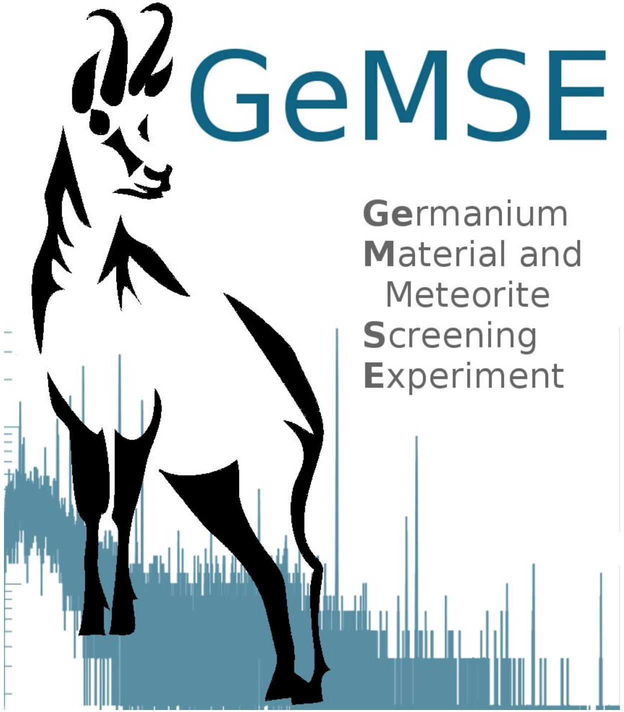
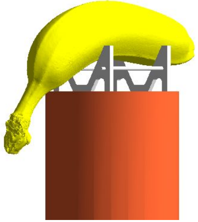


The GeMSE Gamma Spectroscopy Facility for Meteorite and Material Screening

CELLAR Community meeting 2022


Sebastian Lindemann, Universität Freiburg, 28.11.2022

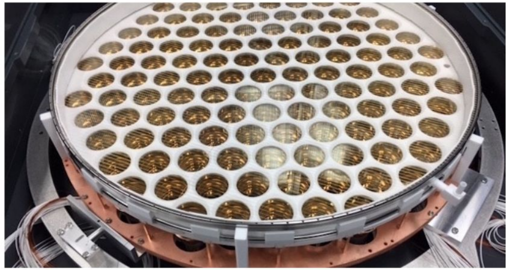
Motivation

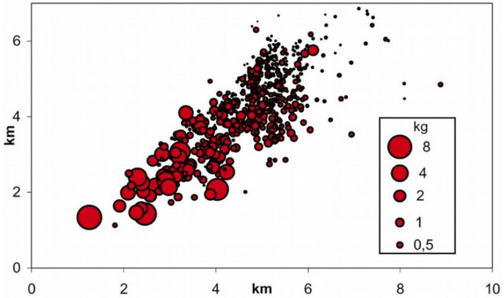
Material screening

- 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

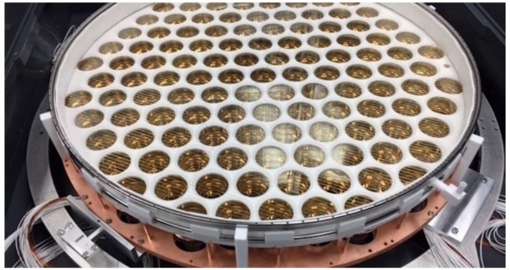
Meteorite research

- Detection of cosmogenic isotopes (e.g., ^{22}Na, ^{44}Ti, ^{27}Al)
  - Determination of **terrestrial age**
  - Information on **average fall rate** of meteorites
- **Non-destructive analysis** of chemical composition (e.g., K/U ratio)
- Identification of paired samples
- Proof of **extraterrestrial origin**
  - primordial ^{26}Al in solar system extinct ($T_{1/2}$ = 7x10^5 yrs)
  - ^{26}Al produced at low levels by cosmic reactions on unshielded materials





Motivation



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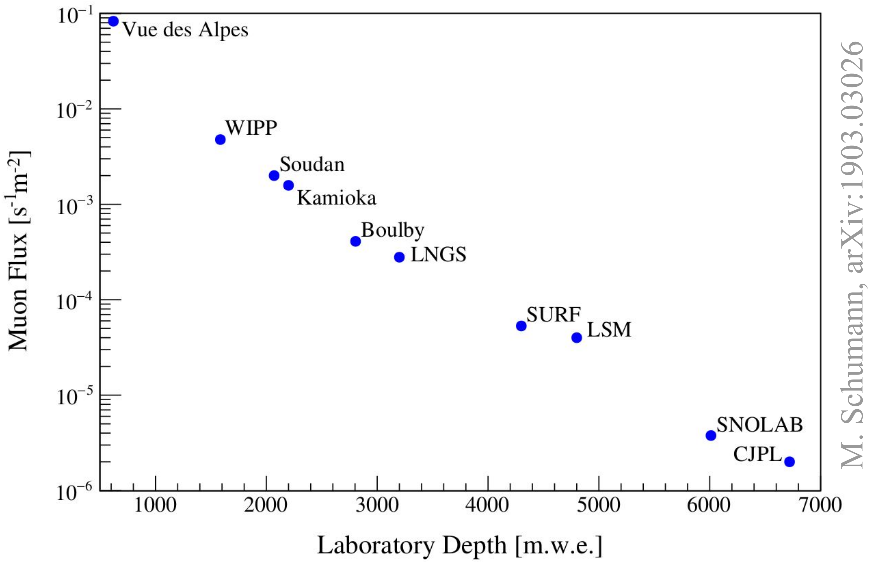
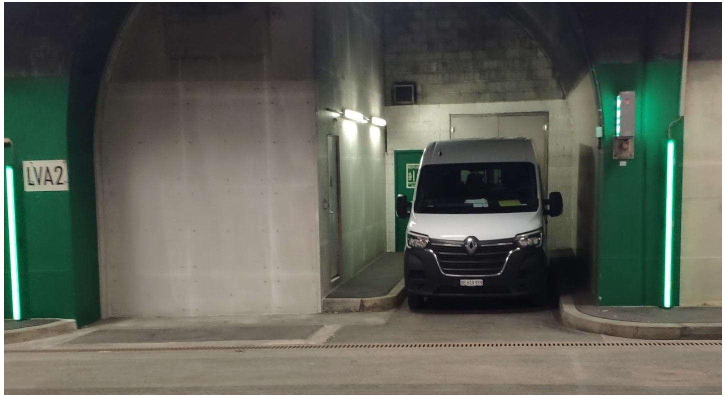
Bernisches Historisches Museum. Fundort Mörigen, Kanton Bern, Schweiz, 19. Jh.

GeMSE: Location

Vue-des-Alpes Underground Laboratory
(near Neuchâtel, Switzerland)

- 230 m rock overburden (**620 m.w.e**)
  → **2000x** reduction of cosmic muons





- Car tunnel provides easy access
- One-hour drive from Bern, 2h from Freiburg

GeMSE: Design

HPGe-Detector

- Canberra Ultra-Low Background **U-style Cryostat**
- Standard coaxial, p-type HPGe detector (2.0 kg)

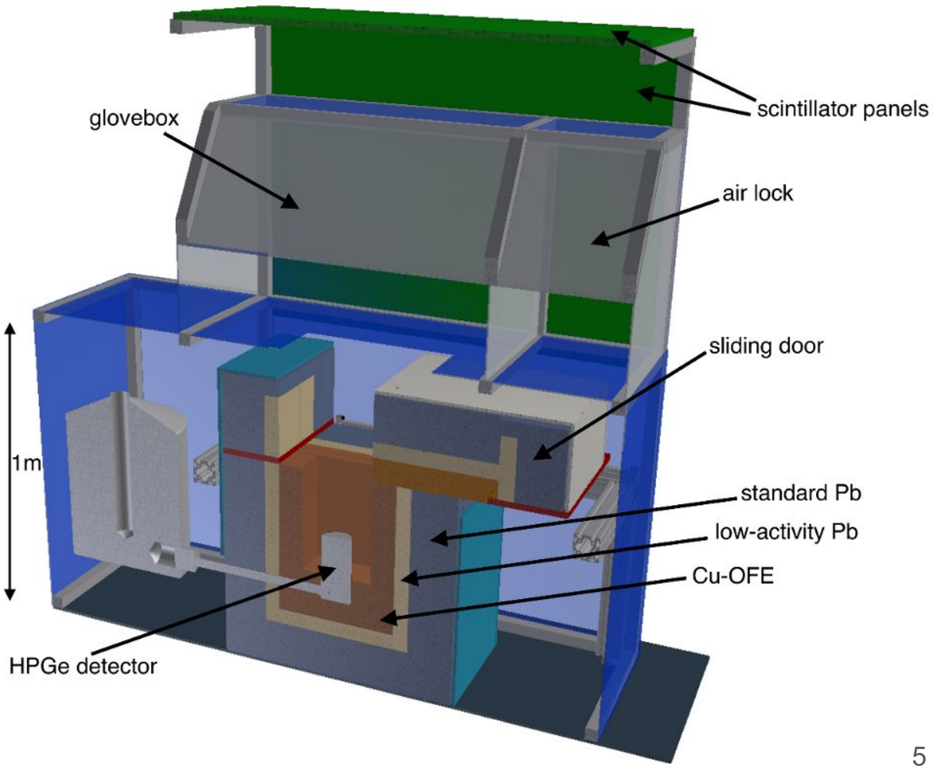
Shielding

- **24x24x35 cm^3 sample cavity**
  - 8 cm Cu-OFE (>99.99% purity)
  - 5 cm low-activity Pb (7 Bq/kg ^{210}Pb)
  - 15 cm normal Pb (91 Bq/kg ^{210}Pb)

- GN-purged glovebox
- Plastic scintillator **muon veto**

Up to 6 weeks of autonomous operation

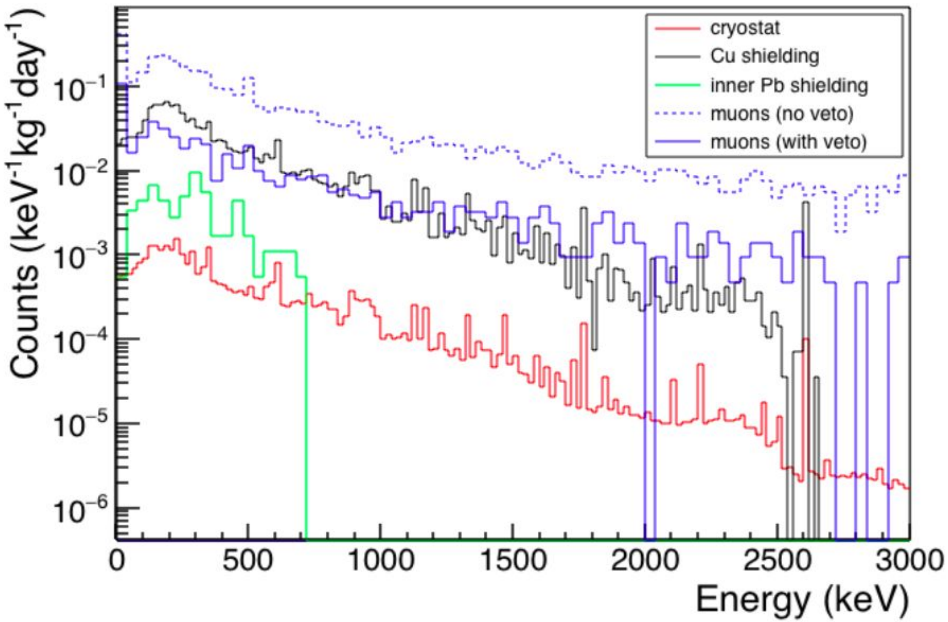
- 14-bit CAEN multichannel analyzer (DT5781A MCA)
- Custom, **open source** slow control github.com/AG-Schumann/Doberman
- InfluxDB + Grafana visualization

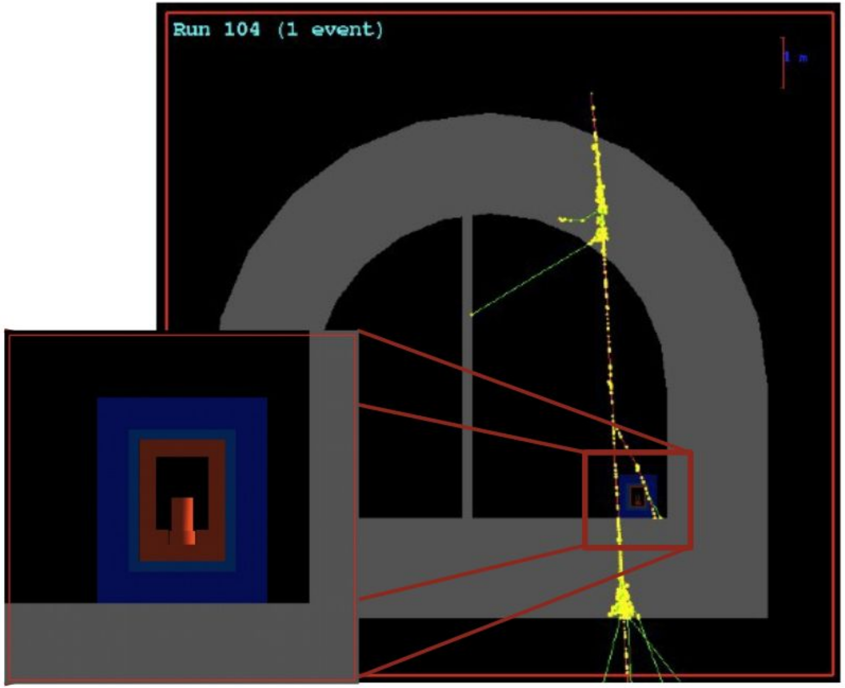


GeMSE: Design

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

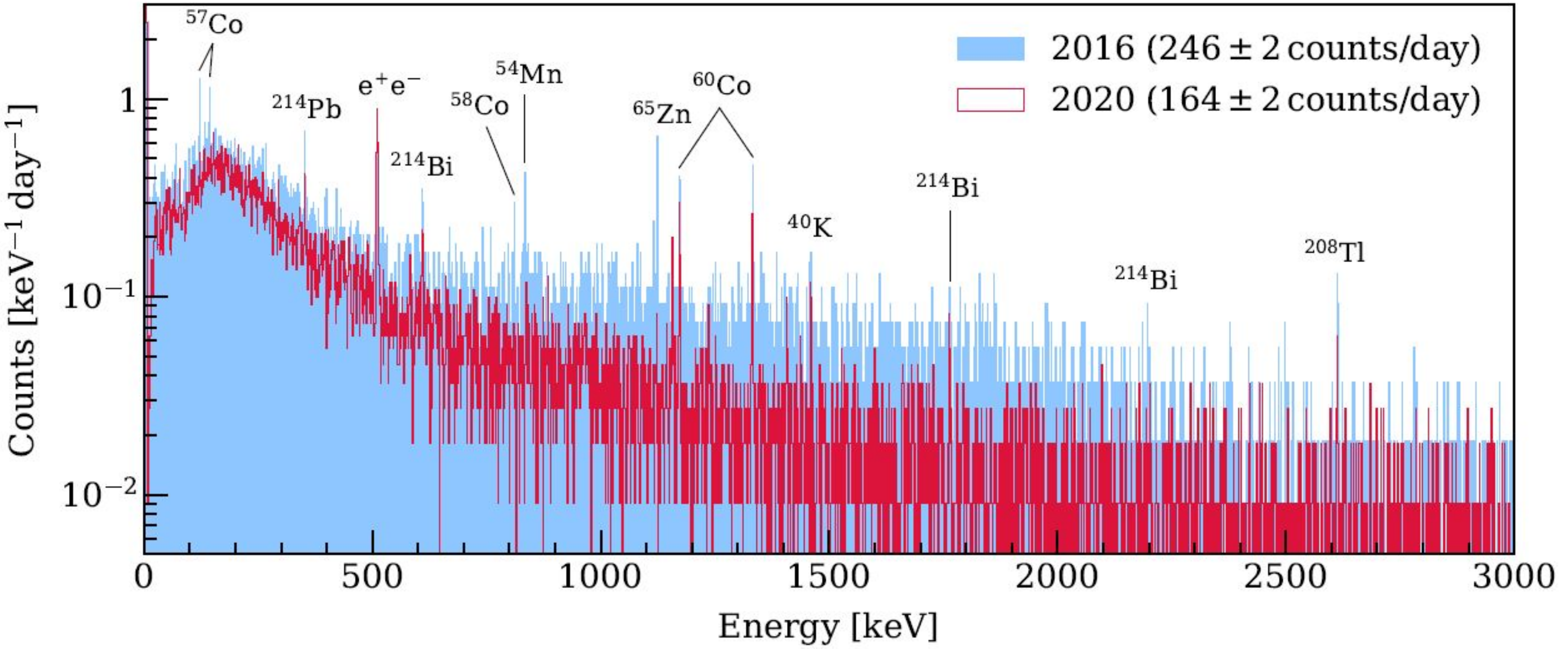
M. v. Sivers et al, arXiv:1505.07015



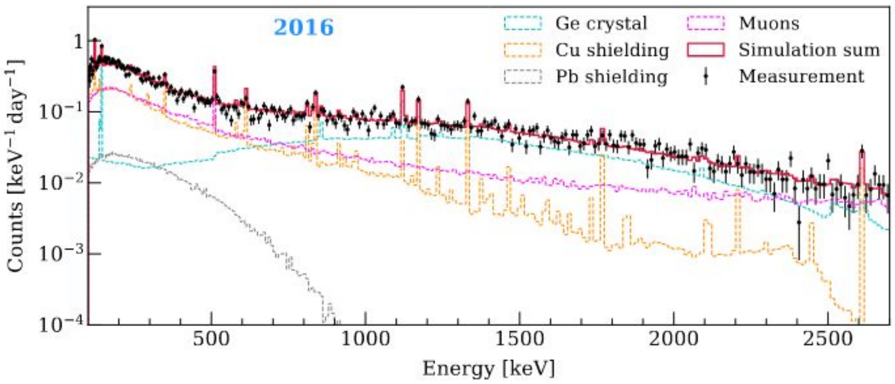


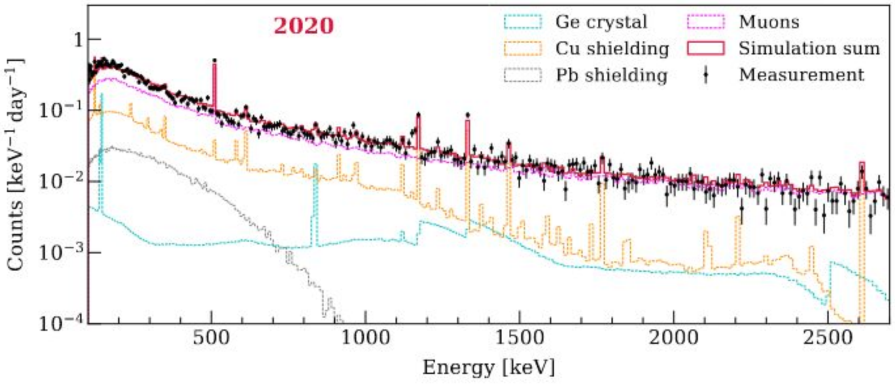
GeMSE: Design

GeMSE: Five-years of underground operation



GeMSE: Five-years of underground operation





Low integral background

- **(164 ± 2) counts/day** (100–2700 keV) GeMSE is among the most sensitive HPGe detectors available, even though it is operated only at moderate depth

Agreement of MC and expectation

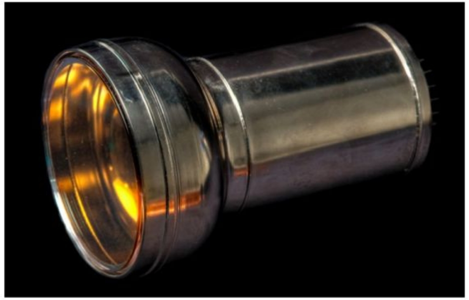
- Multi-component spectral fit
- Rate reduction as predicted
- Today: **muon dominated**
  - Avg. tagging efficiency of (31 ± 4)%
  - Efficiency can be improved

GeMSE: Analyzing a sample

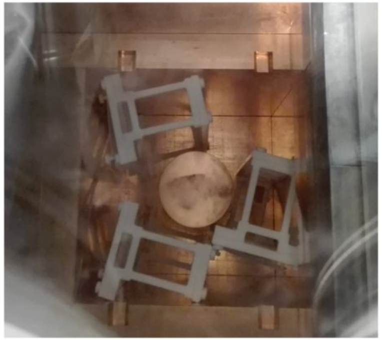
(Analysis environment set up for non-physics users)

I. Measure sample (and background)
II. Remove ^{222}Rn contamination in data
III. Derive energy calibration and resolution
IV. Perform efficiency simulations for sample
V. Fit gamma peaks of interest

XENONnT PMTs (Hamamatsu R11410)



PTFE holders (background)



10-PMTs batch + PTFE holders

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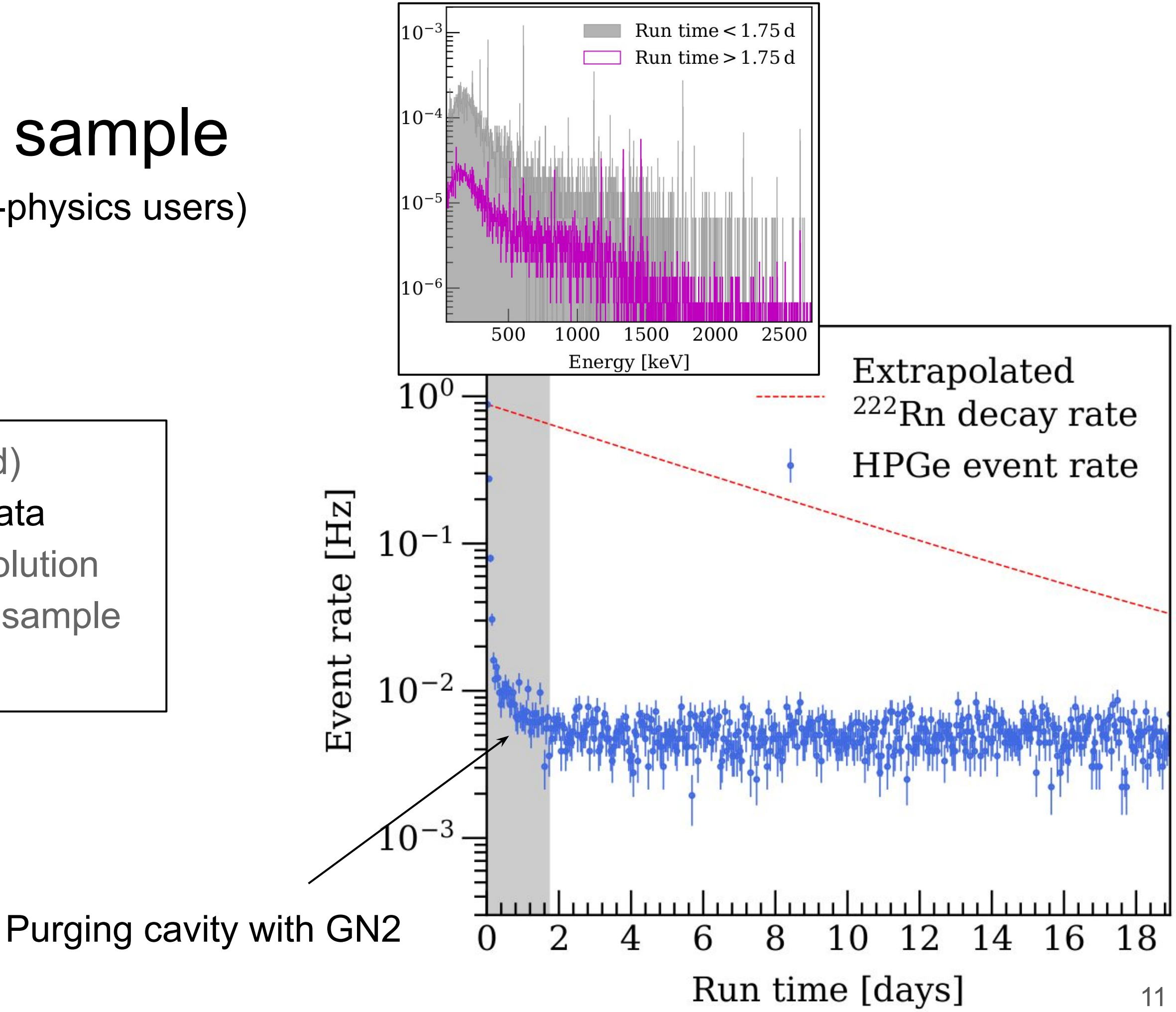

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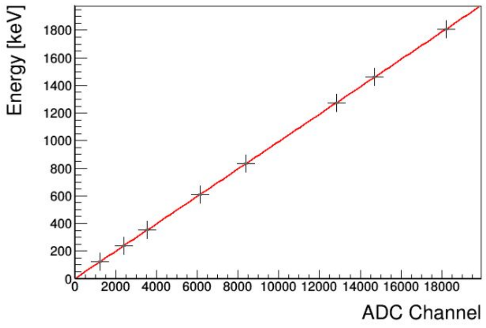
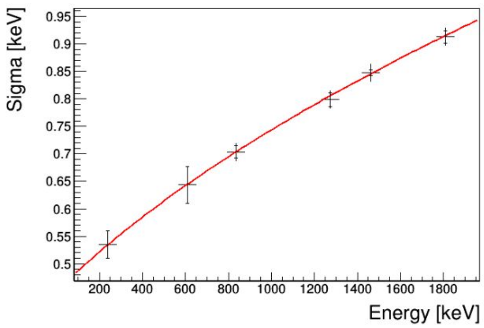
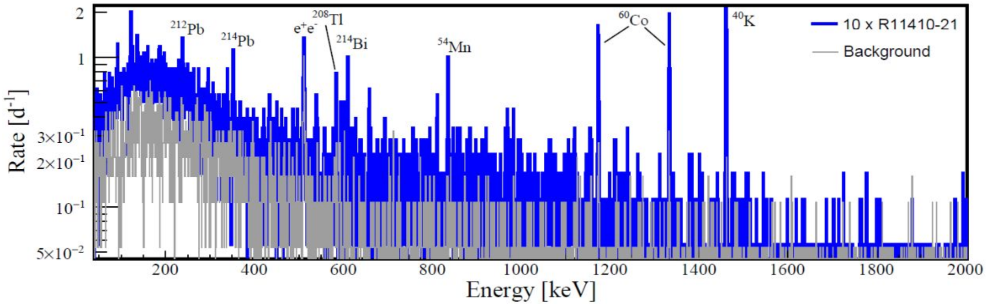




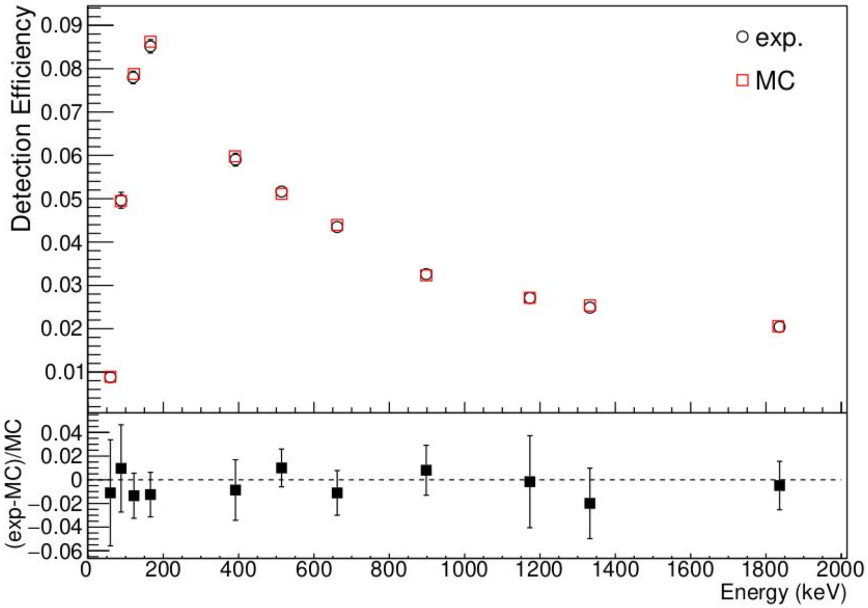
CALIBRATED COUNTING RATE AFTER MV DEAD-TIME CORRECTION



GeMSE: Analyzing a sample

(Analysis environment set up for non-physics users)

- GEANT4 branching ratio validation



M. v. Sivers et al., arXiv:1606.03983 (2016)
Comparison to CBSS2 source

I. Measure sample (and background)
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GeMSE: Analyzing a sample

(Analysis environment set up for non-physics users)

- GEANT4 branching ratio validation
- Sample implementation

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II. Remove ^{222}Rn contamination in data
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IV. Perform efficiency simulations for sample
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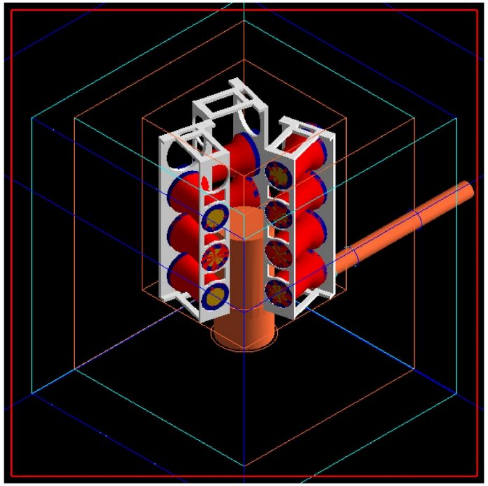

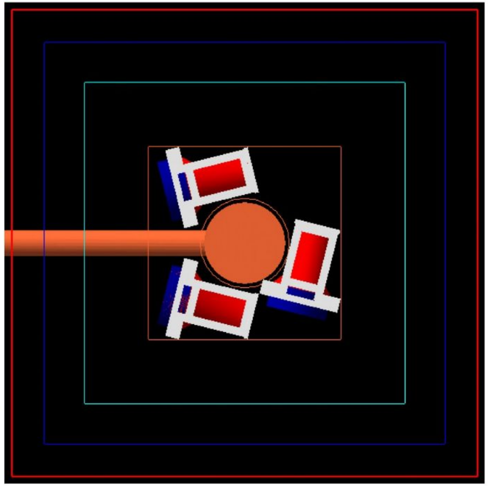

GeMSE: Analyzing a sample

(Analysis environment set up for non-physics users)

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

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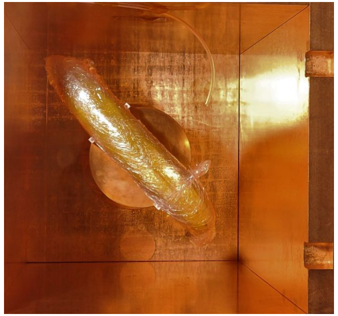

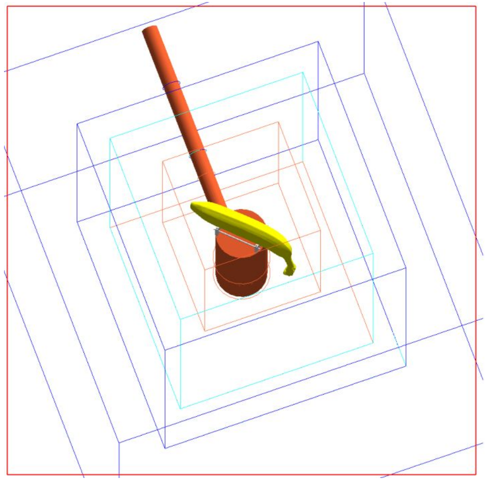

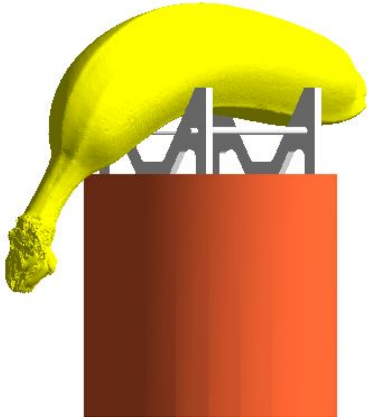

GeMSE: Analyzing a sample

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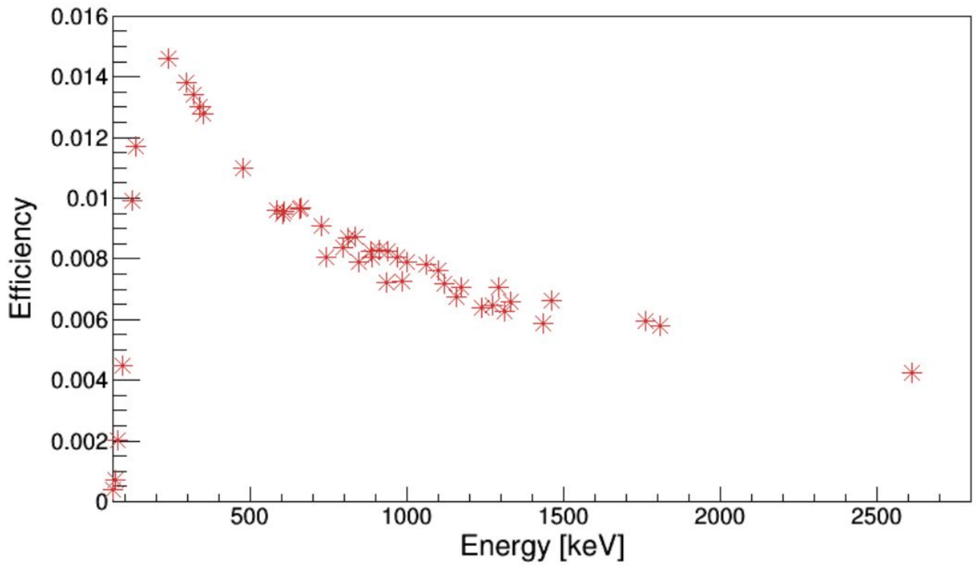
III. Derive energy calibration and resolution
IV. **Perform efficiency simulations for sample**
V. Fit gamma peaks of interest

SIMULATED DETECTOR EFFICIENCY



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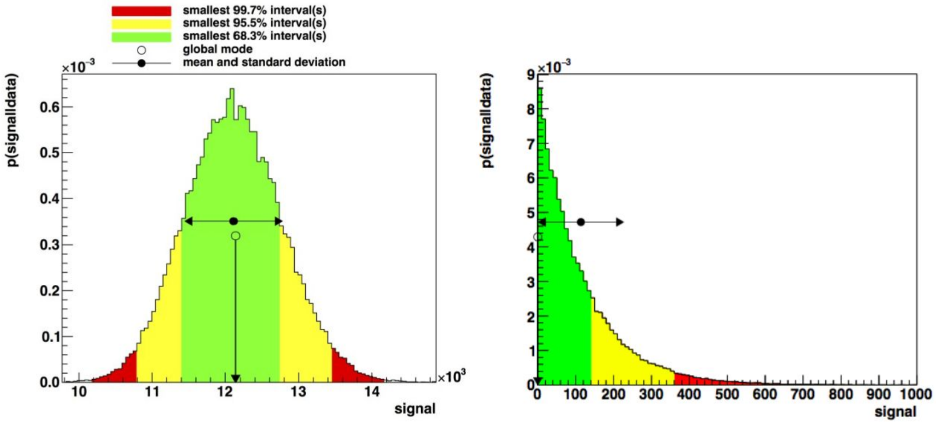
- Analysis based on the *Bayesian Analysis Toolkit* (BAT) A. Cadwell et al., arXiv:0808.2552
- Uncertainty on detection efficiency as Gaussian prior
- *Background-only* (B) and *signal+background* (S) fit in 5σ region
  - $\boxed{\text{BF} = P(B \mid \text{data}) / P(S \mid \text{data})}$
- BF < 0.33: Calculate activity
- BF > 0.33: Calculate upper limit



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	(10 PMTs, 19 days)	(10 PMTs, 21 days)
Isotope	**Batch 1 [mBq/PMT]**	**Batch 2 [mBq/PMT]**
^{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

GeMSE: 2016-background comparisons

Energy (keV)	Chain/Isotope	Count Rate (day^{-1})		
		GeMSE	Gator [23]	GeMPI [24]
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^{1}

- GeMSE @ 620 m.w.e depth
- Gator/GeMPI @ 3600 m.w.e. depth

Thank you for your attention!

GeMSE: M. v. Sivers et al., arXiv:1606.03983 (2016)
Gator: L. Baudis et al., JINST 6 (2011) P08010
GeMPI: G. Heusser et al., Radionuclides in the Environment, Elsevier (2006), pg. 495.

GeMSE: Background fit results (2016 vs 2020)

Source	Specific isotope activity [μBq/kg]									
	^{65}Zn	^{68}Ge	^{60}Co	^{58}Co	^{57}Co	^{56}Co	^{54}Mn	^{238}U	^{232}Th	^{40}K
Ge crystal (2016)	77^{+15}_{-13}	313^{+17}_{-23}	< 118	< 3.5	11^{+2}_{-1}	< 43	< 23	–	–	–
Ge crystal (2020)	< 5.7	< 15.1	< 26.4	–	$3.6^{+1.3}_{-1.1}$	–	< 5.4	–	–	–
Cu shield (2016)	–	–	43^{+7}_{-5}	< 26	374^{+48}_{-39}	< 7.6	< 56	104^{+13}_{-15}	42^{+9}_{-10}	< 196
Cu shield (2020)	–	–	35^{+3}_{-3}	–	121^{+23}_{-24}	–	< 11.5	53^{+7}_{-7}	30^{+5}_{-6}	103^{+36}_{-29}
Pb shield (2016)	^{210}Pb activity < 8.2 Bq/kg									
Pb shield (2020)	$= 7.4^{+0.5}_{-0.5}$ Bq/kg									
Muons (2016)	Flux $= 1.19^{+0.07}_{-0.09} \times 10^{-5}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$									
Muons (2020)	$1.44^{+0.04}_{-0.05} \times 10^{-5}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$									