Muon radiography in Italy

Valeri Tioukov (INFN Napoli)

Groups and projects

Muography with emulsions detectors

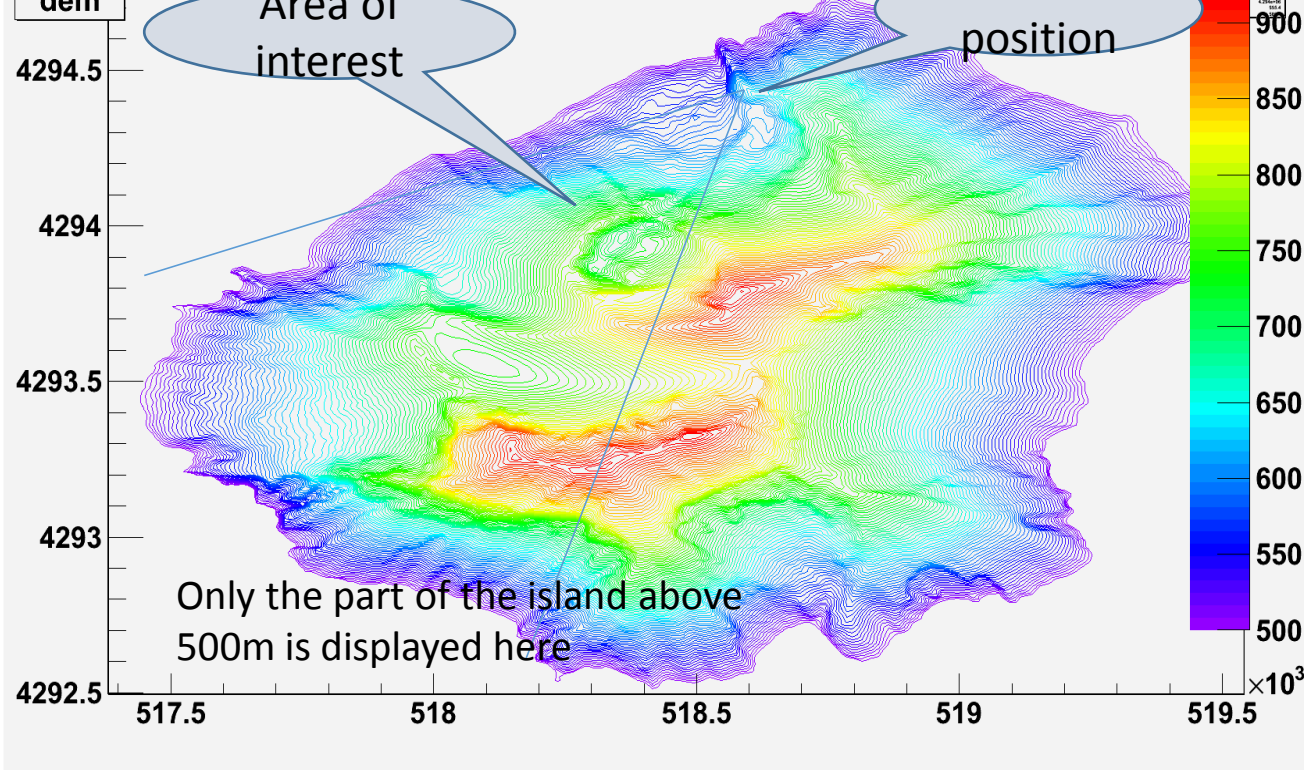
- Laboratories
  - Napoli, Gran Sasso, Salerno (ExOPERA emulsions labs)
- Main projects
  - Stromboli 2011-2012: muography of the volcano with emulsion
  - Stromboli 2017-2018: muography of the volcano with ECC
  - Ipogei 2018 – Archeological project – study of Napoli underground
  - Vesuvio 2018 – background measurements with ECC

Muography using electronic detectors

- Laboratories developing plastic scintillator detectors
  - Napoli, Florence
- Main projects
  - Vesuvio (MuRay, Muraves) – study of the volcano edifice
  - Cumae – archeological sites near Napoli
  - Mt Echia – methodical and demonstration for muography in urban environment

Stromboli 2011-2012

Emulsion detector of 0.94 m^2 was installed at 640 m asl for 5 months.
Main goal – study of the crater region structure of the edifice
OPERA emulsions used for this exposure

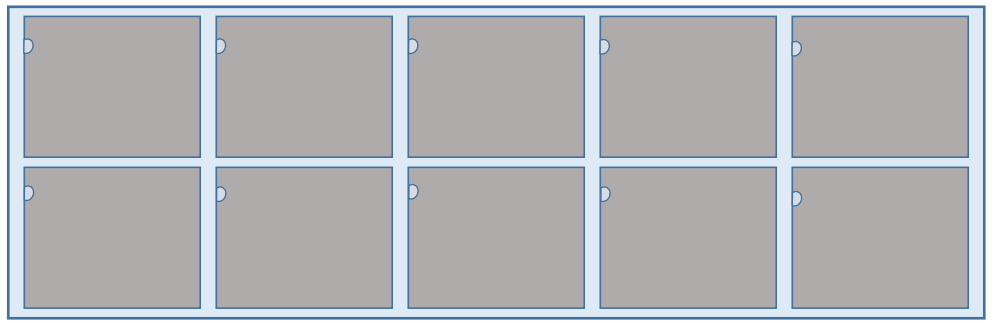


View from the detector position. Linear distance to craters - about 600 m

Scheme of the internal module structure

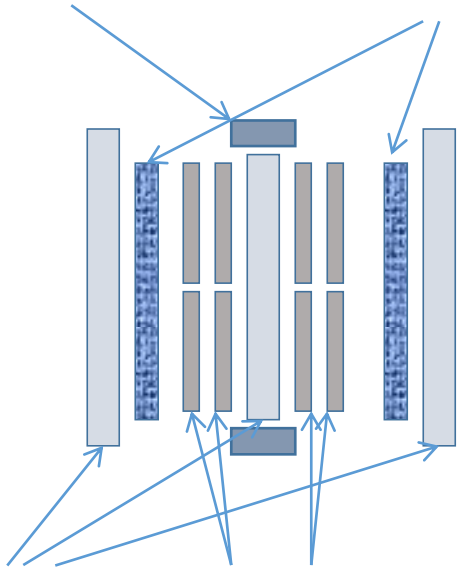
One module with 10 emulsion “cells”
Each cell has 2 emulsions doublets attached to both sides of the central metal plate.

Front view of the central plate (26 x 80 cm)

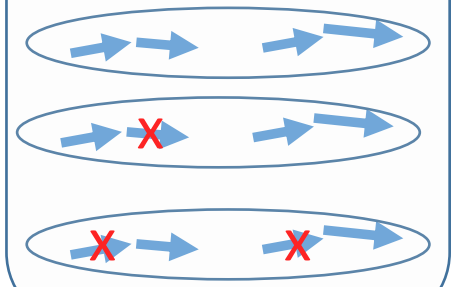


“Exploded view”

Aluminum Frame Elastic (rubber) layers



Track is defined by 2-4 consecutive segments in 4 plates



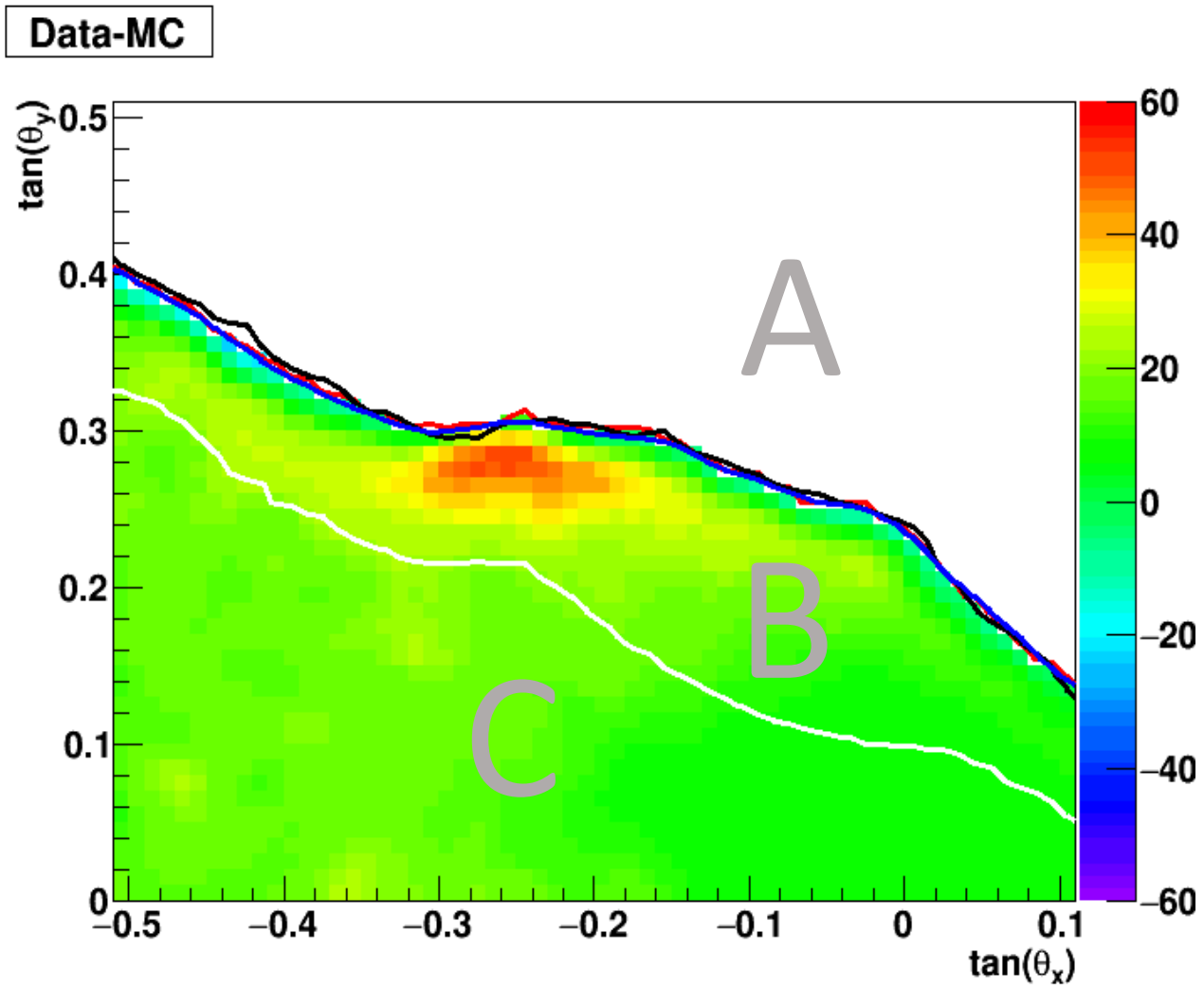
Metal plates of 5mm (inox)

Envelopes with emulsions glued to the central inox plate

The total weight of one module is of 26 kg
Total amount of emulsions/module: 40
The active surface covered is of 1200 cm2

The overall weight of 8 modules and the support frame is about 250 kg

Muons excess was observed in the crater region indicates lower mean density in respect to bedrock



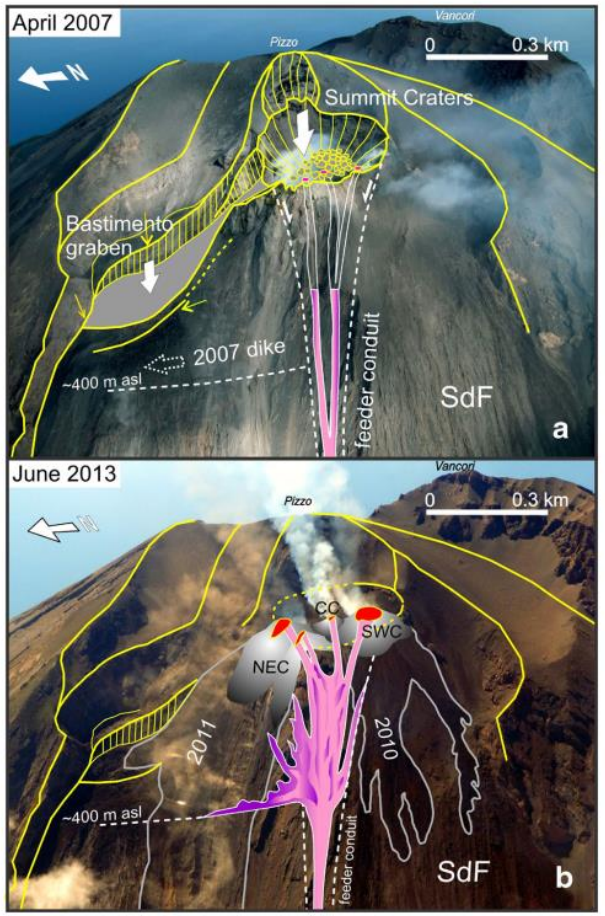


Fig. 7 Aerial photos of Stromboli taken from N, displaying **a** the graben-like collapse formed during the 2007 eruption, and in *pink* the corresponding narrow, pipe-shaped shallow feeder conduit, and **b** the same situation as on June 2013, with the much wider shallow feeder conduit where lava (in *pink*) is fingering in between the debris and scoria. Eruptive vents are in *red*. *Grey lines* in (**b**) indicate the boundaries of the December 2010 and August 2011 lava flows. *SdF* Sciara del Fuoco

frequency has increased more than 25 times, passing from one episode every 5–15 years (Barberi et al. 1993) to an average of 4.8 episodes per year between January 2007 and December 2012 (Table 1). Also, during this time period, the number of major explosions increased, passing from the 2 events per year before 2002, to an average of 4.7 episodes per year between January 2007 and December 2012. A supply of gas-rich magma from the source region was detected at the end of 2009 and perhaps also at the end of 2008, by peaks of fumarole temperature, and CO_2 and SO_2 signals (Fig. 4c, d). While this has typically been linked to triggering of paroxysms, no paroxysms occurred in the period of time here considered. This volcano is reckoned for being characterised by a remarkable steady supply (Calvari et al. 2011c; Francalanci et al. 2012), and we lack signs of a greater input from the source region, given that the supply detected between 2008 and 2009 is much less than that causing the 2007 eruption (Fig. 4c, d). Thus, we suggest that the increase of eruptive activity observed at Stromboli from April 2007 to December 2012 was not caused by a greater supply of gas-rich magma from the source, but instead resulted from a wider and hotter uppermost conduit, initiated by movements that occurred in the SdF after the 2002 landslide events (Acocella and Neri 2009; Falsaperla et al. 2008) and that followed the graben-like collapses that occurred during the 2007 eruption, which involved the entire summit crater zone (Neri et al. 2008; Neri and Lanzafame 2009; Zanon et al. 2009; Di Traglia et al. 2013). This is also confirmed by more recent GBInSAR results that indicate an increased magmastatic pressure within the shallow plumbing system causing its lateral expansion (Di Traglia et al. 2014). The summit of the volcano has evolved through the years to form a wider collapse depression in the uppermost conduit, elongated NE-SW. This allows a greater volume of magma to be stored (Fig. 7), which degas at quasi-equilibrium conditions (Fig. 4 and related discussion). This would keep magma hot for longer, thus enhancing the possi-

Installation 23/11/2017, 640m asl

Installation team:

- Valeri Tioukov (INFN Napoil)
- Nicola D'Ambrosio (INFN LNGS)
- Roberto Cerroni (INFN LNGS)
- Giovanni Macedonio (INGV Napoli)
- Flora Giudicepietro as flight coordinator (INGV Napoli)

Detector filling with emulsions

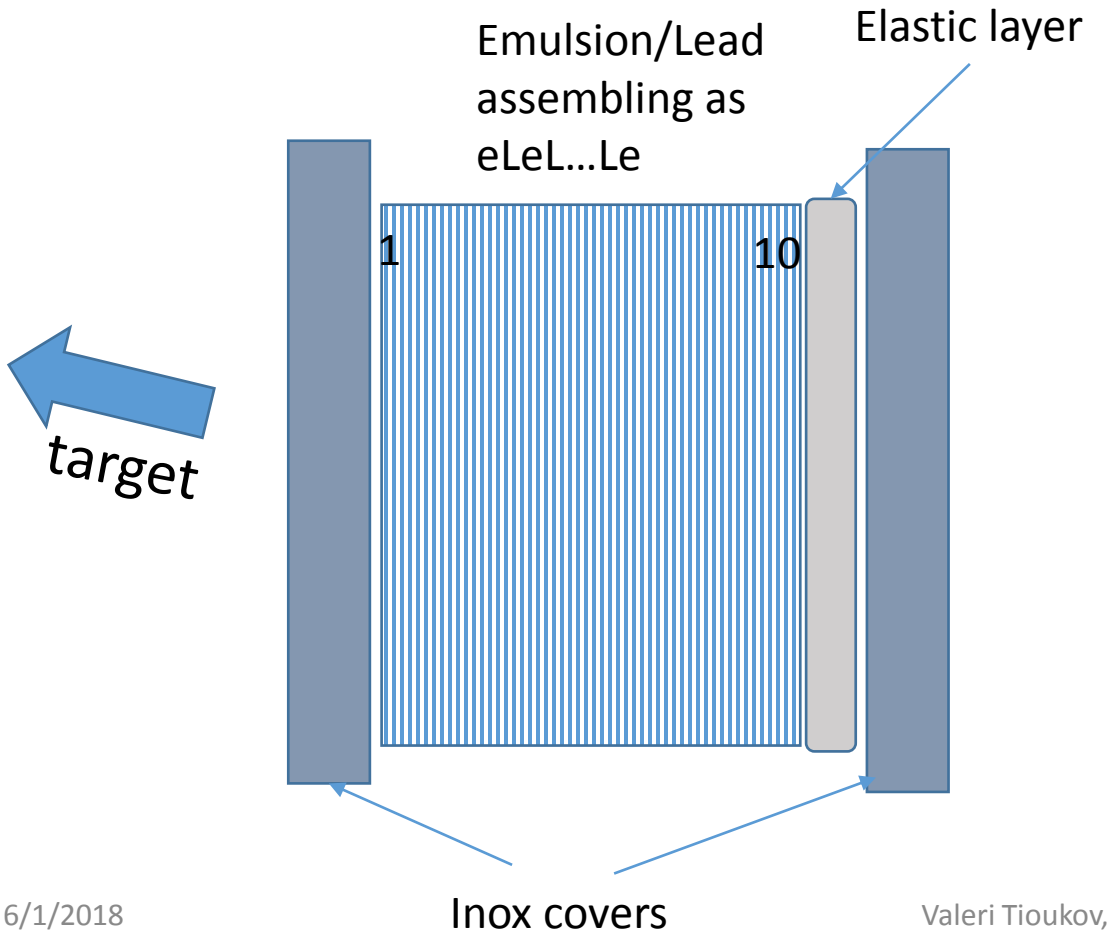
120 plates of 0.25x0.3 m^2 assembled into 12 piles inside 6 modules.

Envelopes *labeling scheme*:
1BL.1 – 1BL.10
1BR.1 - 1BR.10
…….
Plate 10 last in the stack - far from the target

4A (empty) T&H sensor kept inside module	3AL 3AR	2AL 2AR	1A (empty)
4BL 4BR	3BL 3BR	2BL 2BR	1BL 1BR

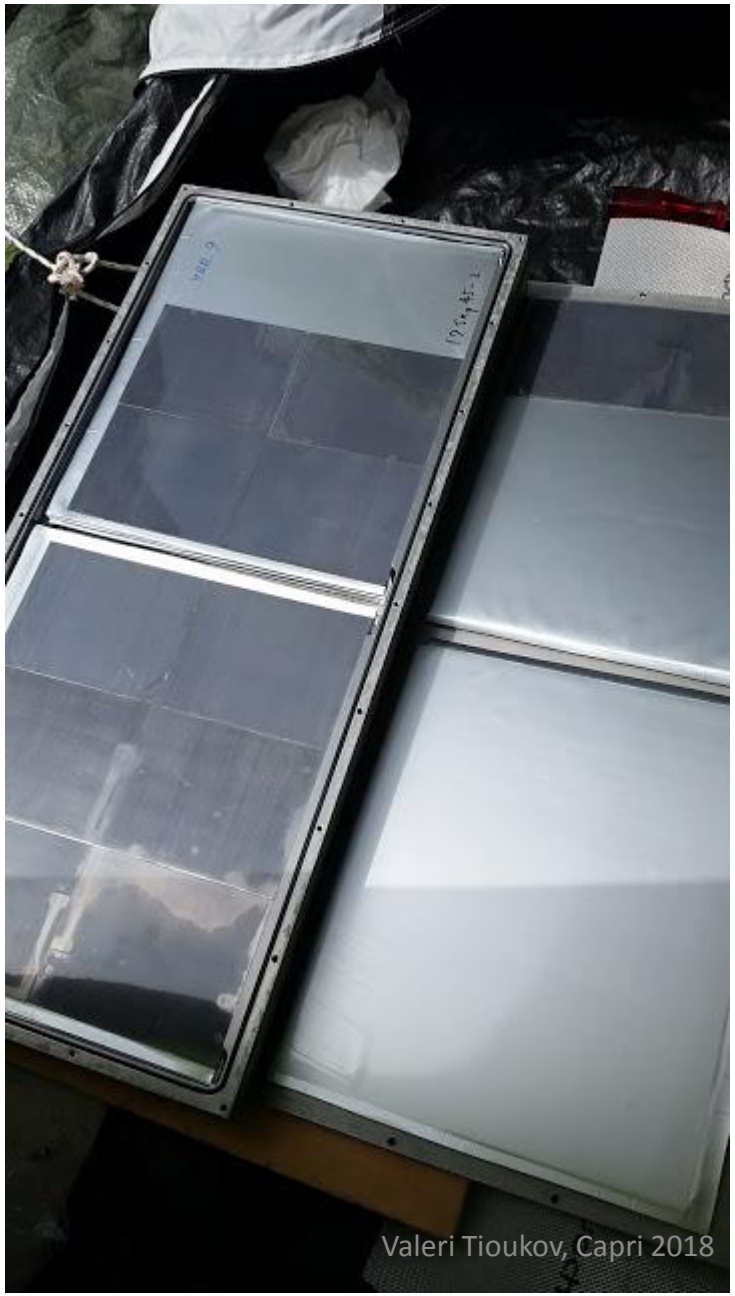
Modules geometry

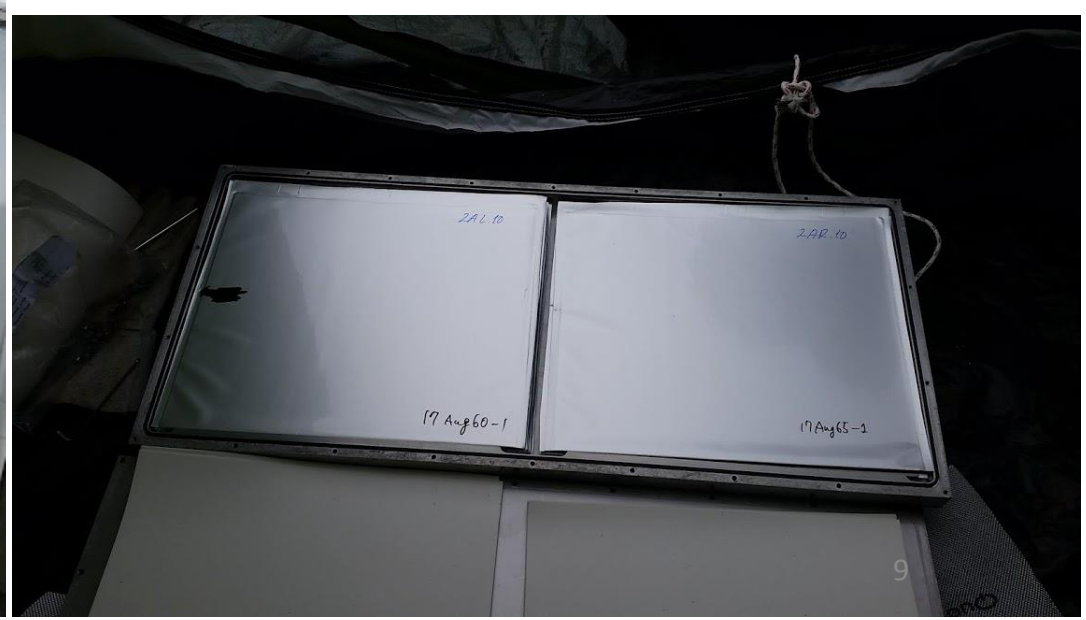
12x10 => 6 modules: 0.9 m2 x 10 layers

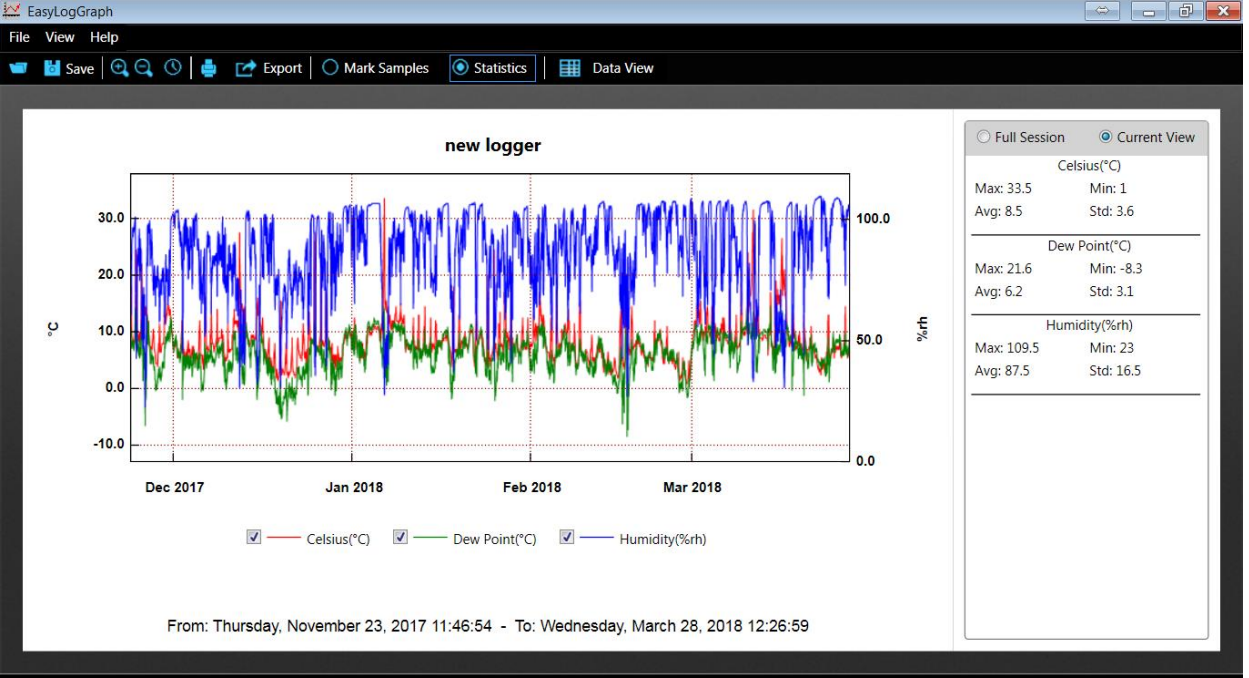


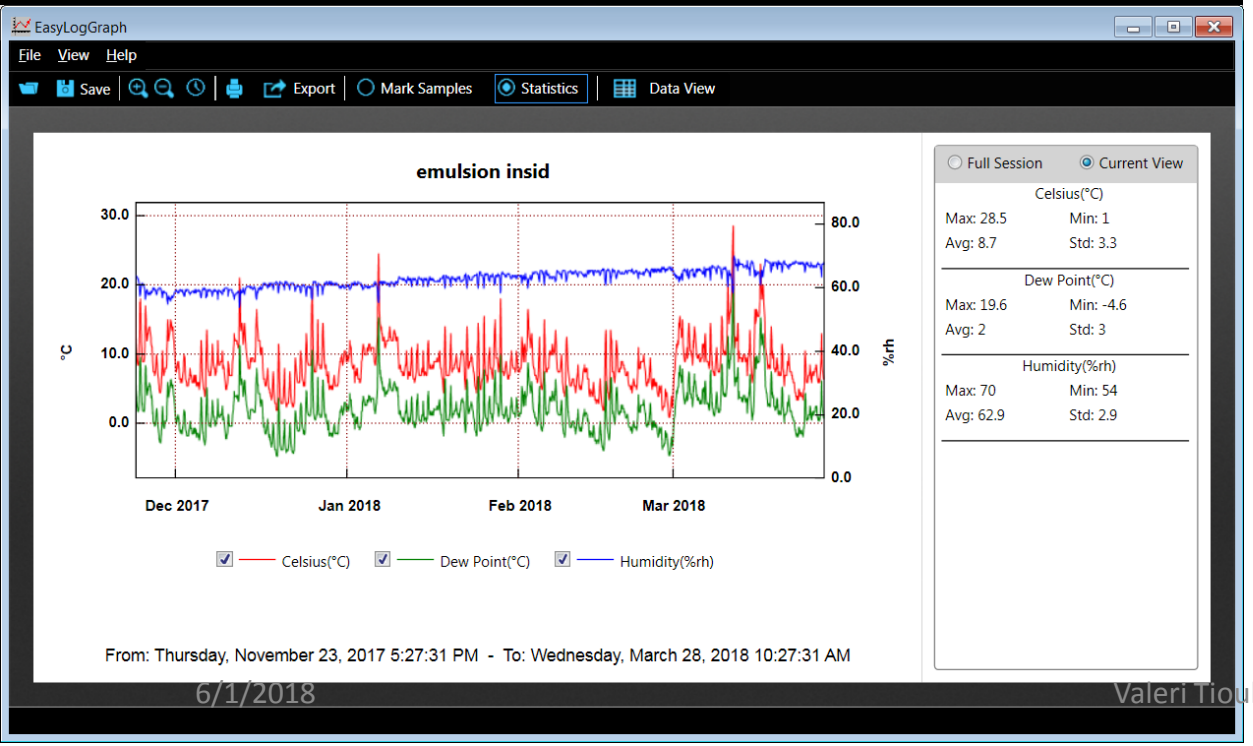
- Emulsion Envelope: 0.585 mm
- Laminated Lead: 1.135 mm
- 0.585*10 = 5.85 (14.15)
- 1.135*9 = 10.215
- Elastic layer: 3.935 mm space is 12% squeezing from 4.5 mm is equivalent to about 0.35 kg/cm2 pressure

Inside modules we found everything in a good conditions, no signs of water or excessive humidity







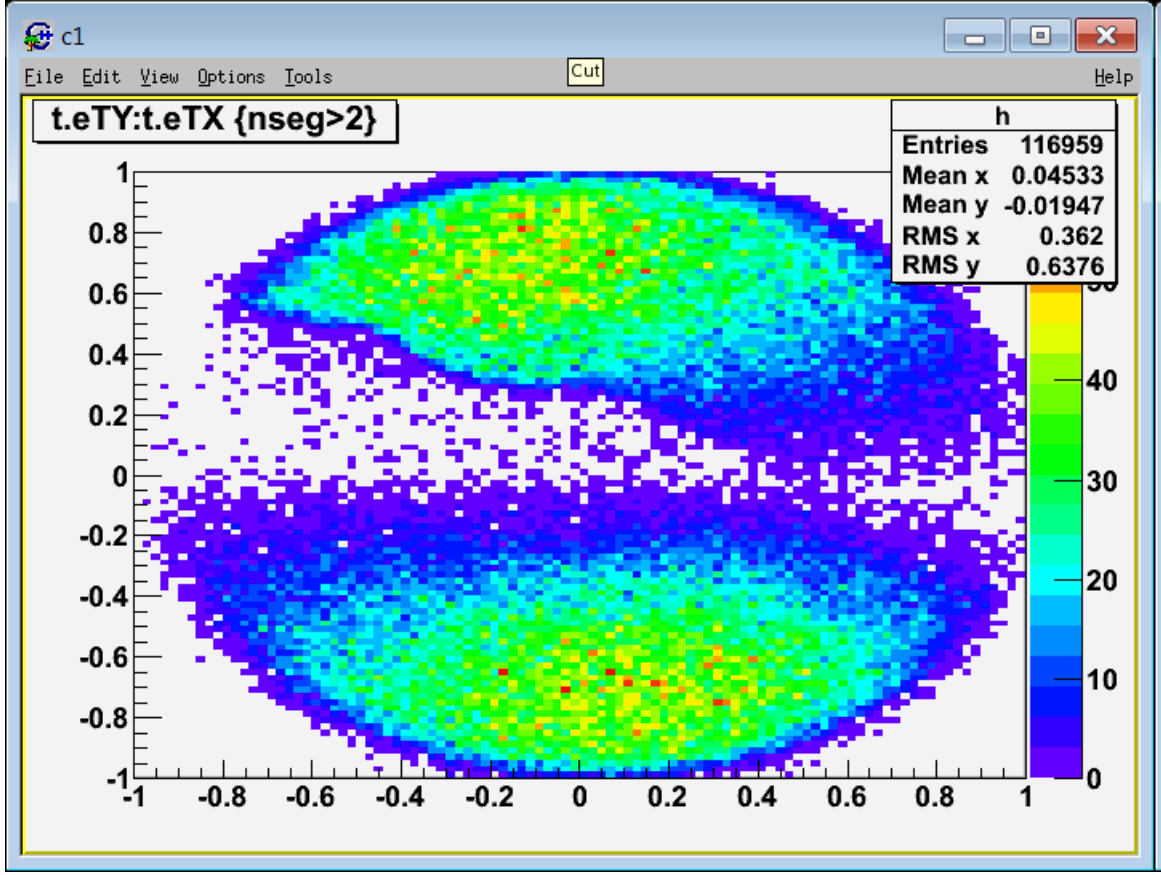


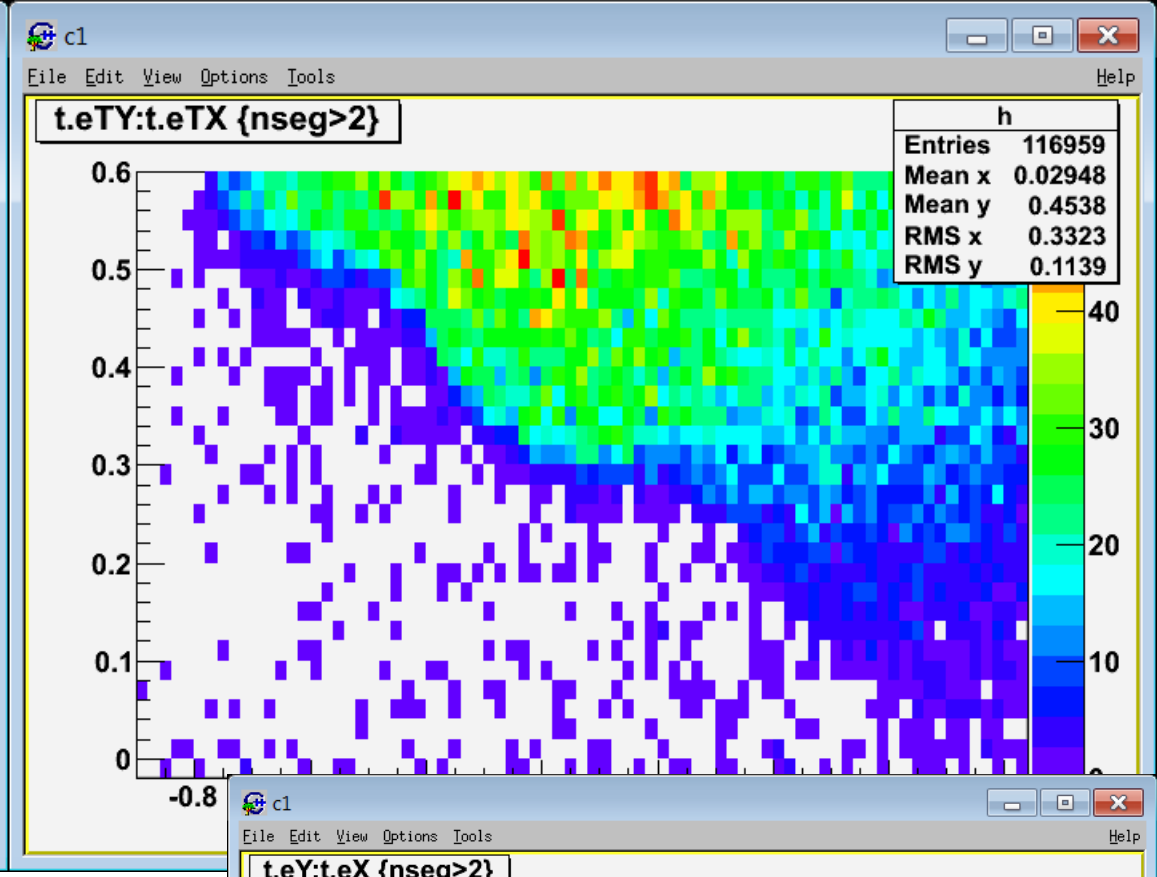
Two sensors were installed for temperature and humidity control

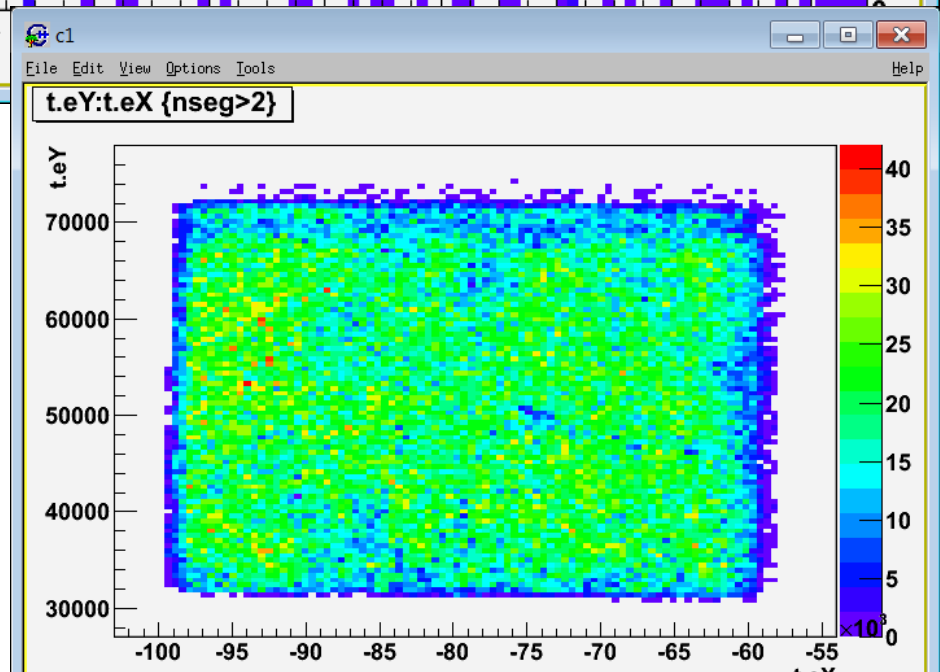
Sensor outside modules was affected by sharp temperature and humidity variations

Sensor inside the module shown smoothed temperature variations and nearly constant humidity

Development at CERN emulsion lab





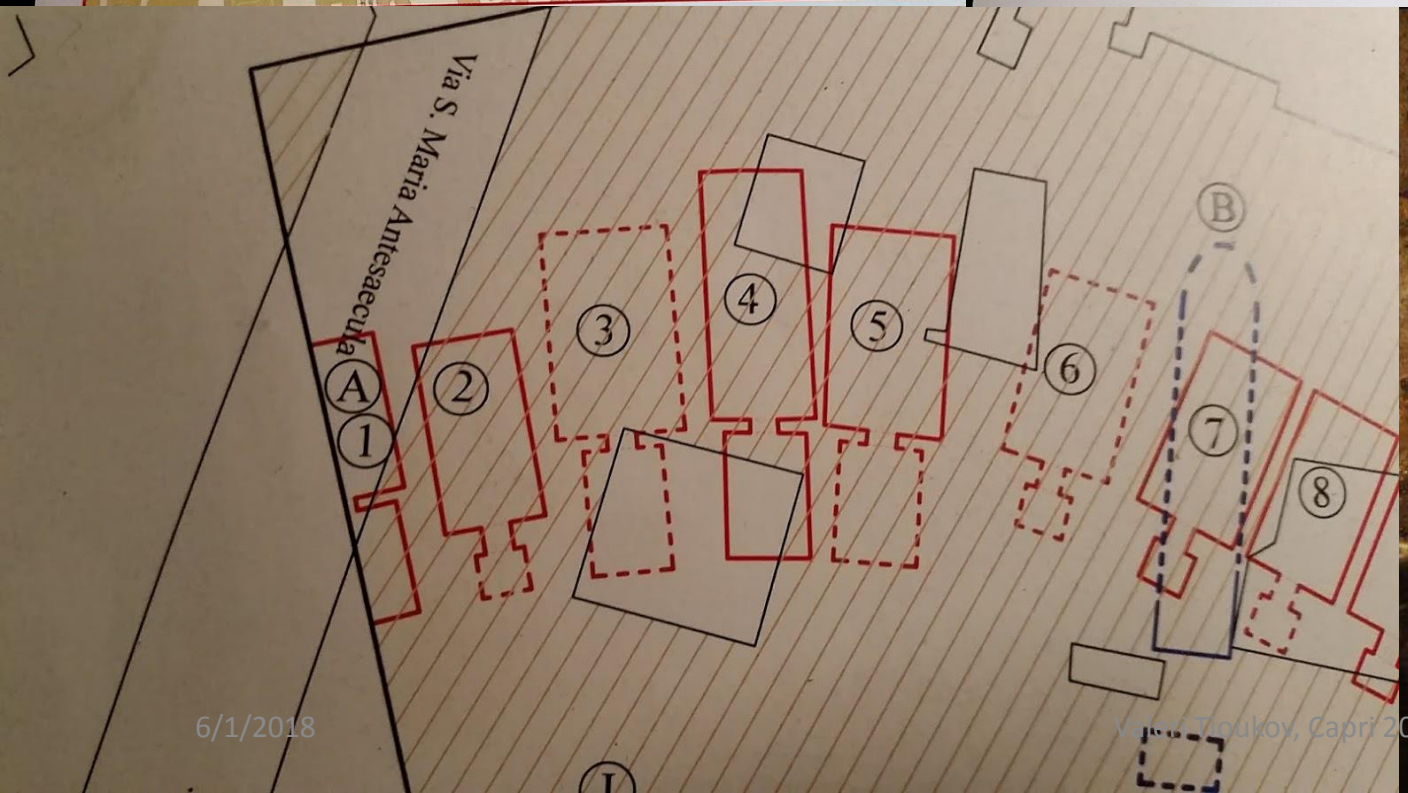


Stromboli2017 scanning ongoing

16x16 cm x10 plates (2.8%) of emulsions scanned
4x4 cm (0.17%) is shown here
Profile is clearly visible


CRISTALLINI
MIRACOLI
VERGINI
STELLA
FONSECA
CELANAPOLI
Via Sanità
Via dei Cristallini
Via Arena Sanità
Via dei Vergini
Via Foria
Via Santa Teresa degli Scalzi
Piazza Cavour
NEAPOLIS


CELANAPOLI
A nord delle poderose *Mura Greche* di piazza Cavour, nel cuore del quartiere Vergini-Sanità, sepolta dalle alluvioni, si estende la straordinaria
NECROPOLI ELLENISTICA DI NEAPOLIS
I monumenti, intagliati nel banco tufaceo, caratterizzati da raffinati prospetti, richiamano potentemente architetture macedoni. Gli ipogei funerari testimoniano il prestigio delle famiglie aristocratiche di IV sec. a.C., costituendo una sottolineatura autorevole dell'identità greca nella quale si riconosce Napoli


Via S. Maria Antesaecula
A
B
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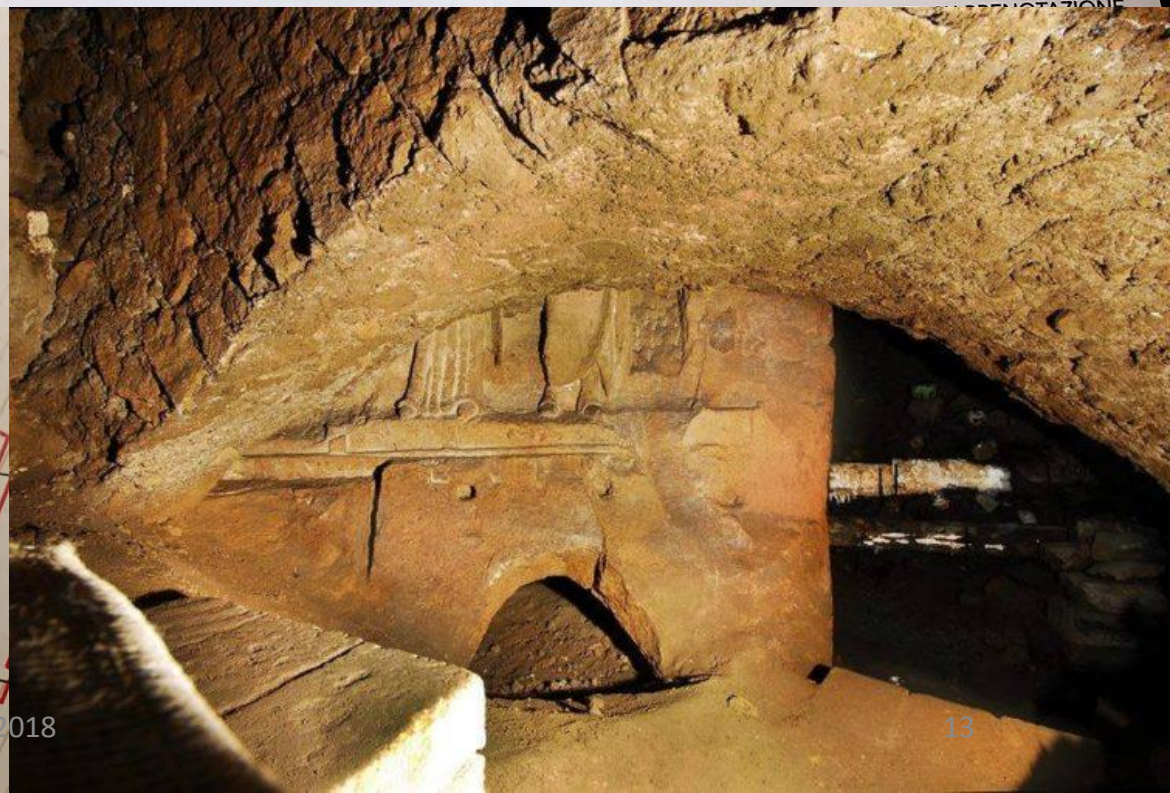
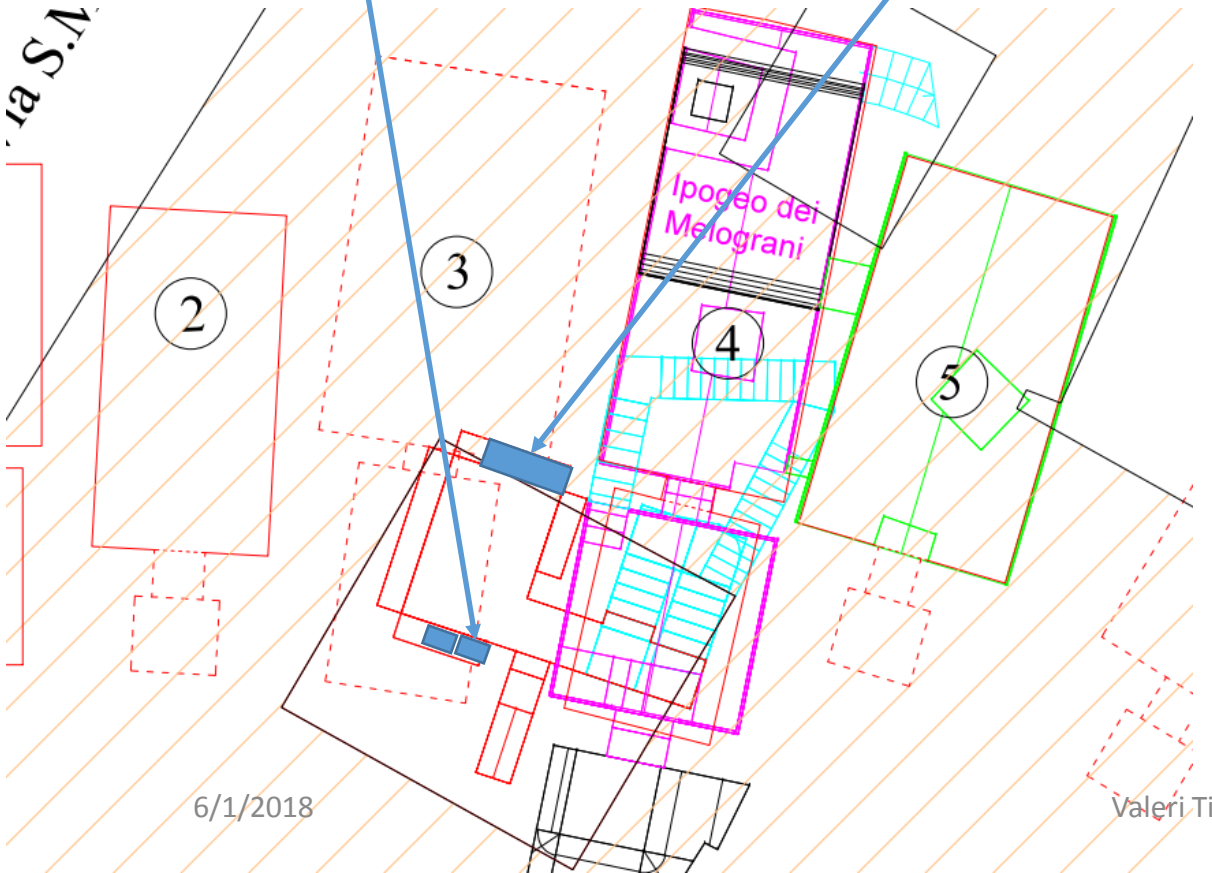


Two detectors, distanced 3 m were installed at 17 m underground.
The total active area: 4x0.3x0.25 = 0.3 m^2



Vesuvius a dangerous (& difficult) volcano

One cannot underestimate the disaster potential of this volcano.

Vesuvius has erupted many times since and is the only volcano on the European mainland to have erupted within the last hundred years. Today, it is regarded as one of the most dangerous volcanoes in the world because of the population of 3,000,000 people living nearby and its tendency towards violent, explosive eruptions of the Plinian type, making it the most densely populated volcanic region in the world.

The specific areas actually affected by the ash cloud will depend upon the particular circumstances surrounding the eruption.

The plan assumes between two weeks and 20 days' notice of an eruption and foresees the emergency evacuation of 600,000 people, almost entirely comprising all those living in the *zona rossa* ("red zone"), i.e. at greatest risk from pyroclastic flows.

Problem of false alarms. In 1984, 40,000 people were evacuated from the Campi Flegrei area, another volcanic complex near Naples, but no eruption occurred.

Slides – courtesy of Raffaello D'Alessandro

The MURAVES/MIVAS project: a muographers view of Vesuvius

MUon RAdiography of VESuvius: MIUR PREMIALE

INGV-Osservatorio Vesuviano ed INFN (Napoli e Firenze)

In collaboration with the: Ente Parco Nazionale del Vesuvio

3 muon trackers with 4 X-Y planes of 1m^2
35 tons of lead for shielding (thanks to OPERA and LNGS)
Gravimetric and geo-electric measurements

Semi-permanent observatory

Goals:

Gran Cono muographic image. Integration with gravimetric and geo-electric measurements

The goal is a better understanding of the structure of Vesuvius, in particular the bottom of the crater.

It does NOT provide useful information for the prediction of an evenutal eruption.

But it will provide thickness measurements of the "plug" at the bottom which can be used to model magma flows during an eruption.

Slides – courtesy of Raffaello D'Alessandro

The MURAVES/MIVAS detector planes with absorber.

35 tonnes Pb from the OPERA experiment

Each detector 1m^2 front surface

4 tracker with three planes <-> 3 tracker with four planes

24 m^2 of active surface (X or Y) + 2 spares

48 modules + 4

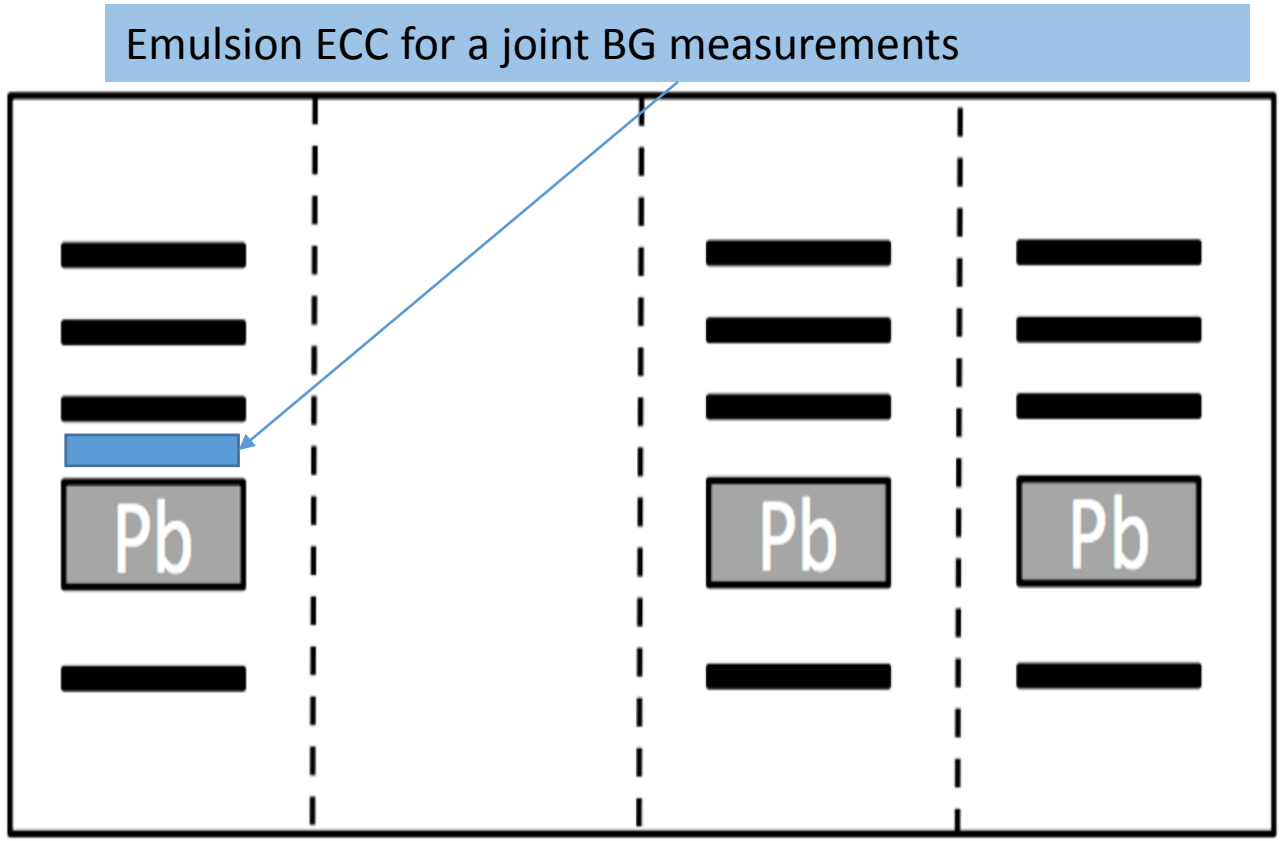
24 Al shells

1643 m of scintillator bars

1800 m of fibres

1536 SiPMs

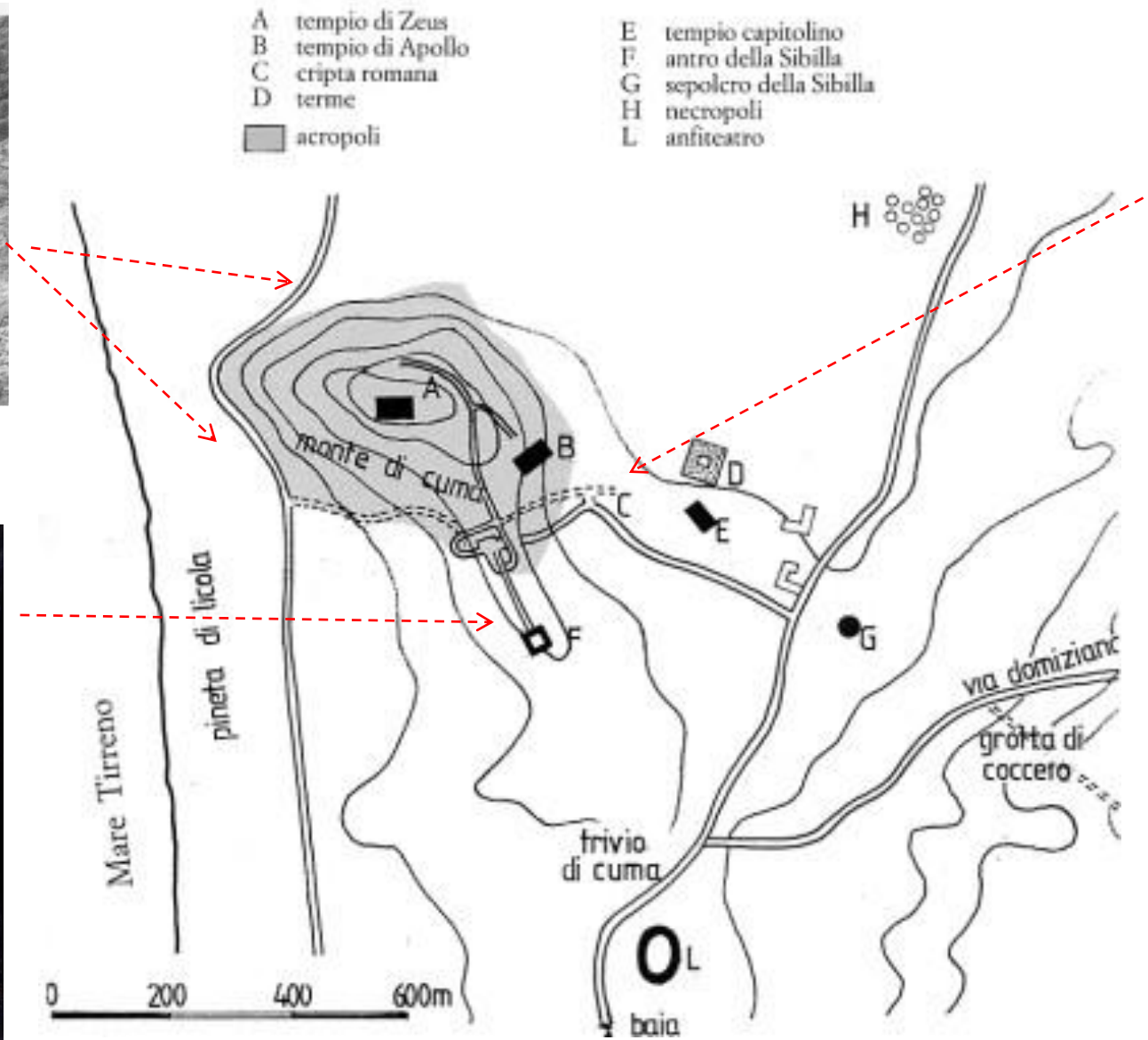
1536 F.E.E. channels



Slides – courtesy of Raffaello D'Alessandro

II W.W. bunkers

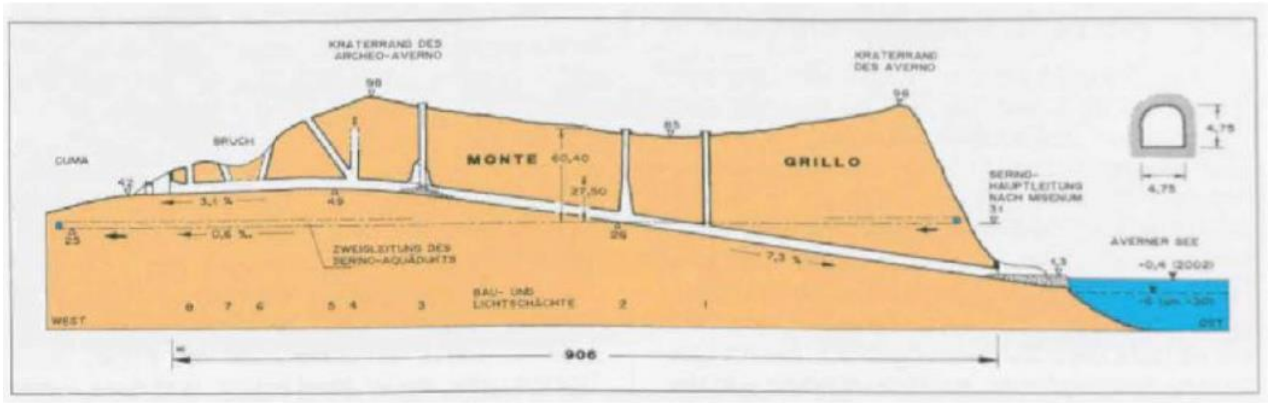
Sibilla Tunnel pre-roman age.



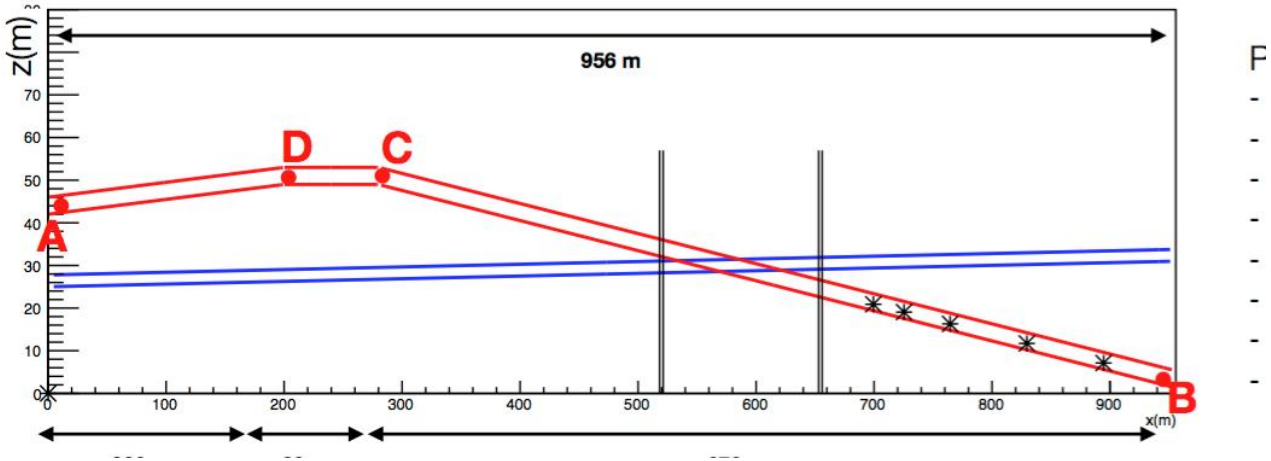
Cripta Romana 37 B.C.

Cocceio Tunnel 37 B.C.

Simulations in the Cocceio tunnel



Grotta di Cocceio e Acquedotto - Schema



The red line is the main gallery

The blue is the roman aqueduct we are looking for

Conclusion

- Muography is a promising technique in active development in Italy
- Emulsions fits very well for this purpose for it’s precision and simplicity of installation
- Volcanoes and Archeology are main items for Muography in Italy now
  - Very interesting and appealing targets: Stromboli, Vesuvio, Napoli underground, Campi Flegrei
- Italian emulsion groups in collaboration with Japanese (Tokyo and Nagoya) and Russian groups are strongly involved in this activity