Gator: A low-background Germanium facility for high sensitivity gamma-ray spectroscopy

Low Radioactivity Techniques, 2026

Aravind Remesan Sreekala on behalf of the Gator team

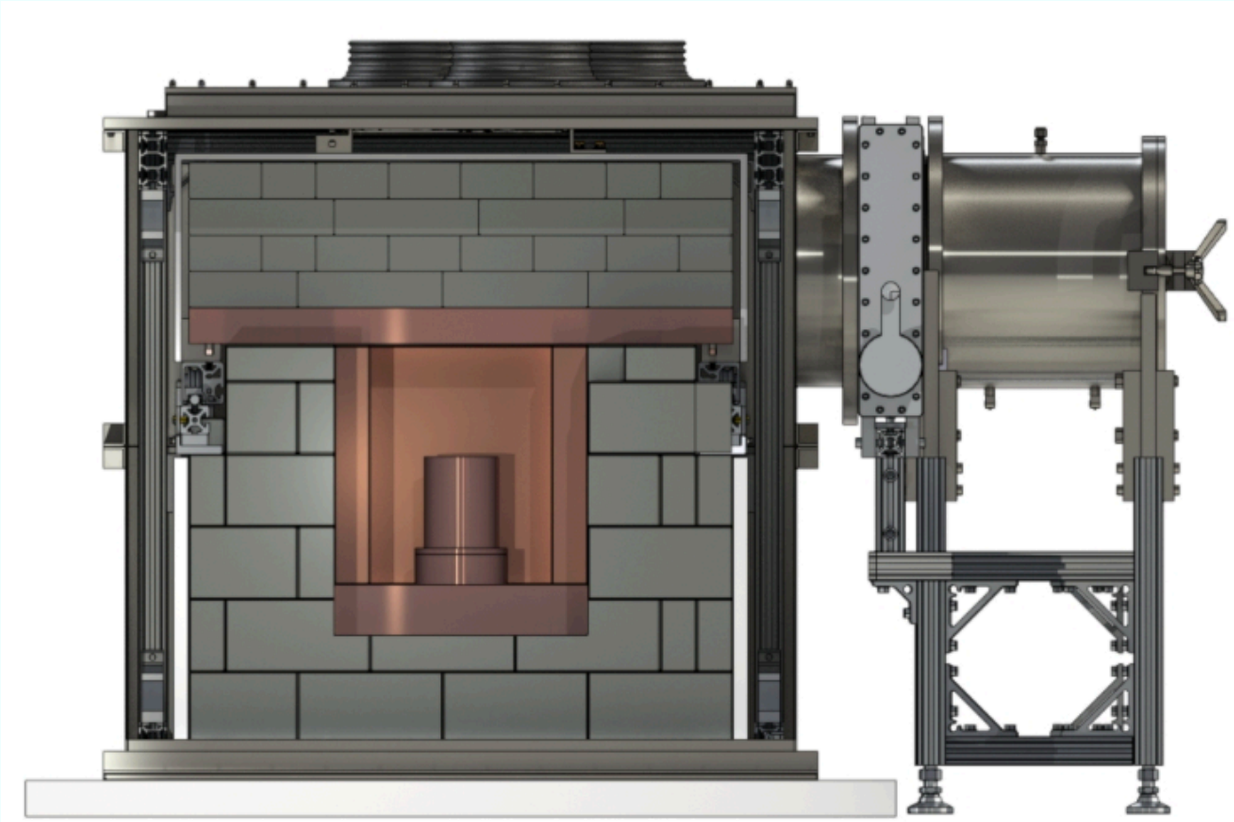
24 September, 2026

Gator Facility

- Great need for **high sensitive screening** facilities for **material screening**

- **Gator** is a low-background HPGe detector facility for **high-sensitivity gamma spectroscopy**

- Located at **LNGS**, 3600 m.w.eq shielding (1400 m overburden of rock)



- Used for screening a number of samples from rare-event search experiments; some recent samples:

  - **Cu rods** & **^{228}Th** calibration sources for **LEGEND-200** (S. Calgaro's talk) ; candidate **steel** for **LEGEND-1000** cryostat

  - **TPC PMTs** for **XENON1T/nT;** candidate **PMTs** for **XLZD**

  - **Bedretto granite** for the background characterisation campaign (F. Jörg's talk)

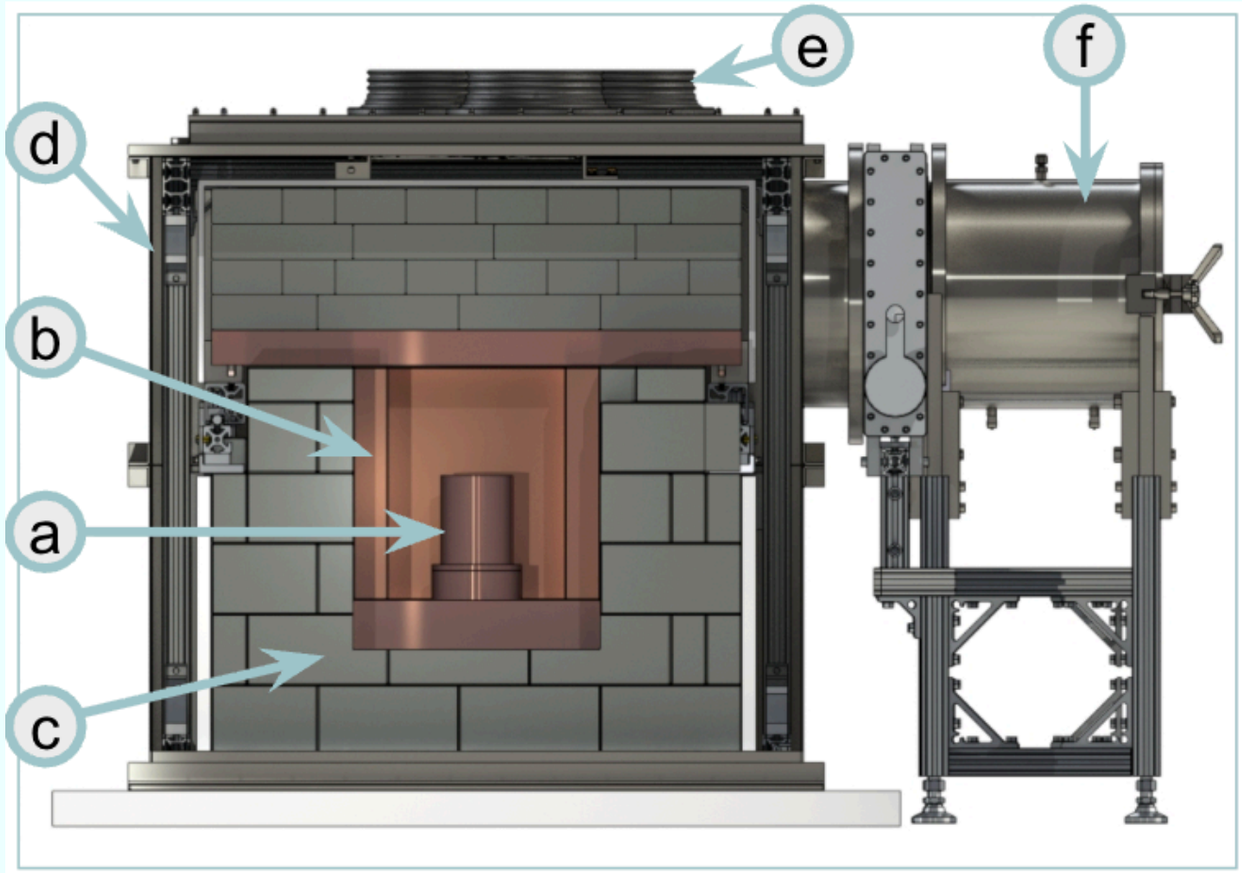
 Gabriela R. Araujo et al 2022 JINST 17 P08010

Gator Facility

(a) Contains a **p-type coaxial HPGe** detector, with **2.2 kg** sensitive mass and a relative efficiency of **100.5%**[1]

(b) O-free high conductivity Cu (5cm)

(c) **Pb shielding**: 5 cm of 3 Bq/kg and 15 cm of 75 Bq/kg



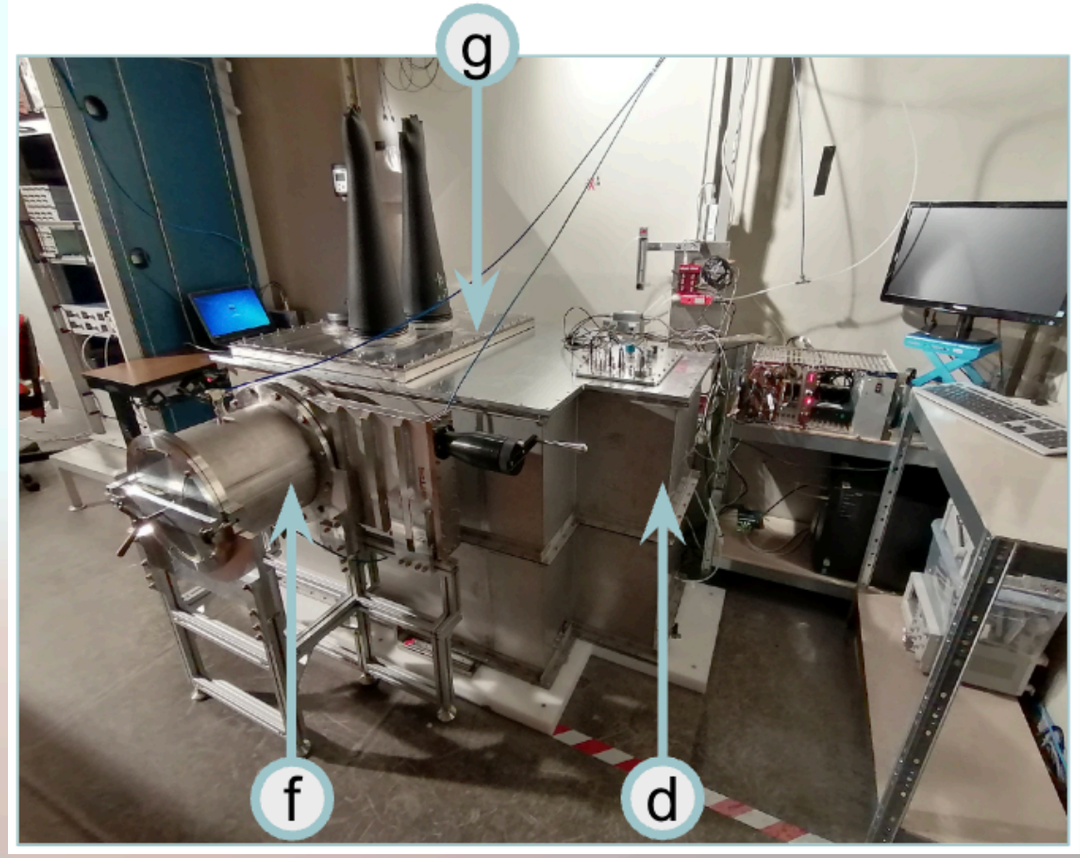
(d) 5 cm borated polyethylene shielding

(e) New stainless steel enclosure

(f) Load-lock chamber for pre-purging the sample

(g) Acrylic plate at the top glove ports

Cavity is flushed with GN2 continuously to purge ^{222}Rn



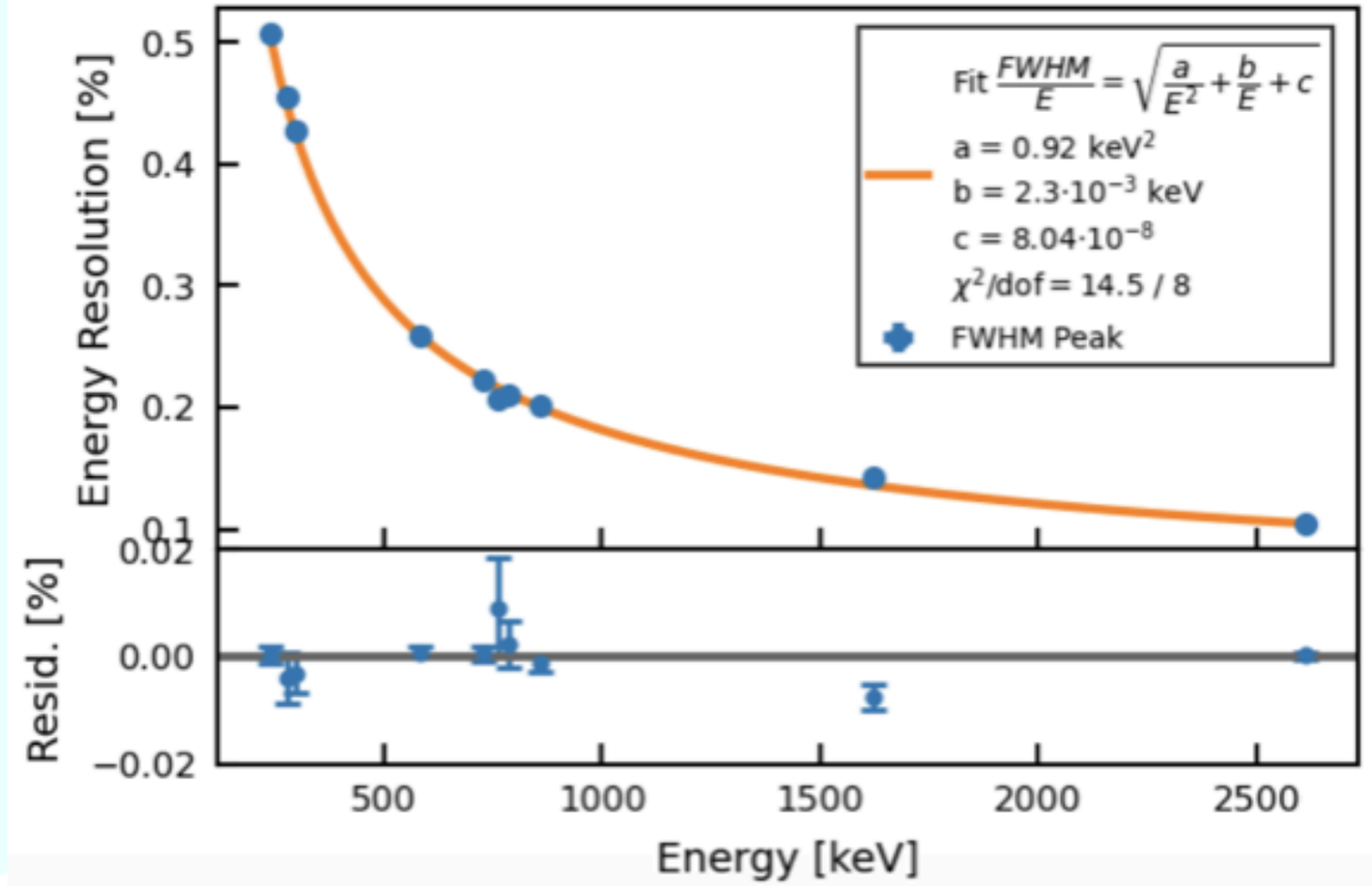
1 Detection efficiency given for the 1.33 MeV γ-ray from ^{60}Co and defined relative to a 3-inch × 3-inch NaI(Tl) crystal placed at a distance of 25 cm from the source

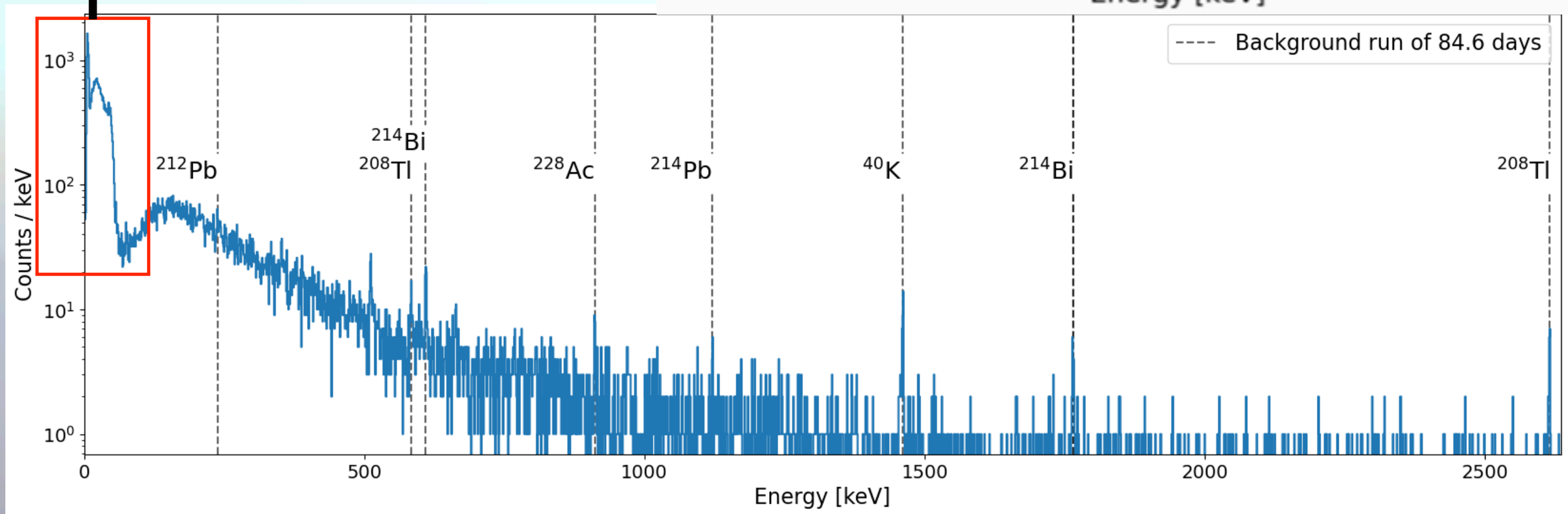
Background and energy resolution

- **Background** of **95.2 ± 1.0 counts / (keV kg day)** in the energy range **100-2700 keV**, using data taken in April-June 2024

- Energy resolution **FWHM** of **2.59 ± 0.24 keV** at **2614.5 keV**

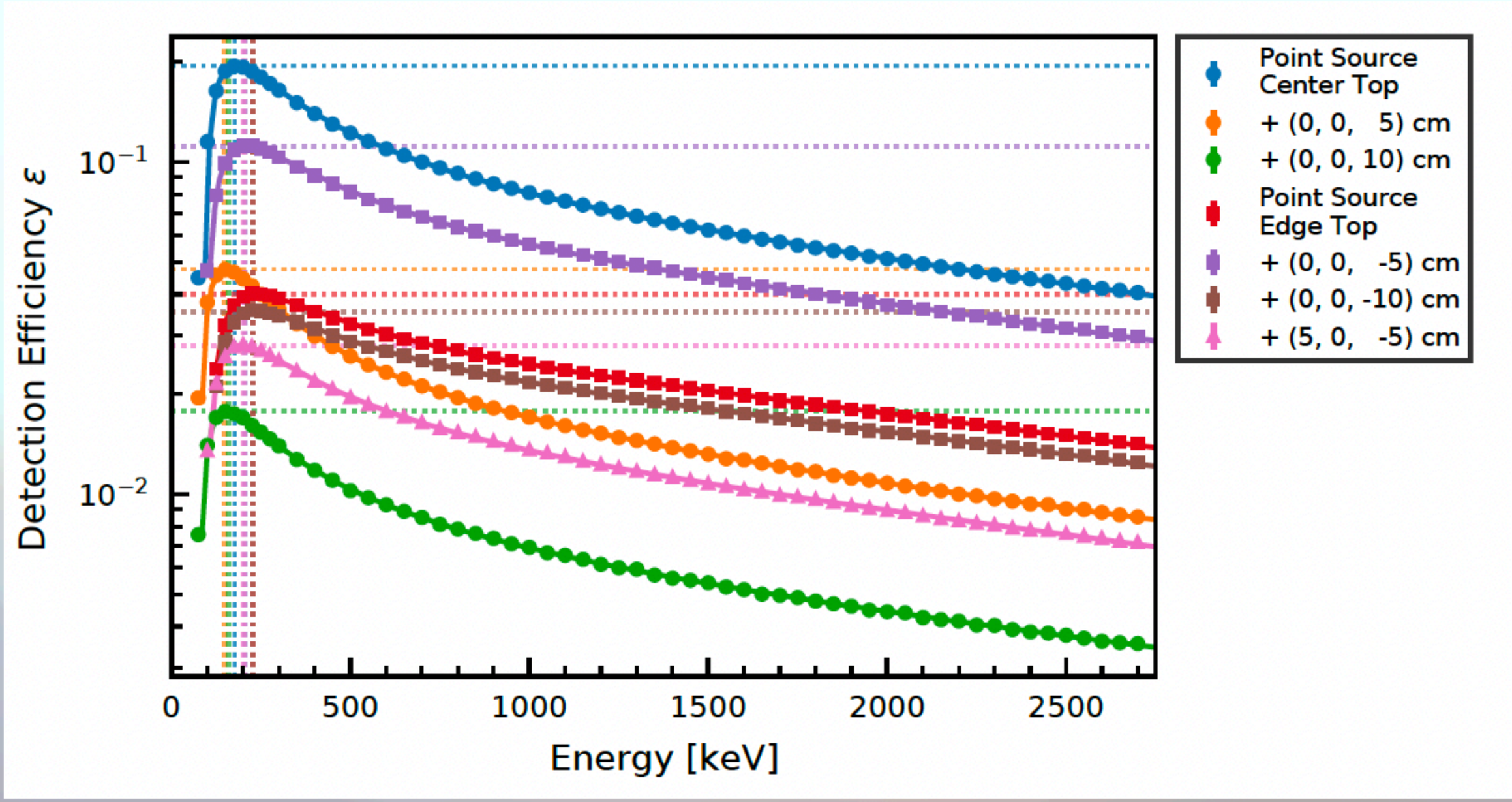
Low energy noise!





Gator Performance: Detection efficiency

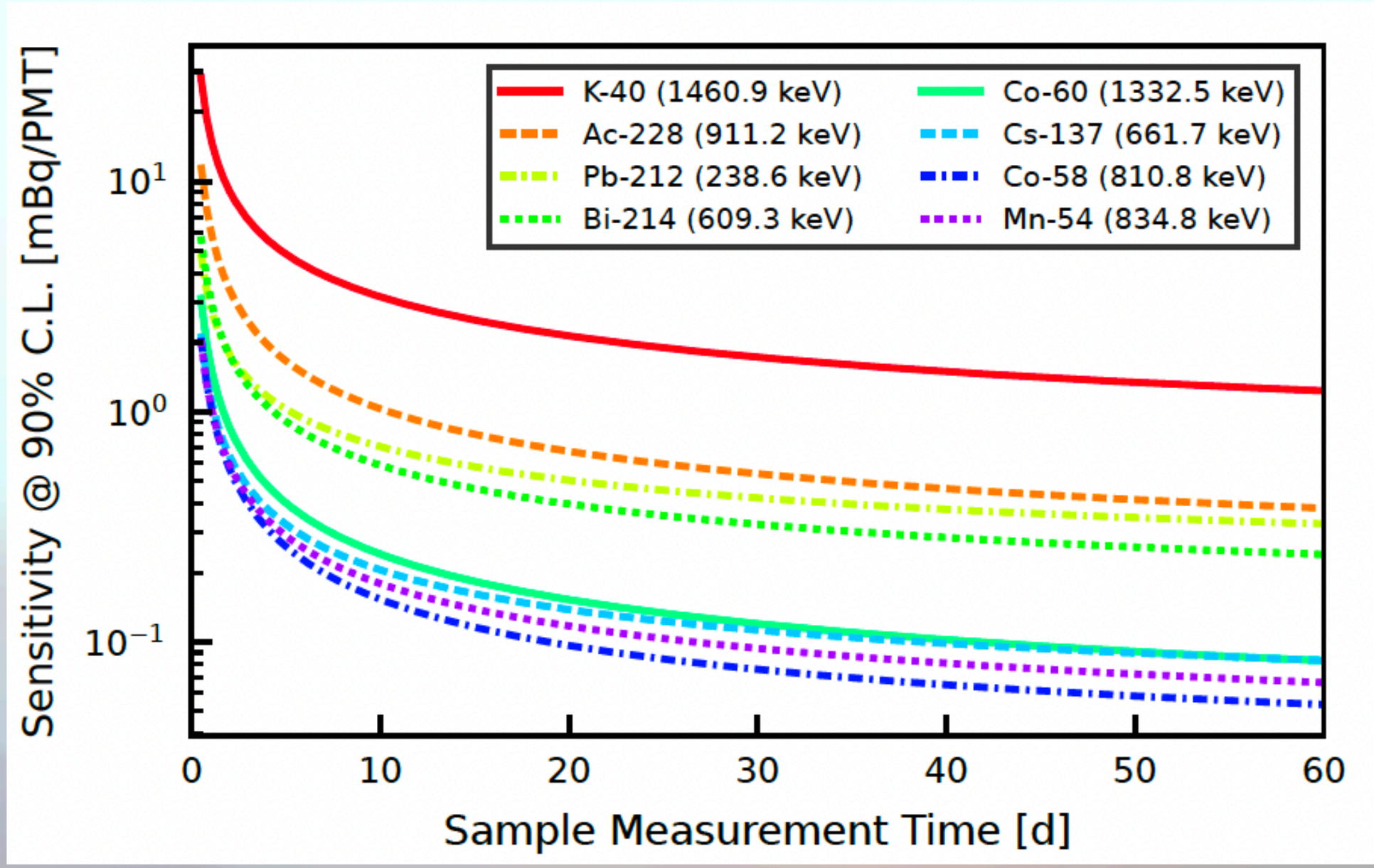
- **Detection efficiency** is needed to convert measured **count rates** to **specific activities** via **GEANT4 Monte Carlo simulations**



Gator Performance: Sensitivity

- For the 2” **Hamamatsu R12699 PMTs, the sensitivity was estimated at 90% CL**

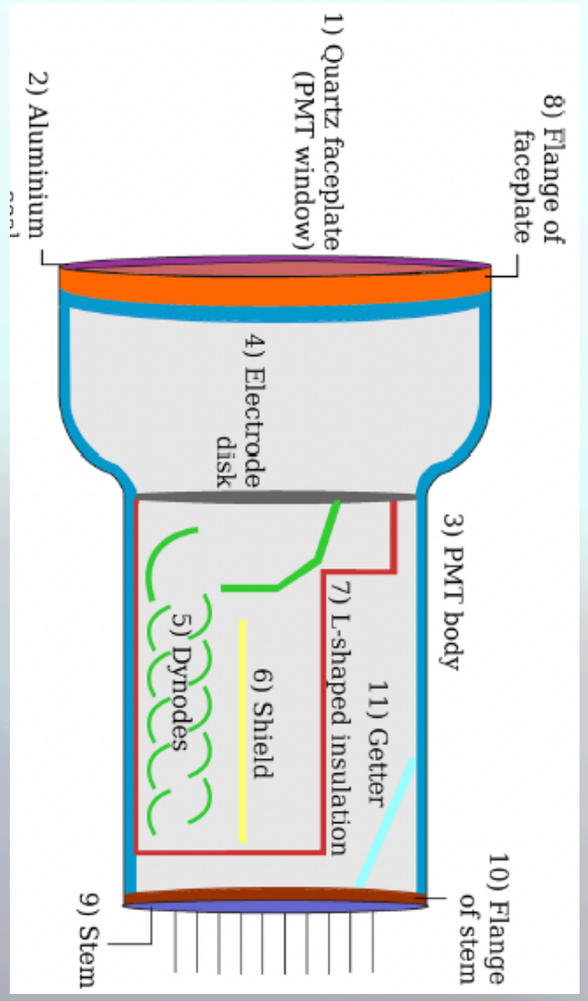
- For **30 days** of measurement, **Gator** has **< 1 mBq** sensitivity **per PMT** for the ^{238}U and ^{232}Th chains

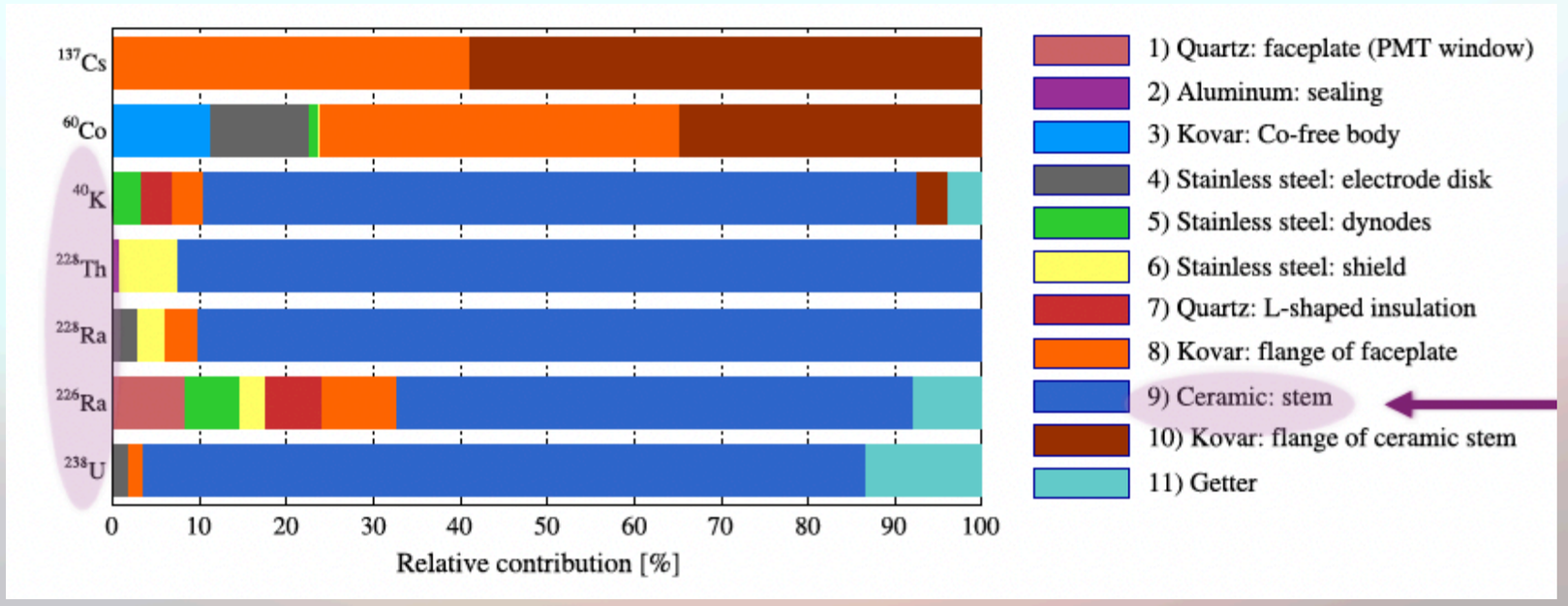


Measurement of low activity stem PMTs

*work of M. Noia

- For the **0νββ** search of **^{136}Xe in XLZD** ($Q_{\beta\beta}$ = 2458 keV), the main background arises from the **^{214}Bi** line at **2448 keV**[1]
- This contribution is **dominated** by the **TPC PMTs** and the cryostat, with the decay lines from the **^{238}U and ^{228}Th chains** arising from the **PMT stems**
- A new **3" R17317 PMTs** with **low activity stems** were produced by **Hamamatsu** as potential candidate PMTs for XLZD



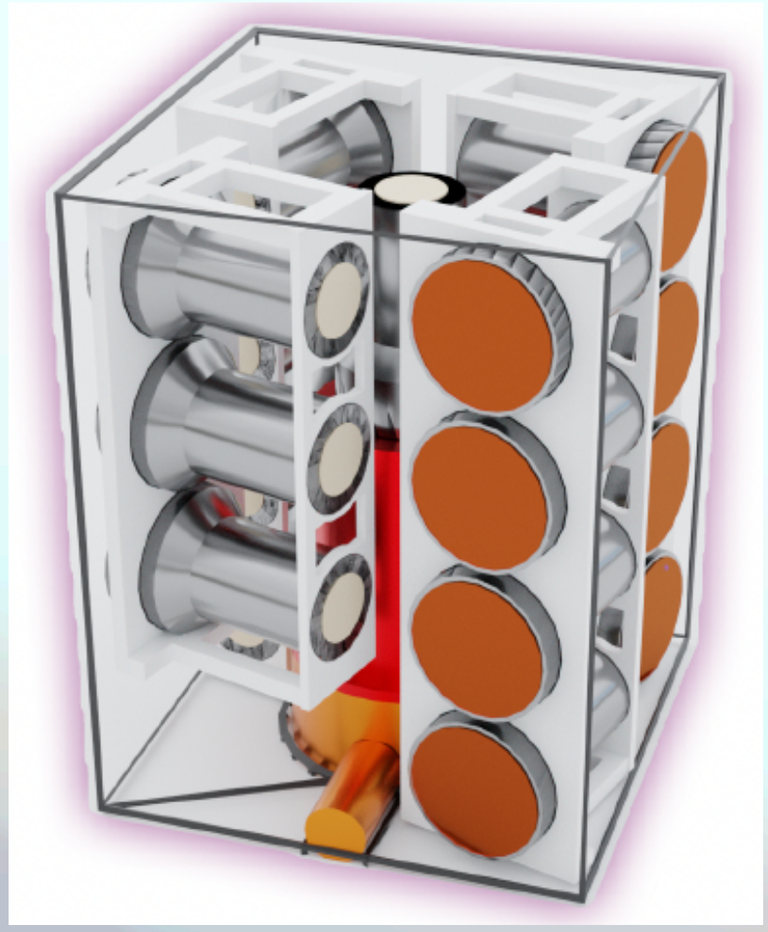


1. J Aalbers et al 2025 J. Phys. G: Nucl. Part. Phys. 52 045102
2. E. Aprile et al Eur. Phys. J. C 75.11 (2015)

Measurement of low activity stem PMTs

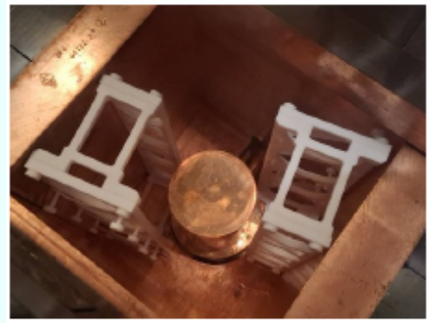
*work of M. Noia

- **16 3” PMTs** were measured together with **PTFE PMT holders** for a period of **102.2 days** in Gator
- **Background run** performed using just the holders for **57.3 days**





16 PMTs in Gator





Background run

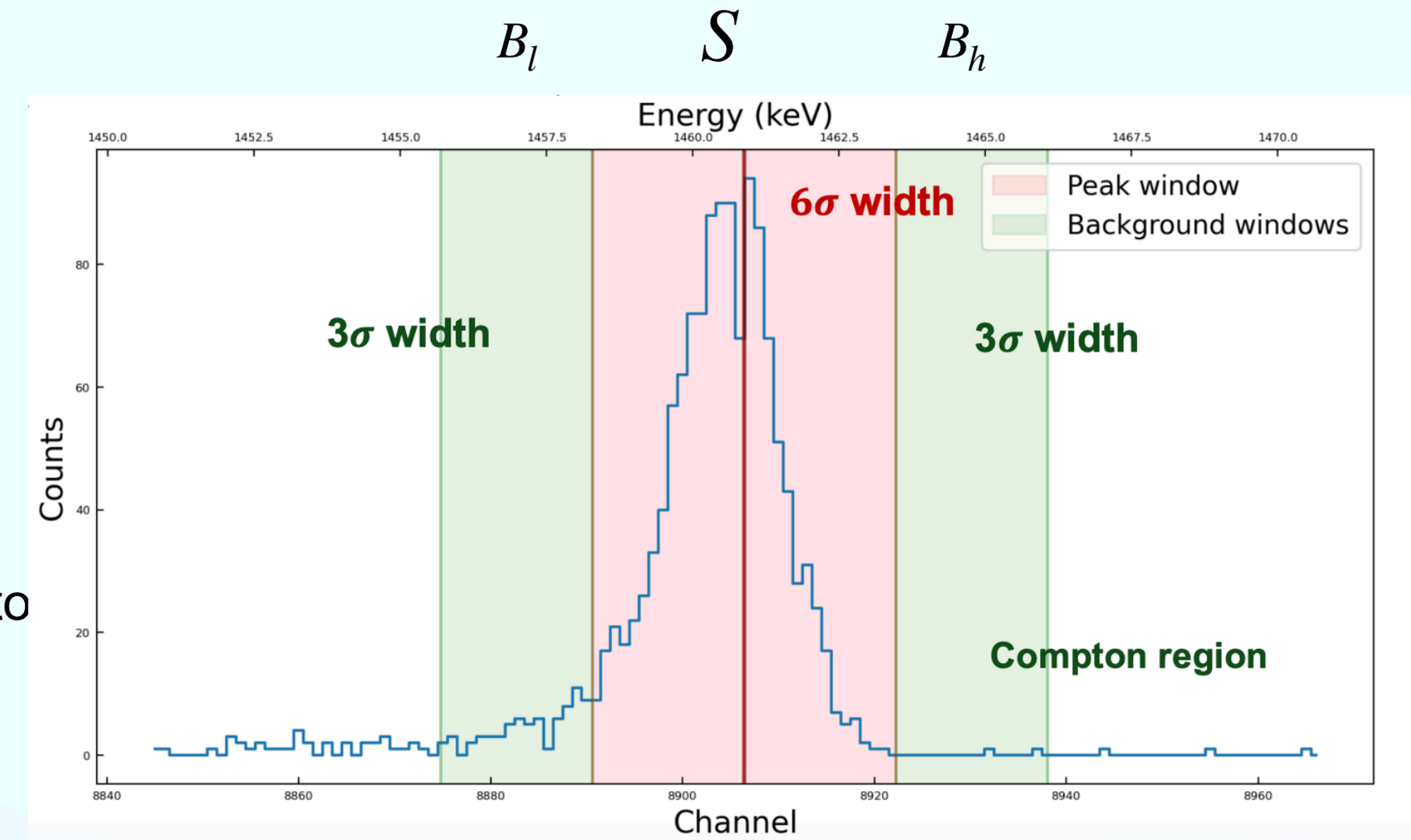
Two separate runs with 3 holders and 2 holders respectively; background rate was unaffected

Analysis framework: Currie method

- The measured sample is simulated in GEANT4 for efficiency estimation

- The **net signal** is obtained from the counts in the **ROI**, subtracting the **continuum background** and the **background contribution** to the **peak**

- If the **net counts** for a line **exceed** the **detection limit,** then an **activity** is reported; otherwise, an upper limit is quoted



$$S_{net} = S - (B_l + B_h) - b \cdot (t_s/t_b)$$

S: signal counts

B$_l$/B$_h$: background contribution in the low/high energy

b: background counts

t$_s$/t$_b$: sample/background measurement time

$$\text{Activity (mBq/kg)} = \frac{1000 \cdot S_{net}}{(\epsilon \cdot \text{BR} \cdot m \cdot t)}$$

C. Hurtgen Appl. Rad. Isot. (2000)

Analysis framework: Likelihood approach

*work of M. Noia

- For **each line**, **sample** and **background** provide information on **the activity** as well as **the background** contributions

	ROI	**Sidebands**
Sample data	$s \cdot \varepsilon \cdot BR + \beta + c + b$	$c + b$
Background	$\beta + b$	B

- Then the **Poisson likelihood P(n|λ)** is contracted for **each contribution for each line**

s: contribution of the sample to the peak
β: contribution of the background to the peak
c: Compton background
b: background continuum

- **Different lines of the same isotope** can be **combined** based on **ε·BR** to **estimate** a **common activity** from the log likelihood

$$log\mathscr{L} = \sum_{k} \sum_{i=1}^{4} log\left(P(n_{ik} \mid \lambda_{ik})\right)$$

i: number of regions (4)
k: number of lines per isotope

Comparison of activities

*work of M. Noia

- A **comparison** of the **activity** estimates for selected radionuclides in the measurement of low activity stem **3" R17317 Hamamatsu PMT** samples was done with the **PMTs** used in **XENONnT** and **LZ**

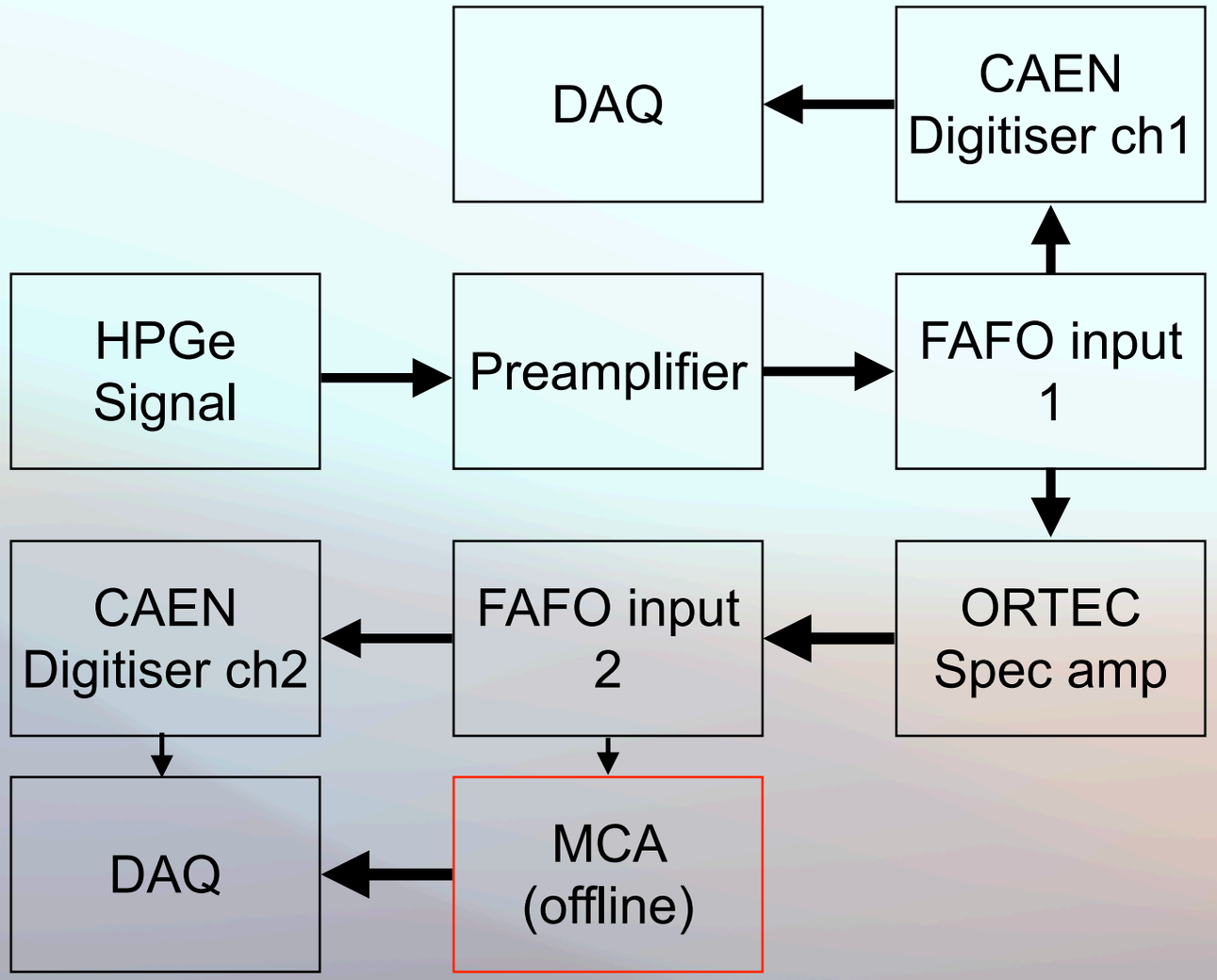
- For **^{228}Ra, ^{226}Ra, ^{228}Th and ^{235}U**, the activity of the **new PMTs** were found to be **lower**

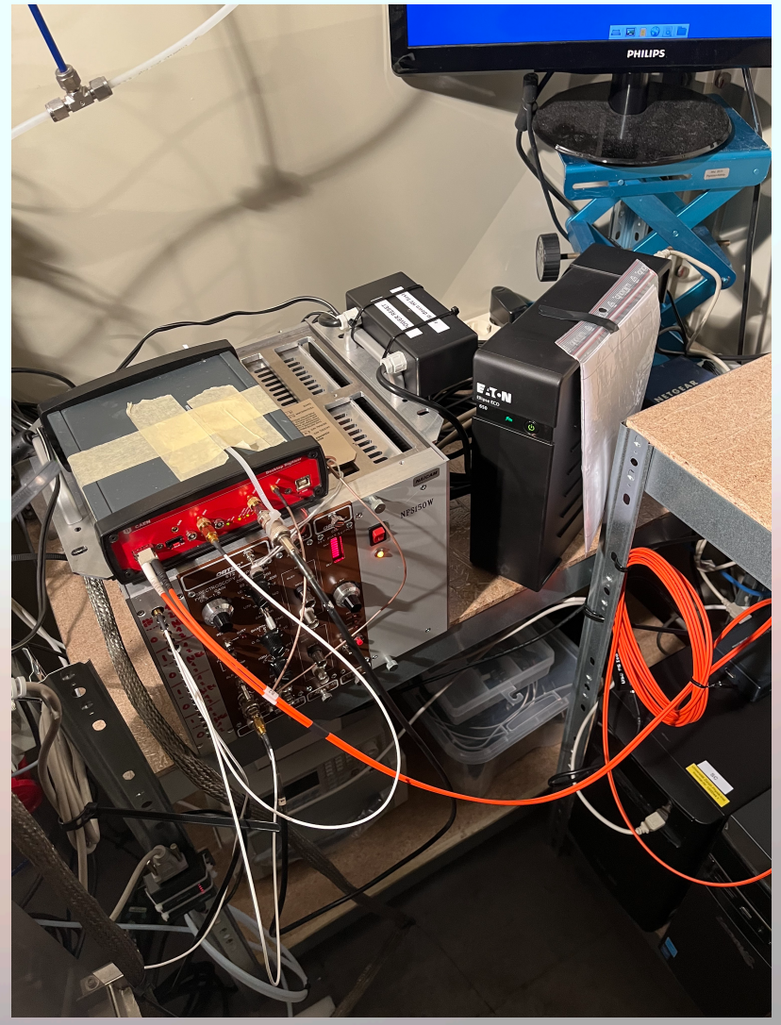
	Currie method	Likelihood method		
Isotope	**R17317 (mBq/PMT)**	**R17317 (mBq/PMT)**	**XENONnT PMTs[1] (mBq/PMT)**	**LZ PMTs[2] (mBq/PMT)**
^{238}U	< 2	< 1.8	9 ± 2	5.0 ± 2.1
^{226}Ra	< 0.21	0.21 ± 0.02	0.47 ± 0.02	0.9 ± 0.2
^{228}Ra	< 0.20	0.12 ± 0.05	0.47 ± 0.07	1.4 ± 0.8
^{228}Th	< 0.37	0.23 ± 0.03	0.46 ± 0.02	0.8 ± 0.2
^{235}U	0.21 ± 0.03	0.18 ± 0.03	0.4 ± 0.1	0.8 ± 0.6
^{40}K	12 ± 1.3	12.0 ± 1.3	14.2 ± 0.5	12.2 ± 1.1
^{60}Co	0.29 ± 0.13	0.30 ± 0.03	1.05 ± 0.03	1.9 ± 0.2
^{137}Cs	0.12 ± 0.03	0.13 ± 0.01	< 0.14	0.51 ± 0.03

1. Eur.Phys.J.C 82 (2022) 7, 599
2. Eur.Phys.J.C 80 (2020) 11, 1044

Gator upgrades

- **Why?** Old hardware (10+ years), low energy noise (< 100 keV)
- **Spectroscopy amplifier** was replaced with a new **ORTEC ASPEC 927**
- **CAEN DT5724 digitiser** was **added**; **existing cables** replaced with **low noise cables**
- **Low noise Fan-In-Fan-Out** was also added (made by the LNGS electronics workshop)

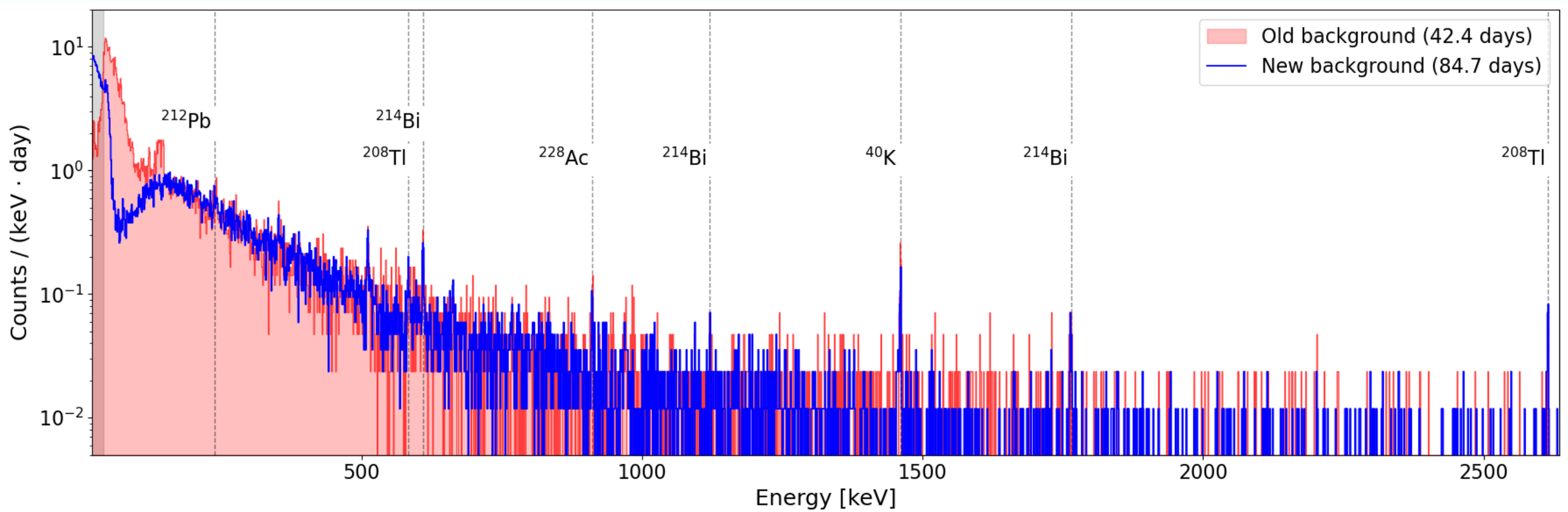




Background

- The **new background** taken after the upgrade (Aug-Sep 2026) **shows considerable reduction in the low energy noise**

- **Background rate is 84.7 ± 0.7 counts / (keV kg day)**; an **11% reduction** in the **100-2700 keV range**

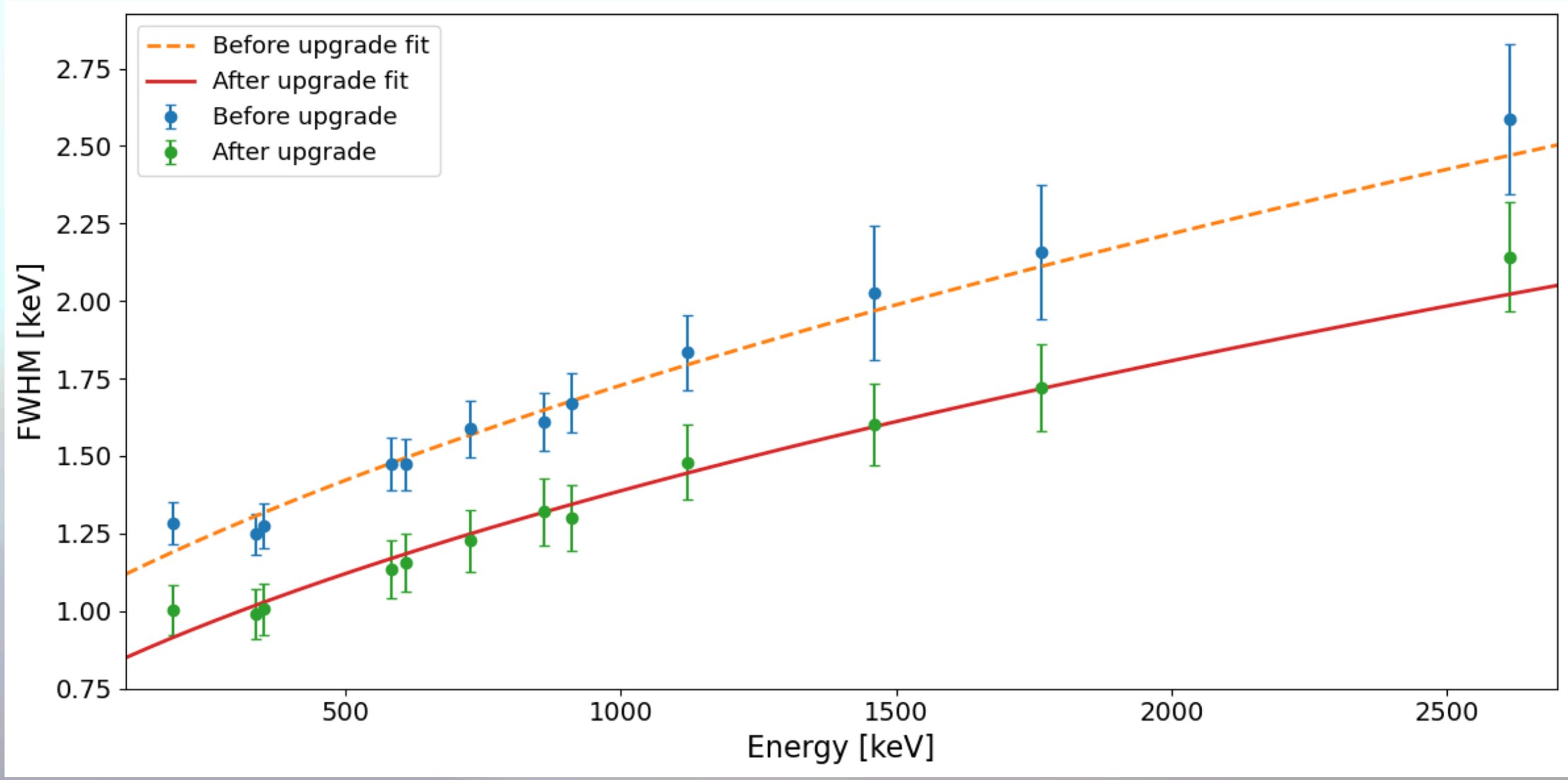


Energy resolution

- **Calibrations** performed with granite from **Bedretto** underground site; **low background** allows the use of such **low activity samples**



- An **improvement** of **17%** after the upgrades, **at** the **2614.5 keV line of ^{208}Tl**; due to **improvements** in the **hardware** and the **digital energy reconstruction**

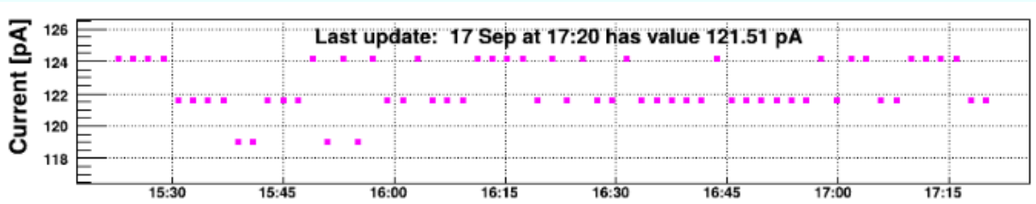


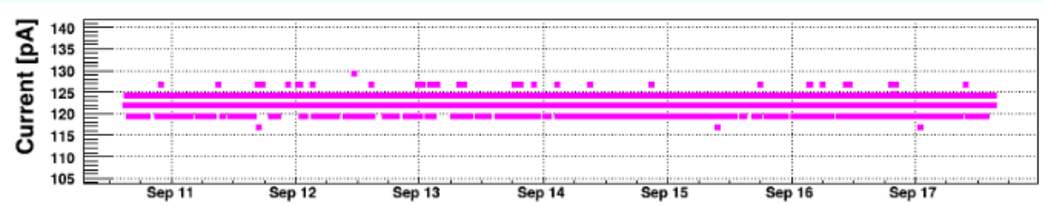
Summary

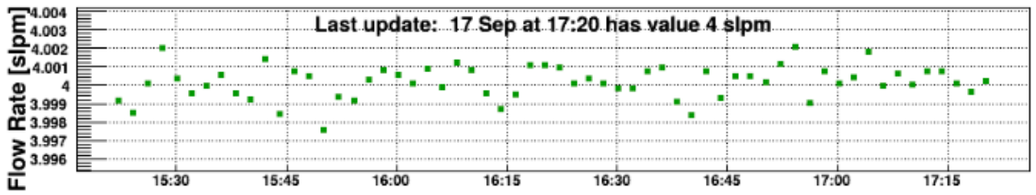
- **Gator** is a **low background HPGe** detector for **high sensitivity gamma spectroscopy**
- A new **Poisson likelihood analysis method** was **implemented** for the **analysis** of the candidate new **3” low activity stem Hamamatsu R17317 PMTs**
- The **U, Th and Ra activities** of the **PMT** were found to be **lower** than the **PMTs** used in **XENONnT** and **LZ**
- After a **recent hardware upgrade**, the **background level** was found to be **11% lower** in the **100-2700 keV** range; the **energy resolution improved by 17%** at the **^{208}Tl FEP**
- **Gator** will be used for **future material radioassay** of **samples** from **LEGEND-1000, XLZD** and other rare-event-search experiments

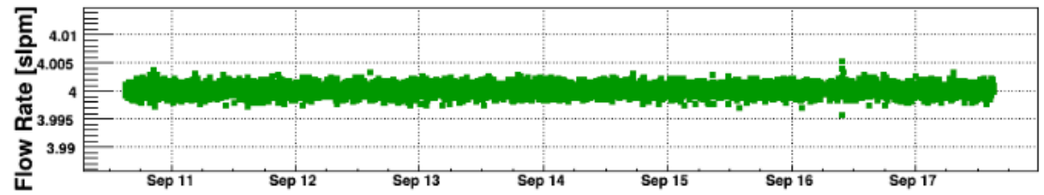
Gator slow control

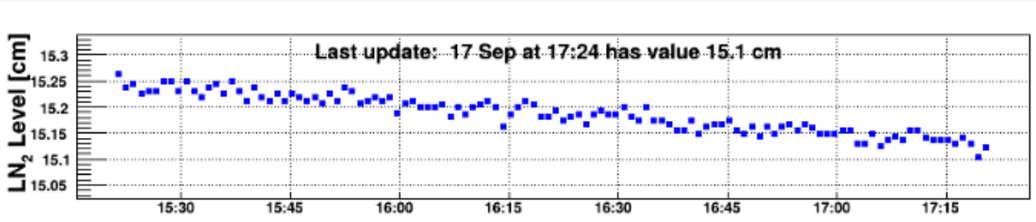
- The slow control keeps track of the important parameters that are necessary for the stable operation of the detector

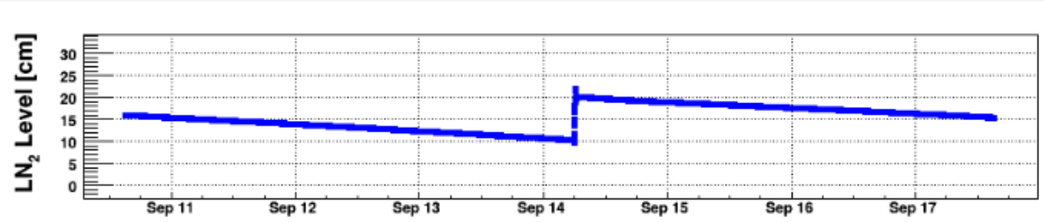


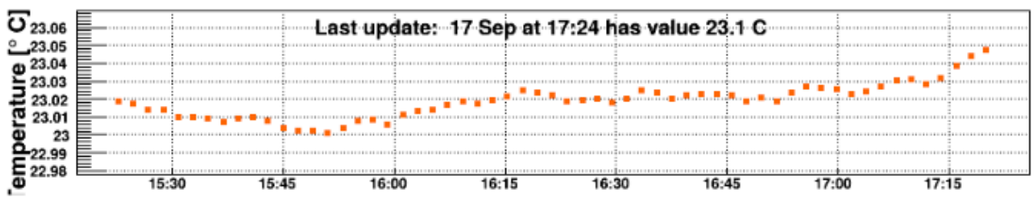


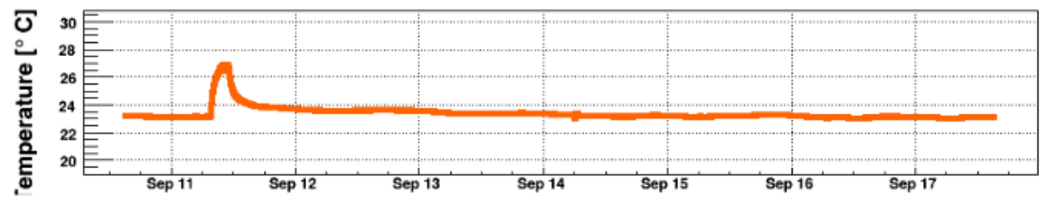


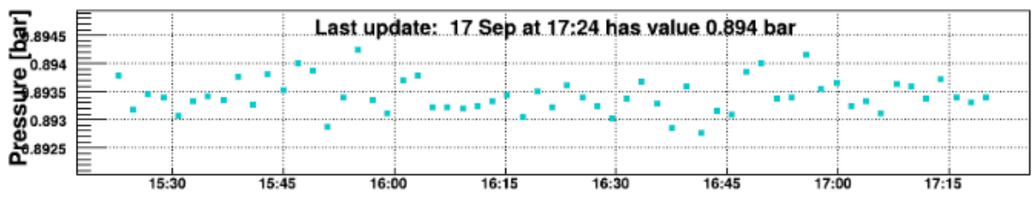


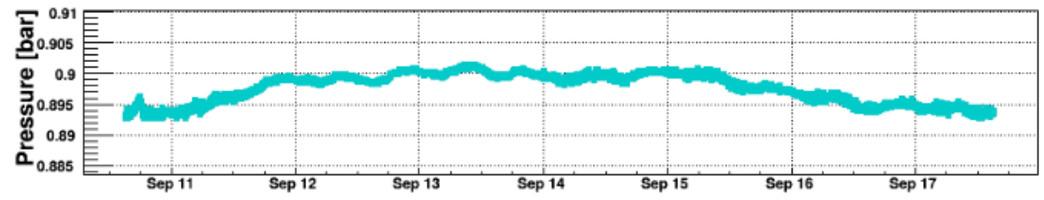


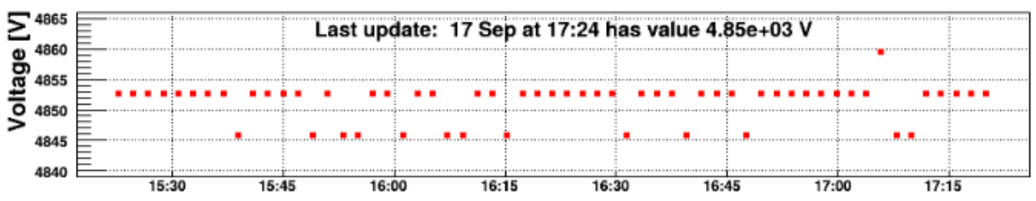


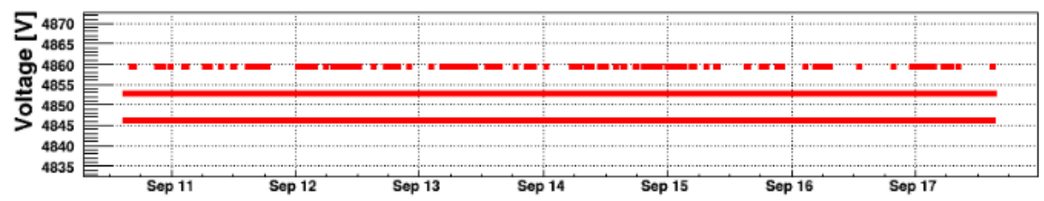












XENONnT PMTs

R11410-21 and R17317



Sensitivity projections

- For the **3” Hamamatsu XLZD PMTs**, with the new DAQ, the **90% CL sensitivity estimate** is computed

- For **30 days** of measurement, **Gator** has **< 1 mBq** sensitivity **per PMT** for lines of all **major primordial radioisotopes**

