Close Cathode Chamber technology for muon radiography experiments

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RMKI ELTE Collaboration on Gaseous Detector Research and Development

Muon Radiography

The collisions of primary cosmic particles with the upper atmosphere generate particle cascades, from which atmospheric muons emerge. These highly penetrating particles reach the Earth surface and below, to a depth of up to few hundred meters, depending on muon energy. **Measuring the number of traversed particles or the change of the trajectory, one can make a radiographic visualization of the density of the object.** This method is not destructive and involves natural radiation, however due to the limited particle flux it is optimal for the investigation of objects in the 1-100 m scale. Muon radiography has been a geological tool to study volcano structure, search for caverns in underground cave systems, and has been implied as detector of hidden nuclear material inside vehicles and cargo containers. The aim of the REGARD group (Wigner RCP and Eötvös University Collaboration on Gaseous Detector R&D) is to develop detector systems for muon radiography experiments.

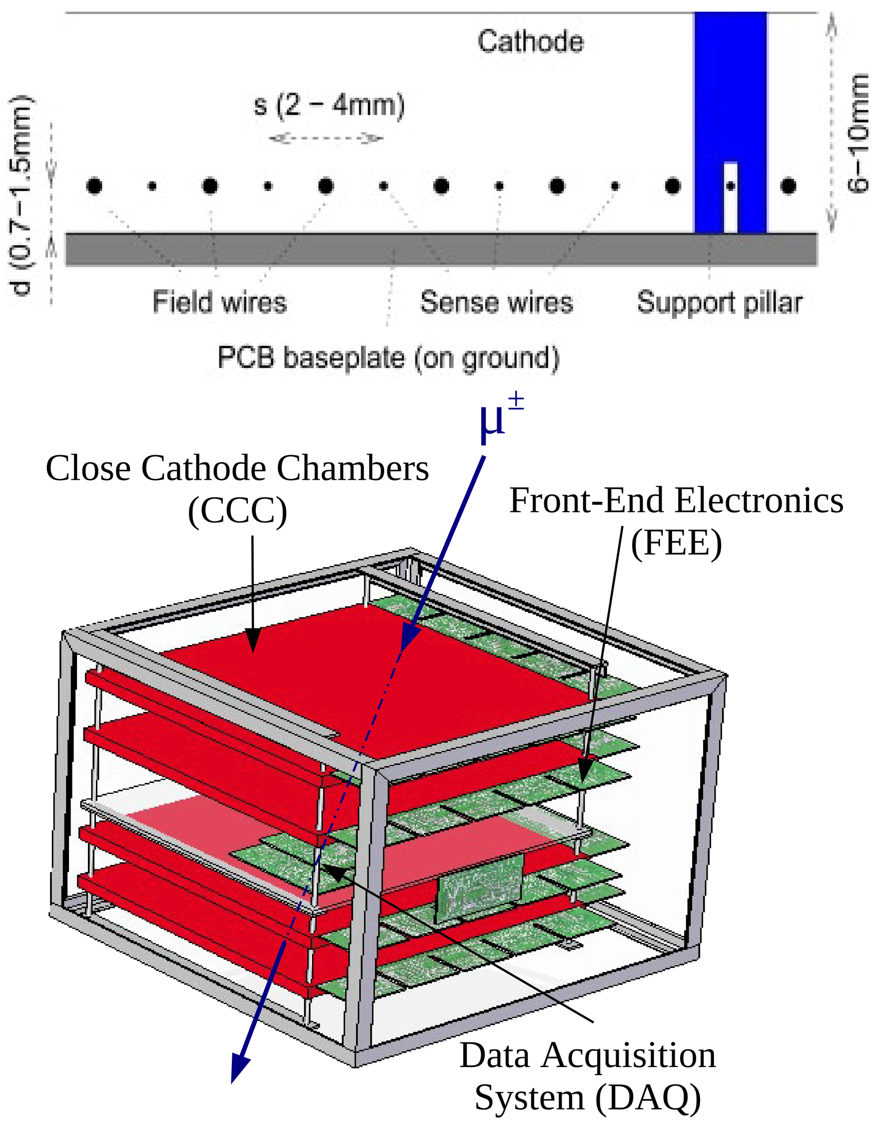

Fig. 1: The structure of Close Cathode Chamber (*upper panel*) and the scheme of the portable muon telescope (lower *panel*).

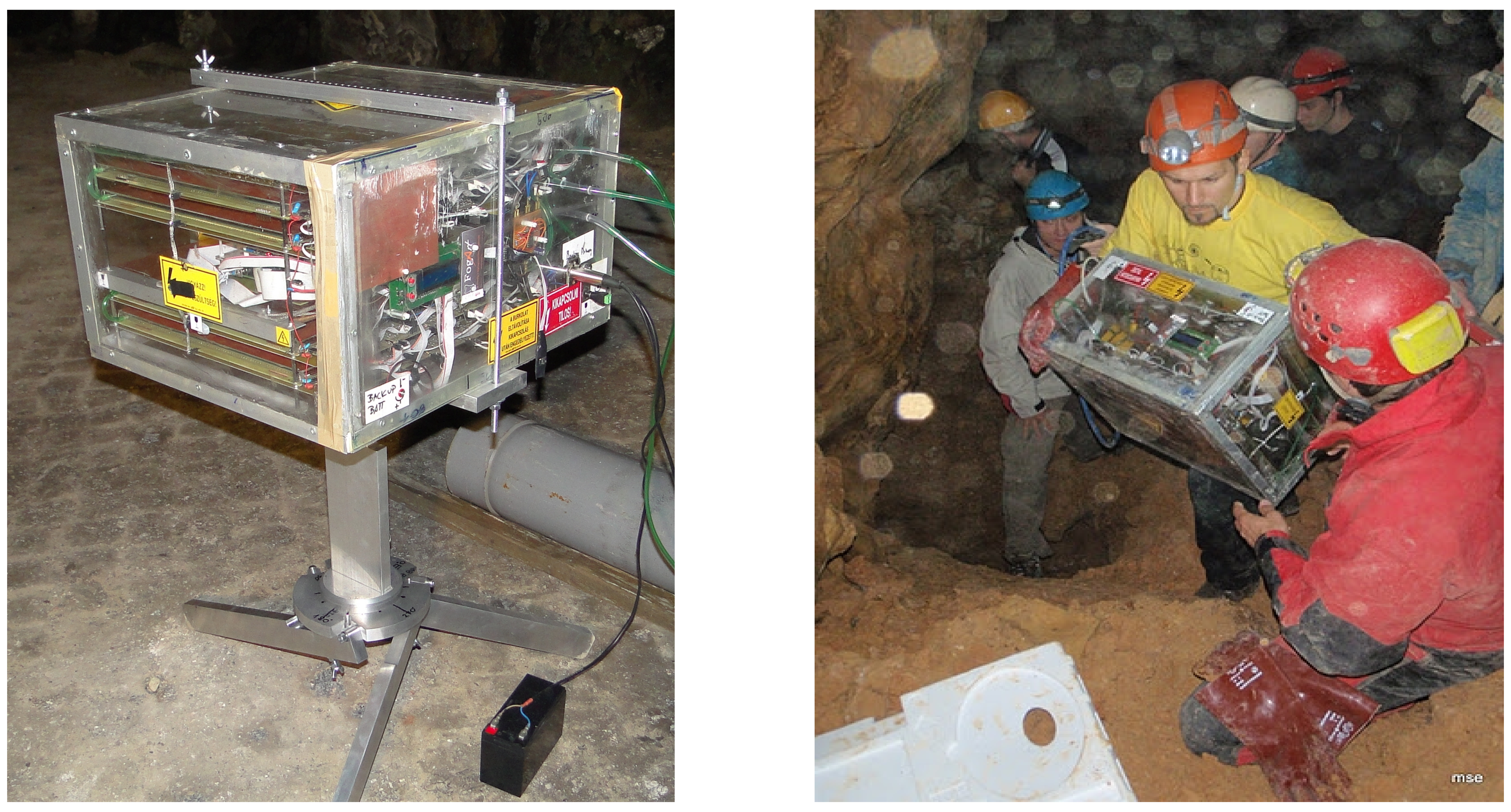

Fig. 2: The Close Cathode Chamber-based tracking device measures the cosmic background in a tunnel system in Felsenkeller Germany (*left panel*) and its installation in the Ariadne Cave System in Pilis Mountains, Hungary (*right panel*).

Data Acqusition and Power Supply System for a Mobile Detector

The data collection and management (Data Acquisition, DAQ) and optimal power supply (both low and high voltage) is a challenge for a versatile application. A small size DAQ based on **PIC32 microcontroller was** specifically developed for outdoor measurements. All functions (high voltage unit, low voltage, trigger system, data handling, permanent storage on SD card, environmental control, human machine interface, etc.) are integrated into a common system plan (*left panel of Fig. 3*). The total power consumption of the complete detector is less than 5 W, which means that **the detector can operate independently for a week by a 50 Ah battery.** An alternative DAQ based on the **Raspberry Pi** (*right panel of Fig. 3*) computer has also been developed for small size, low power cosmic setups, allowing high level remote control and data management.

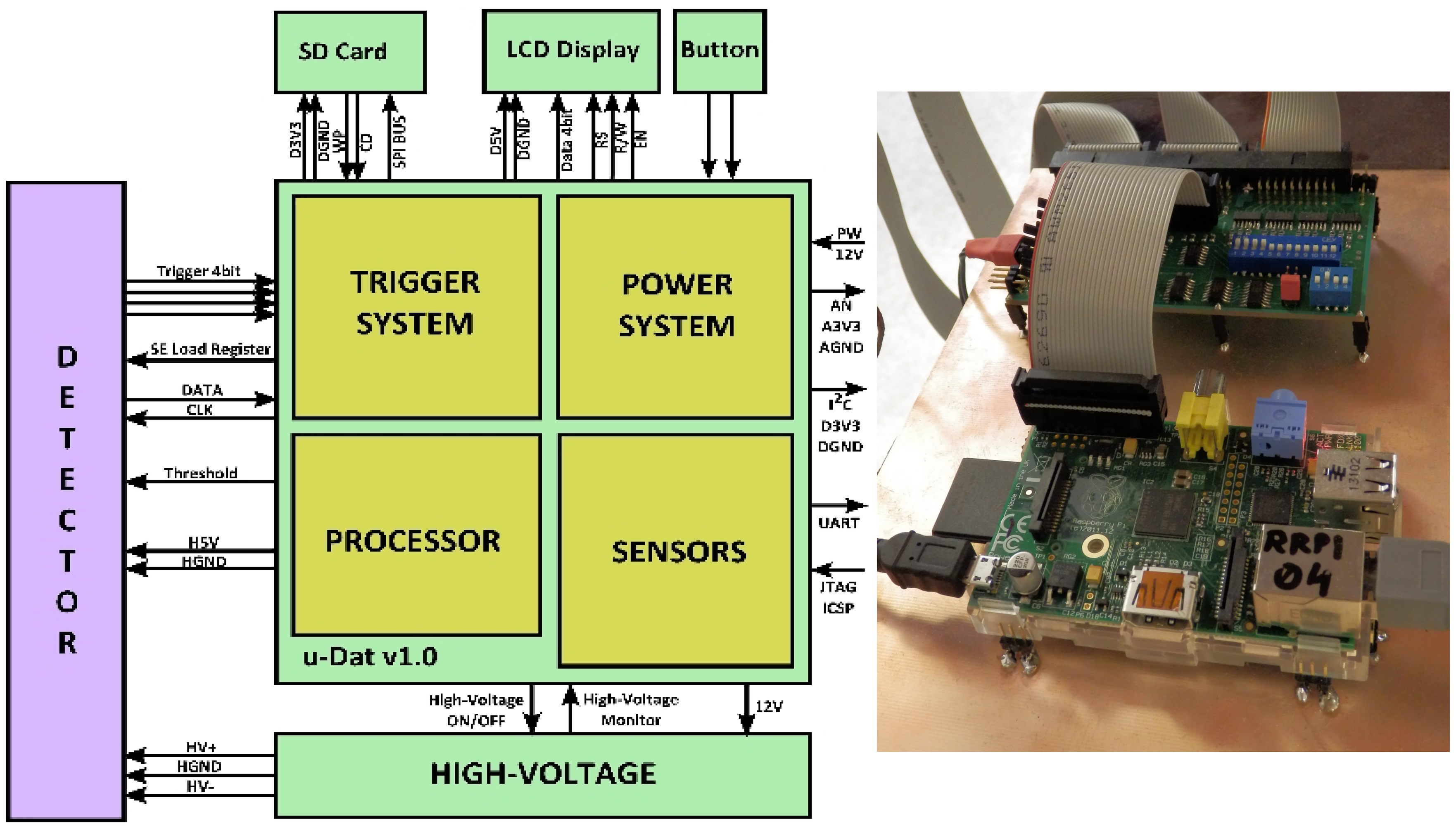

Fig. 3: *Left:* PIC32-based DAQ + power supply system plan. *Right:* Raspberry Pi controlled DAQ.

Radiography by scattering: High Z-material Detection

The effect of multiple scattering changes the muon direction. Dense, high-*Z* materials (e.g. U, Pb) are especially effective scatterers. Charged particle tracking detectors placed around an object of interest (even vehicles or cargo containers) can be used to make a tomographic image of high density regions inside an object, a concept that originates from decades ago. At Wigner RCP, a cosmic setup has been built with four CCC-s of 0.5 m × 0.5 m size to demonstrate applicability of this detector technology for imaging with muon scattering. *Figure 5* shows the 2-dimensional scattering power image for different materials (Pb, Fe and Al). The cost-effective CCC detectors can be a competitive technology for this application.

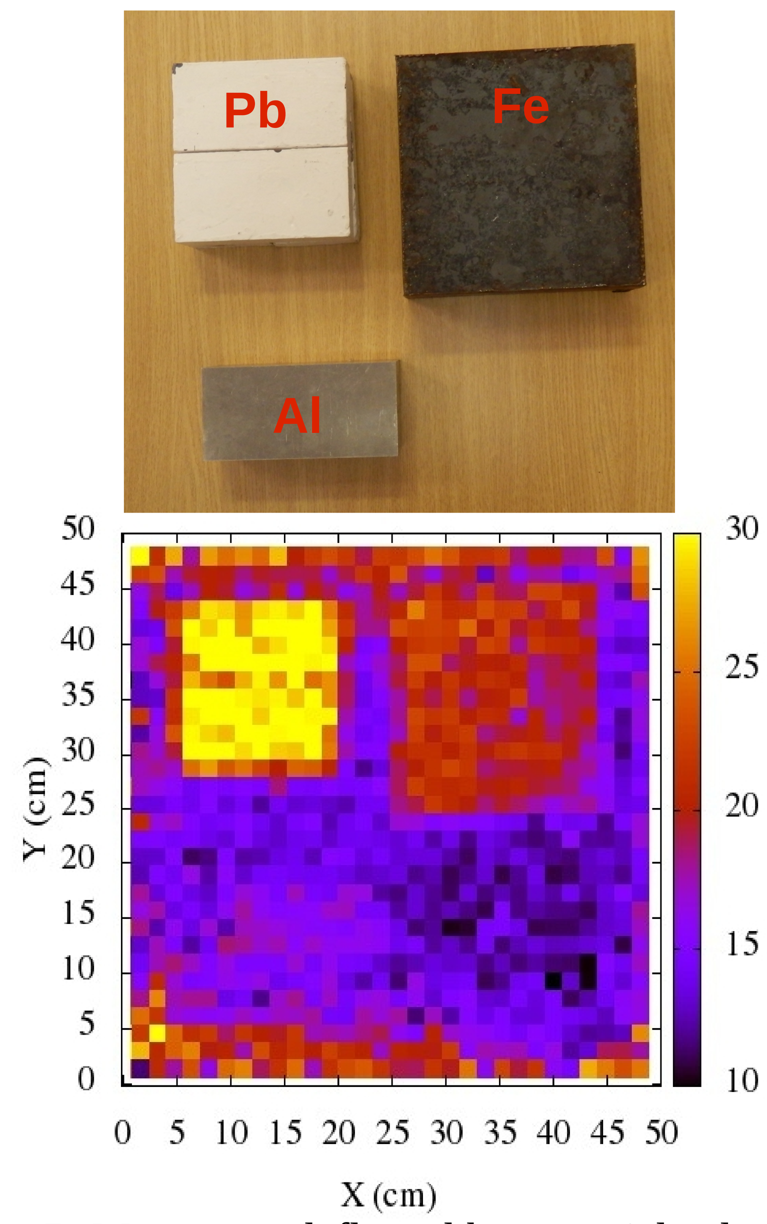

Fig. 5: Muons are deflected by materials placed between tracking layers (*top panel*), and the corresponding measured scattering strength (*lower panel*, arb. units) for various materials, shows clean tagging of dense, high-*Z* materials with CCC detectors.

Cosmic Muon Tracking

For particle tracking, the Close Cathode Chamber (CCC), an asymmetric Multi-Wire Proportional Chamber [1,2] has been applied. The CCC-s do not involve heavy frames to hold the wire tension, and has thinner walls than usual MWPC-s. The *upper panel of Fig. 1* shows the inner wire structure, with the lower segmented cathode on ground potential is as close to the wire plane as 1.5 mm. The distance between the wires is 2 mm. Signals from the wires and the cathode strips provide two-dimensional hit information from a single layer. The CCC's main advantage for portable tracking systems is tolerance for mechanical distortions and shocks. The *lower panel of Fig. 1* shows the scheme of the portable tracking detector which is optimized for environmental [3,4,5] applications with its size of 51 × 46 × 32 cm^3, weight of 15 kg, sensitive area of 0.1 m^2 and angular resolution of 10 mrad. The detector requires continuous gas flow during data taking; few liters per hour of an inexpensive, non-flammable Ar/CO_2 mixture.

Applications of Muon Detection at Shallow Depths Underground

Precision data on the cosmic background is an important element of low background nuclear experiments. **The cosmic background have been measured** at the site of a proposed experiment in Felsenkeller, close to Dresden, Germany. The muon telescope reliably operated during the 40 days of measurements. The map of the measured cosmic muon background is shown in the *left panel of Figure 4*: the flux of cosmic muons appears with color-scale contours in $m^{-2}sr^{-1}s^{-1}$ units. The **results provide a well defined baseline for the design of the proposed accelerator-based experiments** at the Felsenkeller site. The portability and low power consumption allowed remote measurements in highly humid cave and tunnel systems. The applicability has been tested in the Ariadne Cave System (transport is illustrated in the *right panel of Fig. 2*). In the *right panel of Fig. 4 below*, the muon flux is shown to be consistent with the expectation from the known surface geometry, assuming constant rock density [3,4].

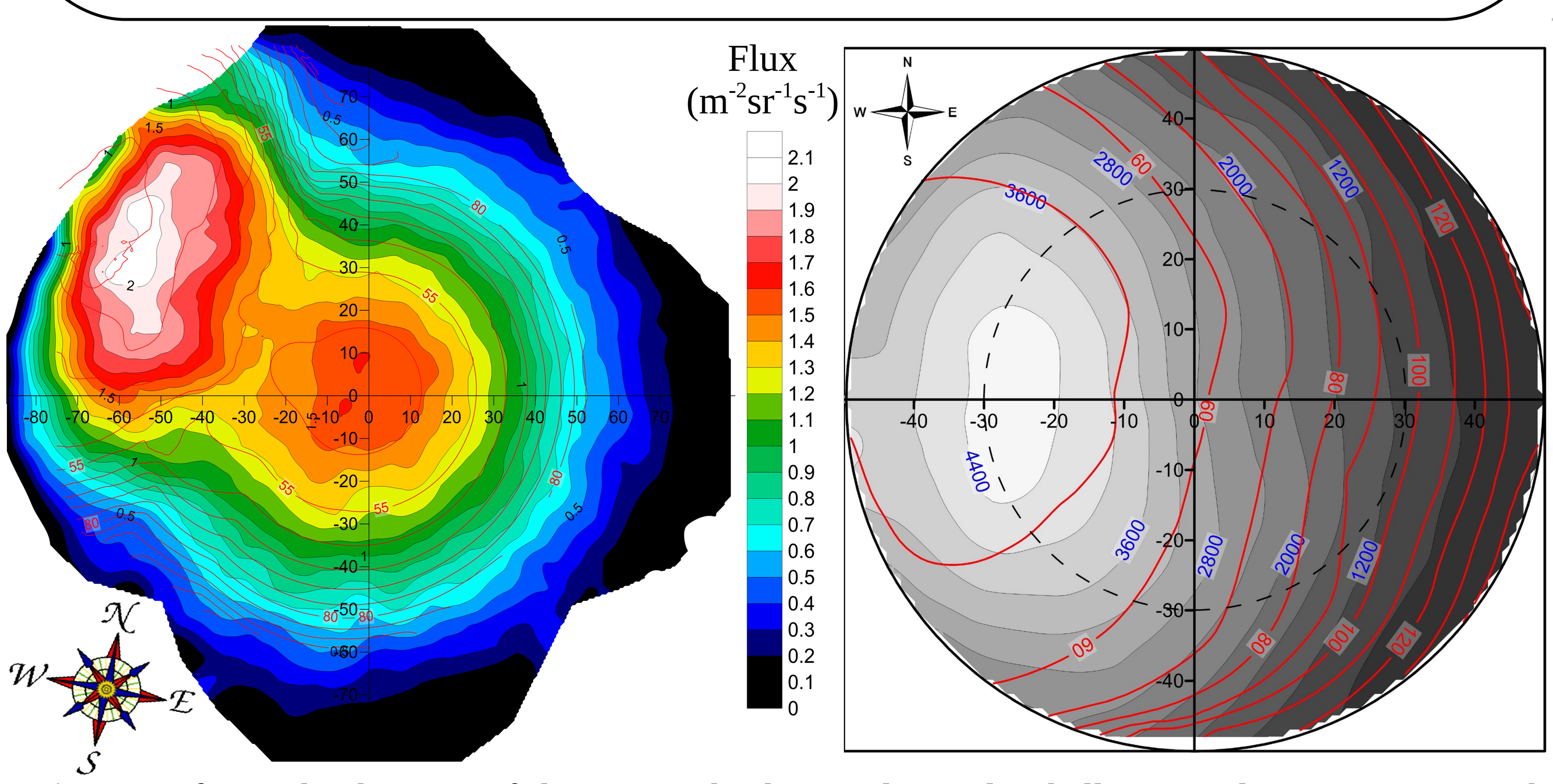

Fig. 4: *Left panel:* The map of the cosmic background in Felsenkeller, Dresden, Germany. *Right panel:* Cosmic muon flux (*gray shaded*) has been measured in the Ariadne Cave System in the Pilis Mountains Hungary, compared with surface distance from the measurement point (*red lines*).

Summary

The Close Cathode Chamber technology and its application for cosmic background measurement, detection underground tunnels and scattering measurement are presented. The cost efficiency, portability, reliable tracking peformance, low power consumption and the good angular resolution makes it a competitive choice for muon radiography.

References:

[1] NIM A648 (2011) 163–167
[2] NIM A698 (2013) 11–18
[3] NIM A689 (2012) 60-69
[4] Geosci. IM, 2, (2012), 781-800
[5] Adv. in HEP (2013) 560192 7

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