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AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Presentation

Exploring the structure of hadronic showers and hadronic energy reconstruction with highly granular calorimeters

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Exploring the structure of hadronic showers and hadronic energy reconstruction with highly granular calorimeters

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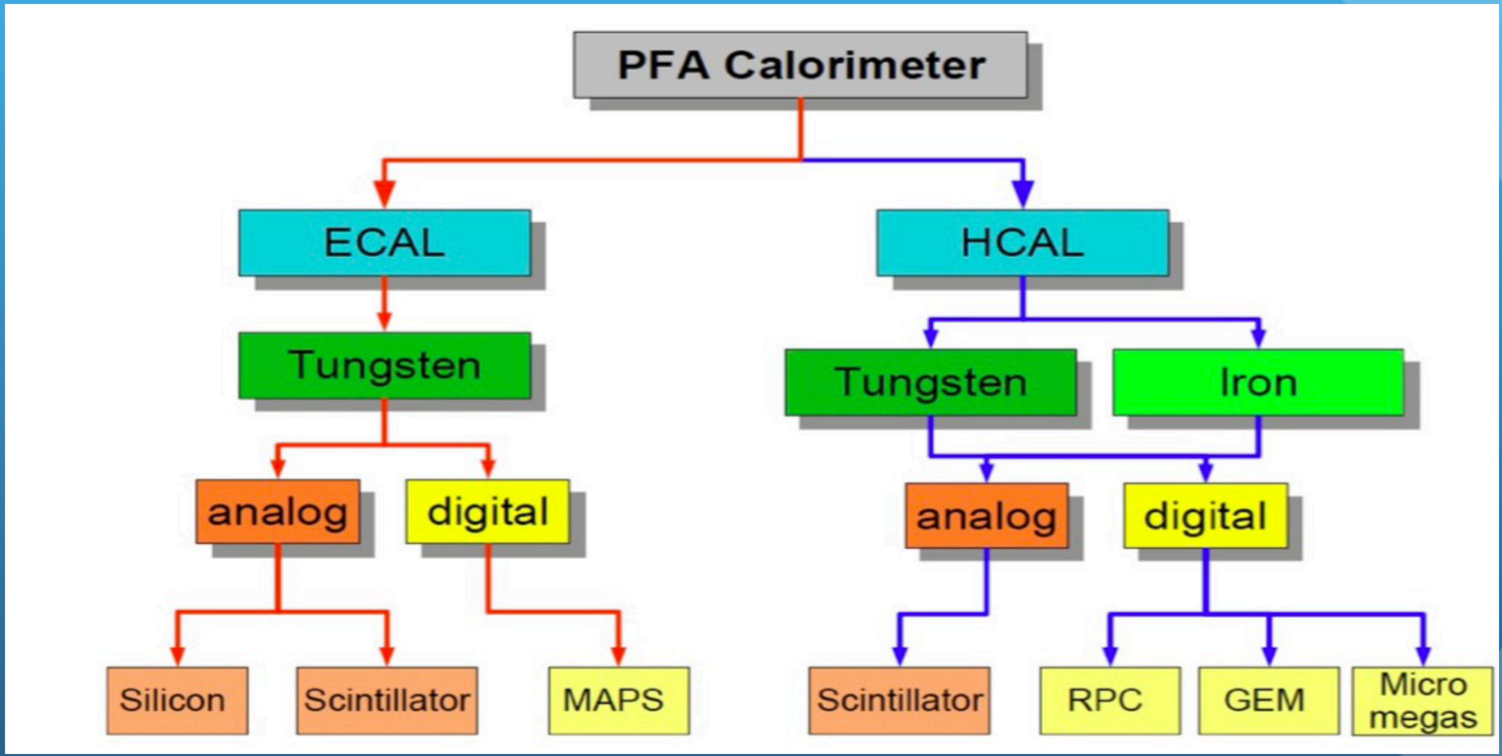
On behalf
of
the Calice Collaboration

CALICE is a collaboration of 59 institutes and 360 people from 4 continents

The goal is to develop highly granular calorimeters for PFA-based experiments for future colliders.



Prototypes

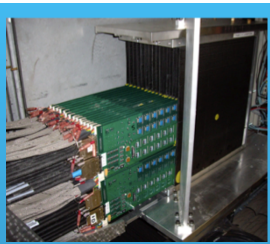
Physics

Granularity
Proof of principal

Technological

Power-pulsed
Embedded electronics
compactness

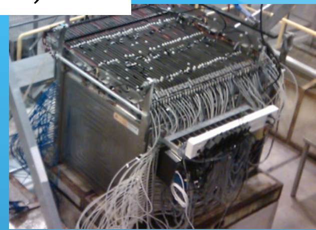
1 cm x 1cm, 24 X_0, 1λ



Si-W

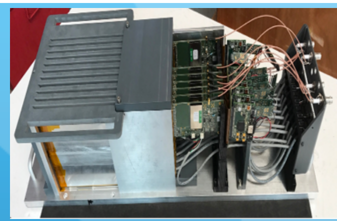
1 cmx 1cm, 6λ

DHCAL



SDHCAL

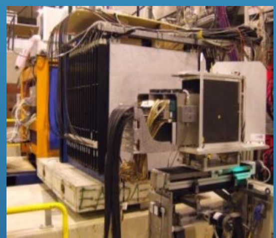
5mm x 5mm, 24 X_0, 1λ



Si-W →

2005 2007 2010 2011 2012 2018

AHCAL



3cmx 3cm, 5.3+12λ

Scint-W

"1cm x 5cm"$_{x,y}$, 24 X_0, 1λ

AHCAL

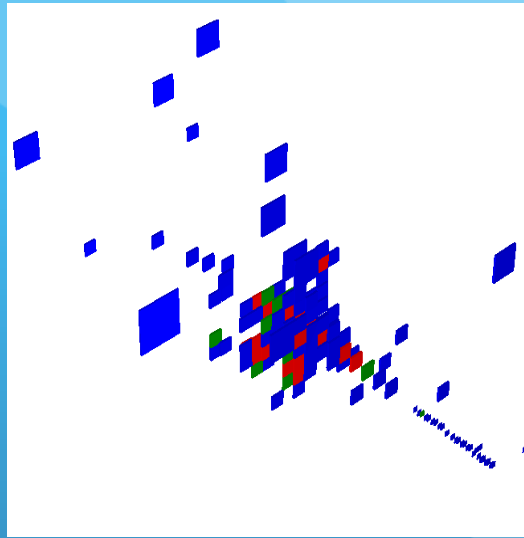
3cm x 3cm, 5.3λ

Several prototypes have been built and exposed to hadron beams at CERN, FERMILAB and DESY.
Some are combined tests (ECAL+HCAL)
The granularity of those prototypes and their high performance provide excellent tools to study the electromagnetic and hadronic showers

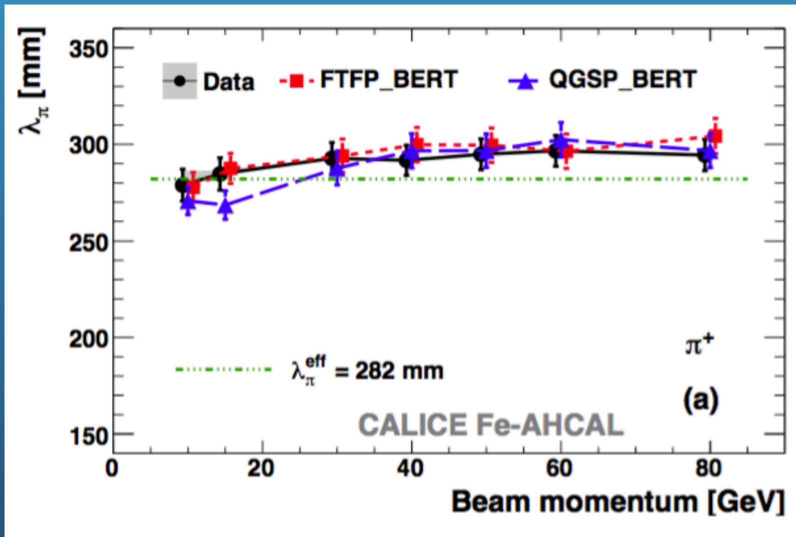
Interaction length: pion vs proton

- ❑ Cerenkov-based separation
- ❑ Determine the shower start by
- ◆ Finding the track segment of the incoming particle (nearest neighbour-based tracking)
- ◆ Finding the first layer of the shower

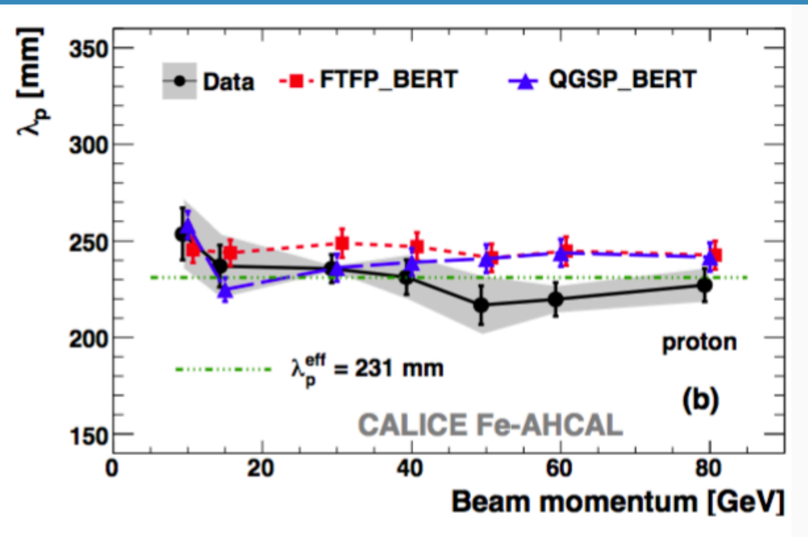
[JINST 10 (2015) P04014]



Pion



Proton

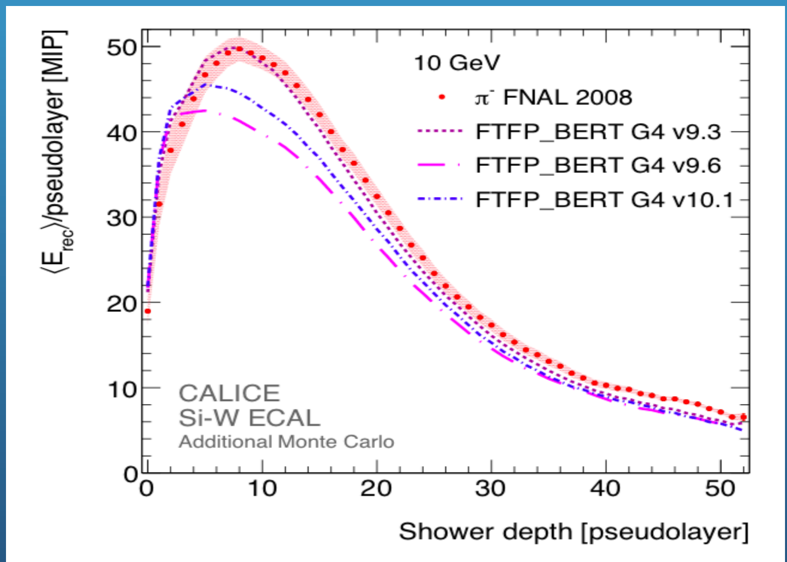


Hadronic shower: longitudinal profile
Si-W ECAL

Test of hadronic shower models at low energies [NIM A794 (2015) 240-254]

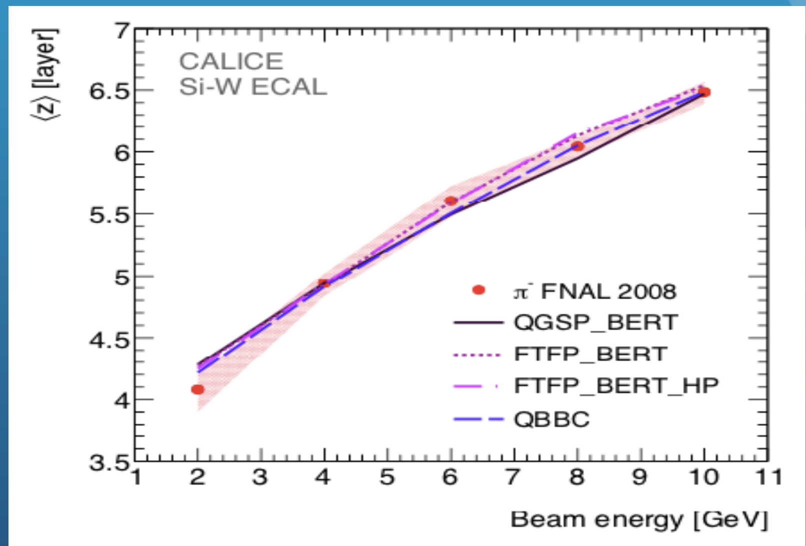
- ❑ Depth of Si-W ECAL prototype is $1\lambda_I$, 60% of hadrons interact in ECAL
- ❑ 3 segments with different absorber thickness - converted into pseudolayers for analysis
- ❑ Interacting events are distinguished from MIP-like events
- ❑ Test beam pions 2-10 GeV; comparison withGeant4 versions 9.6 and 10.1

Visible energy / pseudolayer



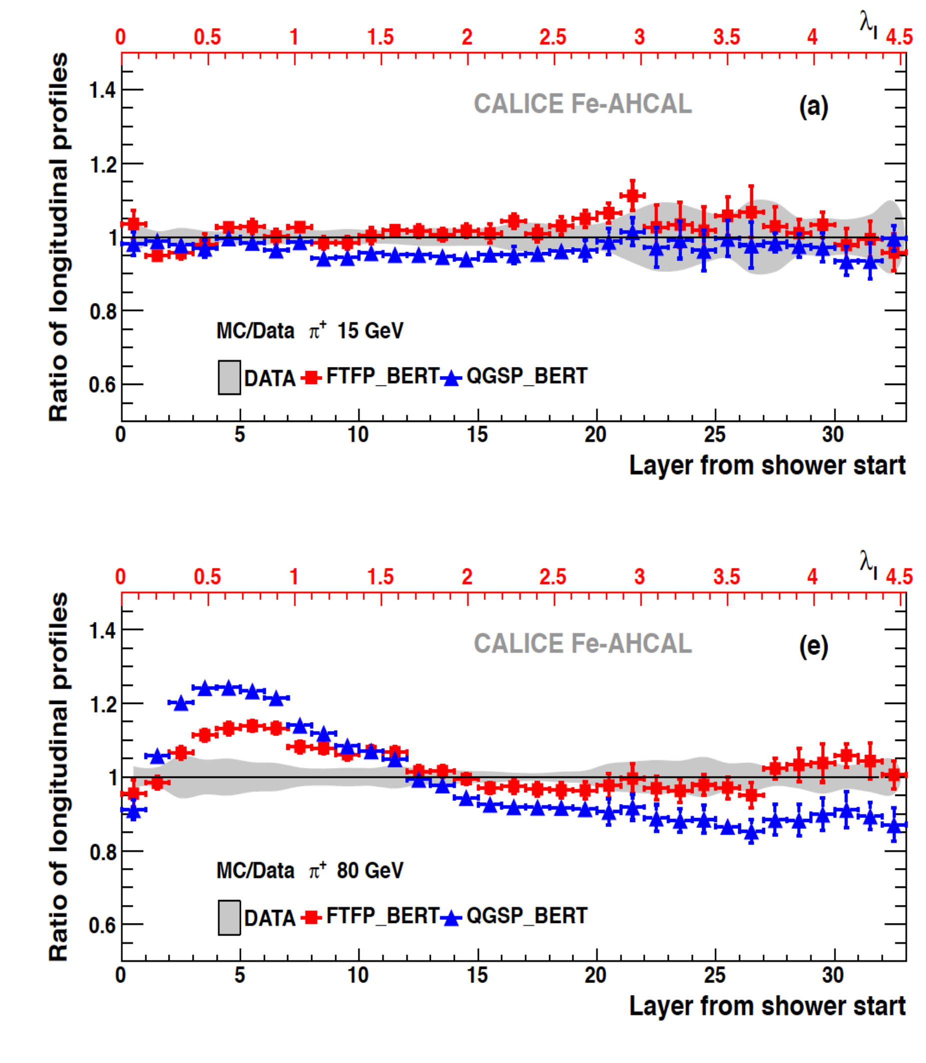
Significant differences between G4 versions

Mean of longitudinal hit position distribution



Good agreement for all G4 models

Hadronic shower: longitudinal profile
AHCAL
MC/data ratio of longitudinal profiles in Sc-Fe AHCAL

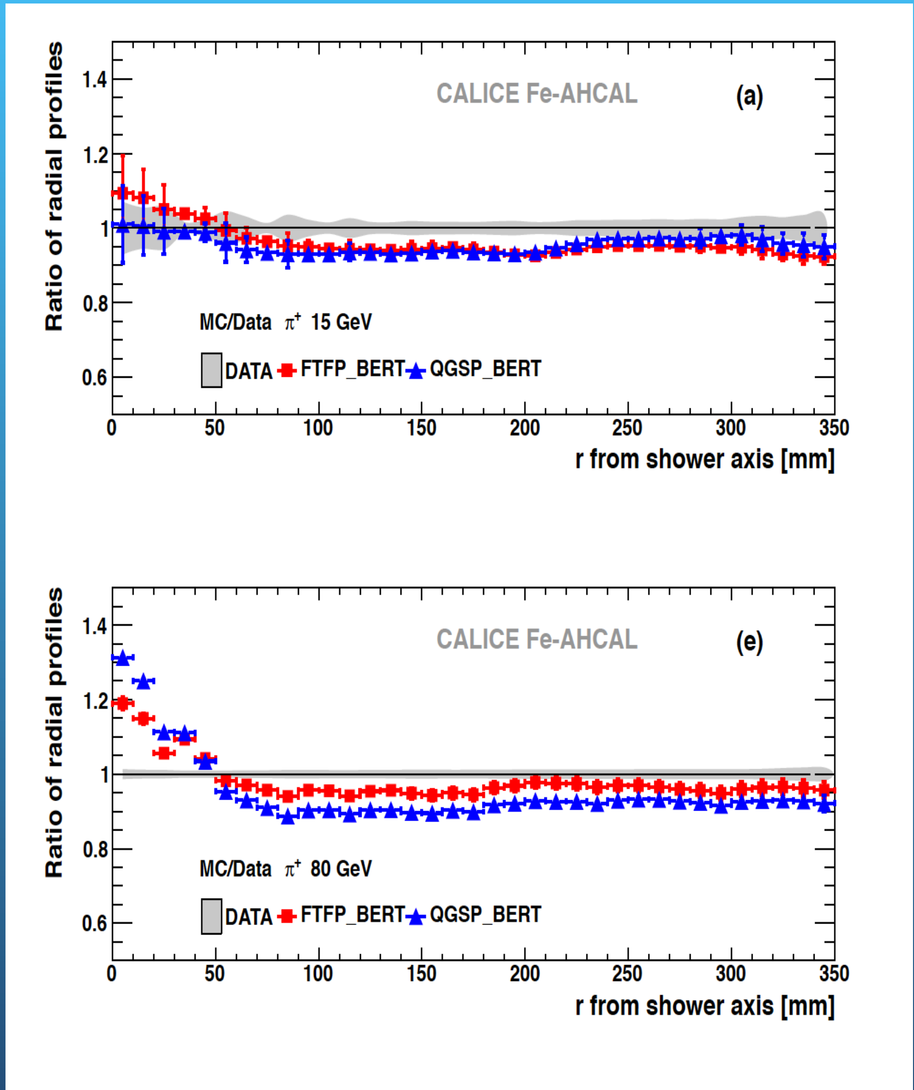


Visible energy E per layer vs. long. distance from the identified shower start
Comparison with Geant4 v9.6

+ 15 GeV
FTFP BERT: agreement within uncertainties
QGSP BERT: little Underestimation

+ 80 GeV
Overestimation around shower maximum:
FTFP BERT: by 10%
QGSP BERT: by 20%
[JINST 11 (2016) P06013]

Hadronic shower: radial profile
AHCAL
MC/data ratio of radial profiles in Sc-Fe AHCAL



Radial profile:
the cylinder of radius r and width delta_r (delta_r = 1 cm) vs. radial distance r.
Comparison with Geant4 v9.6

+ 15 GeV
Within uncertainties (10%) in the shower core
Underestimation in the middle

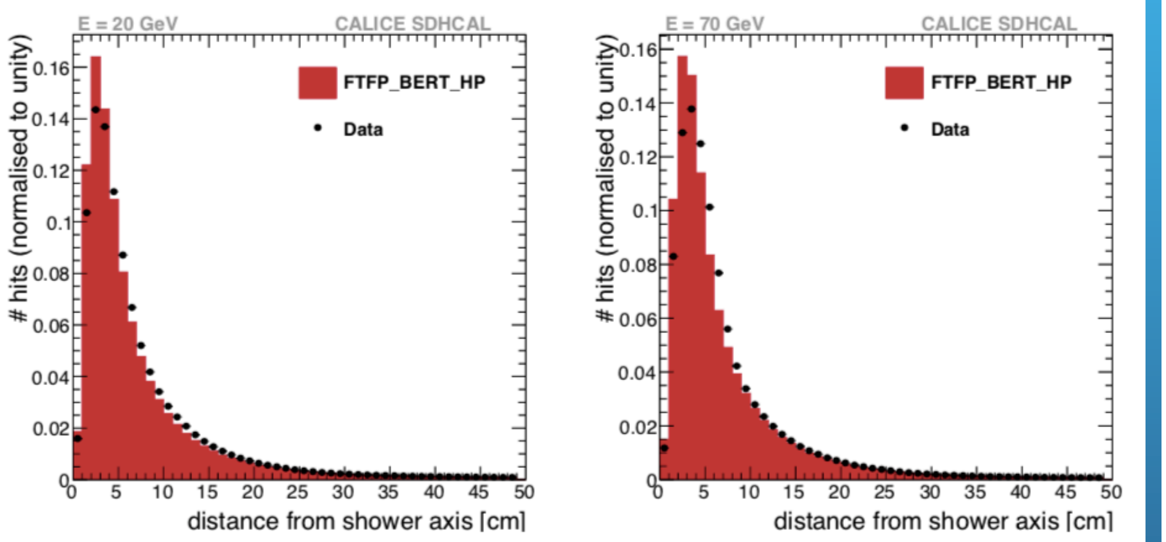
+ 80 GeV
Overestimation in the core
FTFP BERT: by 20%
QGSP BERT: by 30%
[JINST 11 (2016) P06013]

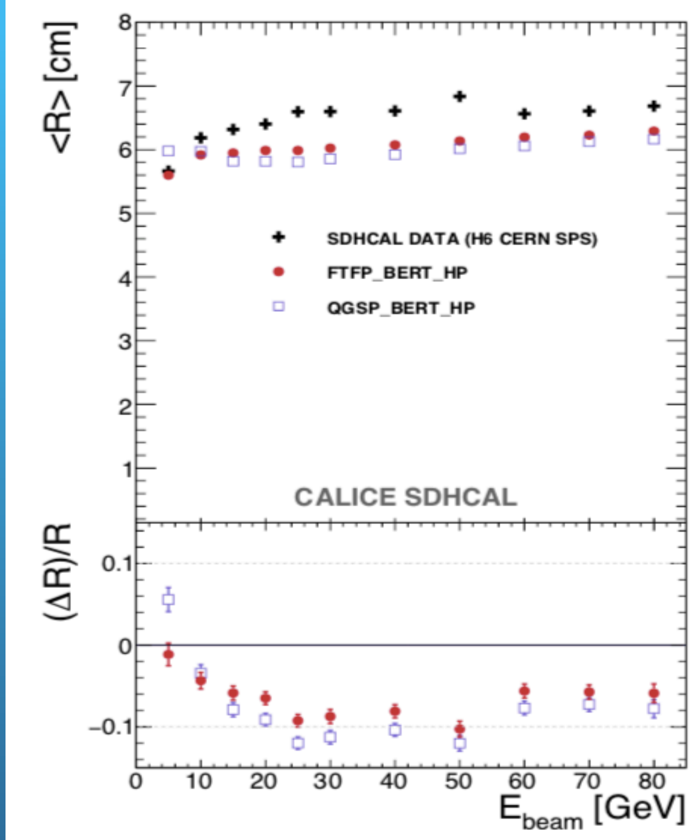
Hadronic shower: radial profile SDHCAL

Test beam data and simulations [JINST 11 (2016) P06013]

Test beam data: hadrons 5-80 GeV

- Simulation with Geant4 v9.6 (with HP)
- Digitisation method for RPC tuned on EM showers





Radial profile: number of hits in 1-cm rings around shower barycenter

Mean of radial profile:

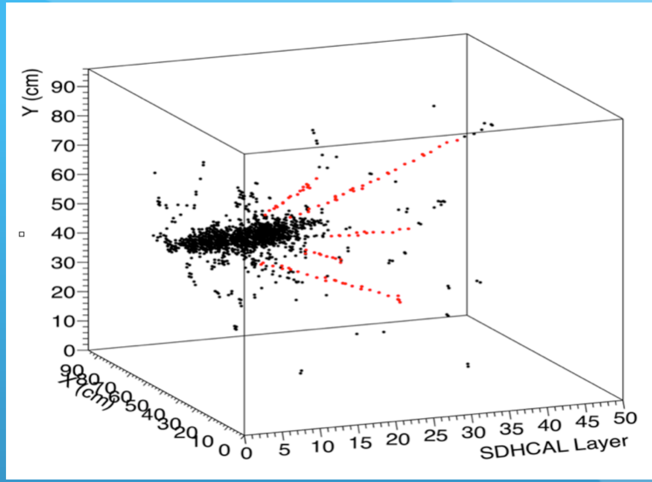
$$\langle R \rangle = \frac{1}{N_{\mathrm{event}}} \sum_{i=0}^{N_{\mathrm{event}}} \sum_{r=0}^{R_{\mathrm{max}}} r \frac{N_{r,i}}{N_{\mathrm{tot},i}}$$

Shower width is underestimated by simulations

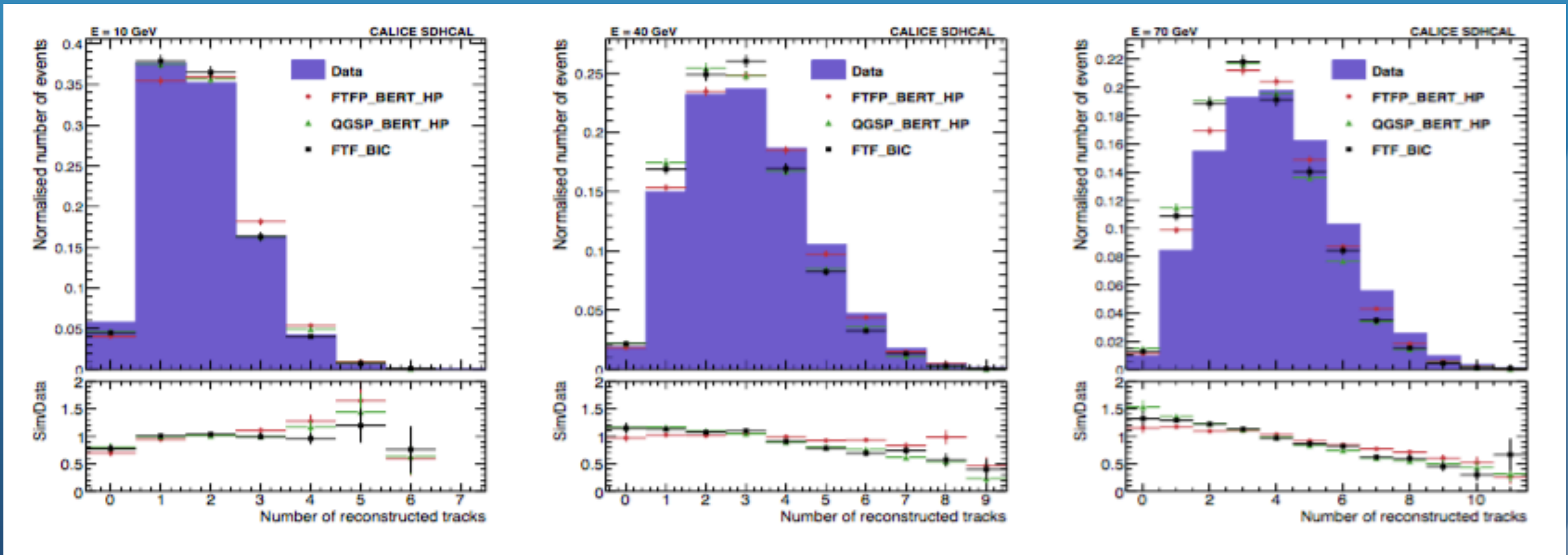
Number of track segments in hadronic shower: SDHCAL

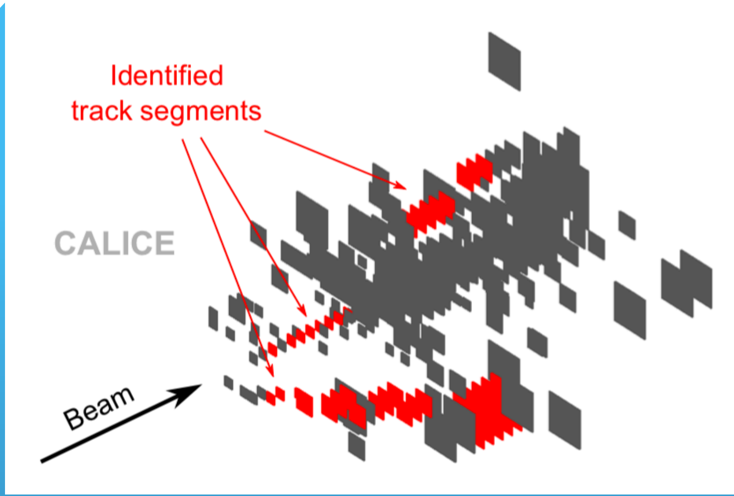
GRPC-Fe SDHCAL [JINST 12 (2017) P05009]
Test beam data: pions of 10-80 GeV

- ❑ simulations: Geant4 9.6
- ❑ Hough Transform for track finding
- ❑ FTFP BERT gives better predictions



- Underestimation by simulation of the mean number of identified track segments
- Increases with energy

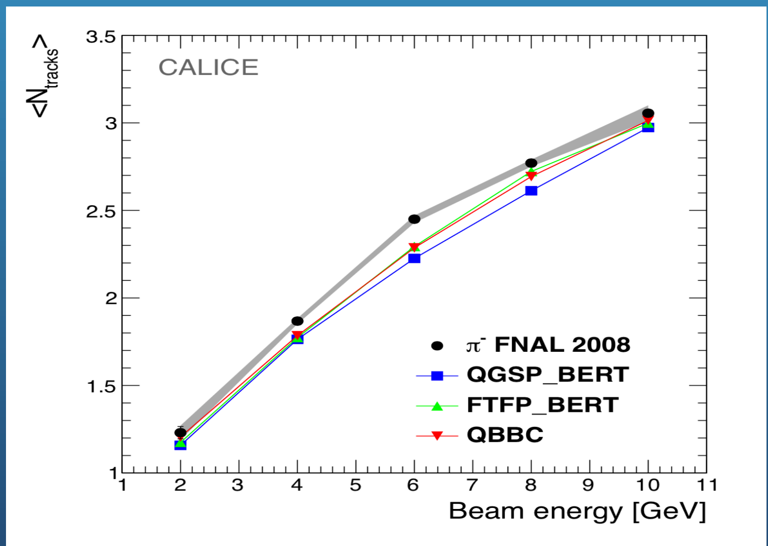


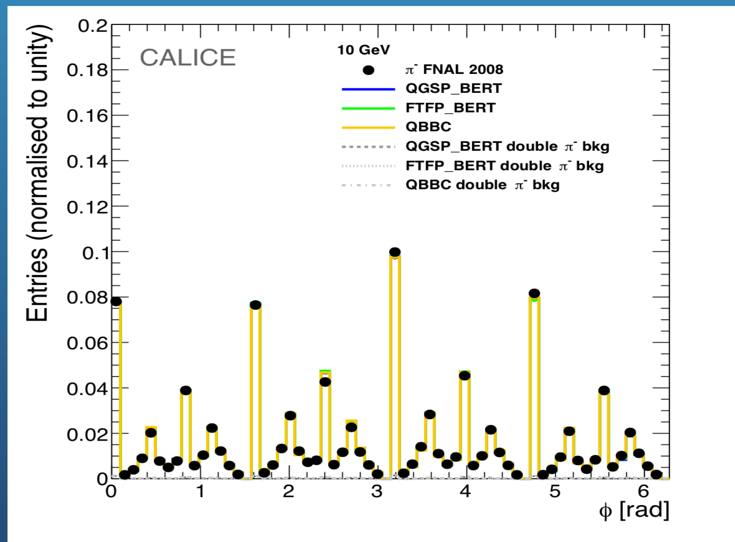


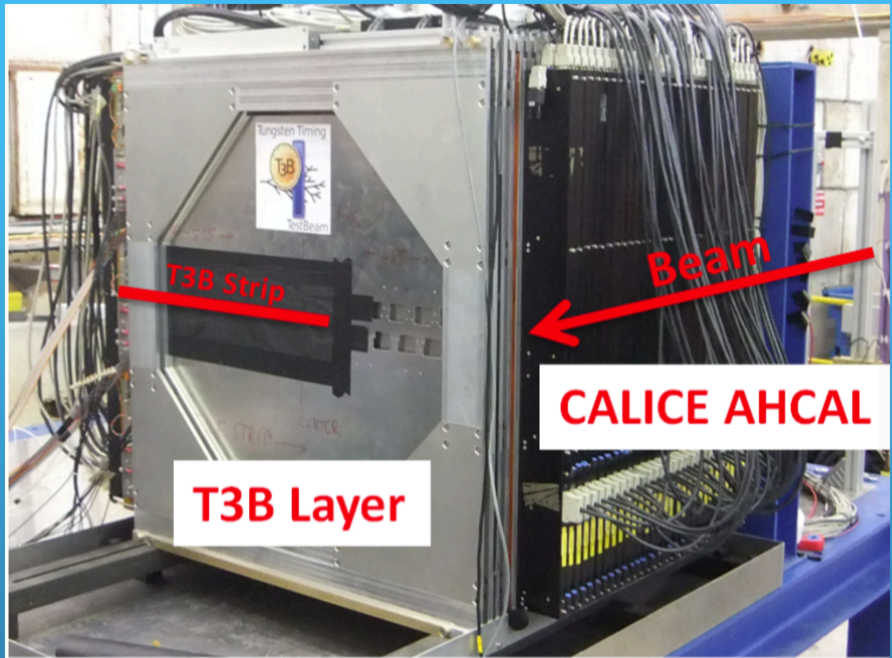
Sc-Fe AHCAL [JINST 8 (2013) P09001]
test beam data: pions of 10-80 GeV
simulations: Geant4 9.4
track finding based on nearest neighbour algorithm for isolated hits
QGSP BERT in best agreement with data
good agreement of FTFP BERT

Si-W ECAL [NIM A937 (2019) 41-52]:
Test beam data: pions of 2-10 GeV, simulations: Geant4 10.1

- Good agreement between data and simulations
- Smaller energy fraction in interaction region in simulation by 10%





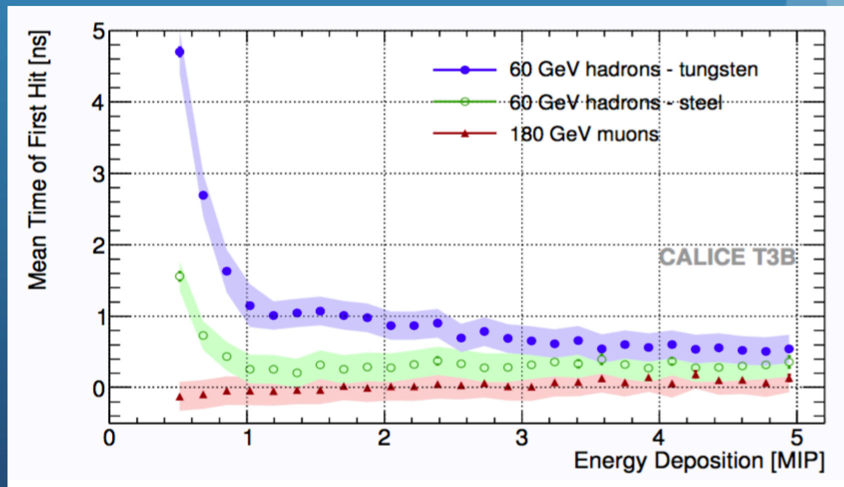


[JINST 9 (2014) P07022]

- Setup of 15 plastic scintillator tiles 330.5 cm2 with SiPM readout, covers 1/2 of transverse size of the calorimeter starting from its center
- Subnanosecond time resolution over a time window of 2.4 s
- Placed behind Sc-W AHCAL or GRPC-Fe SDHCAL
- Test beam muons and 60 GeV positive hadrons

Time structure of hadronic showers measured on a statistical basis

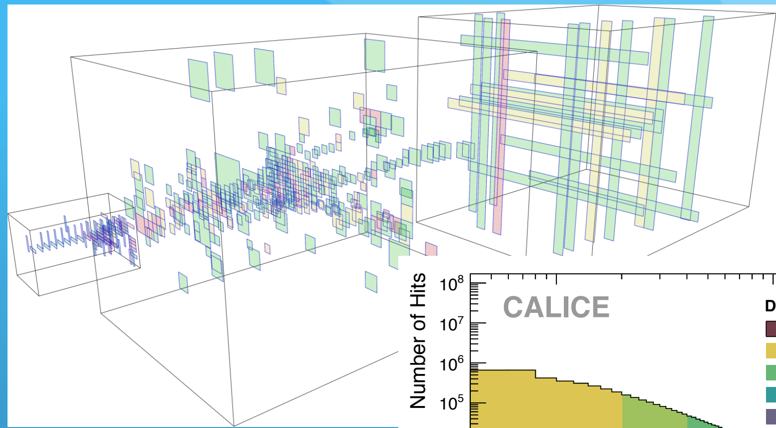
- Waveform is decomposed and the time of first hit is derived
- No late component for muons
- Late component (>50 ns) for hadrons more pronounced in tungsten as expected
- 3 times larger delay of low-energy hits for pions in tungsten than in steel
- Good agreement with Geant4 v9.4, importance of **HP package** for tungsten

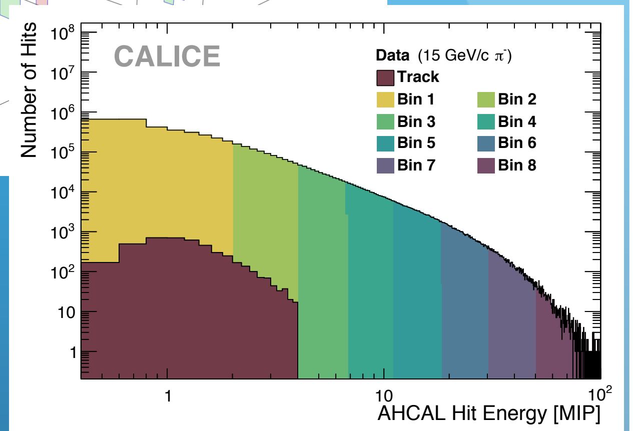


Energy reconstruction: software compensation in analogue calorimeters

The basis of the technique:

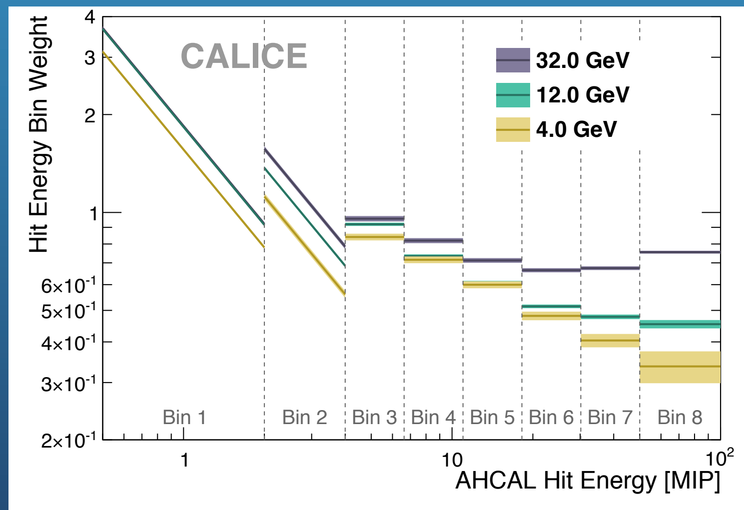
Local shower density depends on origin of energy deposits higher density for electromagnetic subshowers and lower density for the remaining (hadronic) part





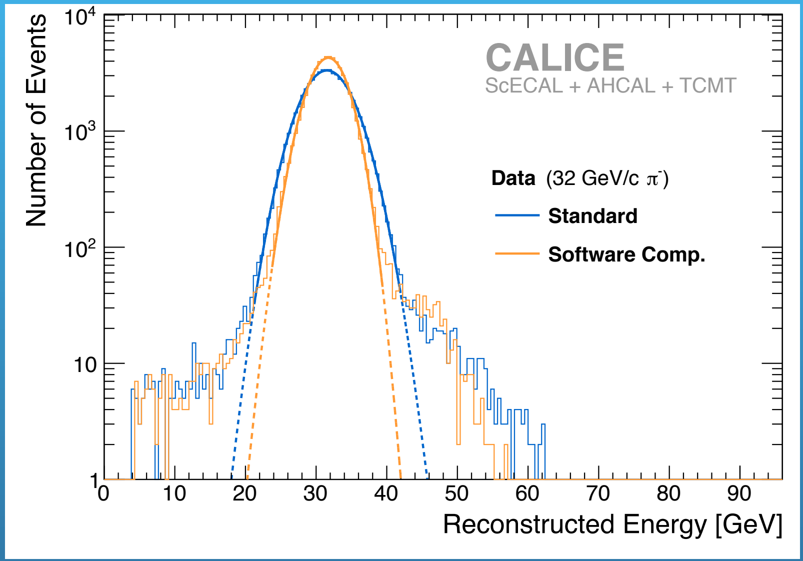
➩ e/h compensation can be achieved by assigning energy-dependent weights to hits in global energy sum, significantly improving energy resolution

- Weights are energy dependent

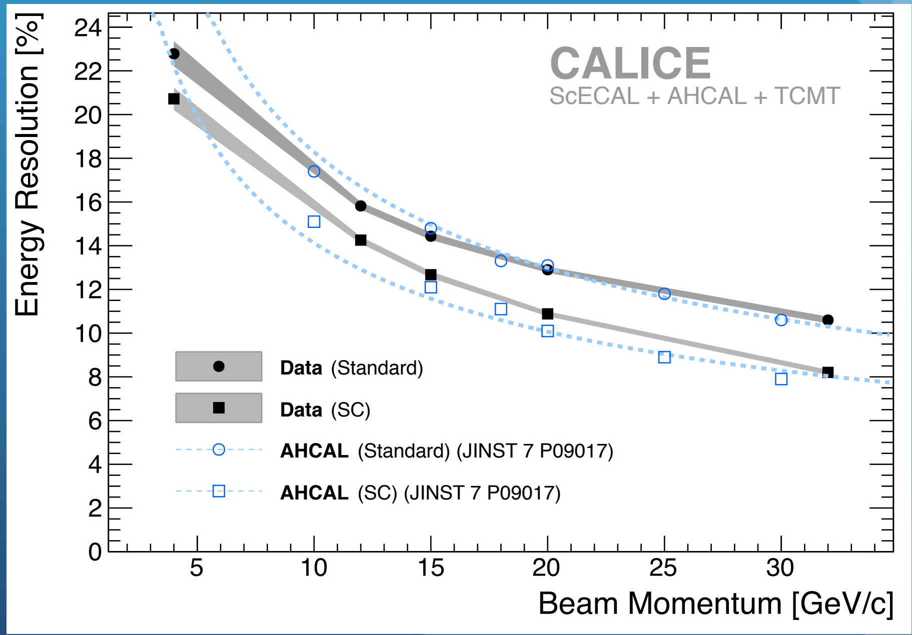


Energy reconstruction: software compensation in analogue calorimeters

Software compensation studied in CALICE for a variety of different detector systems – here: ScintW ECAL + AHCAL + TCMT

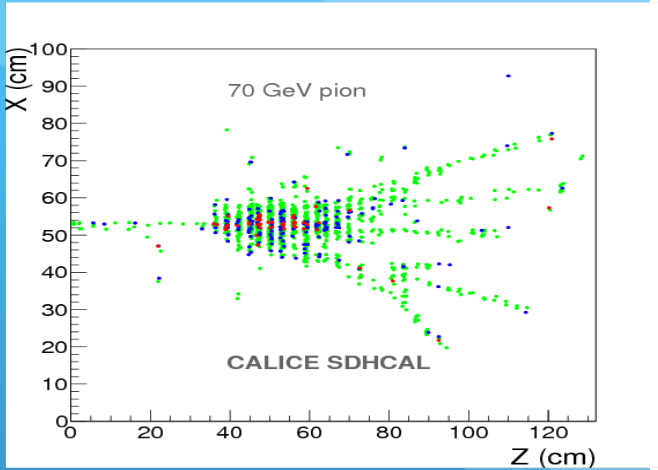


Significant improvement of energy resolution: 10 – 20% compared to « standard » reconstruction



JINST 13, P12022 (2018)

Energy reconstruction: "soft compensation" in SDHCAL



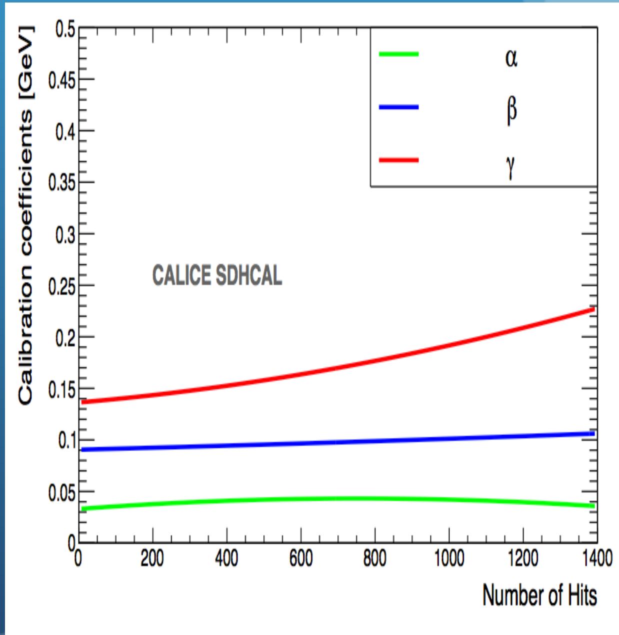
Threshold information is related to charge and this is related to the number of charged particles crossing one 1x1 cm2 cell

$$E_{rec} = \alpha(N_{tot})\, N_1 + \beta(N_{tot})\, N_2 + \gamma(N_{tot})\, N_3$$

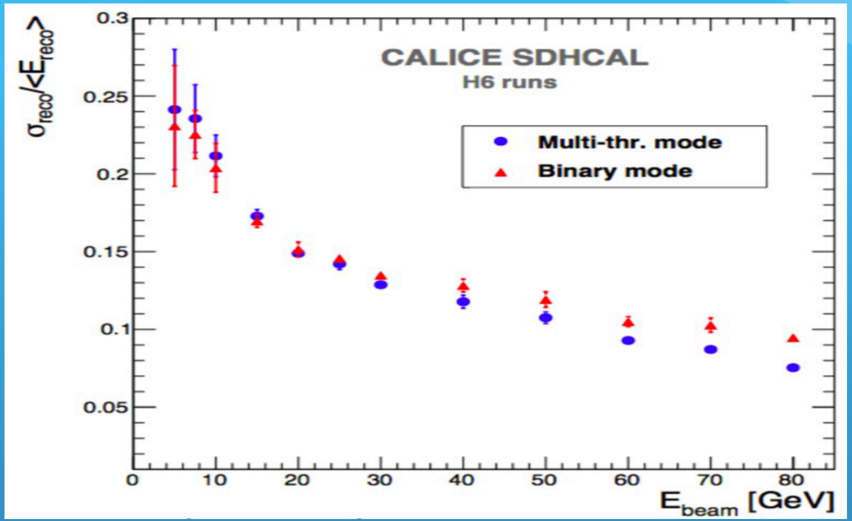
The thresholds weight evolution with the total number of hits obtained by minimizing a x^2
$X^2 = (E_{beam} - E_{rec})^2 / E_{beam}$

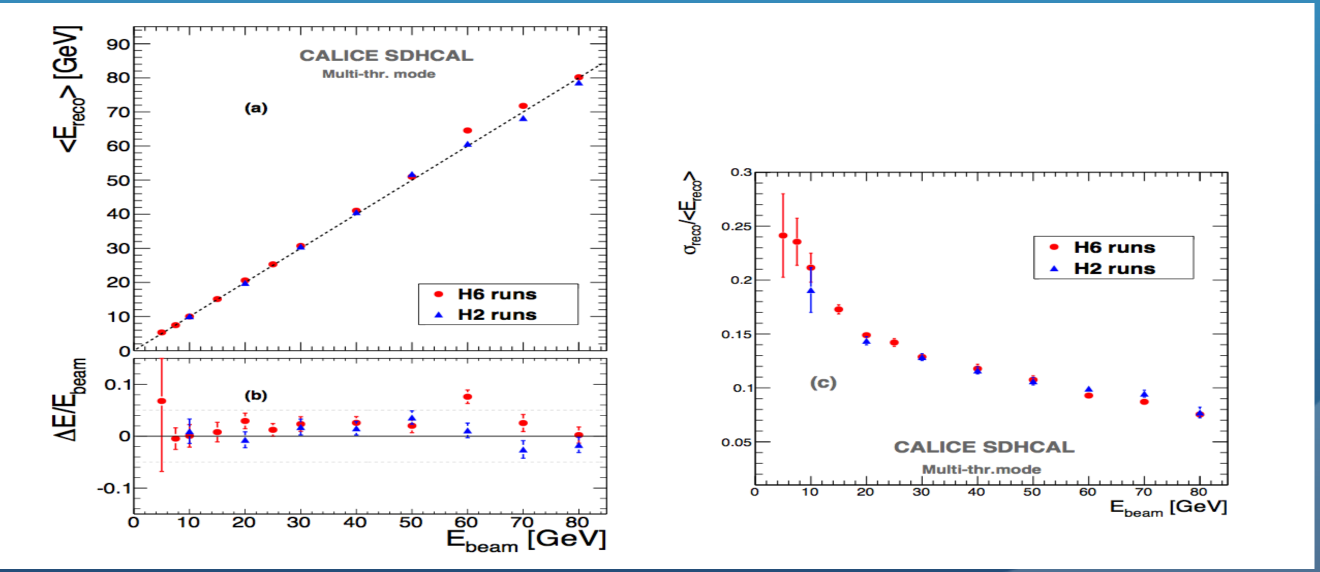
N_1,N_2 and N_3 : exclusive number of hits associated to first, second and third threshold.
α, β, γ are **quadratic functions** of the total number of hits **(N_{tot})**

Events of H2 runs corresponding to energies : **5, 10, 30 , 60** and **80** GeV were used to fit the 9 parameters.



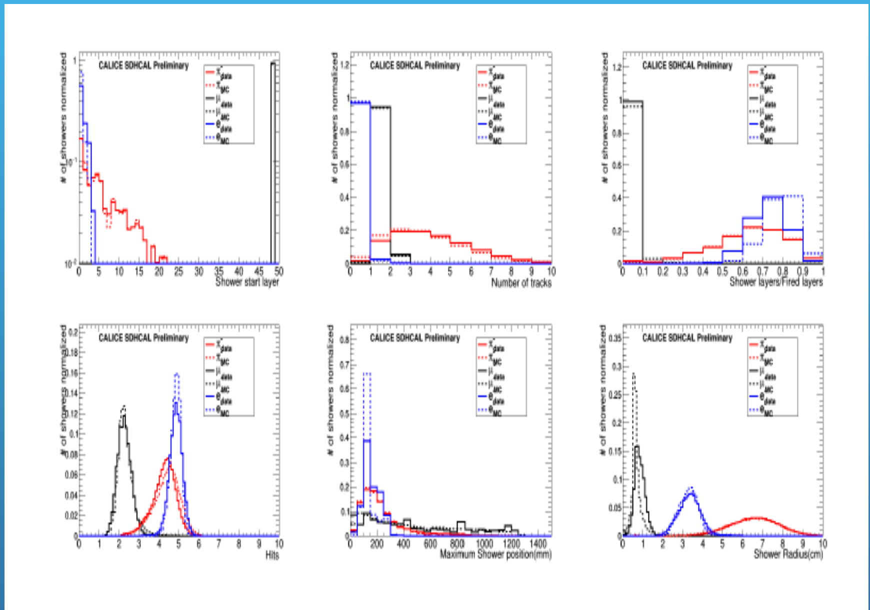
Then the energy of hadronic events in both
H2 (only pions) and **H6** (presence of protons) are estimated

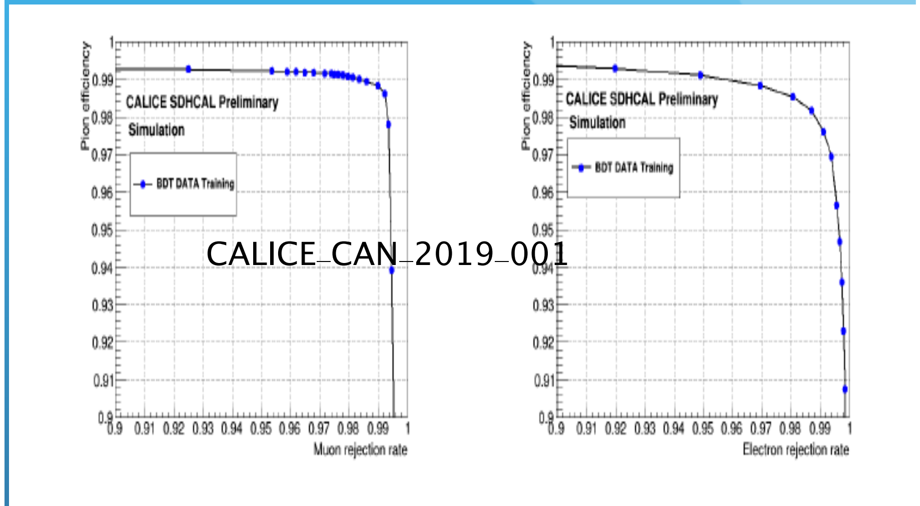




Particle Identification: SDHCAL

Discriminating variables based on shower topology to discriminate different species of particles :
hadrons, electrons and muons are used to train a BDT on both MC and data
Excellent Purity/efficiency performance are obtained

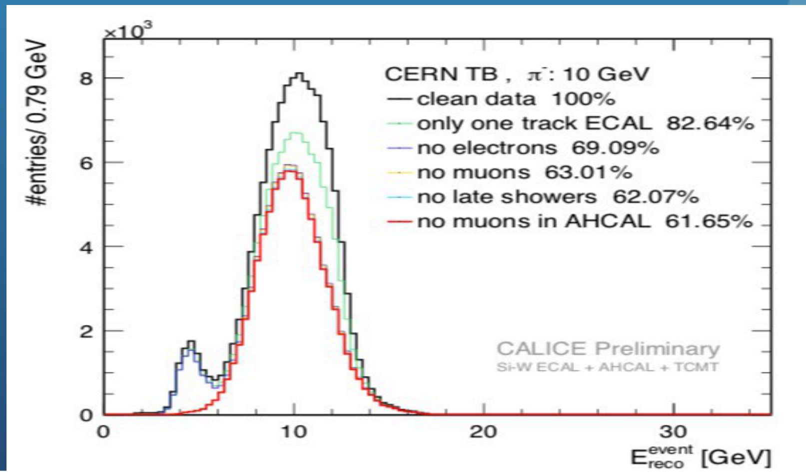




CALICE_CAN_2019_001

Particle Identification: SiW

Tracking capabilities to select single pion events in SiW Ecal



Conclusion

- CALICE prototypes provide a rich source of information concerning the hadronic showers.
- A very fruitful collaboration with G4 collaboration that benefits the both collaborations and beyond.
- The excellent granularity is exploited to identify particles and reconstruct the hadronic energy in optimal way using showers shape