

3rd Training School COST Action COSMIC WISPers CA21106

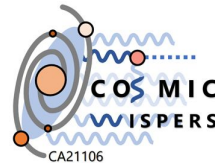
LAPTh, Annecy, France

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# Calibration of PADME beam monitoring calorimeter

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on behalf of the PADME collaboration

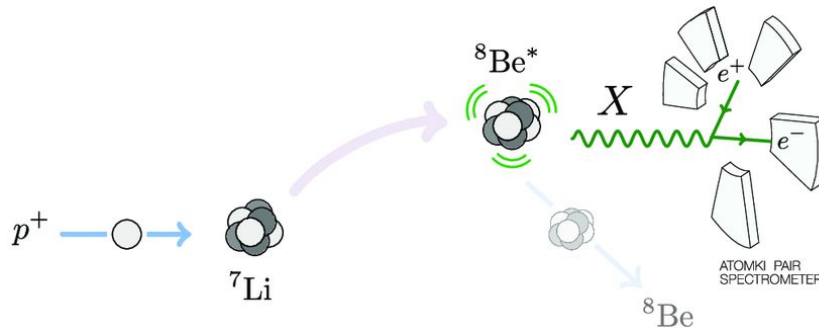


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# X17 Anomaly

## Experimental observation

- study of the nuclear decay of the  ${}^8\text{Be}^*$  by internal pair creation (IPC) at ATOMKI in Debrecen, Hungary
- determination of the opening angle between  $e^+$  and  $e^-$ 
  - theoretical calculation (*Figure 1.*)
  - experimental observation (*Figure 2.*)
- similar result was observed also for  ${}^4\text{He}$  and  ${}^{12}\text{C}$  nuclei



<https://doi.org/10.1103/physrevd.95.035017>

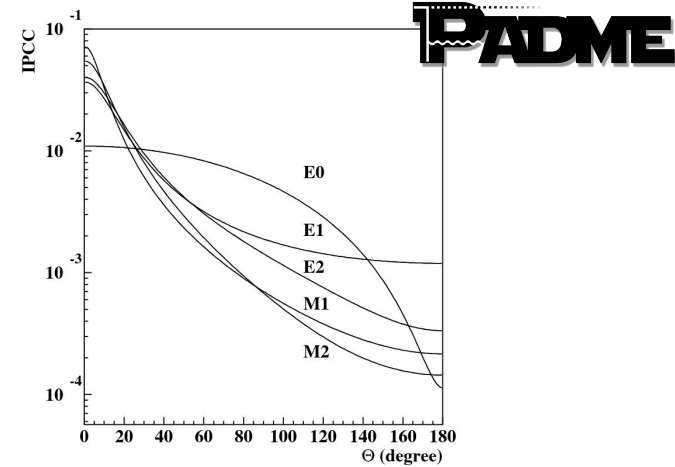


Figure 1.

<https://doi.org/10.1016/j.nima.2015.11.009>

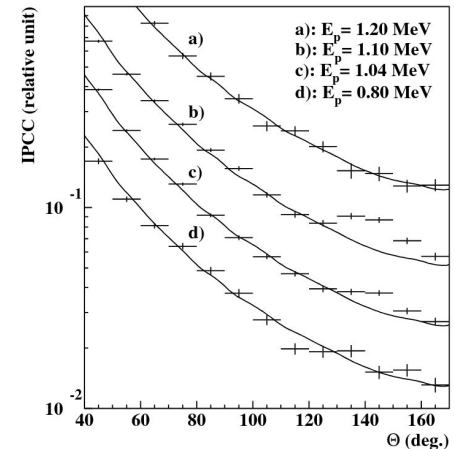


Figure 2.

<https://doi.org/10.1103/PhysRevLett.116.042501>

# X17 Anomaly

## Theoretical interpretation

- The anomaly seems to be compatible with the production and successive decay of a new particle with mass  $\sim 17$  MeV  $\rightarrow$  **X17**
- if X17 is a vector boson particle, extend the Standard Model Lagrangian with a new term (in analogy to QED):

$$\mathcal{L}_X = g_{v\psi} X_\mu(x) \bar{\psi}(x) \gamma^\mu \psi(x)$$

$$\mathcal{L}_{kin}^{mix} = -\frac{\epsilon}{2} F_{\mu\nu}(x) X^{\mu\nu}(x)$$

+ mass term:

$$\mathcal{L}_{X_m} \equiv \frac{1}{2} m_X^2 X_\mu X^\mu$$



<https://doi.org/10.1103/physrevd.95.035017>

$\rightarrow$  test of the X17 hypothesis by many ongoing and new experiments

# The PADME experiment

- **Positron Annihilation into Dark Matter Experiment** - originally planned for searching the dark photon via positron-on-target annihilation (*more in Kalina Dimitrova's talk*)
- Study the production of the X17 boson in resonance annihilation and its decay into electron-positron pair:
- If X17 exists  $\rightarrow$  increase of the number of  $e^+e^-$  pairs in the final state around  $M_X \sim 17$  MeV  $\rightarrow$  observable:  $N_2/N_{\text{POT}}$
- PADME Run III: beam energy scan around the X17 resonance energy  $\sim 289$  MeV (*more about the Run III result in Marco Mancini's talk*)

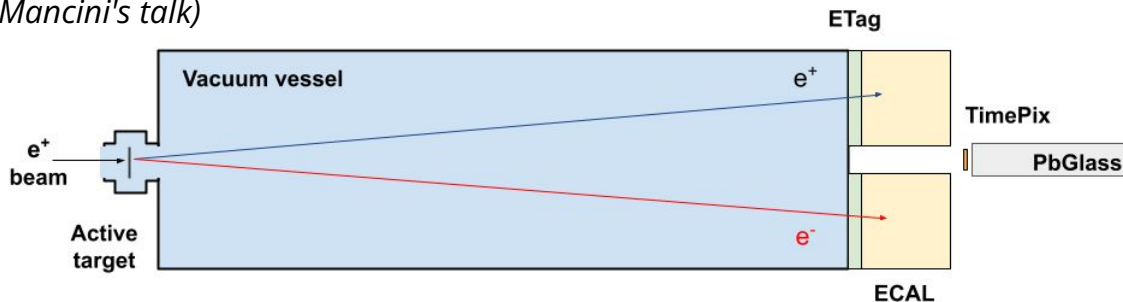
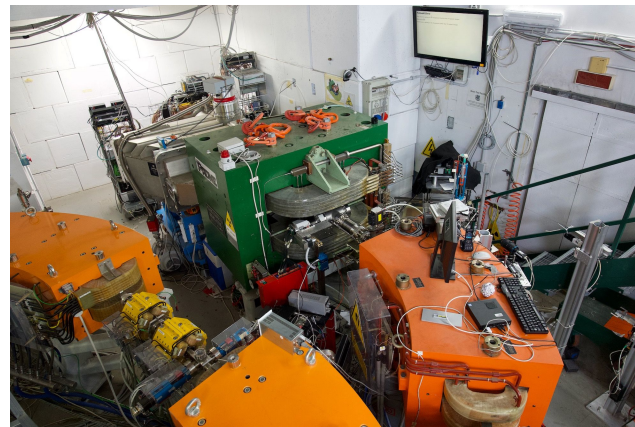


Figure: Experimental setup of PADME Run III

# The PADME experiment

## Beam monitoring detectors

- **Active diamond target** - measures beam spot position and beam multiplicity
- **TimePix** - measures beam spot position and size
- **PbGlass calorimeter** - measures beam multiplicity

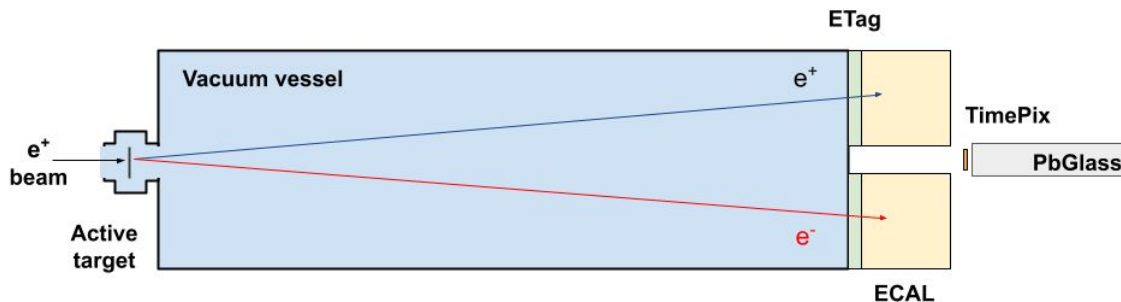
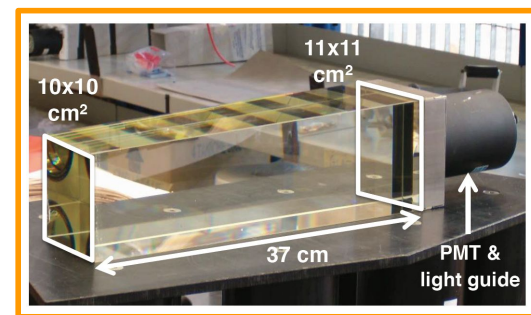
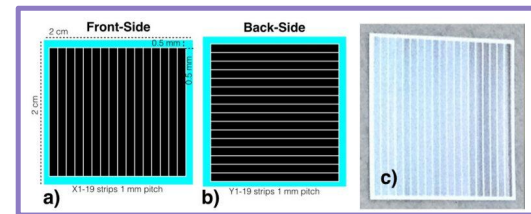
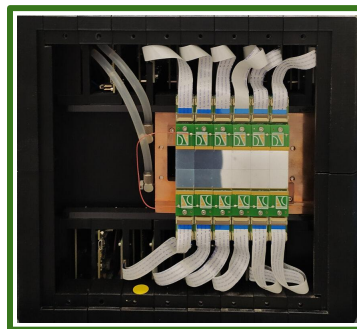


Figure: Experimental setup of PADME Run III

# Precise determination of $N_{\text{POT}}$

## Cherenkov electromagnetic calorimeter

- lead-glass block Schott SF57 (75% PbO) with density of  $\rho = 5.5 \text{ g/cm}^3$
- photomultiplier Hamamatsu R2238
- multichannel ADC V1742

→ measure the collected charge on the photomultiplier anode and convert it to energy:

$$E_{\text{PbGl}}^{\text{tot}} = \frac{Q_{\text{PbGl}}^{\text{tot}}}{Q/E}$$

*total deposited energy in the leadglass*

*calibration coefficient or response of the detector in pC/MeV*

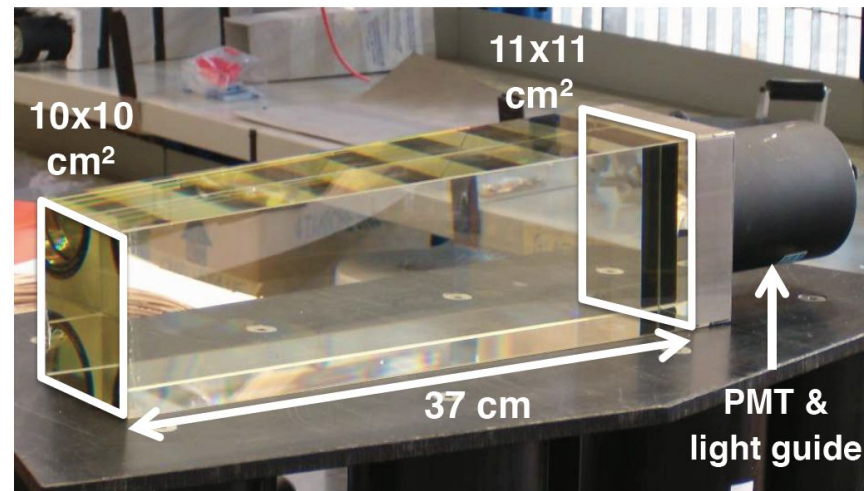
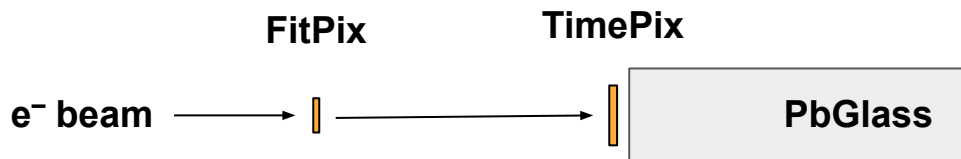


Figure: The Cherenkov lead glass calorimeter with its approximate dimensions

# Test beam for LeadGlass calibration



Two types of corrections needed:

- **Energy-loss correction**
  - due to beam spot movements and variable passive material before the lead-glass calorimeter
- **Radiation induced loss**
  - Run III radiation dose  $\sim 2.5$  krad  $\rightarrow$  transparency changes for O(krad)



# LeadGlass test beam results for Run III calibration

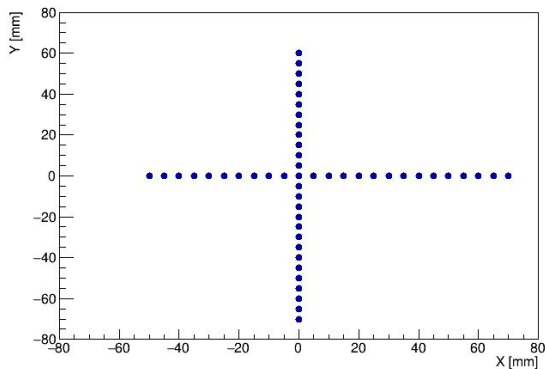


Figure 1: Coordinates of the measured positions of the calorimeter in X and Y.

For every point of the position scan, the distribution of the reconstructed charge is made and plotted.

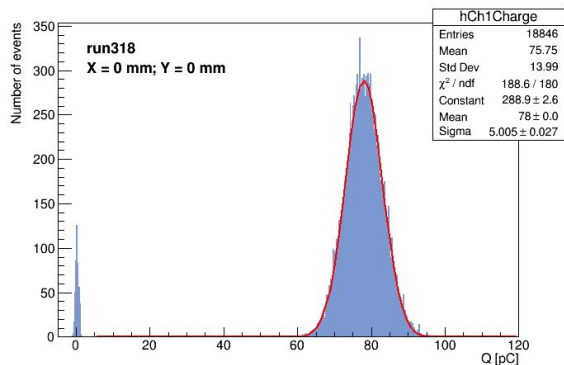


Figure 2: Reconstructed charge distribution for a given position of the calorimeter.

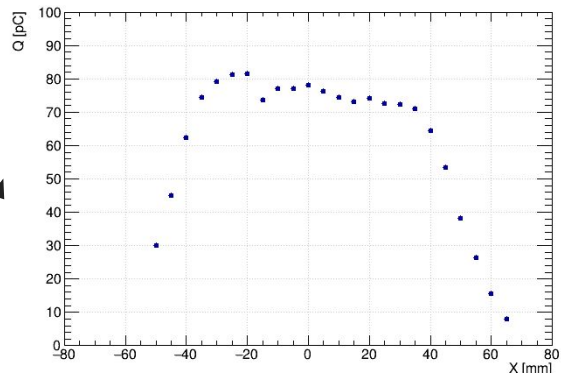


Figure 3: Reconstructed charge as function of beam position on the X axis..

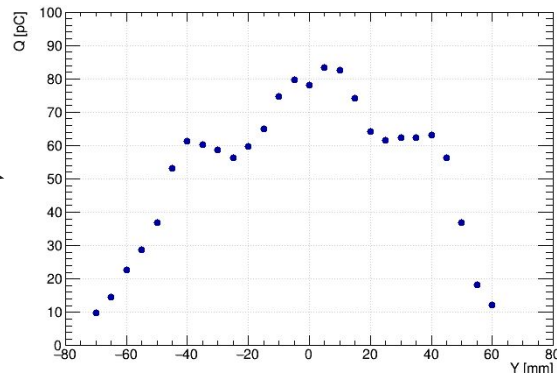


Figure 4: : Reconstructed charge as function of  $\delta$  beam position on the Y axis..

# LeadGlass energy loss in passive material

- TimePix cooling geometry (mostly Cu) was described in detail in the MC simulation
- Very good agreement between the data and the MC simulation  
→ validation of the calorimeter profile shape in Y



Figure 1: Picture of the TimePix detector with its cooling system.

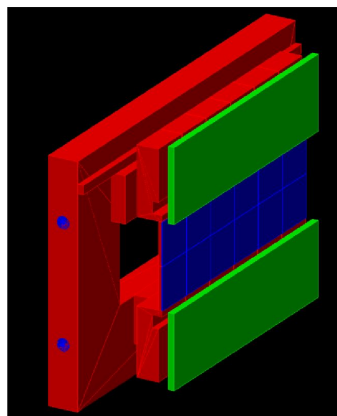
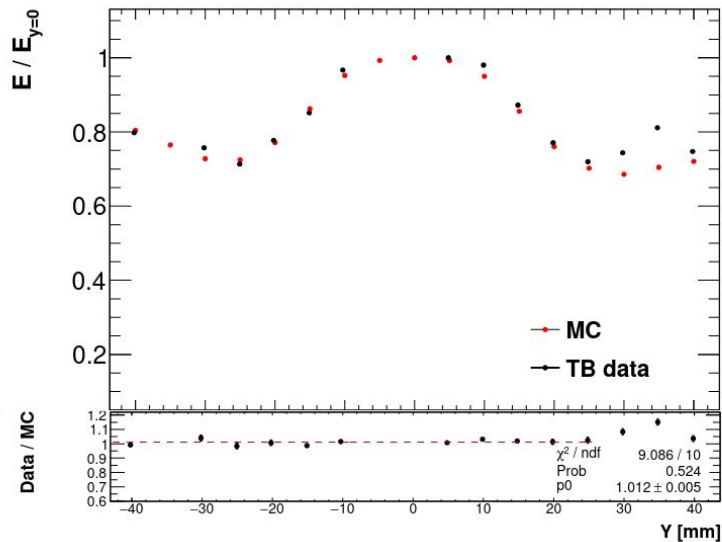


Figure 2: Monte Carlo simulation of the detector geometry.



[arXiv:2505.24797](https://arxiv.org/abs/2505.24797) [hep-ex]

# LeadGlass single particle response

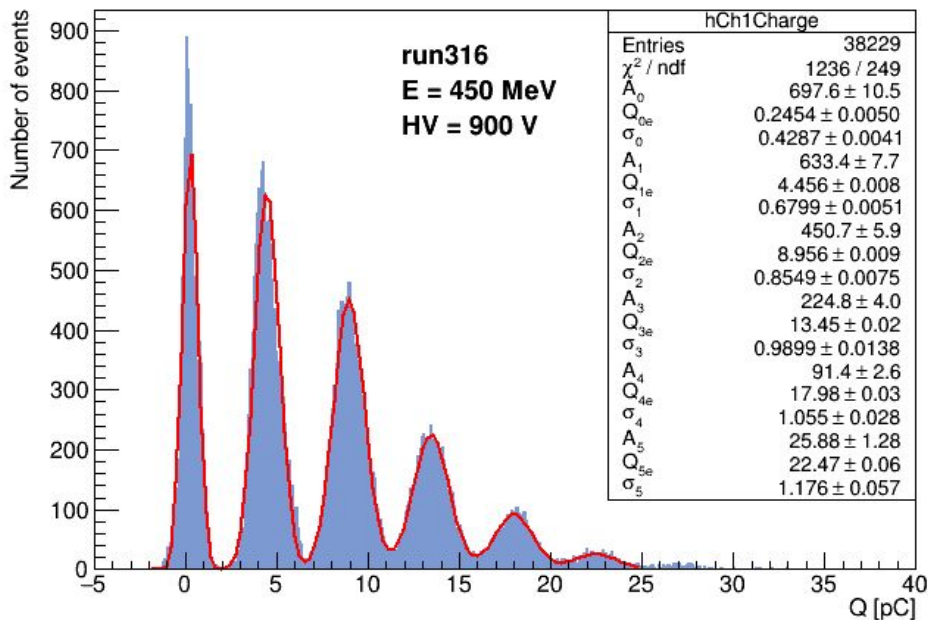


Figure 1: Charge distribution by low multiplicity with fitting function - sum of six gaussian functions.

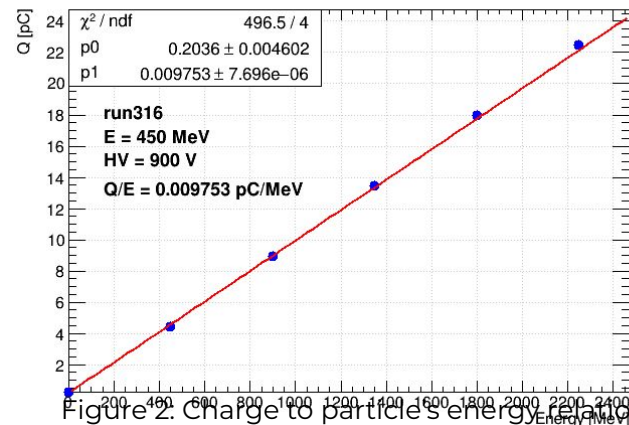


Figure 2: Charge to particle's energy.

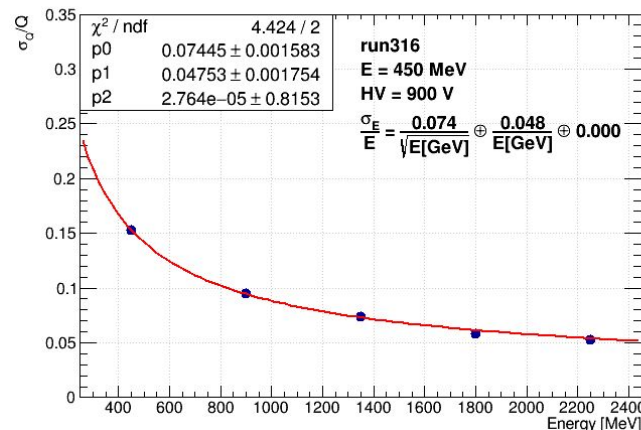


Figure 3: Relative resolution as function of the particle's energy.

# LeadGlass test beam results for Run III calibration

$$G = A.HV^B$$

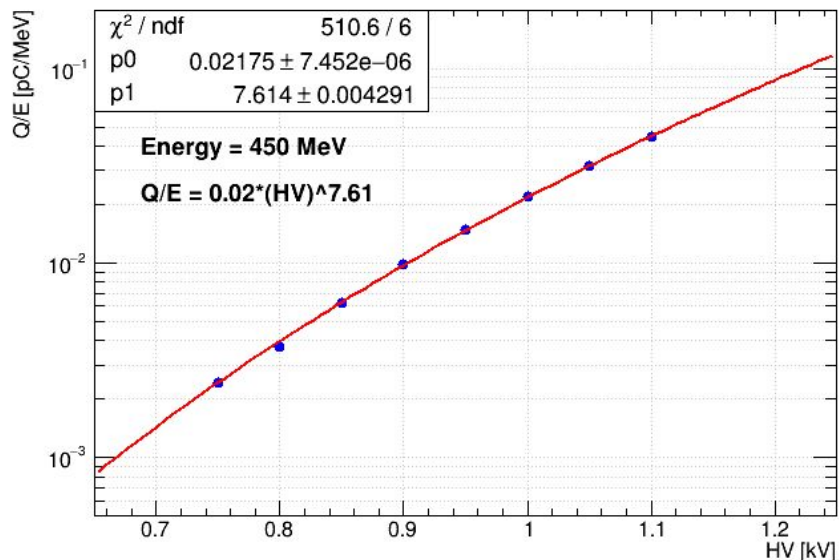


Figure 2: Relation of the detector response to the high voltage at  $E_{\text{beam}} = 450 \text{ MeV}$ .

$$Q/E (650V) = 0.8183 \pm 0.0045 \text{ fC/MeV}$$

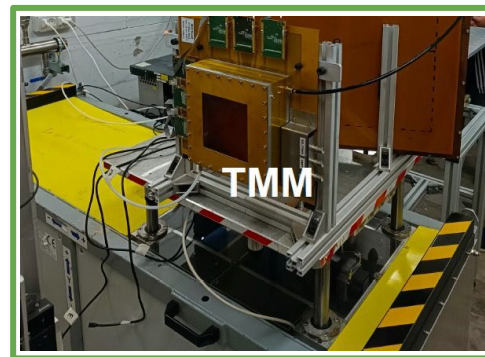
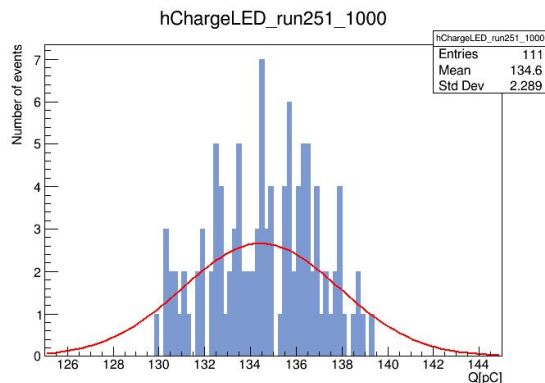
- Fitting parameter less than the expected value (given by Hamamatsu reference)
- Throughout Run III a total of  $7e11$  PoT (of  $\sim 300 \text{ MeV}$  each) has passed through the PbGl block corresponding to a TID of  $25 \text{ Gy}$  ( $2.5 \text{ krad}$ )
- The SF57 transmittance loss was never measured in literature, however for similar blocks (SF5-SF6) a significant loss is shown, especially near Cherenkov wavelengths

Quantity	PWO:R <sup>3+</sup>	SF5 (PbO:50%) [4]	SF6 (PbO:75%) [4]
Density ( $\text{g cm}^{-3}$ )	8.28	4.07	5.19
Radiation length $X_0$ (cm)	0.89	2.55	1.69
Index of refraction	2.2	1.67	1.81
Cutoff in $T$ (%) (nm)	320	340	360
Hygroscopicity	No	No	No
Melting point ( $^{\circ}\text{C}$ )	1123	442	455
Radiation-hardness (rad)	$10^{7-8}$	$10^{3-4}$	$10^{2-3}$
Hardness (Mohs)	3		
Cleavage	(101)	None	None
Available length* ( $X_0$ )	30	Large	Large
Moliere radius (cm)	2.19		

SF57 PbO concentration  $\sim 75\%$

# Run IV beam monitoring strategy

- **LED pulser** Tektronix AFG3101 to control the radiation induced loss
  - Independent trigger included in the DAQ system
  - A second LG block installed (out of the acceptance and only acquiring the LED trigger)
  - Online LG response renormalized to the not-fired-block
  - Reference for light yield response almost on the fly
  
- **TMM Micromegas** replace the TimePix beam monitor
  - Greater active area wrt TimePix and less passive material budget
  - Beam shape and spot monitor



# Conclusions

- The PADME experiment is in a special position because it has the ability to confirm or reject the hypothesis of the existence of X17, but precision of less than 1% in the beam characteristics is required.
- Data from 2024 Test Run obtained from the Cherenkov PbGlass calorimeter were analyzed and in order to determine the calibration coefficient  $Q/E$  required for the accurate determination of the number of particles-on-target.
- Two main effects have been recognised and determined - radiation induced loss and energy loss in passive material - total uncorrelated systematic uncertainty is 0.35%.
- New Run IV (currently ongoing) is employing another calibration technique to decrease the uncertainty in the beam intensity measurement - use LED pulser and a second PbGl block as a reference for light yield response - reduce the systematic uncertainty down to below 0.3%.