SDHCAL technological prototype test beam results

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on behalf of the CALICE collaboration

International Workshop on Future Linear Colliders (LCWS2021)

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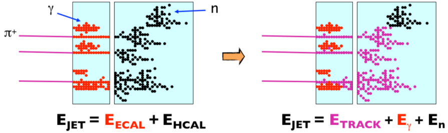
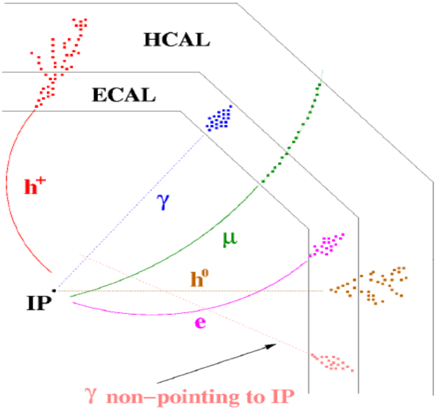
A calorimeter for Particle Flow Algorithms (PFA)

Particle Flow Algorithm: aims to improve the jet energy resolution by measuring the energy and momentum of each particle from the subdetector that provides the most accurate measurement for that kind of particle.

The detectors for this kind of algorithm require:

- High granularity
- Compactness

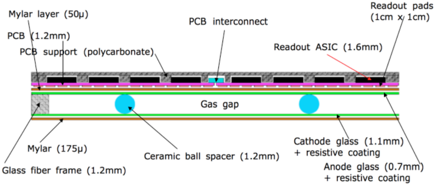




SDHCal Technological Prototype

SDHCal: 48 active layers $1x1m^2$ GRPC with $1x1cm^2$ pads. The absorber plates are 15 mm thick stainless steel.

ASIC HARDROC(64 channel)
three-threshold (Semi-digital)
110fC,5pC,15pC



$(0.12\lambda_I, 1.14X_0)$

Stainless steel Absorber(15mm)

Stainless steel wall(2.5mm)

GRPC(6mm$\approx 0\ \lambda_I, X_0$)

Stainless steel wall(2.5mm)

SDHCal Technological Prototype

SDHCAL 2012

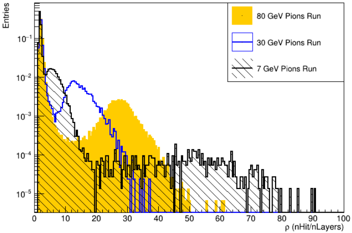
TB 2012, 2015, 2016, 2017 and 2018 with ECal at SPS and PS (CERN)

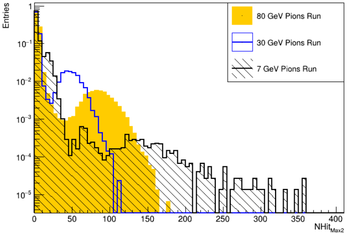
Particle identification

Thanks to the prototype's high granularity it is possible to analyze the topology of registered hits and identify what type of particle crossed the calorimeter.

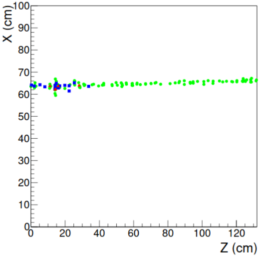
Identification variables:

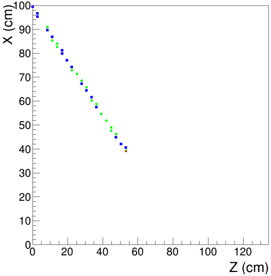
- $\rho = \frac{NHit}{NLayers}$
- $NHit_{Max2}$
- *Penetrability condition*
- *Incident angle*
- *Shower start layer*

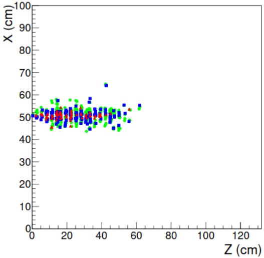


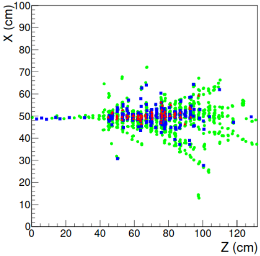


Particle identification


Radiative muon


Cosmic


Electron shower

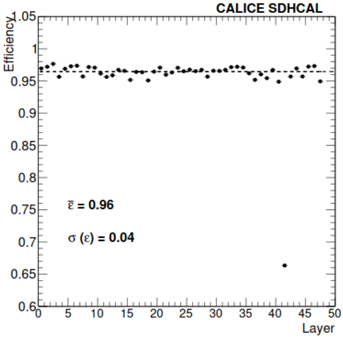

Pion shower

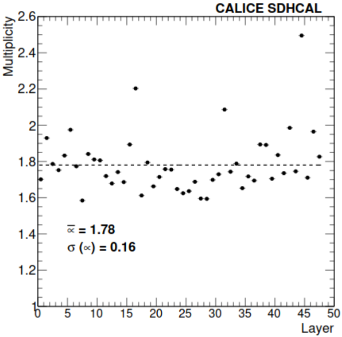
Calorimeter performance

The efficiency (ε) and hit multiplicity (μ) of each layer is estimated using the identified muons from the pion samples.

ε: the track of the muon is reconstructed without the hits form the layer studied. If there is a hit at a distance of less than 3 cm that layer is said to be efficient.

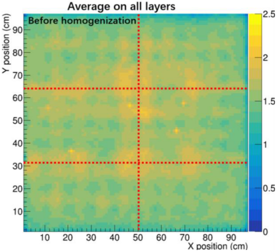
μ: the hit multiplicity is the number of hits of the cluster associated to the muon track in the layer.

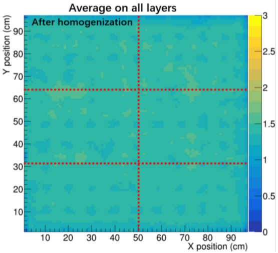


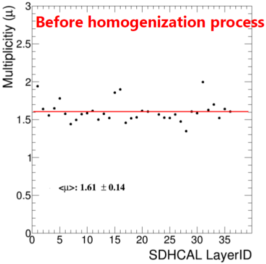


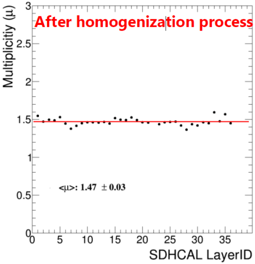
Homogenization process for the SDHCal

Using the muons it is possible to study the multiplicity as a function of the threshold.





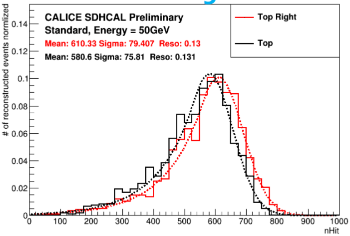




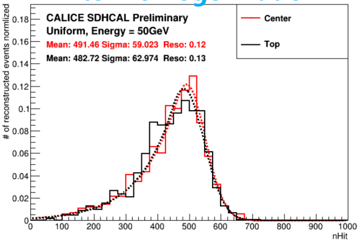
Homogenization process for the SDHCal

50 GeV Pion

Before homogenization

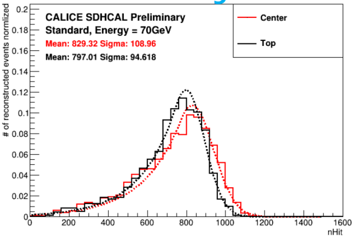


After homogenization

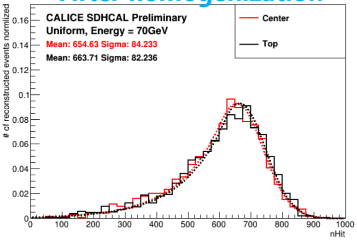


70 GeV Pion

Before homogenization



After homogenization



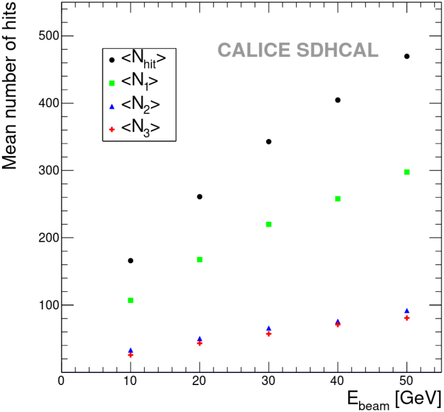
Energy parametrization

From the events identified as pion showers, the energy can be parametrized as a function of the number of hits. In particular as a function of the number of hits per threshold to extract information from within the shower.

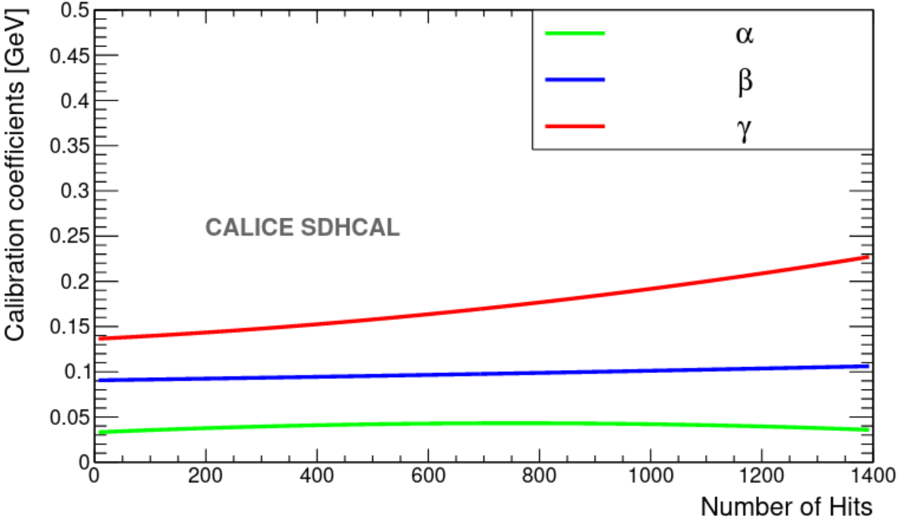
$$E_{Reco} = \alpha N_1 + \beta N_2 + \gamma N_3$$
$$\alpha = \alpha_0 + \alpha_1 N_T + \alpha_2 N_T^2$$
$$\beta = \beta_0 + \beta_1 N_T + \beta_2 N_T^2$$
$$\gamma = \gamma_0 + \gamma_1 N_T + \gamma_2 N_T^2$$
$$N_T = N_1 + N_2 + N_3$$

The set of optimal parameters is found from minimzing the χ^2 function using a third of the data.

$$\chi^2 = \sum_{i=1}^{N} \frac{(E^i_{Beam} - E^i_{Reco})^2}{\sqrt{E^i_{Beam}}}$$

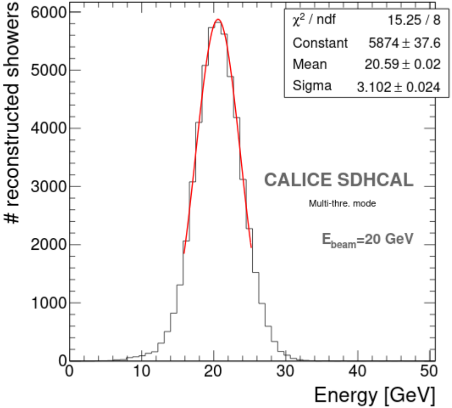


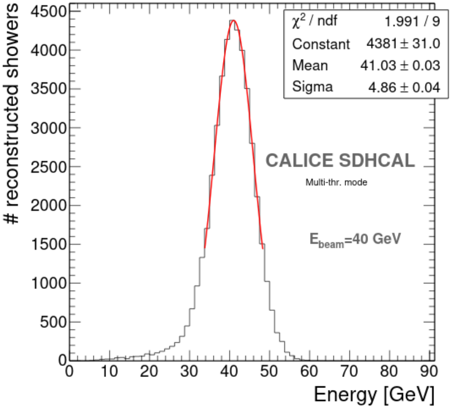
Energy parametrization result



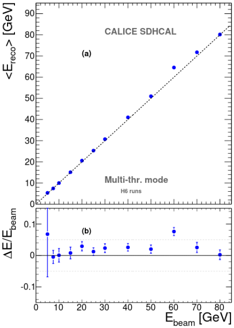
Energy reconstruction

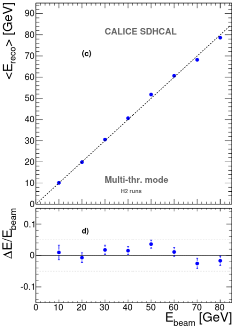
Using the previous parametrization the energy distributionis can be computed and fitted to a Crystal Ball function (to account the tails from energy leakage).





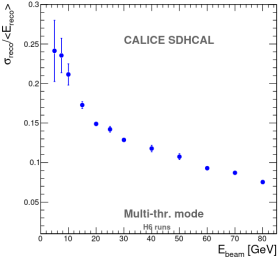
Linearity and resolution

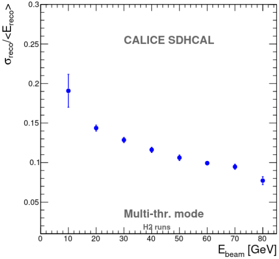




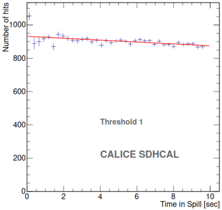
With this parametrization it is possible to ensure linearity in a wide range of energies and using the information from the three thresholds the resolution reaches a 7.7% at 80GeV.

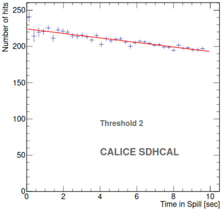
JINST 11 (2016 P04001)

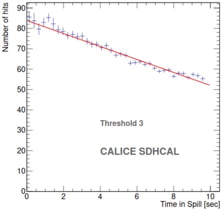




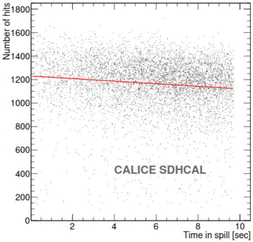
Beam intensity correction

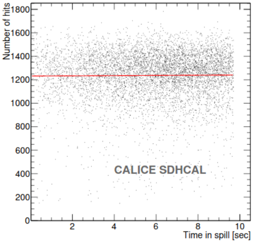






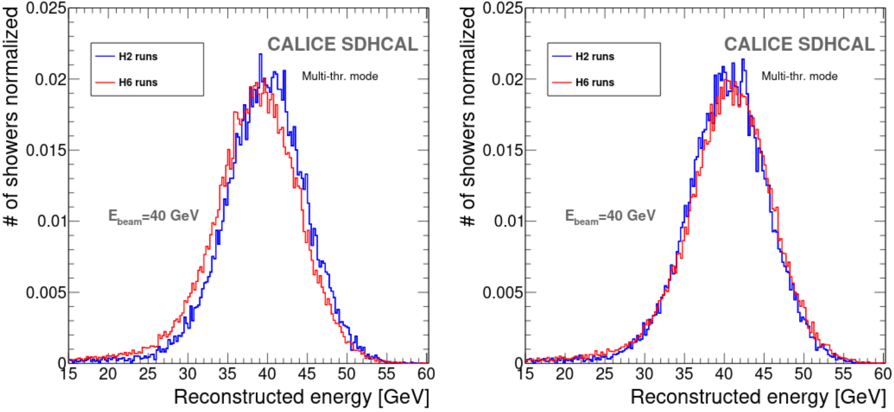
The corrected number of hits is defined by: $N_{corr_j} = N_j - \lambda_j * T$ for each threshold, λ_j is the saturation slope and T is the time since spill start.





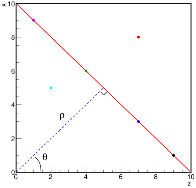
Energy reconstruction corrected

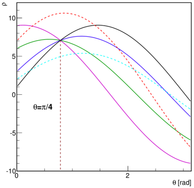
Same energy runs with different particle rates have slight differences in the energy distributions that can be corrected taking into account the saturation.

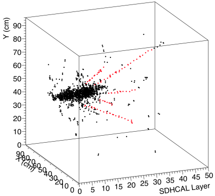


SDHCal High-granularity impact

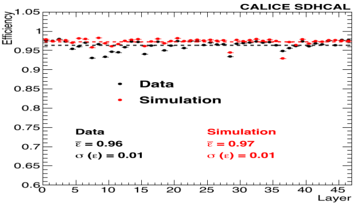
Hough transform is an example to extract tracks within hadronic showers and to use them to control the calorimeter in situ.

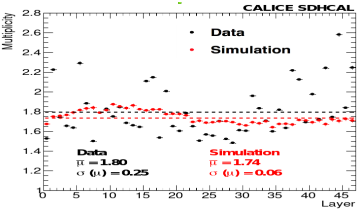






$$\rho_{xz} = z\,sin(\theta) + x\,cos(\theta)$$

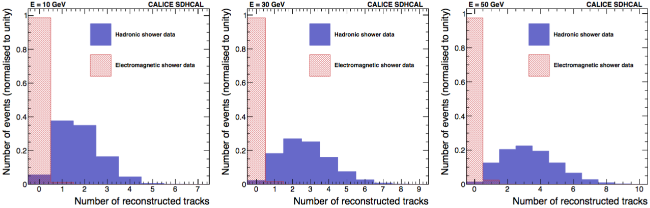




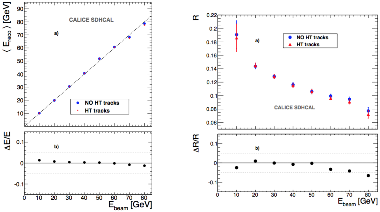
Excellent agreement with efficiency/multiplicity results obtained with cosmic and beam muons. Excellent agreement data/MC

SDHCal High-granularity impact

Good tool to discriminate electron/hadron.



It improves on the energy reconstruction by dealing with the hits belonging to the track segments independently of their threshold.



JINST 12 (2017 P015009)

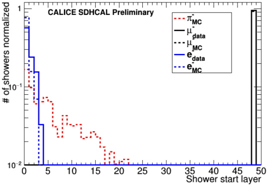
The technique could be extended to hadronic showers in the presence of magnetic field.

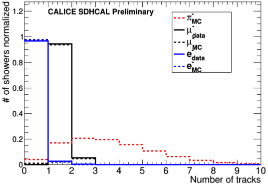
Hadron selection using BDT

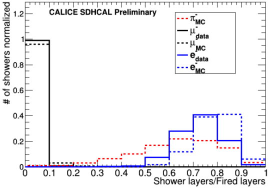
An alternate method to reject electron and muon contamination from the shower samples based on BDT techniques was developed to avoid losing statistics. The BDT was built using the *Toolkit for Multivariate Data Analysis* (TMVA) with *ROOT*. The variables used as input for the BDT are:

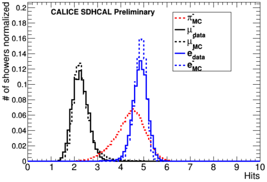
- **First layer of the shower.**
- **Number of track segments in the shower.**
- **Ratio of shower layers over total fired layers (NShowerLayers/FiredLayers).**
- **Shower density.**
- **Shower radius.**
- **Maximum shower position.**

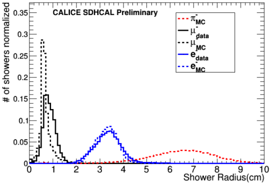
BDT input variables

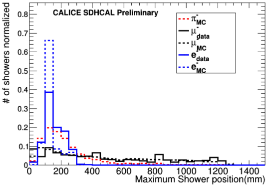






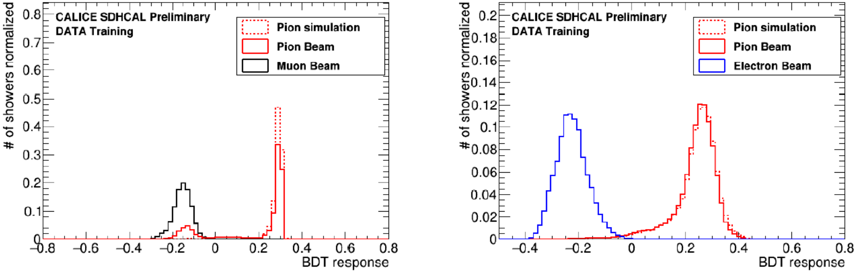






BDT output

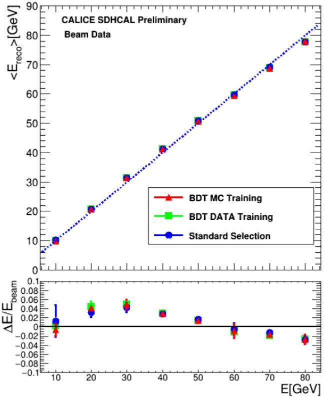
Two classifiers are trained for the selection of signal (pions) from the background (one the background is muons in the other electrons). The output of the BDT is a variable belonging to the $[-1, 1]$ interval, positive values for signal and negative for background.

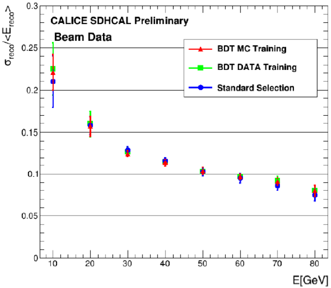


The cuts to select the signal events are: 0.2 in the pion-muon separation and 0.05 in the pion-electron stage.

Method validation

To test this method, the same energy reconstruction presented in slide 6 is applied (using the same parametrization). Similar results are obtained but the BDT method has smaller statistical uncertainties.





Summary

The SDHCAL technological prototype has been tested against several beams producing results about:

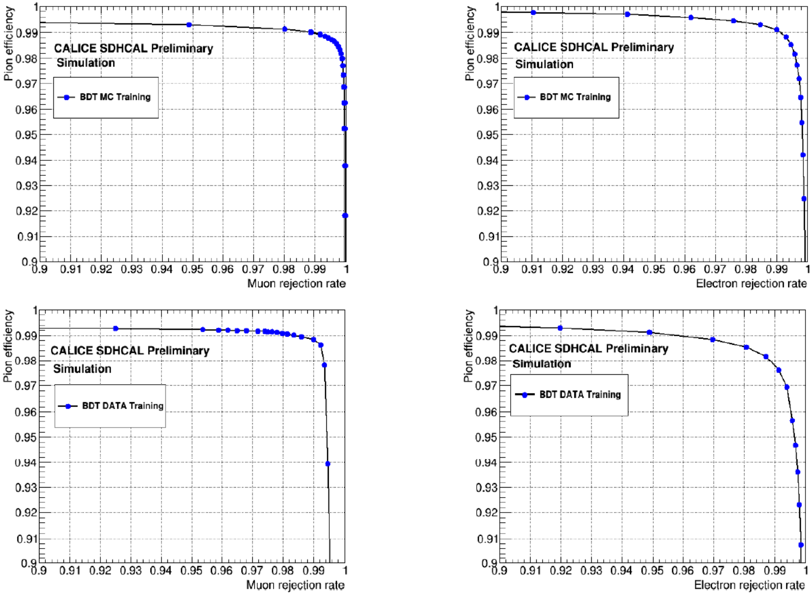
- Capacity to identify particles form the event topology and advanced (machine learning) particle identification methods have been developed.
- High detection efficiency $\varepsilon \approx 0.96$.
- Linearity in a wide range of energies and good resolution (7.7% at 80 GeV).
- Different corrections analyzed (Beam intensity and homogenization).

As future prospects new large chambers and electronics are being developed with the inclusion of timing and also a new analysis about the incident angle effect is on the way.

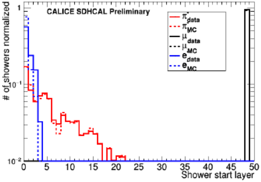
Backup

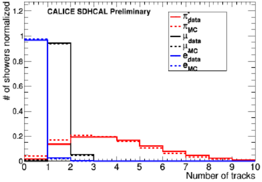
Backup

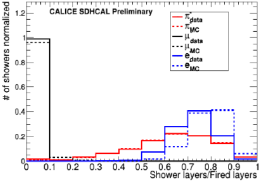
BDT Simulation and Data modes

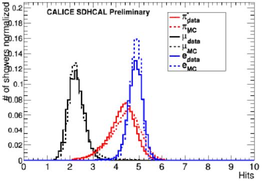


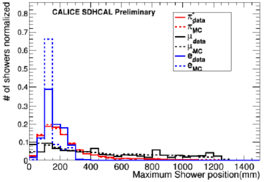
BDT variables after pion selections

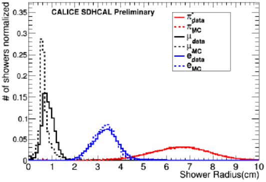




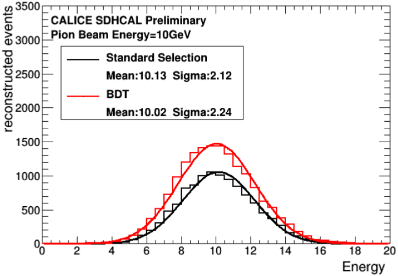


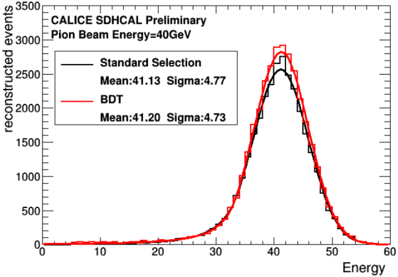


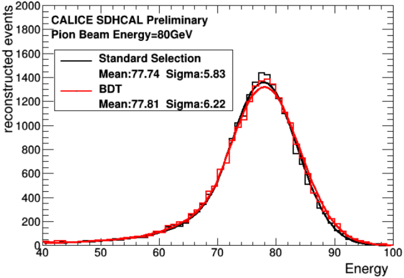




Energy reconstruction comparison







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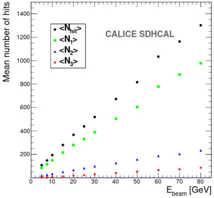
$$\alpha = \alpha_0 + \alpha_1 N_T + \alpha_2 N_T^2$$

$$\beta = \beta_0 + \beta_1 N_T + \beta_2 N_T^2$$

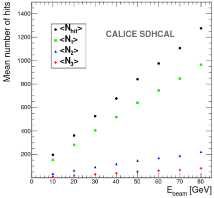
$$\gamma = \gamma_0 + \gamma_1 N_T + \gamma_2 N_T^2$$

$$N_T = N_1 + N_2 + N_3$$

H6 (Π^+)



H2 (Π^-)

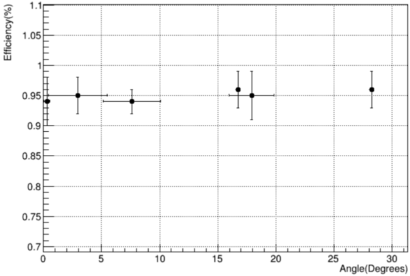


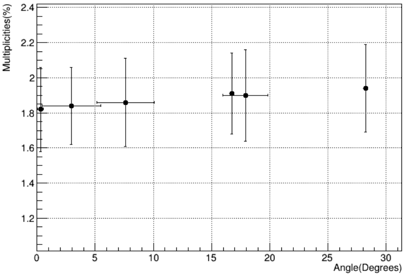
The set of optimal parameters is found from minimzing the χ^2 function using a third of the data.

$$\chi^2 = \sum_{i=1}^{N} \frac{(E^i_{Beam} - E^i_{Reco})^2}{\sqrt{E^i_{Beam}}}$$

Incident angle effect

During the campaigns of May-June 2015 data from pions at different incident angles was collected. As the angle increases so does the multiplicity producing more hits and a different energy parametrization would be necessary per angle.





Angle correction

By applying a correction to the number of hits per threshold as $cos(\theta)$ the linearity and resolutions from the 0° results can be restored with the same parametrization. The angle is taken from the track reconstructed using the first layers of the pion signal, before showering.