Towards a low-background X-ray detector setup
at the Felsenkeller shallow underground laboratory

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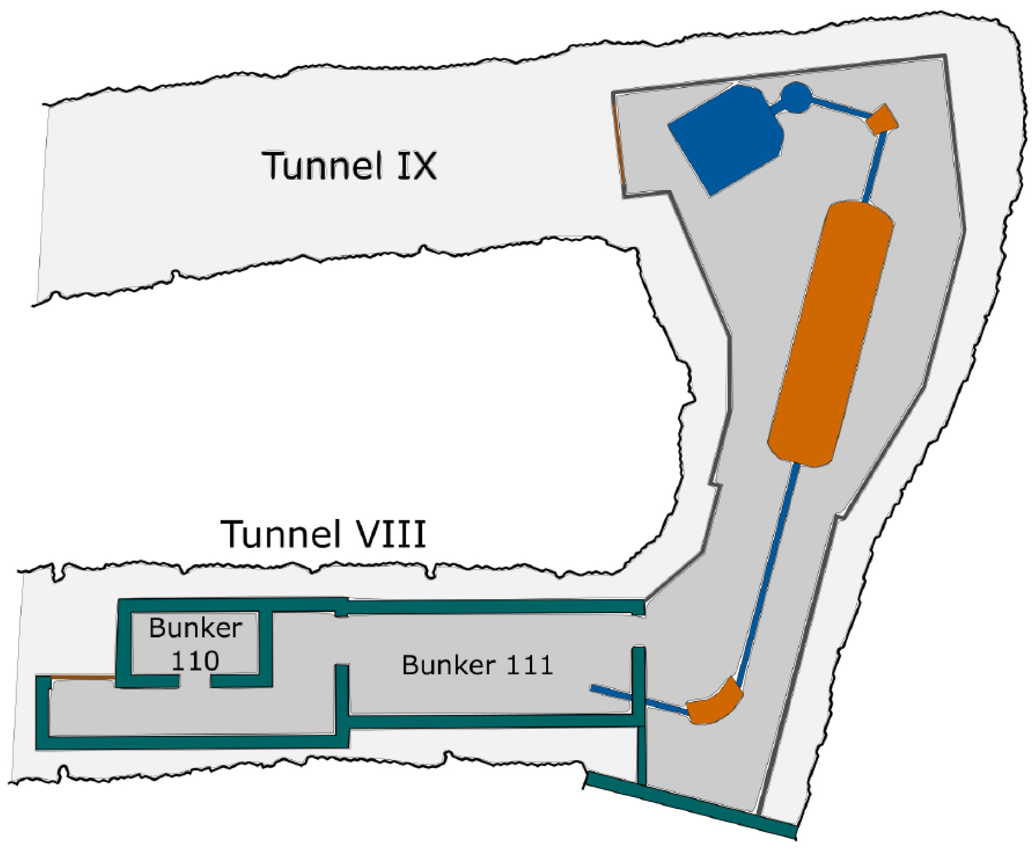
Motivation

X-ray spectrometry has a large variety of purposes within nuclear physics. One of them is the detection of nuclear decay processes. This is normally done by γ spectrometry, which is more universal due to the higher energy range of γ-ray detectors.
X-ray spectrometry can be the main analysis tool for decay processes with (almost) no emissions of high energy γ rays, where analysis with γ spectrometry fails to correctly display the decay. A respective example is the radionuclide ^{193}Pt, which decays via electron capture into the ground state of ^{193}Ir *(Q = 56.6 19 keV)*. Due to the X-ray emission induced by the electron capture, this decay can be displayed with X-ray spectrometry.
To enable and optimize the analysis process of such measurements, a low background setup will be installed at the Felsenkeller shallow underground laboratory. The core part of the setup is a shielding of multiple layers in order to reduce the environmental background measured by the detector as well as X-ray fluorescence within the respective samples.

Experimental setup

The Felsenkeller laboratory [1][2]:

- Contains a 5 MeV ion accelerator
- 45 m rock overburden
  140 m water equivalent
- Experimental bunker (40 cm concrete walls) as low background environment
- 14.9-17.8 Bq/kg and 15.6-17.4 Bq/kg for ^{238}U and ^{232}Th, respectively



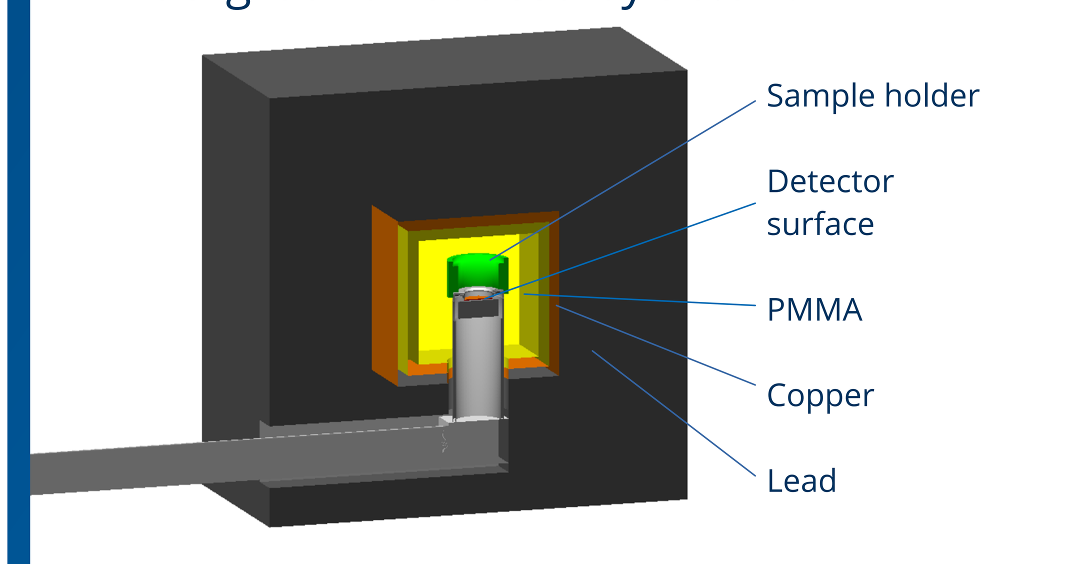
The Felsenkeller laboratory with it's accelerator and the experimental bunkers. Bunker 110 contains the X-ray detector setup.

The silicon drift X-ray detector:

- SiriusSD® Silicon Drift Detector
- 170 mm² total surface area collimated to 150 mm² active area
- 450 µm thick + 25 µm Be-window
- Working at room temperature, sensor chip cooled to -35 °C

The low background passive shielding setup:

- Multi-layer passive shielding consisting of Pb, Cu and PMMA [3]:
  - 64 mm Pb
  - 4 mm Cu
  - 5 mm PMMA
- Background reduced by 98.8 %



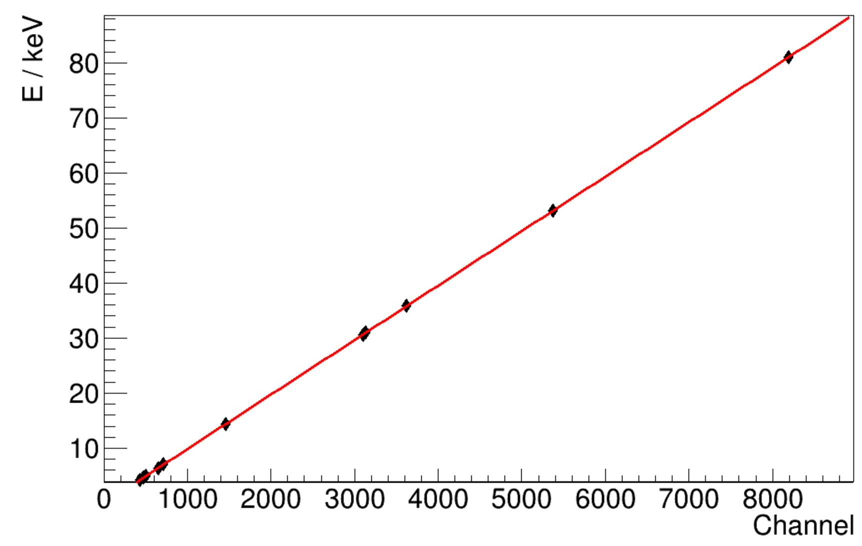
Scheme of the low background X-ray detector setup with multi-layer shielding.

Detector characterization

Calibration sources:

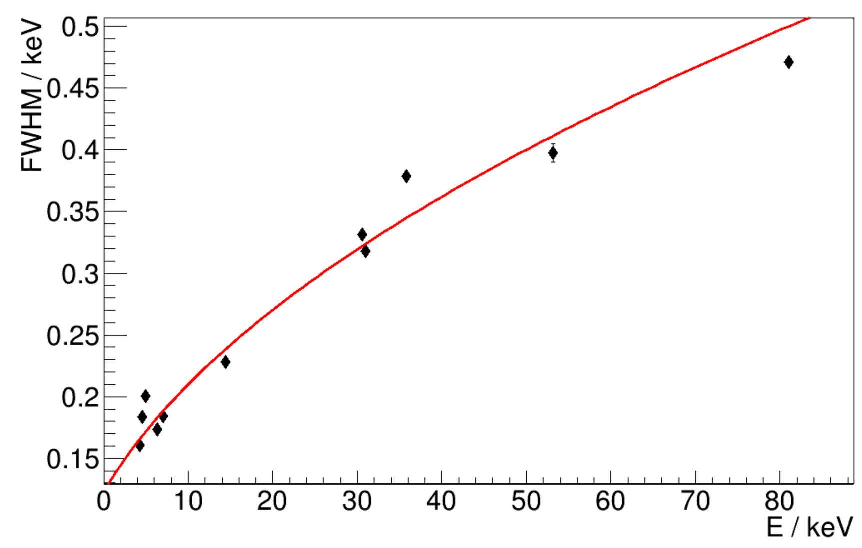
- ^{57}Co, ^{133}Ba
- Energy range from 4 keV to 81 keV (only lines with known emission probability [4][5] were used for efficiency calibration)

Energy calibration:



Energy Calibration with $E = a + b \cdot C$,
a = -4.79903 *22* keV
b = (9.8955 *16*) • 10^{-3} keV

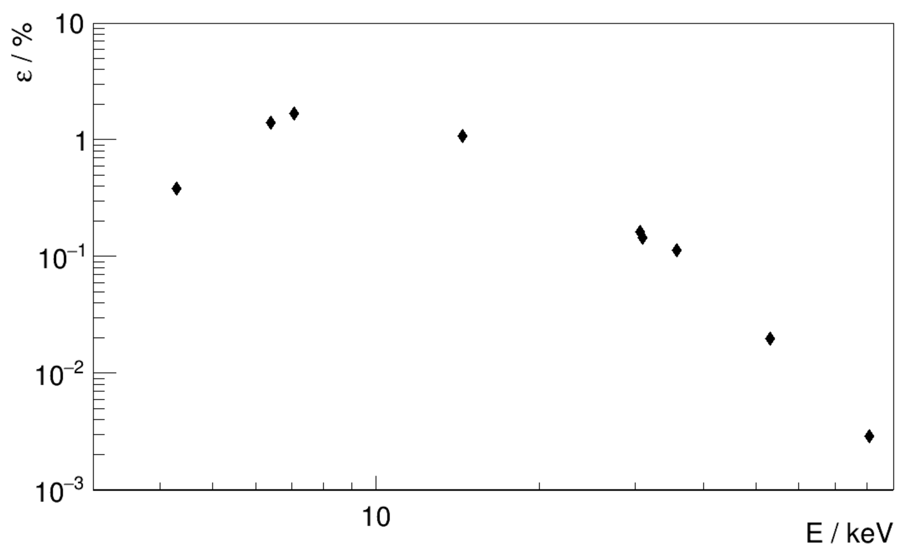
Energy resolution:



Energy Resolution with FWHM = $a \cdot (b+E)^{1/2}$,
a = -0.05385 *11* keV$^{1/2}$
b = 5.19 *5* keV

- 0.2099 *6* keV FWHM at E = 10 keV
- Deviations from fit function due to overlapping peaks

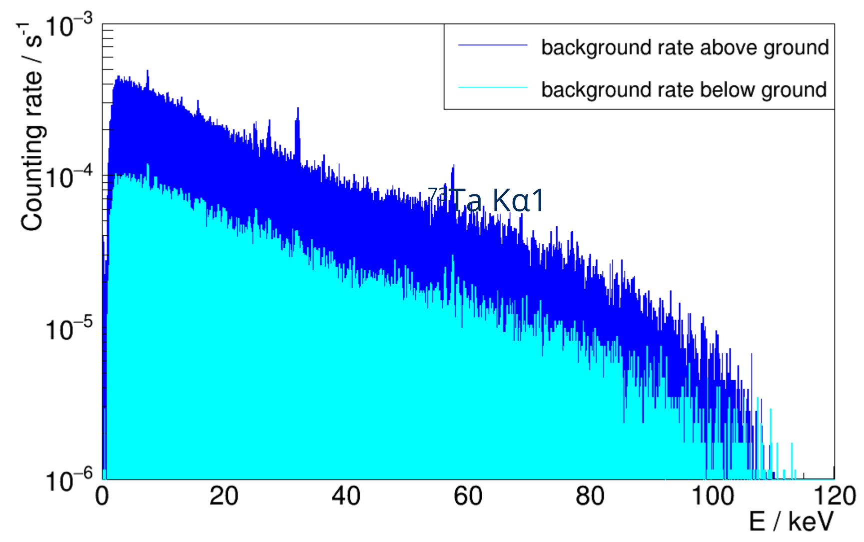
Full energy peak efficiency:



- 1.67 % efficiency at 7 keV
- Efficiency maximum between 7 and 10 keV
- Additional calibration sources necessary

Environmental Background investigation

- Environmental background outside (above ground) and inside the Felsenkeller laboratory (below ground)



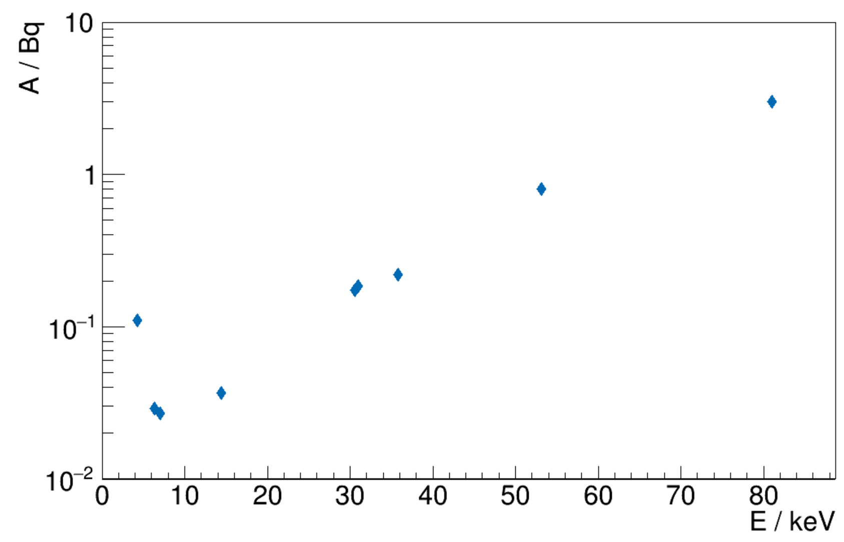
Background counting rates above and below ground without shielding.

Integrated counting rates:

- 2-10 keV:
  - above ground: 331.9 *14* cts • keV^{-1} • day^{-1}
  - below ground: 77.6 *7* cts • keV^{-1} • day^{-1}
  - Background reduced by a factor of 4.3

Activity estimation:

- Estimation of minimal activity of a sample such that the number of counts within the full energy peak equals the respective background:



Outlook

- Background measurements with completed setup
- Calibration with additional sources
- Muon coincidence experiments
- Replacing PMMA with borated PE

References:

[1] T. Szücz *et al.*, Eur. Phys. J. A 55 (10) (2019)
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[3] B. Vergoossen, Bachelor's thesis, TU Dresden (2022)
[4] Yu. Khazov *et al.*, Nuclear Data Sheets 112, 855 (2011)
[5] M. R. Bhat, Nuclear Data Sheets 85, 415 (1998)

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