Detector Optimisation Studies using the Pandora Particle Flow Algorithm

19.1.16

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Introduction

Aims:

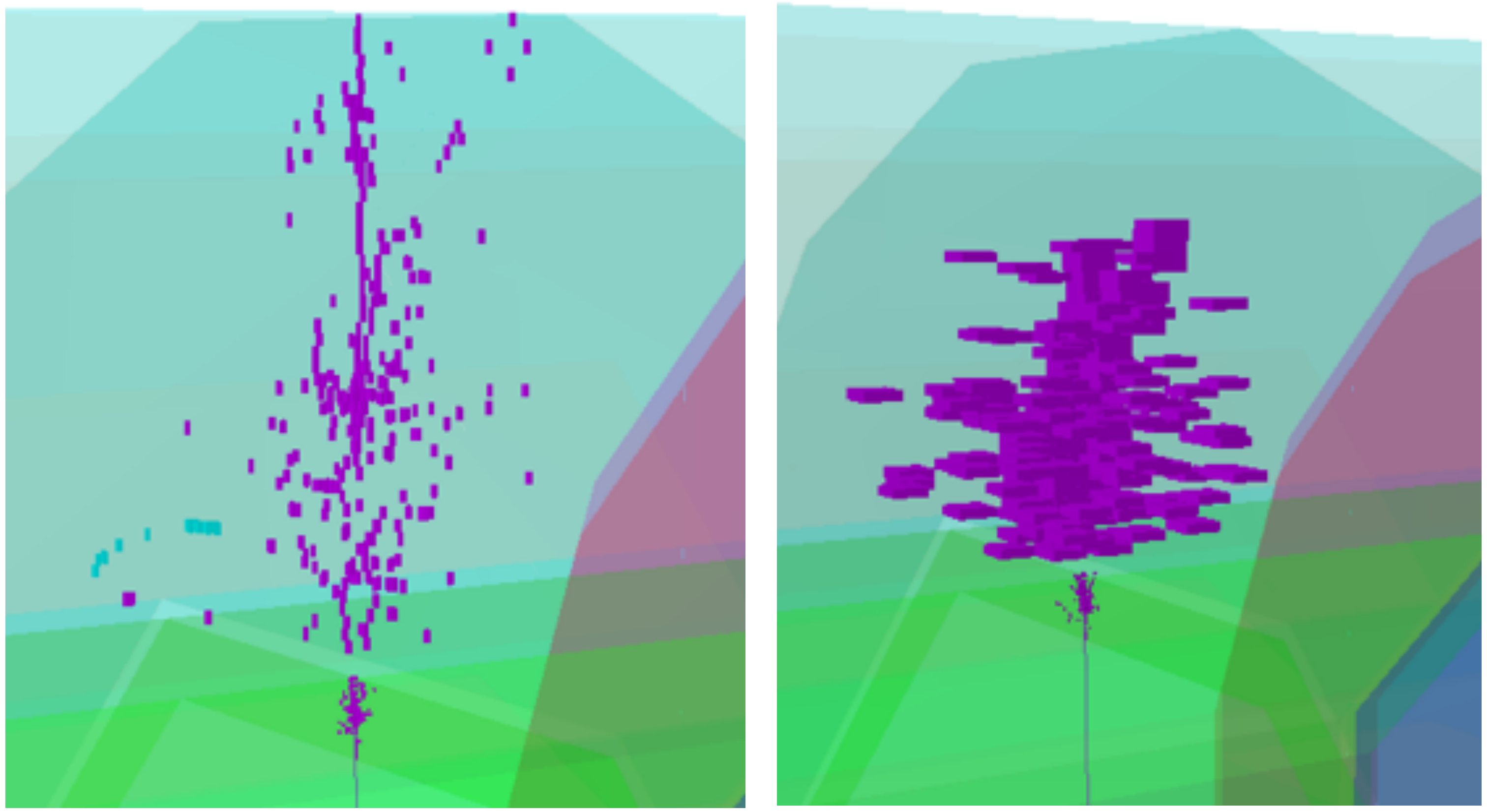
1. Give a brief overview of the results of recent HCal optimisation studies.
2. Introduce software compensation as a method of improving energy resolution for a detector.

Changes To Reconstruction:

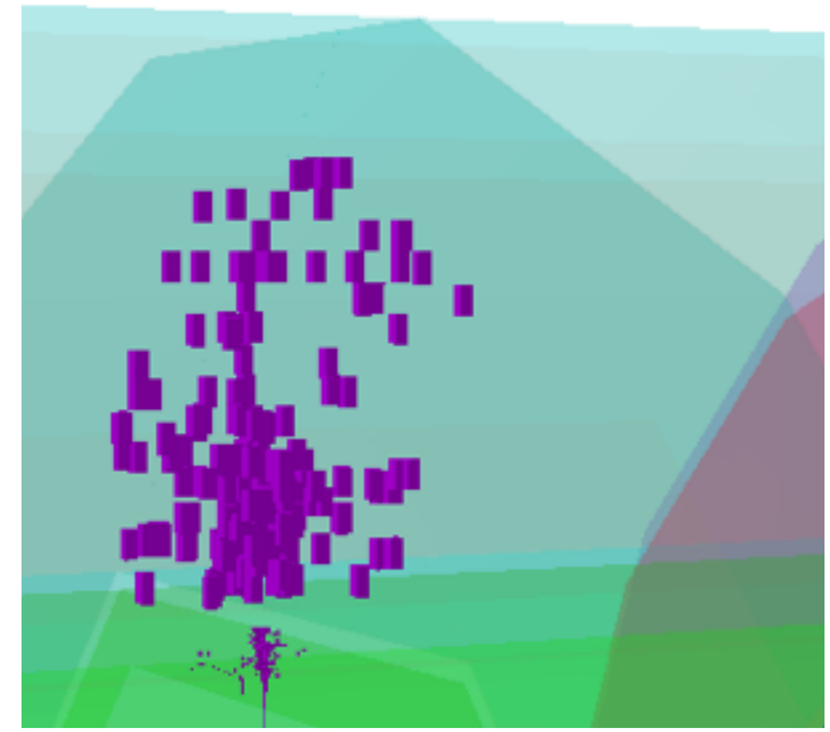
- ☑ Detector Model: ILD00 → ILD_01_v06
- ☑ Reconstruction Software: LoI → ilcsoft_v01-17-07 (including PandoraPFA_v02-00-00)
- ☑ Digitiser: NewLDCCaloDigi → ILDCaloDigi (+ with Realistic Options)
- ☑ Calibration: Default LoI Numbers → PandoraAnalysis toolkit (v01-00-00)
- ☑ Timing cuts: No Timing Cuts → 100 ns
- ☑ Hadronic Energy Truncation: 1 GeV (Fixed) → Optimised For Each Detector Model

Full details of the changes to the reconstruction chain used in the optimisation studies can be found here: http://agenda.linearcollider.org/event/6662/session/32/contribution/237/material/slides/0.pdf

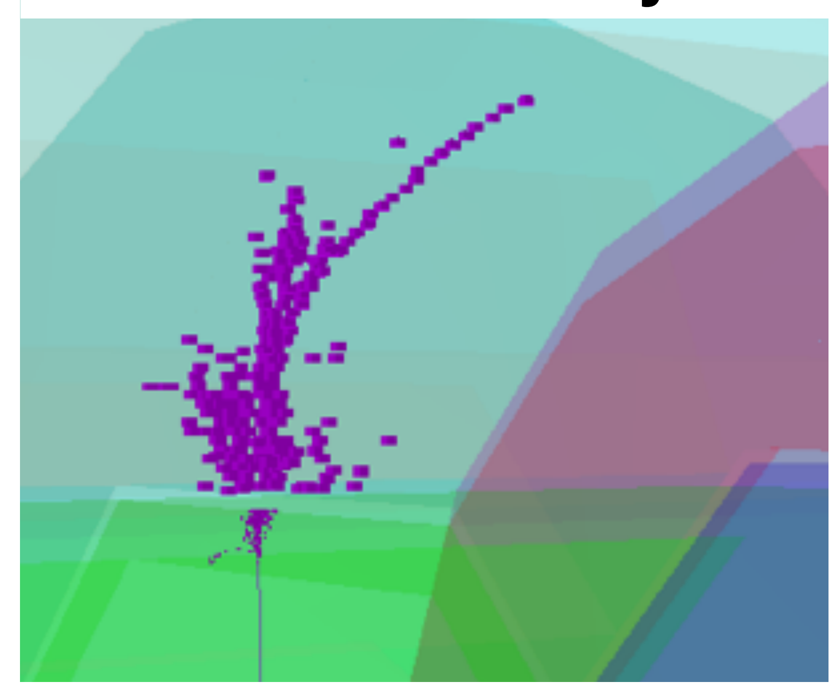
Optimisation of the HCal



HCal Cell Size



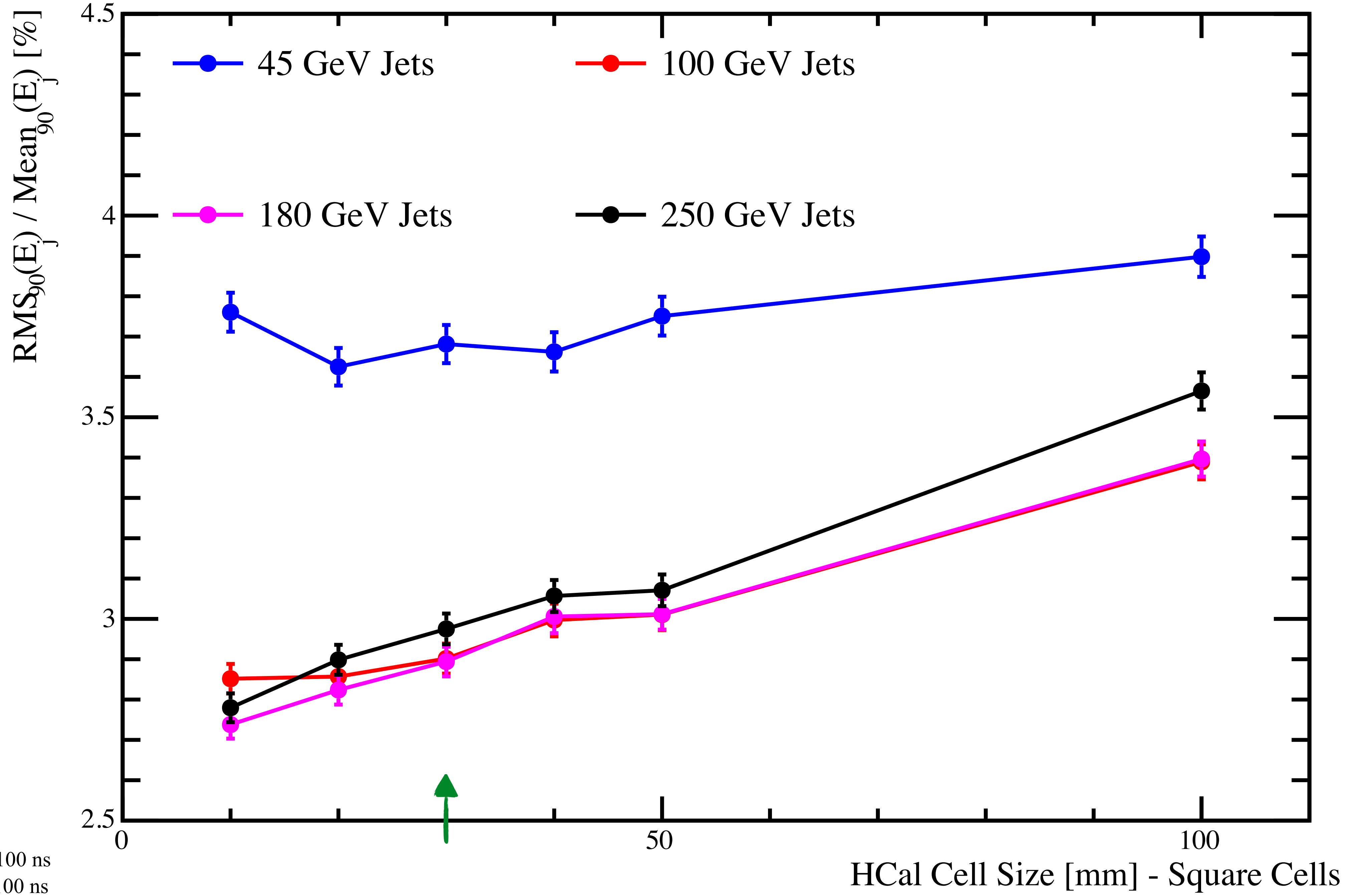
Number Of Layers



Included in Back Up:

- Number of Interaction Lengths in HCal;
- Absorber material in HCal;
- Sampling fraction in HCal;
- ECal inner radius;
- Magnetic field.

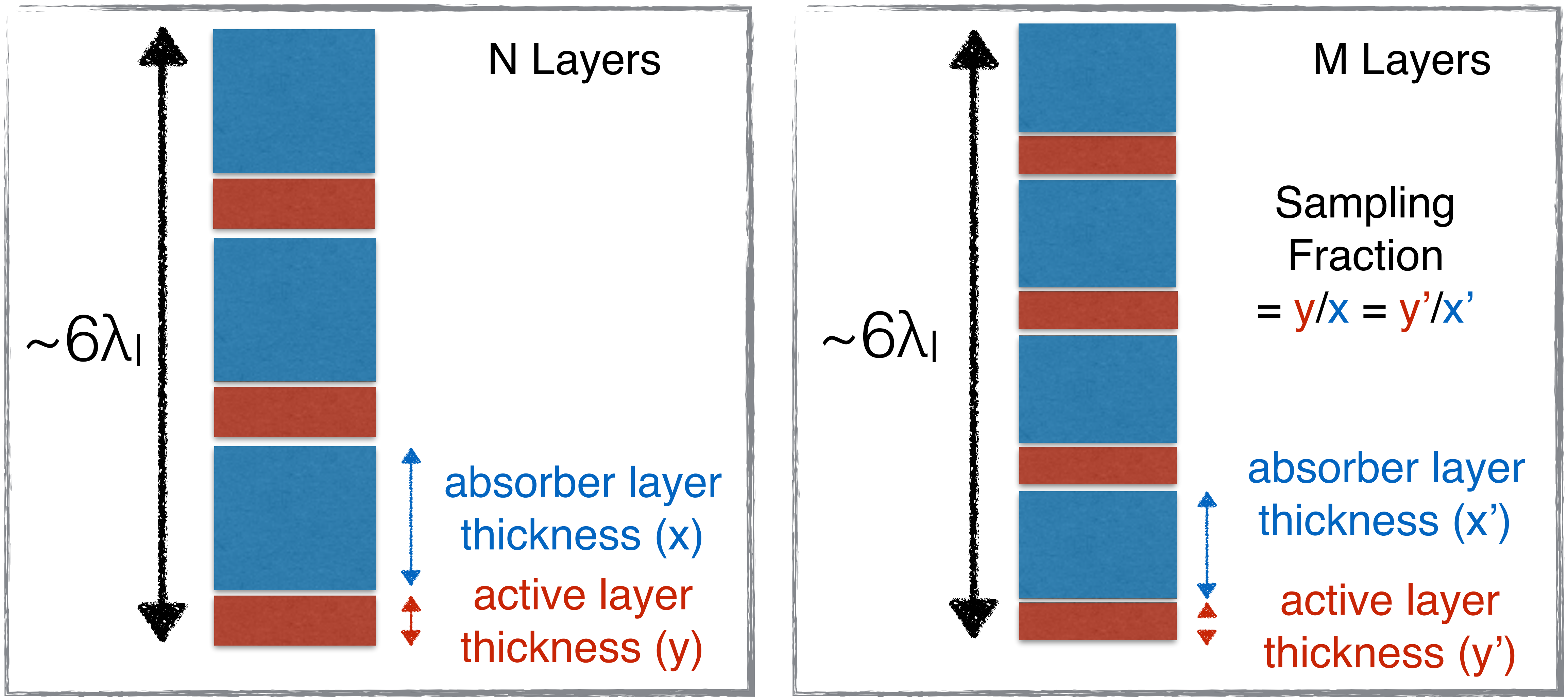
HCal Cell Size Optimisation Results



HCal Timing Cuts : 100 ns
ECal Timing Cuts : 100 ns
HCal Hadronic Cell Truncation: Optimised for each detector model
Software : ilcsoft_v01-17-07, including PandoraPFA v02-00-00
Digitiser : ILDCaloDigi, realistic ECal and HCal digitisation options enabled
Calibration : PandoraAnalysis toolkit v01-00-00

Number of HCal Layers

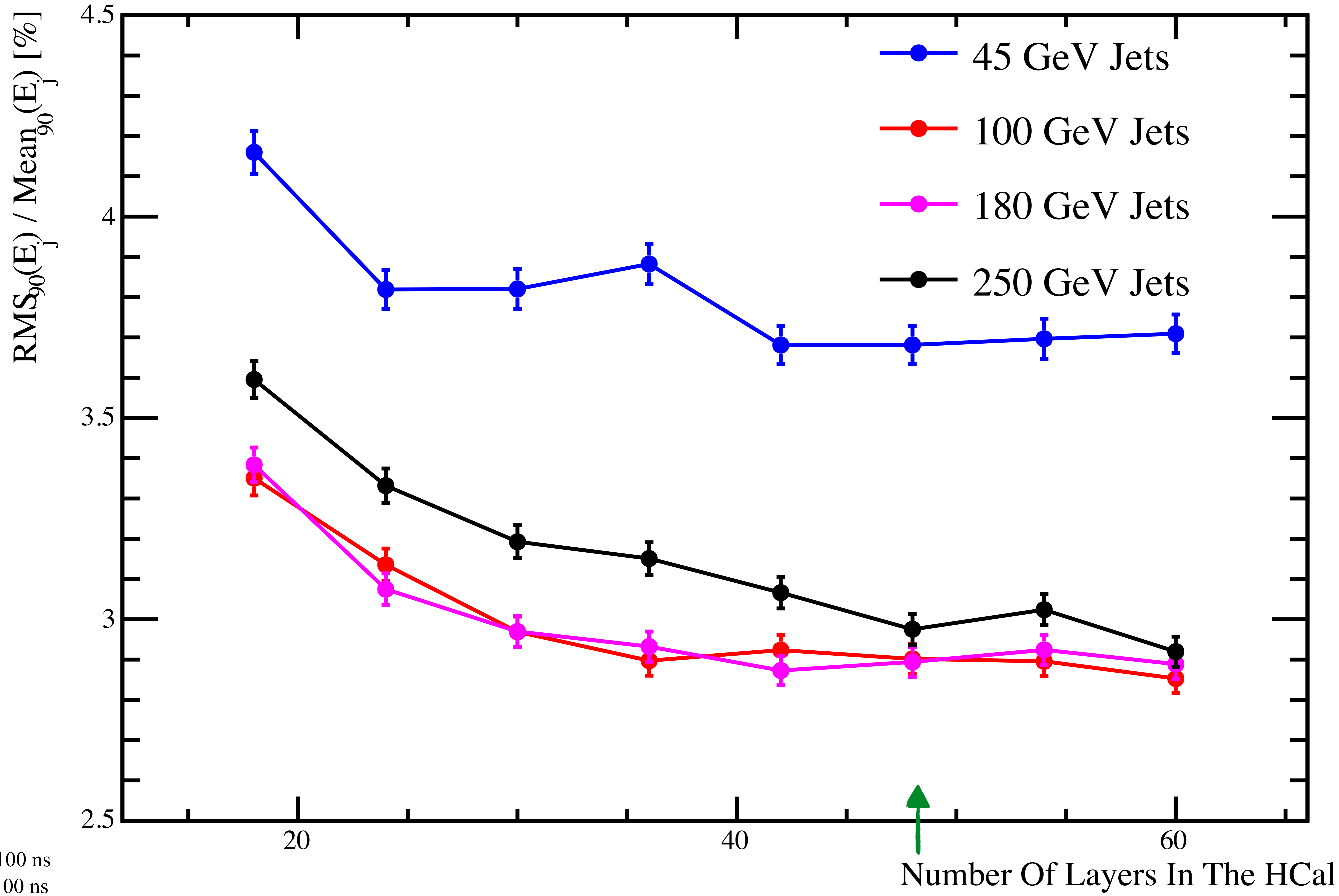
- Optimise the total number of layers in the HCal.
- Do not want to accidentally vary either the total number of interaction lengths or the sampling fraction of the HCal:



Cartoon showing effect of changing number of HCal layers

- The number of nuclear interaction lengths and the ratio of the absorber layers thicknesses to the active layer thicknesses is unchanged in this study.

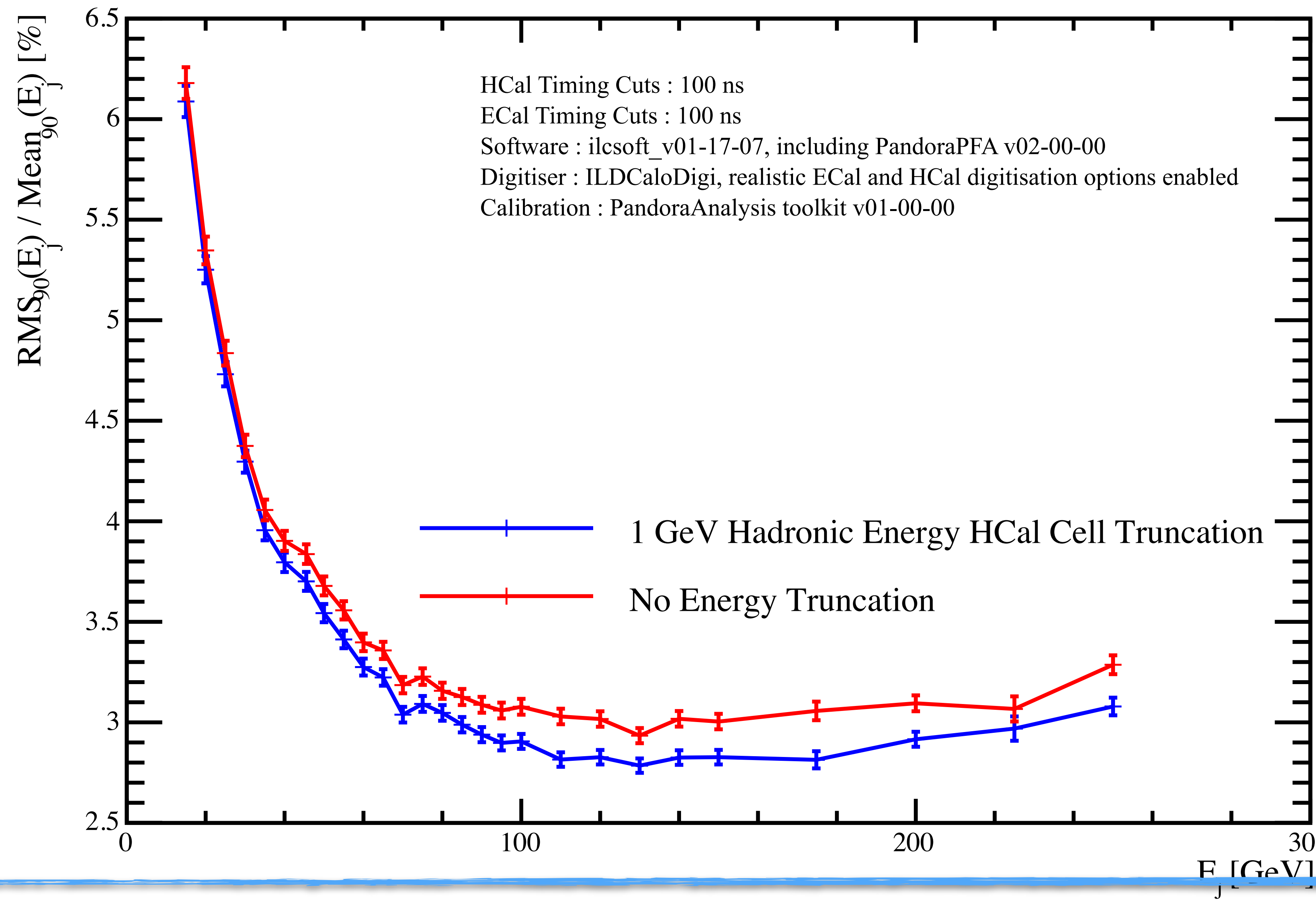
Number of HCal Layers Optimisation Results



HCal Timing Cuts : 100 ns
ECal Timing Cuts : 100 ns
HCal Hadronic Cell Truncation: 1 GeV
Software : ilcsoft_v01-17-07, including PandoraPFA v02-00-00
Digitiser : ILDCaloDigi, realistic ECal and HCal digitisation options enabled
Calibration : PandoraAnalysis toolkit v01-00-00

Software Compensation

- Purpose: Improve the energy estimator for hadronic clusters.
- Currently: Hadronic energy truncation for individual cells in the HCal. This is simplistic, but effective.



Software Compensation

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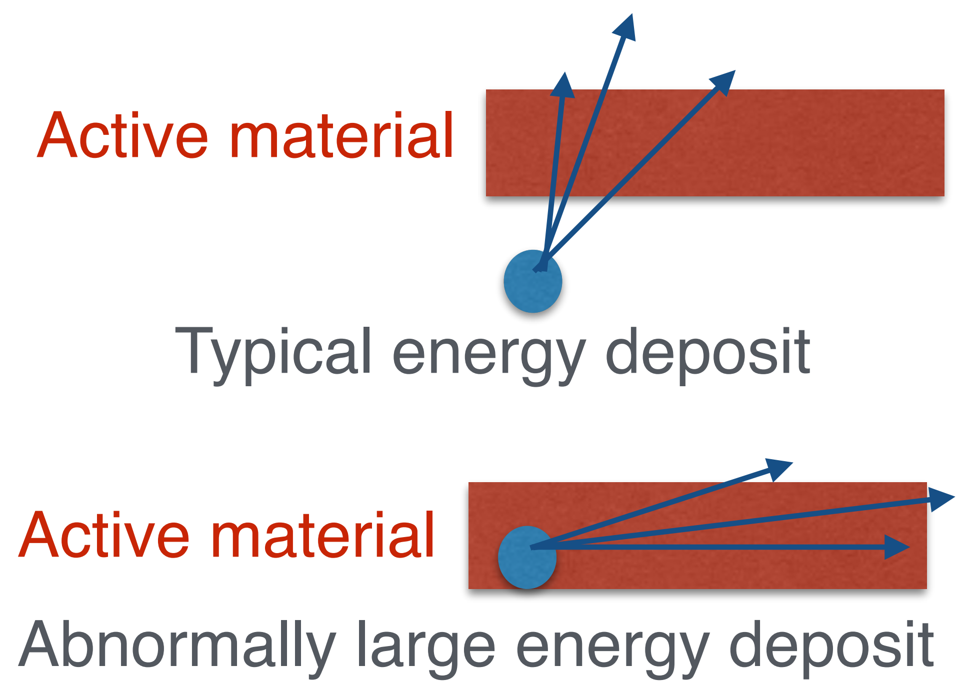
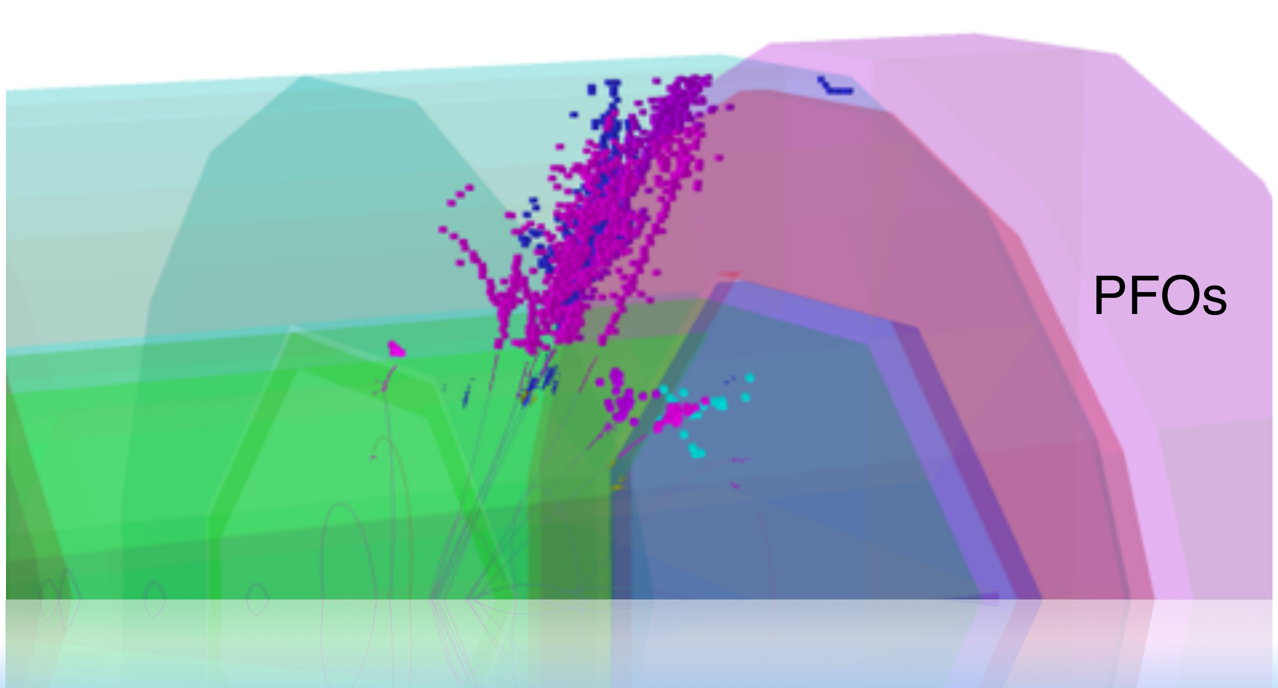
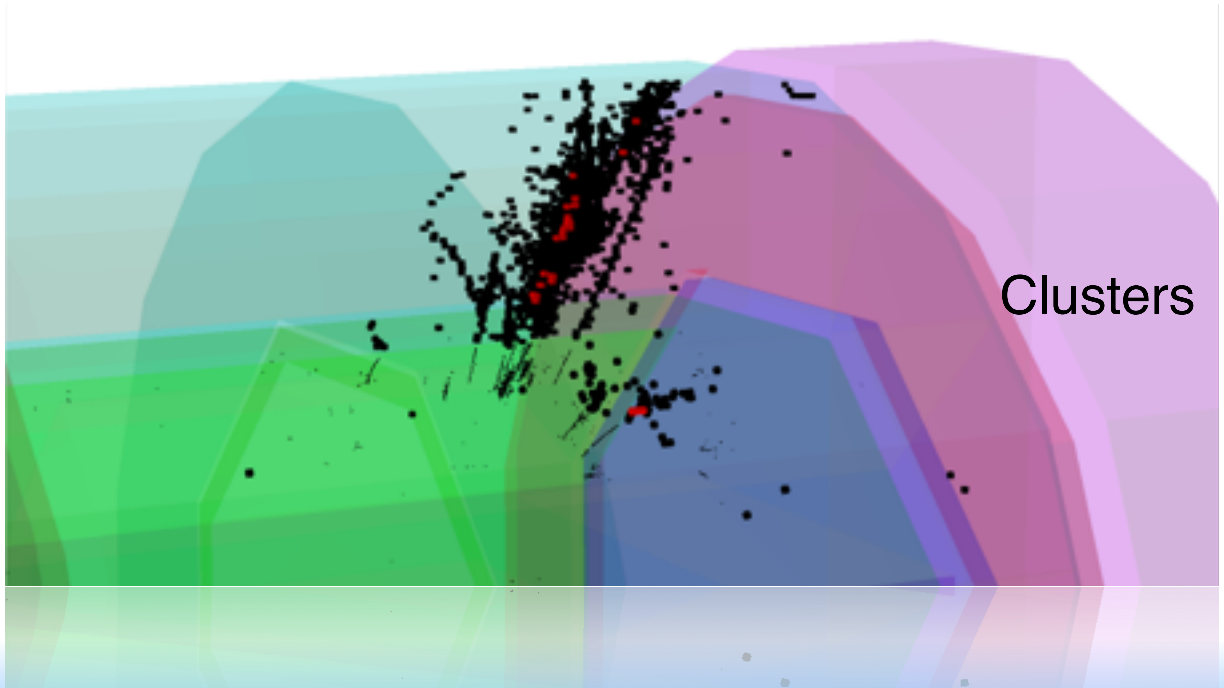
- Why is this needed?: Limit impact of cells with abnormally large energy densities.
- Abnormally large energy densities come from electromagnetic shower cores of hadronic showers and from particles showering parallel to the active material.
- Work is now being done to develop a more sophisticated method of applying software compensation.



Event display from a 500GeV Z→uds jets. Hits in red have energy truncated to 1 GeV.

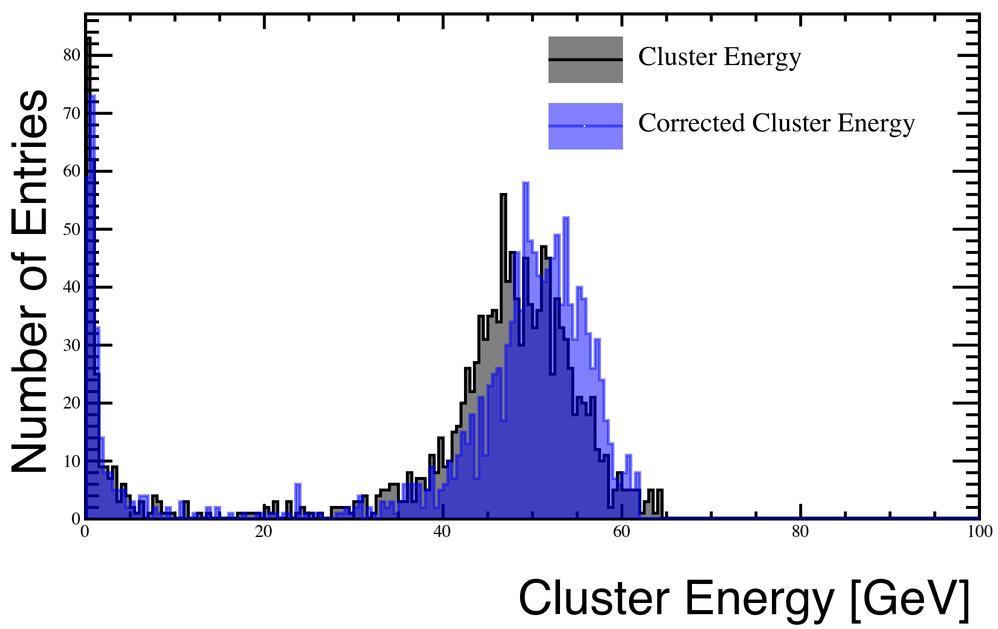


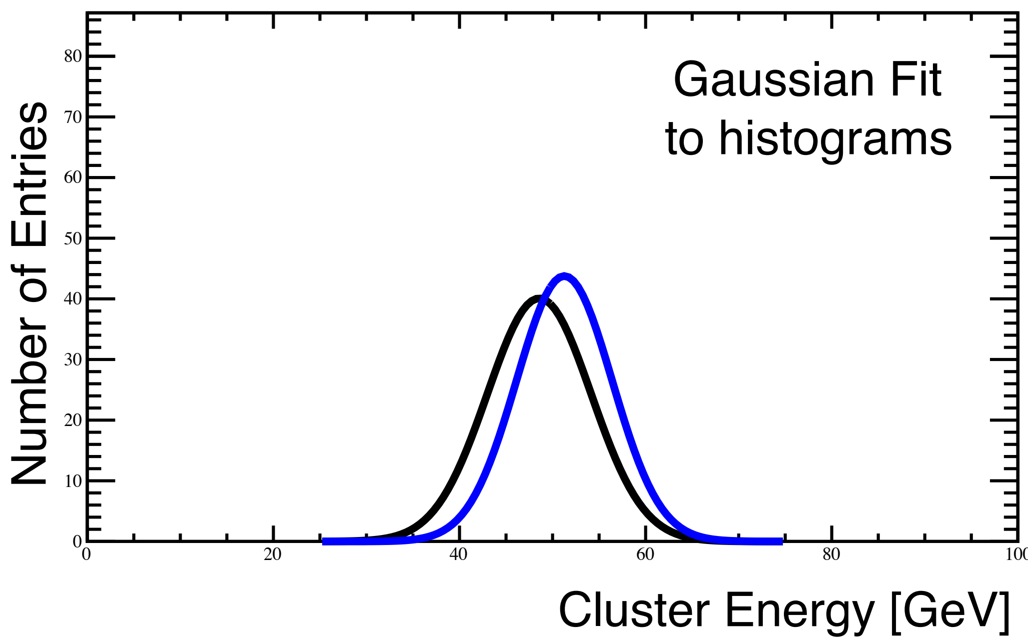


Software Compensation

Thanks to Huong Lan Tran

- Principle: Apply a weight to each digitised calorimeter cell based on the energy density of the cell.
- Parameterisation is: $w(\rho) = p_1 \times \exp(\rho p_2) + p_3$
  - ρ is energy density of calorimeter cell.
  - p1, p2, p3 are numerical constants that vary as a function of total cluster energy





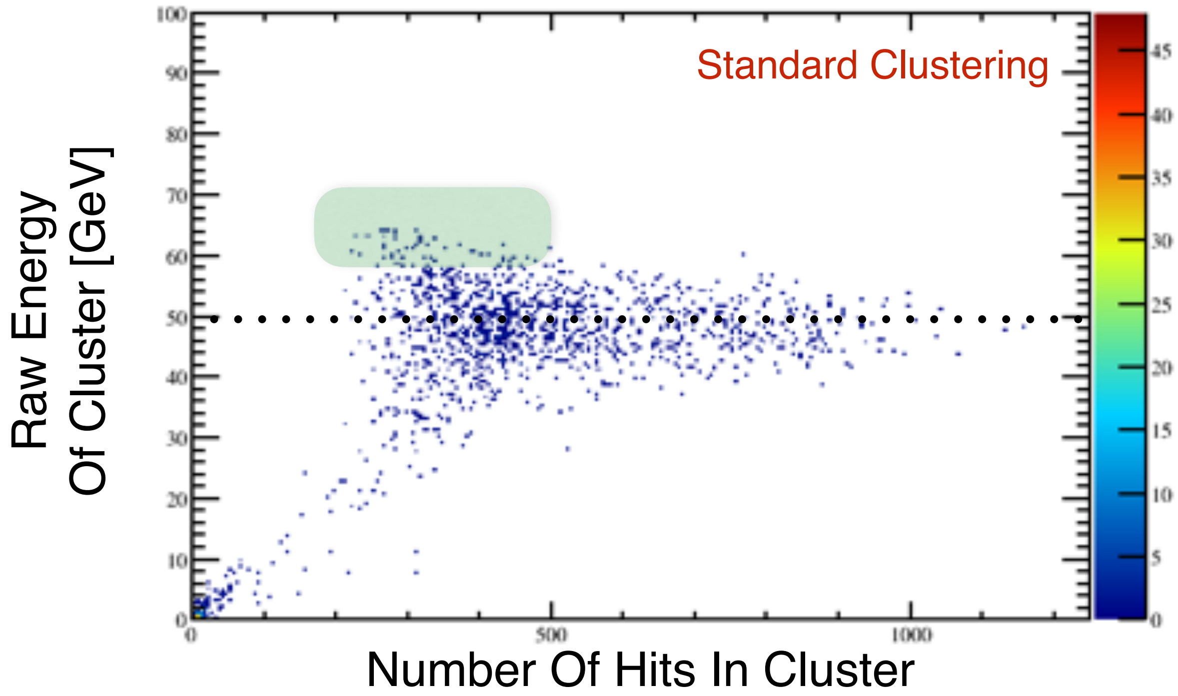
50 GeV π^-

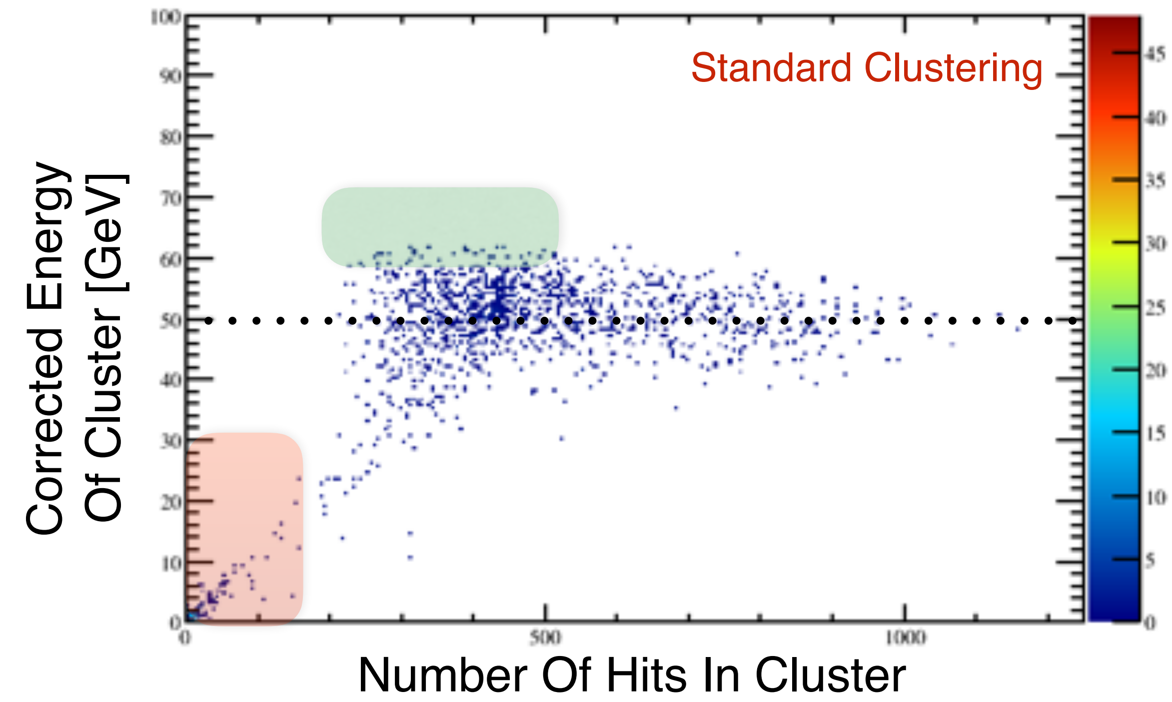
$\sigma_{Raw} = 5.58$

$\sigma_{Corrected} = 5.14$

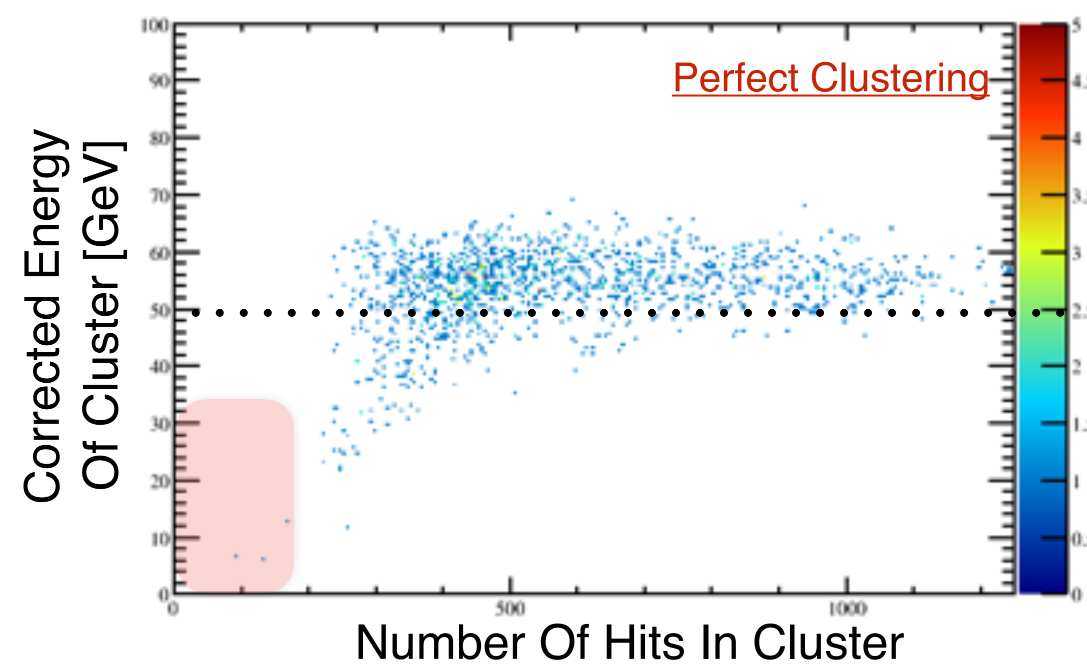
- Software compensation gives narrower distribution of cluster energies
  →better resolution

Software Compensation





- Software compensation effectively re-weights abnormally high energy density clusters.
- The effect on fragments is important and requires further examination.



Conclusions

Optimisation Studies

Parameter	Conclusion
HCal Cell Size	Smaller HCal cell sizes are beneficial to jet energy resolution.
Number of Layers in HCal	A larger number of HCal layers benefits the jet energy resolution.

Software Compensation

* Software compensation looks very promising at improving energy resolution of hadronic cluster.
* Work is being done on optimising an energy correction plugin to PandoraPFA to apply it to both the final PFO energies and at the reclustering stage.
* The effect on fragments is important and requires further examination.

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Thank you!

Back Up

Software Compensation

Software Compensation in Pandora

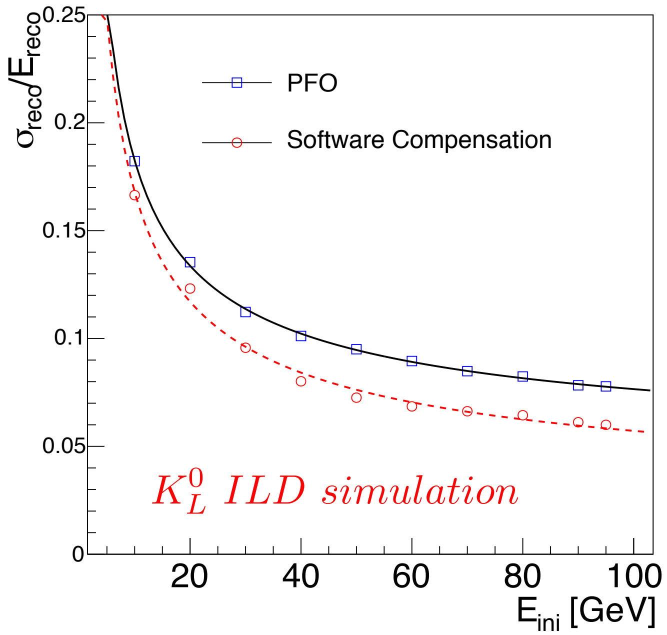
DESY-Cambridge collaboration

- Software compensation techniques developed by CALICE collaboration ***now implemented*** in MarlinPandora:

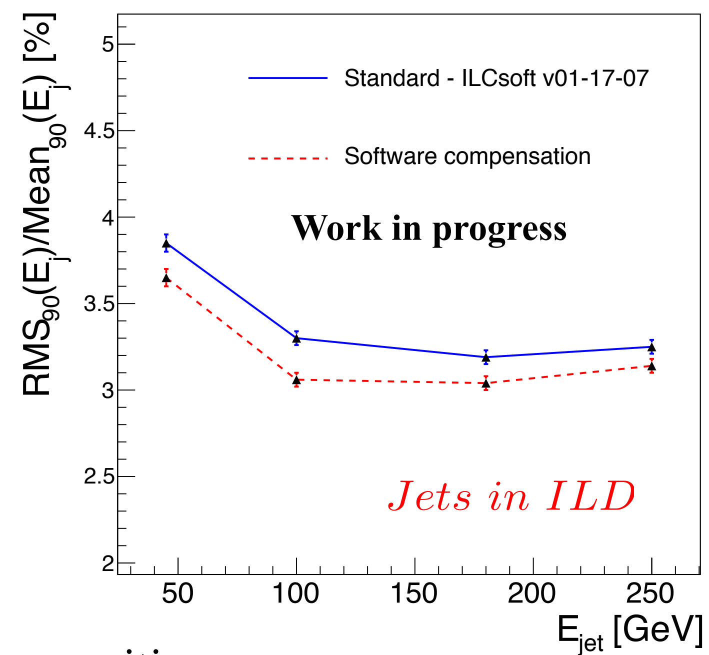
- **<u>At PFO level:</u>** correction of neutral hadron energy

➢ Improved single hadron energy resolution by 20% in energy range from 10 to 95 GeV

➢ Clear improvement also at jet level for the first time



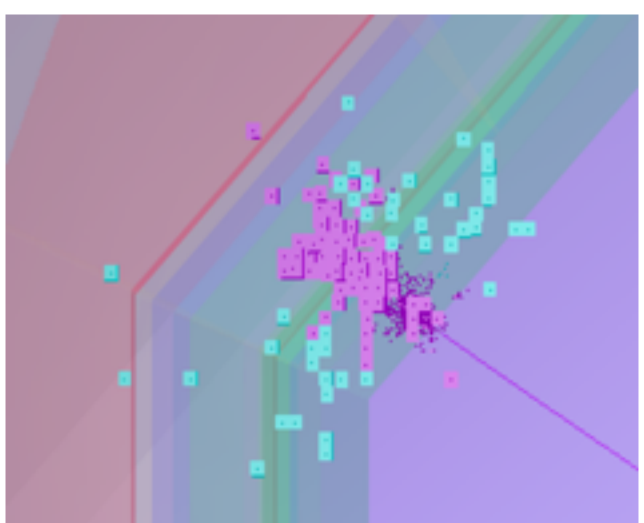
$3 \times 3\ cm^2\ ILD - AHCAL$



- **<u>At re-clustering level:</u>** expected to improve cluster-track compatibility, and therefore pattern recognition

➢ Did show clear improvements for single particle sample

➢ Not always the case and need further investigations

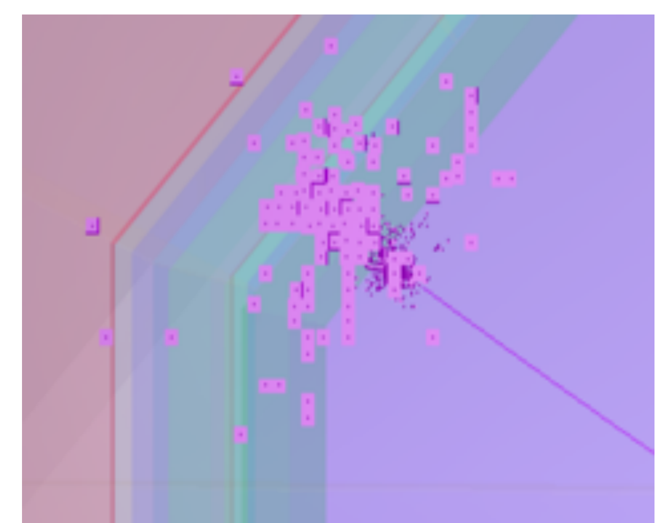


<u>Event 4079:</u> 3 PFO

- Charged object: EtrackPFO = 50.20
  Ecluster = **56.18**
- Neutral object1: EneutralPFO = **3.17**
- Neutral object2: EneutralPFO = **2.56**

After re-clustering:
three objects are **merged**

- Charged object: EtrackPFO = 50.20
  Ecluster = **57.93**

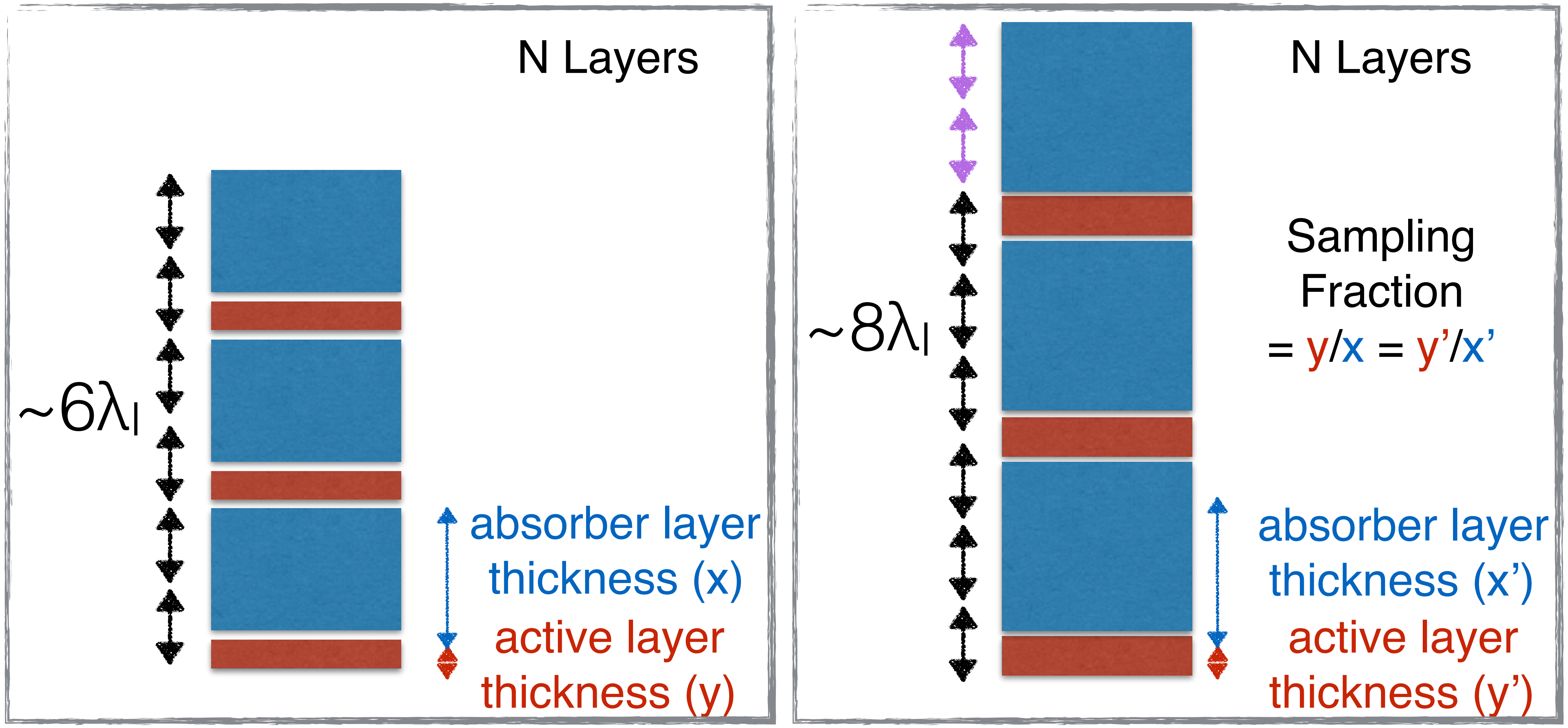


HCal Optimisation Studies

Number of Interaction Lengths in the HCal

* Here we wish to consider varying the total number of nuclear interaction in the HCal.

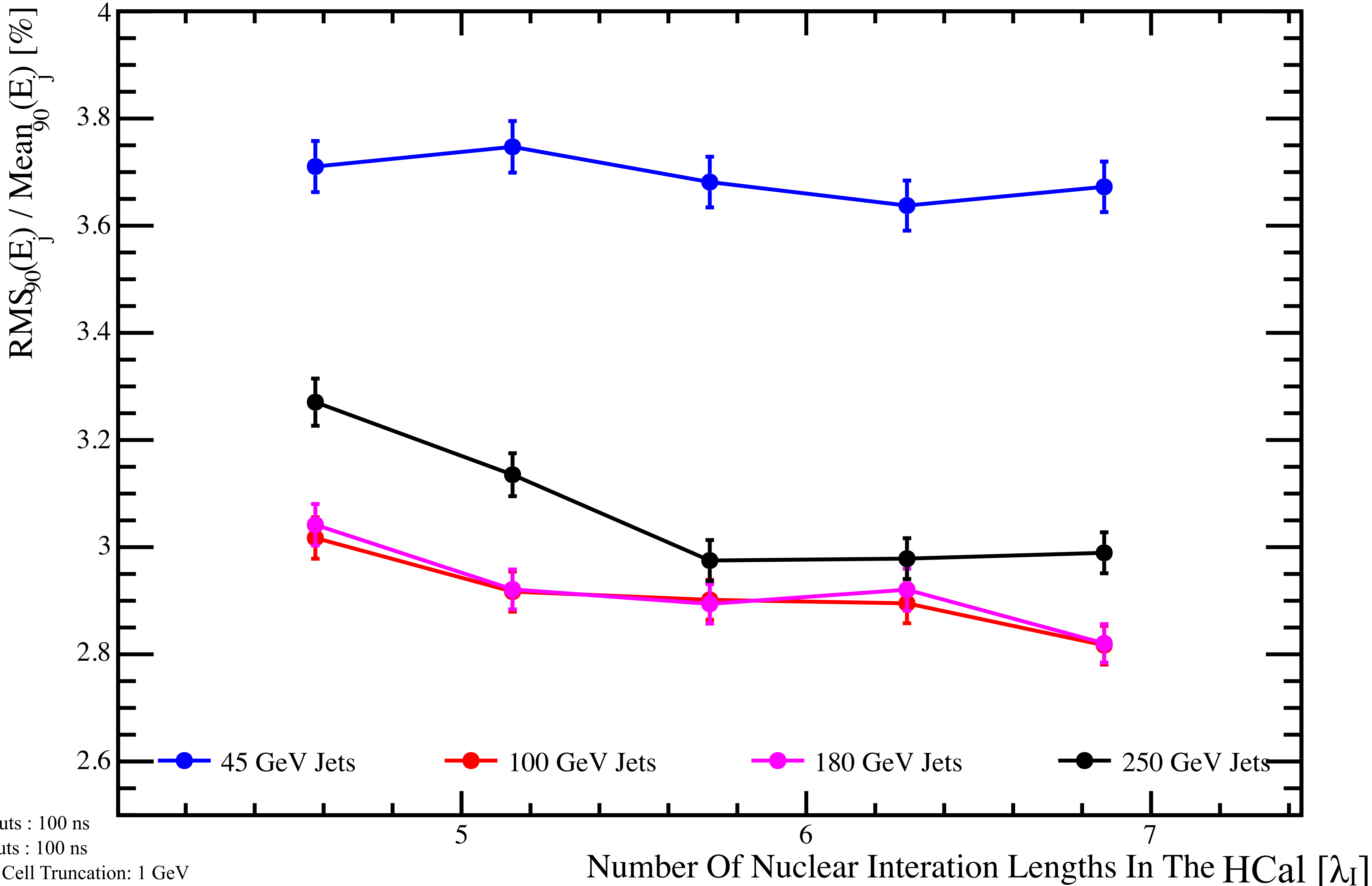
* However, we do not want to implicitly vary either the number of layers in the HCal or the sample fraction when varying this study:



Cartoon showing effect of changing number of nuclear interaction lengths in the HCal

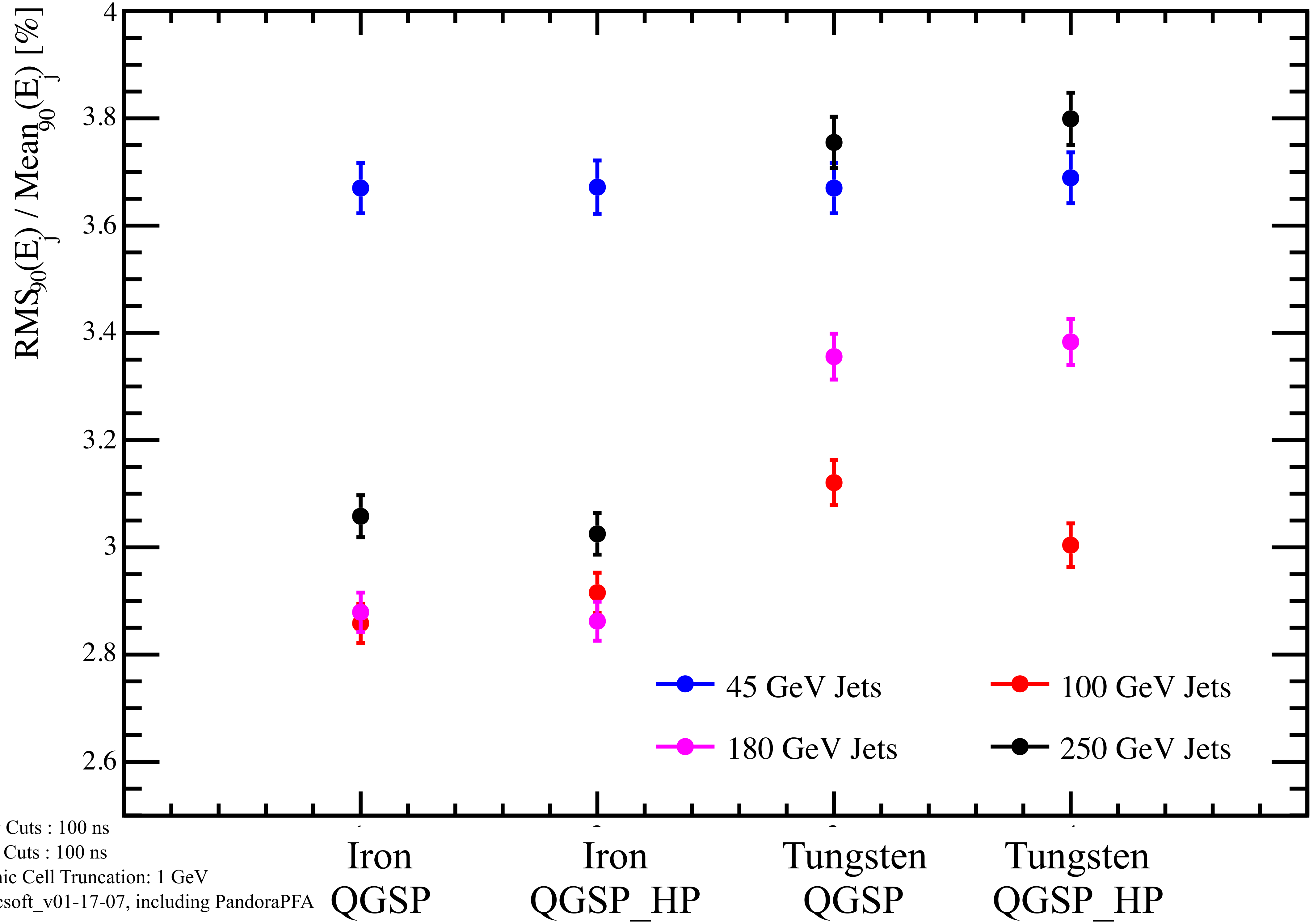
* The number of nuclear interaction lengths and the ratio of the absorber layers thicknesses to the active layer thicknesses is unchanged in this study.

Number of Interaction Lengths in the HCal Optimisation Results



HCal Timing Cuts : 100 ns
ECal Timing Cuts : 100 ns
HCal Hadronic Cell Truncation: 1 GeV
Software : ilcsoft_v01-17-07, including PandoraPFA v02-00-00
Digitiser : ILDCaloDigi, realistic ECal and HCal digitisation options enabled
Calibration : PandoraAnalysis toolkit v01-00-00

HCal Absorber Material



HCal Timing Cuts : 100 ns
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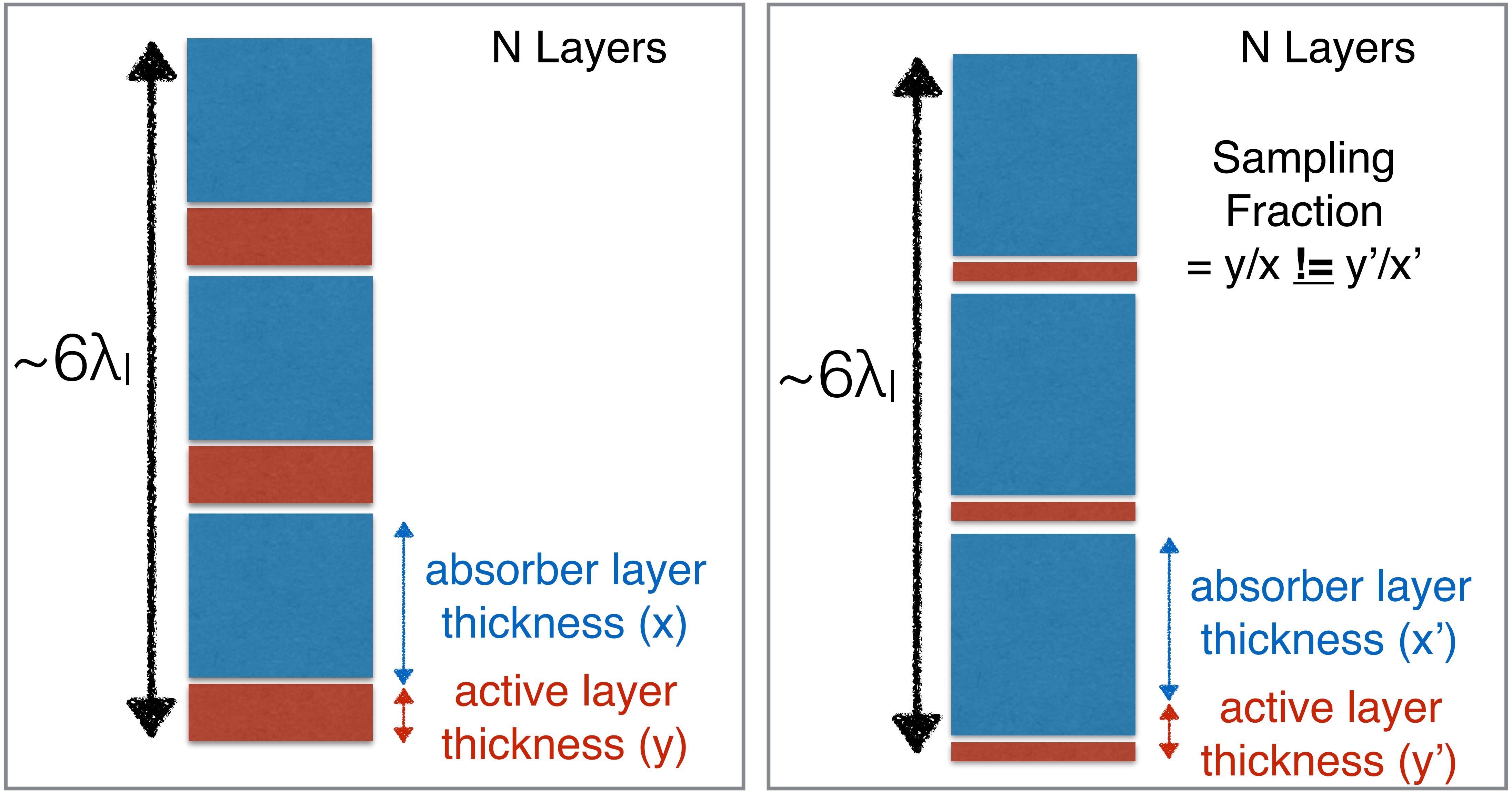
Software : ilcsoft_v01-17-07, including PandoraPFA v02-00-00
Digitiser : ILDCaloDigi, realistic ECal and HCal digitisation options enabled
Calibration : PandoraAnalysis toolkit v01-00-00

Sampling Fraction in the HCal

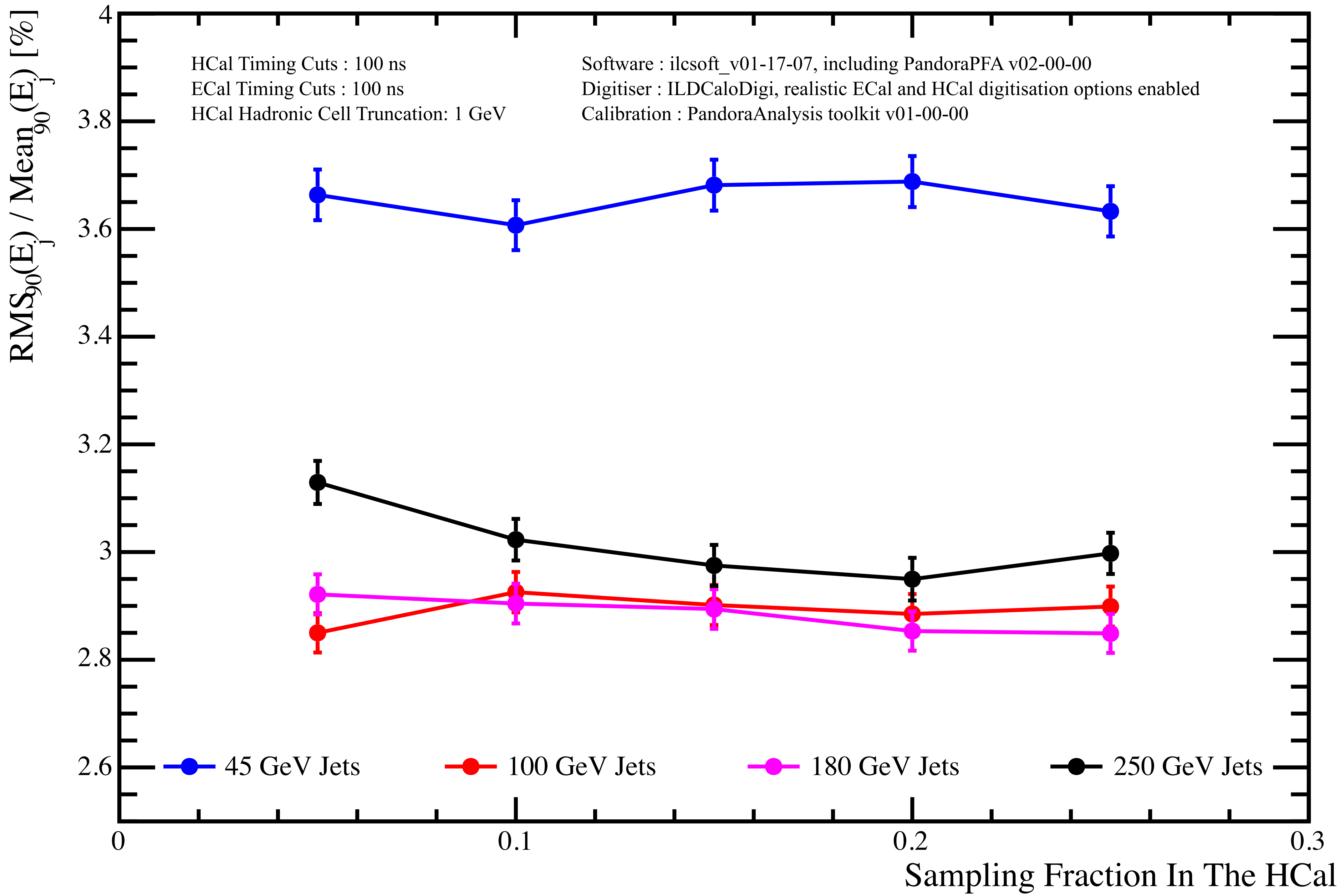
- Here we wish to consider varying the sampling fraction in the HCal.
- However, we do not want to implicitly vary either the number of layers or the number of nuclear interaction lengths in the HCal this study:



Cartoon showing effect of changing number of nuclear interaction lengths in the HCal

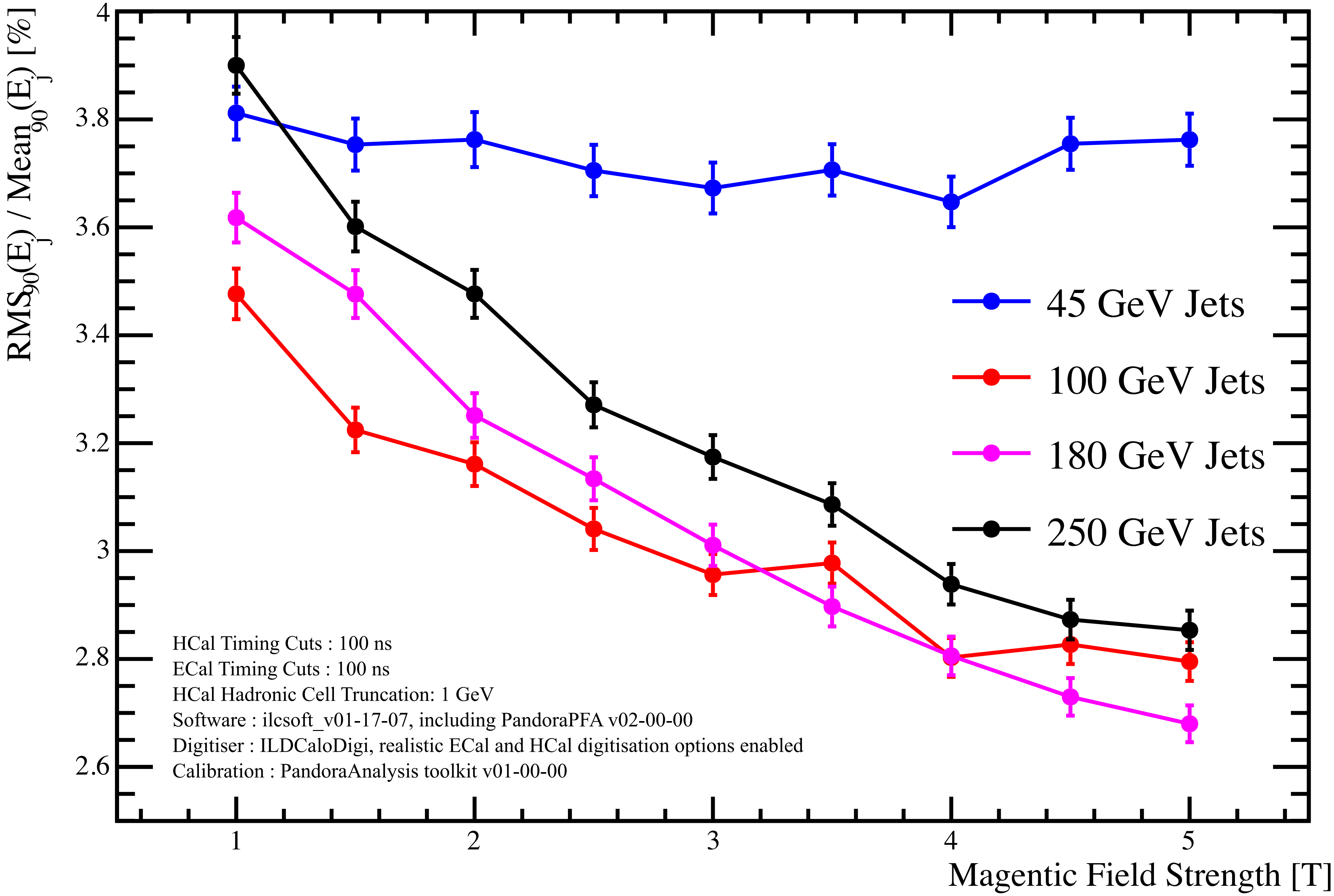
- The number of nuclear interaction lengths and the ratio of the absorber layers thicknesses to the active layer thicknesses is **unchanged** in this study.

Sampling Fraction in the HCal



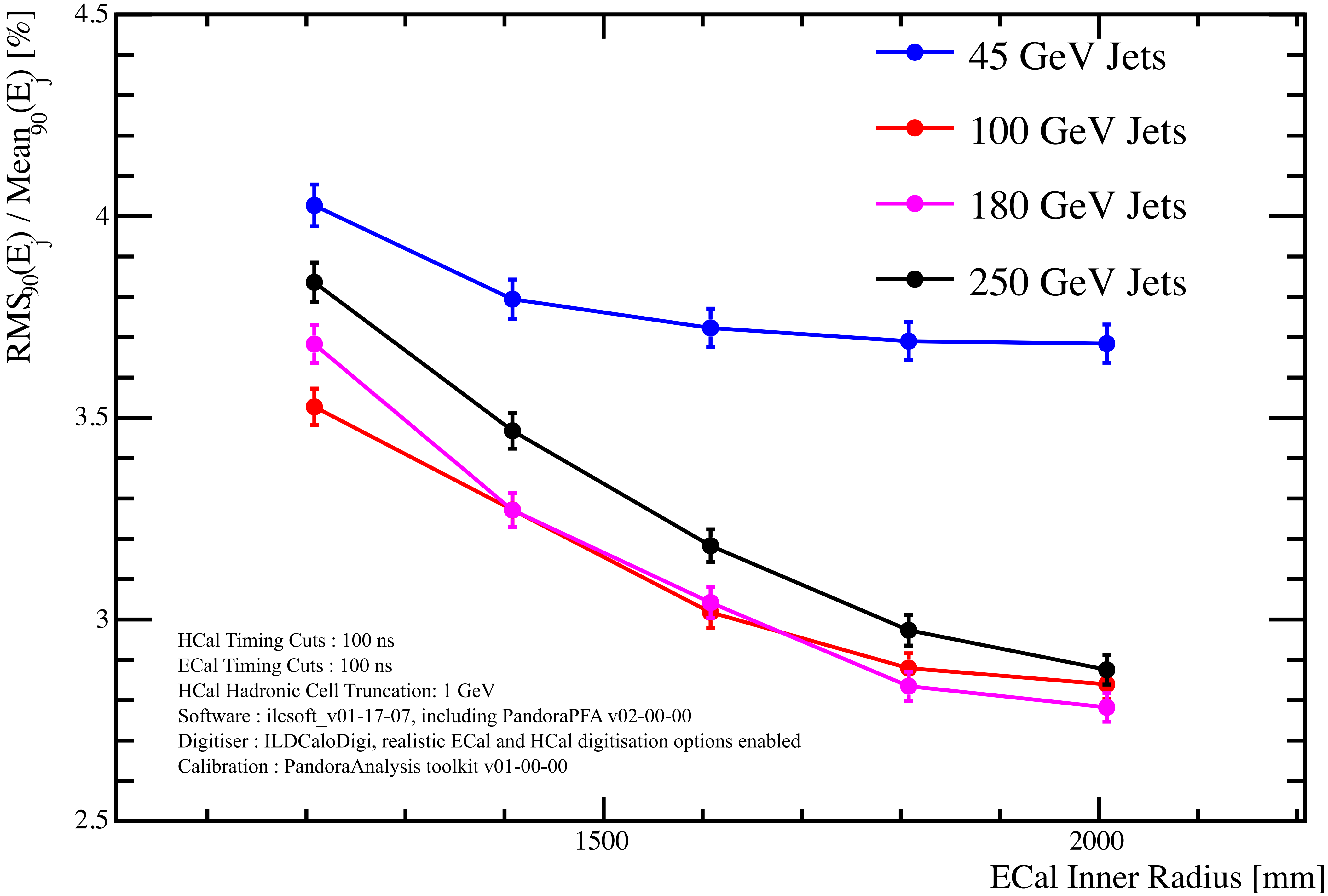
Optimisation of Global Parameters

B Field



RMS90(Ej) / Mean90(Ej) [%]
4
3.8
3.6
3.4
3.2
3
2.8
2.6
1
2
3
4
5
Magentic Field Strength [T]
45 GeV Jets
100 GeV Jets
180 GeV Jets
250 GeV Jets
HCal Timing Cuts : 100 ns
ECal Timing Cuts : 100 ns
HCal Hadronic Cell Truncation: 1 GeV
Software : ilcsoft_v01-17-07, including PandoraPFA v02-00-00
Digitiser : ILDCaloDigi, realistic ECal and HCal digitisation options enabled
Calibration : PandoraAnalysis toolkit v01-00-00

ECal Inner Radius



Simulation and Reconstruction Evolution

- **Aim:** Show evolution of the detector performance from the DBD/LoI up to present day best estimates.

- This incorporates several significant changes such as:
  1. Initial Changes:
     - Updated detector model and reconstruction software (inc. PandoraPFA).
     - New calibration procedure as documented in PandoraAnalysis (v01-00-00).
     - New digitiser, ILDCaloDigi vs NewLDCCaloDigi
     - Realistic ECal and HCal simulations at the digitisation stage.
  2. Timing cuts applied to the simulation.
  3. HCal Hadronic Energy Cell truncation.

- This will be covered in three stages. Initial changes, timing cuts, hadronic energy cell truncation.

The changes, broadly speaking, fit into two categories:

1. Pattern recognition changes;
2. Energy metric changes.

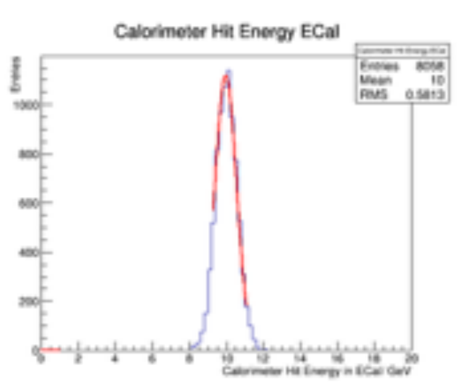
Details of Calibration Procedure

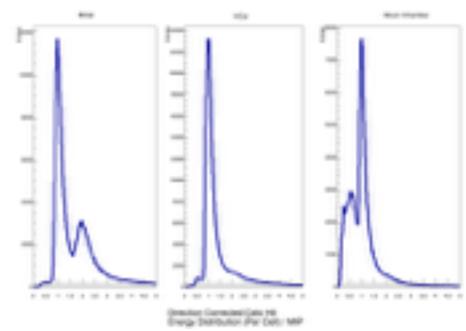
Simulation Output
Energy Deposited in Active Material of Calorimeters

Calorimeter Energy
Energy Deposited in the Total Calorimeter Volume

Reconstructed Particle Energy
Energy of Particle(s) Depositing Energy in Calorimeters

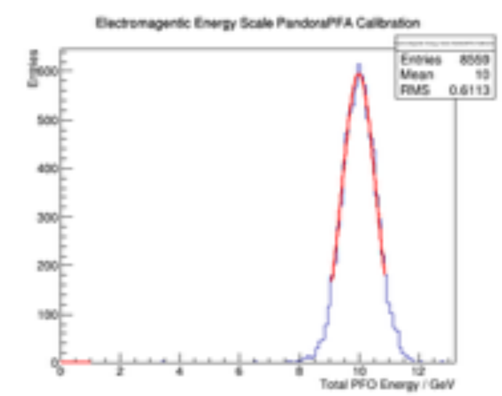
Digitisation
Set by looking at contained kaonL and ɣ events throughout the calorimeters.

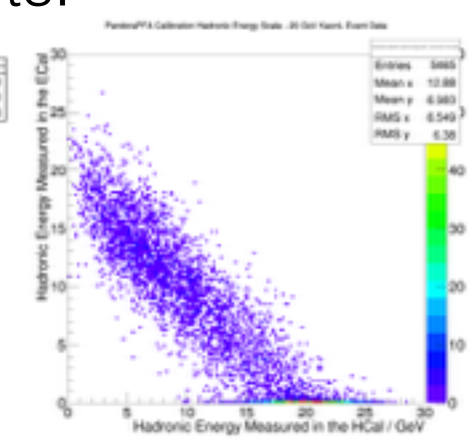




Minimum Ionising Particle (MIP) Detector Response
Determine the response of each part of the detector to a MIP, μ^- events. MIP scale used in PandoraPFA.

Electromagnetic and Hadronic Scale Setting
Electromagnetic/Hadronic scale set using PFO energy of contained ɣ and kaonL events.





The PandoraAnalysis toolkit has several scripts designed for setting the digitisation and calibration constants. The user has to provide samples of kaonL, ɣ and μ^-.
These scripts make automation of this procedure possible.

Timing Cuts

* Now we look into the impact of applying timing cuts to the simulation.
* This will be the first study of this kind produced when we apply timing cuts to the simulation.
* The timing cuts applied to a simulation of a detector model have a significant effect on the performance and, as expected, they degrade performance, but we need to quantify this degradation.
* We will examine this degradation by looking at both single kaon0L and uds jets from the decay of off-shell mass Z bosons.

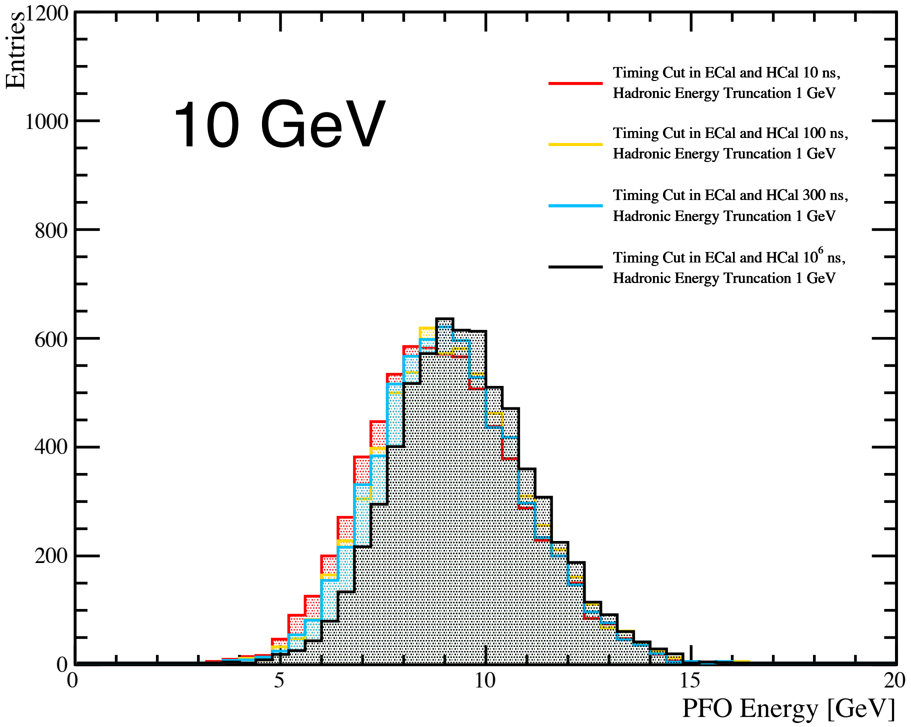
Single Particle Energy Analysis:

* Here we will look at:
  1. Raw reconstructed energy distributions;
  2. Mean reconstructed energy;
  3. Energy resolution.

Jet Energy Analysis:

* Here we will look at:
  1. Raw reconstructed energy distributions;
  2. Mean jet energies;
  3. Jet energy resolution.

Timing Cuts - Single Particle Energy Distributions



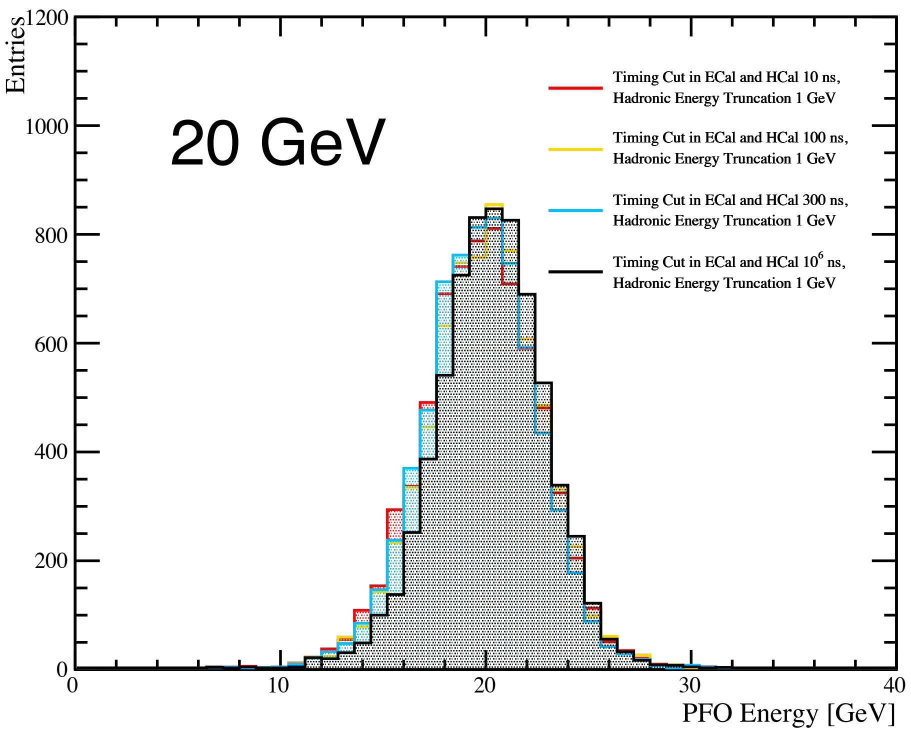
Timing Cut in ECal and HCal 10 ns, Hadronic Energy Truncation 1 GeV

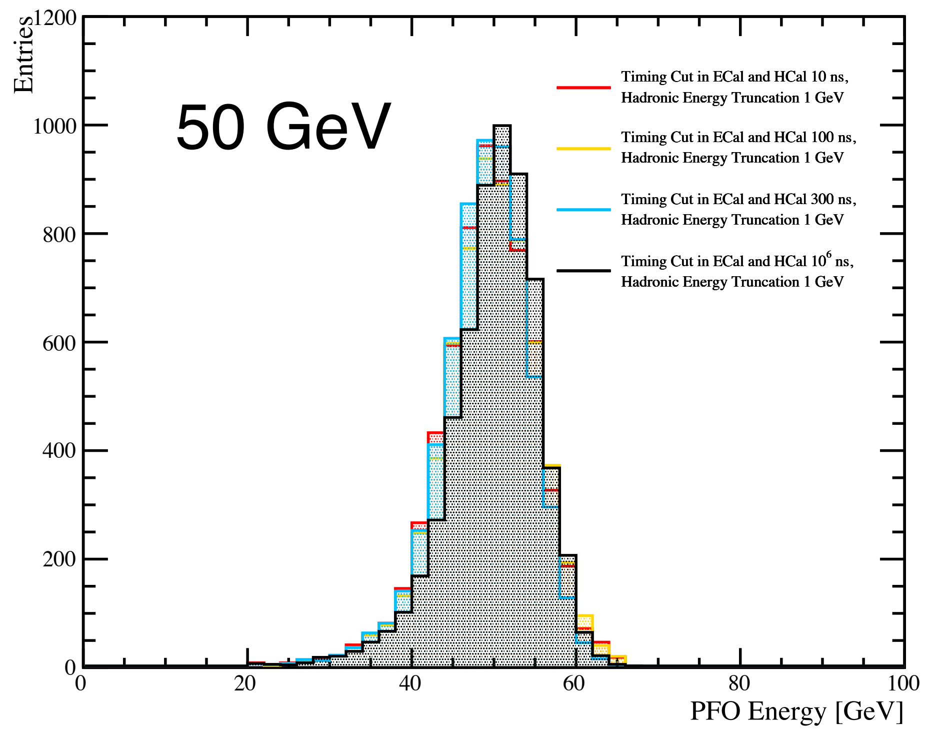
Timing Cut in ECal and HCal 100 ns, Hadronic Energy Truncation 1 GeV

Timing Cut in ECal and HCal 300 ns, Hadronic Energy Truncation 1 GeV

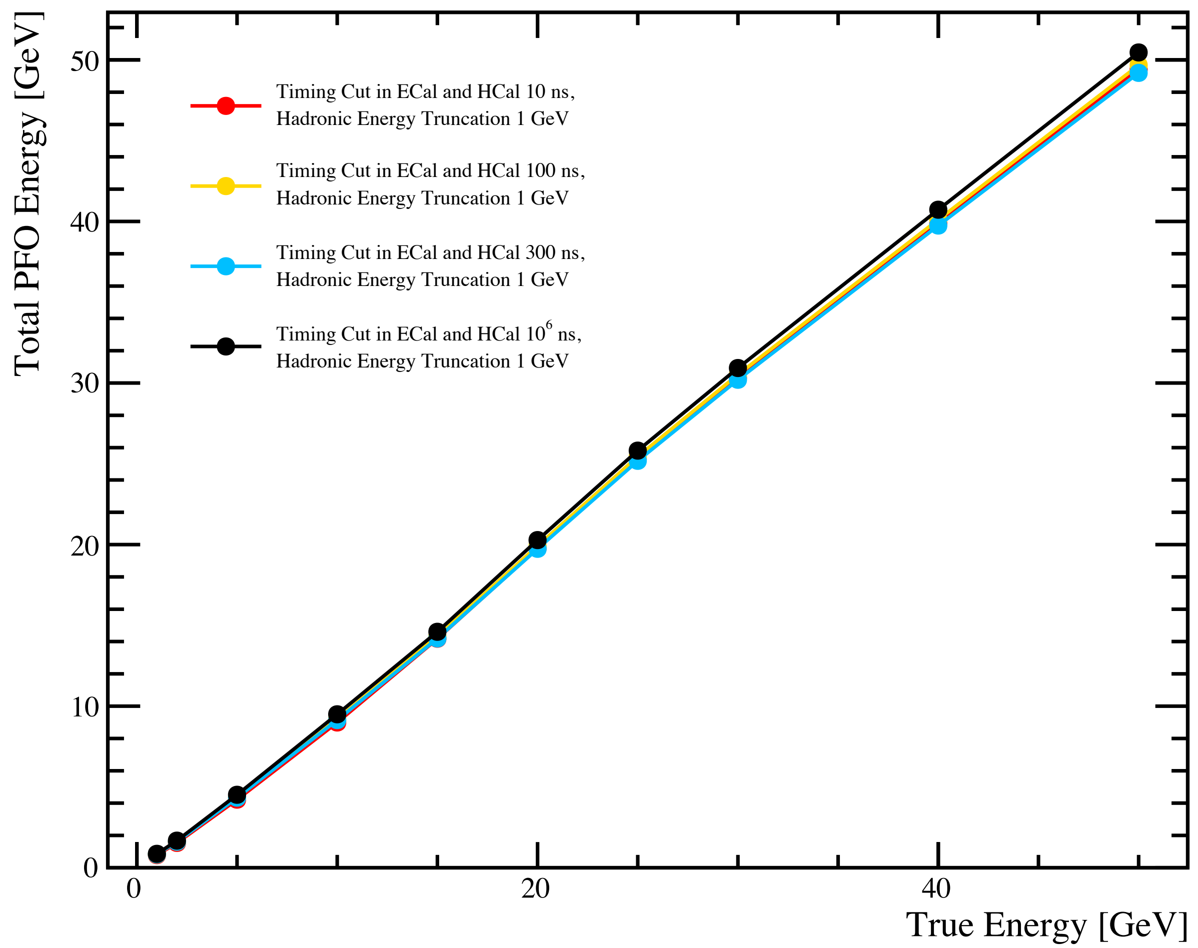
Timing Cut in ECal and HCal 10^6 ns, Hadronic Energy Truncation 1 GeV

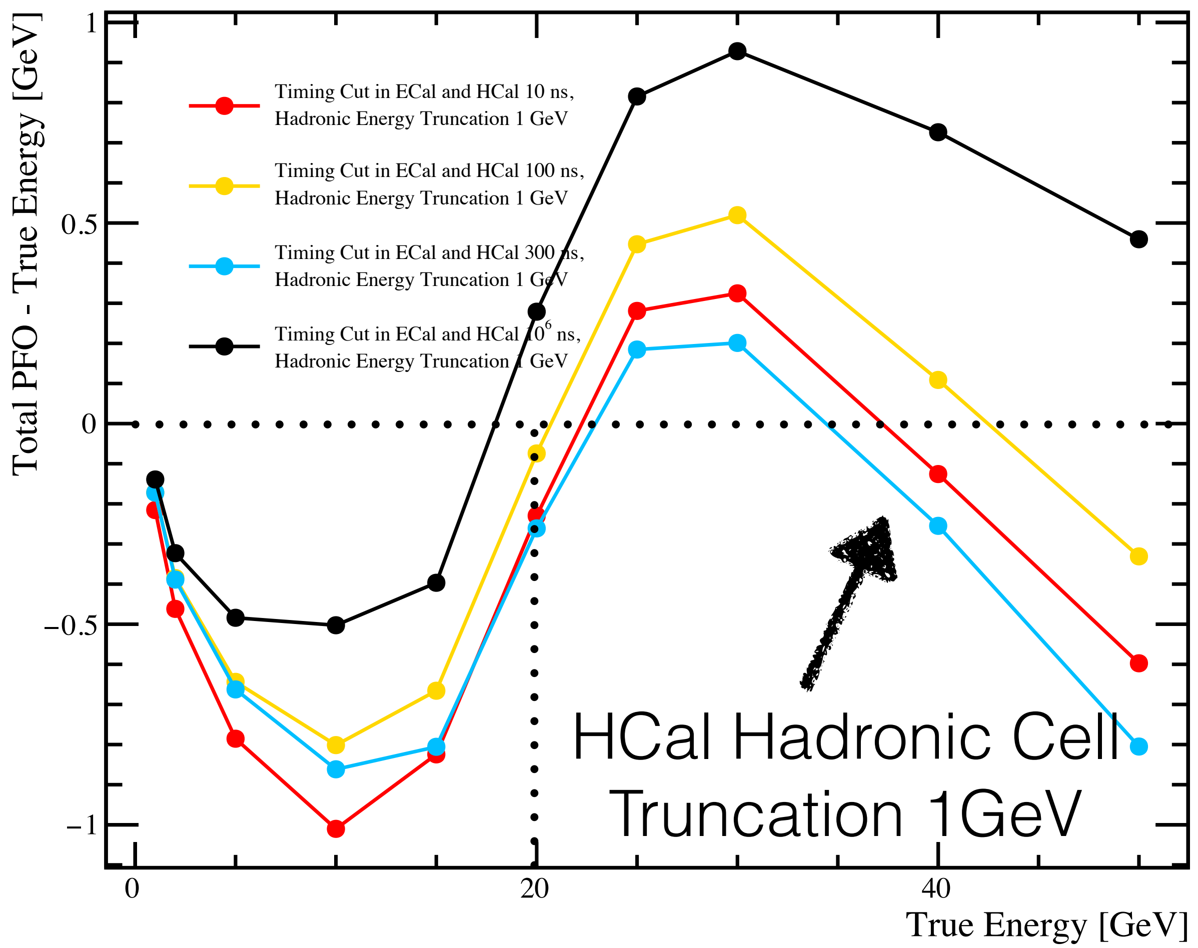
- Histograms of the reconstructed energy for single Kaon0L events of fixed energy.
- Distributions have largely the same shape.
- Calibration fixes the mean of the 20 GeV distributions to be close to 20 GeV.





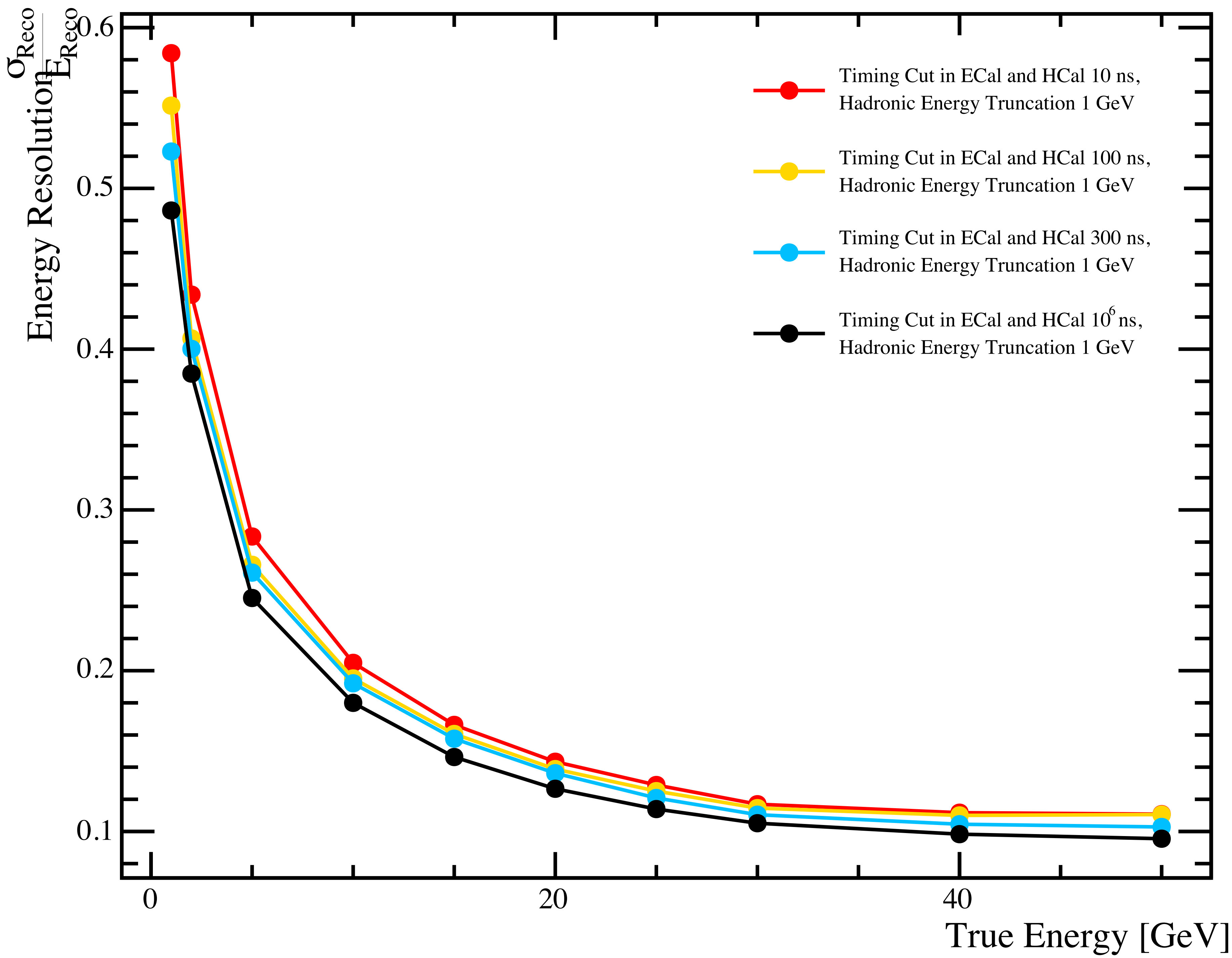
Timing Cuts - Single Particle Mean Energy





- For particle of energy less that 10 GeV the distributions aren't Gaussian so the points for energy less that 10 GeV don't properly represent the data.
- Timing cuts effect the total amount of reconstructed energy, but the trend is unchanged.
- In general larger timing cuts means larger reconstructed energy as expected, but varying the timing cut from 10 to 300ns, doesn't change these results significantly.

Timing Cuts - Single Particle Energy Resolutions



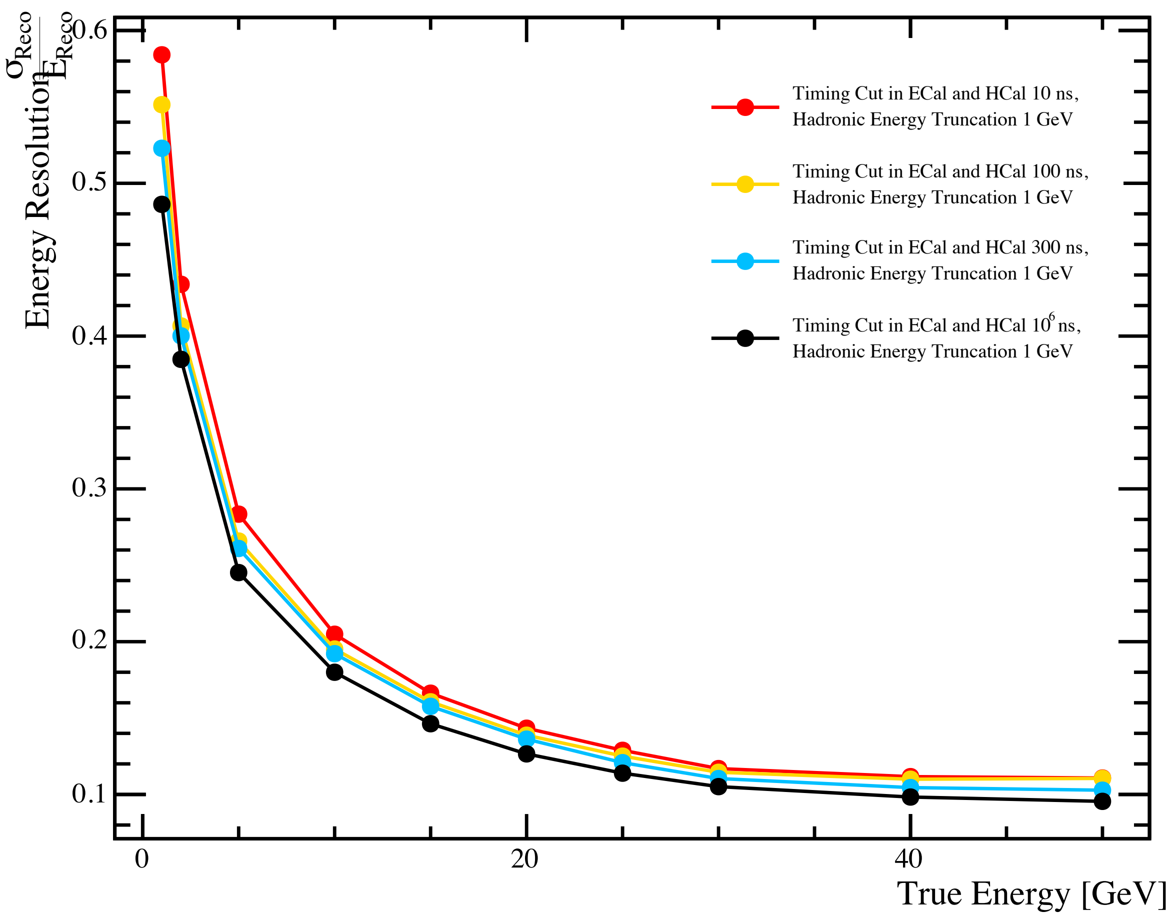
* Plot of energy resolution vs true energy for single Kaon0L events of fixed energy.
* The energy resolution here is defined as:

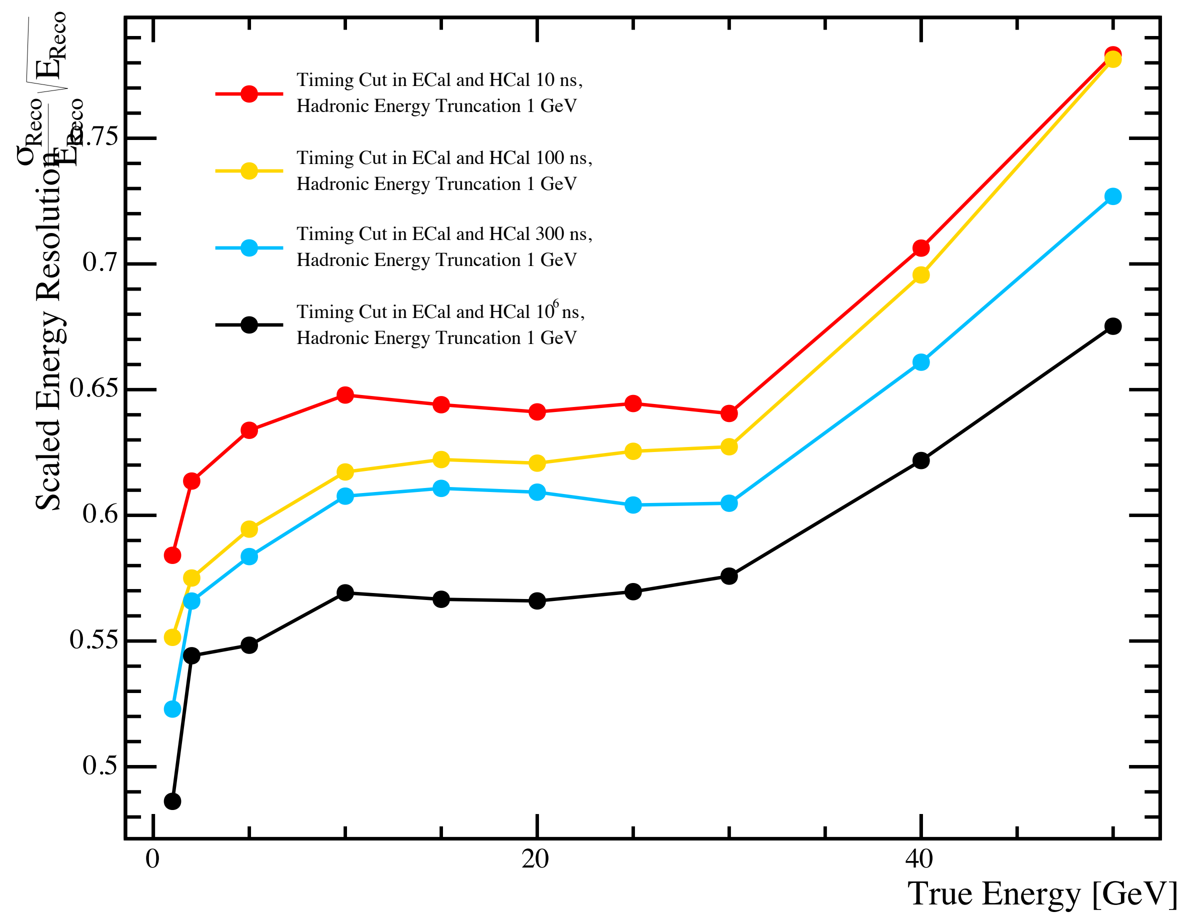
Resolution = σ_E / E

Where both σ_E and E are the standard deviation and mean of a Gaussian fit to the reconstructed energy distribution respectively.

* Energy resolution degrades with decreasing timing cuts.

Timing Cuts - Single Particle Energy Resolutions Scaled





- Quickly look at the scaled energy resolution, which is $\sqrt{E} \times \sigma_E / E$.
- Useful to compare to the generally accepted results that the energy resolution for the HCal is $0.55 / \sqrt{E}$.
- As you increase the timing cut the resolution gets better.

Timing Cuts - Jet Reconstructed Energy Distributions

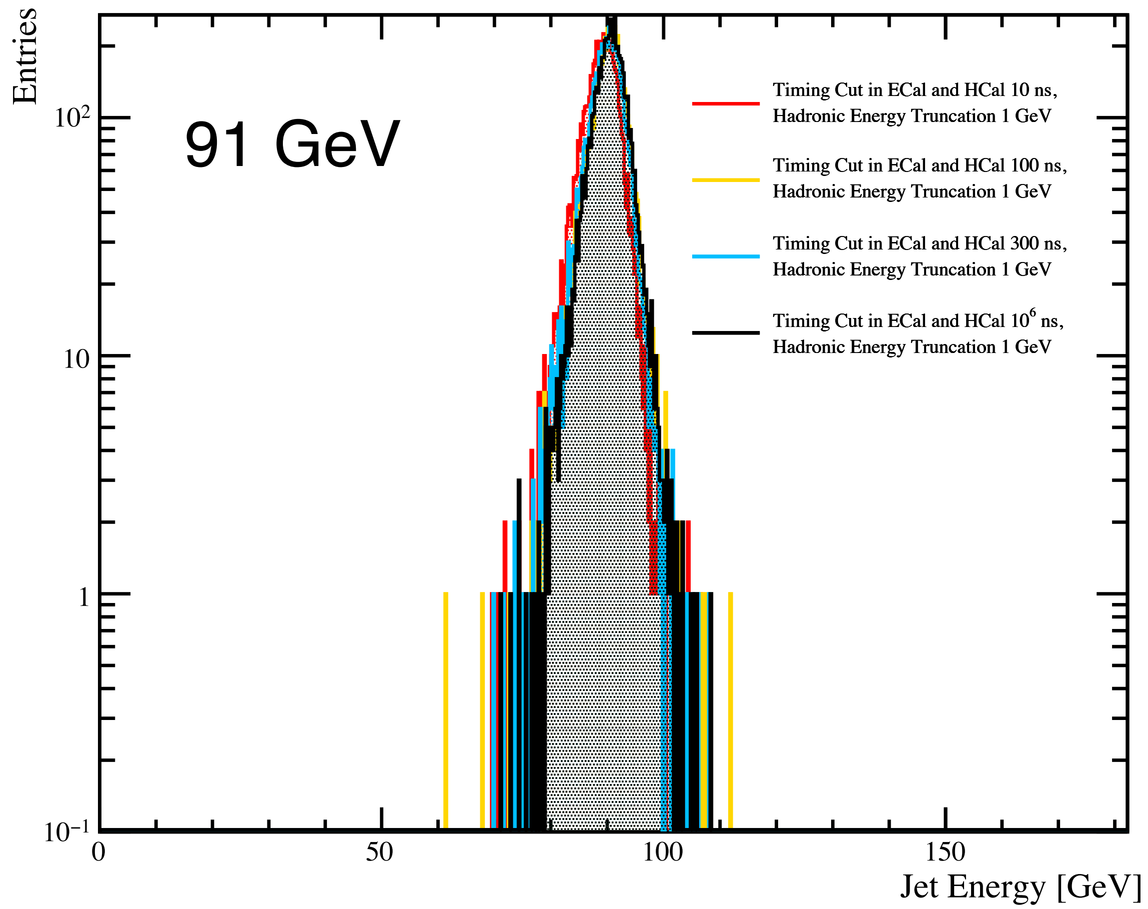
- Histograms of the reconstructed jet energy for Z_uds jet events of fixed energy.
- Distributions look similar when varying the timing cuts.

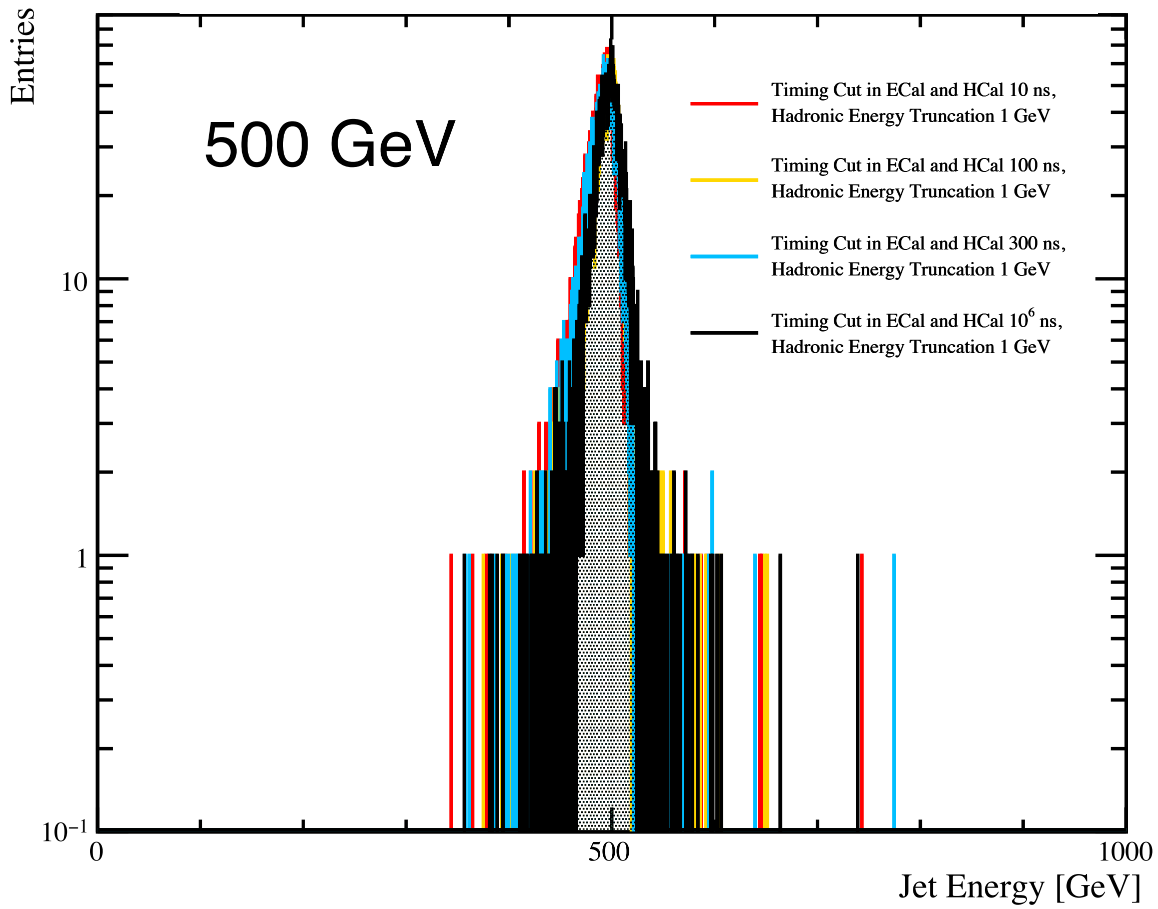
Timing Cut in ECal and HCal 10 ns, Hadronic Energy Truncation 1 GeV

Timing Cut in ECal and HCal 100 ns, Hadronic Energy Truncation 1 GeV

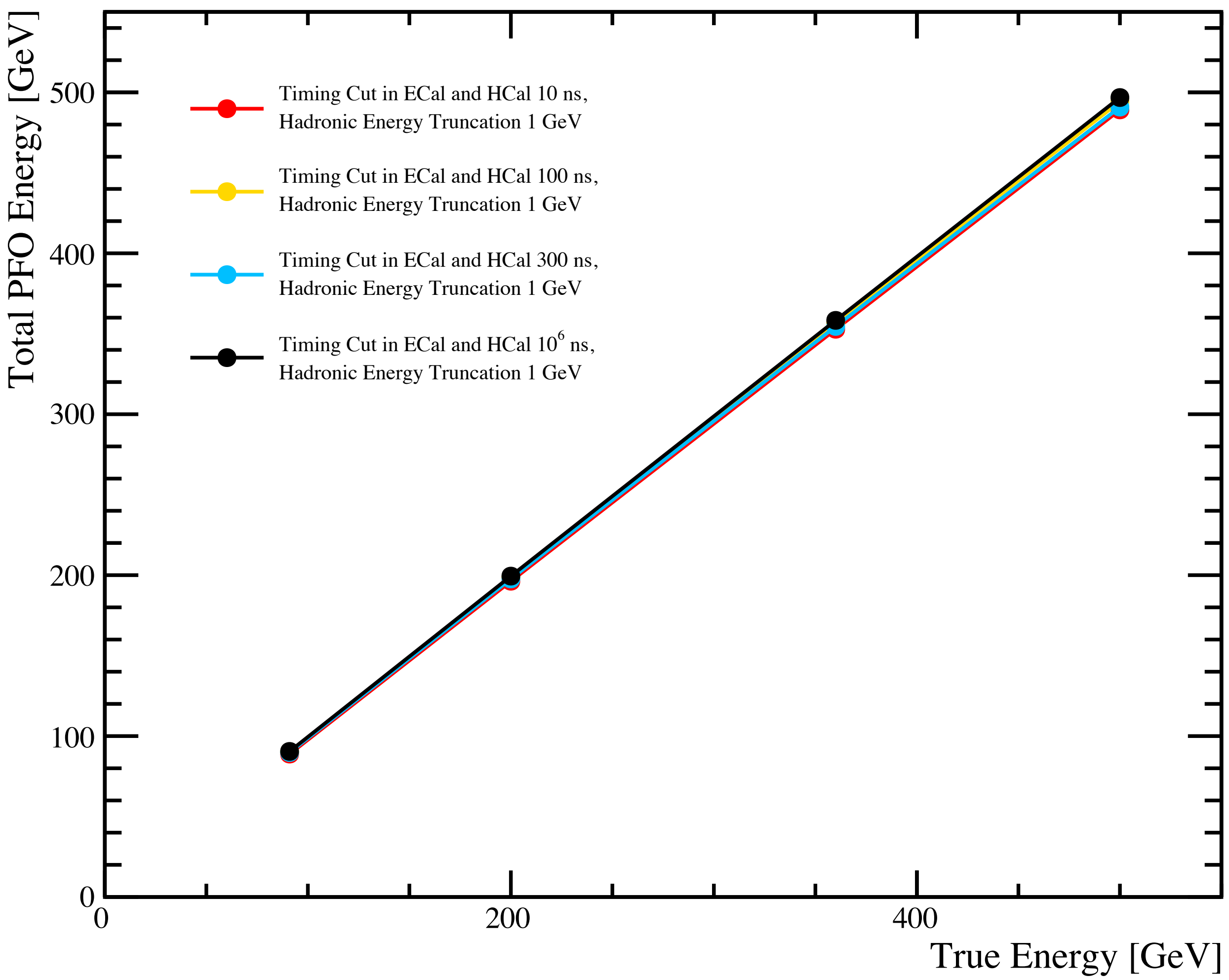
Timing Cut in ECal and HCal 300 ns, Hadronic Energy Truncation 1 GeV

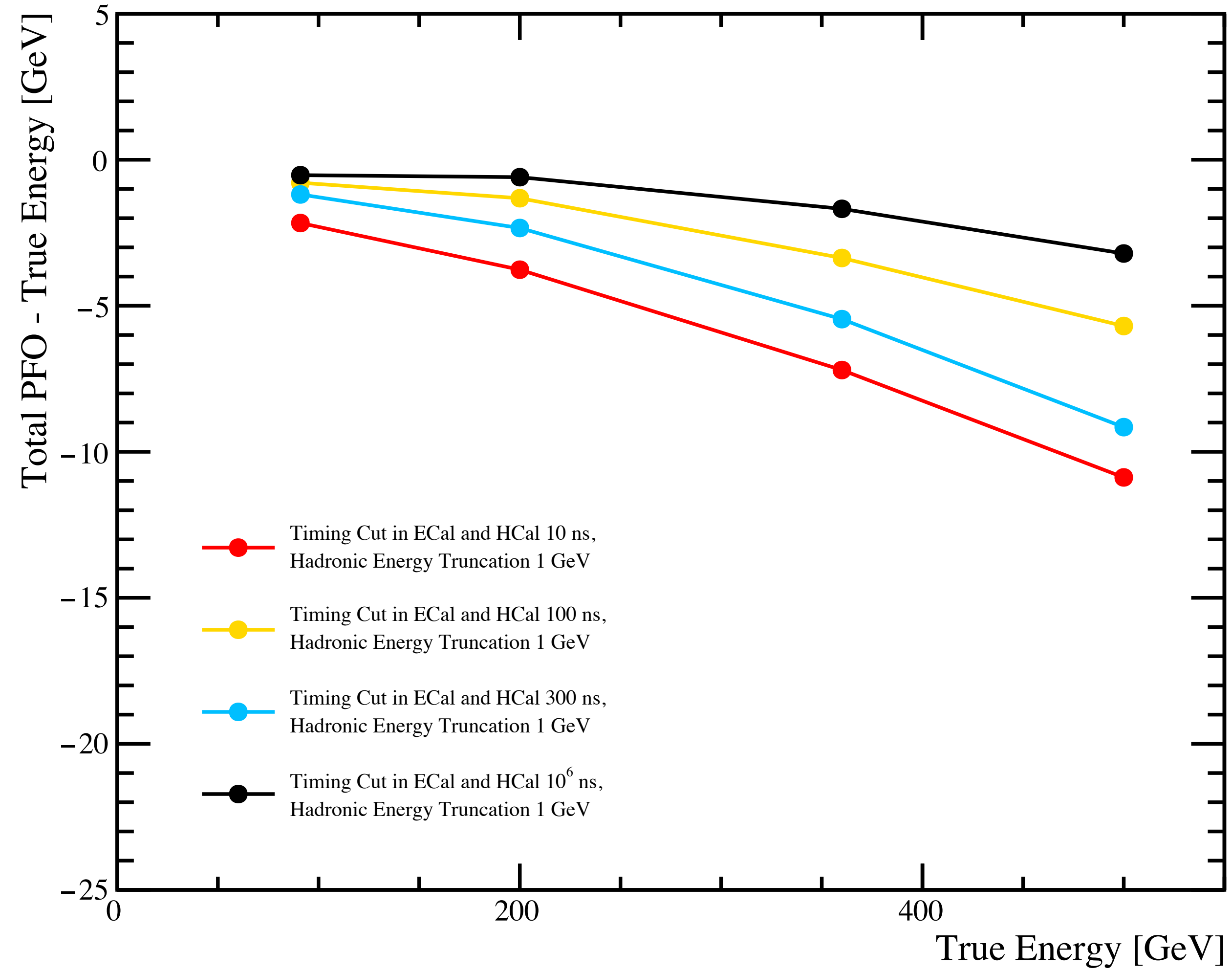
Timing Cut in ECal and HCal 10^6 ns, Hadronic Energy Truncation 1 GeV





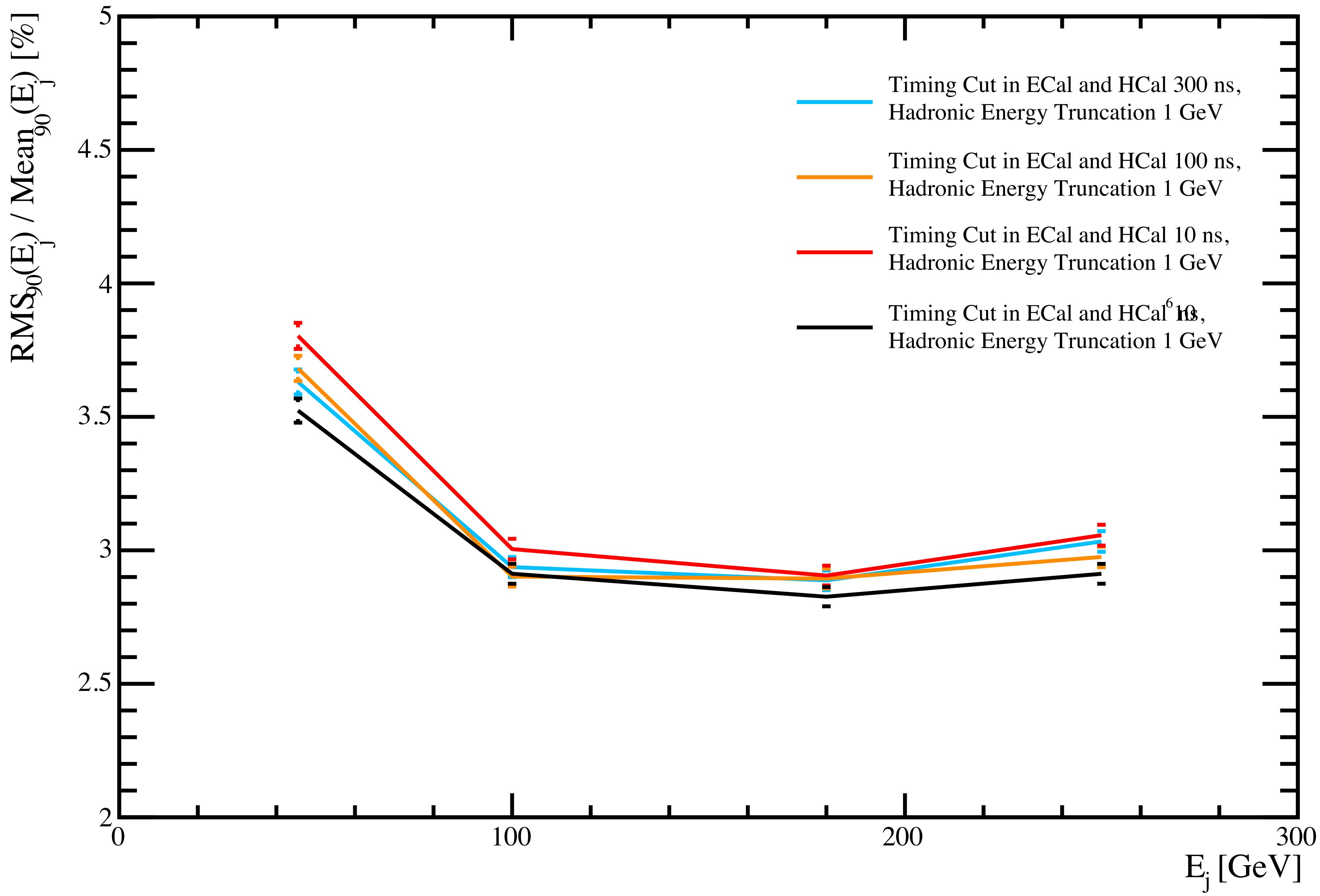
Timing Cuts - Jet Mean Energy





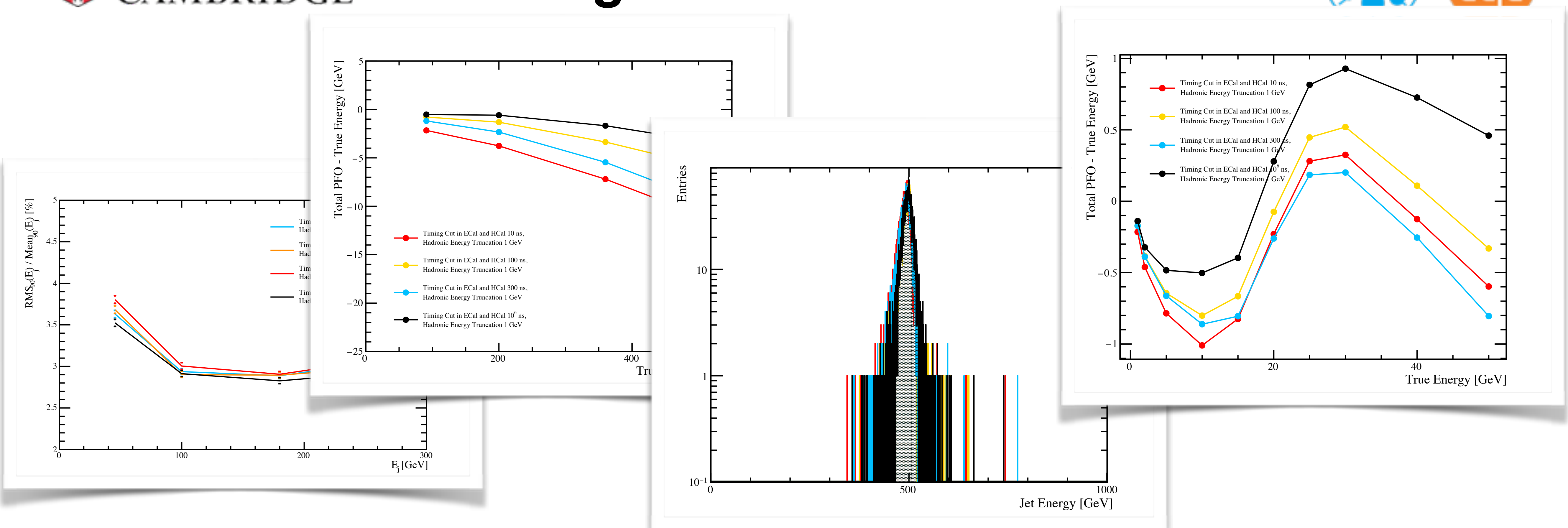
- As expected the mean jet energy decreases with increasing energy due to the HCal cell hadronic energy truncation of 1GeV.
- Also as expected with larger the timing cuts you record more energy.

Timing Cuts - Jet Energy Resolutions



- Plot of jet energy resolution vs true jet energy for Z_uds jets of fixed energy.
- Some variation in performance, but relatively small.

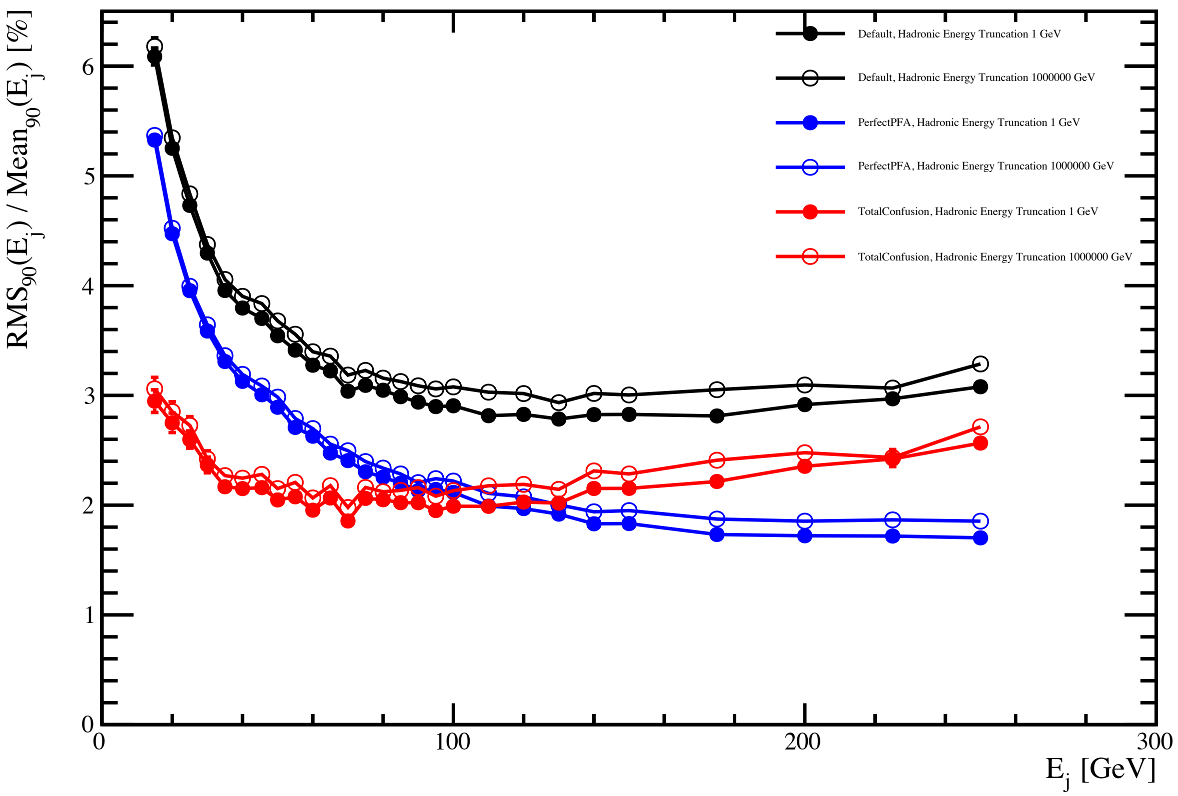
Timing Cuts - Conclusions



- Timing cuts are important.
- They do, as expected degrade performance.
- There is relatively little difference when applying realistic timing cuts. By realistic we mean anywhere between 10ns and 300ns.
- For future studies we will be applying a default timing cut of 100 ns.

HCal Hadronic Energy Truncation

- Within PandoraPFA a hadronic energy truncation can be applied, which aids the reconstruction in both intrinsic energy resolution and pattern recognition, by improving the energy estimator for the calorimeter hits.
- The exact value of this truncation significantly impact the energy resolution.
- Here we aim to show the extent of this impact.



Single Particle Energy Analysis:

- Here we will look at:
  1. Raw reconstructed energy distributions;
  2. Mean reconstructed energy;
  3. Energy resolution.

Jet Energy Analysis:

- Here we will look at:
  1. Raw reconstructed energy distributions;
  2. Mean jet energies;
  3. Jet energy resolution.

Hadronic Energy Truncation in PandoraPFA

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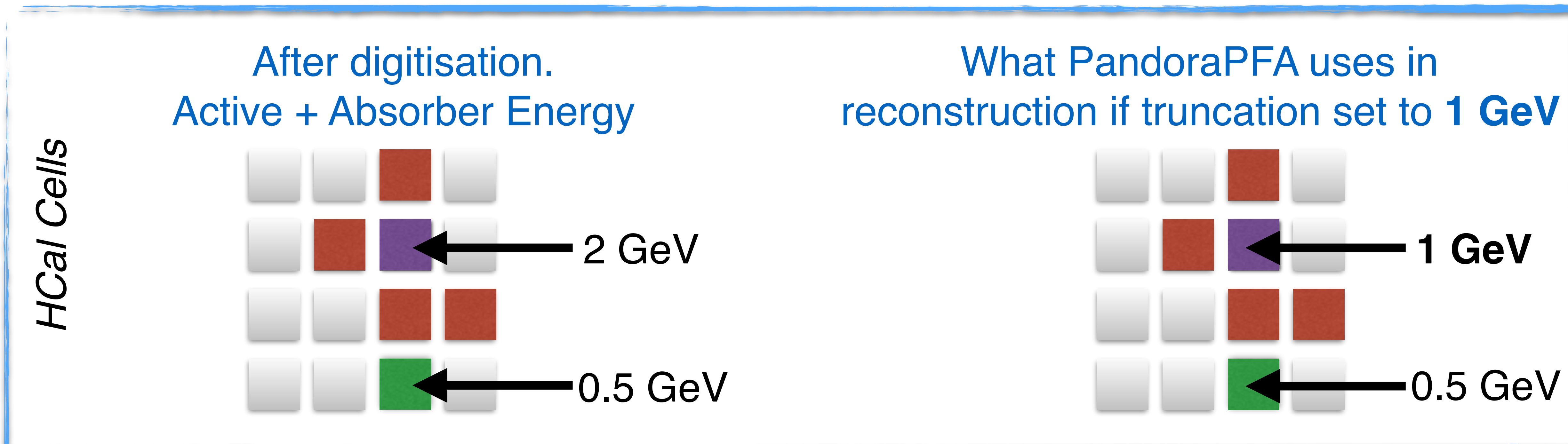
- A variable of key significance in these studies is the hadronic energy truncation applied in the HCal in PandoraPFA.
- Within PandoraPFA, the HCal cells contain an estimate of the energy deposited in both the active and absorber material.
- The cut limits/truncates the amount of hadronic energy that can be measured in an individual HCal cell.
- It's purpose is to act as naive software compensation, which improves the hadronic energy estimator.



HCal Hadronic Energy Truncation - Single Particle Energy Distributions

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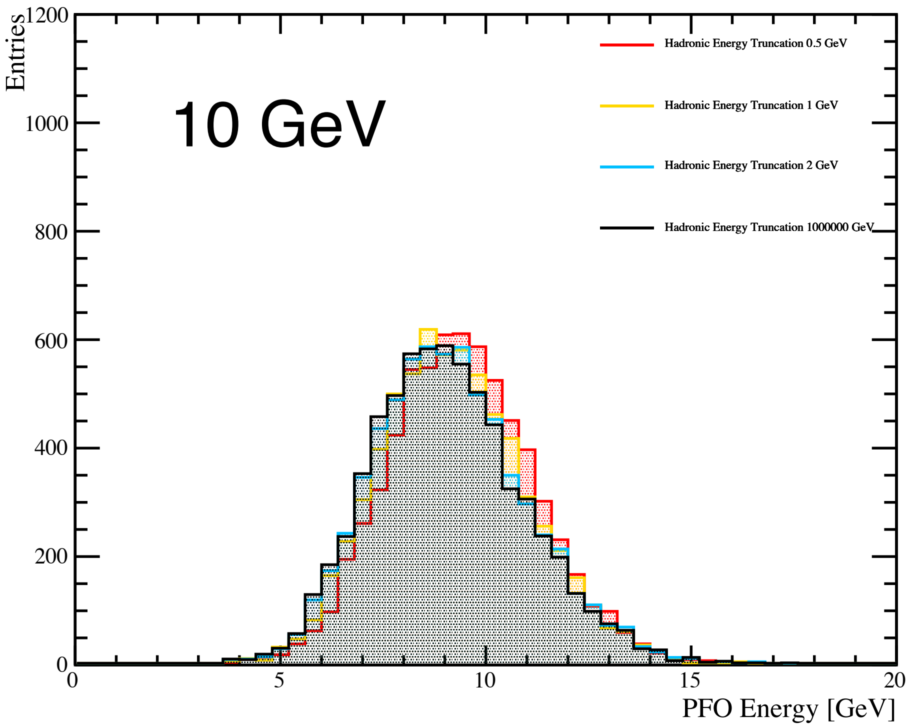
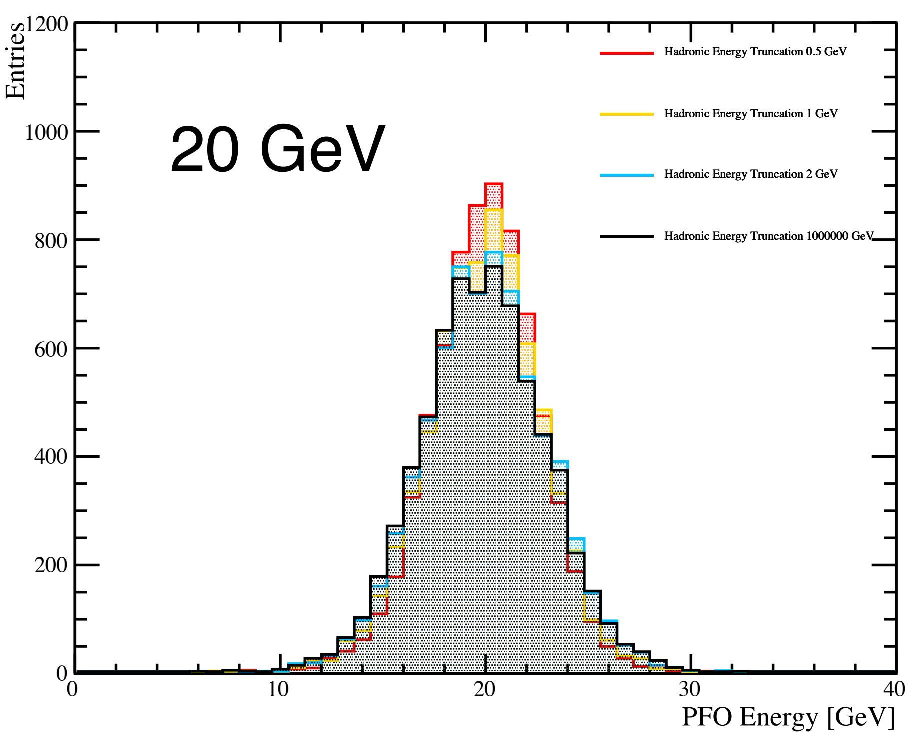


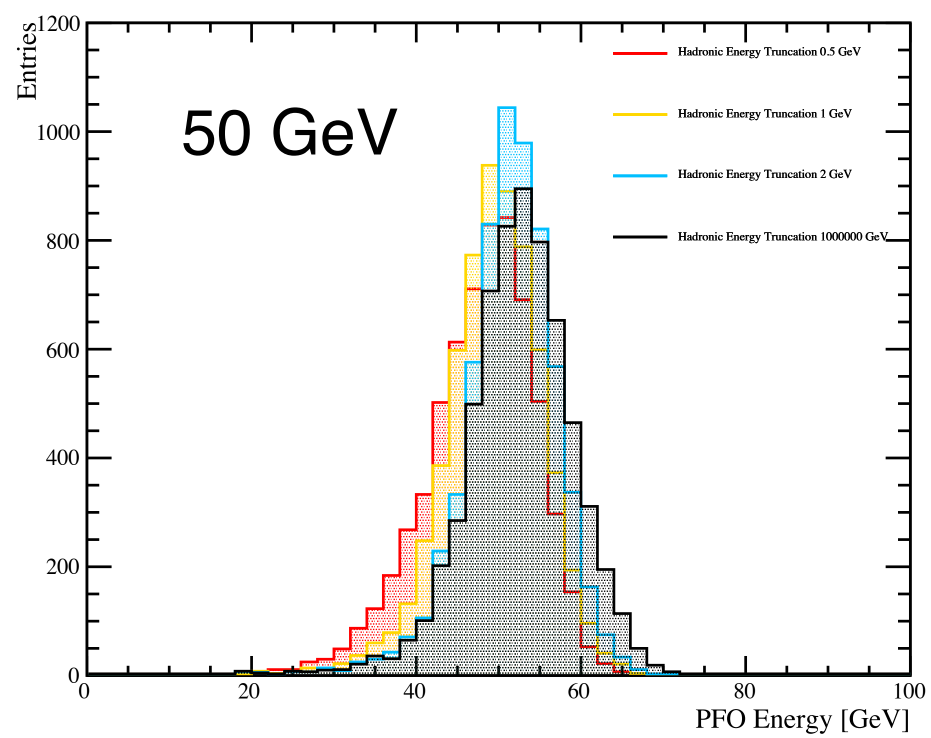
Hadronic Energy Truncations 0.5 GeV

Hadronic Energy Truncations 1 GeV

Hadronic Energy Truncations 2 GeV

Hadronic Energy Truncations 10^6 GeV



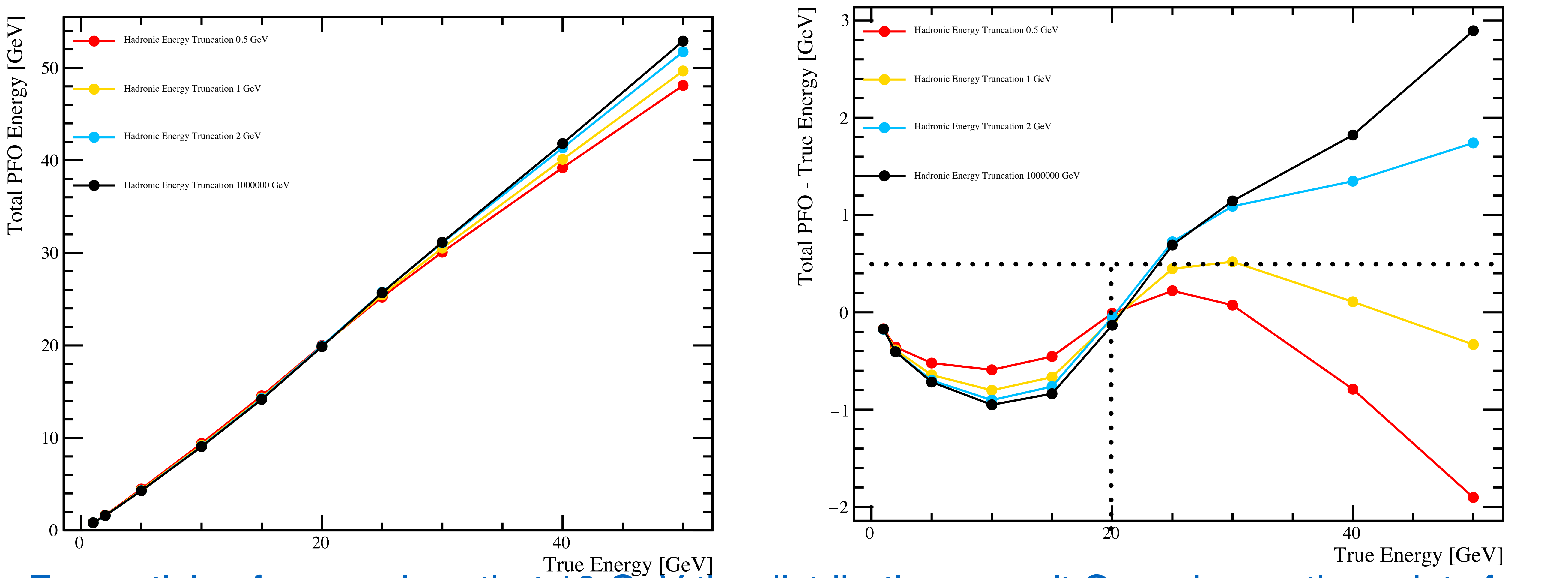


- Histograms of the reconstructed energy for single Kaon0L events of fixed energy.

.

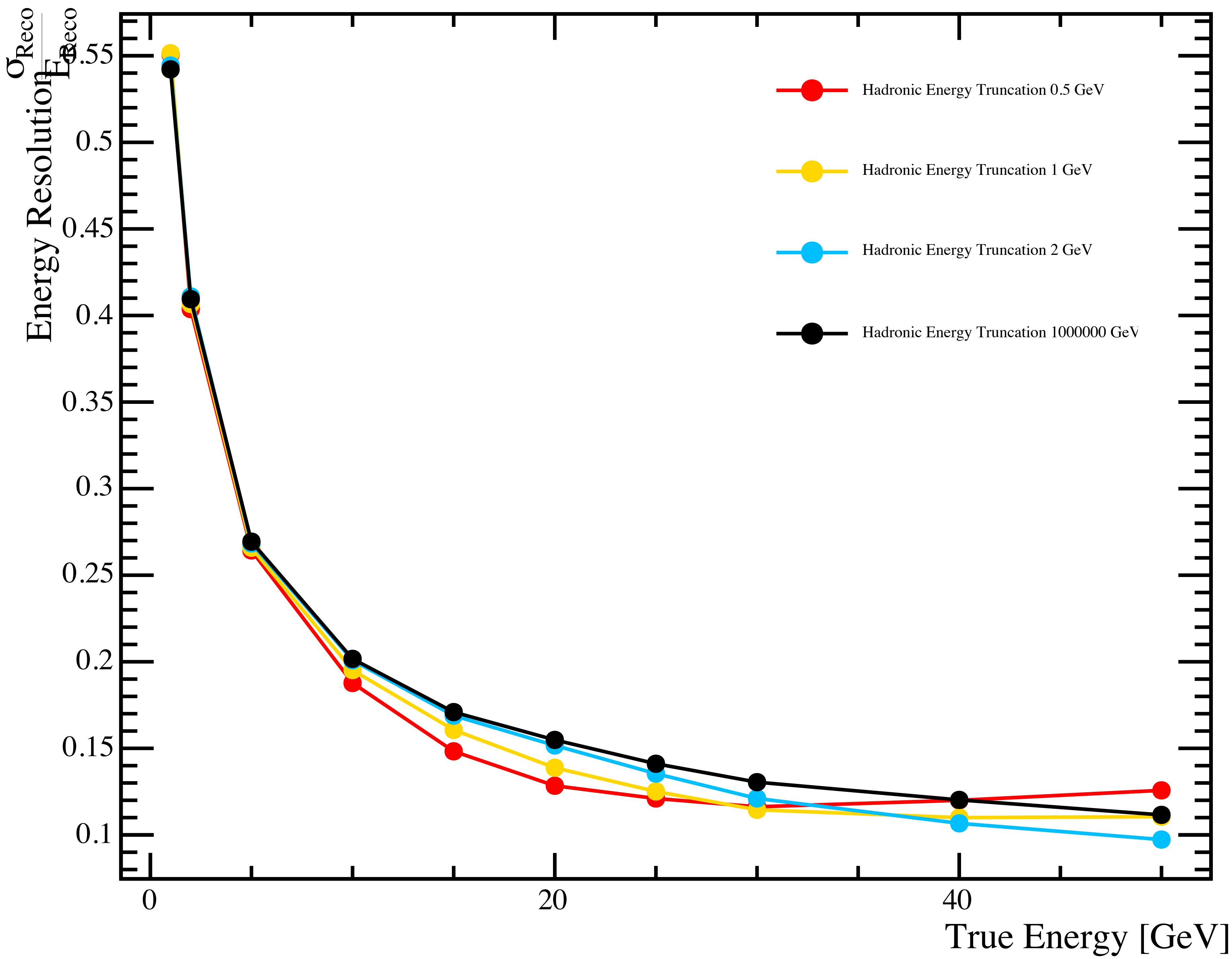
- Distributions have largely the same shape at low energy, <= 20GeV.
- Very big difference in distribution at large energies when several cells will have their energy truncated.
- Calibration fixes the mean of the 20 GeV distributions to be close to 20 GeV.

HCal Hadronic Energy Truncation - Single Particle Mean Energy



- For particle of energy less that 10 GeV the distributions aren't Gaussian so the points for energy less that 10 GeV don't properly represent the data.
- The trend at high energy clearly shows that the hadronic energy truncation is dictating the reconstructed energy.
- Applying too small a cut for a given cell size causes bad degradation in the reconstructed energy,

HCal Hadronic Energy Truncation - Single Particle Energy Resolutions



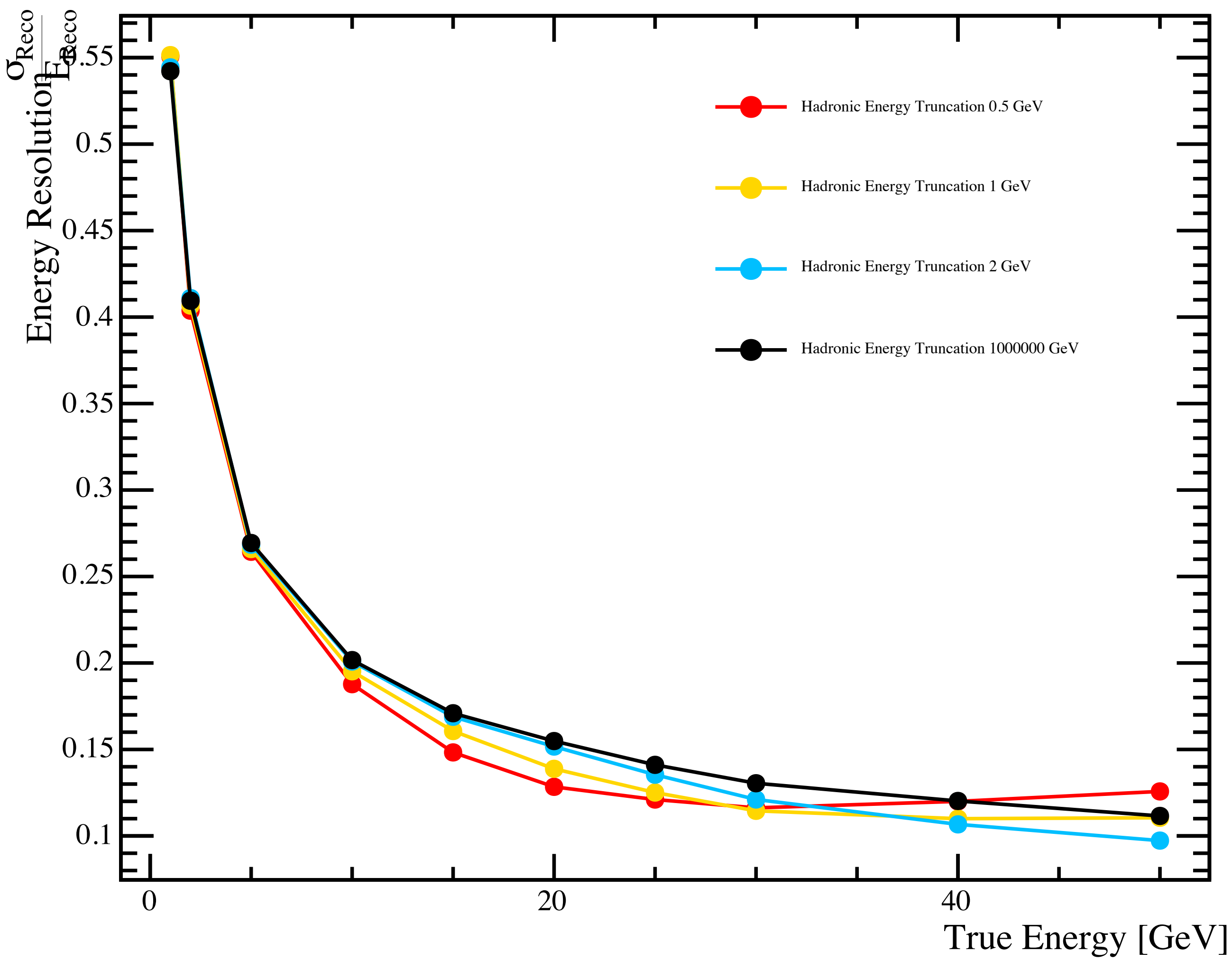
* Plot of energy resolution vs true energy for single Kaon0L events of fixed energy.
* The energy resolution here is defined as:

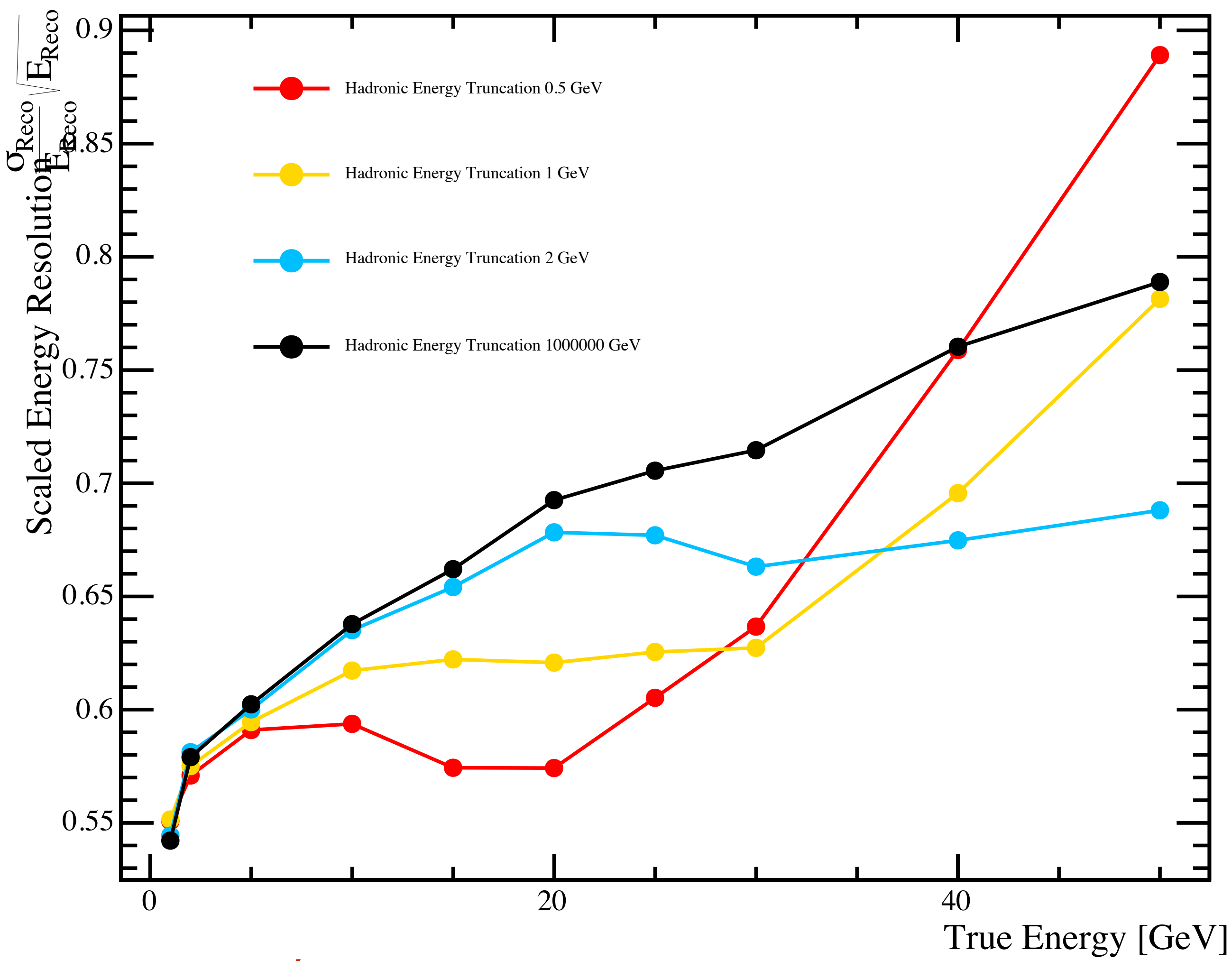
$$\text{Resolution} = \sigma_E / E$$

Where both σ_E and E are the standard deviation and mean of a Gaussian fit to the reconstructed energy distribution respectively.

* Energy resolution is largely unaffected by the hadronic energy truncation at these enegies.

HCal Hadronic Energy Truncation - Single Particle Energy Resolutions Scaled



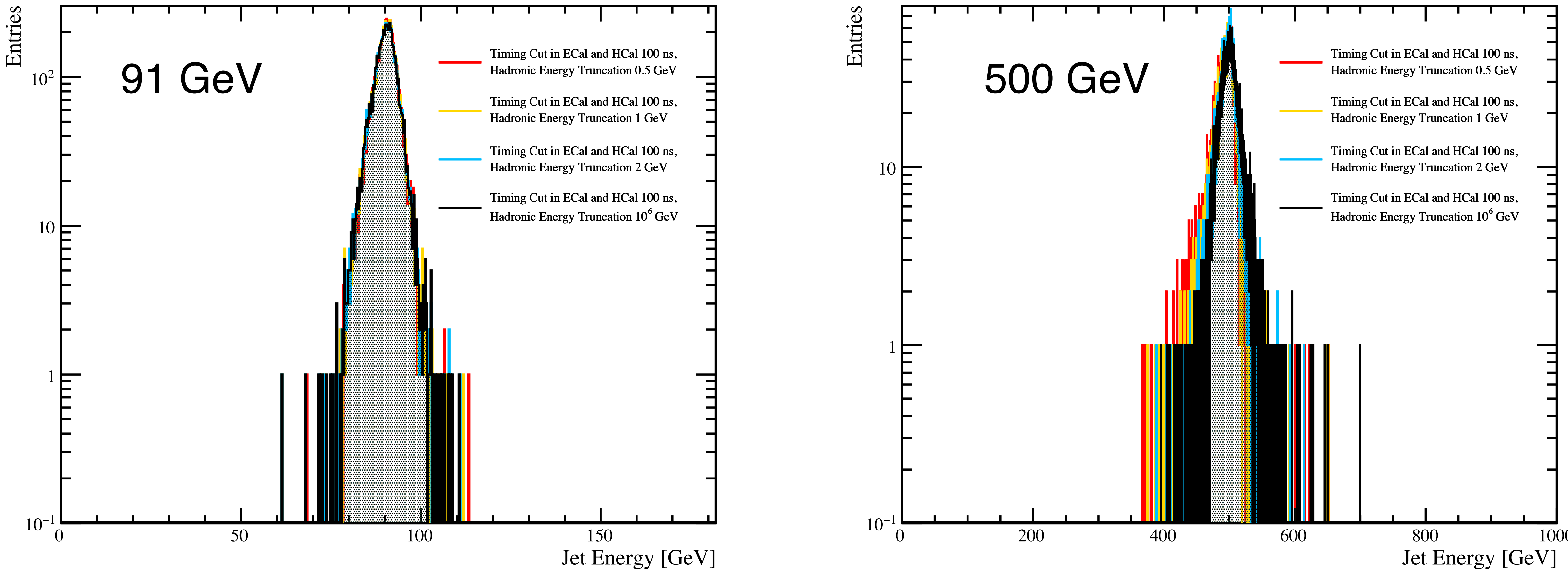


- Quickly look at the scaled energy resolution, which is $\sqrt{E} \times \sigma_E / E$.
- Useful to compare to the generally accepted results that the energy resolution for the HCal is $0.55 / \sqrt{E}$.
- The optimal energy resolution occurs for different energy truncations at different single kaon0L energy samples.

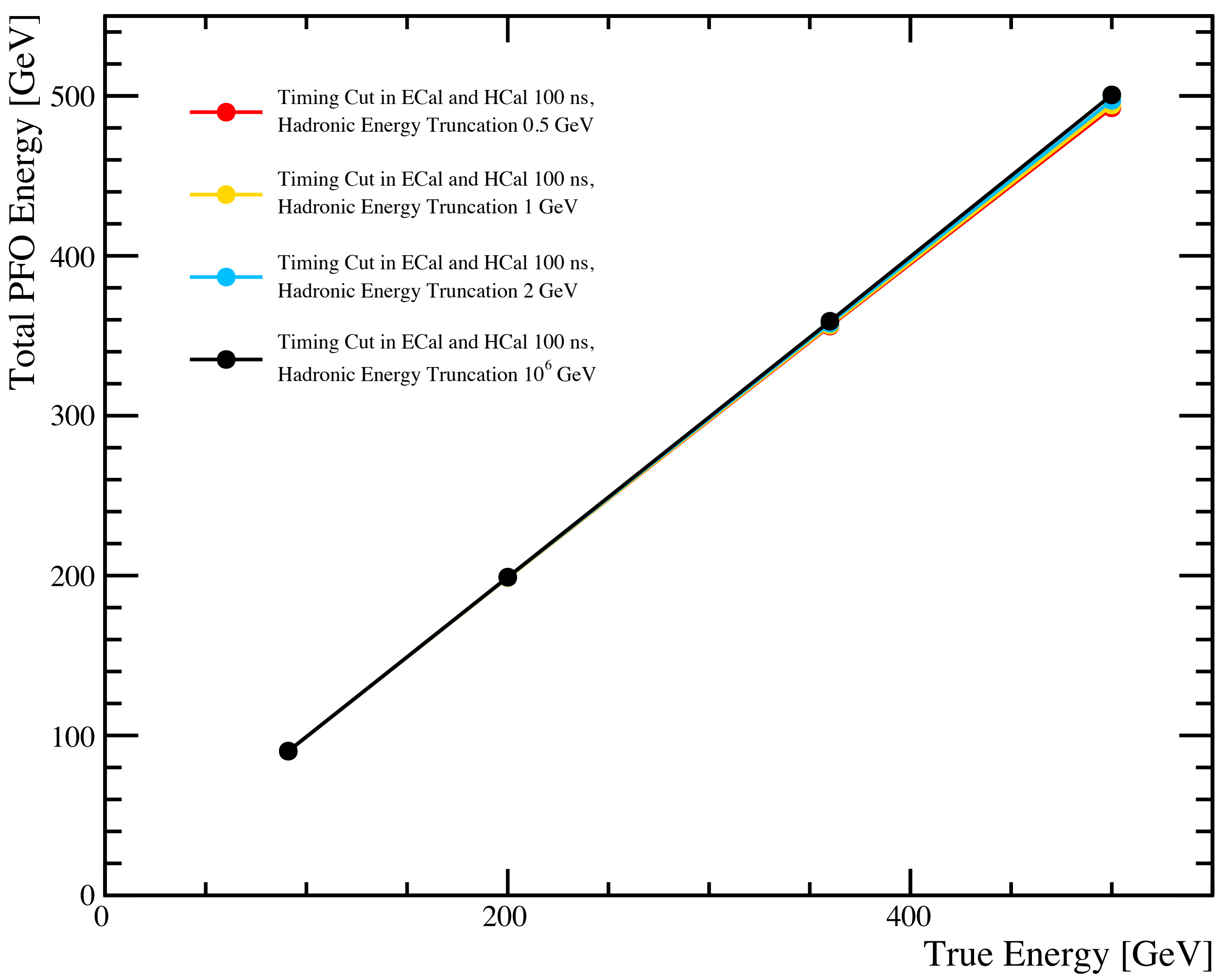
HCal Hadronic Energy Truncation - Jet Reconstructed Energy Distributions

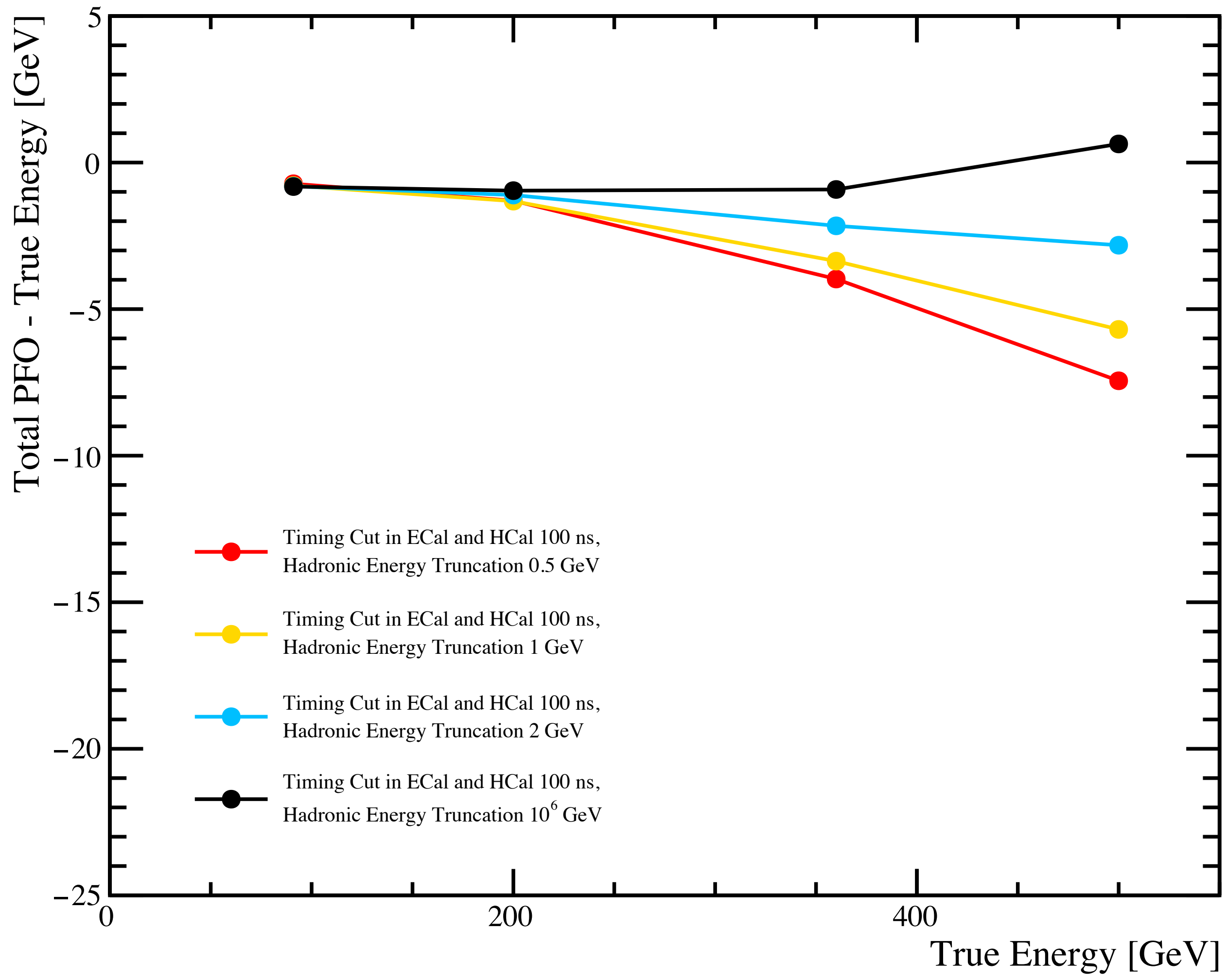
* Histograms of the reconstructed jet energy for Z_uds jet events of fixed energy.
* Distributions look similar at low jet energy where the truncation doesn't impact many cells, but at high energy a clear impact is observed. varying the timing cuts.

Hadronic Energy Truncations 0.5 GeV
Hadronic Energy Truncations 1 GeV
Hadronic Energy Truncations 2 GeV
Hadronic Energy Truncations 10^6 GeV



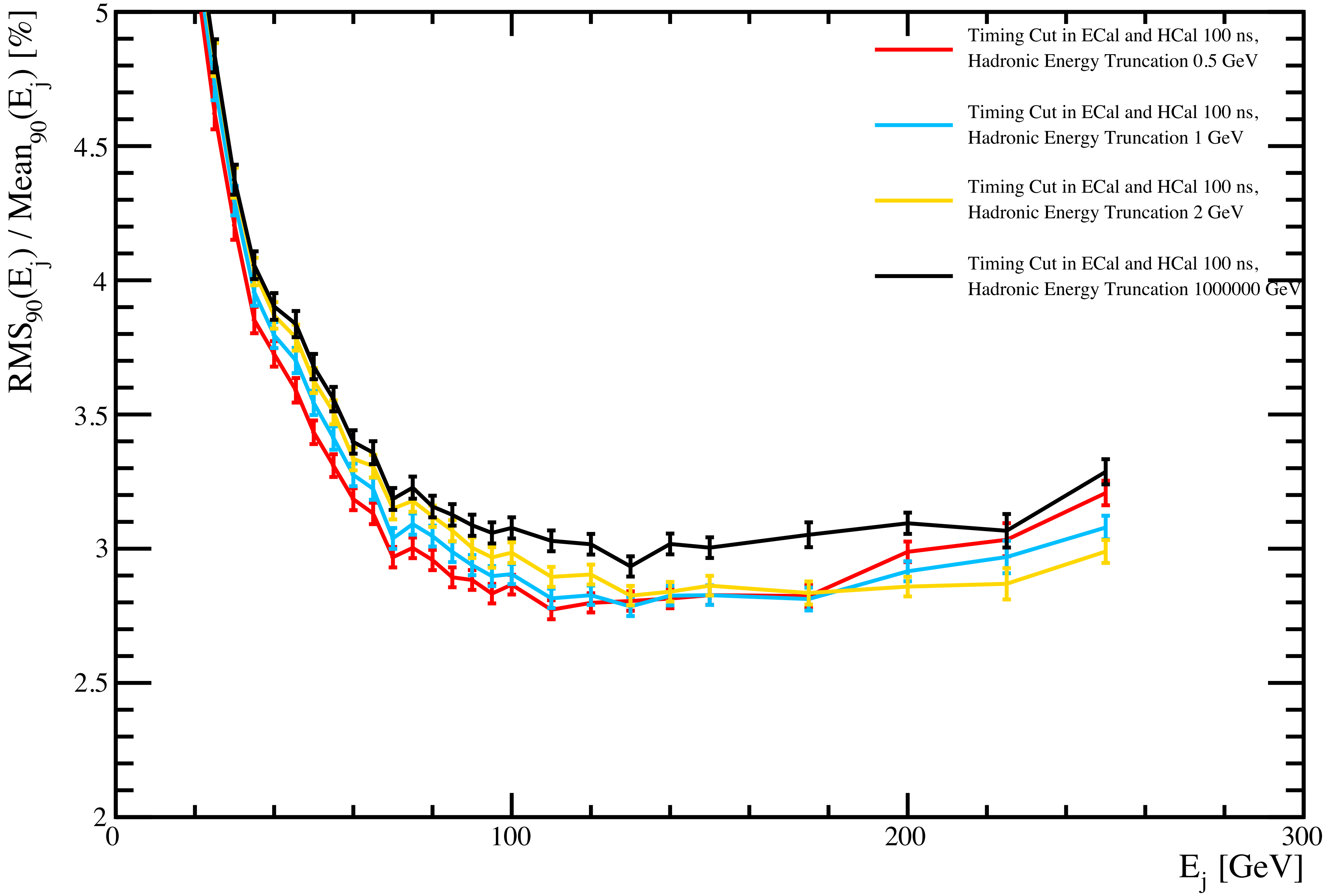
HCal Hadronic Energy Truncation - Jet Mean Energy





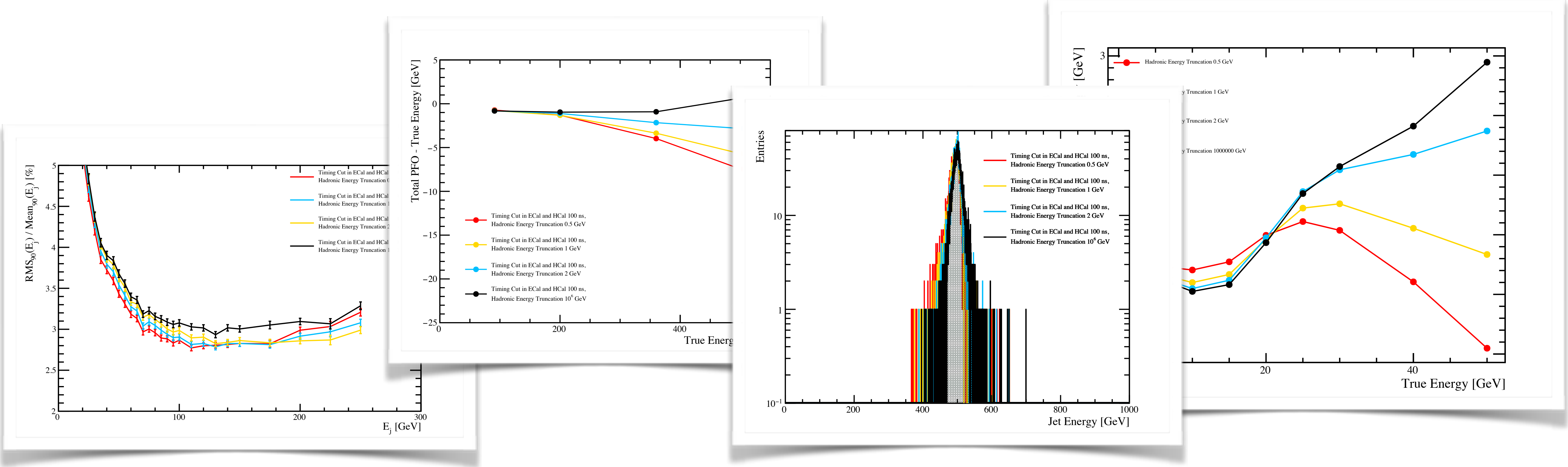
* As expected the mean jet energy decreases with increasing energy when a small HCal hadronic energy truncation is applied, but without this truncation the mean reconstructed energy approaches the expected value.

HCal Hadronic Energy Truncation - Jet Energy Resolutions



- Plot of jet energy resolution vs true jet energy for Z_uds jets of fixed energy.
- Significant variation.
- The best energy truncation varies as a function of energy.

HCal Hadronic Energy Truncation - Conclusions



* The HCal hadronic energy truncation is very important for detector performance.
* It improves both the intrinsic energy resolution as well as reducing confusion in pattern recognition (as the energy estimators are more accurate).
* The optimal energy truncation must be specified for a given detector.
* For future studies we will optimise this truncation as a function of energy.