Muography: cosmic ray imaging

Dezső Varga for the Detector Physics Group
HUN-REN Wigner Research Centre for Physics

Theory and Experiment in HEP
Budapest, 13th March 2024

REGARD
RMKI ELTE Collaboration on Gaseous Detector Research and Development

All colors of Physics

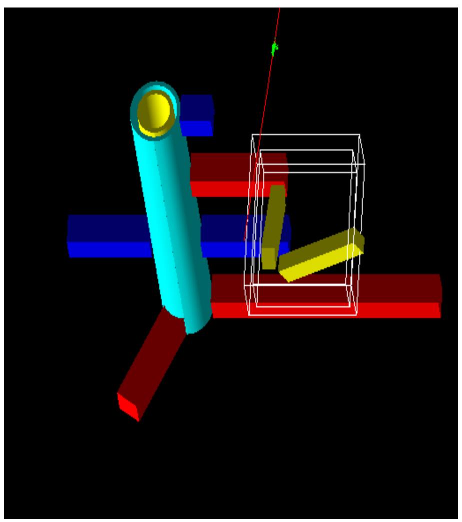
National Research, Development and Innovation Office Hungary
PROJECT FINANCED FROM THE NRDI FUND

Overview

- Muography: an old dream came through by contemporary technology
- Fundamental limitation of flux: need for high performance low background detectors
- Underground and mining application
- Detector operation and maintenance

MuoGraphy: imaging with cosmic muons

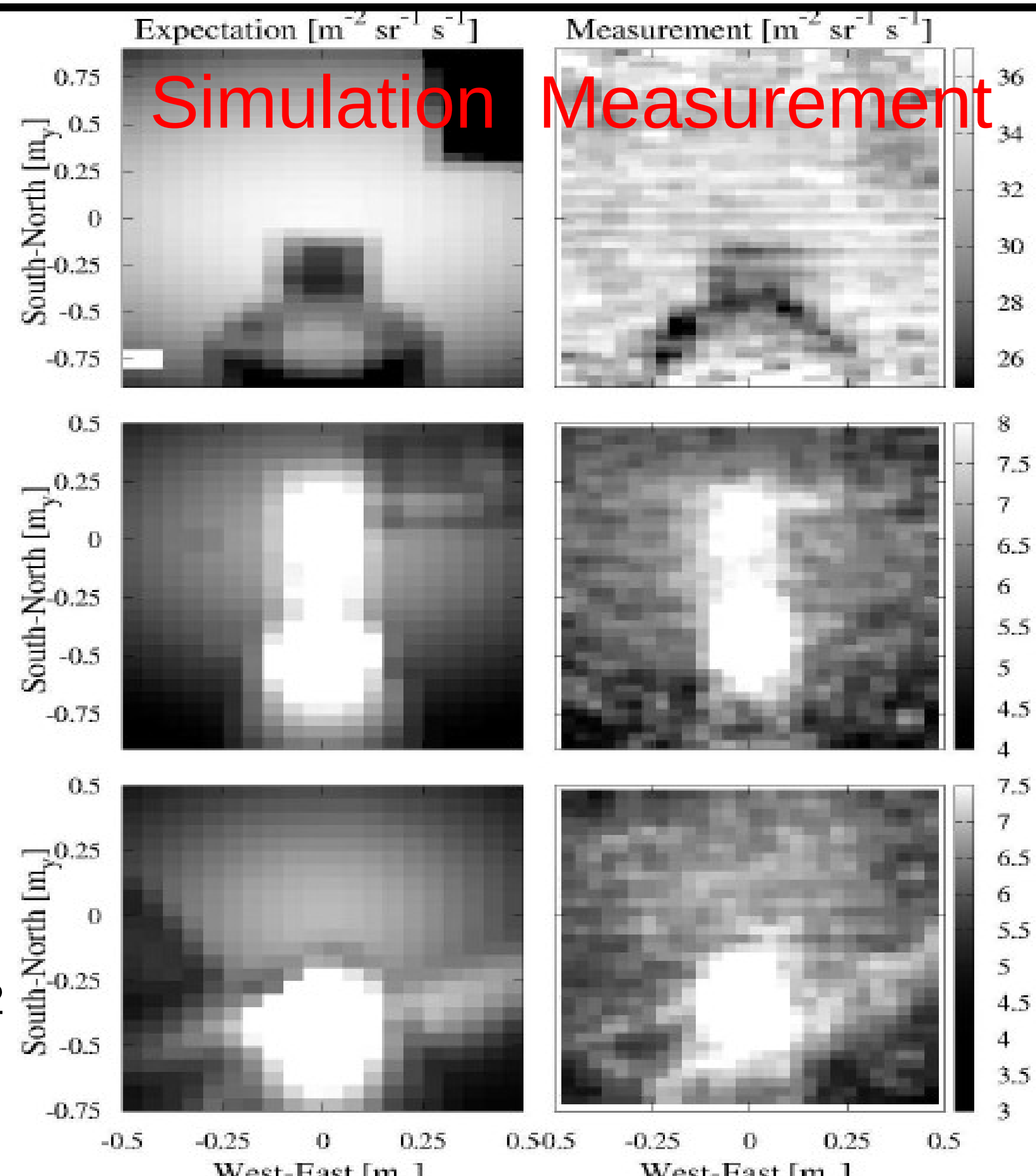
- Jánossy Underground Research Laboratory



10 m

20 m

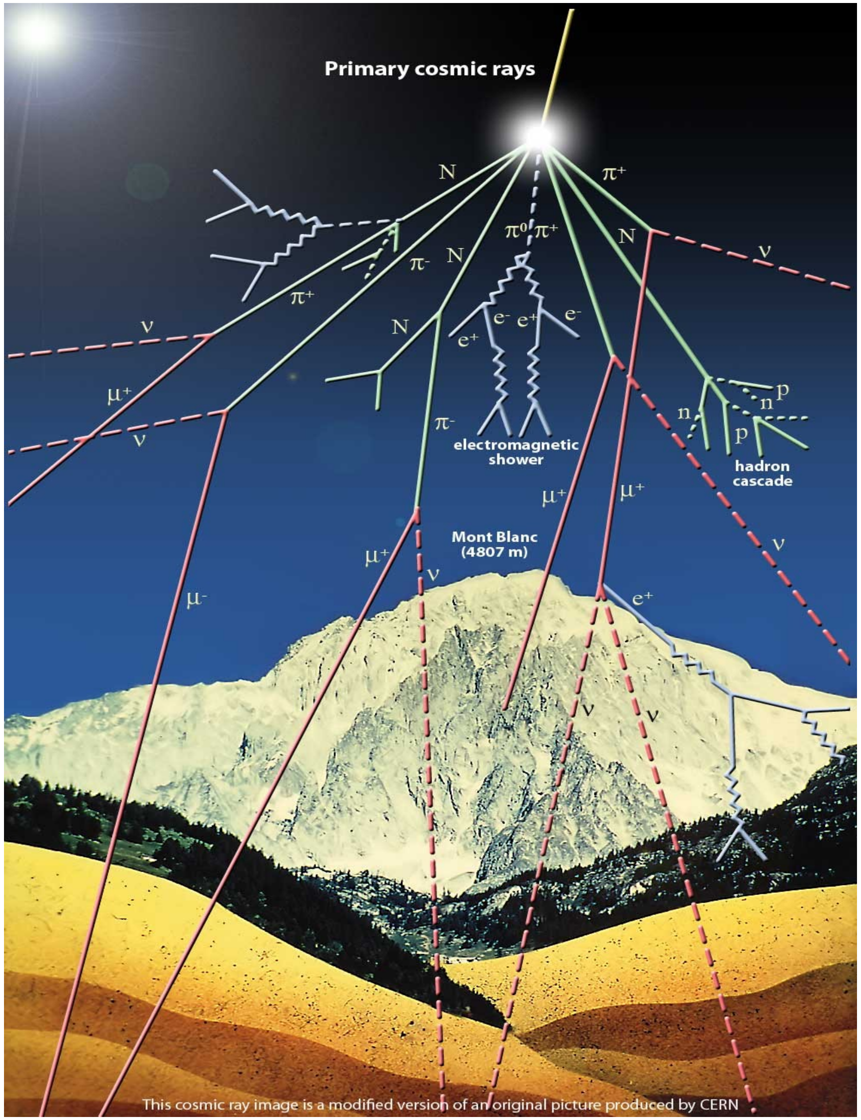
30 m



Adv. in HEP 2013 560192 (2013)
Journ. Phys. Conf. Ser. 665 (2016) 012032
PoS (NIC XIII) 129 (2015) 6p

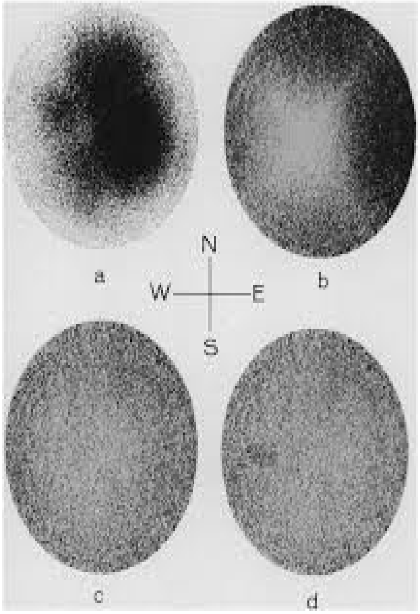
Muons, Nature's highly penetrating cosmic rays

- Cosmic particles from deep space reach Earth upper atmosphere
- Muons created in a shower-like event
- Muons can cross kilometers of material

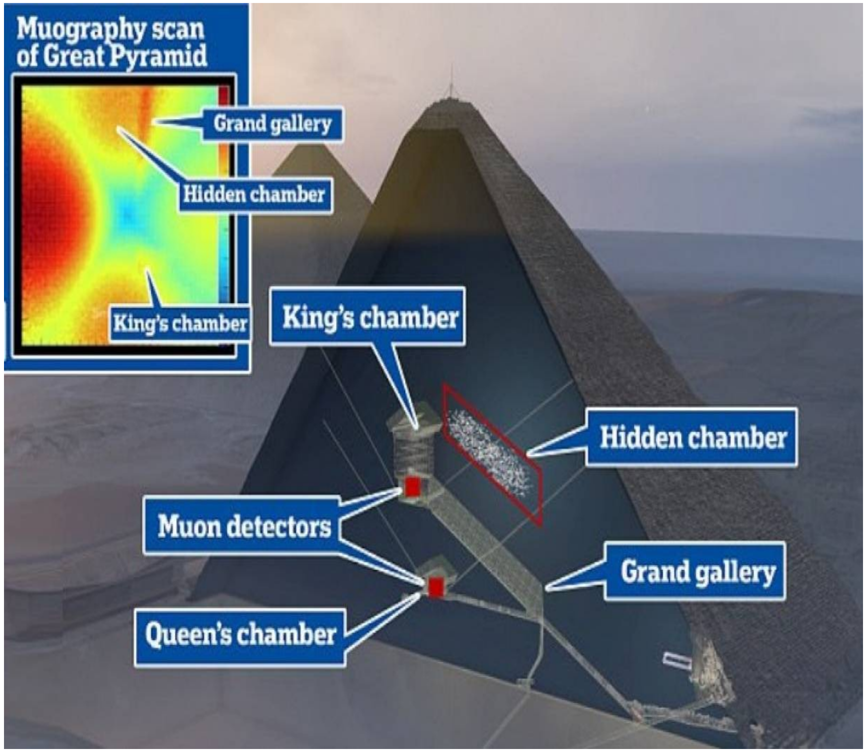


Broad range of applications

- Alvarez (1970!)

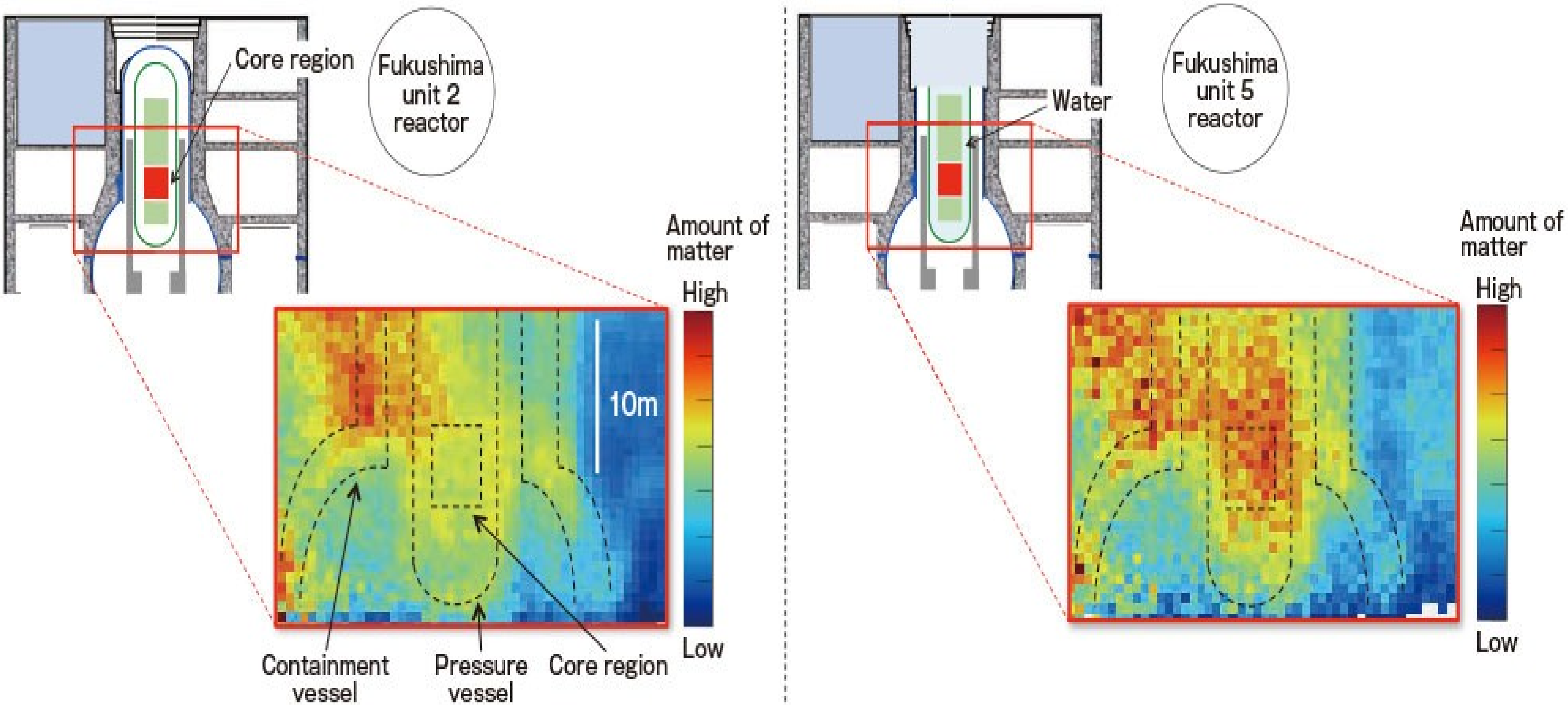


"ScanPyramids" 2018



Nuclear reactor interior

- Post-accident at Fukushima

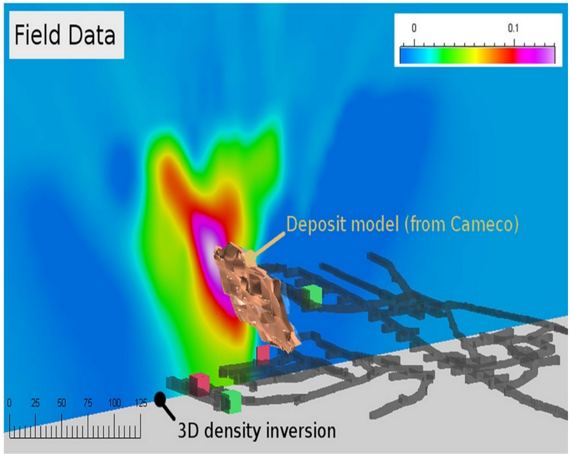


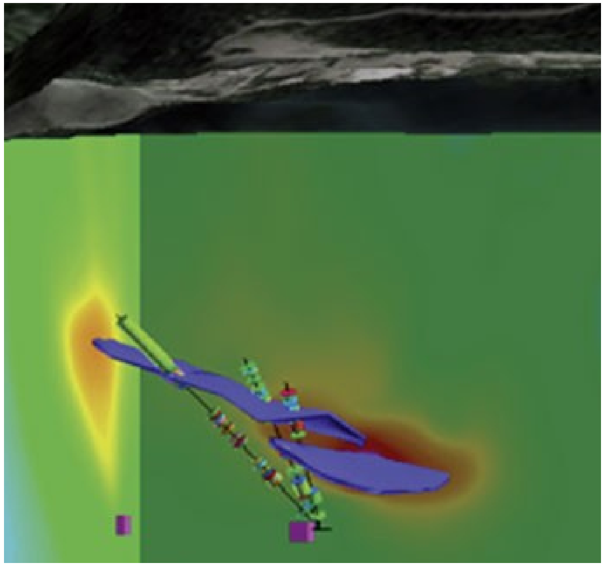
Mining industry

- Breakthroughs in Canada/Australia
- Ore body identification by **density contrast**
- Depths up to 600m

Density tomography in an australian uranium mine. D. Schouten et al, *JGR Solid Earth* **123**, 8637 (2018)

Muon Geotomography… D. Schouten, focus article in Recorder Vol.43, 5 (2018)





“Generations” of muography,

a personal historical notation

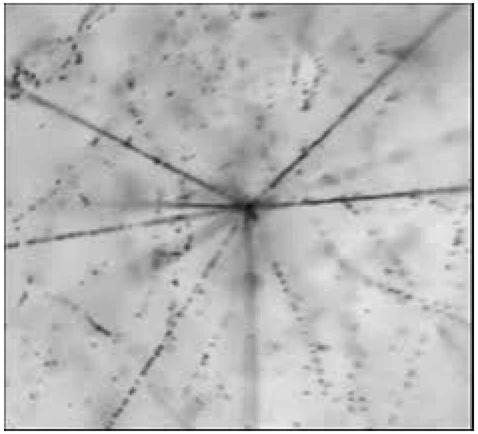
- 1st Generation: George 1955, Alvarez 1970 – demonstration of the principle for underground imaging
- 2nd Generation: around the 90-ies, Los Alamos, Italy, Japan… expanding the possibilities including scattering, various patents
- 3rd Generation: around 2000, breakthroughs in volcanology (dynamics!), 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**

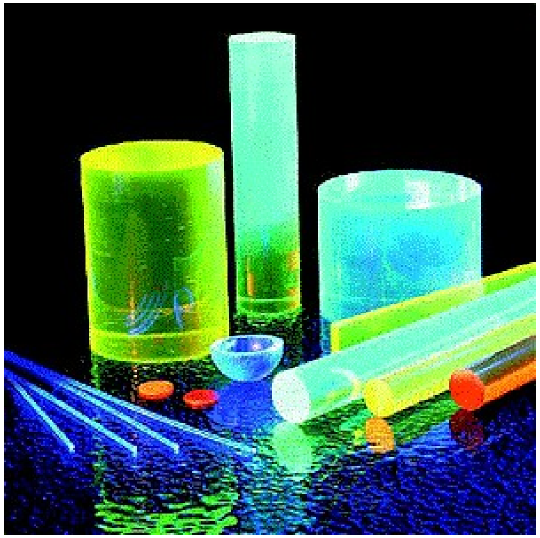
Detection technologies,
developed for fundamental science

- Emulsions, thick "photographic films"

  Easy to deploy,

  no time resolution



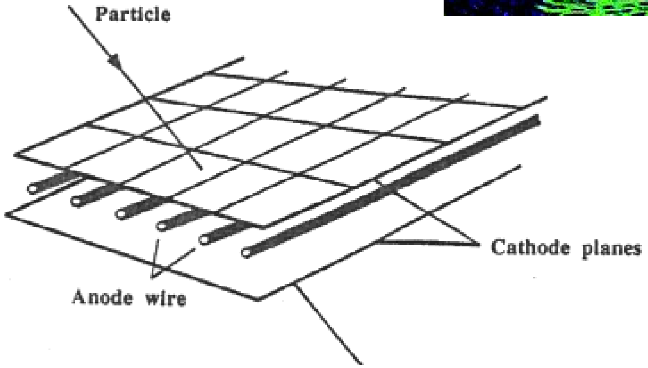


- Scintillators (visible light)

  High efficiency

- Gaseous detectors

  High efficiency, cost efficient



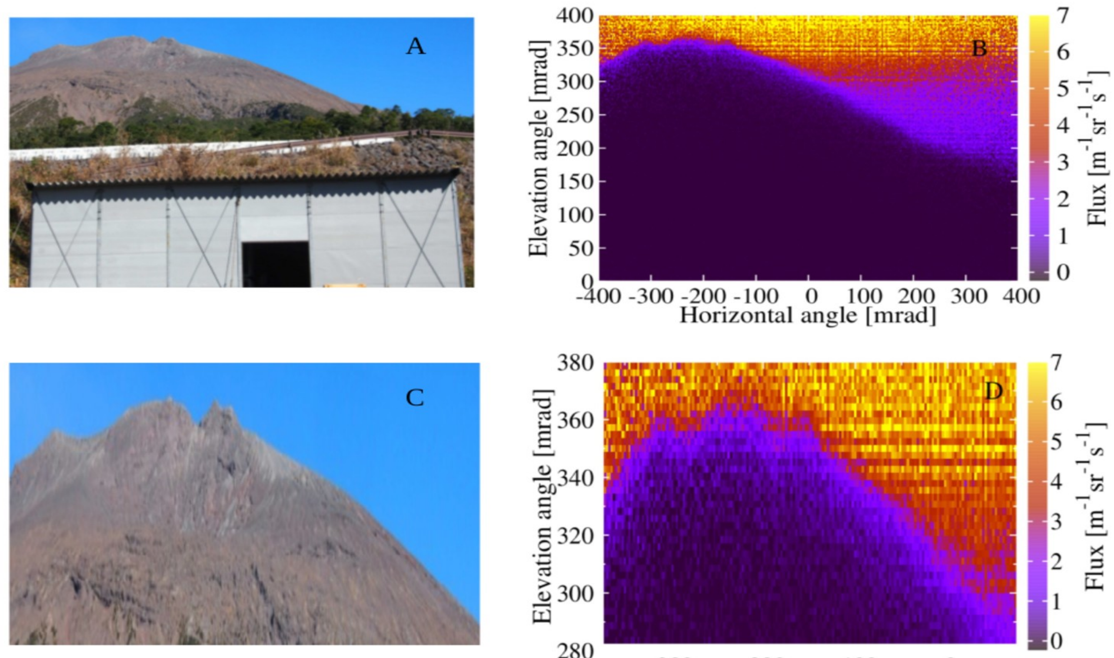
Gaseous: high performance tracking

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

CEA “Pyramid discovery” detectors

Morishima et al, Nature 2017

Detectors at Sakurajima, UT & Wigner



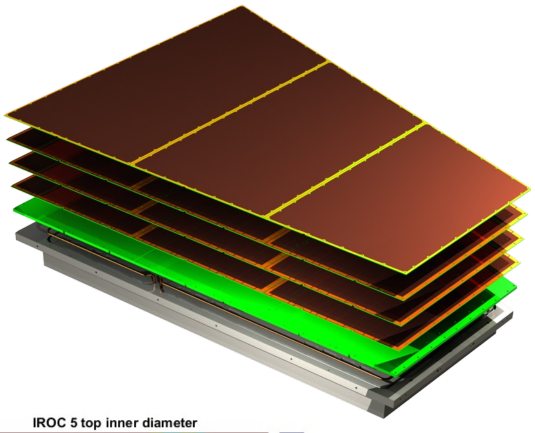
Scientific Reports, Volume 8, Article number: 3207 (2018)

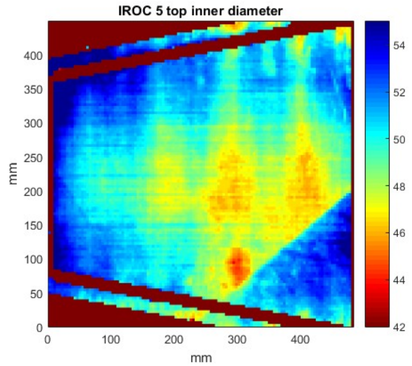
Wigner RCP **Detector Physics** group: HEP instrumentation

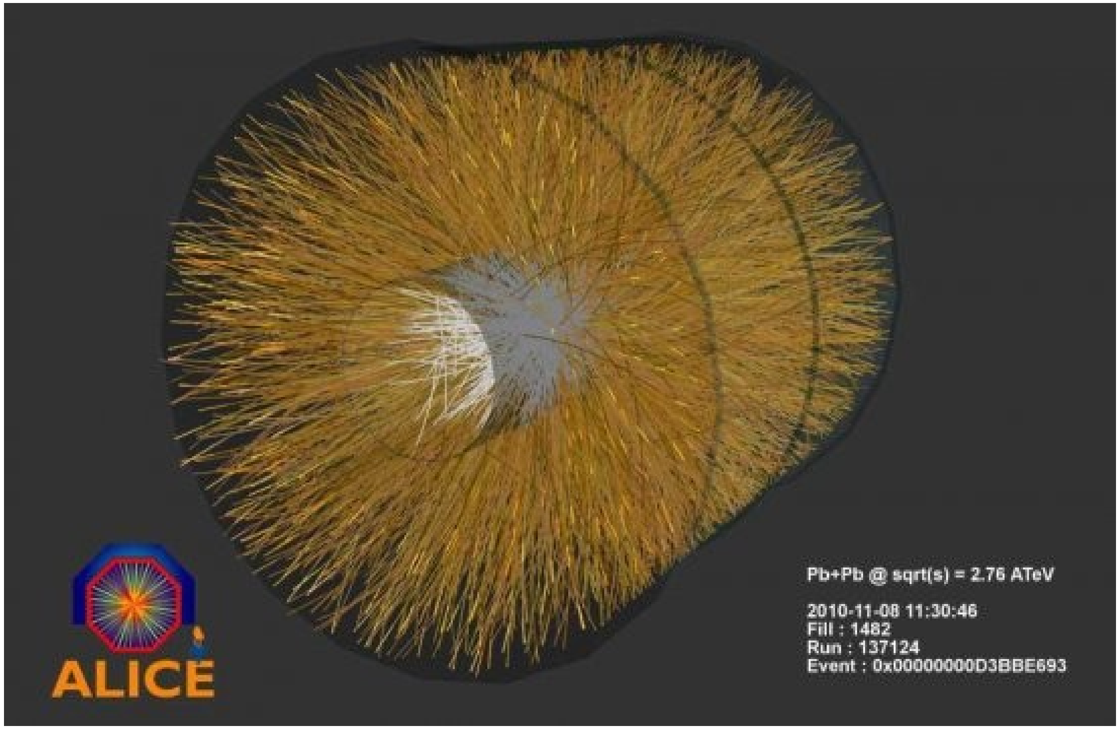
- CERN RD51 (DRD1): gaseous detector R&D
- CERN NA61: detector construction
- CERN ALICE: rebuilding the TPC (ALICE 3 Muon ID)
- ESS BrightnESS: neutron detector development

CERN ALICE highlight: TPC Upgrade participation

- World's largest TPC tracking system, 80 m^3
- Key construction step: individual foil testing

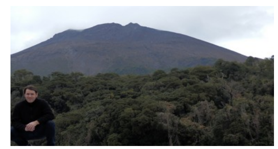
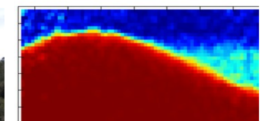




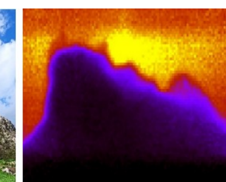


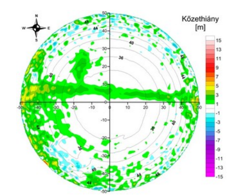
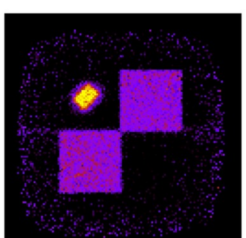
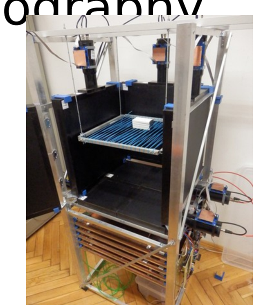
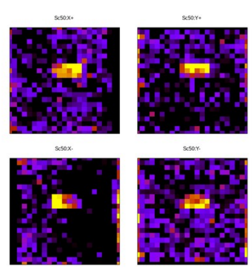
National muography activities
at Wigner RCP, Dept. of High Energy Physics

- Based on **national scientific expertise**, CERN groups
- Muography Observation System (patented) at the **Sakurajima volcano,** Japan, world’s largest
- **Mining** applications (Finland, Poland, Germany, Portugal, Bosnia-H...)
- Speleology, archeology (Buda; Sicily)
- Transmission and secondary emission tomography

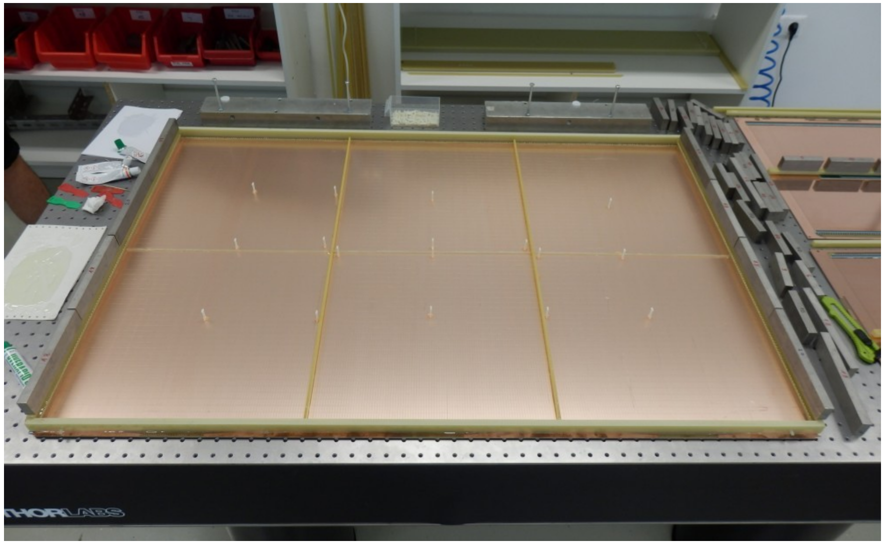


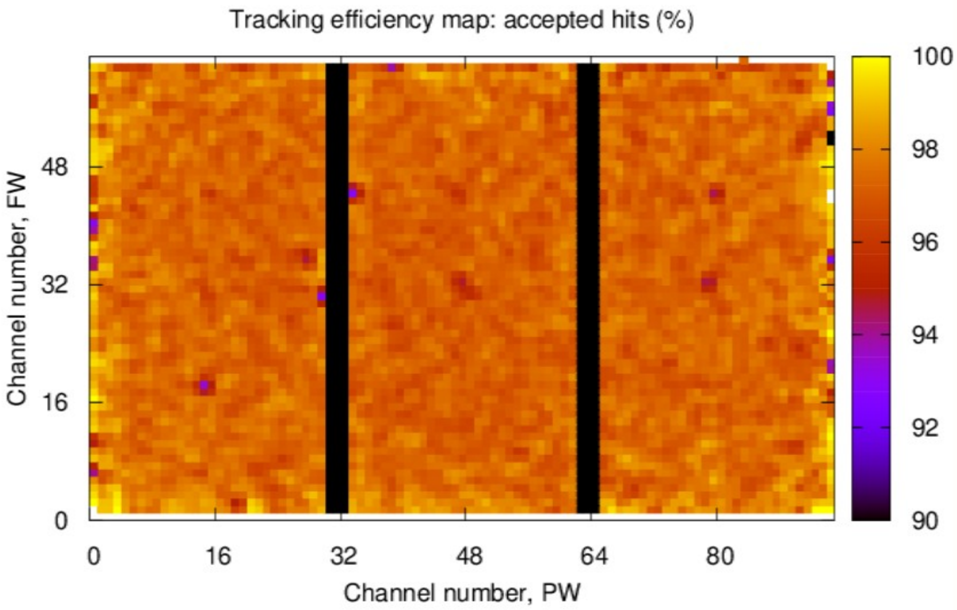


Large area MWPC detector construction

- Reliability, durability, scalability by design
- By now 200+ m^2 produced (70 m^2 at SMO)

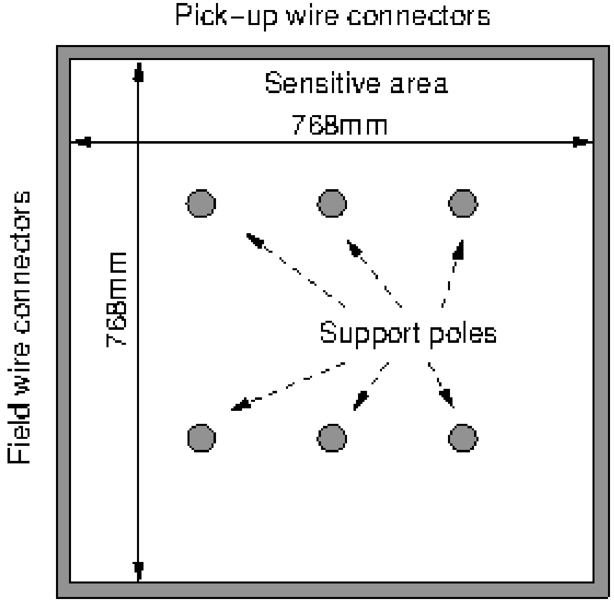


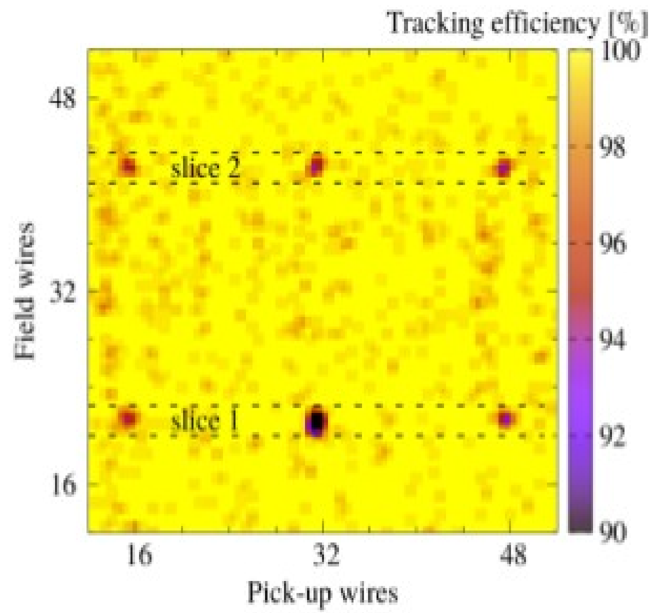


Eur. J. Phys. **36** 065006 (2015), arXiv:1607.08494, AHEP

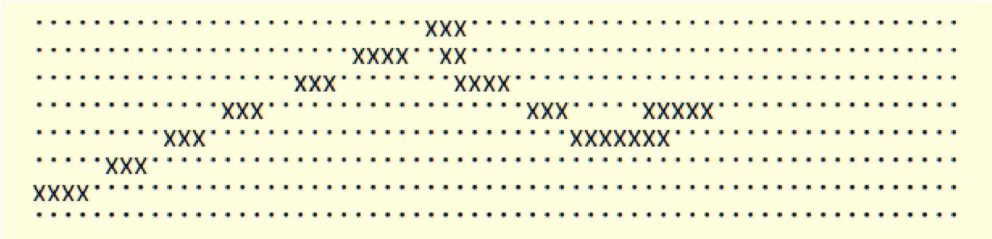
“Large size” detectors (typical 80 x 80 cm)

- High efficiency, high mechanical stability



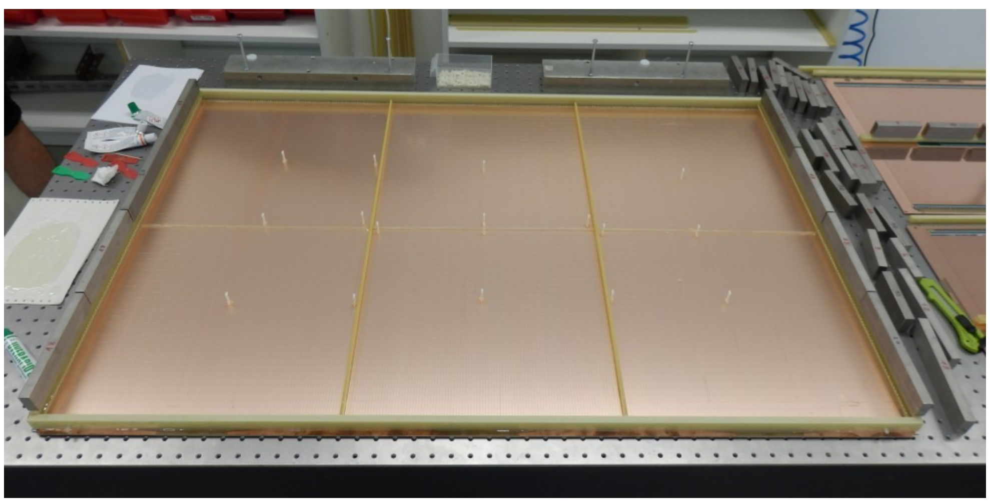
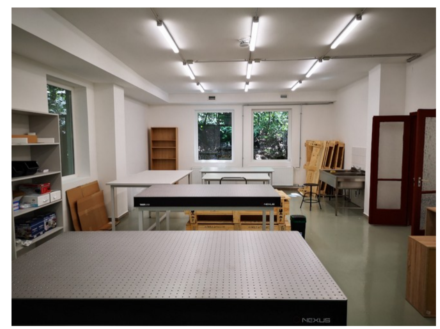
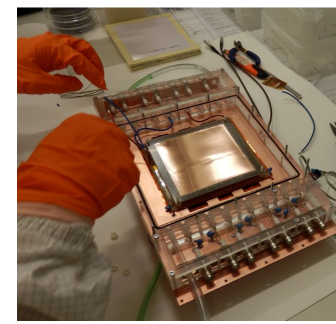
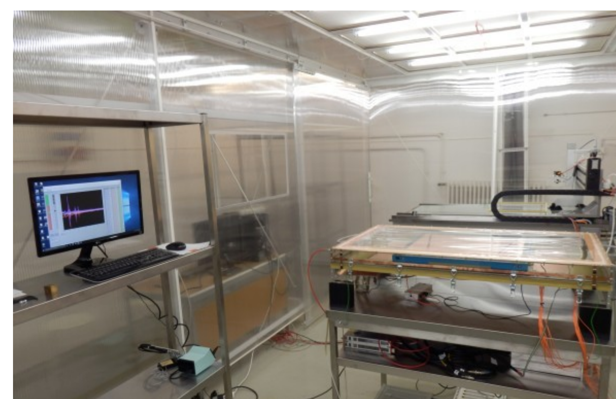


D. Varga et al, Eur. J. Phys. **36** 065006 (2015)
Varga, D., Nyitrai, G., Hamar, G., & Oláh, L.. AHEP, 2016 , 1962317.



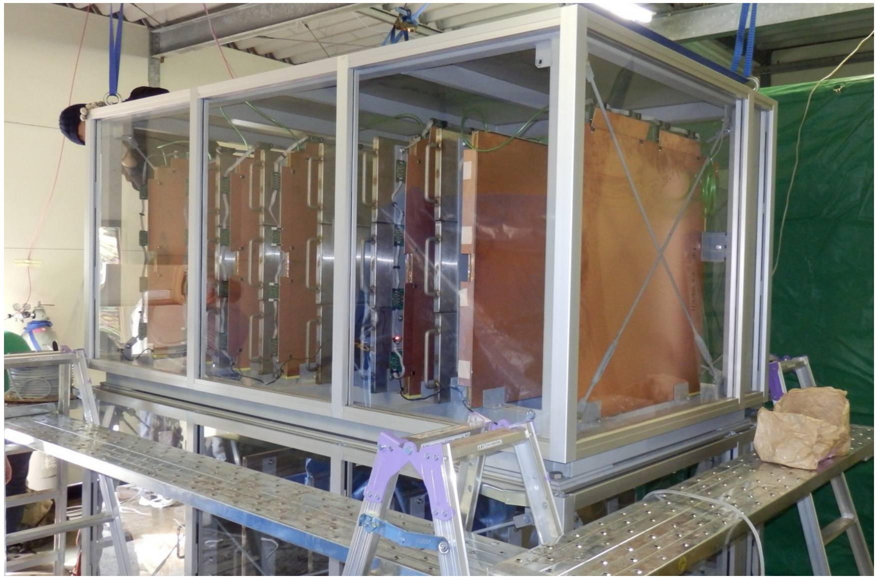
Detector production: “Vesztergombi Laboratory for High Energy Physics”

- Dedicated infrastructure, nominated as excellent (Top50) nationally by the NRDI Office
- Serves 5+ research groups at RMI

Sakurajima Muography Observatory

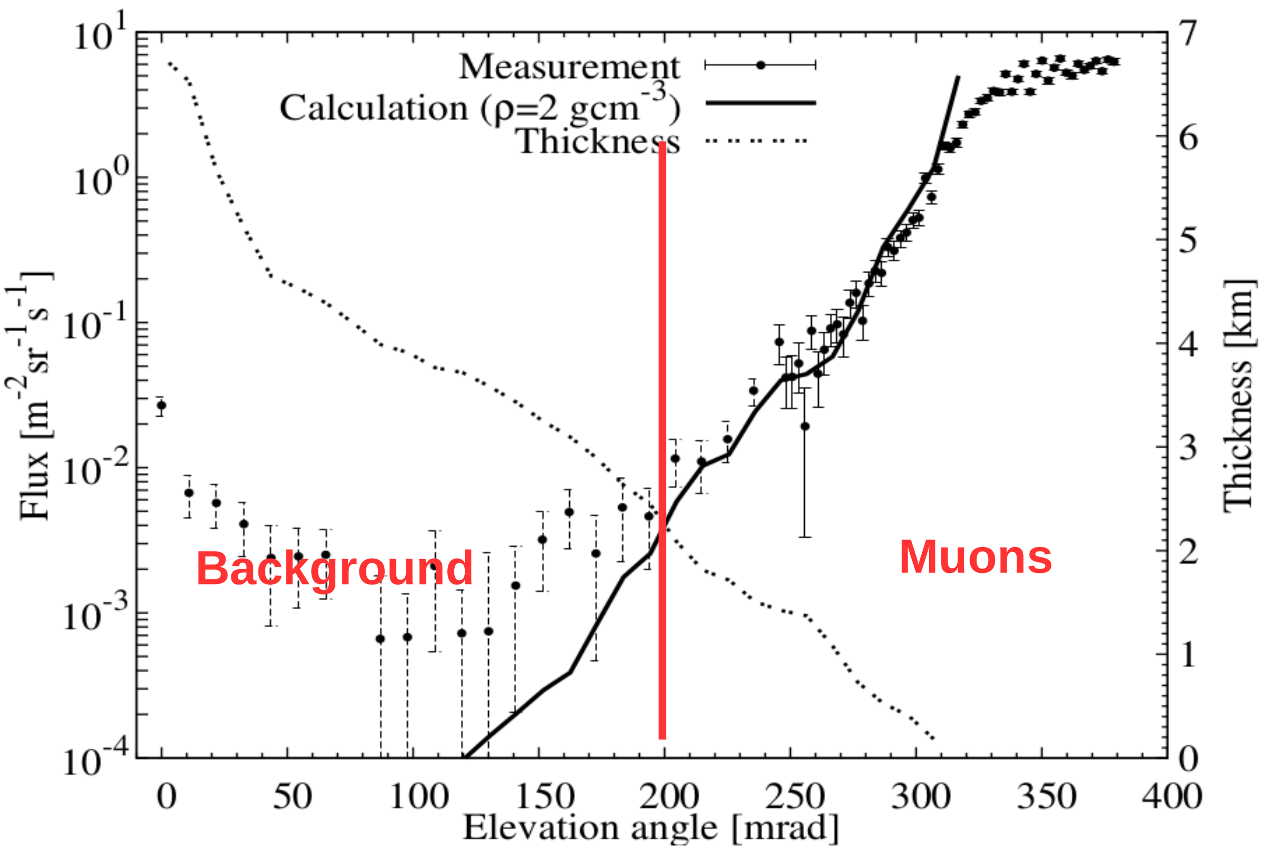
- Currently running at Sakurajima (Kyushu), funded and managed by University of Tokyo
- 5 – 10 W wallplug power consumption per unit (0.5 – 0.8 m²)
- **Now total 8.7 square meter**, the world's largest



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

Background suppression: needed for thick targets

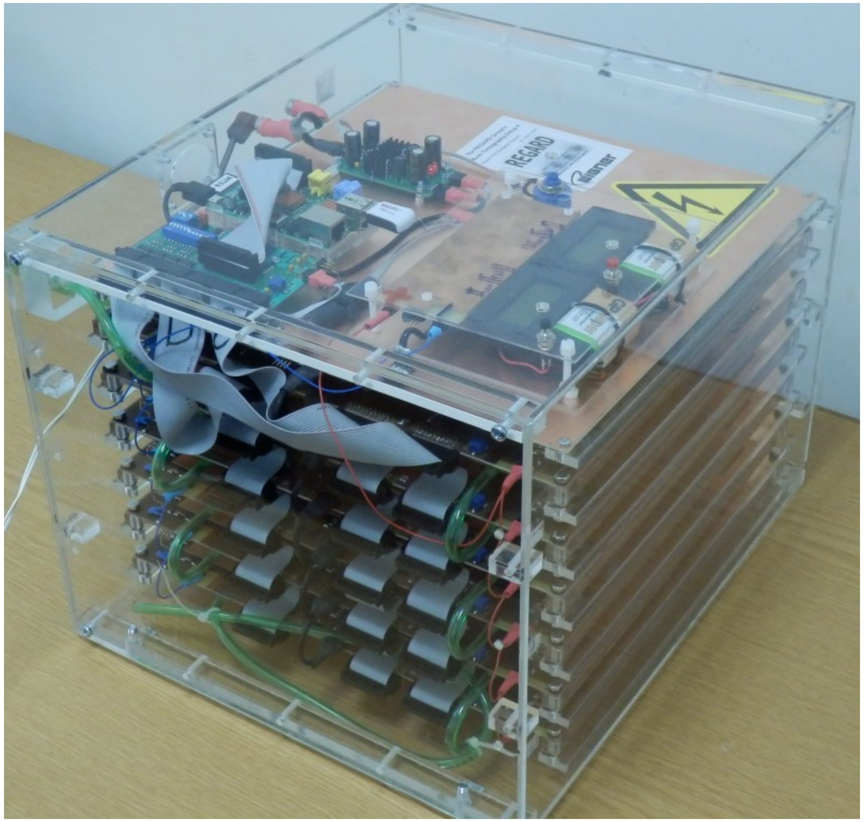
- Stack of detectors and Pb layers works up to 1km of rock



L. Olah, Scientific Reports, Volume 8, no. 3207 (2018), H. Tanaka, K. Tarou, D. Varga, G. Hamar, L. Oláh: Muographic Observation Instrument Japanese Ref. No.: 2016-087436, date 25/04/2016, PCT: WO2017187308A1

Underground detectors: use what fits!! S to L-size

- “Muon Tomograph Large” (MTL1) and “Compact”

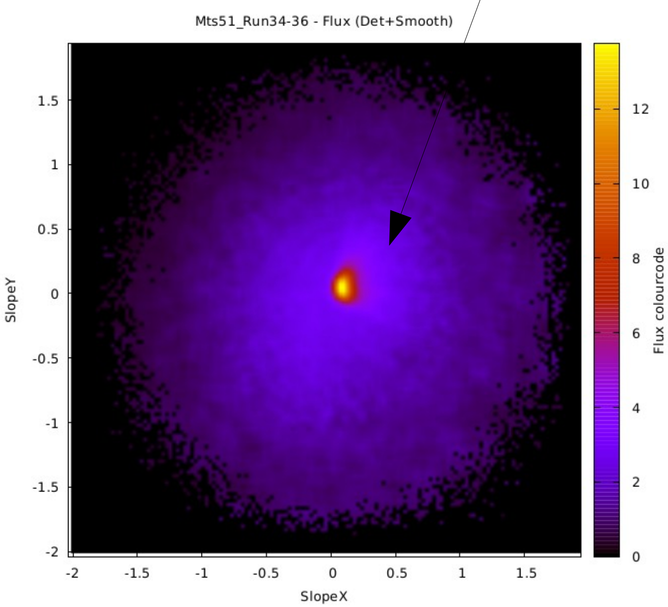


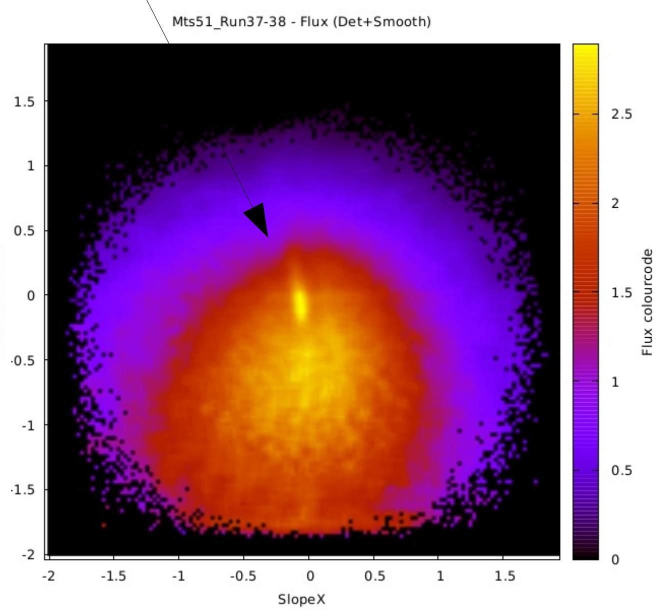
Challenge for particle physicists: from lab to field

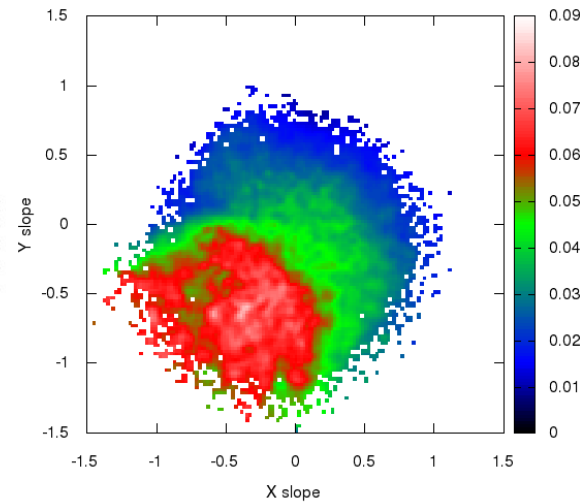
Case examples in mining environment: muon flux

- St Christoph mine in Saxore (Germany)
  30-50 m depth
  vertical shaft

Finland mine
270m depth

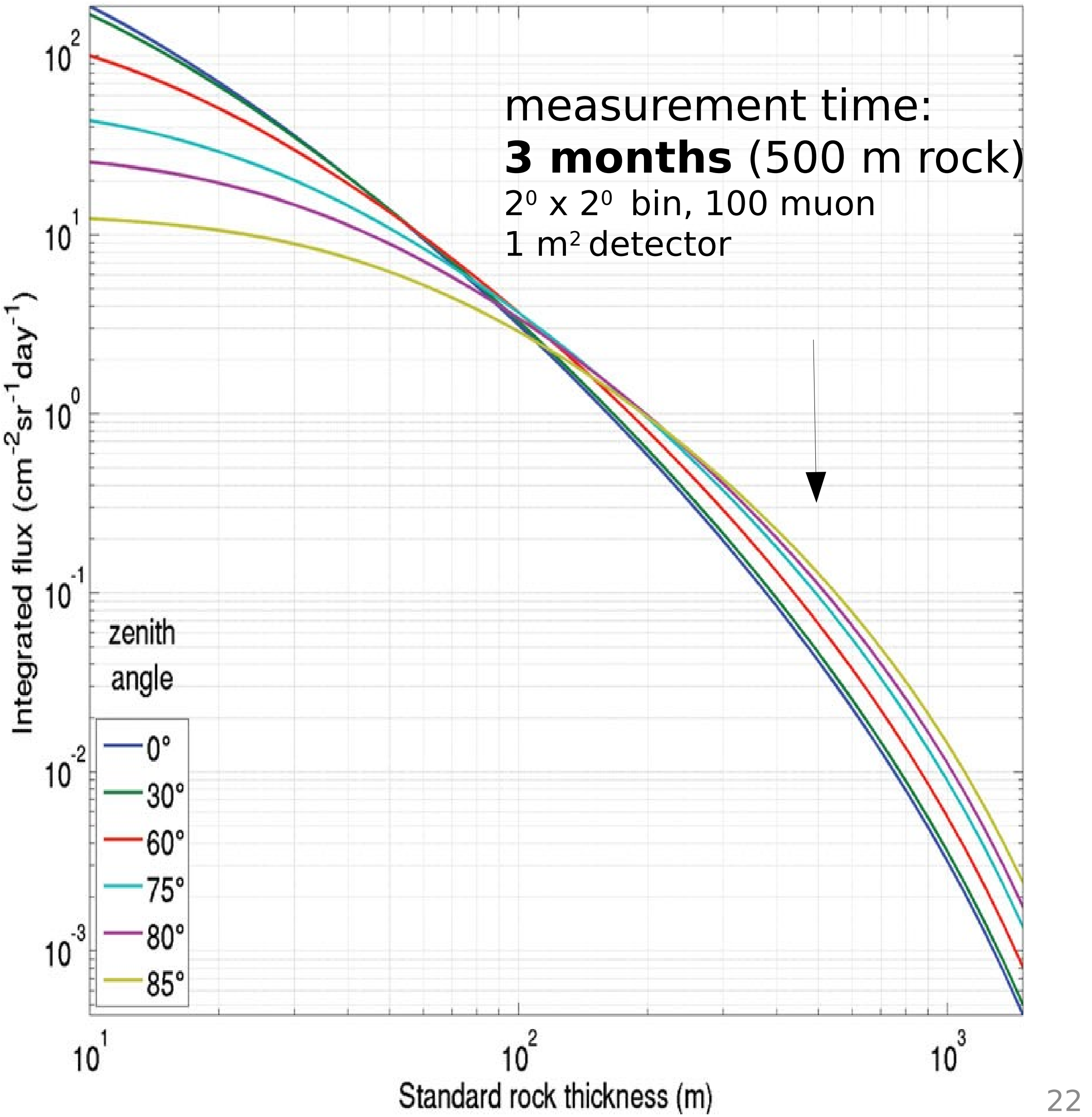






Quantitative muography

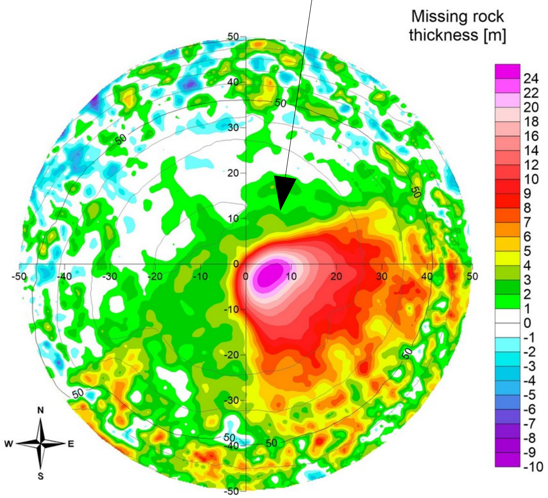
- Exposition time with sufficient area detector
- Surface map (DEM)
- Flux calculations
- Conversion from flux to density-length

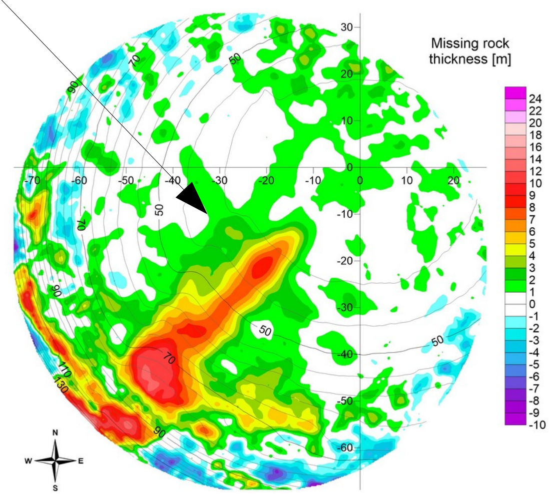


Quantification of density-length from measured flux

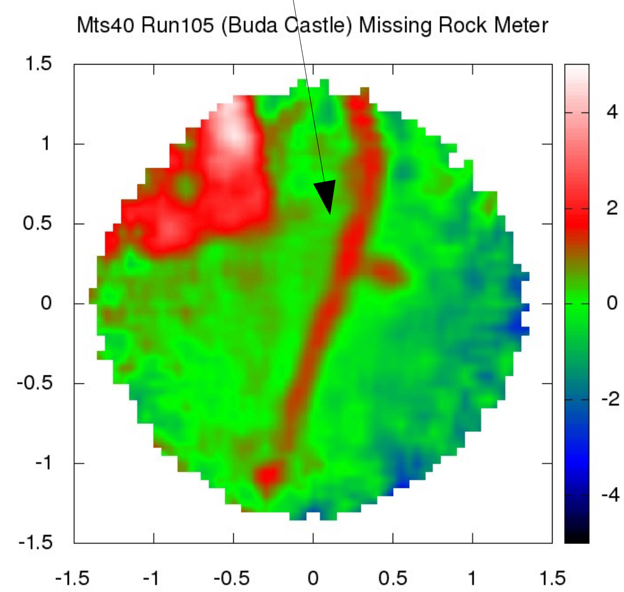
- Missing rock in meters: directly related to density anomaly

Saxore mine,
vertical shaft



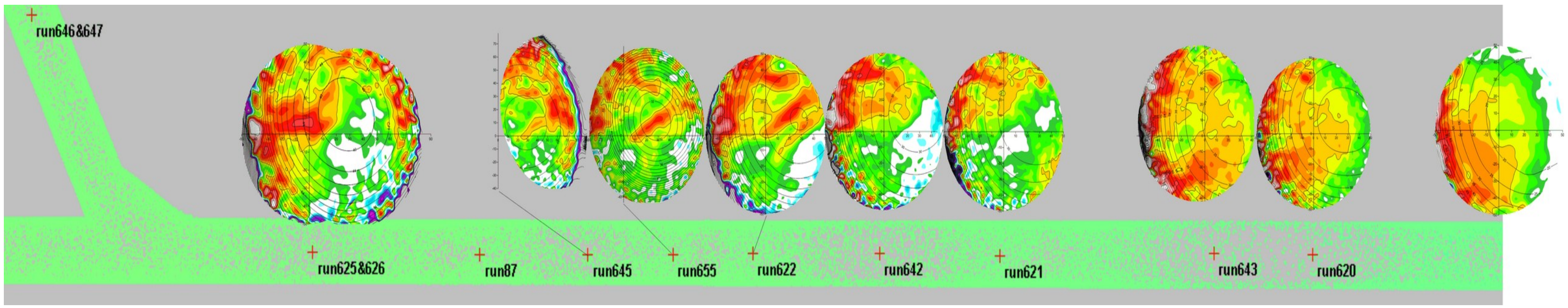


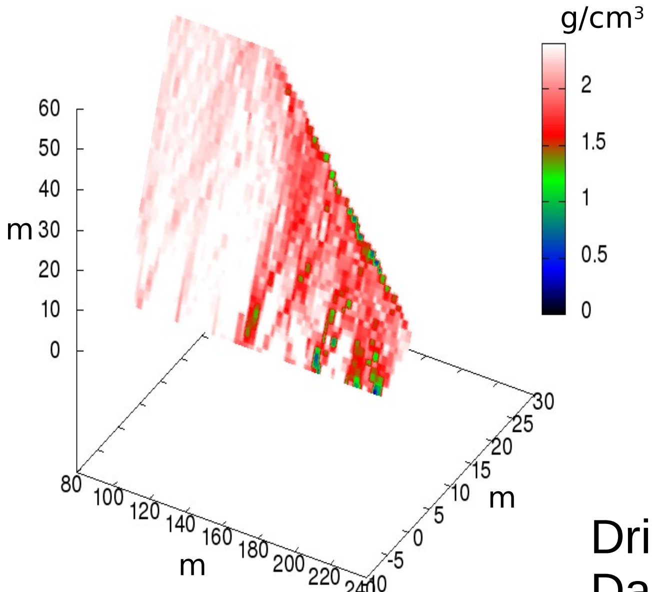
Buda castle tunnel

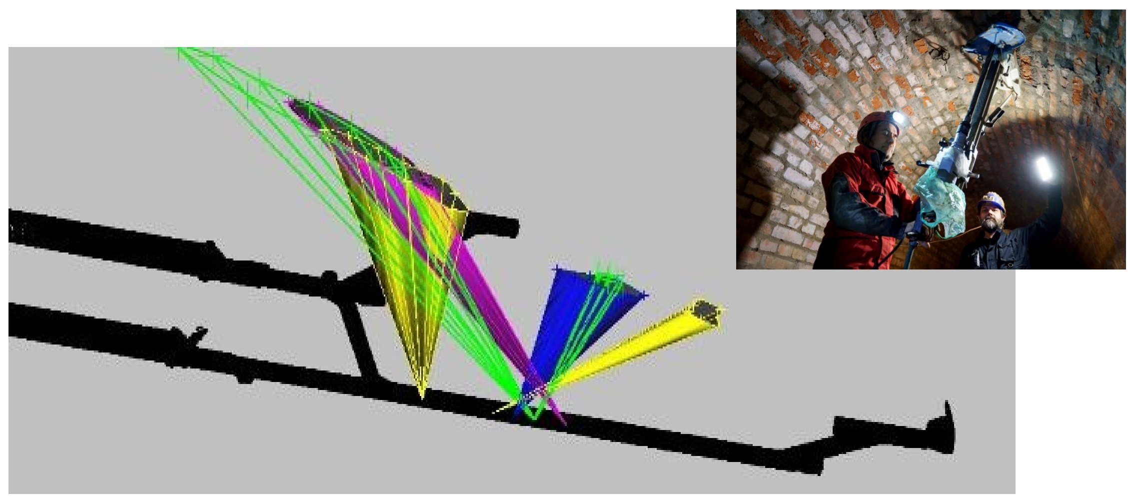


3D: Tomography requires **high quality data**

- Királylak (Budapest): Multiple viewing points







Drilling confirms low density erosion zones (not cave)
Data analysis by G. Hamar, G Surányi, G. Nyitrai, L. Balázs
Geosci. J. Int. 10.1093/gji/ggad428

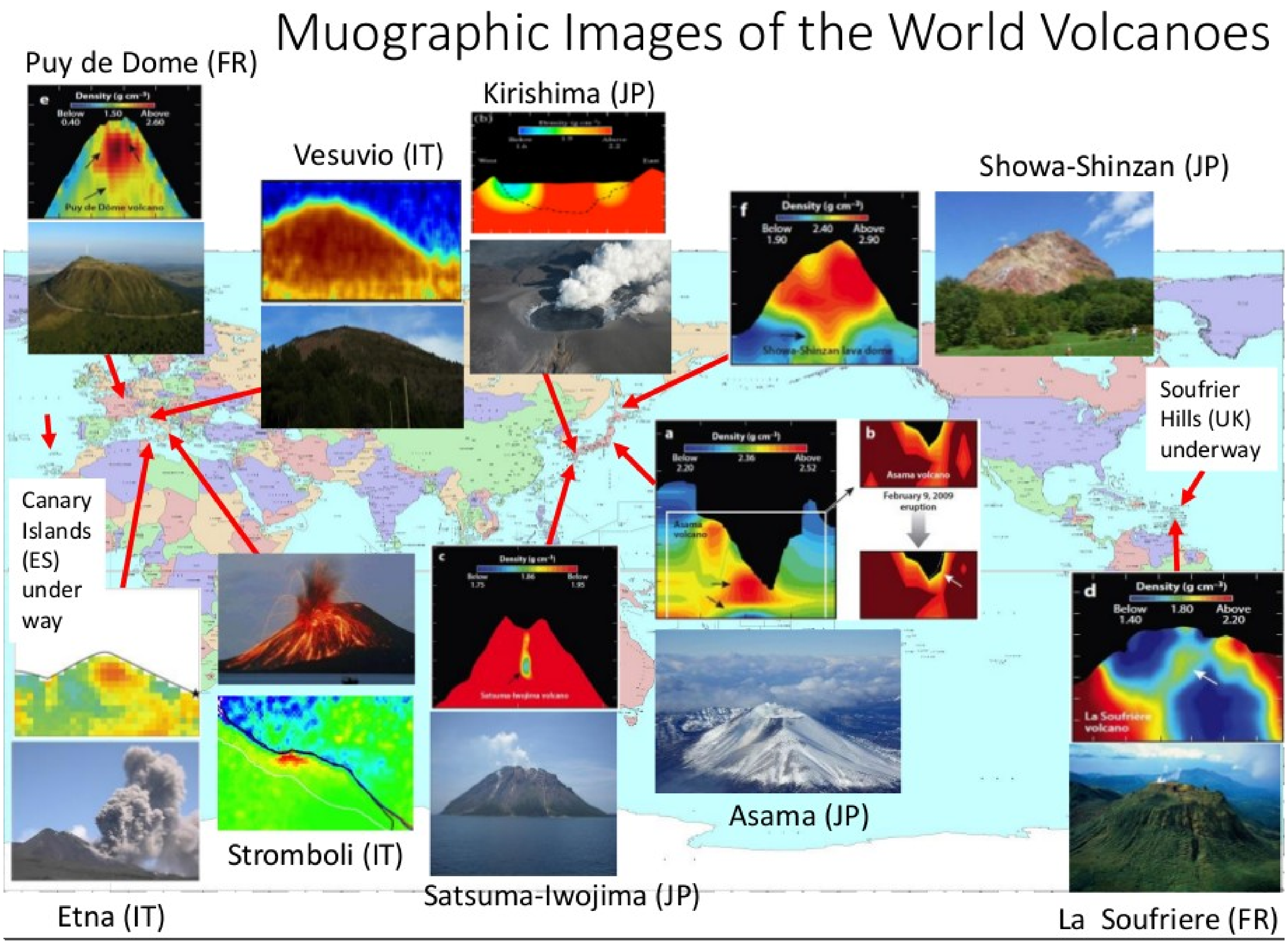
Summary

- Muography is made real by contemporary technology and detector construction methods. Need reliable production and performance
- HUN-REN Wigner Research Centre for Physics, Detector Development group: extensive collaborations (Finland, Japan, Italy, ...), VLAB infrastructure, multiple H2020 / HEU / national projects
- At the heart of that: HEP science and technology!
- Contributions from

  L. Oláh, G. Surányi, G. Hamar, G. Nyitrai, L. Balázs, A. Gera...

BACKUP SLIDES

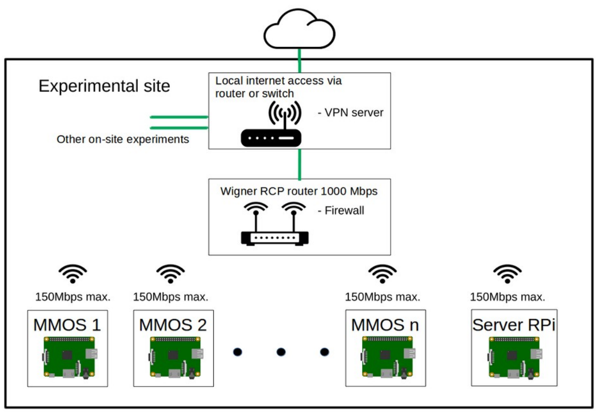
Volcanology applications: a worldwide effort

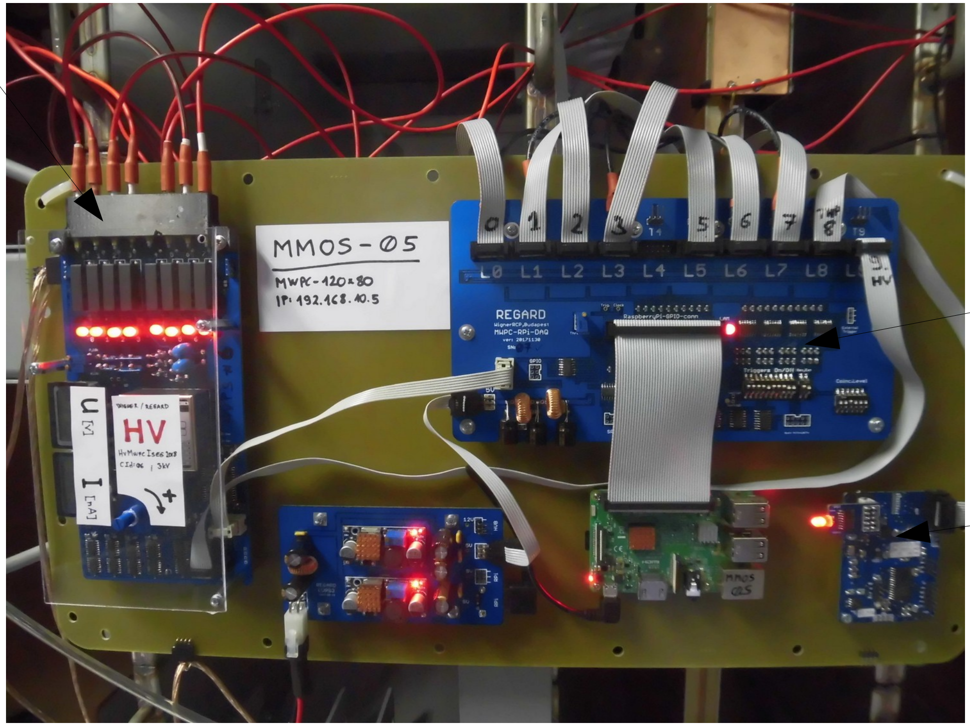


From H.K.M. Tanaka

Data acquisition: based on Raspberry-pi and discrete logic

- Controlled by a single Raspberry Pi
- Integrated trigger logic, serial data acquisition, power supply (LV, HV), and environmental monitoring





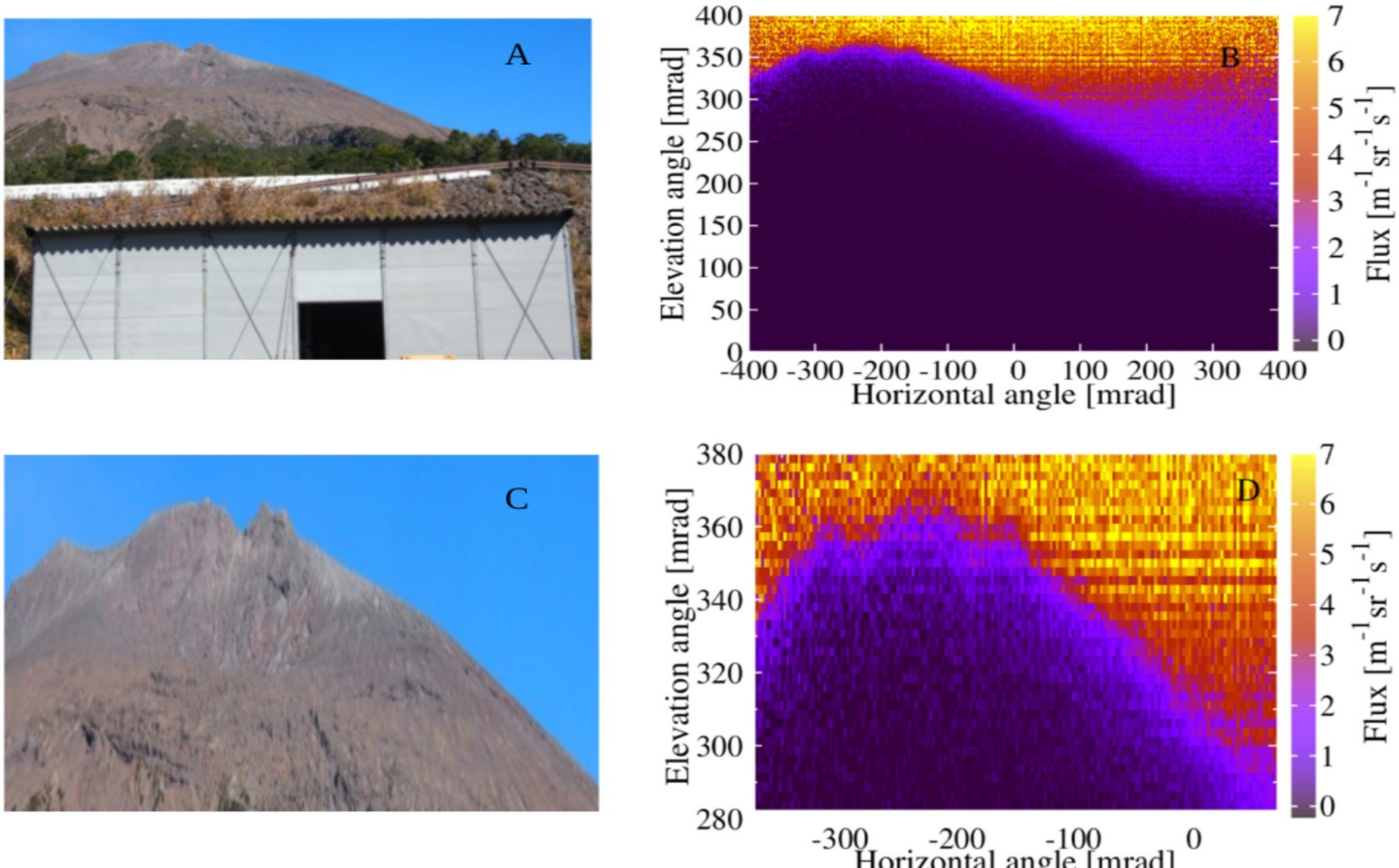
Trigger logic (discrete)

N-out-of-10

T, H, P sensor

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)

Modularity of detector system

- Independent modules, on same target, total **8.7 square meter** sensitive area installed as of Aug. 2019