Muography of Underground Cavities: observations at Mt. Echia (Naples, ITA)
The TECH DISTRICT STRESS

The Technological district STRESS is a mixed partnership of both public institutions and private companies, devoted to the sustainable buildings.

TECNO IN is a joint-stock company specialized on geological survey for the METROPOLIS Project.
The MURAVES DETECTOR PROTOTYPE

- Made of plastic scintillators
- Three X-Y planes tracker
- 1 m² sensitive surface
- Three detectors are under construction for the MURAVES experiment at Vesuvius.

- 2 mm X and Y resolution
- 0.25 m distance between planes
- 8 mrad angular resolution
- 63° angular acceptance
The Mount Echia is a little hill located in the city of Naples. The height at the top is about 70 m a.s.l. Over the centuries a complex system of galleries and conducts has been excavated inside.
GALLERIA BORBONICA

• 1853 Ferdinand II of the Bourbon House - King of the Two Sicilies.
• Restored in recent times and inserted in one of the archaeological underground itineraries.
• Large number of underground structures have been rediscovered.
• The exploration is continuing.
SITES of OBSERVATION

- Pool site
- Tank site
MUOGRAPHY at the POOL SITE

Acceptance cone of the detector

Detector
MUOGRAPHY at the TANK SITE

Acceptance cone of the detector

Detector
Starting from the CAD model we simulated the whole structure of empty spaces finding a good matching between the model and what we have measured.

Known cavity corresponding to the white line on muography.
We simulated all known empty spaces. The scope is to cover the green regions of the muography and all green that rests uncovered should be something unknown.

The regions U1 and U2 aren’t in the CAD model, so they are to be investigated.

We first check for any muographic correspondence at the tank site.
CORRESPONDING SIGNALS

MUOGRAPHY POOL SITE

MUOGRAPHY TANK SITE

\( \alpha (\degree) \)

\( \phi (\degree) \)

U1

U2

R

R

Scale: 1.0 - 2.4

Colorbar:

2.4

2.2

2.0

1.8

1.6

1.4

1.2

1.0

0.8

0.6

0.4

0.2

0.0
A correspondance in the regions U1 and U2 in both muographies, implies the existence of two large empty spaces, plausible just below the top of the hill.

According to experts, chambers like this (extension and position) can not be there and they haven’t any proof of their presence. The urban condition of this zone of the city is well known.
The new hypothesis is the presence of an hidden empty space in the middle and in the acceptance of both point of view.

A "tomosynthesis" of the middle region provided a candidate. By slicing the foreseen chamber at different height, we were able to shape it inside the CAD model.
MODELLING the HIDDEN CHAMBER

Once modelled the so-called hidden chamber, we made a countercheck by simulating its volume.

For what concerns the muographic records, such a cavity foresees the presence of two other empty structures (nU1 and nU2 in the next slide).
SIMULATING the HIDDEN CHAMBER
CONCLUSIONS

In 2016 we started a research program about muography applications in geological survey of cavities.

A sample of $14 \times 10^6$ trigger has been acquired under Mt. Echia at the pool site.

A second muon sample of $7.2 \times 10^6$ trigger was acquired at the tank site.

Known empty structures are now simulated with our software and the agreement with the muography is very high.

Presence of an hidden chamber is under investigation (Observation with a compact MIMA detector in a third site).

Muography from a third site will be available soon.

The cylindrical detector, designed for borehole, is under test.
SPARE SLIDES
VIEW FROM THE POOL SITE
VIEW FROM THE TANK SITE
• R is used to normalize the transmission to the rock thickness
• Zones where R has a minimum are defined Control zones
• A plot of R is obtained in function of the density
• $\rho_{\text{best}}$ is the value of the density corresponding to R=1

(pool) $\rho_{\text{best}} = 1.71 \pm 0.01\,\text{g/cm}^3$
(tank) $\rho_{\text{best}} = 1.74 \pm 0.01\,\text{g/cm}^3$
ADAMO EXPERIMENT energy range between 100 MeV and 130 GeV, zenith between 0° and 80°

Density map related to the rock thickness (top picture). In the black square the measured density is 1.4 g/cm³.
Dal CAD si determinano le posizioni nello spazio del bordo della camera. I punti sono proiettati nella MUOGRAFIA. Ottimo accordo tra il contorno della camera e l’immagine muografica.
TIME RESOLUTION

1 h

3 h

5 h
• EASIROC (Extended Analogue SiPM Integrated Read Out Chip)

• Le Funzioni digitali sono svolte dal FPGA

• Ogni canale è dotato di un contatore a 32 bit

• I regolatori switching forniscono le tensioni richieste dal circuito di espansione del tempo per la misura del tempo di volo

• Un circuito di alimentazione con regolatori lineari fornisce lo high voltage per i SiPM ed alimenta la scheda
L’ASIC EASIROC

- Campionamento del segnale prelevato ai terminali dei SiPM con circuito Sample and Hold
- 32 output digitali che per lo stato di triggers di singolo canale ed OR32 output digitale
- Low and high gain output
IL SISTEMA DI ACQUISIZIONE

- Protocollo a basso livello per la gestione del Sistema di acquisizione
- La trasmissione dati avviene a 20 MHz
L’ELETTRONICA DI FRONT-END

- Elettronica di Front-End a basso consumo
- Le schede Slave sono configurate e lette attraverso la scheda masterPi
- La scheda masterPi controlla 16 schede
- La scheda masterPi è equipaggiata con un Raspberry Pi con cui comunica attraverso la GPIO. I dati RAW sono trasferiti dalle schede Slave al RPi attraverso la scheda Master
- Le condizioni ambientali sono costantemente monitorate con dei termo-igrometri letti da muNet
Detector MURAY (2013) – installazione al Puy de Dome (Fr)
TEST EFFETTUATO AL VESUVIO
MISURA EFFETTUATA AL PUY DE DOME

Puy de Dome
Collaborazione MuRay - Tomuvol a Clermont-Ferrand (Fr)
Da Giugno a Dicembre 2013