#5.1 Update on …

3D alphas –

Additional plots coming from 2-day Analysis meeting discussions

David Marques

Analysis and Reconstruction meeting 03/10/2024, L'Aquila

PMT Reco & Analysis - *Previously*

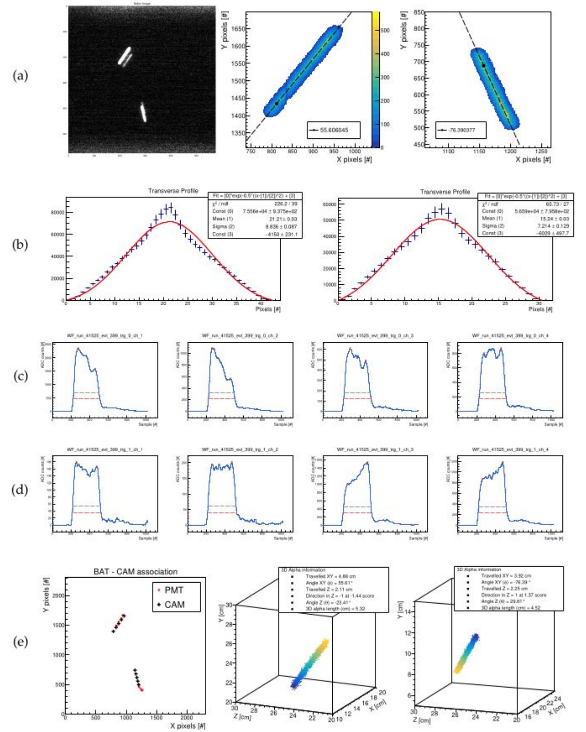


Figure 1.18: Full example of the analysis pipeline for the alpha particles identified in a given picture (run 41525, picture 399): (a) Original picture and sCMOS analysis of both alphas; (b) Light transverse profile of the alpha tracks; (c) and (d) the set of 4 waveforms for each trigger identified as alpha tracks; (e) waveform - cluster association and final 3D projection in the real LIME framework.

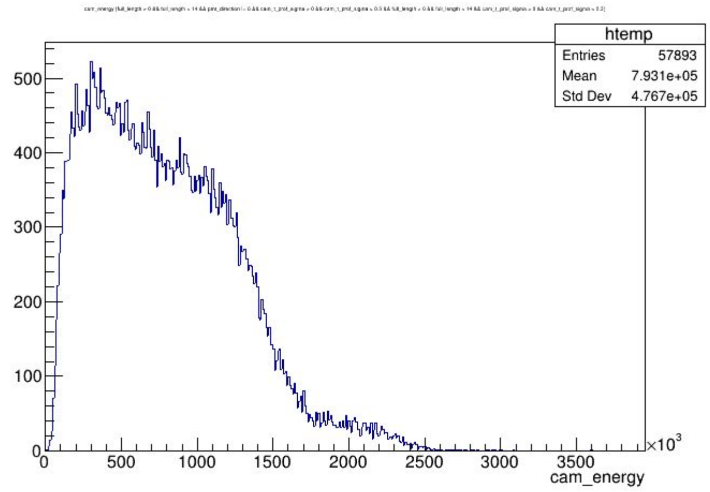
Previous episodes:

1. [Reconstruction and Analysis meeting (16 maggio 2024) · Agenda (Indico)]
   Initial look at alpha tracks for directional & head-tail determination
2. [Technical Reconstruction meeting (5 June 2024)]
   1 Update on … - 3D reconstructed alpha tracks
3. [Reconstruction and Analysis meeting]
   2 Update on … - 3D reconstructed alpha tracks
4. [Technical Reconstruction meeting]
   3 Update on ... Techical_update_**Coordinates_&_Shadows**
5. [Two Days of Reconstruction and Analysis]
   4 Update … - 3D reconstructed alpha tracks - **Real Analysis**

Full framework retrieves and saves all the relevant information automatically, including plots.

7. Pinci's energy plots

*… The more traditional plots are the **energy** ones. These are harder in LIME due to **saturation**, especially on **alpha**-particles due to **very high dE/dx**.*



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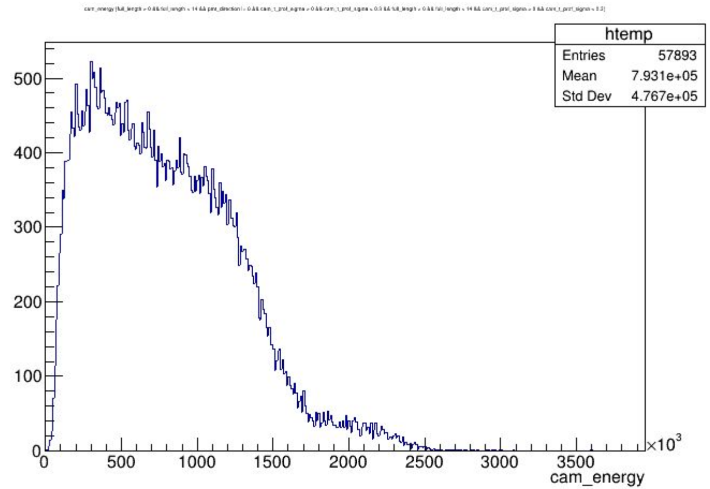
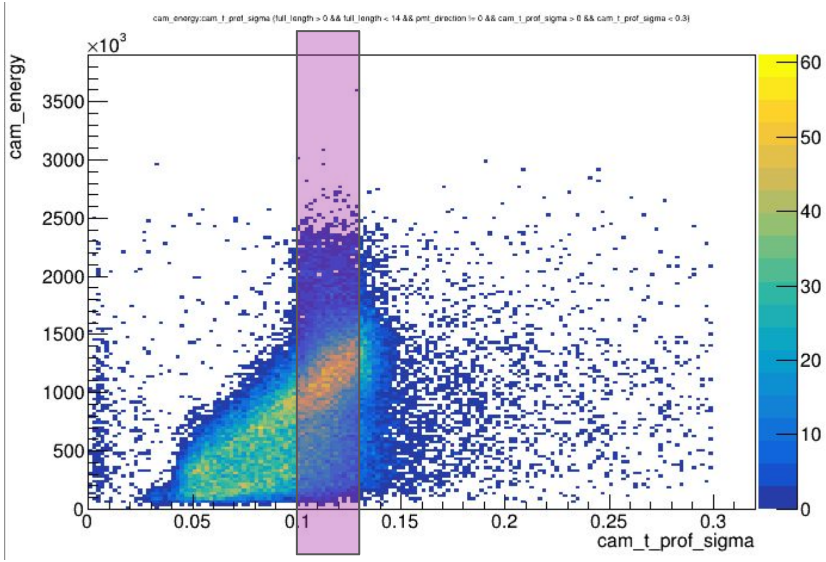
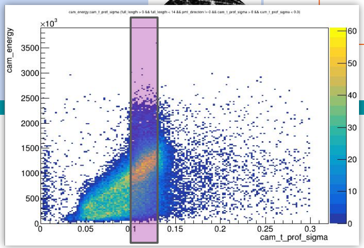


*One can select a **band in absolute Z**, where all alphas should suffer the same saturation.*

➔ ***Band selected:** **0.1-0.13 cm sigma** **(near cathode)***

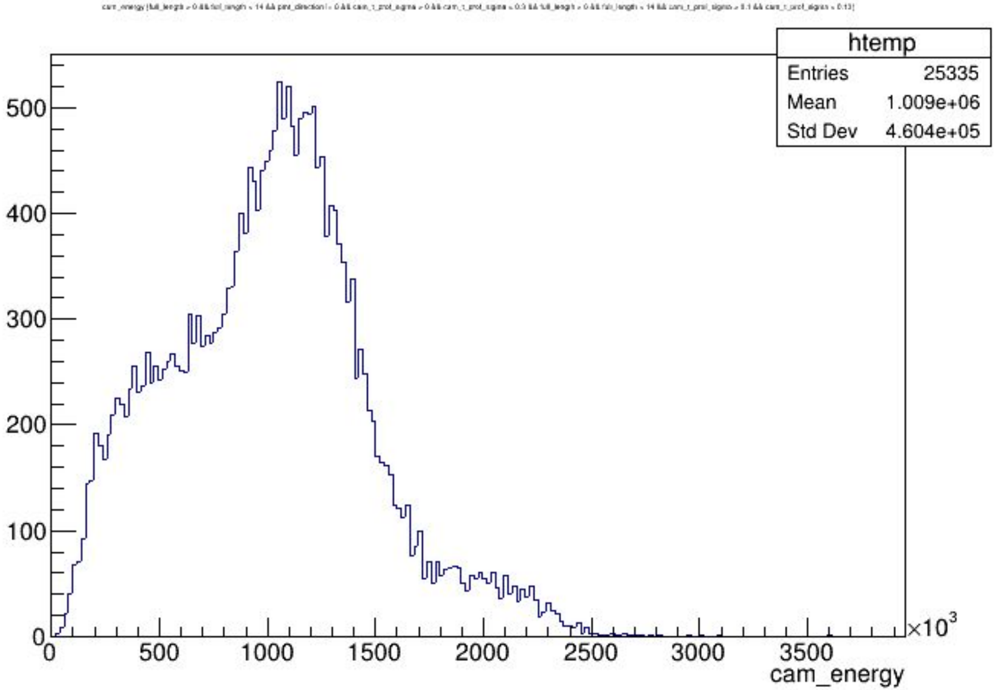


*Data: All



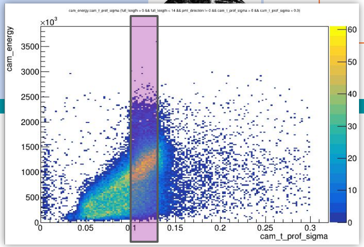
7. Pinci's energy plots

*… This cut already hints for **some energy peaks**, although hard to identify them, perhaps due to overlap*



PMT Reco & Analysis

**Data: All*

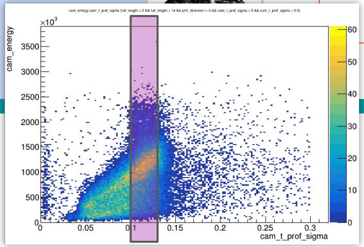


7. Pinci's energy plots

*… What if we **also cut** the energy band*

*with the **known length peaks**…*

(assuming already Z cut)



7. *Pinci's energy plots*

*… What if we **also cut** the energy band*

*with the **known length peaks**…*

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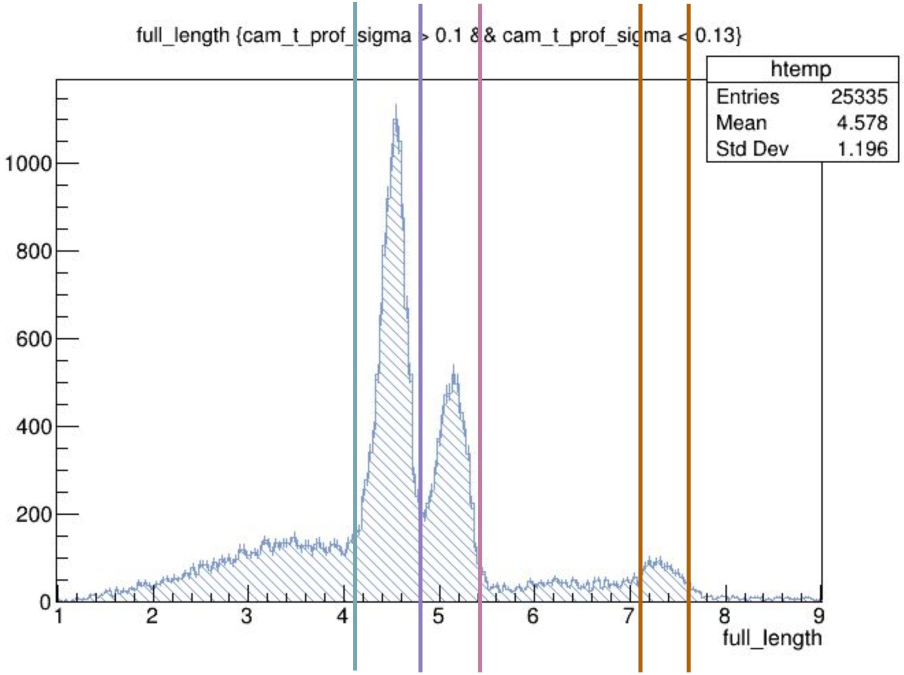
Intervals (in cm length)**:**

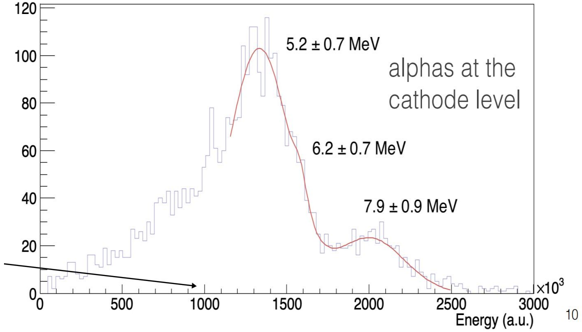
- **4.1 - 4.8**
- **4.8 - 5.4**
- **7.1 - 7.6**



*Data: All

7. Pinci's energy plots

From Pinci…



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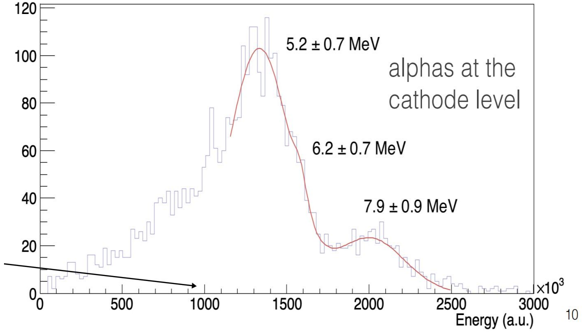
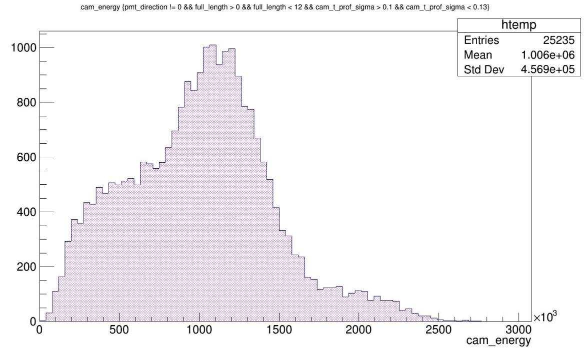
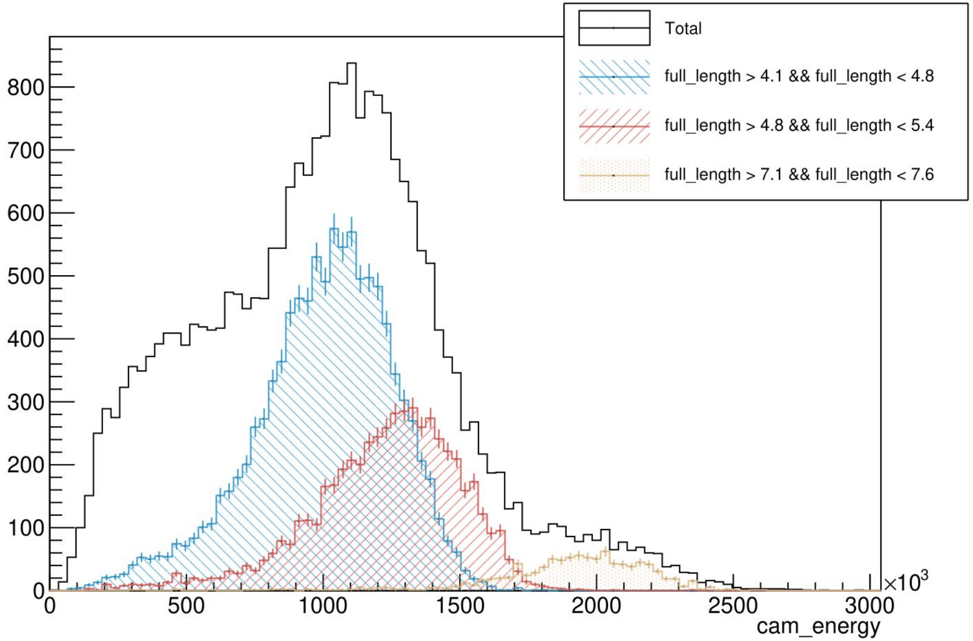


From Marques…





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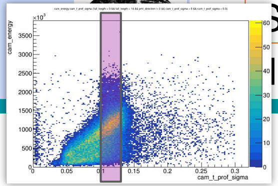
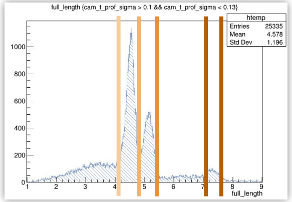
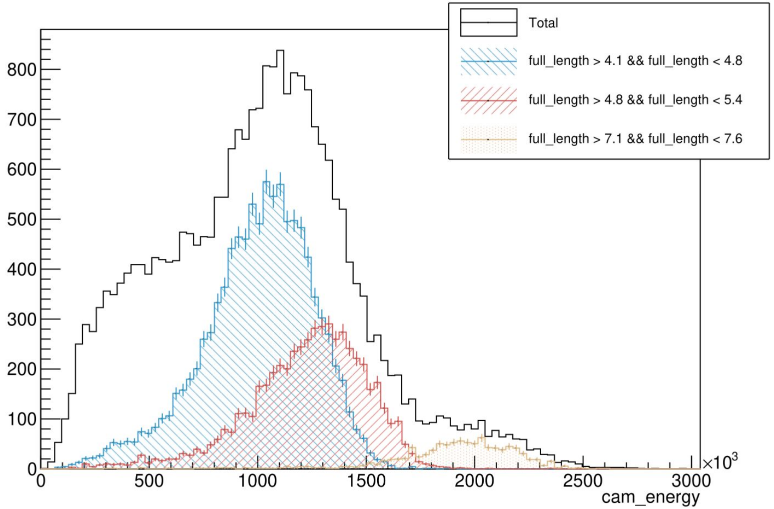




7. Pinci's energy plots

… If we individually fit each peak…



*Data: All

7. *Pinci's energy plots*

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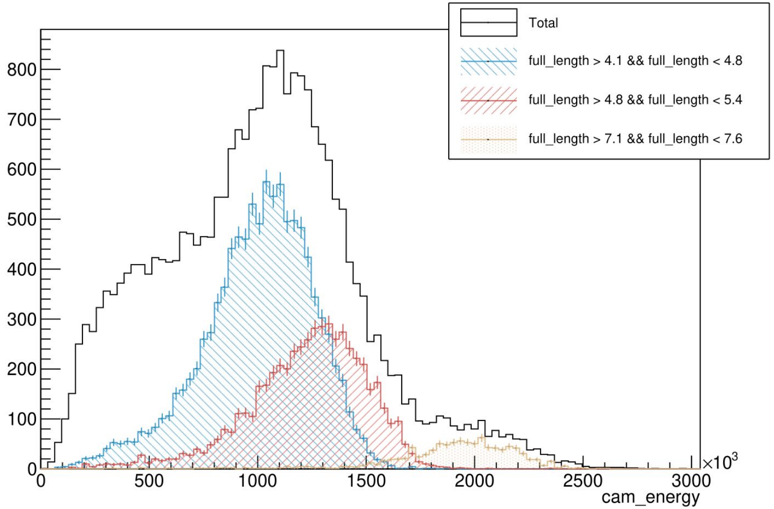
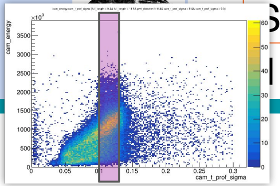
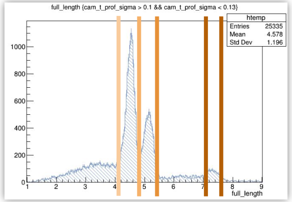


- So, a Rn contamination would produce:
  - 3 alphas:
    - ^{222}Rn -> 5.590 MeV (about 43 mm)
    - ^{218}Po -> 6.115 MeV (about 50 mm)
    - ^{214}Po -> 7.833 MeV (about 73 mm)
  - 2 betas
  - a lot of gammas from 50 keV to 2200 keV





NAME	VALUE	ERROR
Constant	4.94706e+02	6.13898e+00
Mean	**1.07130e+06**	**4.20824e+03**
Sigma	2.05135e+05	1.71237e+03
Constant	2.51362e+02	4.59904e+00
Mean	**1.31034e+06**	**5.42399e+03**
Sigma	1.93262e+05	3.19520e+03
Constant	4.47430e+01	1.90679e+00
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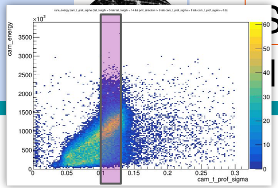
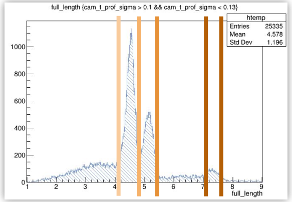
Sigma	2.14658e+05	5.72784e+03

**Data: All*





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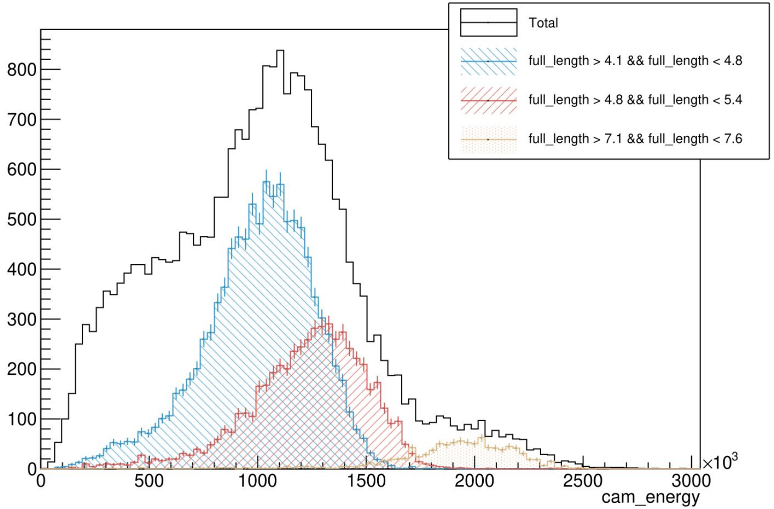

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Expected energy ratios:

α1 = 1

α2/α1 = 1.09

α3/α1 = 1.40

Measured ratios:

α1 = 1

α2/α1 = 1.22

α3/α1 = 1.81

8. Z angle – borders vs. center

The idea was to study the angles distributions by ***cutting the border alphas*** *against the "center" alphas, and other similar comparisons…*

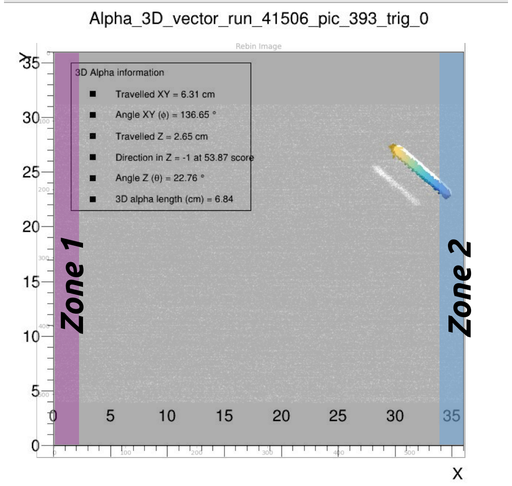
PMT Reco & Analysis

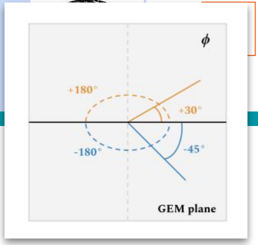
**Data: All*

8. Z angle – borders vs. center

UP vs. DOWN already seen before

*Let's see **LEFT vs. RIGHT***





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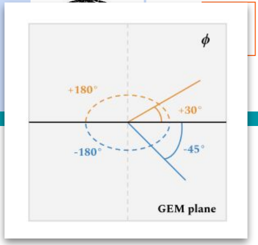

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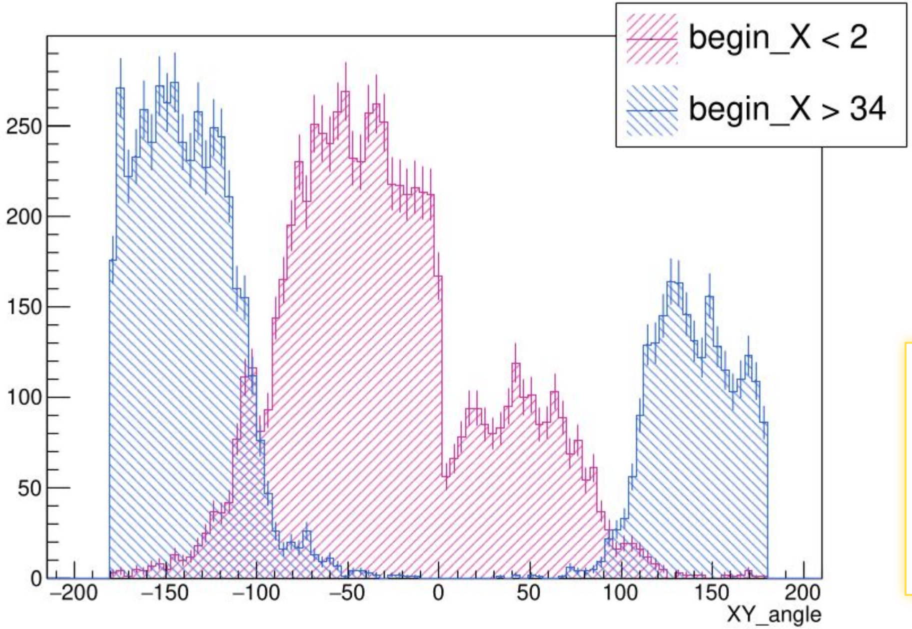

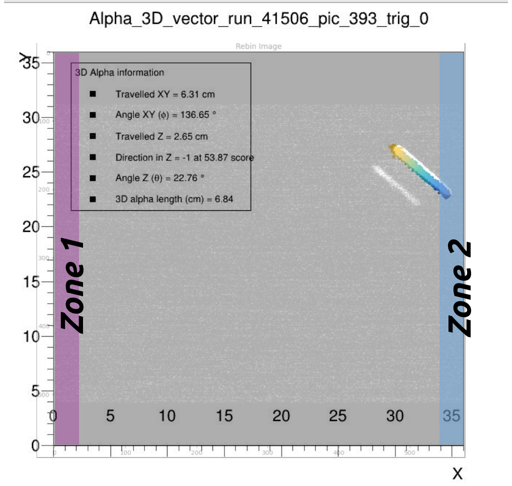

➔ With strong XY start cuts, we select very well the **alphas coming from the vessel**.

- Once again, good way to assess the efficiency of the CMOS:Analyzer for alphas

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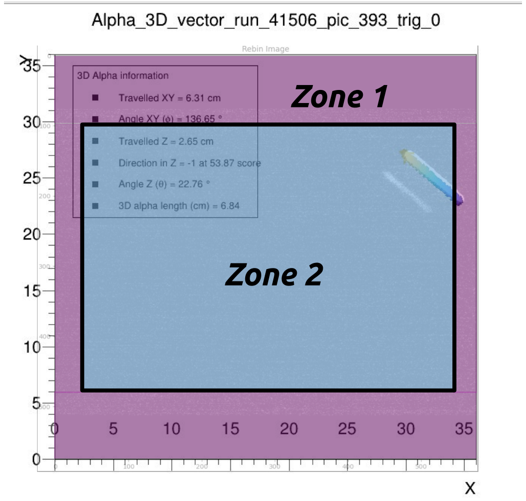

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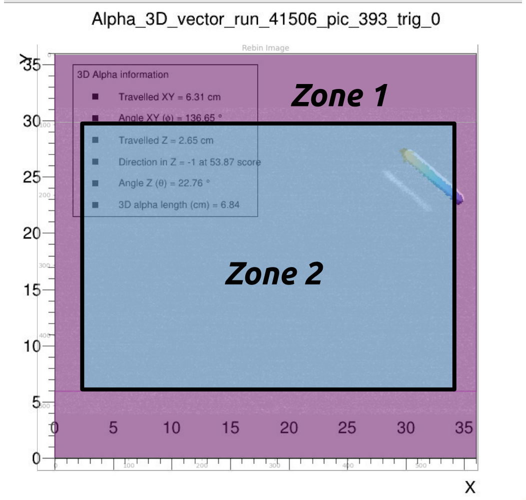
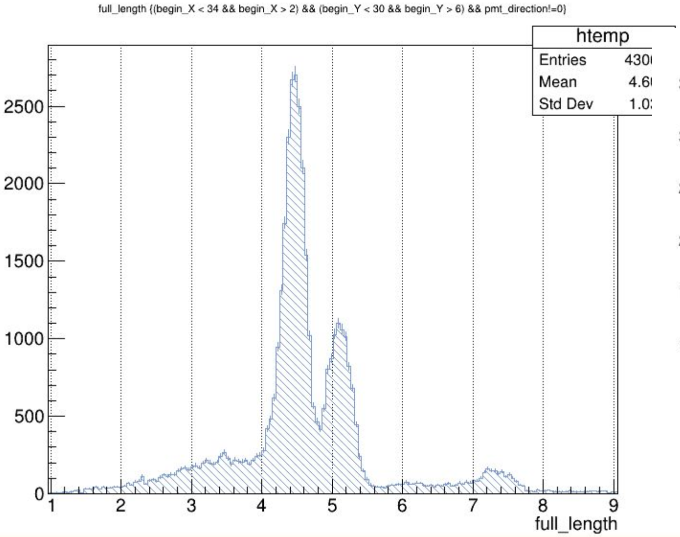
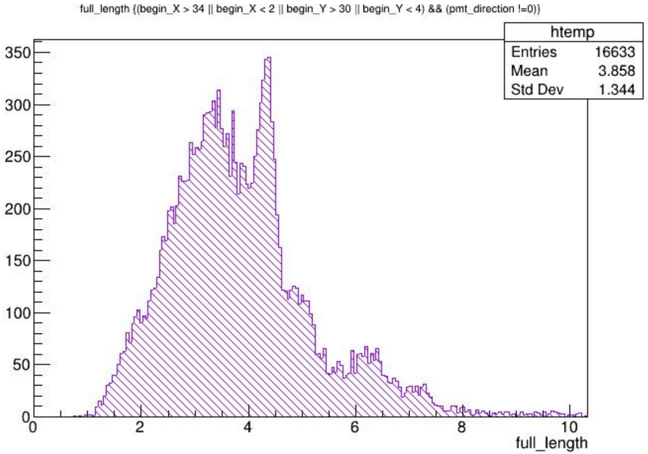






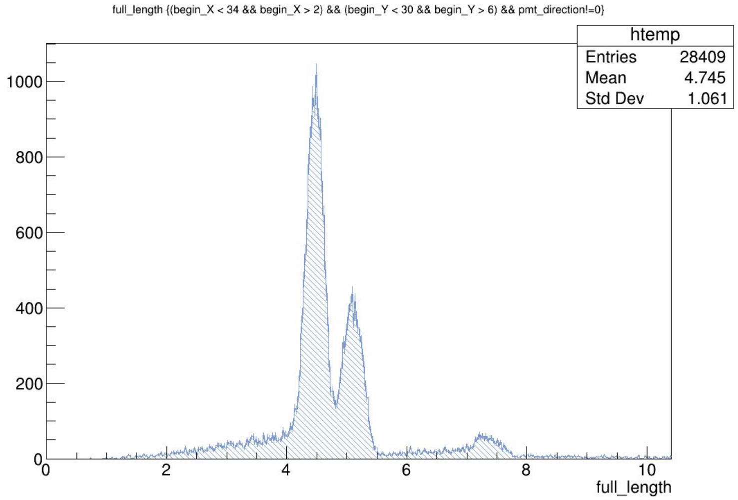
- ➔ Zone 2 very good selection of Rn alphas ⇒ with the typical 3 peaks.
- ➔ Zone 1, a bit of everything, and probably some systematically shorter alphas, from poor reco, geometrical lensing.
  - ◆ Peak at 4.3 from Rn, "removable" if we discard batch1 from data . Still, distinct peak at ~6.25cm ~ XX MeV

8. Z angle – boarders vs. center

*Now, **looking only at only one dataset** to remove stability/LY of LIME differences. **Batch 1 == Rn-full***

Batch 1 (Rn full) , INNER zone

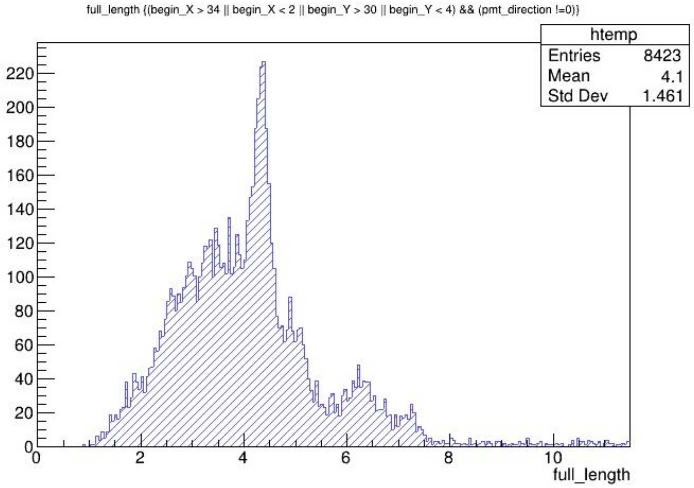
Very clean distribution of Rn alphas



Batch 1 (Rn full) , OUTER zone

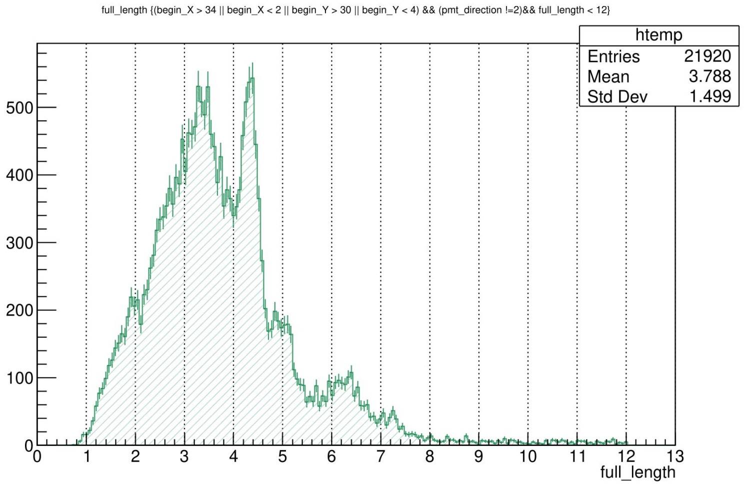
Reminiscent alphas from Rn + broken alphas from vessel

+ distinct peak at ~6.25mm ~~ XX MeV



9. Another look at the families of alphas in LIME

*Now, **all the data, removing the central part (to remove the overburden of Rn)***



… shoulders for days …

What do others see?

9. Another look at the families of alphas in LIME

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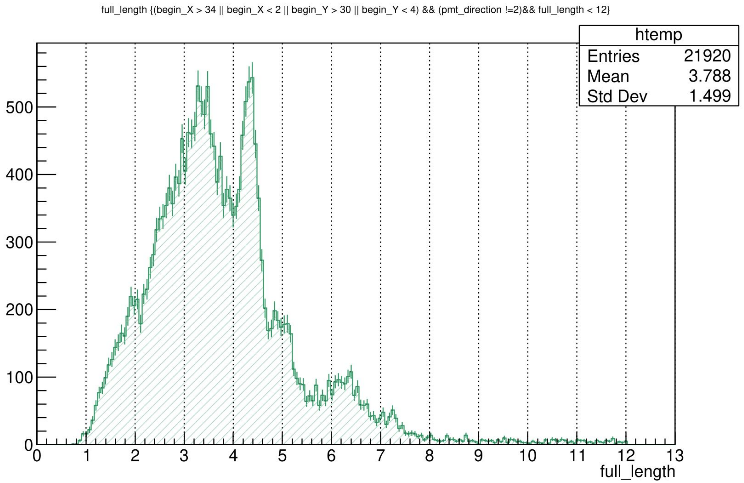
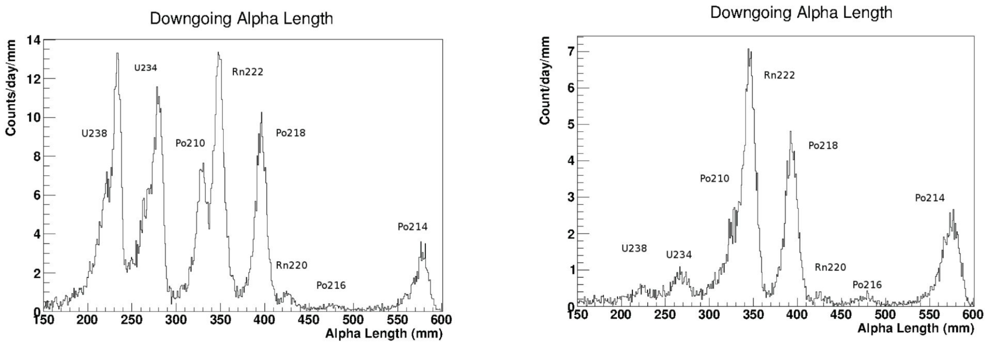


https://doi.org/10.1016/j.phpro.2014.12.022



(a) Spectrum from the first thin-film cathode.

(b) Spectrum from the second thin-film cathode, demonstrating the reduction in uranium.

Fig. 3: Alpha range spectra from DRIFT allow the identification of radioactive contaminants in the vessel. Shown are only alpha tracks which are down-going (oriented away from the central cathode).

In general, DRIFT length are =~ 350 mm / 44.3 mm =~ 8 times bigger

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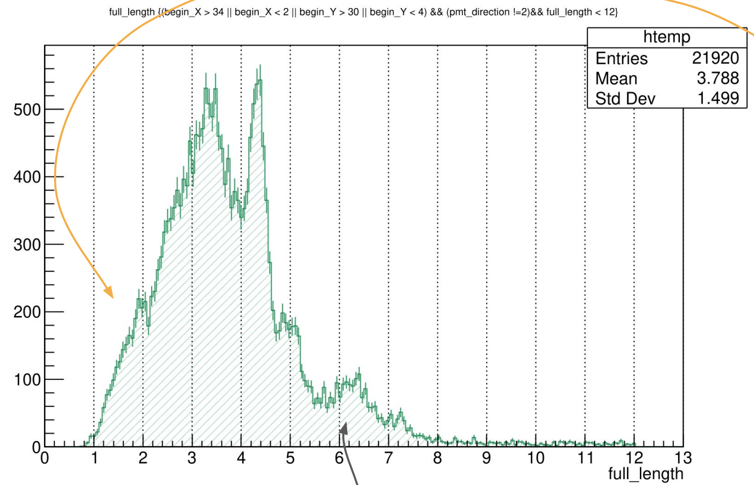

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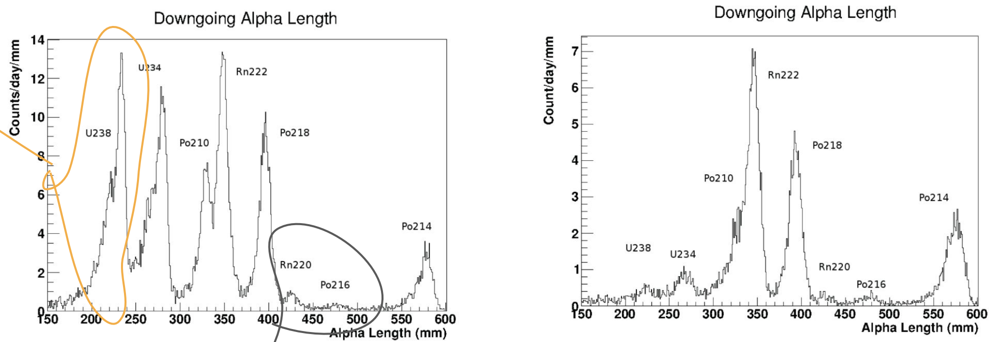

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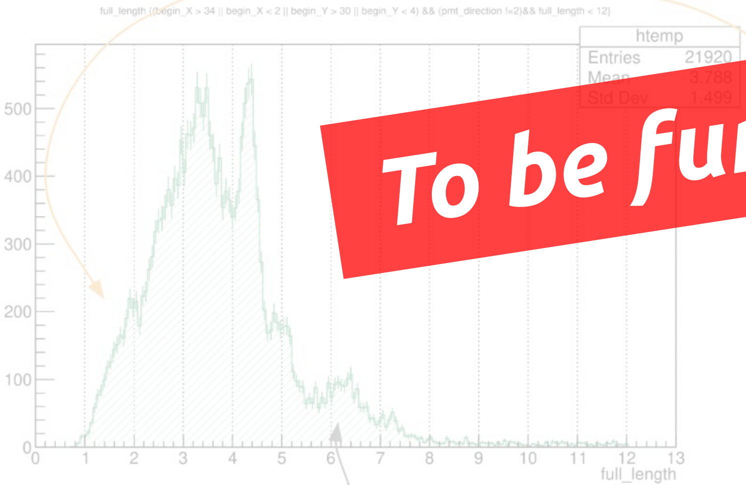

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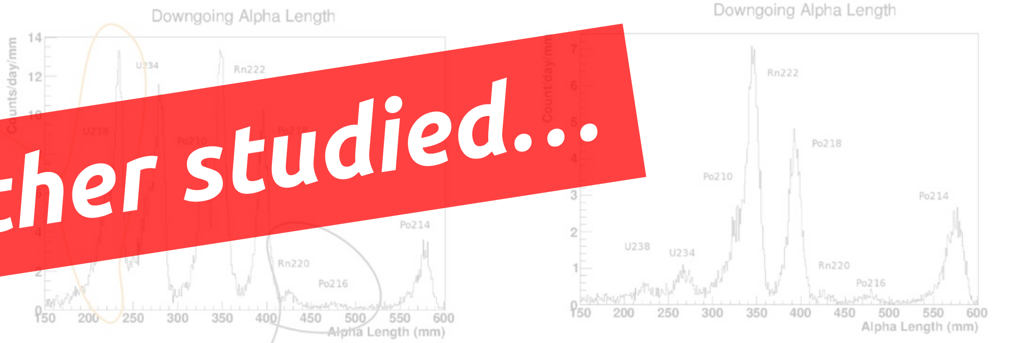

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To be further studied…

#5.2 Update on …

3D alphas -

Rn alpha counting

David(1 + e)

Analysis and Reconstruction meeting 03/10/2024, L'Aquila

^{222}Rn - Counting alphas

Two studies to be carried out, suggested by D. Pinci

1. **Study the effect of the amount of alphas inside LIME after inserting the humidity filter that killed the Rn.**
   - Look at these ranges:
     - The range A: 43232 - 43308 is before the insertion.
     - The range B: 43316 - 43486 are 3 days of files takes after the insertion
   - Check the decrease of the number of alphas inside LIME in range B.
   - Compare with range A (control group).
   - Possibly observe the 3.8-day half-life of ^{222}Rn through fitting the (exponential) reduction of alphas.

2. **Measure the time difference between alphas, identified by length (energy), to observe the ^{222}Rn decay chain in time.**
   - ^{218}Po daughter decays through alpha of 50mm (6.115 MeV) **after 3 min** of being created by the ^{222}Rn parent (which has a half-life of 3.8 days).
   - Eventually observe the ^{214}Po alpha-decay after the 28.6+19.7 minute half-life of ^{124}Pb + ^{214}Bi decays. (*probably impossible*)

^{222}Rn - Alpha reduction (I)

1. **Study the effect of the amount of alphas inside LIME after inserting the humidity filter that killed the Rn.**
   - **a.** I started by taking the reco_runs (`wget https://s3.cloud.infn.it/v1/AUTH_XXXX/cygno-analysis/RECO/Run4/reco_run{YY..ZZ}_3D.root`) and running a small script (C++, available by request) that reads the tree and counts the number of clusters identified as alphas, ***CMOS-only****, using Giorgio's alpha cuts (`sc_integral / sc_nhits > 25 && sc_length > 100 && sc_width > 50`)
     - i. I do this for both data ranges (A & B) and start with a basic absolute plot of the reduction of alphas

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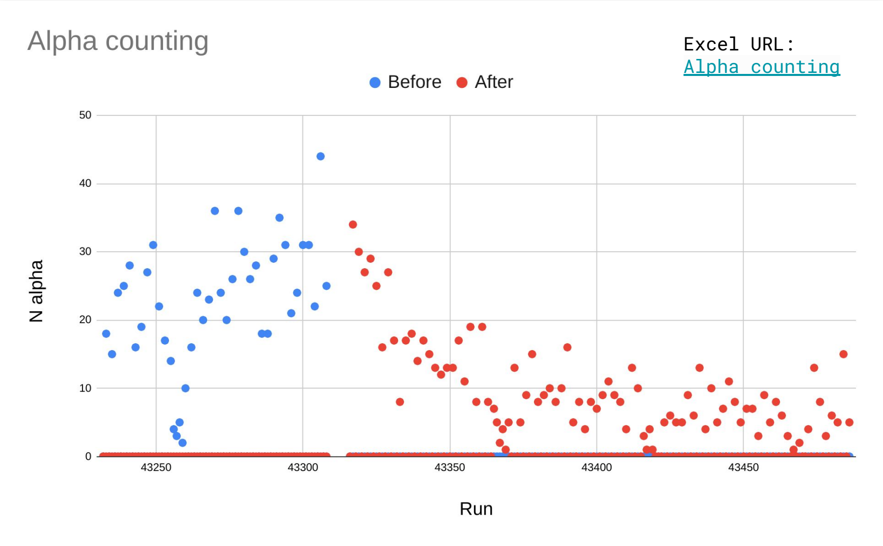
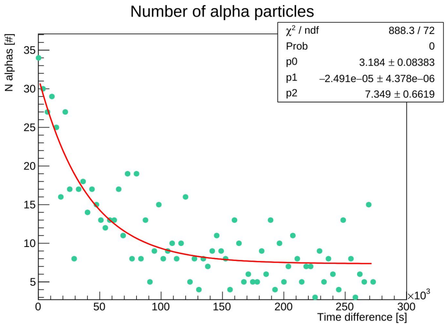


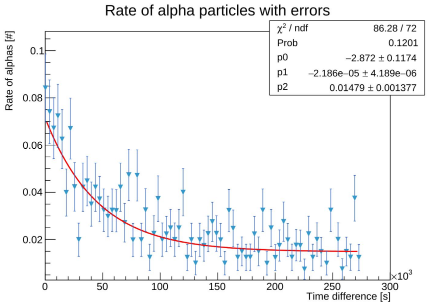
Clear reduction after insertion of the filter, but how much?

^{222}Rn - Alpha reduction (I)

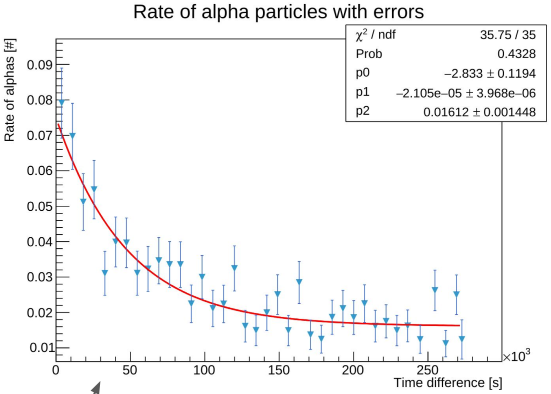
1. **Study the effect of the amount of alphas inside LIME after inserting the humidity filter that killed the Rn.**

   c. Results





"Moving average"



- Data is fitted with an **exponential + constant term** ⇒ $e^{[p0 + p1*x]} + p2$
- Constant accounts for secular decaying elements (U, Th) which are always present.
- Fit results:
  - **p1 = -2.105e-05 +/- 4.458e-06**

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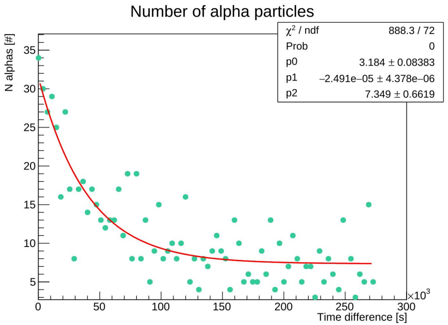
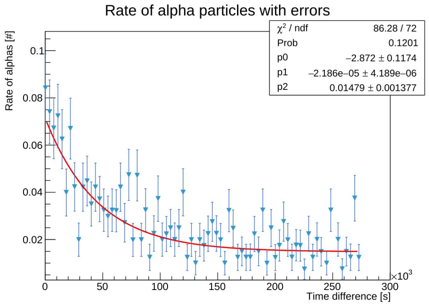
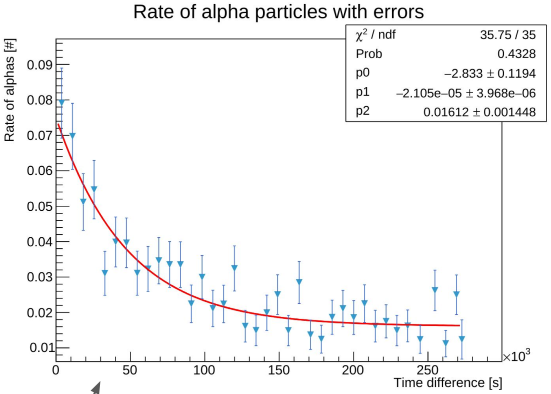
    c. Results





"Moving average"



- ➔ Data is fitted with an **exponential + constant term** ⇒ $e^{[p0 + p1*x]}$ **+ p2**
- ➔ Constant accounts for secular decaying elements (U, Th) which are always present.
- ➔ Fit results:
    - ◆ **p1 = -2.105e-05 +/- 4.458e-06**

- ➔ Exponential decay ⇒ **$dN/dt = N_0 * (1/\tau) * e^{-t/\tau}$**
- ➔ Decay constant = **Lifetime = τ = 1/2.105e-05 s = 0.55 ± 0.11 days**
- ➔ **Half-life = $t_{1/2} = \tau * \ln(2)$ = 0.38 ± 0.08 days**
- ➔ **$t_{1/2}$ (^{222}Rn) = 3.8 days**

^{222}Rn - Alpha reduction (I)

1. **Study the effect of the amount of alphas inside LIME after inserting the humidity filter that killed the Rn.**
   - **d.** Discussion

→ Exponential decay ⇒ **$dN/dt = N_0 * (1/\tau) * e^{-t/\tau}$**

→ Decay constant = **Lifetime = τ = 1/2.105e-05 s = 0.55 ± 0.11 days**

→ **Half-life = $t_{1/2} = \tau * \ln(2)$ = 0.38 ± 0.08 days**

→ **$t_{1/2}$ (^{222}Rn) = 3.8 days**

Why the discrepancy?

→ Rough study in general, with few statistics ⇒ Note the high error

→ **We are counting ALL the alphas, and not only the ^{222}Rn ones.**

- I tried to select them using Pinci's cuts (3D not available since data gone / too much effort to retrieve) , but the statistics is too low

→ Efficiency not considered, and far from 100%

- Can include sensor blindness; alpha out of frame; selection deficiency, etc.
- Especially not considered was the possibility of the ***flushing out of Rn through the gas circulation***

^{222}Rn - Counting alphas

Two studies to be carried out, suggested by D. Pinci

1. **Study the effect of the amount of alphas inside LIME after inserting the humidity filter that killed the Rn.**
   - Look at these ranges:
     - The range A: 43232 - 43308 is before the insertion.
     - The range B: 43316 - 43486 are 3 days of files takes after the insertion
   - Check the decrease of the number of alphas inside LIME in range B.
   - Compare with range A (control group).
   - Possibly observe the 3.8-day half-life of ^{222}Rn through fitting the (exponential) reduction of alphas.

2. **Measure the time difference between alphas, identified by length (energy), to observe the ^{222}Rn decay chain in time.**
   - ^{218}Po daughter decays through alpha of 50mm (6.115 MeV) **after 3 min** of being created by the ^{222}Rn parent (which has a half-life of 3.8 days).
   - Eventually observe the ^{214}Po alpha-decay after the 28.6+19.7 minute half-life of ^{124}Pb + ^{214}Bi decays. (*probably impossible*)

^{222}Rn - Counting alphas

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  - Method:
    - Use stable dataset: before or well after filter insertion.
    - Download data from Bari backup since Cygno data in on tape *(...)*
      - The data saved in Bari is:
        - 40919-42848 – well before filters – batch 1
        - 48055-50891 – well after filters – batch 6
    - Use function from Stefano to open midas file and retrieve picture time-stamp ⇒ Save in txt.
      - https://github.com/CYGNUS-RD/cygno/blob/main/dev/readMidasFile.ipynb
    - **Compare time between alphas of specific energies (Po214 and Rn222)**

^{222}Rn - Counting alphas

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- Some notes for the future:
  - Retrieving the time stamps was a painful process due to missing data in the Bari backup, broken runs, etc.
  - For the future, I believe this information is important and we should start saving it
    - *I request a reconstruction-code addition*
      - If you need this info, I can make available what I already have.

^{222}Rn - Counting alphas

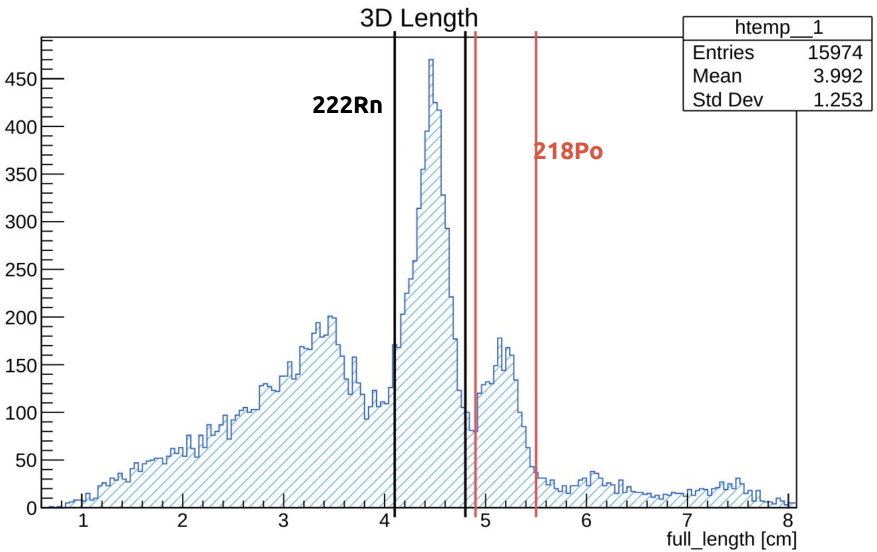
- After some discussion with D. Pinci, we came to the conclusion the best approach was to **calculate the smallest time distance between 222Rn and 218 Po alphas**, ie, time between 218Po and the first 222Rn before that.
  - This is probably the only way of tagging the alphas without choosing/biasing which ones to tag.
  - But, If the rate of 222Rn is too high, this won't work due to overlap/combinatorics
    - We then choose to focus on the **second dataset (Batch 6 - runs 48055-50891** – well after filters) due to the much lower amount of alphas.

  - We might still have a combinatorics issue, how can we confirm/discard that hypothesis?
    - We use **cross-check with D. Pinci Toy-MC** in which we can setup:
      - The time between 222Rn alphas, given by the data
      - The time between 222Rn and 218Po alphas, given by theory
    - Then **the MC gives will tells us if the data is reasonable / consistent**.

^{222}Rn - Counting alphas

- First we need to select the alphas to be tagged.

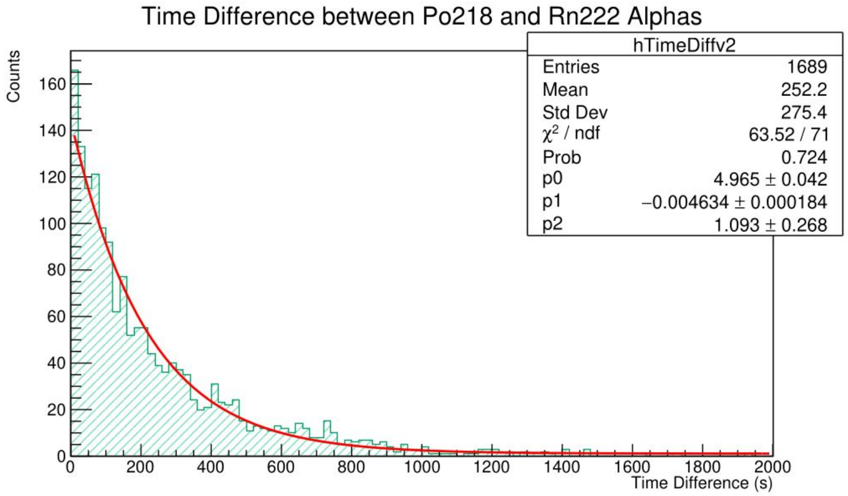
  These were the cuts:



- Some considerations:
  - Since we are looking for a **decay constant (time distance between events)**, the stronger the cuts are, the lower will be the efficiency, thus less likely the "event" to happen, effectively ***increasing the τ*** we are looking for
    - We **need** to be loose with the cuts.
    - We should assume/take into account some **detection/reconstruction efficiency**.

^{222}Rn - Counting alphas

- **Now we can calculate the distance between consecutive 218Po and 222Rn alphas**



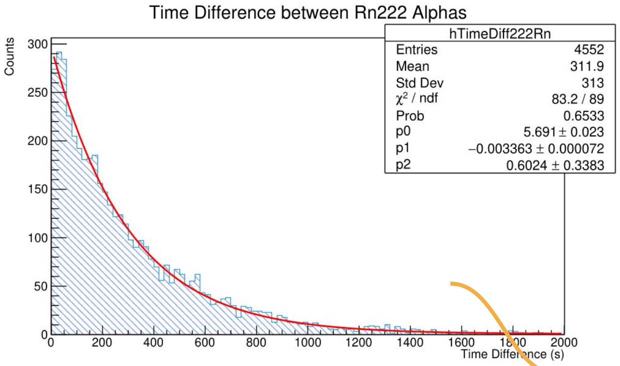
- The fitting functions remains: **$e^{[p0 + p1*x]}$ + p2**
  - The constant term improve the fit and doesn't strongly affect **p1**.
- The result is:
  - **τ = -1/p1 = 1/0.004634 = 215.9 ± 8.6 seconds**
  - **The half-life is = τ * ln(2) = 2.49 ± 0.14 minutes**
- The expected values is:
  - Half-life (218Po) = **3.1 minutes (or lifetime = τ = 268 s)**

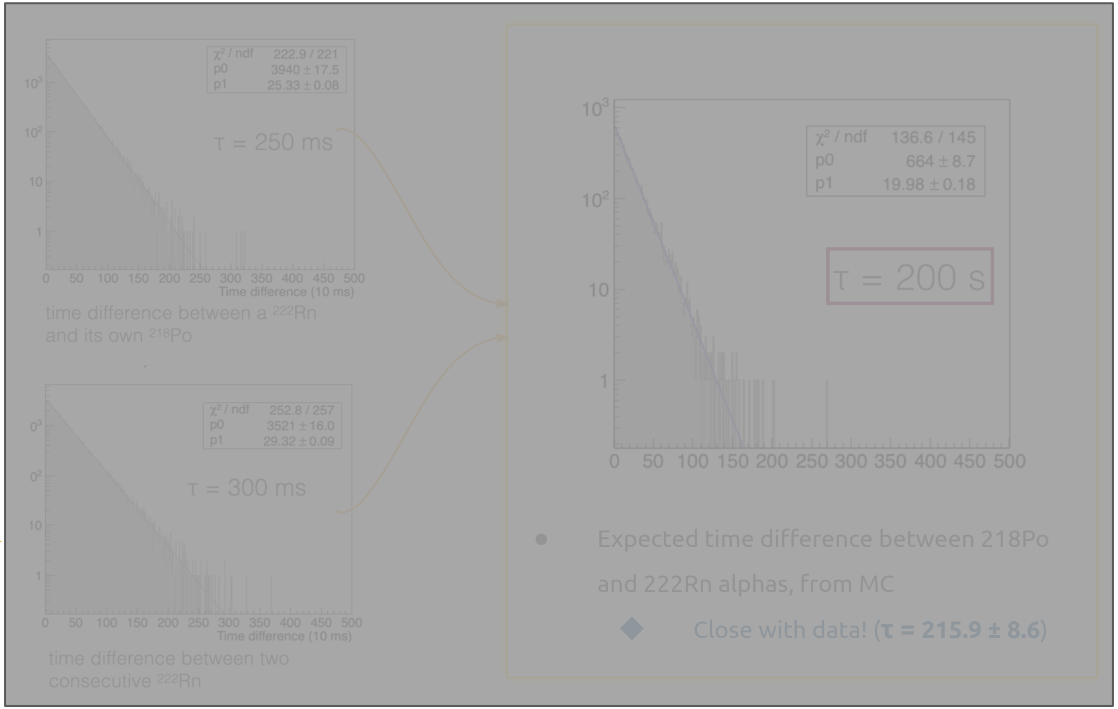
⬇️

Not mathematically consistent at this point, but remember we still have the fake combinatorics

^{222}Rn - Counting alphas

- As mentioned, we should remove the fake combinatorics due to overlap of 222Rn alphas.
  - For that, I give the meantime difference between 222Rn alphas in the data to Pinci's Toy-MC.





^{222}Rn - Counting alphas

- How much would the **detection efficiency affect these results?**
  - By enlarging and tightening the cuts (narrower selection in length + geometrical center), we can “fake” the detector efficiency:

^{222}Rn - Counting alphas

- How much would the **detection efficiency affect these results?**
    - By enlarging and tightening the cuts (narrower selection in length + geometrical center), we can “fake” the detector efficiency:

Case	**Events selected**	**Efficiency**	**Decay constant (τ)**	**Ratio with original**
Reference	1689	* 30 %	215 s	1
Tight	1129	20%	260 s	1.2
Very loose	1850	33 %	198 s	1.1

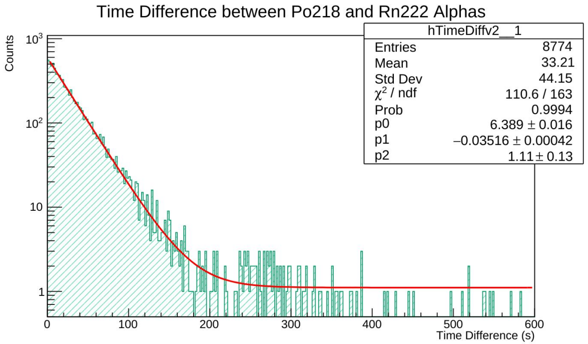
Inefficiencies come from:

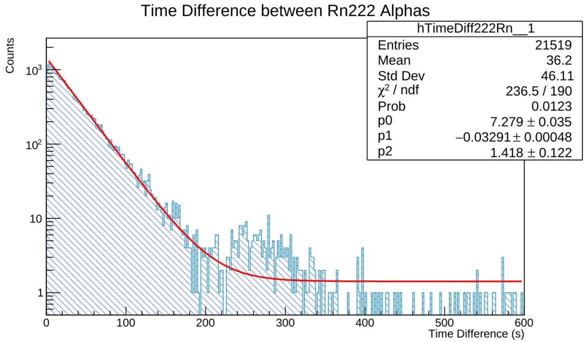
→ Movements of gas (Po goes out-of-bonds), or, ratio between active and sensitive gas volume.
→ CMOS pixel cutted band
→ CMOS dead time
→ PMT blindness to parallel (<10°) tracks
→ Other inefficiencies in the reconstruction and selection of alphas (CMOS and PMT)

… is 30% efficiency in detection reasonable?

^{222}Rn - Counting alphas

- To cross-check, we can still calculate the distance between consecutive 218Po and 222Rn alphas **in the Rn full runs (Batch 1)**





- The distance between family alphas is ~30 seconds, the ~same value between two Rn222 Alphas.

⬇️

The combinatorics are too high, and the statistics too low to see an eventual second tail at the correct tau

⬇️

Let's see what the simulation has to say

^{222}Rn - Counting alphas

- **Conclusions:**
  - By **tagging consecutive alphas from 218Po and 222Rn decays**, we found a **decay rate constant of τ = 215.9 ± 8.6 seconds**, leading to an **half-life of 2.49 ± 0.14 minutes**, not so far from the real value of 3.1 minutes
  - Using a Toy-MC, we assess the expected deviation from the real value due to random combinatorics derived by "overlap" of 222Rn alphas.
    - The expected value results, assuming the combinatorics, is τ = 200s, close to the data of τ = 215.9 ± 8.6s
  - We also join and introduce the concept of detection efficiency in the MC.
  - ***This quick study further leads to the confirmation of the presence of 222Rn in the gas, and it's respective decays particles in the CYGNO/LIME background.***

Conclusions & Future

Conclusions:

1. 3D reconstruction has shown strong potential to identify and select 222Rn alphas.
2. Time stamp seems to further prove the existence of 222Rn alphas.

Future and final steps:

1. Study **expected length of alphas** in LIME
   a. Understand “minimum X-Y-Z dimension” ⇒ Someone volunteers to digitize me some alphas ? :)
2. Study **ratios of integrals of 222Rn alphas** in LIME. ⇒ Hopefully related to decay probability; secular balance between species, detection efficiency
3. Better compare our results with DRIFT ones, to eventually **identify the other alphas** in the spectrum (U, Th chains)
4. Some assessment of the **origin of the alphas** given their Z position and angle of emission.
   a. Some Rn daughters can drift to cathode and emit from there, also DRIFT sees that.
      i. MIMAC paper should also give some info (need to read it still)
5. **Data vs. Simulation statistics** (From Flaminia, no digitization needed)
6. Improvement of 3D Reco
   a. Sensor-cut alphas removal ⇒ Hopefully cleans low energy tail.
   b. Add “minimum X-Y-Z dimension” correction
7. **BRIEF look at AmBe data**
8. Eventually look at **Run 5** (*unlikely, but my analysis is/will be public*)