Individual Particle Reconstruction

The PFA Approach to Detector Development for the ILC

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The PFA Approach

PFA Goal : *1 to 1 correspondence between measured detector objects and particle 4-vectors -> best jet (parton) reconstruction (energy and momentum of parton)*

-> combines tracking and 3-D imaging calorimetry :

- good tracking for charged particles (~60% of jet E)
  -> σ_p (tracking) <<< σ_E for photons or hadrons in CAL
- good EM Calorimetry for photon measurement (~25% of jet E)
  -> σ_E for photons < σ_E for neutral hadrons
  -> dense absorber for optimal longitudinal separation of photon/hadron showers
- good separation of neutral and charged showers in E/HCAL
  -> CAL objects == particles
  -> 1 particle : 1 object -> small CAL cells -> Digital HCAL?
- adequate E resolution for neutrals in HCAL (~10% of jet E)
  -> σ_E < minimum mass difference, e.g. $M_Z - M_W$
  -> still largest contribution to jet E resolution

Track-first Extrapolation PFA

ANL, SLAC, Kansas

1st step – Track-linked mip segments (ANL)

-> find mip hits on extrapolated tracks, determine layer of first interaction based solely on cell hit density (no clustering of hits, no energy measurement)

2nd step - Photon Finder (SLAC, Kansas)

-> use analytic longitudinal H-matrix fit to layer E profile with ECAL clusters as input (any cluster algorithm)

3rd step – Track-linked EM and HAD clusters (ANL, SLAC)

-> substitute for Cal objects (mips + ECAL shower clusters + HCAL shower clusters), reconstruct linked mip segments + clusters loose NN clusterer) iterated in E/p

-> Analog or digital techniques in HCAL

4th step – Neutral Finder algorithm (SLAC, ANL)

-> cluster (tighter NN clusterer) remaining CAL cells, merge, cut fragments

5th step – Jet algorithm

-> tracks + photons + neutral clusters used as input to jet algorithm

Modular PFA – a Collaborative Effort

Flexible, modular structure for PFA development based on input Hit Collections, Cluster algorithms, and Particle ID algorithms (ANL, SLAC, Iowa, NIU, Kansas)

Simulated EMCAL, HCAL Hits (SLAC)
- DigiSim (NIU) X-talk, Noise, Thresholds, Timing, etc.

EMCAL, HCAL Hit Collections
- Track-Mip Match Algorithm (ANL)

Modified EMCAL, HCAL Hit Collections
- MST Cluster Algorithm (Iowa)
  - H-Matrix algorithm (SLAC, Kansas) -> *Photons*

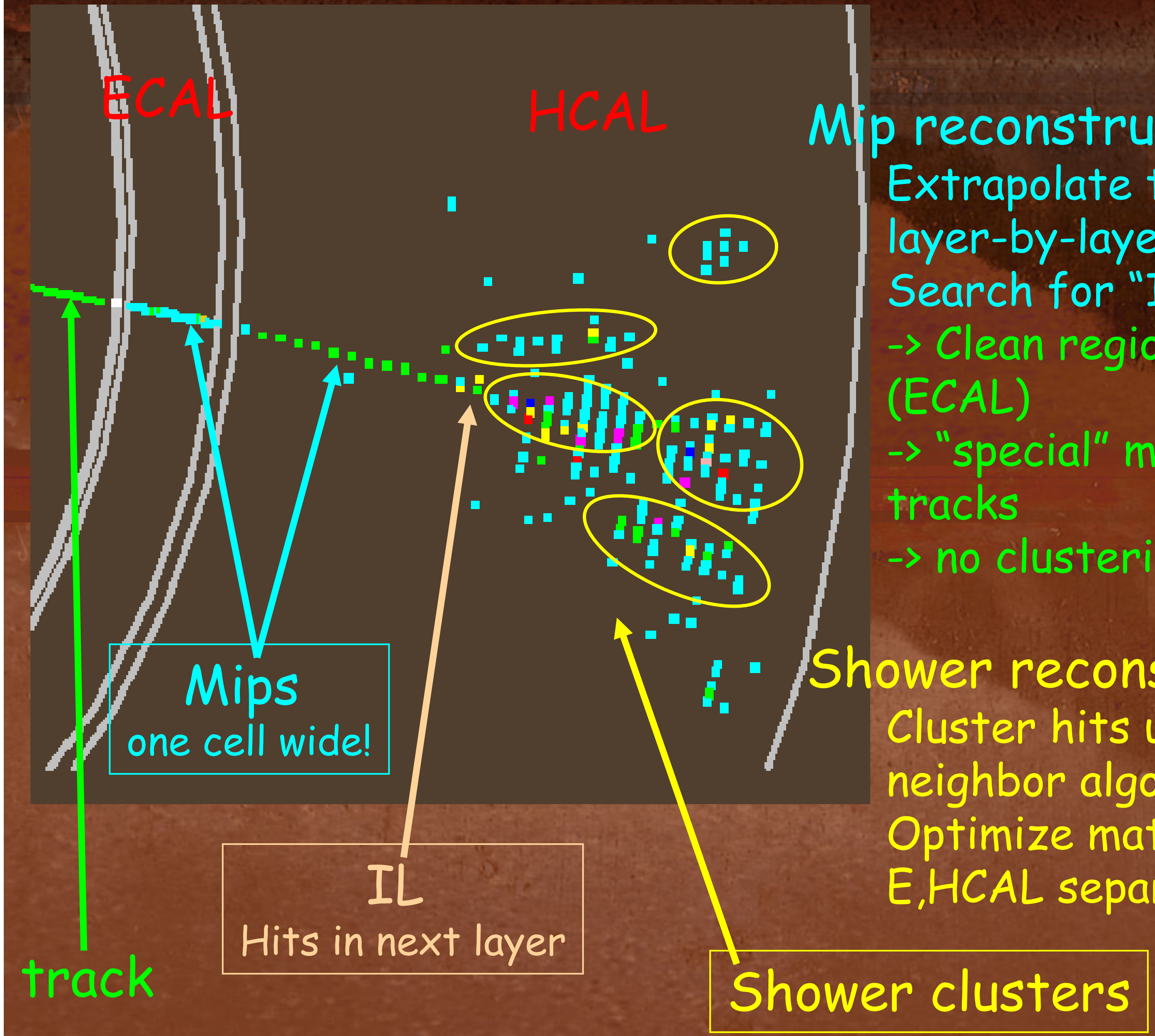
Modified EMCAL, HCAL Hit Collections
- Nearest-Neighbor Cluster Algorithm (SLAC, NIU)
  - Track-Shower Match Algorithm (ANL) -> *Tracks*

Modified EMCAL, HCAL Hit Collections
- Nearest-Neighbor Cluster Algorithm (SLAC, NIU)
  - Neutral ID Algorithm (SLAC, ANL) -> *Neutral hadrons*

Modified EMCAL, HCAL Hit Collections
- Post Hit/Cluster ID (leftover hits?)

Tracks, Photons, Neutrals to jet algorithm

Track Extrapolation -> Shower reconstruction



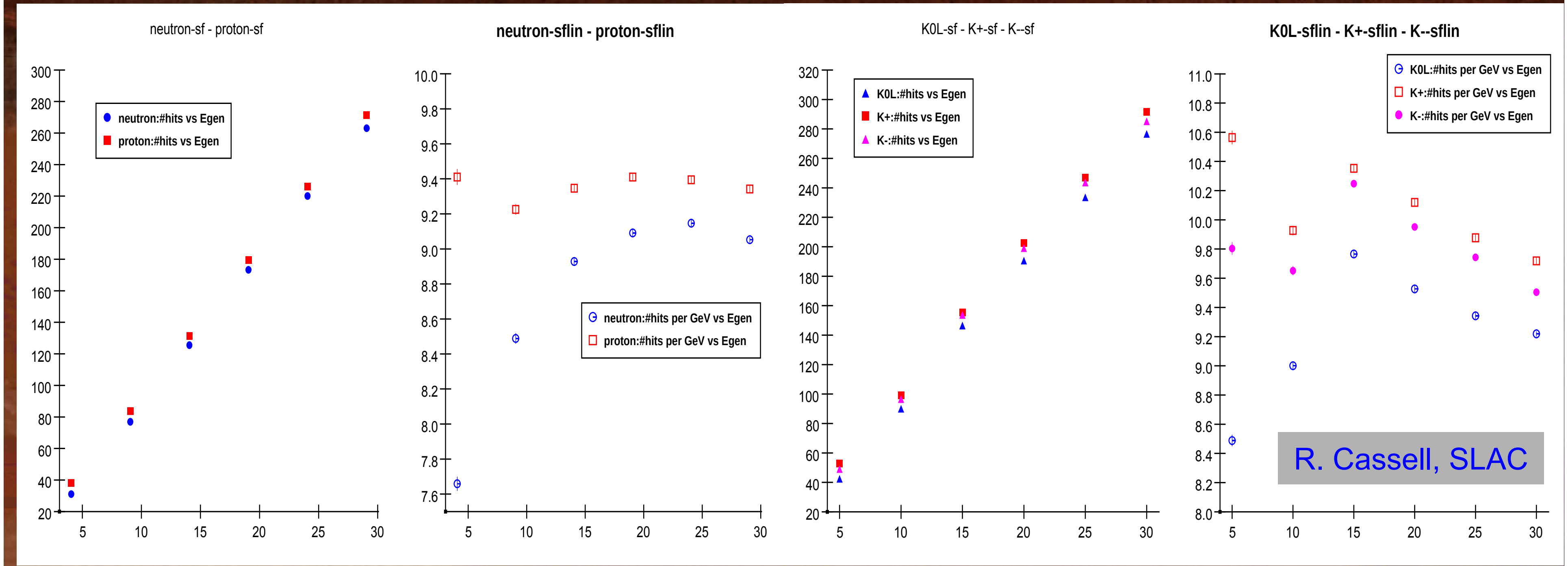
Mip reconstruction :

Extrapolate track through CAL layer-by-layer
Search for "Interaction Layer"
-> Clean region for photons (ECAL)
-> "special" mip hits matched to tracks
-> no clustering, no E info needed

Shower reconstruction :

Cluster hits using nearest-neighbor algorithm
Optimize matching, iterating in E,HCAL separately (E/p test)

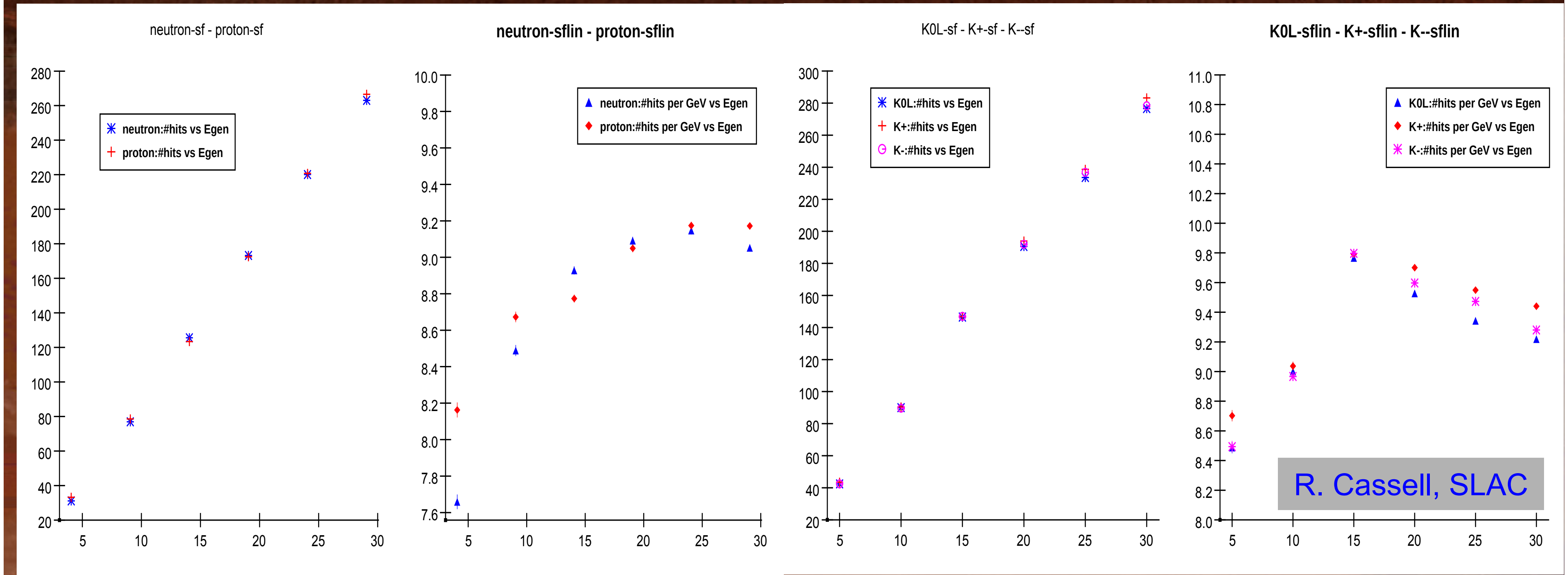
Comparison of Charged/Neutral Hadron Hits



-> linearity of response
-> charged hadrons generate slightly more hits than neutral
-> calibration (#hits/GeV) different, especially at low energy

Mips before showering – charged hadrons lose ~25 MeV per layer in SSRPC isolated detector. (Normal incidence)
Try to correct by weighting N hits (N = # of layers traversed before interacting) by .25

Charged(Mip correction)/Neutral Hadron Hits



-> account for mip trace properly
-> after weighting, #hits charged ~ #hits neutral
-> shower calibration (#hits/GeV) now very similar

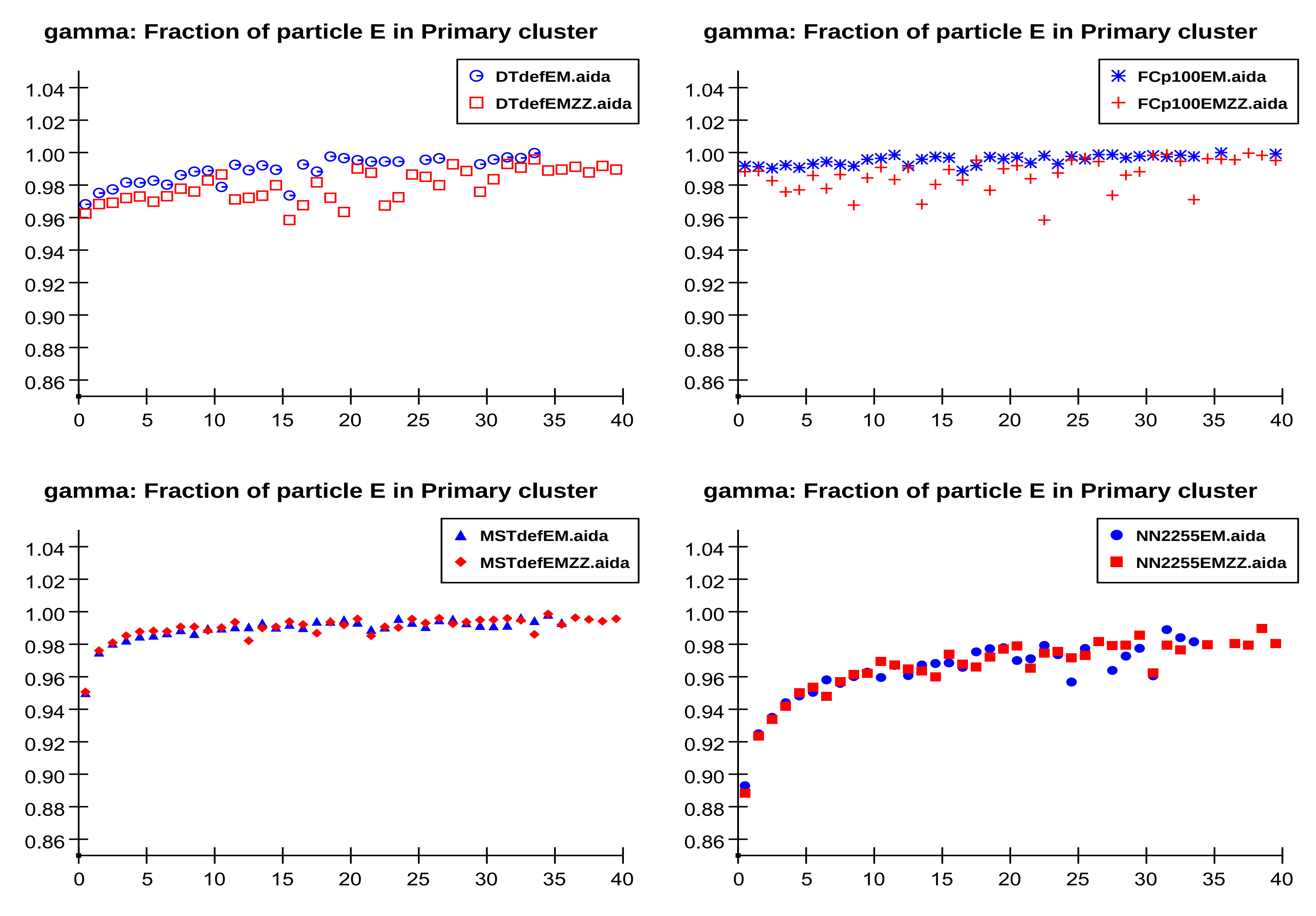
In PFA, find mips first attached to extrapolated tracks, then can cluster remaining hits with same calibration (#hits/GeV) for charged and neutral hadrons*

* remember, this is simulation!

Photon Finding - Clustering

R. Cassell, SLAC

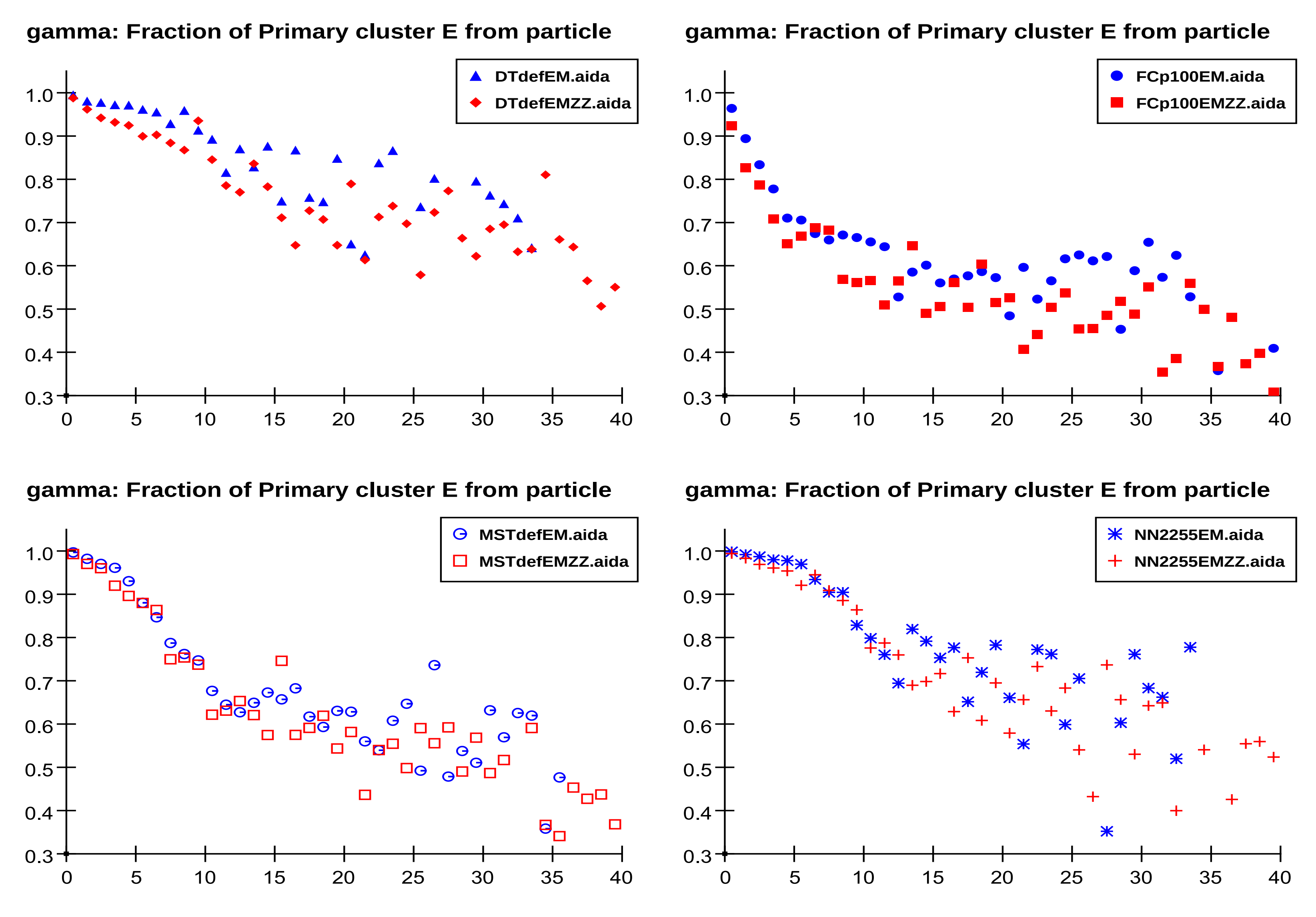
Energy efficiency vs generated energy



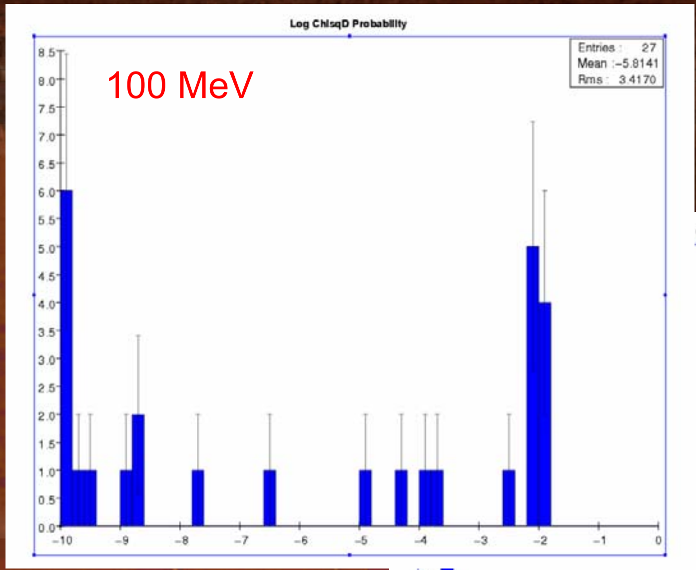
Photon Finding - Clustering

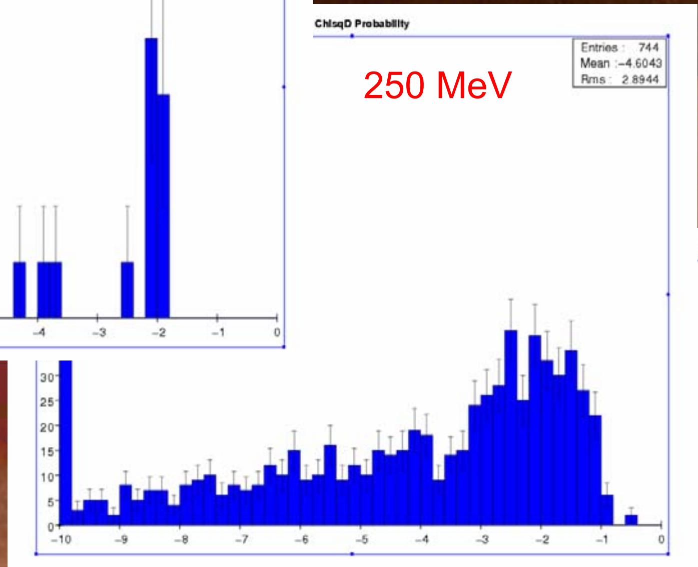
R. Cassell, SLAC

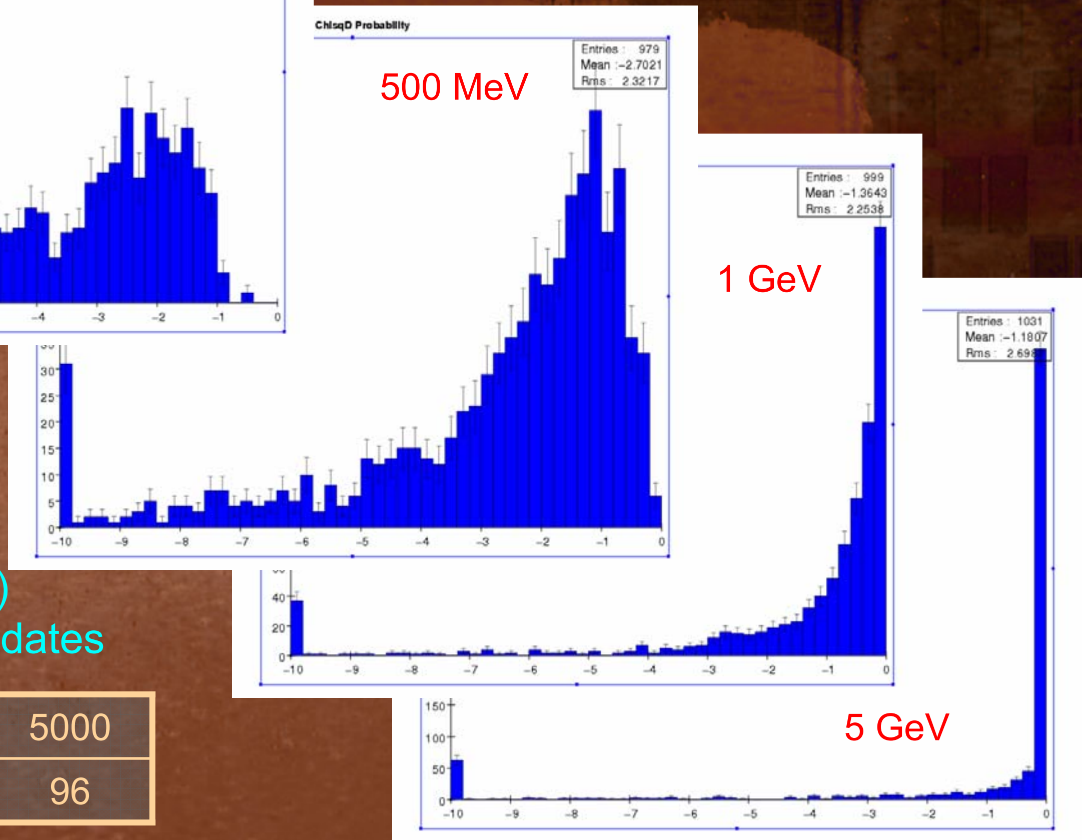
Energy purity vs generated energy



Photon Clusters - (longitudinal) H-Matrix







Average number of hit cells in photons passing H-Matrix cut

E (MeV)	100	250	500	1000	5000
<# hits>	9*	12*	20	34	116

* min of 8 cells required

1000 Photons - W/Si ECAL (4mm X 4mm)
Nearest-Neighbor Cluster Algorithm candidates

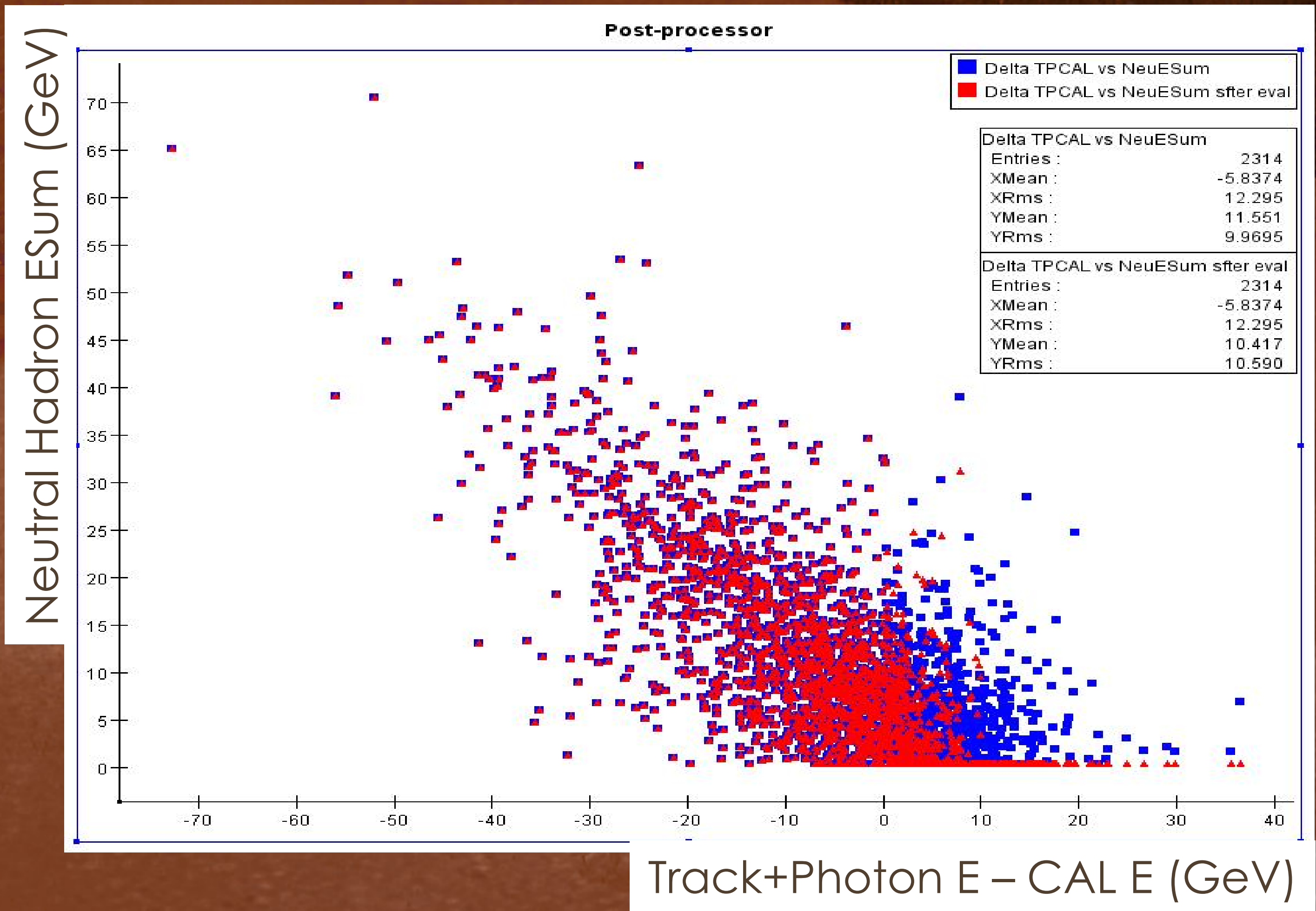
E (MeV)	100	250	500	1000	5000
Effic. (%)	2	66	94	96	96

Neutral Hadron Post-processor

Use total CAL energy estimate to reduce neutral contribution by comparing track P + photon E to total CAL E (estimate)

-> further reduces double counting of track fragments

-> no cheating, but uses total energy, not jets – a sanity check

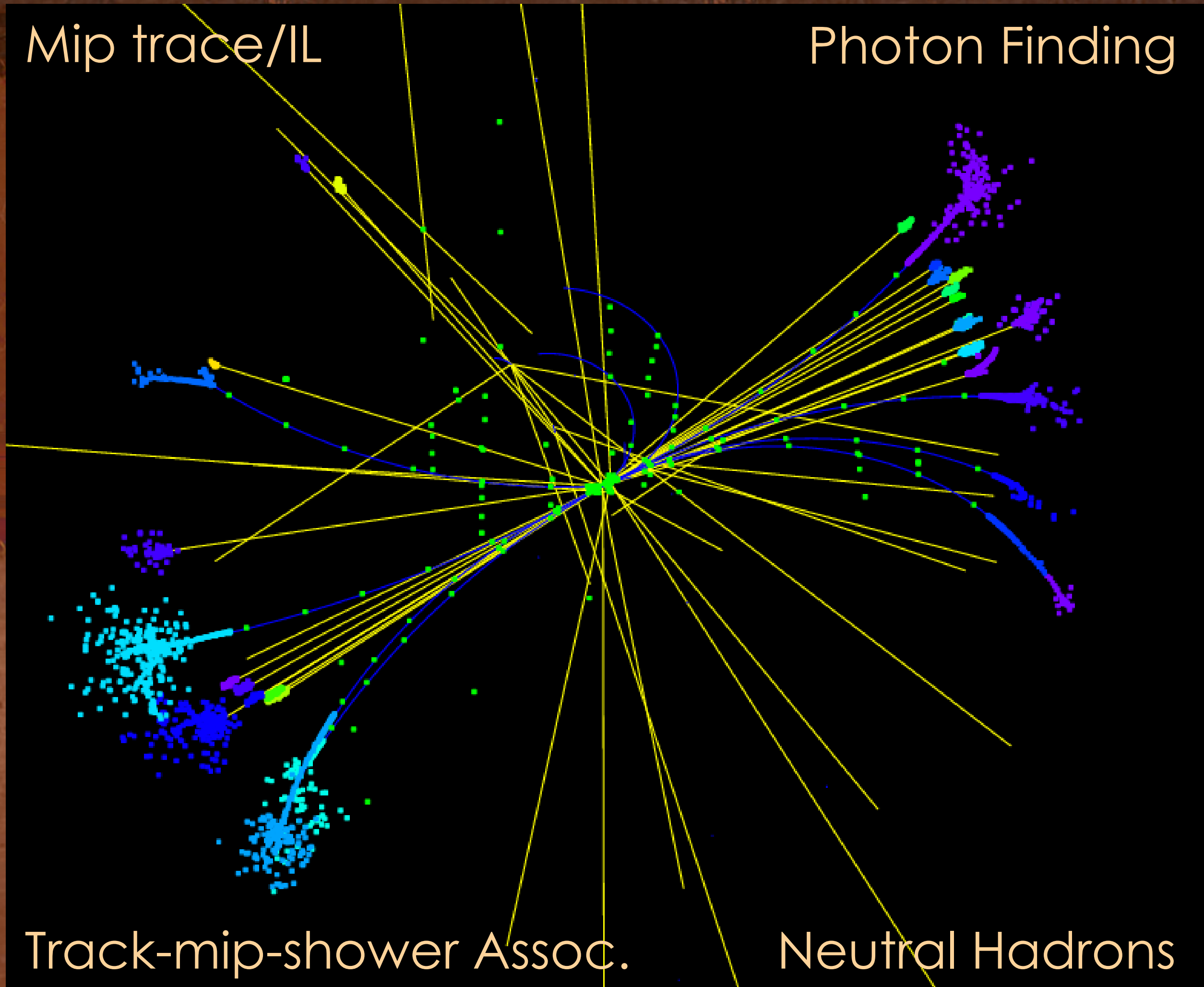


PFA Demonstration

6.6 GeV γ
1.9 GeV γ
1.6 GeV γ
3.2 GeV γ
0.1 GeV γ
0.9 GeV γ
0.2 GeV γ
0.3 GeV γ
0.7 GeV γ

4.2 GeV K+
4.9 GeV p
6.9 GeV π-
3.2 GeV π-

8.3 GeV $\bar{n}$
2.5 GeV K_L^0



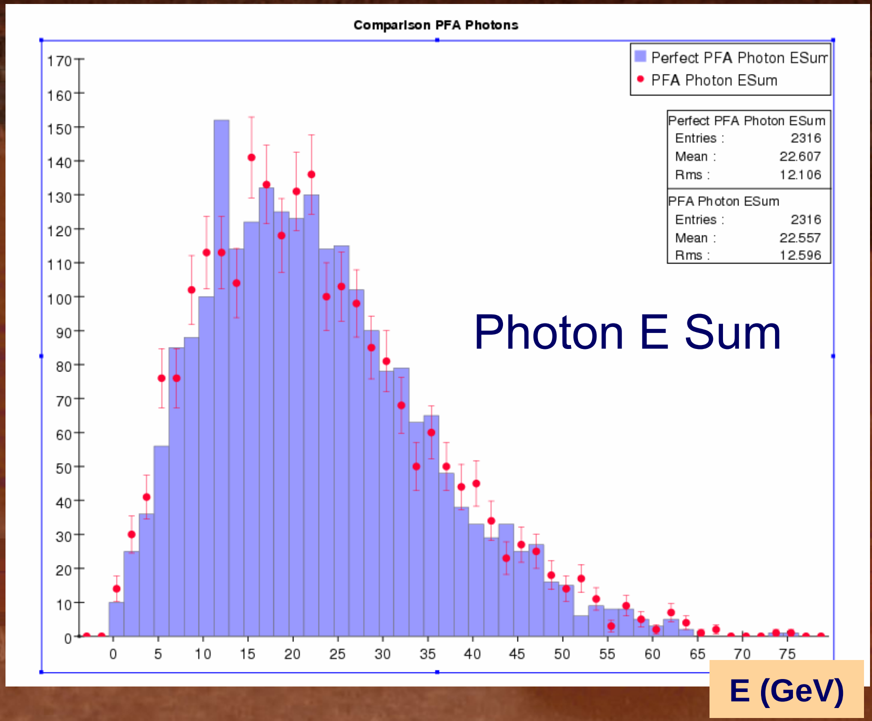
1.9 GeV γ
3.7 GeV γ
3.0 GeV γ
5.5 GeV γ
1.0 GeV γ
2.4 GeV γ
1.3 GeV γ
0.8 GeV γ
3.3 GeV γ
1.5 GeV γ

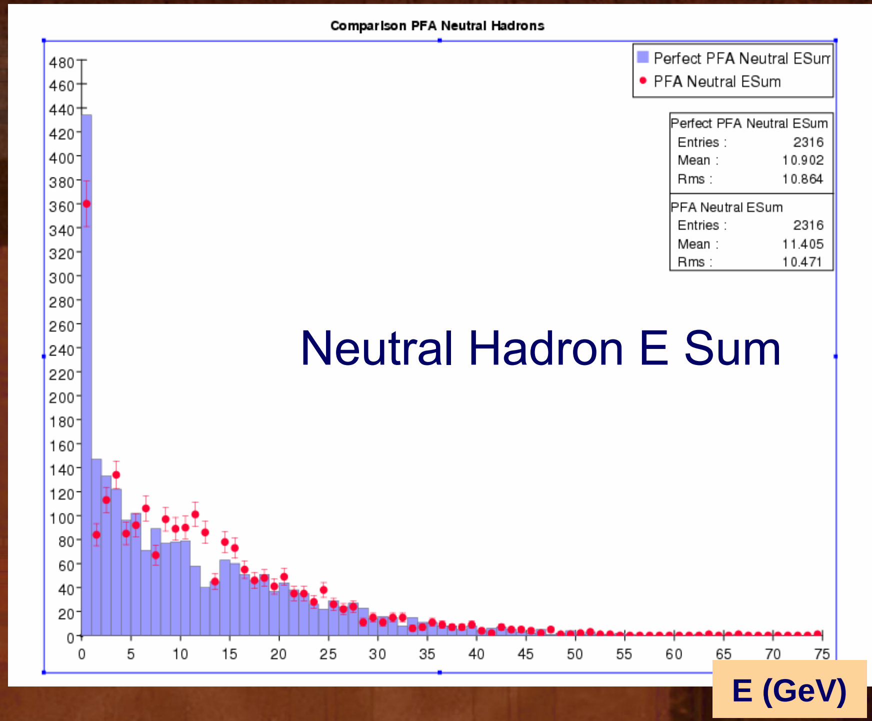
1.9 GeV π-
2.4 GeV π-
4.0 GeV π-
5.9 GeV π+

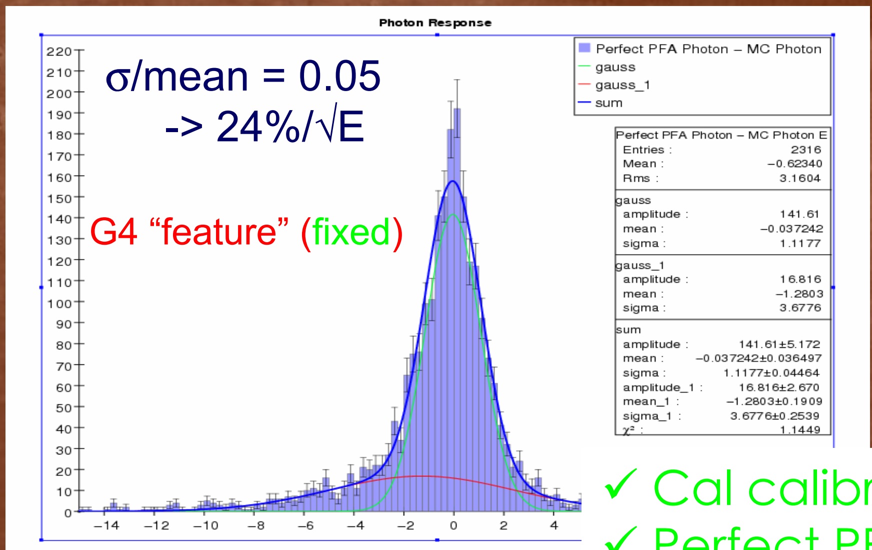
1.5 GeV $\bar{n}$
2.8 GeV n

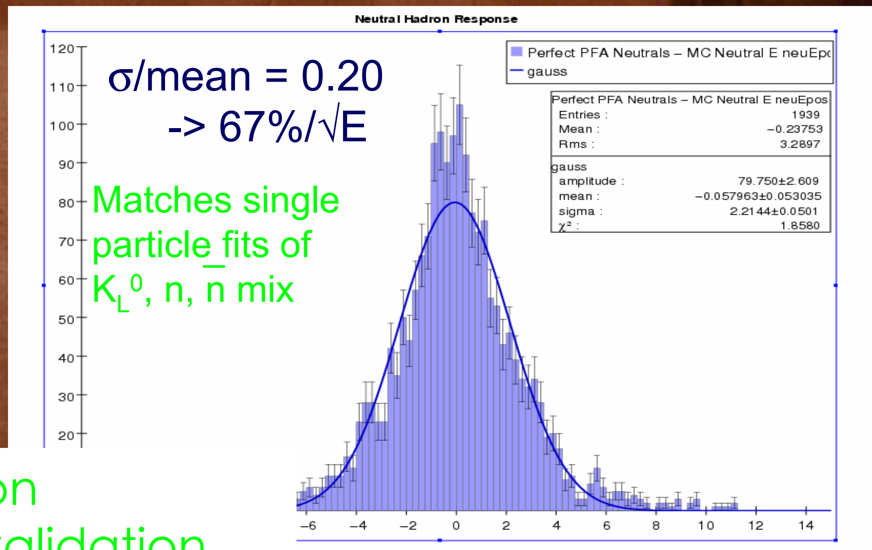
Overall Performance : PFA ~33%/√E central fit

PFA Module Comparisons



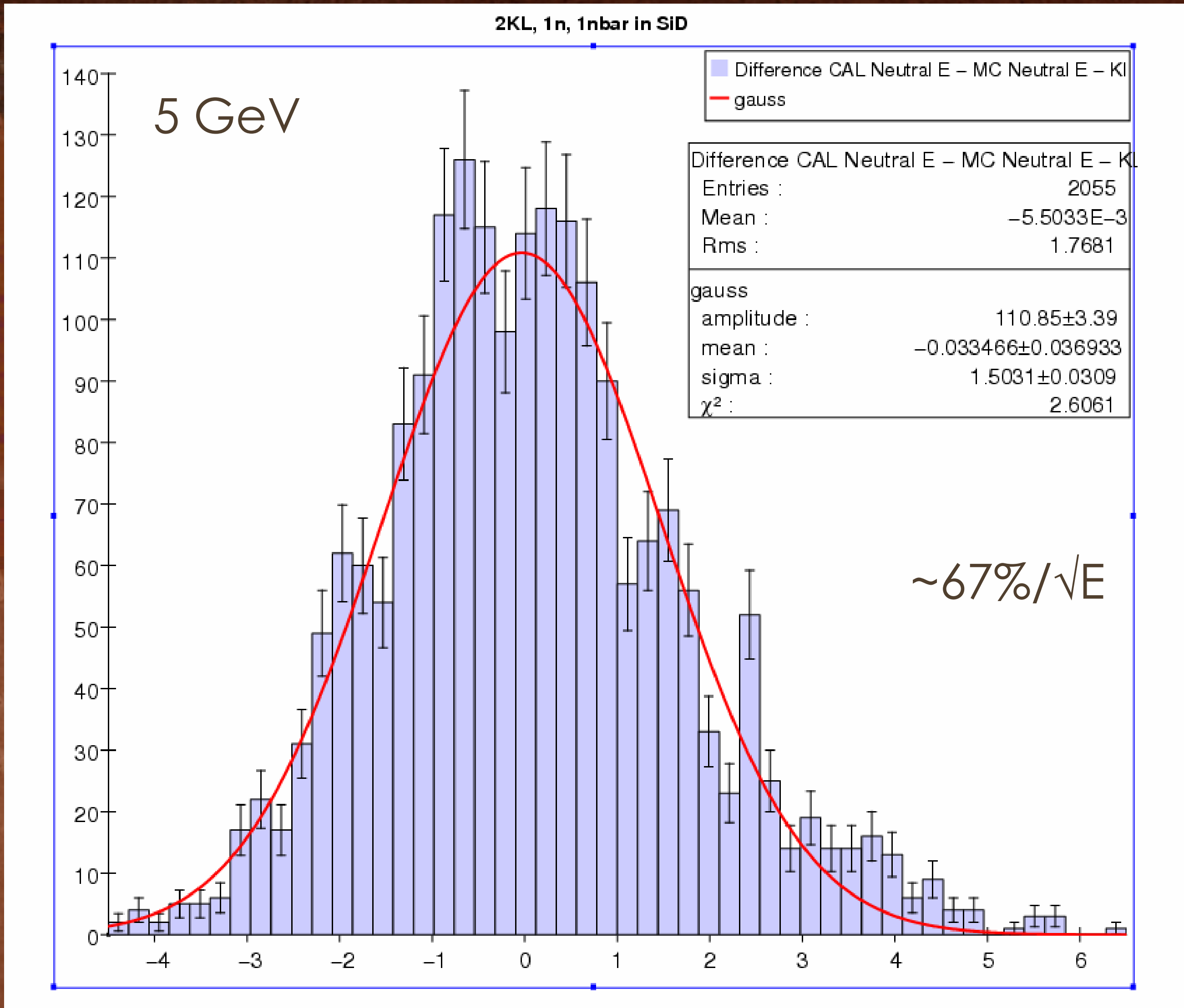






- ✓ Cal calibration
- ✓ Perfect PFA validation

Calibration Check

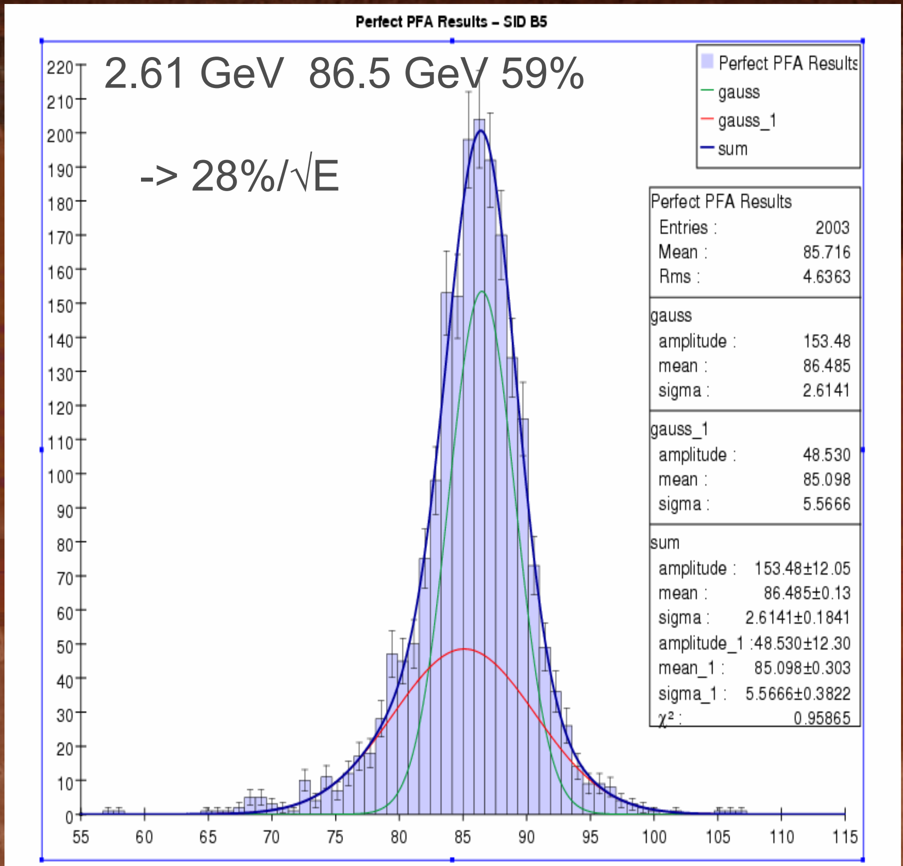


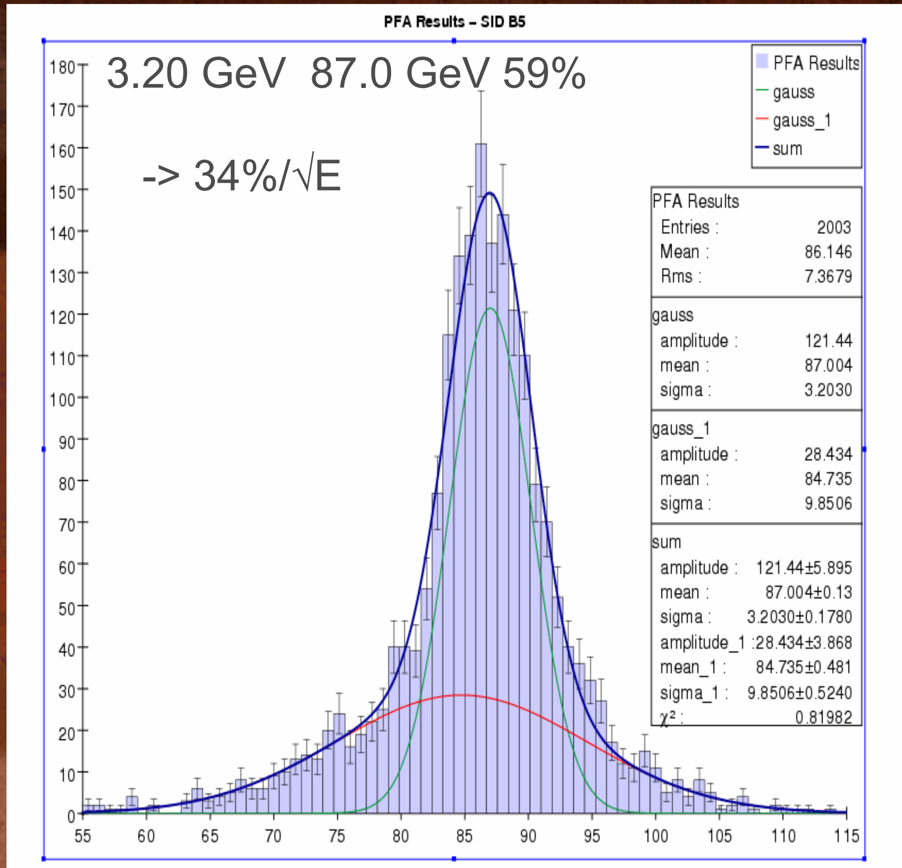
SFs :

ECAL = 0.0120
HCAL = 8.81 hits/GeV
offset = 4 hits
(4+nhits)/8.81 = E

e/neuh = 1.11 ECAL

PFA Results





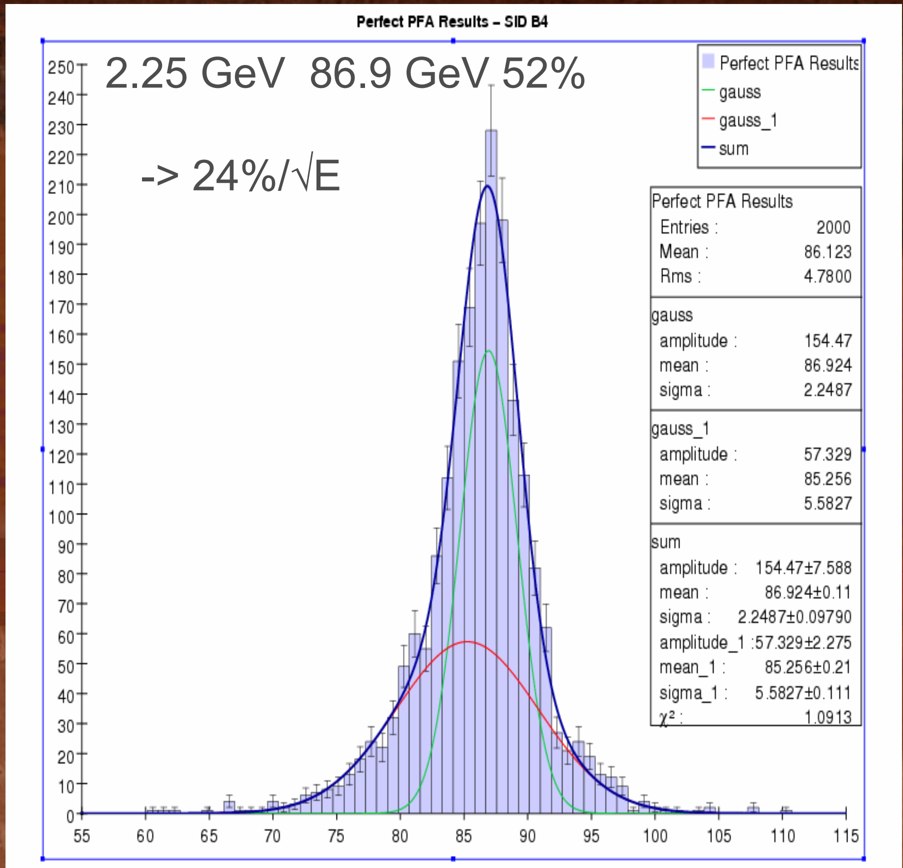
SiD Detector Model
Si Strip Tracker
W/Si ECAL, IR = 125 cm
  4mm X 4mm cells
SS/RPC Digital HCAL
  1cm X 1cm cells
5 T B field (CAL inside)

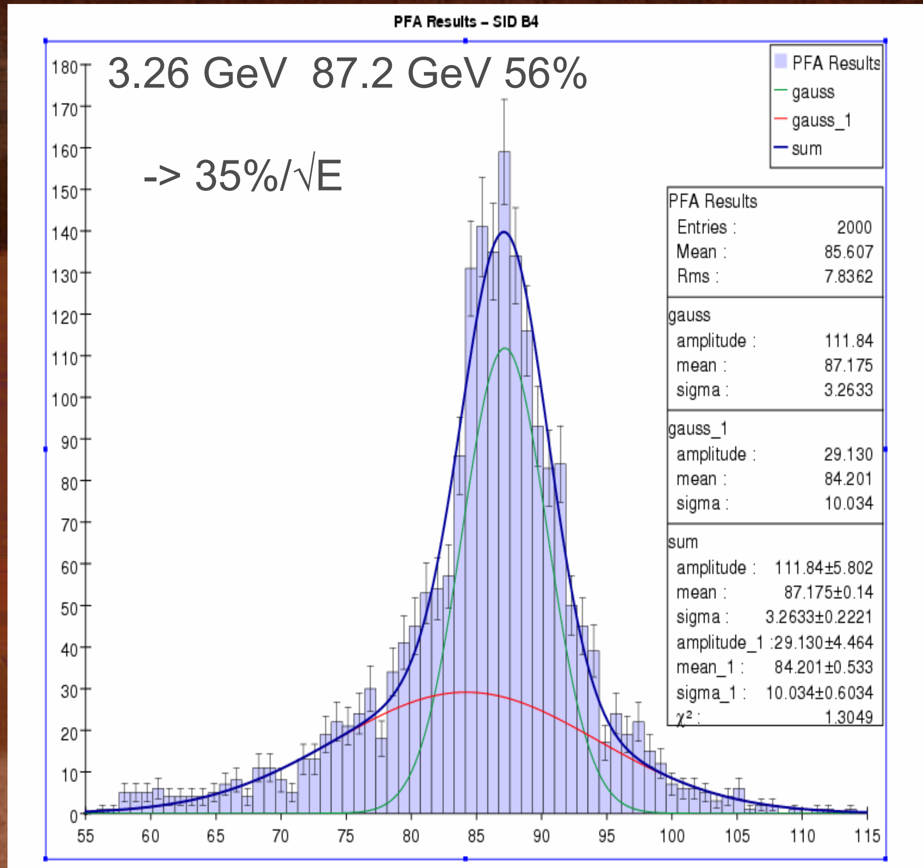
Average confusion contribution = 1.9 GeV
  < Neutral hadron resolution contribution of 2.2 GeV
-> PFA goal!*

* other 40% of events!

Detector Comparisons with PFAs

Vary B-field



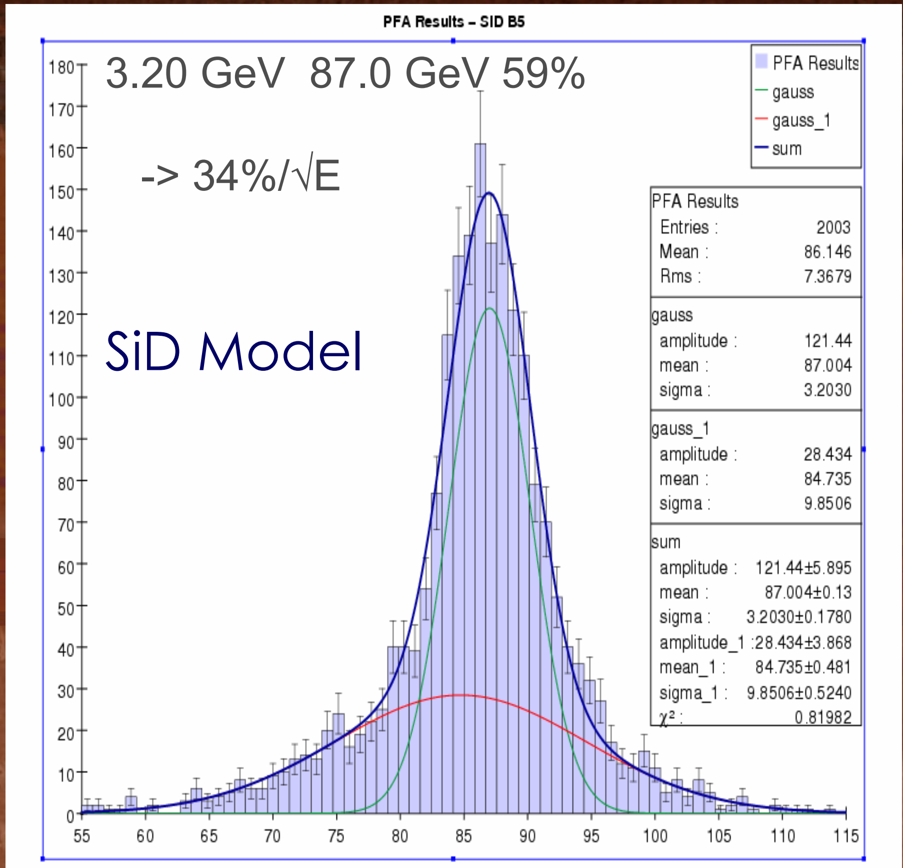


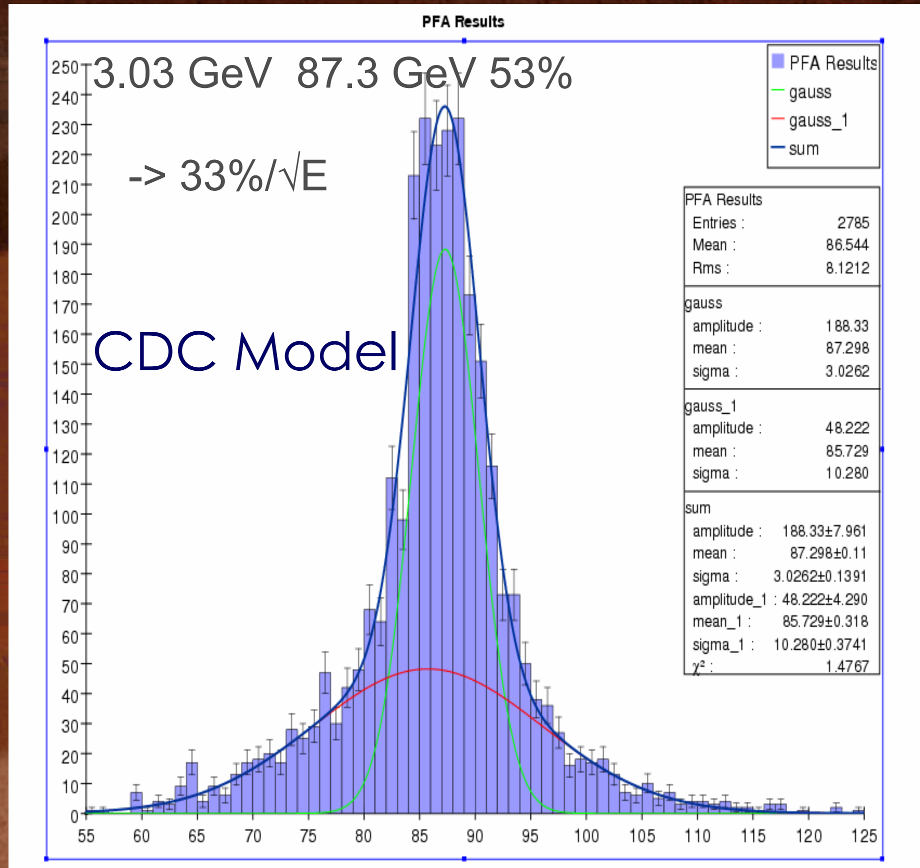
SiD SS/RPC - 5 T field
Perfect PFA σ = 2.6 GeV
PFA σ = 3.2 GeV
Average confusion = 1.9 GeV

SiD SS/RPC - 4 T field
Perfect PFA σ = 2.3 GeV
PFA σ = 3.3 GeV
Average confusion = 2.4 GeV

-> Better performance in larger B-field

Detector Optimized for PFA?





SiD -> CDC 150

- ECAL IR increased from 125 cm to 150 cm
- 6 layers of Si Strip tracking
- HCAL reduced by 22 cm (SS/RPC -> W/Scintillator)
- Magnet IR only 1 inch bigger!
- Improved PFA performance w/o increasing magnet bore

Detector models

- Calorimeters drive the whole detector design!
- Using Si-W as default electromagnetic calorimeter.
- Investigating several hadronic calorimeter designs

Absorbers	Readouts
Steel	RPC
Tungsten	Scintillator
Lead	GEM

- Varying inner radius of barrel, aspect ratio to endcap, strength of B Field, readout segmentation.
- For each detector model, set of generated events includes :
  - Single particles for calibration, testing algorithms (pions, photons, neutrons, Kaons, muons)
  - Physics events for testing PFAs (ZPole, 500 GeV CM dijet, multi-jet)

Summary

A modular approach to PFA development has been chosen which attempts to optimize the choice of cluster algorithms and analysis algorithms at each stage of the PFA :

- Common input (Hit Collection) at each stage of PFA
- Optimized analysis of hits including :
  - Individual hit associations
  - Cluster algorithms
  - Cluster ID algorithms
- Performance evaluation at each stage of PFA
- Common output (modified Hit Collection) at each stage of PFA

The present implementation is approaching PFA performance goal

-> $\sigma_{\text{confusion}} < \sigma_{\text{neutral hadrons}}$