Tracking detector for high performance cosmic muon imaging

Dezső Varga,
Wigner Research Centre for Physics, RMI NFO

REGARD
RMKI ELTE Collaboration on Gaseous Detector Research and Development

IPRD19 Conference
Siena, 14-17 Oct. 2019

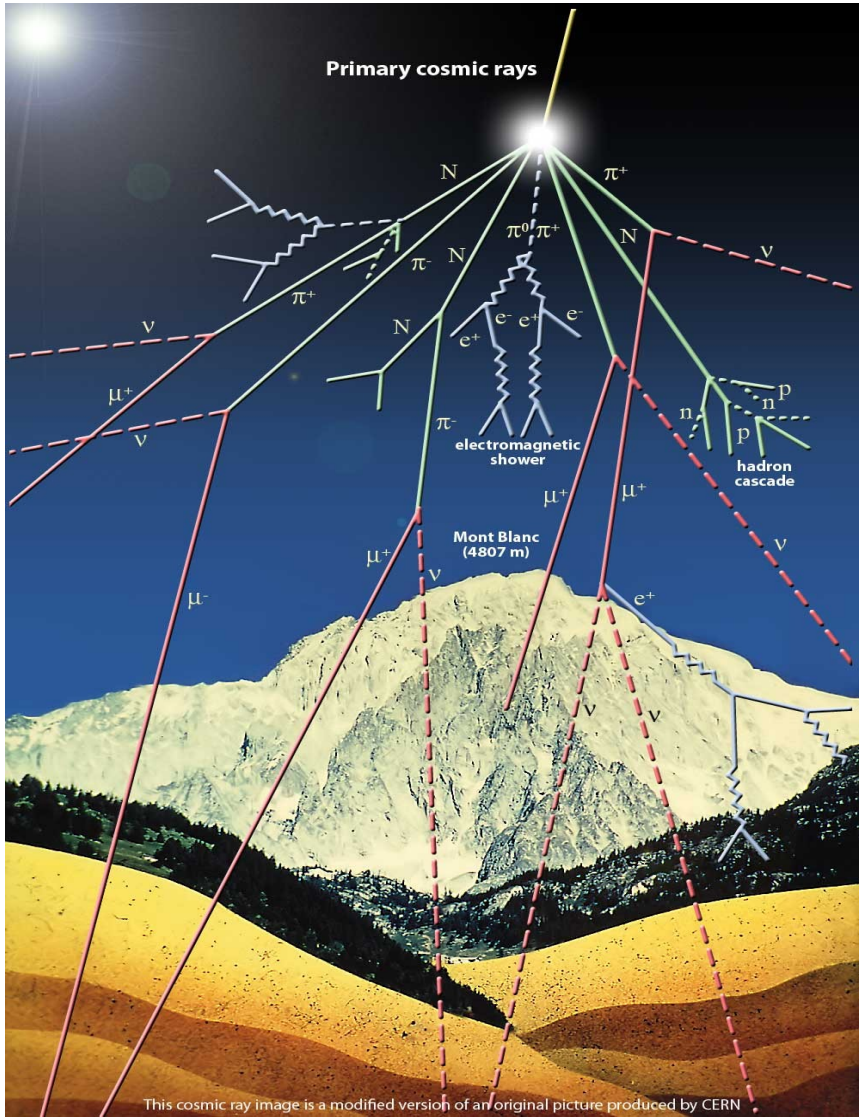
All colors of Physics

Overview

- Muography: an old dream came through by contemporary technology
- Fundamental limitation of flux: need for high performance low background detectors
- Large size detector construction,
  experience at the Sakurajima Muohraphy Observatory
- Detector operation and maintenance issues
- Can we see through a mountain?

Muons, Nature's highly penetrating cosmic rays

- Cosmic particles from deep space reach Earth upper atmosphere, muons created in hadronic shower
- Muons can cross kilometers of material
- Muography applications: volcanology, archeology, mining, large object internal structure (dams, roads, tunnels)



“Generations” of muography,
a personal historical notation

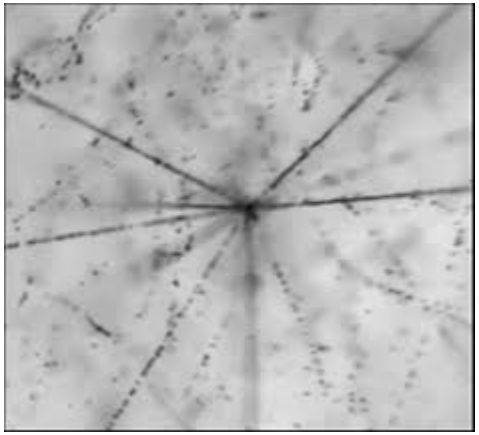
- 1st Generation: George 1955, Alvarez 1970 – demonstration of the principle for underground imaging
- 2nd Generation: around the 90-ies, Los Alamos, Italy, Japan… expanding the possibilities including scattering, various patents
- 3rd Generation: around 2000, breakthroughs in volcanology (dynamics!), developing industries
- 4th Generation: dedicated systems, developments driven by the applications, expansion in possible use cases
  - **High efficiency and resolution, high reliability**
  - **Cost efficiency, durability on field, autonomy**
- … See also the talk on MURAVES

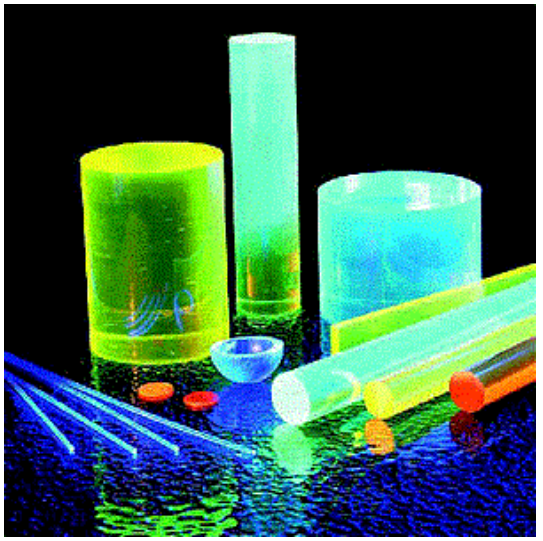
Detection technologies,
developed for fundamental science

- Emulsions, thick “photographic films”

  Easy to deploy,

  no time resolution



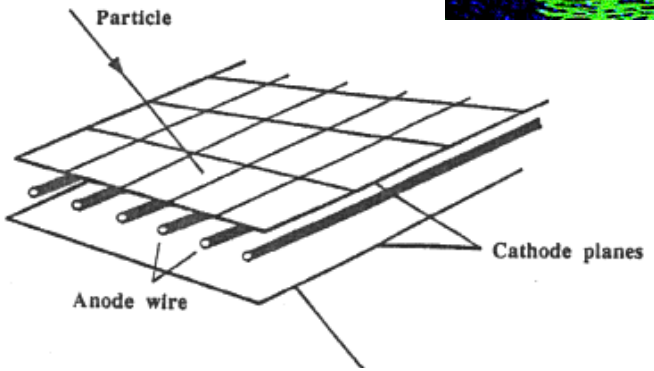


- Scintillators (visible light)

  High efficiency

- Gaseous detectors

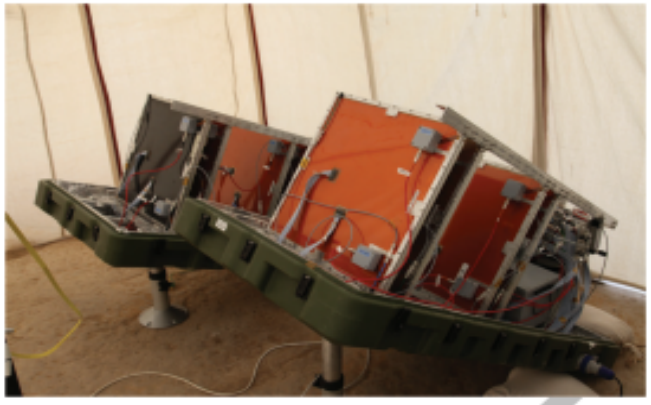
  High efficiency, cost efficient



Gaseous: high performance tracking

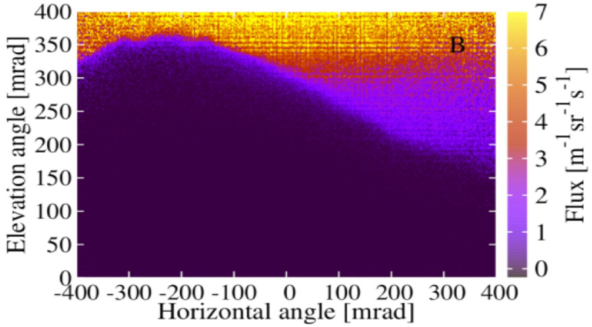
- Precision tracking systems
- No “simple” setup, may need maintenance

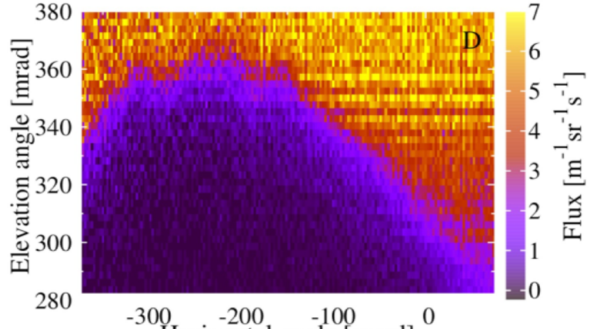
CEA “Pyramid discovery” detectors



Morishima et al, Nature 2017

Detectors at Sakurajima, UT & Wigner

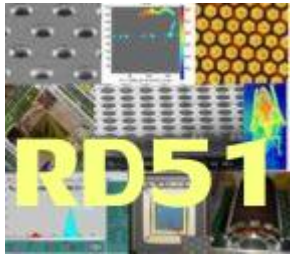




Scientific Reports, Volume 8, Article number: 3207 (2018)

Wigner RCP Detector Physics group: HEP instrumentation

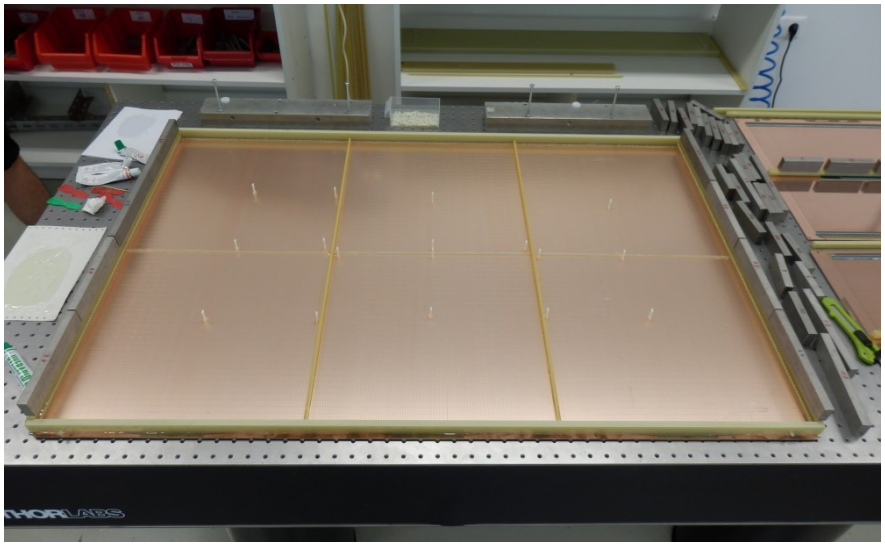
- CERN RD51: gaseous detector R&D
- CERN NA61:
  detector construction
- CERN ALICE: rebuilding the TPC
- ESS BrightnESS: neutron detector development

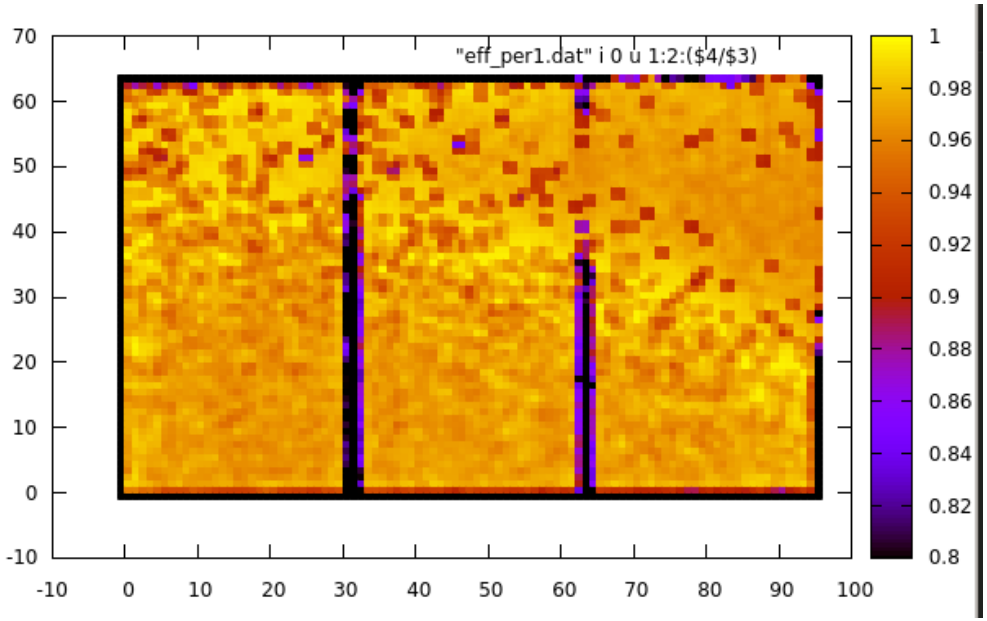


EUROPEAN SPALLATION SOURCE

Large area MWPC detector construction

- Reliability, durability, scalability by design
- By now total of 75 m^2 produced (60 m^2 at SMO)

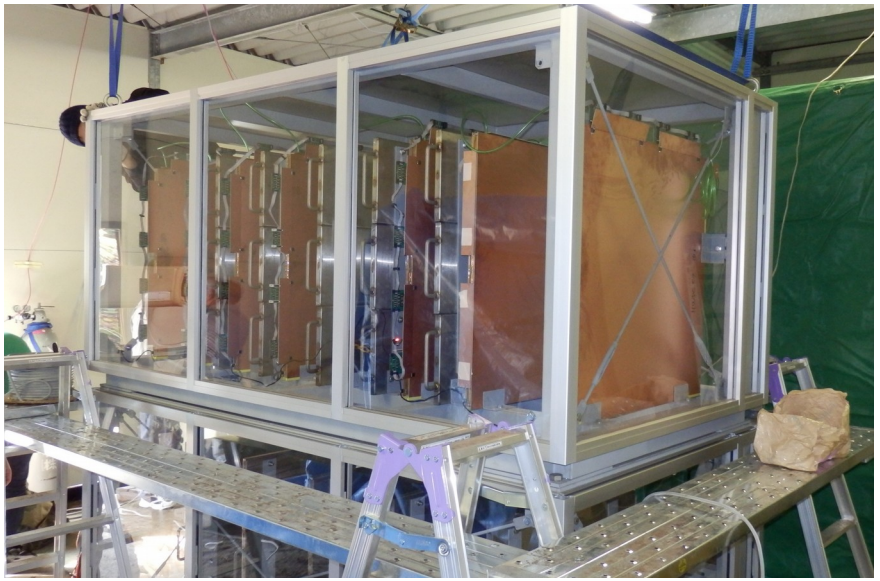




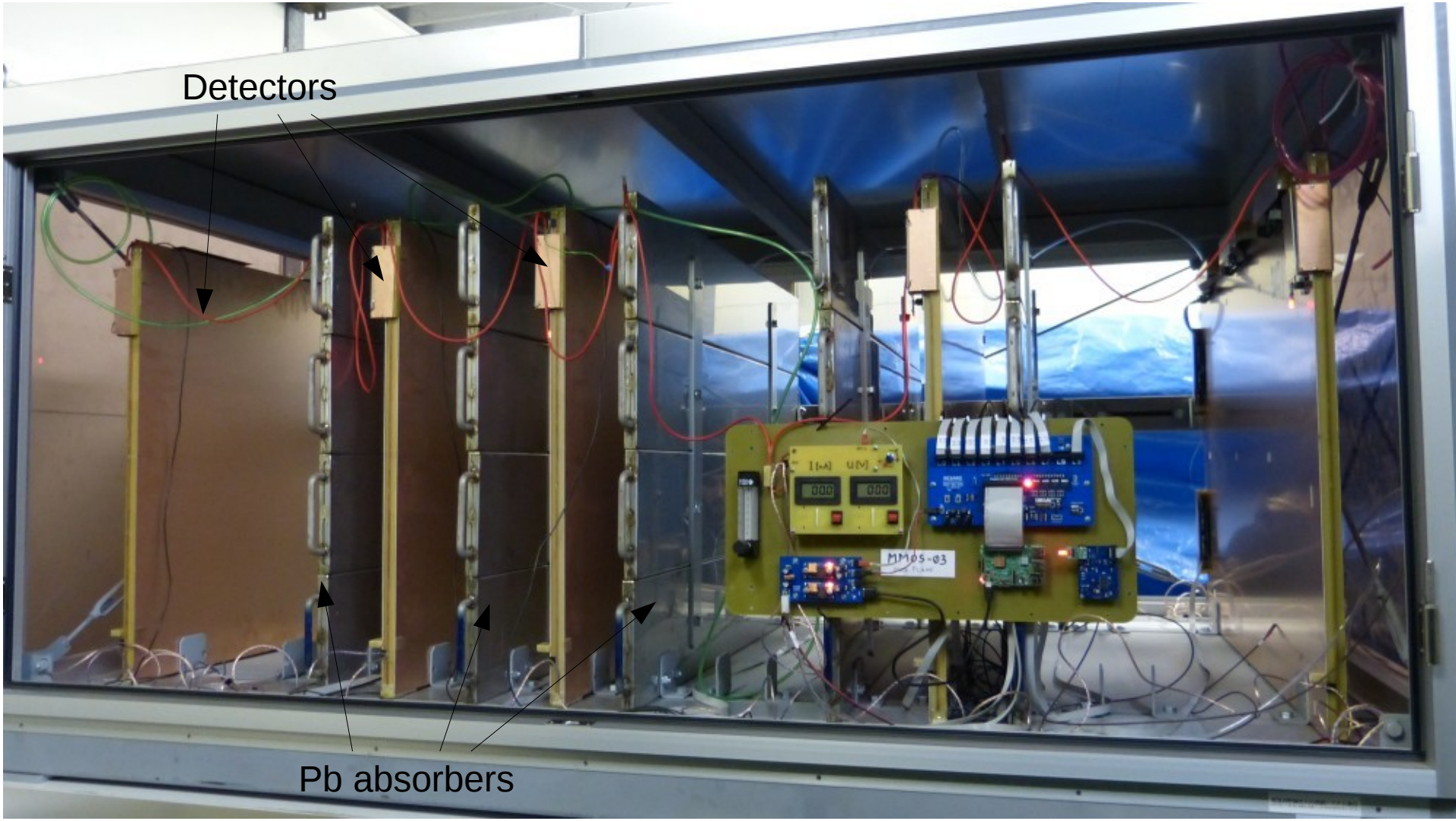
Eur. J. Phys. **36** 065006 (2015), arXiv:1607.08494, AHEP

Sakurajima Muography Observatory

- Currently running at Sakurajima (Kyushu), funded and managed by University of Tokyo
- 7W wallplug power consumption per unit (0.5 – 0.8 m^2)
- **Now total 8 square meter**, the world's largest



Patent: H. Tanaka, K. Tarou, D. Varga, G. Hamar, L. Oláh: Muographic Observation Instrument, Japanese Ref. No.: 2016-087436, date 25/04/2016



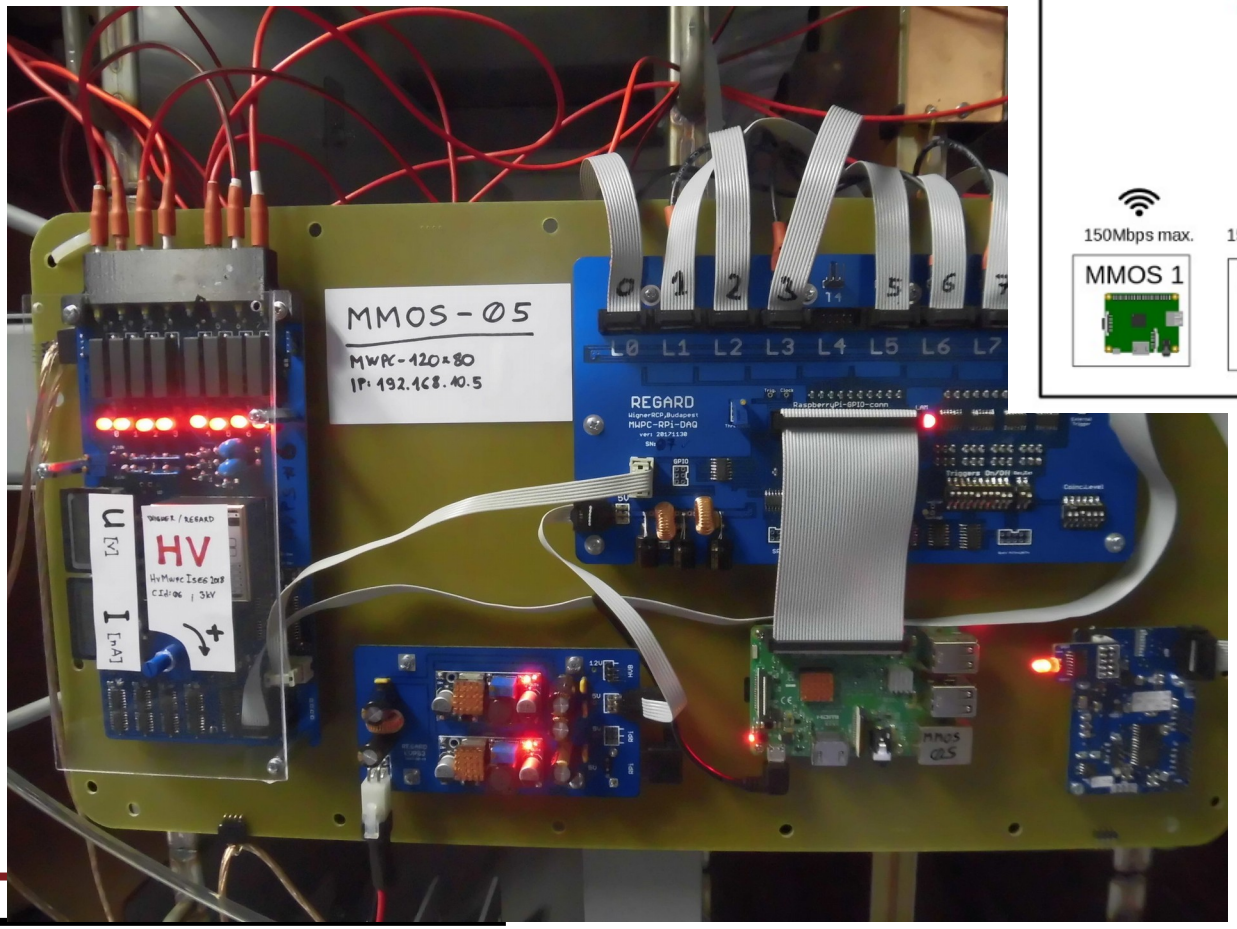
H. Tanaka, K. Tarou, D. Varga, G. Hamar, L. Oláh: Muographic Observation Instrument
Japanese Ref. No.: 2016-087436, date 25/04/2016

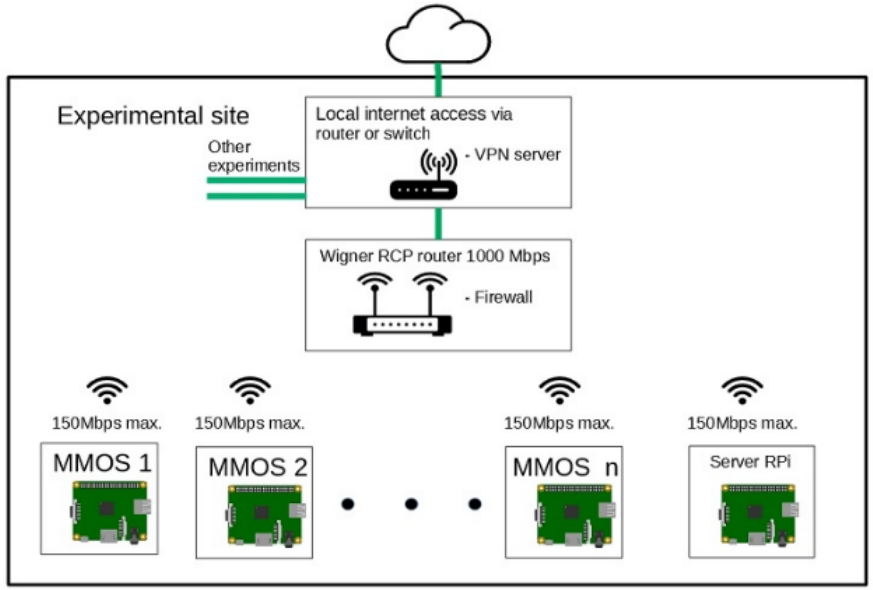
Modularity of detector system

- Independent modules, on same target, total **8 square meter** sensitive area installed as of Aug. 2019

Standalone Data Acquisition system

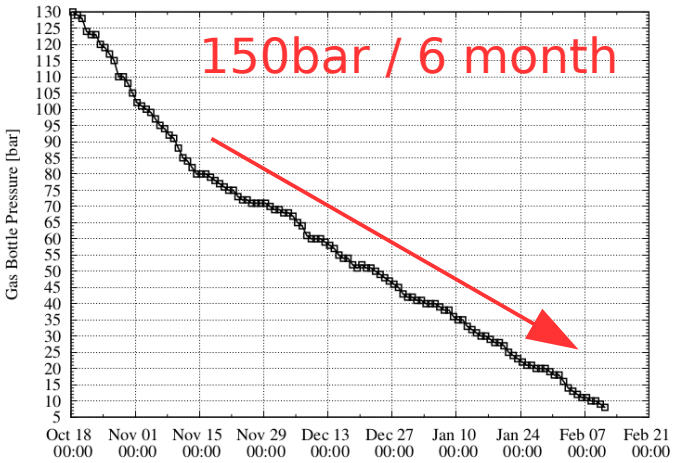
- Integrated system with power supplies and control

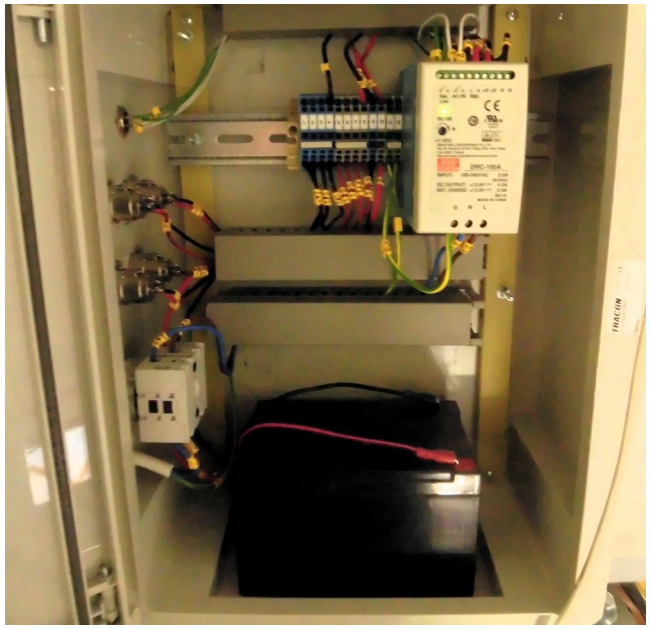




Gas distribution, and power supply boxes with backup and protection

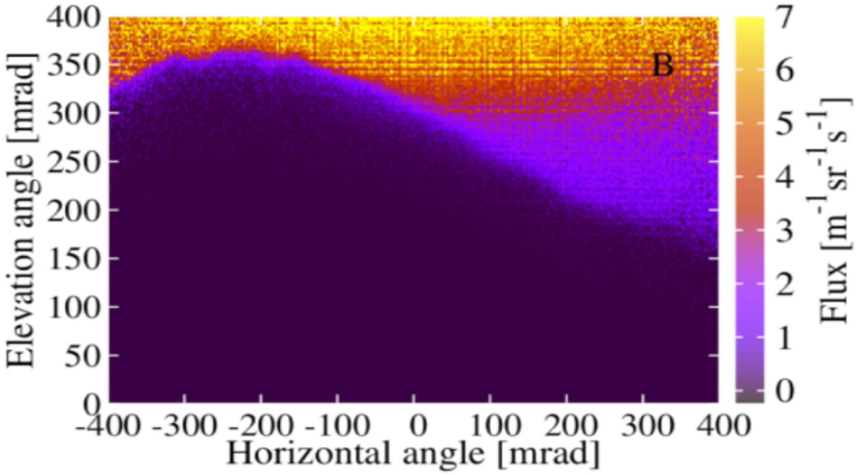
- High level of fail-safety. Gas system serving 10 (up to 16) MOS units parallel, power box serving 4 MOS units

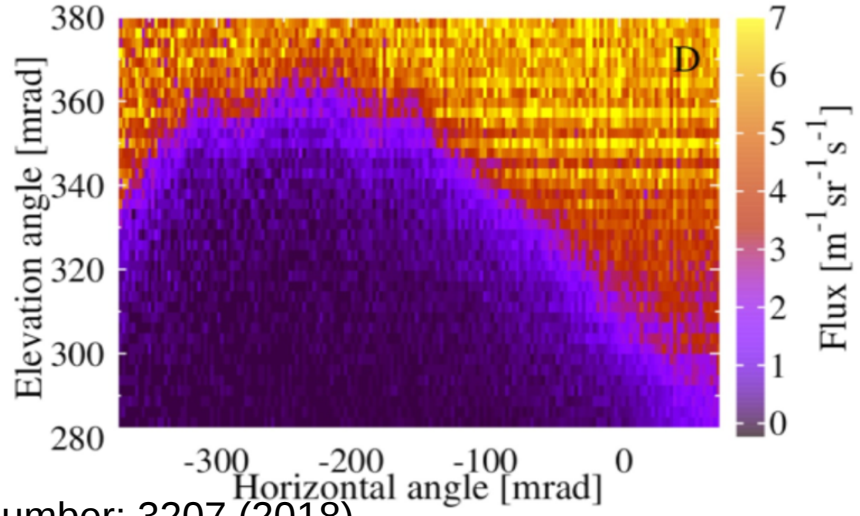




High-definition muography with mMOS

- **Measured muon flux in 2.7 × 2.7 mrad^2 bins (7.5 × 7.5 m^2 from the distance of 2.8 km) reproduces the ridge of the Sakurajima**





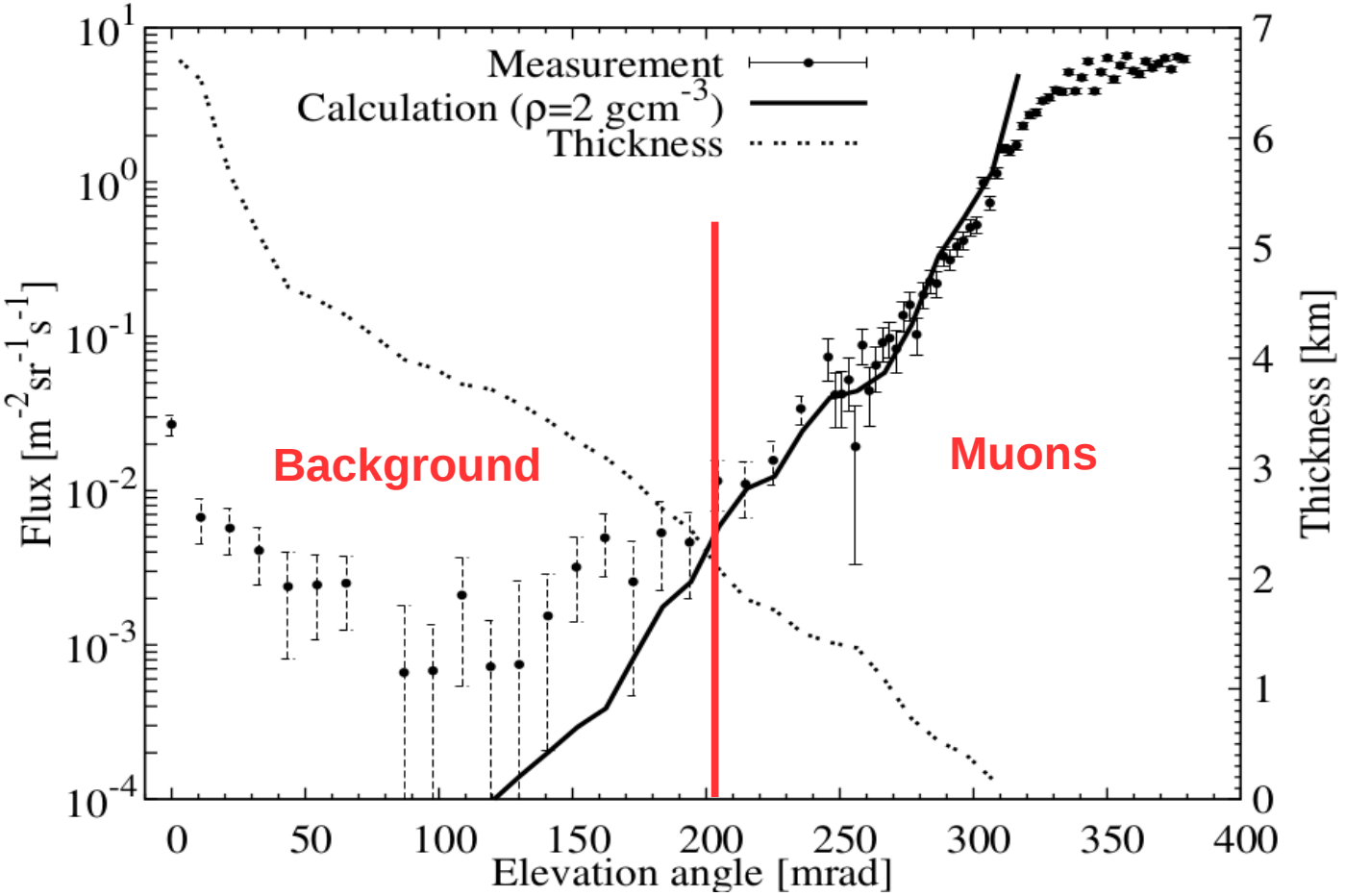
L OLAH, Scientific Reports, Volume 8, Article number: 3207 (2018)

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**

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

Middle slice: 21.8 mrad x 2.725 (10.9) mrad



Can we look through a mountain???

- Nice ridge silhouette visible, density compatible with reality… but do we actually see inside? **Or behind?**

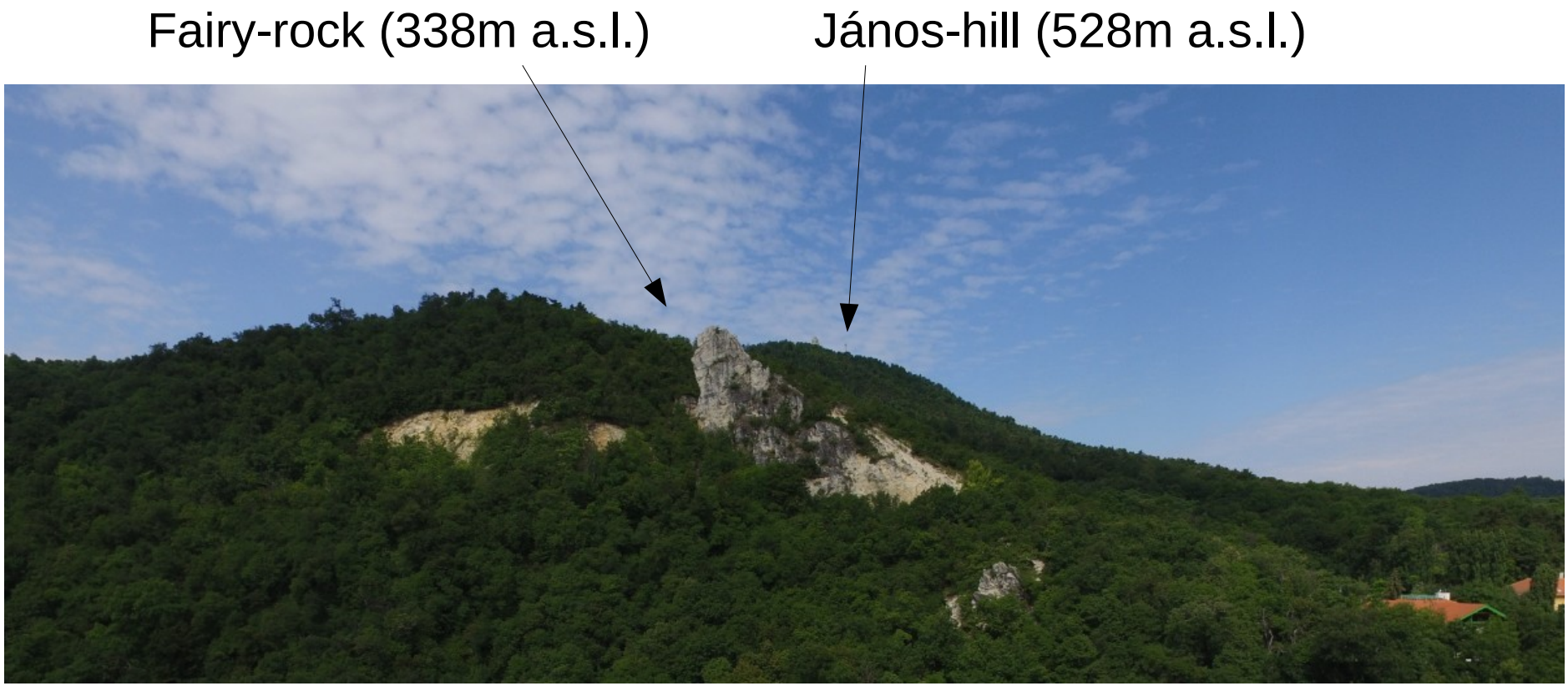


Image taken 270m a.s.l.

Can we look through a mountain???

- Nice ridge silhouette visible, density compatible with reality… but do we actually see inside? **Or behind?**

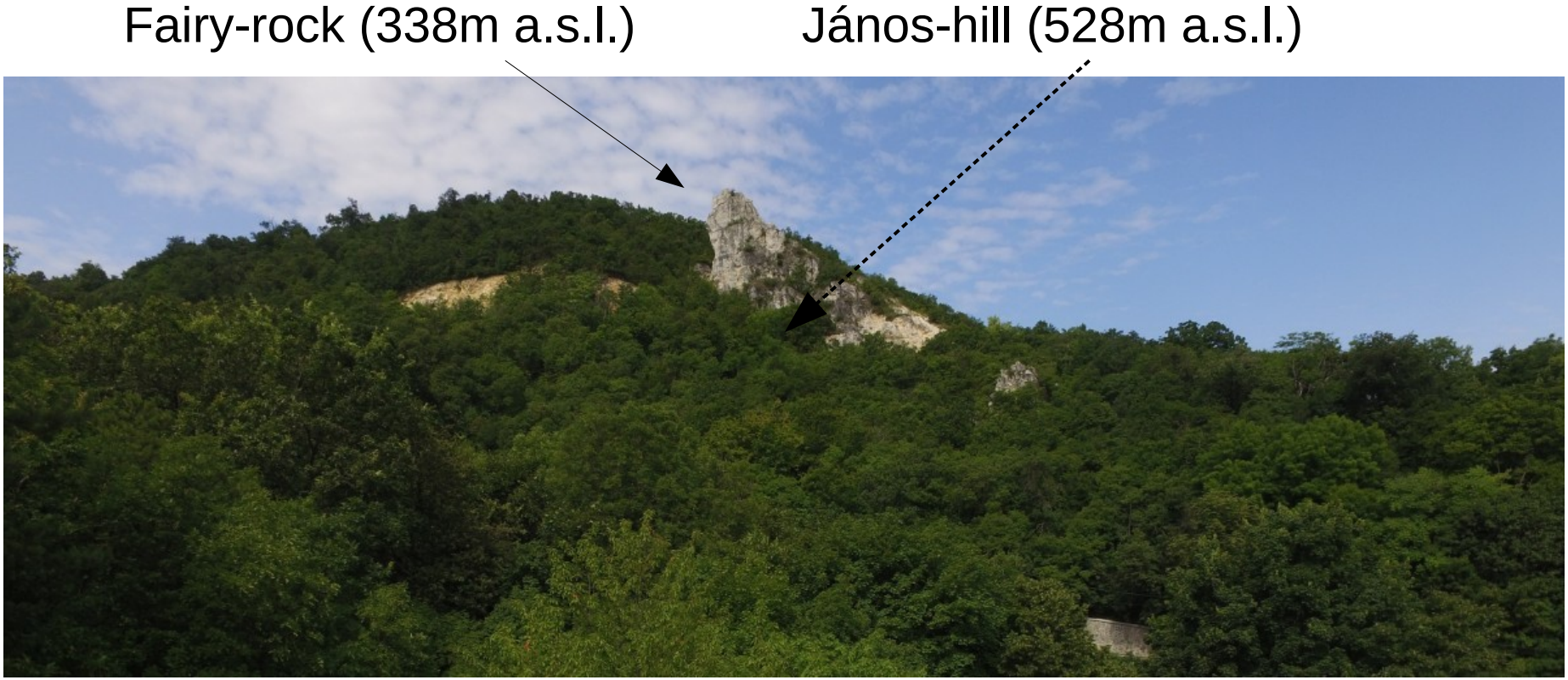


Image taken 238m a.s.l.

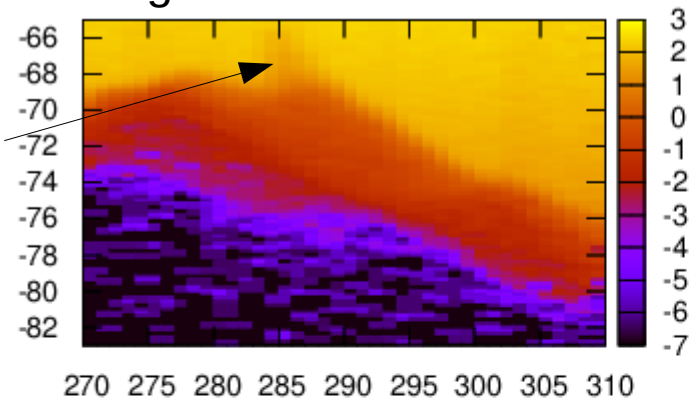
MOS installed in a tent

- 8 detectors, 2 layers of Pb absorbers (2cm + 3cm)
- 30 + 50 days of observation, still ongoing with 2+1 Pb

Very complicated rock length structure

MEASURED FLUX

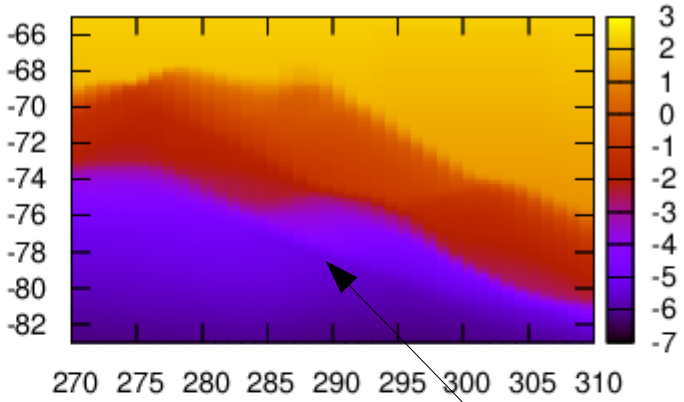
-Zenith angle



Azimuth angle

Fairy-rock

Approx. CALCULATED

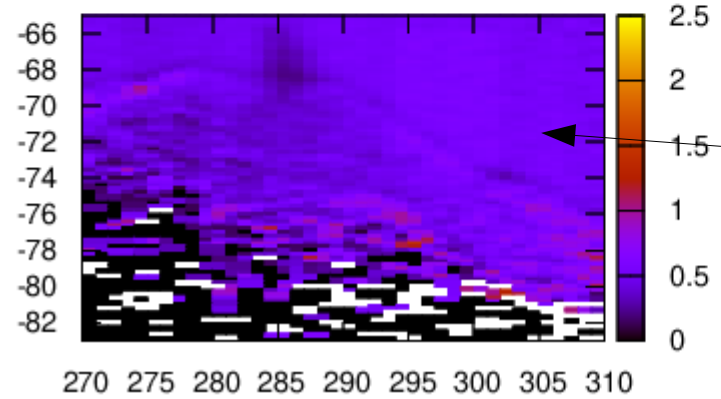


Azimuth angle

Color scale:

log(f)

Valley

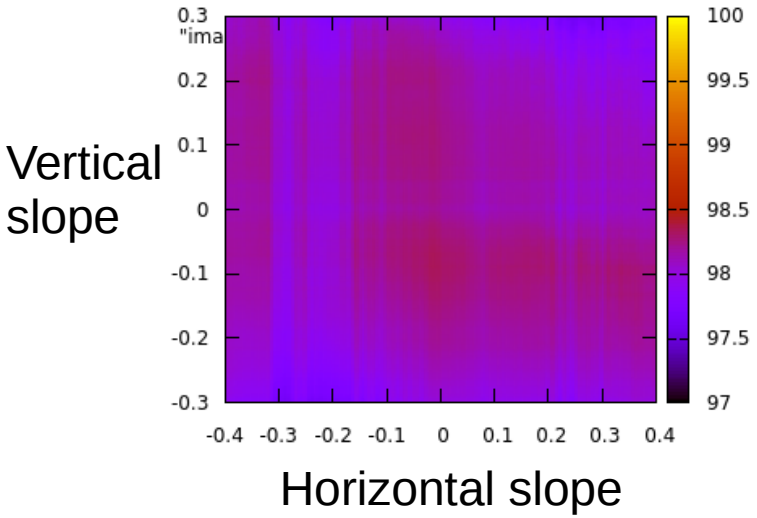


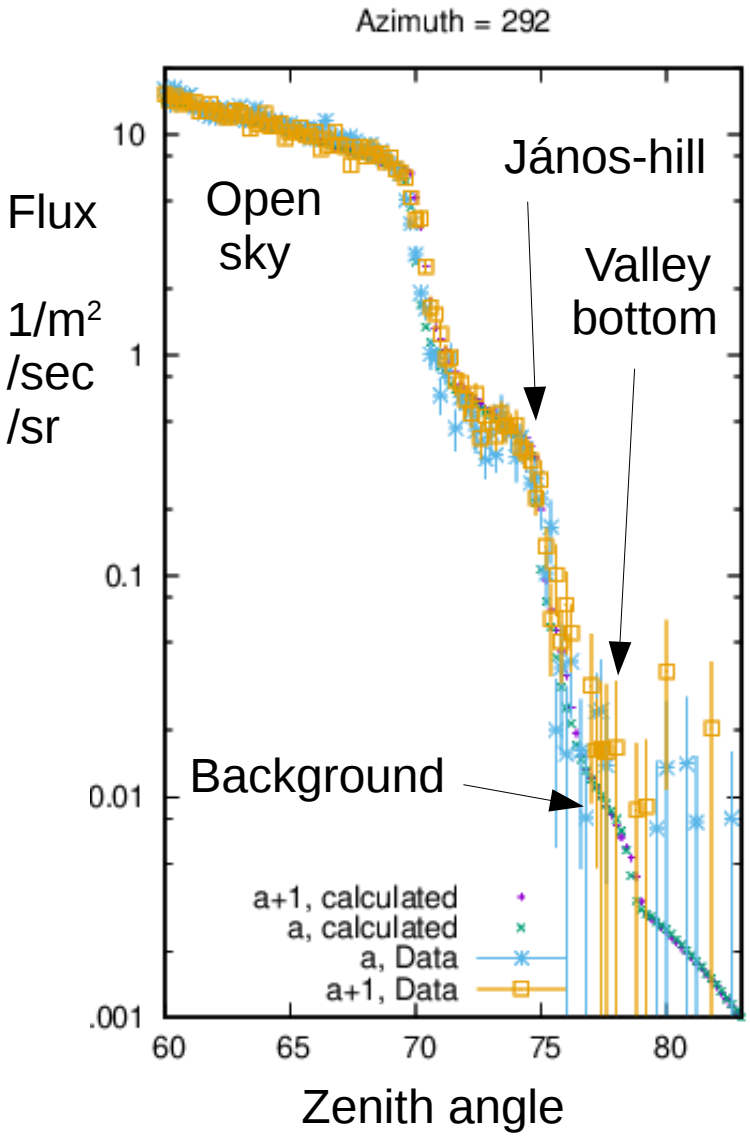
FLUX RATIO

Flux well matches expectation

- Sharp drop at János-hill peak: ridge imaged BEHIND the Fairy-rock hump in the foreground
- Excellent tracking efficiency (98-99%)

(7 or 8 “good” out of 8 points)





Summary

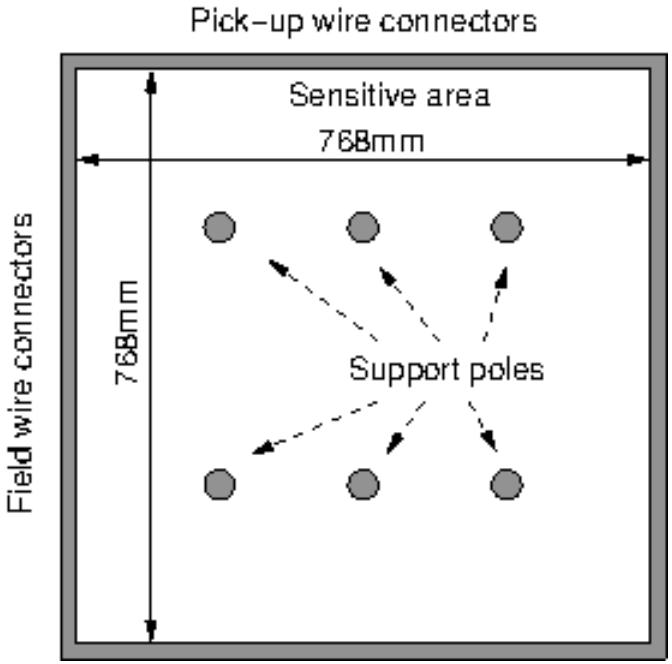
- Muography is made real by contemporary technology and detector construction methods
- Muography instrumentation with “large size” detectors: reliable production and performance
- SMO experience with modular system, solutions for auxiliary systems (gas, power, local network)
- Experimental demonstration of “looking through hill”
- One key application of Sakurajima volcano internal structure and dynamics investigation

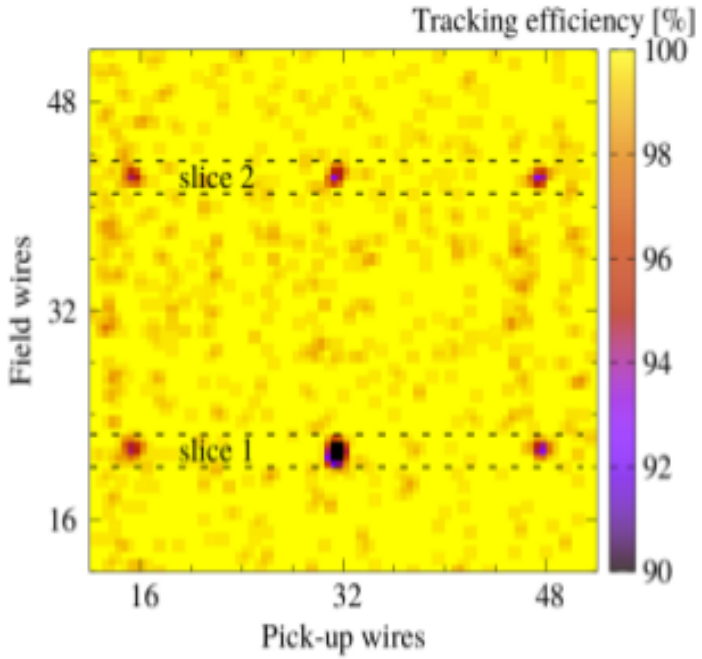
Contributions from

L. Oláh, G. Surányi, G. Hamar, G. Nyitrai, Sz. Balogh, A. Gera...

Detectors viable for **volcano imaging**

- High efficiency, high mechanical stability

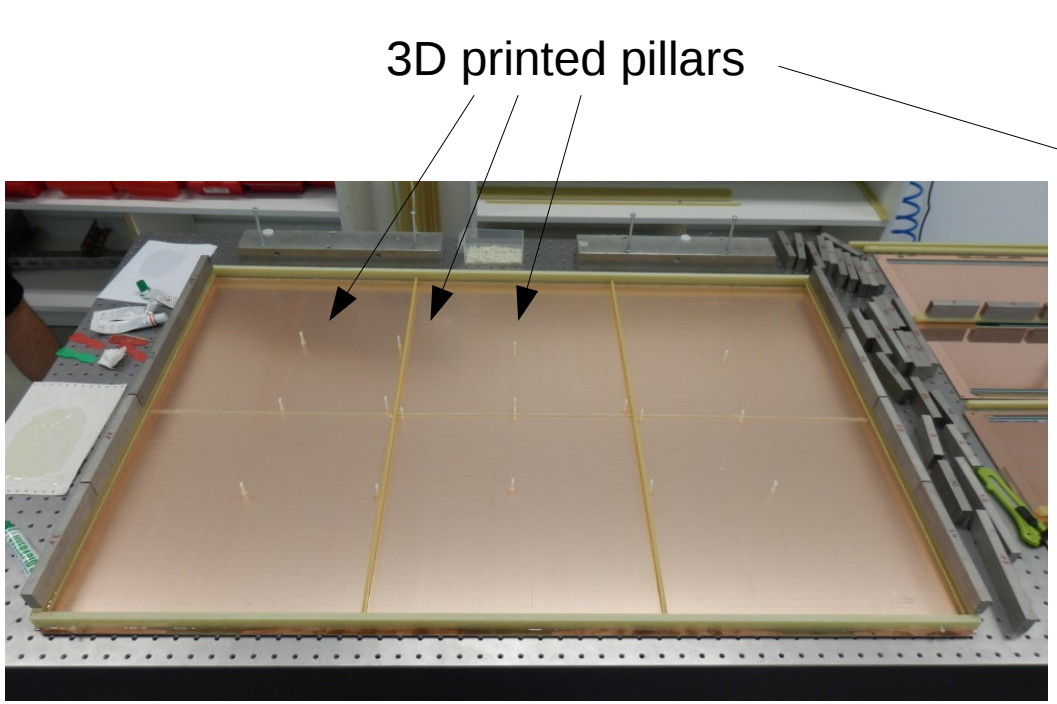




D. Varga et al, Eur. J. Phys. **36** 065006 (2015)
D. Varga et al, arXiv:1607.08494, AHEP In Press

Detector production at our lab

- Standardized structure, by now more than 100 detector layers (total area above 60 m2) produced



Treating IP issues: multi-lateral agreements and patents

- 2015: IP agreement with Tokyo Uni
- 2016: IP agreement with NEC (3-lateral), definition of the Muographic Observation Instrument
- 2017: NEC Licensing and Material Transfer agreements (non-commercial license)
- 2018: Including CRIEPI (4-lateral), detector construction by Technoland