Calorimeters and Pandora Performance

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CLIC calorimeters and PandoraPFA

Fine grain calorimeters at CLIC with high segmentation to achieve best possible performance of particle flow identification:

- PandoraPFA algorithms matching information of all detector subsystems to identify and reconstruct each particle correctly by its type: charged hadrons (assigned type: $\pi\pm$), muons, electrons, photons, neutral hadrons (assigned type: neutrons)
- important task: keep misidentification of particles as low as possible as well as wrong assignment/splitting of calorimeter clusters to avoid double counting

  → this confusion term becomes important contribution in jet energy resolution for high energies, low confusion term essential to achieve large discrimination power between boosted jets from W and Z
- tauFinder run after particle identification by PandoraPFA
- Ongoing work to integrate forward calorimeters (BeamCal and LumiCal) into reconstruction sequence

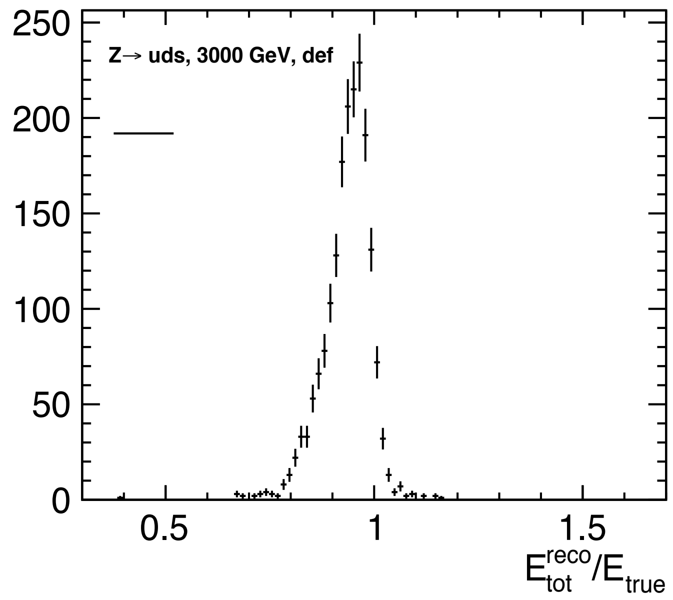
New CLIC default Pandora Settings

Previous CLIC PandoraSettings: CLIC workshop in March

Set a cut on MaxHCalHitHadronicEnergy of 1 GeV

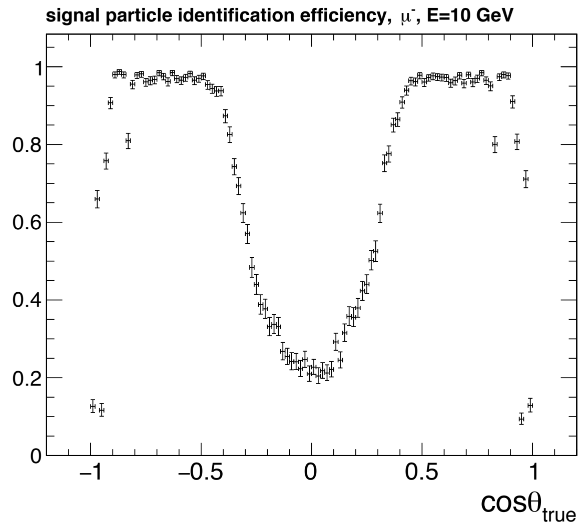
→scales all Hadron Hcal hit energies beyond 1 GeV of hadrons down to 1 GeV

→cut likely too harsh for energy stages at 1.5 and 3 TeV, reconstructed energy largely asymmetric with long tail to lower energies, mean shifted to 5-7 % lower energies



Muon identification cuts not adopted to new detector model with reduced number of muon chambers (six instead of 9)

→ Large muon identifcation inefficiency in barrel



New CLIC PandoraSettings

- Remove cut on MaxHCalHitHadronicEnergy (MHHHE) of 1 GeV
- Use SoftwareCompensation, which reweights hits with very large energy densities. These are more likely to come from electromagnetic component in hadron showers which have higher response in HCAL

→ Proposed default settings by PandoraPFA experts from Cambridge

- Use SoftwareCompensation weights from ILD at the moment, weights not applies for hadrons beyond 100 GeV

  →work on CLIC specific weights has been started

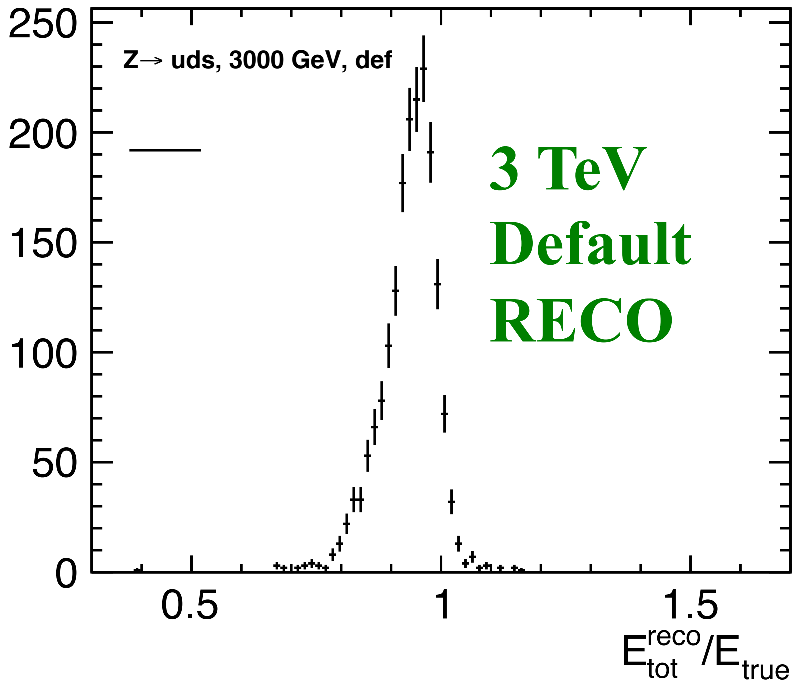
- New muon identification cuts adopted for CLIC

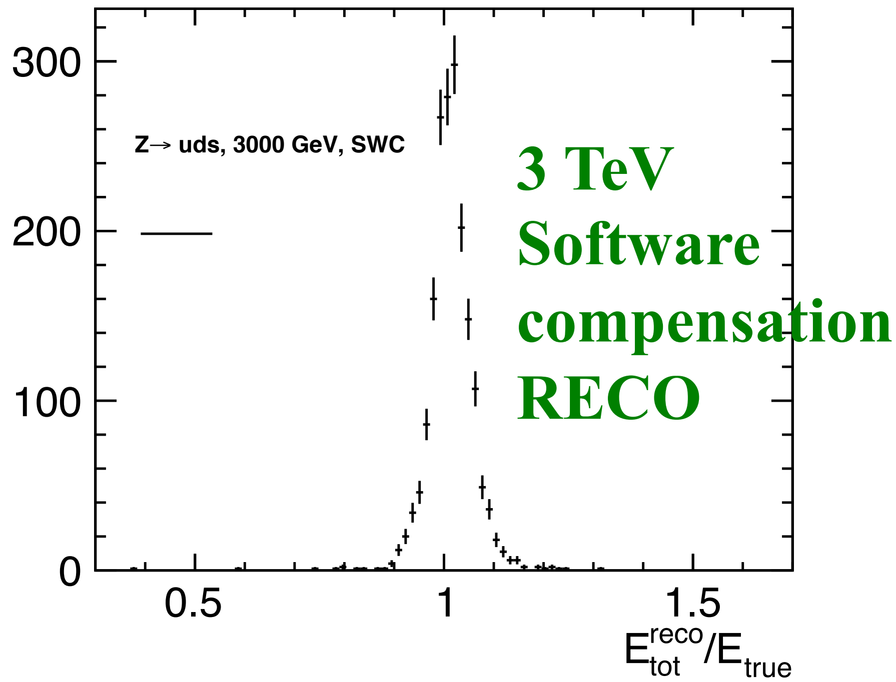
Use new cluster noise cleaning

→ Rescale energy of HCAL hits with large contribution to cluster energy by using information from adjacent layers

Total energy reconstruction

Compare the reconstructed energy using the different settings





This behavior is gone with the software compensation (MHHHE removed), mean of reconstructed energy distribution within 1 % of true energy for all energy points considered, symmetric distribution

Jet Energy Resolution

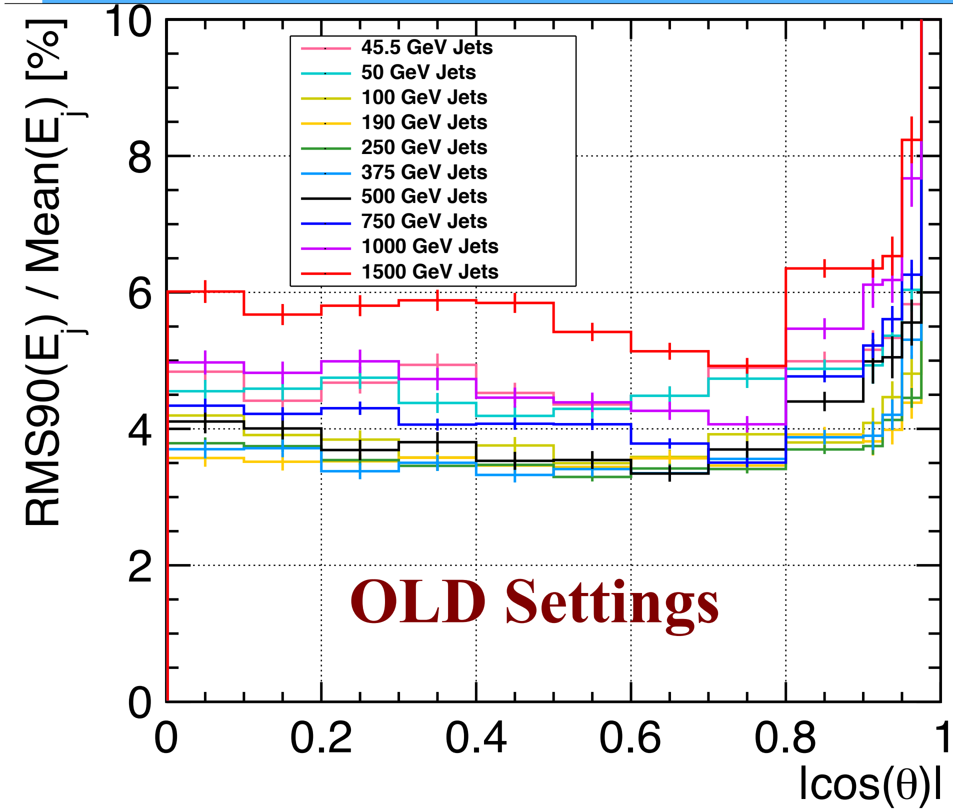
Determined using RMS_{90} the total relative energy resolution

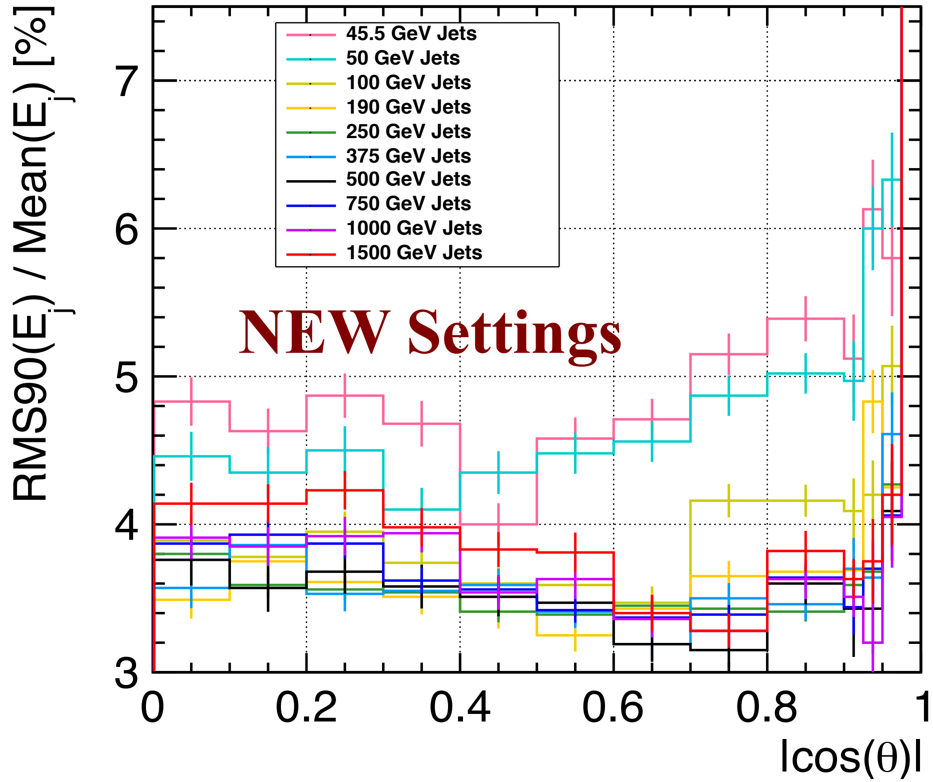
$\Sigma E_{PFO} / \Sigma E_{MC}$, where all stable visible MC particles are used in the denominator, ignoring the energies of neutrinos

→ Multiply by a factor of $\sqrt{2}$ to get the jet energy resolution values

→ Study as function for vs cos θ of leading quark for several energies

Old Settings: Jet Energy Resolution: RMS_{90}

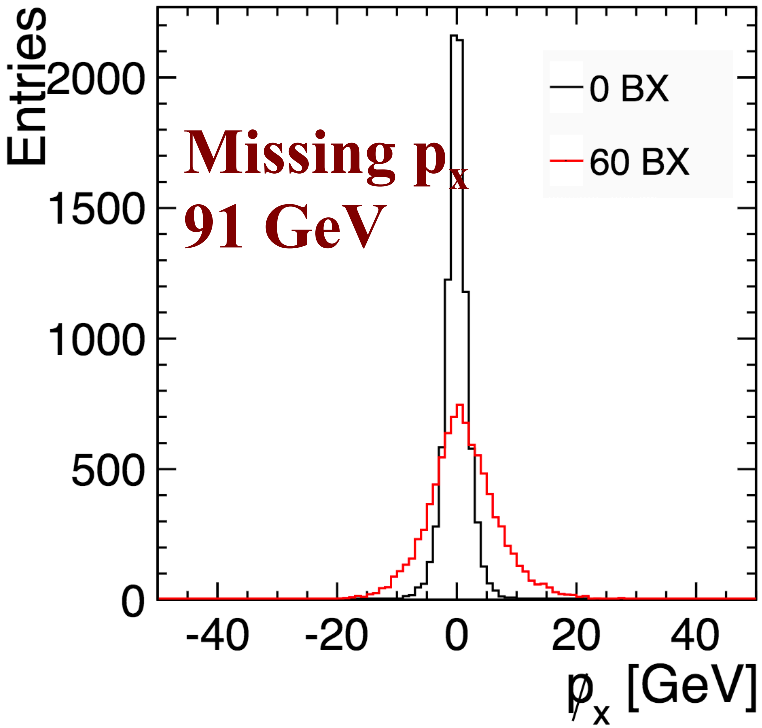


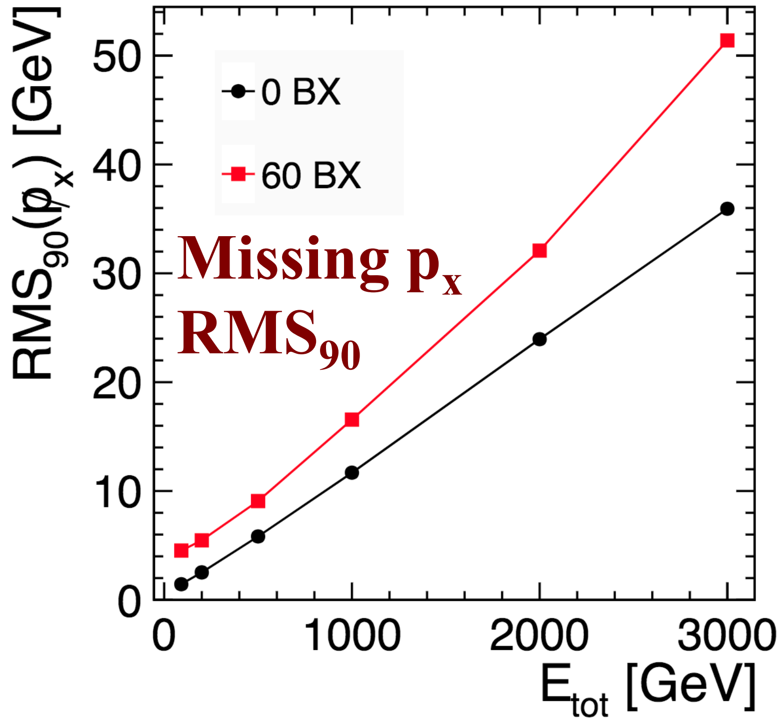


For very low jet energies (50 GeV) resolution around 5 %, for medium jet energies (100-250 GeV) jet energy values resolution around 3.5-4.0 %. Considerable improvement for high jet energies from previously 5 and 6 % reduced to 4-4.5 %

First look:
Overlay in Z→uds dataset

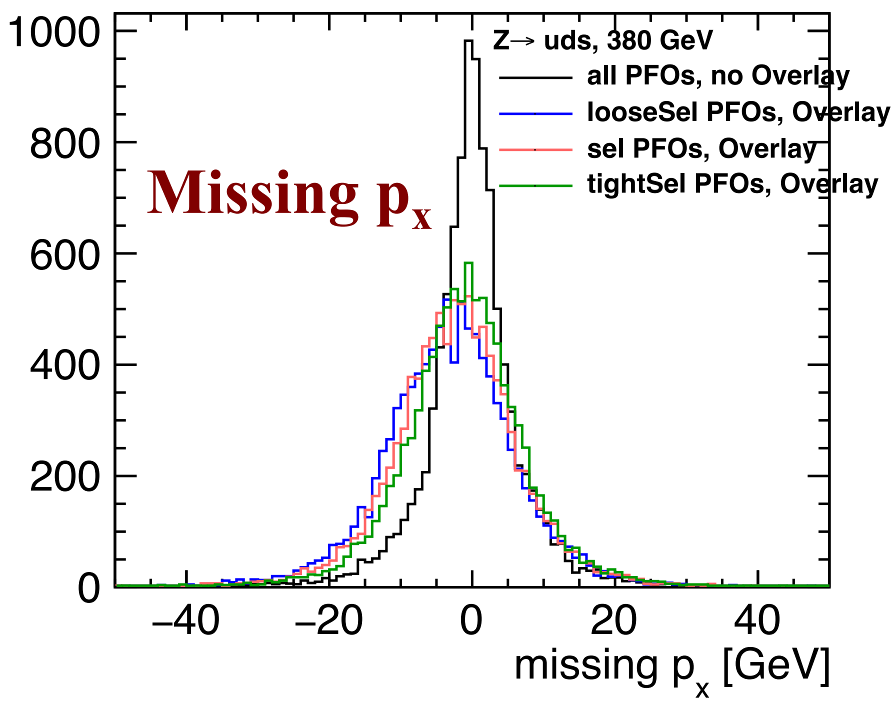
Overlay: previous performance of PandoraPFA old detector model CLIC_ILD

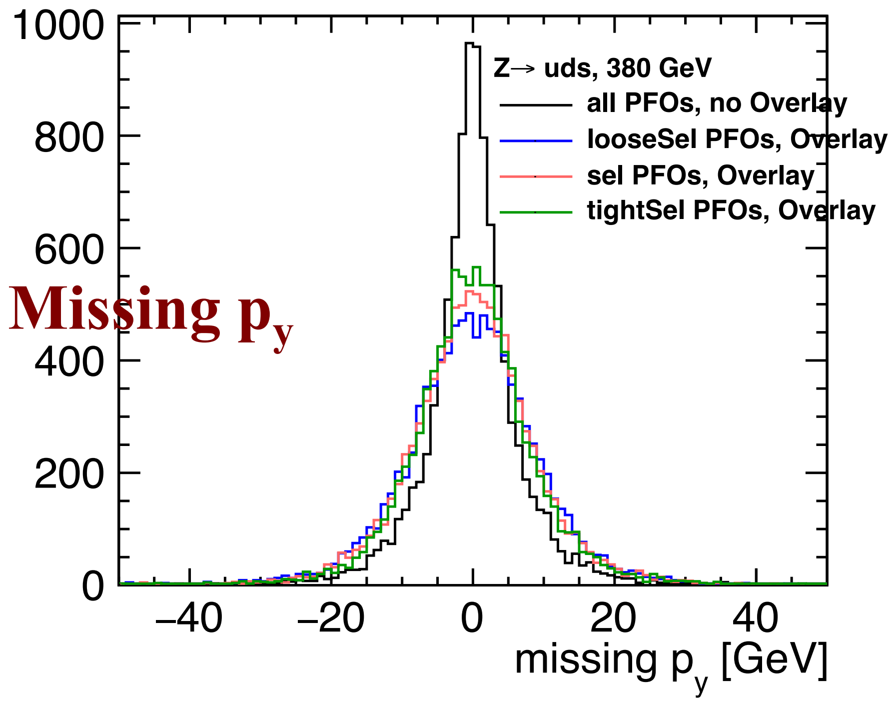




Considerable increase of missing transverse p_x with overlay, tight selected PFOs are used for the overlay plot

Overlay: missing transverse momentum





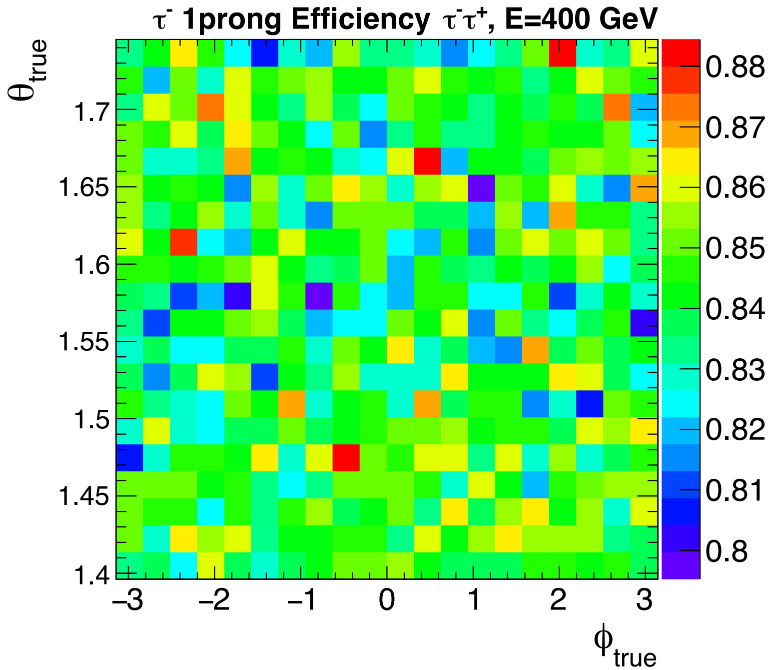
Overlay increases missing p_x RMS_{90} from 4.54 to 6.42 GeV for 380 GeV →previously increased to 9 GeV (no overlay around 4.5 as well)
For 1500 GeV dataset RMS_{90} increased from 19.7 to 21.1 GeV →previously increased to 24 GeV (no overlay around 18.5)
→caveat: use old PandoraPFA settings, expect more improvement for higher energy

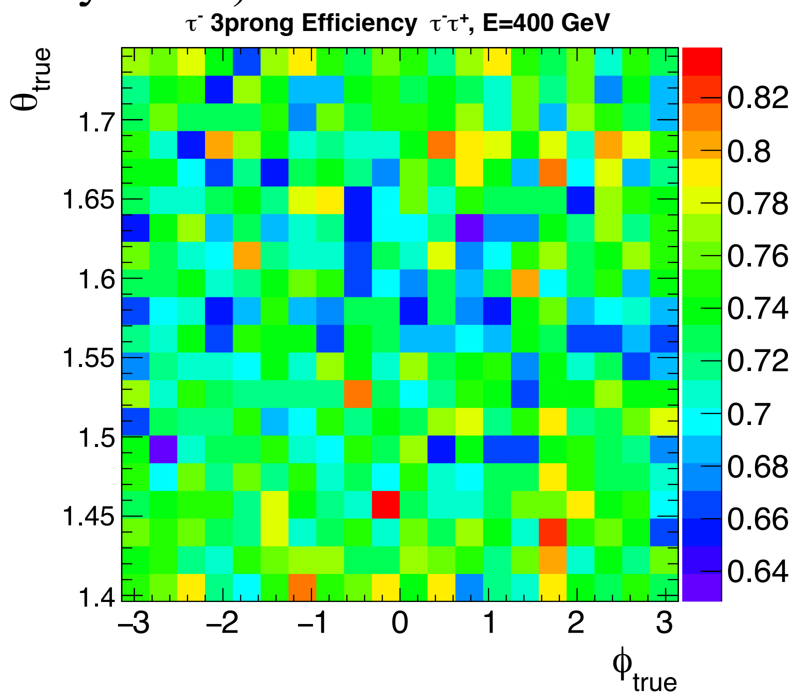
Hadronic tau identification: TauFinder performance

TauFinder

Taufinder integrated into MarlinReco/Analysis, check efficiency for several samples: $e^+e^- \rightarrow \tau^+\tau^-$ at 200, 400, 1000, 2000 GeV, cut on theta between 80-100 degrees

- Require angular matching of reconstructed tau jet and MC truth tau jet of 10 degree (very relaxed 30 degree angular cut does hardly do anything)
- Require charge matching (hardly any inefficiency <1 %)

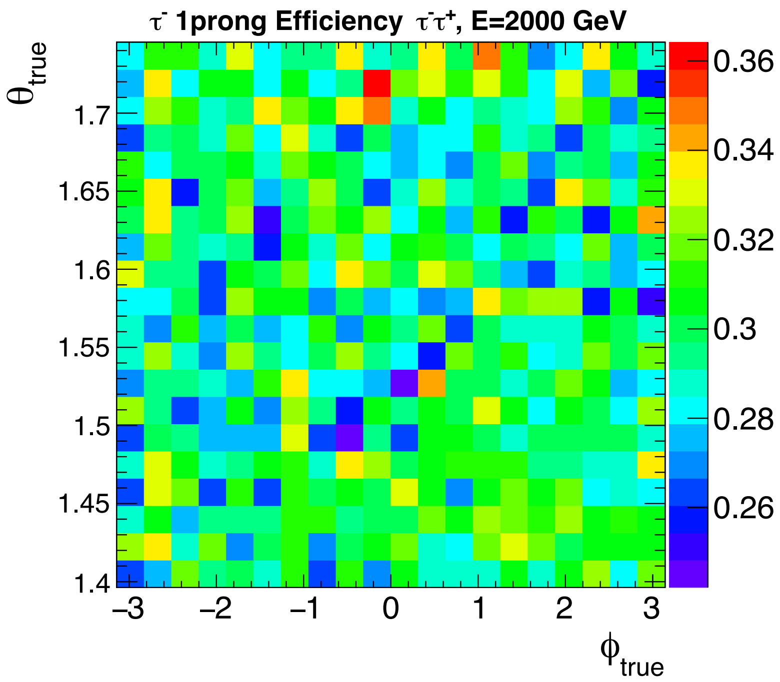


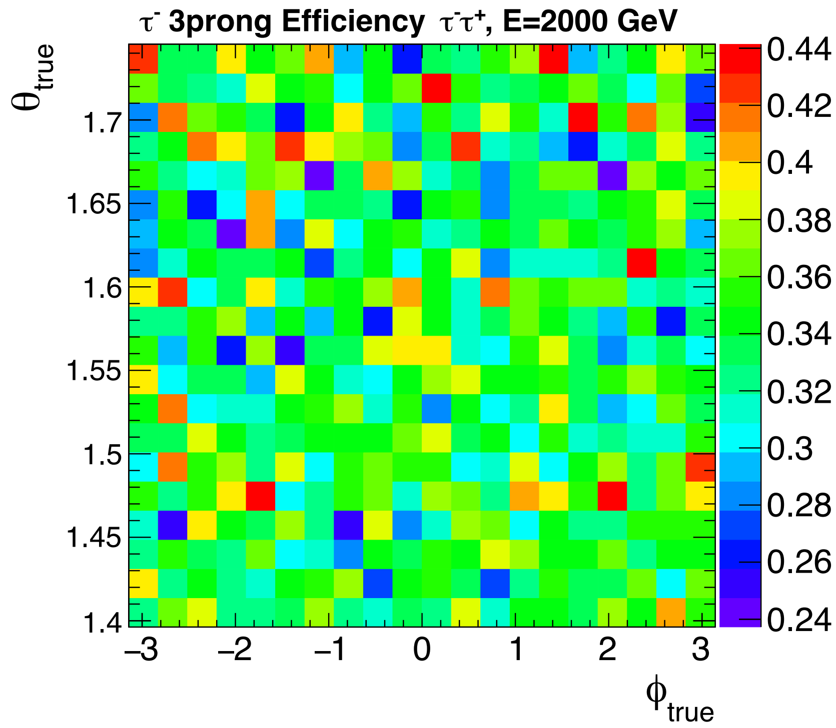


Nice efficiencies for low energy samples (100,200 GeV taus)

Tau identification efficiency: issue at high energies

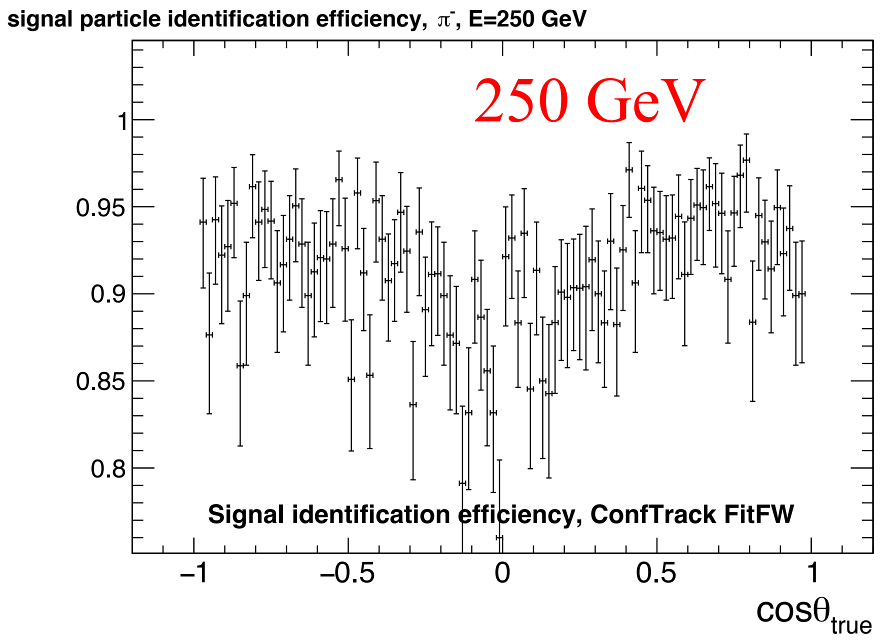
Efficiency for several tau samples: 200, 400, 1000, 2000 GeV
Require angular matching of reconstructed tau jet and MC truth tau jet:
10 degree (very relaxed 30 degree angular cut does hardly do anything)
Require charge matching (hardly any inefficiency <1 %)

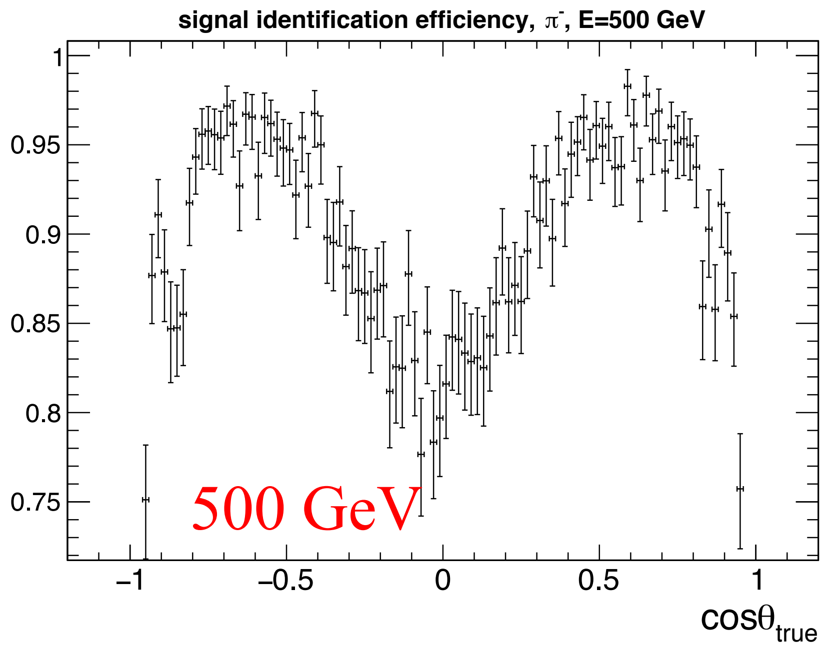




Efficiency decrease by over 50 %

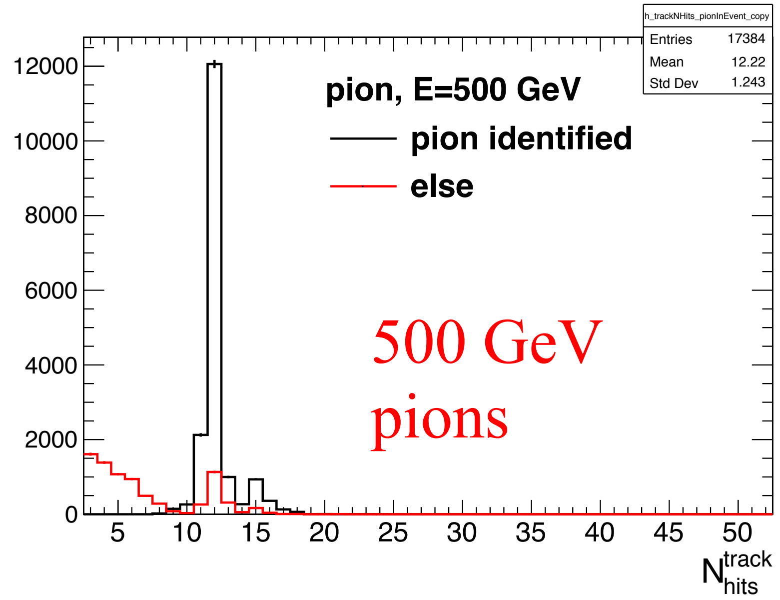
Pions at high energies
250 and 500 GeV identification efficiency

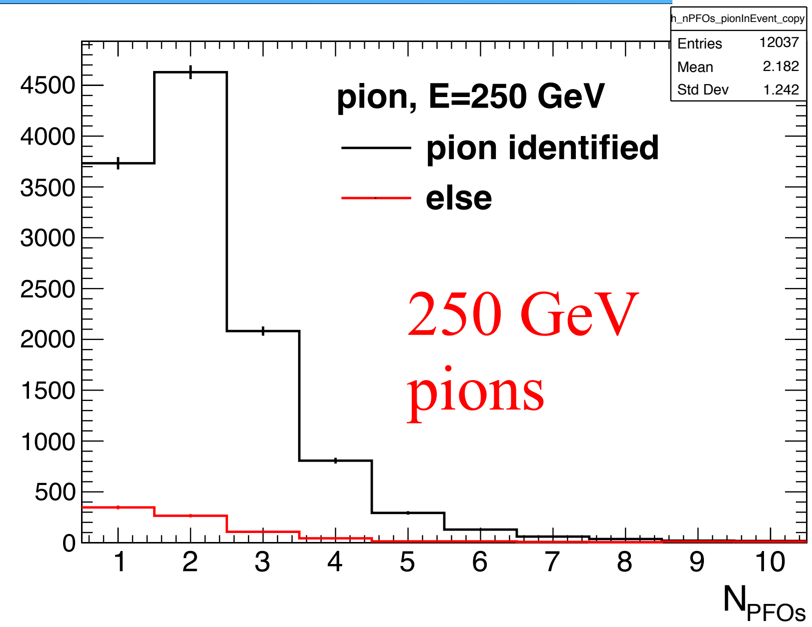




Tau inefficiency for one prong point towards issues in pion identification:
Particle gun samples produced at fixed energy, homogeneous in cosθ
Pion identification efficiency drops to 80 % around 75-105 degrees.
→possibly also an effect of pion Bremsstrahlung
→ Check with muons if tracking is the issue here

High energetic pions

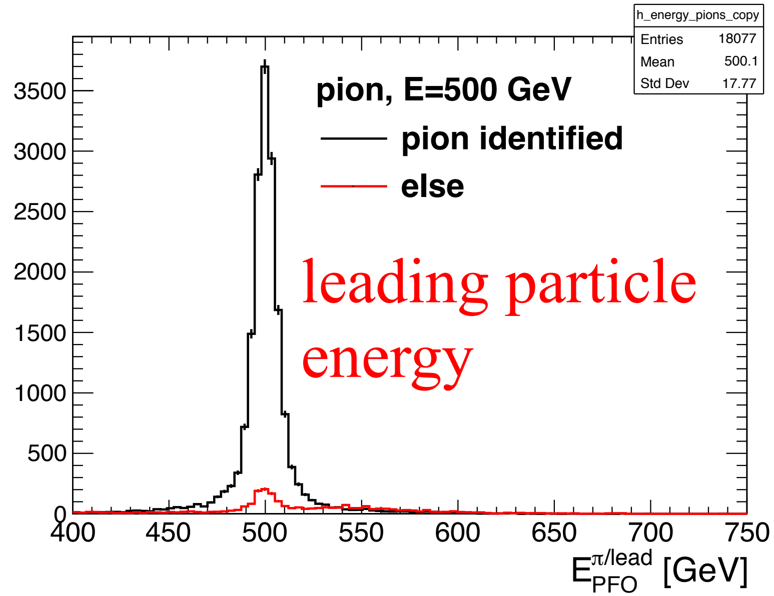


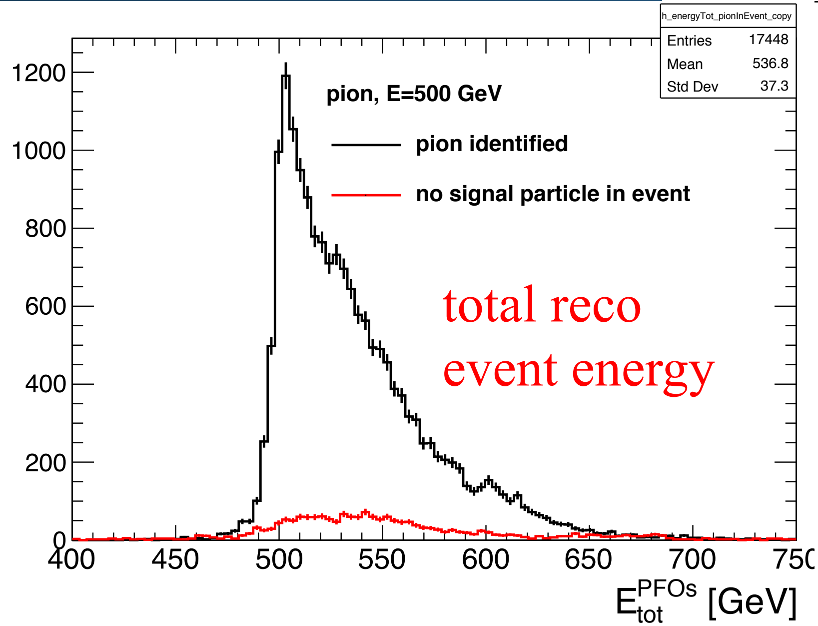


In non correctly identified pion events track exists, but for big majority tracks stop picking up hits well before Calorimeter face → clusters not matched to track by PandoraPFA

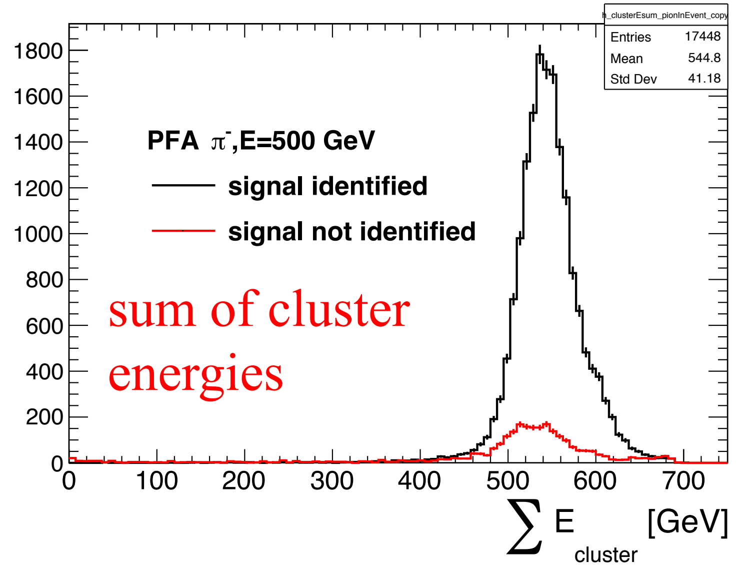
In majority of events Pandora reconstructs two or more particles in the event

High energetic pions: energy reconstruction at 500 GeV

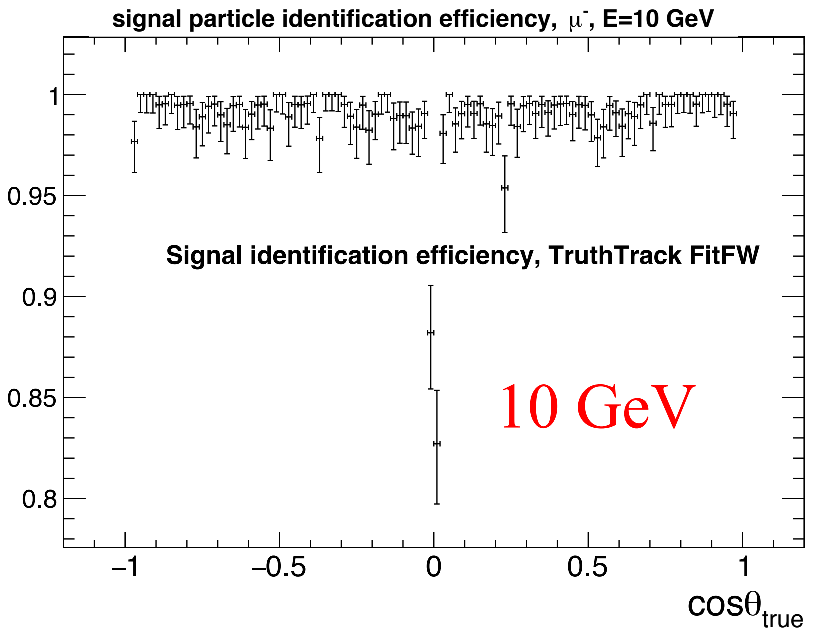


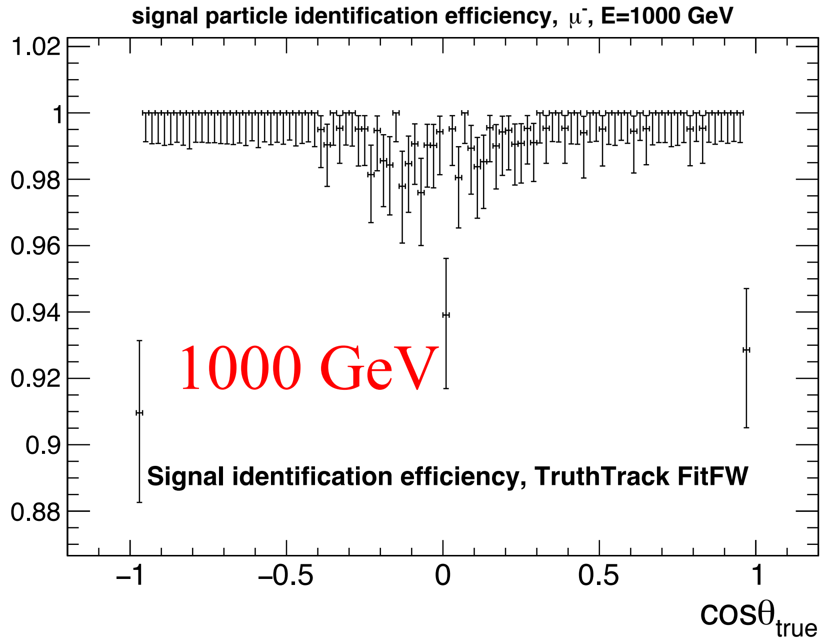


- Leading particle is at correct energy,
- Splitting into several calorimeter clusters creates long tail for total reconstructed energy
- Sum of all calorimeter cluster energy symmetrically distributed (mean higher as 500 GeV at 540 GeV)



Muons identification efficiency



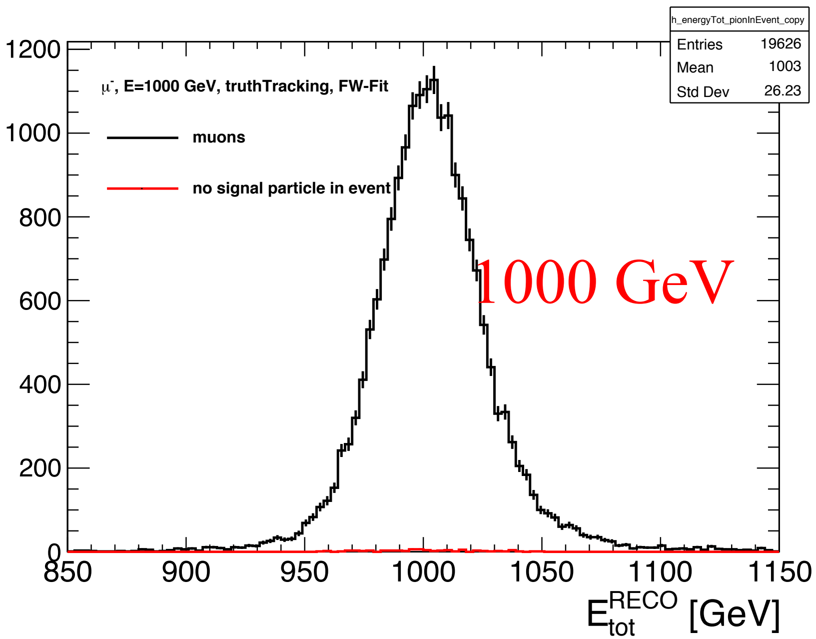


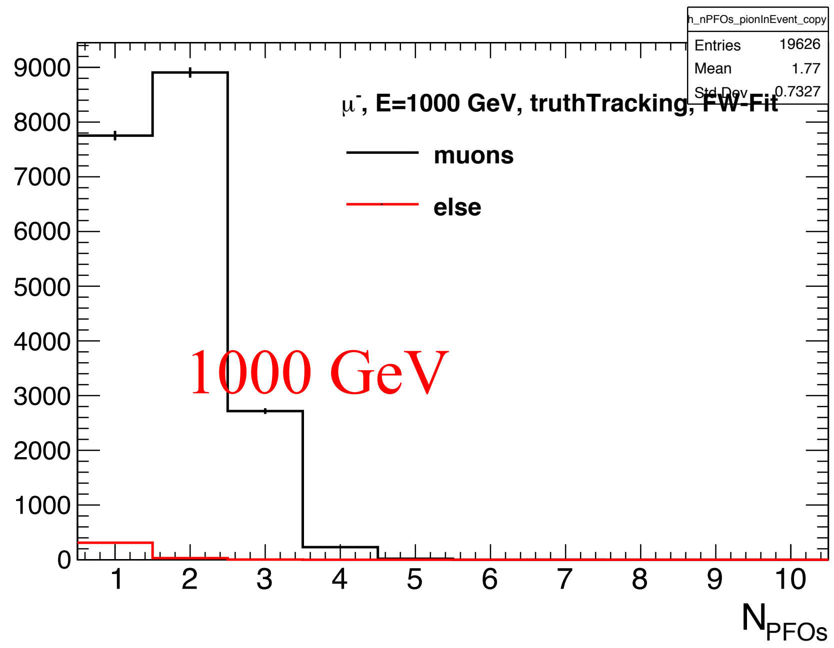
For Muon identification efficiency is over 98 % using newly adopted CLIC Muon identification criteria (besides exactly at 90 degrees) from 10 GeV up to 1000 GeV

→ For muons tracking works perfectly fine up to highest energies

→ issue for pions not only related purely to tracking, physics effects do play a role

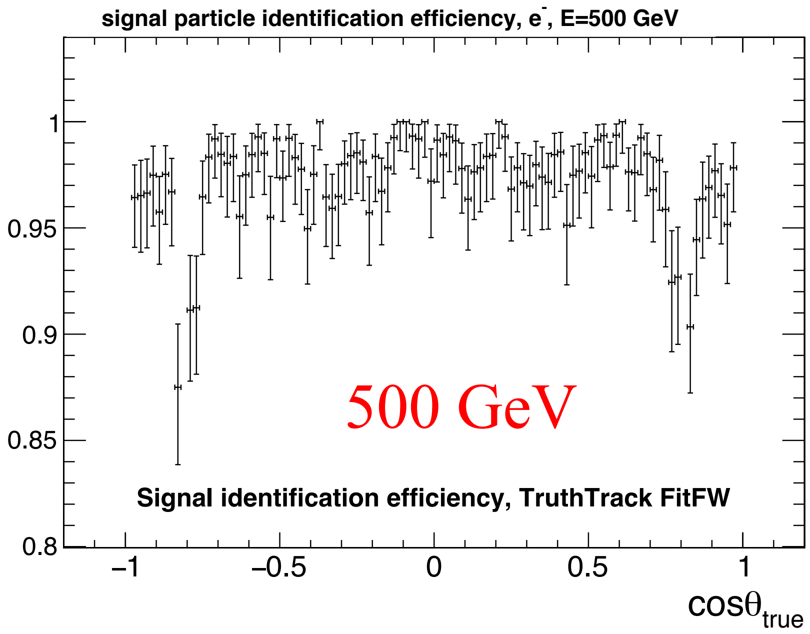
Muons at high energies (1000 GeV)

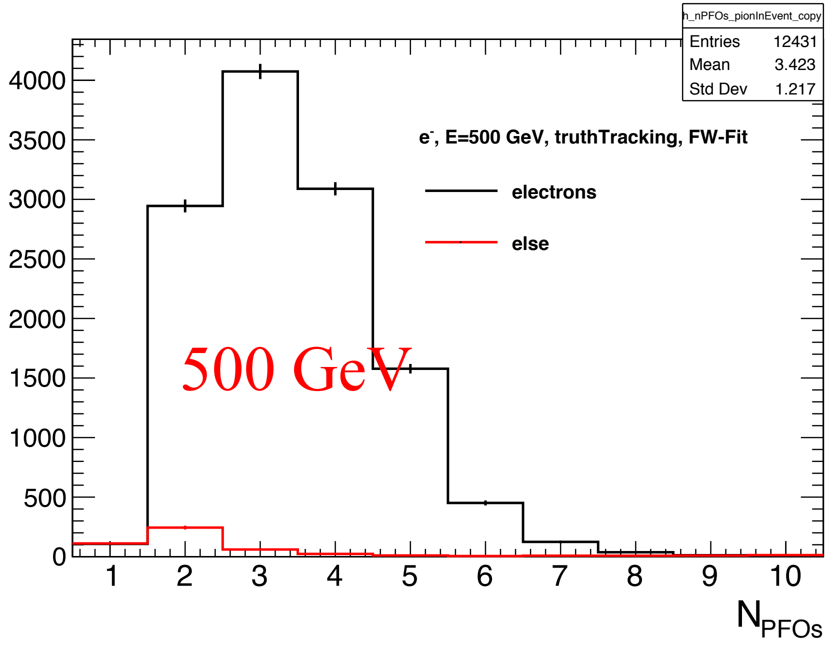




For muons at 1 TeV often an additional neutron is created
As expected hardly changes anything on the total energy

Electron identification efficiency at large energies

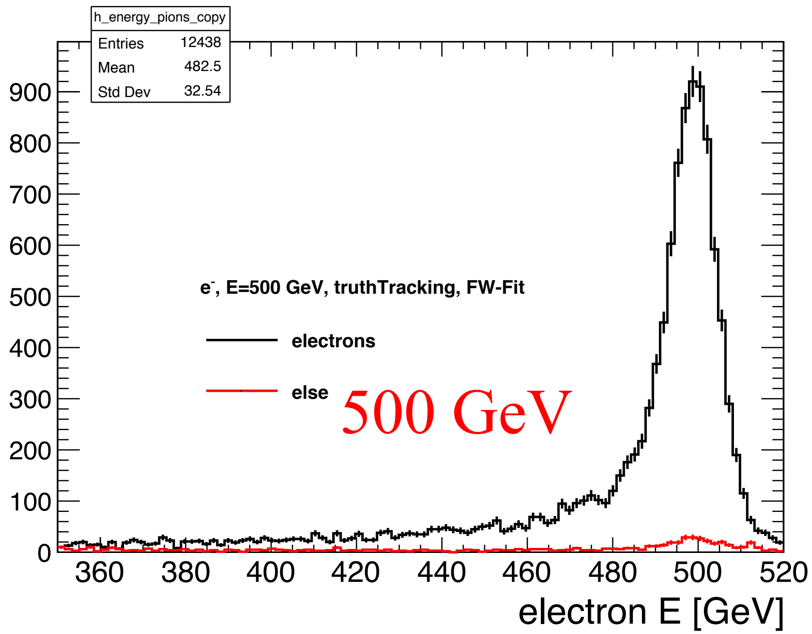


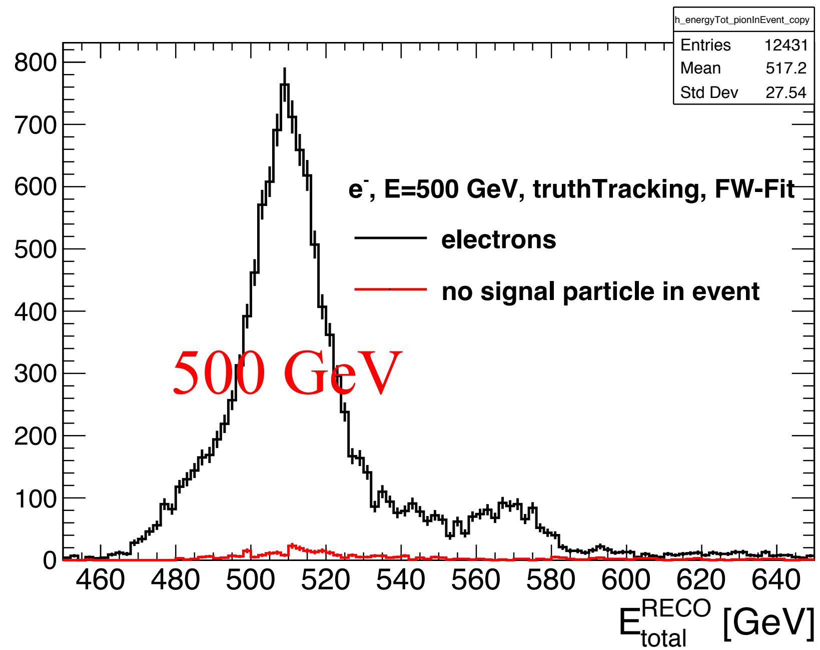


Electrons are identified with efficiencies typically beyond 95 %

For all events at least 1, typically more than two photons are created

Electron energy reconstruction at 500 GeV





Electron energy shows long Bremsstrahlung tail to lower energies, total energy of additional PFO photons overcompensates for this effect

Summary

Move to new default PandoraSetting in clicReconstruction

- Recover energy response deficit of 5 %, mainly a result of removed cut on HCAL hit energy for hadrons with impact on high energetic showers
- Software compensation enabled → started work on CLIC specific weights

Changed muon identification parameters recover identification inefficiency in barrel

- Good identification efficiency over wide energy range

Tau identification efficiency for hadronic tau decays (both 1 and 3 prong decays) around 80 % for tau's up to 200 GeV, tau fake rate typically between 1.5 and 3 % in Z dijet events

- Issue at for very high energetic tau's, traced back to issues in reconstruction for high energetic pions

Check identification efficiency and energy reconstruction for high energetic pions and electrons

- For electrons impact of bremsstrahlung photons
- For pions split of clusters leads to creation of additional neutrons

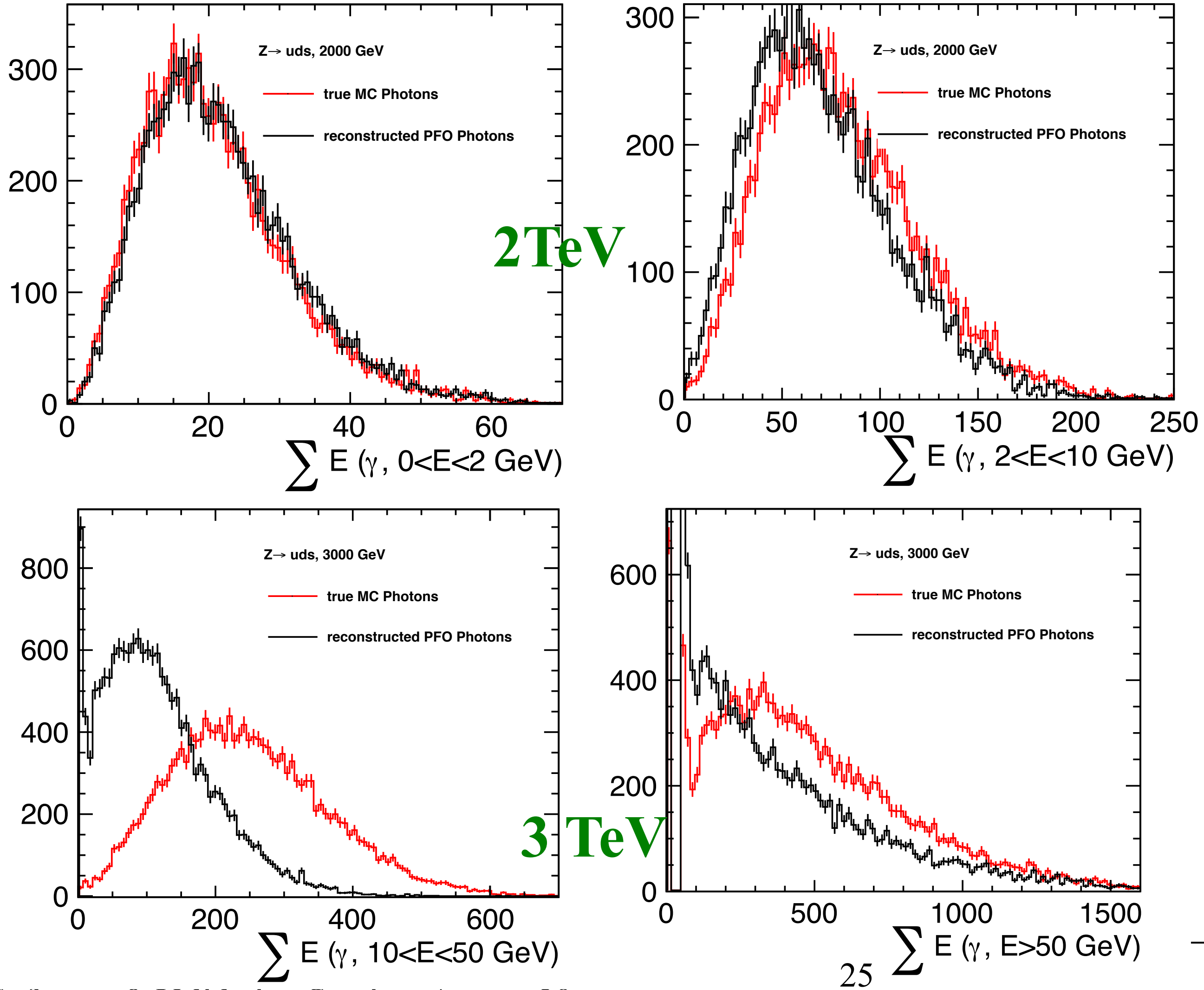
Plans and outlook

- Work on CLIC specific software compensation weights → could further improve jet energy resolution
- Investigate issues of pion reconstruction at very large energies and physics cause of split into two calorimeter clusters
- Run overlay with new PandoraSettings and in study impact in depth
- Forward calorimeters now in default reconstruction sequence
  - Necessary background input file available in CLICPerformance/examples
- Further issues under investigation (not discussed in this talk)
  - Identification inefficiencies of high energetic photons in jet environment
  - Muon identification dip at exactly 90 degrees
  - Pion/Electron identification inefficiency at barrel-endcap transition (cause identified, possible solutions in works)

BACKUP

Remaining issues at high energies: contribution from photons

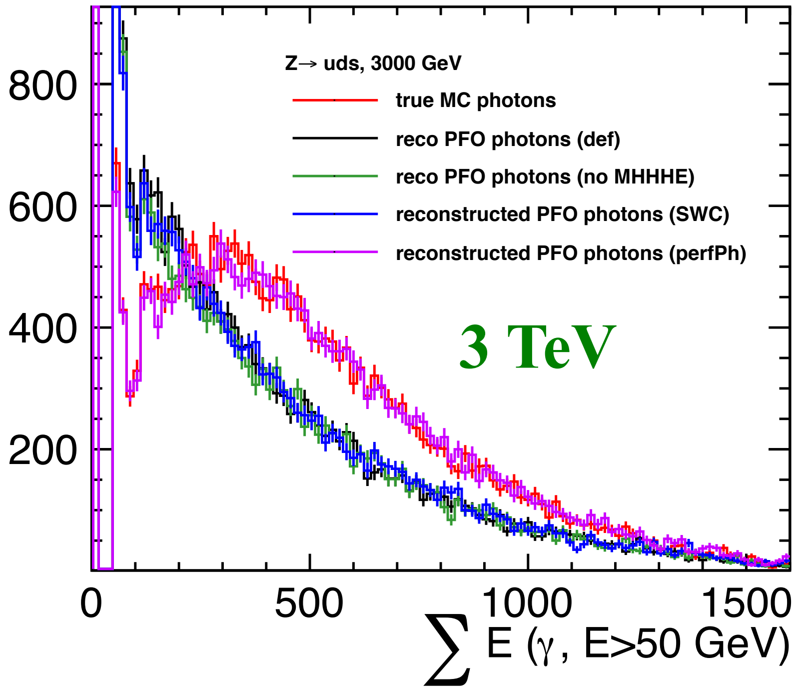
Check what might cause the higher jet energy resolution values for high energetic jets: photon energy distributions

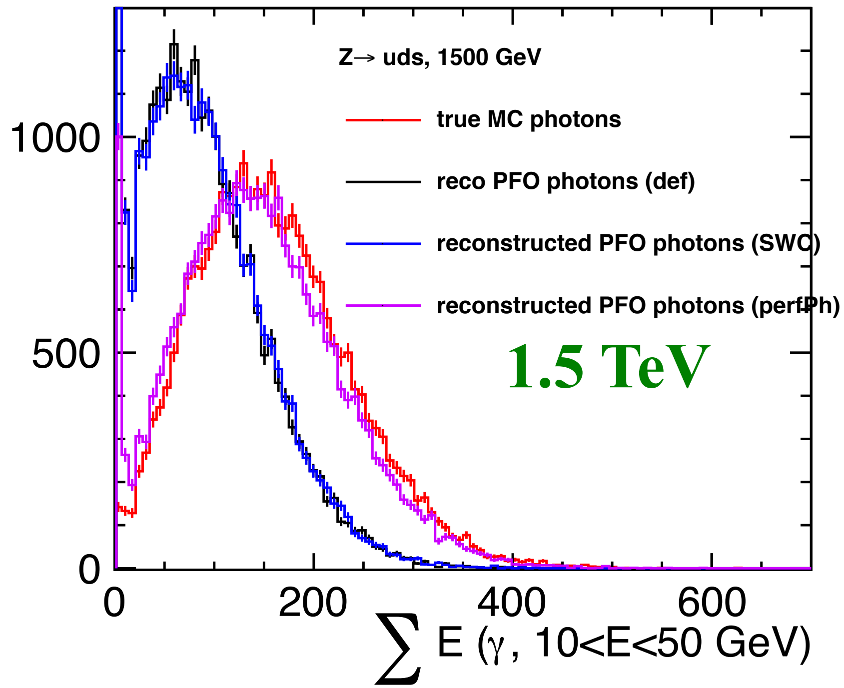


For low energetic photons contribution well reconstructed, contribution from photons between 10 and 50 GeV vastly underestimated

PhotonEnergy component in jets

PandoraPerfectPhoton (cheats photo pattern recognition) gives far better result of energy sum of high energetic photons





Only (cheated) perfect photon pattern recognition achieves to correctly identify the contribution of high energetic photons to the event energy

All other settings (CLIC default settings, default setting removing MHHHE cut, software compensation) shifted to lower values, but agreeing with each other

Photon Identification tuning in PandoraPFA

For each model the photon identification is retuned

→ Use PandoraSettingsPhotonTraining configuration file, result is a likelihood file for photons

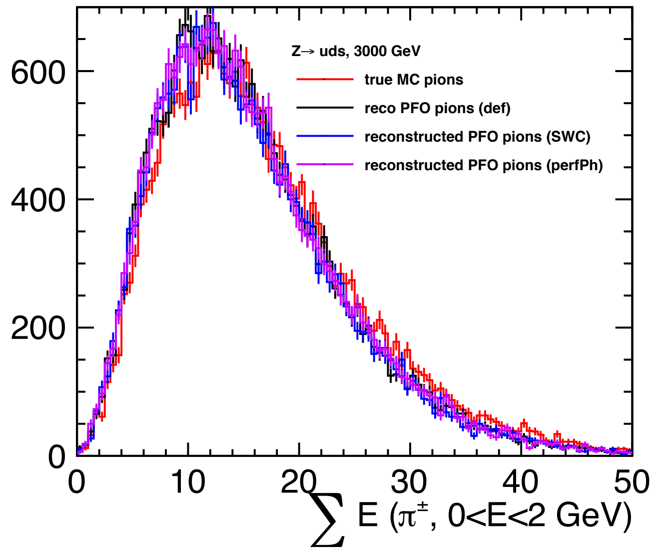
→ Binned in terms of energy (0, 0.2, 0.5, 1, 1.5, 2.0,5,10,20 GeV)

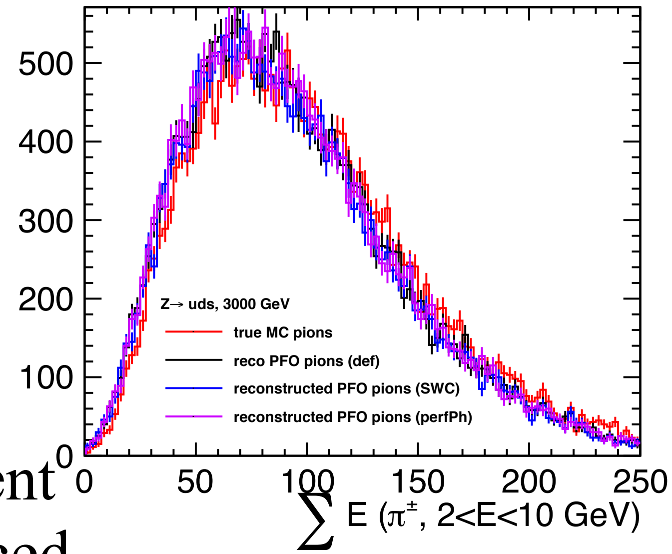
→ After photon likelihood file has been determined rerun calibration

→tested increase in photon identification bins to 11 to account more for possible differences at high photon energies (0, 0.2, 0.5, 1, 1.5, 2.0,5,10,20,35,50 GeV)

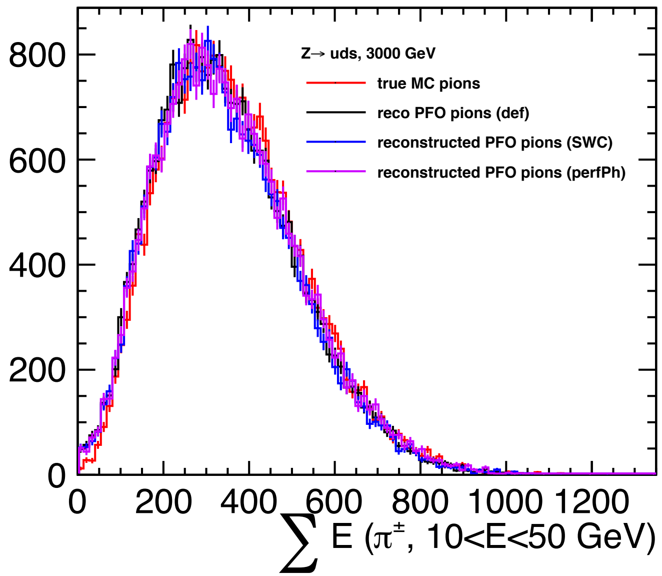
→ Unfortunately no sizeable improvement observed

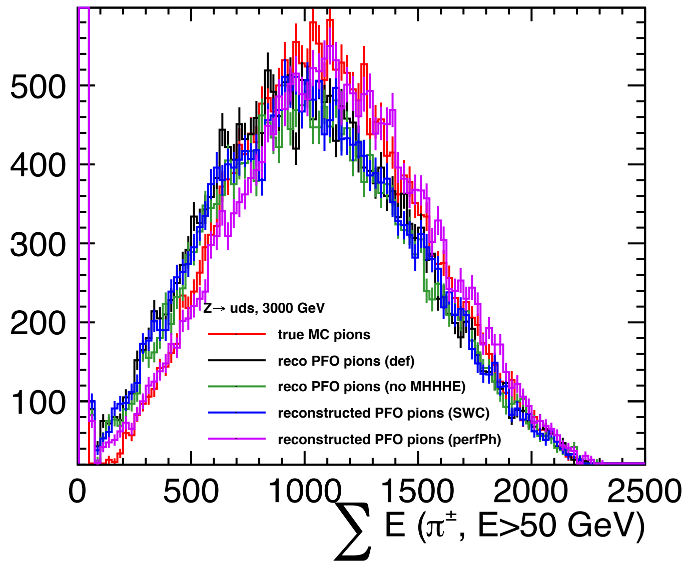
Pion Energy component in jets



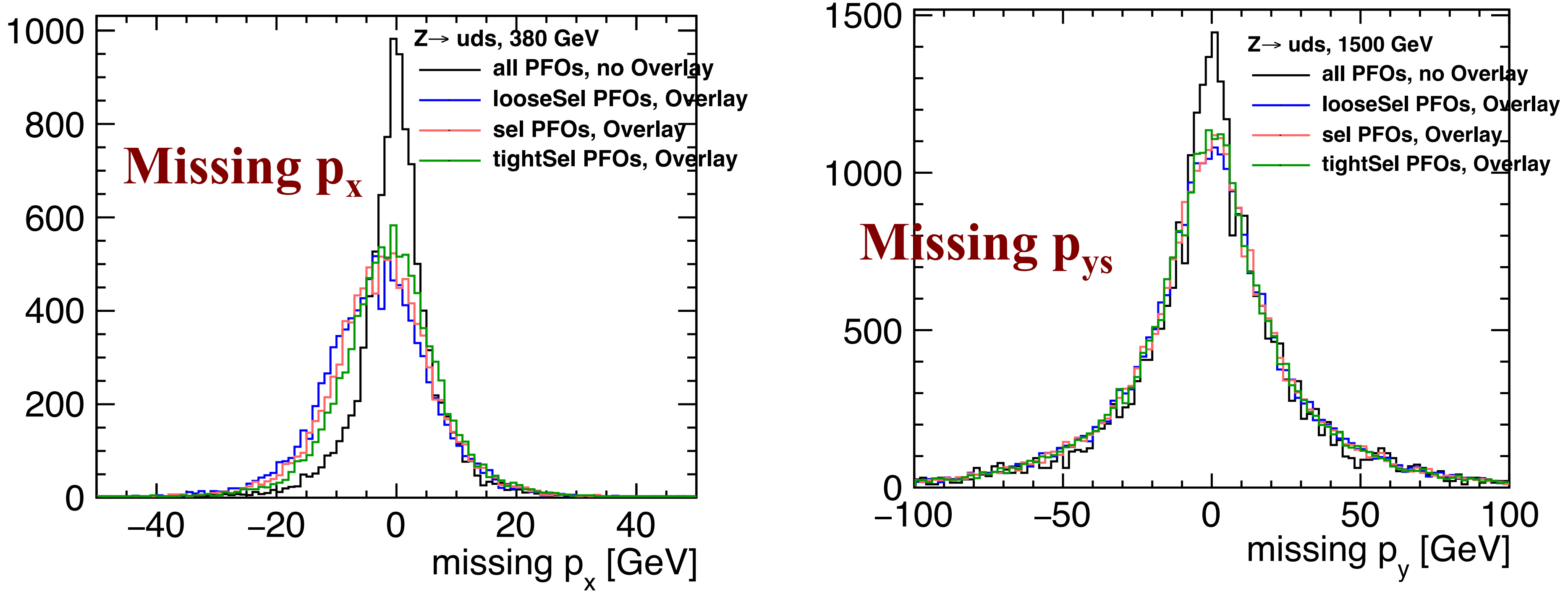


Charged component correctly reproduced





Overlay: missing transverse momentum 1500 GeV

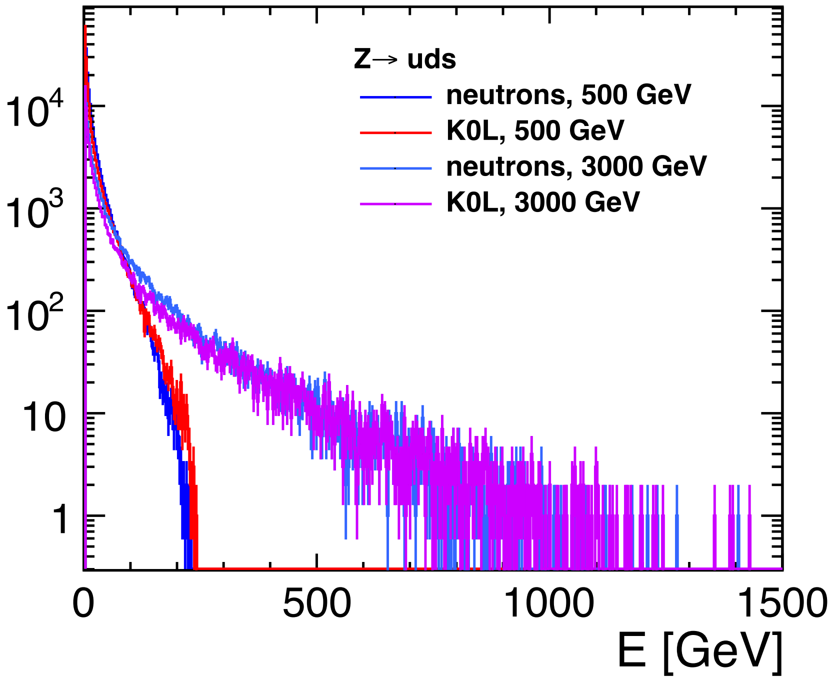


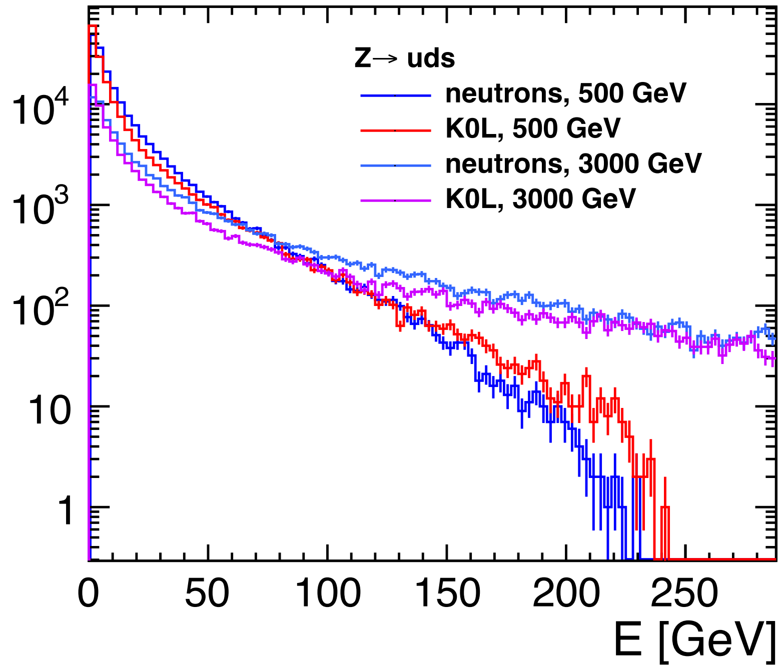
Overlay increases missing p_x RMS_{90} from 4.54 to 6.42 GeV for 380 GeV
→previously increased to 9 GeV
For 1500 GeV dataset RMS_{90} increased from 19.7 to 21.1 GeV →previously increased to 24 GeV

Hadron spectrum for CLIC (Zuds 500 vs Zuds 3000 GeV)

For 500 GeV dataset neutral hadron energies beyond 90 GeV are 1.9 %, for 3000 dataset 13.7 % → if we want same coverage of neutral hadron energy spectrum need to calculate weights for samples up to 400 GeV (1.7 % beyond that point for 3000 GeV sample)

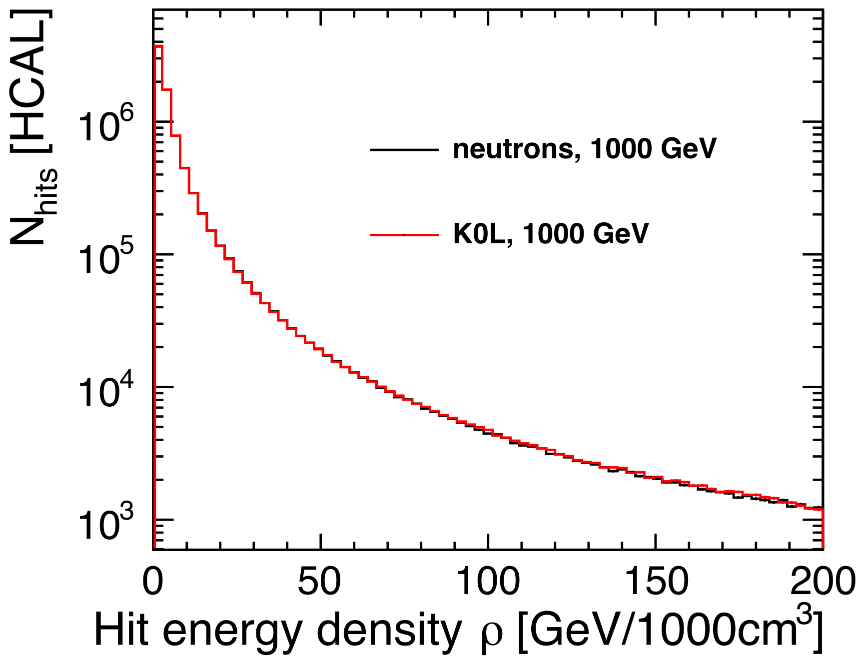
→ For high end tail definitely need CLIC specific weights





Hit energy density for 1000 GeV neutral hadrons

Software compensation weights are determined by minimisation of a χ^2 like function using all energy points and densities up to 30 GeV/1000 cm^3



Quite a few hits with high energy density beyond 100 GeV/dm^3 (cutoff until when weights are applied)