Cosmic Background Measurements at a Proposed Underground Laboratory by the REGARD Muontomograph

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Abstract. A portable cosmic particle tracking detector has been developed by the REGARD group with angular resolution of 10 mrad. The Close Cathode Chamber based tracking system is optimized for environmental and geophysical applications with its weight of 15 kg and size of 51 cm × 43 cm × 32 cm. Our aim was to determine the cosmic background at the site of the proposed accelerator and experimental facilities at an approximate 50 meter depth in Felsenkeller, Dresden, Germany. Here, we present our high-precision muon flux measurements, which have been performed during 44 days in one of the tunnels. Angular acceptance of our mapping covered full $2\pi$ solid angle of the upper hemisphere. The maximum flux value is found to be below $2.5 \text{ m}^{-2}\text{sr}^{-1}\text{s}^{-1}$.

1. Introduction

The next generation of low energy ion beam experiments will provide more details about the reactions of stable nuclei. For better understanding of these processes, more precise cross-section data are needed at low energies which require low-radiation background [1]. Due to this, experimental facilities of this kind are usually located underground, since the muonic component of a cosmic ray induced background is attenuated by the rock overburden. Therefore, the knowledge on the muon flux is a key element to propose and design underground accelerator experiments. Our aim is to perform a high-precision measurement of the cosmic muon background to cover the full $2\pi$ of the upper hemisphere at a proposed laboratory at shallow depth underground in Felsenkeller, Dresden, Germany [2]. In this contribution we briefly describe the detector and present the analysed data.

2. Portable tracking system for charged particle detection

A portable cosmic particle tracking detector has been developed by the REGARD group (Collaboration of the Wigner RCP of HAS and the Eötvös Loránd University on Gaseous Detector R&D). The Close Cathode Chamber based tracking system [3, 4] is optimized for geophysical applications [5, 6] with its weight of 15 kg, size of $51 \times 46 \times 32 \text{ cm}^3$, sensitive area...
of 0.1 m² and angular resolution of 10 mrad. Our muon telescope is housed in a plexiglass box, which besides giving mechanical support, provides environmental isolation as well. In addition the Muontomograph was upgraded with stand including a swivel joint in order to perform tilted measurements in different angles at a fixed location.

The CCC-chambers of the detector require continuous 1 – 5 l/h gas flow during data taking. In our case the gas is a standard, non-flammable mixture of Ar and CO₂ in 82:18 proportion. A PIC32 microcontroller based data acquisition (DAQ) system was developed and its small size units fit well between the middle tracking layers. All functions (high/low-voltage units, trigger system, data handling, environmental control, human-machine interface, etc.) are integrated into the common system plan including a simple, user-friendly control system.

The measured track coordinates are read out by the chains of the Front-End Electronics (FEE) and written to a standard Secure Digital (SD) card. Such a memory card with e.g a 2 GB capacity enables a full year of run time recording in 50 meter-rock-equivalent depth. The total power consumption of the complete detector is less than 5 W, thus the Muontomograph can operate for a week supplied by a standard 50 Ah battery. Using a 10 l gas bottle is enough for about a month of data taking.

3. Cosmic background measurements in Felsenkeller, Dresden, Germany

Our aim was to map the muon flux at the proposed place of the future underground laboratory facilities, which is covering the full 2π solid angle of the upper hemisphere with high-enough statistics. The cosmic muon flux measurements have been performed between 12th February and 27th March 2013 in Felsenkeller. Our detector was at a fixed position during the whole period, where we performed multiple-directional, partially overlapping measurements. Besides the vertical setting (highest statistics) the detector was oriented to 350° relative to the magnetic North, and 5 further directions were also measured, tilted by 45° to the azimuth. Data taking was without degradation in detector performance, which was above 97% efficient – as it used to be in earlier measurements as well [5, 6].

Table 1 summarizes all the parameters of the runs with all angular settings: detector directions given in spherical coordinates (the azimuth angle to the magnetic North and the zenith angle, both are in degree units), the duration of measurements are in days. The number of detected cosmic muon tracks is listed too.

### Table 1. The summary table of our measurements in Felsenkeller: the detector positions in azimuth to the magnetic North and in zenith, the duration of the measurements as well as the number of penetrating muon tracks.

| Azimuth (deg) | Zenith (deg) | Time (day) | Number of tracks |
|---------------|--------------|------------|------------------|
| 350°          | 0°           | 17.5       | 215,000          |
| 350°          | 45°          | 7.5        | 60,000           |
| 80°           | 45°          | 4.5        | 110,000          |
| 170°          | 45°          | 3.5        | 26,000           |
| 260°          | 45°          | 4.5        | 45,000           |
| 305°          | 45°          | 1.5        | 21,000           |

Standard high-energy physics tracking procedures have been applied during the offline data analysis. The first step was the track reconstruction based on the recorded clusters on the CCC planes. The determined muon flux have been corrected for all systematic effects such as detector
acceptance, time of measurement, trigger efficiency and angular-dependent tracking efficiency as well. See more details in Refs. [5, 6].

4. Results

The muon telescope reliably operated during the 44 days meanwhile, about 477k events were collected all together. This statistics were satisfactory for our analysis. The first step was to compare the measured vertical flux to earlier data in the units of m\(^{-2}\)sr\(^{-1}\)s\(^{-1}\). As shown in Fig. 1 data are in good agreement with the earlier measurements and empirically parametrized curve [7].

In Fig. 1, the blue circles are for data and green dashed lines both taken from Ref. [7]. Red and black dots are taken by the Muontomograph from earlier and this measurement respectively. As black triangle denotes, the vertical flux is 1.78 ± 0.23 in the tunnel of Felsenkeller under 50 meter-rock-equivalent depth with the rock density of 2.40 ± 0.2 g cm\(^{-3}\).

![Figure 1](image)

**Figure 1.** The vertical absolute cosmic muon flux (m\(^{-2}\)sr\(^{-1}\)s\(^{-1}\)) versus density depth (hg cm\(^{-2}\)). Our measurements are compared to the empirical formula, which based on an earlier work [7].

Using the 6 data sets listed in Table. 1 all overlapping zenith and azimuth directions were merged and binned using the SURFER 9.0 [8] software. The obtained flux-map of the cosmic muon background is shown in Fig. 2, where the flux of cosmic muons appears with color-scale contours in units, m\(^{-2}\)sr\(^{-1}\)s\(^{-1}\) as a function of zenith and azimuth angles. The red contour lines show the overburden rock thickness above the detector in meter-rock-equivalent, which has been calculated based on our laser scanning total station shots — in parallel with the data taking.

As expected, the measured muon flux correlates well with the overburden rock thickness: the colour scaling and the red contours are mainly parallel to each other in Fig. 2. The maximum muon flux is found to be below 2.5 m\(^{-2}\)sr\(^{-1}\)s\(^{-1}\). The highest flux were measured in the direction of the zenith and the entrance of the tunnel to West.

The obtained vertical absolute flux in Fig. 1 and the flux map in Fig. 2 provide well defined baselines for the design of the proposed accelerator-based experiments in the Felsenkeller site. However, we note, other natural background sources might also exist, which should be targets of forthcoming checks.
Figure 2. The measured $2\pi$ cosmic background in $m^{-2}sr^{-1}s^{-1}$ units from the detector point of view at the place of the proposed accelerator-based experiment. The detector was oriented to $350^\circ$ to the magnetic North. The measurement error is typically 3-10% statistical and 5% systematic.

5. Summary and Conclusions
The cosmic background have been measured in the full $2\pi$ solid angle of the upper hemisphere by the newly developed portable tracking detector at an underground laboratory in Felsenkeller, Dresden, Germany. As we expected, the maximum muon flux value is found to be below 2.5 $m^{-2}sr^{-1}s^{-1}$. The results quantify the shielding of Felsenkeller tunnel system for the proposed radioactive ion beam experiments. The portability, reliable tracking performance, low power consumption and the good angular resolution make the presented Muontomograph to be a useful tool to perform reference measurements of cosmic background.

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