π, K, p mass reconstruction using time-of-flight

ILD Analysis/Software Meeting
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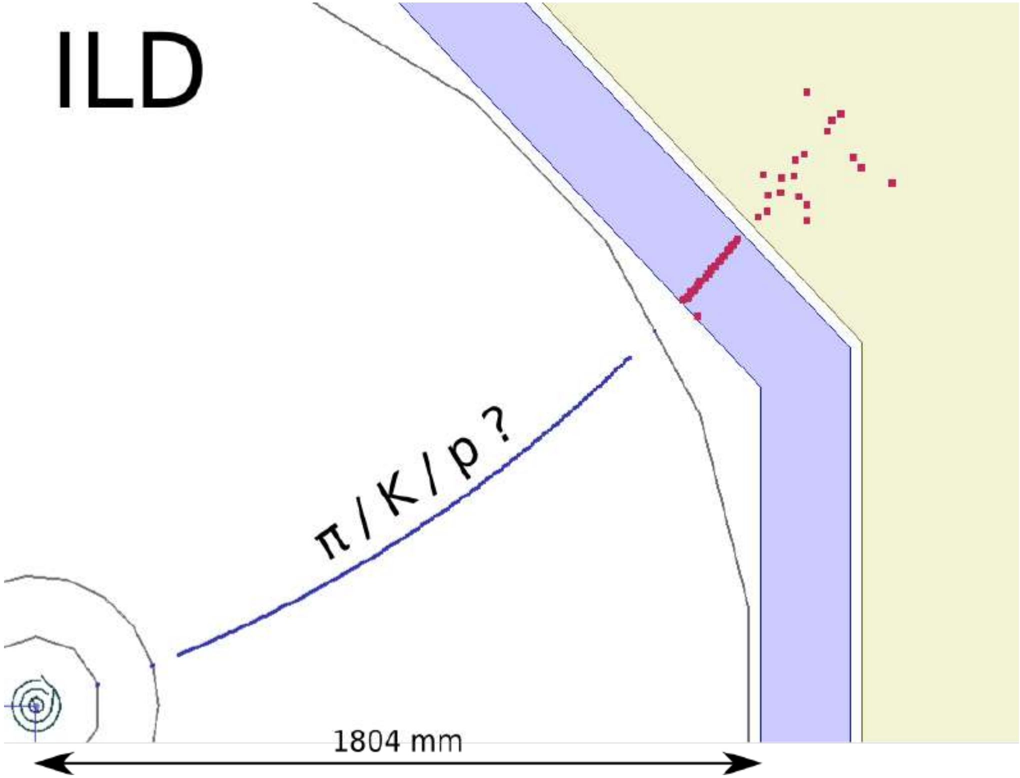
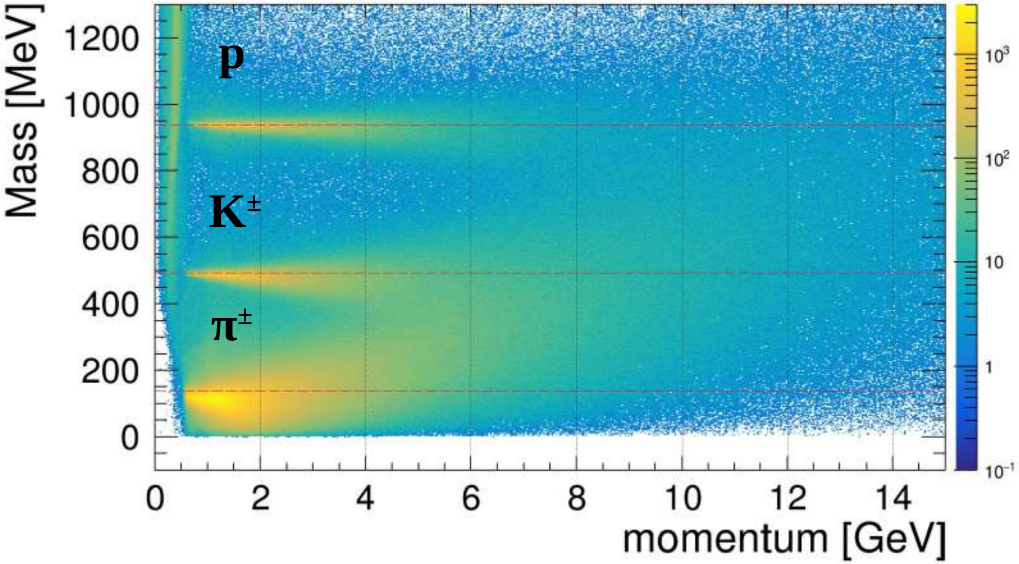
Bohdan Dudar
bohdan.dudar@desy.de

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES · UHH · CLUSTER OF EXCELLENCE QUANTUM UNIVERSE · ILD · FTX · DESY.

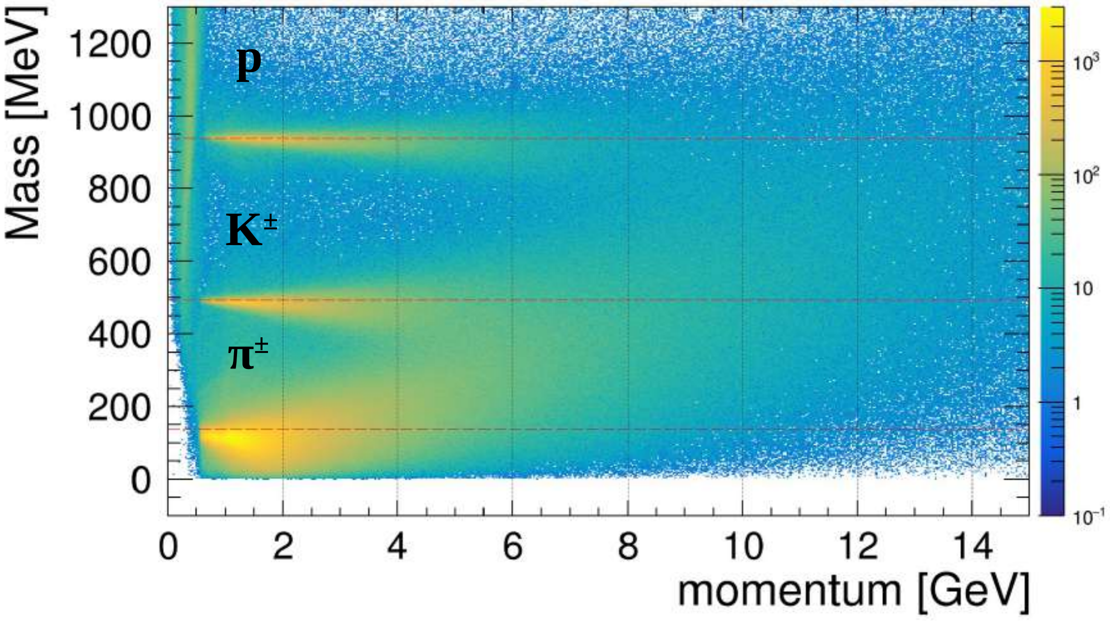
Time-of-flight (TOF) particle identification



$$m = p\sqrt{\frac{c^2 \mathrm{TOF}^2}{\ell^2_{\mathrm{track}}} - 1}$$

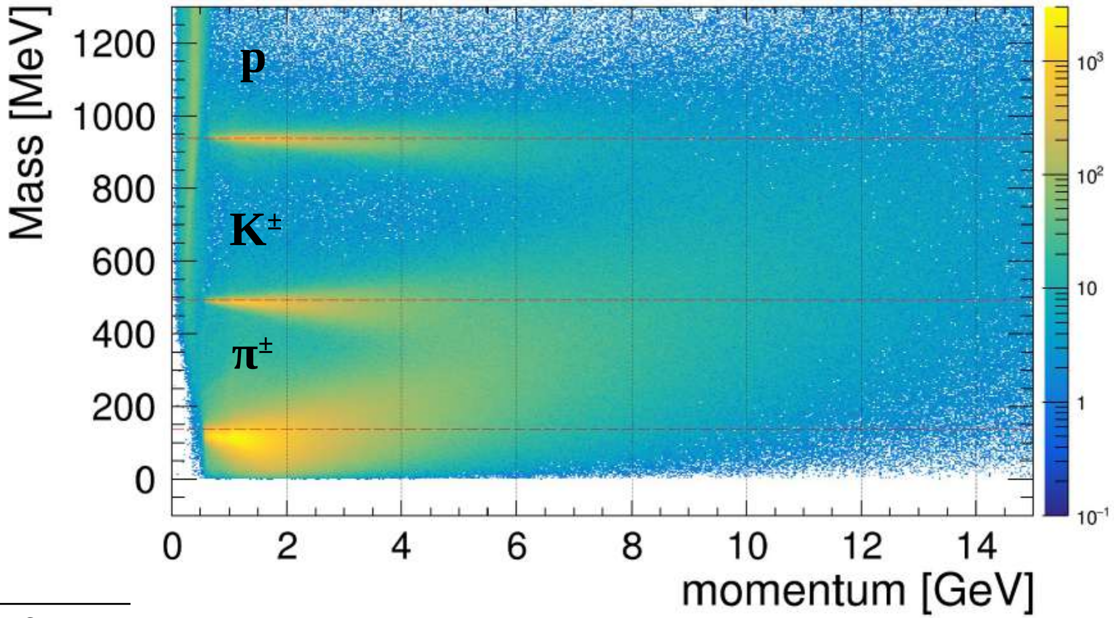


Importance of the track length



Are we happy?

Importance of the track length



$$m = p\sqrt{\frac{c^2\text{TOF}^2}{\ell^2_{\text{track}}} - 1}$$

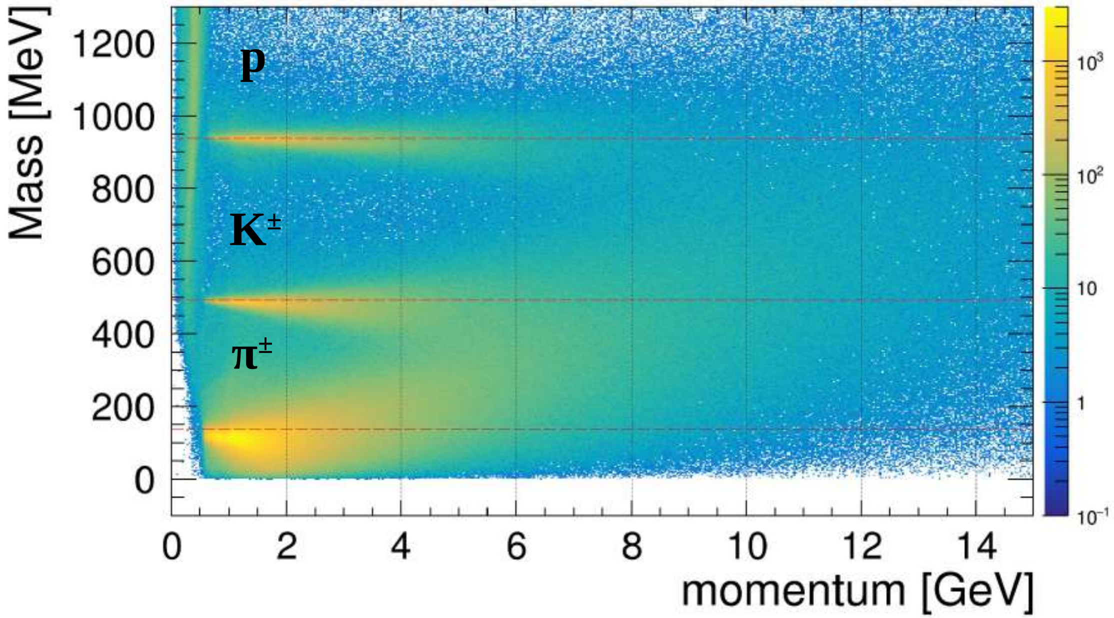
Are we happy?

$$\text{TOF} = t_{\text{MC true of closest hit}} - \frac{d}{c}$$

$$\ell_{\text{track}} = \frac{\varphi_{\text{IP}} - \varphi_{\text{ECAL}}}{\Omega_{\text{IP}}}\sqrt{1 + \tan^2\lambda_{\text{IP}}}$$

$$p = p_{\text{IP}}$$

Importance of the track length



This is the ultimate benchmark with perfect time resolution.

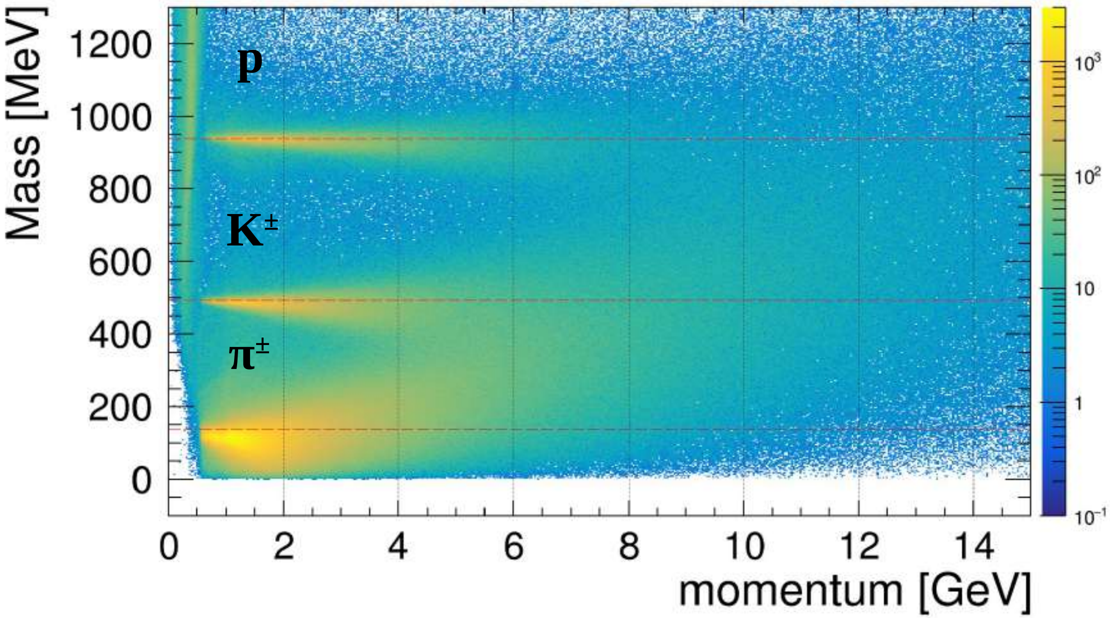
We will never be able to achieve in real life

1) TOF is not the only limitation

2) Track length is very important

Development history of the track length

IDR 2020



const

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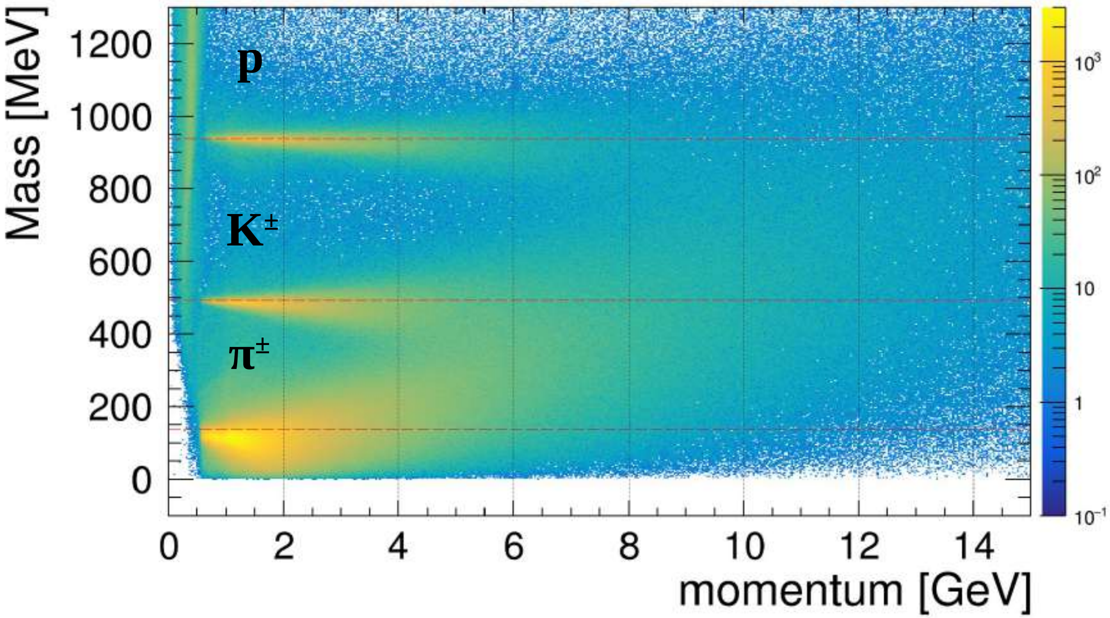

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track length sometimes negative !?
Let's fix this

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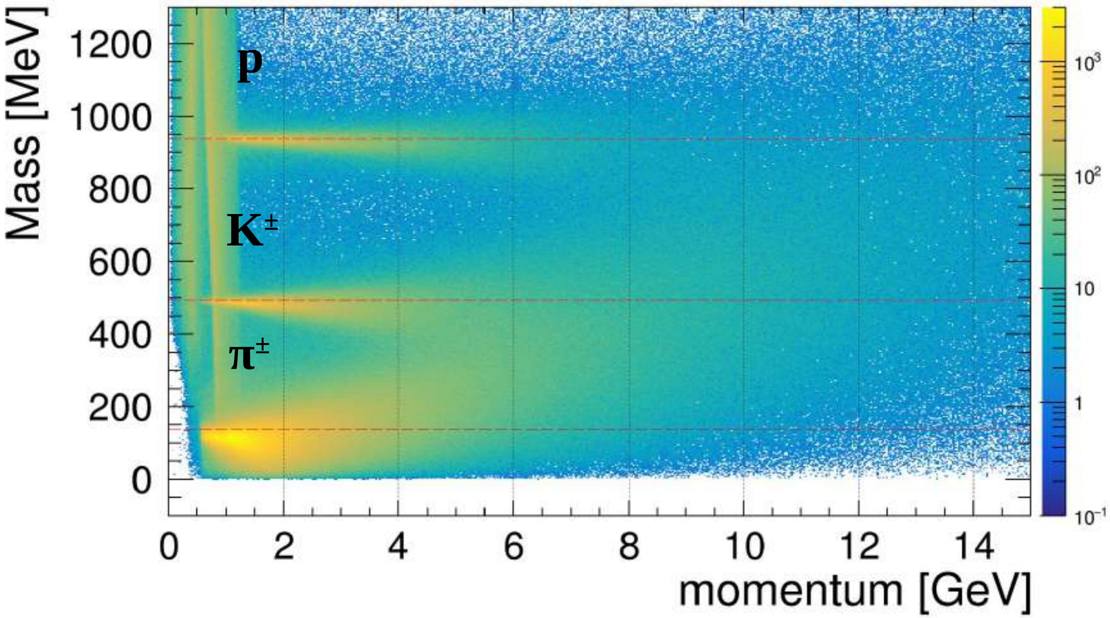

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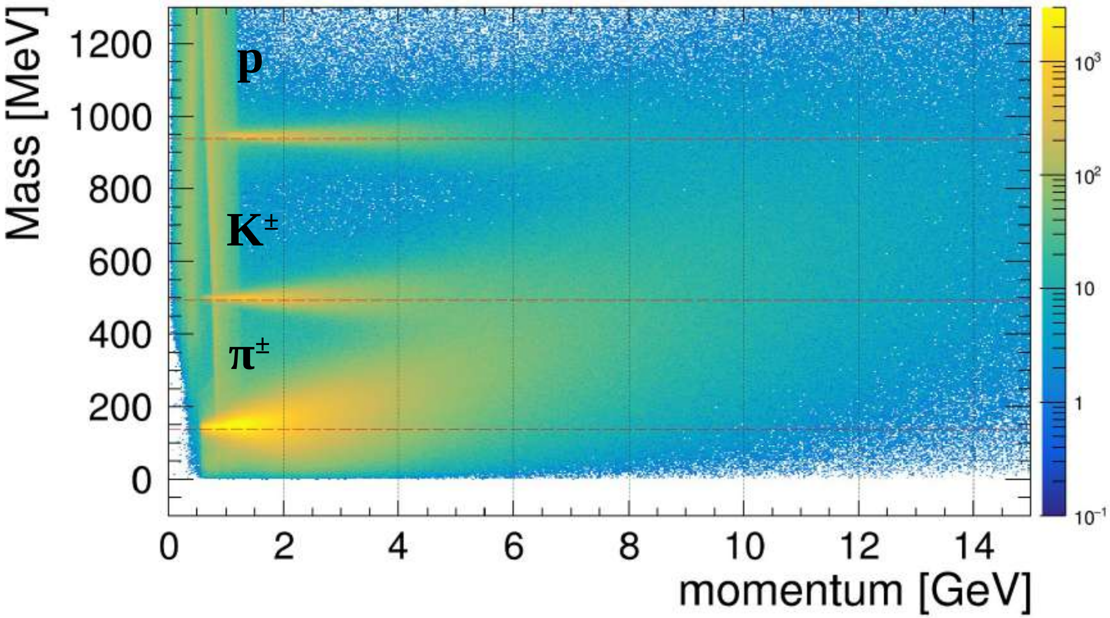
track length sometimes negative !?
Let’s fix this

Ω sign and flight direction better be consistent

Development history of the track length



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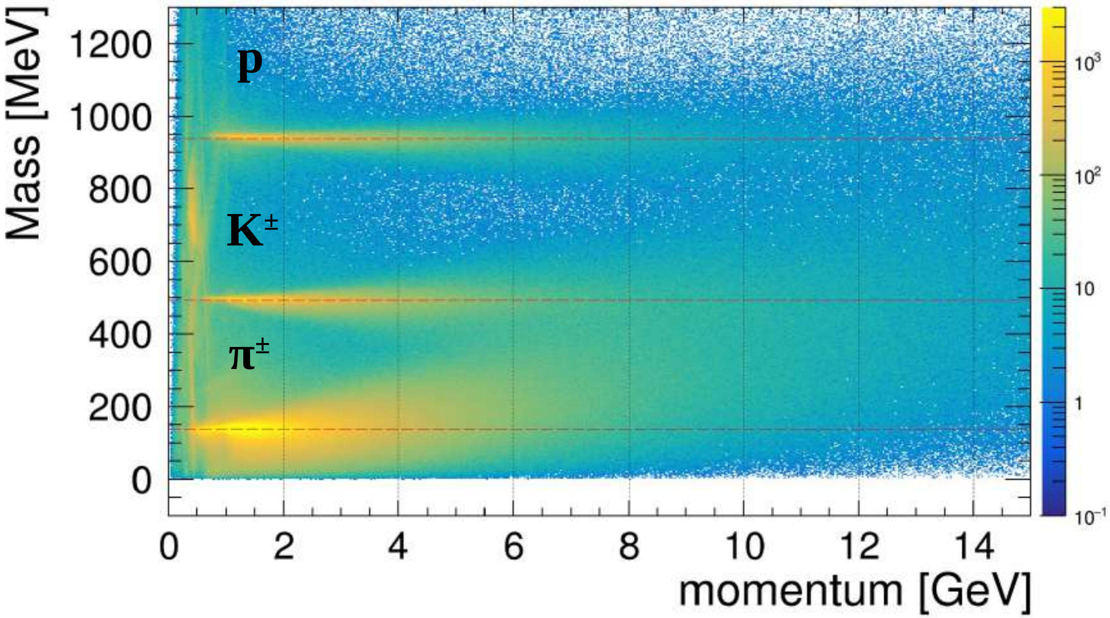
Using track state at ECAL works better

Development history of the track length

Winni's paper (2021) arXiv:2107.02031v2



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$$\mathrm{TOF} = t_{\text{MC true of closest hit}} - \frac{d}{c}$$

$$p = p_{\mathrm{IP}}$$

$$\ell_{\text{track}} = \sum \ell_i$$

$$\ell_i = \sqrt{\left(\frac{\varphi_{i+1} - \varphi_i}{\Omega_i}\right)^2 + (z_{i+1} - z_i)^2}$$

Summing over track segments helps!
But why exactly this formula for the arc length?

Helix arc length: $\ell_{\text{track}} = \sum \ell_i$

Identical formulas for the perfect helix

$$\ell_i = \frac{|\varphi_{i+1} - \varphi_i|}{|\Omega_i|}\sqrt{1 + \tan^2\lambda_i}$$

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Helix arc length: $\ell_{\text{track}} = \sum \ell_i$

Identical formulas for the perfect helix

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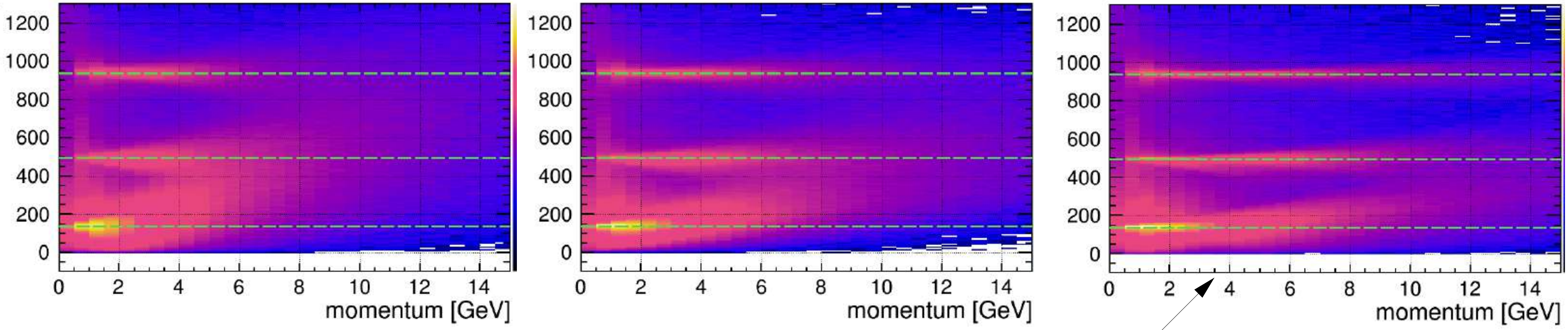
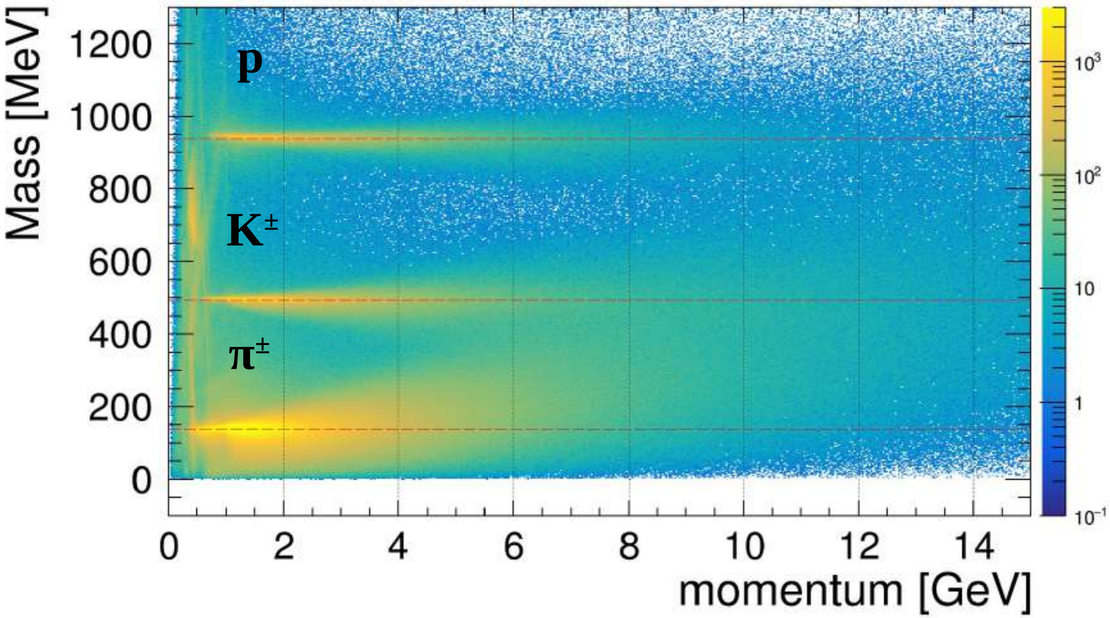


Third option works even better!

Development history of the track length

Winni's paper (2021) arXiv:2107.02031v2



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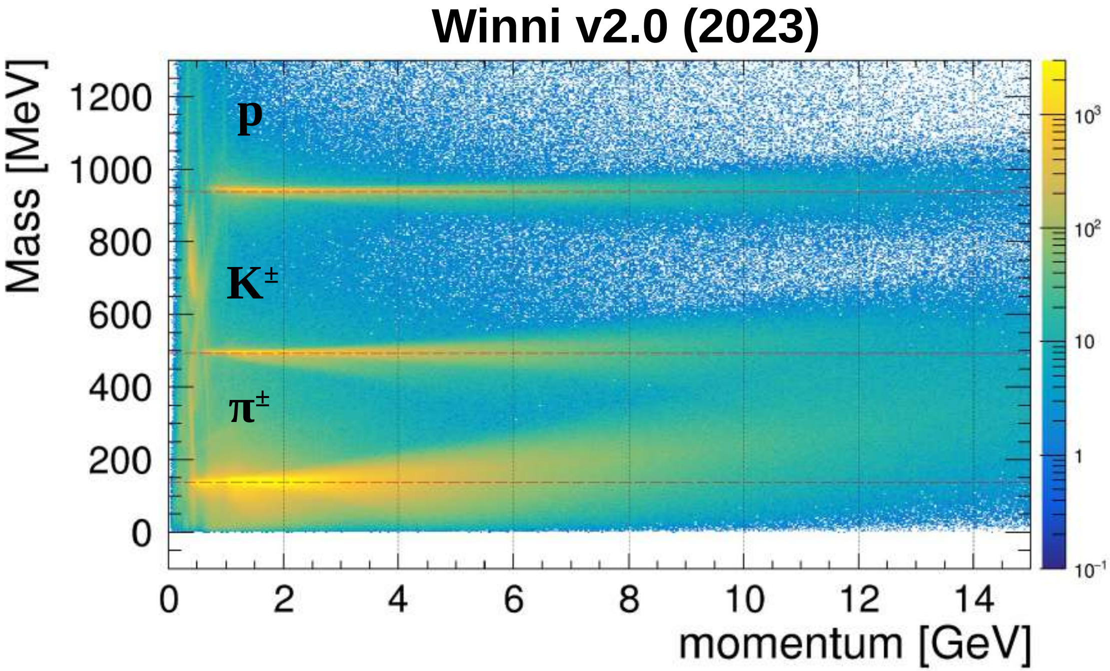

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$$\ell_{\text{track}} = \sum \ell_i$$

$$\ell_i = \frac{|z_{i+1} - z_i|}{|\tan \lambda_i|} \sqrt{1 + \tan^2 \lambda_i}$$

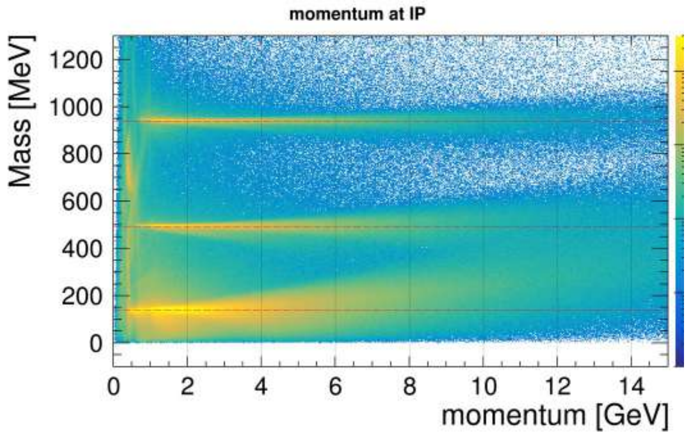
Even better!
But what with this mess at low momentum?

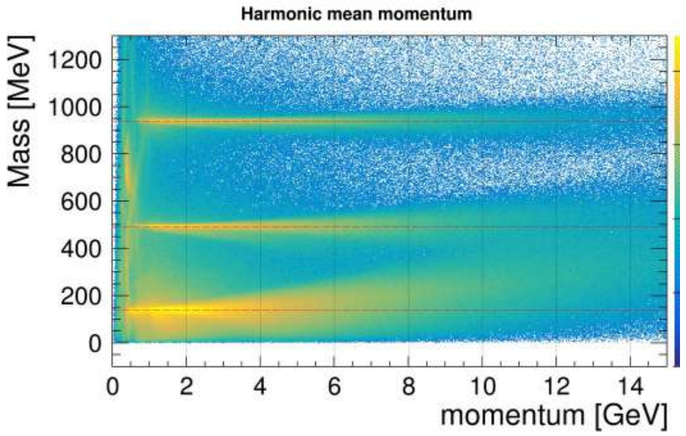
Trying different momentum estimators:

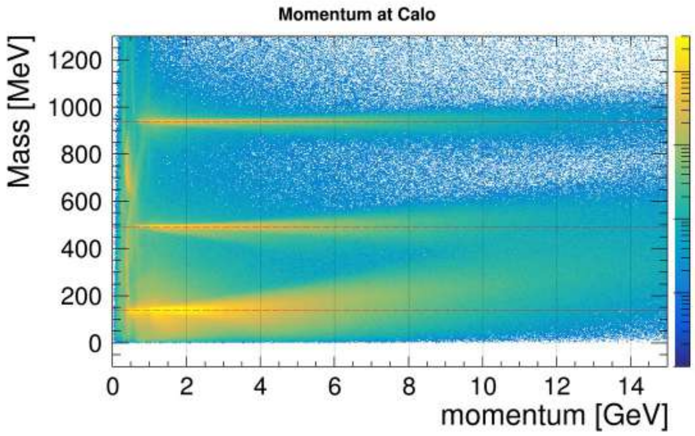
$$p = p_{\mathrm{IP}}$$

$$p = \sqrt{\langle p^2 \rangle_{HM}} = \sqrt{\sum_{i=0}^{n} \ell_i \Big/ \sum_{i=0}^{n} \frac{\ell_i}{p_i^2}}$$

$$p = p_{\mathrm{ECAL}}$$







You don't see a difference

Trying different momentum estimators:

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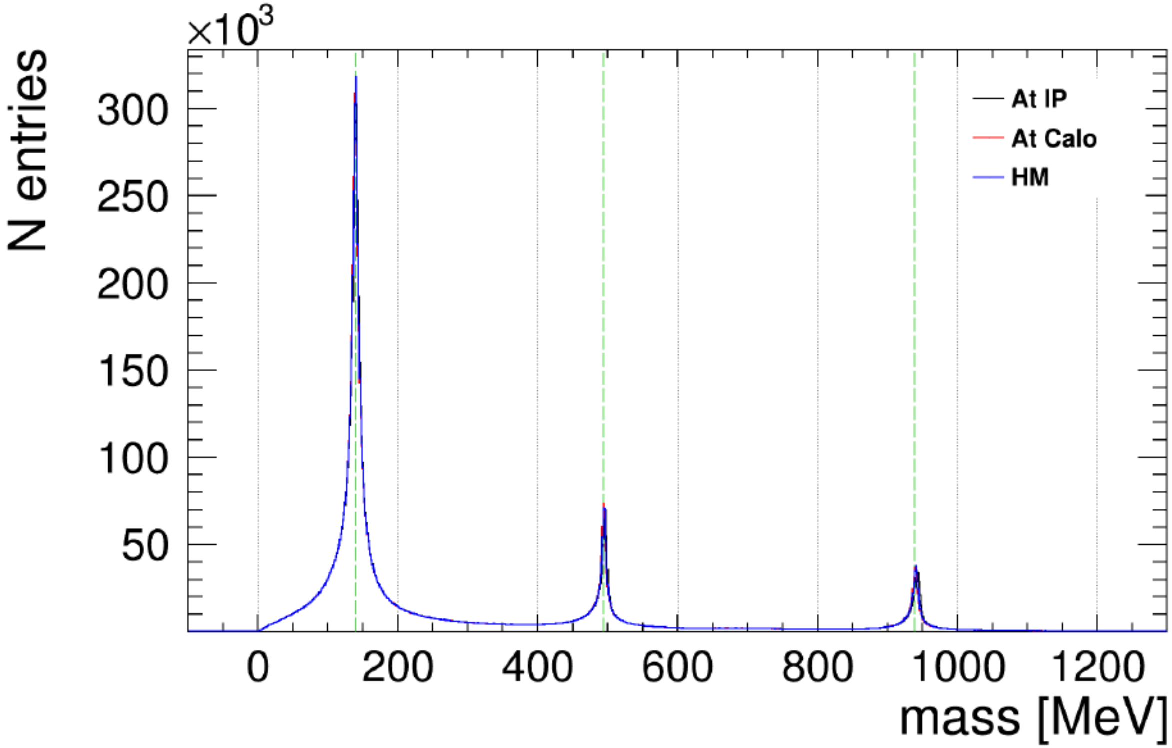
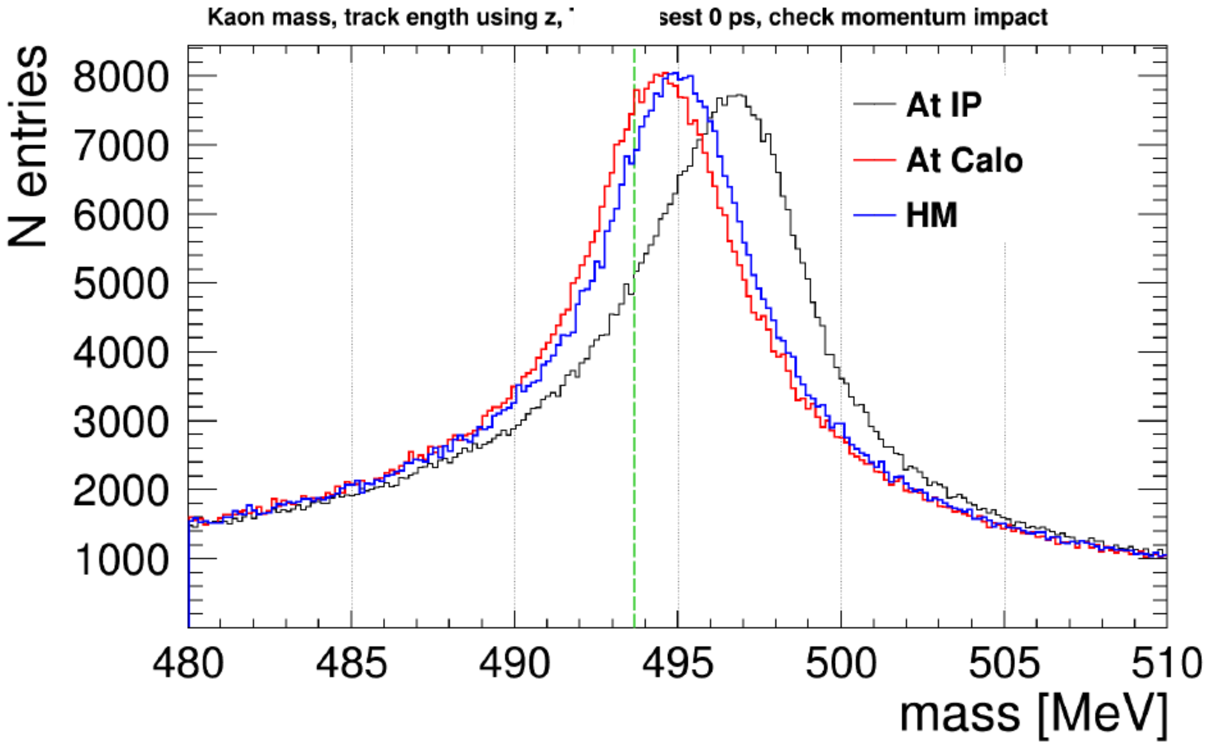


You still don’t see a difference

Trying different momentum estimators:

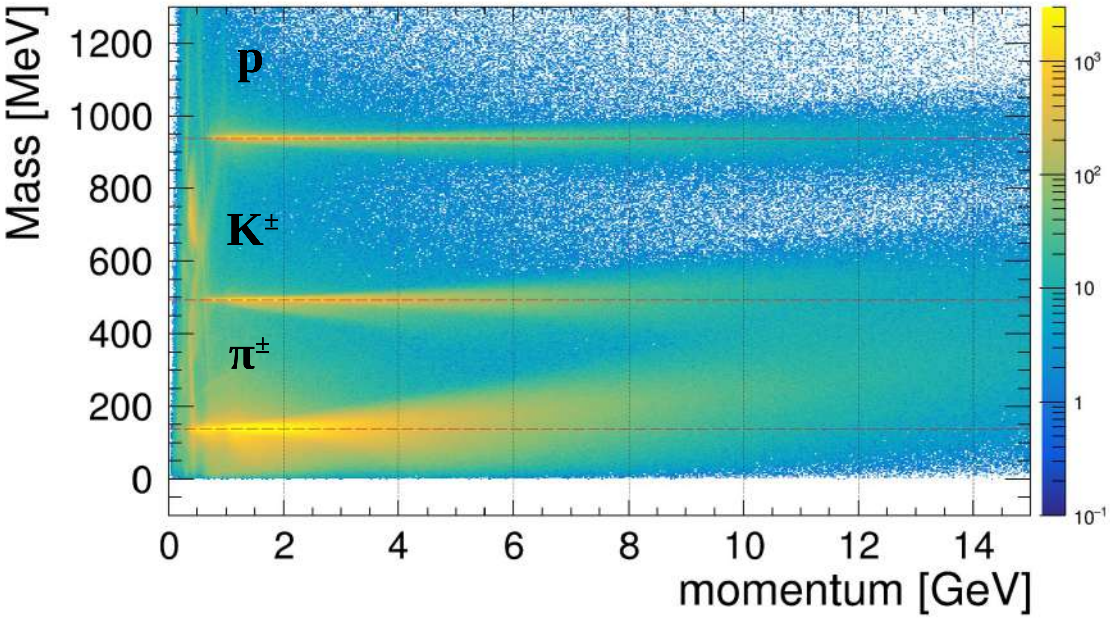
$$p = p_{\text{IP}} \qquad p = \sqrt{\langle p^2 \rangle_{HM}} = \sqrt{\sum_{i=0}^{n} \ell_i \Big/ \sum_{i=0}^{n} \frac{\ell_i}{p_i^2}} \qquad p = p_{\text{ECAL}}$$



Using IP is not ideal. We stick to use HM for consistency

Development history of the track length

Winni v2.0 (2023)



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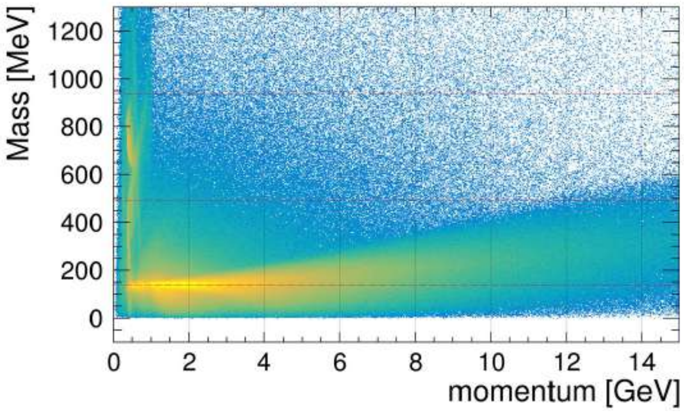
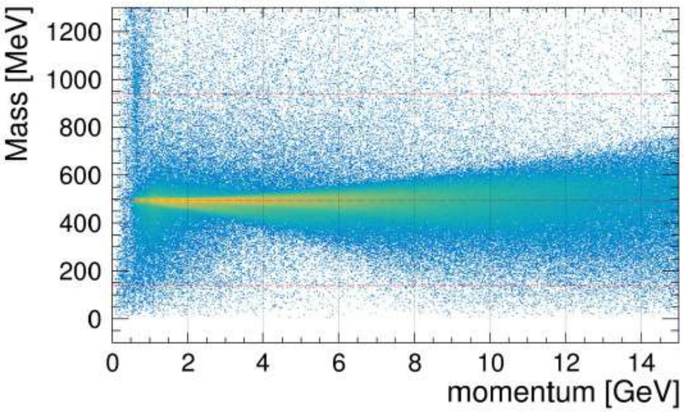
Even better!
But still a mess at low momentum!?

Investigate massive pions: what are they !?

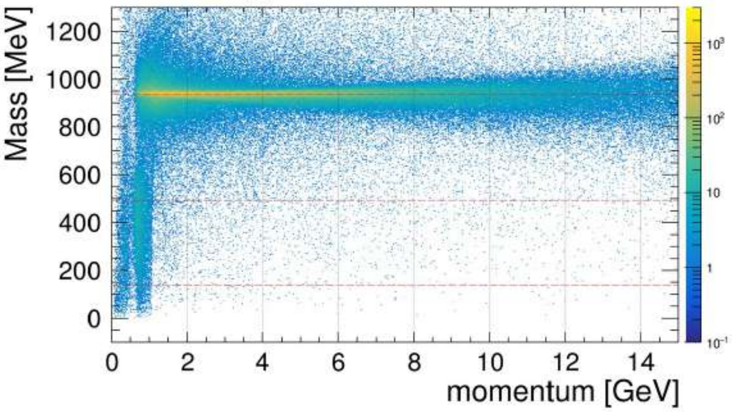
Only pions



Only kaons



Only protons



Let’s define **bad pion**:

m > 200 MeV

Investigate massive pions: what are they !?

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Consistent with our 2D plots

Investigate massive pions: what are they !?

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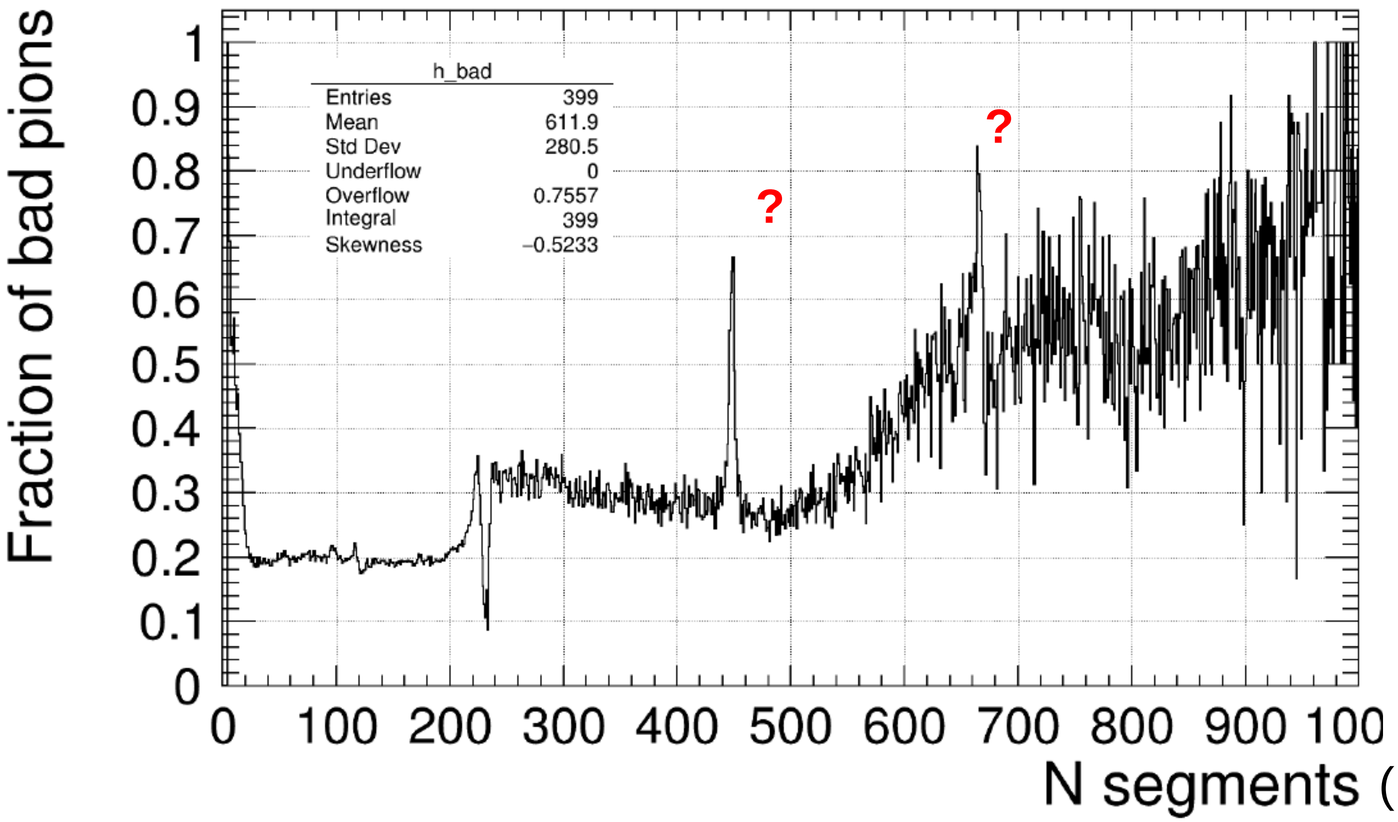


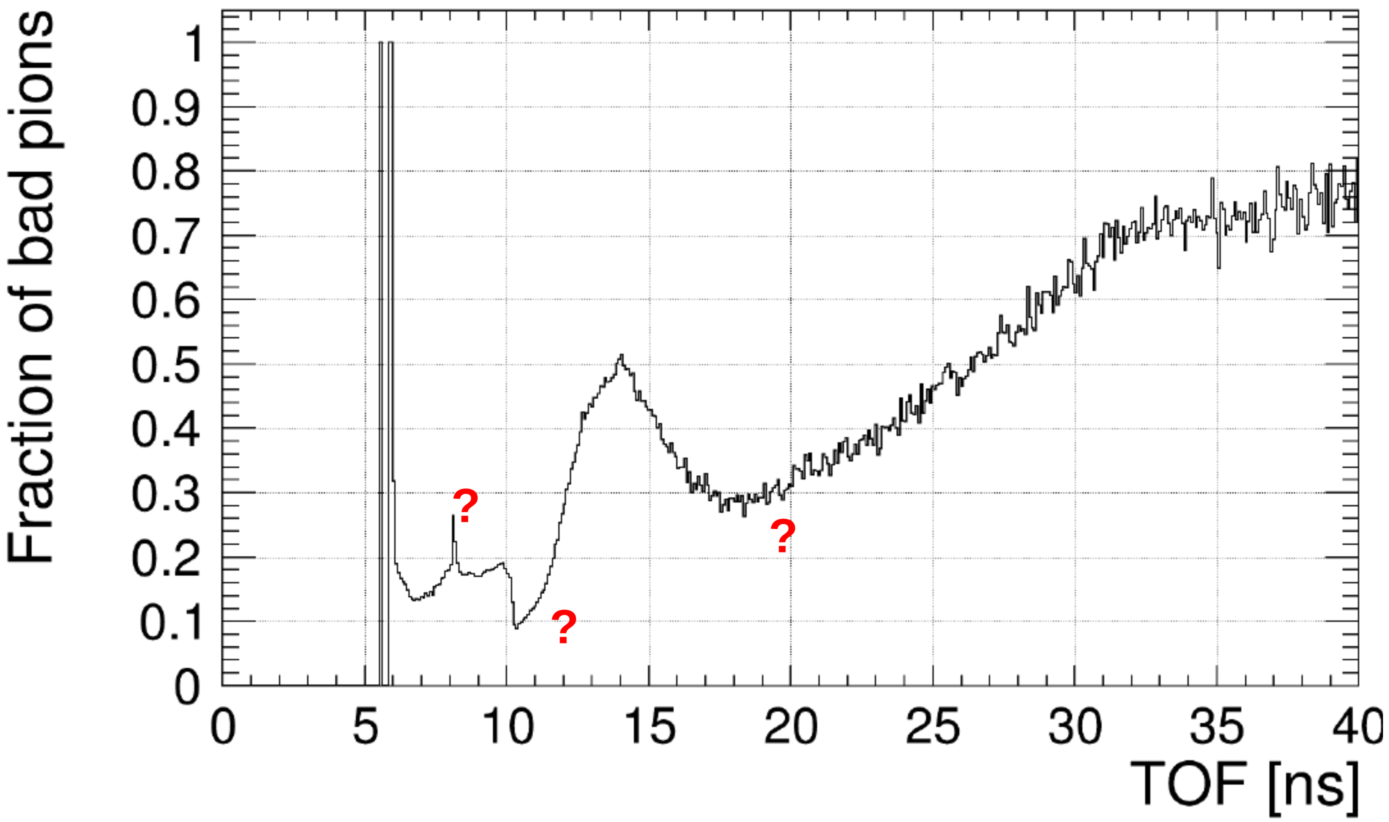
(or N hits)

Usually badly reconstructed are tracks with < 20, 440, 660 hits

Investigate massive pions: what are they !?

Let’s define **bad pion**:

m > 200 MeV

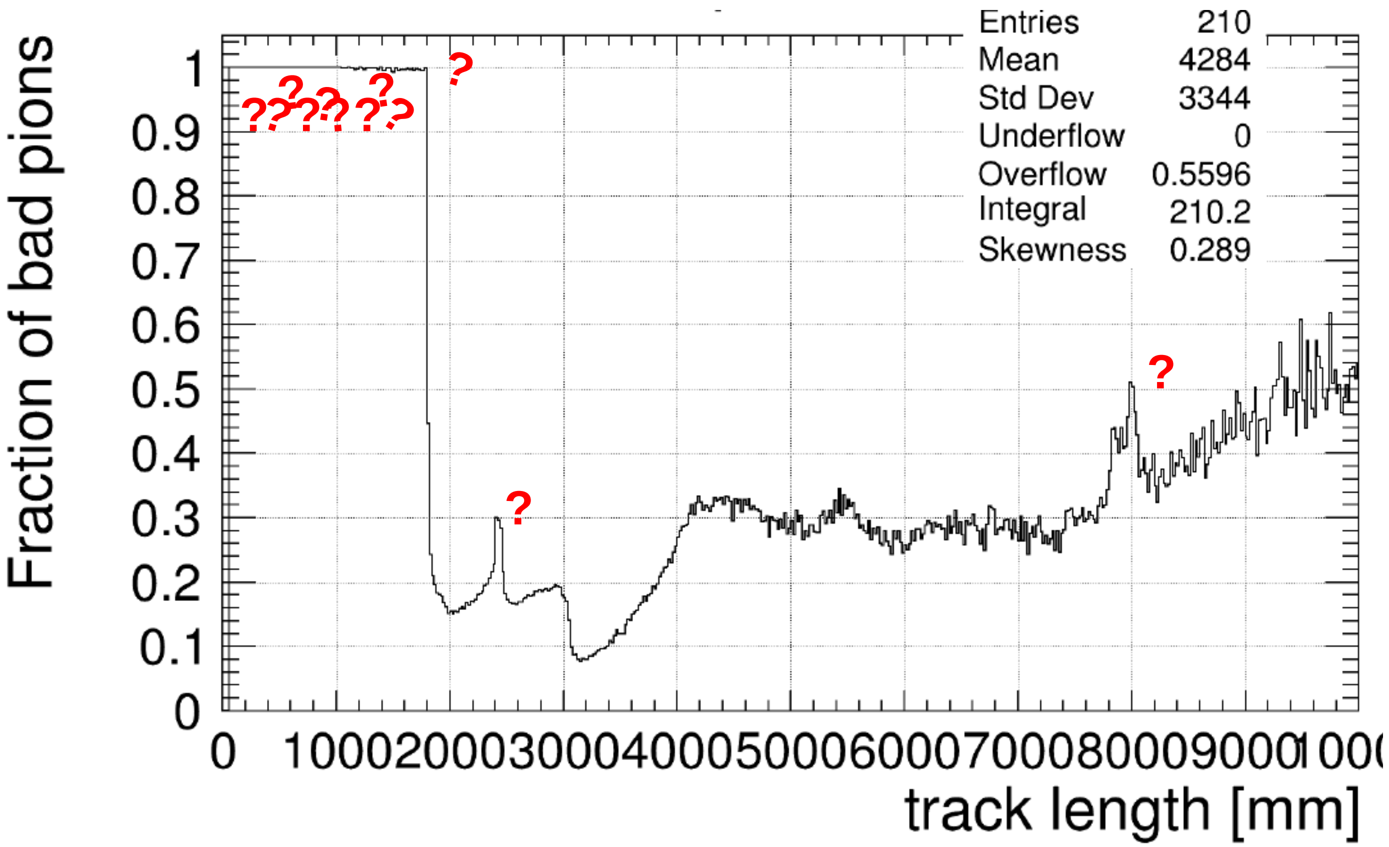


Late hits – usually means bad. Structure is hard to explain

Investigate massive pions: what are they !?

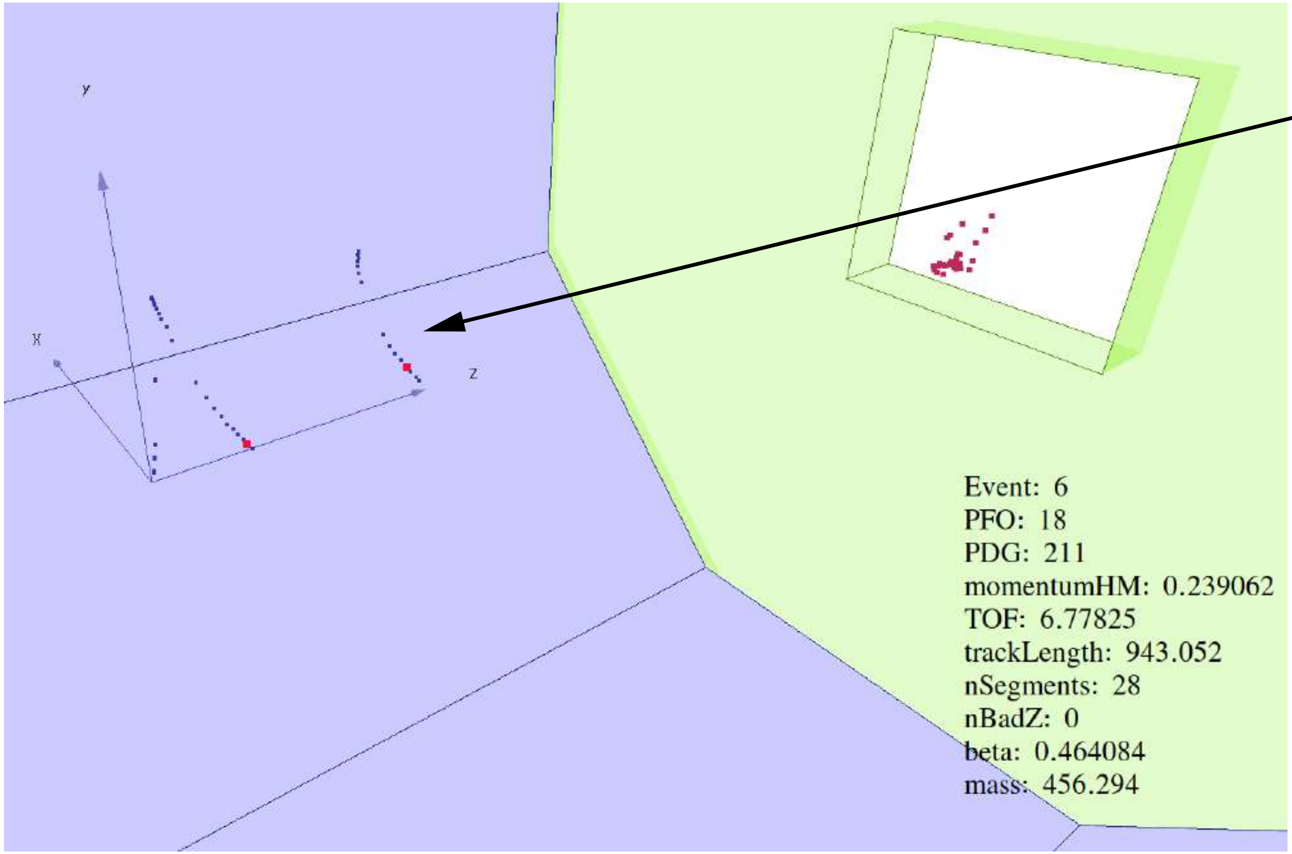
Let’s define **bad pion**:

m > 200 MeV



Track length, bellow 1804 mm !?

Too small track length example



Reason:

Refit failed for the last sub track

→

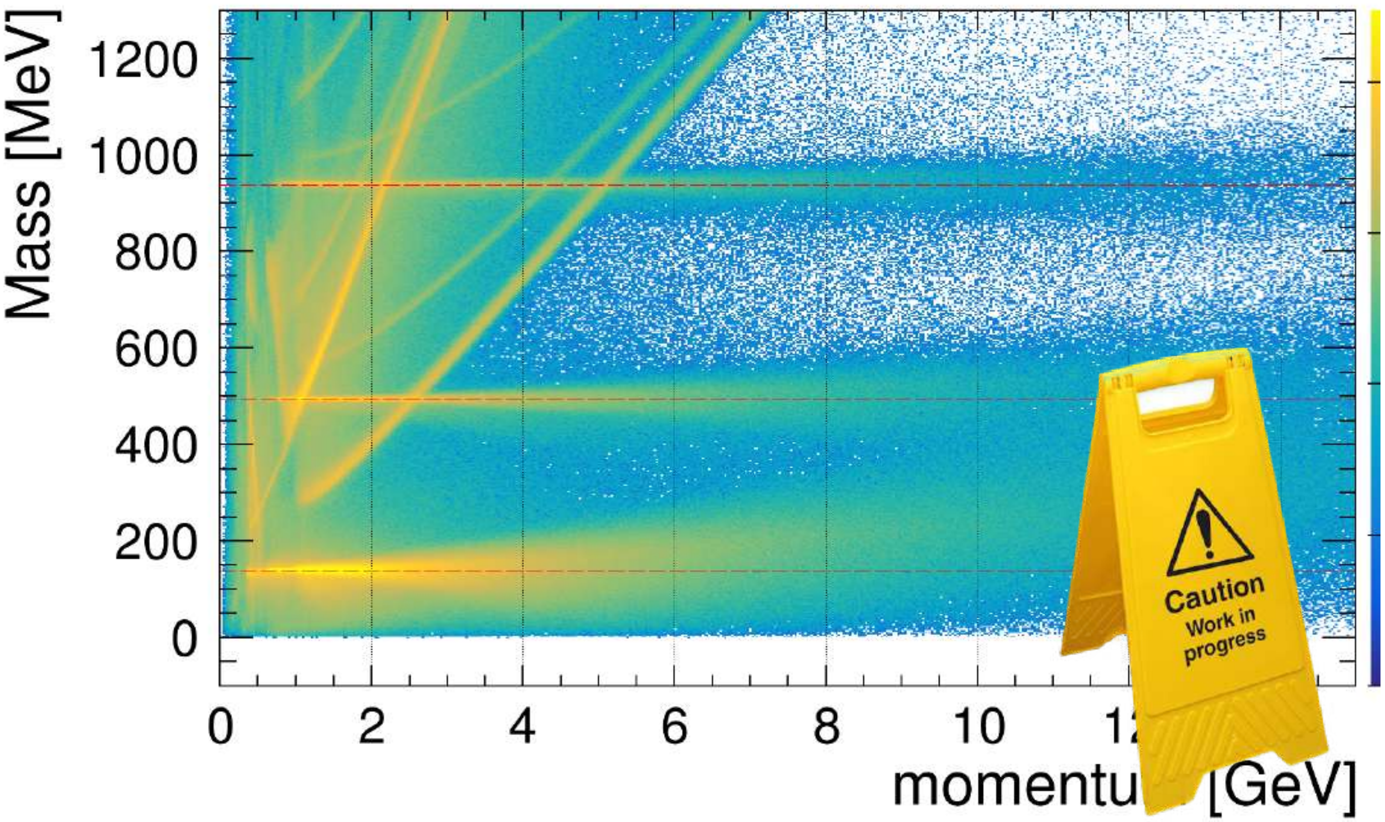
Cannot get trackState::AtCalorimeter

Solution(?):

Extrapolate anyway, using previous sub track

If there is a shower: extrapolating makes sense anyway

Extrapolating to the ECAL anyway



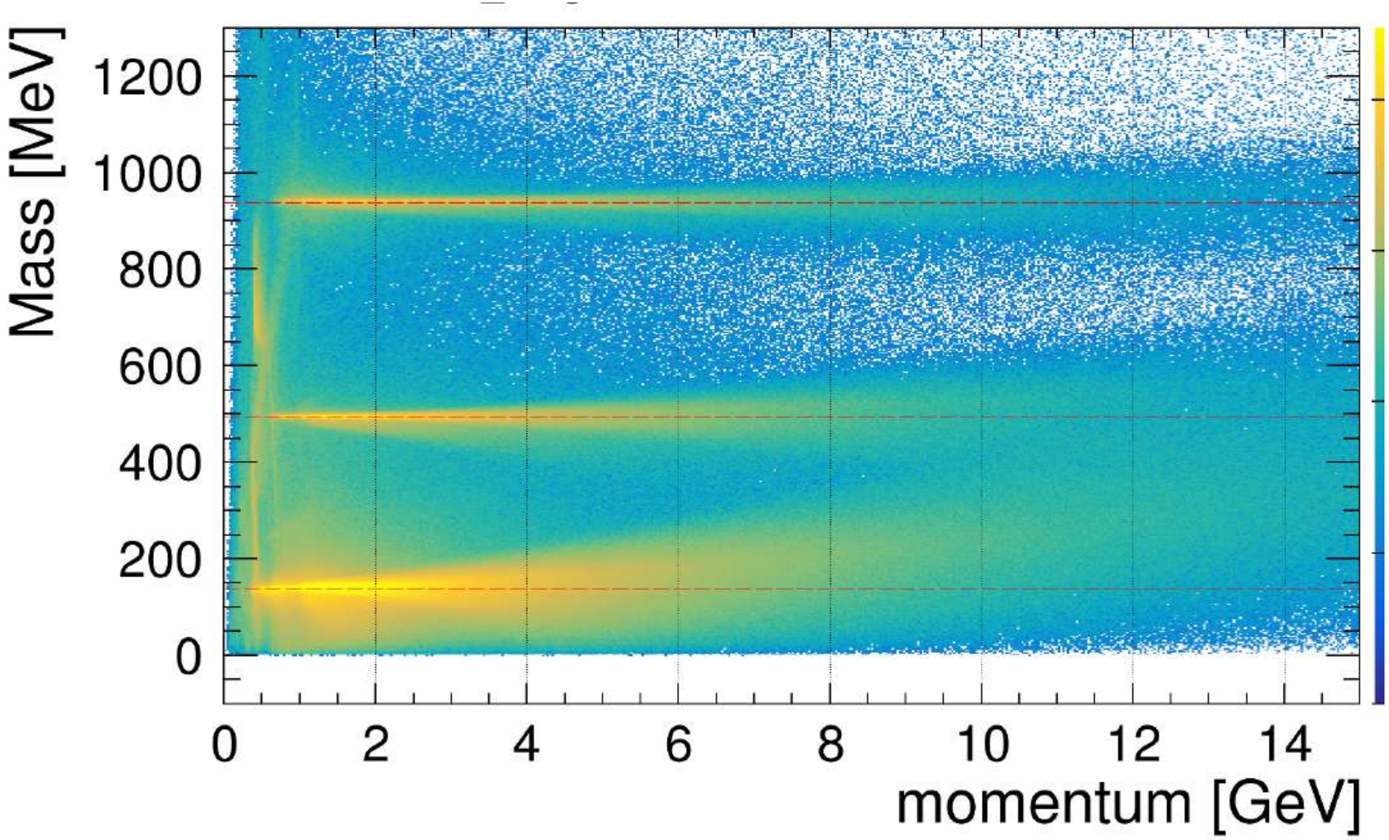
Solution(?):

Extrapolate anyway, using previous sub track

Yesterdays late evening plot.
Probably a bug. Need more coffee and take another look

P.S. main bands became thinner though!

Filtering bad track length (< 1804 mm)

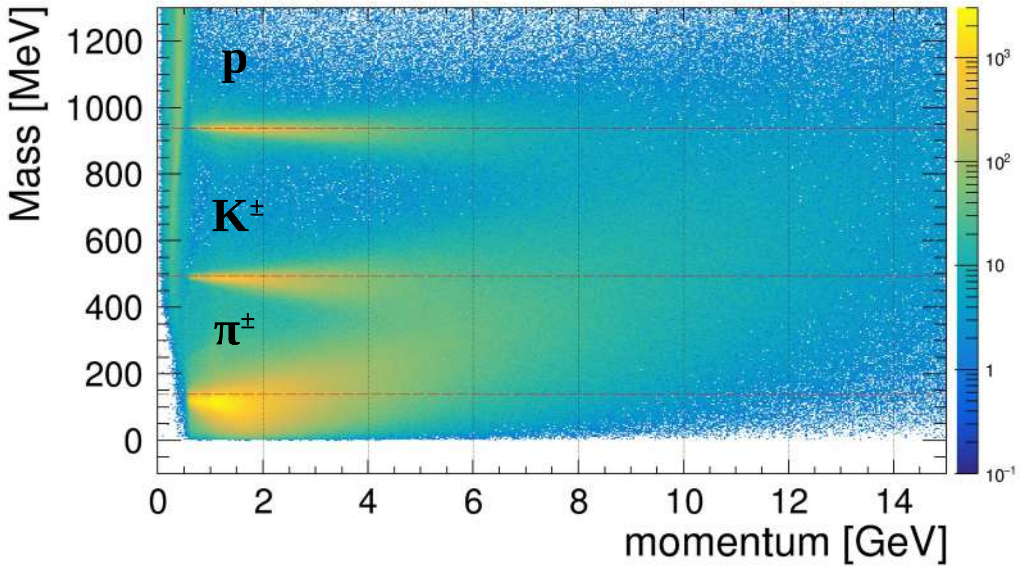


Helps, but doesn’t solve the problem completely

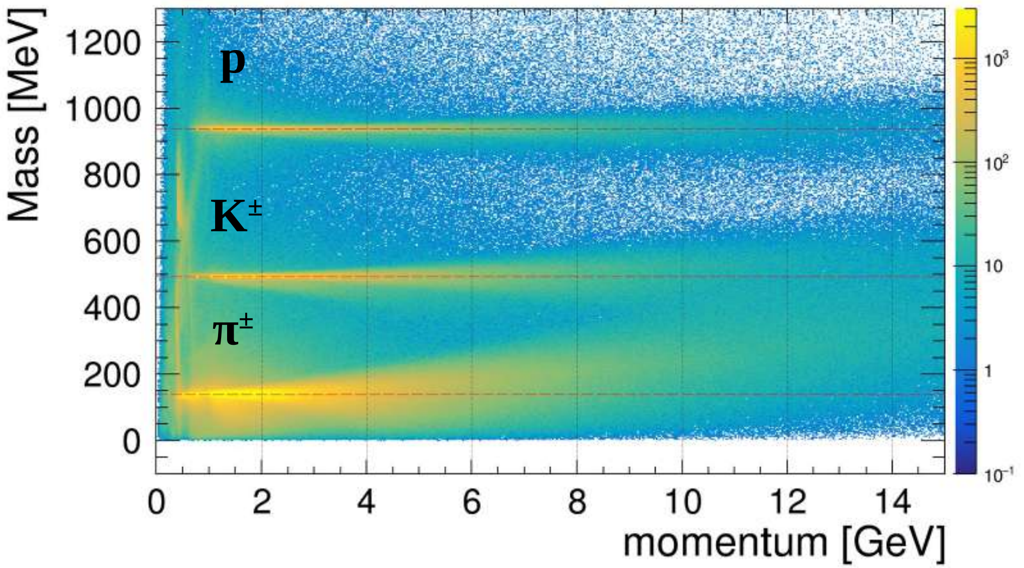
Summary

- Track length is crucial for TOF and we improved a lot ove the years.
  Might not be the end. Some investigations are still ongoing

IDR (2020)



NOW (2023)



Summary

- ❖ Track length is crucial for TOF and we improved a lot ove the years.
  Might not be the end. Some investigations are still ongoing

- ❖ Track length reconstruction is not trivial in the ILD (TPC: 220 radial hits)
  Might be challenging in the detectors with Si tracker (SiD, CLD, CLICdp...)

Summary

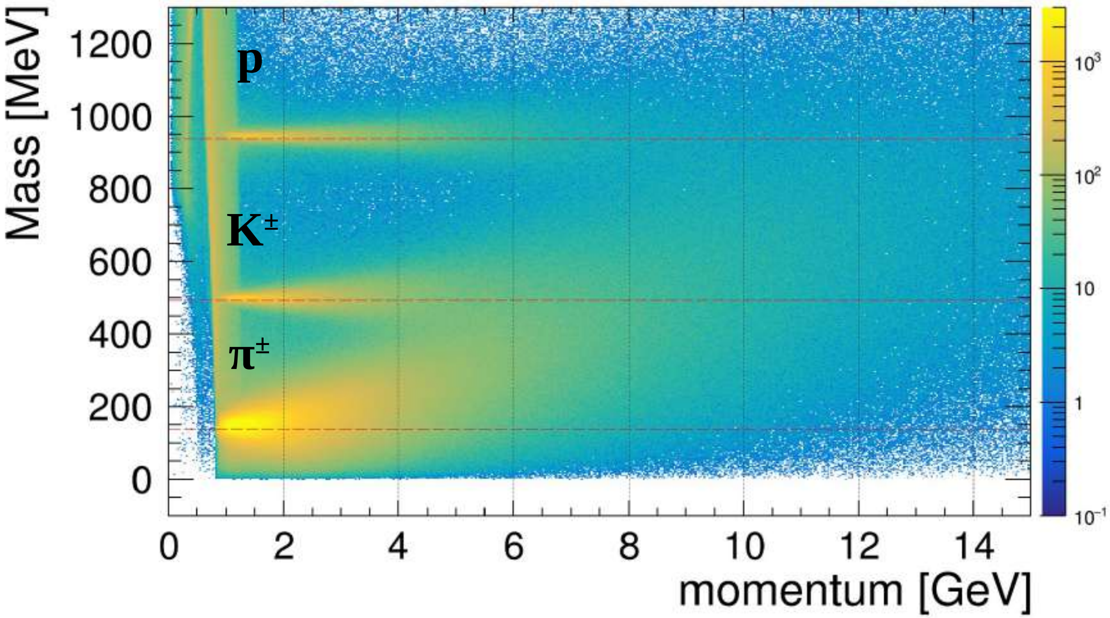
- Track length is crucial for TOF and we improved a lot ove the years.
  Might not be the end. Some investigations are still ongoing

- Track length reconstruction is not trivial in the ILD (TPC: 220 radial hits)
  Might be challenging in the detectors with Si tracker (SiD, CLD, CLICdp...)

- Momentum does not play a crucial role in the mass formula. But curvature changes
  have a big role for the track length reconstruction

BACK UP

BACKUP: Development history of the track length



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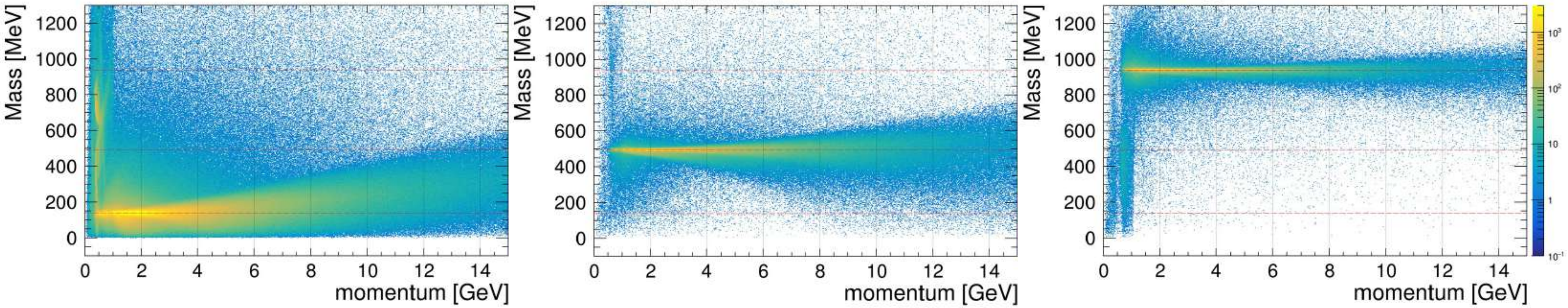
$$\text{if: } (\ \Delta\varphi > \pi\ )\ \Delta\varphi = 2\pi - \Delta\varphi$$

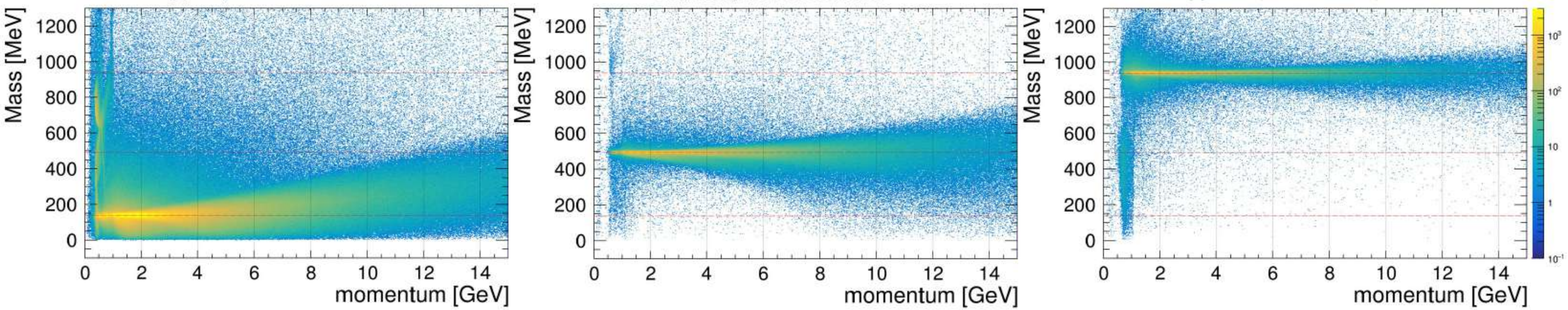
Fix phi flip bug

BAKUP: Looking deeper at individual particles

Only pions | **Only kaons** | **Only protons**



Excluding shower confusion cases



BAKUP: Looking deeper at individual particles

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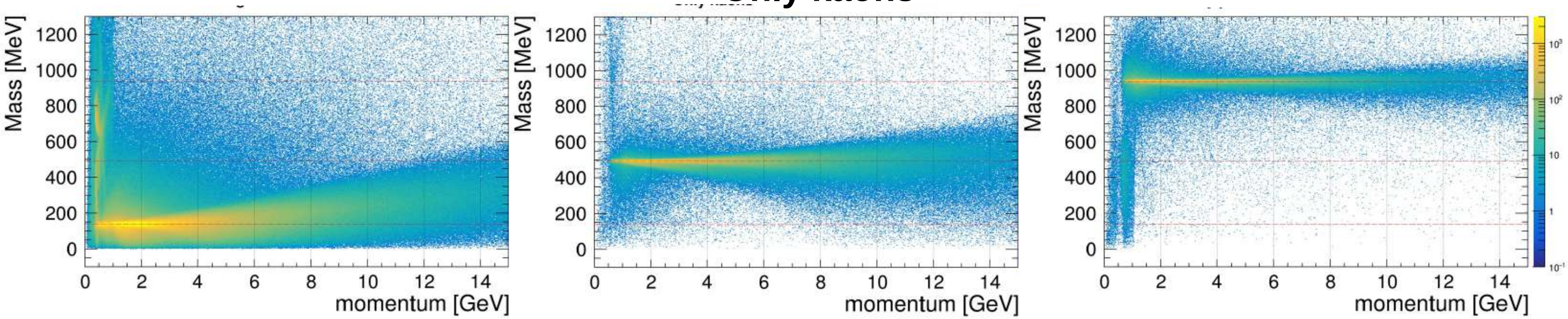

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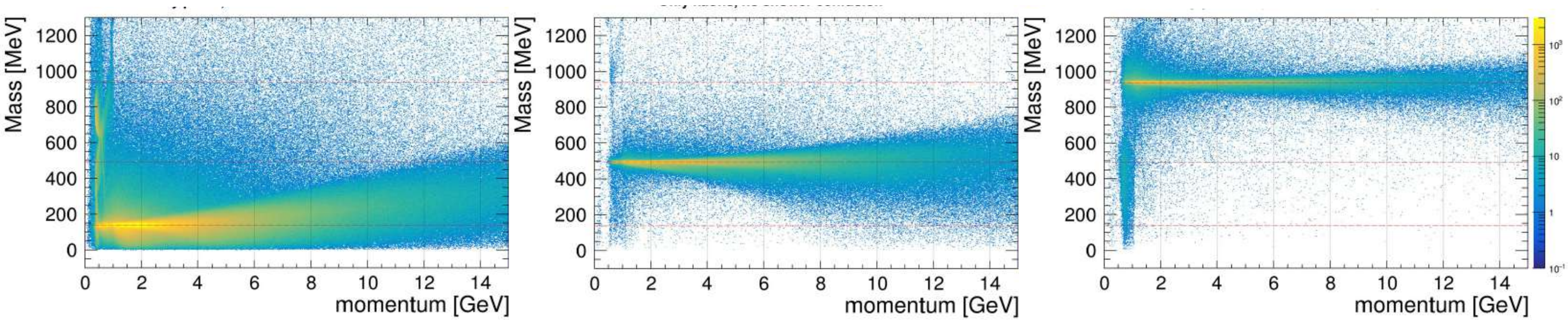


BACKUP: MC samples

Used files:

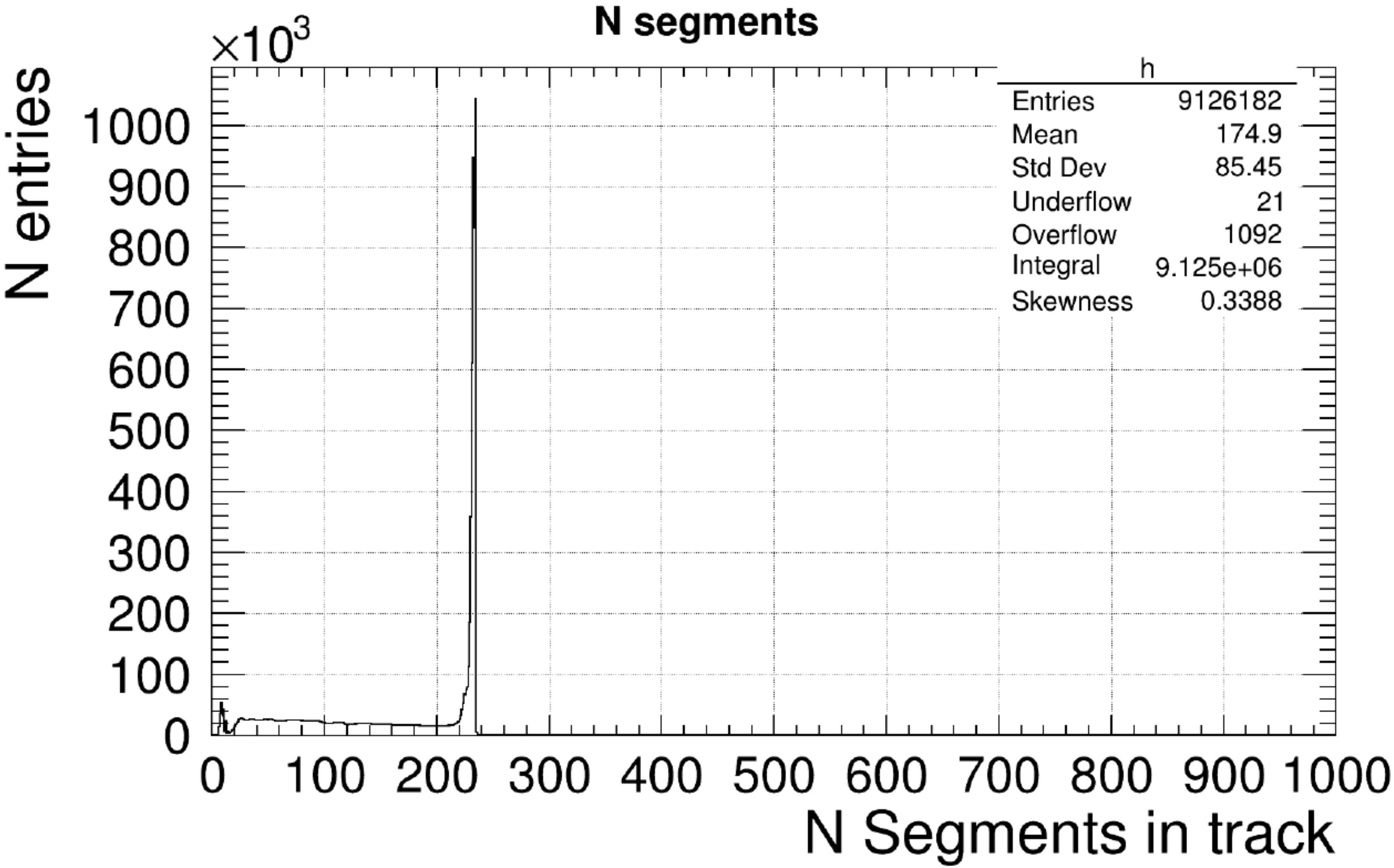
2f_Z_hadronic_250GeV_eL_pR

2f_Z_hadronic_250GeV_eR_pL

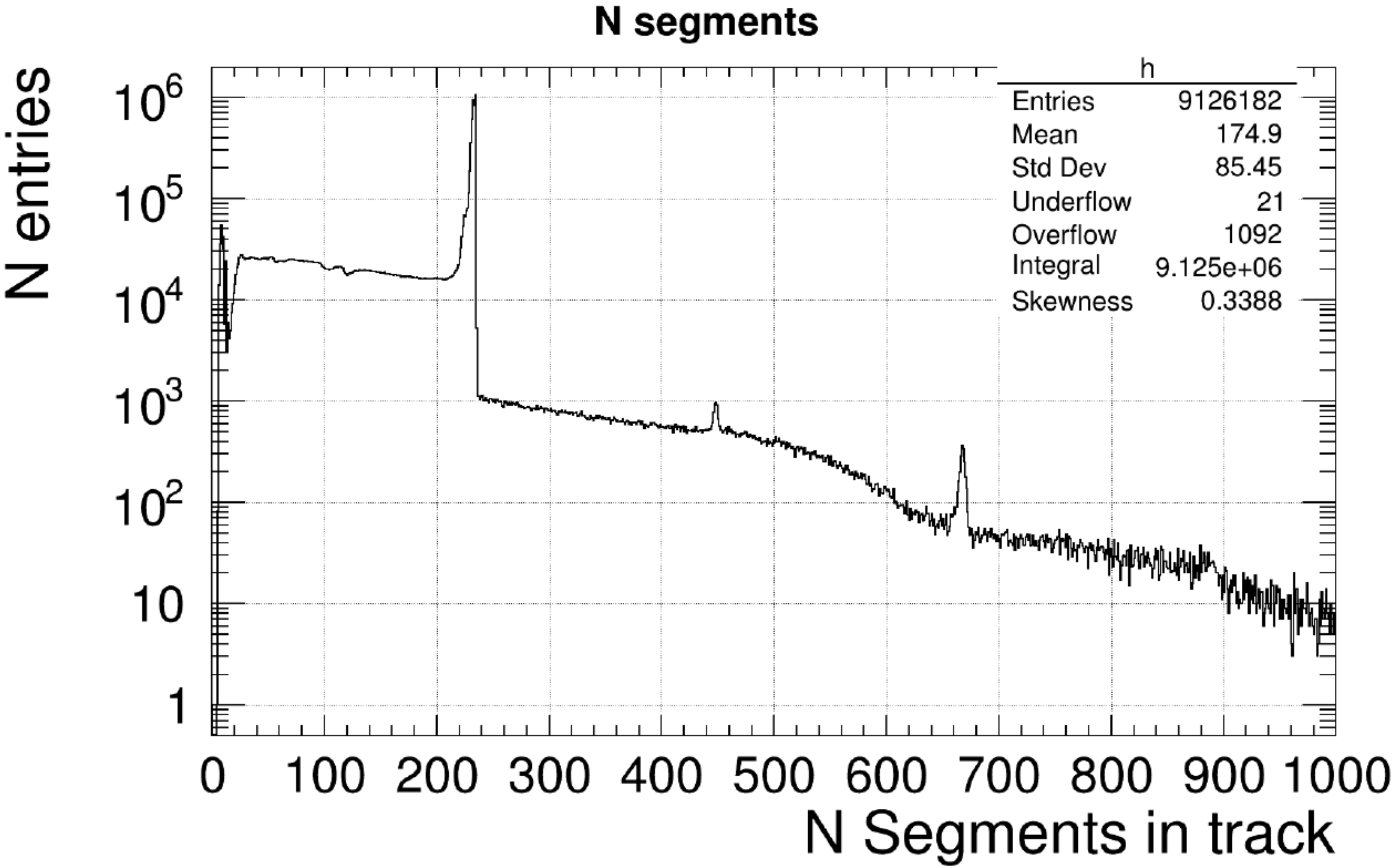
4f_WW_hadronic_250GeV_eL_pR

4f_WW_hadronic_250GeV_eR_pL

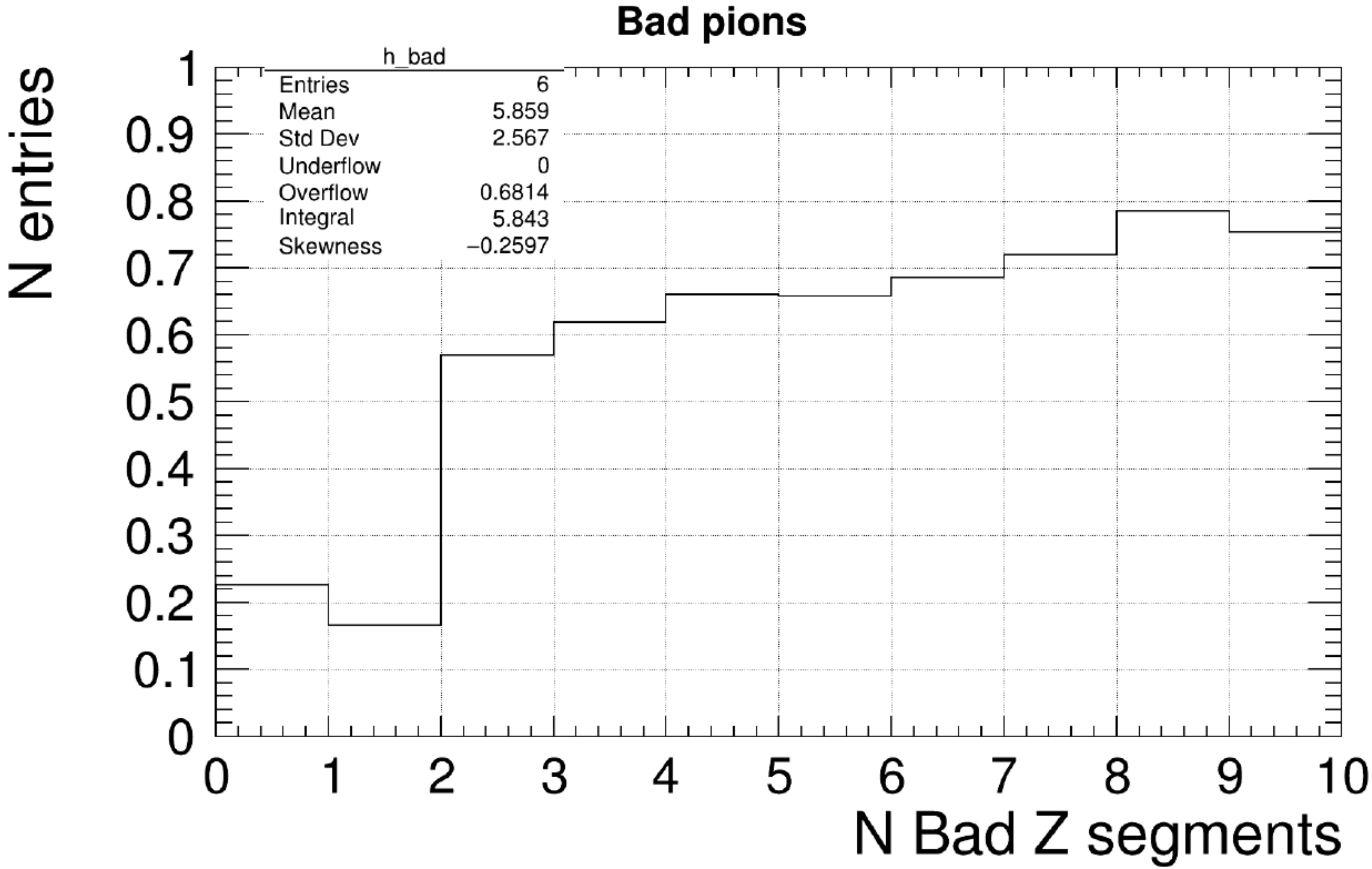
BACKUP: N hits per track (linear scale)



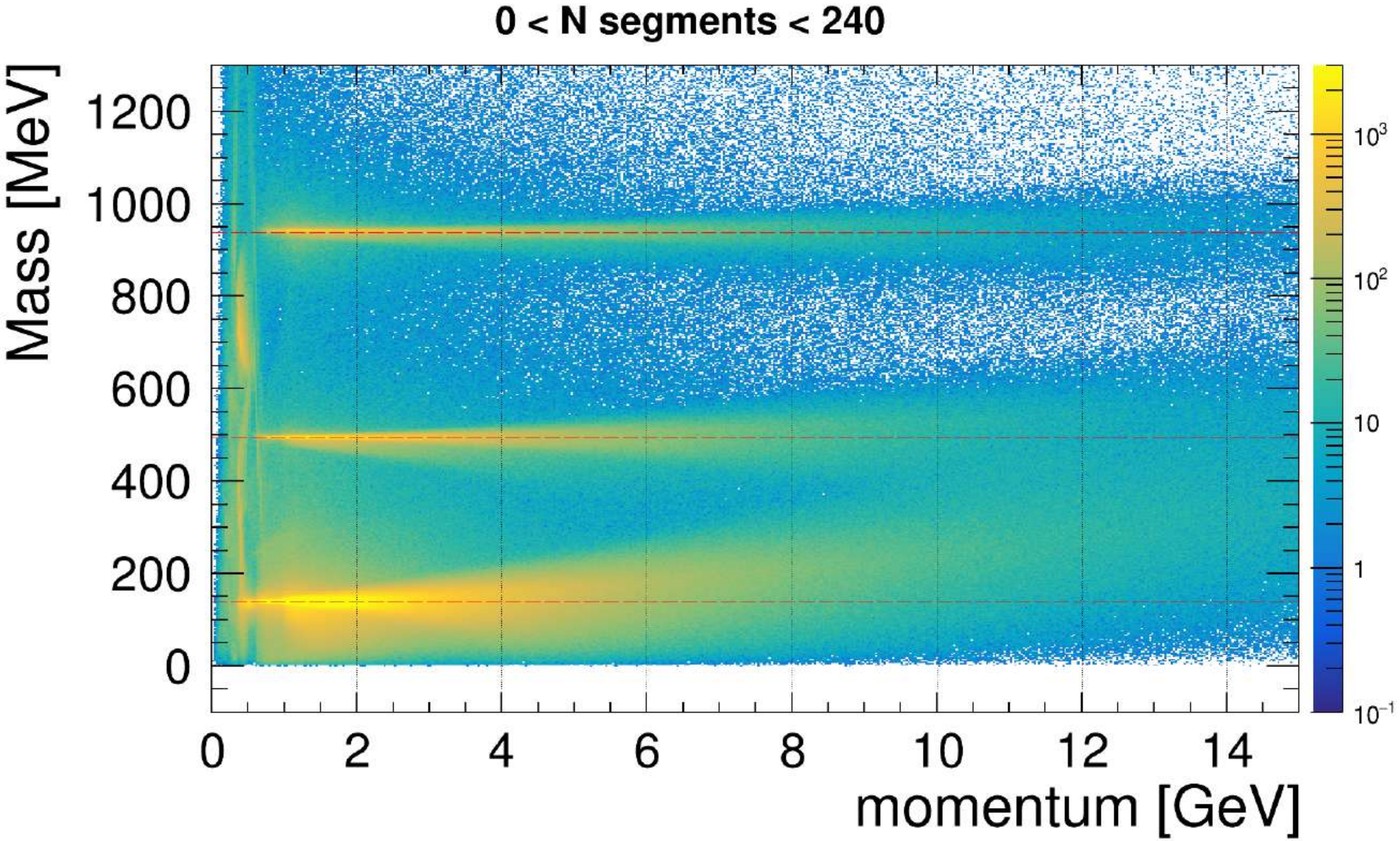
BACKUP: N hits per track (log scale)



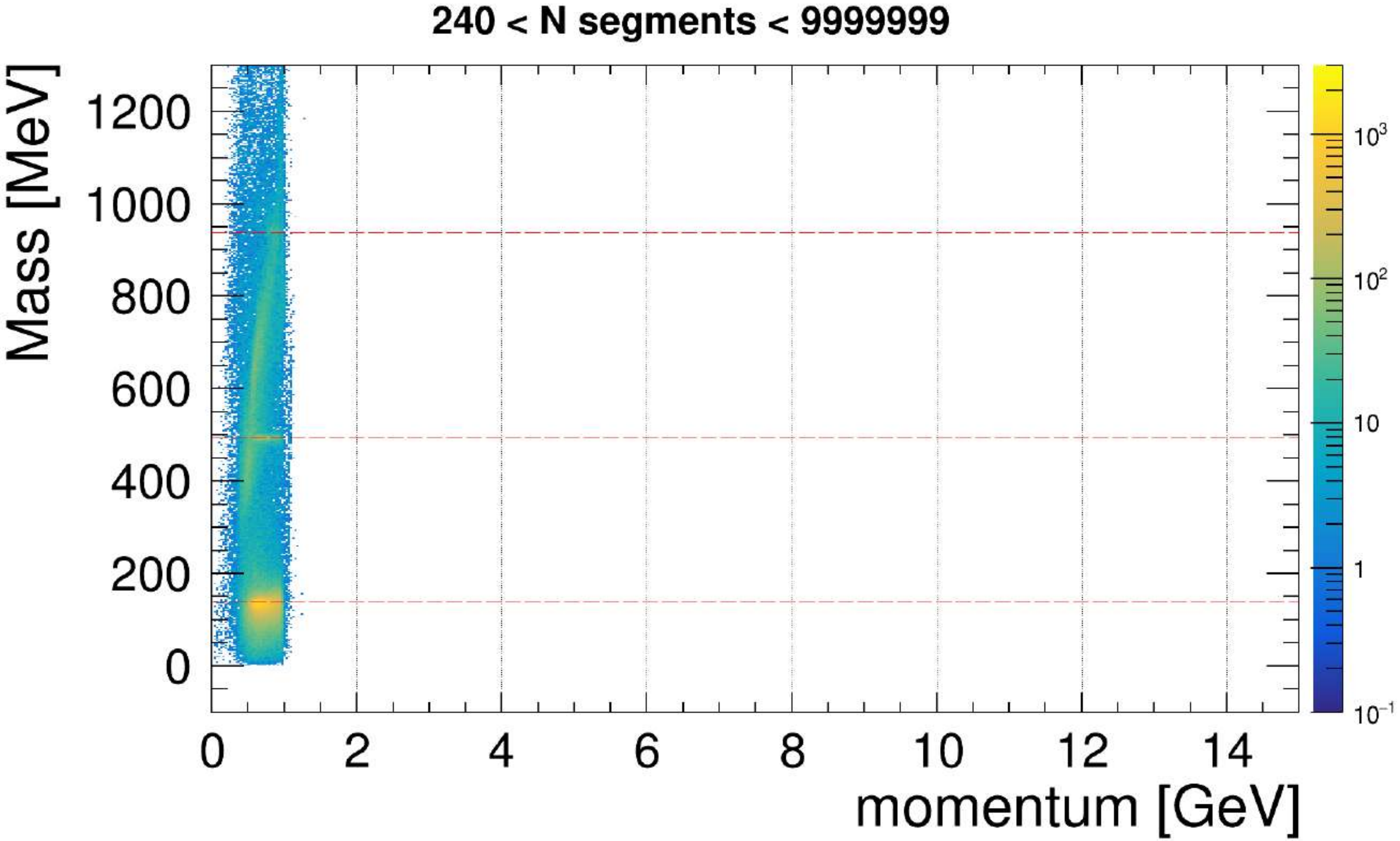
BACKUP: Check sign agreement between Δz and tanλ



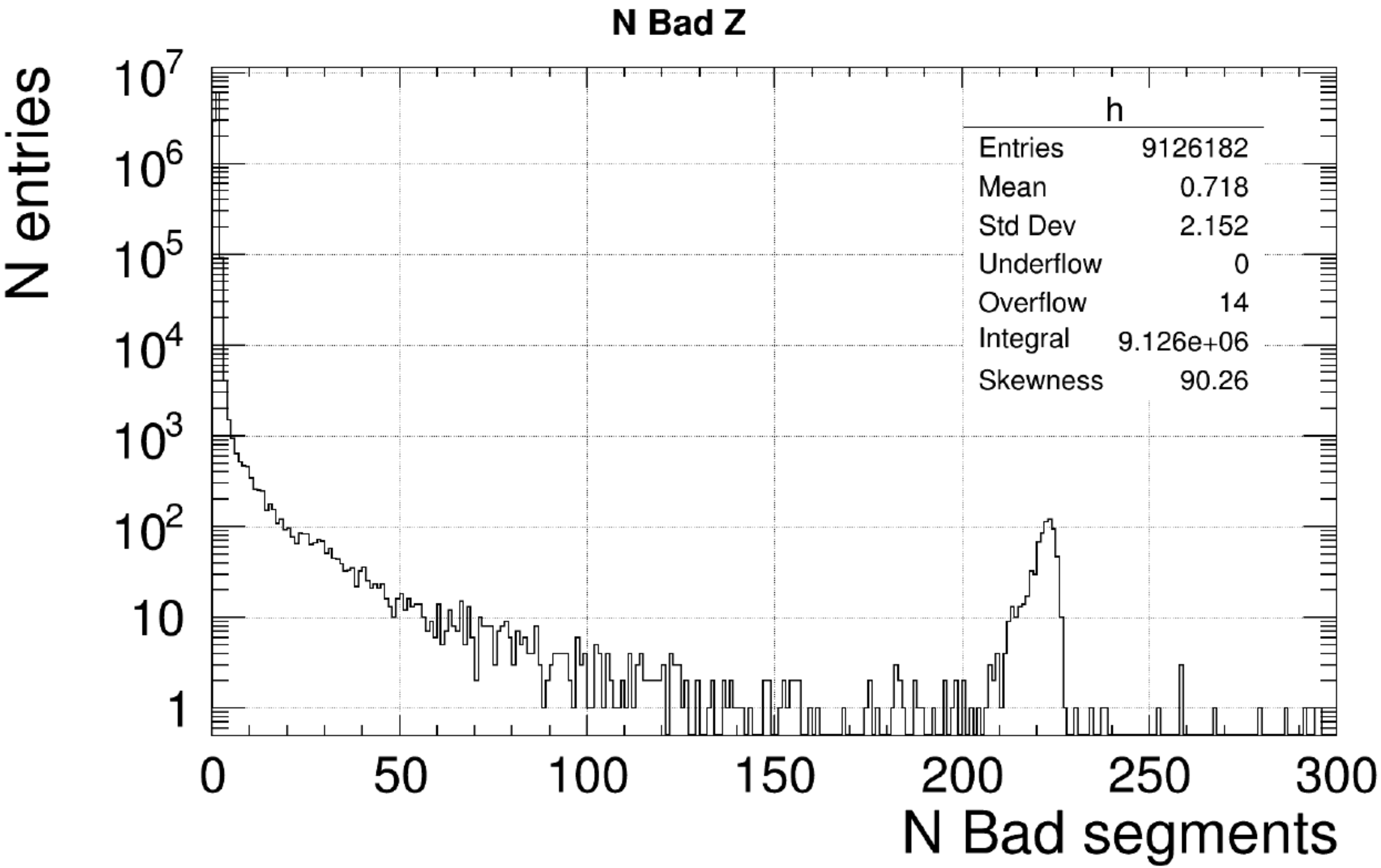
BACKUP: Only short tracks



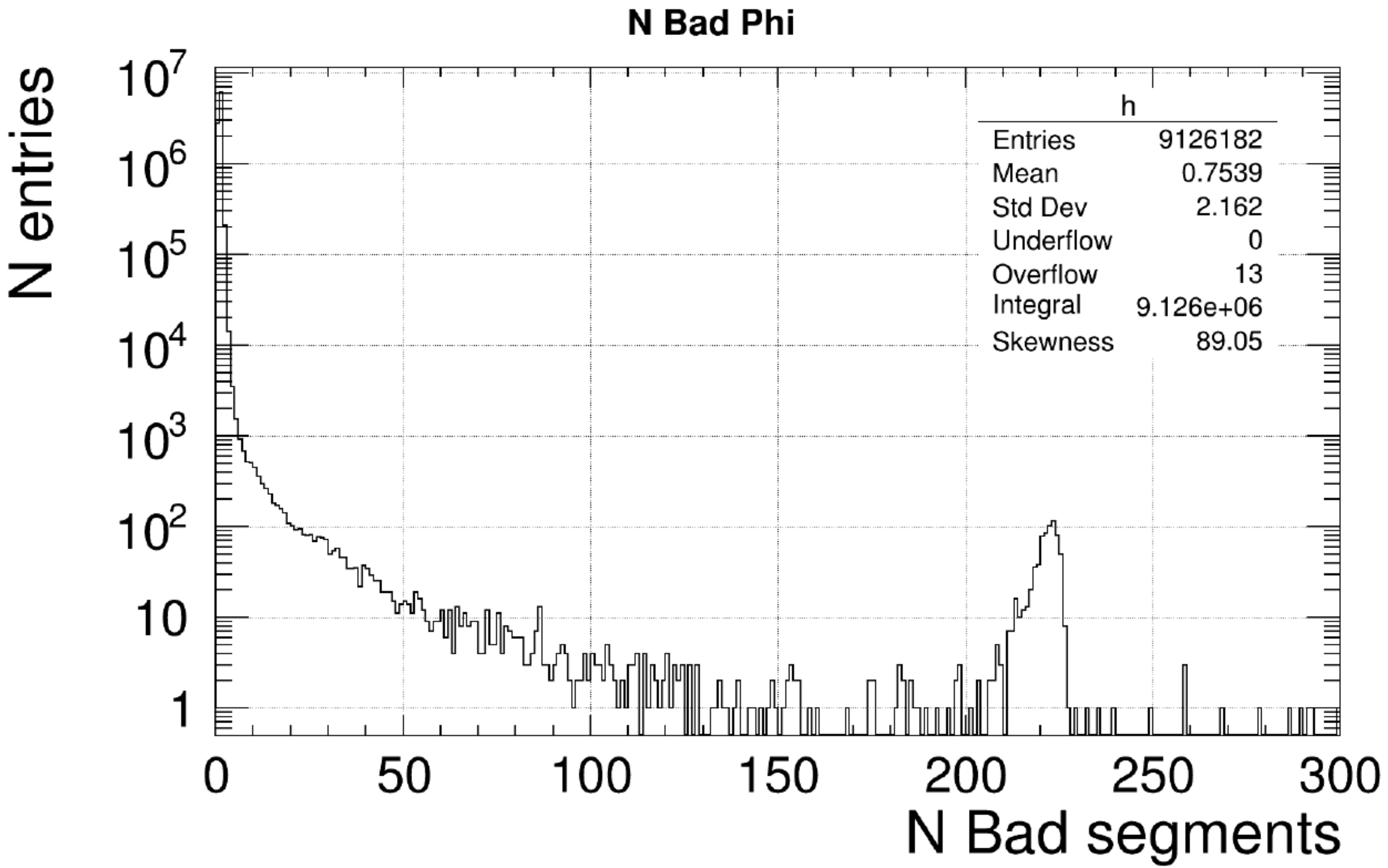
BACKUP: Only long tracks



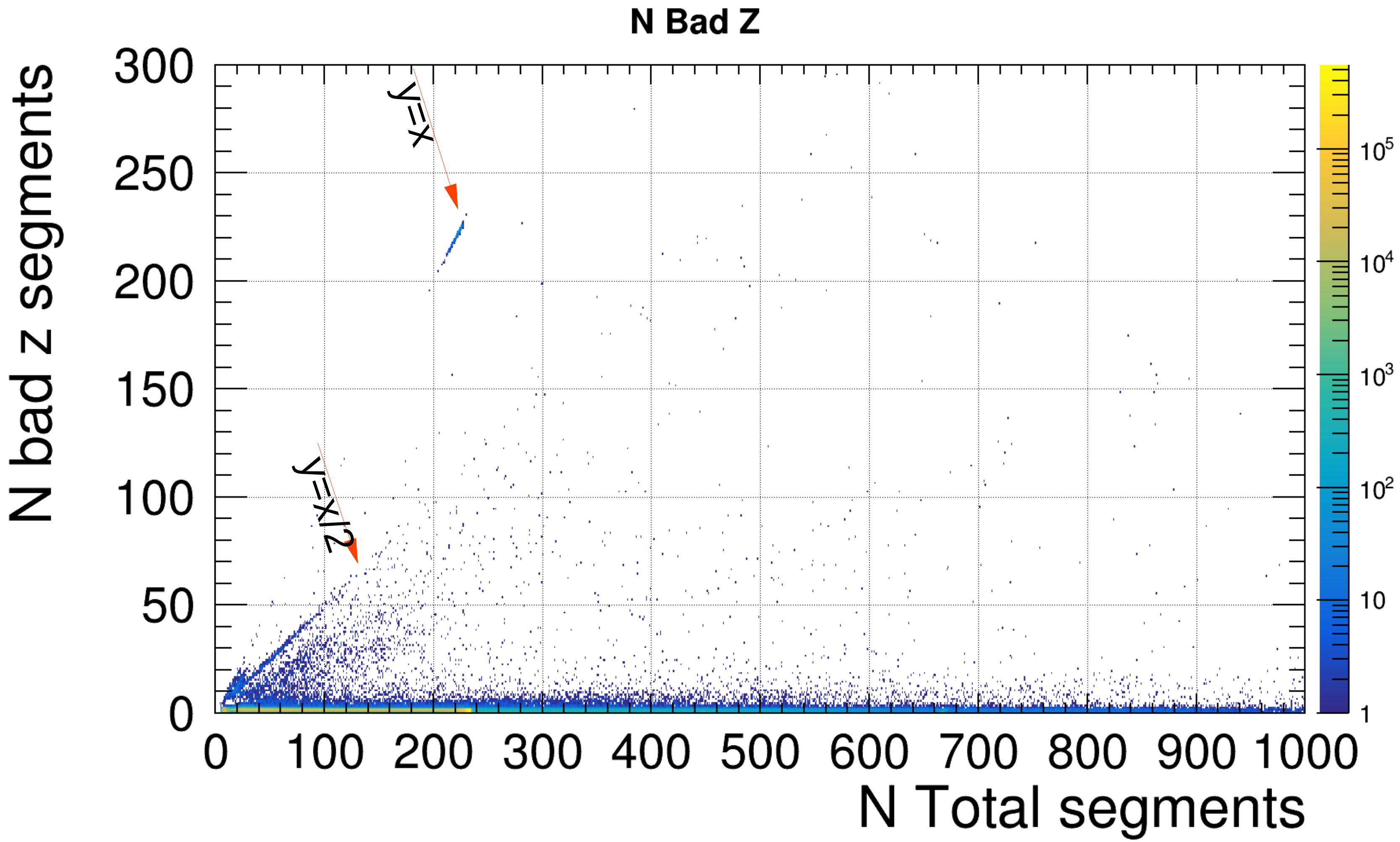
BACKUP: Bad sign agreement between Δz and tanλ



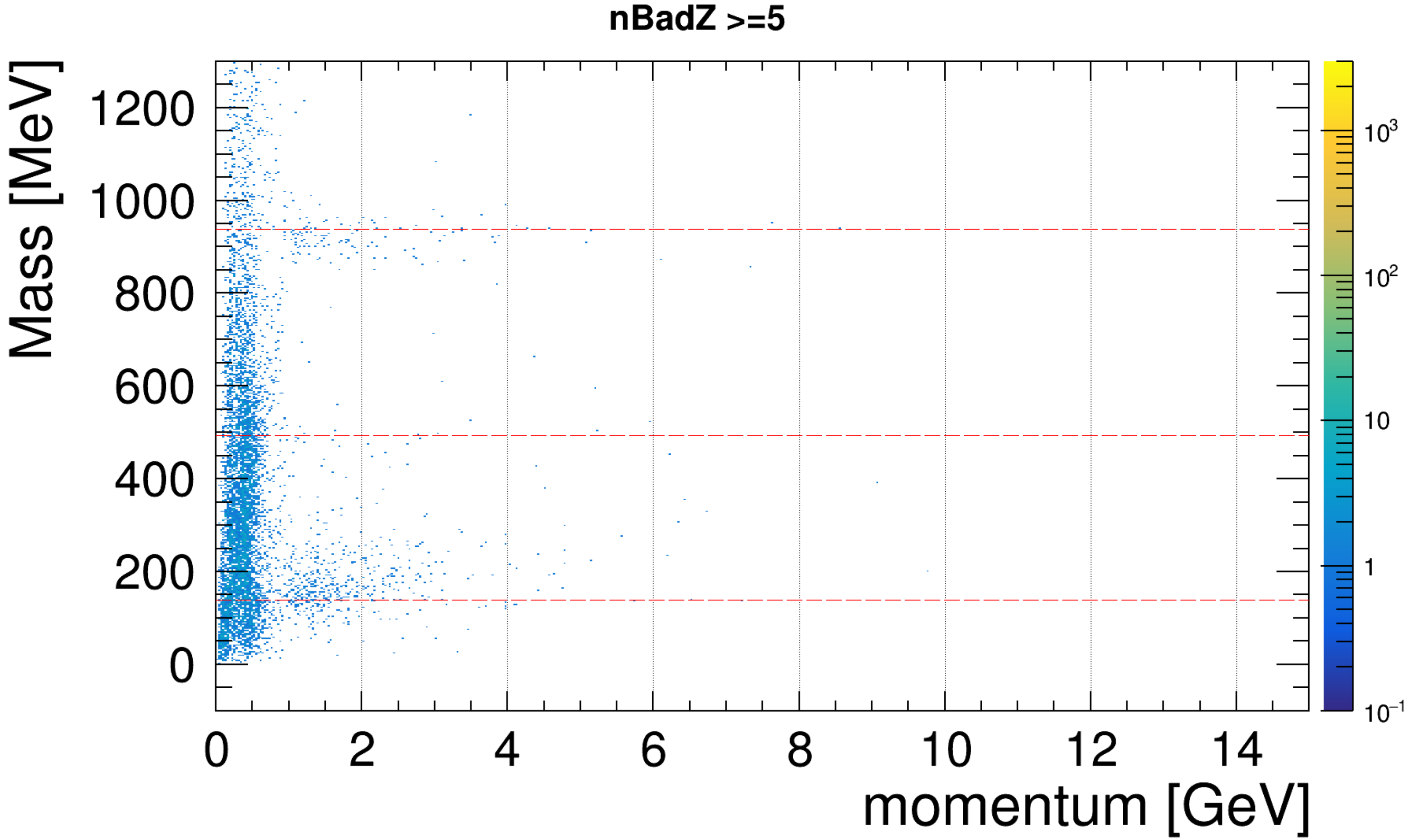
BACKUP: Bad sign agreement between Δφ and Ω



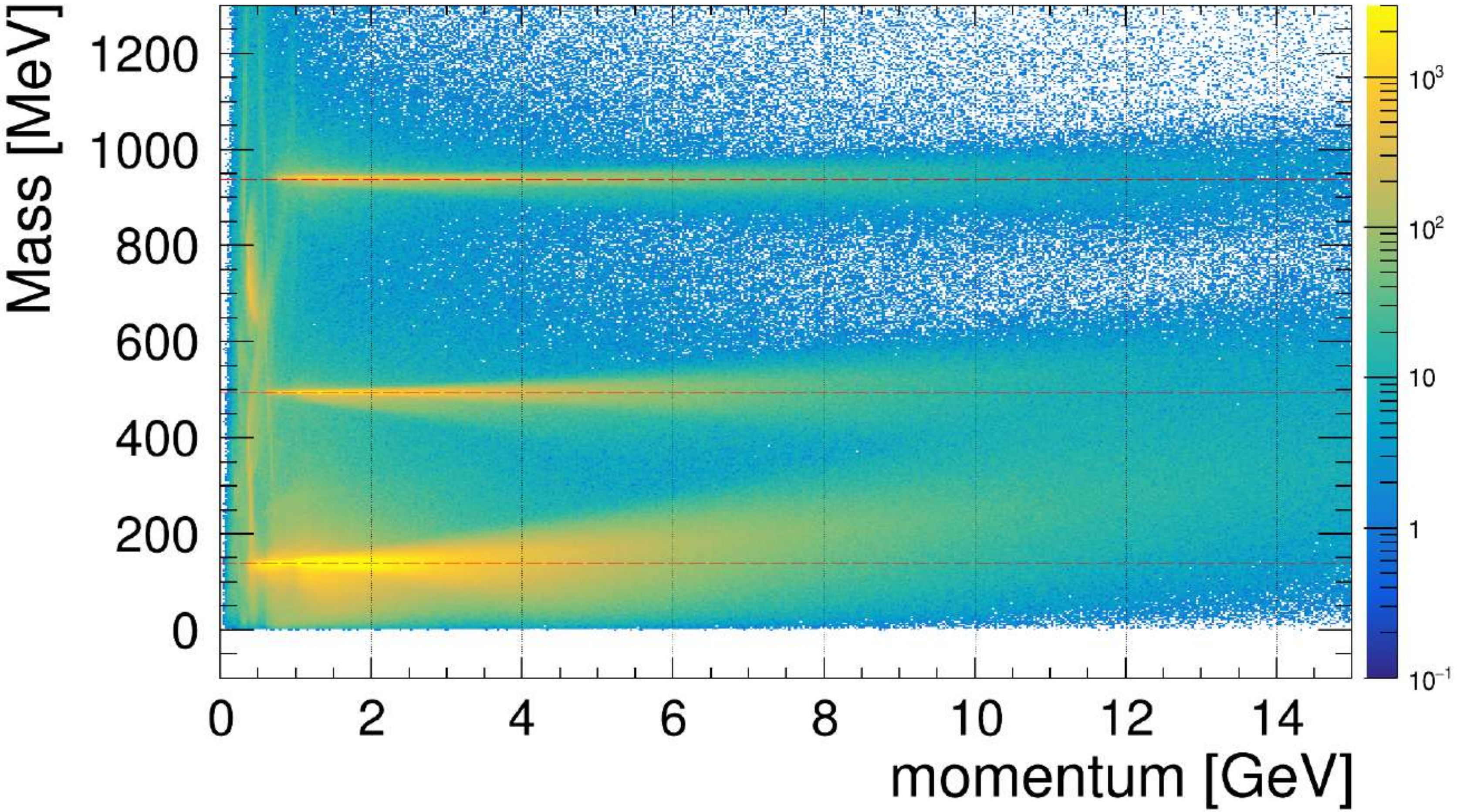
BACKUP: N bad z segments vs N total segments



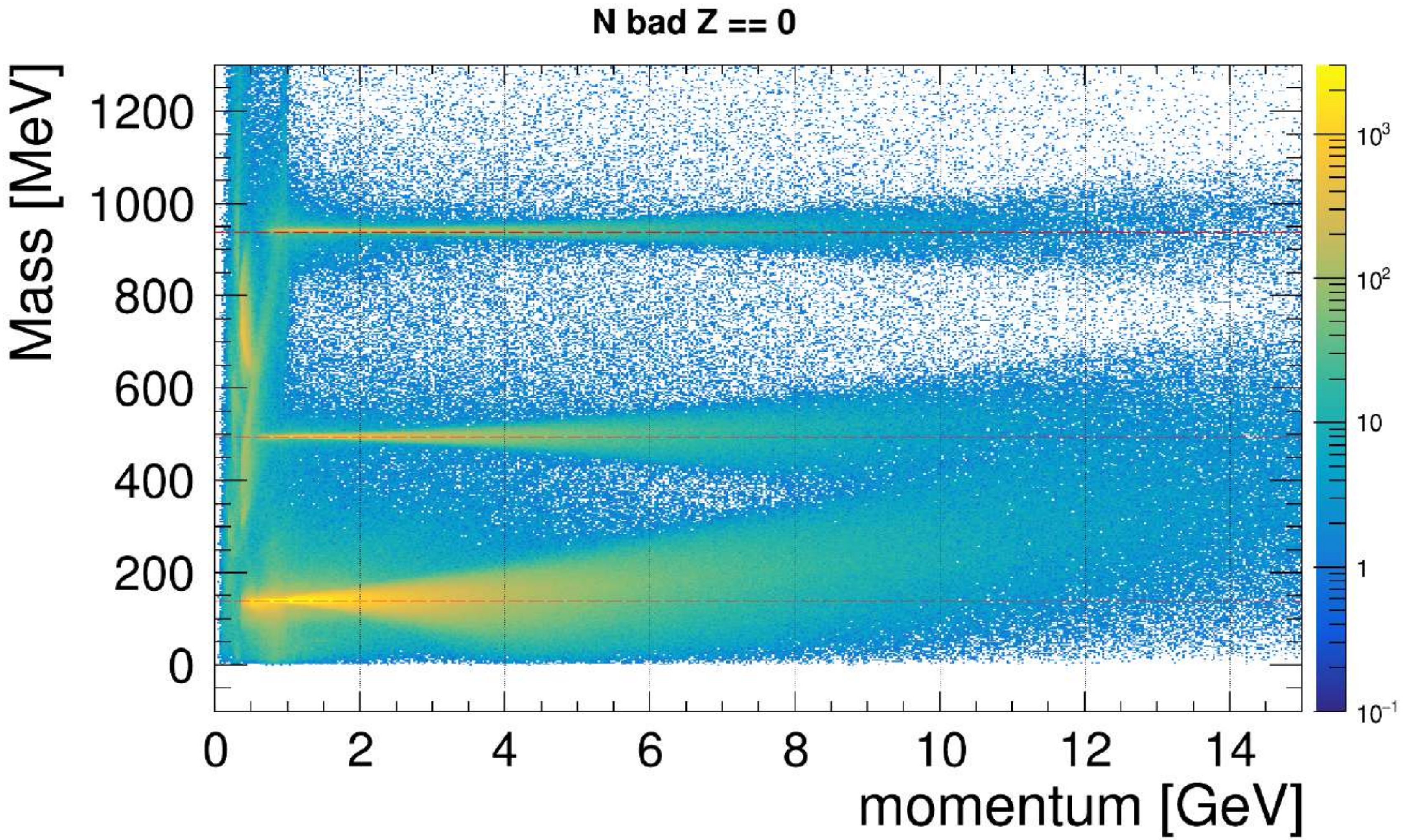
BACKUP: A lot of bad segments



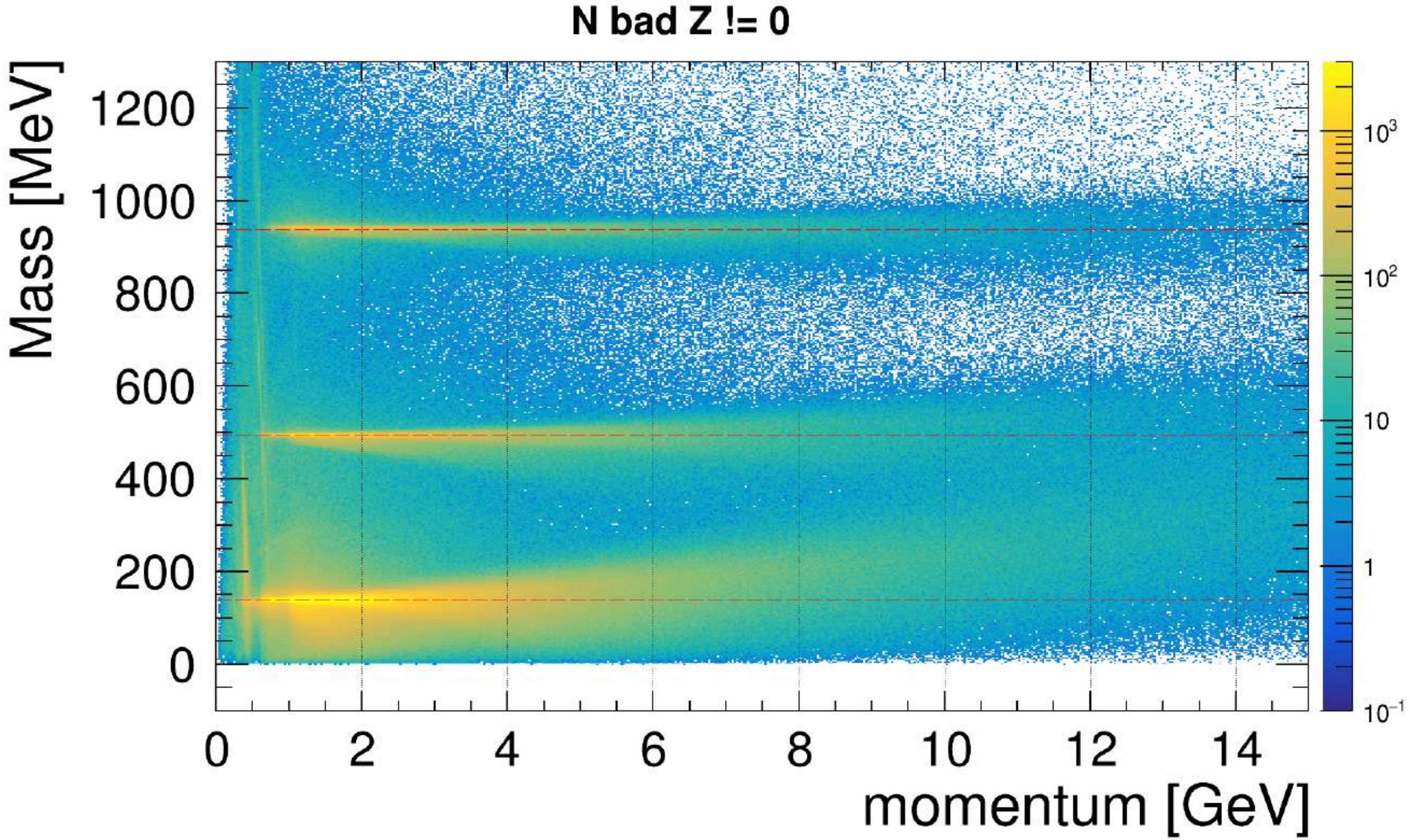
BACKUP: Less than 5 bad segments

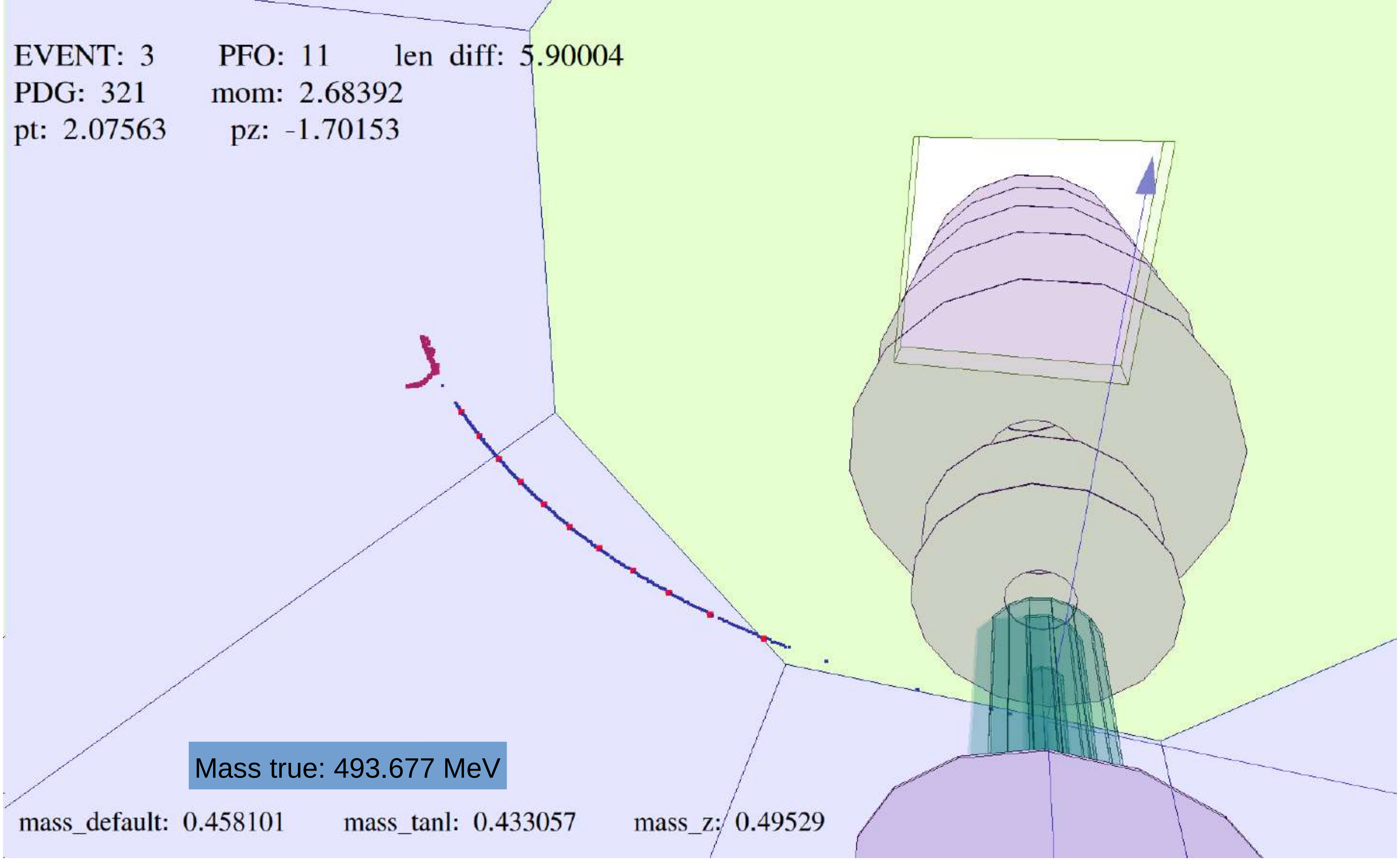


BACKUP: No bad segments at all

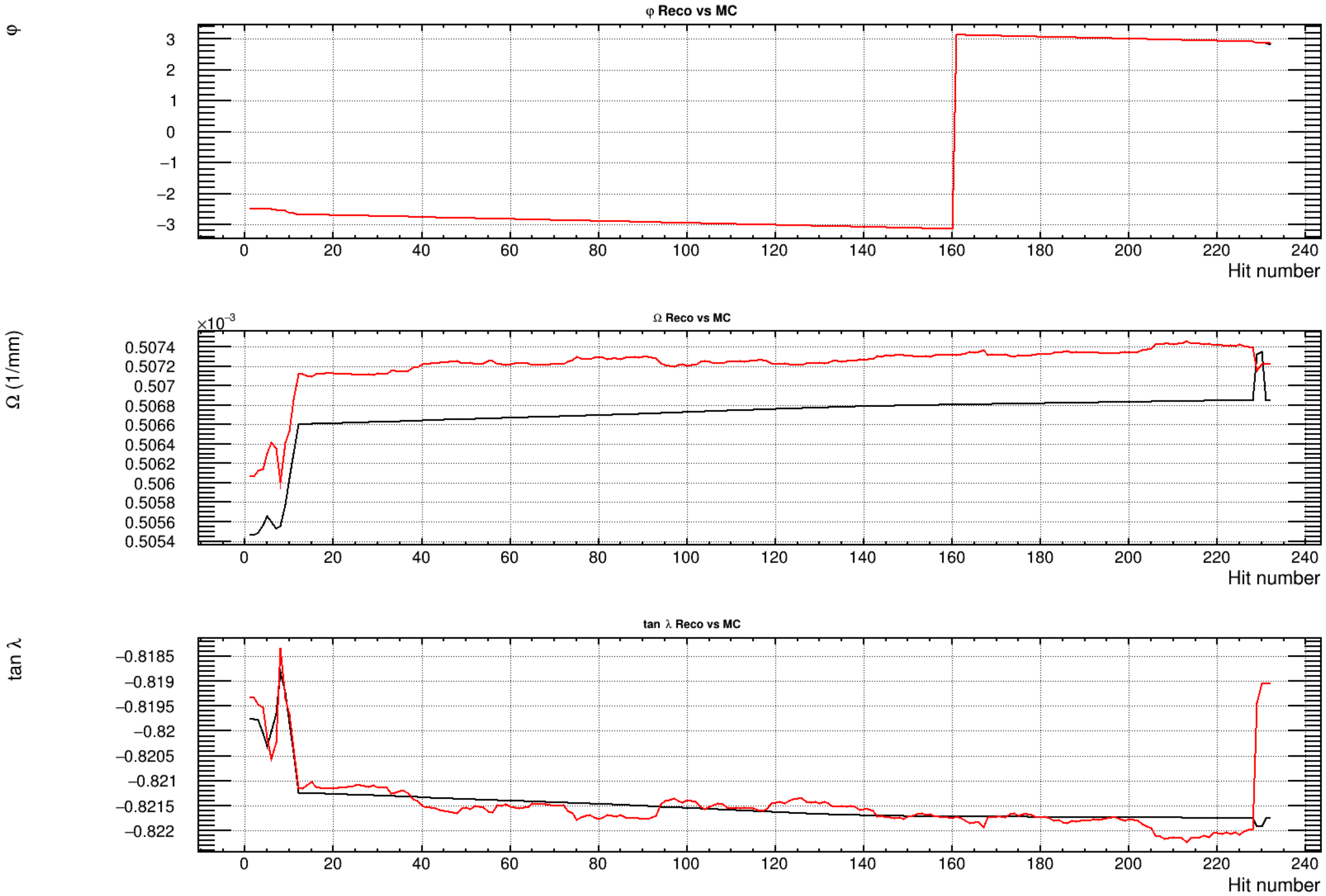


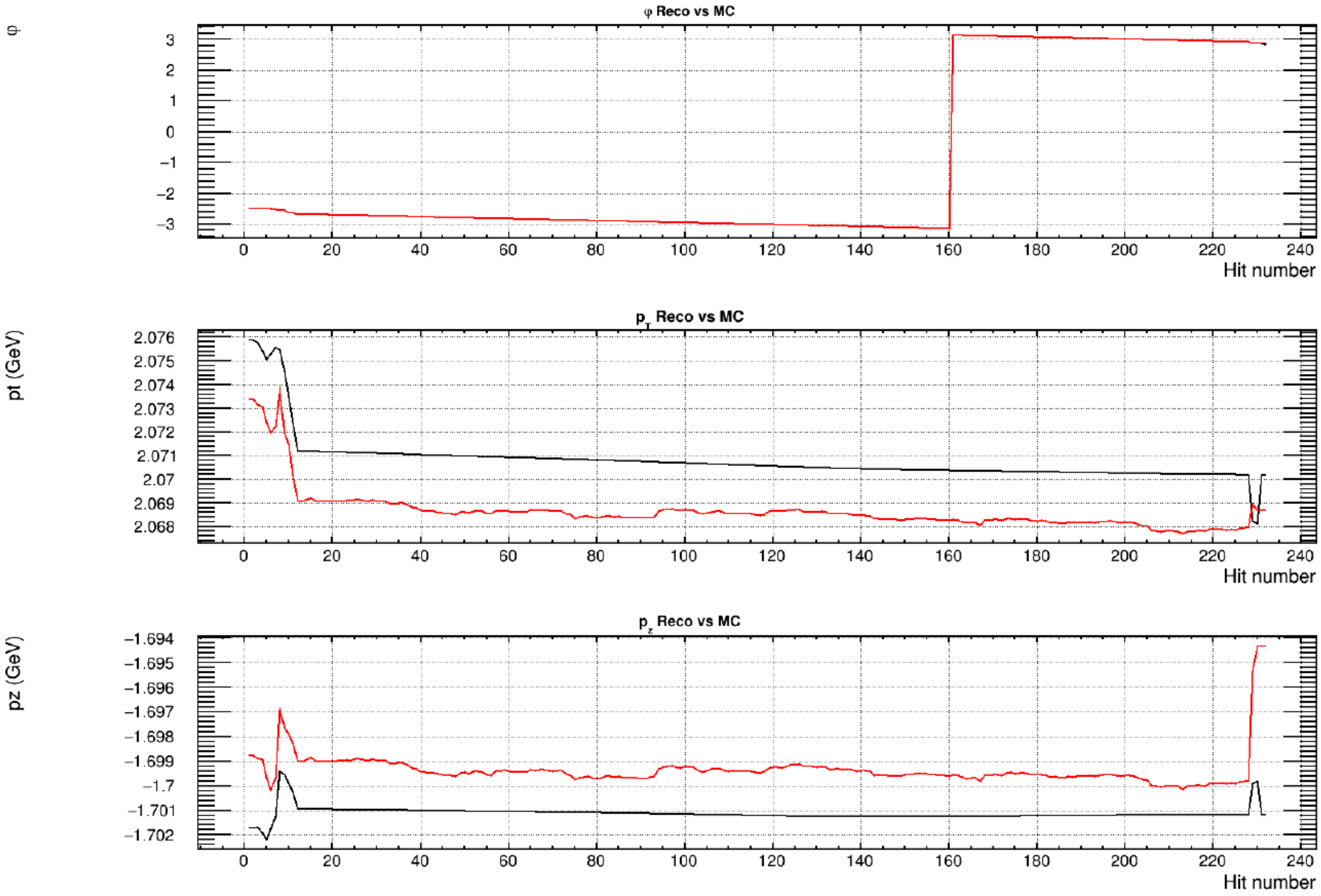
BACKUP: At least one bad segments

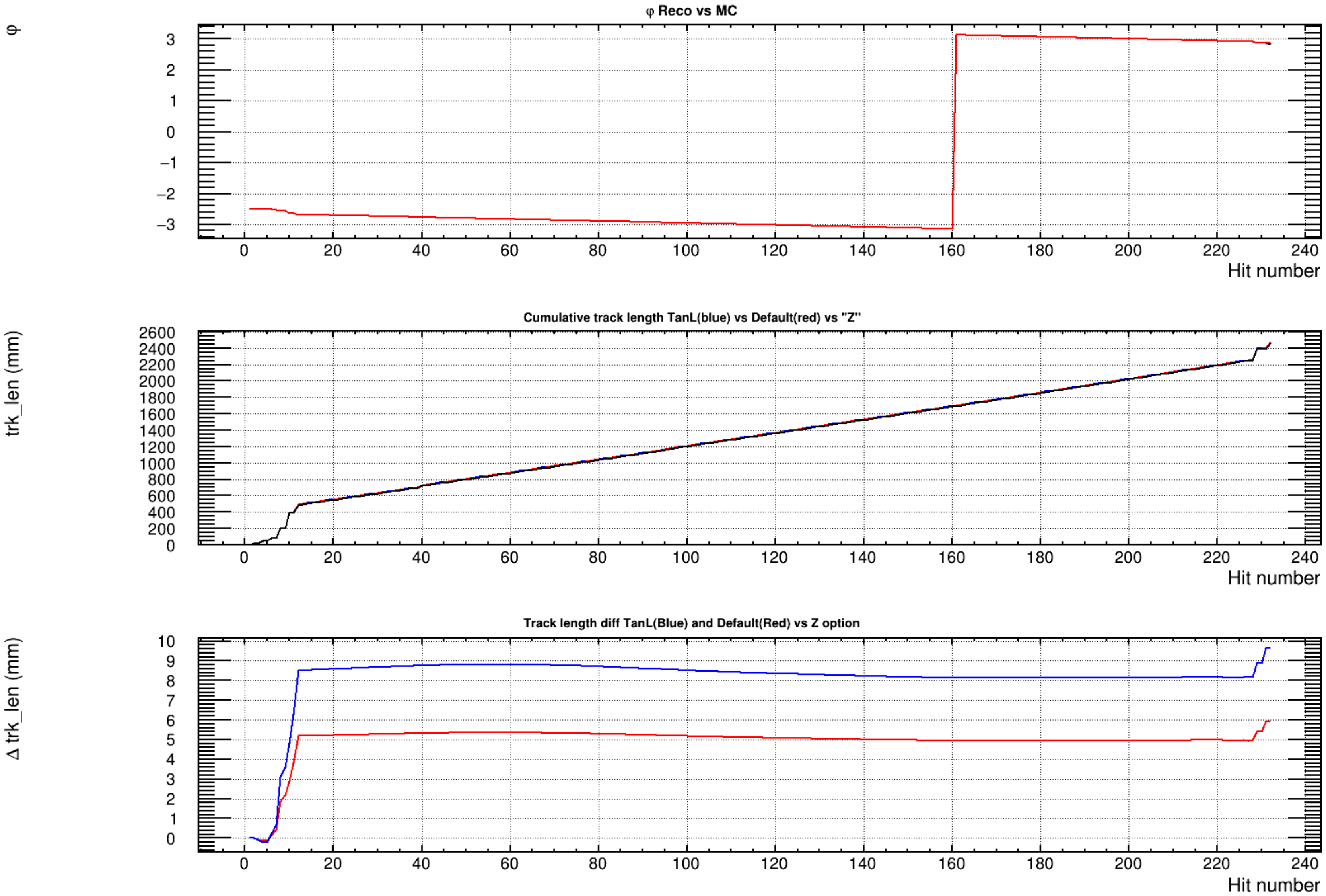


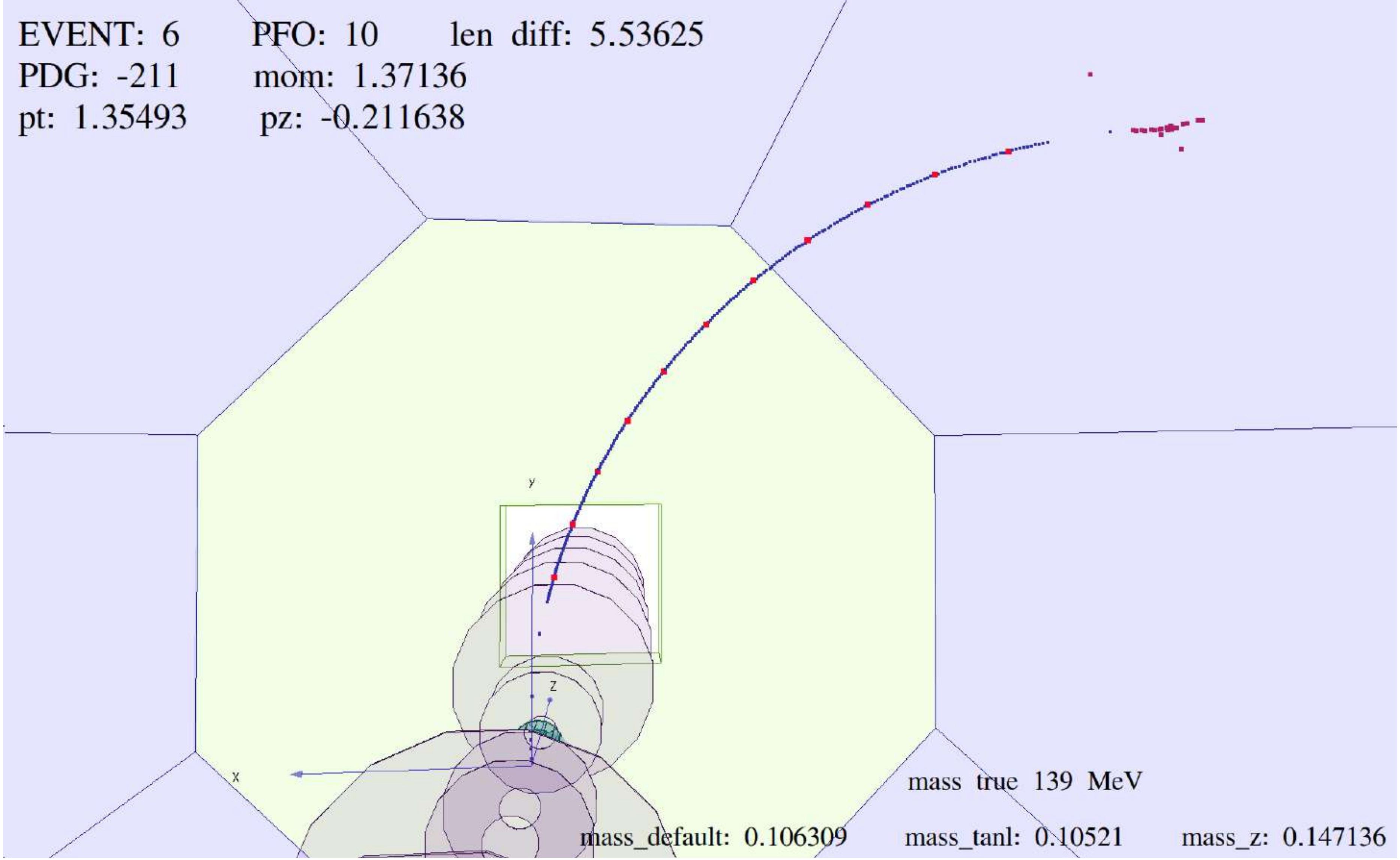


Mass true: 493.677 MeV

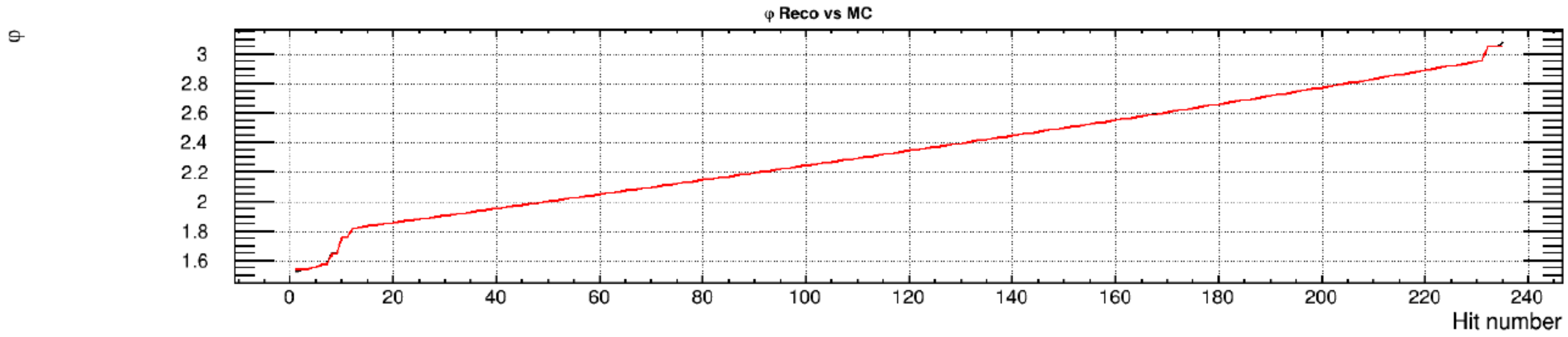

φ Reco vs MC
φ
Hit number
Ω Reco vs MC
Ω (1/mm)
×10⁻³
Hit number
tan λ Reco vs MC
tan λ
Hit number

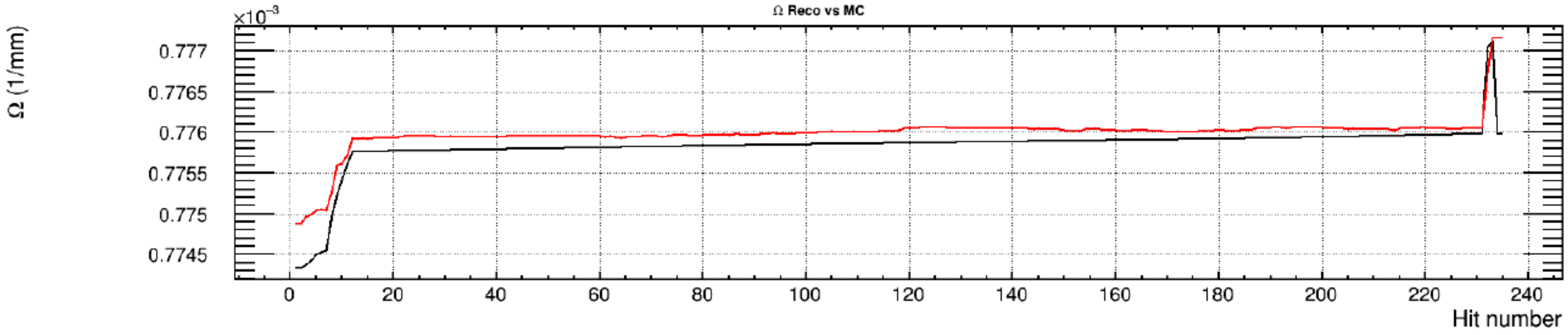

φ Reco vs MC
φ
3
2
1
0
−1
−2
−3
0 20 40 60 80 100 120 140 160 180 200 220 240
Hit number
p_T Reco vs MC
pt (GeV)
2.076
2.075
2.074
2.073
2.072
2.071
2.07
2.069
2.068
0 20 40 60 80 100 120 140 160 180 200 220 240
Hit number
p_z Reco vs MC
pz (GeV)
−1.694
−1.695
−1.696
−1.697
−1.698
−1.699
−1.7
−1.701
−1.702
0 20 40 60 80 100 120 140 160 180 200 220 240
Hit number

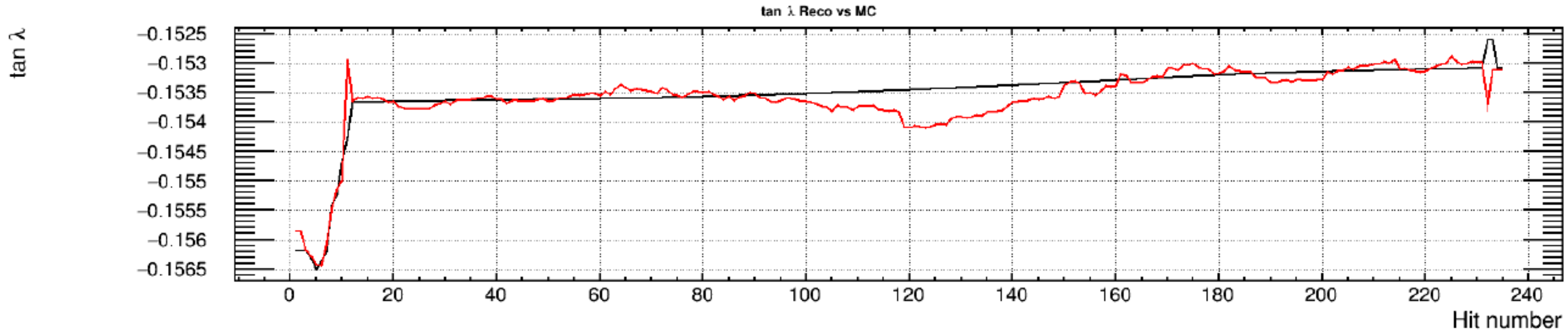

φ Reco vs MC
φ
Hit number
Cumulative track length TanL(blue) vs Default(red) vs "Z"
trk_len (mm)
Hit number
Track length diff TanL(Blue) and Default(Red) vs Z option
Δ trk_len (mm)
Hit number

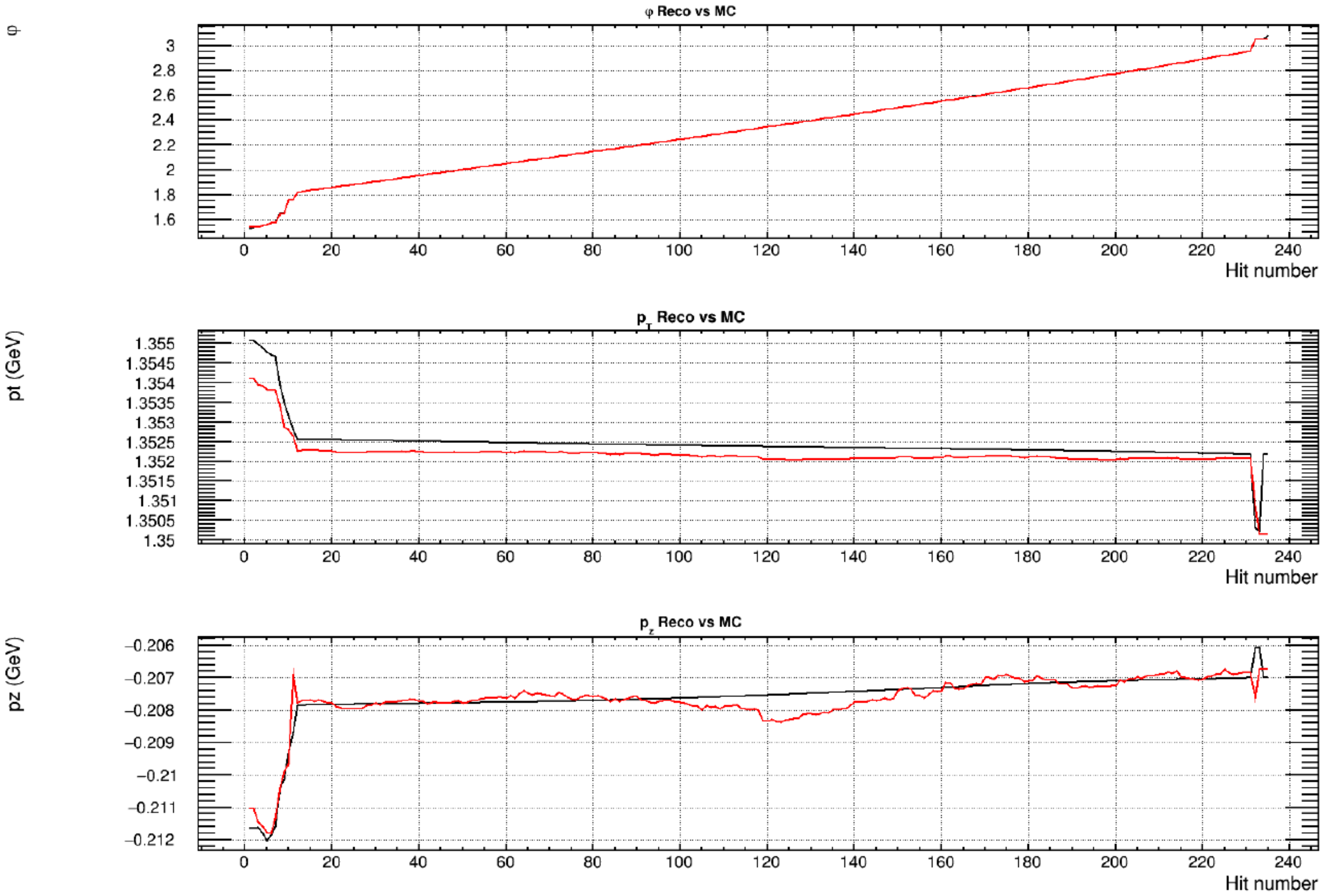


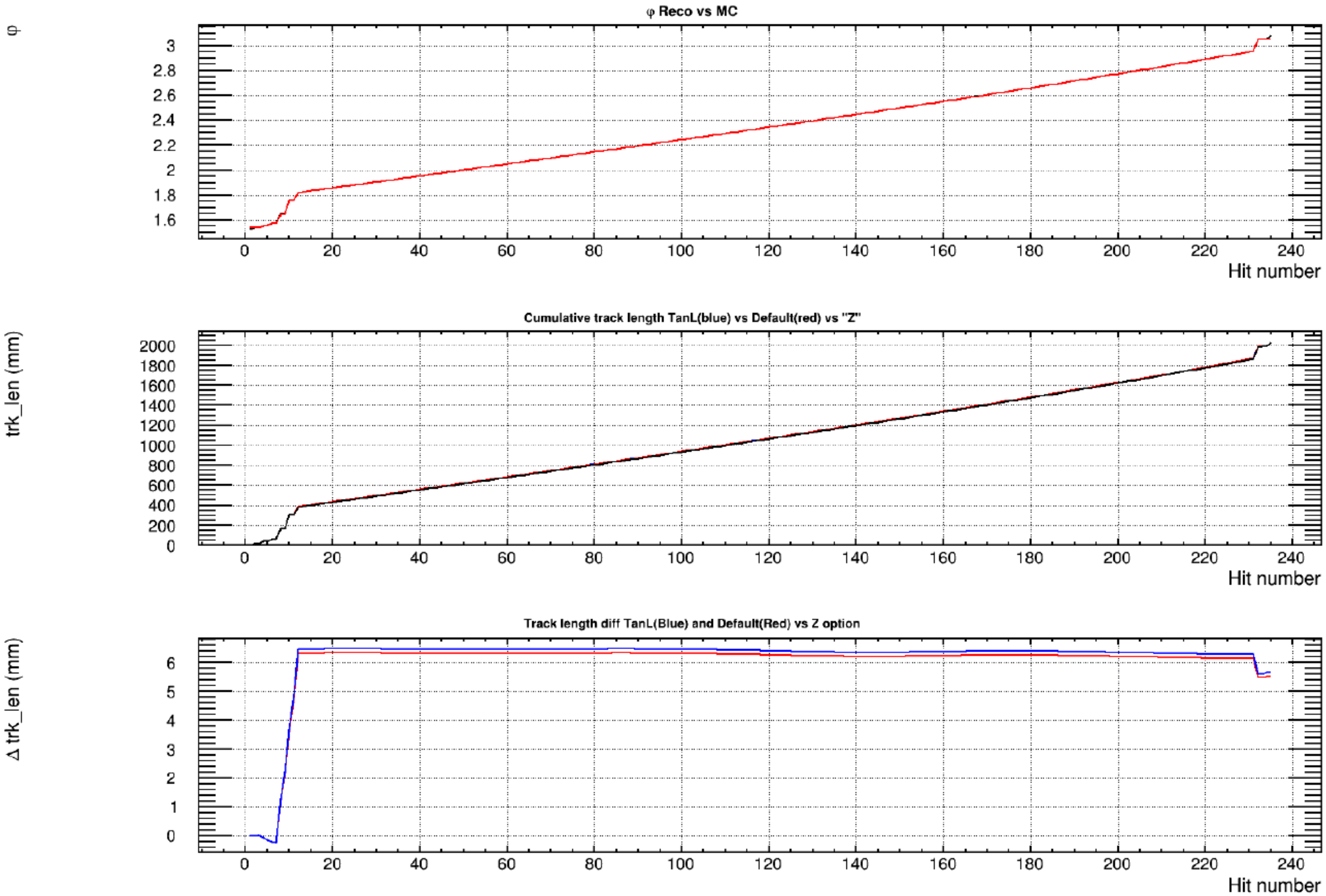
EVENT: 6
PFO: 10
len diff: 5.53625
PDG: -211
mom: 1.37136
pt: 1.35493
pz: -0.211638
y
Z
X
mass true 139 MeV
mass_default: 0.106309
mass_tanl: 0.10521
mass_z: 0.147136


φ Reco vs MC
φ
3
2.8
2.6
2.4
2.2
2
1.8
1.6
0
20
40
60
80
100
120
140
160
180
200
220
240
Hit number


Ω Reco vs MC
×10⁻³
Ω (1/mm)
0.777
0.7765
0.776
0.7755
0.775
0.7745
0
20
40
60
80
100
120
140
160
180
200
220
240
Hit number


tan λ Reco vs MC
tan λ
−0.1525
−0.153
−0.1535
−0.154
−0.1545
−0.155
−0.1555
−0.156
−0.1565
0
20
40
60
80
100
120
140
160
180
200
220
240
Hit number


φ Reco vs MC
φ
Hit number
p_T Reco vs MC
pt (GeV)
Hit number
p_z Reco vs MC
pz (GeV)
Hit number


φ Reco vs MC
φ
Hit number
Cumulative track length TanL(blue) vs Default(red) vs "Z"
trk_len (mm)
Hit number
Track length diff TanL(Blue) and Default(Red) vs Z option
Δ trk_len (mm)
Hit number