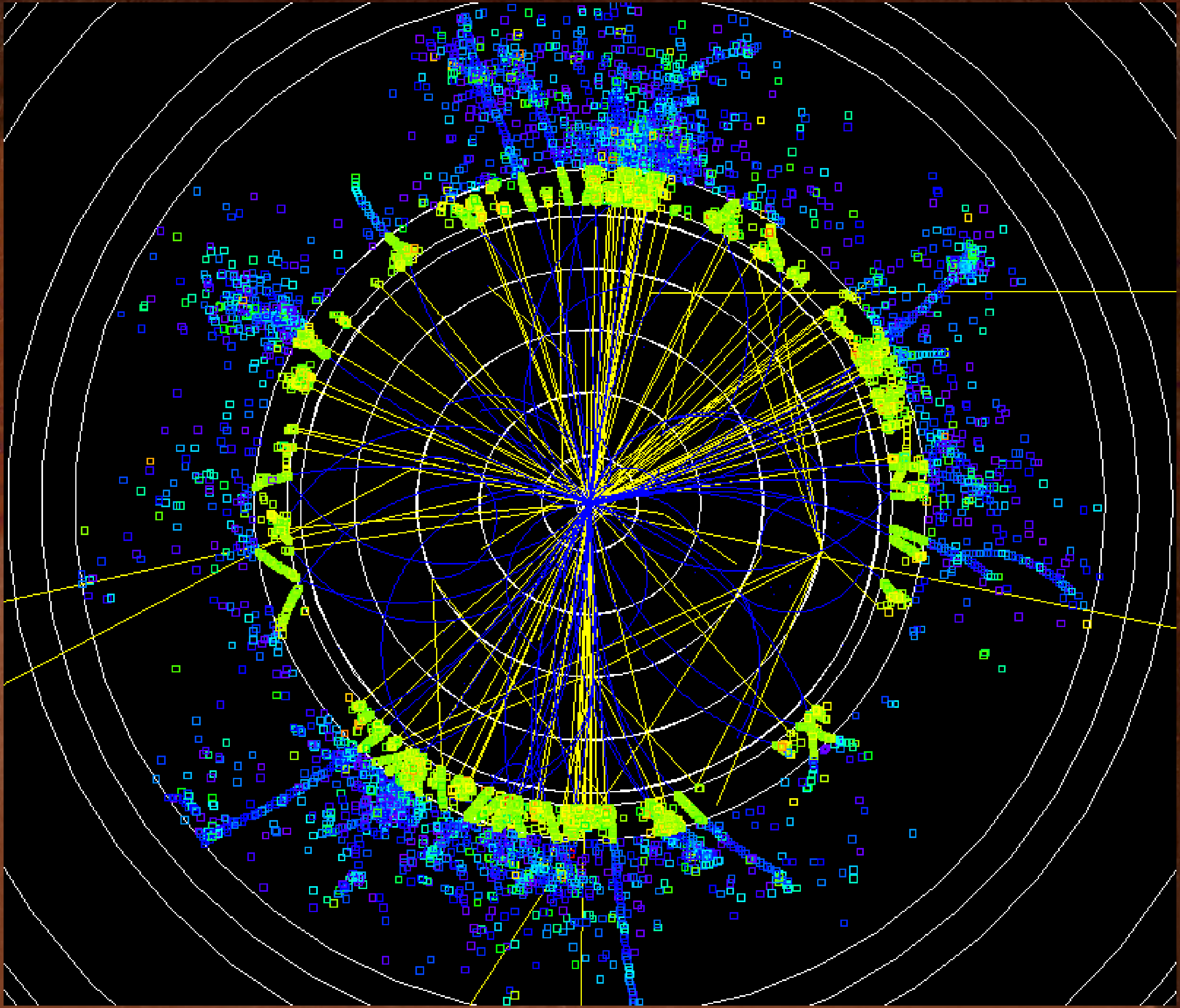
# Particle Flow Template

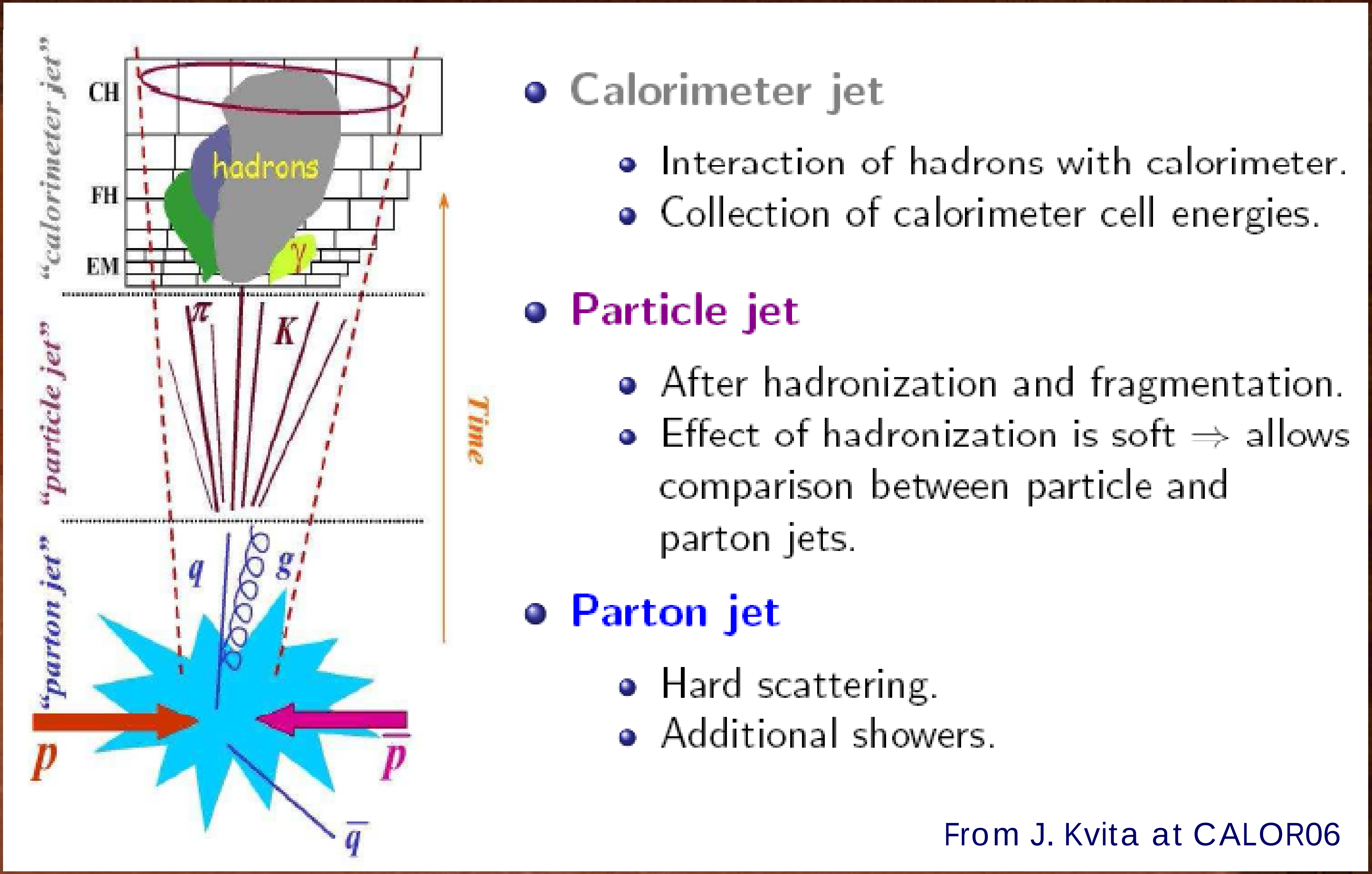
- Modular Particle Flow for the ILC
- Purity/Efficiency-based PFA
- PFA Module Reconstruction
- Jet Reconstruction

Stephen Magill
Argonne National Laboratory

# $e^+e^-$ -> ttbar -> 6 jets @500 GeV CM



# Parton Measurement via Jet Reconstruction



- **Calorimeter jet**
  - Interaction of hadrons with calorimeter.
  - Collection of calorimeter cell energies.
- **Particle jet**
  - After hadronization and fragmentation.
  - Effect of hadronization is soft ⇒ allows comparison between particle and parton jets.
- **Parton jet**
  - Hard scattering.
  - Additional showers.

From J. Kvita at CALOR06

Cal Jet -> *large correction* -> Particle Jet -> *small correction* -> Parton Jet

# PFA Template – Modular Approach

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

# A Systematic PFA Development

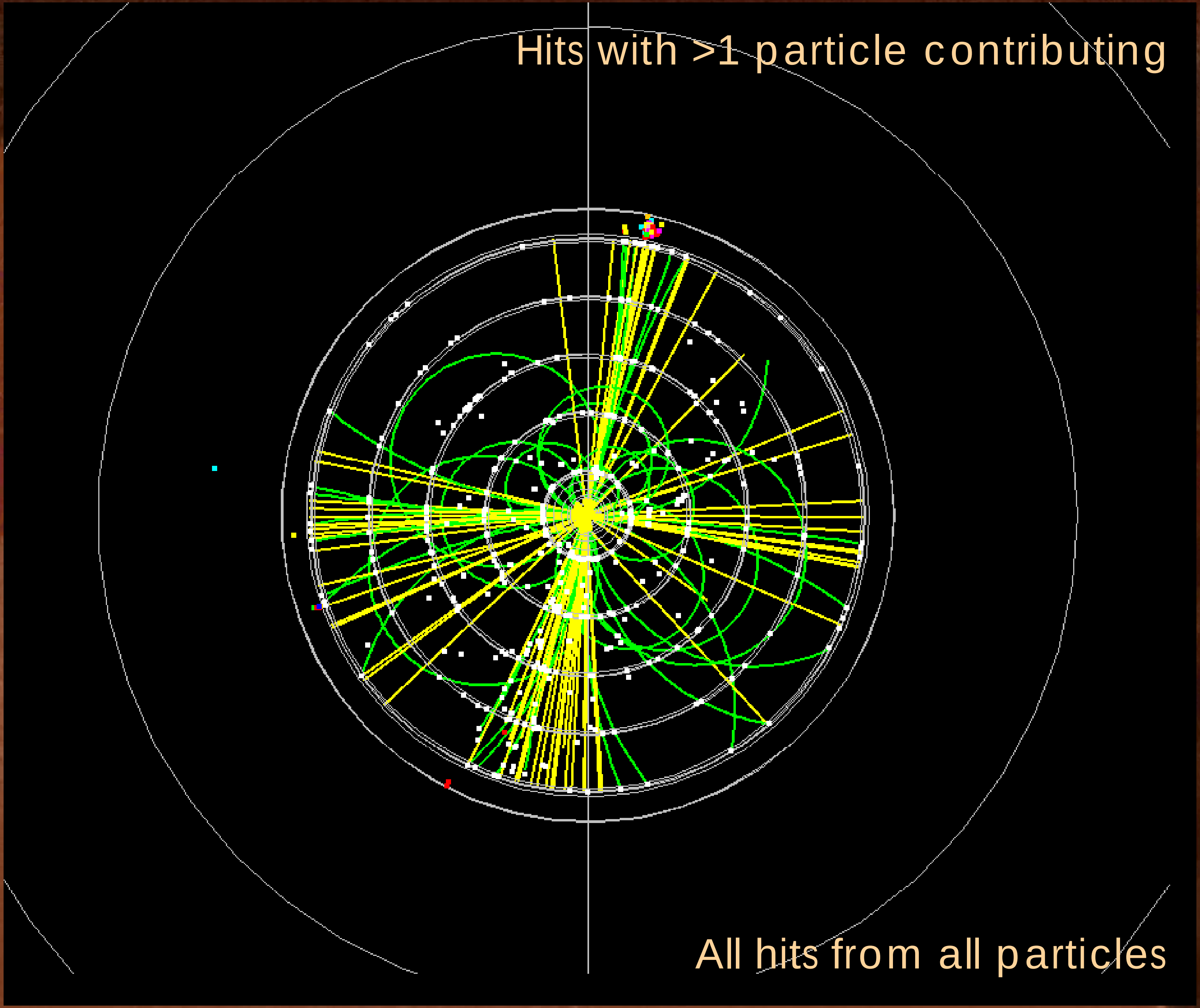
## Starting Point :

100% pure calorimeter cell population – 1 and only 1 particle contributes to a cell
More practically, no overlap between charged particles and neutrals
-> Defines cell volume – $v(d_{IP},\eta,B?)$
-> Start of detector design optimization
-> Perfect PFA is really perfect – no confusion to start

100% pure tracker hits (or obvious crossings)
-> Defines Si strip size
-> Start of design optimization
-> Perfect Tracks are really perfect

PFA is an intelligent mixture of high purity and high efficiency objects – not necessarily both together

# Occupancy Event Display



# Standard Perfect PFA (Perfect Reconstructed Particles)

Takes generated and simulated MC objects, applies rules to define what a particular detector should be able to detect, forms a list of the perfect reconstructed particles, perfect tracks, and perfect calorimeter clusters.

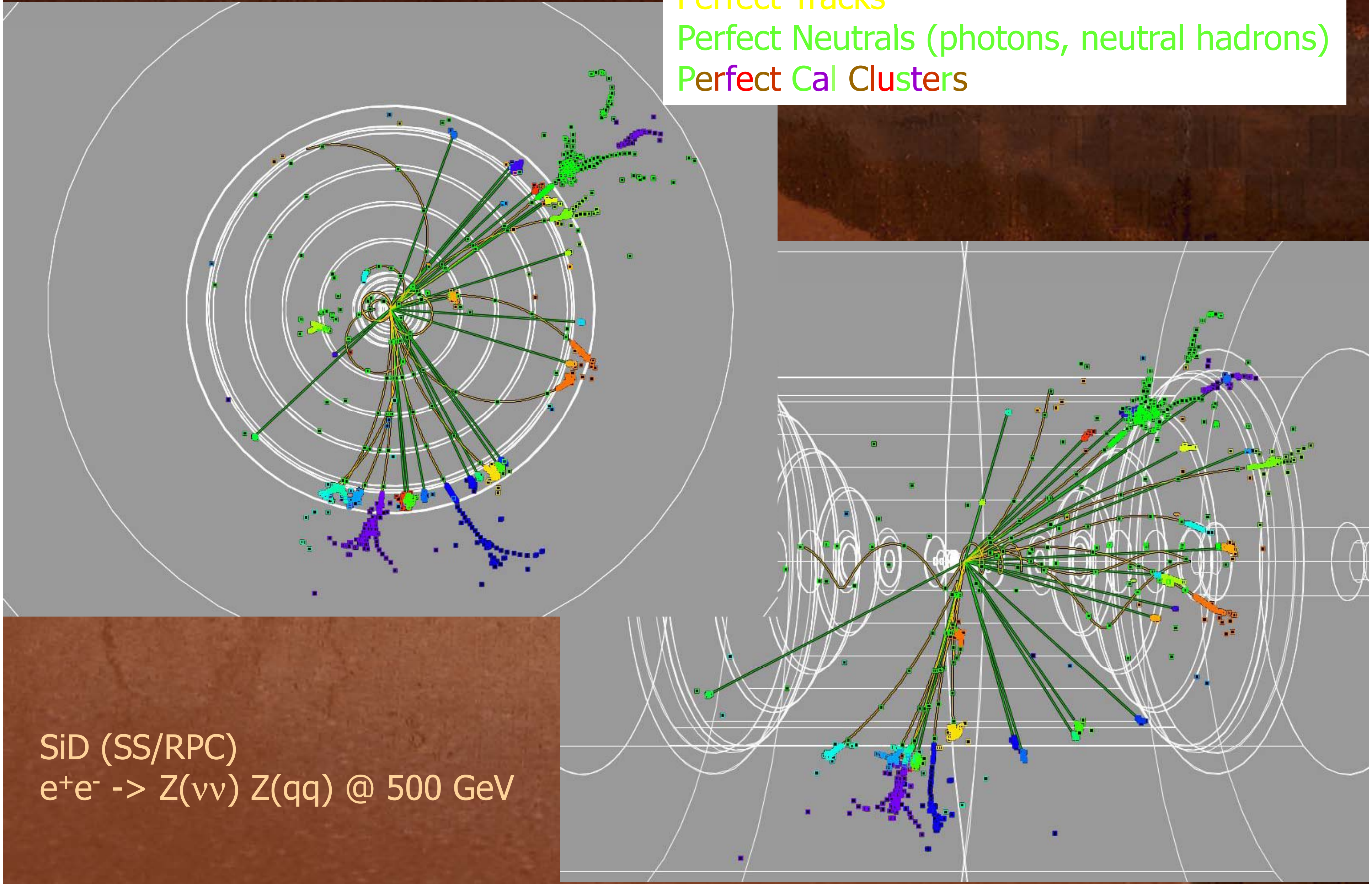
Complicated examples :
-> charged particle interactions/decays before cal
-> photon conversions
-> backscattered particles

Critical for comparisons when perfect (cheated) tracks are used
Extremely useful for debugging PFA

# Standard Detector Calibration

Default detector calibration done with single particles
Basic Clusters contain calibrated energies – analog in ECAL and digital in HCAL
Standard for all SiD variants with analog ECAL, digital HCAL
Checked with Perfect PFA particles

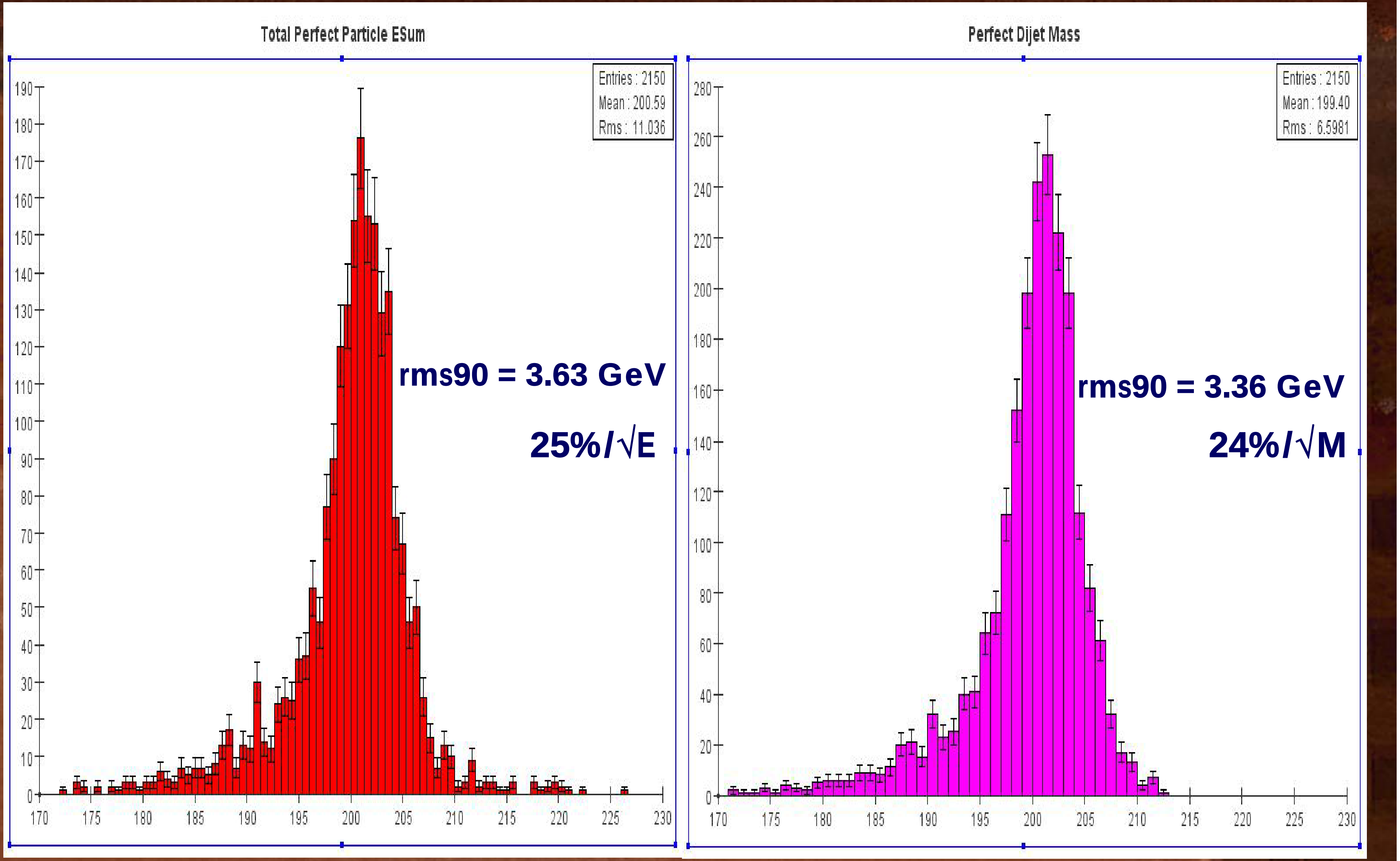
# Perfect PFA



Perfect Tracks
Perfect Neutrals (photons, neutral hadrons)
Perfect Cal Clusters

SiD (SS/RPC)
$e^+e^-$ -> Z(νν) Z(qq) @ 500 GeV

# Perfect PFA – SiD01 $e^+e^-$ -> qq @ 200 GeV



**rms90 = 3.63 GeV**

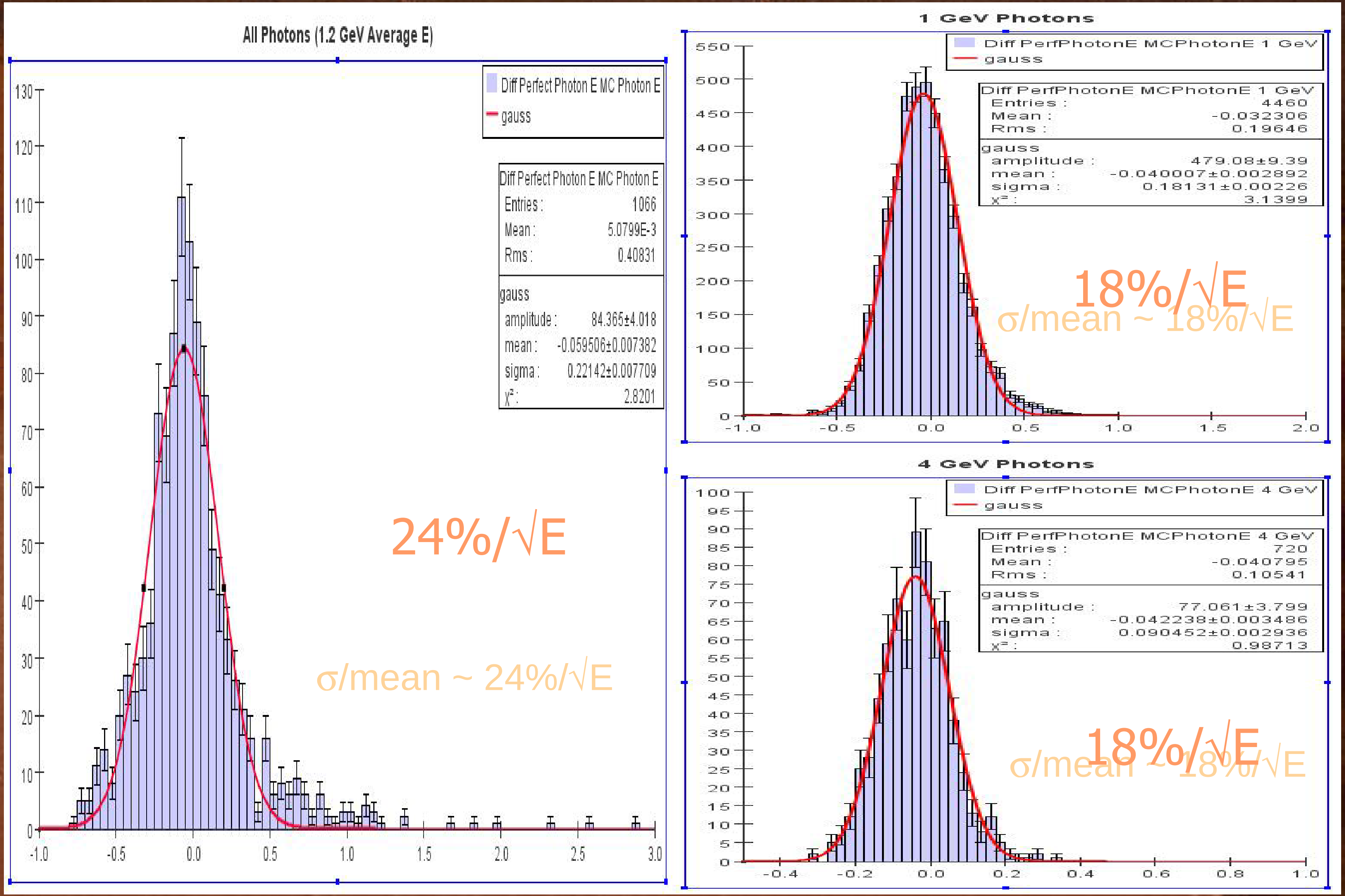
**25%/√E**

**rms90 = 3.36 GeV**

**24%/√M**

# Detector Calibration Check

Photons from Perfect PFA (ZPole events in ACME0605 W/Scin HCAL)



24%/√E

σ/mean ~ 24%/√E

18%/√E

σ/mean ~ 18%/√E

18%/√E

σ/mean ~ 18%/√E

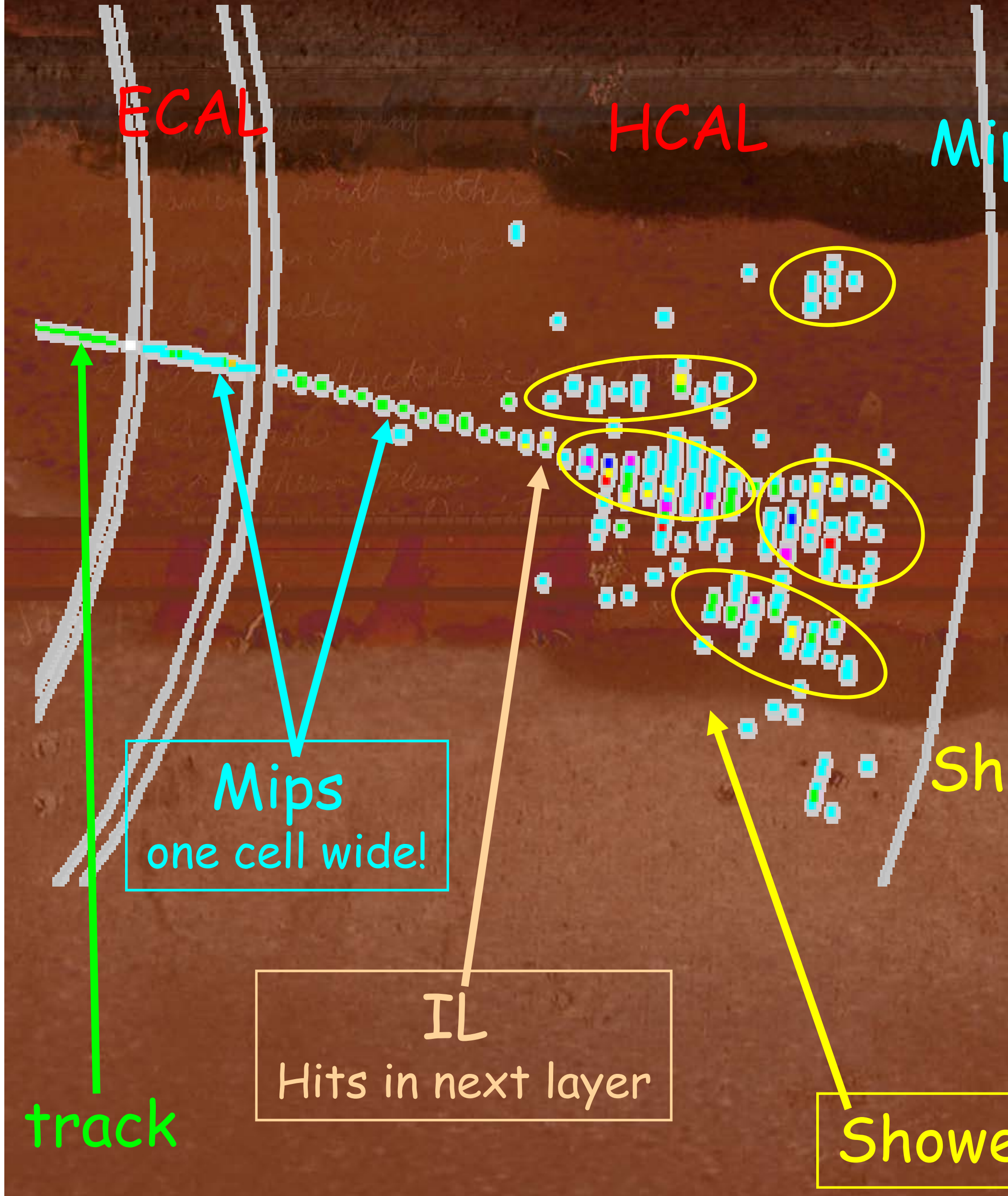
# Track/CAL Shower Matching

This is an example of where high purity is preferred over efficiency
- -> will discard calorimeter hits and use track for particle
- -> better to discard too few hits rather than those from other particles
- -> use hits or high purity cluster algorithm

Example :

1) Associate mip hits to extrapolated tracks up to interaction point where particle starts to shower.
   - -> ~100% pure association since no clustering yet
   - -> tune on muons to get extra hits from delta rays
2) Cluster remaining hits using high purity cluster algorithm – Nearest Neighbor with some fine tuning for neighborhood size
   - -> iterate, adding clusters until $\Sigma E_{cl}/p_{tr}$ in tunable range (0.65 – 1.5)
   - -> can break up cluster if E/p too large (M. Thomson)
   - -> err on too few clusters – can add later when defining neutral hadrons

# 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 Finding

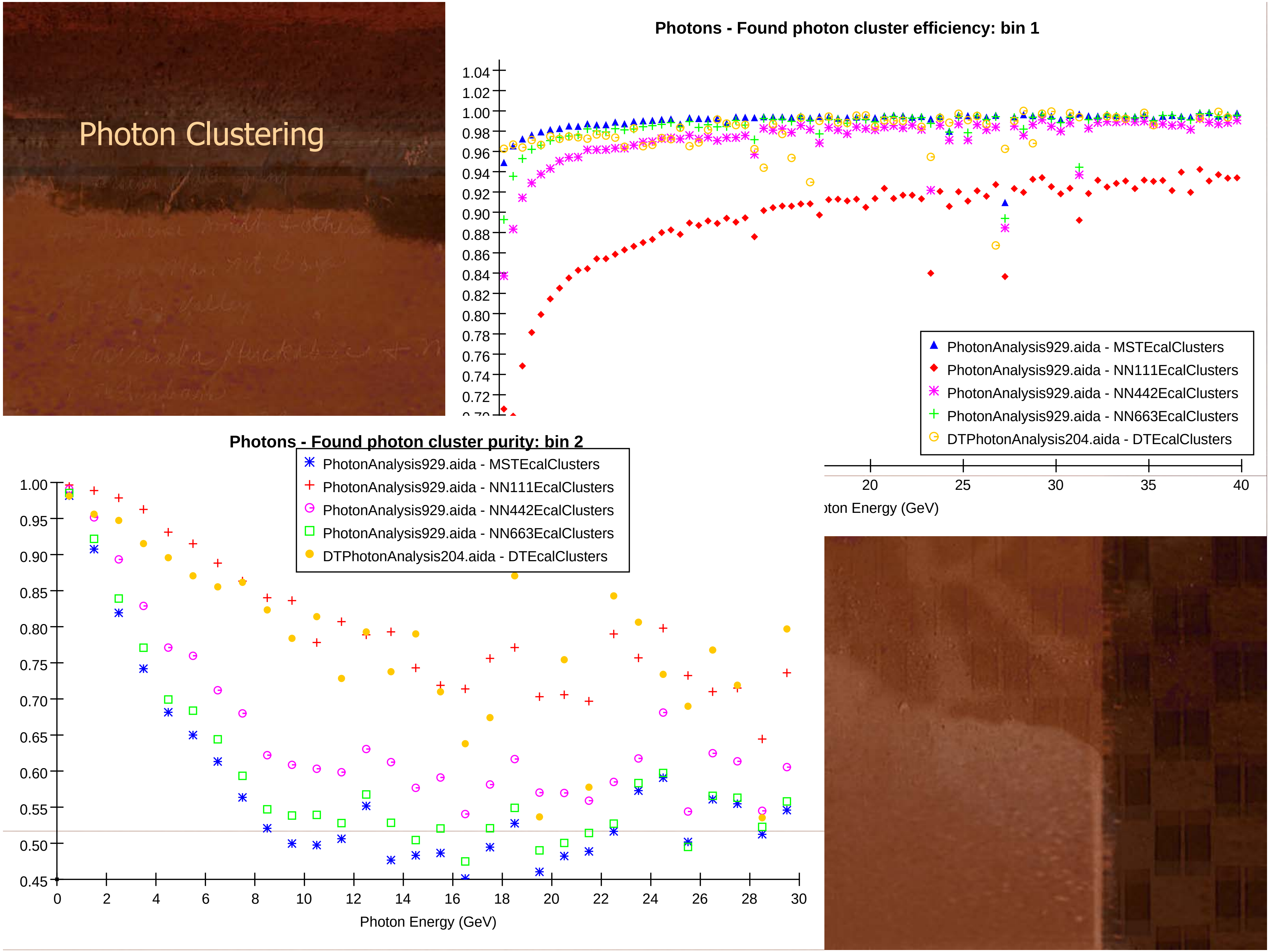
Now, high efficiency is desired so that all photons are defined – can optimize for both high efficiency and high purity by using multiple clustering.

Example :

1) Cone or DT cluster algorithm (high efficiency) with parameters :
    radius = 0.04
    seed = 0.0
    minE = 0.0
2) Cluster hits in cones with NN(1111) to define cluster core (high purity for photons)
    mincells = 20 (minimum #cells in reclustered object)
    dTrCl = 0.02 (no tracks within .02)
3) Test with longitudinal H-Matrix and evaluate $\chi^2$

Other evaluations are done in PhotonFinderDriver – like layer of first interaction if cluster fails mincells test, cluster E in HCAL, etc.

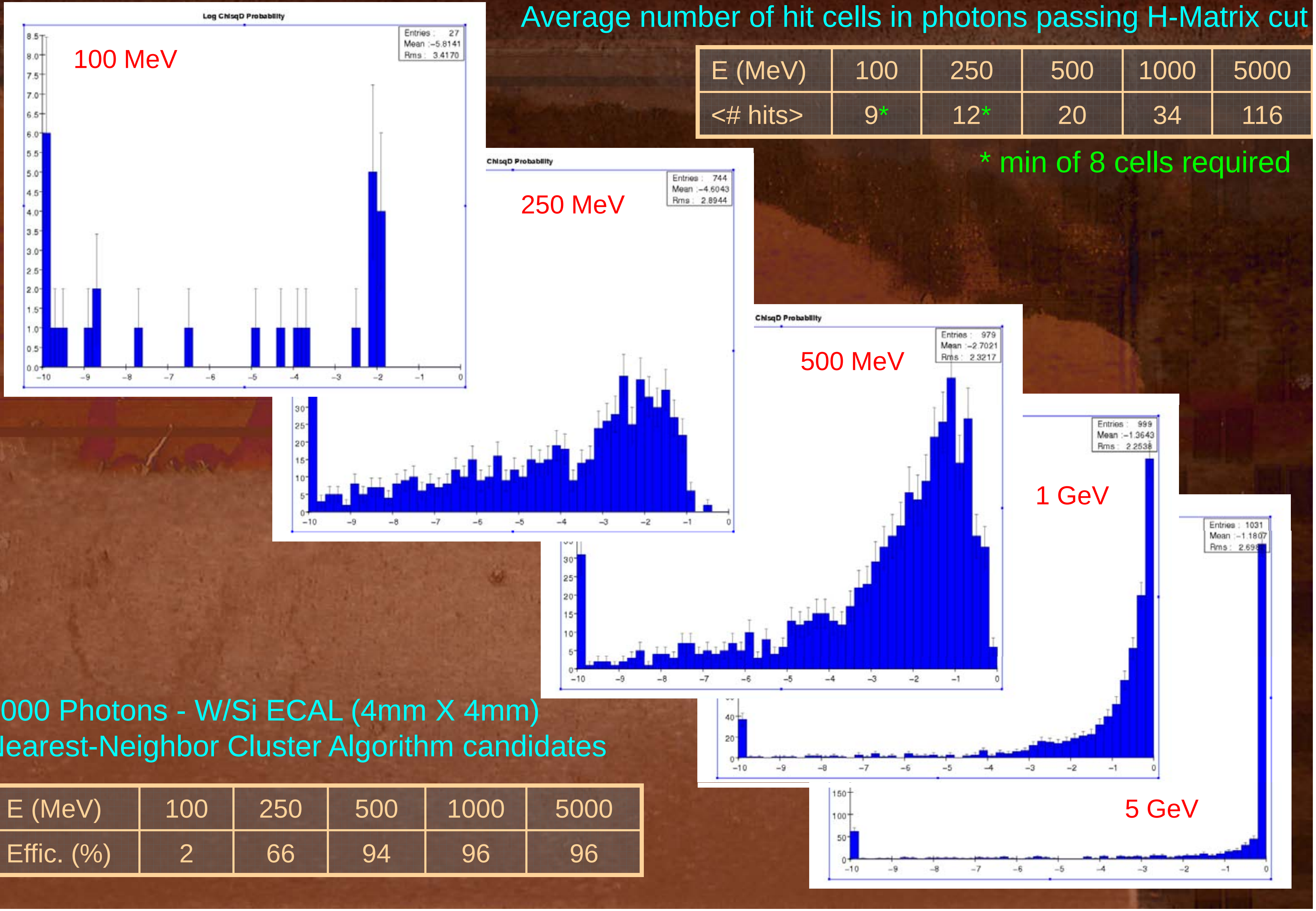
# Photon Clustering



Photons - Found photon cluster efficiency: bin 1

Photons - Found photon cluster purity: bin 2

# 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 |

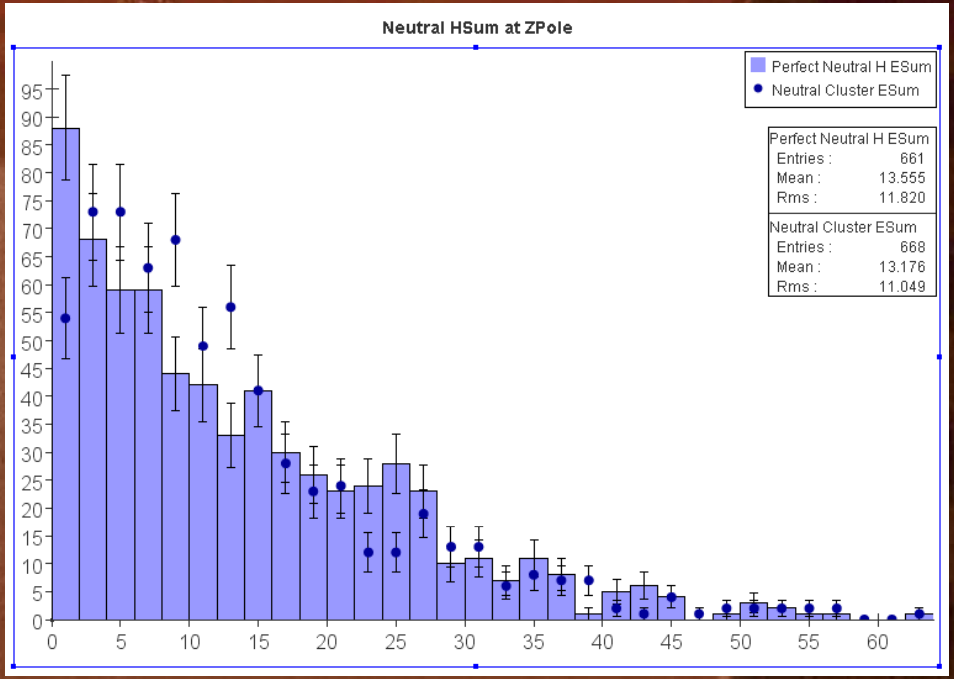
# Neutral Hadron ID

Here again, high efficiency is desired – if previous algorithms have performed well enough, purity will not be an issue.

Example :

Cluster with Directed Tree (another high efficiency clusterer)
- -> clean fragments with minimum cells
- -> check distance to nearest track – if too close, discard
- -> merge remaining clusters if close

Needs additional ideas, techniques – pointing?, shape analysis?

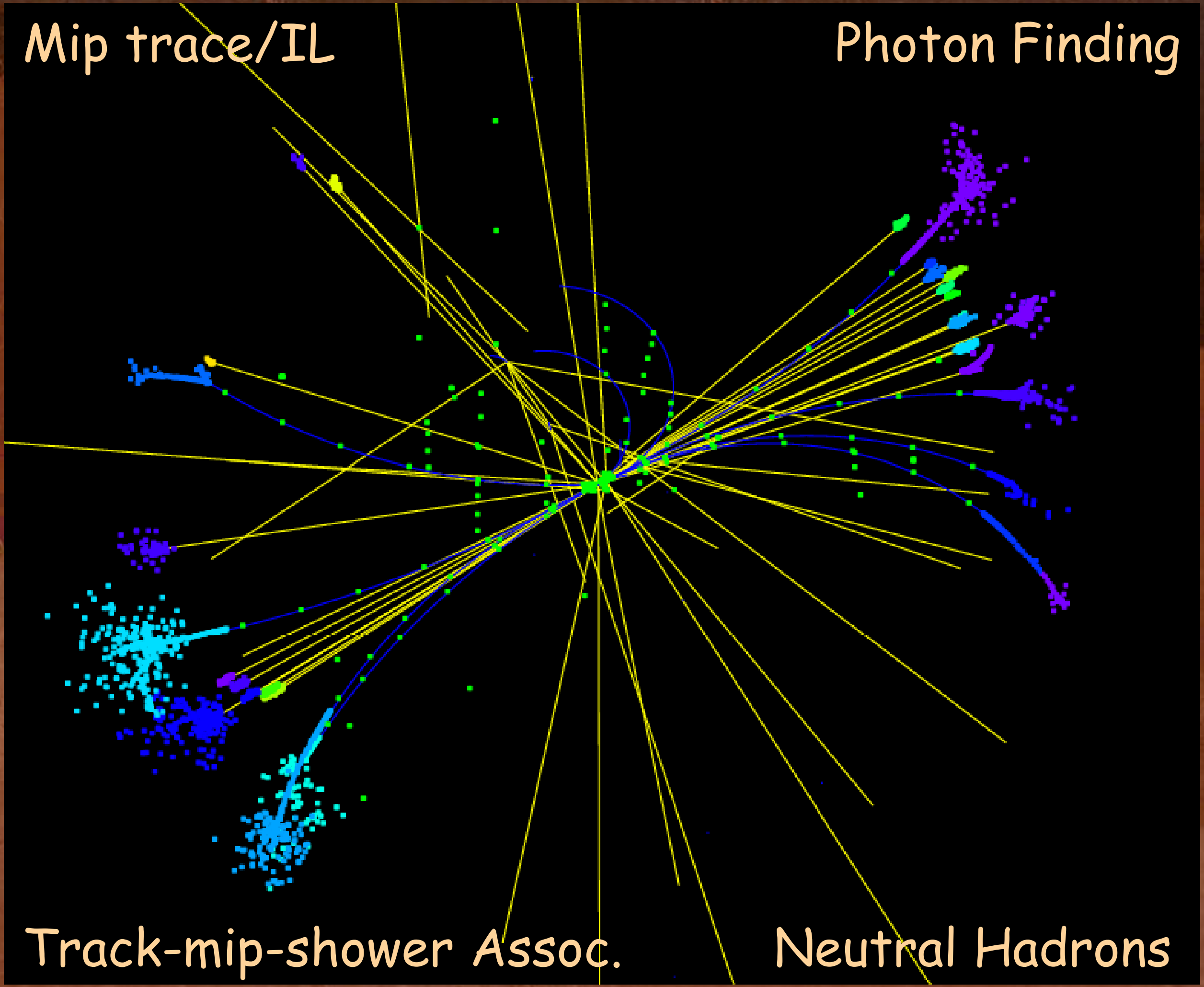


# PFA Demonstration

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

# Plans for PFA Development

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

- Development of PFAs on ~120 GeV jets – most common ILC jets
- Unambiguous dijet mass allows PFA performance to be evaluated w/o jet combination confusion
- PFA performance at constant mass, different jet E (compare to ZPole)
- dE/E, $d\theta/\theta$ -> dM/M characterization with jet E

e+e- -> ZH

## e+e- -> ZZ -> qqqq @ 500 GeV

- 4 jets - same jet E, but filling more of detector
- Same PFA performance as above?
- Use for detector parameter evaluations (B-field, IR, granularity, etc.)

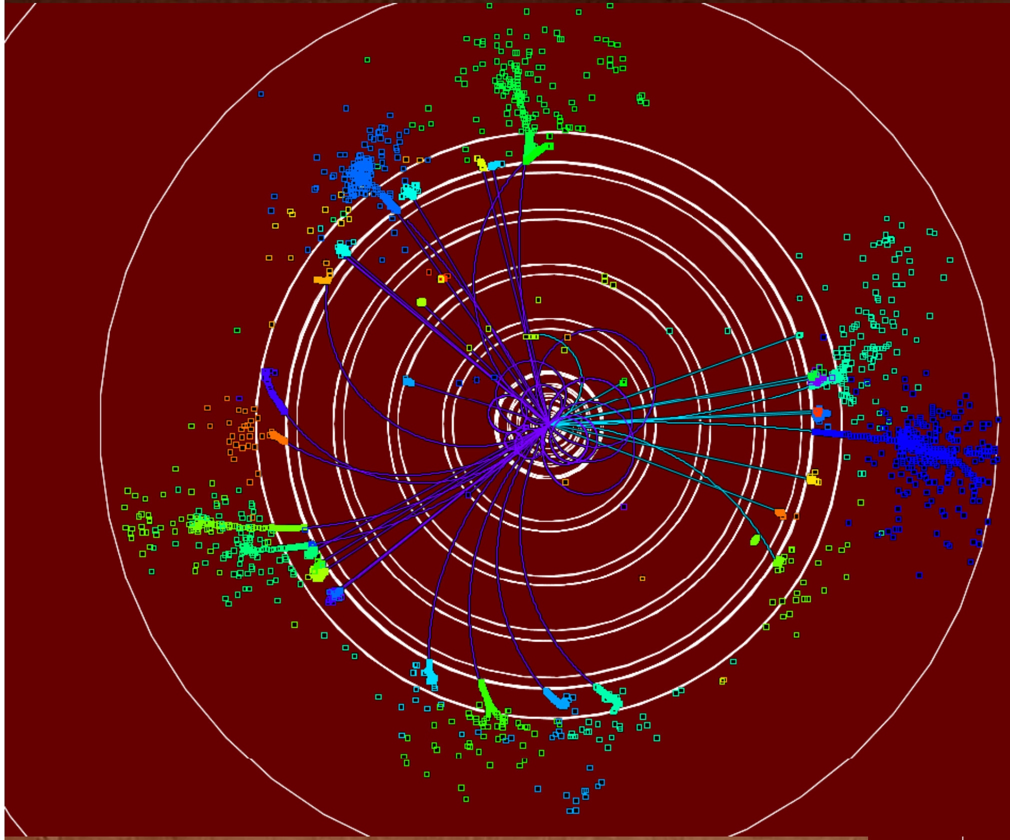
## e+e- -> tt @ 500 GeV

- Lower E jets, but 6 – fuller detector

## e+e- -> qq @ 500 GeV

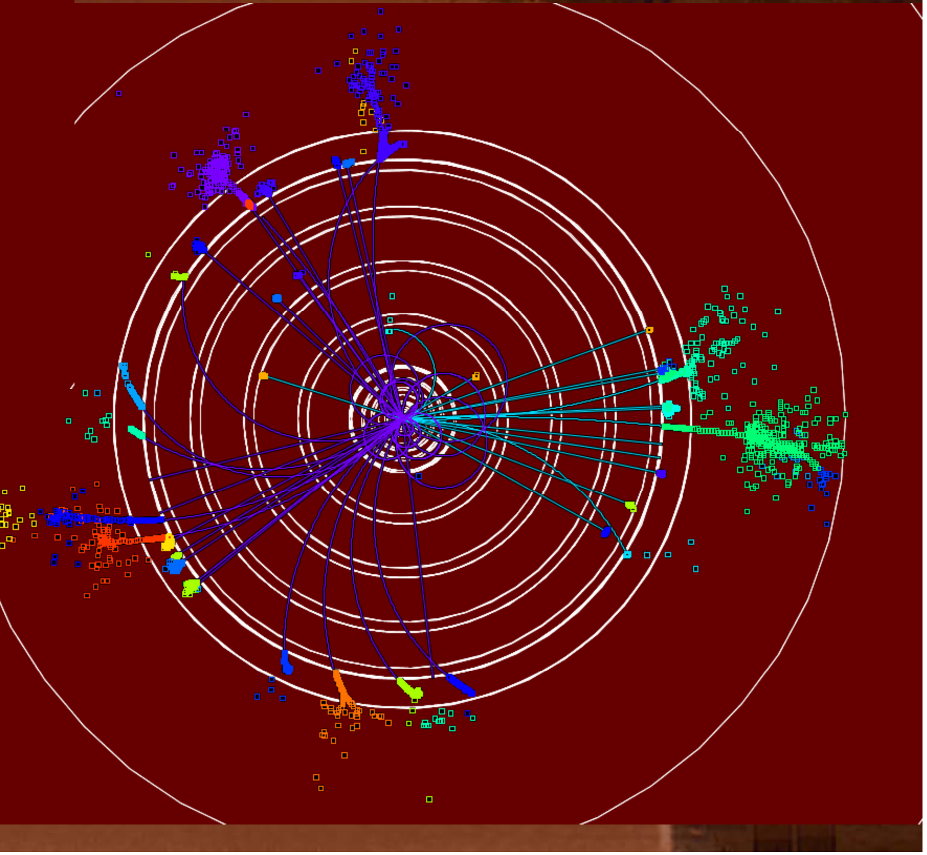
- 250 GeV jets – challenge for PFA, not physics

# PFA Development – ZPole Jets



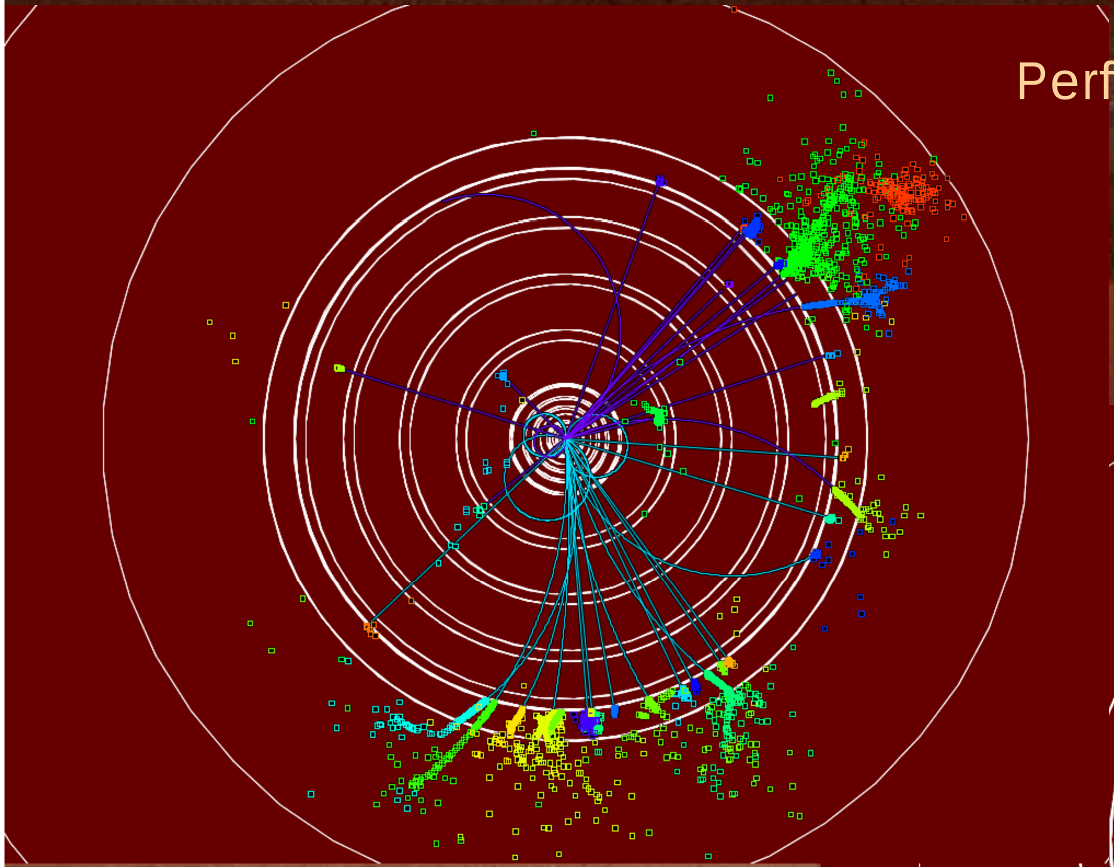
Perfect PFA Jets

kT jet algorithm in 2 jet mode

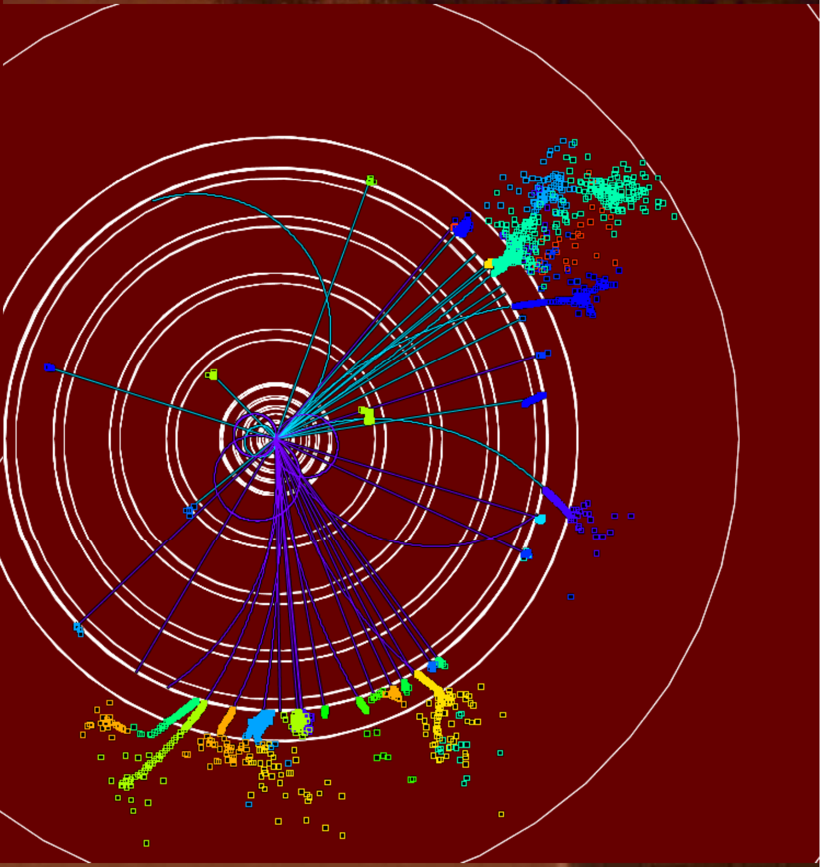


PFA Jets

# Plans for PFA Development – ZZ -> qqνν Jets



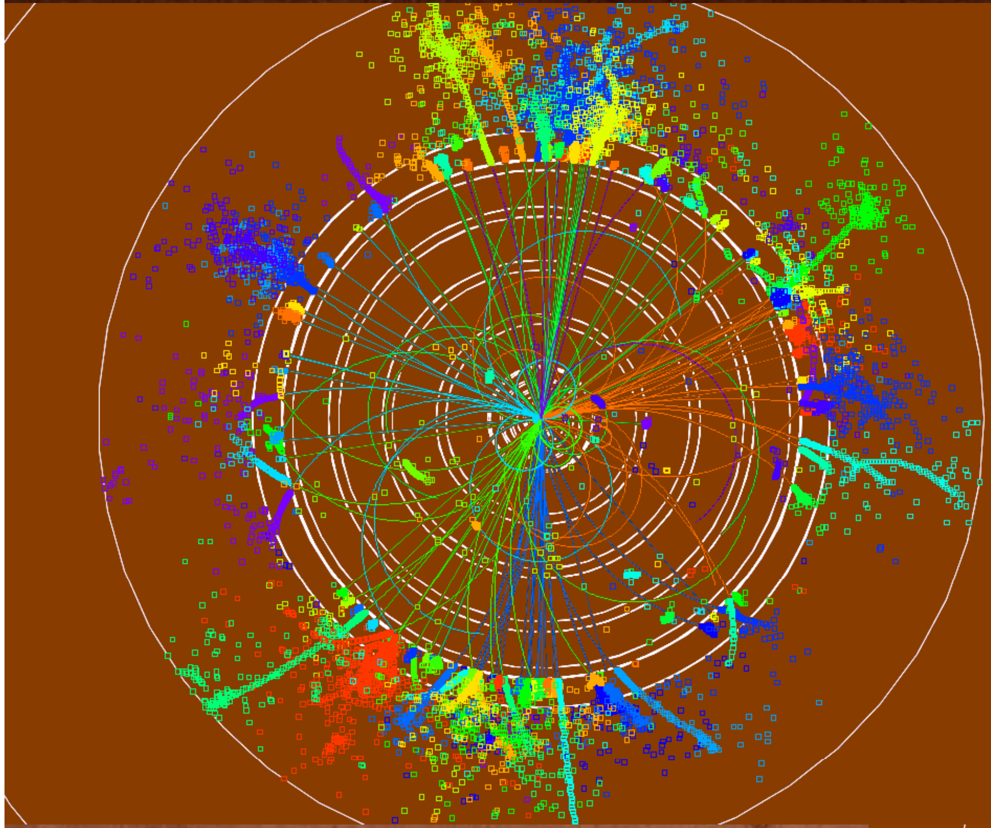
Perfect PFA Jets



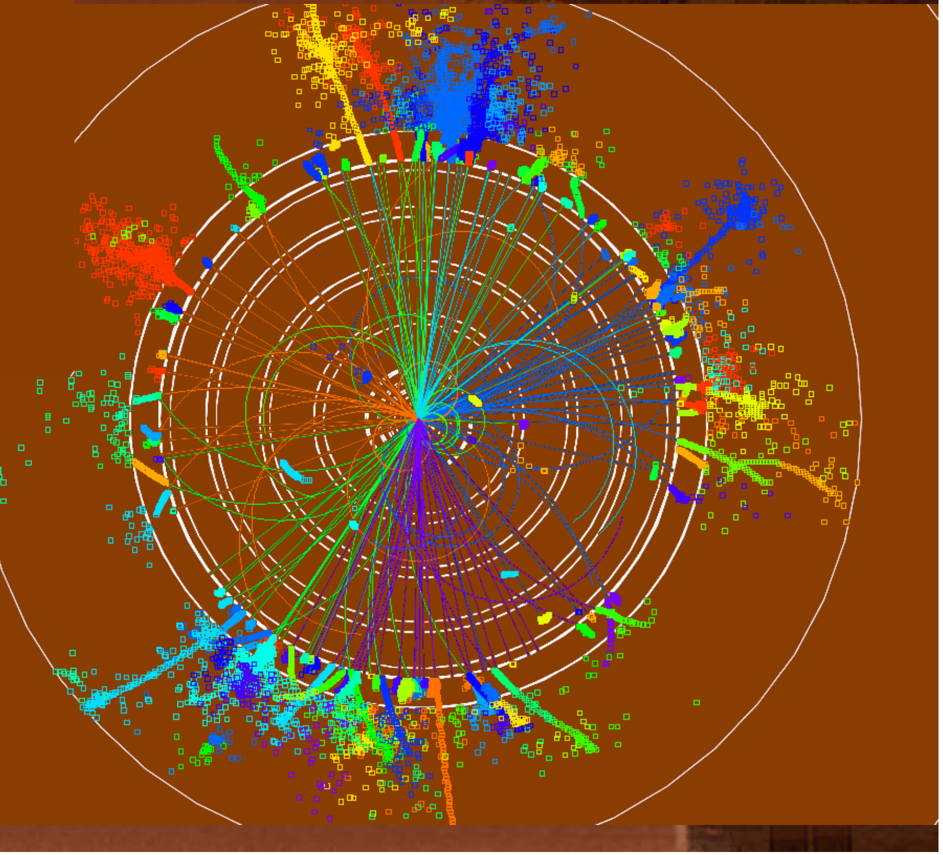
kT jet algorithm in 2 jet mode

PFA Jets

# Plans for PFA Development – tt Jets



Perfect PFA Jets



PFA Jets

6 jets in both events using
ycut = 0.00025 in kT jet algorithm