

#2 Update on ...

3D reconstructed alpha

tracks

David Marques and PMT Working Group

Technical / Analysis meeting 18-07-2024

1. On the previous episode

- https://agenda.infn.it/event/42030/contributions/235552/attachments/120854/176037/PMT_Reco_and_Analysis-05-06-2024.pdf

PMT Alpha 3D reco – Examples

Run 22101, ev 63 - multi-trigger

```
Cam run: 22180; event(pic): 63; asc: 3
Cluster ID: 0
Warning in ~TF1a::Append: Replacing existing TFit: Track_event22180

Track information:
-> Position barycenter: x: 1743.84; y: 1393.0
-> Quadrant: 2
-> Angle: -145.874 degrees.
-> Length (cm): 547963
Warning in ~TF1a::Append: Replacing existing TFit: TrackProf (Pot)

Cluster ID: 1
Cluster ID: 2
PMT run: 22180; event: 63; trigger: 0; channel: 1; sampling: 1824
PMT run: 22180; event: 63; trigger: 0; channel: 2; sampling: 1824
PMT run: 22180; event: 63; trigger: 0; channel: 3; sampling: 1824
PMT run: 22180; event: 63; trigger: 0; channel: 4; sampling: 1824

PMT Track information:
-> Skewness signs: 1 @ 1 -> skewness sign average is: 0.666667
-> This track is moving towards the cathode.
-> The average travelled Z (cm) is: 0.42773
-> The track is in the quadrant: 3

PMT run: 22180; event: 63; trigger: 1; channel: 1; sampling: 1824
PMT run: 22180; event: 63; trigger: 1; channel: 2; sampling: 1824
PMT run: 22180; event: 63; trigger: 1; channel: 3; sampling: 1824
PMT run: 22180; event: 63; trigger: 1; channel: 4; sampling: 1824

PMT Track information:
-> Skewness signs: 1 @ 1 1 -> skewness sign average is: 0.75
-> This track is moving towards the cathode.
-> The average travelled Z (cm) is: 0.3947
-> The track is in the quadrant: 2

# Matched alpha in quadrant: 2; in trigger: 1

** 3D Alpha track information: **
-> Travelled XY: 5.79051
-> Angle XY (alpha): -145.874
-> Travelled Z: 8.7944
-> Direction in Z: 1
-> Angle Z (alphaZ): 0.81369
-> 3D alpha length (cm): 5.9359
** finished **
```

CAM

PMT

Association
(will be improved with other PMT selection / Bays)

David M. PMT reconstruction & analysis

1. Missing (?) features

- Color gradient is fake \Rightarrow Worth to associate it to longitudinal ionization profile?
- Electron cloud not plotted \Rightarrow Worth to take 2D transversal profile and create a 3D cylinder around main vector?
- ToT doesn't take into account minimum signal temporal width \rightarrow travelled Z slightly overestimated
- Improve association
 - Using BAT?
- Improve theta signal calculation \Rightarrow Also probably using BAT
- Get some basic PMT Alpha cuts to allow PMT-only analysis (?)
- Optimize Analyzer code (cross-check parameters, increase speed)

2. Upcoming (?) analysis:

- **Comparison with simulation** \Rightarrow Not available for alphas, neither from the PMT side nor camera (digitization too slow (?))
- **Statistical analysis.** What do we expect?
 - Angle signal – Higher rate towards GEMs than towards cathode (cause cathode is bigger/higher mass)
 - Sense (left/right and up/down) – Higher rate towards *center* from material radioactivity
 - All this on top of flat background from Radon/gas random emission
- **What else?**

1. Missing (?) features

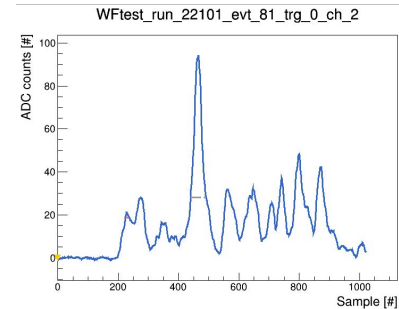
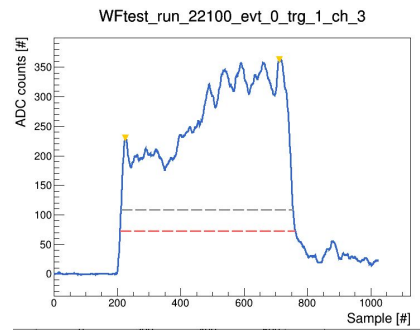
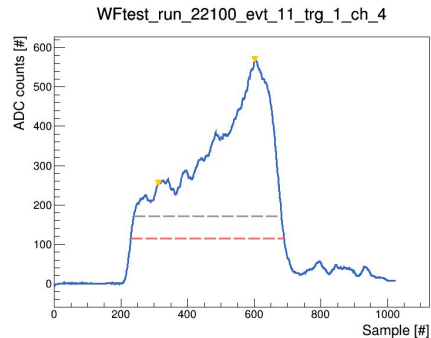
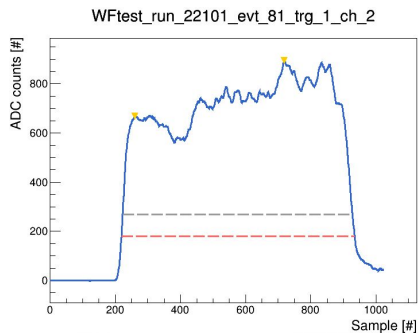
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- *What else?*

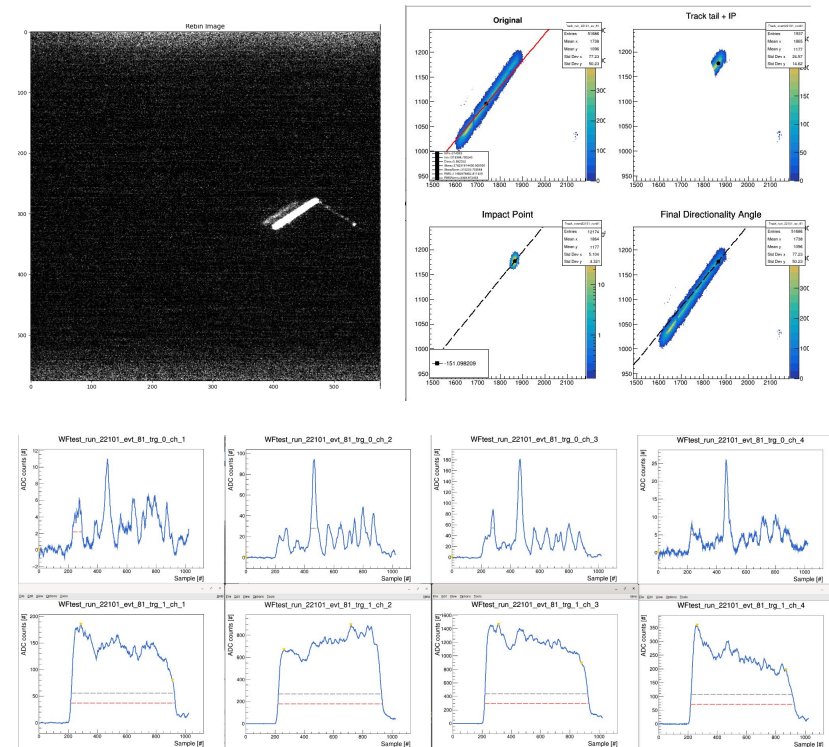
1. Missing (?) features

- **Added some features to improve association and alpha PID through PMT**
 - Initially there was only the “same quadrant” association ([Slide 126](#)). Now added:
 - TOT20 / TOT 30 ratio (TOT calculated at 20 / 30 % of maximum peak)
 - These high values are needed for weird shaped alphas
 - This value should always be between 1 and 2. ⇒ This cuts most cosmics (or any multi-peak waveform) where these TOTs simply “break” the code.
 - TOT20 should always be greater than 80 samples
 - Basic minimum time length of alpha track. ⇒ Cuts most iron like signals which are quite short.



PMT Alpha 3D reco – Examples

- Run 22101, ev 81



```

*Cam run: 22101; event: 81; cluster ID: 0

Warning in <TDirectoryFile::Append>: Replacing existing TH1: Track_event22101_ru
n81 (Potential memory leak).
-> The particle in this cluster was identified as an alpha: true

Track information:
-> Position barycenter: x: 1738.76; y: 1096.59
-> Quadrant: 3
-> Angle: -151.098 degrees.
-> Length (cm): 9.77342
Warning in <TDirectoryFile::Append>: Replacing existing TH1: TrackProf (Potentia
l memory leak).

*PMT run: 22101; event: 81; trigger: 0; sampling: 1024

PMT Track information:
-> Ambiguous, Certainty: 0 %
-> The average travelled Z (cm) is: 0.149085
-> The track is in the quadrant: 3
-> The TOT10/TOT30 ratios were: 4.125 0.215686 0.458333 1.90909
-> The TOT10 lengths were: 66 11 11 21
-> The particle in this trigger was identified as an alpha: false

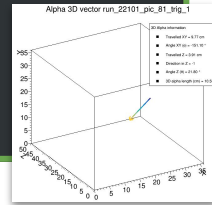
*PMT run: 22101; event: 81; trigger: 1; sampling: 1024

PMT Track information:
-> Moving towards the GEMs with certainty: -135.606 %
-> The average travelled Z (cm) is: 3.90903
-> The track is in the quadrant: 3
-> The TOT10/TOT30 ratios were: 1.01275 1.01558 1.01705 1.02601
-> The TOT10 lengths were: 715 717 716 710
-> The particle in this trigger was identified as an alpha: true

# Matched alpha in quadrant: 3; in trigger: 1; with Alpha-PID = true

** 3D Alpha track information: **

-> Position, X: 28.9113; Y: 18.2436
-> Travelled XY: 9.77342
-> Angle XY (#phi): -151.098
-> Travelled Z: 3.90903
-> Direction in Z: -1
-> Angle Z (#theta): 21.7997
-> 3D alpha length (cm): 10.5262
**Finished**
    
```



CAM

⇒ actually it only saw one cluster, but the noise removal script removed the ER

PMT

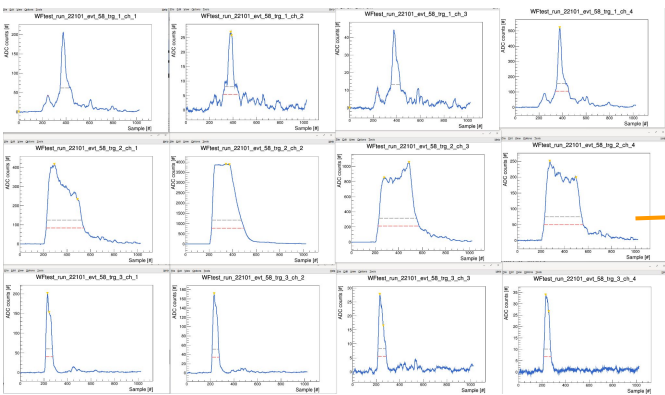
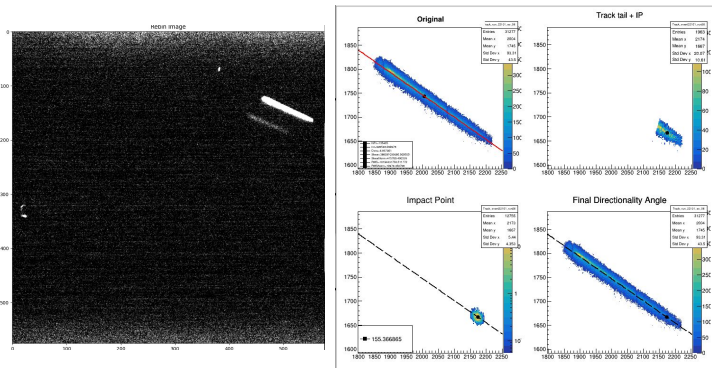
⇒ Saw 2 triggers in the same quadrant.
 ⇒ The first trigger didn't pass the cut, only the second.

Association

⇒ Performed with the only trigger that passed the cut

PMT Alpha 3D reco – Examples

- Run 22101, ev 58

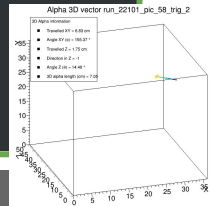


```

*Cam run: 22181; event: 58; cluster ID: 0
Warning in <DirectoryFile::Append: Replacing existing TH1: Track_event22181_run0 (Potential memory leak):
-> The particle in this cluster was identified as an alpha: true
Track Information:
-> Position barycenter: x: 2805.34; y: 1743.61
-> Quadrant: 2
-> Angle: 155.367 degrees.
-> Length (cm): 6.82778
Warning in <DirectoryFile::Append: Replacing existing TH1: TrackProf (Potential memory leak).
*Cam run: 22181; event: 58; cluster ID: 1
-> The particle in this cluster was identified as an alpha: false
*Cam run: 22181; event: 58; cluster ID: 2
-> The particle in this cluster was identified as an alpha: false
**PMT run: 22181; event: 58; trigger: 0; sampling: 1024
PMT Track information:
-> Moving towards the GEMs with certainty: ~50 %
-> The average travelled Z (cm) is: 0.207898
-> The track is in the quadrant: 2
-> The TOT30/TOT30 ratios were: 1.22581 1.25 1.25 1.17241
-> The TOT30 lengths were: 38 48 48 34
-> The particle in this trigger was identified as an alpha: false
**PMT run: 22181; event: 58; trigger: 1; sampling: 1024
PMT Track information:
-> Moving towards the GEMs with certainty: ~50 %
-> The average travelled Z (cm) is: 0.309235
-> The track is in the quadrant: 4
-> The TOT30/TOT30 ratios were: 0.212 1.56977 0.220779 1.53333
-> The TOT30 lengths were: 11 135 17 115
-> The particle in this trigger was identified as an alpha: false
**PMT run: 22181; event: 58; trigger: 2; sampling: 1024
PMT Track information:
-> Moving towards the GEMs with certainty: ~53.2349 %
-> The average travelled Z (cm) is: 1.75346
-> The track is in the quadrant: 2
-> The TOT30/TOT30 ratios were: 1.47667 1.10359 1.09062 1.05714
-> The TOT30 lengths were: 323 279 269 333
-> The particle in this trigger was identified as an alpha: true
**PMT run: 22181; event: 58; trigger: 3; sampling: 1024
PMT Track information:
-> Moving towards the GEMs with certainty: ~37.386 %
-> The average travelled Z (cm) is: 0.363822
-> The track is in the quadrant: 1
-> The TOT30/TOT30 ratios were: 1.18445 1.14288 1.08955 1.14035
-> The TOT30 lengths were: 64 64 73 65
-> The particle in this trigger was identified as an alpha: false
@ Matched alpha in quadrant: 2; in trigger: 2; with Alpha-PID = true
    
```

```

# Matched alpha in quadrant: 2; in trigger: 2; with Alpha-PID = true
** 3D Alpha track information: **
-> Position, X: 33.6976; Y: 25.8371
-> Travelled XY: 6.82778
-> Angle XY (#phi): 155.367
-> Travelled Z: 1.75346
-> Direction in Z: -1
-> Angle Z (#theta): 14.403
-> 3D alpha length (cm): 7.04934
*Finished**
    
```



CAM

⇒ only one out of 3 cluster was identified as alpha (Giorgio's cut)

PMT

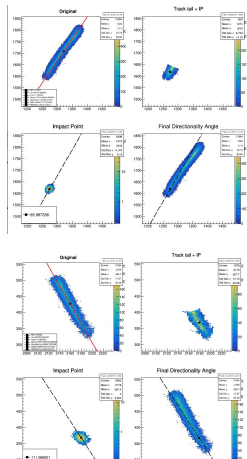
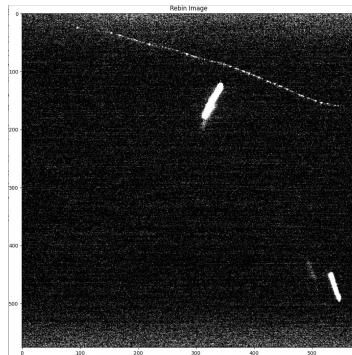
⇒ Saw 4 triggers.
 ⇒ Trigger 4 actually passes first test, but not second test. (⁵⁵Fe like event!)
 ⇒ Only one trigger identified as alpha

Association

⇒ Performed with the only trigger that passed the cut

PMT Alpha 3D reco – Examples

- Run 22101, ev 59



```

*PMT run: 22101; event: 59; trigger: 0; sampling: 1024
PMT Track information:
-> Moving towards the GEMs with certainty: -100.966 %
-> The average travelled Z (cm) is: 2.38262
-> The track is in the quadrant: 2
-> The TOT10/TOT30 ratios were: 1.02347 1.04136 1.0257 1.03294
-> The TOT10 lengths were: 436 428 439 439
-> The particle in this trigger was identified as an alpha: true

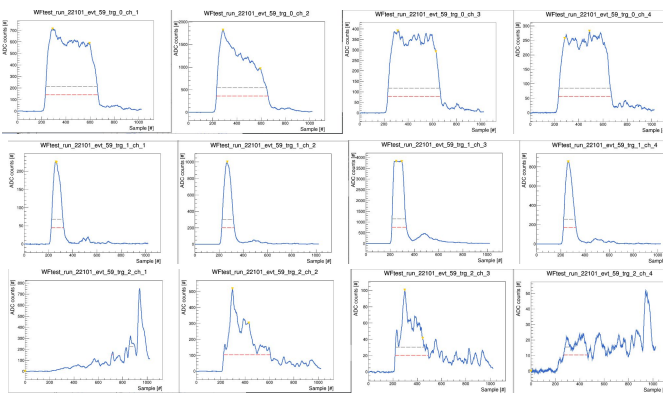
*PMT run: 22101; event: 59; trigger: 1; sampling: 1024
PMT Track information:
-> Moving towards the GEMs with certainty: -83.4087 %
-> The average travelled Z (cm) is: 0.596339
-> The track is in the quadrant: 3
-> The TOT10/TOT30 ratios were: 1.11828 1.11702 1.08036 1.12766
-> The TOT10 lengths were: 104 105 121 106
-> The particle in this trigger was identified as an alpha: true

*PMT run: 22101; event: 59; trigger: 2; sampling: 1024
PMT Track information:
-> Moving towards the GEMs with certainty: -99.2477 %
-> The average travelled Z (cm) is: 1.19485
-> The track is in the quadrant: 2
-> The TOT10/TOT30 ratios were: 0.270833 35 1.13636 4.34783
-> The TOT10 lengths were: 13 385 275 200
-> The particle in this trigger was identified as alpha: false
    
```

```

# Matched alpha in quadrant: 2; in trigger: 0; with Alpha-PID = true
** 3D Alpha track information: **
-> Position, X: 19.7422; Y: 25.0878
-> Travelled XY: 5.60865
-> Angle XY (#phi): 65.9874
-> Travelled Z: 2.38262
-> Direction in Z: -1
-> Angle Z (#theta): 23.0164
-> 3D alpha length (cm): 6.09375

# Matched alpha in quadrant: 3; in trigger: 1; with Alpha-PID = true
** 3D Alpha track information: **
-> Position, X: 33.7718; Y: 5.69878
-> Travelled XY: 3.49178
-> Angle XY (#phi): 111.067
-> Travelled Z: 0.596339
-> Direction in Z: -1
-> Angle Z (#theta): 9.69169
-> 3D alpha length (cm): 3.54233
    
```



```

*Cam run: 22101; event: 59; cluster ID: 0
Warning in <DirectoryFile::Append: Replacing existing TH1: Track_event22101_run59 (Potential memory leak).
-> The particle in this cluster was identified as an alpha: true

Track information:
-> Position barycenter: x: 1321.41; y: 1787.87
-> Quadrant: 2
-> Angle: 65.9874 degrees.
-> Length (cm): 5.60865
Warning in <DirectoryFile::Append: Replacing existing TH1: TrackProf (Potential memory leak).

*Cam run: 22101; event: 59; cluster ID: 1
Warning in <DirectoryFile::Append: Replacing existing TH1: Track_event22101_run59 (Potential memory leak).
-> The particle in this cluster was identified as an alpha: true

Track information:
-> Position barycenter: x: 2159.19; y: 426.071
-> Quadrant: 3
-> Angle: 111.067 degrees.
-> Length (cm): 3.49178
Warning in <DirectoryFile::Append: Replacing existing TH1: TrackProf (Potential memory leak).
Warning in <DirectoryFile::Append: Replacing existing TH1: TrackProf (Potential memory leak).

*Cam run: 22101; event: 59; cluster ID: 2
-> The particle in this cluster was identified as an alpha: false

*Cam run: 22101; event: 59; cluster ID: 3
-> The particle in this cluster was identified as an alpha: false
    
```

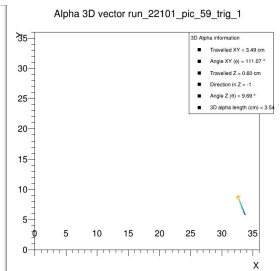
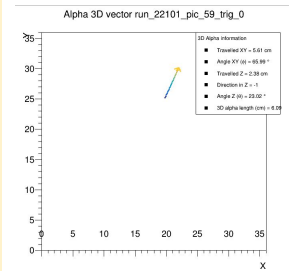
CAM

⇒ 2 out of 4 cluster were identified as alpha (Giorgio's cut)

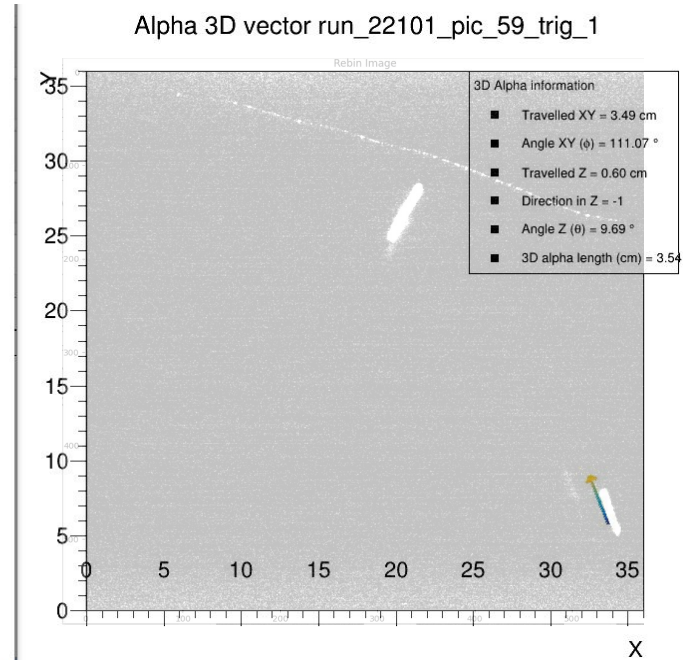
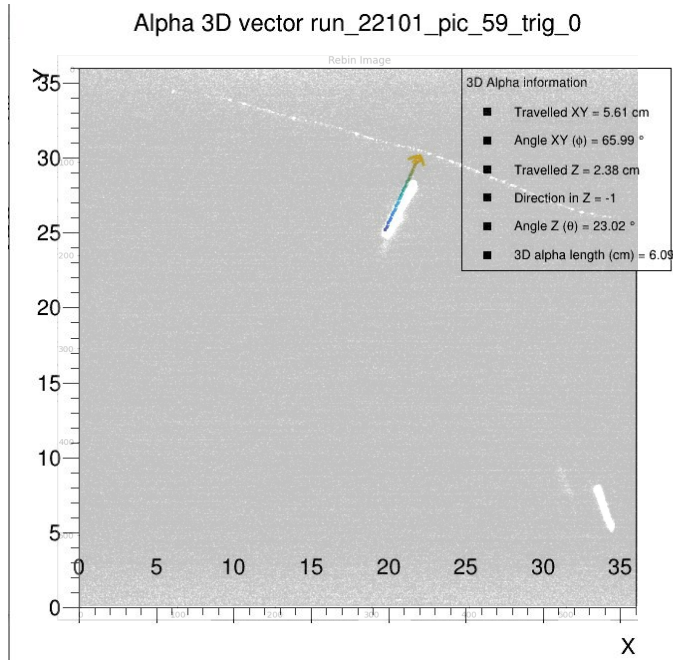
PMT

⇒ 2 out of 3 triggers were identified as alpha

Association
 ⇒ Since there were in different quadrants, **the code** can associate them 1-to-1



... There's still work to be done:



...Maybe there are some coordinate / granularity / centering corrections to do... @Giorgio

→ Conclusion

- ◆ Now I can more easily associate alpha tracks in different quadrants
- ◆ I can also *reject cosmics and low energy ER* (pretty much everything up to now)
- ◆ This won't be further tuned, as suggested by Giorgio, because we want to do full association using BAT/Bayes code.

#2.1 Update on ..

3D reconstructed alpha

tracks

David Marques and PMT Working Group

Technical / Analysis meeting 18-07-2024

1. Missing (?) features

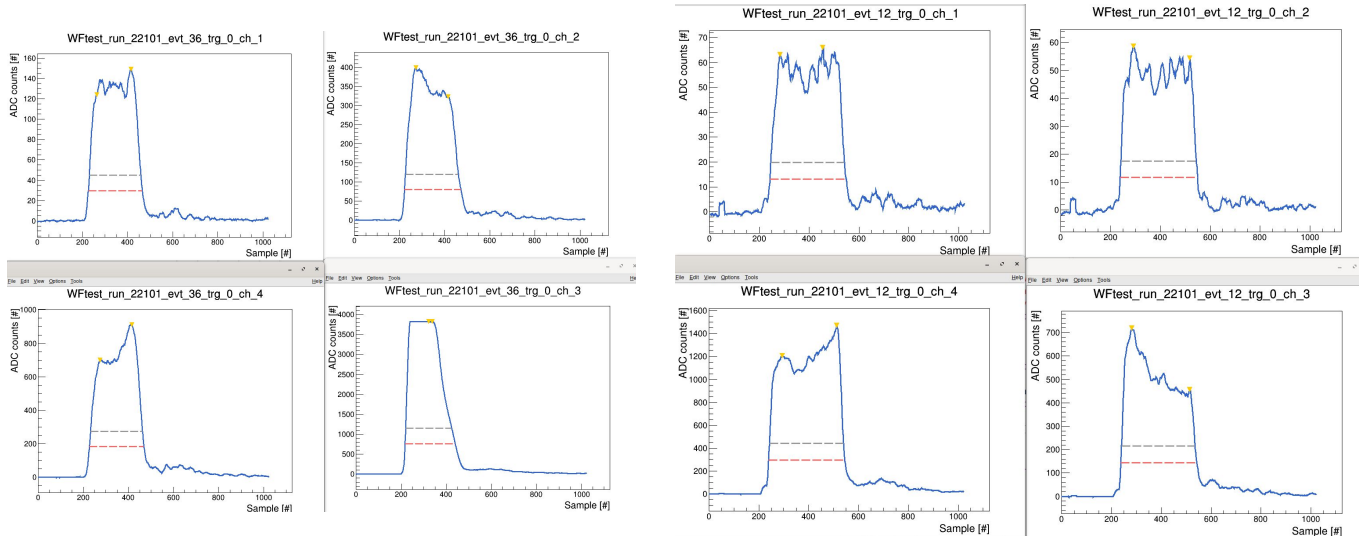
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- Improve association
 - Using BAT?
- **Improve theta signal calculation** \Rightarrow Also probably using BAT
- Get some basic PMT Alpha cuts to allow PMT-only analysis (?)
- Optimize Analyzer code (cross-check parameters, increase speed)

2. Upcoming (?) analysis:

- **Comparison with simulation** \Rightarrow Not available for alphas, neither from the PMT side nor camera (digitization too slow (?))
- **Statistical analysis.** What do we expect?
 - Angle signal – Higher rate towards GEMs than towards cathode (cause cathode is bigger/higher mass)
 - Sense (left/right and up/down) – Higher rate towards center from material radioactivity
 - All this on top of flat background from Radon/gas random emission
- *What else?*

1. What's the problem? (👉)

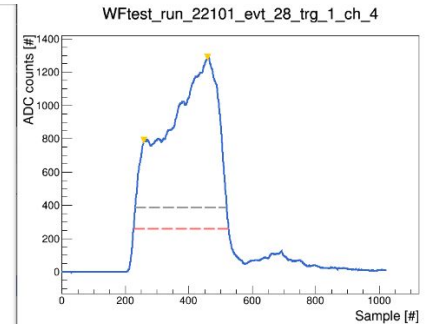
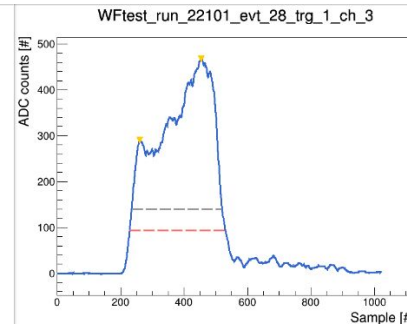
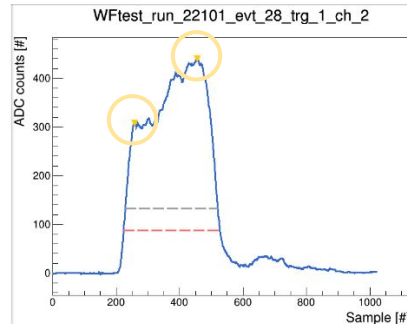
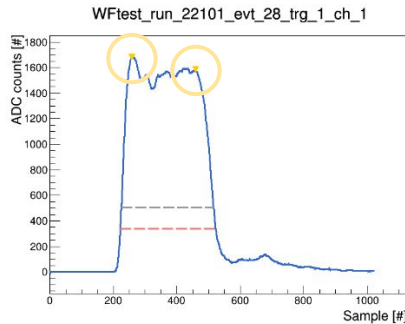
- For the determination of the theta signal (alpha towards cathode or GEMs, I was using a **binary search**: if waveform first half integral > second == towards GEMs, and vice-versa
 - I needed a way to **quantify** **how obvious** is the theta signal



When there are very flat or saturated waveforms, the halves integral comparison becomes **too sensible** to **be acceptable**.

1. What's the problem? (👉)

- I worked a lot with the integrals \Rightarrow dividing, scaling, normalizing, averaging, but no easy way of doing it.
 - Then I realized that it's more correct to actually **work with the skewness of the "Bragg peak"**
 - So I added some **"peak finder"** so I can calculate the ratio between maximum and minimum peak.



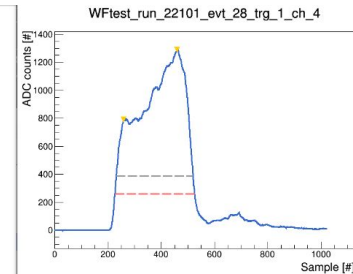
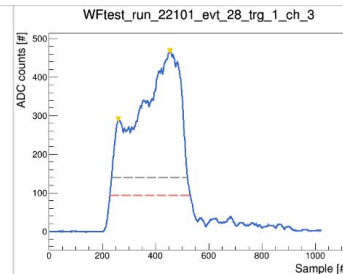
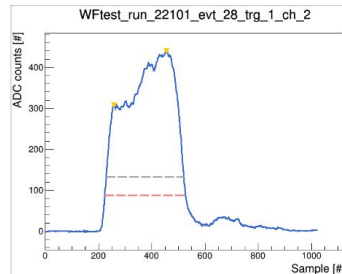
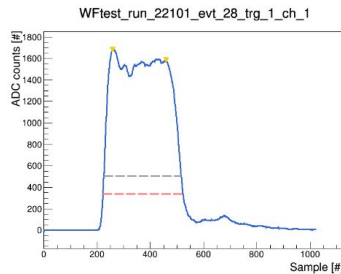
I find the higher amplitude peak in the waveform-half with higher integral, and then find the first peak on the other half

1. What's the solution? (👉)

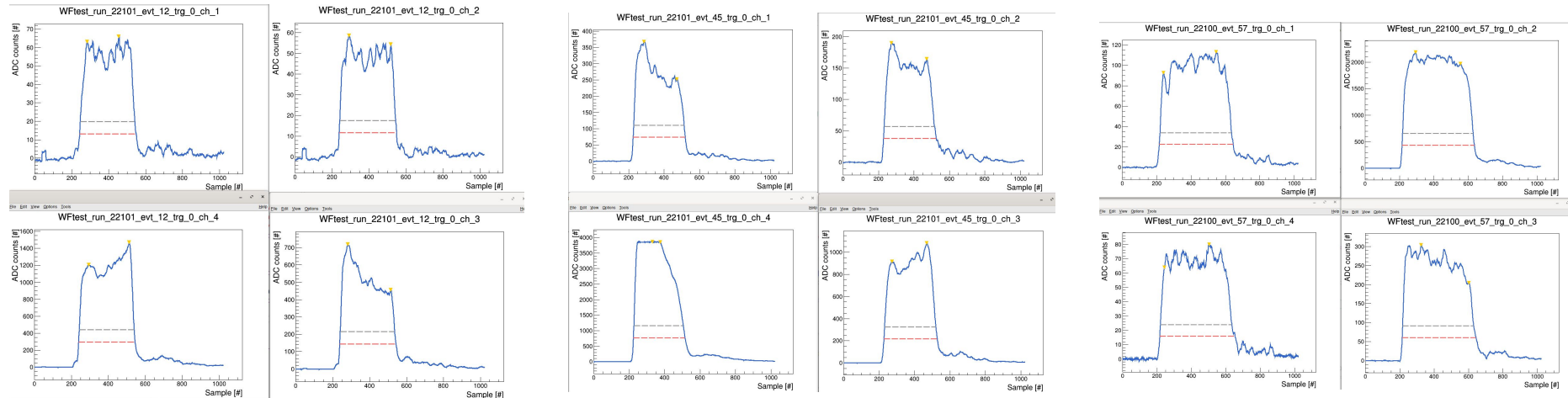
- Finds the first and last peaks in the “crown”. ⇒ Calculates ratio
- Does this for all channels, and then normalized to greatest ratio.
 - **Sums** all ratios, and the greatest counts 0.5.
 - **Does NOT total to 100**, but it becomes nonetheless very useful!
 - This score (not probability) works like

- Score < -100 : towards GEM 100% sure
- Score > 100 : towards cathode 100% sure
- -50 < score < 50 : ambiguous

```
*PMT run: 22101; event: 28; trigger: 1; sampling: 1024
--> Skewness:
#Ratios: -0.0609774 * 0.432452 * 0.615033 * 0.634494 *
Abs max ratio: 0.634494
#Normalized: -0.0961041 # 0.68157 # 0.96933 # 1 #
*Final probability: 205.48 %
```



Some examples – ambiguous



```

*PMT run: 22101; event: 12; trigger: 0; sampling: 1024
--> Skewness:
#Ratios: 0.0476025 * -0.0796681 * -0.578662 * 0.221218 *
Abs max ratio: 0.578662
#Normalized: 0.0822631 # -0.137676 # -1 # 0.382293 #
*Final probability: -17.312 %

PMT Track information:
--> Ambiguous. Certainty: -17.312 %
    
```

```

*PMT run: 22101; event: 45; trigger: 0; sampling: 1024
--> Skewness:
#Ratios: -0.458183 * -0.156125 * 0.1817 * -0.00367452 *
Abs max ratio: 0.458183
#Normalized: -1 # -0.340747 # 0.396566 # -0.00801976 #
*Final probability: -45.2201 %

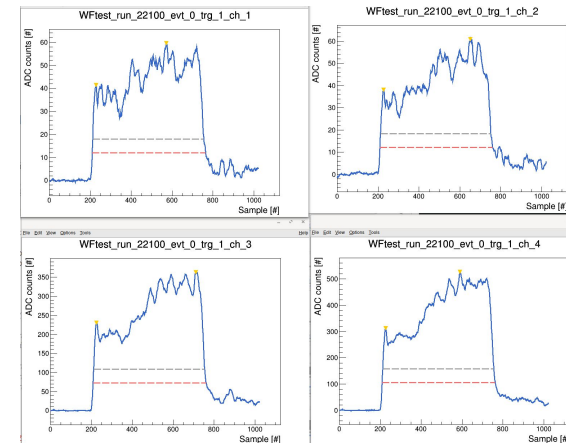
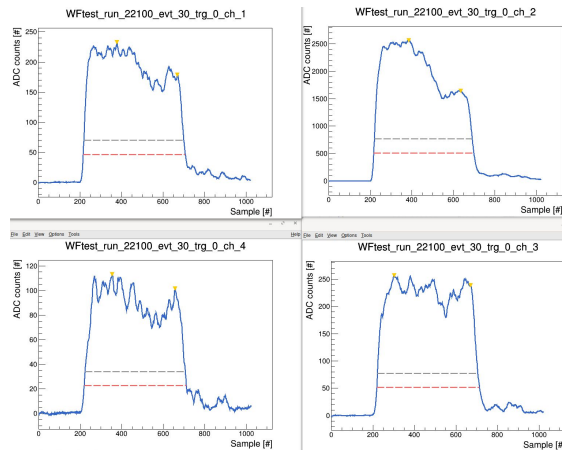
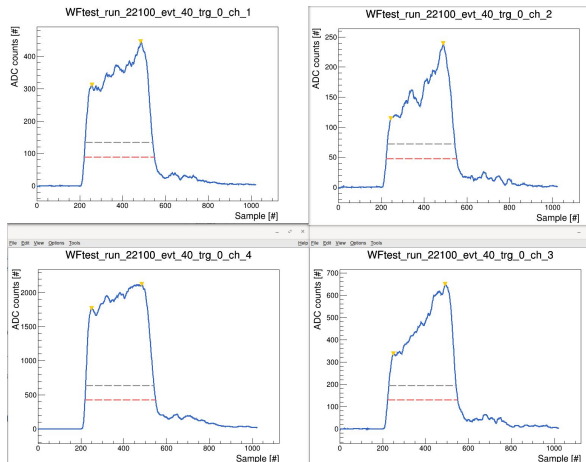
PMT Track information:
--> Ambiguous. Certainty: -45.2201 %
    
```

```

*PMT run: 22100; event: 57; trigger: 0; sampling: 1024
--> Skewness:
#Ratios: 0.223051 * -0.112506 * -0.489334 * 0.253461 *
Abs max ratio: 0.489334
#Normalized: 0.455826 # -0.229917 # -1 # 0.517971 #
*Final probability: 24.388 %

PMT Track information:
--> Ambiguous. Certainty: 24.388 %
    
```


Some examples – easy pizzi



```
*PMT run: 22100; event: 40; trigger: 0; sampling: 1024
--> Skewness:
#Ratios: 0.43394 * 1.10023 * 0.929424 * 0.202533 *
Abs max ratio: 1.10023
#Normalized: 0.394409 # 1 # 0.844756 # 0.184083 #
*Final probability: 192.325 %

PMT Track information:
--> Moving towards the cathode with certainty: 192.325 %
```

```
*PMT run: 22100; event: 30; trigger: 0; sampling: 1024
--> Skewness:
#Ratios: -0.305974 * -0.563199 * -0.0785279 * -0.114925 *
Abs max ratio: 0.563199
#Normalized: -0.543279 # -1 # -0.139432 # -0.204058 #
*Final probability: -138.677 %

PMT Track information:
--> Moving towards the GEMs with certainty: -138.677 %
```

```
*PMT run: 22100; event: 0; trigger: 1; sampling: 1024
--> Skewness:
#Ratios: 0.44445 * 0.599192 * 0.578153 * 0.692824 *
Abs max ratio: 0.692824
#Normalized: 0.641504 # 0.864854 # 0.834487 # 1 #
*Final probability: 284.085 %

PMT Track information:
--> Moving towards the cathode with certainty: 284.085 %
```

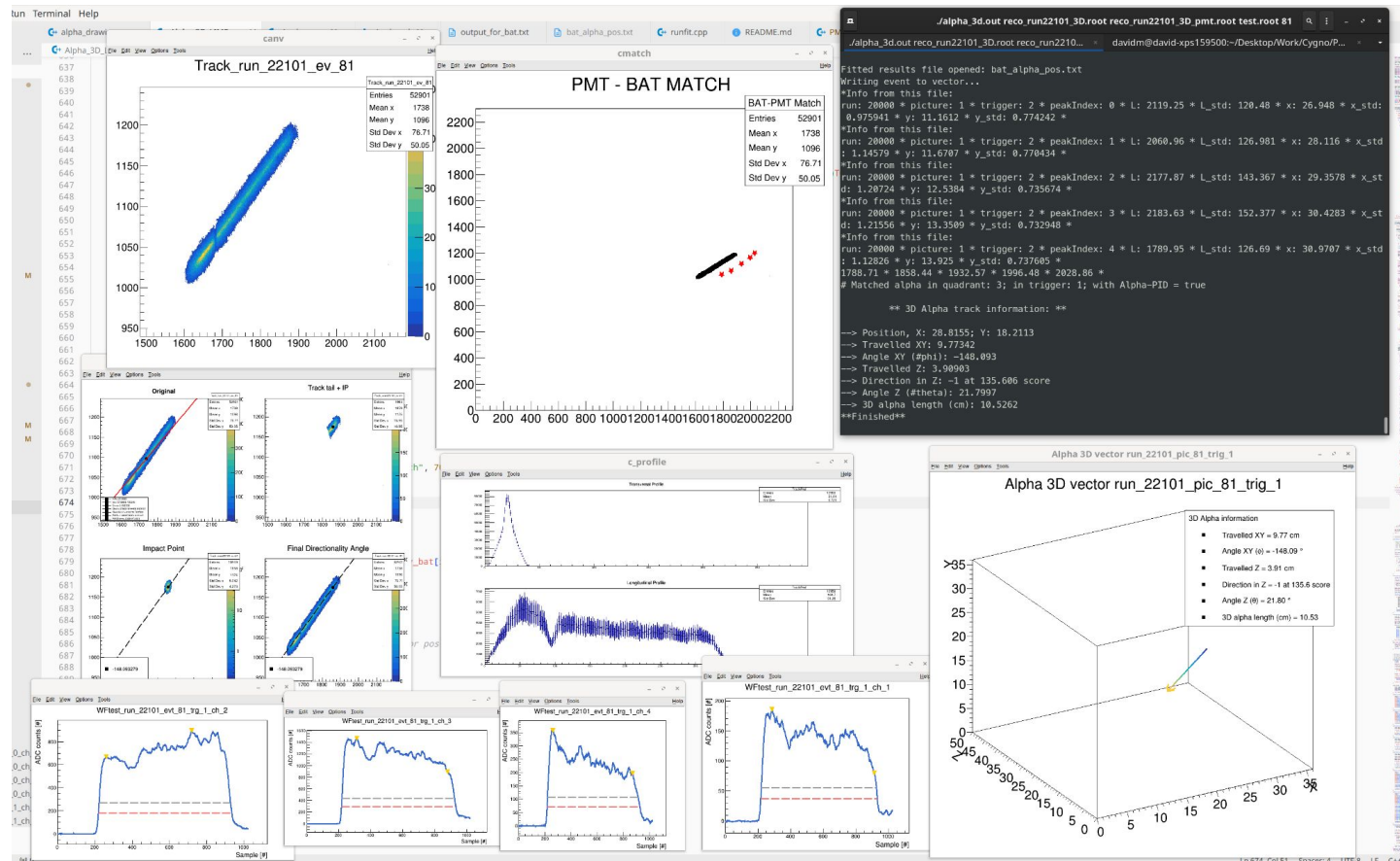
→ Conclusion

- ◆ Now I can have a general idea of how sure am I of the direction in the longitudinal plane.
 - Anything between -50 and 50 I can exclude.
 - Anything < -100 or $> +100$, I'm pretty sure it's correct.
 - If the value > 200 , basically mean that all 4 PMT showed a very similar waveform, thus the direction is unequivocal.
- ◆ As for last time, This won't be further tuned, as suggested by Giorgio, because we want to do full association using BAT/Bayes code.
 - BAT can help me disentangle the position dependency, so I can get the *"real waveform"*.
 - This would make obvious the theta sign, and additional features of the waveform.
 - ◆ (plus the perfect 1-to-1 association).

Side note on framework

Full framework includes all this information automatically

These are **not** cherry-picked events



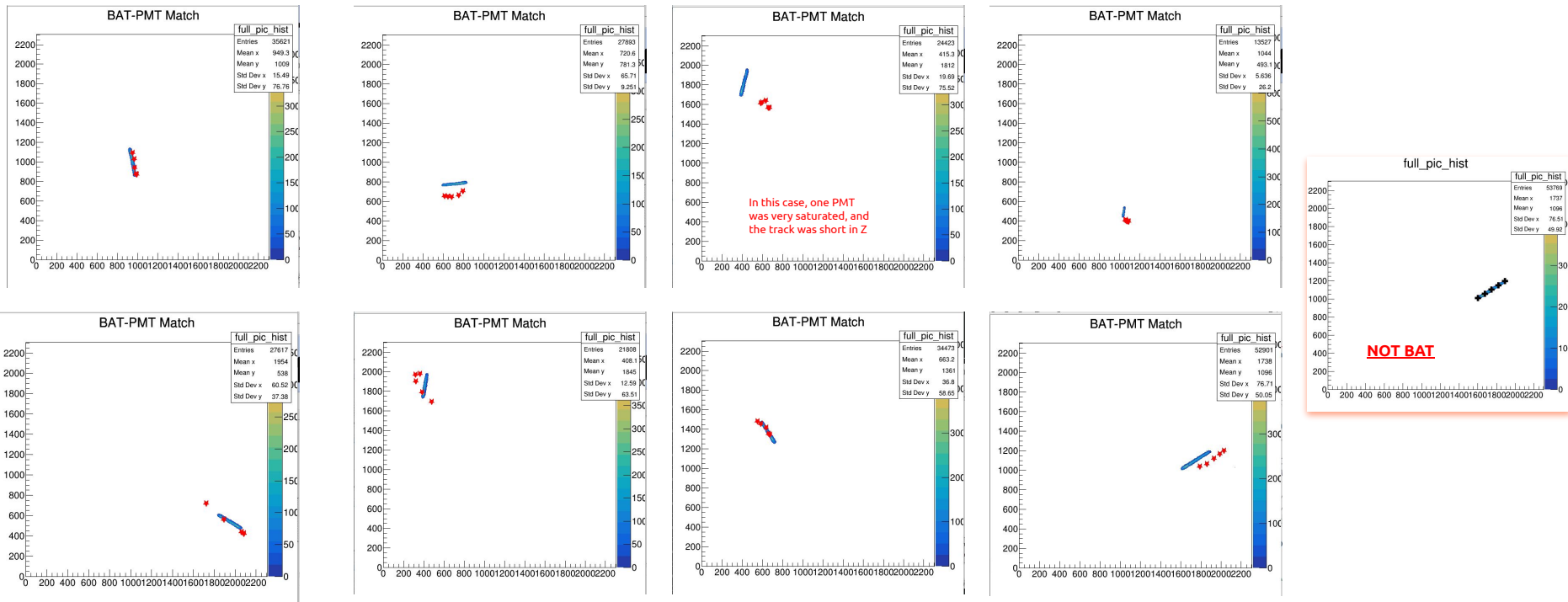
1. Missing (?) features

- Color gradient is fake \Rightarrow Worth to associate it to longitudinal ionization profile?
- Electron cloud not plotted \Rightarrow Worth to take 2D transversal profile and create a 3D cylinder around main vector?
- ToT doesn't take into account minimum signal temporal width \rightarrow travelled Z slightly overestimated
- **Improve association**
 - **Using BAT?**
- Improve theta signal calculation \Rightarrow Also probably using BAT
- Get some basic PMT Alpha cuts to allow PMT-only analysis (?)
- Optimize Analyzer code (cross-check parameters, increase speed)

2. Upcoming (?) analysis:

- **Comparison with simulation** \Rightarrow Not available for alphas, neither from the PMT side nor camera (digitization too slow (?))
- **Statistical analysis.** What do we expect?
 - Angle signal – Higher rate towards GEMs than towards cathode (cause cathode is bigger/higher mass)
 - Sense (left/right and up/down) – Higher rate towards center from material radioactivity
 - All this on top of flat background from Radon/gas random emission
- *What else?*

Very preliminary association results \Rightarrow *Alphas sliced and fit applied to each slice*



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- **What else?**

→ Should we write a paper on the PMT data / analysis?

Could include:

- ◆ Waveform basic reconstruction
- ◆ Particle ID (for selection of alphas but also rejection of ERs)
- ◆ Association of waveforms and images (cuts and BAT)
- ◆ 3D reco of alphas
- ◆ Longitudinal diffusion (?)
- ◆ Other comparisons with camera measurements