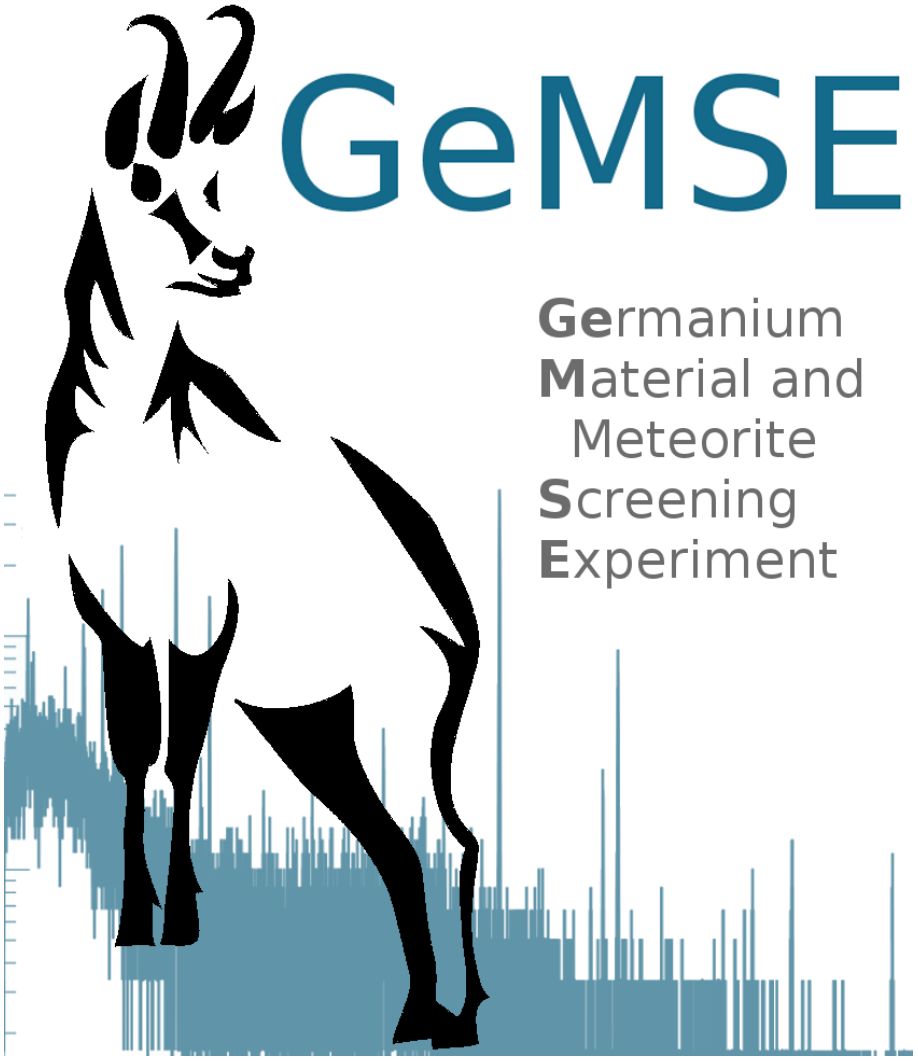


Bundesministerium
für Bildung
und Forschung

UNIVERSITÄT
BERN

UNI
FREIBURG

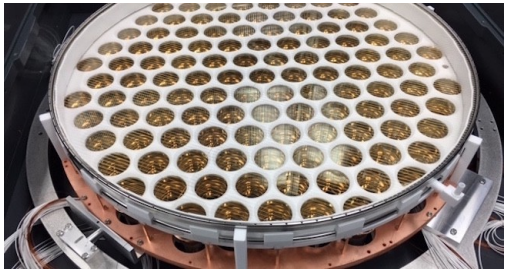
The GeMSE Low-Background Facility for Meteorite and Material Screening

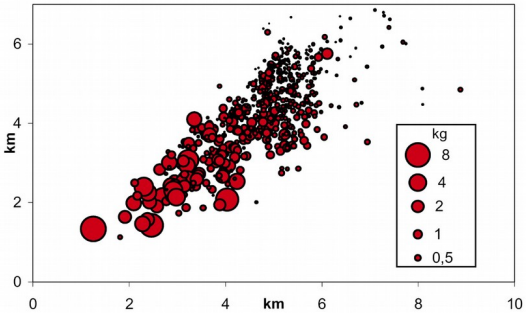
Diego Ramírez García
Albert-Ludwigs-Universität Freiburg

Low Radioactivity Techniques 2019
May 20th, Jaca (Spain)

Motivation

- Material screening
  - Rare event searches (e.g., Dark Matter, 0νββ) require low-background detector components
  - Selection of suitable materials for the construction of XENONnT and DARWIN projects
- Meteorite research
  - Identification of cosmogenic activated isotopes (e.g., ^{22}Na, ^{27}Al, ^{44}Ti) in meteorites allows for terrestrial age determination
  - Pairing of samples
  - Need for a non-destructive analysis of chemical composition
  - User-friendly remote control and analysis/simulations framework

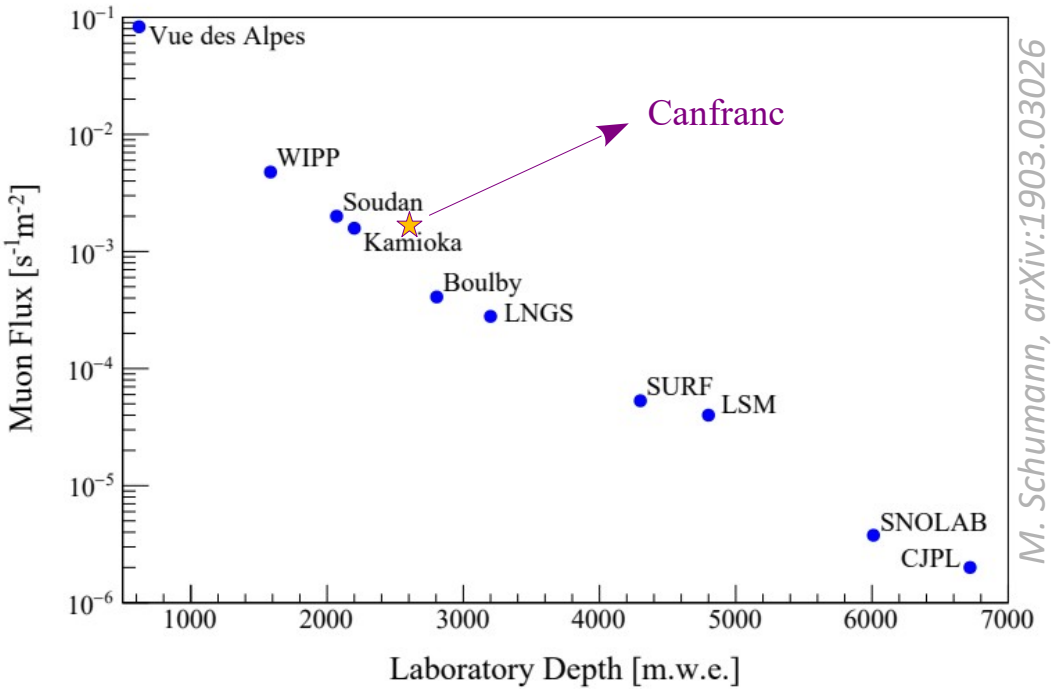




GeMSE Location

- Vue des Alpes underground laboratory (Switzerland)
  - 620 m.w.e. rock overburden

    → 2000x reduction of cosmic muons



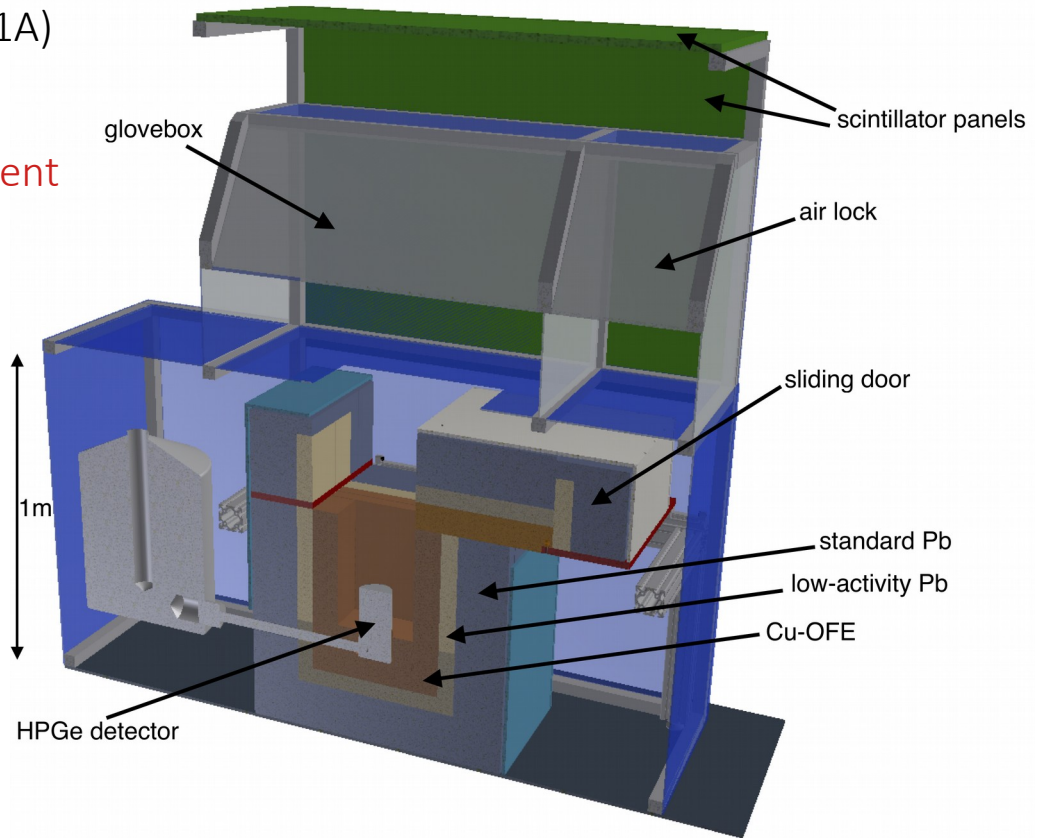
- Location in a car tunnel provides very easy access
- One-hour drive from Bern

  → Short-lived isotopes from meteorites can be measured

GeMSE Design

- 24 x 24 x 35 cm^3 sample cavity
- HPGe read-out by 14-bit digital MCA (CAEN DT5781A)
  - 10 ns resolution
  - Saves pulse height and time stamp for each event
- Scintillator panels as muon veto
  - Discard HPGe signals 10 µs after veto trigger

    → ~ 0.5 % dead time introduced
- Multi-layer passive shielding
  - 8 cm of Cu-OFE (> 99.99 % purity)
  - 5 cm low activity Pb (7 Bq/kg ^{210}Pb)
  - 15 cm normal Pb (91 Bq/kg ^{210}Pb)
- N_2 purged glovebox
  - Remove ^{222}Rn and protection against dust

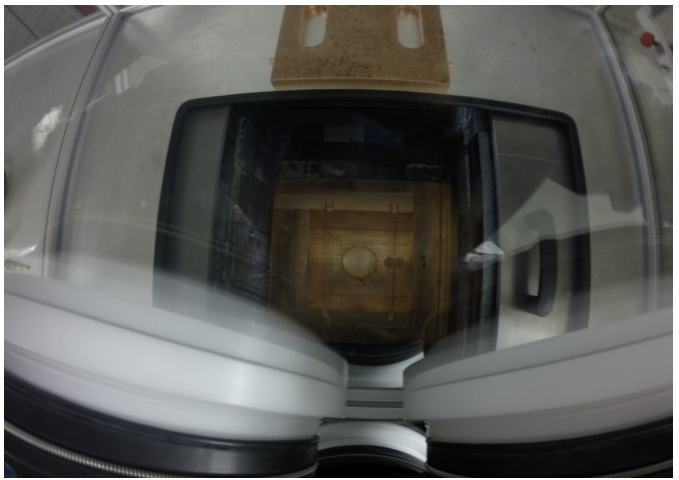


GeMSE Design

Canberra ultra-low background HPGe

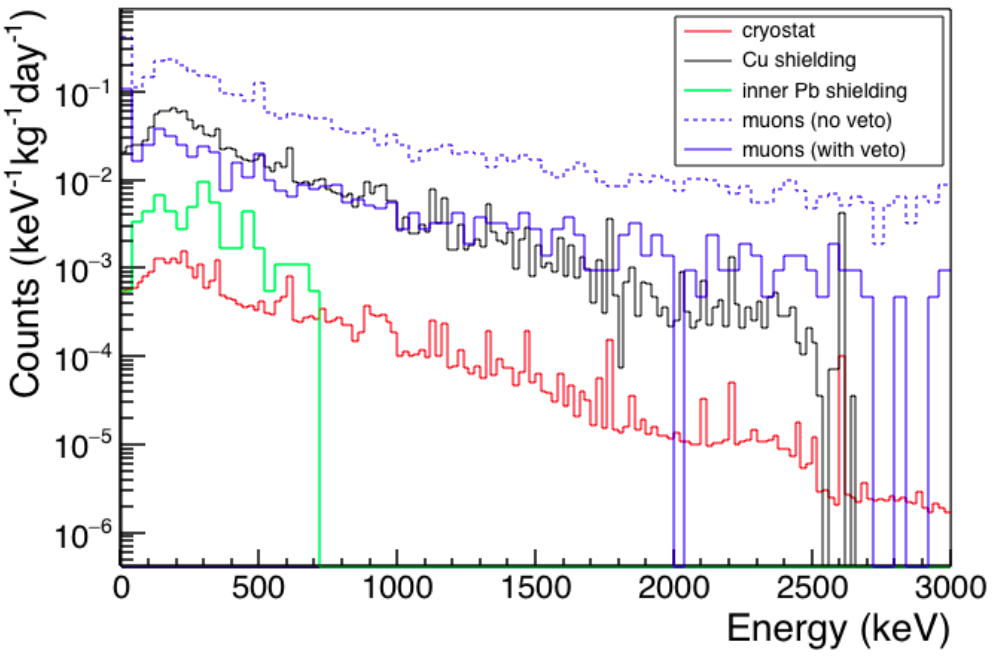
- 2.2 kg Ge crystal
- Standard coaxial, *p* type
- U-style cryostat
- Low-background Cu housing

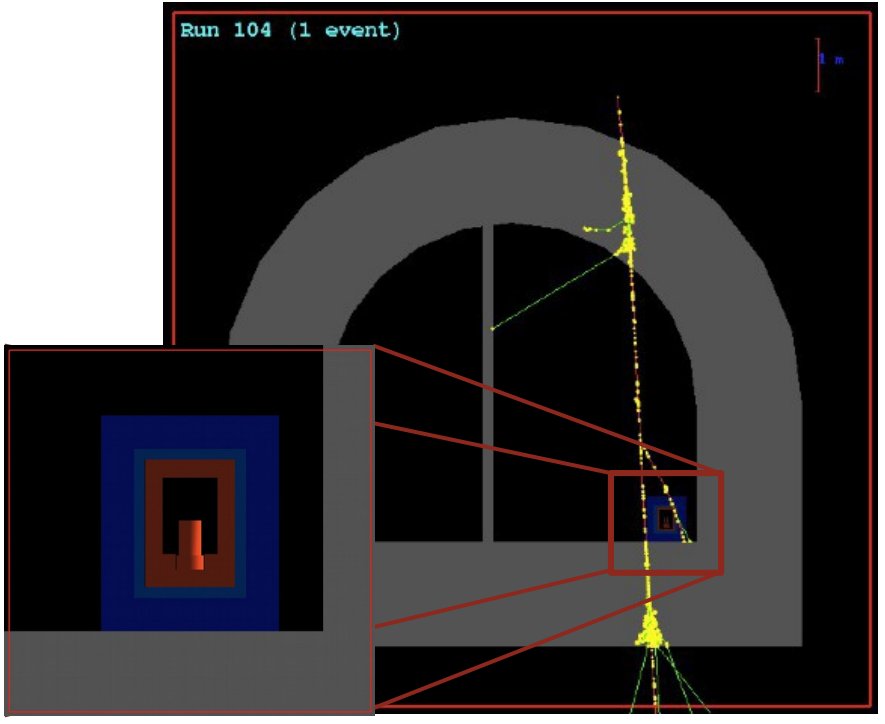
GeMSE Design



GeMSE Background

- Initial background goal of 250 counts/day (100-2700 keV)
- Location and shielding design optimized via GEANT4 simulations



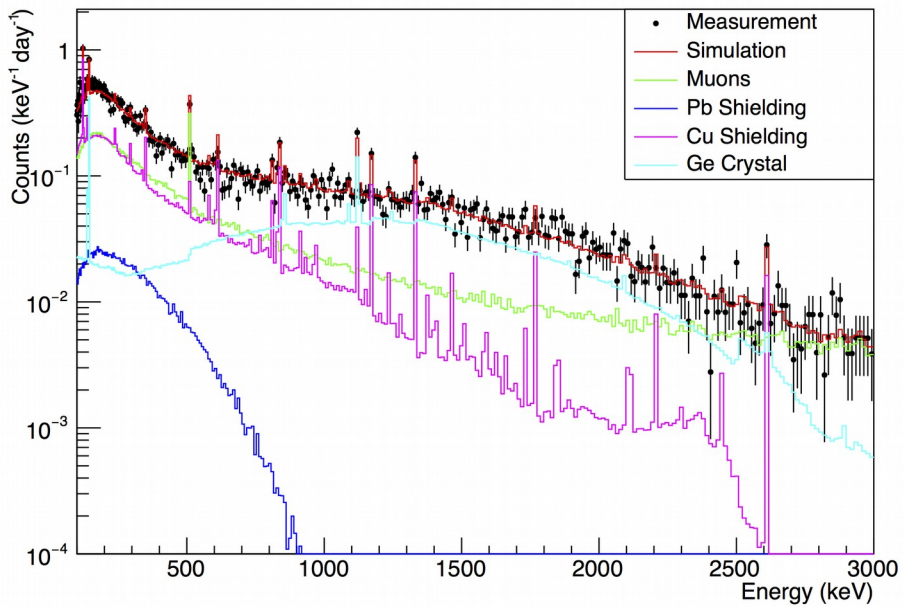


M. v. Sivers et al., AIP Conf. Proc. 1672, 120004 (2015), arXiv:1505.07015

GeMSE Background

- Initial background goal of 250 counts/day (100-2700 keV)
- Location and shielding design optimized via GEANT4 simulations
- Total reduction by a factor of ~ 10^5 with respect to above-ground levels

BACKGROUND MC-DATA MATCHING



M. v. Sivers et al., JINST 11 P12017 (2016), arXiv:1606.03983

620 m.w.e. depth

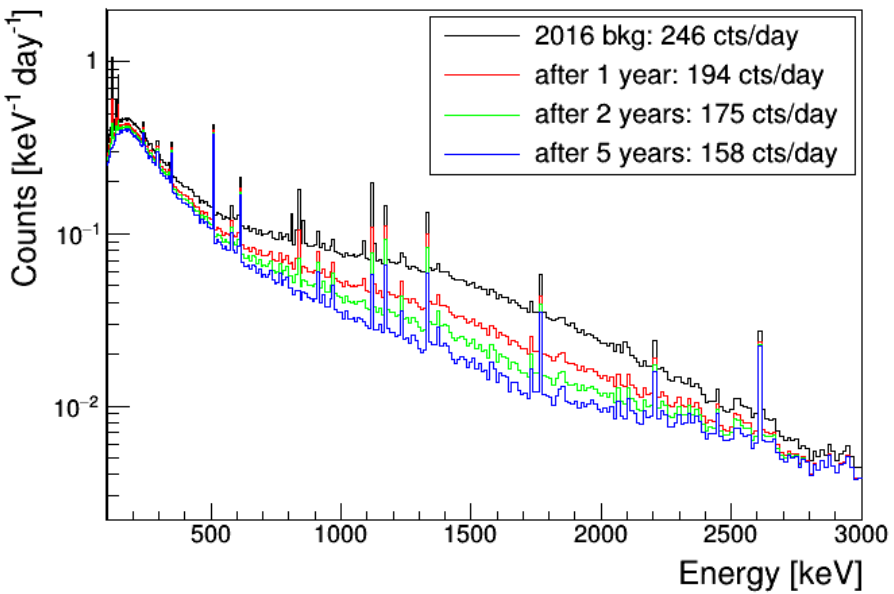
3600 m.w.e. depth (@ LNGS)

Energy (keV)	Chain/Isotope	Count Rate (day^{-1})		
		GeMSE	Gator	GeMPI
122	^{57}Co (ext.)	1.6 ± 0.2	-	-
144	^{57}Co (int.)	1.1 ± 0.2	-	-
1125	^{65}Zn	1.2 ± 0.2	-	-
1173	^{60}Co	0.84 ± 0.15	0.5 ± 0.1	0.26 ± 0.06
1333	^{60}Co	0.84 ± 0.15	0.5 ± 0.1	0.21 ± 0.05
662	^{137}Cs	< 0.03	0.3 ± 0.1	0.34 ± 0.16
1461	^{40}K	0.23 ± 0.10	0.5 ± 0.1	0.52 ± 0.07
239	^{232}Th/^{212}Pb	0.34 ± 0.17	< 0.5	-
583	^{232}Th/^{208}Tl	0.17 ± 0.10	-	≤ 0.13
911	^{232}Th/^{228}Ac	< 0.14	< 0.5	-
2615	^{232}Th/^{208}Tl	0.27 ± 0.08	0.2 ± 0.1	0.11 ± 0.03
352	^{238}U/^{214}Pb	0.67 ± 0.17	0.7 ± 0.3	≤ 0.14
609	^{238}U/^{214}Bi	0.51 ± 0.14	0.6 ± 0.2	≤ 0.15
1120	^{238}U/^{214}Bi	< 0.02	0.3 ± 0.1	-
1765	^{238}U/^{214}Bi	0.14 ± 0.08	0.08 ± 0.06	-
100-2700	integral	246 ± 2	226 ± 1	41 ± 1

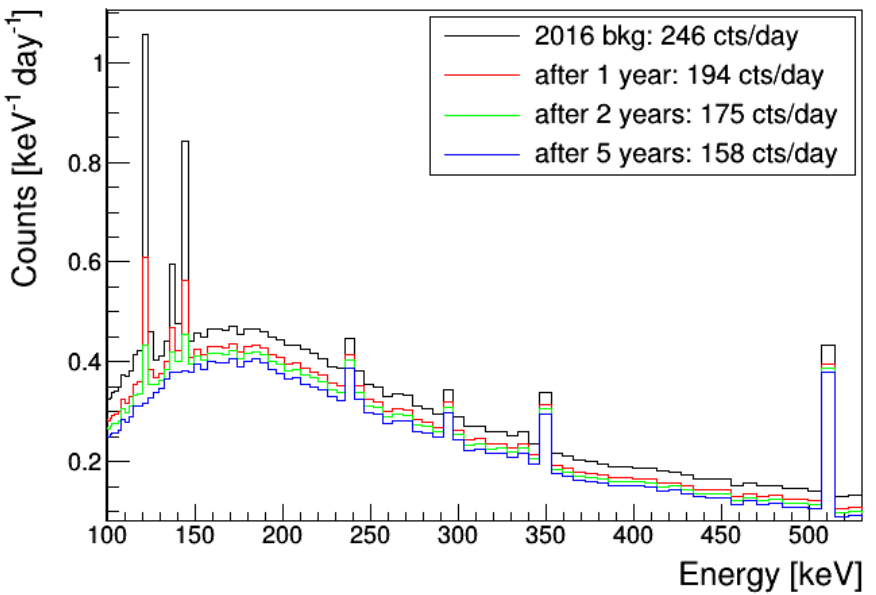
GeMSE Background

- Initial background goal of 250 counts/day (100-2700 keV)
- Location and shielding design optimized via GEANT4 simulations
- Total reduction by a factor of ~ 10^5 with respect to above-ground levels
- Expected decrease of cosmogenic lines

MC PREDICTION

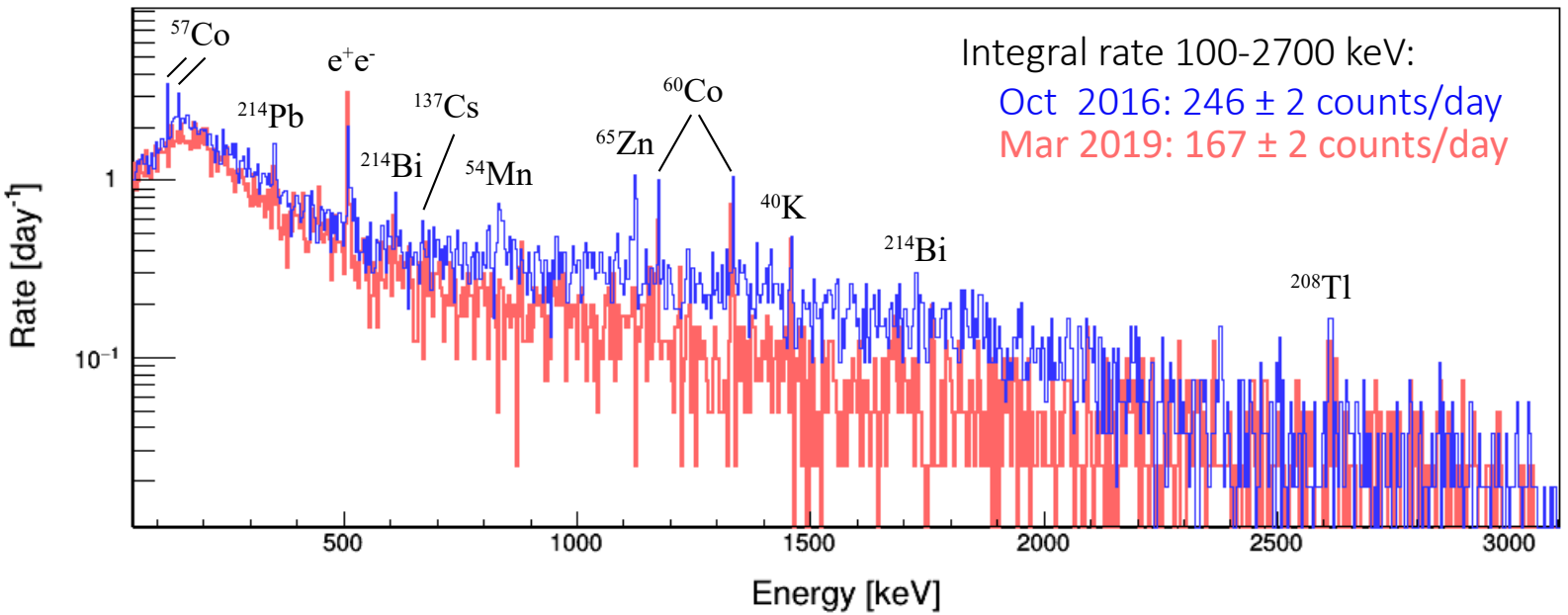


MC PREDICTION

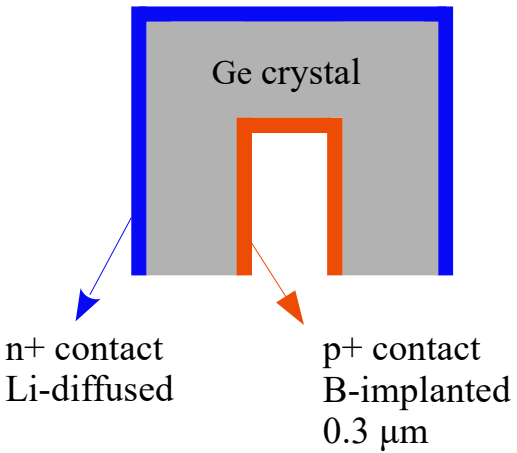


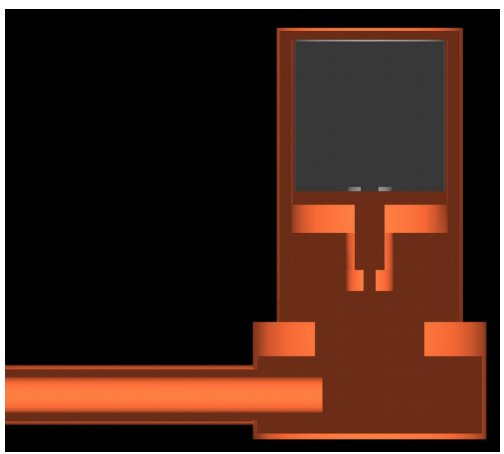
GeMSE Background

- Initial background goal of 250 counts/day (100-2700 keV)
- Location and shielding design optimized via GEANT4 simulations
- Total reduction by a factor of ~ 10^5 with respect to above-ground levels
- Expected decrease of cosmogenic lines → In agreement with measurement after 2.5 years!

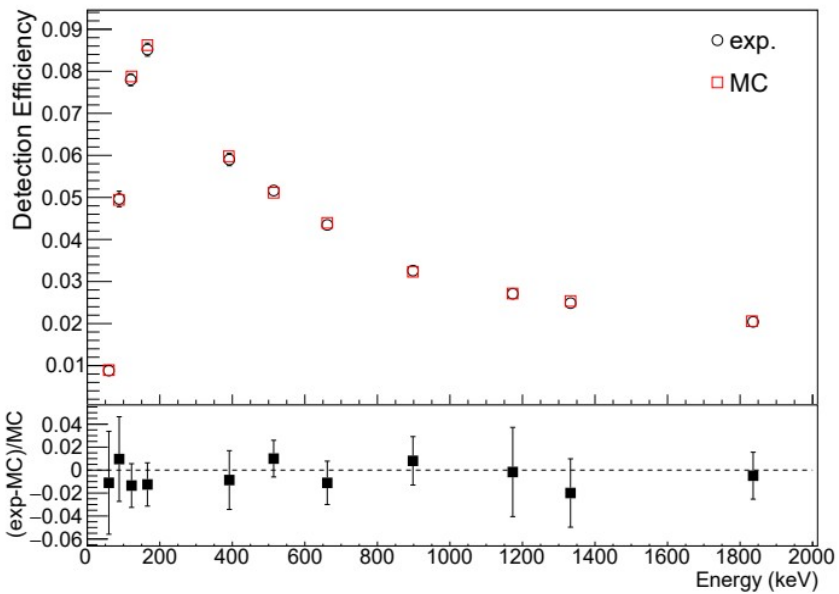


GeMSE Efficiency





- Dead layer from Li-difussed n+ contact
- Determined by MC matching
  - 81 keV / 356 keV peak ratio of ^{133}Ba → 0.67 ± 0.01 mm
  - CBSS2 source with certified activity → 0.65 ± 0.05 mm
- Active volume implemented in GeMSE GEANT4 framework for efficiency calculation



M. v. Sivers et al., JINST 11 P12017 (2016), arXiv:1606.03983

GeMSE Remote Operation

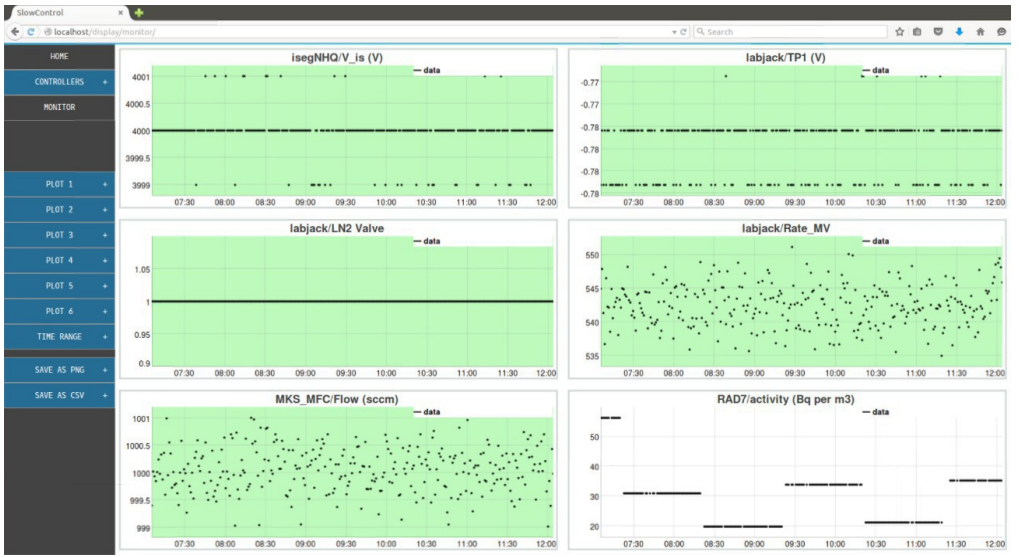
DOBERMAN Slow Control (v4):

- Monitoring:
  - HV of HPGe detector
  - Leakage current of HPGe detector
  - Muon veto rate
  - Automatic LN_2 refill
  - N_2 flow inside glovebox
  - Temperature inside glovebox
  - …
- 100 % uptime
- Configurable without restarting
- Remotely accessible

In addition, remote switch for:

- HPGe DAQ
- LN_2 refill

P. Zappa et al., JINST 11 (2016) T09003, arXiv:1607.08189



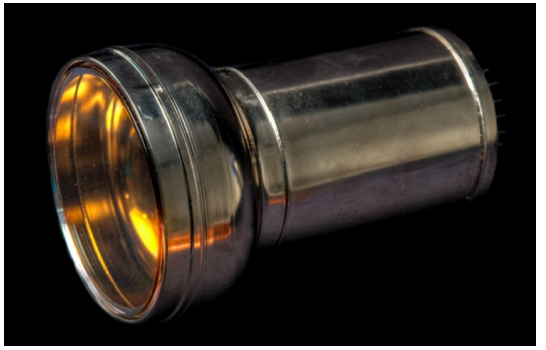
→ Three to four weeks of autonomy ←

Analyzing a Sample with GeMSE

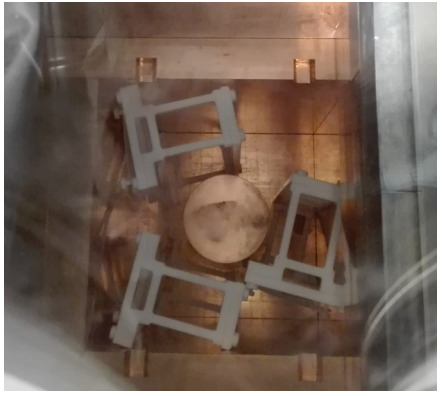
(Analysis environment set up for non-physics users)

i. **Measure your sample and background**
ii. Get rid of Rn contamination in your data
iii. Derive energy calibration and resolution
iv. Perform efficiency simulations for your sample
v. Fit gamma peaks of interest

XENONnT PMTs (Hamamatsu R11410)



PTFE holders (background)

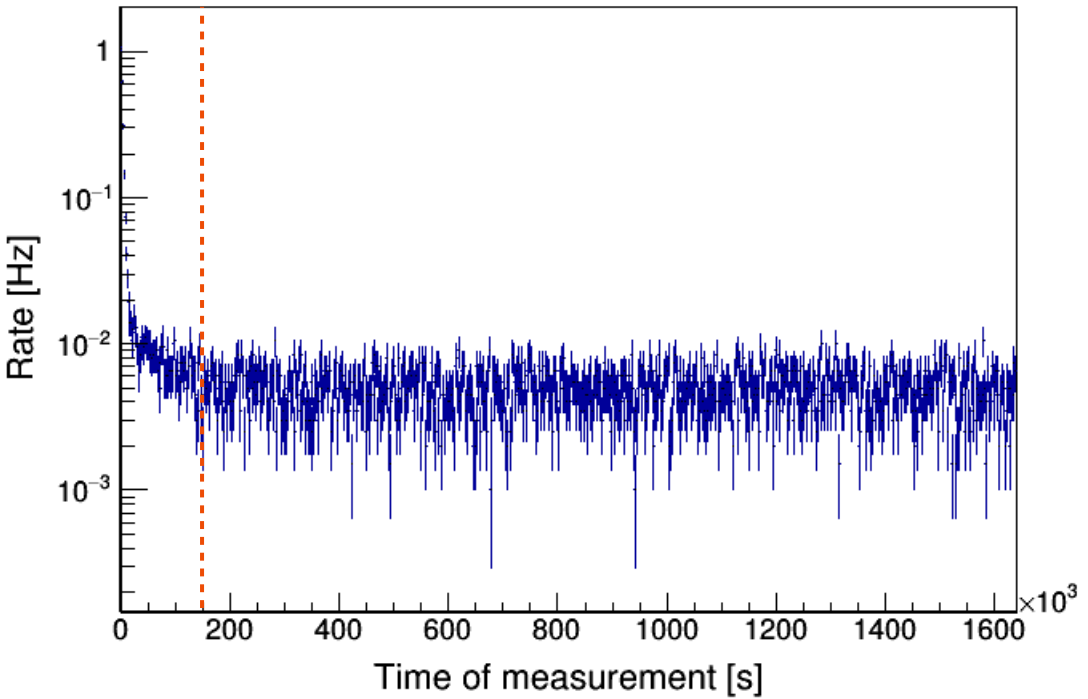


10-PMTs batch + PTFE holders

Analyzing a Sample with GeMSE

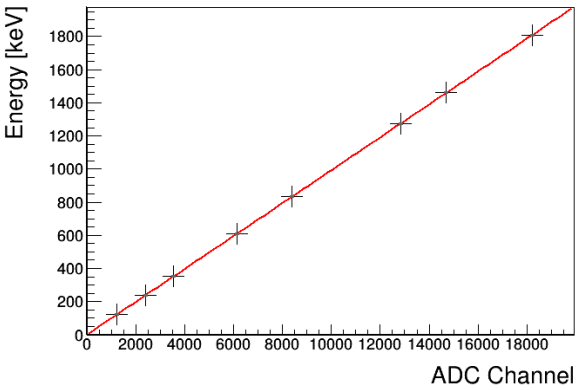
i. Measure your sample and background
ii. **Get rid of Rn contamination in your data**
iii. Derive energy calibration and resolution
iv. Perform efficiency simulations for your sample
v. Fit gamma peaks of interest

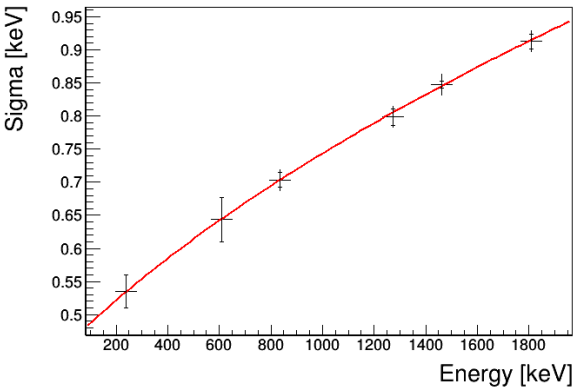
Using the timestamps of the hits:



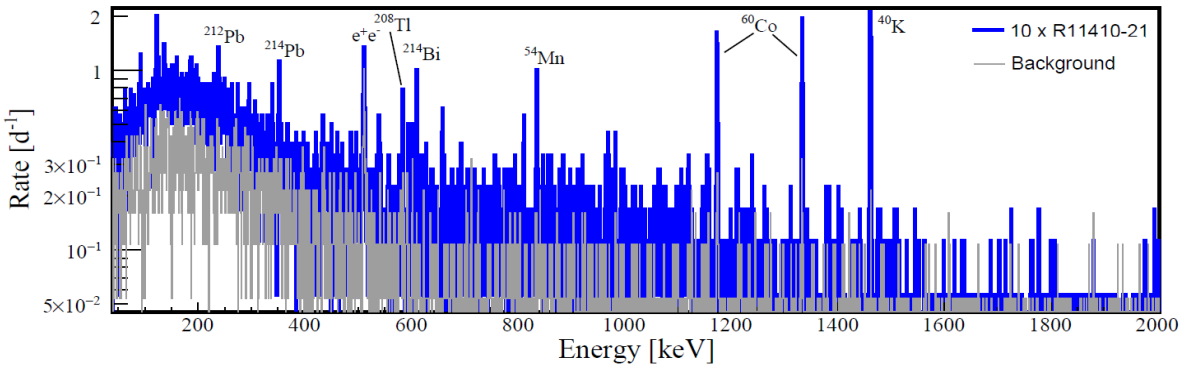
Analyzing a Sample with GeMSE

i. Measure your sample and background
ii. Get rid of Rn contamination in your data
iii. **Derive energy calibration and resolution**
iv. Perform efficiency simulations for your sample
v. Fit gamma peaks of interest





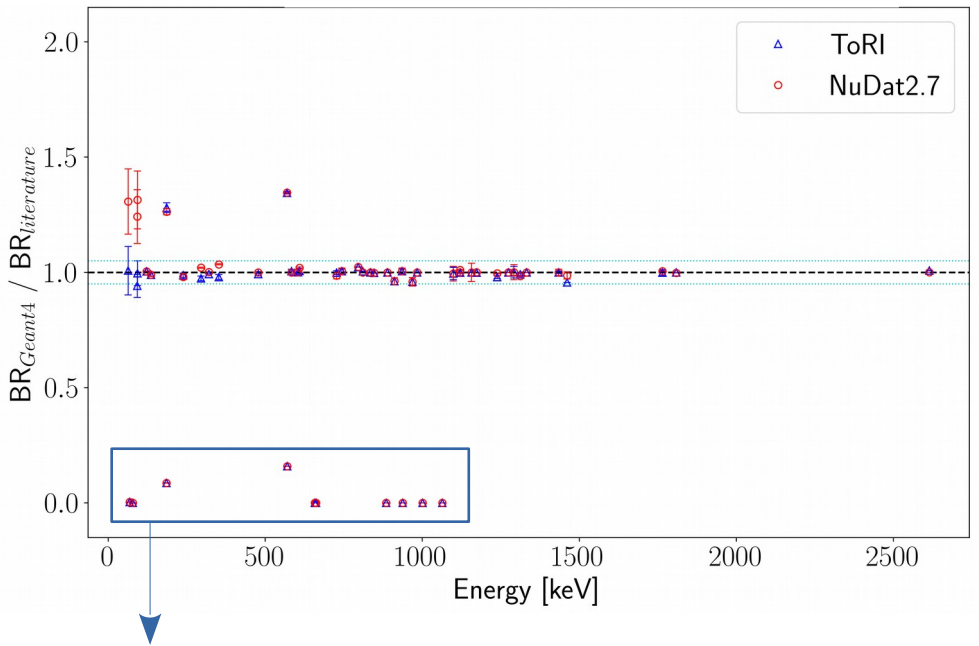
CALIBRATED COUNTING RATE AFTER MV DEAD-TIME CORRECTION



Analyzing a Sample with GeMSE

i. Measure your sample and background
ii. Get rid of Rn contamination in your data
iii. Derive energy calibration and resolution
iv. **Perform efficiency simulations for your sample**
v. Fit gamma peaks of interest

- GEANT4 branching ratio validation

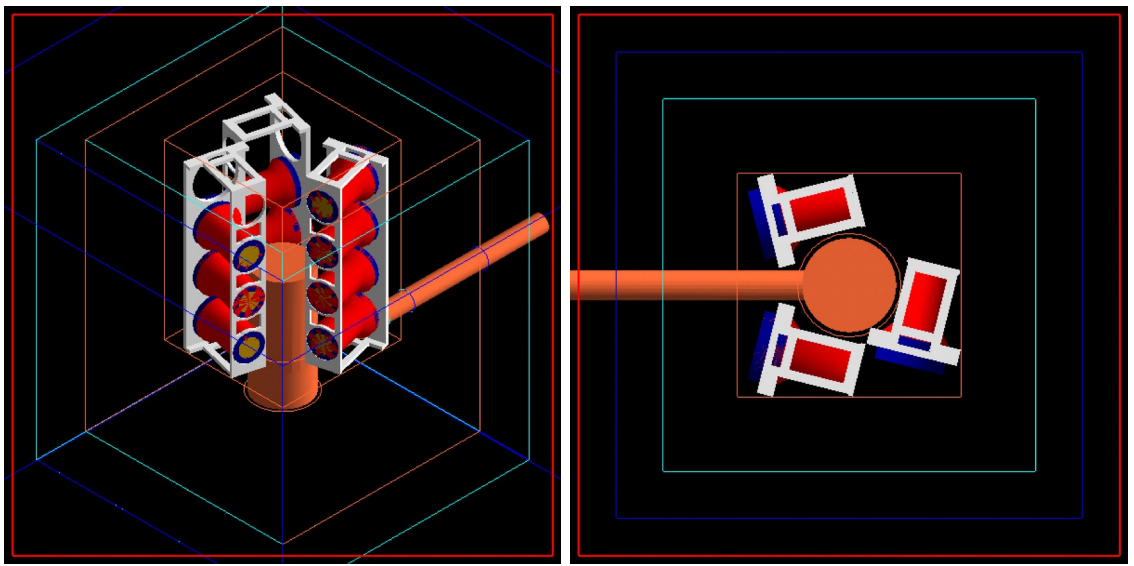


Gammas to be simulated separately

Analyzing a Sample with GeMSE

i. Measure your sample and background
ii. Get rid of Rn contamination in your data
iii. Derive energy calibration and resolution
iv. **Perform efficiency simulations for your sample**
v. Fit gamma peaks of interest

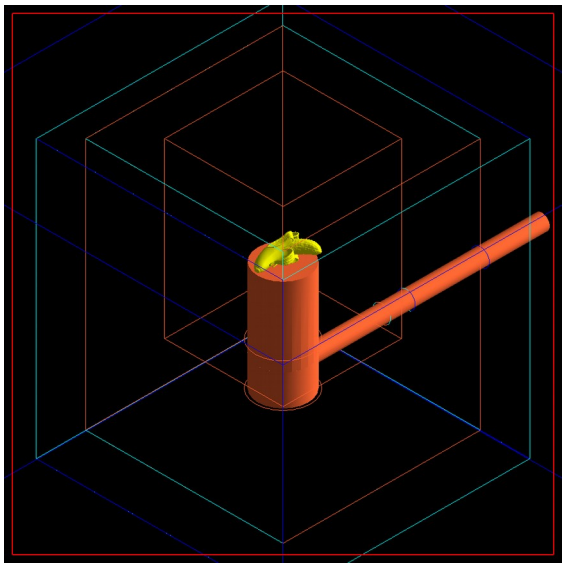
- GEANT4 branching ratio validation
- Sample implementation

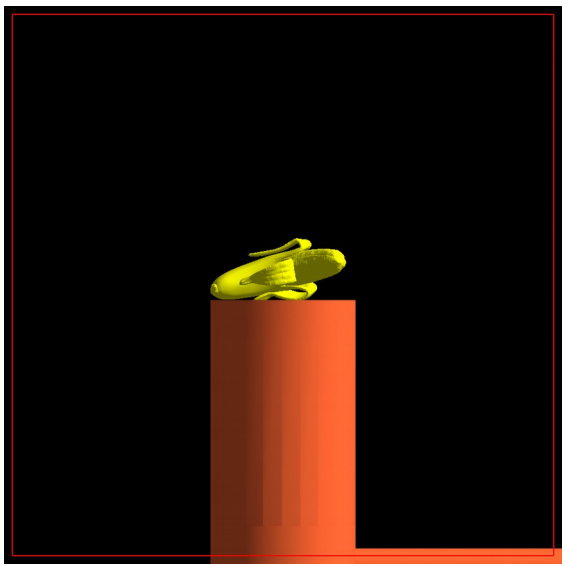


Analyzing a Sample with GeMSE

i. Measure your sample and background
ii. Get rid of Rn contamination in your data
iii. Derive energy calibration and resolution
iv. **Perform efficiency simulations for your sample**
v. Fit gamma peaks of interest

- GEANT4 branching ratio validation
- Sample implementation
- Complex 3D geometries can also be imported
  - Relevant to determine self-absorption of meteorites

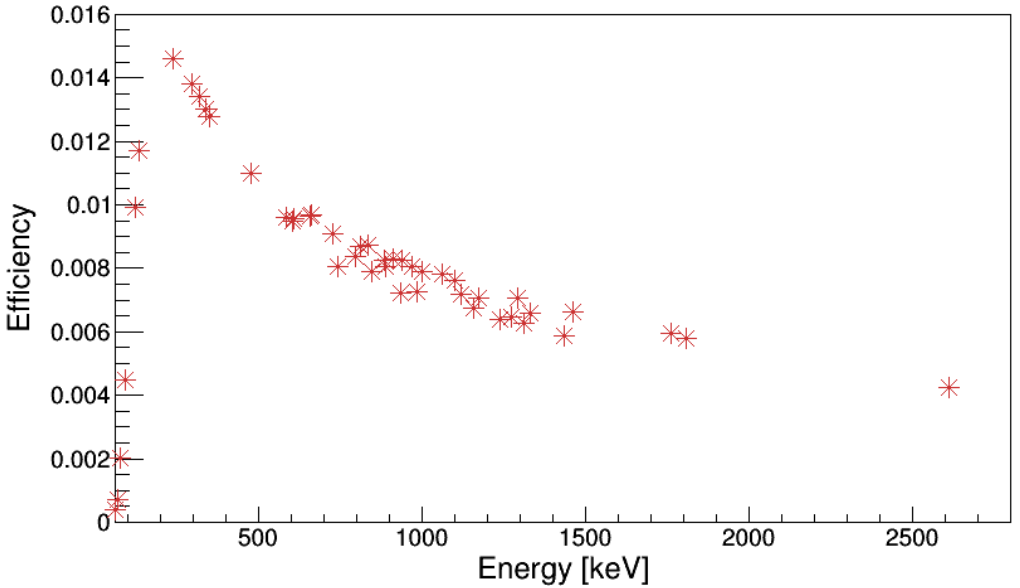




Analyzing a Sample with GeMSE

i. Measure your sample and background
ii. Get rid of Rn contamination in your data
iii. Derive energy calibration and resolution
iv. **Perform efficiency simulations for your sample**
v. Fit gamma peaks of interest

SIMULATED DETECTOR EFFICIENCY



Analyzing a Sample with GeMSE

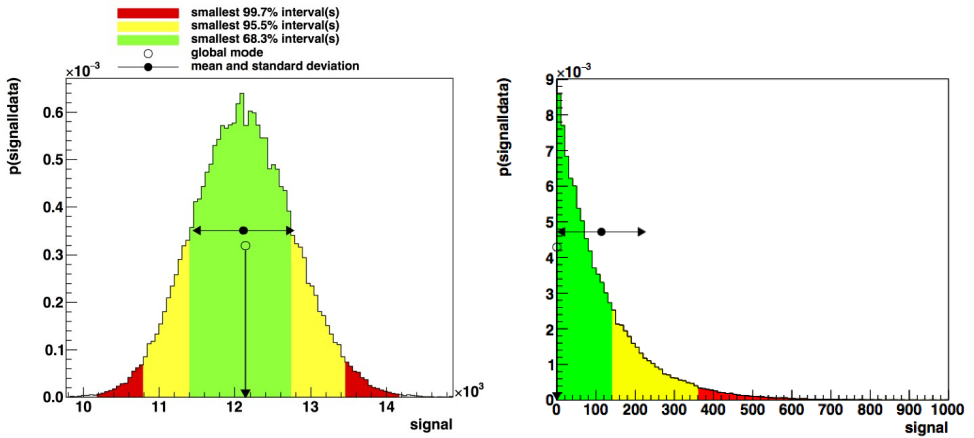
A. Cadwell et al., Comput. Phys. Commun. 180 (2009) 2197,arXiv:0808.2552

i. Measure your sample and background
ii. Get rid of Rn contamination in your data
iii. Derive energy calibration and resolution
iv. Perform efficiency simulations for your sample
v. **Fit gamma peaks of interest**

- Analysis based on the *Bayesian Analysis Toolkit*
- Uncertainty on detection efficiency as Gaussian prior
- *Background-only* and *signal+background* fit in 5σ region

Calculate Bayes Factor $BF = \frac{P(B \mid data)}{P(S \mid data)}$

- BF < 0.33: Calculate activity
- BF > 0.33: Calculate upper limit



Analyzing a Sample with GeMSE

i. Measure your sample and background
ii. Get rid of Rn contamination in your data
iii. Derive energy calibration and resolution
iv. Perform efficiency simulations for your sample
v. **Fit gamma peaks of interest**

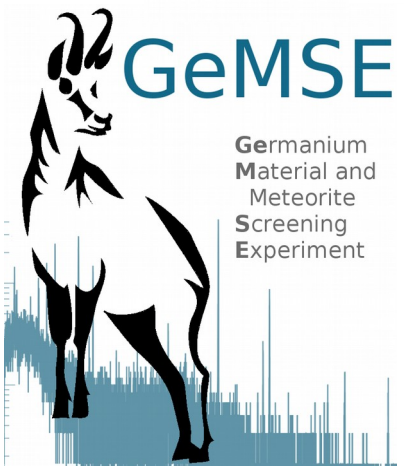
Isotope	Batch 1 [mBq/PMT] (10 PMTs, 19 days)	Batch 2 [mBq/PMT] (10 PMTs, 21 days)
^{238}U	< 5.0	< 6.3
^{228}Th	$< 1.6 \cdot 10^{-1}$	$(1.1 \pm 0.4) \cdot 10^{-1}$
^{226}Ra	$(4.1 \pm 0.9) \cdot 10^{-1}$	$(2.4 \pm 0.9) \cdot 10^{-1}$
^{228}Ra	$(2.5 \pm 1.4) \cdot 10^{-1}$	< 0.4
^{60}Co	$(3.8 \pm 0.8) \cdot 10^{-1}$	$(5.3 \pm 0.8) \cdot 10^{-1}$
^{137}Cs	$< 6.0 \cdot 10^{-2}$	$< 5.0 \cdot 10^{-2}$
^{40}K	5.5 ± 1.2	6.1 ± 1.7

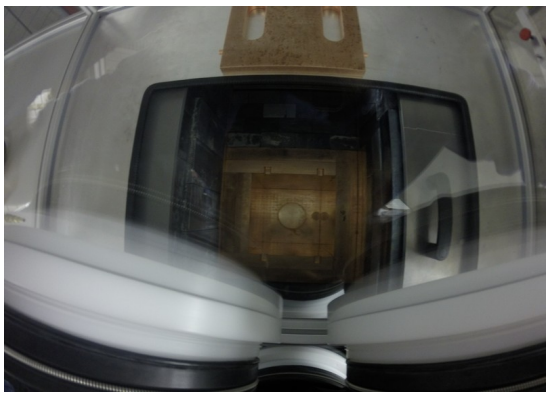
Results fit expectations from bulk materials' contamination

E. Aprile et al. Eur. Phys. J. C (2015) 75: 546, arXiv:1503.07698

Summary

- GeMSE operates under very stable conditions since November 2015
- Slow control allows for three to four weeks of autonomous activity
  - Foreseen improvements in LN_2 refill system and remote control
- Reached background design goal in 2016
  - Current rate of 167 ± 2 counts/day (100-2700 keV), from the decrease on the cosmogenic-activated component
  - Comparable to most sensitive screening facilities in the world
- Flexible and user-friendly sample analysis chain
- Precise efficiency simulations framework based on the GEANT4 toolkit
  - Able to process complex-shaped volumes
- Participating in the XENONnT screening campaign
- Essential role in the (non-invasive) verification and classification of claimed meteorite falls from various point in the planet





Diego Ramírez García, Albert-Ludwigs-Universität Freiburg
diego.ramirez@physik.uni-freiburg.de

Link to GeMSE construction timelapse