Muography: Imaging volcanos using gaseous tracking detectors

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Overview

• Detector Physics Group (REGARD): HEP instrumentation projects
• What is Muography (Muon “radiography”)
• Underground muography: challenge of mobility
• Surface-based muography: challenge of large size and reduction of low energy background
• Tracking detectors for vulcanology
“Large” collaboration involvements by the group

- CERN RD51: gaseous detector R&D
- CERN NA61: detector construction
- CERN ALICE: rebuilding the TPC
- ESS BrightnESS: neutron detector development
Cosmic muons on surface

- Primary Cosmic Ray (CR) hits upper atmosphere nuclei, starts hadronic shower
- Mostly muons survive (except for ultra-high energy primaries)
- Complicated angular dependence of spectrum
Muography potential: large scale imaging

- Natural radiation, revealing otherwise not accessible structures

Imaging: muon flux at observation point(s)

- Example: imaging underground shafts

Adv. in HEP 2013 560192 (2013)
PoS (NIC XIII) 129 (2015) 6p
Natural caves are interesting objects to study but...

- ... a challenging environment

Advances in High Energy Physics, 560192 (2013) 1
Comparing surface with flux may reveal hidden structures

- Indication of a fissure/cave close to Királylaki cave

G. Surányi, Speleo2017 conference
Volcano imaging

- Geosciences: how do volcanoes truly work?
- High social impact in preparation, evacuation

Hiroyuki Tanaka et al.: Nat. Commun. 5 3381 (2014) 9p
Penetrating muon is very rare (<0.1/sec/m²), background is 10³ times higher

All (low energy) background sources to consider

Cartoon by László Oláh
Detectors viable for volcano imaging

- High efficiency, high mechanical stability

Detector construction

- Application-driven design
Japanese-Hungarian initiative: Muographic Observation Instrument

- Currently running at Sakurajima (Kyushu)
- 20W wallplug power consumption, now 2 m²

Japanese Ref. No.: 2016-087436, date 25/04/2016
Data Acquisition System
(REGARD group own development)

- Integrated, portable (< 3 kg), low power (< 5 W) and cost efficient DAQ
- Off-the-shelf component CMOS front-end
- Intermediate DAQ boards:
  - Trigger receiving + coincidence unit
  - Measurable dead time (totally few 100 μs)
  - Measurable parameters (T, H, p)
- DAQ system is operated by Raspberry Pi:
  - Peripherals: SD card, USB, Ethernet, HDMI, Wifi Accesspoint, GPIO pins
  - Remote control, data management and analysis
Test of mMOS at the Sakurajima Volcano, Kyusu, Japan

- Imaging with near-horizontal muons: flux $10^{-3} - 10^{-1} \text{ m}^2 \text{ sr}^{-1} \text{ s}^{-1}$ after 1-5 km rock
- mMOS was placed 2.8 km far from the Showa crater
  $\rightarrow \sim 25 \text{ m} \times 25 \text{ m}$ resolution image can be achieved about the volcano by mMOS
Imaging the mountain

- Mountain “shadow” muogram
- Optical image
High-definition muography with mMOS

- Measured muon flux in $2.7 \times 2.7 \text{ mrad}^2$ bins ($7.5 \times 7.5 \text{ m}^2$ from the distance of 2.8 km) reproduces the ridge of the Sakurajima
Background suppression with MOS

- Measured flux in good agreement with the expected flux up the thickness of 2km rock – high degree of low energy background suppression

Scientific Reports, Volume 8, Article number: 3207 (2018)

Middle slice: 21.8 mrad x 2.725 (10.9) mrad
Summary

- Mugraphy instrumentation developments: high efficiency gaseous tracking detectors
- Background suppression and good angular resolution (<5 mrad) requires good tracking detectors
- Emerging community, “Muography” as a science

Red titled slides are from László Oláh

Contributions from

G. Surányi, G. Hamar, G. Nyitrai, Á. Gera, P. Pázmándi etc..
Régészeti kutatások: Khufu

- K. Morishima és munkatársai (Japán-Francia-Egyiptomi csoport):
  Discovery of a big void in Khufu’s Pyramid by observation of cosmic-ray muons, Nature Letters 2017. November 2. doi:10.1038/nature24647

- Emulziós és scintillációs detektorokat helyeztek el a Khefren (139 m magas, 230 m széles) piramis belsejében, gáztöltésű detektorokat installáltak a piramison kívül → 2-6 hónapos mérések