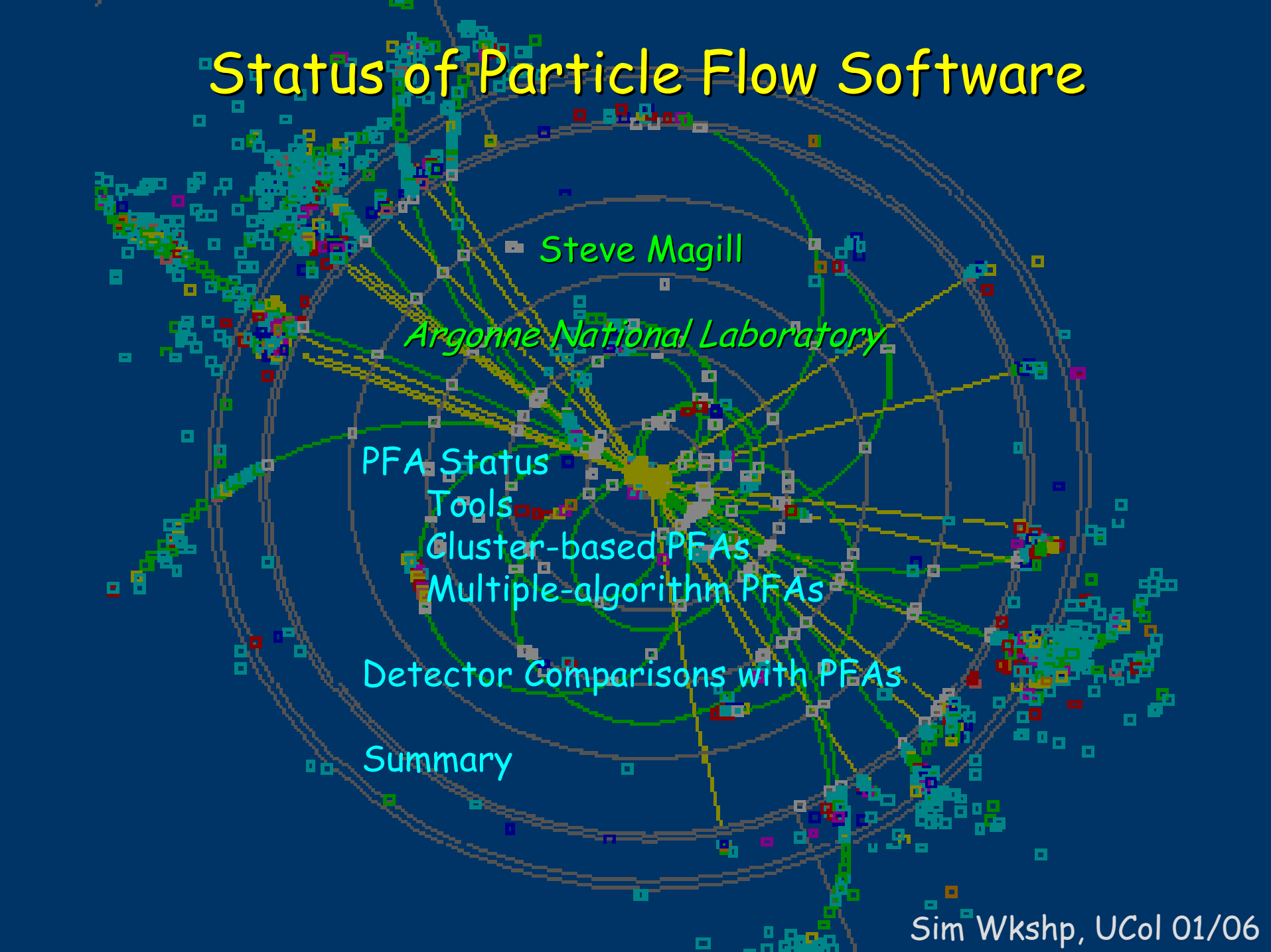
Status of Particle Flow Software



Steve Magill

Argonne National Laboratory

PFA Status

Tools

Cluster-based PFAs

Multiple-algorithm PFAs

Detector Comparisons with PFAs

Summary

PFA Status : Progress since Snowmass

Some Meetings :

Simulation : weekly Tuesday 1:30 PT phone/shared screen
-> http://confluence.slac.stanford.edu/display/ilc/LCDWeekly

SiD Calorimetry : ~weekly Wednesday 2:00 PT phone/web agenda page
-> http://www.slac.stanford.edu/xorg/lcd/SiD-Cal/

ANL-FNAL-NIU : bi-weekly focused on PFA development
-> http://docdb.fnal.gov/ILC-public/DocDB/DocumentDatabase

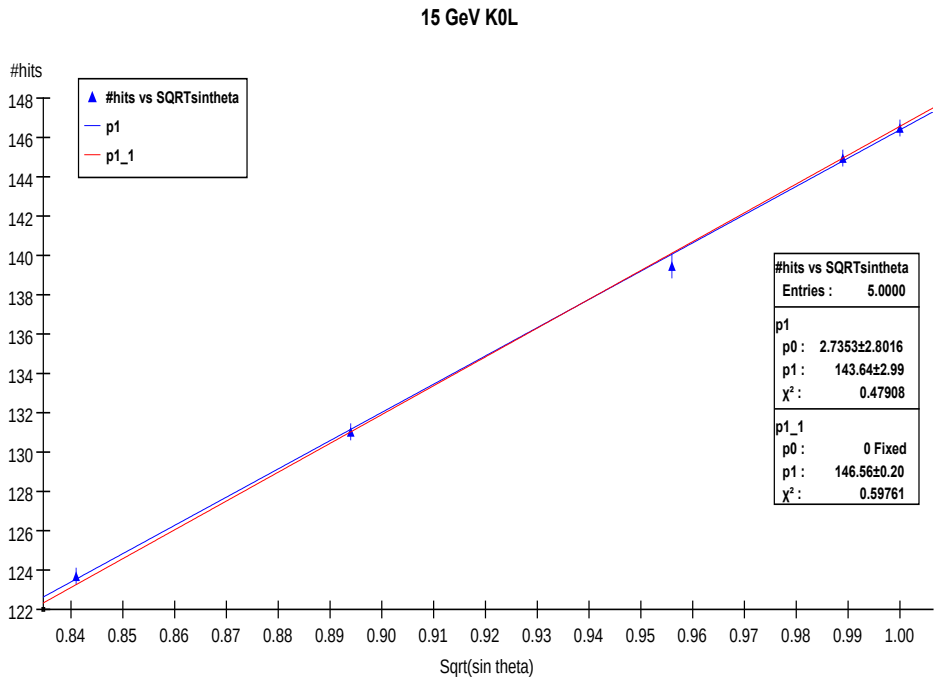
ALCPG Calorimetry : scheduled as needed – next 12/19/05
-> http://www.slac.stanford.edu/xorg/lcd/calorimeter/

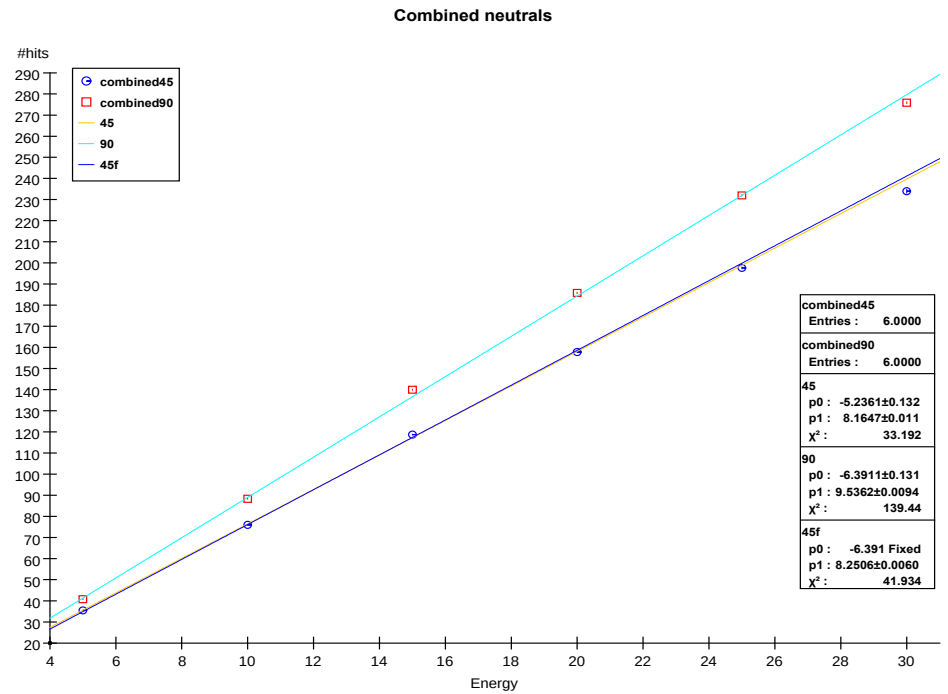
Linear Collider Simulation Workshops : next 1/9-11/06 U of Colorado, Boulder
-> http://www-hep.colorado.edu/cuilc/sim-workshop.html

Tools for PFA Development

Angular corrections in SiD
- R. Cassell SLAC

Similar response for each neutral
Energy independent
~ 16% effect at 45 degrees





Response should be related to additional path length through absorber

Plot response vs 1/sqrt(pathlength) = sqrt(sin theta)

Can determine response at 90 degrees and then correct for angle

-> Implemented for SiD

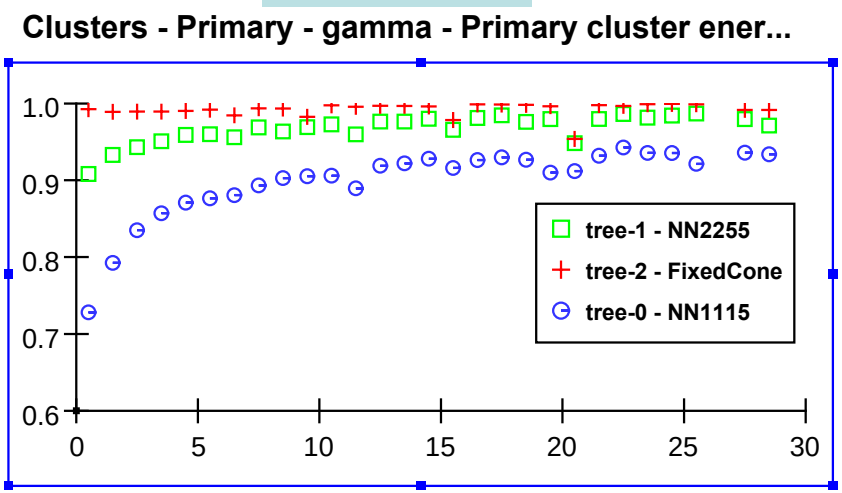
Tools for PFA Development

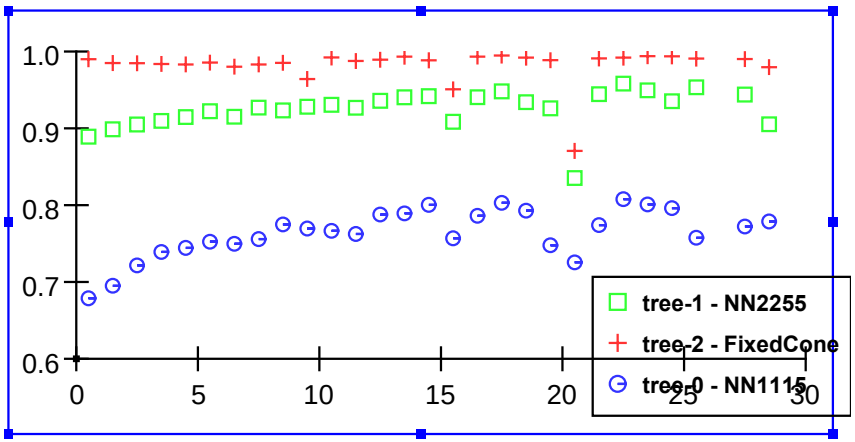
Package to compare cluster algorithms

Cluster Analysis – R. Cassell SLAC

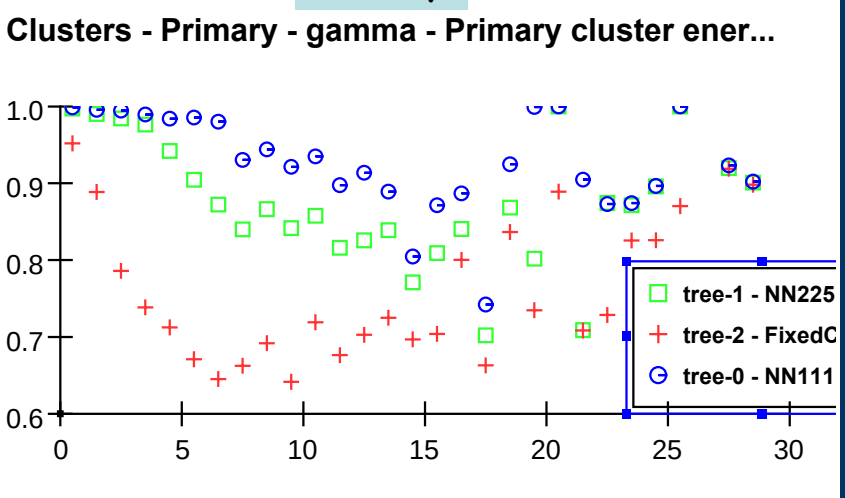
-> Available for use (in cvs)

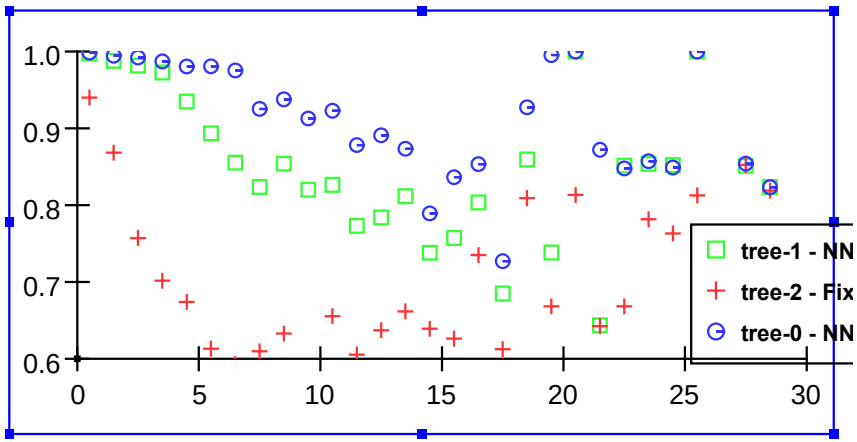
Efficiency





Purity





Tools for PFA Development

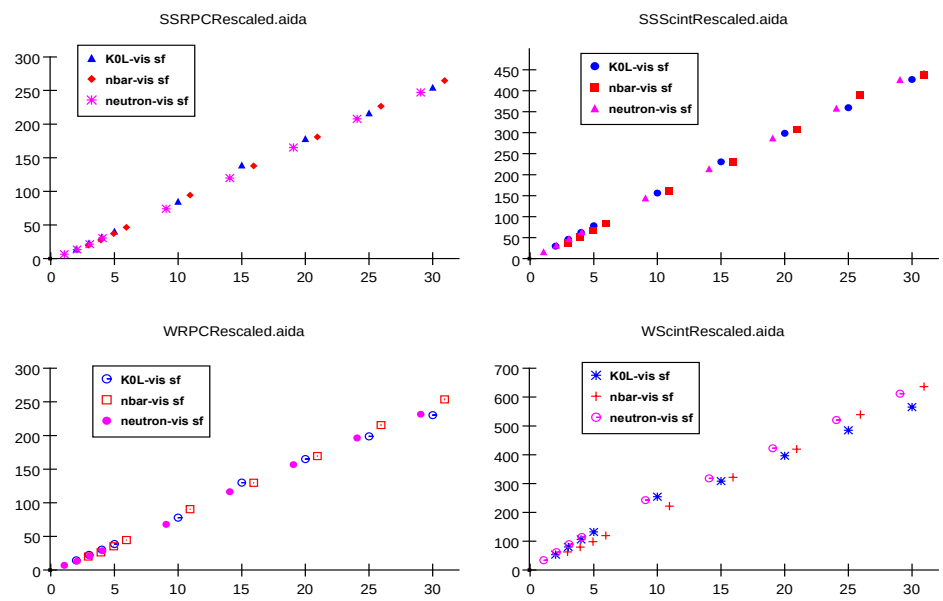
HCAL Studies - R. Cassell SLAC

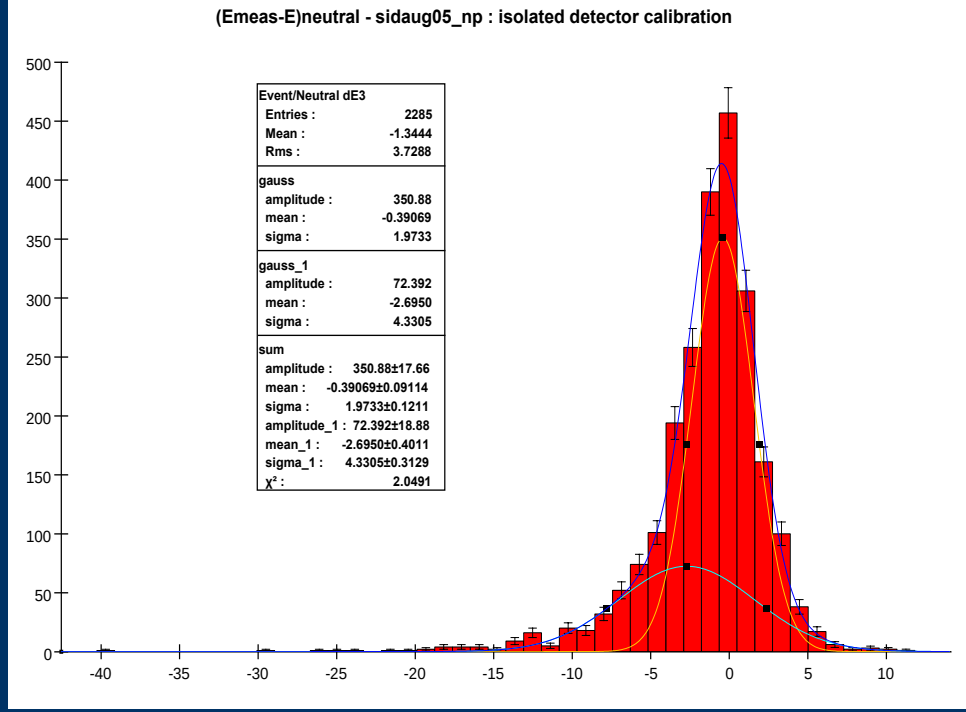
For each detector model, remove all elements except the HCAL barrel, extend it to 1000 layers and 30m in Z. (keep the B field)

Uses scaled energy = max available -> combine K_0^L, n and nbar for study

Single particle studies can compare different detector designs

Useful for calibrating detectors?





Calibrations applied to full detector simulation data give reasonable results

-> calibrations for SiD, CDC

Cluster-based PFAs

Cluster Association Algorithms
- D. Chakraborty, G. Lima, V. Zutshi NIU

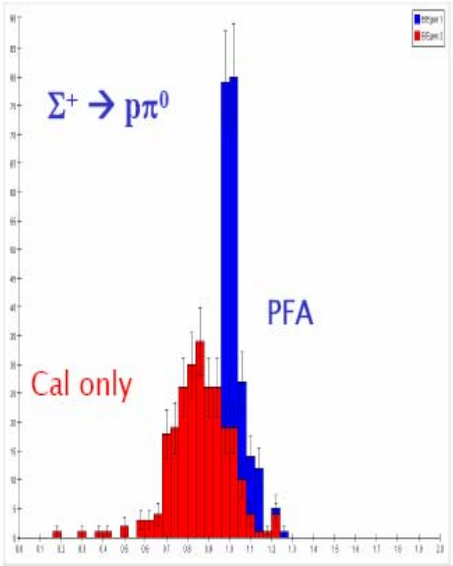
Ongoing Work on 2 different cluster algorithms – different applications?

- The Basic Algorithm
  - Density-weighted Clustering in Calorimeter
    - Calorimeter-only (no track-seeding)
    - Same for ECal (e, γ), and HCal (h^+, h^0).
  - Replace cal clusters with matching (MC) tracks, if any.
- The Directed Tree Algorithm
  - Association of isolated "fragment"s or "satellite"s.

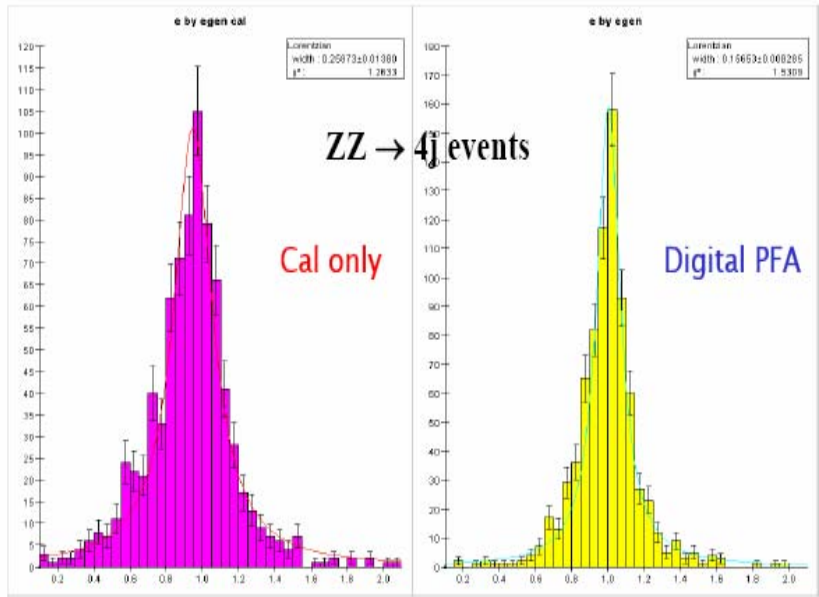
Using density-weighted clustering in PFA

DHCal: Particle-flow algorithm (NIU)

- Nominal SD geometry.
- Density-weighted clustering.
- Track momentum for charged,
- Calorimeter E for neutral particles.



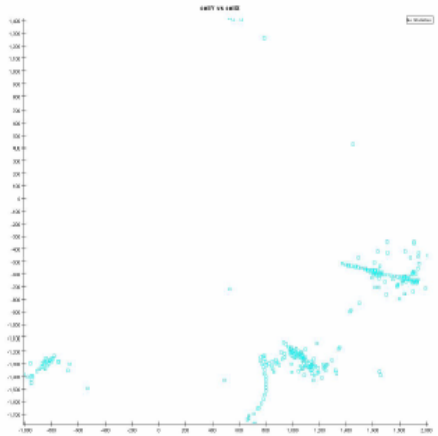
DHCal: Particle-flow algorithm (NIU) Reconstructed jet resolution



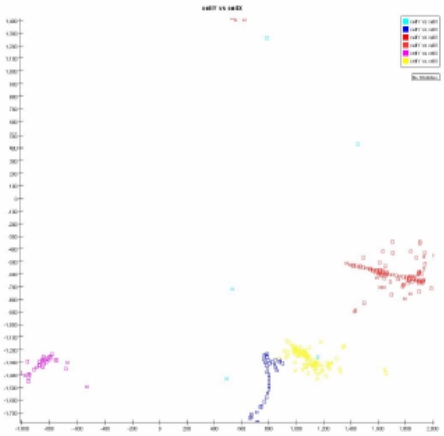
Using Directed Tree clustering

Single hadrons in the ECal

Generated clusters



Reconstructed clusters

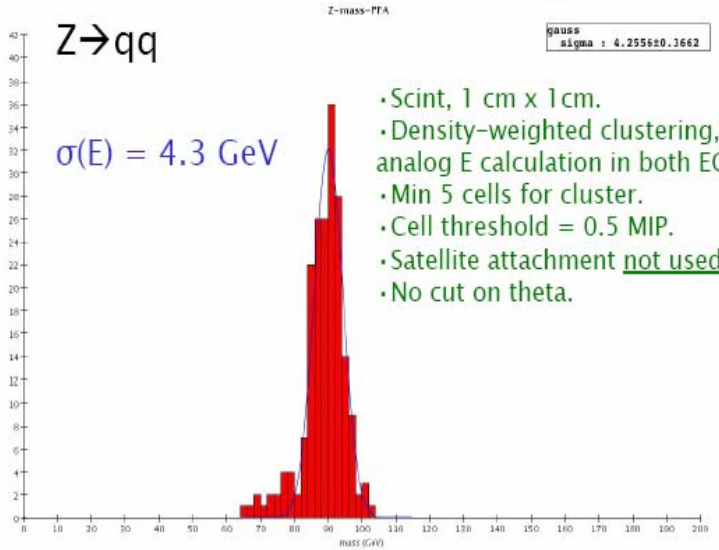


Clusters from single hadrons are reconstructed well.
Some "fragment"s or "satellite"s remain unassociated.

Cluster Matching and Merging

- Stage 1: one-to-one gen-reco matching based on distances (3D or angular)
  → unassociated clusters ("satellites")
- Stage 2: attach satellites to reco clusters based on angular distances: possible cuts on angular separation, satellite energies, number of hits,...

Current Status (contd.)



With Perfect PFA (no confusion term), σ(E) = 3.1 GeV

-> improve results with directed tree on satellite clusters?

Cluster-based PFAs

Cluster Association Algorithm with MST
- M. Charles, U. Mallik, N. Meyer U of Iowa

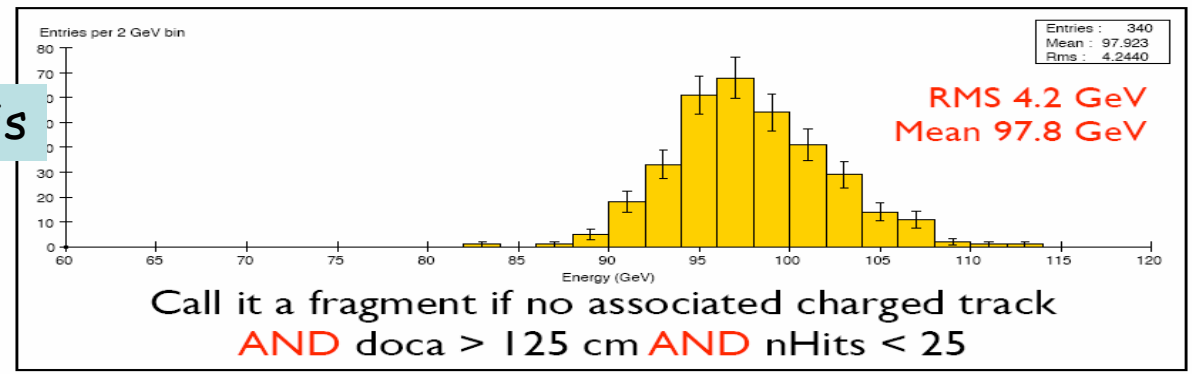
General approach

- Need to separate and identify hadronic clusters.
- Hadronic clusters have substructure (unlike typical EM clusters)
- Approach is to break down MST clusters into pieces, check whether they should really be linked, then reassemble them.
- Parts of the skeleton:
  - Clumps -- dense collections of hits
  - Track segments
- ... plus halo/fragments/satellites

List of likelihood variables

- Clump-Clump:
  - DOCA
  - Smallest distance from a hit in one cluster to a hit in the other
- Track-Clump:
  - DOCA
  - Smallest distance from a hit in one cluster to a hit in the other
- Track-Track:
  - DOCA
  - Smallest distance from track hit to POCA
  - Whether POCA is inside calorimeter
  - Extrapolating track to POCA (or joint CoE for parallel & disjoint tracks)...
    - # Layers where a hit is not found
    - Fraction of layers where a hit is not found (ignoring layers with a hit from cluster itself)

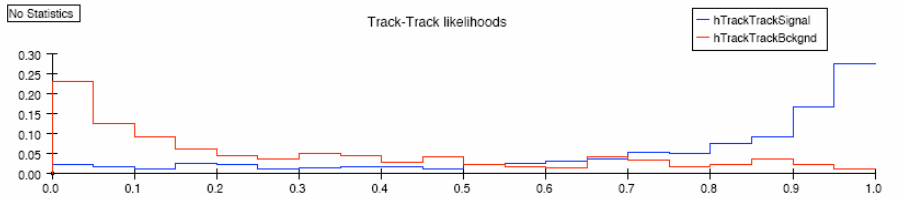
Cut-based analysis

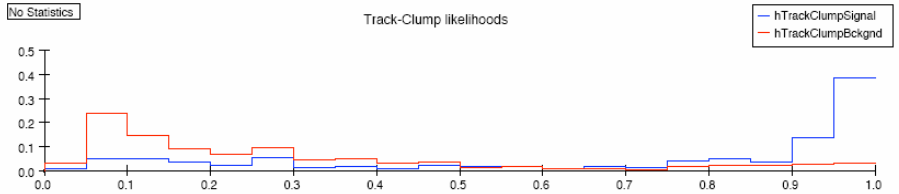


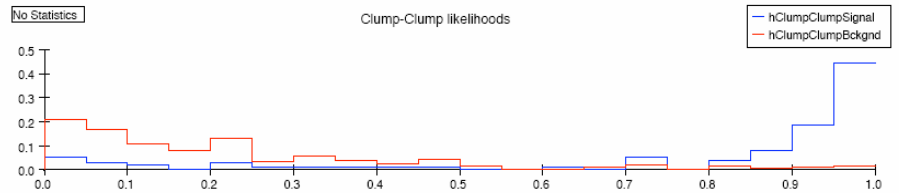
Structual algorithm package

- Package "structural" contains drivers to:
  - Find clumps & track segments in calorimeter
  - Extrapolate charged MC particles to the ECAL (derived from Steve McGill's code)
  - Obtain likelihood PDFs for linking components
  - Use likelihood selector to link components
  - Break up & reassemble clusters
  - Identify fragments & assign them to clusters (crude)
  - Report total event energy
- ... and a driver to tie it all together (ExamplePFA)

Likelihood distributions

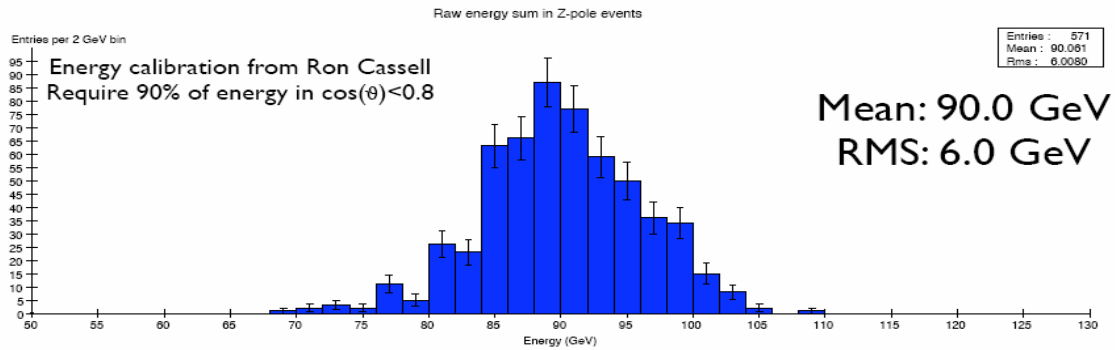






Results

- ... are not ready yet.
- I'm at the stage where I can plot the total raw energy in Z-pole events and trust that:



Mean: 90.0 GeV
RMS: 6.0 GeV

But I do not yet have the full algorithm properly debugged and producing useful results.

Promising approach to separate charged and neutral showers AFTER photons are found and track mip segments are discarded

-> part of full PFA

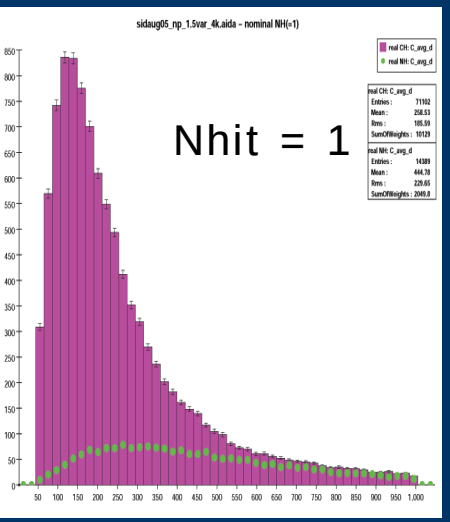
-> available in cvs

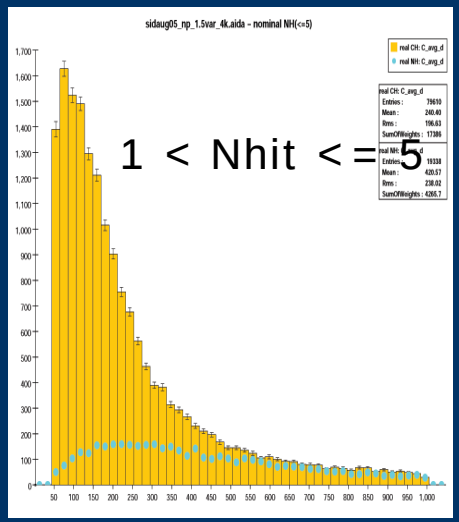
Cluster-based PFAs

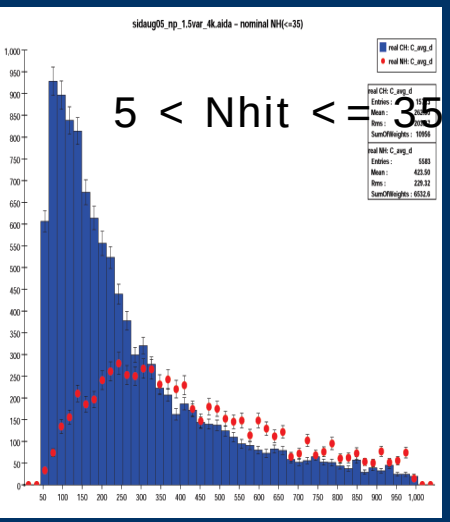
Cluster Association Algorithm with Hit Density-driven Clusterer
- L. Xia ANL

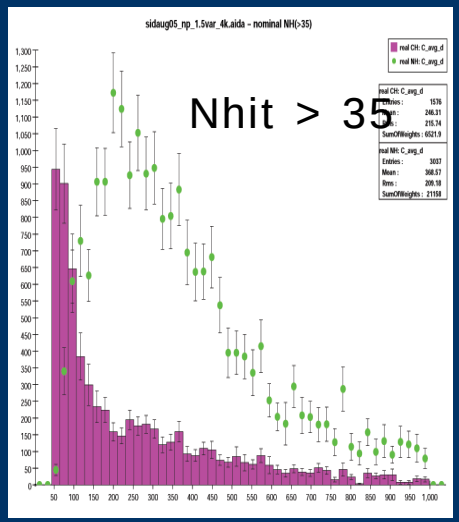
- What's in it
  - Calibration of calorimeter
    - including Ron's angular correction
  - Clustering algorithm
    - hit density driven
  - Track-cluster matching
    - based on track-cluster distance, no E/p check
  - Charge fragment cleanup: ← new!
    - After track-cluster matching
    - use geometrical variables to distinguish and remove charge fragments from real neutral clusters
- What's still needed (currently using MC information)
  - 'cluster ID'
    - Tells me whether a cluster is from an EM or a HAD shower
  - Track finding algorithm
  - Jet algorithm
- Detector mode
  - SiDaug05_np
    - Si tracker, Si/W EM calorimeter, RPC/SS DHCAL non-projective

Cluster Distance to Track



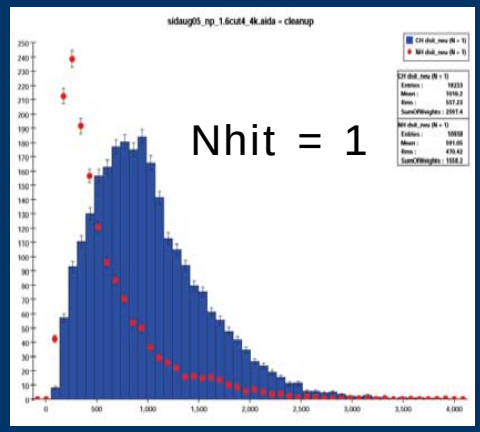


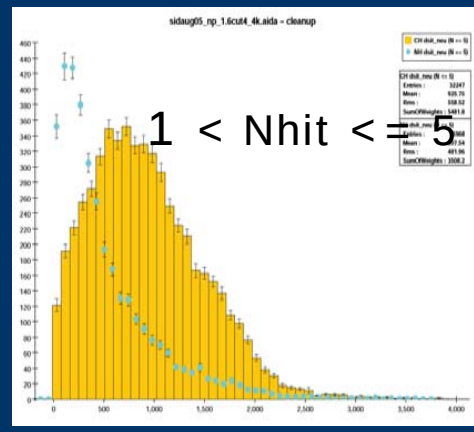


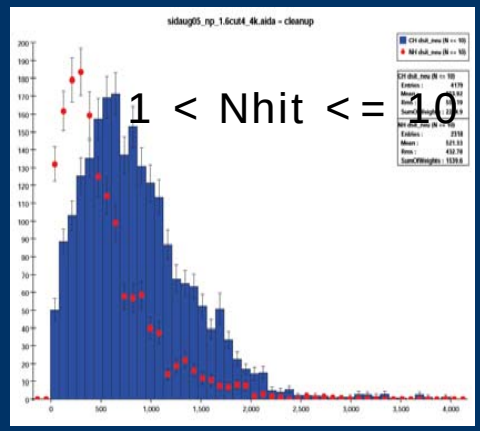


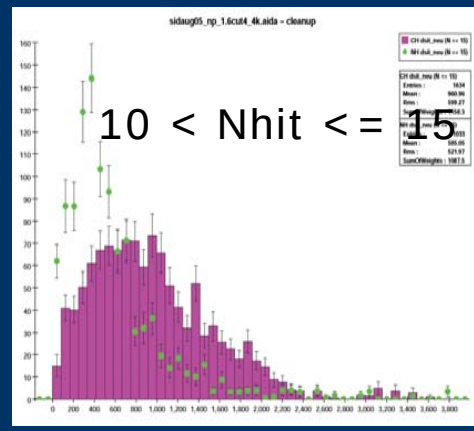
Use distances, ratio of distances to associate clusters with tracks, neutrals

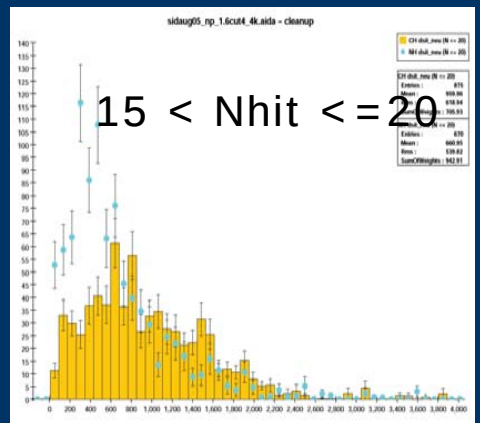
Cluster Distance to Neutral

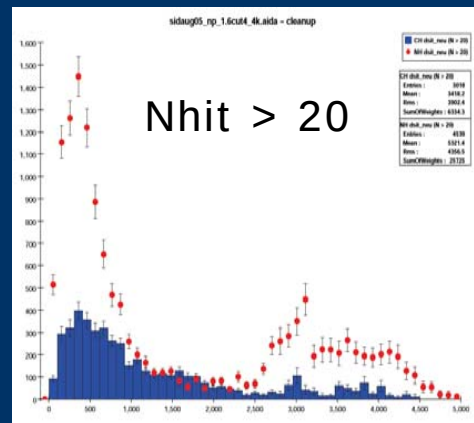




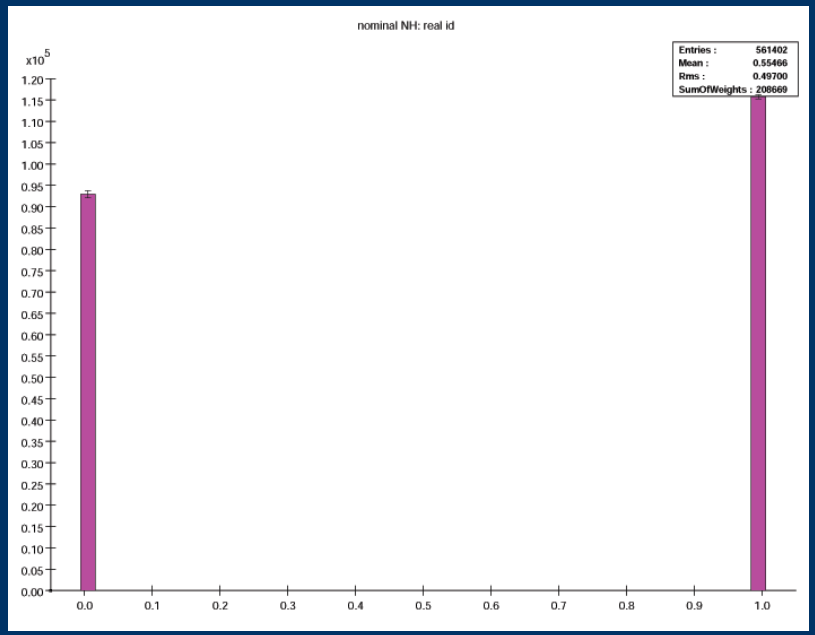


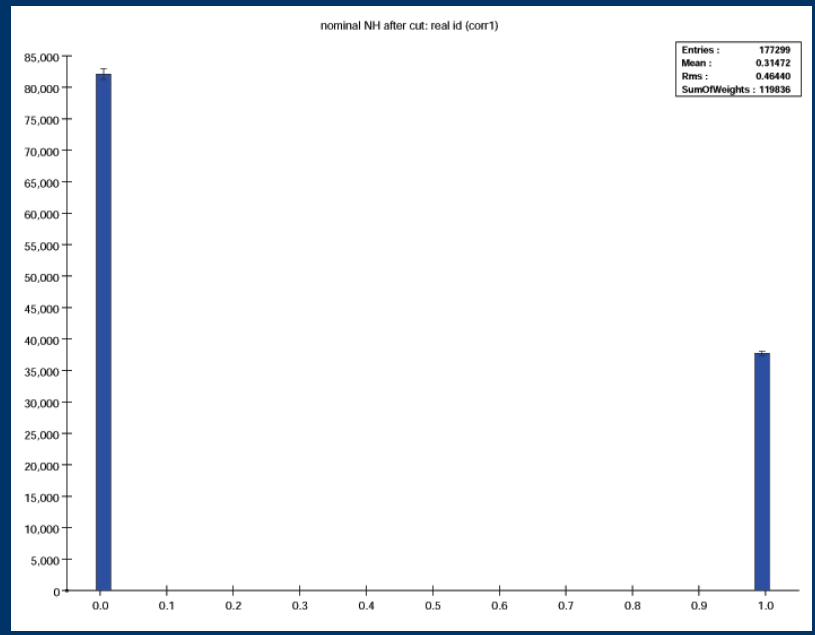






Using cuts on Distance to Neutral variable





1 : 1.24

1 : 0.46
Eff(neu) ~ 88%

Cuts:

1. For Nhits = 1, cluster-neutral distance > 1000mm
2. For 1<Nhits<=5, 1200mm
3. For 5<Nhits<=10, 1400mm
4. For 10<Nhits<=15, 1600mm
5. For 15<Nhits<=20, no cut
6. For Nhits>20, no cut

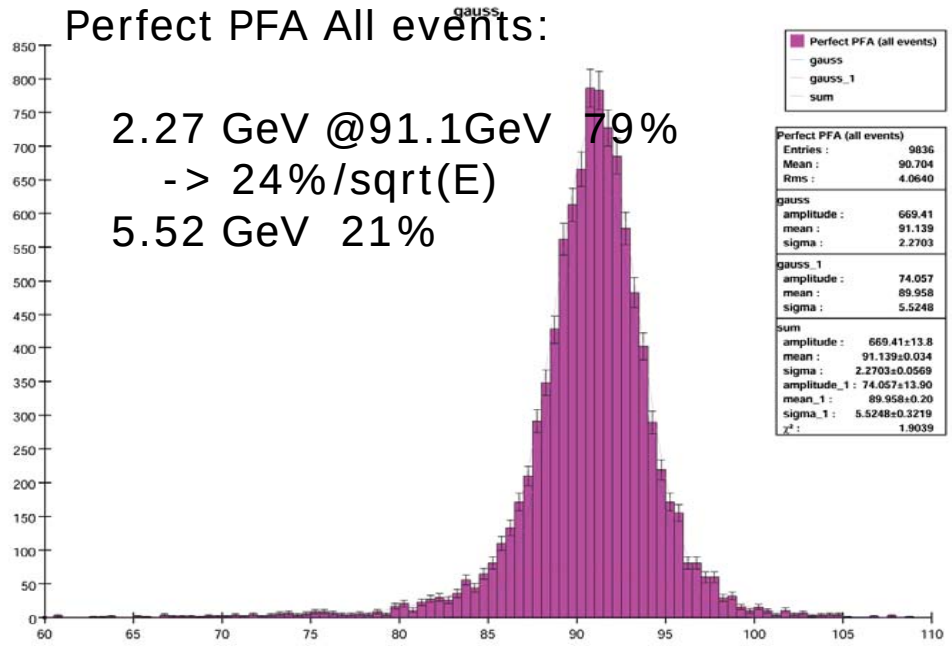
Neutral:

Any cluster with Nhits > max (10, Nhits,current)

Similar results using ratio variable

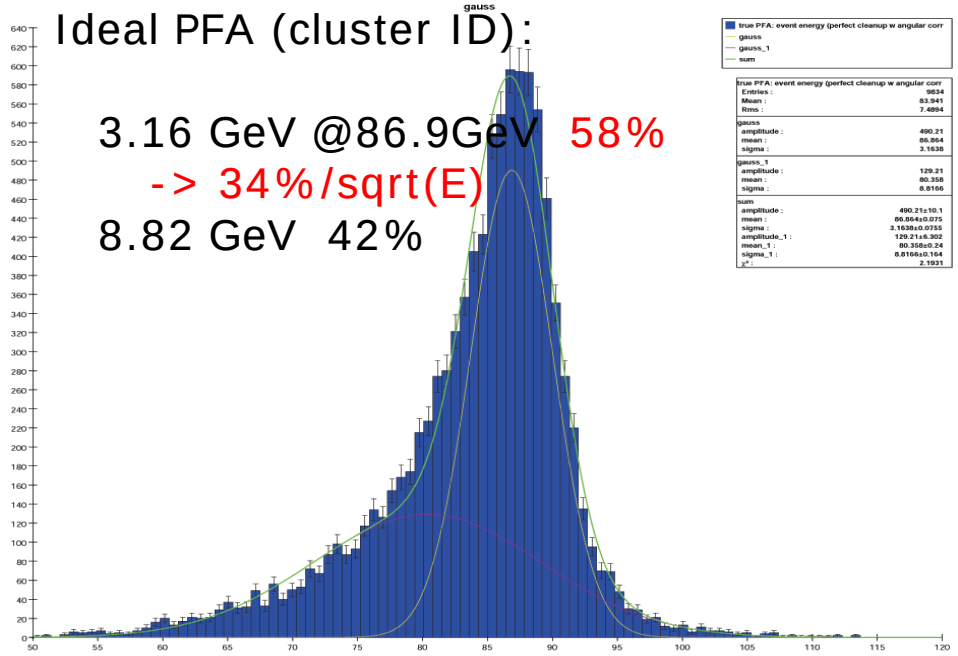
Perfect PFA All events:

2.27 GeV @91.1GeV 79%
-> 24%/sqrt(E)
5.52 GeV 21%



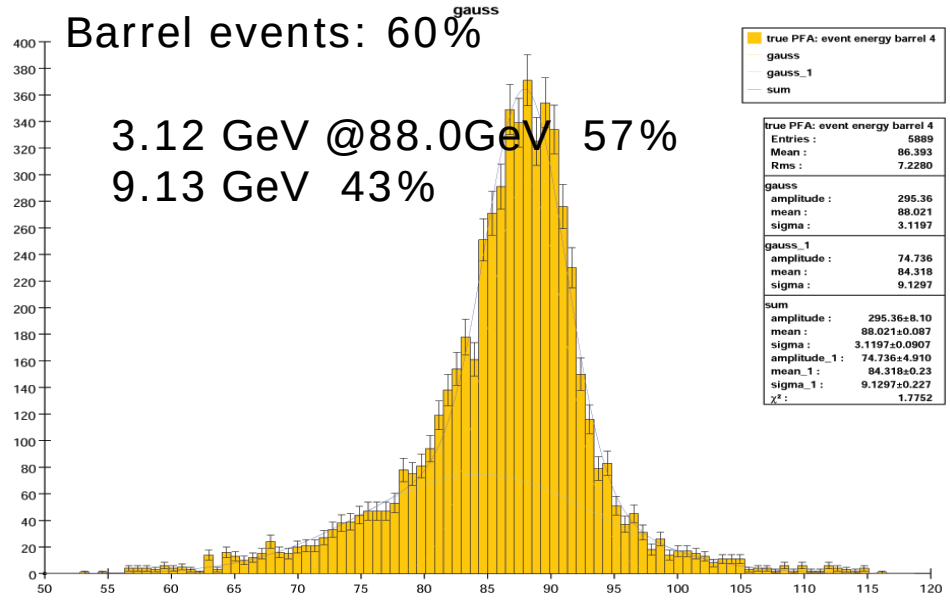
Ideal PFA (cluster ID):

3.16 GeV @86.9GeV 58%
-> 34%/sqrt(E)
8.82 GeV 42%



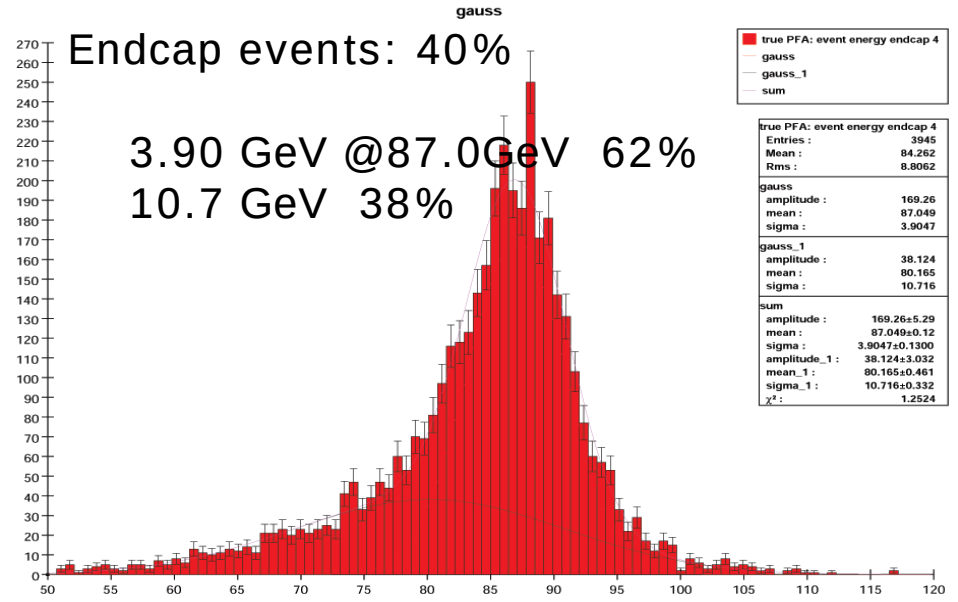
Barrel events: 60%

3.12 GeV @88.0GeV 57%
9.13 GeV 43%



Endcap events: 40%

3.90 GeV @87.0GeV 62%
10.7 GeV 38%



Results using both distance and ratio

Multiple-algorithm PFA

Track-first algorithm with optimized hit clustering and modular analysis

- S. Kuhlmann, S. Magill ANL
- R. Cassell, N. Graf SLAC
- C. Hensel, E. Benavidez, G. Wilson, Kansas

PFA Construction :

EM Hit Map (t<100 ns)
HAD Hit Map (t<100 ns, Ethr>0.5 Mips

Track/CAL Mip Match -> IL for charged hadron showers

Modify EM, HAD Hit Maps

Nearest Neighbor Clusterer on EM Hits (2,2,5,8)

H-Matrix Photon Finder

Modify EM Hit Map

Nearest Neighbor Clusterer on EM Hits (3,3,8,6)
Nearest Neighbor Clusterer on HAD Hits (3,3,6,8)

Track + Mip/CAL Shower Match (E/P test with iteration)

Modify EM,HAD Hit Maps

Nearest Neighbor Clusterer on HAD Hits (4,4,10,20)

Neural Net Cluster ID*

Modify EM,HAD Hit Maps

Tracks, Photons, Neutrals to Jet Algorithm*

Ingredients :

Hit Maps

Algorithms

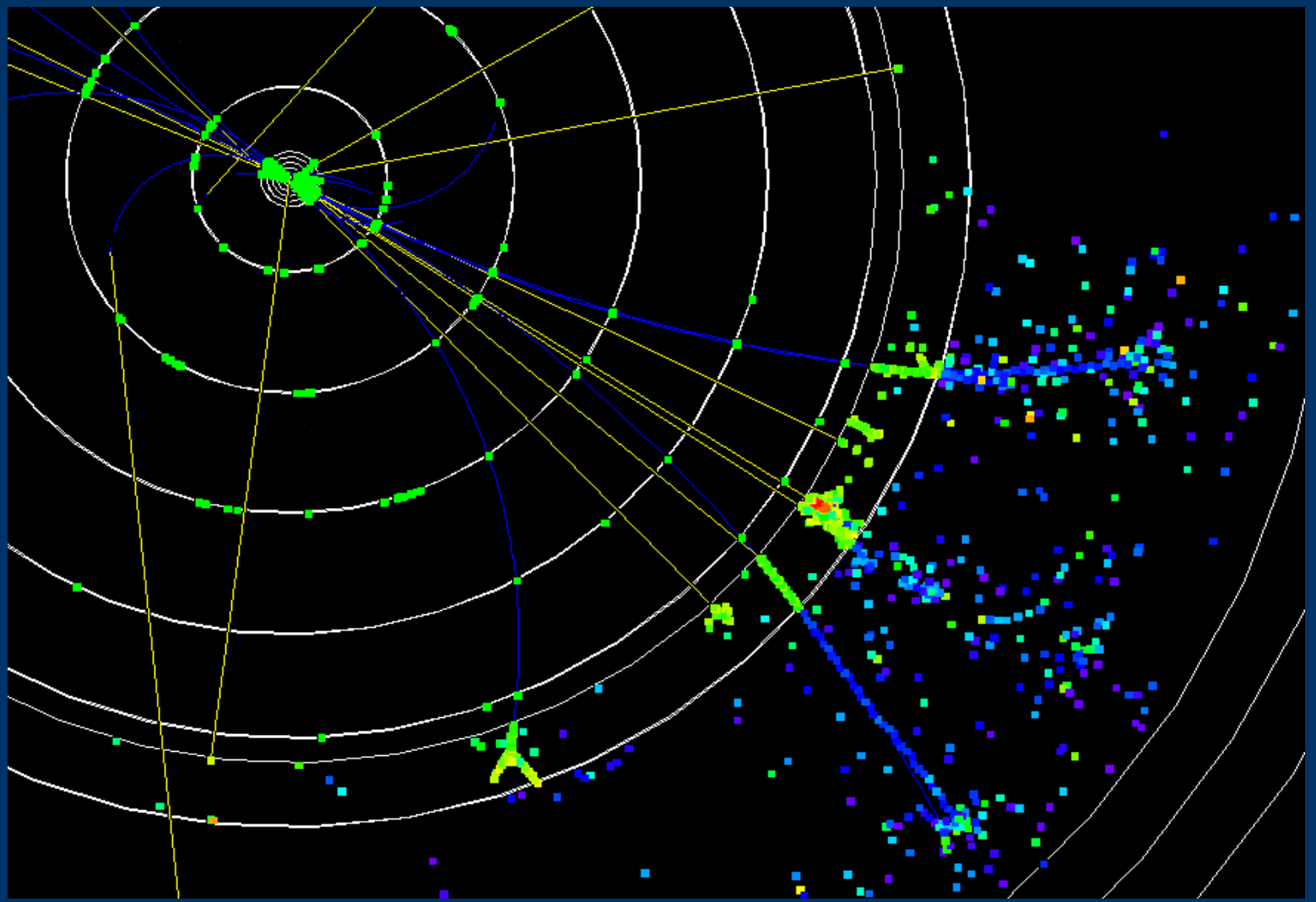
Clusterers

All modular construction

Full event reconstruction with PFA

e+e- -> Z -> qqbar event

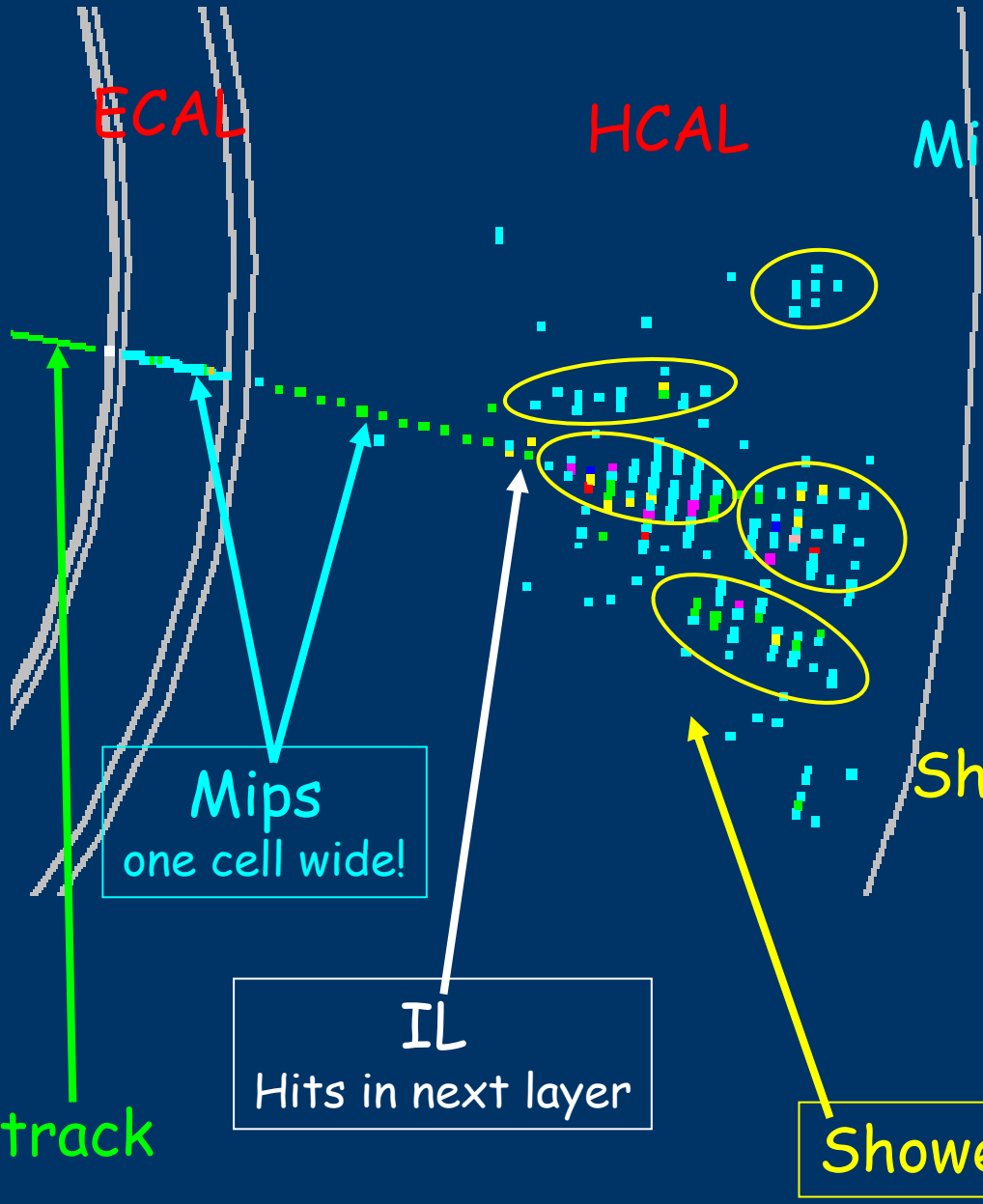
Calorimeters :
ECAL - W/Si
HCAL - W/Scintillator



Top, CW

66 MeV γ
6 GeV π-
5 GeV π-
131 MeV γ
12 GeV γ
12 GeV K_L^0
5 GeV π+
2 GeV n
400 MeV γ
2 GeV π+
40 MeV γ

Shower reconstruction by track extrapolation



Mip reconstruction :

Extrapolate track through CAL layer-by-layer

Search for "Interaction Layer"

-> Clean region for photons (ECAL)

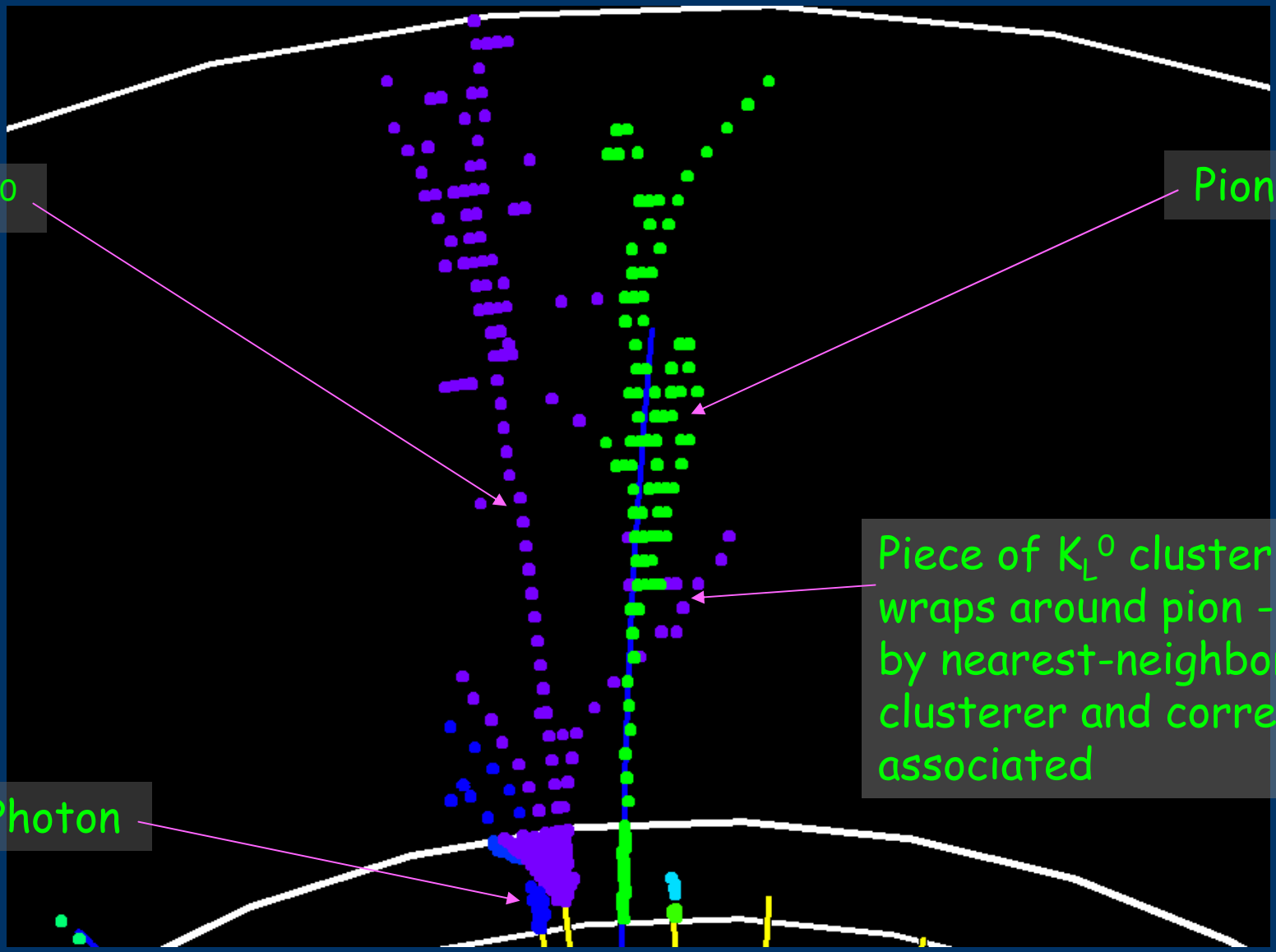
-> "special" mip clusters matched to tracks

Shower reconstruction :

Cluster hits using nearest-neighbor algorithm

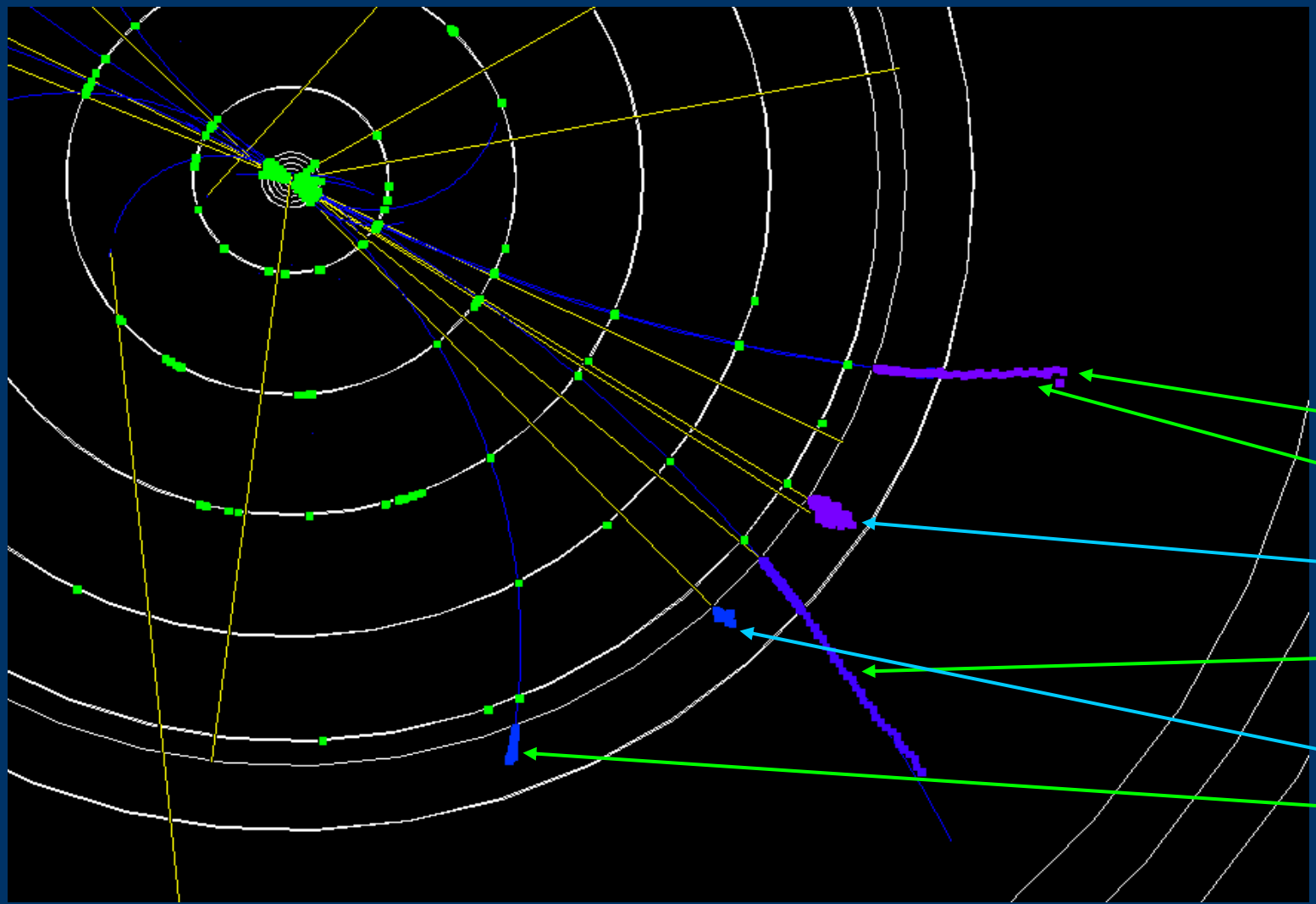
Optimize matching, iterating in E,HCAL separately (E/p test)

Nearest-Neighbor Clustering for Charged/Neutral Separation – SLAC/ANL



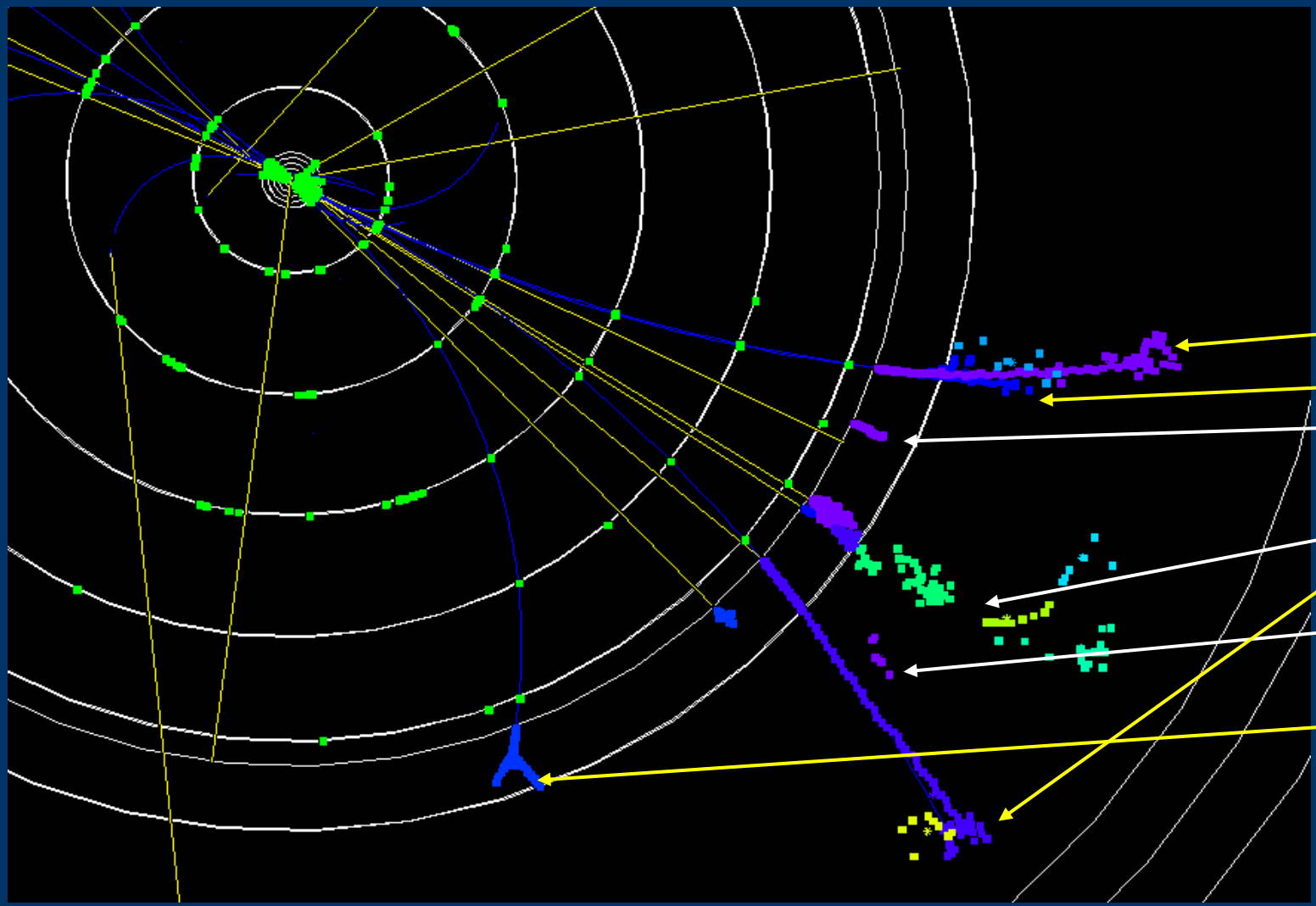
1. Mips on Track extrapolation

2. Photons



3. Track/mip matches to EM, HAD showers

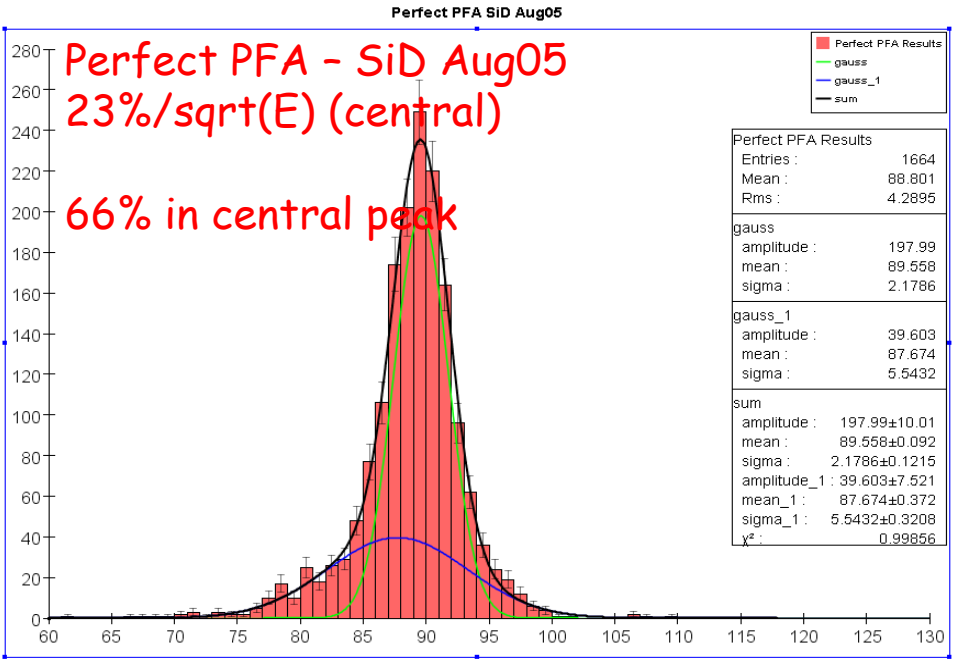
4. Neutral Showers

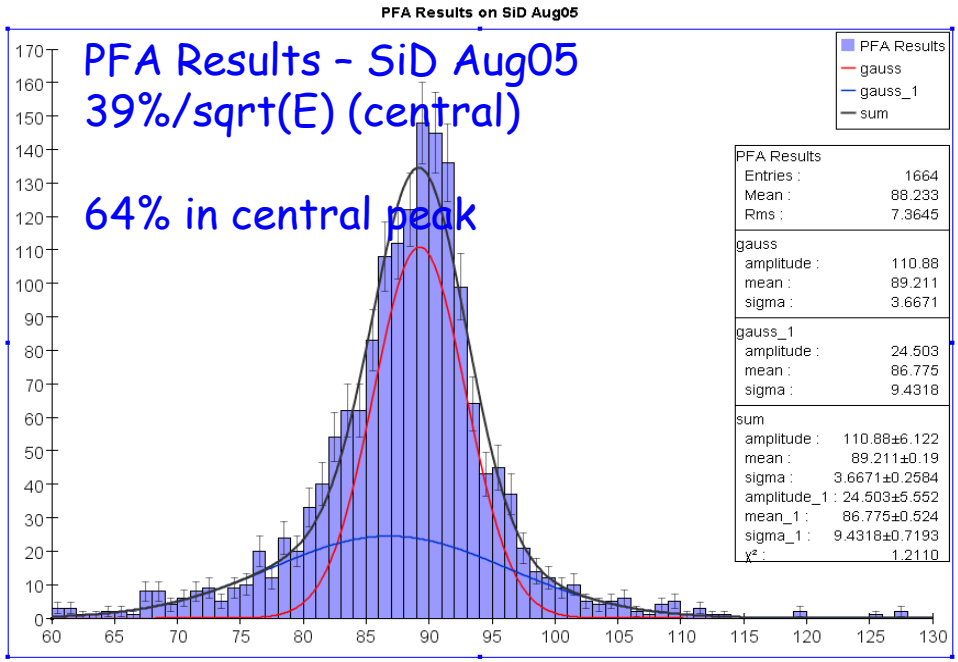


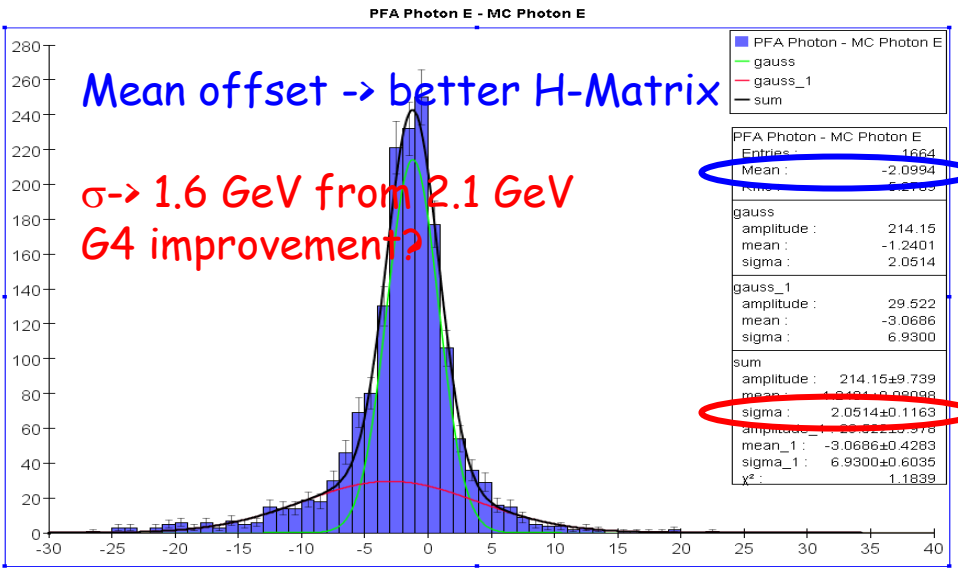
Top, CW

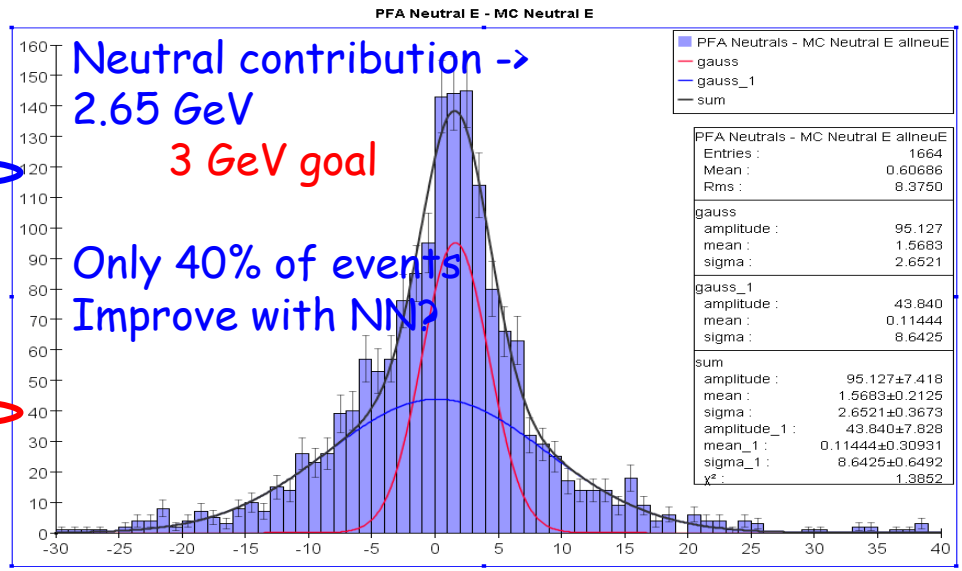
66 MeV γ
6 GeV π-
5 GeV π-
131 MeV γ
12 GeV γ
12 GeV K_L^0
5 GeV π+
2 GeV n
400 MeV γ
2 GeV π+
40 MeV γ

Sum ~45 GeV





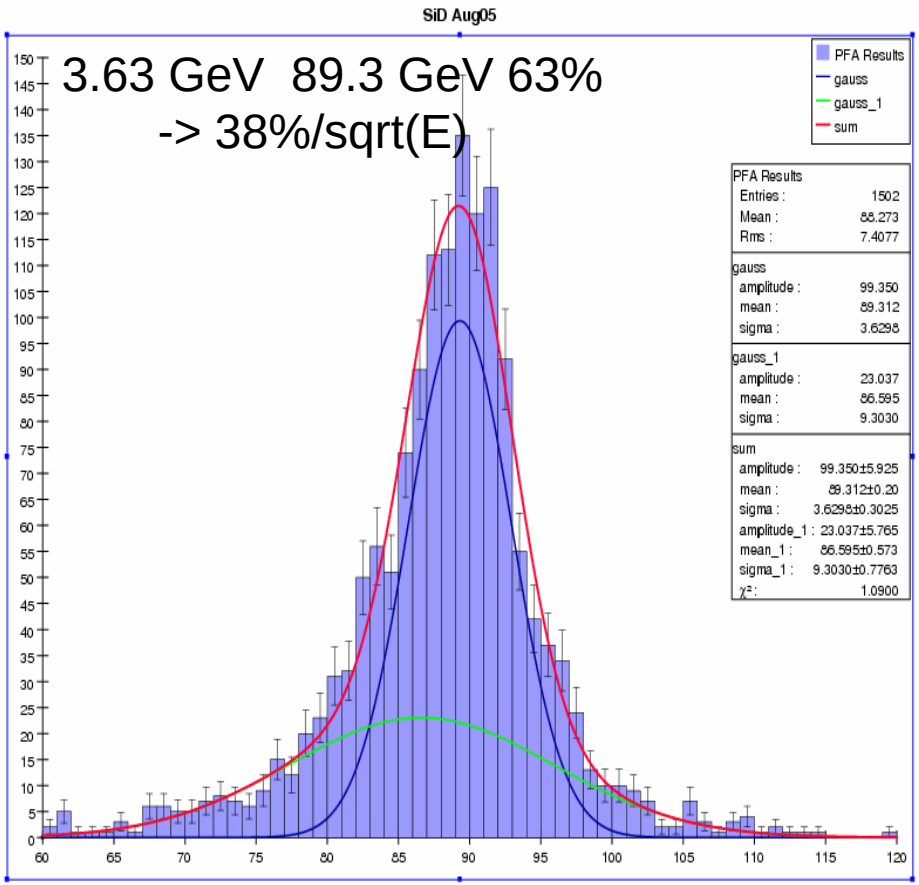


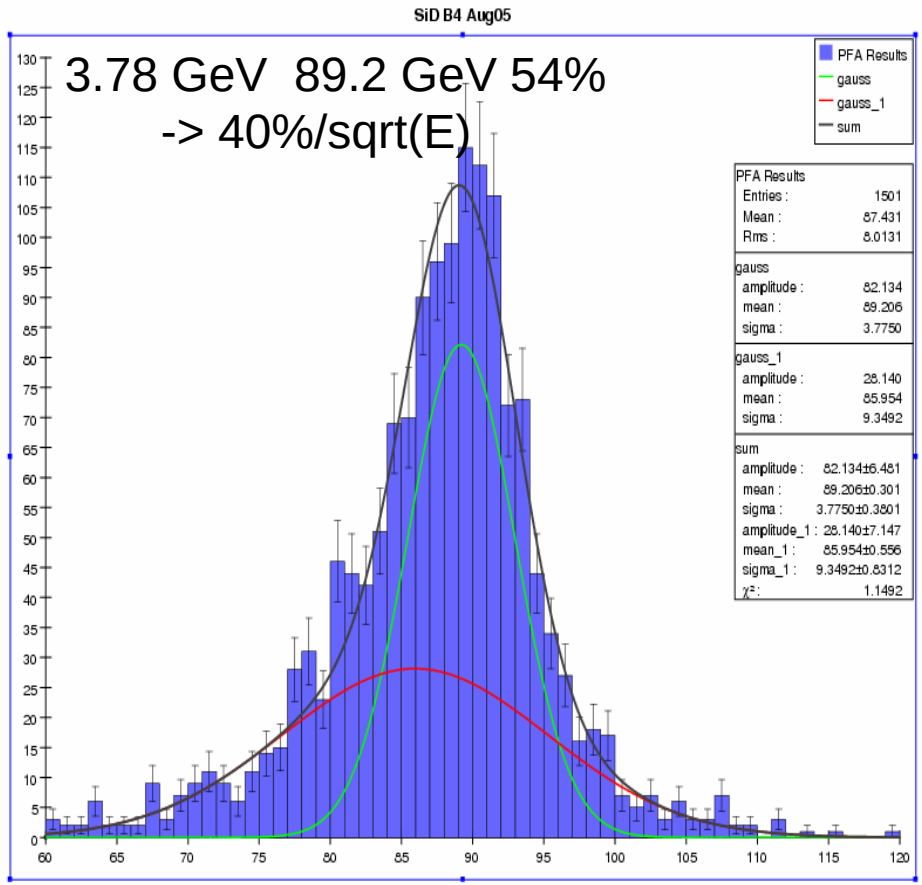


Resulting contribution from confusion term : sqrt(3.67**2-2.65**2-2.05**2) = 1.5 GeV
-> smaller than algorithm contributions

Detector Comparisons with PFAs

Vary B-field





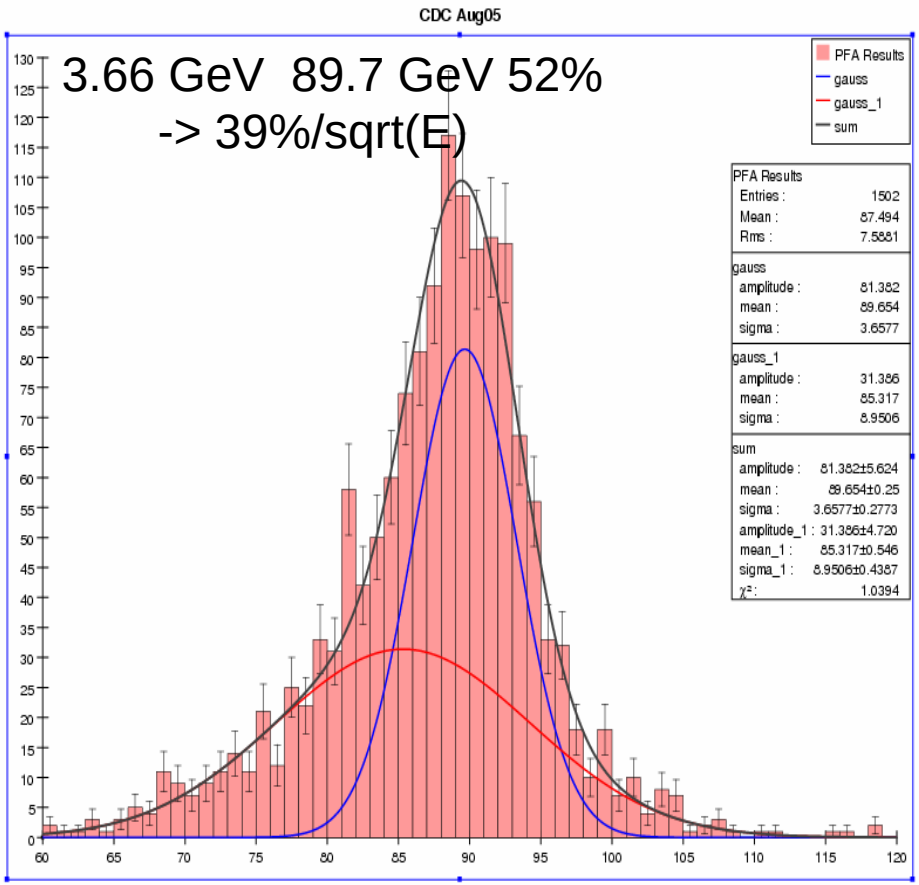
SiD SS/RPC - 5 T field

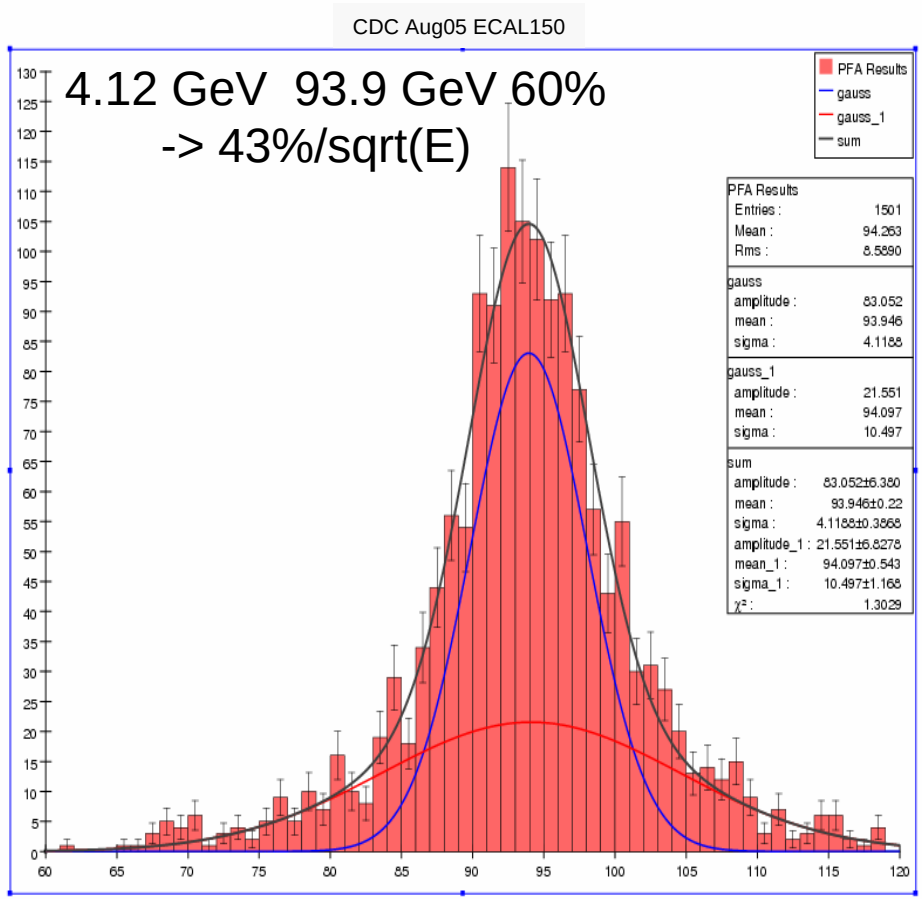
SiD SS/RPC - 4 T field

-> Somewhat worse performance in smaller field

Detector Comparisons with PFAs

Vary CAL inner radius





CDC W/Scin – CAL IR ~ 125 cm

CDC W/Scin – CAL IR ~ 150 cm

-> better performance at larger R (more events in central peak)

PFA Building Blocks

SLAC SLIC package is ideally suited for PFA development and detector optimization

-> Physics process and single particle generation

-> Compact description of detector geometries

-> Analysis package including event display

Tools for detector characterization, comparison analyses, etc.

-> sampling fractions for calorimeters

-> angular corrections to sfs

-> cluster algorithm comparison code

-> perfect PFA calculators

-> track extrapolation codes

-> DigiSim package – detector response, thresholds, timing, noise, etc.

PFA Building Blocks (cont.)

Cluster Algorithms :

- -> Fixed Cone
- -> Nearest-Neighbor (proj and non-proj)
- -> Cheater
- -> Minimal Spanning Tree
- -> Density-Weighted (2 varieties)
- -> Directed Tree
- -> others?

Usefullness measures :

- -> org.lcsim + LCIO
- -> comparison to other cluster algorithms (compatible with cluster comparison code?)
- -> fits into PFA template (later)?
- -> documented studies of performances

PFA Building Blocks (cont.)

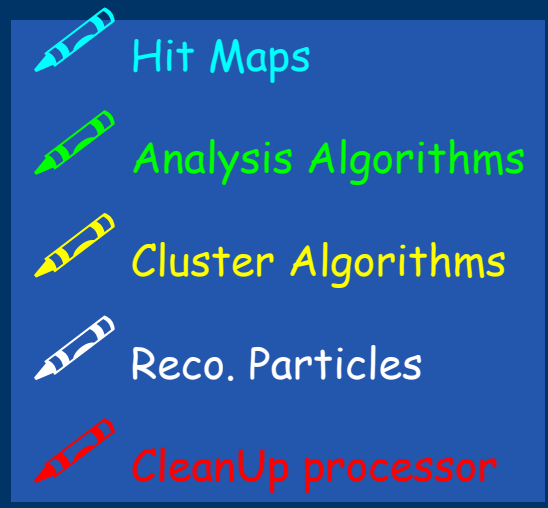
Analysis Algorithms :

- -> Mip Finders (several varieties)
- -> H-Matrix
- -> Cluster IDs (several varieties including Neural Net)
- -> Track/CAL object association
- -> Distance-based analyses

Usefullness measures :

- -> org.lcsim + LCIO
- -> comparison to other algorithms where applicable
- -> fits into PFA template (later)?
- -> documented studies of performances

Optimized PFA using PFA Template



Simulated EMCAL, HCAL Hits

DigiSim (NIU) X-talk, Thresholds, Timing, etc.

EMCAL, HCAL HitMaps

Track-Mip Match Algorithm (ANL)

Modified EMCAL, HCAL HitMaps

MST Cluster Algorithm (Iowa)

H-Matrix algorithm (SLAC, Kansas) -> Photons

Modified EMCAL, HCAL HitMaps

Nearest-Neighbor Cluster Algorithm (SLAC, NIU)

Track-Shower Match Algorithm (ANL) -> Charged Hadrons

Modified EMCAL, HCAL HitMaps

Density-weighted Cluster Algorithm (NIU, ANL)

Neutral ID Algorithm (SLAC) -> Neutral hadrons

Modified EMCAL, HCAL HitMaps

Post Hit/Cluster ID (leftover hits?)

Tracks, Photons, Neutrals to jet algorithm

Summary

In their present state, PFAs can be :

- Made modular to incorporate multiple cluster/analysis algorithms
- Used to optimize detector models
- Tuned to optimize detector performance

At this workshop :

1) Agree on standard PFA template in JAS3 analysis
   - -> release template to CVS
   - -> provides shell for PFA development/construction
2) Adapt existing software to standard template
   - -> Nearest-Neighbor clusterer only one so far?
   - -> modify others here?
3) Document existing tools and algorithms that can be used in this form for analysis