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Full Background Characterization of Felsenkeller Underground Laboratory

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Abstract. Felsenkeller underground laboratory is a new 140 m.w.e. deep shallow-underground laboratory housing a 5 MV Pelletron ion accelerator for studies of nuclear astrophysics in Dresden, Germany. The no-beam background has been extensively studied for muons, neutrons and γ-rays and obtained data were matched by Monte-Carlo simulations for muons and neutrons with excellent agreement.

1. Introduction

Felsenkeller is a shallow underground site in Dresden, Germany shielded by 45 m rock overburden. This former brewery site houses a low background γ-counting facility in tunnel IV and a new laboratory with a 5 MV NEC 15SDH-2 Pelletron for nuclear astrophysics as well as a 150% HPGe detector for activation studies in tunnels VIII and IX.

An external cesium sputter source type 134 MC-SNICS provides negative ions for tandem mode usage and has already produced a carbon beam [1]. Additionally an internal radio frequency source can provide $^{1}\mathrm{H}^{+}$ and $^{4}\mathrm{He}^{+}$ ion beams running in single ended mode.

The laboratory walls consist of low radioactive concrete with activities of $16.4 \pm 1.4\,\mathrm{Bq/kg}$ $^{238}\mathrm{U}$ and $16.5 \pm 0.9\,\mathrm{Bq/kg}$ $^{232}\mathrm{Th}$.

This accelerator provides high beam intensities at background levels that are suitable for Nuclear Astrophysics. This contribution elaborates on the efforts made to categorize the background in the laboratories of Felsenkeller.

2. Muon Background

A muon detector using the close cathode chamber design was employed to measure the muon intensity in Felsenkeller with an angular resolution of $0.85°$ [2].

This detector is built of six chambers each with $25.6 \times 25.6\,\mathrm{cm}^2$ active area spaced apart by 3.5 cm in vertical direction housed in a plexiglas box. Each chamber is divided into 64 pads and 64 field wires which allows for a 64×64 areal resolution. A full skymap of the muon intensity (see Fig. 1) is created by combining all runs in seven different orientations, which lasted 3–4 days each. Two maxima can be seen at $\theta = 0°$ and 55–65° in NW direction which are the expected vertical maximum from cosmic radiation and the direction of the least overburden given by the terrain shape. The integrated intensity is $4.9\,(4)\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}$ which is a fourty-fold suppression compared to above ground.

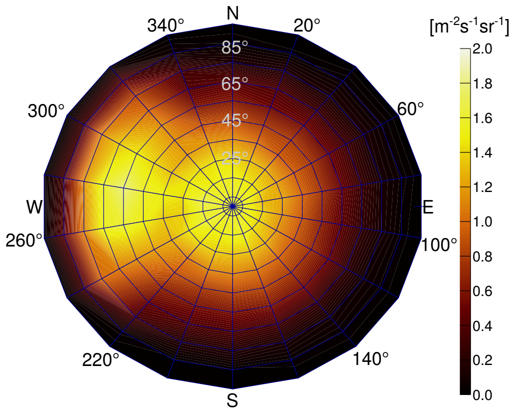

Figure 1. Muon intensity in tunnel VIII. Two maxima are visible at $\theta = 0°$ and 55–65°.

To supplement the data a prediction for the muon intensity was made using GEANT4. For this, the geometry of Felsenkeller was used based on aircraft-based laser scanning outside and georeferenced laser scanning inside. Very good agreement was reached and the skymaps could be reproduced very well.

3. Neutron Background

The neutron background was measured using seven polyethylene moderated, one bare and one lead-lined polyethylene moderated ^{3}He proportional counters [3]. The measurement was carried out in two campaigns A and B. Campaign A employed LND-252248 detectors with an active length and diameter of 60 cm and 2.44 cm with a pressure of 10 bar (97% ^{3}He, 3% CO_2). Campaign B featured three LND-252189 with a shorter active length of 30.5 cm but otherwise same properties. ^{3}He proportional counters are used to detect thermal neutrons with a cross section of $\sigma = 5333 \pm 7$. In order to resolve the ambient neutron spectrum over a wide range of energies, the tubes are placed into differently sized moderators each with distinctive neutron sensitivities $S(E)$. The neutron flux is then obtained by solving the under-determined problem for each detector rate R_i:

$$R_i = \int_0^\infty S_i(E)\Phi(E)dE \tag{1}$$

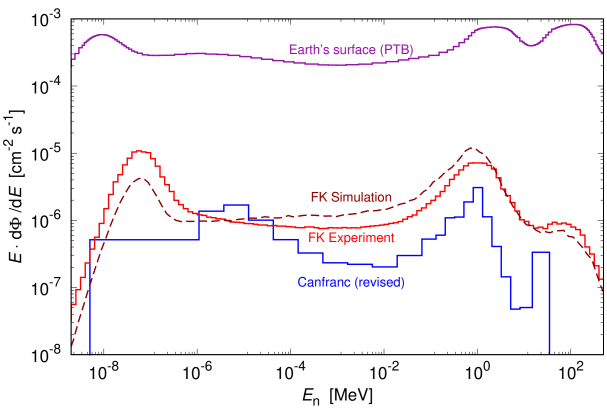

Figure 2. Neutron flux in Felsenkeller in comparison to the surface measured at PTB [4] and deep underground in LSC Canfranc [5, 6].

FLUKA simulations have been used extensively to simulate the energy-sensitivity as well as to develop a first guess neutron spectrum for the unfolding with MAXED and GRAVEL. Furthermore the guess spectrum is in good agreement with the final measurement results (Fig. 2).
Given the shallow-depth of the Felsenkeller laboratory, the neutron flux is dominated by muon-induced neutrons, which is different to deep underground laboratories. We find the lowest total neutron flux in a low radioactive rock shielded environment to be $0.67\,(5)\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}$.

4. Gamma Background

The γ-background has been measured underground in Felsenkeller as well as overground at HZDR site (300 m a.s.l.) with three HPGe detectors [1]. HZDR-1 and -2 are coaxial p-type HPGe detectors with a cylindrical shape and respective efficiencies of 88% and 60%. The third detector HZDR-3 consists of three Euroball HPGe each with 60% relative efficiency mounted together into a miniball triple cryostat. When used in add-back mode, a 240% relative efficiency is achieved. All detectors feature an active veto against the remaining muon flux made of BGO scintillator.
For detectors HZDR-1, -2 and -3 the respective running times were 26, 36 and 66 days. In the 6–8 MeV energy range we find a total suppression in respect to surface measurements of 1730 ± 160 and 2400 ± 300 for HZDR-1 and -2, as well as 688 ± 17 (single mode) and 557 ± 14 (addback mode) for HZDR-3. Comparing HZDR-1 and -2, it seems the larger Ge crystal of HZDR-1 leads to a lower suppression factor. In case of HZDR-3 the BGO covers a smaller solid angle than for the other two detectors.
For HZDR-2 the γ-ray energy spectra are shown in Fig. 3. The detector was placed at the surface and in two different locations in Felsenkeller. At low energy $E_\gamma < 3\,\mathrm{MeV}$, the background is dominated by the radionuclides of the wall. For MK1 the serpenite rock contains only 1.3 and 0.34 Bq/kg of ^{238}U and ^{232}Th, compared to 16 Bq/kg in tunnel VIII and 130–170 Bq/kg at surface. For energies above 3.5 MeV, both underground locations are very similar. This is the energy range where nuclear astrophysics experiments will be conducted in Felsenkeller.

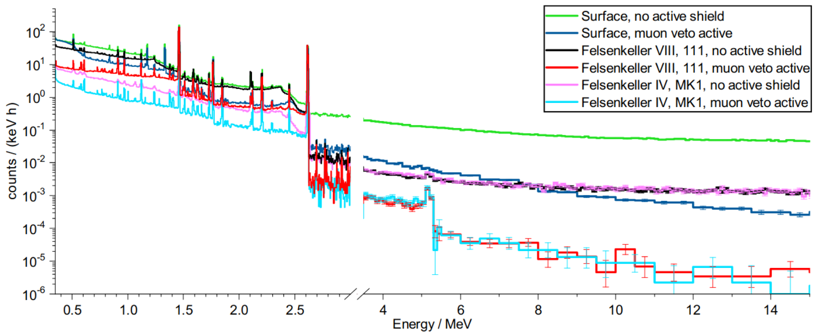

Figure 3. γ-ray energy spectra recorded with detector HZDR-2 (60% HPGe) at Earth's surface, underground at Felsenkeller tunnel VIII, room 111, and at Felsenkeller tunnel IV, MK1.

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