Gaseous tracking detectors at the Sakurajima Muography Observatory

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Abstract. Muography is a novel imaging technology to reveal density structure of hill-sized objects. The cosmic muons predictably lose their energy and penetrate hundreds of meters into the ground, thus their differential local flux correlates with the crossed density-length. The Sakurajima Muography Observatory in Kagoshima, Japan, is the largest muography experiment targeting an active volcano. A set of multilayered gaseous detectors are used to reconstruct the muon tracks, thus by measuring the flux, imaging of the inner part of the volcano become possible. The paper focuses on the technical challenges of such a particle tracking system, the designed multi-wire proportional chambers, and the recent results from the measurements.

1. Introduction

Muography is a novel field of research where the detector technology and instrumentation of particle physics meets applications in geo-sciences and industry to reveal inner structure of large solid volumes.

As cosmic rays encounter high-energy hadronic interactions in the upper atmosphere the secondary particles decay, and the produced muons could reach the penetrate the surface of Earth. The energy of the muon defines its penetration depth in units of density-length, thus the attenuation of the flux correlates with the overall mass along its track. Measuring the attenuation of the angular-dependent flux an imaging of the interior structure of hill-sized objects became possible.

Muography got first known for archaeological inspections of a pyramid [1]. Nowadays the most highlighted application is the survey of volcanoes [2, 3, 4, 5, 6, 7, 8], while it is also used to locate unknown cave systems [9, 10], disclose various ore-bodies in mines [11], in cultural heritage exploits [12], or directly in industry [13, 14].

Several groups involved in R&D of detectors for HEP use cosmic muons for calibration, and a few started to use these state-of-the-art devices for muography. Muographs based in solid state emulsion (eg. [8]) or scintillator devices (eg. [2]) are used, while various gaseous detectors as Micromegas [15] Resistive Plate Chambers [4] or Close Cathode Chambers [16] [17] had been proven usable.

2. Modified MWPC Detectors for Muography

Gaseous detectors offer high efficiency particle detection with an extremely well known technology [18]. Numerous realizations exist for the challenges in high energy physics, optimized for resolution (DC), rate capability (MPGD), excellent timing (MRPC), or gigantic volumes (TPC).

Muography being typically moderate-scale outdoor experiments, the focus of design and developments shifted towards simplicity, robustness, out-of-the-lab operability, low-power consumption, and cost efficiency.

The sharpness of the muographical image depends on the detector's angular resolution; thus when large lever arm shall be used the position resolution can be degraded, which could reduce the number of electronic channels relieving power-consumption and cost issues.

Our Group has designed a modified multi-wire proportional chamber, that is optimized to be used in large-area muographic trackers [19]. Spacing of sense-wires is 12 mm, while connected all-together to get an instant trigger if a muon is crossed. Field wires are applied to reduce sensitivity to cathode flatness and serves as individual readout elements. As the etching of large-area (≈ 1 m^2) PCB would be cumbersome, requiring expensive high-end-infrastructure and/or extra gluing steps; thus instead an extra plane of pickup-wires has been introduced serving as 1 dimensional pads. The projective readout is applicable due to the low occupancy, and thus reducing the number of channels to twice-of-squareroot, namely 160 channels for a 120×80 cm^2 chamber.

Figure 1 shows a photo of the MWPC tester setup in the Laboratory at Wigner RCP in Budapest, where eight 80×80 cm^2 chambers are tested for tracking performance, in a realistic close-to-final (lead sheets are not included) setup.

In most cases muographs shall be autonomous and low-power devices, as power source is limited (usually from batteries and solar panels). While the detector layers themselves do not require large currents (especially for gaseous ones), the crucial part is the data acquisition system. The tasks of the DAQ includes powering the chambers and front-end electronics, readout of the raw data, storage of recorded data, control of runs and user interactions, and monitoring of environmental parameters. Figure 2 shows a photo of a full DAQ plane with the main components listed below. The total power consumption of a portable Muographs of WignerRPC is 6-10 W, all functions included.

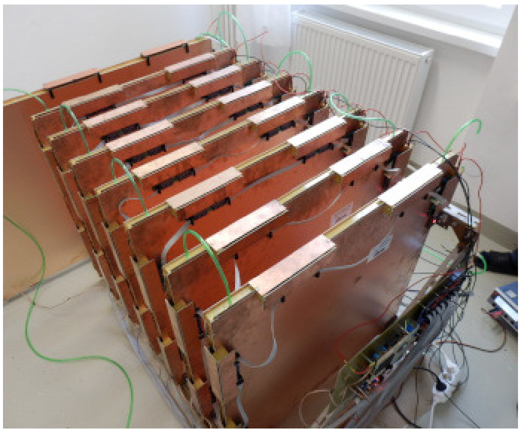

Figure 1. Tester setup for the Modified MWPC detectors in close-to-final layout in the Laboratory at Wigner RCP in Budapest.

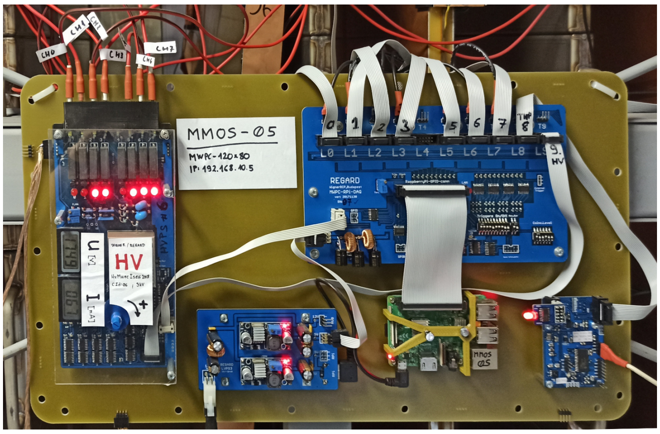

Figure 2. Photo of the DAQ plane of a MMOS, containing DaqBoard and the RPi (middle), the High Voltage supply (left), LV regulator (middle down), and THP sensor (right).

3. MMOS at Sakurajima Muography Observatory

The Sakurajima Muography Observaroty (SMO) is the world's largest muography experiment [21], that targets an active volcano, Sakurajima, in south Japan in Kyushu. While SMO started as a scintillator based experiment, the modified MWPC technology of the previous section has been tested there, and soon became the main component of the system. Right now, in 2021, there are 11 working gaseous trackers there, called MWPC-based Muography Observatory System (MMOS), each with mostly 8 layers of the described MWPC chambers and DAQ. Figure 3 presents a close-up photo of an MMOS, where the individual chambers, the scattering lead plates, and its DAQ is visible.

SMO, as all other volcano muography experiments, shall deal with extreme low flux, as close-to-horizontal muons are required and the absorption is high during the order-of-mile long muon paths inside the hills. The imaging time and/or image resolution can be enhanced using larger surface, practically including multiple muographs into a combined system. At SMO all the MMOS modules measure individually, and regularly sending their data to a local server, which is in connection with a remote data storage and analysis computer. Figure 4 presents a farther photo inside SMO building, showing 2+2 MMOS in their containers.

The SMO based on the modified MWPC tracking units have shown an excellent performance in the last years [21], with roughly 99% efficiency on the individual MMOS units. With the MWPC based system the increase in effective area was such, that the images projected onto the volcano showed localization better than 8 m, and density changes around the three craters could be measured [20].

In a separate study a similar single-MMOS-like system has been used to determine the imaging capabilities behind gigantic objects, namely the distortion of resolution behind/inside a hill/volcano [21]. The measurements at Sakurajima Muography Observatory could first proof formation of a volcanic plug via the novel method of muography [22].

The experiment of SMO is still active, data is analysed and correlations to effects of geo-scientific and volcanologic interest are now in focus.

Figure 3. An MMOS with 8 Modified MWPC detectors (green and copper colours are visible) and the lead plates inbetween them, while the corresponding DAQ is mounted to a well-accessible side.

Figure 4. Photo where 2+2 MMOS-es are visible within their container boxes, all inside the simple builing of SMO on the hillside of Sakurajima.

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