

Arbor & Shower Fractal Dimension

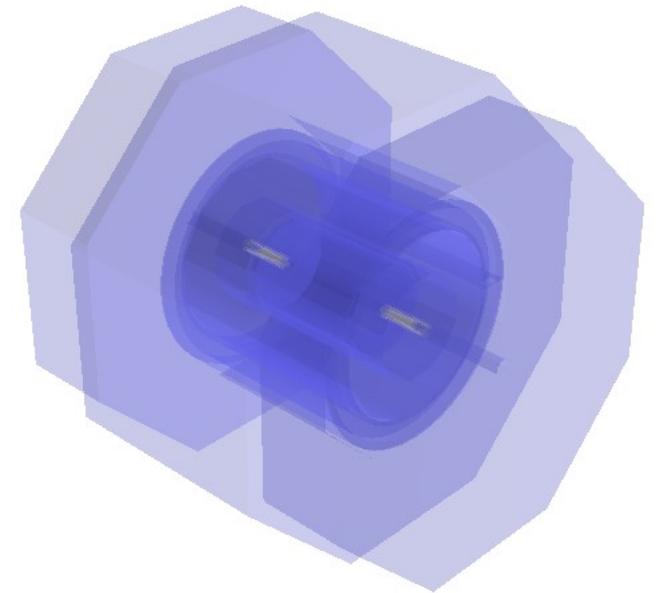
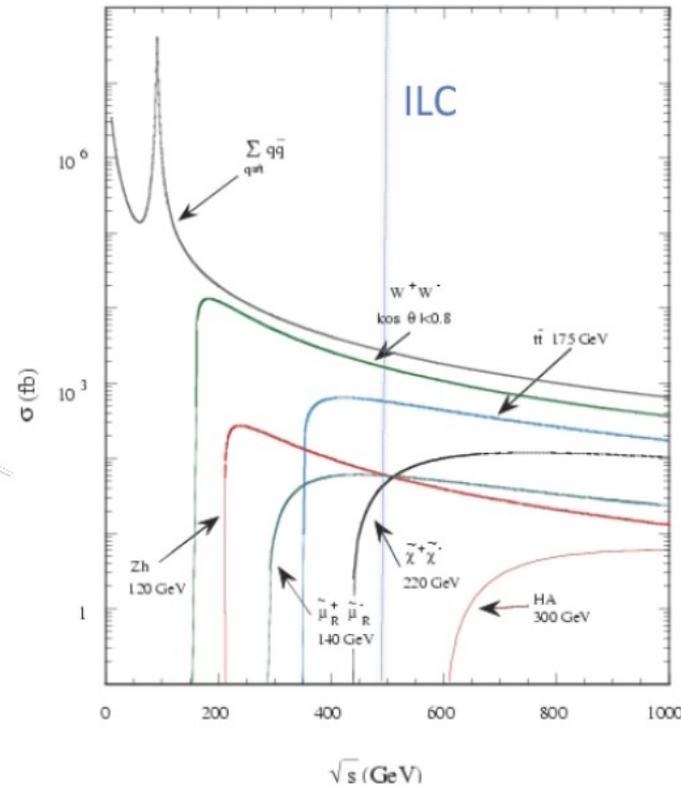
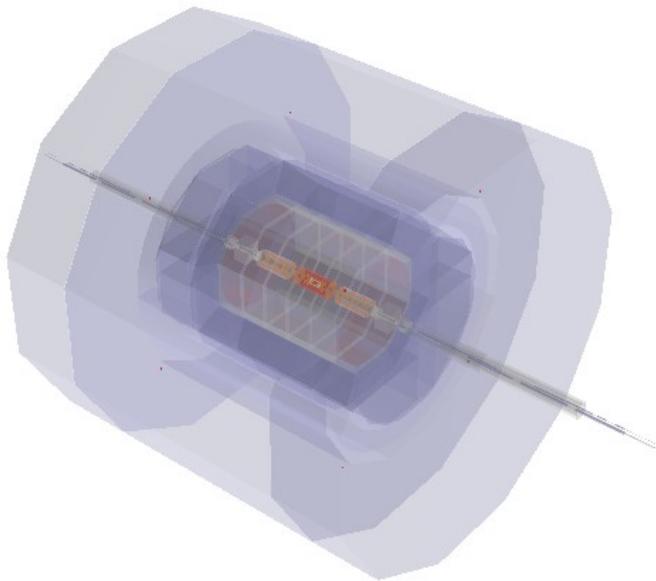
*- advanced shower reconstruction
at a highly granular calorimeter*

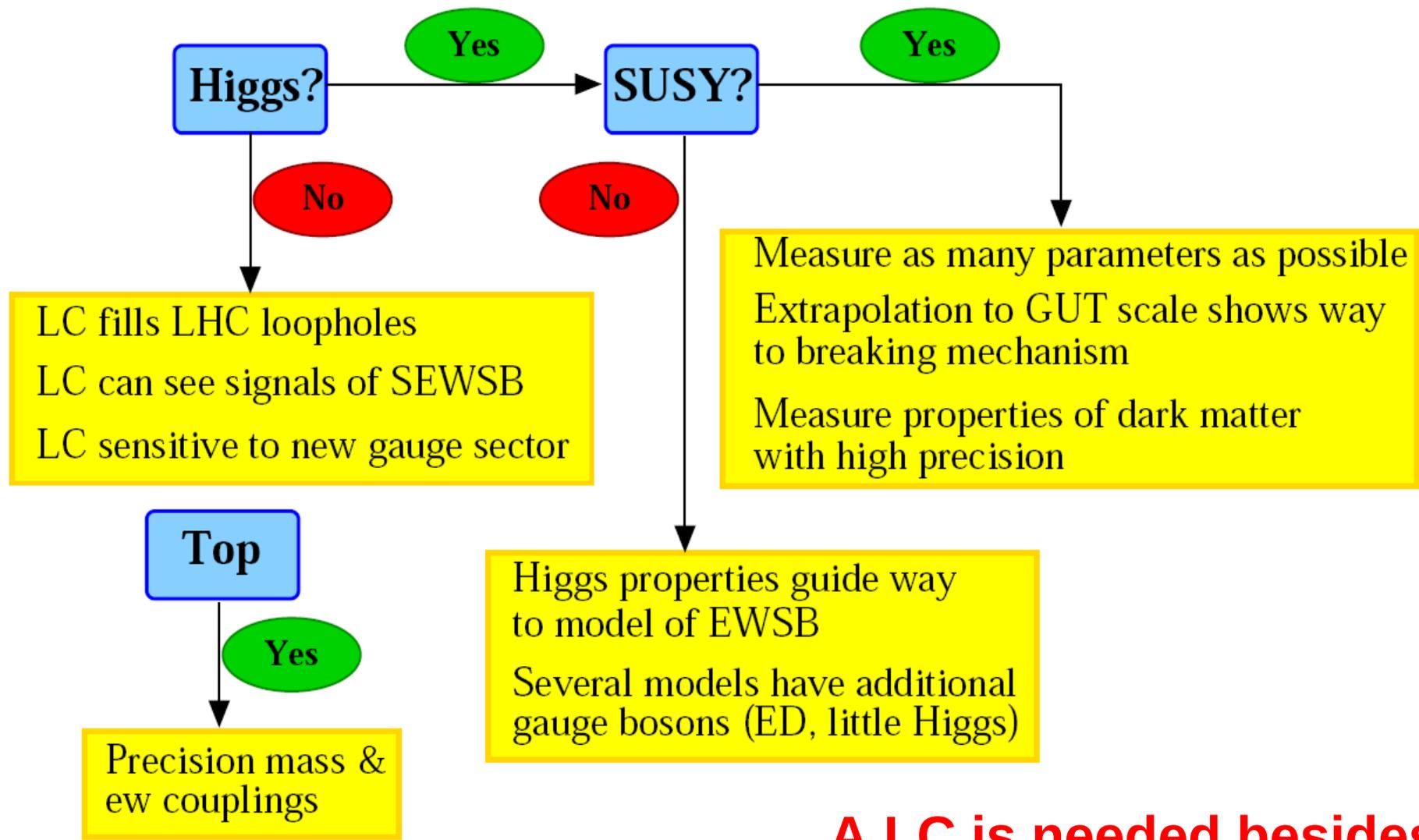
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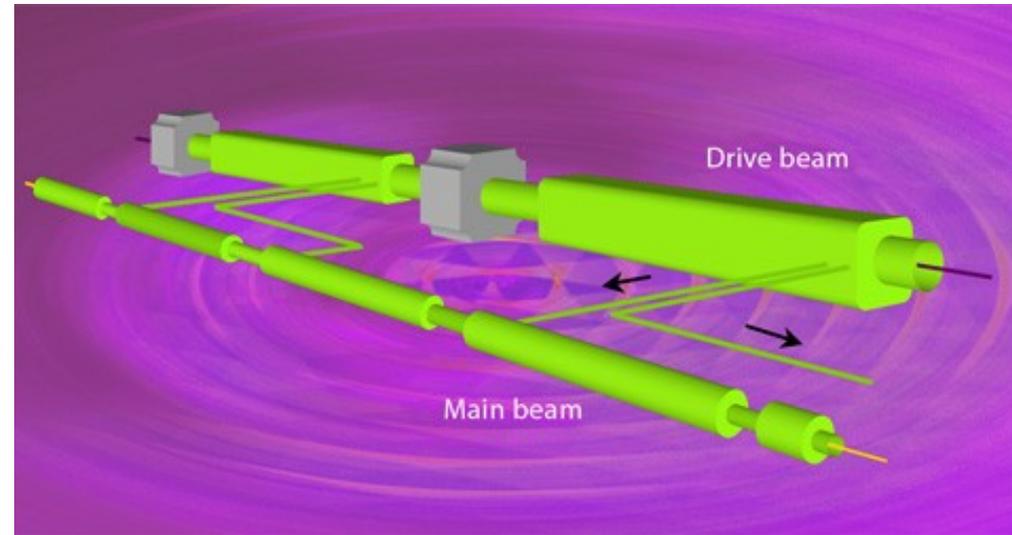
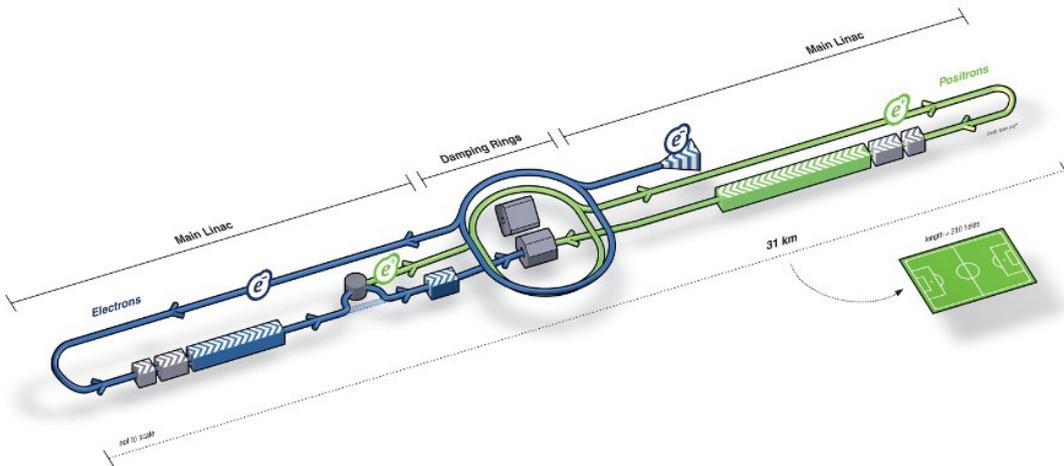
Part I: Physics @ LC & Highly Granular Calorimeter





A LC is needed besides the LHC in any case

Klaus Moenig: Physics potential of LC



- CLIC: Compact Linear Collider, center-of-mass energy: 0.5 - 3 TeV. Warm technology (Room temperature & gradient $\sim 100\text{MV/m}$, small bunch spacing)
- ILC: International Linear Collider, center-of-mass energy: 0.5 - 1.0 TeV. Cold technology (2K & low gradient $\sim 31.5\text{ MV/m}$, large bunch spacing)
- CLIC & ILC: very different accelerators with similar detectors.
- Stage 2012: ILC, TDR; CLC, CDR.

Particle Flow Algorithm:

Idea (originally from ALEPH):
Measure jets as collections of particles, in the best suited sub detectors

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

Multi bosons

ZH
WW
ZZ
ZHH
ZZZ
ZWW

Multifermions + Boson(s)

e⁺e⁻ H , e⁺e⁻ Z
νν H , νν Z
ttH
e ν W
νν WW, νν ZZ
ttbar

$$E_{\text{jet fraction}} = E_{\text{charged tracks}} \text{ (65\%)} + E_{\gamma} \text{ (26\%)} + E_{h^0} \text{ (9\%)}$$

Charged Particle – Tracker:

$$\Delta(1/p) \sim 2 \cdot 10^{-5} \text{ (1/GeV)}$$

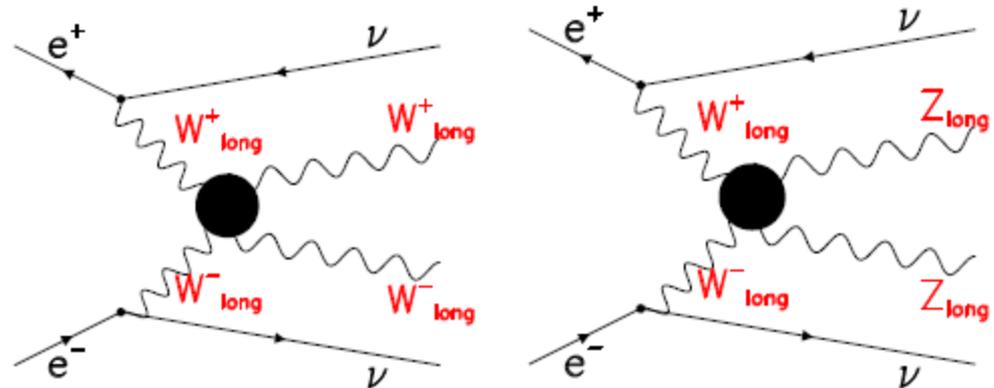
Photon – ECAL:

$$\Delta E/\sqrt{E} \sim 15\%$$

Neutron Hadron – HCAL:

$$\Delta E/\sqrt{E} \sim 50\%$$

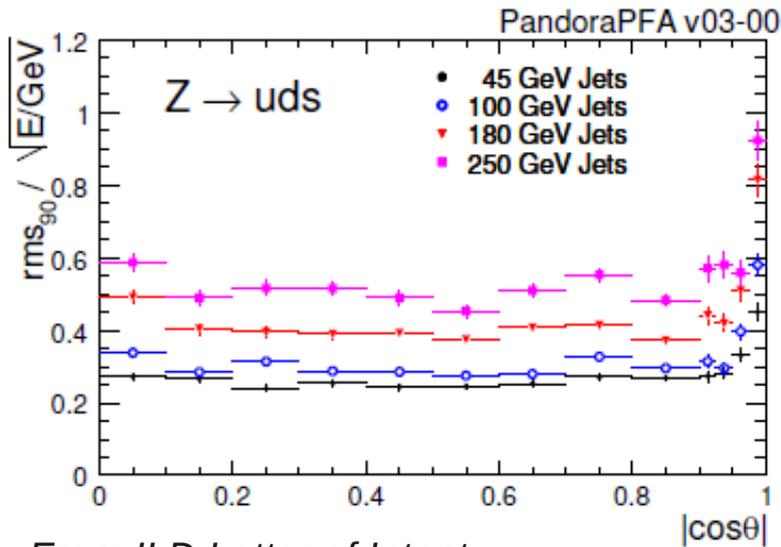
If perfectly reconstructed:



To separate WWνν & Zzνν: Jet energy resolution:
 $30\%/\sqrt{E}$

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

Initial goal: Achieved



From ILD Letter of Intent

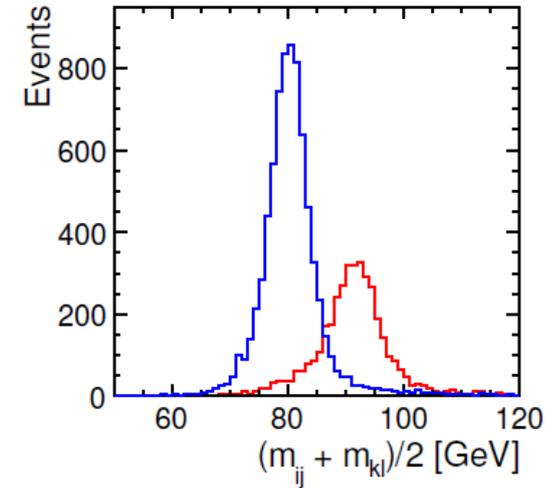
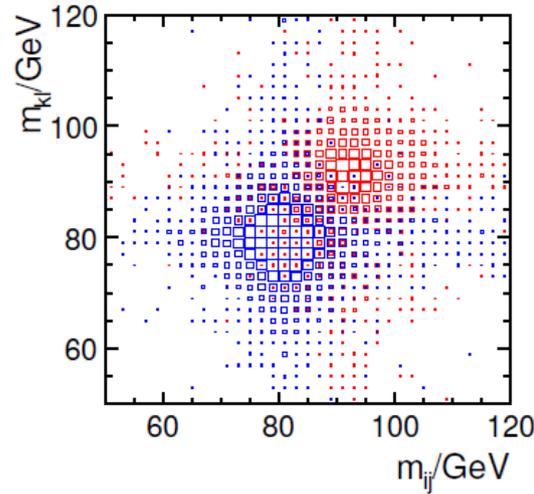


FIGURE 3.3-14. a) The reconstructed di-jet mass distributions for the best jet-pairing in selected $\nu_e \bar{\nu}_e WW$ (blue) and $\nu_e \bar{\nu}_e ZZ$ (red) events at $\sqrt{s} = 1 TeV$. b) Distributions of the average reconstructed di-jet mass, $(m_{ij} + m_{kl}^B)/2.0$, for the best jet-pairing for $\nu_e \bar{\nu}_e WW$ (blue) and $\nu_e \bar{\nu}_e ZZ$ (red) events.

Dependence on Detector Parameters and Jet energy:



$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E/\text{GeV}}} \oplus 0.7 \oplus 0.004E \oplus 2.1 \left(\frac{R}{1825 \text{ mm}} \right)^{-1.0} \left(\frac{B}{3.5 \text{ T}} \right)^{-0.3} \left(\frac{E}{100 \text{ GeV}} \right)^{0.3} \%$$

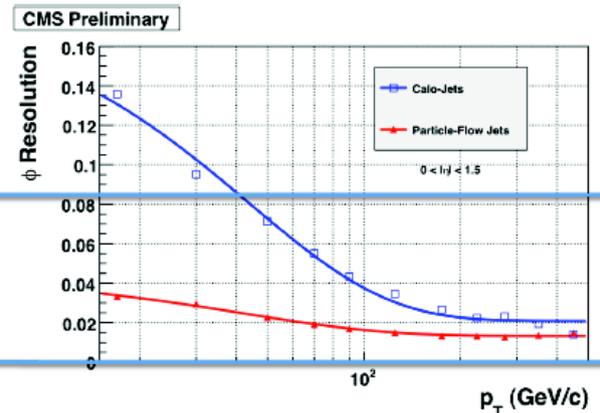
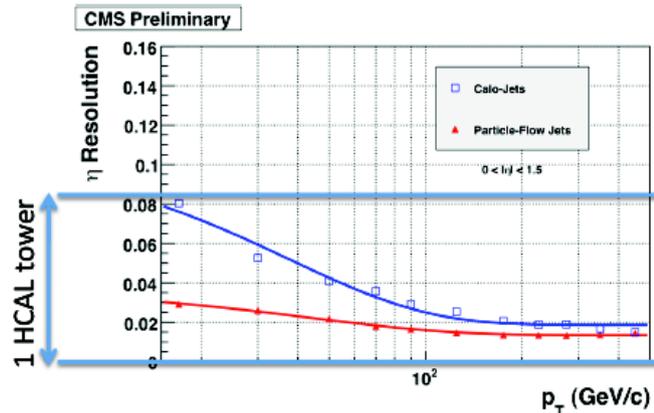
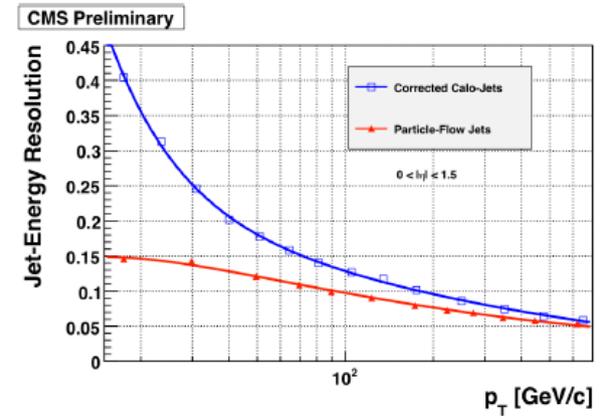
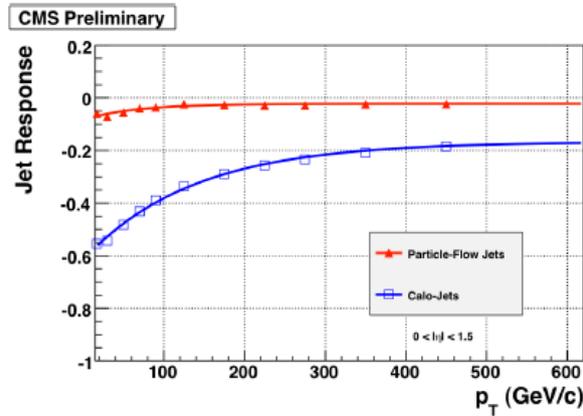
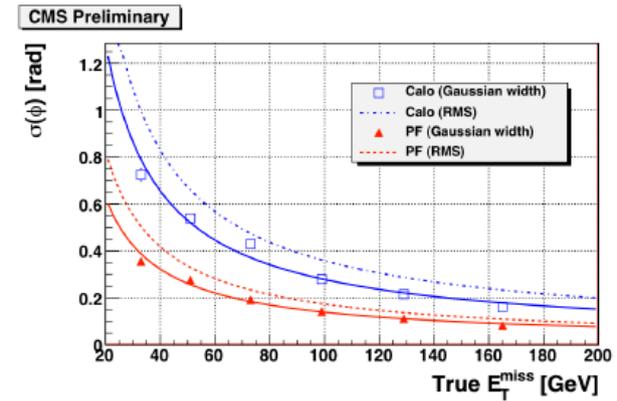
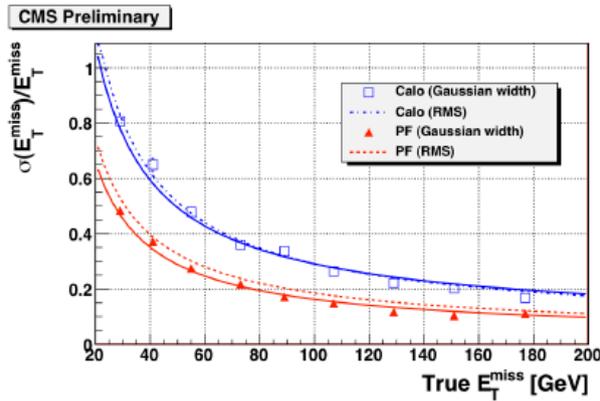
Energy Flow @ CMS

Improves significantly:

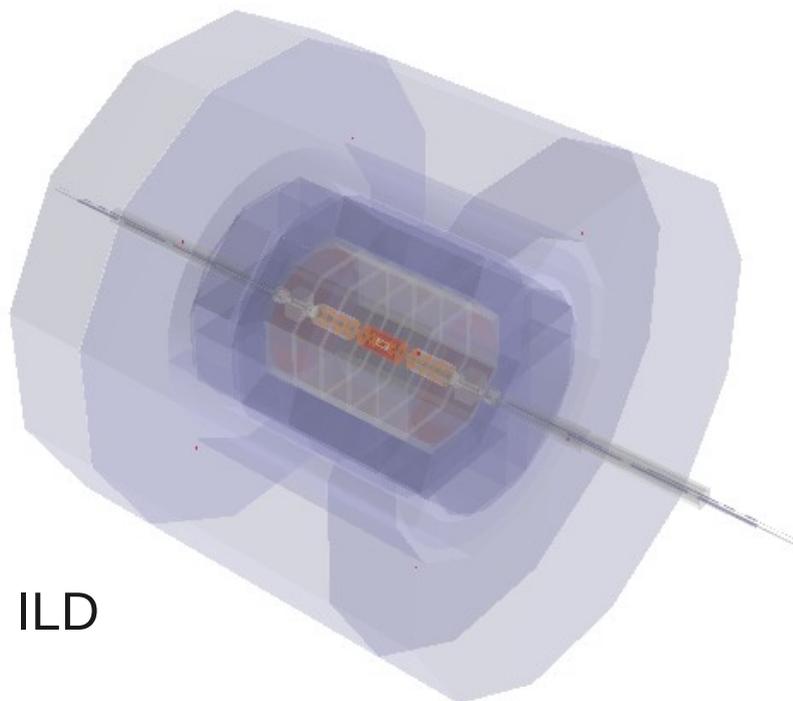
Missing Transverse Momentum, energy & Direction (ϕ)

Jet momentum resolution: energy & direction (η , ϕ)

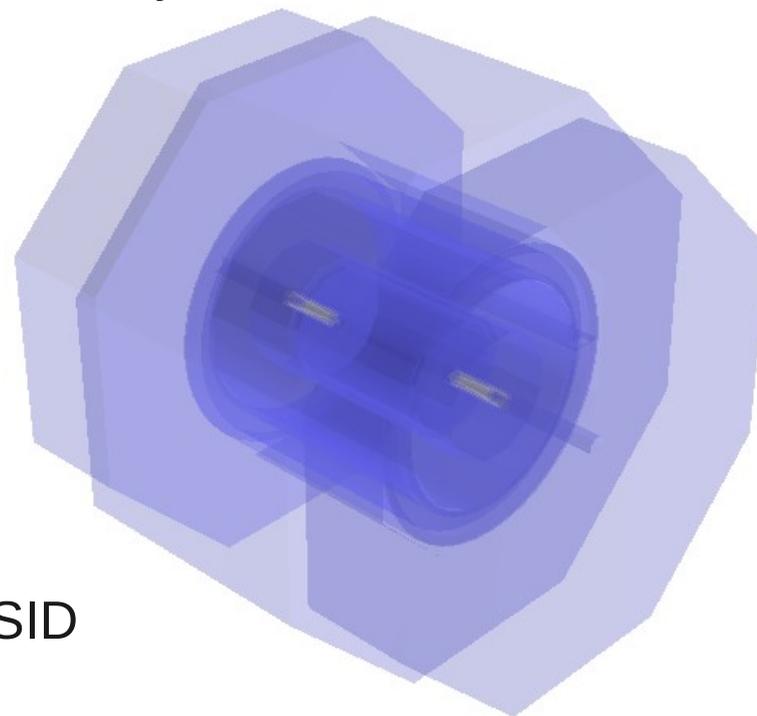
Lepton identification



- ↑ • PFA: less confusion ~ good separation:
Granularity > Energy Resolution for the Calorimetry...



ILD

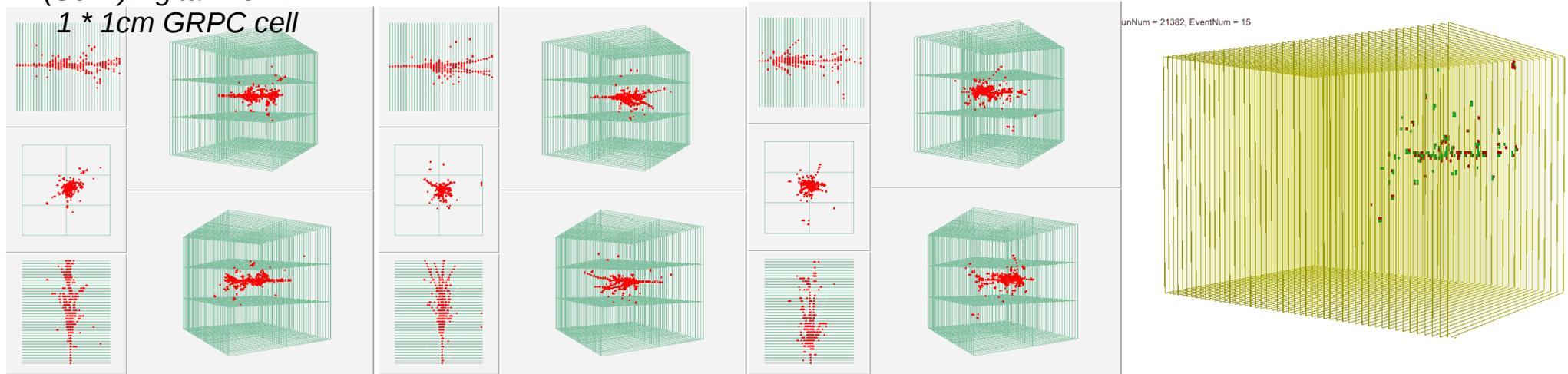


SiD

- PFA Oriented detector (both have ILC/CLIC Versions):
 - ILD (International Large Detector, mostly European + Asia): TPC + Silicon inner detectors tracking with $B = 3.5T/4T$
 - SiD (Silicon Detector, mostly in US): Silicon tracking with $B = 5T$
- Electronic channels of Calorimeter: ~ **100M**

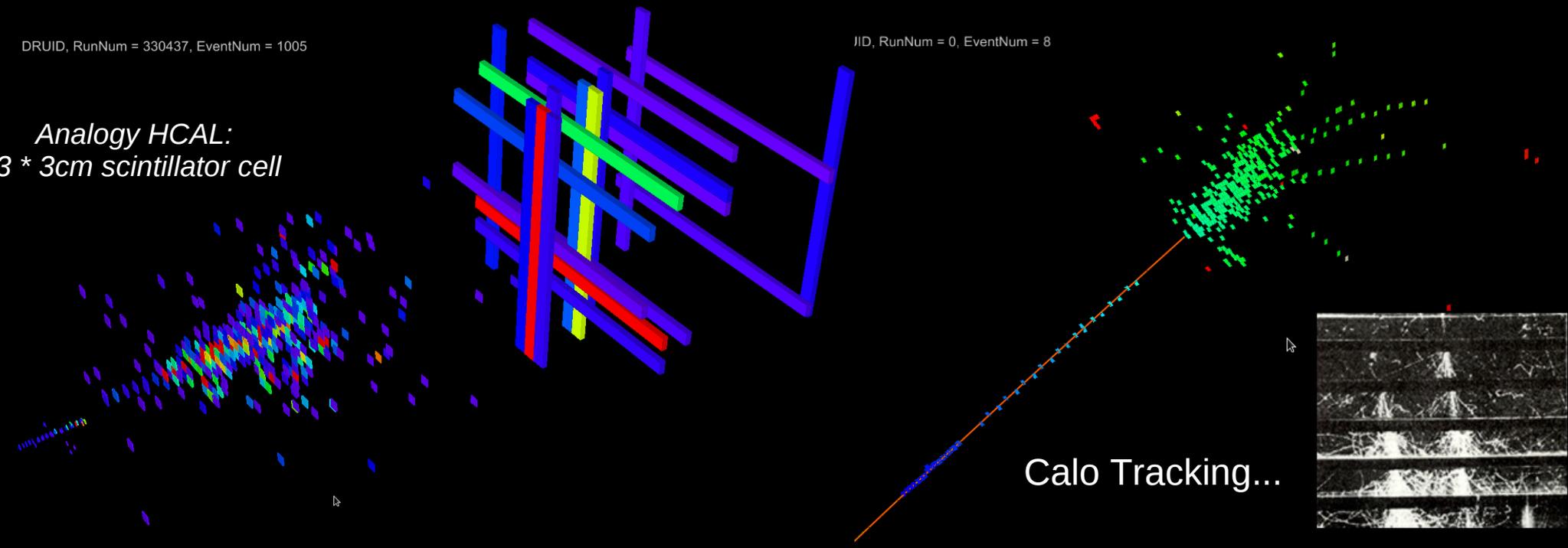
Part II: Shower Reconstruction at an Imaging Calorimetry

(Semi)Digital HCAL:
1 * 1cm GRPC cell



DRUID, RunNum = 330437, EventNum = 1005

Analogy HCAL:
3 * 3cm scintillator cell



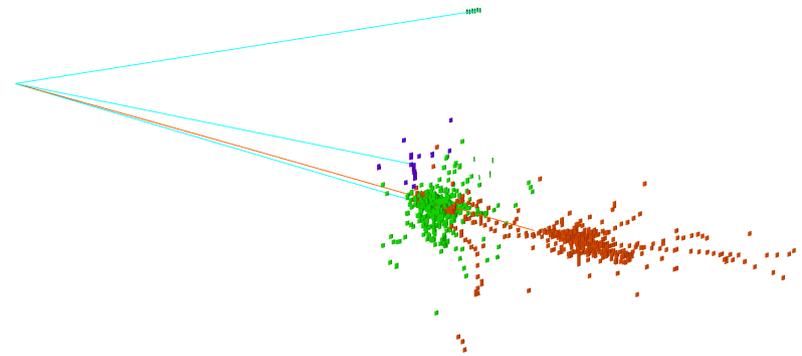
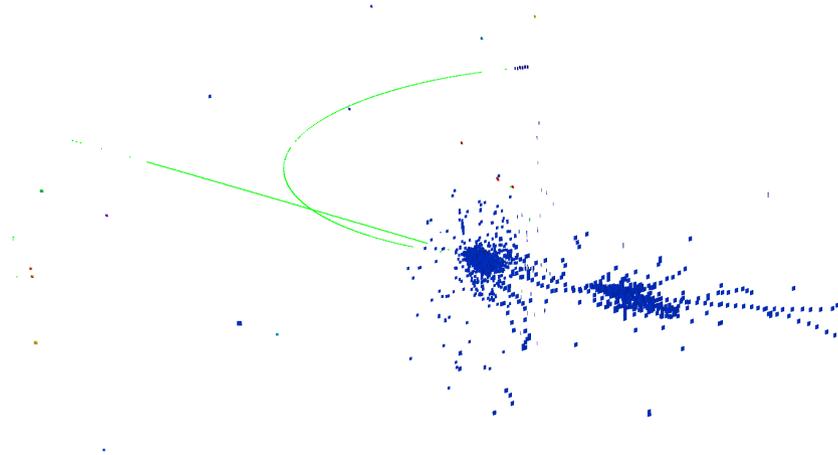
PandoraPFA: Promising performance.

But:

Optimized for AHCAL with 3 * 3 cm cells, while DHCAL has 1 * 1 cm cell

Confusion not negligible (worse at higher energy):

eg, ~10% of pions affected by PFA double counting



To improve:

Higher granularity ~ Better separation

Alternative Algorithm

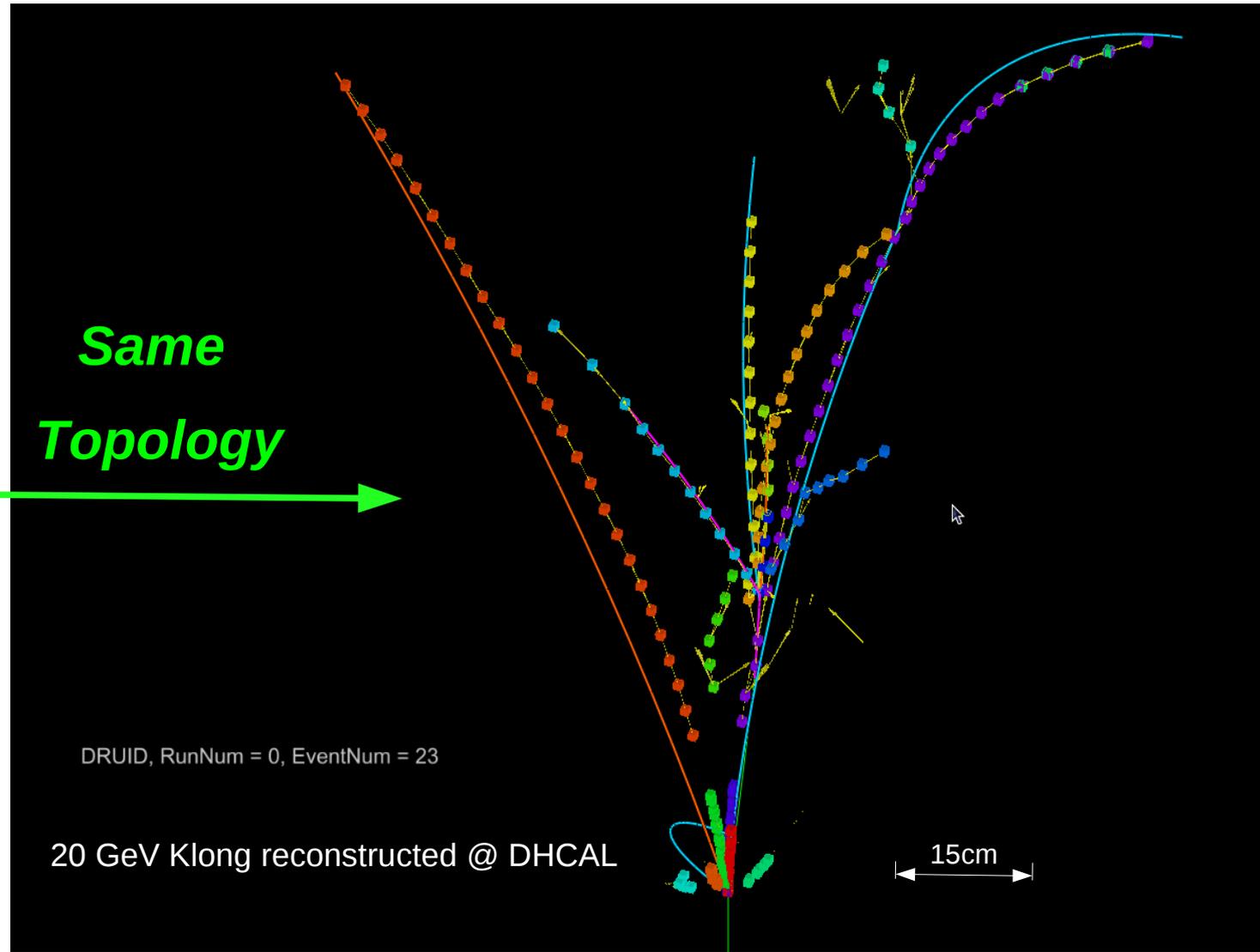
Better pattern recognition based on shower geometry

Better Measurement: more dedicate estimators

Arbor: shower ~ tree



**Same
Topology**

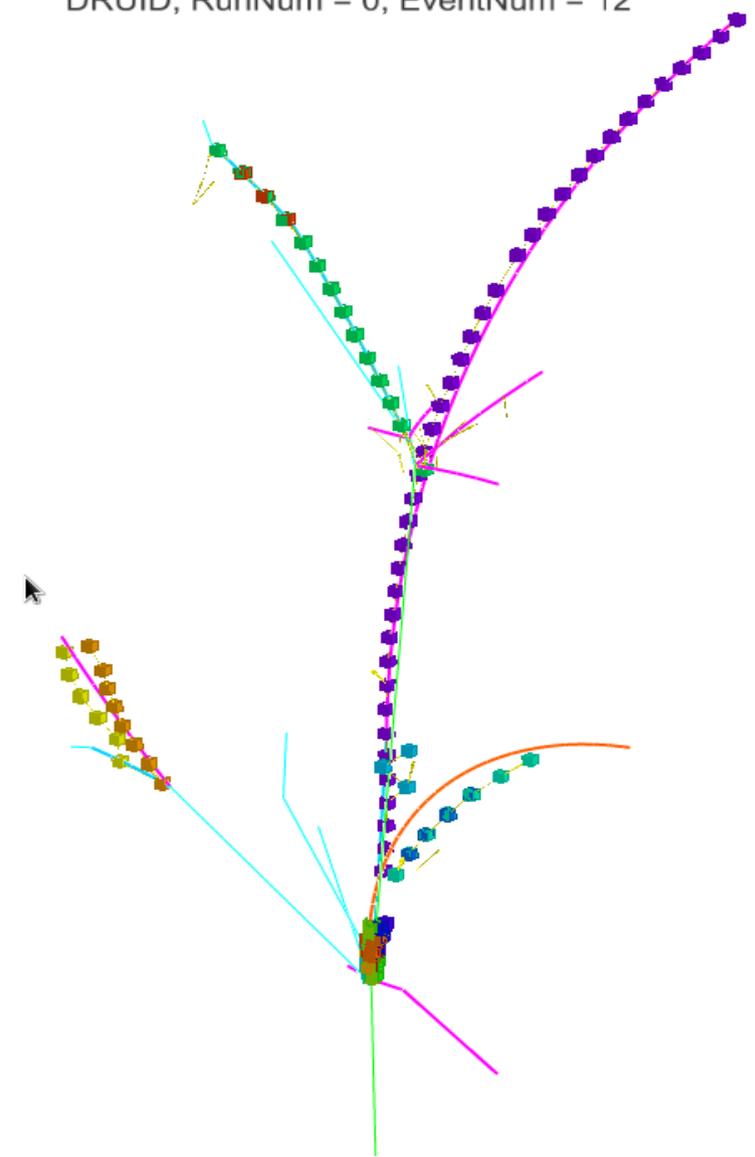


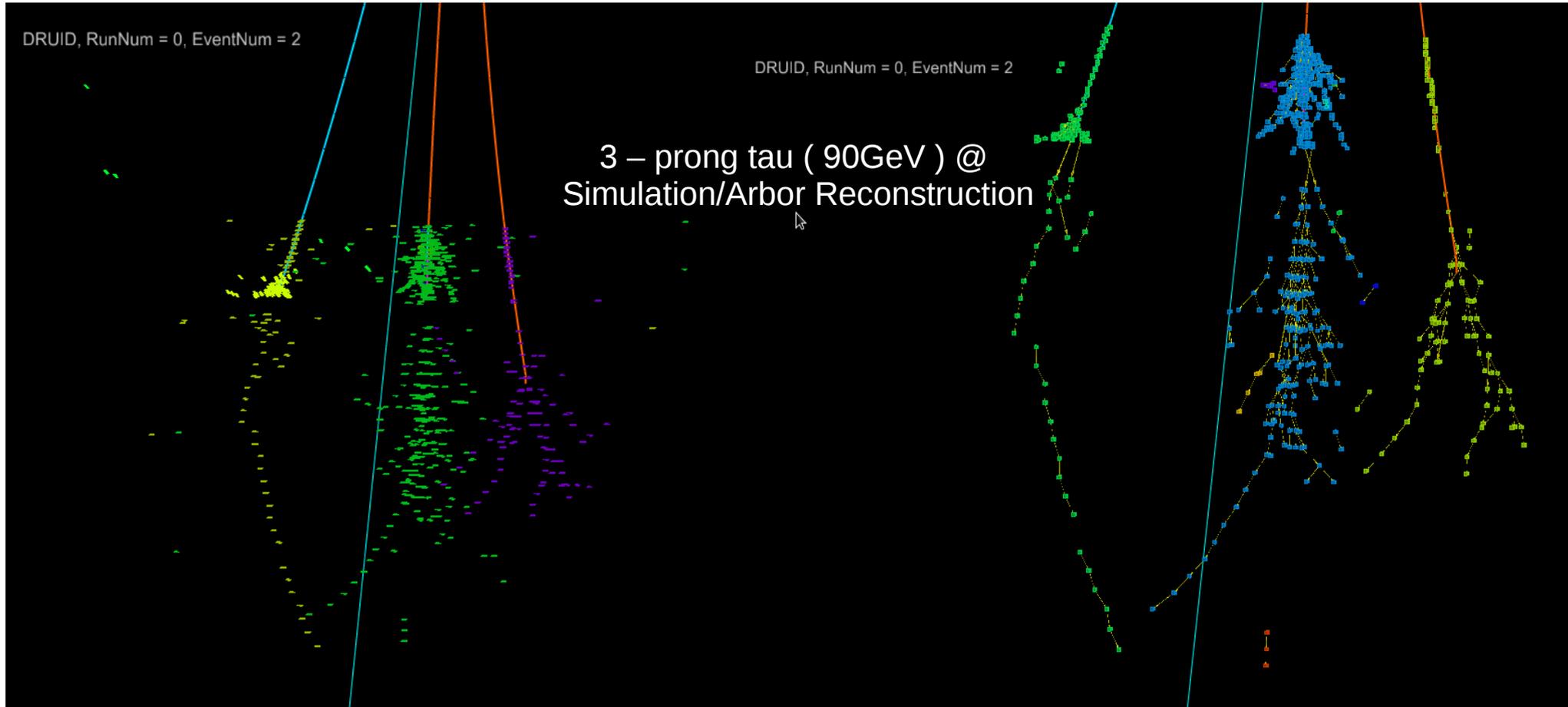
- *Start from Micro structures: Full usage on high granular information*
- *Original idea from Henri Videau, in hadronic shower reconstruction @ ALEPH*

DRUID, RunNum = 0, EventNum = 12

- Arbor: Promising branch tagging, with lots of potential applications
 - In situ Calibration/Stability monitoring
 - Kink & Pre interaction tagging
 - Track – Cluster linking
 - Calo Tracks Measurement:
 - Energy Estimation ~ Leakage correction
 - EM/Had hits tagging
 - ...

- Momentum reconstruction with Fit (J. Sniff, Princeton/LLR)
 - ~10% resolution on MIP track in the barrel & leakage correction using 1 cm² DHCAL cells

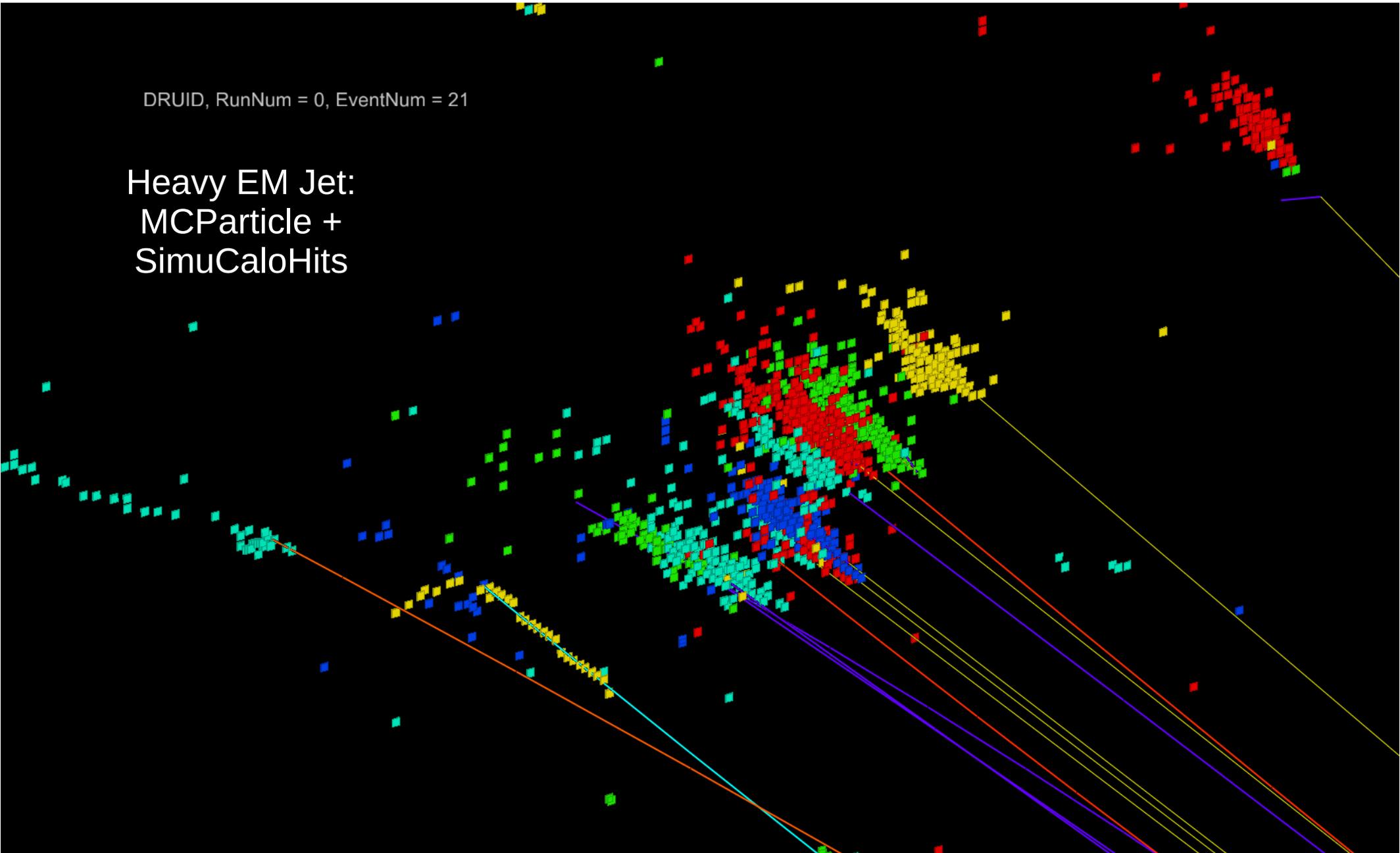




Merging Branches together : Reconstruction of Shower @ Calo

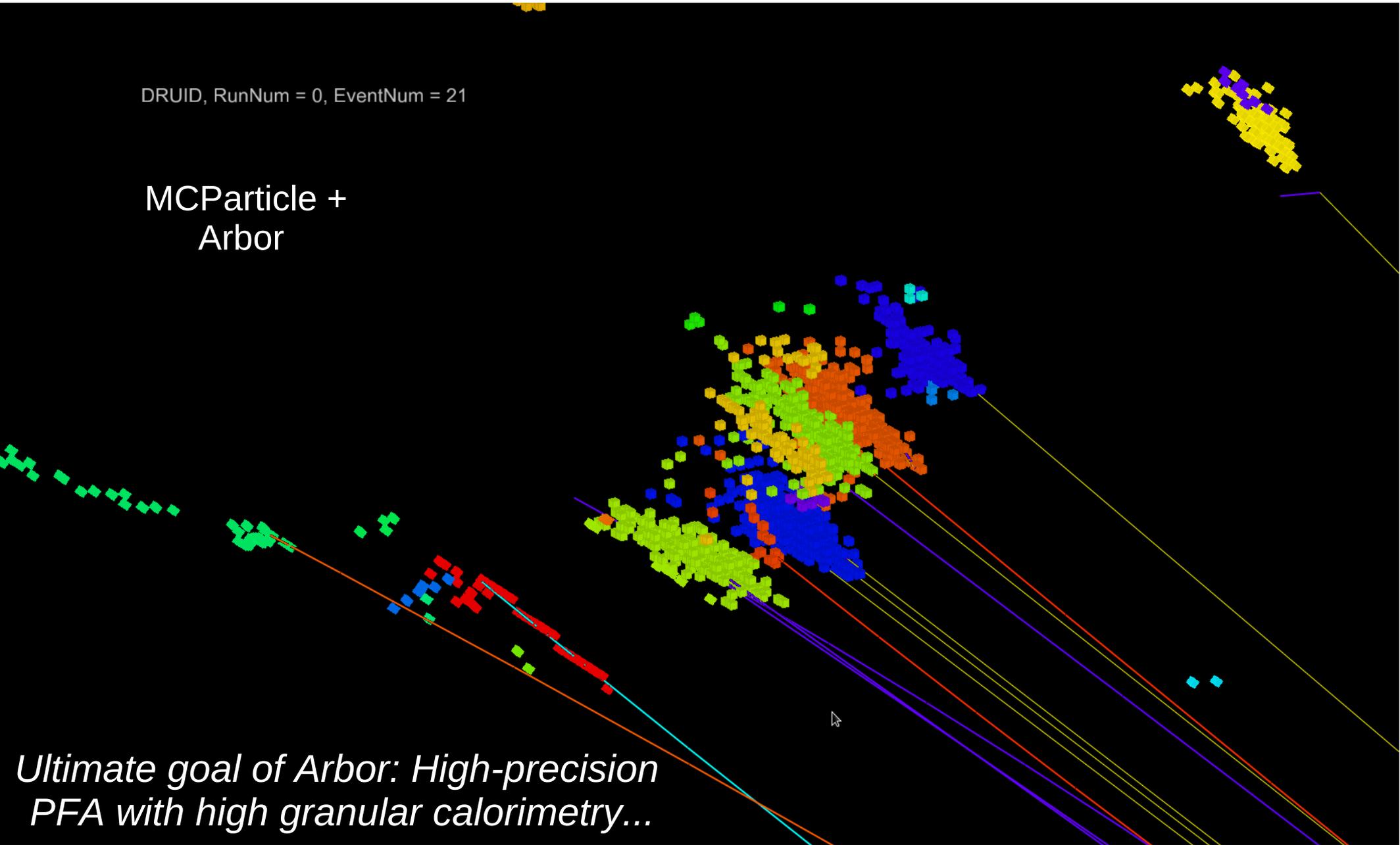
DRUID, RunNum = 0, EventNum = 21

Heavy EM Jet:
MCParticle +
SimuCaloHits



DRUID, RunNum = 0, EventNum = 21

MCParticle +
Arbor

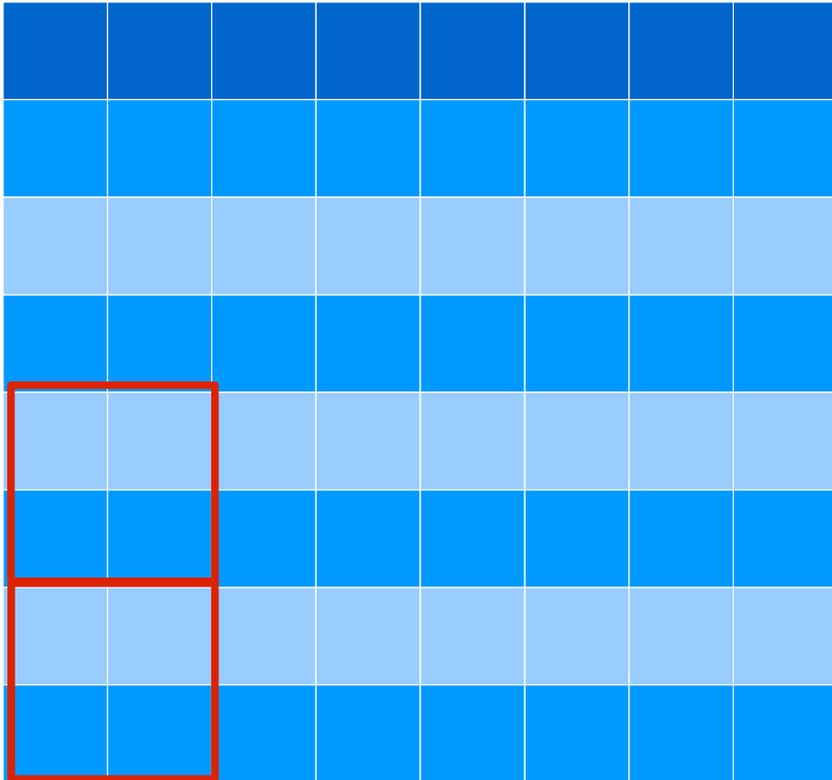


*Ultimate goal of Arbor: High-precision
PFA with high granular calorimetry...*

Shower particle: to interact or not

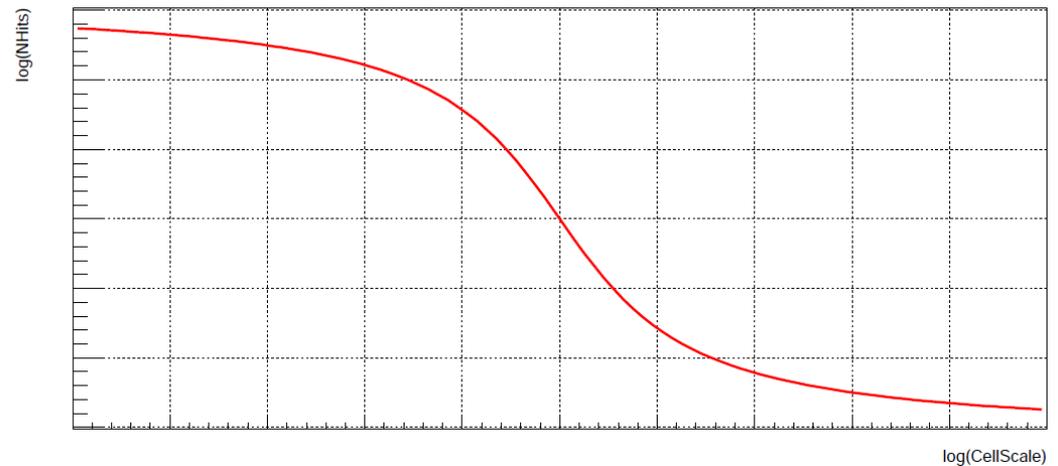


Shower: self similar object



Measure shower **Fractal Dimension (FD)** at high granularity calorimeters

- *Varying scale by grouping neighbouring cells*

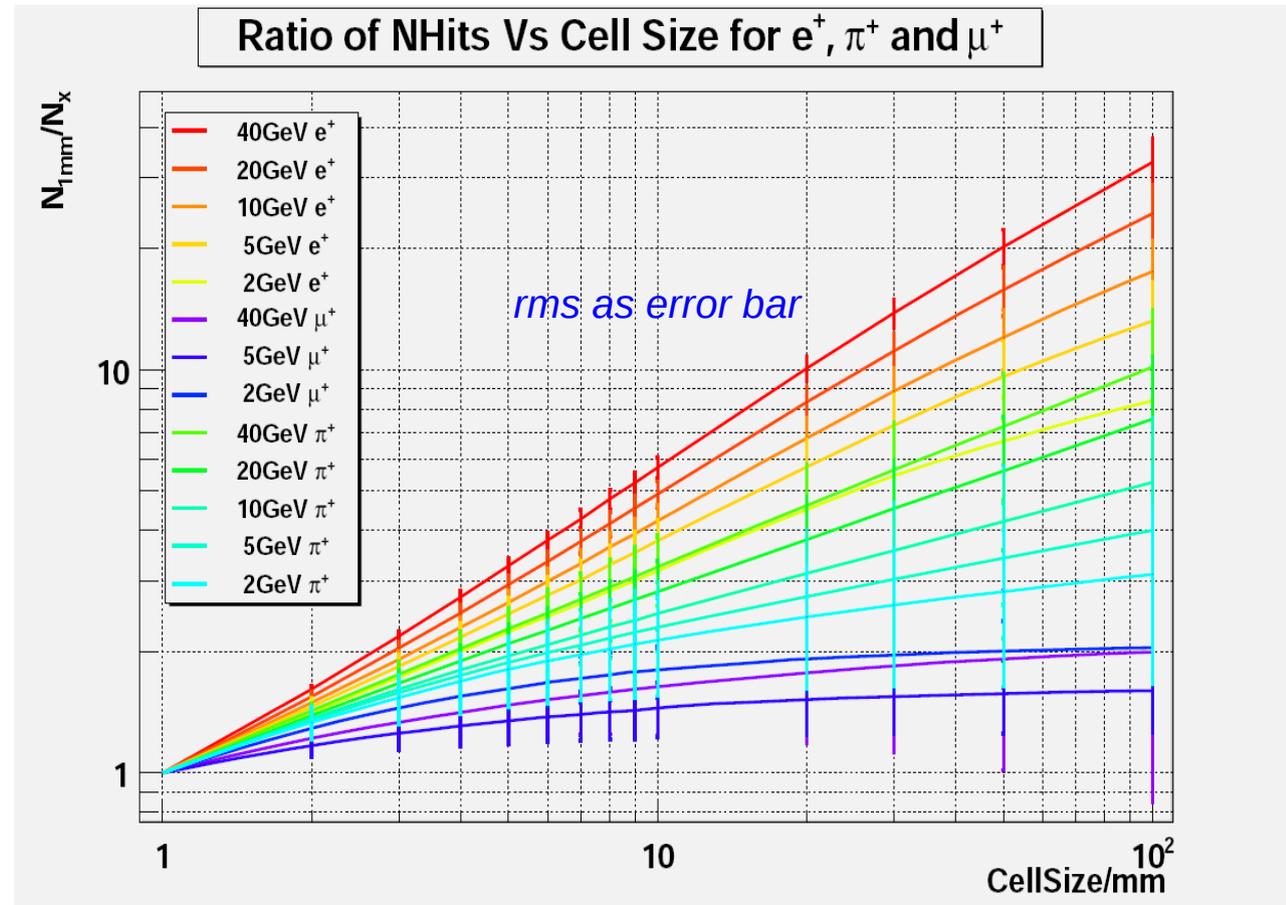


- Count Number of hits at different scale
(define $RN_x = N(\text{initial cell size})/N(\text{ganging size } x)$)

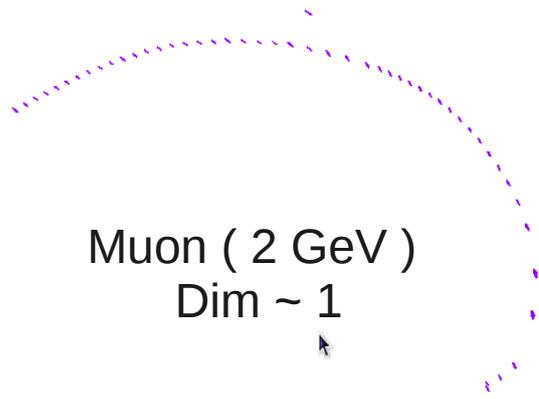
- Characteristic constant based on energy/PID:

$$FD = \langle \ln RN_a / \ln(a) \rangle + 1$$

- *a*: ratio between ganged cell size and initial cell size
- Initial cell size: 1mm in simulation
- Ganged Cell Sizes: 2 – 10, 20, 30, 50, 60, 90, 120, 150mm.
- Samples: Particles shot directly to GRPC DHCAL with only B Field

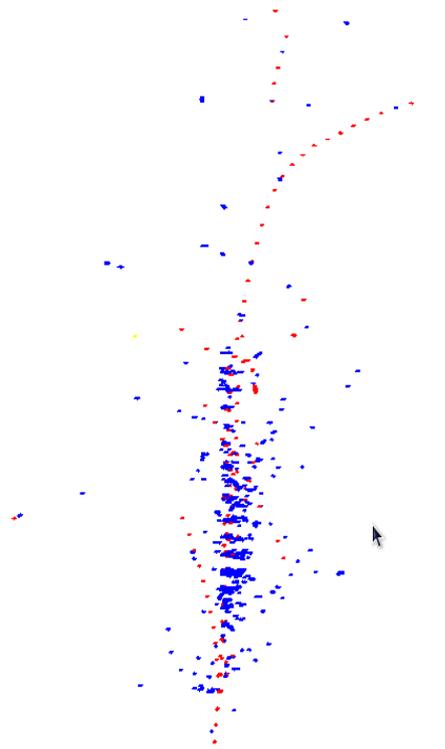


Fractals in Nature

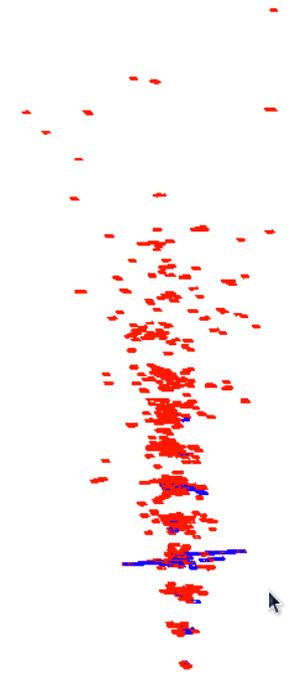
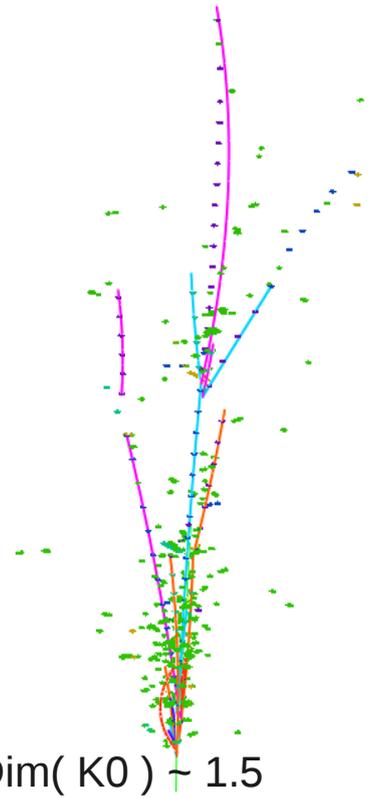


Muon (2 GeV)
Dim ~ 1

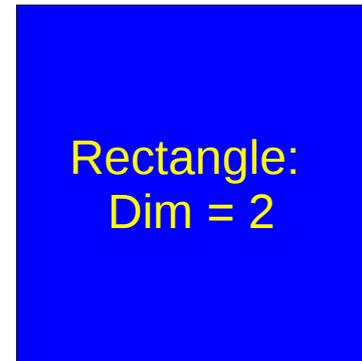
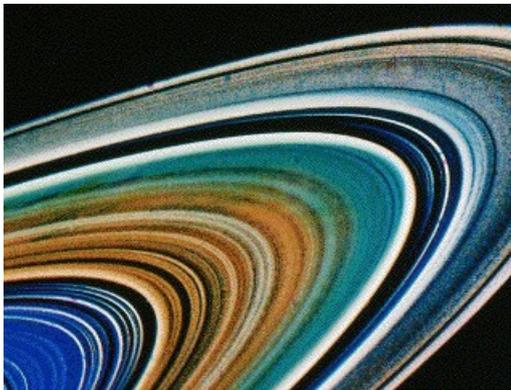
Curve/line:
Dim = 1

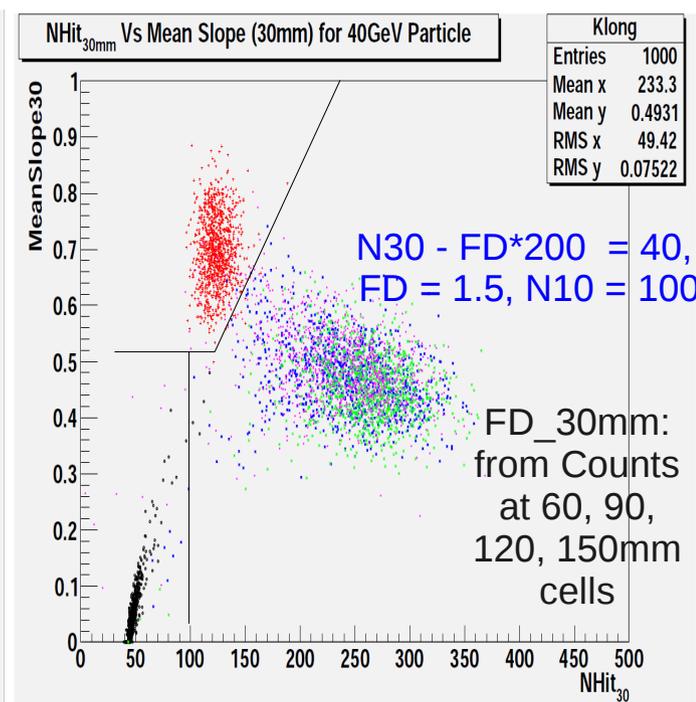
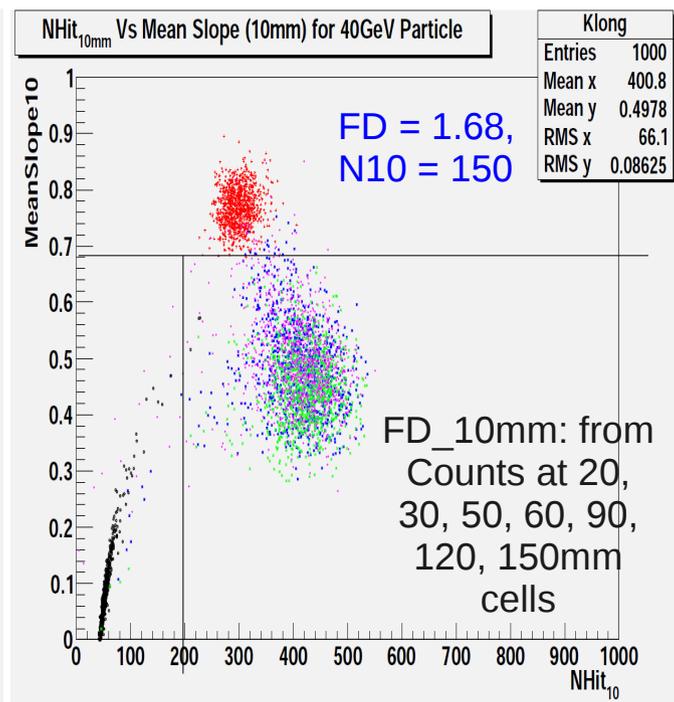
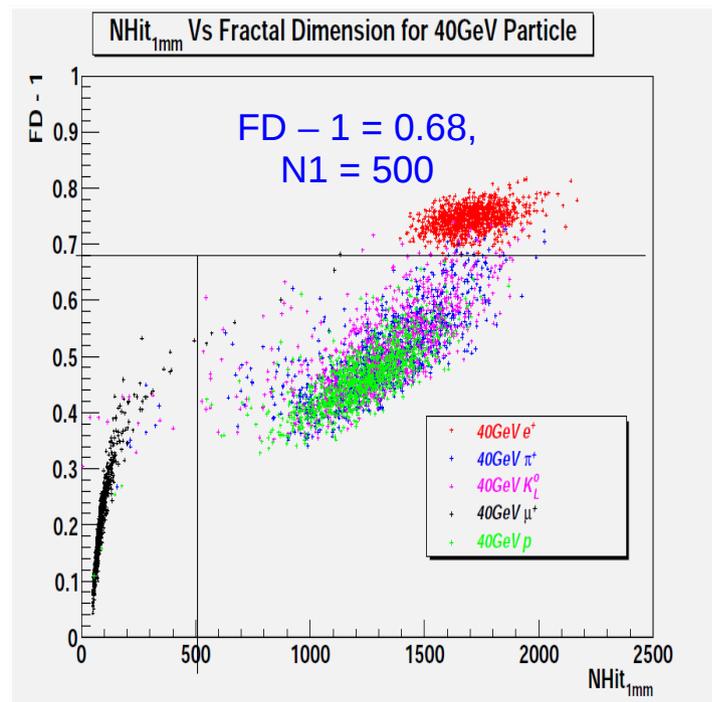


Hadrons: Dim(pi) < Dim(K0) ~ 1.5



Positron (40GeV)
Dim ~ 1.75





FD together with other info (Nhits): Clear separation at different scales

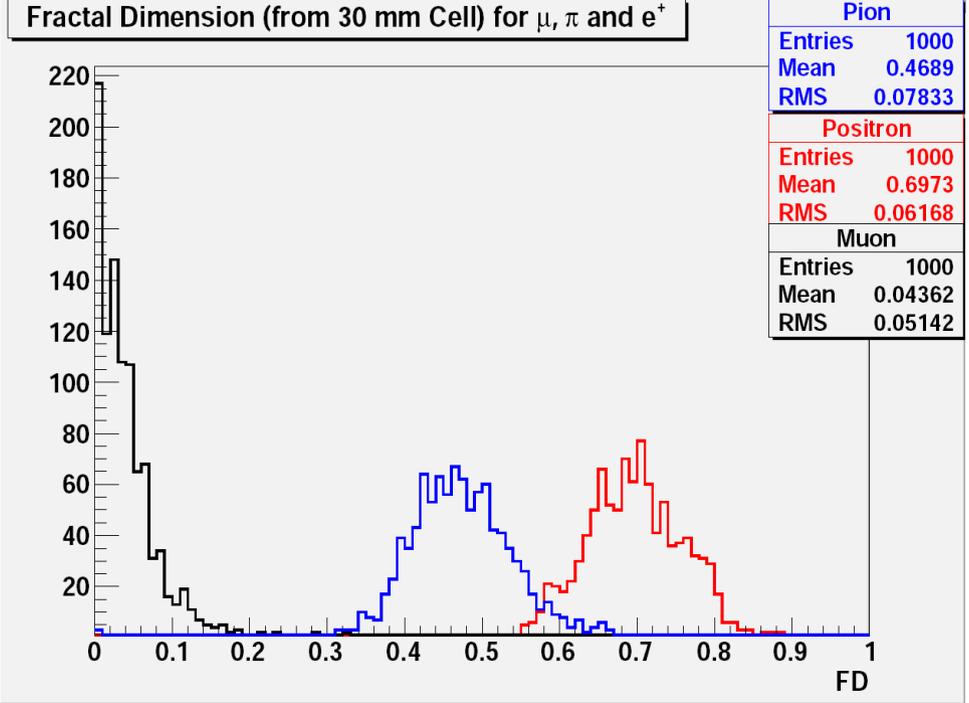
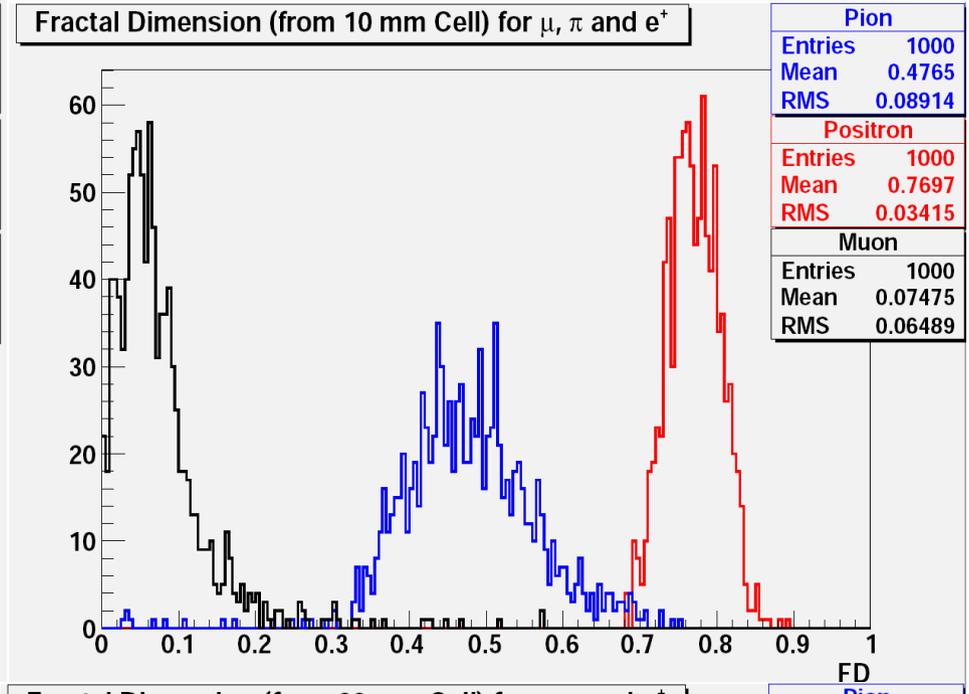
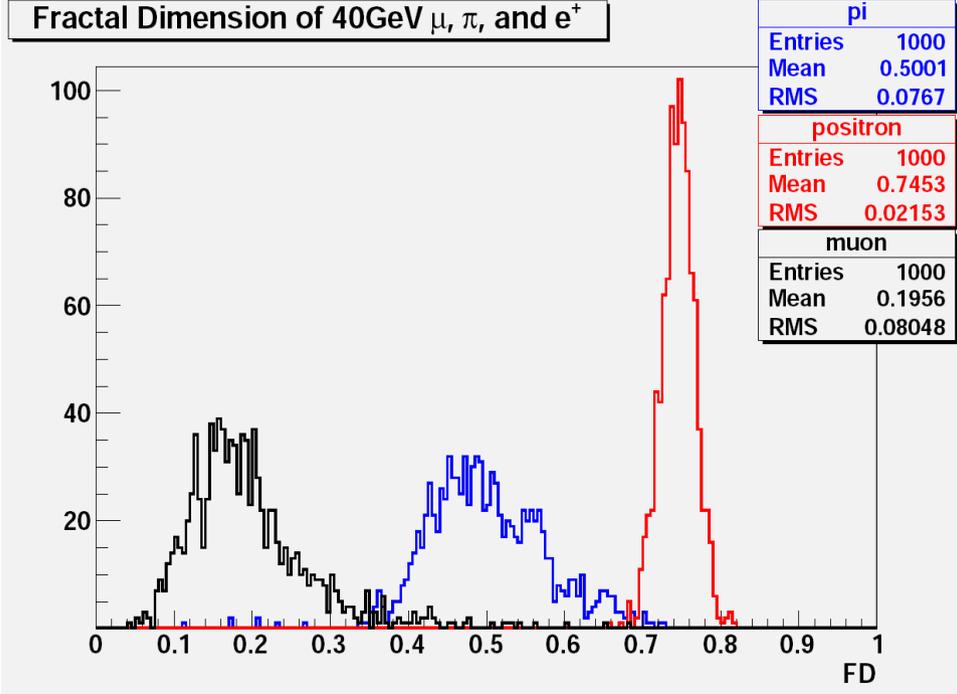
Remark: Energy dependent Cuts, easier for charged particles

1mm	e+	u	h
e+	998	0	2
u	1	994	5
h	15	14	971

10mm	e+	u	h
e+	1000	0	0
u	0	995	5
h	17	14	969

30mm	e+	u	h
e+	1000	0	0
u	0	996	4
h	18	11	971

FD @ different size



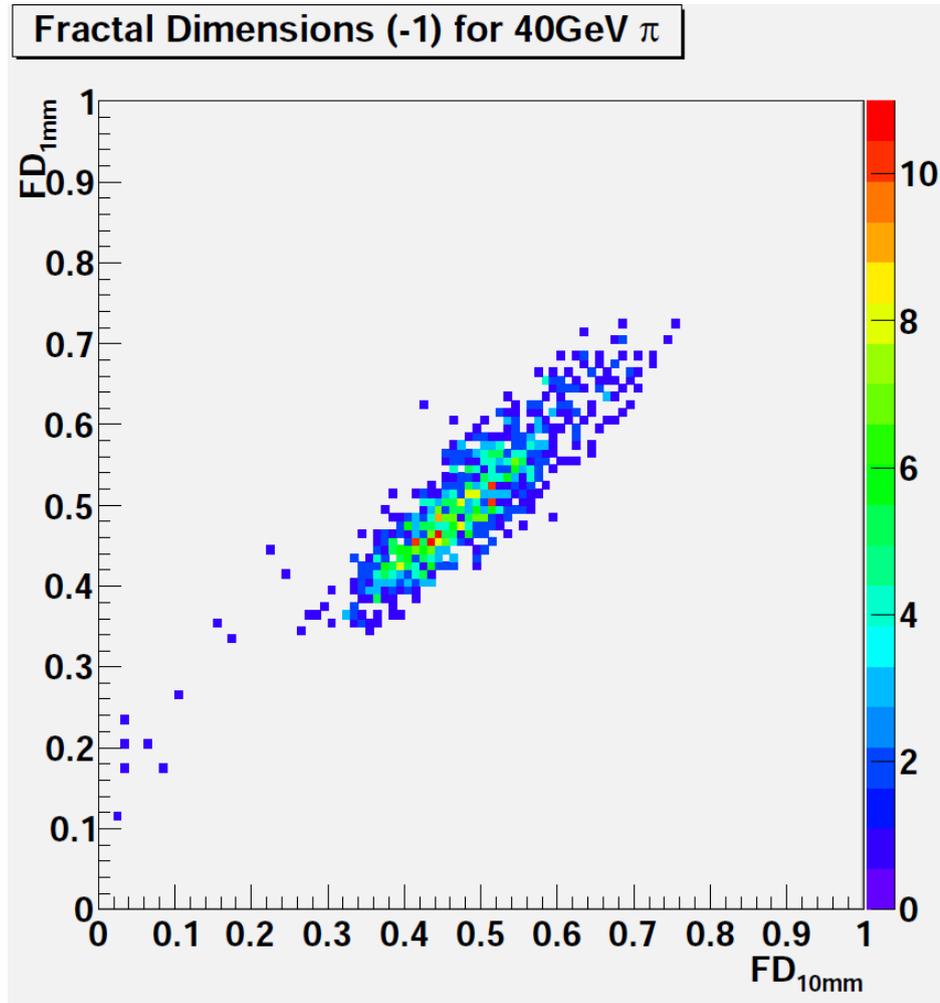
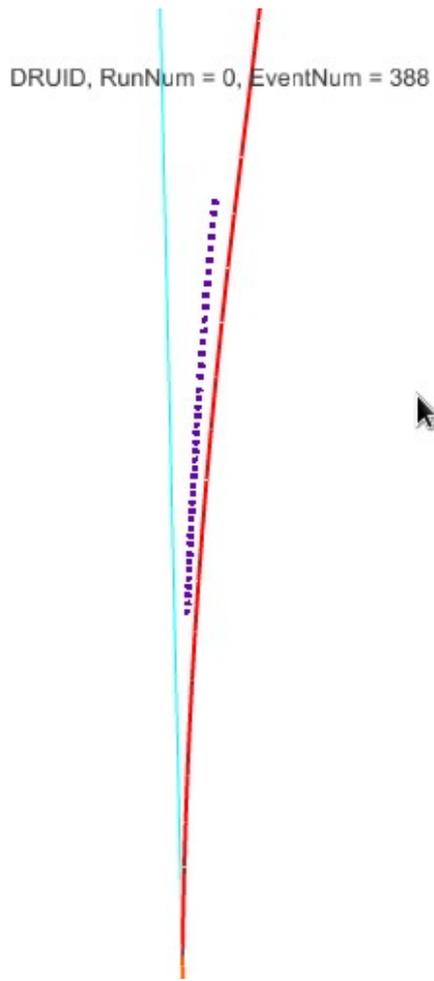
From small to large cell size:

Positron Peak Smeared

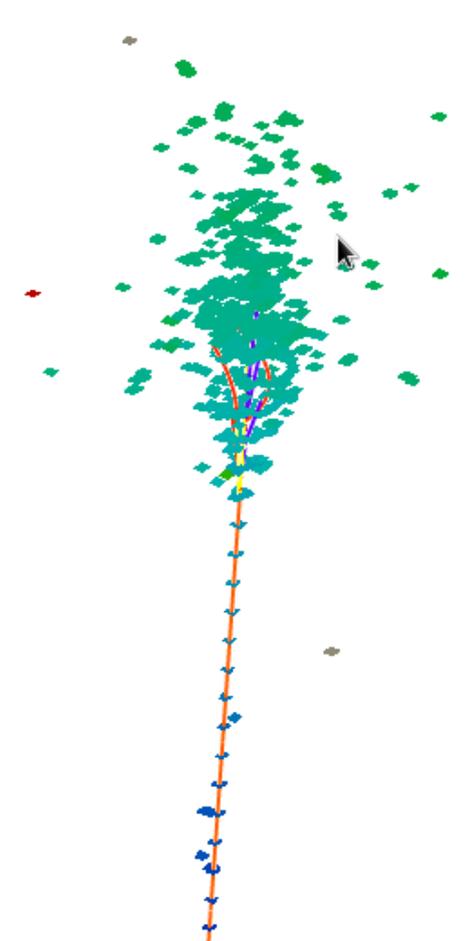
Better $\mu - h$ separation: μ acts more like a line (FD = 1); (*we can create large cells from small ones...*)

π : continuous distribution from MIP to EM

Pions



DRUID, RunNum = 0, EventNum = 112



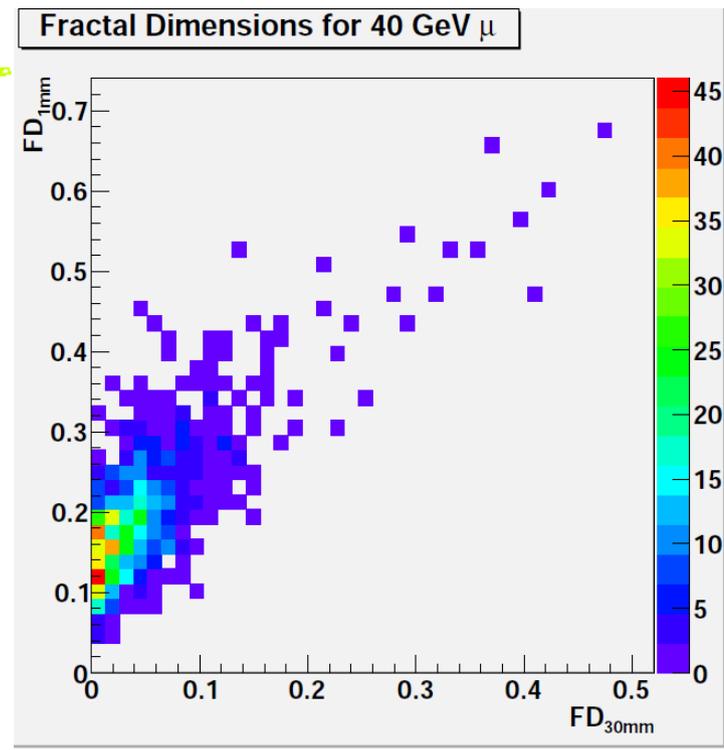
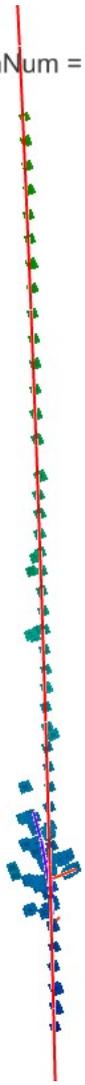
- Pion: MIP, Pion decay;
- EM interaction ($\pi + N = P + \pi^0$); partially identified by interaction point tagging

Muon

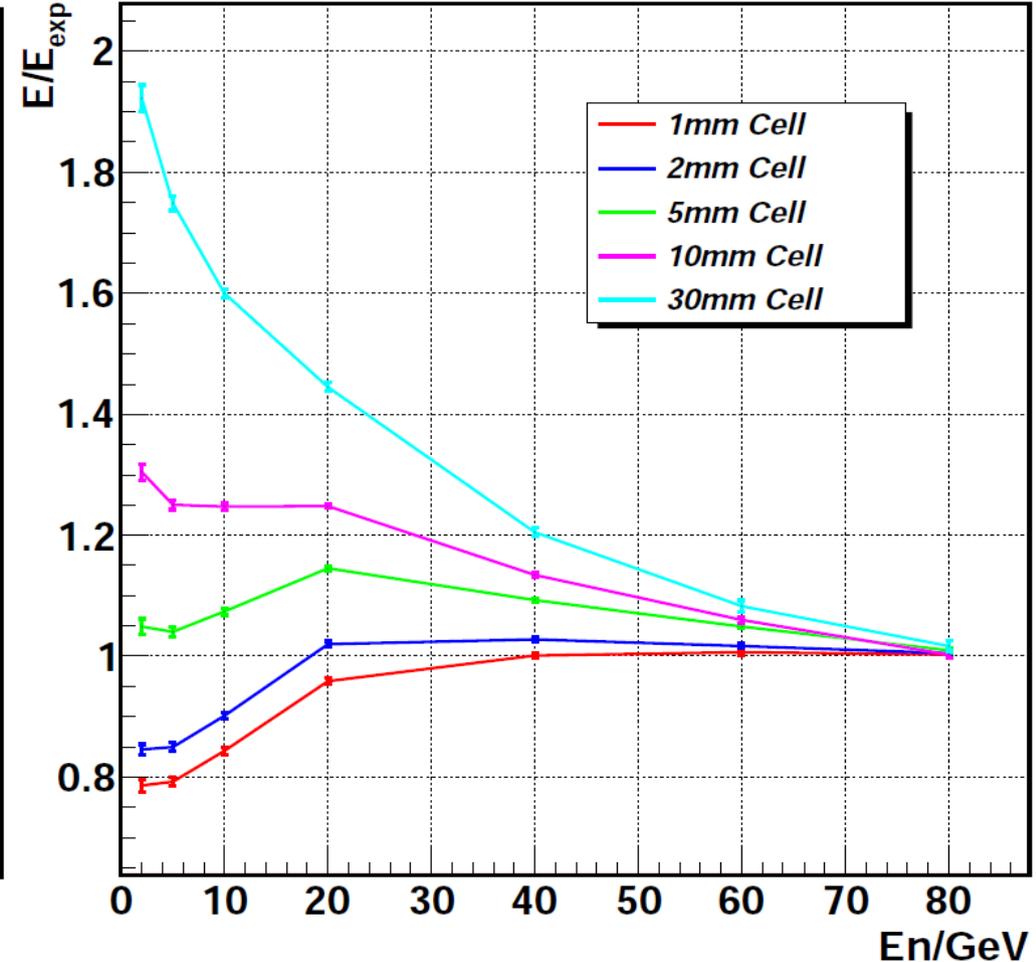
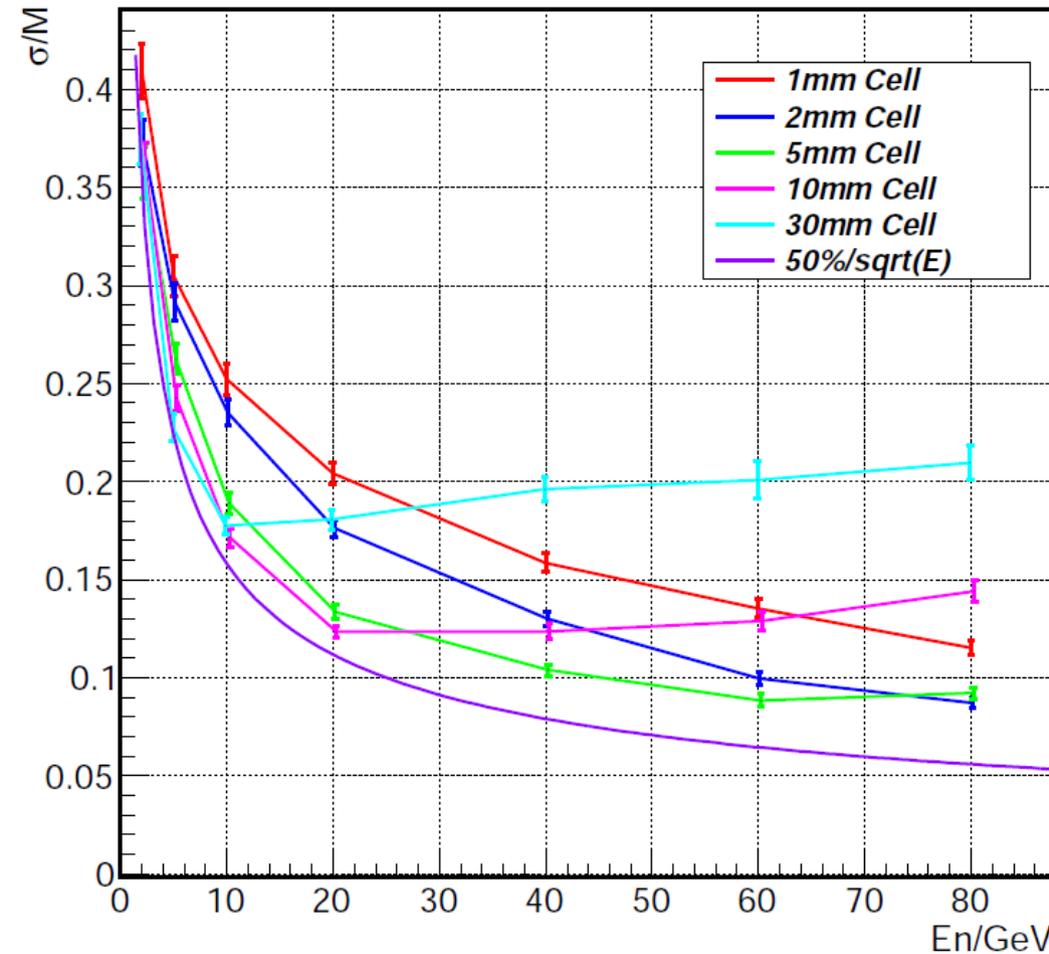


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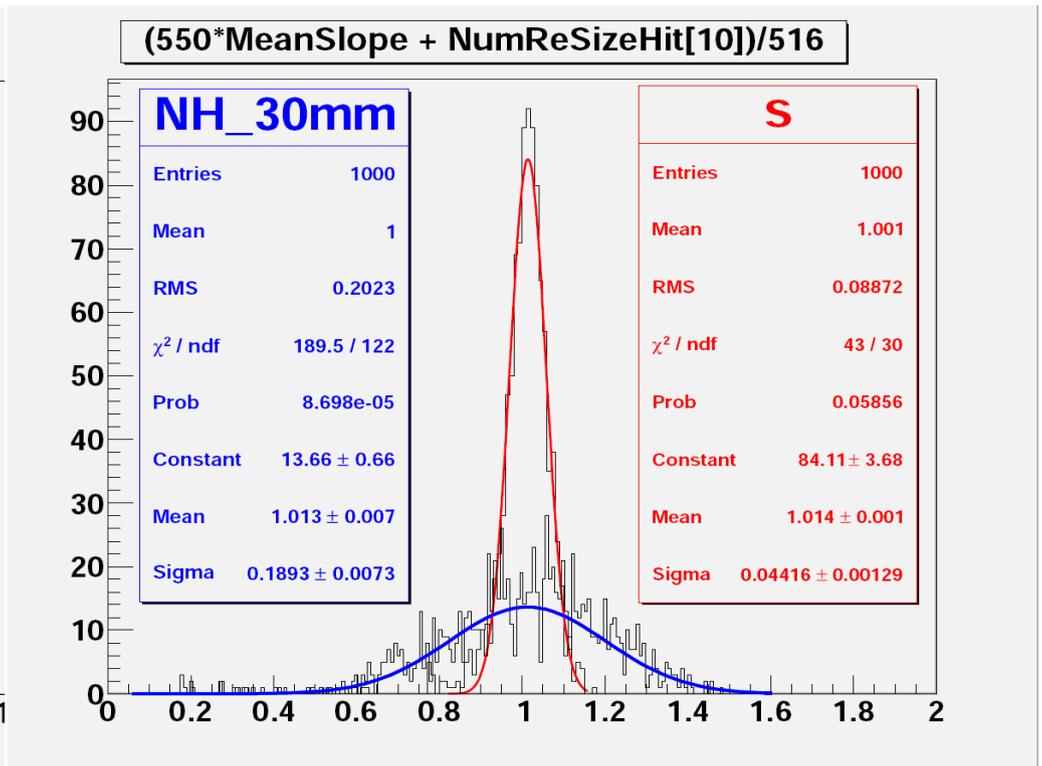
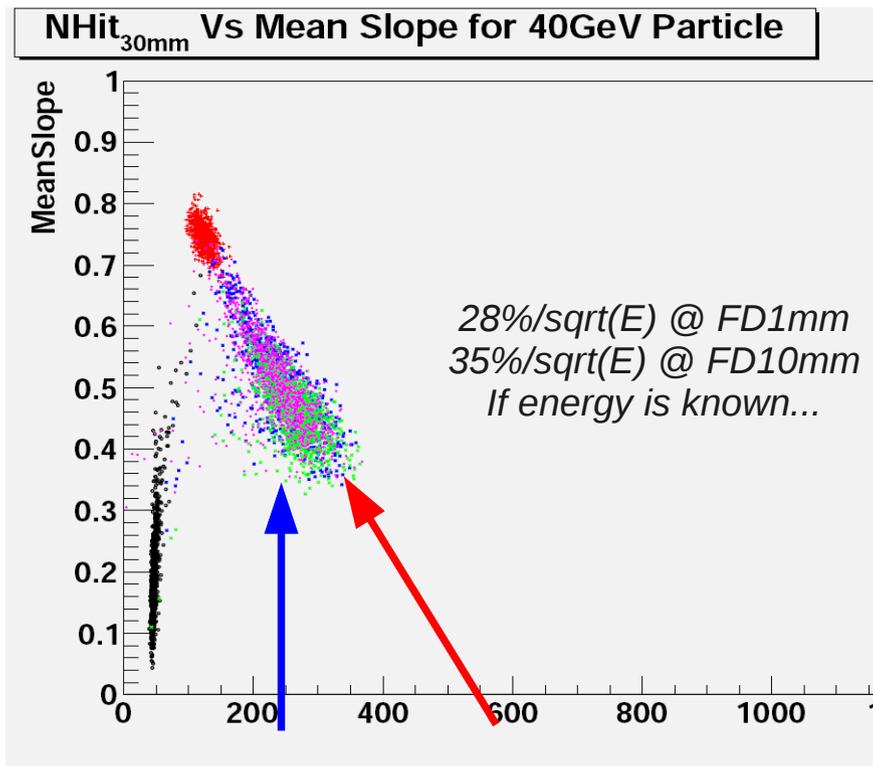
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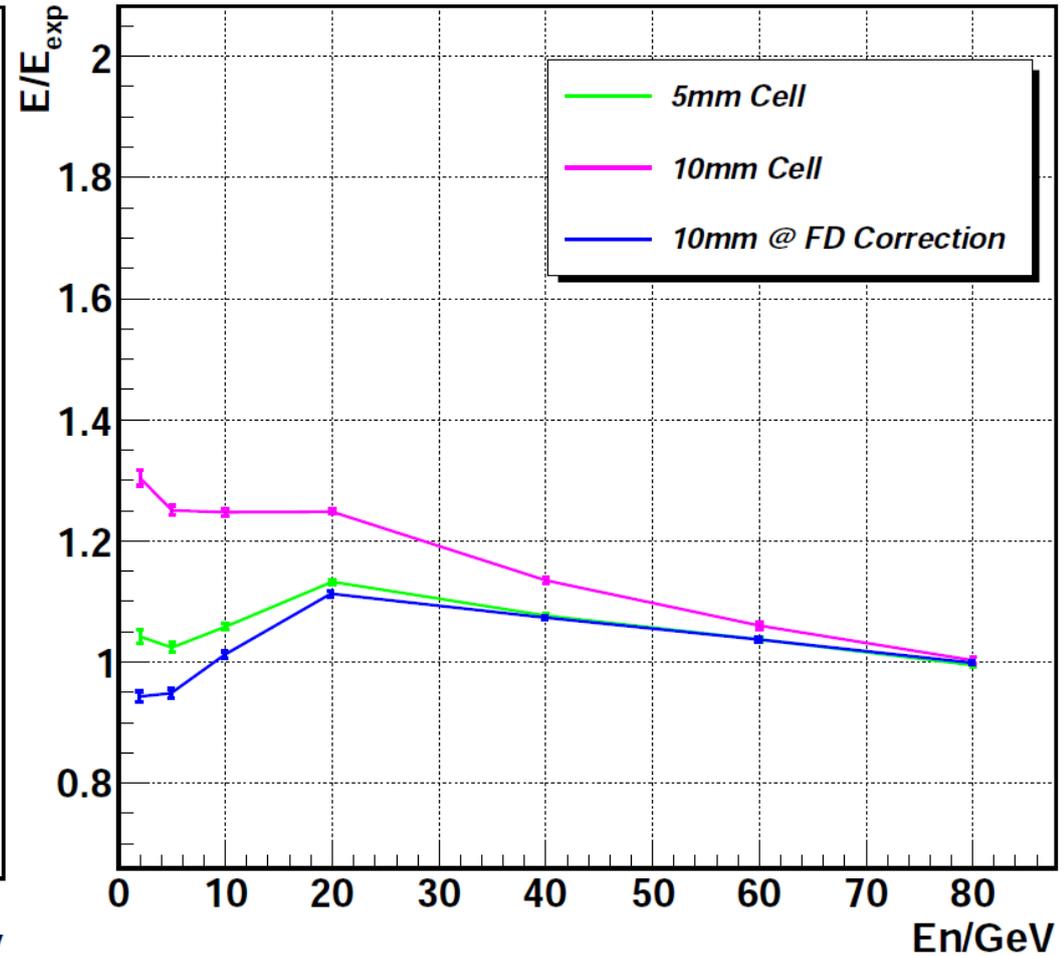
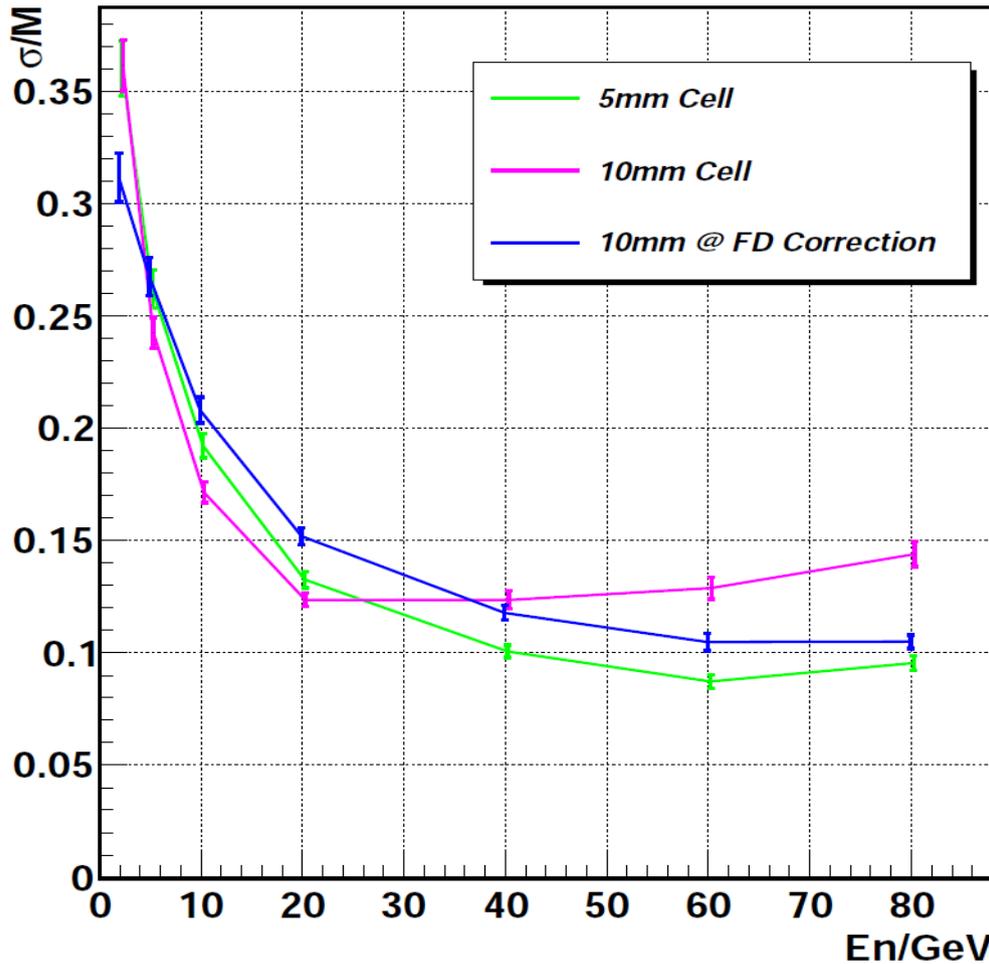
Muon radiation & String noise (electrons trapped in gas layer)...



σ/M : Large cell better at low energy & Small cell at high energy.
 Linearity: Better at 2 – 5 mm, stronger saturation effects at larger cell...
 Naively: 5/10mm seems a nice choice...



- For example: Compensation based on the correlation of NH_30mm & FD1mm:
 $E = a * NH_{30} + b * FD \sim 30\%/\sqrt{E}$! But...
- Correlation coefficient depending on Energy: $b \sim 0.0266 * E$. To measure cluster energy of charged particle (with track info): to improve track-cluster linking...
- Energy independent (LO) estimator: $E = a' * NH_x / (1 - FD * b')$



Hand put Energy Estimator with FD: $NH10/(1-0.65*FD10)$
 Energy resolution improved at high energy: ~ saturation effect correction
 Linearity improved: closed to 5mm Cell

Spin-off: Gas Calorimeter Digitizer

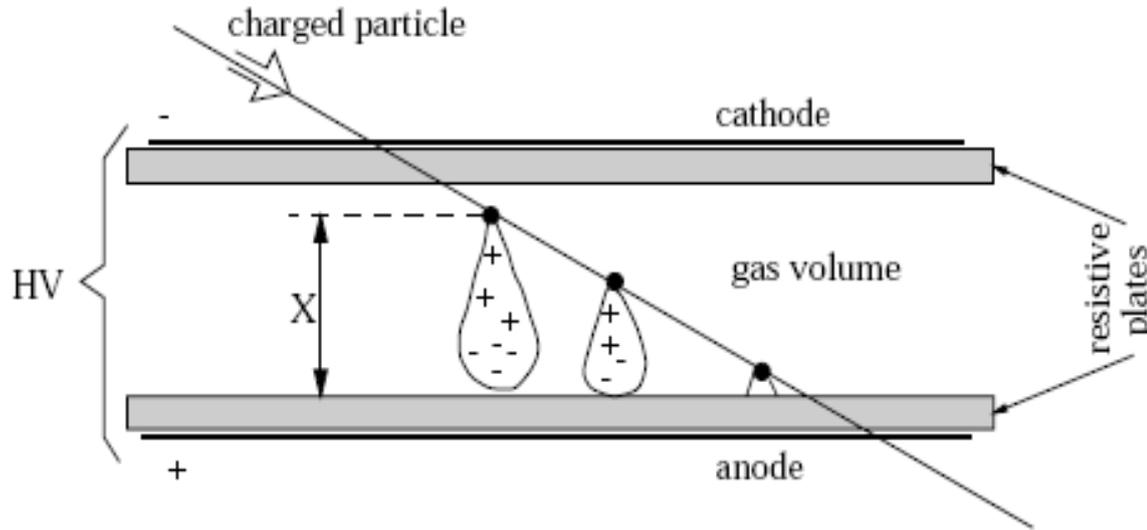
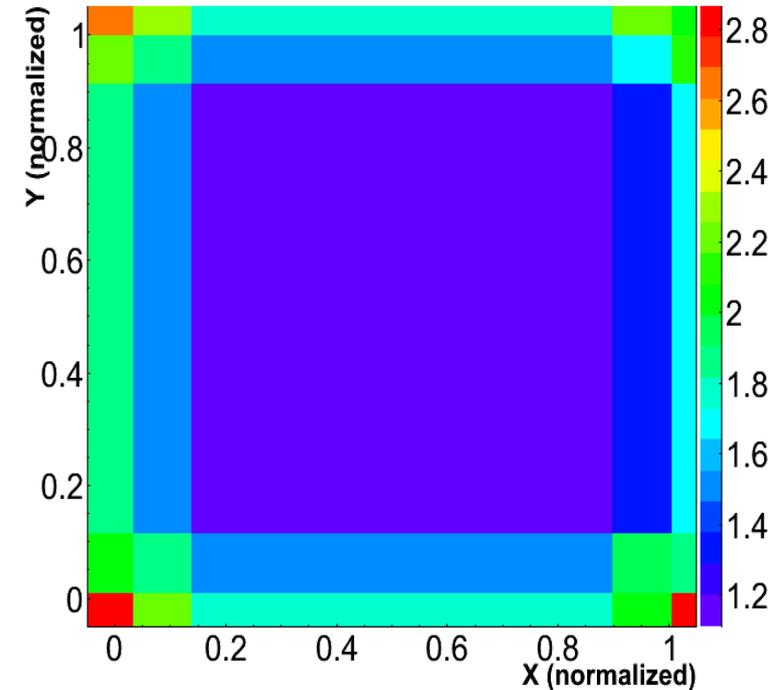


Fig. 1. Sketch of RPC gap.

Cell Multiplicity Vs Track Position

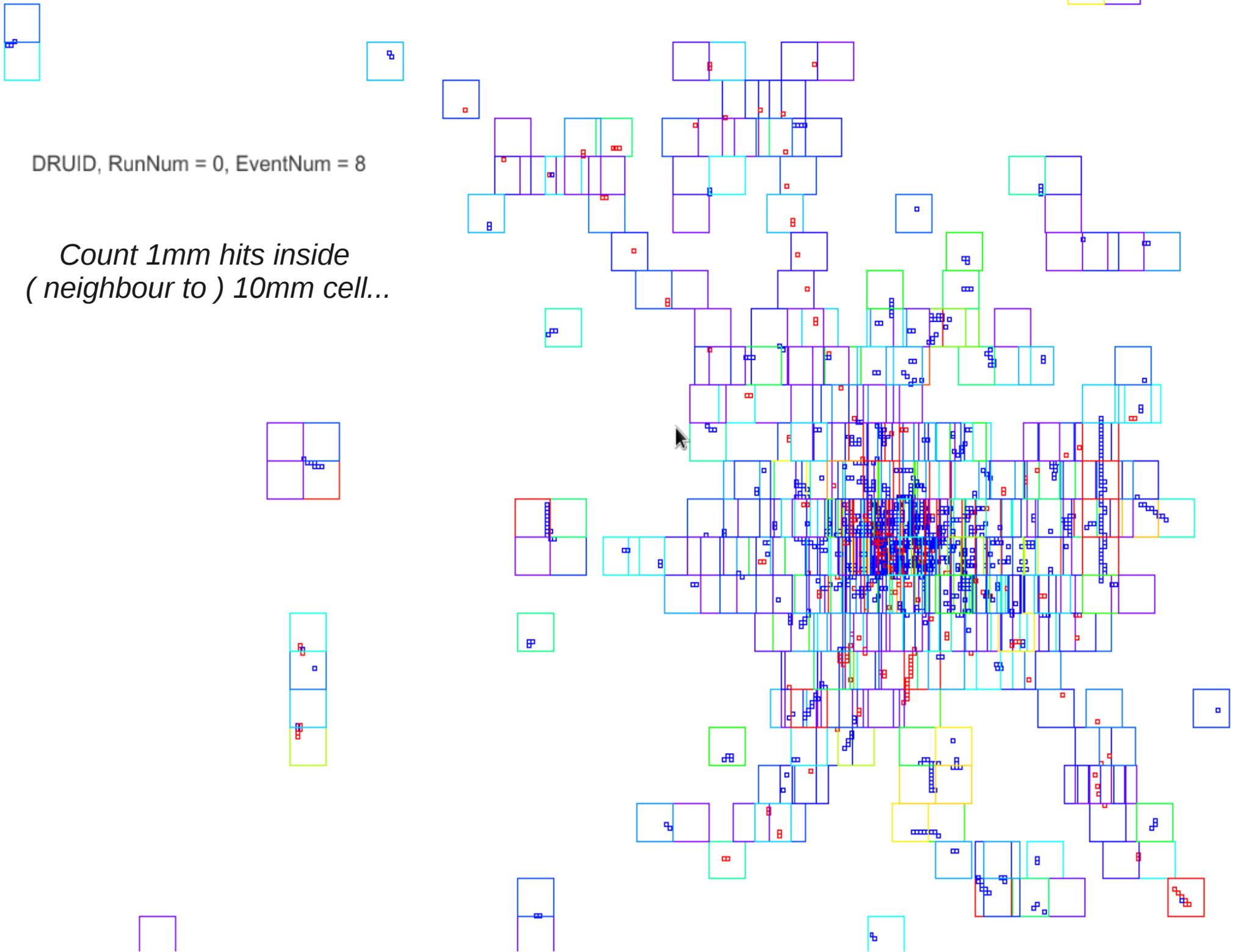


- Efficiency & Multiplicity: to be repeated by Digitizer
 - Efficiency: ~ 95% (depends on threshold, HV...)
 - Multiplicity: global ~ 1. - 2 (depends on charge Image Size: ~ 1mm)

- Keep **simulation** level information to **1mm cells**: Digitize by ganging into arbitrary cell size
 - Advantages:
 - Natural cut off: 1mm ~ gas gap thickness ~ size of charge image
 - Self Saturation & easy to integrate other saturation effects
 - Reliable estimation of multiplicity
 - Samples: available for other analysis, like cell size optimization study
 - Cost:
 - Machine time: the same
 - Data size:
 - Nhits increased by ~ 3 times (FD ~ 1.5 for hadronic shower)
 - If ParticleCont (energy deposition at each step in simulation) recorded: total size increased by ~ 5%
 - **Negligible** at full detector event: ***Utilize as Simulation base line?***

DRUID, RunNum = 0, EventNum = 8

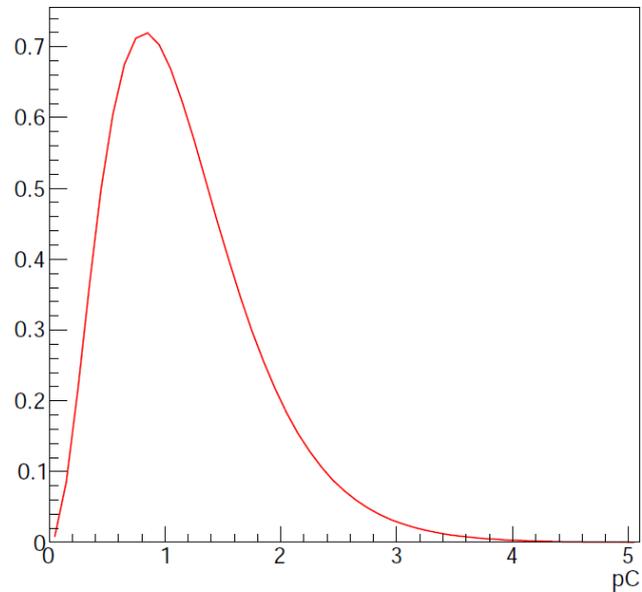
*Count 1mm hits inside
(neighbour to) 10mm cell...*



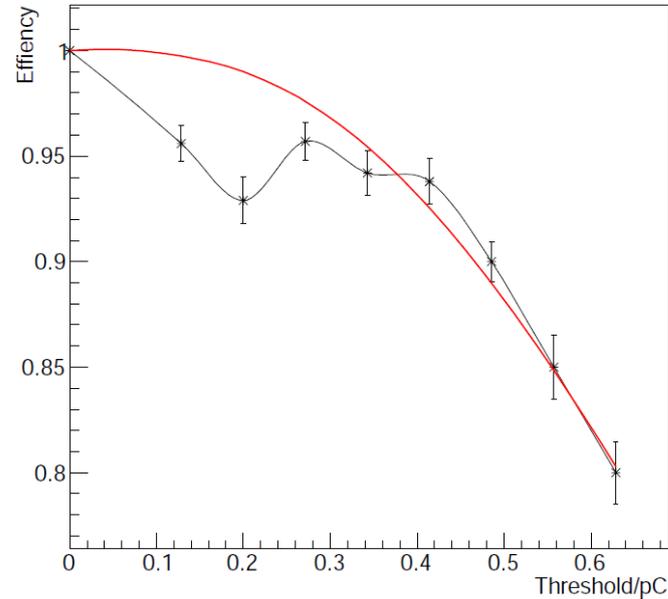
Parametrize from TB Test on 20GeV Muon Sample



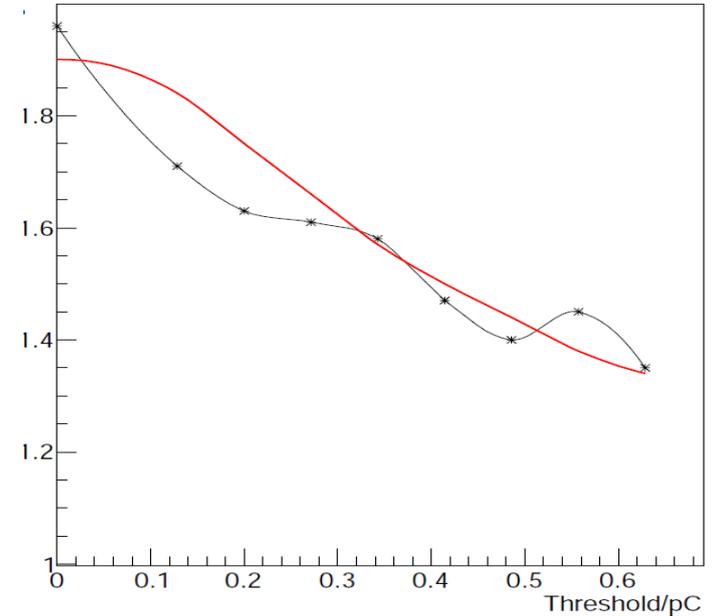
Induced Charge Spectrum $x^{(2.4)} \cdot \exp(-2.9 \cdot x)$



Expected Efficiency Curve Vs Measured



Expected Multiplicity Curve Vs Measured



For 1 mip \sim (1 hit at 1mm cell)
 Total Charge: Polya function
 Spatial: distribution over 5 * 5 mm region

Efficiency & Multiplicity VS Threshold: Result repeated to the first order

Summary



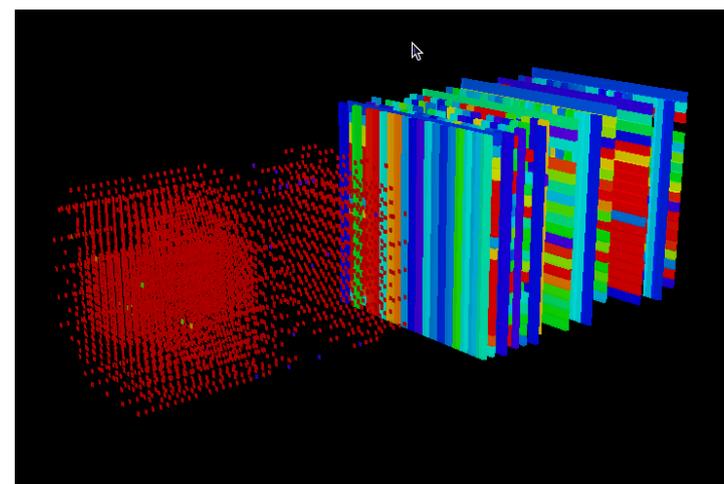
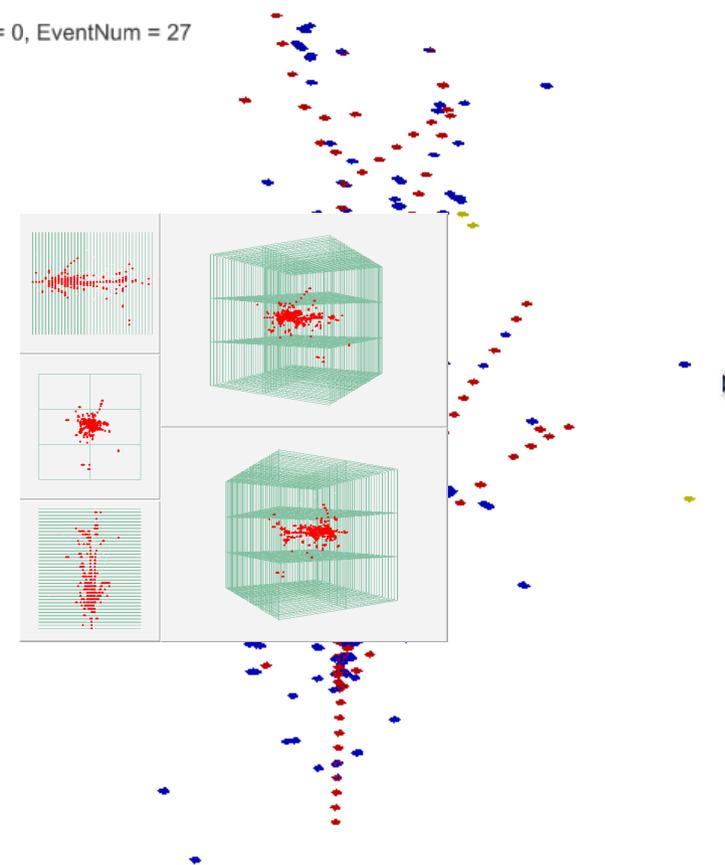
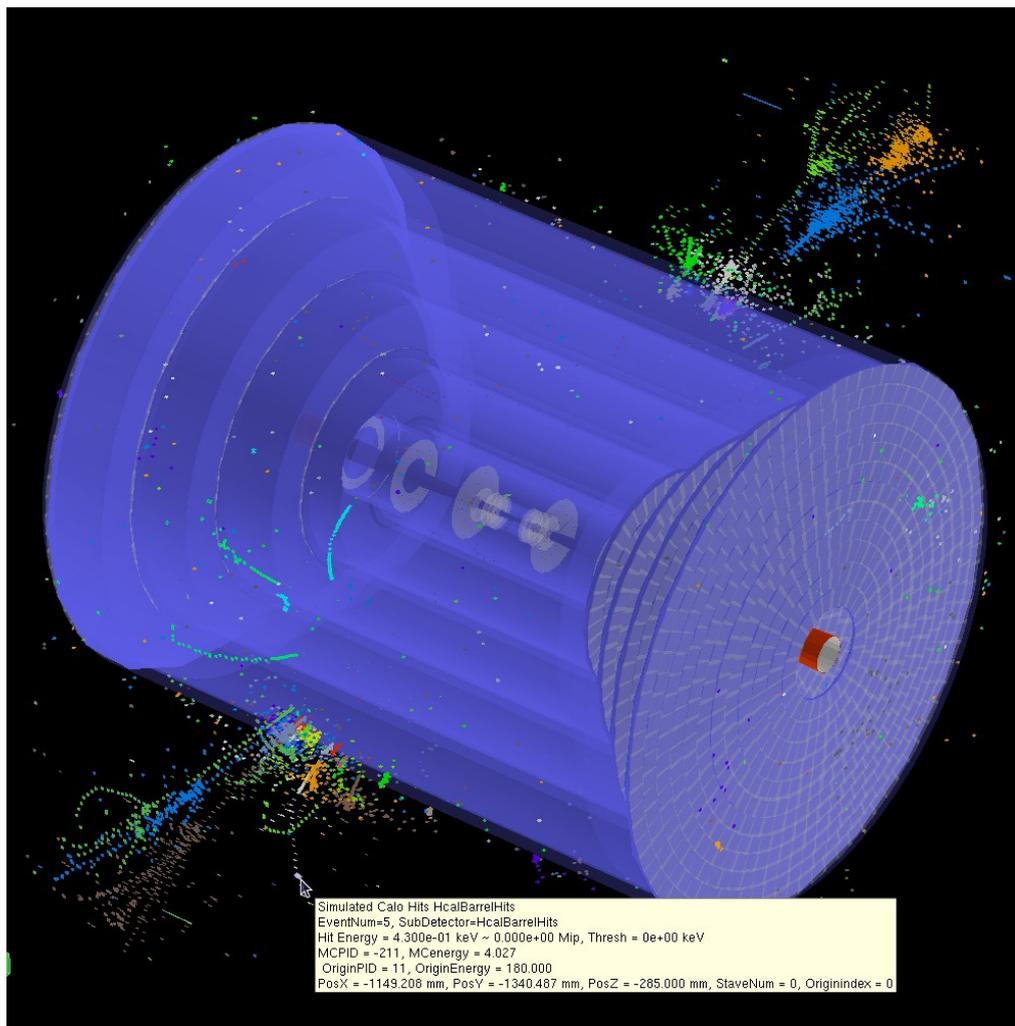
- Huge reconstruction potential at high granularity calorimeter...
 - Arbor:
 - MIP tagging with lots of potential application:
 - Energy Estimation,
 - Leakage correction
 - ...
 - Pre-mature PFA Framework: **better separation**, pattern recognition
 - Fractal Dimension:
 - Promising PID
 - Track-clustering matching & energy estimation
 - Spin-off: Gas Calorimeter Digitizer
 - Not fully investigated...
 - **Your dreamed but never realised algorithms**

Thank you!

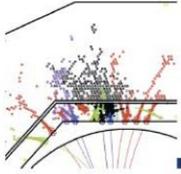


Wish you a happy & fruitful Dragon's Year!

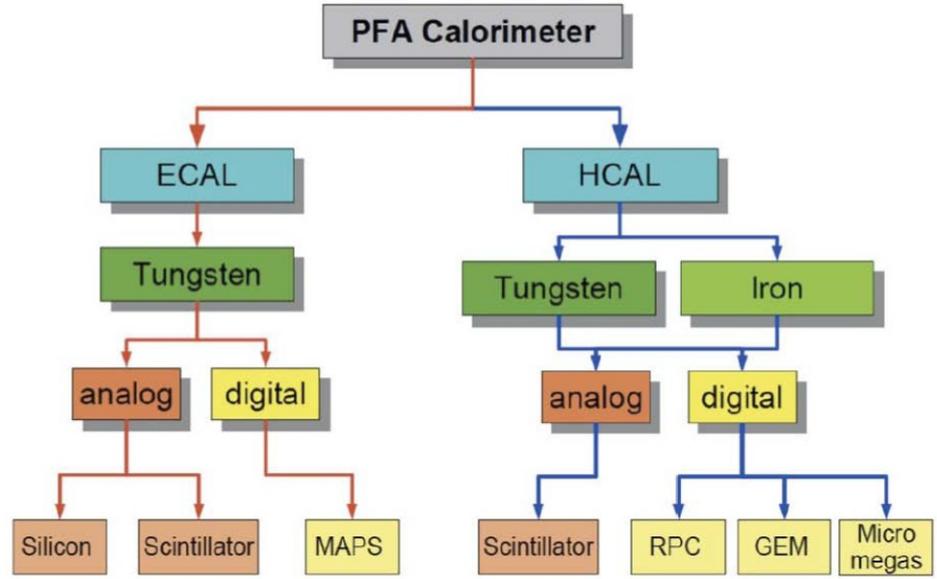
Spare Slides



CALICE: PFA Oriented Calorimeter



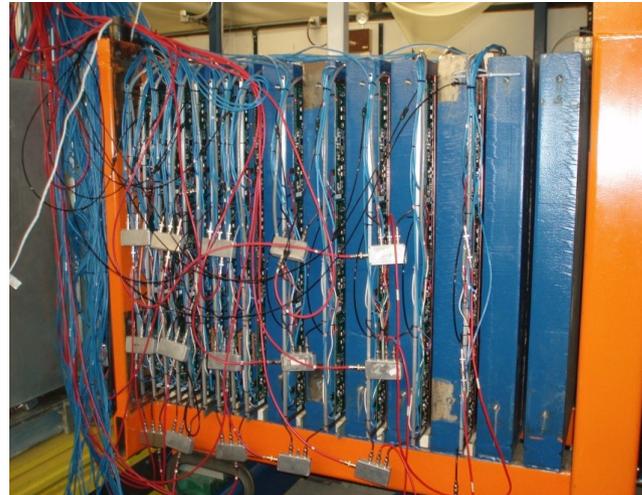
Technology tree

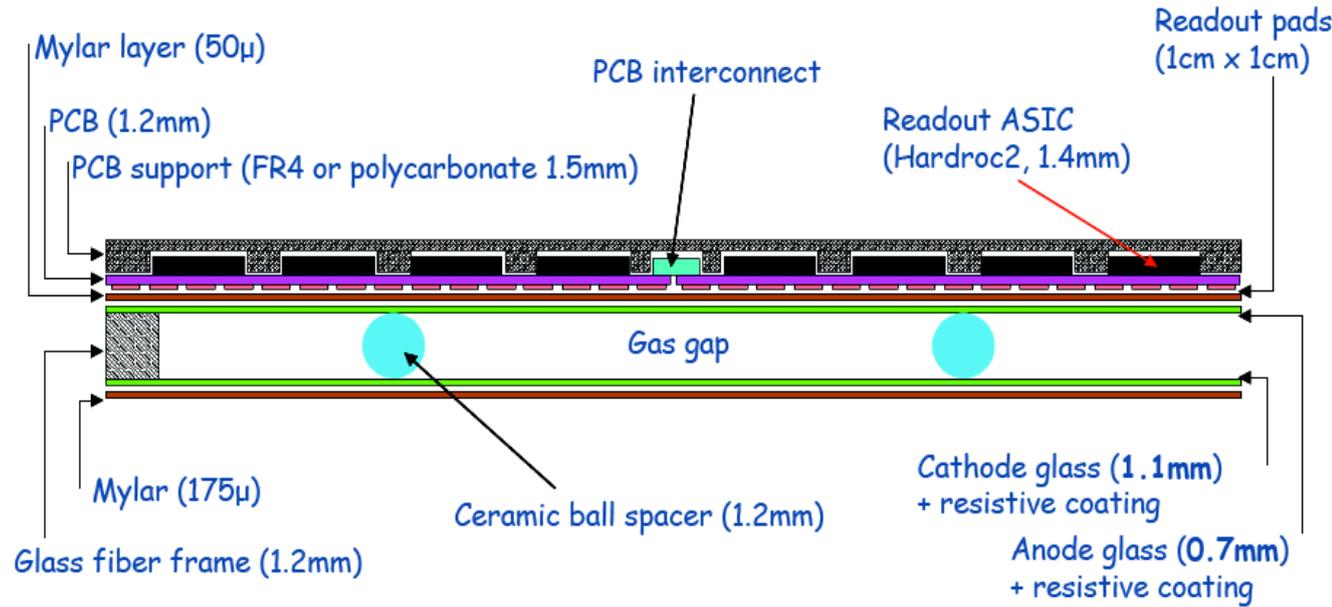
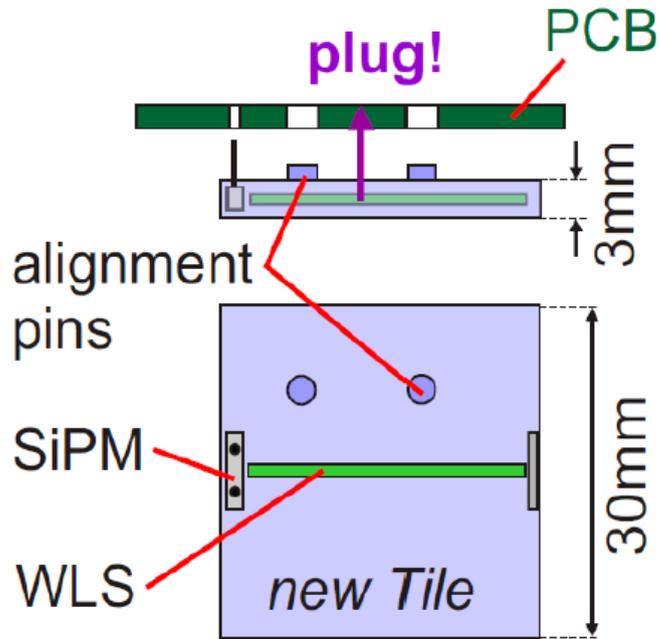


AHCAL@DESY

DHCAL@US

Si-W ECAL prototype: 10k channels in a cube of 18 cm³ ~ 1/8 of CMS ECAL





IWLC 2010 - M. Vander Donckt

Scintillator:

3*3*0.3 cm³ cell size & analogy readout

Gas:

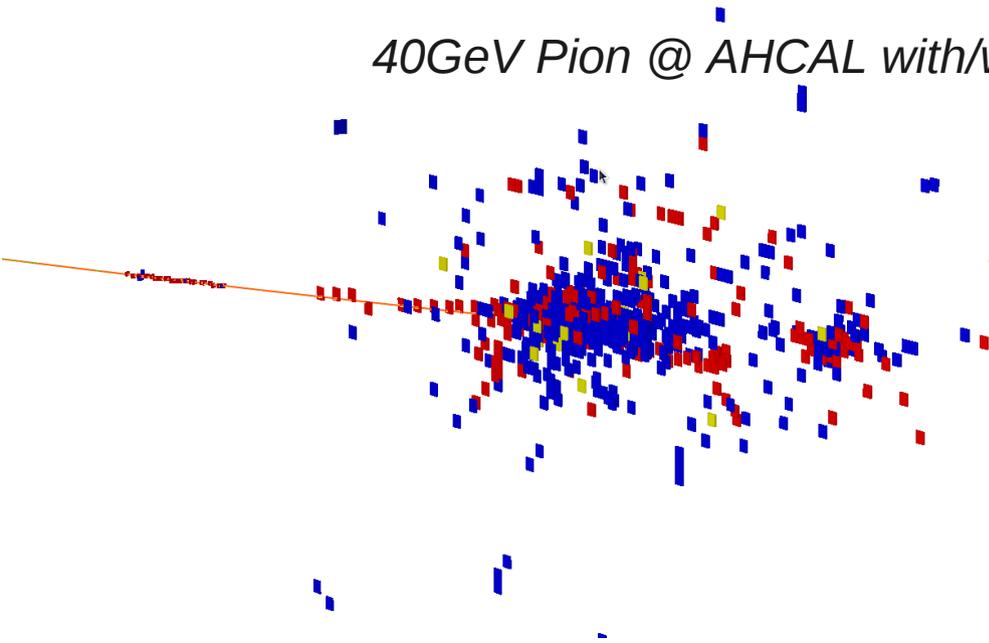
- High granularity (1*1*0.12 cm³ or smaller)
- RPC: high efficiency, homogeneous, robust...
- Low cost: digital or **Semi-digital** (channel coded in 1 or 2 bits) readout...
- Free of direct neutron hits

Neutron hits

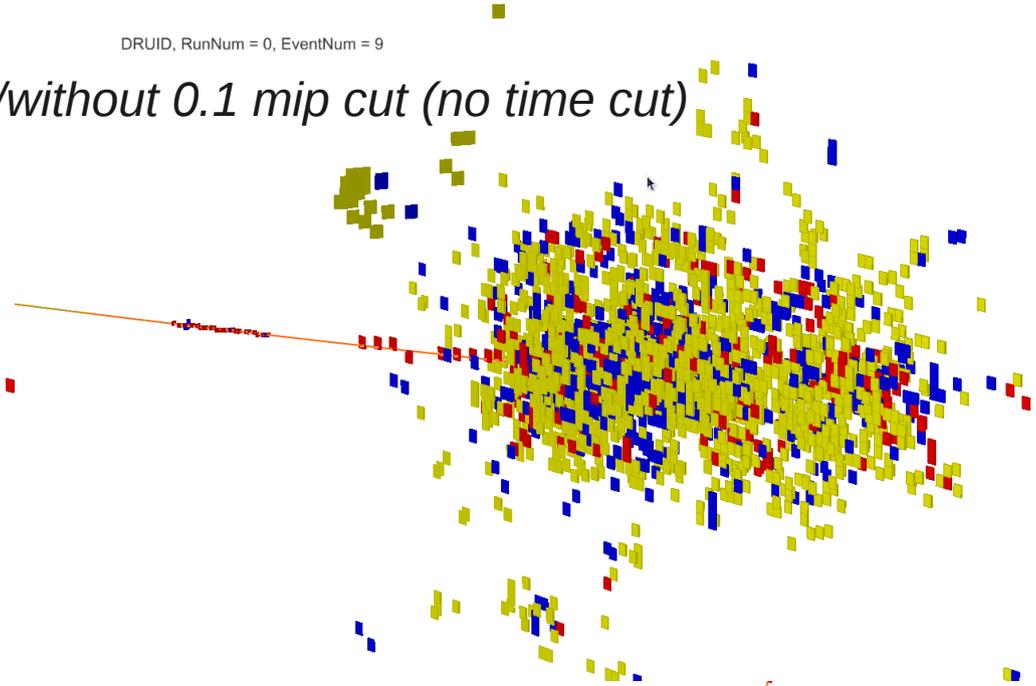


DRUID, RunNum = 0, EventNum = 9

40GeV Pion @ AHCAL with/without 0.1 mip cut (no time cut)



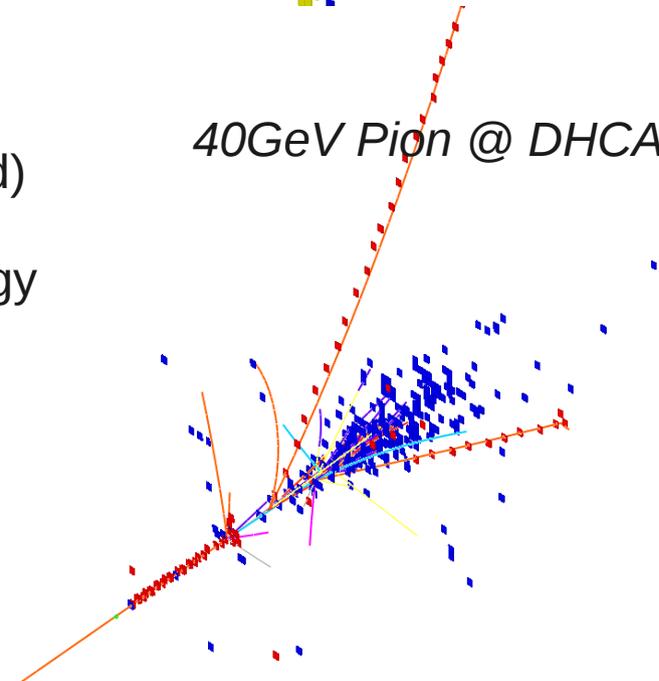
DRUID, RunNum = 0, EventNum = 9



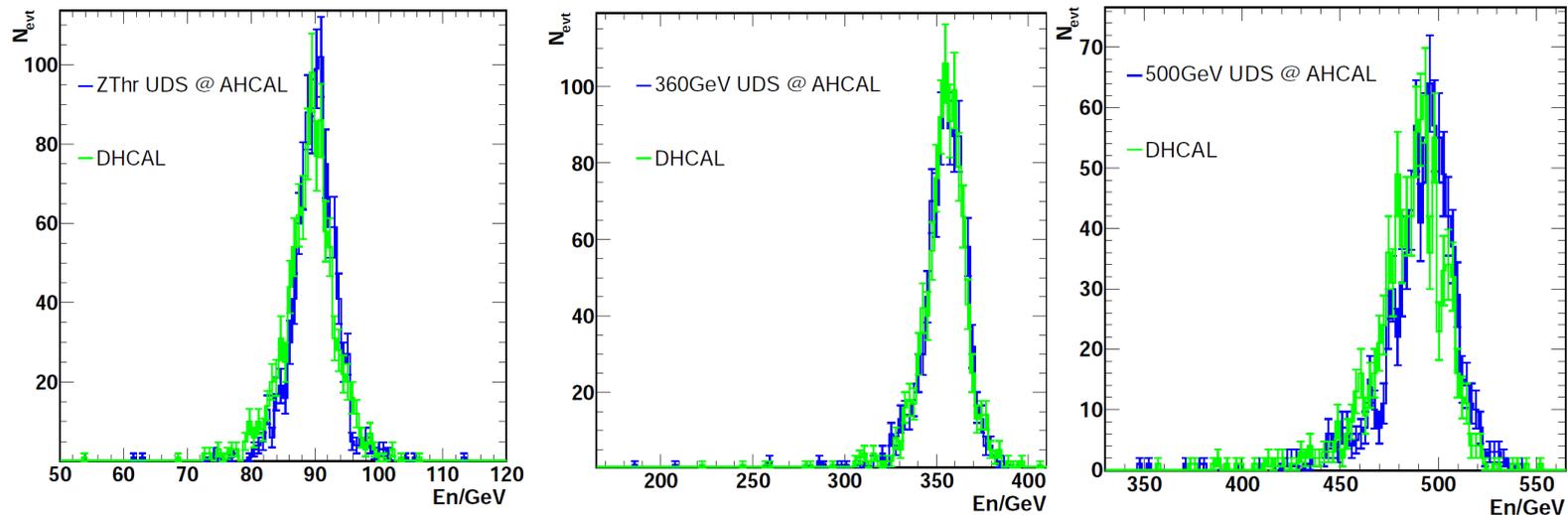
Hit Colour: EM (blue), Neutron (yellow) or hadronic (red)

- AHCAL: Shower center surrounded by lots of low energy neutron hits
- Need careful analysis: **Confusion & Energy resolution**

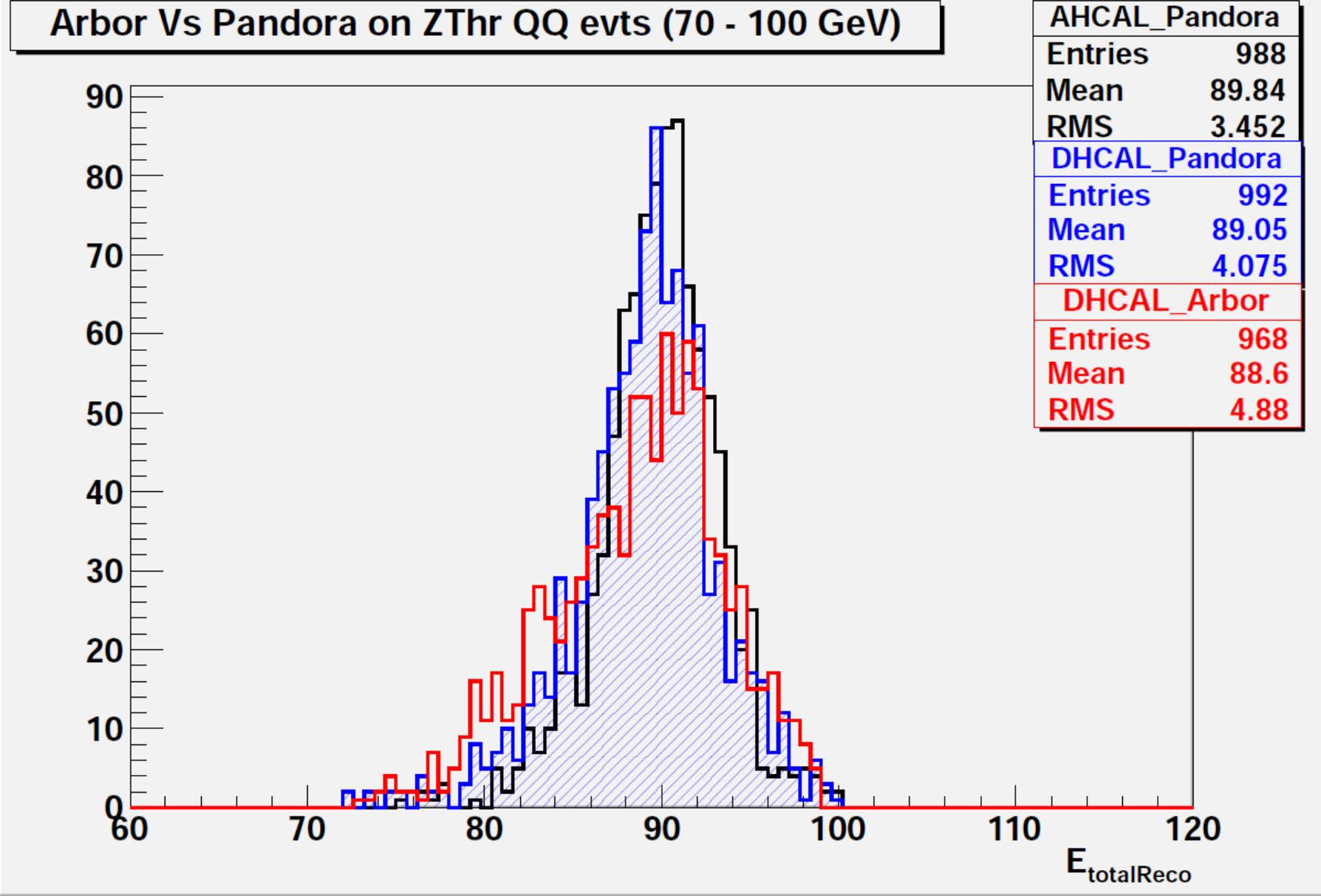
40GeV Pion @ DHCAL



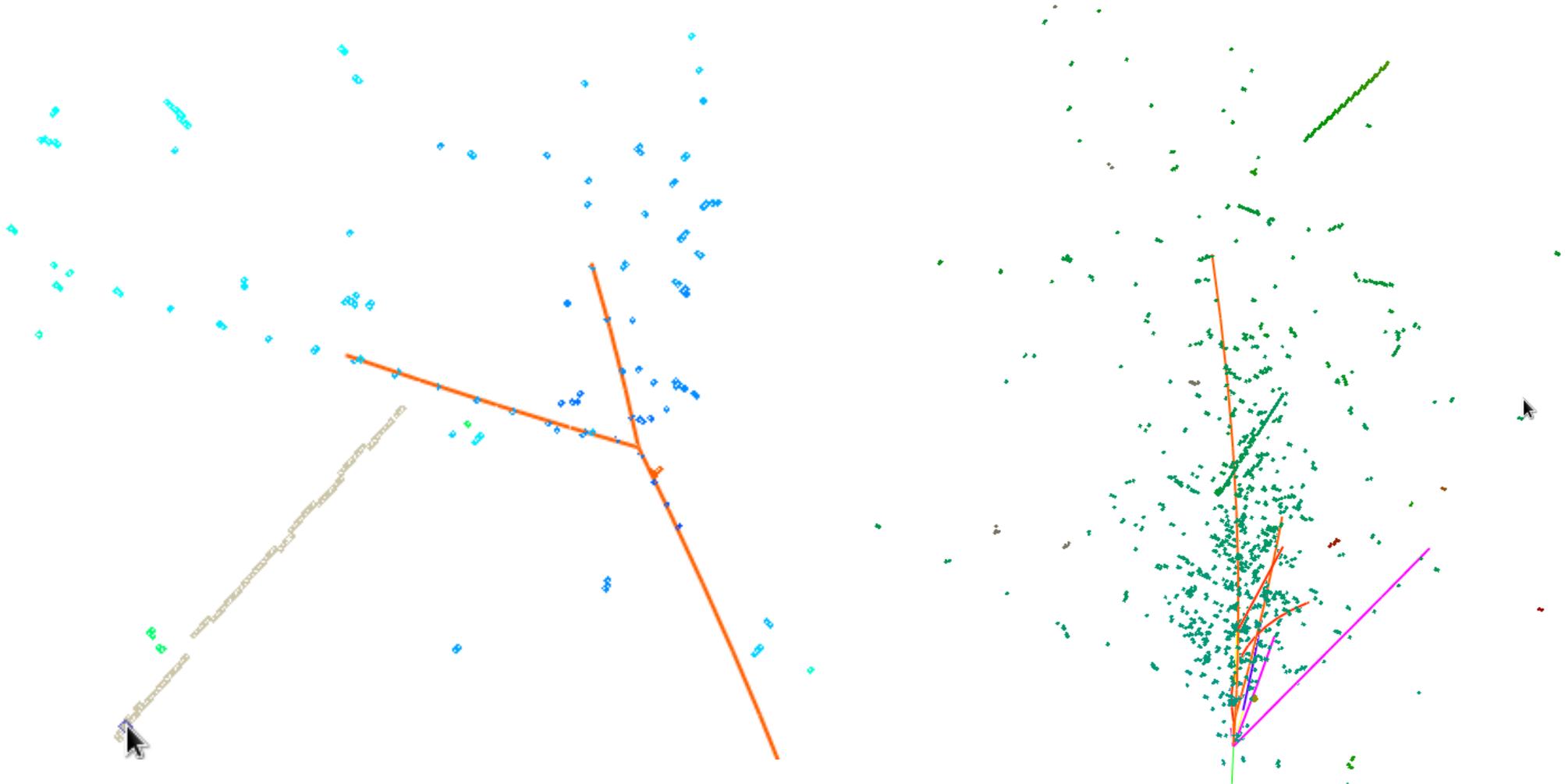
- Goal: **develop & optimize the reconstruction chain** for ILD with SDHCAL
- Status & Plans:
 - Detailed simulation and Digitization with experimental input
 - PandoraPFA (*Currently Best PFA for the LC*) adapted & to be optimized



- Huge potential to improve
 - Shower Clustering & Reconstruction: [Arbor](#)
 - PID & Energy Estimation: impactation from [Shower Fractal Dimension](#)
- Druid (event display): heavily employed in algorithm development



Noise cleaning



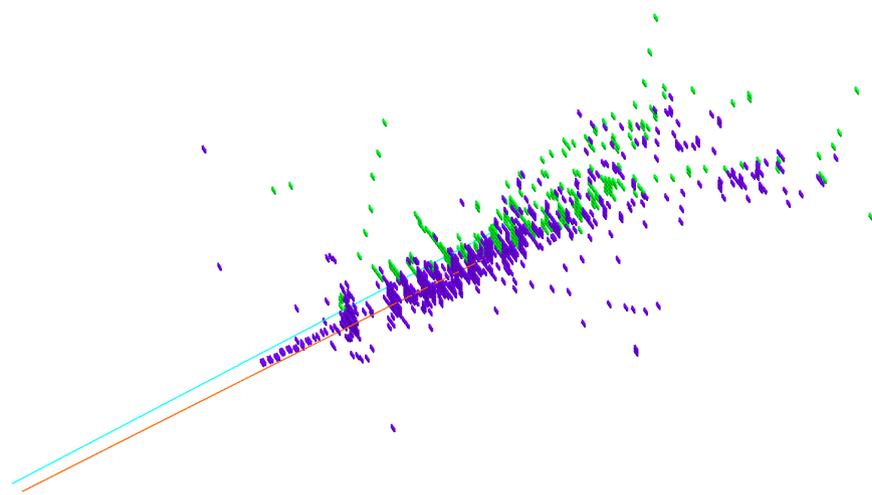
*String Noise: Typical in gaseous detector: charged particle tripped In the gas layer
(display of 1mm hits Information)*

Roughly improve 5% - 10% on Energy Resolution by Cleaning

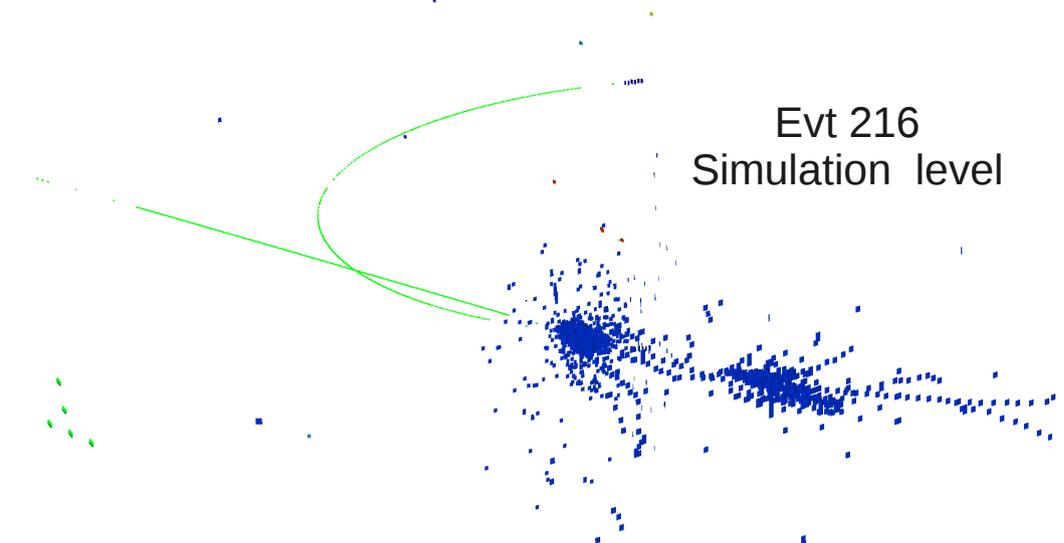
Double counting



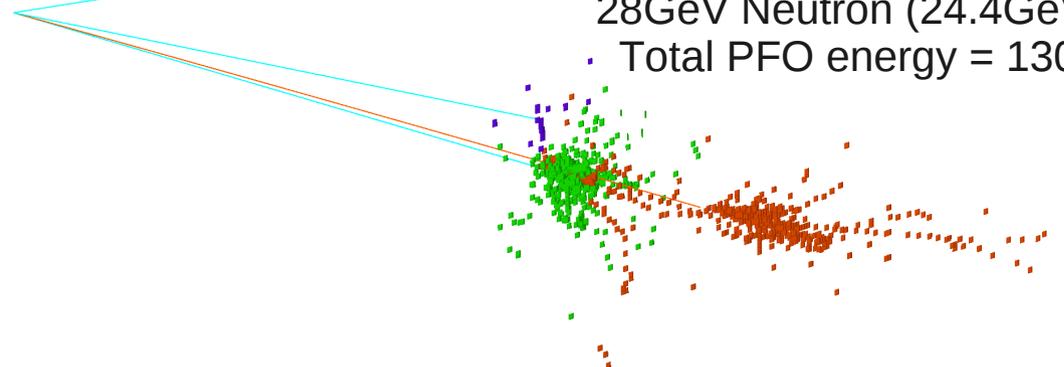
(Evt 286) 2 PFOs, Identify as
100GeV Pion (80.7GeV cluster) +
45GeV Neutron (45.4GeV)
Total PFO energy = 145GeV
Seed at deep ECAL Layer...



Evt 216
Simulation level



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



**Clustering
To be improved...**

Interaction based double counting



Near the Calo

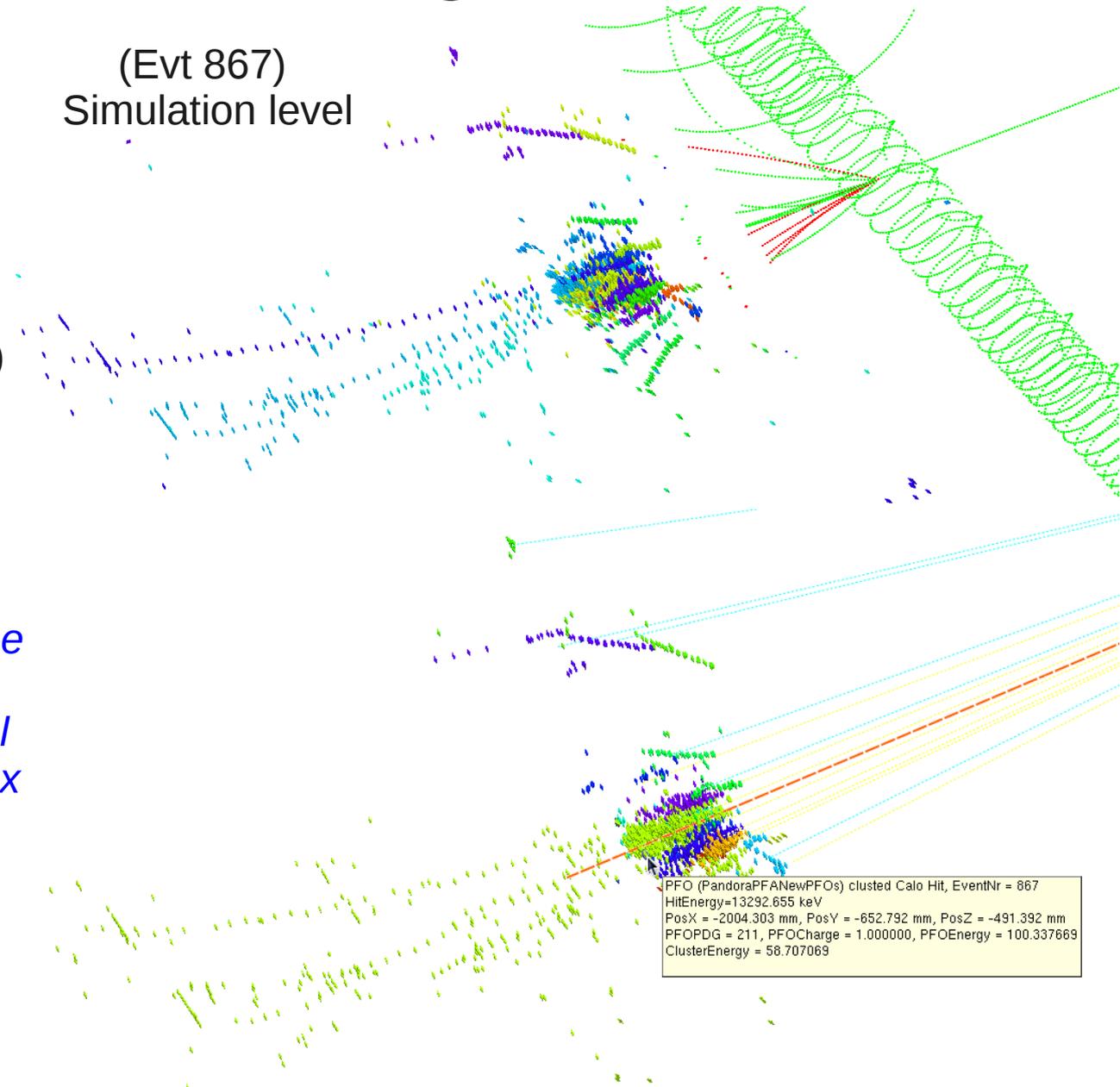
Reconstruction level:

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...*

(Evt 867)
Simulation level



PFO (PandoraPFANewPFOs) clustered Calo Hit, EventNr = 867
HitEnergy=13292.655 keV
PosX = -2004.303 mm, PosY = -652.792 mm, PosZ = -491.392 mm
PFOPDG = 211, PFOCharge = 1.000000, PFOEnergy = 100.337669
ClusterEnergy = 58.707069

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?*

