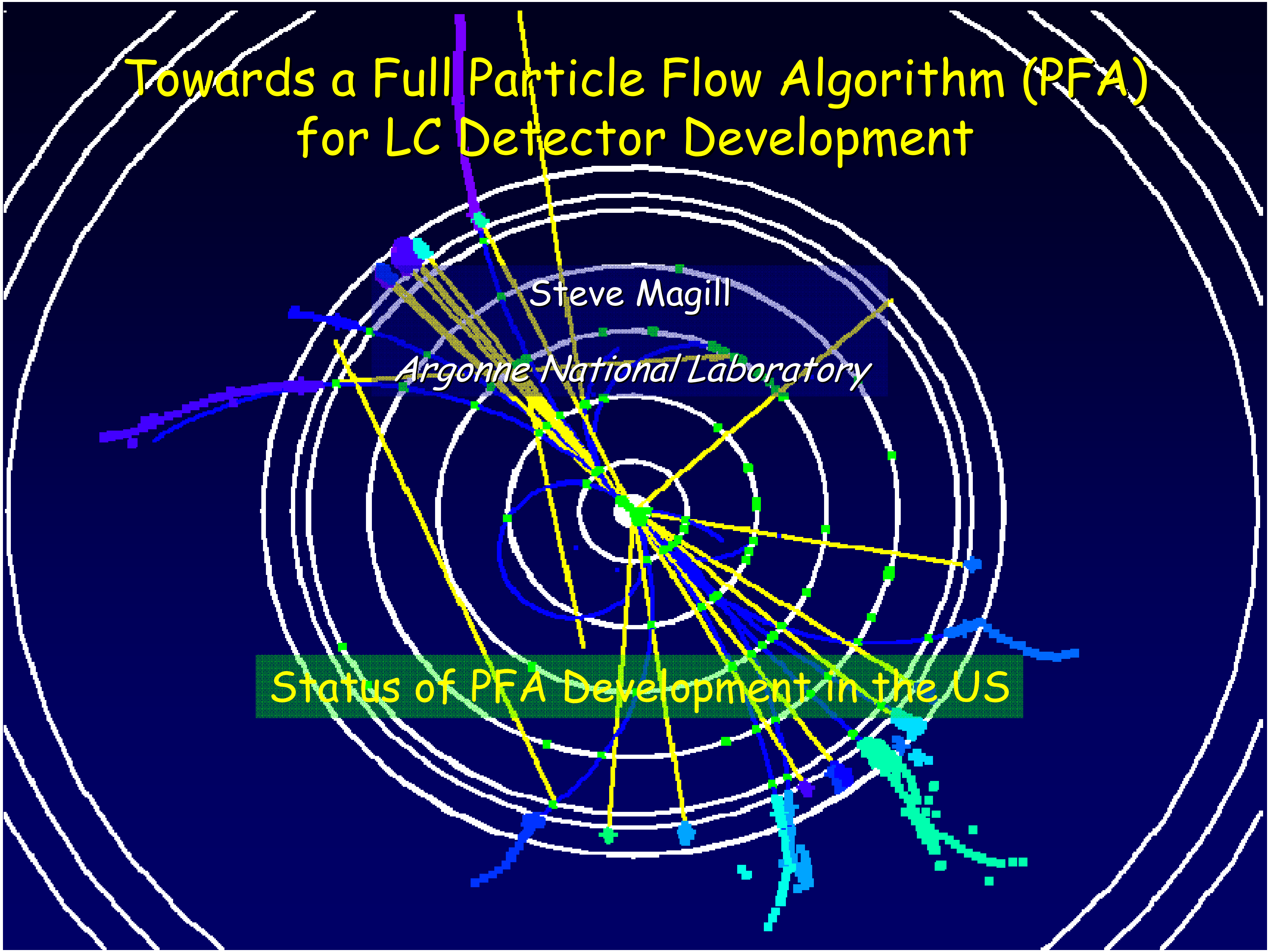
Towards a Full Particle Flow Algorithm (PFA) for LC Detector Development

Steve Magill

Argonne National Laboratory

Status of PFA Development in the US



from Vishnu Zutshi's talk at Bangalore :

Two Density-based Clustering Algorithms

L. Xia (ANL)

V. Zutshi (NIU)

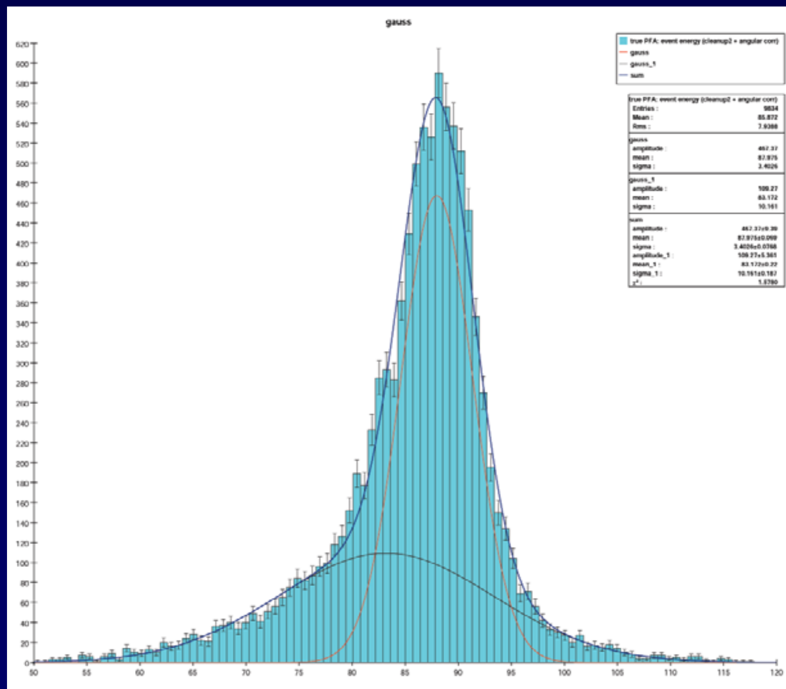
General Comments

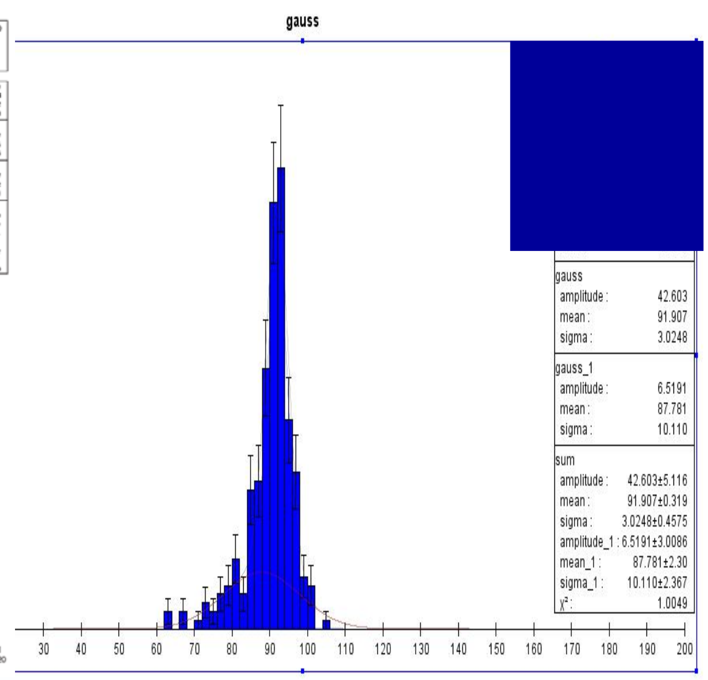
- Both are calorimeter first approaches

  clustering → track match → fragment....
- SiD geometry

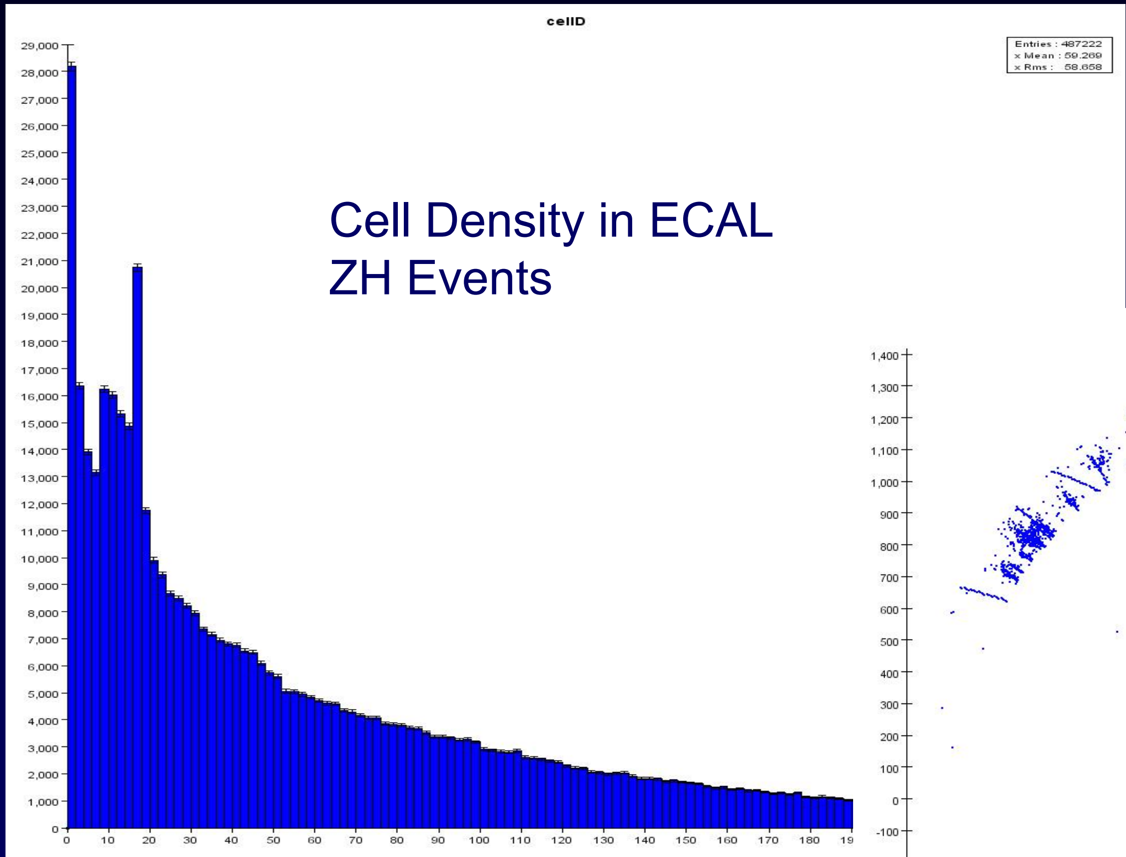
  Si-W ECAL, RPC or Scintillator HCAL

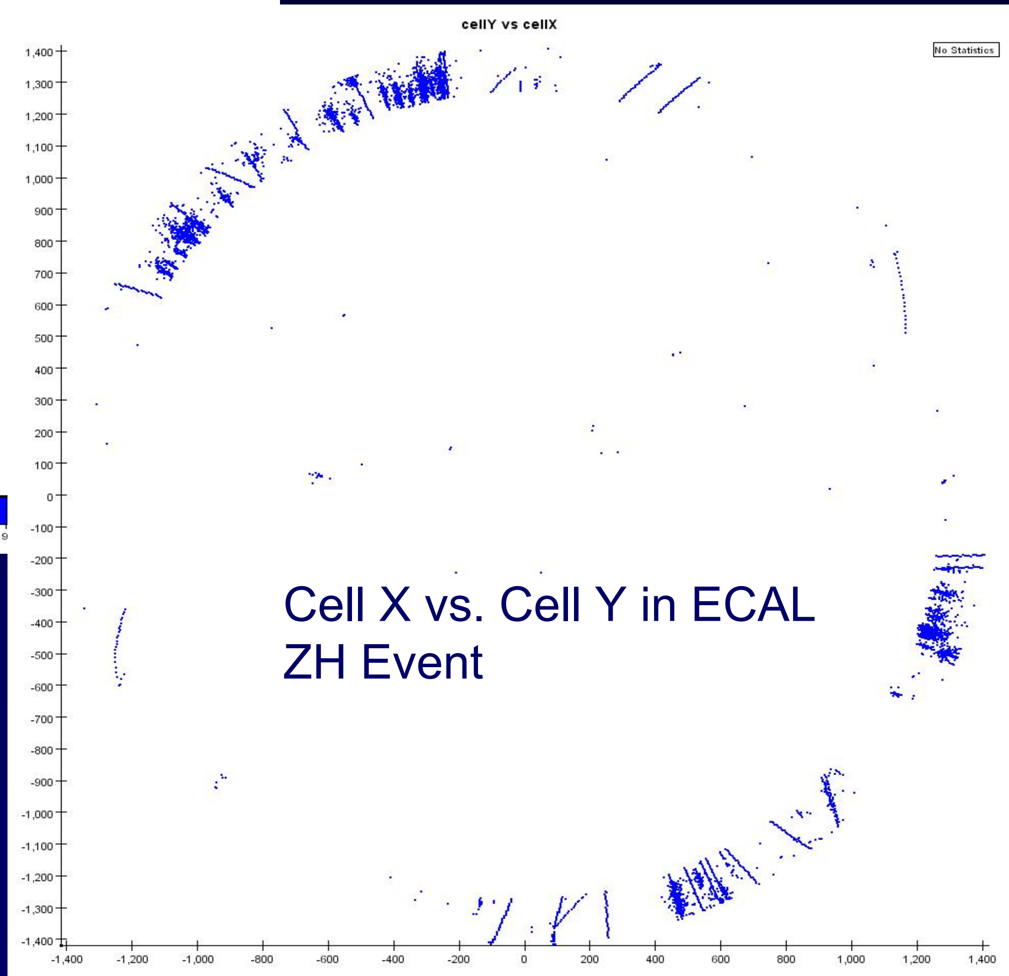
‘Cheating’ involved in some steps

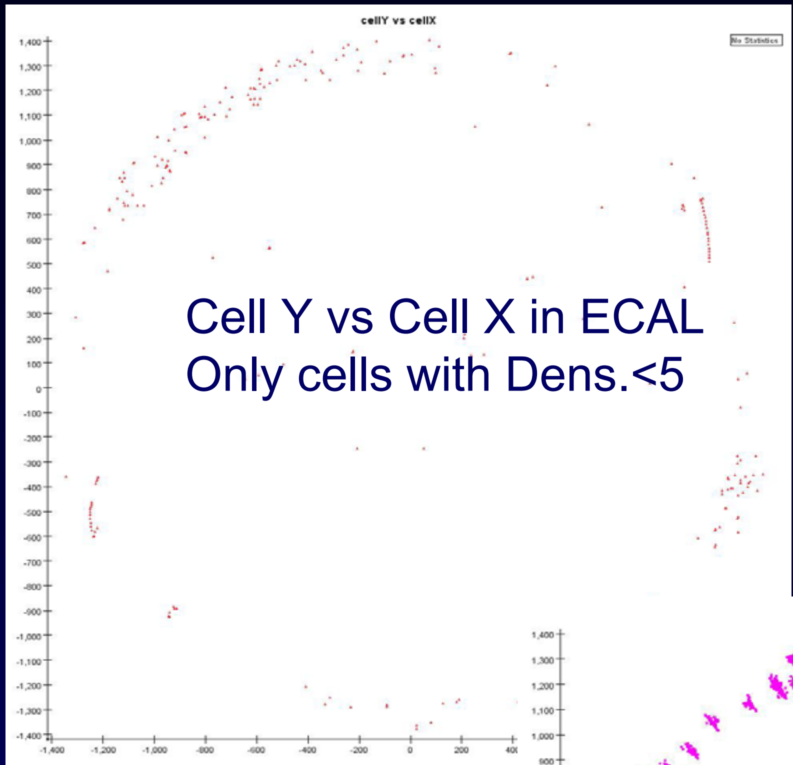


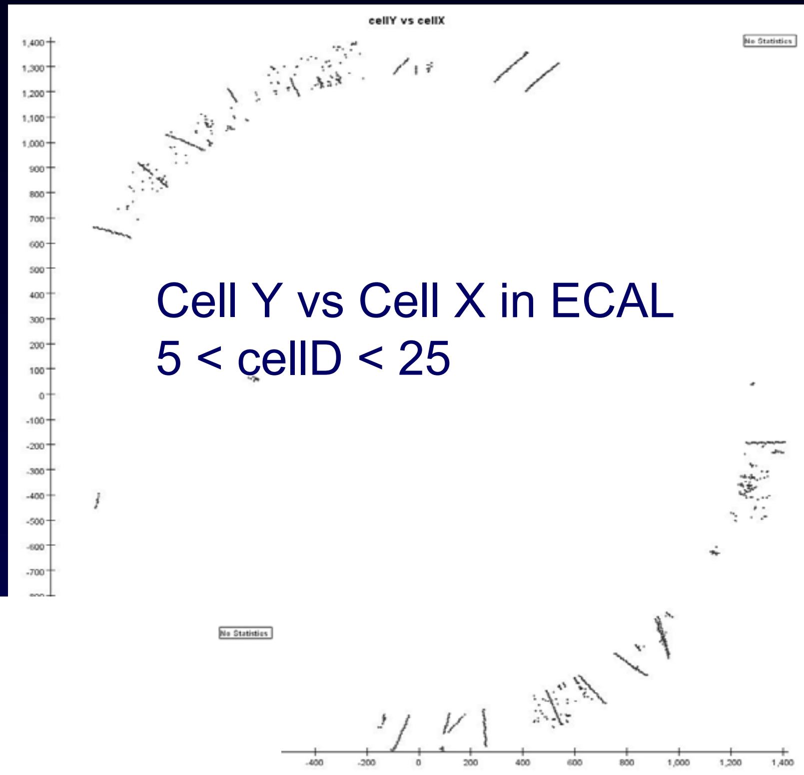


Density-Weighted Clustering

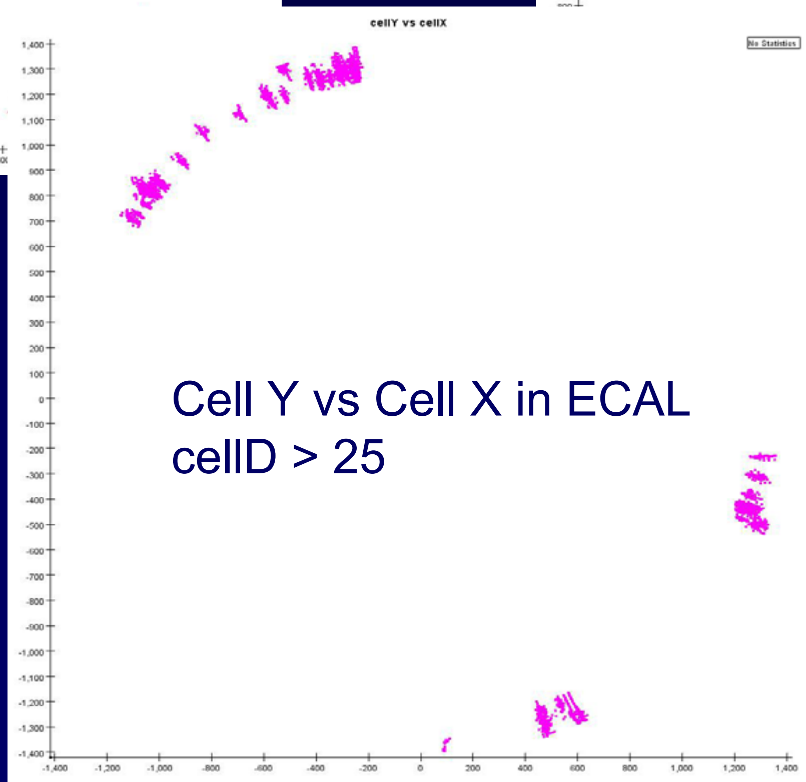








One-time clustering?



Optimal multi-pass clustering is better

Grad-based

Z-pole Events

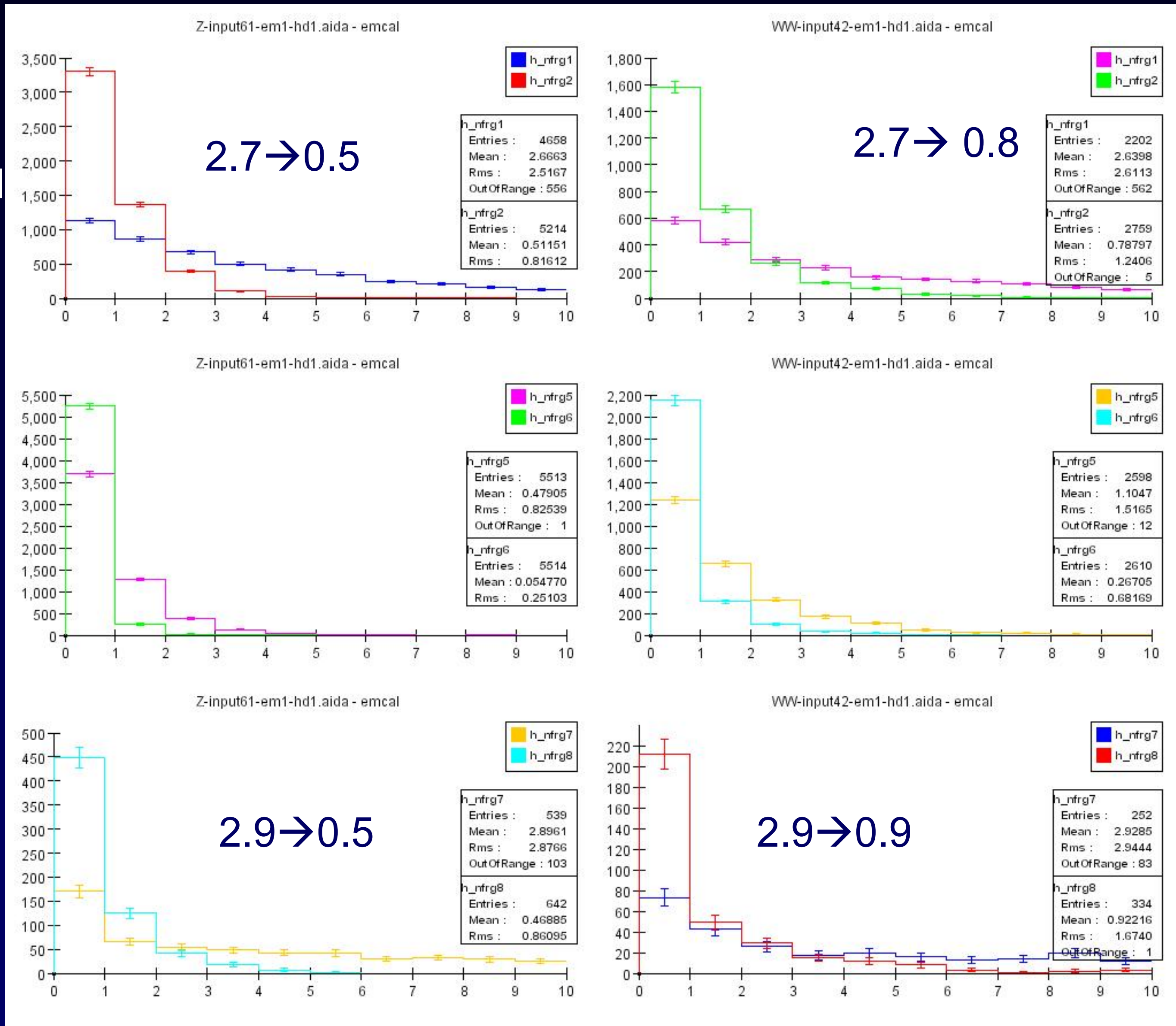
WW Events

Charged hadrons

Photons

Neutral hadrons

ECAL



No. of fragments w/ and w/o cut on fragment size

Grad-based

Z-pole Events

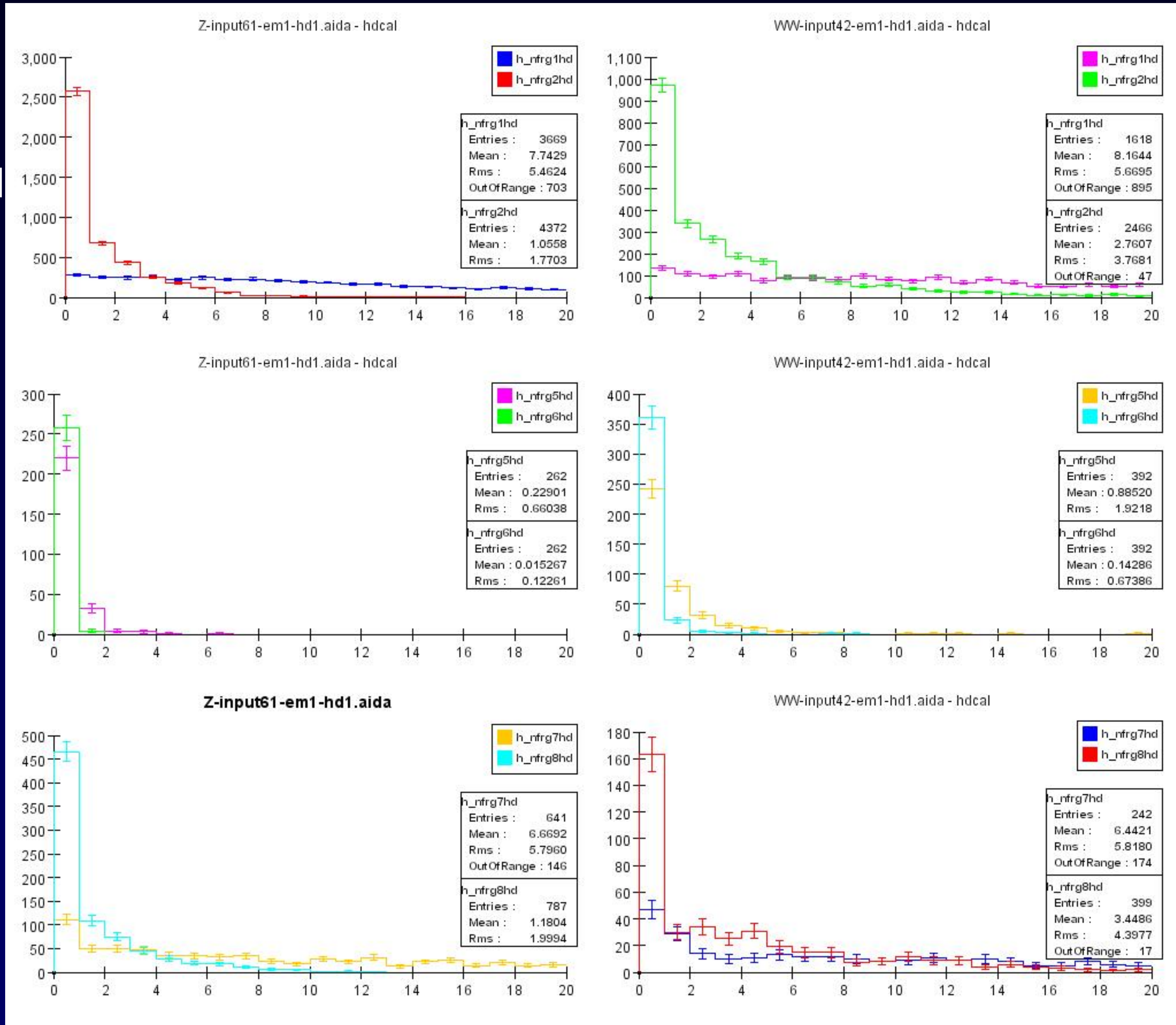
WW Events

Charged hadrons

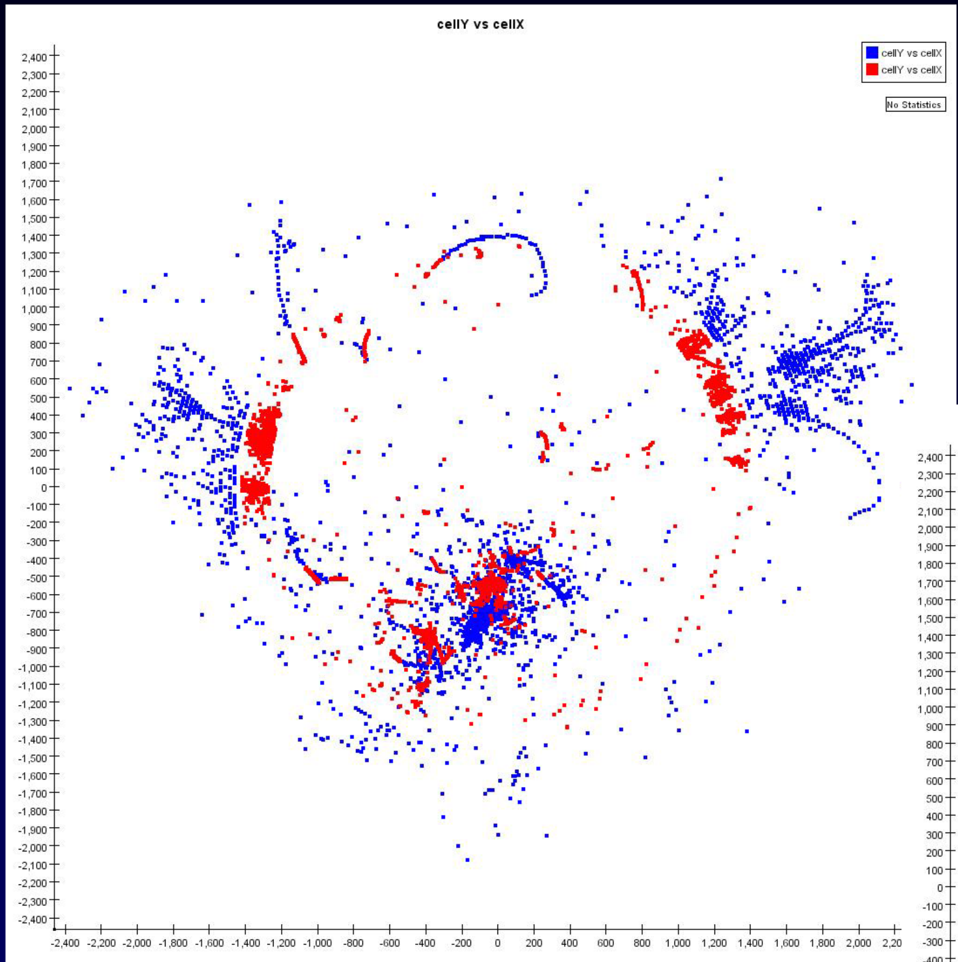
Photons

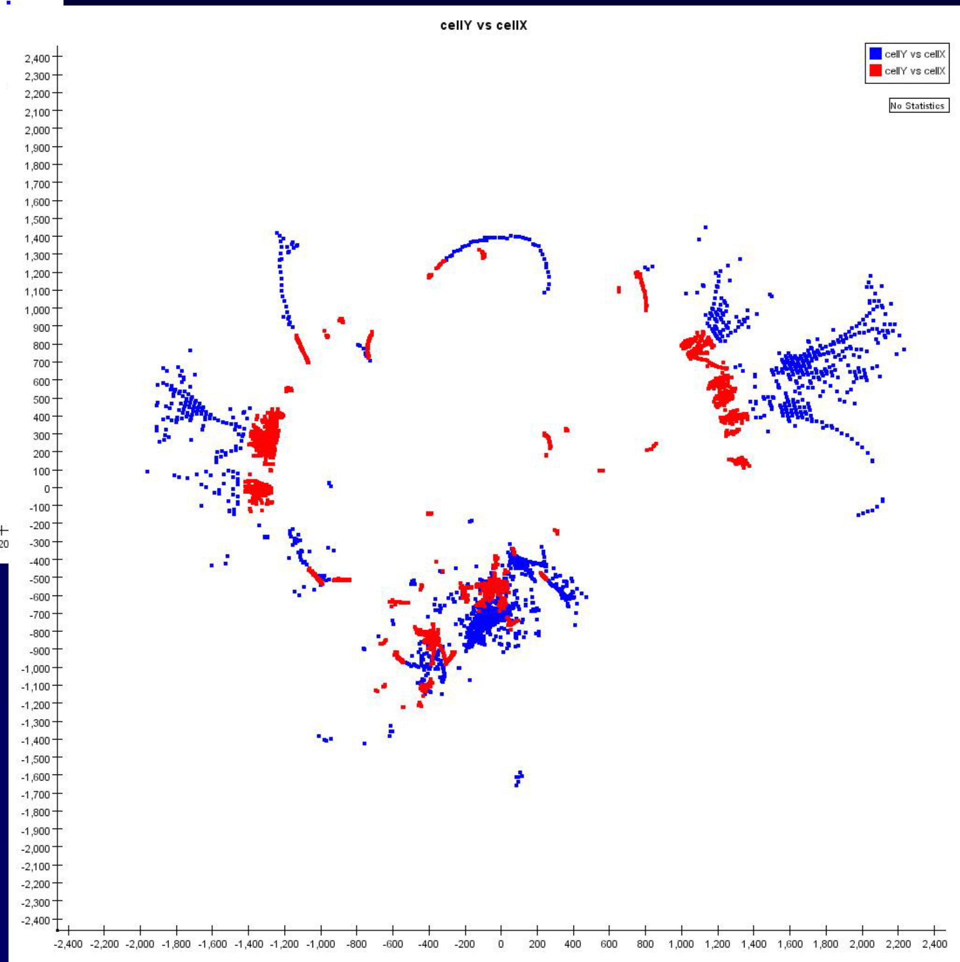
Neutral hadrons

HCAL



No. of fragments w/ and w/o cut on fragment size

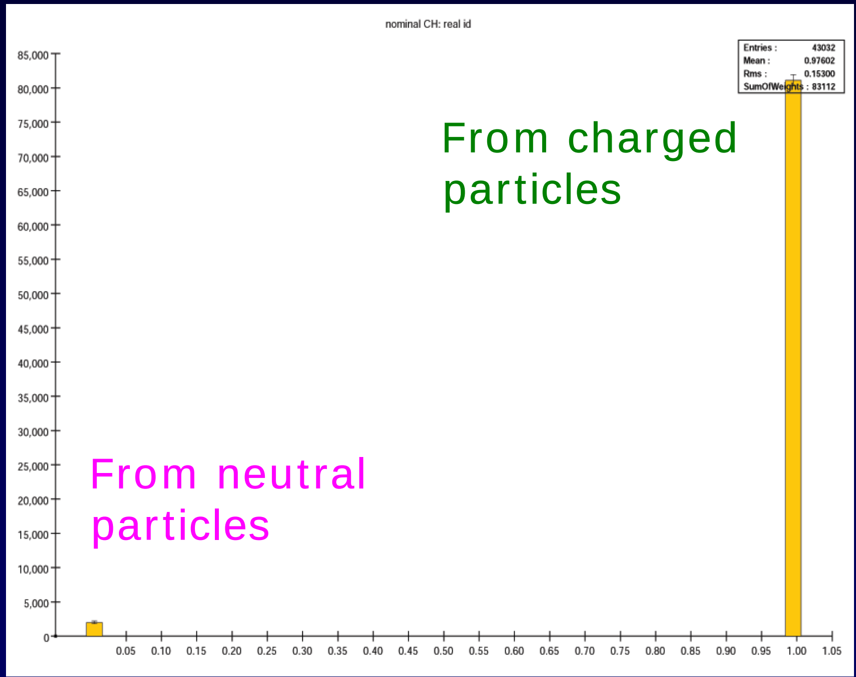

cellY vs cellX
cellY vs cellX
cellY vs cellX
No Statistics
2,400 2,300 2,200 2,100 2,000 1,900 1,800 1,700 1,600 1,500 1,400 1,300 1,200 1,100 1,000 900 800 700 600 500 400 300 200 100 0 -100 -200 -300 -400 -500 -600 -700 -800 -900 -1,000 -1,100 -1,200 -1,300 -1,400 -1,500 -1,600 -1,700 -1,800 -1,900 -2,000 -2,100 -2,200 -2,300 -2,400
-2,400 -2,200 -2,000 -1,800 -1,600 -1,400 -1,200 -1,000 -800 -600 -400 -200 0 200 400 600 800 1,000 1,200 1,400 1,600 1,800 2,000 2,20


cellY vs cellX
cellY vs cellX
cellY vs cellX
No Statistics
2,400 2,300 2,200 2,100 2,000 1,900 1,800 1,700 1,600 1,500 1,400 1,300 1,200 1,100 1,000 900 800 700 600 500 400 300 200 100 0 -100 -200 -300 -400 -500 -600 -700 -800 -900 -1,000 -1,100 -1,200 -1,300 -1,400 -1,500 -1,600 -1,700 -1,800 -1,900 -2,000 -2,100 -2,200 -2,300 -2,400
-2,400 -2,200 -2,000 -1,800 -1,600 -1,400 -1,200 -1,000 -800 -600 -400 -200 0 200 400 600 800 1,000 1,200 1,400 1,600 1,800 2,000 2,200 2,400

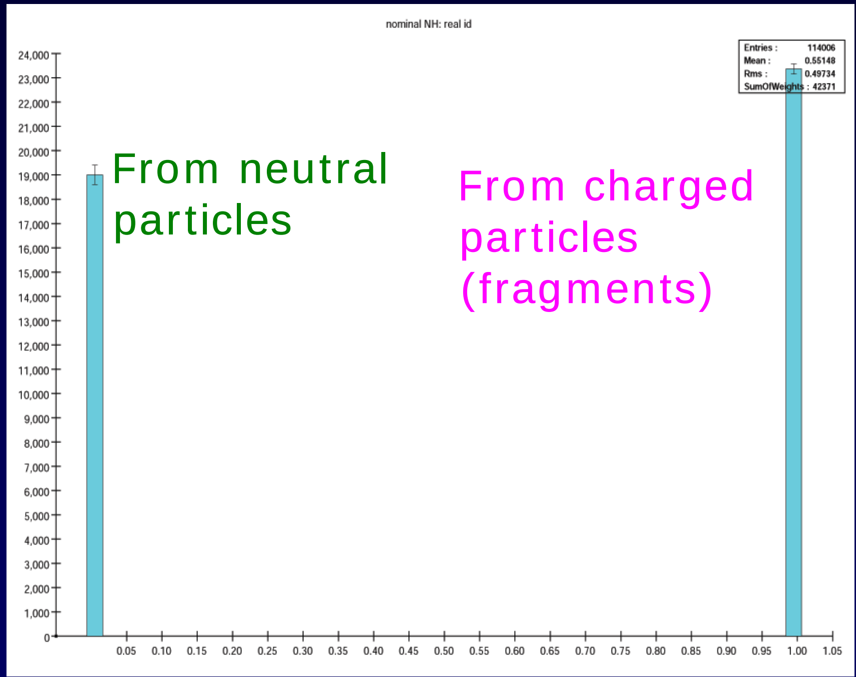
Dist-based

After track-cluster matching*

Energy of matched clusters



Energy of clusters not matched to any track: neutral candidate



On average
~3% came from neutral

Energy from charged particles is more than real neutral
-- need to work on it!

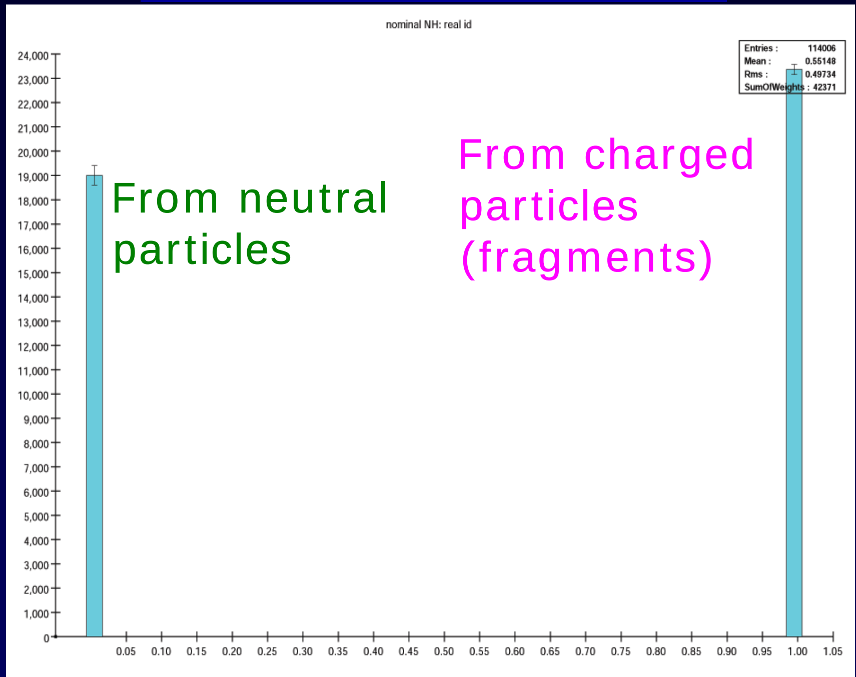
* Perfect Photon ID – hits removed

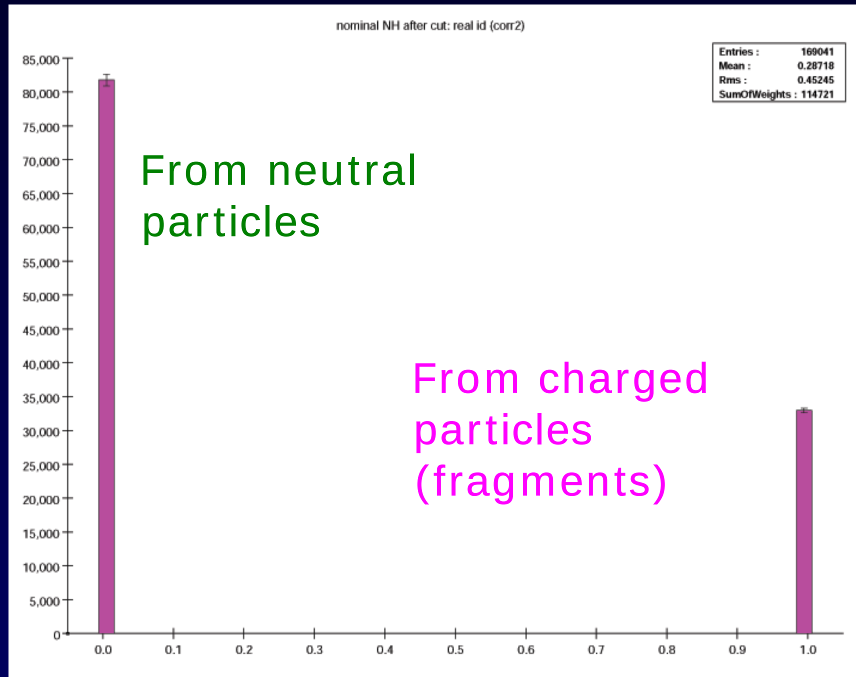
Dist-based

Fragment identification

Energy of clusters not matched to any track: neutral candidate

After removing identified fragments





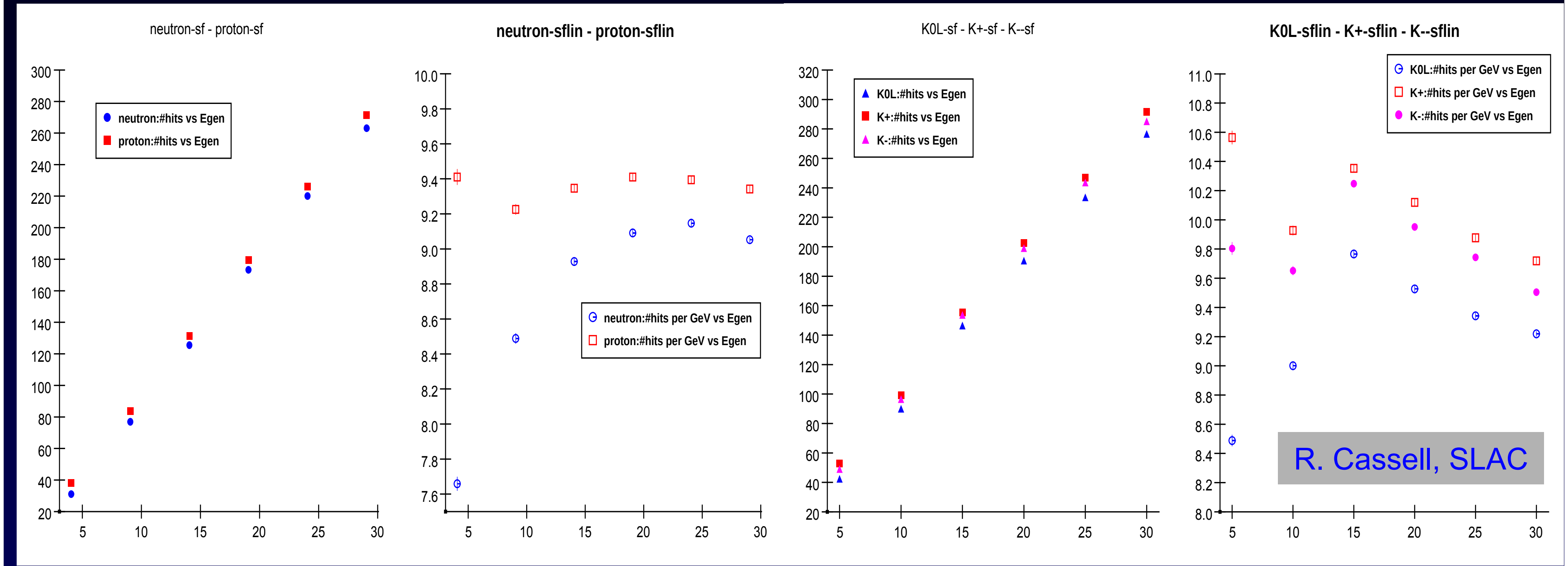
1 : 1.24 → 1 : 0.40

Eff(neu) ~ 88%

Use the three variables to identify fragments:

1. 72% of the energy from fragments is removed
2. Only lose 12% of real neutral energy

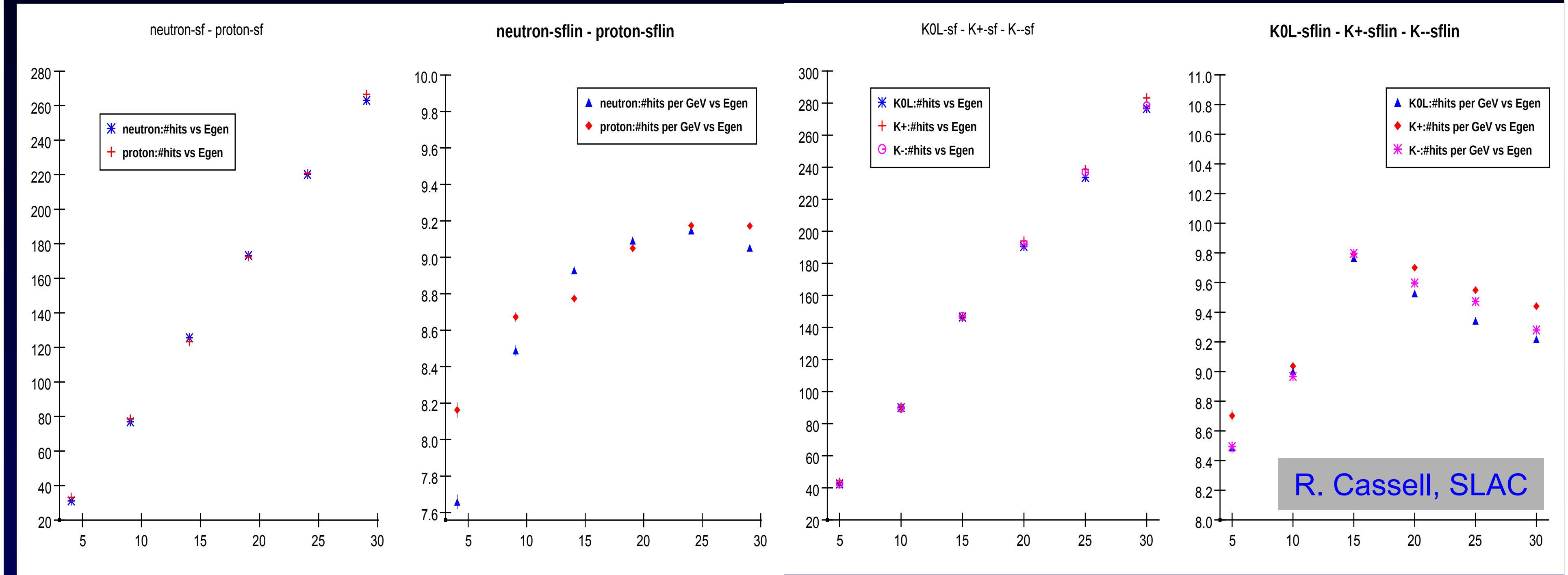
Comparison of Charged/Neutral Hadron Hits



-> 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

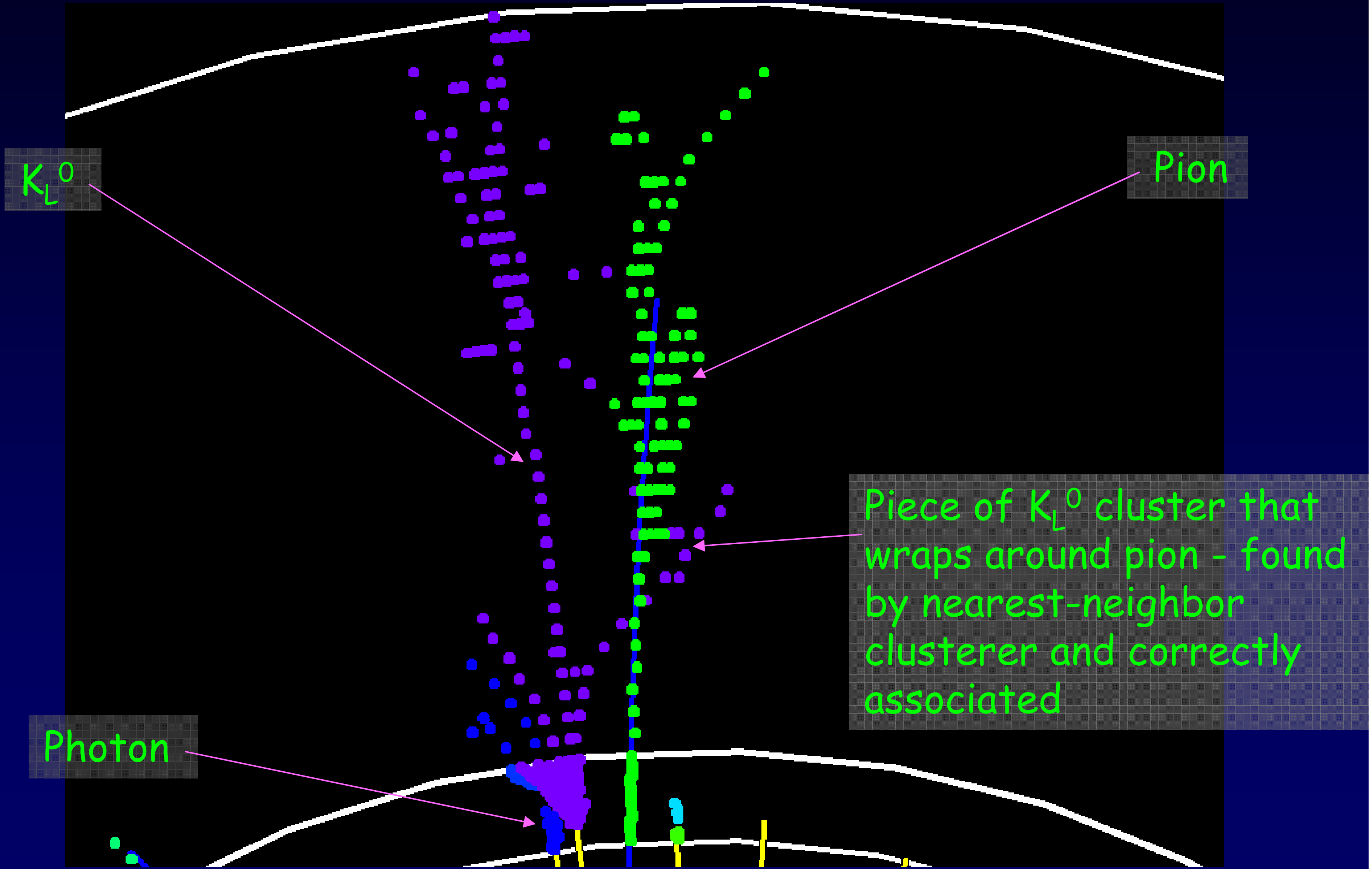


-> account for mip trace properly
-> after weighting, #hits charged ~ #hits neutral
-> shower calibration (#hits/GeV) now very similar

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!

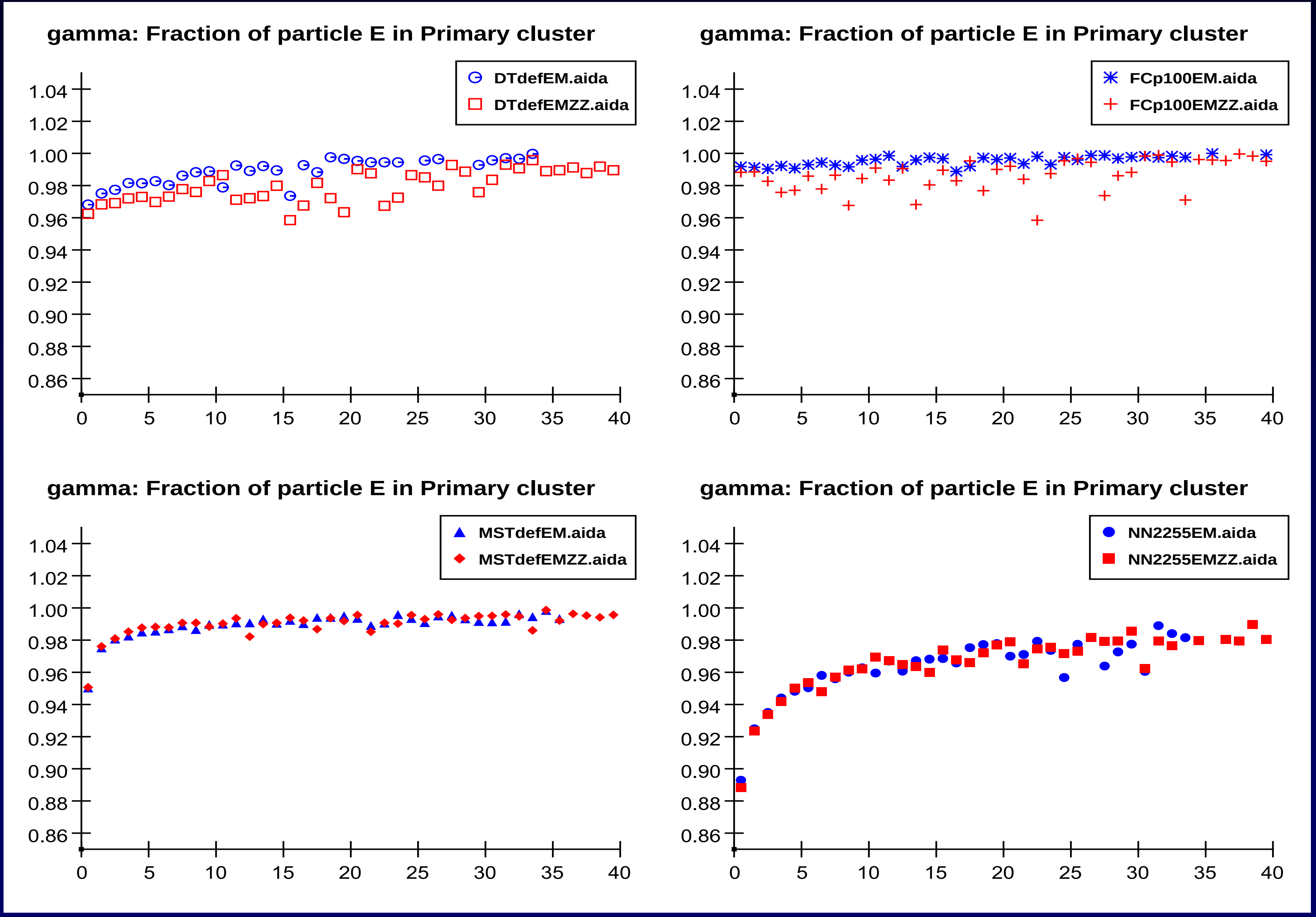
Nearest-Neighbor Clustering for Charged/Neutral Separation - SLAC/ANL



Photon Finding

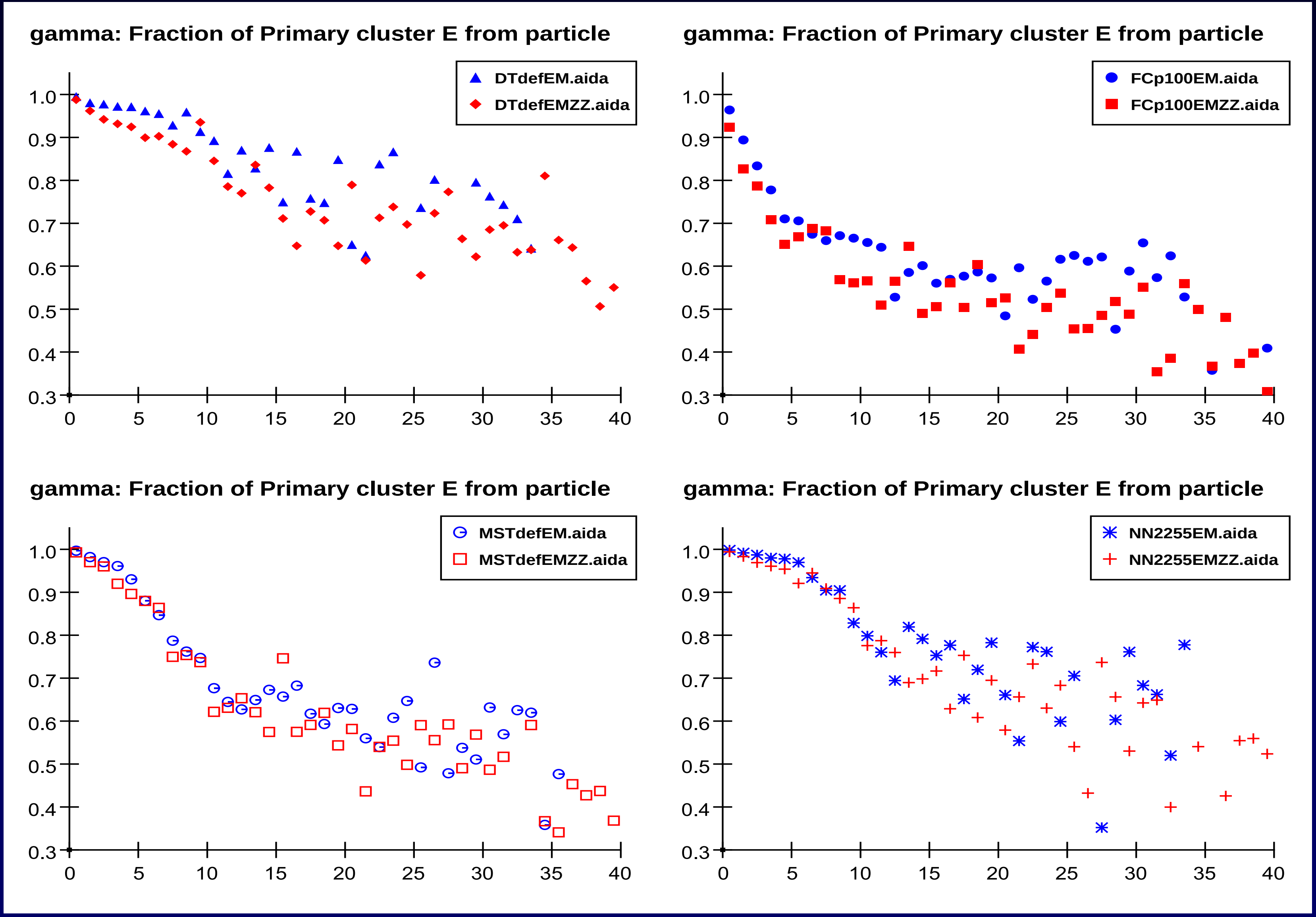
R. Cassell, SLAC

Energy efficiency vs generated energy



R. Cassell, SLAC

Energy purity vs generated energy



Track 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 density (no clustering of hits)

2nd step - Photon Finder (SLAC, Kansas)

-> use analytic longitudinal H-matrix fit to layer E profile with ECAL clusters as input

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 iterated in E/p

-> Analog or digital techniques in HCAL

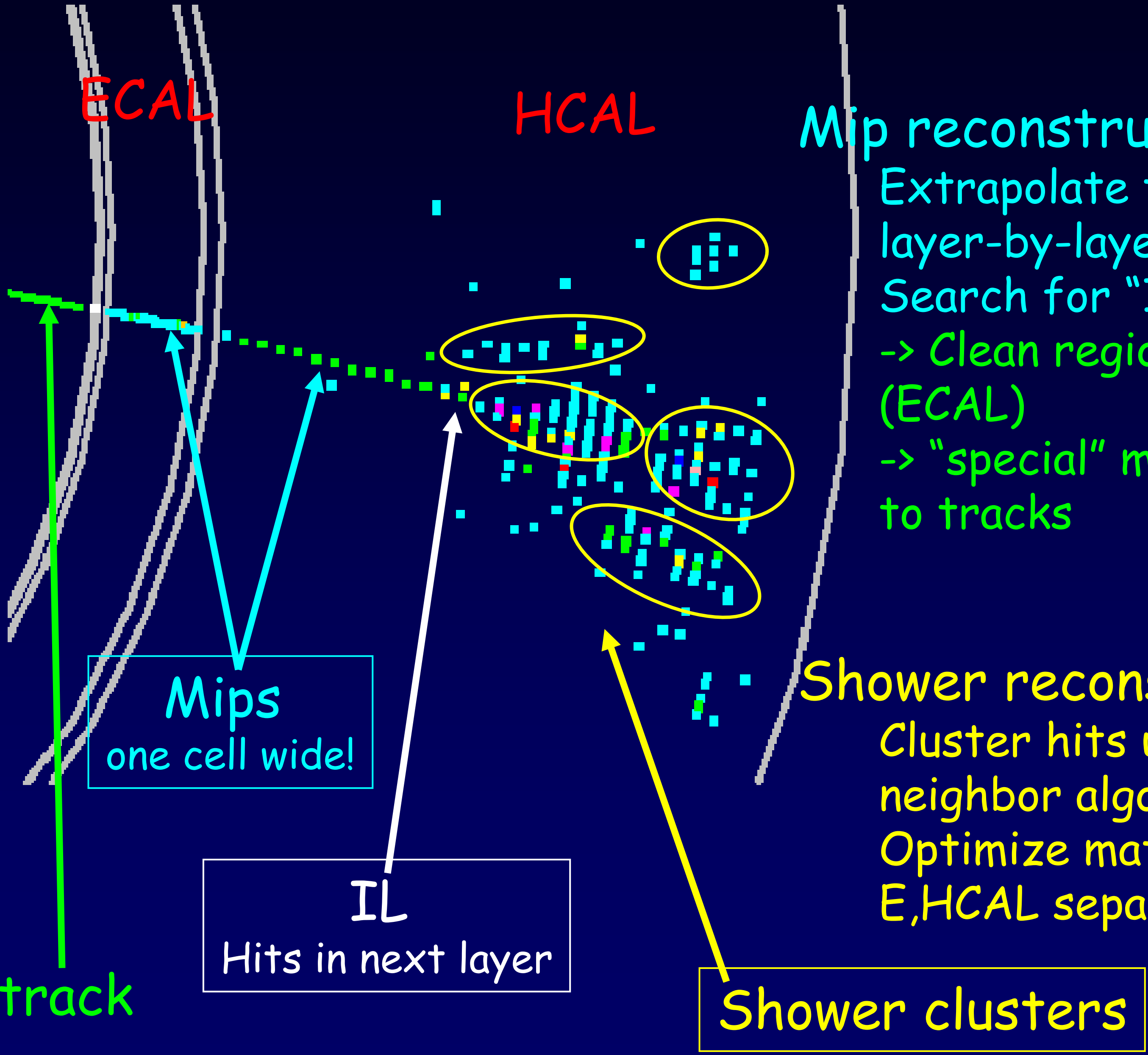
4th step – Neutral Finder algorithm (SLAC, ANL)

-> cluster remaining CAL cells, merge, cut fragments

5th step – Jet algorithm

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

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

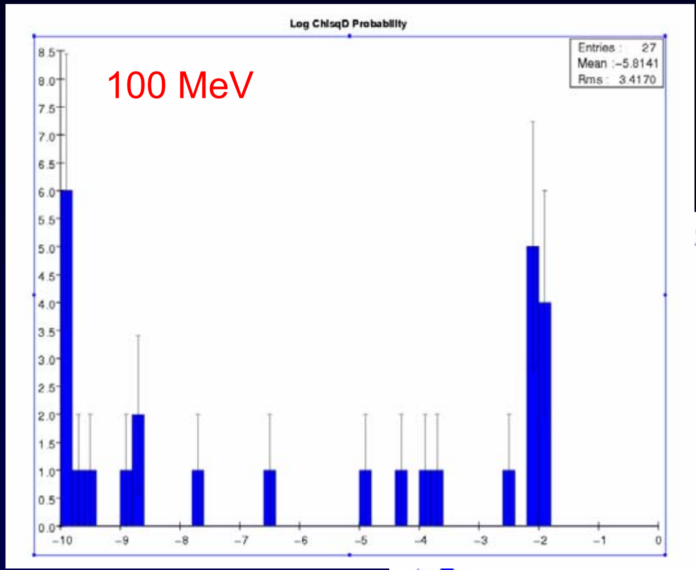
Optimize matching, iterating in E,HCAL separately (E/p test)

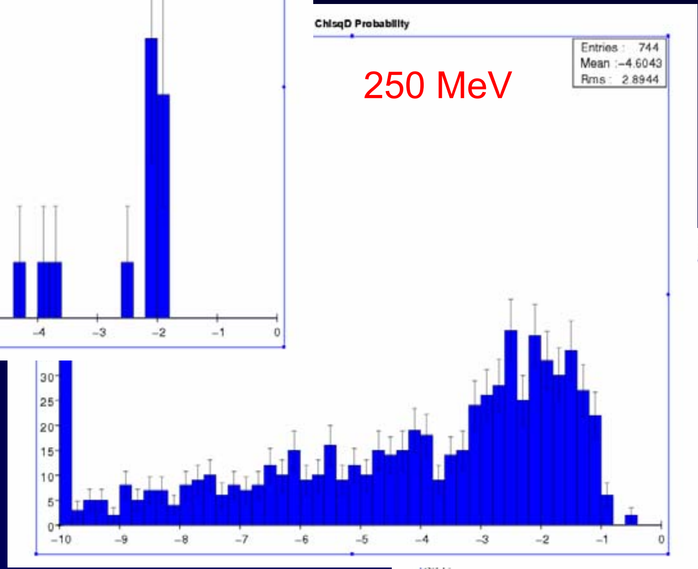
Photon Cluster Evaluation with (longitudinal) H-Matrix

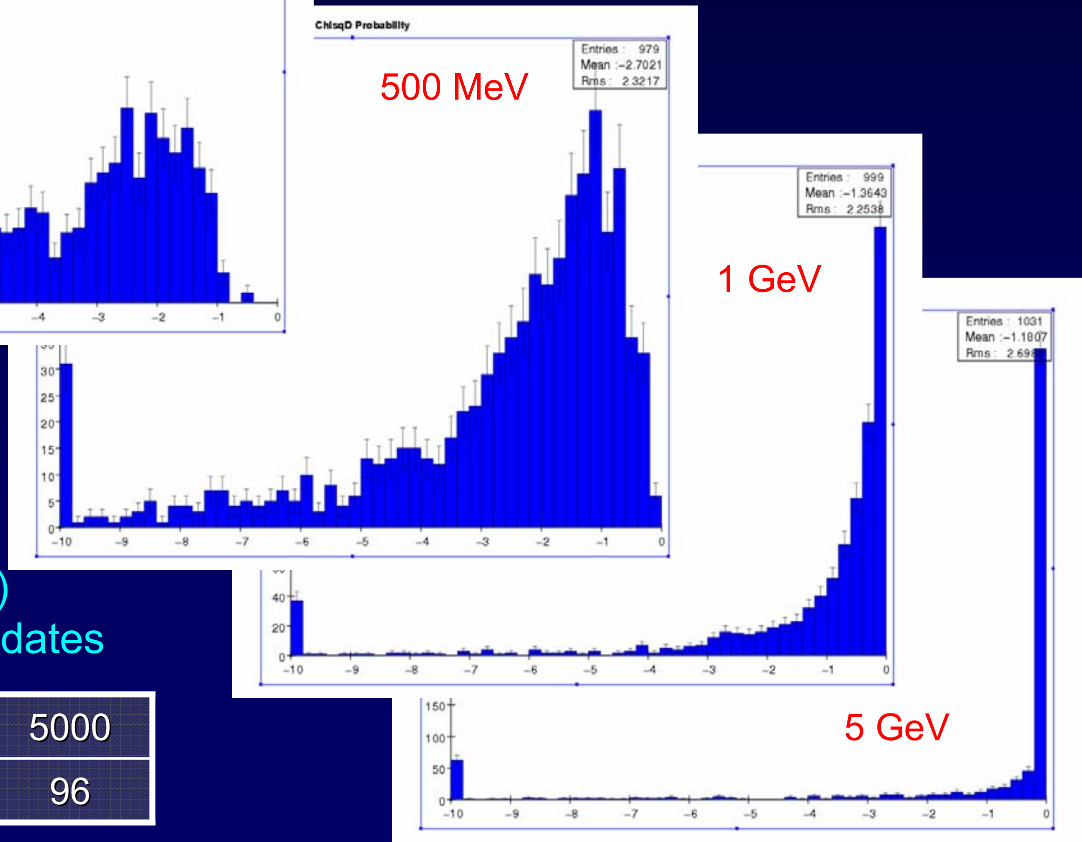
Average number of hit cells in photons passing H-Matrix cut

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

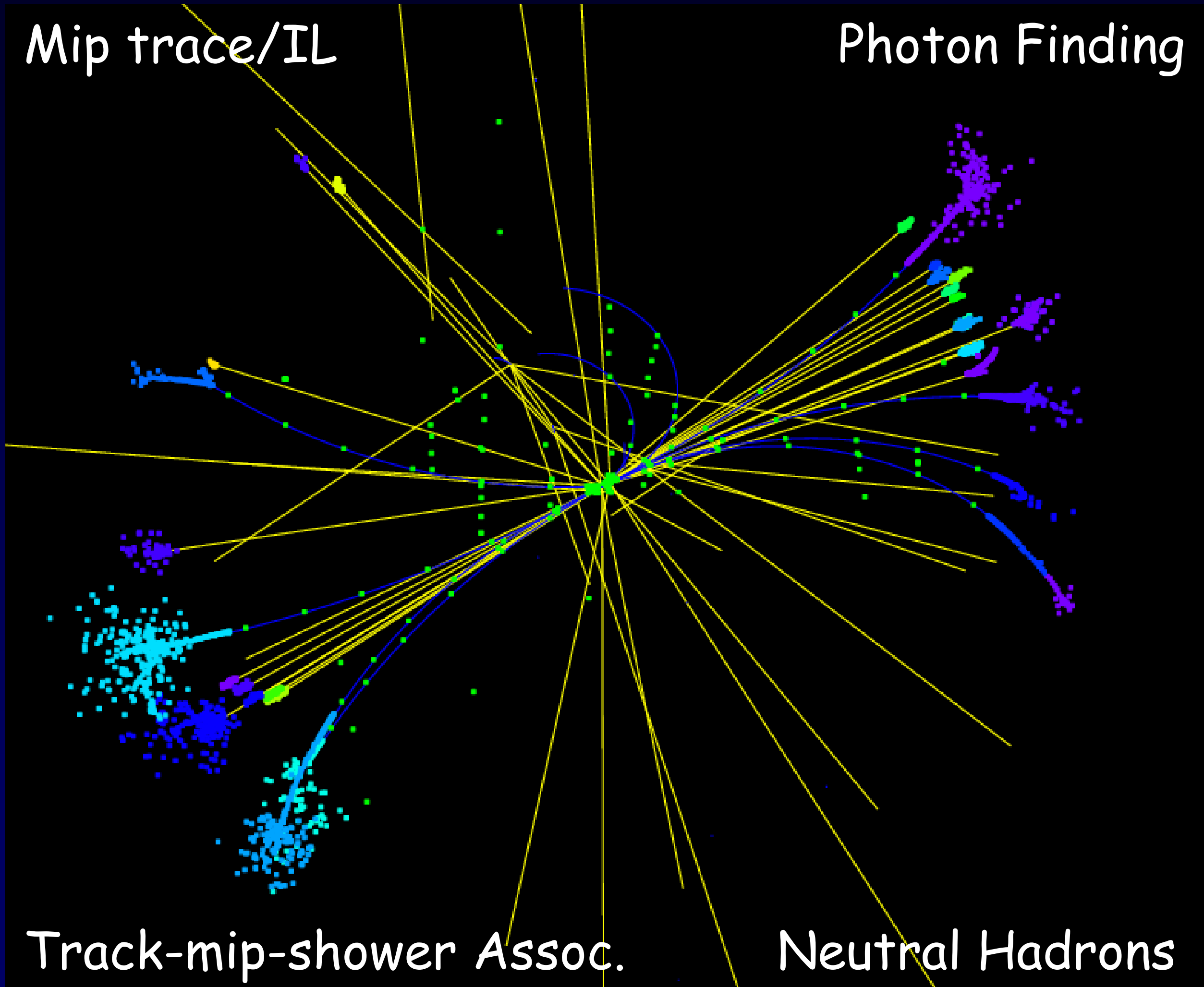
E (MeV)	100	250	500	1000	5000
Effic. (%)	2	66	94	96	96

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



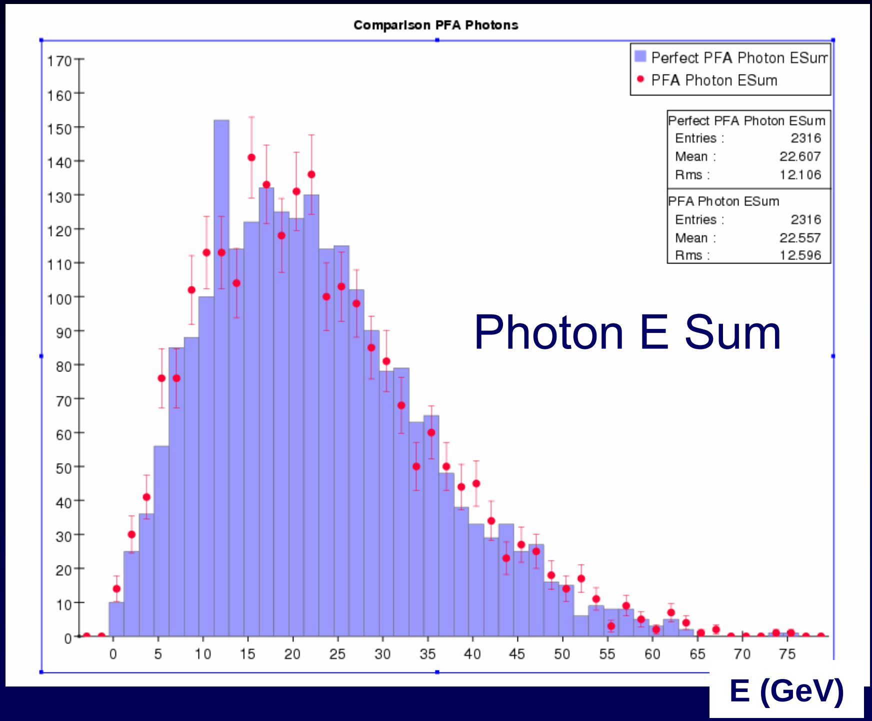
1.9 GeV γ
3.7 GeV γ
3.0 GeV γ
5.5 GeV γ
1.0 GeV γ
2.4 GeV γ
1.3 GeV γ
0.8 GeV γ
3.3 GeV γ
1.5 GeV γ

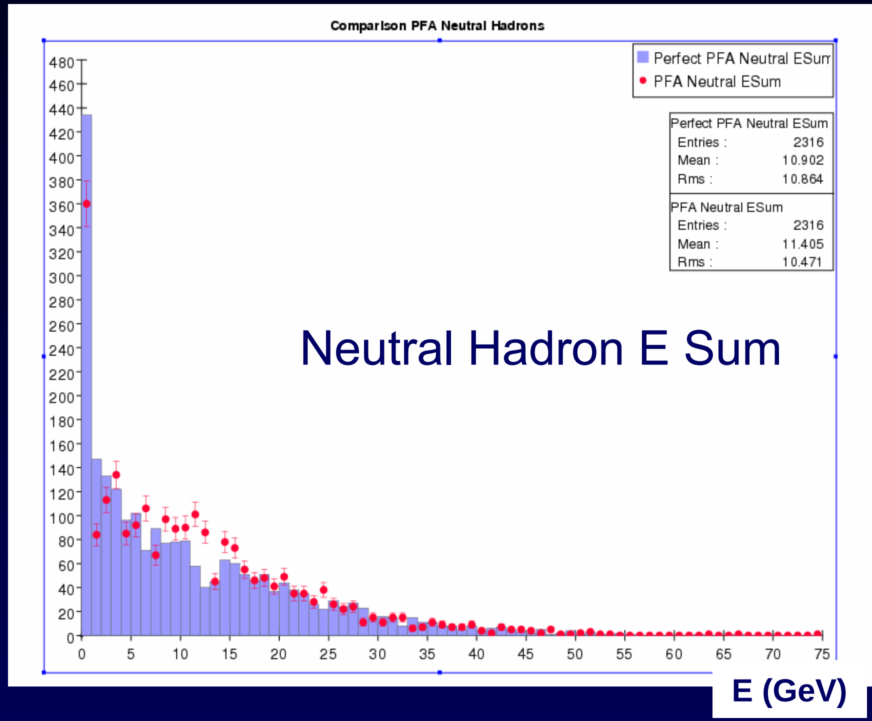
1.9 GeV π-
2.4 GeV π-
4.0 GeV π-
5.9 GeV π+

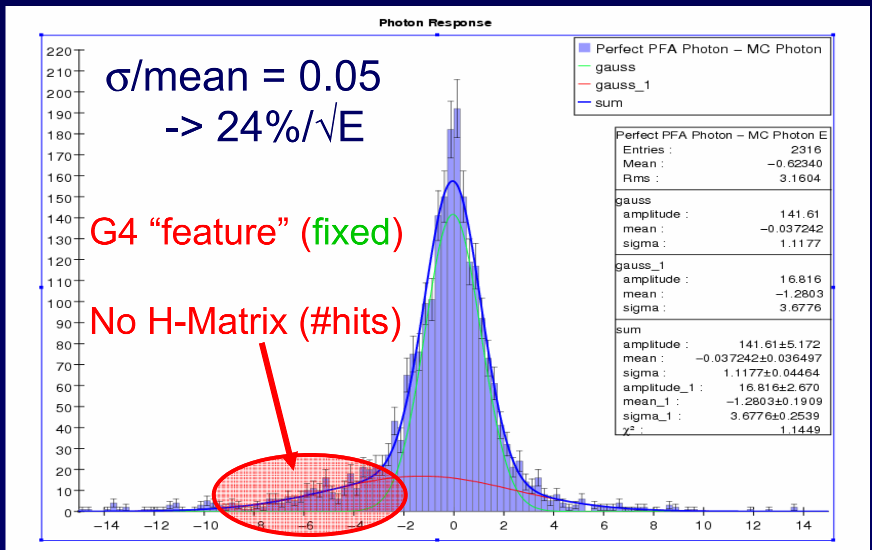
1.5 GeV $\bar{n}$
2.8 GeV n

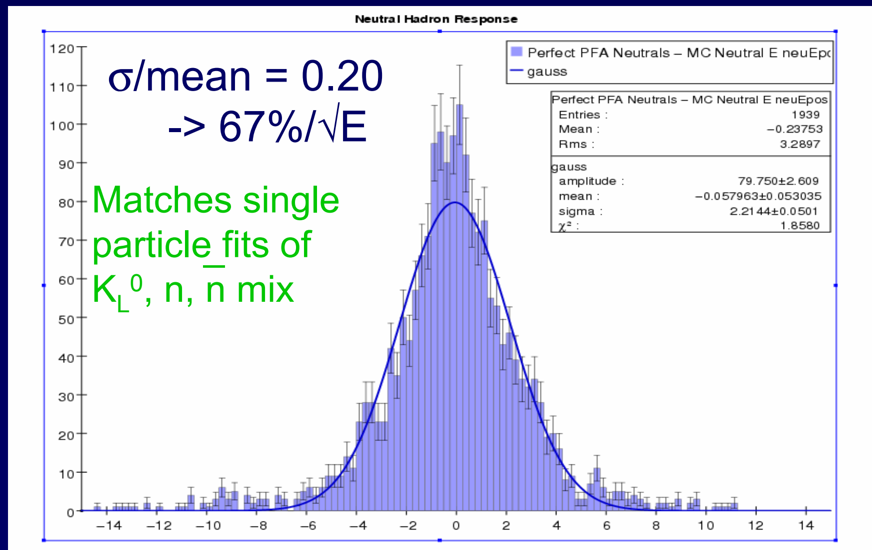
Overall Performance : PFA ~33%/$\sqrt{E}$ central fit

PFA Module Comparisons

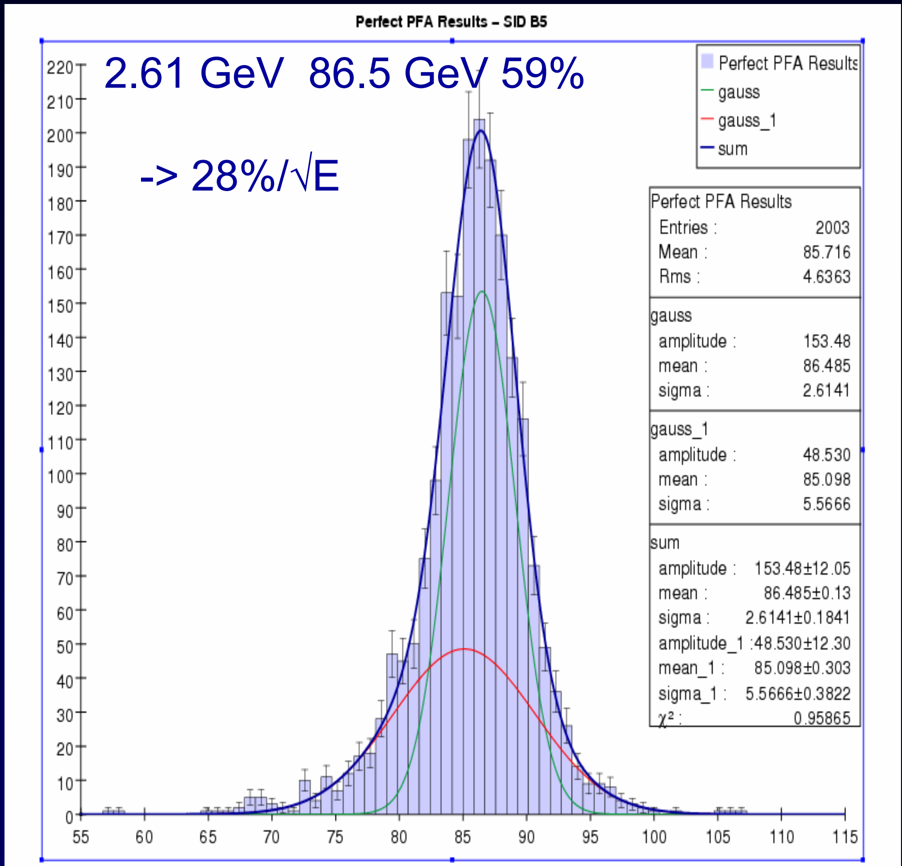


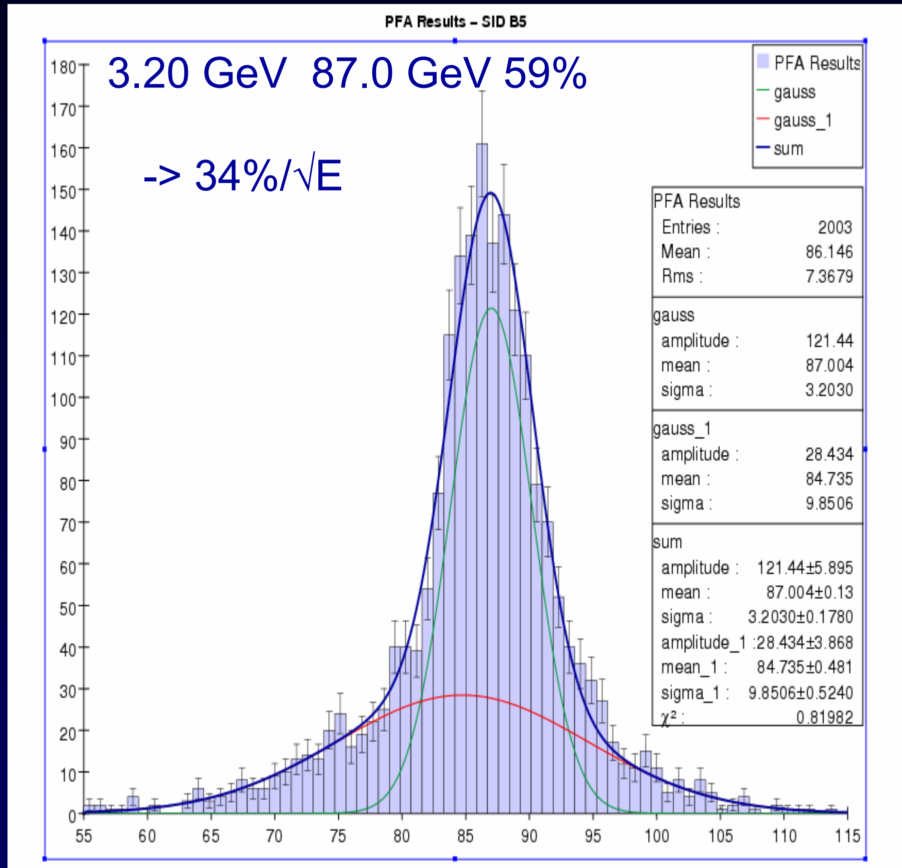






PFA Results





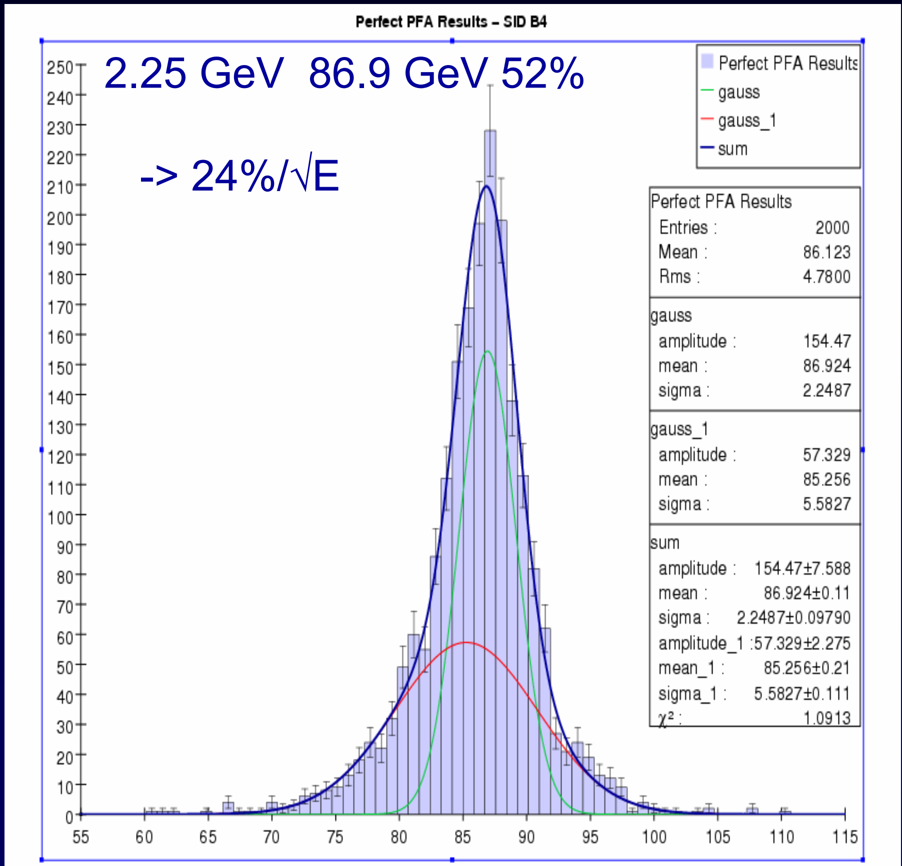
SiD Detector Model
Si Strip Tracker
W/Si ECAL, IR = 125 cm
  4mm X 4mm cells
SS/RPC Digital HCAL
  1cm X 1cm cells
5 T B field (CAL inside)

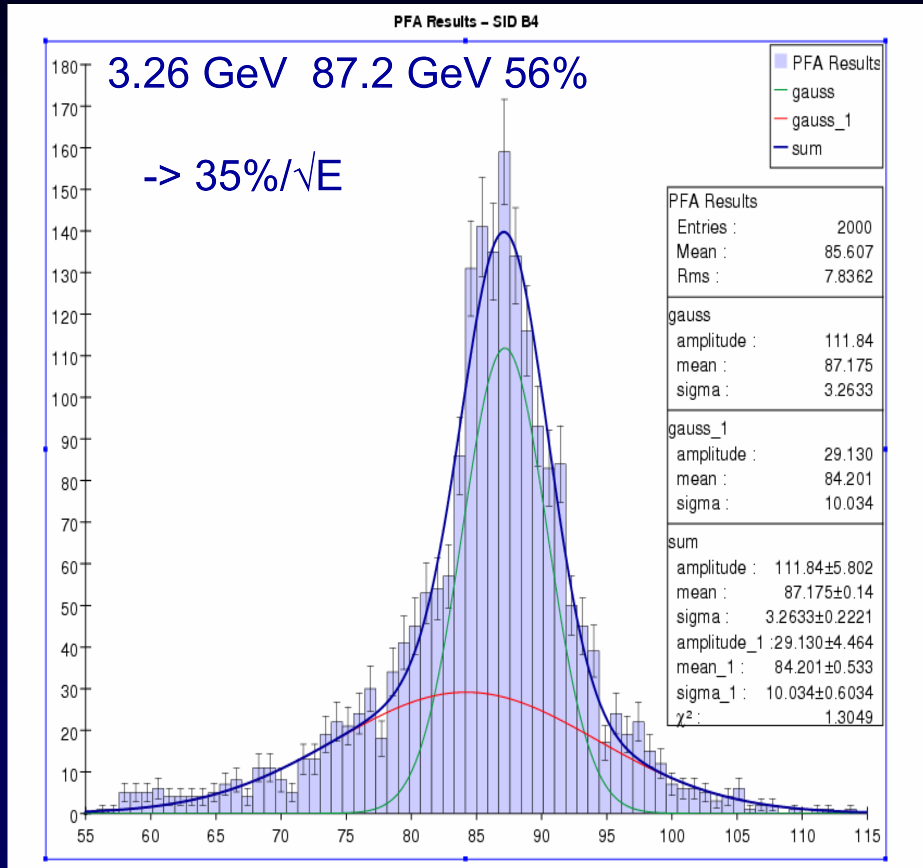
Average confusion contribution = 1.9 GeV
< Neutral hadron resolution contribution of 2.2 GeV
-> PFA goal!*

* other 40% of events!

Detector Comparisons with PFAs

Vary B-field



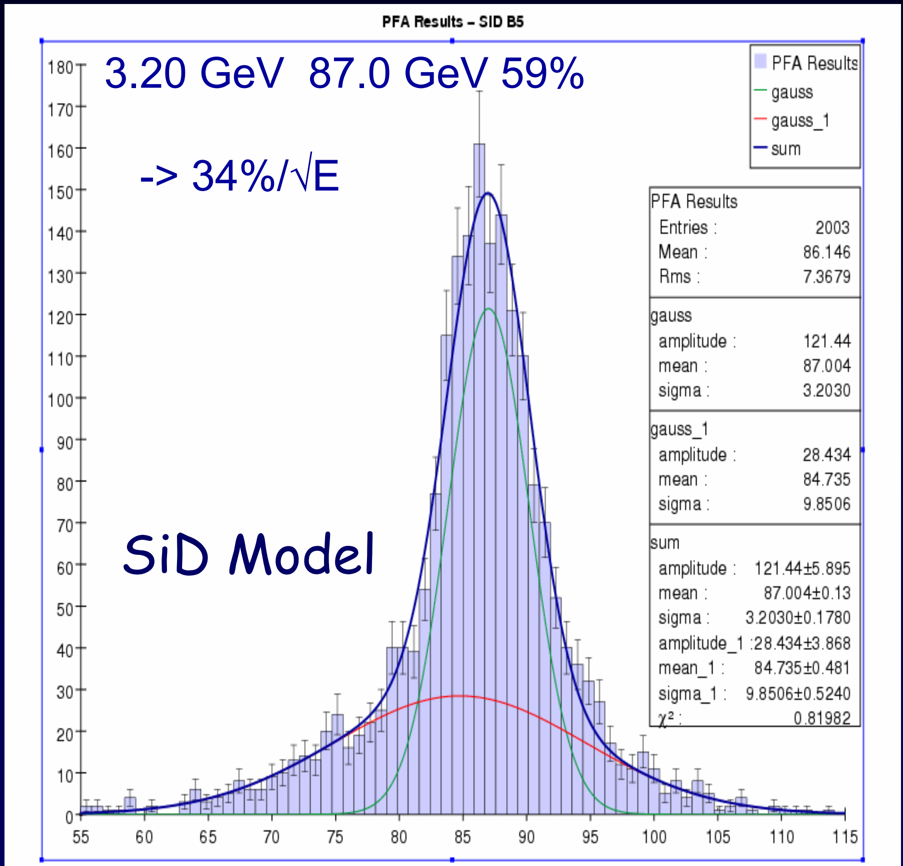


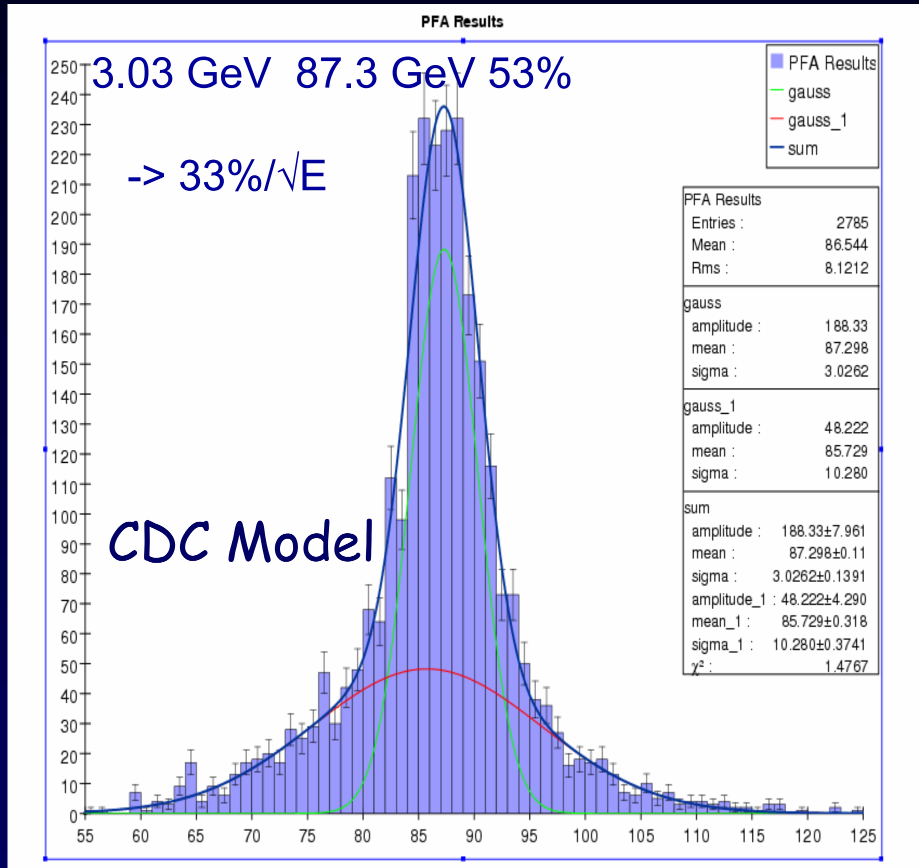
SiD SS/RPC - 5 T field
Perfect PFA σ = 2.6 GeV
PFA σ = 3.2 GeV
Average confusion = 1.9 GeV

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!
- Moves CAL out to improve PFA performance w/o increasing magnet bore

Optimized PFA Construction – a Collaborative Effort

Flexible structure for PFA development based on "Hit Collections" (ANL, SLAC, Iowa)

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

Summary

PFA goal is to use the LC detector optimally -> best measurement of final-state particle properties :

- LC detector becomes a precision instrument - even for jets
- Key part is separation of charged and neutral hadron showers in the calorimeter – strong influence on calorimeter design

R&D priorities are :

- PFA development and optimization
- Detector design using PFAs to optimize the calorimeter and its parameters – in particular, the design of the HCAL

Approaching PFA performance goal

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

Currently, PFAs can be :

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