HCal Simulation Studies

Steven Green

University of Cambridge

sg568@hep.phy.cam.ac.uk

January 28, 2015

Overview

Introduction

Looking to optimise the physics performance of the **HCal** in the context of a future linear collider. These studies are focused on ILD.

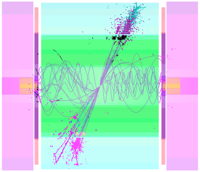


Figure : 500 GeV Di-Jet.

Figure of merit: jet energy resolution. Jets from decay of off-shell mass Z bosons to light quarks → typically forms two mono energetic back to back jets.

HCal parameters to be optimised:

Absorber Material

Default for ILD: Steel

Tile Size

Default for ILD: $30 \times 30\text{mm}^2$ square cells. HCal cell size variation will primarily impact **pattern recognition** in Particle Flow calorimetry.

Total Thickness

Default for ILD: 5.911 λ_I. HCal thickness variation will primarily impact **leakage** of energy out of the detector.

Number of Layers

Default for ILD: 48 layers.

Sampling Fraction

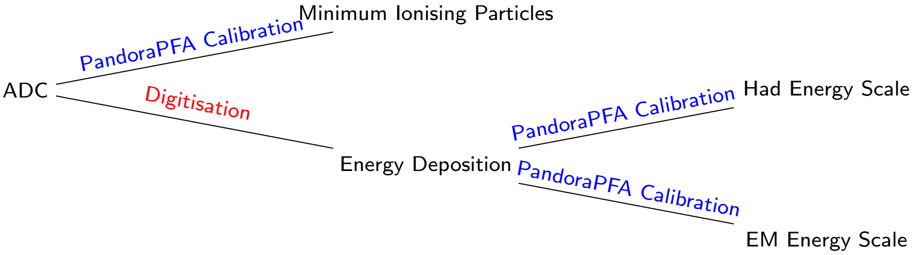
Default for ILD: Scintillator to Absorber thickness ratio 0.15.

Calibration

Reliable calibration procedure is **essential**. The calibration procedure breaks down into two distinct phases:

Digitisation

Setting of the digitisation constants. These convert the ADC current into an energy deposition measurement in each calorimeter cell.



PandoraPFA Calibration

- ADC to MIPs, which are used as an energy measure within PandoraPFA.
- Energy rescaling factors used to differentiate hadronic and electromagnetic energy deposition measurements within the calorimeters.

Absorber Material Study

Study

- Change HCal Absorber Material : Default $\rightarrow$ Steel.
- Otherwise default ILD detector.

Absorber materials considered:

Steel, Tungsten

Added Complication

- Physical (w.r.t. CLIC) timing cuts were applied in the HCal:
  - Steel HCal : 10ns timing cut
  - Tungsten HCal : 100ns timing cut.
- Choice of physics list:
  - QGSP_BERT: Default list, quick.
  - QGSP_BERT_HP: Similar to QGSP_BERT but with the addition of the high precision neutron package (deals with transportation of neutrons below 20MeV down to thermal energies), more realistic but slower.
- For completion both physics lists were used in the analysis.

Absorber Material Study

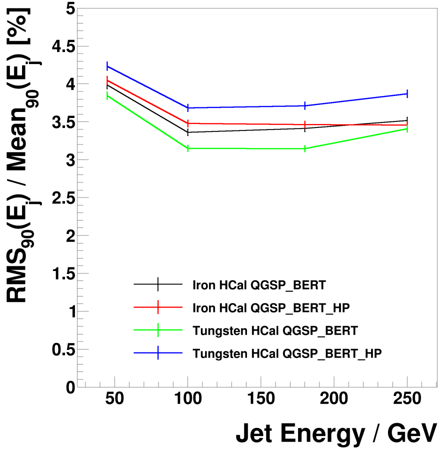


Figure : Jet energy resolution vs jet energy. Results shown are for detector models using steel (iron) and tungsten (WMod) HCal absorber materials. For each absorber material results are shown using both the QGSP_BERT and the QGSP_BERT_HP physics lists.

Summary

- Similar performance using both steel and tungsten HCal absorber materials.
- Significantly different performance between the QGSP_BERT and the QGSP_BERT_HP physics lists for tungsten HCal absorber materials.

Tile Size Study

Study

- Change HCal Tile Size : Default $\rightarrow 30 \times 30\text{mm}^2$ square cells.
- HCal Absorber Material : Steel
- Physics List : QGSP_BERT
- Changes should impact **pattern recognition** in the particle flow paradigm.

Tile sizes considered:

$10 \times 10\text{mm}^2$, $20 \times 20\text{mm}^2$, $30 \times 30\text{mm}^2$, $40 \times 40\text{mm}^2$, $50 \times 50\text{mm}^2$, $100 \times 100\text{mm}^2$

Added Complication

HCal timing cuts impact results. For completion results have been produced using a 10ns and semi-infinite (10^6ns) timing cut in the HCal.

Tile Size Study

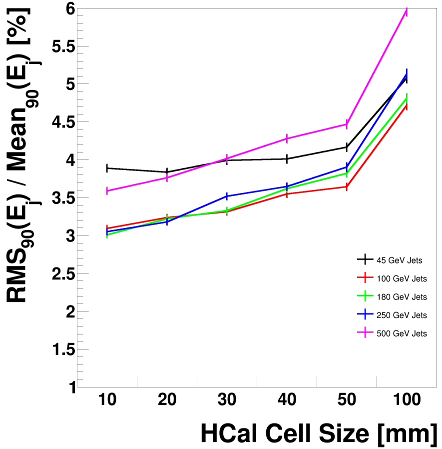


Figure : Jet energy resolution vs HCal tile size. A 10 ns timing cut was applied in the HCal.

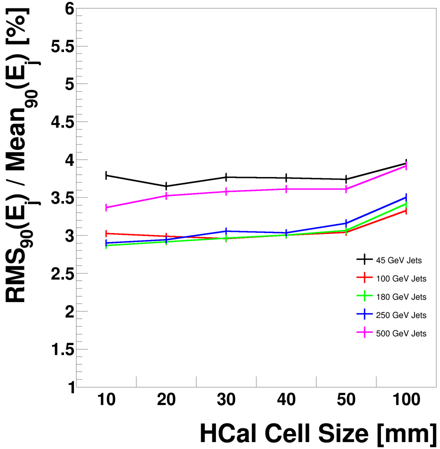


Figure : Jet energy resolution vs HCal tile size. A 10^6 ns timing cut was applied in the HCal.

Thickness Study

Study

- Change HCal Total Thickness : Default $\rightarrow 5.911\lambda_I$ (Scintillator and Absorber Material).
- HCal Absorber Material : Steel
- HCal Tile Size : $30 \times 30\text{mm}^2$
- Physics List : QGSP_BERT
- **Sampling Fraction** : 0.15 (3 mm Scintillator, 20 mm Absorber).
- Changes should impact **leakage** of energy from the detector (more prominent at higher energies).

HCal Thicknesses Considered:

$4.729\lambda_I$, $5.320\lambda_I$, $5.911\lambda_I$, $6.502\lambda_I$, $7.093\lambda_I$. $(80\%, 90\%, 100\%, 110\%, 120\%$ of default)

Added Complication

HCal timing cuts impact results. For completion results have been produced using a 10ns and semi-infinite (10^6ns) timing cut in the HCal.

Thickness Study

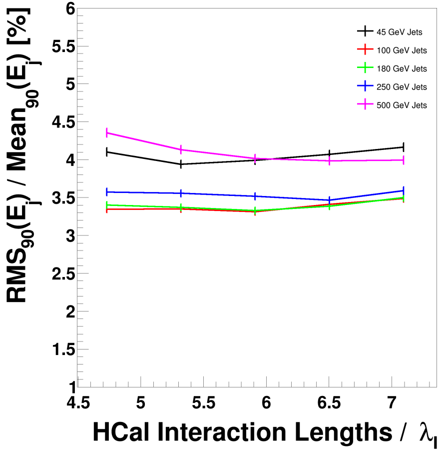


Figure : Jet energy resolution vs number of nuclear interaction lengths in the HCal. A 10 ns timing cut was applied in the HCal.

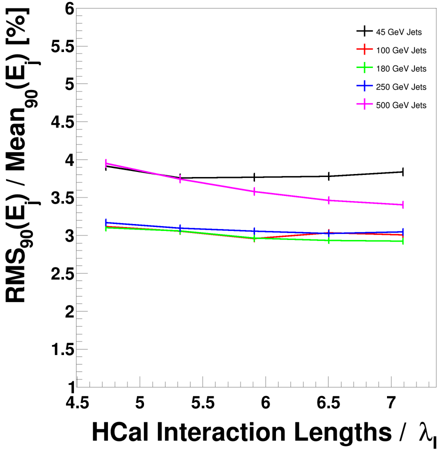


Figure : Jet energy resolution vs number of nuclear interaction lengths in the HCal. A 10^6 ns timing cut was applied in the HCal.

Number of Layers Study

Study

- Change Number of Layers in HCal : Default $\rightarrow$ 48.
- HCal Absorber Material : Steel
- HCal Tile Size : $30 \times 30mm^2$
- HCal Total Thickness : 5.911 λ_I
- Physics List : QGSP_BERT
- **Sampling Fraction** : 0.15 (3 mm Scintillator, 20 mm Absorber).

HCal Number of Layers Considered:

18, 24, 30, 36, 42, 48, 54, 60

Added Complication

HCal timing cuts impact results. For completion results have been produced using a 10ns and semi-infinite (10^6ns) timing cut in the HCal.

Number of Layers Study

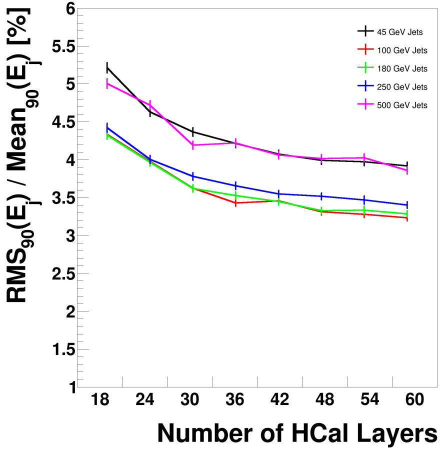


Figure : Jet energy resolution vs number of layers in the HCal. A 10 ns timing cut was applied in the HCal.

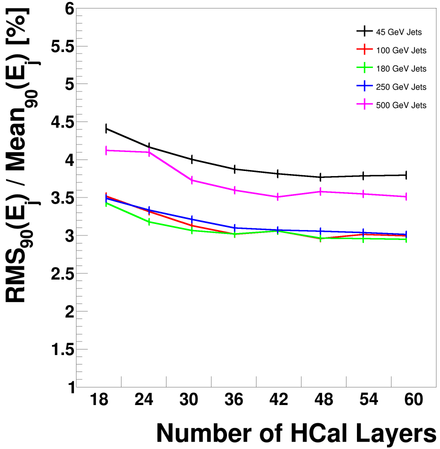


Figure : Jet energy resolution vs number of layers in the HCal. A 10^6 ns timing cut was applied in the HCal.

Sampling Fraction Study

Study

- Change Sampling Fraction : Default $\rightarrow$ 0.15 (3mm Scintillator, 20mm Absorber)
- HCal Absorber Material : Steel
- HCal Tile Size : $30 \times 30\text{mm}^2$
- HCal Total Thickness : 5.911 λ_I
- Number of HCal Layers : 48
- Physics List : QGSP_BERT

HCal Sampling Fraction Considered:

- 0.05 (1mm Scintillator, 20mm Absorber)
- 0.10 (2mm Scintillator, 20mm Absorber)
- 0.15 (3mm Scintillator, 20mm Absorber)
- 0.20 (4mm Scintillator, 20mm Absorber)
- 0.25 (5mm Scintillator, 20mm Absorber)

Added Complication

HCal timing cuts impact results. For completion results have been produced using a 10ns and semi-infinite (10^6ns) timing cut in the HCal.

Sampling Fraction Study

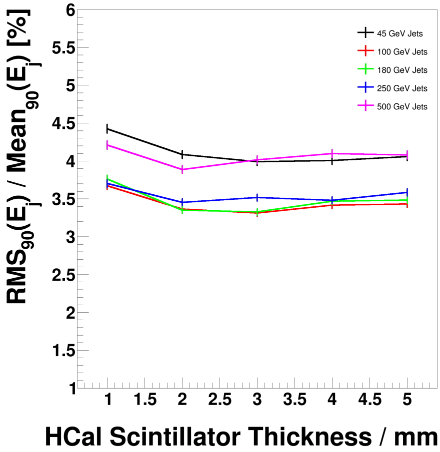


Figure : Jet energy resolution vs HCal sampling fraction. A 10 ns timing cut was applied in the HCal.

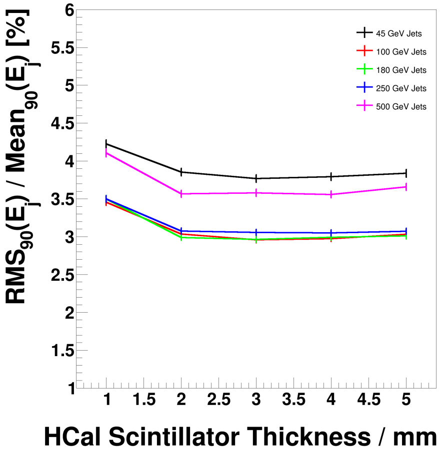


Figure : Jet energy resolution vs HCal sampling fraction. A 10^6 ns timing cut was applied in the HCal.

Timing Cut Analysis

Introductory steps into impact of changing the HCal timing cuts:

- Examine the decomposition of the jet energy resolution into **intrinsic energy resolution** and various **confusion** terms changes with HCal timing cuts:

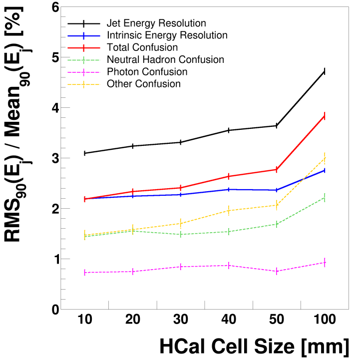


Figure : Jet energy resolution breakdown vs HCal tile size for 100 GeV jets. A 10 ns timing cut was applied in the HCal.

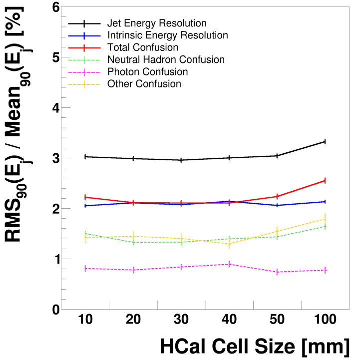


Figure : Jet energy resolution breakdown vs HCal tile size for 100 GeV jets. A 10^6 ns timing cut was applied in the HCal.

Timing Cut Analysis

- Second step was to find out what particles were causing the changes to the jet energy resolutions.
- Not a single or small group of particles causing the differences.
- Work is currently work is ongoing into examining the confusion terms in further detail.

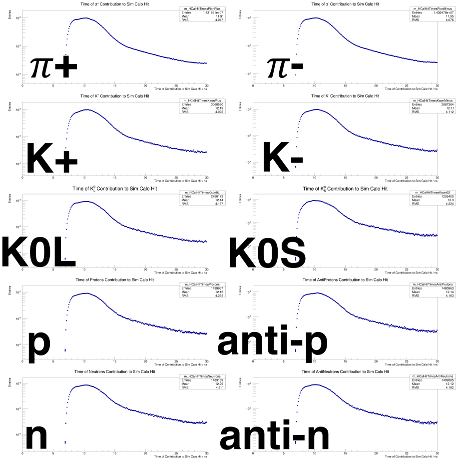


Figure : Normalised distributions of the time of a Monte Carlo particle hit. Each distribution corresponds to a different MC particle.

Conclusions

- Extensive study of detector performance as a function of HCal absorber material, tile size, thickness, layer number and sampling fraction has been performed.
- Steel is comparable in performance to tungsten as a HCal absorber material.
- Smaller HCal tile sizes improve the jet energy resolution by reducing confusion in jet reconstruction.
- Thicker HCals reduce the impact of leakage of energy out of the back of the detector.
- Reducing the number of layers in the HCal degrades the jet energy resolution.

Key Future Work

- Fully understand the impact of timing cuts in the HCal.

Thank You For Your Attention!

HCal Cell Size Study JER Breakdowns

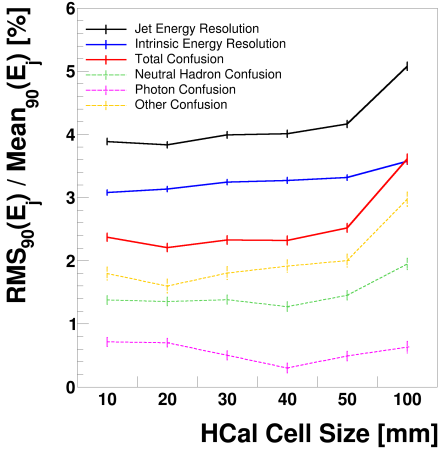


Figure : Jet energy resolution breakdown vs HCal tile size for 45 GeV jets. A 10 ns timing cut was applied in the HCal.

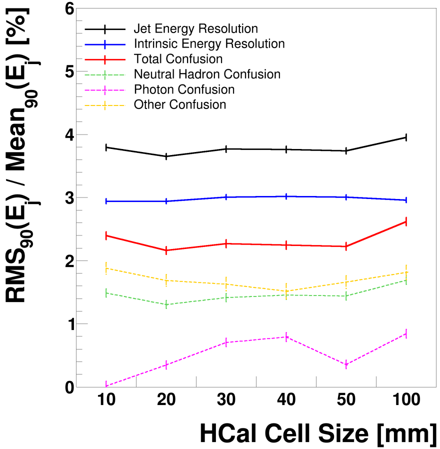


Figure : Jet energy resolution breakdown vs HCal tile size for 45 GeV jets. A 10^6 ns timing cut was applied in the HCal.

HCal Cell Size Study JER Breakdowns

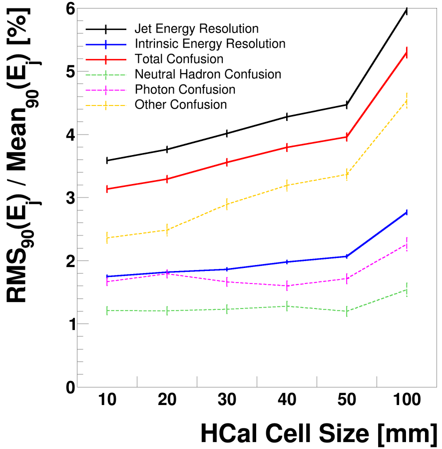


Figure : Jet energy resolution breakdown vs HCal tile size for 500 GeV jets. A 10 ns timing cut was applied in the HCal.

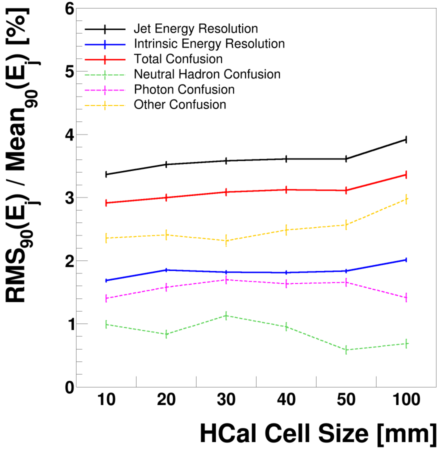


Figure : Jet energy resolution breakdown vs HCal tile size for 500 GeV jets. A 10^6 ns timing cut was applied in the HCal.

HCal Number of Layers - Comparison To Previous Study

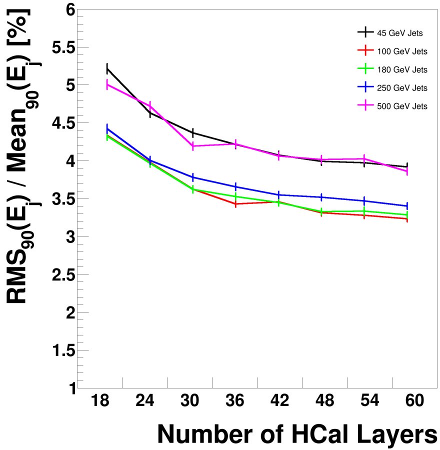


Figure : Jet energy resolution vs number of layers in the HCal. A 10 ns timing cut was applied in the HCal. Sampling fraction constant at 0.15 (default, 3mm Scintillator, 20mm absorber).

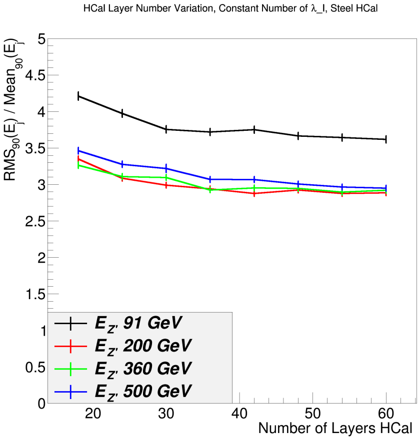


Figure : Jet energy resolution vs number of layers in the HCal. A 10 ns timing cut was applied in the HCal. Scintillator thickness fixed at 3mm. + **Hadronic Energy Truncation**