LC GRPC Semi-Digital HCAL Reconstruction algorithm development

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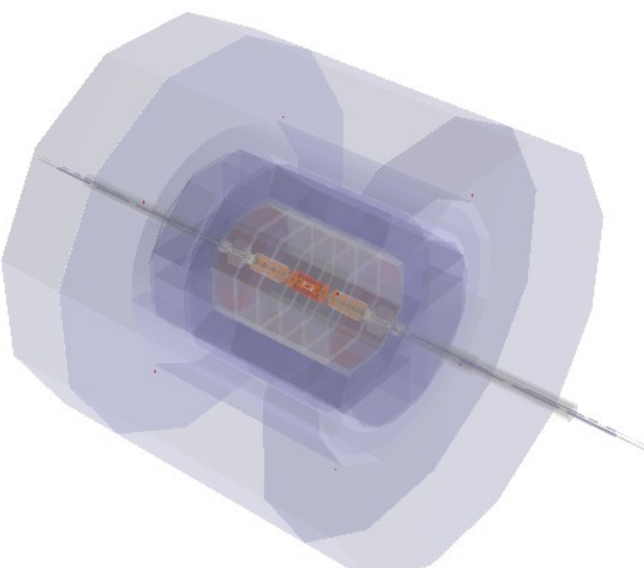
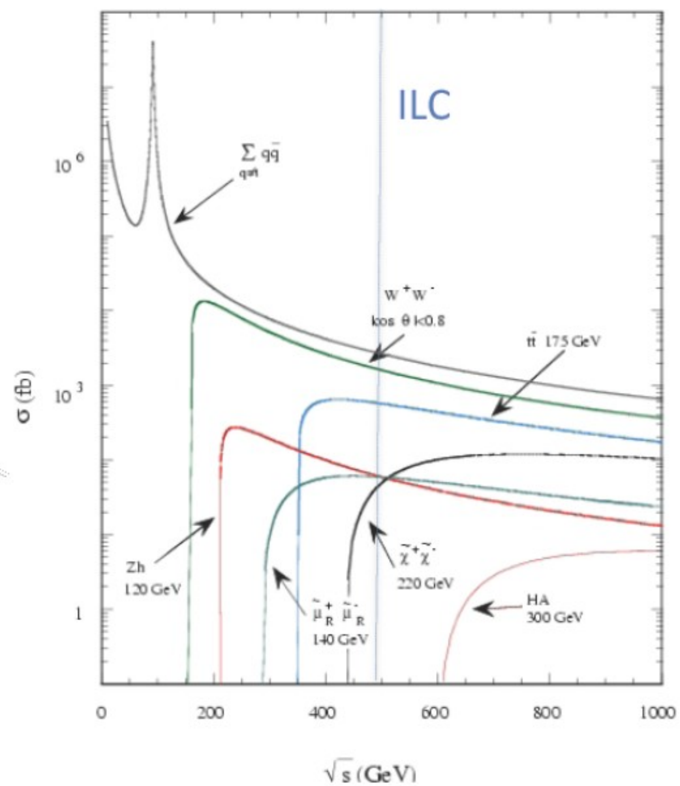
Content

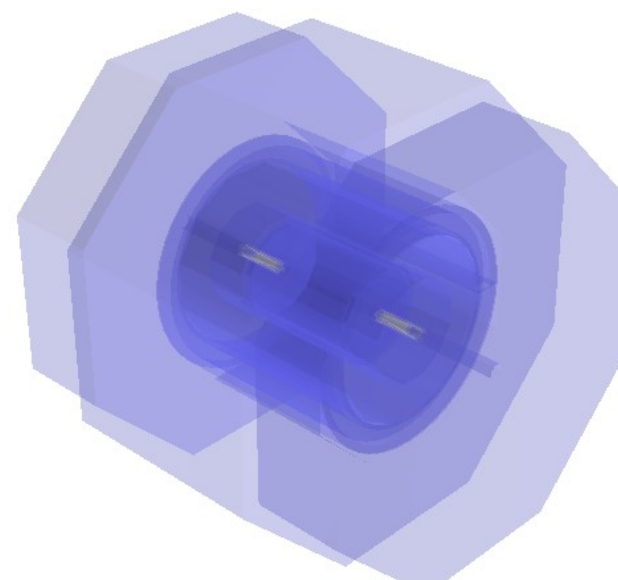
- Part I: LC Physics & GRPC DHCAL

- Part II, Software developments:
  - *Druid, Event Display for the LC*
  - *PandoraPFA @ DHCAL & performance Diagnose*
  - *Toward reliable simulation: detailed geometry implimentation, comparison and digitization*
  - *Hints to improve Energy Estimation*

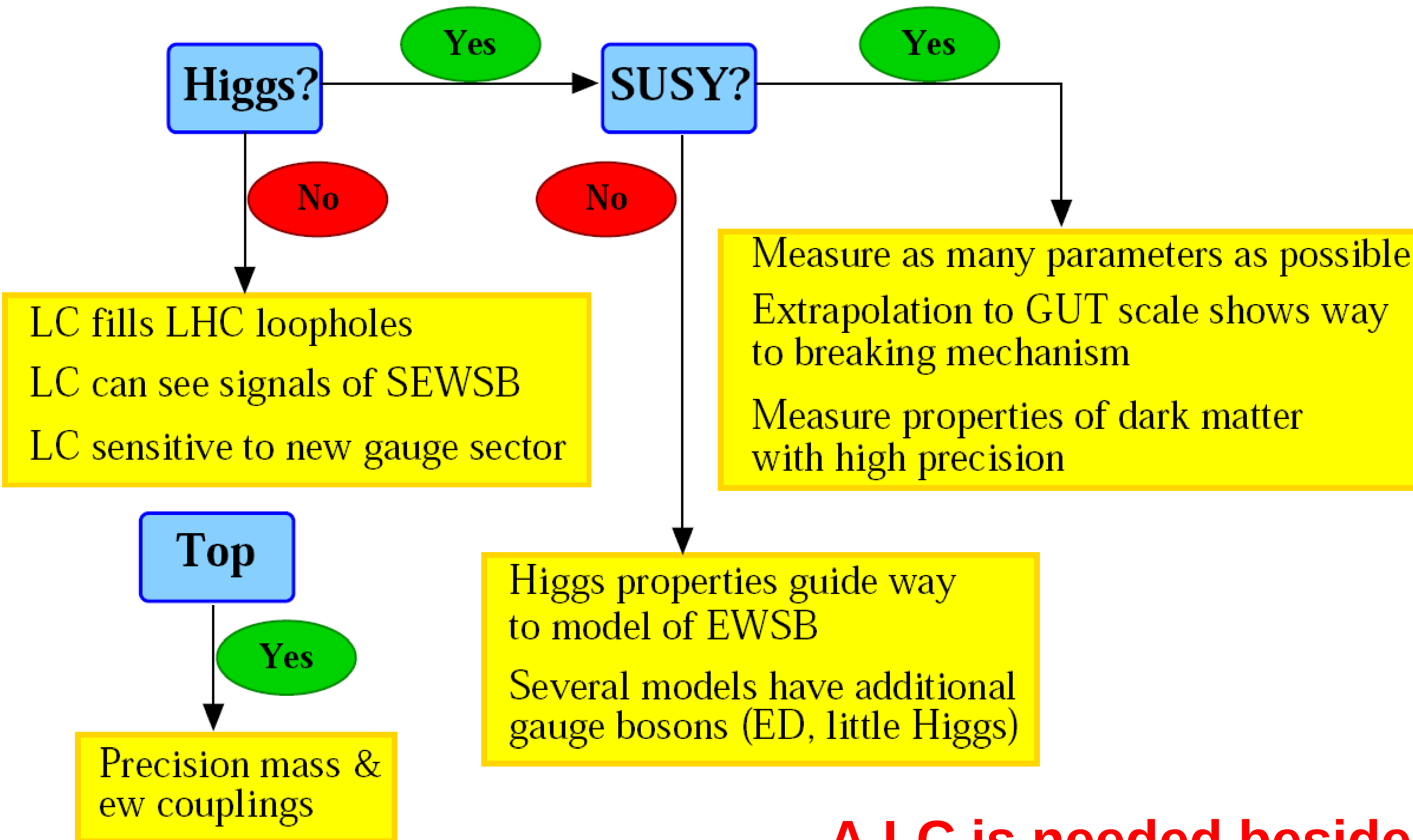
Part I: Physics @ LC & GRPC SDHCAL







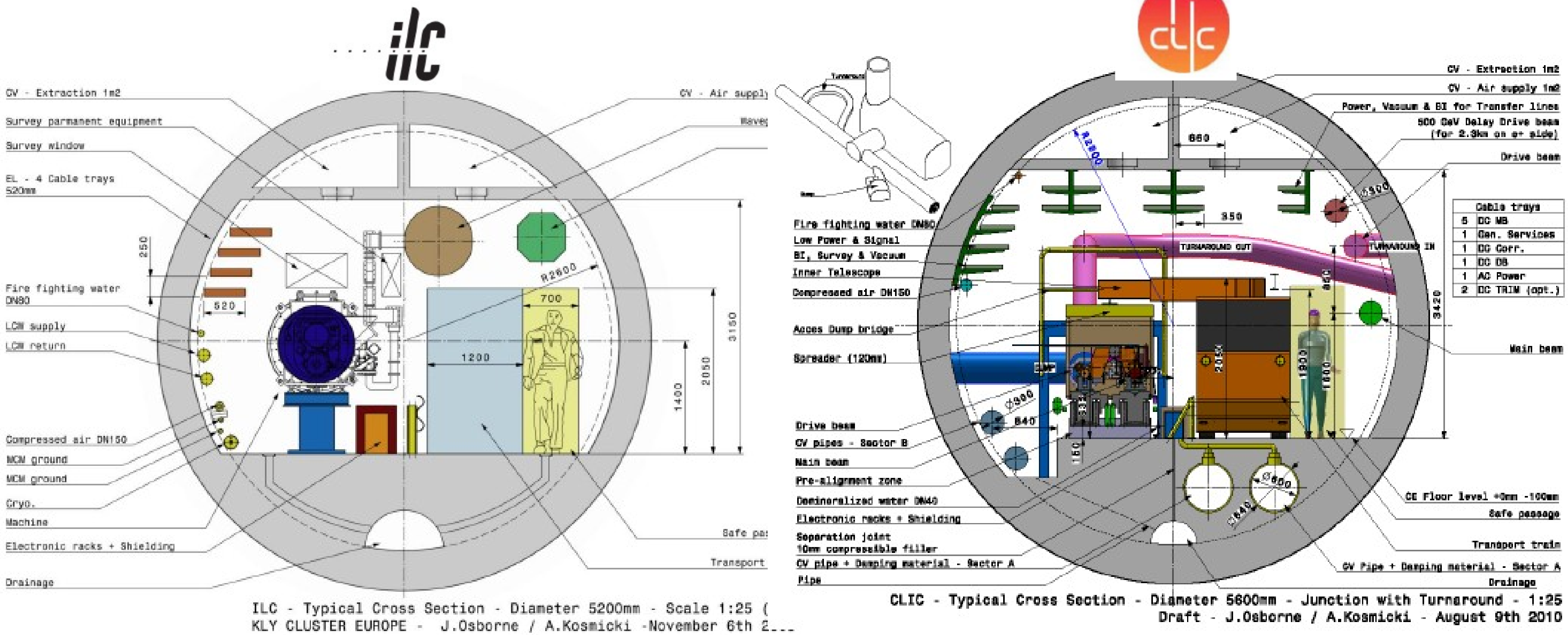
Physics @ LC



Klaus Moenig: Physics potential of LC

A LC is needed besides the LHC in any case

Candidate Linear Collider



- CLIC: Compact Linear Collier, center-of-mass energy: 0.5 - 5 TeV. Warm technology (Room temperature & high gradient (~ 100MV/m), small bunch spacing).
- ILC: International Linear Collider, center-of-mass energy: 0.5 – 1.0 TeV. Cold technology (2K & low gradient (~ 31.5 MV/m), large bunch spacing)
- CLIC & ILC: very different accelerators with similar detector.

Jet resolution & PFA

Particle Flow Algorithm:

Measure jet particles in different sub detector!

$$E_{jet} = E_{charged\ tracks} + E_{\gamma} + E_{h^0}$$

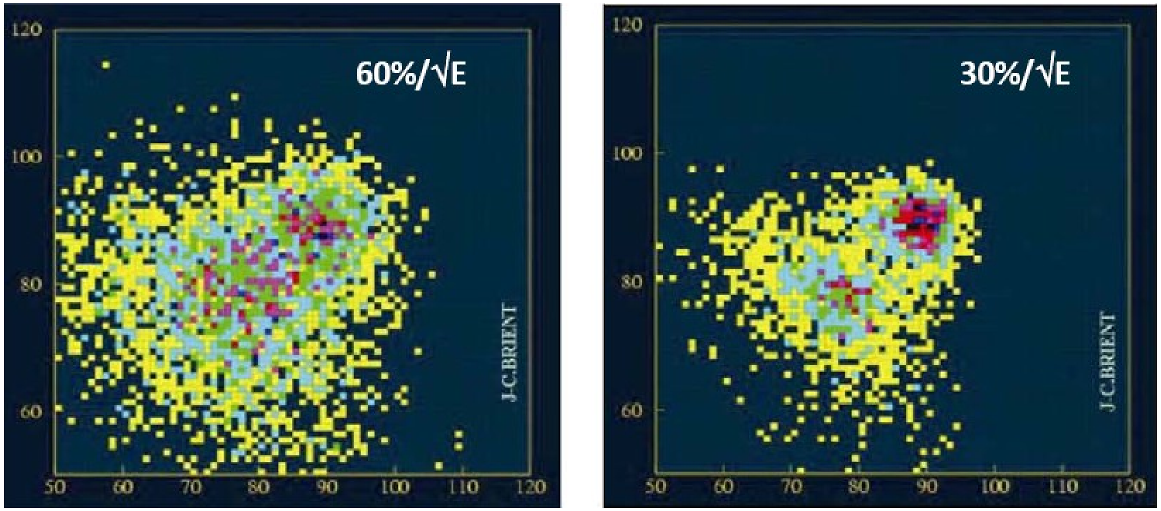
fraction: 65% (charged tracks), 26% (γ), 9% (h^0)

Charged Particle – Tracker:
Δp/(p*p) ~ 2E-5 (1/GeV)
Photon – ECAL:
ΔE/sqrt(E) ~ 15%
Neutron Hadron – HCAL:
ΔE/sqrt(E) ~ 50%

Final states in e+e- interaction up to 1 TeV c.m.s

Multi bosons	Multifermions + Boson(s)
ZH	e^+e^- H , e+e− Z
WW	νν H , νν Z
ZZ	ttH
ZHH	e ν W
ZZZ	νν WW, νν ZZ
ZWW	ttbar

Di-jet mass for WWνν & ZZνν @ 500GeV



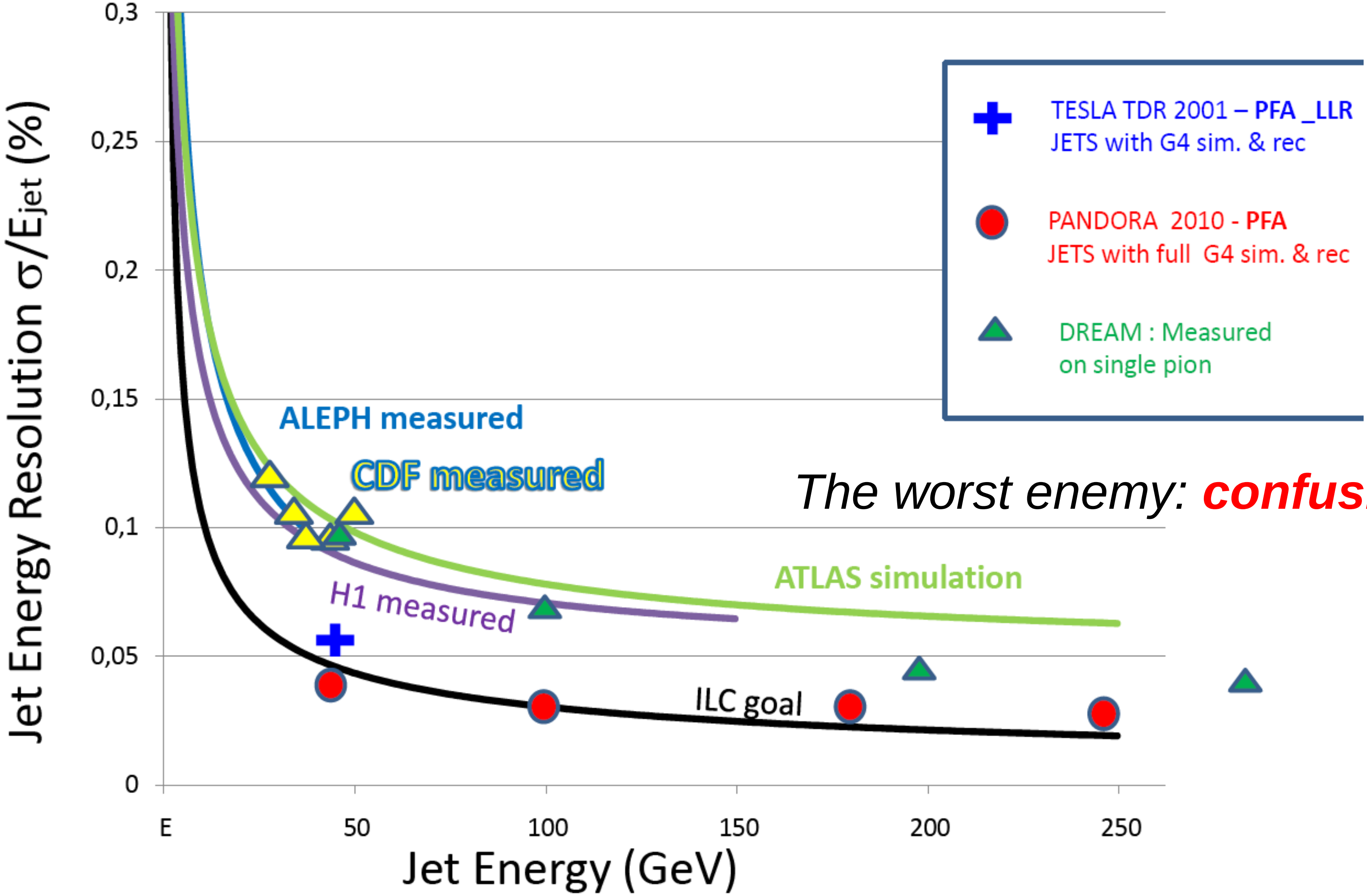
J-C. Brient - IWLC 2010

Given a perfect detector with no confusion:

$$\sigma^2_{jet} = \sigma^2_{ch.} + \sigma^2_{\gamma} + \sigma^2_{h^0} \quad \text{gives about} \quad (0.14)^2 E_{jet}$$

Jet energy resolution

Calorimeter for ILC



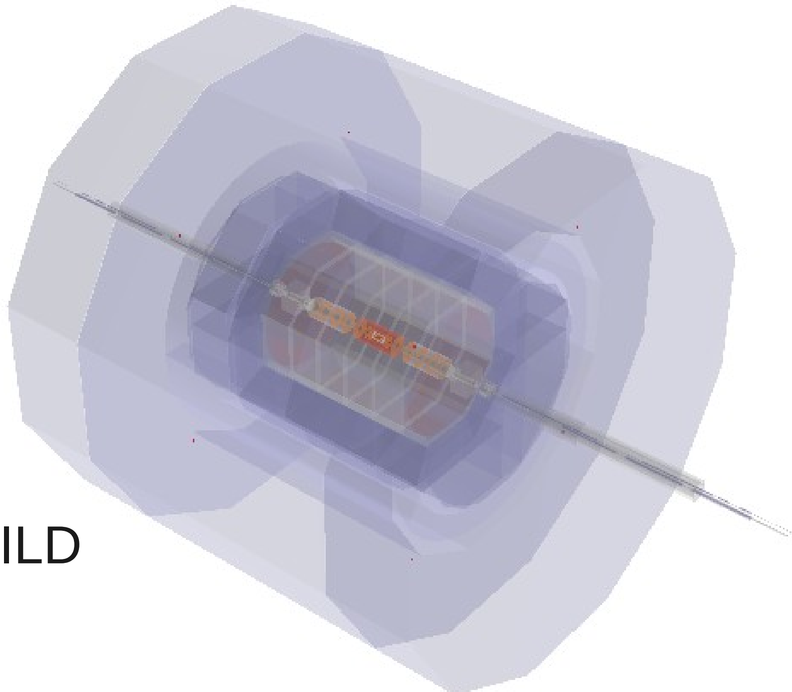
The worst enemy: ***confusion***

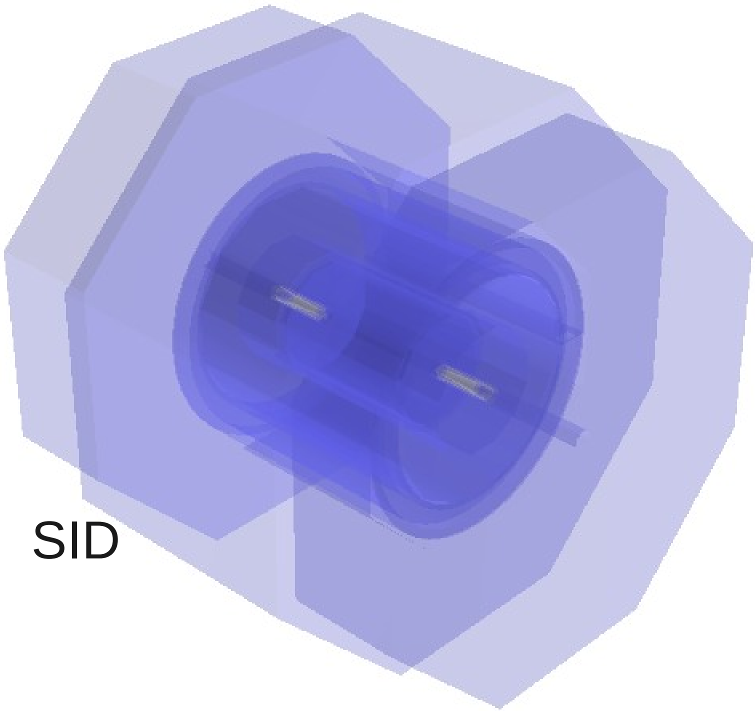
J-C. Brient - IWLC 2010

Real life and real detector →

- $\sigma^2_{threshold}$ → Energy threshold to be rec. (depends on species)
- $\sigma^2_{efficiency}$ → loss of particles (not reconstructed)
- $\sigma^2_{confusion}$ → Mixing between particles in the calorimeter

PFA Oriented LC detectors


ILD

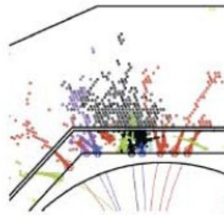

SID

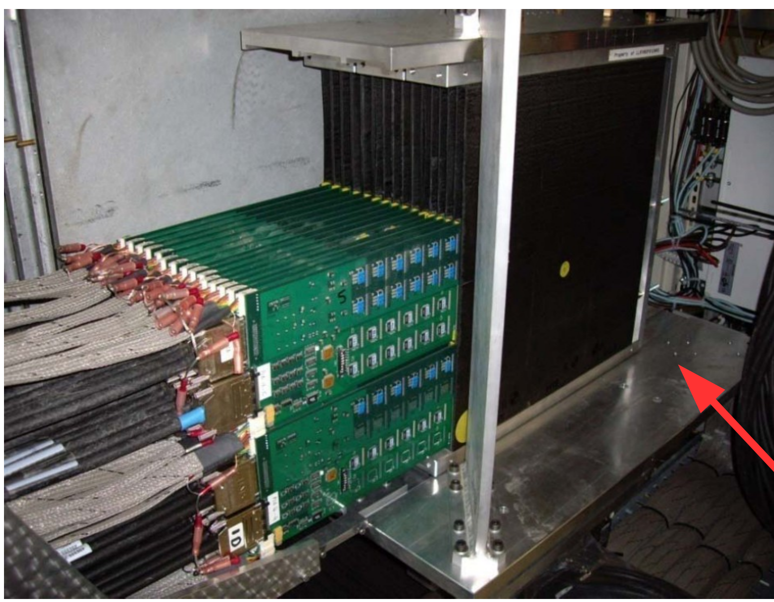
- PFA: less confusion ~ good separation ~ high granularity
  Granularity > Energy Resolution for the Calorimetry... → CALICE Calorimeter for ILC
  (exception: 4^{th} concept with dual readout HCAL)

- PFA Oriented detector (both have ILC/CLIC Versions):
  - ILD (European + Asia, International Large Detector): TPC (+ Silicon inner detectors) tracking with B = 3.5T
  - SiD (US, Silicon Detector): Silicon tracking with B = 4T

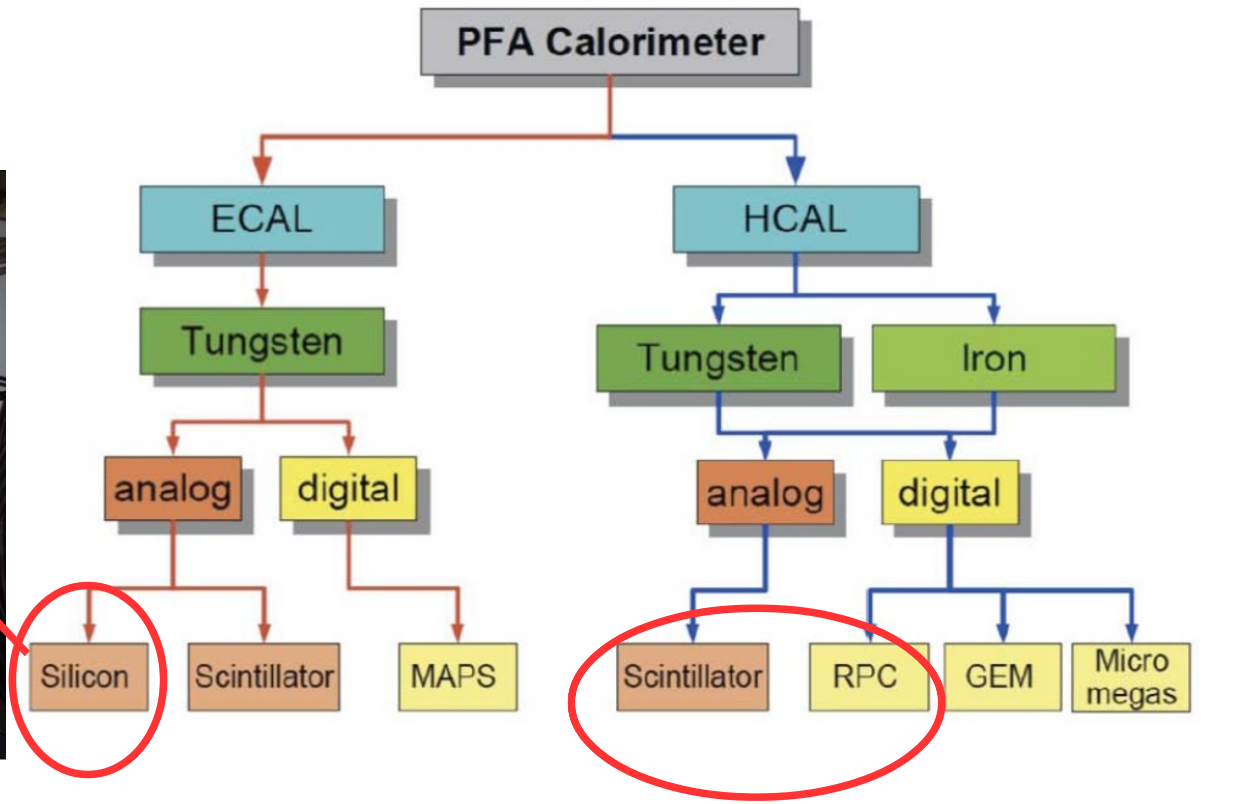
High granularity Calorimetry

eg: ECAL Prototype, 10k channels in a cube of 18 cm side ~ 1/8 of CMS ECAL





Technology tree

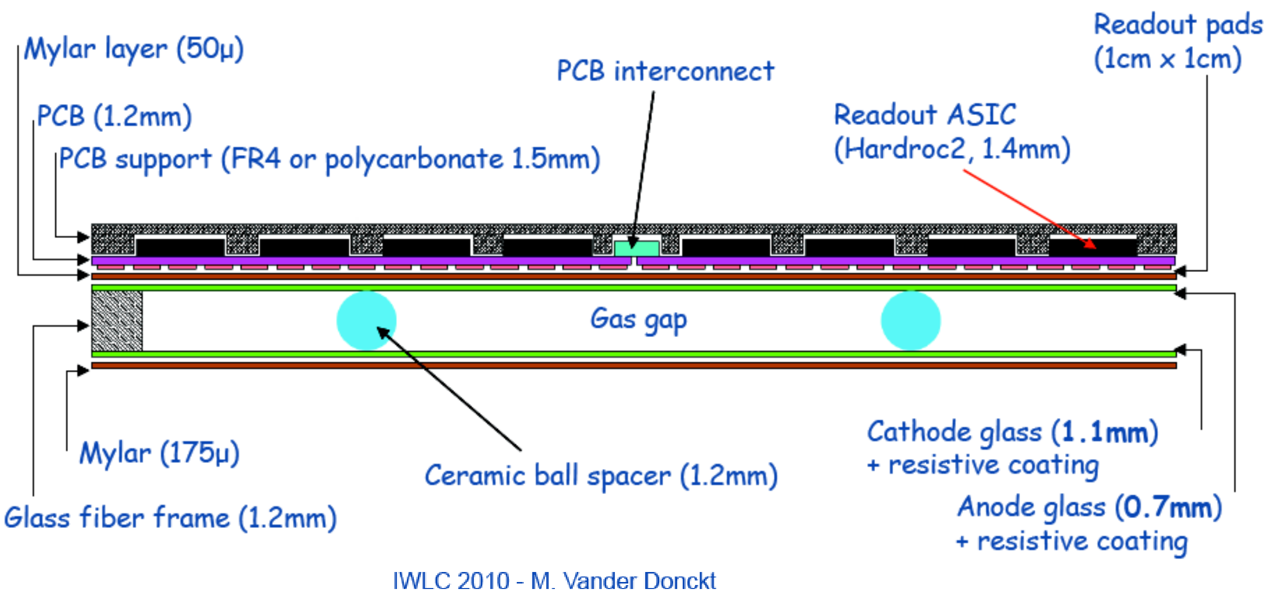


Scintillator AHCAL with 3 * 3 cm cell @ DESY

2 GRPC Digital HCAL with 1 * 1 cm cell: SDHCAL @ IPNL et al
DHCAL @ Fermi Lab

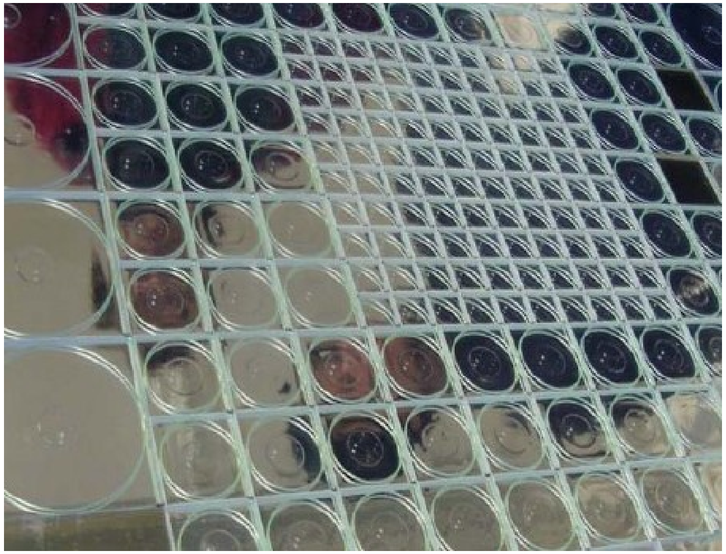
Gas Vs Scintillator

Gas: High granularity (1*1 cm) @ low cost



To compare:

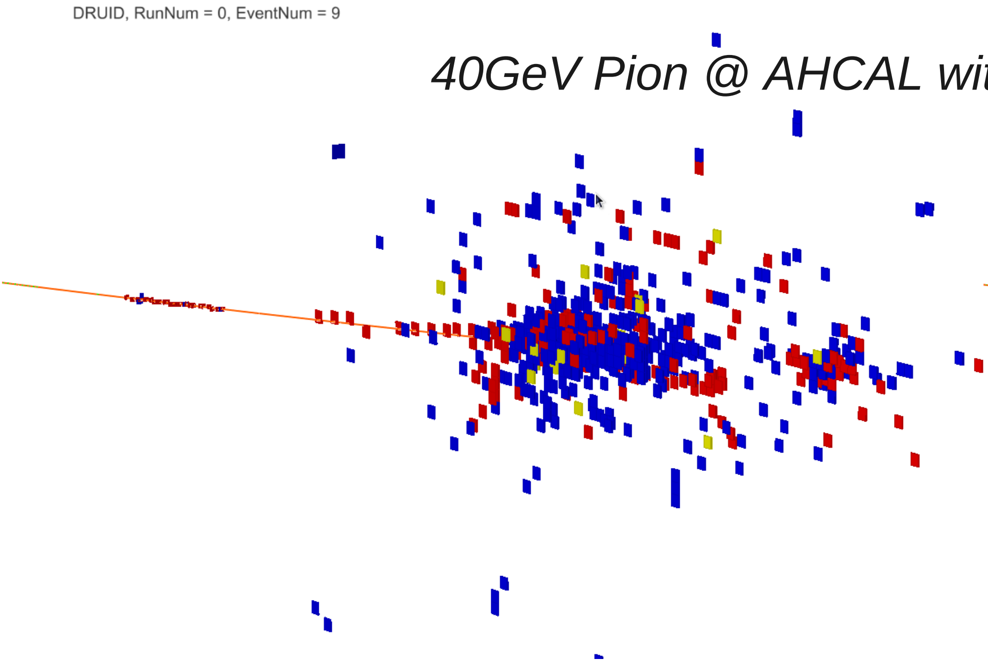
Sensor layer in Scintillator AHCAL. Cell size: 3*3 cm, 6*6 cm & 12 * 12 cm

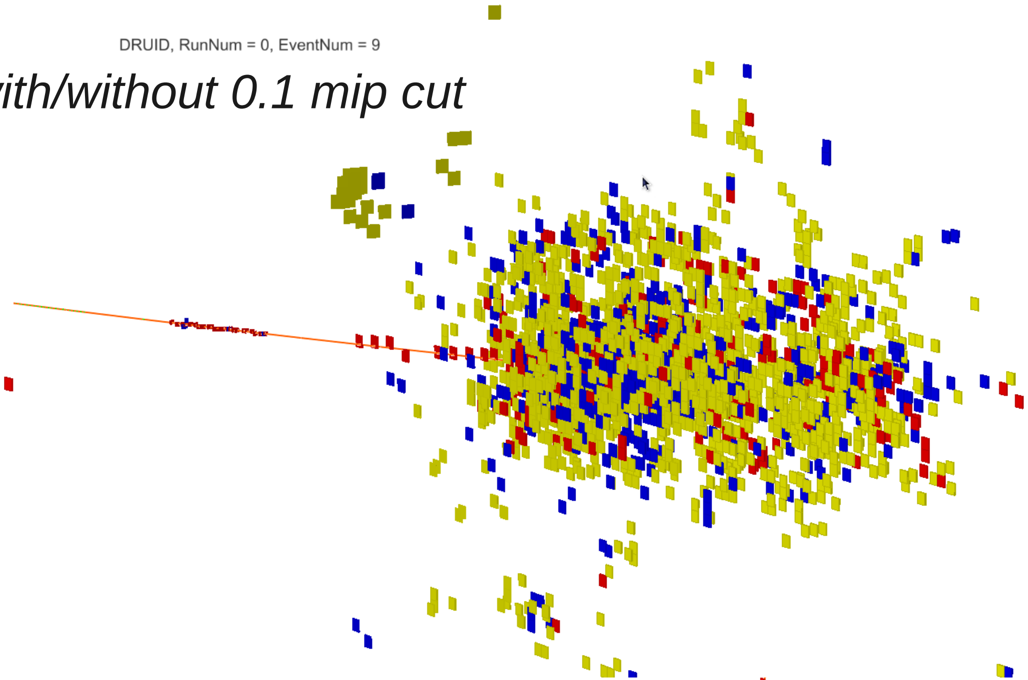


- Gaseous detector:
  - RPC: High efficiency, homogeneous, low cost, robust...
  - Huge fluctuation on induced charge: Semi-digital (channel coded on 2 bits)
  - Free of neutron hits

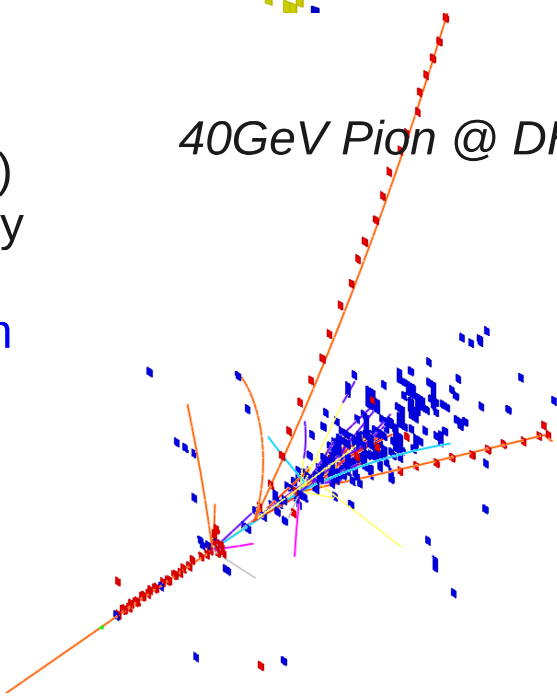
Neutron hits

40GeV Pion @ AHCAL with/without 0.1 mip cut





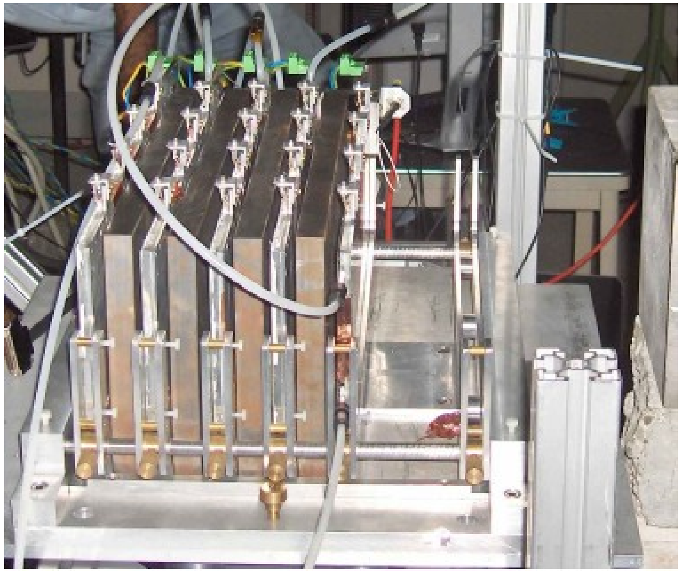
40GeV Pion @ DHCAL

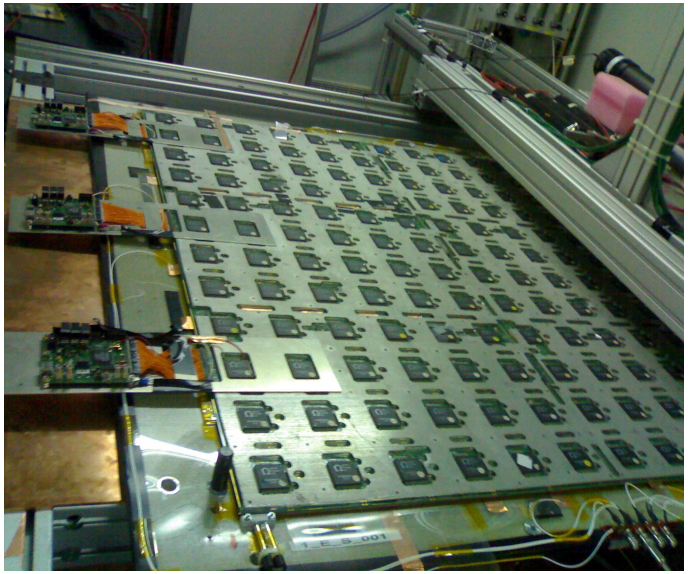


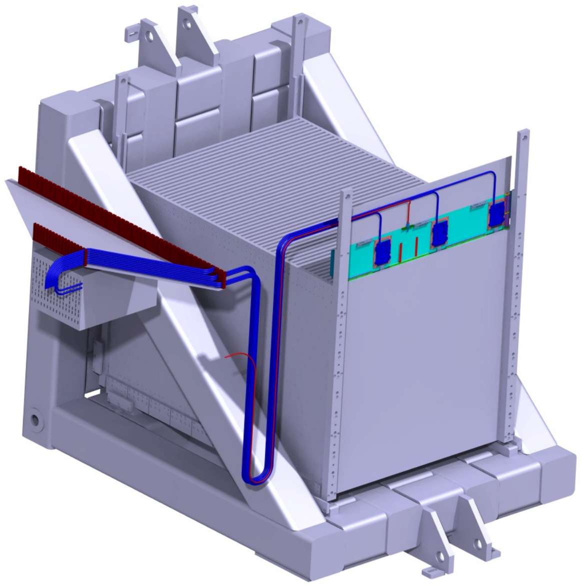
Hit Colour: EM (blue), Neutron (yellow) or hadronic (red)
- AHCAL: Shower centre surrounded by lots of low energy neutron hits
- Needs carefully analysis: Confusion & Energy resolution

GRPC SDHCAL

- Prototypes & test beam
  - Toward the proof of principle for Detector Baseline Design (DBD, end of 2012)
  - Mini DHCAL, m² → m³ ANR DHCAL with various new technologies
  - Performance study @ test beam & cosmic ray: homogeneity, efficiency, multiplicity, stability, noise rate, induce charge spectrum...







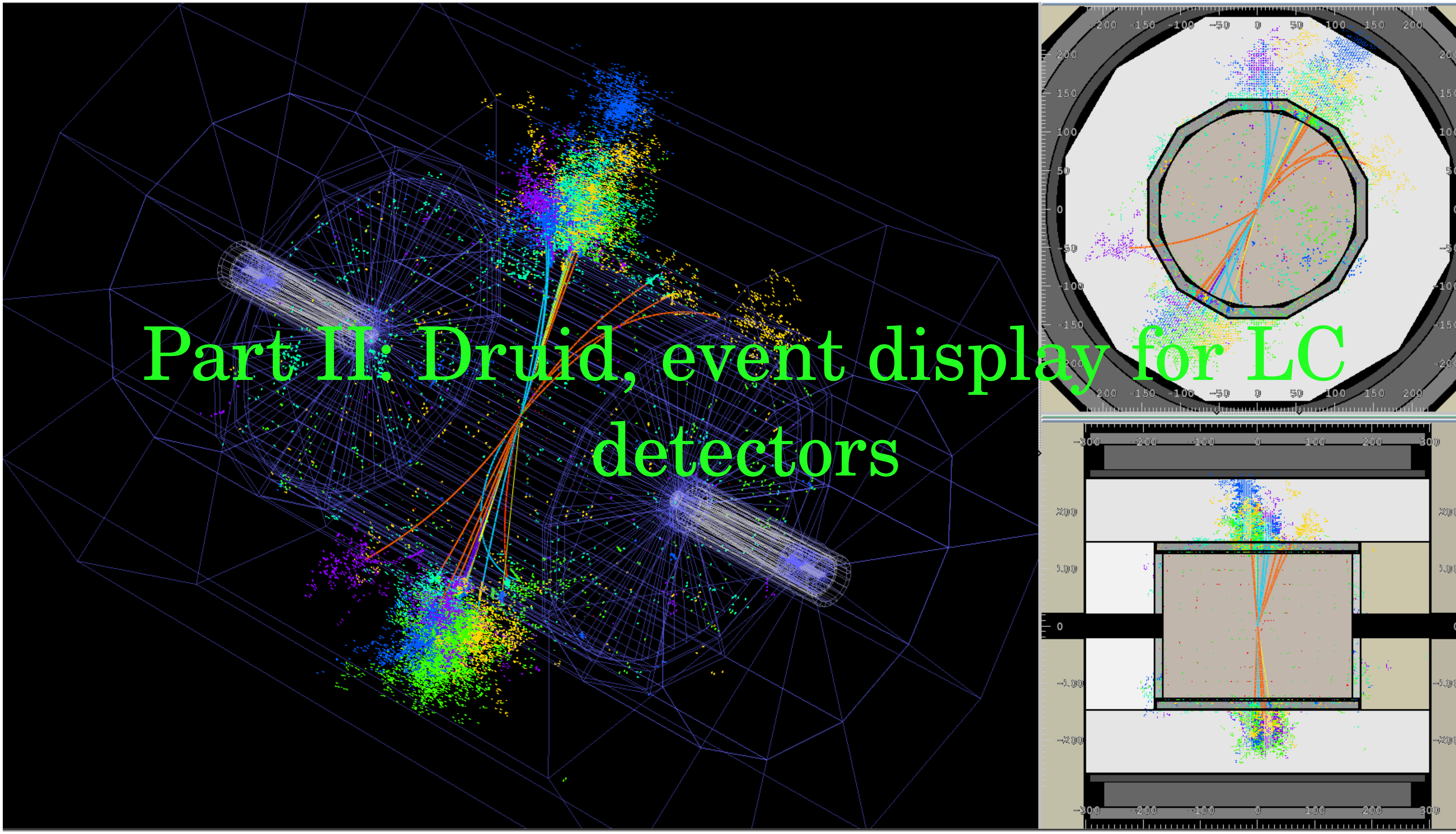
1k channels → **10k** channels → **400k** channels!

Reconstruction Software

- Goal: develop & optimize the reconstruction chain for ILD with SDHCAL

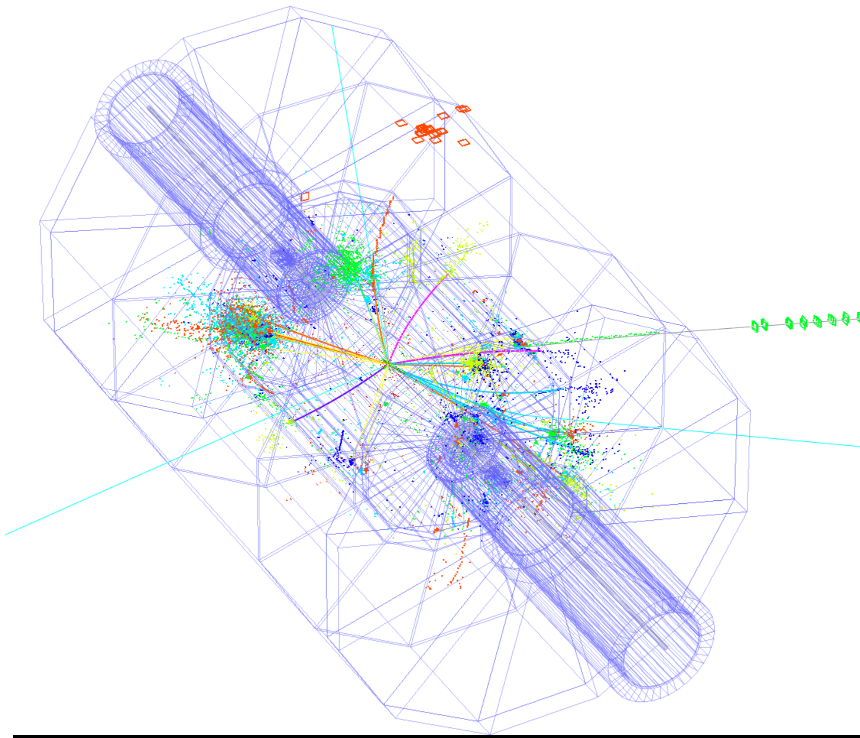
- Status & Plans:
  - Detailed simulation (*full detector and prototypes*) and with experimental input
  - PandoraPFA (*Currently Best PFA for the LC*) adapted:
    - Preliminary RPC digitization
    - To optimize PandoraPFA for SDHCAL
  - Specialized SDHCAL algorithms: under development
    - Density & NN analysis, Kalman filter, Hough transform...
    - Specialized clustering + Energy estimator
  - Druid (event display): heavily employed in algorithm development

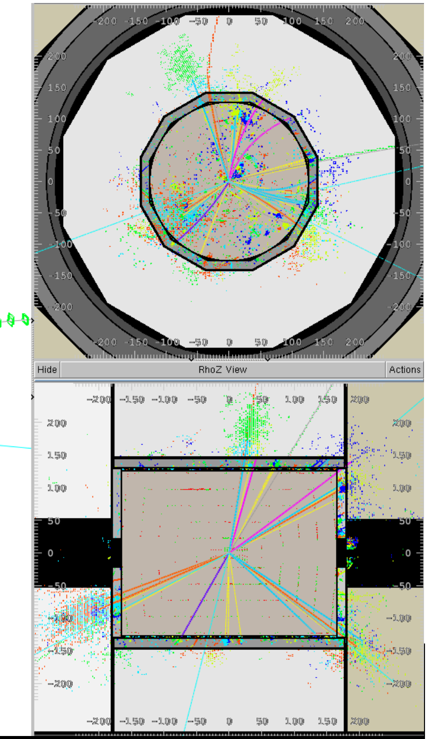
Part II: Druid, event display for LC detectors

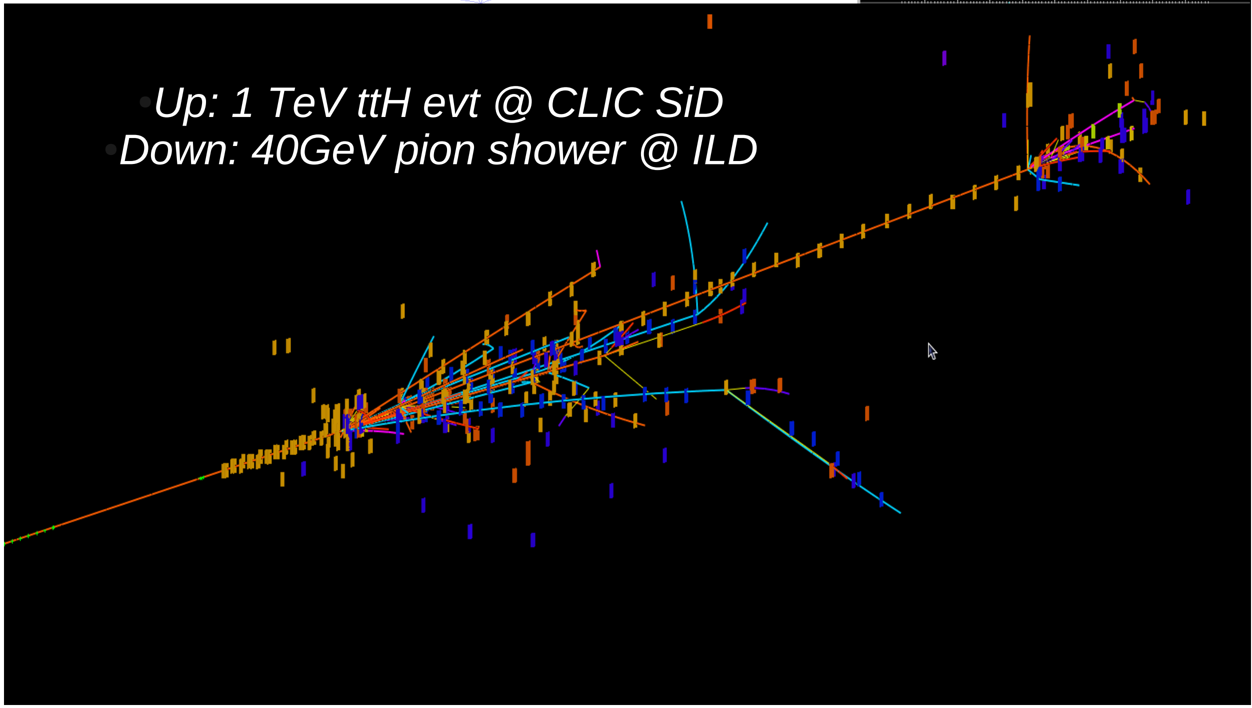


DRUID

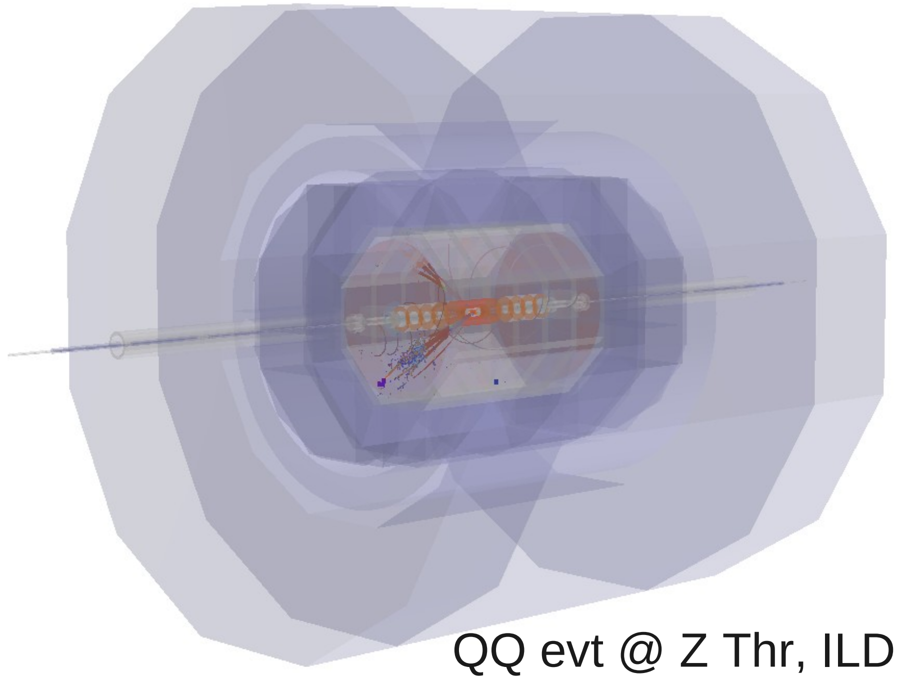
- Motivation:
  - To understand the ILC events & jet/shower details
  - To debug simulation and reconstruction algorithm
- Based on ROOT Teve:
  - Visualize event information (slcio file) and/or detector geometry (gdml file) in arbitrary combination & different styles
- Compact (src code < 10k line), Minimal dependency (LCIO (latest > v01-51-02) & ROOT (latest > v05-28-00)) and fast (~ 3 sec for 1 TeV ttH event @ SiD with projections)



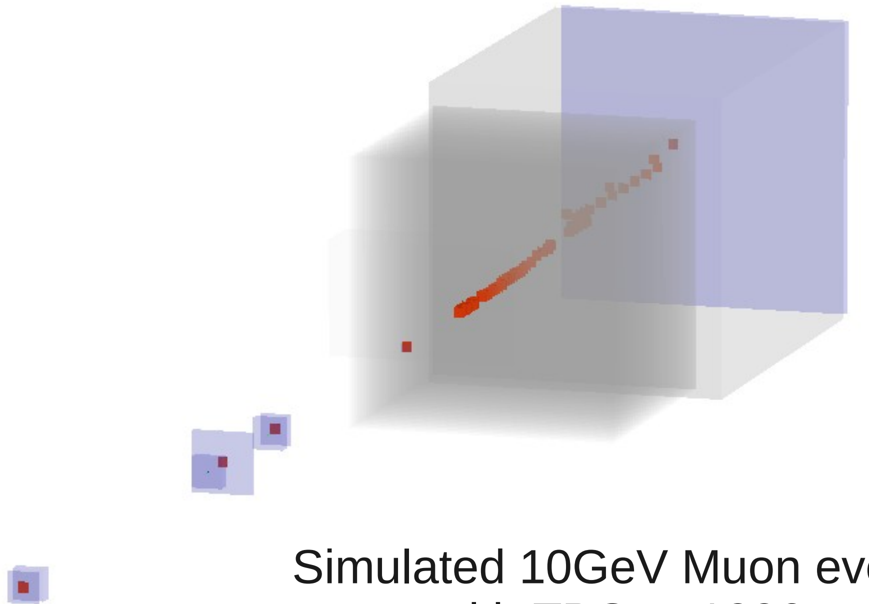




GDML Geometry browser



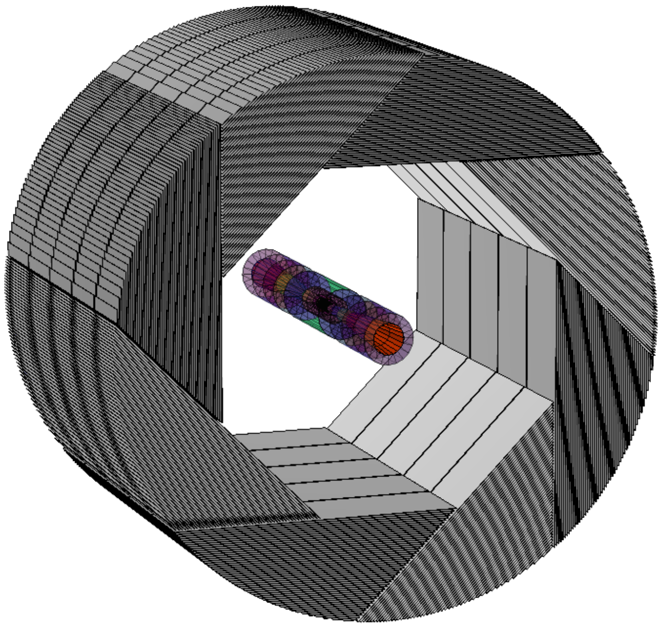
QQ evt @ Z Thr, ILD

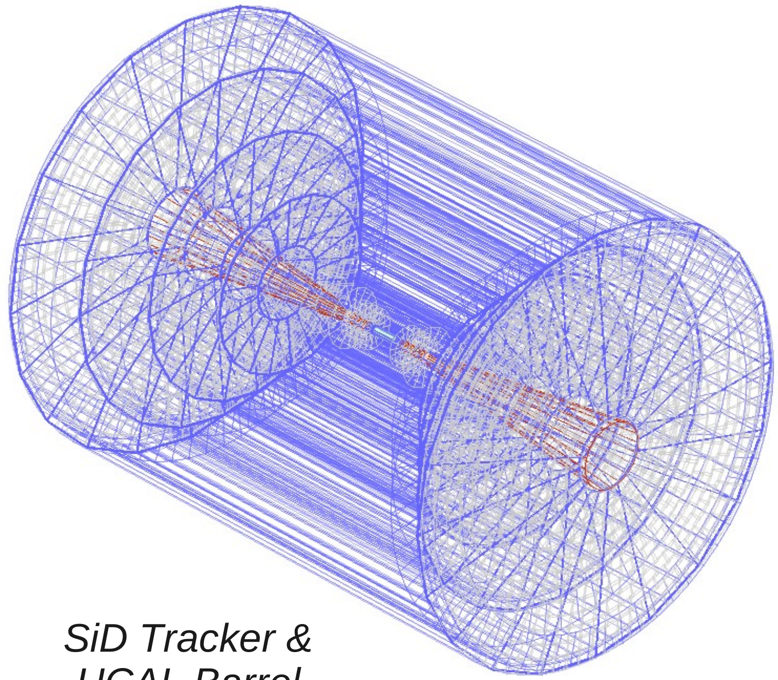


Simulated 10GeV Muon event with TBCern1006

- GDML file: simulation level geometry information, dumped from official simulation package Mokka (*version higher than 07-03*)
- Druid: contains all the latest detector models: (ILD00, ILD00_Dhcal, clic01_ild, sidloi3, clic_sid_cdr_b, test beam prototypes...)
  - Tunable display depth, transparency, color, bkgrd, mount/unmount sub detectors...

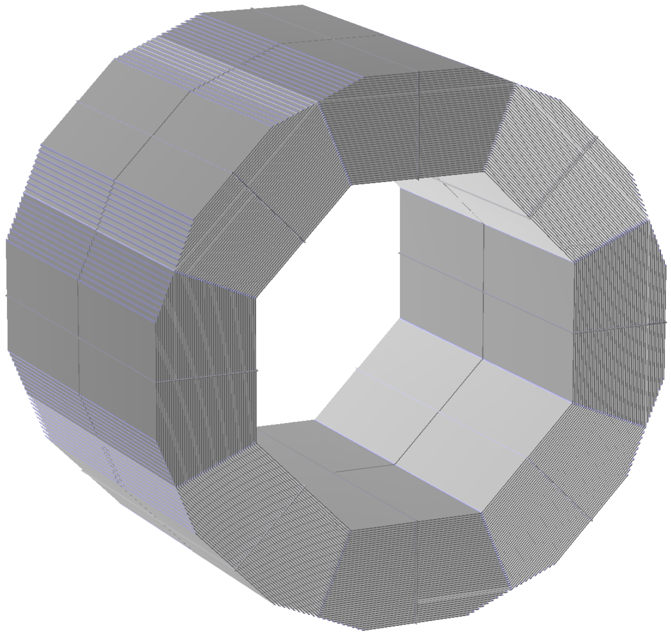
Example geometries

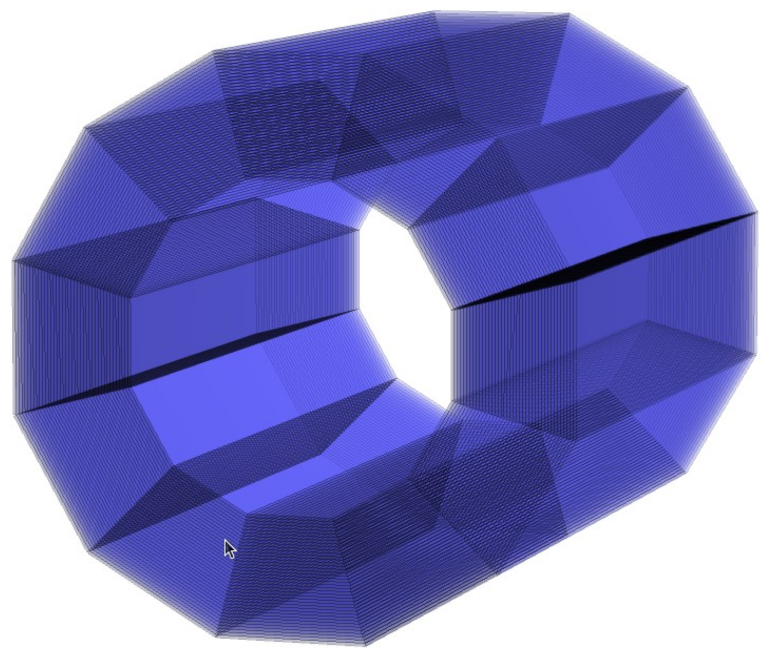




ILD a la Videau HCAL (for DHCAL) + inner & TESLA HCAL (for AHCAL)

SiD Tracker & HCAL Barrel

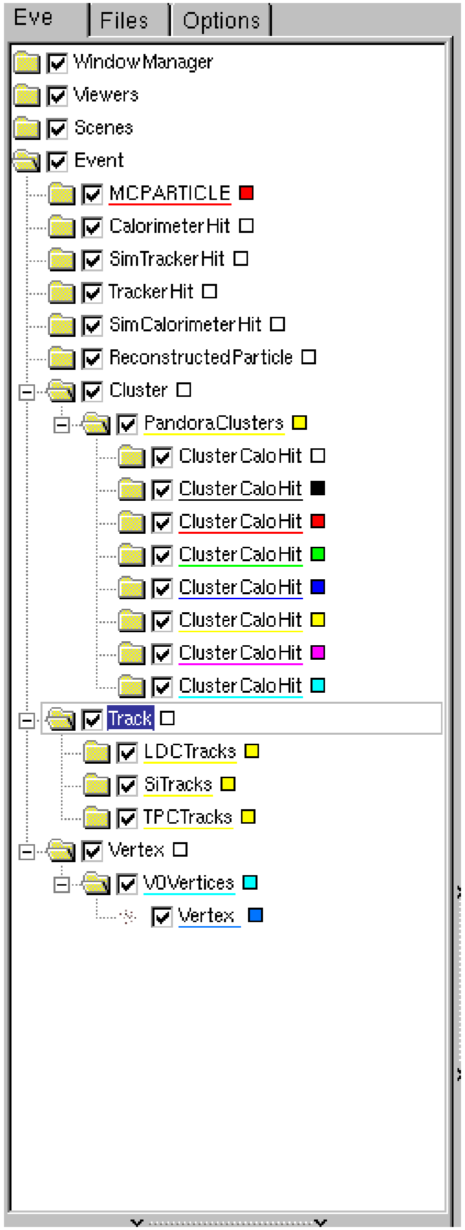




LCIO data browser

- Organized by collections:
  - MCTruth level: MCParticle tracks
  - Simulation level: simulated detector hits: cuboid/points with tunable size/color
  - Reconstruction level:
    - Intermediate reconstruction collections: Digitized detector hits, reconstructed tracks, clusters, Vertexes...
    - Reconstructed Particle: PFO (Particle Flow Objects)

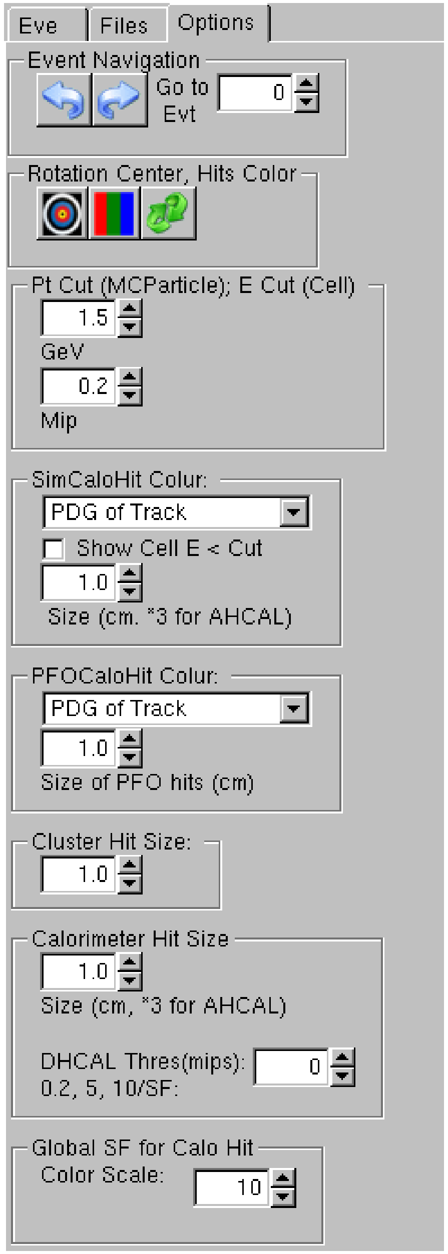
- General Options
  - General: Zoom, Rotate, Project, Illuminating, bkgrd...
  - For Individual objects:
    - Pick up & read attached information
    - Display/hidden: inherit the status from last event
    - Color/size options



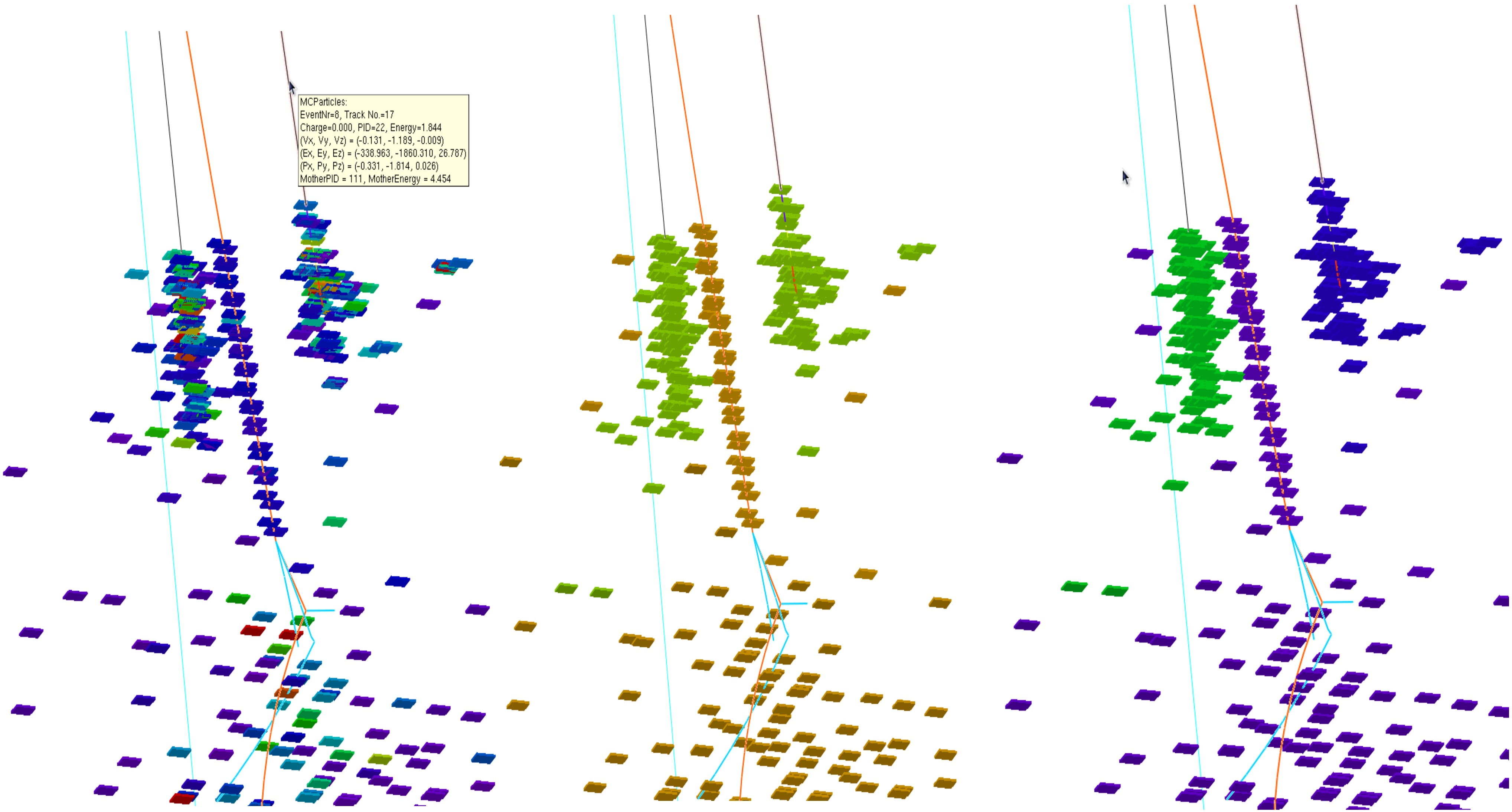
Options & Control

- Buttons:
  - Specify event number
  - Select rotation centre
  - Reroll object color if supported, i.e, clusters
  - Collection selection: switch between two scenarios
    - Minimal (default):

      MCParticle + Simulated Hits (+ Reconstructed PFO)
    - Maximal: *All supported collection, to include intermediate reconstructed collections*
- Cuts:
  - PT Cut on MCParticle: ignore event detail
  - Energy Cut on Calorimeter hits
- Hits options: specify color/size options



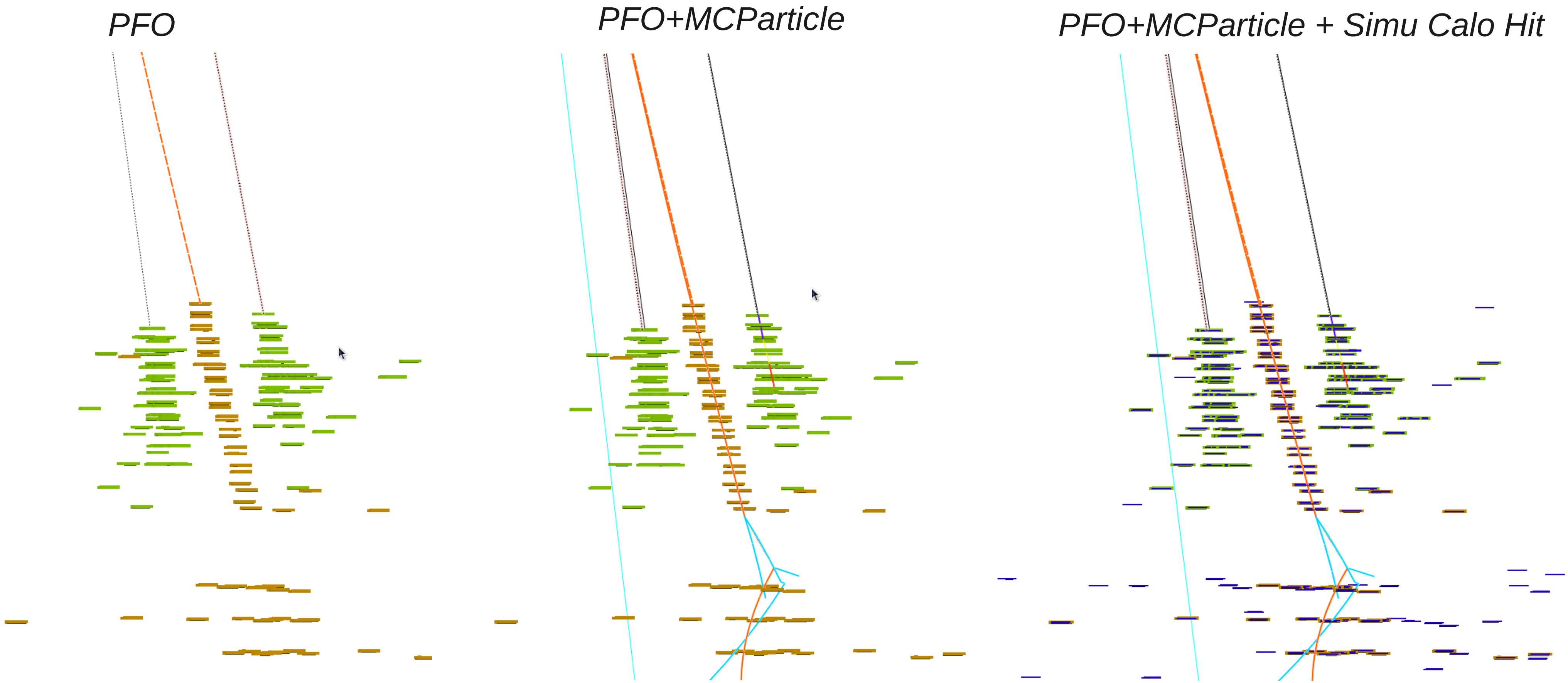
Examples



Tau jet ($\tau \rightarrow \nu+\pi^0+\pi^+$) with different color option (L - R): energy, PID & index

To debug reco algorithm

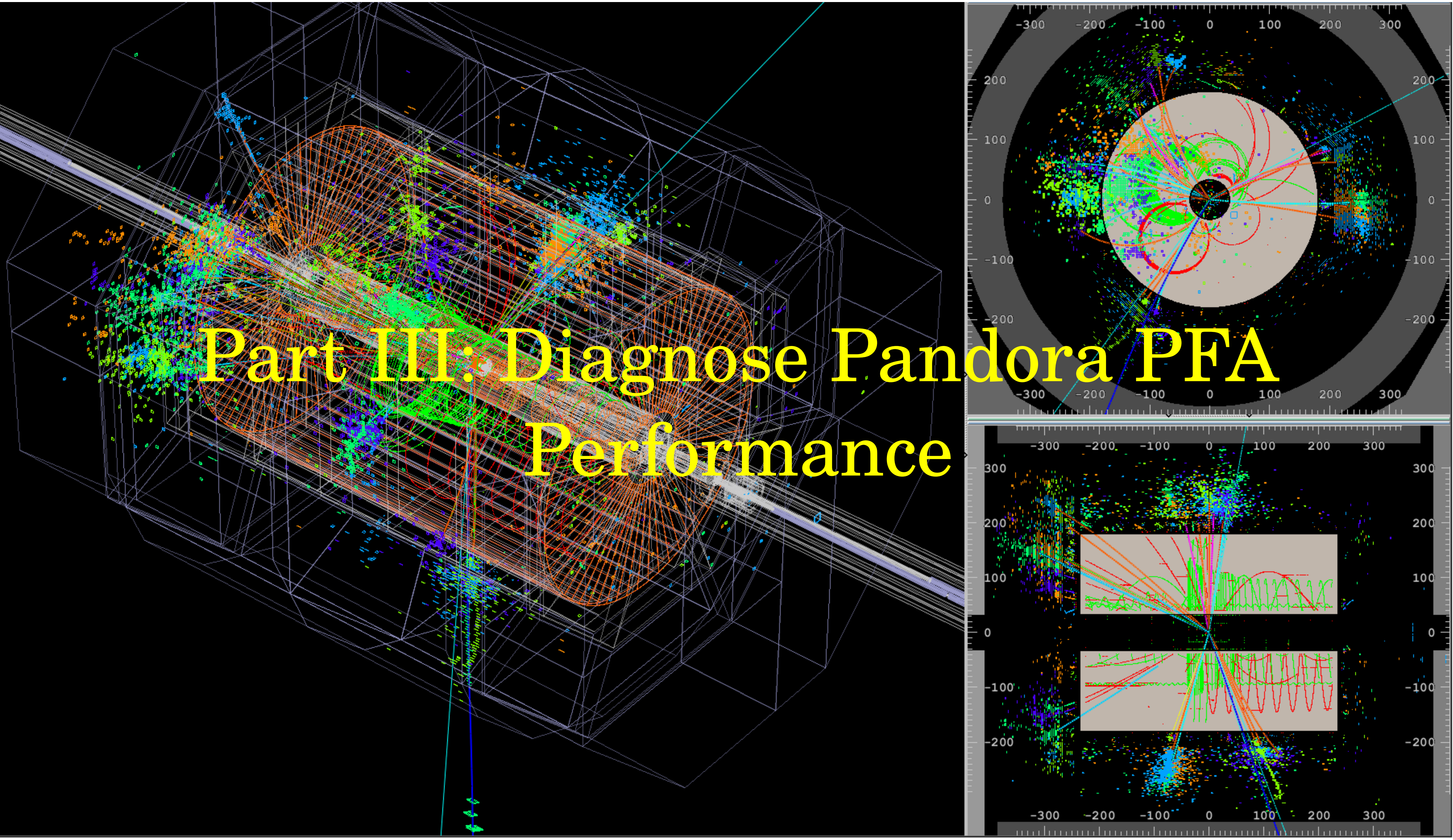
Comparing reconstructed & MC objects...



Tool is ready... to be utilized in the reconstruction algorithm developments

Accessory: http://llr.in2p3.fr/~ruan/ILDDisplay/Druid_1.9.8.tar.gz (Manual inside)

Part III: Diagnose Pandora PFA Performance



Reconstruction toolkit

- Sub detector:
  - Tracker: Kink & vertex tagging & treatment
  - Calorimeter: shower recognition for extremely high granularity:
    - Optimize the algorithm & parameters

- Particle reconstruction:
  - Charged particle: Matching & Linking
  - Neutral particle: Energy estimator based on topological information
    - Identify EM/MIP part in hadronic shower; Kalman filter to reconstruct MIP track momentum...
    - Compensation
  - Particle Identification

Pandora PFA

- Currently the Best PFA for the LC. Developed by M Thomson @ Cambridge & Organized into an extendible reconstruction frame work
- Optimized for ILD with AHCAL + TESLA
- Achieved the physics goal of Jet energy resolution: RMS90/EJ ~ 3% - 4%

1) Performance

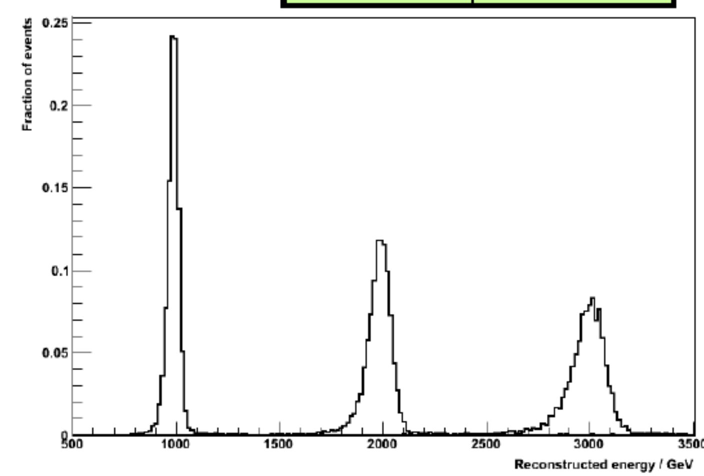
★ Now tested for jets in range 45 GeV – 1.5 TeV

CLIC_ILD

E_{JET}	RMS_{90}/E_J
45 GeV	3.6 %
100 GeV	2.9 %
250 GeV	2.8 %
500 GeV	3.0 %
1 TeV	3.2 %
1.5 TeV	3.2 %

ILD

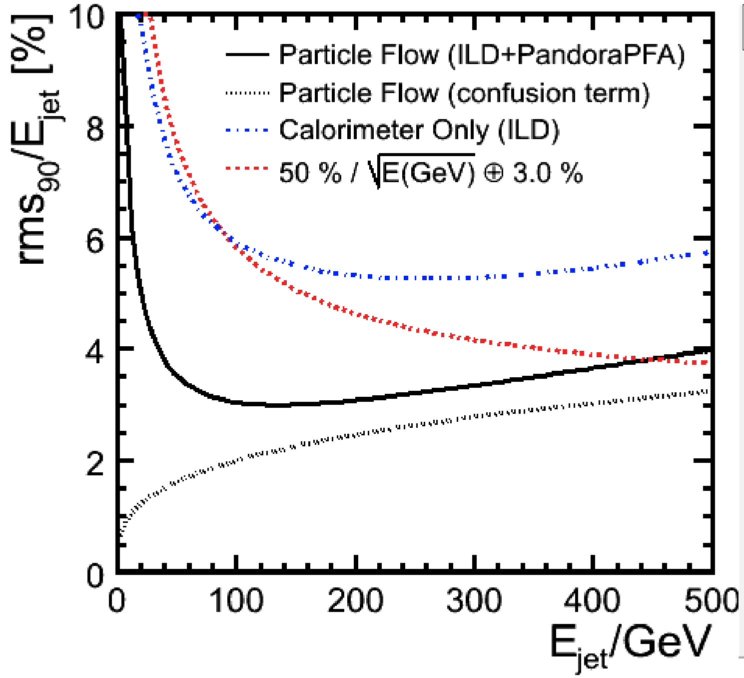
E_{JET}	RMS_{90}/E_J
45 GeV	3.6 %
100 GeV	3.1 %
180 GeV	3.0 %
250 GeV	3.3 %

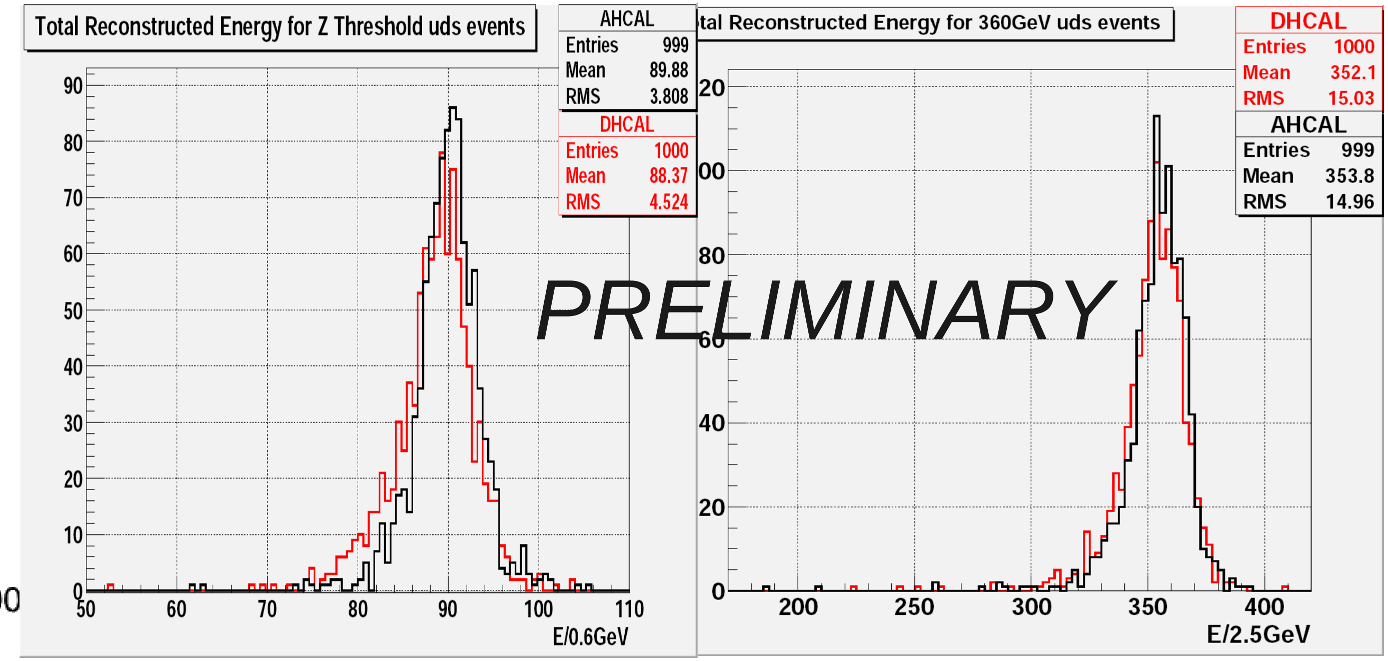


Jet Energy Resolution better than 3.6 % over whole range

IWLC2010, Geneva   Mark Thomson   4

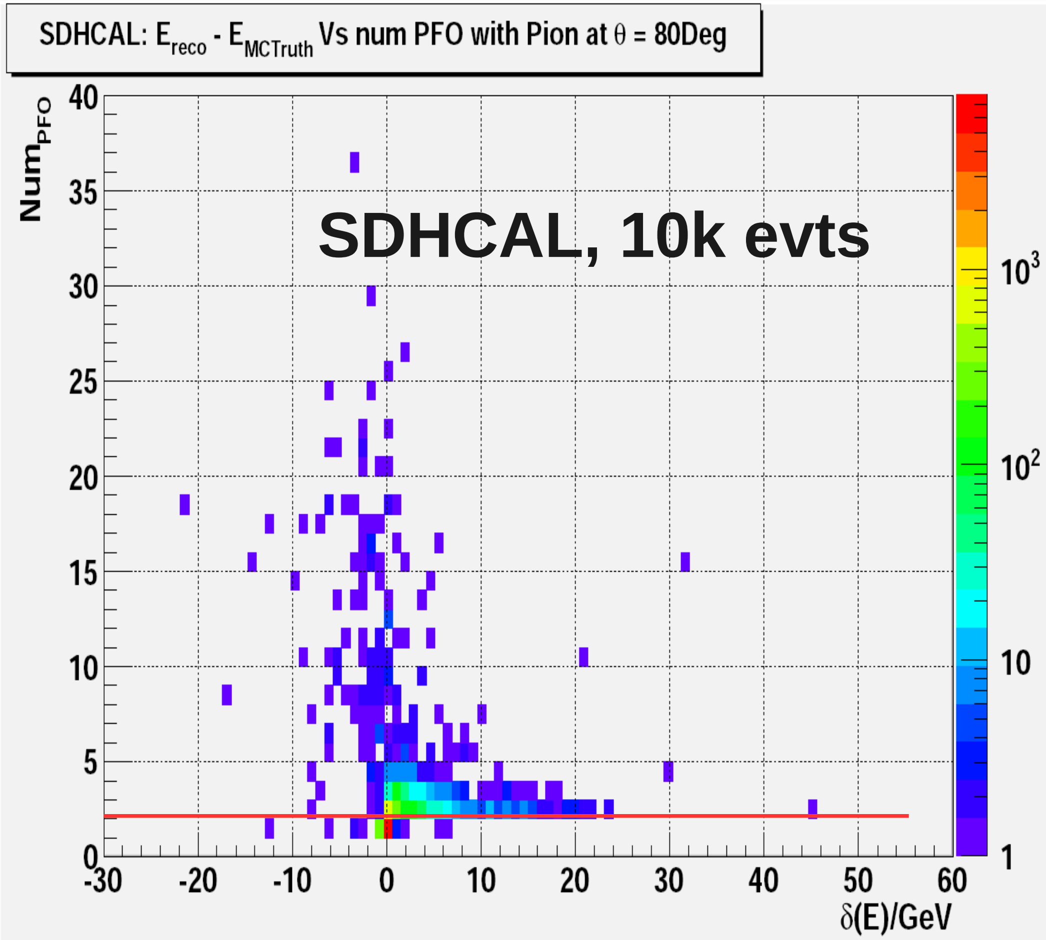
SDHCAL & Pandora PFA

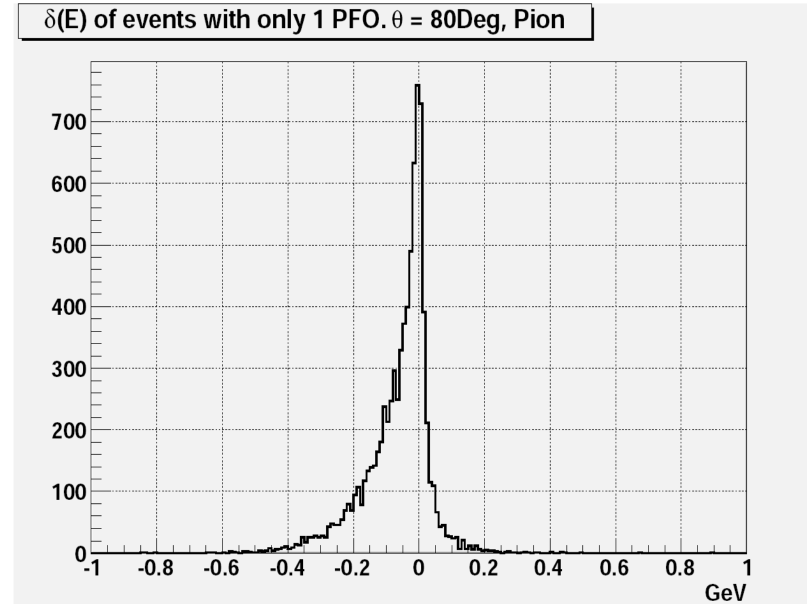


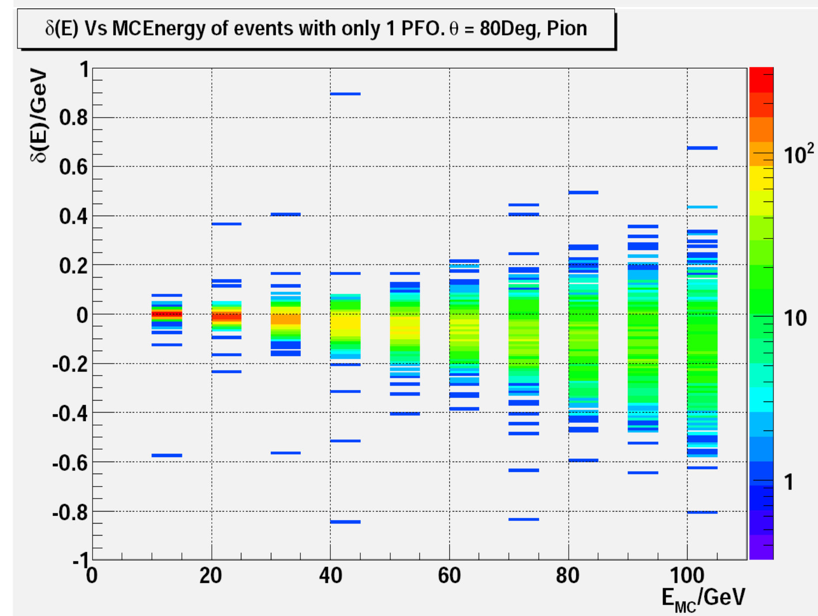


- SDHCAL: finer granularity (1 * 1 cm Vs. 3 * 3 cm)
- PandoraPFA @ SDHCAL
  - Pandora + Preliminary Digitization + Calibration constant tuning
  - Performance with uds evts: slightly worse @ Zthreshold, much closed @ 360GeV
- Performance analysis/comparison with single Pion/Klong events
  - Statistic: ~300k each. 1k ~ 2k * 10 energies (10 ~ 100GeV) * 9 polar angles * 2 concepts

SDHCAL, Pion at θ = 80º



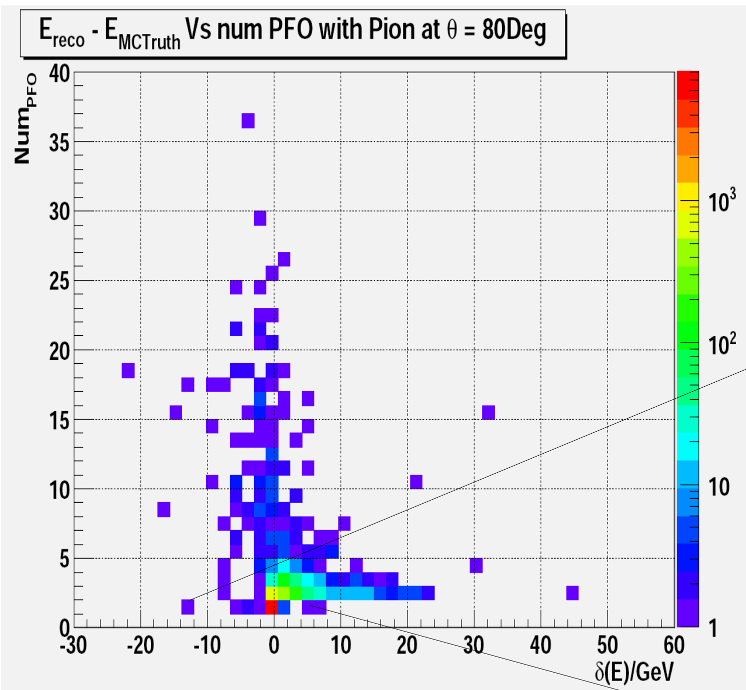


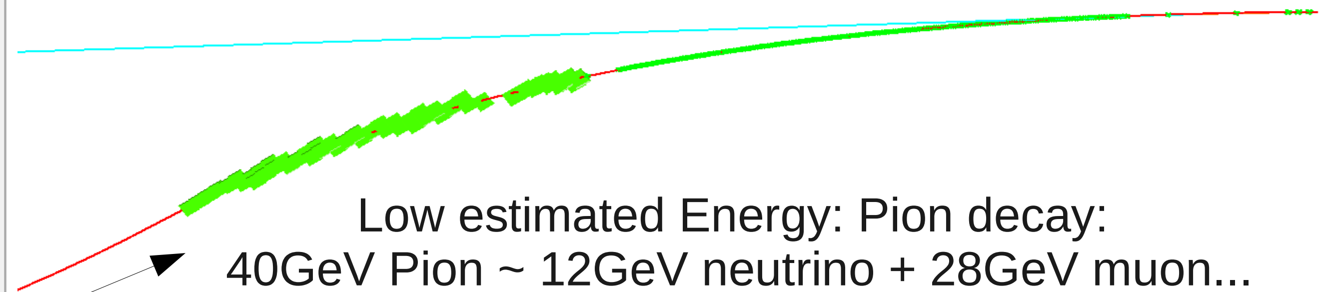


81% evts (8097) has single PFO

Low energy tail in delta(E) spectrum, energy loss

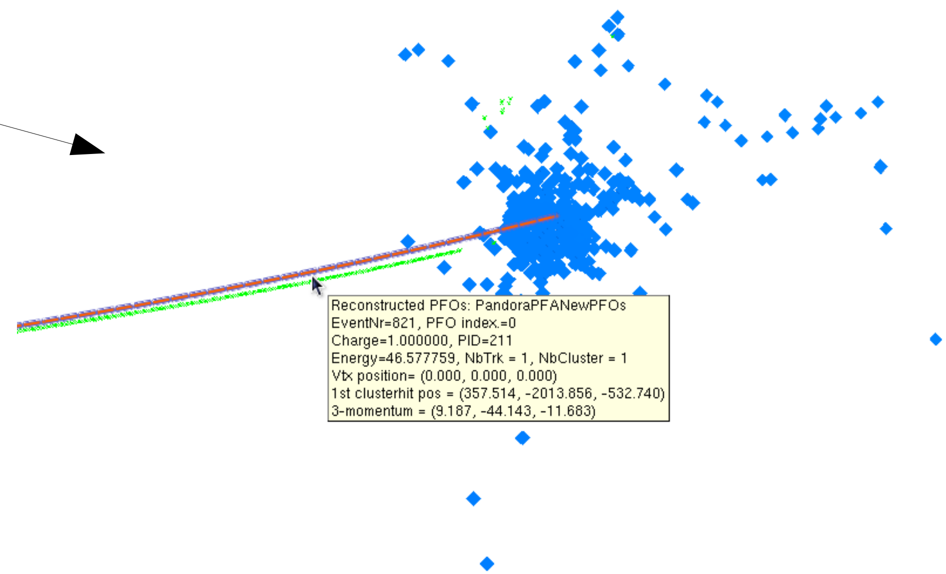
Single PFO evts in the tail, θ = 80º





Low estimated Energy: Pion decay:
40GeV Pion ~ 12GeV neutrino + 28GeV muon...

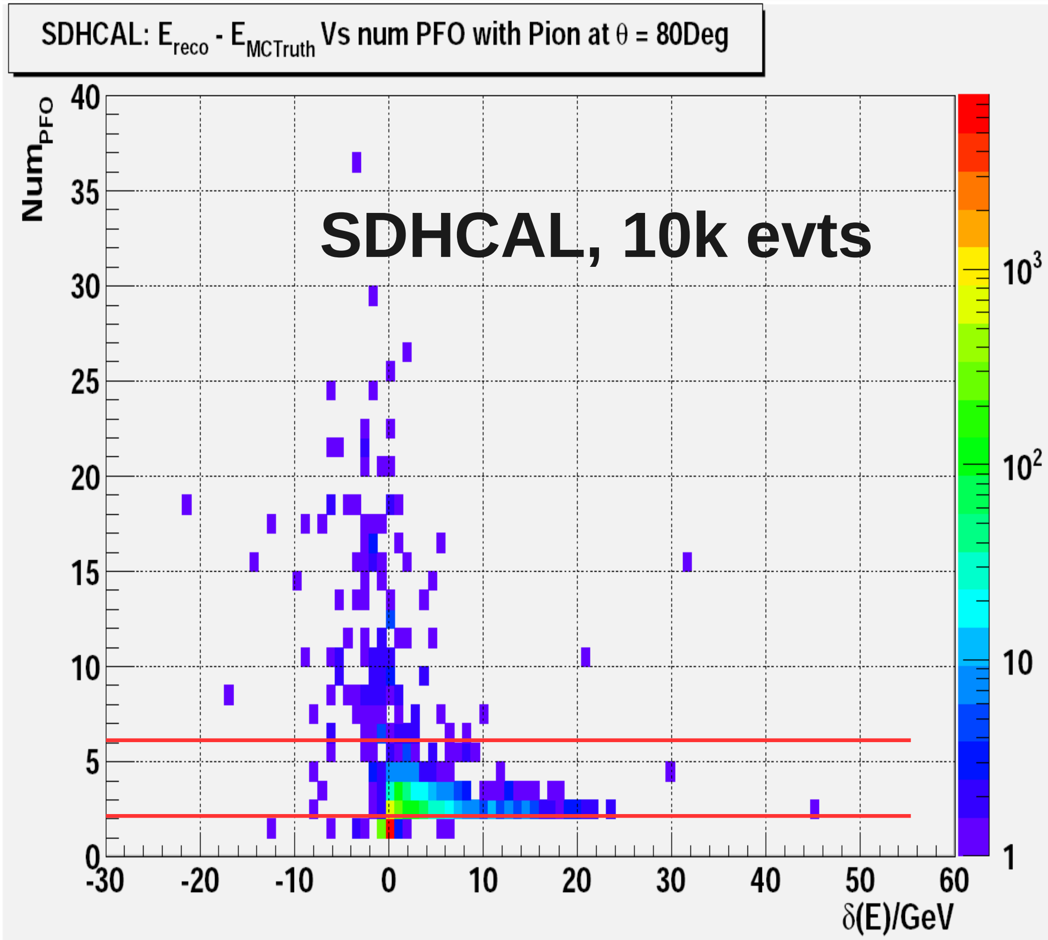
Possible to be detected by finding kinks along the track
& comparison of Calo track momentum Vs track momentum

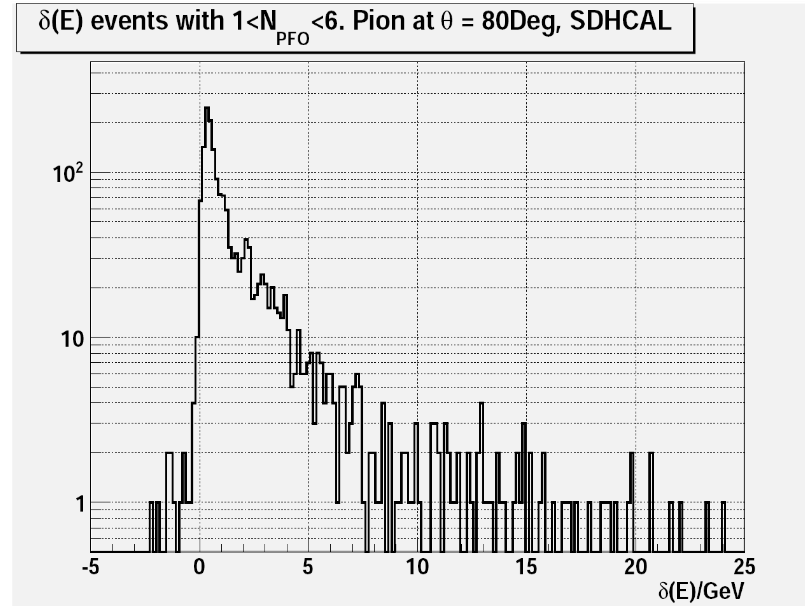


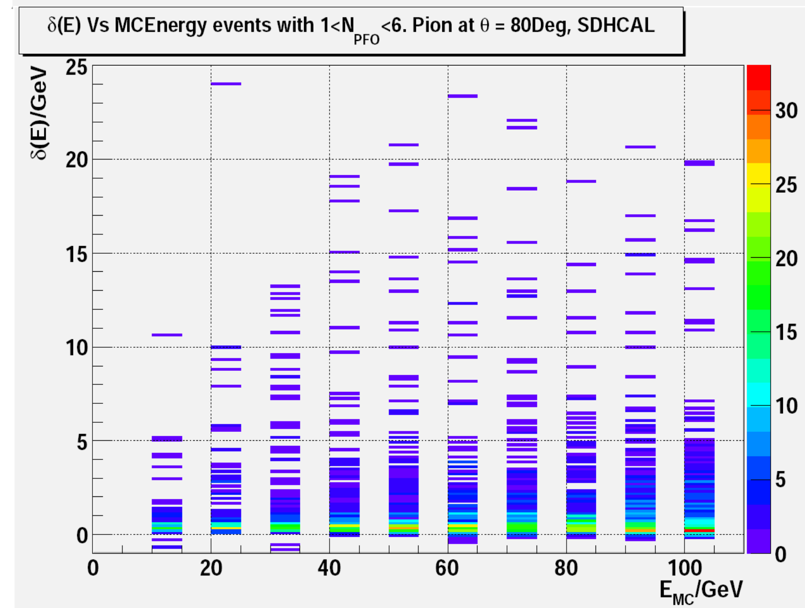
Higher Energy (Evt 821)
40GeV Pion at MCTruth
Identify as 46.6GeV PFO
with 38GeV cluster

Track energy
Reconstruction Smearing

Events with 2 - 5 PFOs





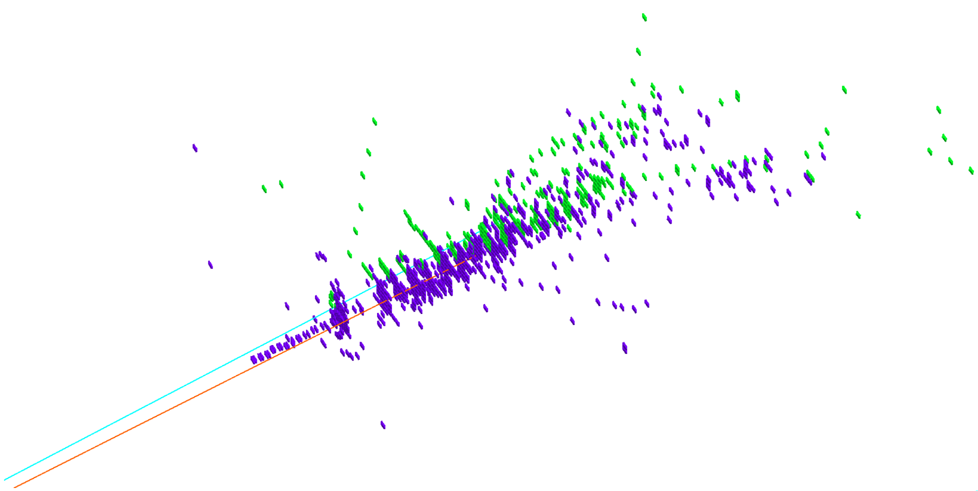


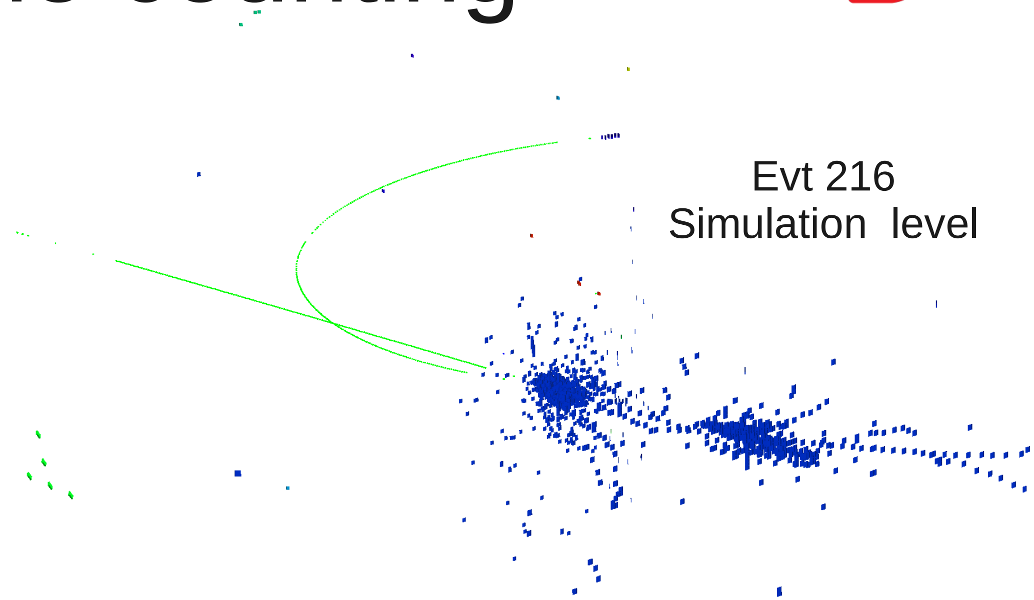
~ 18% (1766) events has 2 - 5 PFOs

Higher estimated energy

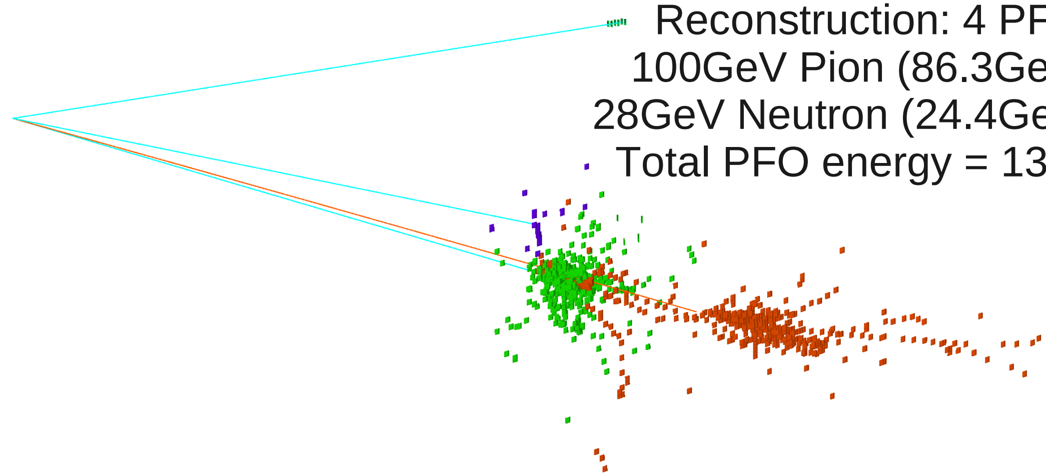
Double counting

(Evt 286) 2 PFOs, Identify as
100GeV Pion (80.7GeV cluster) +
45GeV Neutron (45.4GeV)
Total PFO energy = 145GeV
Seed at deep ECAL Layer...





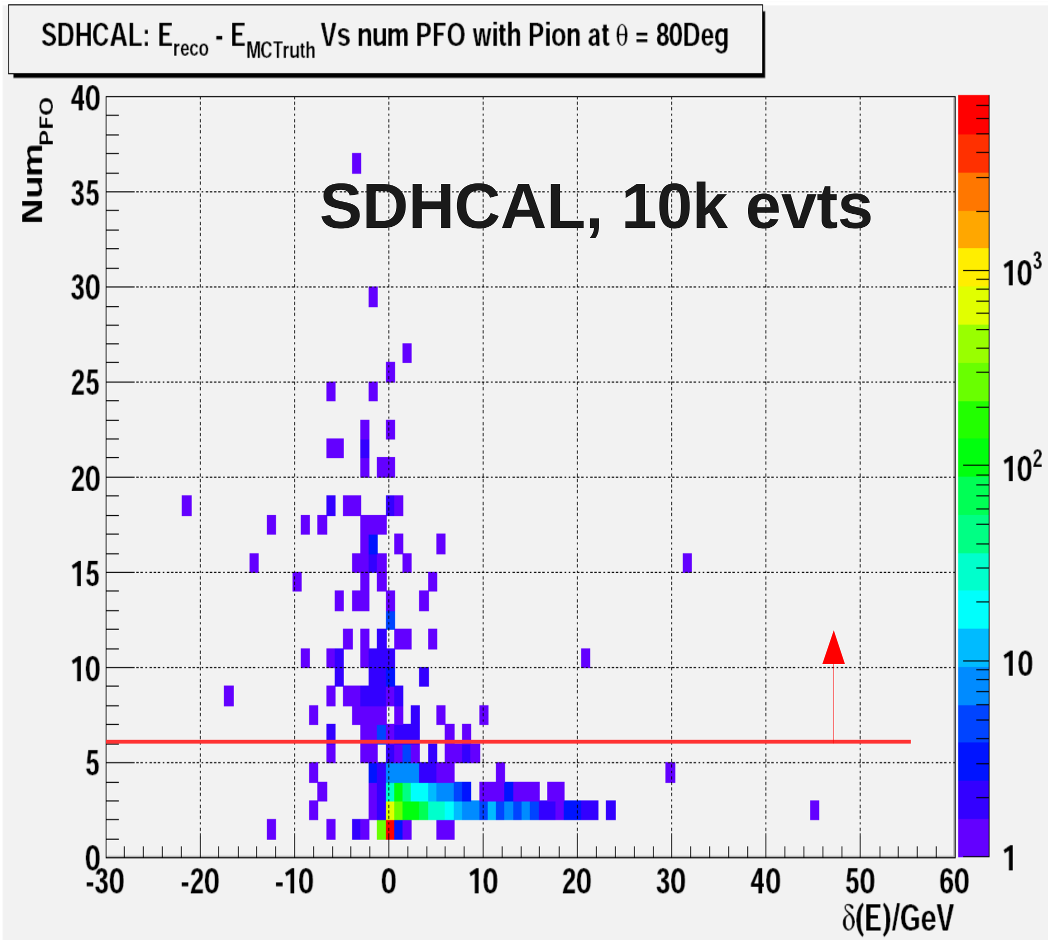
Evt 216
Simulation level

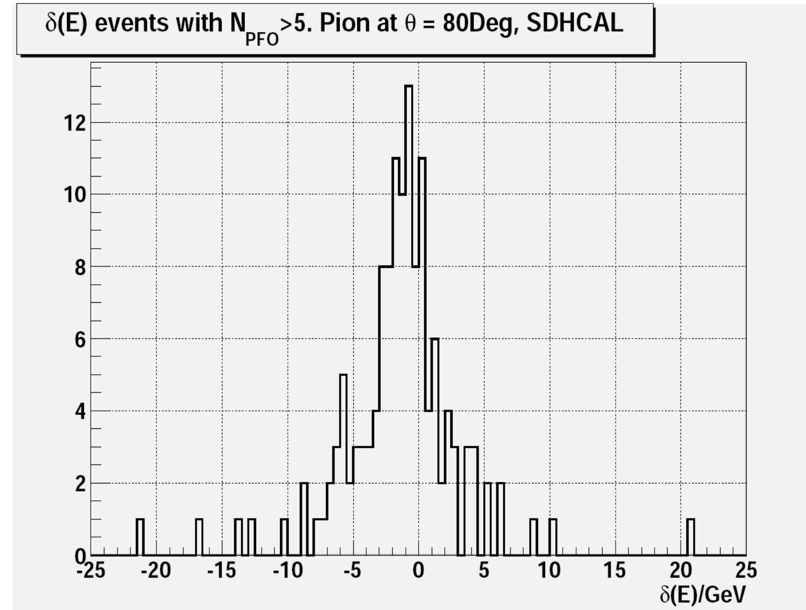


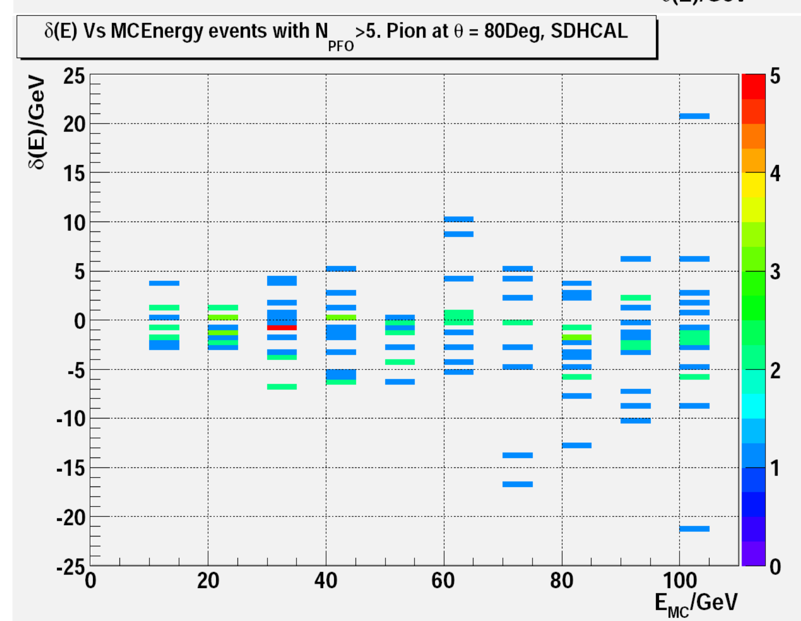
Reconstruction: 4 PFOs:
100GeV Pion (86.3GeV) +
28GeV Neutron (24.4GeV) + ...
Total PFO energy = 130GeV

Clustering
To be improved...

Events: more than 5 PFOs



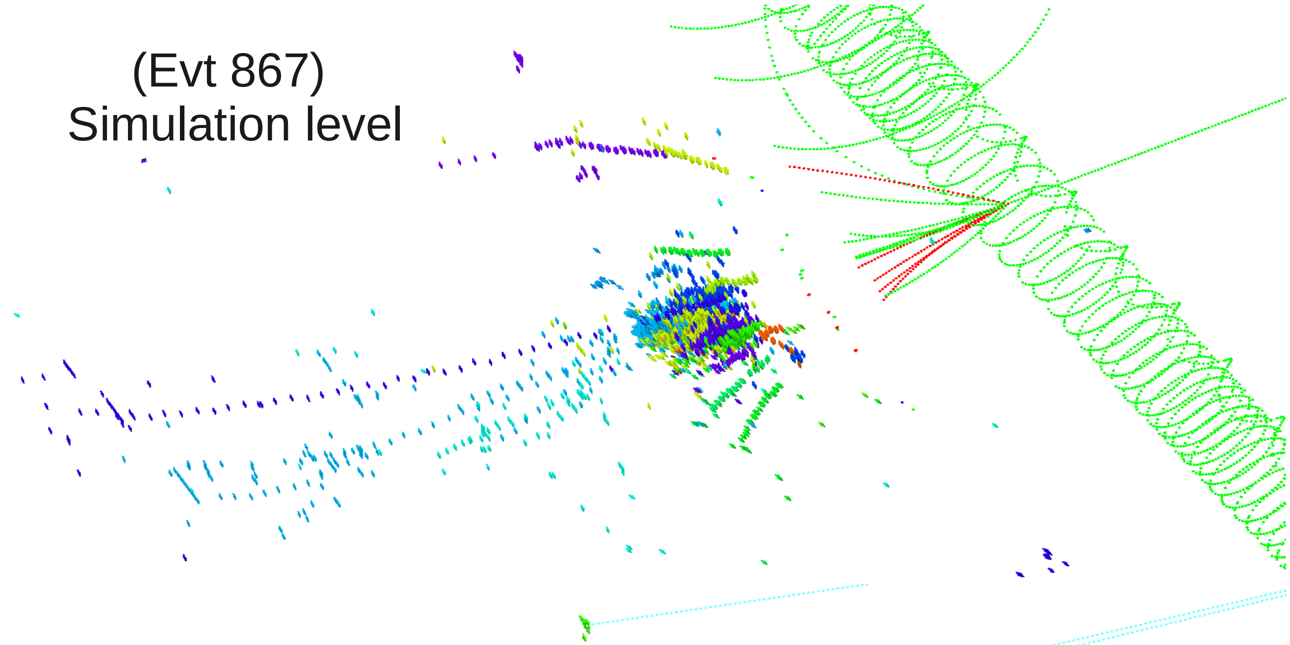




~ 1.4% (137) events have more than 5 PFOs
Large smearing in measured energy
(*Smearing amplitude increase with MC energy*)

Interaction based double counting

(Evt 867)
Simulation level

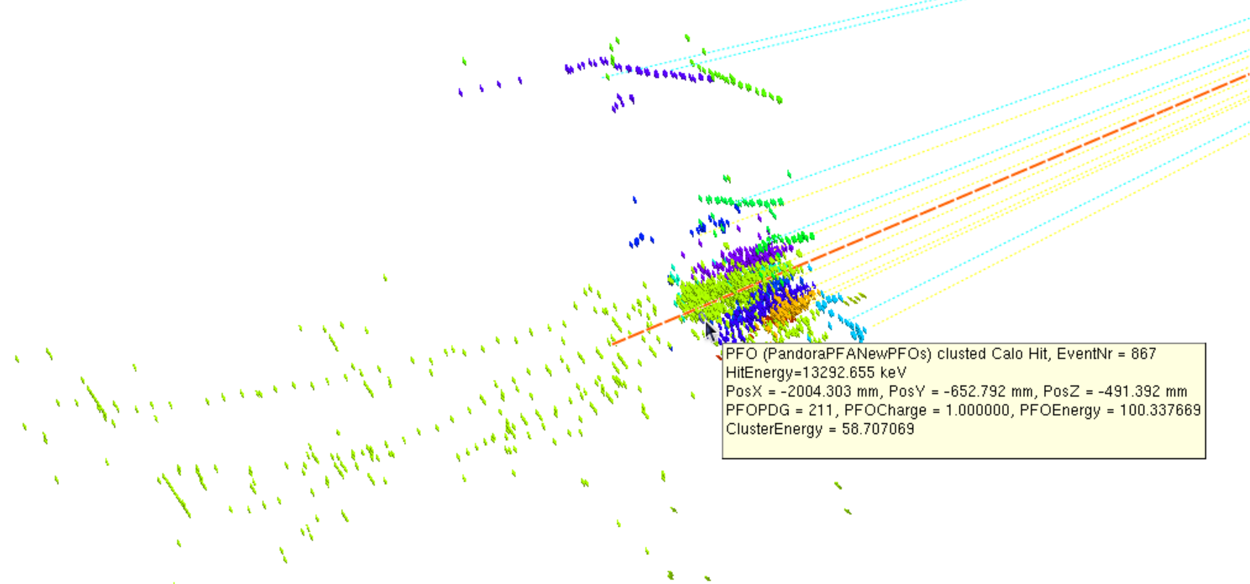


Near the Calo

Reconstruction level:

15PFOs
Leading PFO (59GeV cluster) identified as 100GeV pion.
Others contribute to double counted 32GeV...

To be improved by fitting the PFO position & direction... if coming from same spatial point (besides IP) & Vertex Reconstruction in Tracker...



Even more crazy...

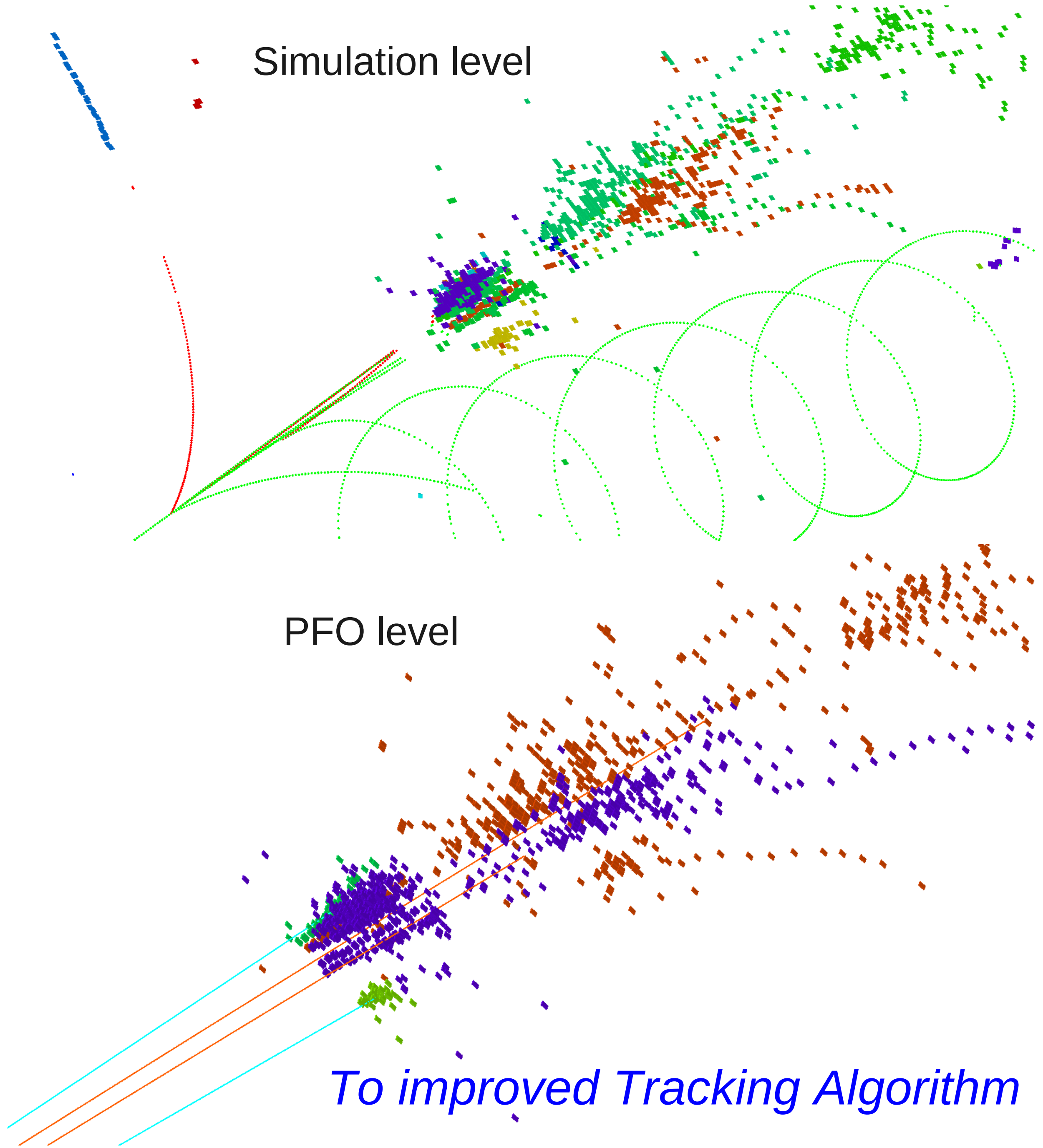
Evt 646: Interaction Inside TPC (1/3 of the radius)

Confused tracker: 3 LDCTrack found

6PFOs:
2 leading PFO assigned with tracks + cluster, with energy 110GeV (40GeV cluster) and 148GeV (55GeV cluster)

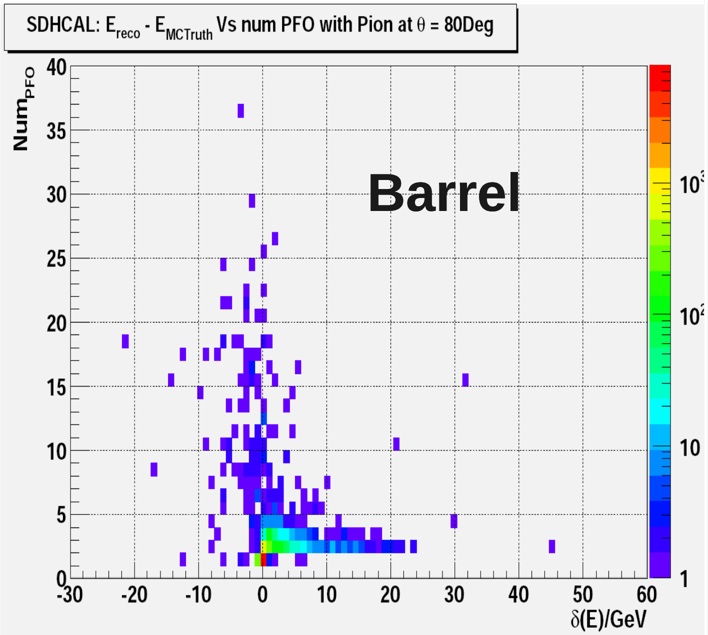
Totally reconstructed energy: 264GeV

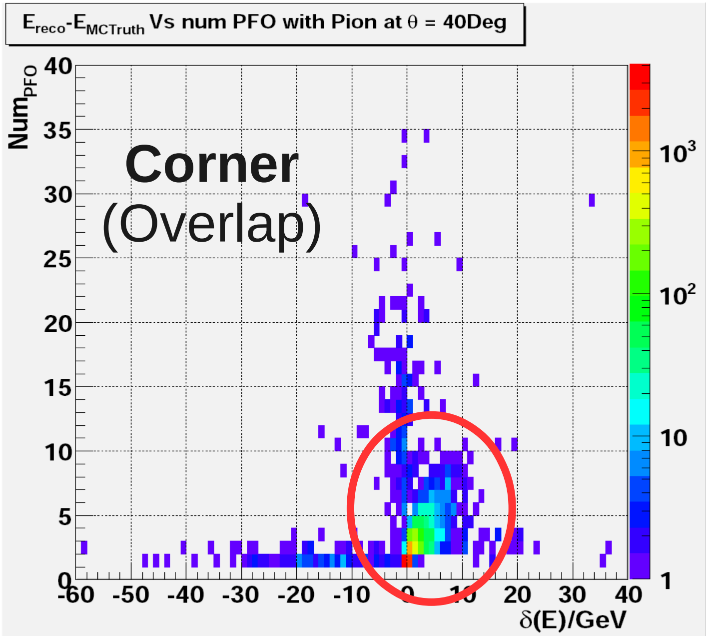
Judgement on trk quality?
Flag on those kind of evts
Rely more on cluster info?

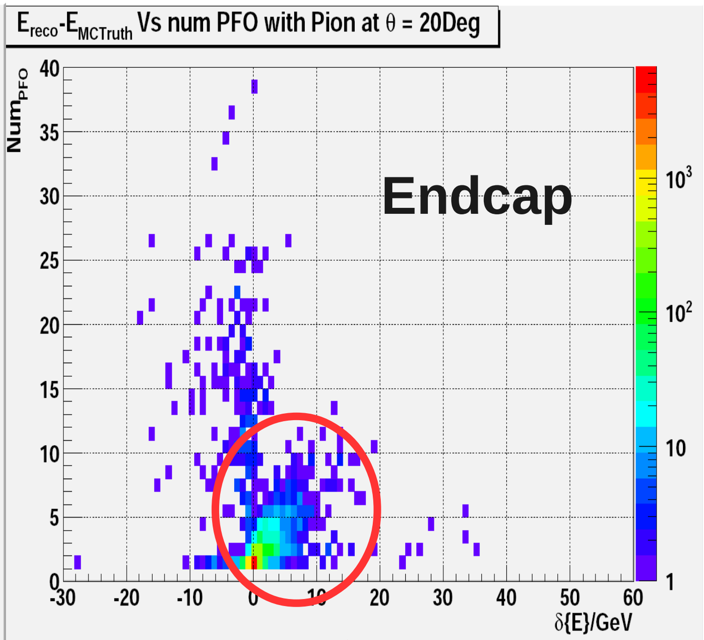


To improved Tracking Algorithm

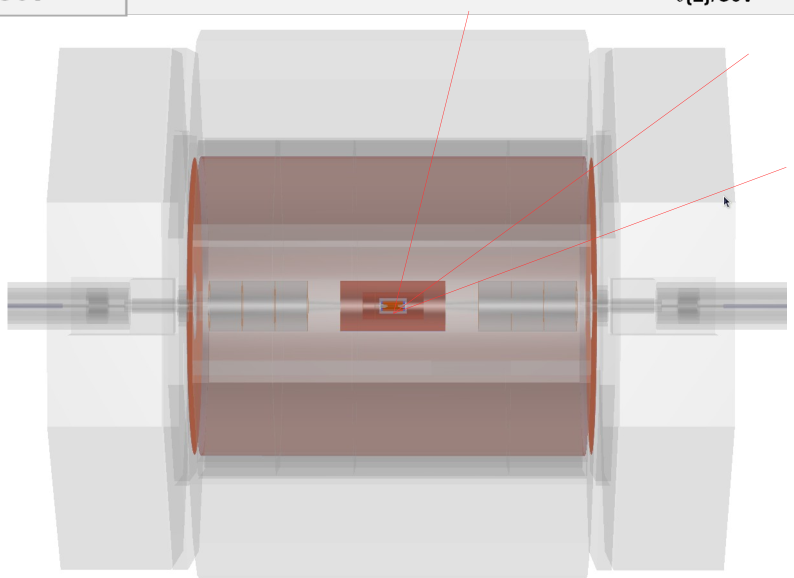
Compare to corner & endcap



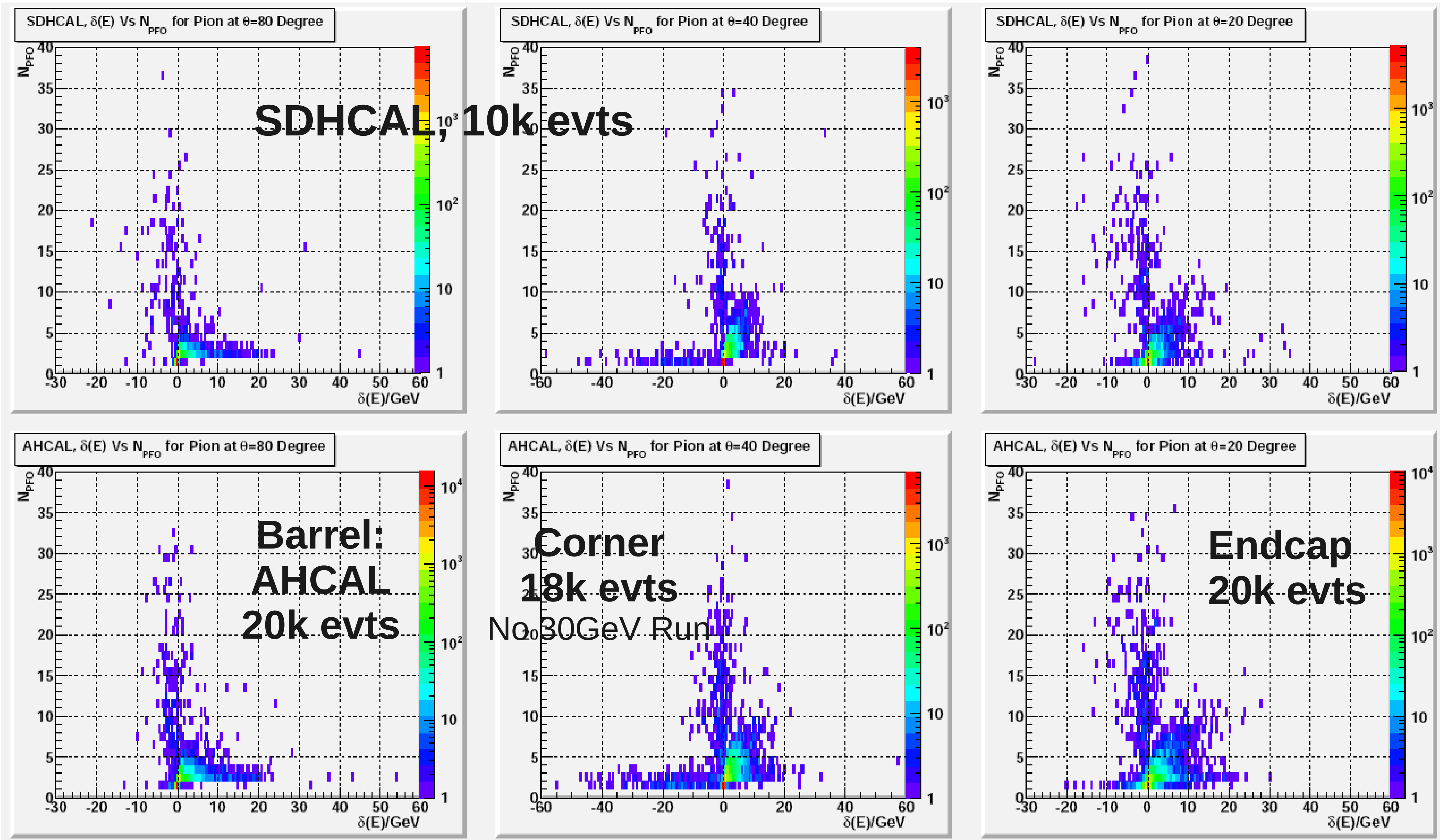




- For single PFO events:
  - Large low energy tail in Corner (also for 2-PFO events): Failure of Track-clustering linking + dead zone
  - Large energy smearing in Endcap region (track smearing)
- Corner & Endcap: More material, More interactions
  - Linear dependency of δ(E) and NPFO

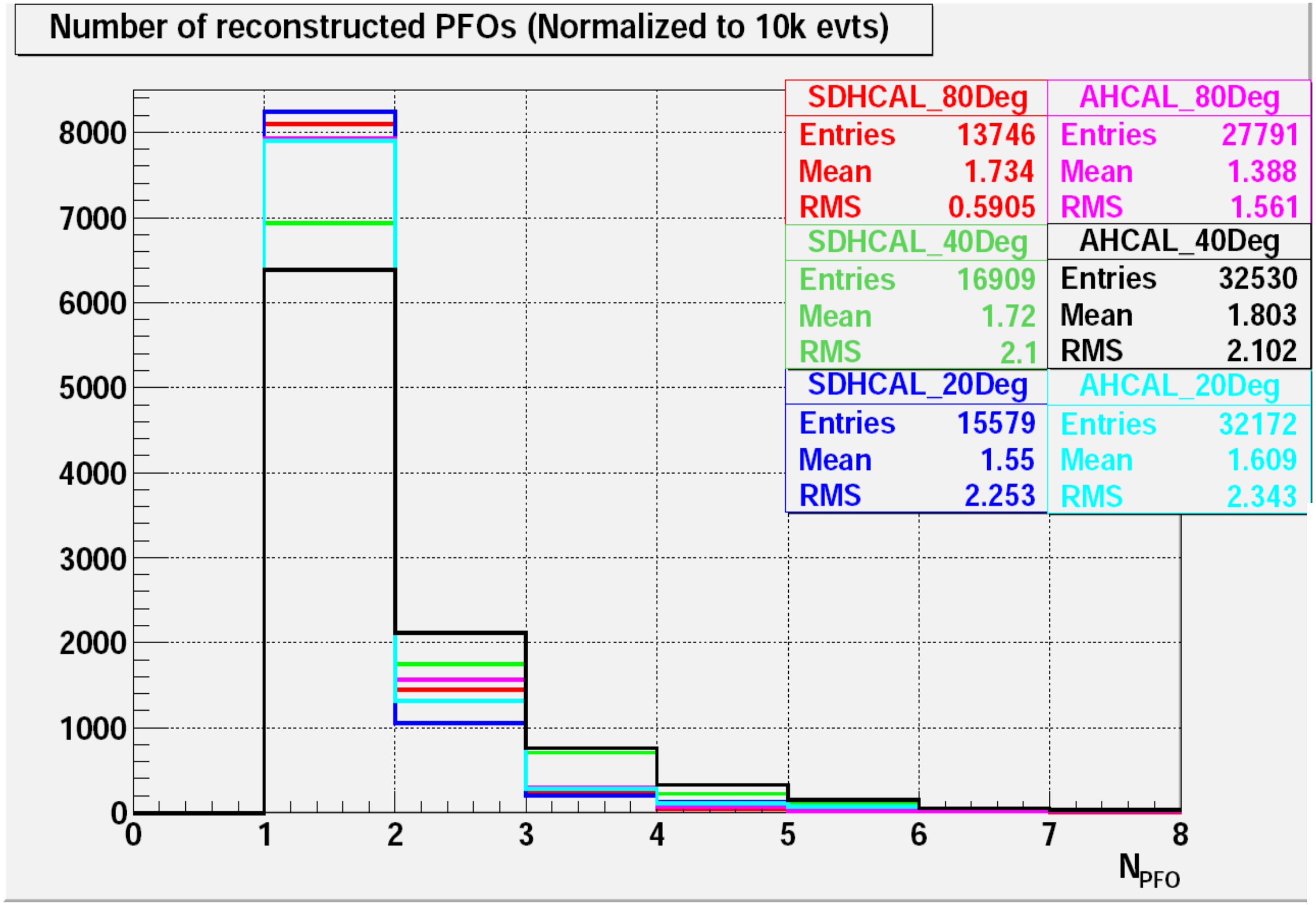


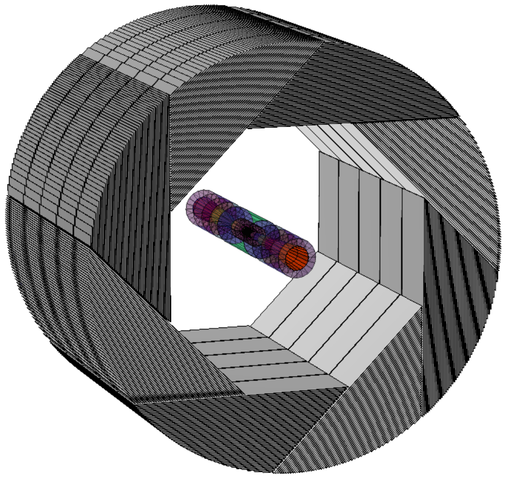
Comparing with AHCAL



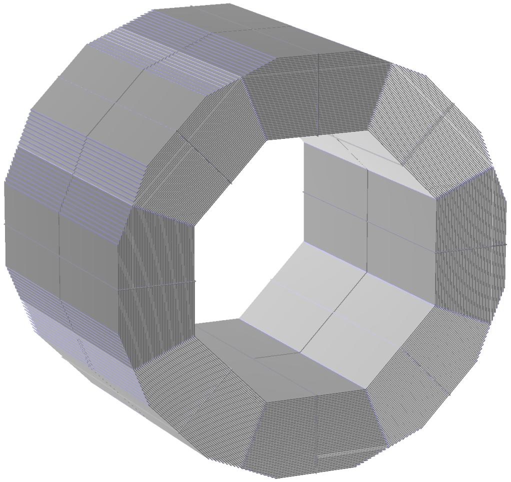
Similar...

Compare to AHCAL: NPFO





Barrel Geometry: DHCAL & AHCAL



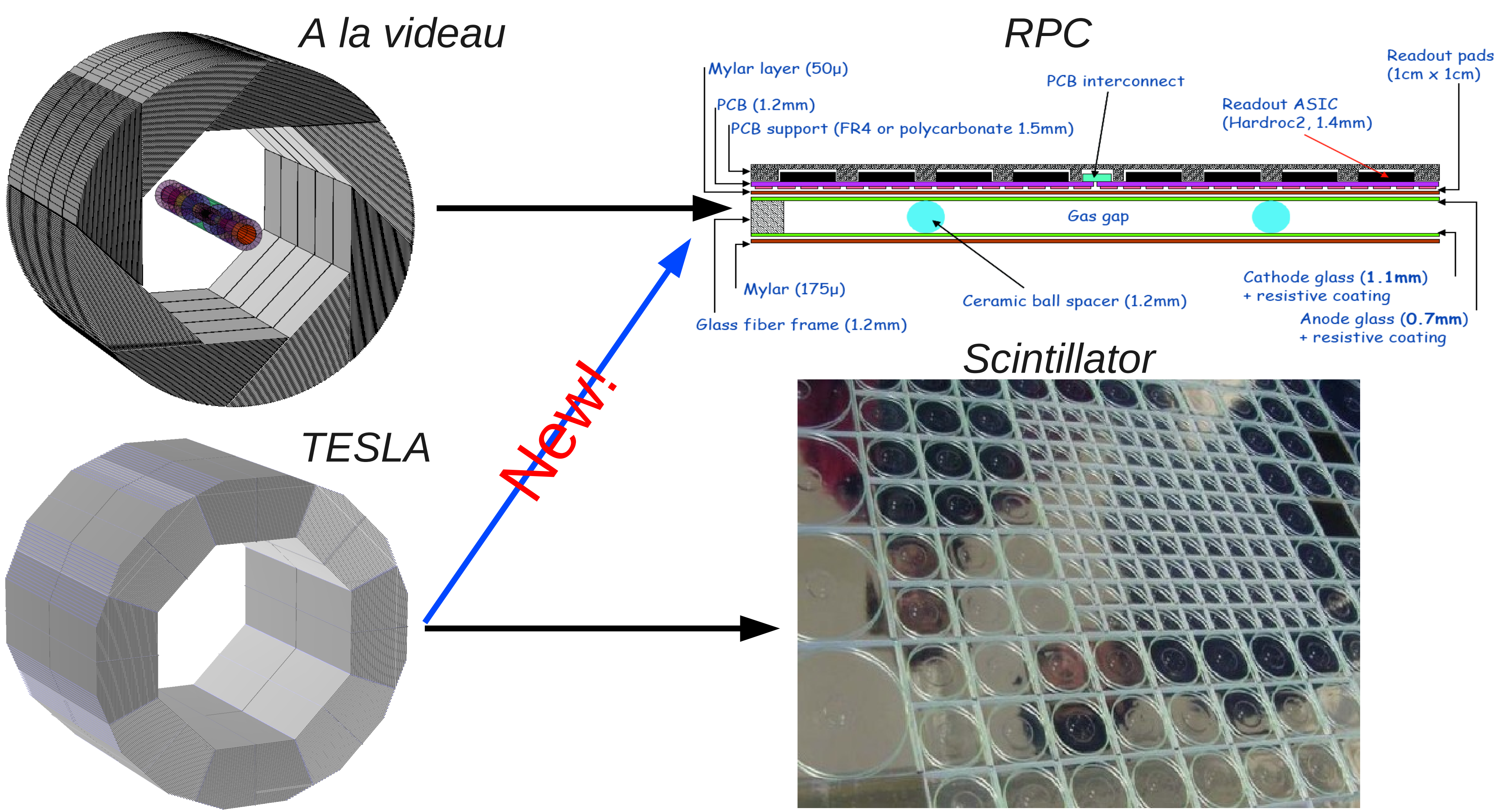
Less double counting in SDHCAL:

Geometrical effects? Neutron effect? Less confusion (better clustering) ?

Disentangled with Simulation with GRPC TESLA HCAL: R Han

Simulation

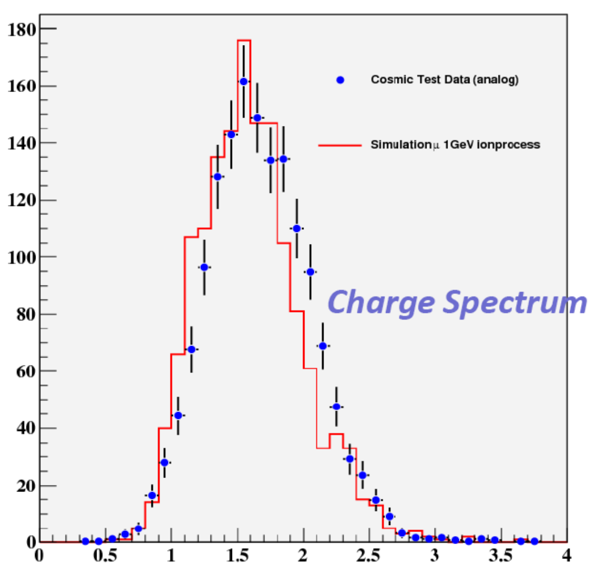
- MC Models: To distinguish sensor performance from detector geometry: RPC adapted to Tesla (R. Han @ IPNL, G. Musat @ LLR)

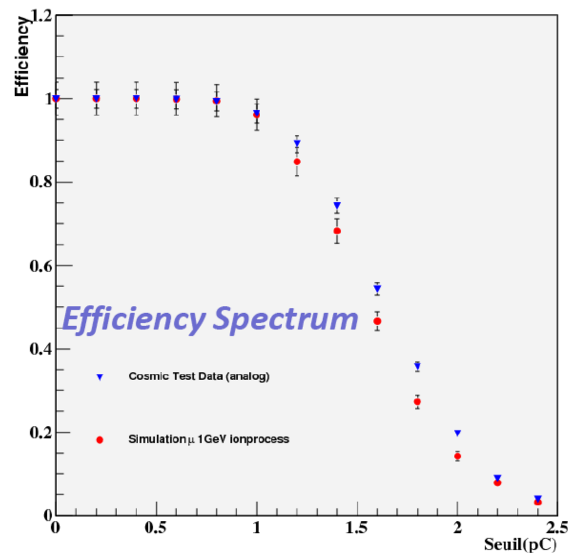


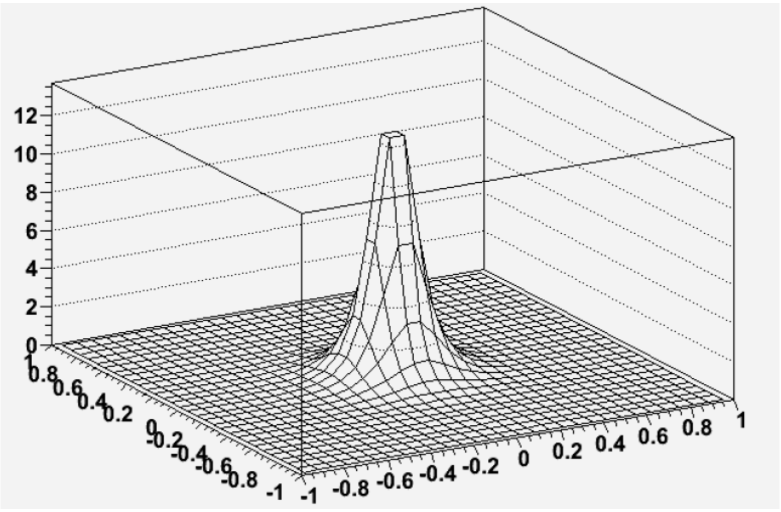
Reliable Simulation

- Digitization module:
  - Energy deposition - induced charge dependence, saturation effects
  - Test beam input: efficiency, multiplicity, noise rate, homogeneity fluctuation

R. Han @ IPNL: induced charge & avalanche spatial distribution

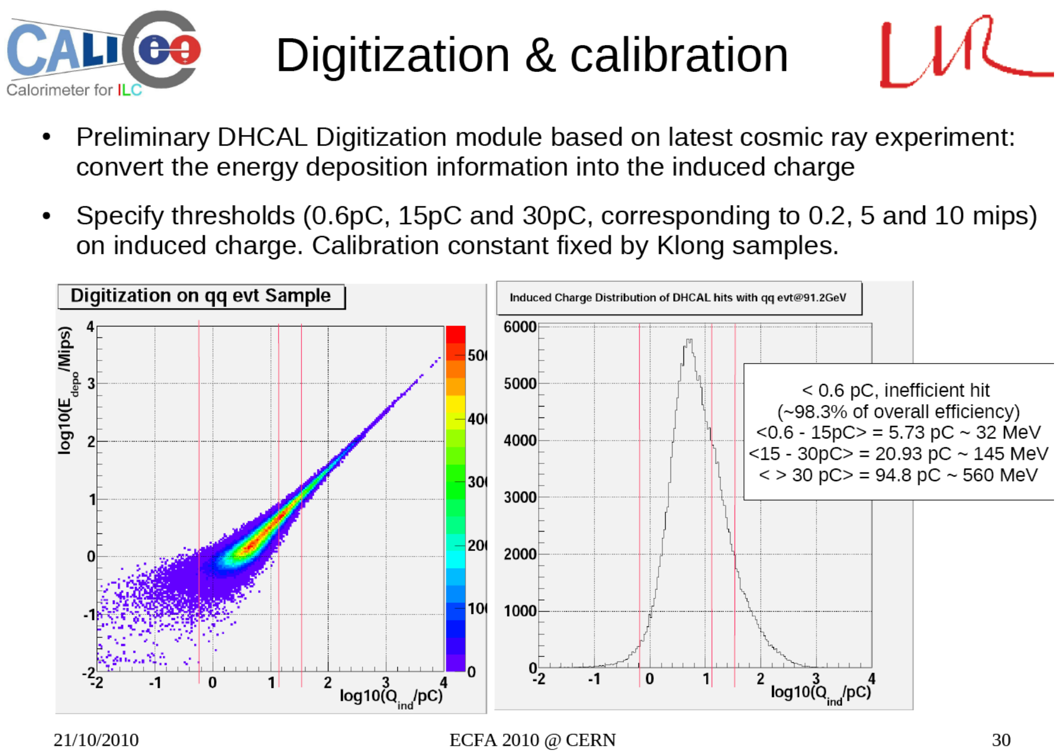


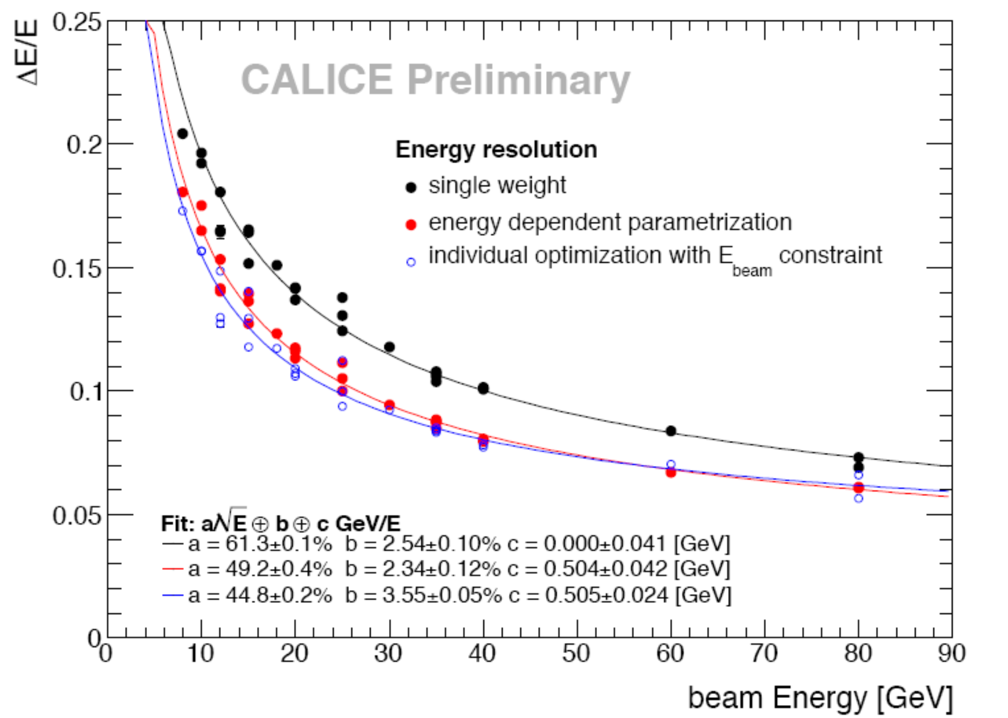




- Geant 4 comparison with TB data (cubic meter)

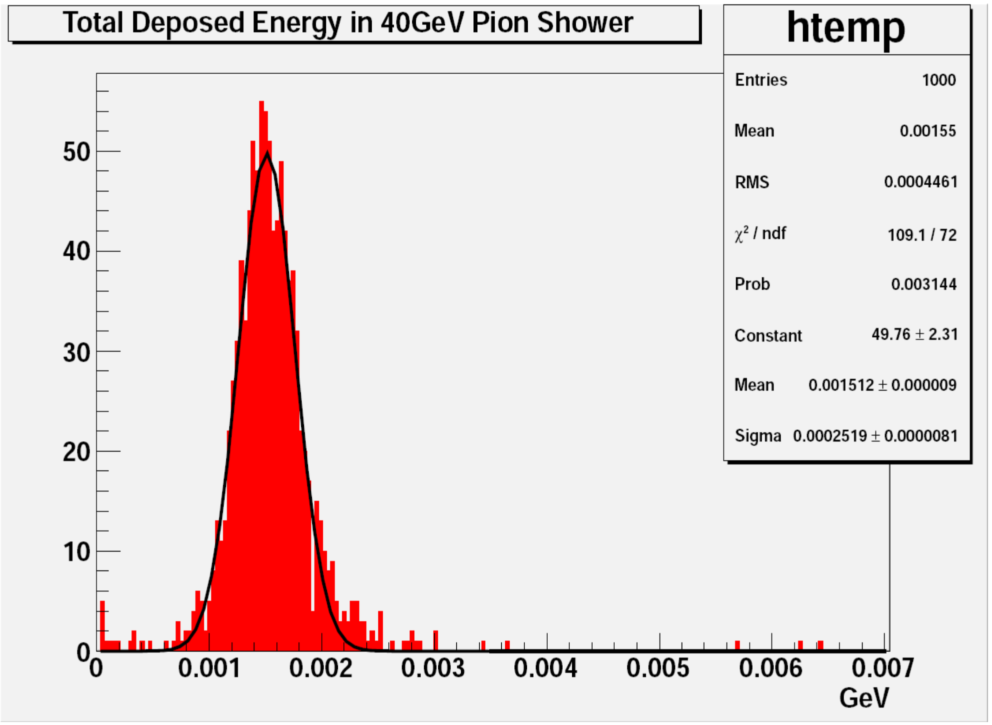
Energy Estimator

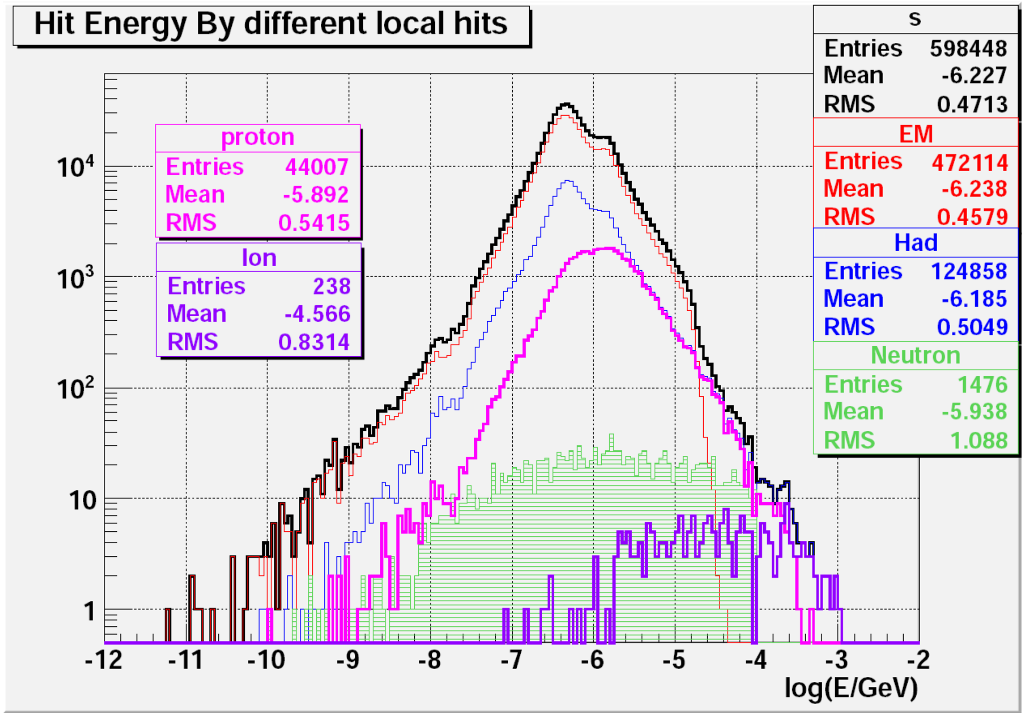




- For SDHCAL: with Calibration constant proportional to mean energy deposition: 80 – 90%/sqrt(E)
- AHCAL: ~ 60%/sqrt(E) before compensation & ~45%/sqrt(E) + 4% after compensation!
- **To improve our energy estimator**

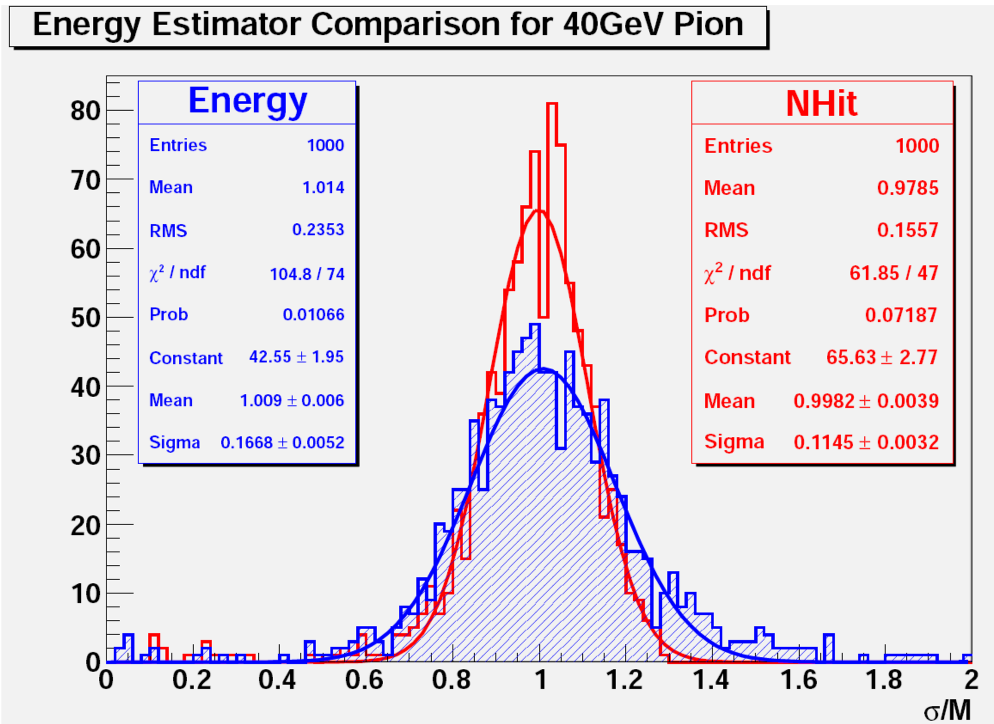
E.E: Nhits or Energy

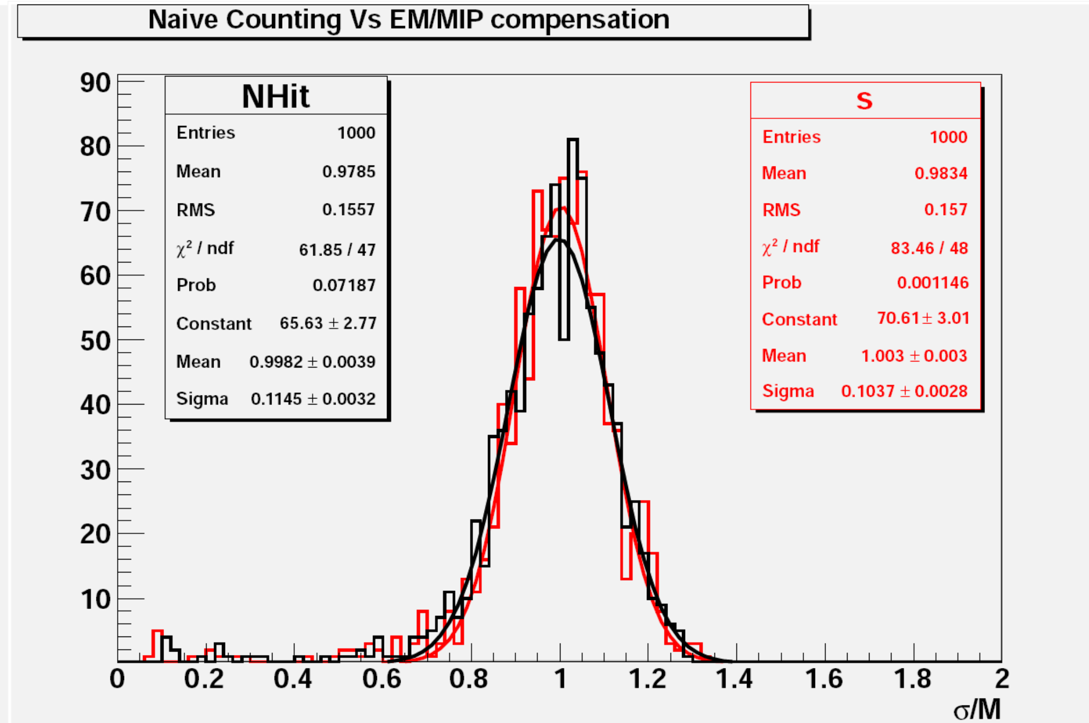




- Gaseous detector: Very small sampling factor ~ huge fluctuation in analogue readout (esp, ion/proton hits) ~ resolution ~ 100%/sqrt(E)

E.E: Nhits or Energy

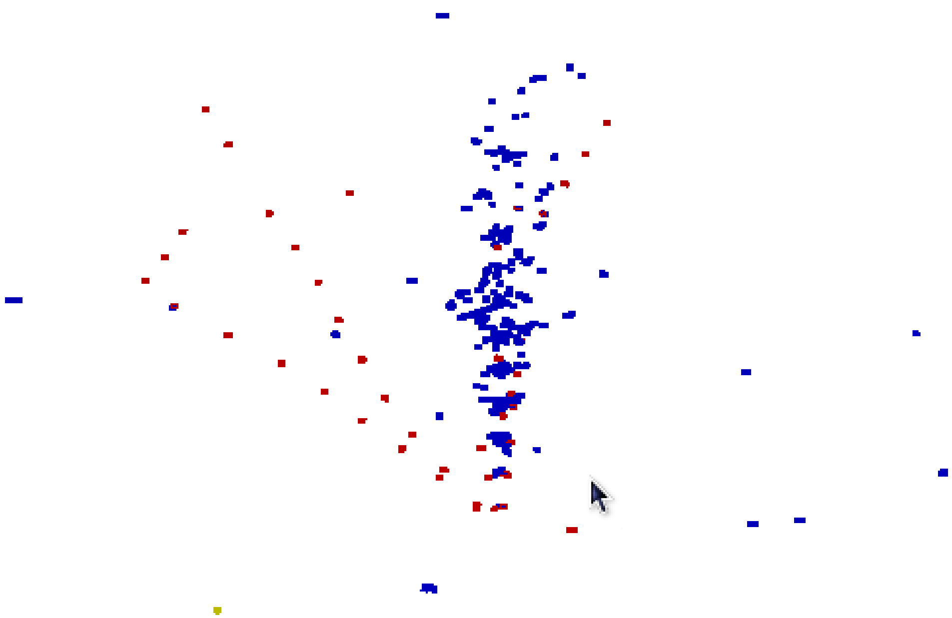


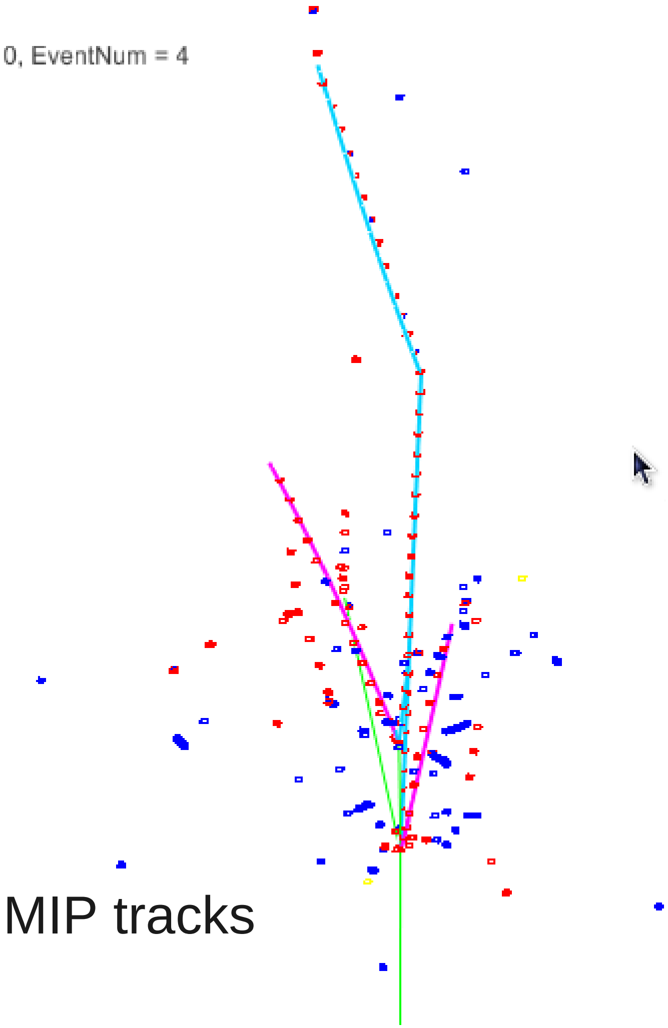


- Using Num of Hits as Energy Estimator ~ 72%/sqrt(E)
- With identify and balance the EM/MIP components (N_{EM} + 0.55*N_{MIP}): ~65%/sqrt(E)
- Ongoing study: SDHCAL thresholds/calibration constant optimization (S.Mannai et.al)

Better Energy Estimator?

20GeV Klong @ DHCAL with
1mm cell size





Hadronic Shower = compact EM core + long loose MIP tracks

- MIP tracks: Kalman Filter? Length?
- EM shower: rely more on geometry size?

Summary

- SDHCAL project: Toward the proof of Principle in 2012 for the DBD
- Reconstruction algorithm:
  - DRUID allows a precise visualization to the geometry, MC, Simulated and reconstructed objects for many detectors
  - PandoraPFA has reached the initial goal of jet energy resolution and adapted to SDHCAL, but there are lots of Hints to improve:
    - To reduce the double counting
    - To improve the track cluster linking & optimize geometry for overlap region
    - To improve tracking algorithms: detect pre-interaction vertex, kinks...
    - To improve hadronic cluster energy estimator:
      - Identify the EM/Had components for compensation; estimate MIP momentum with Kalman fiter...
    - Cooperated with LHC experiments on PFA application
- Detector optimisation (eg, overlap region), Benchmark physics analysis.
- Lots of things remains to be understood & Dense work... but fun!

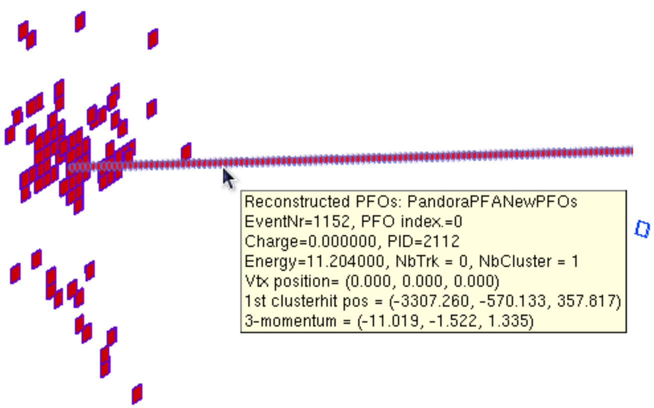
Spare slides

Neutral Hadron: Klong

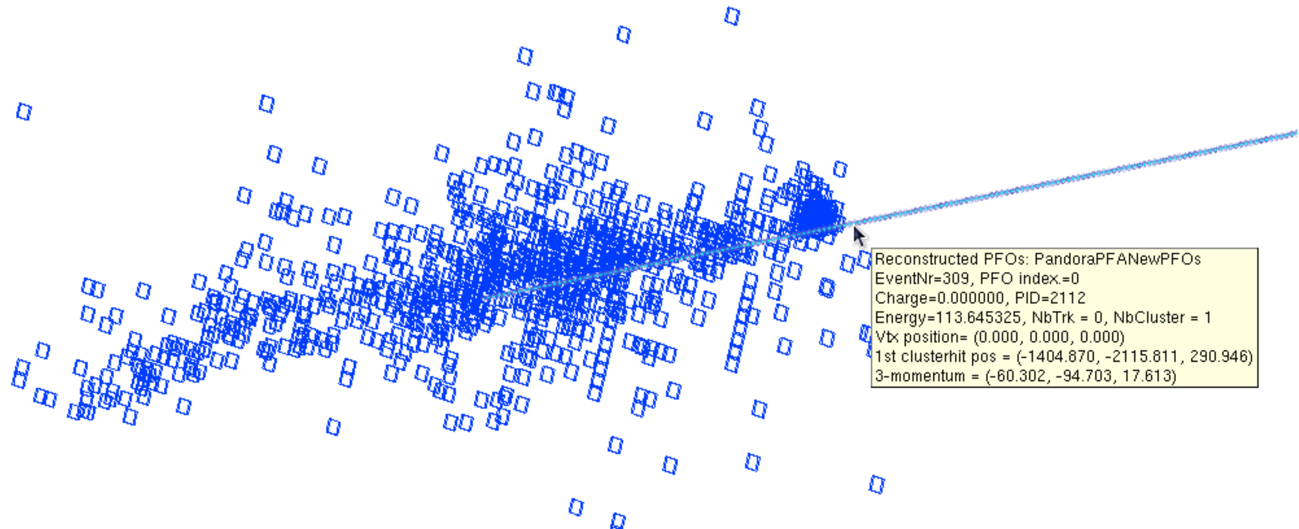
Klong (90GeV)

Can deposit only 11GeV energy in the end of Calo (ECAL + HCAL ~ 6λ)

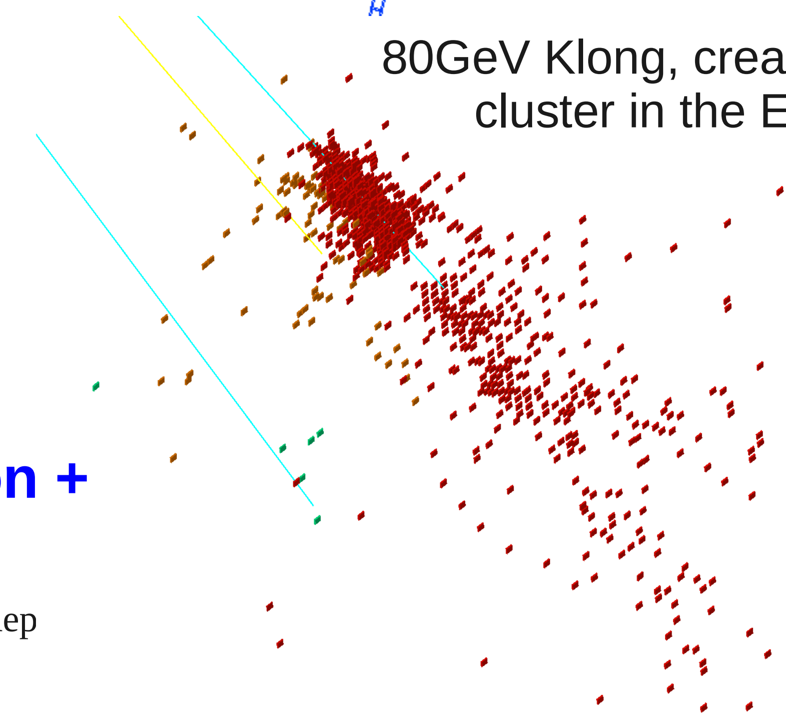
Additional weight to deep layer?



Or create a huge cluster...

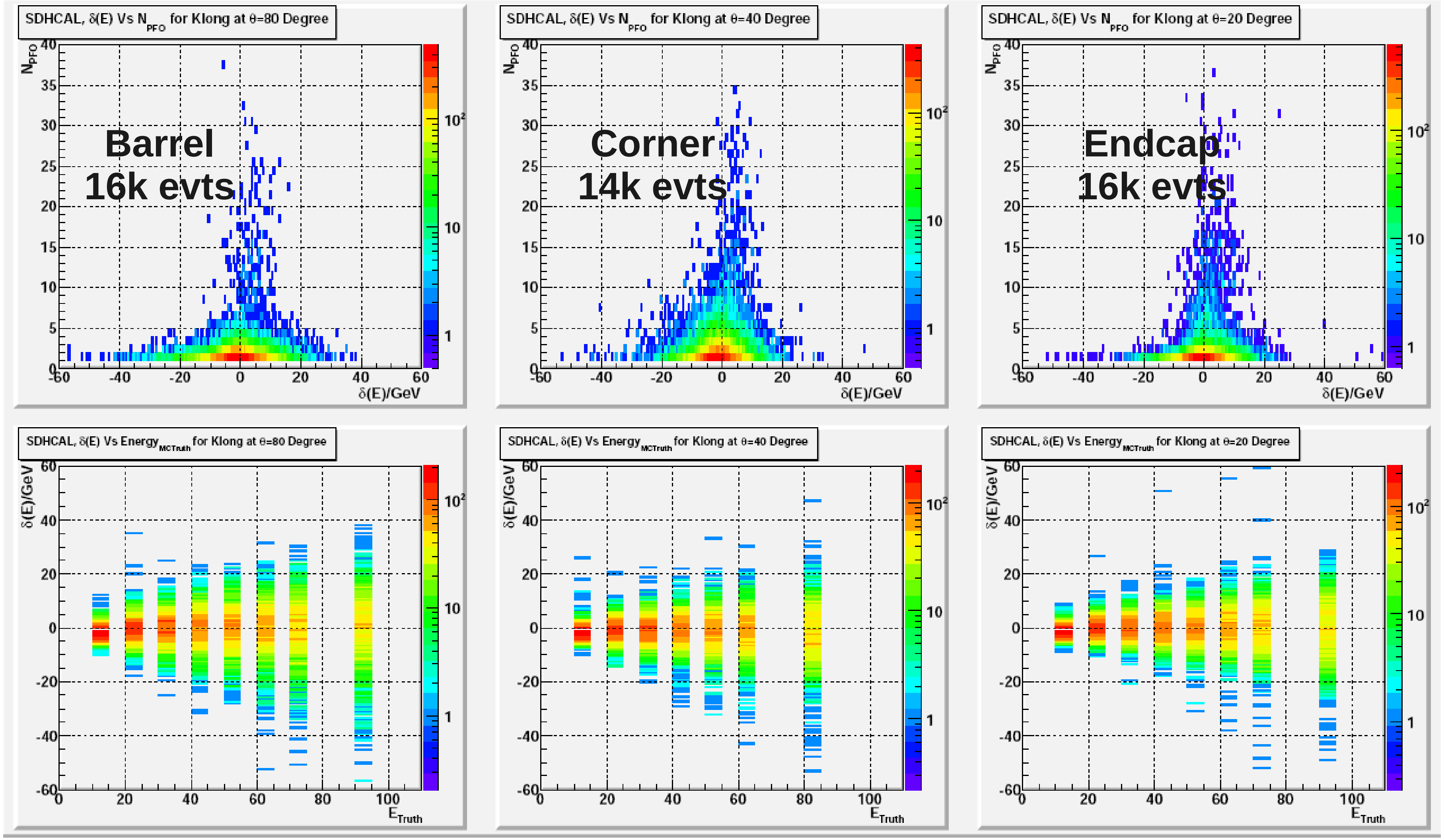


80GeV Klong, create 127GeV cluster in the Endcap



Neutral Hadron = Huge Fluctuation + Leakage

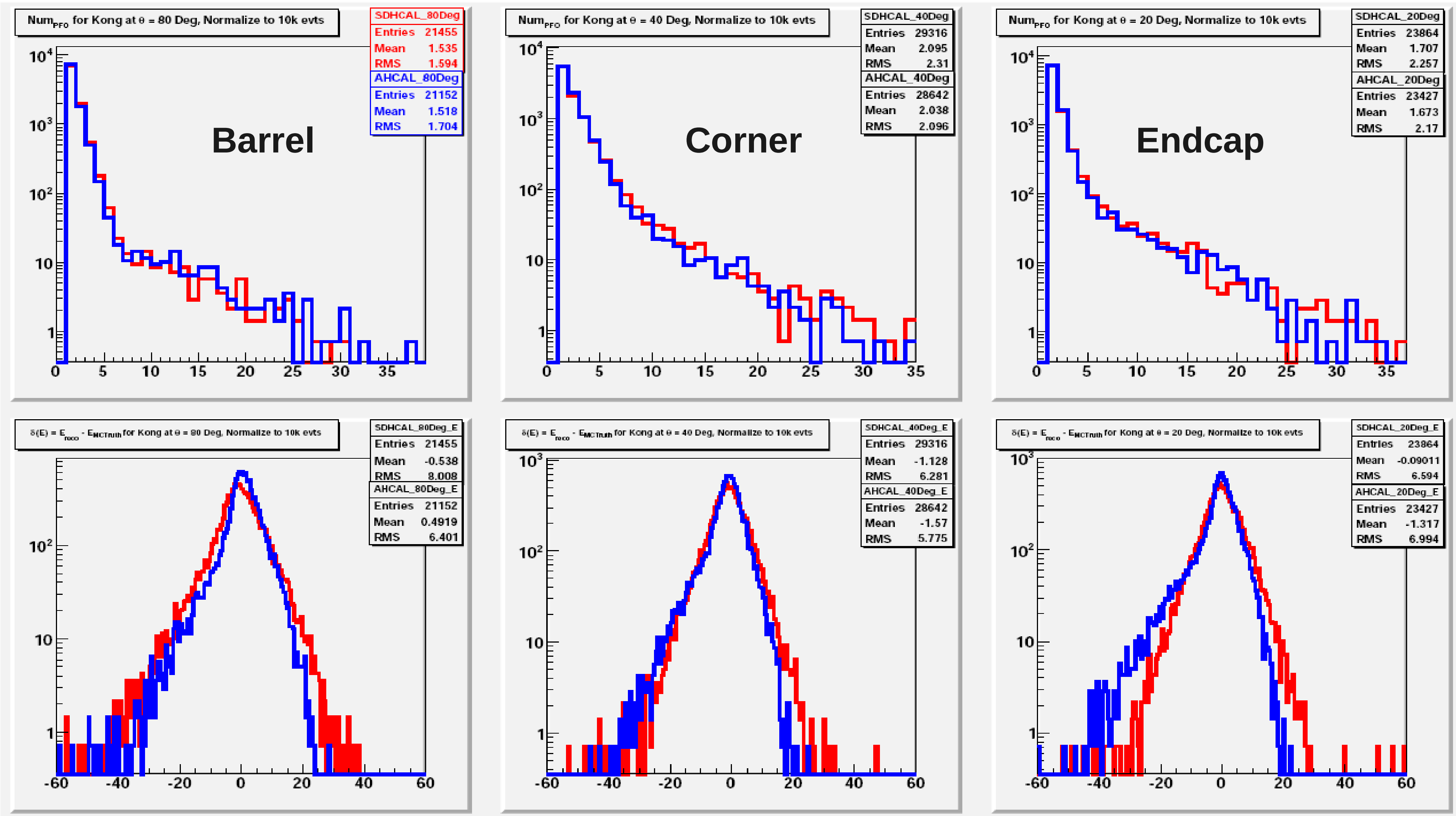
SDHCAL, Klong



NPFO(Barrel) < NPFO(EndCap) < NPFO(Corner)

Large smearing in energy resolution: better energy estimator and leakage correction

SDHCAL/AHCAL Comparison



Similar NPFO distribution & Better energy resolution @ AHCAL