# PandoraPFA: Software Compensation

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# Software Compensation

Hadron showers in the detector consist of electromagnetic and purely hadronic sub-showers

Electromagnetic component originates from production of $\pi^0$ and $\eta$ particles in hadronic showers, which decay into two photons

→ response for electromagnetic sub-showers typically higher than for hadronic sub-showers

→ Electromagnetic component typically denser and narrower

Use local energy density to reweight hit-energy contributions based on the fact that electomagnetic sub-showers tend to be denser

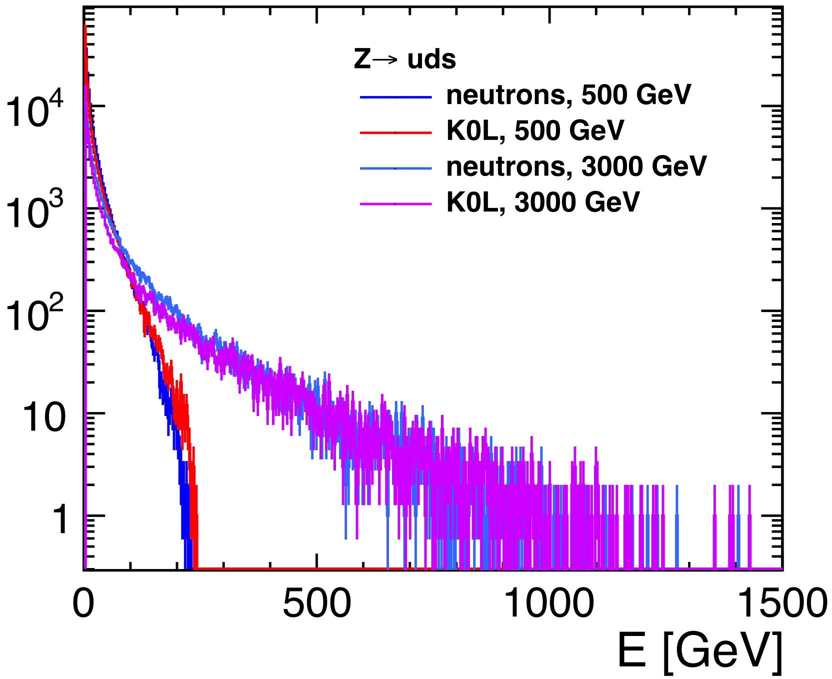
→ Local **software compensation** technique developed by CALICE

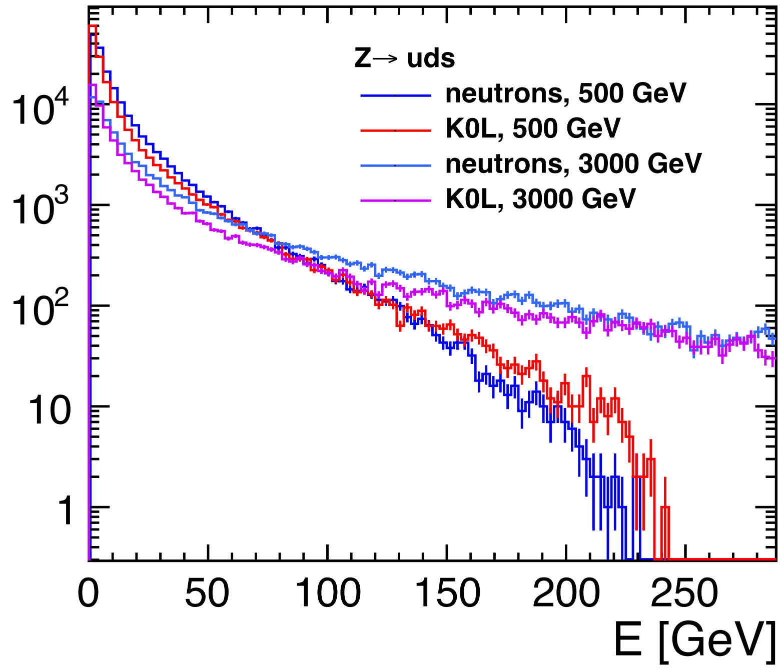
More information about software compensation as concept and the derivation of weights can be found in the paper **Eur. Phys. J. C 77, 698 (2017)**
https://arxiv.org/abs/1705.10363

# First training of SoftwareCompensation
# With model CLIC_o3_v13

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

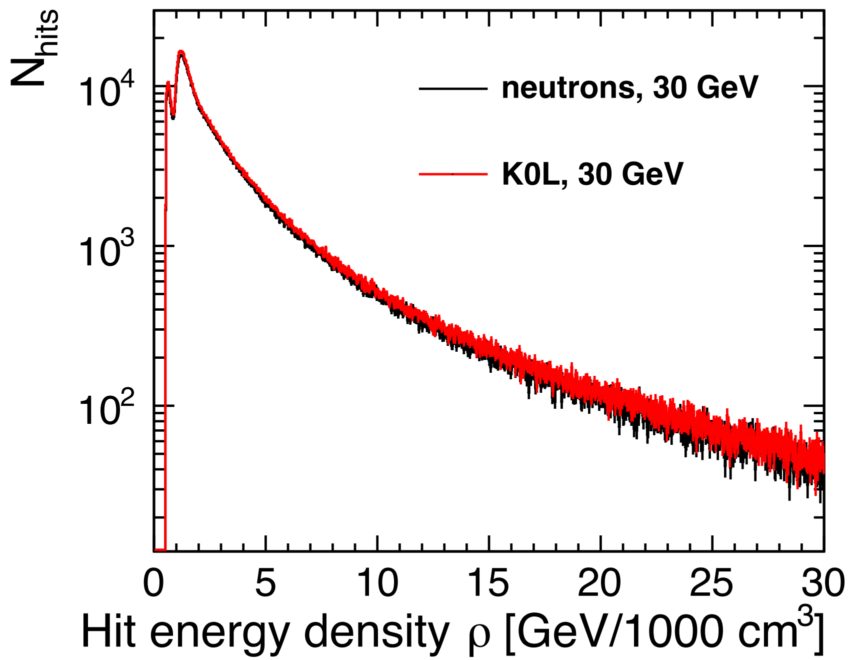
For 500 GeV dataset neutral hadron energies beyond 90 GeV are 1.9 %, for 3000 dataset 13.7 % → if we want same coverage of neutral hadron energy spectrum need to calculate weights for samples up to far higher energies (1.7 % of hadrons with energies beyond 400 GeV for 3000 GeV sample)

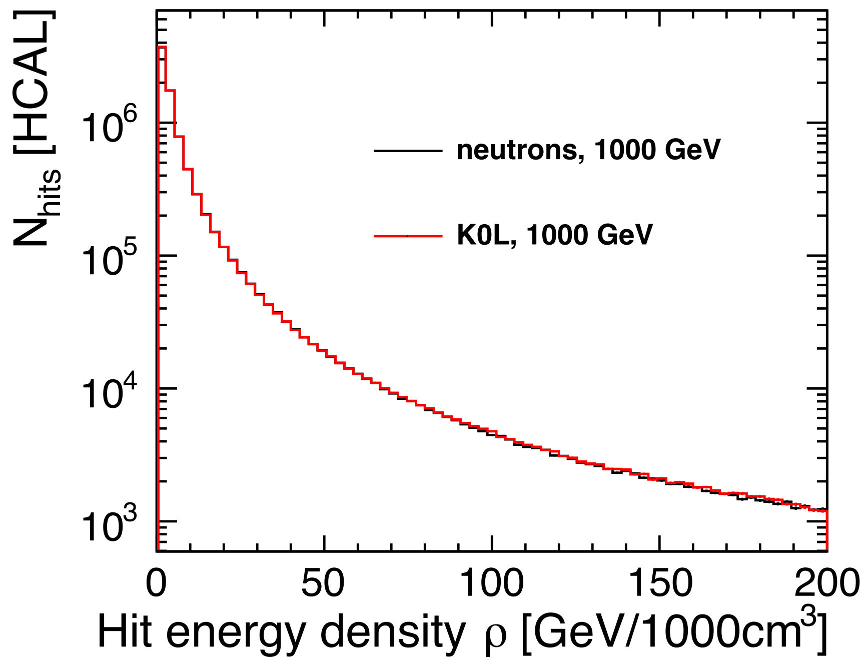


# Check on hit energy densities for very high K0L

Re-weighting applied in energy density bins → extend weight bins to densities of 100 GeV/dm$^3$, set overflow bin to 110 GeV/dm$^3$ (default overflow bin at 30 GeV/dm$^3$)




The energy of calorimeter clusters are computed as:

$$E_{SC} = \sum_{\text{hits}} E_{ECAL} + \sum_{\text{bin } i} (E^i_{HCAL} \times \omega(\rho_i))$$

$$\text{with } E^i_{HCAL} = \sum_{\text{hits} \in \text{bin } i} E_{hit},$$

$$\omega(\rho) = p_1 \exp(p_2 \rho) + p_3$$

# Samples and Software used

Produce single particle gun samples of neutrons and K0L's separately, for each point simulate and reconstruct 80000 events
Use the PandoraSettingsSoftwareCompensationTraining script for reconstruction

Cleaning of clusters in the Pandora training script identical to cleaning for default reconstruction
→Then run **PandoraPFACalibrate_SoftwareCompensation** script in PandoraAnalysis/calibration

Energy points at 2,5,10,20,30,40,50,60,75,90,100,150,200,250,400,500,1000 GeV for neutrons and Kaons, for Kaons additional energy point at 1 GeV

Merge Kaons and neutrons in one sample and use energy points of 2,5,10,30,50,75,150,200,400 for software compensation training
→using all samples lead to too high memory comsumption

Density binning: 0 2 5 7.5 9.5 13 16 20 23.5 28 33 40 50 75 100, overflow 110

# Default vs CLIC Software compensation

Default: apply software compensation for hadron energies up to 100 GeV, extend the range to all hadrons (i.e. as value give 1800 GeV)
Weight applied as function of hit energy density:
Default binning: 0 2 5 7.5 9.5 13 16 20 23.5 28, last bin set to 30 (overflow bin set to 30 GeV/dm$^3$ for reweighting)

NEW CLIC binning (lower binning identical):
28 33 40 50 75 100, last bin set to 110

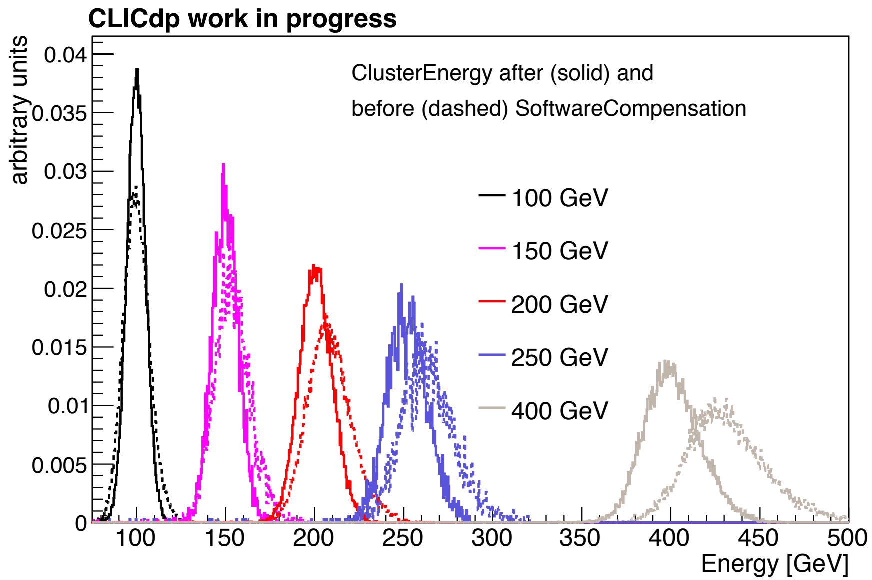
→weights are separately very different, default weight energy dependence leads to an almost constant reweighting at high energies for various hit energy densities

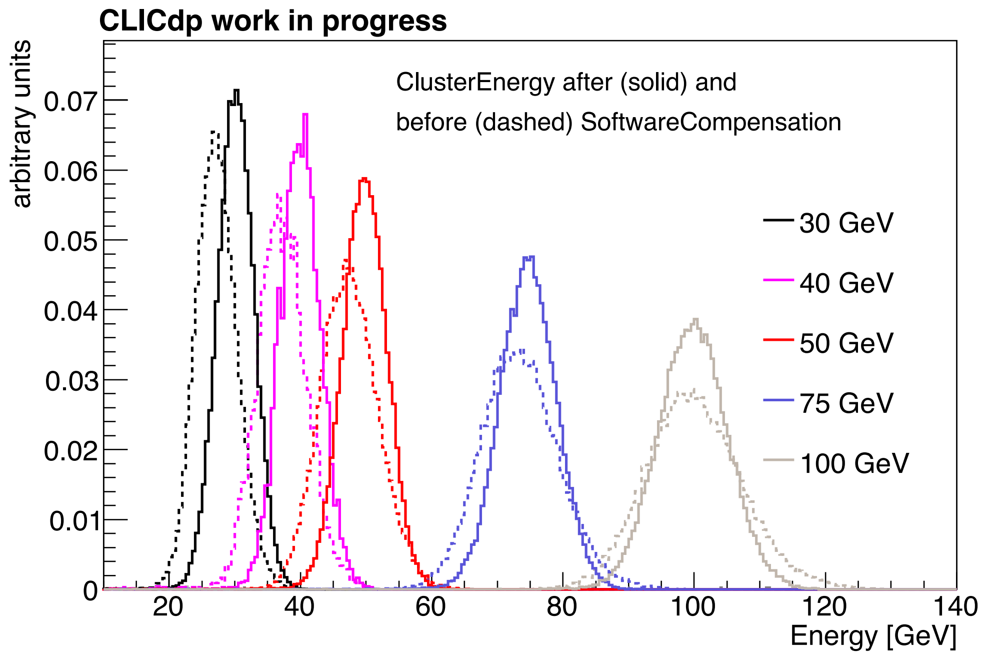
Previously for a 200 GeV neutron reweighting is 0.752 for 3 GeV/dm$^3$ hit as well as for 30 GeV/dm$^3$

Now for 200 GeV neutron weight for 3 GeV/dm$^3$ is 0.881 and for 30 GeV/dm$^3$ it is 0.878 (n+K0L)

# Self-closure of training: neutrons

Compare cluster distribution without software compensation and after applying the software compensation weights on the hits for self-closure of the training



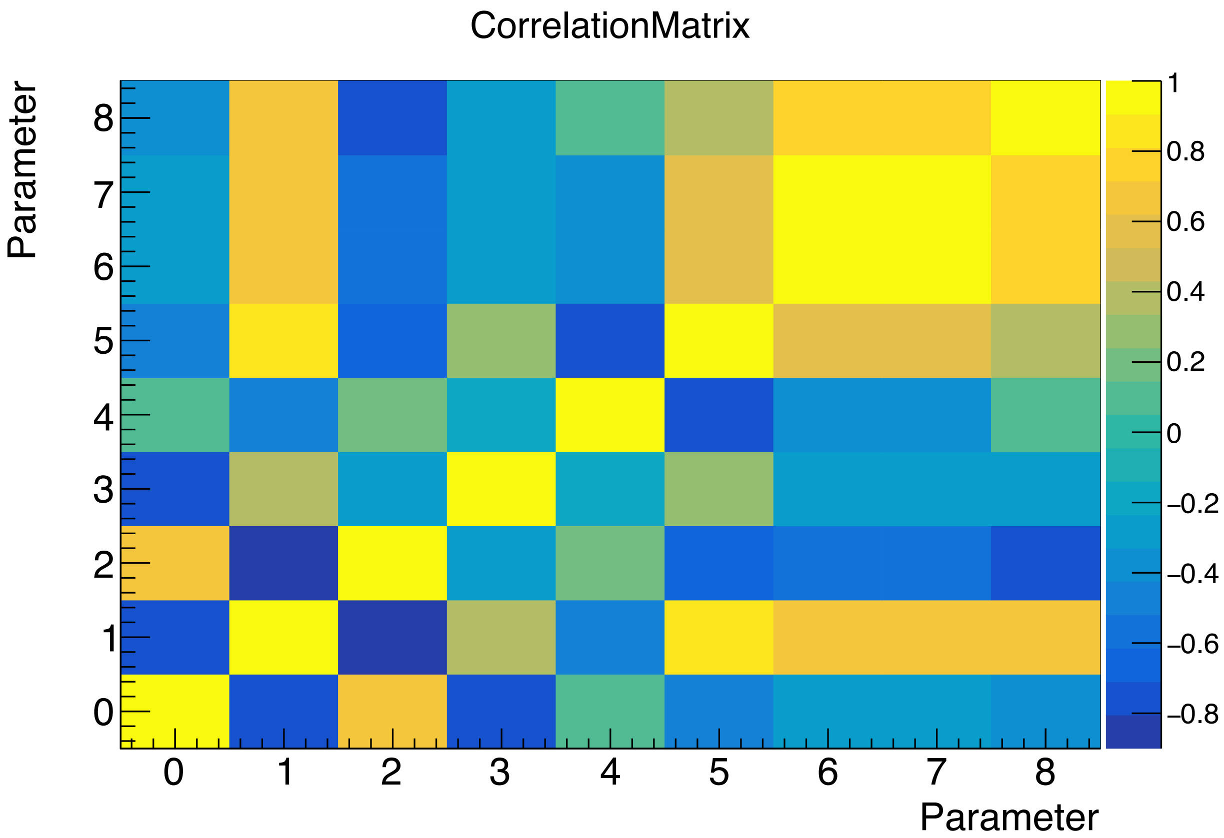




Nice closure of procedure, takes care of non-linearities in response as well

# Errors of Parameters

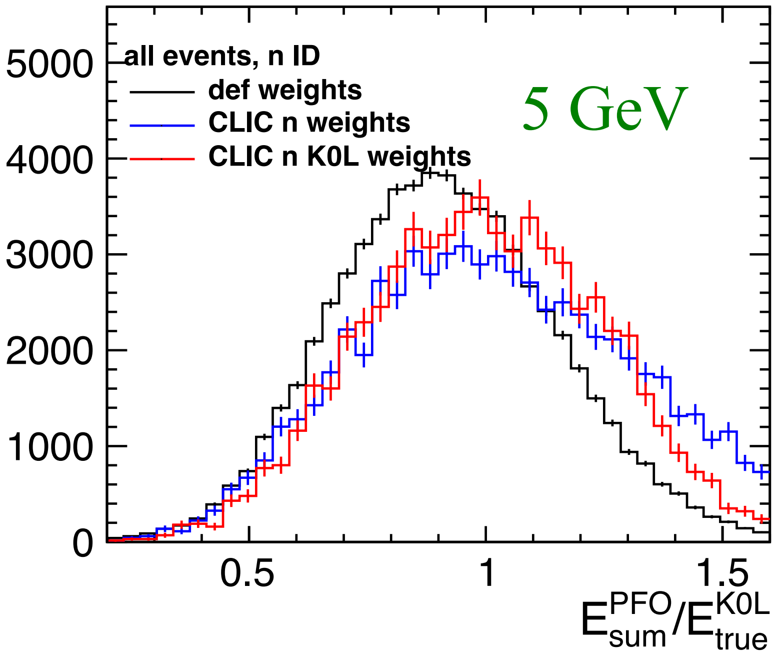
Estimate error and covariance matrix using the Hessian Matrix: Large (anti)correlations between different parameters →is this behavior expected or has this been studied previously

Upper/lower error determination by Minos fails to converge

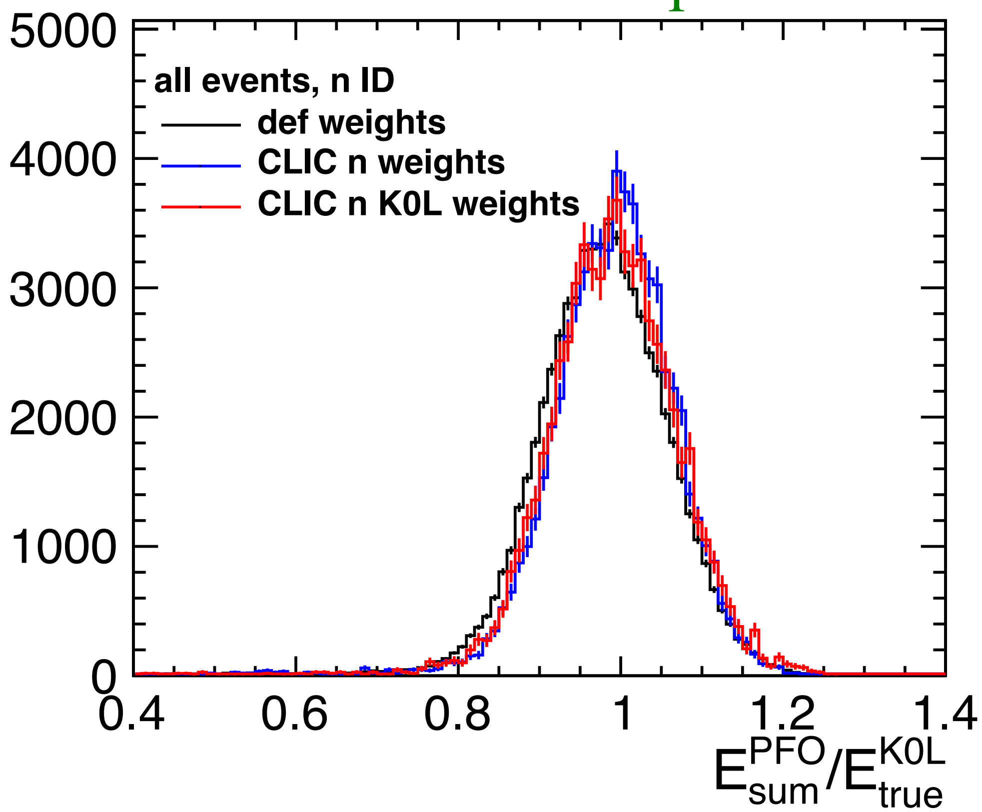


# Single Hadron response closures: low energy Kaons

Recalibrate PandoraPFA for each of the software compensation (SWC) weights (neutrons, K0L, neutrons+K0L combined), apply n and n+K0L weights on Kaons and compare with previous SWC weights




50 GeV: calibration point




Combined samples weight seems to work best

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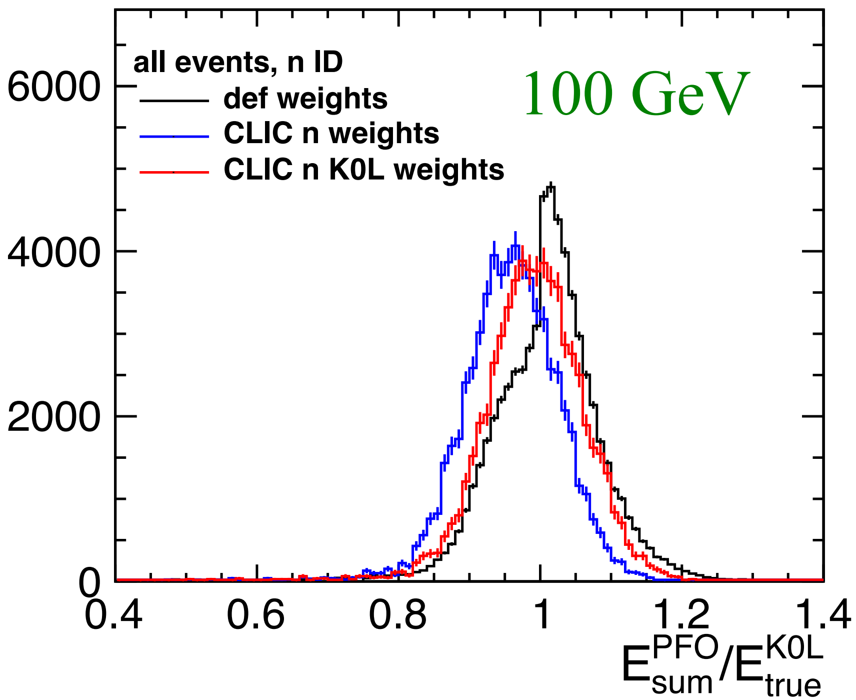
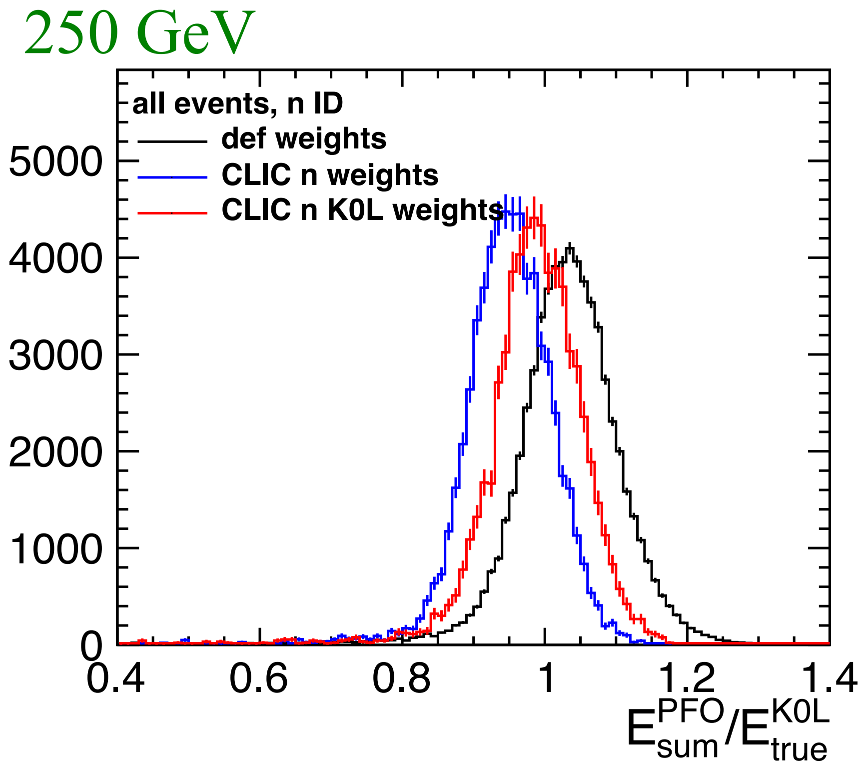
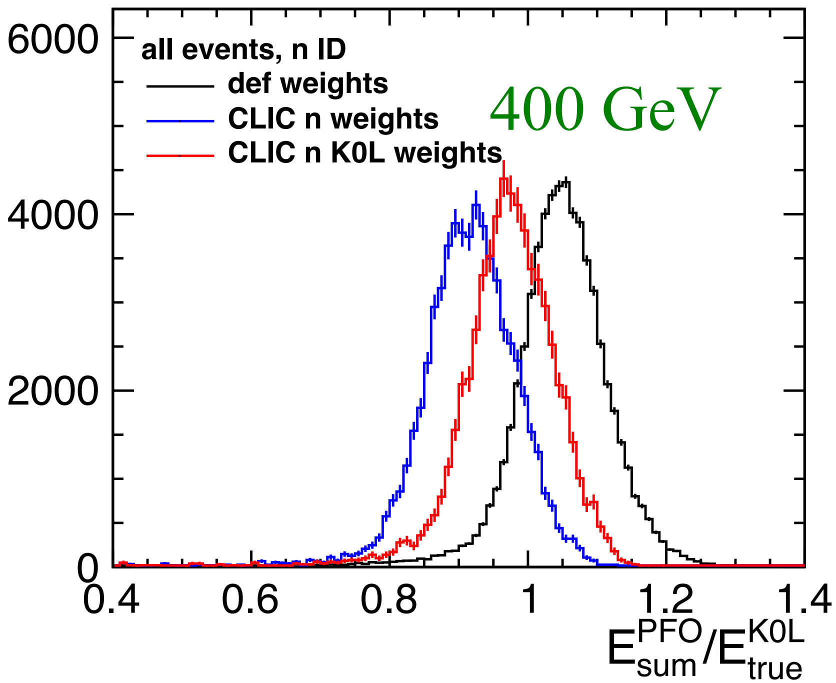


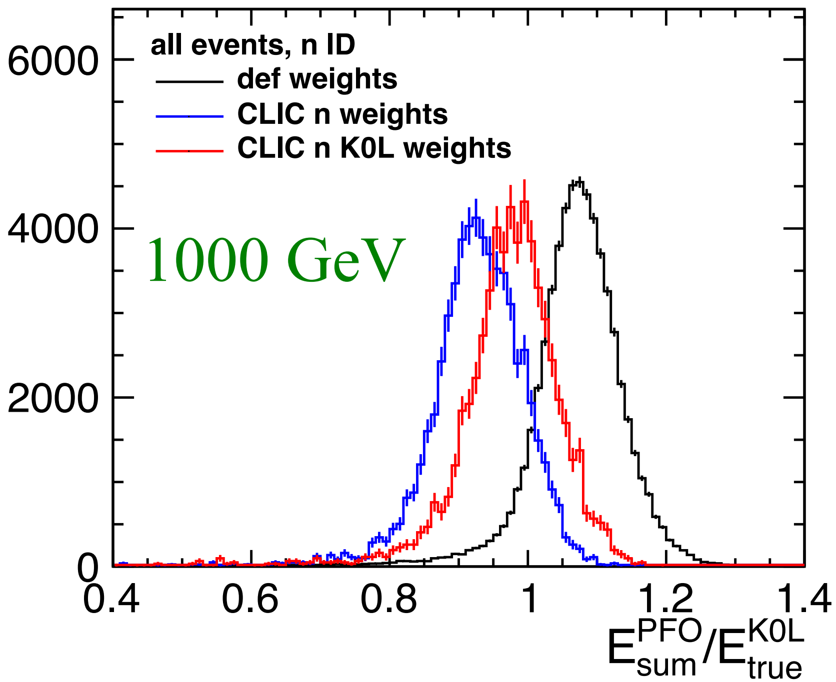




Combined samples weight works best, at 100 GeV default setting stops applying software compensation → weird shape of distribution

# Single Hadron response closures: high energy Kaons

Apply n and n+K0L weights on Kaons and compare with previous SWC weights

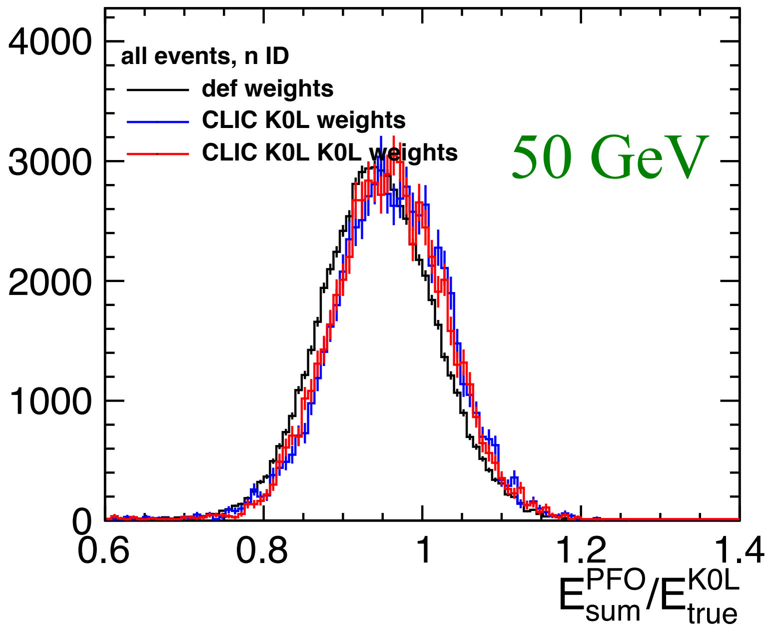


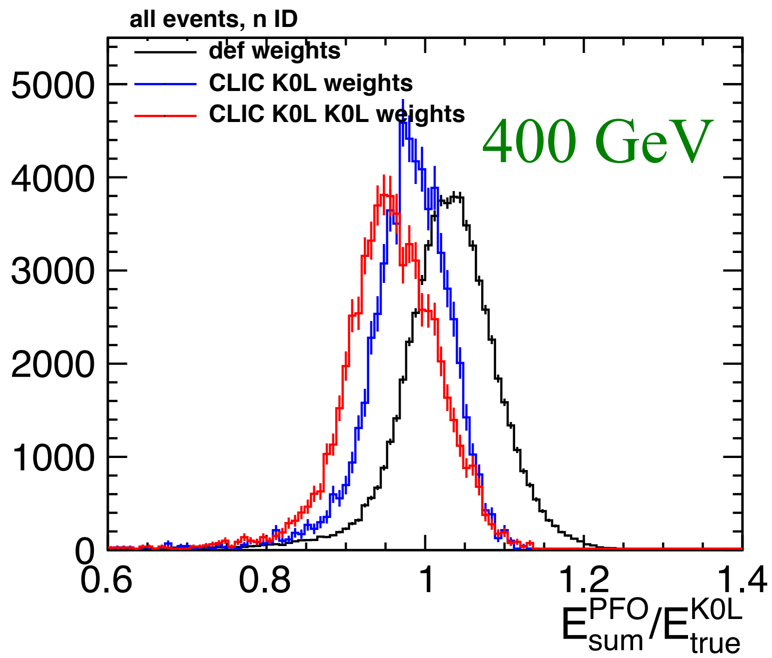




Best performance for Kaons using the weights of the combined sample, neutrons weights seem to be lower

# Single Hadron response closures: neutrons

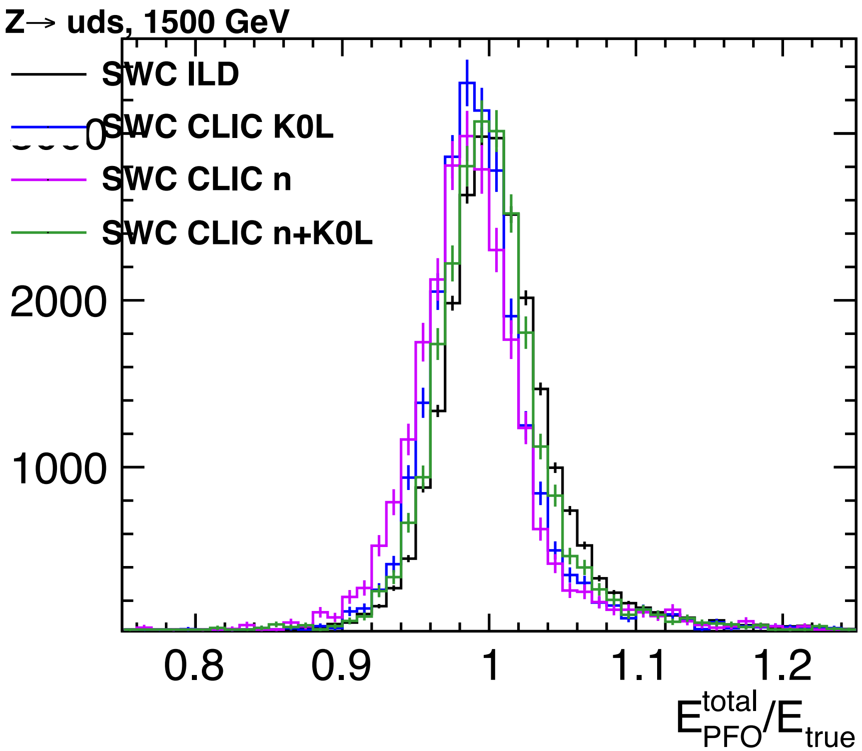
apply K0L and n+K0L weights on neutrons and compare with previous SWC weights

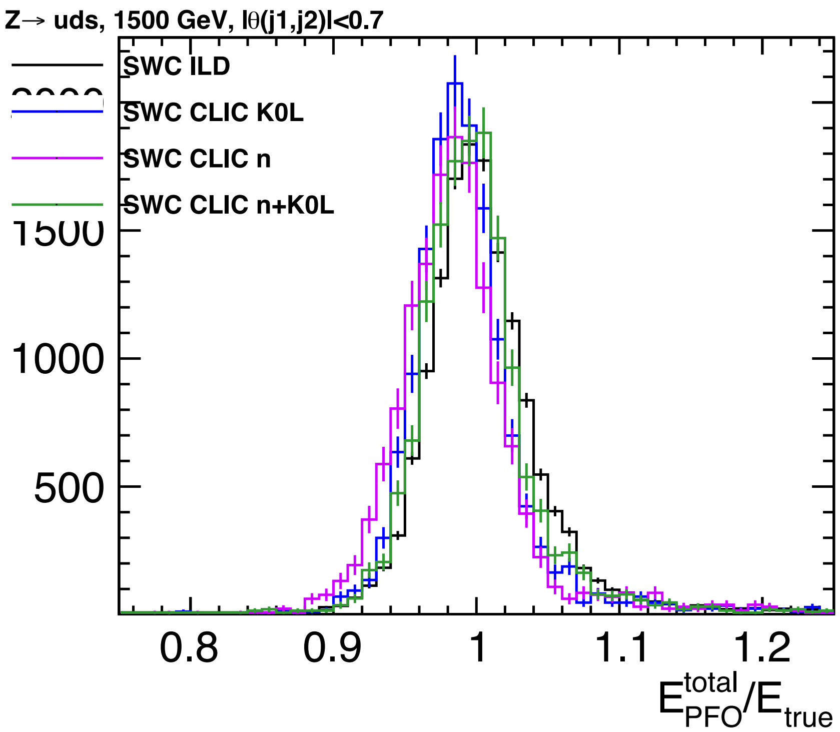



Response too low for all weights, K0L weights work better than from combined sample

# Outlook for Jet Energy Resolution
# Z to u/d/s sample at 1500 GeV




Best values of means for n+K0L settings,
Same for RMS values

mean/RMS 0.7 ILD 1.00531/0.0450967
mean/RMS 0.7 K0L 0.993323/0.0439417
mean/RMS 0.7 n 0.987313/0.0468662
mean/RMS 0.7 K0L+n 0.99924/0.0427059