Initial results of the MURAVES muon telescope at Mt. Vesuvius

EGU General Assembly 2022 - EGU22-9746

Michael Tytgat - *Ghent University*
Michael.Tytgat@ugent.be
*on behalf of the **Muraves** Collaboration*

Sharing is encouraged

MURAVES Collaboration: M. Al Moussawi (2), F. Ambrosino (5,6), A. Anastasio (6), G. Baccani (3,4), S. Basnet (2), L. Bonechi (4), M. Bongi (3,4), A. Bross (8), A. Caputo (7), R. Ciaranfi (4), L. Cimmino (5,6), C. Ciulli (3,4), R. D'Alessandro (3,4), M. D'Errico (5,6), A. Giammanco (2), F. Giudicepietro (7), S. Gonzi (3,4), R. Karnam (2), G. Macedonio (7), V. Masone (6), N. Mori (3,4), M. Orazi (7), G. Passeggio (6), R. Peluso (7), A. Pla-Dalmau (8), C. Rendon Hinestroza (1), A. Samalan (1), G. Saracino (5,6), G. Scarpato (7), P. Strolin (5,6), M. Tytgat (1), E. Vertechi (7) and L. Viliani (3,4)

(1) Ghent University, Ghent, Belgium; (2) Université Catholique de Louvain, Louvain-La-Neuve, Belgium; (3) University of Florence, Florence, Italy; (4) INFN sez. di Firenze, Florence, Italy; (5) University of Naples Federico II, Naples, Italy; (6) INFN sez. di Napoli, Naples, Italy; (7) INGV, Osservatorio Vesuviano, Naples, Italy; (8) Fermilab, Batavia, IL, USA

INFN Istituto Nazionale di Fisica Nucleare

GHENT UNIVERSITY

UCLouvain

Mt. Vesuvius

Aerial view of Mount Vesuvius
(Tatiana Mironenko—iStock/Getty Images)

Mt. Vesuvius sits on top of the subduction zone that was created after the collision of the African and Eurasian tectonic plates; the volcano formed during the caldera collapse of Mt. Somma ~25ka ago

Quiescent since ~80 years, but still active and considered as one of the most dangerous in the world due to its proximity to a large population in the city of Naples and its tendency for explosive eruptions

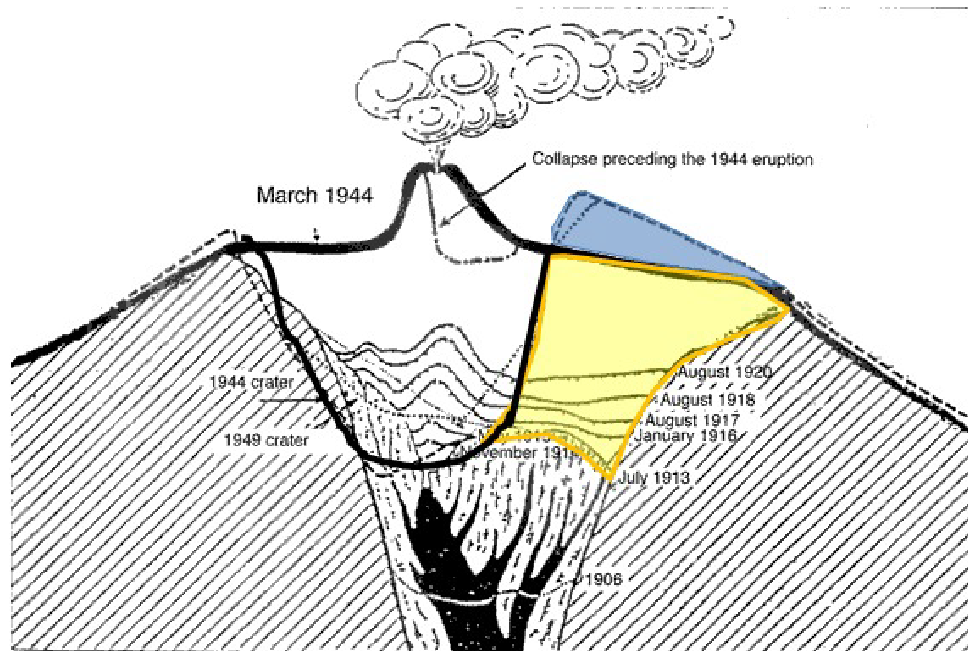
Long history of violent eruptions, with the most commonly known one the Plinian eruption in 79 BC burying Roman cities of Pompeii, Oplontis, Stabiae under ashes and lapilli and city of Herculaneum under mudflow; between 79 BC and its last eruption in 1944 27 significant eruptions occured; **last few eruptions were effusive-explosive**, i.e. combining flowing lava with violent expulsions of rock and ash

Mt. Vesuvius

In the course of history, the Vesuvius morphology drastically changed due to its activity; subsequent eruptions in the last period of activity caused the collapse of caldera and the formation of the present-day crater

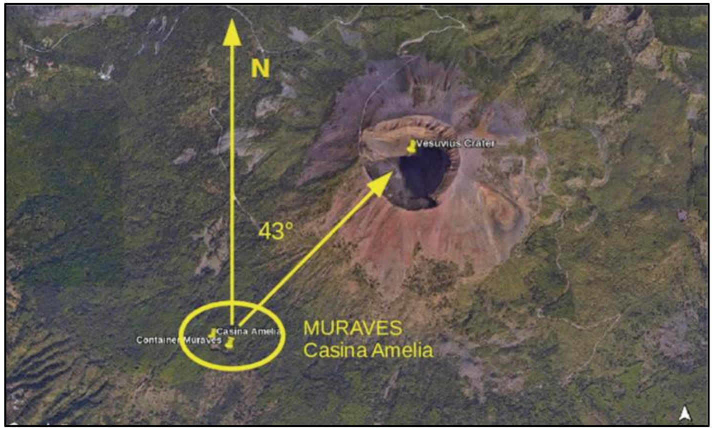
Interior of summit cone is thought to have a layered structure of materials with different densities

Muography will hopefully shed light on the distribution of different densities along the body of the volcano, providing a direct high-resolution image (voxel size ~10m) of the material layers



Width of the Vesuvius crater was reduced after 1944 eruption (yellow: lava, blue: pyroclasts); right part of the crater (filled with lava lake until 1944) is denser than rest of the cone (mostly incoherent material)
[modified after Imbò (1949)]

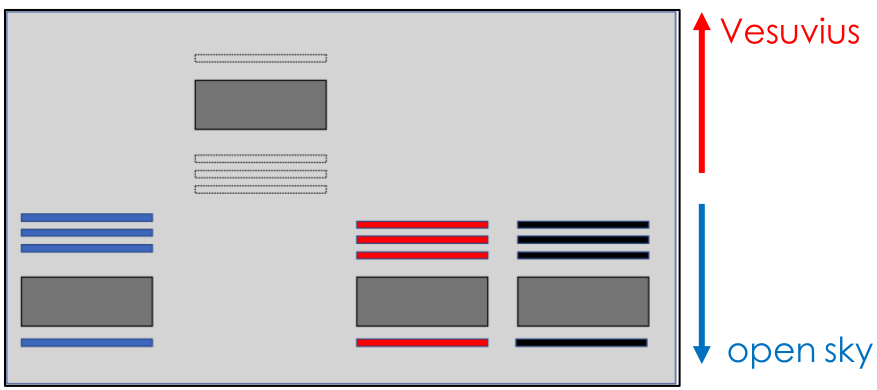
Muraves @ Mt. Vesuvius



Muraves is located 1500m away from crater and ~640m asl, i.e. slightly below the bottom of the Vesuvius crater

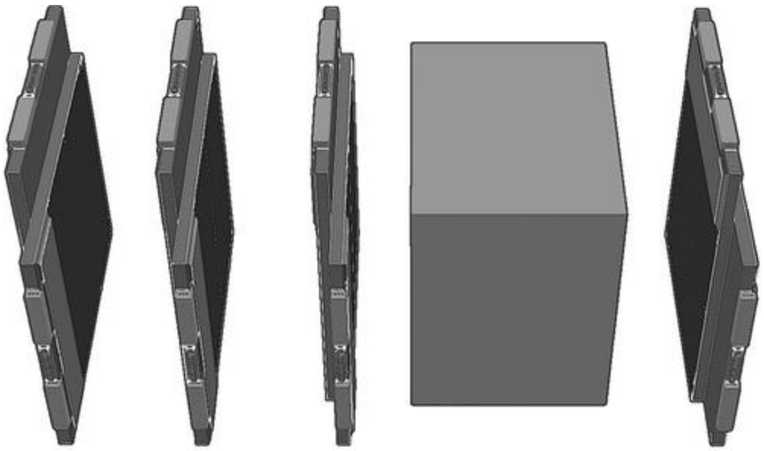
Powered via solar panel system on the container roof connected to array of batteries

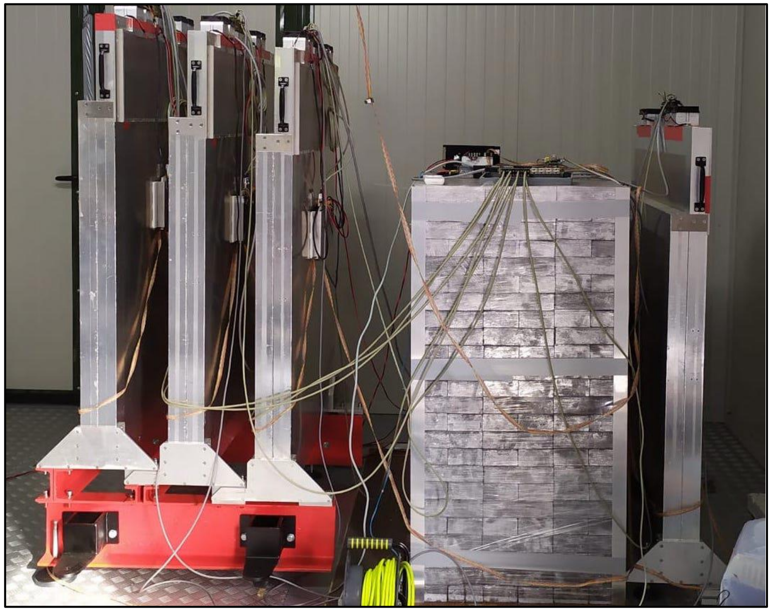
4 concrete platforms inside container, i.e. 3 pointing to Vesuvius and 1 open-sky calibration position



3 muon trackers inside the Muraves container

The Muraves muon trackers



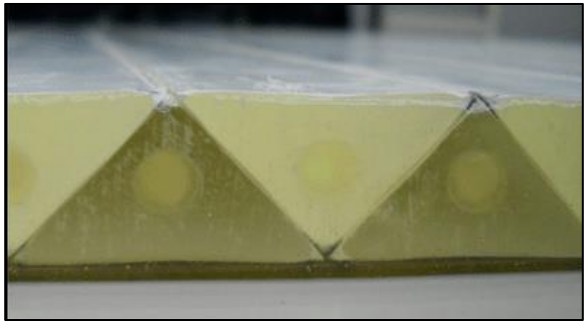


3 equal muon trackers ("ROSSO, NERO and BLU") giving a 3m^2 muon telescope

Each tracker has 4 tracking stations of 1m^2 active area, distributed over ~2m, with **60cm of lead** in between the two downstream stations

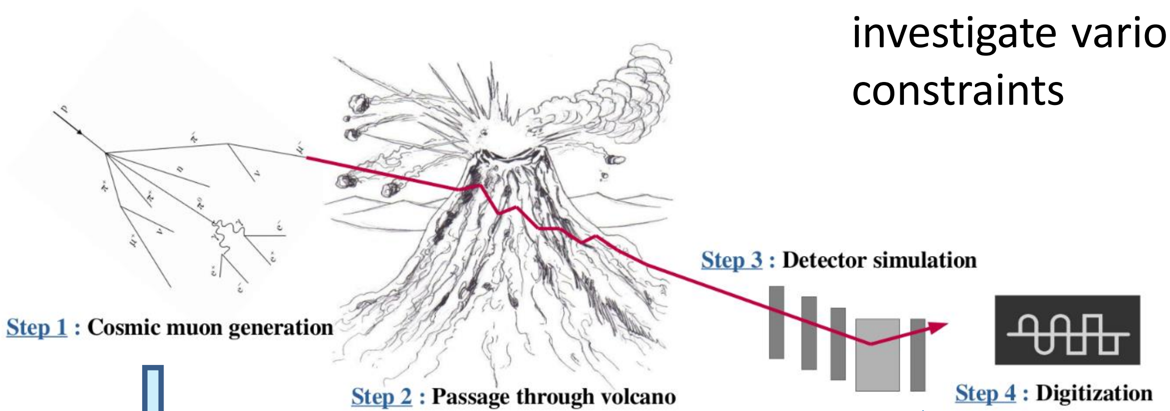
Each station consists of a pair of orthogonal (XY) planes, where each plane is made of 2 modules, composed of 32 **triangular scintillator bars** (produced at Fermilab) each (leading to ~3mm position resolution)

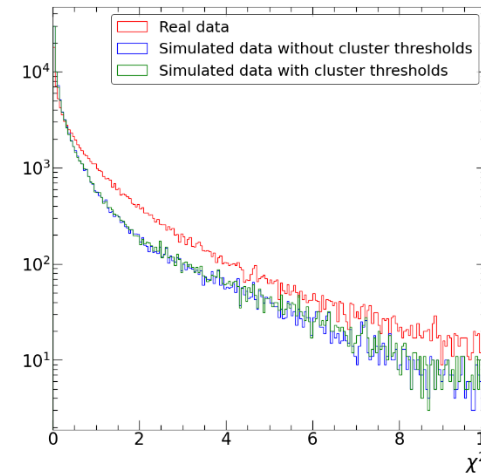
Light collection via 1.2mm WLS fibers (Kuraray) inserted into each strip and coupled to SiPM (Advansid)



Simulation chain

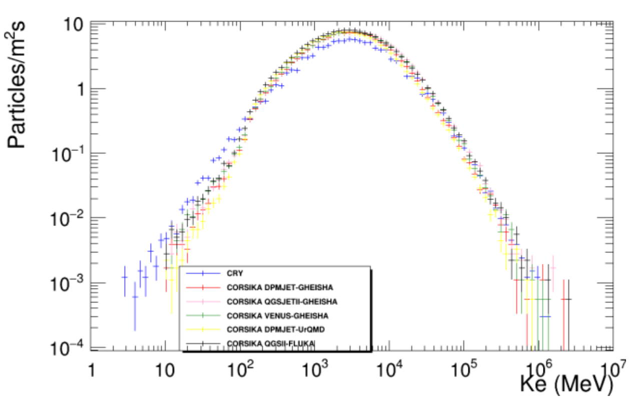
Comparing data with Monte Carlo simulations is crucial for the imaging of a target and to investigate various effects of the experimental constraints



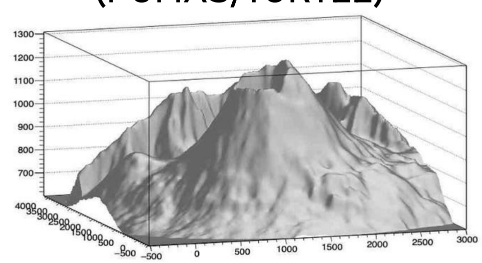


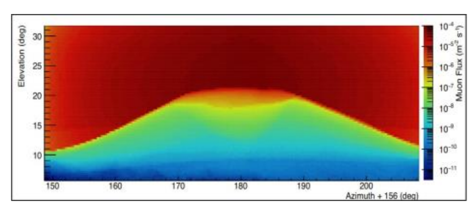
Comparison of χ^2 of tracks in real and simulated data

Muon energy spectrum

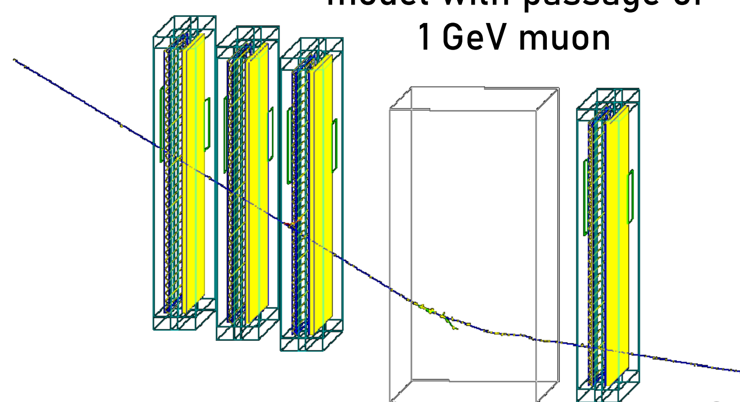


DTM with 1 m resolution [Vilardo *et al.*, Journal of maps 9(4):635 (2013)] and expected muon flux (PUMAS/TURTLE)



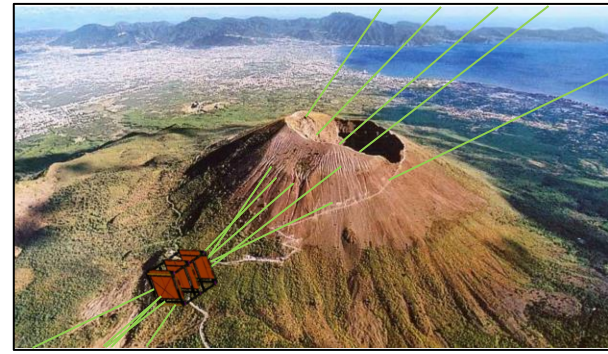


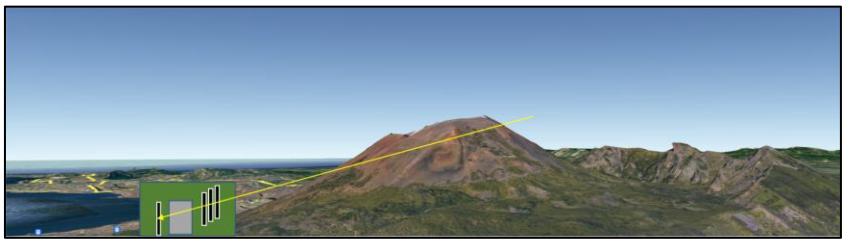
GEANT4 muon tracker model with passage of 1 GeV muon

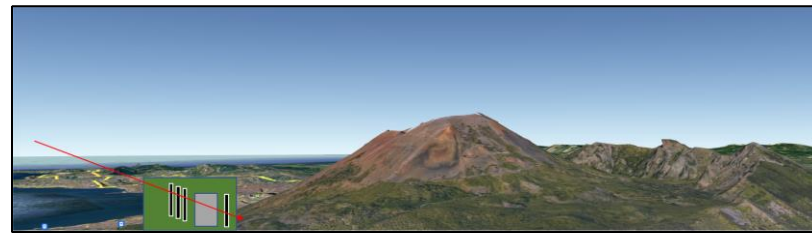


Measurement principle & aim

Aim is to map the mean density of the matter crossed by muons in the traversal of the volcano, through measurement of the muon flux reaching the telescope



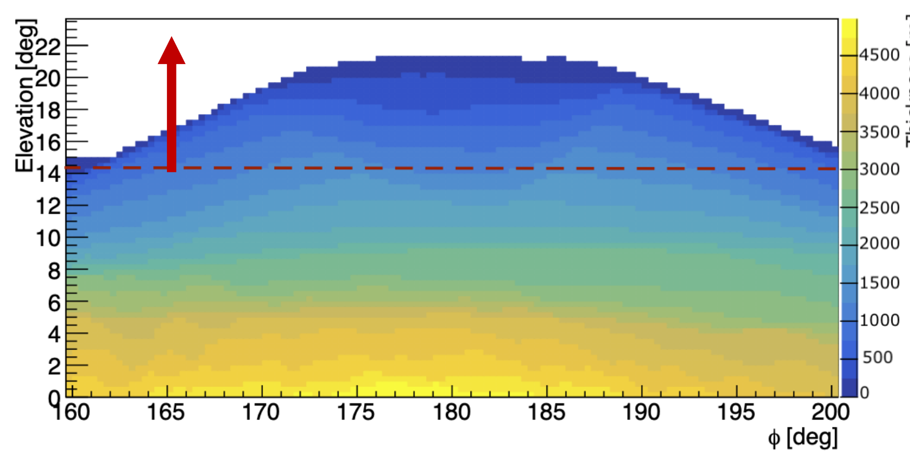




Muon transmission (ratio between the muon flux measured in acquisition runs and in calibration runs with the muon tracker pointing to open sky in the opposite direction)

$$T(\theta,\phi) = \frac{N_\mu^v(\theta,\phi)/\Delta t^v}{N_\mu^{fs}(\theta,\phi)/\Delta t^{fs}} = \frac{\epsilon^v \cdot S_{eff}(\theta,\phi) \int_{E_{min(\rho)}}^{\infty} \Phi(\theta,\phi;E)dE}{\epsilon^{fs} \cdot S_{eff}(\theta,\phi) \int_{E_0}^{\infty} \Phi(\theta,\phi;E)dE}$$

Rock thickness to be traversed by muons through Mt. Vesuvius as function of the elevation and horizontal angles; horizontal line reflects the detector's geometrical acceptance

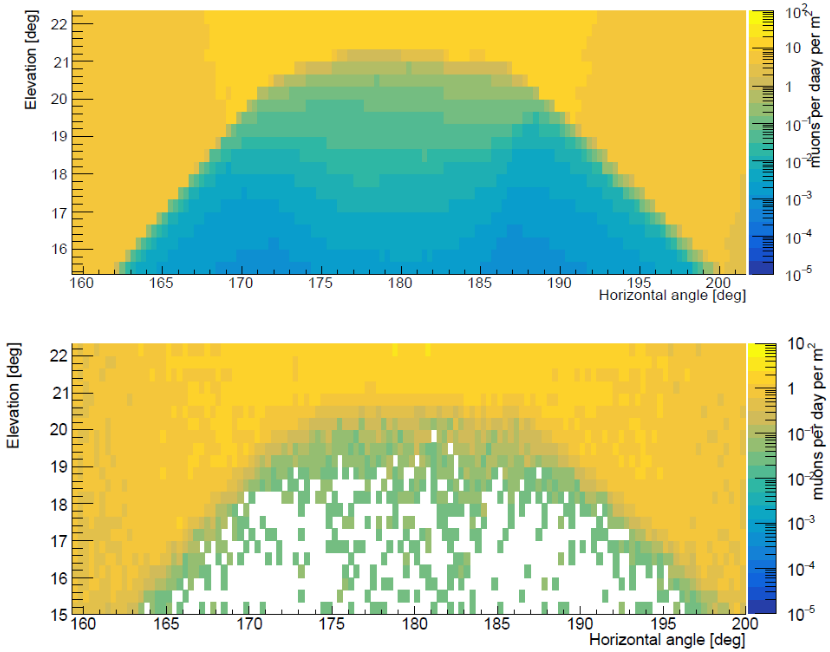


Initial datasets

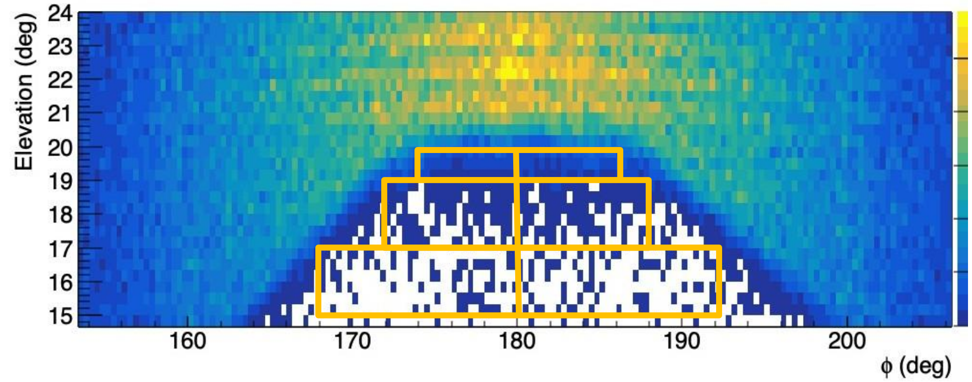
Preliminary analysis based on initial datasets from the Rosso and Nero trackers (both installed in 2019)

Dataset	Vesuvius	Free-sky
ROSSO wp 15°C	51 days	9.5 days
ROSSO wp 20°C	40 days	14.3 days
NERO wp 15°C	43 days	10 days
NERO wp 20°C	26 days	17 days

1-2 months of exposure time, taken at 2 different working points corresponding to 2 SiPM temperature settings



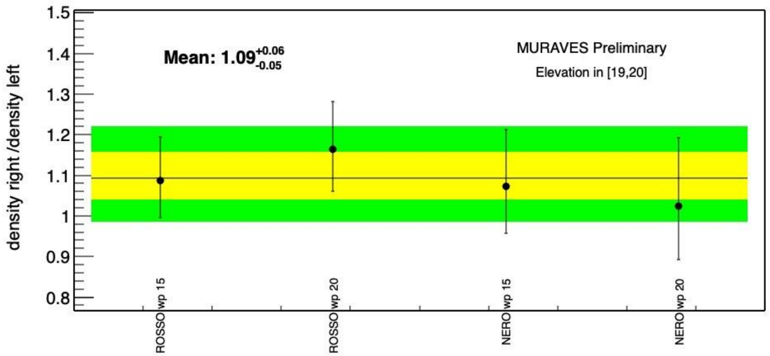
Expected muon flux (PUMAS, taking the lead wall energy threshold into account) and measured flux obtained from one of the datasets

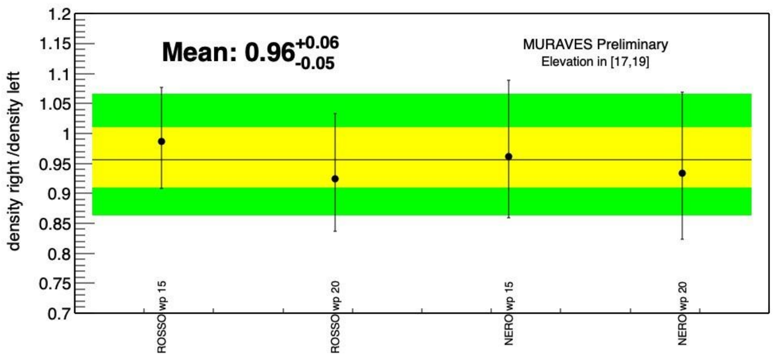


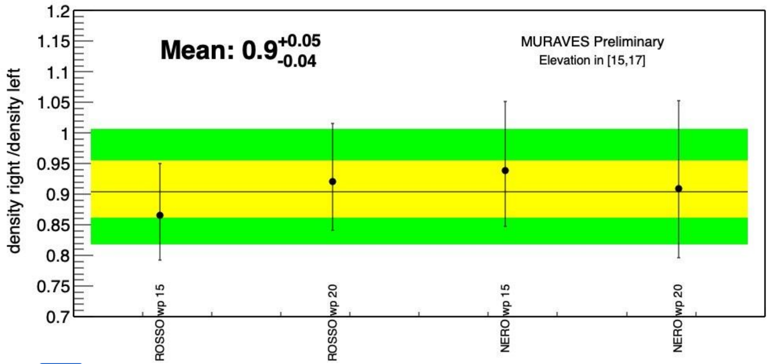
Upper part of the cone was divided into regions/layers large enough to contain a reasonable amount of events (Δx=180-315m; Δy=26-52m), to study expected layered structure

Further subdivision in left and right parts (from the point of view of the detector) in order to reveal possible asymmetries

Preliminary results







A relative horizontal asymmetry ρ_{right}/ρ_{left} is evaluated; density ratio only, to reduce systematic uncertainties from e.g. differences between datasets, background substraction, simulation inaccuracies …

- Results from the different datasets agree within 1 sigma
- **Very preliminary results seem to indicate density variations in different layers**, i.e
  - top layer shows right side more dense than left side
  - middle layer shows left side more dense than right side
  - Bottom layer same as middle layer but stronger difference between right and left

1 sigma
2 sigma

Summary & outlook

- ❑ MURAVES is operating at Mt. Vesuvius a muon telescope consisting of 3 equal scintillator-based trackers with a total active area of 3 m^2, with the aim to measure the density distribution of the volcano body
- ❑ Data taking is ongoing and a complete simulation chain for the setup is being developed
- ❑ Very preliminary results from two muon trackers seem to indicate a right/left density asymmetry for various layers

- ➢ Muraves will continue taking data at least 1-2 years more
- ➢ Data analysis and simulation will be expanded (more detailed systematic studies, comparison between different muon trackers, data-simulation comparison ...)
- ➢ Muon telescope upgrades being considered

Recent references

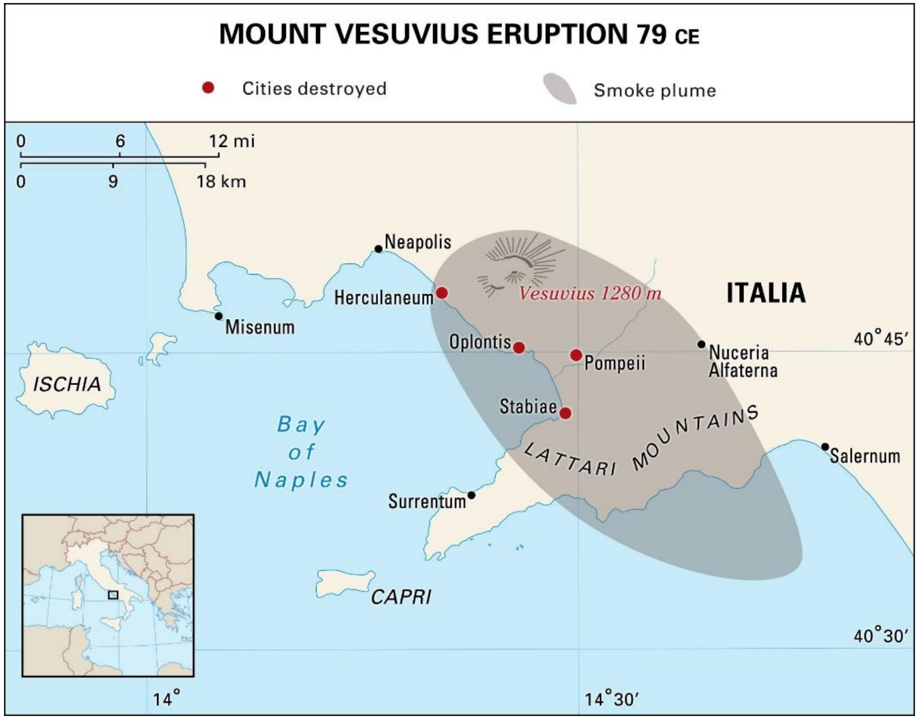
1. M. D'Errico et al., *The MURAVES experiment: study of the Vesuvius Great Cone with Muon Radiography*, e-Print: 2202.12000 [physics.ins-det]
2. M. Moussawi et al., *The simulations chain of the MURAVES experiment*, e-Print: 2202.03375 [physics.ins-det]

backup

Mt. Vesuvius

Long history of violent eruptions, with the most commonly known one the Plinian eruption in 79 BC burying Roman cities of Pompeii, Oplontis, Stabiae under ashes and lapilli and city of Herculaneum under mudflow

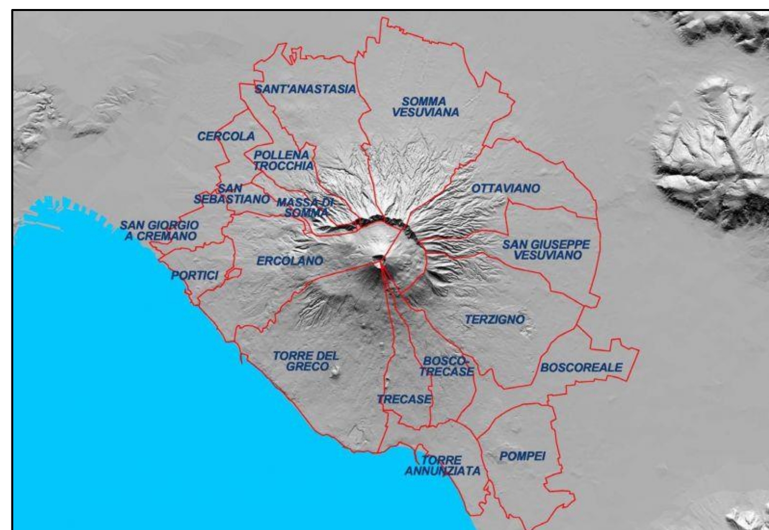
Between 79 BC and its last eruption in 1944 27 significant eruptions; some have been so large that the whole of southern Europe has been blanketed by ashes; in 472 and 1631, Vesuvian ashes fell on Constantinople, i.e. >1,200 km away



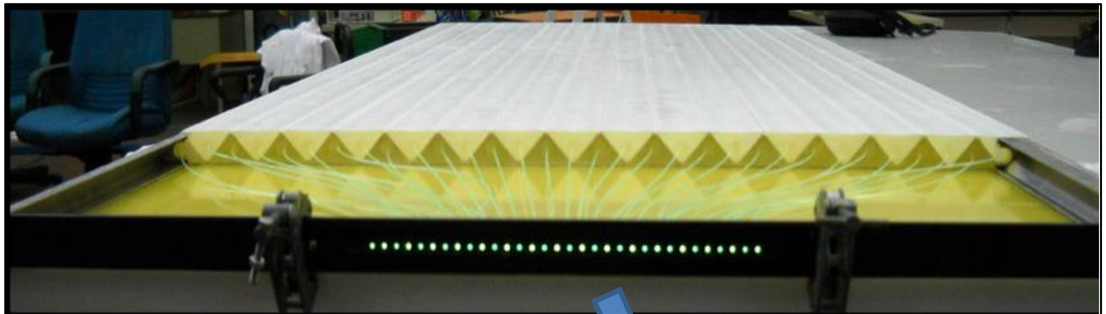
Area of Italy affected by the eruption of Mt. Vesuvius in 79 BC *(Encyclopædia Britannica, Inc.)*

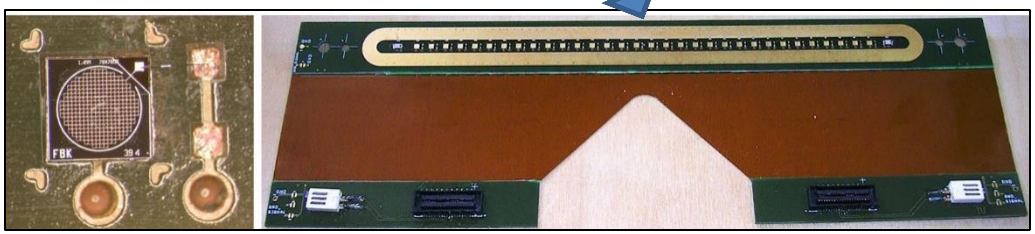
Last few eruptions were effusive-explosive, i.e. combining flowing lava with violent expulsions of rock and ash

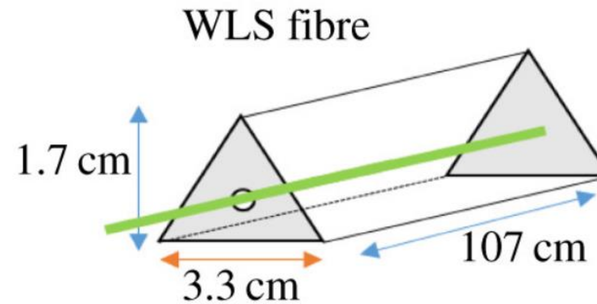
The red zone around Mt. Vesuvius



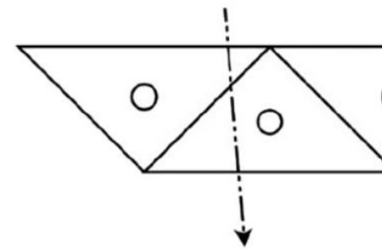
The Muraves muon trackers







Triangular section of scintillators yields improved spatial resolution (~3mm): muon hit position is computed as an energy weighted mean



SiPMs are glued in groups of 32 to a custom flex PCB hybrid, which provides biasing of the SiPMs, amplification, discrimination and ADC conversion of the signals, and hosts T&H sensors

Every hybrid is read out by 1 SLAVE EASIROC based FEE board

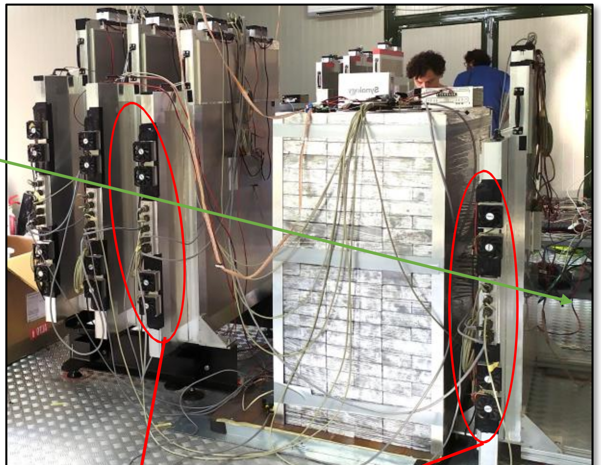
...

16 FEE boards of one tracker are read out by 1 MASTER board (equipped with a Raspberry Pi) which controls the trigger logic and data-acquisition

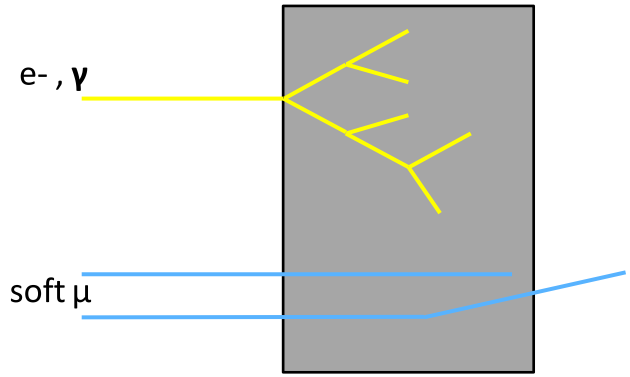
The Muraves muon trackers

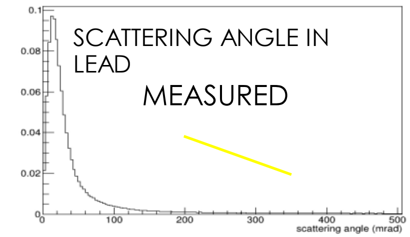
TECHNOLOGY AND INFRASTRUCTURE - THE TELESCOPE

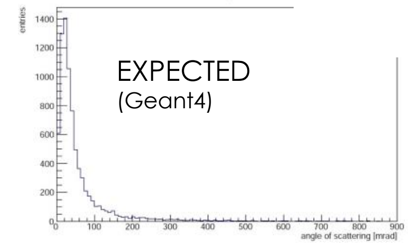
μ



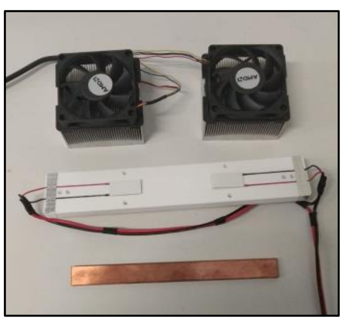
lead-wall reduces the background contaminations







Temperature control system is crucial to mantain **SiPMs work conditions stable** against environment changes



Fans to cool Peltier system

Peltier system

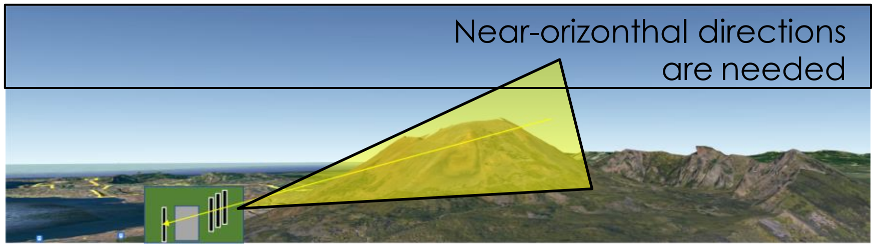
Copper bar to couple peltiers to SiPMs uniformly

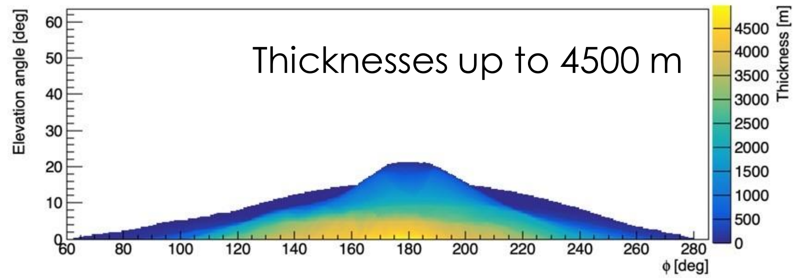
Working points : V_{bias} and temperature on SiPMs are changed according to:

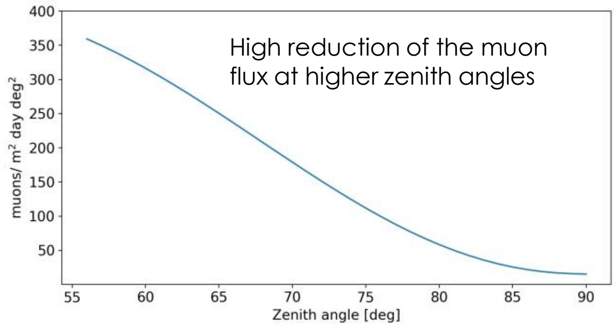
- Environmental temperature (Delta T ≤ 5°C)
- Dew Point (condensation must be avoided to prevent damages)
- $V_{overvoltage}$ (mantained stable)

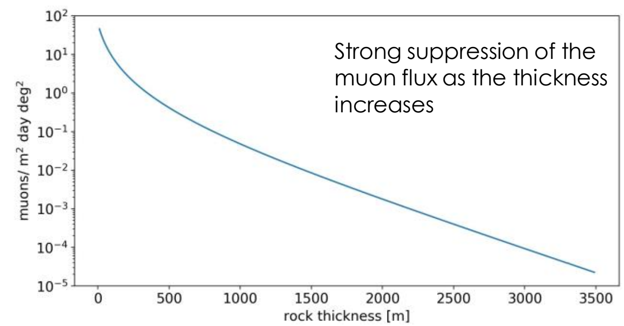
Challenge for Muraves

Long exposure time needed to achieve acceptable resolutions









Δy	Δx	500 m	1000 m	3000 m
9 m	9 m	8 months	3 years	100 years
9 m	26 m	3 months	1 years	33 years
9 m	130 m	15 days	2.5 months	6 years
26 m	130 m	5 days	1 month	2 years
52 m	260 m	2 days	6 days	16 months

Sensitive area 3 m²
Not accounting for detector efficiencies, except geometrical acceptance

Preliminary results

	ROSSO wp 15°C	ROSSO wp 20°C	NERO wp 15°C	NERO wp 20°C	Average
layer 1	$1.08^{+0.11}_{-0.09}$	$1.16^{+0.12}_{-0.10}$	$1.07^{+0.14}_{-0.11}$	$1.02^{+0.17}_{-0.13}$	$\mathbf{1.09^{+0.06}_{-0.05}}$
layer 2	$0.99^{+0.09}_{-0.08}$	$0.92^{+0.11}_{-0.09}$	$0.96^{+0.13}_{-0.10}$	$0.93^{+0.14}_{-0.11}$	$\mathbf{0.96^{+0.06}_{-0.05}}$
layer 3	$0.87^{+0.09}_{-0.08}$	$0.92^{+0.09}_{-0.08}$	$0.94^{+0.11}_{-0.09}$	$0.91^{+0.14}_{-0.11}$	$\mathbf{0.90^{+0.05}_{-0.04}}$