Атестационен семинар

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04.06.2026

Изследване параметрите на позитронния сноп в Run III и Run IV на експеримента PADME

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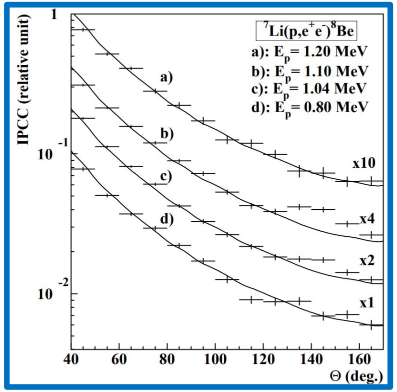
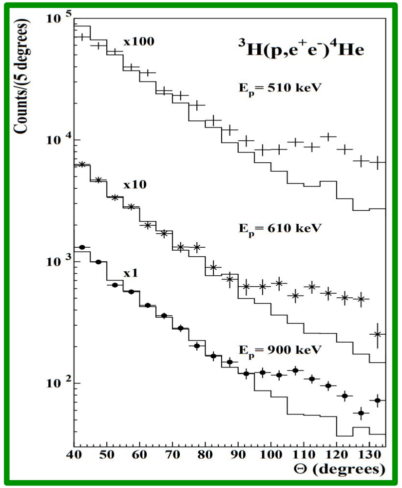
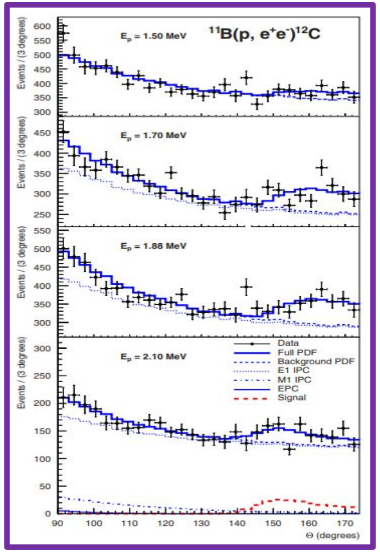
Phys.Rev.Lett. 116 (2016) 4, 042501



Phys.Rev.C, 104(4):044003



Phys. Rev. C 106, L061601



Motivation:
X17 anomaly

- Study the nuclear decay of the ^{8}**Be*** by internal pair creation (IPC) at ATOMKI in Debrecen, Hungary
- Anomalous excess in angular correlation of $e^{+}e^{-}$ pairs produced via IPC in ^{8}**Be**, ^{4}**He** and ^{12}**C** nuclei is observed
- The anomaly seems to be compatible with the production and successive decay of a **new ~17 MeV mass particle**
- If X17 is a vector boson particle, extend the Standard Model Lagrangian with a new term (in analogy to QED):

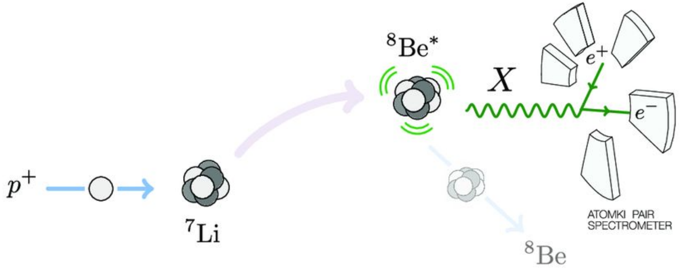
$$\mathcal{L}_X = g_{v\psi} X_\mu(x)\bar{\psi}(x)\gamma^\mu\psi(x)$$

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

\+ mass term:

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

→ **Test of the X17 hypothesis by many ongoing and new experiments**



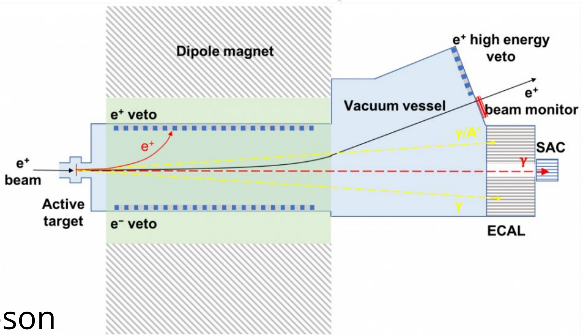
https://doi.org/10.1103/physrevd.95.035017

The PADME experiment

Positron Annihilation into Dark Matter Experiment

@ National Laboratory of Frascati (LNF-INFN)

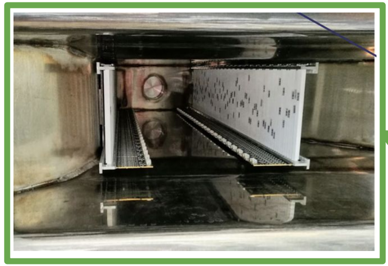
$$e^+ + e^- \rightarrow \gamma A'$$



- Fixed target experiment originally planned for searching the dark photon via associate production in positron-on-target annihilation - **Run I** and **Run II**
- **Run III** and **Run IV** - study the resonant production of the hypothetical X17 boson

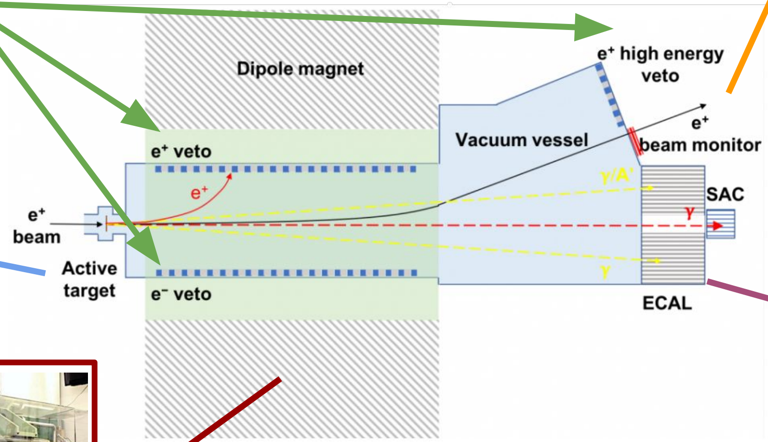
$$e^+ + e^- \rightarrow X17 \rightarrow e^+ + e^-$$

The PADME detectors

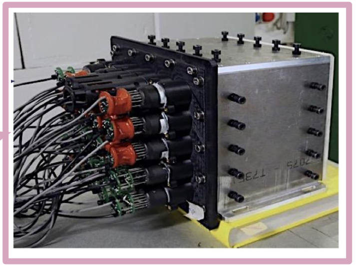


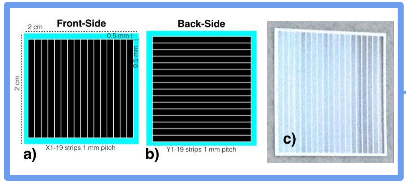
Scintillating
e^+/e^- VETO

TimePix
Beam monitor

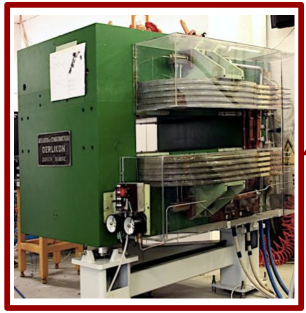


Small Angle PbF_2 calorimeter

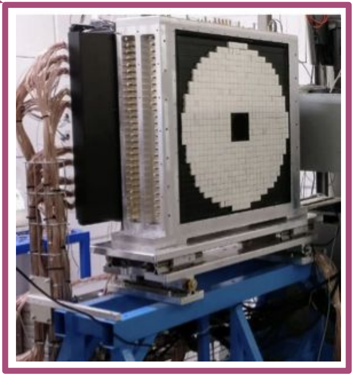




Active
diamond
target



Dipole Magnet

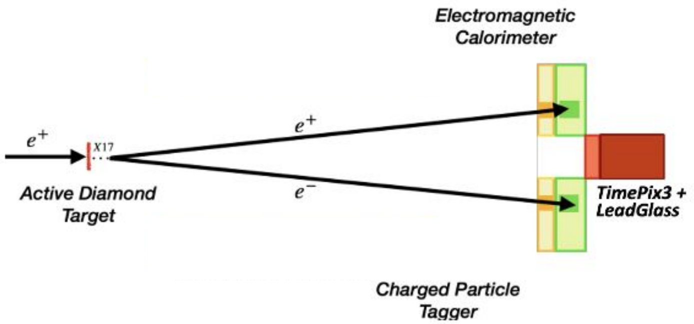


BGO ECAL

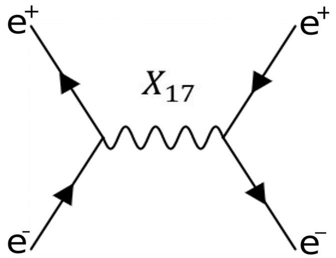
Resonant search on fixed thin target experiment

- $\sigma_{res} \propto \frac{g_{Ve}^2}{2m_e} \pi Z \delta(E_{res} - E_{beam})$ goes with $Z \to$ dominant process with respect to alternative signal production processes

- $\sqrt{s}$ has to be as close as possible to the expected mass
  $\to$ fine energy scan procedure with positron beam
  $\to$ expected enhancement over the SM background



At PADME X17 to be produced via resonant annihilation in diamond target: $e^+ + e^- \to X17 \to e^+ + e^-$



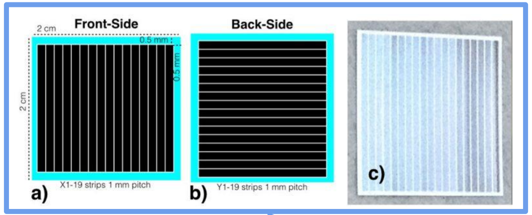
PADME Run III: Beam energy scan in the range E_{beam} = [262, 296] MeV
$\to$ corresponding to center-of-mass energy range for the e^+e^- pair of $\sqrt{s}$ = [16.4, 17.4] MeV

$\to$ **measure two-body final state yield N_2**

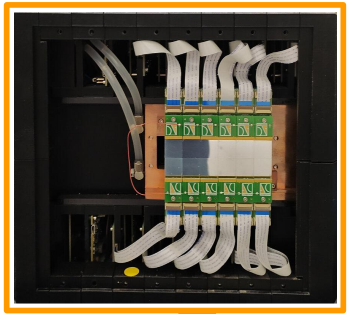
$$N_2(s) = N_{POT}(s) \times [\, B(s) + S(s; M_X, g)\, e_S(s)\,] \quad \text{vs.} \quad N_2(s) = N_{POT}(s) \times B(s)$$

The PADME beam monitoring detectors

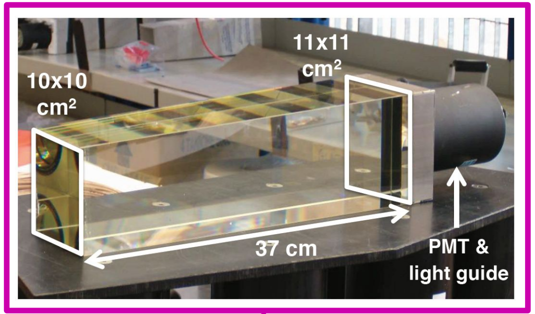
Active diamond target
measuring beam spot position and beam multiplicity

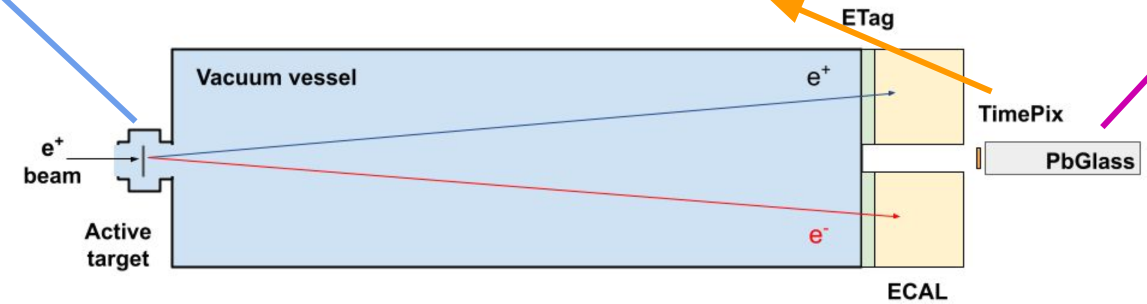


TimePix
measuring beam spot position and size



Cherenkov lead-glass calorimeter
measuring beam multiplicity





Experimental setup for PADME Run III

Precise determination of N_{POT}

Cherenkov electromagnetic calorimeter

- Lead-glass block Schott SF57
  (75% PbO) with density of ρ = 5.5 g/cm^3
- Photomultiplier Hamamatsu R2238
- Multichannel ADC V1742

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

$$E^{tot}_{PbGl} = \frac{Q^{tot}_{PbGl}}{Q/E}$$

total deposited energy in the leadglass

calibration coefficient or response of the detector in pC/MeV

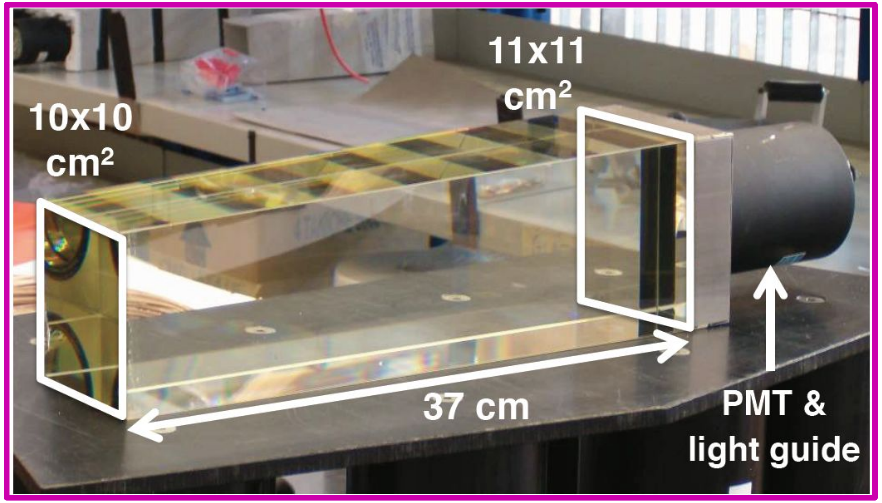
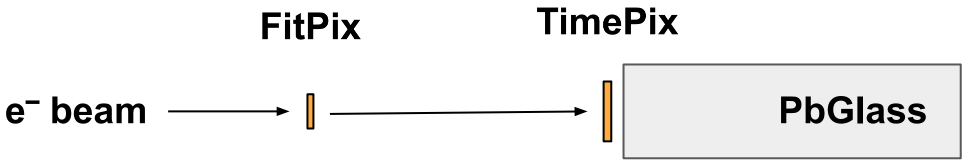
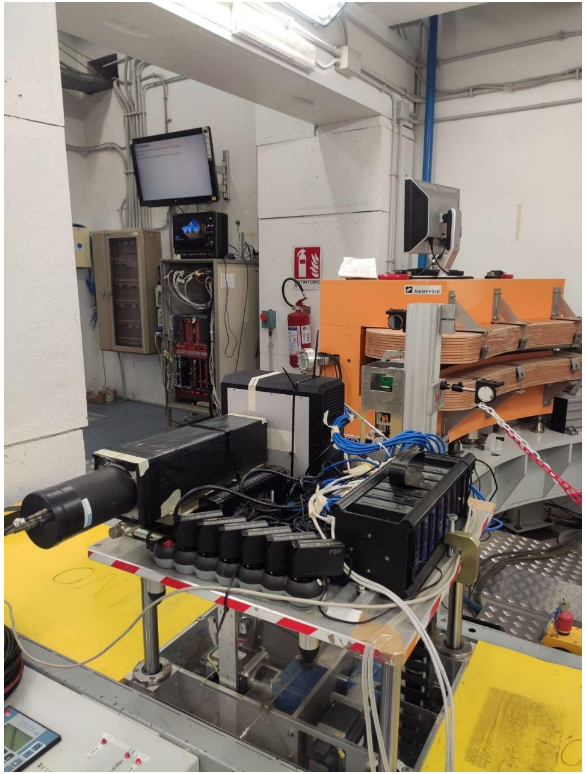


Figure: The Cherenkov lead-glass calorimeter with its approximate dimensions

Test beam for LeadGlass calibration



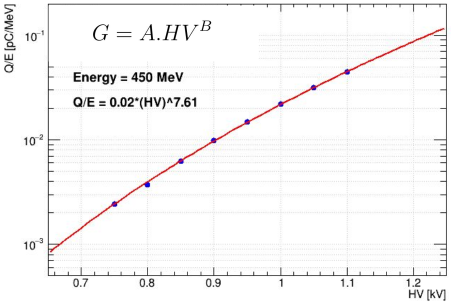


Two types of corrections needed:

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

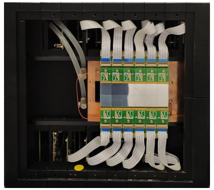
Precise determination of the N_{POT}

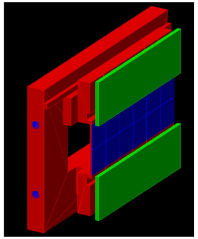
→ two types of corrections applied on the beam monitor

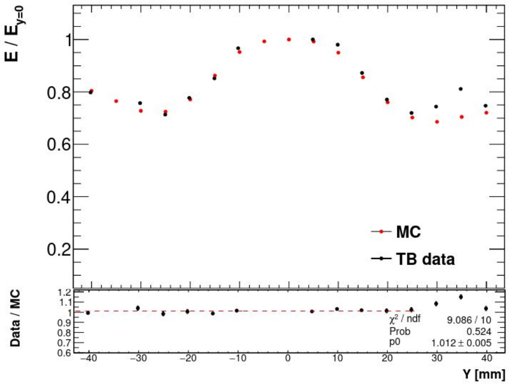


Energy loss in the PbGI calorimeter

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







arXiv:2505.24797 [hep-ex]

Radiation induced loss

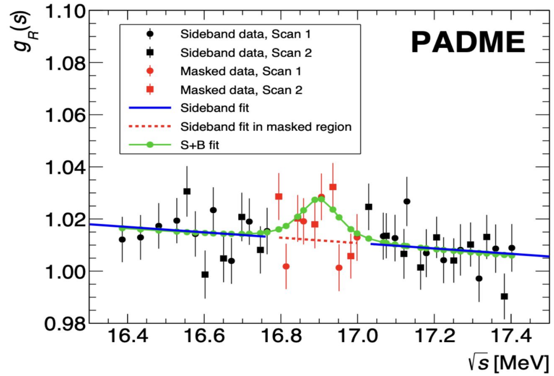
- Fitting parameter less than the expected value (given by Hamamatsu reference)
- Throughout Run III a total of 7e11 PoT (of ~300 MeV each) has passed through the PbGI block corresponding to a TID of 25 Gy (2.5 krad)
- The SF57 transmittance loss was never measured in literature, however for similar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

Quantity	PWO:R^{3+}	SF5 (PbO:50%) [4]	SF6 (PbO:75%) [4]
Density ($g\,cm^{-3}$)	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 (°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[a] (X_0)	30	Large	Large
Moliere radius (cm)	2.19		

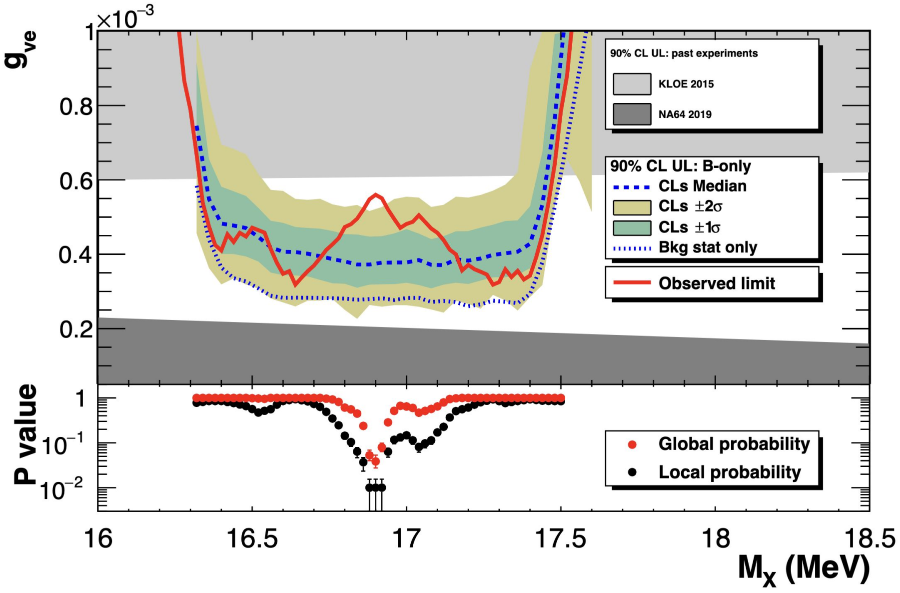
SF57 PbO concentration ~ 75%

PADME Run III result

- At $\mathbf{M_X = 16.90(2)}$ **MeV**, $\mathbf{g_{ve} = 5.6 \times 10^{-4}}$, the global probability dip reaches $\mathbf{3.9_{-1.1}^{+1.5}}$ **%**, corresponding to **(1.77 ± 0.15) σ** one-sided (look-elsewhere calculated exactly from the toy pseudo-events)
  - A second excess is present at ~17.1 MeV, but the absolute probability there is ~ 40%
- If a 3σ interval is assumed for observation following the estimate M_X = 16.85(4) MeV of PRD 108, 015009 (2023), the p-value dip deepens to $2.2_{-0.8}^{+1.2}$ % corresponding to (2.0 ± 0.2) σ one-sided



Some excess is observed a ~2.5 σ local coverage



JHEP 11 (2025) 007

Need for more data → Run IV in 2025

Run IV improvements

→ **for increased sensibility to confirm/disprove Run III result**

- **Active diamond target** position moved downstream ~ 30 cm
  → increase acceptance
- Passive material removed and magnet fully degaussed → B_{PADME} < 1 G
- Beam kept stable in the central position during the full data-taking period
  → NO LATERAL LEAKAGE on the beam catcher

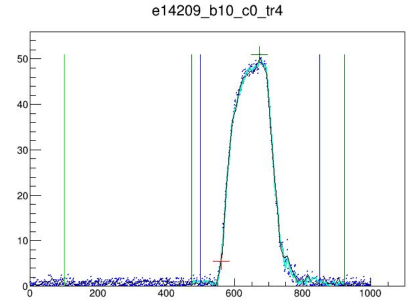
New detectors:

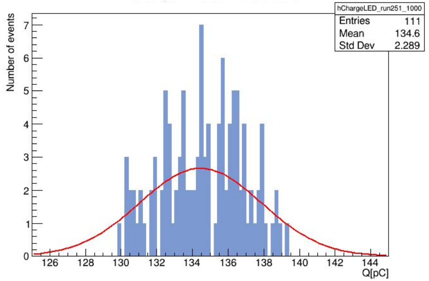
- **TMM Micromegas** replace the TimePix3 beam monitor
  - 10cm x 10cm MM gas chamber, with x-y strips readout, with ~250 μm pitch for beam shape and spot monitor
  - Greater active area wrt TimePix and less passive material
- **PadMMe Micromegas** chamber in front of ECAL
  - e/γ discrimination
  - spatial resolution ~350 μm
  - beam spot monitor already implemented in Run IV online monitoring

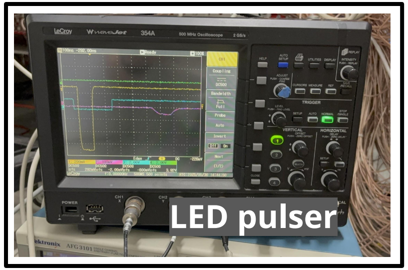
Run IV improvements

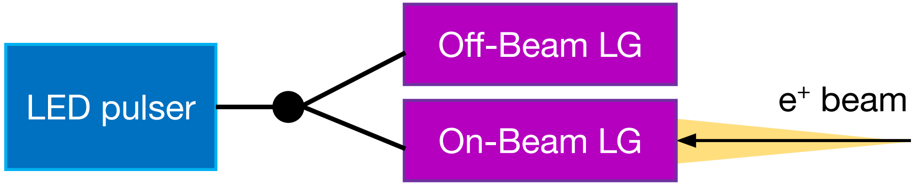
LED pulse generator + 2nd lead-glass detector

- **LED pulser** Tektronix AFG3101 to control the radiation induced loss of the lead-glass calorimeter
- Independent trigger included in the DAQ system
- A **2nd lead-glass block** installed (out of the acceptance and only acquiring the LED signals)
- Online LG response renormalized to the non-fired-block
  → monitor and calibration
  → reference for light yield response







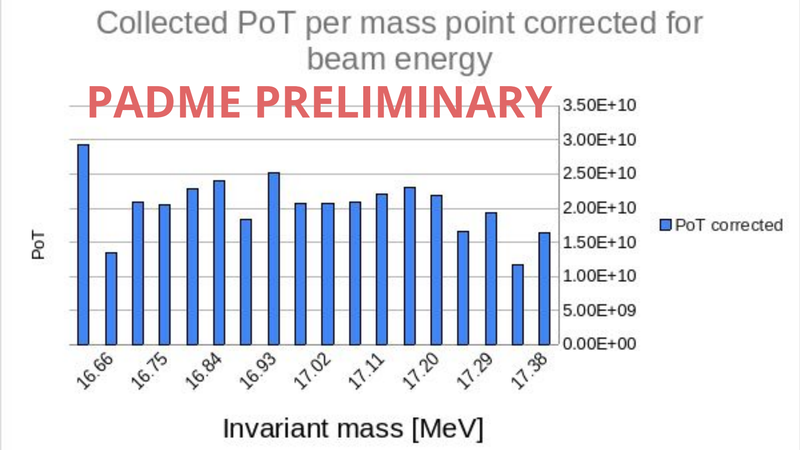


LED independent Trigger $\mathcal{O}$(2-4 Hz)

Run IV data-taking

→ Energy scan technique as in Run III

- 36 energy scan points collected (~2×10^{10} PoT each) equally separated by 0.75 MeV in the resonance region
- 3 out-of-resonance energy points @ 260,300, 330 MeV
- 15 no-target (for multiple scattering bkg evaluation)



Source	Uncertainty [%]	
	Run III	**Run IV target**
N_2	0.6	**0.3**
B	0.35	**0.3**
N_{PoT}	0.55	**0.3**
TOTAL	**0.88**	**0.5**

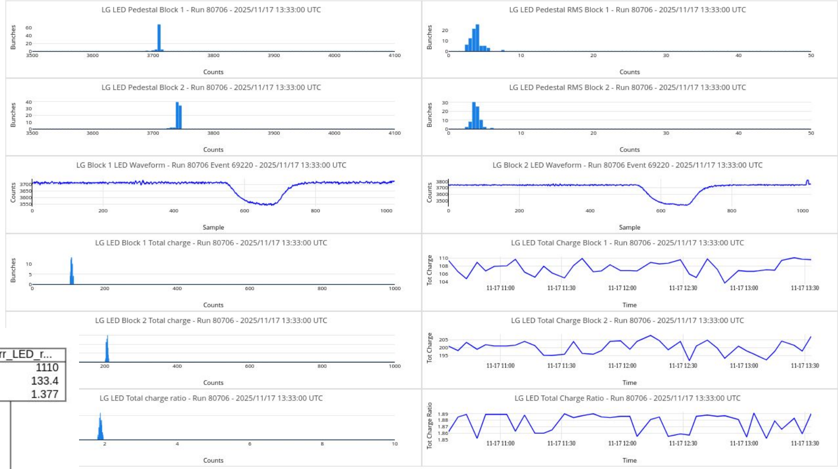
→ Overall uncertainty to be decreased from 0.88% to ~0.5%

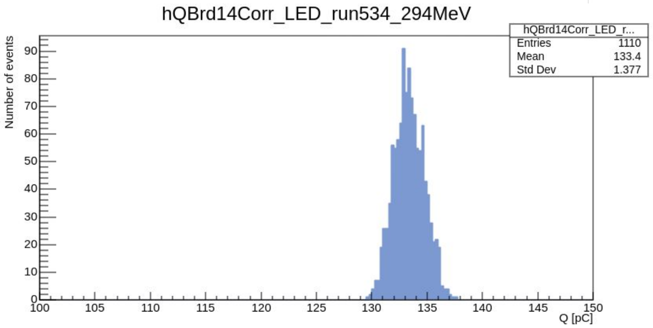
Run IV beam monitoring with LG

- LG radiation-induced loss monitor - system continuously operated during Scan 2

offline analysis - work in progress:

- study different pedestal evaluation methods
- correct for electronics effects
- calibrate the response of the two detectors
- compare run-by-run LG response normalised to the off-beam-LG block to evaluate the aging effect





Заключение

- Експериментът PADME има възможност да потвърди или отхвърли хипотезата за съществуването на нова хипотетична частица X17, но за това е необходима прецизно измерване с неопределеност от по-малко от 1% на характеристиките на снопа.
- Бяха анализирани данните от тестов набор на данни през 2024 г., получени от черенковския калориметър от оловно стъкло, с цел определяне на калибрационния коефициент Q/E, необходим за точното изчисляване на броя на частиците, попаднали в мишената.
- Два основни ефекта бяха установени и характеризирани - загуба на енергия в пасивния материал пред калориметъра и влошаване на отклика на детектора поради голяма получена радиационна доза → **общата некорелирана систематична неопределеност е 0,35%.**
- В рамките на новия Run IV се използва нова техника за калибриране с цел намаляване на неопределеността при измерването на интензитета на снопа – чрез използване на LED импулсен генератор и втори детектор от оловно стъкло като референтен детектор за отклика на светлинния добив – като по този начин **систематичната неопределеност се очаква да се подобри до под 0,3%.**

Публикувани статии и доклади на конференции
през първата година от докторантурата

Публикувани статии:

- ★ ***Calibration of the PADME beam monitoring calorimeter****,*
  K. Kostova for the PADME Collaboration, PoS COSMICWISPers2025 (2026) 064 (Q4)
- ★ ***Search for a new 17 MeV resonance via e+e− annihilation with the PADME experiment****,*
  PADME Collaboration, JHEP 11 (2025) 007 (Q1)

Доклади на конференции:

- ★ *„Calibration of the PADME beam monitoring calorimeter“,*
  3rd Training School COST Action COSMIC WISPers (CA21106), Анси, Франция, 16 - 19.09.2025 г.
- ★ *„Detector studies and services development with BTF @ INFN-LNF Test Beam“,*
  EURO-LABS (Fourth Annual MEeting (FAME)) в JSI, Любляна, Словения, 29.09 – 01.10.2025 г.
- ★ *„Searching for Dark Photons with PADME“,*
  Национален форум за съвременни космически изследвания 2025 (НАФСКИ-VI), София, България, 27.10.2025 г.
- ★ *„Изследване параметрите на снопа в Run III и Run IV на експеримента PADME“,*
  Катедра Атомна физика на 80 години, София, България, 18.04.2026 г.
- ★ *„Searching for new light particles with PADME“,*
  SUMMIT THIRD ANNUAL CONFERENCE, SOFIA UNIVERSITY ST. KLIMENT OHRIDSKI, Sofia, Bulgaria, 22.04.2026 г.