



# Energy reconstruction study in a Semi-Digital Hadronic Calorimeter for ILC CHEP 2015 - Computing in High Energy and Nuclear Physics

Sameh Mannai

Université Catholique de Louvain

CHEP April 13-17 2015

A D > A B > A

# Outline

#### Introduction

- Motivation
- The Semi Digital Hadronic Calorimeter prototype

#### 2 Beam Tests campaigns at Cern

- Tests beam summary
- SDHCAL Performance
- Event Selection

Hadronic energy reconstruction techniques in SDHCAL

- Energy reconstruction: Quadratic Parametrisation
- Energy reconstruction: Artificial Neural Network

#### 4 Conclusion

- ILC should be equiped with high precision detectors
- Excellent Jet energy Resolution  $3\%/E_{jet}$  $\sigma_{jet} = \sqrt{\sigma_{Track}^2 + \sigma_{Had}^2 + \sigma_{elm}^2 + \sigma_{confusion}^2}$
- 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



500 1000 1500 2000



• 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

Image: A math a math

# SDHCAL prototype technology

- Sampling calorimeter
- Size: 48 stainless steel plates + 48 active layers  $\implies 1 \times 1 \times 1.3m^3$
- Active layer
  - Gaseous detector: GRPC (Glass Resistive Plate Chamber) of  $1m^2$
  - Gas mixture: tetrafluoroethane(TFE, 93%), isobutane (5%) and  ${\rm SF}_6$  (2%)
  - HV:  $\sim 6.9 kV$  in avalanche mode
- Readout
  - 96  $\times$  96 pads of 1*cm*<sup>2</sup> per layer $\iff$  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  $\times$  20mm stainless steel  $\iff \sim 6\lambda$





- A technological prototype was built with a self-supporting mechanical structure, fulfilling almost all the ILD requirements
  - compactness
  - homogeneity
  - low power consumption
  - Successfully tested with Triggerless mode and Power pulsing mode



- August-September 2012 on H6 line for 2 weeks
- November 2012 on H2 line for 1 week
- December 2014 on H6 line for 1 weeks
- Large beam size, low particle rate < 1000 particle/spill
- Triggerless acquisition: readout all data recorded
- Power pulsing: idle electronics between 2 beam spills

A D > A B > A

- $\bullet$  Efficiency: probability to find at least 1 hit within 3cm of the reconstructed track in the studied layer.  $\bar{\epsilon}\sim96\%$
- $\bullet\,$  Multiplicity: mean number of hits matched on studied layer within 3cm of the impact track  $\bar{\mu}\sim 1.7$



< □ > < 同 >

#### Event selection

- Pions Data are contaminated with muons, cosmics, electrons  $\implies$  Event selection
  - Electron rejection: Shower Start > 4
  - Muon rejection:  $N_{hit}/N_{layer} > 2.2$
  - Neutral rejection: N<sub>hit</sub> in the first 5 layers> 4
  - Double incident particles rejection: distance between hits in each of the first 5 layers  $\leq 5 cm$



Sameh Mannai (UCL)

- Pions Data are contaminated with muons,cosmics, electrons ⇒ Event selection
  - Electron rejection: Shower Start > 4
  - Muon rejection:  $N_{hit}/N_{layer} > 2.2$
  - Neutral rejection: N<sub>hit</sub> in the first 5 layers> 4
  - Double incident particles rejection: distance between hits in each of the first 5 layers ≤ 5cm



A B A A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A

#### Energy reconstruction: Quadratic parametrisation

- $E_{\rm rec} = \alpha(N_{\rm tot}) \times N_1 + \beta(N_{\rm tot}) \times N_2 + \gamma(N_{\rm tot}) \times N_3$
- N<sub>1</sub>,N<sub>2</sub>,N<sub>3</sub>: number of hits for thresholds 1,2,3  $N_{\text{tot}} = N_1 + N_2 + N_3$   $\alpha(N_{\text{tot}}) = \alpha_1 + \alpha_2 \times N_{\text{tot}} + \alpha_3 \times N_{\text{tot}}^2$   $\beta(N_{\text{tot}}) = \beta_1 + \beta_2 \times N_{\text{tot}} + \beta_3 \times N_{\text{tot}}^2$  $\gamma(N_{\text{tot}}) = \gamma_1 + \gamma_2 \times N_{\text{tot}} + \gamma_3 \times N_{\text{tot}}^2$
- $\alpha, \beta, \gamma$ : quadratic weights of  $N_{tot}$  obtained from like  $\chi^2$  minimisation:
- $\chi^2 = \sum_{i=1}^{N} \frac{((E_{\text{beam}} (E_{\text{rec}}))^2)}{E_{\text{beam}}}$





3

・ロト ・日下・ ・ ヨト・

### Energy resolution results



< □ > < □ > < □</p>

Energy reconstruction in SDHCAL

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



Image: A math a math

CHEP April 13-17 2015 14 / 18

# ANN results in MonteCarlo Simulation



CHEP April 13-17 2015 15 / 18

- Architecture of the ANN : One hidden layer of 8 neurons.
- $\bullet$  The input variables:  $N_1,\!N_2,\!N_3$  .
- $\bullet$  The output variable is the reconstructed energy:  $E_{\rm rec}$  .
- Data SPS H6 2014
  - Training Samples: Trained with Simulation samples(1000 events per energy), Energies:1-50GeV)
  - Test Samples: 2014 test beam data (4500 events per energy): Energies(20,25,30,35,40,45 GeV)







A B > 4
 B > 4
 B

- The SDHCAL prototype is built and successfully tested in tests beam
- Good data quality and stability were observed
- Analytic energy reconstruction method: energy resolution reaches < 6% at  $80\,\text{GeV}$  with satisfactory linearity
- ANN technique giving promised results: To be improved
  - Ongoing study: To improve Energy resolution with ANN, more variables added as inputs to ANN is under investigation
  - topologic variables of hadronic shower: shower start, Mean radius shower, Lenght of the shower...
  - Add more energy points: Next test beam at Cern May 2015

# Back-up

æ

▲□▶ ▲圖▶ ▲国▶ ▲国▶

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

$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E/\text{GeV}}} \oplus 0.7 \oplus 0.004E \oplus 2.1 \left(\frac{E}{100 \text{ GeV}}\right)^{0.3} \%$$
Calorimeter Track Leakage
Sameh Manai (UCL)
Energy reconstr



uction in SDHCAL

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





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





CHEP April 13-17 2015 18 / 18

< □ > < □ > < □</p>