The upgraded low-background germanium counting facility Gator for high-sensitivity γ-ray spectrometry

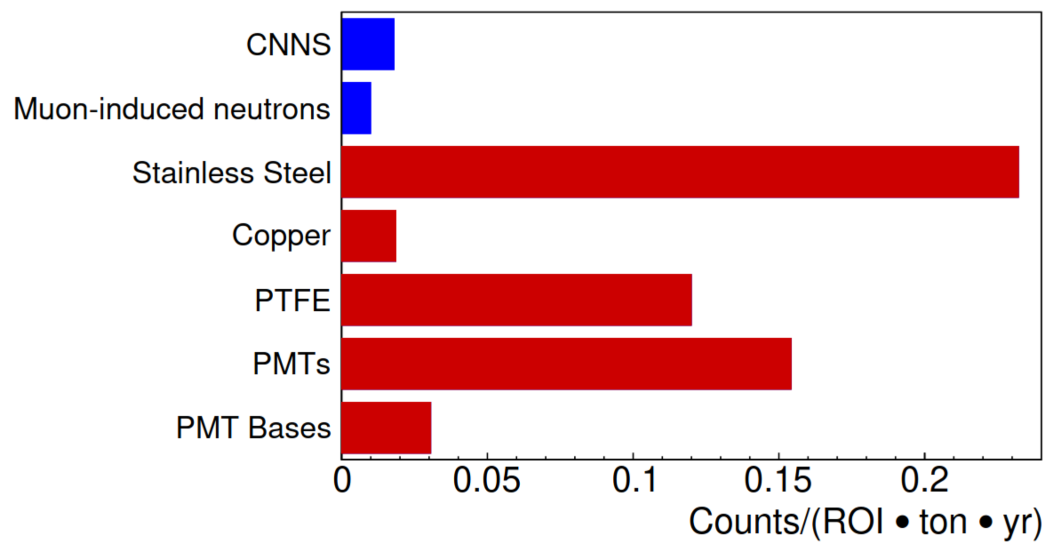
Gabriela R. Araujo, Laura Baudis, Yanina Biondi, Alexander Bismark, Michelle Galloway
Physik-Institut, Universität Zürich (2021)

Universität Zürich[UZH]

Motivation

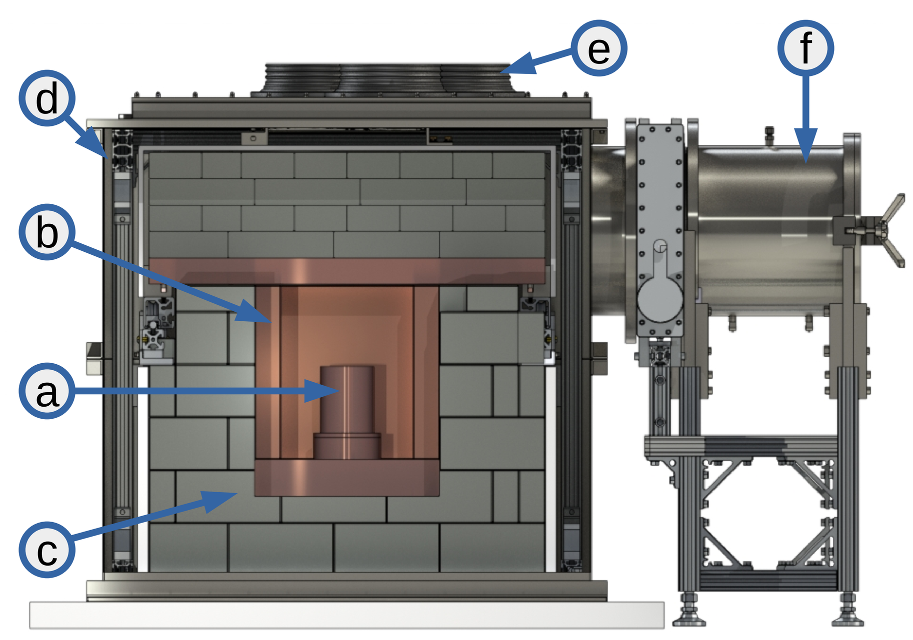
- Rare event searches, such as dark matter (for example XENONnT or DARWIN) and neutrinoless double beta decay experiments (e.g. GERDA or LEGEND), require extremely low backgrounds to achieve high sensitivities.
- Germanium spectroscopy, as provided by the Gator facility, offers a non-destructive and high resolution screening method for material radioactivity quantification for these experiments.
- Radioassay results allow for selection of radiopure detector materials and precise background simulations.

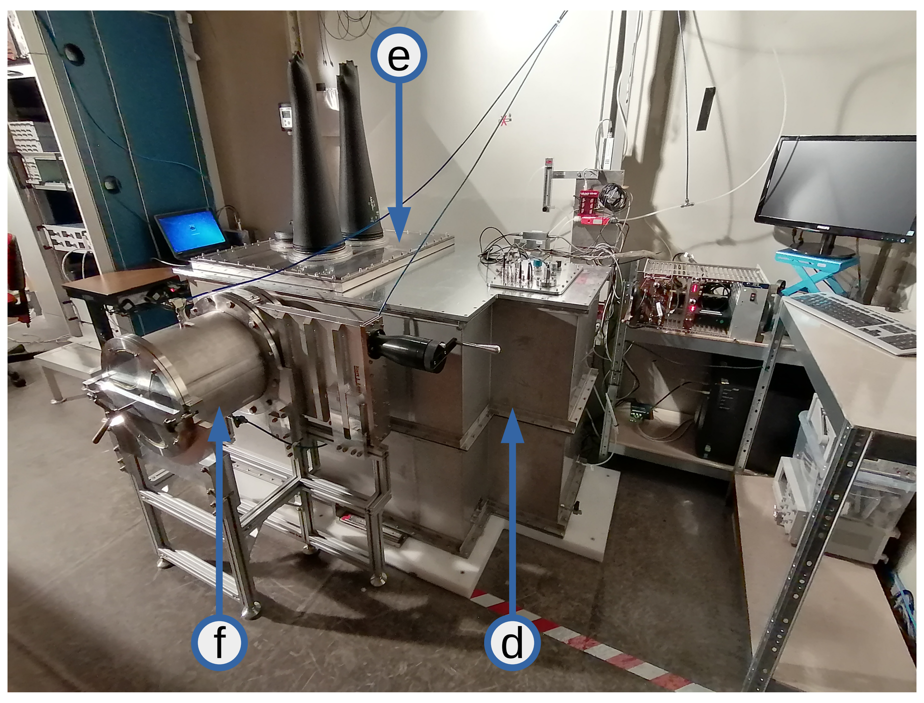
Nuclear recoil backgrounds in XENON1T from materials (red), predicted from screening measurements, and external sources (blue) [2].



The Upgraded Gator Facility

- Located at the Gran Sasso underground laboratory in Italy (LNGS) at a depth of 3600 m water equivalent.
- The core consists of a p-type coaxial high-purity germanium (HPGe) detector with 2.2 kg sensitive mass. It is enclosed in an ultra-low activity, oxygen-free copper cryostat and cooled with liquid nitrogen via a copper coldfinger.
- Several layers of shielding material:
  - oxygen-free high-conductivity (OFHC) copper,
  - four layers of low-activity lead, and
  - a polyethylene sheet for ambient neutron mitigation.
- Airtight stainless steel enclosure is continuously purged with gaseous nitrogen for radon suppression.
- Sample pre-purging with nitrogen in load-lock chamber and subsequent loading using glove ports with access to the entire sample chamber volume (25×25×33 cm^3).

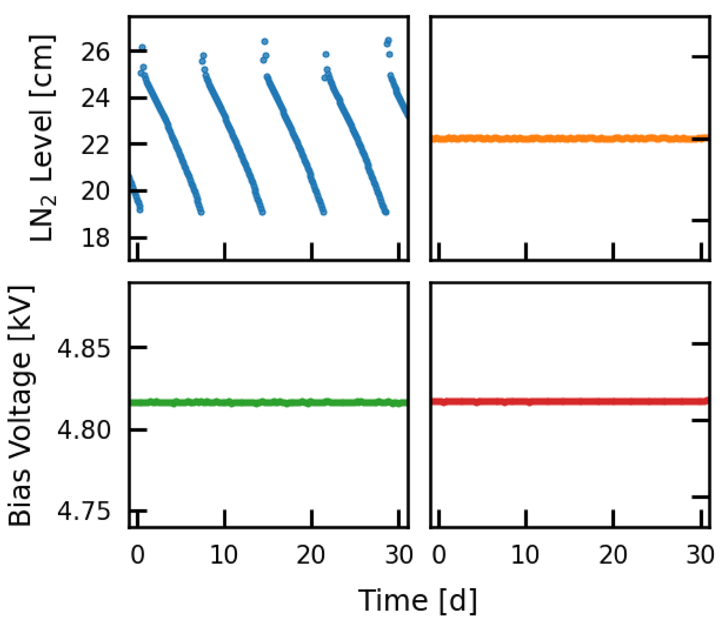


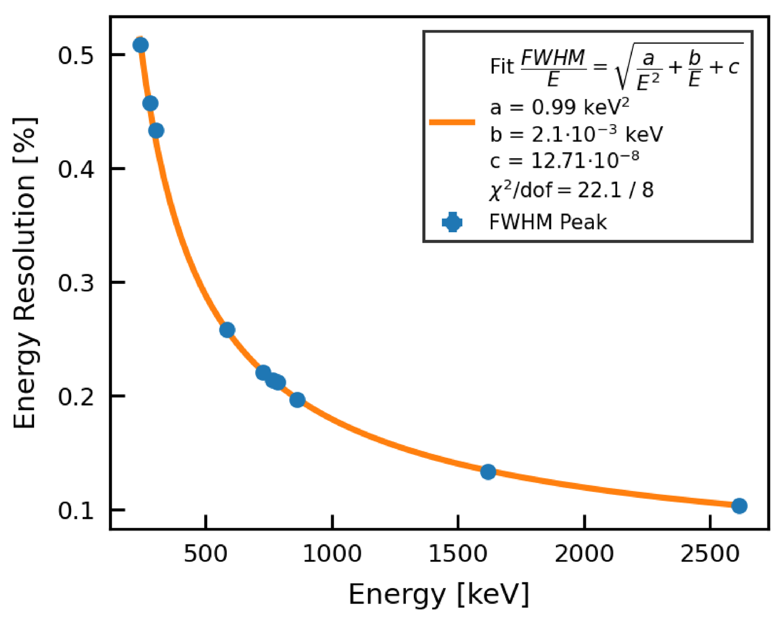


***(a)** HPGe detector, **(b)** OFHC Cu cavity, **(c)** lead shield, **(d)** airtight enclosure, **(e)** glove ports, **(f)** sample load lock.*

Detector Performance

- One of the world's most sensitive HPGe detectors with an integrated background rate of (86.2±0.7) $d^{-1}kg^{-1}$ in the energy region 100-2700 keV (as compared to value from 2010: (102.8±0.7) $d^{-1}kg^{-1}$ [1]).
- Typical sensitivities of < a few mBq/kg for exposures of 1-3 weeks and tens of kg sample mass (a few µBq/kg for radiopure samples and longer exposure).
- Regular calibrations of the detector with radioactive sources such as ^{228}Th, ^{137}Cs, or ^{60}Co (FWHM at 1332 keV is 2.0 keV).
- Remote monitoring of operations parameters to ensure detector stability and data quality.

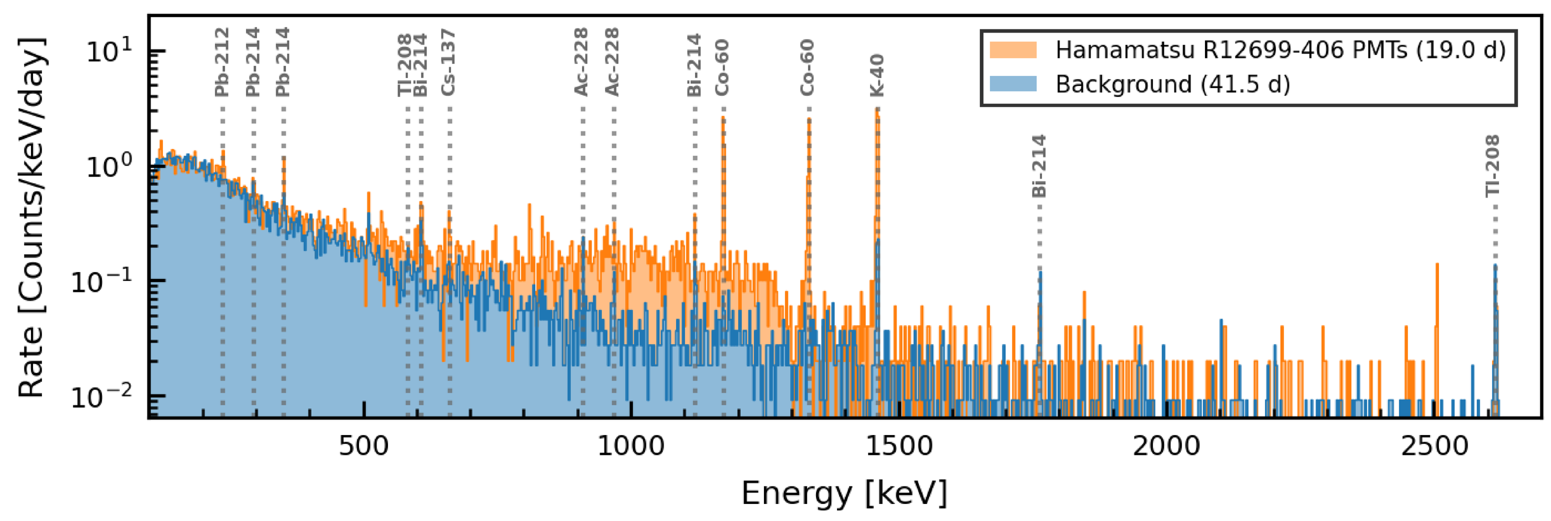




***Left:** Time-evolution of selected operations parameters.*
***Right:** Energy-dependent detector resolution.*

Simulations & Analysis

- Determination of the detection efficiency ε through GEANT4 Monte Carlo simulations for each sample.
- Calculation of the specific activities A from the background- and Compton-subtracted counts S_{net} at the location (±3σ) of the most prominent lines as $A = S_{net} / (r \cdot \varepsilon \cdot m \cdot t)$, with branching ratio r, sample mass m, and measuring time t.
- Of particular interest are gamma lines emitted by primordial (^{238}U, ^{232}Th, ^{40}K), cosmogenic (^{54}Mn, ^{46}Sc, ^{60}Co,...), and anthropogenic (^{137}Cs, ^{110m}Ag,...) isotopes, whose decay products may mimic signals (e.g. nuclear recoils of neutrons from (α,n) reactions in XENON experiments) or leak into the signal region.



Measured energy spectrum of sample photosensors (orange) as compared to the background (blue). Prominent isotopes are labeled.

References:

[1] L. Baudis et al., "Gator: a low-background counting facility at the Gran Sasso Underground Laboratory", JINST 6:08 (2011)
[2] F. Piastra, "Materials Radioassay for the XENON1T Dark Matter Experiment, and Development of a Time Projection Chamber for the Study of Low-energy Nuclear Recoils in Liquid Xenon", PhD dissertation, Physik Institut Universität Zürich (2017)
[3] E. Aprile et al., "Material radioassay and selection for the XENON1T dark matter experiment", Eur. Phys. J. C 77:890 (2017)