CALICE Digital Hadron Calorimeter: Calibration and Response to Pions and Positrons

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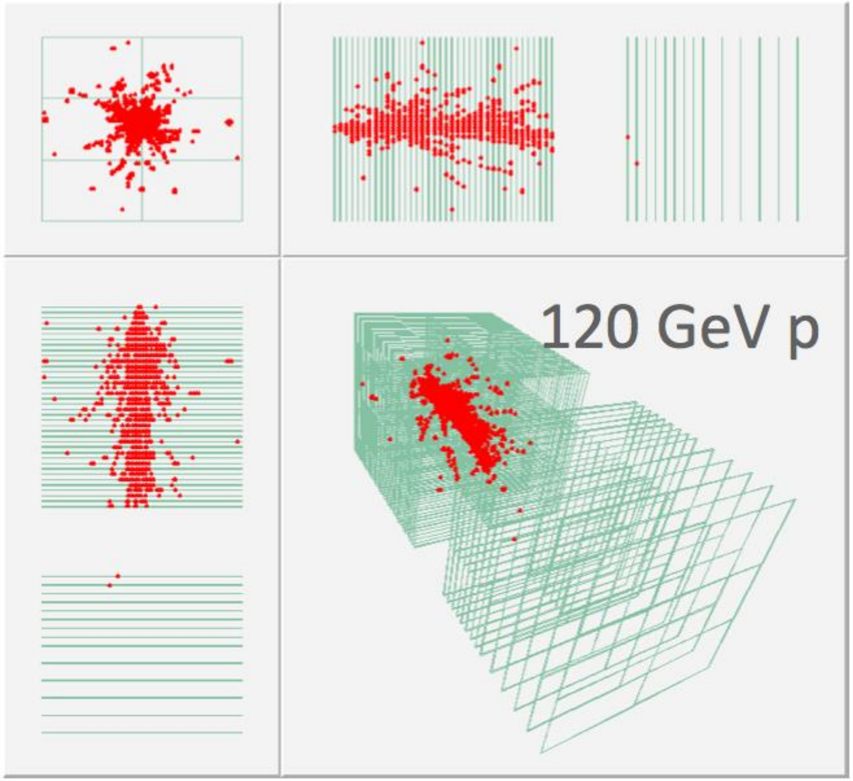
Digital Hadron Calorimeter (DHCAL)

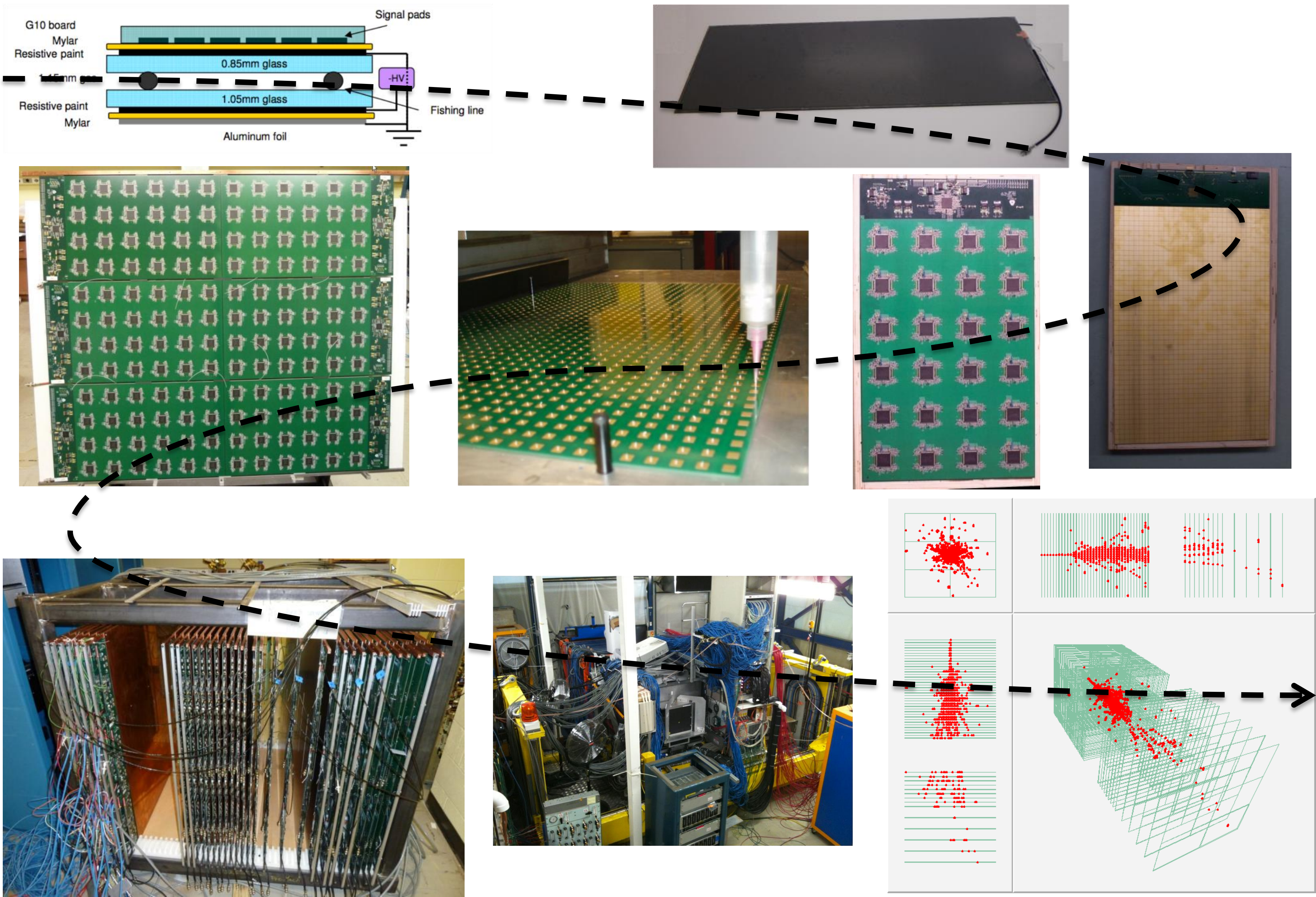
Concept of the DHCAL

- Imaging hadron calorimeter optimized for use with PFA
- 1-bit (digital) readout
- 1 x 1 cm^2 pads read out individually (embedded into calorimeter!)
- Resistive Plate Chambers (RPCs) as active elements, between steel/tungsten

- Each layer with an area of ~ 1 x 1 m^2 is read out by 96 x 96 pads.
- The DHCAL prototype has up to 54 layers including the tail catcher (TCMT) ~ 0.5 M readout channels (world record in calorimetry!)



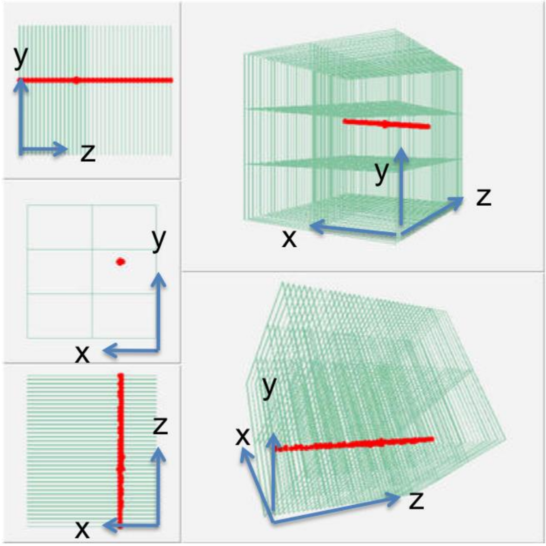
DHCAL Construction



DHCAL Data

Muon Trigger:
2 x (1 m x 1 m scintillator)

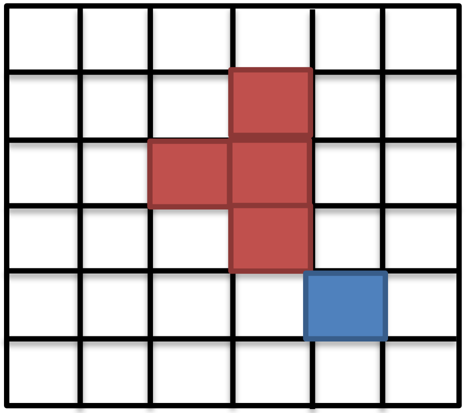
Secondary Beam Trigger:
2 x (20 cm x 20 cm scintillator)



Nearest neighbor clustering in each layer

Event

Particle ID: Čerenkov/μ tagger bits
Hit: x, y, z, time stamp



Cluster: x, y, z

Calibration/Performance Parameters

Efficiency (ε) and pad multiplicity (μ)

Track Fits:

- specifically for muon calibration runs
- Identify a muon track that traverse the stack with no identified interaction
- Measure all layers

Track Segment Fits:

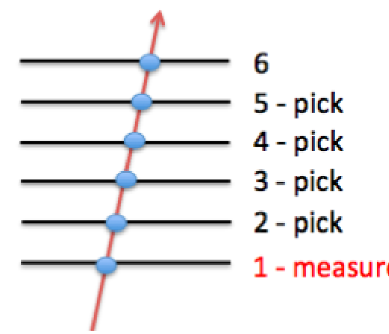
- for online calibration
- Identify a track segment of four layers with aligned clusters within 3 cm
- Measure only one layer (if possible)

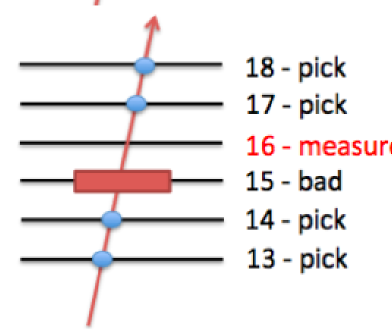
- Fit to the parametric line: $x=x_0+a_xt$; $y=y_0+a_yt$; $z=t$

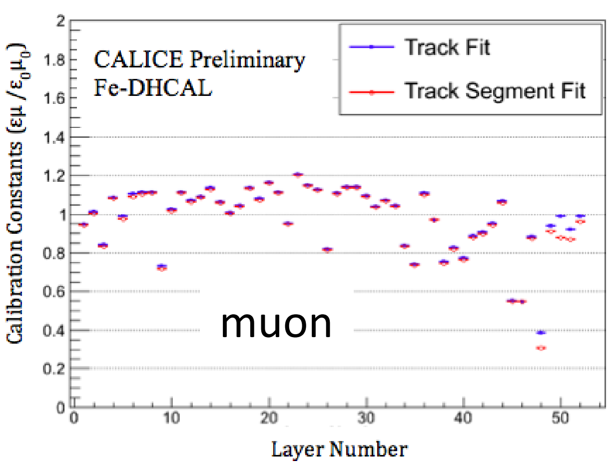
A cluster is found in the measurement layer within 2 cm of the fit point?

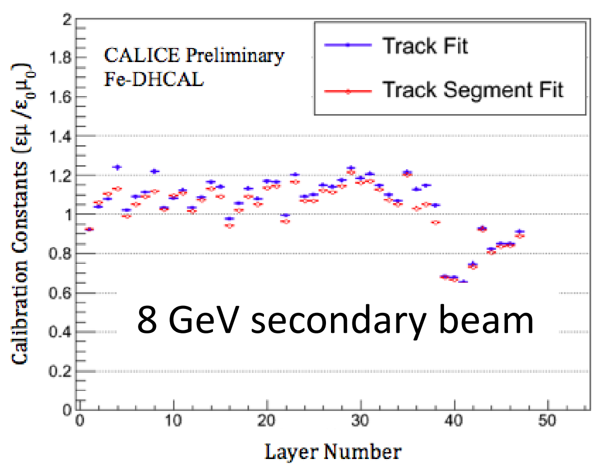
Yes → $\varepsilon=1$, μ=size of the found cluster

No → $\varepsilon=0$, No μ measurement

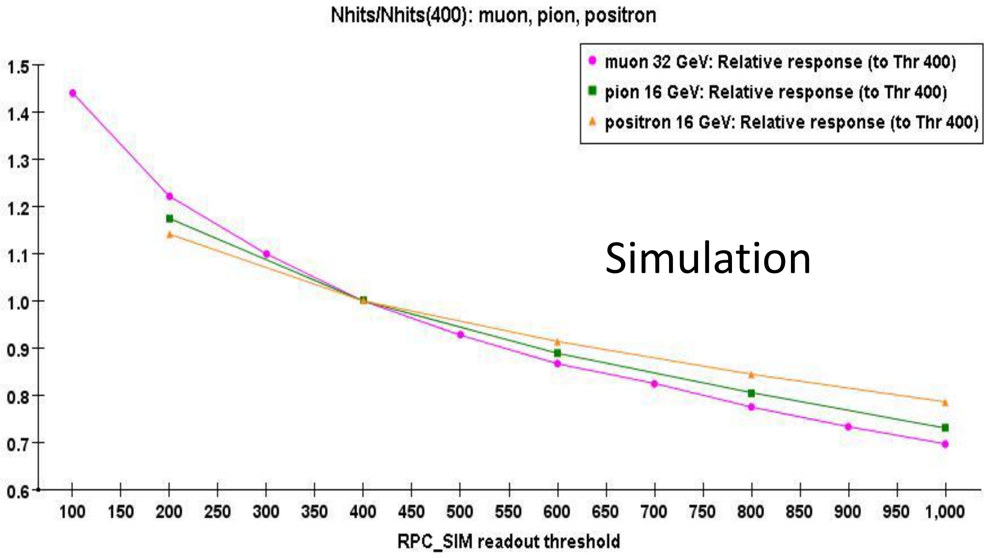








Calibration of the DHCAL



RPC performance

Efficiency to detect MIP ε ~ 96%
Average pad multiplicity μ~ 1.6
Calibration factors C = εμ

Equalize response to MIPS (muons)

$$H_{calibrated} = \sum_{i=RPC_0}^{RPC_n} \frac{\varepsilon_0 \mu_0}{\varepsilon_i \mu_i} H_i$$

Full calibration

H_i … Number of hits in RPC_i

Calibration for secondary beam (p, $\pi^{\pm}$,$e^{\pm}$)

If more than 1 particle contributes to signal of a given pad
→ Pad will fire, even if efficiency is low
→ Full calibration will overcorrect

More sophisticated schemes

Calibration Procedures

1. Full Calibration

$$H_{calibrated} = \sum_{i=RPC_0}^{RPC_n} \frac{\varepsilon_0 \mu_0}{\varepsilon_i \mu_i} H_i$$

H_i … Number of hits in RPC_i

2. Density-weighted Calibration:

Developed due to the fact that a pad will fire if it gets contribution from multiple traversing particles regardless of the efficiency of this RPC. Hence, the full calibration will overcorrect. Classifies hits in density bins (number of neighbors in a 3 x 3 array).

3. Hybrid Calibration:

Density bins 0 and 1 receive full calibration.

Density-weighted Calibration Overview

Warning:
This is rather
COMPLICATED

Derived entirely based on Monte Carlo

Assumes correlation between

Density of hits ↔ Number of particles contributing to signal of a pad

Mimics different operating conditions with

Different thresholds T

Utilizes the fact that hits generated with the

Same GEANT4 file, but different operating conditions can be correlated

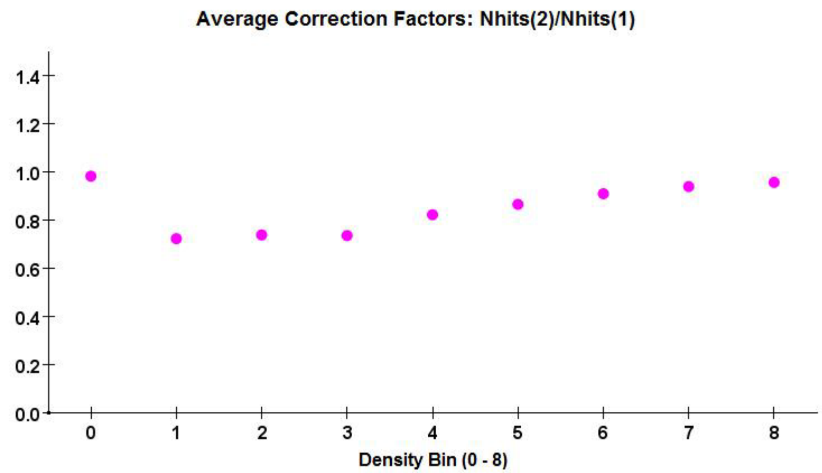
Defines density bin for each hit in a 3 x 3 array

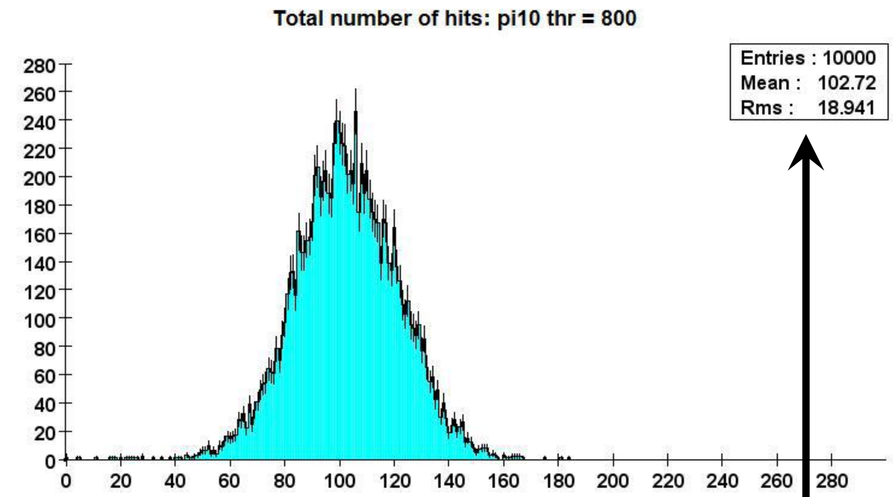
Bin 0 – 0 neighbors, bin 1 – 1 neighbor …. Bin 8 – 8 neighbors

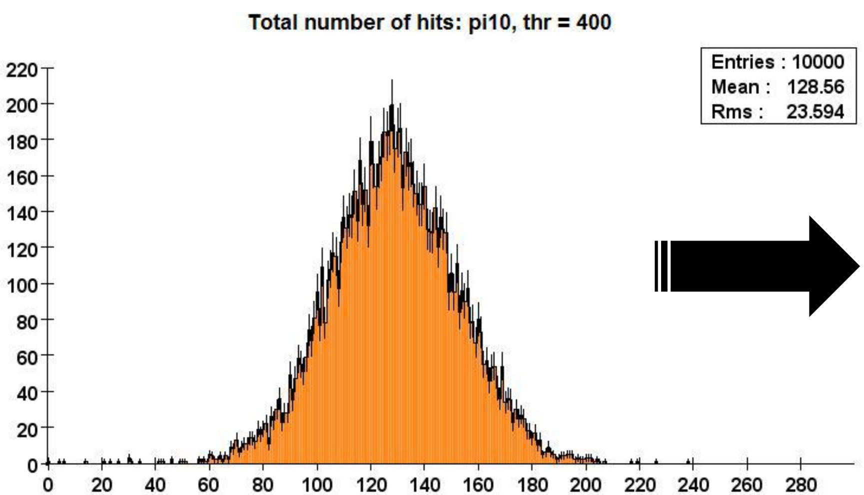
Weighs each hit

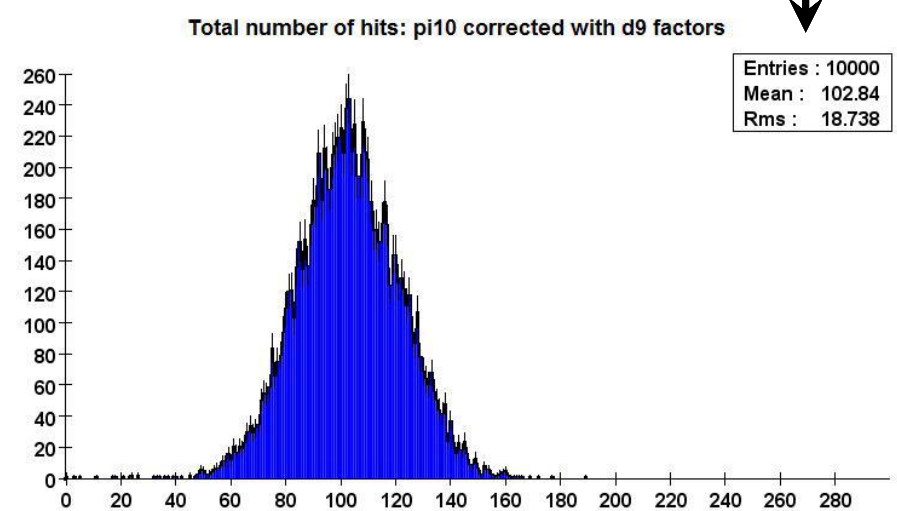
To restore desired density distribution of hits

Density-weighted Calibration Example: 10 GeV pions: Correction from T=400→ T=800









Mean response and the resolution reproduced.
Similar results for all energies.

Density-weighted Calibration: Expanding technique to large range of performance parameters

GEANT4 files

Positrons: 2, 4, 10, 16, 20, 25, 40, 80 GeV
Pions: 2, 4, 8, 10, 10, 25, 40, 80 GeV

Digitization with RPC_sim

Thresholds of 200, 400, 600, 800, 1000 (~ x 1fC)

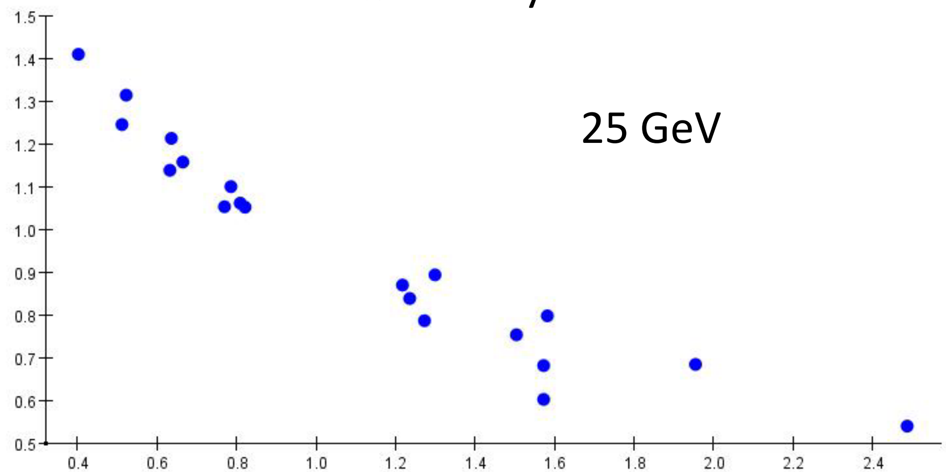
Calculate correction factors (C)

- for each density bin separately
- as a function of ε_i, μ_i, ε_0 and μ_0 (i : RPC index)

Plot C as a function of $R = (\varepsilon_i\mu_i)/(\varepsilon_0\mu_0)$

→ Some scattering of the points, need a more sophisticated description of dependence of calibration factor on detector performance parameters

π: Density bin 3



$R = (\varepsilon_i\mu_i)/(\varepsilon_0\mu_0)$

Only very weak dependence on energy:
Common calibration factor for all energies!

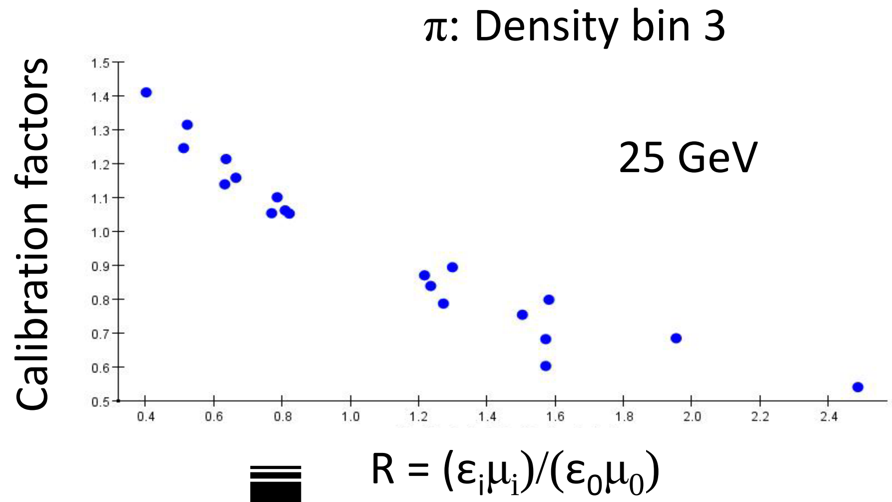
Density-weighted Calibration: Empirical Function of ε_i, μ_i, ε_0, μ_0

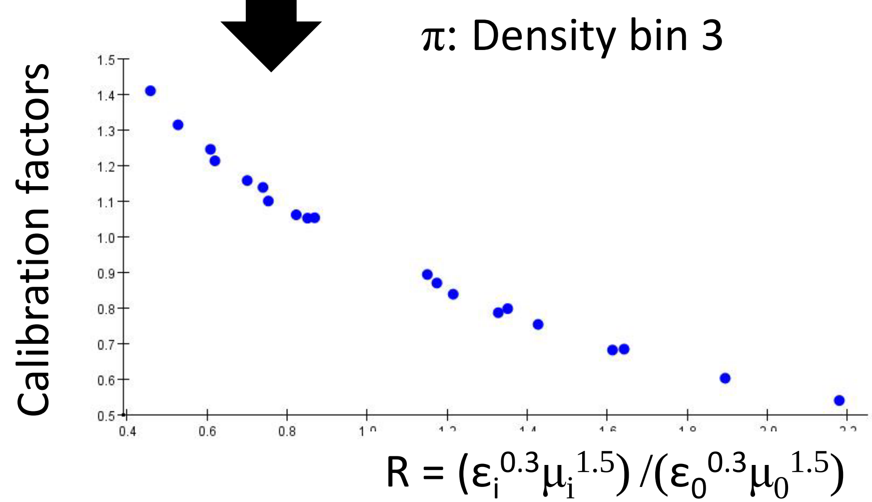
Positrons

$$R_e = \frac{e_i^{0.3} m_i^{2.0}}{e_0^{0.3} m_0^{2.0}}$$

Pions

$$R_p = \frac{e_i^{0.3} m_i^{1.5}}{e_0^{0.3} m_0^{1.5}}$$



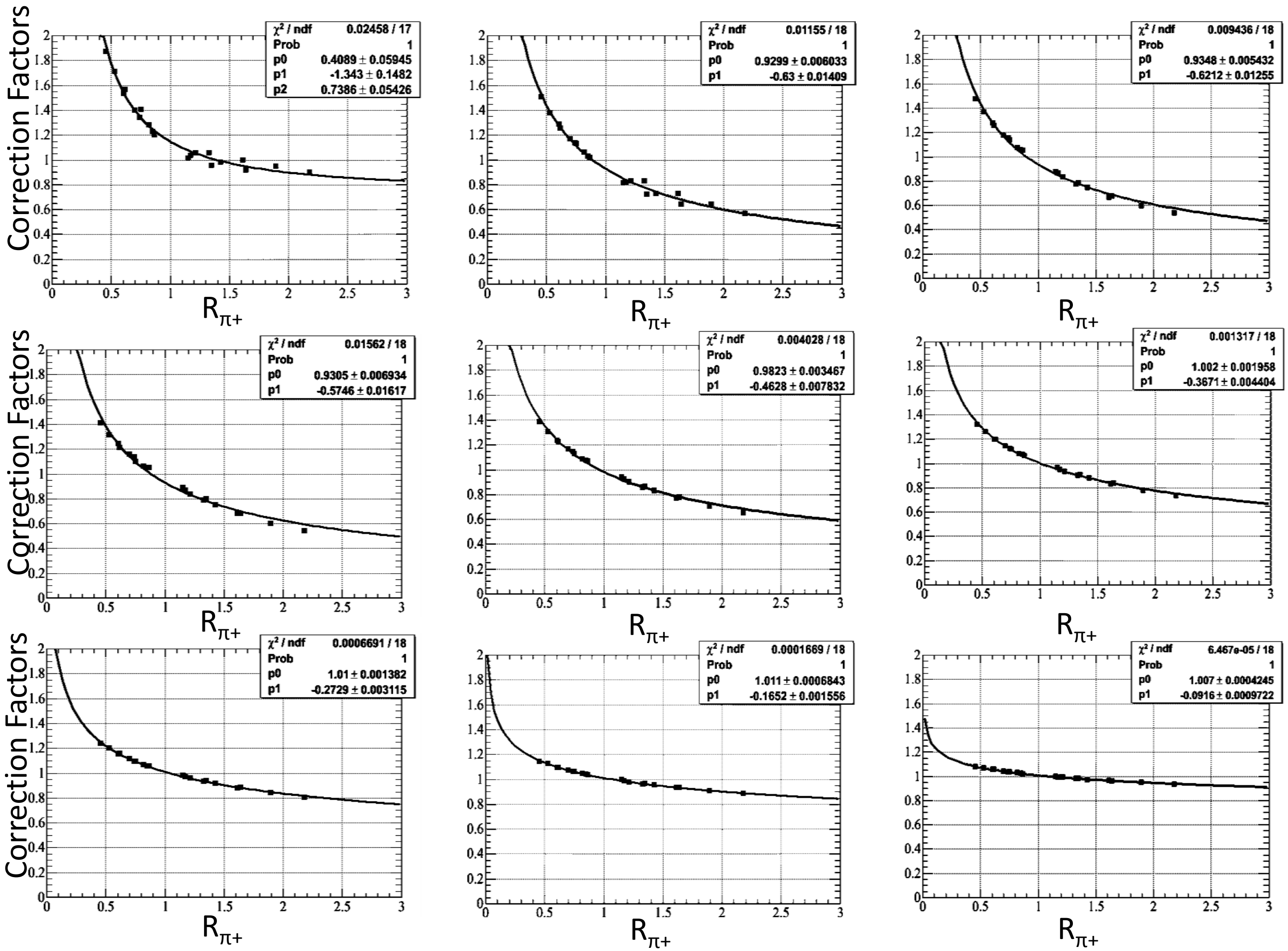


Functional dependence of calibration factors depends on particle type!
(Due to different shower topologies: Different density distribution leads to different impact of performance)

Density-weighted Calibration: Fits of Correction Factors as a Function of R

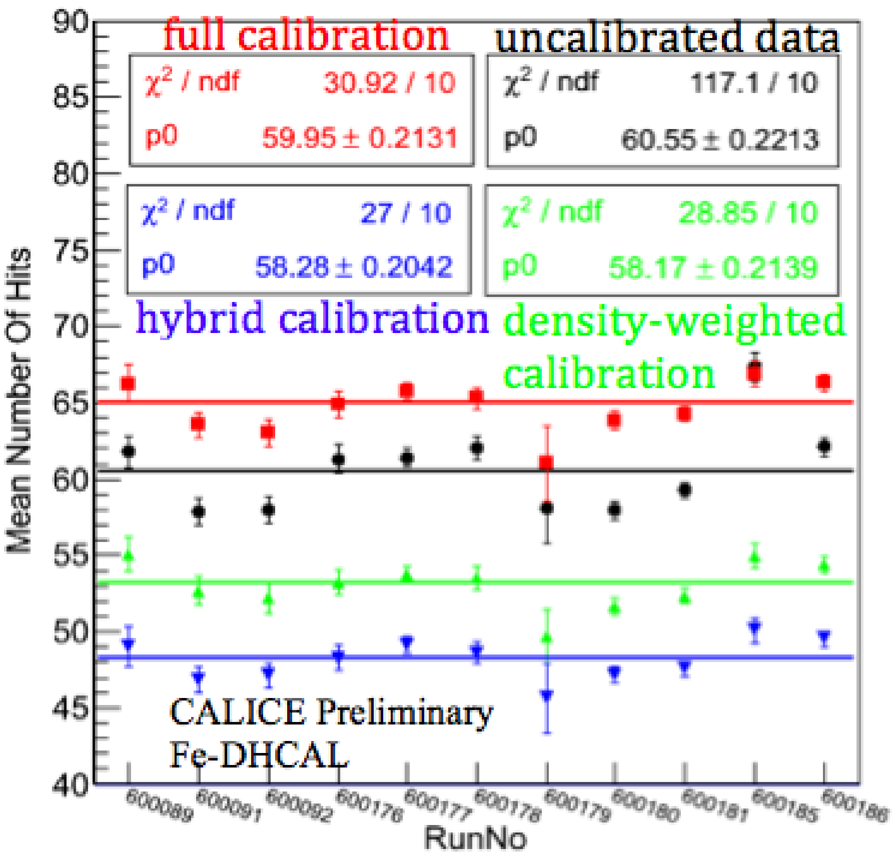
Power law $C = aR_p^b$

Fit results for p=pion, similar results for p=positron

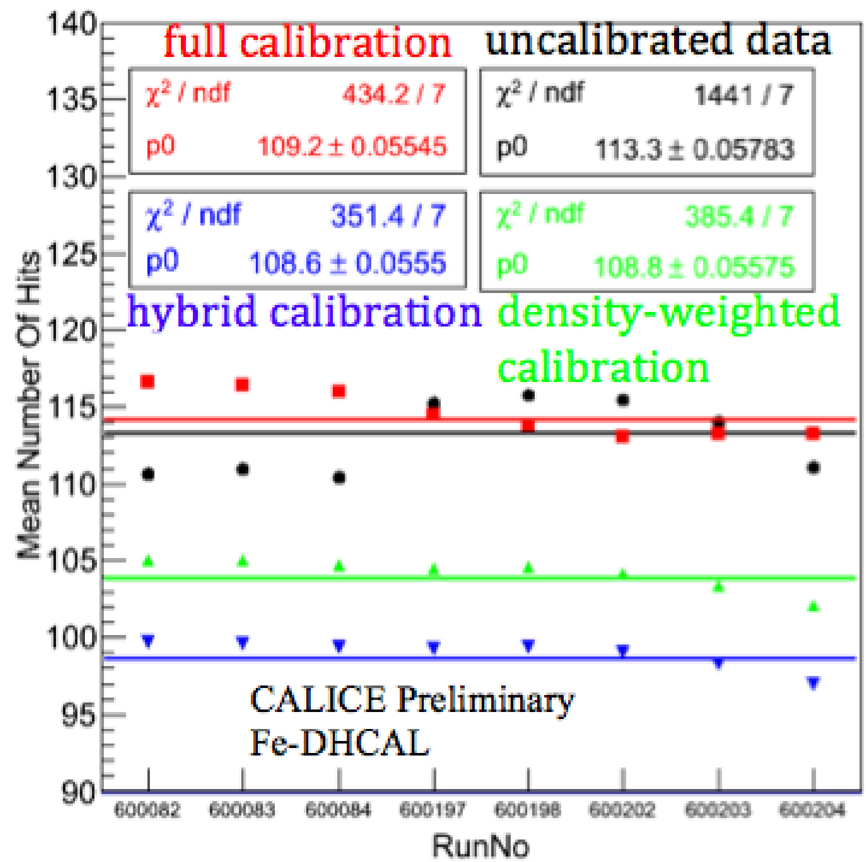


Calibrating Different Runs at Same Energy

4 GeV π^+



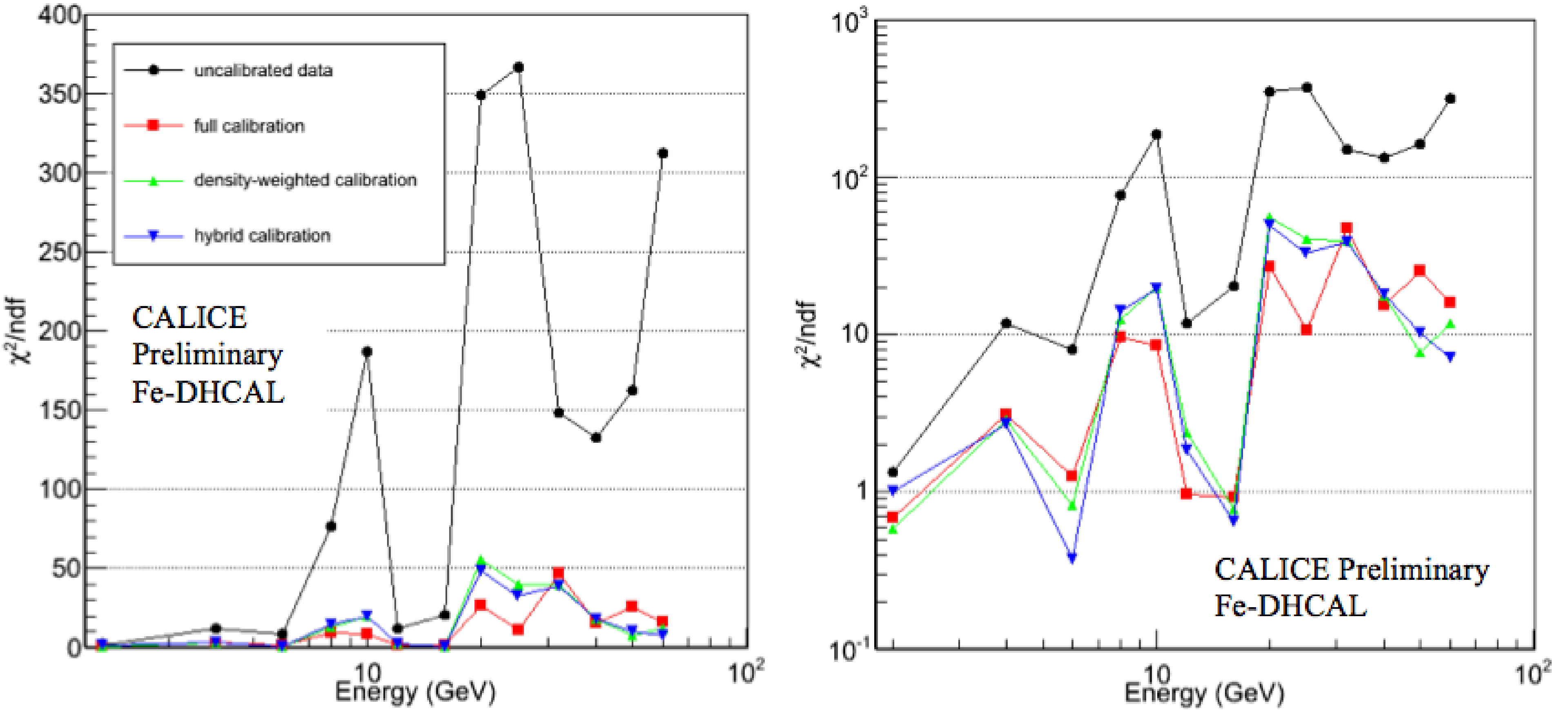
8 GeV e^+



Uncalibrated response (No offset in y)
Full calibration (+5 offset in y)
Density – weighted calibration (-5 offset in y)
Hybrid calibration (-10 offset in y)

Comparison of Different Calibration Schemes

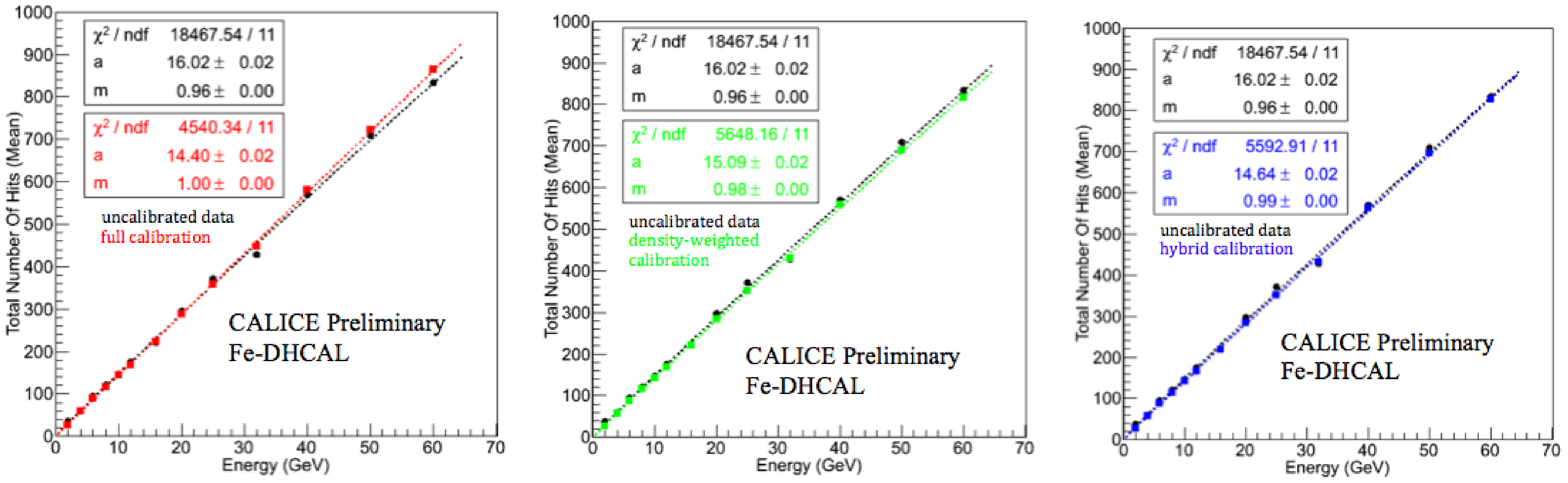
χ^2/ndf of constant fits to the means for different runs at same energy



→ **All three schemes reduce the spread of data points: Benefits of calibration!**

No obvious “winner”: Similar performance of different techniques

Linearity of Pion Response: Fit to $N=aE^m$



Uncalibrated response

4% saturation

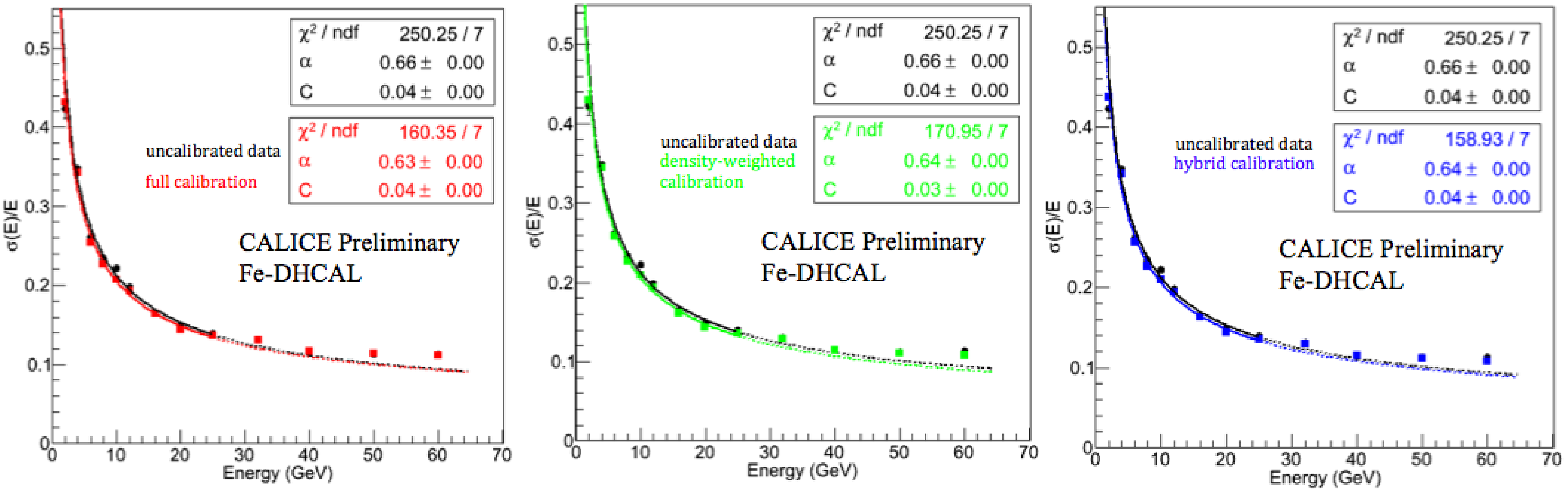
Full calibration

Perfectly linear up to 60 GeV (in contradiction to MC predictions)

Density- weighted calibration/Hybrid calibration

1 – 2% saturation (in agreement with predictions)

Resolution for Pions



Calibration

Improves result somewhat

$$\frac{\sigma(N)}{N} = \frac{\alpha}{\sqrt{E}} \oplus C$$

Monte Carlo prediction

Around 58%/√E with negligible constant term

Saturation at higher energies

→ Leveling off of resolution
→ see next talk on software compensation

Summary

- Calibration of the DHCAL is not a trivial process
- Calibration improves both linearity and resolution
- Calibration not final yet (use of better digitizers)

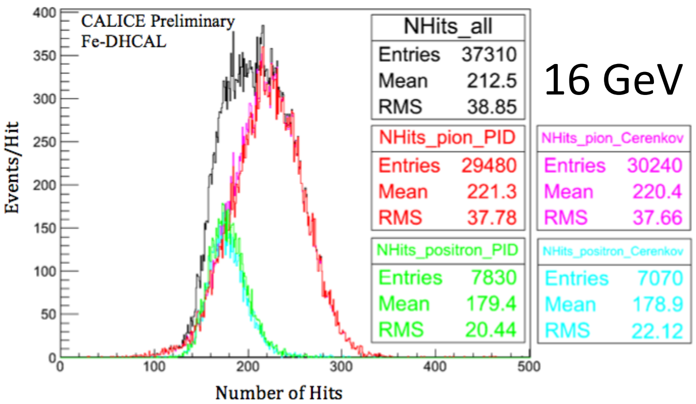
DHCAL concept validated both technically as well as from the physics point of view

Backup

Particle Identification (PID)

0. Čerenkov counter based PID (good for 6, 8, 10, 12, 16, and 20 GeV)

1. Topological PID: Starts with the trajectory fit (used for 2, 4, 25 and 32 GeV)



Visually inspect the positron events in the ~10% excess in the topological PID

→ They are positrons

→ 10 % compatible with the inefficiency of the Čerenkov counter, which was ≥ 90% for most energies

→ Topological PID works nicely!

Topological Variables

- Interaction Layer *IL*: If there are hits with a *ΔR* between 1.5 and 20 cm with respect to the trajectory point in two consecutive layers *i* and *i*+1, the interaction layer is identified as *i*-1.
- Longitudinal Barycenter: Average z-position of the event: $LB = \frac{\sum N_i z_i}{\sum N_i}$ (sum is over all layers).
- Average cluster size: $AC = \frac{N_{Hits}}{N_{Clusters}}$
- Last layer with at least one hit: *LL*
- Lateral shower shape: $R_{rms} = \sqrt{\frac{\sum r_i^2}{N}}$ where r_i is the distance from the trajectory line and N is the total number of hits in the entire stack.
- R_{90}: 90% confinement radius measured with respect to the trajectory (i.e. 90% of the hits in the event are contained in a cylinder of radius R_{90} where the cylinder axis is coincident with the particle trajectory).
- Compactness Index: $\frac{\sqrt{\sum |\vec{r}_i - \vec{r}_{BC}|^2}}{N}$ where $\vec{r}_i$ is the position vector of the hit and $\vec{r}_{BC}$ is the position vector on the trajectory at the longitudinal barycenter. The sum is over all hits.
- $\frac{N_{10}}{N_{20}}$: (Number of hits within 10 cm) / (Number of hits within 20 cm) of the particle trajectory.