

# Simulation calorimetry studies without a PFA

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SiD Workshop

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# Hcal design parameters

- Absorber material (W, Steel, Cu, Pb, other?)
- Active material (Gas, Plastic)
- Segmentation
- Total lambda, and lambda/layer
- If plastic, analog or digital
- Other parameters (B field, inner radius, etc.) probably driven by features other than neutral hadron reconstruction

# Designing for PFlow

- Vary design parameters, tune PFlow algorithm and analyze a set of physics processes.
- Figure of merit: dijet mass resolution
- Not yet there with PFlow algorithms ?
- Even when we can, will need to understand results at a more fundamental level.
- So ... see what we can find out about Hcal parameters -> dijet mass resolution in the context of a PFlow algorithm without a Pflow algorithm

# Plan

- In the context of PFlow, the Hcal measures neutral hadrons.
- Study energy resolution varying parameters
- Quantify effect of energy resolution on dijet mass resolution
- Study shower spread varying parameters
- Study confusion as a function of shower spread
- Quantify effect of shower spread on confusion
- Quantify effect of confusion on dijet mass

# So far ...

- Effect of varying design parameters on intrinsic resolution of neutral hadrons has been quantified. (Not a complete study of entire parameter space, but enough to get a good idea of variations)
- Effect of intrinsic neutral hadron resolution on dijet mass resolution (no confusion) has been quantified. Within the range of resolutions of the parameter space studied, there is at most a tiny effect on dijet mass resolution.
- Differences in radial and transverse spread in neutral hadron showers have been observed for gas/plastic active elements, with some attempts to quantify them.
- Some attempts to quantify shower spread -> confusion, but so far only hints.

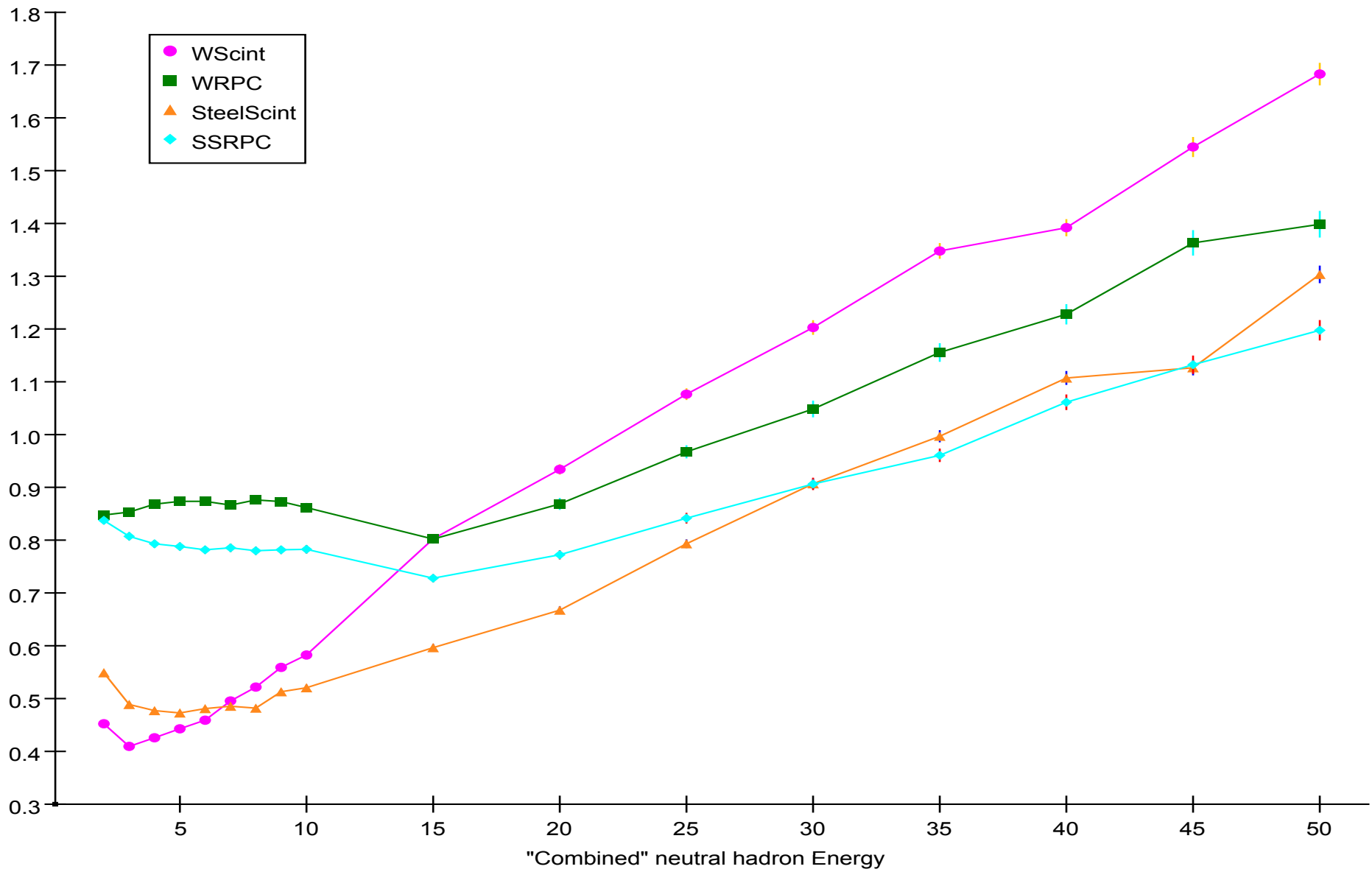
# Energy resolution studies

- Single particles in infinite detector
- Energy sums in mono-energetic jets: full detector simulations, requires adding energy from Ecal, imposes physics distribution of particles. Remove as yet unknown identification problems by cheating on pattern recognition
- Dijet mass resolution in physics events: impose physics distribution of jet energies and particles in jets

# Single particle resolution: parameter space

- Vary absorber, active element, segmentation, analog/digital, depth of calorimeter
- Infinite parameter space, but with finite comparisons can find some trends
- Basic comparisons with (W,SS)X(gas,plastic)
- For a more complete set of resolution curves, see  
<http://www.slac.stanford.edu/~cassell/SiDHcalStudies.ppt>

### Finite detector: $(\sigma/\mu)\sqrt{E}$





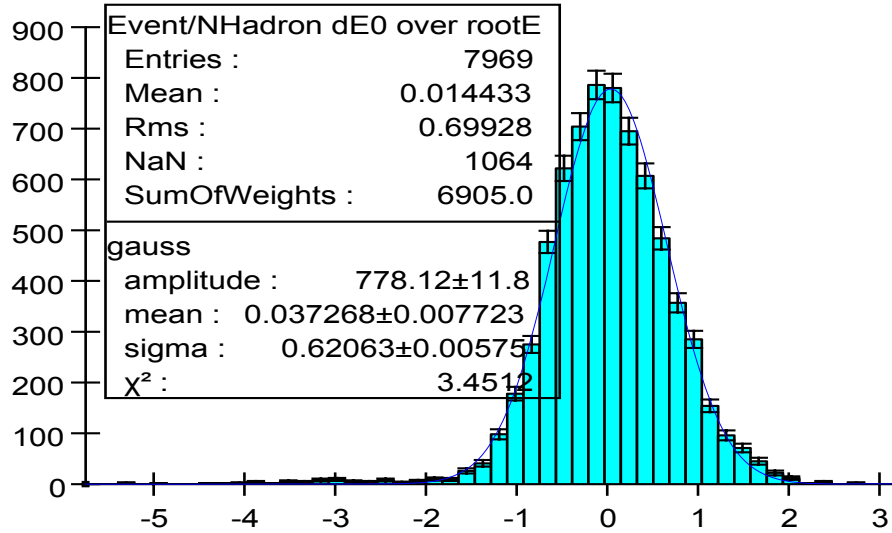
# Single particle resolutions from isolated detector studies

- Absorber: SS better than W, especially at higher energies. Cu similar to SS, Pb worse than W at lower energies. For fair comparison, need to compare fixed lamda per layer configurations.
- Active element: Scint better than gas below  $\sim 15\text{GeV}$
- For digital readout, significant degradation at higher energies for coarser segmentation
- Resolution gain for thicker Hcal quantified
- No resolution curve has flat  $1/\sqrt{E}$  dependence as function of E

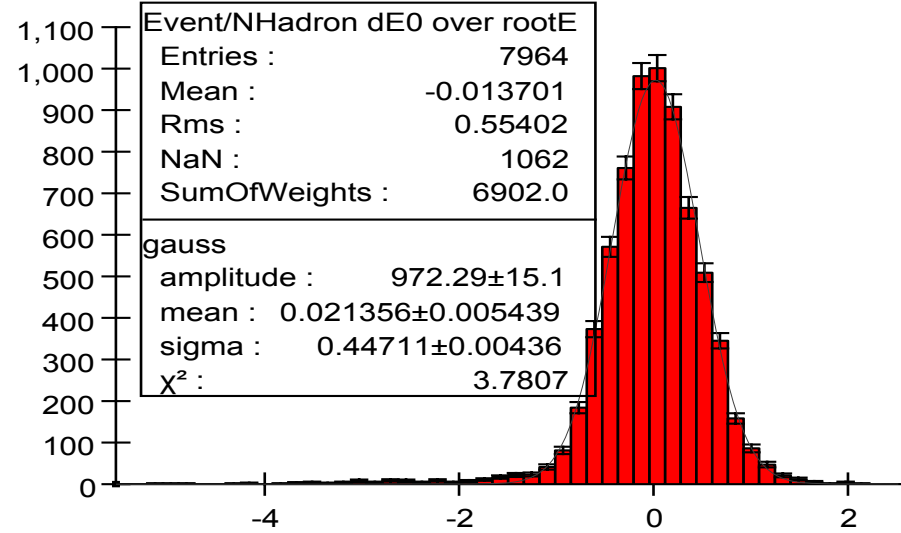
# Energy sums in mono-energetic jets

- Full detector simulations
- Still cheat on pattern recognition
- Look at “effective” neutral hadron resolution
- Use rms90, mean90, and  $\alpha = (\text{rms90}/\text{mean90}) * \sqrt{E}$  for comparisons of energy sums

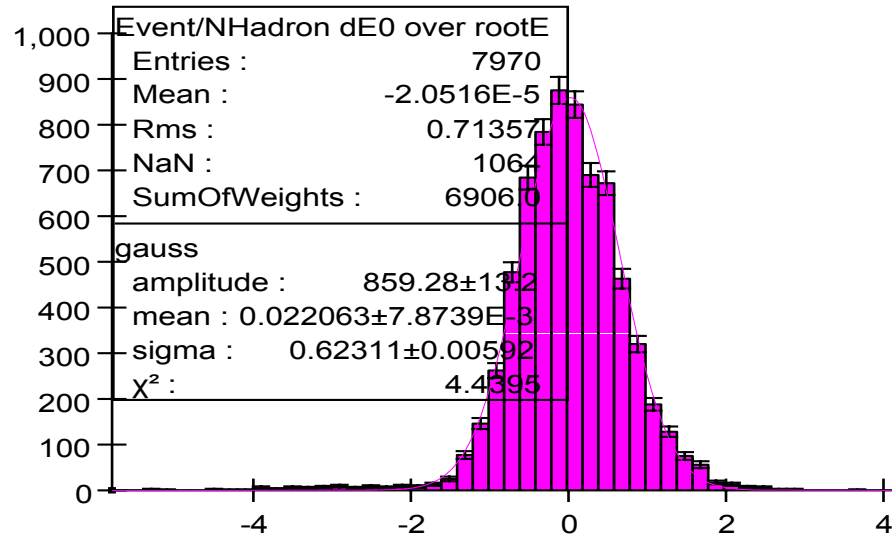
**SSRPC:Zpole Event nhad dE/rootE**



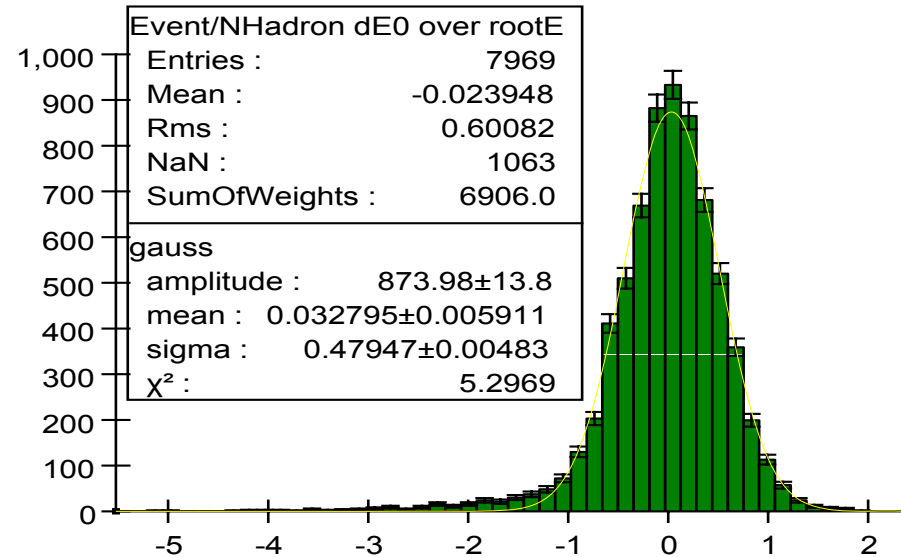
**SSScint:Zpole Event nhad dE/rootE**



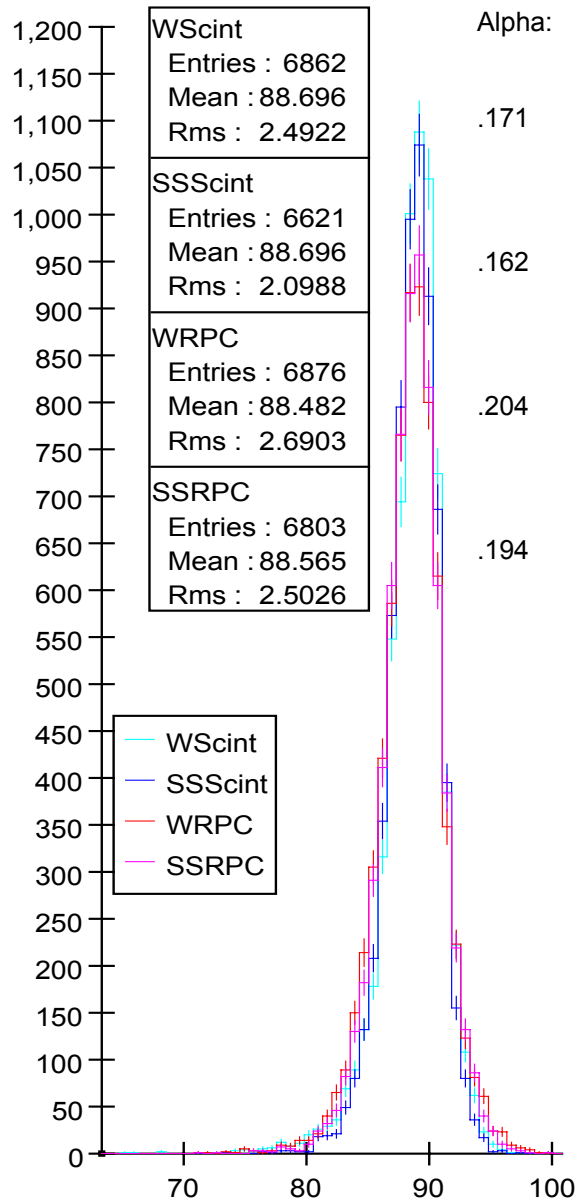
**WRPC:Zpole Event nhad dE/rootE**



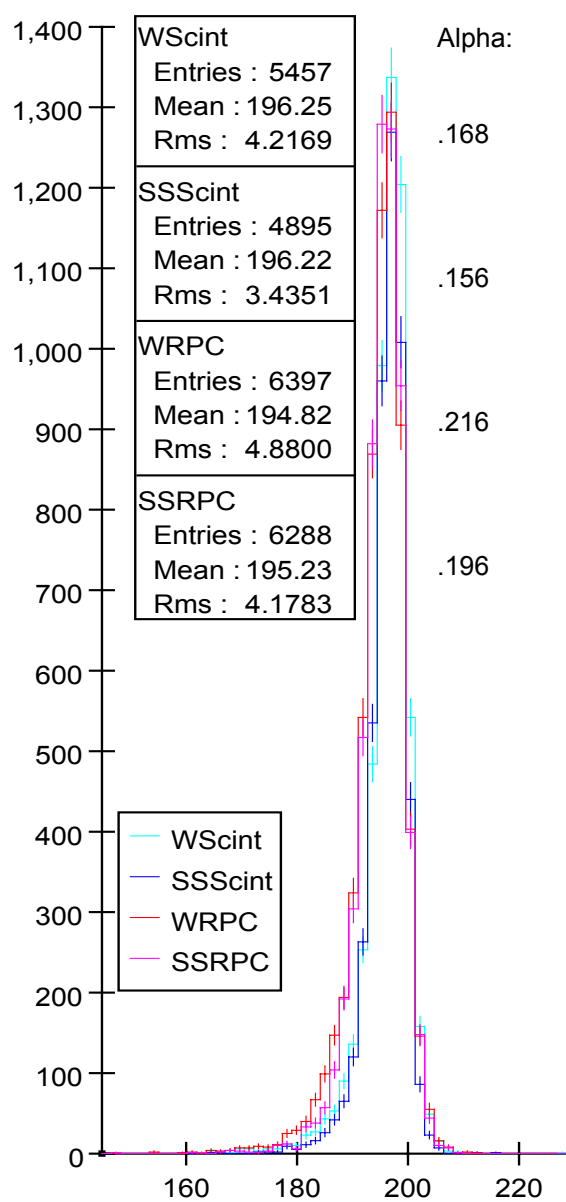
**WScint:Zpole Event nhad dE/rootE**



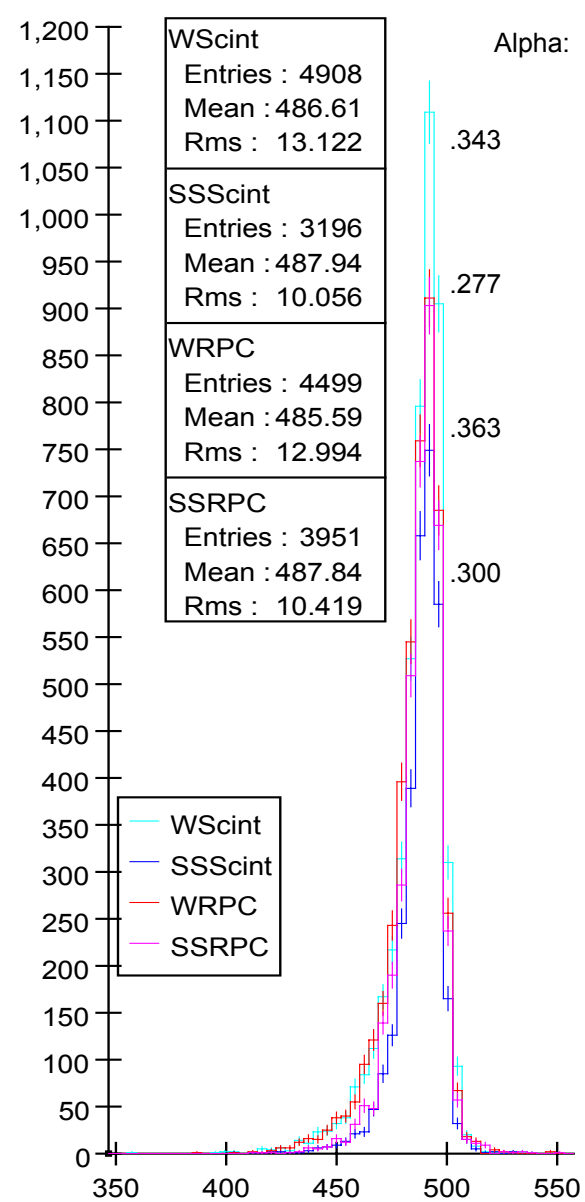
Perfect Pattern recognition PFlow



PFlow



PFlow



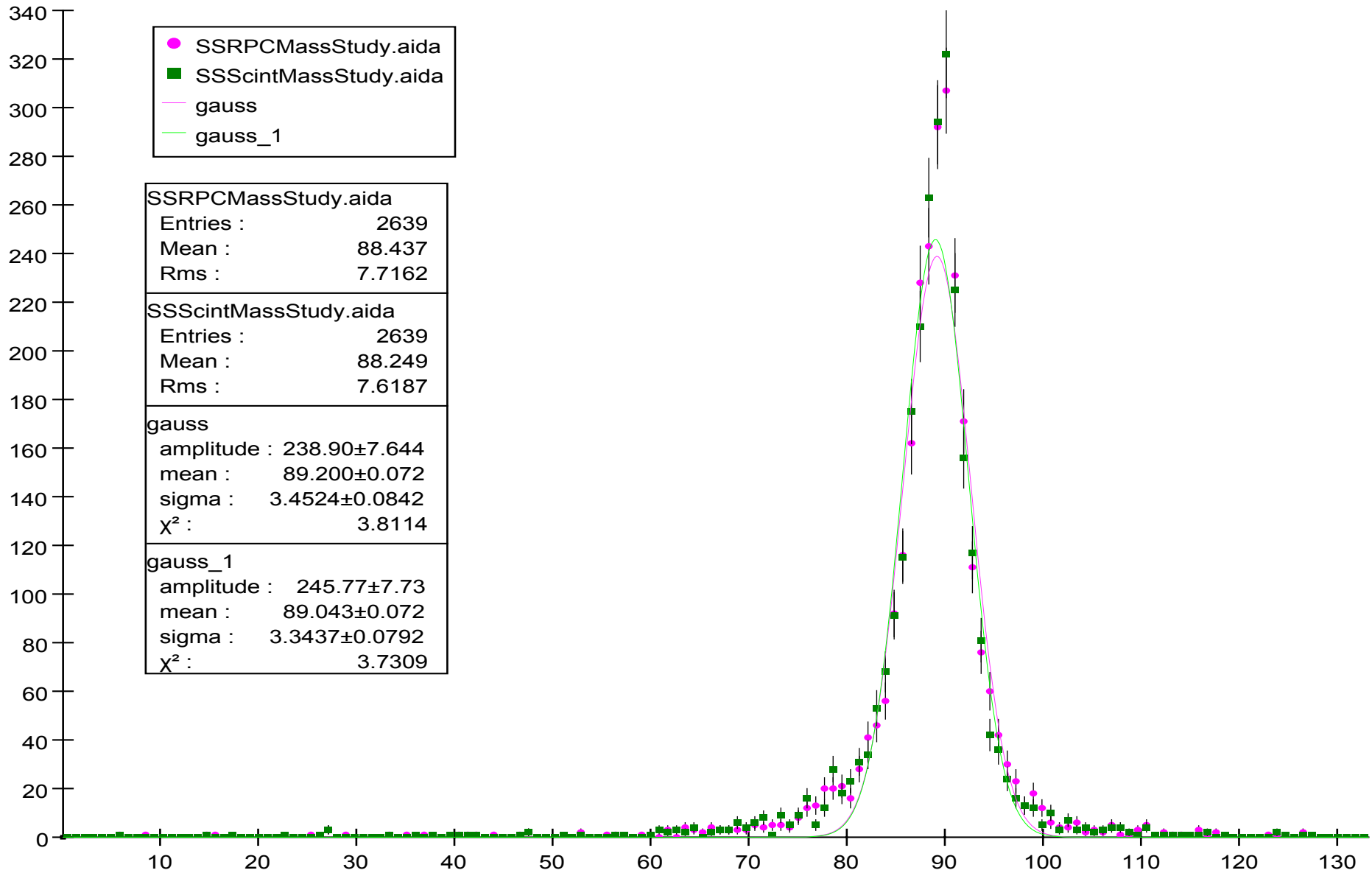
# Energy sum results

- Can now track single particle resolution curve to effective resolution (at 3 jet energies) to jet energy resolution
- Beware, big difference in single gaussian fit for effective resolution and rms90.
- Rms90 should be fine for comparisons
- But we really want the dijet mass resolution

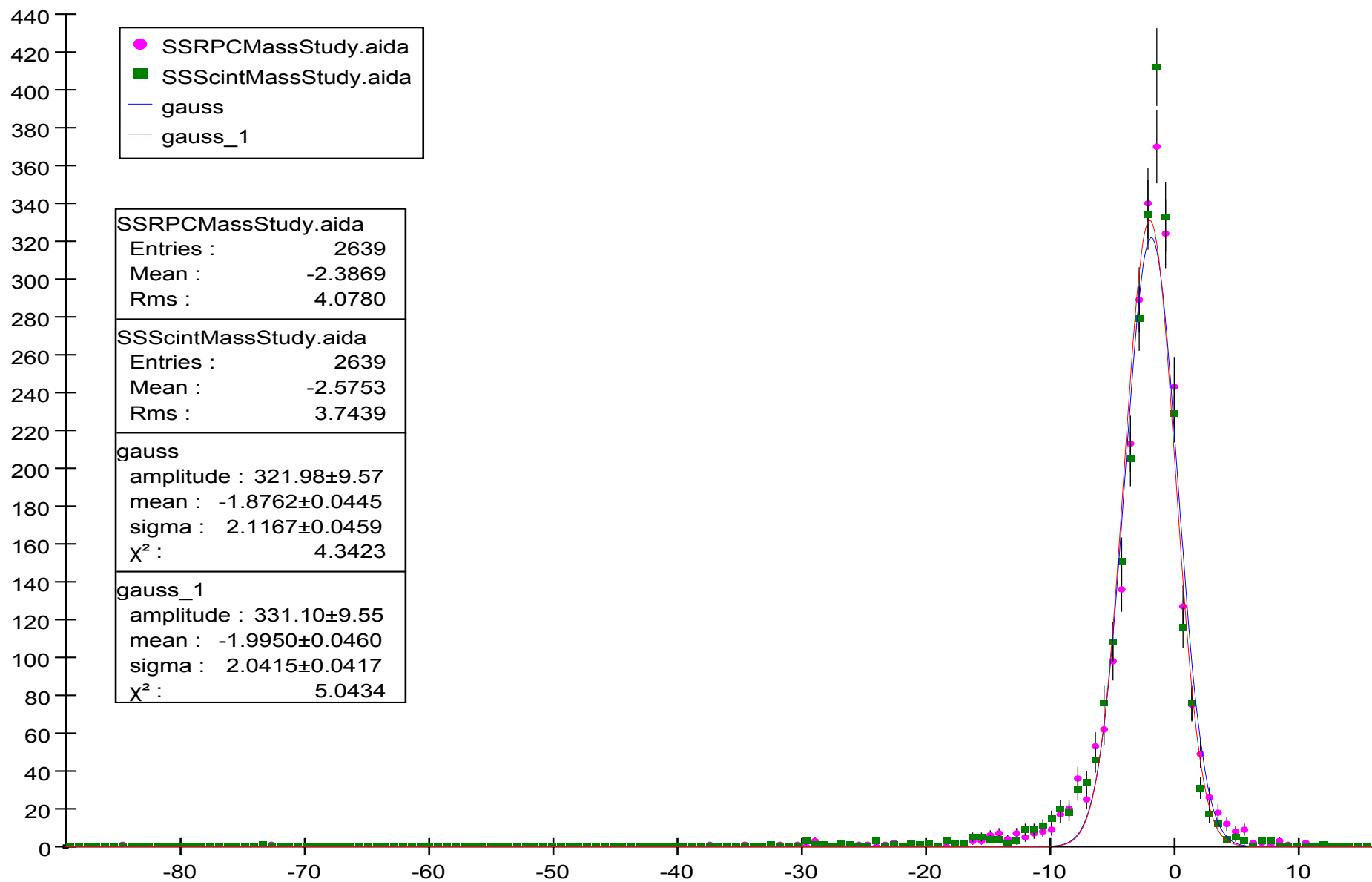
# Pattern recognition cheating analysis

- Take all tracker and calorimeter hits created by a final state particle. For now, use the Generator final state particles.
- For charged particles with  $> 3$  tracker hits, create perfect momentum reconstructed particle. Use pi mass for energy.
- For neutrals, and charged with less than 4 tracker hits, use calorimeter hits and calibration to determine energy of particle.
- Find position of core cluster for direction
- Feed ReconstructedParticles to jet finder
- Use ZZ->nunuqq events at 500 GeV, q=uds.
- Ask jet finder for exactly 2 jets
- Look at dijet mass with both jets  $|\cos\theta| < .8$

# perfect pattern recognition: dijet mass



### perfect pattern recognition: delta Zmass





# Neutral hadron energy resolution results

- With no confusion (perfect pattern recognition) a Hcal with 70% worse intrinsic resolution (at low energies) results in less than 5% broader Z mass peak in 500 GeV  $zz$  events
- Many factors still not taken into account, but all tend to spread the peak, thus reducing the difference.
- Can we understand this result? Perhaps we should look at mass resolution analytically.

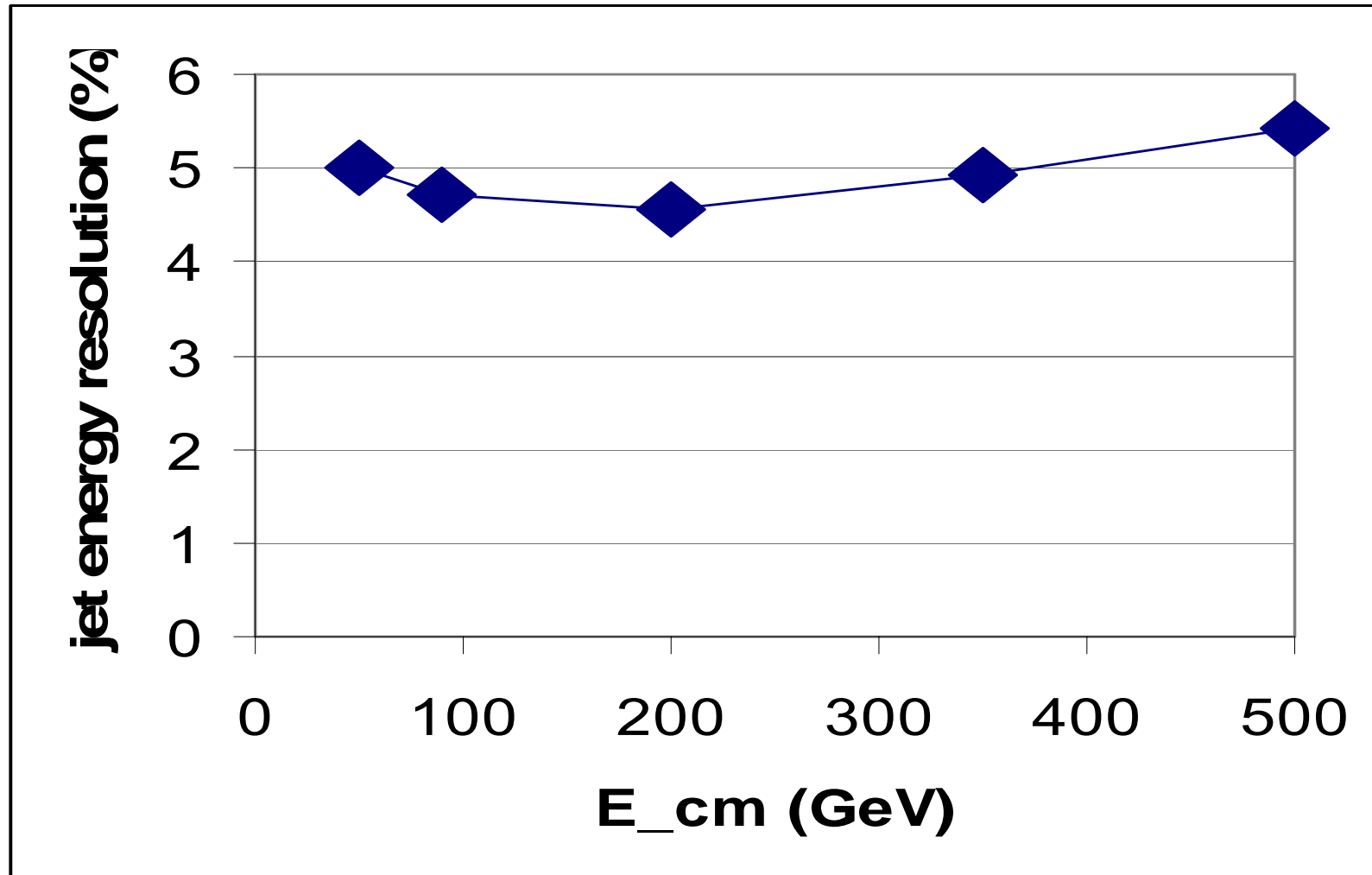
# Need to be guided by analytical calculations!

- Effective mass resolution:
- $M^2 \approx E_1 E_2 (1 - \cos\theta_{12})$
- $dM_{12}/M_{12} \approx \frac{1}{2}(dE_1/E_1 + dE_2/E_2 + \dots)$
- Elementary considerations show:
- 3-4% jet energy resolution required
- NOT  $dE/E = 30\%/\sqrt{E}$
- Physics simulations needed to more accurately specify  $x$ :  $dE/E=x$

# How Well is PFA Doing?

- Interesting study in draft DCR PFA section
- Jet energy resolution in the case of  $ee \rightarrow qq$  (light quarks only) at several center of mass energies from 50 to 500 GeV for the case of the GLD detector reconstructed by GLD-PFA. It showed  $dE/E \approx 85\%/\sqrt{E}$  for highest energy. Plotted as just  $dE/E$ :

# Light quark jets $ee \rightarrow qq$ GLD-PFA



# Conclusions

- We need ILC jet energy resolution of  $dE/E \approx 3 - 4\%$
- Need physics simulations to give a more accurate number
- Present state of the art with PFA is  $dE/E \approx 4.5 - 5.5\%$ .

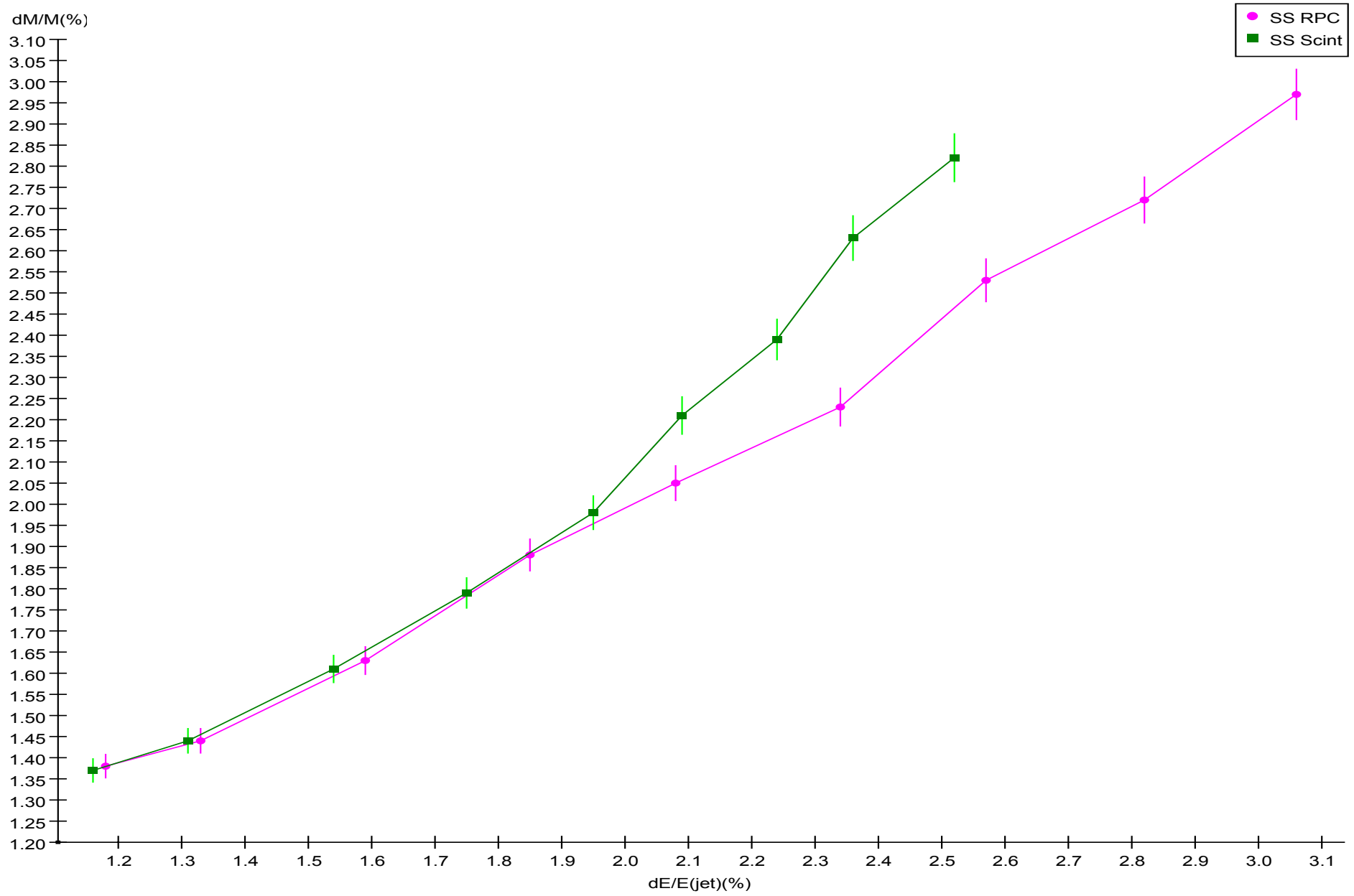
# Understanding dijet mass resolution

- A study is underway to understand the dijet mass resolution looking at  $dE_1/E_1 + dE_2/E_2 + d(\cos\theta)/(1-\cos\theta)$ .
- Many problems with approximation, cross terms, independence of variables, etc.
- Even if we ask the jet finder for exactly 2 jets on perfectly measured particles, the mean jet mass is 15 GeV.
- However, a preliminary look (last night) suggests that  $dE/E(\text{jet})$  correlates well with  $(\text{dijet mass} - Z_{\text{mass}})/Z_{\text{mass}}$ .

# Procedure

- ZZ->qqnunu at 500 GeV events.
- Find 2 jets (and jet Energy) with perfectly measured particles.
- Cheat on pattern recognition, and use calibration for photon energy.
- For neutral hadrons, cheat on pattern recognition and use calibration for energy, and then vary  $dE$  particle by particle by a fraction [0. ... 1.6].
- Fit  $dE/E(\text{jet})$  and  $dM/M$  to single gaussian for each fraction.

dM/M vs dE/E(jet)

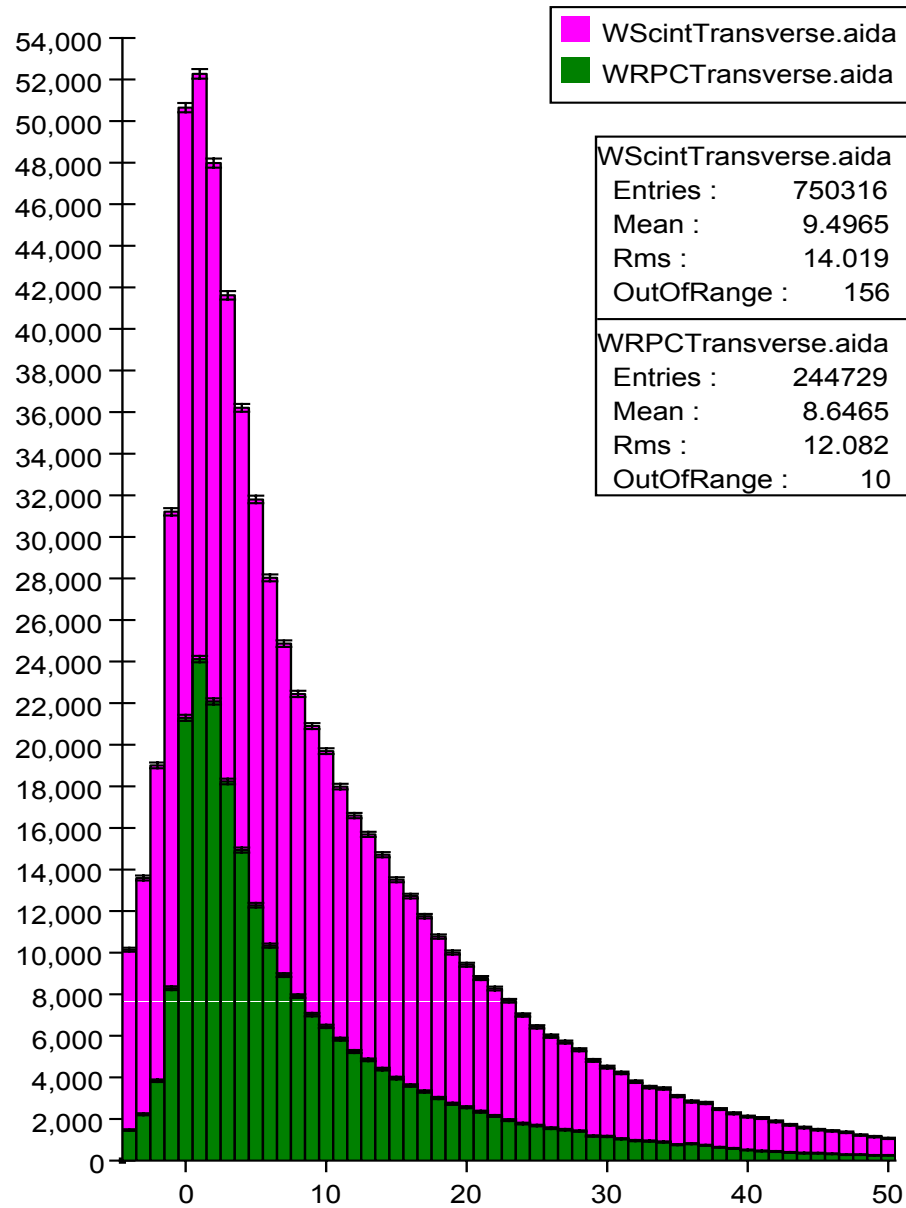




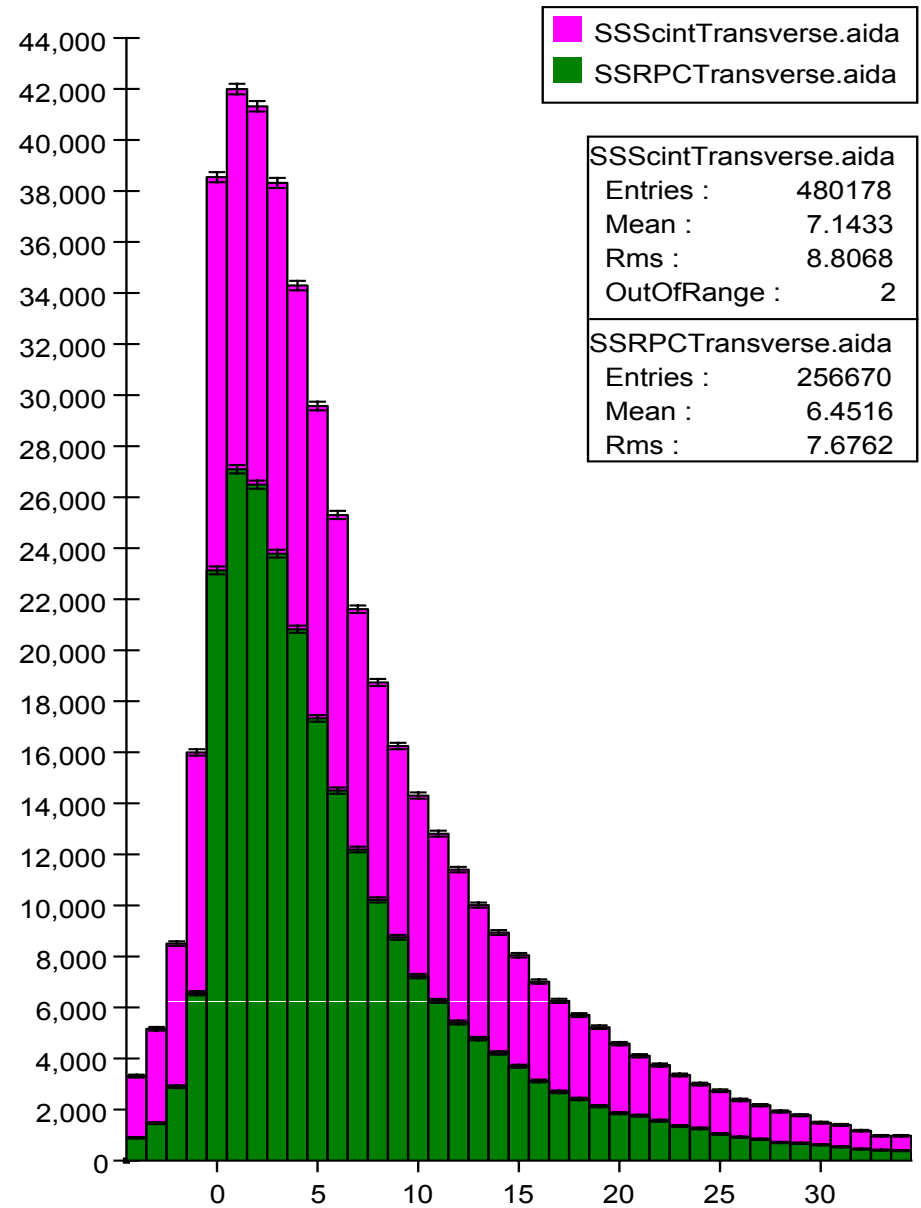
# Confusion

- In the context of a PFA, how well can we reconstruct neutrals.
- Try to get hints as to the difficulty by looking at radial and transverse spread of the hadron showers
- Start with the isolated Hcals.

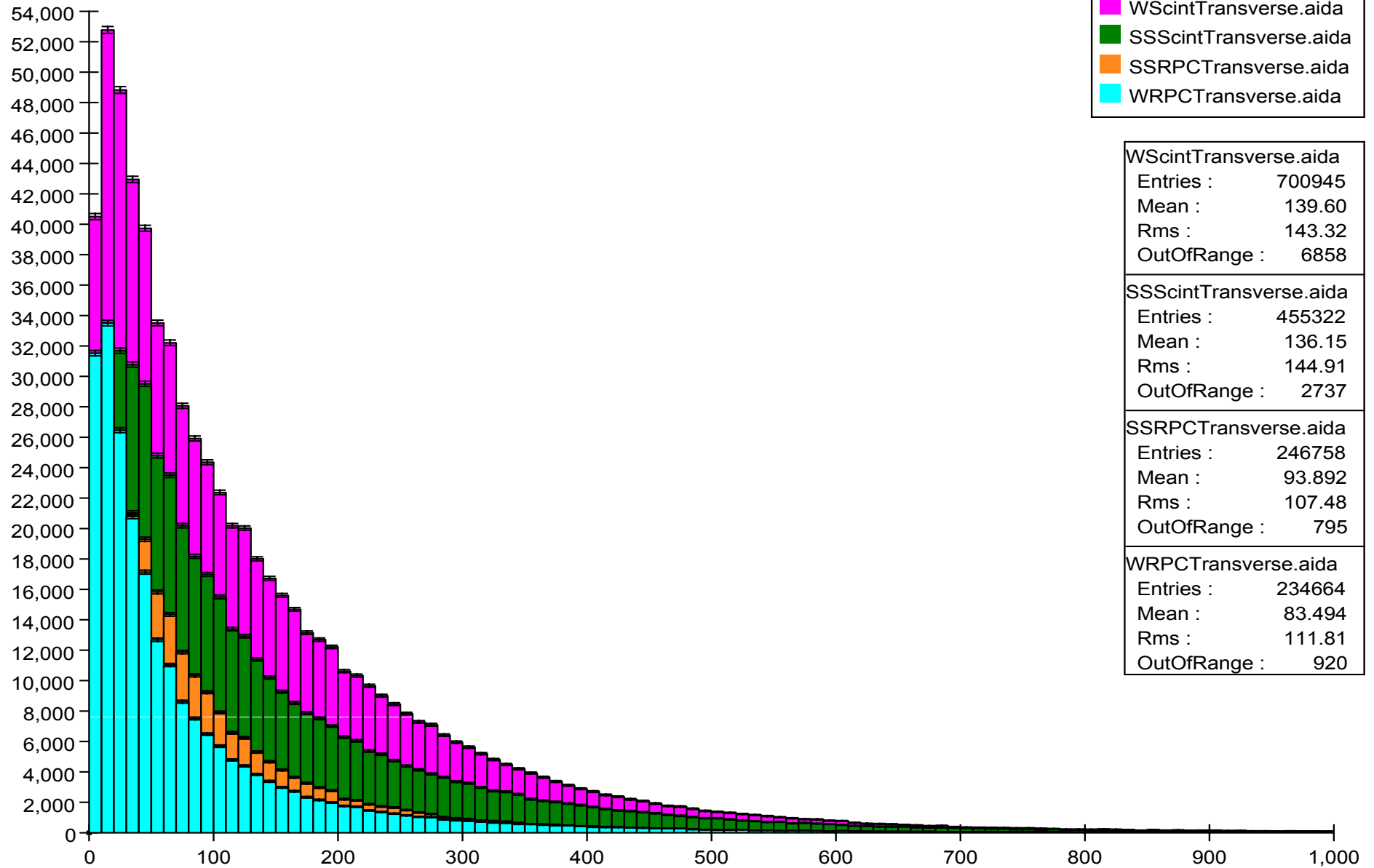
K0L - E=5 - : hits per layer



K0L - E=5 - : hits per layer



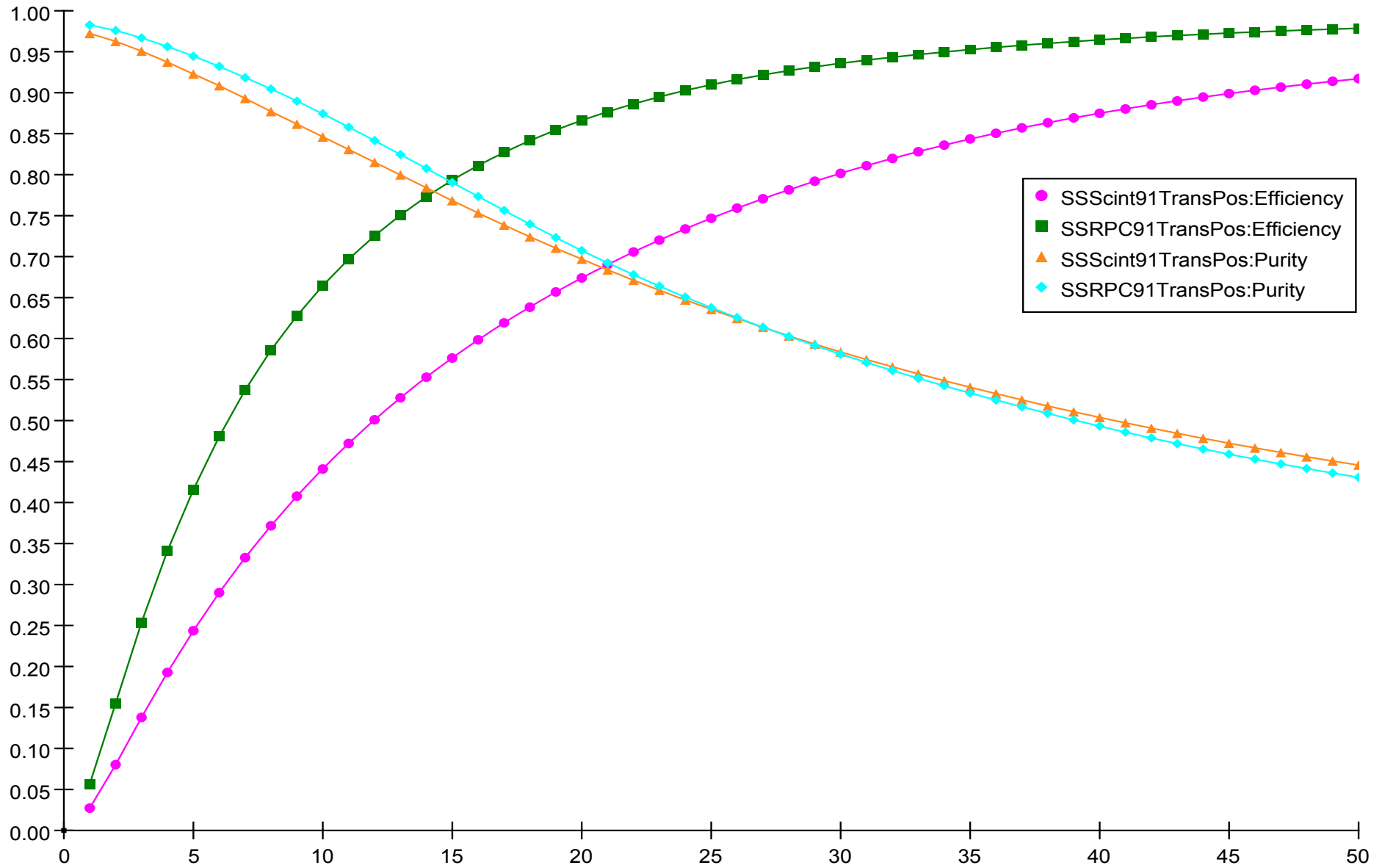
K0L - E=5 - Transverse distance(mm)



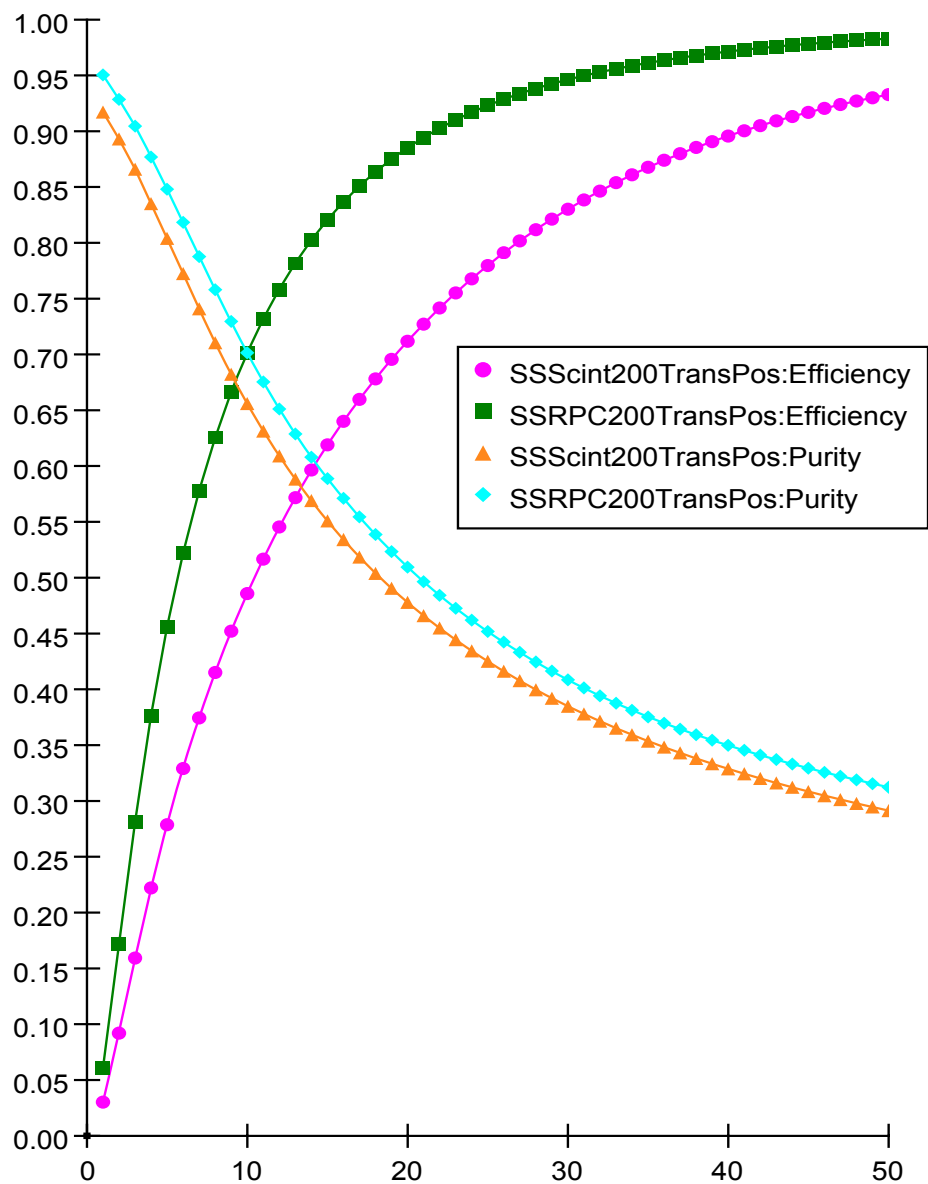
# 5 GeV k0L conclusions

- Somewhat larger radial spread in plastic vs gas.
- Considerably larger transverse spread in plastic vs gas
- Fine for 5 GeV k0L's, but really want to correctly average over particle type, energy and interaction point
- Use full detector simulations of mono-energetic jets
- Define a cylinder of radius  $R$  around each neutral hadron.
- Look at efficiency and purity vs  $R$

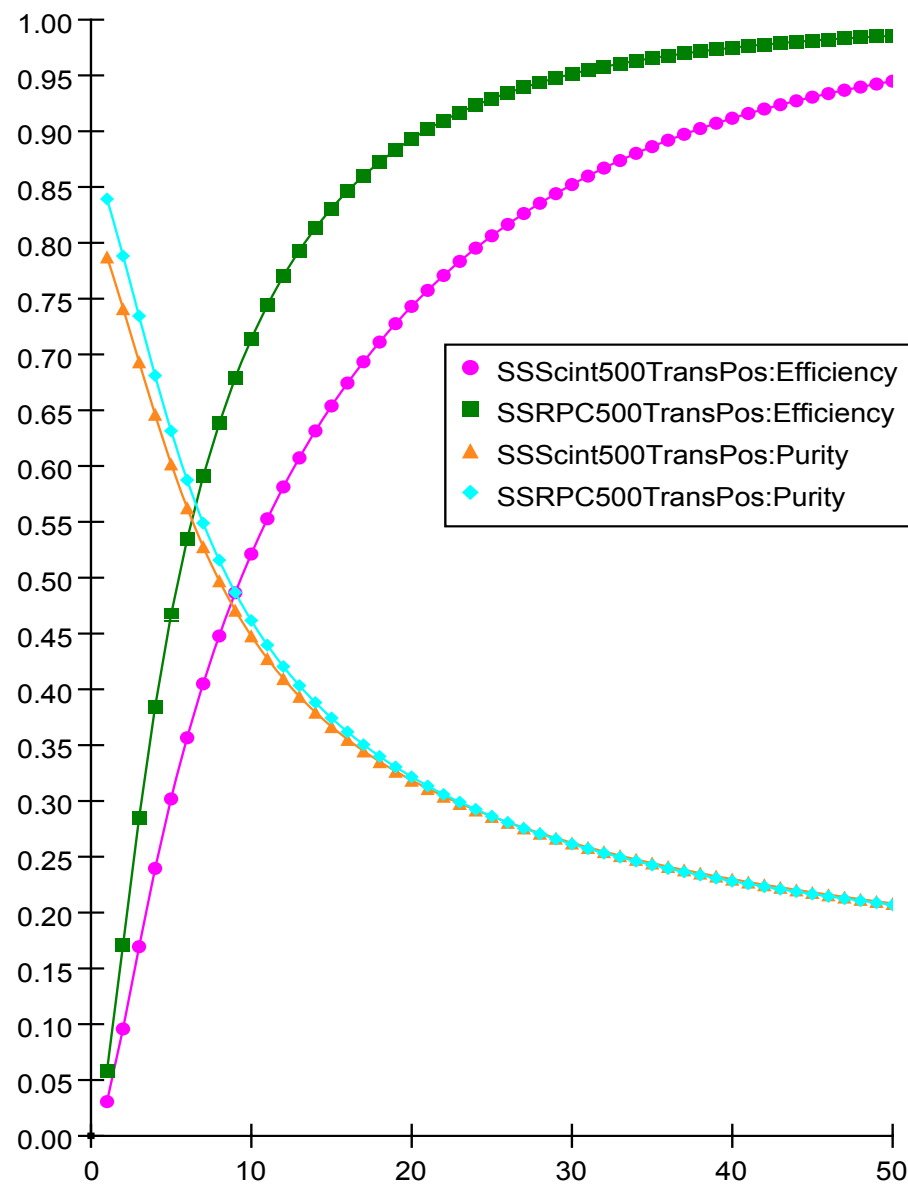
Efficiency/Purity vs cylinder radius(cm) in 45.5 GeV jets



Eff/Pur vs cylinder radius(cm) in 100 GeV uds jets



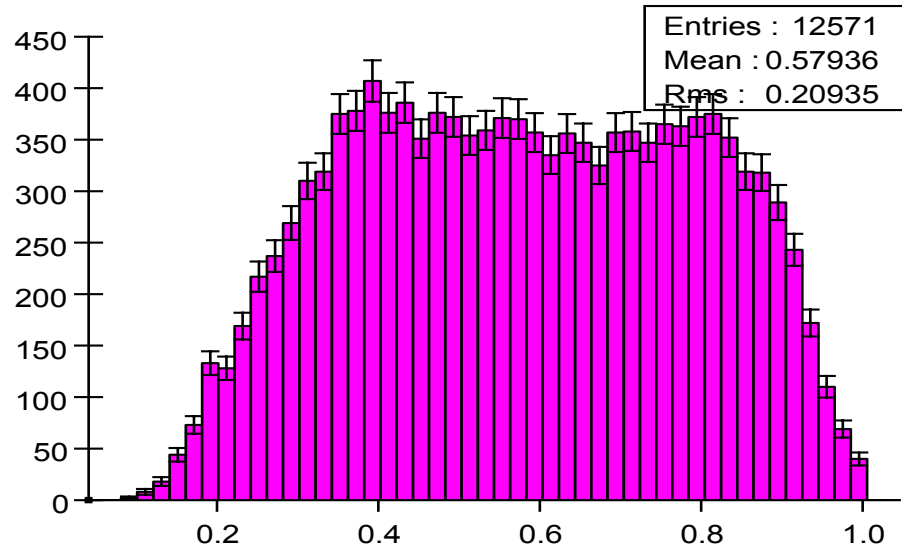
Eff/Pur vs cylinder radius(cm) in 250 GeV uds jets



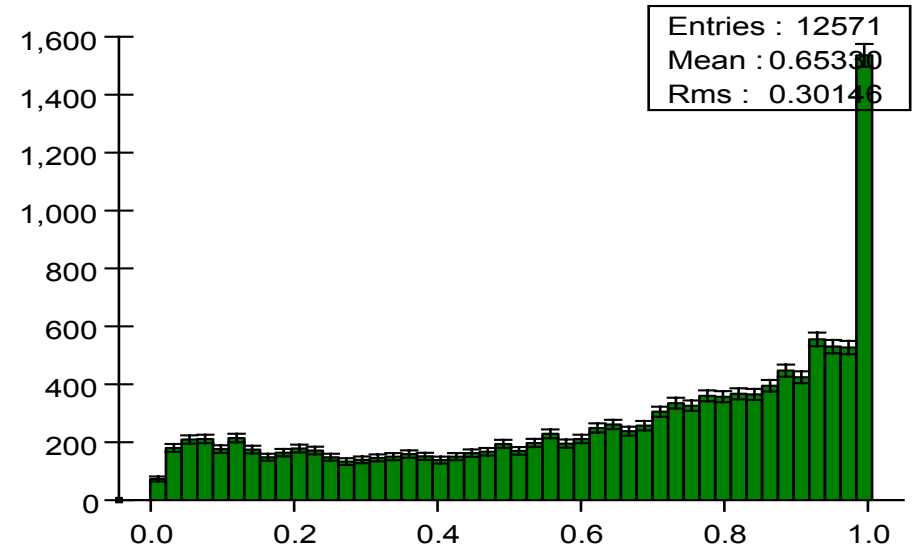
# Confusion: transverse distributions

- Not suggesting a fixed radius cylinder through the HCAL as a particle finding algorithm. However, it gives a feel for the extent of the overlap problems.
- Another approach: use actual clustering algorithms.
- This moves us to a completely different level of cheating. Instead of assigning individual hits to the correct particle, now we must do our cheating on clusters, thus including some purity and overlap loss effects

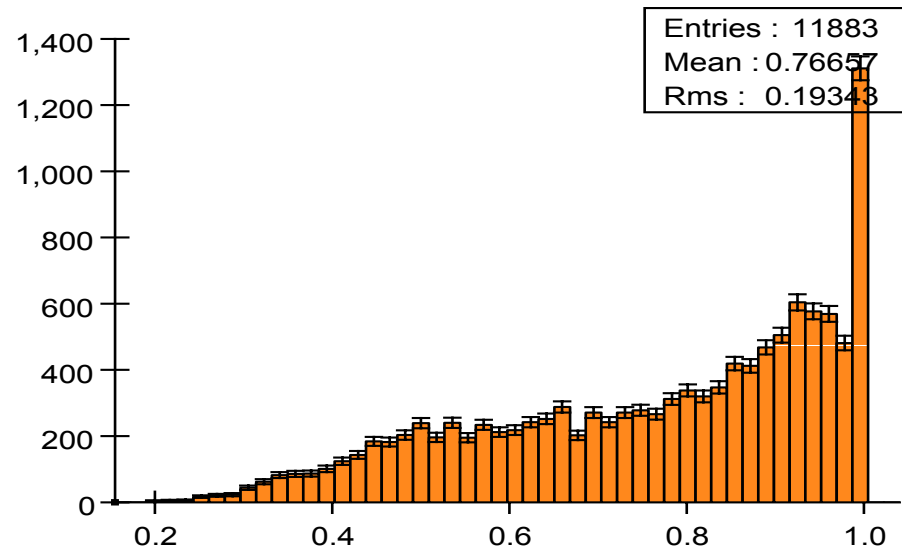
SSScint:Single nh primary nh>11: efficiency



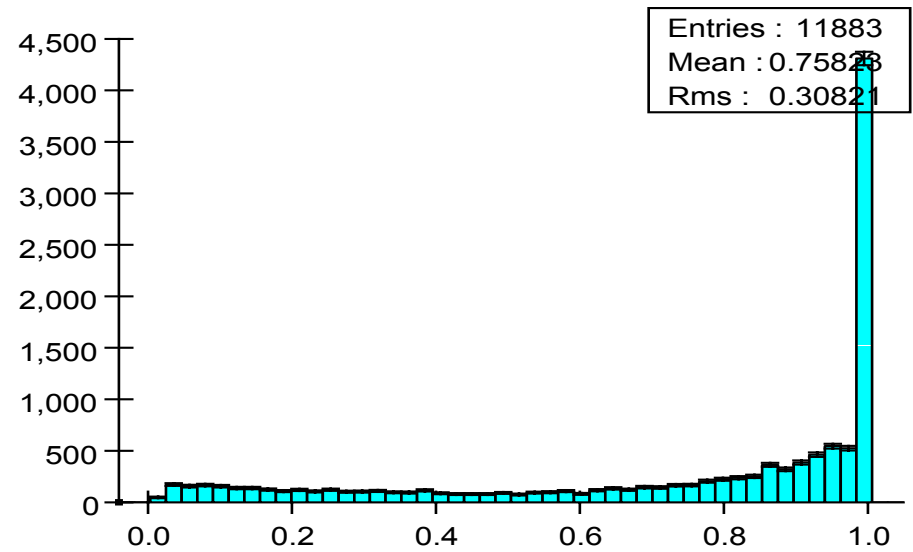
SSScint:Single nh primary nh>11: purity



SSRPC:Single nh primary nh>5: efficiency



SSRPC:Single nh primary nh>5: purity

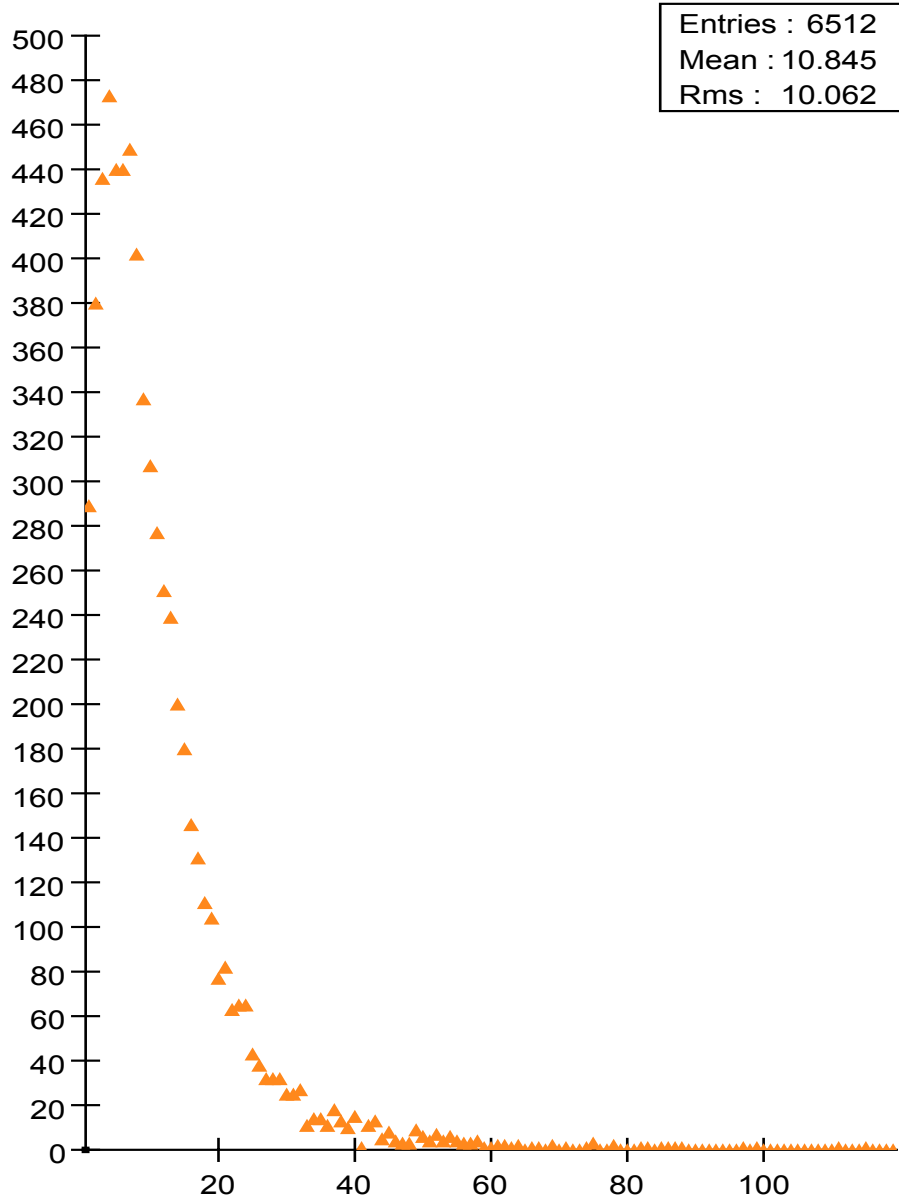




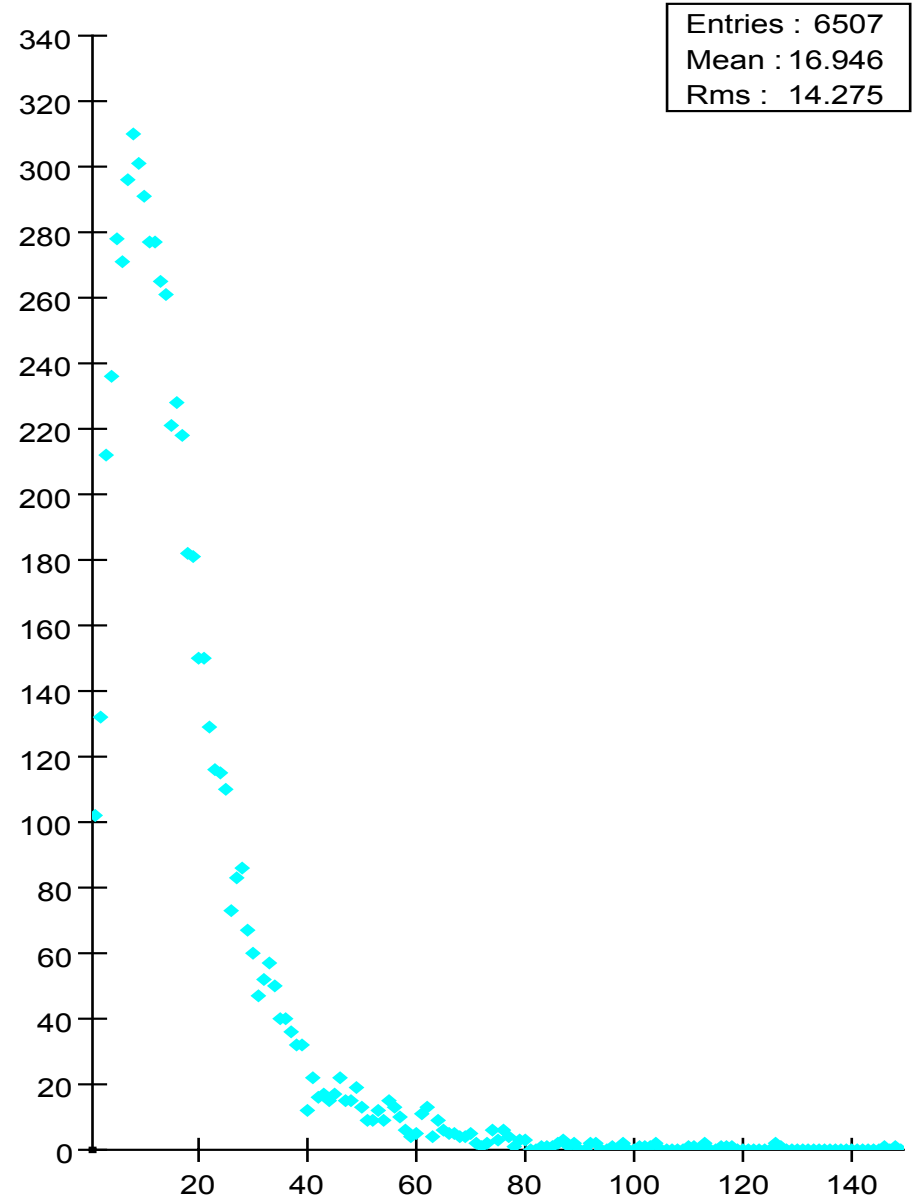
# ClusterIDCheater

- For each cluster, assign it neutral or charged from simple majority of hits.
- For charged, assign cluster to largest charged particle final state contributor
- For neutral, assign cluster to largest neutral particle final state contributor
- Store map of final state particles to list of clusters
- For this presentation, I used ZZ->qqnunu events at 500 GeV, acme0605\_steel\_scint and acme0605\_steel\_rpc detectors, and the DT clusterer with all defaults.
- Only events with both initial light quarks having  $\text{abs}(\cos \theta) < .8$  were used.

SSRPC:NHads/Cut0/#clusters to combine



SSScint:NHads/Cut0/#clusters to combine



# Cheat results

	Zmass width/Zmass	(delta Zmass)width/Zmass
Perfect pattern recognition PFA	SSRPC – 3.96% SSScint – 3.78%	SSRPC – 2.38% SSScint – 2.28%
Cheat clusterID – no minimum #hits cut	SSRPC – 5.21% SSScint – 5.14%	SSRPC – 3.67% SSScint – 3.75%
Cheat clusterID – clusters > 3 hits		
Cheat clusterID – throw out all fragments	SSRPC – 6.21% SSScint – 6.29%	SSRPC – 4.70% SSScint – 4.80%

# Conclusions

- Intrinsic neutral hadron resolution (within the spread of Hcal parameters examined) has little effect on the dijet mass resolution.
- Reducing confusion (finding neutral hadrons) is more difficult in plastic than in gas. However, how much more difficult and the effect of increased confusion have yet to be quantified. May be impossible without a PFlow algorithm.
- For those who still think PFlow should be easy, see page 34.

