Muography Instrumentation at the Wigner Research Centre for Physics

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- Muography: an extreme example of a multidisciplinary field
- Instrumental challenges under various conditions
- Detector construction quality control
- Mining applications
- Community: human and funding aspects

NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION OFFICE HUNGARY
PROJECT FINANCED FROM THE NRDI FUND

Why Muography is so special?

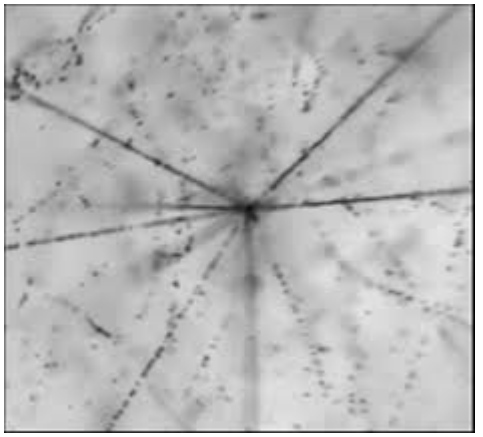
- Muography (cosmic muon imaging) is an awfuly **interdisciplinary** field!
- **Application**-based: always need the “Why?”
- Requires special nuclear physics instruments
- Most basic methods already existing for 20-40 years: **no “fundamental”** research is needed
- Direct link to **private sector**: notorious difficulty with collaboration (**IP issues**)

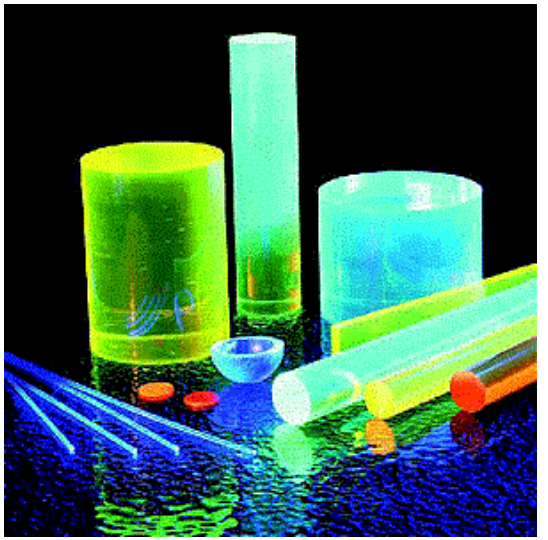
Detection technologies,
developed for fundamental science

- Emulsions, thick “photographic films”

  Easy to deploy,

  no time resolution



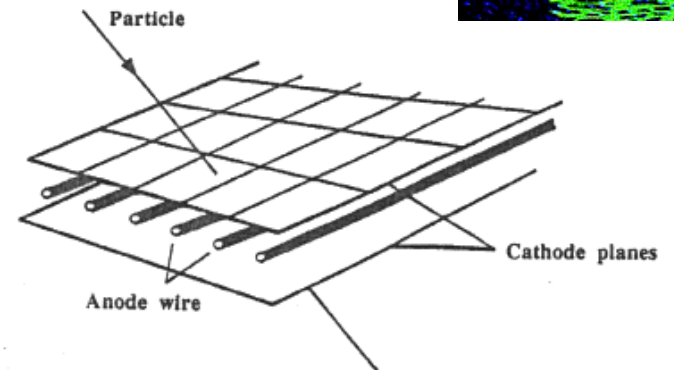


- Scintillators (visible light)

  High efficiency

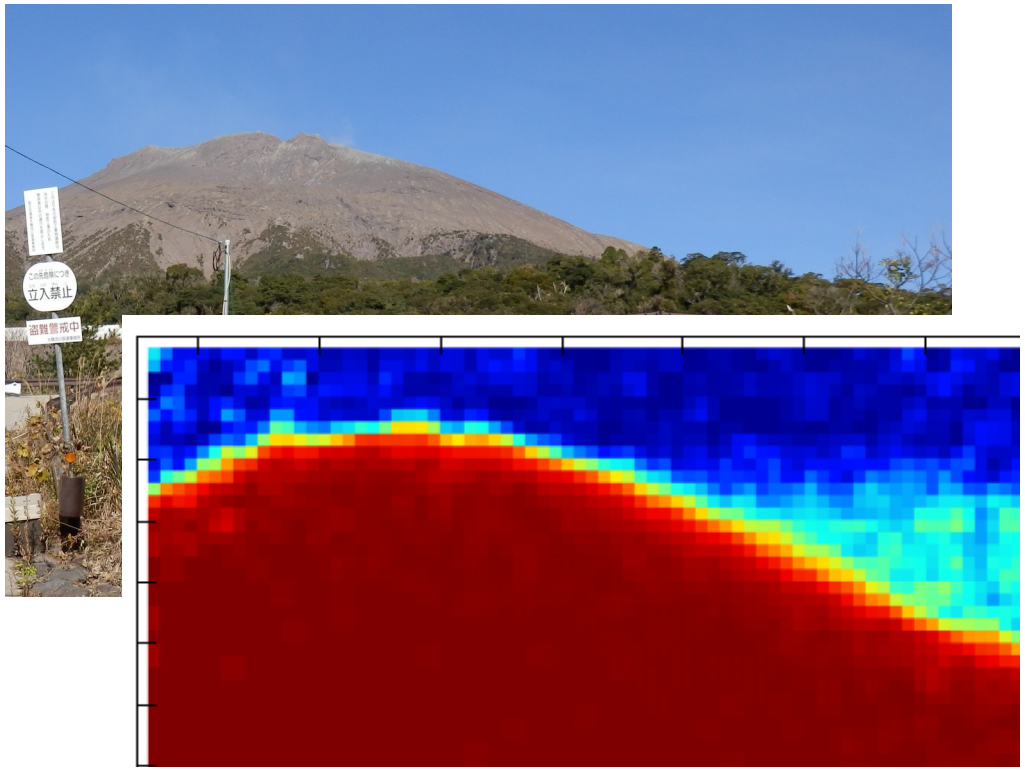
- Gaseous detectors

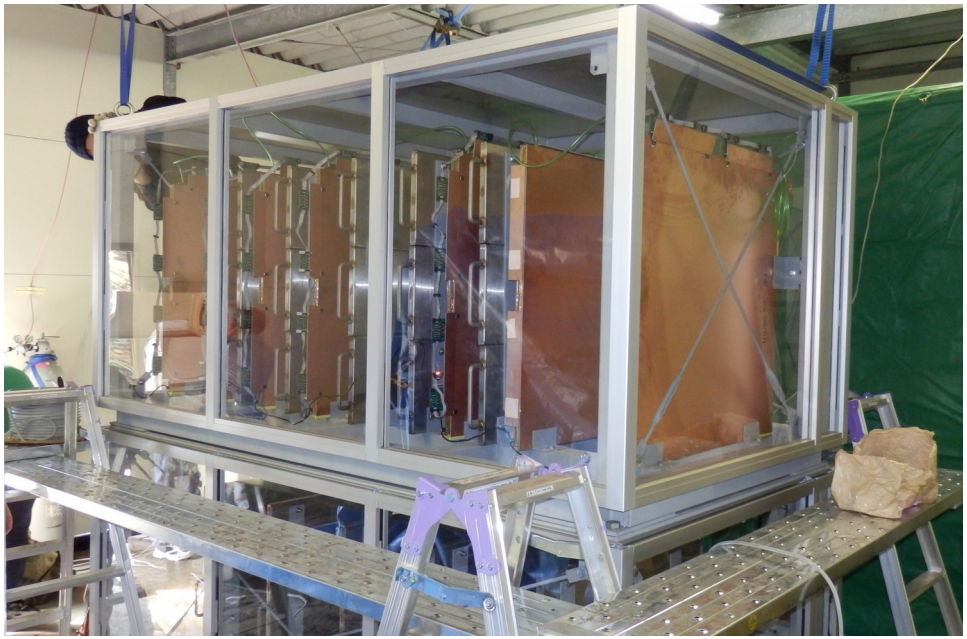
  High efficiency, cost efficient



The Volcano challenge: large size and high background suppression

- Sakurajima Observatory: large size using a modular, redundant system
- Currently running, seems to saturate size (around 8 square meters)

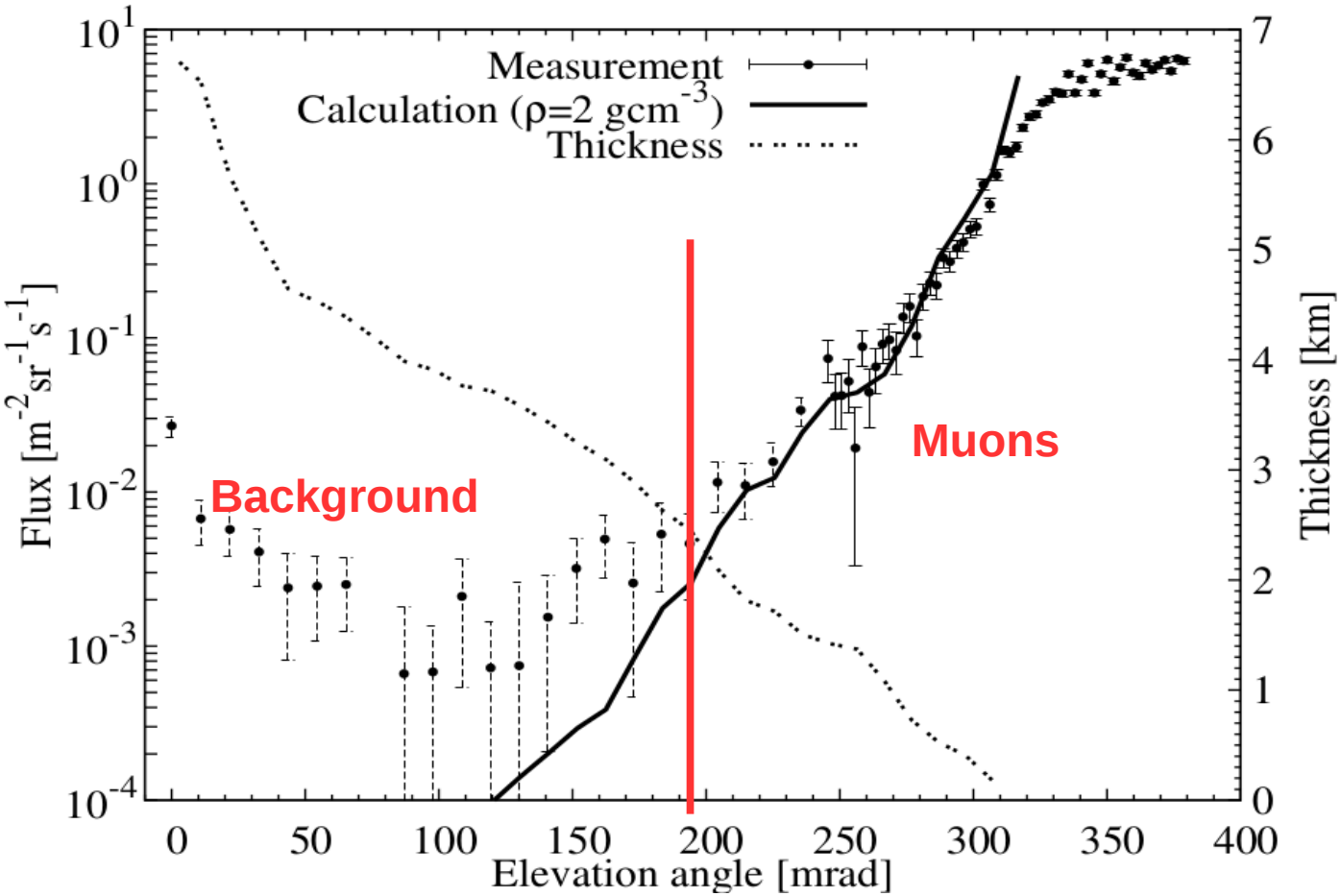




Patent: H. Tanaka, K. Tarou, D. Varga, G. Hamar, L. Oláh: Muographic Observation Instrument, Japanese Ref. No.: 2016-087436, date 25/04/2016, PCT WO2017187308A1

The Volcano challenge: large size and high background suppression

- Measured flux agrees with expectation up to 1km rock (3km w.e.)



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

The Underground challenge: highly durable, low maintenance

From lab…

… to an operational mine

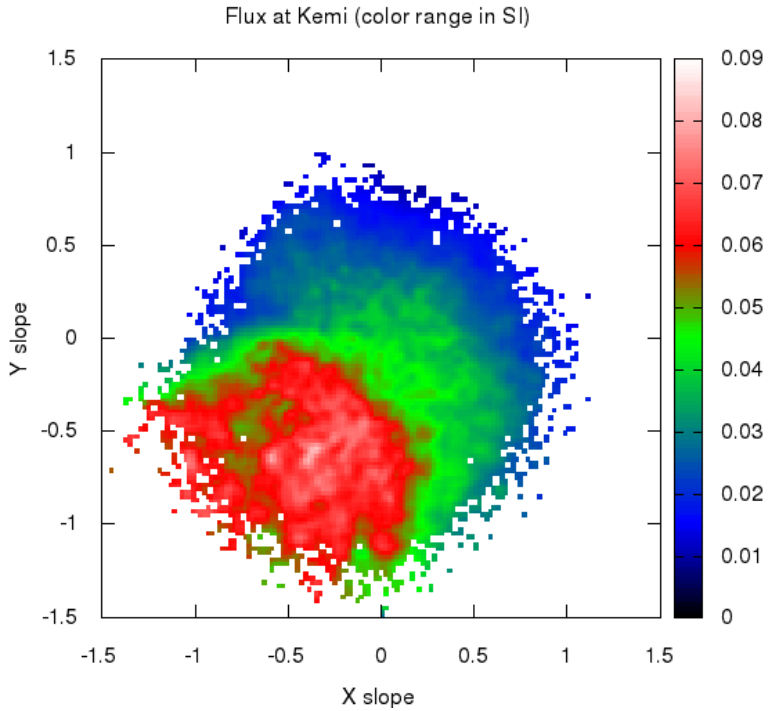
Advances in High Energy Physics, vol. 2016, Article ID1962317

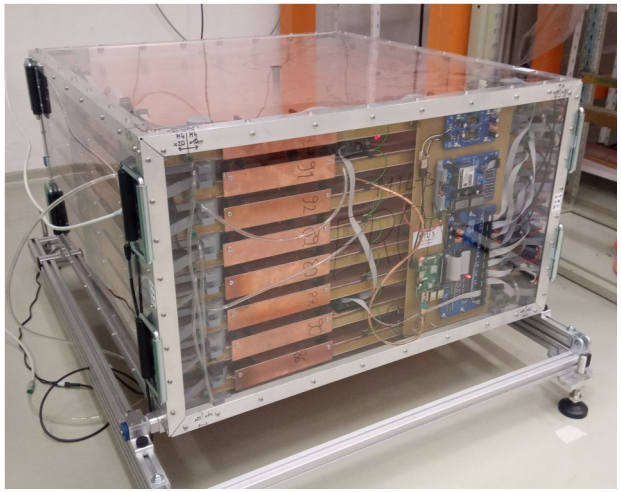
Development of Muographic Instruments: Outstanding Project financed by NRDI Fund

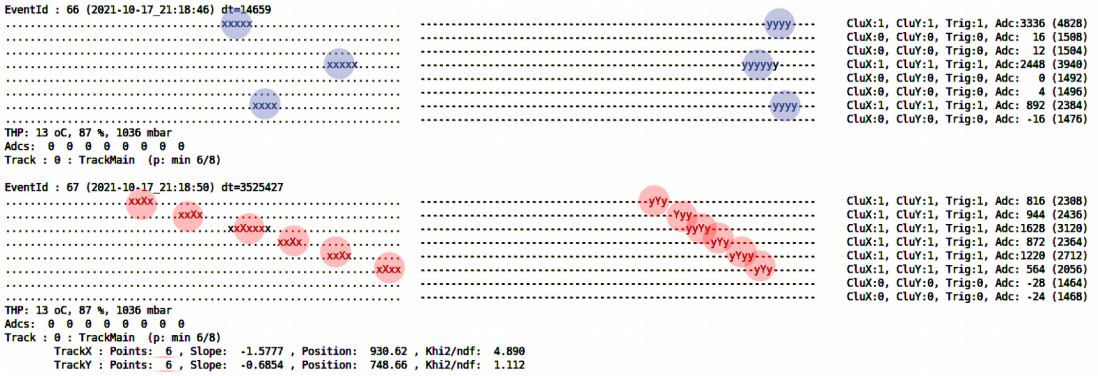
Nyitrai et al, JAP **129**, 244901 (2021)
AHEP, vol. 2016, Article ID1962317

Deeper underground: non-muon background possible

- Case example in an operational mine, 200-300m depth. Flux down to 0.03 – 0.06 $(m^2\ s\ sr)^{-1}$ (3 orders of magnitude below surface flux)
- Very clear tracks (red) with some rejectable background (blue)



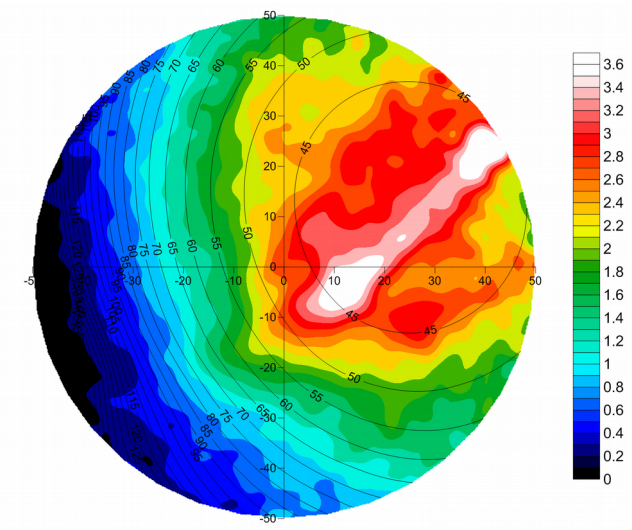


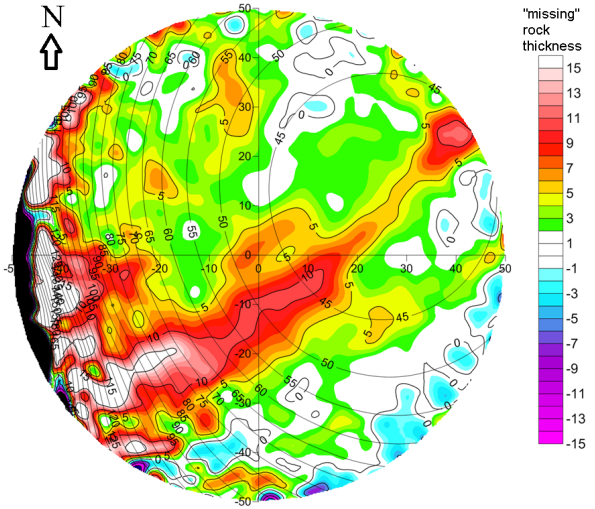


Collaboration with Muon Solutions Ltd, Finland

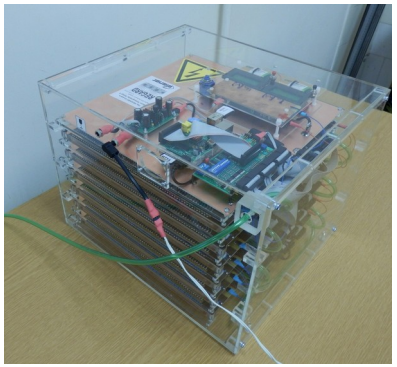
Underground challenge: limitation in size and complexity

- Usually absolute density mapping is needed (unlike temporal change in a volcano): high quality tracking





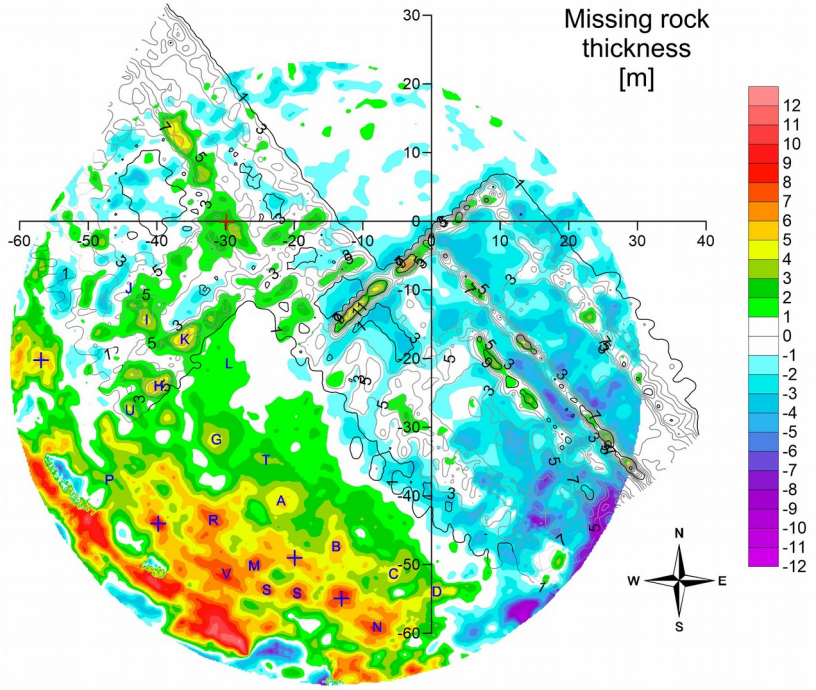
- One size never fits all! Largest possible, which just fits

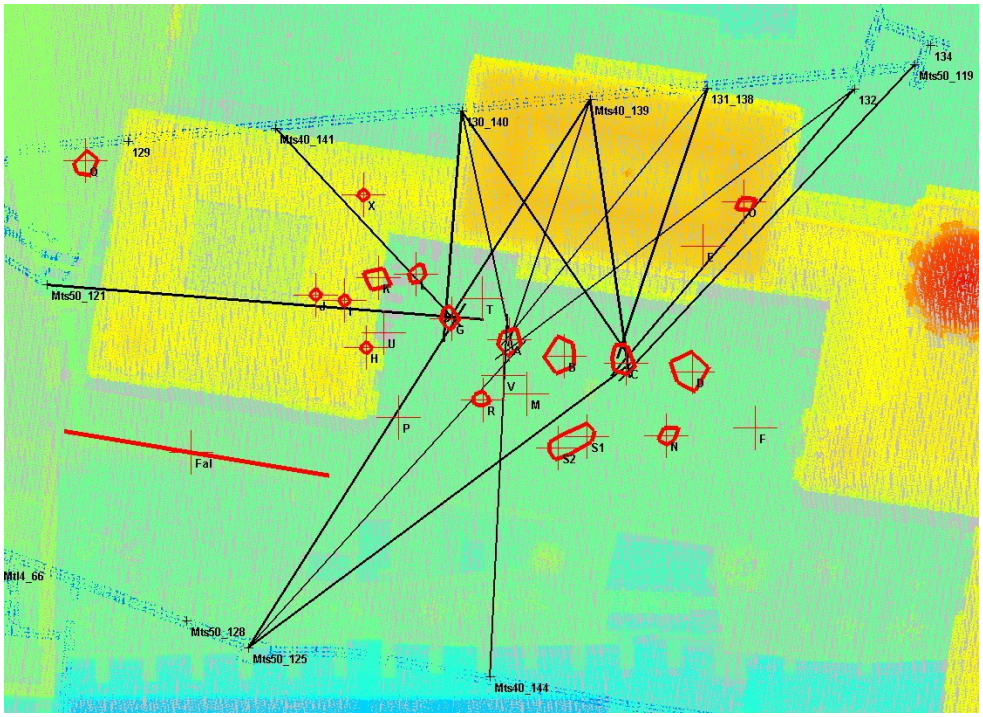


Geosci. Instrum. Method. Data Syst., 1, 229–234
Nucl. Inst. Methods A 958,162236.

Underground challenge: limitation in size and complexity

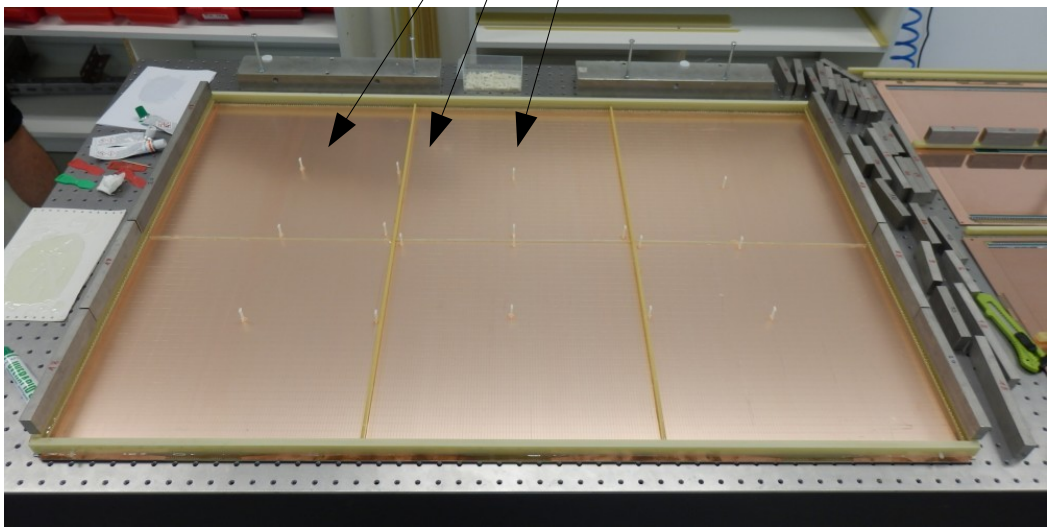
- Very complicated surface structure from buildings!
- Imaging from multiple locations reveal consistent “anomalies”, of archeological origins. Underground voids could be excluded





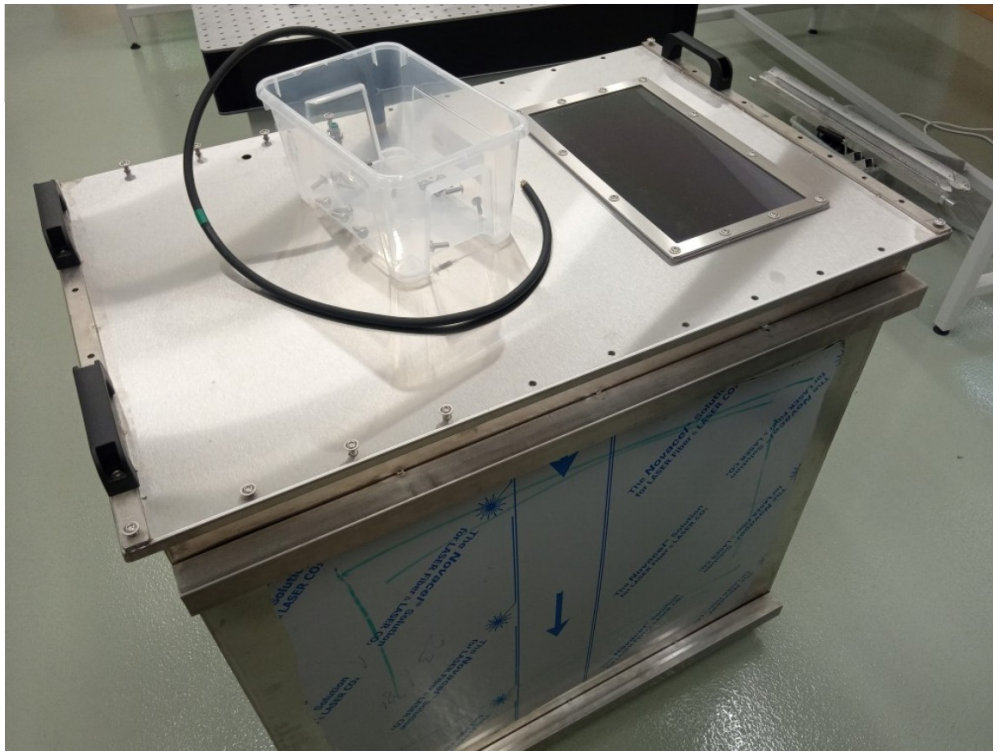
Construction challenge: reliability, robustness, quality control

- Standardized structure, by now more than 150 detector layers (total area above 100 m2) produced



Quality control and mechanical reliability

- Means to check quality: including “Heat Box” (50 deg)
- Steel box for water tightness



A. Gera et al, Gaseous Detectors for Field Applications… Muography Special Issue Instruments 2022 6, 74

Application-oriented innovation: **Mine.Io** (Horizon Europe RIA)

- Sustainable future of mining industry and mineral processing; Muography as a tool. Start 01.2023.
- Very well organized structure, clear but not too specified objectives, schedules – what funding agencies love
- **Underwater and underground** detectors

A Holistic Digital Mine 4.0 Ecosystem

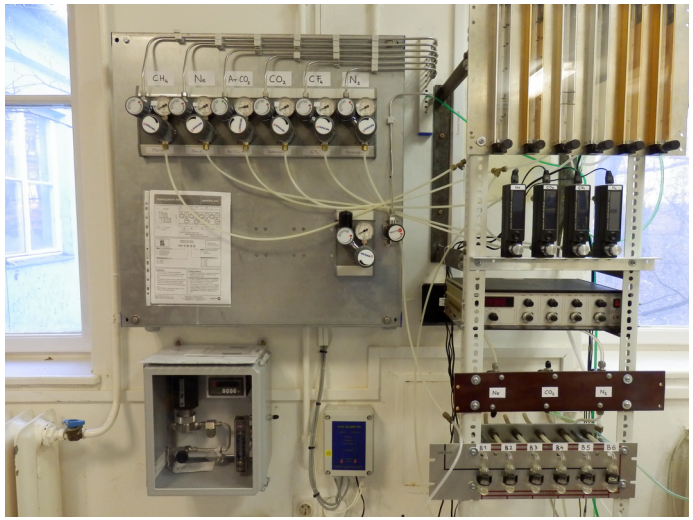
National funding

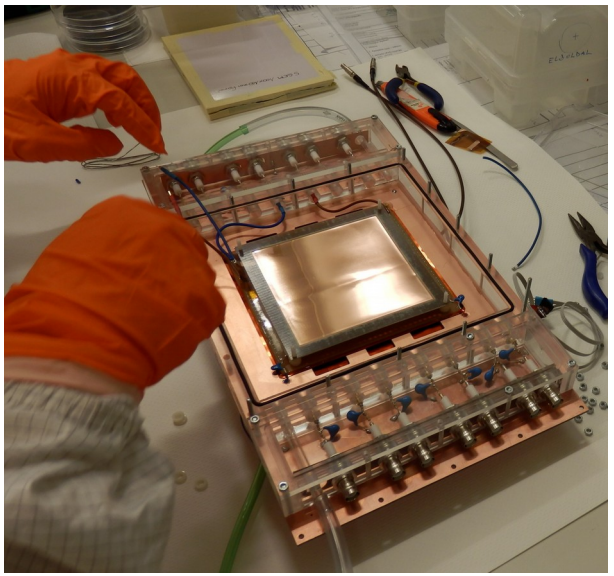
- **National interests**, do not always encourage healty collaboration, may distort competition
- **In Hungary**: undergone very positive changes around 2000-2010, many schemes from the EU “Excellent Research” pillar, under **NRDI Office**
- **Highly successful,** improved and efficient national research ecosystem! E.g. Innovation funds, Research Infrastructures
- **Stipulates** participation in EU and international calls!

Iuographers 2023

Vesztergombi Laboratory for High Energy Physics

- Coordinated allocation, maintenance and improvement of the laboratory infrastructure
- Both internal and external “users”
- Lab spaces, gas systems, expertise
- Underground laboratory (10-20-30m)
- Electronics, readout, HV supplies, ...





Expanded infrastructure for muography detector construction

- Pipelined construction
- Pipelined testing (gas tightness, HV, readout, thermal cycling, ...)

“Human” vs. “Funding” reality bubbles

- Carreer, family, research interest, working atmosphere
- Seeing the world, new opportunities
- Critical mass of expertise: minimal size of group
- Stability

- Global challenges and policies, national and regional interests
- Mobility
- Technology transfer, commercialization and innovation
- Win or Lose

Conclusions

- Muography is amazingly diverse, broad range of applications and expectations
- Various scenarios need drastically different instruments – note that “users” do not care about “how” the goal is achieved. Many solutions can co-exist
- Contemporary systems require “industrial” approach: quality control, production line, broad range of operational parameters, robustness
- The Muographers community seems to address these efficiently, collaboration and funding improves gradually