Results of the SDHCAL technological prototype

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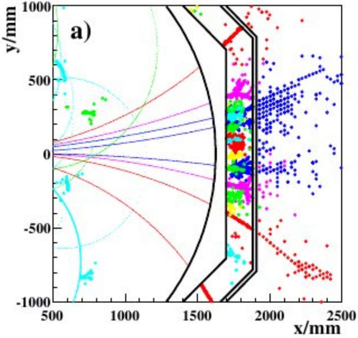
Outline

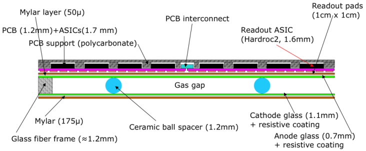
SDHCAL Motivation

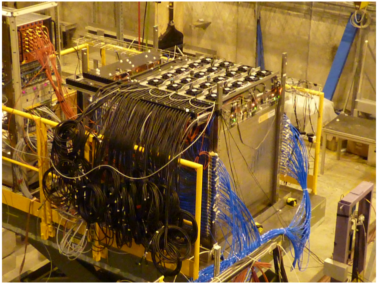
- Highly granular gaseous hadronic calorimeters provide:
  - a powerful tool for the PFA (Particle Flow Algorythm)
  - a good energy resolution
  - a robust detector for the study of hadronic showers
- Compatible with ILC requirement:
  ⇒ low power of consumption



SDHCAL Description

- Sampling calorimeter
- Size : 51 stainless steel plates + 50 active layers $\rightarrow$ $1 \times 1 \times 1.3 m^3$
- Active layer :
  - Gaseous detector : GRPC (Glass Resistive Plate Chamber) of $1 m^2$
  - Gas mixture : $93\% TFE$; $5\% CO_2$; $2\% SF_6$
  - HV : $\sim 6.9 kV$ in avalanche mode
- Readout :
  - 96×96 pads per layer $\Rightarrow$ more than $460k$ channels for the whole prototype
  - Semi-digital readout : 3 thresholds on the induced charge to have a better idea on the deposited energy
- Radiator :
  - $50 \times 20 mm$ stainless steel $\Rightarrow$ $\sim 6\lambda_I$



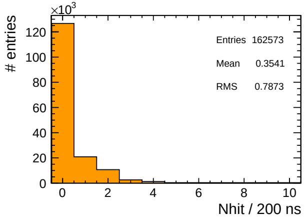


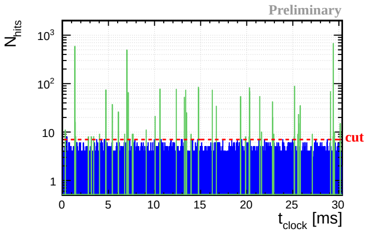
Test beam

- Test beam periods and statistics
  - CERN SPS May 2012 on H2 (2 weeks)
  - CERN SPS August-September 2012 on H6 (2 weeks)
  - CERN SPS November 2012 on H2 (1 week)
  - Totally : $>400k$ of π, $>1M$ of μ
  - Several dedicated runs for a threshold scan during Aug-Sep test beam.
- GRPC running conditions
  - 48 active layers
  - Average MIP induced charge $\sim 1.2\ pC$
  - Threshold values : $0.114, 5.0, 15.0\ pC$ $(0.1, 4, 12.5\ MIP)$
  - No gain correction
- Beam set-up
  - Beam energy known with 1% of accuracy
  - Large beam profile to have a low particle rate ($< 100Hz/cm^2$) and keep a good efficiency

Data taking

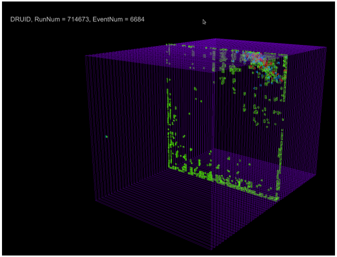
- Trigger less mode : all events recorded until memory is full
- Power pulsed mode : according to the time spill structure
  - 10 s every 45 s @ SPS
- ASIC internal clock : $200ns$
- Average noise for the full detector :
  - $0.35 Hits/200 ns$
- Physical events construction :
  - Nhit>7 in one time tick (t_0) is needed
  - Sum all hits recorded at $t = t_0 \pm 200$ ns





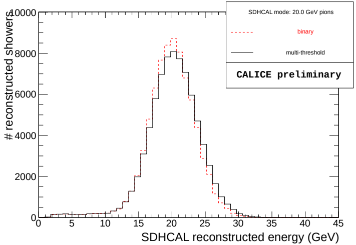
Data quality control

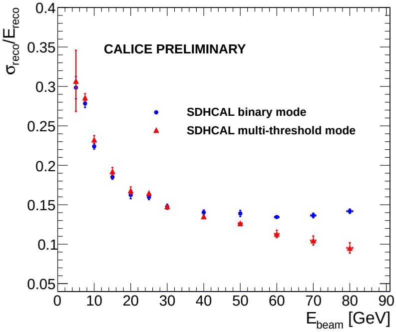
- Online control :
  - ASIC occupancy → chip noise
  - Efficiency per layer estimated using tracks (cosmics and muons from the beam)
- Offline control :
  - Part of noise removed by the event construction
  - Coherent noise :
    - Due to grounding problem in some layers
    - Easy to remove those events with their particular topology

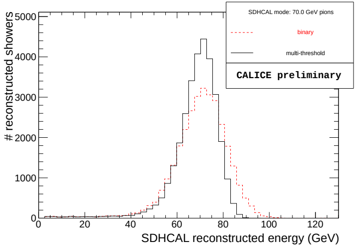


First results

- Different particle identification ⇒ electron rejection based on fractal dimension cuts (eq. 5).
- Significant impact of 2^{nd} & 3^{rd} thresholds on the energy resolution at high energy (for $E_\pi \geq 40 GeV$)

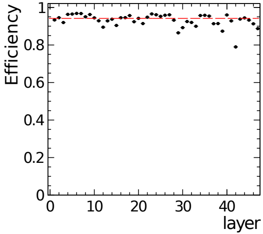


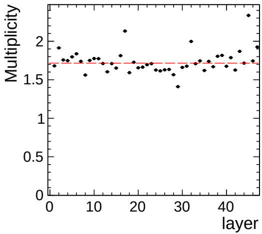




μ track selection

- Track construction :
  - hits grouped into cluster in each layer using nearest neighbors
  - isolated clusters removed
  - track reconstructed if remaining 7 layers
  - linear fit applied
- Track selection
  - $\chi^2 < 20$
  - $N_{cluster} \leq 1$ in each layer
  - $N_{hit}(cluster) \leq 5$
- Efficiency and multiplicity per layer estimated from reconstructed tracks from other layers
  - Efficiency = presence of at least one hit within $2cm$ radius around the expected impact point of the track $\bar{\epsilon} \simeq 0.95$
  - Multiplicity = number of hits per cluster $\bar{\mu} \simeq 1.73$



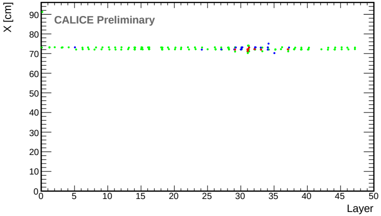


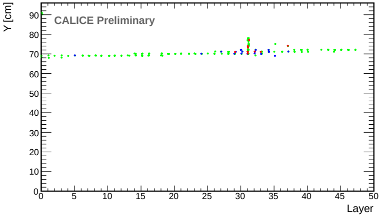
Particle identification

Proton contamination in H6 beam line above 20 GeV : *[Study of energy response and resolution of the ATLAS barrel calorimeter to hadrons from 20 to 350 GeV, Nuclear Instruments and Methods in Physics Research A 621 (2010) 134-150]* .

No Cherenkov counter ⇒ simple topological selection :

- Beam-Cosmic muons rejection : $\frac{N_{hit}}{Nlayer} > 2.2$.
- Neutrals rejection : $N_{hit \in First\ 5\ layers} \geq 4$.
- Radiatives muon rejection : $\frac{N_{layer} \setminus RMS > 5cm}{N_{layer}} > 20\%$.
- Electrons rejection.





Electron rejection

Shower Starting Layer (SSL) $\Rightarrow$ first layer with at least 4 hits and with the three following layers with at least 4 hits.

Electron cut :

$$SSL \geq 5 \text{ OR } N_{layer} \geq 30$$

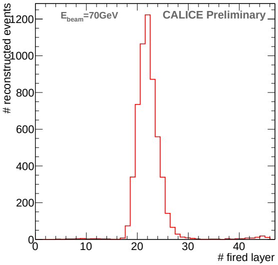


Figure : Distribution of number of fired layers for a 70 GeV electron run.

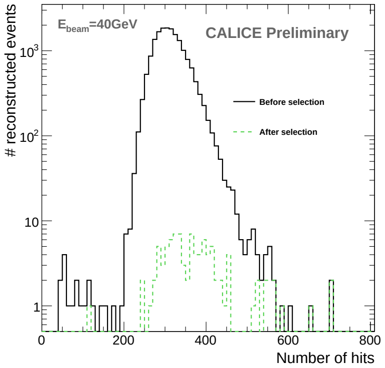


Figure : Hit distribution for a 40 GeV electron run before (solid black line) and after (dashed green line) electron rejection.

Final selection

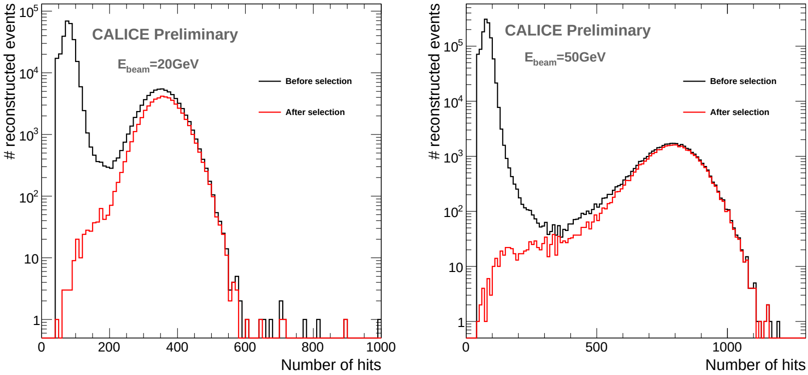
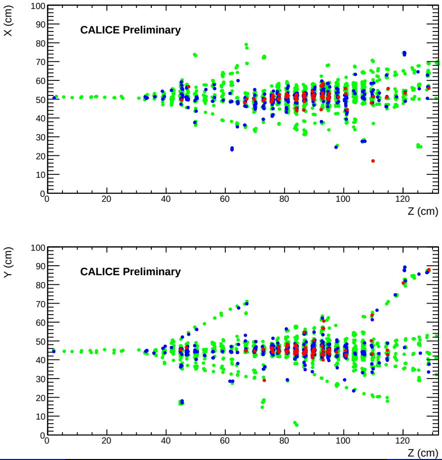


Figure : Number of hit distribution for 20 and 50 GeV pion runs before (black line) and after (red line) the selection.

Semi-digital information

- Threshold position : $0.114, 5.0, 15.0pC$ ($0.1, 4, 12.5$ MIP)
- Additional information on shower structure
  - 2^{nd} and 3^{rd} thresholds are in the core of the shower
- 1^{st} threshold; 2^{nd} threshold; 3^{rd} threshold



Energy reconstruction

- N_i : number of hits per threshold
- Reconstructed energy :
  - $E_{reco} = \alpha N_1 + \beta N_2 + \gamma N_3$
  - $\alpha, \beta, \gamma = f(N_{hit})$
  - Chosen parametrisation : quadratic function of N_{hit}
  - α, β, γ determined using a χ^2 minimisation

$$\chi^2 = \sum_{i=1}^{N} \frac{(E^i_{beam} - E^i_{reco})^2}{E^i_{beam}} \quad (1)$$

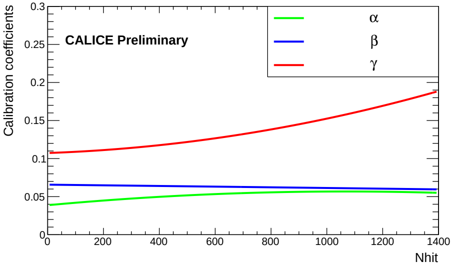
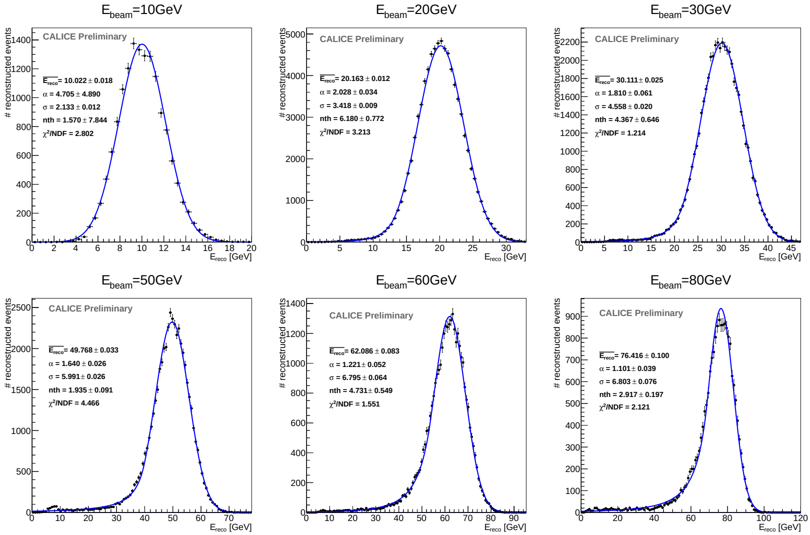


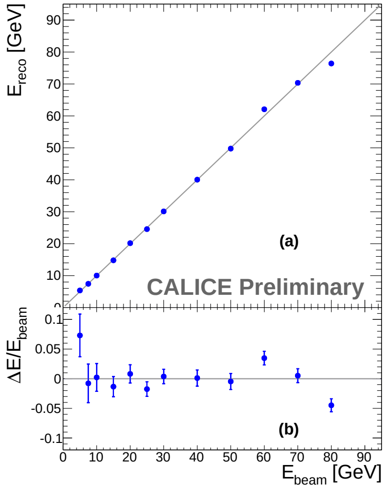
Figure : α, β and γ evolution in terms of the total number of hits.

Energy reconstruction

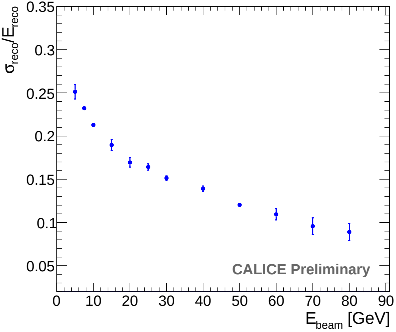
Fit with a Crystall Ball function (eq. 2)



Linearity and energy resolution



- Good linearity $\frac{\Delta E}{E} \leq 5\%$ (except at 5 GeV).
- Nice energy resolution without gain correction, local correction.

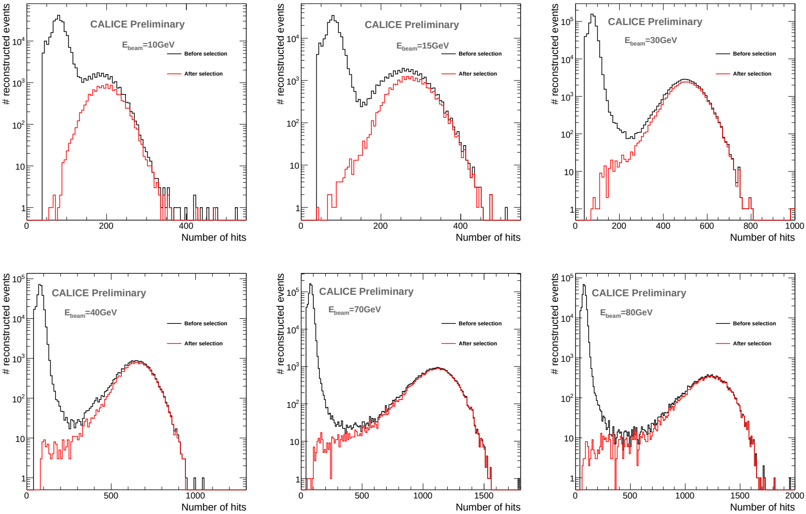


Summary

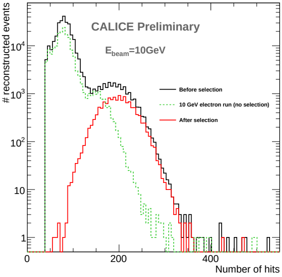
- The CALICE technological SDHCAL_GRPC prototype using 48 layers with its 6 λ_I was successfully tested at CERN
  - Power-Pulsing mode allows optimal conditions (temperature, noise) and it was the running mode during those different TB.
  - Excellent data quality was obtained in TB.
- Multi-Threshold mode brings significant improvement @ $E_{beam} \geq 40\ GeV$
- Results with simple selection without data treatment (no gain correction, no local calibration ...) indicate a good single particle energy resolution for pions
- We intend to use the shower topology (neural networks, boost decision tree) to better reconstruct the energy and improve on the energy resolution.

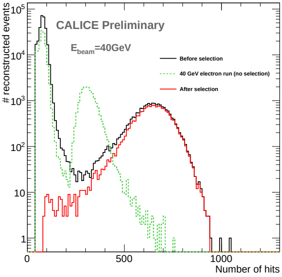
Back-up

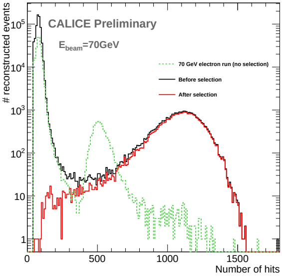
Pion selection



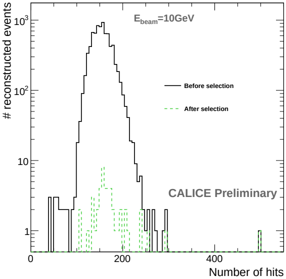
Electron-Pion separation

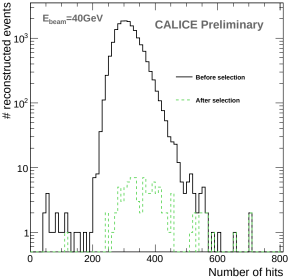


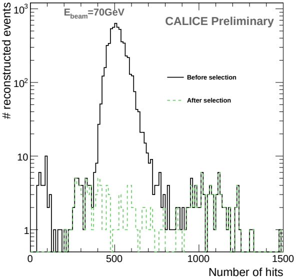




Electron-Pion separation







Crystall Ball function

$$f(x;\alpha,nth,\bar{x},\sigma) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}) & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-nth} & \text{for } \frac{x-\bar{x}}{\sigma} \leq -\alpha \end{cases} \quad (2)$$

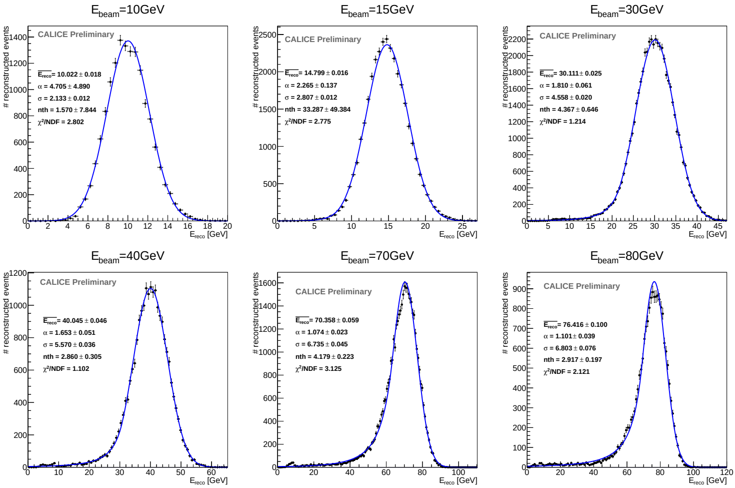
where:

$$A = \left(\frac{nth}{|\alpha|}\right)^{nth} \cdot \exp\left(-\frac{|\alpha|^2}{2}\right) \quad (3)$$

$$B = \frac{nth}{|\alpha|} - |\alpha| \quad (4)$$

N is a normalization factor.

Energy distribution



Previous Analysis

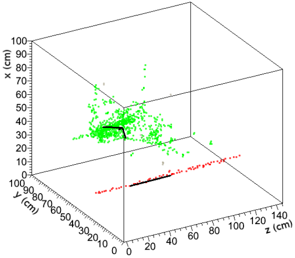
- Principal component analyis (PCA)
  - Principal axes computed $\Rightarrow$ eigen values λ_1, λ_2, λ_3
  - $\lambda_1 < \lambda_2 < \lambda_3$; $\lambda_i \equiv \sigma_i(hits)$ for the axis i
  - Transverse ratio $TR = \frac{\sqrt{\lambda_1^2+\lambda_2^2}}{\lambda_3}$
- Interaction plan
  - PCA applied also in each plane $\Rightarrow (\lambda_{1,p},\ \lambda_{2,p})$
  - Interaction plane = Layer with $\sqrt{\lambda_{1,p}^2 + \lambda_{2,p}^2} > 1.5cm$ and $N_{hit} > 5$
- Density
  - $V1 = \frac{N_{hit}^{25}}{N_{hit}}$ where N_{hit}^{25} is the number of hit in the $5 \times 5cm$ arround the barycenter
  - $V2 = \frac{FD_{3D}}{\ln N_{hit}}$

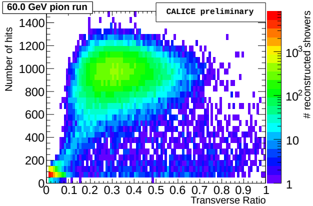
$$FD_{3D} = \frac{1}{|I|} \frac{\sum_{n \in I} \ln(N_{hit}/N_{cube}(n))}{\ln n} \quad (5)$$

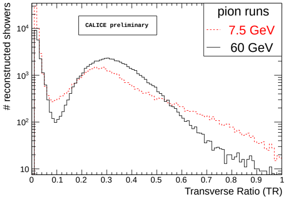
$I = \{2, 3, 4, 6, 8, 12, 16\}$
$N_{cube}(n)$: number of cubes containing $n \times n \times n$ pads with at least one hit

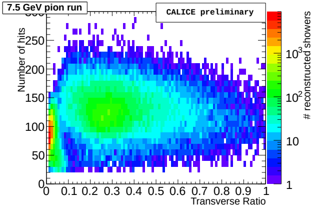
Previous Analysis : beam and cosmic muon rejection

- $TR \geq 0.1 \Rightarrow 98\%$ rejection of muons





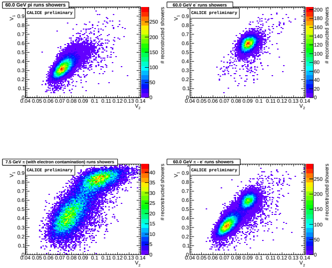


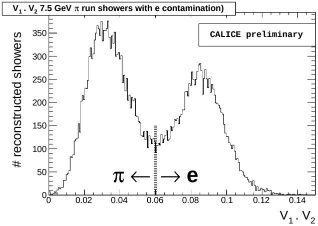


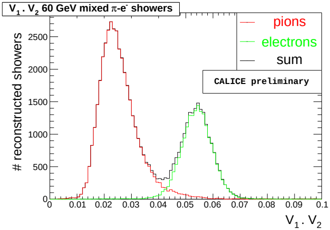
e/π separation

- Cut on V1.V2 for the electron rejection
- Negligible loss of pions at high energy
- Cut on V1.V2 depends on the energy :

Energy [GeV]	cut V1.V2
5	0.065
7.5 — 15	0.06
20 — 25	0.055
30 — 40	0.05
50 — 60	0.045
70 — 80	0.04

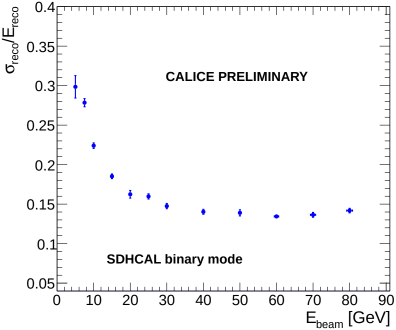


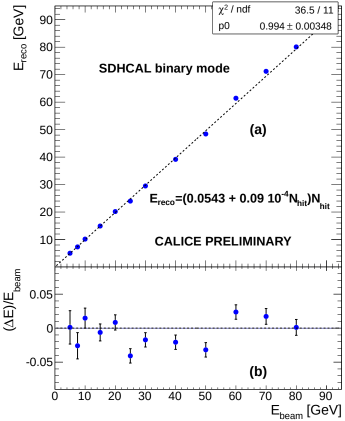




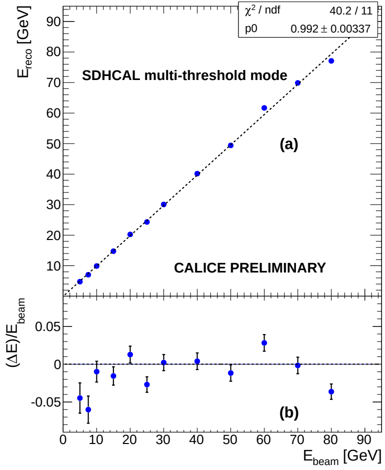
Binary mode : Linearity & energy resolution

- Additional cut for leakage reduction:
  - shower starting layer < 15
  - $\frac{N_{hit \in last\ 7\ layers}}{N_{hit}} < 0.15$
- $E_{reco} = (C + DN_{hit}) \times N_{hit}$
- Energy resolution increases above $60 GeV$





Multi-threshold mode : Linearity & energy resolution



- Significant impact on the energy resolution at high energy