Shower Fractal Dimensional Analysis at PFA Oriented Calorimeter

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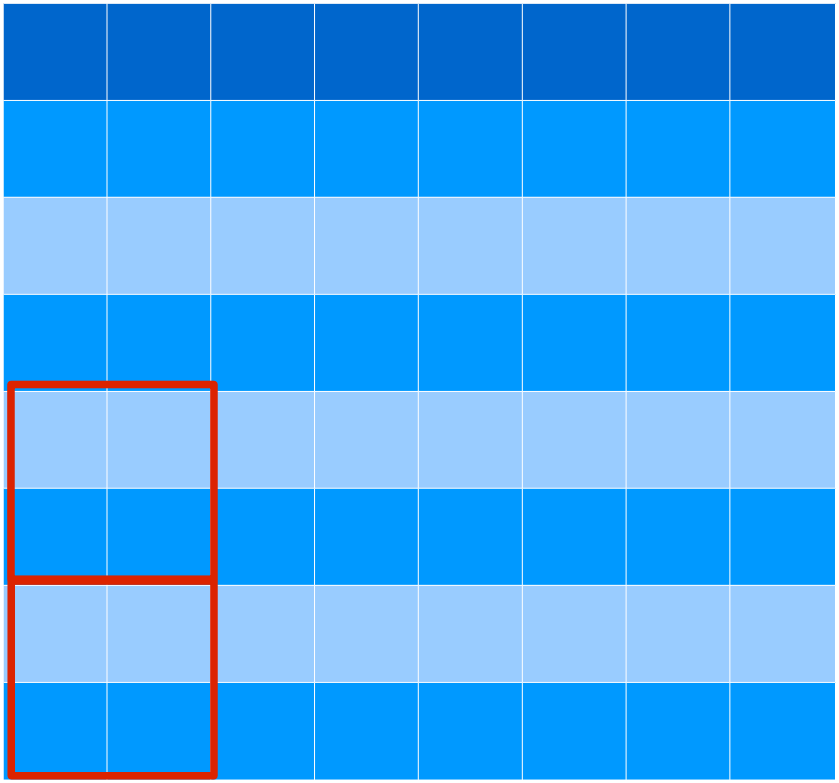
Outline

- Introduction:
  - Fractal Dimension of particle shower
  - Analysis with Full Simulated data
- Fractal dimensional analysis at CALICE DHCAL data
- One step further: Fractal dimension at SDHCAL...
- Summary & to do

Shower particle: to interact or not



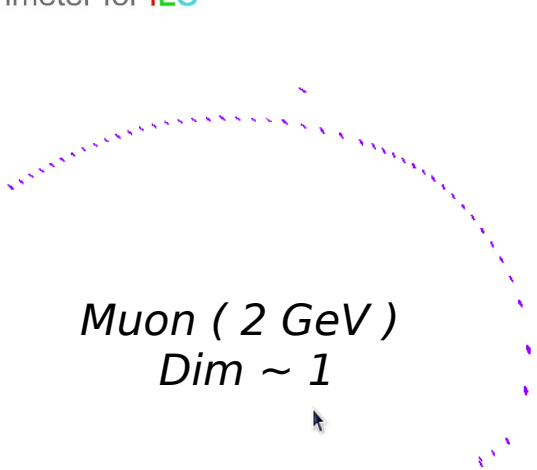
shower ~ self similar

Measure shower Fractal Dimension (FD) at high granularity calorimeter

- Varying scale by grouping neighbouring cells
- Count Number of hits at different scale *(define* $RN_x = N_{1\text{mm}}/N_{x\text{mm}}$ *)*

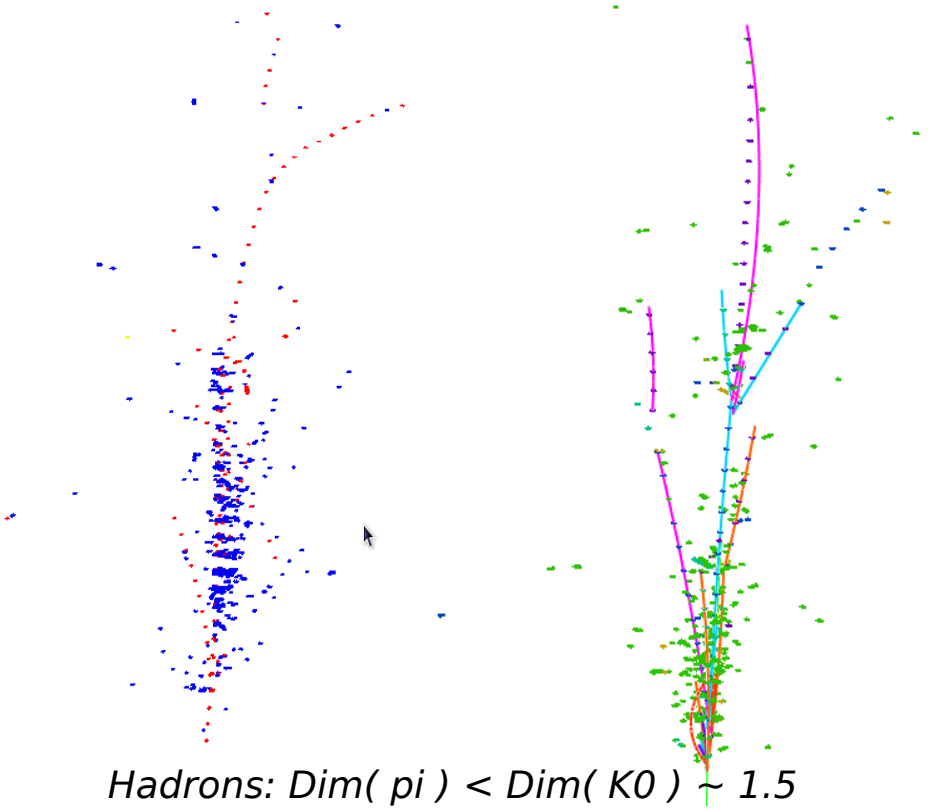
Test sample:
2–40 GeV particles (e^+, K_{long}, π, μ^+, p) normally injected into GRPC DHCAL with 1mm cell size

Fractals in Nature



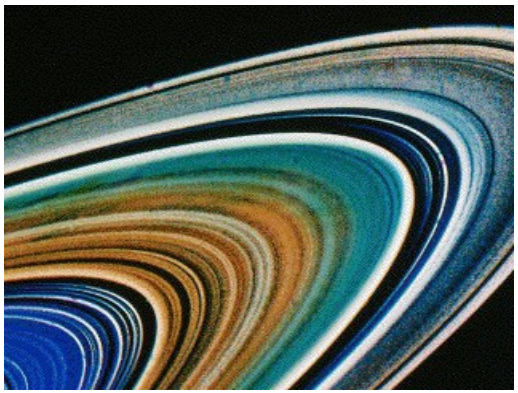
Muon (2 GeV)
Dim ~ 1

Straight line:
Dim = 1



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

Positron (40GeV)
Dim ~ 1.75



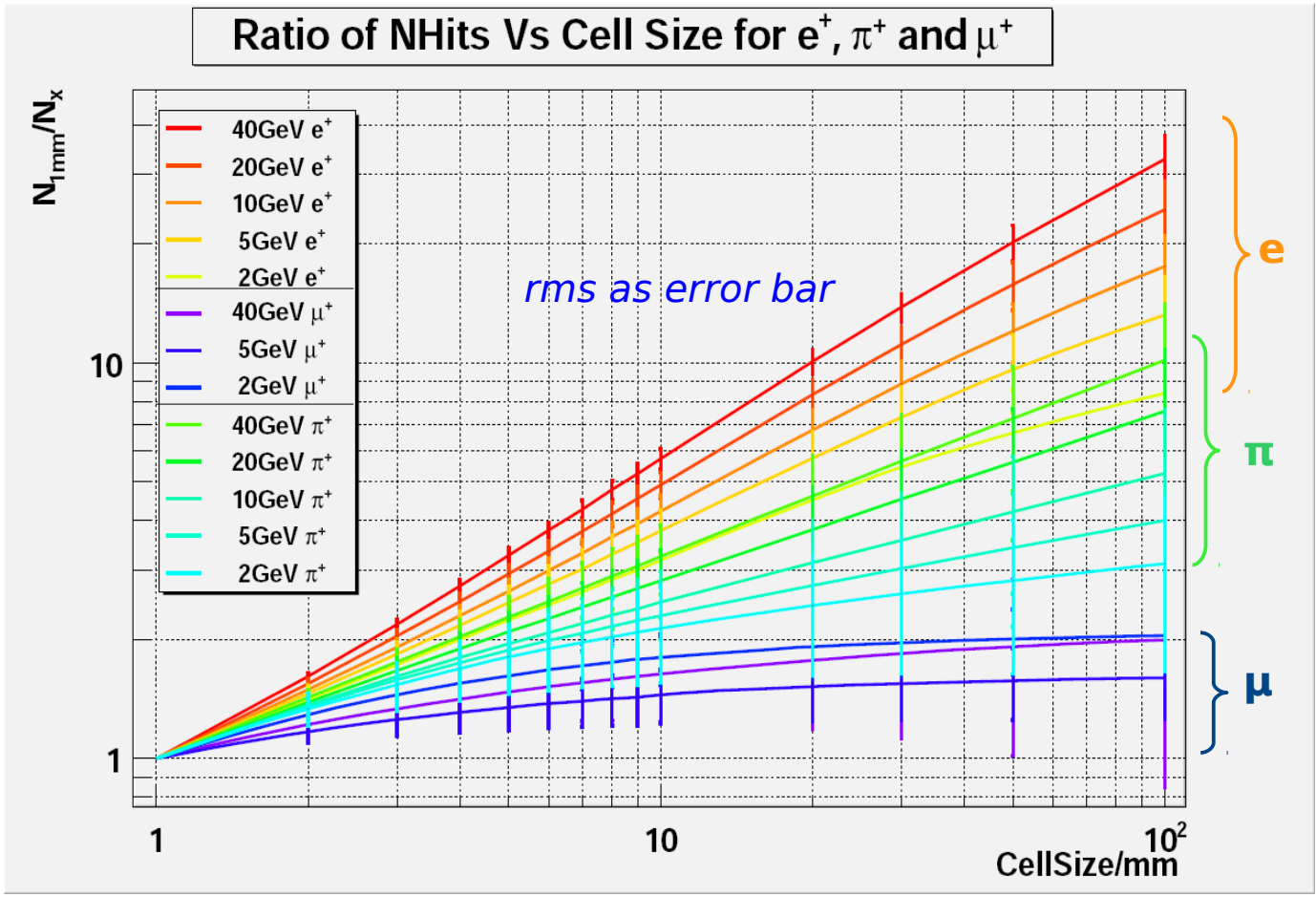
Rectangle:
Dim = 2

Shower: Self Similar

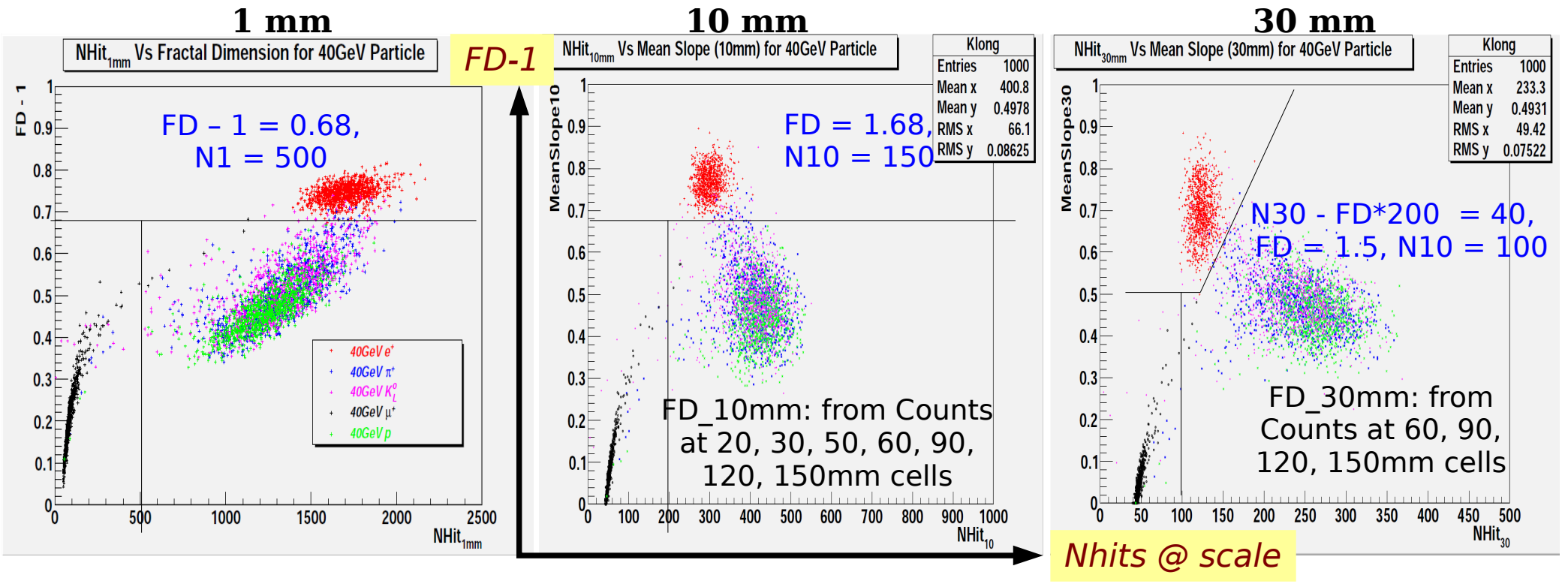
- Characteristic constant based on energy/PID:

$$FD = 1 + \left\langle \frac{\ln RN_a}{\ln a} \right\rangle$$

  - *a: ratio between ganged cell size and initial cell size*
  - *Initial cell size: 1mm in simulation*
  - *Changed Cell Sizes: 2 – 10, 20, 30, 50, 60, 90, 120, 150mm.*



Potential tool for PID



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

Remark: Energy dependent Cuts, easier for charged particles

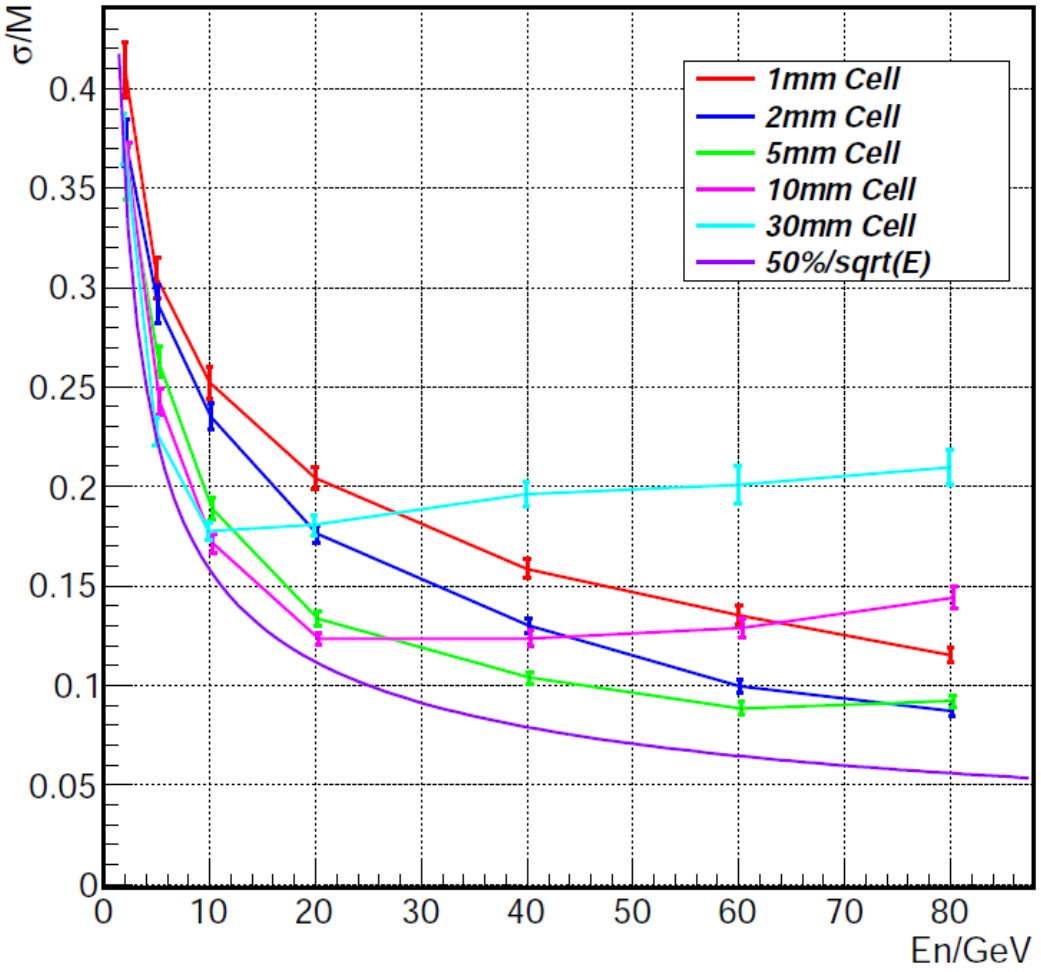
IN / OUT

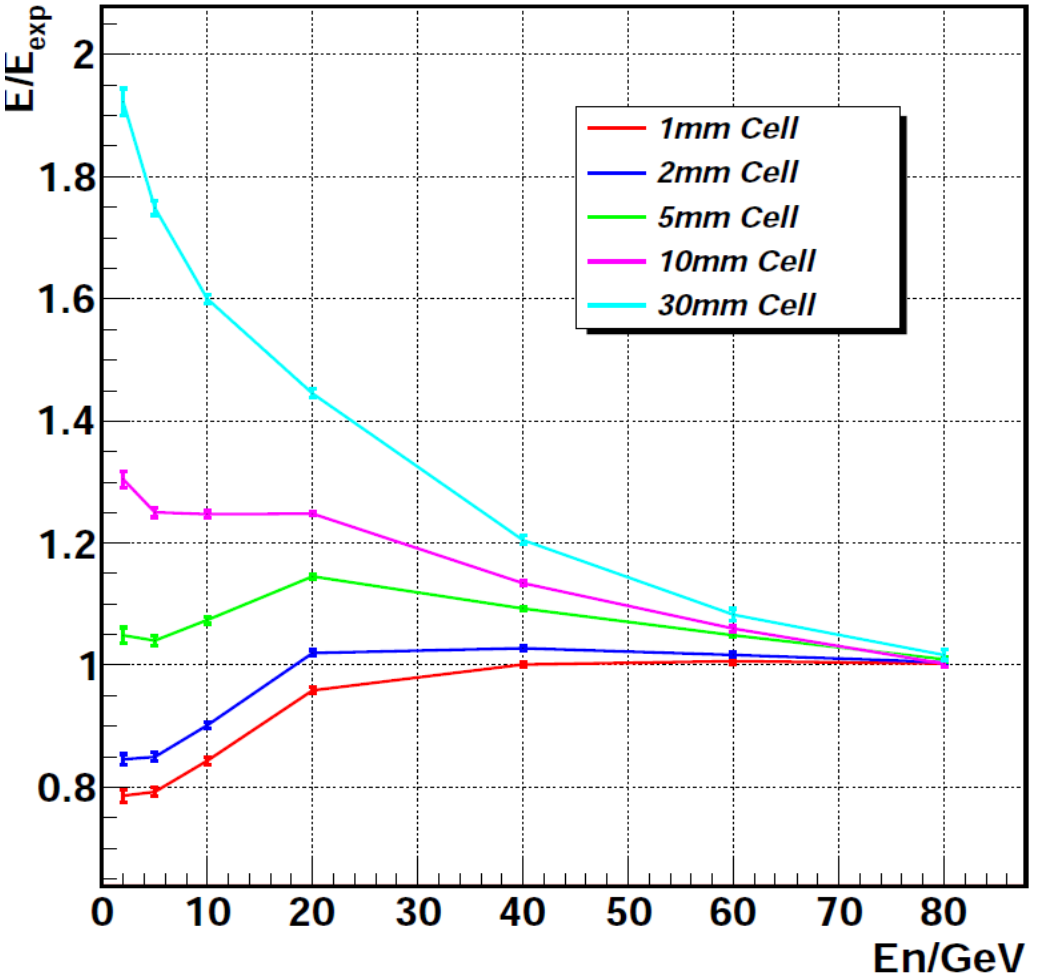
1mm	e+	μ	h
e+	998	0	2
μ	1	994	5
h	15	14	971

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

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

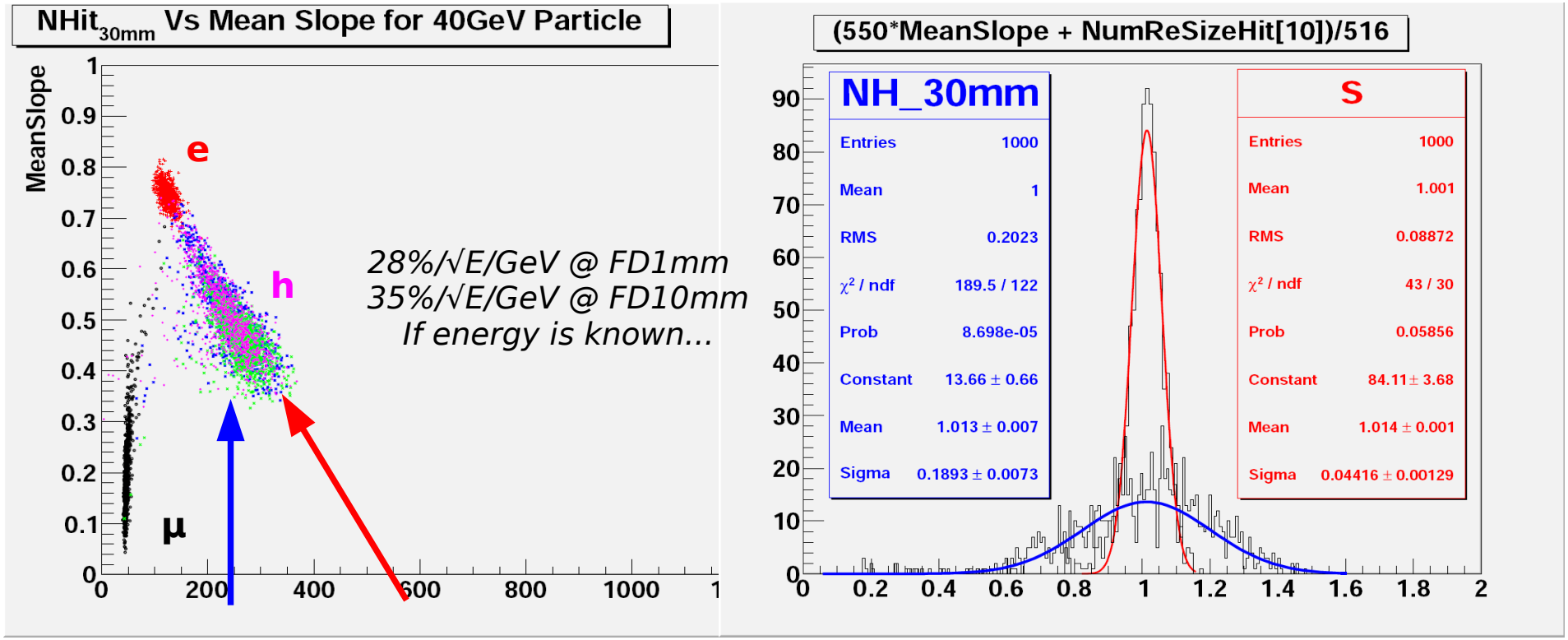
Energy Estimation: with Naive Counting





σ/M: Large cell better at low energy & Smaller cell at high energy.
Linearity: Better at 2 – 5 mm cell, strong saturation effects at larger cell...
Naively: 5mm seems a nice choice (as EM & hadronic hits are compensated)...

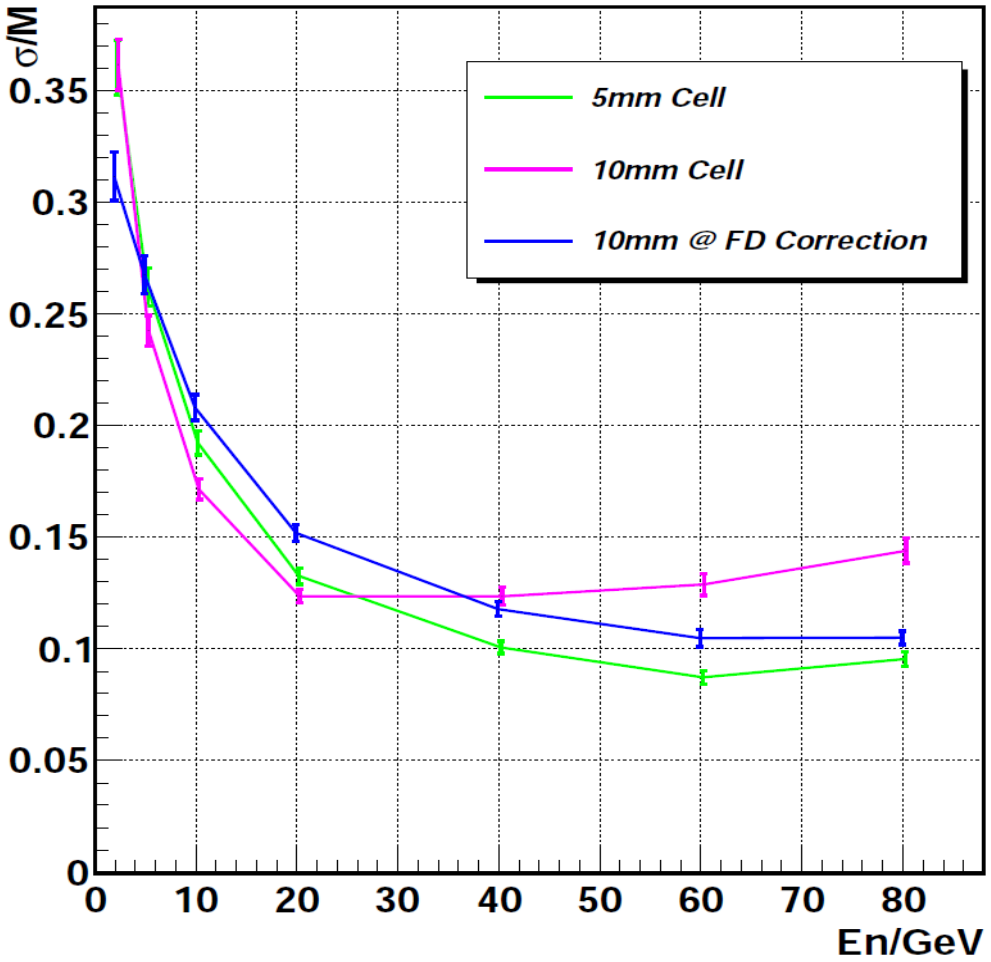
FD for Energy Estimation

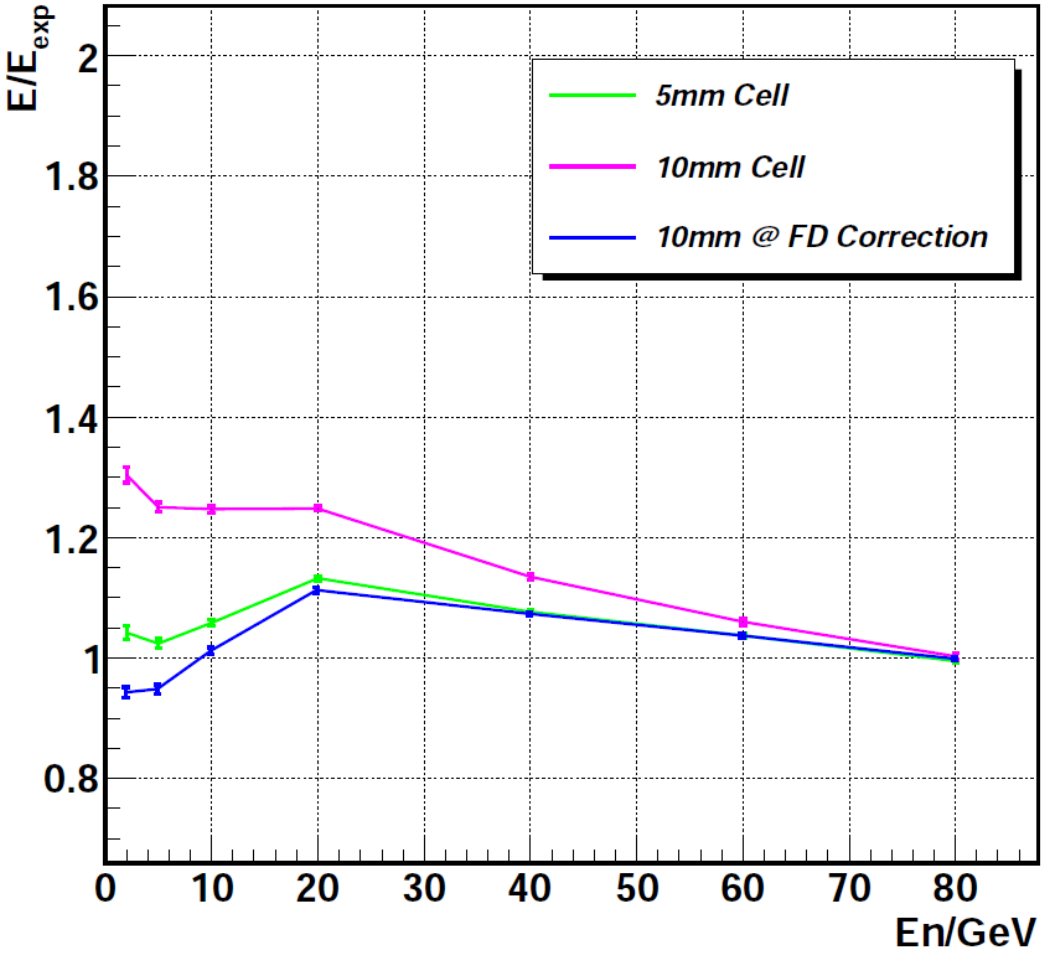


- Strong correlation at FD vs Nhit (large scale): only loose shower makes lots of hits!
- For example: compensation based on NH_30mm & FD1mm:

  E = a * NH_30 + b * FD ~ 30%/sqrt(E)! But...
- b = b(E) ~ kE. To improve track-cluster matching ?
- A set of energy independent (LO) estimator: E = a' * NH_x/(1 – FD*b')

Energy Estimation with FD Correction





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

CALICE DHCAL data

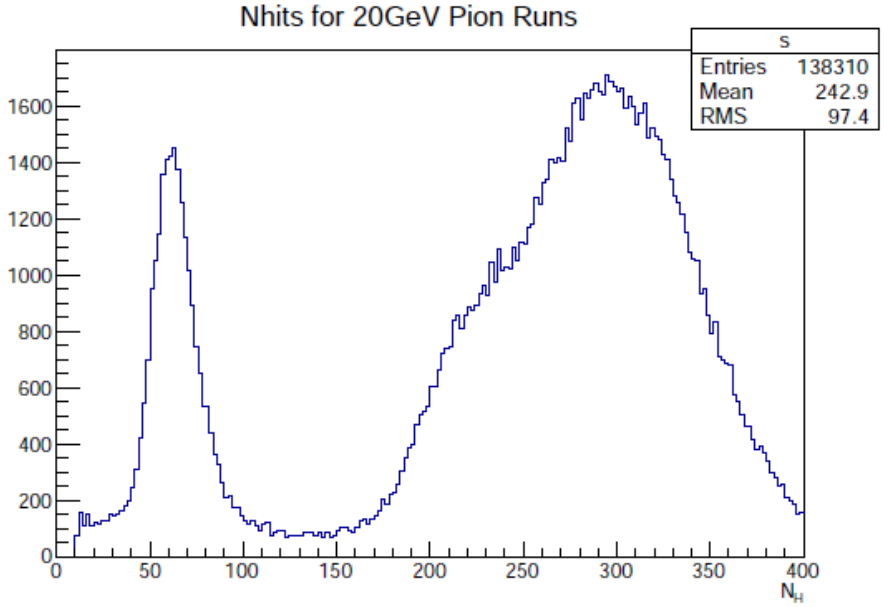
Pion/ Combine	2GeV	4GeV	8GeV	10GeV	12GeV	16GeV	20GeV	25GeV	32GeV
Run Number	600094 600095 600096	600086 600087 600089 600091 600092	600082 600083 600084	600097 600098	600073 600075 600076 600079 600080	600063 600067 600069	600054 600055 600058 600059 600062	600052 600049 600050 600053	600032 600034 600037 600038 600040 600043 600048
Statistic	48.2k	116.5k	87.7k	33.3k	103.3k	22.2k	138.3k	144.1k	112.2k

Using 2010 DHCAL test beam data:

Event pre-selection: Nhits > 10

Statistic: 210k Muon (610036, 38, 39, 47, 64) + 807k Mixed

Fractal Dimension calculation: with Nhits at 20mm – 80mm (7 points)



FD @ DHCAL data

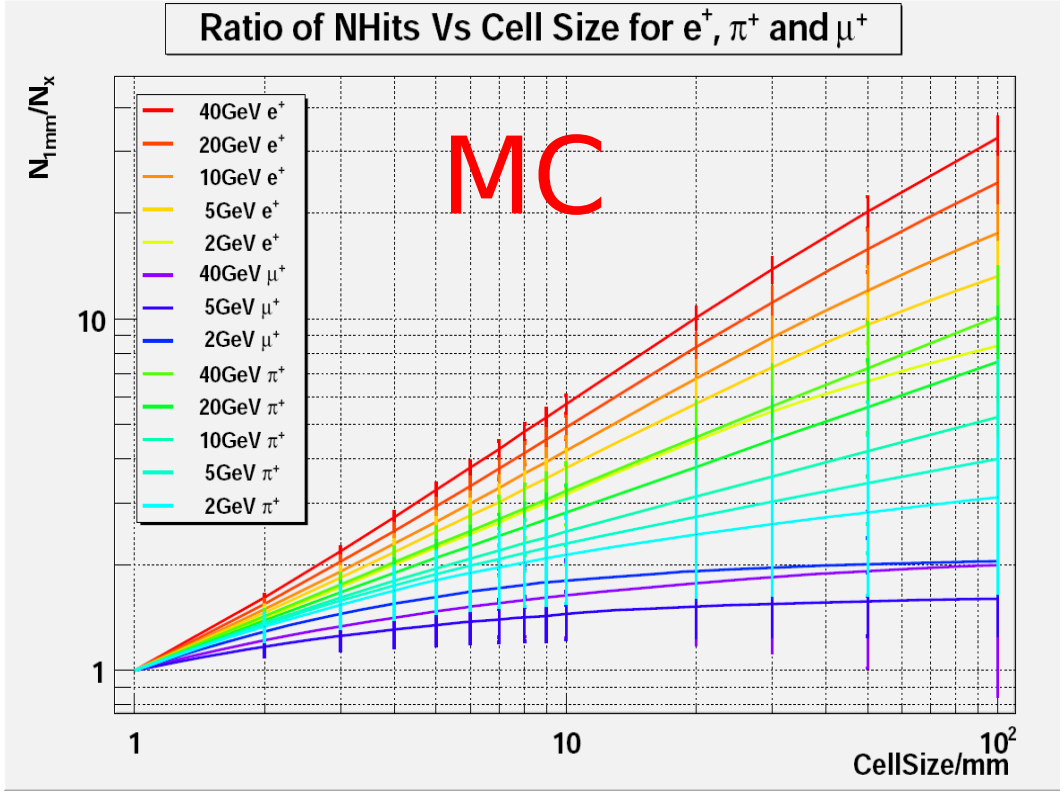
FD method, from MC:

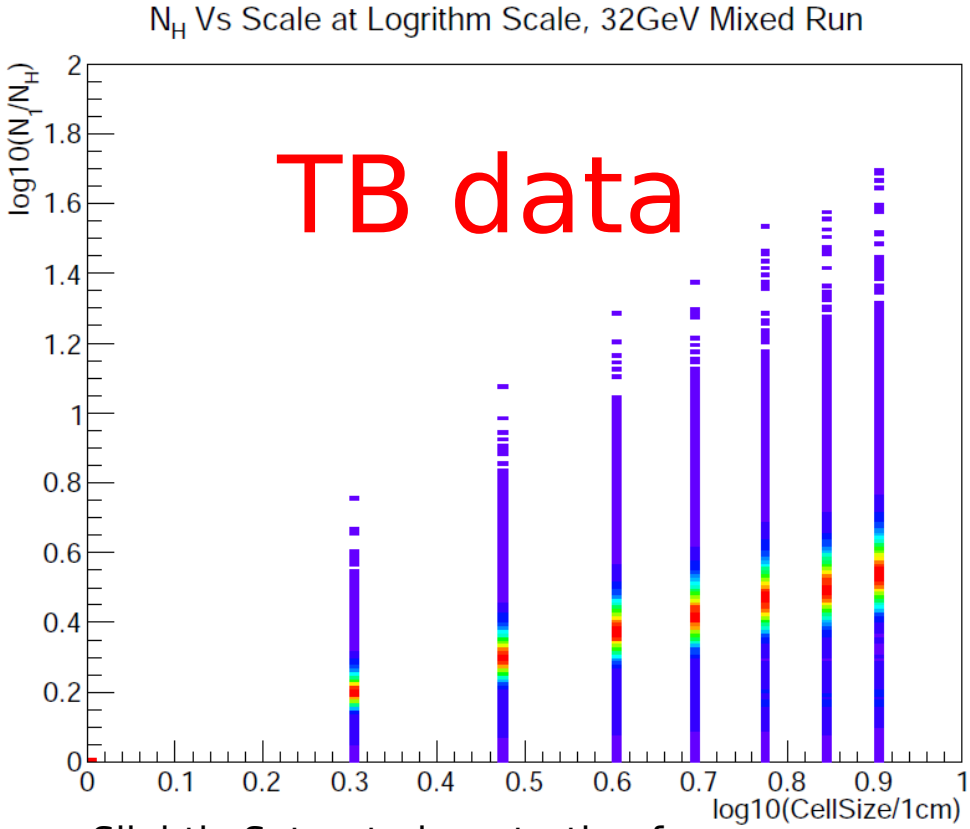
PID: promising, with capability to tag detailed interaction information

Energy Estimation:

Charge particle: Resolution largely improved...

Neutral hadron: Slightly improve resolution/linearity

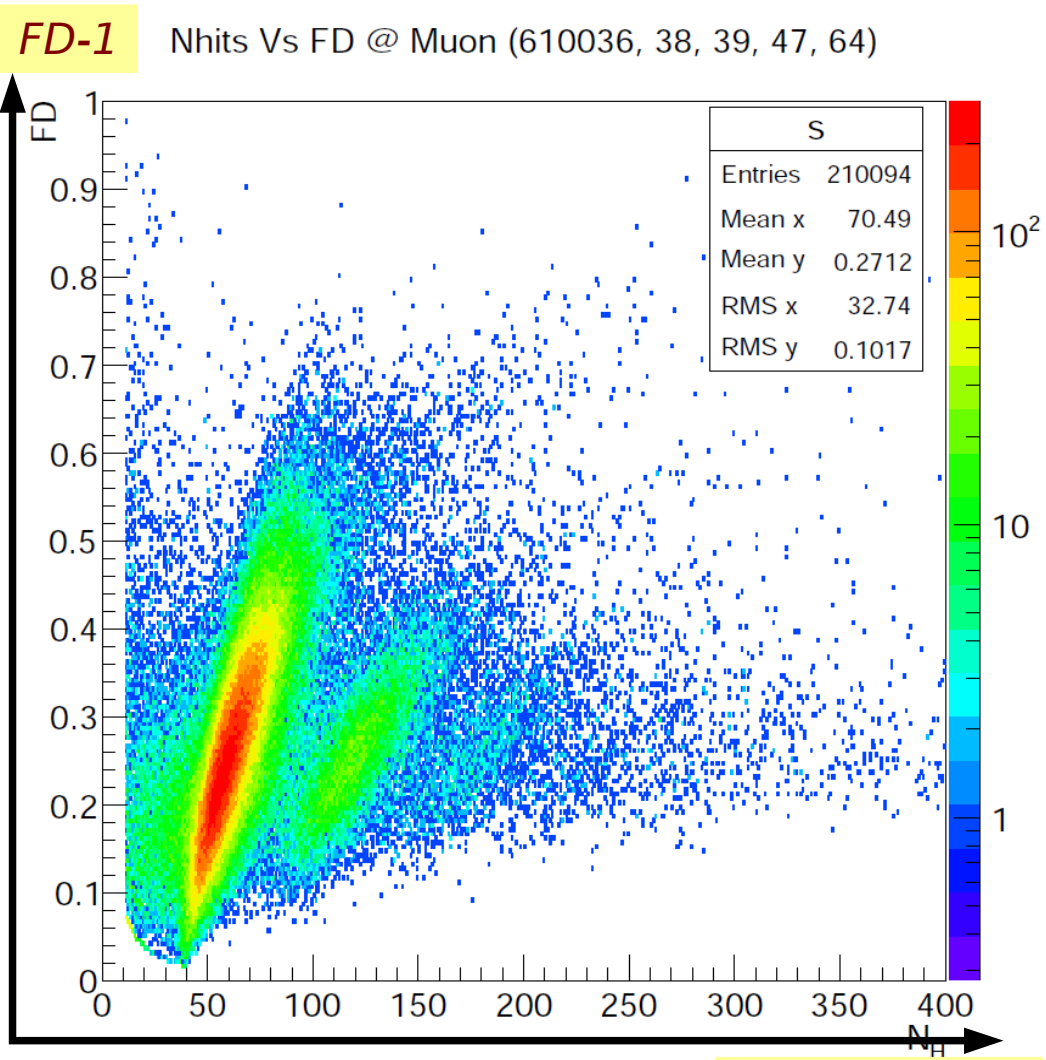




Slightly Saturated as starting from 1cm cell size

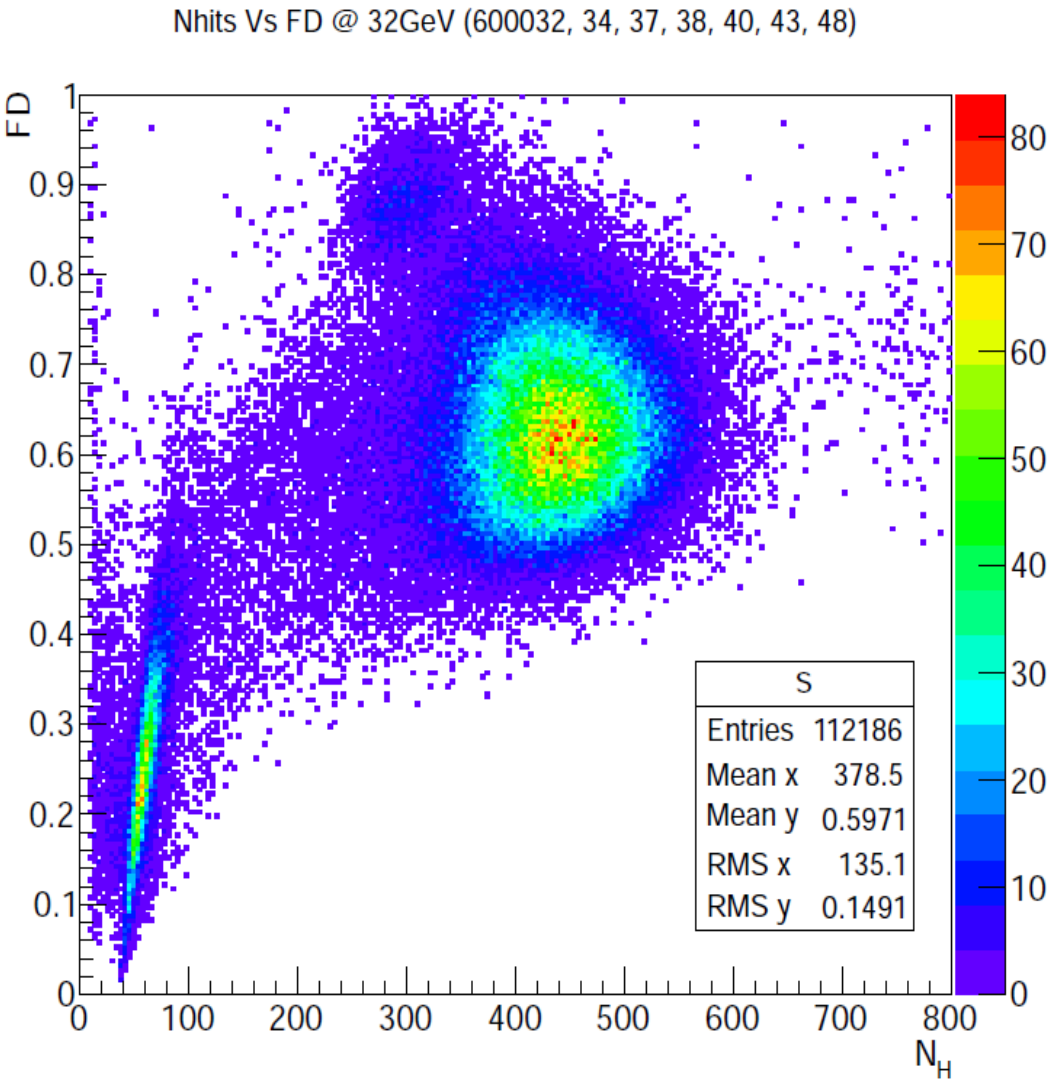
FD @ DHCAL data

FD-1



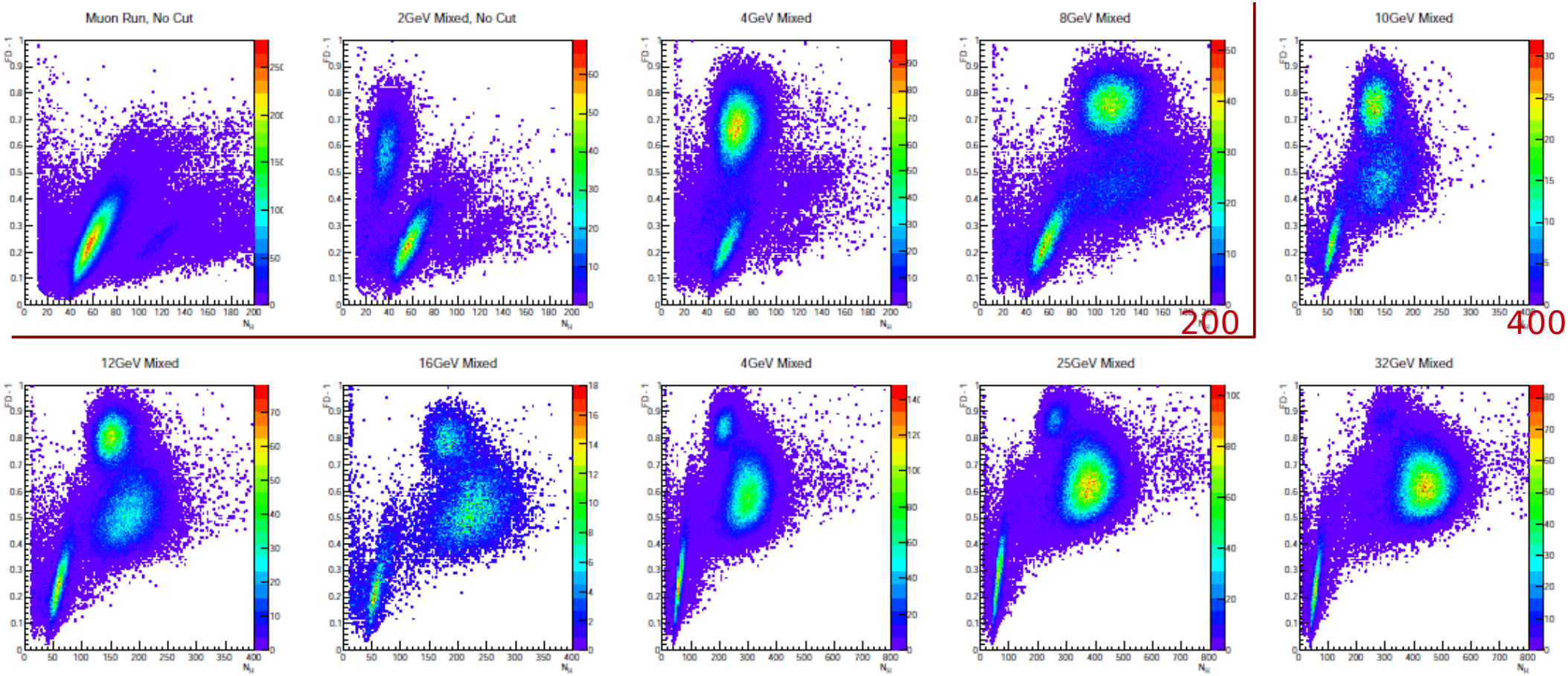
Nhits @ scale

Muon Run:
double/multiple particle events & strong interaction in a few events
(large FD + large Nhits)



Energetic Pion Run:
Clear separation between Mip, Positron and Pion

FD Vs Nhits @ all events



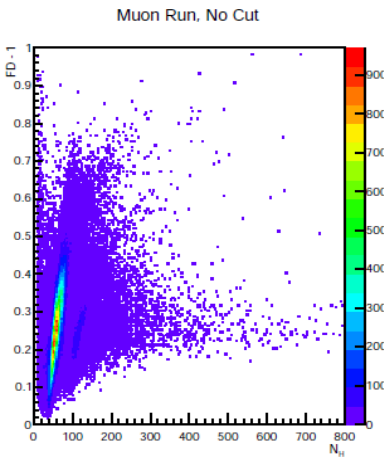
For all events with Nhits > 10

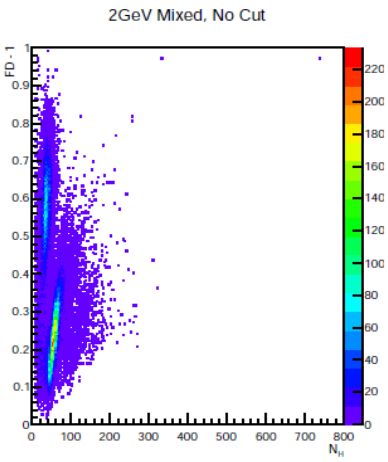
Muon Run: significant double event component

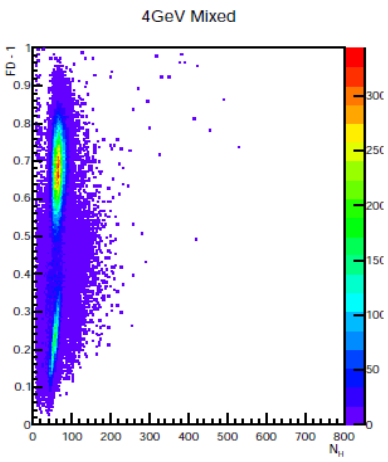
Mixed Run @ 2, 4GeV: Clear separation between positron and MIP component, with significant double events

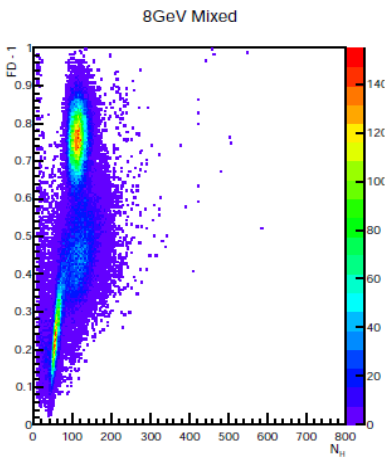
Mixed Run @ En > 4GeV: Clear separation between EM, MIP & Hadron component

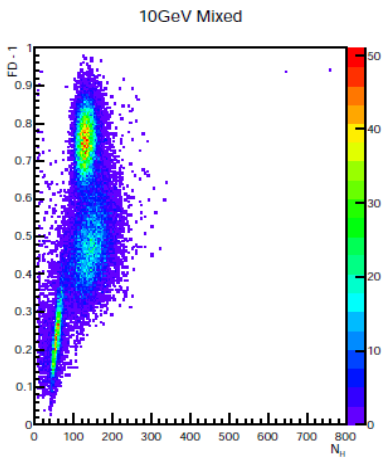
FD Vs Nhits @ all events

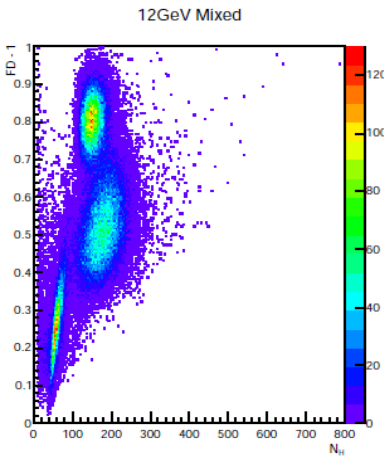


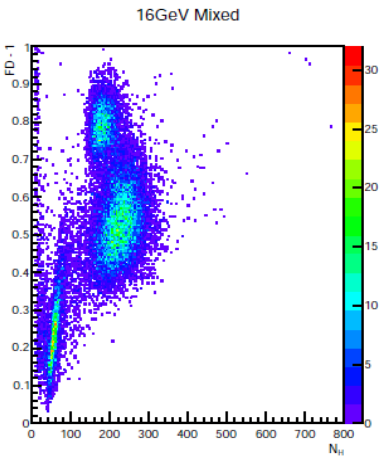


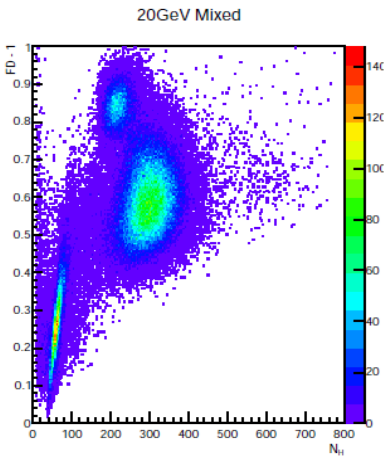


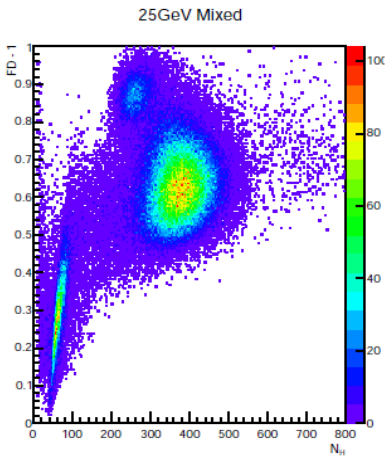


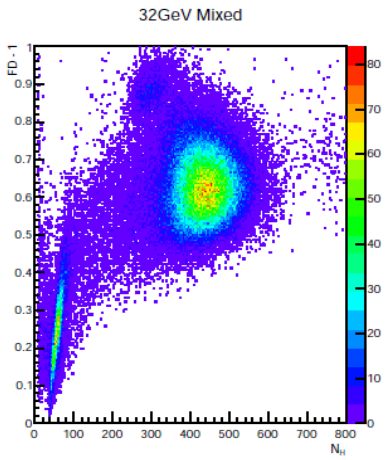












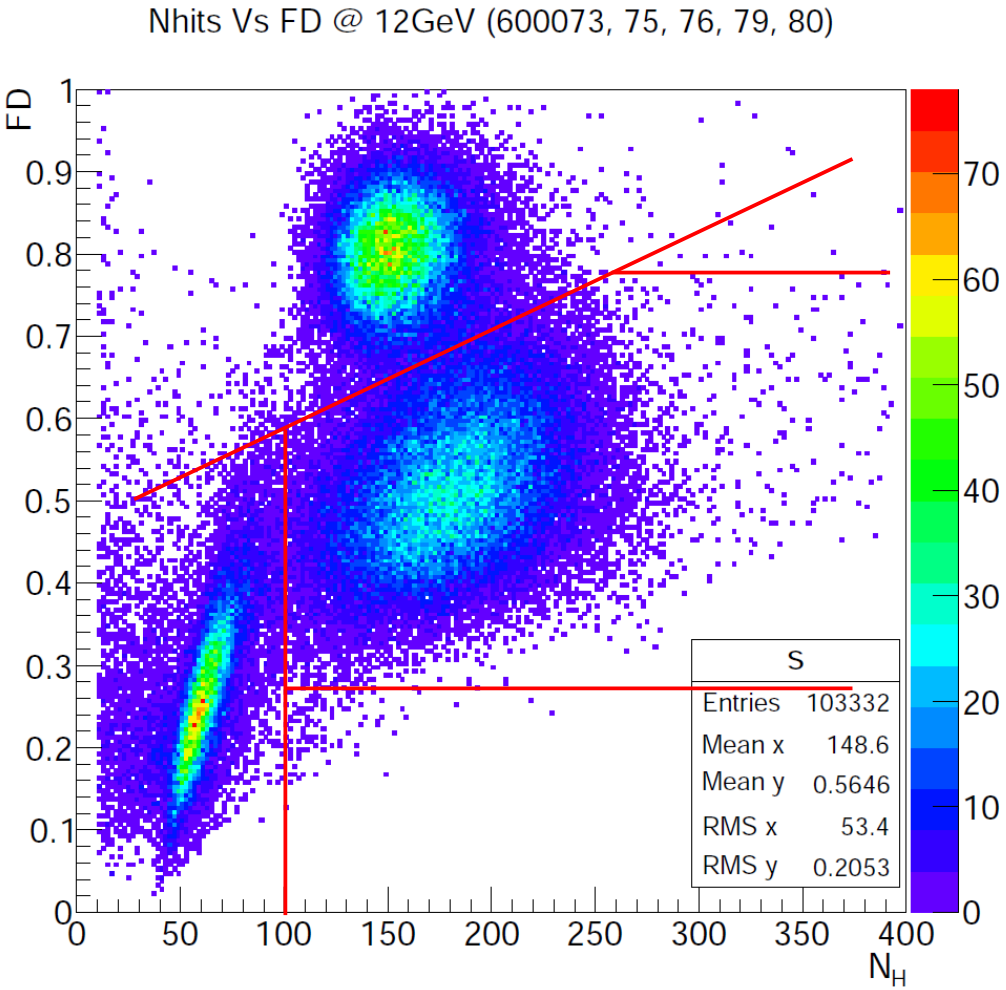
For all events with Nhits > 10

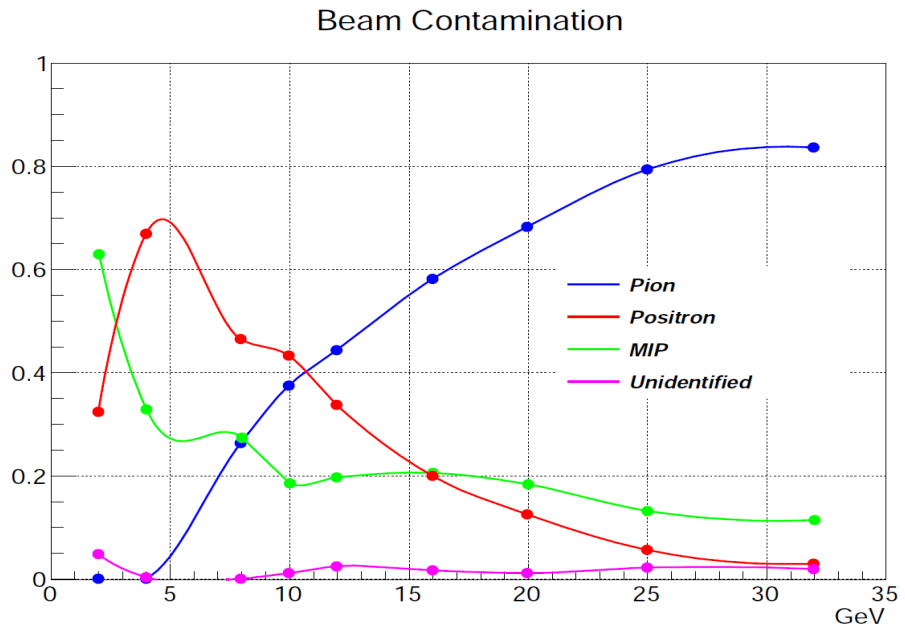
Muon Run: significant double event component

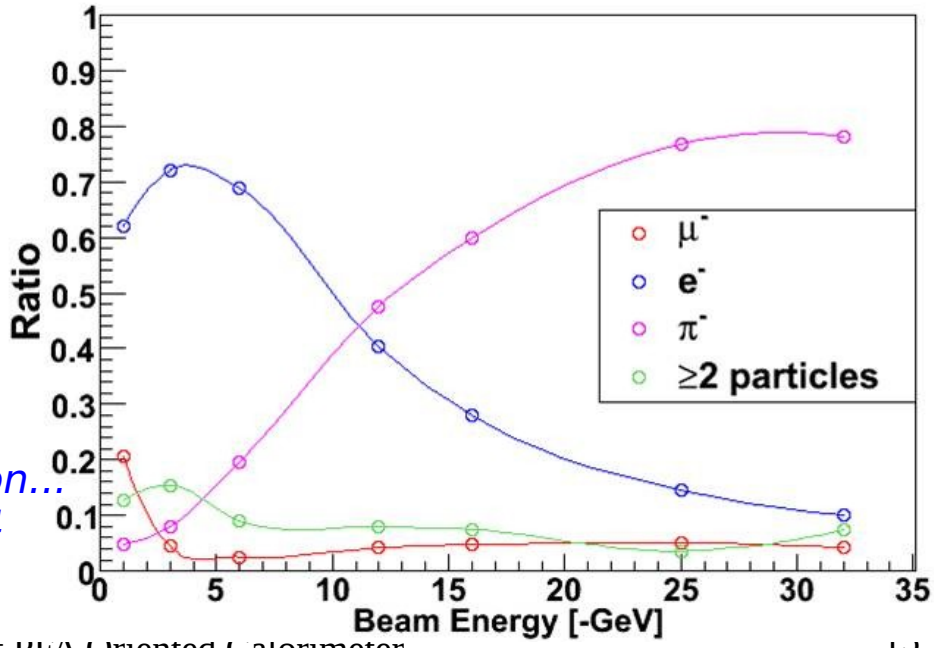
Mixed Run @ 2, 4GeV: Clear separation between positron and MIP component, with significant double events

Mixed Run @ En > 4GeV: Clear separation between EM, MIP & Hadron component

PID with hand put cut

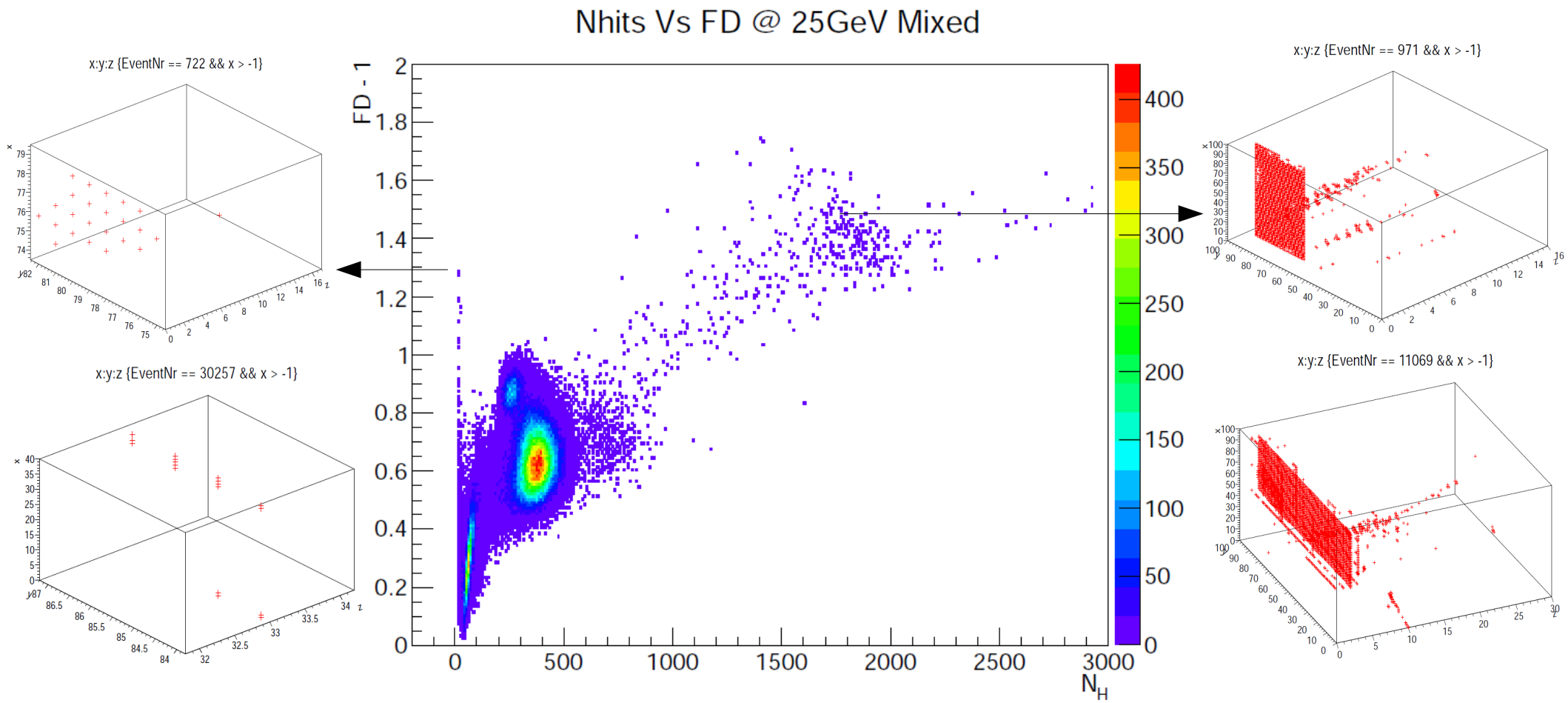






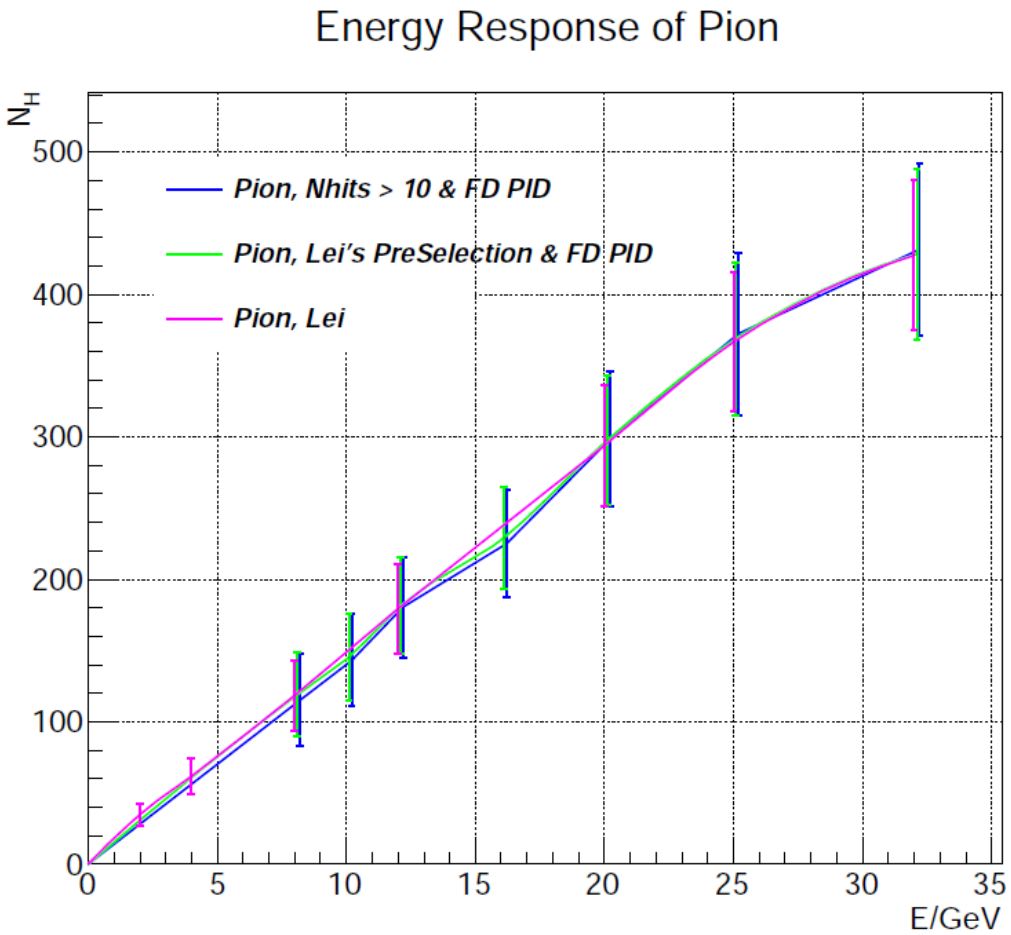
No cleaning, No identification on double events...
Low energy (2, 4GeV) pions regard as MIP
Remark: contamination can depends on rate selection...
Detail cuts can be traced on spare slides P31 – 34

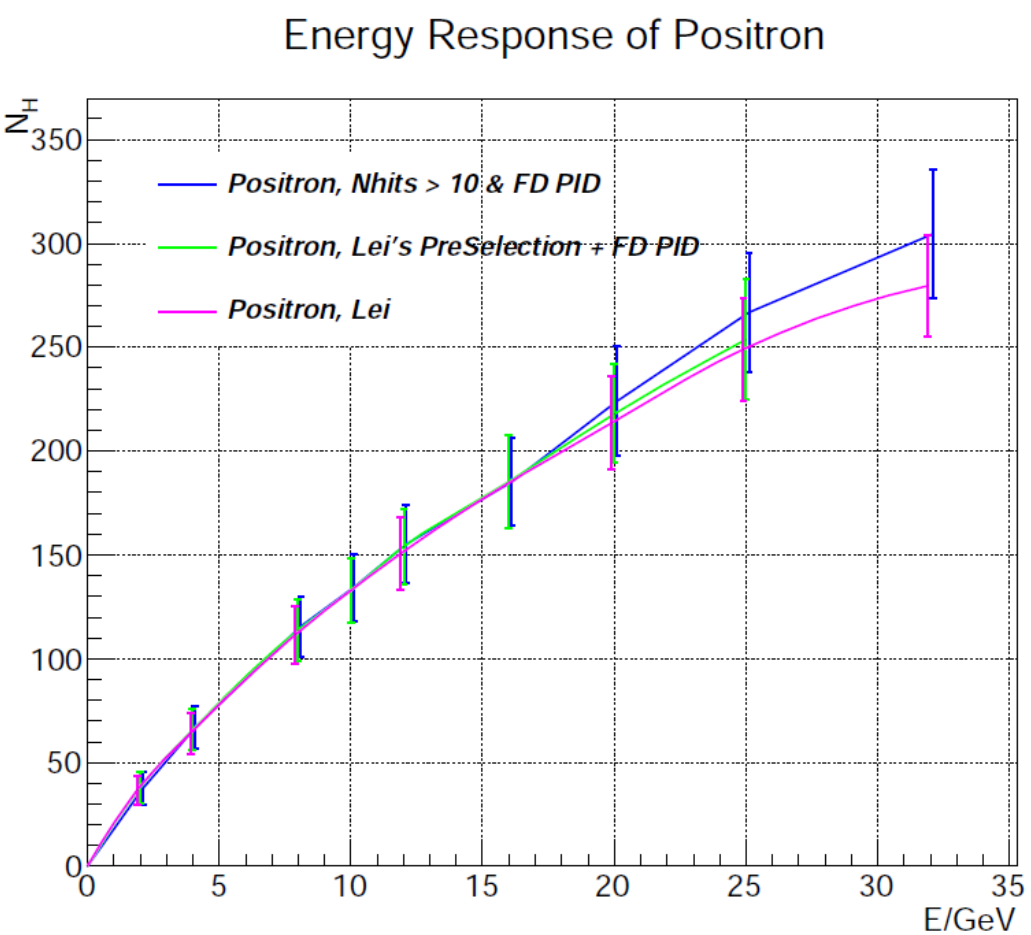
FD & Typical Patterns



DHCAL Runs: pretty clean... but not completely free of noises...

Energy Response





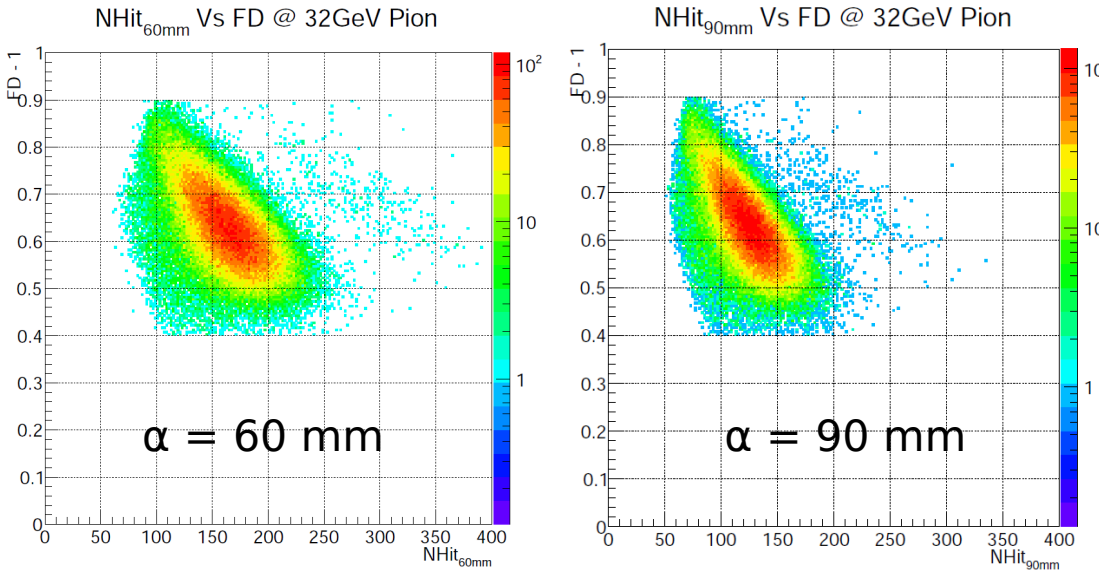
Energy Response:

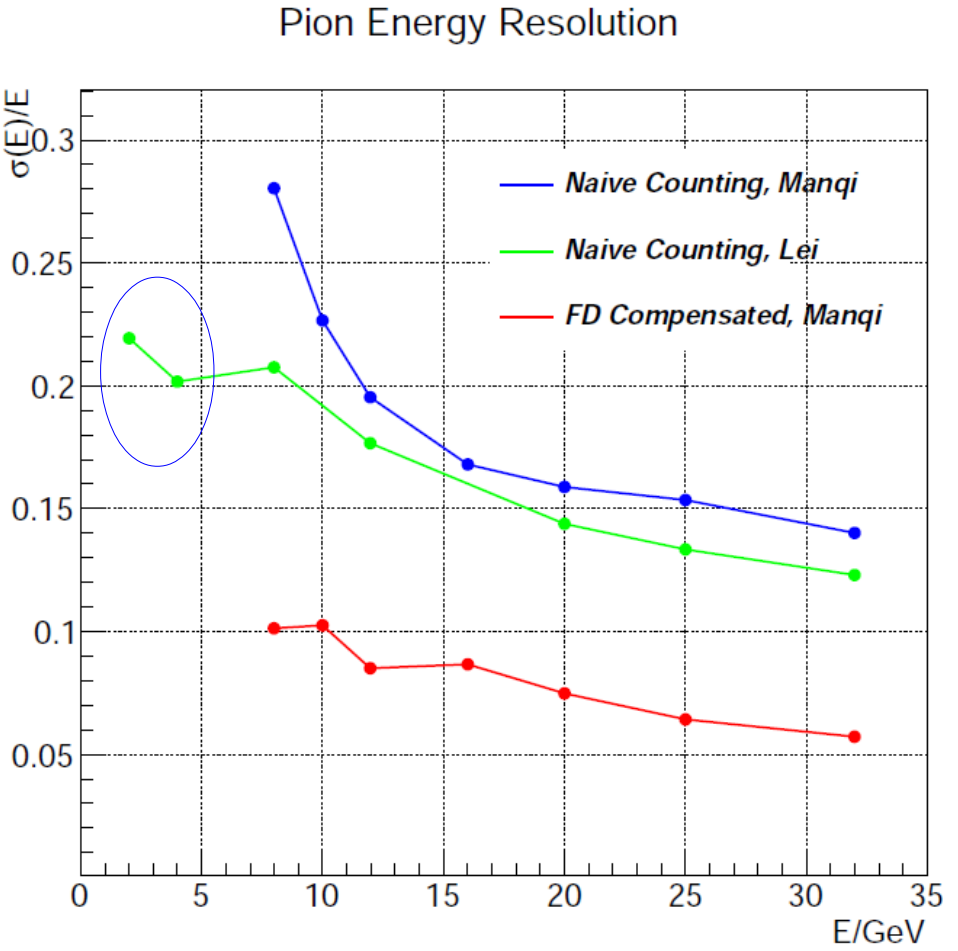
Basically agrees, especially with same pre selection
Non-linear behaviour of positron and high energy pion
Pion: lower response at 16GeV...

Lei's pre selection

* *Exactly 1 cluster in layer 1*
* *Not more than 4 hits in layer 1*
* *At least 3 layers with hits*
* *No hits within 2 cm to layer edges*

Track-Cluster matching (with known track E)





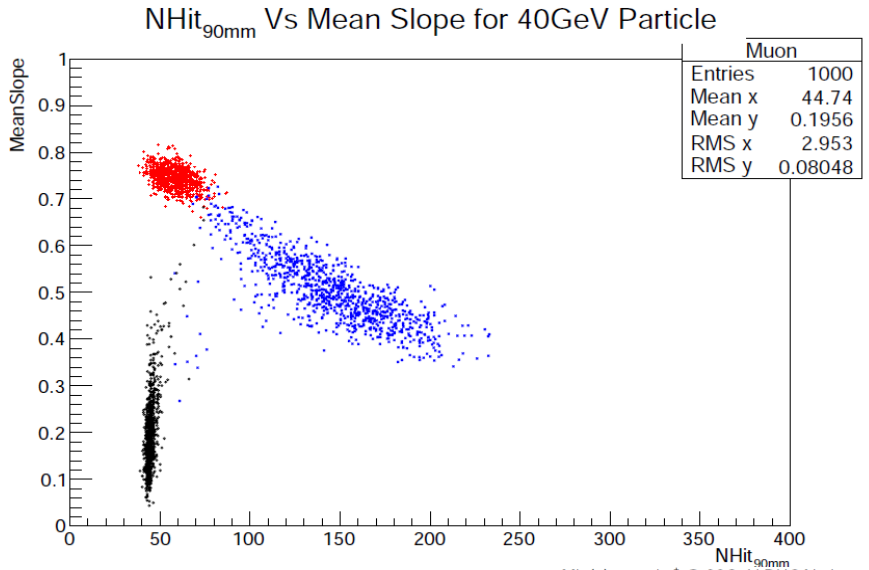
- FD & Nhits(large_scale) (extreme case: Num of fired layer): strong correlation holds for test beam data
- Hand put energy estimator

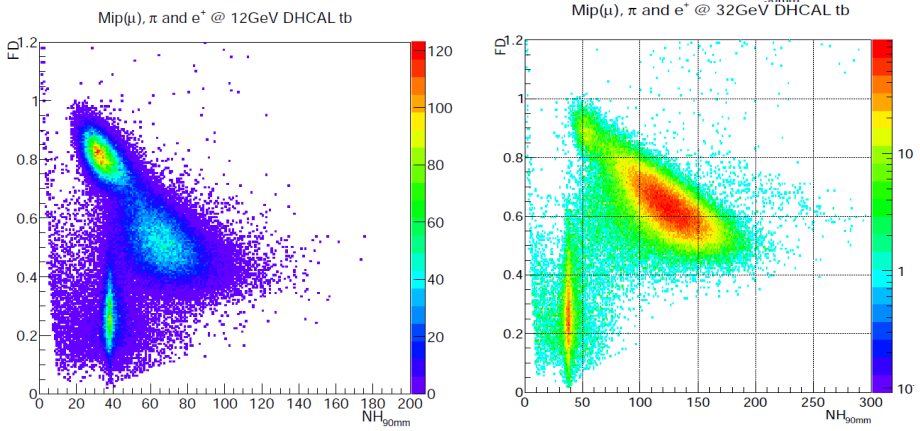
  E = N*(NH_90mm + 10*E*FD)

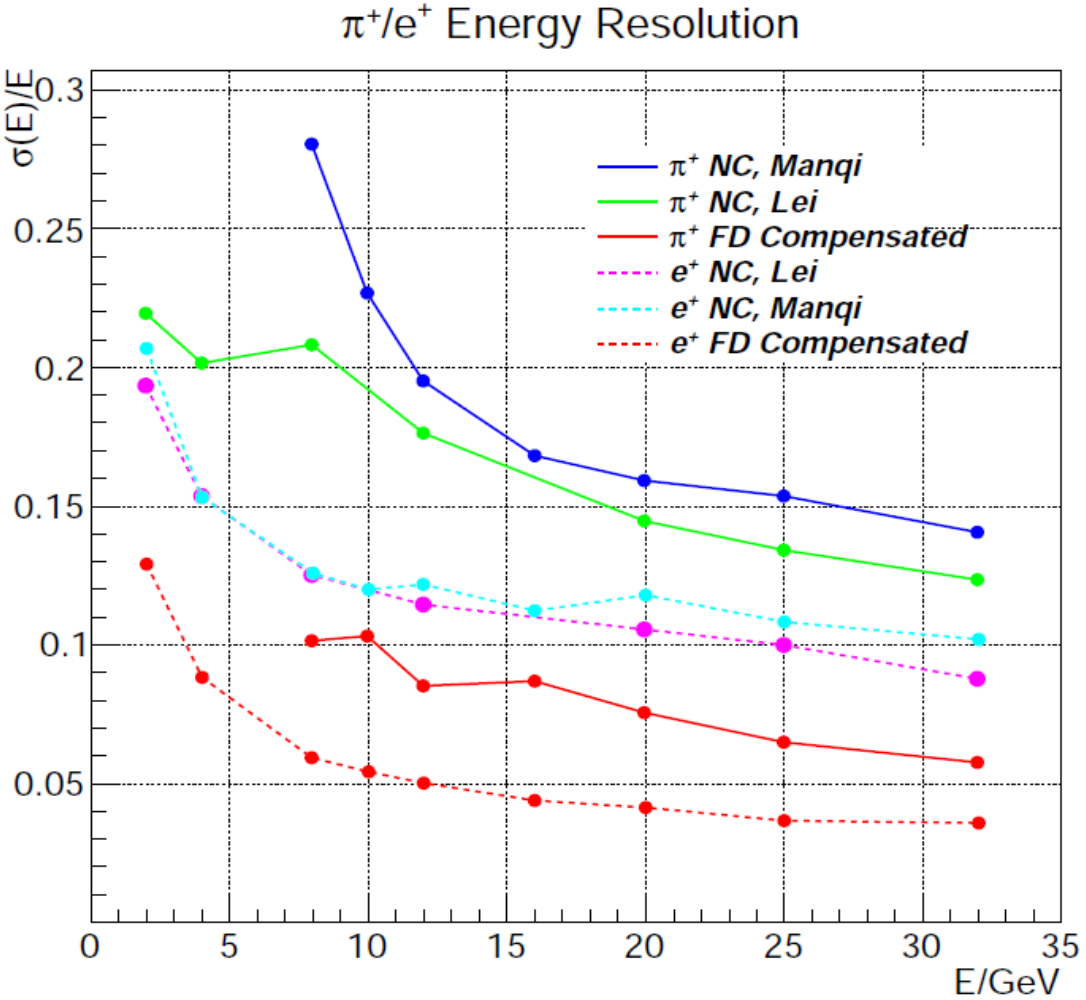
  Energy Resolution easily improved by a factor of 2...

The difference between naive counts is due to different cut chain

For electron/positron

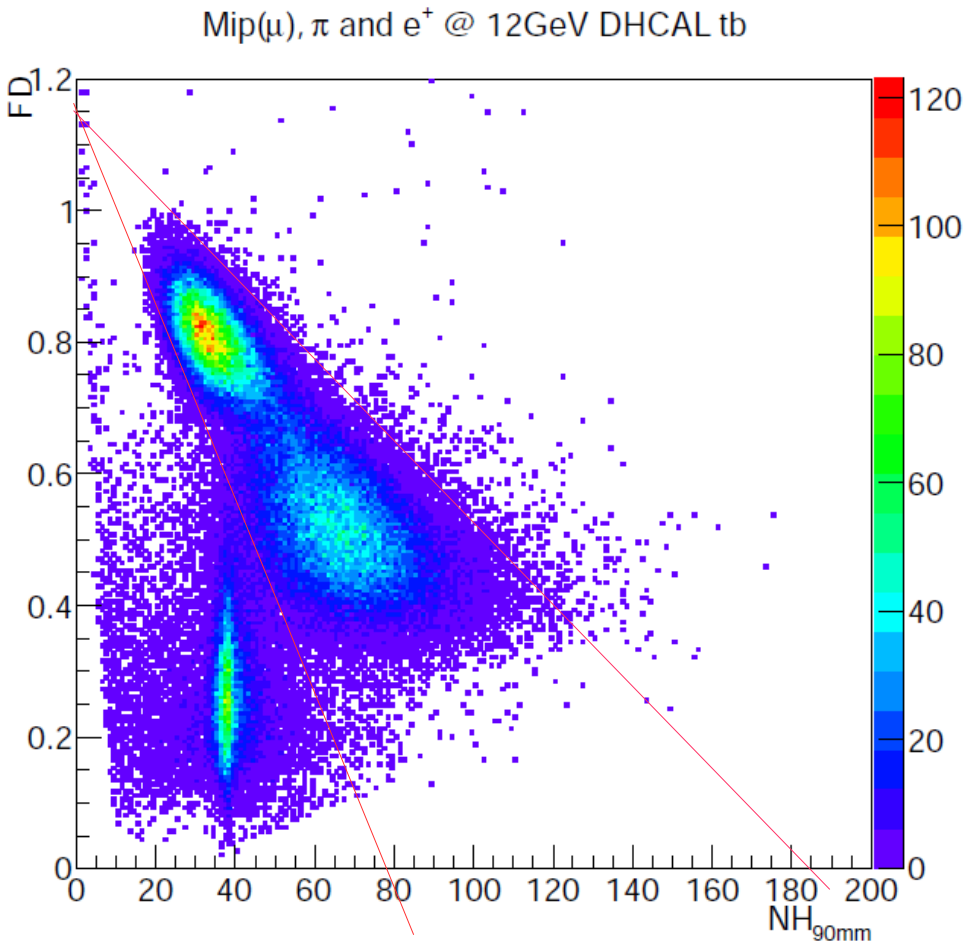


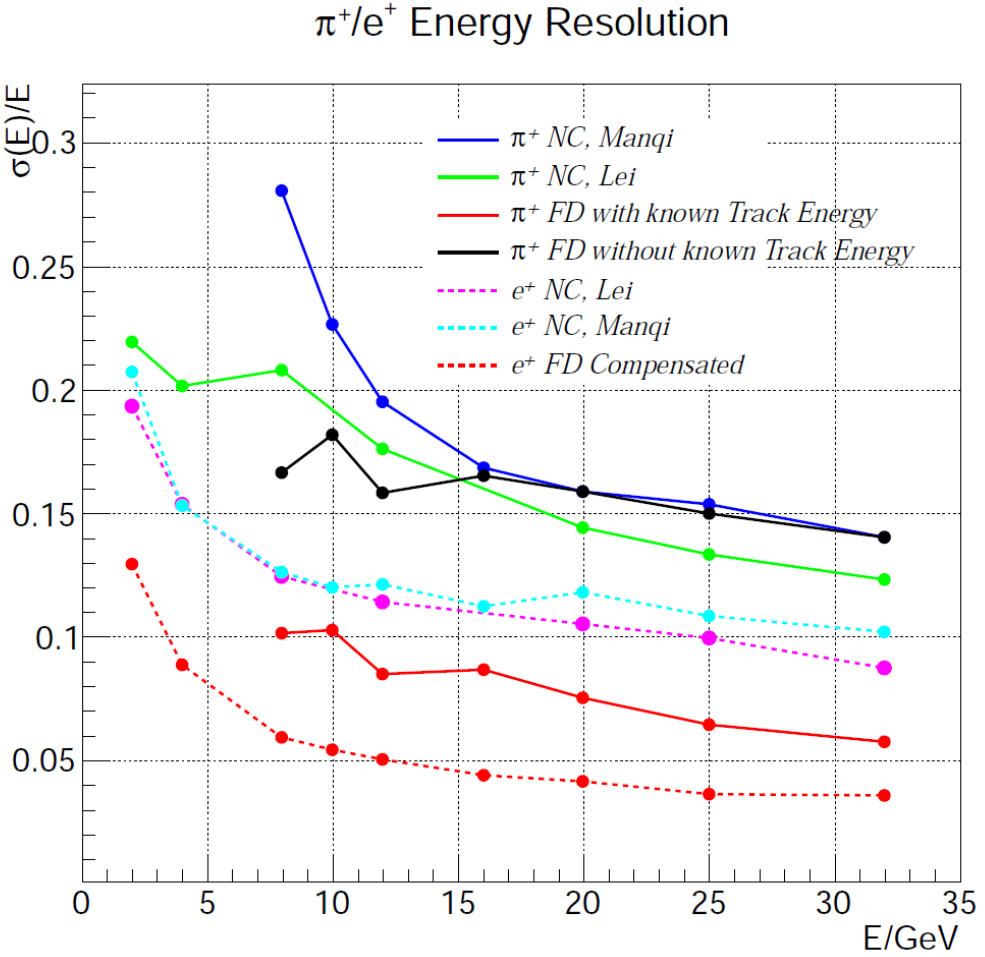




- e^+ and π^+: continuous & aligned distribution on the Nhits(large scale) - FD plane (extreme case is $\pi^+ + n \rightarrow \pi^0 + p$): Estimate positron energy with same estimator as pion.
- Track-cluster matching can be improved by the use of FD, but complete performances still have to be studied

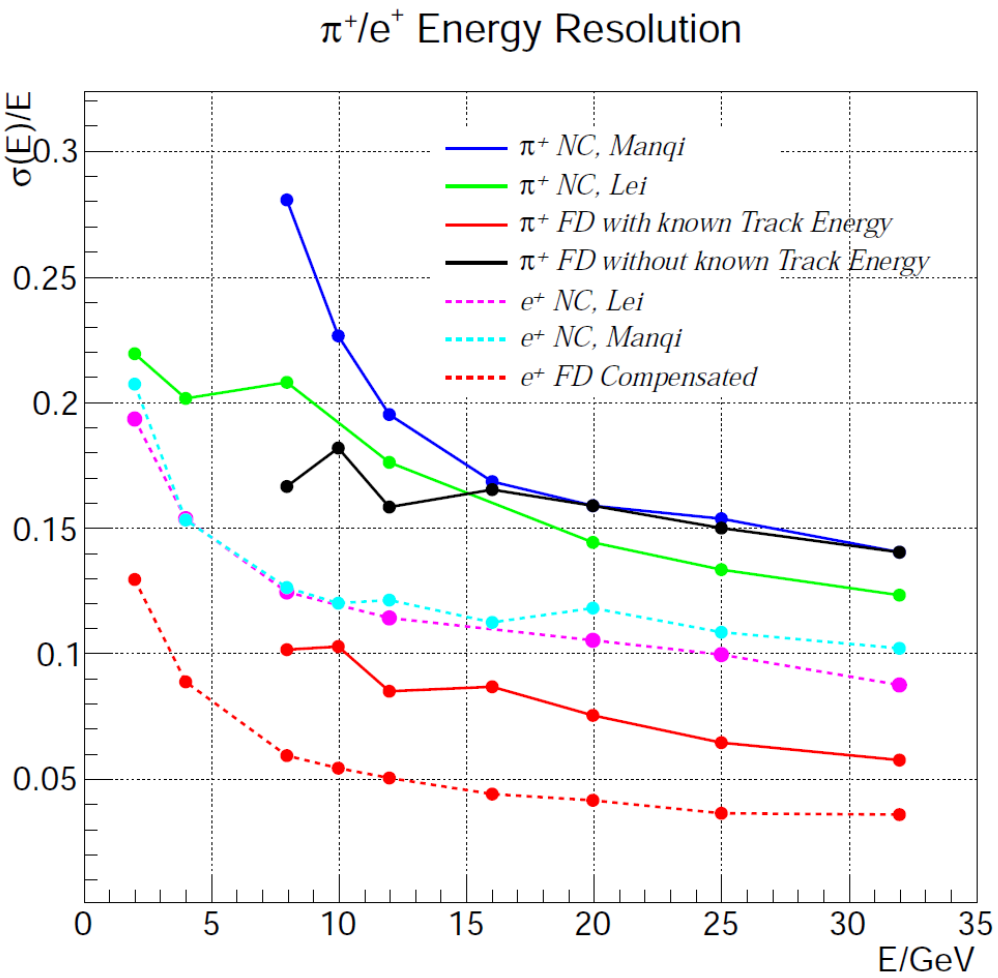
Without knowing track energy

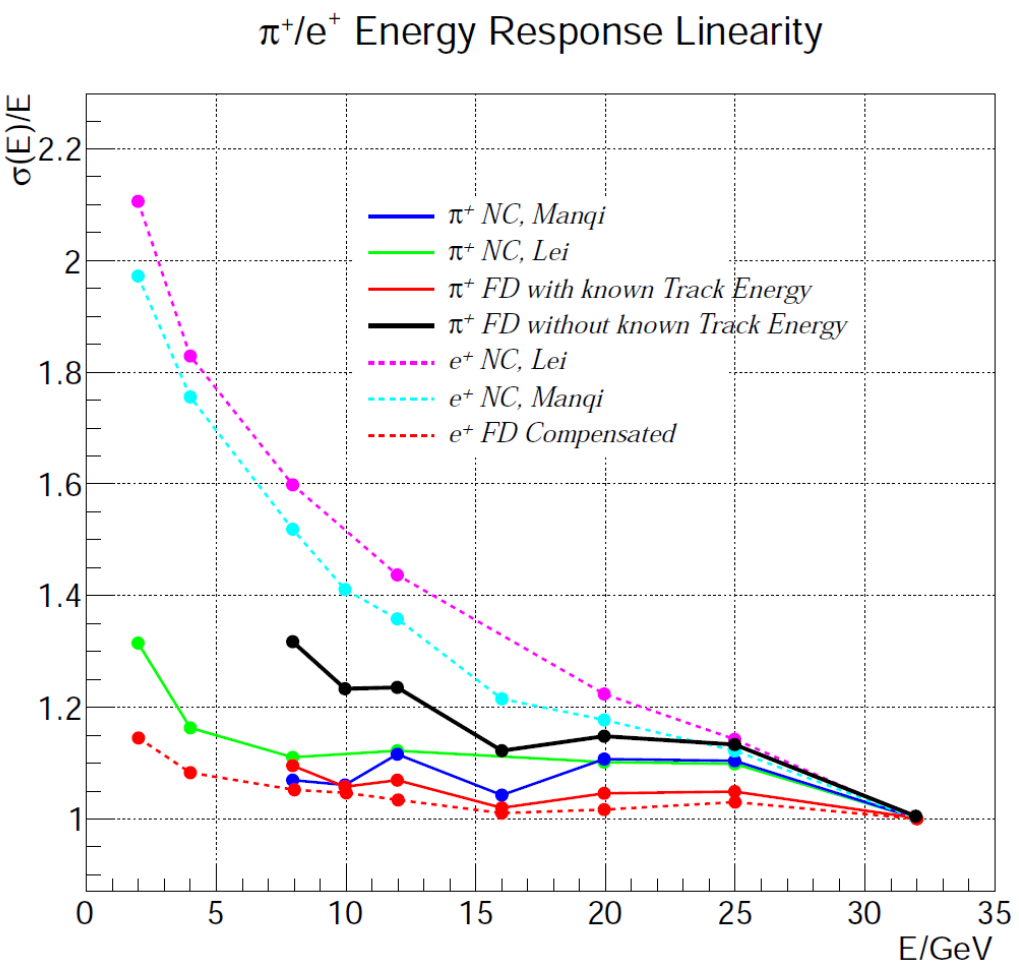




- Without knowledge on initial energy E ~ NH/(a – FD) : Projection from the invariance point on FD axis to Nhit axis.
- EM & Hadronic distribution has the same boundary (FD ~ contamination of EM interaction inside hadronic shower) ~ Hard limit: Measure Hadronic as precisely as EM component?

And Linearity...





Charged particle: Significantly improve energy resolution & linearity (i.e, positron saturation effects corrected)

"Neutral" particle: Energy Resolution could be improved at low energy, but lose a bit the linearity... contrary to MC prediction.

FD @ SDHCAL

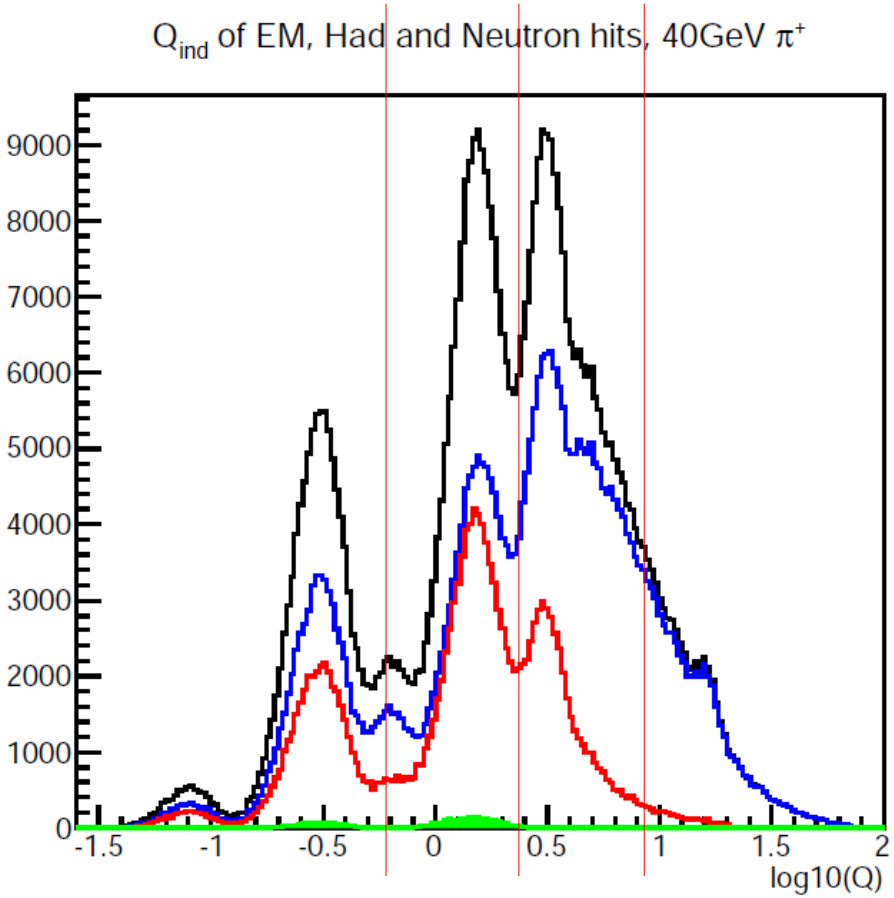
Objective: to find optimised threshold and energy estimator, with best linearity and resolution of particle energy

$$En = En\ (\ Resize_NH(i),\ FD(i),\ \ldots\ );\ i = (1),\ 2,\ 3,\ 4$$

To study correlations @ different thresholds
(Code done)

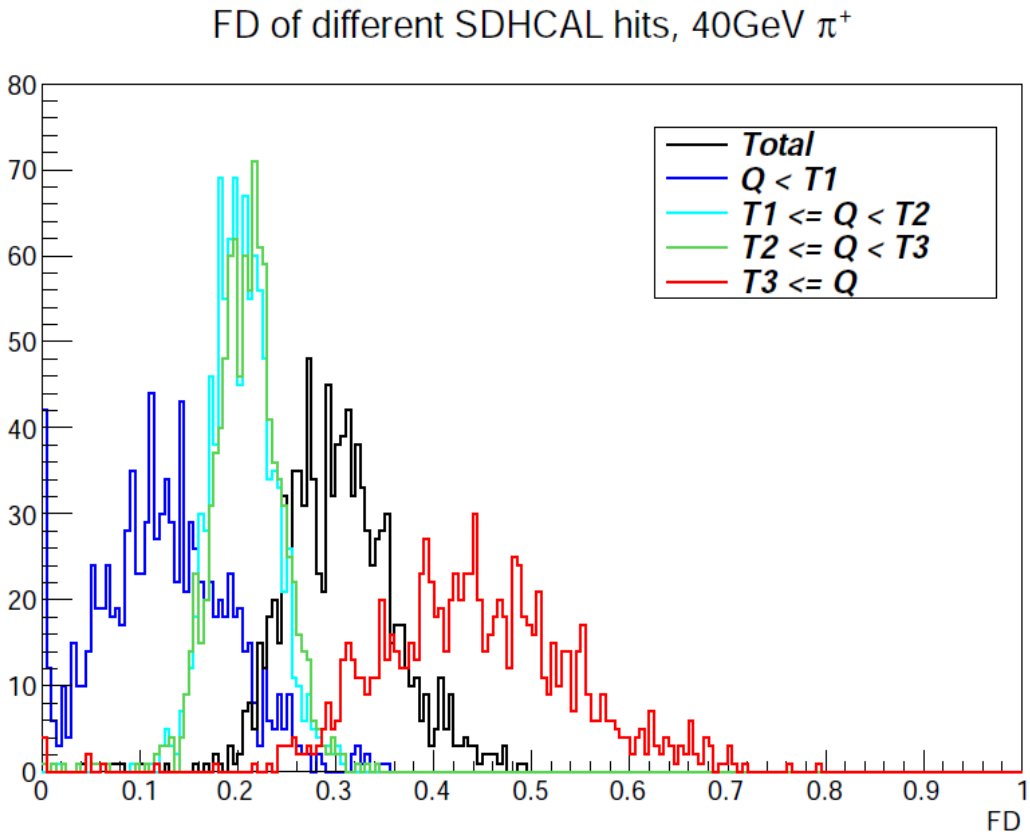
Open questions:

Besides e/h ratio, any information else Presented by FD?
...

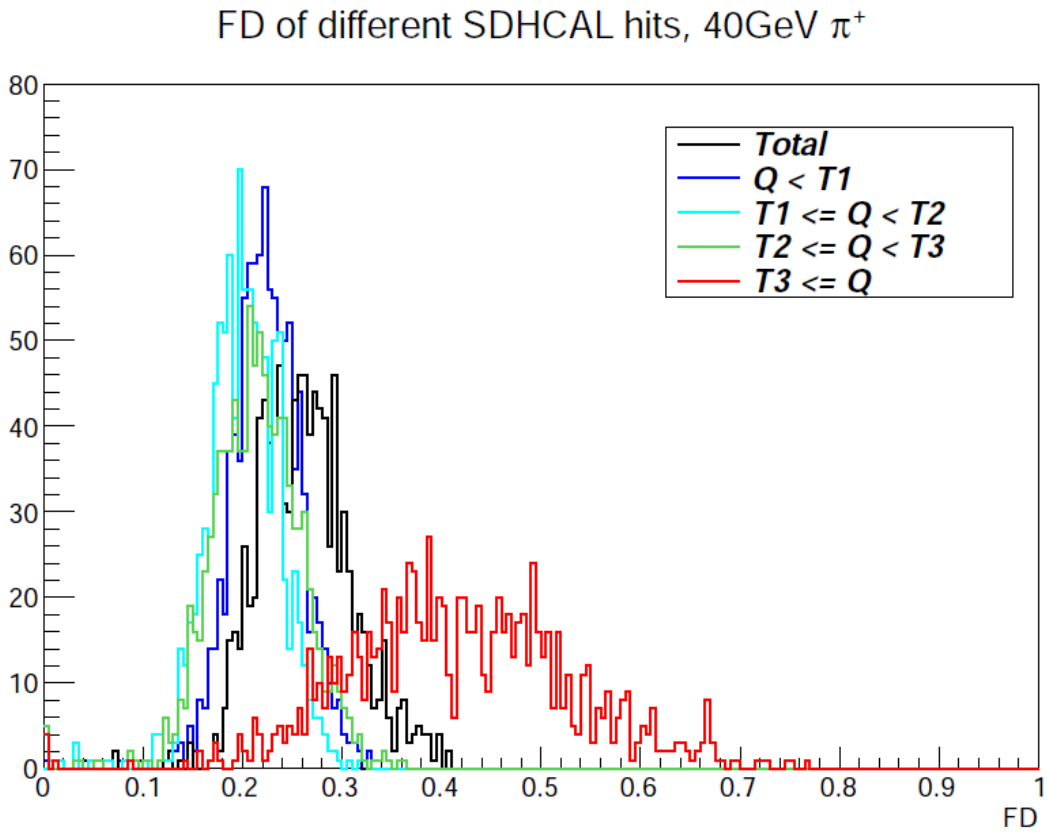


FD @ SDHCAL hits

Thresholds: 0.2, 1.0, 2.5 pC



Thresholds: 0.8, 2.2, 4.5 pC



Significantly different behaviour...
Most interesting part: Q > T3 hits - Core of EM interaction?

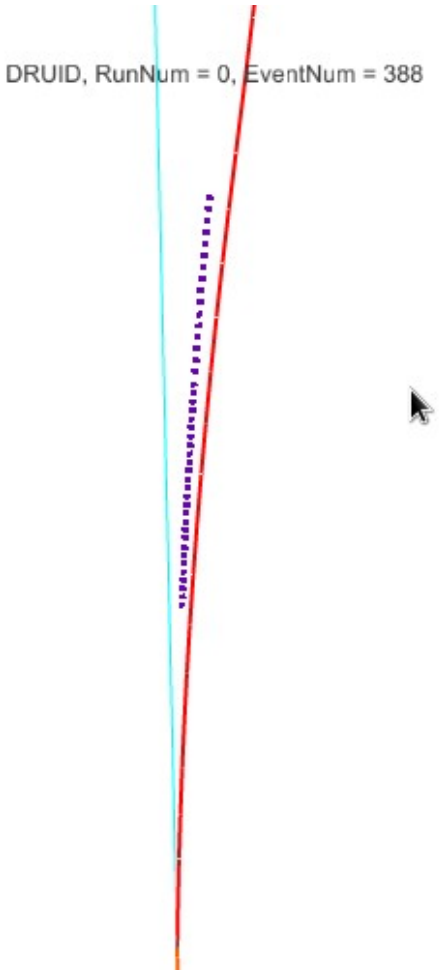
Summary & To do

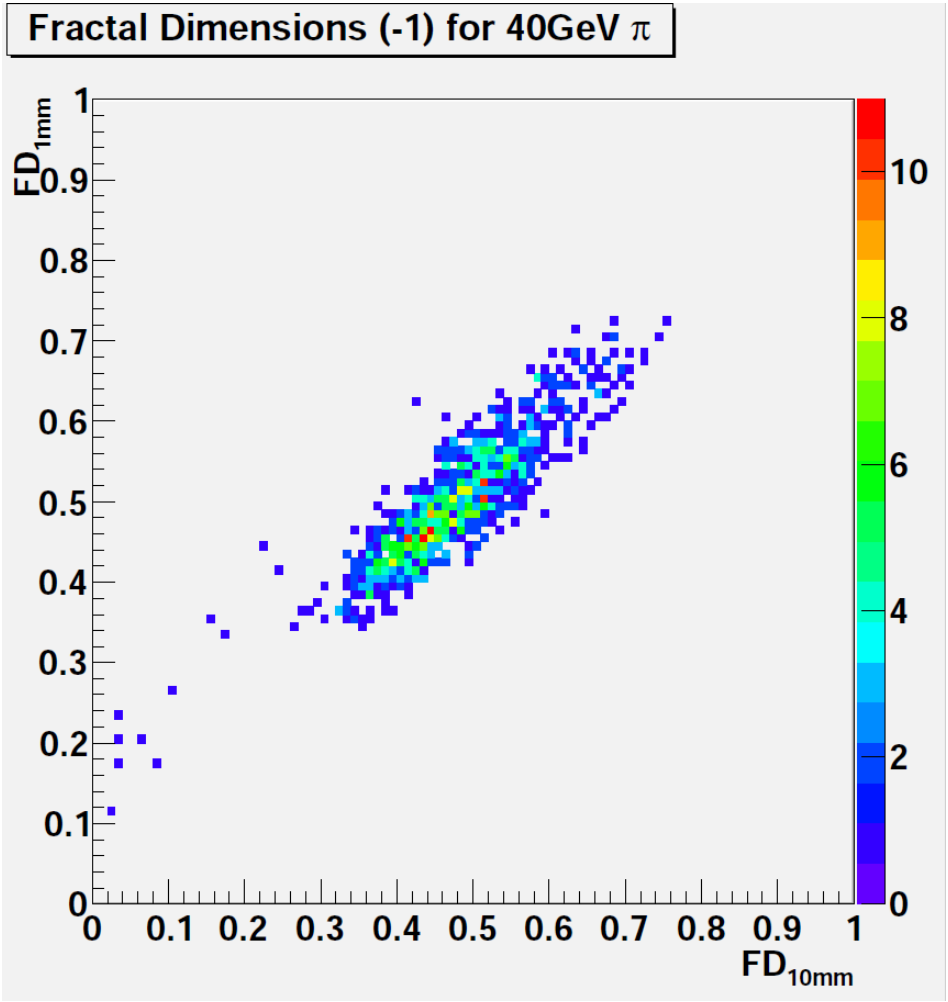
- Fractal Dimensional: Validated @ simulation and real data
  - Roughly repeat:
    - Fermi Lab Beam contamination measurement in previous CALICE TB
    - e+ and pi energy resolution (compare to Lei's Granada slides)
  - PID: *Čerenkov seems no longer needed for the prototype*…
  - Energy Estimation:
    - With known track energy: resolution easily improved by a factor of 2
    - Possibility to measure hadronic shower energy as precisely as EM shower?

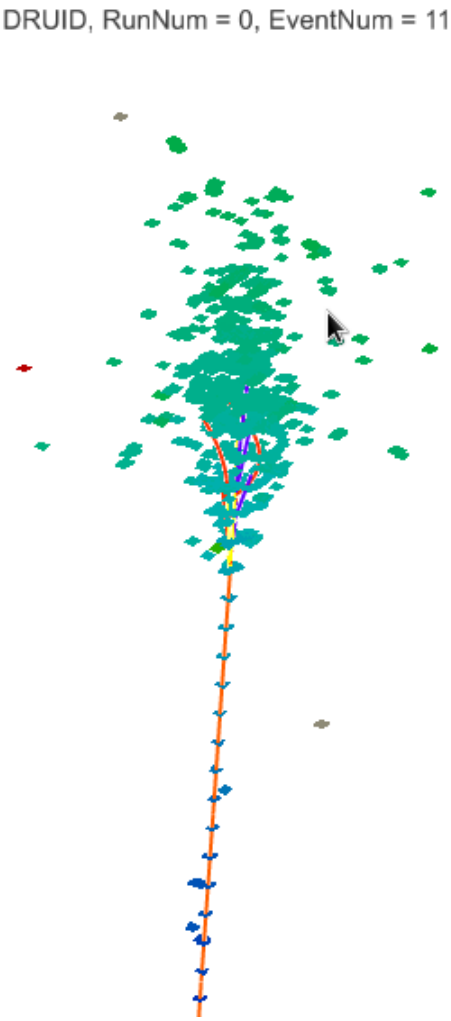
- To do:
  - Better understanding to FD
    - FD @ ECAL, SDHCAL, AHCAL…
    - FD Vs Geometry…
  - Note & Paper

Spare slides

Extreme Cases: Pion

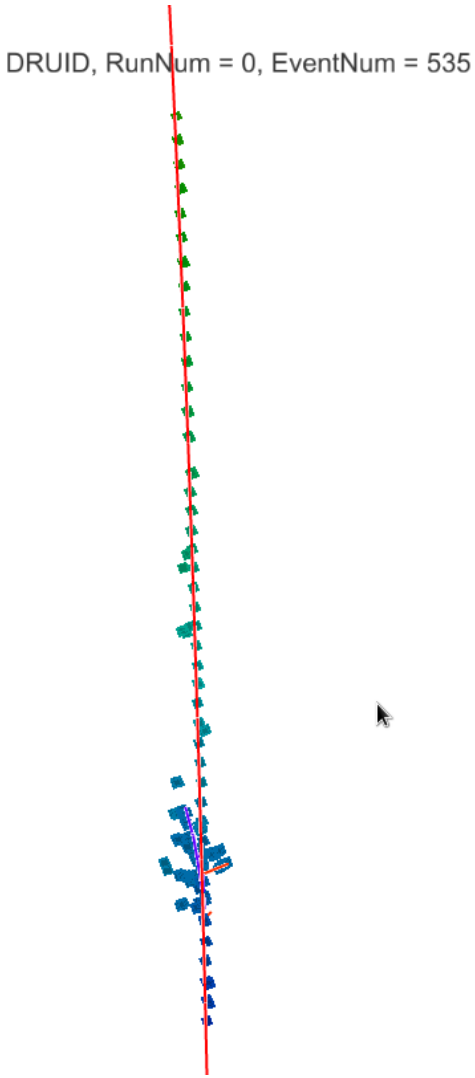


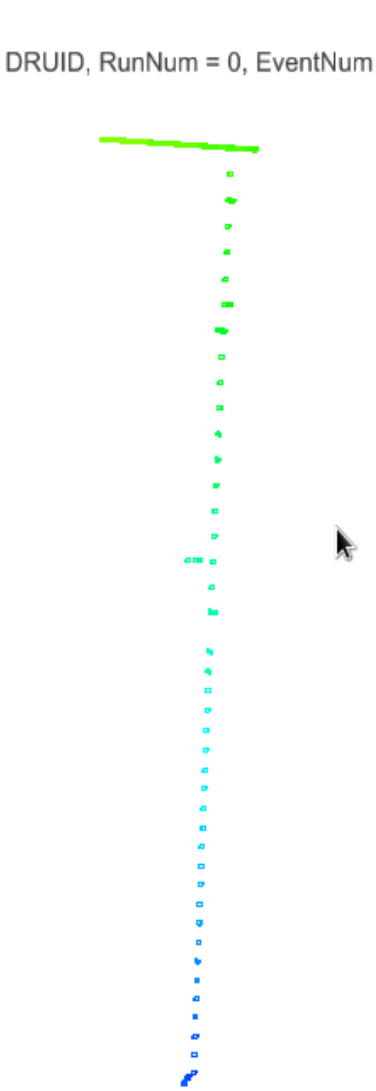


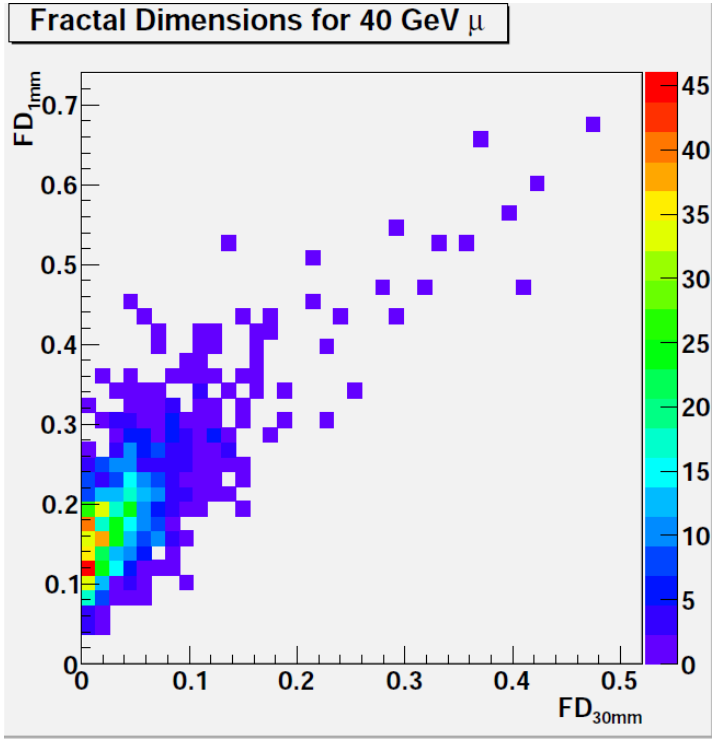


- Pion: MIP, Pion decay;
- EM interaction (π + n = p + $π^0$); partially identified by interaction point tagging

Extreme Cases: Muon

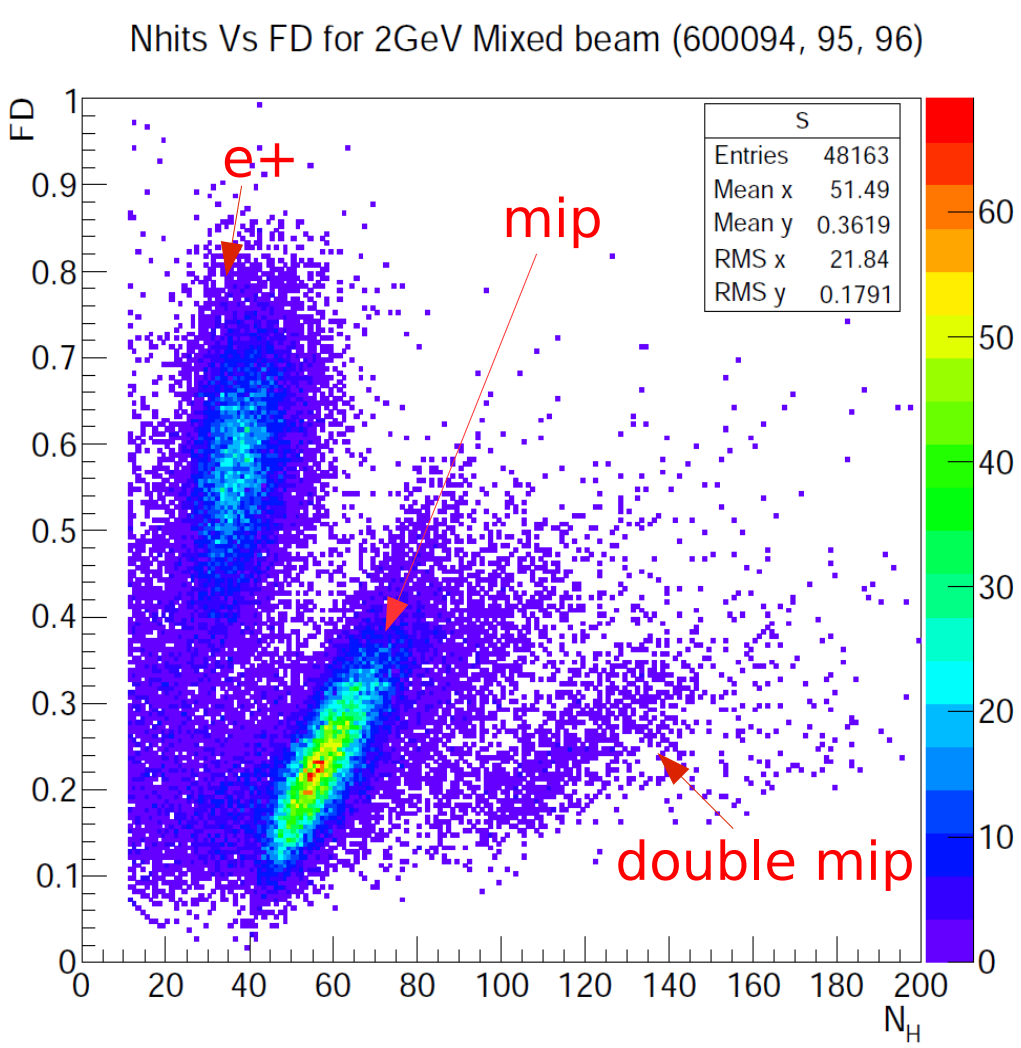


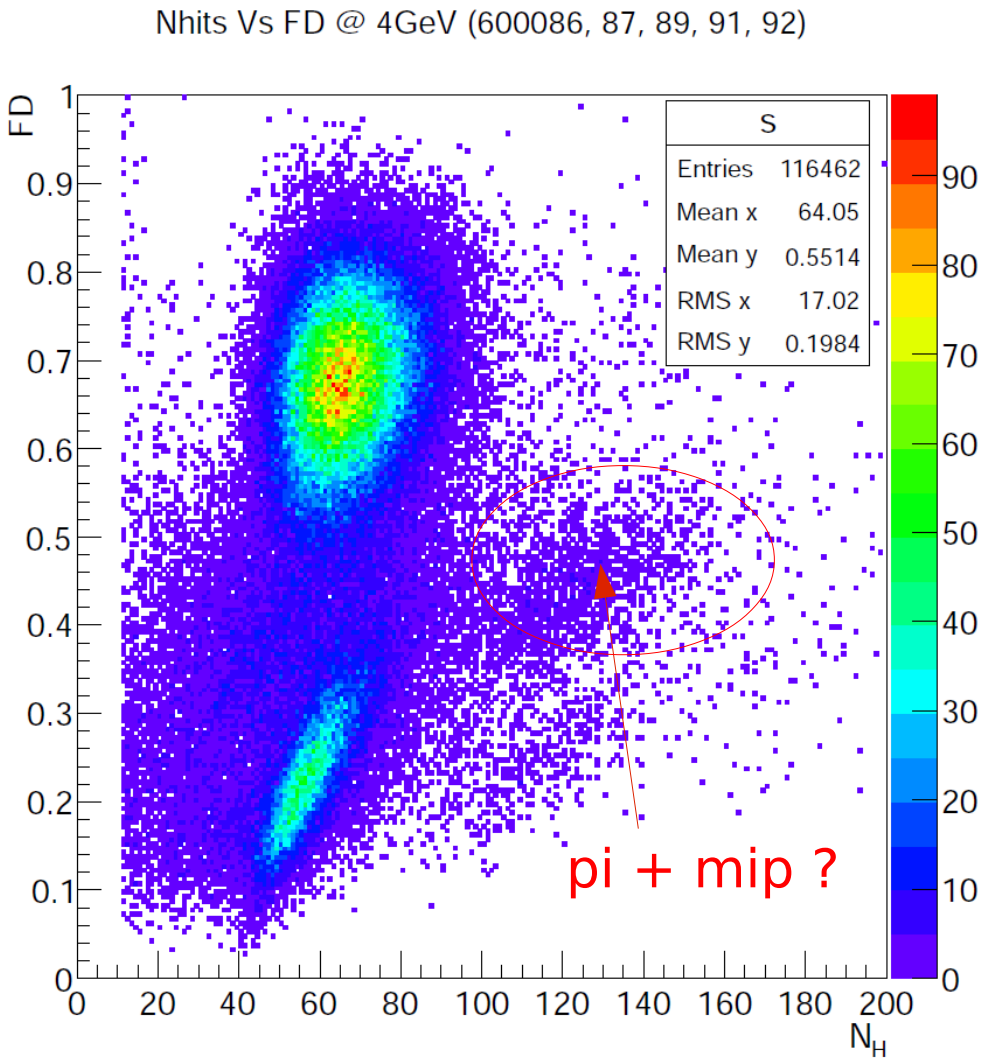




Together with N_{hit} information: to identify Muon radiation & String noise...

Notes: 2, 4GeV



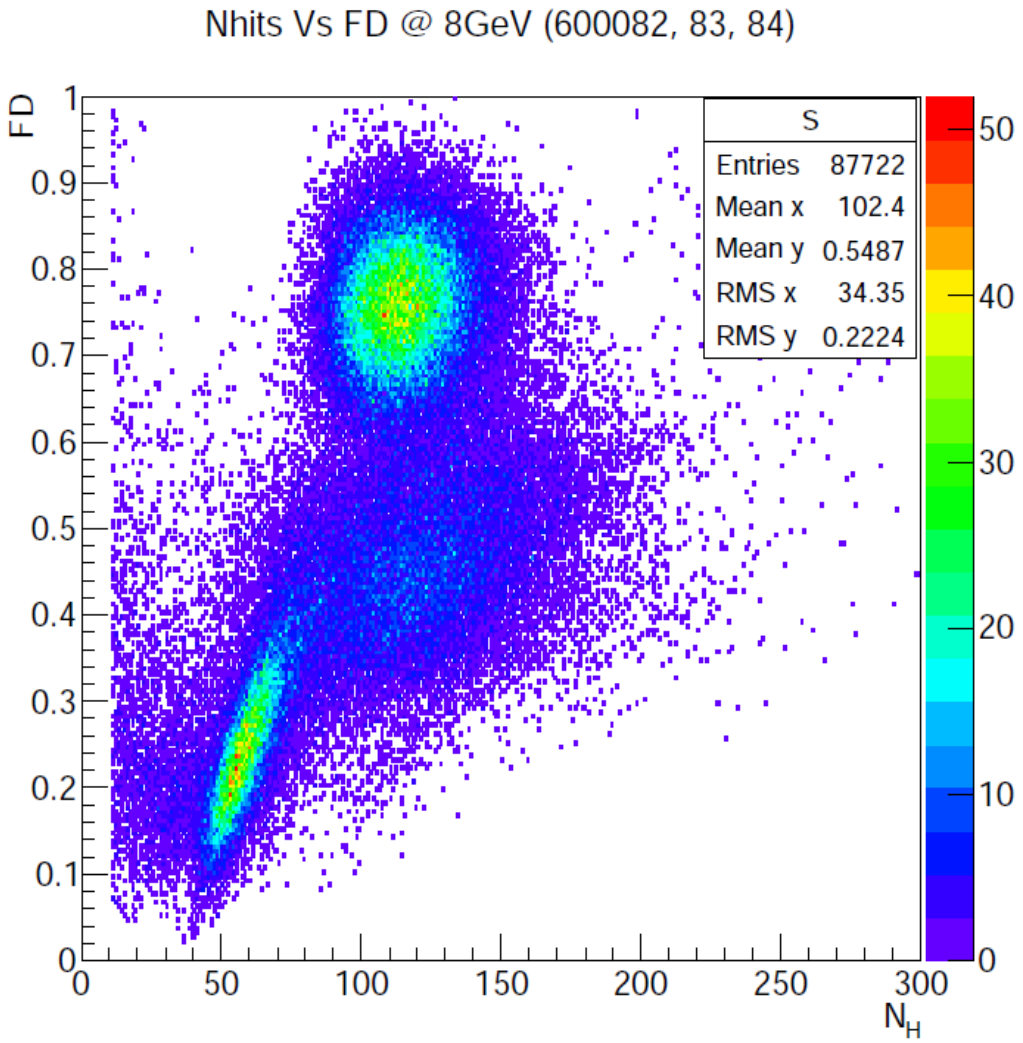


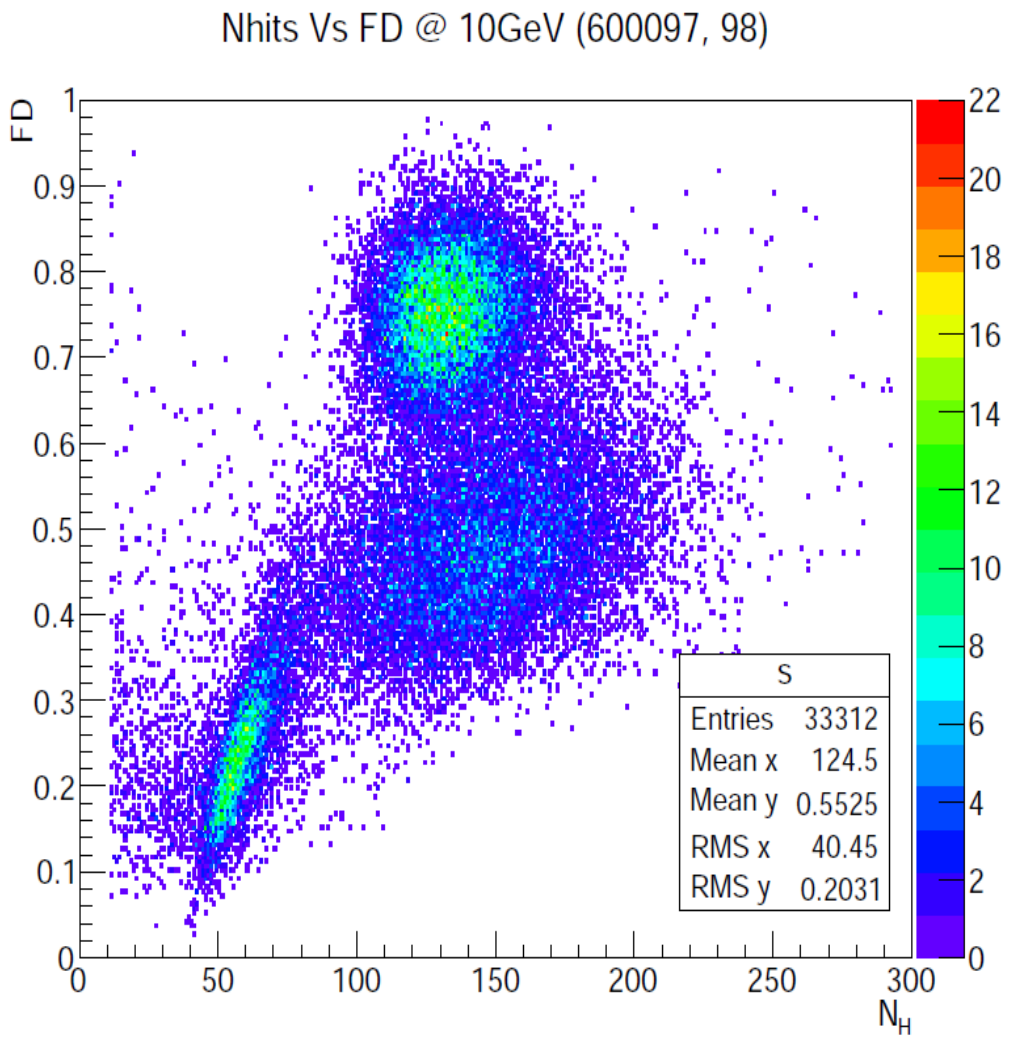
Low Energy Mixed Run:

Significant Positron component

Low contamination of pion & difficult to identify... reliable MC input should help

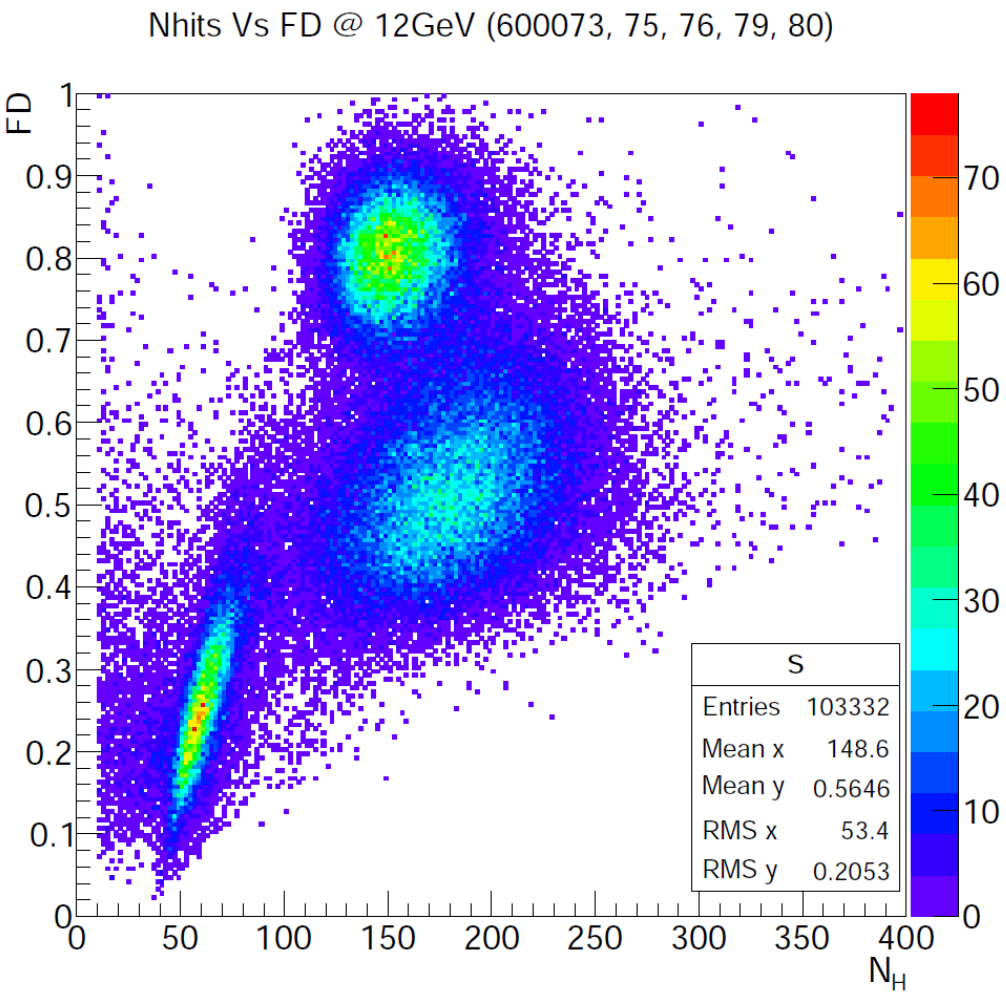
Notes: 8, 10GeV

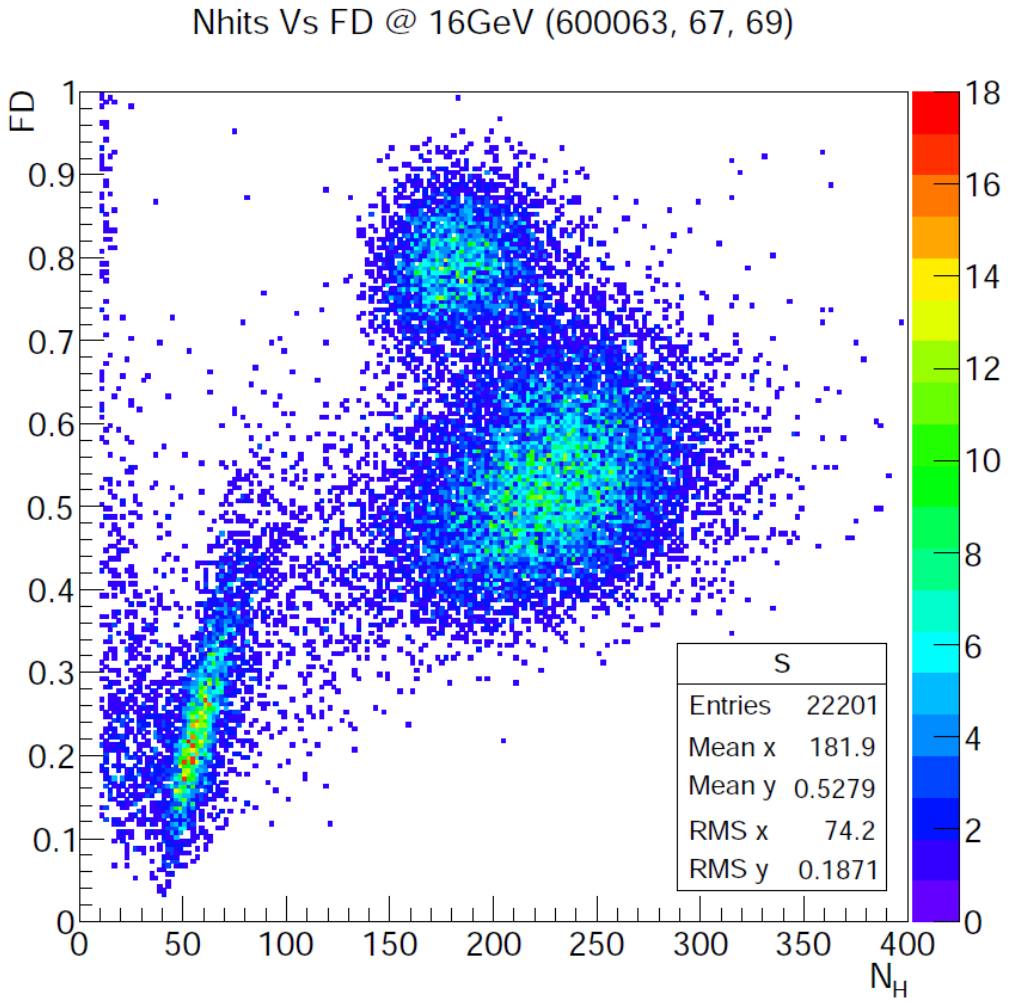




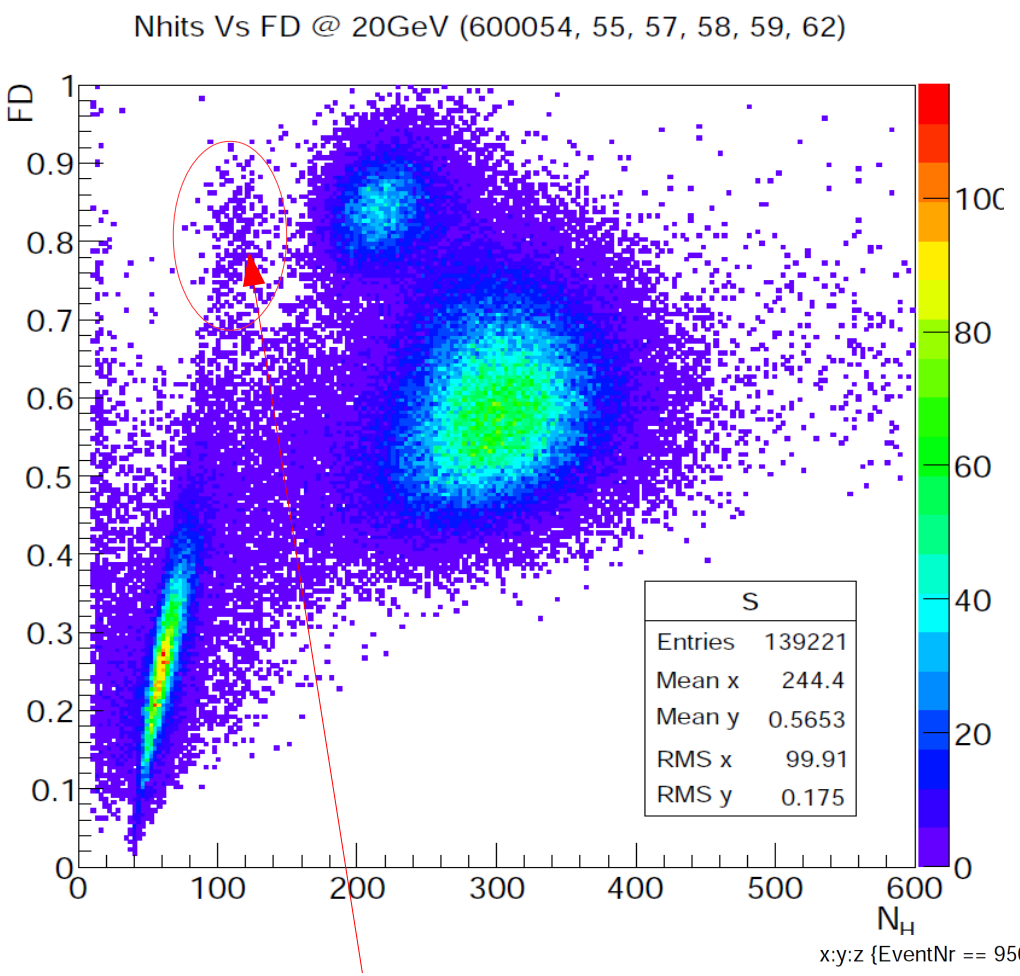
From 8GeV: Start to have good μ-π separation.
Could be improved with more dedicated FD definition

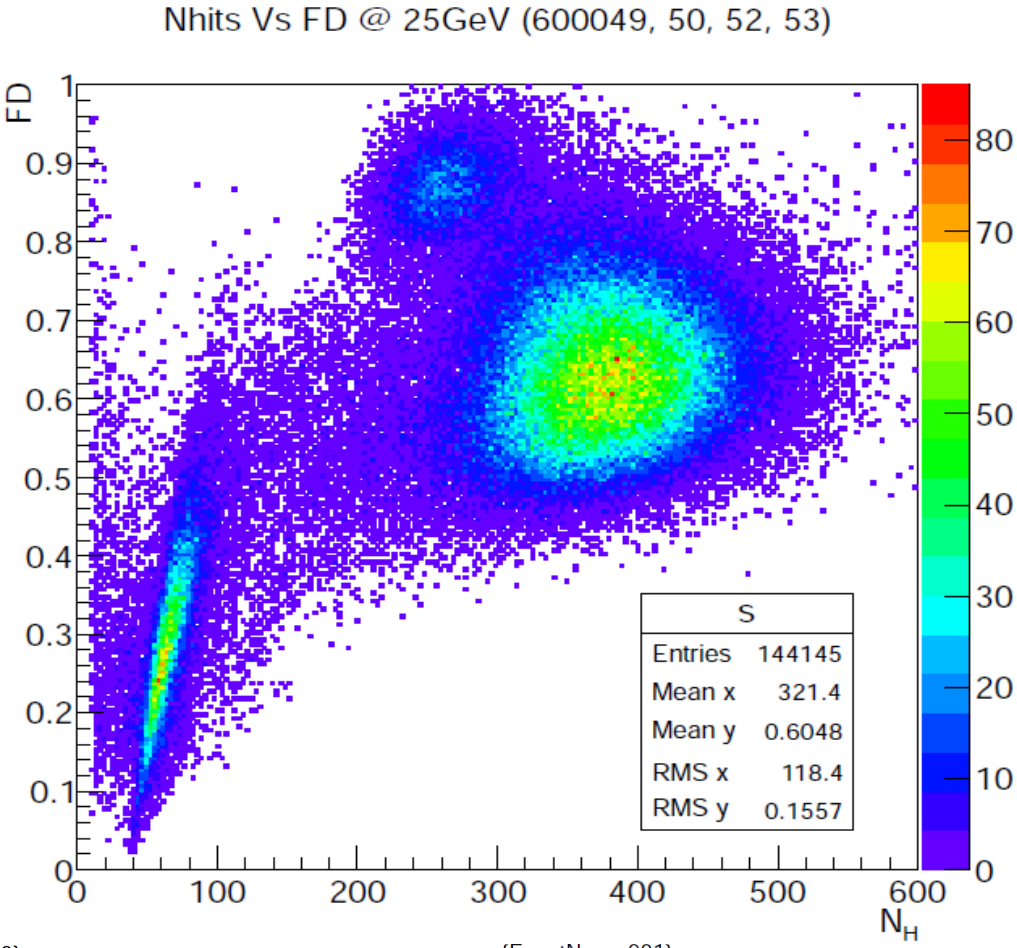
Notes: 12, 16GeV



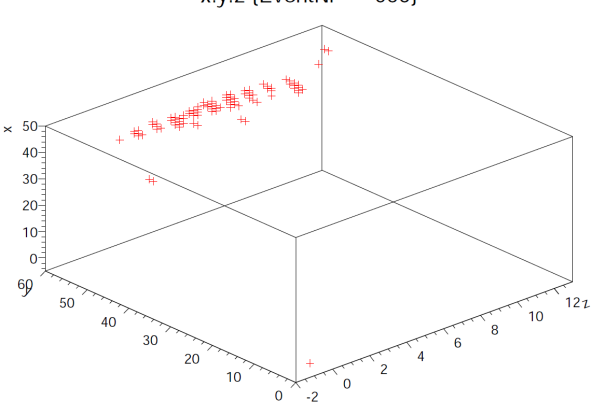


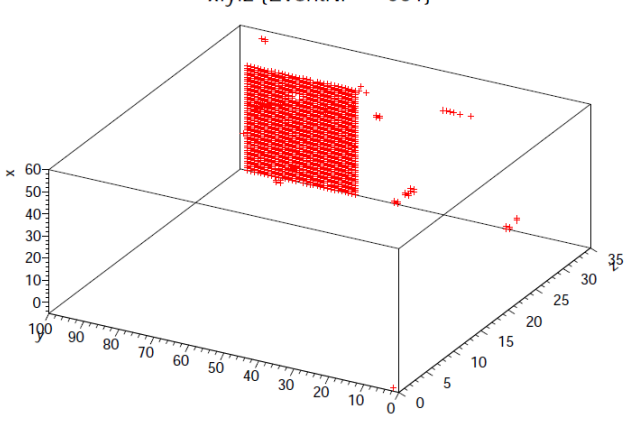
Notes: 20, 25GeV



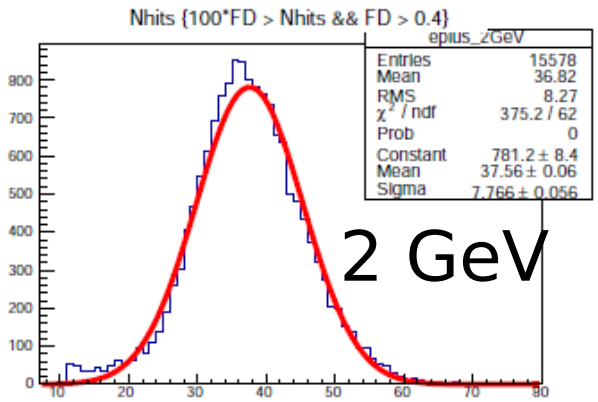


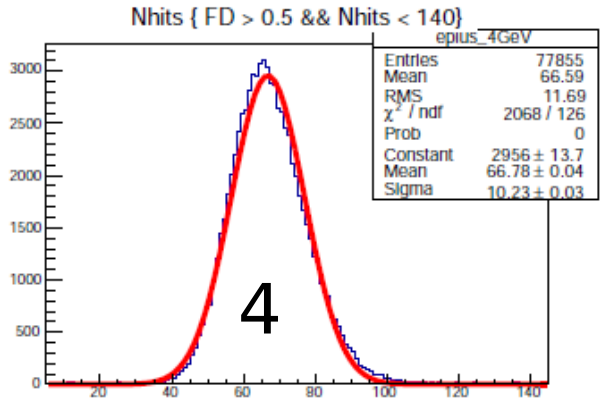
From Run 600057:
Low energy positron?
Mip multiplicity?

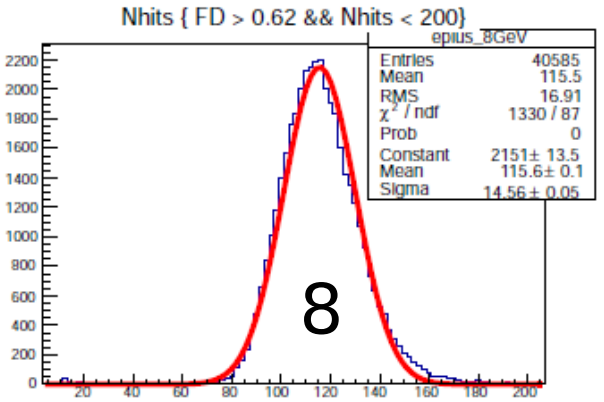


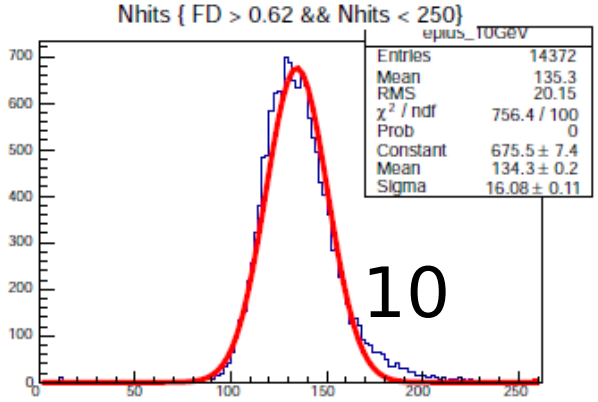


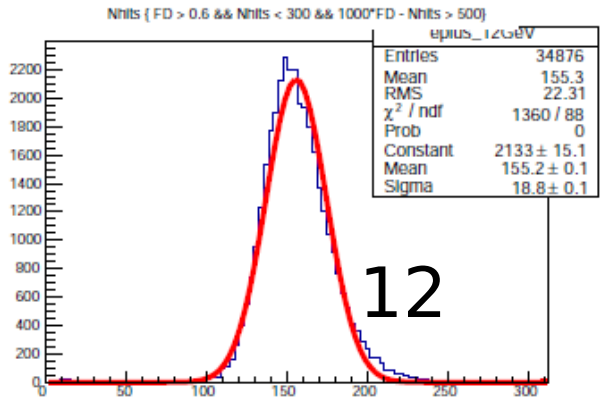
Nhits Response: Positron

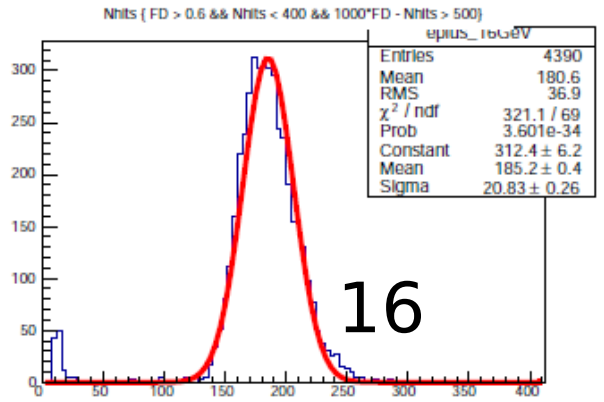


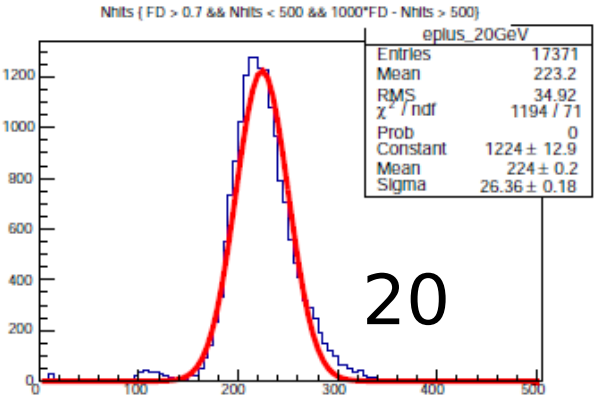


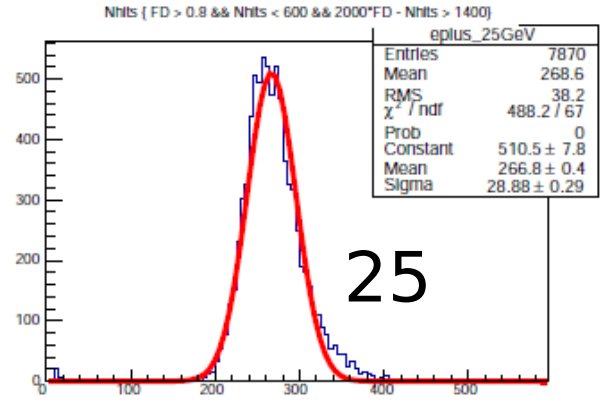


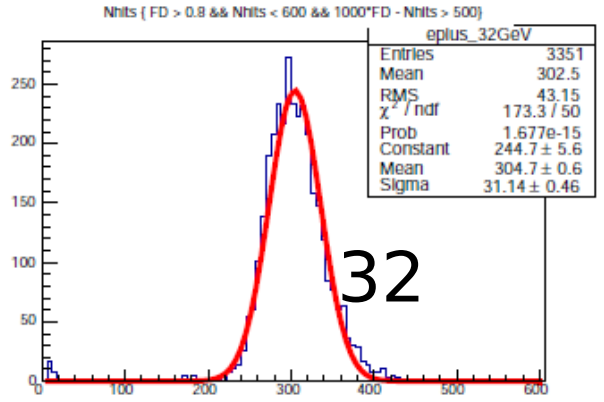












Nhits Response: Pion

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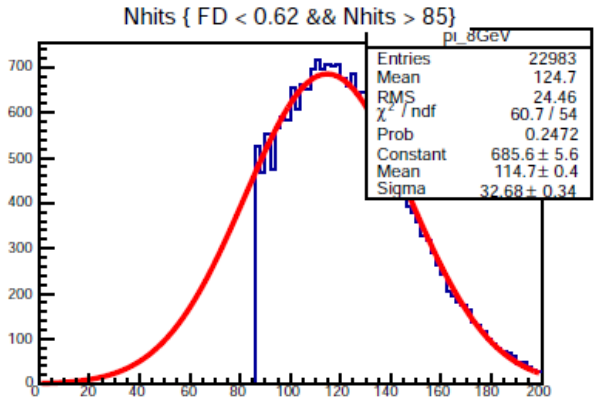
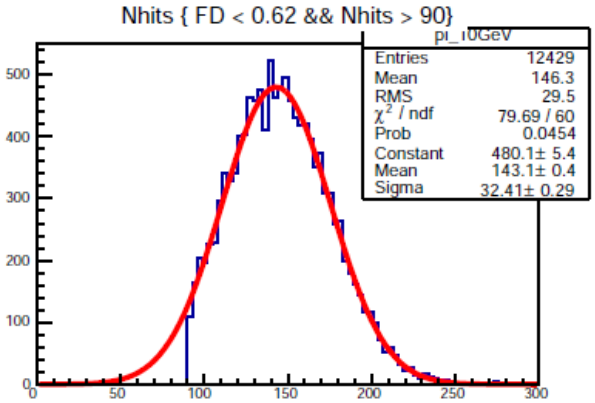
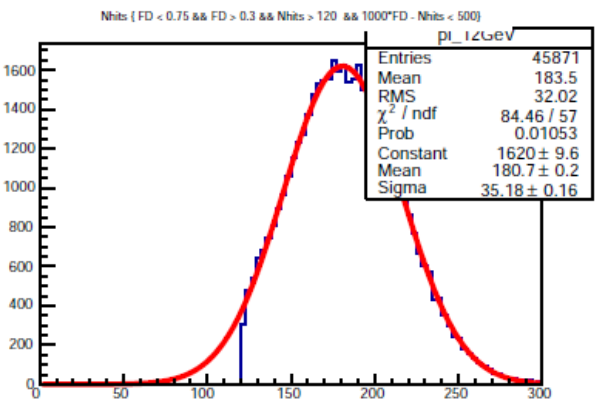
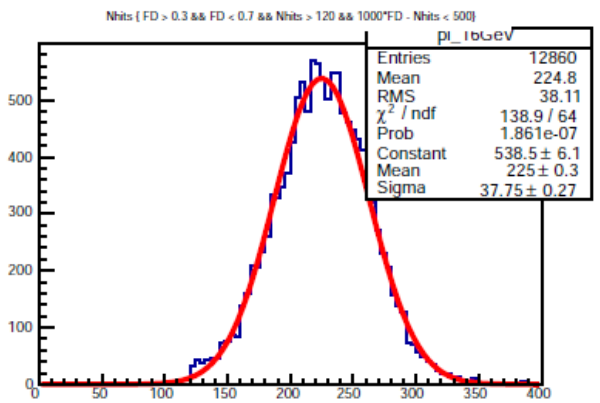
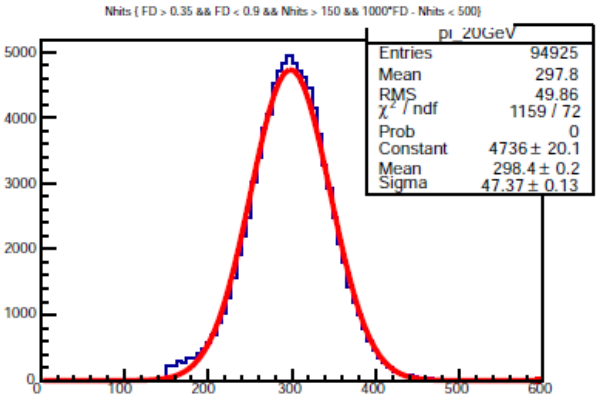
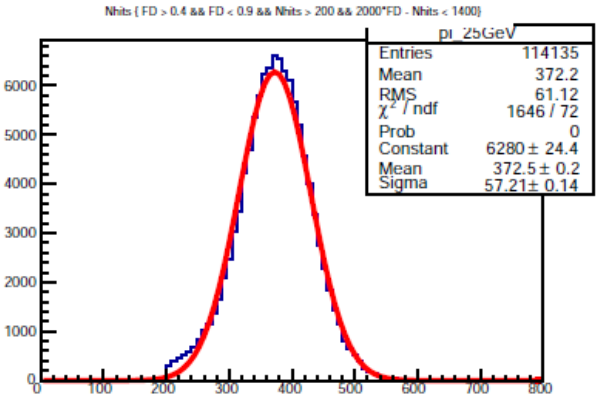


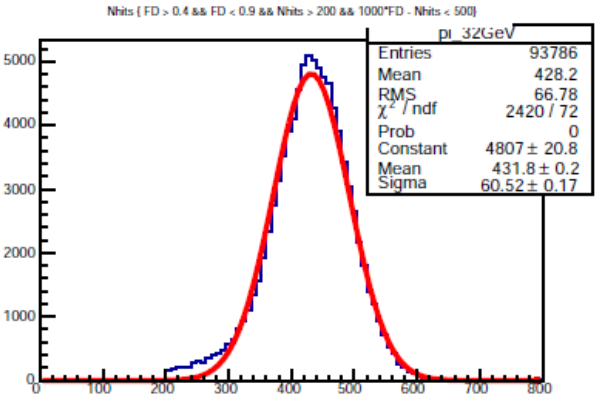




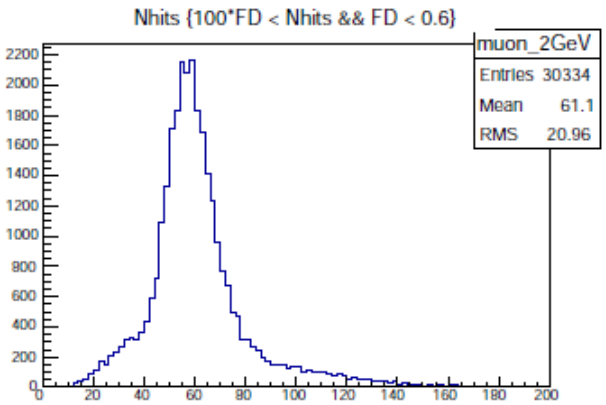


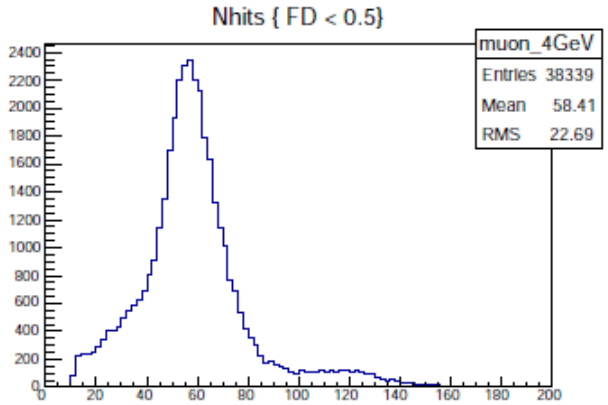


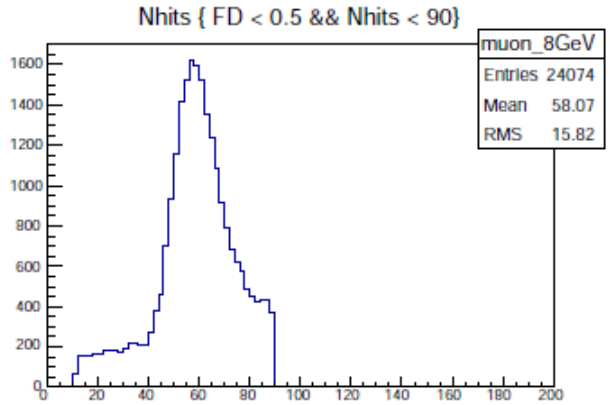


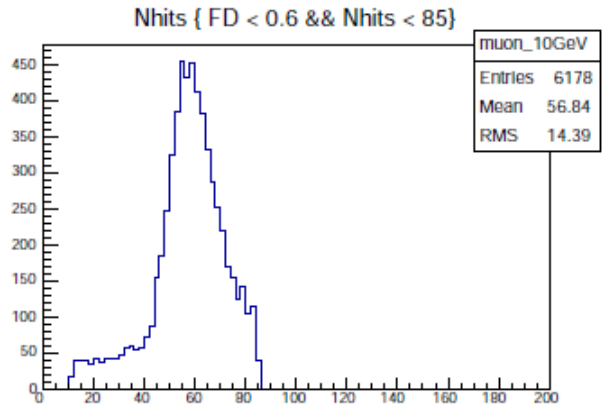


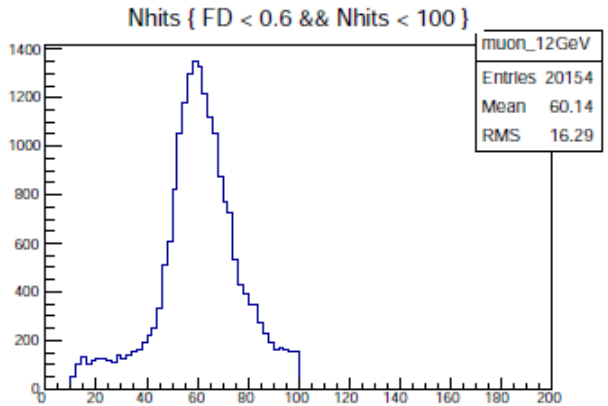
Nhits response: Muon

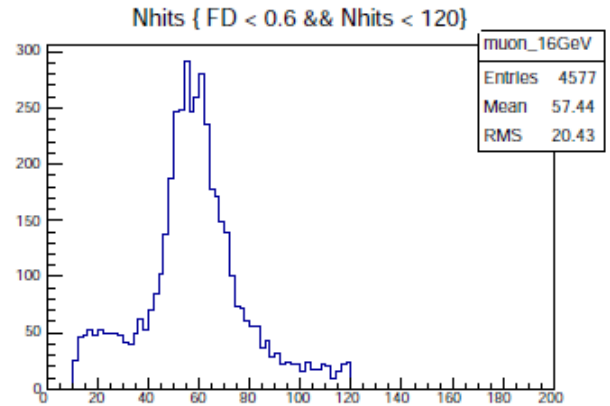


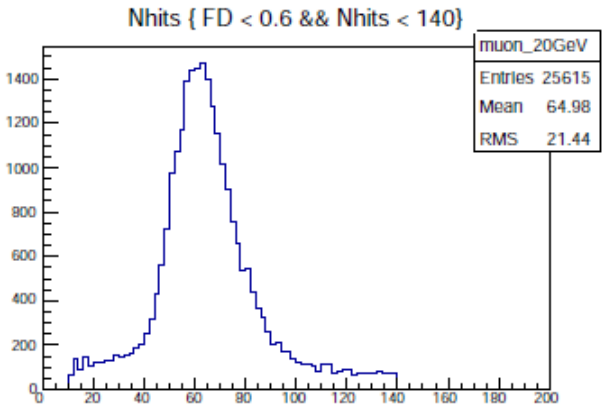


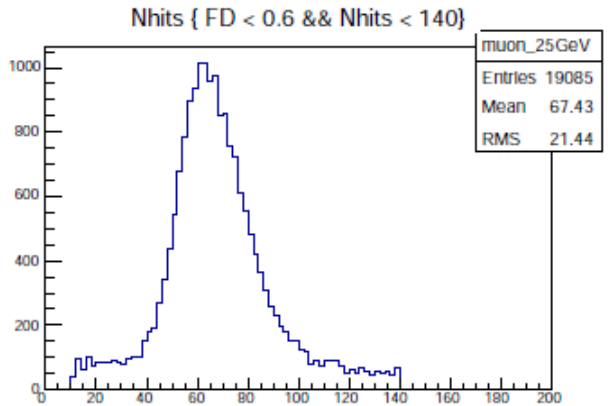


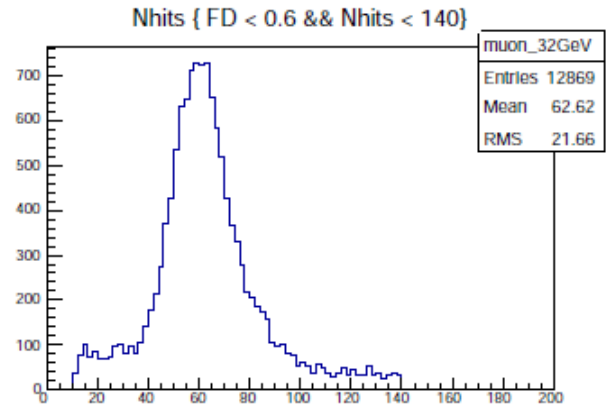




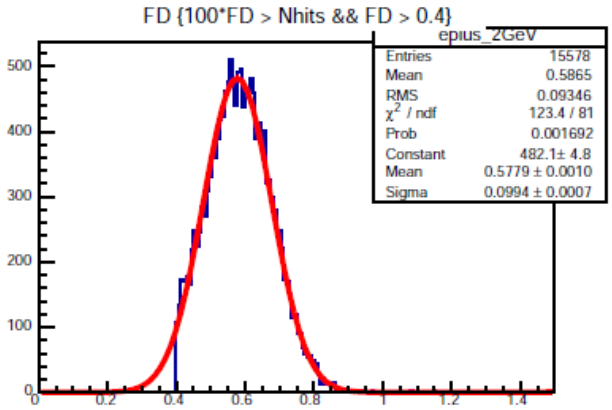


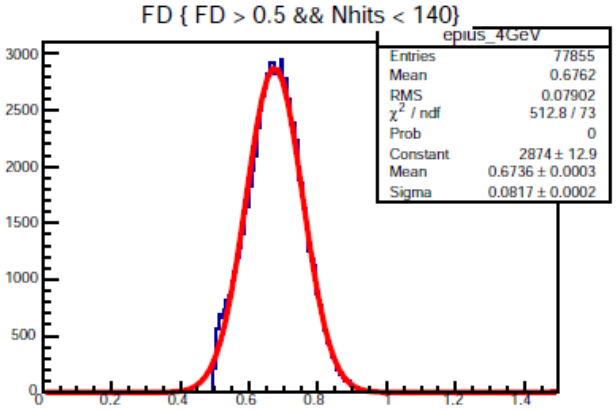


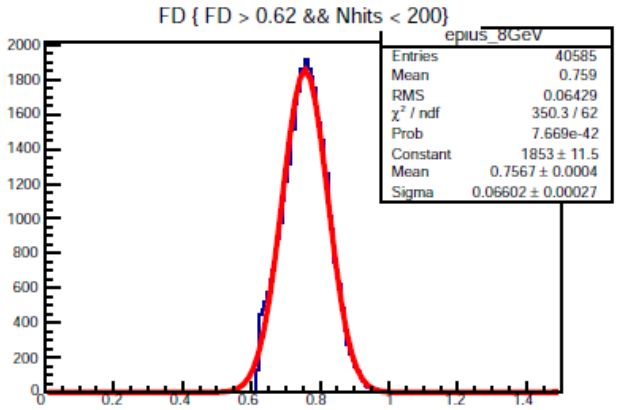


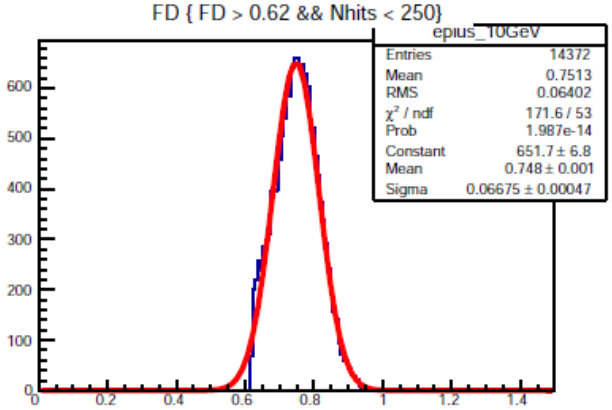


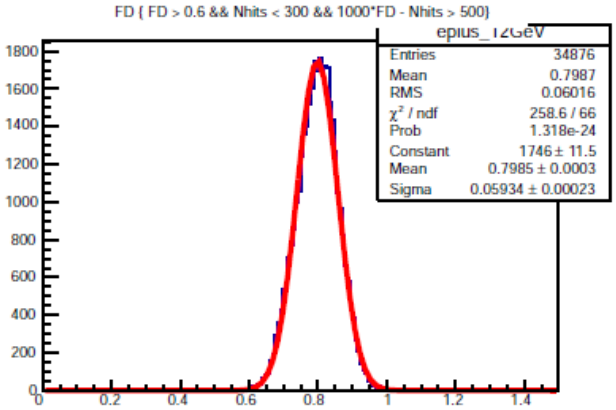
FD Vs Energy: Positron

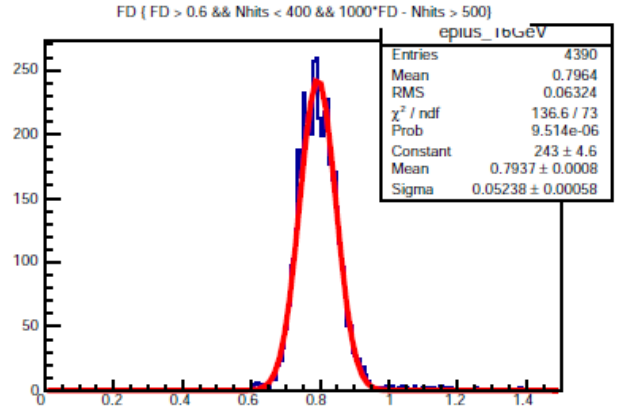


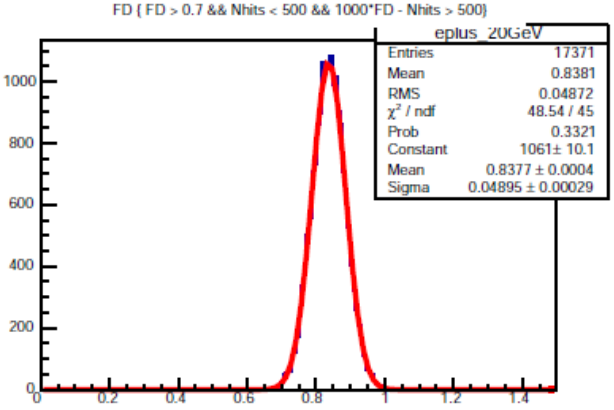


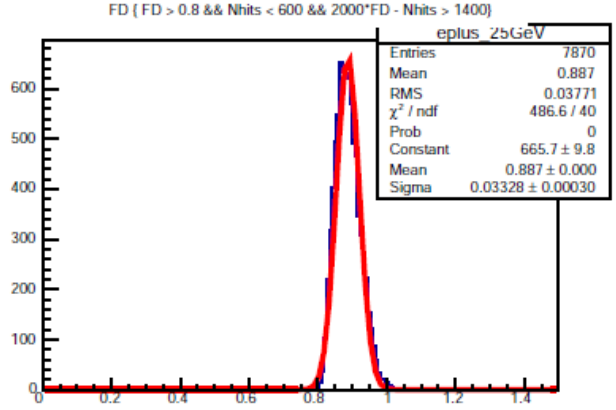


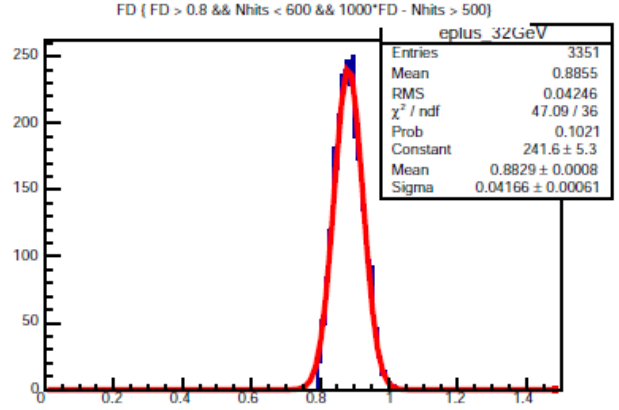












FD Vs Energy: Pion

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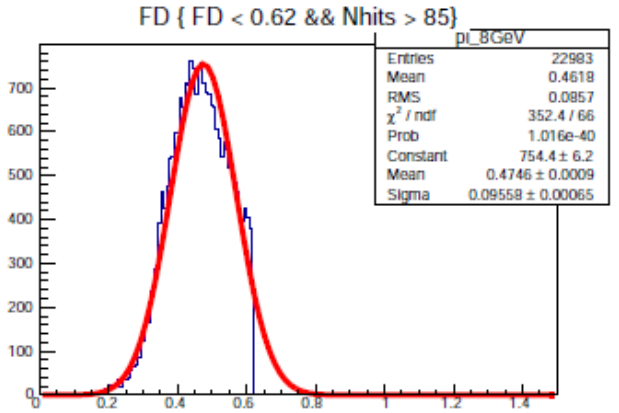
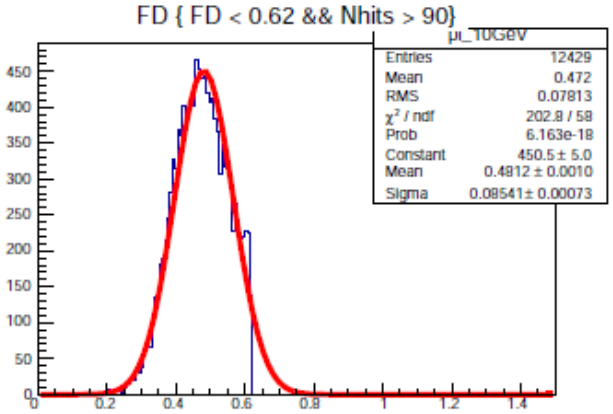
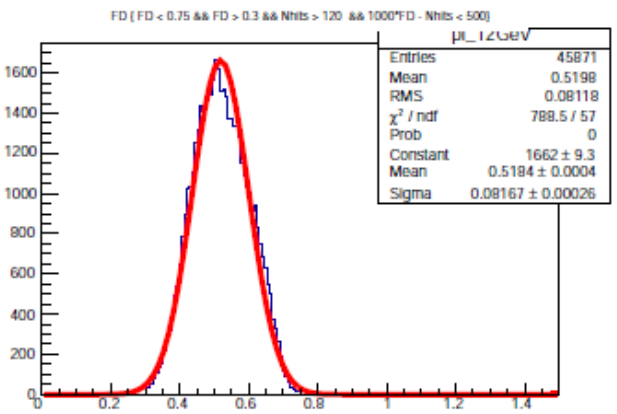
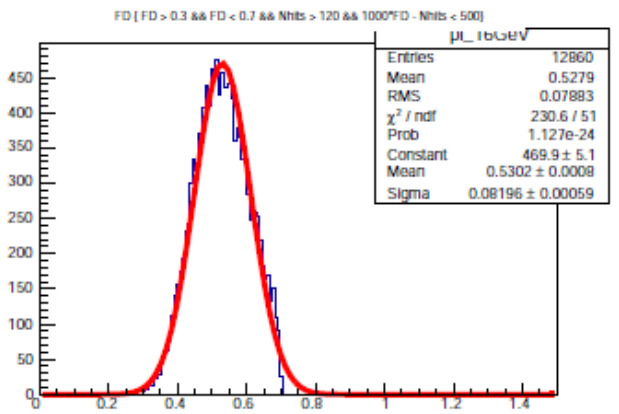
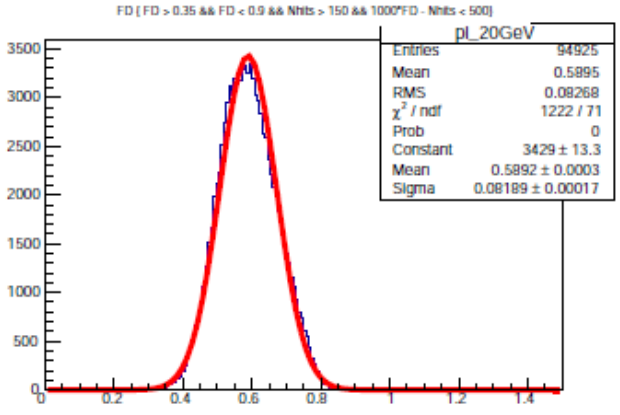
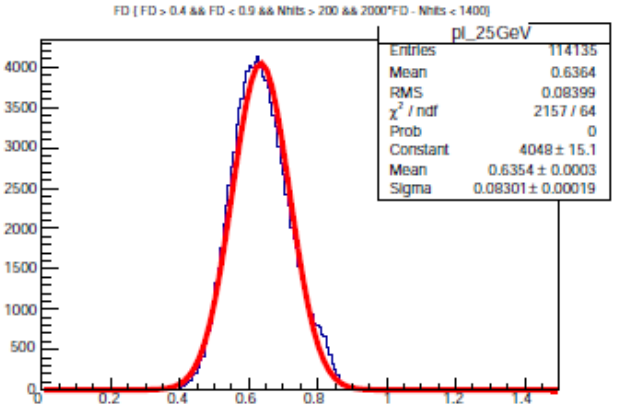


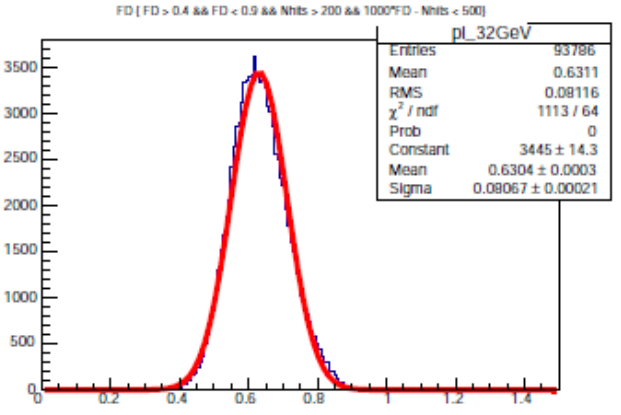




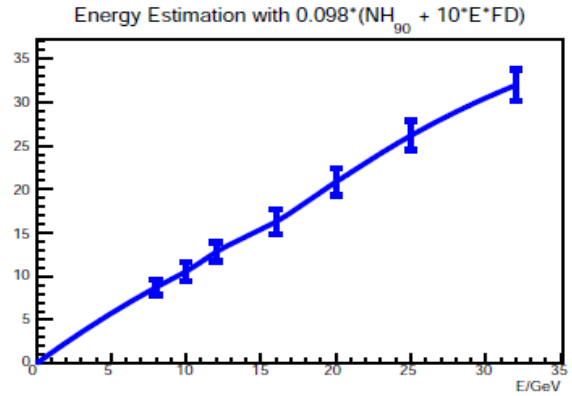


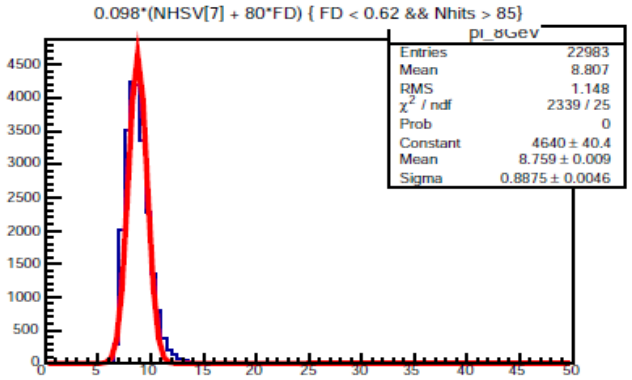


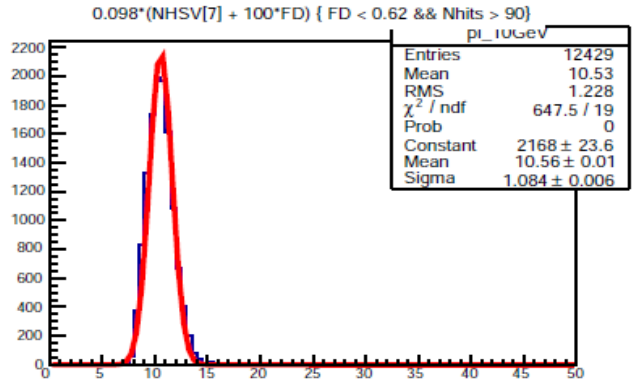


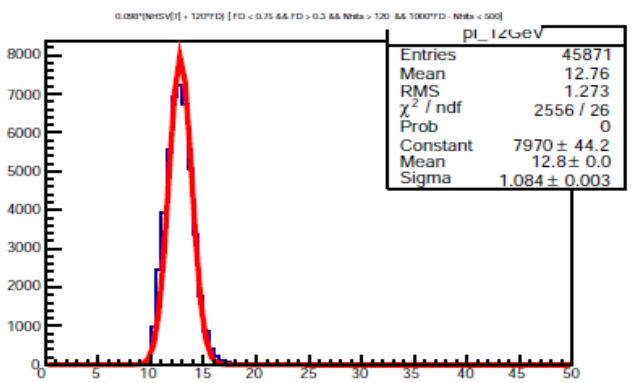


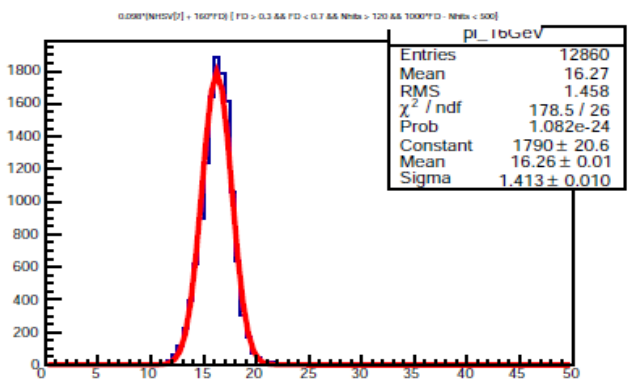
Pion Energy Measurement: with known track energy

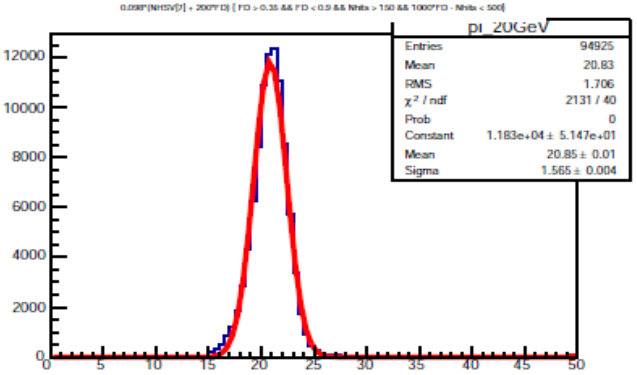


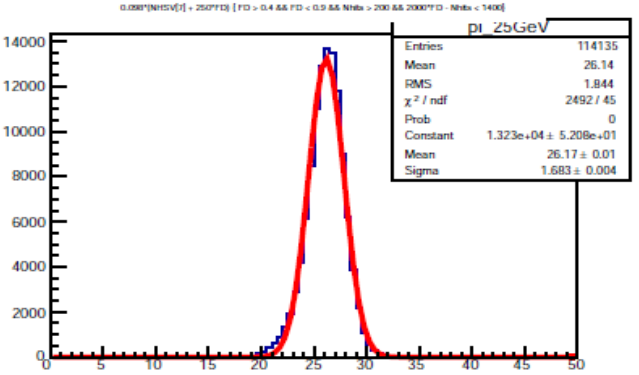


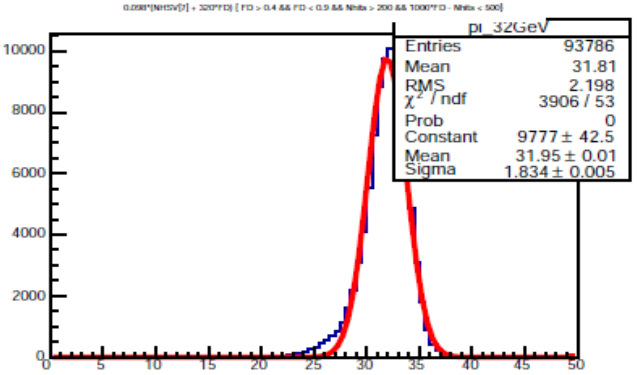
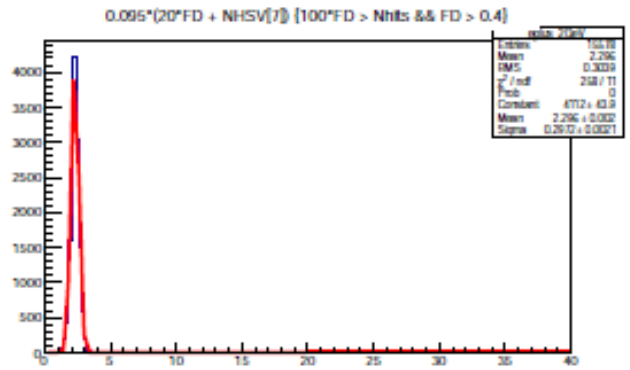
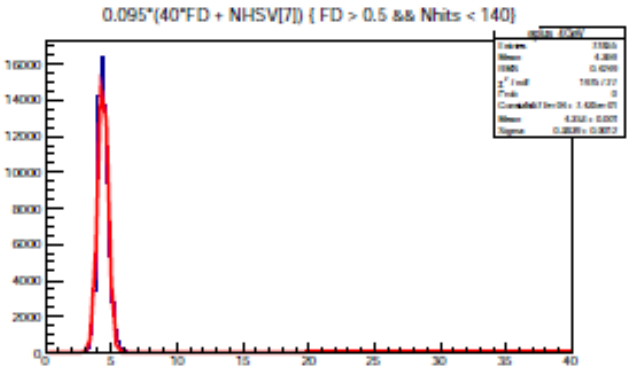
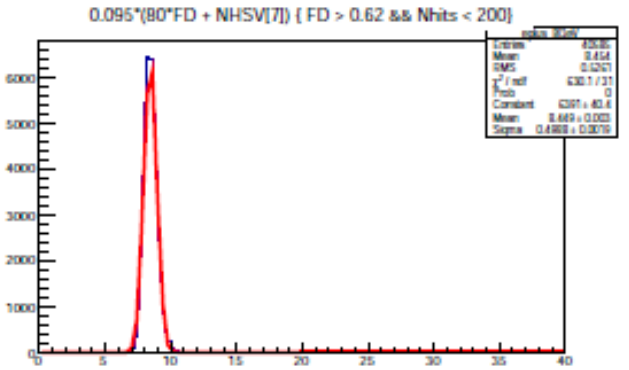
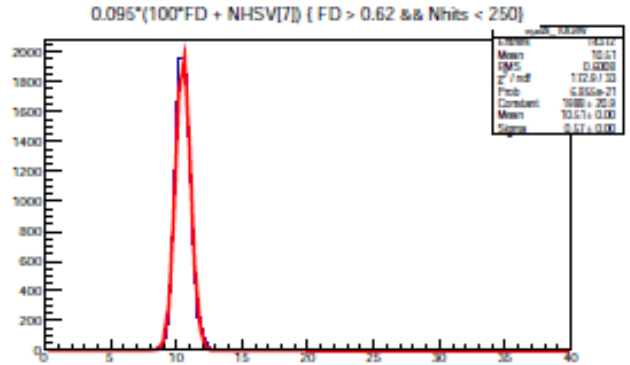
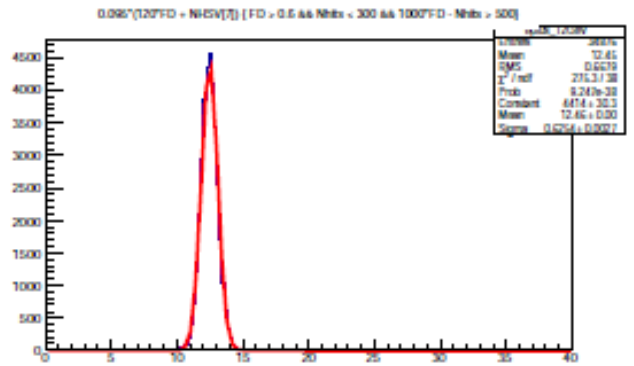
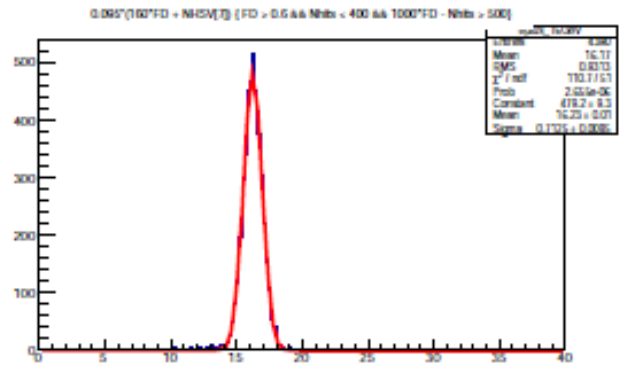
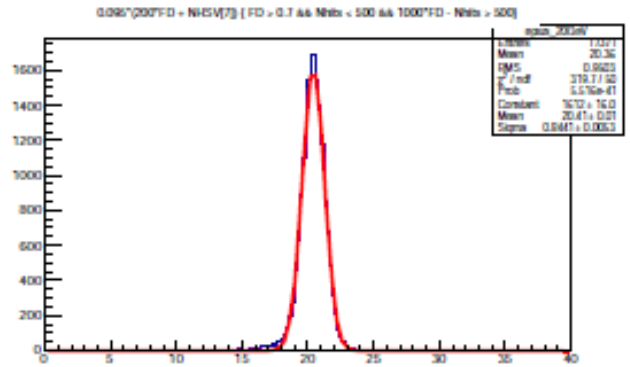
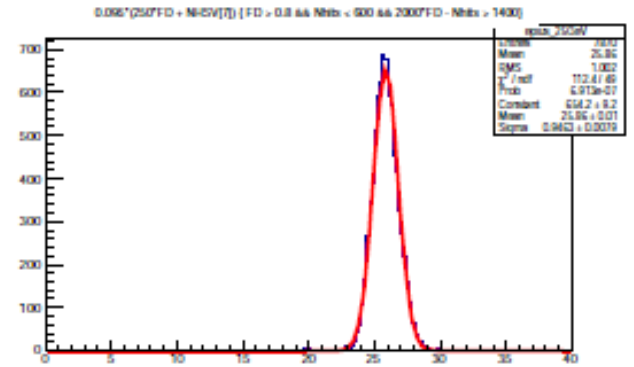
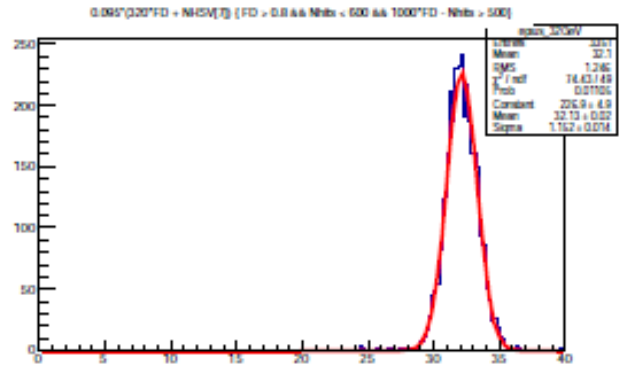












Positron Energy Measurement: with known track energy