Tower Energy Scale Corrections and JES/JER: Implications for IHCAL Design

J. Lajoie

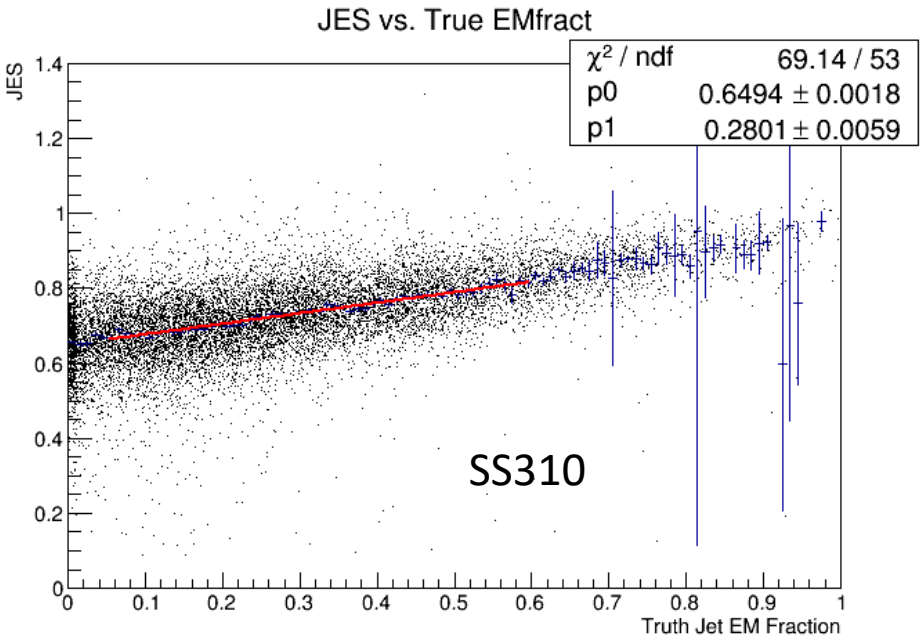
Iowa State University

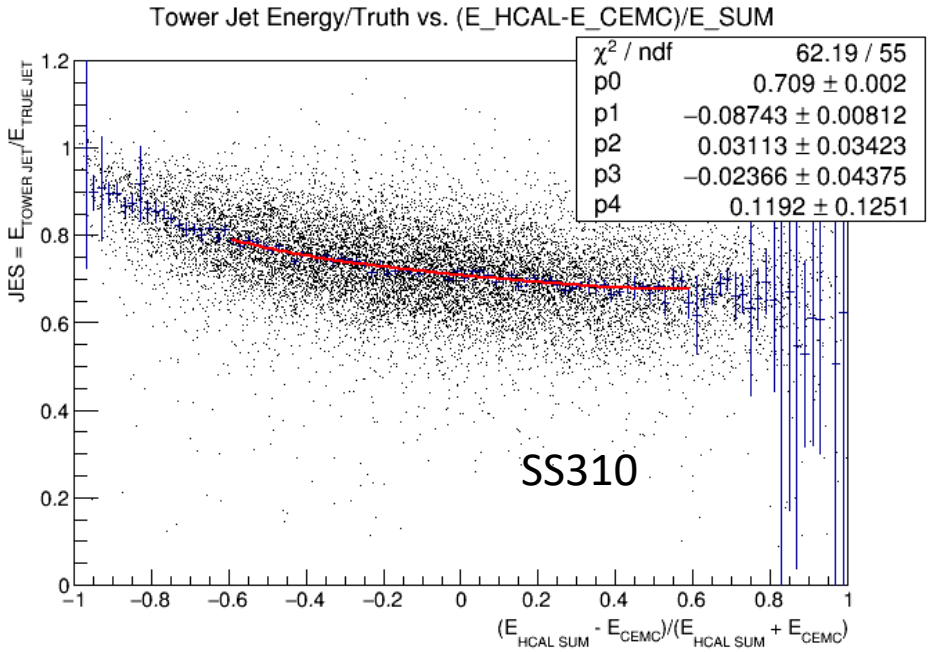
The Setup

- Revised G4 simulation geometry from Chris P. (9/29/2017)
  - Main effect is SS310 IHCAL is ~0.15 interaction lengths thinner
- Used an analysis code that was originally developed to study jets with forward instrumentation:
  - /sphenix/user/lajoie/sPHENIX/jet_simulations/FastTrackingEval
- Start with the same Pythia8 HepMC files as Dennis:
  - /sphenix/user/dvp/gen/QCD35/
  - Jets >50 GeV, R=0.4 jet in $|\eta|<0.6$, 10k events
- Reconstructed jets three ways, R=0.4:
  - Primary Particle Jets
    - No muons, neutrinos
  - Track Jets
    - Tracks require ndf>60, χ^2/ndf<1.5, DCA2D<0.1cm
  - Calorimeter Tower Jets
    - Require tower energy > 100 MeV
- Conditions – SS310, SS310 w/o readout, Al, and Al w/o readout, and SS310 frame (steel cylinder)
- "Matched" jets require track and tower jets match the primary jet within $\Delta R<0.4$: (note was $\Delta R<0.3$ from previous studies)
  - Primary jet must have $|\eta|<0.6$, E>50 GeV consistent with trigger

JES vs. EM Fraction

Calculate a "truth" EM jet fraction using the constituents of the truth jet. "EM" energy is summed from γ, $e^{+/-}$, π^0, η. Look at tower jets (E_{truth}>50GeV, $|\eta|$<0.6, ΔR<0.4 from truth):





No correction for JES – strong variation in JES as a function of EM fraction. Both HCAL and CEMC energy scales are not correct!

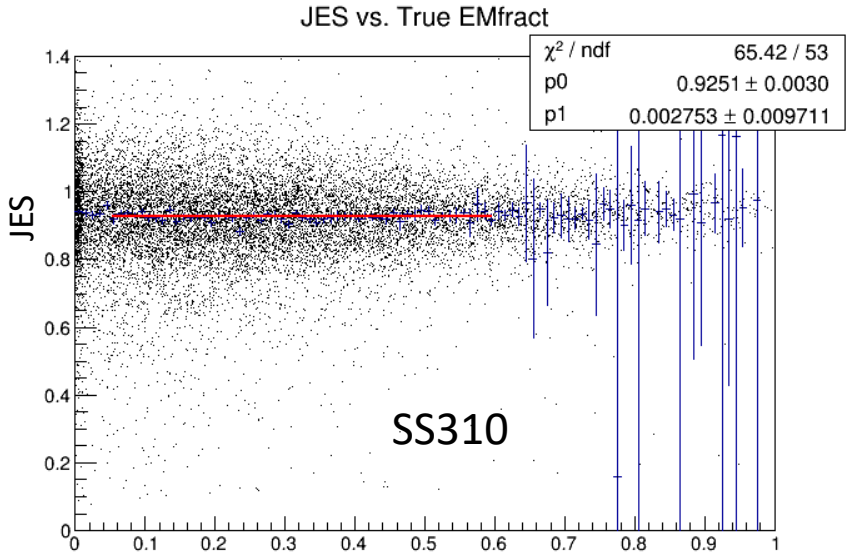
JES vs. difference fraction: as x->1 this asymptotes to the HCAL scale correction.

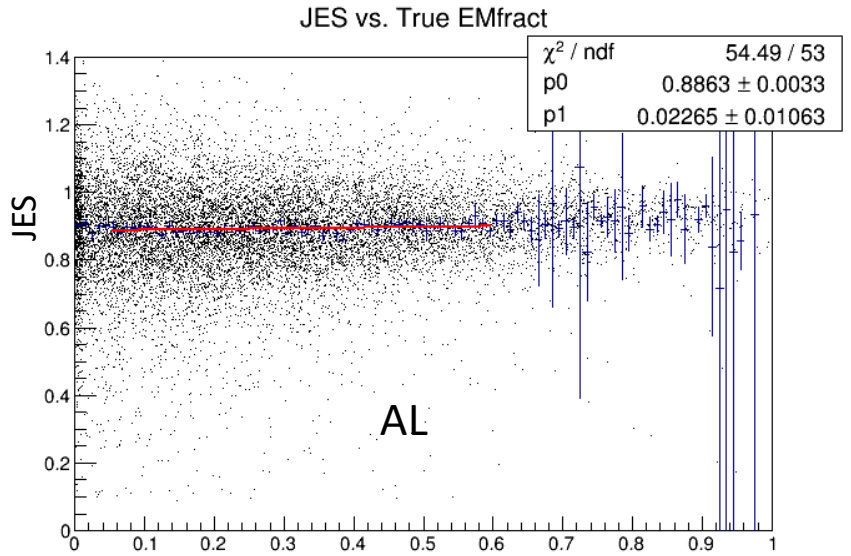
Tower Corrections

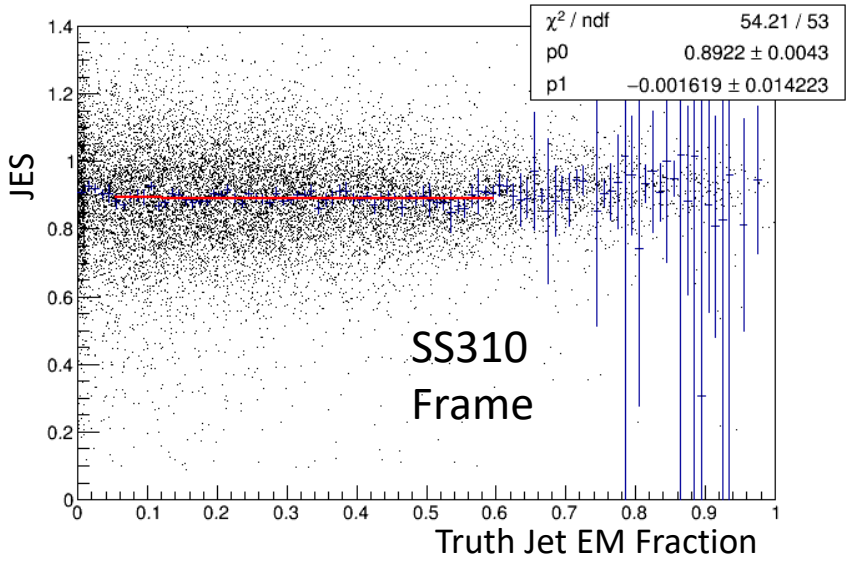
- There are (at least) two important scale corrections:
  - HCAL: correction for nuclear binding energy
  - CEMC: correction for e/h tower response
- From the previous slide we can extract the HCAL correction (inverse of x->1 intercept):
  - Consistent with test beam results
  - Constant as a function of energy
    - Test beam results highly linear…
- Correction procedure:
  - Apply HCAL correction to HCAL towers
  - Apply correction (empirically determined) to hadronic energy in CEMC tower; rescale tower energy
    - This uses “truth” information – equivalent to perfect tracking, clustering and cluster splitting
  - Perform jet finding on rescaled towers
- Needs more study, but alleviates EM fraction dependence
  - More study needed to fully optimize

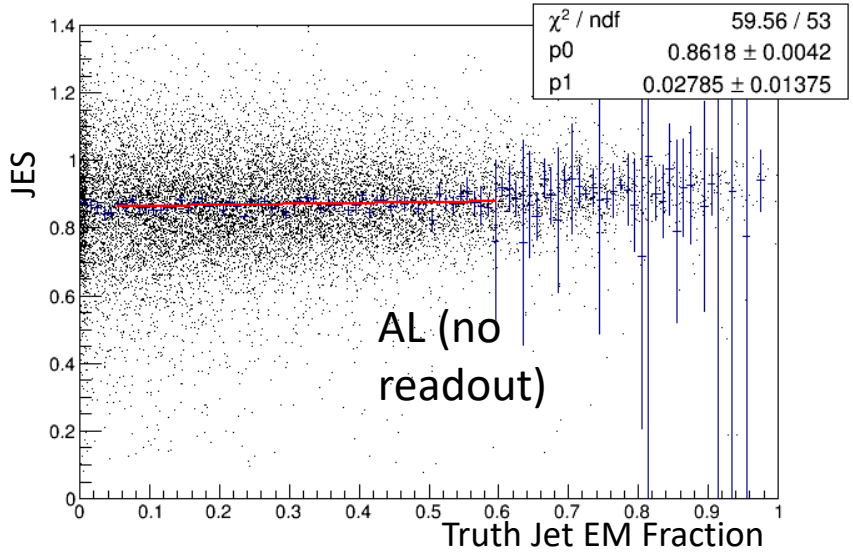
	HCAL SCALE	CEMC SCALE
SS310	1.49	1.25
SS310 (no readout)	1.67	1.85
AL	1.49	1.25
AL (no readout)	1.56	1.25
SS310 Frame	1.61	1.45

After Tower Corrections I

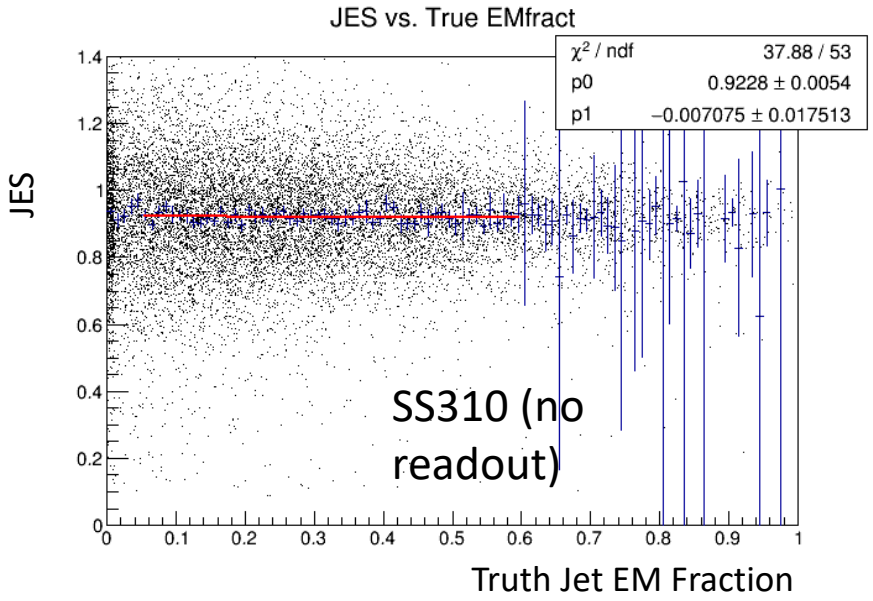








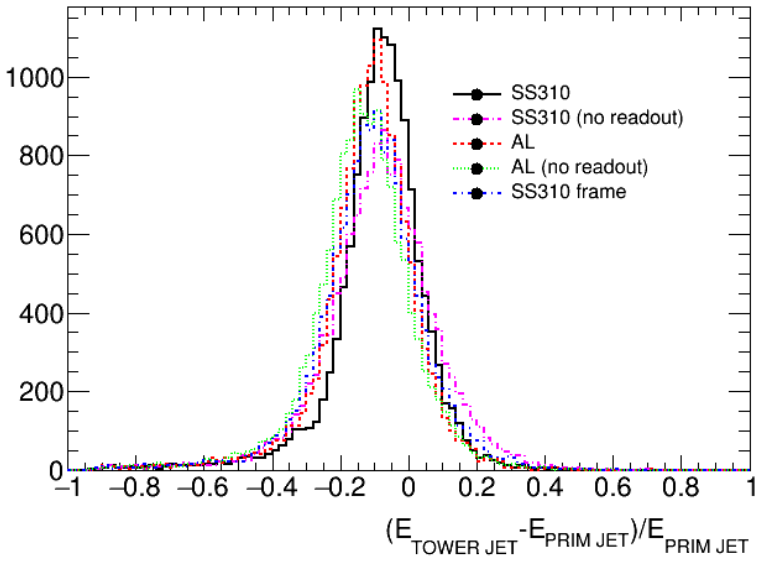
After Tower Corrections II

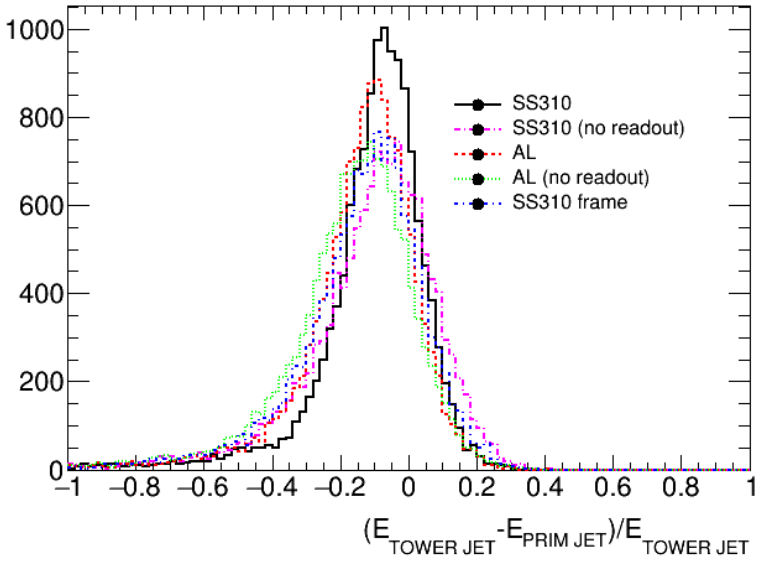


Thoughts on Scale Factors

- The HCAL scaling constant takes into account:
  - Average energy lost to binding energy in nuclear interactions. This is the dominant contribution.
  - Energy lost for showers that start in dead material and then is partially measured in the HCAL
    - Magnet cryostat, coils, etc.
    - This includes the iHCAL when it is not instrumented!
- The CEMC scaling constant takes into account:
  - The differential response for hadrons and EM showers
  - Energy from hadronic showers that start in the CEMC and is lost (absorbed) in dead material
    - Magnet cryostat, coils, iHCAL (un-instrumented), etc.
- Both the HCAL and CEMC scaling constants increase when there is more dead material between the CEMC and active HCAL sections.

Tower Jets JES and JER





	JES (+/- 0.002)	JER (+/- 0.002)
SS310	0.929	0.104
SS310 (no readout)	0.926	0.146
AL	0.898	0.114
AL (no readout)	0.874	0.136
SS310 Frame	0.899	0.144

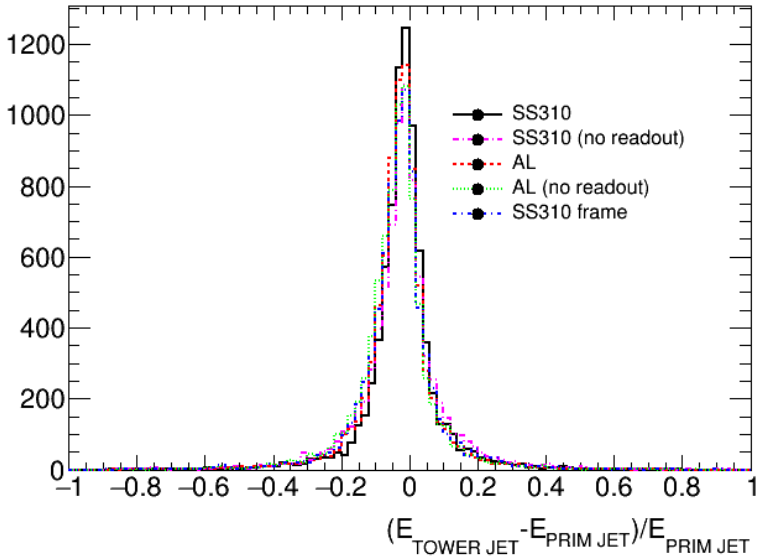
Fits iterated +/- 2σ

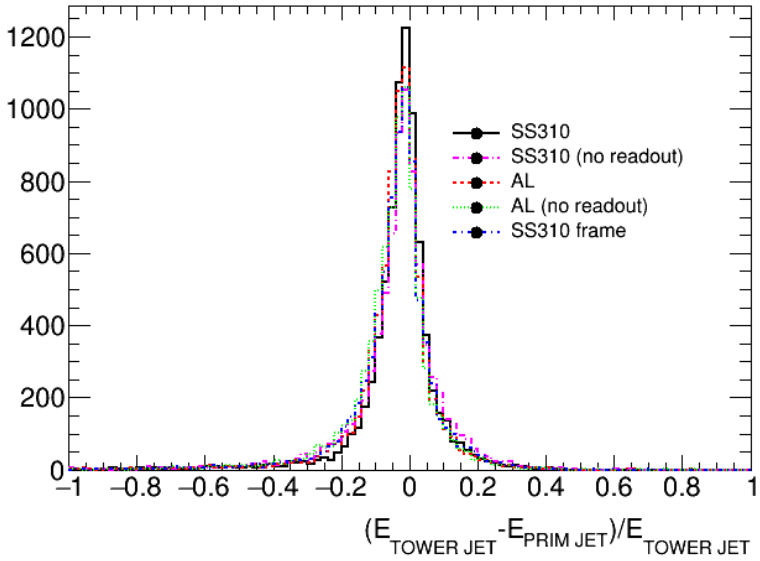
Low-side tails visible

Combined Jets

- Combine the tower and track jets to use the best information from both:
  - Analysis code includes bookkeeping of particle energy contribution to calorimeter tower energy
    - This uses truth information (think of it as perfect clustering/cluster splitting)
  - Point each track jet constituent into the calorimeter, sum up the energy it contributed to the tower jet in each calorimeter segment
  - Combine the tower and track jet information:
    - Expected energy/momentum resolution calculated using measured quantities:
      - Track momentum resolution $\delta p_T / p_T = 0.005 + (0.001 * p_T)$
      - Sort EM/hadronic particles by CEMC tower energy fraction > 0.9
      - CEMC resolution 0.12/sqrt(E) for EM particles,
        CEMC+HCAL resolution 0.15 + 0.7/sqrt(E) for hadrons
    - If the track momentum resolution is better than the tower resolution, add the track to the combined jet
    - If the calorimeter energy resolution is better, rescale the track total momentum to match the tower energy.
      - Improves energy resolution but keeps improved pointing resolution of tracking (eta,phi)
    - Remaining tower energy after all particles is "neutral energy" and is added to the combined jet.
  - This is *similar* to a particle flow algorithm, with the exception that it uses truth information instead of a real clustering/cluster splitting algorithm
  - Gives an idea of what is the best you could possibly do, or how much information is in principle available for you to take advantage of
    - Leakage out the back is a loss of information.

Combined Jets JES and JER





	JES (+/- 0.002)	JER (+/- 0.002)
SS310	0.981	0.053
SS310 (no readout)	0.978	0.065
AL	0.972	0.057
AL (no readout)	0.967	0.060
SS310 Frame	0.971	0.064

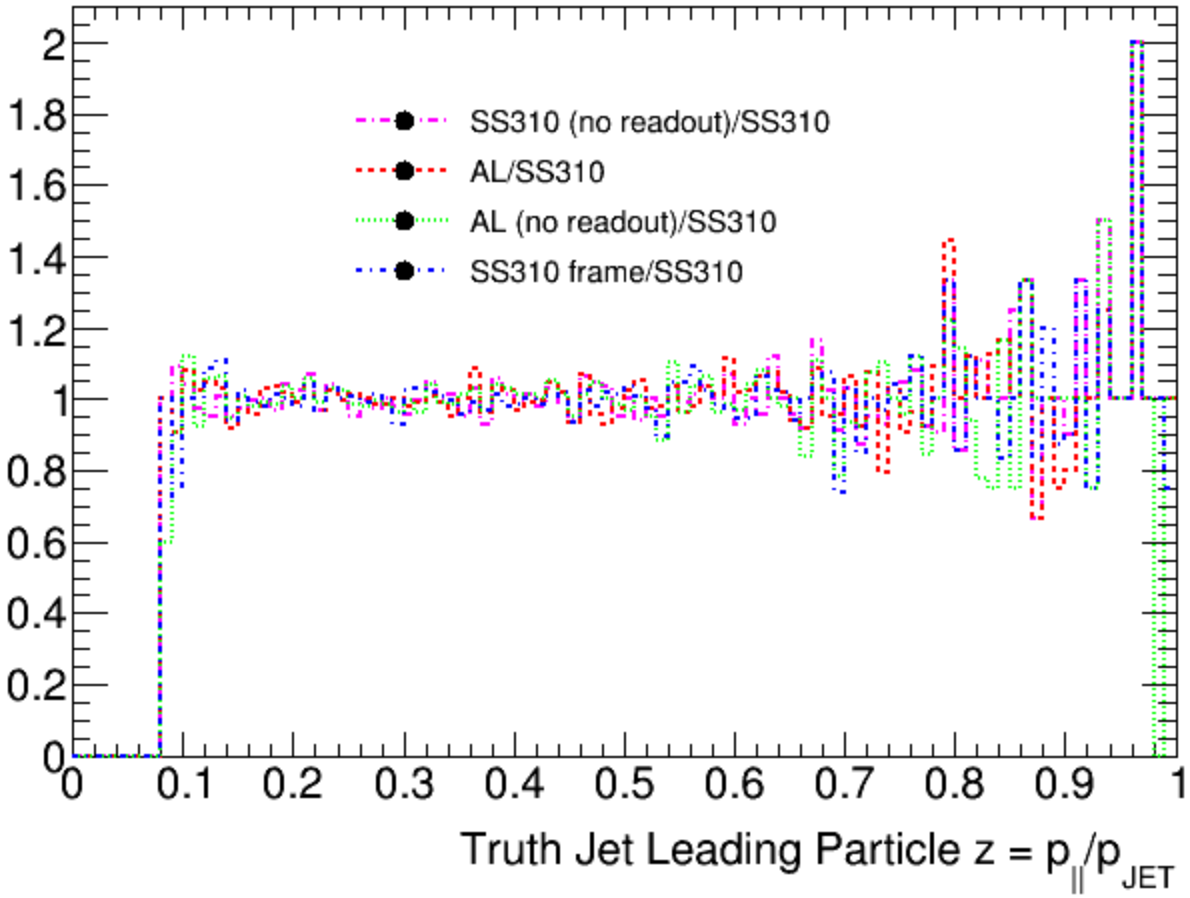
Fits iterated +/- 2σ

Distributions reasonably symmetric, pronounced low-side tail seen previously is now not evident.

Fragmentation Dependence

Look at tower jets found as a function of z of leading particle in truth jet.

Needs more statistics, but there is a hint of a depletion at high z for thinner options.



Conclusions

- Properly accounting for the HCAL and CEMC energy scales takes out JES variation with EM fraction
  - Details at the few % level still need investigation
- Differences between IHCAL options now more clear:
  - In “rank order” based on tower jet JER performance:
    - SS310
    - AL
    - AL (no readout)
    - SS310_FRAME or SS310 (no readout)
- In principle, a particle flow algorithm can recover most of the JES/JER performance
- Hint of depletion at high-z for thinner options
  - Adding additional Pythia8 events (same configuration)