Best PMT position for CYGNO 04

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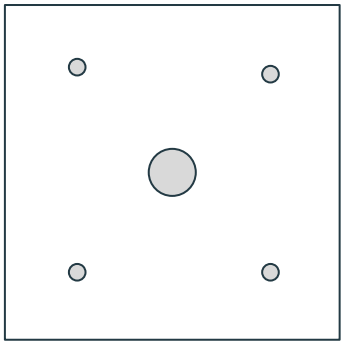
General Meeting - 25/07/2024

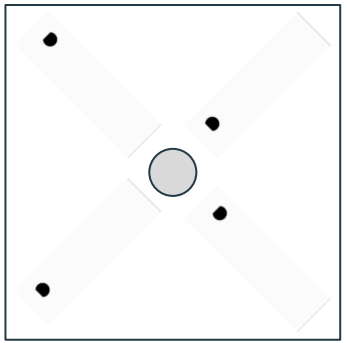
Steps overview - Motivation

- When upgrading from LIME to CYGNO-04, we were requested to identify the best position for the PMTs.
- Over the last months there were discussions regarding this topic:
  - Should we place them more inside or more outside the diagonal? 🤔

LIME

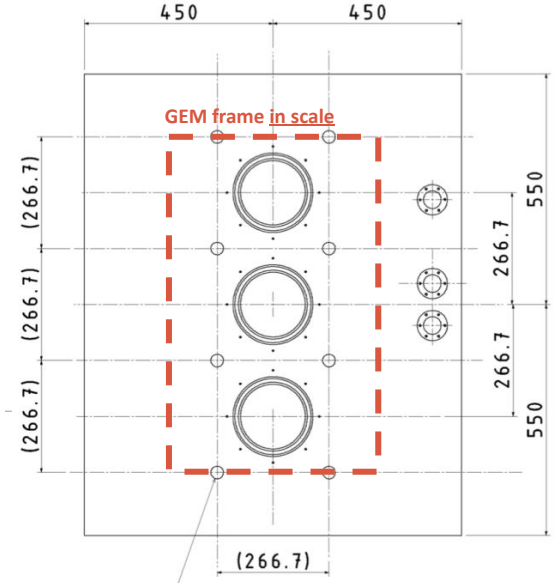


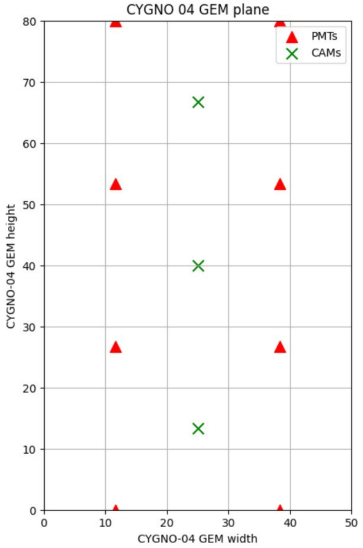
Where to put the PMTs now?



Steps overview - Motivation

- ➔ **Since we are going to use 8 PMTs, to conserve symmetry, the Y position is locked.**
- ➔ For this study, we focused on changing **only** the **PMTs X positions**

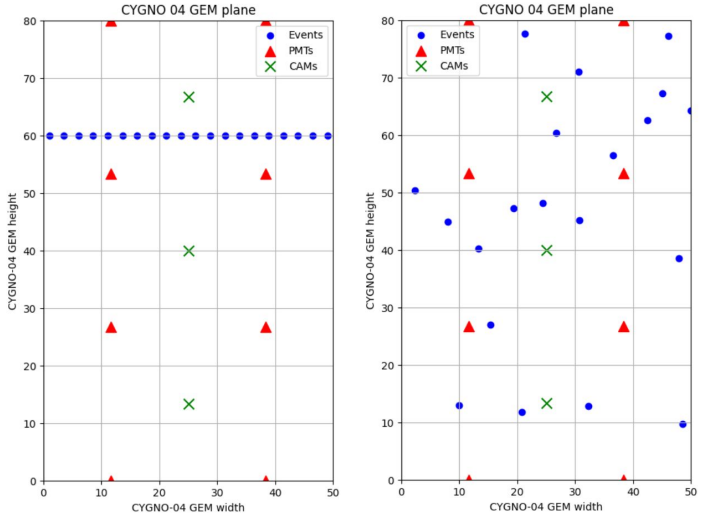


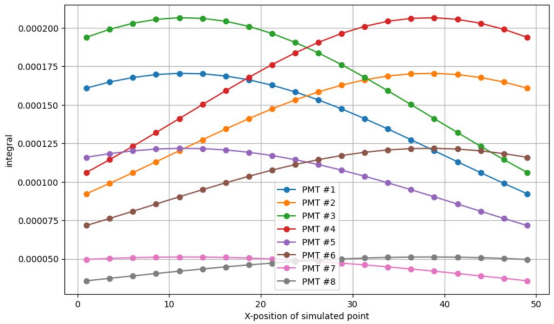


ROI

Steps overview - Rational

1. **Create a 50x80 cm plane** to represent **GEM plane** in CYGNO-04.
2. **Create points** in this plane (randomly or evenly distributed)
   - Each point represents a ^{55}Fe-like spot, calibrated from LIME and converted to CYGNO-04 (details on backup)
3. **Retrieve the distances** between each point and PMTs.
4. **Calculate integral** each PMT sees for each points.





Steps overview - Analysis

1. For a change in PMTs X's position, we performed two studies:

   1.1. Overall coverage of GEM plane with PMTs

      1.1.1. What's the total general LY emitted by the GEM plane and received by the PMTs at different positions

   1.2. Ability of BAT association code to correctly properly detect the simulated signals

      1.2.1. To help us assess how good will be out 1-to-1 association

BAT association

➔ With the **simulated points**, we create **two files**:

- **Input file for BAT**
  - Additional changes were made to make BAT compatible with CYGNO-04 “data” ⇒ already useful for the future CYGNO-04 data reco/analysis.
  - We use only 4 PMTs for association. ***Addition of >4 PMTs for BAT association*** is in the work pipeline
- **MC truth file**
  - Simple .txt with the X-Y positions of the simulated points

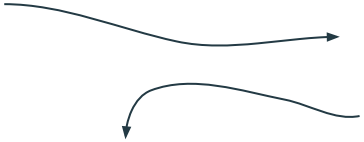
➔ Calculate the **X-Y differences between MC-fitted points**, **for different PMTs X-positions**, to estimate which position is reconstructed better.

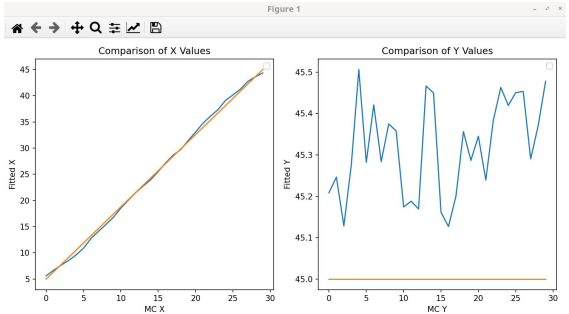
➔ **Notes:**

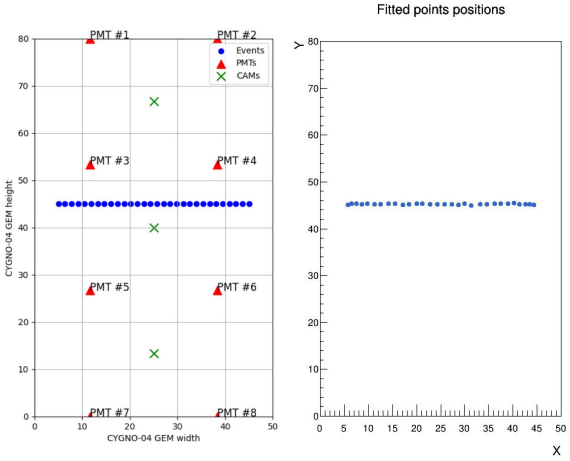
- The study of the **BAT intrinsic efficiency** is out of scope for this work ⇒ Could be a future work.
- These **are not** simulated waveforms. Points represent what a ^{55}Fe spot would look like in CYGNO-04

BAT association

- **Example:**





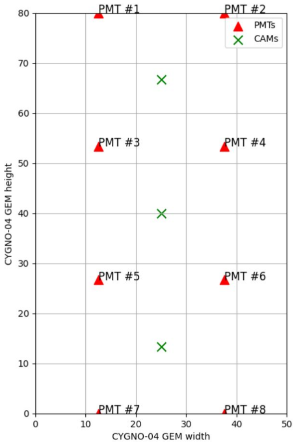


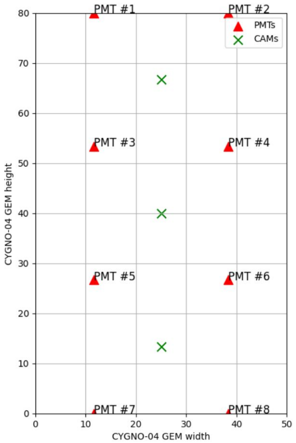
- I'm using the **middle 4 PMTs** for this study.
  - This because the system is **symmetric**
    - If the tracks were on the top, I would use the **PMTs 5-6-7-8** ⇒ **result would be the same!** (check backup)
  - I'm using the **middle PMTs** because the BAT fit struggles with events very close to the borders

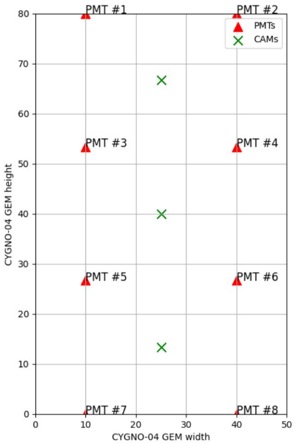
BAT association

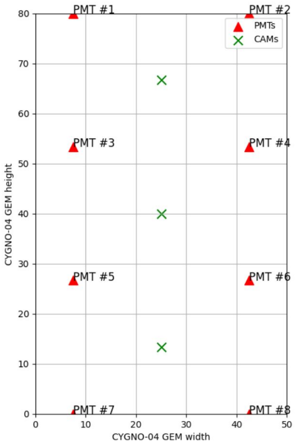
- **Tests:**
  - We tested 4 positions of the PMTs:

• **DX = -0.833**	• **DX = 0.000**	• **DX = 1.666**	• **DX = 4.166**









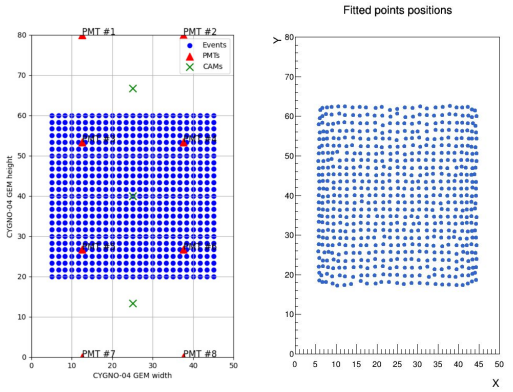
Moving away from the center

BAT association - Position 1

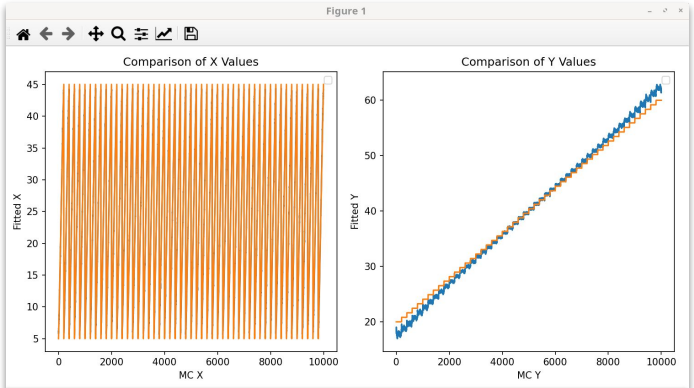
- PMTs position exactly between camera and gem border ⇒ **DX = -0.833**

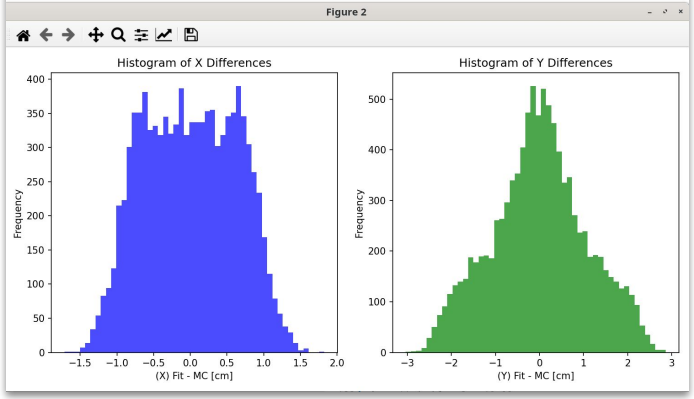
PMT #	**Pos X**	Pos Y
1	**12.50**	53.33
2	**37.50**	53.33

PMT #	**Pos X**	Pos Y
3	**12.50**	26.67
4	**37.50**	26.67



625
↓
10.000
points





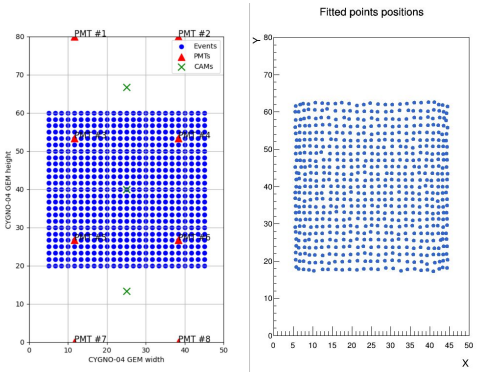
BAT association - Position 2

- PMTs position from original/current design

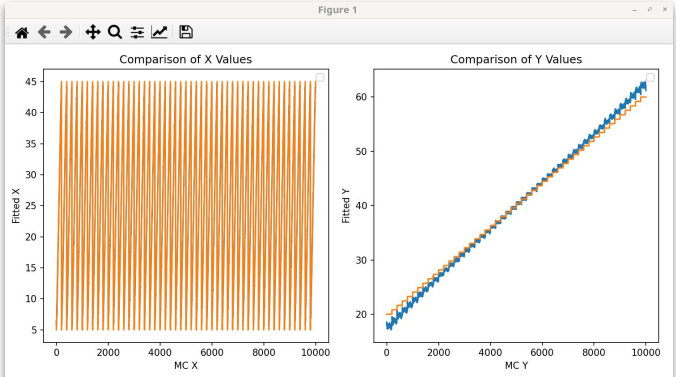
  ⇒ DX = 0.000

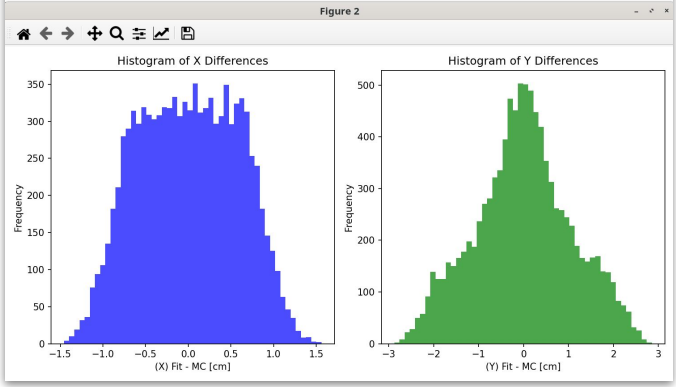
PMT #	**Pos X**	Pos Y
1	**11.67**	53.33
2	**38.33**	53.33

PMT #	**Pos X**	Pos Y
3	**11.67**	26.67
4	**38.33**	26.67



625
↓
10.000
points





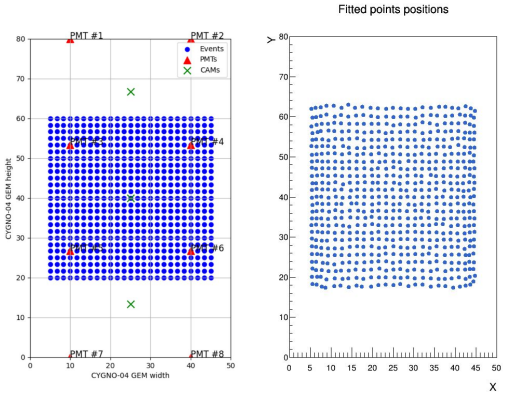
BAT association - Position 3

- PMTs position more towards the sides

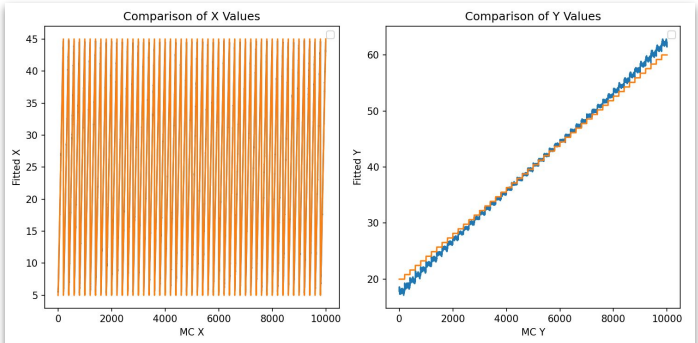
  ⇒ DX = 1.666

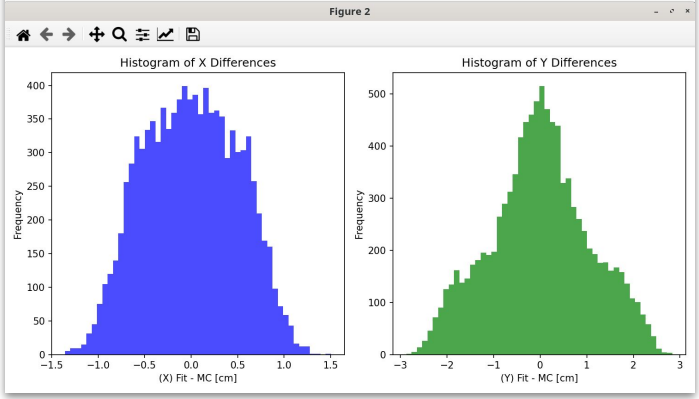
PMT #	**Pos X**	Pos Y
1	**10**	53.33
2	**40**	53.33

PMT #	**Pos X**	Pos Y
3	**10**	26.67
4	**40**	26.67



625
↓
10.000
points





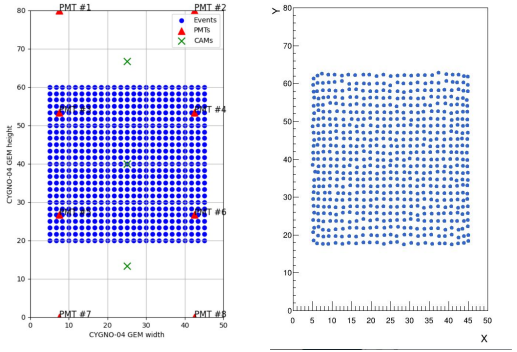
BAT association - Position 4

- PMTs position more towards the sides

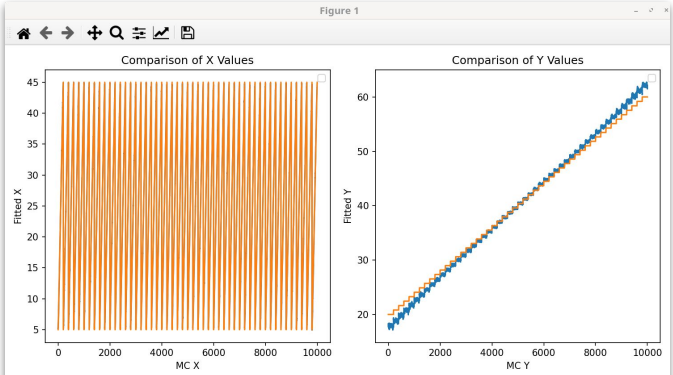
  ⇒ DX = 4.166

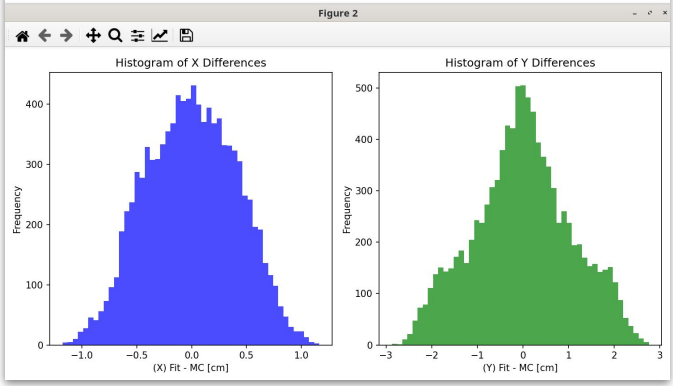
PMT #	**Pos X**	Pos Y
1	**7.5**	53.33
2	**42.5**	53.33

PMT #	**Pos X**	Pos Y
3	**7.5**	26.67
4	**42.5**	26.67

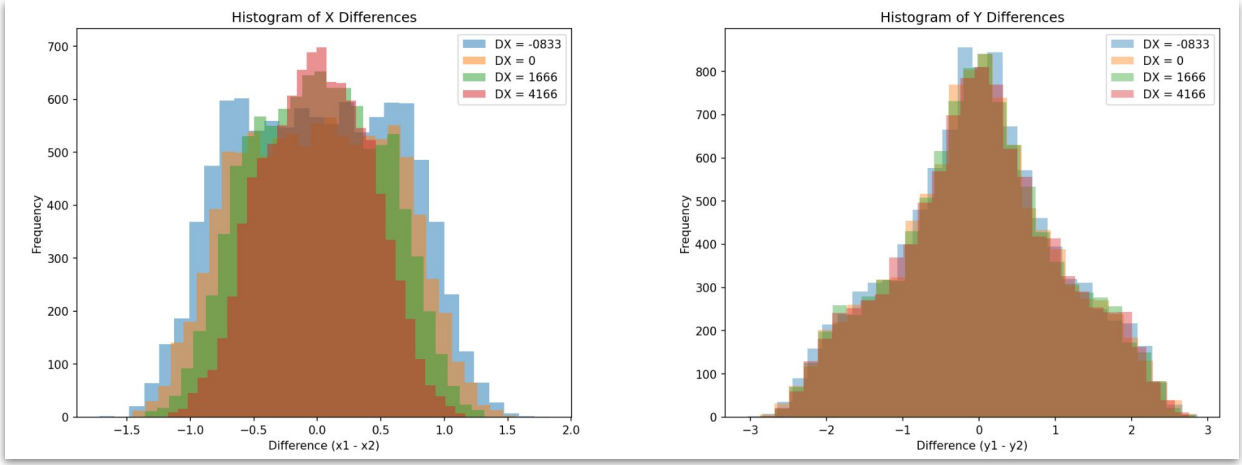


625
↓
10.000
points





BAT association - Comparisons



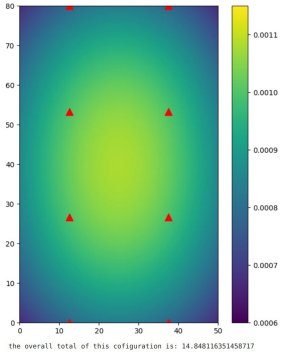
- **Y difference is negligible** for each configuration ⇒ Assumed to be due to the **fixed Y**.
- **X difference improves with placing the PMTs further away to the sides:**
  - This is a 4 variable fit ⇒ the ***more different the values are*** from each other ⇒ better will be the fit.
  - Outside the "4 PMTs square", 2 PMTs see very poorly ⇒ The farther we place the PMTs to the sides, the more likely is the event happens "between" the PMTs, thus easier to fit.

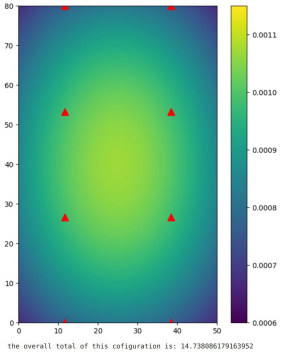
- ***NB:*** *The code could / should be improved further with data, not vice-versa, but this is what we have right now.*

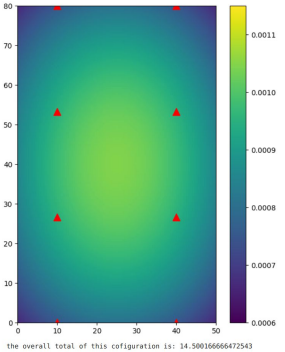
Frame coverage

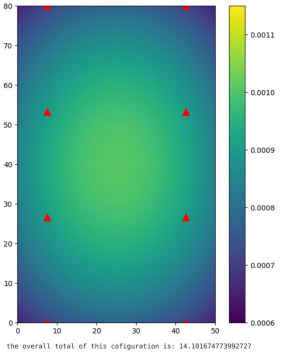
- The second test consisted in **placing 500.000 ^{55}Fe-like points in the whole GEM frame** and plotted the sum of amplitudes of the 8 PMTs in each bin (100*160 bins) ⇒ ***Overall coverage***

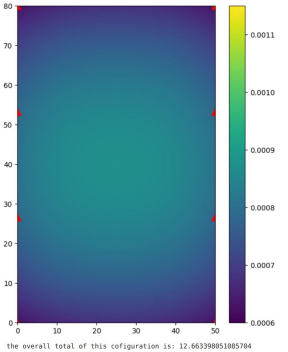
• DX = -0.833	• DX = 0.000	• DX = 1.666	• DX = 4.166	• DX = 11.66











- Overall similar coverages (besides the extreme case (last))
- The sum of all the points comes within 14-15 C for all cases.
- Testing the amount of **points below 20% of the range** for two cases: **DX = 0 ⇒ 0.9% ; DX=1.66 = 1.15%**

Conclusion - 1

- Initially, there was the idea of choosing where within the diagonal to place the PMTs.
  - Since we are gonna use 8 PMTs, the **Y is fixed by definition**, thus our analysis was simpler and **less impactful** than it could.
- From a general point of view, we **believe** that **placing the PMTs farther to the sides it's useful**:
  - The center is already well covered, while the sides became better covered
  - To avoid drastic changes, **we are looking mostly towards dx=0 or dx=1.66**

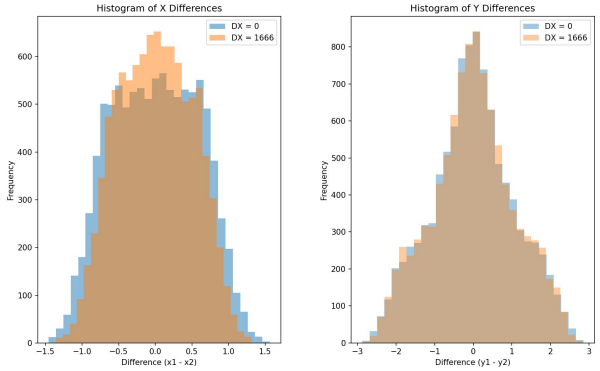
1. Testing the amount of points below 20% of the range for two cases:

   DX = 0 ⇒ 0.9% **DX=1.66 ⇒ 1.15%**

2. Comparing the BAT efficiency for these two cases:

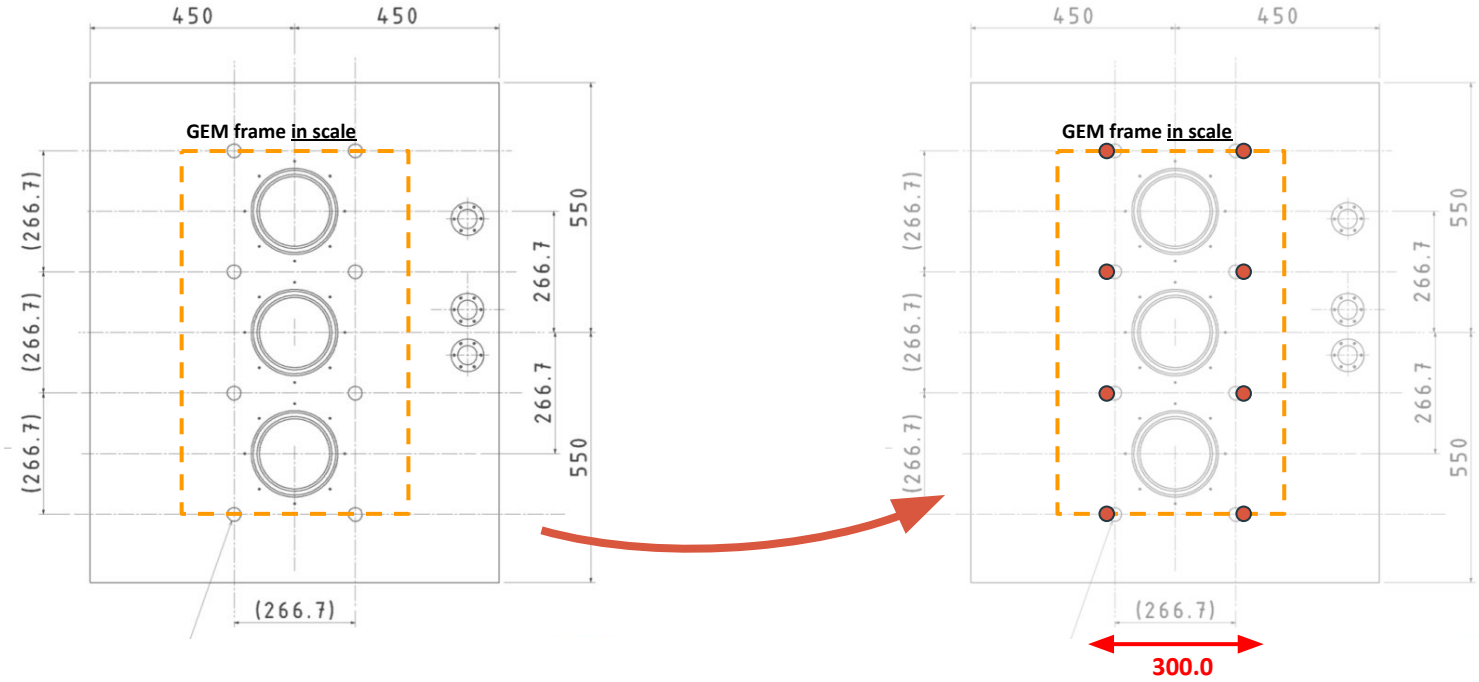
   A better and more peaked distribution is found for DX = 1.66

We think the best option is moving the PMTs to the outside for 1.66 cm.



Conclusion - 2

➔ We think the best option is moving the PMTs to the outside for 1.66 cm



Conclusion - 3

- We hope this study, while simple, can help to choose the position of the PMTs.
  - Might also make it easier to justify for committees, TDRs, judges, etc.

- Additionally, this tool will be made available for the collaboration to cross-check and use in the future.
  - Perhaps once a more robust PMT simulation exist, we can use this procedure to retrieve other important information regarding the PMTs.
  - Link to repo: *https://github.com/piacent/PMTPosition*

Back-up and others

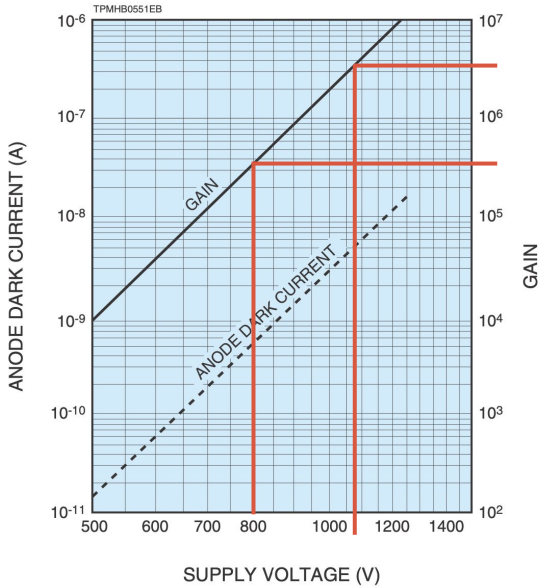
Will our signals be above threshold?

Current PMTs: [R7378A]

$$\frac{LY_{LIME}}{LY_{CY04}} \sim \frac{{Z_{LIME}}^2}{{Z_{CY04}}^2} = \frac{59^2}{19^2} = 9.64 \sim 10$$

- ➔ Back of the envelope, if the light will be 10x smaller from the PMT point of view, one should increase their voltages from ~800 to ~ 1200V to arrive to 10 times the current gain, which is reasonable and acceptable for these PMTs. *(to be further tested…)*
- ➔ *Trying to simulate this feature is hard at this point as we don't have a real PMT simulation*

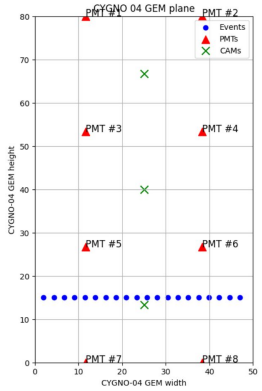
Figure 2: Typical gain and dark current characteristics



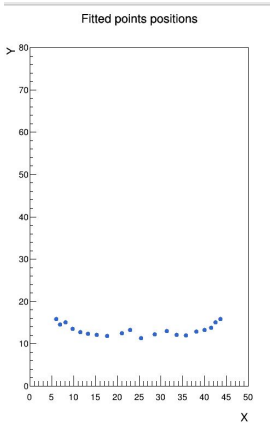
* Proof of what I just said

Return to presentation ⏎

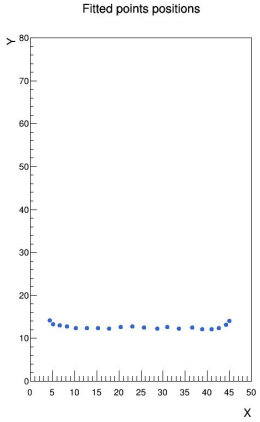
➔ Here I placed points at y = 15 cm, and compared the fitted points with different sets of 4 PMTs



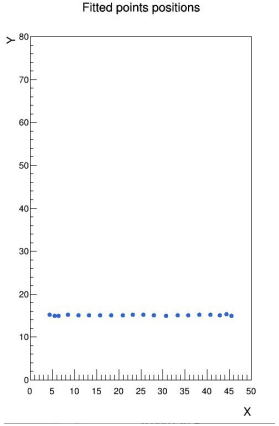
Original distribution



Using PMTs 1-2-3-4: Visibly not flat line



Using PMTs 3-4-5-6: Flatter, but not perfect



Using PMTs 5-6-7-8: Almost perfect

Interesting note: This clearly looks like a good way of testing BAT's capabilities! *If somebody is interested… :)*

Simulated ^{55}Fe-like points

Return to presentation ⏎

- For this toy-MC, we simulated what a ^{55}Fe spot would look like in CYGNO-04.
  - Not the actual waveform, but simply the **integral** of the "typical" ^{55}Fe peak/waveform seen in LIME data.
- The luminosity of a ^{55}Fe spot in sc_integrals, independent of the distance to the PMTs, was retrieved from Matteo's thesis, image 3.28.
- The intensity of light of these signals is given by: $I = A * Energy / R^4$, where $A = e^{17.26}$ **C*cm^4/sc_integral**
- Then we convert A to be energy dependent ⇒ $A = A / (5.9/LY_{55Fe})$
- Then A is converted into CYGNO-04 (note below*):
  - $A_{CY04} = (A * Z^2_{GEM\ CY04} / Z^2_{GEM\ LIME}) / (5.9/LY_{55Fe})$
- Then we calculate the distances between the simulated point and each PMT ⇒ get ***R***
- Then we apply $I = A_{CY04} * 5.9 / R_{PMT}\text{^}4$

- *Note that "A" grows for CYGNO-04 because we want to compensate the R^4 dependency, which is true only on a plane parallel to the GEM. So you compensate by basically removing the dependency on Z at x = 0 and y = 0 (moving only in the Z direction) which is Z^2 or R^2.
- This reduction in LY will/should be corrected by later possibly increasing the gain on the PMTs.

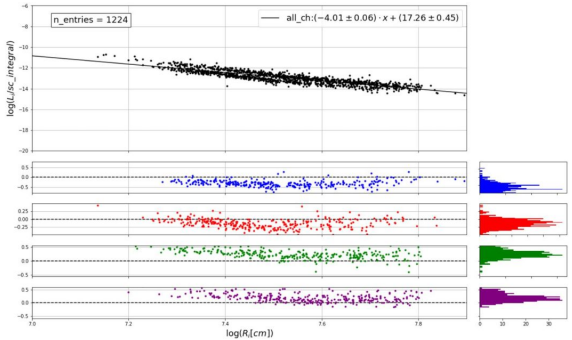


Figure 3.28. Best fit and relative residuals of the alpha power law in double log scale for the four PMTs combined