IL NUOVO CIMENTO **47 C** (2024) 132
DOI 10.1393/ncc/i2024-24132-x

Colloquia: IFAE 2023

A new muon tomographer for glaciers melting monitoring(*)

A. Cervelli(1), S. Rabaglia(1)(2) and M. Sioli(1)(2)

(1) *INFN, Sezione di Bologna - Bologna, Italy*
(2) *Università di Bologna - Bologna, Italy*

received 13 February 2024

Summary. — The project aims to develop a portable and easily replicable detector system that utilizes muon tomography to monitor and study glaciers. Muon tomography is a proven technique for studying large objects, and it take advantage in the on the natural flux of muons reaching the Earth's surface. Since the density of rock and ice differs, the detector can provide insights into ice thickness and the ice-rock interface, through the measurement of the directional muon flux. The detector design consists of five modules, each composed of two layers of scintillating fibers arranged orthogonally to determine the three-dimensional coordinates of muon hits. Silicon Photomultipliers (SiPMs) are used for signal acquisition and the read-out system was developed and tested in collaboration with CAEN S.p.A. Simulation results include assessments of angular resolution, reconstruction uniformity, and the stopping power of ice and rock. These simulations are essential for optimizing detector performance. Additionally, preliminary tests on the read-out boards and fully simulations involving real mountain profiles have been conducted. This project has the potential to significantly enhance our understanding of glacier behavior in the context of global warming.

1. – Introduction

Muon tomography is an imaging technique that utilizes cosmic ray muons produced by interactions with the Earth's upper atmosphere. These muons have a long decay time and reach the Earth's surface with a measurable flux ($\sim 70\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$), making them ideal for imaging. This technique is used in various fields like geology [1], archaeology [2], and volcanology [3], thanks to advancements in particle detectors.

Absorption-Based Muography (AM) involves measuring the directional muon flux that pass through the target, comparing it to the "open-sky" flux, and using this comparison to determine the object's density along a path length. This information helps assess the average density along a specific solid angle of sight, revealing the depth of interfaces between different materials. However, AM provides only 2D imaging.

(*) IFAE 2023 - "Poster" session

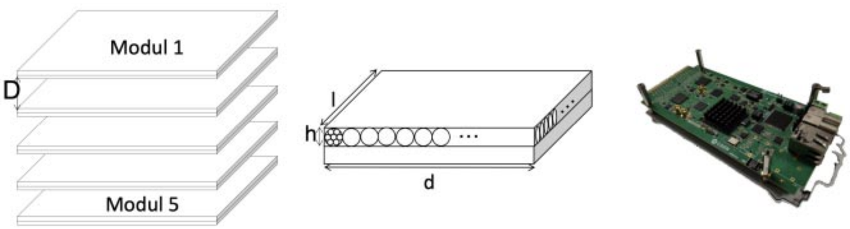

Fig. 1. – From left to the right: the whole detector composed by 5 module; one module composed by 2 layers containing 110 bundle of 7 scintillating fibers. On the left the FERS board A5202.

To perform imaging, muon tracks are collected and used to reconstruct the paths and angles of detected muons. The main sources of uncertainty come from muon scattering within the target, taken under control averaging on the muon arrival directions, and spurious coincidences from muons not passing through the target. Various detector types, including scintillating bars [4] and gaseous detectors [3], offer high resolutions and are well-suited for specific applications. Emulsion-based detectors [5] excel in reconstruction but are better for low flux environments and not continuous monitoring.

2. – Detector

Our project aims to reate a muon tomographer capable of high angular resolution (5 mrad), accurate ice thickness measurement (5 meters), operable in open-sky, low power consumption, and resilience in all weather conditions for long-term study. The detector (fig. 1) is organized into 5 modules, each consisting of 2 layers of scintillating fiber bundles embedded in plastic cladding for mechanical stability. These layers are arranged orthogonally to provide three-dimensional coordinate information (x, y, z) for each hit within a module. Each bundle contains 7 scintillating fibers (fig. 1), serving as an unique read-out elements, connected to a SiPM array. In this preliminary study, light detection is binary, but future developments plan to use the number of fired SiPMs in the array to enhance tracking capabilities.

The optimal distance (D) between each module has been determined through simulations, with three configurations tested: $D = 18$ cm, 27 cm, and 36 cm, resulting in total detector lengths of 99 cm (basic), 144 cm (medium), and 189 cm (long). For light detection, various SiPM geometries and array arrangements were evaluated to match with the fibers. For light detection, various SiPM geometries and array arrangements were evaluated to match the fibers. FERS boards (A5202) [6] (fig. 1) are used to drive and power supply the SiPMs, them main components are two Citiroc-1A chips (64 readout channels), produced by WeeRoc [7], and an FPGA to process the signals. The processed signals are sent through optical links to a Concentrator (DT5215) [8], used for synchronization and communication with a PC via USB or Ethernet.

3. – Results

We present the optimization and feasibility studies for the detector for glacier muon tomography. The results presented are based on a comprehensive simulation of the entire detector using GEANT4 [9]. It's worth noting that a 100% detection rate for muons was

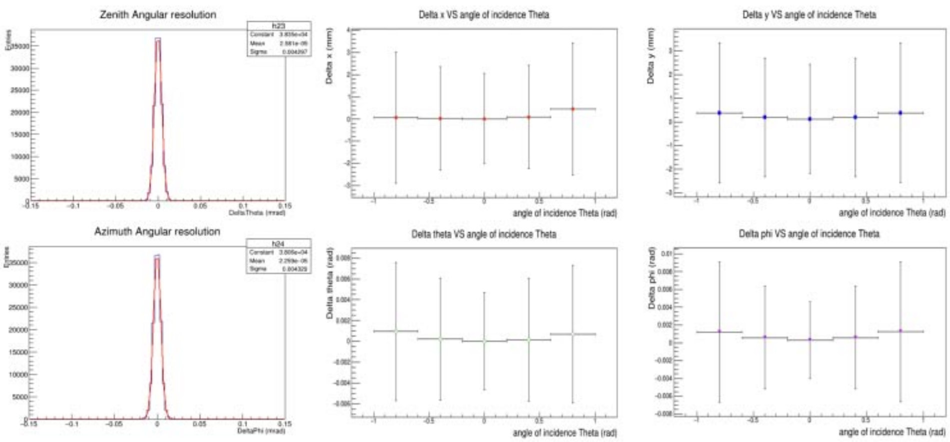

Fig. 2. – Angular resolution and uniformity of detector response as a function of the polar and azimuthal angle, from top left and clockwise: detector resolution of zenith angle, hit residual for different axes on top, reconstruction error for θ and ϕ at the bottom as a function of polar angle, detector resolution of azimuthal angle.

assumed, and no additional data on energy deposition for tracking or efficiency were incorporated.

We evaluated the angular resolution of the detector in three different configurations (basic, medium, long) using a particle gun to direct muons at the detector from various angles. The hits detected were used to reconstruct the directions of the incoming muons, which were then compared to the true directions generated by the simulation. Results indicated that the resolution in track direction ranged from 10 mrad for the basic configuration to 5 mrad for the long configuration, showed in fig. 2.

The presentation also examined the uniformity of the detector's response across the field of view, with variations of less than 3%, even at high impinging angles (fig. 2). Real data acquisition was explored by introducing a mountain profile into the simulation. The plot in fig. 3 was obtained generating 6M of muons uniformly inside the range $\theta \in [60^\circ, 90^\circ]$ and $\phi \in [0^\circ, 110^\circ]$, and considering the real energy distribution for muon generation.

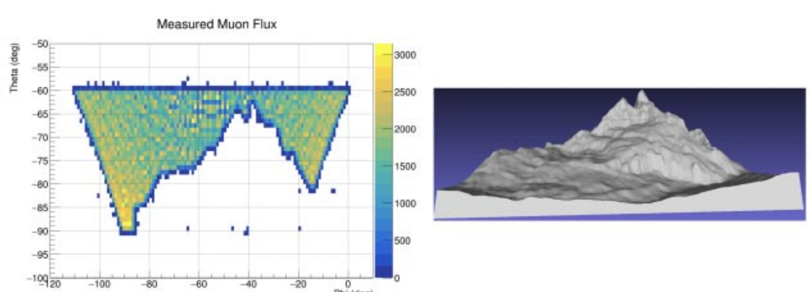

Fig. 3. – Left: Measured muon flux as function of theta and phi. Right: CAD step of the mountain.

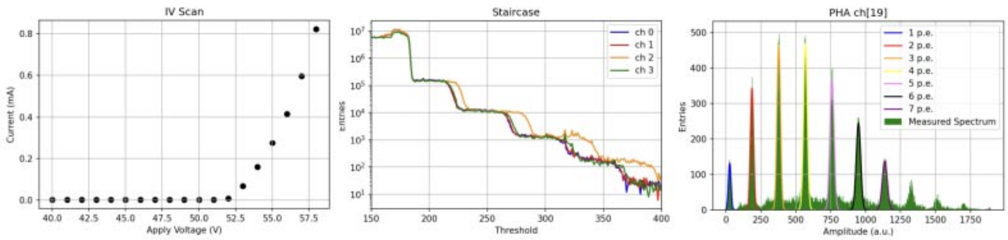

Fig. 4. – Left: IV plots. Center: Staircase (scan of threshold). Right: Single photo-electron spectrum.

In collaboration with CAEN S.p.A, we are conducting tests on read-out boards (FERS A5202) to analyze their features and performance through the characterisation of a SiPM matrix. The results (see fig. 4) includes an IV plot, which is used to set the appropriate bias voltage, a staircase plot that represents a threshold scan to optimize background rejection, and a single photo-electron spectrum for studying the SiPM's response to individual photon events.

4. – Outlook

A novel glacier monitoring detector based on muon tomography is designed for open-sky operation with minimal maintenance. Preliminary simulations show good tracking resolution, background rejection, and stable performance. The read-out system, based on FERS boards A5202, was tested in collaboration with CAEN S.p.A. A prototype is to be tested in collaboration with the University of Glasgow in the coming months.

REFERENCES

[1] Caffau E., Coren F. and Giannini G., *Nucl. Instrum. Methods Phys. Res. A*, **385** (1997) 480.
[2] Morishima K., Kuno M., Nishio A. *et al.*, *Nature*, **552** (2017) 386.
[3] Rosas-Carbajal M. *et al.*, *Geophys. Res. Lett.*, **44** (2017) 6743.
[4] Avgitas Theodoros, Elles Sabine, Goy Corinne, Karyotakis Yannis and Marteau Jacques, arXiv:2203.00946v2 [physics.geo-ph].
[5] Nishiyama R., Ariga A., Ariga T., Käser S., Lechmann A., Mair D., Scampoli P., Vladymyrov M., Ereditato A. and Schlunegger F., *Geophys. Res. Lett.*, **44** (2017) 6244.
[6] `https://www.caen.it/products/a5202/`.
[7] `https://www.weeroc.com/products/sipm-read-out/citiroc-1a`.
[8] `https://www.caen.it/products/dt5215/`.
[9] `https://geant4.web.cern.ch/`.