PMT Analysis for 3D tracking

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CYGNO collaboration

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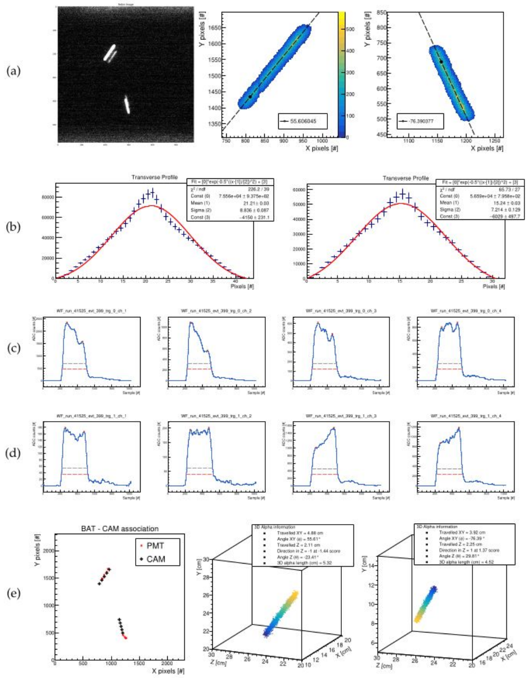
PMT Reco & Analysis - *Previously*



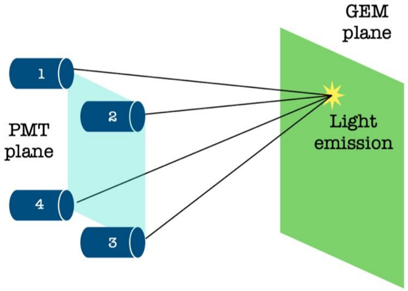
Full framework retrieves and saves all the relevant information automatically.

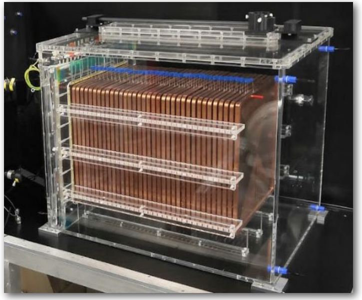
Previous episodes:

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**
6. [Reconstruction and Analysis meeting]
   Update … - 3D alphas analysis
7. **This one** [CYGNO Collaboration Meeting 2024]
   3D reconstruction - David

★ **My thesis** 🏇

LIME - Detector and Data





- ➔ **50 L** & **50 cm** drift gaseous **TPC**
- ➔ **He:CF4**, 60:40, **1 Atm** (910 mbar), 293 K
- ➔ 4 PMTs + 1 sCMOS camera

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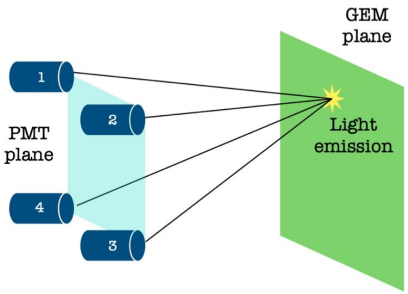

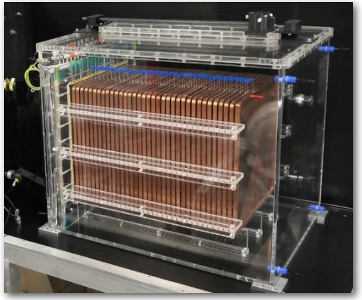

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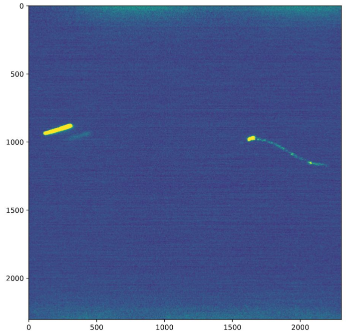
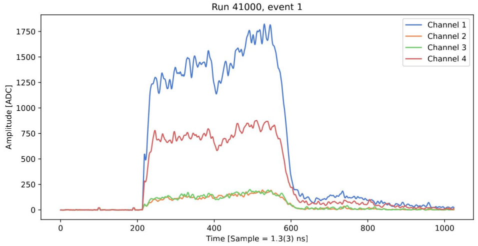
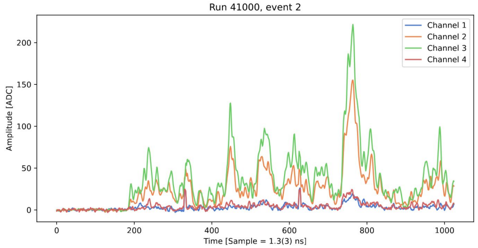
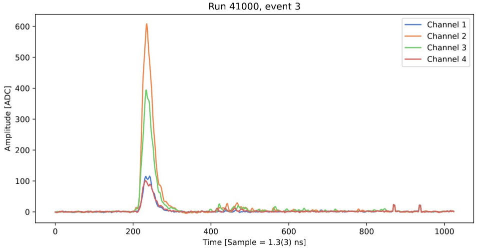
- ➔ **He:CF4**, 60:40, **1 Atm** (910 mbar), 293 K
- ➔ 4 PMTs + 1 sCMOS camera
- ➔ One event =
  - ◆ **1 CMOS pic:** $R_{\Delta t}$ = 300 ms
  - ◆ **X PMT WFs** = $N_{triggers} * N_{PMTs} * N_{digitiz}$
    - $R_{\Delta t}$ = **1.3 ns** & **4 ns**









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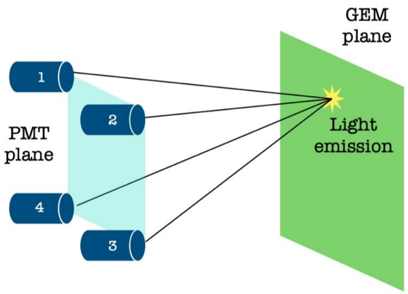

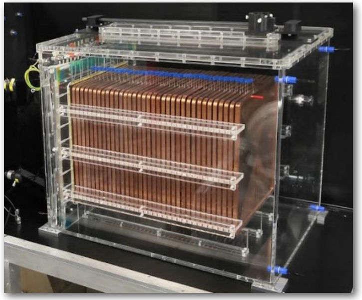

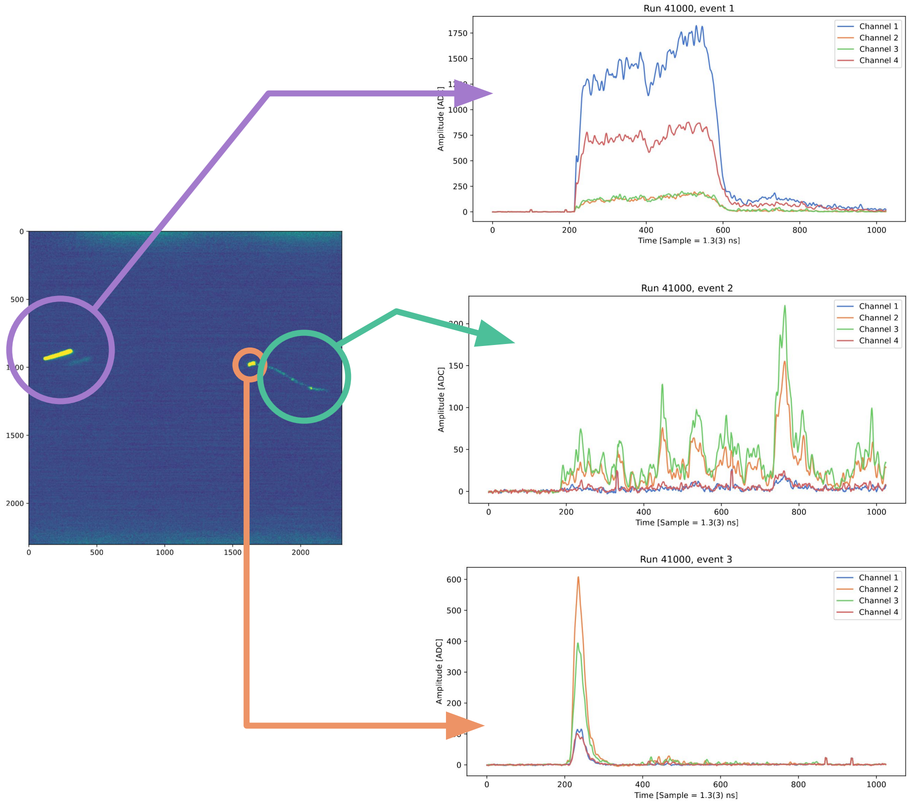

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- ➔ One event =
  - ◆ **1 CMOS pic:** $R_{\Delta t}$ = 300 ms
  - ◆ **X PMT WFs** = $N_{triggers} * N_{PMTs} * N_{digitiz}$
    - • $R_{\Delta t}$ = **1.3 ns** & **4 ns**
- ➔ The information needs to be matched!

3D Event Reconstruction

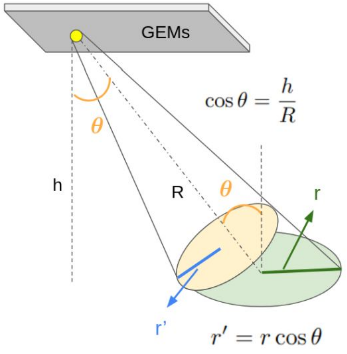
One-to-One association

3D Events - One-to-One association

➔ To **fully reconstruct** the information of **one event** we need to merge the **CMOS** and **PMTs** information.

- We developed a **1-to-1 association** to merge the ***CMOS clusters*** to ***PMT triggers***.

1. **Light** seen by each PMT depends on their **relative positions**.



$$L_{PMT} = \frac{L_{spot}}{4\pi R_i^2}\frac{\pi r^2 h}{R_i}$$

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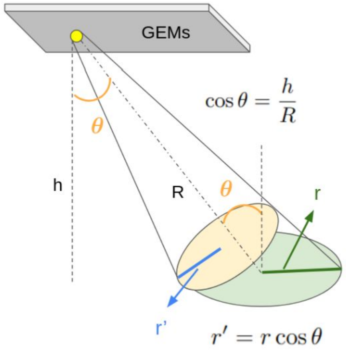
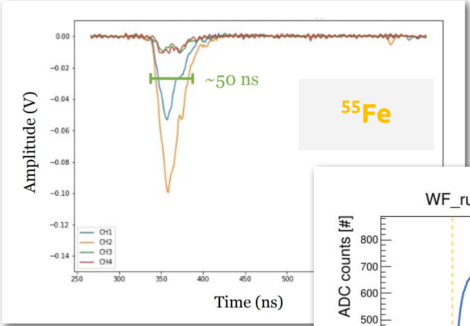
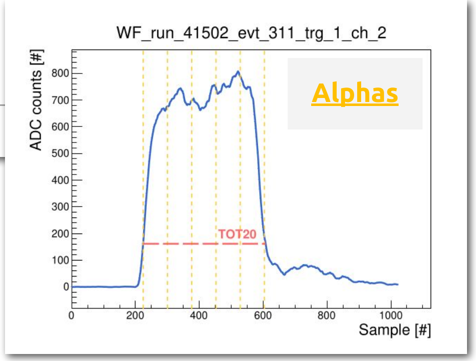


$$L_{PMT} = \frac{L_{spot}}{4\pi R_i^2}\frac{\pi r^2 h}{R_i}$$

2. We apply a **multi-variable Bayesian fit** in a time window by **integrating the charge** ⇒ We retrieve **(x, y, L) information**





$$p(\{x_{ij}\}\,|\,\theta) = \prod_{j=1}^{N_{points}}\prod_{i=1}^{4}\mathcal{N}(\{x_{ij}\}\,|\,L'_{ij}(\theta))$$

With:

- $L'_{ji} = c_i \frac{L_j}{R_{ij}^{\alpha}}$
- $R_{ji} = \sqrt{x_{ji}^2 + y_{ji}^2 + z^2}$

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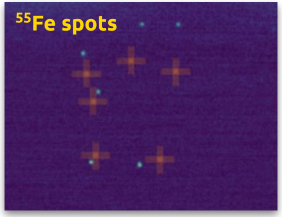
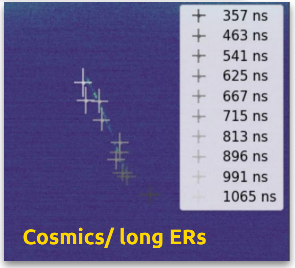
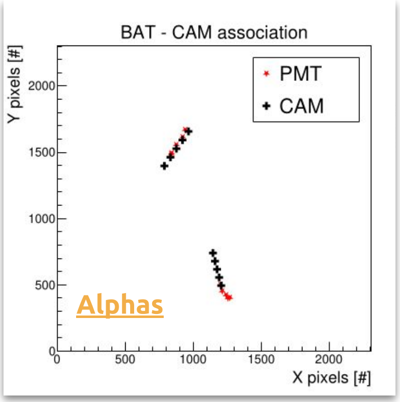
3. With (x, y, L) retrieved, we compare with CMOS clusters and assign them through the closest neighbor.







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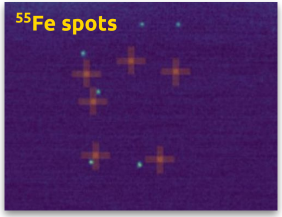
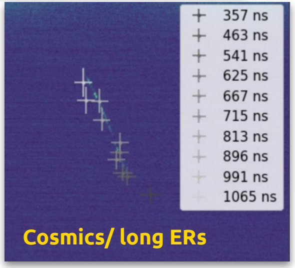
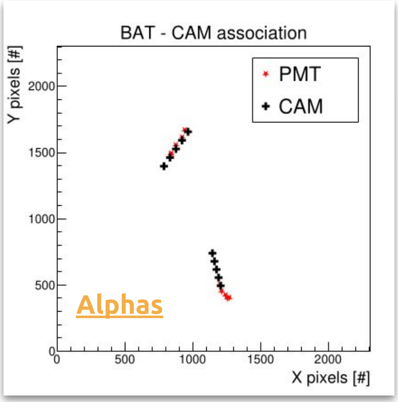
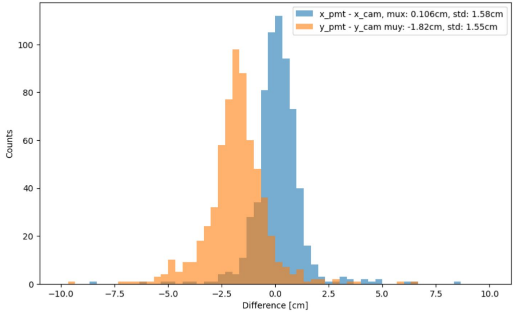
3. With **(x, y, L)** retrieved, we **compare** with **CMOS clusters** and assign them through the **closest neighbor**.

4. The **final goal** is to implement this technique at the detector **front-end level**. The **efficiencies** are promising! (The reference is the 33x33cm^2 GEM plane)









Performances for

- ^{55}**Fe** (spot-like) events:
  - X_{std}/Y_{std} **~ 1.6 cm**
- **Alphas**:
  - X_{std}/Y_{std} **~ 2,3 cm**

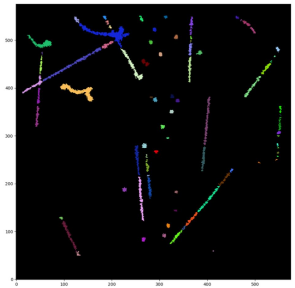
➔ ***Optimization undergoing*** concerning effects like saturation, lens barreling, gain inter-calibration, etc.

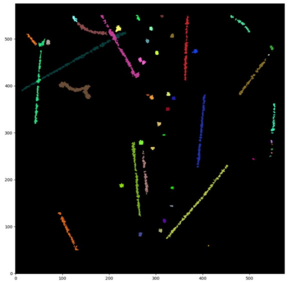
3D Event Reconstruction

CMOS analysis

3D Events - CMOS analysis

1. The **analysis of the CMOS images** starts with a directional iDBSCAN algorithm which clusters groups of pixels belonging to the same ionization event.
   a. For PID, each cluster can be selected through its: ***light integral, length, slimness, photon density, dE/dx, etc.***





Directional iDBSCAN to detect cosmic-ray tracks for the CYGNO experiment - IOPscience

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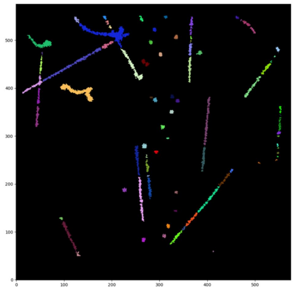
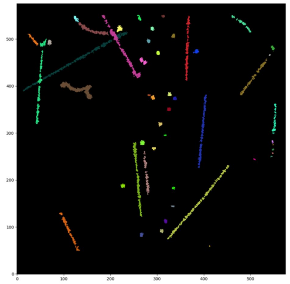
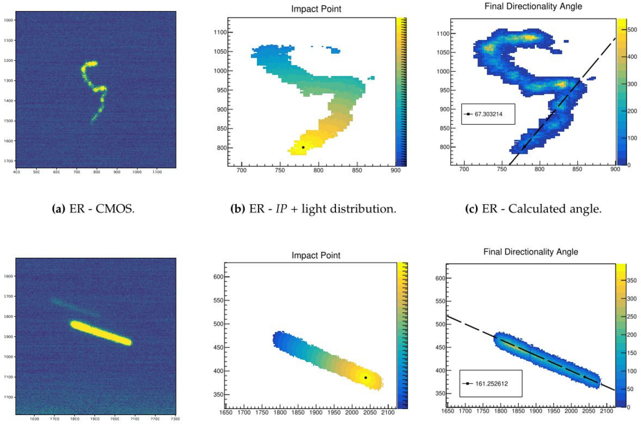




[Directional iDBSCAN to detect cosmic-ray tracks for the CYGNO experiment - IOPscience]

2. A second layer analysis is used to determine other more dedicated variables such as <u>2D direction</u>



(a) ER - CMOS. **(b)** ER - *IP* + light distribution. **(c)** ER - Calculated angle.

(d) Alpha - CMOS. **(e)** Alpha - *IP* + light distribution. **(f)** Alpha - Calculated angle.

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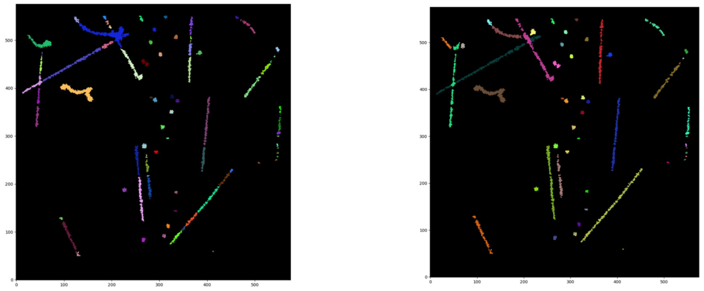

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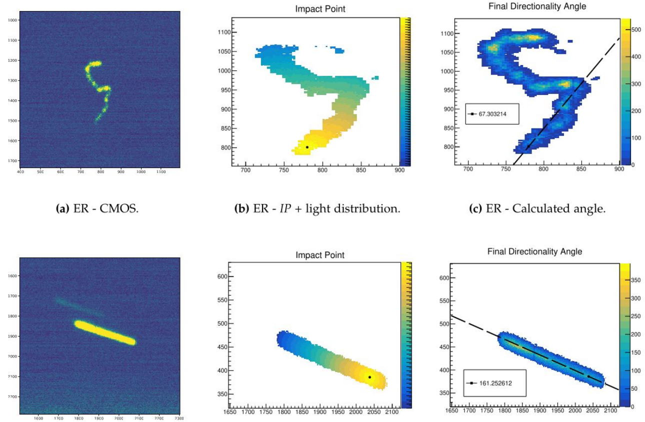


(a) ER - CMOS. (b) ER - *IP* + light distribution. (c) ER - Calculated angle.

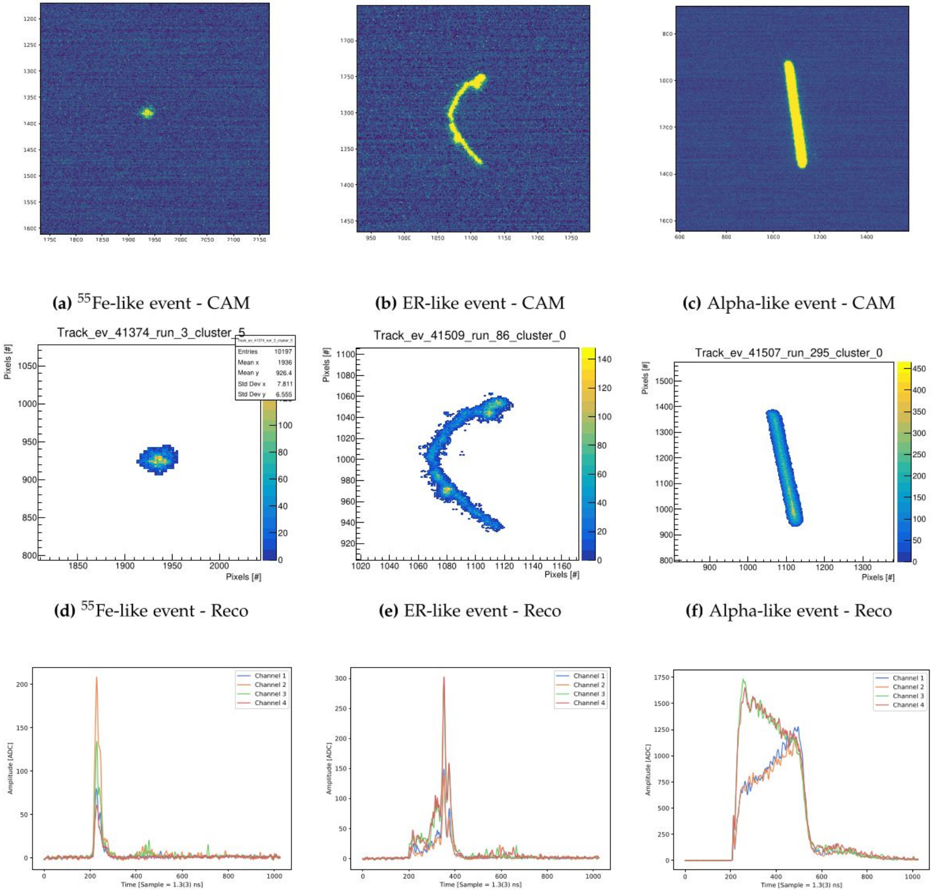
(d) Alpha - CMOS. (e) Alpha - *IP* + light distribution. (f) Alpha - Calculated angle.

Reconstructed info here:

- **ΔXY**
- **X-Y angle (ϕ)**
- **2D direction**

3D Event Reconstruction

PMT analysis



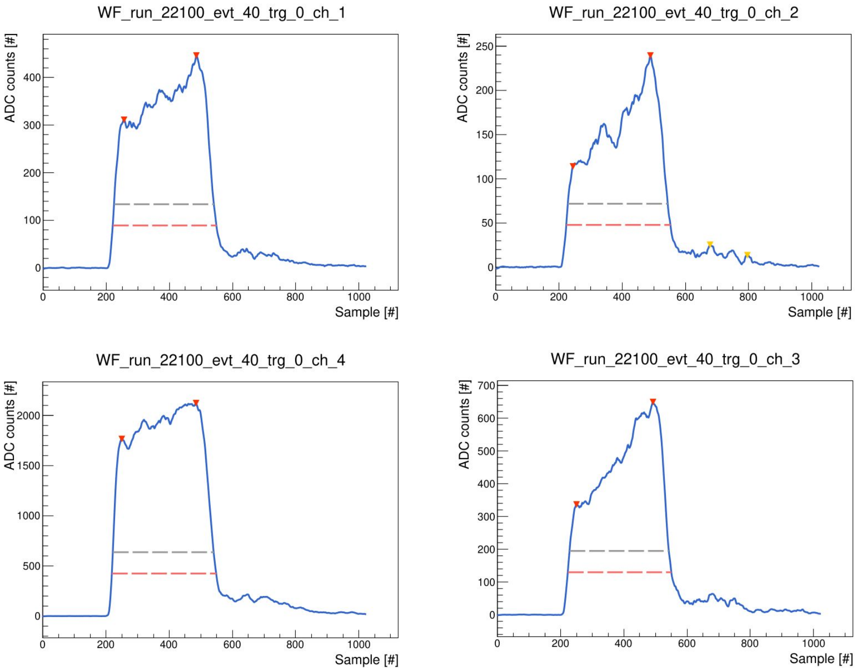
(a) ^{55}Fe-like event - CAM (b) ER-like event - CAM (c) Alpha-like event - CAM

(d) ^{55}Fe-like event - Reco (e) ER-like event - Reco (f) Alpha-like event - Reco

(g) ^{55}Fe-like event - PMT (h) ER-like event - PMT (i) Alpha-like event - PMT

3D Events - PMT analysis

➔ The **PMTs** gives us information regarding the **longitudinal coordinate Z**, and allows us to close the **3D geometry**



3D Events - PMT analysis

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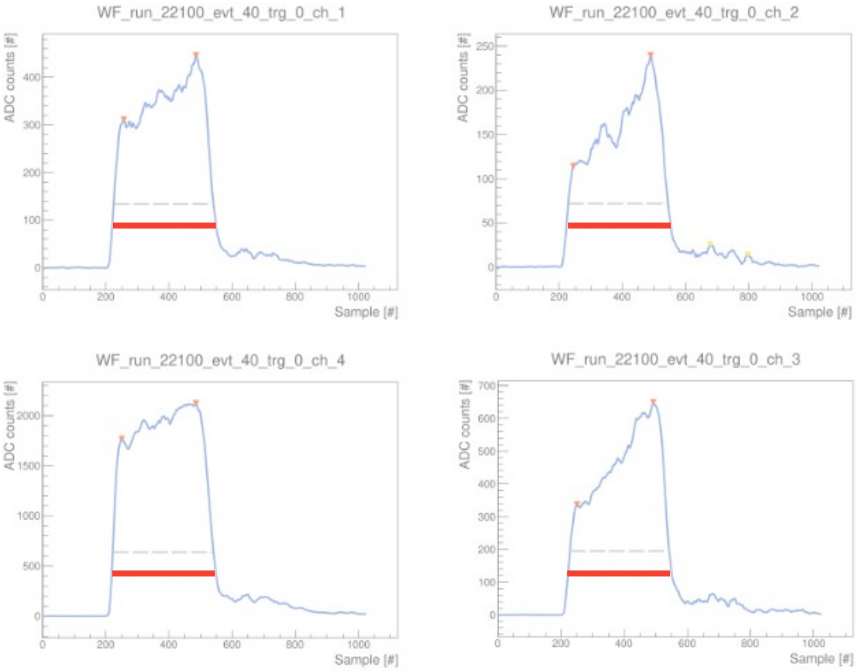
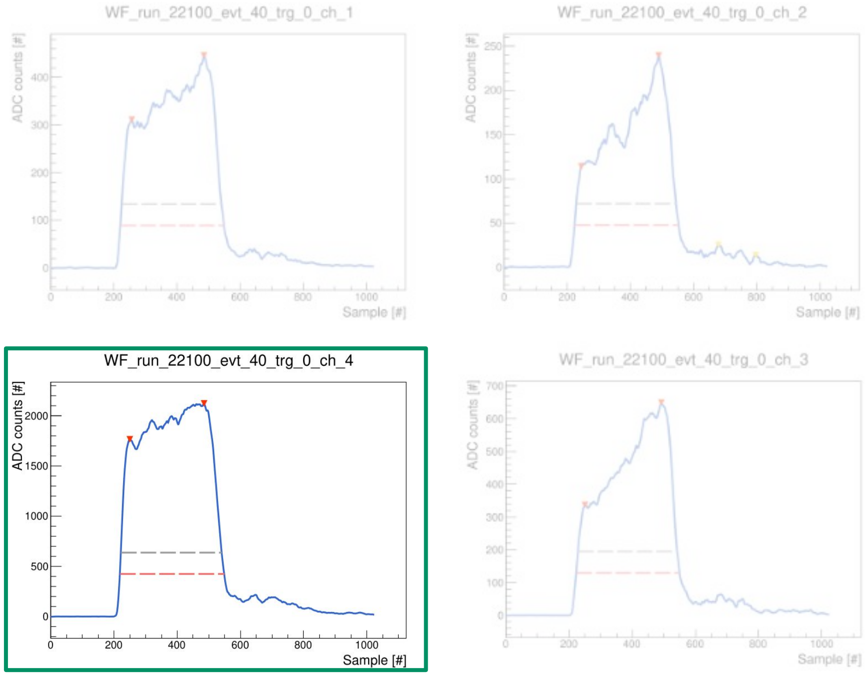
1. **Time-over-Threshold ⇒ Traveled Z**



3D Events - PMT analysis

➔ The **PMTs** gives us information regarding the **longitudinal coordinate Z**, and allows us to close the **3D geometry**

1. Time-over-Threshold ⇒ Traveled Z
2. **Highest integral ⇒ XY Quadrant**



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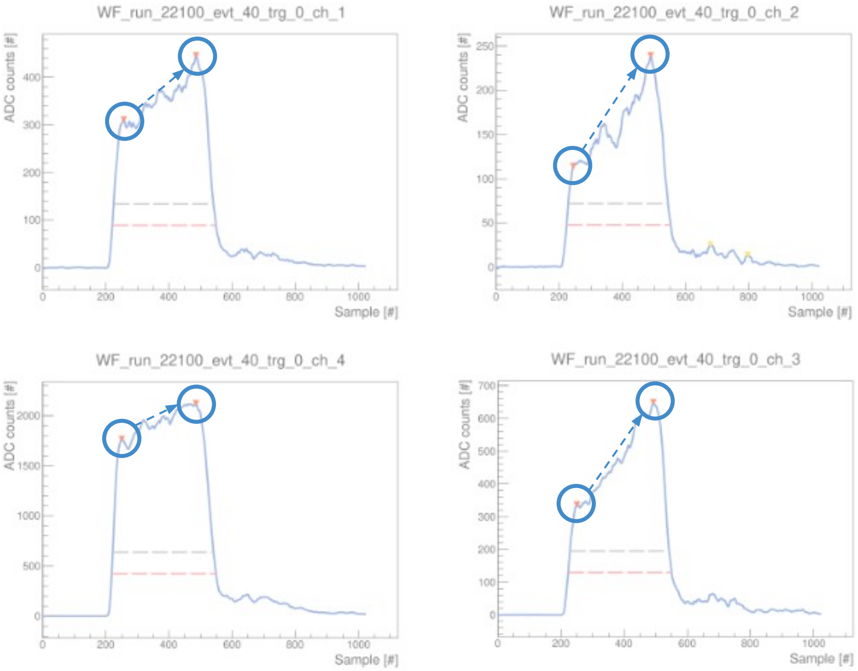
3. **Bragg peak position ⇒ Moving towards GEMs or cathode**



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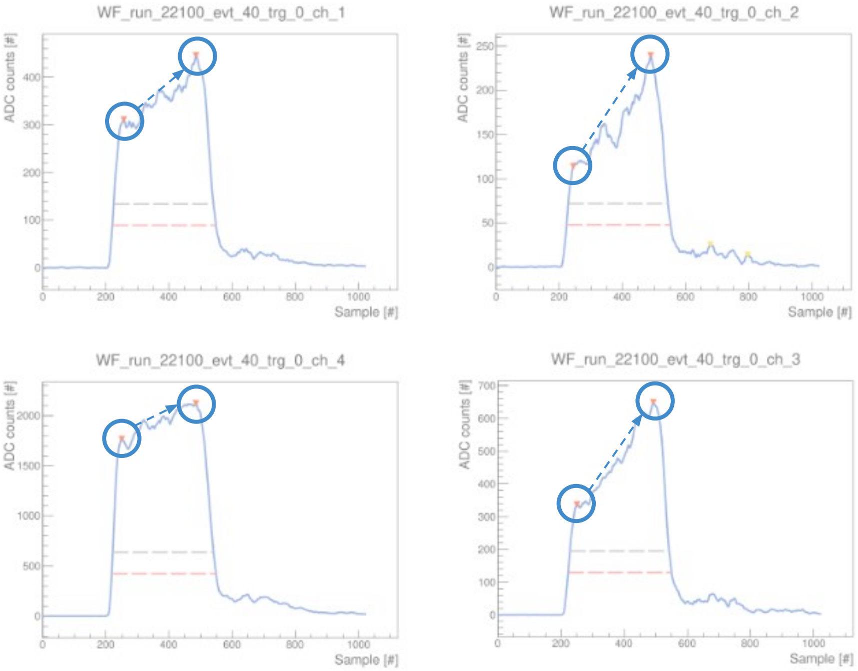

***Additionaly, the alpha PID is performed at this stage, using these and others variables.**

Non-alphas are discarded.

Optimized?

3D Events - PMT analysis

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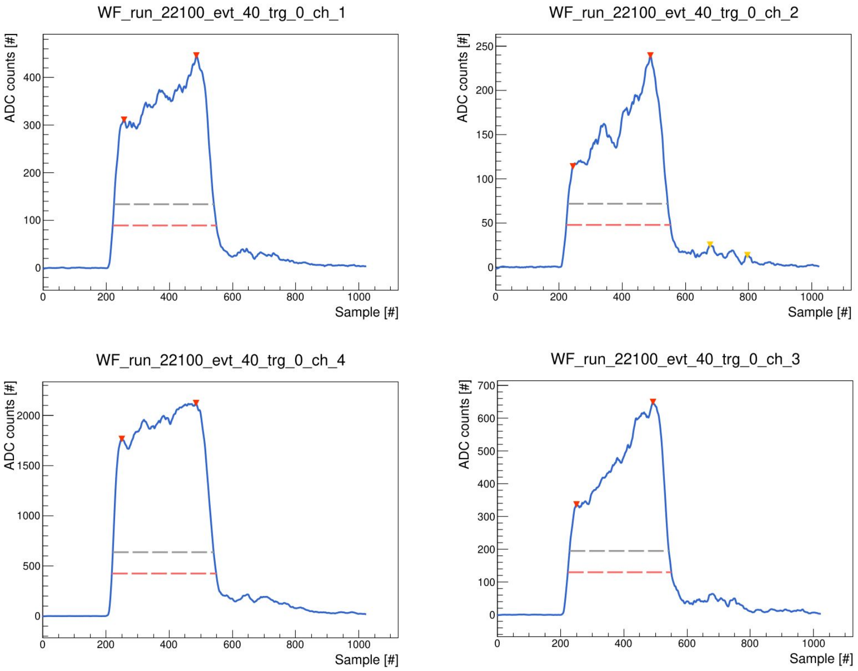
Additional reconstructed info:

- **ΔZ**
- **Sign of θ**



3D Events - PMT analysis

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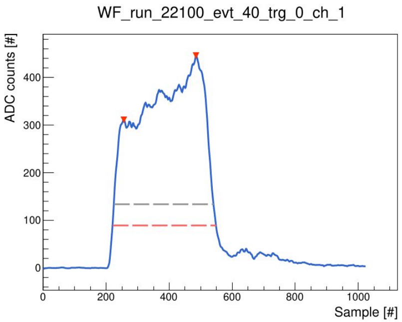
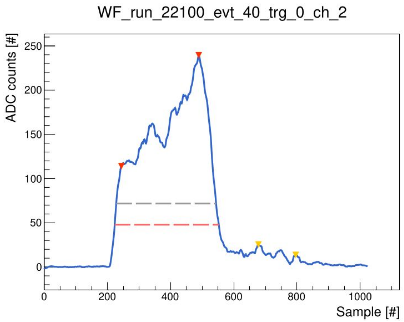
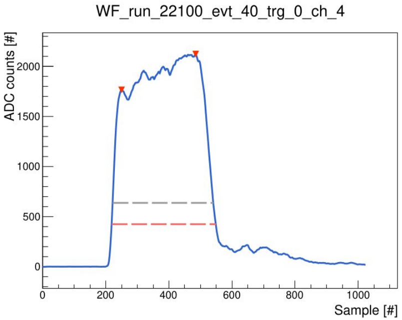
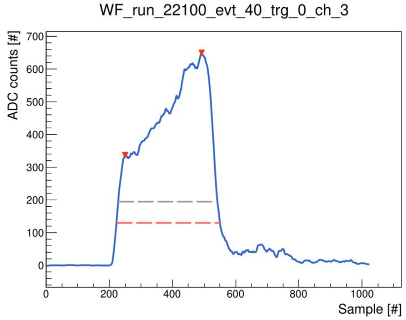
Additional reconstructed info:

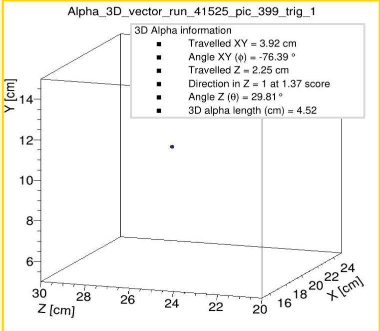
- **ΔZ + ΔXY = Z angle (theta)**
- **Sign of θ + sign of ϕ = Head-tail**

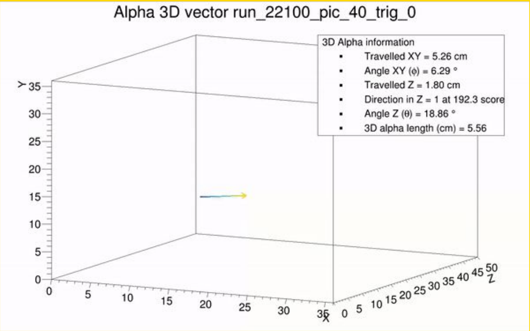












3D Event Reconstruction

Recent Improvements

3D Events - Absolute Z

➔ When studying the distribution of the supposedly Rn alphas, two variables are important:

- **Absolute Z position** + **Angular distribution**

3D Events - Absolute Z

- When studying the distribution of the supposedly Rn alphas, two variables are important:
  - **Absolute Z position** + **Angular distribution**
- The absolute Z position, or ***fiducialization***, is determined by fitting the **track distribution of light** in the **orthogonal direction** ⇒ **"Transverse profile"**

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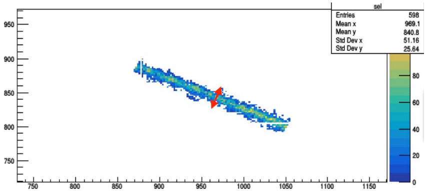

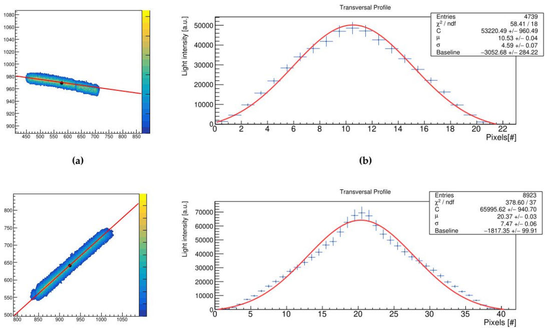

(a) (b)

(c) (d)

for production points farther in Z from the GEMs. This is reflected in the transverse (Y) light distribution of each segment of the track: the σ_Y obtained from the Gaussian fit is in fact increasing with $\sqrt{Z}$. Therefore, the segment's original Z can be deduced by measuring σ (Fig. 8).

The observed values of σ are related to the track's Z coordinate by $\sigma = \sqrt{\sigma_0^2 + B^2 Z}$

The transverse diffusion coefficient B in the gas is measured to be $129.7 \pm 3.1 \frac{\mu m}{\sqrt{cm}}$, well in agreement with the expected value obtained with Garfield simulation ($130 \frac{\mu m}{\sqrt{cm}}$) [47].

The intercept at zero $\sigma_0 = 292 \pm 12$ μm is due to the contribution of the electron avalanche propagation in the GEM stack and confirms results obtained with a radioactive source [47].

https://www.sciencedirect.com/science/article/pii/S0168900221001935

of the diffusion parameters.

Now we can use these parameters to predict absolute z for any segment of ionization charge detected:

$$z = \frac{\sigma^2 - A^2}{B^2}. \quad (3)$$

The absolute z accuracy is measured by the horizontal standard deviation of the distribution from the fit curve in Fig. 4. For all segments, without any selections on fit quality besides requiring that the fit not fail (efficiency 0.994), the absolute z measurement accuracy is 0.5–1.5 cm throughout the full z range. For nuclear

https://www.sciencedirect.com/science/article/pii/S0168900215003320

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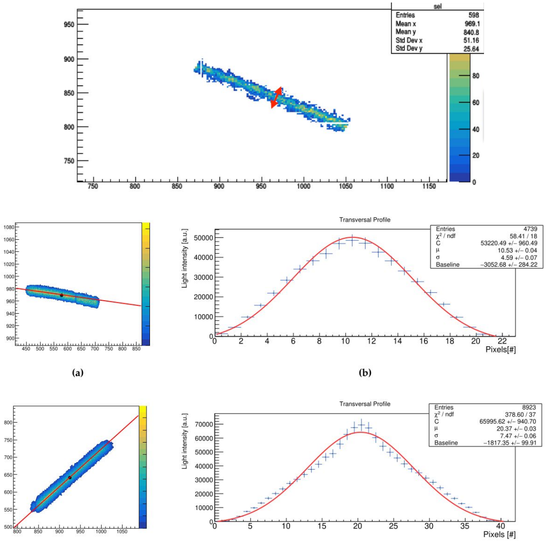
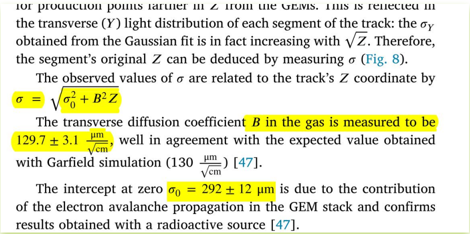
  - ◆ Absolute Z position + Angular distribution
- ➔ The absolute Z position, or ***fiducialization***, is determined by fitting the **track distribution of light** in the **orthogonal direction** ⇒ "Transverse profile"



(a) (b)
(c) (d)


for production points farther in Z from the GEMs. This is reflected in the transverse (Y) light distribution of each segment of the track: the σ_Y obtained from the Gaussian fit is in fact increasing with $\sqrt{Z}$. Therefore, the segment's original Z can be deduced by measuring σ (Fig. 8).

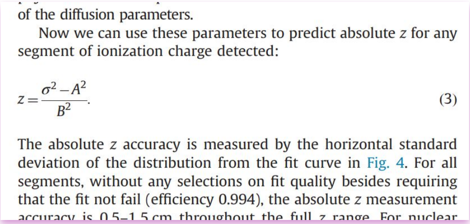
The observed values of σ are related to the track's Z coordinate by

$$\sigma = \sqrt{\sigma_0^2 + B^2 Z}$$

The transverse diffusion coefficient B in the gas is measured to be $129.7 \pm 3.1\ \frac{\mu m}{\sqrt{cm}}$, well in agreement with the expected value obtained with Garfield simulation ($130\ \frac{\mu m}{\sqrt{cm}}$) [47].

The intercept at zero $\sigma_0 = 292 \pm 12\ \mu m$ is due to the contribution of the electron avalanche propagation in the GEM stack and confirms results obtained with a radioactive source [47].

https://www.sciencedirect.com/science/article/pii/S0168900221001935

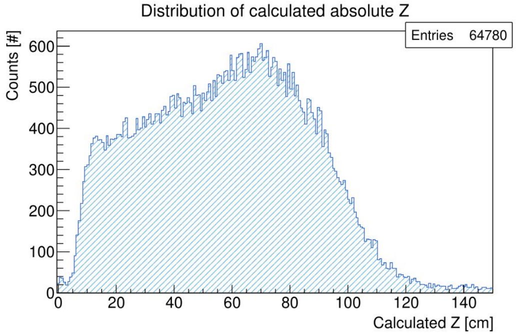

of the diffusion parameters.

Now we can use these parameters to predict absolute z for any segment of ionization charge detected:

$$z = \frac{\sigma^2 - A^2}{B^2}. \quad (3)$$

The absolute z accuracy is measured by the horizontal standard deviation of the distribution from the fit curve in Fig. 4. For all segments, without any selections on fit quality besides requiring that the fit not fail (efficiency 0.994), the absolute z measurement accuracy is 0.5–1.5 cm throughout the full z range. For nuclear

https://www.sciencedirect.com/science/article/pii/S0168900215003320



- ➔ I used LEMOn values. Clear offset since LIME is 50 cm.
- ➔ I also tried Roque's result ⇒ Huge uncertainty, and similar result
- ➔ ***Usable to hint absolute Z position***

3D Events - Cutted tracks

3D Events - Cutted tracks

6. Improvement of 3D Reco

a. Sensor-cut alphas removal ⇒ ***Cleans low energy tail***

b. This can affect the effectiveness of the directionality code, thus decreasing our **head-tail capabilities**.

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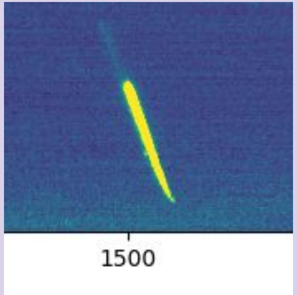
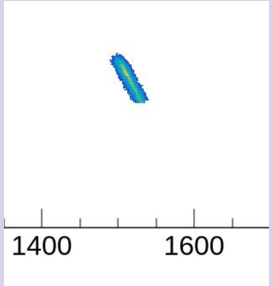
◆ **Noisy band cut on the reconstruction code**





- **Accounts for 15% of events**

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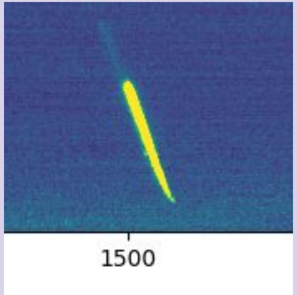

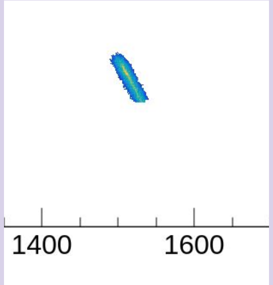

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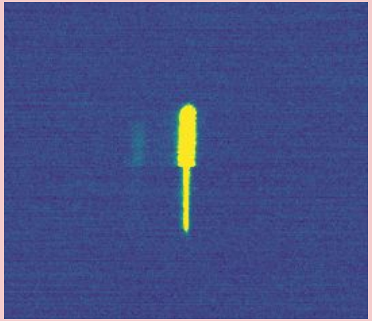
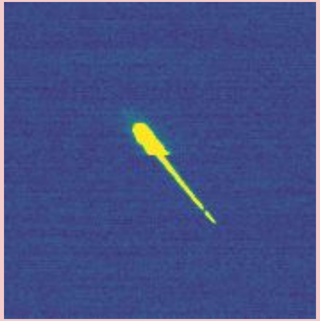
◆ **CMOS sensor active row cut**





$$\mathrm{TTT} < 184.4\ \mathrm{ns}\ :\ \mathrm{moving\ row} = 2304.0 - 2304.0 * \frac{\mathrm{TTT}}{184.4}$$

$$184.4 < \mathrm{TTT} < 300.0\ \mathrm{ns}\ :\ \mathrm{Global\ exposure\ (sensor\ fully\ open)}$$

$$\mathrm{TTT} > 300.0\ \mathrm{ns}\ :\ \mathrm{moving\ row} = 2304.0 - 2304.0 * \frac{\mathrm{TTT} - 300.0}{184.4}$$

- **Requires 3D match**
- **6% of events**

3D Event Reconstruction

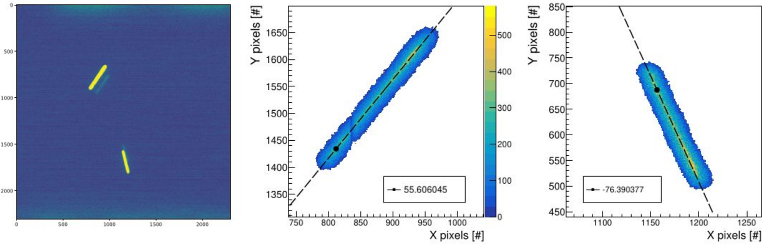
Dual sensor 3D analysis

3D Events - 3D analysis

➔ With the sensors' individual and merged information, we can now fully analyze the events and perform **particle ID**, **reject backgrounds** from known sources, and fully **characterize the 3D direction** ⇒ ***Directionality***

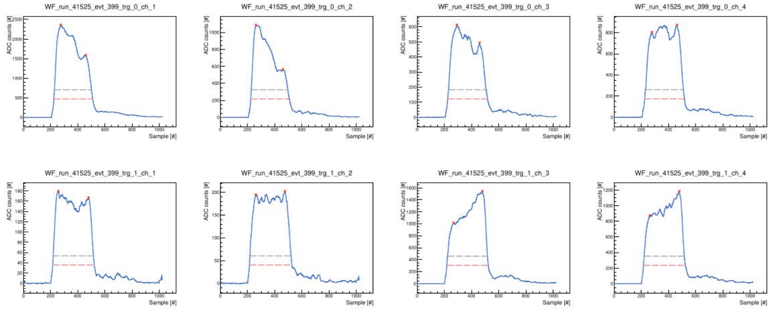
- The first studies were focused on **Alpha Particles**

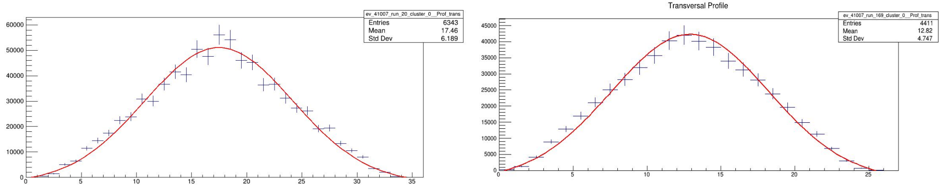
(a)



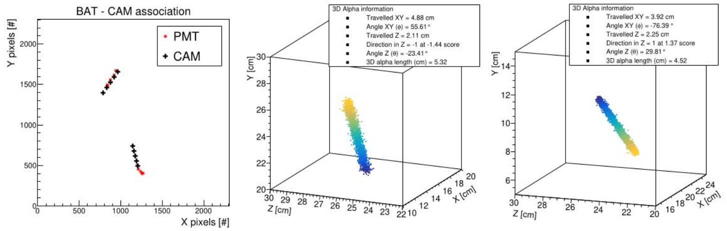
(c)

(d)





(e)



Alpha studies

The Rn case study

What I have been showing...

3D Events - The Rn study

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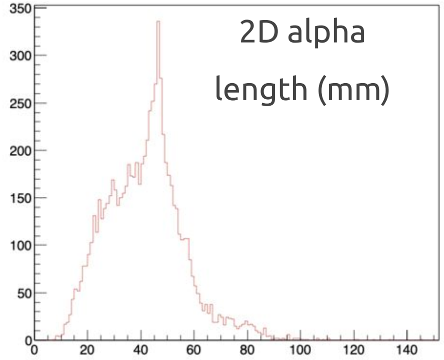
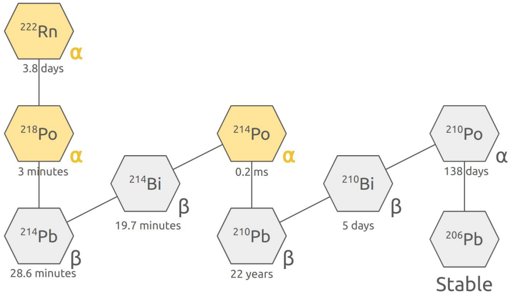
➔ When comparing our data vs. simulation, we found discrepancies, ***possibility attributed to ^{222}Rn***.

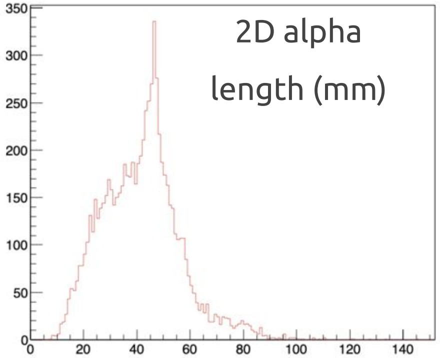


3D Events - The Rn study

What I have been showing...

- ➔ When comparing our data vs. simulation, we found discrepancies, ***possibility attributed to ^{222}Rn***.
- ➔ The ^{222}Rn decay chain produces 3 alphas in ~equilibrium. Due to their high energy, we are more sensitive to the length.





- ★ ^{222}Rn ⇒ 5.59 MeV ⇒ **4.3 cm**
- ★ ^{218}Po ⇒ 6.12 MeV ⇒ **5.0 cm**
- ★ ^{214}Po ⇒ 7.83 MeV ⇒ **7.3 cm**

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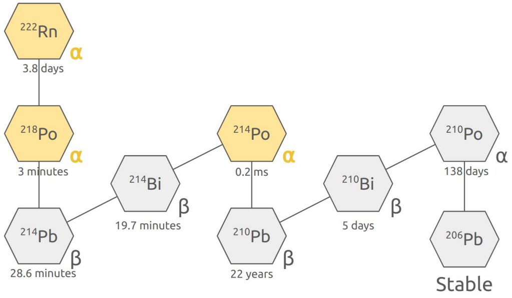

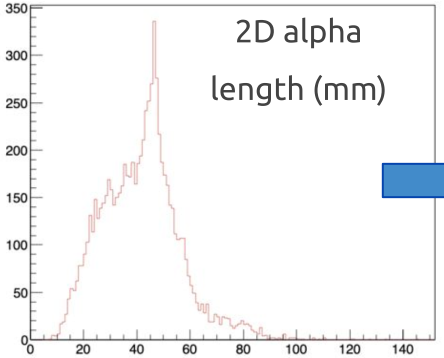

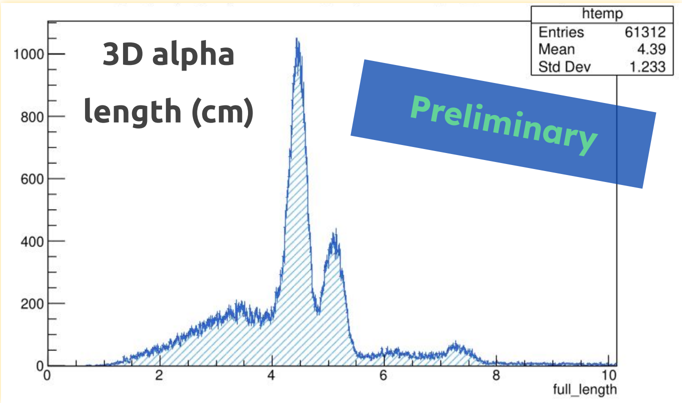

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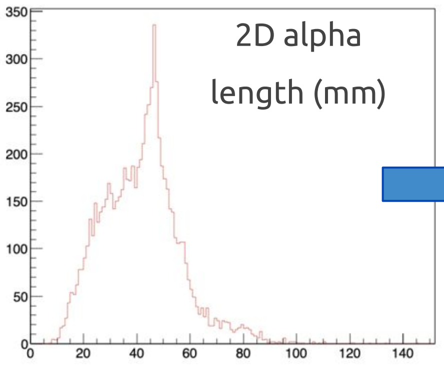

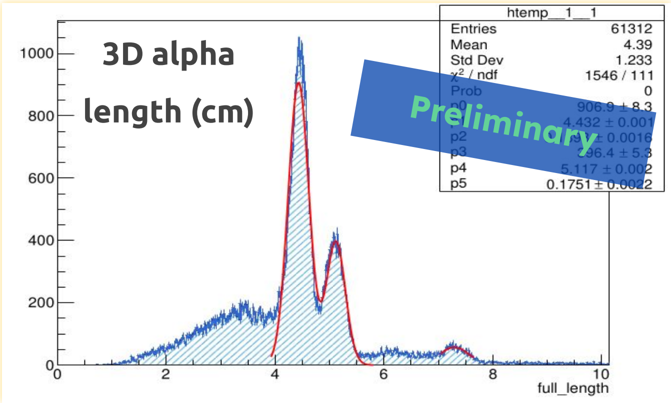

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Very similar!

Additional resolution reassure us of the presence of Rn in the gas.

Fitted peaks:

- **4.43 cm**
- **5.12 cm**
- **7.29 cm**

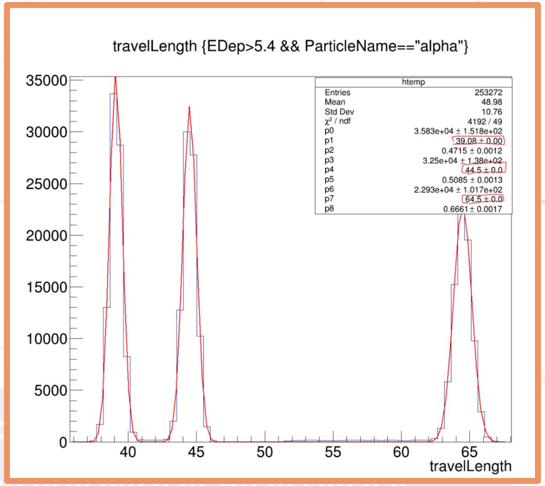
3D Events - The Rn study

What I have been showing...

➔ When comparing our data vs. simulation, we found discrepancies, ***possibility attributed to*** ^{222}***Rn***.

➔ The ^{222}Rn decay chain produces 3 alphas in ~equilibriu ... the length.

Geant4 simulation not compatible with measured nor "expected"



Measured MC ranges:

- **64.5**
- **44.5**
- **39.1**

★ ^{222}Rn ⇒ 5.59 MeV ... 4.3 cm

★ ^{218}Po ⇒ 6.12 ... ⇒ 5.0 cm

★ ^{214}Po ⇒ 7.83 ... ⇒ 7.3 cm

- 4.43 cm
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Alpha studies

Alpha range in LIME

Alphas - Alpha range in LIME

- But where do these ranges come from? Flaminia's thesis? Geant4? SRIM?
- We have seen previously that the **alpha length** could be slightly overestimated due to the ***"minimum signal possible".*** "Consistent" with the fact Geant4 shows smaller lengths…

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- We have seen previously that the **alpha length** could be slightly overestimated due to the ***"minimum signal possible".*** "Consistent" with the fact Geant4 shows smaller lengths…
  - I tried to understand the origin of this… I checked and compared:
    - **Davide Pinci's values ⇒** Compatible with data, but no source (?)
    - **Flaminia's thesis ⇒** No final values in the thesis ⇒ "range tables by SRIM for our gas mixture"
    - **CYGNO Simulation ⇒** Incompatible with data, consistent between simulators (Fiorina & Melba)
    - **Theoretical calculation using NIST calculators ⇒** Approximated for He:CF4 starting from air ⇒ Inconsistent with everything.
    - **SRIM ⇒** Supposedly the source of evertyhing
    - **My 3D analysis** (= data)

Alphas - Digitization

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  - (Thanks Melba for the alphas, and Giorgio & Piacentini for digi details)

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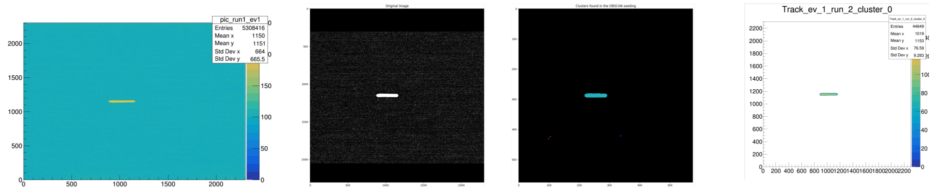

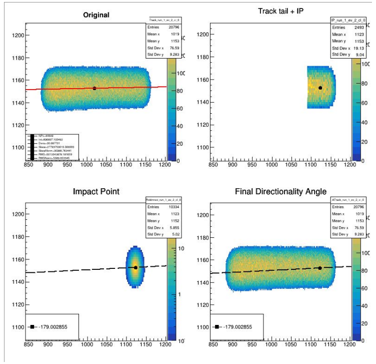

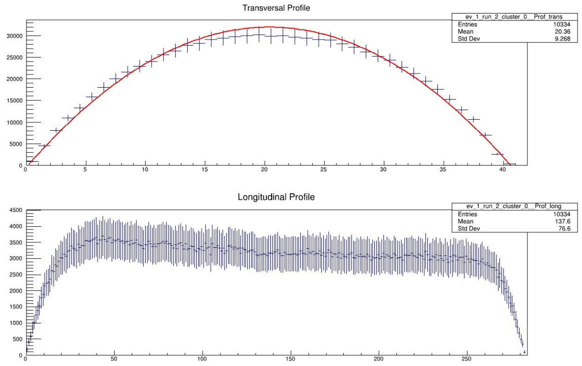

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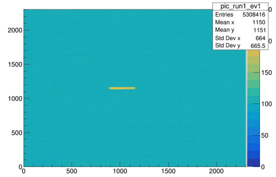

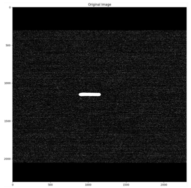

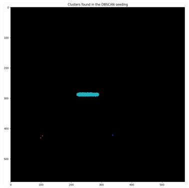

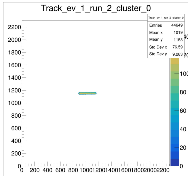

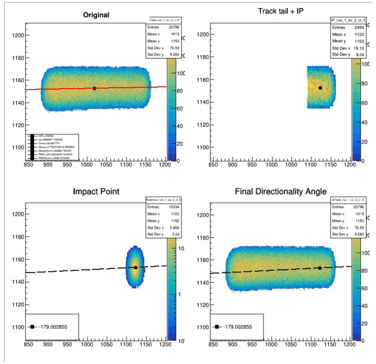

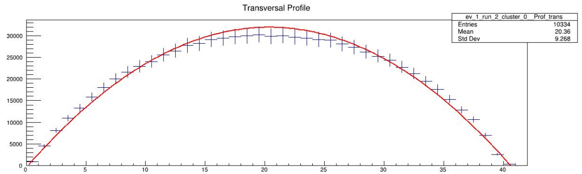

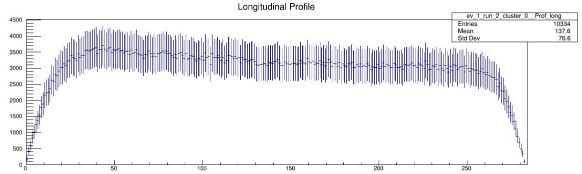

Outcomes…

- Lengths for the 3 Rn alphas are, on average:
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- They are bigger than simulation ✅
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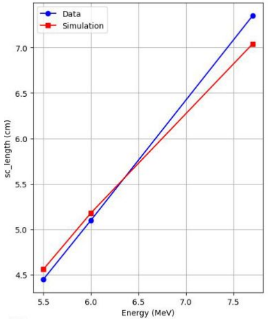
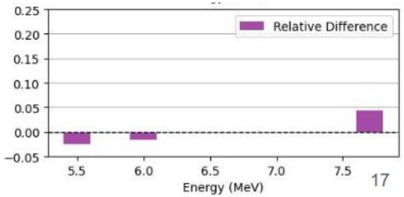
***Actually Pietro found encouraging results on these!**





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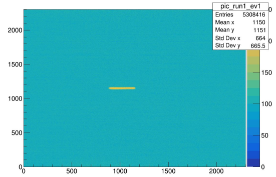

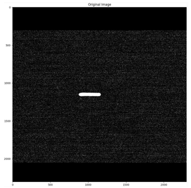

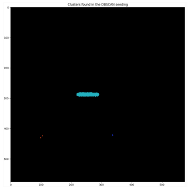

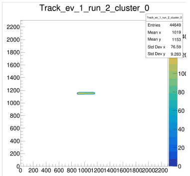

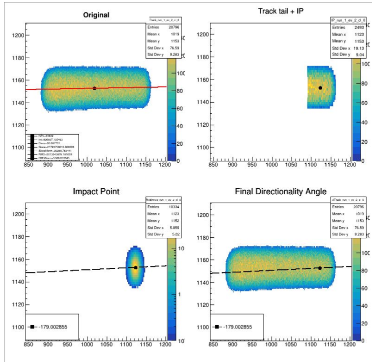

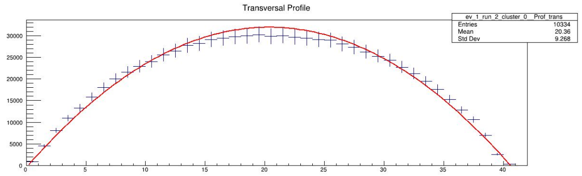

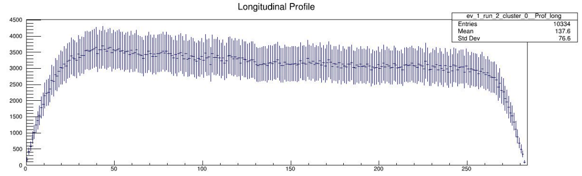

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***Actually Pietro found encouraging results on these!**

➔ Profile of digitized track not really Gaussian
- Neither data, but hint for improvement!
    - ***Saturation UNDERSTANDING ?!***

★ Digi not there to help me, but almost
- ***Empirical explanation incoming***

Alphas - SRIM

SRIM

- SRIM needs two important inputs: stoichiometry of gas mixture and ***gas density***. ***What's the gas density of LIME?***

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  - Theoretical: **d = 1.4 kg/m³**
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    - Now we know SRIM works.

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6.00 MeV	6.382E-01	3.983E-04	44.93 mm
6.50 MeV	6.023E-01	3.712E-04	50.68 mm
7.00 MeV	5.707E-01	3.478E-04	56.77 mm
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Energy	Range (avg) ± Error (1/2*max diff)
5.49	37.37 ± 0.51
6.0	42.50 ± 0.58
7.69	62.14 ± 0.84

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Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range
5.50 MeV	6.790E-01	4.299E-04	39.51 mm
6.00 MeV	6.382E-01	3.983E-04	44.93 mm
6.50 MeV	6.023E-01	3.712E-04	50.68 mm
7.00 MeV	5.707E-01	3.478E-04	56.77 mm
7.69 MeV	5.337E-01	3.201E-04	65.69 mm

*Flaminia wrote in her thesis the CYGNO gas mixture density is 1.53 kg/m^3

Energy	Range (avg) ± Error (1/2*max diff)
5.49	37.37 ± 0.51
6.0	42.50 ± 0.58
7.69	62.14 ± 0.84

Let's re-start the discussion…

With correct energies & ranges

3D Events - The Rn study

With correct energies & ranges

- When comparing our data vs. simulation, we found discrepancies, ***possibility attributed to ^{222}Rn.***
- The ^{222}Rn decay chain produces 3 alphas in ~equilibrium. Due to their high energy, we are more sensitive to the length.

★ ^{222}Rn ⇒ 5.49 MeV ⇒ 3.74 cm

★ ^{218}Po ⇒ 6.00 MeV ⇒ 4.25 cm

★ ^{214}Po ⇒ 7.69 MeV ⇒ 6.21 cm

Similar!

Not consistent anymore! ⇒ Possible missing component

Fitted peaks:

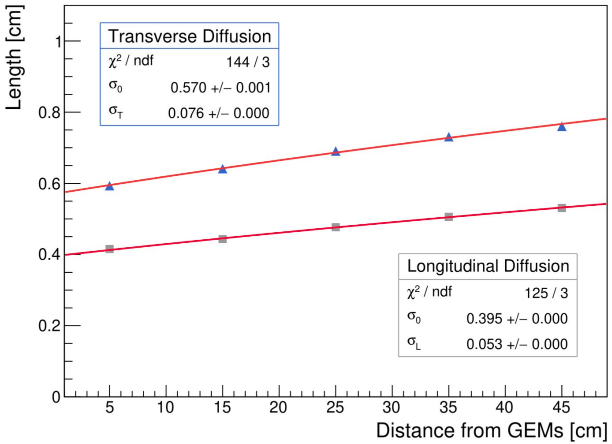
- 4.43 cm
- 5.12 cm
- 7.29 cm

3D Events - The Rn study

- ➔ There's a missing component not being account for: the ***minimum XYZ signal***
- ➔ I calculated the transverse and longitudinal diffusion from ^{55}Fe signals, and add the average to the expected ranges.
- ➔ Since I don't know the position of the event in Z à priori, I will take the ***mean value (step 3)*** to correct the 3D lengths.

3D Events - The Rn study

- ➔ There's a missing component not being account for: the ***minimum XYZ signal***
- ➔ I calculated the transverse and longitudinal diffusion from ^{55}Fe signals, and add the average to the expected ranges.
- ➔ Since I don't know the position of the event in Z à priori, I will take the ***mean value (step 3)*** to correct the 3D lengths.
  - ◆ **Minimum 3D length = 8.39 mm** ± **half of the maximum variation = 1.04mm**



- **Final result for the Minimum XY / Z: XY: 5.7mm Z: 3.95 mm**
- Longitudinal diffusion smaller than transverse ✅

3D Events - The Rn study

- ➔ There's a missing component not being account for: the ***minimum XYZ signal***
- ➔ I calculated the transverse and longitudinal diffusion from ^{55}Fe signals, and add the average to the expected ranges.
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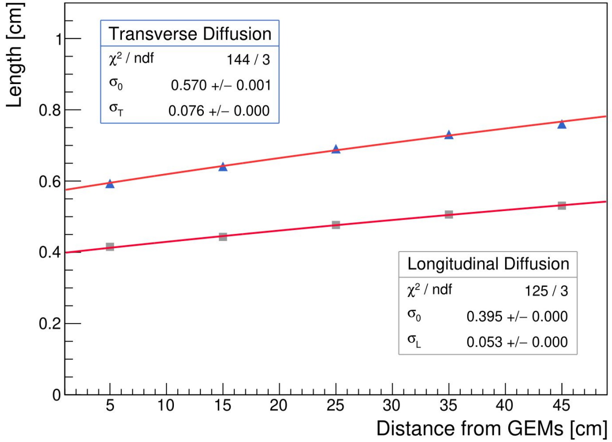


Table 1.7: Summary of the expected ranges for the energies of the 3 major ^{222}Rn alphas along with the 3 major peaks visible in the distribution of measured 3D lengths of alphas in LIME.

Energy [MeV]	Range in LIME [mm]	Range + 3D min length [mm]	Measured 3D length [mm]
5.49	37.37 ± 1.01	45.76 ± 0.51 ± 1.04	44.3 ± 1.8 (1σ)
6.00	42.50 ± 1.15	50.89 ± 0.58 ± 1.04	51.2 ± 1.8 (1σ)
7.69	62.14 ± 1.68	70.53 ± 0.84 ± 1.04	72.9 ± 2.6 (1σ)

Now the results are consistent!

- **Final result for the Minimum XY / Z: XY: 5.7mm Z: 3.95 mm**
- Longitudinal diffusion smaller than transverse ✅

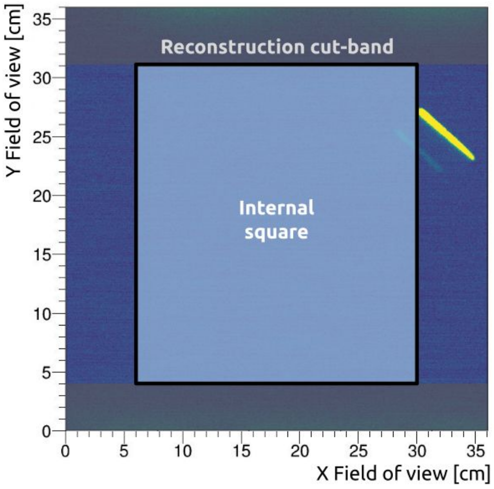
No shady business!

But is it really *Radon?*

3D Events - The Rn study

➔ If I remove the contribution from the field rings…

- Clear selection of events in the center (likely Radon)

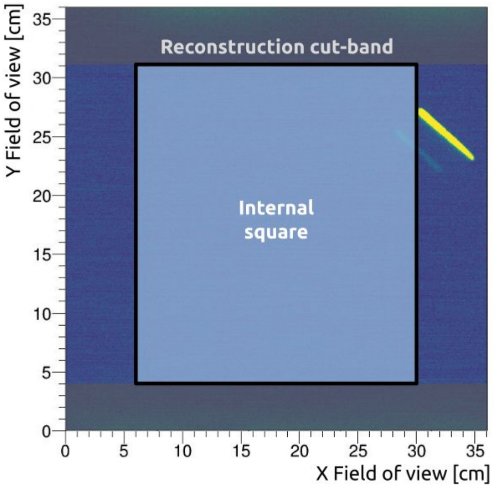


(a) Geometrical cut - central square

3D Events - The Rn study

➔ If I remove the contribution from the field rings…

- Clear selection of events in the center (likely Radon)



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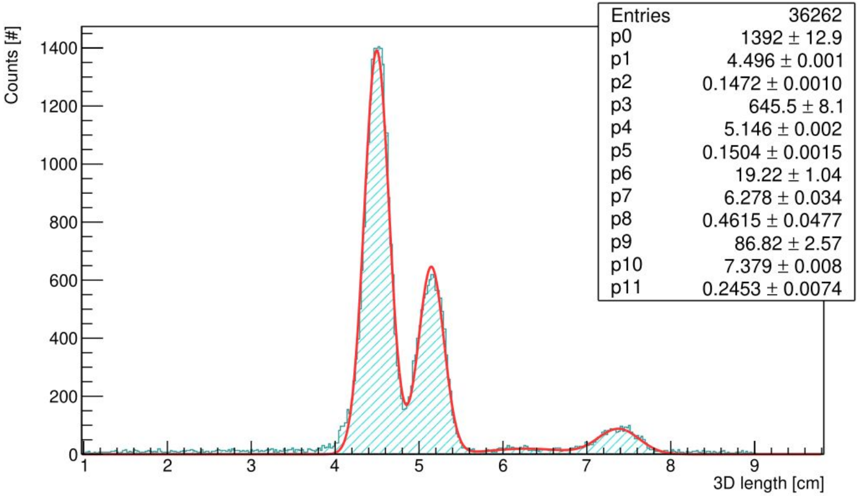

(b) 3D length of alphas

3D Events - The Rn study

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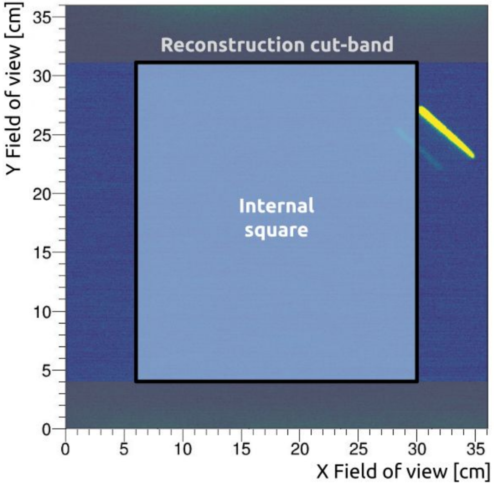

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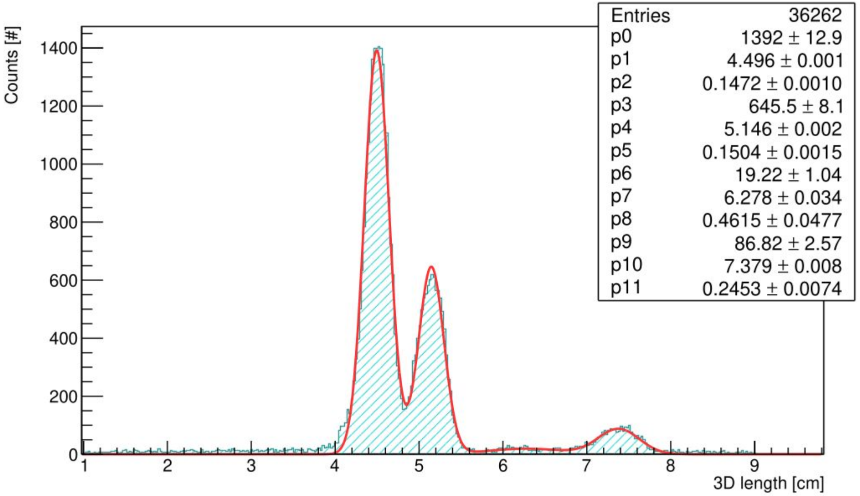

(b) 3D length of alphas

*I studied the area ratios (~50%, 25%), with assumptions of charged daughters, but no conclusions once we looked at the distribution in Z.

3D Events - The Rn study

➔ When studying the distribution of the supposedly Rn alphas, two variables are important:

- **Absolute Z position** + **Angular distribution**

3D Events - The Rn study

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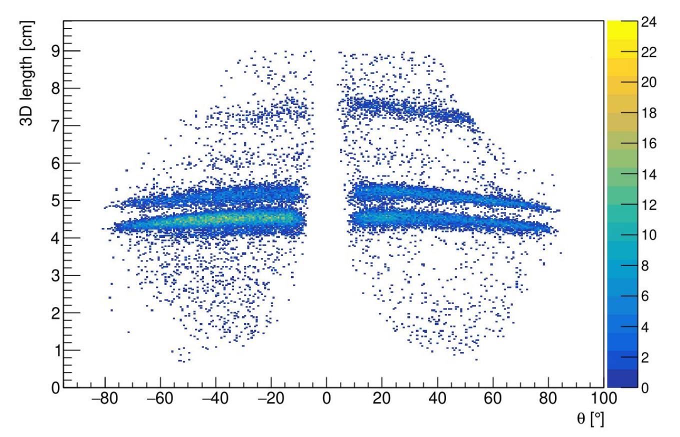

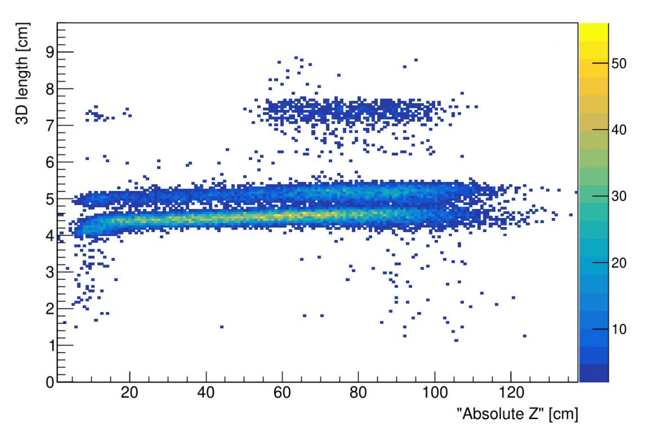

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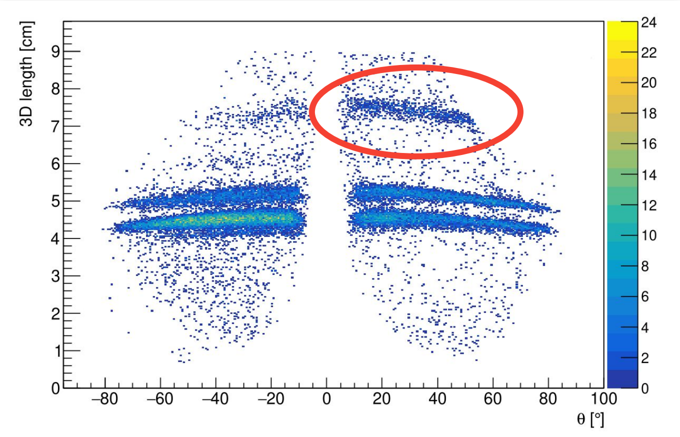
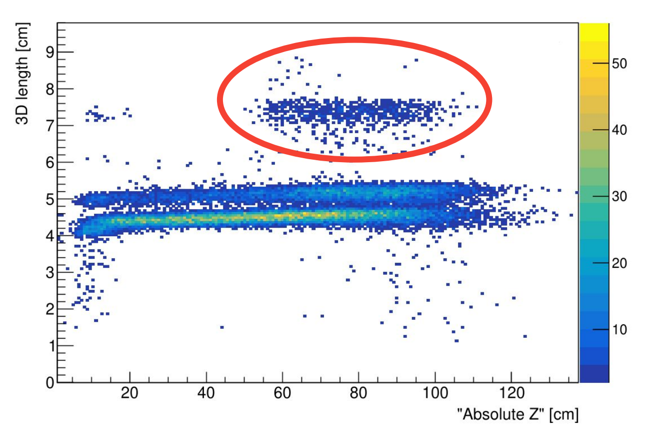




➔ **Alphas emitted at higher Z at each step of the chain because the Rn daughters are emitted charged (mostly)**

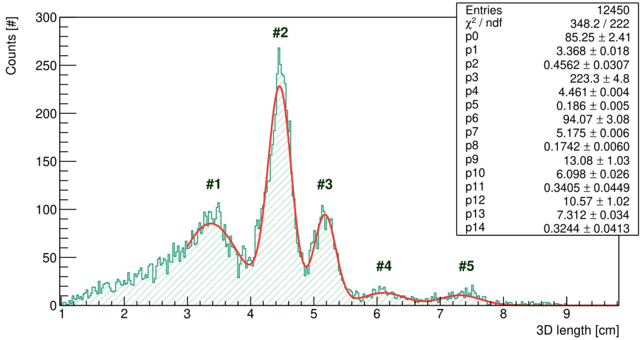
- Thus why 7.69 MeV alpha is emitted mostly towards the GEMS (from the cathode). **Seen also by DRIFT, MIMAC, and other**

➔ Alphas at ~4 cm length (^{222}Rn) see a preferential emission towards the cathode instead, although it's ***not clear*** why.

➔ Remaining alphas at lower (< 4 cm) length are thought to come from the U/Th chains…

3D Events - The Rn study

➔ If we look at the other peaks, at ~3.4 cm and ~6.1 cm, we can estimate their energies



Peak #	Measured 3D length (mm)	Estimated real range = 3D length - 3D min length (mm)	Estimated energy from range (MeV)
1	33.68 ± 4.56 (1σ)	25.29 ± 4.56 ± 1.04	$4.170^{+0.645}_{-0.725}$
4	60.98 ± 3.41 (1σ)	52.59 ± 3.41 ± 1.04	$6.905^{+0.375}_{-0.385}$

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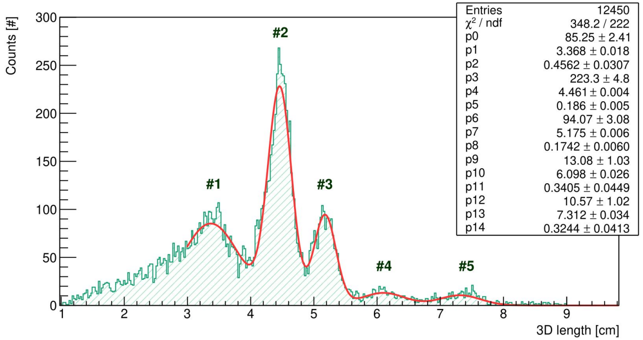

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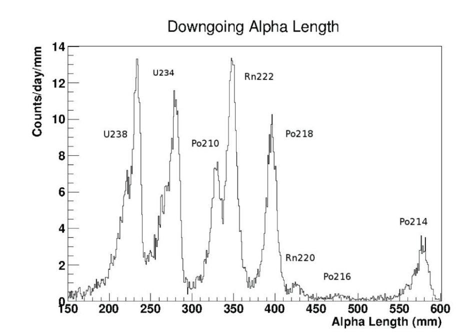
DRIFT results



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

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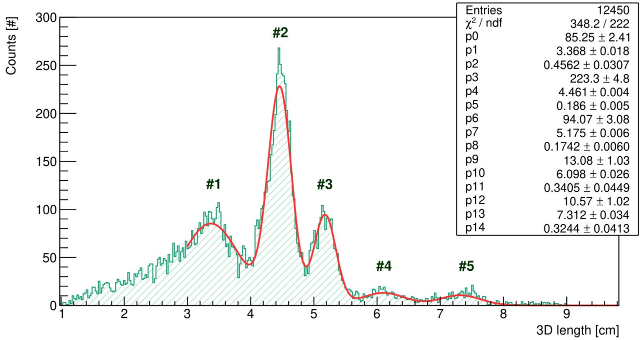

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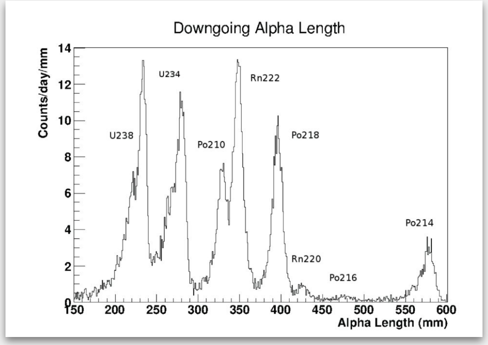

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Energy (keV)	Intensity (%)*	Type	Origin*	Levels Start*	Levels End*	Parent
4 038 (5)	0.13 (3)	α	U-238	0	2	U-238
4 151 (5)	22.3 (5)	α	U-238	0	1	U-238
4 198 (3)	77.5 (5)	α	U-238	0	0	U-238
5 748.46 (11)	0.118 (15)	α	Rn-220	0	1	Rn-220
6 288.22 (10)	99.882 (15)	α	Rn-220	0	0	Rn-220
5 988.4 (7)	0.0019 (3)	α	Po-216	0	1	Po-216
6 778.4 (5)	99.9981 (3)	α	Po-216	0	0	Po-216

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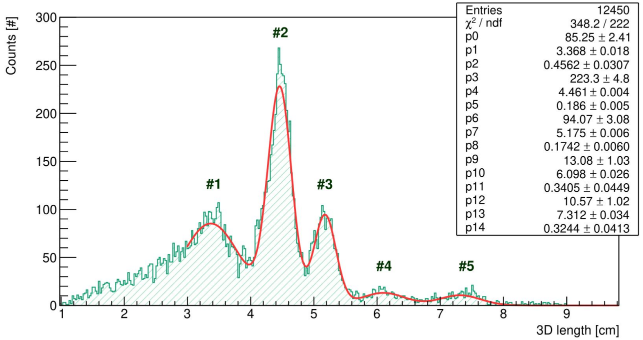

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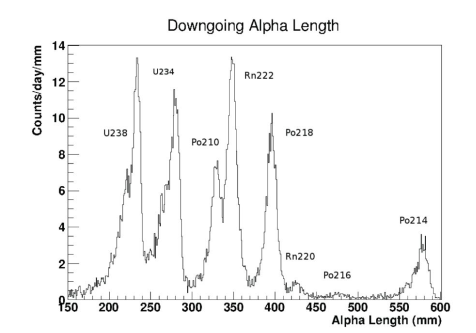
DRIFT results



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

*The tails could be U alphas that lose part of energy in material.

*We also kind of see Po210 shoulder.

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3D Events - The Rn study

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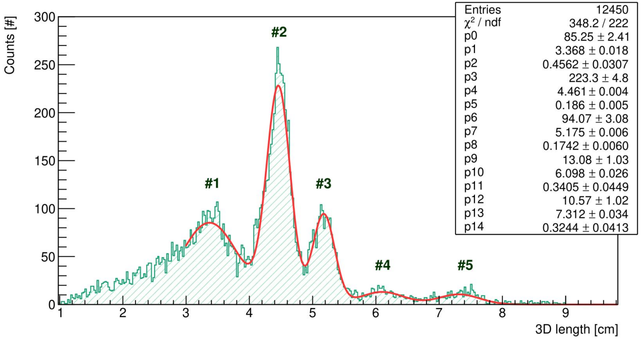

➔ **And who is emitting all this Uranium?**

3D Events - The Rn study

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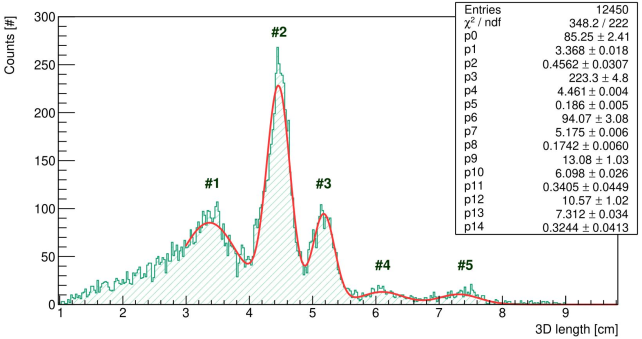

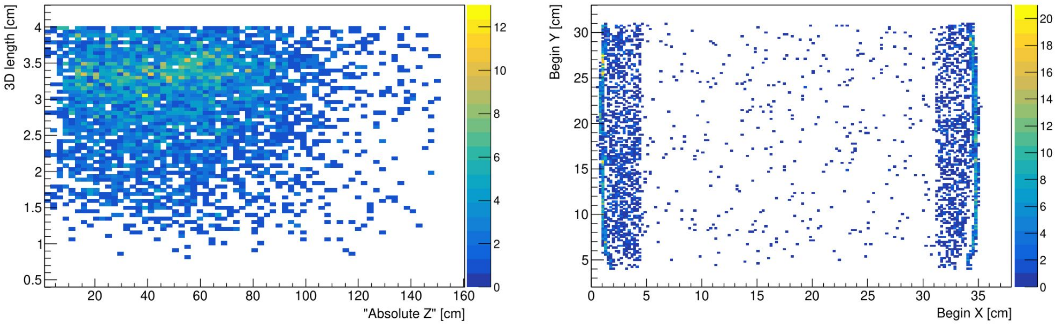

(a) (b)

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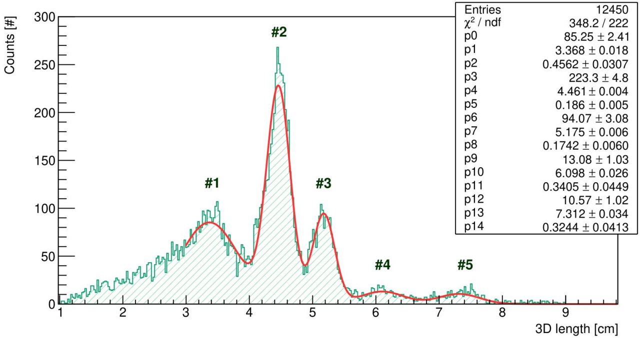
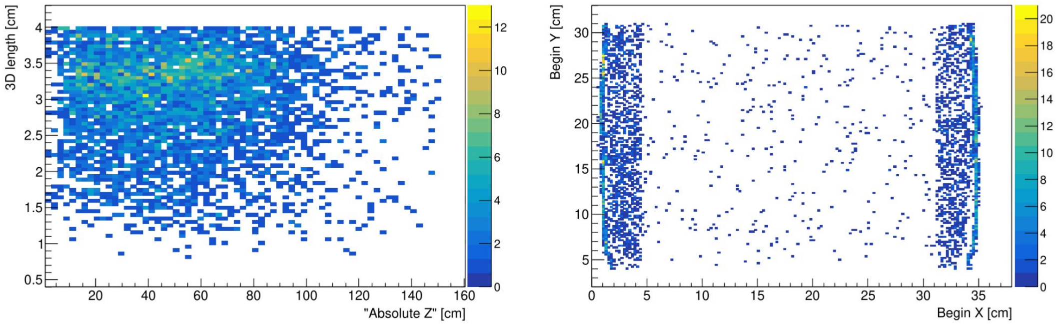




(a) (b)

➔ **And who is emitting all this Uranium?**

➔ **The field rings!**

➔ Alphas emitted throughout all detector in Z

➔ Mostly at the borders

◆ Not surprising!

But what about the energy? Measurable?

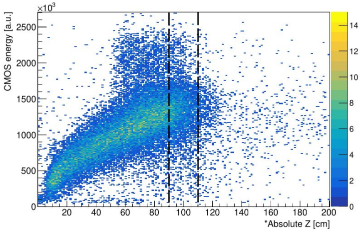
3D Events - The Rn study

➔ ***First we need to select alphas with the same saturation:***

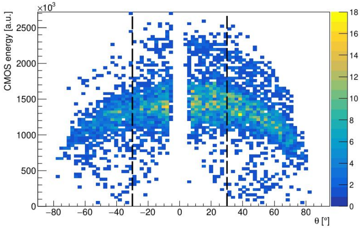
3D Events - The Rn study

➔ ***First we need to select alphas with the same saturation:***

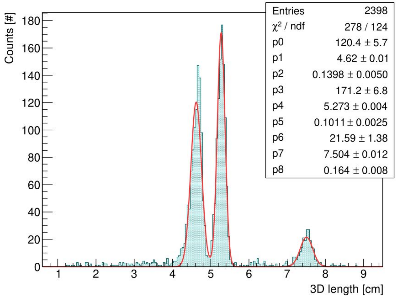
- Cuts on: absolute Z; Z angle (!); central region (only Rn alphas)



(a) Alpha particle - Zoomed view.



(b) Alpha particle - Reconstructed event.



(c) CMOS field of view showing one long high energy ER, one alpha particle and the *noise-band-cut*.

3D Events - The Rn study

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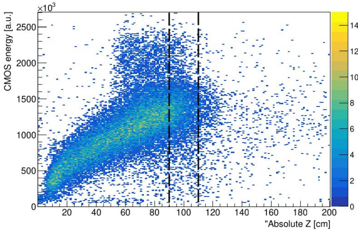

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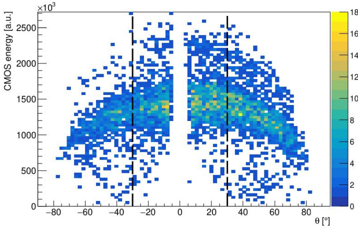

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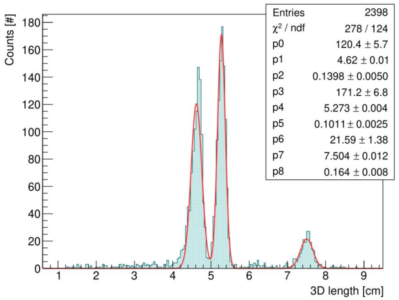

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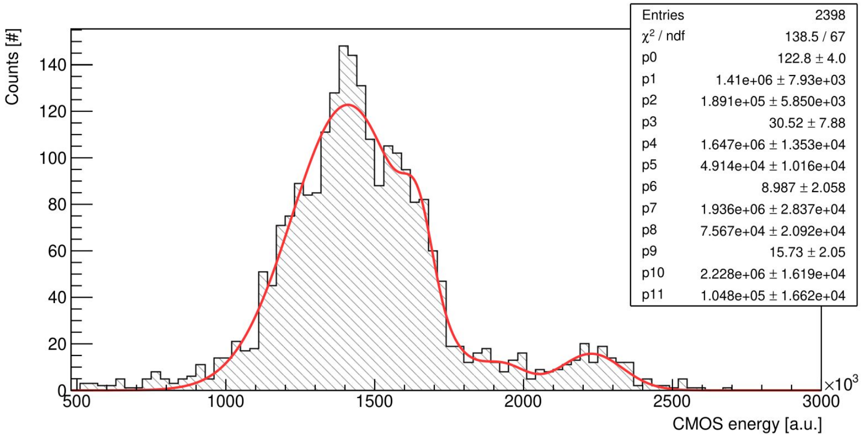

Figure 1.44

➔ Peaks clearly suggested a priori…

3D Events - The Rn study

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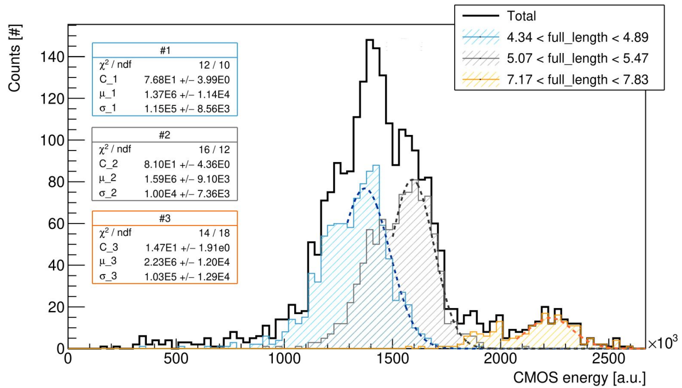

➔ But if I look at the singular contributions…

3D Events - The Rn study

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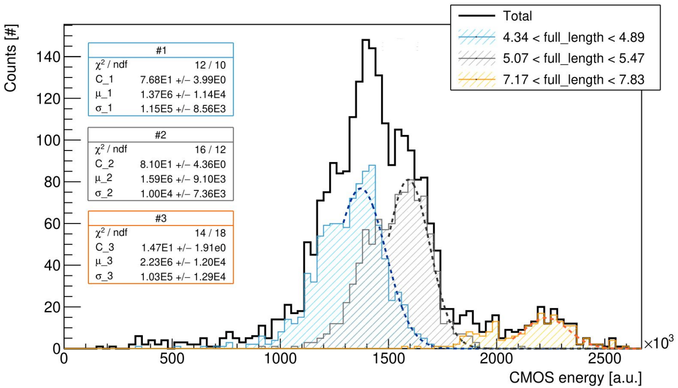

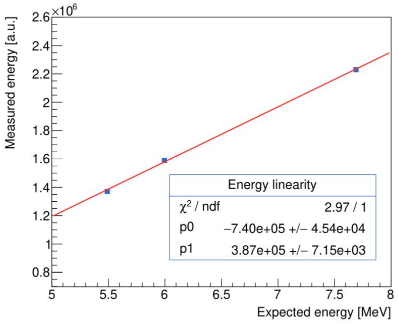

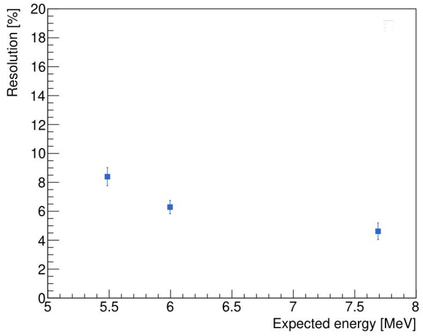

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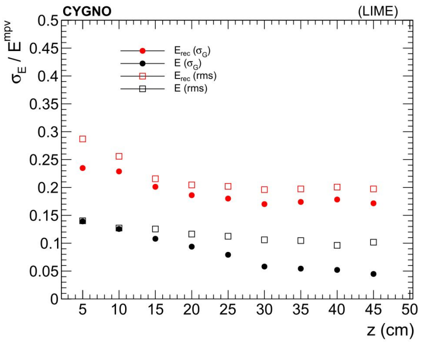
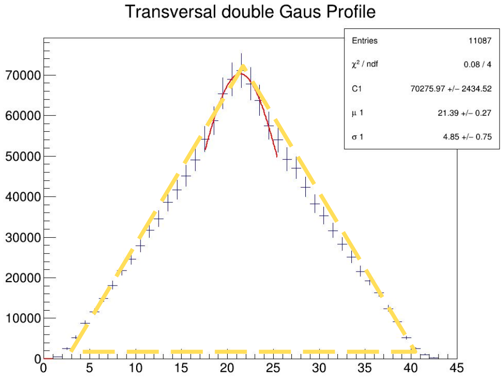


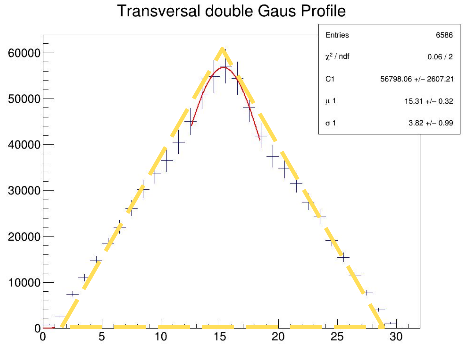
➔ Comparing with "good" ^{55}Fe resolution published, it's even compatible… stiamo 🏇

Yesterday analysis…

Alphas - The profile shape

➔ The alphas are not really Gaussian… they seem ***more triangular*** (!?) … also different from in NID…





- ➔ Gaussian fit not really appropriate
- ➔ Alphas strongly saturated
  - ◆ The study of the profile could help the study or understanding / **modelling of the saturation with the help of digitization**
- ➔ Samuele suggested me to use the Transverse Profile distribution (histo) ***RMS***

3D Events - The Rn study

➔ **Samuele** suggested me to use the alpha profile **RMS** isntead of the (poorly calculated) sigma…

Profile Sigma

Profile RMS

3D Events - The Rn study

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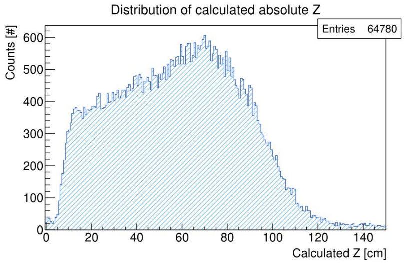
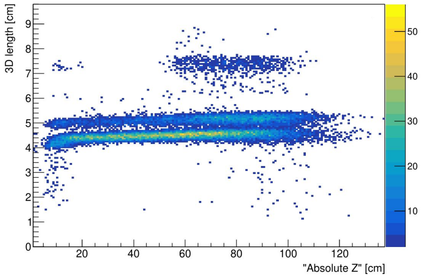
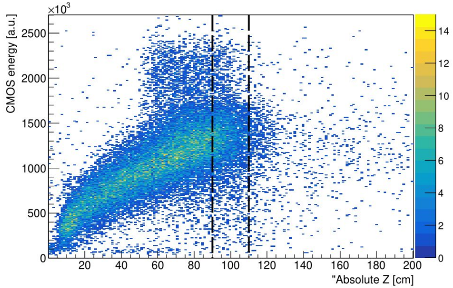
Profile Sigma







Profile RMS

3D Events - The Rn study

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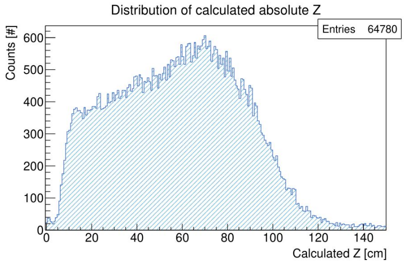
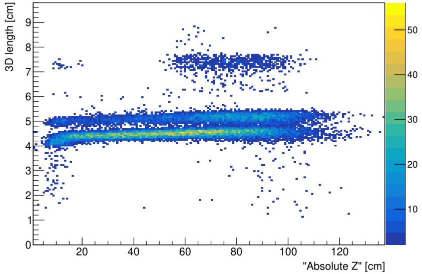
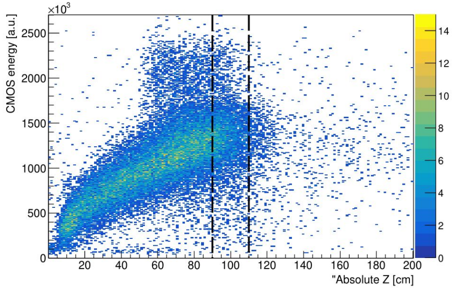
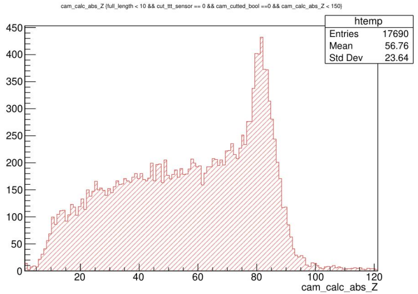
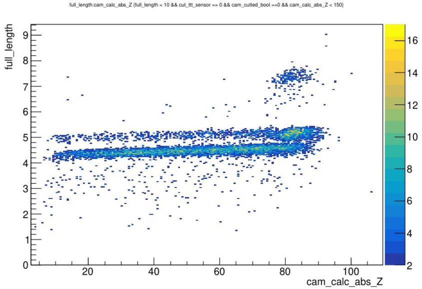


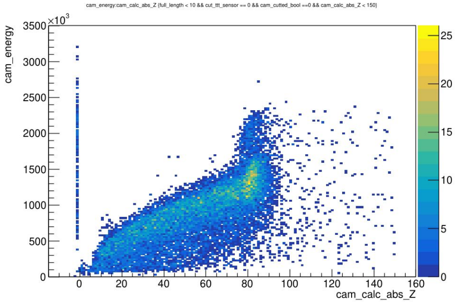




Profile RMS



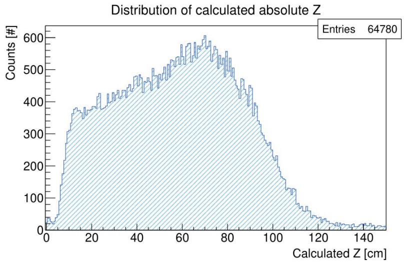


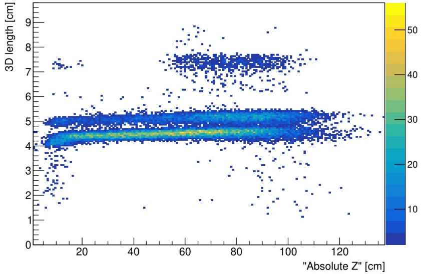


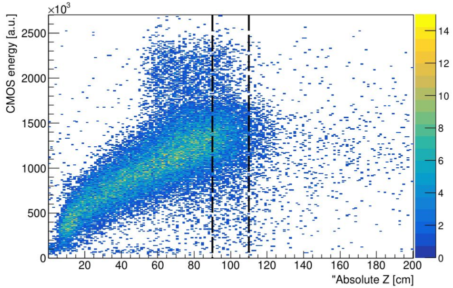
3D Events - The Rn study

➔ **Samuele** suggested me to use the alpha profile **RMS** isntead of the (poorly calculated) sigma…

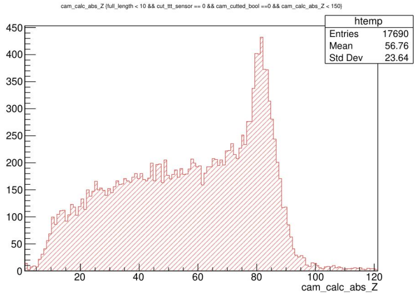
Profile Sigma

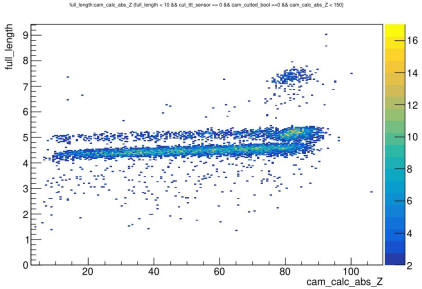


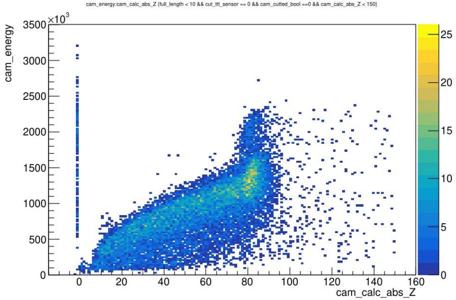




Profile RMS







➔ **Gained much resolution! Rn alpha confirm!**

➔ **Rn progeny drift towards cathode even more clear!**

➔ **Is RMS (from PROFILE) a good measure of diffusion and subsequently absolute Z?**

➔ **Maybe LIME is really 80 cm long (did you measure it?)**

Conclusions - What has been done

- The merging of CMOS (X-Y) with PMT (Z) information is performed with a Bayesian fit.
  - Reconstructing ionization events in 3D greatly improves spatial resolution and our PID capabilities.

- From the suspicion of the presence of Rn, the 3D analysis allows us to almost confirm its presence and, through its emission direction, its origin became more clear.
  - Other decay chains identified with this method
  - 3D analysis is more efficient than energy analysis (better resolution)
  - Shape of the alpha cloud profile interesting ⇒ Relation to saturation and absolute Z

- Currently paper on CMOS+PMT association, 3D reco and Rn lengths undergoing.

Conclusions - What should be done

- ➔ Studies on the application of the 3D analysis for NR and others.
  - ◆ The framework is there ⇒ Just need to PID different particles and analyze them
- ➔ Improvements in the code
  - ◆ I'm lacking optimization of parameters, and there are a lot!
    - ***PMT simulation is paramount!***
- ➔ Implement the new version of BAT
  - ◆ And probably implement it at DAQ level 0
- ➔ Alphas are cool, but what now?
  - ◆ Additional following paper on 3D results with discussion of the origin of the background? With possible comparison with MC?
    - We can still work together after I'm gone! ❤️🏳️

Thank you for your attention!

The CYGNO Project counts with the collaboration of several international researchers, coming from:

Backups
&
more details

Alphas - Improvement of 3D reco

- The CMOS sensor active row cut is checked using Piacentini's formula. I use a 2 mm window for small variations.

```
bool cutted_frame = false;
double activeRow = 0, active_row_cm = 0;

double active_range_low  = std::min(c_begin_Y, c_end_Y), active_range_high = std::max(c_begin_Y, c_end_Y);
double window_check = 0.2;

if (ttt_time > 184.4 && ttt_time < 300) {

    active_row_cm = 36.;         // inside Global exposure
    std::cout << "--> This track is *NOT* cut by the sensor." << std::endl;
} else {
    std::cout << "--> This track *COULD* be cut, let's check..." << std::endl;

    if      (ttt_time < 184.4)  activeRow = 2304.0 - (2304.0 * (ttt_time / 184.4));
    else if (ttt_time > 300.0)  activeRow = 2304.0 - (2304.0 * ((ttt_time - 300.0) / 184.4));
    active_row_cm = activeRow * granu;

    if (active_row_cm > (active_range_low - window_check) && active_row_cm < (active_range_high + window_check)) {
        std::cout << "--> This track *IS* cut by the sensor!" << std::endl;
        cutted_frame = true;
```

Alphas - Improvement of 3D reco

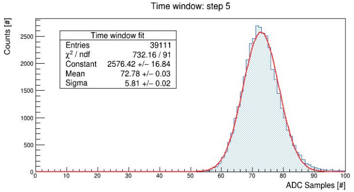
- A cross-check is now performed in order to identify alphas where this happens.
- The noisy cut band it's easy to check, and I check if the track starts or end within 1 mm from the cuts:

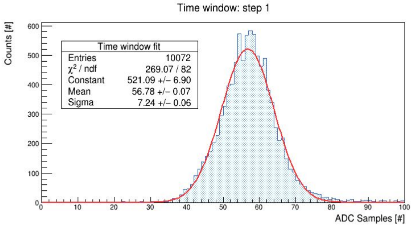
```
// To ensure we consider the correct limits independently of the track direction
double active_range_low  = std::min(c_begin_Y, c_end_Y);
double active_range_high  = std::max(c_begin_Y, c_end_Y);

// 1 mm window to mitigate mismatch between pixel rows and cm position due to granularity
double window = 0.1; //millimiter

double noisy_Y_band_high     = (2304. - 304.) * granu - window;
double noisy_Y_band_low      = (0. + 250.)    * granu + window;

if (active_range_high > noisy_Y_band_high || active_range_low < noisy_Y_band_low) {

    std::cout << "--> This track *IS* cut by the noisy band cut in the reco."  << std::endl;
    cutted_track = true;
```

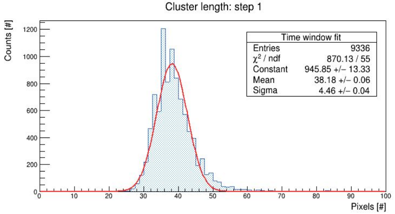
Alphas - Trans/Long Diffusion

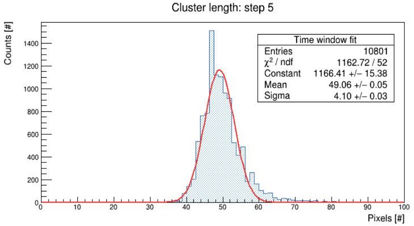
- I took about 20 calibration runs * 5 steps from batch6 of the alpha dataset.
- I measure the total time and space length of the ^{55}Fe signal seen by the PMT and CMOS, respectively.
- For the PMT ⇒ `PMT_Avg_Events->Draw("pmt_peak_FullWidth>>hist_tw" , "pmt_wf_sampling == 1024 && pmt_peak_Number == 1" , "goff");`
- For the CMOS ⇒ `Events->Draw("sc_length>>hist_sc_length", "sc_length < 200 && sc_rms > 6 && sc_tgausssigma > 0.5/0.152 && sc_tgausssigma/sc_lgausssigma > 0.7 && sc_width/sc_length > 0.7 && sqrt((sc_xmean-2304/2)**2 + (sc_ymean-2304/2)**2) < 800","goff");`
- I perform a Gaussian fit for each **step**
- I convert the mean to cm:
  - **d.** `μ_new[cm] = μ[ADC]       * time_to_cm   = μ * (4./3.) * 5.471E-3`
  - **e.** `μ_new[cm] = μ[pixels]    * granularity = μ * 0.0155`
- I plot the mean of the Gaussian (μ_{new}) as a function of the step position in cm
- I fit these points with `sqrt([0]*[0] + [1]*[1]*x)`

$$\text{Minimum 3D length} = \sqrt{(44.57 * 0.0155)^2 + \left(65.35 * \frac{4}{3} * 5.471 * 10^{-3}\right)^2} \pm \sqrt{(7.6 - 5.9)^2 + (5.3 - 4.1)^2} \Big/ 2 = 8.39 \pm 1.04\ \text{mm} \tag{1.12}$$









Alphas - LIME Gas density

$\rho\,(He : CF_4)$ $\quad T = 21\,°C$

$M_{He} = 4\ g/mol$

$M_{CF_4} = 88\ g/mol$

$\rho_{He} = \dfrac{91000 \cdot 0{,}004}{8{,}314 \cdot 29\cancel{3}4} = \ \ kg/m^3$

$PV = nRT \Leftrightarrow \rho = \dfrac{PM}{RT}$

$\rho_{CF_4} = \dfrac{91000 \cdot 0{,}088}{8{,}314 \cdot 29\cancel{3}4} =$

$R = 8{,}314\ J/mol \cdot K$

$1\ mbar = 100\ Pa$

$T = 20\,°C = 293\ K$

$\boxed{\rho_{He,CF_4}\ 60:40\ 910\,mbar} = 0.6 \times \rho_{He} + 0.4 \cdot \rho_{CF_4}$

$= \boxed{1{,}40\ kg/m^3}$