HCal Simulation Studies

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Overview

Introduction

The main aim of these studies is to optimise the physics performance of the HCal in the context of a future linear collider. These studies are focused on ILD.

Key topics to be analysed:

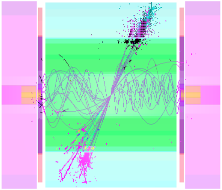


Figure : 500 GeV Di-Jet.

The **figure of merit** used to judge detector performance is the jet energy resolution. This is determined from the decay of off-shell mass Z bosons to light quarks, which typically forms two mono energetic back to back jets.

HCal Absorber Material

Choice between steel and tungsten. Steel is default in ILD detector model.

HCal Tile Size

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

HCal Thickness

Default is 5.72 λ_I. HCal thickness variation will primarily impact **intrinsic energy resolution** in Particle Flow calorimetry.

Number of HCal Layers

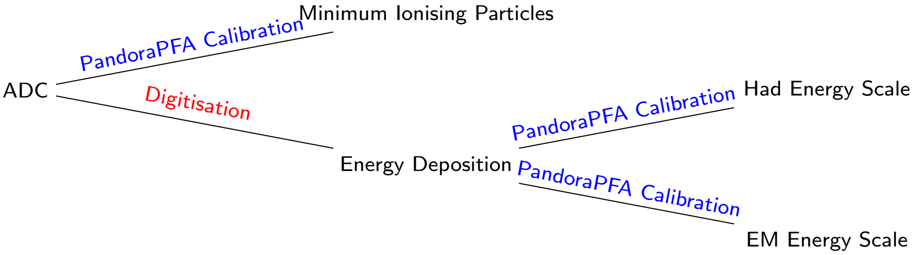
Default number of layers is 48, which corresponds to $5.72\lambda_I$. This will determine the impact of **leakage** out of the detector.

Calibration

For each difference detector model a calibration procedure must be applied to ensure reliability in the results being produced. 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.

HCal Absorber Material

- Steel and tungsten HCal absorber materials have been considered in this analysis.
- With the exception of the absorber material, the analysis was performed using the default ILD detector model.
- This decision was recently made for the CLIC detector and in an attempt to contribute to these studies realistic timing cuts were applied in the HCal for these studies.
- A 10ns timing cut was used for the steel HCals studied and a 100ns timing cut was used for the tungsten HCals studied.
- An added complication was the 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.

Jet Energy Resolution Variation with HCal Absorber Material

Summary

- Similar performance using different physics lists for steel HCal.
- Large difference between performance using different physics lists for tungsten HCal.
- Comparable performance between steel and tungsten HCal.

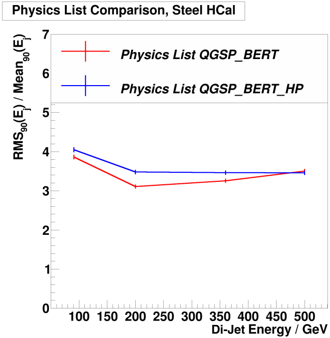


Figure : Jet energy resolution vs jet energy for a steel HCal using the QGSP_BERT and QGSP_BERT_HP physics lists.

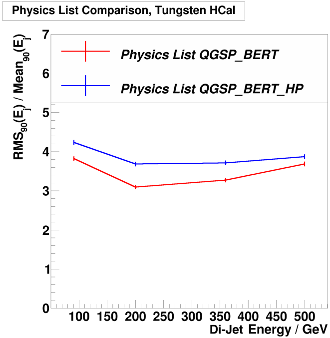


Figure : Jet energy resolution vs jet energy for a tungsten HCal using the QGSP_BERT and QGSP_BERT_HP physics lists.

Jet Energy Resolution Breakdown for Steel HCal Absorber Material

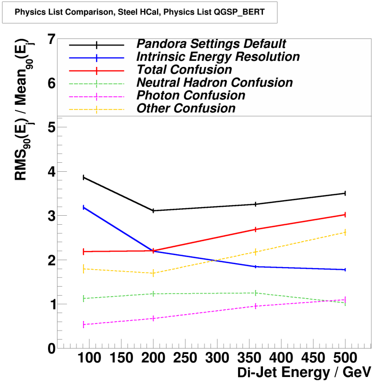


Figure : Jet energy resolution breakdown vs jet energy using a steel HCal using Physics List QGSP_BERT.

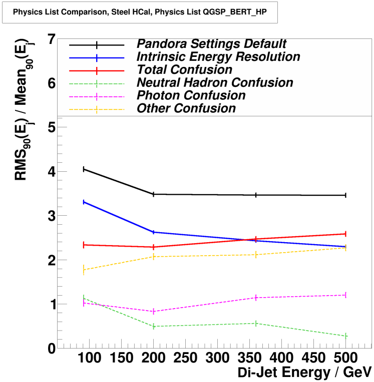


Figure : Jet energy resolution breakdown vs jet energy using a steel HCal using Physics List QGSP_BERT_HP.

Summary

Similar breakdown of jet energy resolution for both physics lists when considering a steel HCal.

Jet Energy Resolution Breakdown for Tungsten HCal Absorber Material

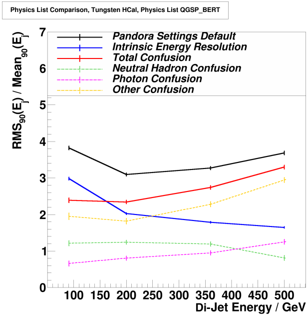


Figure : Jet energy resolution breakdown vs jet energy using a tungsten HCal using Physics List QGSP_BERT.

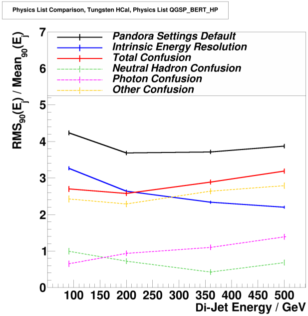


Figure : Jet energy resolution breakdown vs jet energy using a tungsten HCal using Physics List QGSP_BERT_HP.

Summary

- QGSP_BERT physics lists overestimates the energy resolution for a tungsten HCal.
- This confusion terms are comparable using both physics lists.
- This leads to worse performance using the QGSP_BERT_HP physics lists than using the QGSP_BERT physics list.

HCal Tile Size

- Consider variations in the HCal tile size. Default value is $30 \times 30\text{mm}^2$.
- The detectors modelled in this study have a steel HCal and use the QGSP_BERT physics list.
- The values of tile sizes considered in this study are:
  1. $10 \times 10\text{mm}^2$
  2. $20 \times 20\text{mm}^2$
  3. $30 \times 30\text{mm}^2$
  4. $40 \times 40\text{mm}^2$
  5. $50 \times 50\text{mm}^2$
- It is expected that these changes will impact the confusion term within the jet energy resolution.

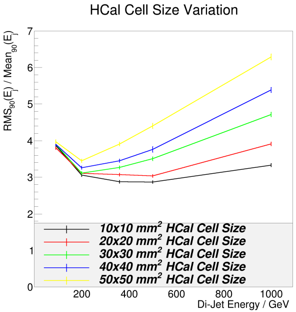
Added Complications

- HCal cell hadronic energy truncation (implemented to limit impact of Landau fluctuations and beneficial for infinite timing cuts)
- HCal timing cuts.

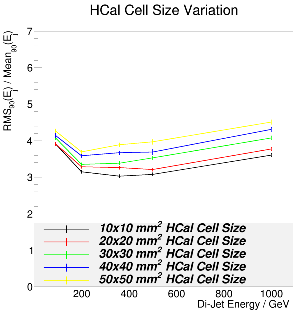
For completion results have been produced using both a hadronic energy truncation of 1GeV and no energy truncation, as well as using a 10ns and an infinite timing cut in the HCal.

HCal Timing Cut: TC, HCal Cell Hadronic Energy Truncation: ET

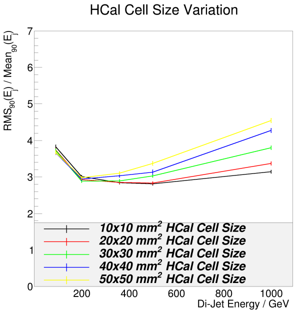
ET=1GeV, TC=10ns



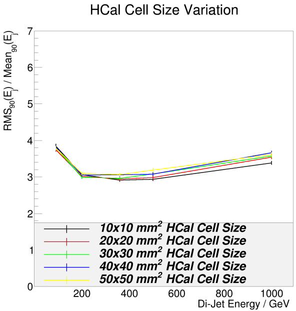
ET=10^6GeV, TC=10ns



ET=1GeV, TC=10^6ns



ET=10^6GeV, TC=10^6ns



Summary of HCal Tile Size Results

Summary

- Reducing HCal tile size improves the jet energy resolution.
- The magnitude of the change in jet energy resolution between detector models is dominated by timing cuts and energy truncation.
- Studies are being performed to fully understand the impact of timing cuts on jet energy resolution.

HCal Thickness

- Look into varying the total HCal thickness. Default number of nuclear interaction lengths in ILD is $5.72\lambda_I$.
- The detectors modelled in this study have a steel HCal, a $30 \times 30\text{mm}^2$ tile size and use the QGSP_BERT physics list.
- The values of total number of interaction lengths in the HCal considered in this study are:
  1. $4.58\lambda_I$ 80%
  2. $5.15\lambda_I$ 90%
  3. $5.72\lambda_I$ 100% Default
  4. $6.29\lambda_I$ 110%
  5. $6.86\lambda_I$ 120%
- It is expected that these changes will impact the leakage term within the jet energy resolution.

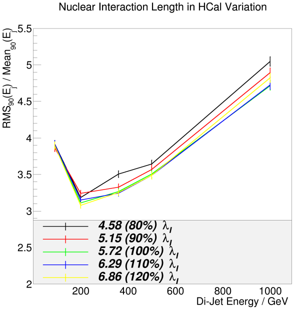
Added Complications

- HCal cell hadronic energy truncation.
- HCal timing cuts.

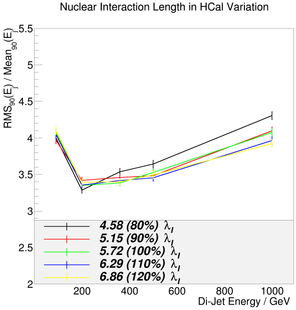
For completion results have been produced using both a hadronic energy truncation of 1GeV and no energy truncation, as well as using a 10ns and an infinite timing cut in the HCal.

HCal Timing Cut: TC, HCal Cell Hadronic Energy Truncation: ET

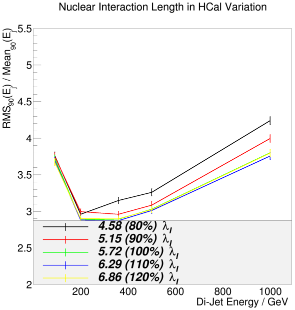
ET=1GeV, TC=10ns



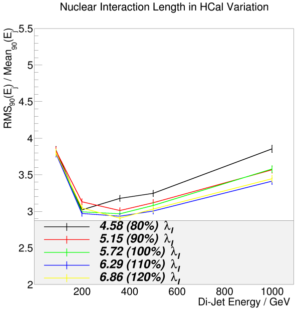
ET=10^6GeV, TC=10ns



ET=1GeV, TC=10^6ns



ET=10^6GeV, TC=10^6ns



Summary of HCal Thickness Results

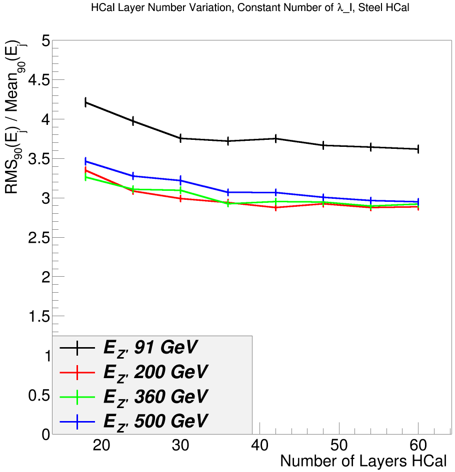
Summary

- Thicker HCals perform better in terms of jet energy resolution, especially at high energies where leakage starts to become prominent.
- The magnitude of the change in jet energy resolution between detector models **is not** dominated by timing cuts and energy truncation, but the absolute jet energy resolutions are.
- Again studies are being performed to fully understand the impact of timing cuts on jet energy resolution.

Number of HCal Layers

- The final study looks at varying the number of layers in the HCal.
- The default number of layers in the ILD detector is 48, which corresponds to $5.72\lambda_I$.
- This study has been performed using both a steel and tungsten HCal.

Number of HCal Layers



- Steel HCal.
- Infinite timing cut in HCal.
- HCal cell hadronic energy truncation 1 GeV.
- QGSP BERT physics list.

Summary

- Relatively small degradation in detector performance when reducing layer number.

Figure : Jet energy resolution breakdown vs number of HCal layers using a steel HCal.

Conclusions

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

Key Future Work

- Fully understand the impact of timing cuts in the HCal.
- Develop more sophisticated hadronic energy corrections to remove the hadronic energy truncation in the HCal cells.

Thank You

Minimum Calibration Constants

```
CalibrECAL was found to be:                         42.7537535736 85.5075071472
CalibrHCALBarrel was found to be:                   56.8332428504
CalibrHCALEndcap was found to be:                   61.0013802667
CalibrHCALOther was found to be:                    34.3366322984
ECalGeVToMIP was found to be:                       153.846
HCalGeVToMIP was found to be:                       34.6021
MuonGeVToMIP was found to be:                       8.26446
MaxHCalHitHadronicEnergy was found to be:           1
ECalToEMGeVCalibration was found to be:             1.00094235794
HCalToEMGeVCalibration was found to be:             1.00094235794
ECalToHadGeVCalibrationBarrel was found to be:      1.1277945999
HCalToHadGeVCalibration was found to be:            1.1138197782
HCALBarrelTimeWindowMax is:                         10
HCALEndcapTimeWindowMax is:                         10
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Figure : Minimum number of calibration constants needed for each detector model. Missing off the list is ECal timing cuts, Pandora minimum threshold cuts, non linearity corrections...

Timing Cut Differences - Visual Display

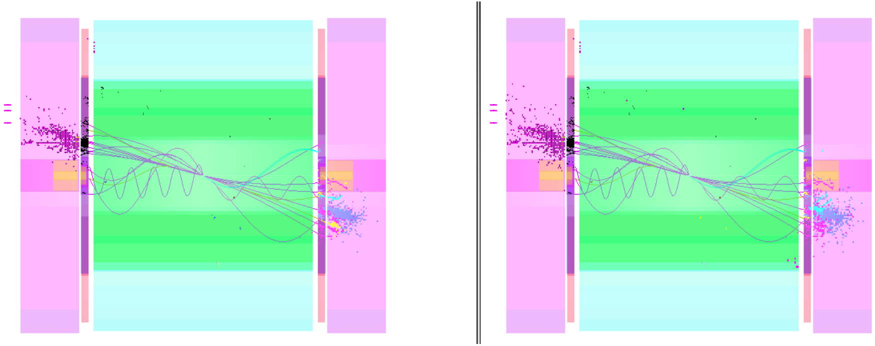


Figure : 500 GeV Di-Jet, Left: HCal Timing Cut 10 ns, Right: HCal Timing Cut 10^6.

Direct Comparison of JER Breakdown for Different Physics Lists

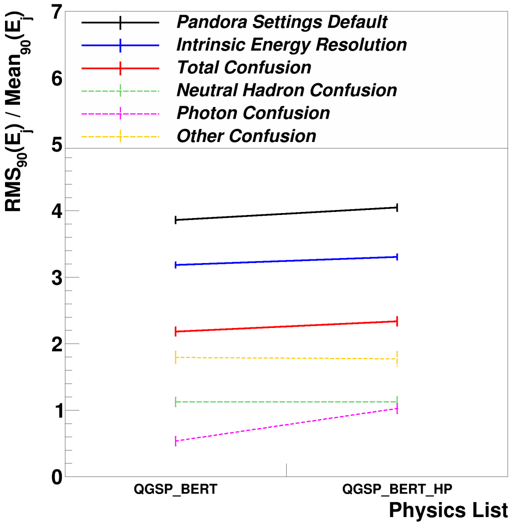


Figure : 91 GeV Di-Jet Energy, Steel HCal.

Direct Comparison of JER Breakdown for Different Physics Lists

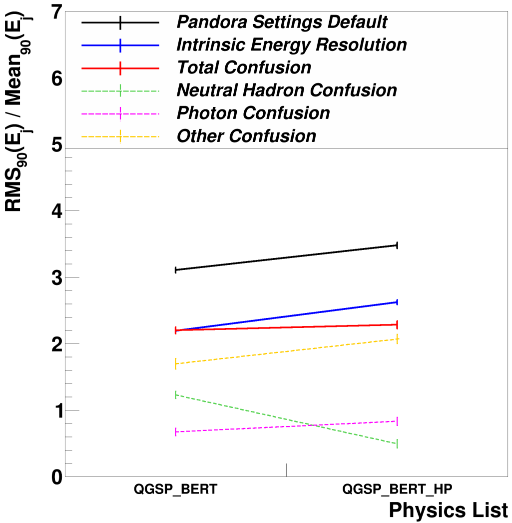


Figure : 200 GeV Di-Jet Energy, Steel HCal.

Direct Comparison of JER Breakdown for Different Physics Lists

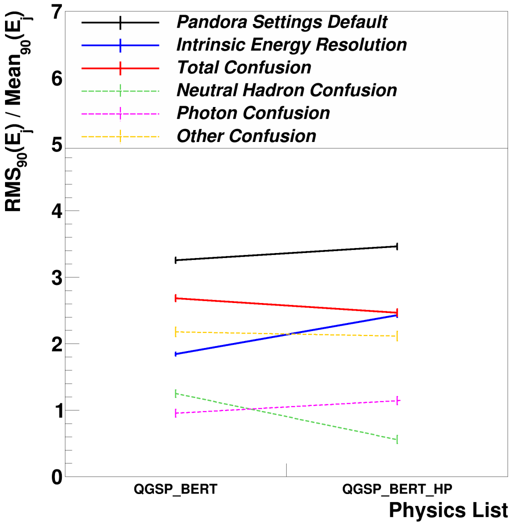


Figure : 360 GeV Di-Jet Energy, Steel HCal.

Direct Comparison of JER Breakdown for Different Physics Lists

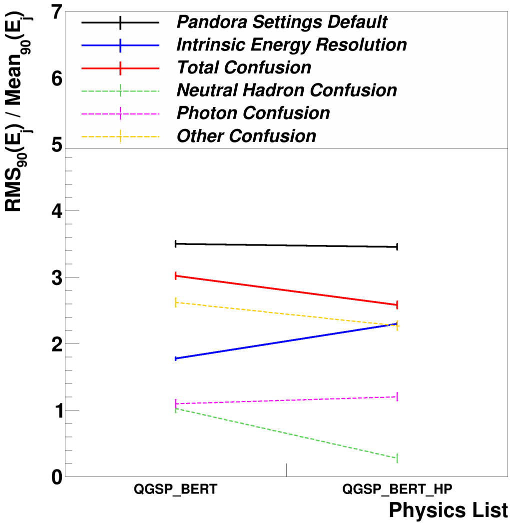


Figure : 500 GeV Di-Jet Energy, Steel HCal.

Direct Comparison of JER Breakdown for Different Physics Lists

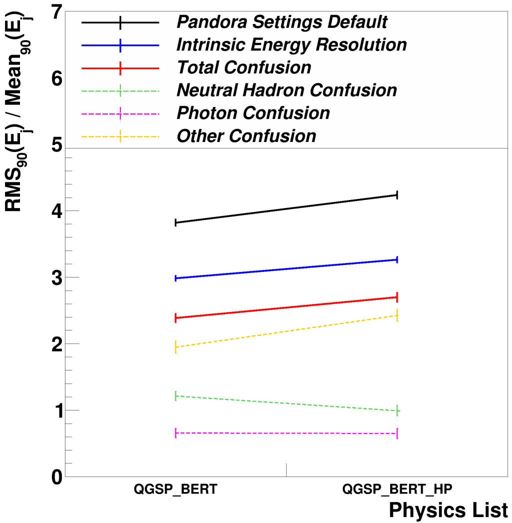


Figure : 91 GeV Di-Jet Energy, Tungsten HCal.

Direct Comparison of JER Breakdown for Different Physics Lists

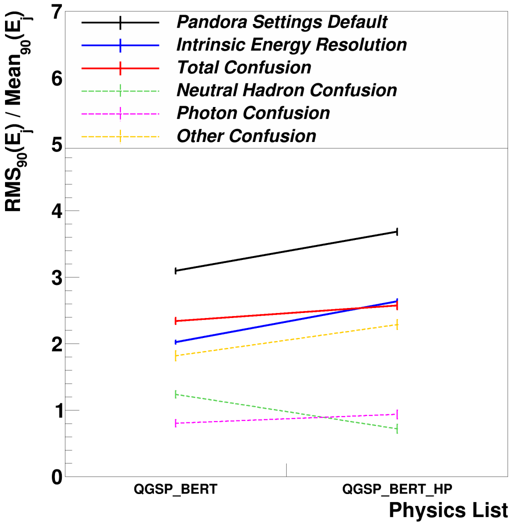
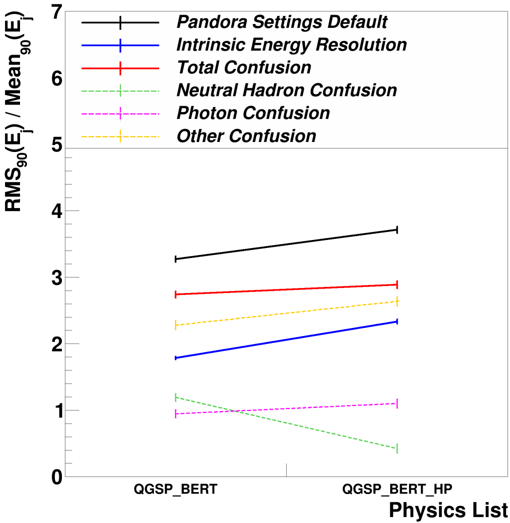


Figure : 200 GeV Di-Jet Energy, Tungsten HCal.

Direct Comparison of JER Breakdown for Different Physics Lists



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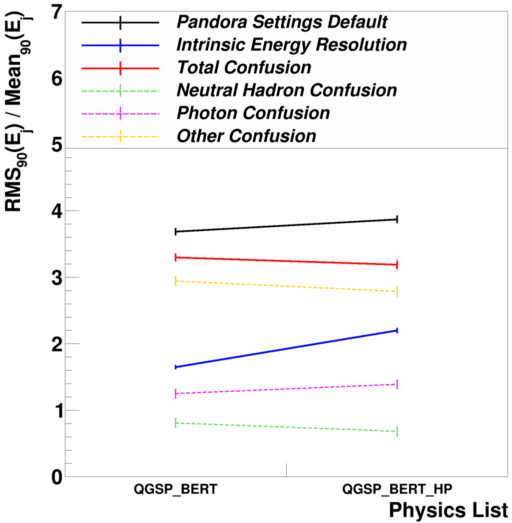

Figure : 500 GeV Di-Jet Energy, Tungsten HCal.