Multi-Wire Detectors for Underground Muography

Gergő HAMAR (1), Gergely SURÁNYI (2), Dezső VARGA (1), Szabolcs J. BALOGH (1), Gábor NYITRAI (1), Gábor MOLNÁR (2), Ádám L. GERA (1), Gábor GALGÓCZI (1) & Gergely G. BARNAFÖLDI (1)

(1) Wigner Research Centre for Physics, 29-33. Konkoly-T.M. str., 1121 Budapest, Hungary, hamar.gergo@wigner.hu (corresponding author)
(2) MTA-ELTE Geological Geophysical and Space Science Research Group, Pázmány P. s. 1/c, 1117 Budapest, Hungary, surda007@gmail.com

Abstract

The use of cosmic muons in imaging large artificial or geological structures started to flourish in the last decades, with the technological advancement in particle physics instrumentations. Muography became a most effective way to locate hidden density anomalies in geological structures, which includes revealing unknown parts of natural cave systems underneath the mountains.

Our group has developed a series of gaseous multi-wire particle detectors for muography applications, with targets ranging from volcanology to speleology. Advancements in durability, power consumption, portability, and acquisition system have been proven via field measurements in natural sites besides extensive laboratory testing.

The poster is dedicated to give details on the main requirements, components, and solutions which are means to transform standard particle detectors to be practically applicable in underground muography. We will present the expanded scale of experimental systems, targeting upgraded high-resolution tomography, hole-fit small-scale devices, and even economical simplified versions for exploratory measurements. These muography detectors could soon become effective novel tools in geo-sciences.

1. Underground muography in speleology

Muography is a novel field of research merging the detector technology of particle physics with applications in geo-sciences. Imaging with underground muography opened a novel way to explore and locate hidden caves inside mountains.

As the particles of cosmic radiation enter the atmosphere of the Earth, high-energy collisions take place, producing hundreds of particles which then decay in chains. The longlived muons reach the surface and penetrate further into the ground, the more energy they have the deeper they reach. The attenuation depends on the integrated density along the path.
The cosmic radiation is perpetual, the differential flux has been measured and studied in detail (GAISSER et al. 1990). Based on these information, and measuring the muons deep inside a hill, the density-map of the overburden rock can be calculated, which can disclose and locate unknown caves and tunnels.
One of the first application of this idea was introduced by ALVAREZ et al. (1970) to search for hidden chambers in a pyramid.

The progress in instrumentation for particle physics together with the advancement in technology and industry made the high-performance detectors accessible for practical applications in the emerging field of muography (TANAKA & OLÁH 2018). Various detector systems could be used, like emulsion films (eg. MORISHIMA et al. 2017), scintillators (eg. CIMMINO et al. 2019), or gaseous chambers (eg. BARNAFÖLDI et al. 2012).

The broad energy range of the muons allows muography imaging of objects from 10 m to a few km in size. The flux decreases from ~120 Hz/(m^2*srad) from the zenith with ~cos^2. Surface-based muography count the close-to-horizontal muons for imaginge eg. volcanoes (TANAKA et al. 2013) thus use large detectors while shall deal with extreme low flux and high background. Underground muography can benefit from close-to-zenith flux, while detectors shall be portable and autonomous; possibilities include speleologic research (SURÁNYI et al. 2016), archeology (MORISHIMA et al. 2017), or exploration of mineral treasures (SCHOUTEN & LEDRU 2018).

2. Gaseous detectors for muography

Gaseous particle detectors are efficient trackers for charged particles (BLUM & ROLANDI 1993), and thus favored in muography experiments. In these detectors the muon ionizes the gas and the electrons get collected and multiplied in high electric field. Usually using a set of parallel chambers each with two-dimensional readout, the trajectory and thus the incoming direction can be recovered.
Several types of these detectors are in use for muography. The micropattern technology can reach excellent positioning (BOUTEILLE et al. 2016), the RPC family could use sub-nanosecond time resolution (CARLOGANU et al. 2013). Several modified Multi-Wire Proportional Chambers (MWPC) have been designed directly for muography purposes resulting in high performance tracking with costefficient and durable structures. The transportation of a large wire-chamber based muograph inside a cave is shown in Fig. 1.

Figure 1: Transportation of the Large Muograph inside a tunnel in the Esztramos cave system.

3. Multi-wire muographs adapted to the various scenes

Figure 2: Small (25 cm) and large (80 cm) muographs next to each other in a tunnel underneath the Castle of Buda in Budapest.

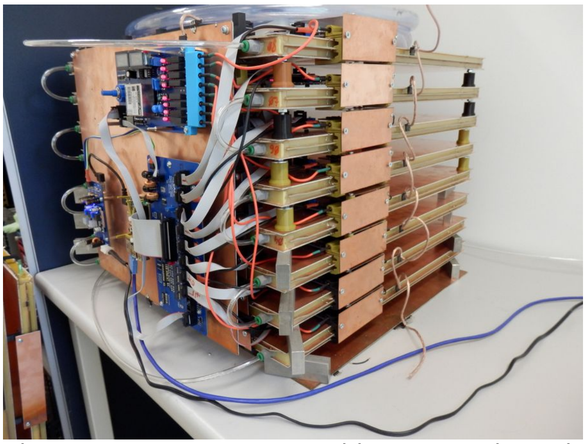

Figure 3: Compact 50 cm wide muograph made of modified MWPC chambers, with readout and high-voltage system mounted on the front.

The classical MWPC detectors are excellent trackers (BLUM & ROLANDI 1993), while the cumbersome construction, heavy frames, and high-power electronics have to be overcome for muographic applications. Developments of our group for portable multi-wire detectors directly for muography solved these issues, and simple-structure, cost efficient, and lightweight chambers have been designed.

Large area detectors for general muographic usage requires modification of the MWPCs with simple and cost-efficient construction, high efficiency and tolerance in rough environment. Using large wire-spacing of 12 mm, additional field wires, and pickup-wires instead of pads resulted in excellent performance (VARGA et al. 2016). Our chambers of 120x80 cm^2, and 80x80 cm^2 are used in the Sakurajima Muograpy Observatory in Japan for volcano imaging (VARGA et al. 2020) (OLÁH et al. 2018). For underground measurements a system containing the 80 cm detectors was encased and mounted onto a rotatable support, as shown on the right side of Fig. 2.

Access to various sites, especially cave systems, demand hard limitations in size. A scale-down version of the modified MWPCs has been produced, with 8 mm wire-spacing and active area of 50x50 cm^2 for chambers, that is shown in Fig. 3. The encased version could fit through commercial doors, ideal for general tunnel passage.
A simplified version with large spacing and mode-rate size is used for multi-layer spectrometer, facile measurements, and for educational purposes in visual trackers (VARGA et al. 2015).

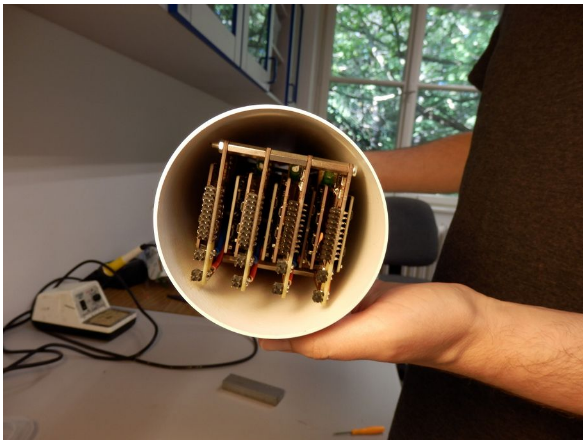

Figure 4: The BoreHoleDetector with four layers of CCC type chambers, that can fit into a tube with 100 mm inner diameter.

Speleology requires high resolution portable detectors. The Close Cathode Chamber (VARGA et al. 2011) includes negative potential field wires to reduce sensitivity to precision flatness, thus excellent uniformity could meet low material budget (VARGA et al. 2013). Position resolution even with simplest digital electronics is better than 2mm, thus a typical system has angular resolution of 0.5o. Muography detector with six CCC chambers can be seen on the left side of Fig. 2. These muography trackers were successfully used for several underground measurements (BARNAFÖLDI et al. 2012), (OLÁH et al. 2012), (SURÁNYI et al. 2016).
Recently a compacted design has been developed for borehole applications, where a system of four longish-but-narrow CCC chambers fit into a tube of diameter 100mm, a photo of the first set is shown in (Fig. 4).

4. Technical advancements and power consumption

The data acquisition (DAQ) is the most crucial part of a muograph, especially for portable systems eg. in speleology. These detectors need compact DAQ structure and low-power operation, as in general no electricity is present in natural cave environments.
The DAQ system shall provide adjustable accurate HighVoltage for the gaseous chambers, LowVoltage for the electronics, and is responsible for collection and storage of raw data, and access for human interactions.

The readout system is based on a RaspberryPi microcomputer (RPi) and a custom designed DAQ board. The programmable GPIO pins of the RPi are used for low-level high-speed communication, while hardware-level solutions are realized within the DaqBoard. The RPi runs a linux kernel giving straightforward access and operation for files with data and code. It runs a wireless hotspot, thus with a simple mobile phone we can connect via wifi, start runs or copy the collected data. Photo of the DAQ of the BoreHoleDetector is shown in Fig. 5.

High resolution requires plenty of channels, each equipped with front-end electronics for signal amplification, shaping, and digitalization. We have developed digital (one-bit per channel) front-end electronics with high sensitivity and with consumption about 2 mW/channel.

The total power consumption has been successfully reduced to about 5-10 Watts for a full muograph system. Commercial batteries are usually placed inside the cave near the entry point, and are replaced after a couple of weeks. Introducing a solar panel close to the entrance can enhance the duration of the battery system. Photo of a placement of solar panels used at Sátorkőpusztai cave in Hungary is shown on (Fig. 4).

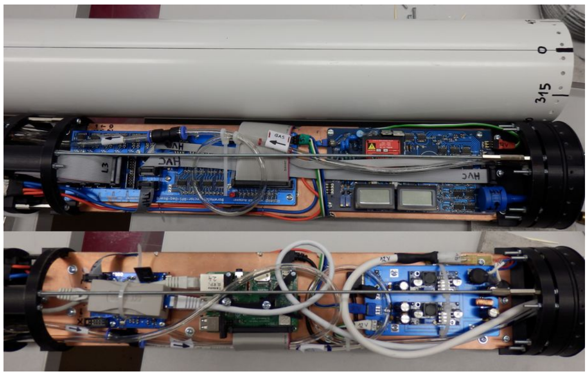

Figure 5: Photos of the data acquisition system of the BoreHoleDetector. Shown above the 100mm diameter tube, the DaqBoard and the HighVoltage unit, shown below the temperature sensor, the RaspberyPi, and the LowVoltage regulator.

Figure 6: Photo of the solar panels, placed close to the entrance of the Sátorkőpuszrtai cave in Hungary.

These autonomous muographs operate without any supervision, although regular monitoring would be advisable. Therefore a GSM-based daily communication has been established, sending information from the batteries or the status of the measurement itself.

5. Conclusion

Muography uses cosmic muons to make density mapping of hill-sized objects. Underground muography could become a perfect tool for exploration of unknown / hidden caves, performed from the deeper accessible parts.

Our modified multi-wire gaseous detectors offer a high resolution, portable, and cost-efficient option for tracking. For the various scenes muographs in size from 80 cm large detectors to narrow borehole-mountable tubes have been designed.

Aided with the developed compact and low-power data acquisition system the technology became perfectly usable in speleology.

Applications of the detailed muographs are presented in the same conference and proceedings by Surányi G. et al. titled 'Cavity location by muon tomography'.

Acknowledgments

The authors acknowledge the support of the Hungarian OTKA grant FK-135349, the János Bolyai Research Fellowship of the Hungarian Academy of Sciences, the Joint Usage Research Project of the University of Tokyo, Earthquake Research Institute ID 2020-H-05, and the support of the ELKH-KT-SA-88/2021 and the TKP2021-NKA-10 grants. The authors would like to thank the work and support of all the members of the REGARD Detector Physics Research Group of the Winger RCP.

References

ALVAREZ L.W. et al. (1970) Search for hidden chambers in the pyramids, Science NS 167 3919 , 832

BARNAFÖLDI G.G., VARGA D., OLÁH L., HAMAR G., MELEGH H.G., SURÁNYI G. (2012) Portable Cosmic Muon Telescope for Environmental Applications, Nucl.Instrum.Meth. A 689, 60.

BLUM W. and ROLANDI L. (1993) Particle Detection with Drift Chambers, Springer-Verlag

BOUTEILLE S. et al. (2016) A micromegas-based telescope for muon tomography: the watto experiment, Nucl.Instrum.Meth. A 834, 223.

CARLOGANU C. et al. (2013) Towards a muon radiography of the Puy de Dome, Geosci.Inst.Meth.Data Syst. 2, 55

CIMMINO L. et al. (2019) 3D muography for the search of hidden cavities, Scientific Reports 9 , 2974

GAISSER T.K., ENGEL R., RESCONI E. (1990) Cosmic rays and particle physics, Cambridge University Press 2016

MORISHIMA K. et al. (2017) Dicovery of a big void in Khufu's Pyramid by observation of cosmic rays, Nature 552, 386

OLÁH L., BARNAFÖLDI G.G., HAMAR G., MELEGH H.G., SURÁNYI G., VARGA D. (2012) CCC-based Muon Telescope for Examination of Natural Caves, Geosci. Instrum. Method. Data Syst. 1 , 229

OLÁH L., TANAKA H.K.M., OHMINATO T., VARGA D. (2018) High-definition and low-noise muography of the Sakurajima volcano with gaseous tracking detectors, Scientific Reports 8 , 3207.

SCHOUTEN D.W. and LEDRU P. (2018) Muon tomography applied to a dense uranium deposit at the McArthur River mine, Journal of Geophysical Research: Solid Earth 123 , 8637

SURÁNYI G. et al. (2016) Locating of density anomalies using highly penetrating cosmic muons, Karsztfejlődés 2016 , 203

TANAKA H.K.M. et al. (2013) Development of a two-fold segmented detection system for near horizontally cosmic-ray muons to probe the internal structure of a volcano, Nucl.Instrum.Meth. A 507 , 657

TANAKA K.K.M., OLÁH L. (2018) Overview of muographers, Phil. Trans. R. Soc. A 377 , 20180143

VARGA D., HAMAR G., KISS G., (2011) Asymmetric multi-wire proportional chamber with reduced requirements to mechanical precision, Nucl.Instrum.Meth. A 648 , 163

VARGA D., GÁL Z., HAMAR G., MOLNÁR J.S., OLÁH É., PÁZMÁNDI P. (2015) Cosmic muon detector using proportional chambers, European J. of Physics 36 , 065006

VARGA D., NYITRAI G., HAMAR G., OLÁH L. (2016) High efficiency gaseous tracking detector for cosmic muon radiography, Advances in High Energy Physics 2016 , 1962317

VARGA D., HAMAR G., NYITRAI G., GERA Á., OLÁH L., TANAKA H.K.M. (2020) Tracking detector for high performance cosmic muon imaging, Journal of Instrumentation 15 , C05007