DR. CIMMINO, L.
UNIVERSITY OF NAPLES FEDERICO II AND INFN
OCTOBER 2, 2017 – TOKYO, JAPAN

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.

stress

Project

METROPOLIS

INTEGRATED AND SUSTAINABLE METHODS AND TECHNOLOGIES FOR RESILIENCE AND SAFETY IN URBAN SYSTEMS

URBAN SYSTEM KNOLEDGE

TECNO IN GEOSOLUTIONS

INFN Istituto Nazionale di Fisica Nucleare

TECNO IN is a joint-stock company specialized on geological survey

Detector developed for the METROPOLIS Project

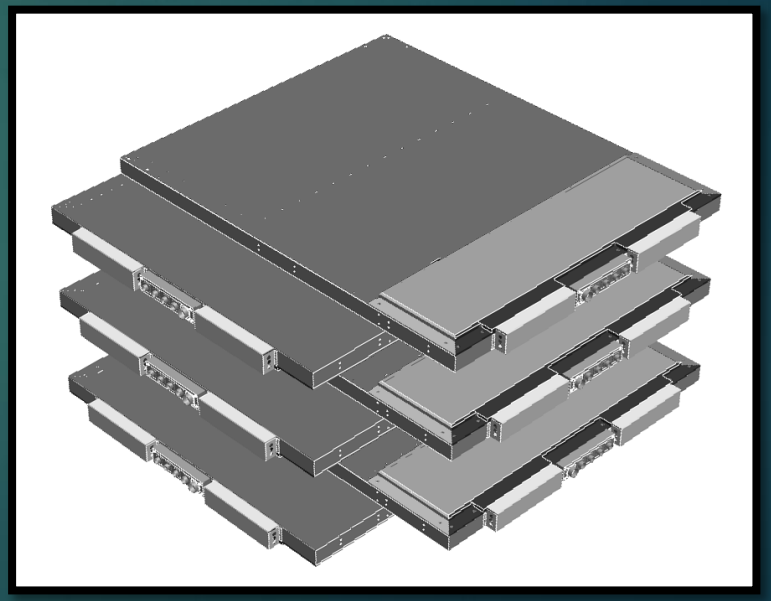
The MURAVES DETECTOR PROTOTYPE

Detector MURAVES at the GBorb.

Detector MURAVES in the lab

- Made of plastic scintillators
- Three X-Y planes tracker
- 1 m^2 sensitive surface
- Three detectors are under construction for the MURAVES experiment at Vesuvius.

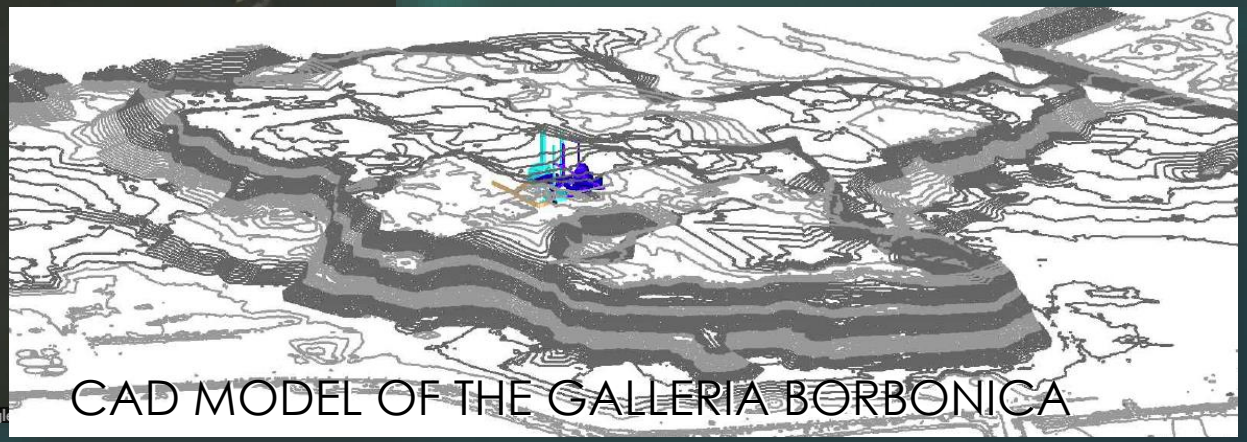
- 2 mm X and Y resolution
- 0.25 m distance between planes
- 8 mrad angular resolution
- 63° angular acceptance



Schematic of the detector MURAVES

Mt. ECHIA

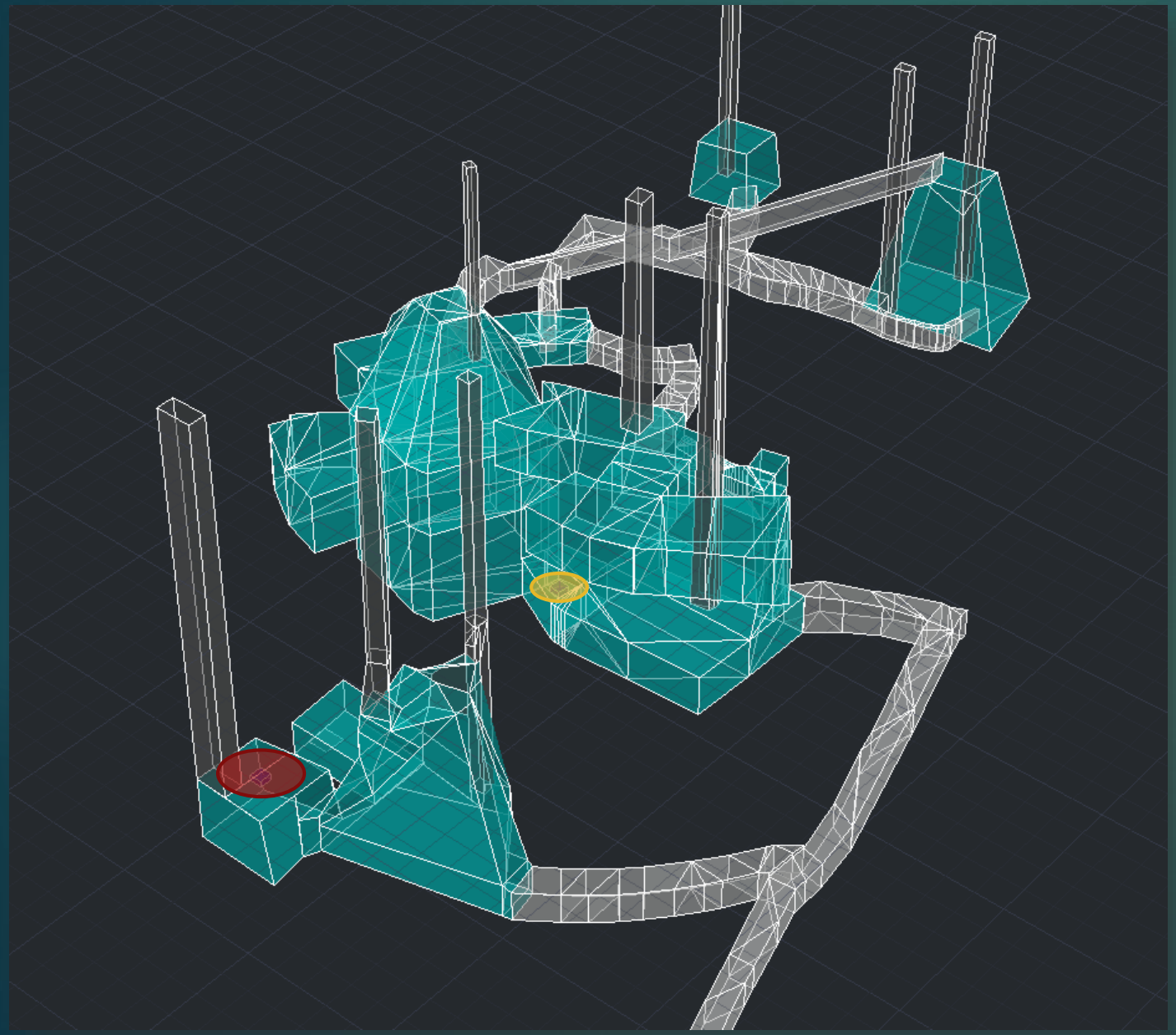
The Mount Echia is a little hill located in the city of Naples. The height at the top is about 70 m a.s.l. Over the centuries a complex system of galleries and conducts has been excavated inside.

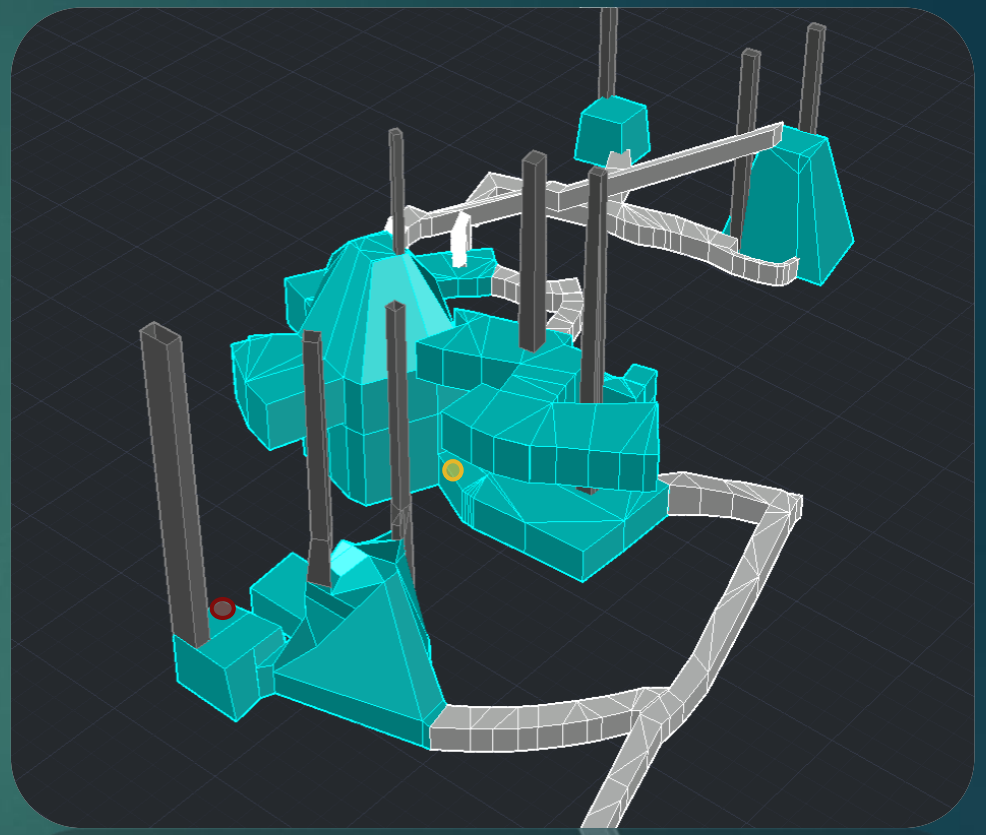


GALLERIA BORBONICA

- 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.

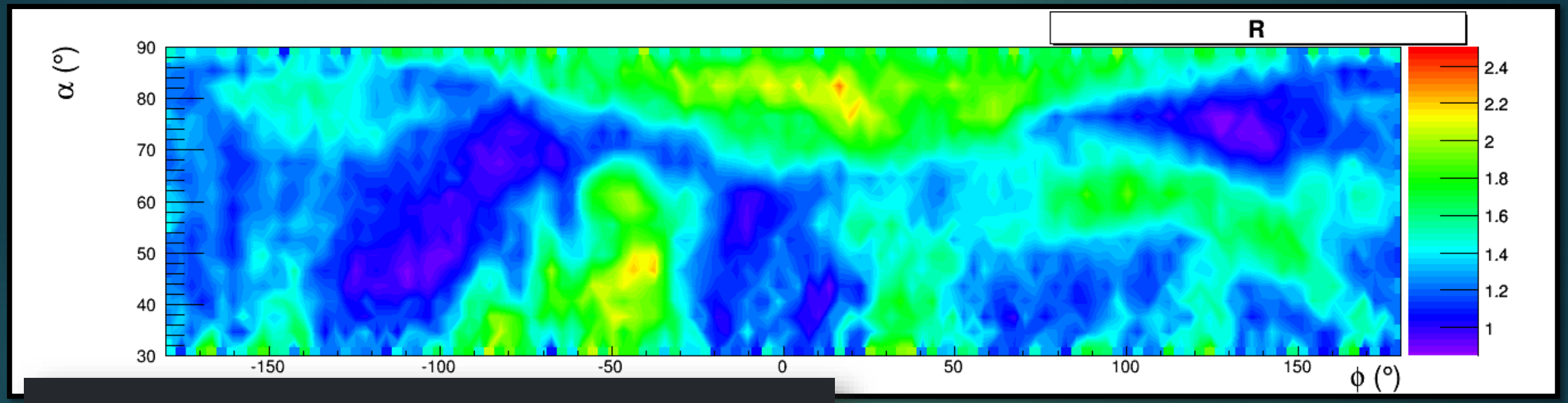
SITES of OBSERVATION

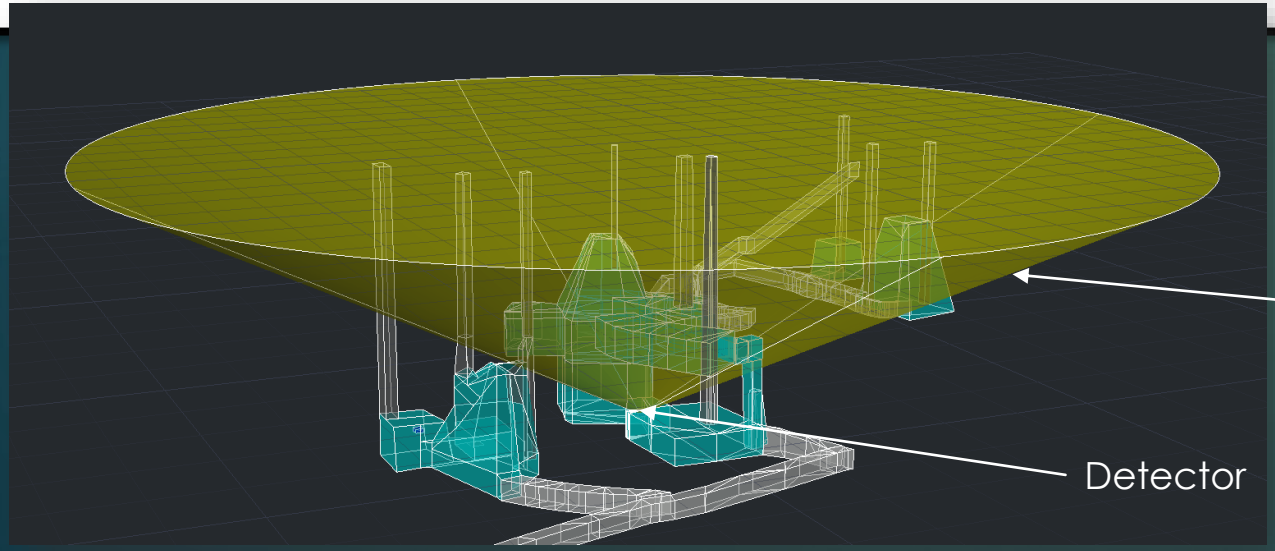




- Pool site
- Tank site

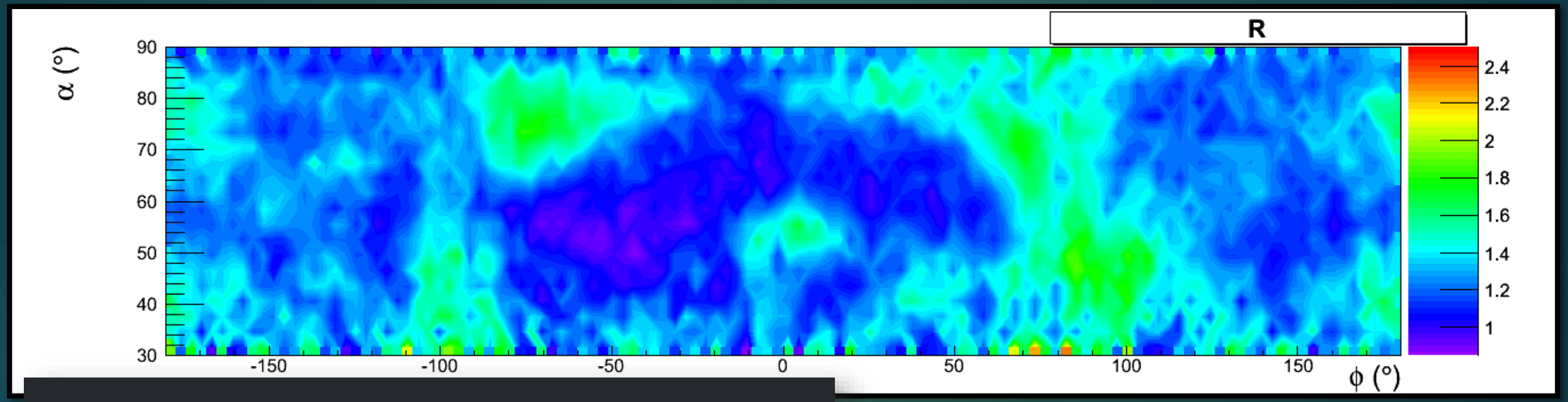
MUOGRAPHY at the POOL SITE

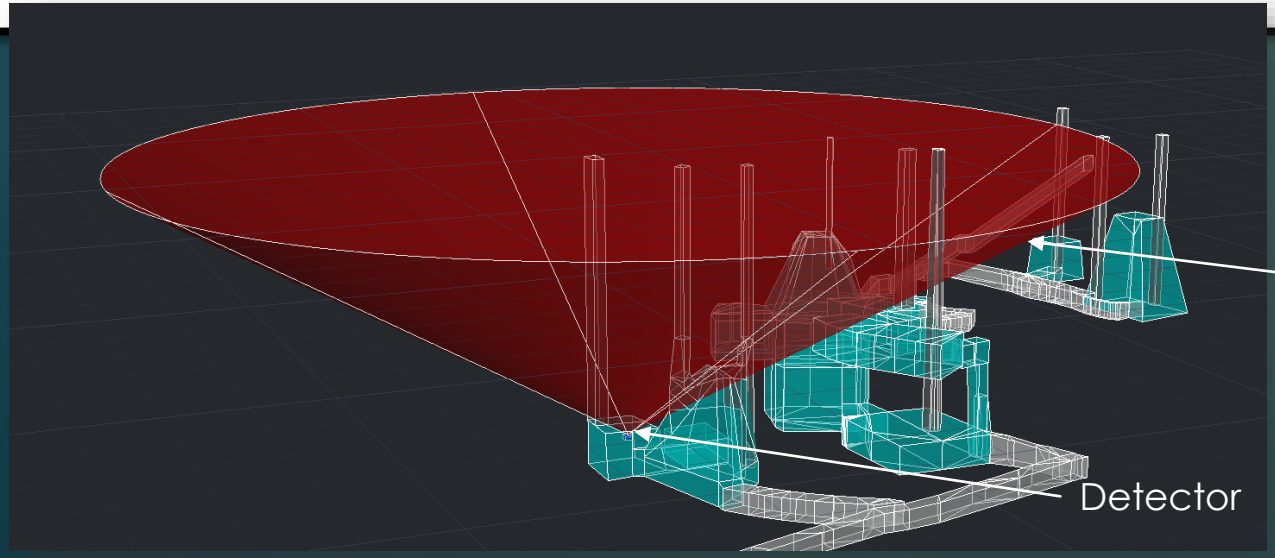




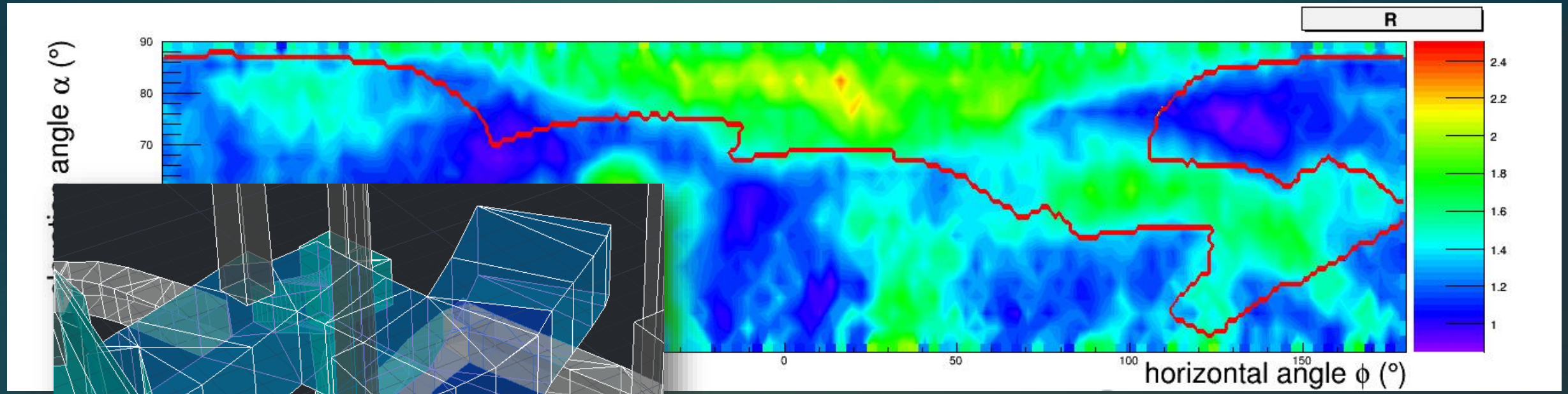
Acceptance cone of the detector

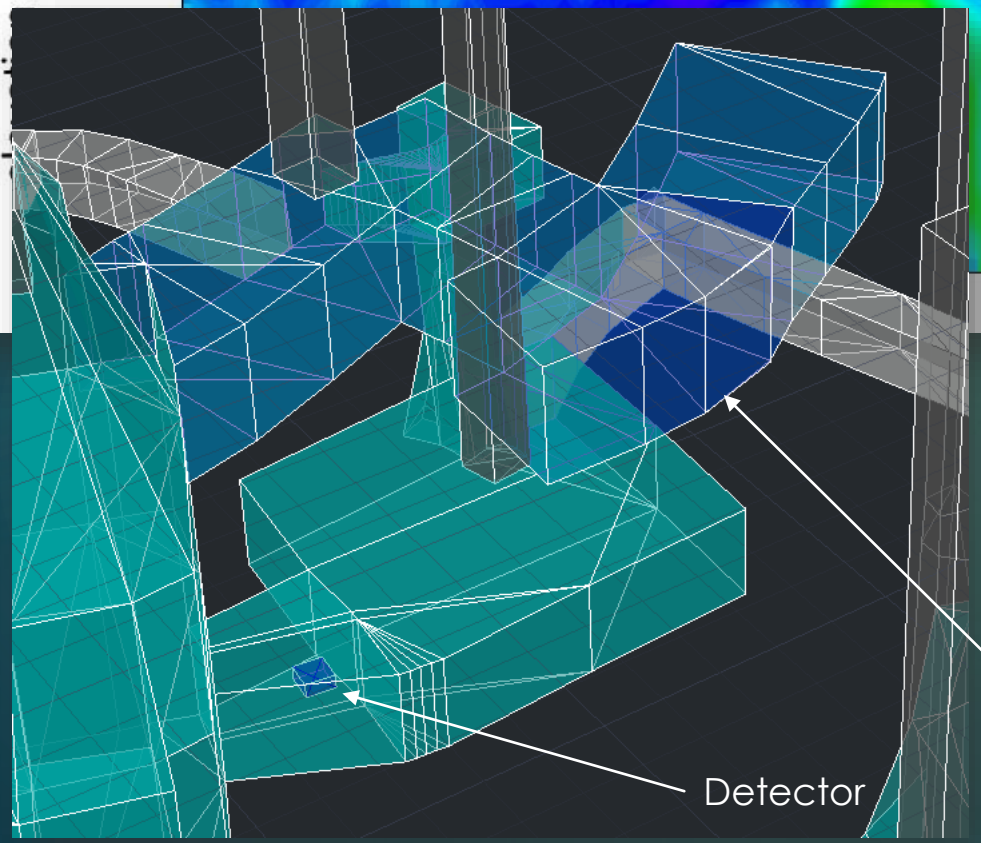
MUOGRAPHY at the TANK SITE





An ANALITIC METHOD

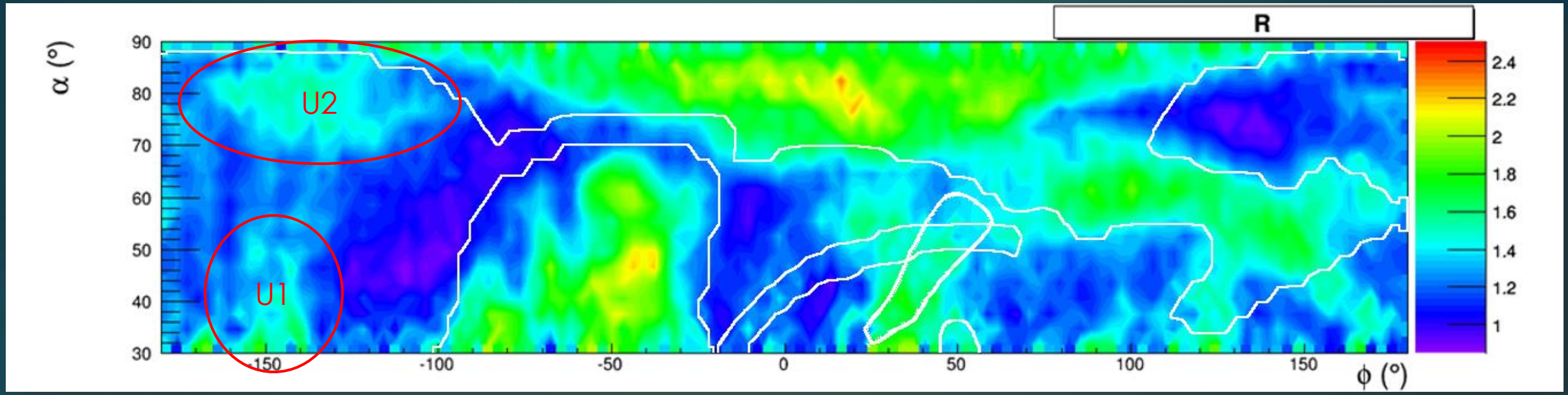




Starting from the CAD model we simulated the whole structure of empty spaces finding a good matching beetwen the model and what we have measured

Known cavity corresponding to the white line on muography

UNKNOWN CAVITIES AT THE POOL SITE

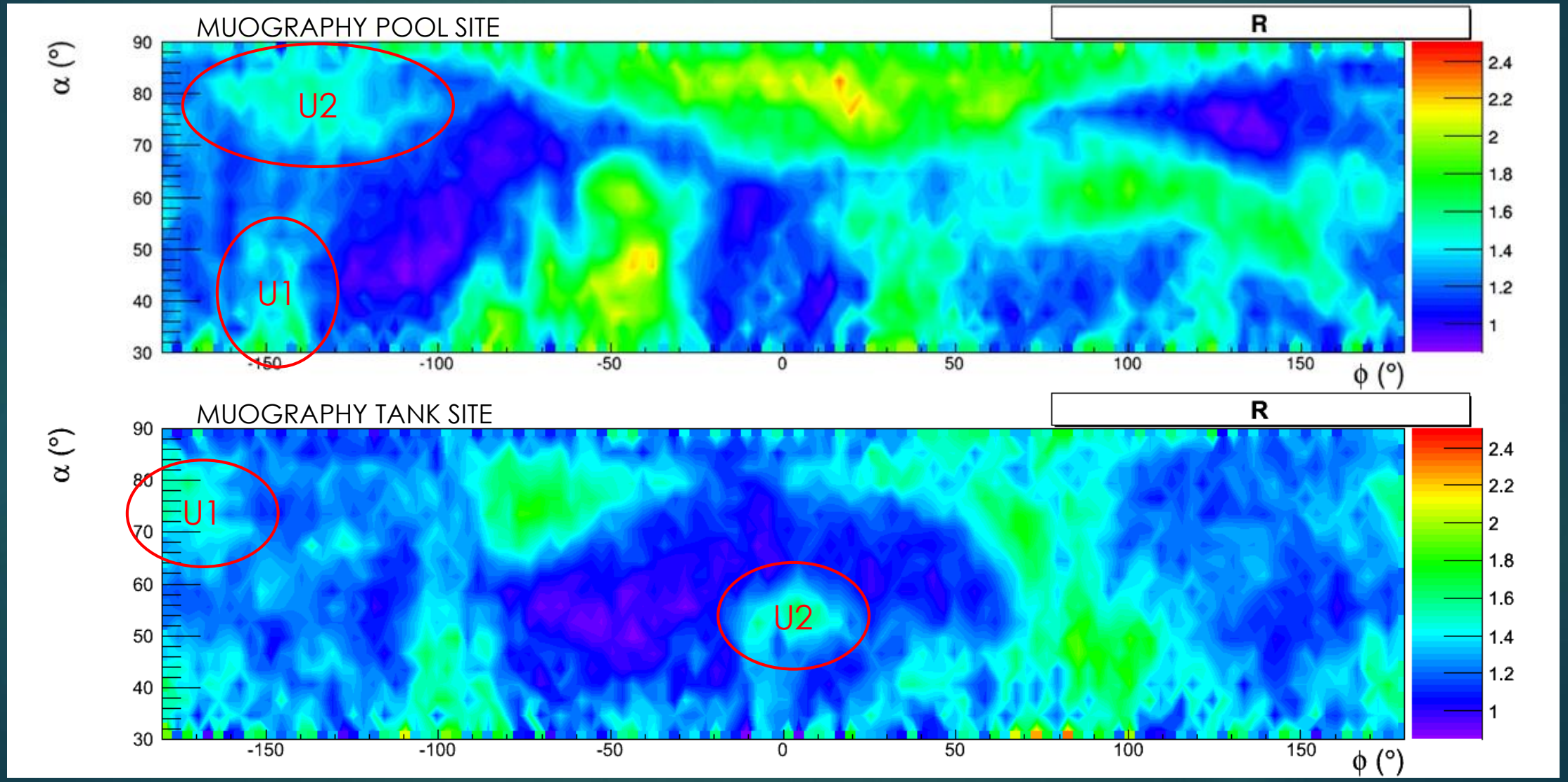


We simulated all known empty spaces. The scope is to cover the green regions of the muography and all green that rests uncovered should be something unknown.

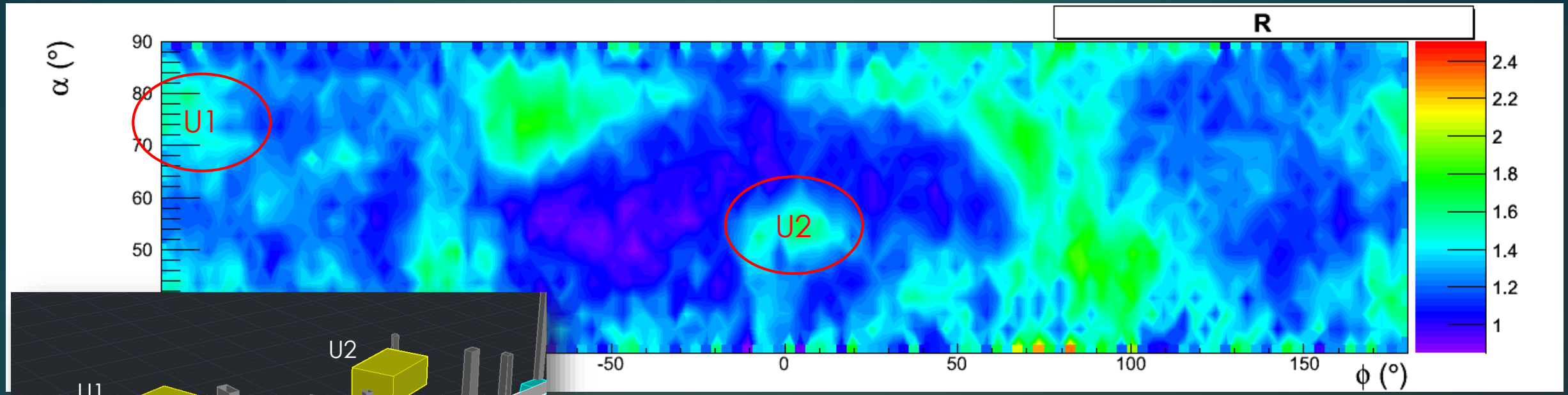
The regions U1 and U2 aren't in the CAD model, so they are to be investigated.

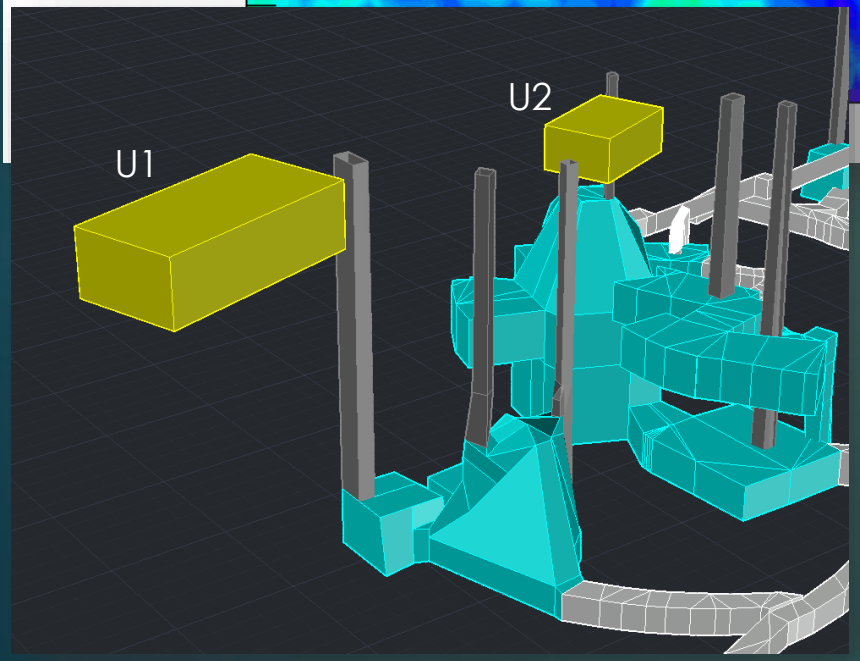
We first check for any muographic correspondence at the tank site.

CORRESPONDING SIGNALS



A FIRST HYPOTHESIS

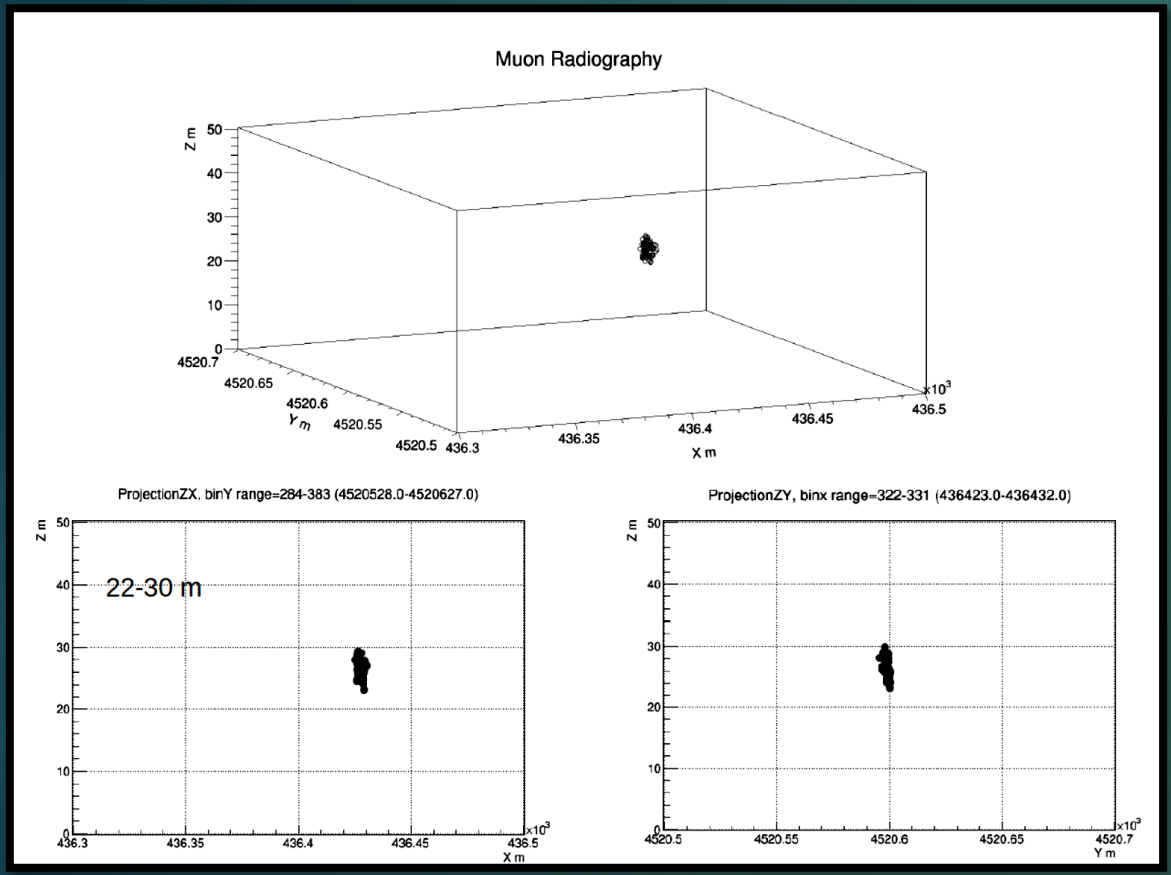


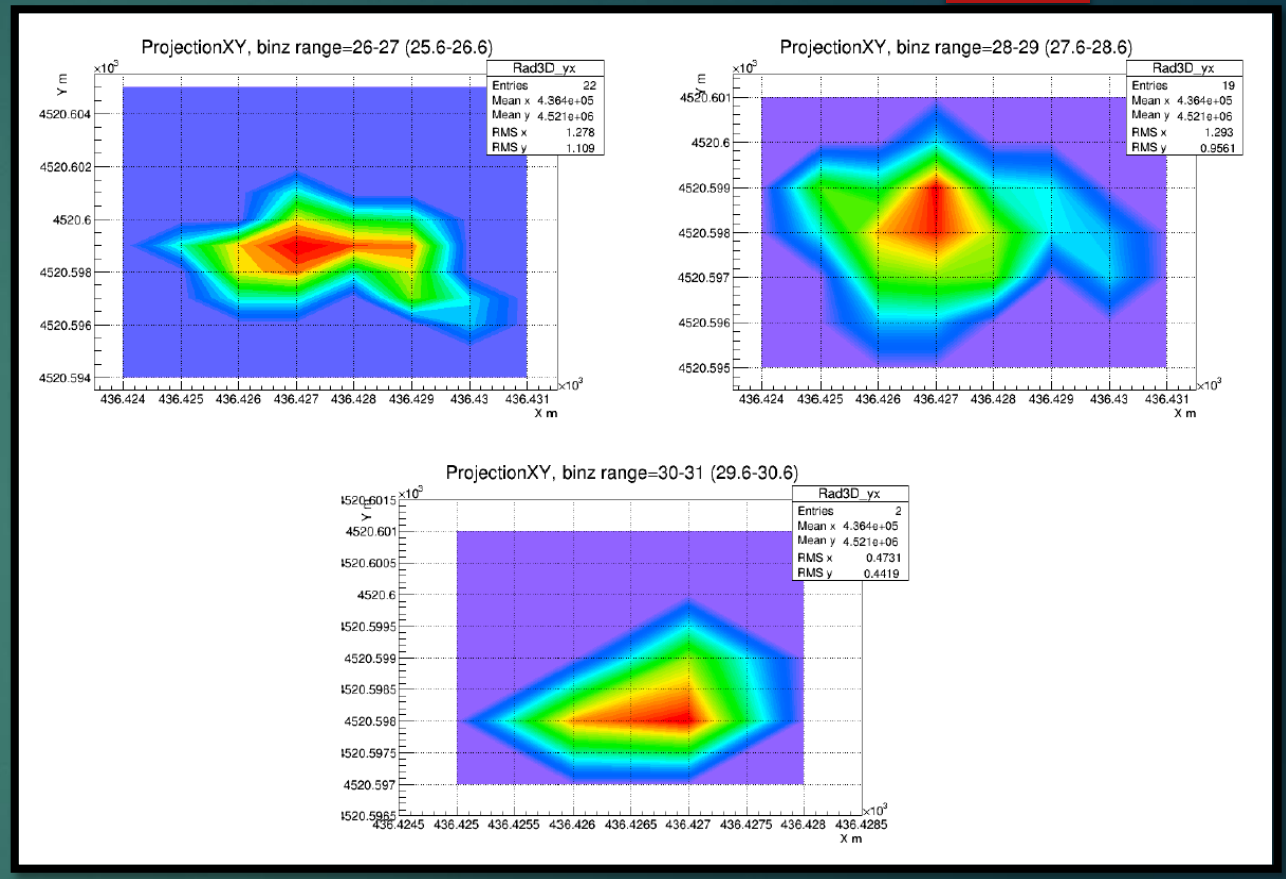


A corresponce in the regions U1 and U2 in both muographies, implies the existence of two large empty spaces, plausible just below the top of the hill.

According to experts, chambers like this (extention 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.

HIDDEN CHAMBER HYPOTHESIS

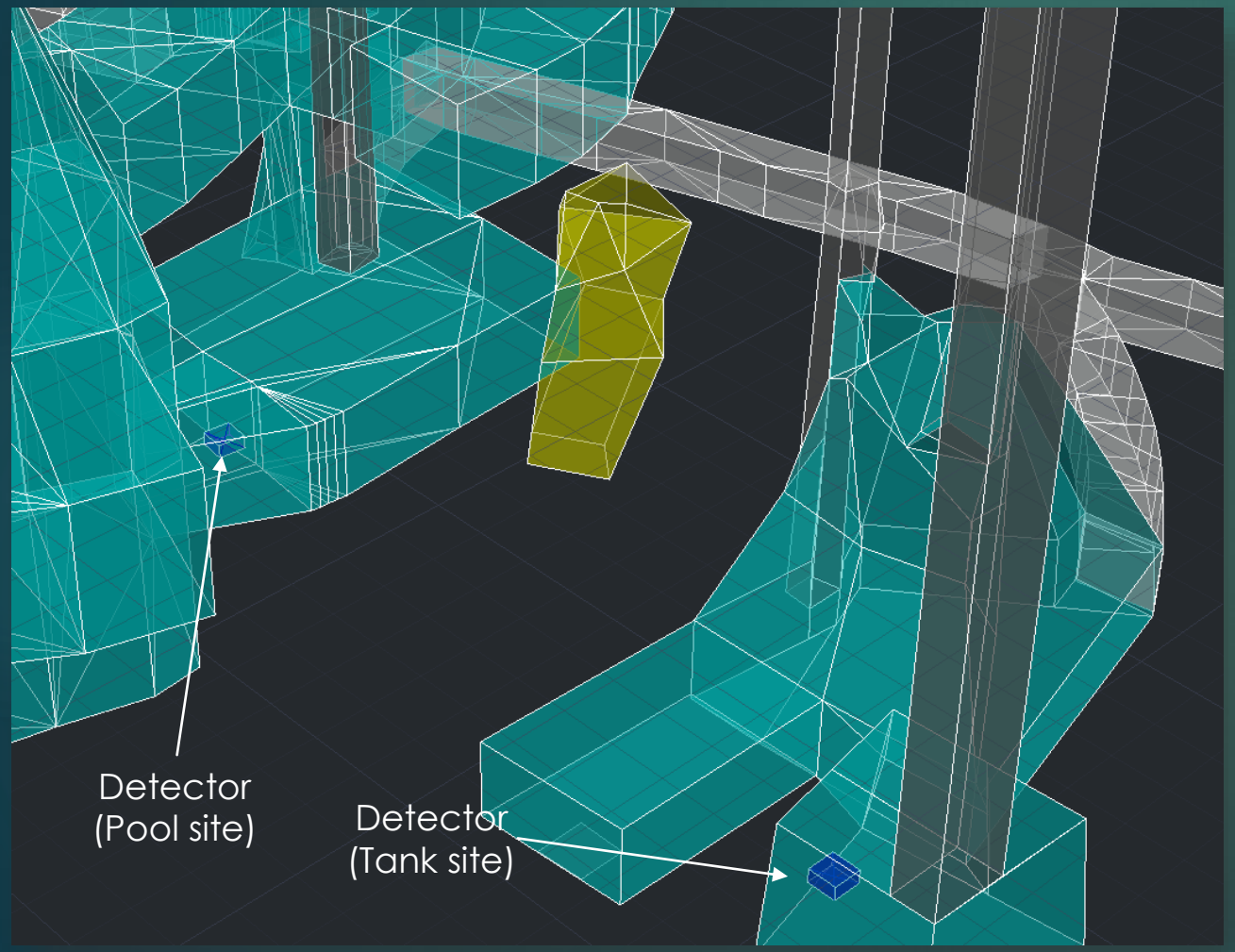




The new hypothesis is the presence of an hidden empty space in the middle and in the acceptance of both point of view.

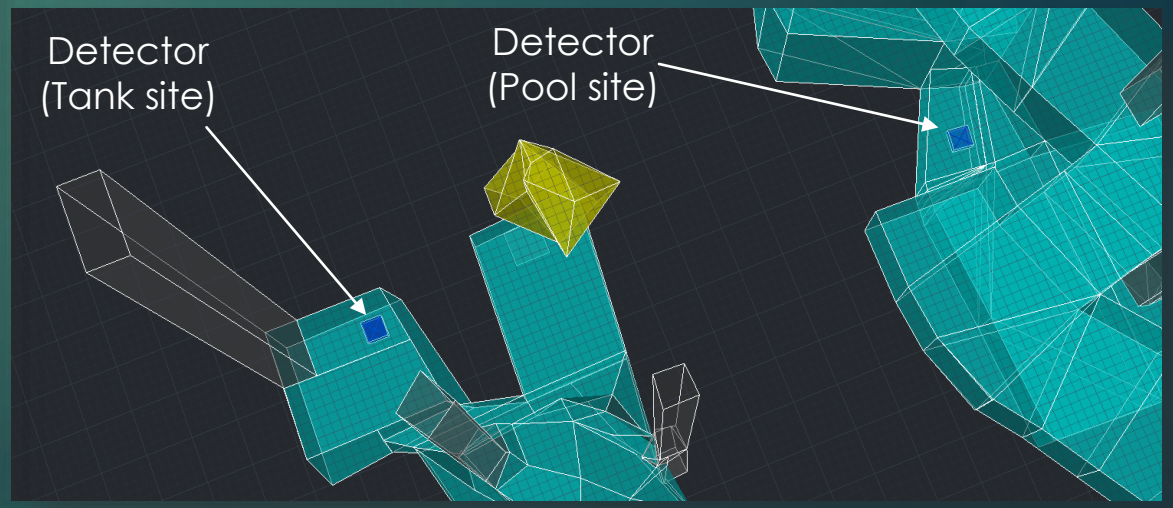
A ''tomosynthesis'' of the middle region provided a candidate. By slicing the foreseen chamber at different height, we were able to shape it inside the CAD model.

MODELLING the HIDDEN CHAMBER

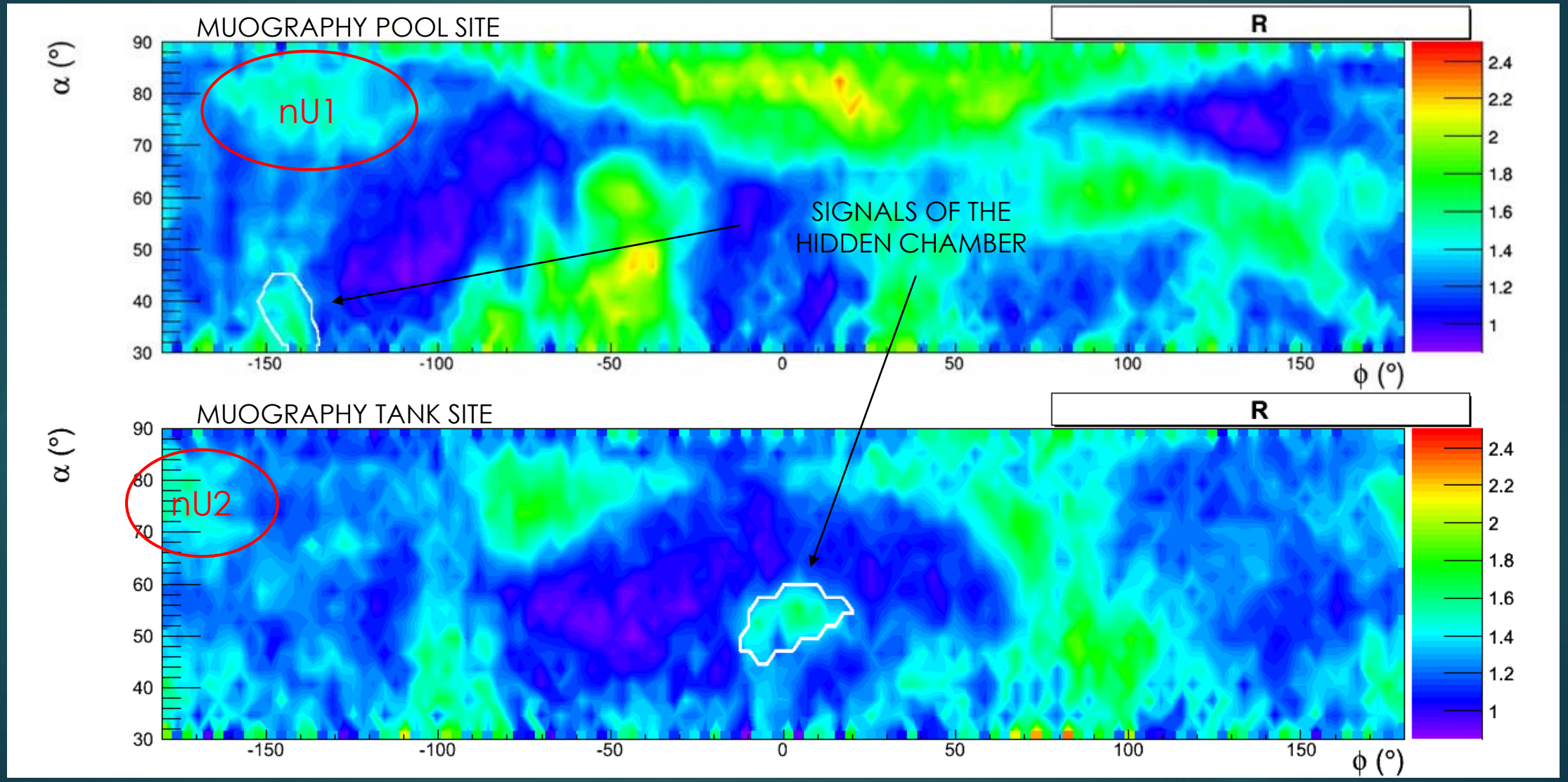


Once modelled the so-called hidden chamber, we made a countercheck by simulating its volume.

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

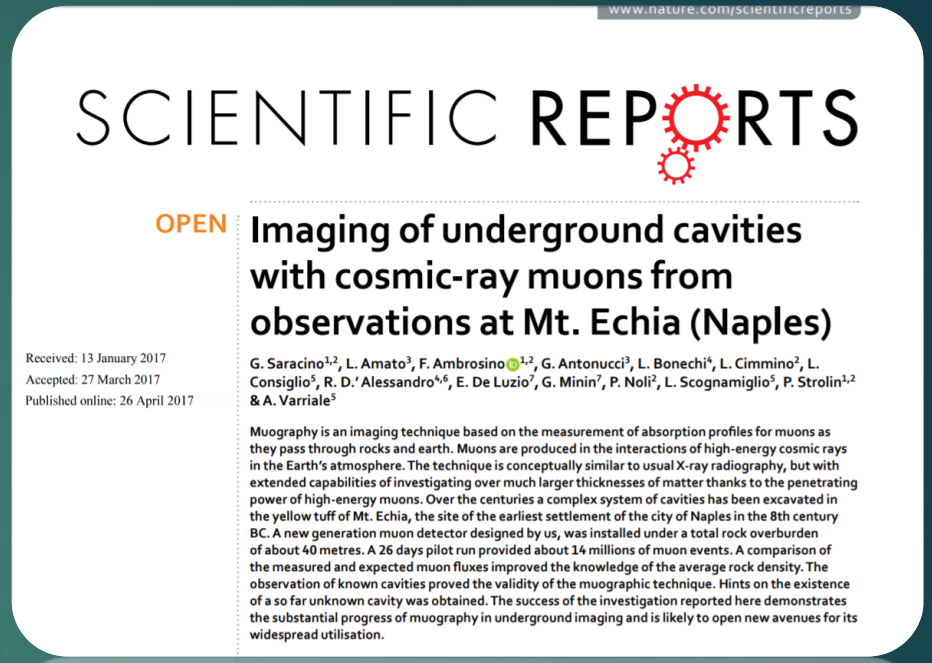


SIMULATING the HIDDEN CHAMBER



CONCLUSIONS

- In 2016 we started a research program about muography applications in geological survey of cavities.
- A sample of 14×10^6 trigger has been acquired under Mt. Echia at the pool site
- A second muon sample of 7.2×10^6 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)



www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Imaging of underground cavities with cosmic-ray muons from observations at Mt. Echia (Naples)

Received: 13 January 2017
Accepted: 27 March 2017
Published online: 26 April 2017

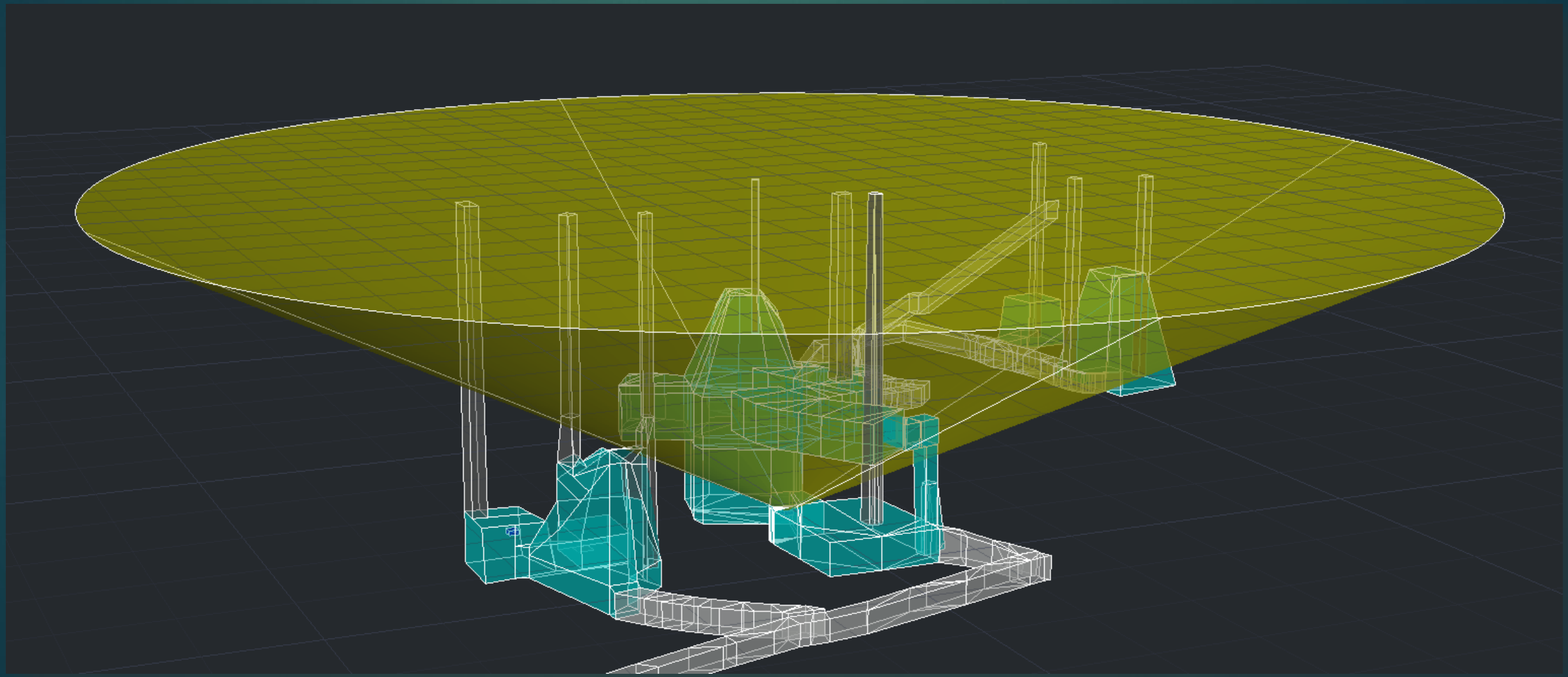
G. Saracino[1,2], L. Amato[3], F. Ambrosino[1,2], G. Antonucci[3], L. Bonechi[4], L. Cimmino[2], L. Consiglio[5], R. D.' Alessandro[4,6], E. De Luzio[7], G. Minin[7], P. Noli[2], L. Scognamiglio[5], P. Strolin[1,2] & A. Varriale[5]

Muography is an imaging technique based on the measurement of absorption profiles for muons as they pass through rocks and earth. Muons are produced in the interactions of high-energy cosmic rays in the Earth's atmosphere. The technique is conceptually similar to usual X-ray radiography, but with extended capabilities of investigating over much larger thicknesses of matter thanks to the penetrating power of high-energy muons. Over the centuries a complex system of cavities has been excavated in the yellow tuff of Mt. Echia, the site of the earliest settlement of the city of Naples in the 8th century BC. A new generation muon detector designed by us, was installed under a total rock overburden of about 40 metres. A 26 days pilot run provided about 14 millions of muon events. A comparison of the measured and expected muon fluxes improved the knowledge of the average rock density. The observation of known cavities proved the validity of the muographic technique. Hints on the existence of a so far unknown cavity was obtained. The success of the investigation reported here demonstrates the substantial progress of muography in underground imaging and is likely to open new avenues for its widespread utilisation.

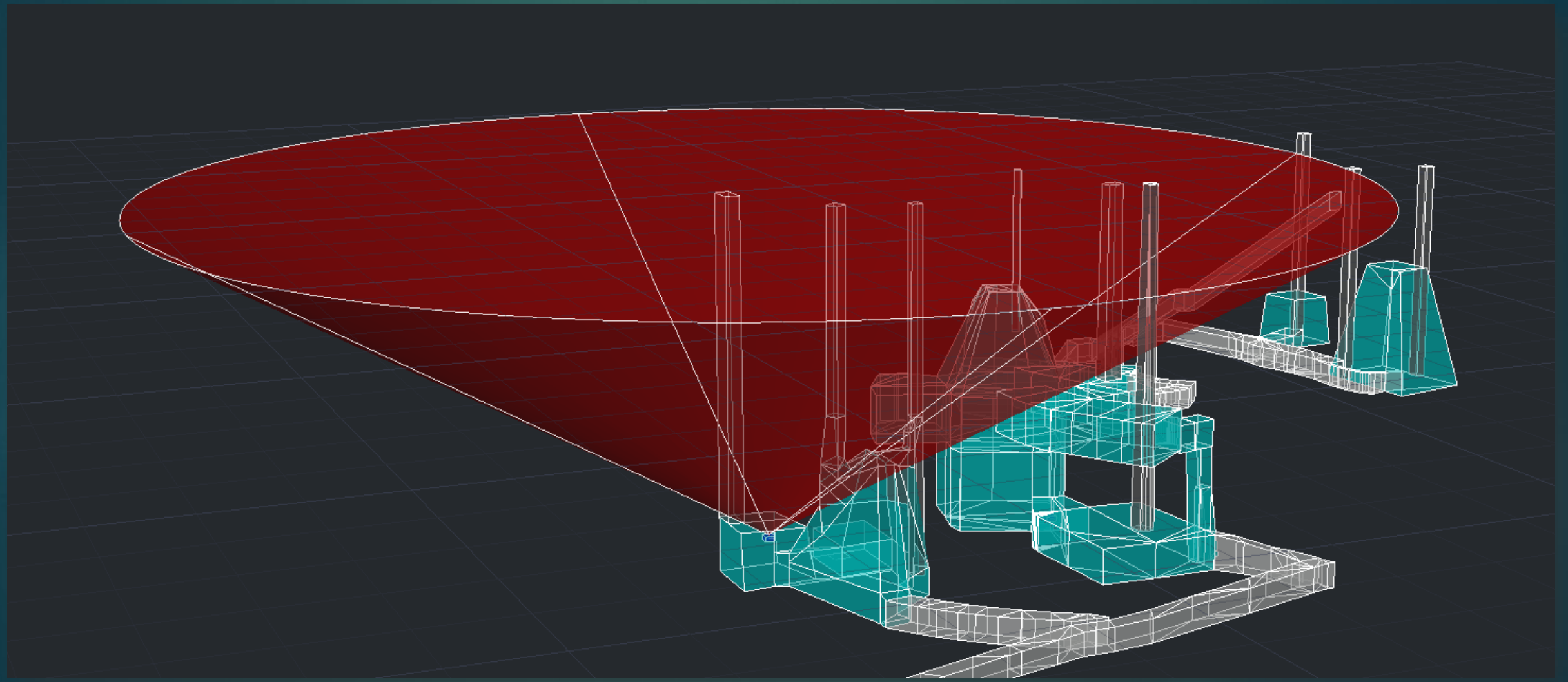
- Muography from a third site will be available soon
- The cylindrical detector, designed for bore-hole, is under test

SPARE SLIDES

VIEW FROM THE POOL SITE

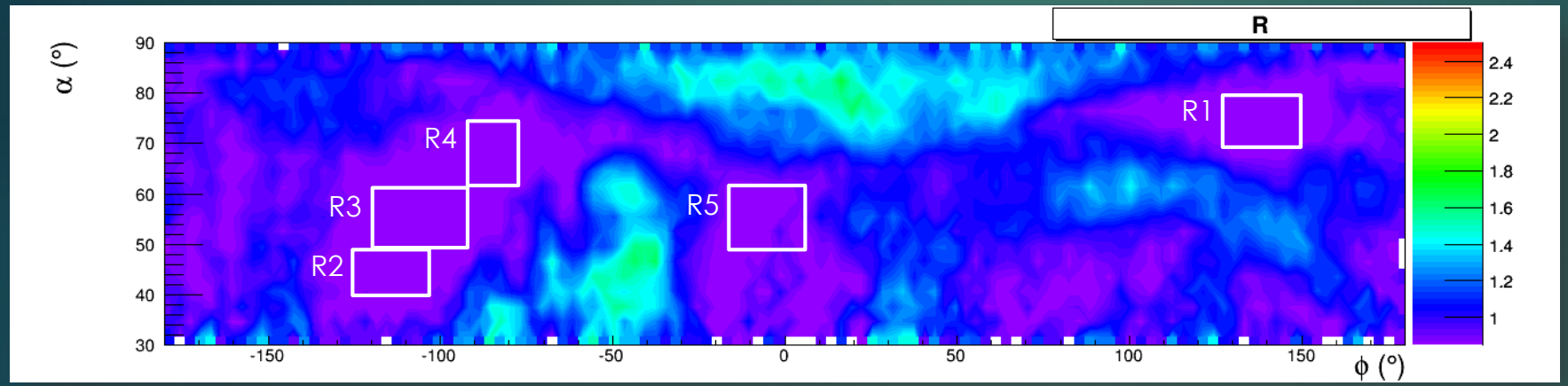


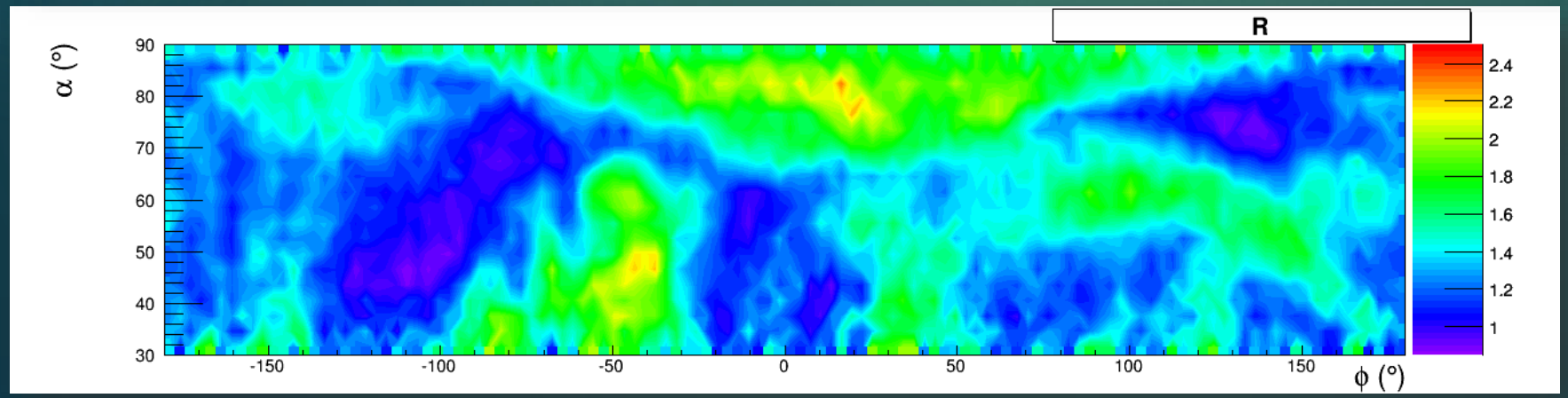
VIEW FROM THE TANK SITE

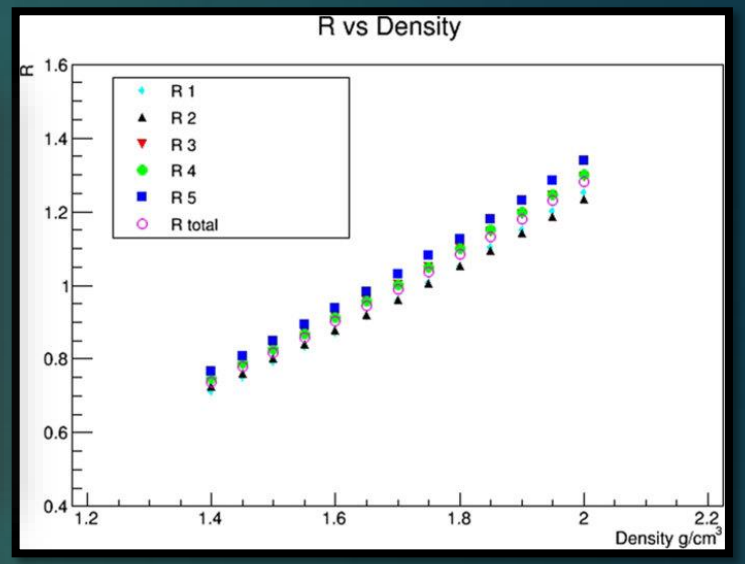


DATA ANALYSIS

- 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
- ρ_{best} is the value of the density corresponding to R=1



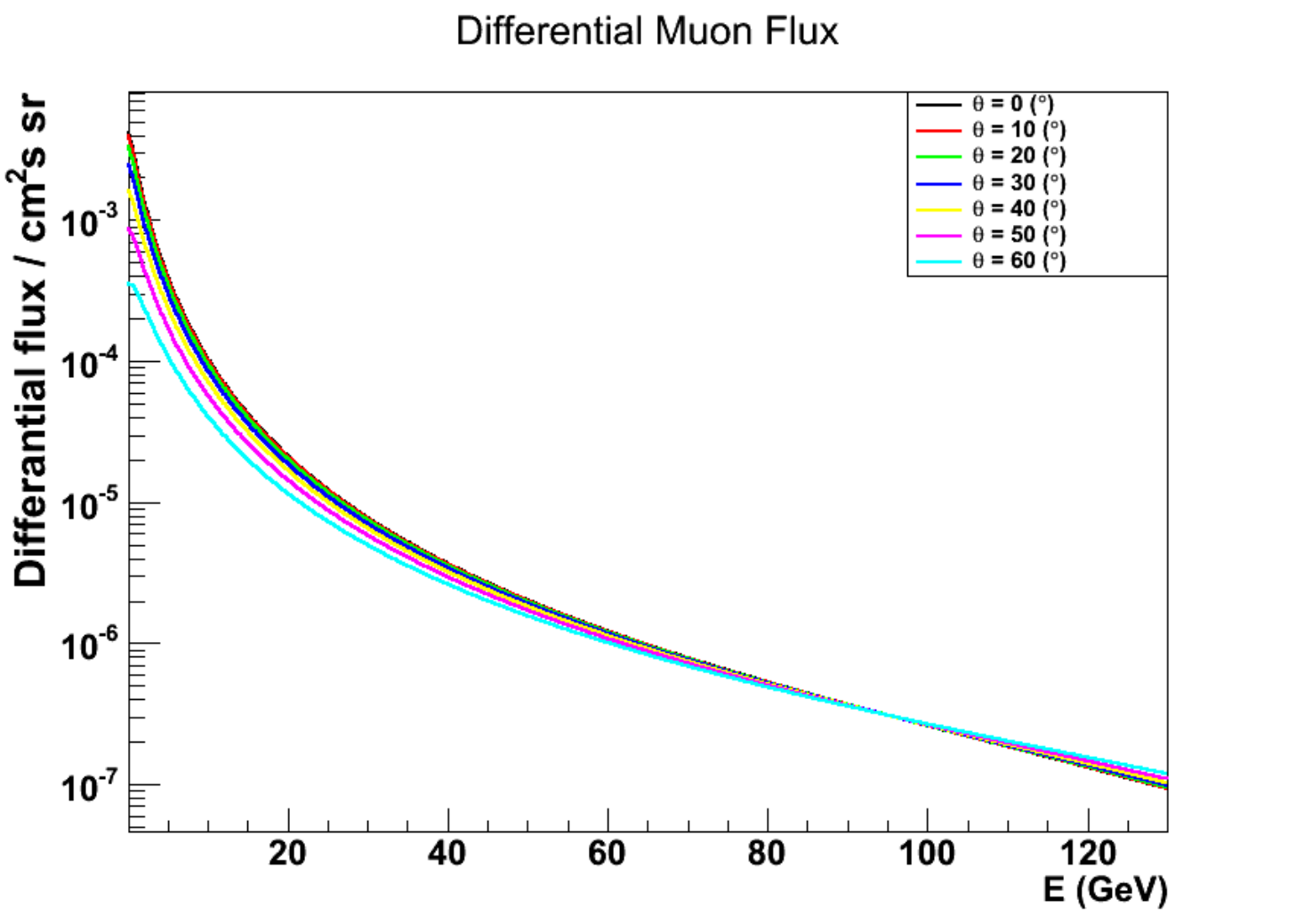




(pool) $\rho_{best} = 1.71 \pm 0.01$ g/cm³

(tank) $\rho_{best} = 1.74 \pm 0.01$ g/cm³

ADAMO FLUX SPECTRUM

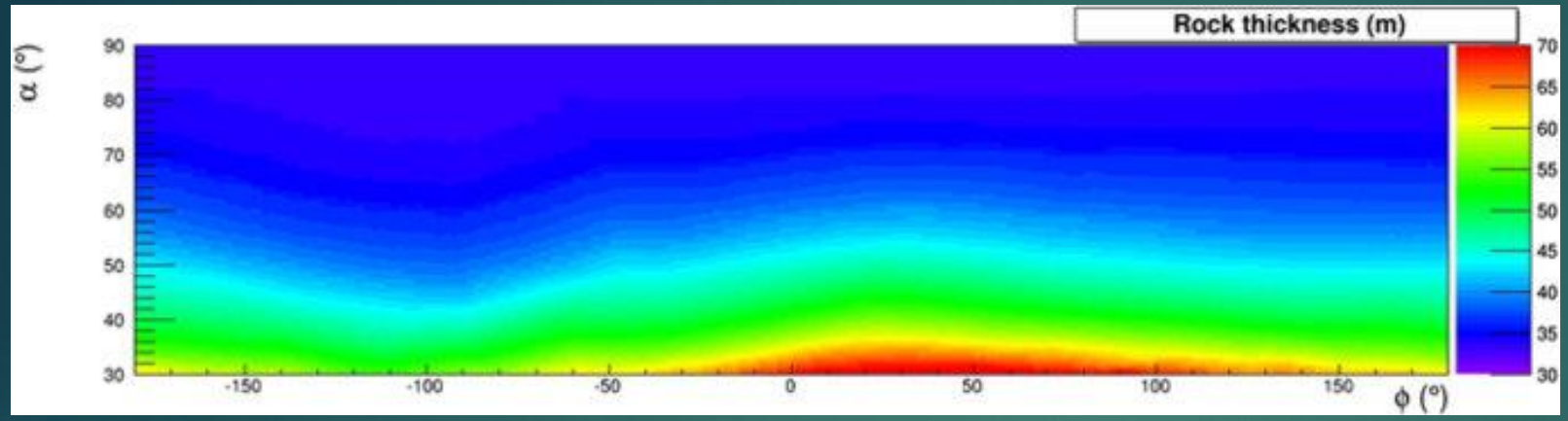


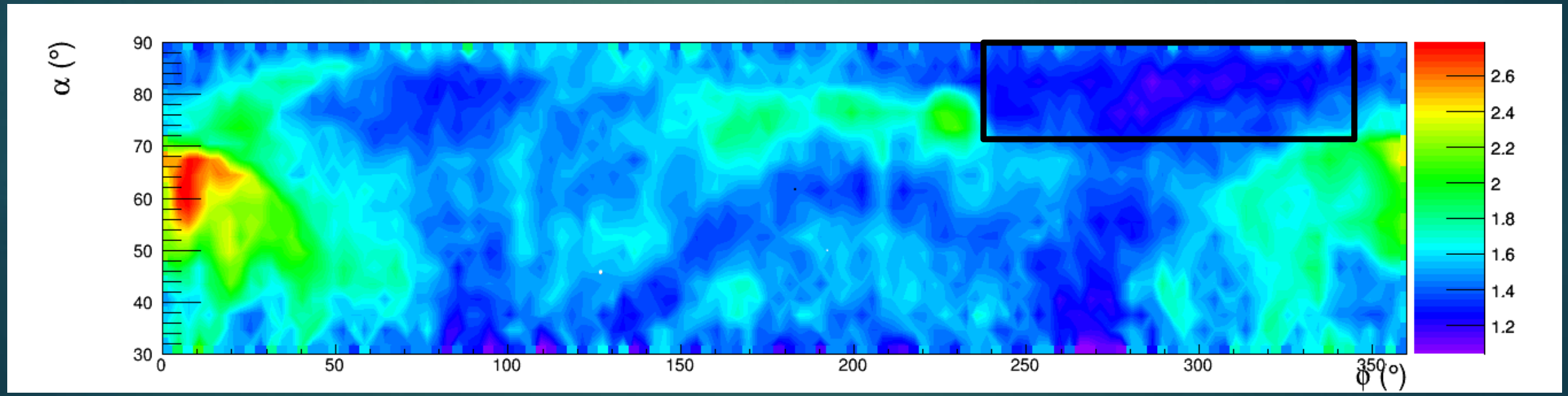
No electron and muon separation

E>130 GeV all together

ADAMO EXPERIMENT energy range between 100 MeV 130 GeV, zenith between 0° and 80°
L. Bonechi et al. Development of the ADAMO detector: test with cosmic rays at different zenith angles, 29th International Cosmic Ray Conference Pune (2005) 9, 283{286

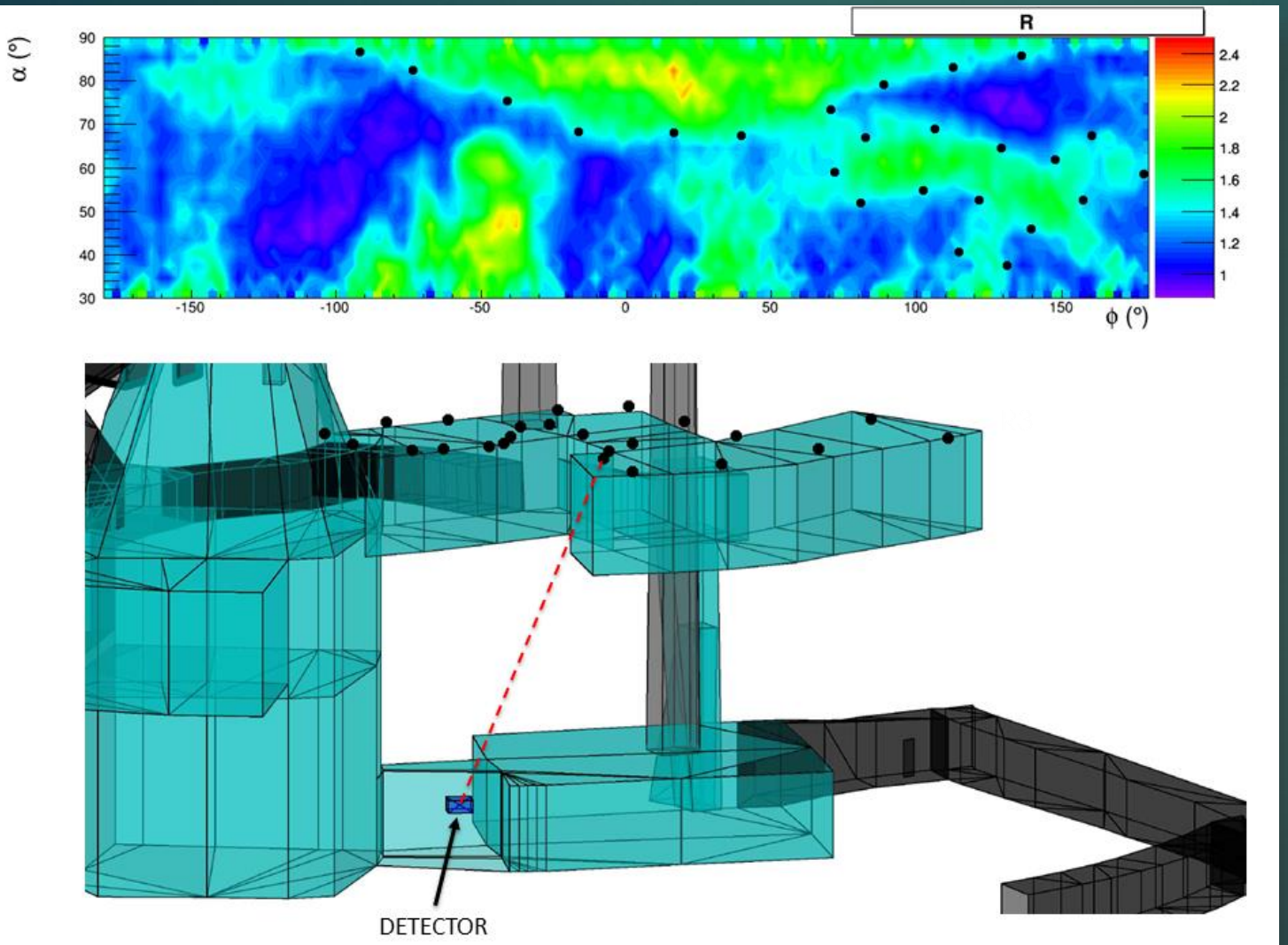
DENSITY MAP





Density map related to the rock thickness (top picture). In the black square the measured density is 1.4 g/cm^3.

GEOMETRICAL APPROACH



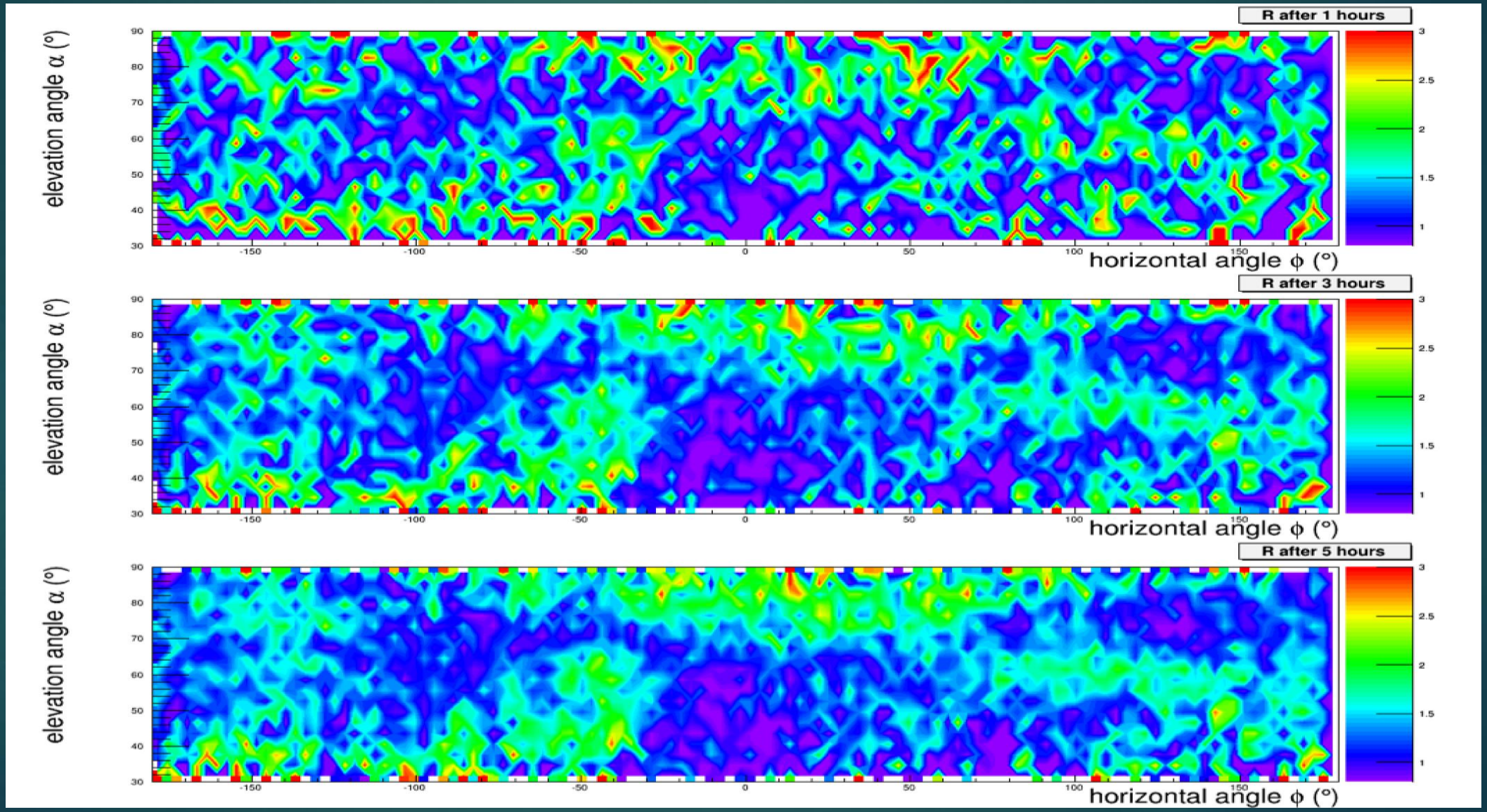
Dal CAD si determinano le posizioni nello spazio del bordo della camera.
I punti sono proiettati nella MUOGRAFIA.
Ottimo accordo tra il contorno della camera e l'immagine muografica

TIME RESOLUTION

1 h

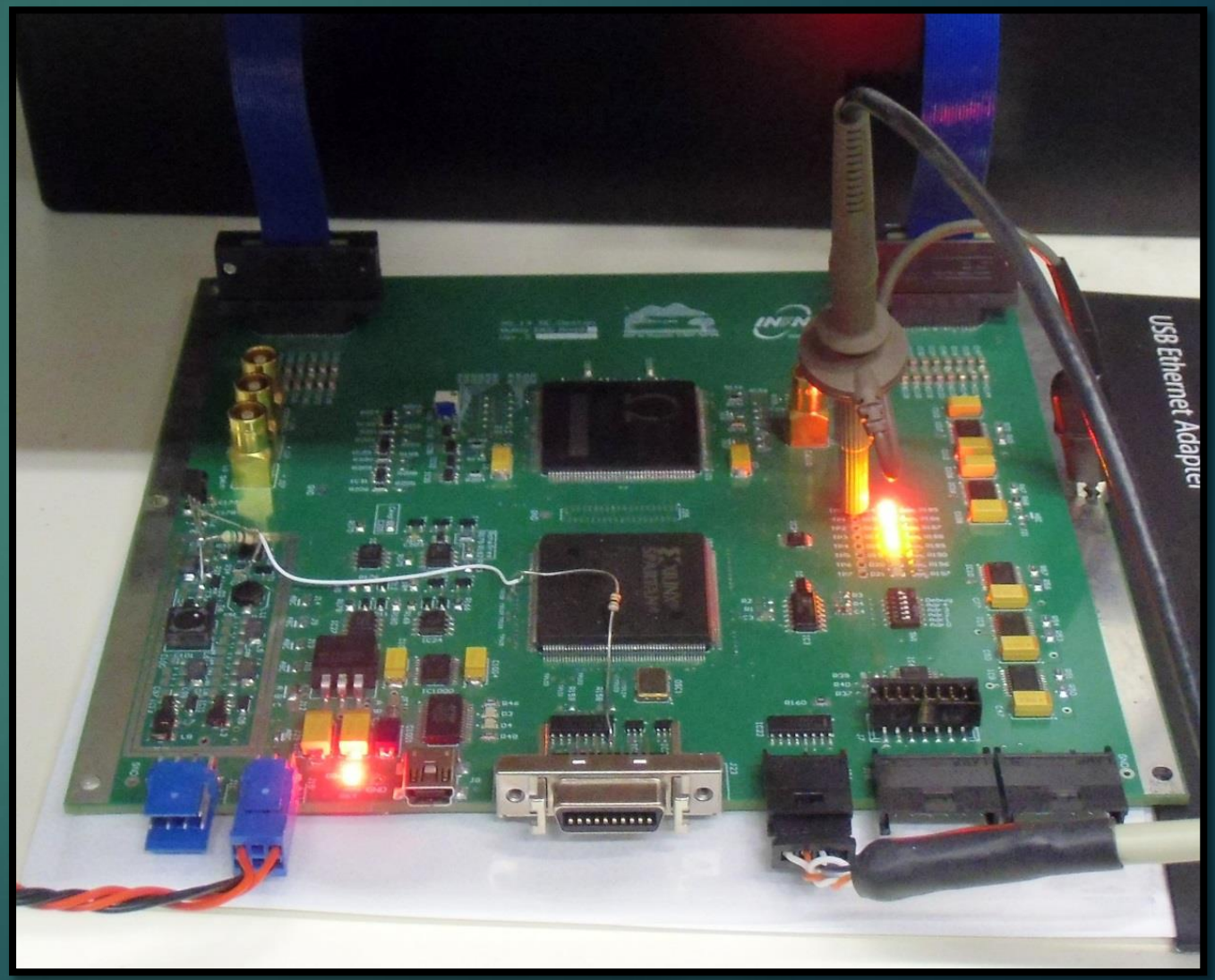
3 h

5 h

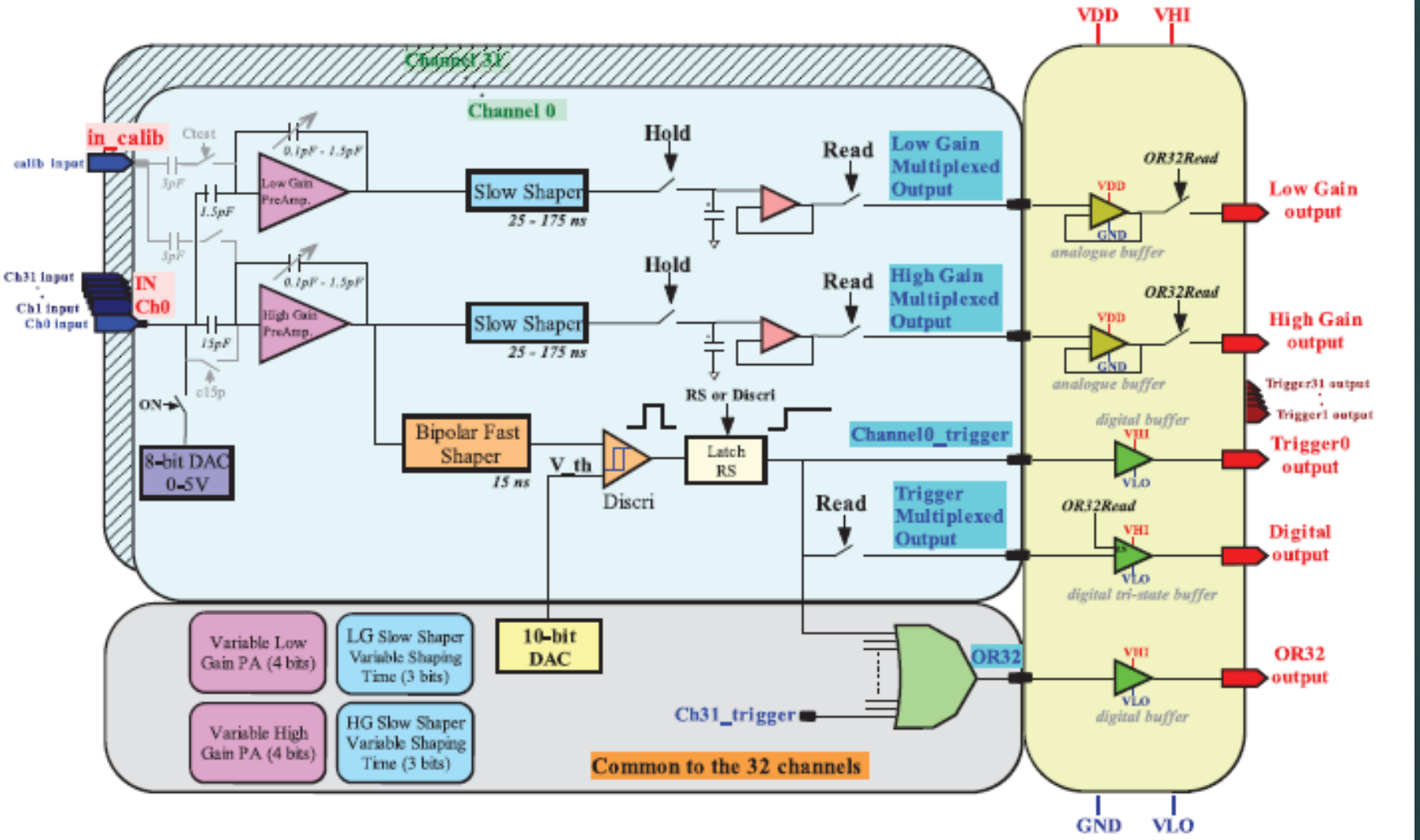


LA SCHEDA SLAVE

- 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 alimetazione con regolatori lineari fornisce lo high voltage per i SiPM ed alimenta la scheda



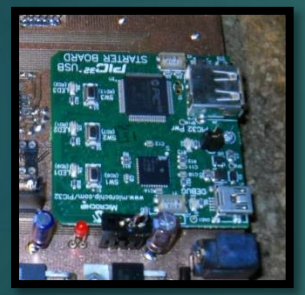
L'ASIC EASIROC



- 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 outpu digitale
- Low and high gain output

IL SISTEMA DI ACQUISIZIONE

PRIMA



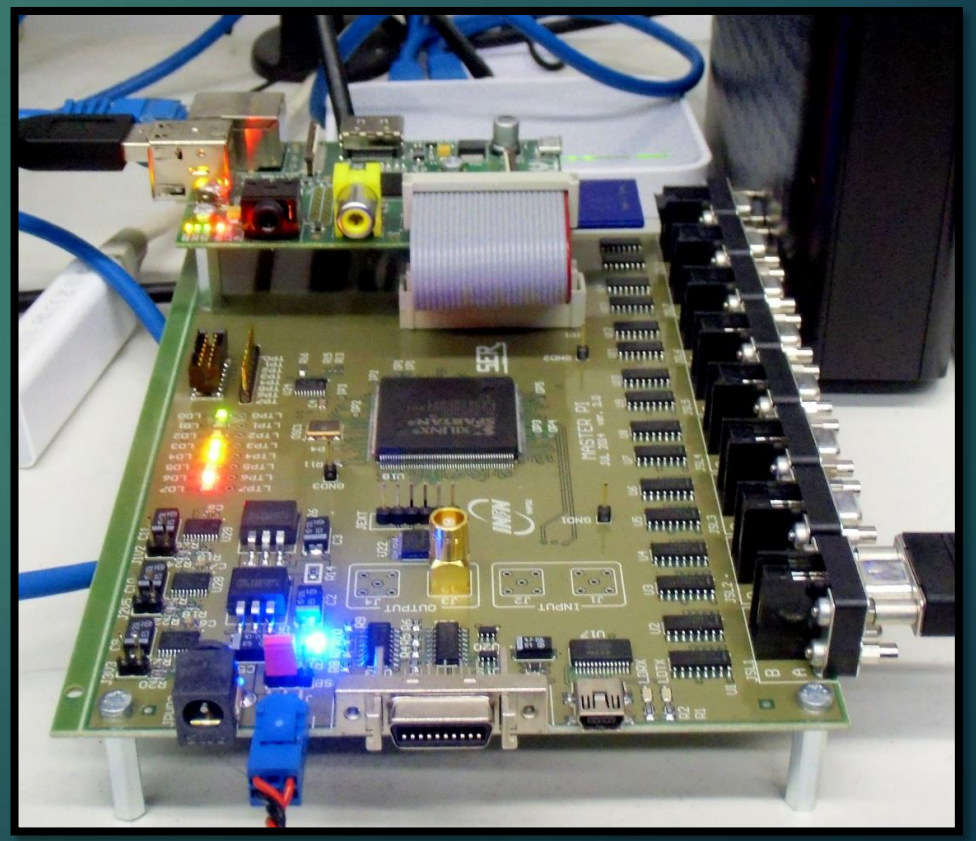
Dedicated COM Device
(PIC Micro Controller in the picture)

DOPO

Raspberry PI

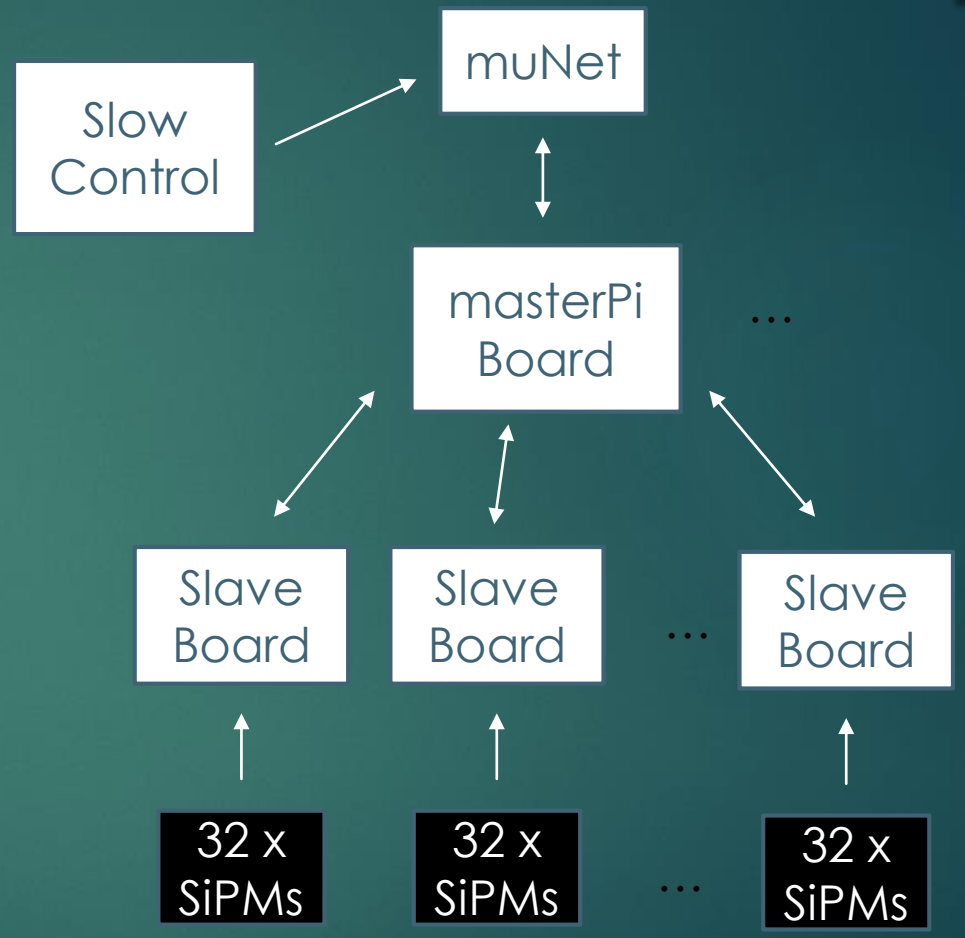
MASTER Board

- 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 dale schede Slave al RPi attraverso la scheda Master
- Le condizioni ambientali sono costantemente monitorate con dei termo-igrometri letti da muNet

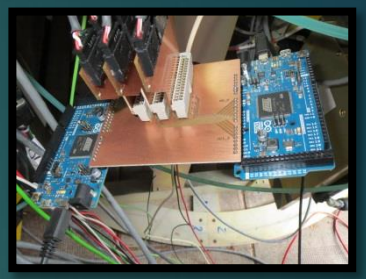


PROTOTIPO DEL DETECTOR MURAY

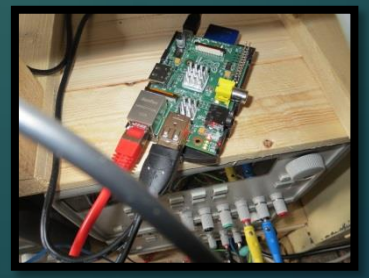
Sistema di alimetazione

Scheda Master

Detector MURAY (2013) – installazione al Puy de Dome (Fr)

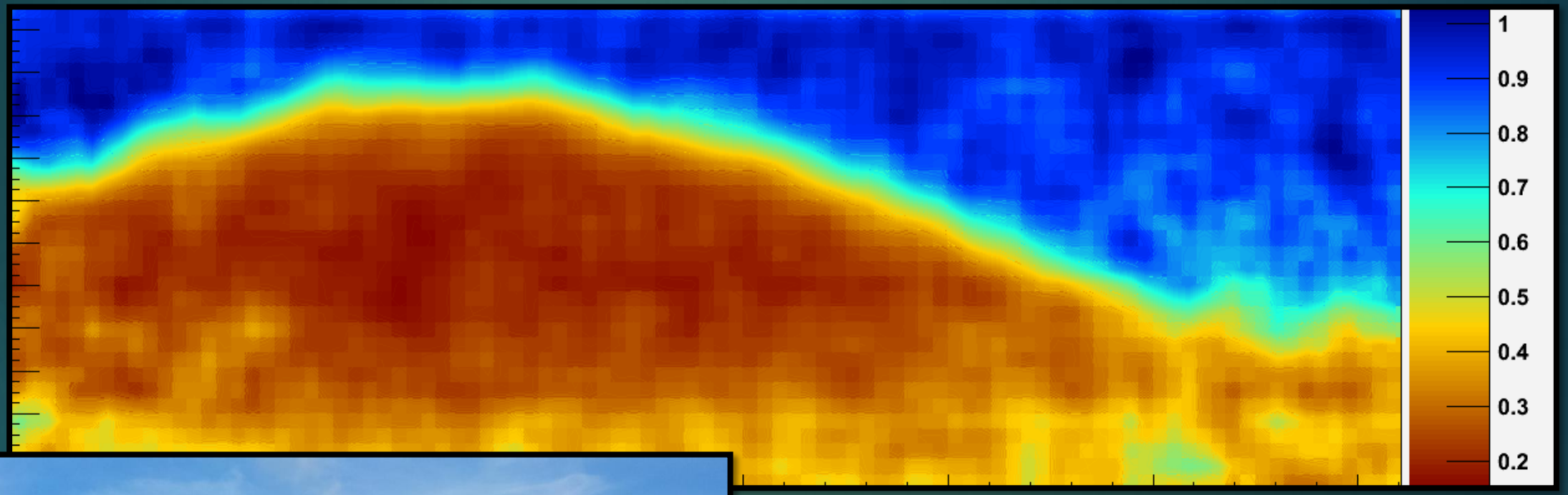


Sistema di controllo della temperatura



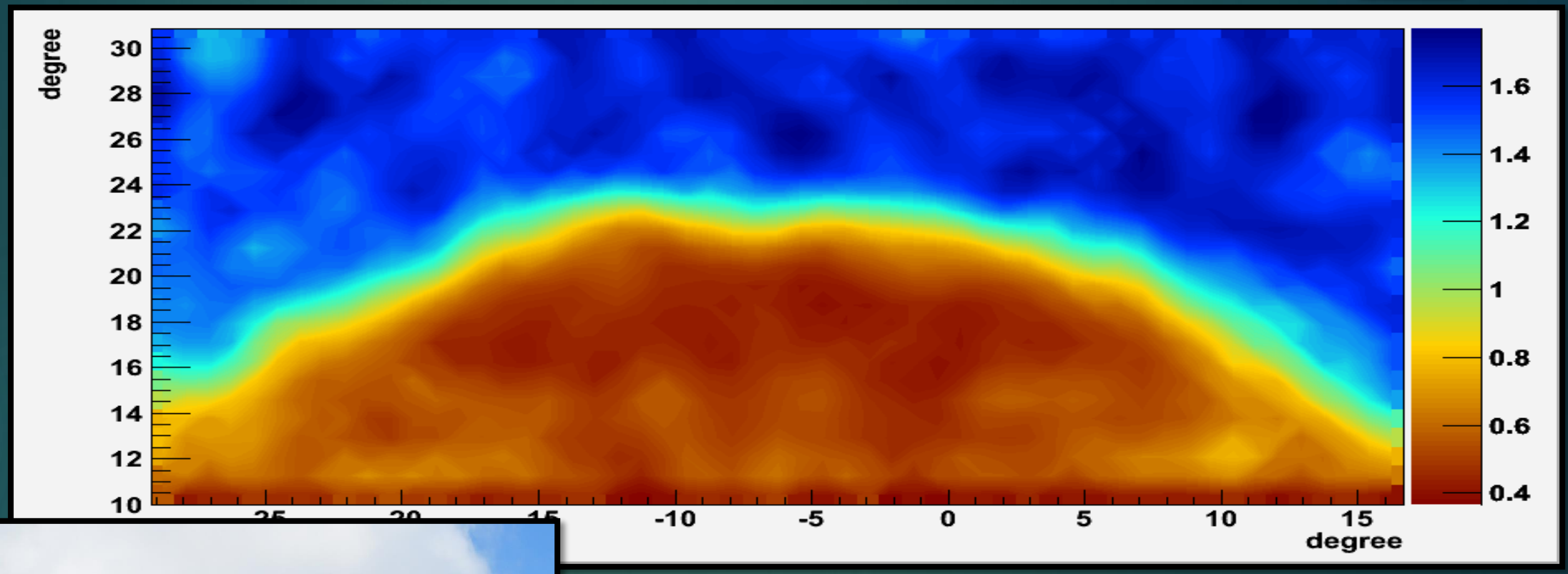
Sistema di controllo del detector

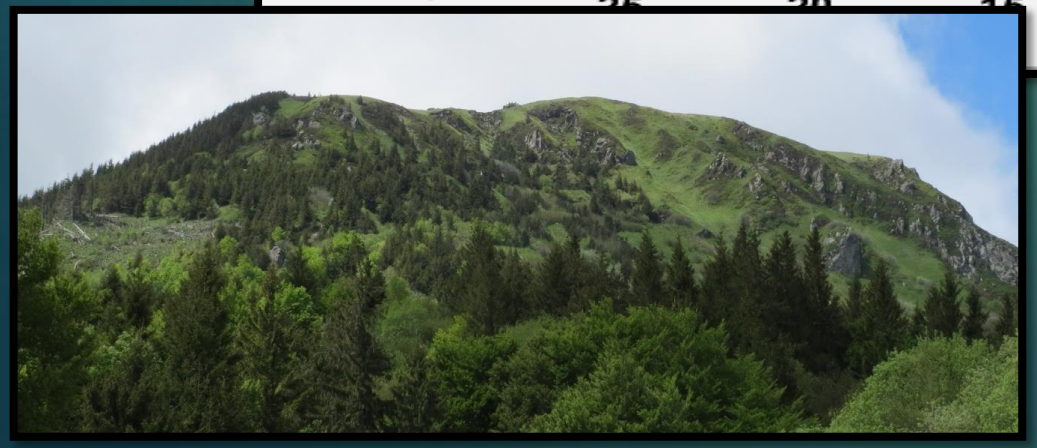
TEST EFFETTUATO AL VESUVIO



Vesuvio
Progetto MuRay
Napoli (Ita)
Aprile 2013

MISURA EFFETTUATA AL PUY DE DOME





Puy de Dome

Collaborazione MuRay - Tomuvol a Clermont-Ferrand (Fr)

Da Giugno a Dicembre 2013