6 Month Status Report

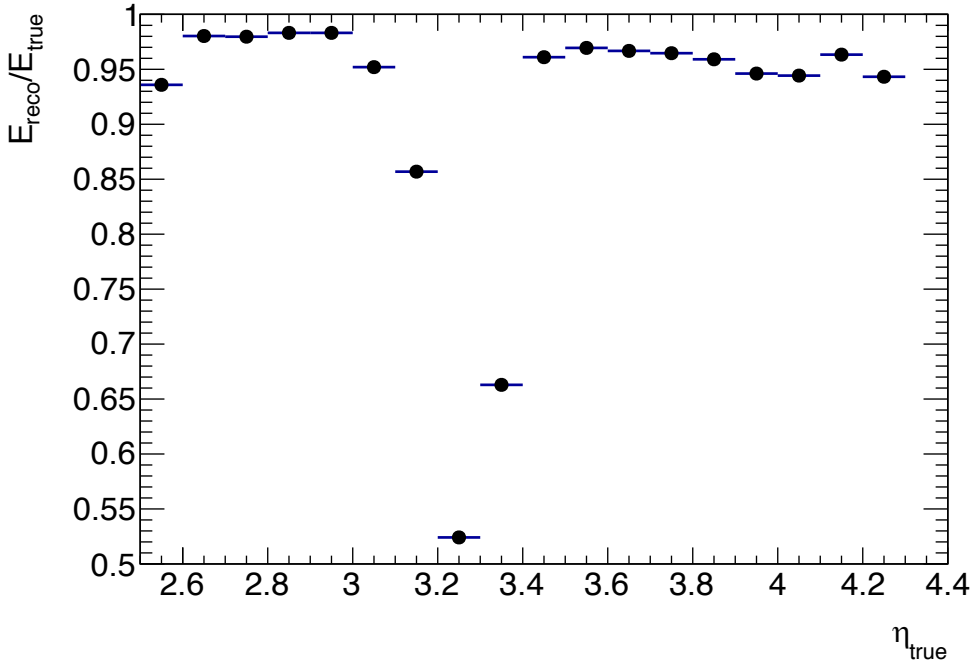
Craig Wells

MVA Calibration for Forward Electrons

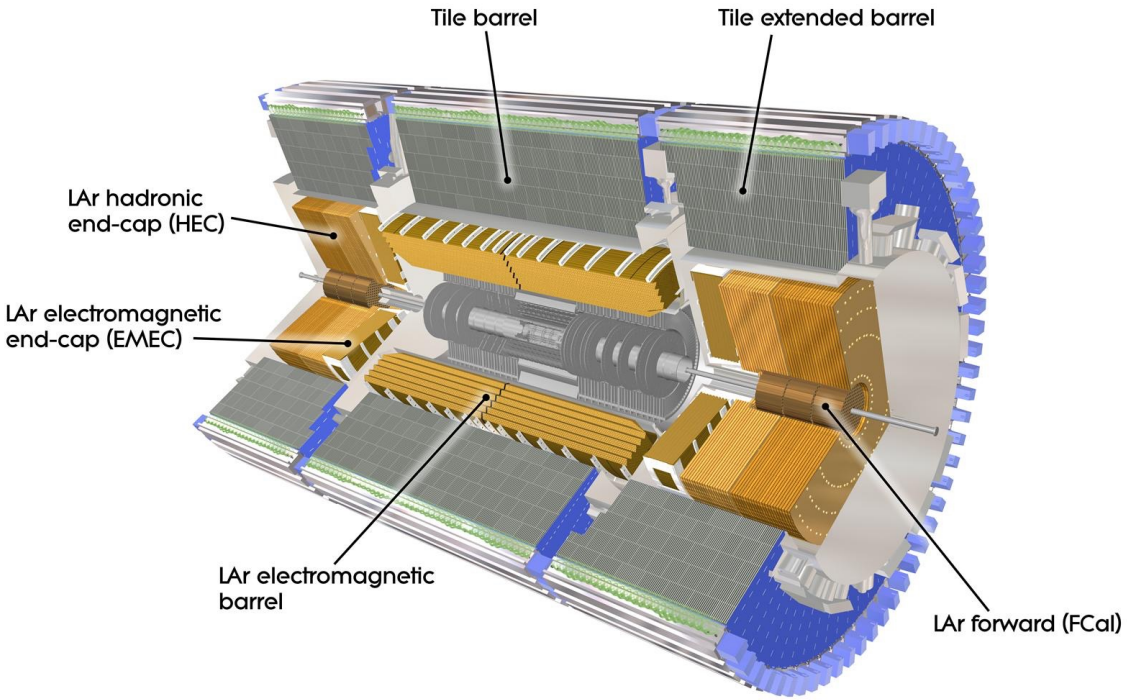
JIRA

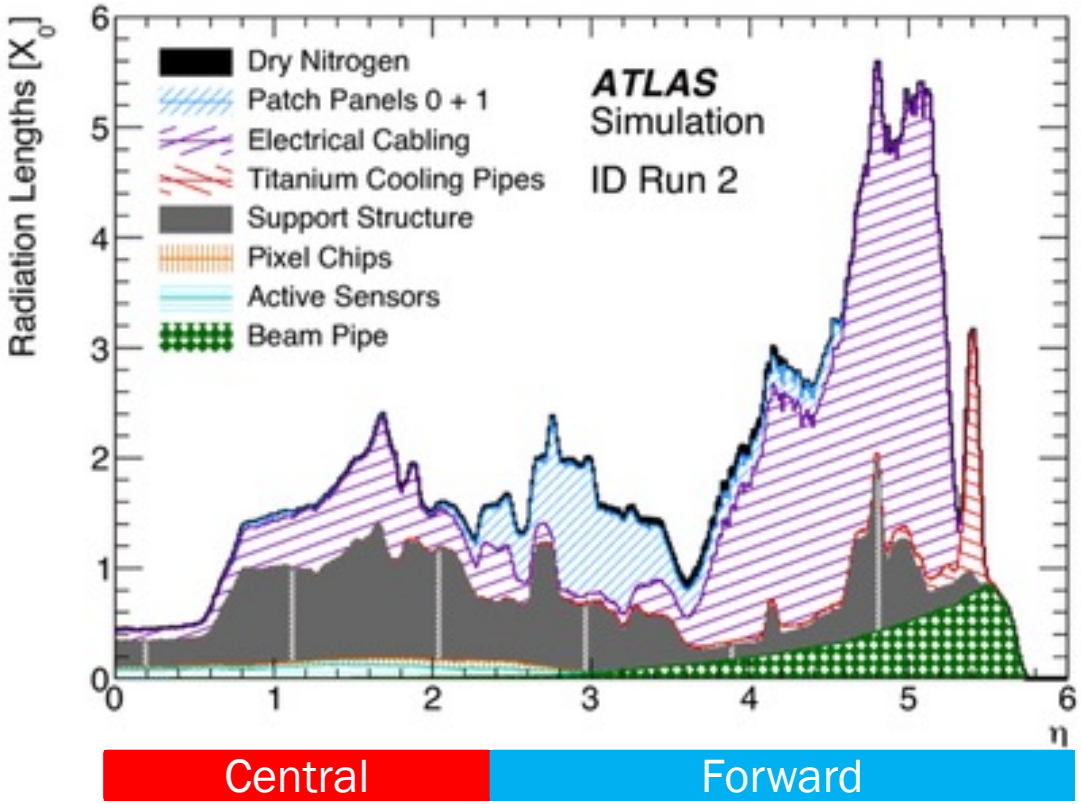
Why Calibrate?

- Electron energy measured in the calorimeter is less than energy the electron has when it is produced.
- Interactions with matter cost energy.
- No universal correction possible.



ATLAS Forward Region





EMEC Coverage – $2.5 < \eta < 3.2$

FCAL Coverage – $3.1 < \eta < 4.9$

Training Process and Object Selection

- Carry out the training using the Light Gradient Boosted Machine (LightGBM) package developed by Microsoft:
  - *LightGBM is already being used for the Athena release 22 central electron global calibration*
  - *Results in a quicker training time and easier implementation than the TMVA package in ROOT*
- Train a boosted decision tree (BDT) to minimise the value of E_{true}/E_{reco} which can then be used as a correction factor to the raw energy i.e:

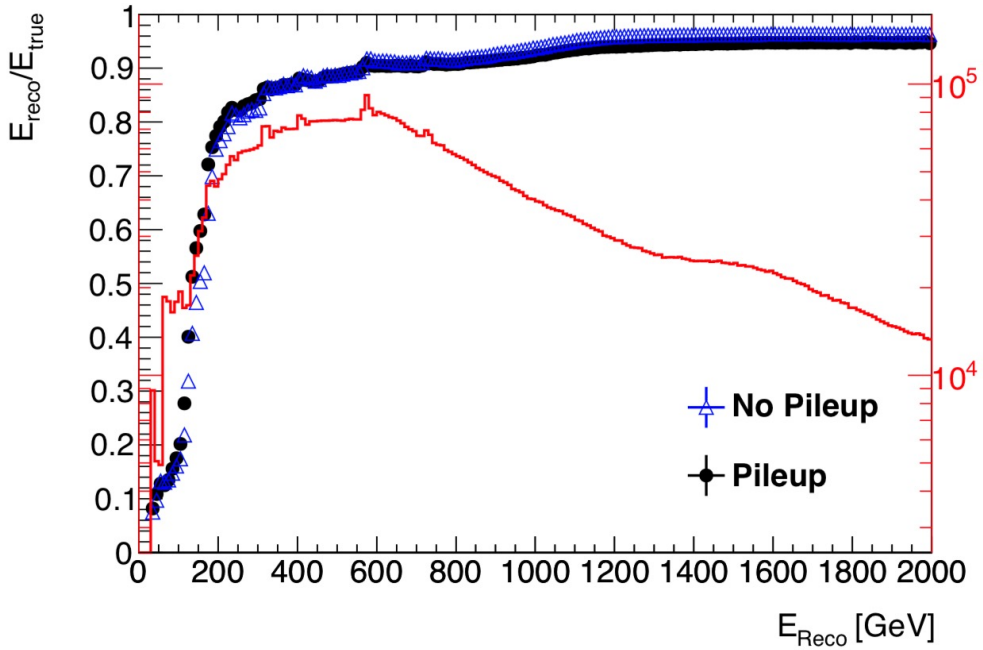
$$BDT\ output = \frac{E_{true}}{E_{reco}} \rightarrow E_{calib} = E_{reco} \times BDT\ output$$

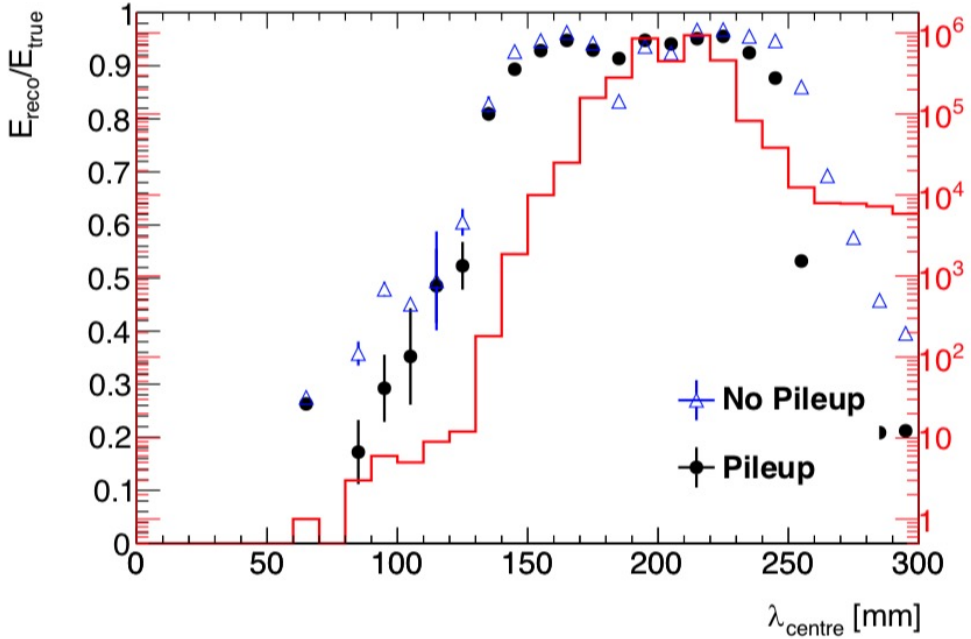
- Train using single electron particle gun samples in the forward region with separate pileup and no pileup MC samples.
  - *Flat η distribution from 2.5 – 4.3*
  - *Flat p_T range from 20 – 100 GeV*
  - *Flat μ distribution from 0 - 80*

Training Process and Object Selection

- Impose minimal selection criteria:
  - $0.5 \leq E_{true}/E_{reco} \leq 3$
  - $\Delta R \leq 0.1$ *between truth and reco level*
  - *Truth matched particles*
- To reduce complexity in the final result, the training is carried out with minimal binning in η or p_T :
  - *Test the training with no splitting at all (No Splits training)*
  - *Separate trainings for events in the EMEC and events in the FCAL (Splits training)*
- Variables chosen for training must describe:
  - *The position of the cluster in the calorimeter*
  - *The shower shape development of the cluster*
  - *The energy deposited in the calorimeter*

Variable Selection





- When choosing variables it is important to choose ones that show a correlation between E_{reco}/E_{true} and the corresponding variable.
- Feed rubbish in to the BDT and you'll get rubbish out!

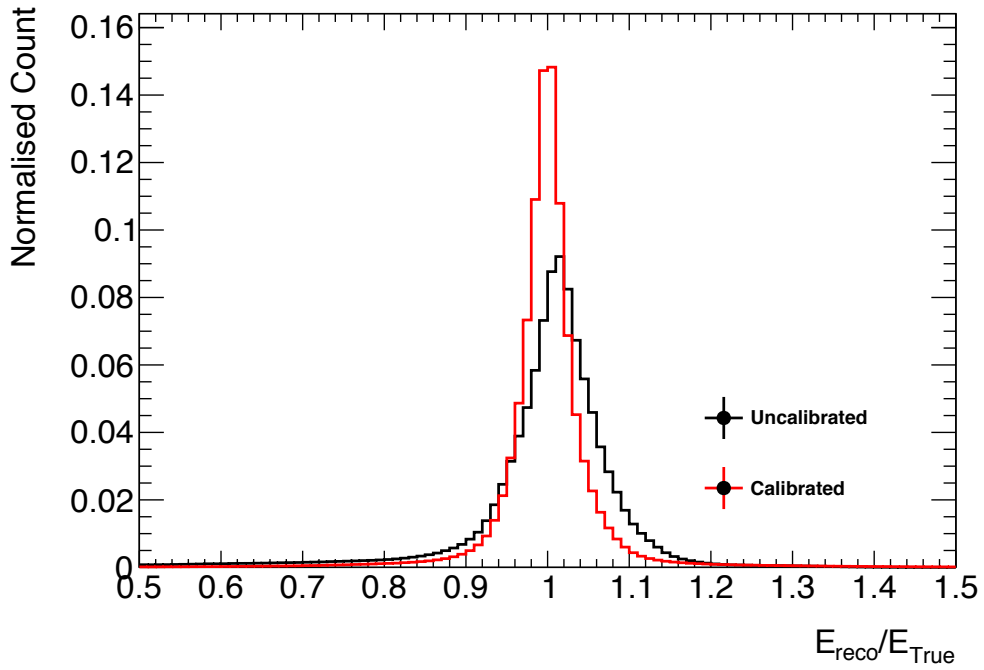
Training Without Shower Shape Variables

Training Variables

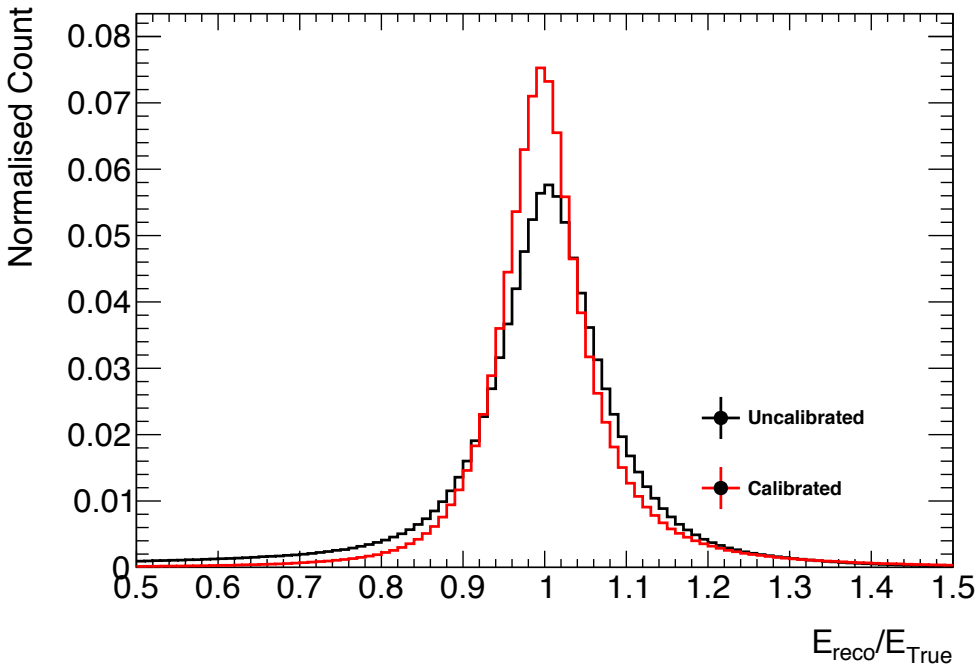
NoSplits	Splits	
	EMEC ($\eta < 3.15$)	FCal ($\eta > 3.15$)
Cluster eta (η_{cl})	η_{cl}	$CentreX/Y/Z$
Cluster phi (ϕ_{cl})	ϕ_{cl}	
Cluster energy (E_{raw})	E_{raw}	E_{raw}
–	$E^{Max}_{cell,layer1}/E^{Max}_{cell,layer2}$	–
Pileup Training Only		
Number of primary vertices (NPV)	NPV	NPV

- Use centre X/Y/Z in the FCAL instead of η and φ. Due to the geometry of the FCAL, η and φ can be ambiguous at the cell level. This ambiguity does not exist for centre X/Y/Z.

No Splits – Energy Distributions



No Pileup

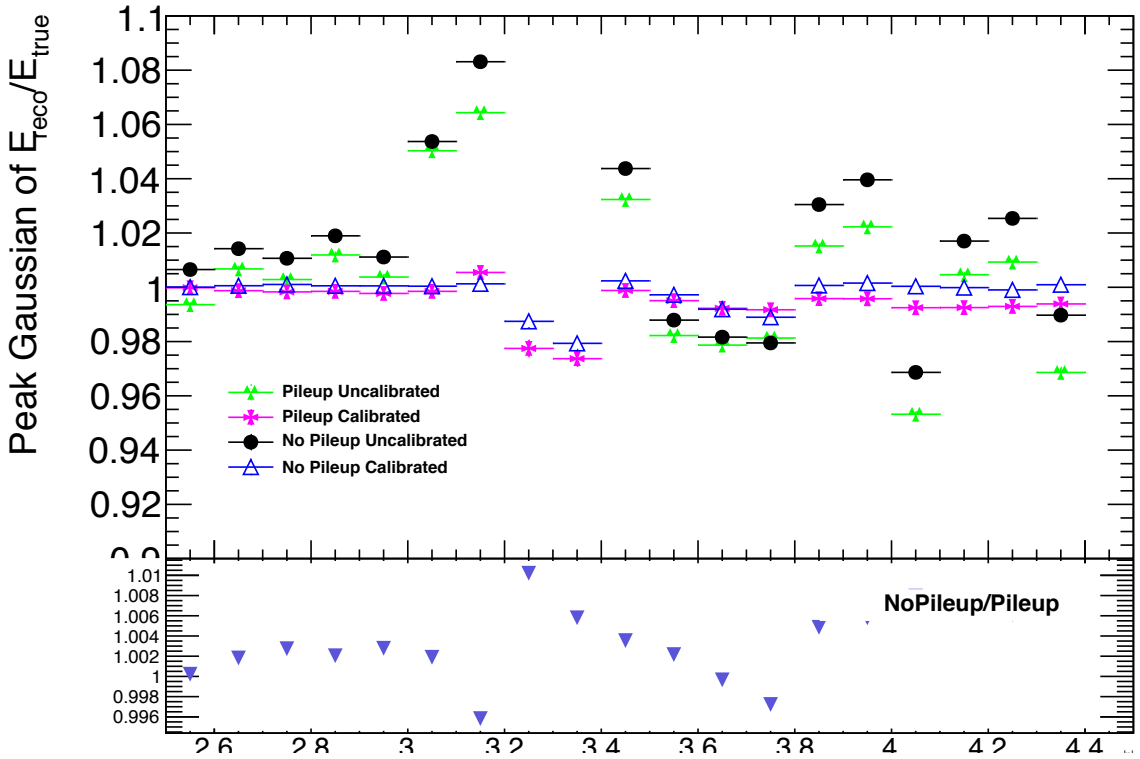


Pileup

Plots integrated with respect to η and p_T

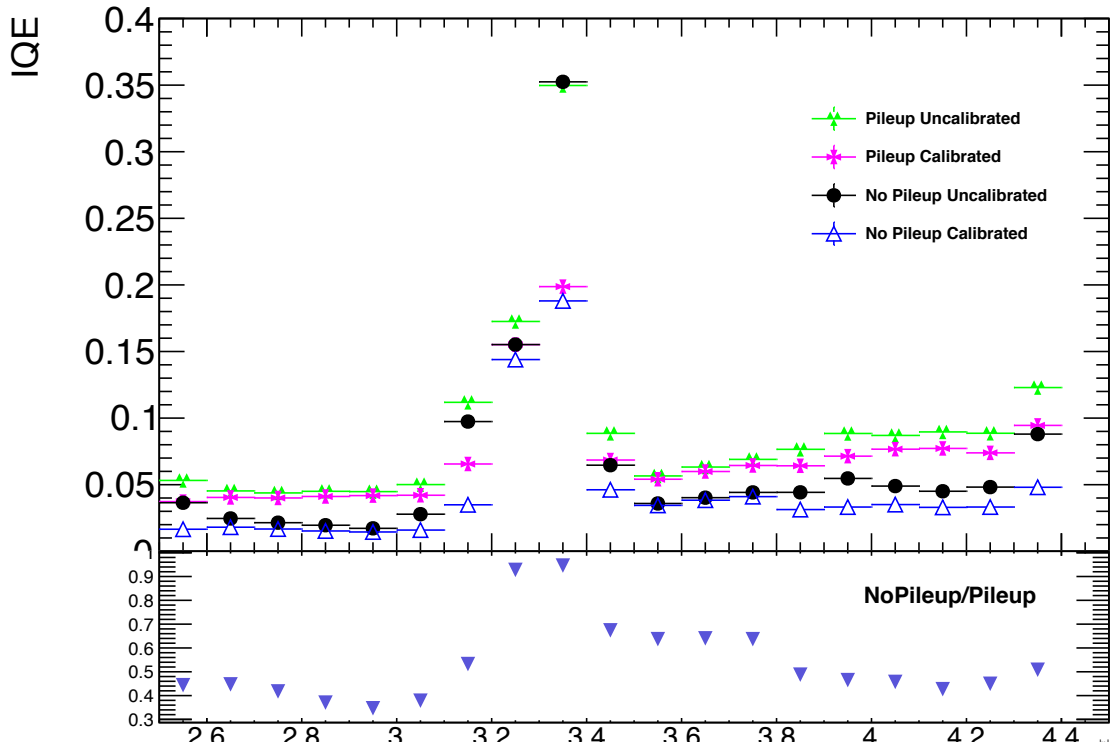
No Splits Peak Gaussian – Evaluating vs η

- BDT training works!
- Energy response improves in every η bin.
- Distribution peaks at almost exactly one in the EMEC.
- Slight deviations from one in the FCAL but still a massive improvement from the uncalibrated case.

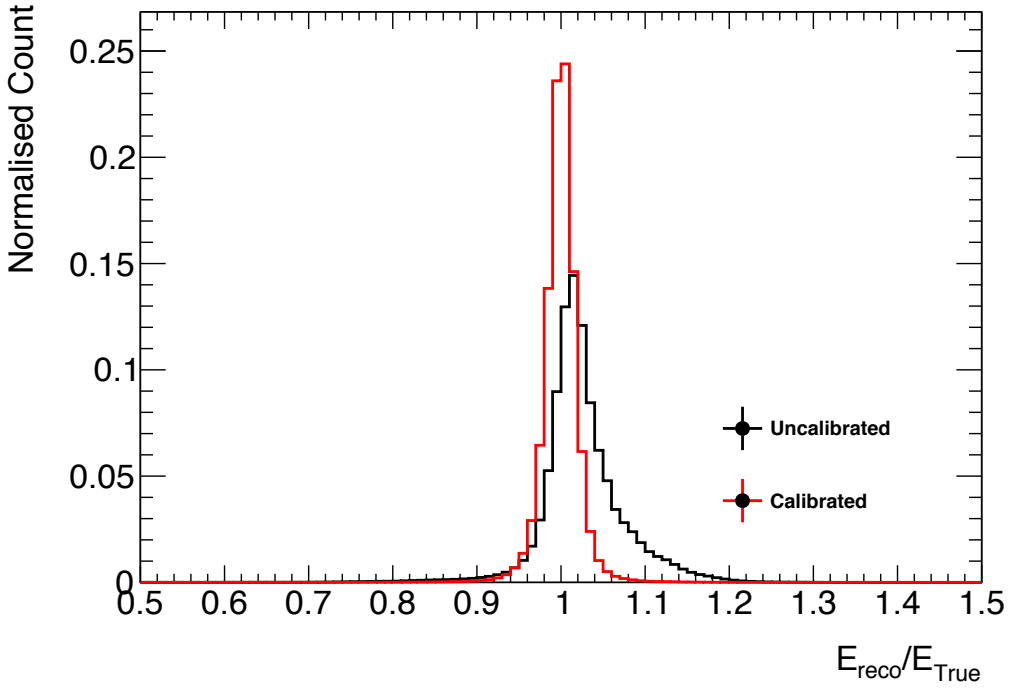


No Splits IQE – Evaluating vs η

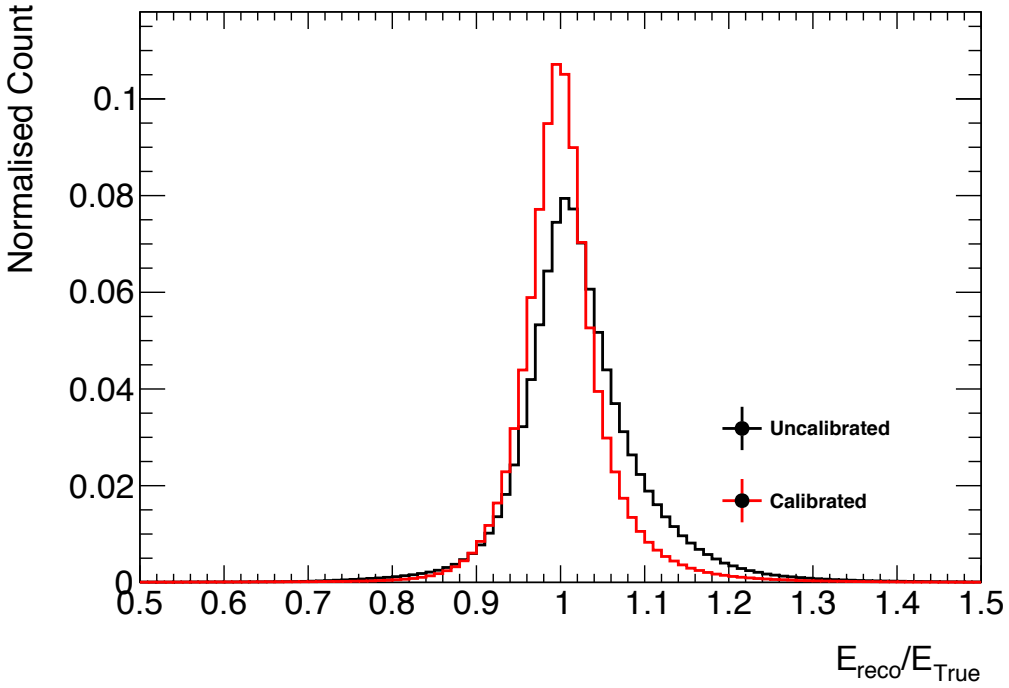
- $IQE = \frac{Q_3 - Q_1}{2\phi^{-1}(0.75)}$
- Like the PG plots we see an improvement in resolution in every η bin.
- Best bins see an improvement of approximately a factor of two in resolution.



Splits – EMEC Energy Distribution



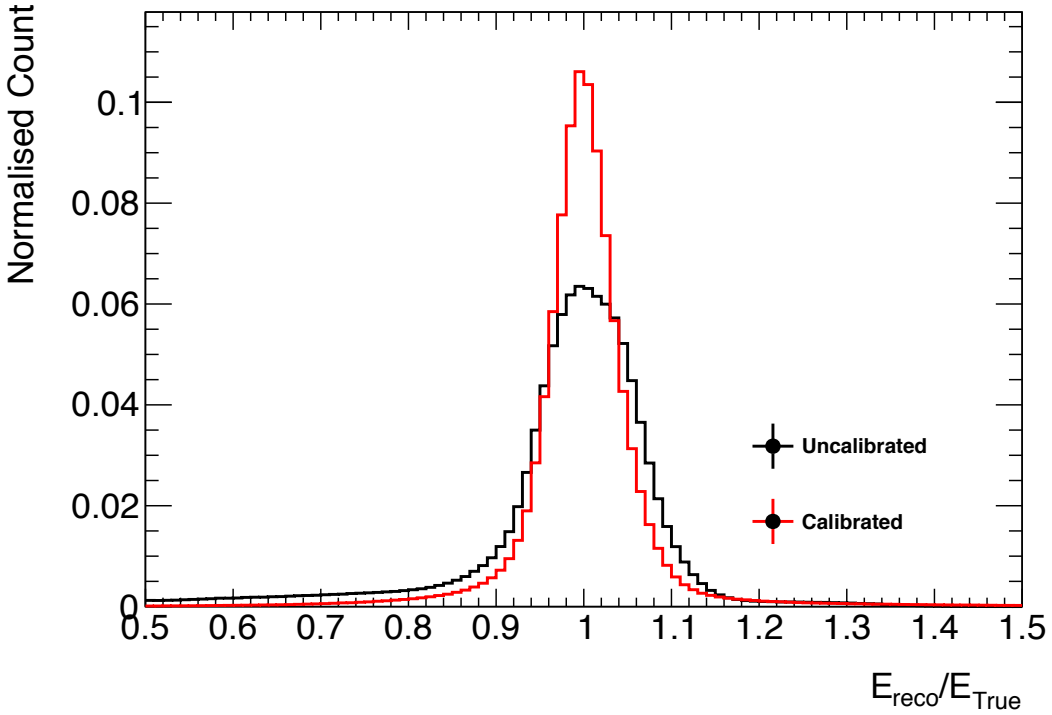
No Pileup



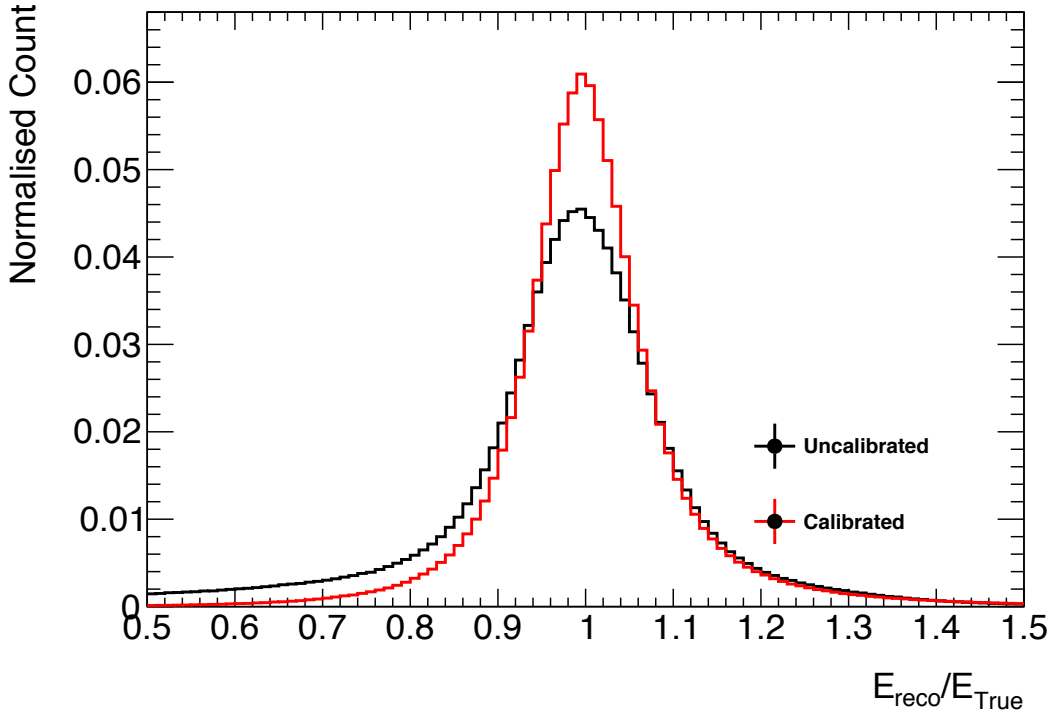
Pileup

Plots integrated with respect to η and p_T

Splits – FCAL Energy Distribution



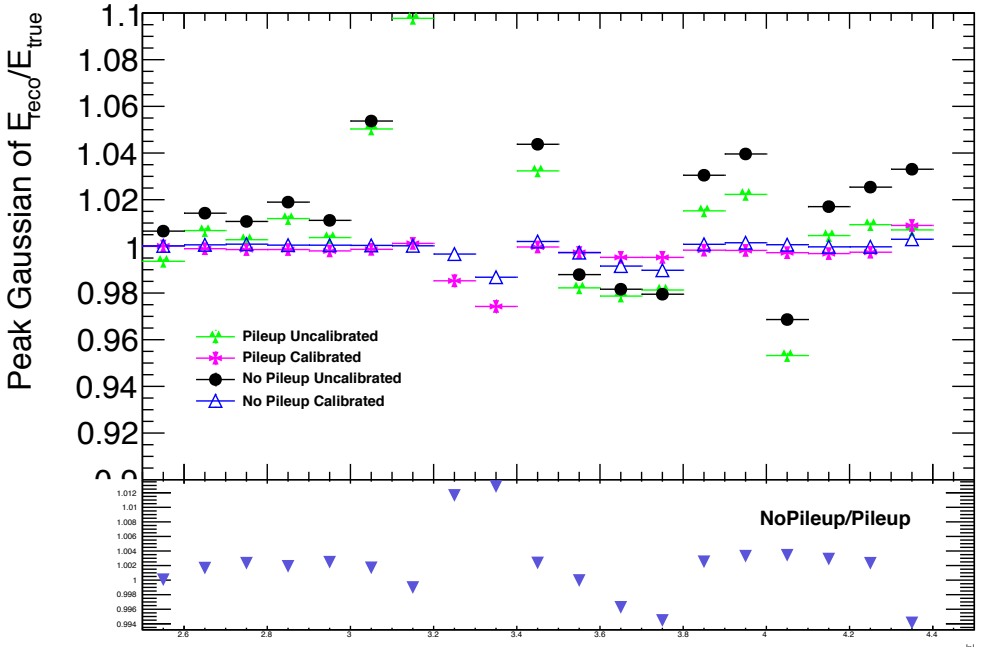
No Pileup

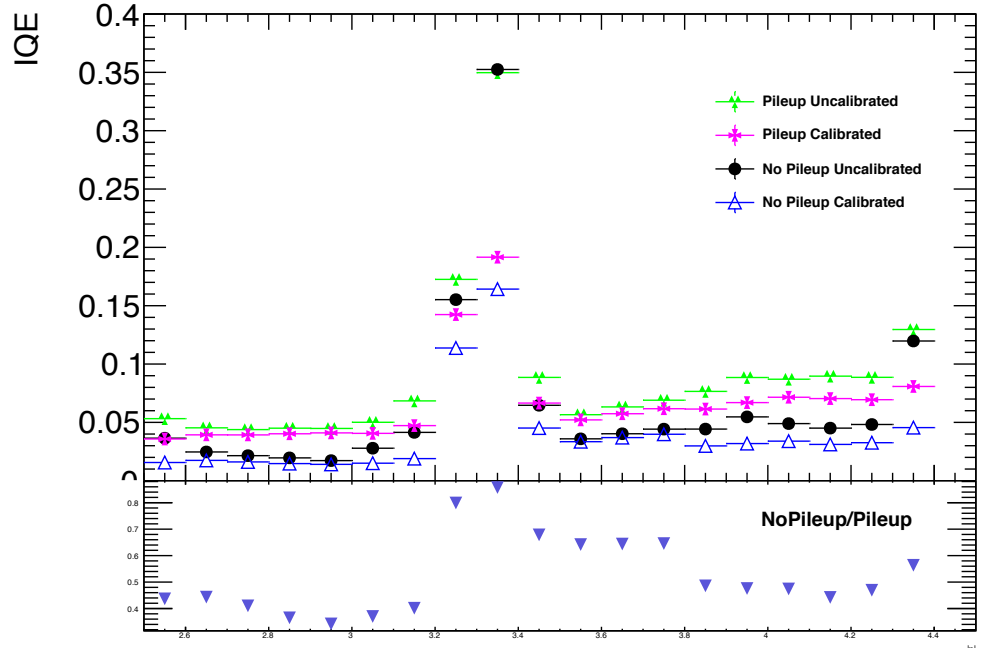


Pileup

Plots integrated with respect to η and p_T

Splits – Evaluating vs η

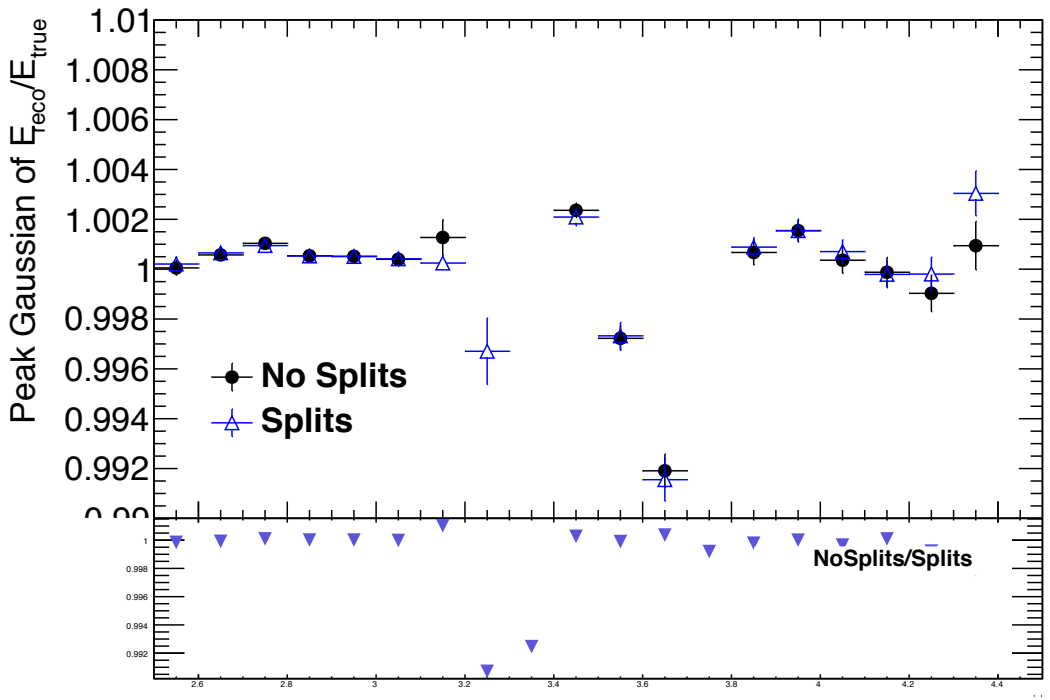




- As expected both the energy response and the resolution improve when compared to the uncalibrated values.
- Better agreement between no pileup and pileup in the FCAL PG values suggests that splitting gives a better result than not splitting.

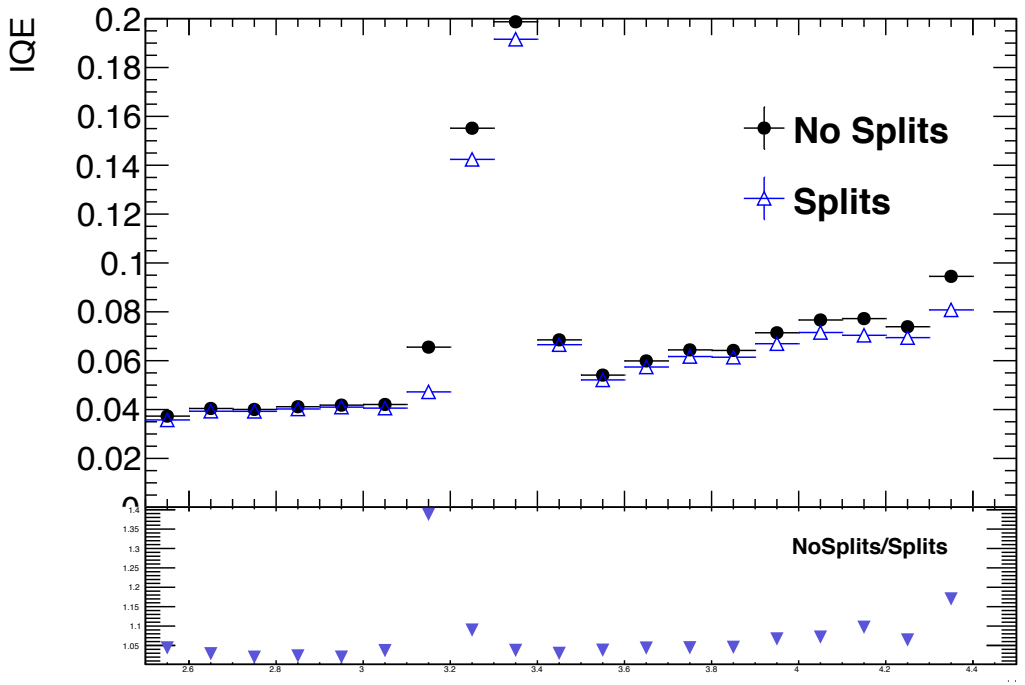
Splits or No Splits?

- Looking at the PG values when plotted against η reveal little difference between the two.
- IQE plot shows approximately 5% improvement in resolution in the FCAL.
- Looking at the E_T^{True} spectrum shows approximately 10% improvements in resolution in the best bins in the FCAL.
- Splitting helps to improve the resolution but does little for the energy response.



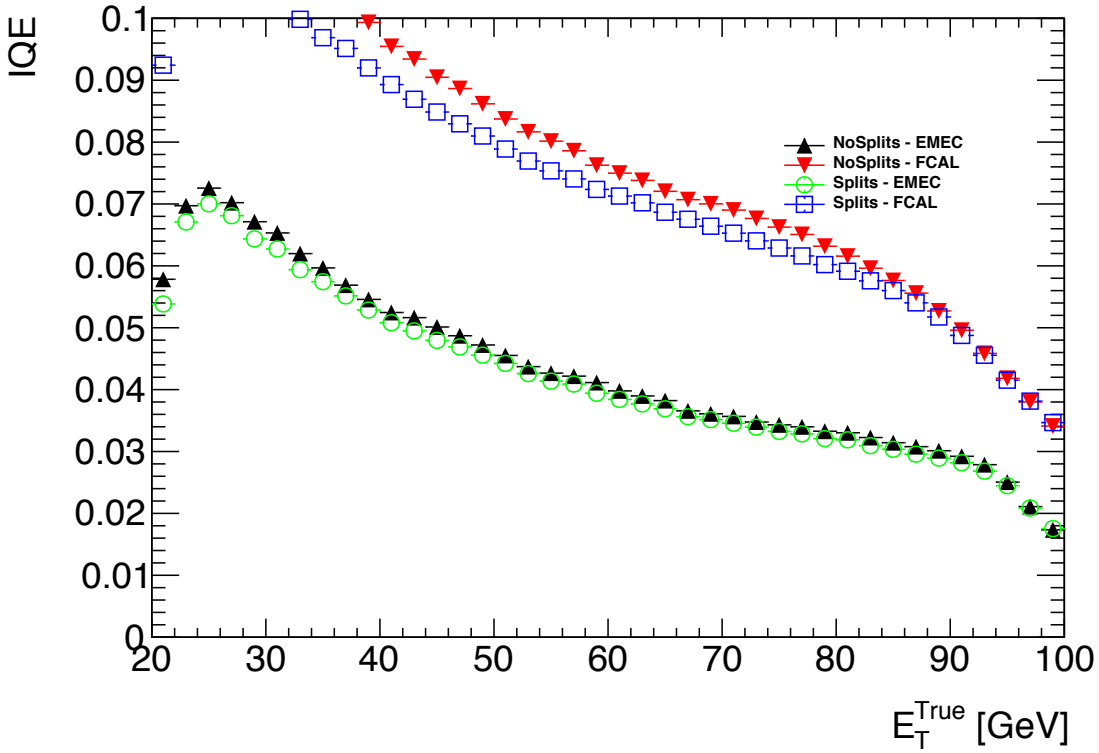
Splits or No Splits?

- Looking at the PG values when plotted against η reveal little difference between the two.
- IQE plot shows approximately 5% improvement in resolution in the FCAL.
- Looking at the E_T^{True} spectrum shows approximately 10% improvements in resolution in the best bins in the FCAL.
- Splitting helps to improve the resolution but does little for the energy response.



Splits or No Splits?

- Looking at the PG values when plotted against η reveal little difference between the two.
- IQE plot shows approximately 5% improvement in resolution in the FCAL.
- Looking at the E_T^{True} spectrum shows approximately 10% improvements in resolution in the best bins in the FCAL.
- Splitting helps to improve the resolution but does little for the energy response.



Training With Shower Shape Variables

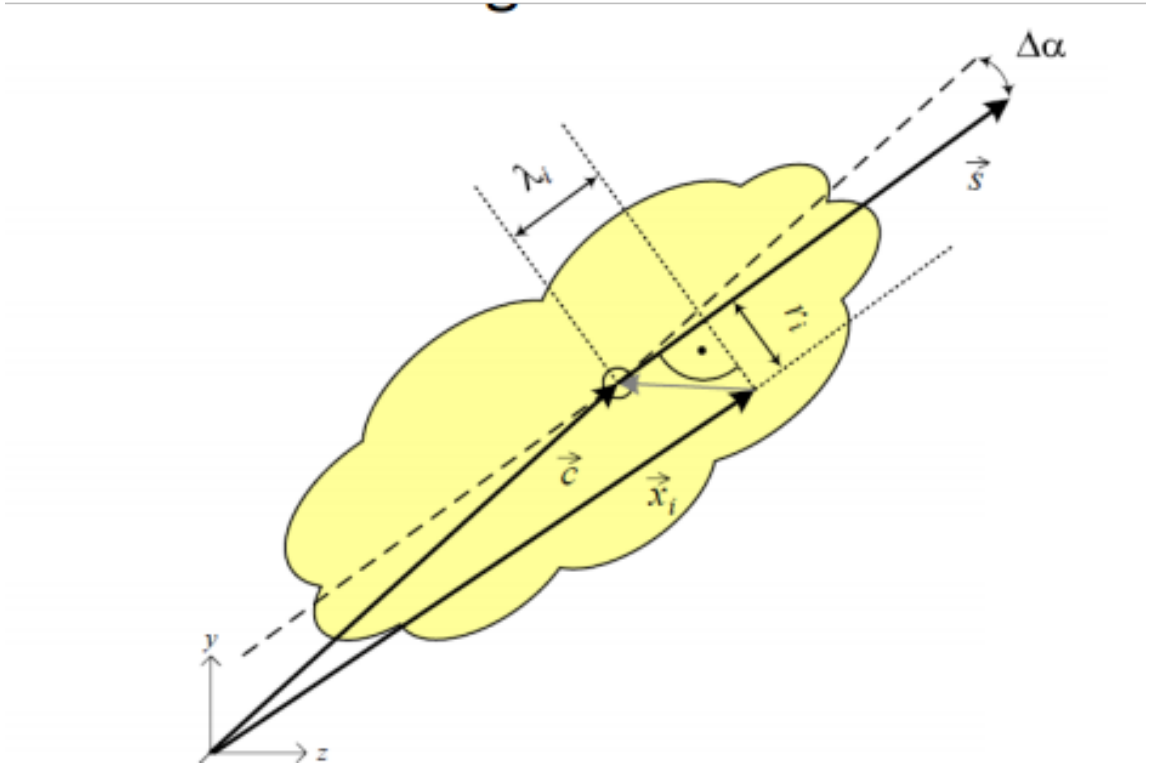
Shower Shape Development

- We choose variables currently available in the xAOD for release 21 that characterise the shape of the shower in the forward region:
  - *Longitudinal development (λ)*
  - *Radial development (r)*

- Variable moments as well:

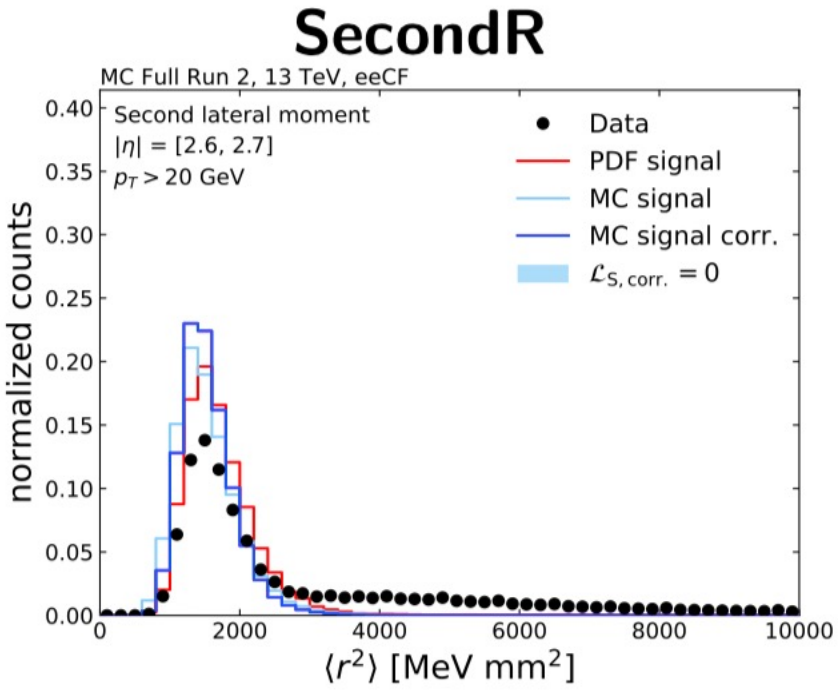
$$\langle x^n \rangle = \frac{1}{E_{norm}} \times \sum_{\{i|\, E_i > 0\}} E_i \cdot x_i^n$$

$$E_{norm} = \sum_{\{i|E_i > 0\}} E_i$$

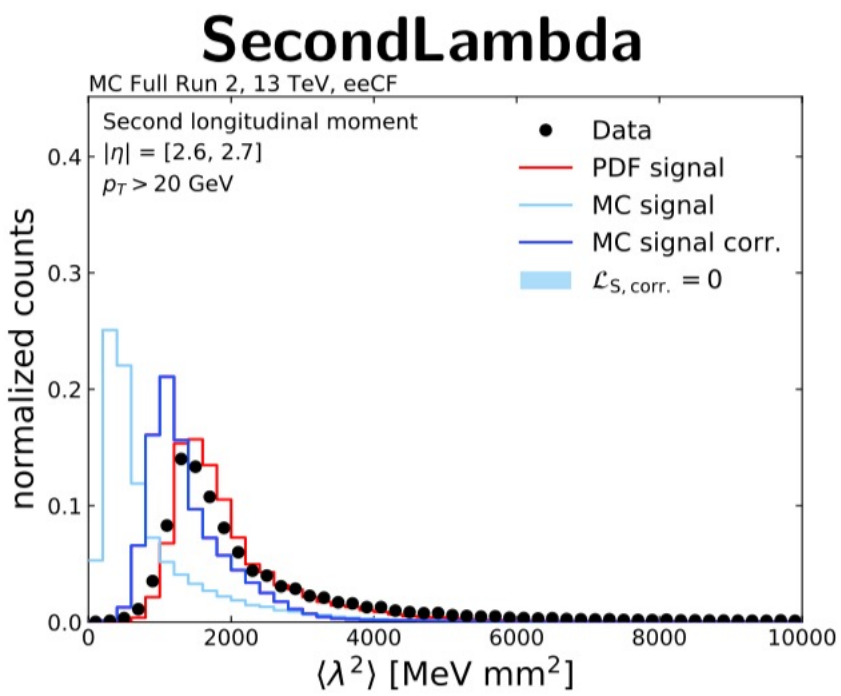


MC and Data (Mis)modelling

M. Hohmann



Good modelling



Not as good modelling

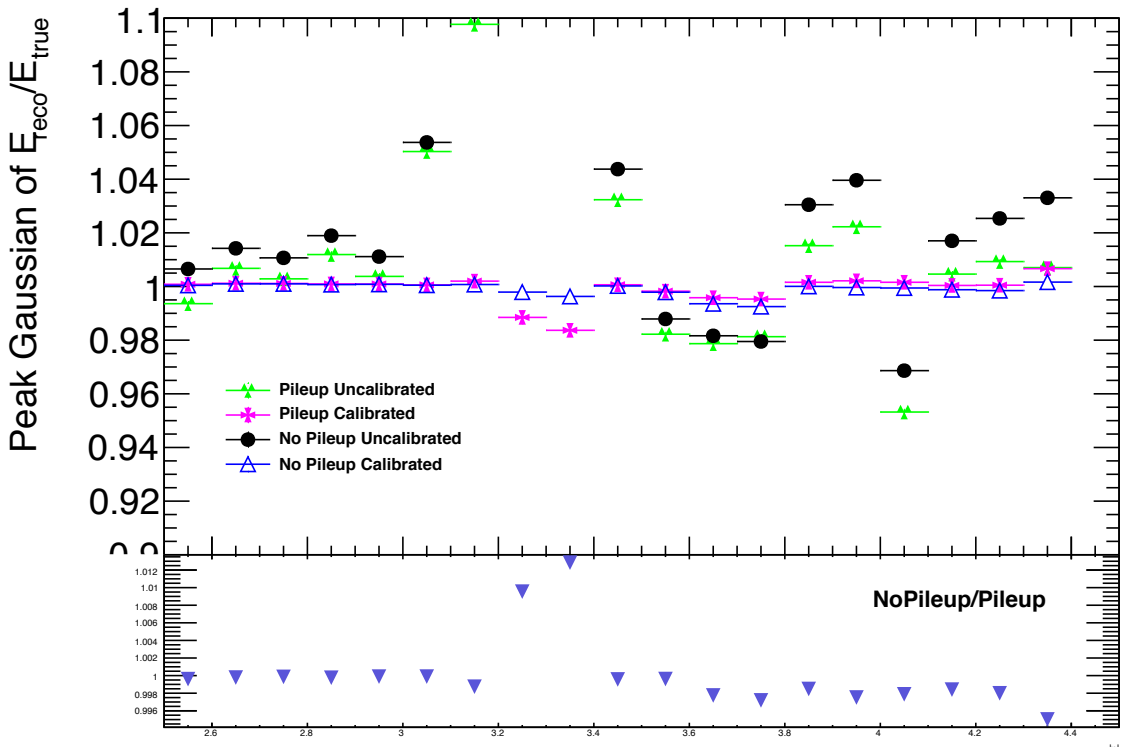
- MC modelling in the EMEC is known to not always be accurate for some shower shape variables.
- Care was taken to only include variables where the modelling was accurate.

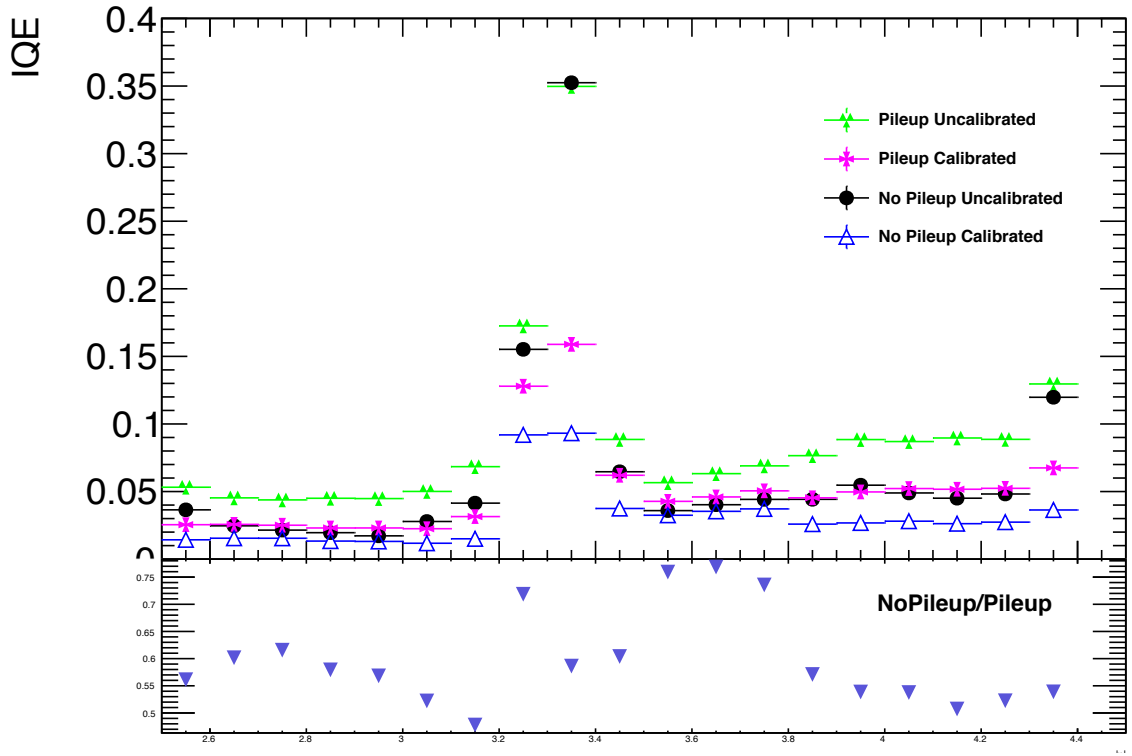
Training Variables

NoSplits	Splits	
	EMEC ($\eta < 3.15$)	FCal ($\eta > 3.15$)
Cluster eta (η_{cl})	η_{cl}	$CentreX/Y/Z$
Cluster phi (ϕ_{cl})	ϕ_{cl}	
Cluster energy (E_{raw})	E_{raw}	E_{raw}
Second Rho ($\langle\rho^2\rangle$)	$\langle\rho^2\rangle$	$\langle\rho^2\rangle$
Second r ($\langle r^2\rangle$)	$\langle r^2\rangle$	$\langle r^2\rangle$
Centre Lambda (λ_{centre})	λ_{centre}	λ_{centre}
–	$E^{Max}_{cell,layer1}/E^{Max}_{cell,layer2}$	–
Pileup Training Only		
Number of primary vertices (NPV)	NPV	NPV

ADD DESCRIPTION

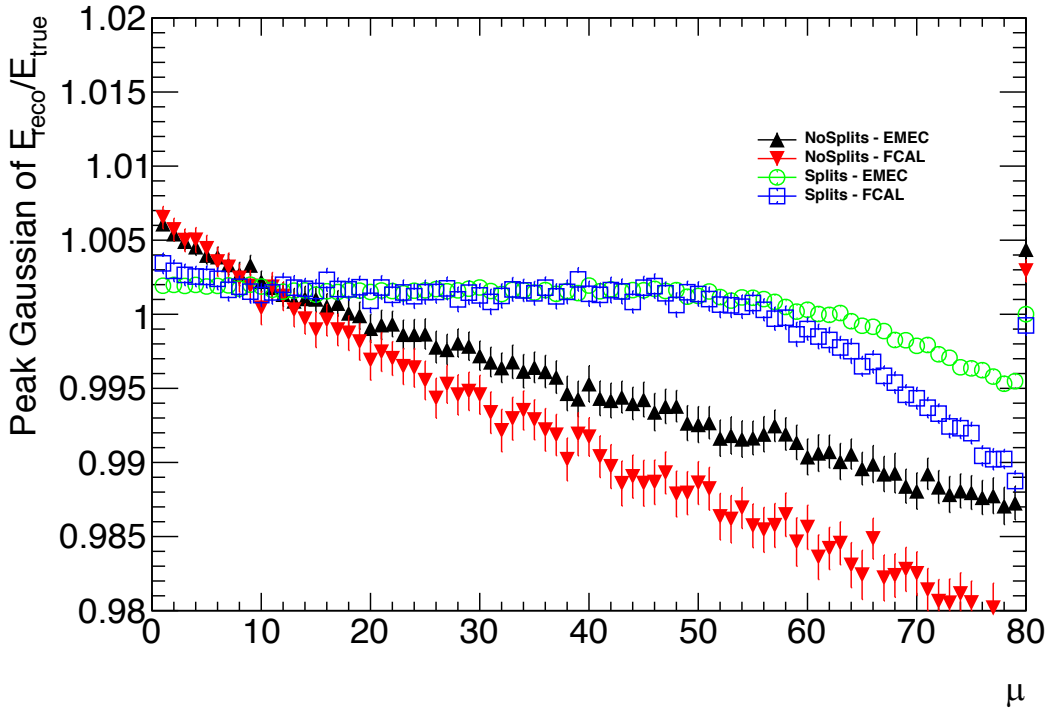
Splits – Evaluating vs η

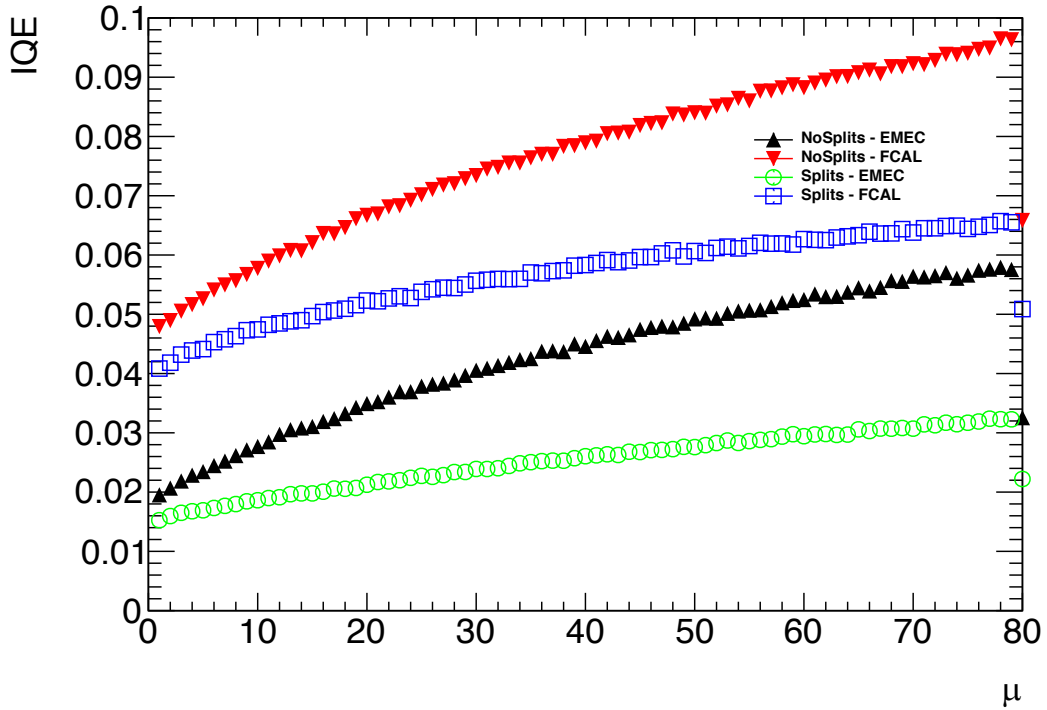




- Again, the peak of the distribution moves towards one for both the non-pileup and pileup trainings.
- Approximately factor of two improvement in resolution in the FCAL.

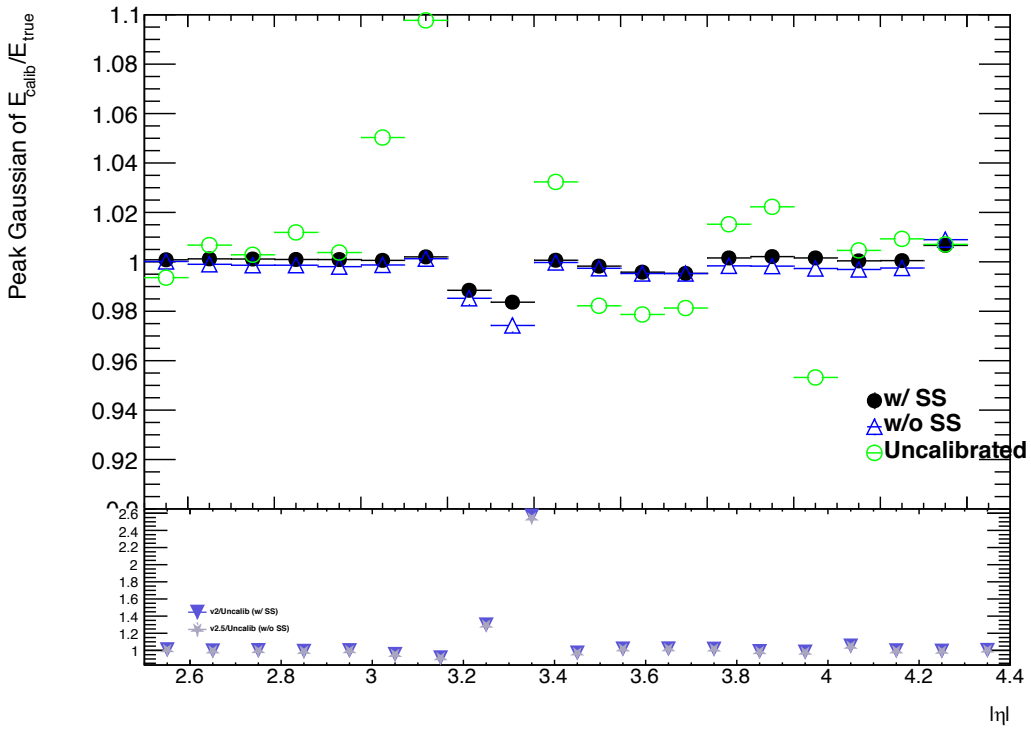
Splits/No Splits IQE – Evaluating vs μ

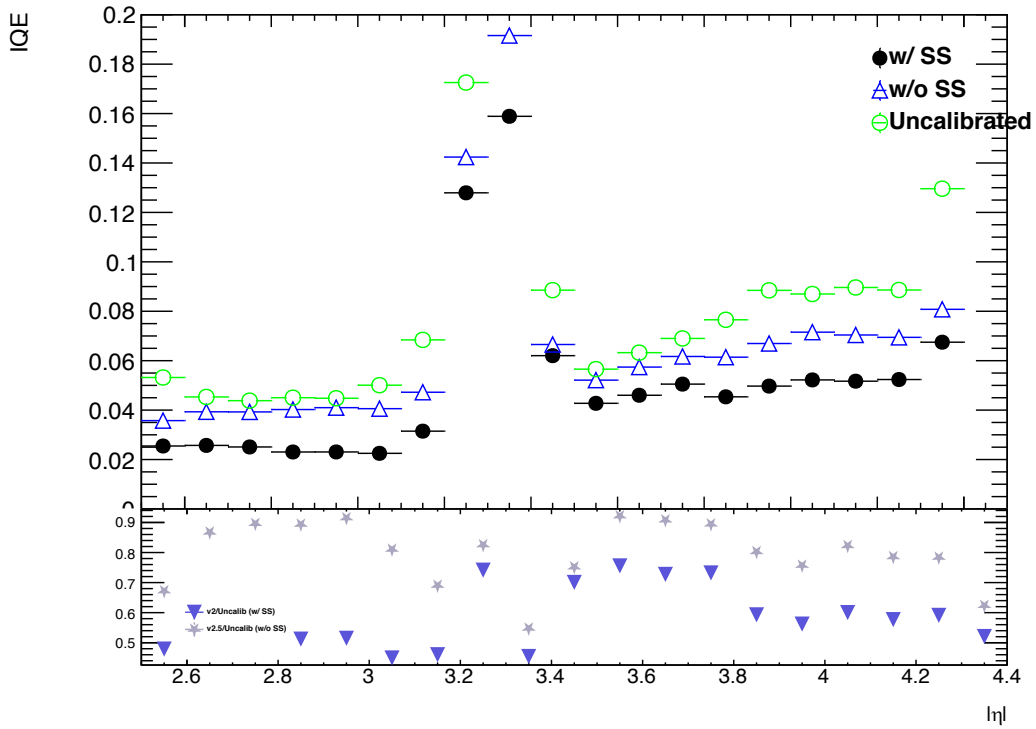




- Splitting not only helps to improve the resolution but maintains the quality of the energy response as pileup increases.
- At high pileup, resolution is improved by approximately 40% by implementing splitting.

With Shower Shapes or Without? - Splits with Pileup



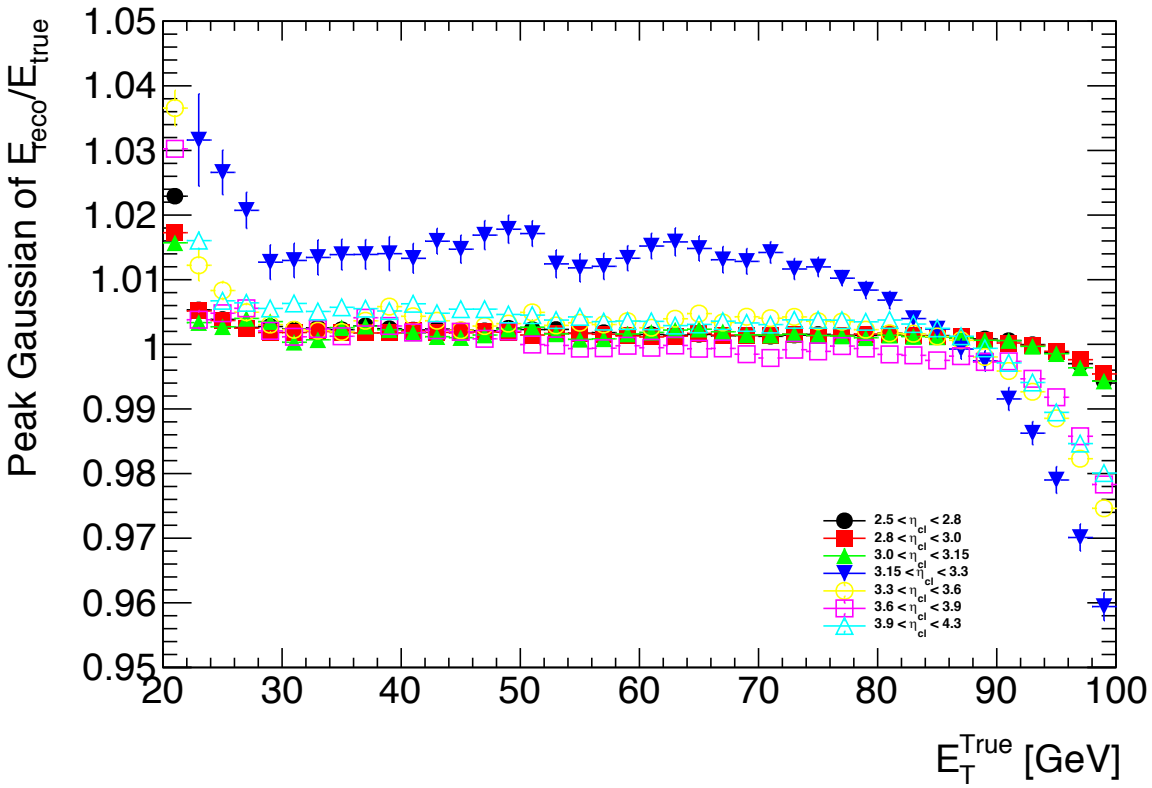


- Including the shower shapes helps with both the energy response and resolution in both the EMEC and the FCAL.
- Energy response moves to within the permille level of one in almost every η bin.
- Factor of two improvement in resolution in almost every η bin when including shower shapes.

Further Splits?

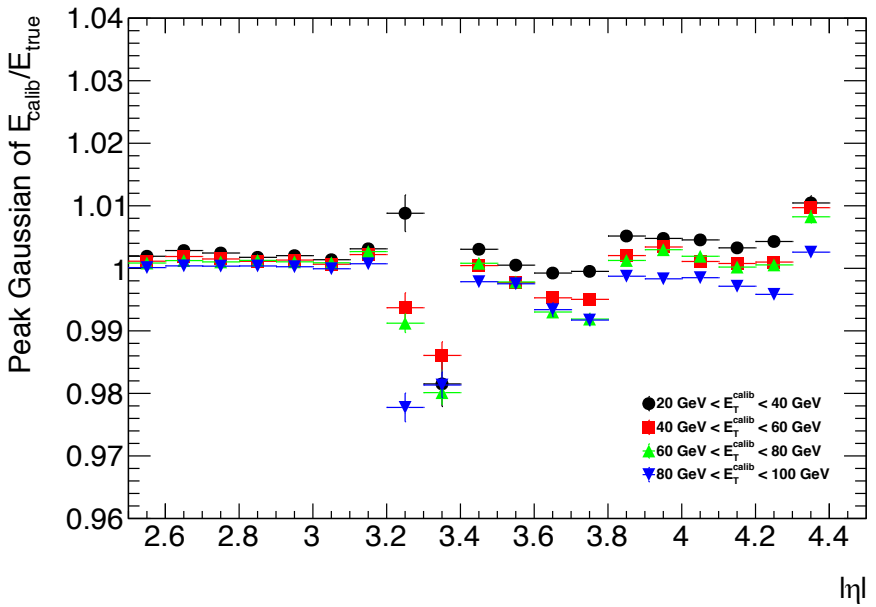
Further η Splits?

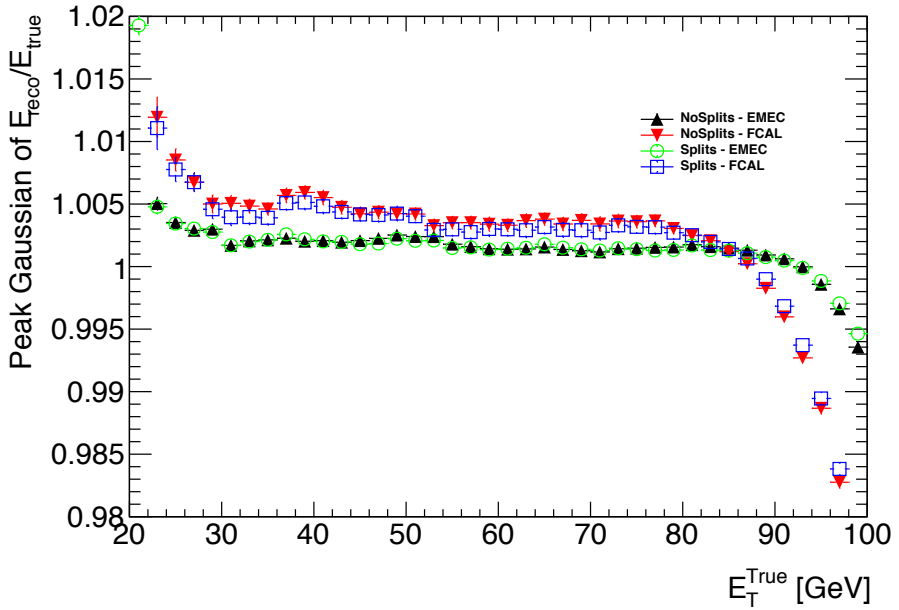
- Split calibrated results into 6 η bins and plot the Peak Gaussian vs E_T^{True}.
- Good agreement between EMEC and FCAL bins with only one outlier.
- Calibration performance is degraded in the crack region between the EMEC and FCAL.
- Performing a specific calibration in this region may help performance.



Split in E_T bins?

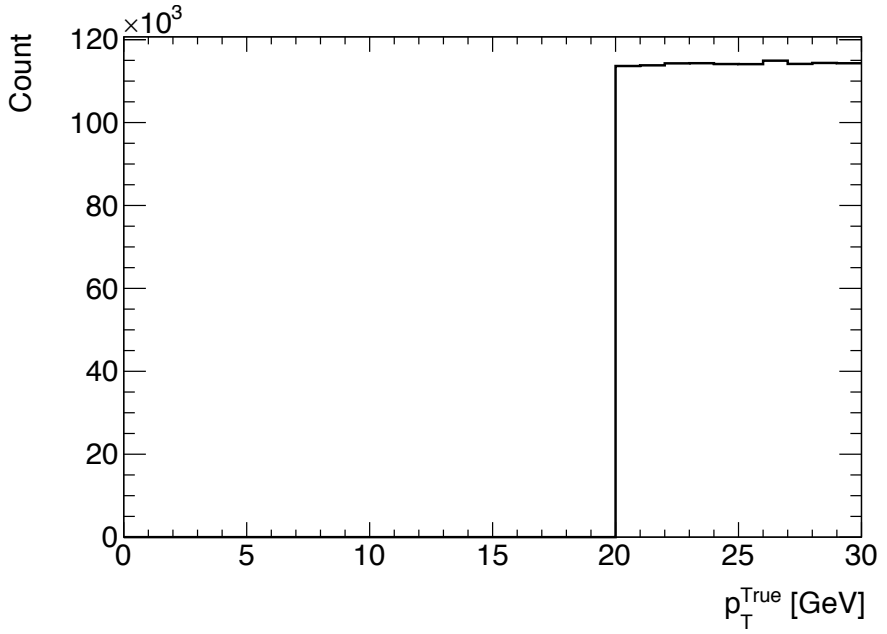
- Looking at the η spectrum shows a spread of PG values in the FCAL after calibrating and binning in E_T^{calib}.
- Difference is much smaller for the EMEC.
- Splitting the FCAL events into E_T bins may help at high and low energies.

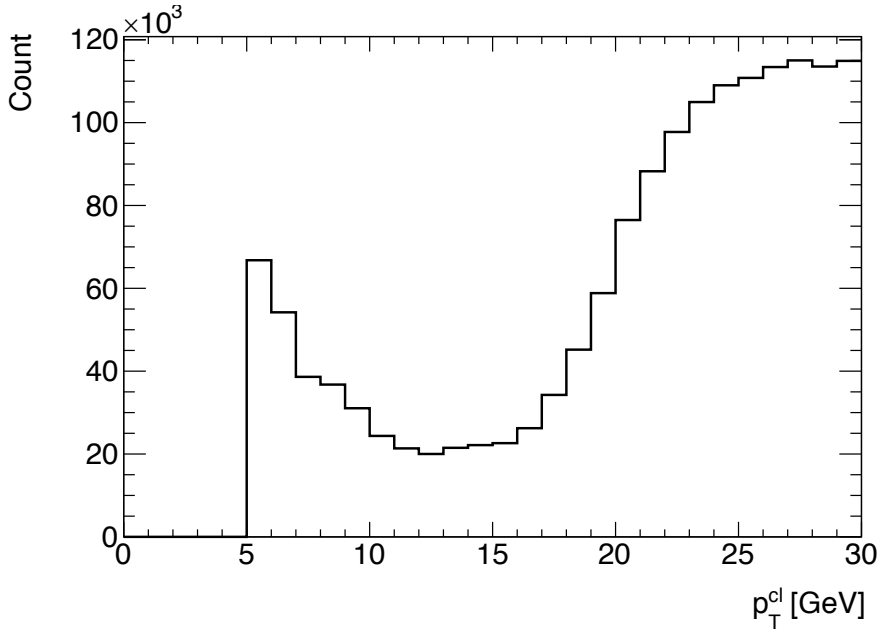




Future Trainings

- Base training with μ added in for pileup training.
- Base training with E_T splits for the no (η) splits training and for the separate FCAL training.
- Base training with additional selection criteria:
  - *Electron loose ID*
  - $p_T^{Reco} > 20\ GeV$
- All of the above trainings have been done, they just need to be analysed!



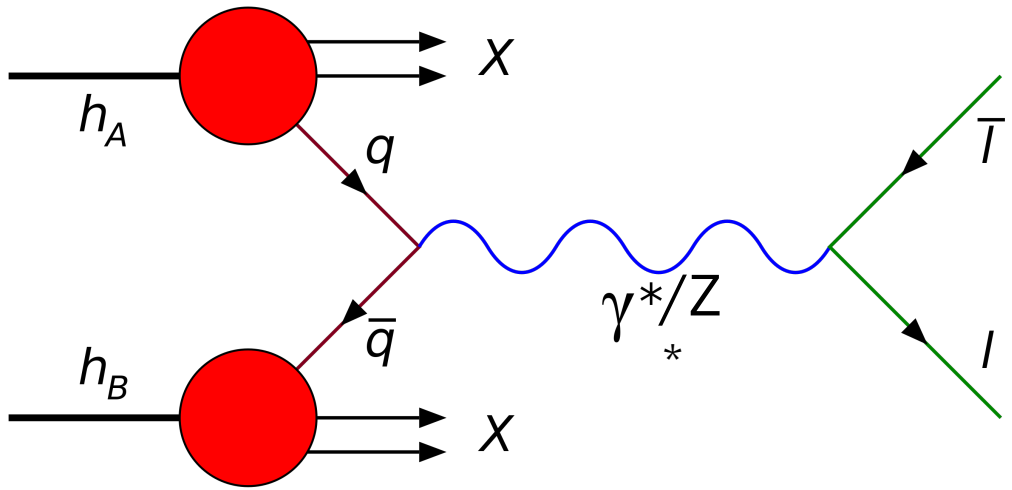


Looking Forward

- Evaluate performance of the training when fudging the shower shapes.
- Choose the best training!
- Perform the same analysis using Athena 22.0
- Write a tool to apply the corrections that can be used by the entire ATLAS collaboration.
- Start work on my thesis topic.

Thesis Topic – Measurement of 4-fold Drell-Yan Differential Cross Section

- Use full LHC Run 2 data set to decompose cross section in terms of:
  - *Invariant mass of leptons.*
  - *Rapidity of dilepton system.*
    - *Lepton decay angles in quark rest frame.*
    - *Boson pT.*
- Use electrons in both central and central-forward regions.
- Act as a control for BSM searches.
- Improve determination of PDFs.
- Improve Monte Carlo tuning.



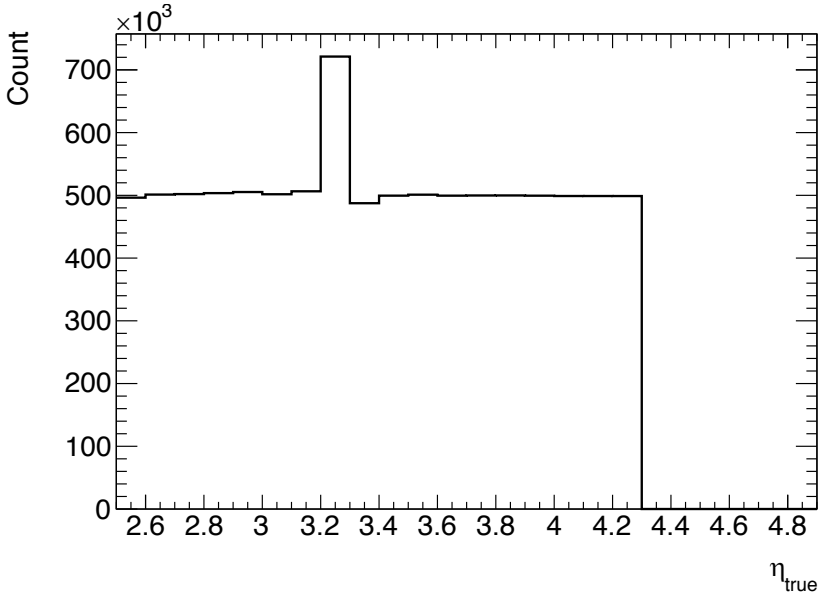
Summary

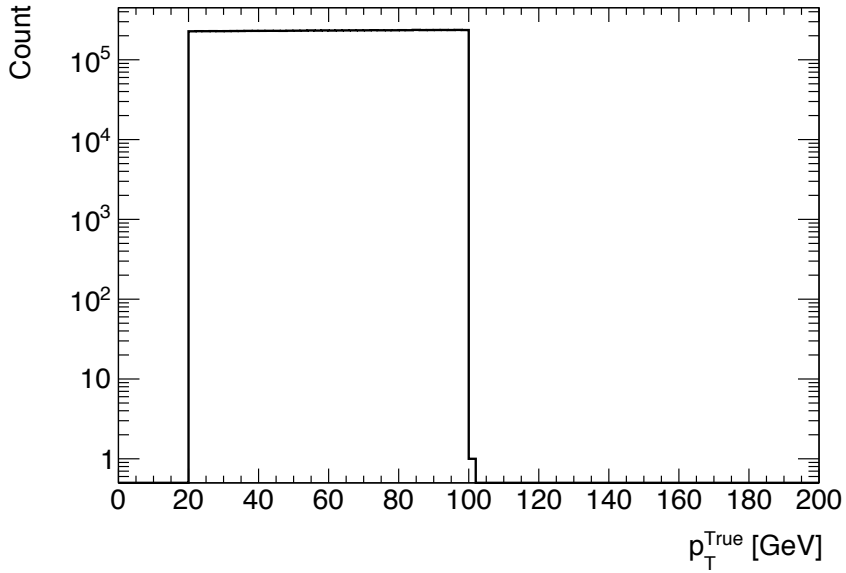
- Very promising initial results show an approximately factor of two improvement in electron energy response and resolution across the η spectrum.
- Shower shape variables are important to the training and cannot be removed without degrading the overall calibration.
- Various further optimisations to the training have been implemented but are still to be analysed.
- Qualification task should be wrapping up within the coming months and work on the thesis topic will begin. I'm looking forward to it!

Backup

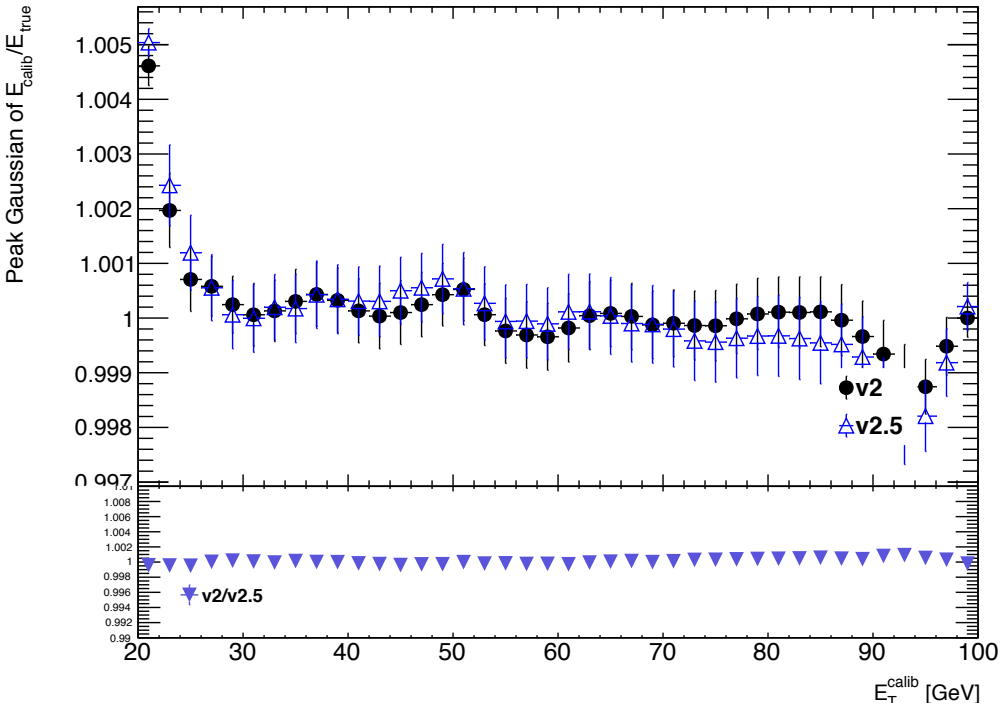
Input Files

- Two single electron samples, with and without pileup (JIRA):
  - mc16_13TeV:mc16_13TeV.415013.ParticleGun_single_ele_PtFlat20_100_etaFlatp23_43.merge.AOD.e8296_s3126_r12058_r10726 (Pileup)
  - mc16_13TeV:mc16_13TeV.415013.ParticleGun_single_ele_PtFlat20_100_etaFlatp23_43.merge.AOD.e8296_s3126_r12290_r10726 (No pileup)
- 10 million events in each file.
- Flat distribution in eta from 2.5 to 4.3.
- Flat p_T spectrum from 20 GeV to 100 GeV

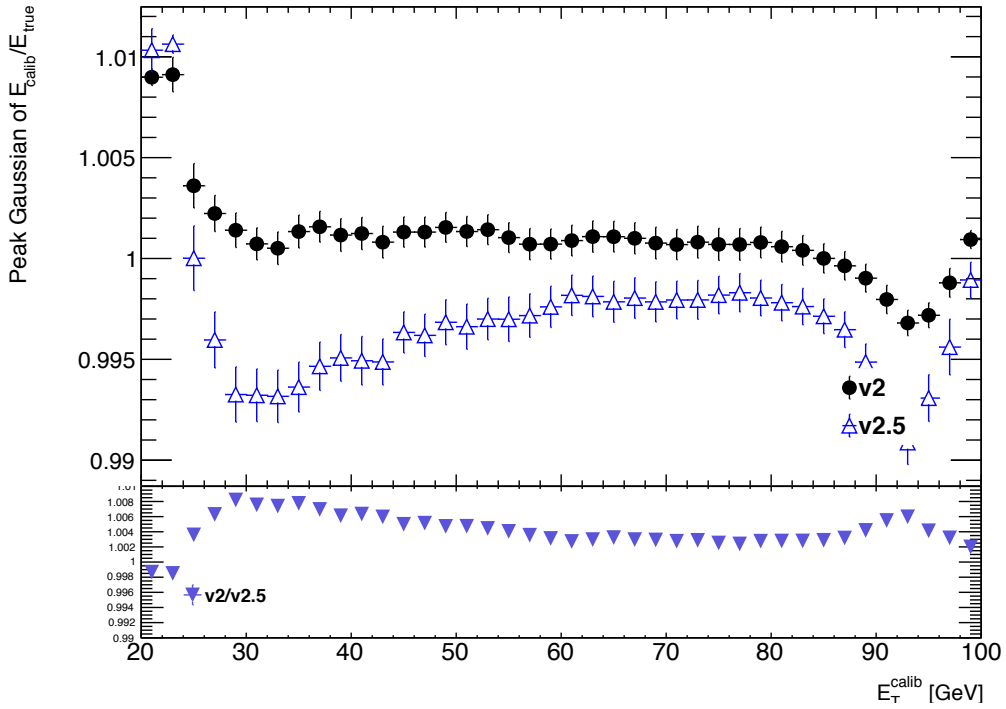




No Splits PG – Evaluating vs E_T

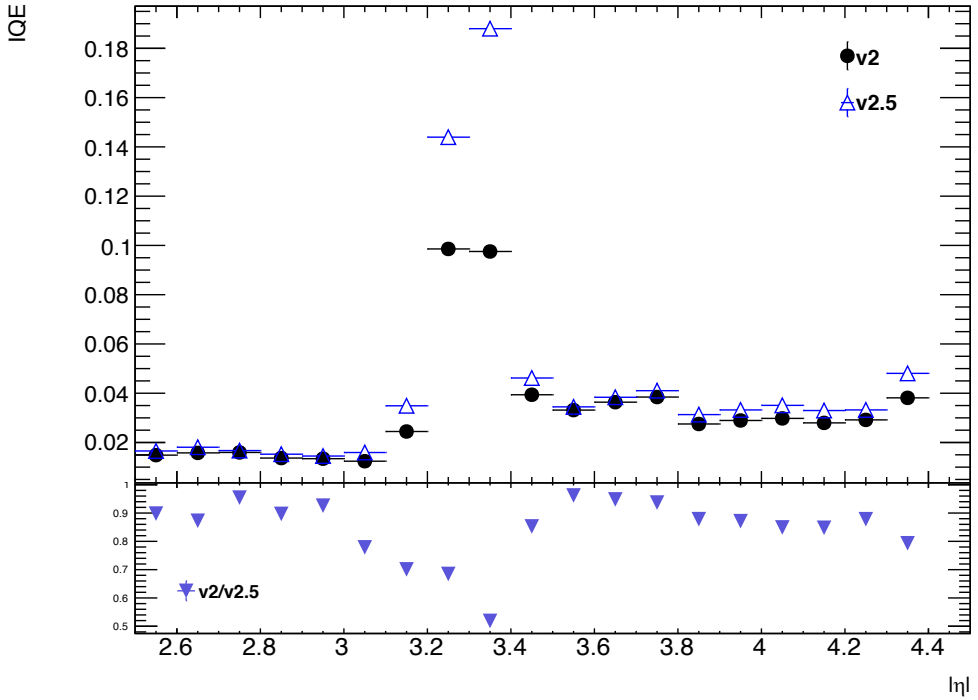


No Pileup

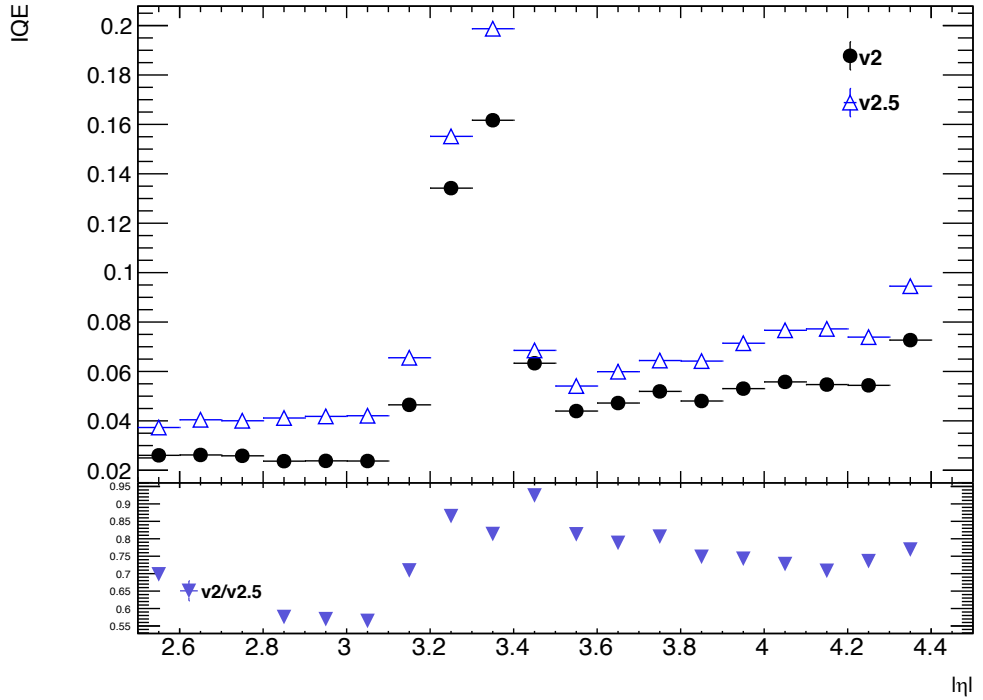


Pileup

No Splits IQE – Evaluating vs η

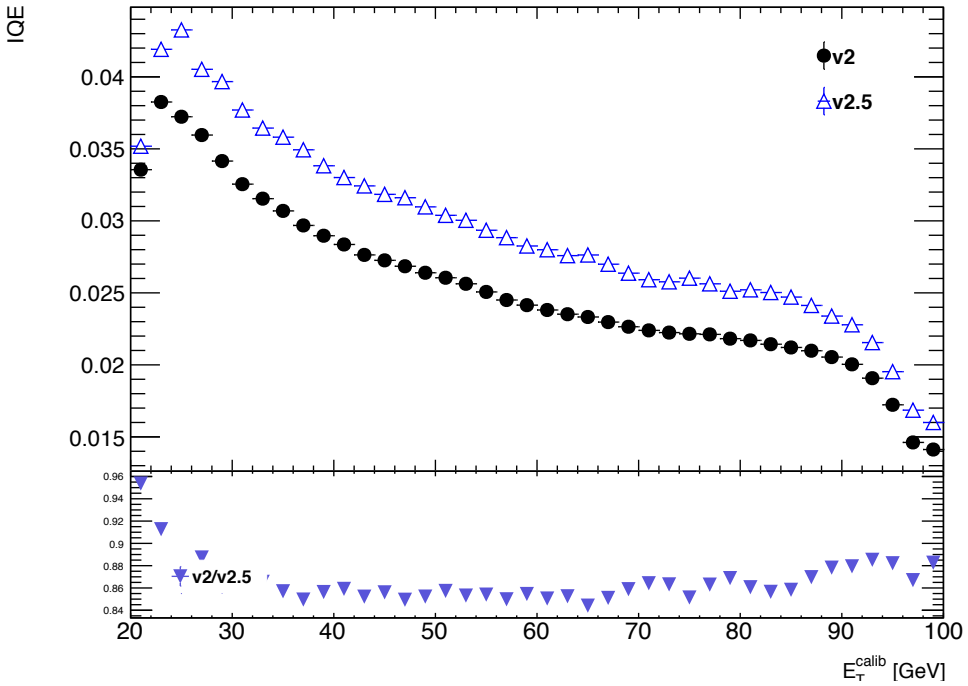


No Pileup

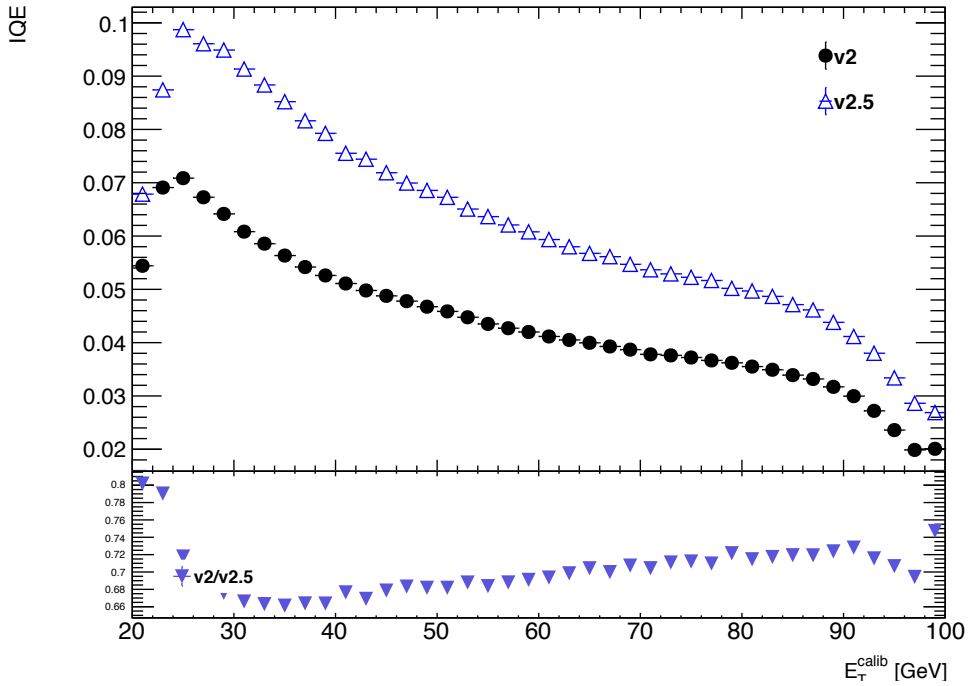


Pileup

No Splits IQE – Evaluating vs E_T

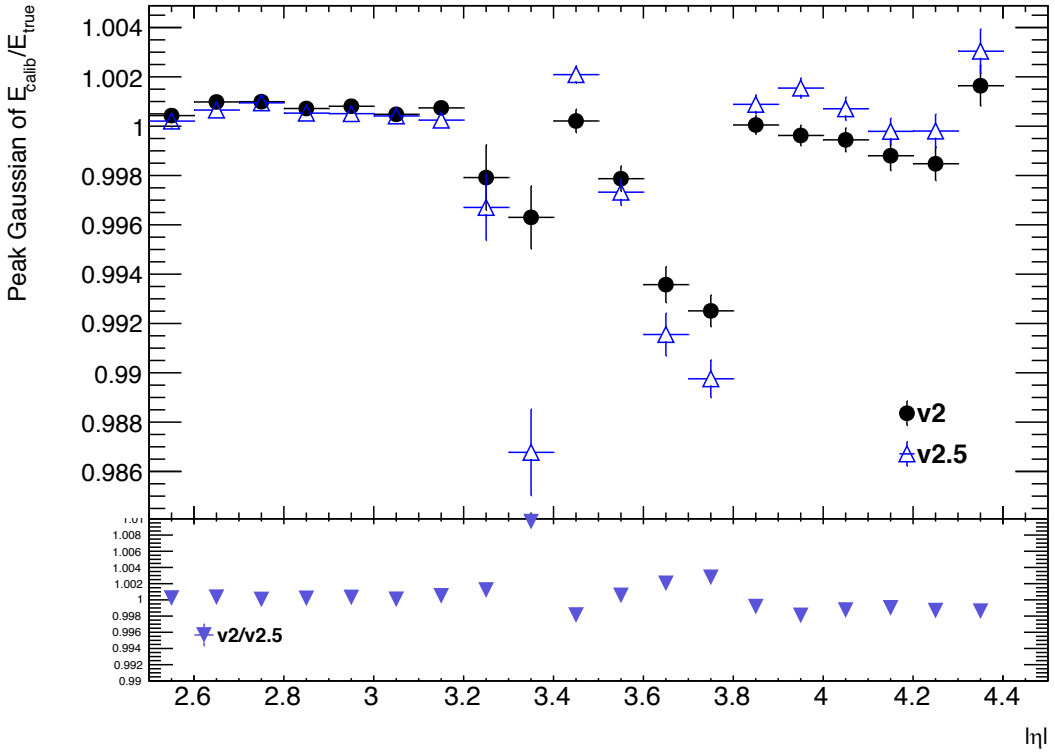


No Pileup

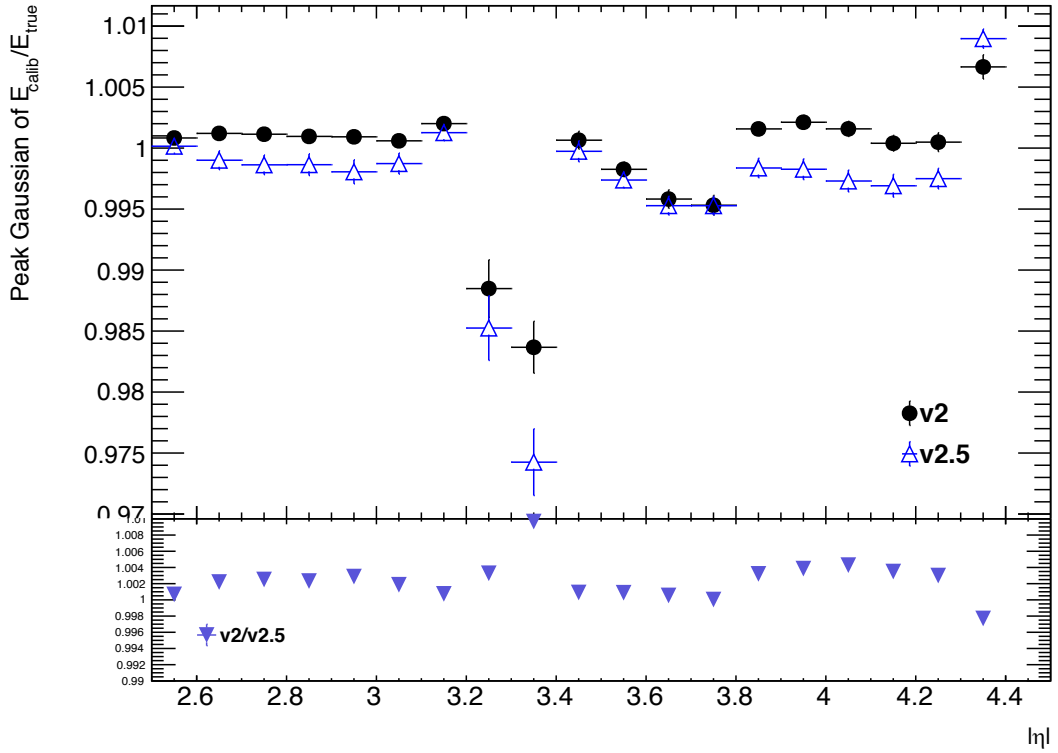


Pileup

Splits PG – Evaluating vs η

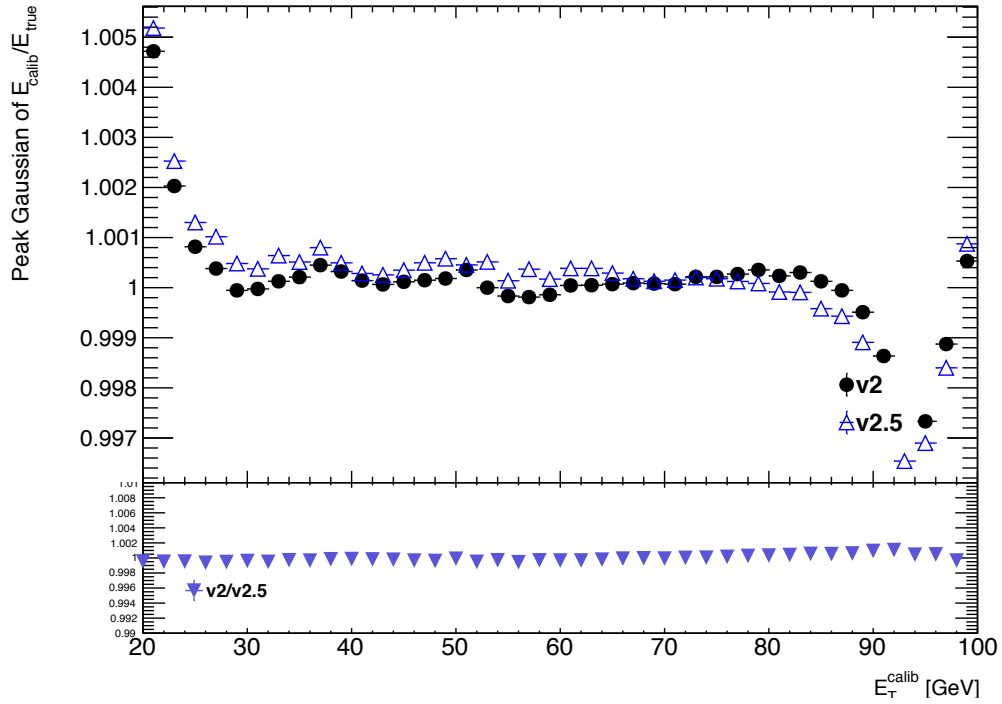


No Pileup

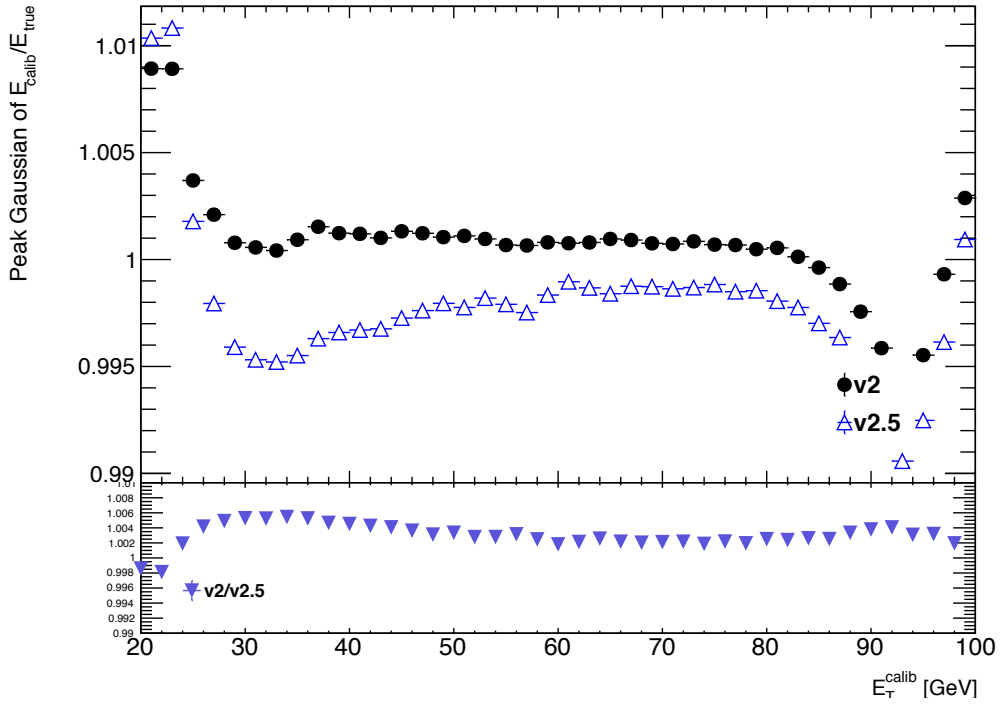


Pileup

Splits PG – Evaluating vs E_T

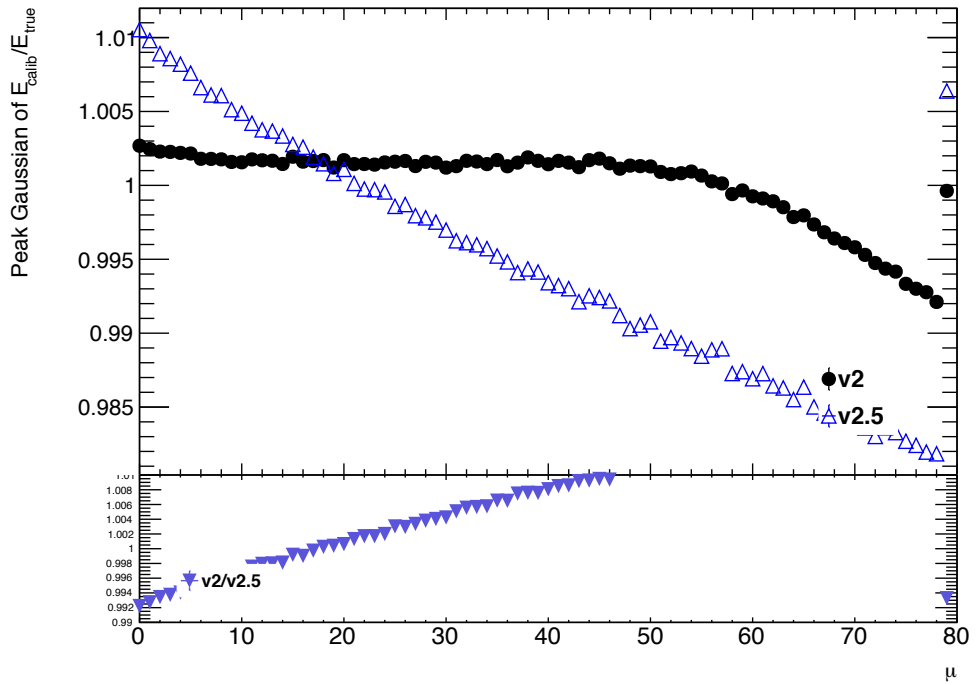


No Pileup

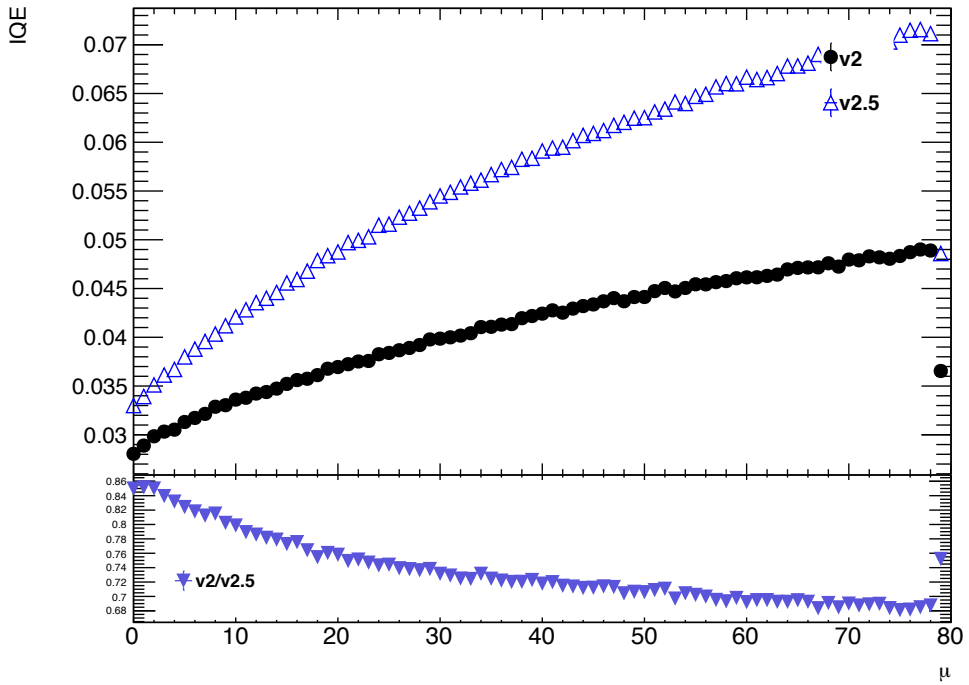


Pileup

Splits PG - Evaluating vs μ

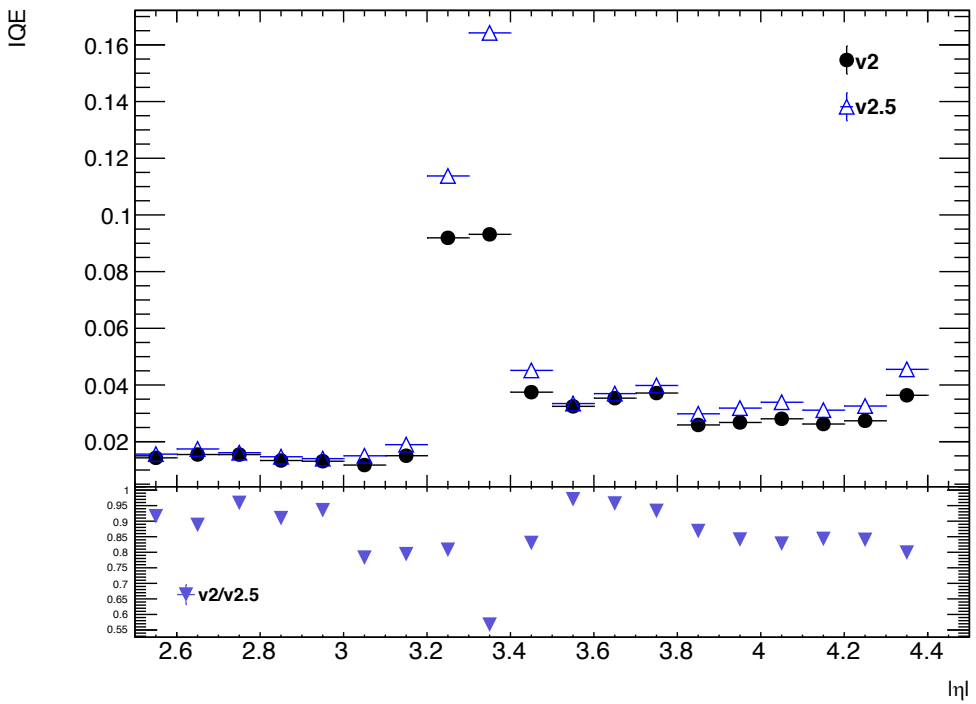


PG

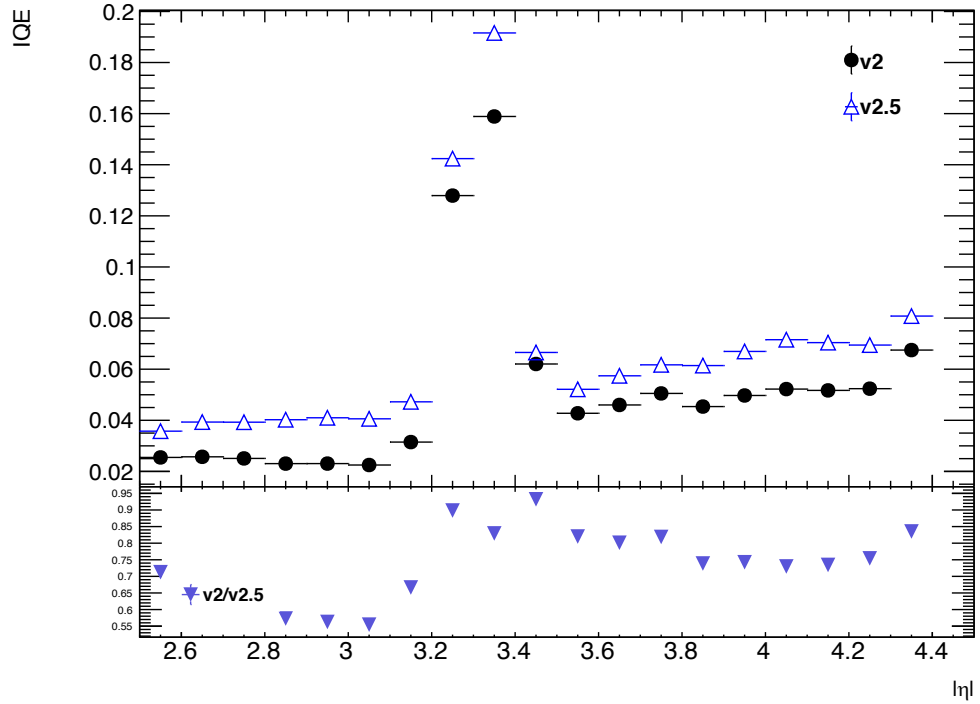


IQE

Splits IQE – Evaluating vs η

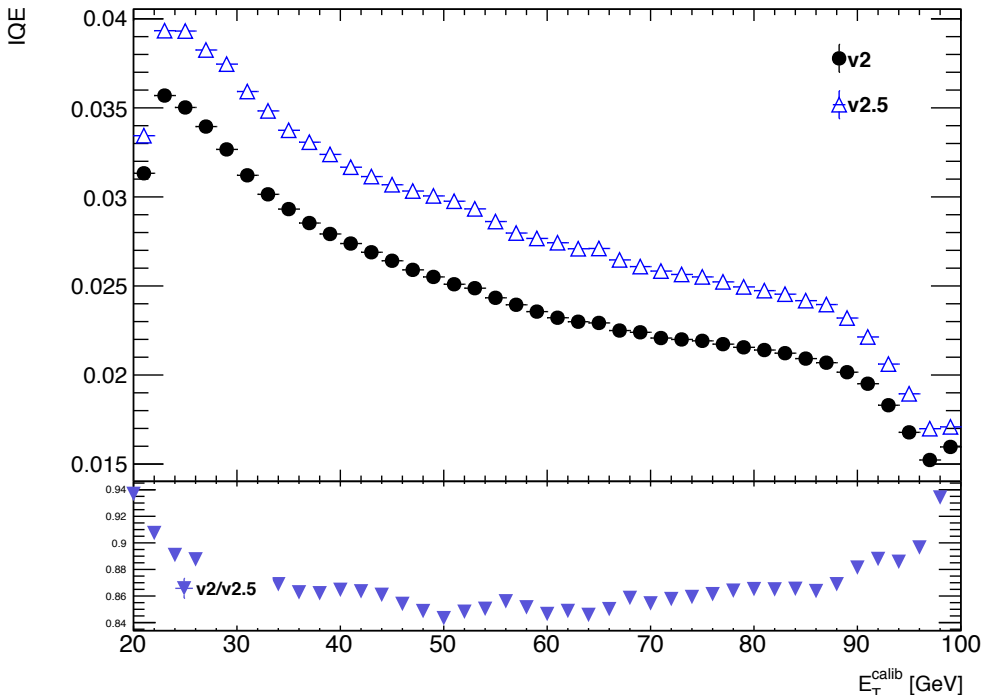


No Pileup

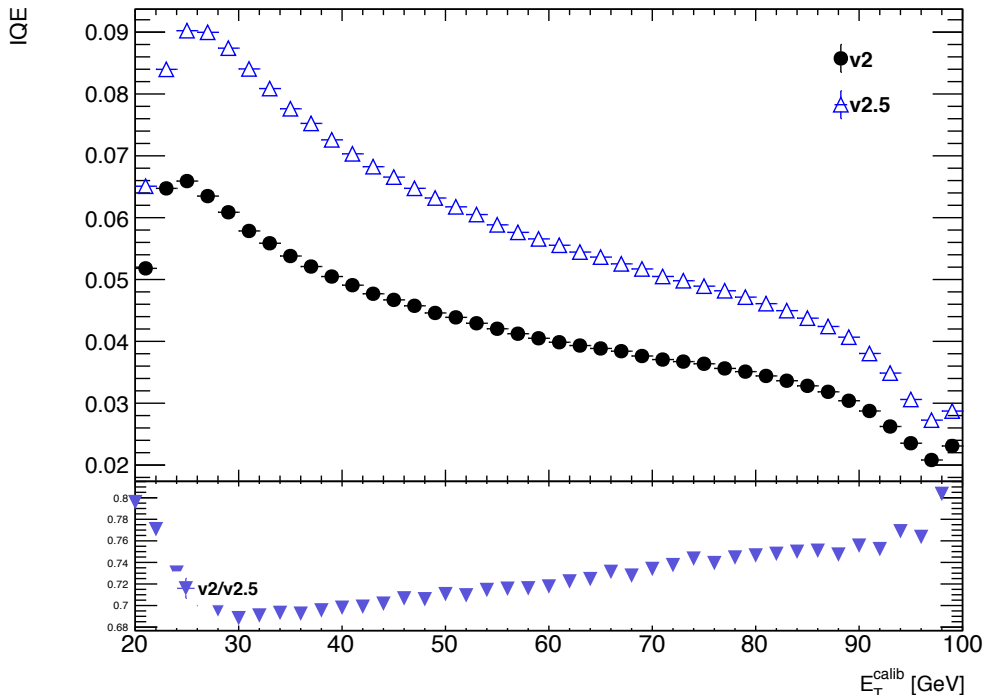


Pileup

Splits IQE – Evaluating vs E_T

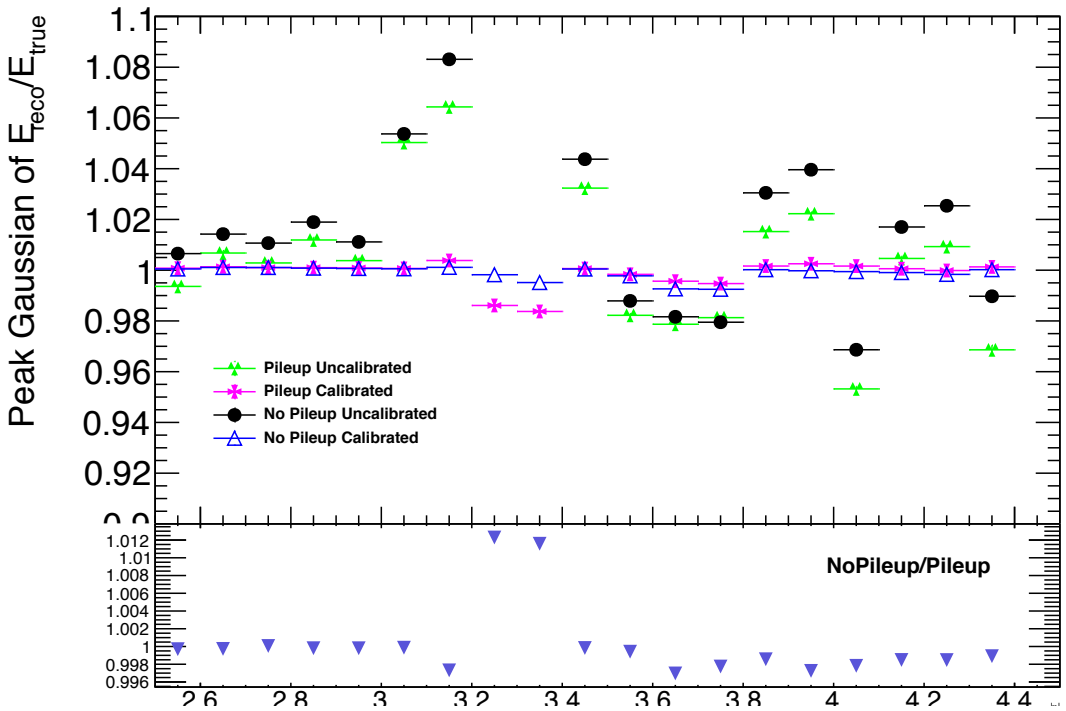


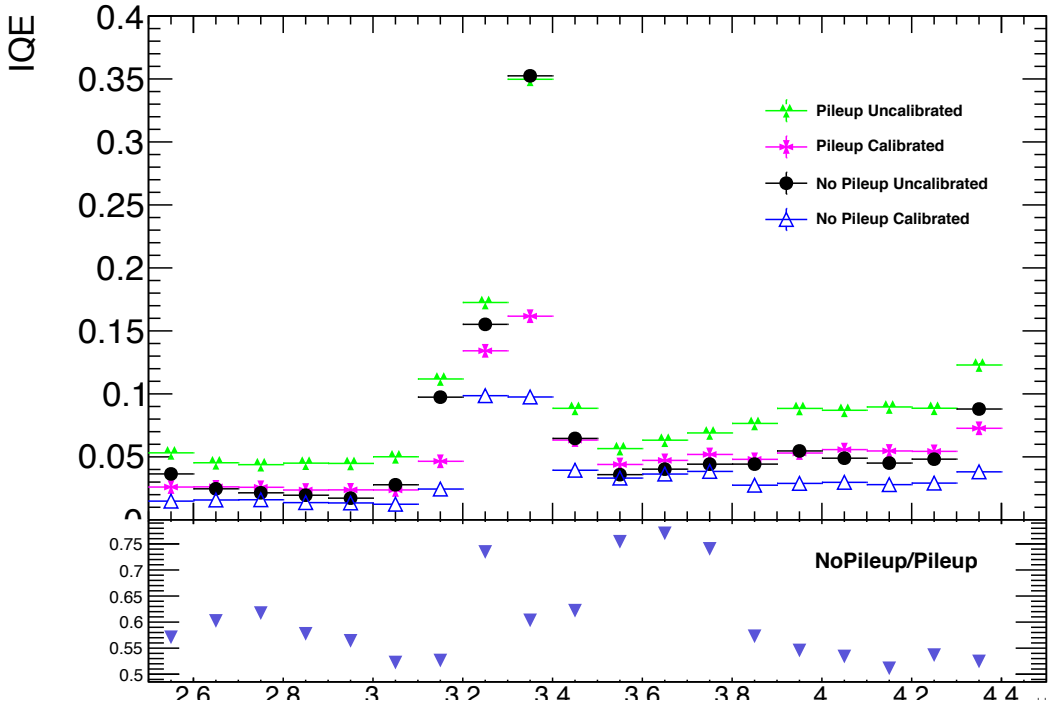
No Pileup



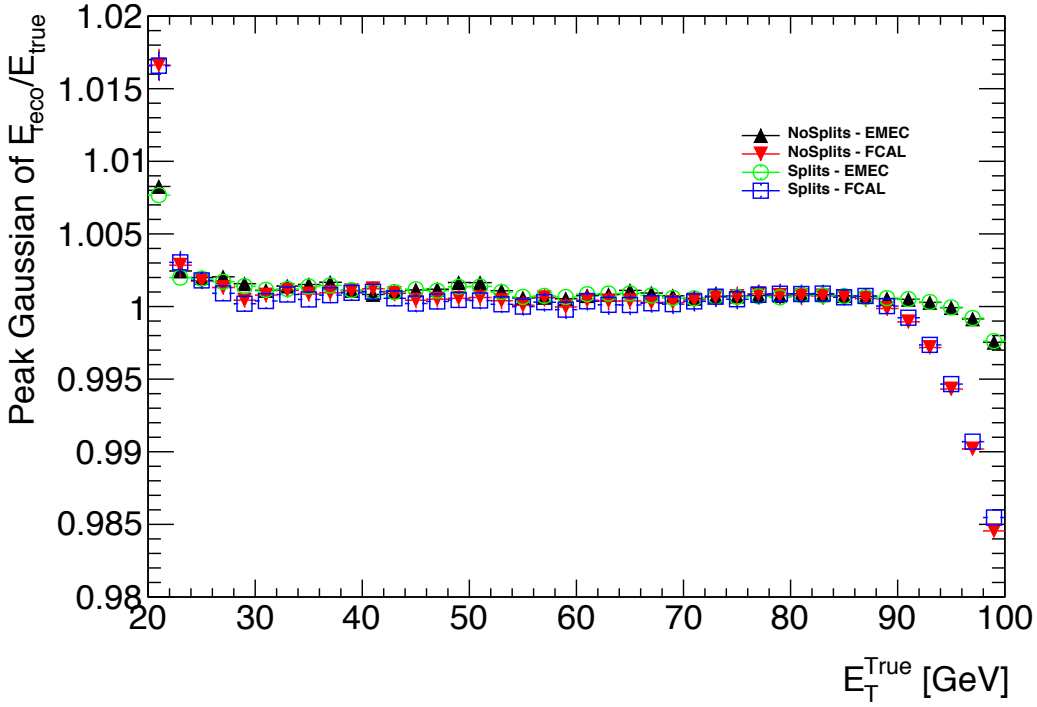
Pileup

No Splits w/SS – Evaluating vs η

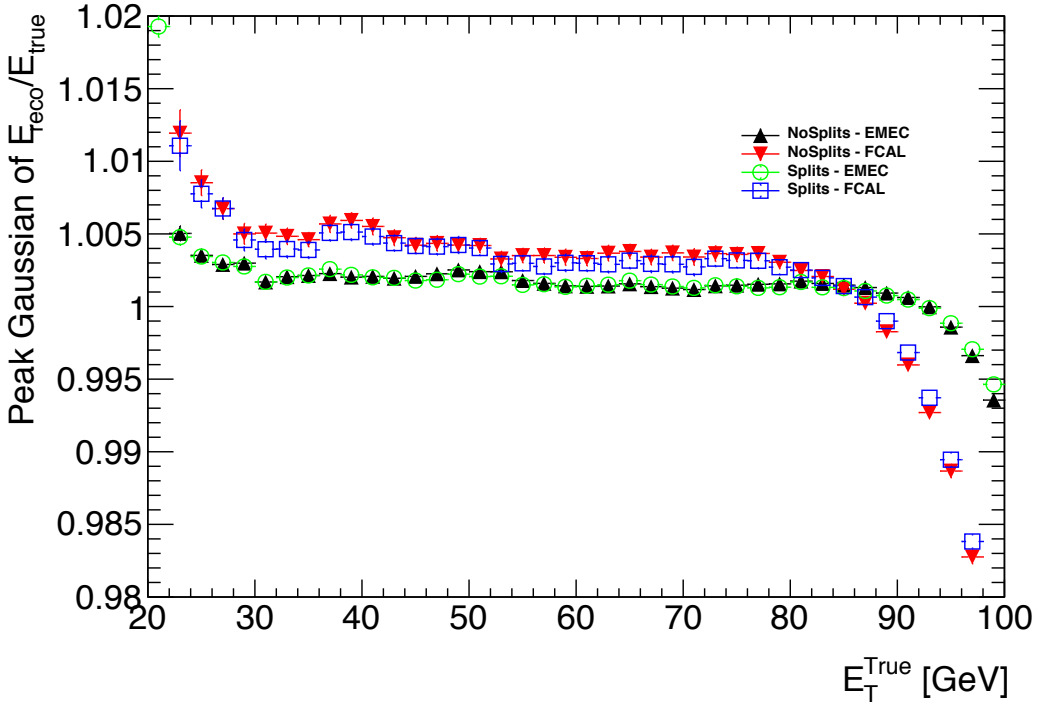




Splits/No Splits PG w/SS – Evaluating vs E_T

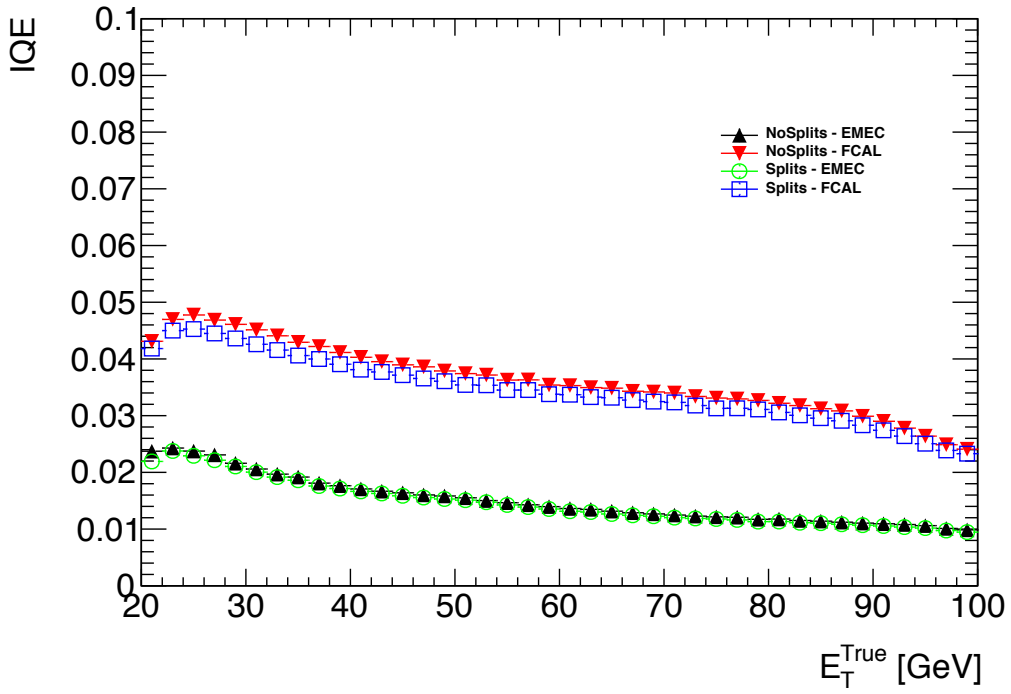


No Pileup

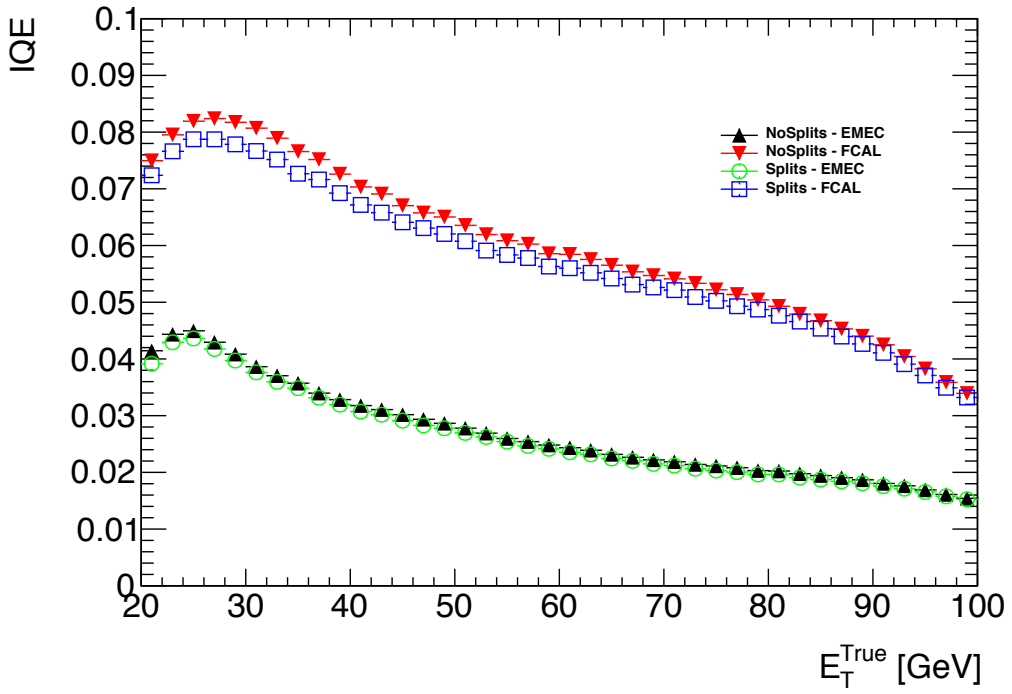


Pileup

Splits/No Splits w/SS – Evaluating vs E_T

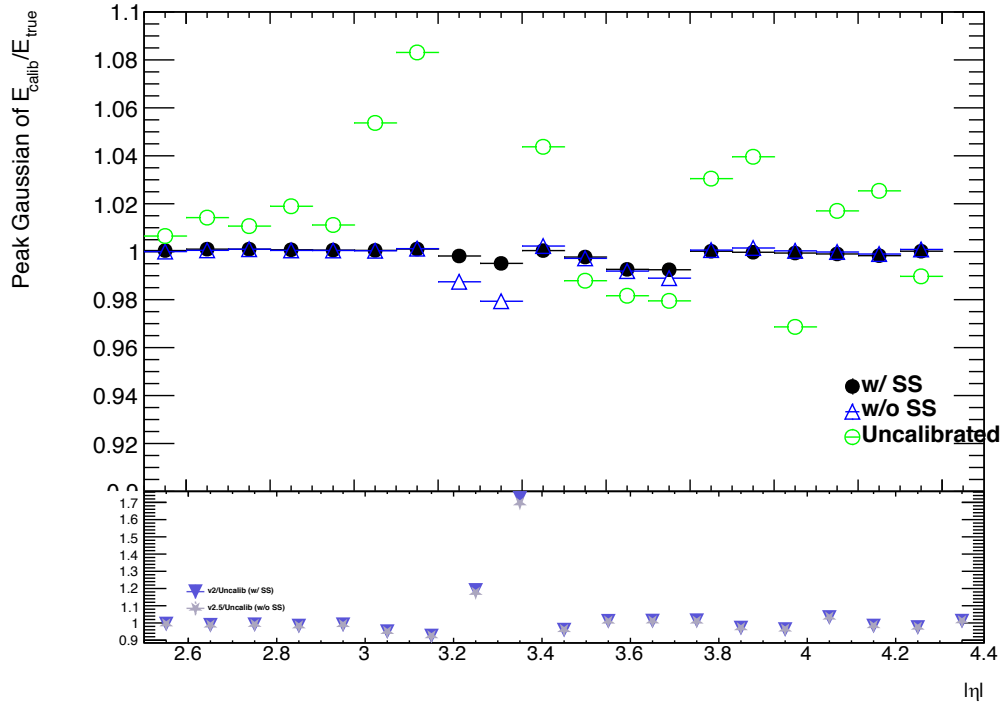


No Pileup

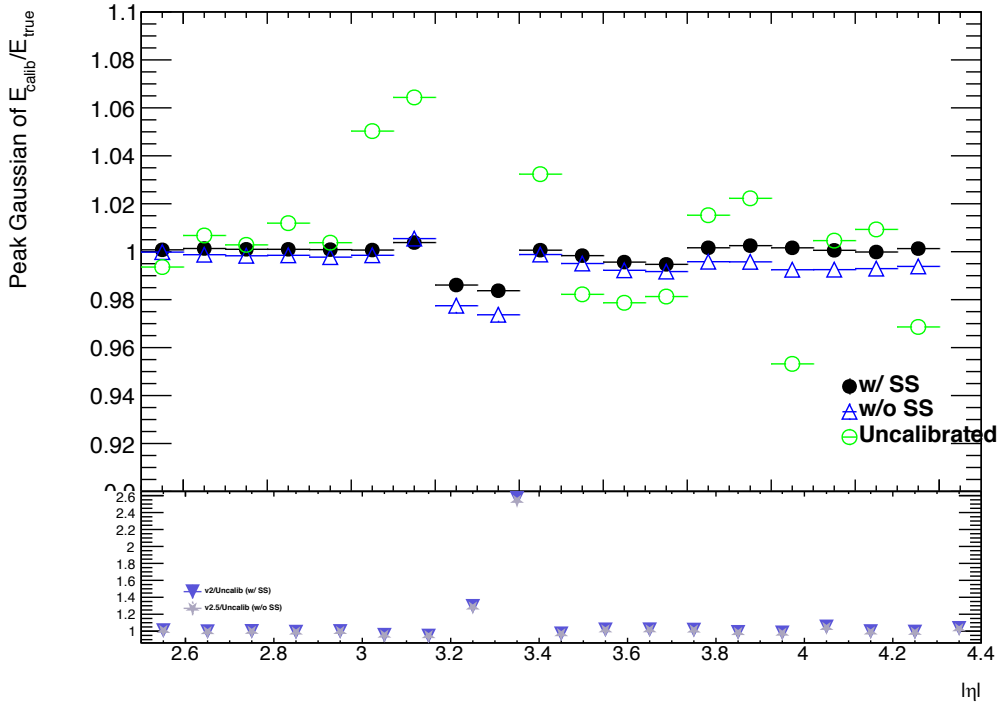


Pileup

No Splits PG - Summary

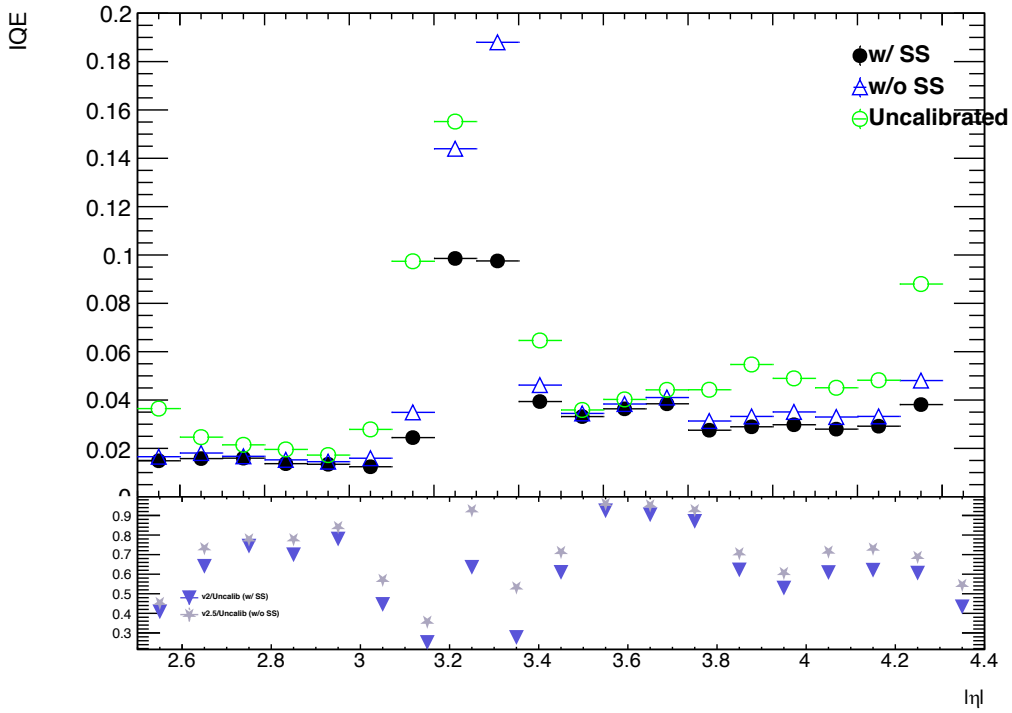


No Pileup

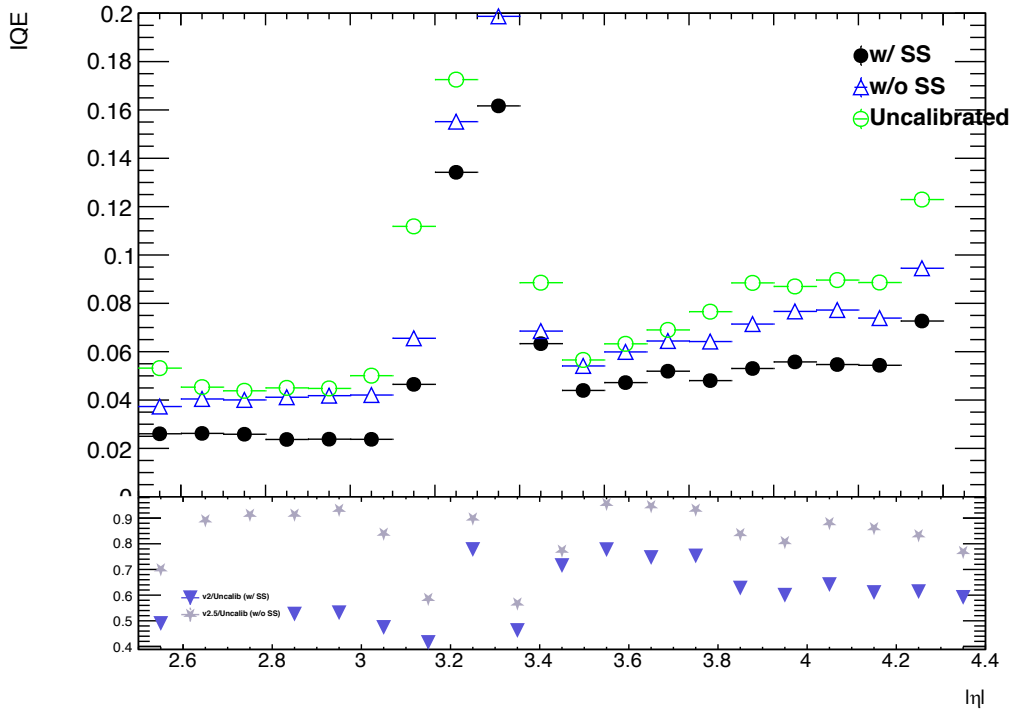


Pileup

No Splits IQE - Summary

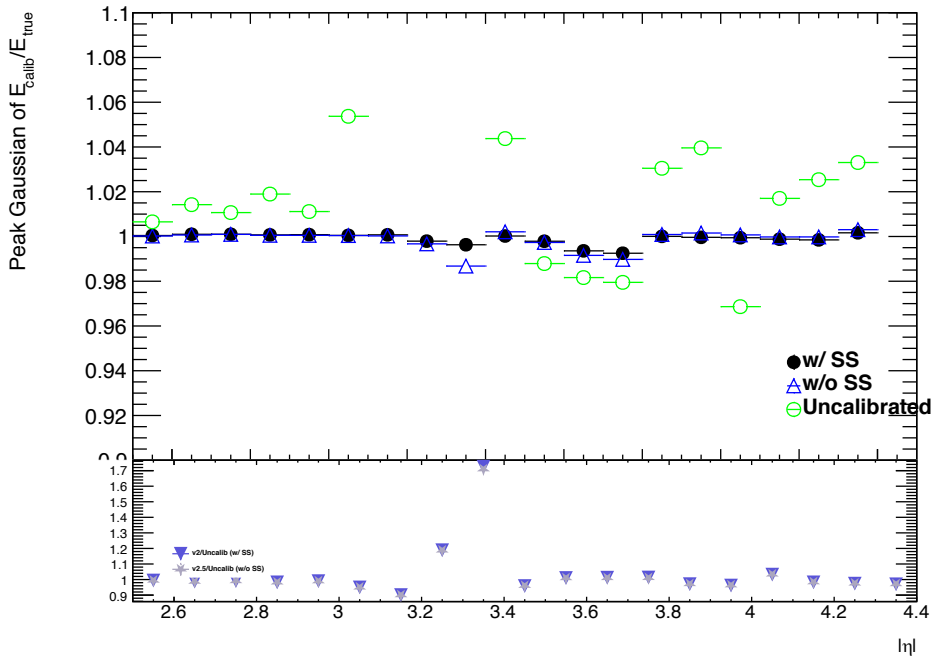


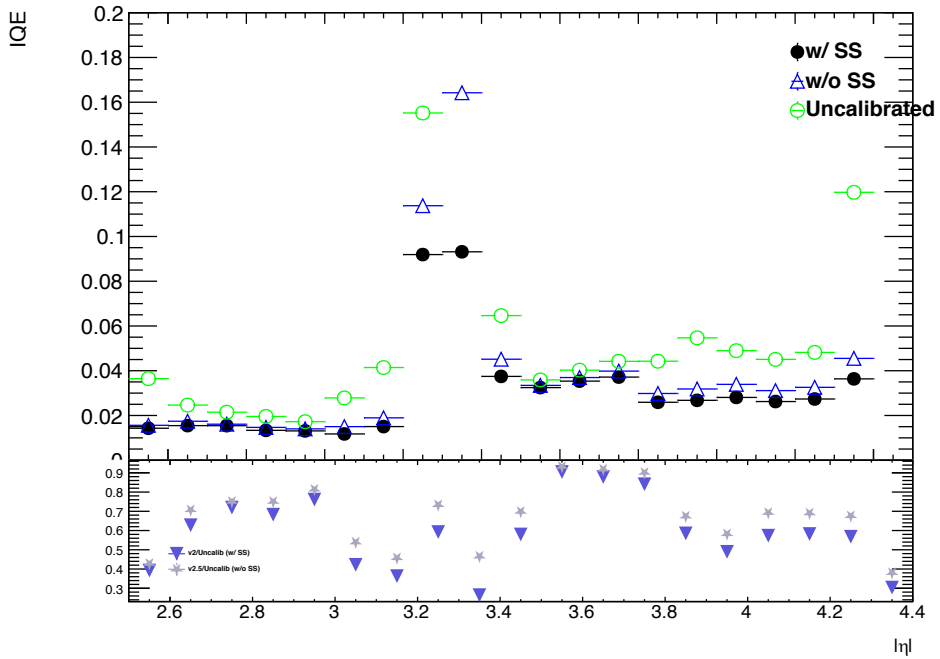
No Pileup



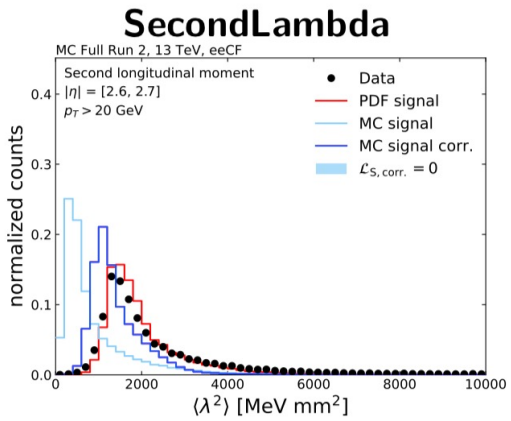
Pileup

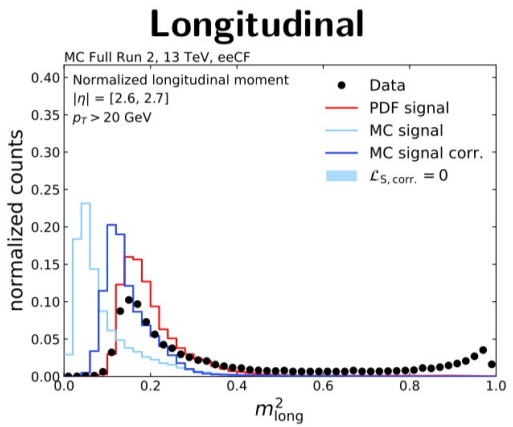
With Shower Shapes or Without? – Splits without Pileup

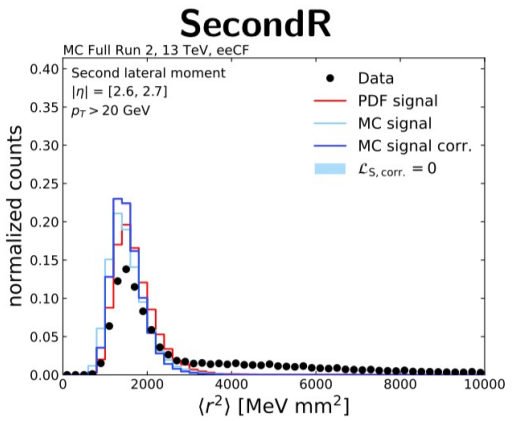


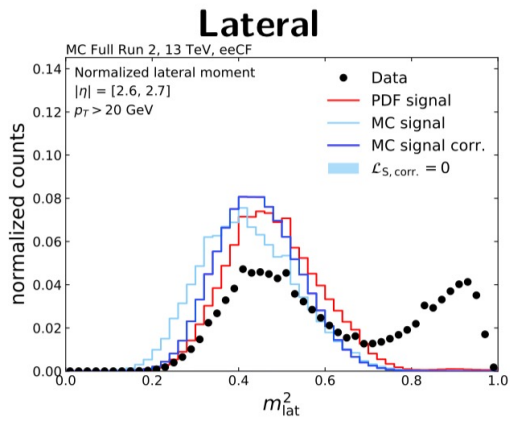


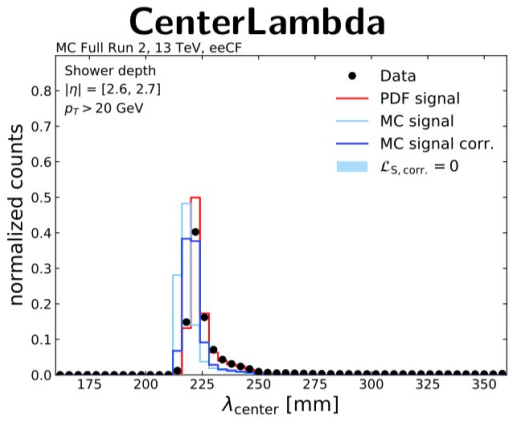
MC and Data (Mis)modelling

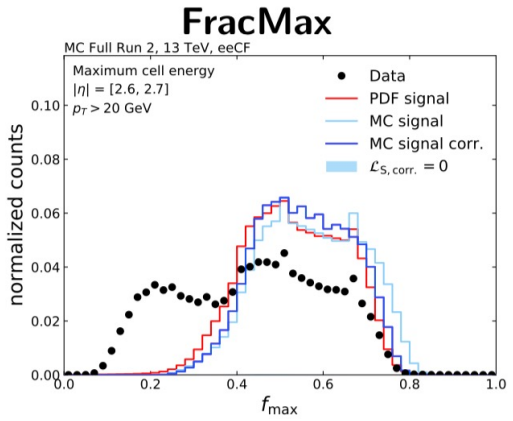


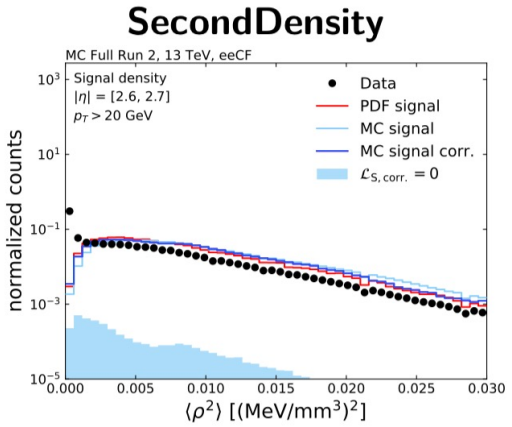


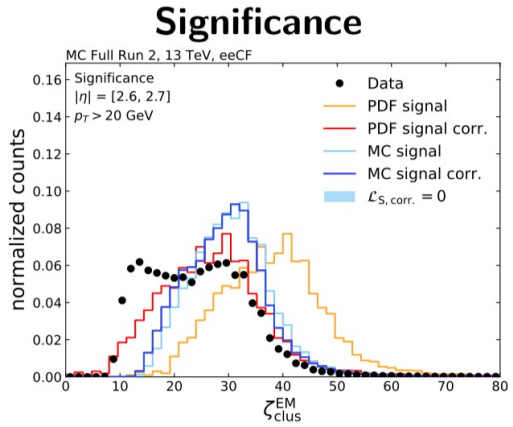




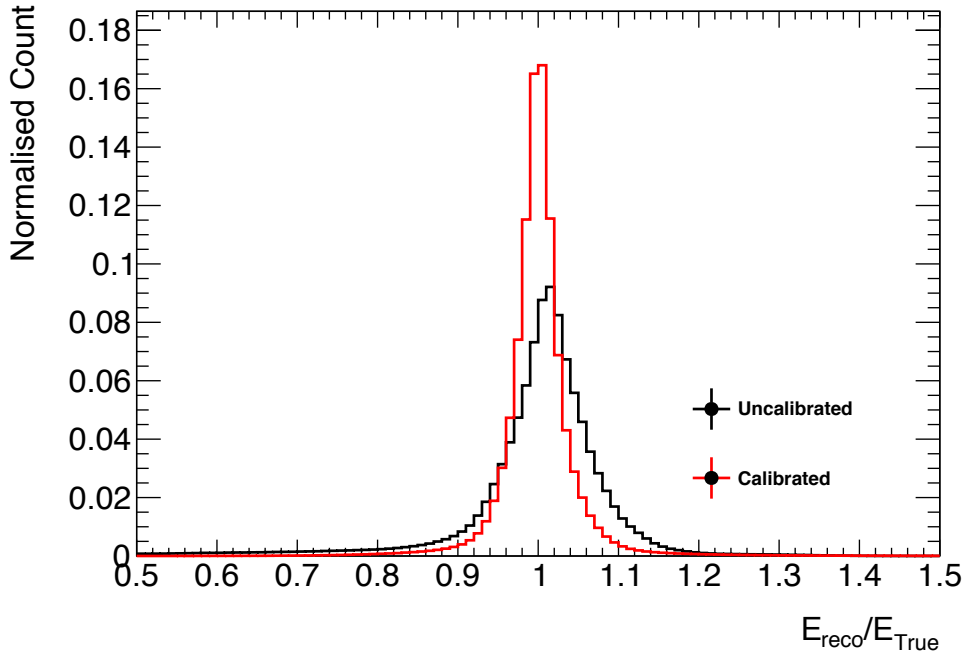




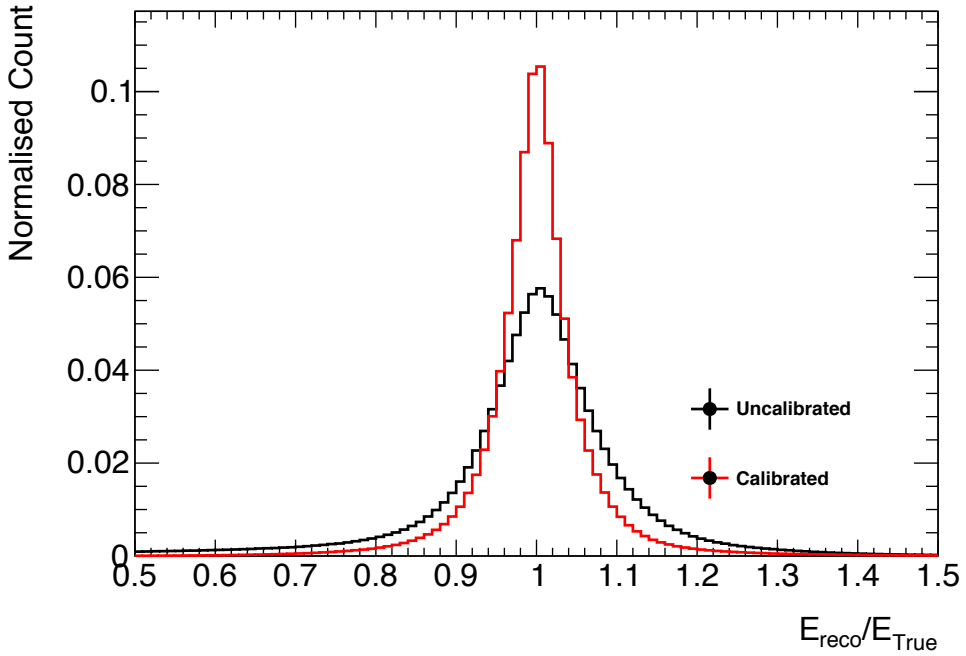




V2 No Splits – Energy Distributions

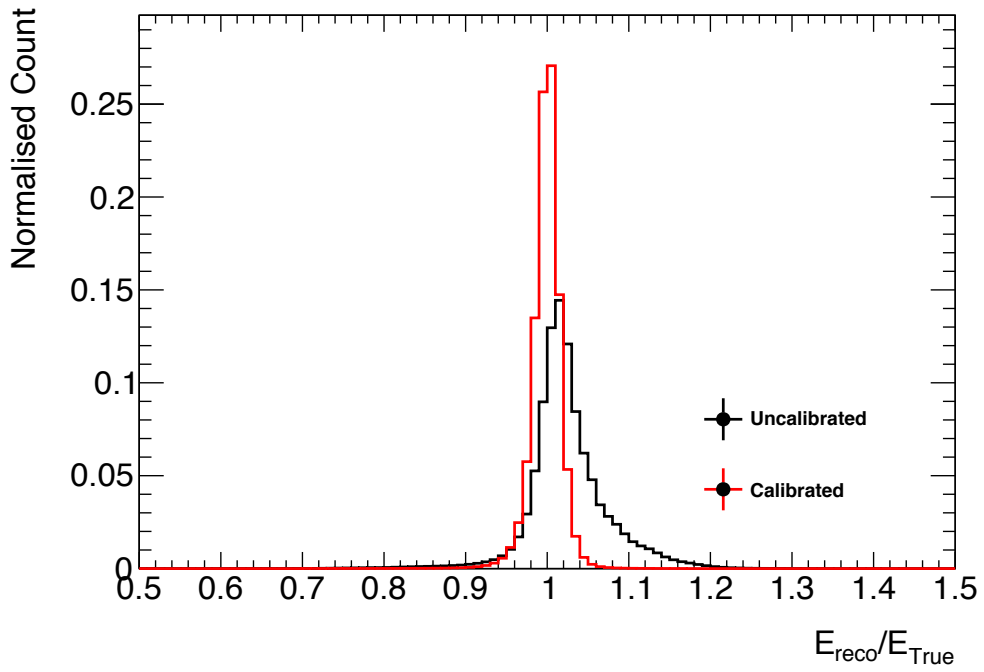


No Pileup

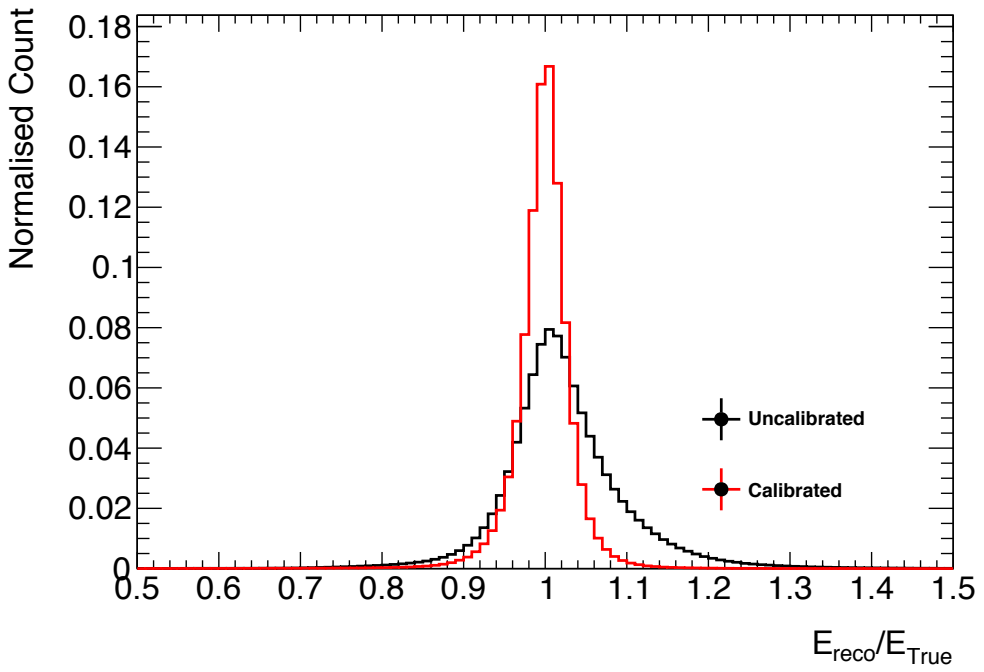


Pileup

V2 Splits – EMEC Energy Distributions

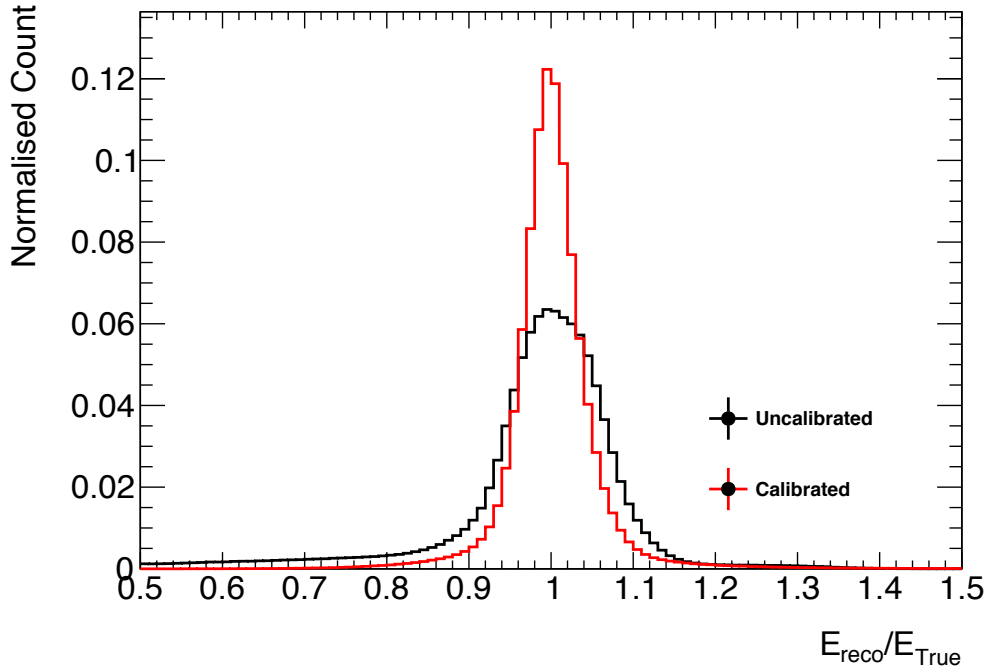


No Pileup

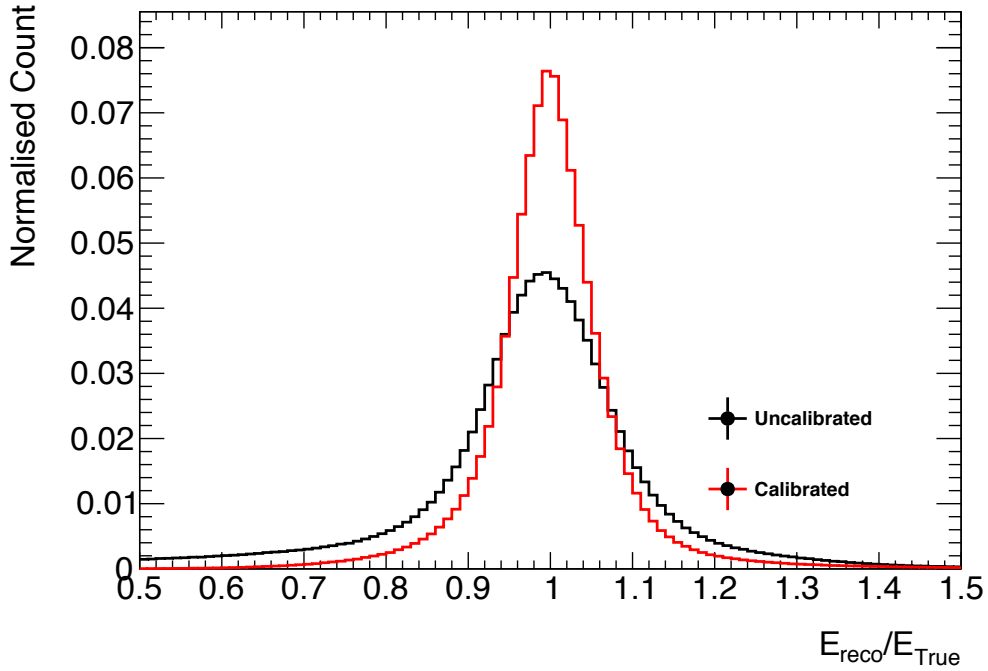


Pileup

V2 Splits – FCAL Energy Distributions



No Pileup



Pileup