PandoraPFA and AHCal Optimisation Studies

24th February 2016

Steven Green, John Marshall

Overview

* Overview of Pandora and developments in iLCsoft.
* Working with Pandora.
* Improvements to Photon reconstruction.
* AHCal optimisation studies.

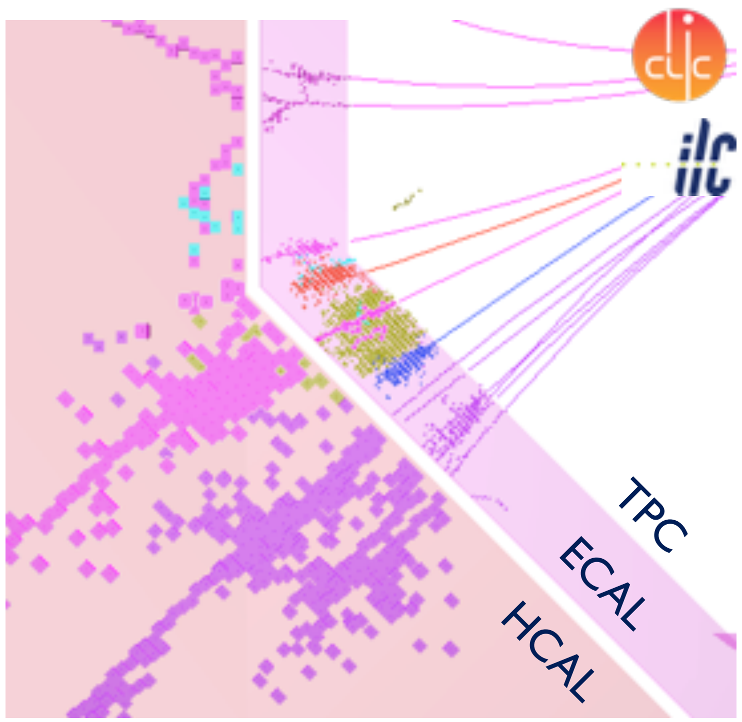
UNIVERSITY OF CAMBRIDGE

Pandora Overview and Developments in iLCsoft

Pandora Particle Flow

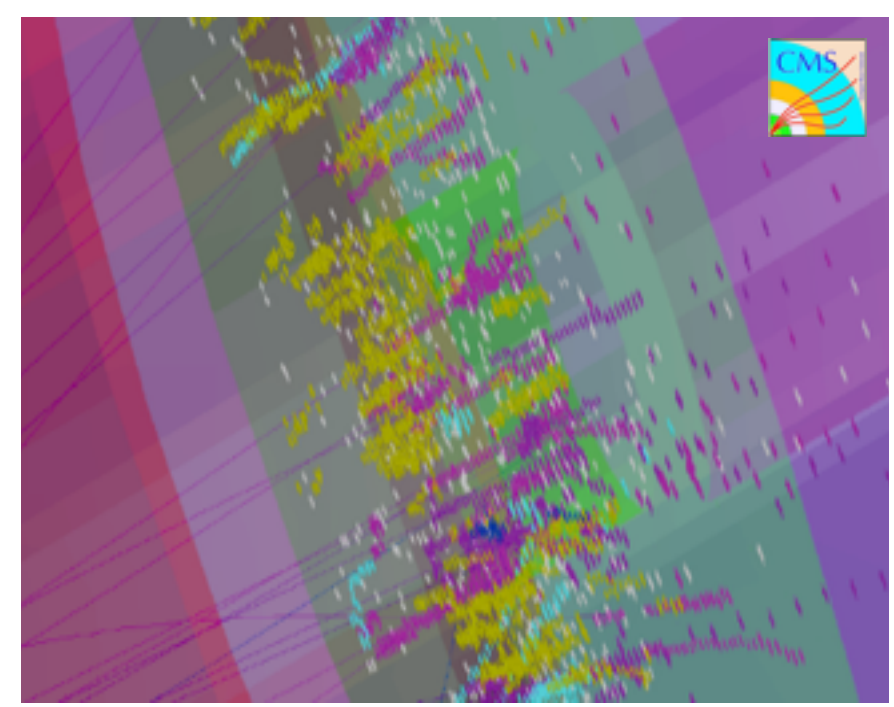
- **Pandora Software Development Kit:** aids multi-algorithm approach to pattern recognition, with advanced reclustering and recursion abilities and visualisation.
- Development of new client applications, enabling use of algorithms for different detector concepts and in different software frameworks.
- Development of pattern recognition for both LC (inc. LHC upgrade) and LAr TPC. Continued validation and exploitation of existing algorithms e.g. via detector optimisation studies.
- A lot of work ongoing!

ILC/CLIC event topology



Example LAr TPC event topology

Showers in CMS HGCAL

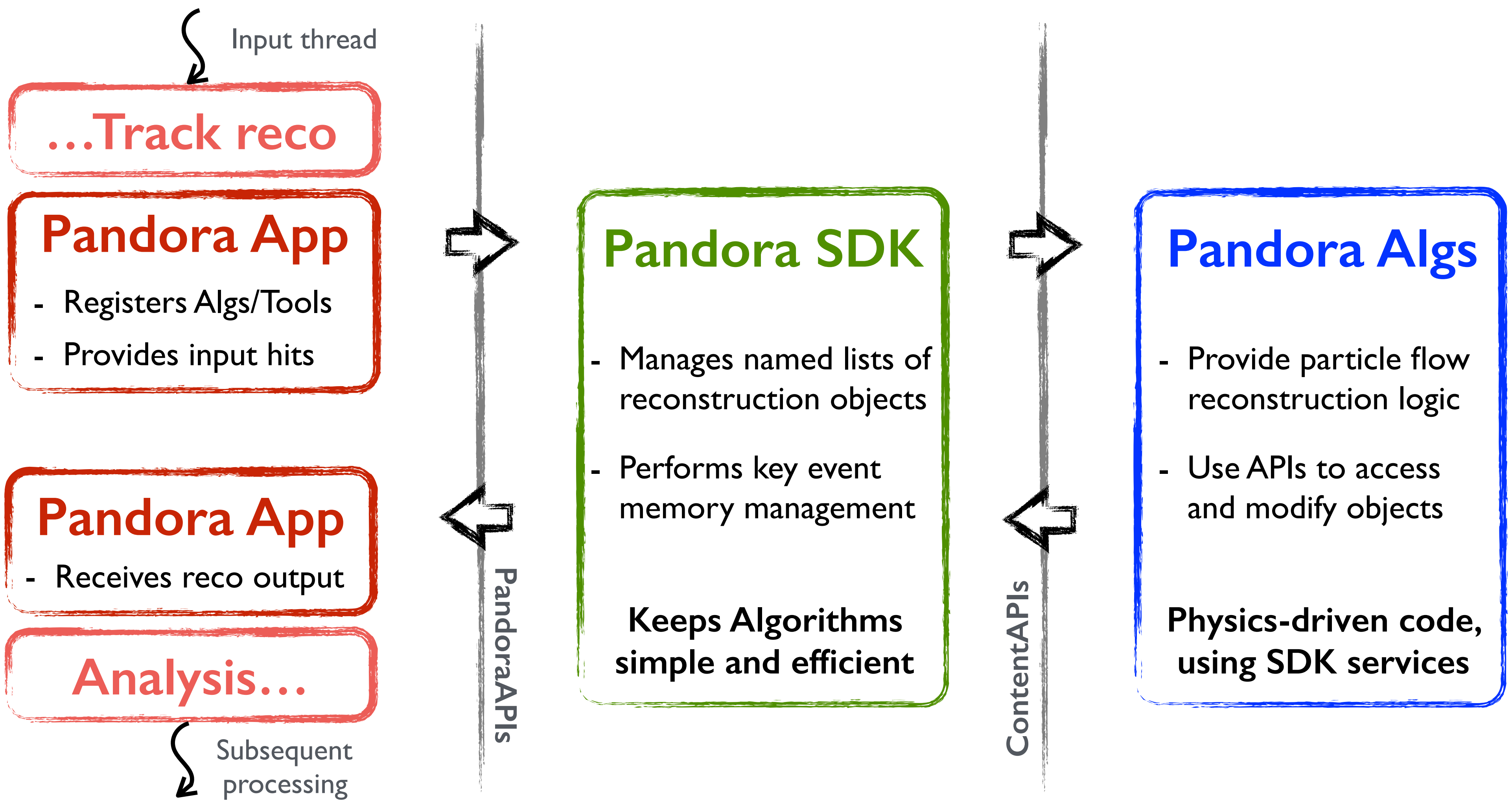


Current Pandora use-cases: ILC (NIMA.2009.09.009), CLIC (NIMA.2012.10.038), LAr TPC reco at DUNE/MicroBooNE (arXiv:1307.7335, 1506.05348) and CMS HGCAL upgrade (LHCC-P-008).

Pandora Particle Flow in iLCsoft

UNIVERSITY OF CAMBRIDGE

- Pandora is **not** a replacement/alternative to iLCSoft.
- It is an ideal framework for pattern recognition. Carefully designed APIs enable multi-alg approach.
- Client App creates Pandora instance(s), registers algs and provides alg config. Each event, it passes details about Hits, Tracks to Pandora and receives Particles.

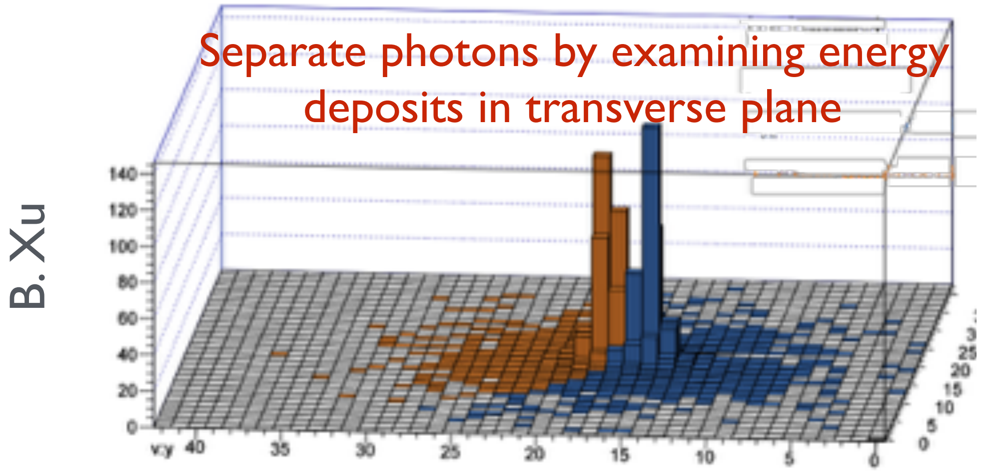


https://www.github.com/PandoraPFA

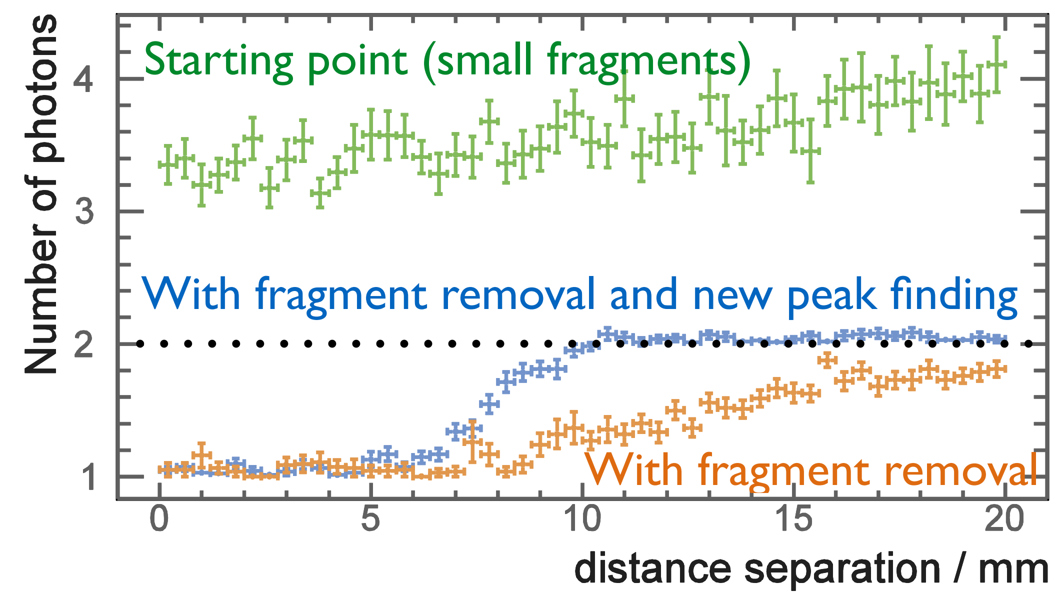
Pandora Developments in iLCSoft

UNIVERSITY OF CAMBRIDGE

- Improvements to reconstruction (fragment removal and separation of nearby photons) recently released:

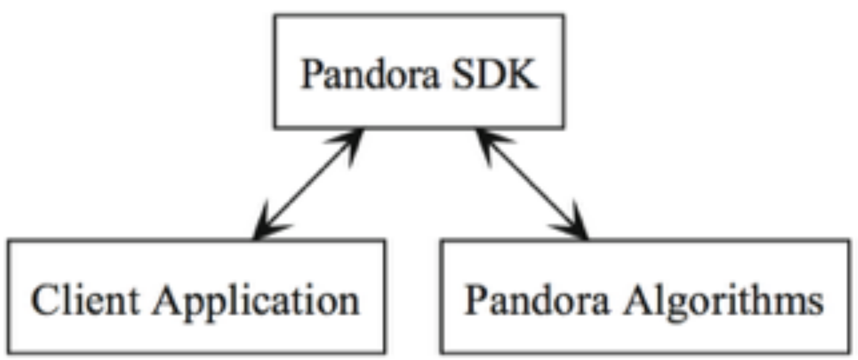


E.g. Separation of nearby high energy (500GeV) photons



Full details of updates to the photon reconstruction see the following talk: photon reconstruction updates

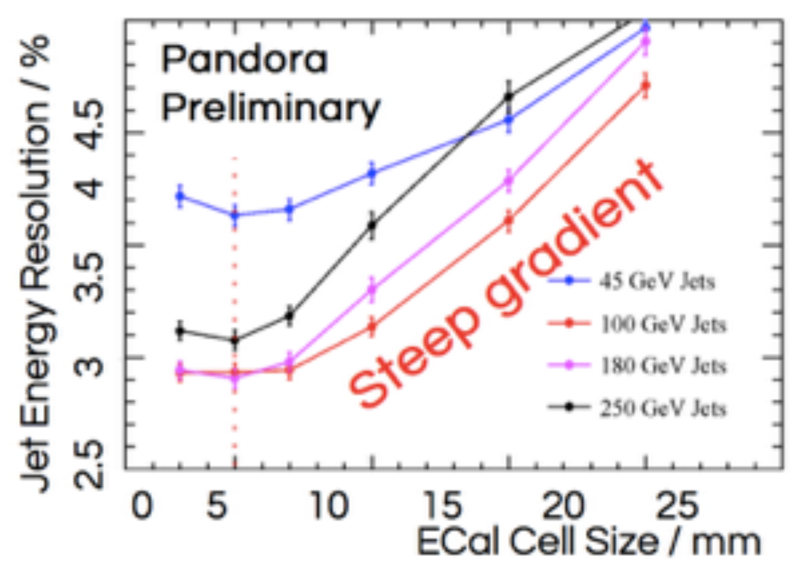
- Currently supported:

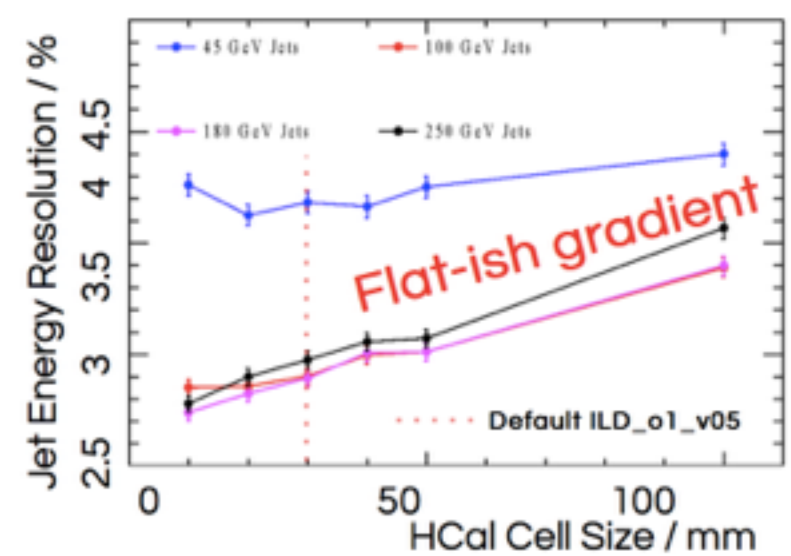


MarlinPandora
DDMarlinPandora
CMSPandoraTranslator
[SlicPandora]

LCPandoraContent

- Detector optimisation studies (Cambridge/DESY):





*See optimisation studies slides for reconstruction details.

UNIVERSITY OF CAMBRIDGE

Working with Pandora

Working With Pandora

```
<processor name="MyMarlinPandora" type="PandoraPFANewProcessor">
    <parameter name="PandoraSettingsXmlFile" type="String">PandoraSettingsDefault.xml</parameter>
    <!-- Collection names -->
    <parameter name="TrackCollections" type="StringVec">MarlinTrkTracks</parameter>
    <parameter name="ECalCaloHitCollections" type="StringVec">ECALBarrel ECALEndcap ECALOther</parameter>
    <parameter name="HCalCaloHitCollections" type="StringVec">HCALBarrel HCALEndcap HCALOther</parameter>
    <parameter name="LCalCaloHitCollections" type="StringVec">LCAL</parameter>
    <parameter name="LHCalCaloHitCollections" type="StringVec">LHCAL</parameter>
    <parameter name="MuonCaloHitCollections" type="StringVec">MUON</parameter>
    <parameter name="MCParticleCollections" type="StringVec">MCParticle</parameter>
    <parameter name="RelCaloHitCollections" type="StringVec">RelationCaloHit RelationMuonHit</parameter>
    <parameter name="RelTrackCollections" type="StringVec">MarlinTrkTracksMCTruthLink</parameter>
    <parameter name="KinkVertexCollections" type="StringVec">KinkVertices</parameter>
    <parameter name="ProngVertexCollections" type="StringVec">ProngVertices</parameter>
    <parameter name="SplitVertexCollections" type="StringVec">SplitVertices</parameter>
    <parameter name="V0VertexCollections" type="StringVec">V0Vertices</parameter>
    <parameter name="ClusterCollectionName" type="String">PandoraClusters</parameter>
    <parameter name="PFOCollectionName" type="String">PandoraPFOs</parameter>
    <parameter name="StartVertexCollectionName" type="String">StartVertices</parameter>
    <!-- Calibration constants -->
    <parameter name="ECalToMipCalibration" type="float">153.846</parameter>
    <parameter name="HCalToMipCalibration" type="float">38.0228</parameter>
    <parameter name="ECalMipThreshold" type="float">0.5</parameter>
    <parameter name="HCalMipThreshold" type="float">0.3</parameter>
    <parameter name="ECalToEMGeVCalibration" type="float">1.00356141304</parameter>
    <parameter name="HCalToEMGeVCalibration" type="float">1.12083052744</parameter>
    <parameter name="ECalToHadGeVCalibrationBarrel" type="float">1.14127910463</parameter>
    <parameter name="ECalToHadGeVCalibrationEndCap" type="float">1.14127910463</parameter>
    <parameter name="HCalToHadGeVCalibration" type="float">1.12083052744</parameter>
    <parameter name="MuonToMipCalibration" type="float">10.3093</parameter>
    <parameter name="DigitalMuonHits" type="int">0</parameter>
    <parameter name="MaxHCalHitHadronicEnergy" type="float">1.0</parameter>
    <parameter name="AbsorberRadLengthECal" type="float">0.2854</parameter>
    <parameter name="AbsorberIntLengthECal" type="float">0.0101</parameter>
    <parameter name="AbsorberRadLengthHCal" type="float">0.0569</parameter>
    <parameter name="AbsorberIntLengthHCal" type="float">0.0060</parameter>
    <parameter name="AbsorberRadLengthOther" type="float">0.0569</parameter>
    <parameter name="AbsorberIntLengthOther" type="float">0.0060</parameter>
</processor>
```

Pandora Settings File

Collection Names

Calibration Constants

Additional Geometry Information

- For details of how to set calibration constants see talk earlier this week (calibration talk).

Working With Pandora

Marlin Steering Xml Snippet

```
<marlin>
    <execute>
        <!-- ========== the post tracking patrec   ================= -->
        <processor name="MyKinkFinder"/>
        <processor name="MyV0Finder"/>
        <!-- ========== calorimeter digitization ======= -->
        <!--processor name="MyILDCaloDigi"/-->
        <!-- ========== PFA ======= -->
        <processor name="MyRecoMCTruthLinker"/>
        <processor name="MyMarlinPandoraDefault"/>
        <processor name="MyPfoAnalysisDefault"/>
        <processor name="MyMarlinPandoraPerfectPhoton"/>
        <processor name="MyPfoAnalysisPerfectPhoton"/>
        <processor name="MyMarlinPandoraPerfectPFA"/>
        <processor name="MyPfoAnalysisPerfectPFA"/>
    </execute>
...
<processor name="MyMarlinPandoraDefault" type="PandoraPFANewProcessor">
    <parameter name="PandoraSettingsXmlFile" type="String">PandoraSettingsDefault.xml</parameter>
    ...
</processor>

<processor name="MyMarlinPandoraPerfectPhoton" type="PandoraPFANewProcessor">
    <parameter name="PandoraSettingsXmlFile" type="String">PandoraSettingsPerfectPhoton.xml</parameter>
    ...
</processor>

<processor name="MyMarlinPandoraPerfectPFA" type="PandoraPFANewProcessor">
    <parameter name="PandoraSettingsXmlFile" type="String">PandoraSettingsPerfectPFA.xml</parameter>
    ...
</processor>
...
</marlin>
```

Multiple Instances of Pandora

Default Reconstruction

Cheat Photon Clusters

Cheat All Clustering

* You can apply multiple instances of pattern recognition logic in Pandora, each producing a unique set of PFOs.

UNIVERSITY OF CAMBRIDGE

Pandora Algorithm Steering

- Pandora is configured via an XML file, provided by the client application.
- It looks for algorithm XML tags within the top level Pandora tags, creating instances of any algorithms found. It will run these algorithms, in order, for each event.
- Each algorithm receives a ReadSettings callback, with a provided XML handle. Algorithms can have mandatory or optional parameters (override default values).
- Algorithms can use the ReadSettings callback to control the creation of daughter Algorithms or AlgorithmTools. Allows for use of (multiple) alternative approaches to solving a problem.

Pandora Settings Xml Snippet

```xml
<!-- Pandora settings xml file -->
<pandora>
    <!-- GLOBAL SETTINGS -->
    <IsMonitoringEnabled>true</IsMonitoringEnabled>
    <ShouldDisplayAlgorithmInfo>false</ShouldDisplayAlgorithmInfo>
    <ShouldCollapseMCParticlesToPfoTarget>true</ShouldCollapseMCParticlesToPfoTarget>

    <!-- PLUGIN SETTINGS -->
    <HadronicEnergyCorrectionPlugins>CleanClusters ScaleHotHadrons</HadronicEnergyCorrectionPlugins>
    <EmShowerPlugin>LCEmShowerId</EmShowerPlugin>
    <PhotonPlugin>LCPhotonId</PhotonPlugin>
    <ElectronPlugin>LCElectronId</ElectronPlugin>
    <MuonPlugin>LCMuonId</MuonPlugin>

    <!-- ALGORITHM SETTINGS -->

    <!-- Set calo hit properties, then select tracks and hits to use for clustering -->
    <algorithm type = "CaloHitPreparation"/>
    <algorithm type = "EventPreparation">
        <OutputTrackListName>Tracks</OutputTrackListName>
        <OutputCaloHitListName>CaloHits</OutputCaloHitListName>
        <OutputMuonCaloHitListName>MuonYokeHits</OutputMuonCaloHitListName>
        <ReplacementTrackListName>Tracks</ReplacementTrackListName>
        <ReplacementCaloHitListName>CaloHits</ReplacementCaloHitListName>
    </algorithm>
```

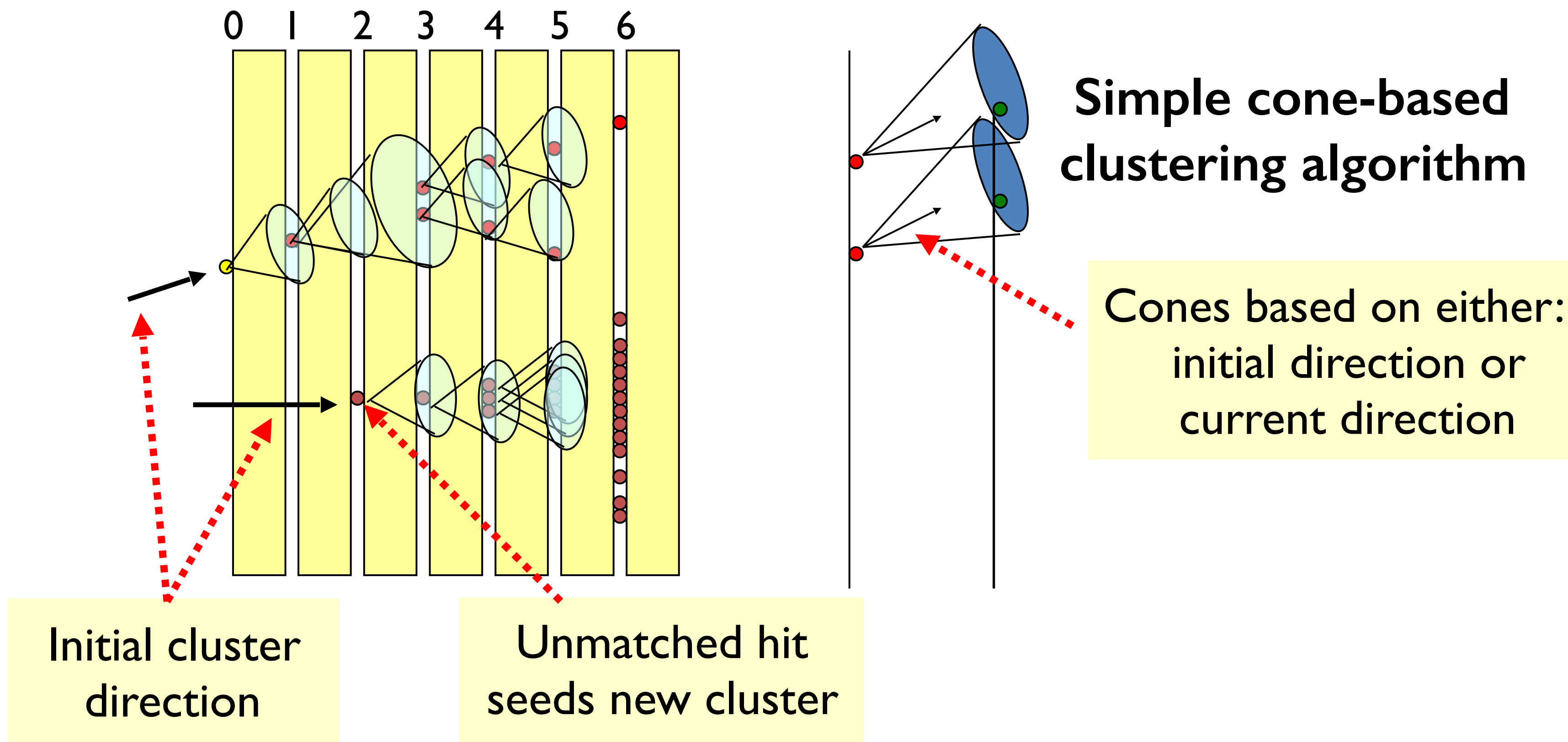
Non-default global parameters

Particle Id and Energy correction Plugins (Software compensation ideally goes here)

First algorithm, with required parameters

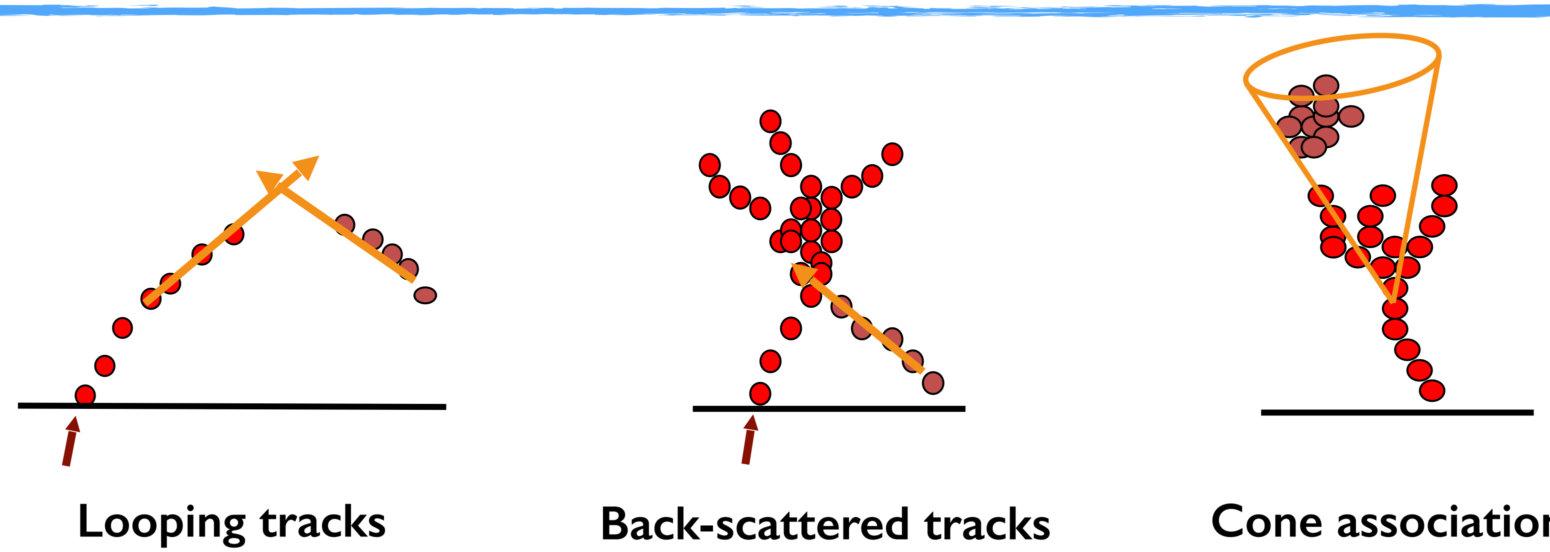
Pandora Clustering Example

- **Philosophy:** "It's easier to put clusters together, than to split them up again."
- Clustering algorithm very careful to avoid accidentally merging energy deposits from separate particles.



Topological Associations

- Fine granularity of the calorimeters exploited to merge cluster fragments that are clearly associated.
- Very few mistakes made.



Pandora Clustering Config

Parent clustering algorithm

Cluster formation daughter algorithm

```
<algorithm type = "ClusteringParent">
    <algorithm type = "ConeClusteringFast" description = "ClusterFormation"/>
    <algorithm type = "TopologicalAssociationParent" description = "ClusterAssociation">
        <associationAlgorithms>
            <algorithm type = "LoopingTracks"/>
            <algorithm type = "BrokenTracks"/>
            <algorithm type = "ShowerMipMerging"/>
            <algorithm type = "ShowerMipMerging2"/>
            <algorithm type = "BackscatteredTracks"/>
            <algorithm type = "BackscatteredTracks2"/>
            <algorithm type = "ShowerMipMerging3"/>
            <algorithm type = "ShowerMipMerging4"/>
            <algorithm type = "ProximityBasedMerging">
                <algorithm type = "TrackClusterAssociationFast"/>
            </algorithm>
            <algorithm type = "ConeBasedMerging">
                <algorithm type = "TrackClusterAssociationFast"/>
            </algorithm>
            <algorithm type = "MipPhotonSeparation">
                <algorithm type = "TrackClusterAssociationFast"/>
            </algorithm>
            <algorithm type = "SoftClusterMergingFast">
                <algorithm type = "TrackClusterAssociationFast"/>
                <AdditionalClusterListNames>PhotonClusters</AdditionalClusterListNames>
            </algorithm>
            <algorithm type = "IsolatedHitMerging">
                <AdditionalClusterListNames>PhotonClusters</AdditionalClusterListNames>
            </algorithm>
        </associationAlgorithms>
    </algorithm>
    <ClusterListName>PrimaryClusters</ClusterListName>
    <ReplaceCurrentClusterList>true</ReplaceCurrentClusterList>
</algorithm>
```

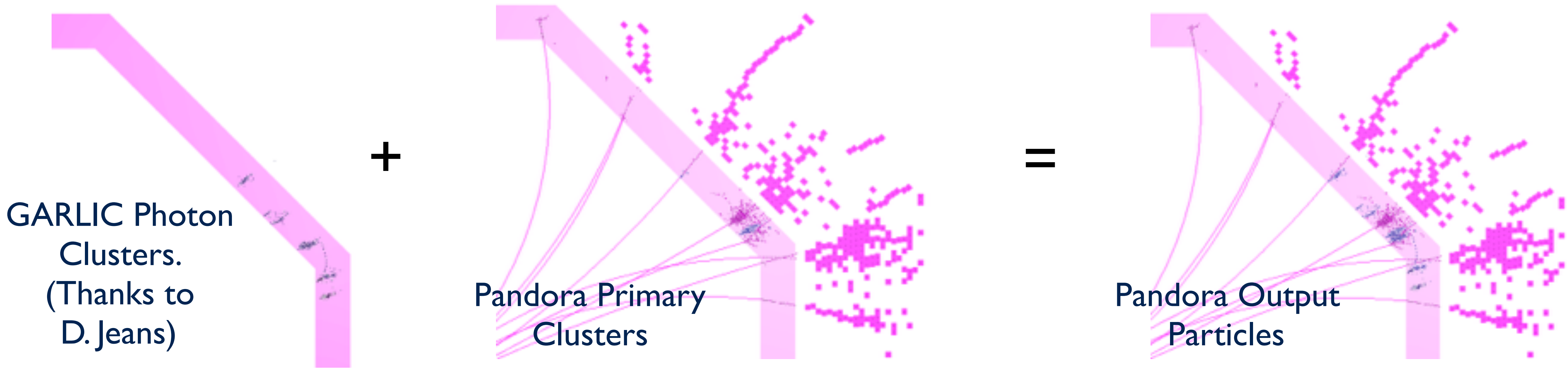
List of topological association daughter algorithms

Some topological association algs use daughter algs

Configuration of output Cluster list

Pandora External Clusters

- It is possible to import external Cluster collections (e.g. from GARLIC) directly into Pandora. The **ExternalClusteringAlgorithm**, built with MarlinPandora, understands lcio and Pandora.
- The external Clusters are recreated as Pandora Clusters and can then be included, or modified, as required in the Pandora output e.g. can replace the standard Pandora photon Clusters.




```
<algorithm type = "ClusteringParent" >
  <algorithm type = "ExternalClustering" description = "ClusterFormation">
      <ExternalClusterCollectionName>GARLICPhotonClustersTightSel</ExternalClusterCollectionName>
      <FlagClustersAsPhotons>true</FlagClustersAsPhotons>
  </algorithm>
  <ClusterListName>PhotonClusters</ClusterListName>
  <ReplaceCurrentClusterList>false</ReplaceCurrentClusterList>
</algorithm>
```

Input lcio collection name

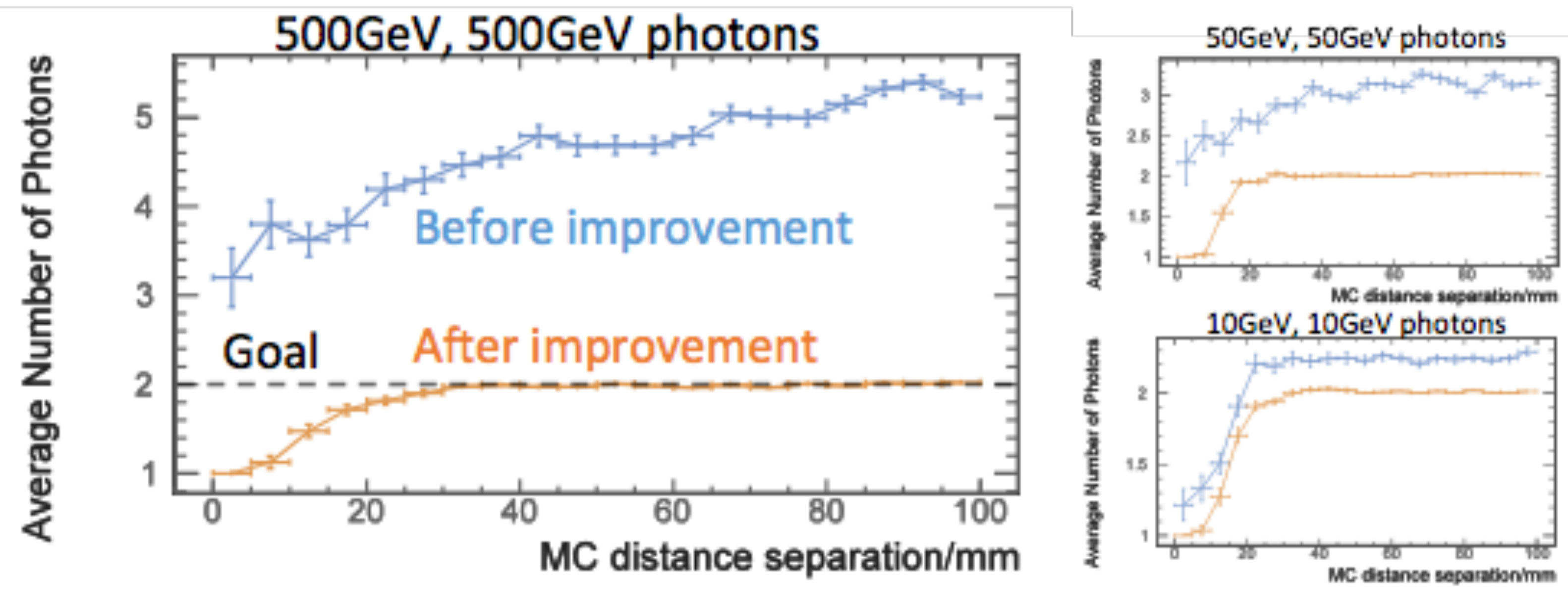
Output Pandora list name

Improvements to Photon Reconstruction

UNIVERSITY OF CAMBRIDGE

Improvements to Photon Reconstruction

- Goal: Improve completeness of reconstructed photons, particularly at high energies.
- Small fragments of EM showers could be reconstructed as separate particles.



B.Xu

- Three new Pandora algorithms carefully merge fragments based on cluster separation and energy profiles.

Pandora Settings Xml Snippet

```
<pandora>
    <!-- Standalone photon clustering -->
    <algorithm type = "PhotonReconstruction">
        ...
        <algorithm type = "RecoPhotonFragmentMerging" description = "PhotonFragmentMerging">
            ...
        </algorithm>
    </algorithm>
    ...
    <!-- Clustering parent algorithm runs a daughter clustering algorithm -->
    <algorithm type = "ClusteringParent">
        ...
        <algorithm type = "TopologicalAssociationParent" description = "ClusterAssociation">
            <associationAlgorithms>
                ...
                <algorithm type = "HighEnergyPhotonRecovery">
                    ...
                </algorithm>
                ...
            </associationAlgorithms>
        </algorithm>
        ...
    </algorithm>
    ...

    <algorithm type = "PhotonFragmentMerging"/>
    <!-- Create particle flow objects -->
    ...
</pandora>
```

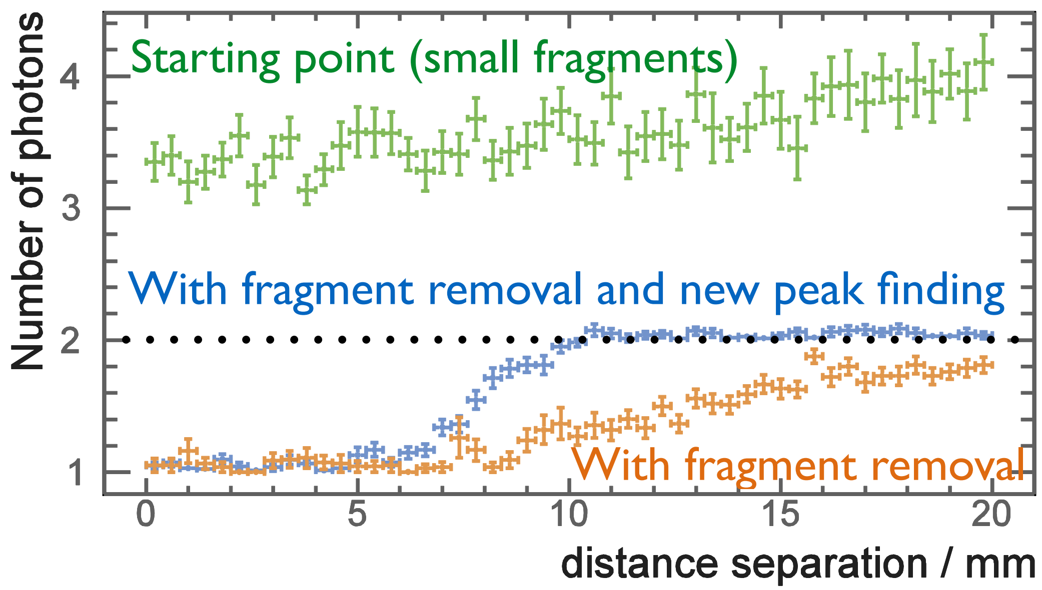
→ RecoPhotonFragmentMerging
(This is not on by default in the ilcsoft v01-17-09 PandoraSettingsDefault.xml)

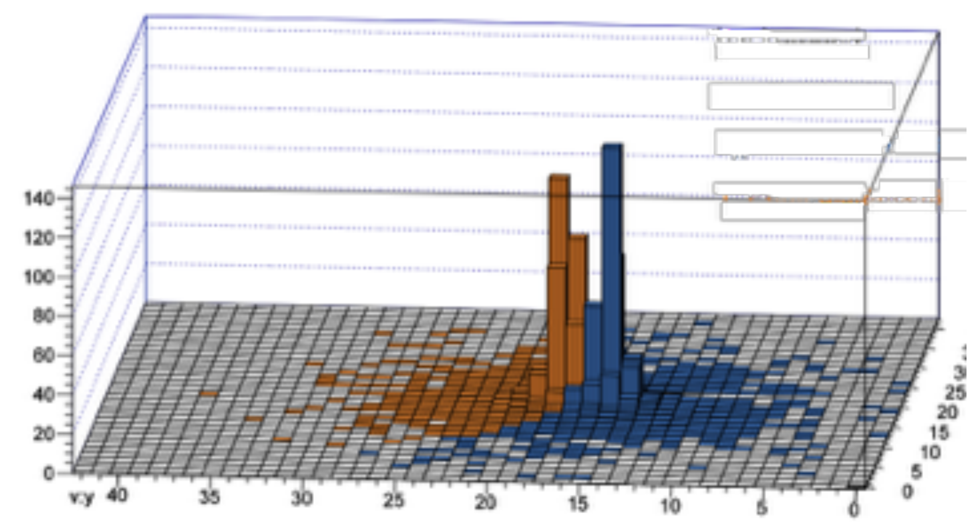
→ HighEnergyPhotonRecovery

→ PhotonFragmentMerging

Improvements to Photon Reconstruction

* Improve photon separation resolution and reduce confusion in jet reconstruction.
* Identify EM shower cores by projecting ECal energy deposits into a transverse plane.
* Apply updated algorithms to identify energy deposition peaks and collect hits contribution to each peak.





B.Xu

Pandora Settings Xml Snippet

```
<pandora>
    <!-- Standalone photon clustering -->
    <algorithm type = "PhotonReconstruction">
        ...
    </algorithm>
    ...
    <algorithm type = "PhotonSplitting"/>
    ...
</pandora>
```

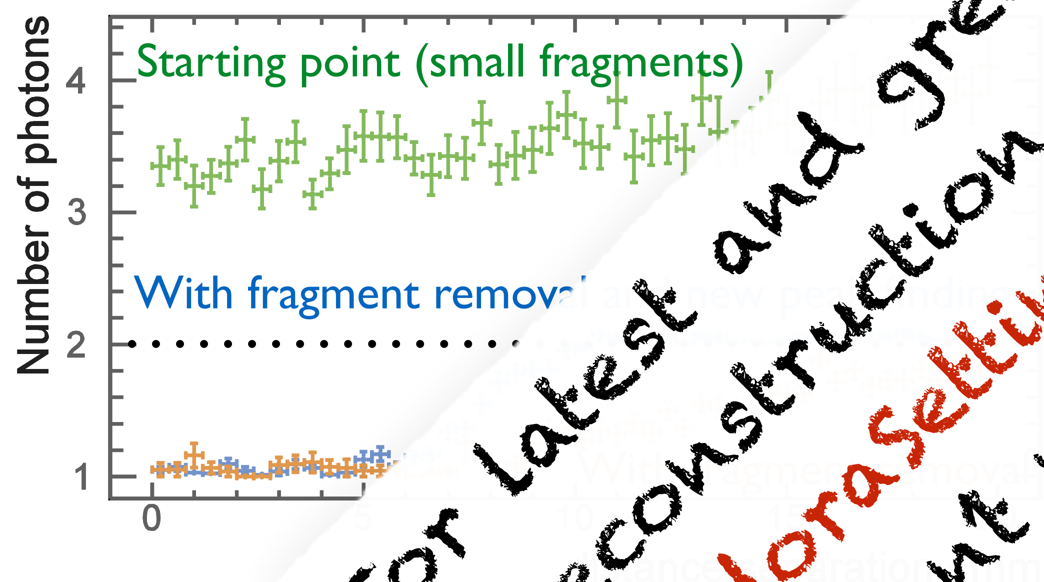
→ PhotonReconstruction

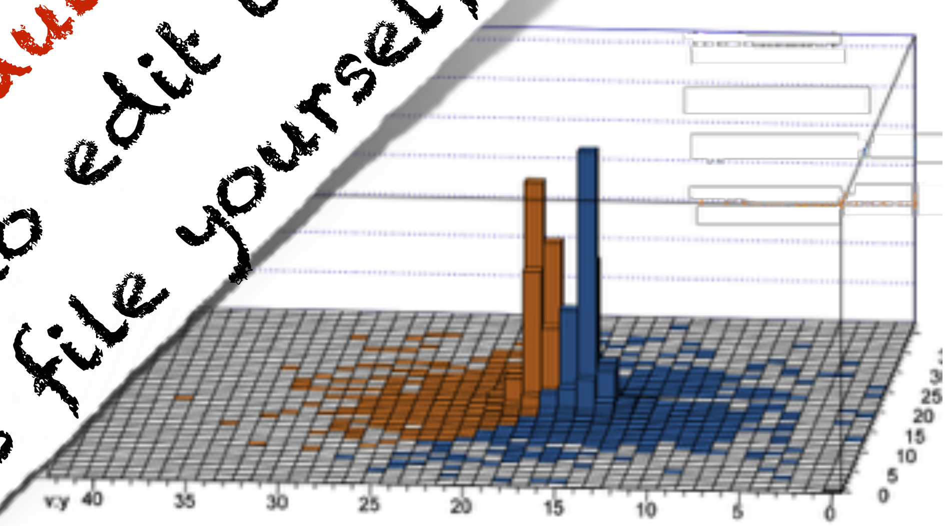
→ PhotonSplitting

No RecoPhotonFragmentMerging

Improvements to Photon Reconstruction

- Improve photon separation resolution and reduce confusion in jet reconstruction.
- Identify EM shower cores by projecting ECal energy deposits into a transverse plane.
- Apply updated algorithms to identify energy deposition peaks and collect hits contribution to each peak.





B.Xu

For latest and greatest photon reconstruction please use **PandoraSettingsDefault.xml**

You dont need to edit the PandoraSettings file yourself.

Pandora Settings Xml Snippet

```
<pandora>
    <!-- Standalone [illegible] -->
    <algorithm type = "[illegible]on">
        ...
    </algorithm>
    ...
    <algorithm type = "Photon[illegible]tting"/>
    ...
</pandora>
```

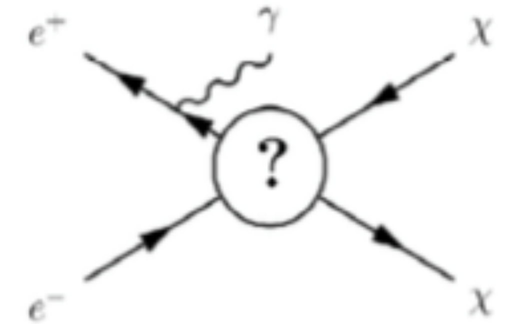
→ PhotonReconstruction

→ PhotonSplitting

No RecoPhotonFragmentMerging

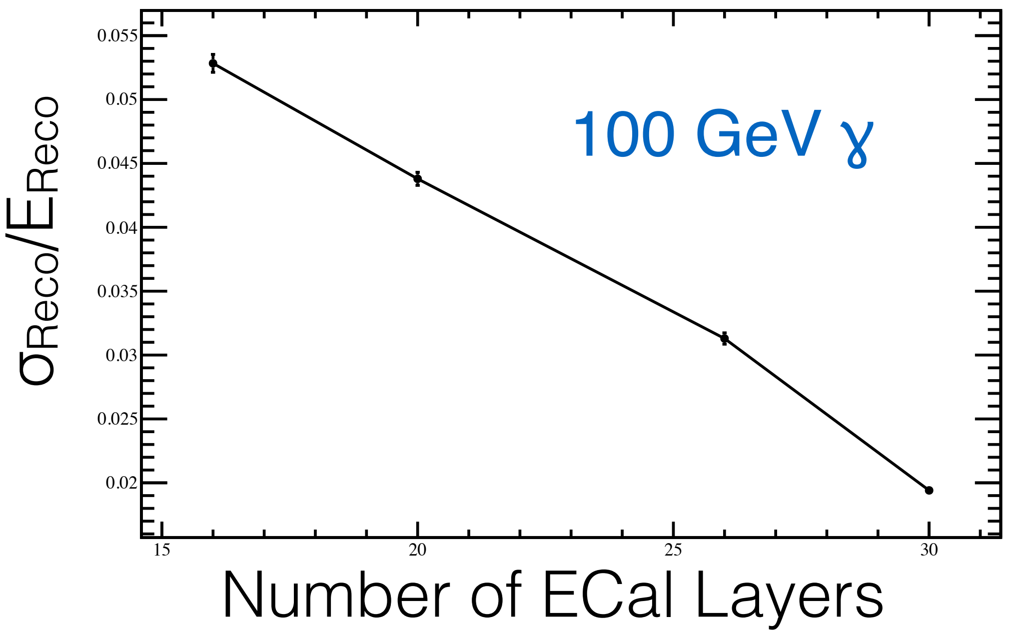
Single Particle Reconstruction

* The reconstruction of individual photons is extremely important to a number of physics analyses. For example:
  * Single and multi photon events with missing energy are predicted in BSM processes. For example: $e^+e^- \rightarrow \gamma + E_{missing}$ High energy ILC/CLIC (T. Tanabe)
  * Tau reconstruction. ILC/CLIC. (D.Jeans, B. Xu)
  * $H \rightarrow \gamma\gamma$ CLIC 3 TeV. (G. Kacarevic)
  * $e^+e^- \rightarrow \gamma\gamma$ CLIC 3 TeV. (I. Boyko.)



Example single photon BSM process

* The improvements to the photon reconstruction algorithms (B. Xu) will aid in these studies.
* For the ongoing ECal optimisation studies, alongside jet energy resolution, the single photon energy resolution is another key metric, which must be considered:



University of Cambridge

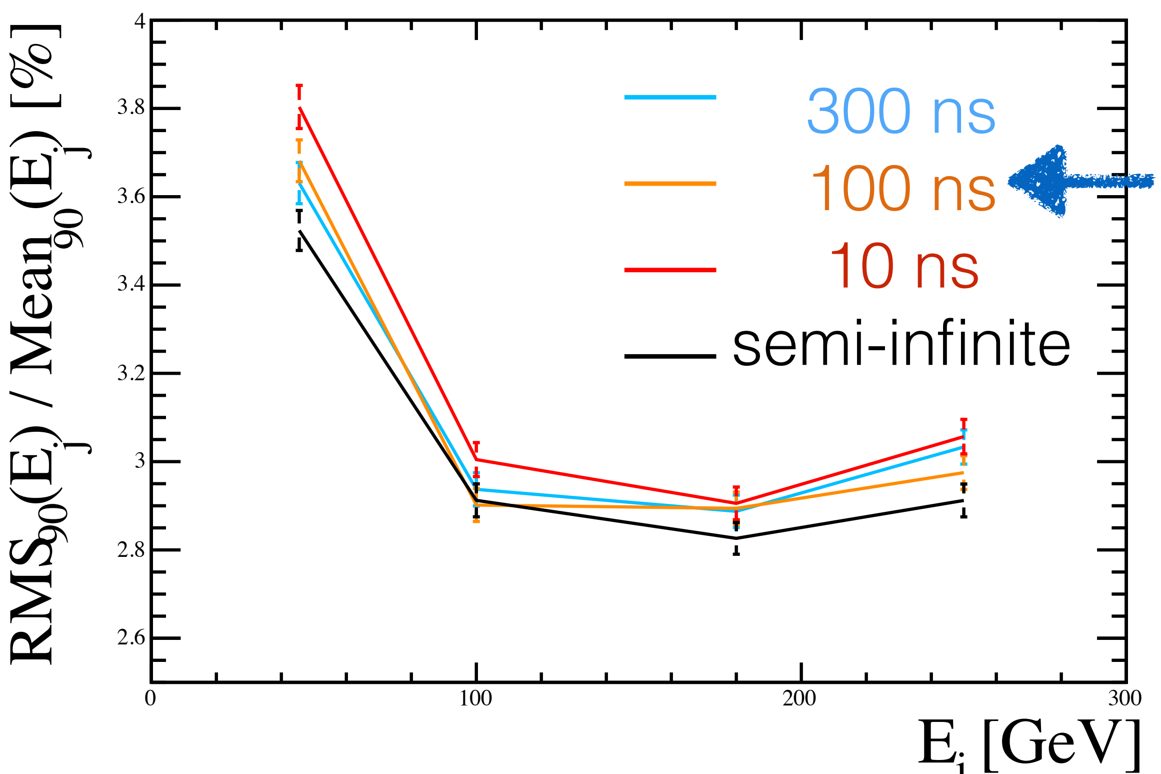
AHCal Optimisation Studies

Optimisation Study
Reconstruction Settings

UNIVERSITY OF CAMBRIDGE

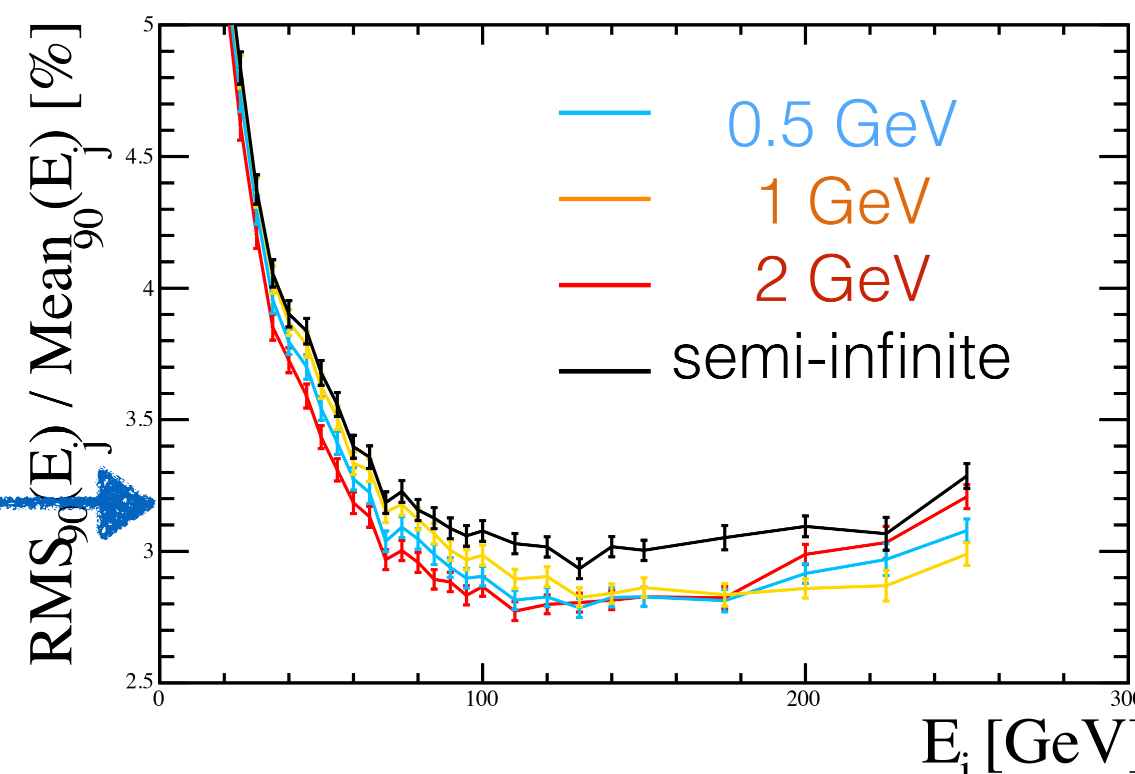
Changes To Reconstruction:

- ☑ 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



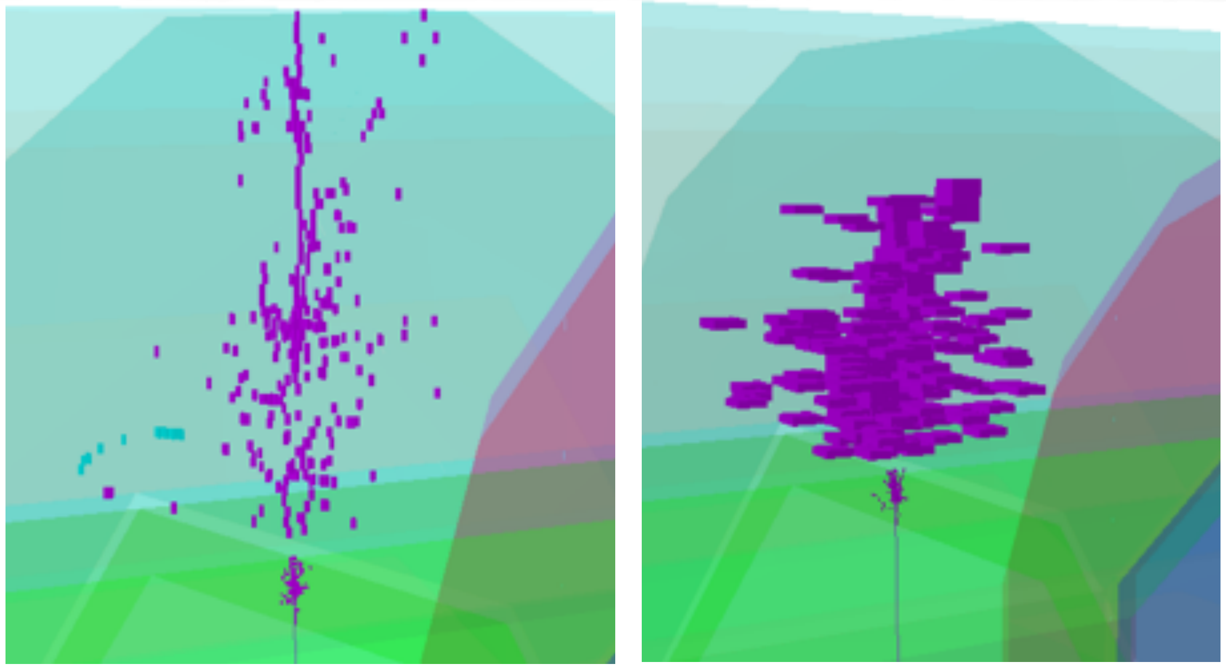
Timing Cut Study

Hadronic Energy Truncation Study

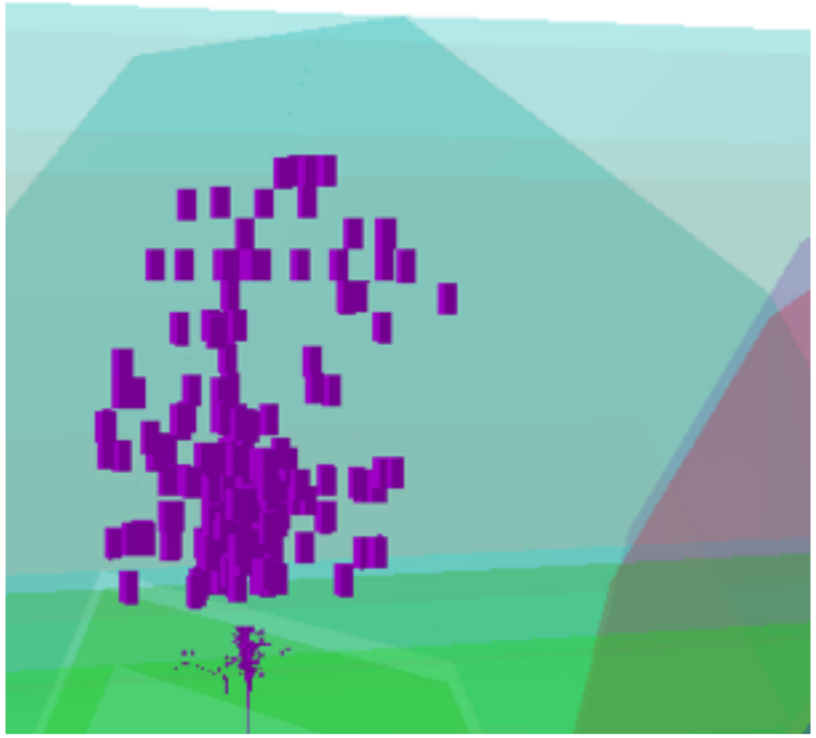


Full details of the changes to the reconstruction chain used in the optimisation studies can be found here:
LCWS15 optimisation studies talk

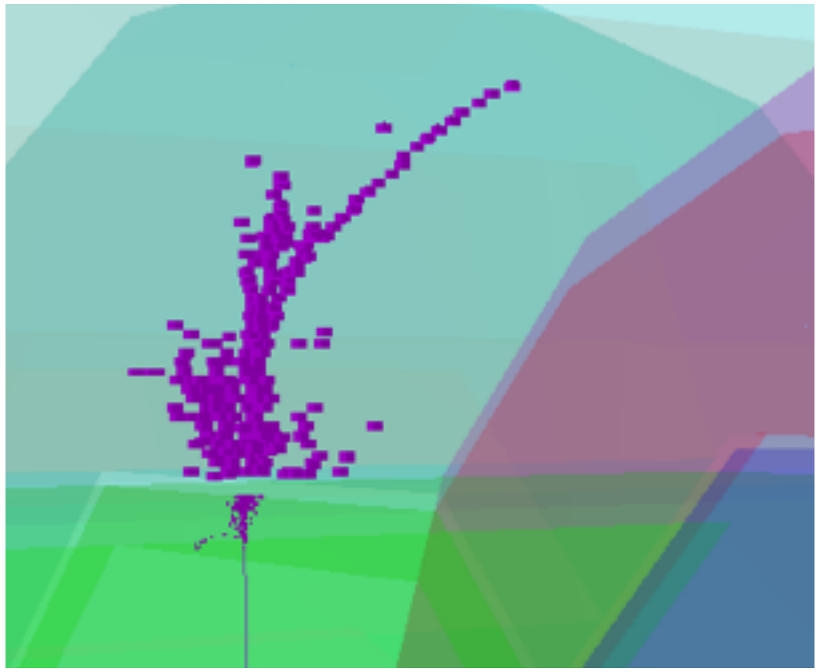
AHCal Optimisation Studies



HCal Cell Size



Number Of HCal Layers

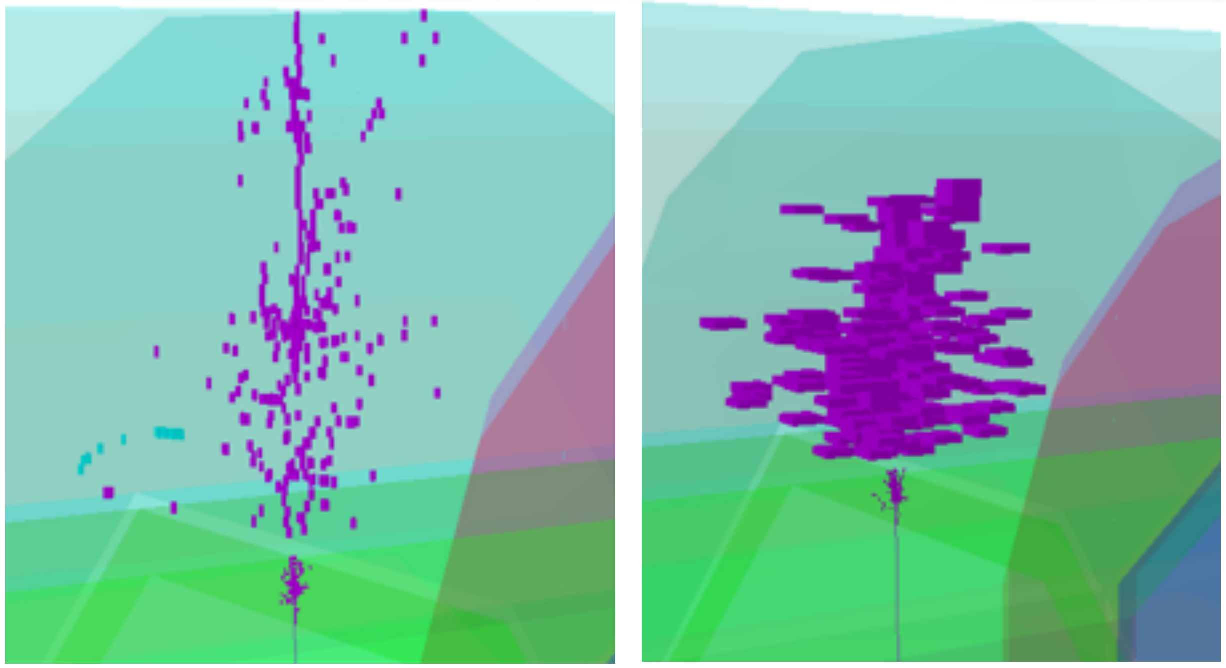


Number of Interaction Lengths in HCal

See backup for further details on methodology and for other studies.

UNIVERSITY OF CAMBRIDGE

AHCal Optimisation Studies



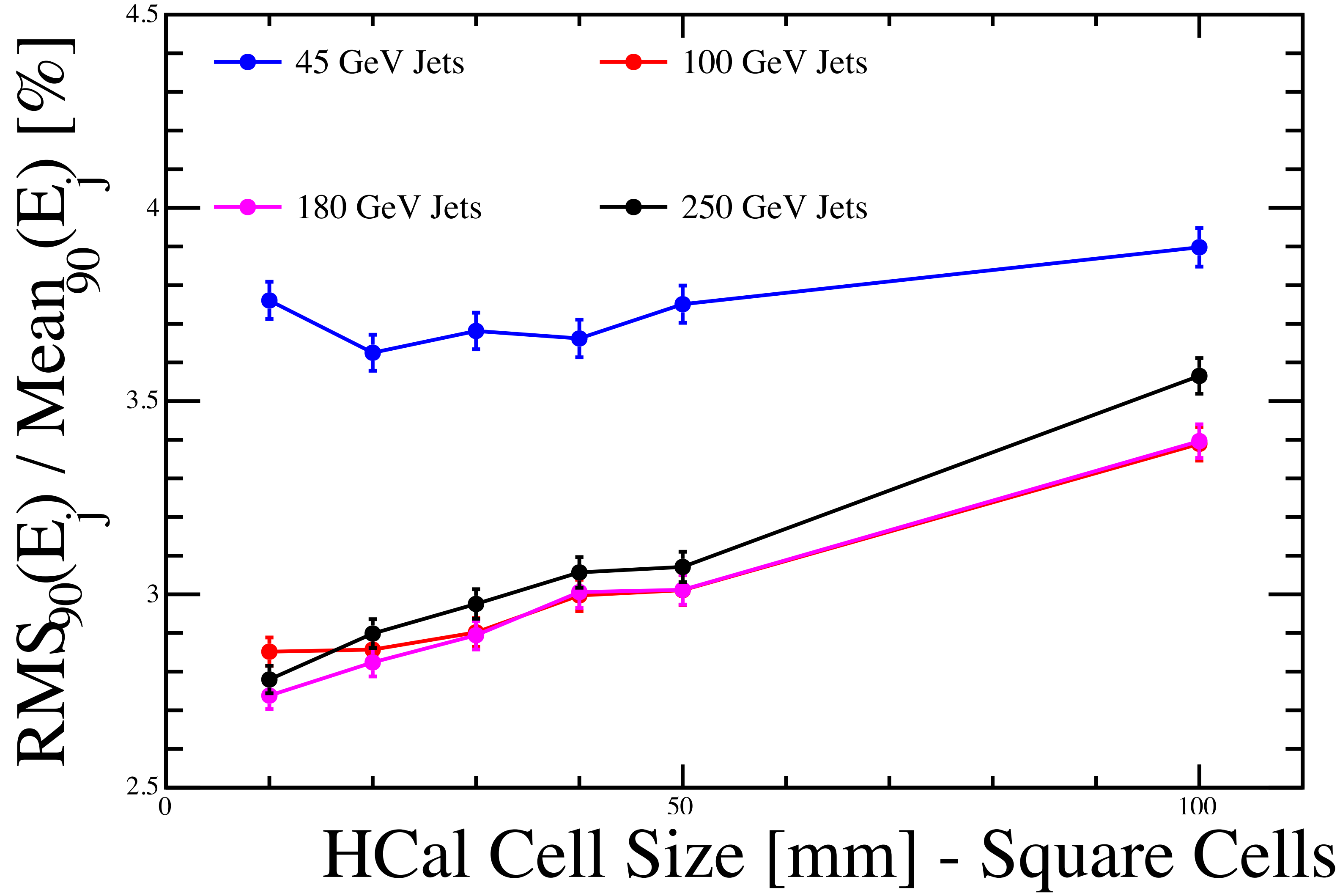
HCal Cell Size

Number Of HCal Layers

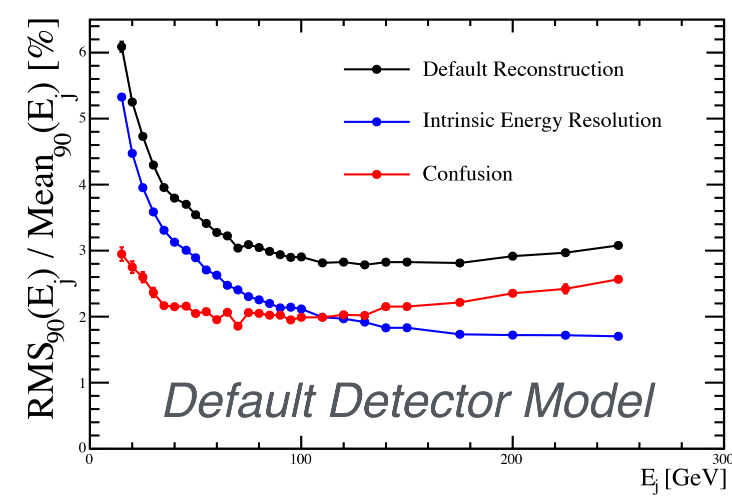
Number of Interaction Lengths in HCal

See backup for further details on methodology and for other studies.

AHCal Optimisation Studies



* Smaller HCal cells yield better jet energy resolution.
* Especially true at higher energies when reconstruction not dominated by intrinsic energy resolution.

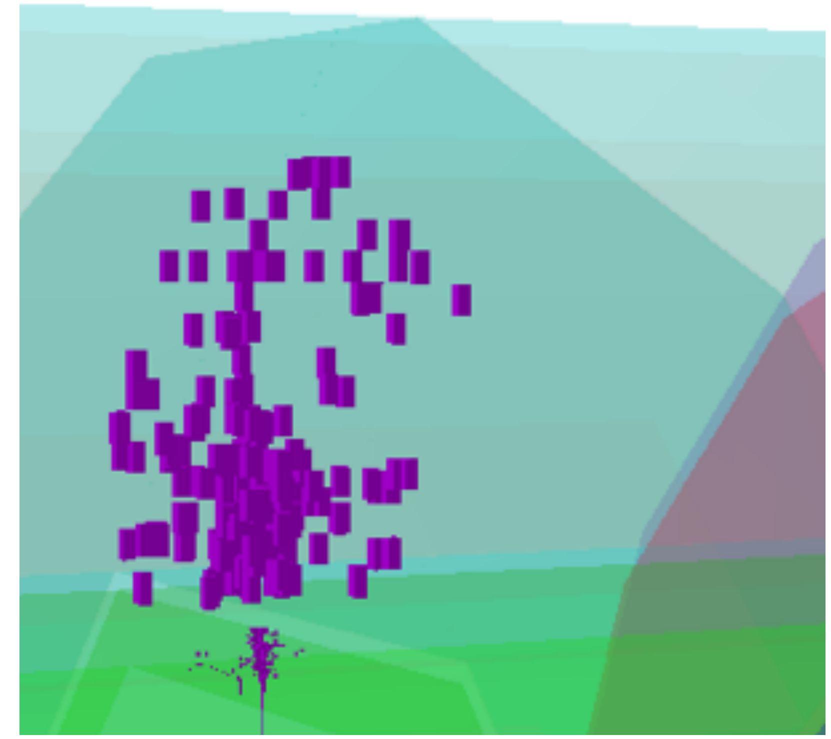


ECal and HCal Timing Cuts : 100 ns
HCal Hadronic Cell Truncation : Optimised on a detector model basis
Software : ilcsoft_v01-17-07, including PandoraPFA v02-00-00
Digitiser : ILDCaloDigi, realistic ECal and HCal digitisation options enabled
Calibration : PandoraAnalysis toolkit v01-00-00

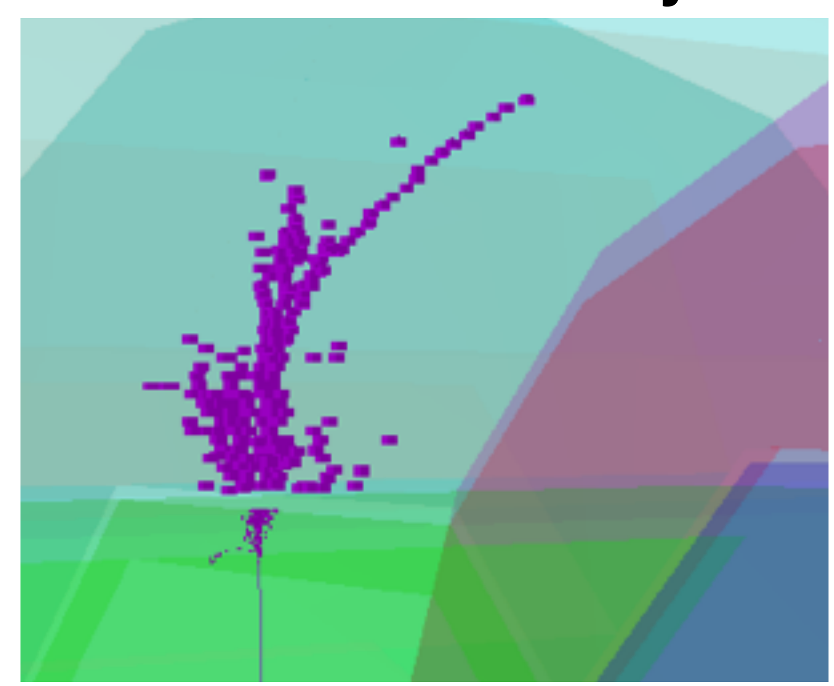
AHCal Optimisation Studies

HCal Cell Size

Number of Interaction Lengths in HCal



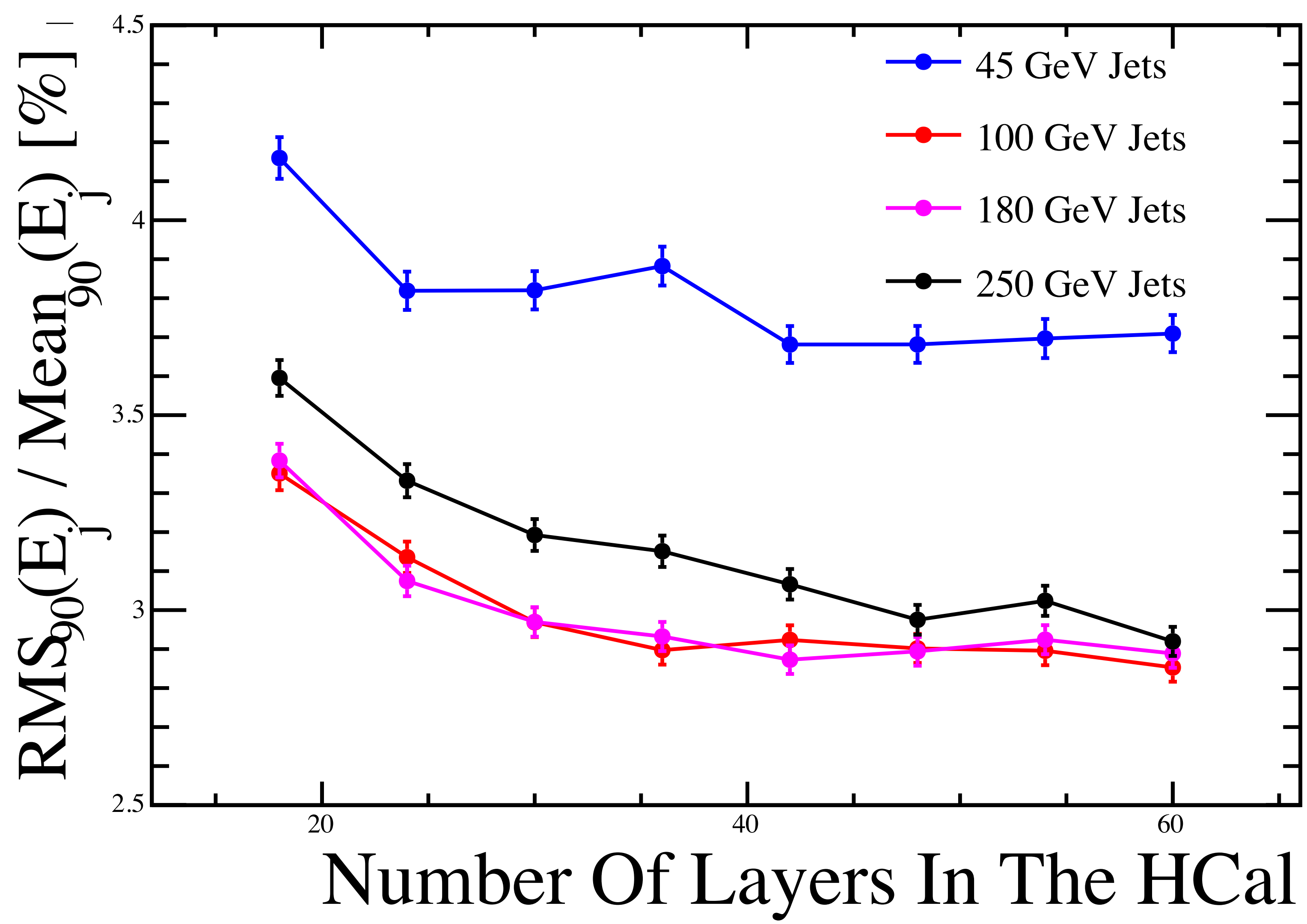
Number Of HCal Layers



See backup for further details on methodology and for other studies.

AHCal Optimisation Studies

UNIVERSITY OF CAMBRIDGE



- Reduction in number of layers in the HCal degrades detector performance.
- True across all energy ranges considered.

ECal and HCal 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

AHCal Optimisation Studies

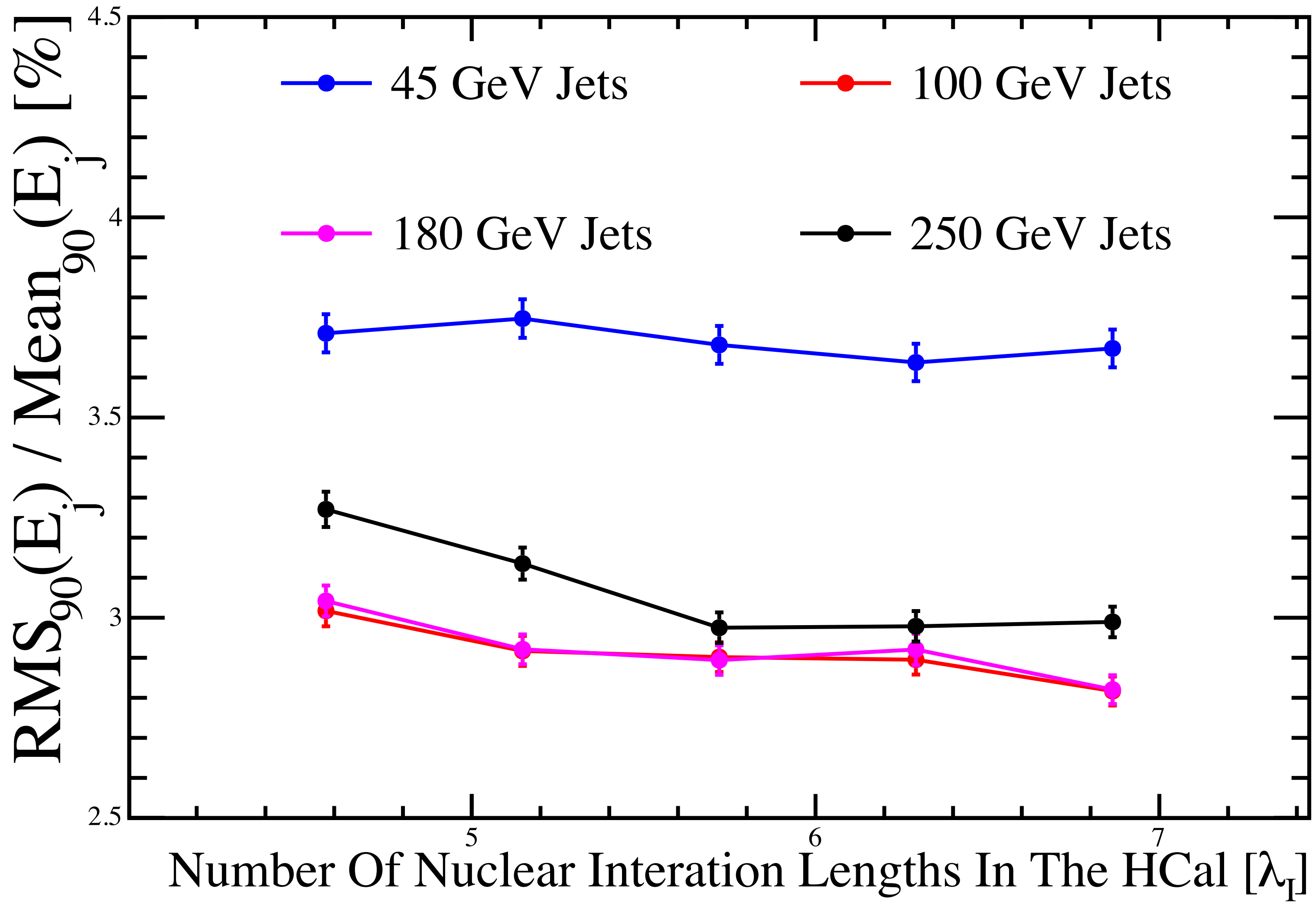
HCal Cell Size

Number Of HCal Layers

Number of Interaction Lengths in HCal

See backup for further details on methodology and for other studies.

AHCal Optimisation Studies



- Increasing number of nuclear interaction lengths in the HCal is beneficial to jet energy resolution particularly at high energies.
- Larger number of nuclear interaction lengths in the HCal helps to reduce leakage.

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

UNIVERSITY OF CAMBRIDGE

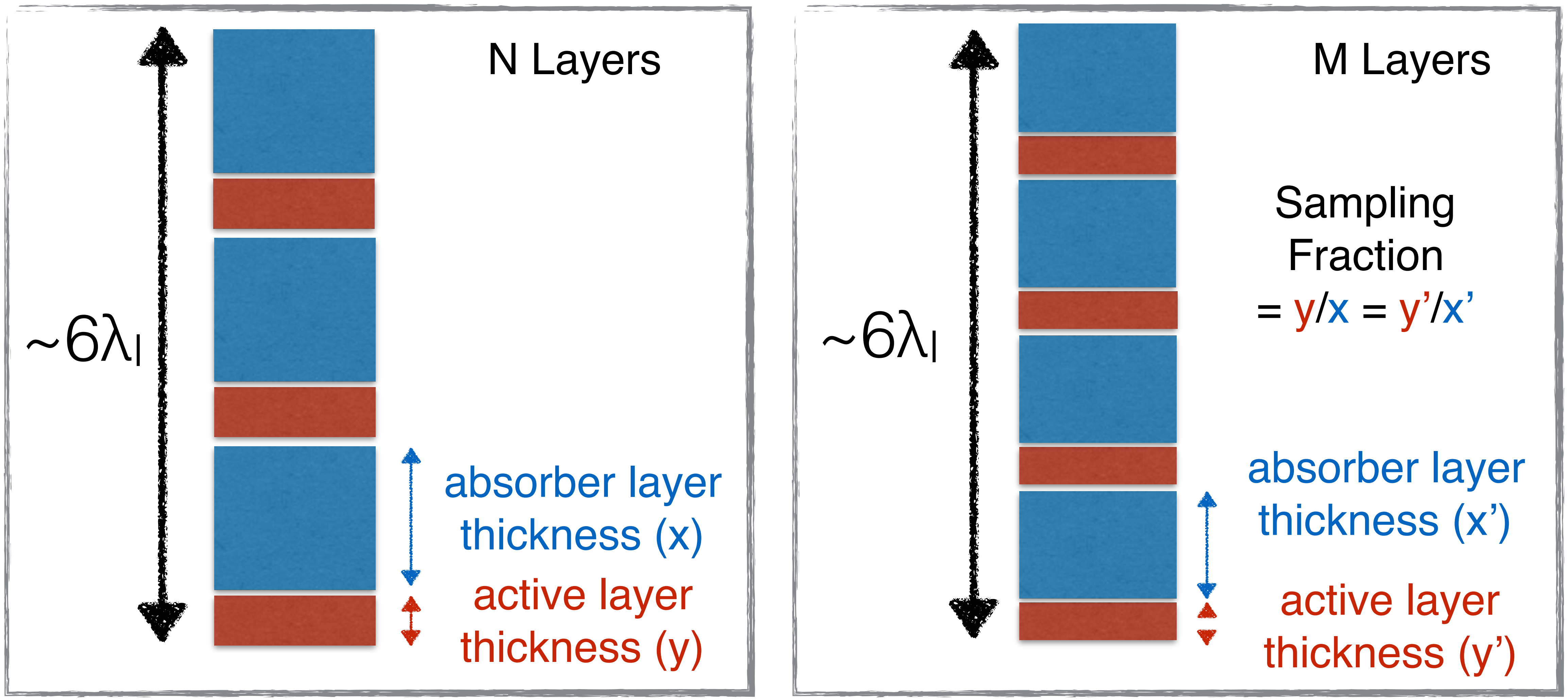
Thank you for your attention!

HCal Optimisation Studies - BackUp

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:

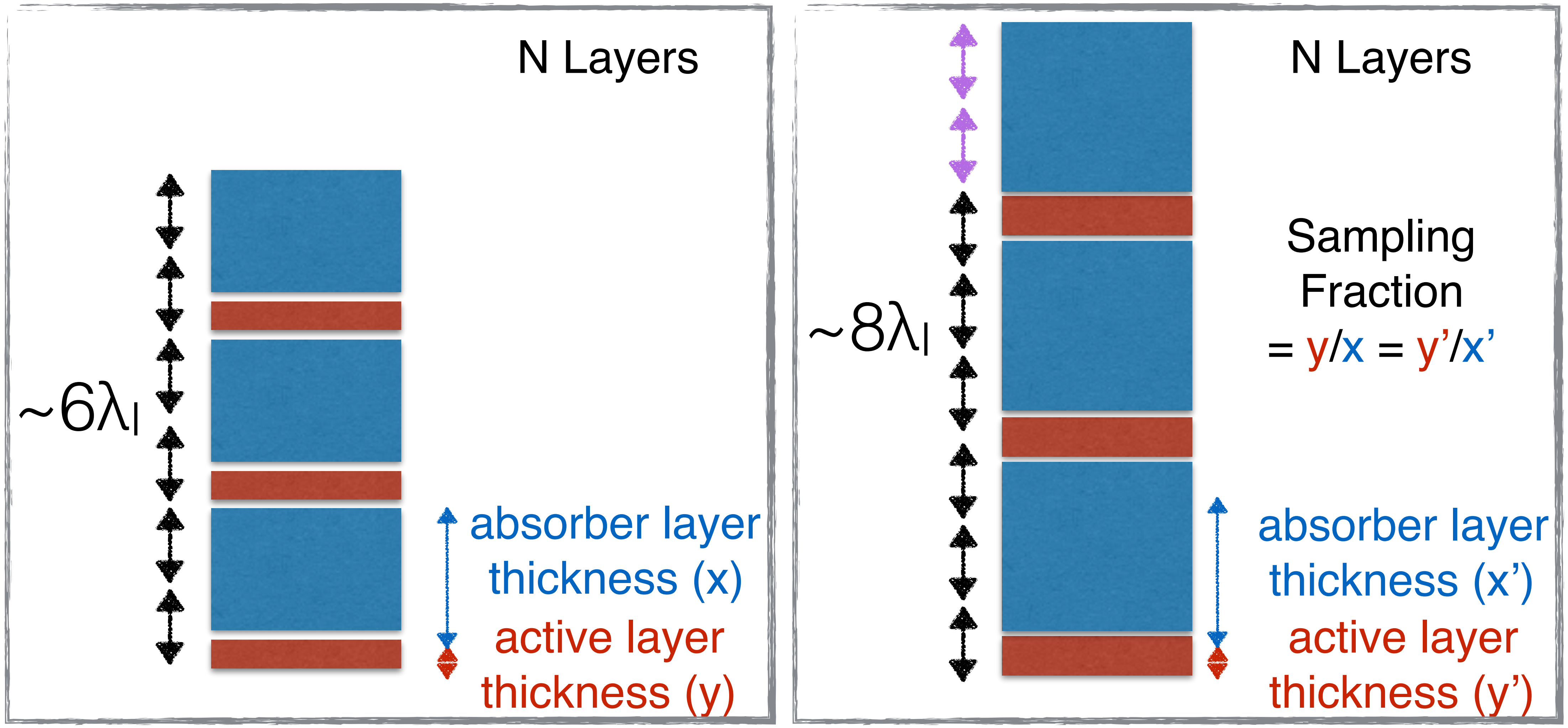


Cartoon showing effect of changing number of HCal layers

* 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 Interaction Lengths in the HCal

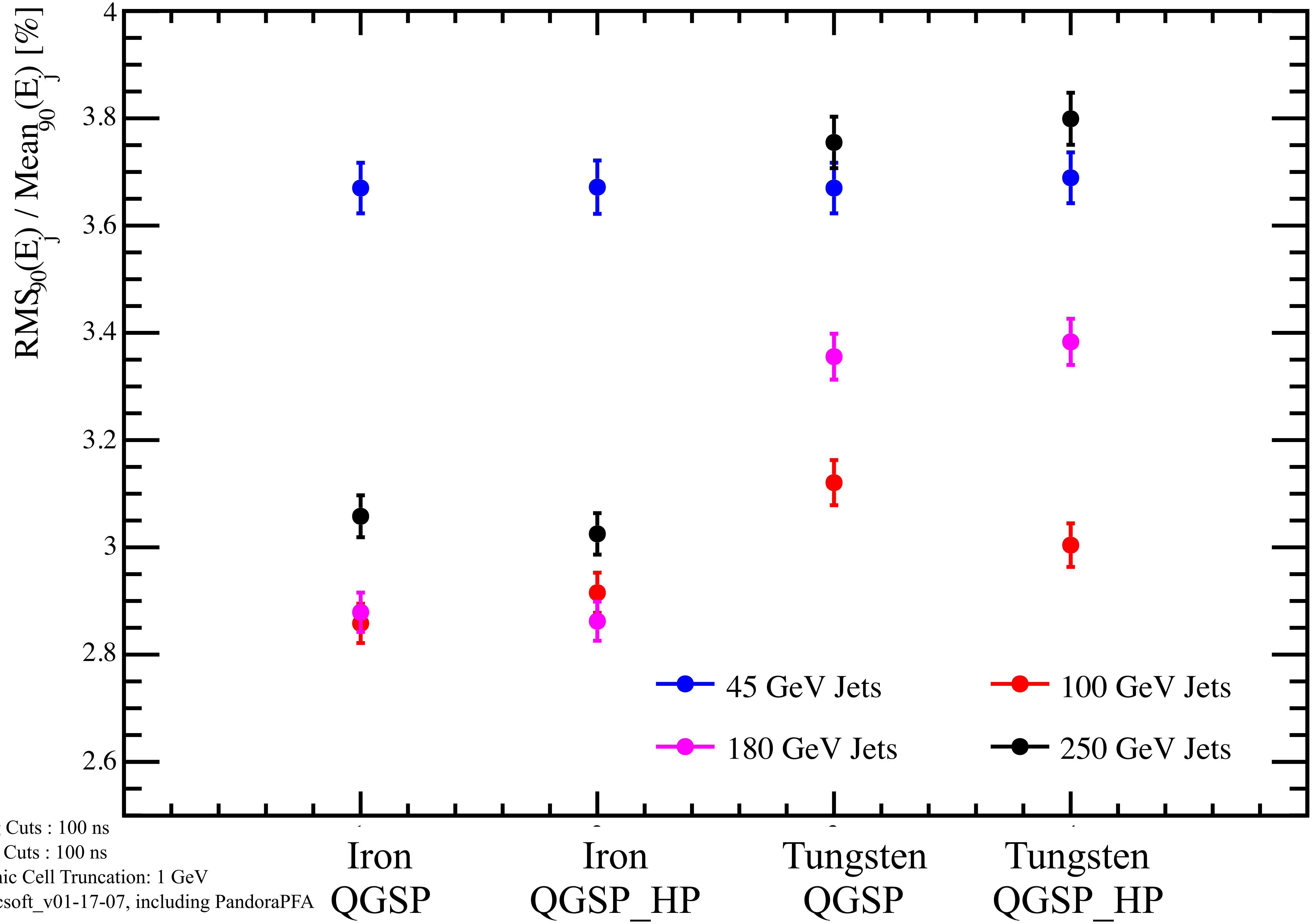
* Here we wish to consider varying the total number of nuclear interaction in the HCal.
* However, we do not want to implicitly vary either the number of layers in the HCal or the sample fraction when varying this study:



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.

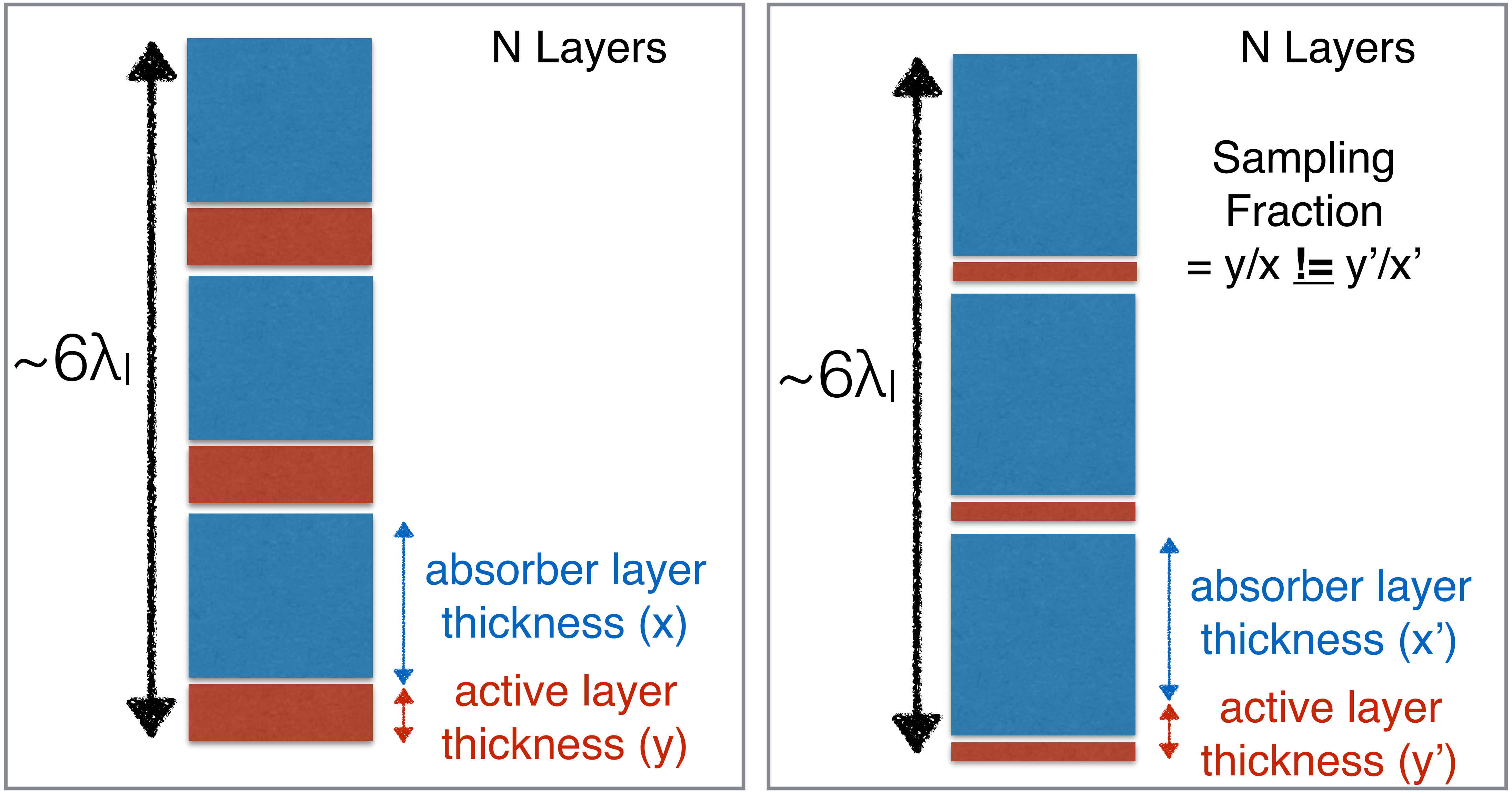
HCal Absorber Material



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

Sampling Fraction in the HCal

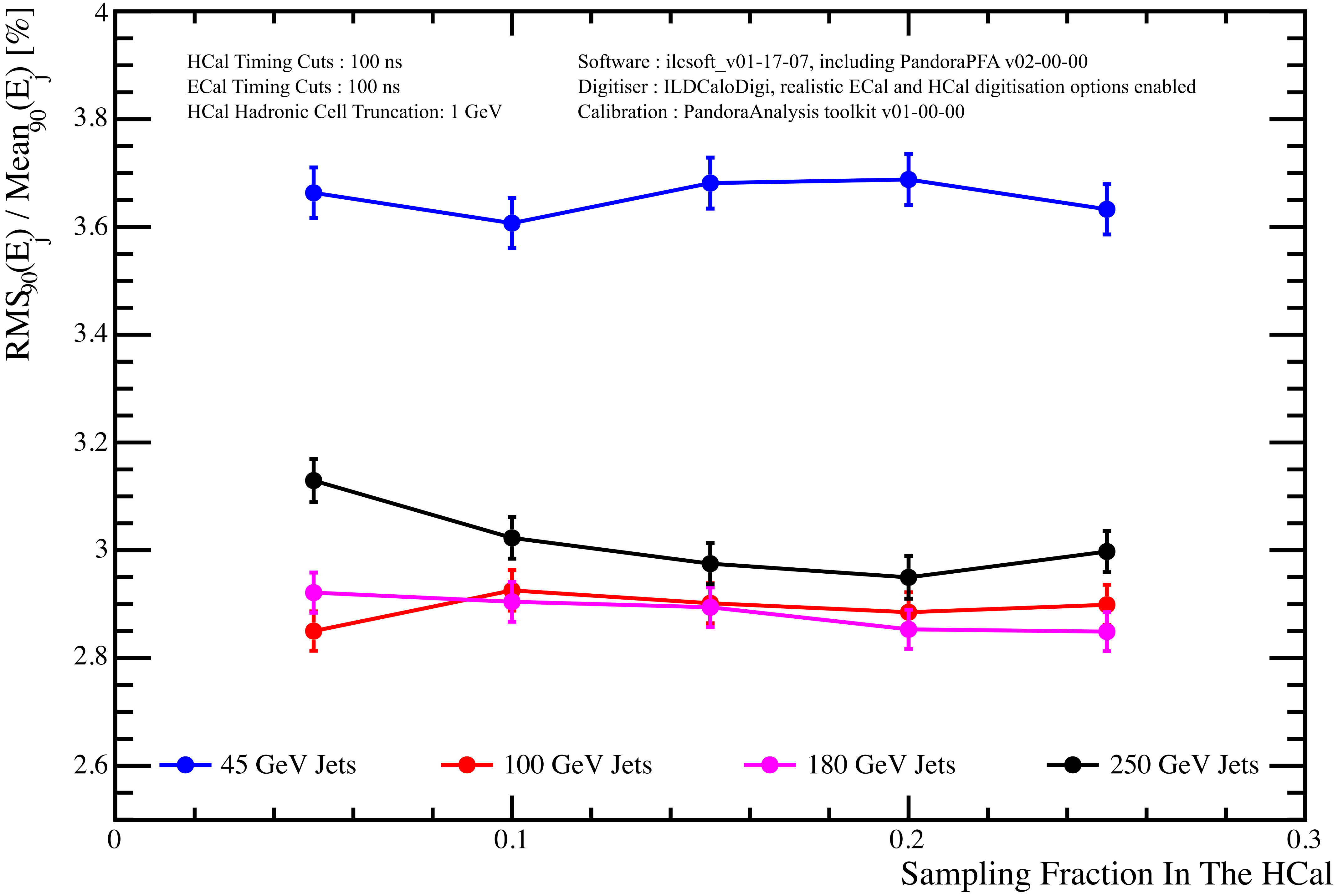
- Here we wish to consider varying the sampling fraction in the HCal.
- However, we do not want to implicitly vary either the number of layers or the number of nuclear interaction lengths in the HCal this study:



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

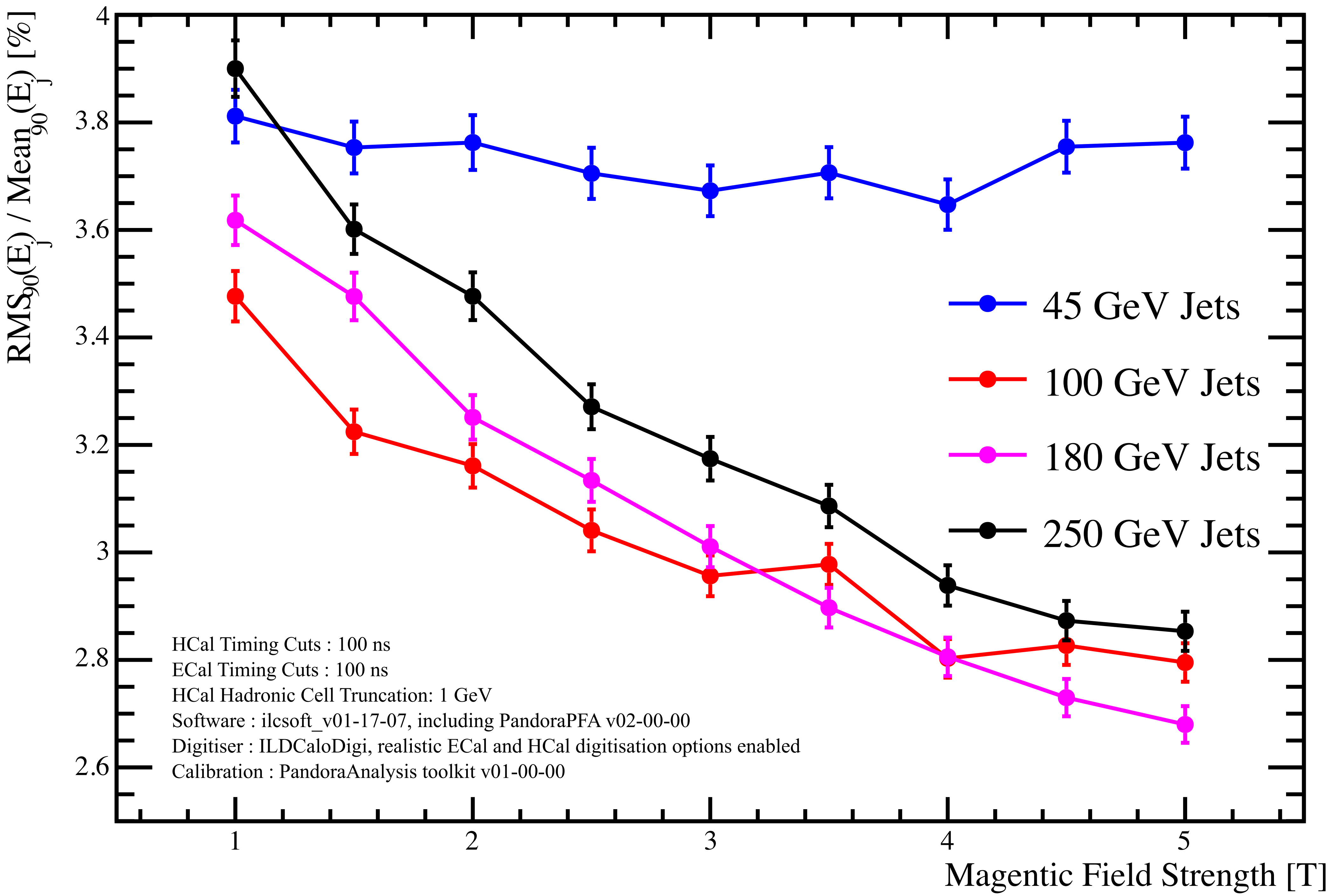
- The number of nuclear interaction lengths and the ratio of the absorber layers thicknesses to the active layer thicknesses is **unchanged** in this study.

Sampling Fraction in the HCal



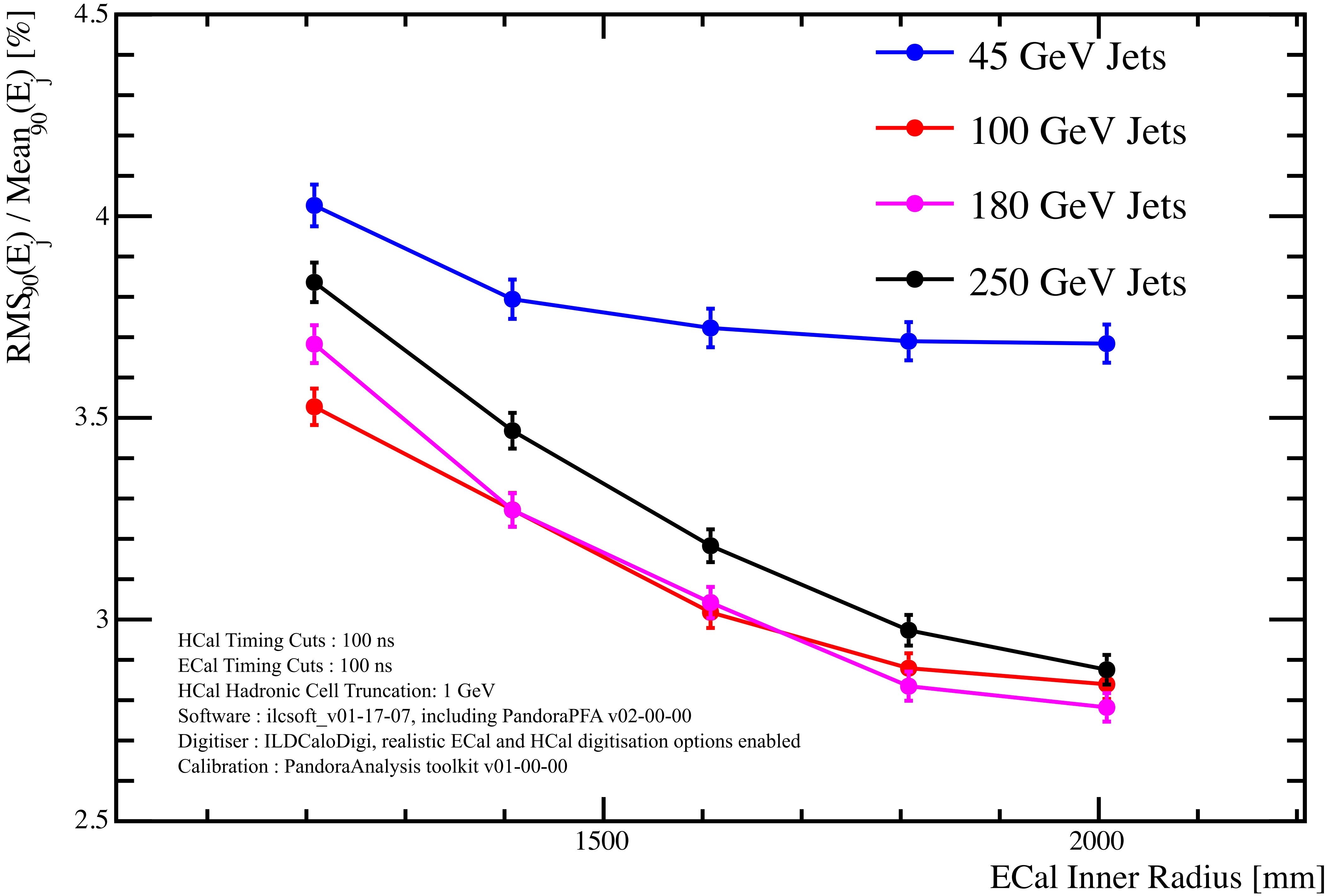
Optimisation of Global Parameters

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



Photon Settings in iLCsoft

Photon Algorithm Changes in Pandora

ilcsoft	PandoraPFA	MarlinPandora	PandoraSettings	Photon
v01-17-07	v02-00-00	v02-00-00	Default	Old Approach
v01-17-08	v02-00-00	v02-00-00	Default	Old Approach
v01-17-08	v02-00-00	v02-00-00	DefaultNewPhoton	Agressive Reduced Fragments
v01-17-09	v02-05-00	v02-02-00	Default	Reduced Fragments and Better Photon Separation

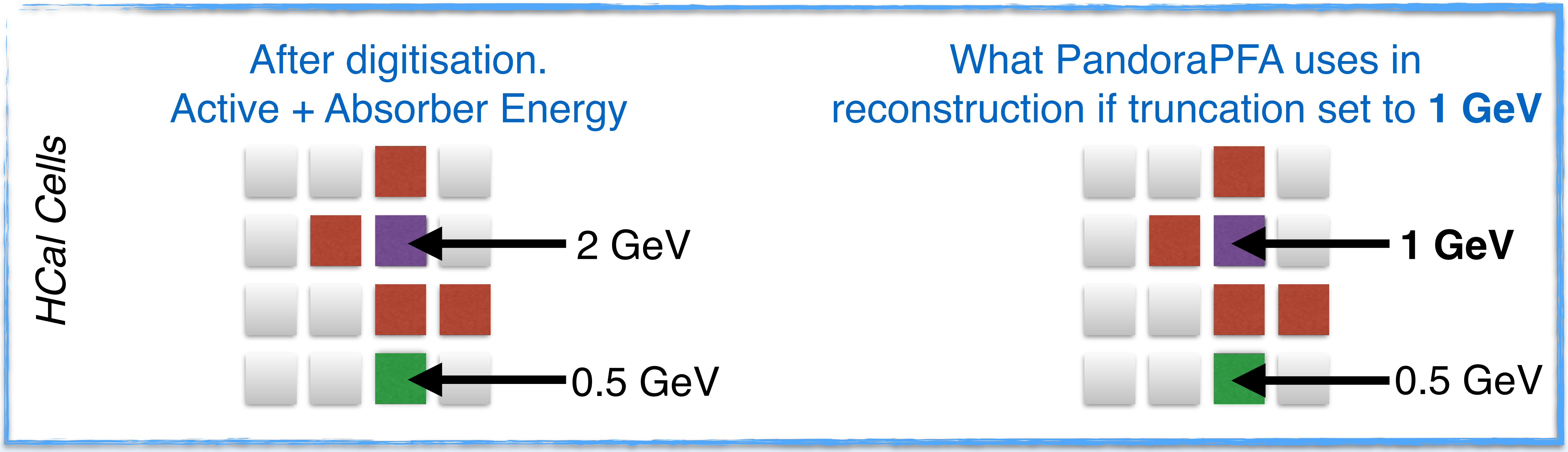
Algorithm Details

ilcsoft	PandoraPFA	MarlinPandora	PandoraSettings	Recophoton Fragment Merging	HighEnergy PhotonRecovery	Photon Fragment Merging	BX Photon Reconstruction Updates	Photon Splitting
v01-17-07	v02-00-00	v02-00-00	Default	Implemented, Off	Not Implemented	Implemented, Off	Not Implemented	Not Implemented
v01-17-08	v02-00-00	v02-00-00	Default	Implemented, Off	Not Implemented	Implemented, Off	Not Implemented	Not Implemented
v01-17-08	v02-00-00	v02-00-00	DefaultNewPhoton	On	Not Implemented	On	Not Implemented	Not Implemented
v01-17-09	v02-05-00	v02-02-00	Default	Implemented, Off	On	On	On	On

Details of Simulation and Reconstruction Evolution

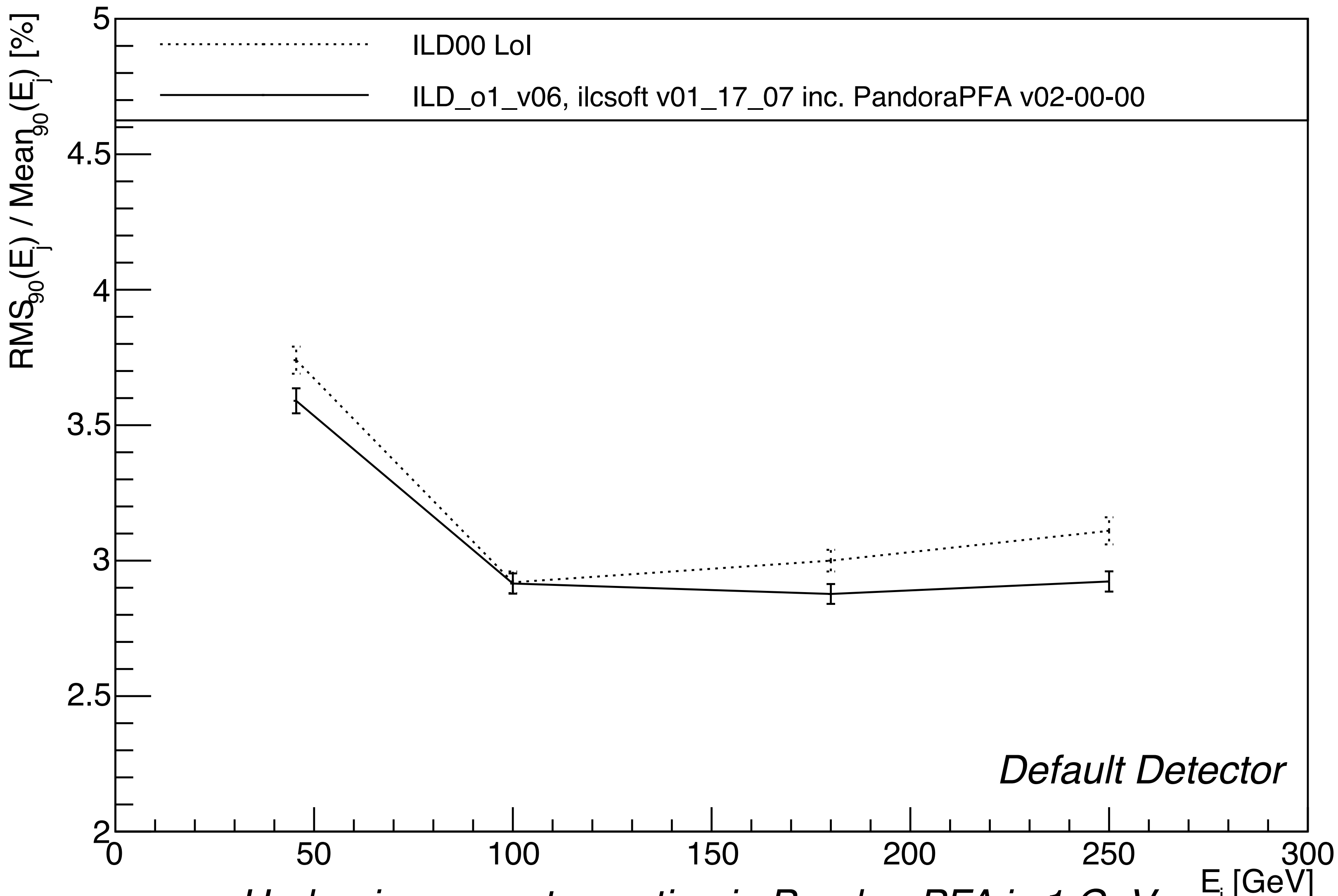
Hadronic Energy Truncation in PandoraPFA

- 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.



LoI vs PandoraPFANew v02-00-00

- Examine the change in detector performance when:
  - Updating the detector model from the time of the LoI to ILD_o1_v06.
  - Updating reconstruction software from that at the time of the LoI to version ilcsoft v01-17-07 including Pandora v02-00-00.

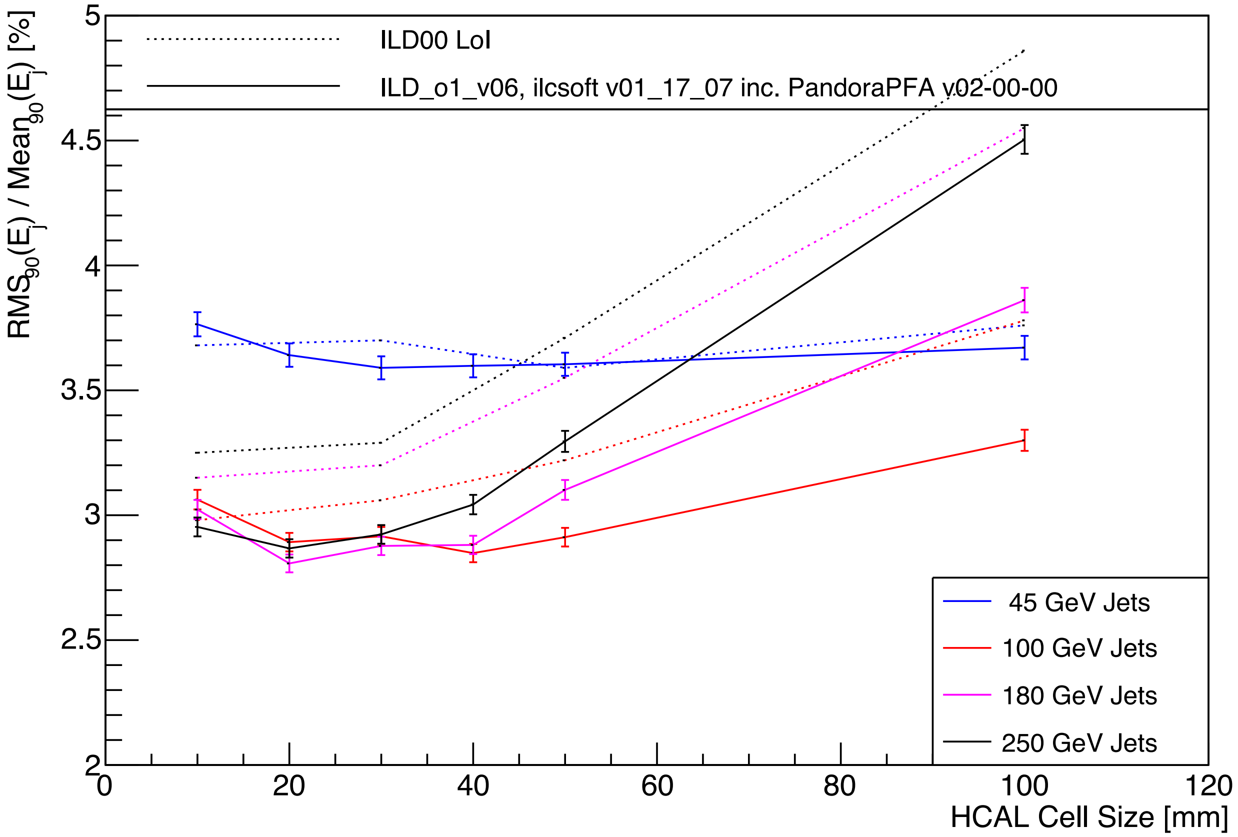


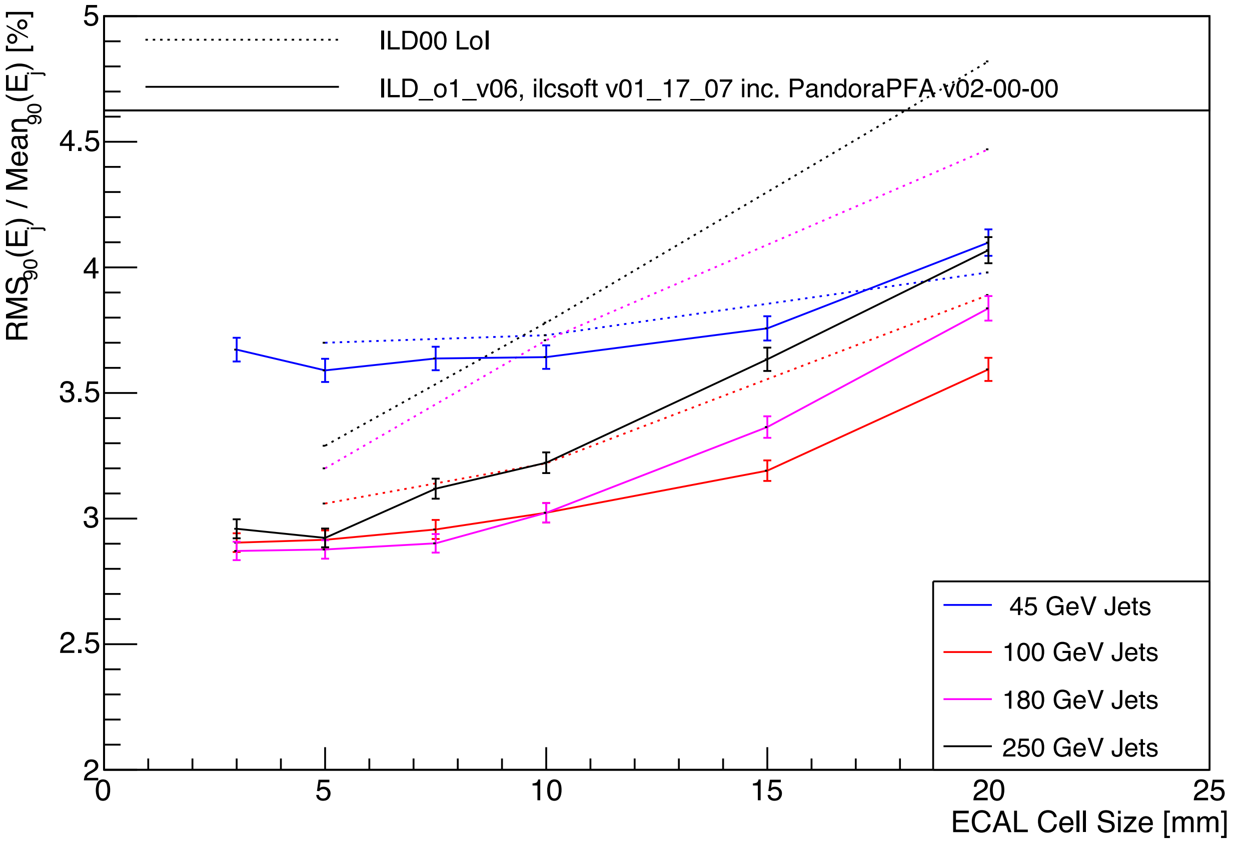
Hadronic energy truncation in PandoraPFA is 1 GeV.

- All input variables to the simulation and reconstruction are unchanged.
- Improvements seen across the energy range considered for the default detector.

LoI vs PandoraPFANew v02-00-00

Look at the non default detector models…





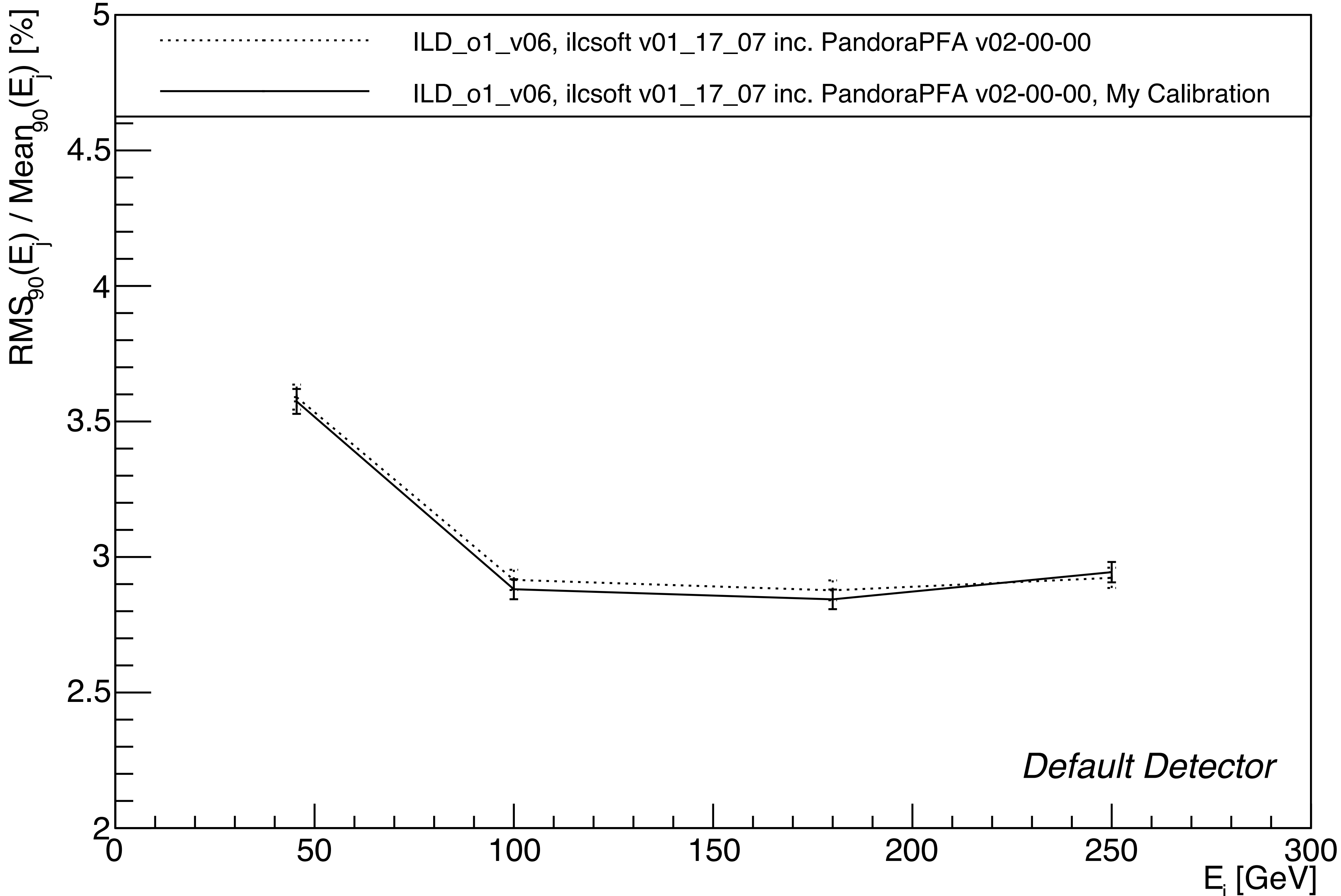
Hadronic energy truncation in PandoraPFA is 1 GeV.

* Improvements seen when we vary the ECal and HCal cell sizes (otherwise detector is default ILD_o1_v06).

☑ Changes to the detector model and reconstruction software since the time of the LoI have improved the detector performance.

DBD vs New Calibration

- Examine the change in detector performance when going from the default calibration numbers used for the DBD to the newly developed calibration procedure (see back up slides for further detail).



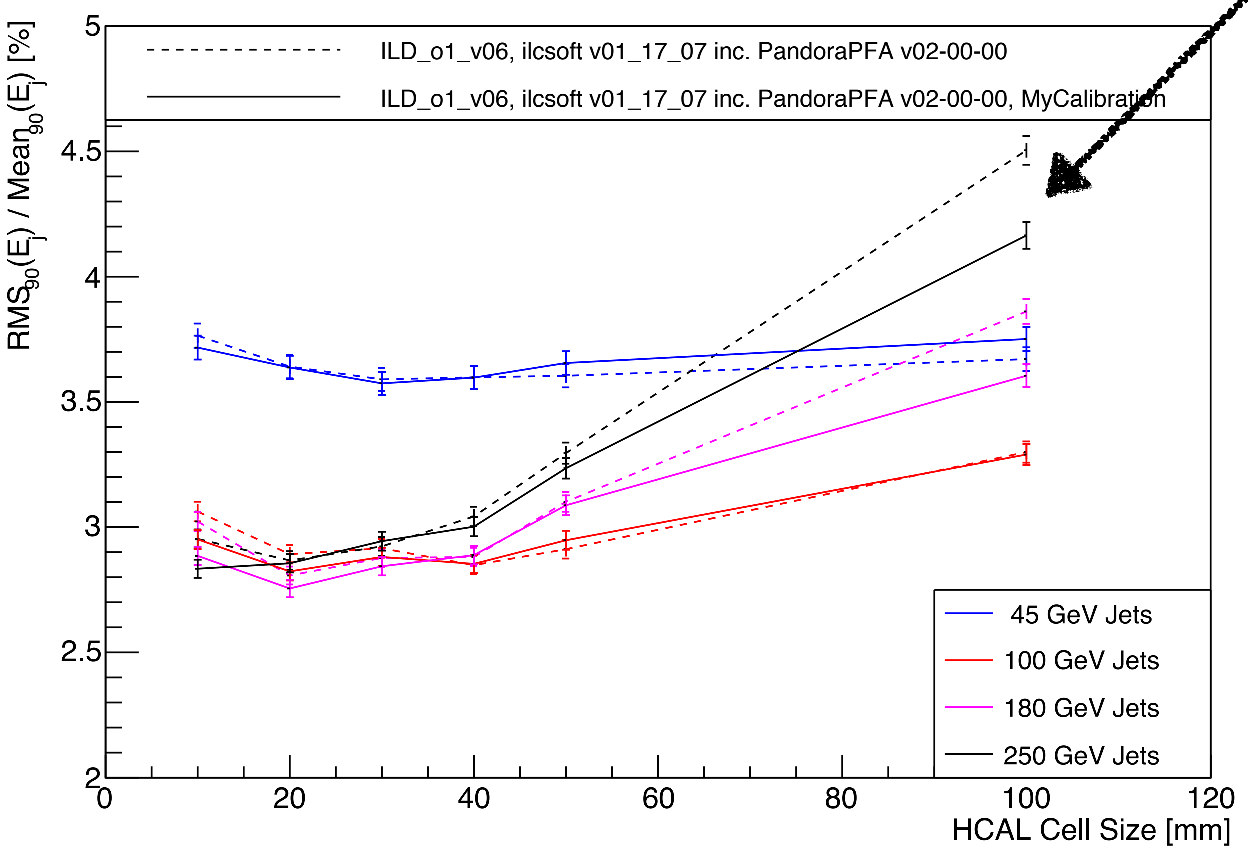
Hadronic energy truncation in PandoraPFA is 1 GeV.

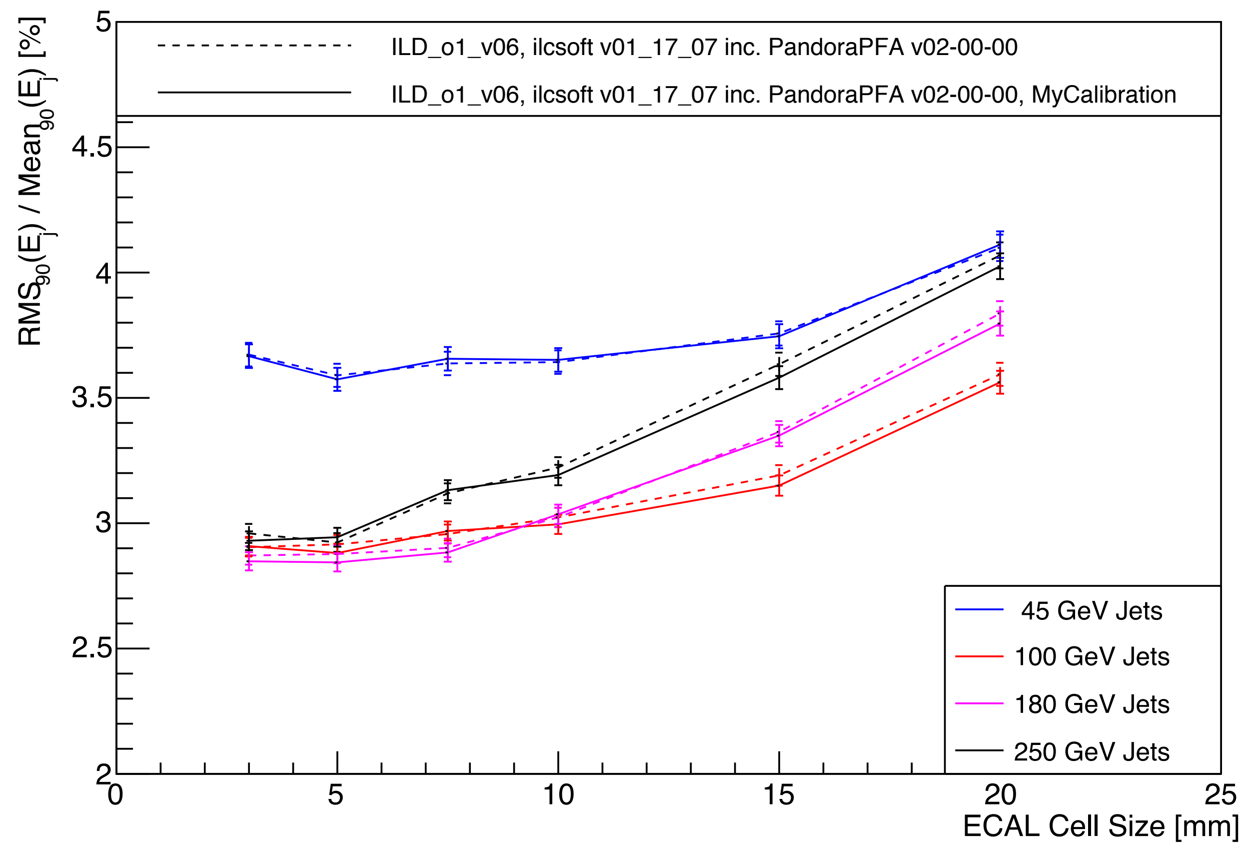
- New calibration procedure is documented in the PandoraAnalysis toolkit (cf. pdf in doc folder).
- No difference in performance.

DBD vs New Calibration

Look at the non default detector models…

Calibration compensates for lost energy due to truncation at large HCal cell sizes.





Hadronic energy truncation in PandoraPFA is 1 GeV.

- New calibration procedure either reproduced the DBD calibration or improves it for large HCal cell sizes and high energy jets.

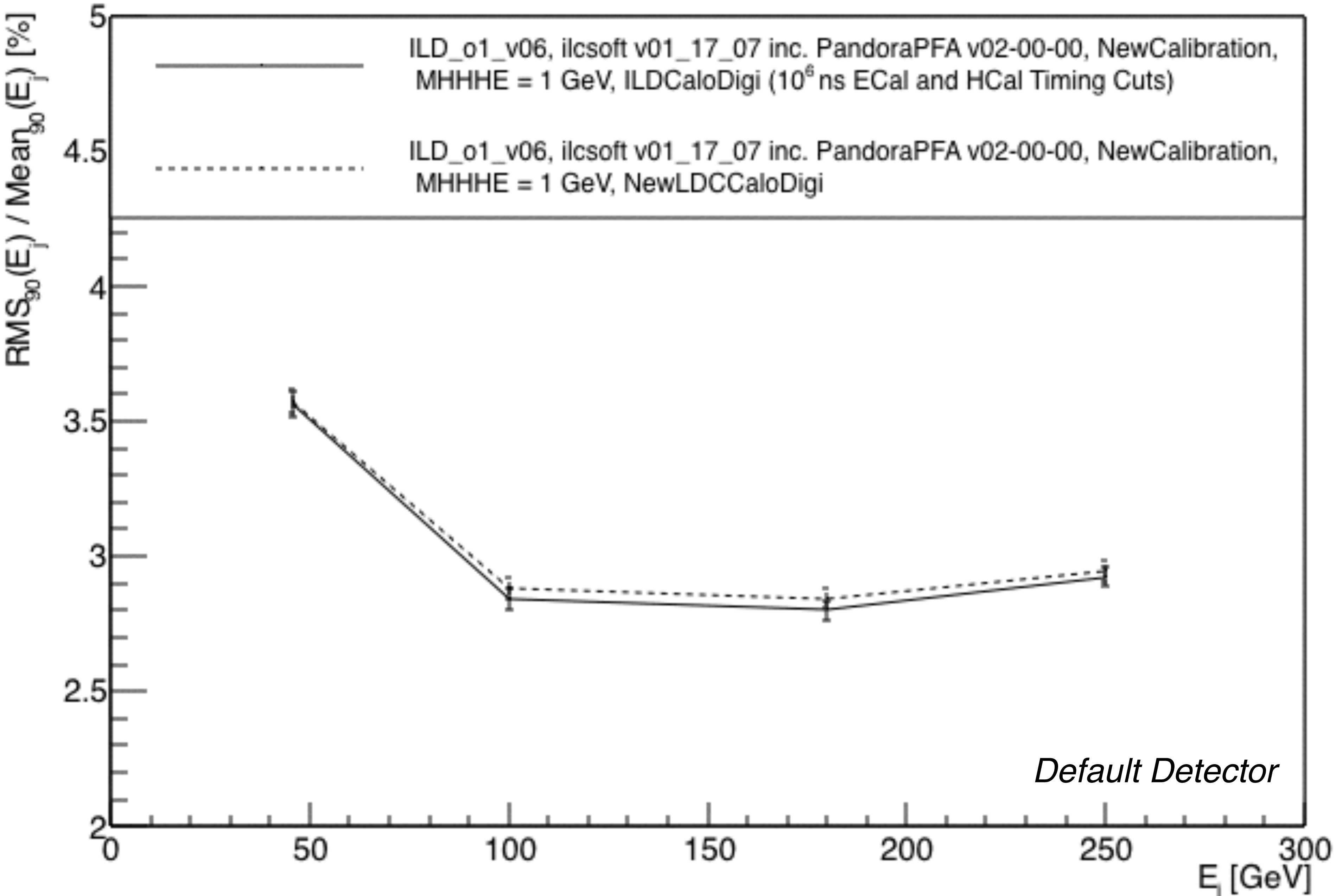
☑ New calibration procedure produces consistent results, is physically justifiable and so should be used for future studies.

NewLDCCaloDigi vs ILDCaloDigi

- There are two different digitisation options available to us:
  - **NewLDCCaloDigi**. This is what was used for the LoI and DBD.
  - **ILDCaloDigi**. This is a modified version of NewLDCCaloDigi, which has features such as timing cuts and realistic options (details in later slide), both of which we would like to study further.
- There is a subtle difference in the grouping of SimCalorimeterHits into CalorimeterHits between these two digitisers (details in back up slide). Could be significant as thresholds are place on CalorimeterHits once they are in PandoraPFA.
- NewLDCCaloDigi places no timing cuts and so in the following comparisons, unless explicitly stated, we set the timing cut in ILDCaloDigi to be a very large value 10^6ns.

NewLDCCaloDigi vs ILDCaloDigi

- Examine the change in detector performance when going from the NewLDCCaloDigi digitiser to the ILDCaloDigi digitiser.

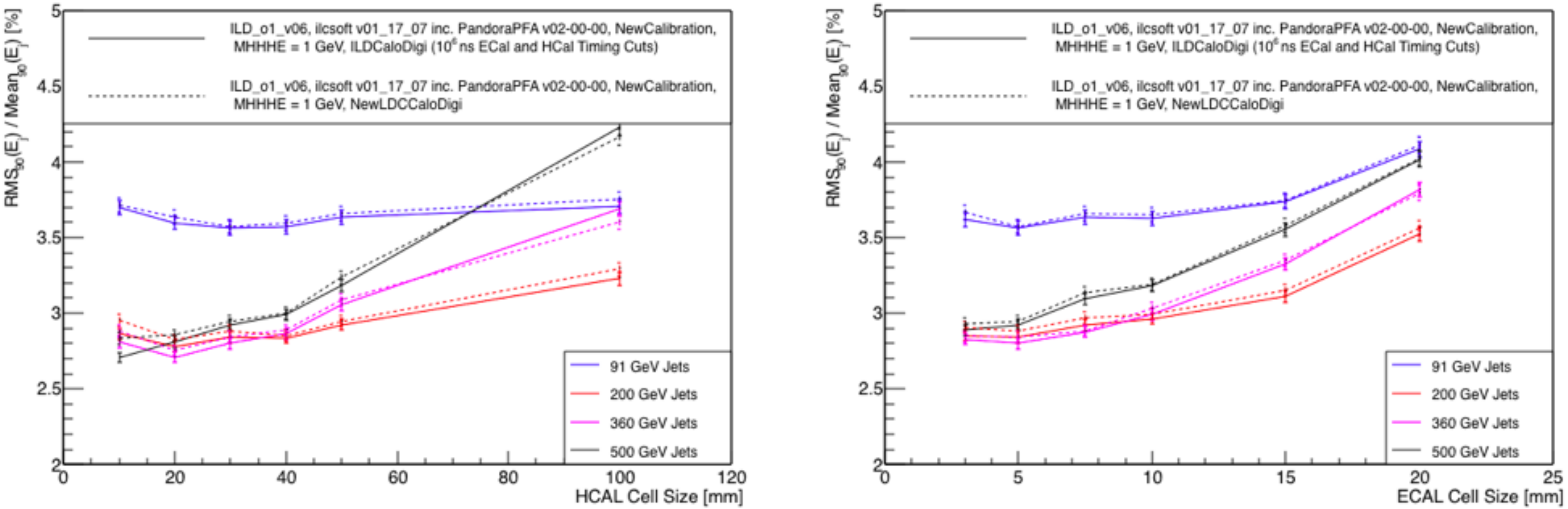


Hadronic energy truncation in PandoraPFA is 1 GeV.

- Slight performance difference. Most likely from grouping of SimCalorimeterHits differences.
- ILDCaloDigi performs slightly better than NewLDCCaloDigi.

NewLDCCaloDigi vs ILDCaloDigi

Look at the non default detector models…



Hadronic energy truncation in PandoraPFA is 1 GeV.

- No significant changes when moving from NewLDCCaloDigi to ILDCaloDigi.

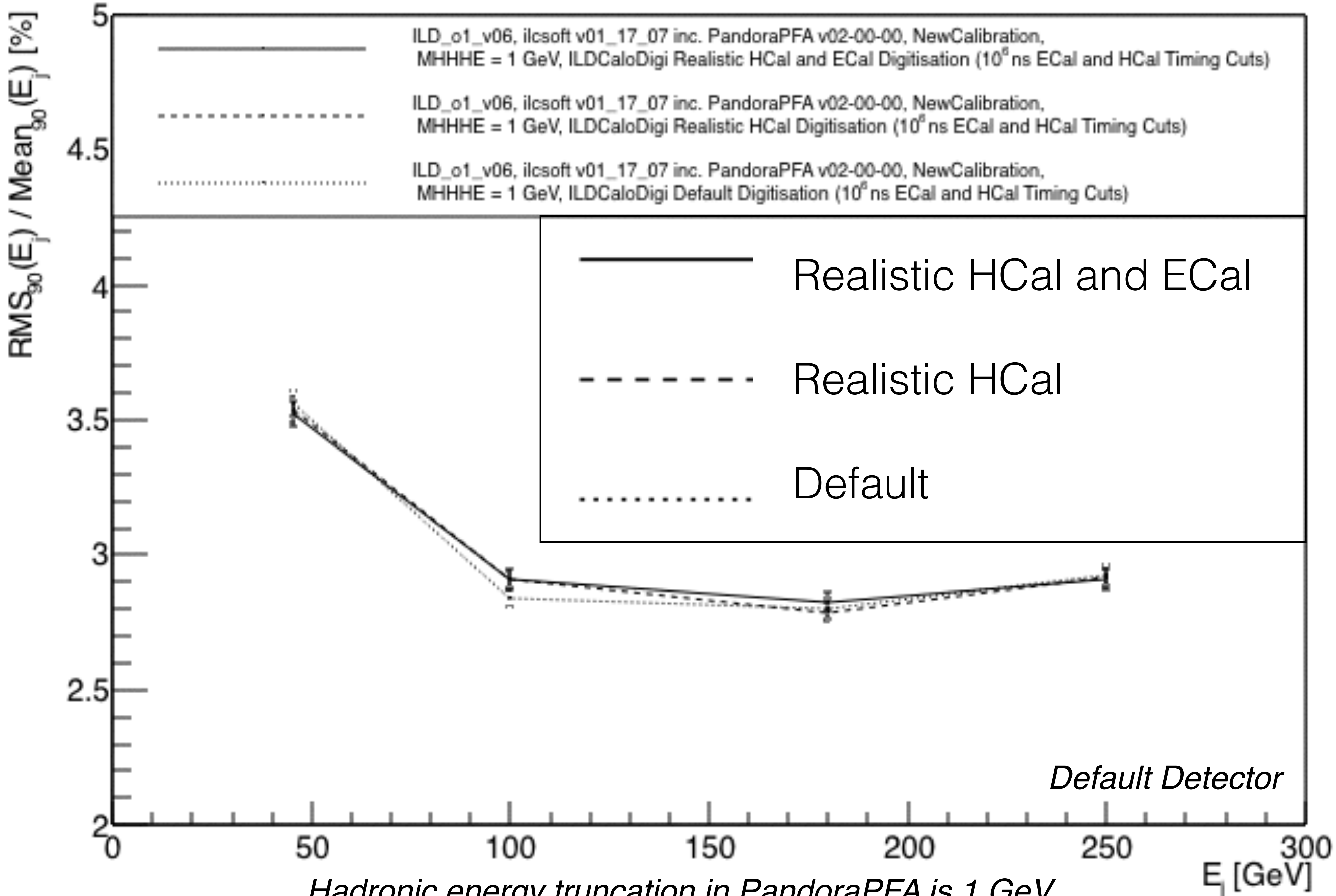
☑ Should use ILDCaloDigi in latest studies as it has more added functionality e.g. timing cuts can be applied.

Realistic Digitisation in ILDCaloDigi

- Thanks to the efforts of Daniel Jeans, Oskar Hartbrich and Katsu Coterra et al. the ILDCaloDigi processor has a number of realistic options.
- The realistic digitisation of the calorimeters allows for simulation of mis-calibration, limited dynamic ranges in readout technology and signal fluctuations.
- The effects that we were advised to simulate were the electronics read out range and the electrical noise. The read out range is determined in MIP units this required modification of the calibration procedure.
- The realistic digitisation of the ECal was applied to the silicon ECal we have been using in the studies, however, there is also a realistic ECal scintillator option that can be used.

Realistic Digitisation in ILDCaloDigi

* Comparing the default digitisation in ILDCaloDigi with the realistic HCal option and the realistic ECal and HCal option.



Hadronic energy truncation in PandoraPFA is 1 GeV.

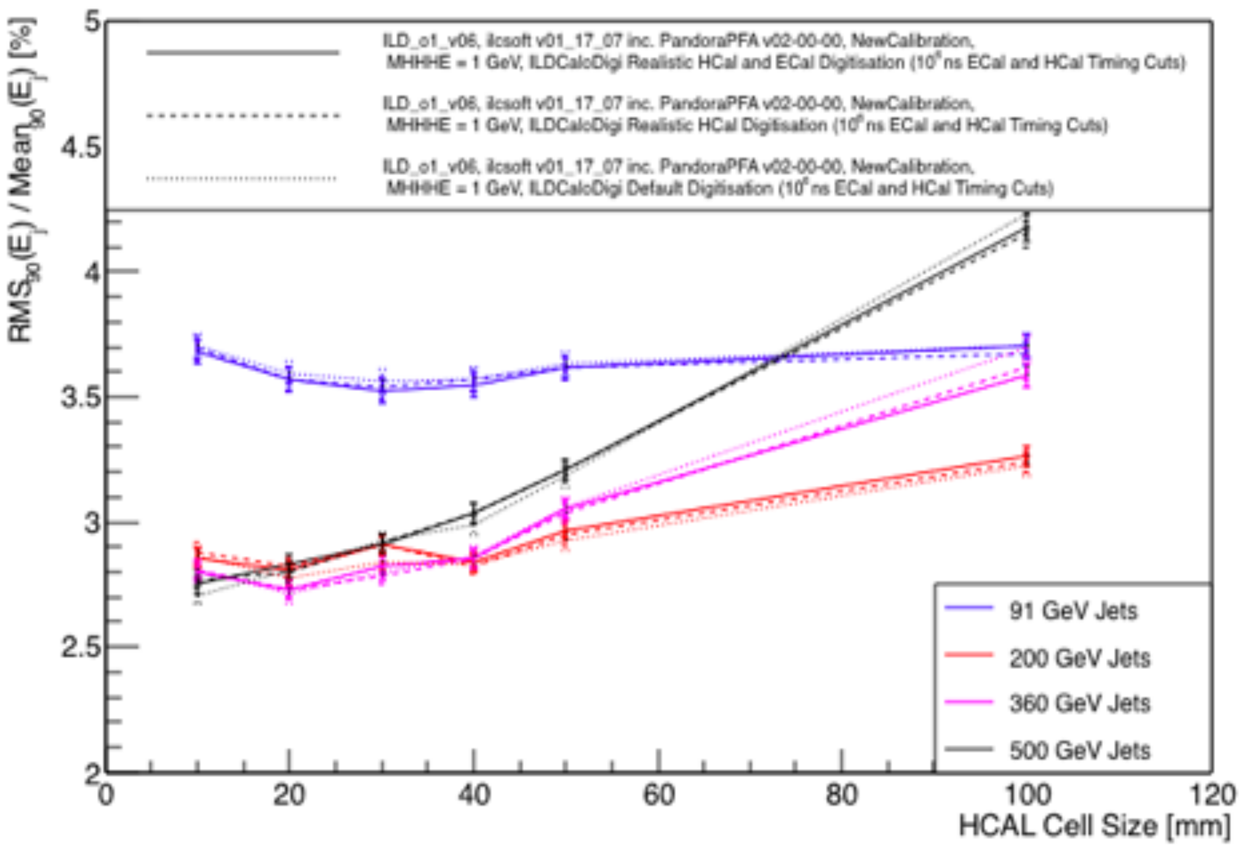
* Consistent performance between all digitisation options.

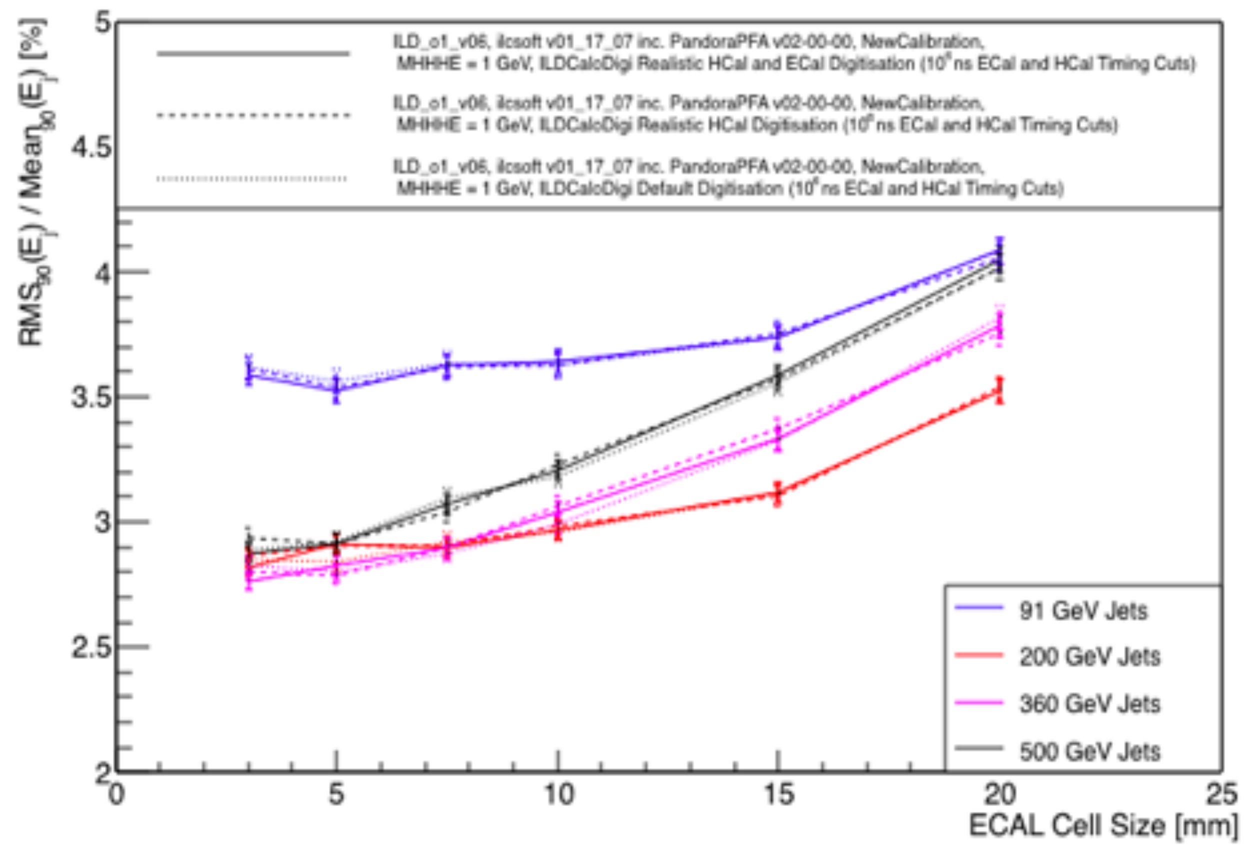
Thanks to D. Jeans, O. Hartbrich and K. Coterra et al

Realistic Digitisation in ILDCaloDigi

UNIVERSITY OF CAMBRIDGE

Look at the non default detector models…





Hadronic energy truncation in PandoraPFA is 1 GeV.

- We find consistent performance between ILDCaloDigi digitisation options for this energy truncation also.

☑ Evidence to suggest we should be using the realistic ECal and HCal options for further studies.

———	Realistic HCal and ECal
- - - - - -	Realistic HCal
....	Default

UNIVERSITY OF CAMBRIDGE

Timing Cuts

For the following studies we will be using ILD_01_v06, ilcsoft_v01-17-07 (inc. PandoraPFA v02-00-00), the calibration procedure as described in the PandoraAnalysis toolkit (v01-00-00), the ILDCaloDigi digitiser with the realistic digitsation options enabled.

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:

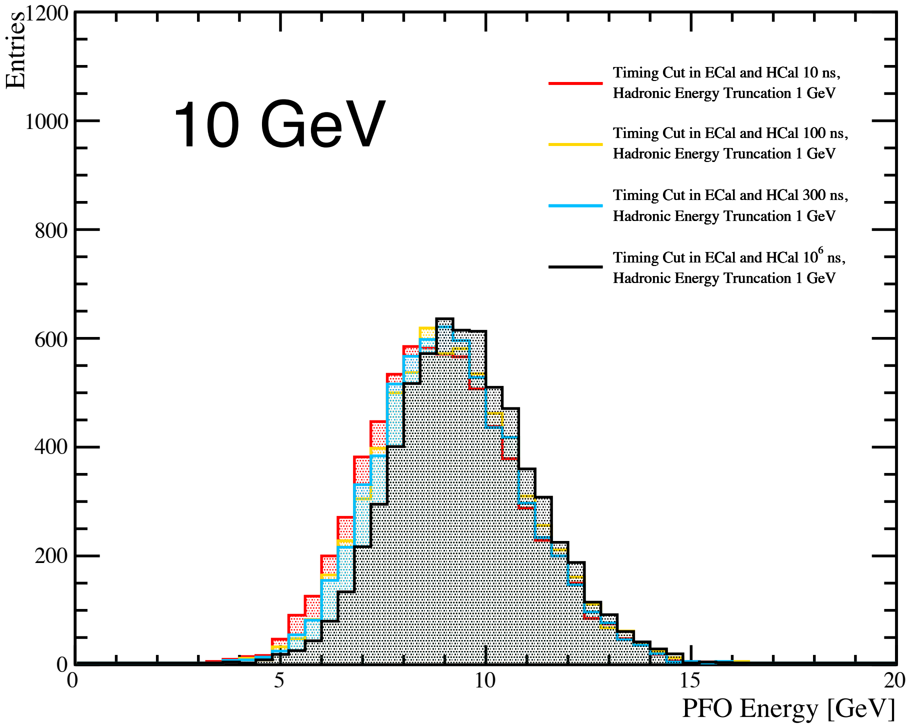
- Here we will look at:
  1. Raw reconstructed energy distributions;
  2. Mean reconstructed energy;
  3. Energy resolution.

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

UNIVERSITY OF CAMBRIDGE



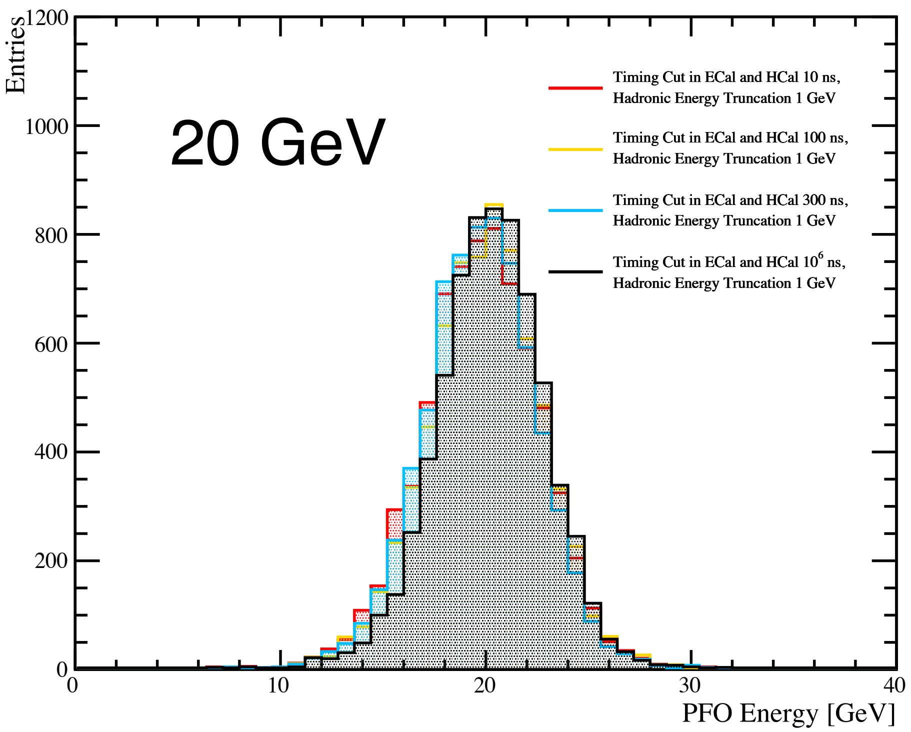
Timing Cut in ECal and HCal 10 ns, Hadronic Energy Truncation 1 GeV

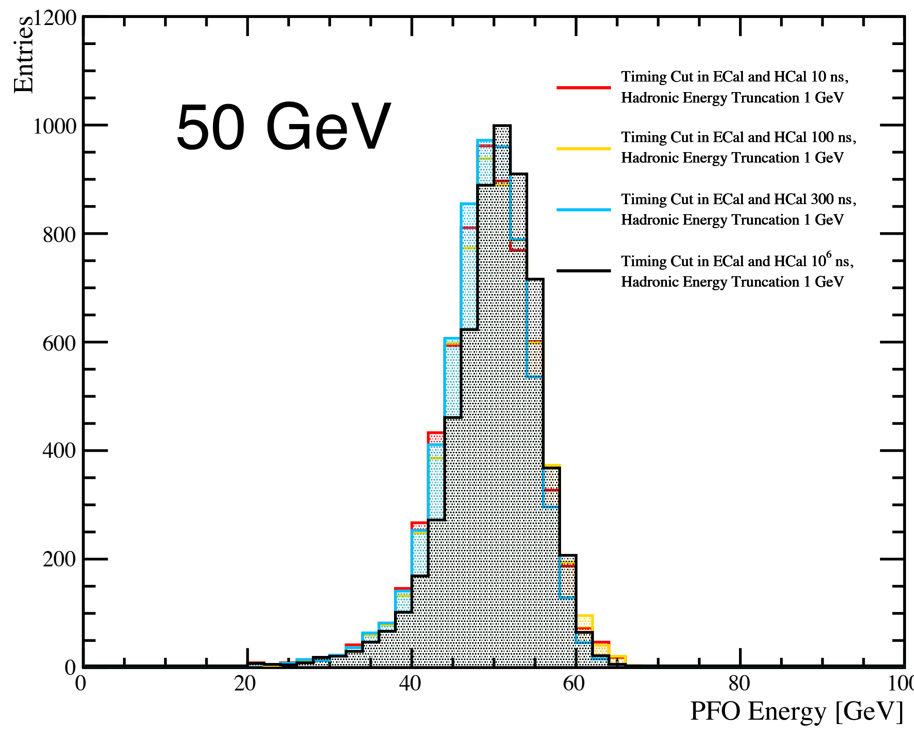
Timing Cut in ECal and HCal 100 ns, Hadronic Energy Truncation 1 GeV

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

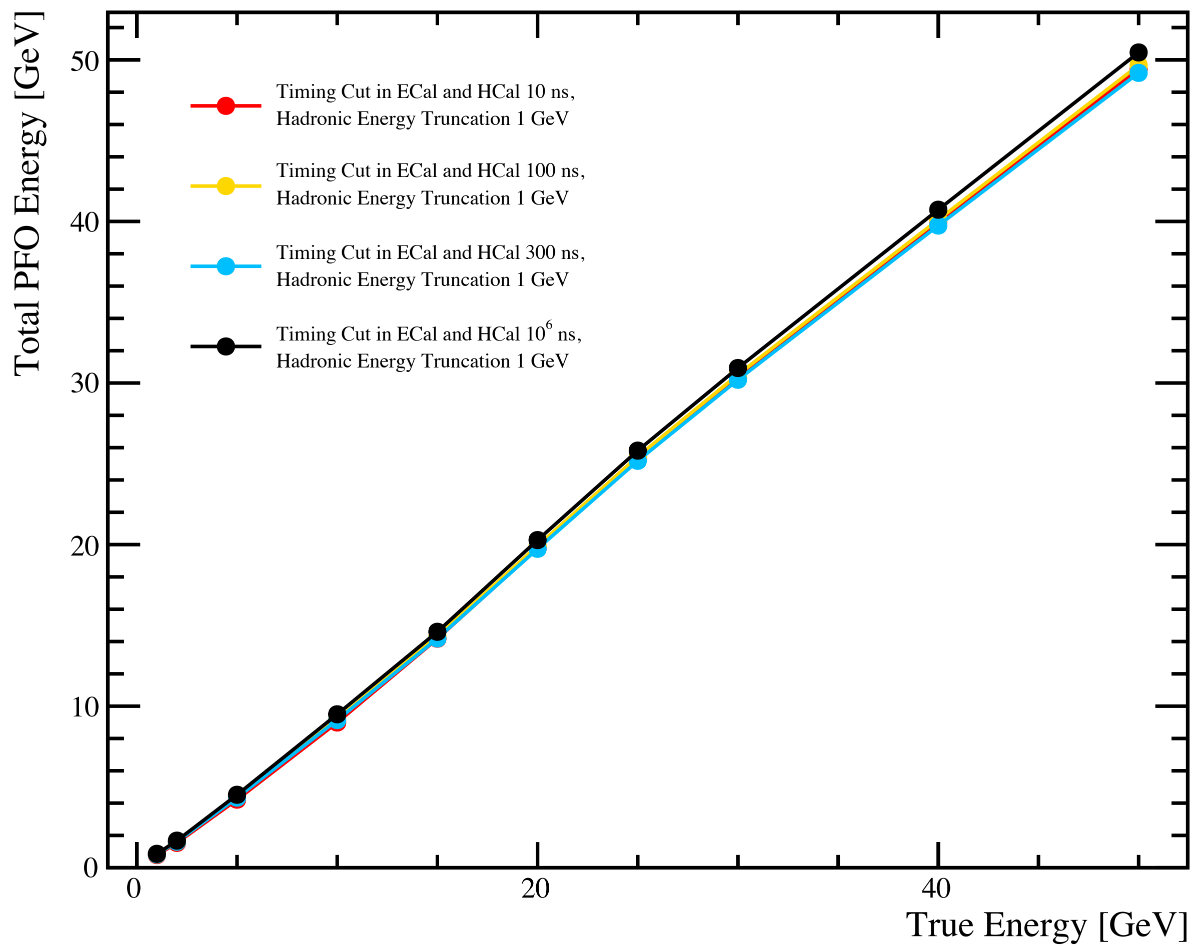
Timing Cut in ECal and HCal 10^6 ns, Hadronic Energy Truncation 1 GeV

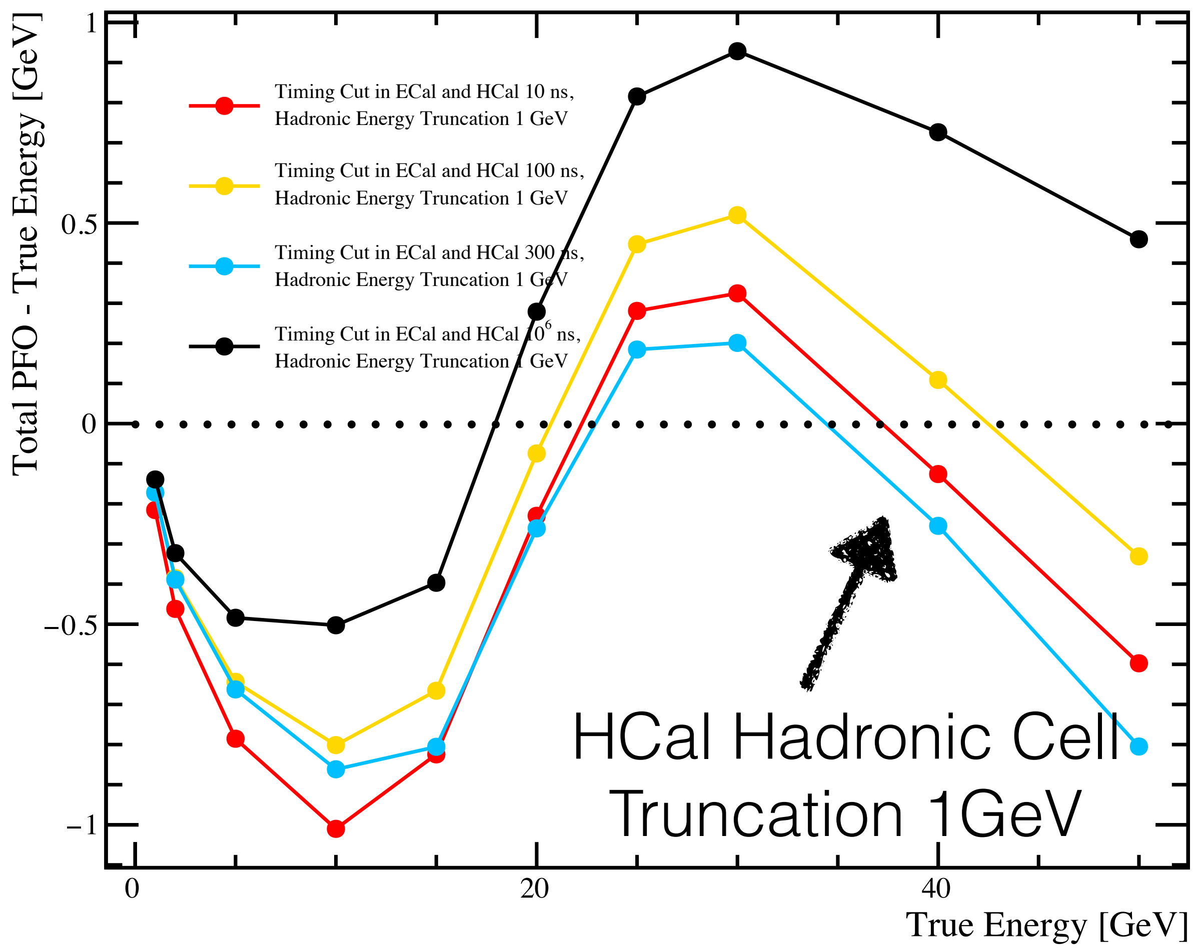
- Histograms of the reconstructed energy for single Kaon0L events of fixed energy.
- Distributions have largely the same shape.
- Calibration fixes the mean of the 20 GeV distributions to be close to 20 GeV.





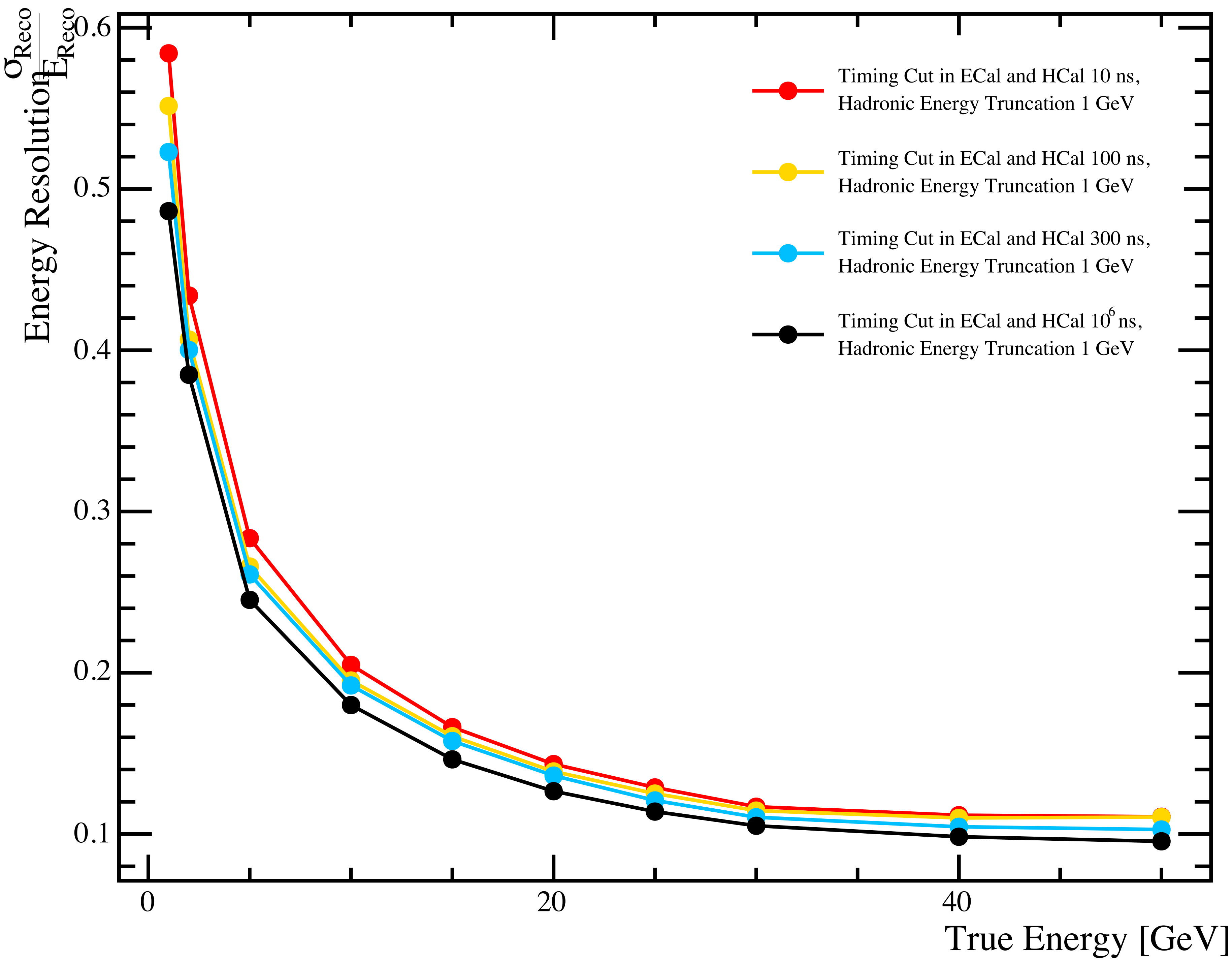
Timing Cuts - Single Particle Mean Energy





- 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



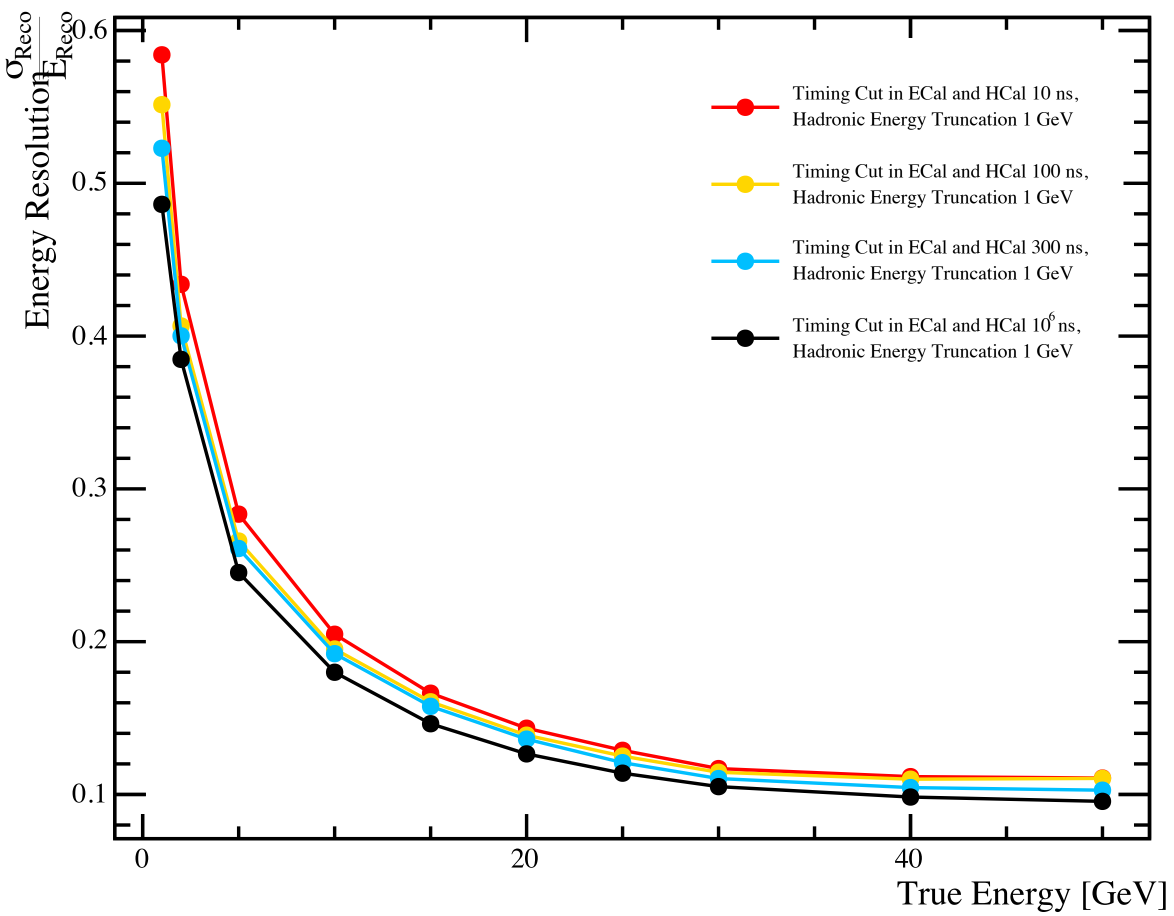
- Plot of energy resolution vs true energy for single Kaon0L events of fixed energy.
- The energy resolution here is defined as:

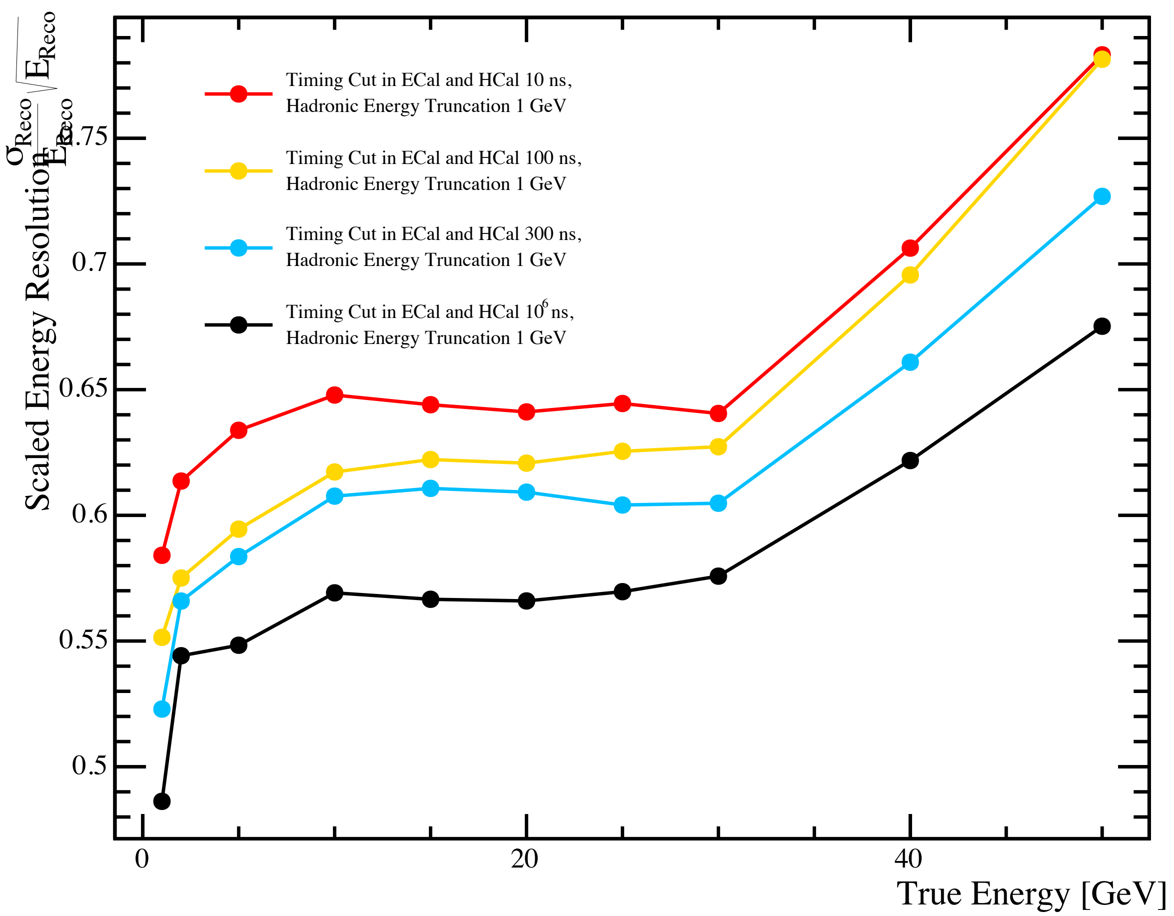
Resolution = σ_E / E

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.

UNIVERSITY OF CAMBRIDGE

Timing Cuts - Jet Reconstructed Energy Distributions

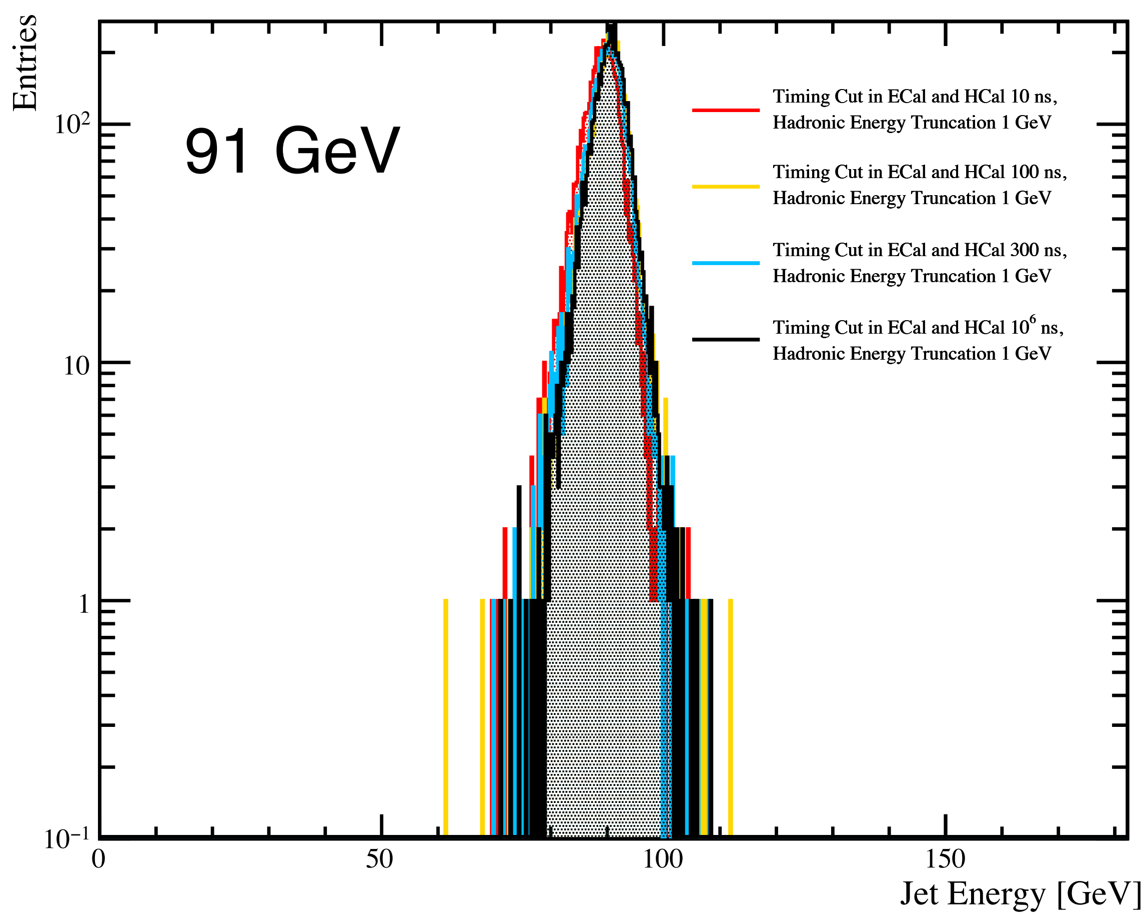
* Histograms of the reconstructed jet energy for Z_uds jet events of fixed energy.
* Distributions look similar when varying the timing cuts.

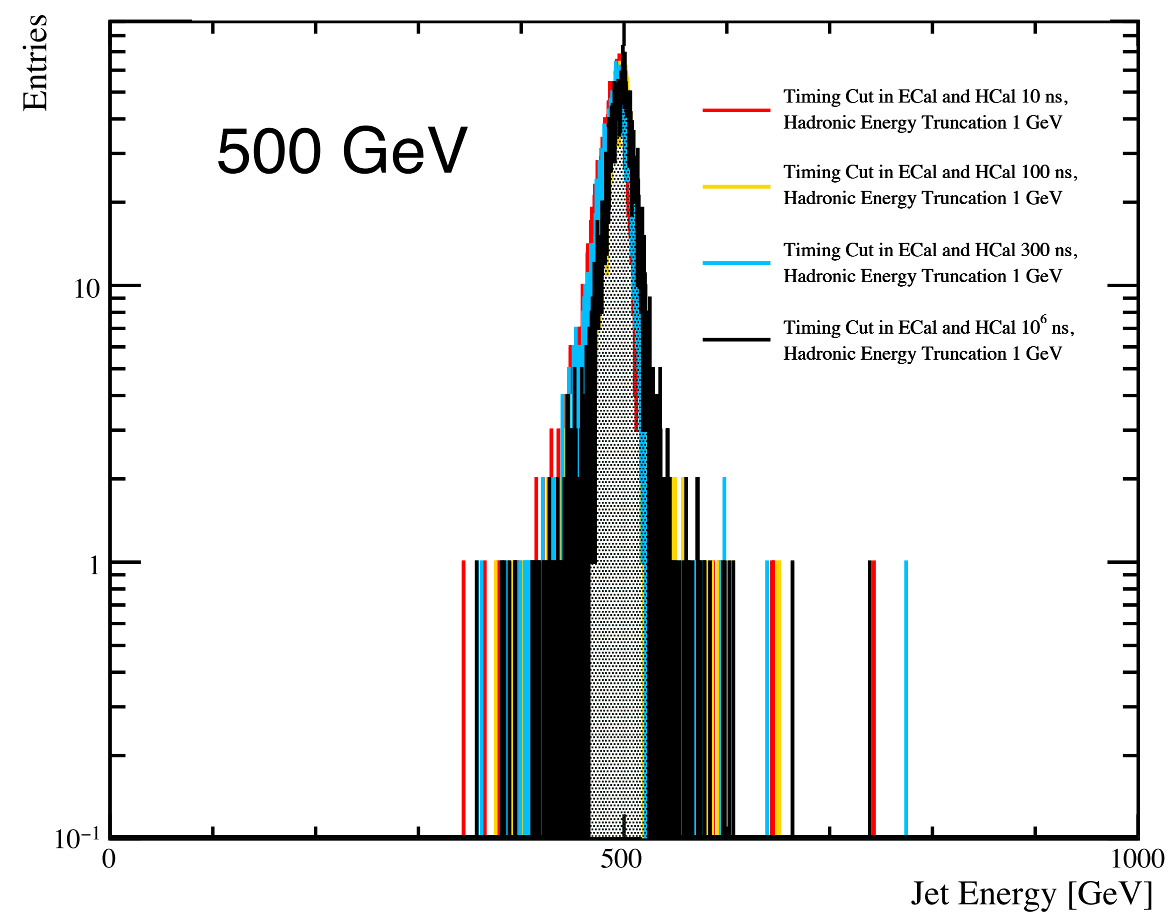
Timing Cut in ECal and HCal 10 ns, Hadronic Energy Truncation 1 GeV

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

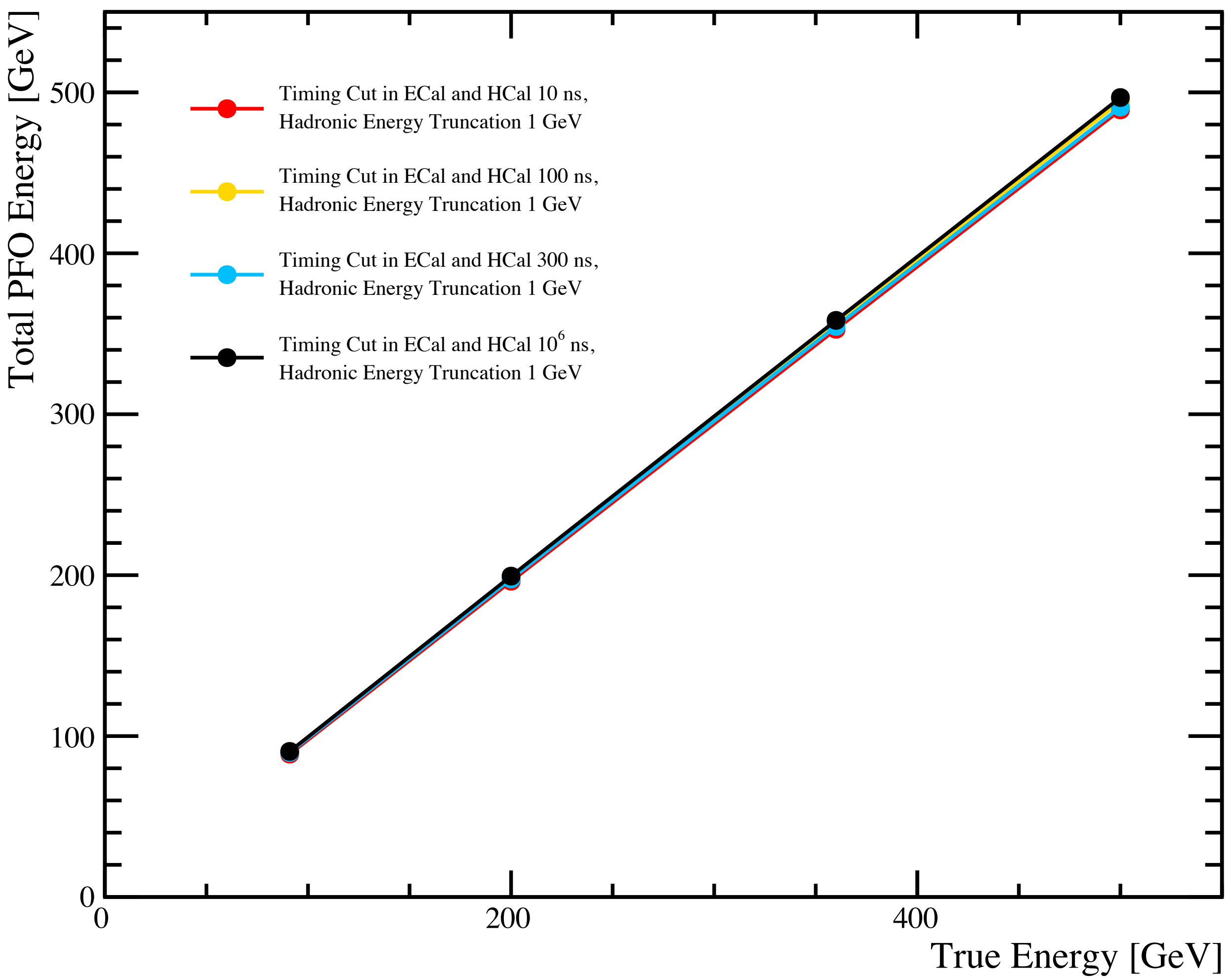
Timing Cut in ECal and HCal 300 ns, Hadronic Energy Truncation 1 GeV

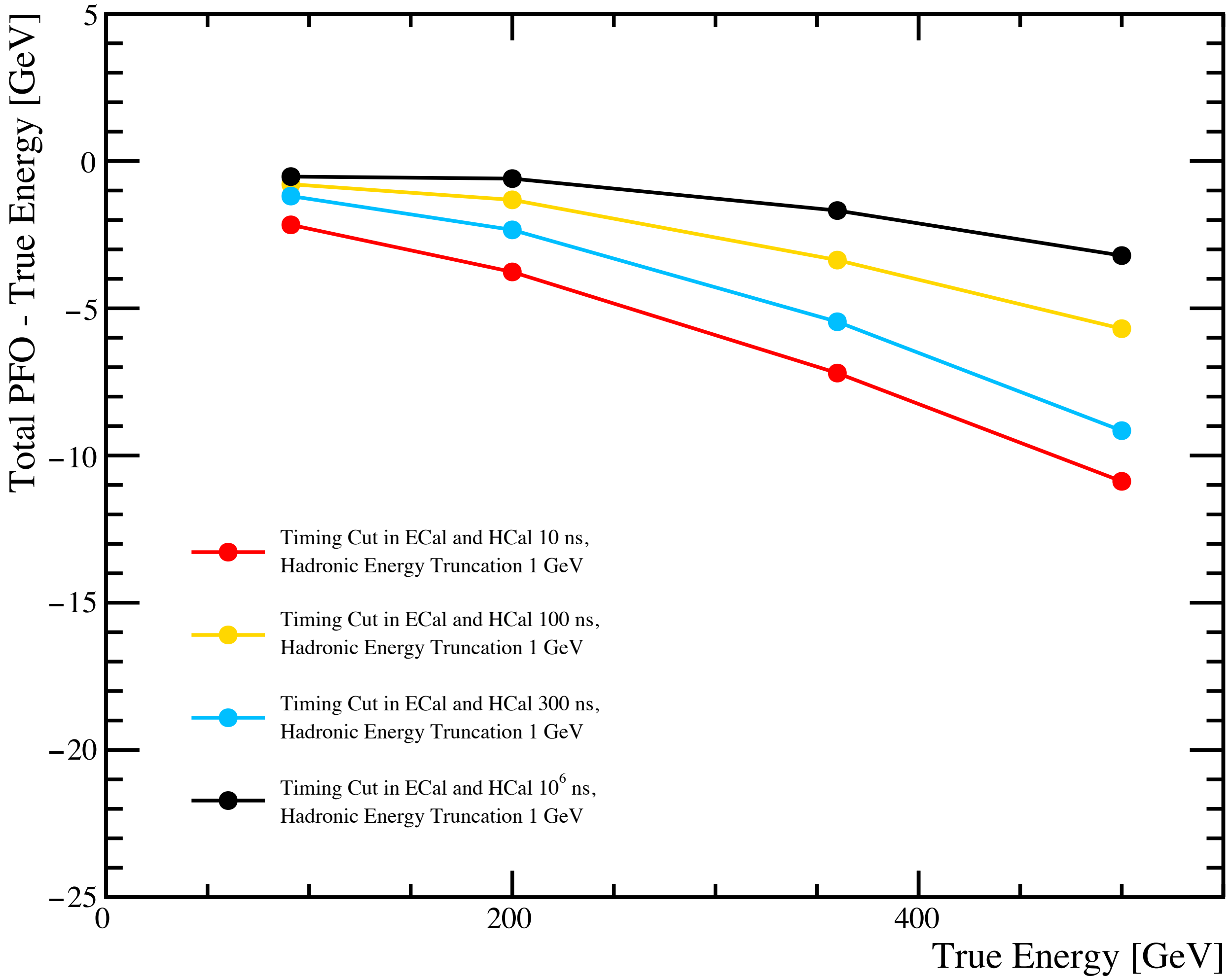
Timing Cut in ECal and HCal 10^6 ns, Hadronic Energy Truncation 1 GeV





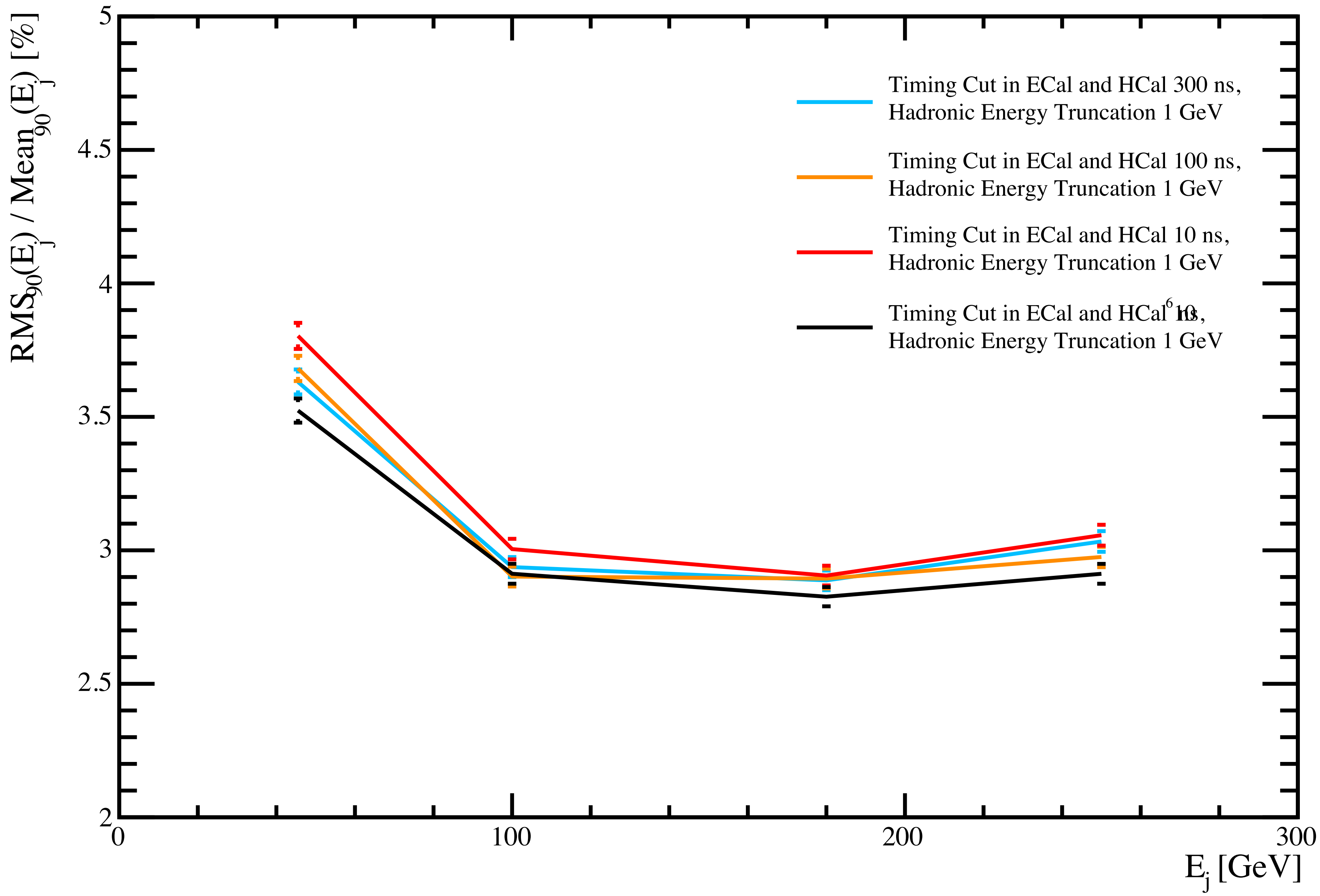
Timing Cuts - Jet Mean Energy





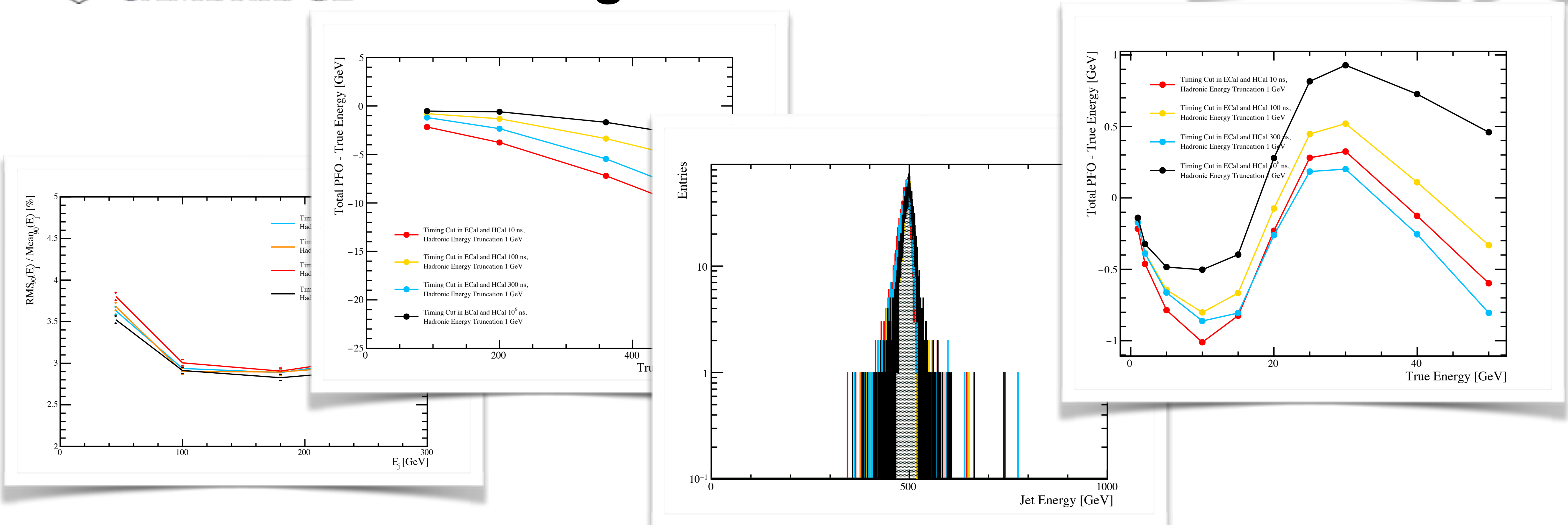
- As expected the mean jet energy decreases with increasing energy due to the HCal cell hadronic energy truncation of 1GeV.
- Also as expected with larger the timing cuts you record more energy.

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

For the following studies a 100 ns timing cut was applied.

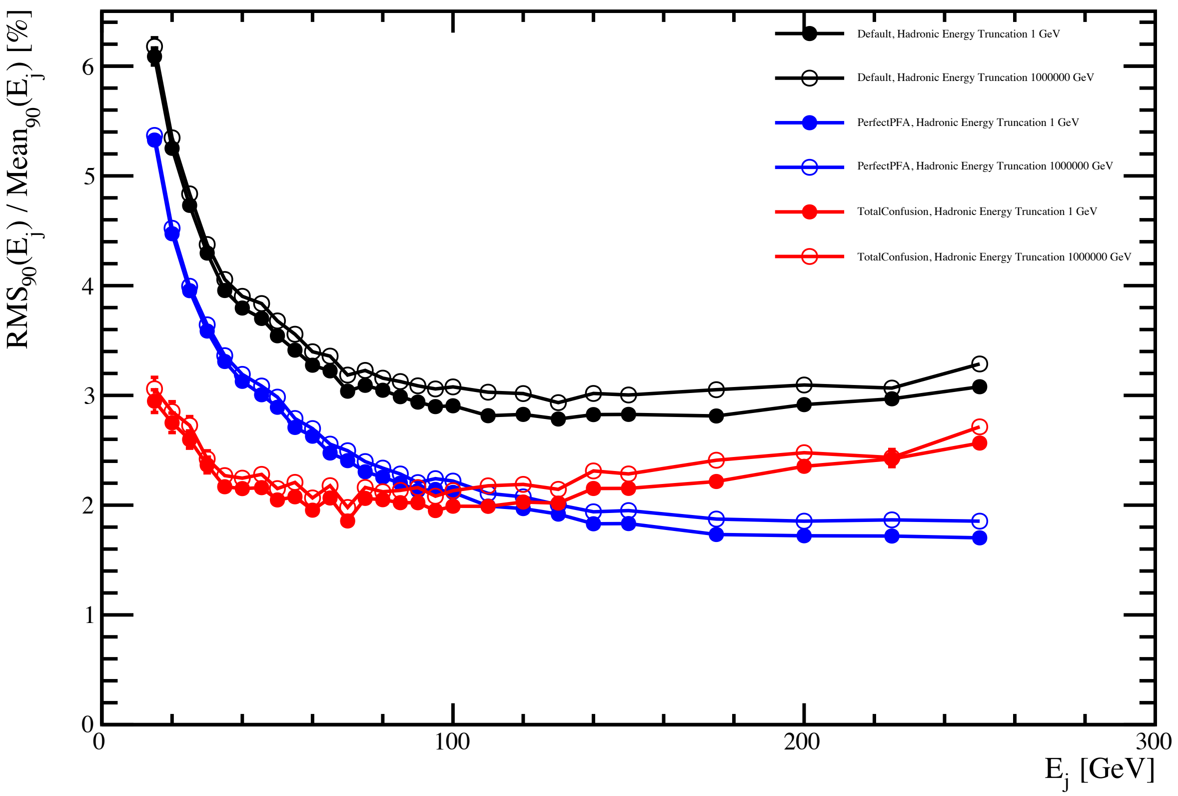
HCal Hadronic Energy Truncation

UNIVERSITY OF CAMBRIDGE

- 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:

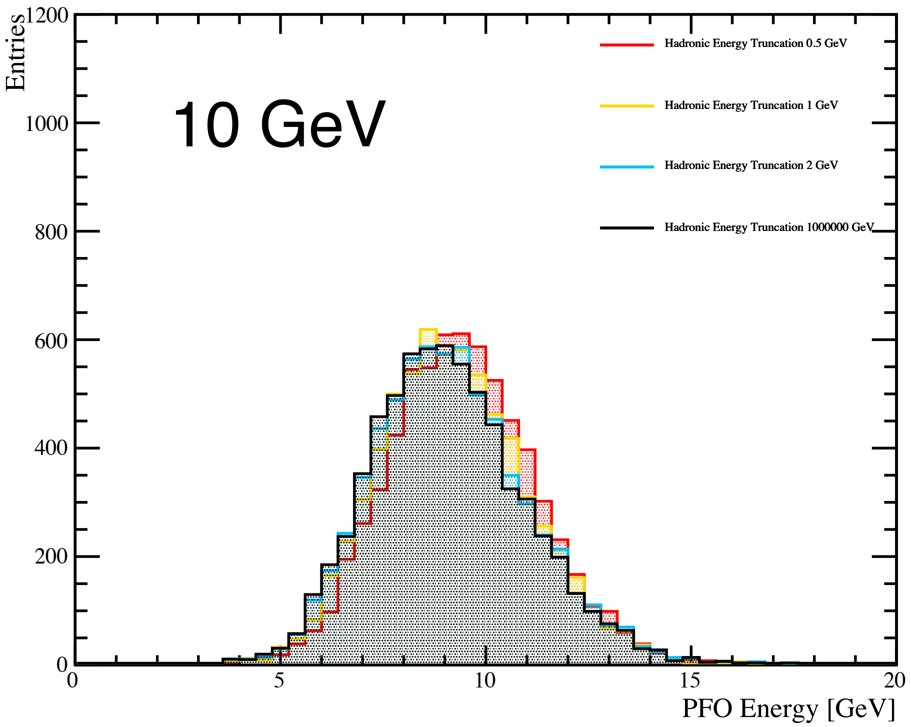
- Here we will look at:
  1. Raw reconstructed energy distributions;
  2. Mean reconstructed energy;
  3. Energy resolution.

Jet Energy Analysis:

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

HCal Hadronic Energy Truncation - Single Particle Energy Distributions

UNIVERSITY OF CAMBRIDGE

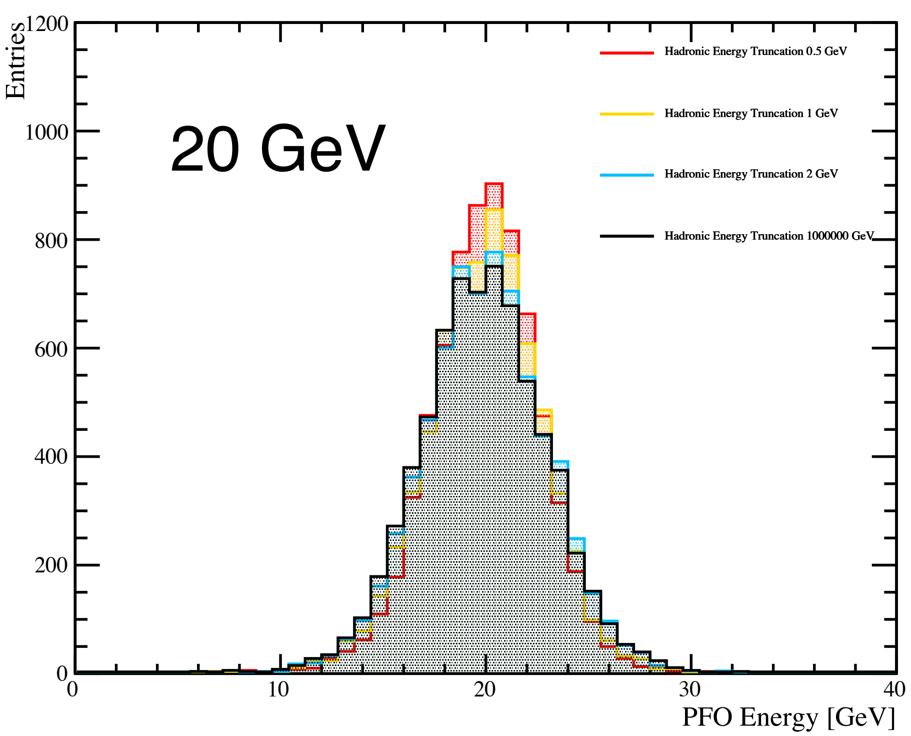


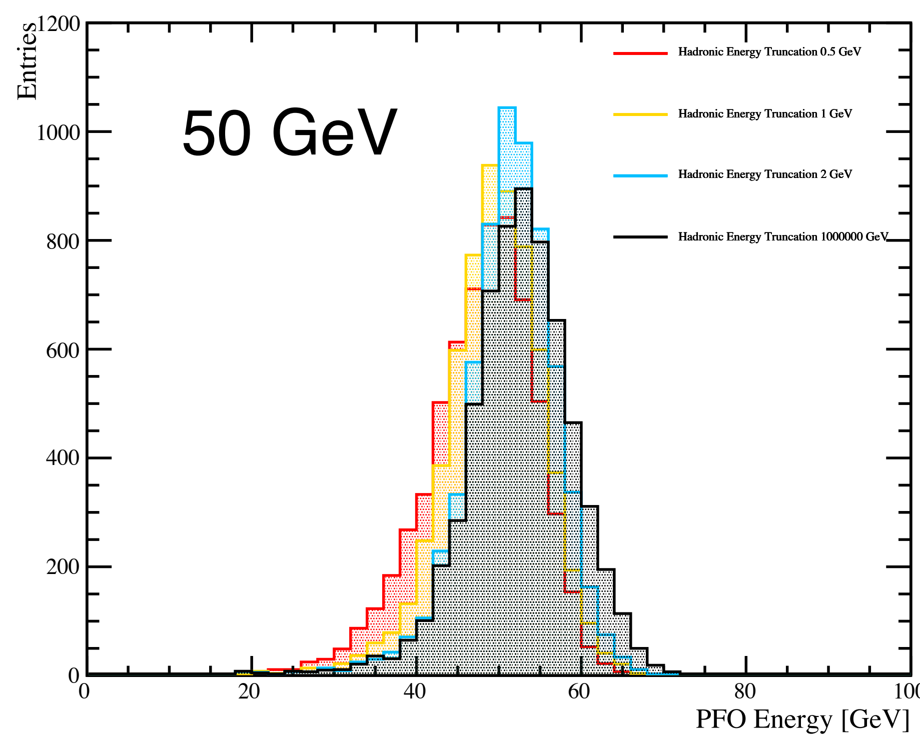
Hadronic Energy Truncations 0.5 GeV

Hadronic Energy Truncations 1 GeV

Hadronic Energy Truncations 2 GeV

Hadronic Energy Truncations 10^6 GeV



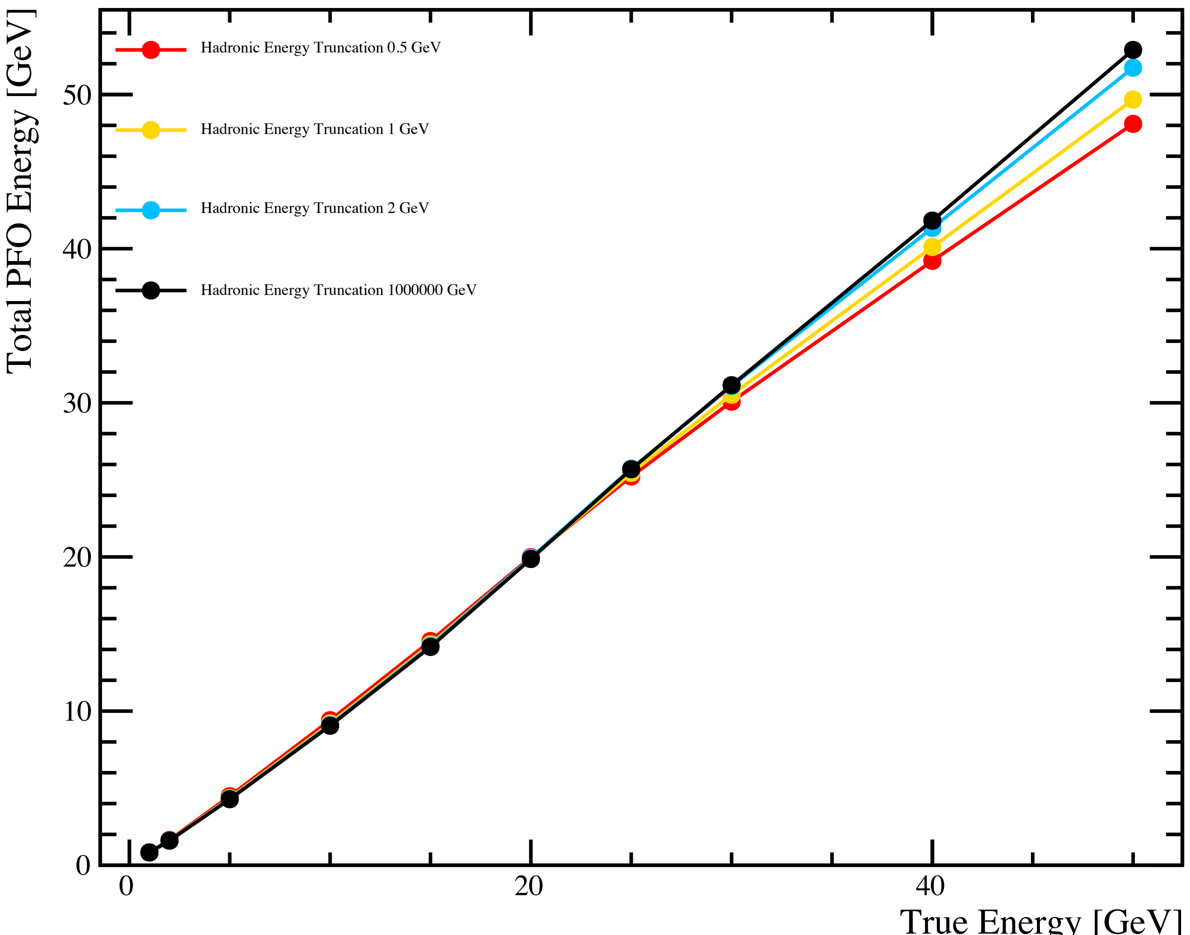


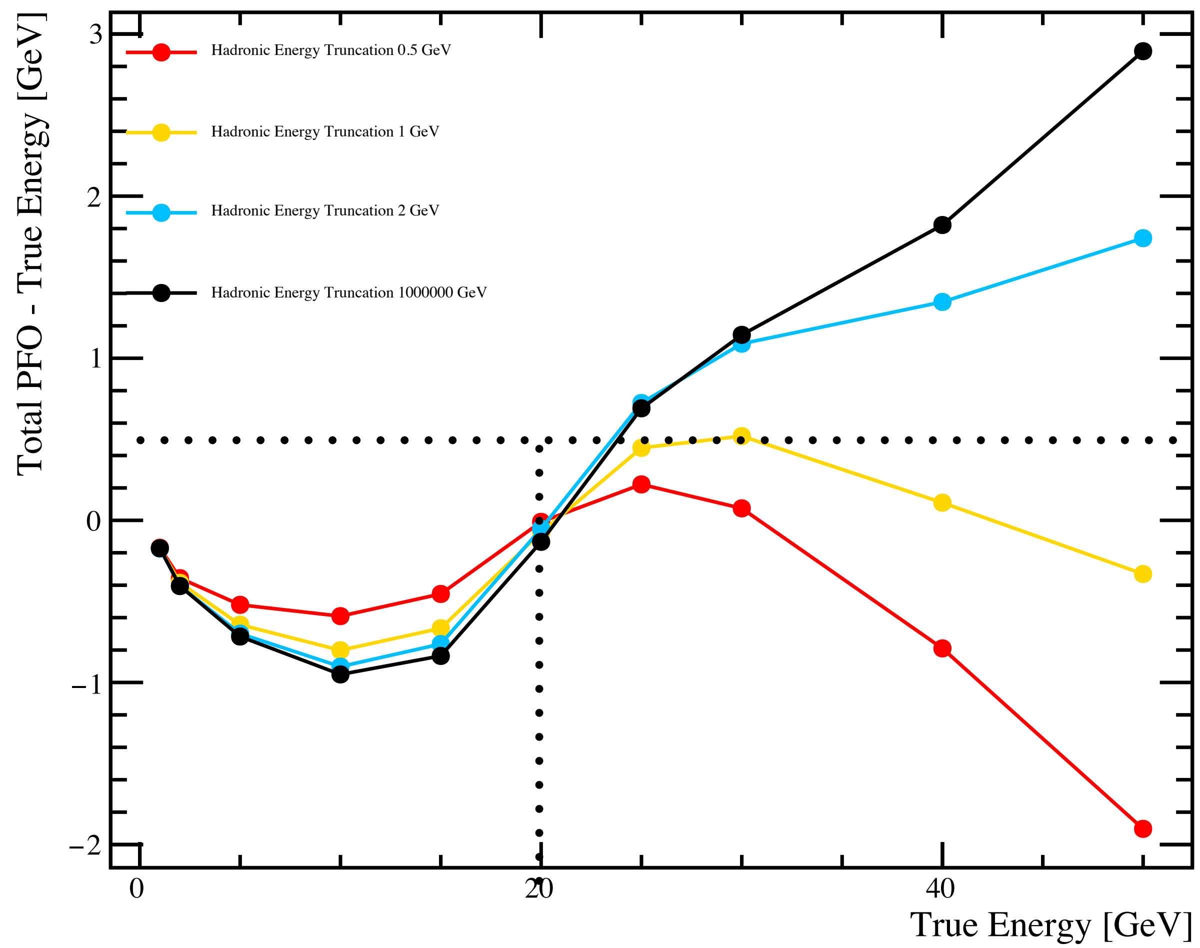
- Histograms of the reconstructed energy for single Kaon0L events of fixed energy.

.

- 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.

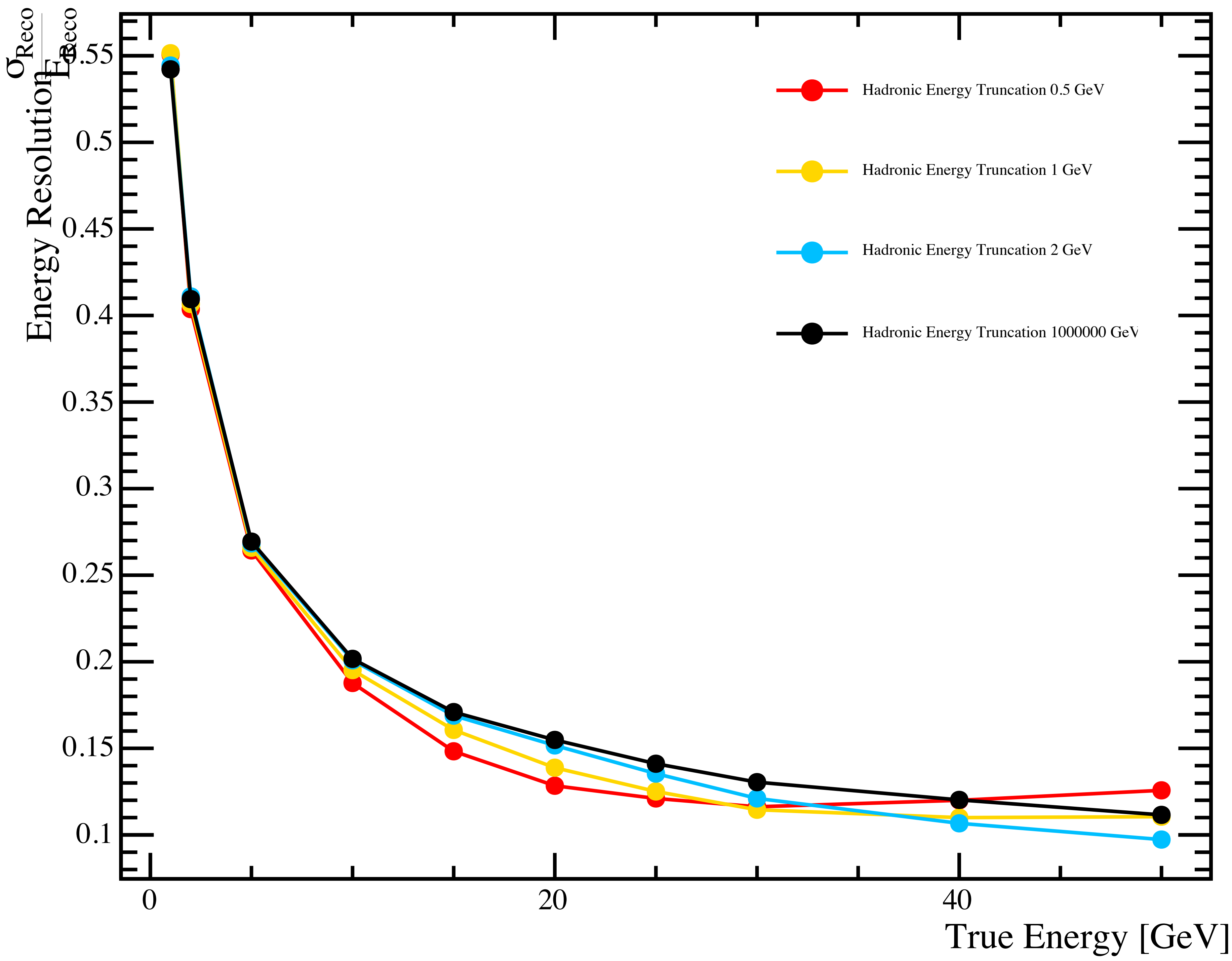
HCal Hadronic Energy Truncation - Single Particle Mean Energy





- 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



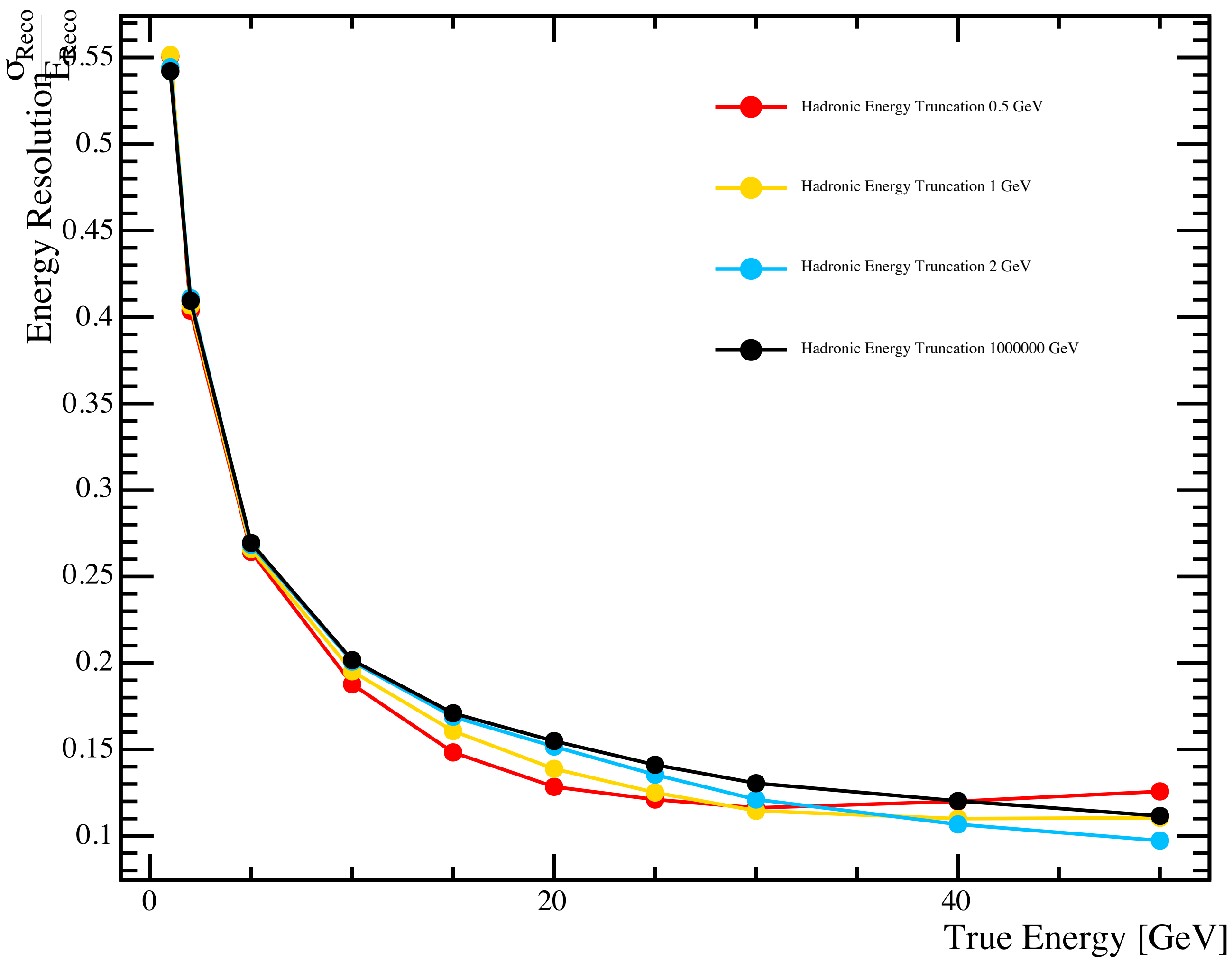
- Plot of energy resolution vs true energy for single Kaon0L events of fixed energy.
- The energy resolution here is defined as:

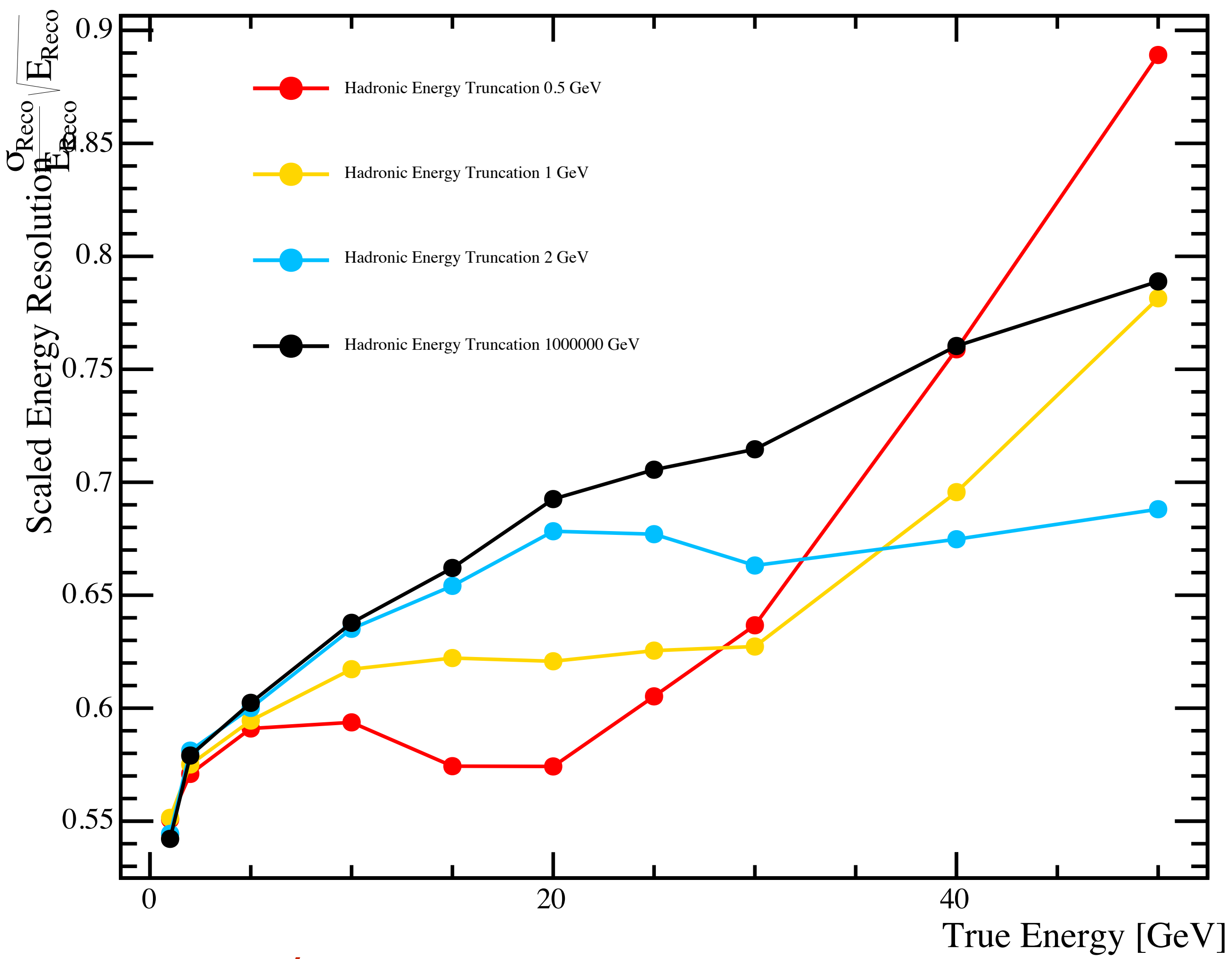
$$\text{Resolution} = \sigma_E / E$$

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

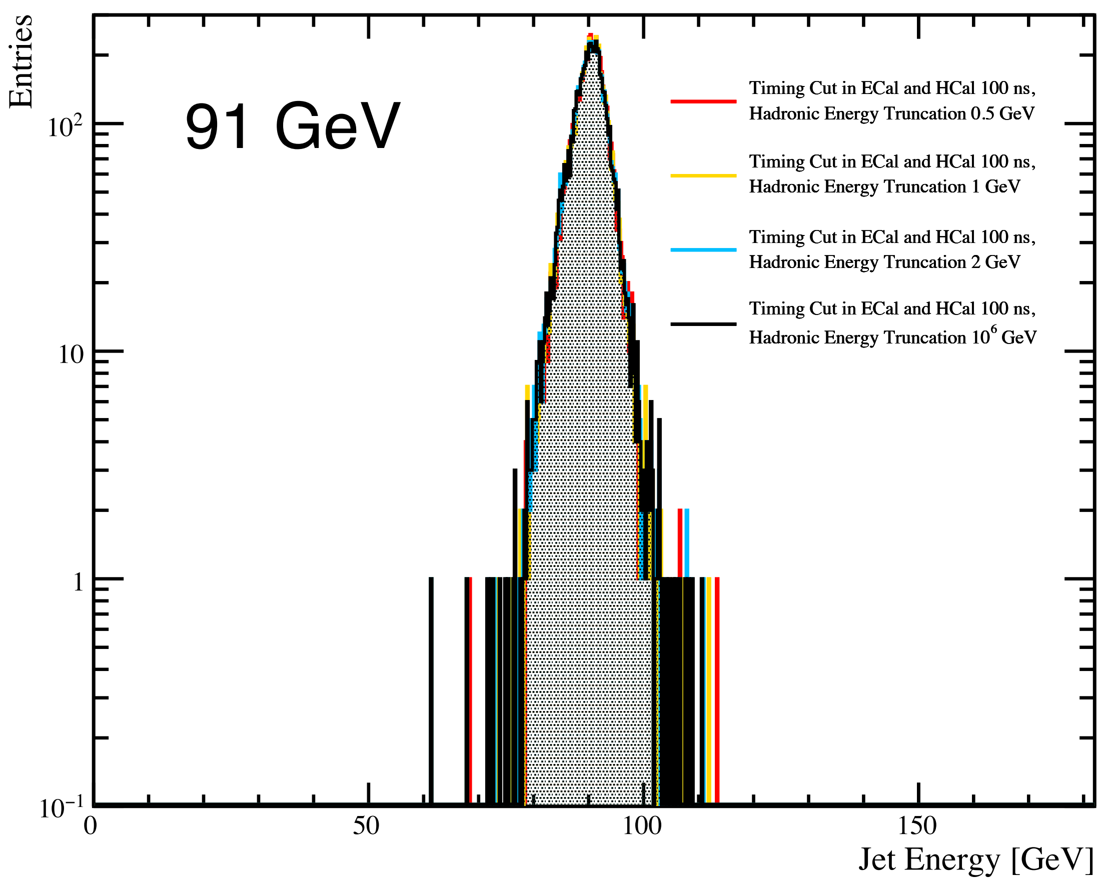
- Histograms of the reconstructed jet energy for Z_uds jet events of fixed energy.
- Distributions look similar at low jet energy where the truncation doesn't impact many cells, but at high energy a clear impact is observed. varying the timing cuts.

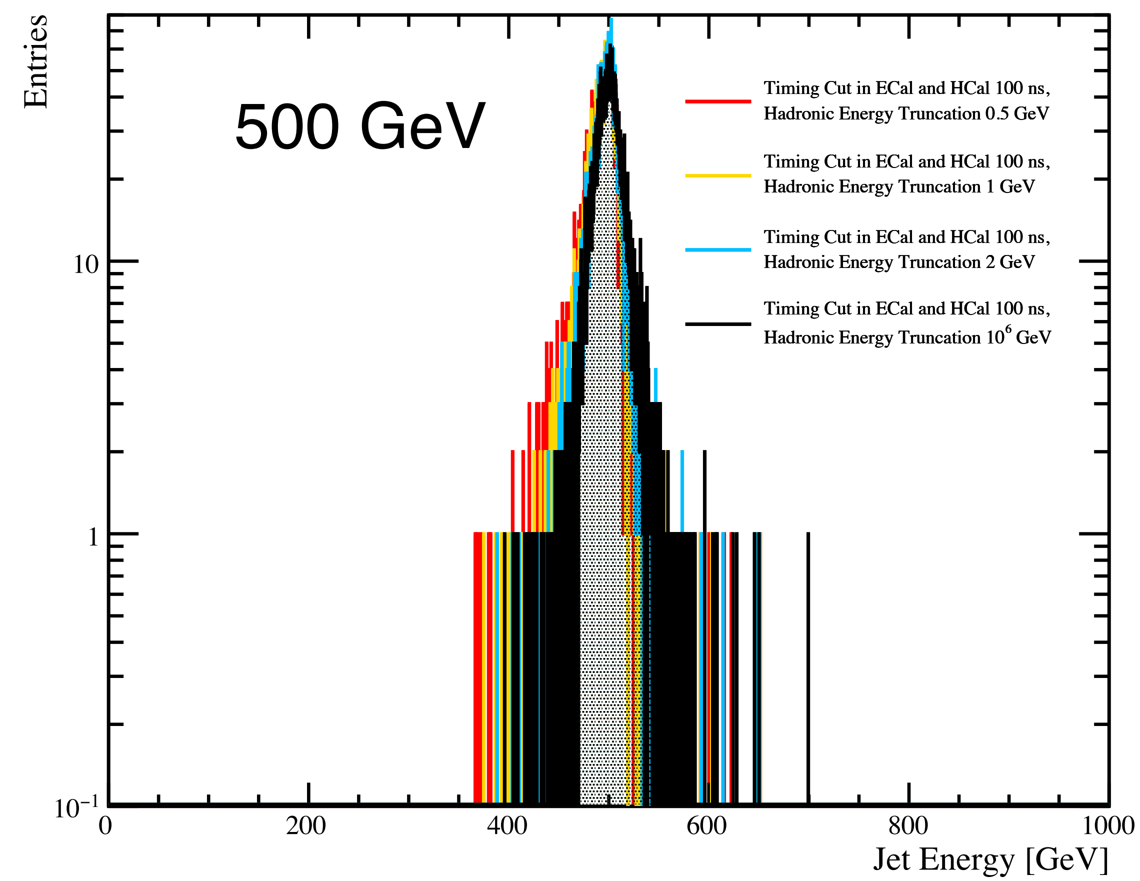
Hadronic Energy Truncations 0.5 GeV

Hadronic Energy Truncations 1 GeV

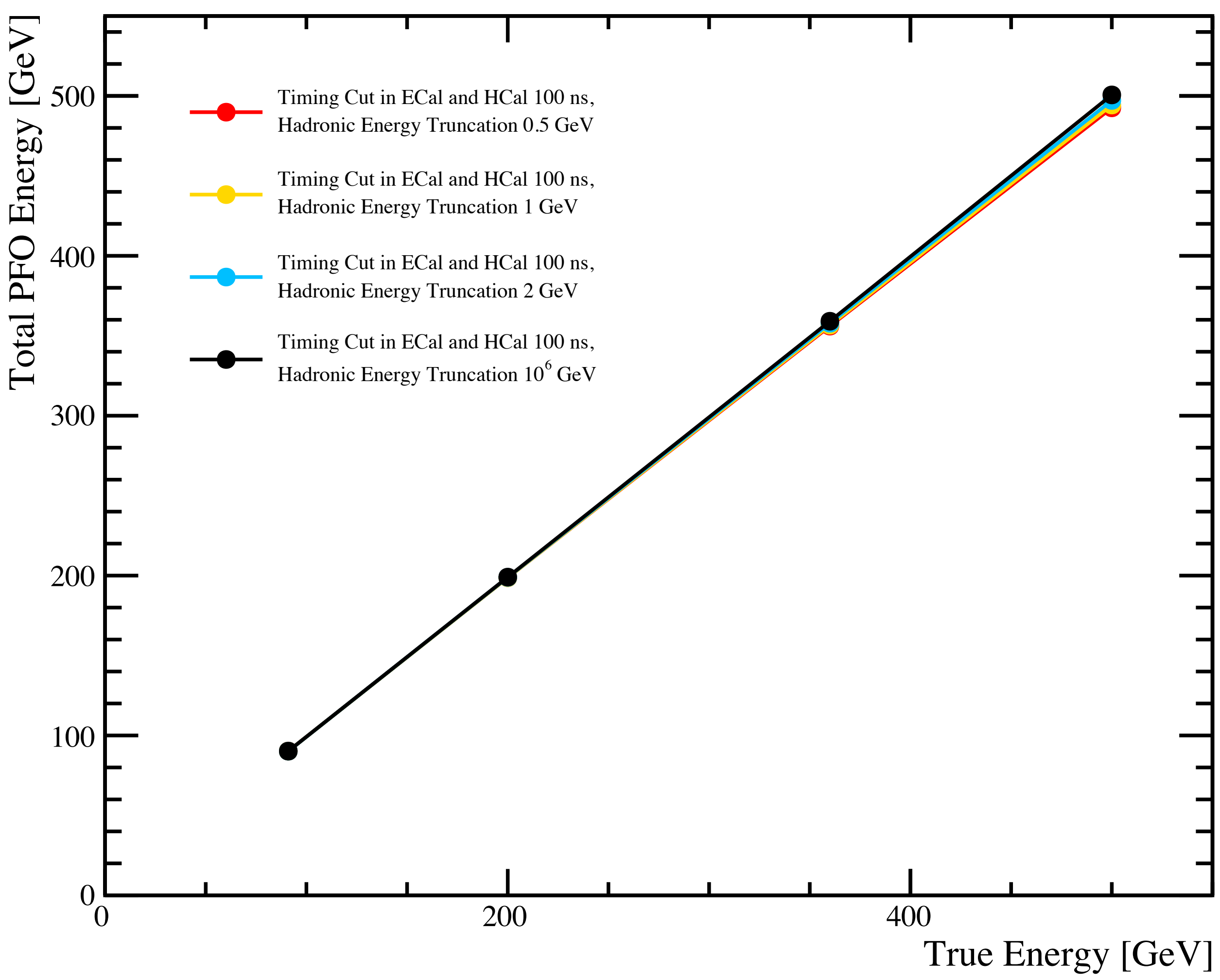
Hadronic Energy Truncations 2 GeV

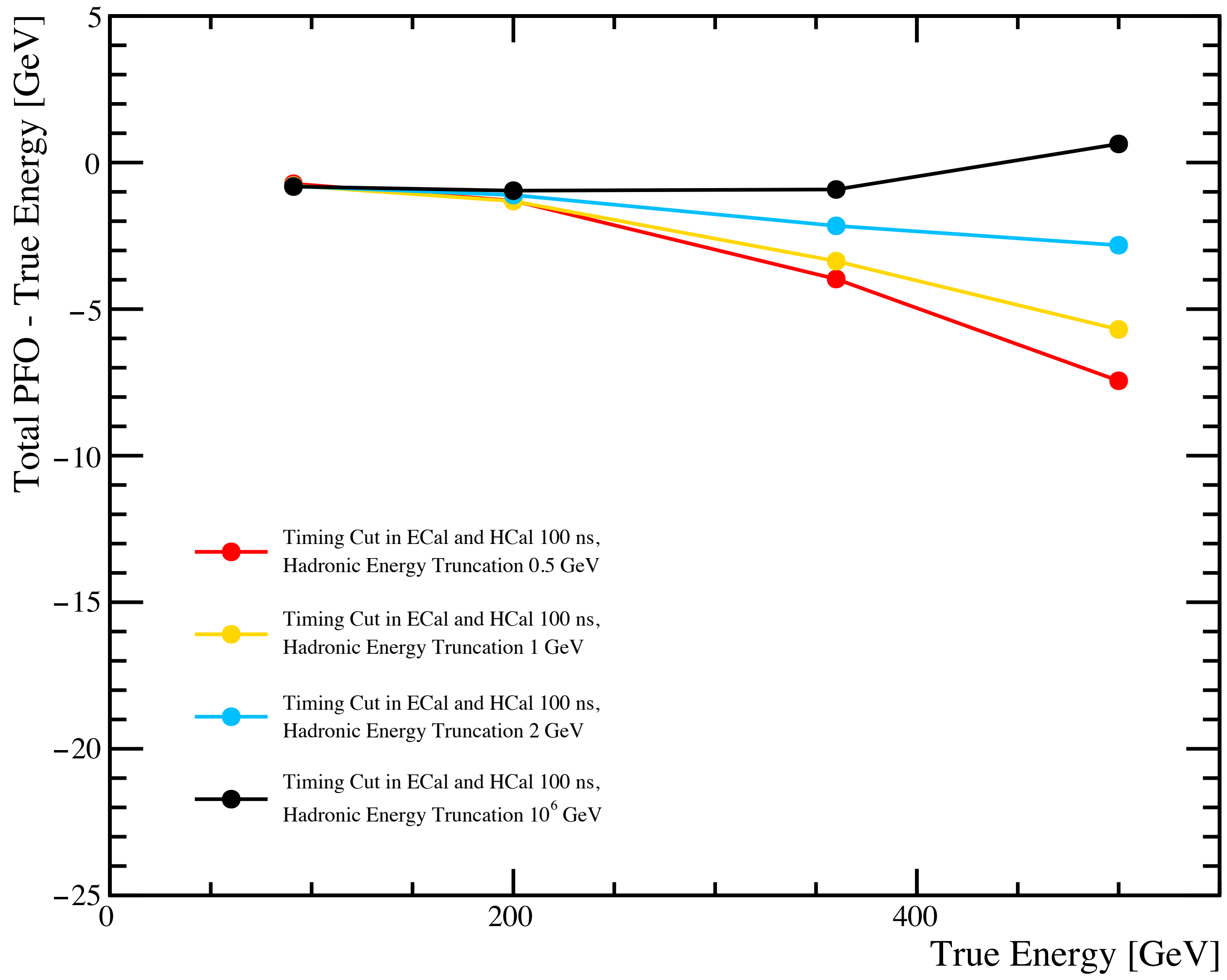
Hadronic Energy Truncations 10^6 GeV





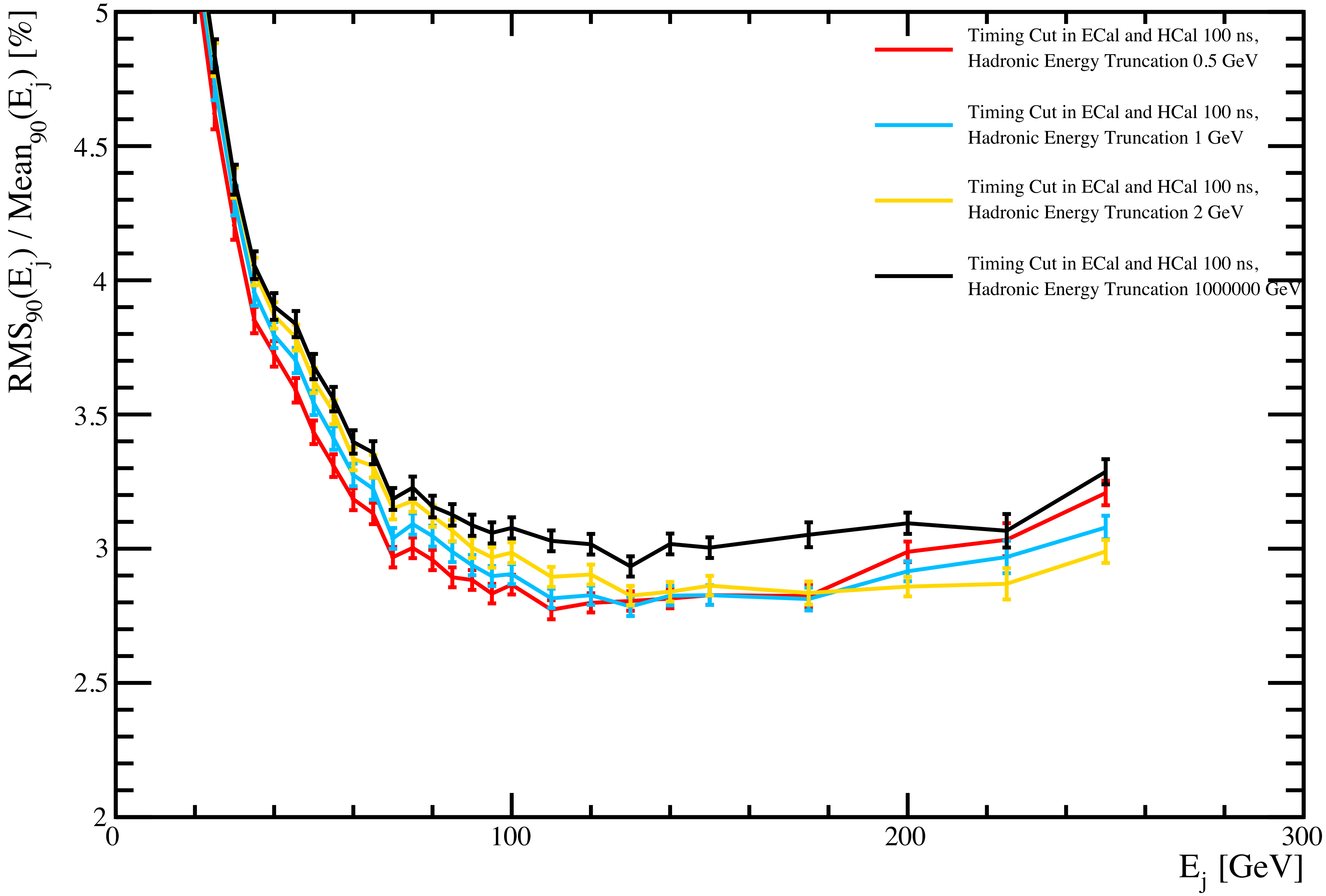
HCal Hadronic Energy Truncation - Jet Mean Energy





* 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.

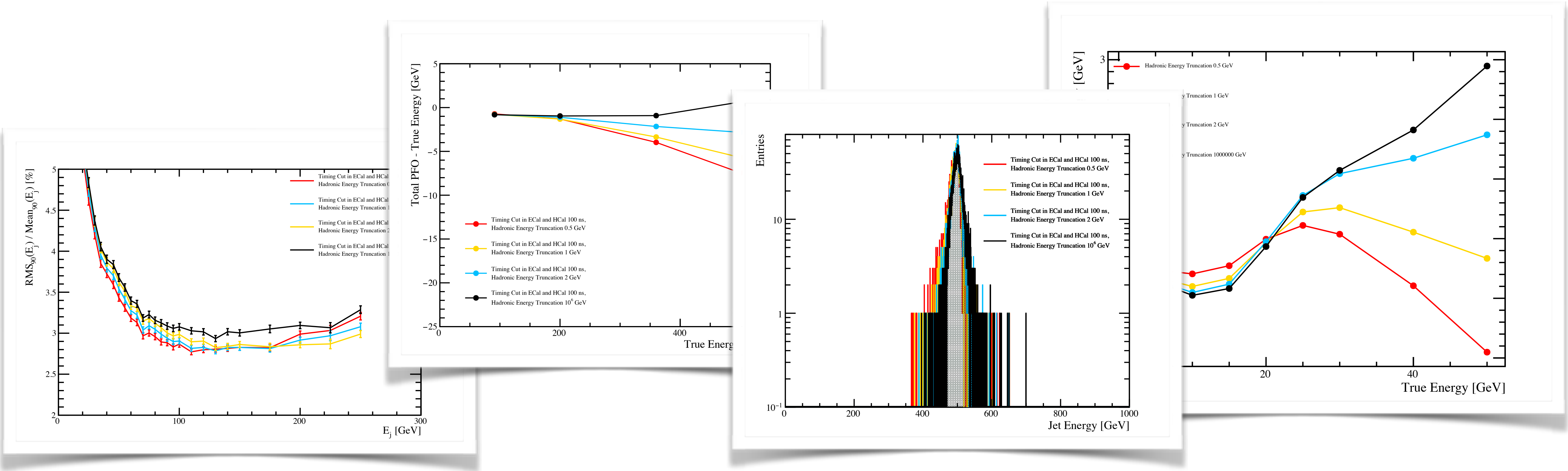
HCal Hadronic Energy Truncation - Jet Energy Resolutions



- 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.

UNIVERSITY OF CAMBRIDGE

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.