PFA-Enhanced Dual Readout Crystal Calorimetry

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Outline :

- Motivation
- Detector Parameters
- Use of a PFA in Dual Readout Crystal Calorimetry
- Summary

Motivation

- Development of clear, dense crystals (PbWO, BGO, PbF, . . .) with both scintillator and cerenkov response
  -> Cerenkov response is prompt, short λ
  -> Scintillator response has longer time, longer λ

7-9 g/cc densities -> 5-6 λ_I total absorption crystal calorimetry in, e.g., CDF barrel calorimeter volume

- Development of photodetectors (SiPM, APD, . . .)
  -> for scintillator response, small area (1 mm^2) SiPMs
  -> for cerenkov response, development of (thin) large area (~1 inch^2) detectors

On-crystal photodetectors -> highly segmented and granular calorimeter

Cerenkov/scintillator response ratio correction optimizes energy resolution of calorimeter objects

Resulting high-purity particle shower content per calorimeter cell

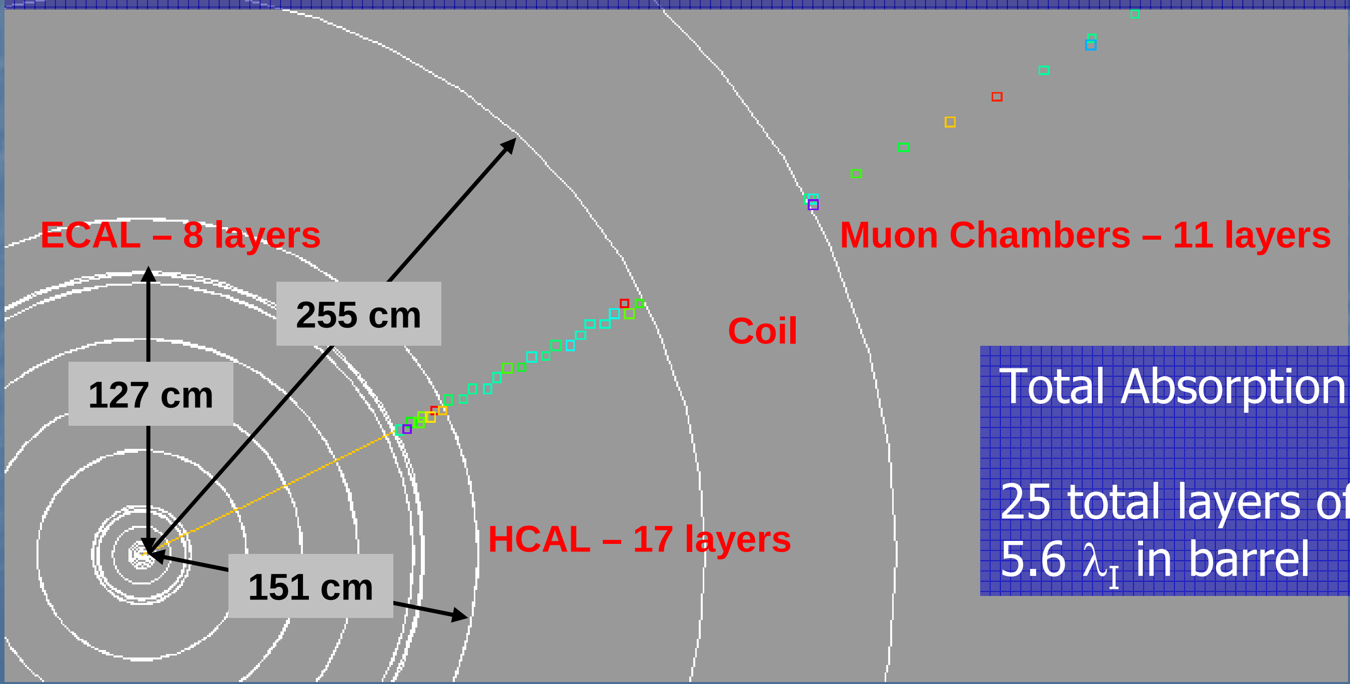
-> Use of PFA algorithms to categorize clusters

Dual Readout Calorimeter Detector Parameters

Dual Readout Calorimeter *in SiD02 Shell (Barrel and EC)*

DR ECAL
- 3 cm x 3 cm x 3 cm BGO
- 8 layers – 21.4 X_0 (1.1 λ_I)
- 127 cm IR – 151 cm OR
- Scin/Ceren analog hits

DR HCAL
- 5 cm x 5 cm x 6 cm BGO
- 17 layers – 4.6 λI
- 151 cm IR – 253 cm OR
- Scin/Ceren analog hits



Total Absorption Crystal Calorimeter

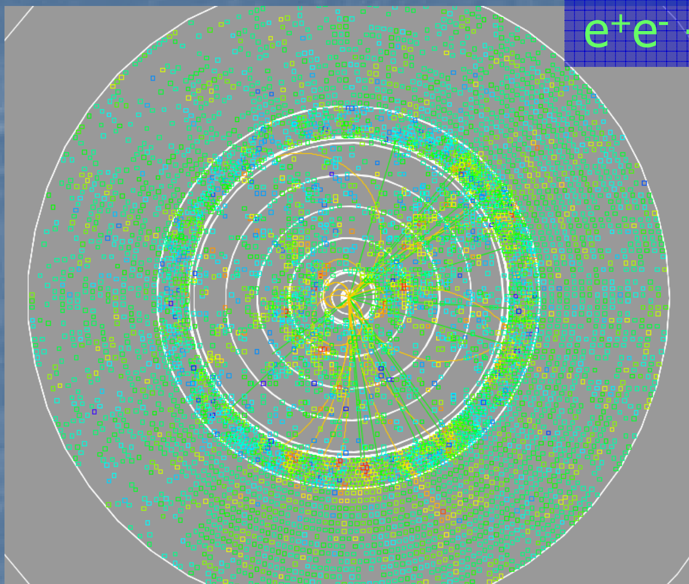
25 total layers of BGO
5.6 λ_I in barrel

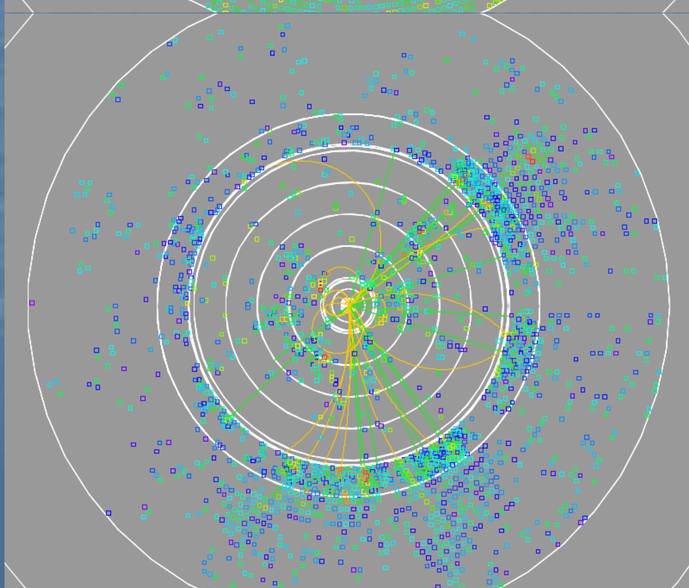
PFA-enhanced Dual Readout Procedure

- Apply threshold, timing cuts to both scintillator and cerenkov hit cells
- Extrapolate charged particle tracks to calorimeter and use cerenkov hits to define a “mip” cluster and spacepoint at start of shower
- Cluster remaining cells using Nearest-Neighbor cluster algorithm
- Correct each cluster using C/S ratio (+ corrections for clustering, thresholds)
- Apply PFAs to match clusters with tracks
  - -> Core cluster algorithm
  - -> Cluster pointing algorithm
  - -> Track/Shower cluster algorithm
- Find jets from Tracks, Clusters, PFA Particles
- Link track jets to Cluster, PFA jets
- Make ΔM corrections to Cluster, PFA jets using linked tracks
- Determine DiJet mass from jets

Threshold/Timing Cuts on Calorimeter hits

$e^+e^- \to ZZ \to \nu\nu qq$ @ 500 GeV





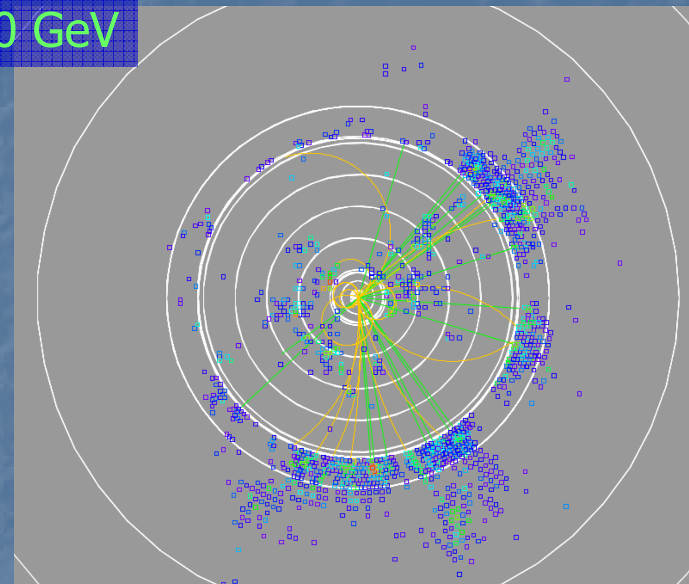
Scintillator Hits

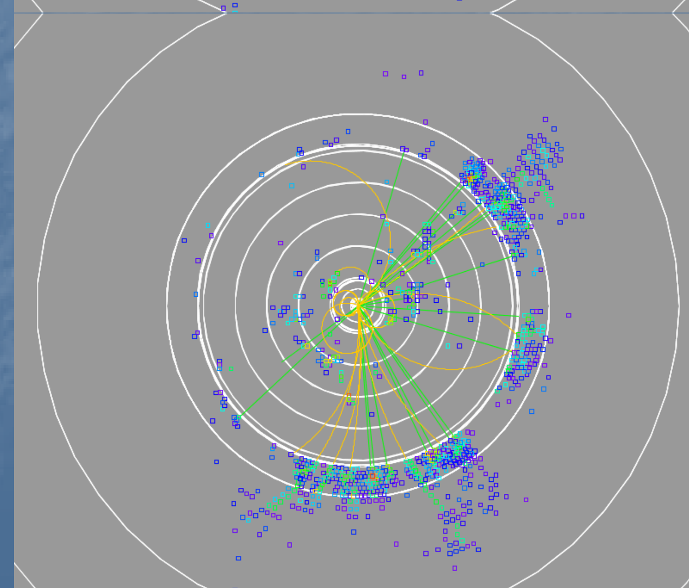
dE/dx ~ 30, 60 MeV per mip

Threshold ~1/50 mip
Timing t<100 ns

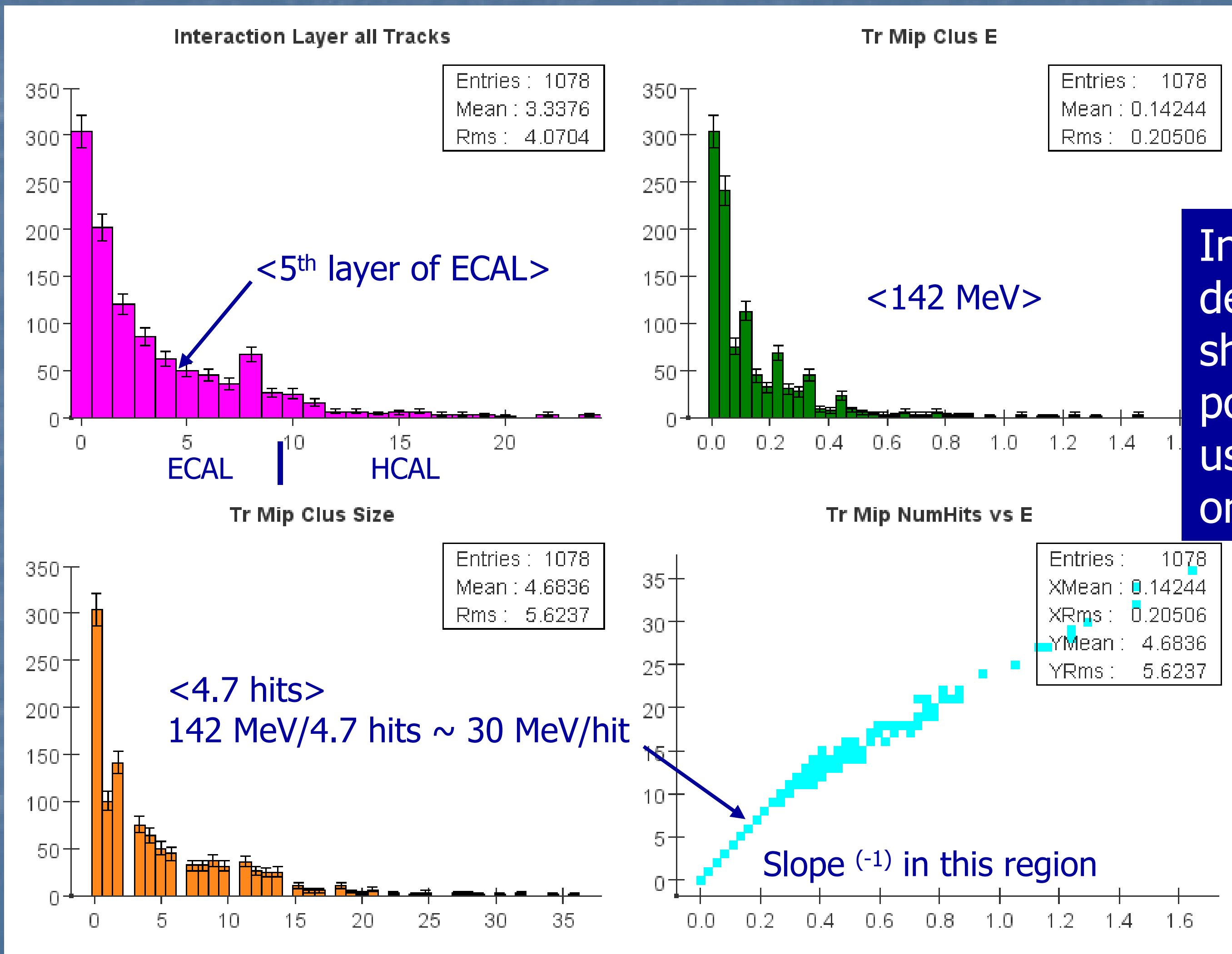
Cerenkov Hits

Similar (magnitude) threshold
Timing t<100 ns





Mip Cluster/Interaction SpacePoint Algorithm



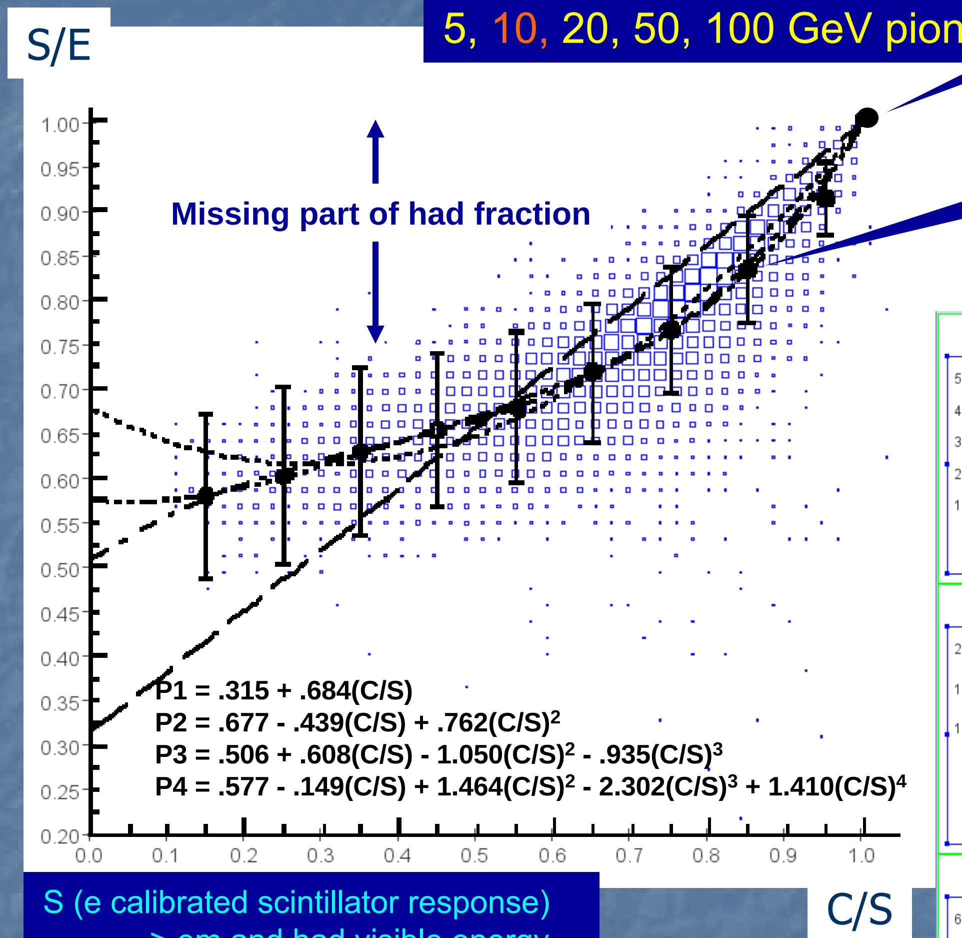
$e^+e^- \to ZZ$
$\to \nu\nu qq$ @ 500 GeV

Interaction spacepoint defines the start of showering and the end point of the track –> used for ΔM correction on jets

C/S Corrections

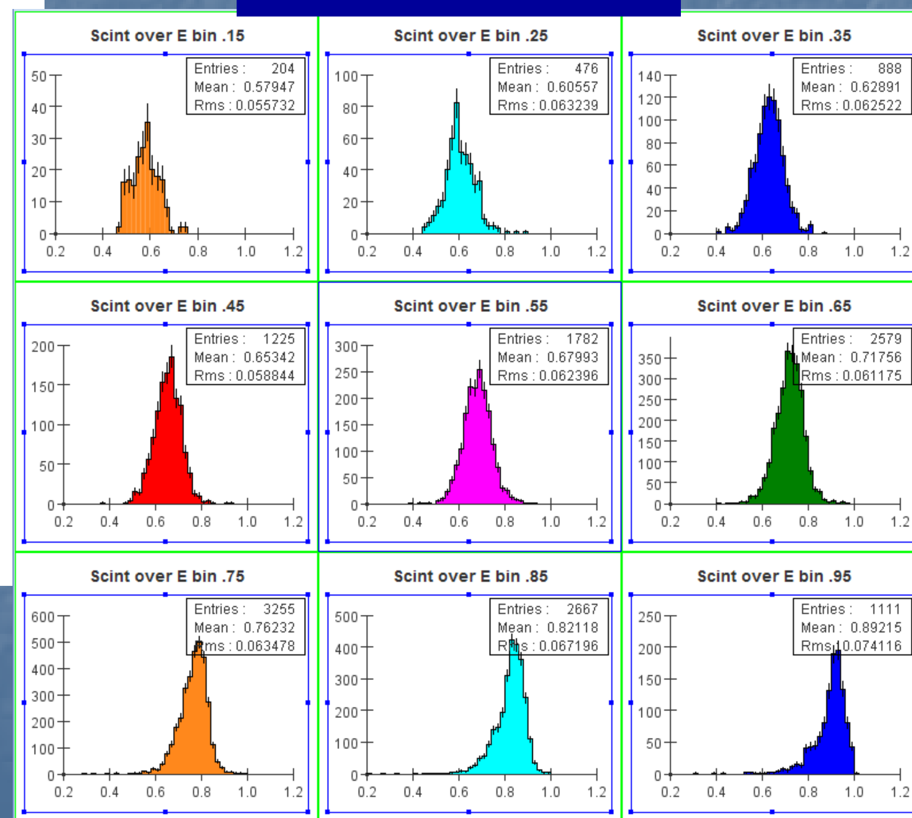
em fraction = 1
S/E, C/S = 1
-> calibration with e^-

5, 10, 20, 50, 100 GeV pions



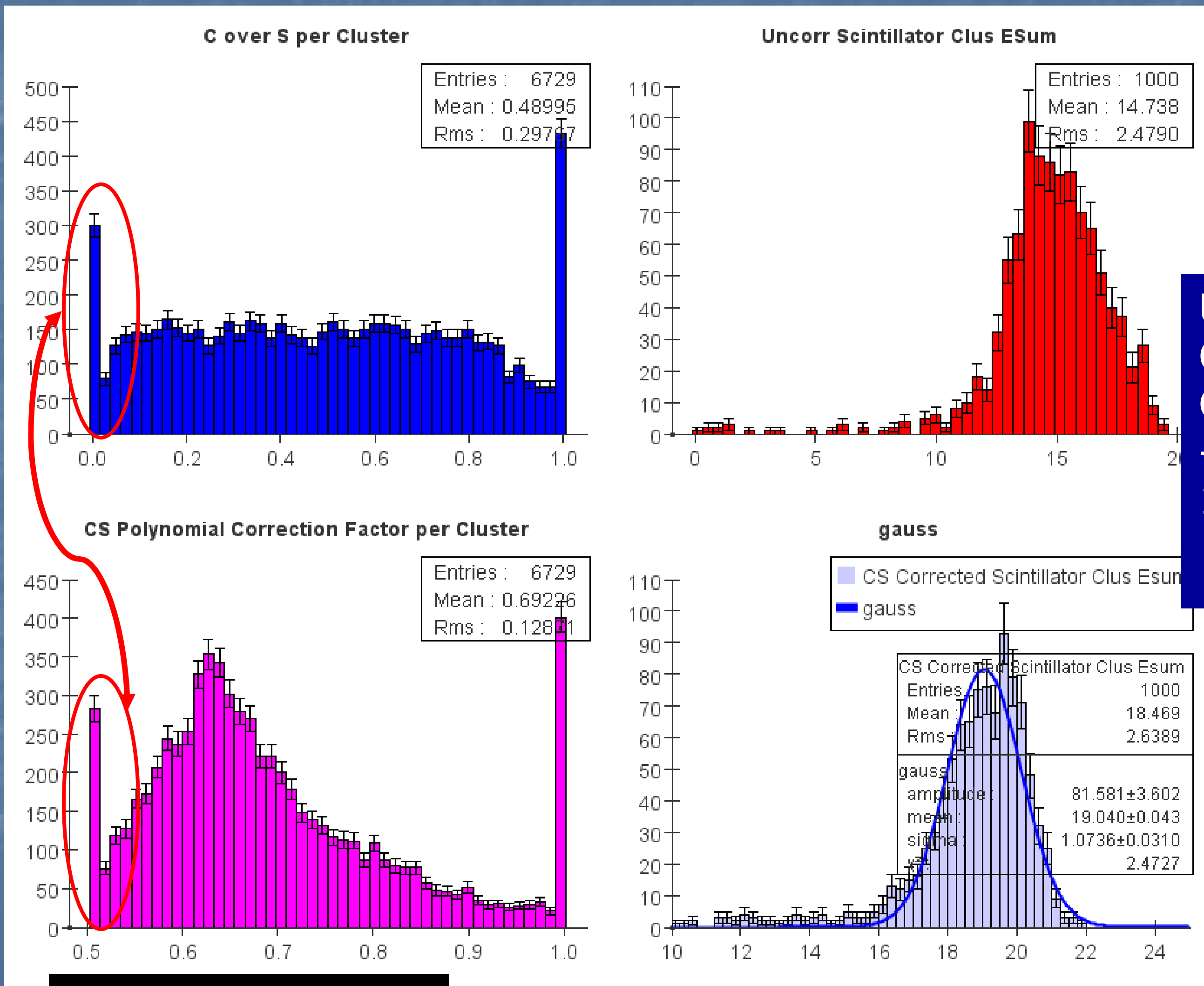
Mean and σ/mean of fit plotted for each C/S bin
-> resolution improves with C/S

S/E slices in C/S bins



S (e calibrated scintillator response)
-> em and had visible energy
C (e calibrated cerenkov response)
-> ~ em part of shower
C/S = ~ em fraction of visible energy
S/E = total visible energy fraction

Clustering Corrections



C/S = 0, P3 corr = .506

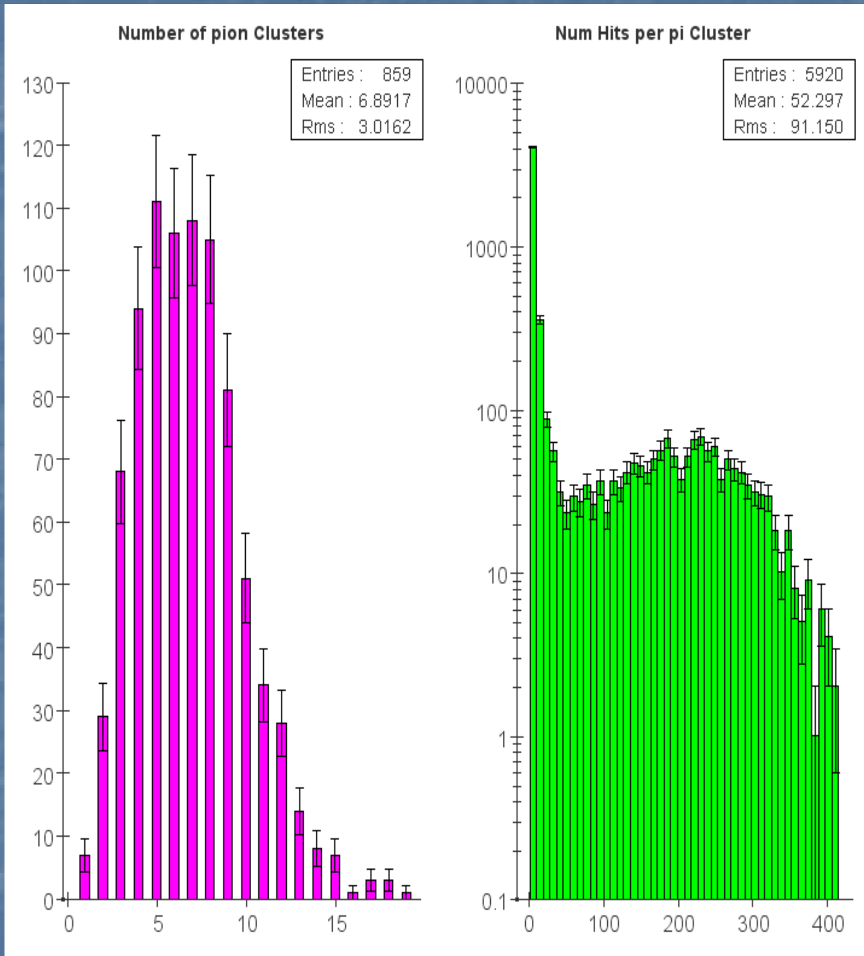
Single particle
20 GeV pions
NN clustering
(4 hit min)

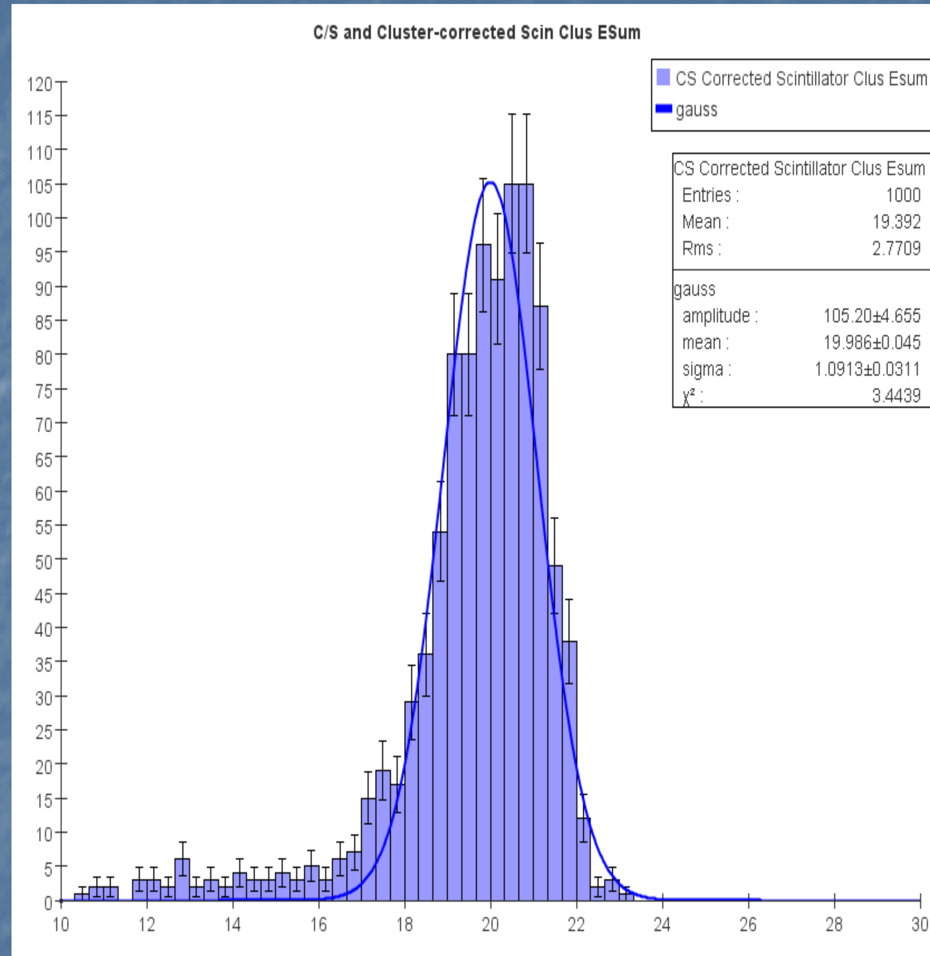
Using all clusters, mean of C/S-corrected ESum is 19.0 GeV
-> correction for clustering of 1.05

σ/mean ~ 25%/$\sqrt{E}$

Cluster and C/S corrections

Single Particle 20 GeV pions
NN clustering (4 hit min)



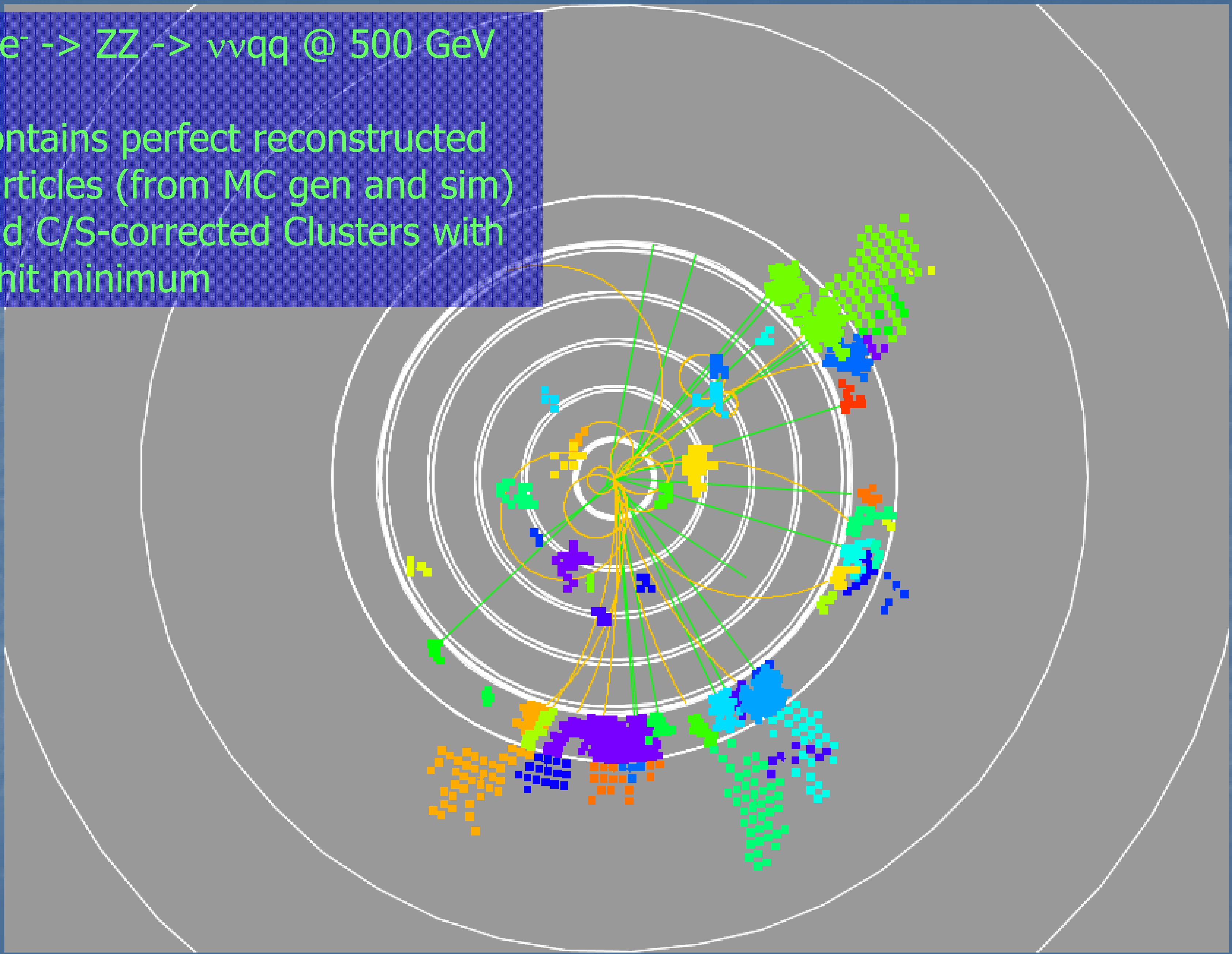


~7 clusters per pion, many small fragments

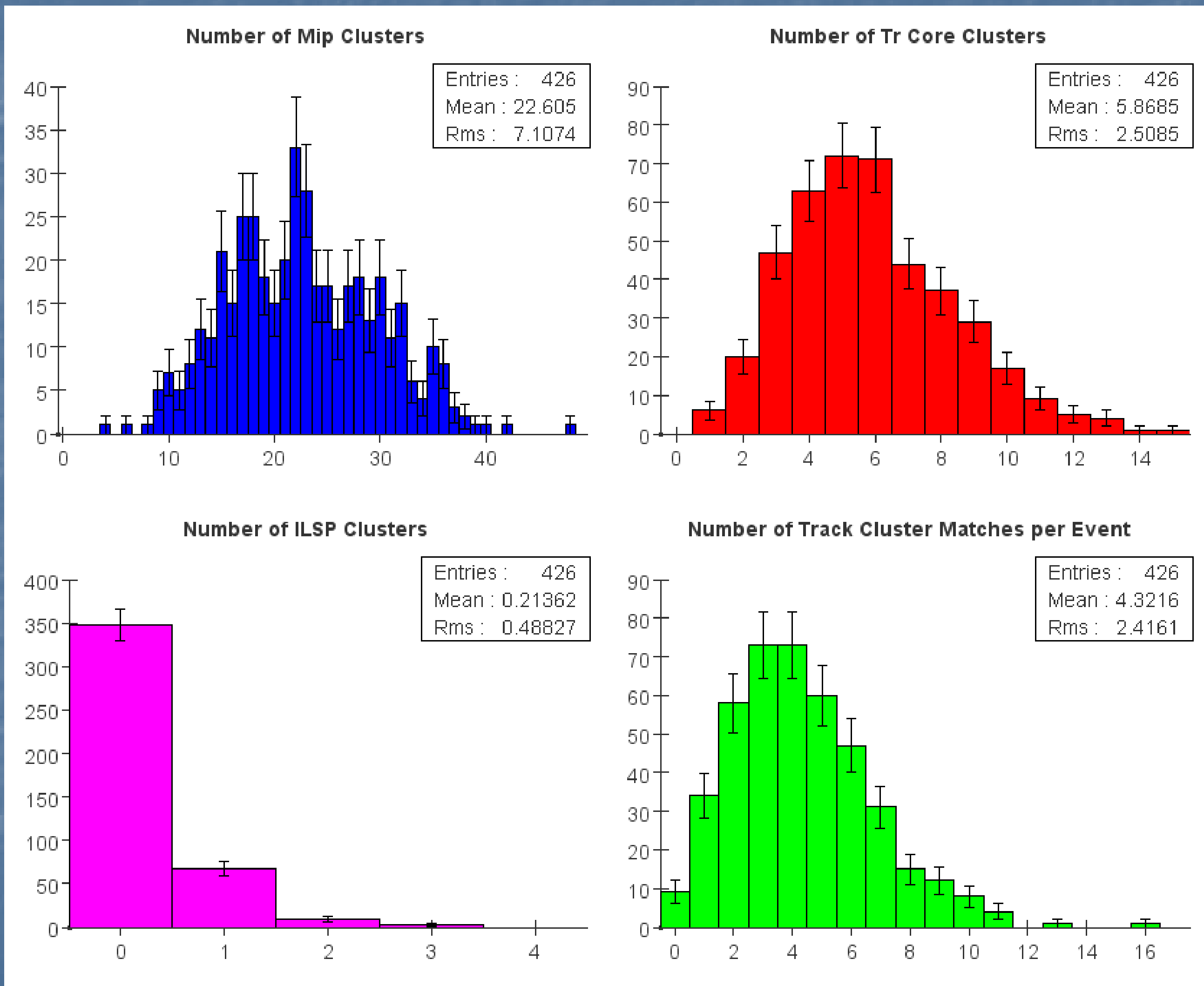
Fit gives mean of ~20 GeV
$\sigma/E \sim 24\%/\sqrt{E}$

e^+e^- -> ZZ -> $\nu\nu qq$ @ 500 GeV

Contains perfect reconstructed particles (from MC gen and sim) and C/S-corrected Clusters with 4-hit minimum



PFA Performance – Track/CAL Cluster Match



e^+e^- -> ZZ
-> $\nu\nu$qq @ 500 GeV

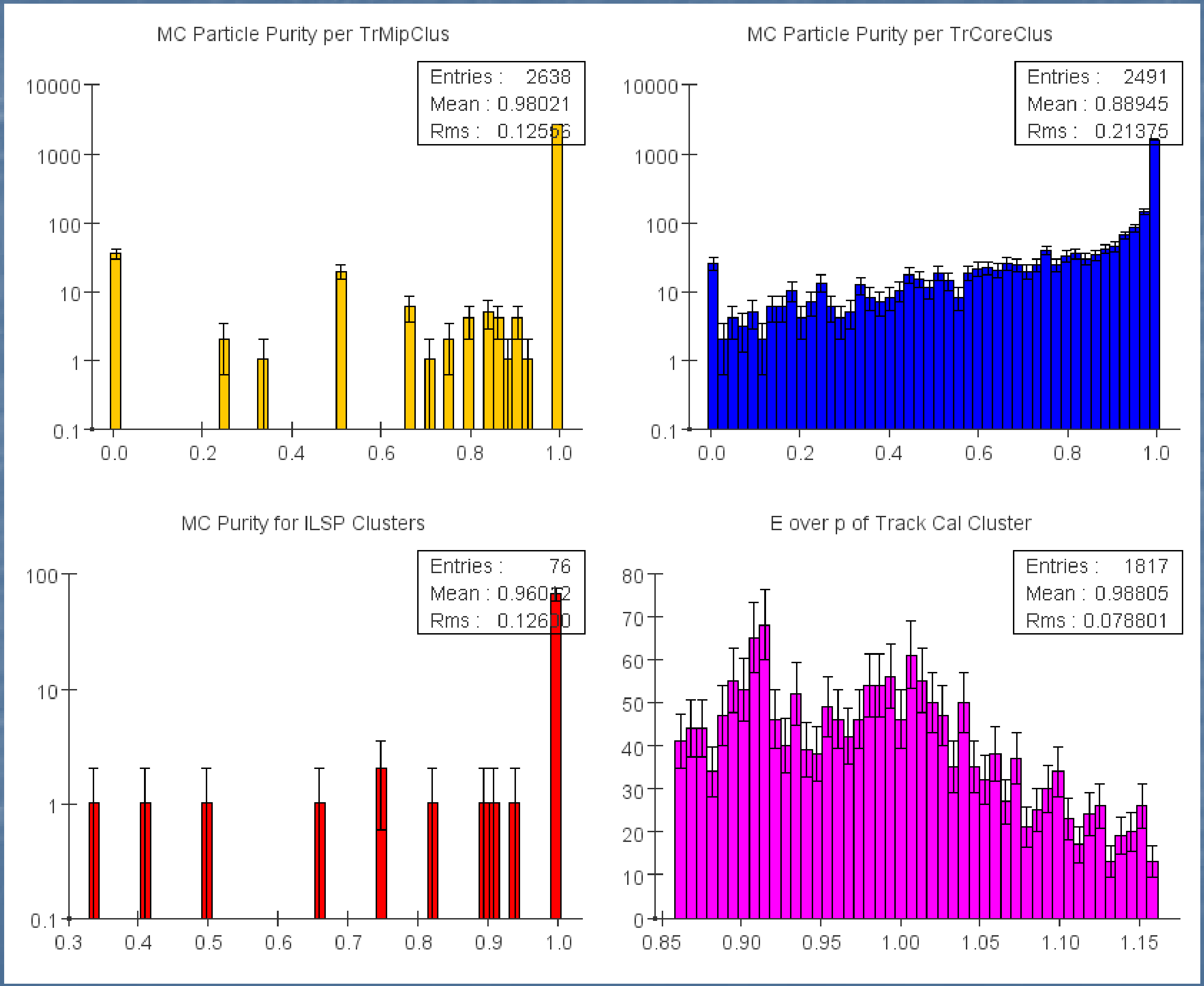
tracks = # mip clus (but sometimes start of shower is layer 0, so mip cluster has 0 hits)

Track Core clusters lie on extrapolated track

Clusters pointing to the end of the mip cluster (ILSP Clusters) are rare after cores are removed

4.3 Tracks per event (19%) are matched to clusters by PFA

PFA Cluster Purities



e^+e^- -> ZZ
-> $\nu\nu qq$ @ 500 GeV

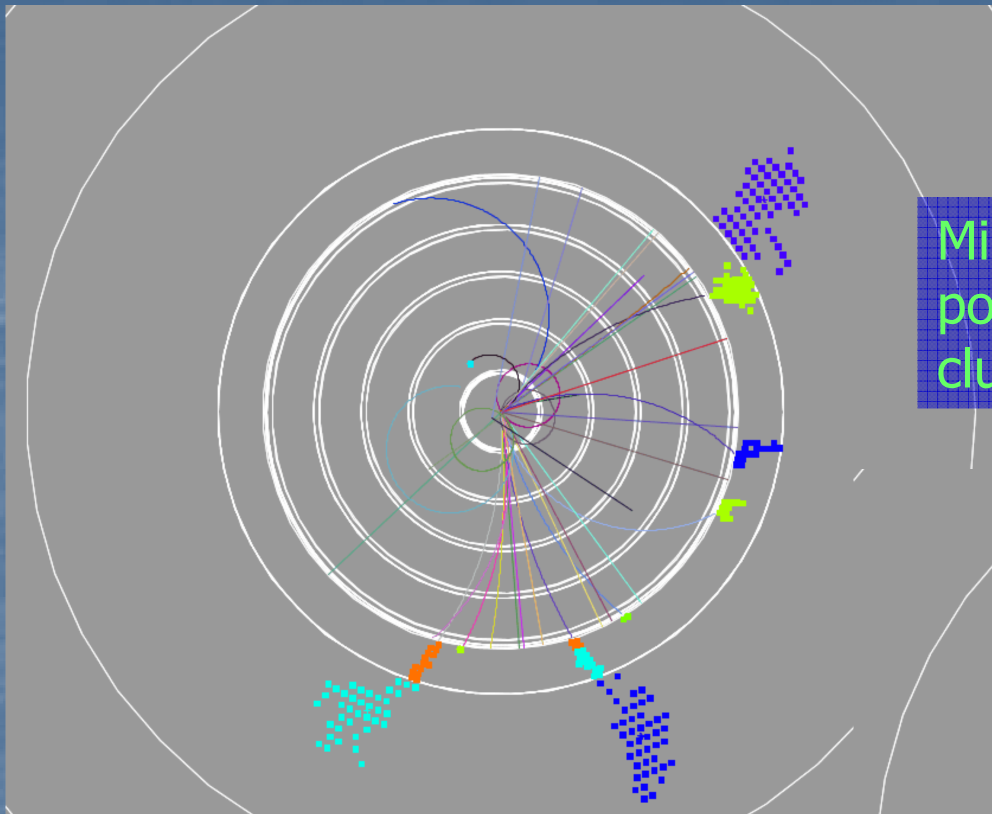
Purity of mip clusters is > 98%

Purity of core clusters ~90%

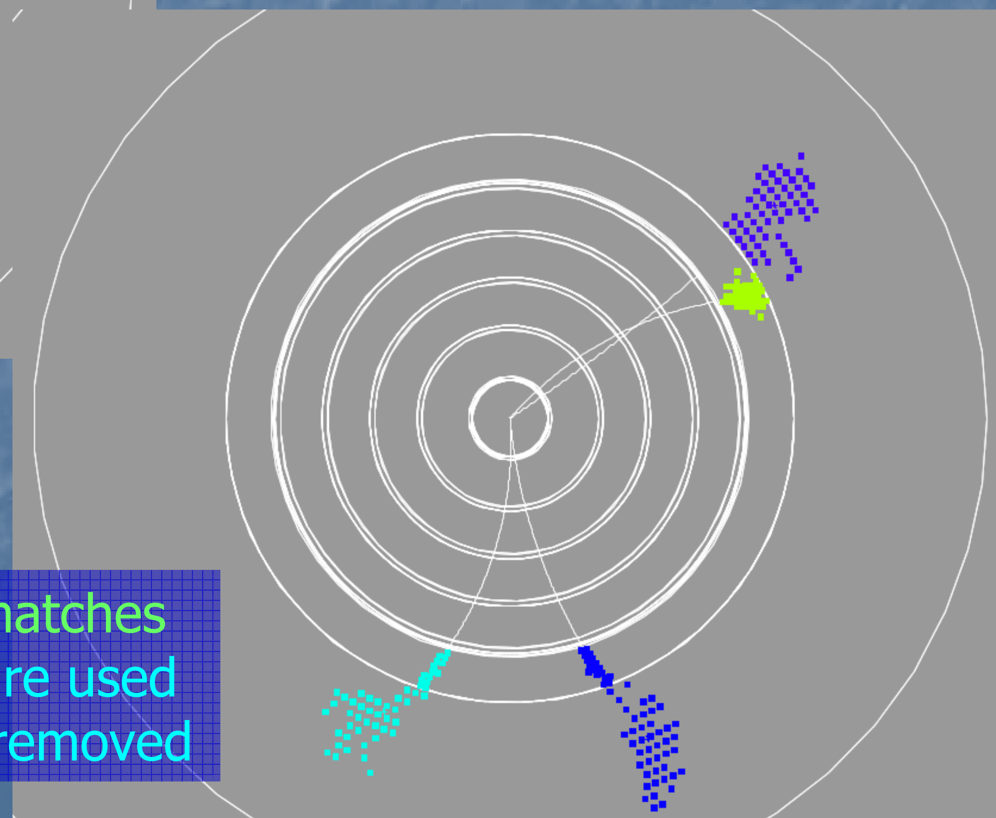
Purity of ILSP clusters is > 96%

Final E/p range for matched clusters determined by CAL resolution for charged pions

e^+e^- -> ZZ -> $\nu\nu qq$ @ 500 GeV



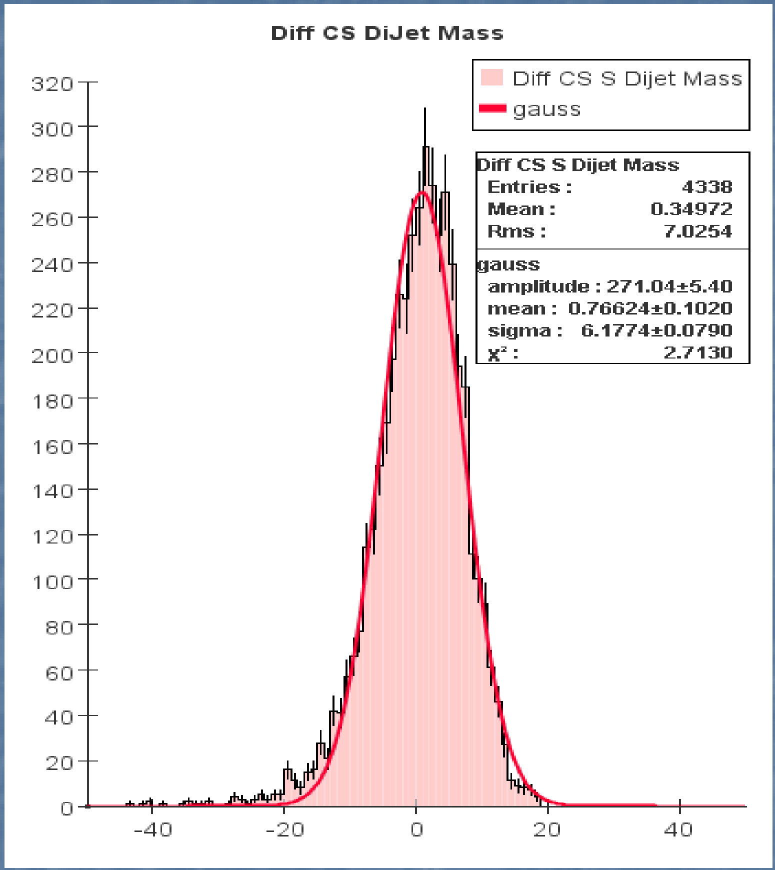
Mip clusters, core clusters, pointing clusters, and shower clusters

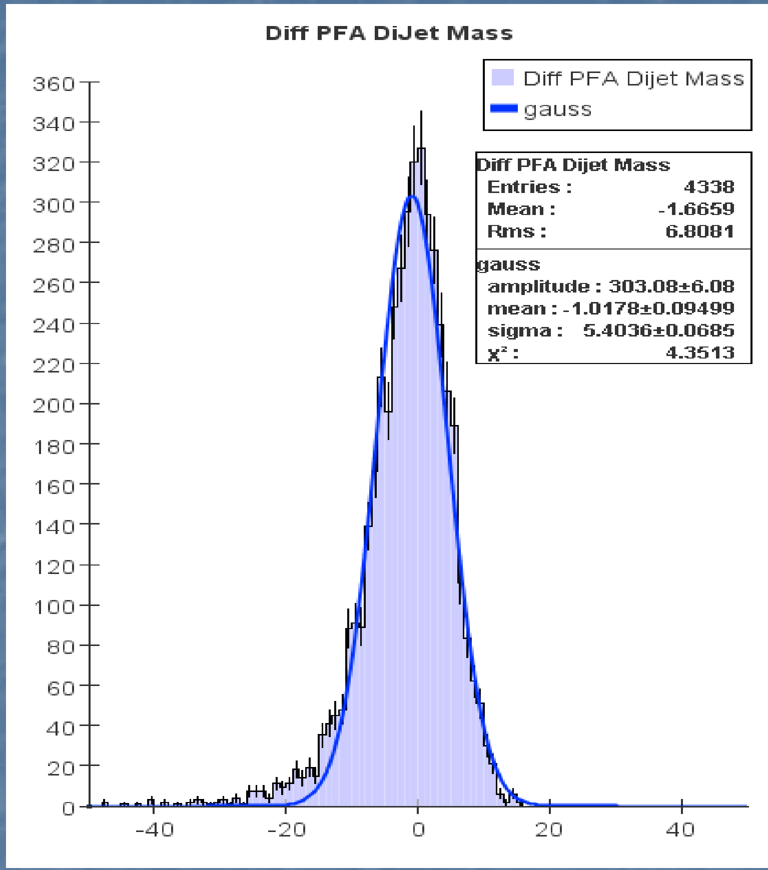


Final Track/Cal Cluster matches
-> Track 4-vectors are used in PFA, clusters are removed

e^+e^- -> ZZ -> $\nu\nu qq$ @ 500 GeV

Difference -> DiJet Mass – qq Mass





C/S-corrected Clusters

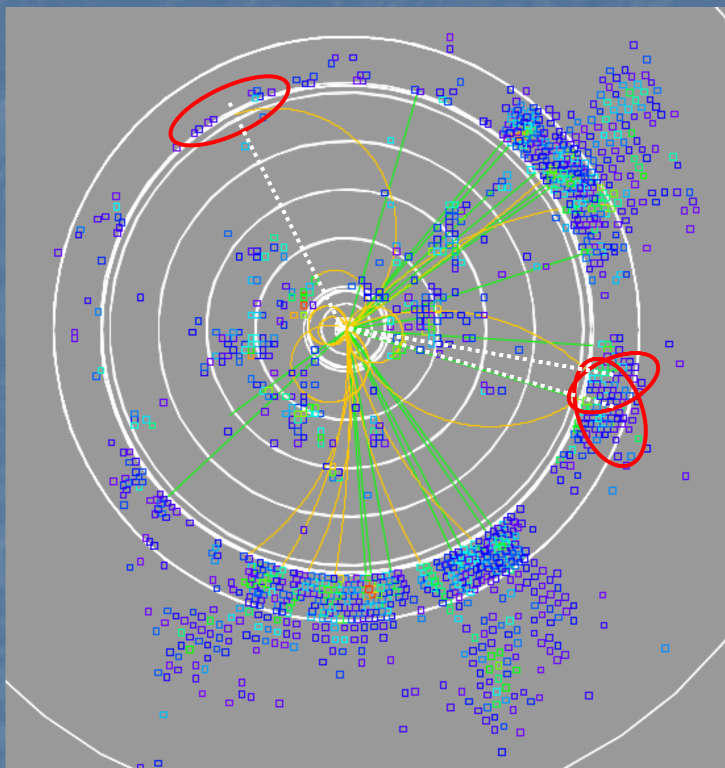
$\sigma/M = 0.068$

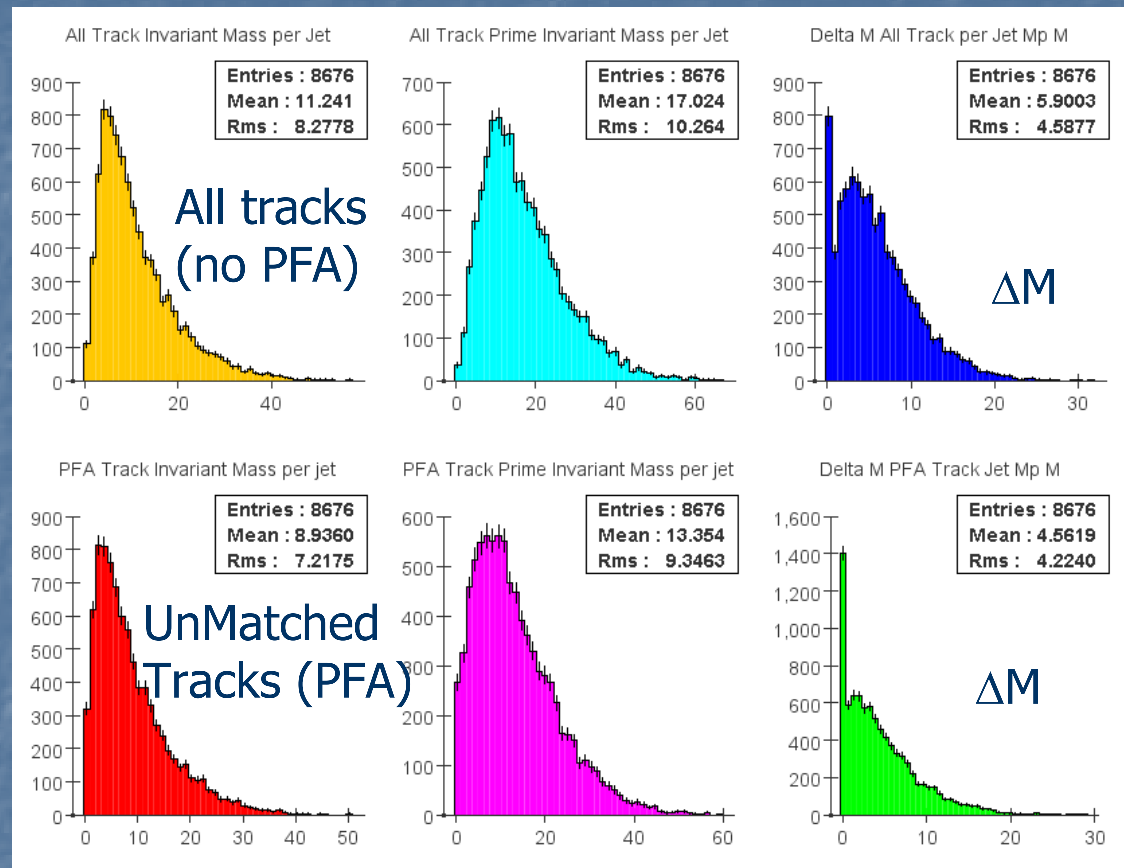
13% improvement

PFA-enhanced Clusters

$\sigma/M = 0.059$

ΔM Corrections with and without PFA





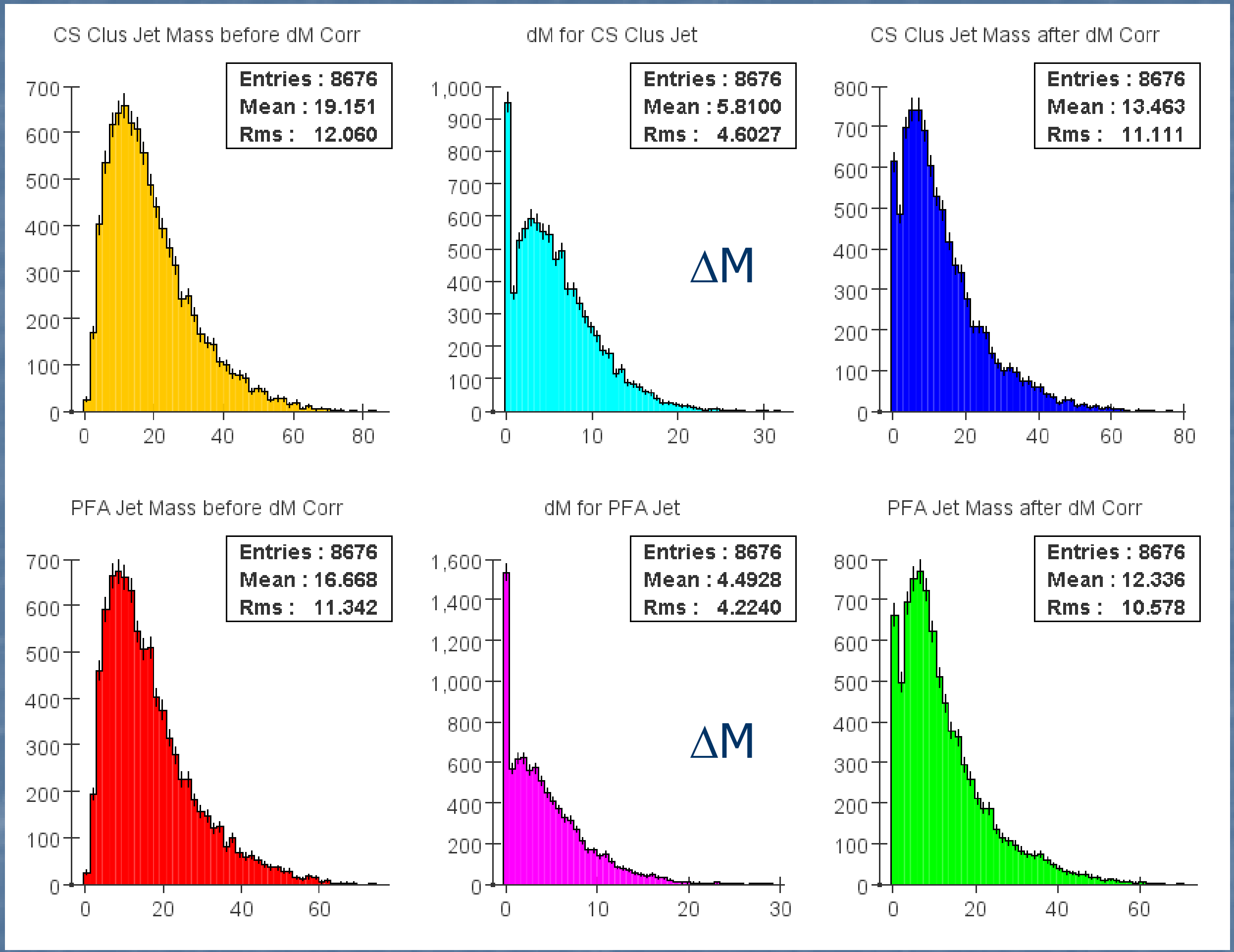
Track on left, large difference between track 4-vector at origin and 4-vector from cluster -> IP, but PFA match chance is high, so correct 4-vector is used
Tracks on right, smaller differences, but lower chance of matching due to overlap, so ΔM correction must be made

e+e- -> ZZ -> ννqq @ 500 GeV

Effect of ΔM Correction on Jet Masses

All-Track ΔM for C/S-corrected cluster jets

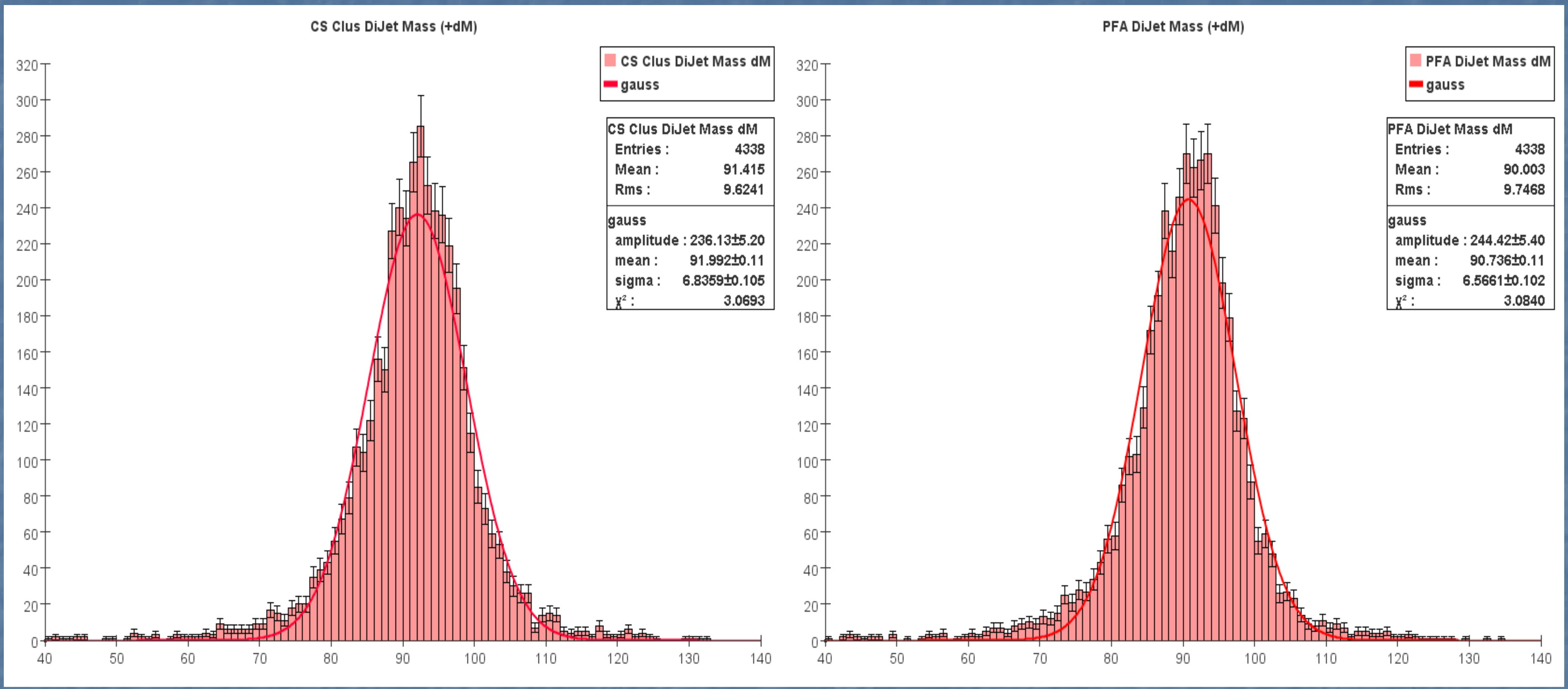
Unmatched Track ΔM for C/S-corrected + PFA jets



Use of PFA results in smaller mass per jet

DiJet Mass + ΔM Correction

$e^+e^- \to ZZ \to \nu\nu qq$ @ 500 GeV



C/S-corrected Clusters

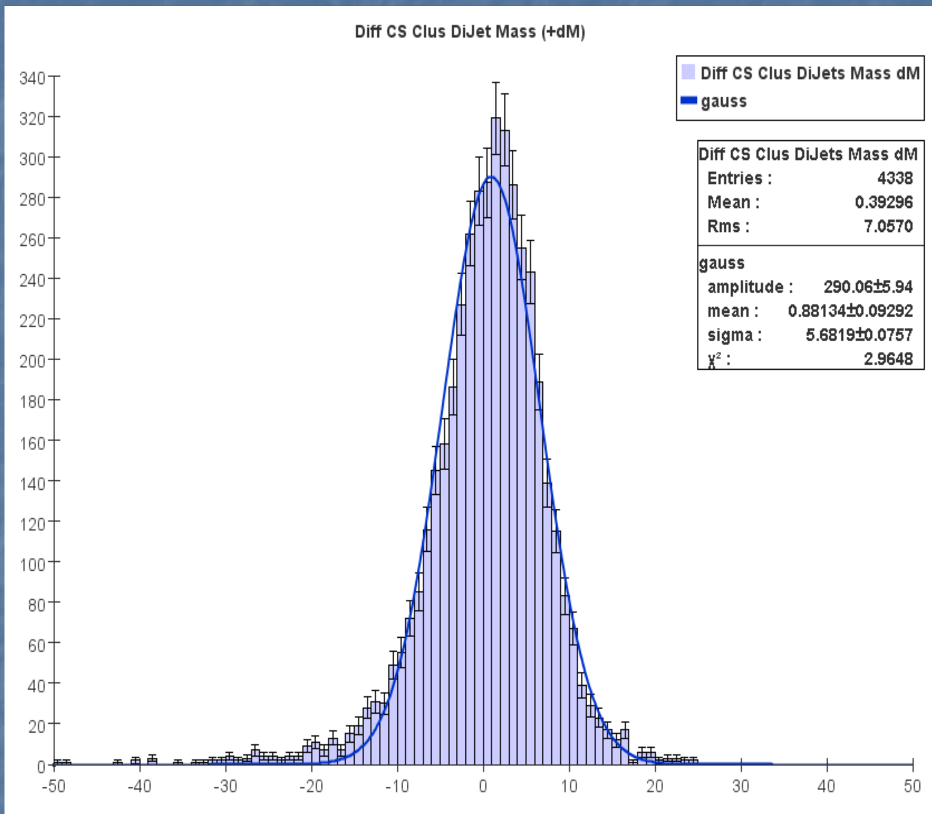
$\sigma/M = 0.075$

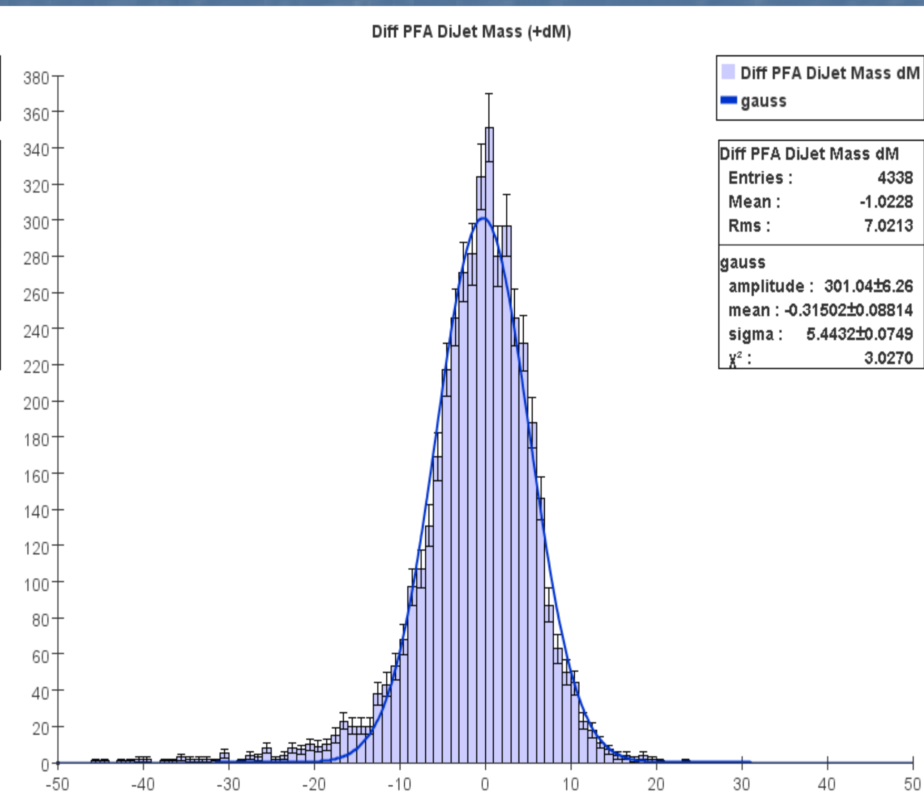
19% improvement

PFA-enhanced Clusters

$\sigma/M = 0.061$

Difference -> DiJet Mass – qq Mass + ΔM Correction





C/S-corrected Clusters

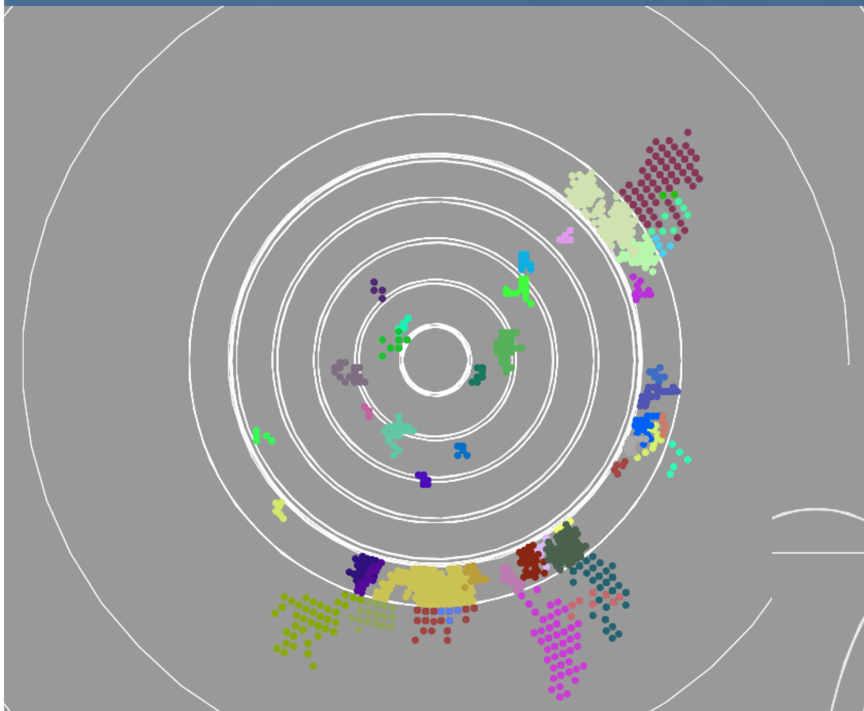
$\sigma/M = 0.062$

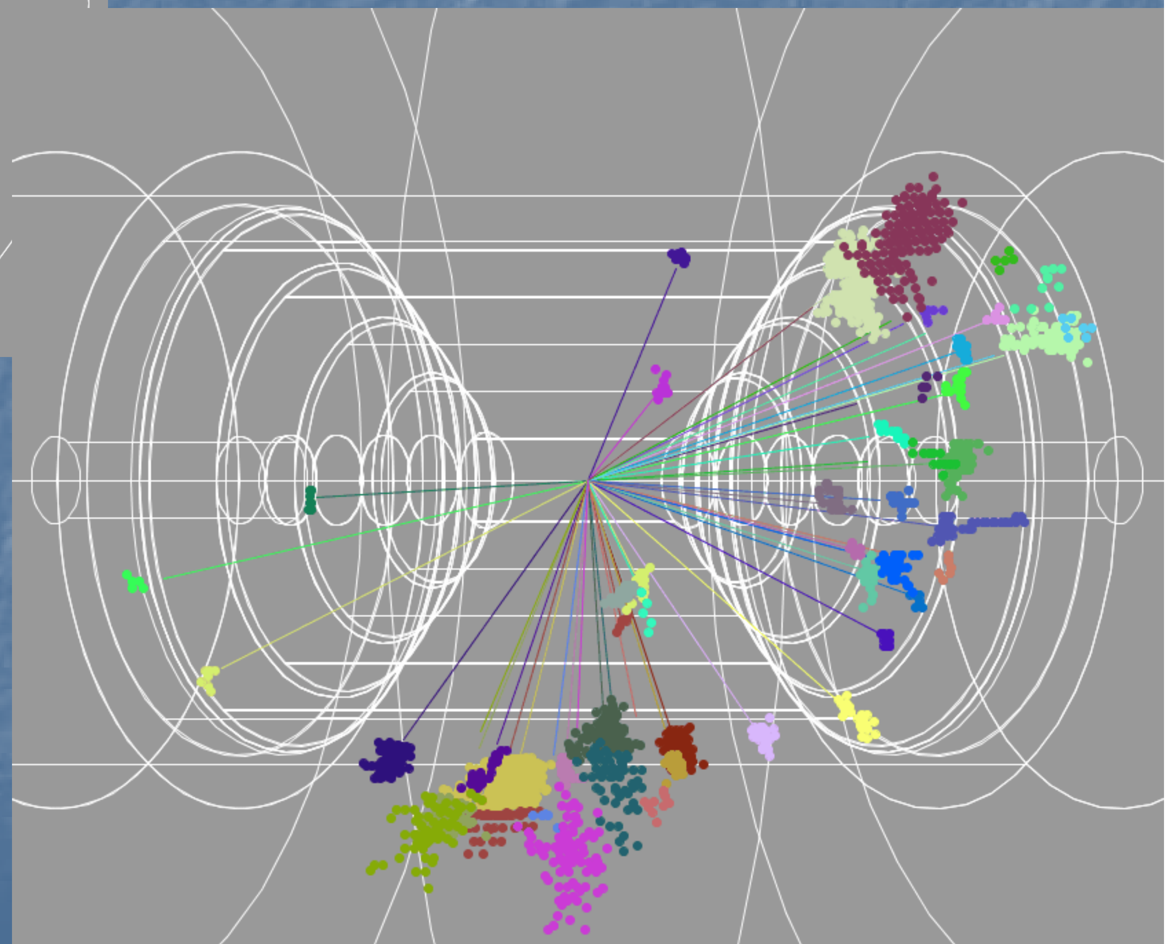
5% improvement

PFA-enhanced Clusters

$\sigma/M = 0.059$

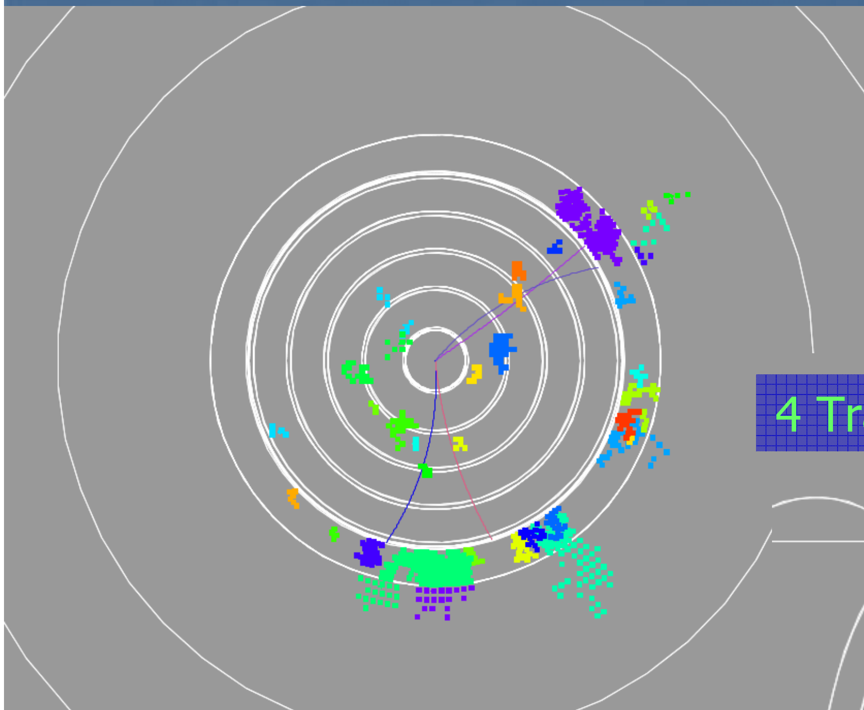
e^+e^- -> ZZ -> $\nu\nu$qq @ 500 GeV





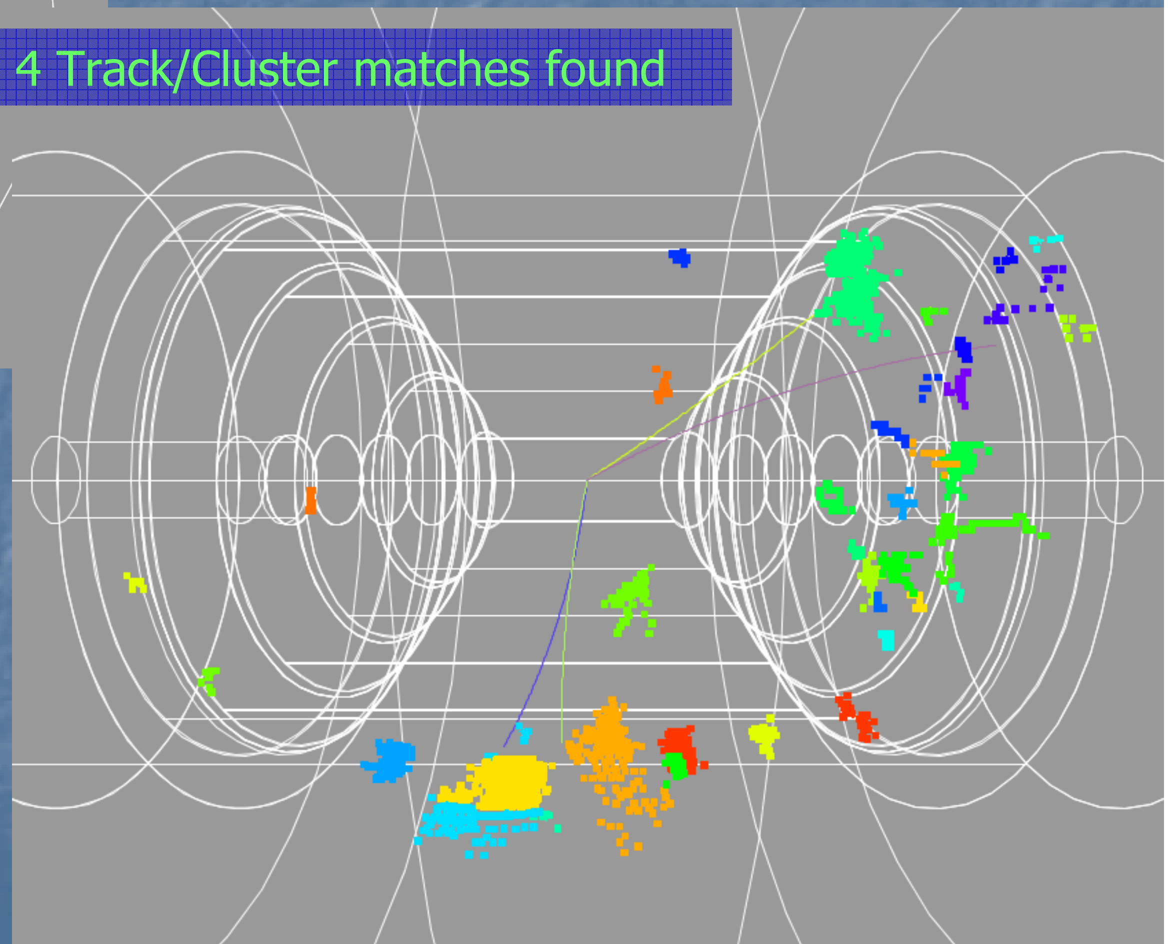
C/S-corrected Cluster RPs

C/S-corrected Clus



e^+e^- -> ZZ -> $\nu\nu$qq @ 500 GeV

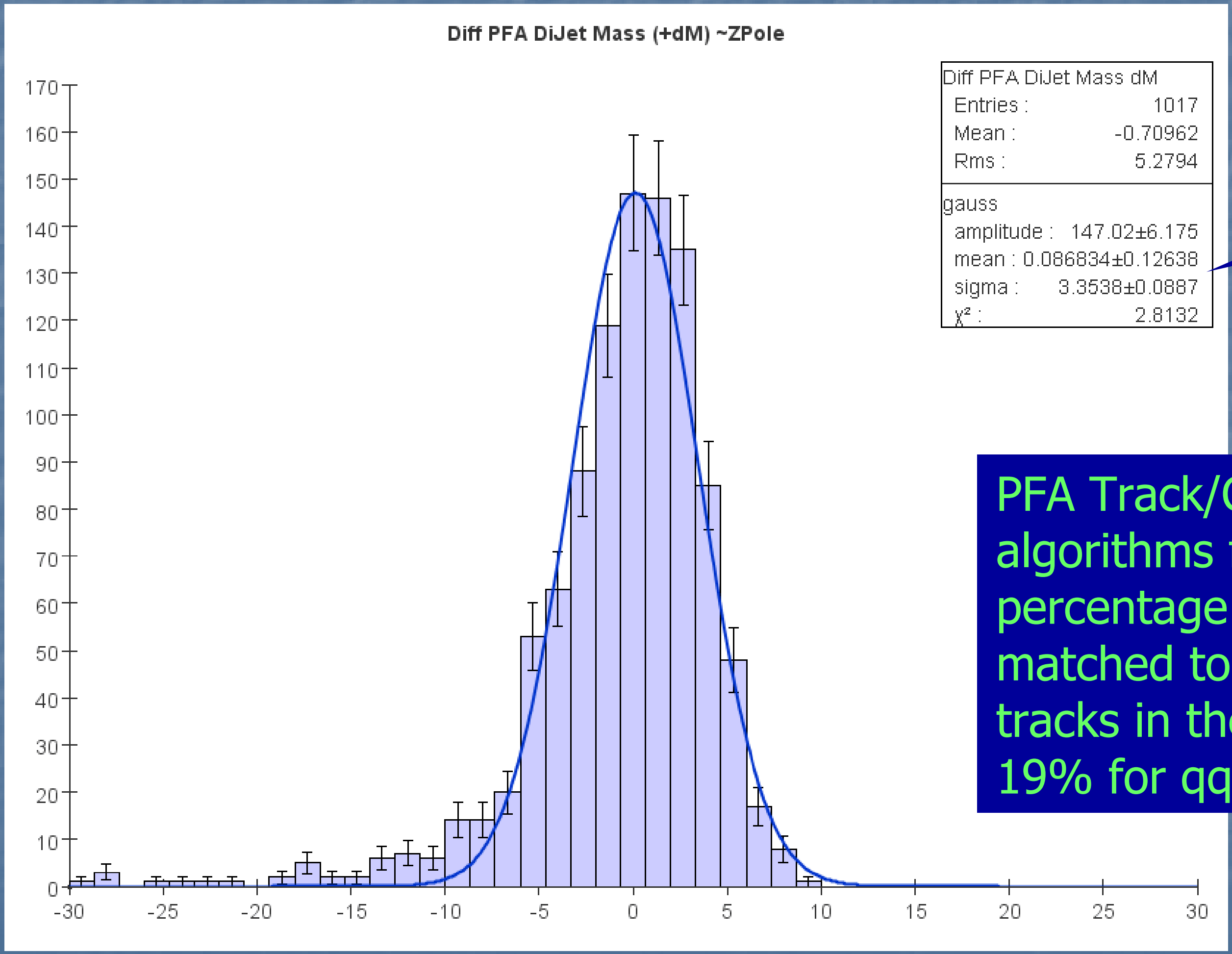
4 Track/Cluster matches found



PFA Tracks + C/S-corrected Cluster RPs

PFA-Enhanced

PFA (+ ΔM) – qq mass @ E_{qq} = 104 GeV



PFA DiJet Mass – qq mass

$\sigma/M = 0.037$

PFA Track/CAL Cluster match algorithms find a larger percentage of isolated clusters matched to tracks -> 23% of the tracks in these events compared to 19% for qq at 500 GeV

Summary

- A total absorption calorimeter using dense crystals and employing dual readout of both scintillator and cerenkov light has been simulated and used to study high energy e^+e^- interactions.
- Because of the high segmentation and granularity of the crystal calorimeter configuration, high purity of particle contribution per calorimeter cell was obtained -> PFA approach to event reconstruction.
- Dual Readout corrections were applied to pion shower fragments from a NN cluster algorithm, resulting in an energy resolution stochastic term of ~24%/√E for single pions.
- Modular PFAs developed for a pixelized sandwich calorimeter have been used without modification in the crystal calorimeter including :
  - Determination of the starting layer of hadron showers
  - Matching of core clusters to tracks
  - Cluster pointing algorithms
  - Iterative track shower association with E/p evaluation
- Using the PFA-enhanced approach along with the DR corrections to clusters and mass corrections to jets, improvement of the dijet mass resolution in the range of 5-19% has been obtained when compared to the non-PFA reconstruction.