DHCAL FNAL
Data Analysis and Calibration

Burak Bilki

University of Iowa
Argonne National Laboratory

Calibration of the DHCAL using Muons and Track Segments in Hadron Showers

0. Hits → Clusters

Only the hits in two time bins are considered (possibly different for CERN runs).

Hits belong to the same cluster if they share a common edge.

Cluster x and y are the averages of its constituent hits.

1. Event selections/Additional Requirements:

Require at least 5 active layers.

Measure DHCAL, TCMT1 and TCMT2 separately

Use the run conditions to decide whether the layer is measurable or not (i.e. exclude dead areas)

Do not measure pads within 1 cm to RPC boundaries and dead cells.

Track Fit:

* Group clusters that are within 3 cm in x-y in different layers

* Require at least one cluster in the first three and last three layers of the corresponding section (DHCAL/TCMT1/TCMT2)

* No two consecutive layers can have clusters with more than 4 hits (interaction)

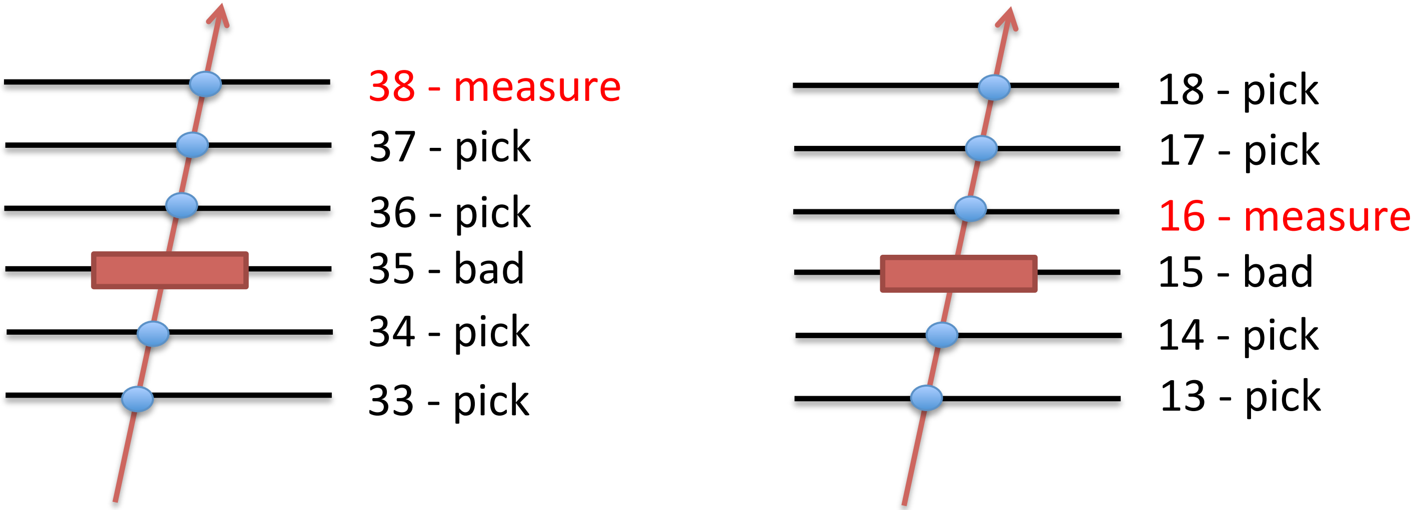
* Fit the track (3D parametric line: $z=t$; $x=x_0+a_xt$; $y=y_0+a_yt$)

* Require $\Delta r/\Delta z<0.5$ (ε and μ change with the track angle)

* Measure all layers by searching for clusters within 2 cm to the track

Track Segments:

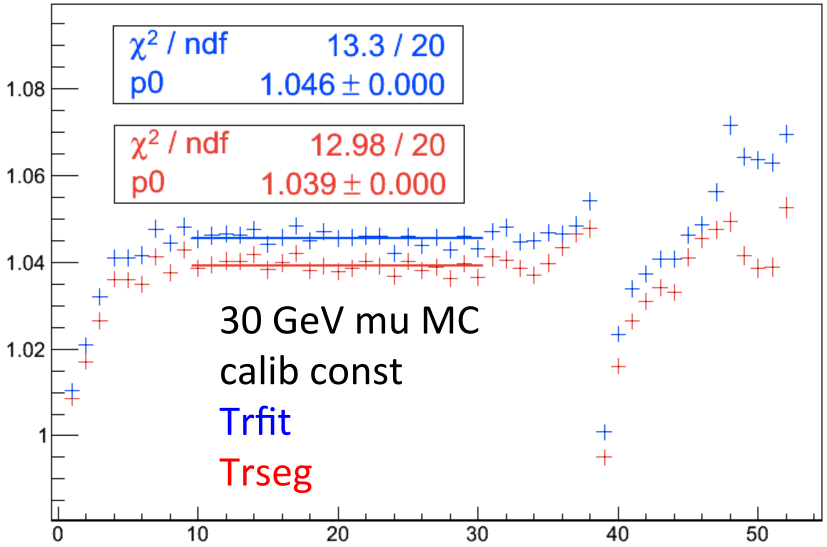
- Find four clusters with size at most 4 hits and are aligned within 3 cm
- No other clusters within 4 cm in the same layer.
- Require $\Delta r/\Delta z<0.5$ for the track segment
- Allow only one measurable layer both for interpolation and extrapolation
- Measure it by searching for clusters within 2 cm to the track segment

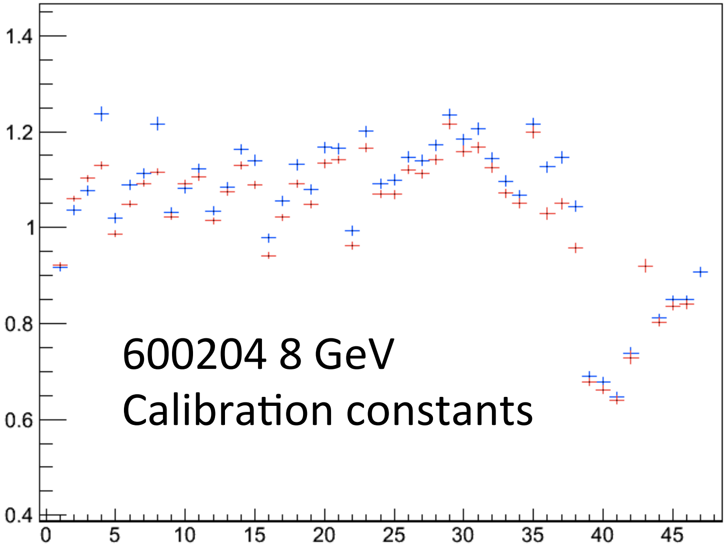


38 - measure
37 - pick
36 - pick
35 - bad
34 - pick
33 - pick

18 - pick
17 - pick
16 - measure
15 - bad
14 - pick
13 - pick

Calibration Constants: $\varepsilon\mu/\varepsilon_0\mu_0$

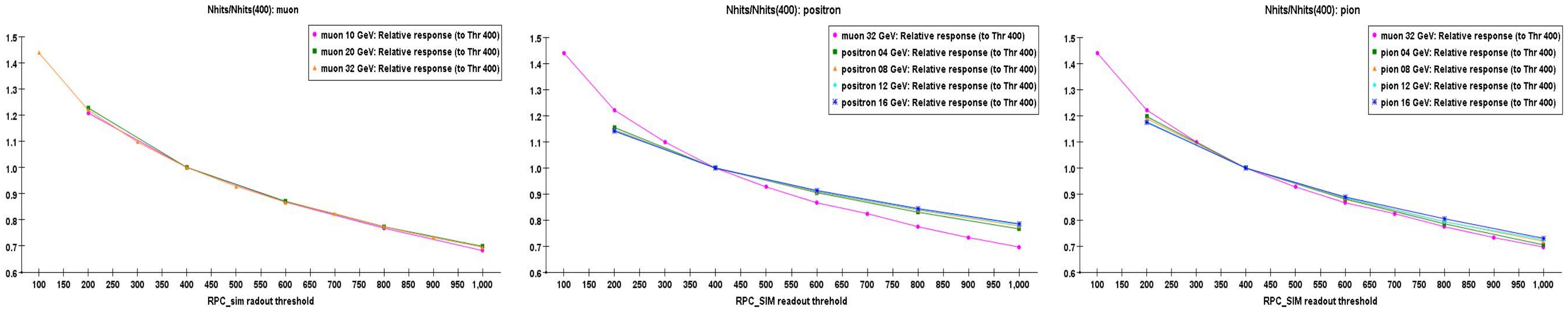




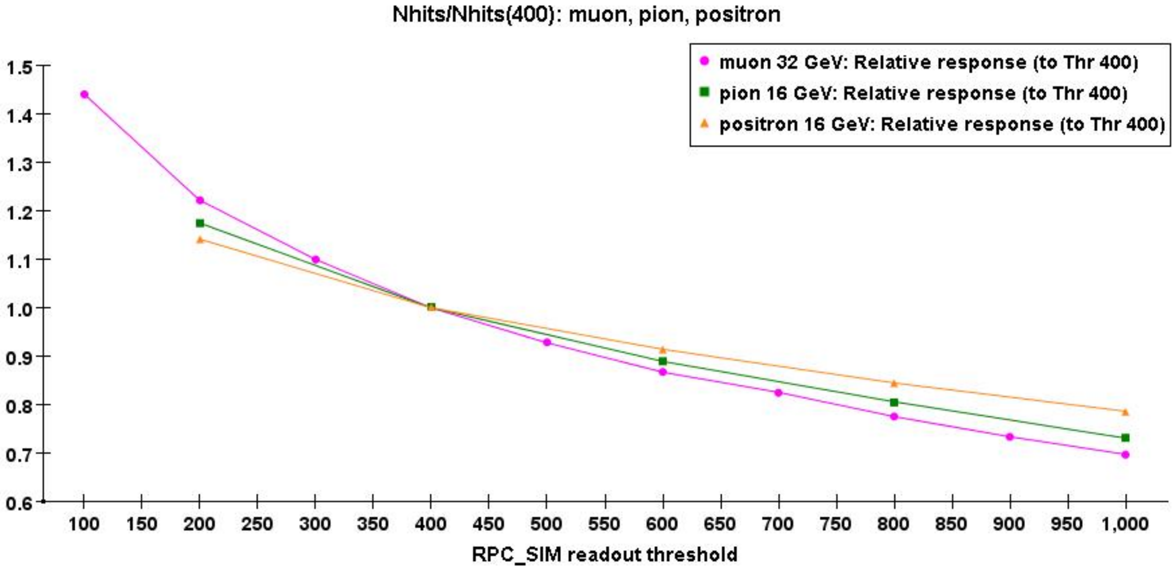
- DHCAL calibration was thought to be simple and painless
  - Control parameters: RPC efficiency (ε), multiplicity (μ)
  - DHCAL response, to first order, should scale with 'calibration factor' = $\varepsilon\mu/\varepsilon_0\mu_0$
  - Indeed, this calibration scheme works to first order, more or less

- To go further, things become complicated
  - Due to the fact that some pads were hit by more than one particle, these hits scale differently from the others
  - Number of particles hitting a pad can be approximated by local hit density, which changes with energy and type of showering particle
  - As a result, calibration may have hit density, energy, particle type dependences
  - Simulation samples were generated at different signal charge thresholds, in order to study the calibration scheme

Density Weighted Calibration Overview



Average number of hits as a function of readout threshold: scaling is energy dependent
(muon, pion and positron at several energies, all normalized to the number of hits at threshold = 400)



Scaling of number of hits as a function of readout threshold: particle type dependence
(muon, positron, pion: all response are scaled to their own response at threshold of 400)

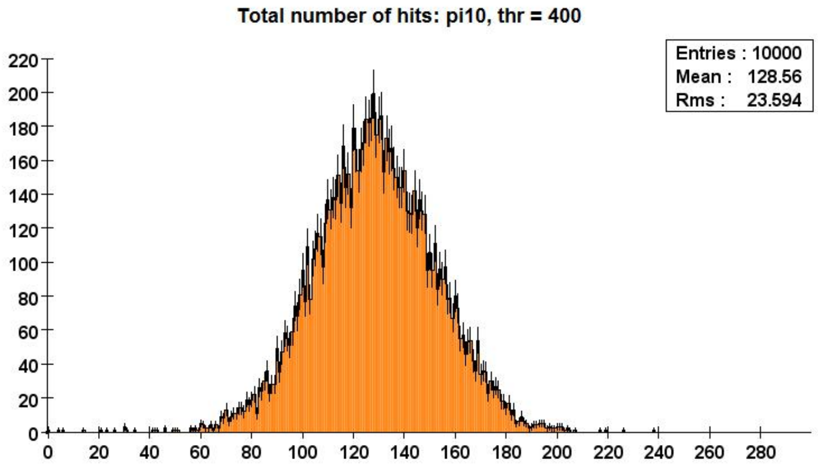
Density Weighted Calibration Test Samples

- Positron samples at 2, 4, 10, 16, 20, 25, 40, 80 GeV
- Pion samples at 2, 4, 8, 9.9, 19.9, 25, 39.9, 79.9 GeV
- All samples are simulated with threshold of 0.200, 0.400, 0.600, 0.800, 1.000

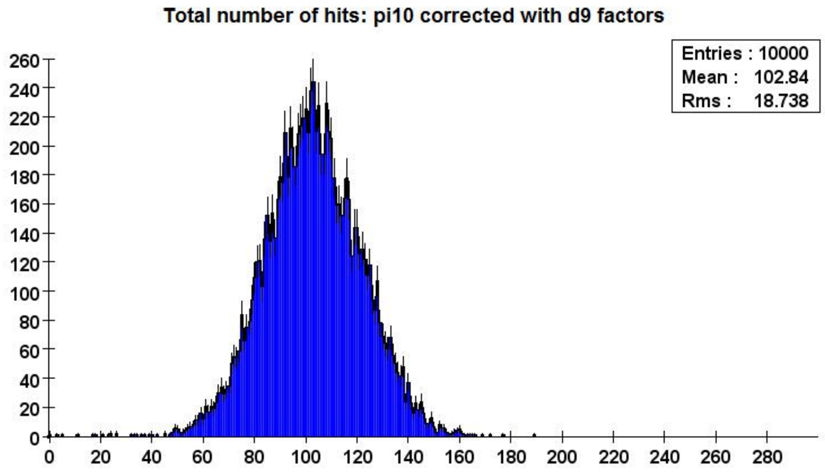
- Use one sample as ‘data’: thr1, e1, m1
- Use another sample as ‘target’: thr2, e2, m2
- Study possible correction based on hit density that can take 1 → 2
- The final correction should not use any information from sample 2, other than e2, m2

Example: 10 GeV pion, thr 400 (1) → thr 800 (2)

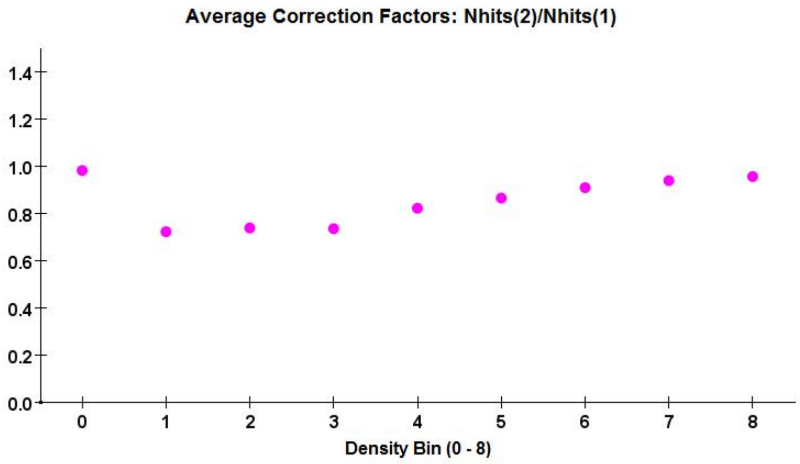
- Use the average correction factor as the weight for hits in each density bin → hope to recover thr2 response from thr1 data



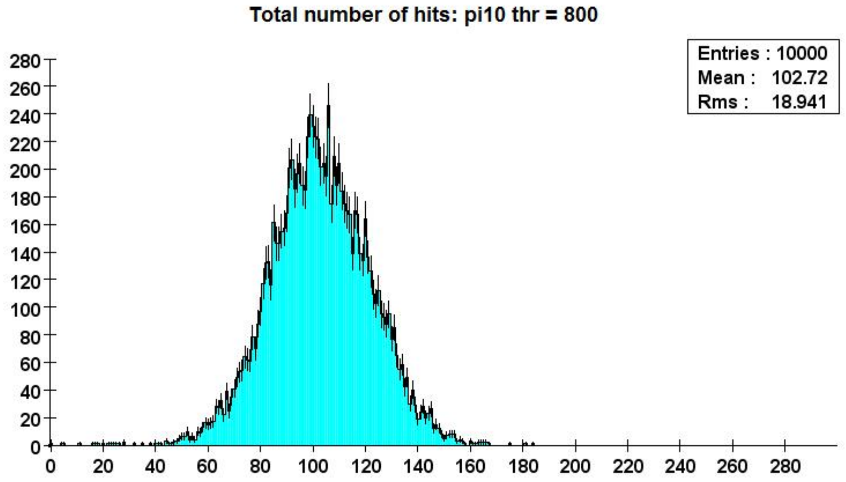
Total number of hits: pi10, thr = 400



Total number of hits: pi10 corrected with d9 factors



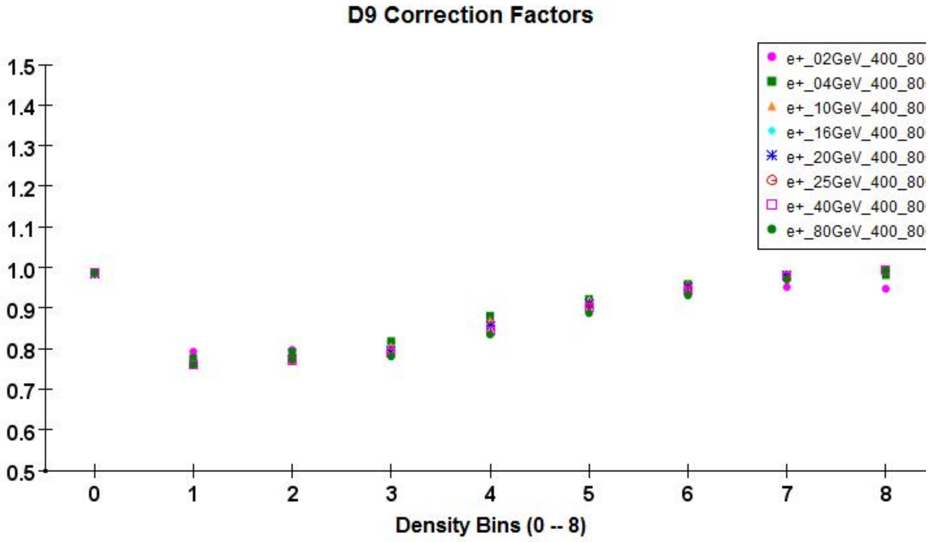
Average Correction Factors: Nhits(2)/Nhits(1)



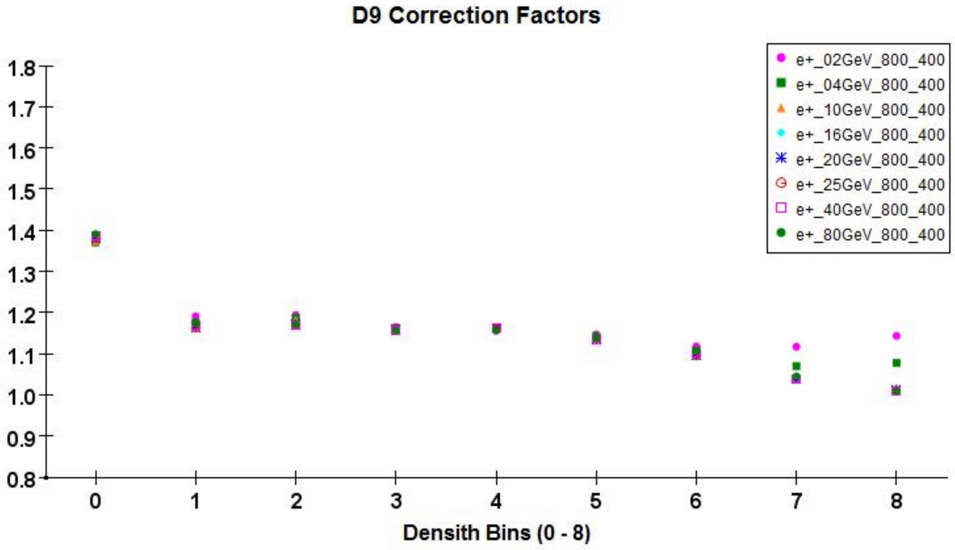
Total number of hits: pi10 thr = 800

Average response is precisely reproduced, energy resolution preserved

e+: 400 → 800 and e+: 800 → 400



D9 Correction Factors

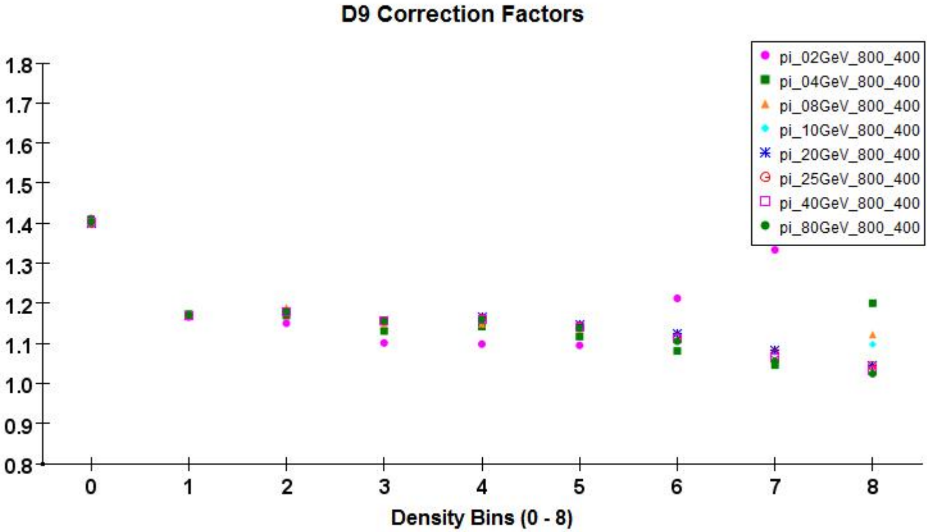


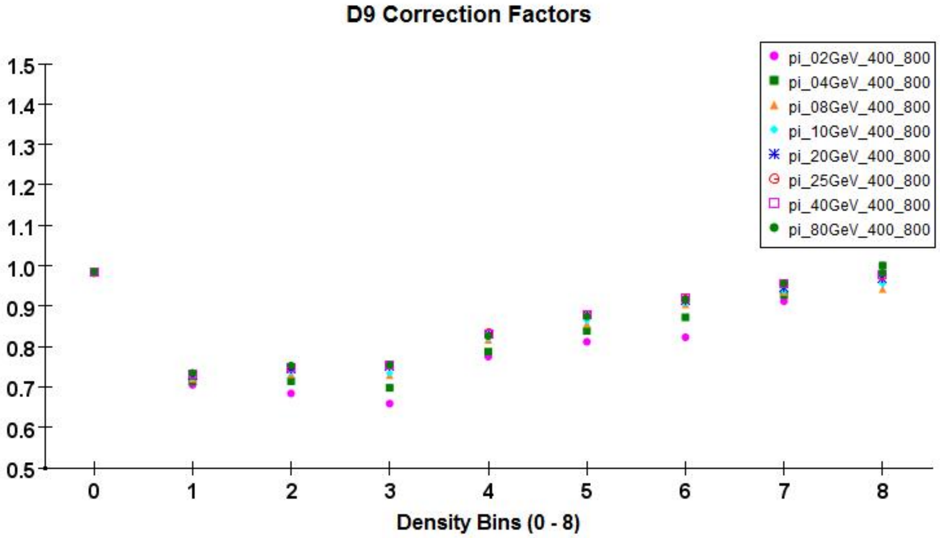
D9 Correction Factors

The bin by bin correction factor don’t seem to have energy dependency.
(or, the dependency is very week)

Note: the scattered points are all at low energy and high density bins,
where there’s not enough statistics

pi: 400 → 800 and pi: 800 → 400





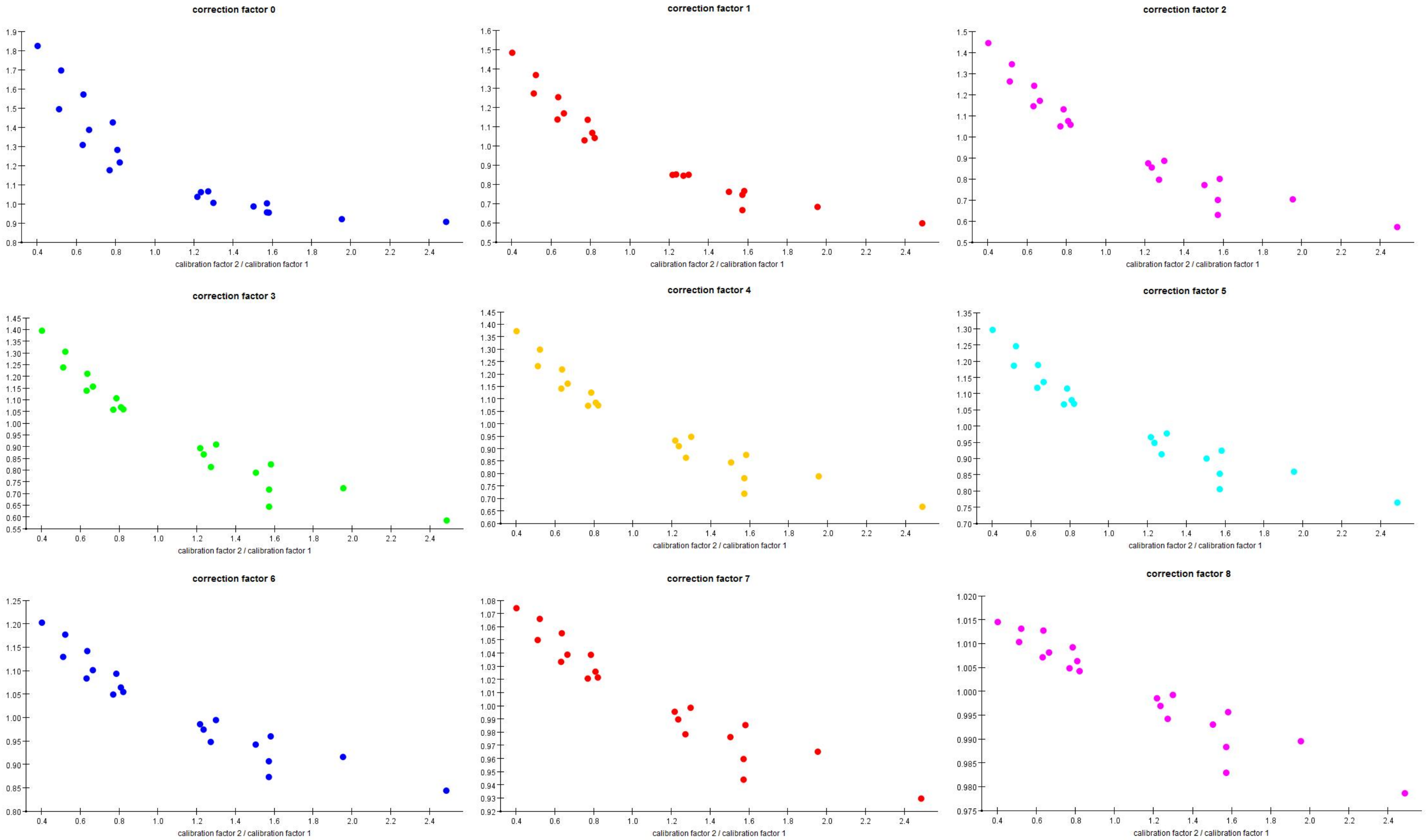
Similar conclusion for pion: very week energy dependency
And scattered points are at low energies

This is great news! → now at least we can expect one calibration procedure at all energies

Next step: efficiency and multiplicity dependencies

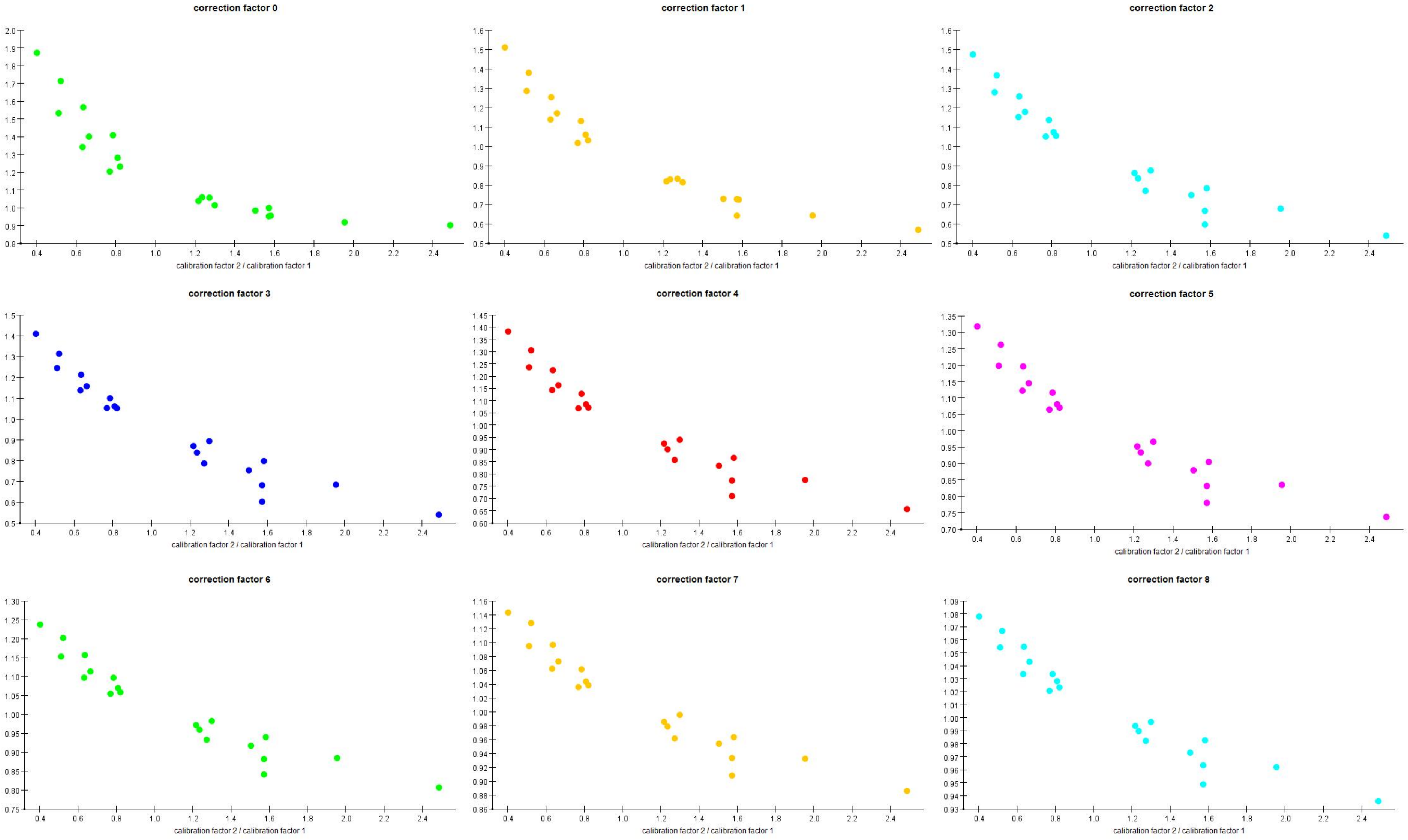
- In principle, calibration should depend on all the four parameters (e1,m1) and (e2,m2)
  - This will make things overly complicated (and almost impossible)
  - It would be really great if we can find a function F
    - F = F(e1,m1,e2,m2), where all the correction factors only depends on F
    - But this is not always possible

e+: F = (e1 x m1)/(e2 x m2)



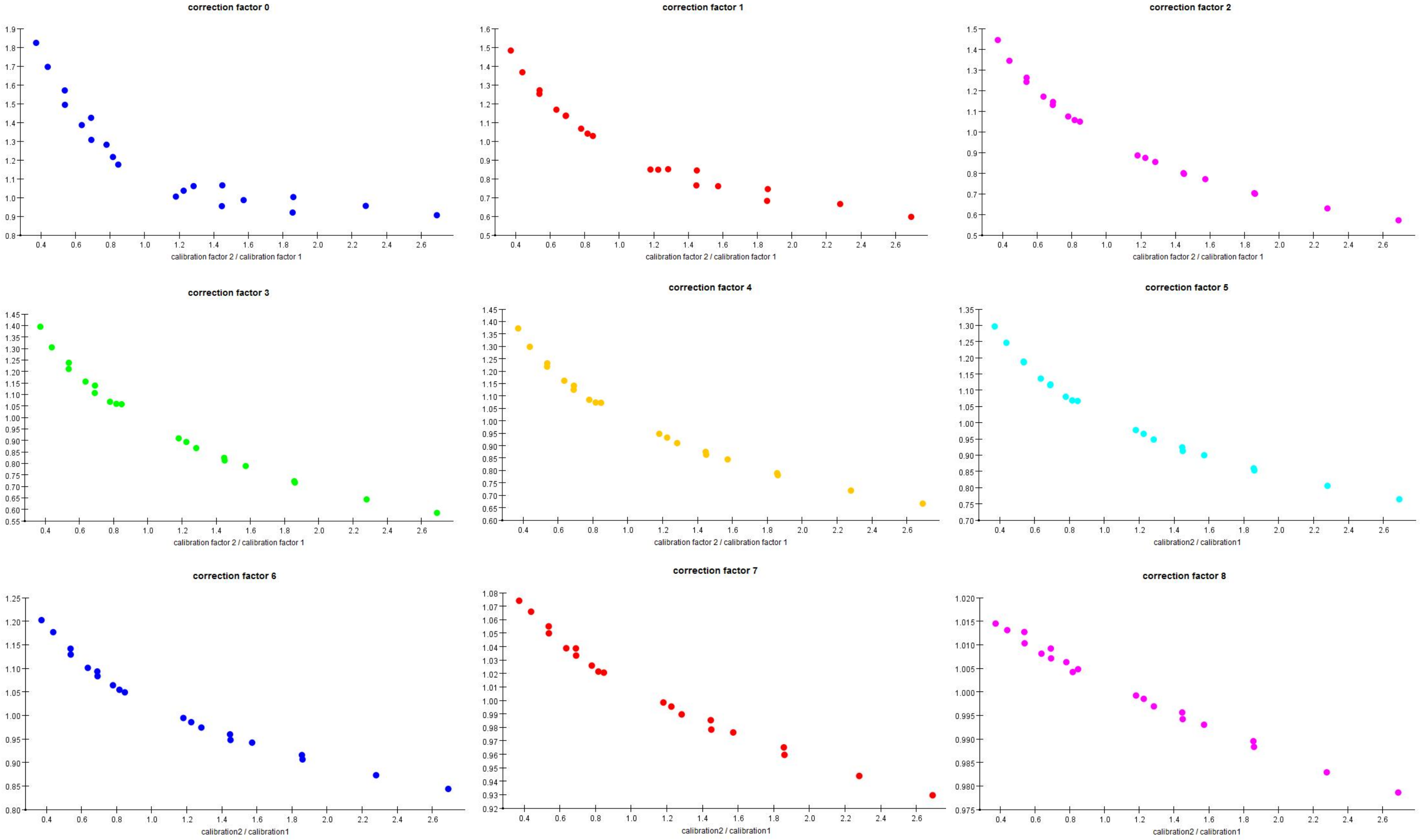
The correction factors are clearly not simple functions of this choice of F, but showed some hope

pi+: F = (e1 x m1)/(e2 x m2)



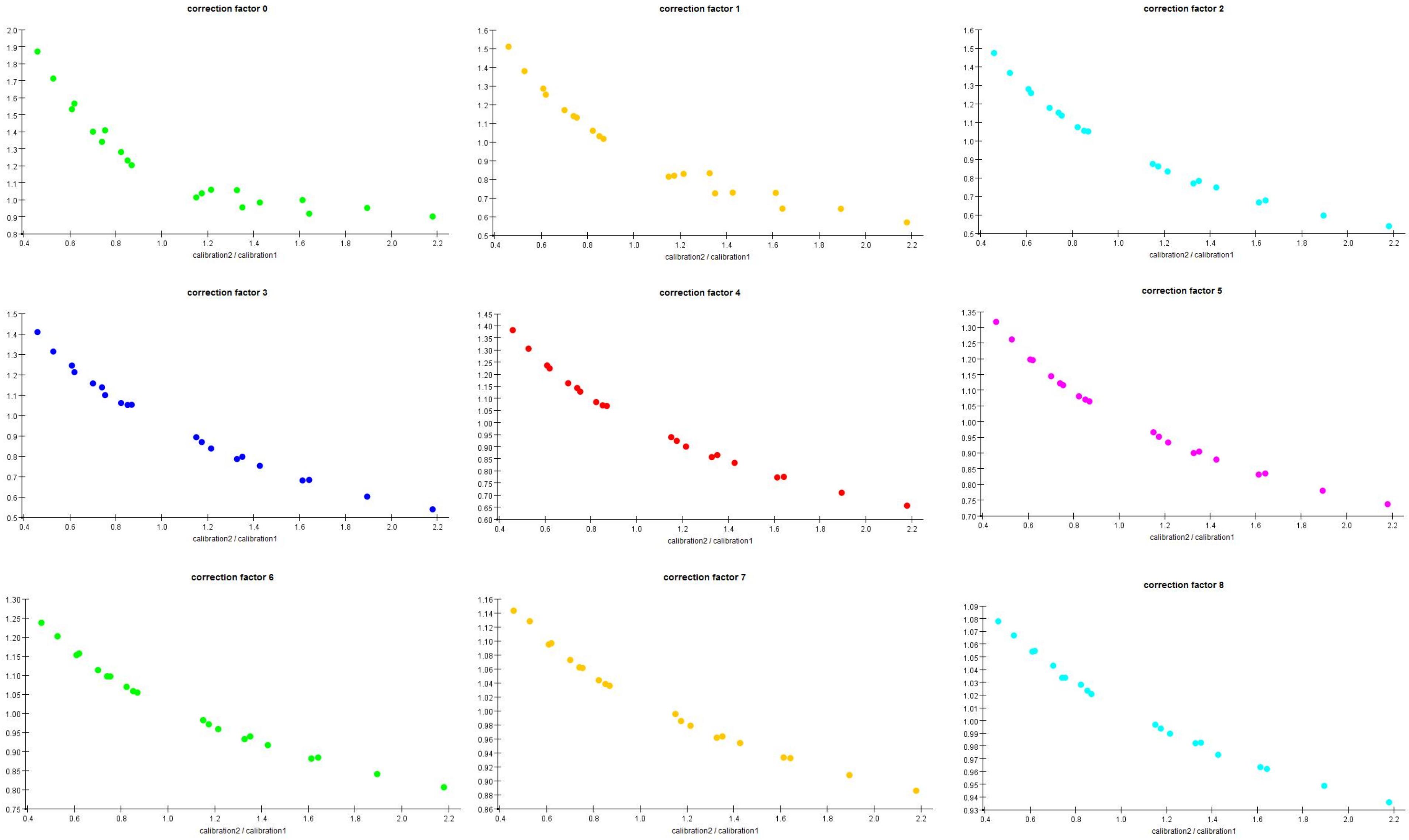
Similar conclusion for pion correction factors

e+: $F = (e1^{0.3} \times m1^{2.0}) / (e2^{0.3} \times m2^{2.0})$



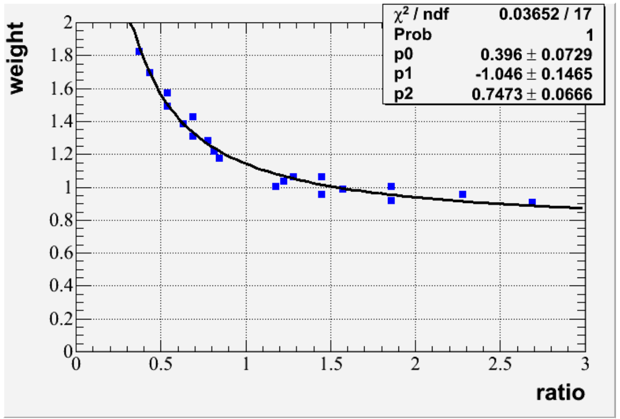
With some black magic, it seems that this F works reasonably well!

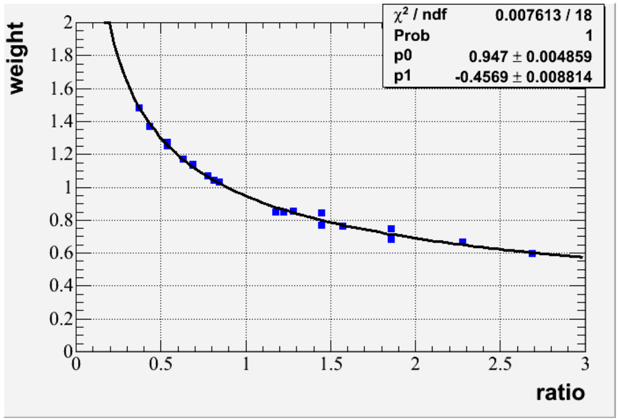
pi+: calibration factor = $e^{0.3} \times m^{1.5}$

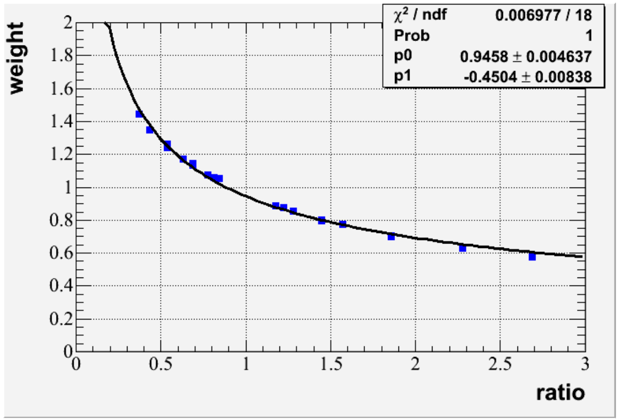


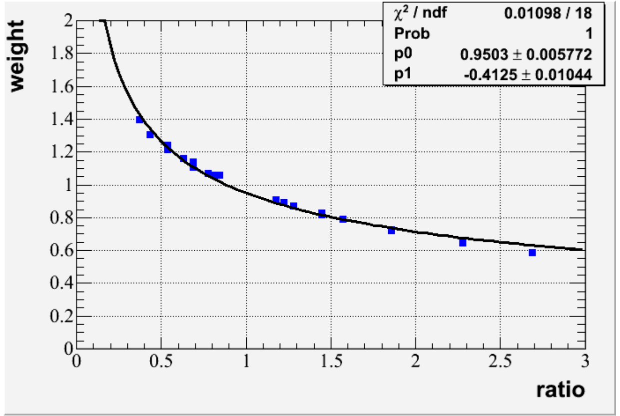
Found a similar F for pion as well → things look good now!

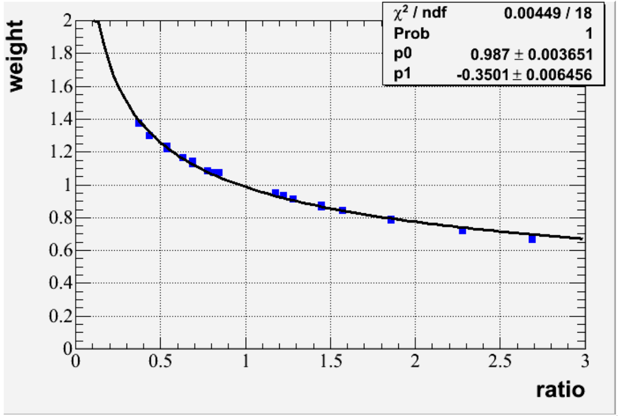
e+ correction factors

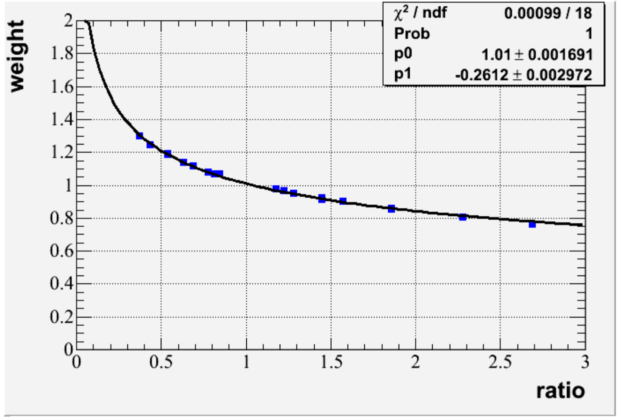


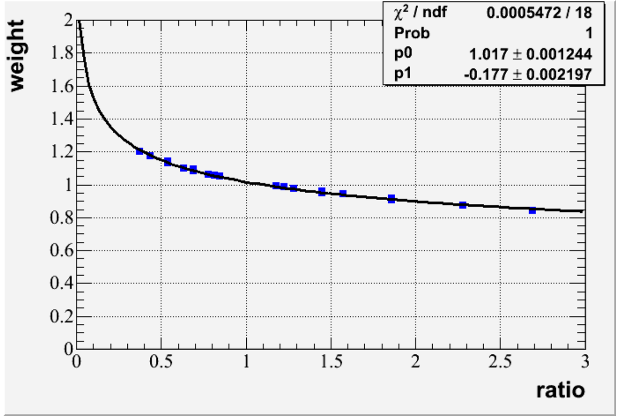


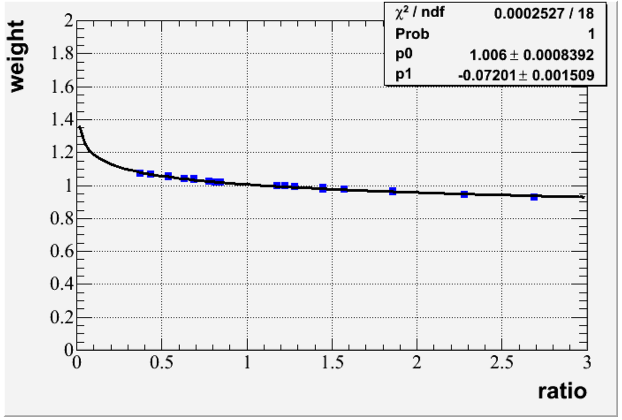


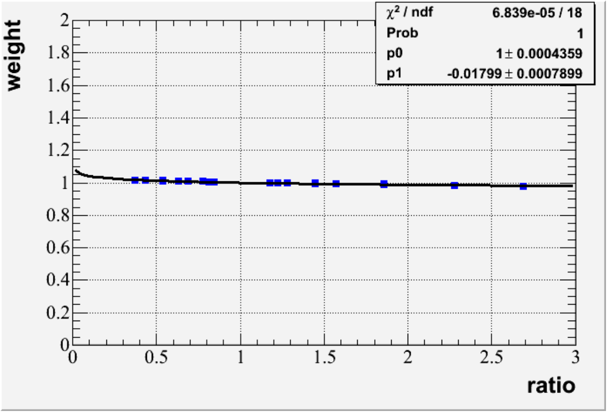




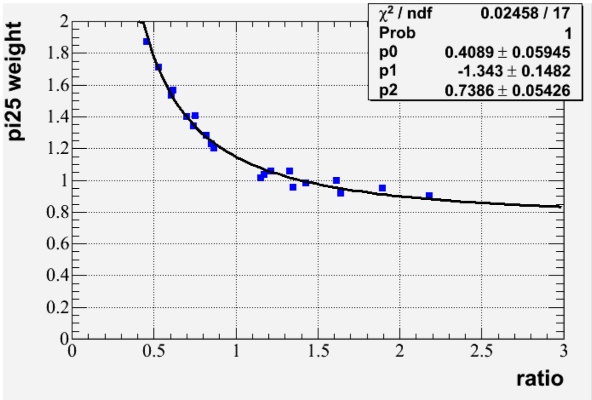


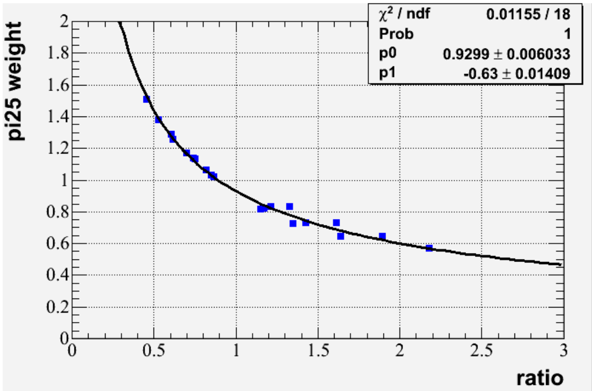


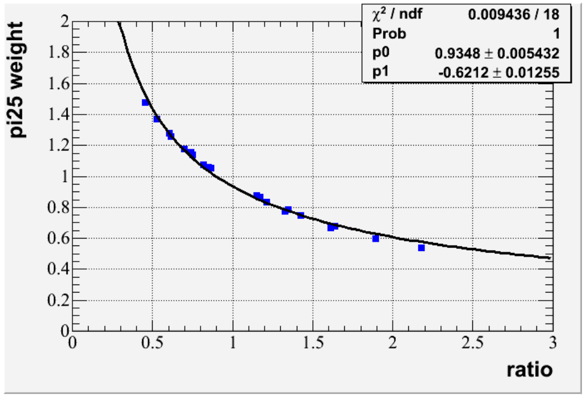


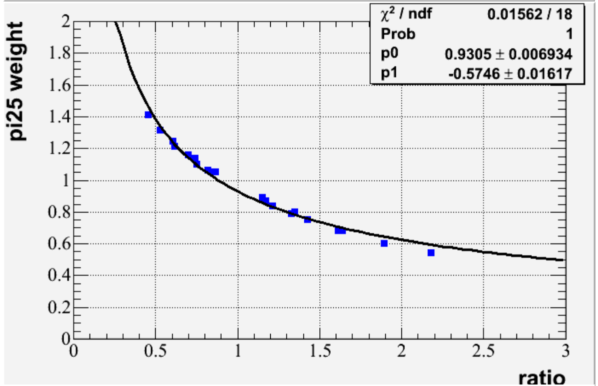


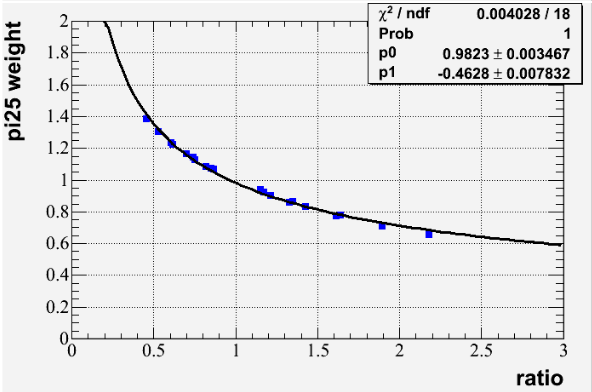
pi+ correction factors

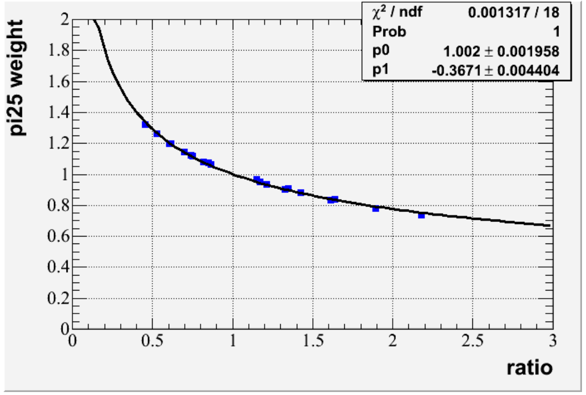


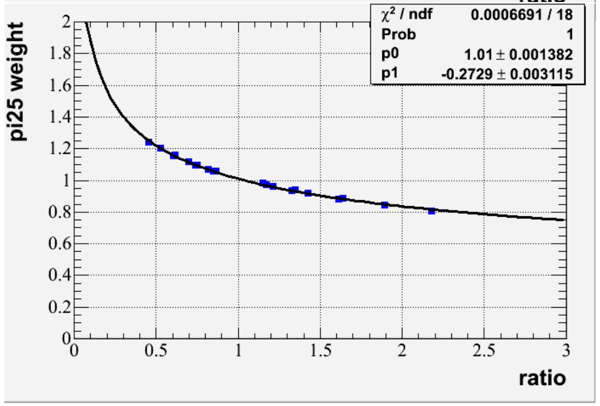


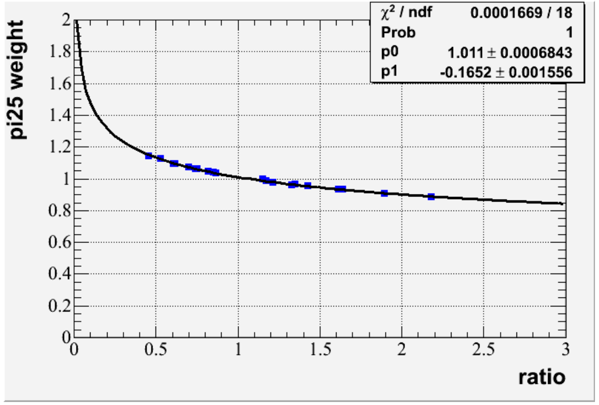


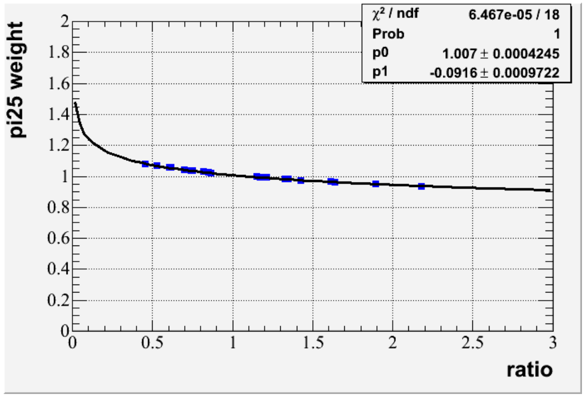








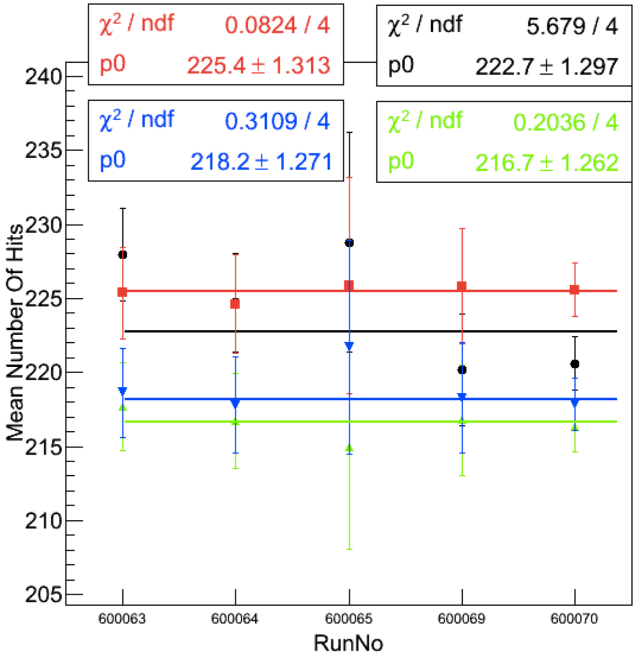




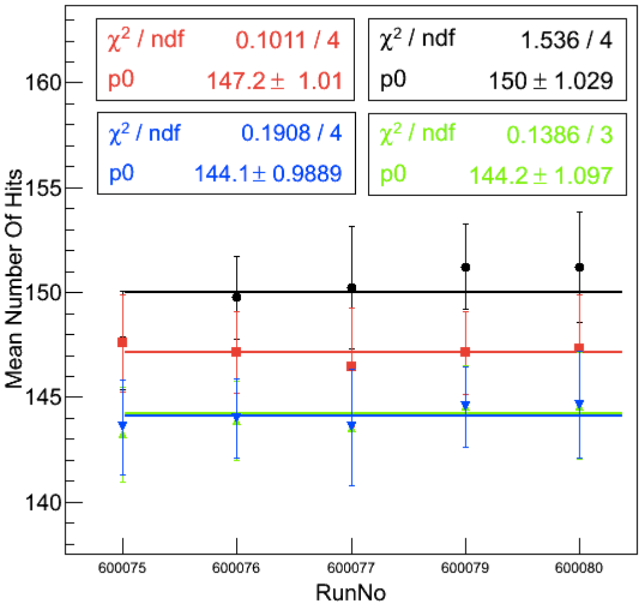
Density Weighted Calibration

- Decide the target efficiency and multiplicity (MC values - e2, m2)
- Obtain the efficiency and multiplicity per RPC per RUN (default calibration procedure - e1, m1)
- Count the neighbors of hits in 3 x 3 grid and calculate $(e1^{0.3} \times m1^{2.0}) / (e2^{0.3} \times m2^{2.0})$ for positrons and $(e1^{0.3} \times m1^{1.5}) / (e2^{0.3} \times m2^{1.5})$ for pions.
- Use the fit functions to obtain the correction factors C
- Nhits_raw+=1; Nhits_densitycalib+=C
- Also have hybrid calibration where the full calibration is used for the density bins of 0 and 1, and the density weighted calibration for the remaining bins.

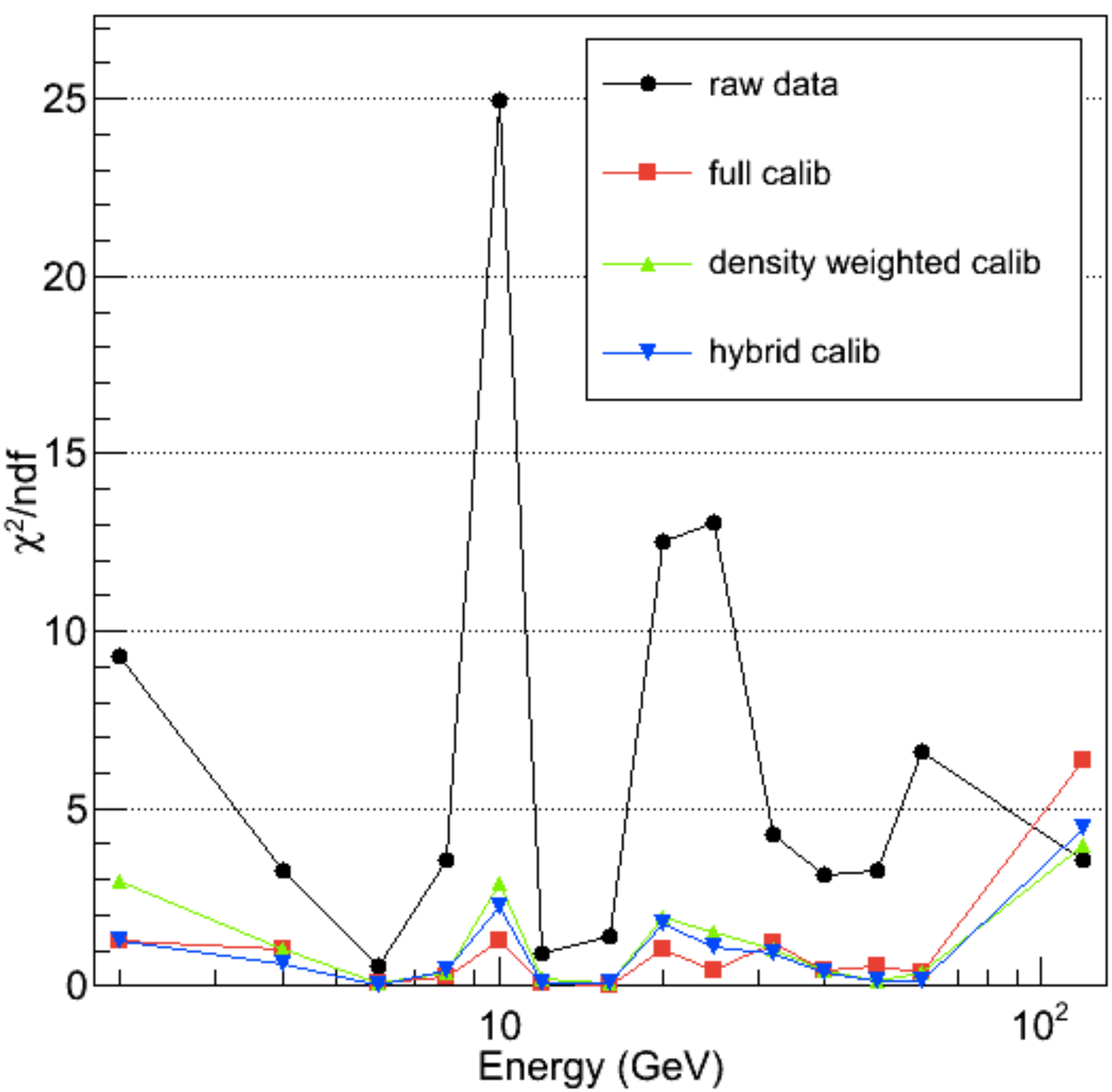
16 GeV π^+



12 GeV e^+



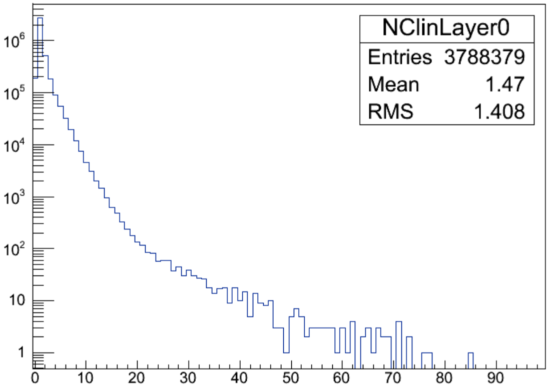
π^+

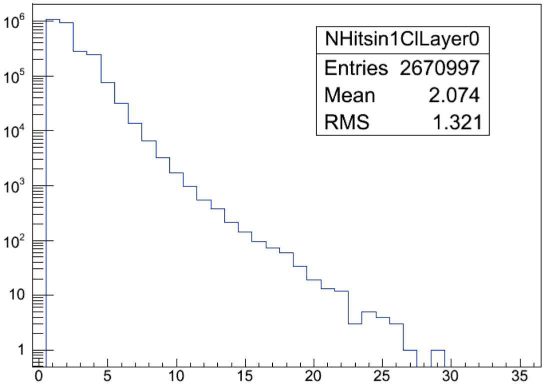


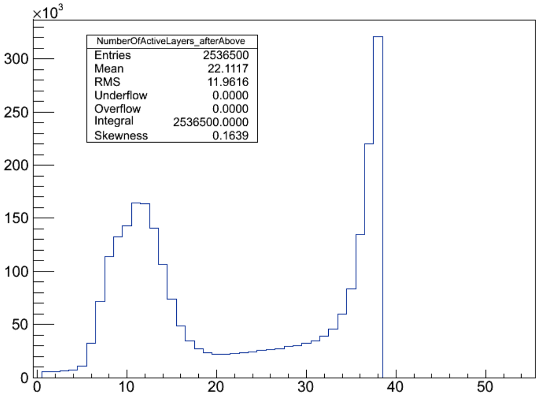
Secondary Beam FNAL Runs

Total Number of Events:	3788379
Events with only one cluster in Layer 1:	2670997
Events with at most 4 hits in this 1 cluster in Layer 1:	2536500
Events with activity in at least 5 layers (on top of above):	2511487

➔ 66.3% is analyzed







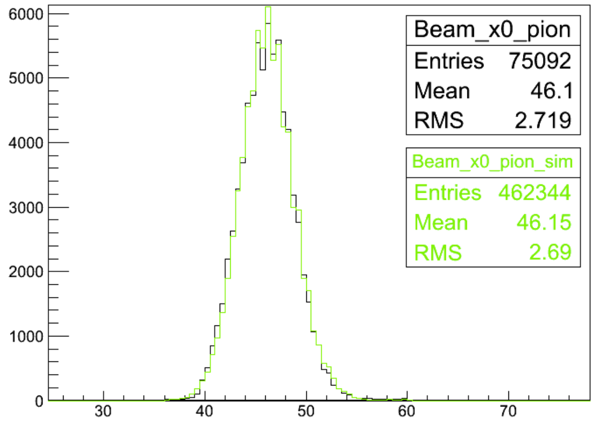
Further event selection

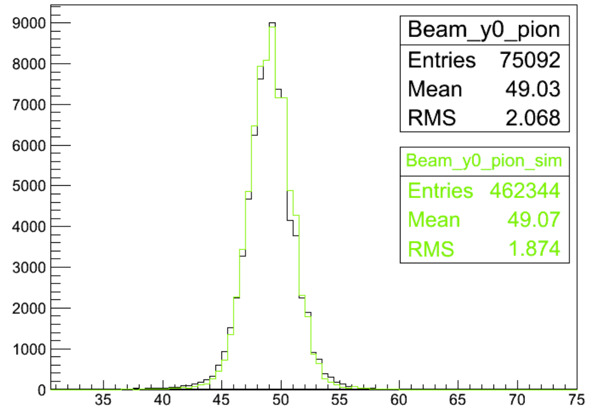
Require activity in at least 3 of the first 5 layers

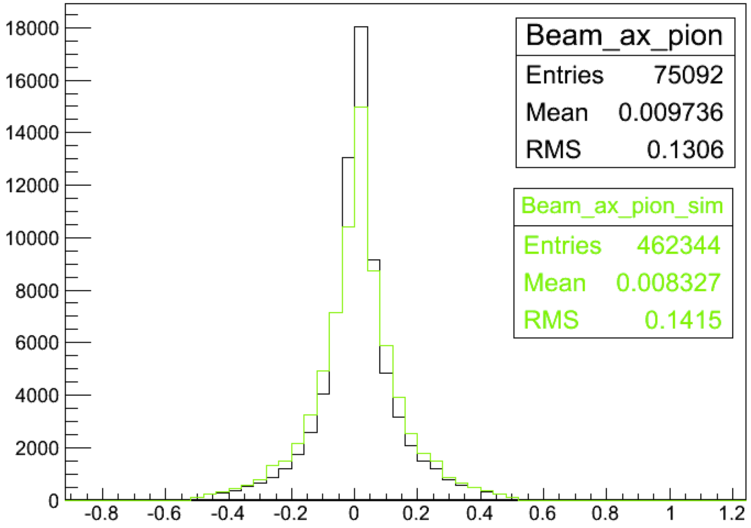
To define the particle direction, select hits within a cylinder of radius 5 cm from (X_0,Y_0) .

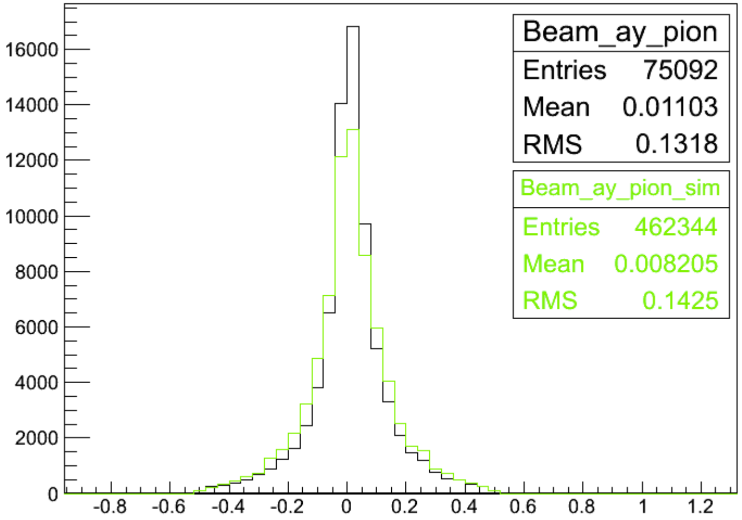
Calculate the average x,y for these hits.

Fit a line to as many layers as possible where the average positions lie in the cone ≤ 1 pad/layer.









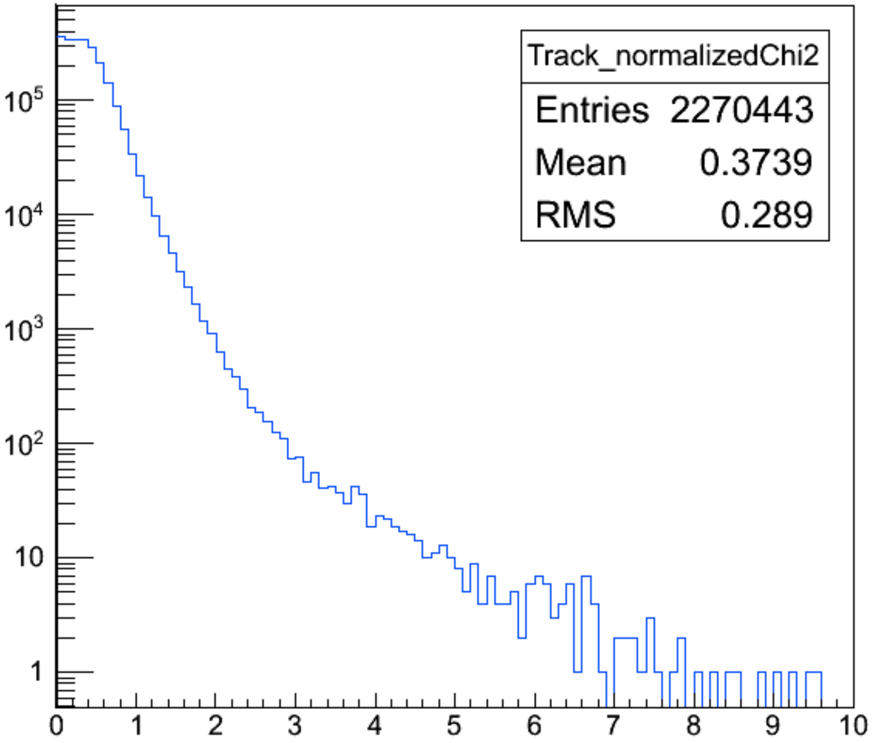
8 GeV pi

Cut on chi2/ndf

chi2/ndf>1 → 2%
chi2/ndf>1.5 → 0.5%

Contribution to chi2/ndf>1 comes from low energies (~25% is from 2 GeV)

Require chi2/ndf>1.5



Definition of IL

- If there are hits from 1.5 to 20 cm of the trajectory point in two consecutive layers i and i+1, IL is layer i-1.

Assign muon ID to everything with IL>25

PID parameters

IL: Interaction layer

BC: Barycenter

$N_{Hits}/N_{Clusters}$: Average cluster size

L_{last}: last layer with hit

R_{rms}: $\sqrt{\frac{\sum r_i^2}{N}}$ r_i: distance from the trajectory line; N: total number of hits

R_{90}: 90% confinement radius

CI: Compactness index $\frac{\sqrt{\sum \left|\vec{r}_i - \vec{r}_{BC}\right|^2}}{N}$

N_{10}/N_{20}: (Nhits in 10 cm)/(Nhits in 20 cm) distance from the trajectory line

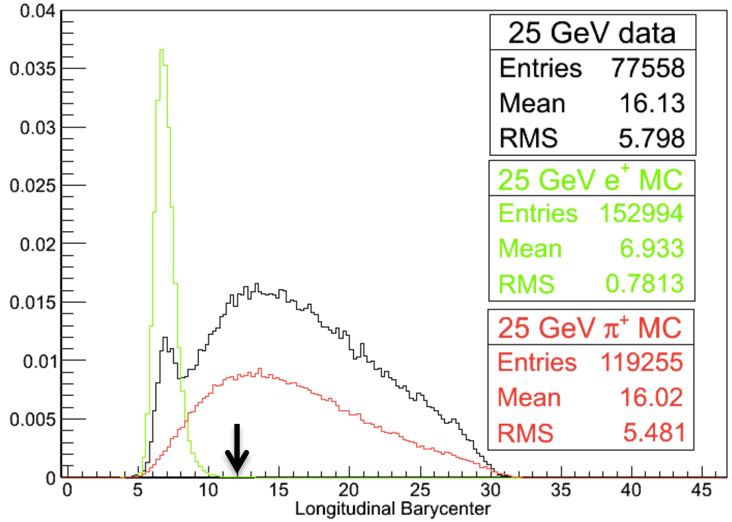
Assume all are pions, cut positrons out based on MC

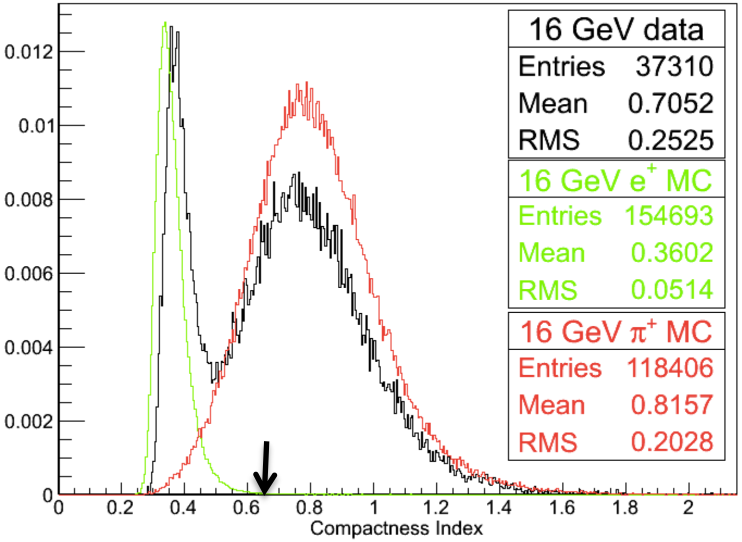
Beam Energy (GeV)	Interaction Layer (<)	R_{rms} (<)	R_{90} (<)	Compactness Index (<)	N_{10}/N_{20} (>)	$N_{Hits}/N_{clusters}$ (>)	Barycenter (<)	L_{last} (<)
32	4	6	10	0.5	0.9	4	9.5	-
25	5	6	10	0.45	0.9	3.5	12	-
20	5	5.5	12	0.7	0.9	3.5	12	-
16	6	5.5	12	0.7	0.9	3.5	12	25
12	6	6	12	0.75	0.9	3	12	35
10	7	6	12	0.8	0.85	3	12	35
8	7	6.5	12	0.9	0.85	2.5	11	35
6	10	6.5	14	0.65	0.85	2.3	10	34
4	16	6.5	16	1.4	0.85	2	10	32
2	20	8	20	2	0.75	1.5	9	27

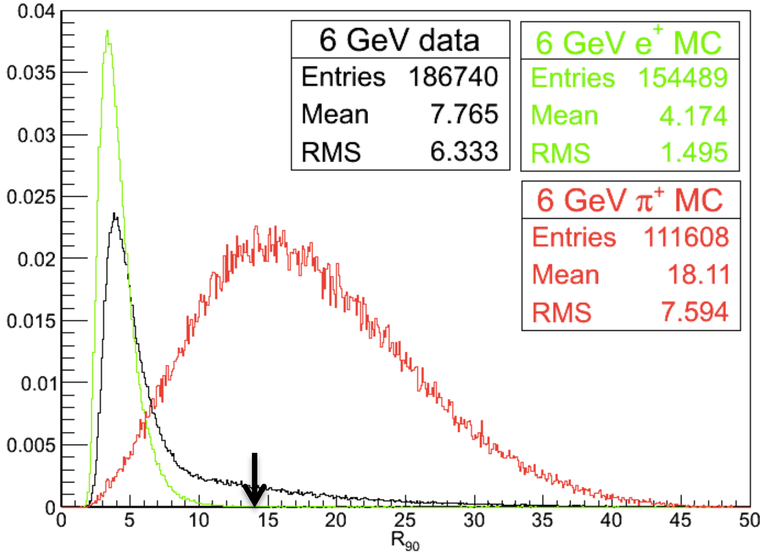
MC Efficiencies

Energy (GeV)	% Analyzed	PID eff (%)
2	70.9	100.0
4	71.3	99.9
6	70.8	99.6
8	70.0	99.7
10	69.1	99.7
12	69.3	99.8
16	69.0	98.5
20	68.3	99.9
25	67.2	98.8
32	66.1	98.6
2	47.7	23.5
4	51.6	90.4
6	52.7	95.3
8	52.4	94.3
10	54.3	96.0
12	54.8	95.9
16	54.9	97.6
20	55.2	96.6
25	55.2	97.8
32	54.3	99.0
40	53.6	99.6
50	52.4	100.0
60	51.7	100.0
120	48.8	99.5

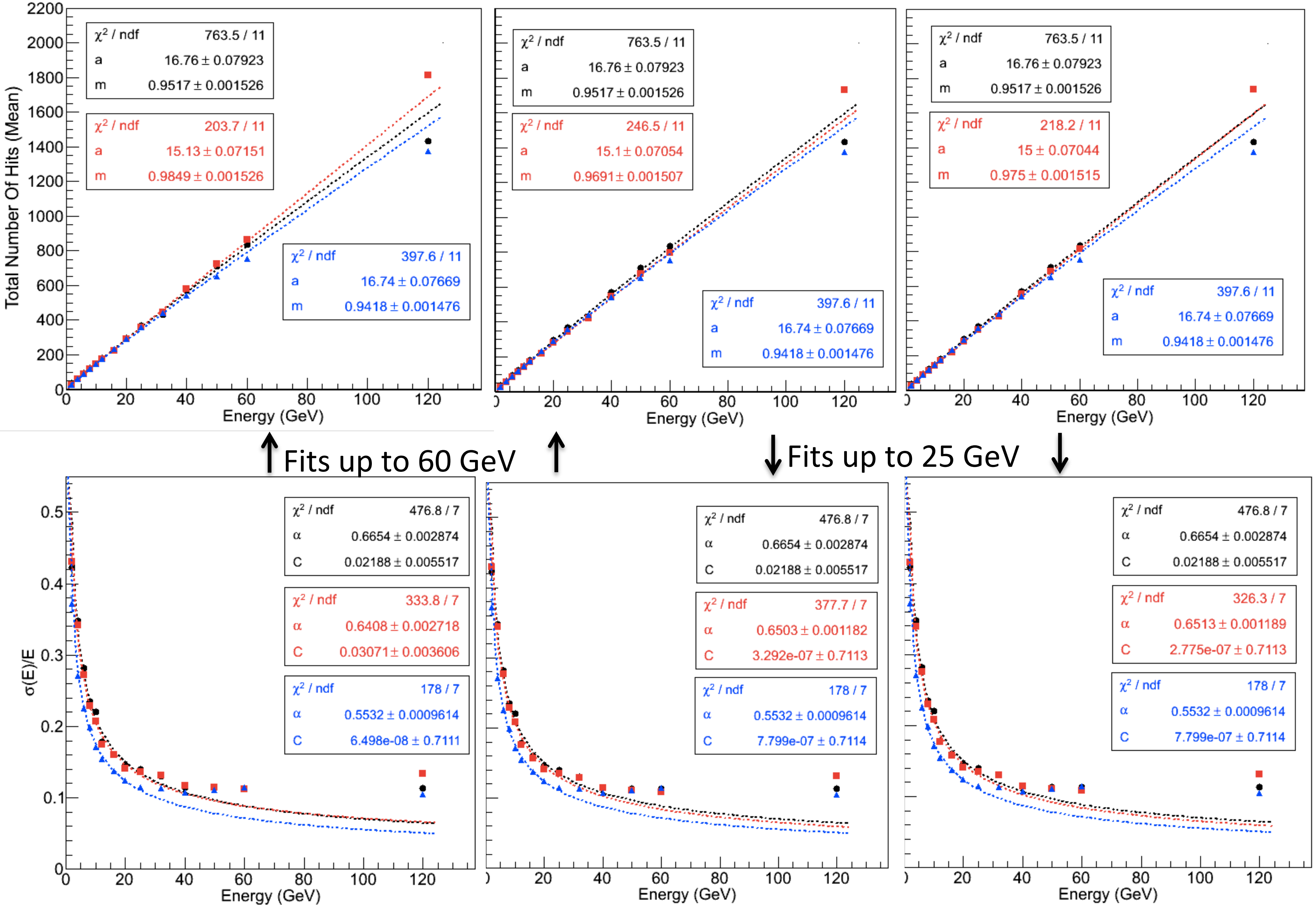
Examples of PID cuts







Full calib Density calib Hybrid calib



↑ Fits up to 60 GeV ↑

↓ Fits up to 25 GeV ↓

Conclusions

- Calibration is not simple and is clearly density dependent.
- Topological PID is working at > 95% efficiency for most part of the energy spectrum.
- Both raw and calibrated response resolutions are ~ 65%/√E. The calibration schemes improve the resolution and eliminate the constant term.
- Disagreement with MC is under investigation.