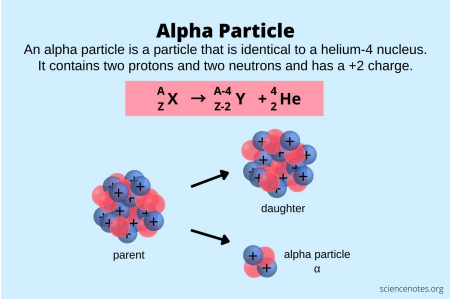
Initial look at alpha tracks for directional & head-tail determination

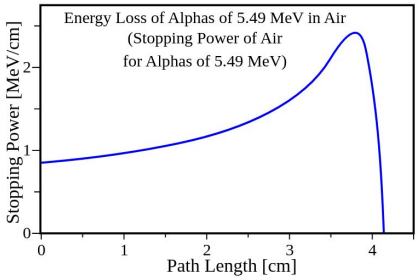
David Marques and PMT Working Group

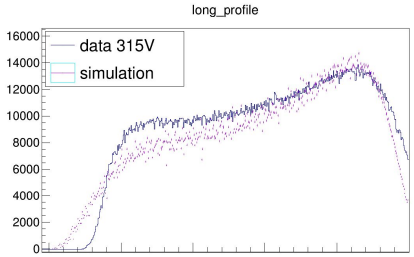
Analysis meeting 16-05-2024

PMT Signal basic properties

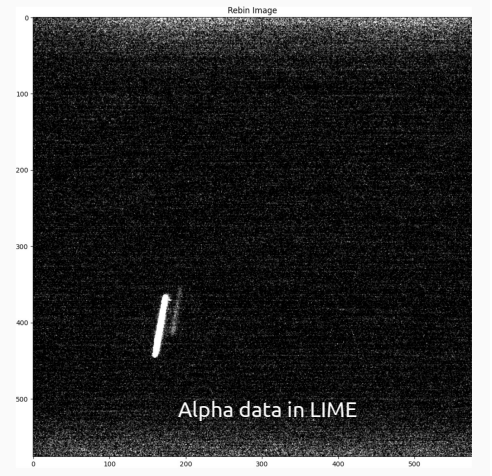
1. To start, we should understand some of the **basic properties** of the **PMT signal**, and what's **imprinted** in them.
2. Let's consider **alpha tracks**
   - Short range (< 10 cm)
   - High stopping power (dense ionization cloud)
   - Straight







Alpha simulated in LIME (*Flaminia)



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2. Let's consider **alpha tracks**
   - Short range (< 10 cm)
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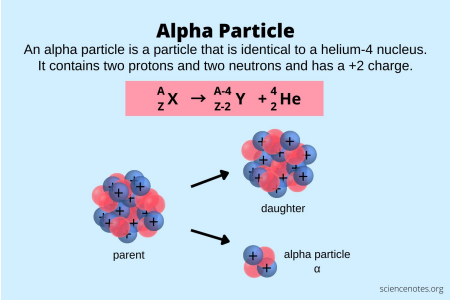
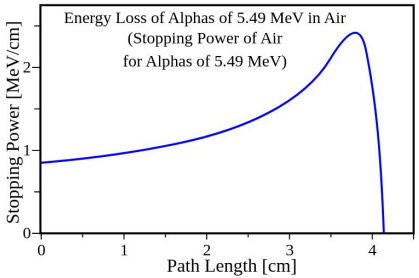
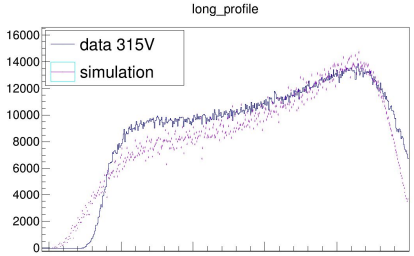
3. I looked into data from the high alpha rate (runs 22100 and 22101)
4. I used Giorgio's reco fork because it has **the correct image rotation**
   - This is further confirmed by the PMT waveforms
5. Looked directly into alphas in ~200 events







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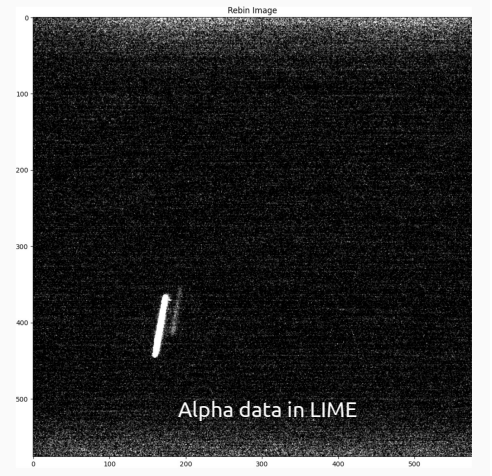

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- If the track is parallel to the GEM plane, the PMT is “blind” to features
- The time over threshold gives me the ΔZ (⊕ energy or X-Y length = angle w.r.t. GEM plane)

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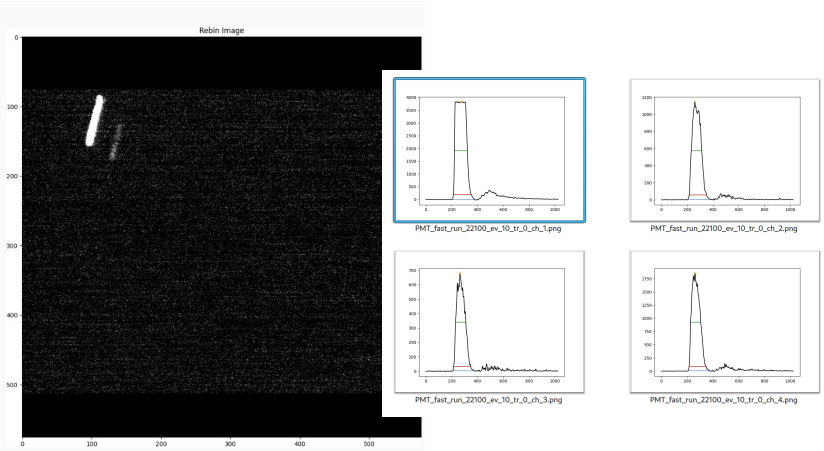
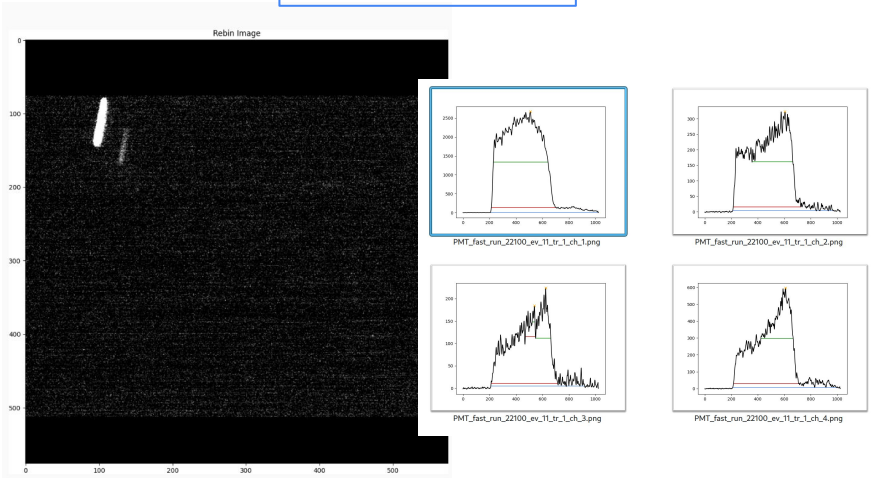


Run 22100, ev 11



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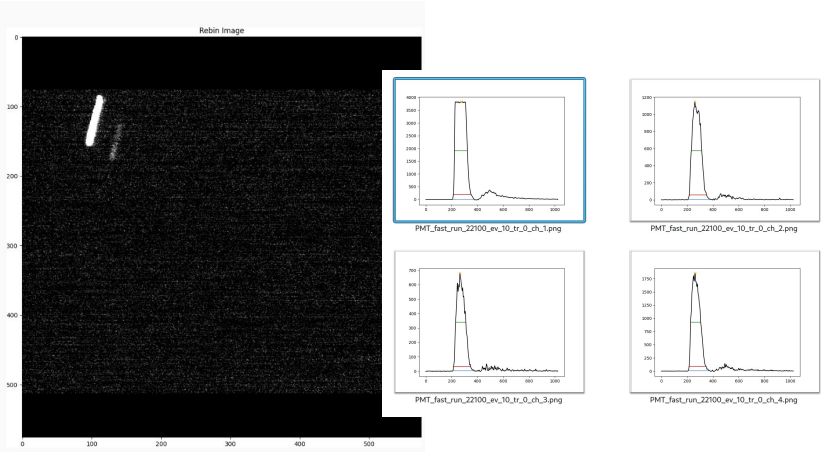

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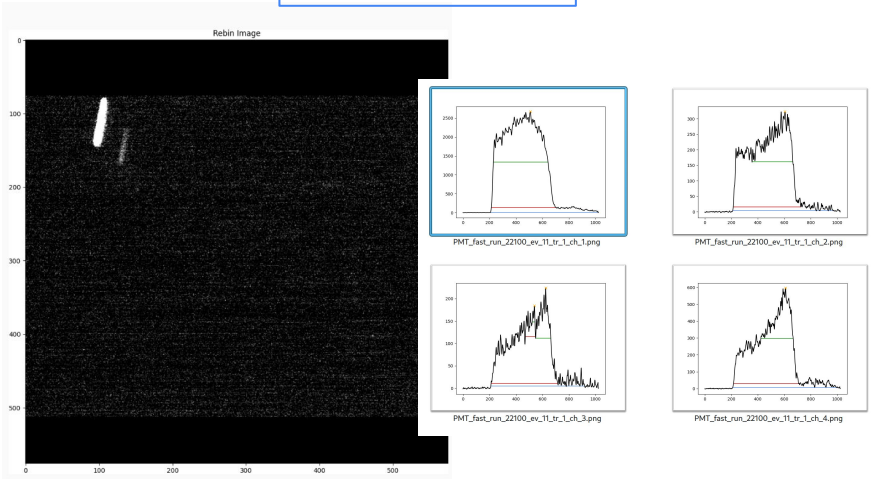

⇒ While from the camera they are similar events, they are greatly different from the PMT point of view!

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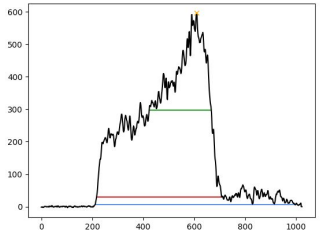
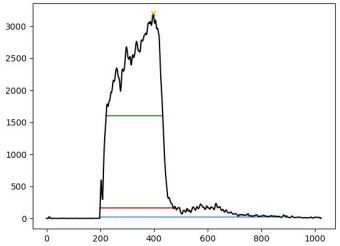
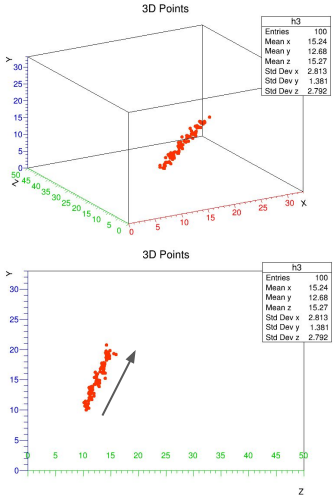


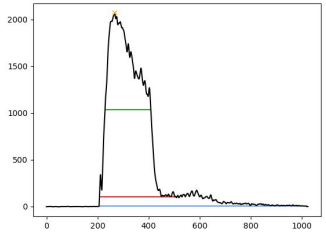
Case 1, example 2



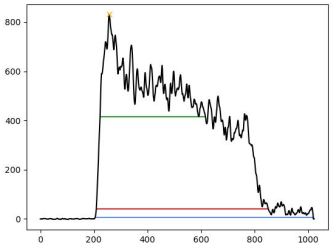
Explanation for case 1



Case 2, example 1



Case 2, example 2



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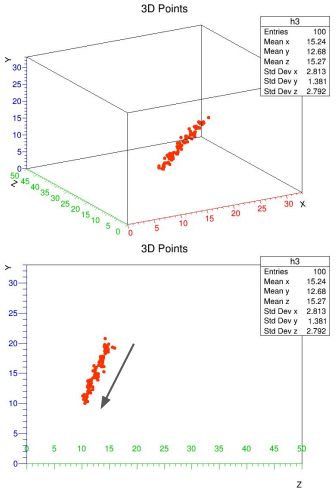

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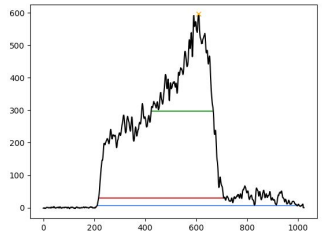
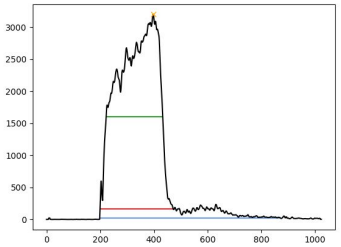


Case 1, example 2



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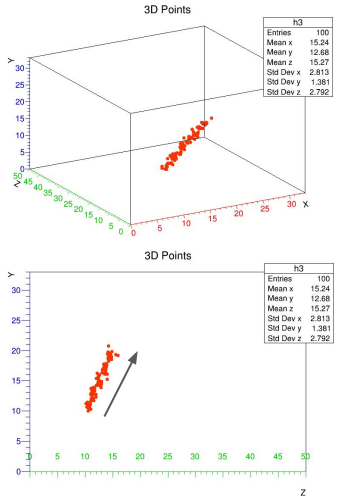
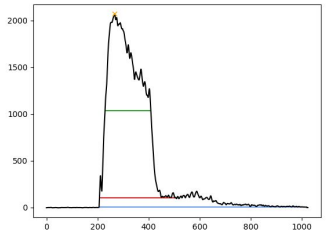
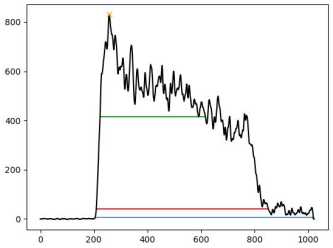


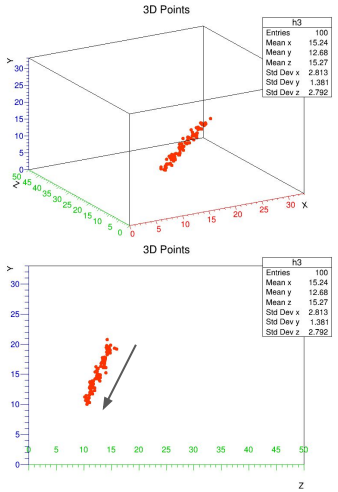
Case 2, example 1



Case 2, example 2



Explanation for case 2



⇒ You can understand the direction of the particle wrt to cathode/GEMs… ***BUT it’s ambiguous!***

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- Position of the Bragg peak tells us what arrive first to the GEMs (head or tail)
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    - ***By why is it ambiguous?***

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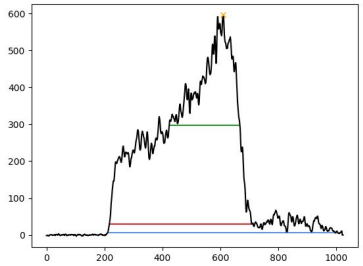
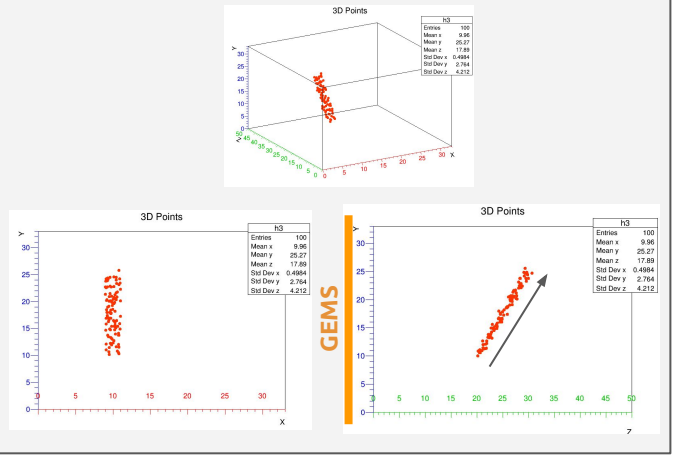
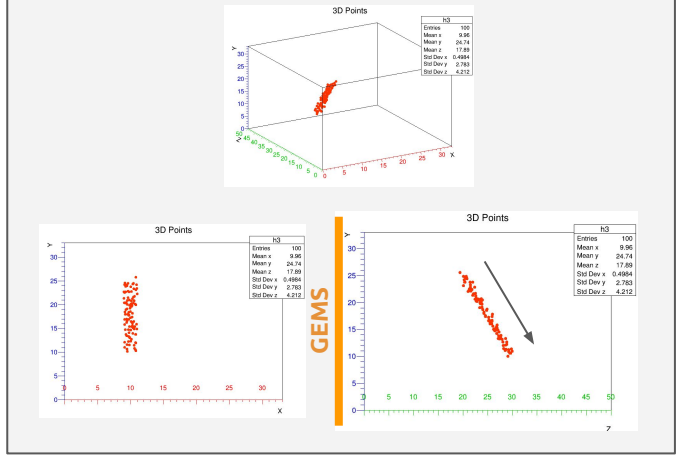


Possible explanation 1



Possible explanation 2



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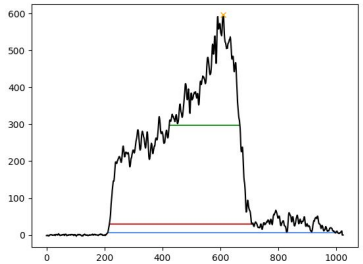

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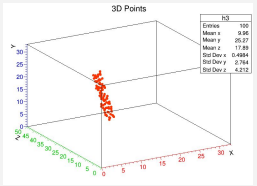
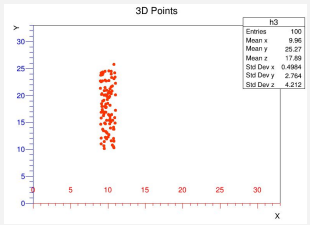
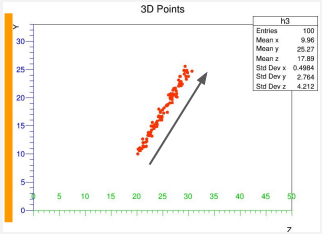




GEMS



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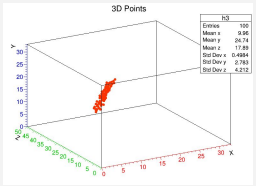

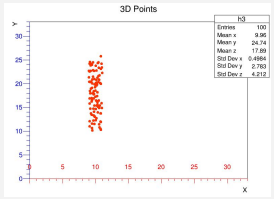

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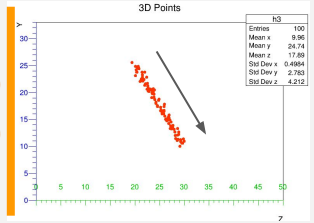

⇒ The Bragg peak itself just gives me direction in Z, is still ambiguous in X-Y, because it only sees what arrived first (head-tail) and this is independent of the track direction, assuming “instantaneous” ionization. In this case it might be moving both upwards or downwards, and from the camera side we don’t see the difference

Property 3

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  - **Amplitude comparison between PMTs ⇒ Higher amplitude corresponds to track closer to that PMT**

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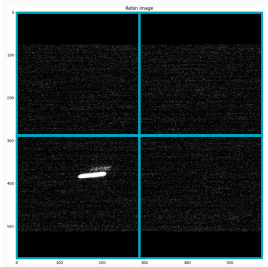
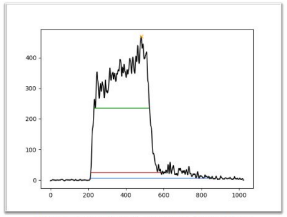
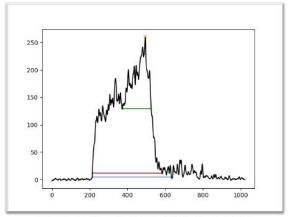
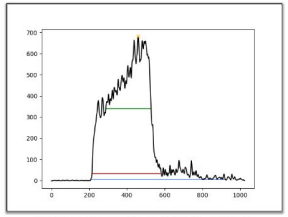




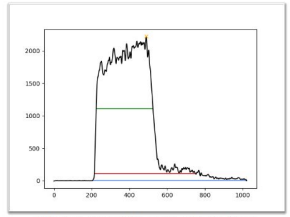
PMT_fast_run_22100_ev_40_tr_0_ch_1.png



PMT_fast_run_22100_ev_40_tr_0_ch_2.png



PMT_fast_run_22100_ev_40_tr_0_ch_3.png



PMT_fast_run_22100_ev_40_tr_0_ch_4.png

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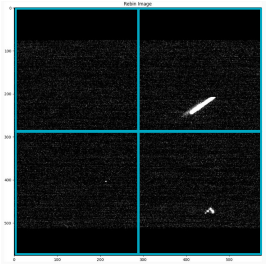
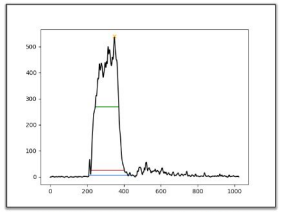
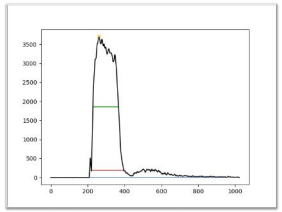
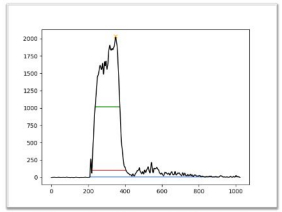




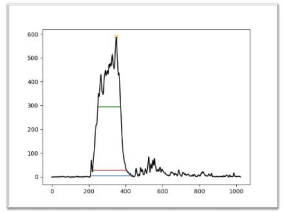
PMT_fast_run_22100_ev_63_tr_1_ch_1.png



PMT_fast_run_22100_ev_63_tr_1_ch_2.png



PMT_fast_run_22100_ev_63_tr_1_ch_3.png



PMT_fast_run_22100_ev_63_tr_1_ch_4.png

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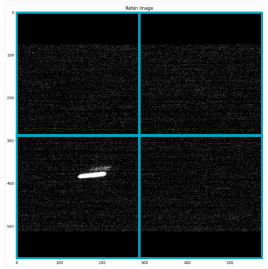

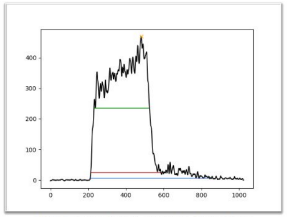
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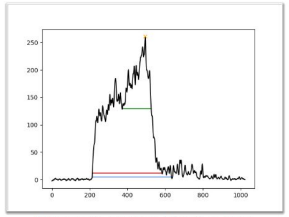
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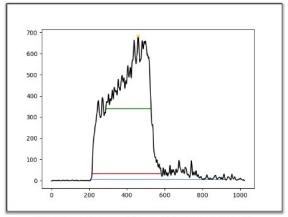
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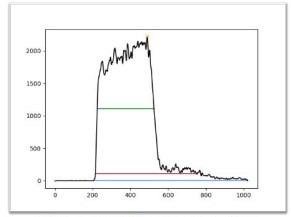
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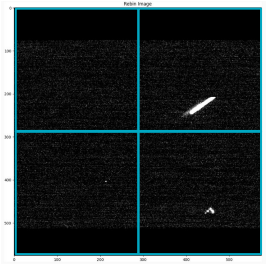
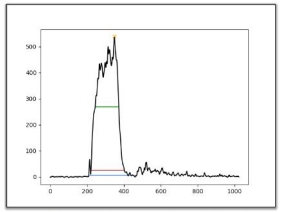
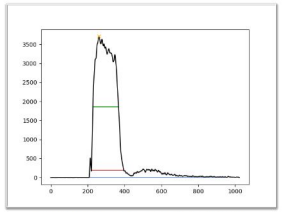
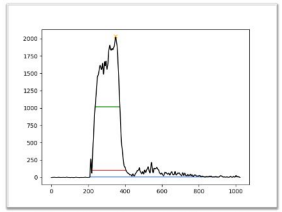
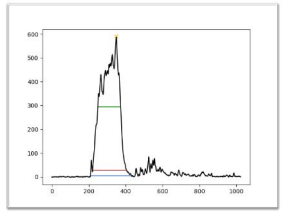



PMT_fast_run_22100_ev_63_tr_1_ch_1.png


PMT_fast_run_22100_ev_63_tr_1_ch_2.png

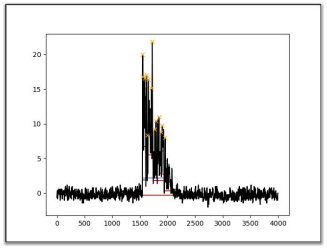

PMT_fast_run_22100_ev_63_tr_1_ch_3.png


PMT_fast_run_22100_ev_63_tr_1_ch_4.png

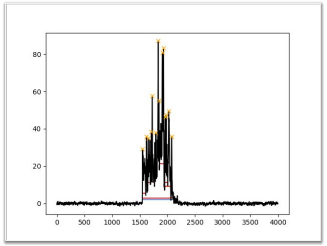
⇒ Easy way of identifying the main quadrant of the alpha ➡ Not enough to fully position the track in the image, but enough to do a simple 1-to-1 association between camera and PMT (easier for high intensity signals like alphas)

Property 4

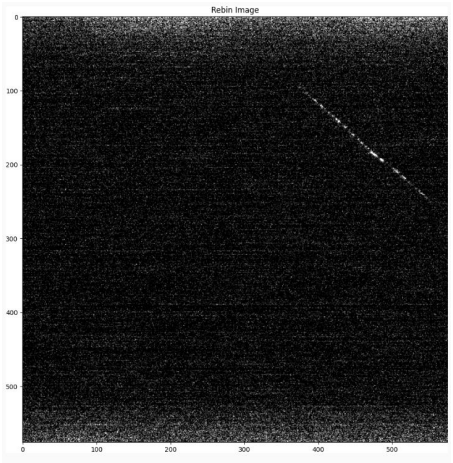
- Geometrical “displacement” of alpha in X-Y (amplitude comparison <u>within the PMT</u> waveform)
  - ***Not to be confused with X-Y direction!***

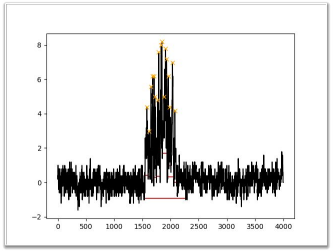


PMT_slow_run_22100_ev_9_tr_0_ch_1.png

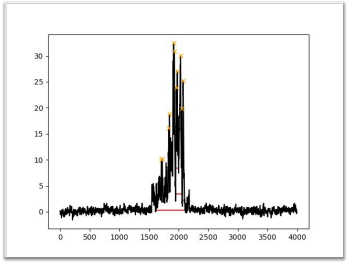


PMT_slow_run_22100_ev_9_tr_0_ch_2.png





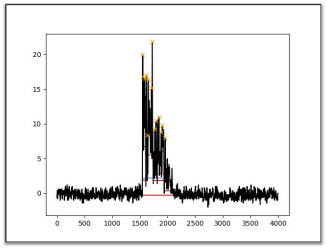
PMT_slow_run_22100_ev_9_tr_0_ch_4.png



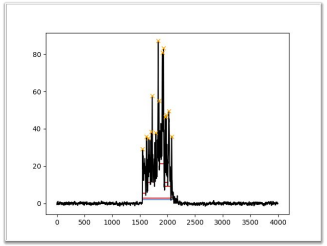
PMT_slow_run_22100_ev_9_tr_0_ch_3.png

Property 4

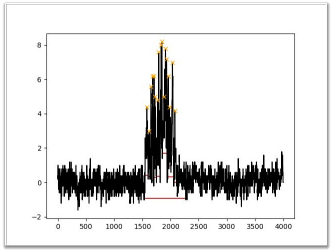
- Geometrical “displacement” of alpha in X-Y (amplitude comparison within the PMT waveform)
  - ***Not to be confused with X-Y direction!***



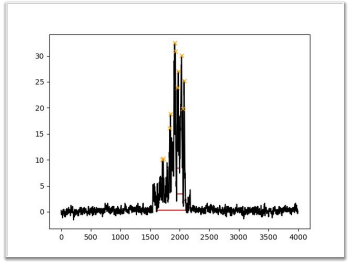
PMT_slow_run_22100_ev_9_tr_0_ch_1.png



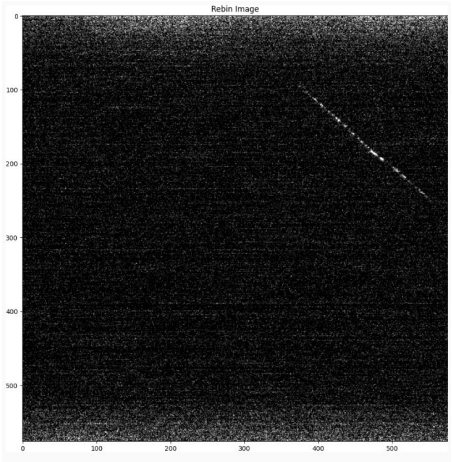
PMT_slow_run_22100_ev_9_tr_0_ch_2.png

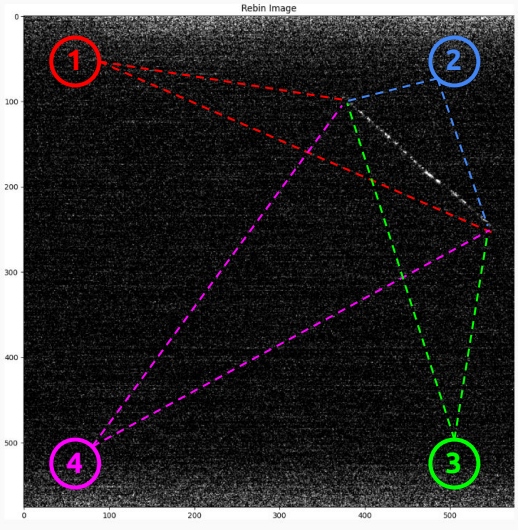


PMT_slow_run_22100_ev_9_tr_0_ch_4.png



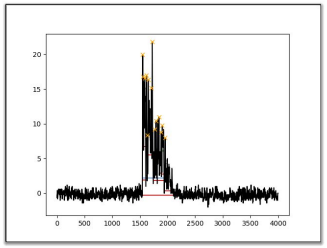
PMT_slow_run_22100_ev_9_tr_0_ch_3.png

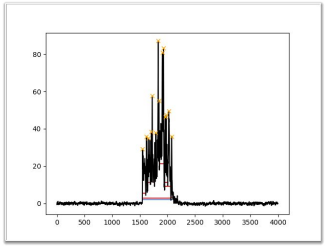


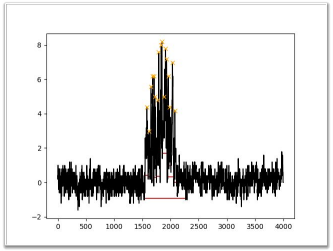


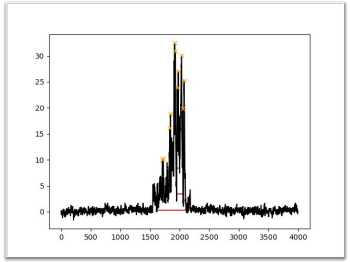
Property 4

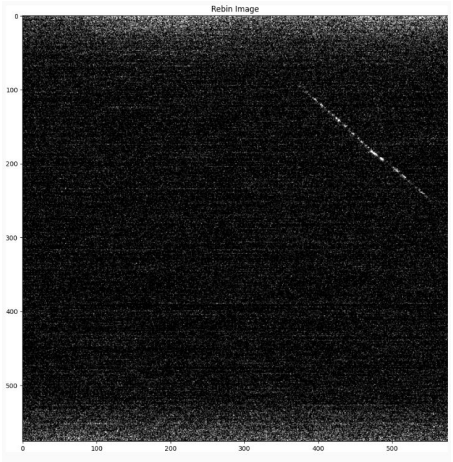
- Geometrical “displacement” of alpha in X-Y (amplitude comparison within the PMT waveform)
  - ***Not to be confused with X-Y direction!***

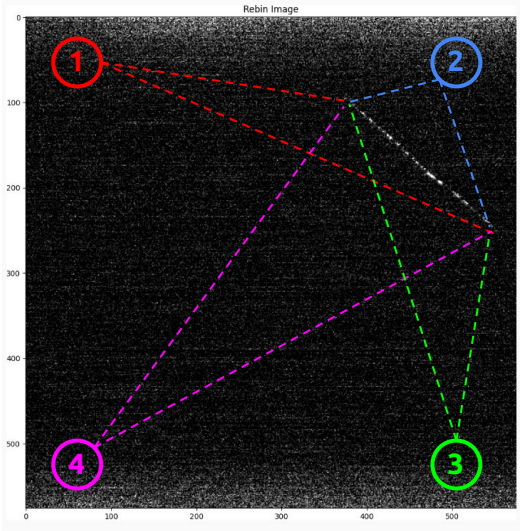

PMT_slow_run_22100_ev_9_tr_0_ch_1.png


PMT_slow_run_22100_ev_9_tr_0_ch_2.png


PMT_slow_run_22100_ev_9_tr_0_ch_4.png


PMT_slow_run_22100_ev_9_tr_0_ch_3.png

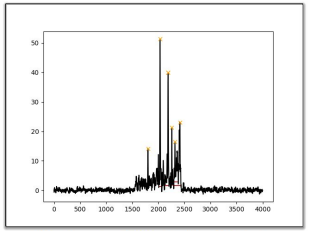


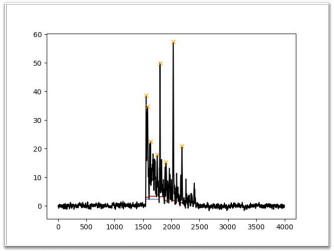


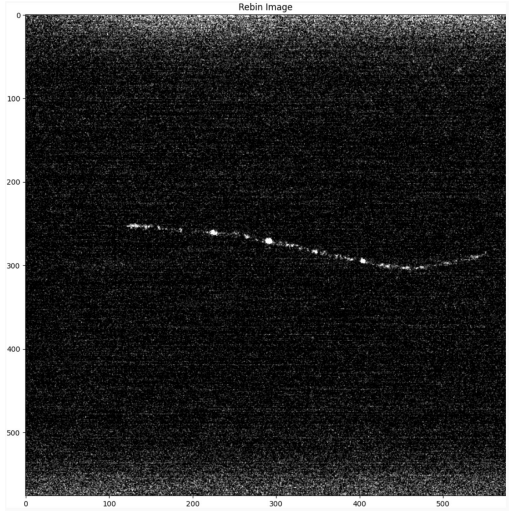
⇒ Purely from geometry and how radiated light changes with $1/R^{\sim 4}$, the PMTs see “a shape” BUT this *does not* give me information about the particle direction (*is it going left or right?*) because the ionization profile is flat (MIP-like). It’s just geometrical

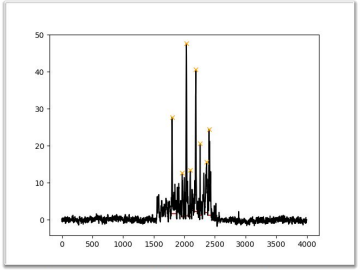
Property 4

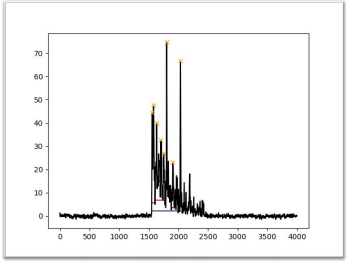
- Geometrical “displacement” of alpha in X-Y (amplitude comparison within the PMT waveform)
  - ***A better example…***


PMT_slow_run_22100_ev_24_tr_1_ch_1.png


PMT_slow_run_22100_ev_24_tr_1_ch_2.png



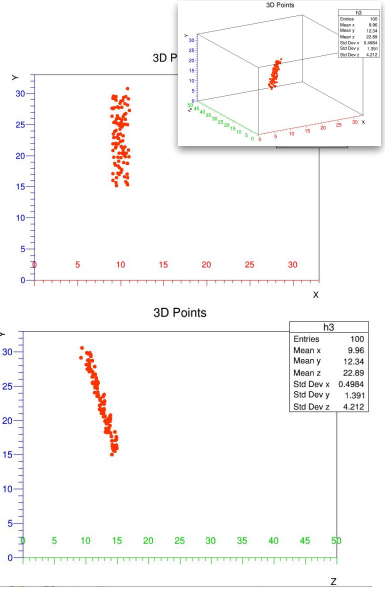

PMT_slow_run_22100_ev_24_tr_1_ch_4.png


PMT_slow_run_22100_ev_24_tr_1_ch_3.png

⇒ You might think it’s moving from the right to the left, but we don’t know that, since the PMT see the light after drift. What we do know, instead, it that likely the particle is moving towards the cathode, because the first electrons to arrive produced a more intense signal in PMTs 2 & 3 (right hemisphere), and almost nothing for 1 & 4, while for the last electrons was the opposite.

PMT Signal basic properties – 4

- Geometrical "displacement" of alpha in X-Y (amplitude comparison within the PMT waveform)
  - *A better example…* How would a *"maximum ionizing particle"* look like, geometrically, assuming *flat energy deposit:*



PMT Signal basic properties – 4

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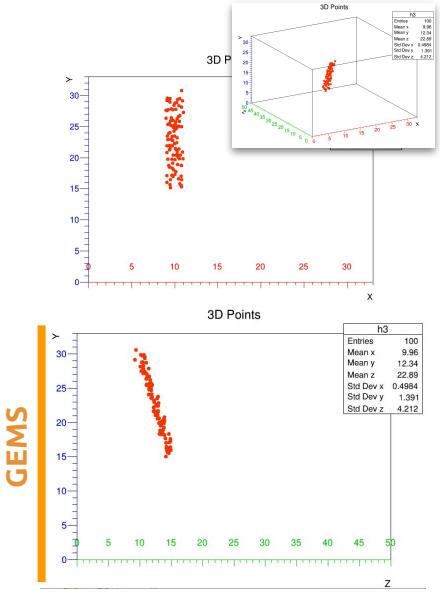
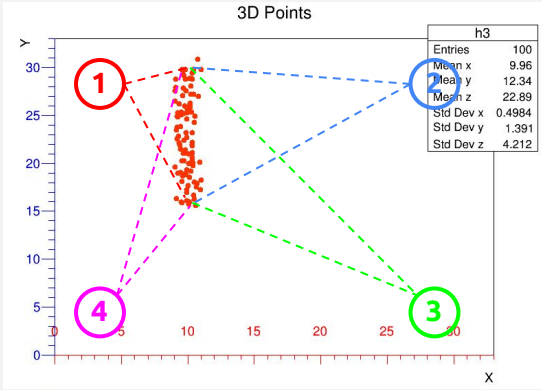
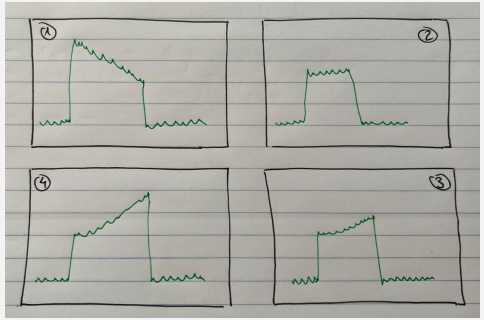
  - *A better example…* How would a *"maximum ionizing particle"* look like, geometrically, assuming *flat energy deposit:*



1. **Tilt in Z** gives me no information, besides ToT length
2. **Geometrical emission** of light will show in the waveforms.

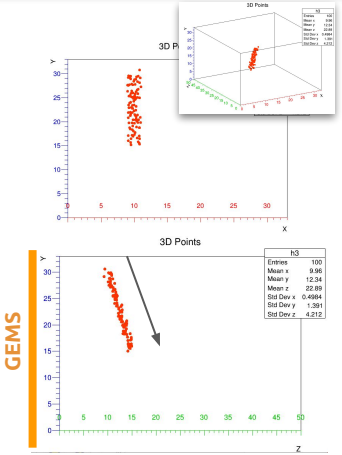


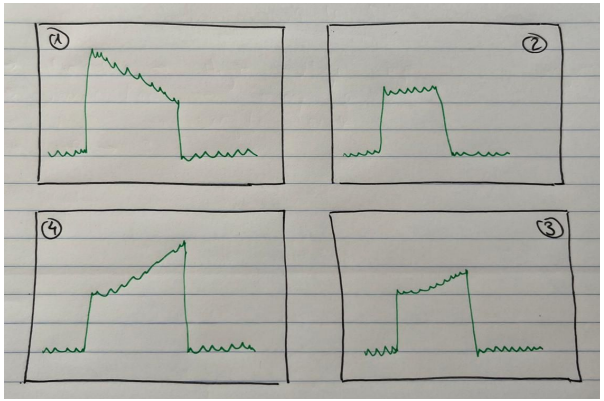


PMT 1 - closer (X-Y) electrons arrive first; PMT 2 - all electrons are equidistant; PMT 3 - closer (slightly) electrons arrive later;
PMT 4 - closer electrons arrive later. ⇒ **No sensitivity to head-tail, but sensitive to particle displacement in X-Y**

PMT Signal basic properties – 4

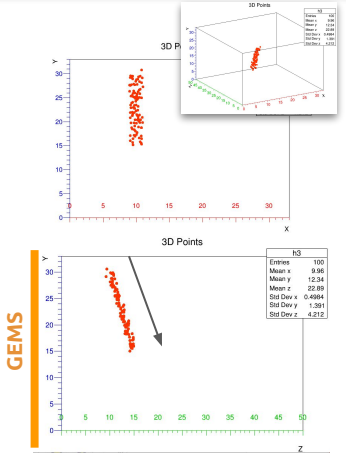
- Geometrical "displacement" of alpha in X-Y (amplitude comparison within the PMT waveform)
  - And now let's assume it's an *alpha* with a *Bragg peak*, moving *towards the cathode*:
    - **Now I have the geometrical "factor", plus the Bragg peak convoluted** (at the end in *this case*)

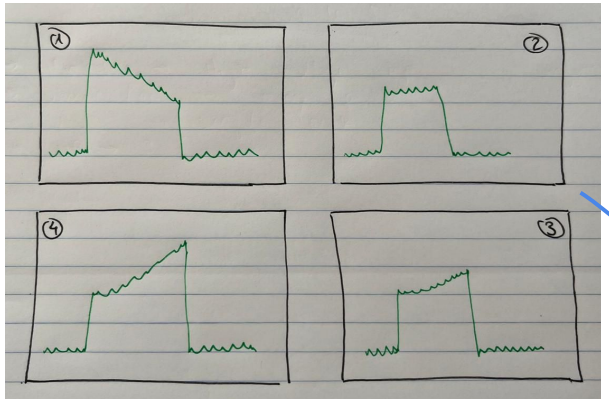




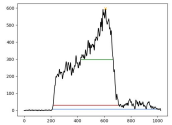
PMT Signal basic properties – 4

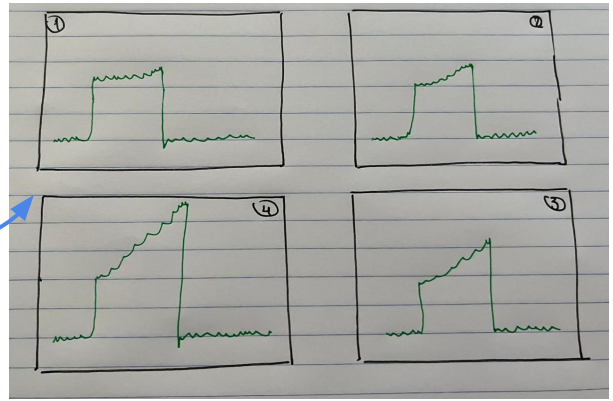
- Geometrical "displacement" of alpha in X-Y (amplitude comparison within the PMT waveform)
  - And now let's assume it's an *alpha* with a *Bragg peak*, moving *towards the cathode*:
    - Now I have the geometrical "factor", plus the Bragg peak convoluted (at the end in *this case*)





+ Bragg peak at the end (in time)





PMT 1 - Signal flattens because Bragg peak "cancels" out with geometry;

PMT 2 - going from flat to some shape;

PMT 3 - Same as PMT 4

PMT 4 - Peak much more evident ⇒ the Bragg peak occurs at the X-Y position closer to it;

PMT Signal basic properties – 4

- Geometrical "displacement" of alpha in X-Y (amplitude comparison within the PMT waveform)
  - And now let's assume it's an *alpha* with a *Bragg peak*, moving *towards the cathode*:
    - Now l… …d in *this case*)

Two PMTs see a flatter waveform, and the other two see a more pronounced (Bragg) peak.

There are always two pairs of PMTs that see one of the effects

The signals encode both the Z angle, and the direction (head-tail) !

PMT 1 - Signal flattens because Bragg peak "cancels" out with geometry;

PMT 2 - going from flat to some shape;

PMT 3 - Same as PMT 4

PMT 4 - Peak much more evident ⇒ the Bragg peak occurs at the X-Y position closer to it;

PMT Signal basic properties – Resume

Let's resume all the information and look at some examples:

1. **Time over threshold** gives me the alpha **ΔZ**
    - Not sure if it gives the angle if we don't know the energy
        - Rethought about it, and the camera gives the other side, so the angle is retrievable

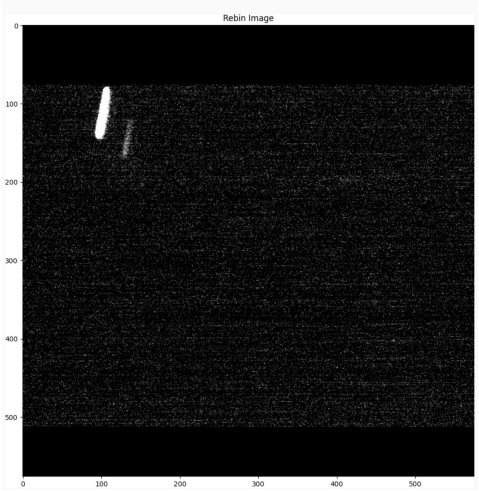
2. The **position of the Bragg** peak tells me if it's moving **towards the cathode or GEMs**

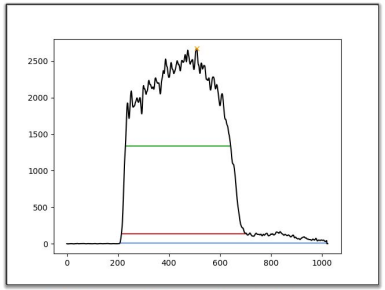
3. **Relative amplitudes between PMTs** give me the **quadrant position** in X-Y
    - Useful for **basic association** cluster-waveform

4. **Skewness of Bragg peak** (within the waveform) **difference** between PMTs gives me the **direction** of the particle (**head-tail**)
    - Bragg peak more prominent because the track are small, thus geometrical effect plays a smaller role
    - Also gives a hint of the X-Y angle, but this is easier to get with the camera

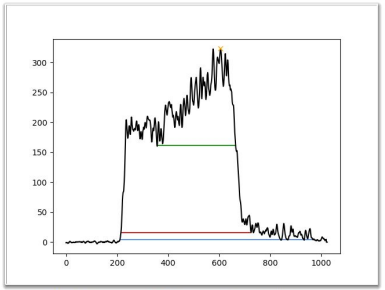
PMT Signal basic properties – Examples

- Run 22100, ev 11

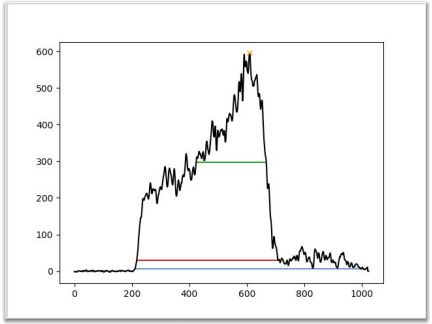




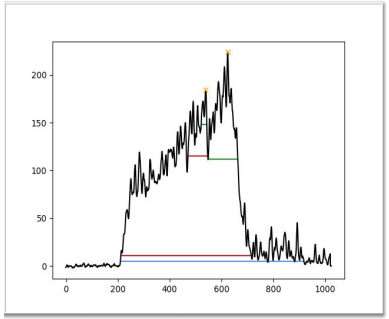
PMT_fast_run_22100_ev_11_tr_1_ch_1.png



PMT_fast_run_22100_ev_11_tr_1_ch_2.png



PMT_fast_run_22100_ev_11_tr_1_ch_4.png

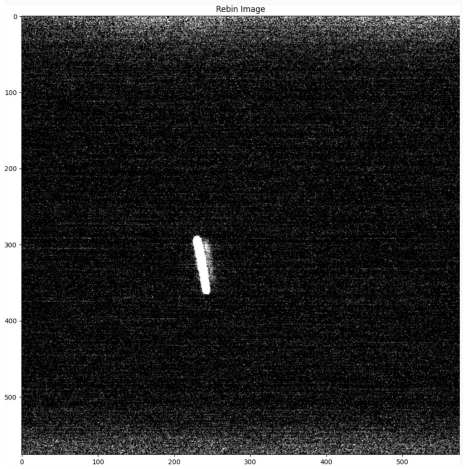


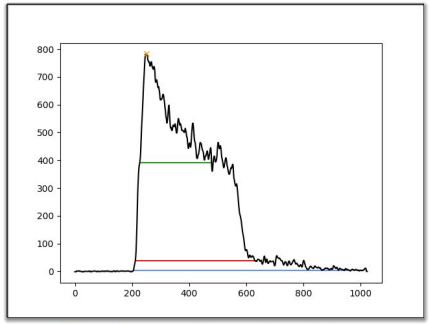
PMT_fast_run_22100_ev_11_tr_1_ch_3.png

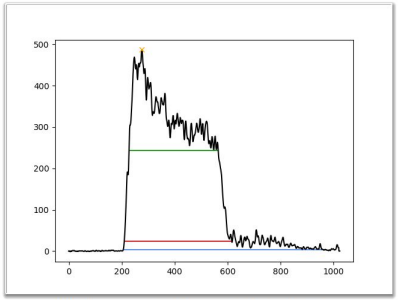
- Bragg peak on the right ⇒ moving **towards cathode**.
- Upwards or downwards? ⇒ Skewness higher for PMTs 3 and 4, moving **downwards**

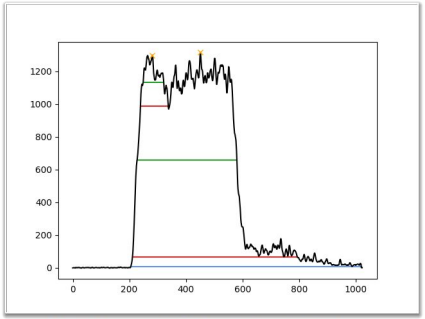
PMT Signal basic properties – Examples

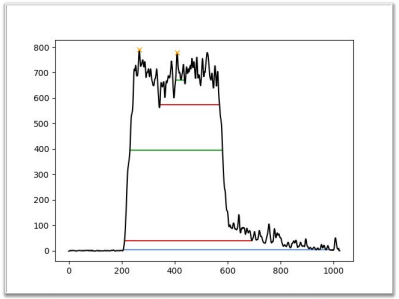
- Run 22101, ev 33




PMT_fast_run_22101_ev_33_tr_0_ch_1.png


PMT_fast_run_22101_ev_33_tr_0_ch_2.png

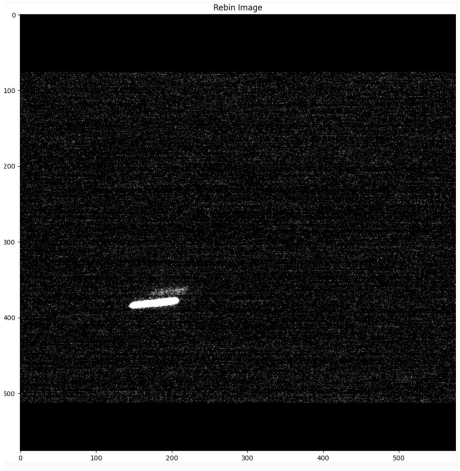

PMT_fast_run_22101_ev_33_tr_0_ch_4.png

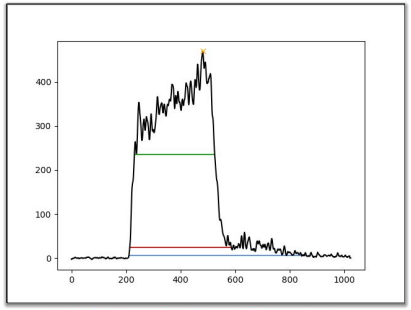

PMT_fast_run_22101_ev_33_tr_0_ch_3.png

- Bragg peak on the left ⇒ moving **towards GEMs**.
- upwards or downwards? ⇒ Skewness higher for PMTs 1 and 2, moving **upwards** (again, the Bragg happened farther away for 3 and 4, so not so prominent)

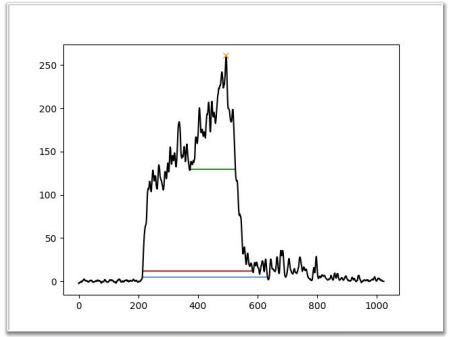
PMT Signal basic properties – Examples

- Run 22100, ev 40

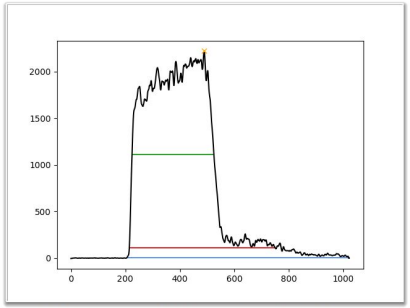




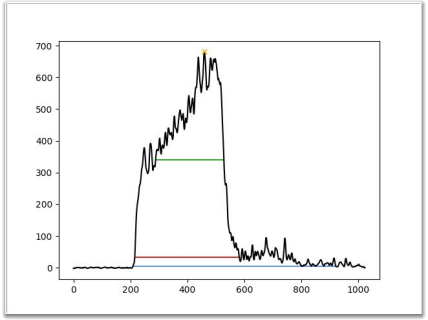
PMT_fast_run_22100_ev_40_tr_0_ch_1.png



PMT_fast_run_22100_ev_40_tr_0_ch_2.png



PMT_fast_run_22100_ev_40_tr_0_ch_4.png

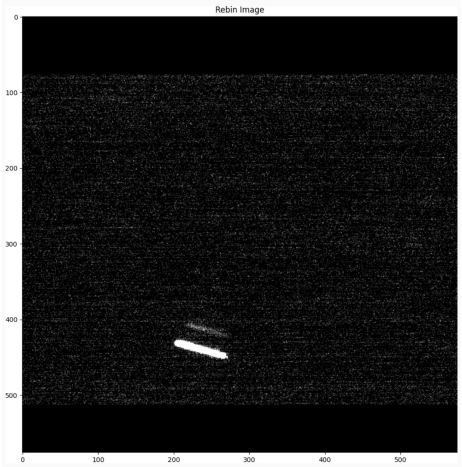


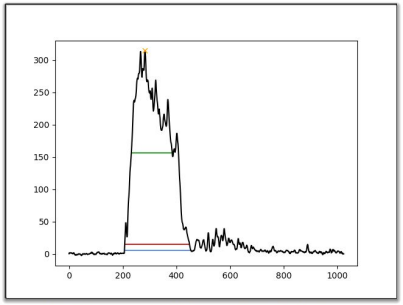
PMT_fast_run_22100_ev_40_tr_0_ch_3.png

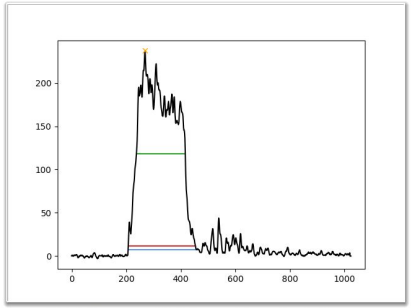
- Bragg peak on the right ⇒ moving **towards cathode**.
- Leftwards or rightwards? ⇒ Skewness higher for PMTs 2 and 3, moving **rightwards**

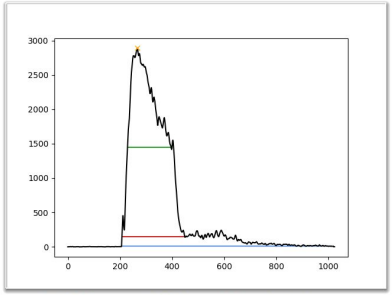
PMT Signal basic properties – Examples

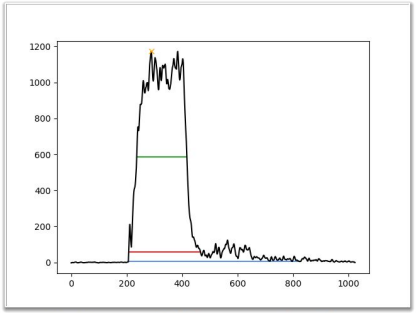
- Run 22100, ev 46




PMT_fast_run_22100_ev_46_tr_0_ch_1.png


PMT_fast_run_22100_ev_46_tr_0_ch_2.png

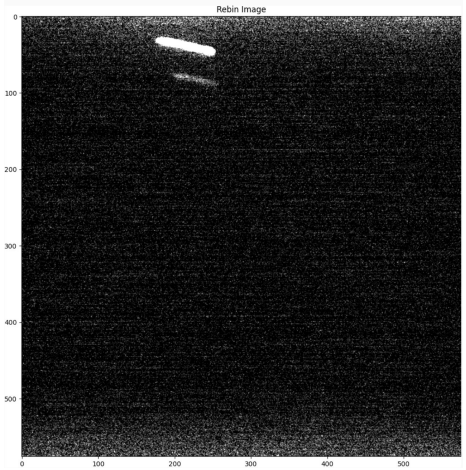

PMT_fast_run_22100_ev_46_tr_0_ch_4.png

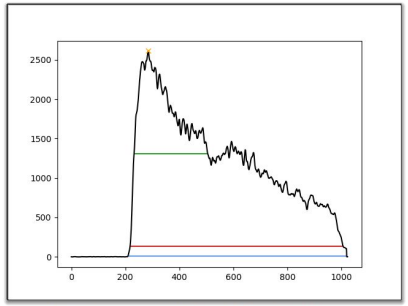

PMT_fast_run_22100_ev_46_tr_0_ch_3.png

- Bragg peak on the left ⇒ moving **towards GEMs**.
- Leftwards or rightwards? ⇒ Skewness higher for PMTs 1 and 4, moving **leftwards**

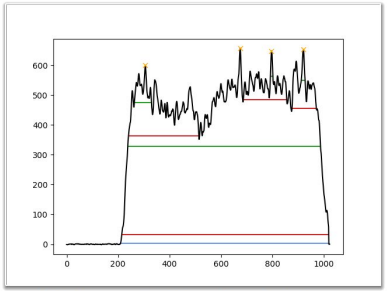
PMT Signal basic properties – Examples

- Run 22100, ev 18

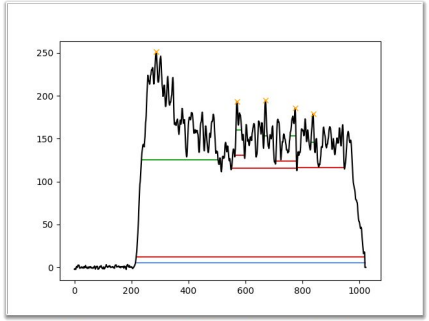




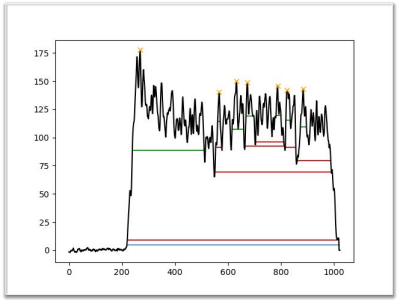
PMT_fast_run_22100_ev_18_tr_0_ch_1.png



PMT_fast_run_22100_ev_18_tr_0_ch_2.png



PMT_fast_run_22100_ev_18_tr_0_ch_4.png

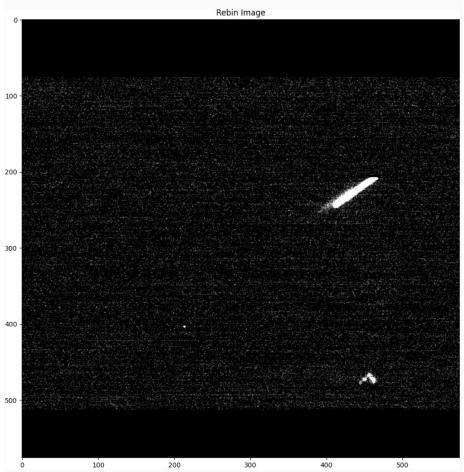


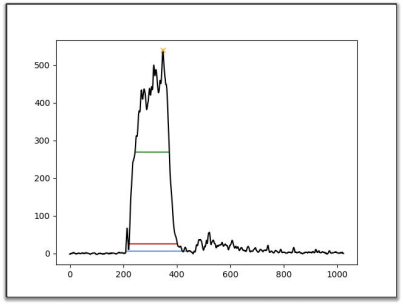
PMT_fast_run_22100_ev_18_tr_0_ch_3.png

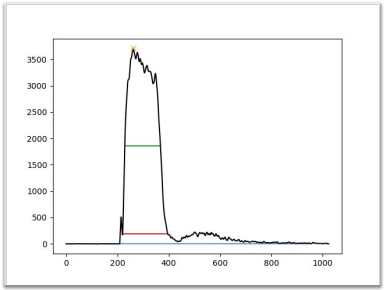
- Bragg peak on the left ⇒ moving **towards GEMs**.
- Leftwards or rightwards? ⇒ Skewness especially high for PMT 1 and especially flat for PMT 2 ⇒ moving **leftwards**

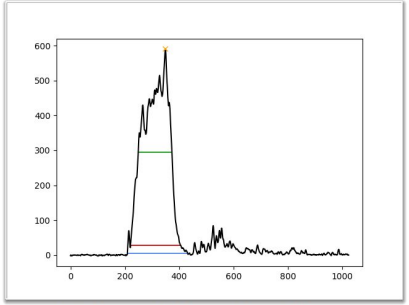
PMT Signal basic properties – Examples

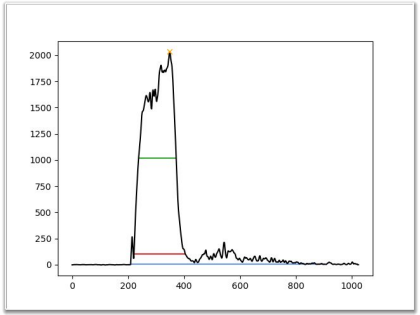
- Run 22100, ev 63




PMT_fast_run_22100_ev_63_tr_1_ch_1.png


PMT_fast_run_22100_ev_63_tr_1_ch_2.png

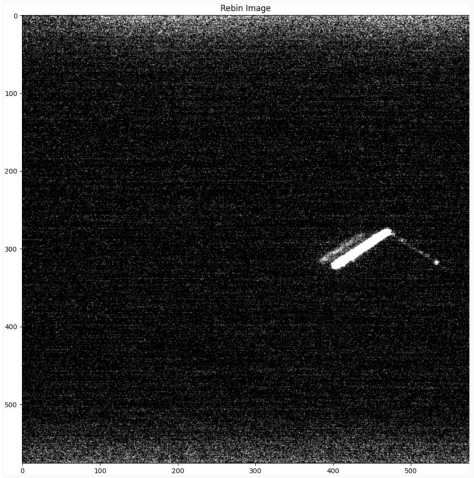

PMT_fast_run_22100_ev_63_tr_1_ch_4.png

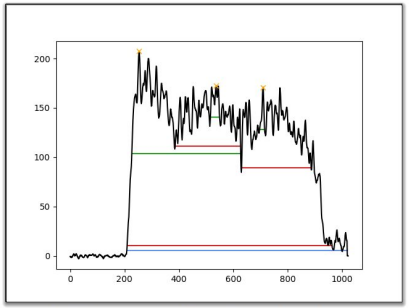

PMT_fast_run_22100_ev_63_tr_1_ch_3.png

- Bragg peak on the right ⇒ moving **towards cathode**.
- Direction? ⇒ Skewness similar in 3 PMTs and different in another ⇒ Diagonal ⇒ moving **away from PMT2**, otherwise the Bragg peak would be even more pronounced (and not reversed)

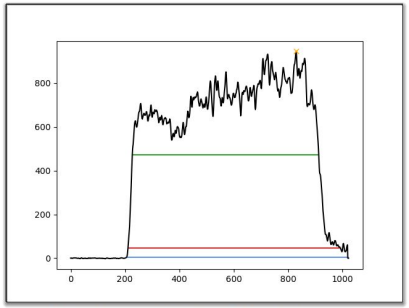
PMT Signal basic properties – Examples

- Run 22101, ev 81
  - Also Migdal like

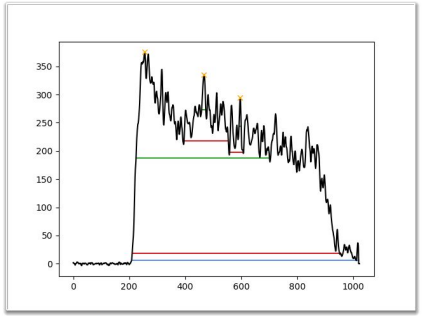




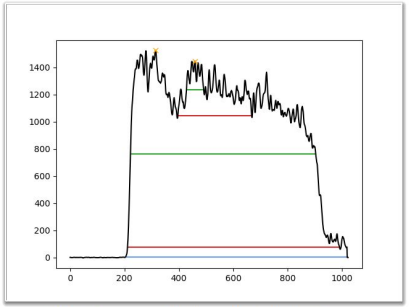
PMT_fast_run_22101_ev_81_tr_1_ch_1.png



PMT_fast_run_22101_ev_81_tr_1_ch_2.png



PMT_fast_run_22101_ev_81_tr_1_ch_4.png

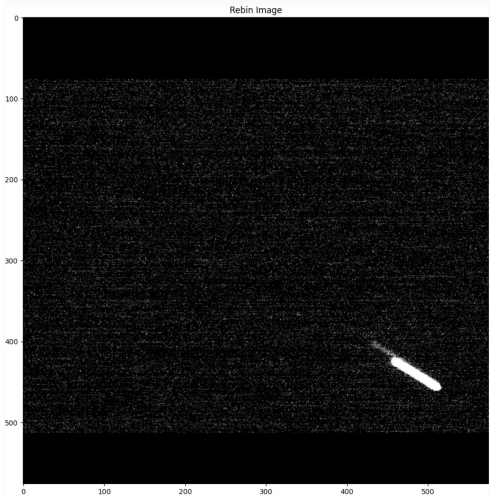


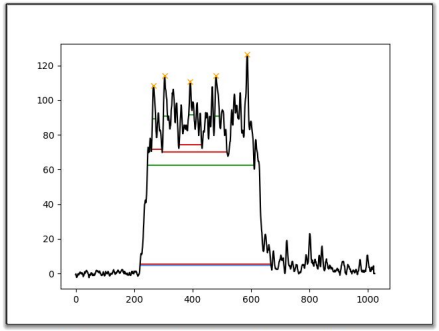
PMT_fast_run_22101_ev_81_tr_1_ch_3.png

- Bragg peak on the left ⇒ moving **towards GEMs**.
- Direction? ⇒ Skewness similar for all PMTs, and reversed for 2, moving **away from PMT 2**

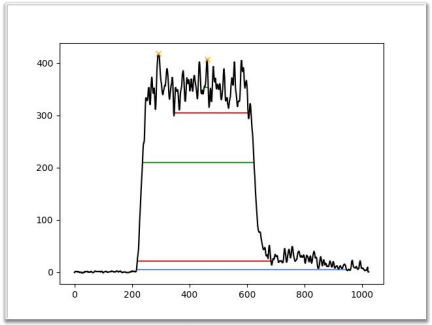
PMT Signal basic properties – Examples

- Run 22100, ev 47 – HARD

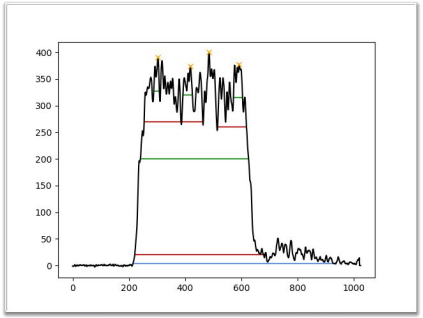




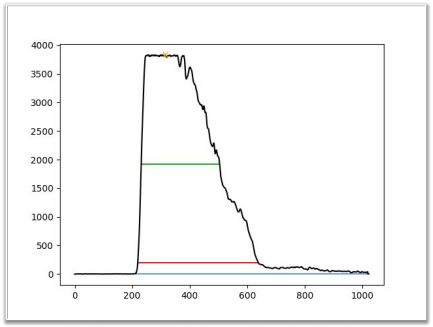
PMT_fast_run_22100_ev_47_tr_0_ch_1.png



PMT_fast_run_22100_ev_47_tr_0_ch_2.png



PMT_fast_run_22100_ev_47_tr_0_ch_4.png

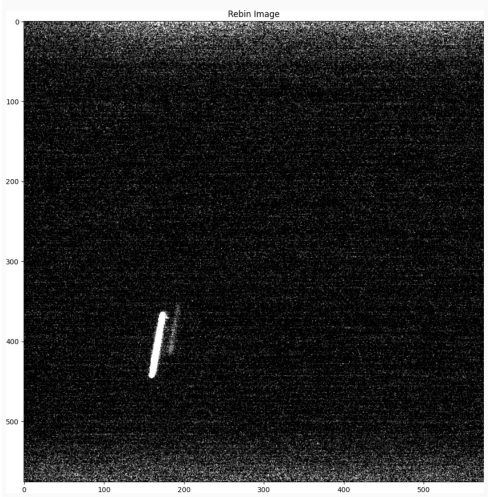


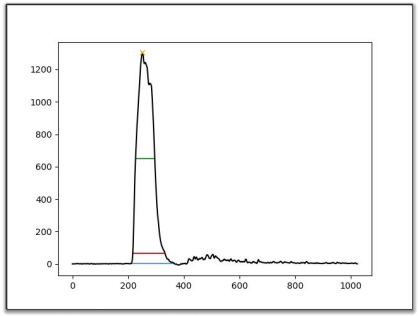
PMT_fast_run_22100_ev_47_tr_0_ch_3.png

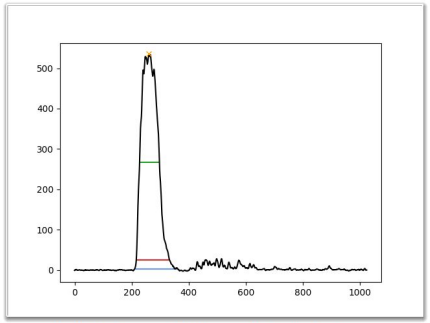
- Difficult case -> Bragg peak on the left at least of PMT 3 ⇒ moving **towards GEMs** (MAYBE)
- Direction? ⇒ Skewness similar for all PMTs, negative for 3, moving **away from PMT 3** (assuming the PMT is farther down)

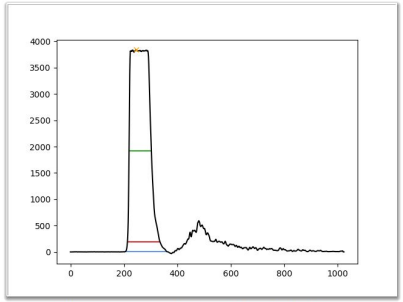
PMT Signal basic properties – Examples

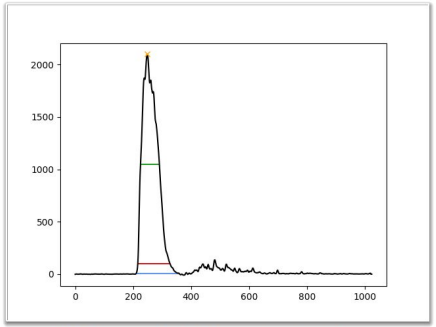
- Run 22100, ev 89 – HARD




PMT_fast_run_22100_ev_89_tr_1_ch_1.png


PMT_fast_run_22100_ev_89_tr_1_ch_2.png


PMT_fast_run_22100_ev_89_tr_1_ch_4.png


PMT_fast_run_22100_ev_89_tr_1_ch_3.png

- Difficult case -> Bragg peak on the left MAYBE ⇒ moving **towards GEMs**
- Direction? ⇒ UNCLEAR ⇒ very flat track

Conclusions

PMT Signal basic properties – Conclusions

1. **I think I found a way of determining the alpha's:**
   - **Angle signal in Z** (towards cathode or GEMs)
     - Merging with the X-Y length and ToT length, **precise angle** is retrievable
   - **Angle in X-Y** (from the camera I supposed it's "easy", not my work)
   - **Sense or direction or head-tail**

3D Reconstruction

PMT Signal basic properties – Conclusions

1. **I think I found a way of determining the alpha's:**
   - **Angle signal in Z** (towards cathode or GEMs)
     - Merging with the X-Y length and ToT length, **precise angle** is retrievable
   - **Angle in X-Y** (from the camera I supposed it's "easy", not my work)
   - **Sense or direction or head-tail**

   } **3D Reconstruction**

2. **How do I know if this rational makes sense:**
   - Ask my colleagues… ***so what do you think?***
   - **Comparison with simulation** ⇒ 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

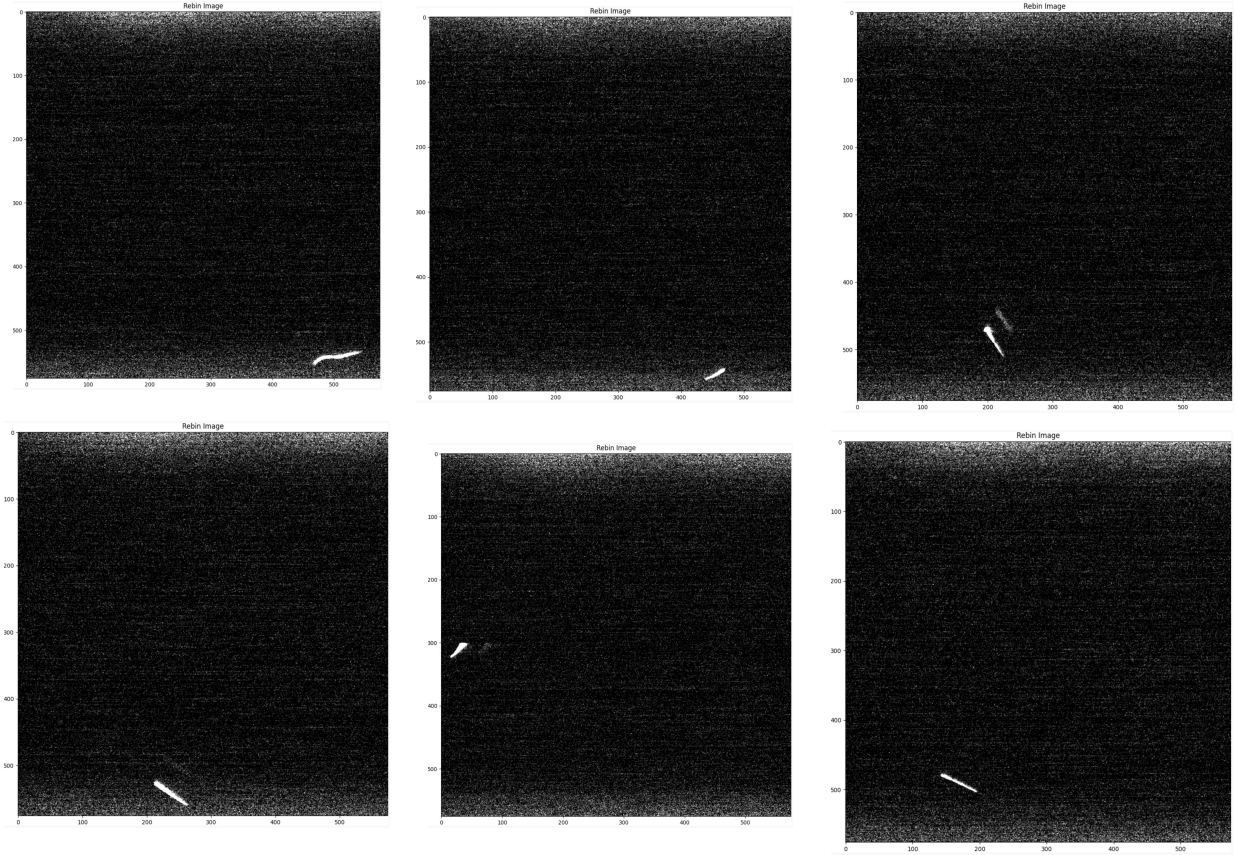
3. **I would also like to somehow give a score to how probable is the determination of being correct**
4. **Proceed with this?**

PMT Signal basic properties – Examples

Weird and

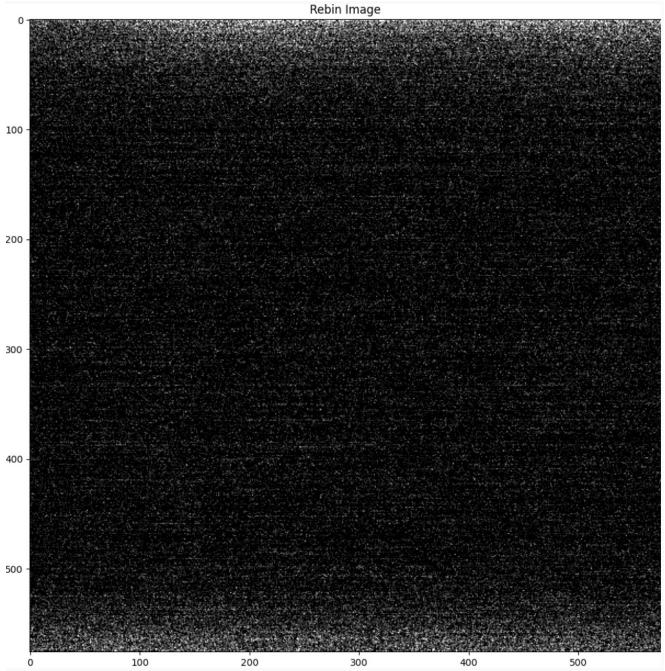
funny cases

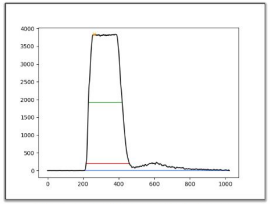
PMT Signal basic properties – Examples

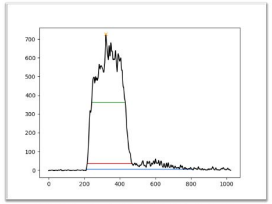


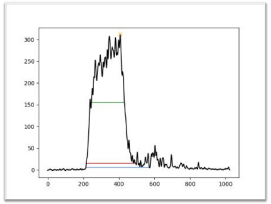
- Weirdly shaped alphas
- Looks sharp in one side, and diffused on the other.
- Lens effect?
- Electrical field effect?

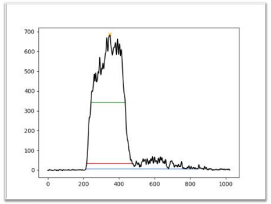
PMT Signal basic properties – Examples




PMT_fast_run_22100_ev_97_tr_1_ch_1.png


PMT_fast_run_22100_ev_97_tr_1_ch_2.png


PMT_fast_run_22100_ev_97_tr_1_ch_3.png


PMT_fast_run_22100_ev_97_tr_1_ch_4.png

- There are many empty pictures with Alpha waveforms
- This could be due to the global exposure / dead time feature
- When Flaminia calculated the alpha rates, she took this into account based on Stefano's dead time assumptions
  - I could do check the alpha rate from the PMT side to see if it matches
    - This also tests the alpha selection through both sensors