



# MURAVES muon telescope:

a low power consuming muon tracker for muon radiography applications

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# OUTLINE

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**1**  
**Muon Radiography**

**2**  
**The MURAVES detector**

**3**  
**Mt. Vesuvius**

**4**  
**Data&Simulations**

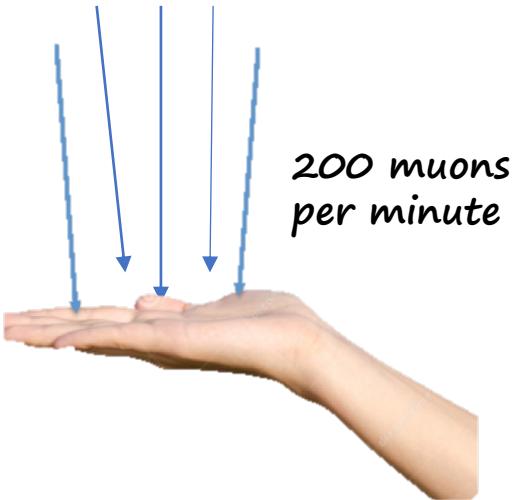
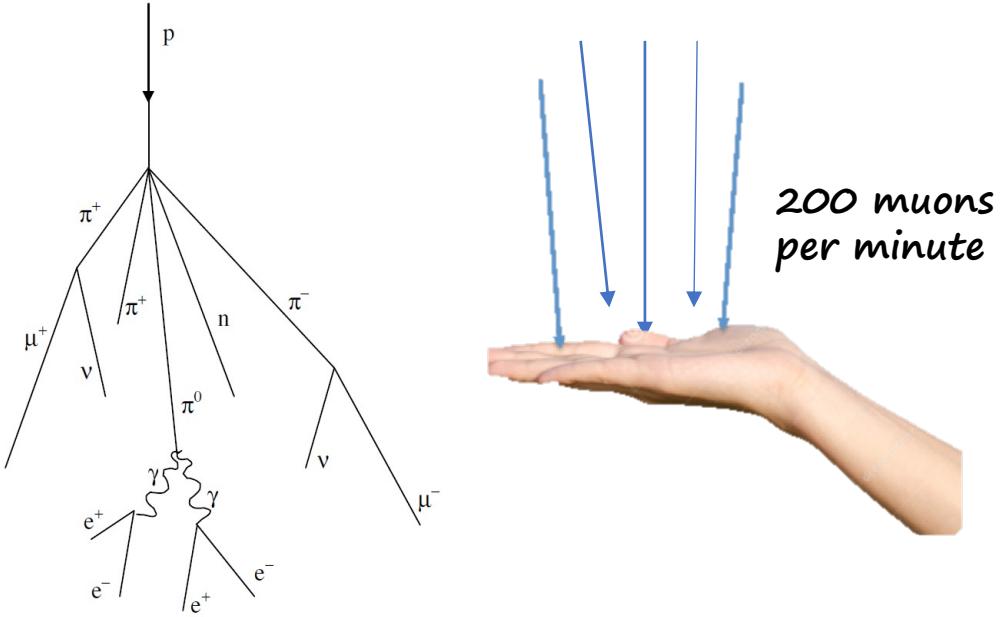




# MUON RADIOGRAPHY

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# MUON RADIOGRAPHY (1/3)



- Cosmic –ray muons: natural source of high energy particles
- well-known constant flux
- Muons have a high penetration power through rock (~ hundreds meters)
- Measuring the outcoming muon flux we can indirectly measure the mean density of the object

Applications in :

- Volcanology
- Archaeology
- Civil Engineering
- Industry

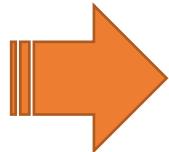
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# MUON RADOGRAPHY (2/3)

Muons passing through rock are involved in interactions with matter:

- Ionization
- Bremsstrahlung
- Scattering (lower energies)



$$-\frac{dE}{dX} = aE + b \quad b \sim 2 \text{ MeV g}^{-1} \text{ cm}^2 \text{ and} \\ a \sim 4 \times 10^{-6} \text{ g}^{-1} \text{ cm}^2$$

*Energy loss in standard rock (approximation)*

$$R_\mu = \int_0^{E_\mu} -\left(\frac{dE}{dx}\right)^{-1} dE$$

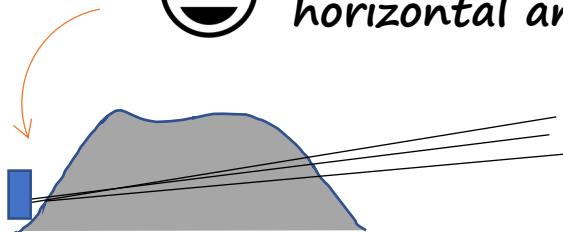
Energy	10 GeV	100 GeV	1 TeV	10 TeV
Range	19 m	115 m	0.9 km	2.3 km



Lower flux



Dominant at near horizontal angles



High energy muons are needed



Typical rock thicknesses of volcanoes

# MUON RADIOGRAPHY (3/3)

$$N_\mu(\theta, \phi) = \Delta T \cdot \epsilon(\theta, \phi) \cdot A(\theta, \phi) \cdot \int_{E_{min}}^{\infty} I(E; \phi, \theta) dE$$

$\times$  (opacity) = density \* thickness

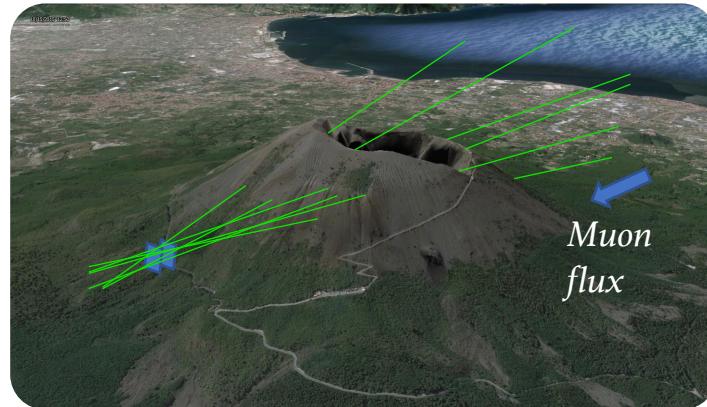
Observed muons exiting the target

$$N_\mu^{fs}(\theta, \phi) = \epsilon(\theta, \phi) \cdot A(\theta, \phi) \cdot \Delta T^{fs} \cdot \int_{E_{detector}}^{\infty} I(E; \theta, \phi) dE$$

Observed muons without the target (free-sky calibration)

$$T(\theta, \phi) = \frac{N_\mu(\theta, \phi) \Delta T^{fs}}{N_\mu^{fs}(\theta, \phi) \Delta T_\mu}$$

Transmission is independent by acceptance and efficiencies



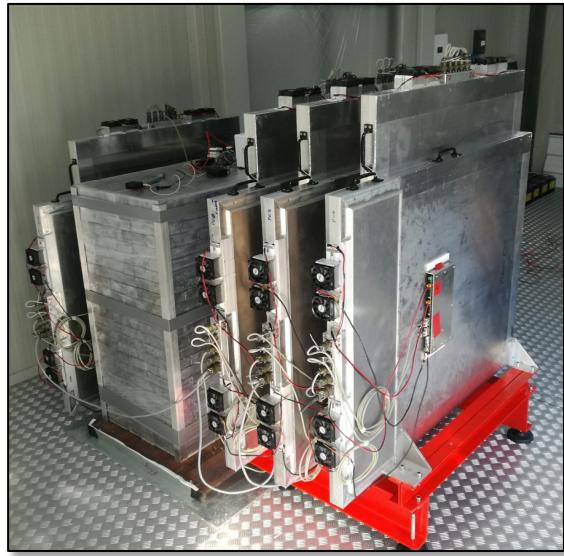
Directionality to measure density distribution along the body



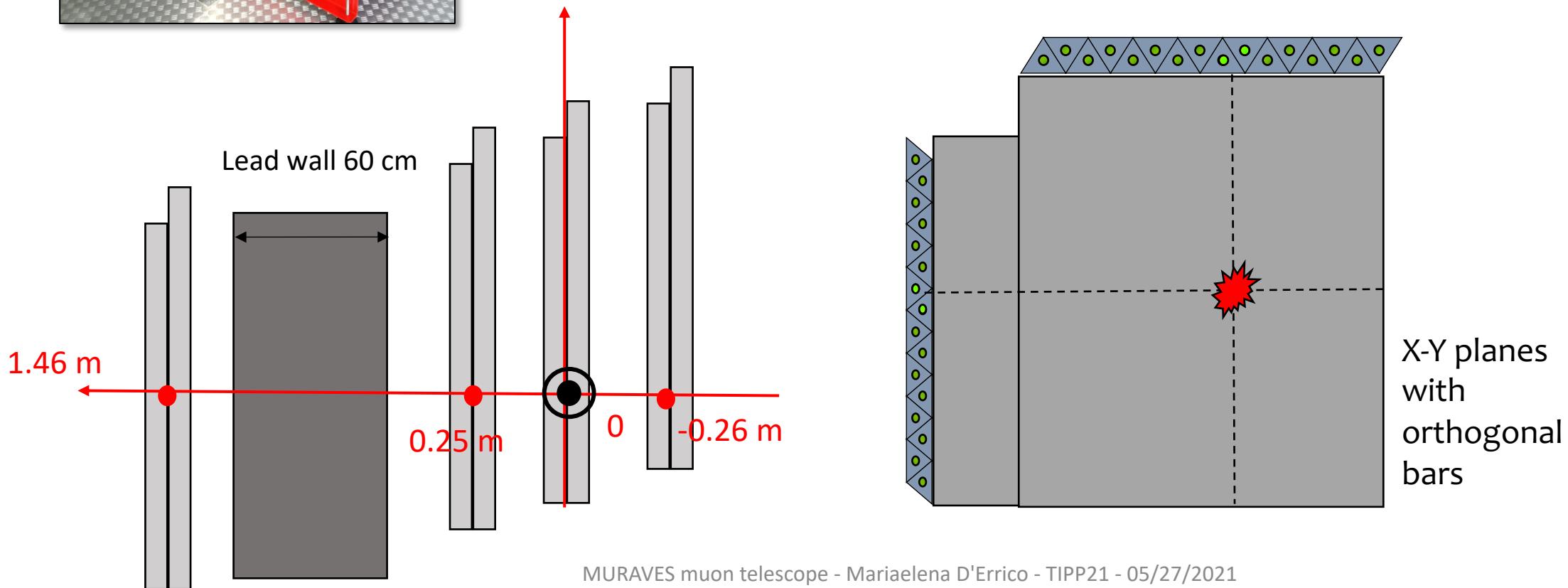
# THE MURAVES DETECTOR

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# THE MURAVES DETECTOR (1/6)

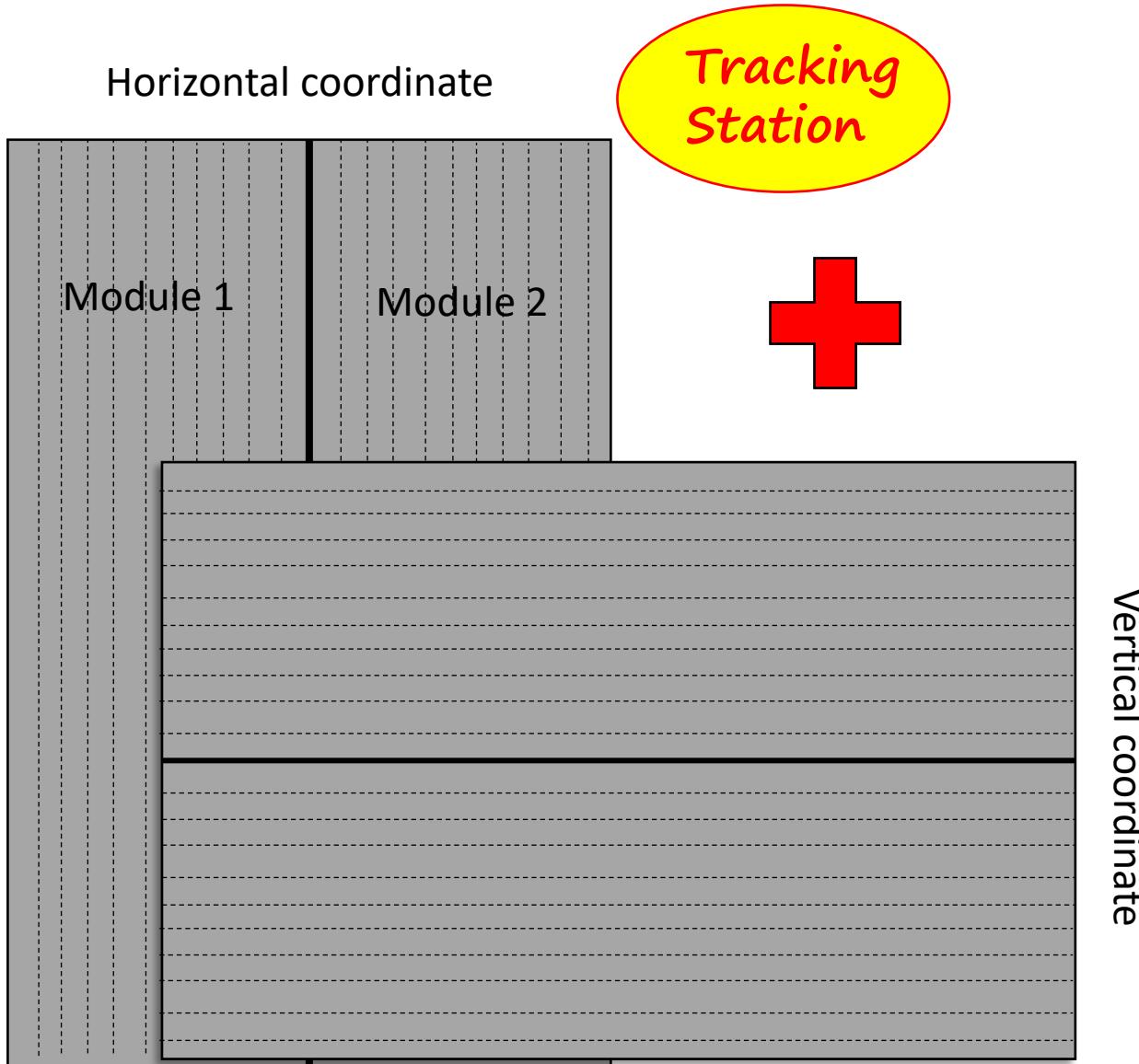


- An array of three equal hodoscopes ( $3 \times 1 m^2$  sensitive area)
- Each hodoscope consists of four planes of orthogonal bars
- Triangular shaped scintillator bars to improve spatial resolution
- Scintillators are coupled with SiPMs
- Each hodoscope consumes about **30 W**



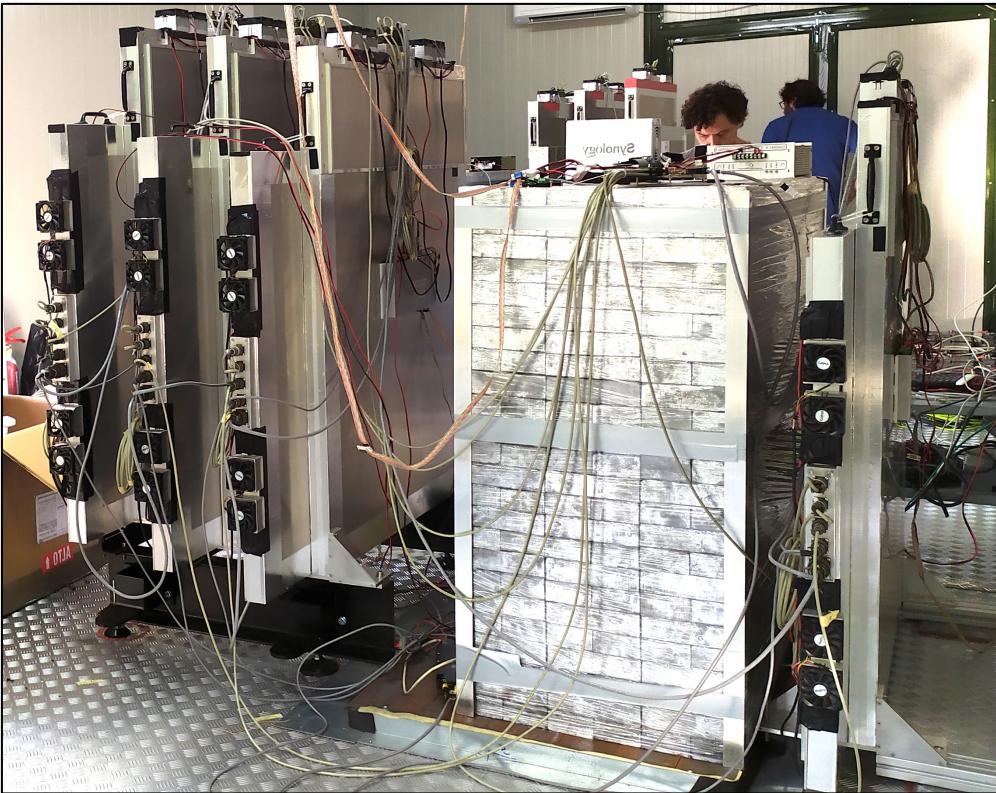
# THE MURAVES DETECTOR (2/6)

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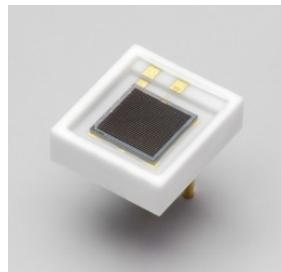


- Each station consists of **2** planes of orthogonal bars
- Each plane is divided in two modules
- Each module is segmented with **32** bars for a total of **128** bars per station
- Each bar has an WLS fiber inside coupled with a SiPM
- Each module is connected to an hybrid board, hosting an array of **32** SiPMs

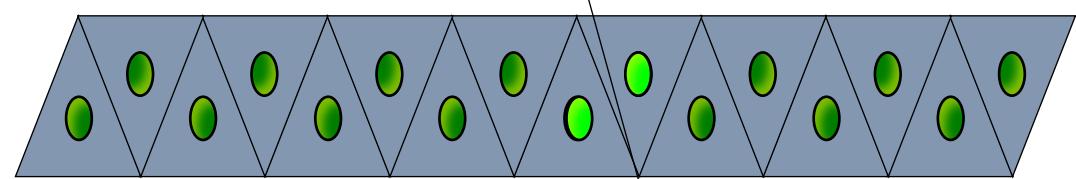
# THE MURAVES DETECTOR (3/6)



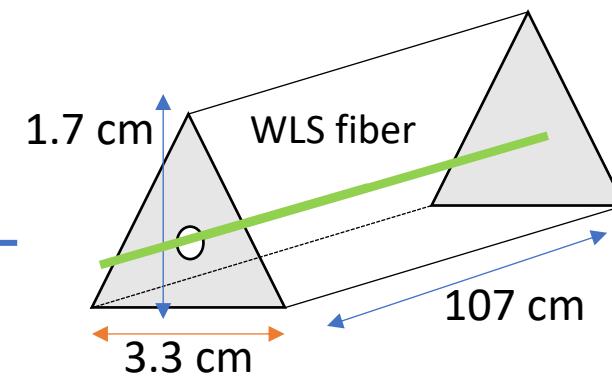
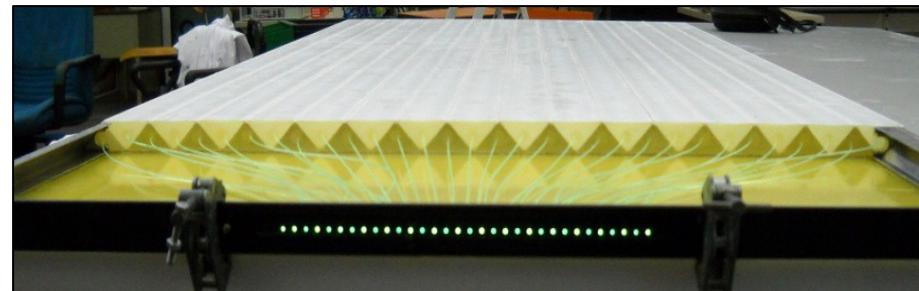
Spatial resolution:  
2-3 mm  
Angular resolution:  
< 3 mrad



SiPM  
light sensor



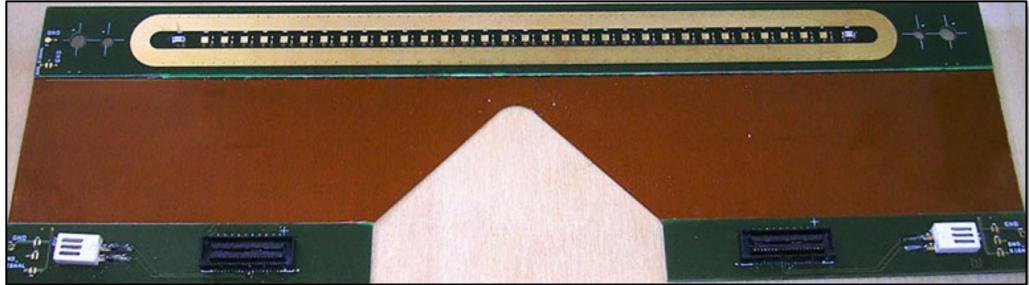
Triangular section  
improves spatial  
resolution



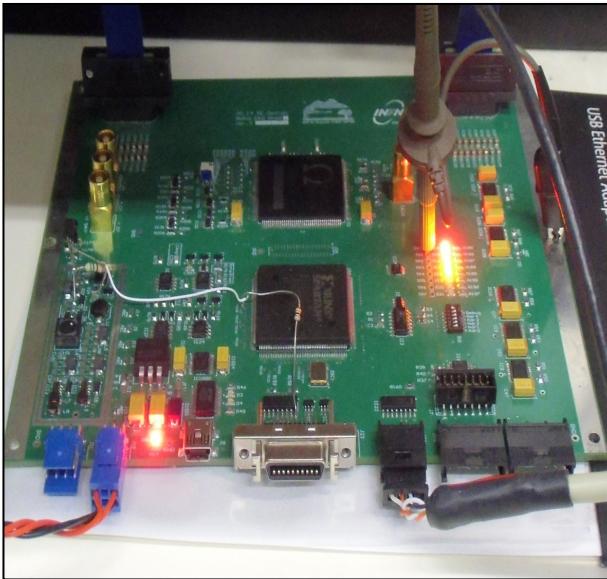
WLS fibers  
along the bar  
improves  
efficiency

# THE MURAVES DETECTOR (4/6)

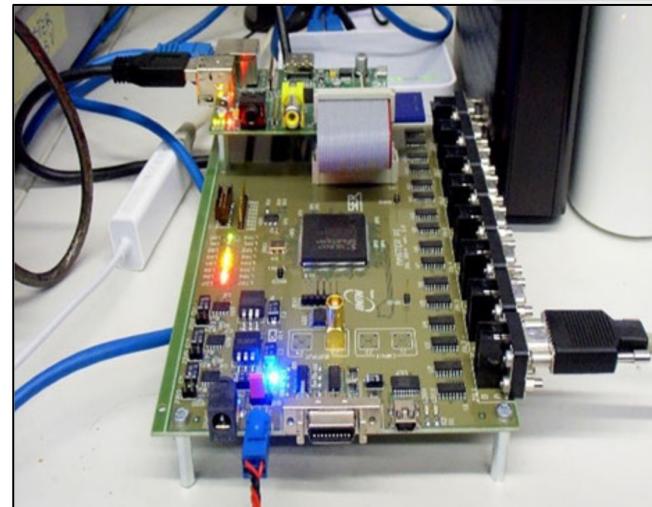
## Readout system



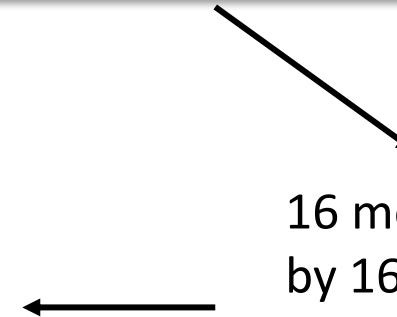
SiPMs hybrid board: 32 channels  
connected to a **SLAVE**



F.E.E.  
ASIC EASIROC  
(OMEGA)  
FPGA  
HV on board  
32 Ch  
3W power



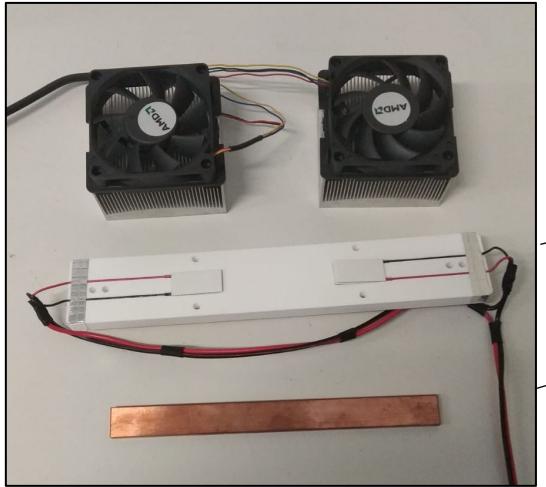
TRIGGER and DAQ  
FPGA +  
Raspberry-Pi  
  
Up to 32 F.E. boards



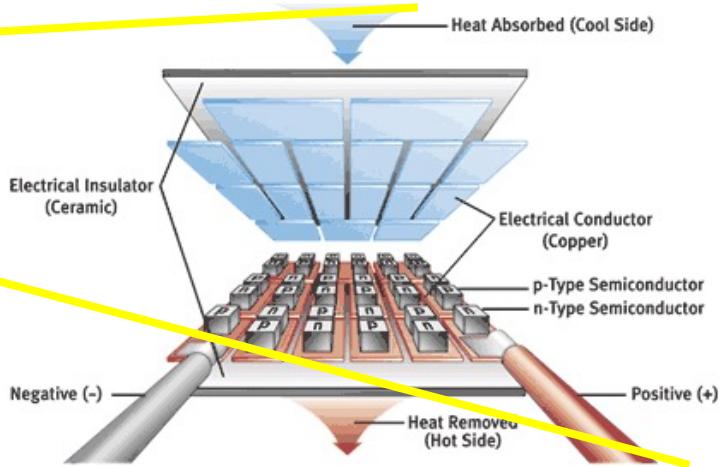
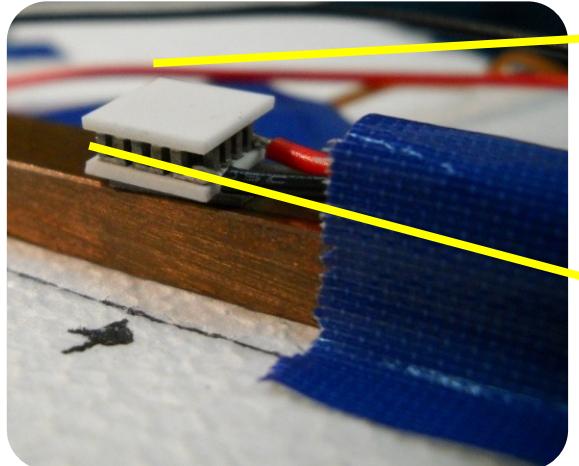
16 modules read  
by 16 SLAVE board  
connected to the  
MASTER BOARD

# THE MURAVES DETECTOR (5/6)

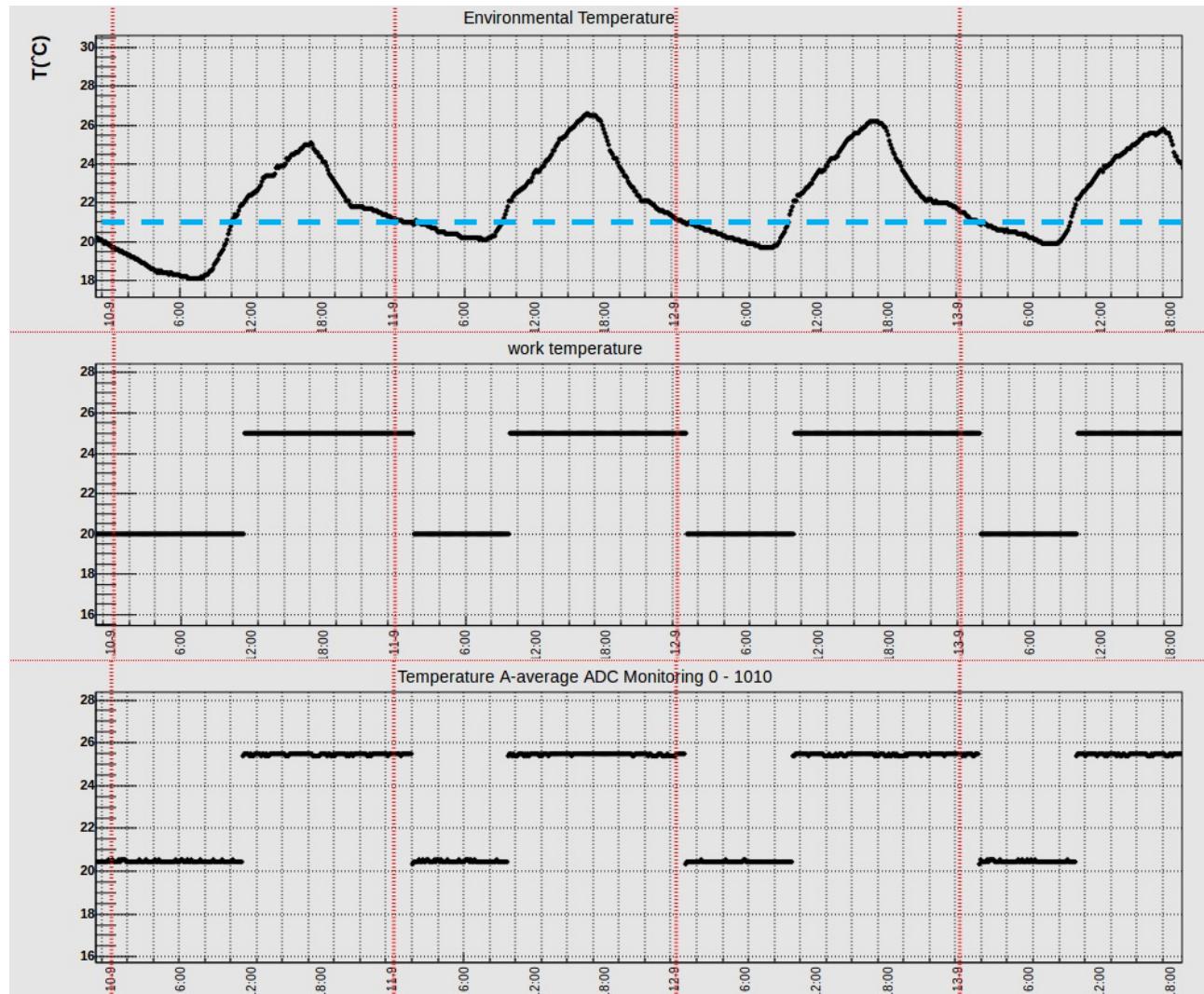
## Temperature Stability



- Fans to cool Peltier system
- Peltier system
- Copper bar to couple peltiers to SiPMs uniformly



# Temperature Stability



Environmental temperature

Nominal work-temperature on  
SiPMs (choosen to reduce  
consumes)

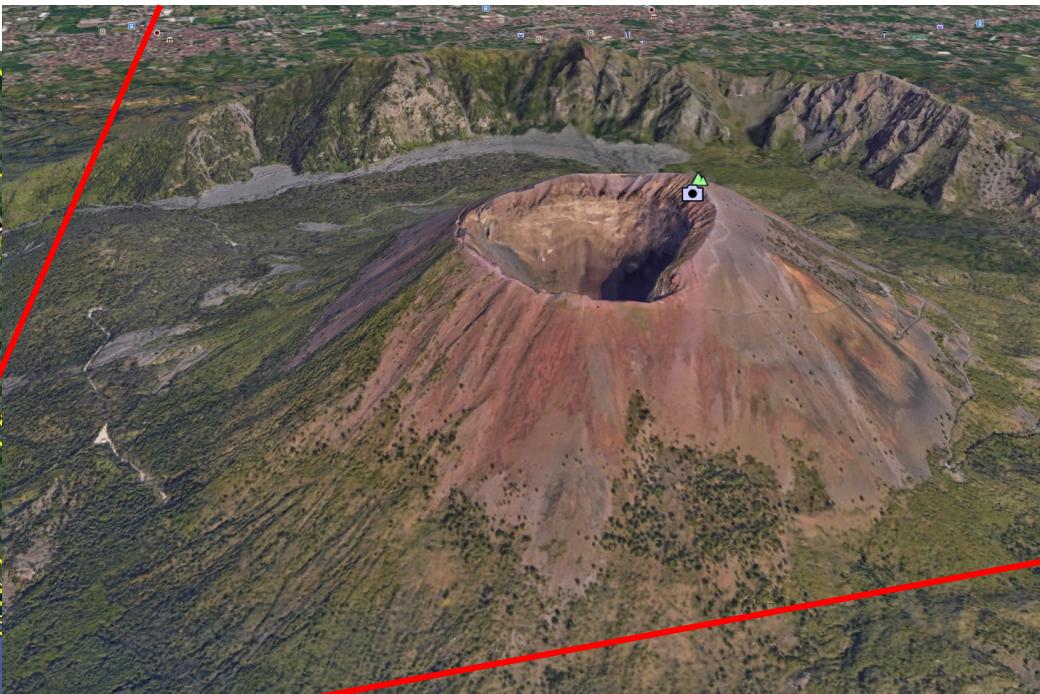
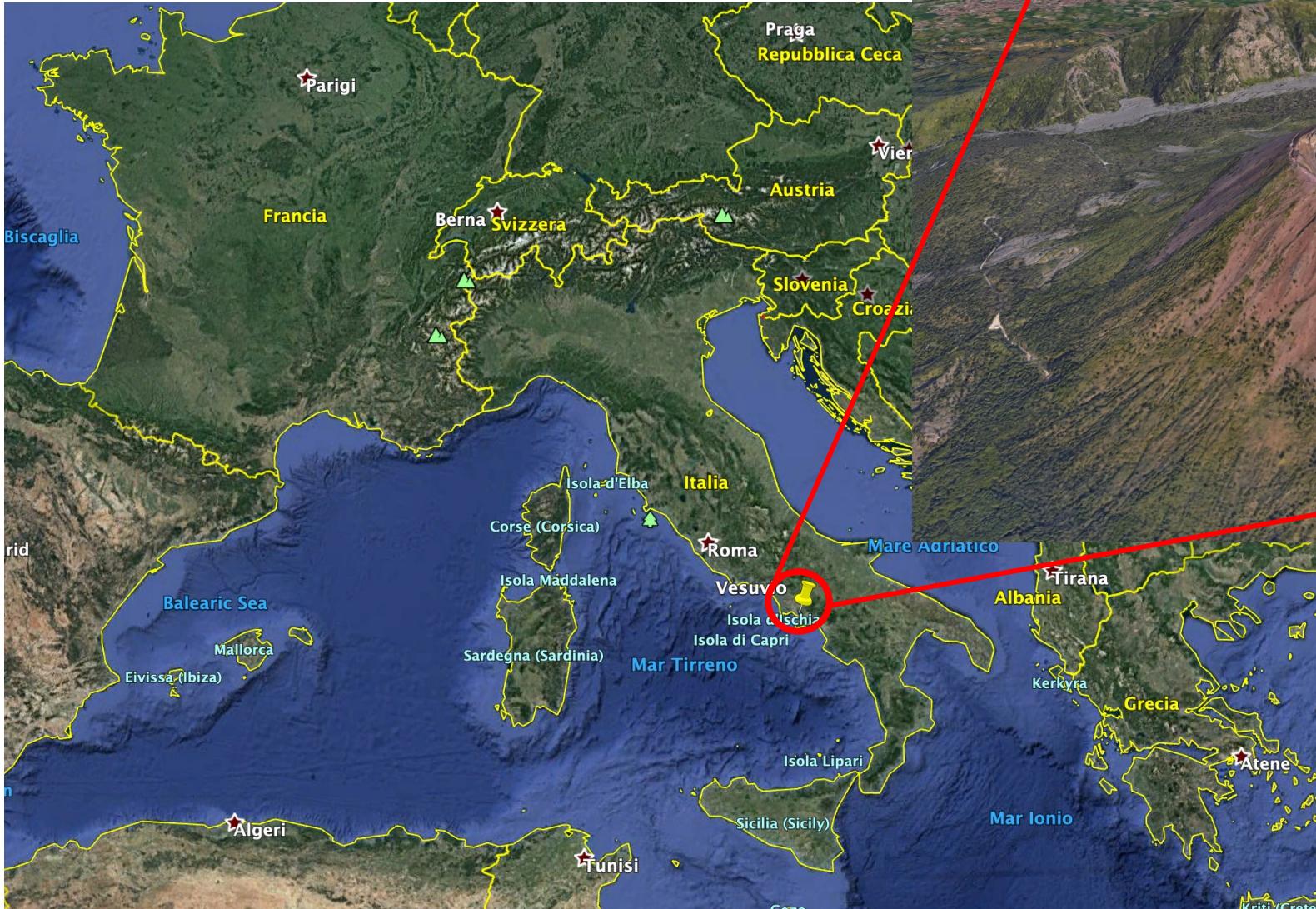
Measured work-temperature  
of SiPMs



# MT. VESUVIUS

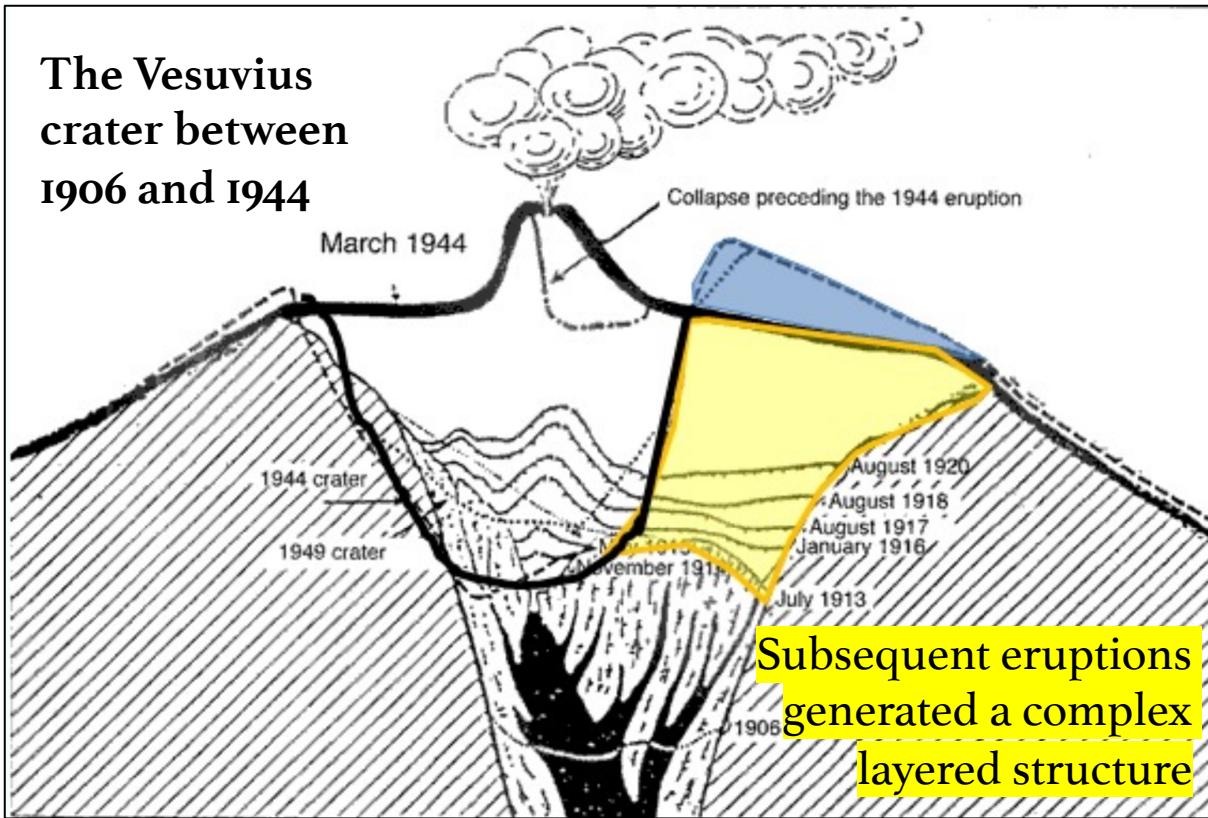
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Mt. Vesuvius is located in the south of Italy is one of the **most dangerous active volcanoes** in the world

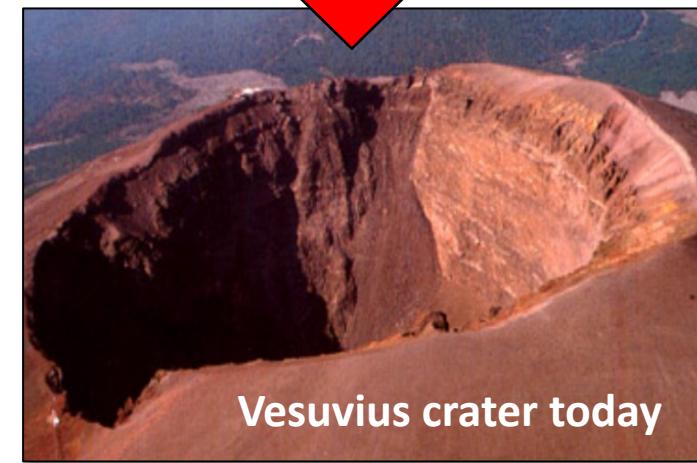
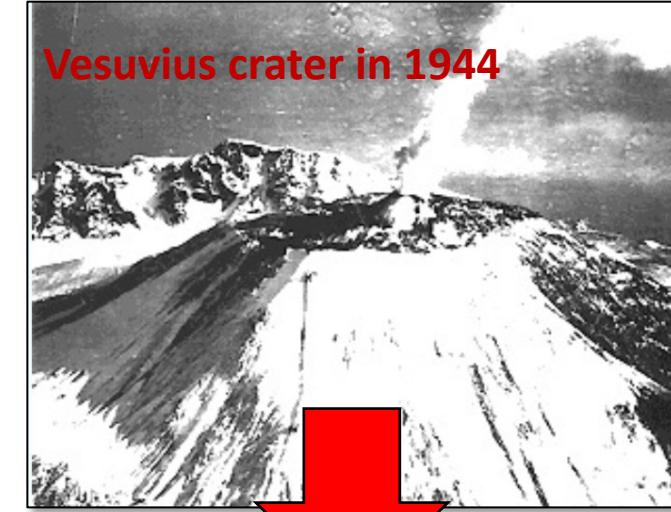


# MT. VESUVIUS (2/3)

## The Vesuvius crater between 1906 and 1944



Vesuvius crater in 1944

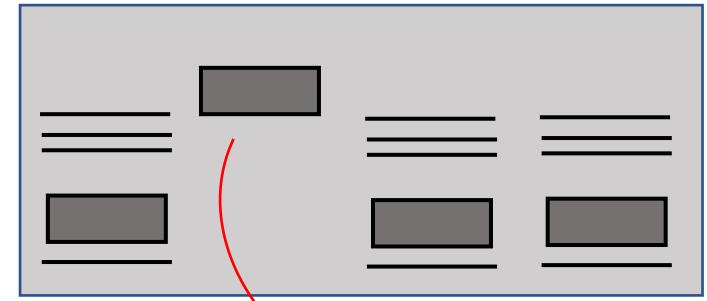


Muography can shed light on the distribution of different densities along the body of the volcano, providing a direct image of the layers that form the structure of Vesuvius

# MT. VESUVIUS (3/3)



- ~45 square meters area
- 4 stations to install the detectors (3 + 1 to calibration )
- 35 tons of lead ( 3 walls 60 cm wide)
- Photovoltaic system of 5,4 kWp



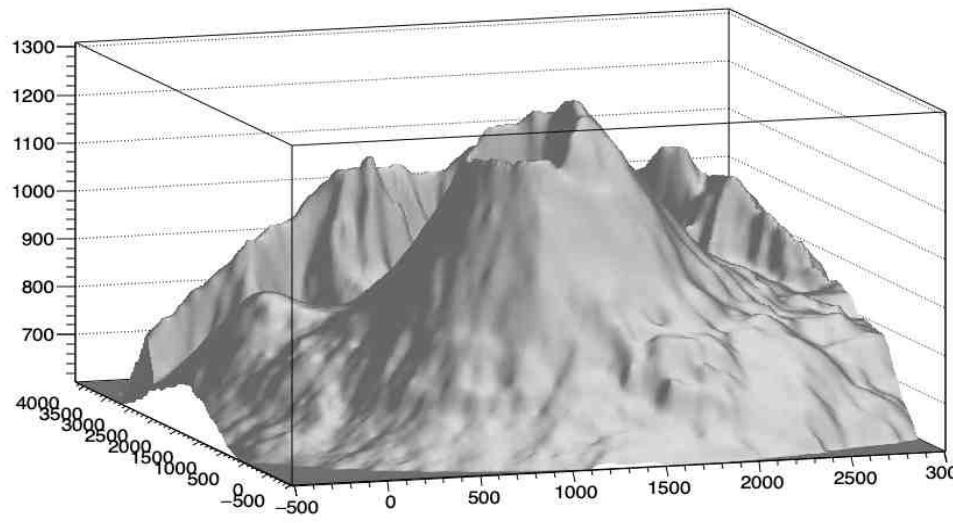
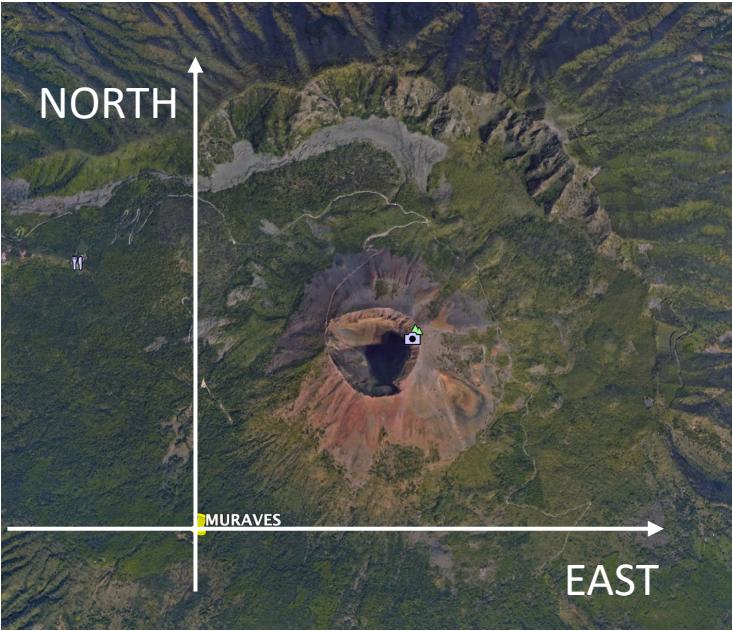
Calibration station



# DATA & SIMULATIONS

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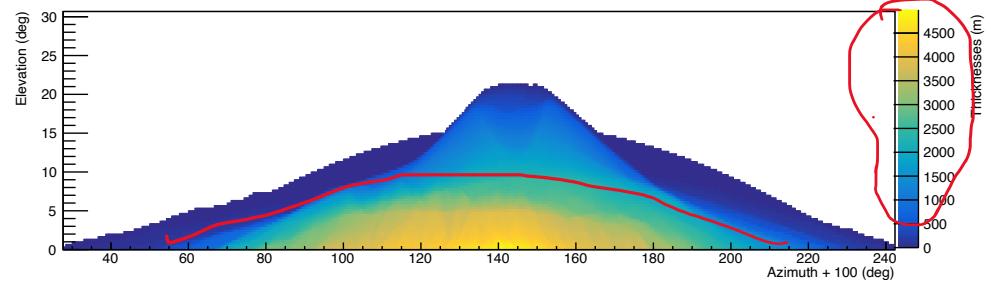
# DATA & SIMULATIONS(1/2)



A digital elevation model (DEM) has been used to obtain information about the topology of the site

Crossing rock vs direction evaluated from TURTLE (\*)

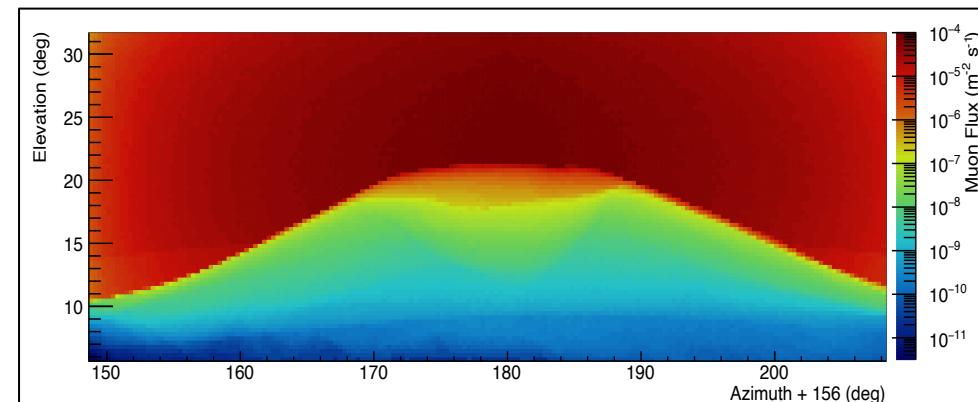
We are interested in the summit



Few kilometers -> very prohibitive !

(\*) [arXiv:1904.03435](https://arxiv.org/abs/1904.03435)

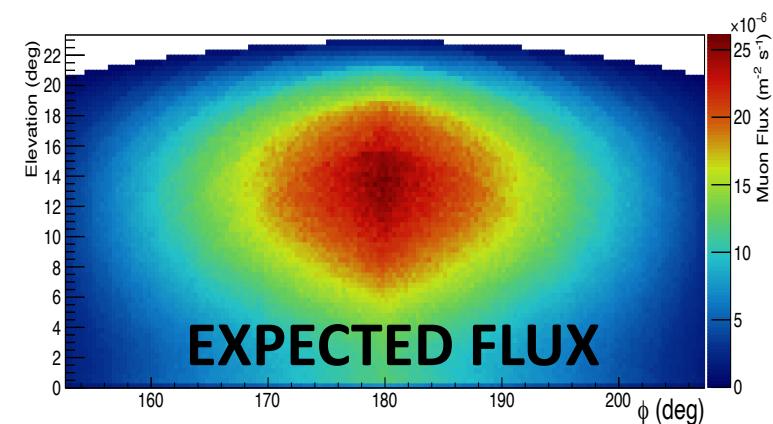
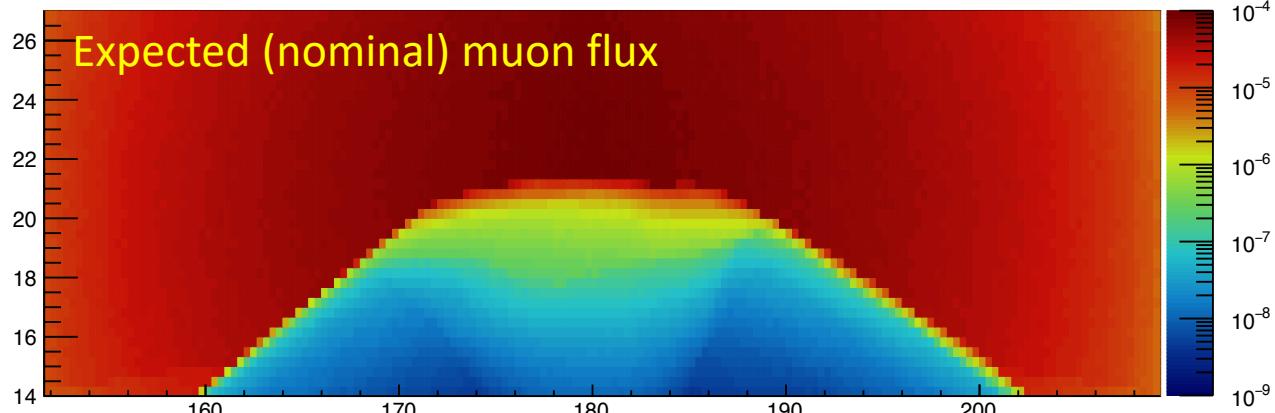
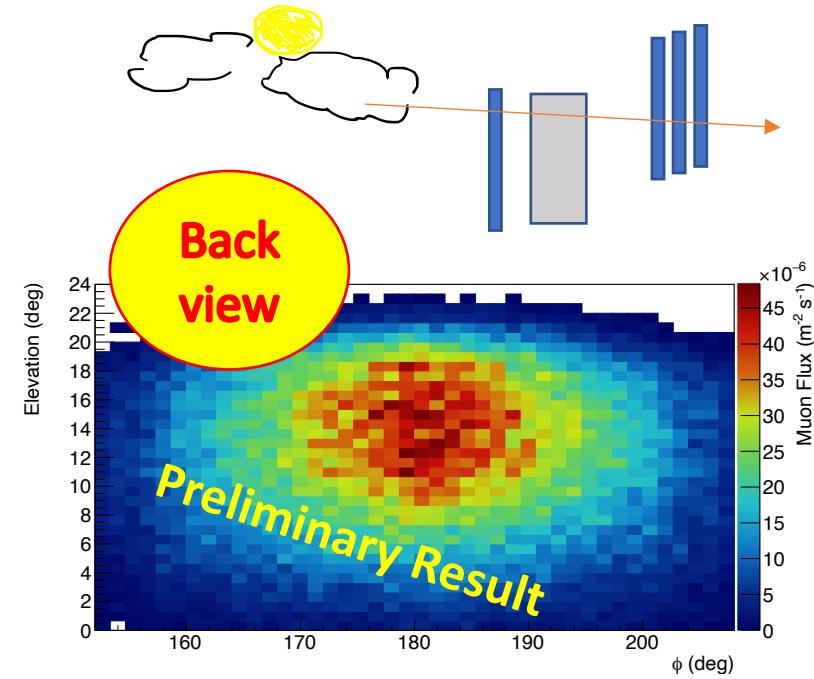
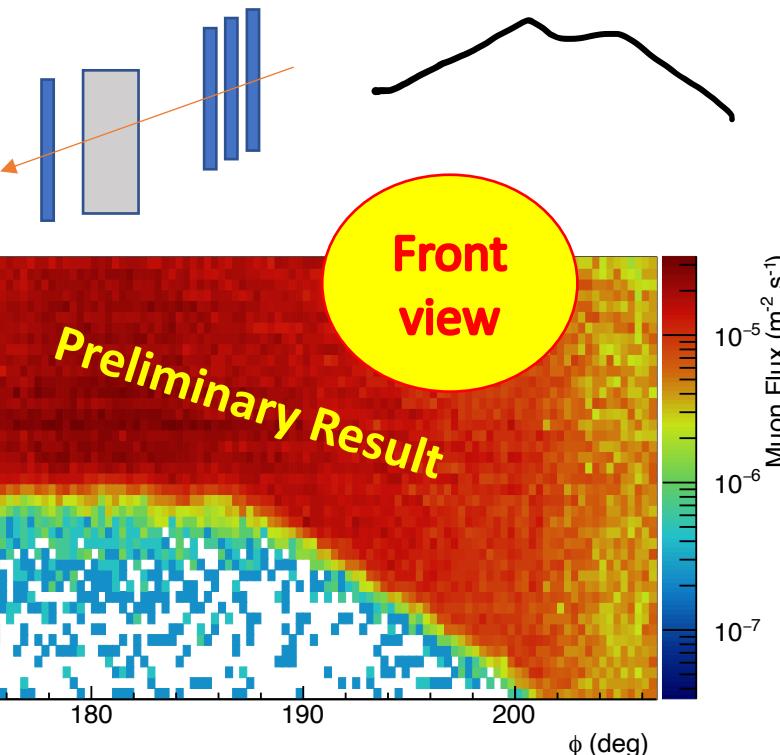
(\*\*) [arXiv:1705.05636](https://arxiv.org/abs/1705.05636)



Expected muon flux considering also geometrical acceptance of the detector (binning  $0.33 \times 0.33$  degrees) with PUMAS (\*\*)

# DATA & SIMULATIONS (1/2)

**~ 52 days of data acquisition from one detector**



# SUMMARY&OUTLOOKS

- 
- 1** Muon Radiography is a relatively young technology to explore the interior of big bodies
  - 2** MURAVES project is a muon radiography experiment aiming to study the summit of the Mt. Vesuvius, a dangerous volcano in Italy
  - 3** The technology used to realize MURAVES hodoscopes is smart and low-power consuming
  - 4** Very preliminary results are promising compared with simulated expectations
  - 5** We are collecting and analyzing data from two detectors to increase statistics and consequently improve uncertainties
  - 6** Next step in the analysis will be approaching the measure of the density distribution