Challenges of on-surface absorption muography

Muographers 2021

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Outline

- Technical challenges of muography on the surface
- Our gaseous detector technology and low gas consumption operation
- Background suppressions, flux calculation methods and errors
- Some of our surface muography projects

Challenges of the on-surface measurements

Requirements for detector design:

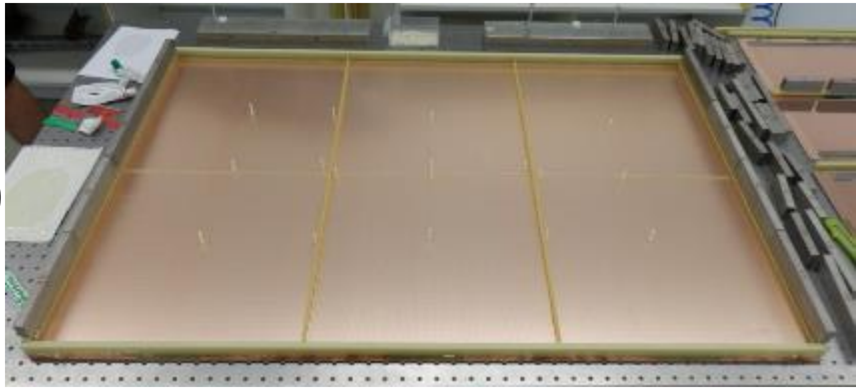
- Resolution
- Size
- Environmental conditions (THP)
- Robustness
- Mobility
- Autonomy
- Consumption
- Cost-efficiency

Measurement preparation:

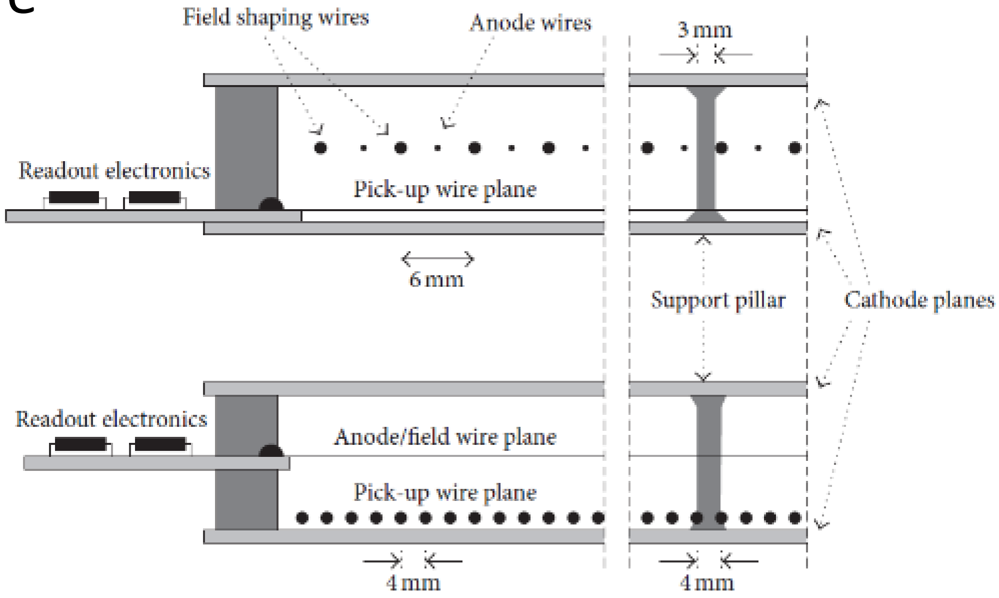
- Background suppression strategy
- Required exposition time (precalculations)
- Infrastructure preparation, transportation, installation

Data analysis:
Flux and uncertainty calculations/simulations

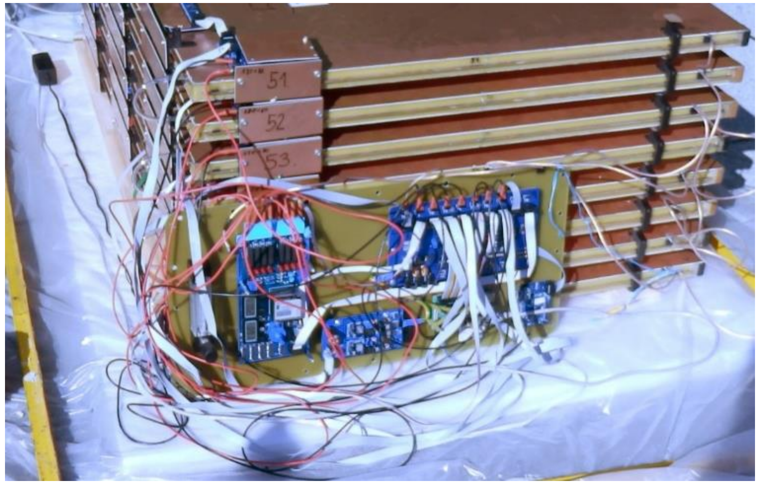
Detector technology
developed at Wigner RCP



- Gaseous detector (MultiWire Proportional Chamber, MWPC)
- >98% tracking efficiency, 4 mm RMS position resolution
- Gas: commercial, nontoxic, non-flammable (Ar:CO_2 82:18)
- Robust, lightweight, cost-efficient mechanical structure
- Wide range of sizes (40x40 – 120x80 cm^2)
- Custom designed DAQ and electronics (5—10 W)



D.Varga, *AHEP* **2016,** 1962317 (2016).



Low gas consumption

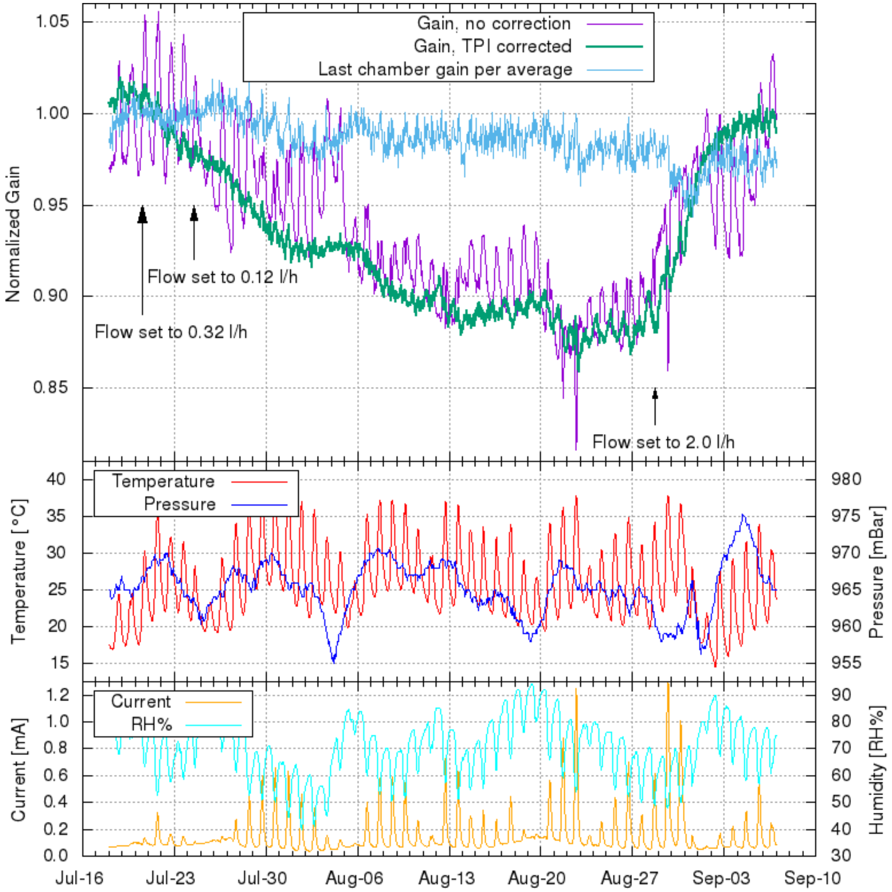
Gas system:

- Open outlet → no stress due to atm. pressure change
- Daily temperature change could cause air backflow → properly designed buffer tube solves the issue
- Low intrinsic outgassing → low input flow possible
- Generally used 1—2 l/h can be decreased to **0.12 l/h**

➢ Less maintenance (10 l bottle for a year)

➢ More autonomy

G.Nyitrai
TIPP (2021)



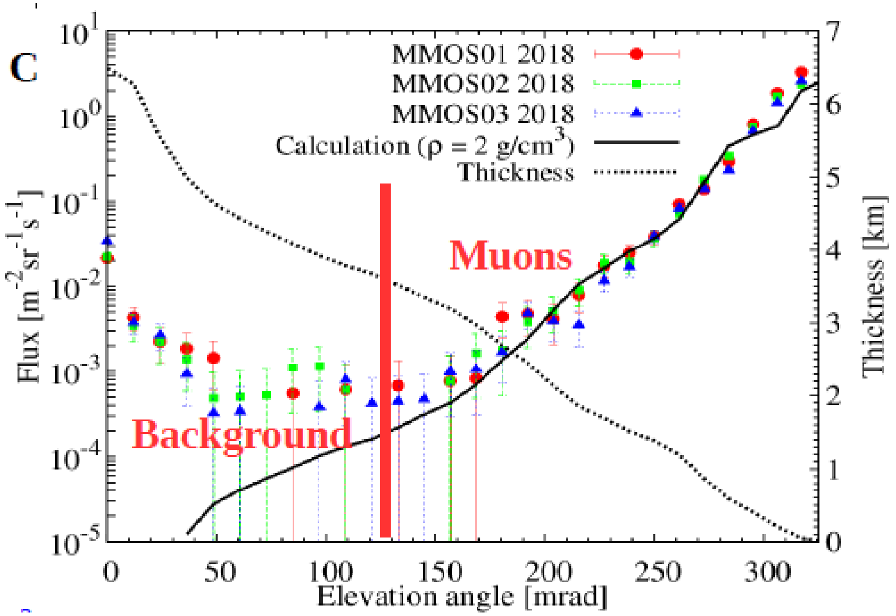
G.Nyitrai, *JAP* **129,** 244901 (2021).

Background suppression

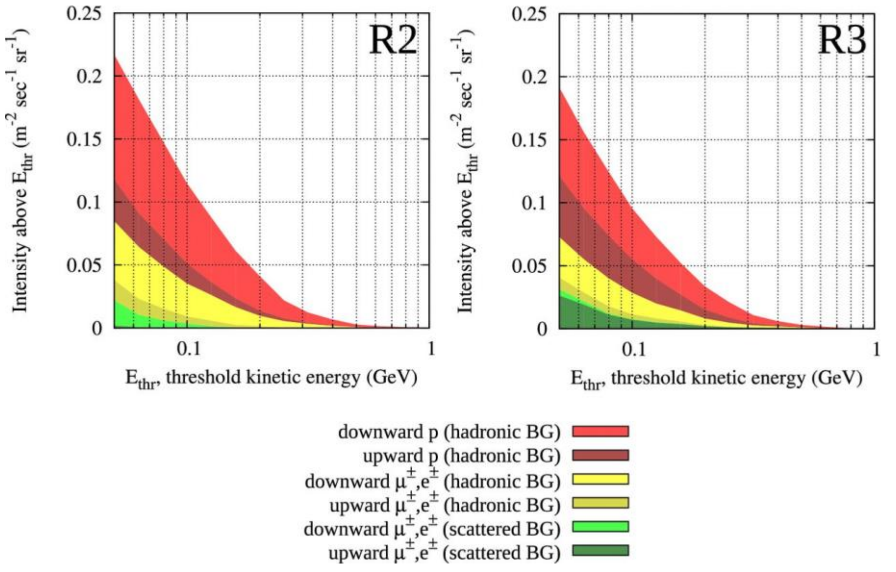
A review of background sources in:
L. Bonechi *Rev. Phys* **5**, 100038 (2020)

Practices to assort low energy particles

- Scattering lead wall for 0.1—1 GeV cut-off
  [L. Oláh *Sci. Rep.* **8**, 3207 (2018)]
  Background as low as 10^{-3} 1/m^2/s/sr with 5—10 cm lead
- Cherenkov detector and/or ToF measurement against backscattering
  [J. Peña-Rodríguez, PoS ICRC2021, 395 (2021)]



L.Oláh, Pisa Meeting (2018).



R. Nishiyama, *GJI* **206**, 2 (2016)

Flux calculations

$$I(\rho,\Theta) = \int_{E_{min}(\rho)}^{\infty} \Phi(E_0,\Theta)dE_0 \ \ [\mathrm{m}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}]$$

- 1990 Gaisser

$$\Phi_G(E_0,\Theta) = A_G E_0^{-\gamma}\left(\frac{1}{1+\hat{E}_0\cos\Theta/E_{0,\pi}^{cr}} + \frac{B_G}{1+\hat{E}_0\cos\Theta/E_{0,\pi}^{cr}} + r_c\right)$$

- **2006 Tang**: modified Gaisser
- **2015 Guan**: modified Gaisser

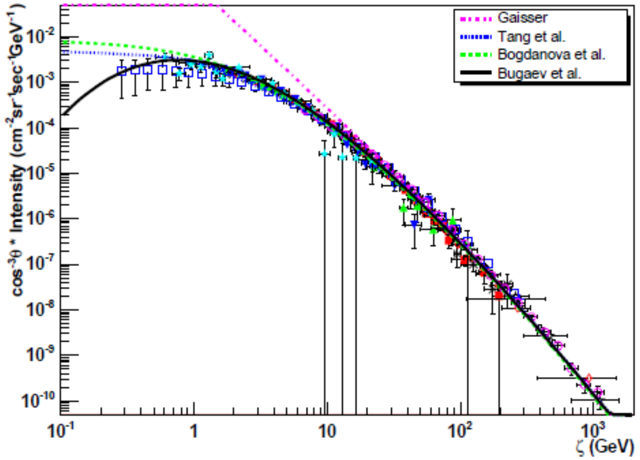
- 1998 Bugaev paraméterezés

$$\Phi_B(p) = A_B p^{-(\alpha_3 y^3 + \alpha_2 y^2 + \alpha y + \alpha_0)}$$

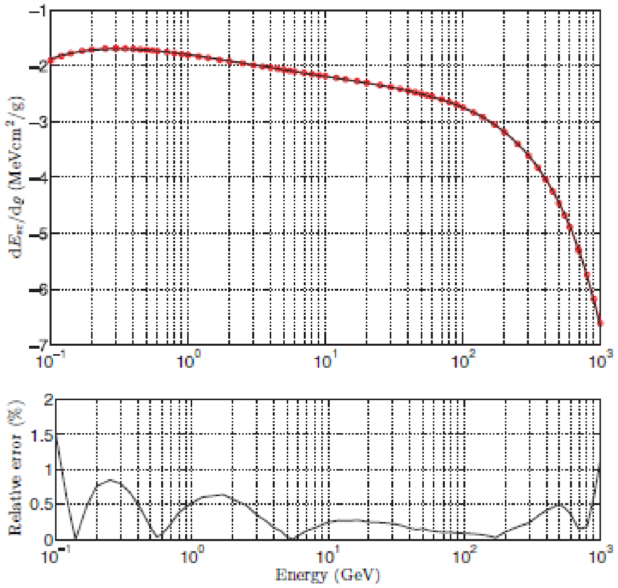
- **2006 Reyna**: Bugaev + angle dependence

$$\Phi_R(p,\Theta) = \cos^3(\Theta)\,\Phi_B(p\cos\Theta)$$

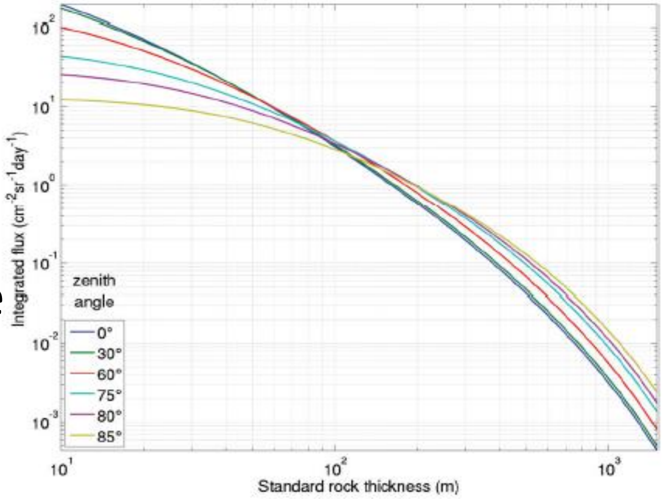
- MC simulations



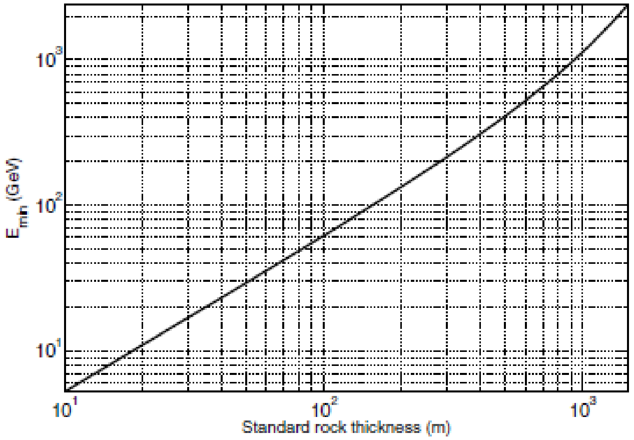
$\Phi(E_0,\Theta)$ Muon spectrum [2006 Reyna]



$\mathrm{d}E/\mathrm{d}\rho$ [PDG]



$I(\rho,\Theta)$ Flux [2012 Lesparre]



$E_{min}(\rho)$ [2010 Lesparre]

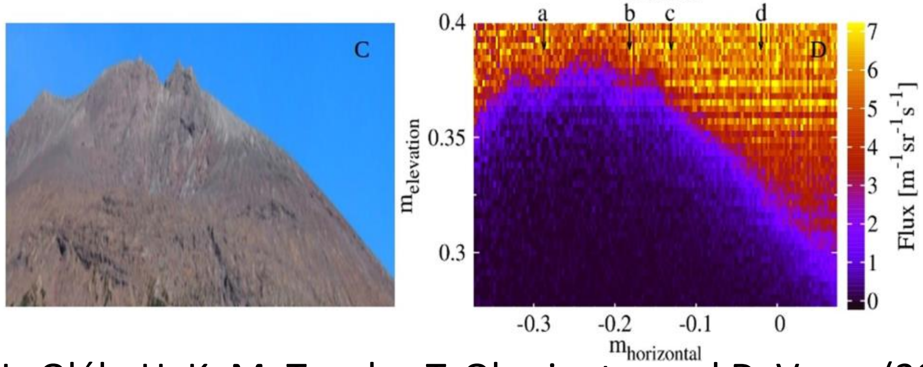
Systematic errors

- Different flux calculation methods
- Altitude-correction
  [2002 Hebbeker & Timmermans]
  $$\Phi(h) = \Phi(h=0) \cdot \exp(-h/h_0)$$
- Geomagnetic effect
  [2000 Cecchini]
- Solar wind
  [1978 Bhattacharyya]
- Temperature/Pressure
  [1997 Ambrosio, 2009 Tilav]
- Rock composition
  [2018 Lechmann]
- Energy minimum calculation
- Multiple scattering
  [2018 Oláh]
- Detection errors
  (resolution, efficiency, acceptance, etc.)
- Density-length errors
  (detector position/angle, surface map accuracy, etc.)
- The angle dependence of the errors

+ Statistical errors..
(number of muons)

Surface muography projects: Sakurajima volcano

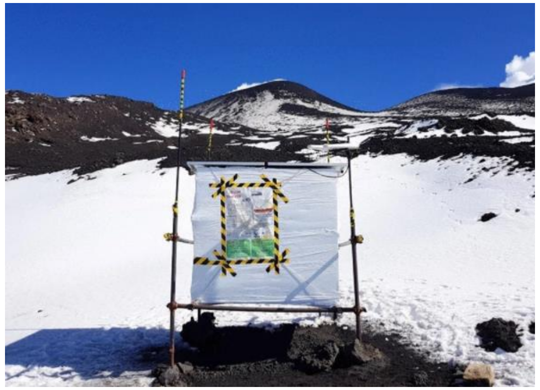
- Collaboration and patent with the University of Tokyo since 2016
- Continuous development of SMO (Sakurajima Muography Observatory)
- 8.7 m^2, 11 detector module, 6-8 chamber/module
- See more in the presentation of L. Oláh (presented by me ☺)

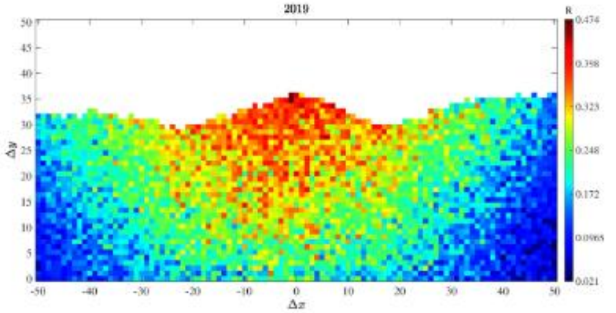


L. Oláh, H. K. M. Tanaka, T. Ohminato, and D. Varga (2018). Scientific reports, 8(1), 1-13.

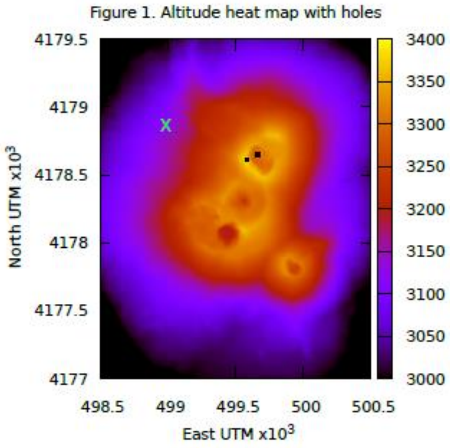
Surface muography projects:
Etna volcano

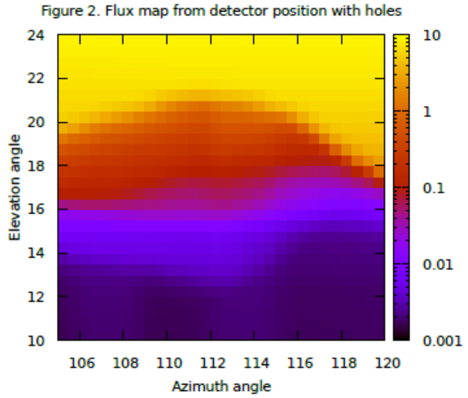
- New collaboration will be with the University of Catania
- For observation and tomography of the Etna
- Combination of scintillator and gaseous detector
- Challenges: 3000 m altitude, several m snow in winter, regular large eruptions (area closed)

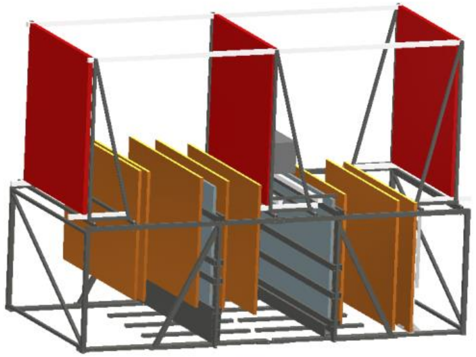




[Lo Presti, *SciRep* **10**, 11351 (2020)]



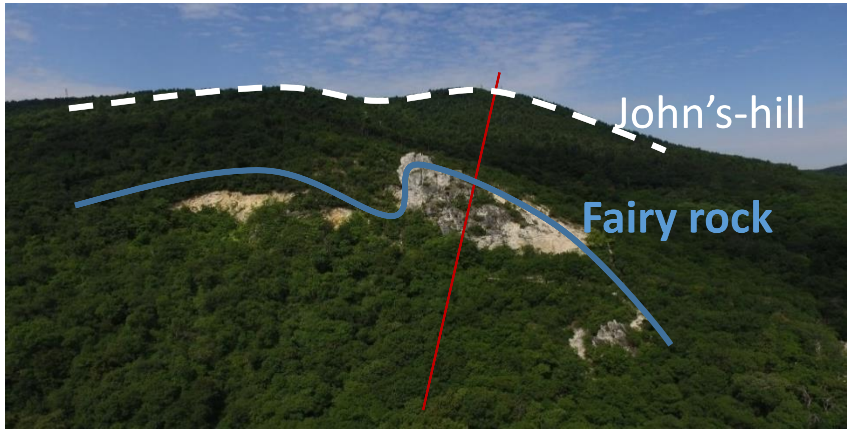




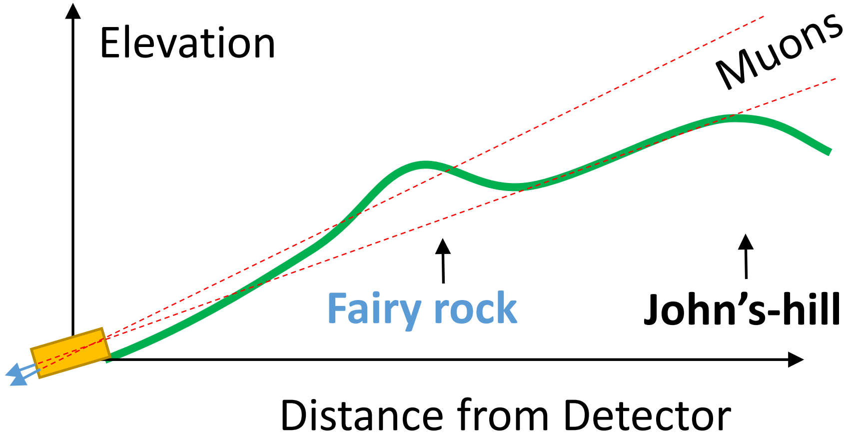
Surface muography projects:
Budapest Fairy Rock

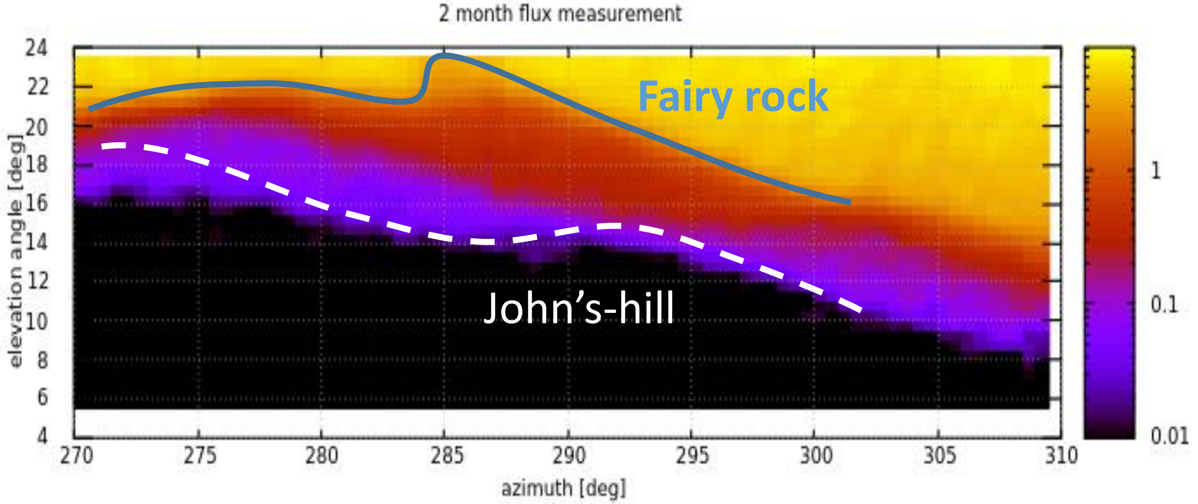
- Motivation:
  - Demonstration of looking through a mountain
  - Measuring the effect of multiple scattering
  - Measuring the imaging resolution of muography
- Idea:
  finding a geographical place where there is a high gradinet of density-length behind a hill
- Setup:
  Fairy Rock (50—100 m rock length) in front of the detector
  Contour of John’s hill behind the Fairy Rock is a high gradient region

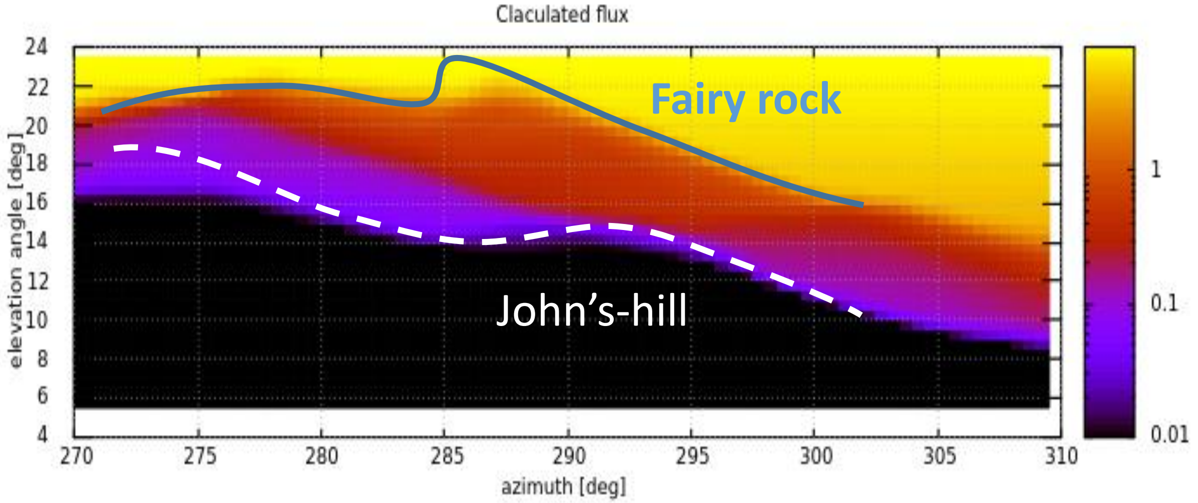
Surface muography projects:
Budapest Fairy Rock



Drónkép a detektor fölött 50 m-el.







Summary

- On-surface muography has a lot of technical challenges
- The MWPC detector in Wigner has been developed to meet these challenges
- A common question about on-surface muography is the background suppression
- Further issues are the different flux calculation methods and systematic errors
- Some of our on-surface projects presented:
  - Japan Sakurajima volcano observation (collab. with the University of Tokyo)
  - Italian Etna volcano observation (new collab. with University of Catania)
  - Budapest Fairy Rock for measuring the imaging capabilities of muography

Thank you for your attention!

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- 2013-2017 MTA "Lendület" Innovatív Detektorfejlesztő Kutatócsoport
- NKFIH TÉT: Japán (2016-2018), Olasz (2021-2023), Szerb (2016-2018 és 2021-2023)
- OTKA - FK-135349 (2020-2024) "Modern müografikus képalkotás vizsgálata" 2020-2024
- ELKH - Kiemelt Téma : SA-88/2021 (2021-2023) "Modern müografikus képalkotó rendszerek hazai és nemzetközi gyakorlati alkalmazása„
- TéT - Olasz : TÉT-2020-00224 (2021-2023) "Sokszálas nyomkövető detektor alkalmazása az Etna vulkán müografikus vizsgálatához"