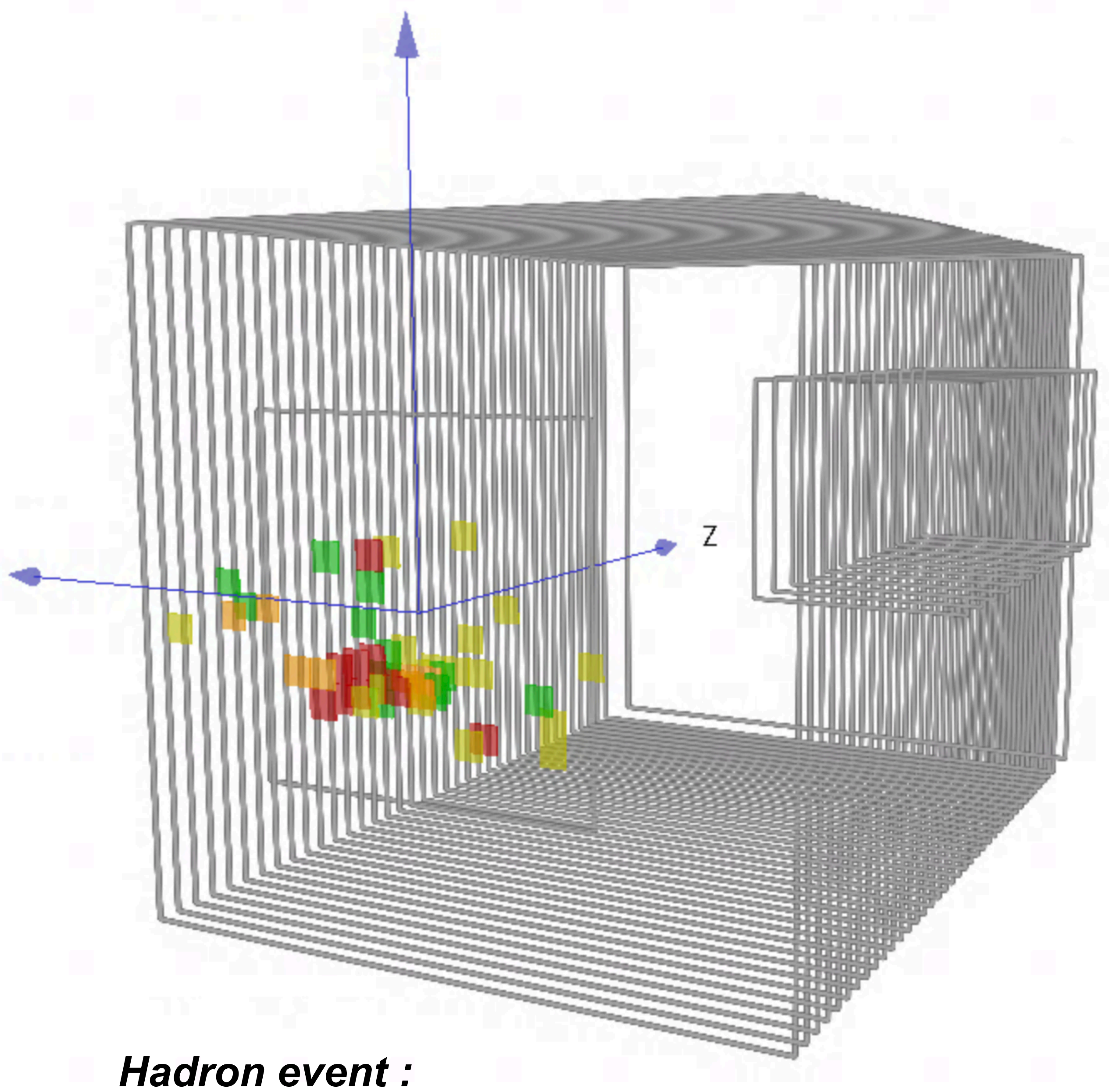


Signal efficiency
0.9975
0.9950
0.9925
0.9900
0.9875
0.9850
0.9825
0.9800
hadron efficiency
average=0.9927
10 20 30 40 50 60 70 80 90100 120 160 200
Run energy, GeV

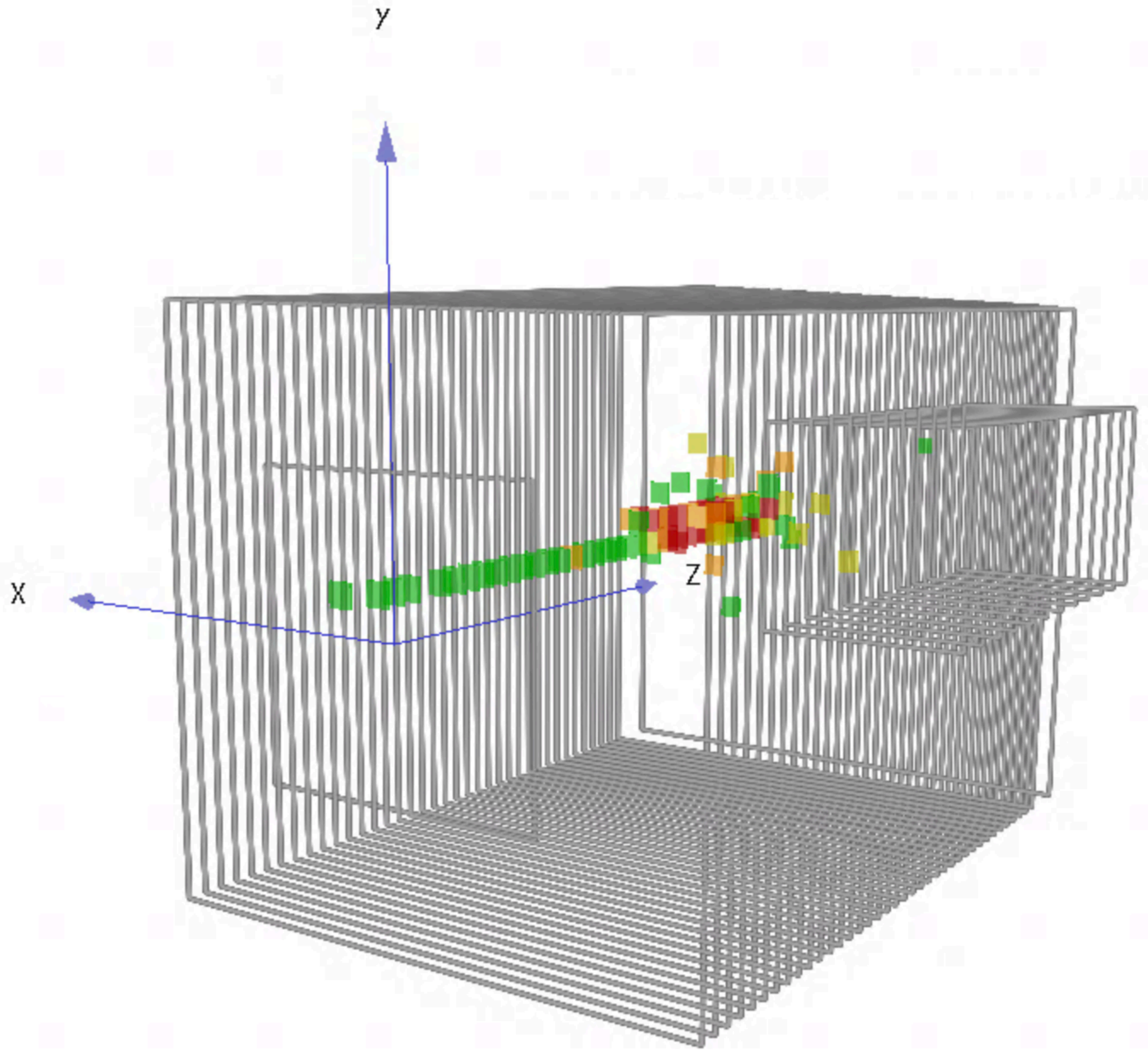


Misidentification rate
0.008
0.006
0.004
0.002
0.000
electron misID
average=0.0029
muon misID
average=0.0023
10 20 30 40 50 60 70 80 90100 120 160 200
Run energy, GeV

PID

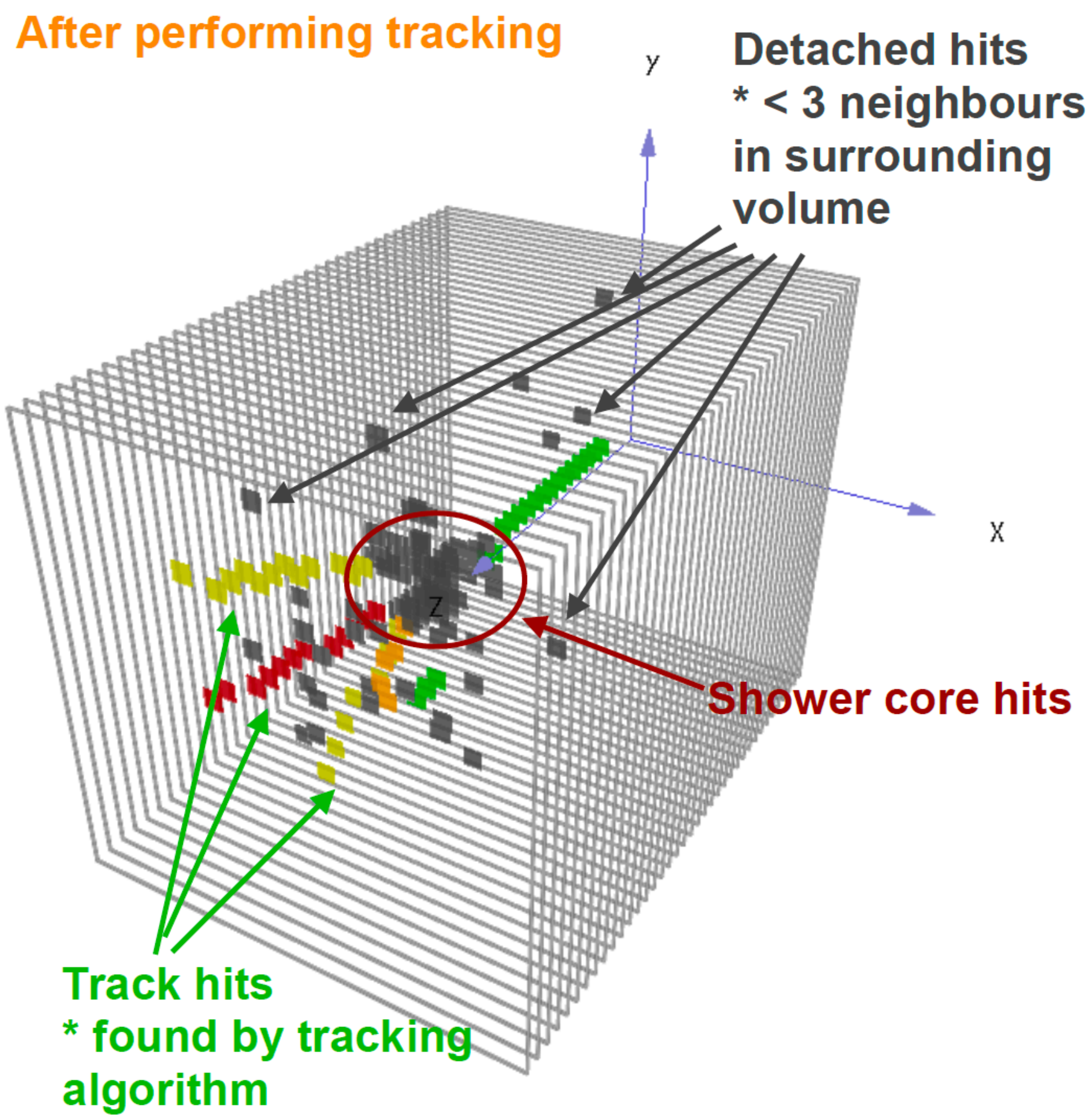


Hadron event :
Had score is ~0.9



Muon-like event :
Mu-like score is 0.51
Had score is 0.48

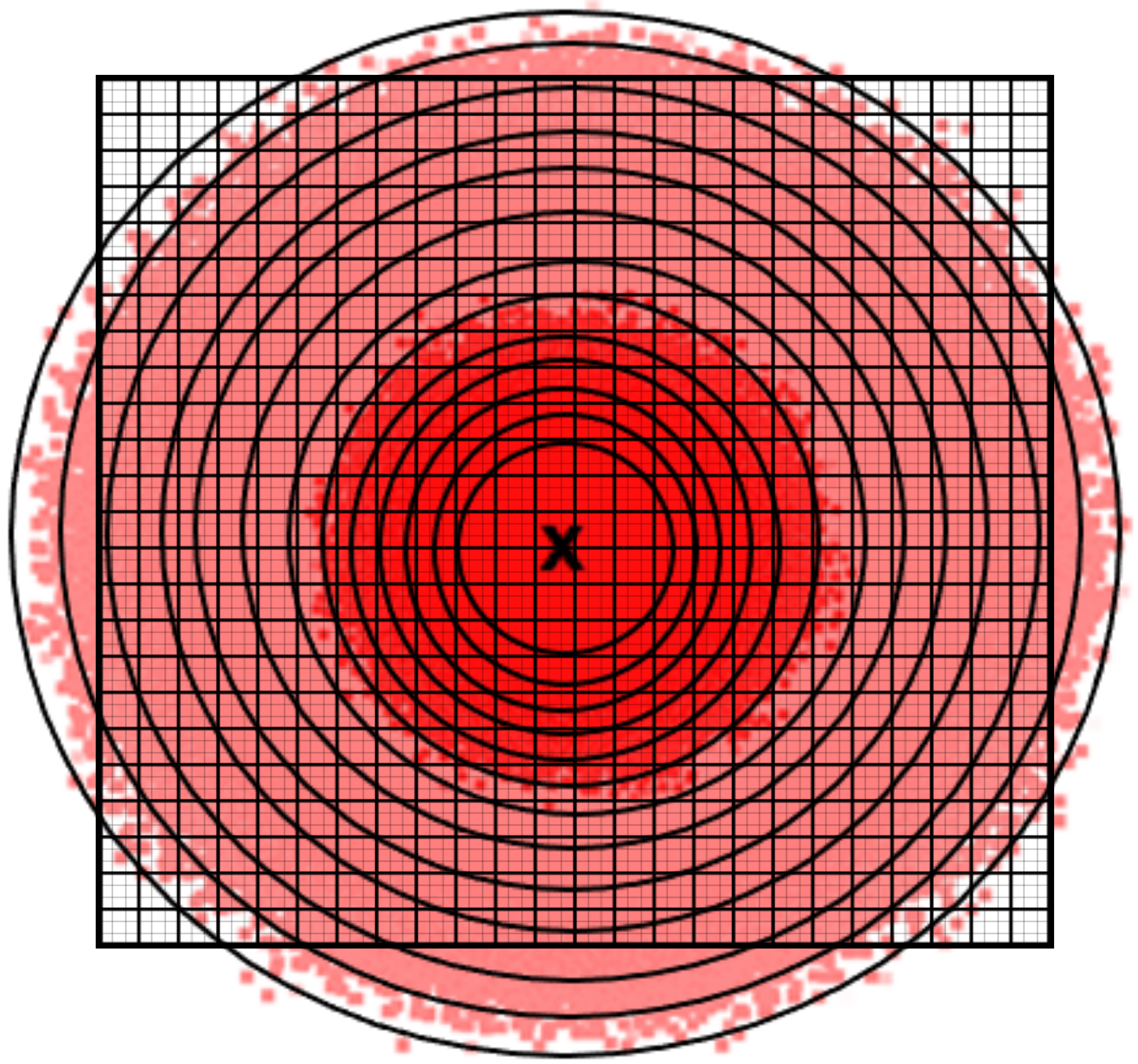
PID



After performing tracking
y
Detached hits
* < 3 neighbours
in surrounding
volume
X
Z
Shower core hits
Track hits
* found by tracking
algorithm

Virtual Cells

- To analyse the radial shower profile, finer width is chosen
- All physical AHCAL cells (30×30 mm²) are subdivided into virtual cells of 10×10 mm²
- In this method, the energy deposited in the physical cells is equally distributed over the virtual cells covering its area



Timing Setup

Stack of 4 Tiles:

- BC408 or Polystyrene (AHCAL)
- Hamamatsu S13360-1325PE

↓ **Ethernet Cat 7**

Receiver Box:

- USB controlled power supply
- Split signal and power lines

↓ **BNC**

Picoscope:

- Up to 2.5GHz sampling rate on 4 channels
- 300kHz peak trigger rate
- Save complete analog waveform