Energy reconstruction study in a High Granularity Semi-Digital Hadronic Calorimeter for ILC

ACAT 2016 - 17th INTERNATIONAL WORKSHOP ON ADVANCED COMPUTING AND ANALYSIS TECHNIQUES IN PHYSICS RESEARCH

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Outline

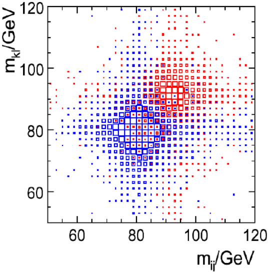
- The Semi-Digital Hadronic CALorimeter(SDHCAL) is one of the calorimeters developped within the CALICE collaboration proposed for the Future International Linear Collider experiments.
- ILC should be equiped with high precision detectors
- Excellent Jet energy Resolution $3\%/E_{jet}$

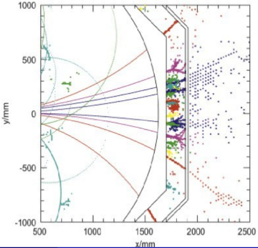
$$\sigma_{jet} = \sqrt{\sigma^2_{Track} + \sigma^2_{Had} + \sigma^2_{elm} + \sigma^2_{confusion}}$$

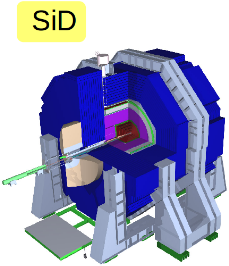
- PFA: Construction of individual particles and estimation of their energy/momentum in the most appropriate sub-detector

Construction of Highly Granular Calorimeters to separate overlapping showers

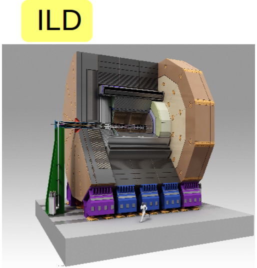
W, Z separation in the ILD Concept







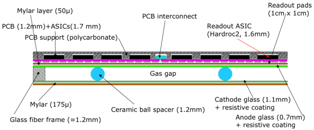
- DHCAL: Binary readout
  1-bit readout electronics (1 threshold)
  Lateral segmentation of 1 cm2

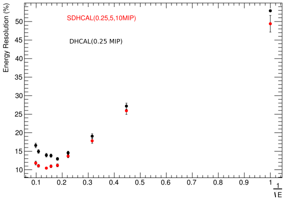


- Analog HCAL readout directly by SiPM and embedded electronics
- SDHCAL: 2-bit electronics (3 thresholds)
  Lateral segmentation of 1 cm2

SDHCAL prototype technology

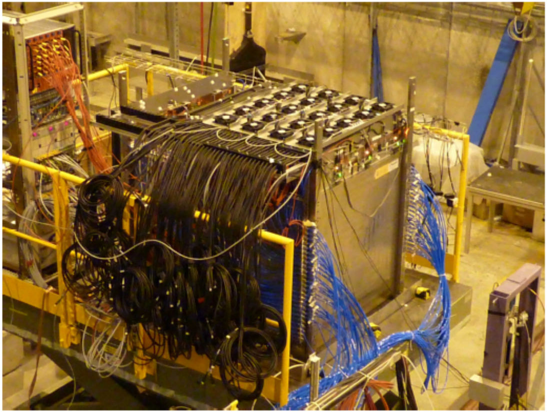
- Sampling calorimeter
- Size: 48 stainless steel plates + 48 active layers $\Longrightarrow 1 \times 1 \times 1.3 m^3$
- Active layer
  - Gaseous detector: GRPC (Glass Resistive Plate Chamber) of $1 m^2$
  - Gas mixture: tetrafluoroethane(TFE, 93%), isobutane (5%) and SF_6 (2%)
  - HV: $\sim 6.9 kV$ in avalanche mode
- Readout
  - 96×96 pads of $1 cm^2$ per layer $\Longleftrightarrow$ more than 460000 chanels for the whole prototype
  - Semi-digital readout: 3 thresholds on the induced charge to have a better idea on the deposited energy
- Absorber:$48 \times 20 mm$ stainless steel $\Longleftrightarrow \sim 6\lambda$





SDHCAL prototype technology

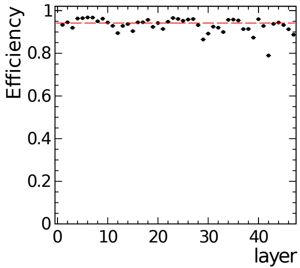
- A technological prototype was built with a self-supporting mechanical structure, fulfilling almost all the ILD requirements
  - compactness
  - homogeneity
  - low power consumption
    - Power pulsing mode: Important feature of ILC detectors to reduce power consumption and heating for highly-granular detectors
      Electronics switched on just before the bunches train and off after

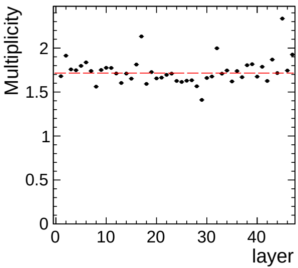


Tests beam summary

- August-September 2012 on *H*6 line for 2 weeks
- November 2012 on *H*2 line for 1 week
- December 2014 on H6 line for 1 week
- Large beam size, low particle rate $<$ 1000 particle/spill
- Triggerless acquisition: all hits are recorded untill a ramfull occurs, then data transferred and acquisition starts again
- Power pulsing

- Efficiency: probability to find at least 1 hit within 3cm of the reconstructed track in the studied layer. $\bar{\epsilon} \sim 96\%$
- Multiplicity: mean number of hits matched on studied layer within 3cm of the impact track $\bar{\mu} \sim 1.7$



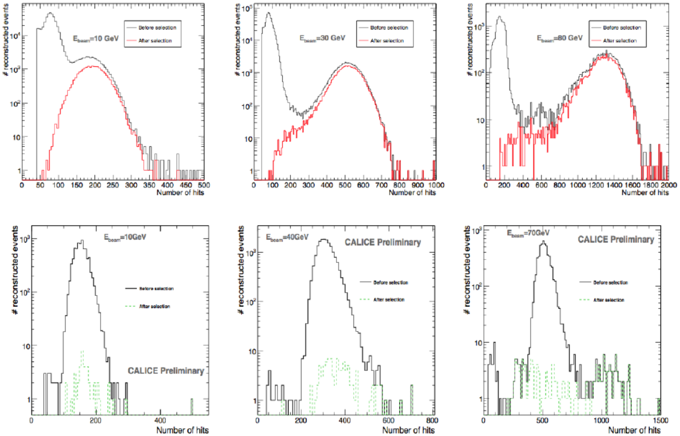


Event selection

Event selection

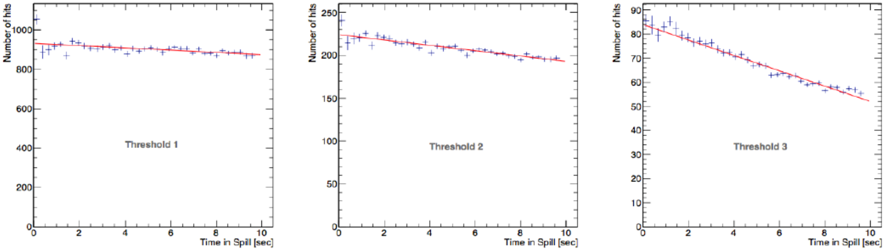
Electron rejection	Shower start ≥ 5 or $N_{layer} \geq 30$
Muon rejection	$\frac{N_{hit}}{N_{layer}} > 2.2$
Radiative muon rejection	$\frac{N_{layer} \backslash RMS>5cm}{N_{layer}} > 20\%$
Neutral rejection	$N_{hit \in First\ 5\ layers} \geq 4$

No containement cuts



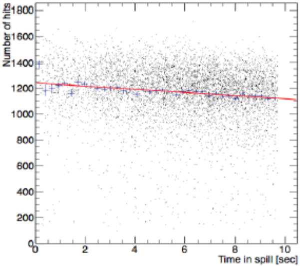
Calibration

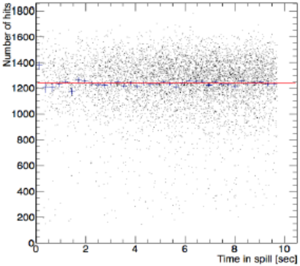
- the beam parameters were optimized to get spills containing less than 1000 particles
- For some runs with rather high intensity, the number of hits go down with time within a spill especially with the number of hits associated to the second and the third thresholds.
- Limitation of the GRPC rate capability
- Degradation of the energy resolution.

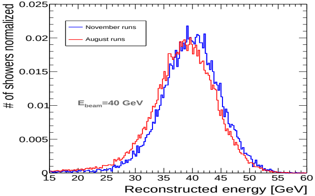


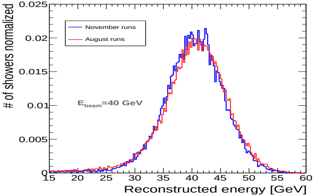
Calibration

- We correct for using a simple formula $N_{\mathrm{corr_i}} = N_{\mathrm{i}} - S_{\mathrm{lope_i}} \times T_{\mathrm{imeInSpill}}$.
- N_{i} : number of hits for each event



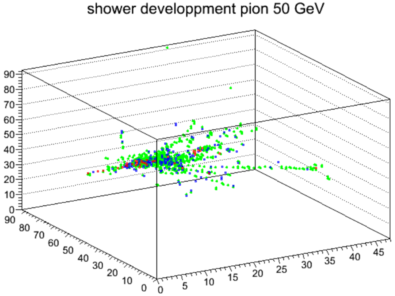


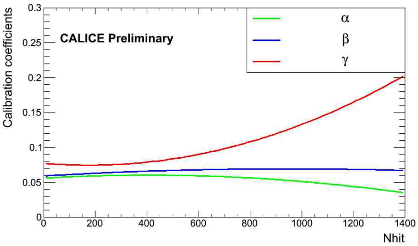




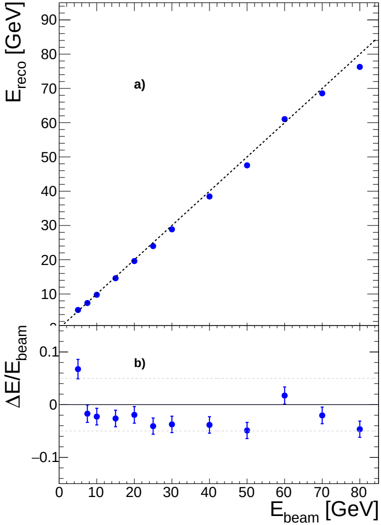
Energy reconstruction: Quadratic parametrisation

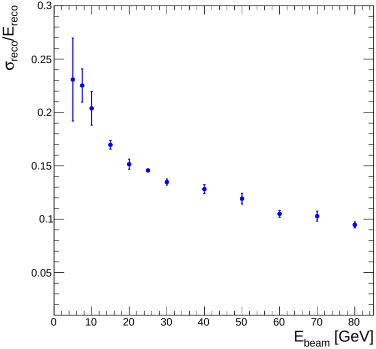
- $E_{\rm rec} = \alpha(N_{\rm tot}) \times N_1 + \beta(N_{\rm tot}) \times N_2 + \gamma(N_{\rm tot}) \times N_3$ in case of S.D readout.
- $E_{\rm rec} = CN_{\rm tot} + DN_{\rm tot}^2 + FN_{\rm tot}^3$ in case of Binary readout
- $\rm N_1, N_2, N_3$: number of hits for thresholds 1,2,3(0.114pC,5pC,15pC)
  $N_{\rm tot} = N_1 + N_2 + N_3$
  $\alpha(N_{\rm tot}) = \alpha_1 + \alpha_2 \times N_{\rm tot} + \alpha_3 \times N_{\rm tot}^2$
  $\beta(N_{\rm tot}) = \beta_1 + \beta_2 \times N_{\rm tot} + \beta_3 \times N_{\rm tot}^2$
  $\gamma(N_{\rm tot}) = \gamma_1 + \gamma_2 \times N_{\rm tot} + \gamma_3 \times N_{\rm tot}^2$
- α, β, γ: quadratic weights of $\rm N_{tot}$ obtained from like χ^2 minimisation:
- $\chi^2 = \sum_{i=1}^{N} \frac{((E_{\rm beam} - (E_{\rm rec}))^2}{E_{\rm beam}}$





Binary-based study

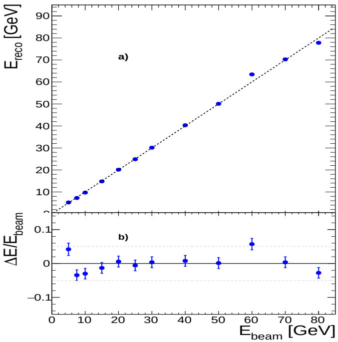


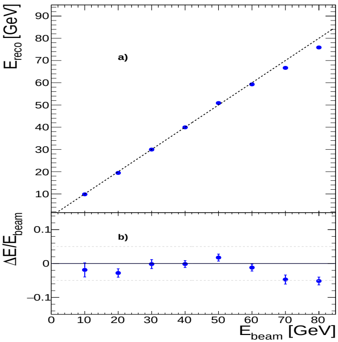


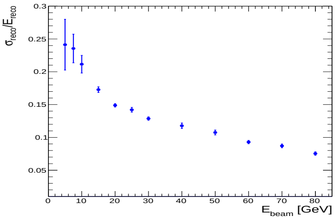
Systematics

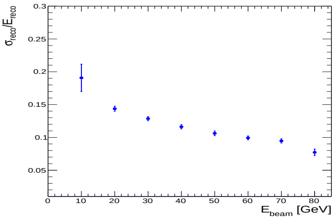
- Systematics
- Changing the cuts (5% changes)
- Differences observed in simulation with and without cuts
- Beam energy (2%). this includes difference coming from proton/pion (in case of H6 data)
- Difference between fit using CB and Gaussian fits)

Multithreshold-based study

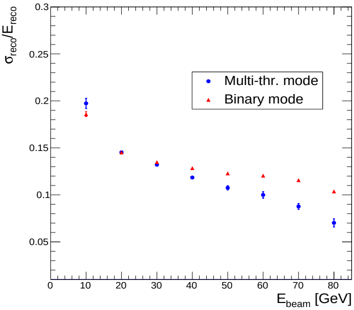


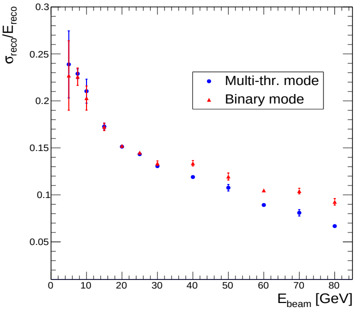


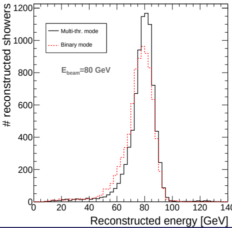


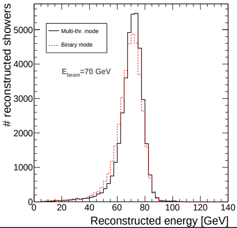


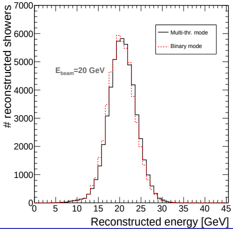
Multi-threshold vs Binary





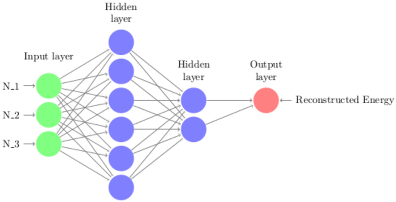




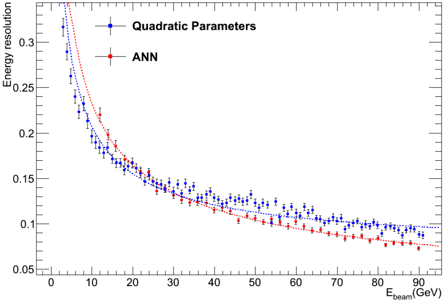


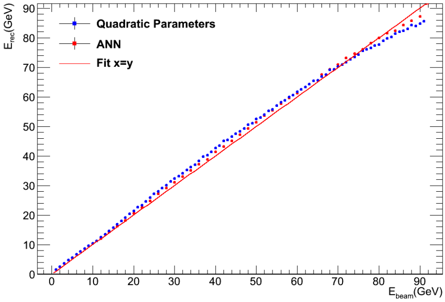
Energy reconstruction: Artificial Neural Networks

- TMultiLayerPerceptron of root package.
- 2 hidden layers with 6 and 2 neurons.
- The input variables: N_1,N_2,N_3 .
- The output variable is the reconstructed energy: $\mathrm{E}_{\mathrm{rec}}$.
- Monte Carlo Simulation
  - Training Samples: Odd energies, 1-99 GeV (50 training samples)
  - Test Samples: Even energies, 10-90 GeV (40 test samples)



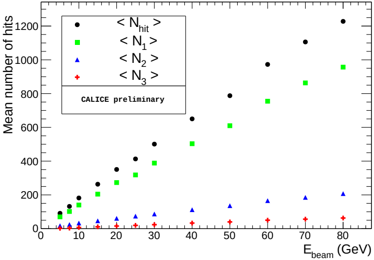
ANN results in MonteCarlo Simulation

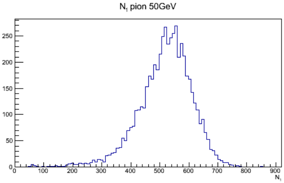


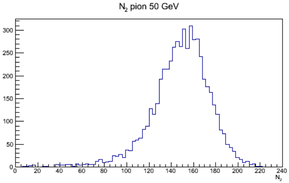


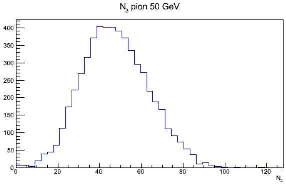
ANN results in Data

- Architecture of the ANN : One hidden layer of 8 neurons.
- The input variables: $\mathrm{N_1}$,$\mathrm{N_2}$,$\mathrm{N_3}$.
- The output variable is the reconstructed energy: $\mathrm{E_{rec}}$.
- Data SPS H2 and H6 taken during 2012
  - Training Samples: Trained with Simulation samples, odd energies:1-99GeV
  - Test Samples: 2012 tests beam data: Energies(5,7.5,10,15,20,25,30,40,50,60,70 and 80 GeV)
  - An improvement in energy resolution reaching 13% at high energies comparing to quadratic method



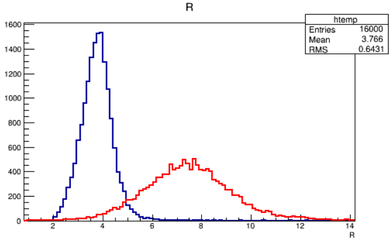


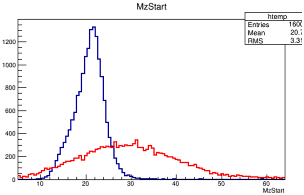


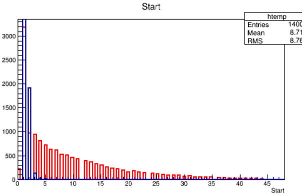


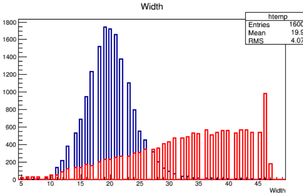
Muon/electron identification using ANN in MC

- TMVA of root.
- Method: Multilayer perceptron MLP.
- Training
  - 28000 electron : energies: 2,3,8,10,15,20,25,30,40,50,60,70 and 80 GeV
  - 14000 pion with energies 10,20,30,40,50,60,70 and 80 GeV
  - 9000 muons events with energies: 0.5, 2 and 10 GeV
- Variables: the total number of hits, start, width, mean radius, longitudinal centre of gravity of the shower

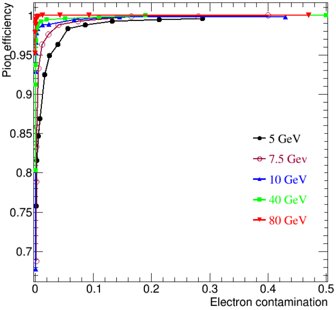


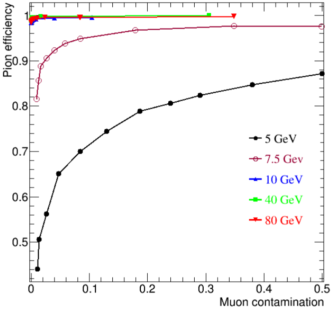


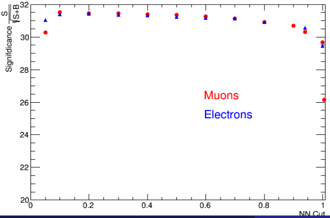


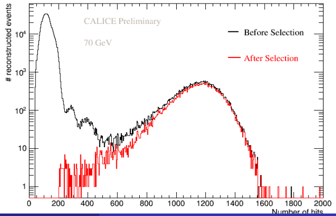


Muon/electron identification using ANN in MC









Conclusion

- The SDHCAL prototype is built and successfully tested in tests beam
- Good data quality and stability were observed
- Analytic energy reconstruction method is well understood: Good energy resolution with satisfactory linearity
- ANN technique used for energy estimation giving promising results
- ANN used in particles identification giving similar results to classic event selection with a slight improovement in energy resolution but a better linearity.

Back-up

PFA

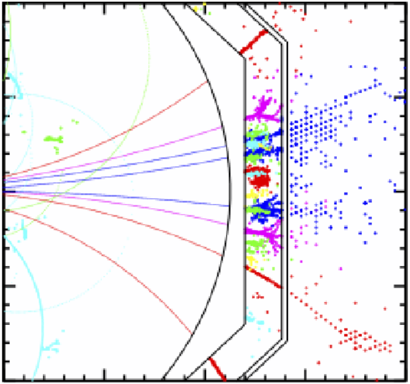
Charged particles: 65%
precise measurement by Tracker

Photons : 25 % measured by EM calorimiters

Neutral hadrons : 10 % measured by HCAL

Tracker measure the Energy deposited of **charged particules** then eliminate them of the calorimeters.

Calorimeters are used to measure **Neutral particules** once deposited energy of charged particles eliminated

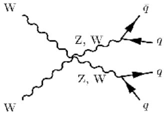


$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E/\,\mathrm{GeV}}} \oplus 0.7 \oplus 0.004E \oplus 2.1 \left(\frac{E}{100\,\mathrm{GeV}}\right)^{0.3} \%$$

Calorimeter **Track** **Leakage** **Confusi**

To distinguish between Z,W± jets, the ILD energy resolution should be comparable to the widht of the bosons mass spectrum < $30\%/\sqrt{E}$.

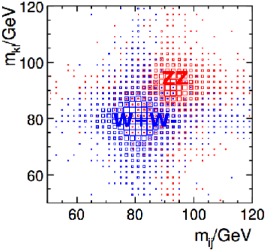
mZ/mW = 1.13	
mZ- mW = 10.7698 GeV	
mZ = 80.42 GeV	mW =91.18GeV
ΓW = 2.046±0.049 GeV	
ΓZ = 2.4952±0.0041 GeV	

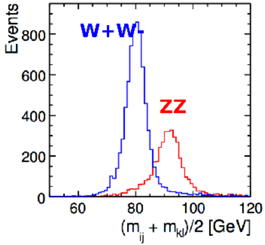


$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E/\,\mathrm{GeV}}} \oplus 0.7 \oplus 0.004E \oplus 2.1\left(\frac{E}{100\,\mathrm{GeV}}\right)^{0.3} \%$$

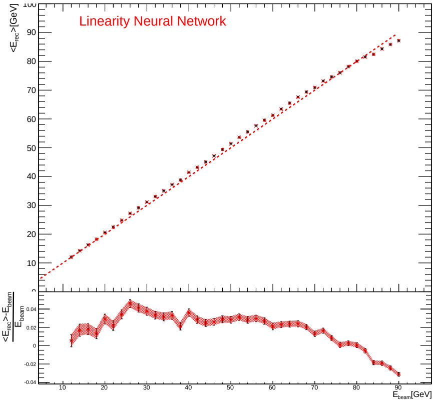
Calorimiters **Tracker** **Leakage** **Confusion**

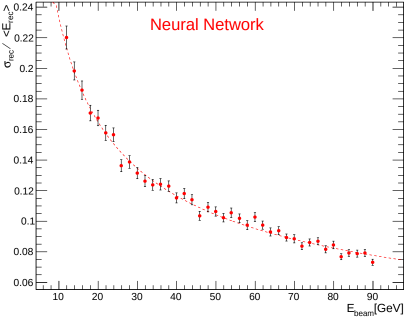
High granular calorimiters allow the minimisation of the confusion term in energy resolution



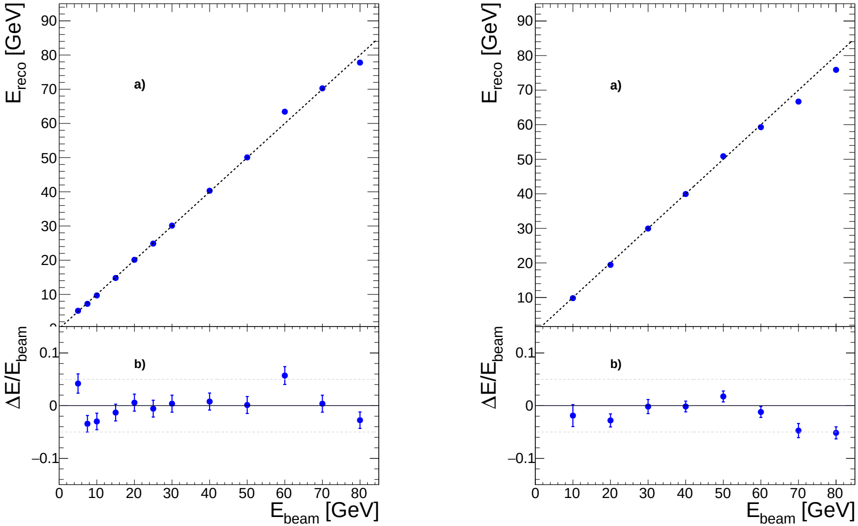


ANN MonteCarlo





Multithreshold-based study



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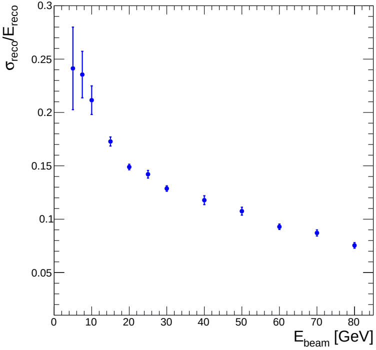
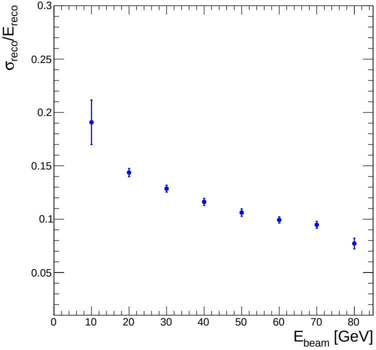
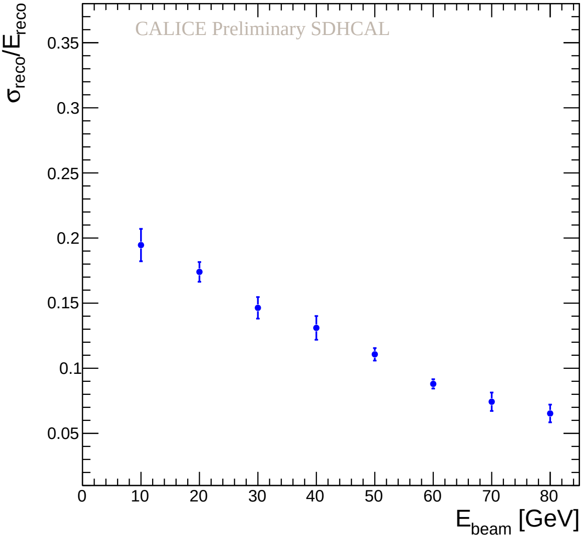
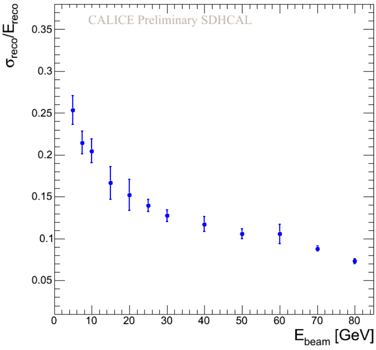


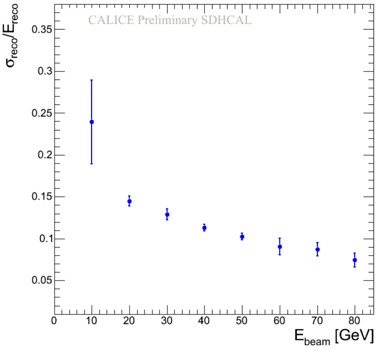


NN regression estimation

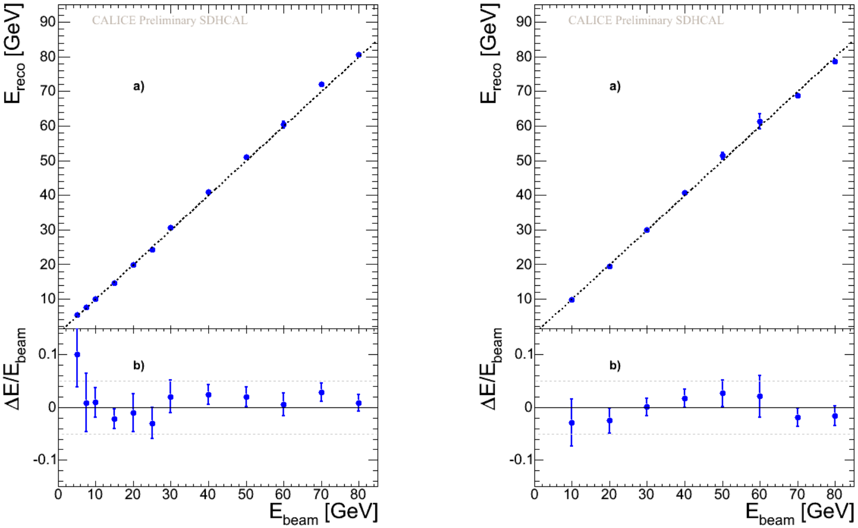


NN Identification





NN Identification



Event selection

- Pions Data are contaminated with muons,cosmics, electrons $\Longrightarrow$ Event selection
  - Electron rejection: Shower Start > 4
  - Muon rejection: $N_{hit}/N_{layer} > 2.2$
  - Neutral rejection: N_{hit} in the first 5 layers> 4