Jet Energy Resolution - Evolution Study

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Overview

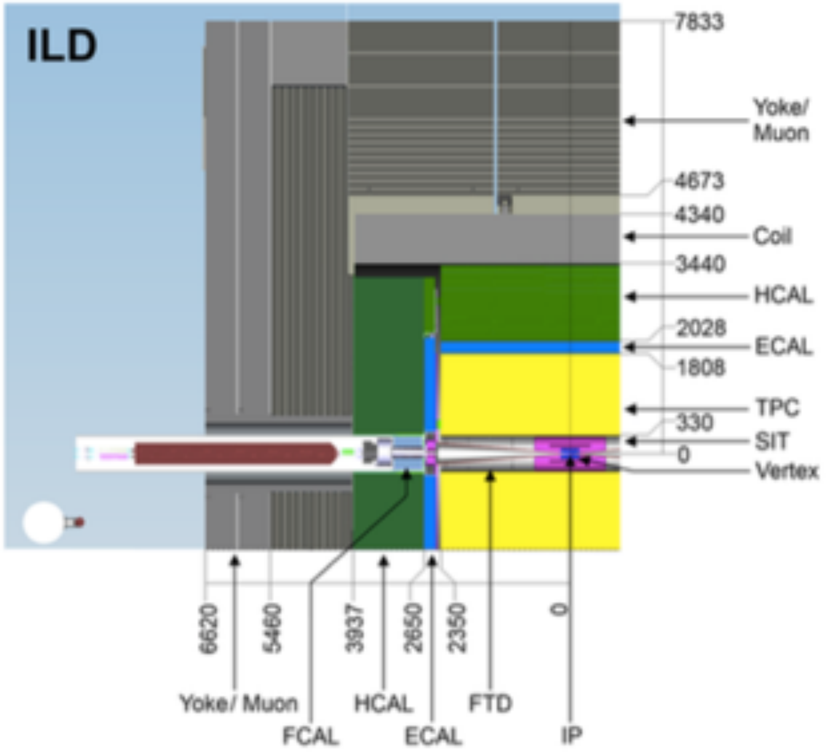
- The primary aim of these studies is to show evolution of the detector performance, using the jet energy resolution metric, from the DBD/CDR/LoI up to the present day best estimates.

- This incorporates several different changes:
  1. Updated reconstruction software (inc. PandoraPFA).
  2. New calibration procedure.
  3. New digitiser, ILDCaloDigi vs NewLDCCaloDigi
  4. Realistic ECal and HCal simulations at the digitisation stage.
  5. Optimisation of jet energy resolution based on hadronic energy truncation in the HCal.

Jet Energy Resolution Evolution Studies

ILD Default Detector Model

* These studies are based around the default ILD detector model at the time of the DBD.
* The key parameters regarding to the calorimeter optimisation studies are:

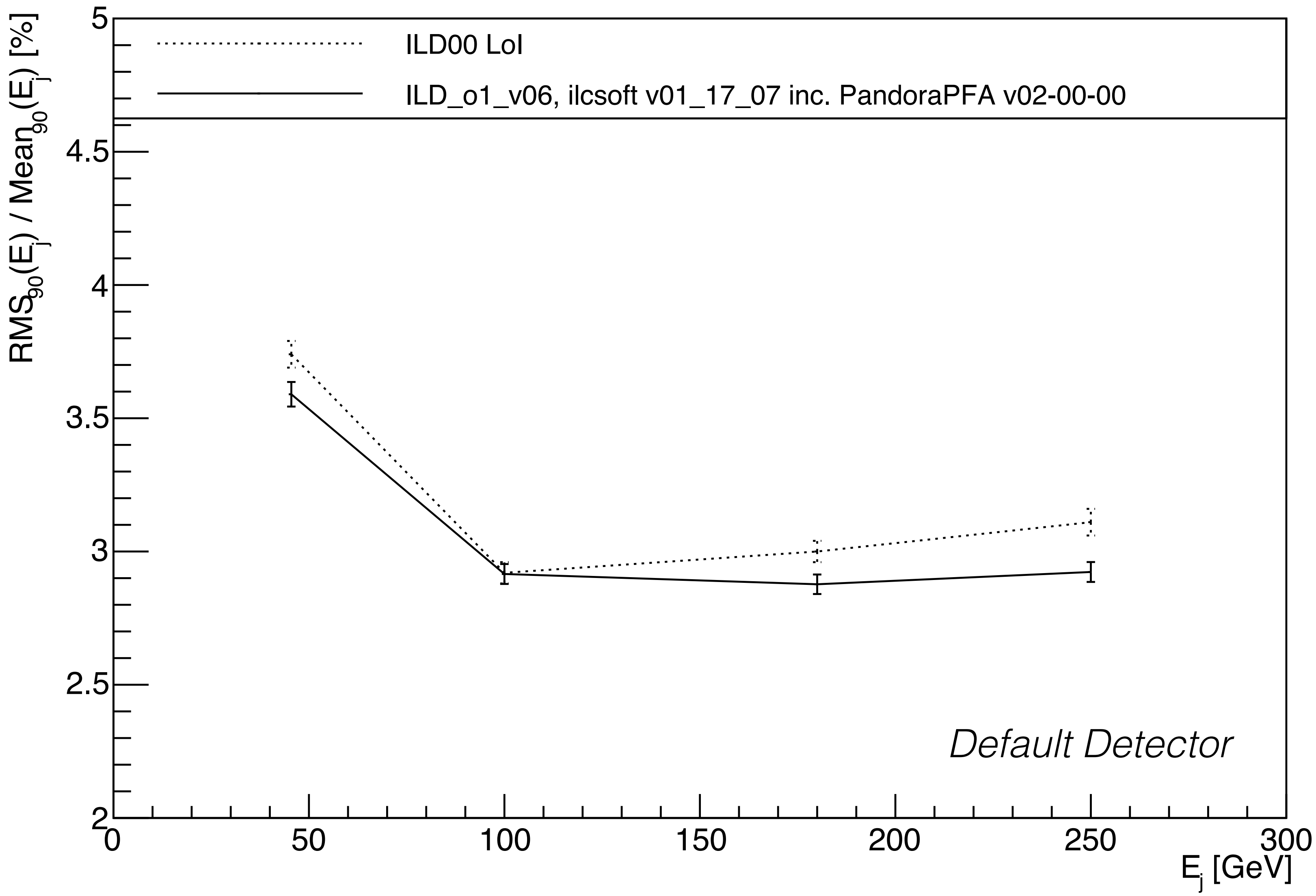


	Absorber Material	Active Material	Number of Layers	Cell Size	Comments
ECal	Tungsten	Silicon Sensor	30	5x5 mm^2	-
HCal	Iron	Scintillator	48	30x30 mm^2	Analogue Readout

Default Detector - Referenced in future slides

LoI vs PandoraPFANew v02-00-00

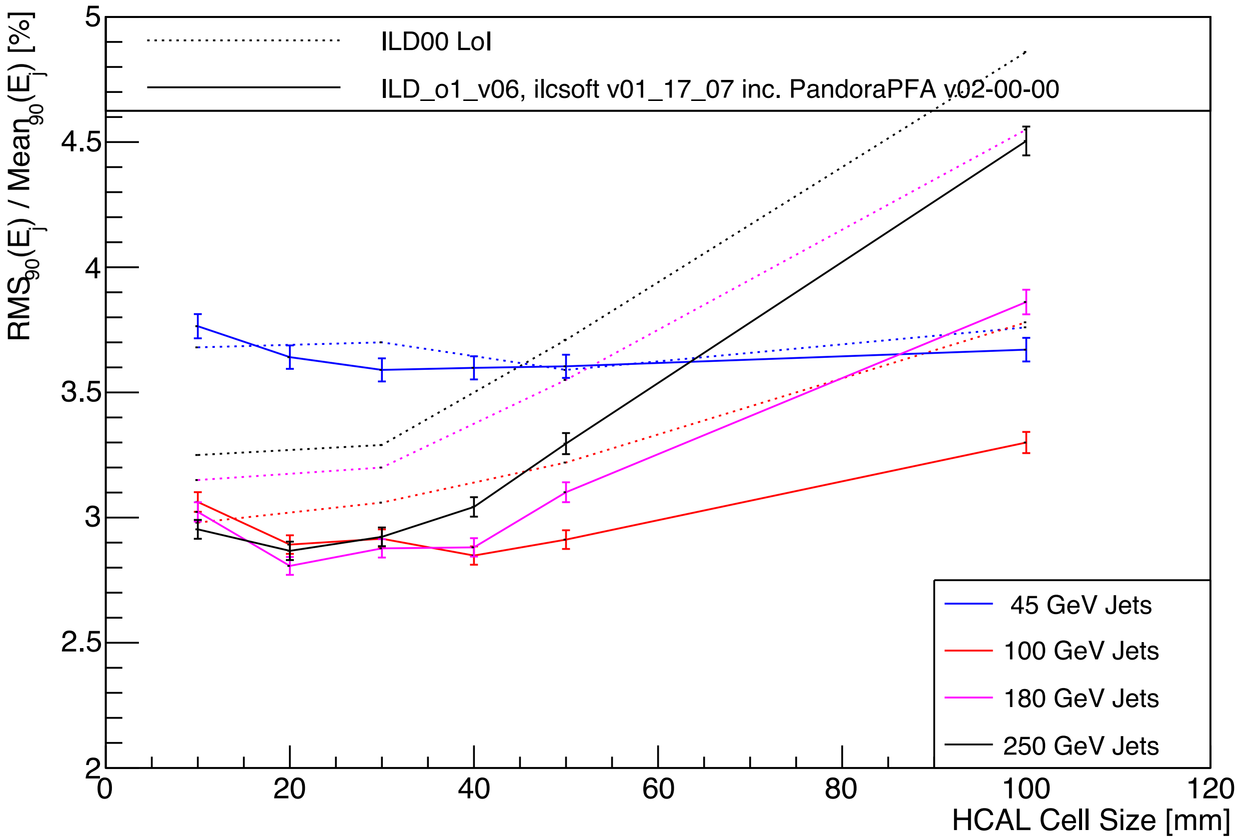
- Examine the change in detector performance when:
  - Updating the detector model from the time of the LoI to that used for the DBD (ILD_o1_v06).
  - Updating reconstruction software from that at the time of the LoI to version ilcsoft v01-17-07 including Pandora v02-00-00.

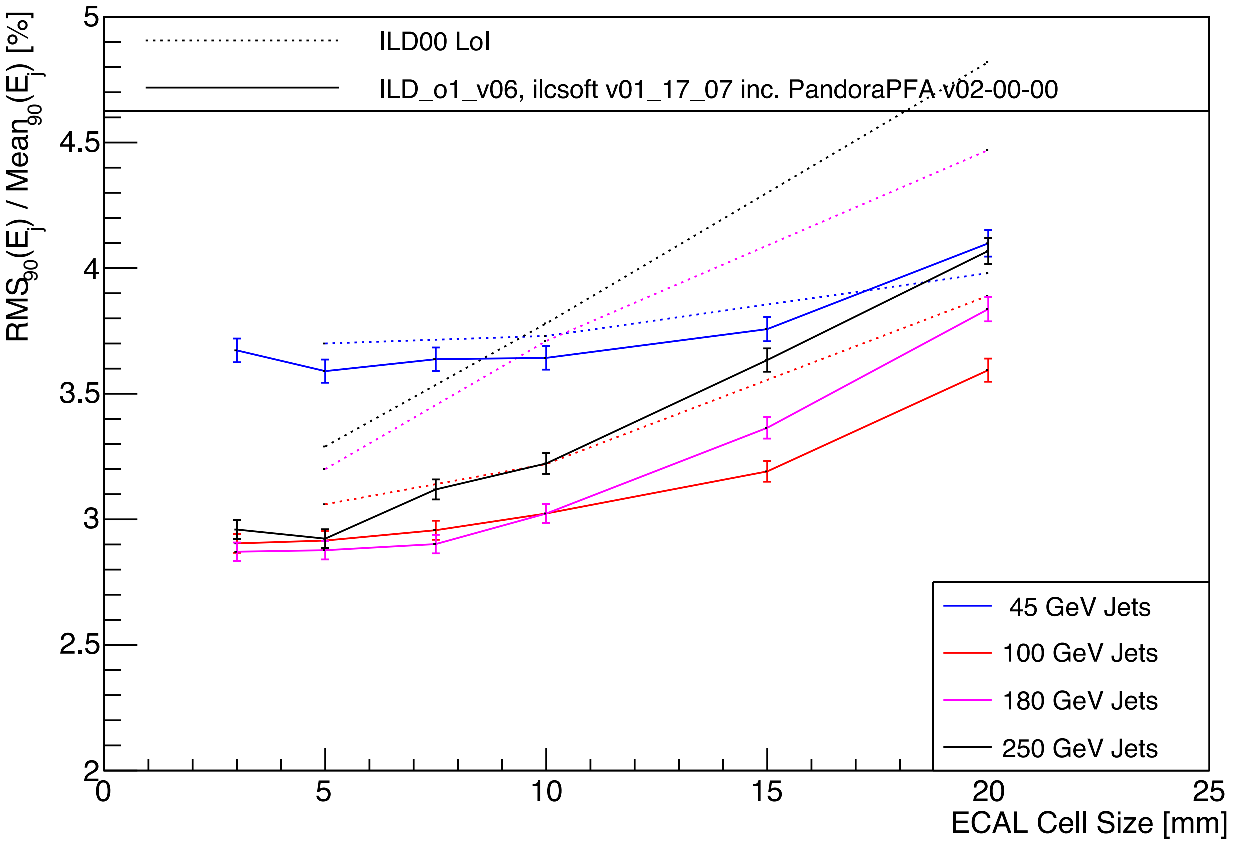


- All input variables to the simulation and reconstruction are unchanged (same calibration and same energy truncation in HCal etc).
- Improvements seen across the energy range considered for the default detector.

LoI vs PandoraPFANew v02-00-00

Look at the non default detector models…

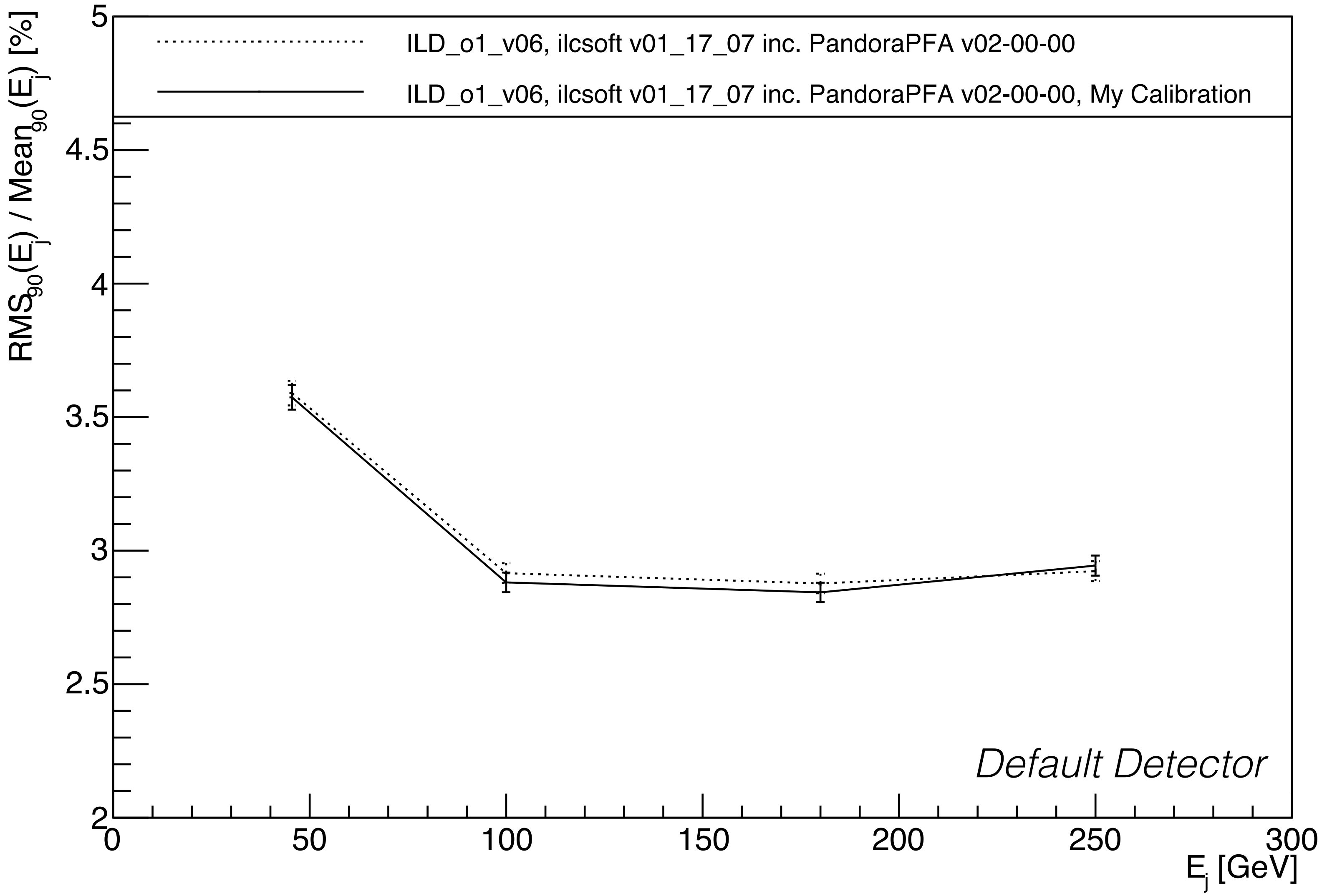




- Improvements also seen when we vary the ECal and HCal cell sizes, otherwise (ILD_o1_v06).
- Changes to the detector model and reconstruction software since the time of the LoI have improved the detector performance.
- We should be using the latest software in future simulations.

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.
- New calibration procedure is documented in the PandoraAnalysis toolkit (pdf generated when building, found in doc folder).

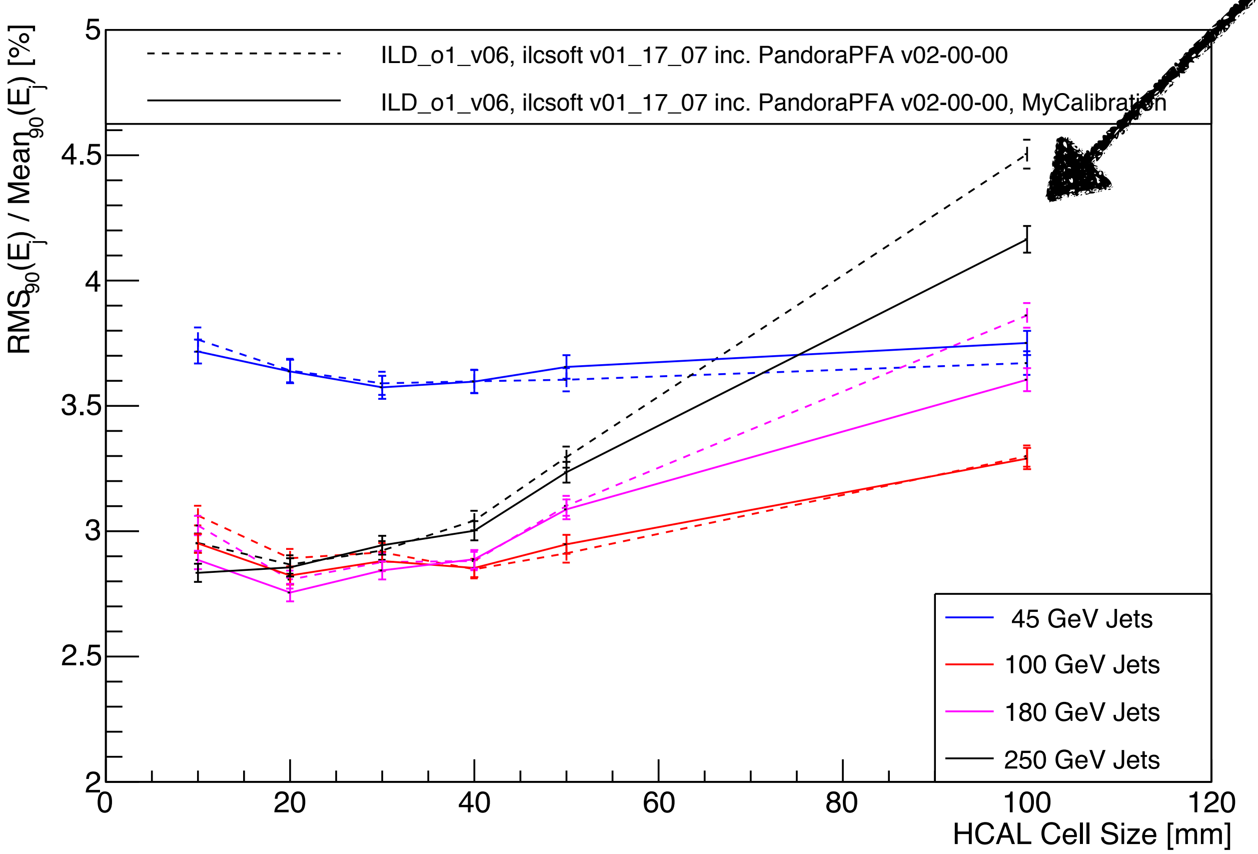


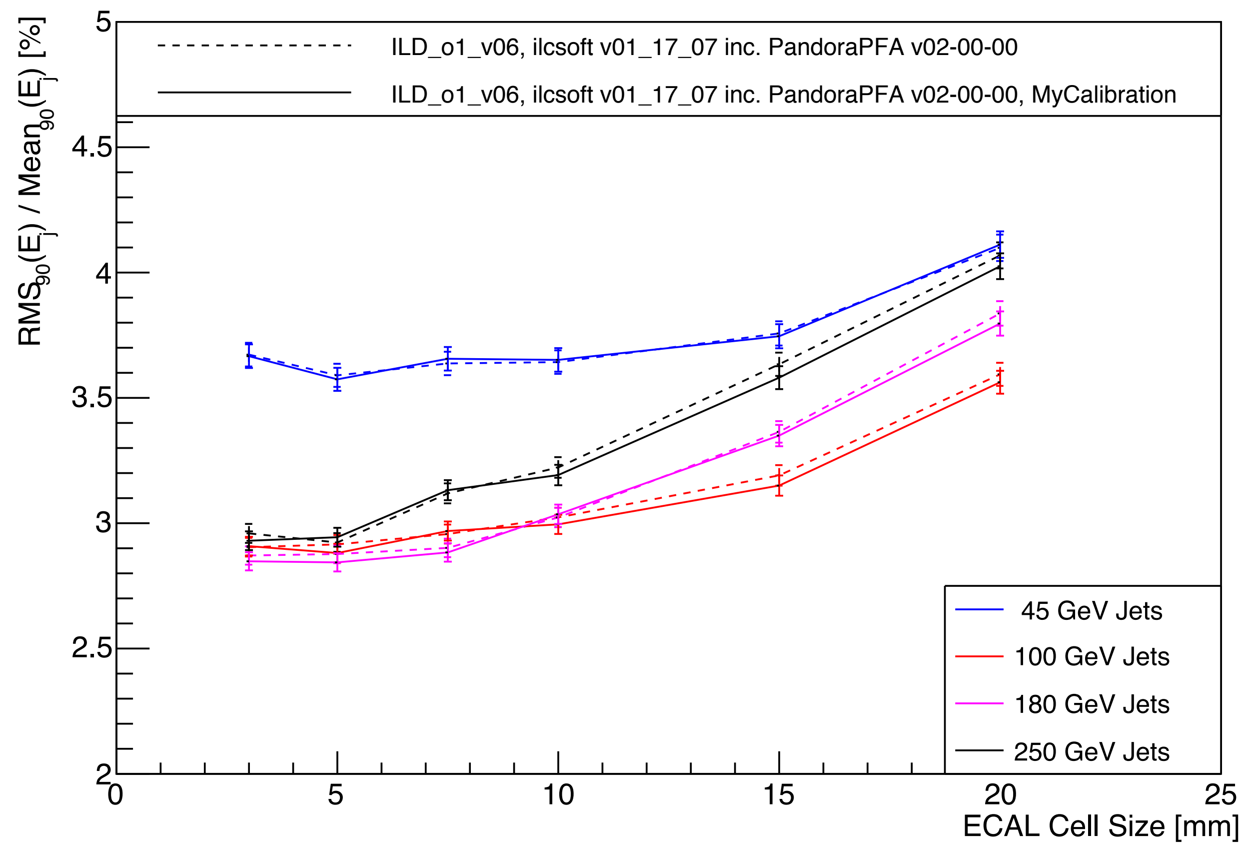
- Within Pandora the hadronic energy in the HCal cells (post digitisation, active + absorber layer) energy is truncated at 1 GeV.
- No difference in performance.

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 the HCal 1 GeV.

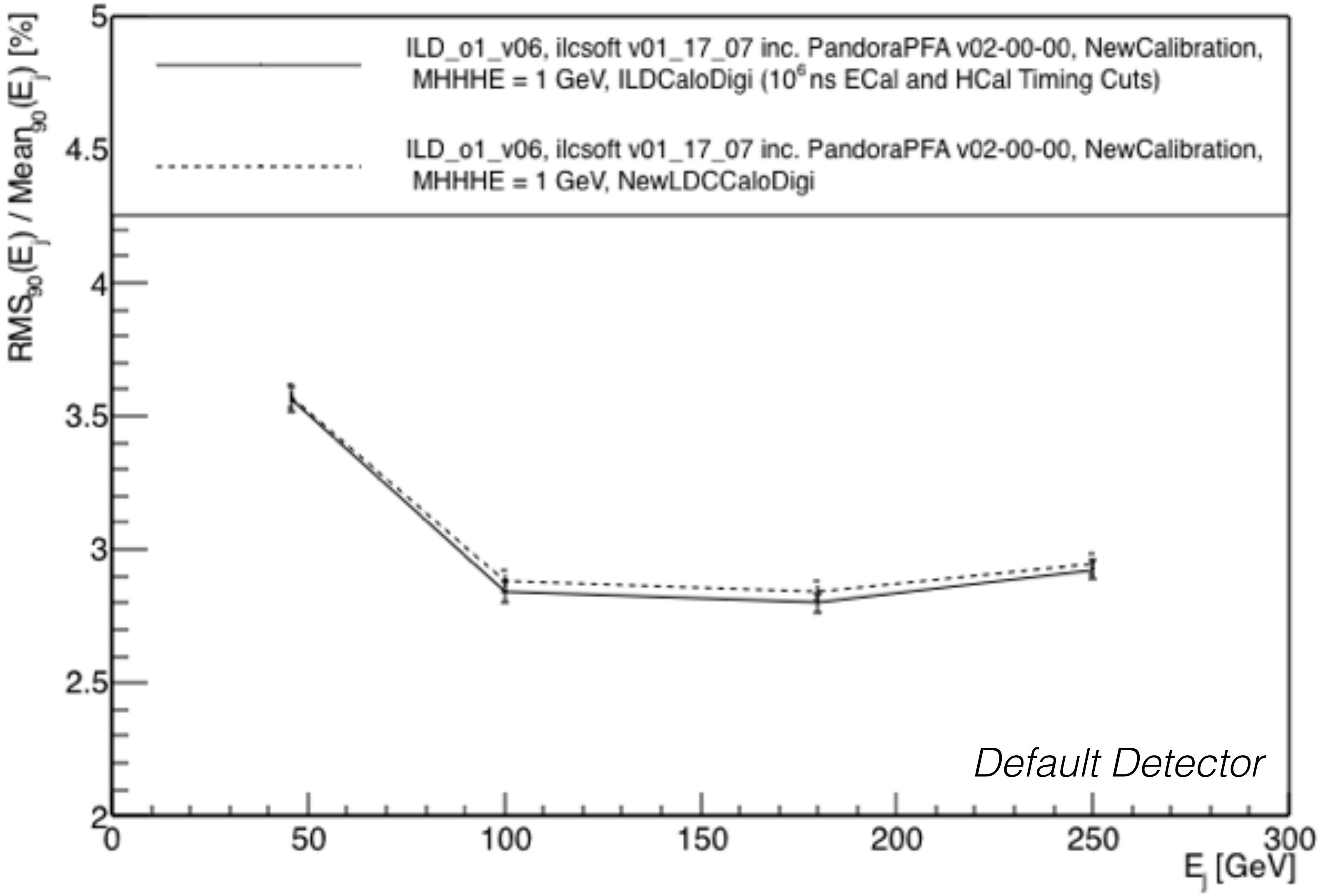
- New calibration procedure either reproduced the DBD calibration or improves it for large HCal cell sizes and high energy jets.
- New calibration procedure produces consistent results, is physically justifiable and so should be used for future studies.

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 now has features such as timing cuts and realistic options (details in later slide), both of which we would like to study further.
- One subtle point is that ILDCaloDigi groups SimCalorimeterHits in a cell together if they fall within the timing window being considered, while NewLDCCaloDigi creates a new CalorimeterHit for every SimCalorimeterHit. This could be significant if thresholds are place on CalorimeterHits as they are in Pandora.
- Therefore, we will examine the performance of the detector when we change digitisation processors.

NewLDCCaloDigi vs ILDCaloDigi

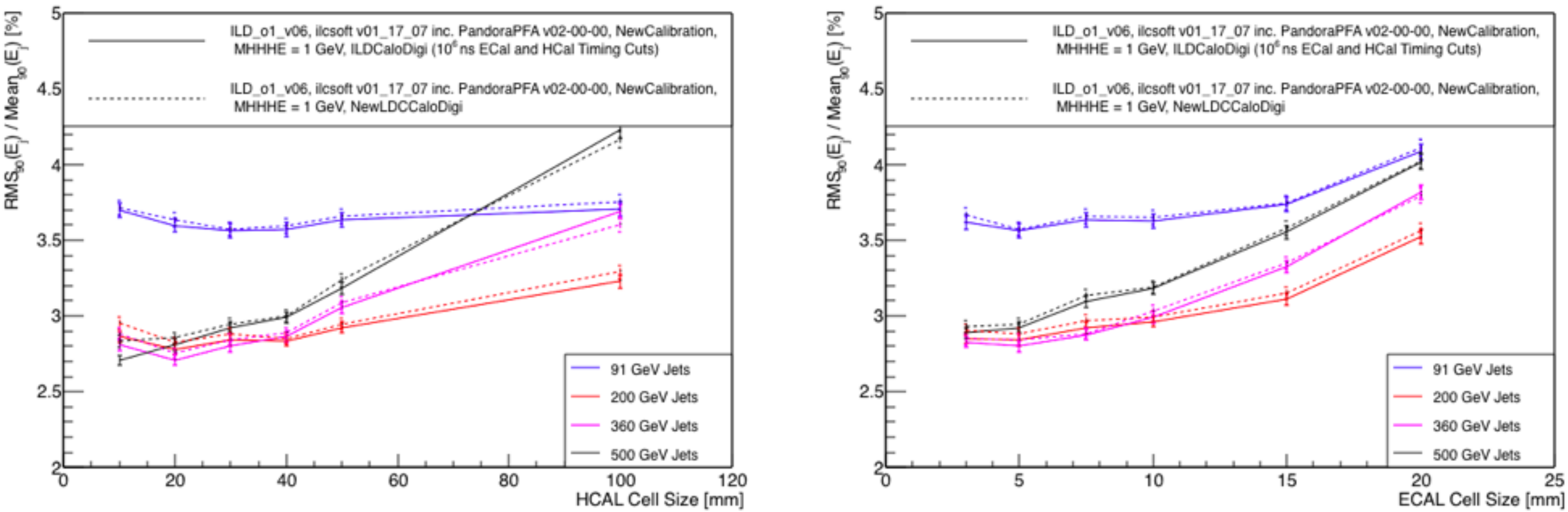
- Examine the change in detector performance when going from the NewLDCCaloDigi digitiser to the ILDCaloDigi digitiser.
- The same hadronic energy truncation in the HCal was applied. For this study this was set to 1 GeV.



- Slight performance difference.
- ILDCaloDigi performs slightly better than NewLDCCaloDigi.

NewLDCCaloDigi vs ILDCaloDigi

Look at the non default detector models…



Hadronic energy truncation in the HCal 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.

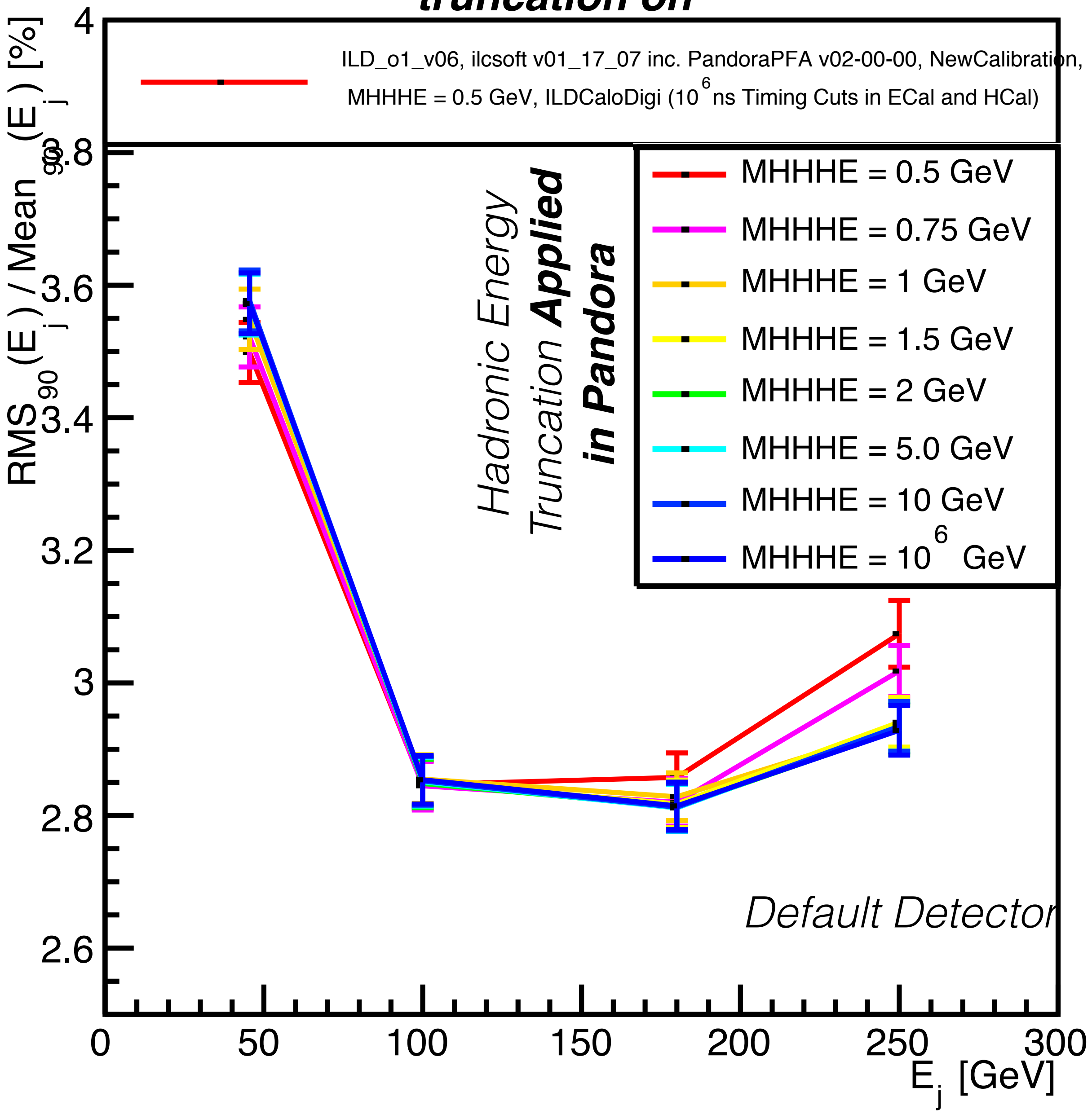
NewLDCCaloDigi vs ILDCaloDigi

- For the digitiser studies, an unfortunate choice of default parameters in the ILDCaloDigi processor (*not same as Pandora HCal energy truncation!*) leads to an energy truncation being applied in the HCal of ~1 GeV per cell (active + absorber).

- Upon further research it was found that the simulation of the dynamic range of the readout electronics, was producing the truncation.

- These defaults have been updated to more realistic values, which removes this aggressive energy truncation. (Thanks to Oskar Hartbrich, DESY).

ILDCaloDigi - With the accidental digitiser truncation on



- <u>Accidental truncation in the ILDCaloDigi studies not active anywhere else in this presentation except for this slide!</u>

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.

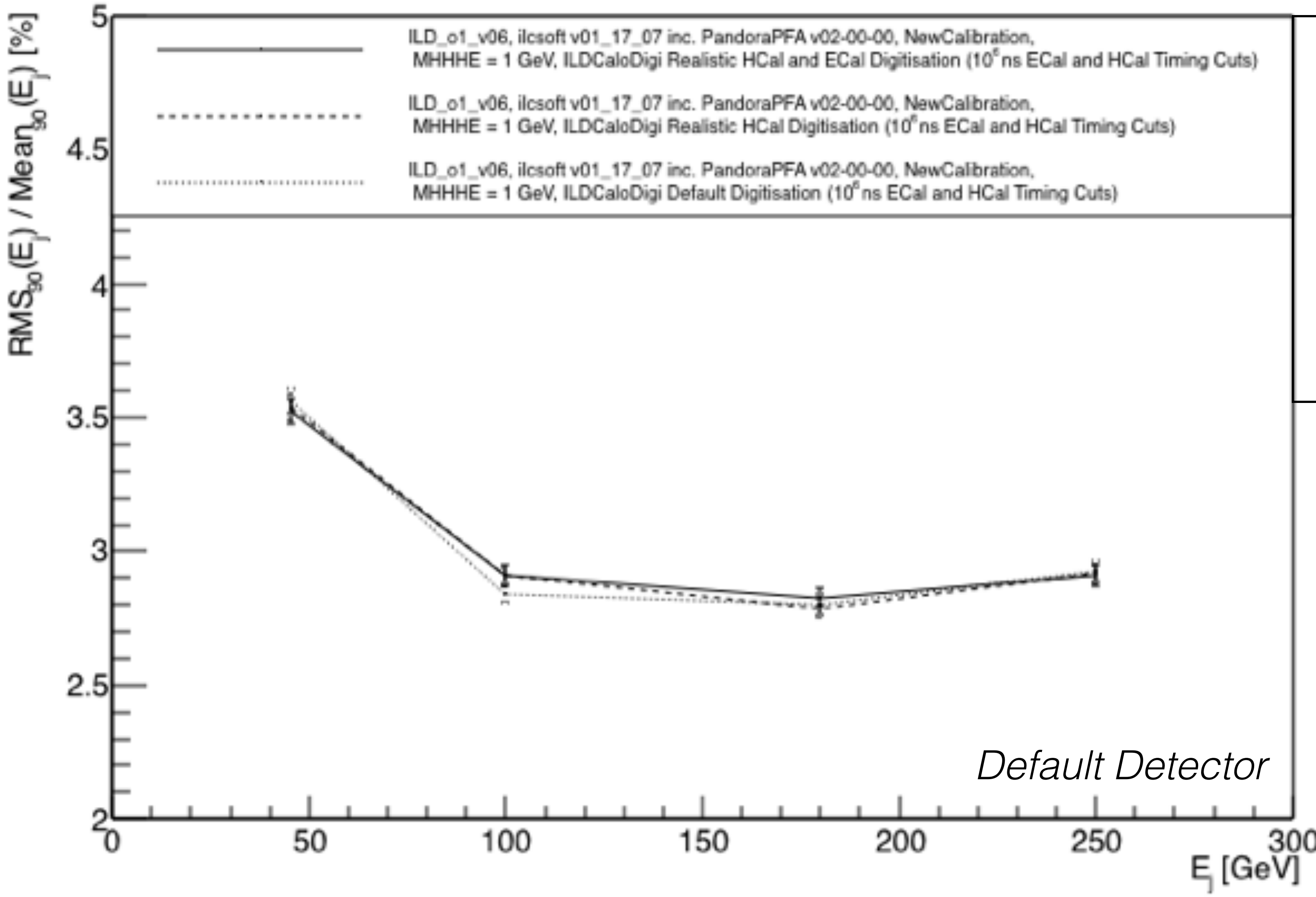
- The effects that we were advised to simulate were the electronics read out range and the electrical noise. The read out range is determined in MIP units this required modification of the calibration procedure.

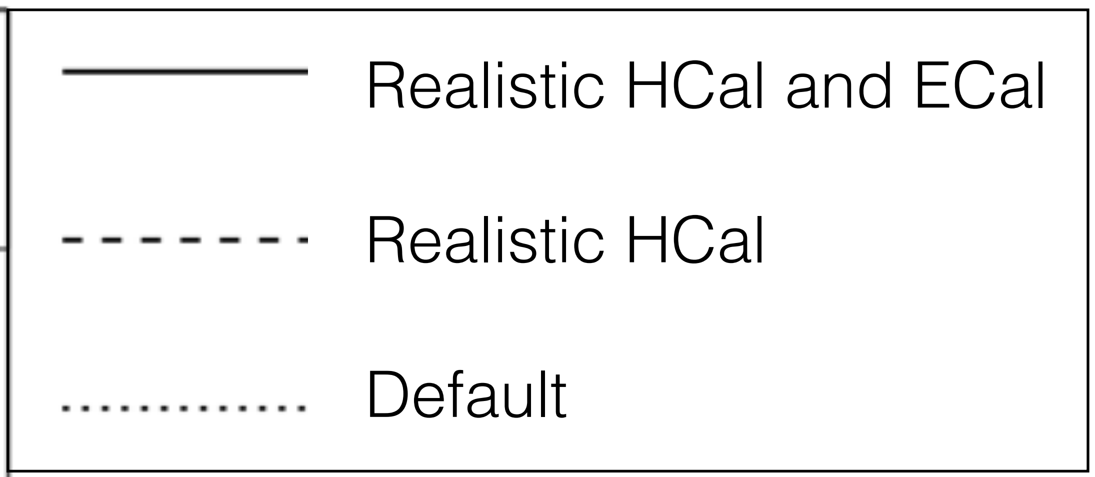
- The realistic digitisation of the ECal was applied to the silicon ECal we have been using in the studies, however, there is also a realistic ECal scintillator option, which can be applied.

Realistic Digitisation in ILDCaloDigi

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

- The same hadronic energy truncation in the HCal was applied. For this study this was set to 1 GeV.



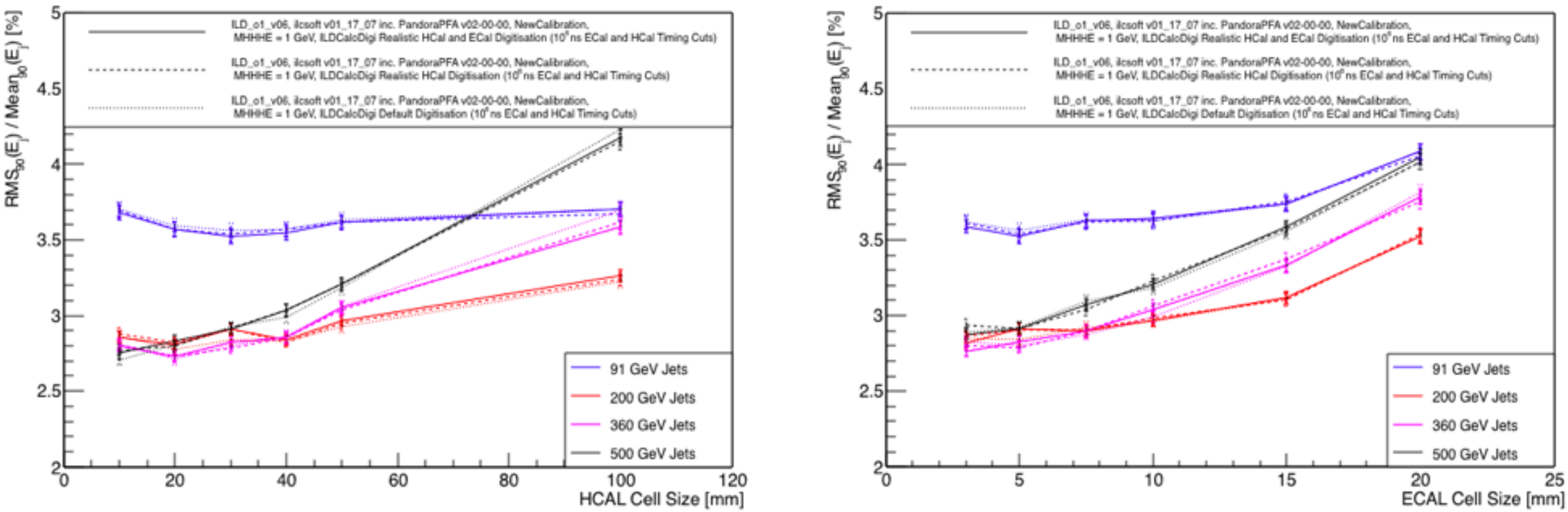


- Consistent performance between all digitisation options.

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

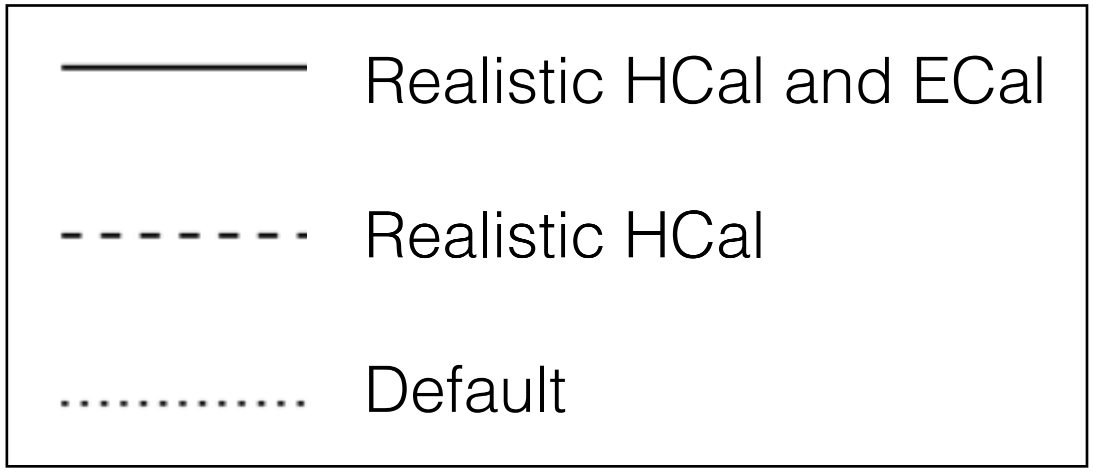
Realistic Digitisation in ILDCaloDigi

Look at the non default detector models…



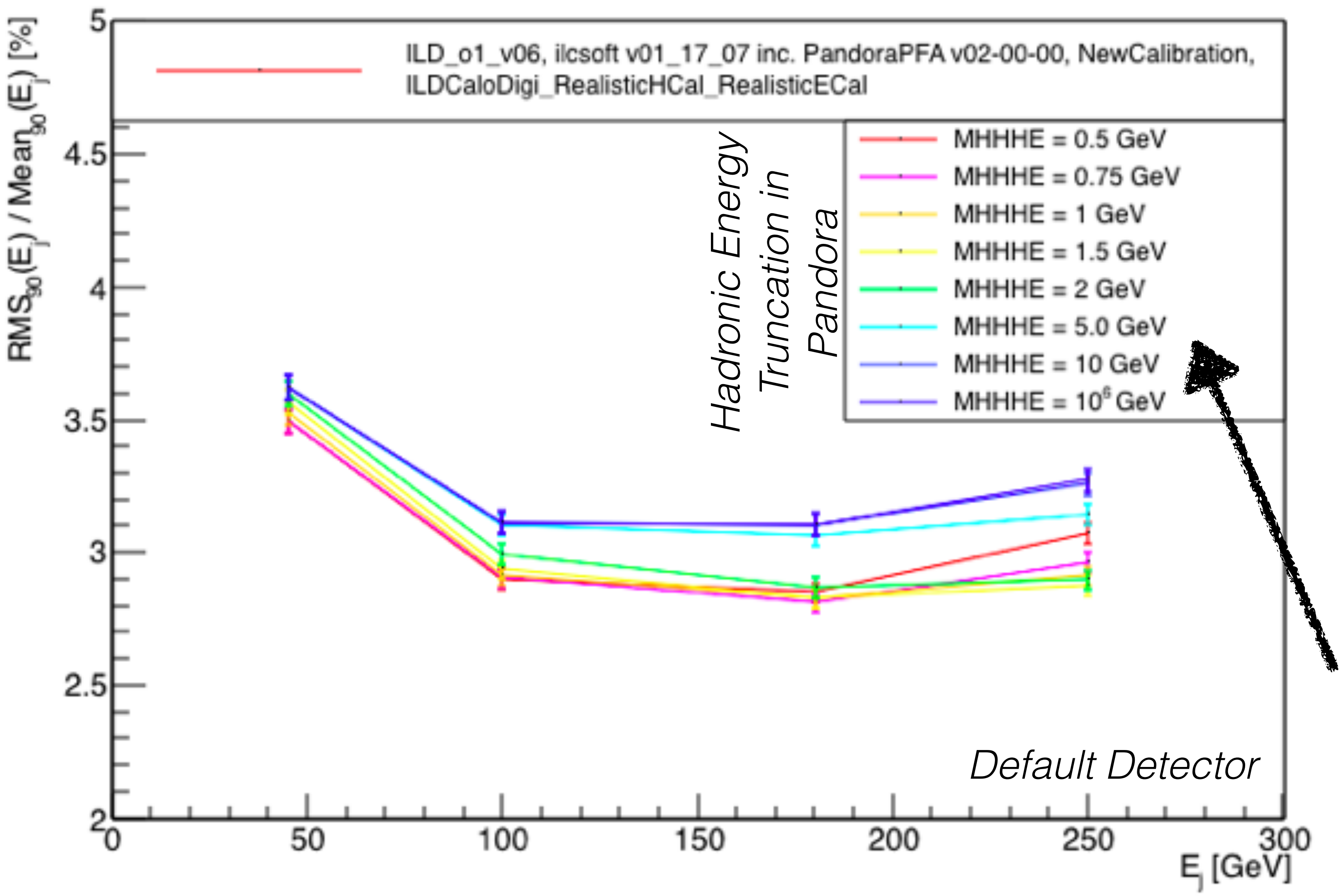
Hadronic energy truncation in the HCal 1 GeV.

- 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.



Hadronic Energy Truncation

- Conclusions derived so far have no strong dependancy on the hadronic energy truncation applied in PandoraPFA.
- However, the absolute values of the jet energy resolution have a strong dependancy on his value.
- We want determine the best truncation for each detector model.

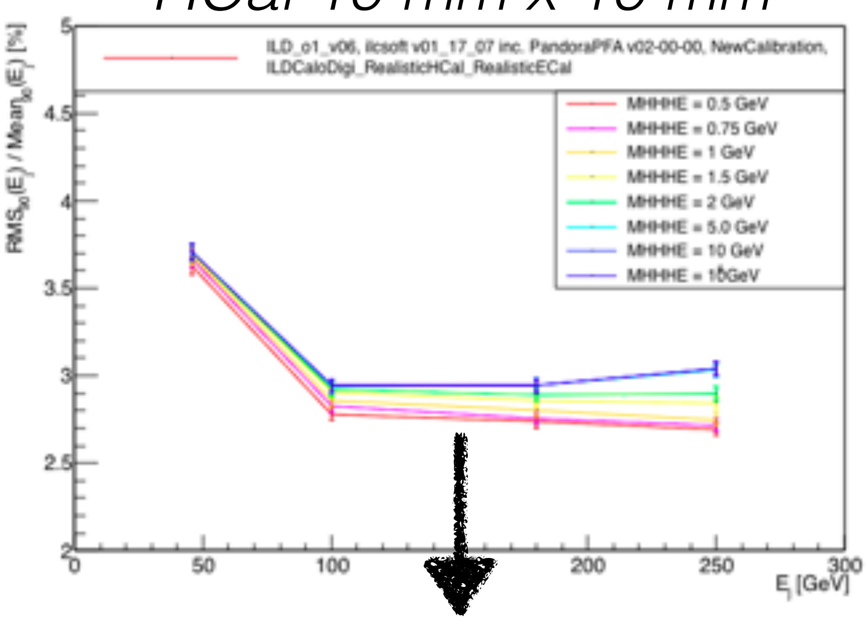


- This study will be performed using the conclusions of the previous studies i.e:
  - Latest Pandora
  - ilcsoft v01-17-07
  - New calibration
  - ILDCaloDigi
  - Realistic HCal and ECal digitisation
- Look at the performance as a function of the hadronic energy truncation applied in Pandora.

Hadronic Energy Truncation

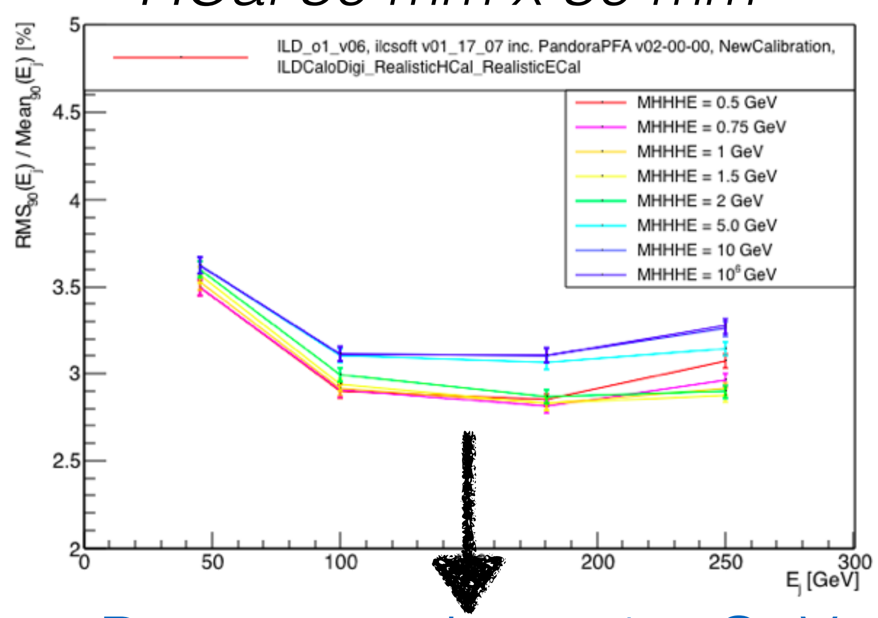
- For each detector model scan across the energy truncations and then look for the best detector performance.
- Only do this when varying the HCal cell size as the truncation will not be affected by the ECal cell size.

HCal 10 mm x 10 mm



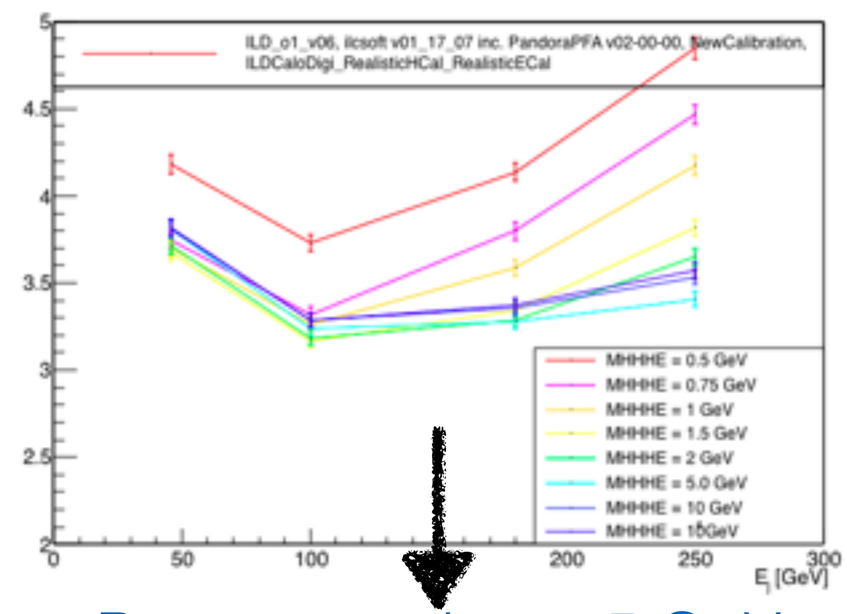
Best truncation = 0.5 GeV
Red line

HCal 30 mm x 30 mm



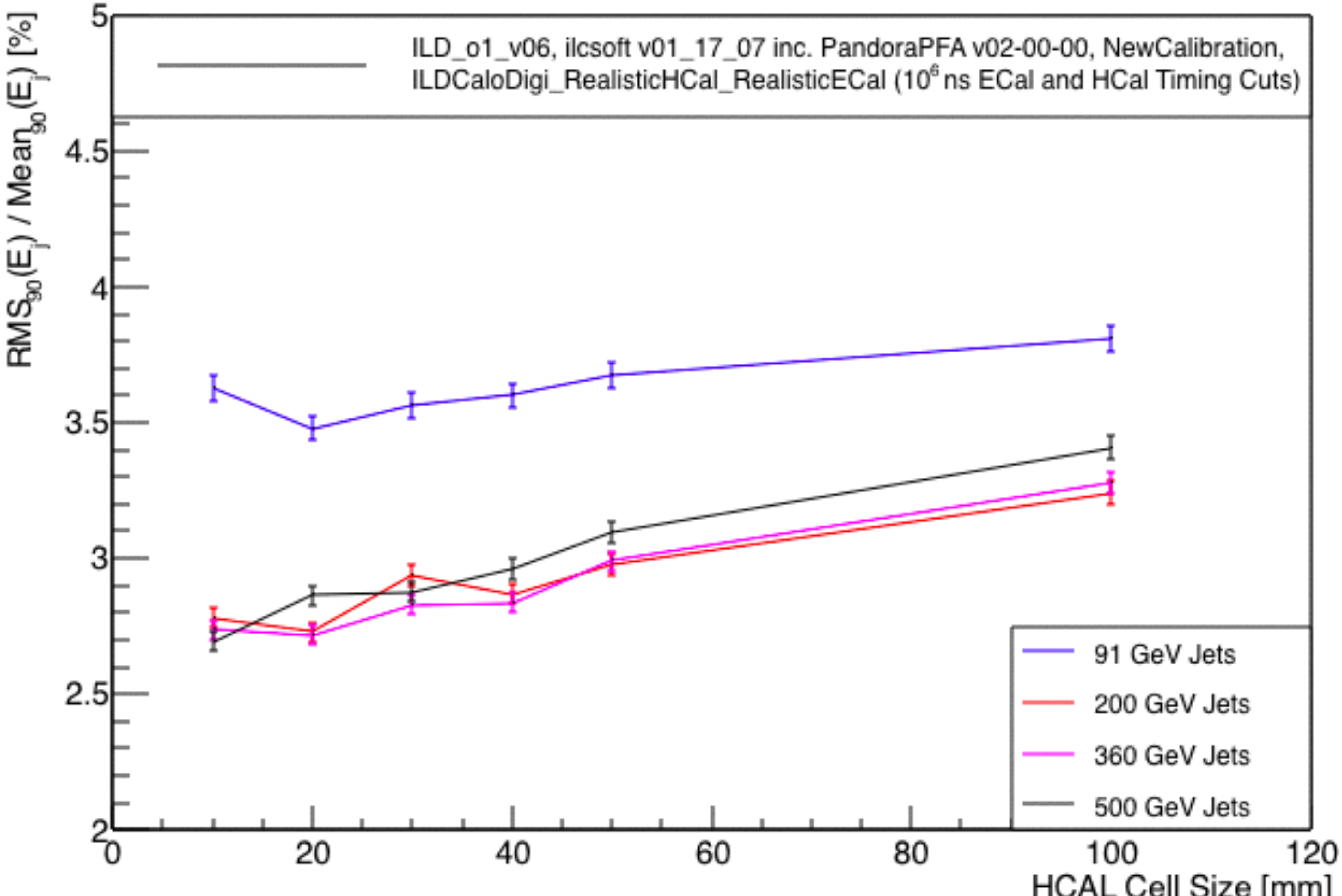
Best truncation = 1.5 GeV
Yellow line

HCal 100 mm x 100 mm



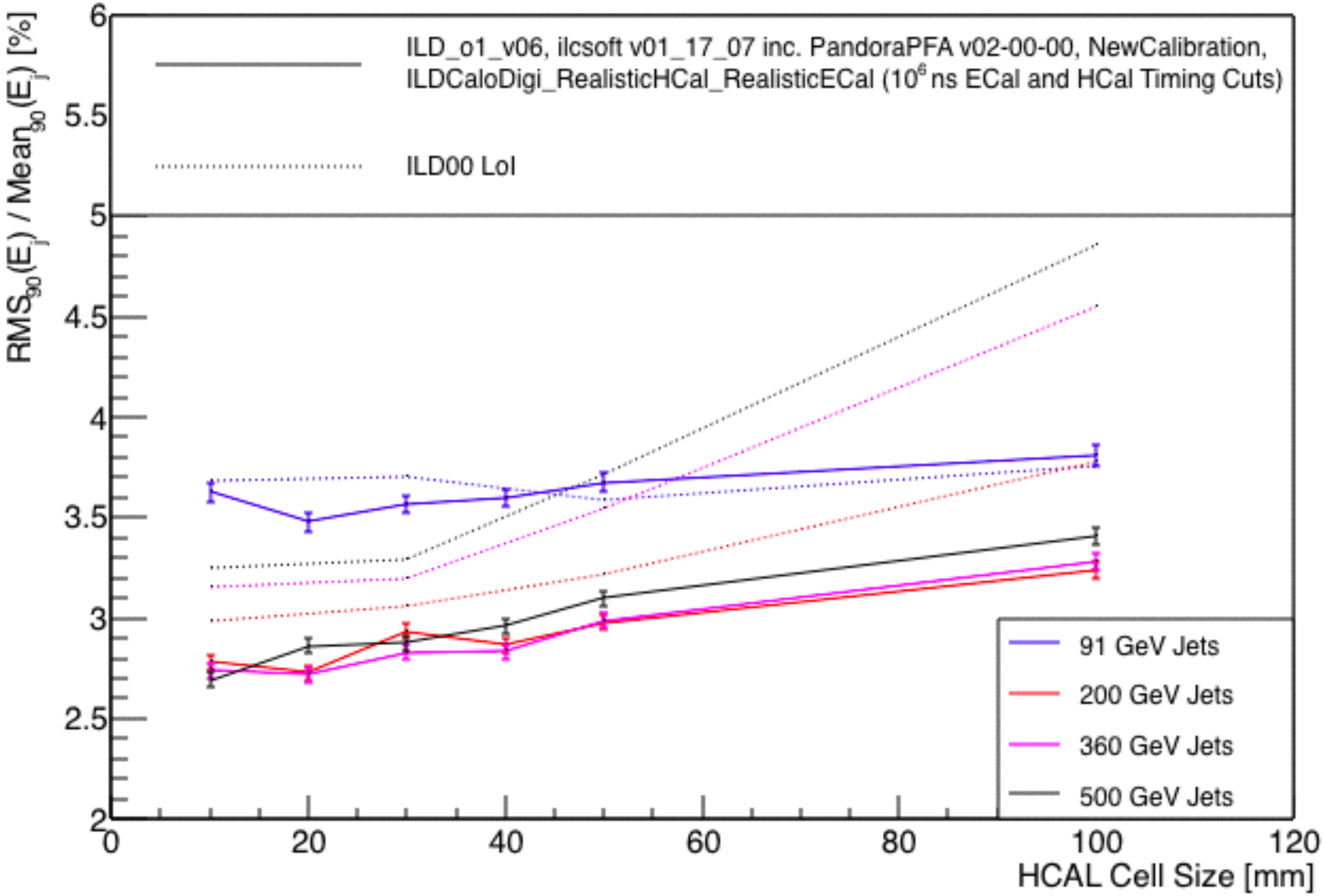
Best truncation = 5 GeV
Cyan line

Current Best Estimate of HCal Cell Size Dependancies on the ILD Detector

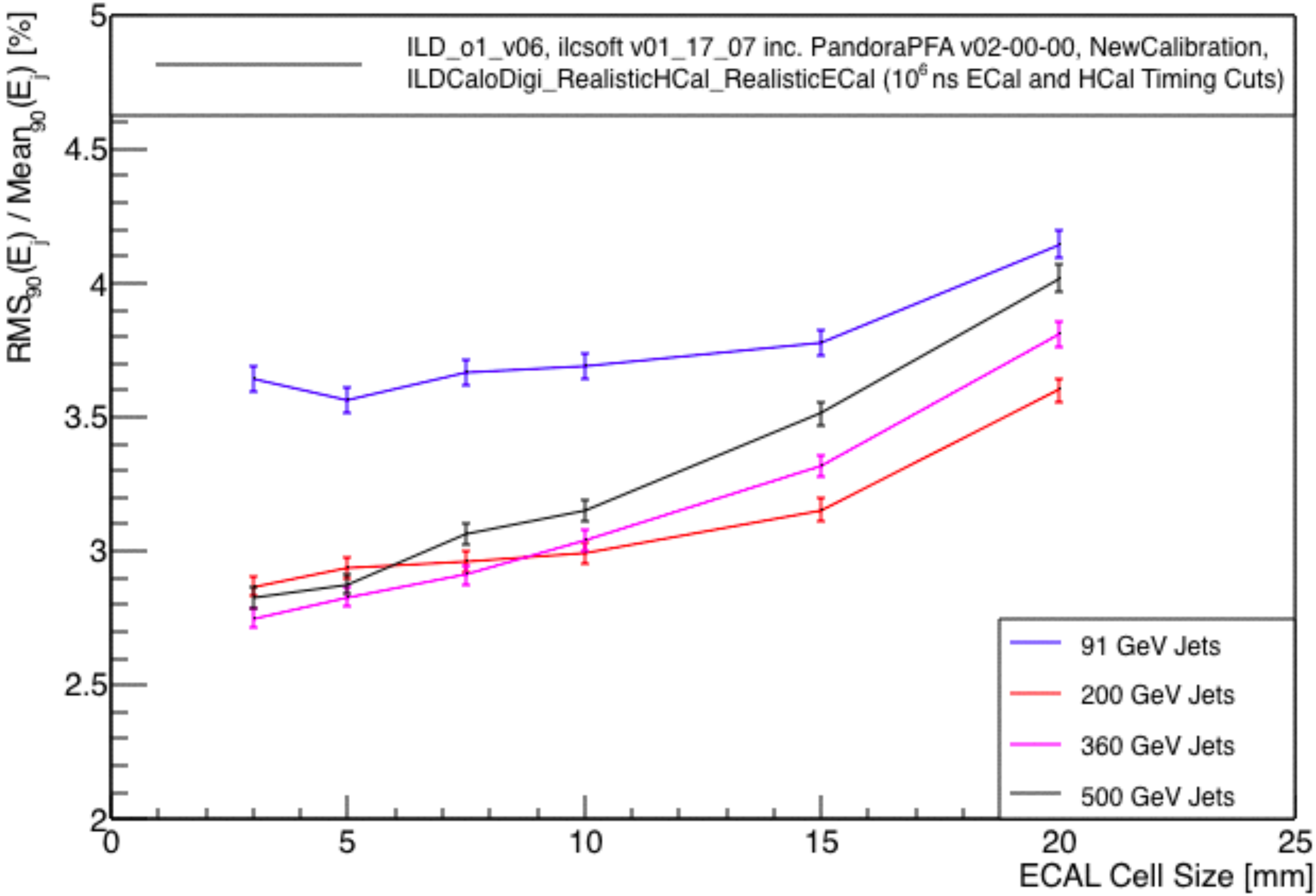


- Here the optimal hadronic energy truncations have been applied to each detector model.

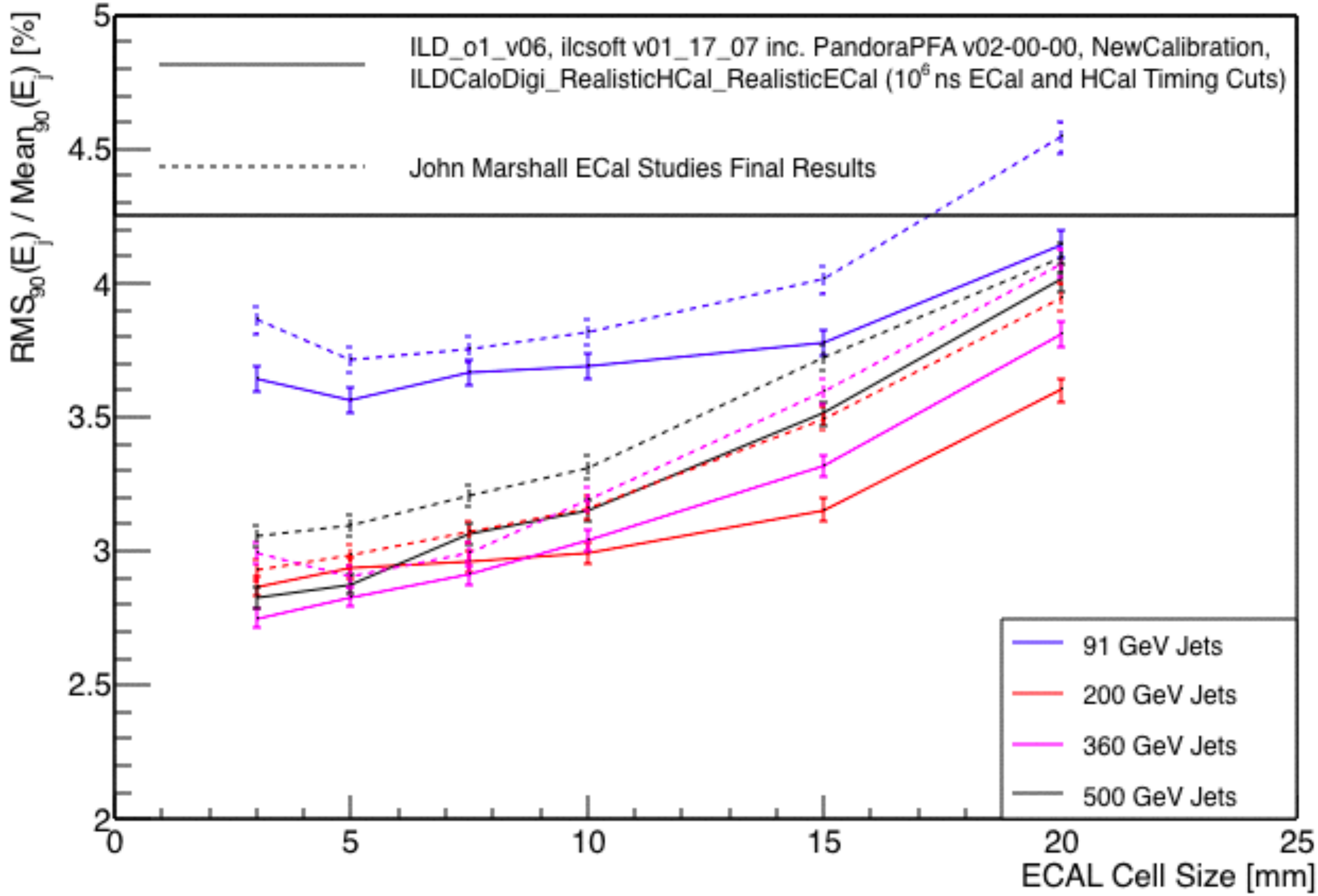
Current Best Estimate of HCal Cell Size Dependancies on the ILD Detector - Compared to LoI



Current Best Estimate of ECal Cell Size Dependancies on the ILD Detector

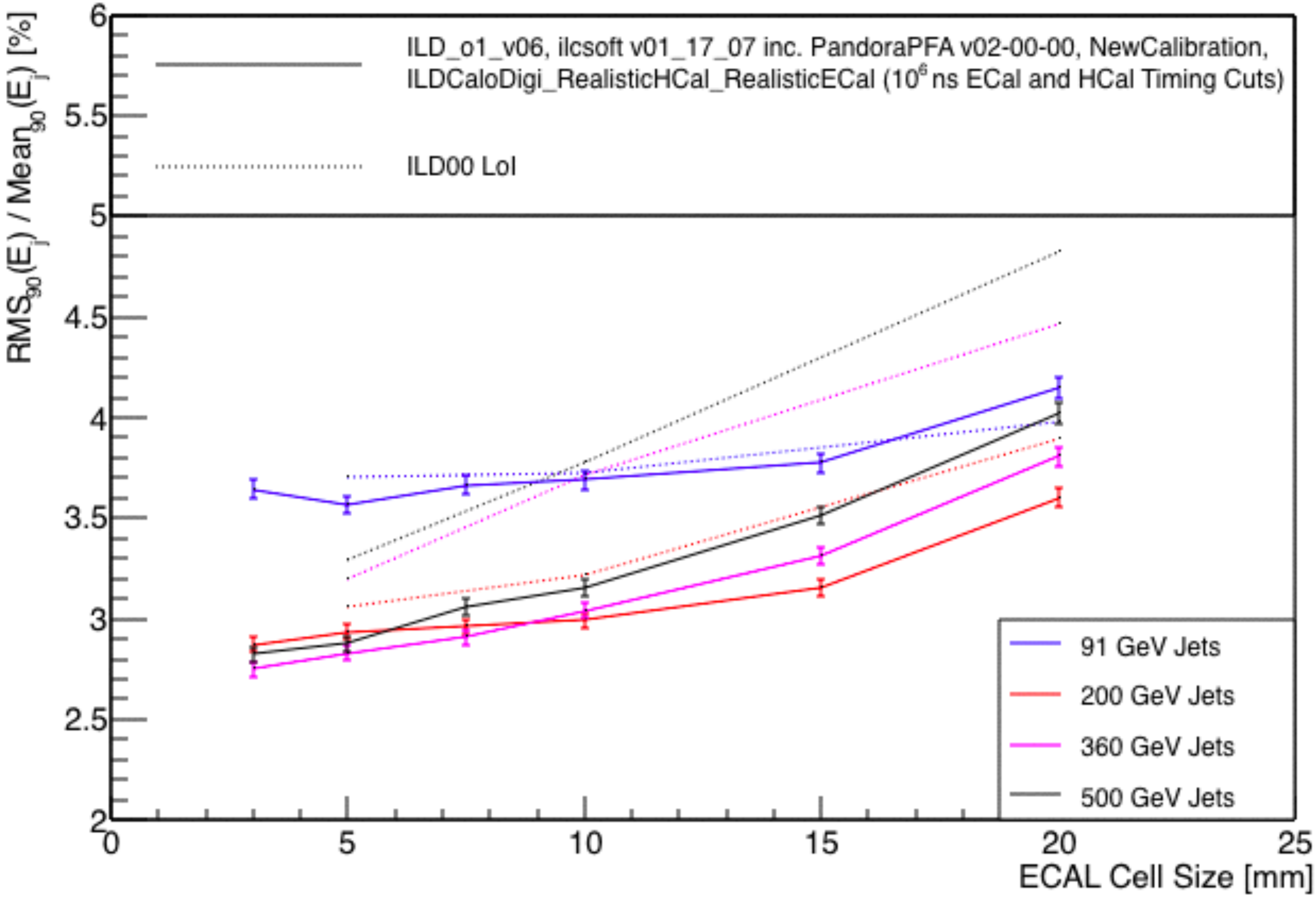


Current Best Estimate of ECal Cell Size Dependancies on the ILD Detector - Compared to Previous ECal Studies



Thanks to J. Marshall

Current Best Estimate of ECal Cell Size Dependancies on the ILD Detector - Compared to LoI



Conclusions for the Jet Energy Resolution Evolution Studies

- There have been significant improvements to Pandora since the LoI.
- The new calibration procedure either produces consistent results to the DBD calibration or improves it for the larger HCal cell sizes considered.
- Using the ILDCaloDigi processor improves the detector performance in comparison to using the NewLDCCaloDigi processor.
- The realistic ECal and HCal digitisation features in ILDCaloDigi produce consistent results with using the default ILDCaloDigi settings.
- The HCal hadronic energy truncation in Pandora plays a very large role in detector performance and needs to be specified for each detector model.

Thank you for your attention!

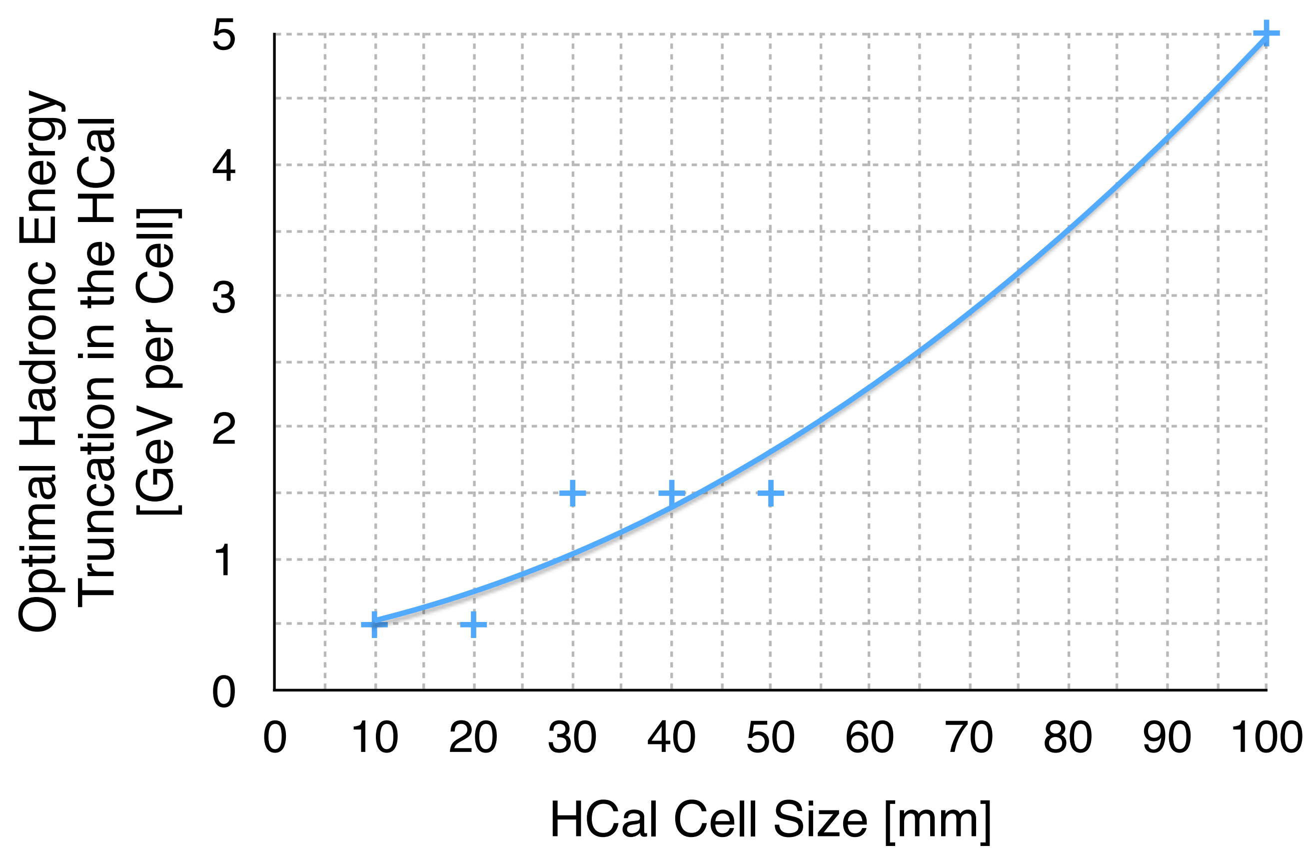
Many thanks to, J. Marshall, M. Thomson, H.L. Tran, F. Sefkow, K. Krüger, D. Jeans, O. Hartbrich and K. Coterra for contributing to these studies!

Back Up

Hadronic Energy Truncation

- Following results were found.

HCal Cell Size [mm]	Optimal Hadronic Energy Truncation in the HCal [GeV Per Cell]
10	0.5
20	0.5
30	1.5
40	1.5
50	1.5
100	5.0

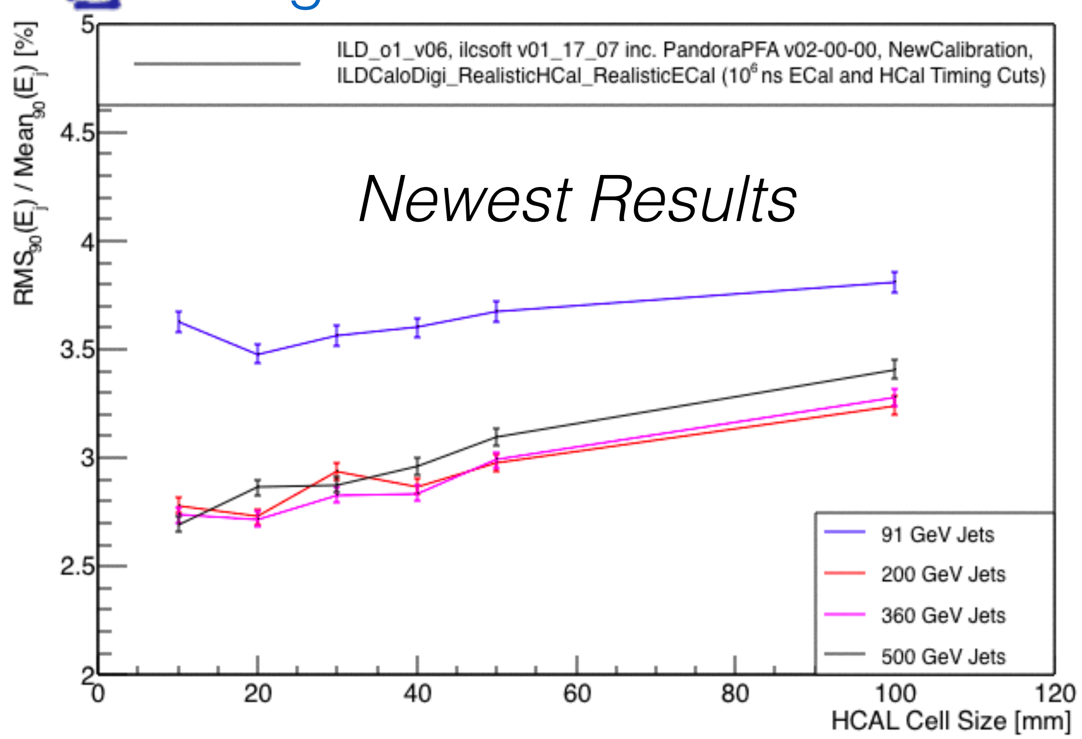


- Very roughly they follow the quadratic dependancy we would expect if we applied a cut based on energy density. (Of course nothing too conclusive with 6 data points and 3 degrees of freedom!)

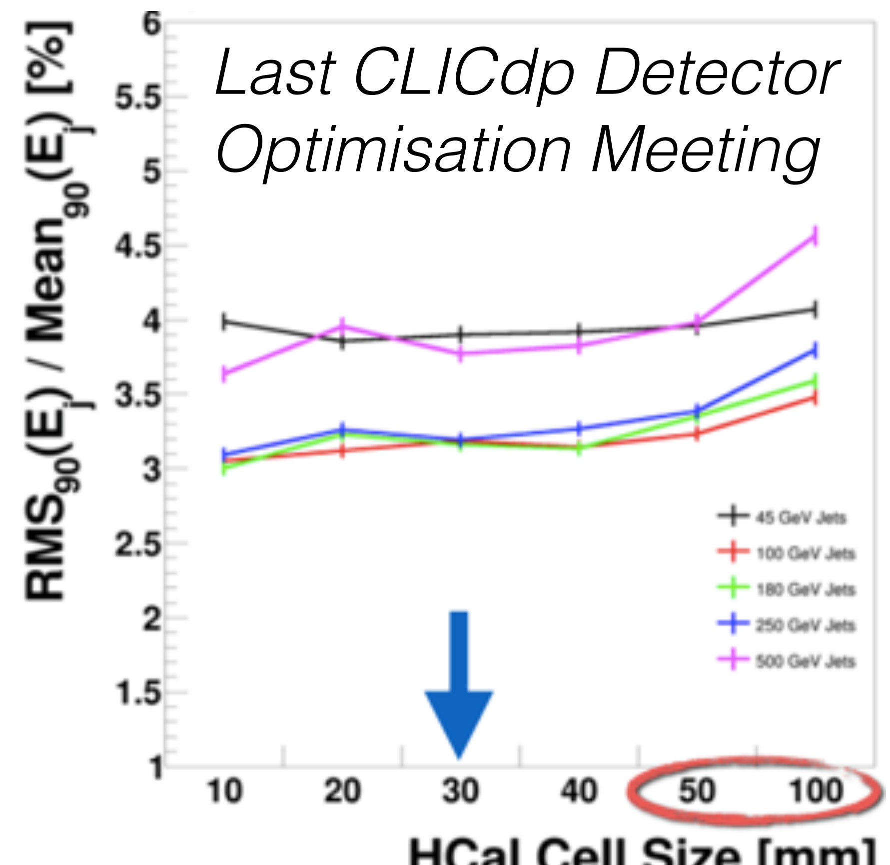
My Previous Studies

* There have been many changes in between these results and those shown in the last detector optimisation meeting:

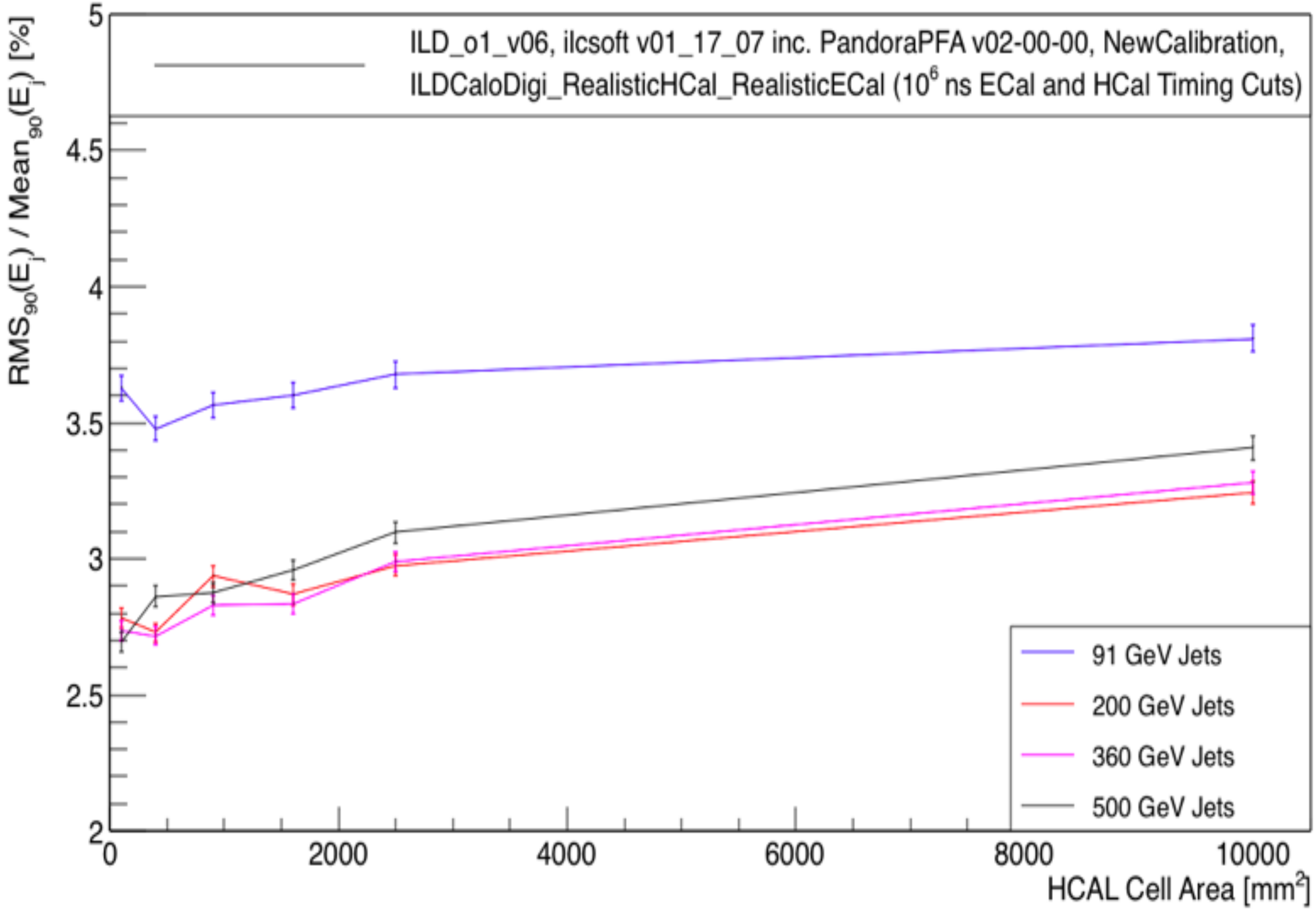
- [x] Pandora from ilcsoft_v01-17-07
- [x] ILDCaloDigi
- [x] New Calibration
- [x] Realistic ECal
- [x] Realistic HCal
- [x] Optimal Hadronic Energy Truncation
- [ ] Timing Cuts



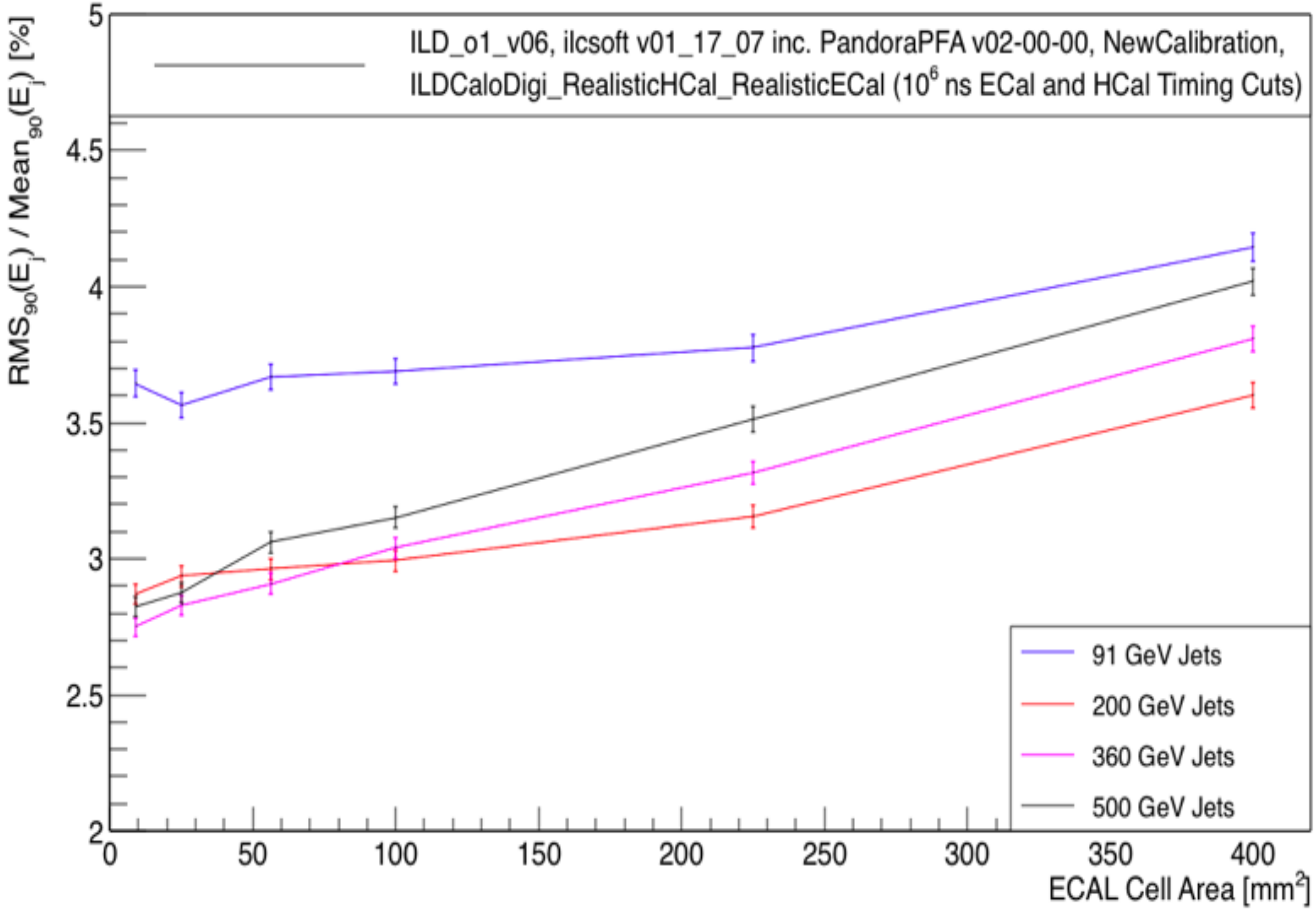
- [ ] Pandora from ilcsoft_v01-17-07. (v01-17-05 used)
- [x] ILDCaloDigi
- [x] New Calibration
- [ ] Realistic ECal
- [ ] Realistic HCal
- [ ] Optimal Hadronic Energy Truncation
- [x] Timing Cuts



Current Best Estimate of HCal Cell Size Dependancies on the ILD Detector - Plotted vs Cell Area



Current Best Estimate of ECal Cell Size Dependancies on the ILD Detector - Plotted vs Cell Area



Realistic HCal Digitiser Settings

```
<!-- Realistic HCal -->
 <parameter name="HCAL_apply_realistic_digi" type="int">1</parameter>
 <parameter name="HCALThresholdUnit" type="string">MIP</parameter>
 <parameter name="CalibHCALMIP" type="float">0.0004925</parameter>
 <parameter name="HCAL_maxDynamicRange_MIP" type="float">99999999</parameter>
 <parameter name="HCAL_elec_noise_mips" type="float">0.06</parameter>
 <parameter name="HCAL_deadCellRate" type="float">0</parameter>
 <parameter name="HCAL_PPD_N_Pixels" type="int">2000</parameter>
 <parameter name="HCAL_PPD_PE_per_MIP" type="float">15</parameter>
 <parameter name="HCAL_pixel_spread" type="float">0.05</parameter>
 <parameter name="HCAL_PPD_N_Pixels_uncertainty" type="float">0</parameter>
 <parameter name="HCAL_miscalibration_uncorrel" type="float">0</parameter>
 <parameter name="HCAL_miscalibration_correl" type="float">0</parameter>
```

- ***CalibrHCalMIP*** sets MIP scale in digitiser.
- ***HCAL_maxDynamicRange_MIP*** sets the dynamic range of the electronics readout in units of MIPs.
- ***HCAL_elec_noise_mips*** sets the electrical noise. HCAL_elec_noise_mips is the standard deviation of a Gaussian with mean 0. A random number with this distribution is added to the energy measure to simulate electrical noise.
- ***HCAL_PPD_N_Pixels*** sets the number of pixels which are fired for a given number of photo electrons produced.
- ***HCAL_PPD_PE_per_MIP*** sets the number of photo electrons produced by one MIP in the pixelated photo detectors.
- ***HCAL_pixel_spread*** sets variations in pixel response (e.g. from different capacitances).
- No dead cells or mis-calibration simulated.

$$n_{pix}^{sig} = n_{pix} \times \mathtt{RandGauss}(1, \S\mathtt{CAL\_pixel\_spread}/\sqrt{(}n_{pix}))$$

Realistic ECal Digitiser Settings

```
<!-- Realistic ECal -->
<parameter name="ECAL_apply_realistic_digi" type="int">1</parameter>
<parameter name="CalibECALMIP" type="float">0.0001475</parameter>
<parameter name="ECAL_maxDynamicRange_MIP" type="float">2500</parameter>
<parameter name="ECAL_elec_noise_mips" type="float">0.07</parameter>
<parameter name="ECAL_deadCellRate" type="float">0</parameter>
<parameter name="ECAL_miscalibration_uncorrel" type="float">0</parameter>
<parameter name="ECAL_miscalibration_uncorrel_memorise" type="bool">false</parameter>
<parameter name="ECAL_miscalibration_correl" type="float">0</parameter>
<parameter name="energyPerEHpair" type="float">3.6</parameter>
```

- ***CalibrECalMIP*** sets MIP scale in digitiser.
- ***ECAL_maxDynamicRange_MIP*** sets the dynamic range of the electronics readout in units of MIPs.
- ***ECAL_elec_noisemips*** is the standard deviation of a Gaussian with mean 0. A random number with this distribution is added to the energy measure to simulate electrical noise.
- ***energyPerEHpair*** sets the energy required to produce and electron hole pair. Energies are converted to numbers of electrons hole pairs. A smearing of the energy distribution is applied by exchanging the number of electron hole pairs (n) produced by a randomly drawn number from a Poisson distribution, which has mean n.
- No dead cells or mis-calibration simulated.