# Imaging underground cavities by cosmic-ray muons: observations at Mt. Echia, Naples, Italy

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# Summary

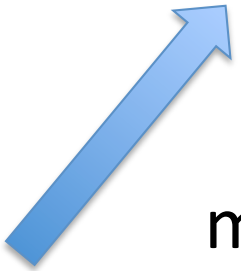
- METROPOLIS Project
- Mt. Echia site
- MU-RAY detector
- Data tacking
- Bulk density
- Cavities detection
- Conclusions

# Technological district STRESS

Technological district (mixed partnership public and private)

Devoted to the sustainable buildings

company partner



member of STRESS

joint-stock company specialized on geological survey

# METROPOLIS Project

Project devoted to the

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

Six work packages

- URBAN SYSTEM KNOWLEDGE
- DISRUPTION OF URBAN SYSTEM
- PHYSICAL SYSTEM VULNERABILITY
- INTEGRATED HAZARD OF URBAN SYSTEM
- SOCIAL AND ECONOMIC SYSTEM VULNERABILITY
- STRATEGIES AND TECHNOLOGIES FOR SUSTAINABLE URBAN SYSTEM

End of the project: December 2016

Funded by
Italian Ministry of Instruction, University and Research

METROPOLIS PON 03PE_00093_4

# URBAN SYSTEM KNOWLEDGE W.P.

Beside traditional survey methods an experimentation task on muography was inserted.

The focus is on underground cavity detection, in particular in urban context.

The project was articulated in three work packages:

- Feasibility Studies
- Cylindrical detector for bore hole
- An experiment to test the method

INFN was engaged to supervise this task.

# Mt Echia as a laboratory

## VIII B.C.

The ancient Greek village "Parthenope"

Then Palepolis (Old City)

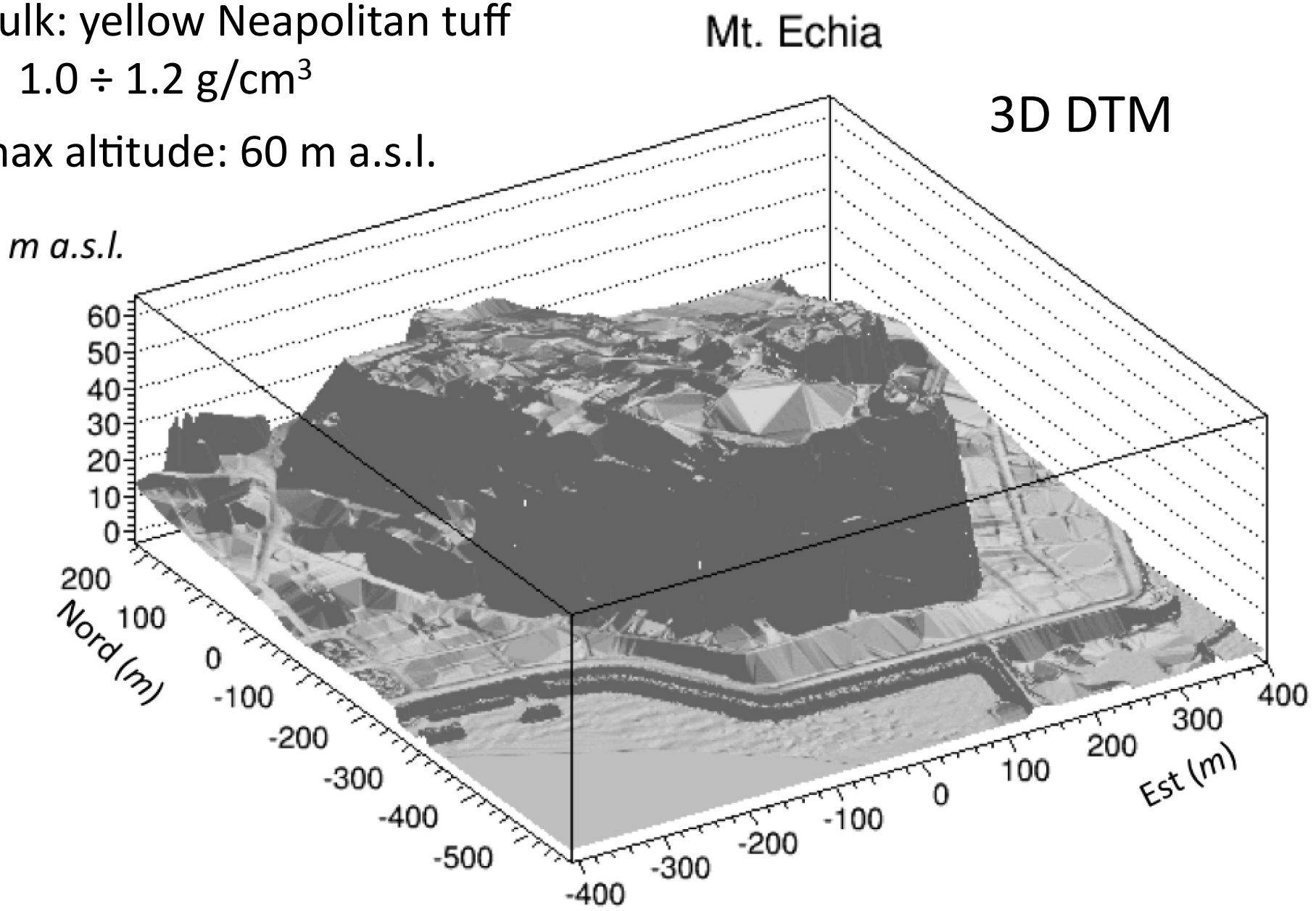
when the new city of Neapolis was founded.

# Mt Echia

bulk: yellow Neapolitan tuff

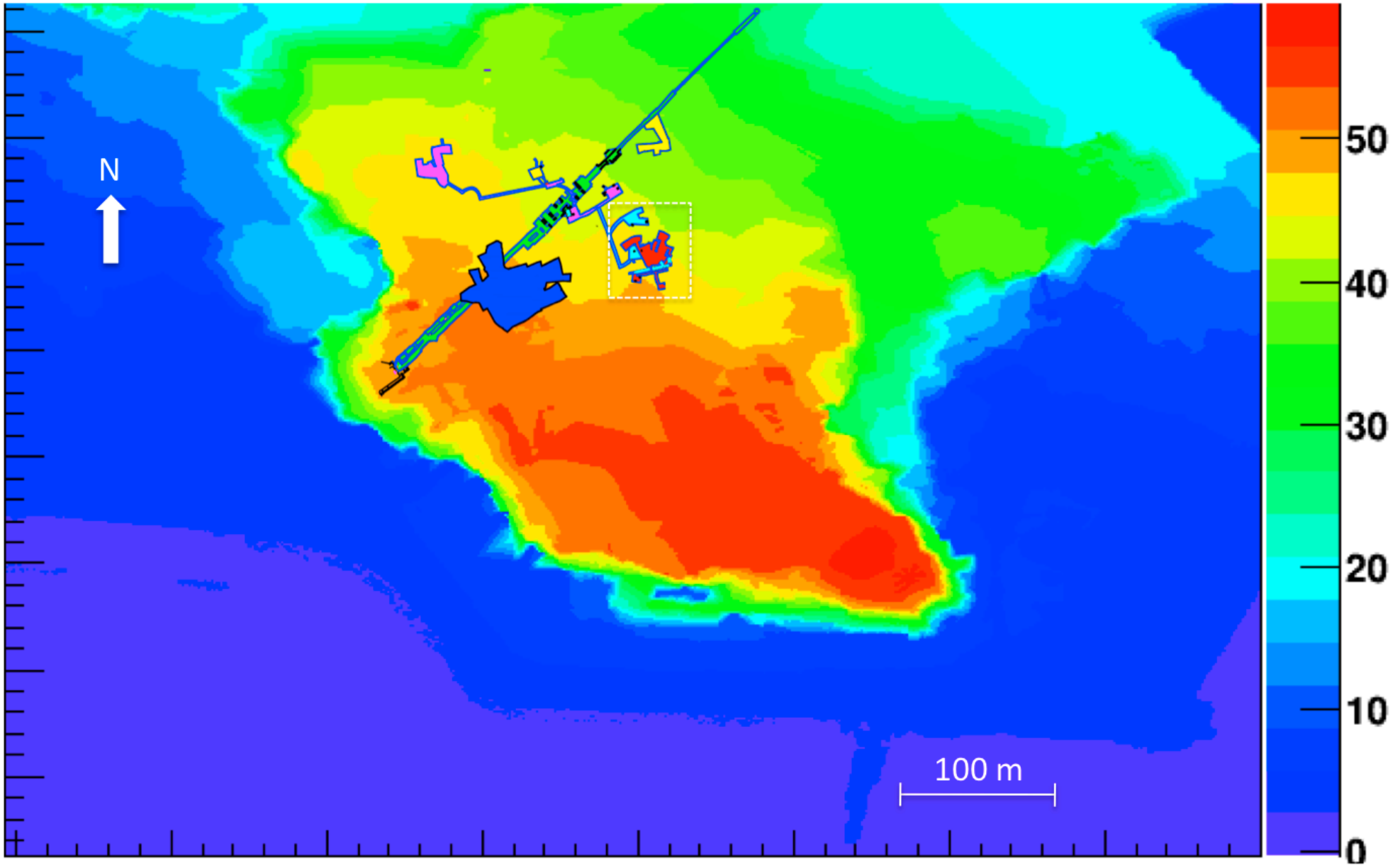
ρ 1.0 ÷ 1.2 g/cm$^3$

max altitude: 60 m a.s.l.



# Mt Echia

Large number of natural as well as anthropic caverns



# The Bourbonic Tunnel

1853 Ferdinand II of the Bourbon House - King of the Two Sicilies.

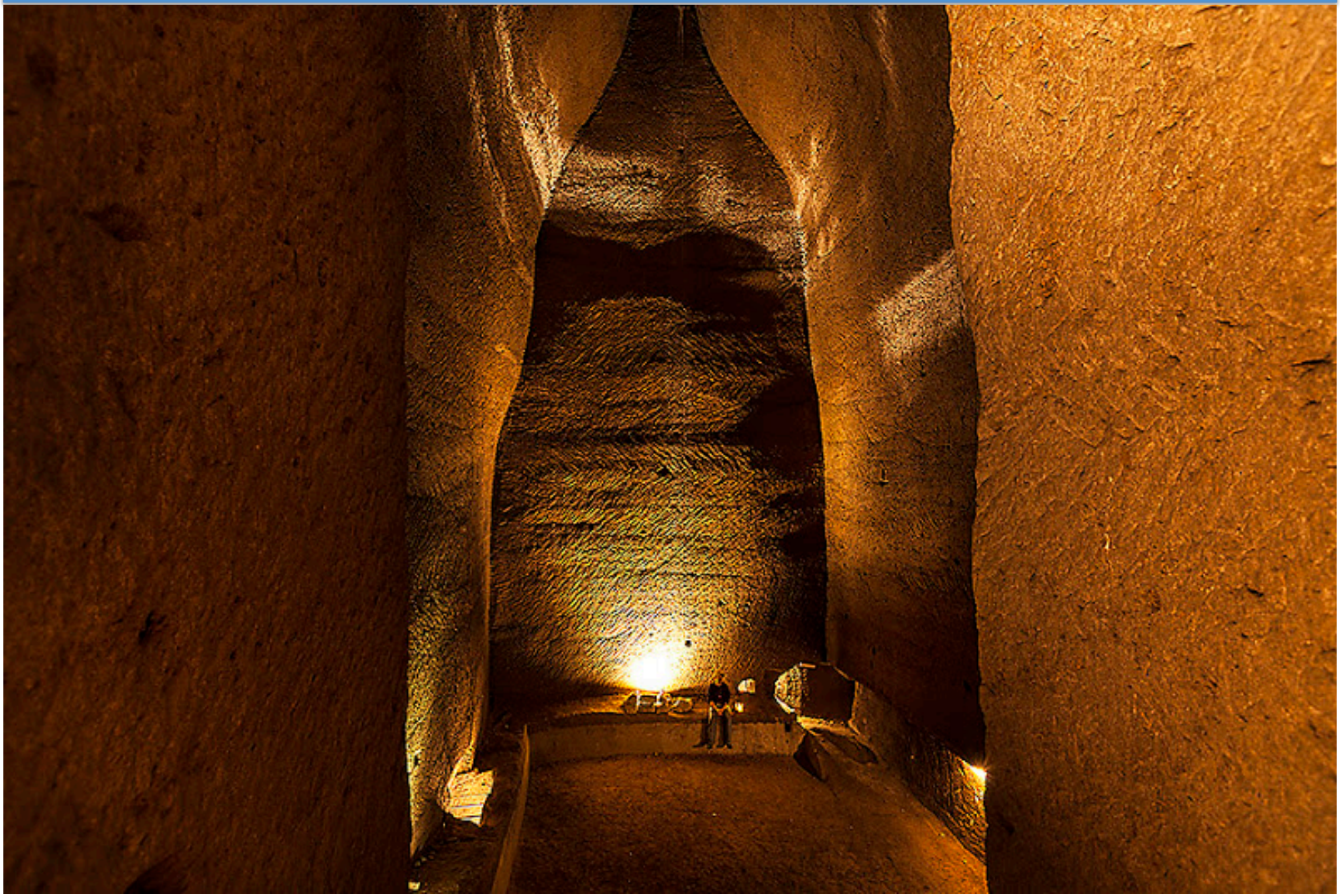
Restored in recent times and inserted in one of the archaeological underground itineraries.

Large number of  underground structures have been rediscovered.

The exploration is continuing.

# The Bourbonic Tunnel

# The Bourbonic Tunnel



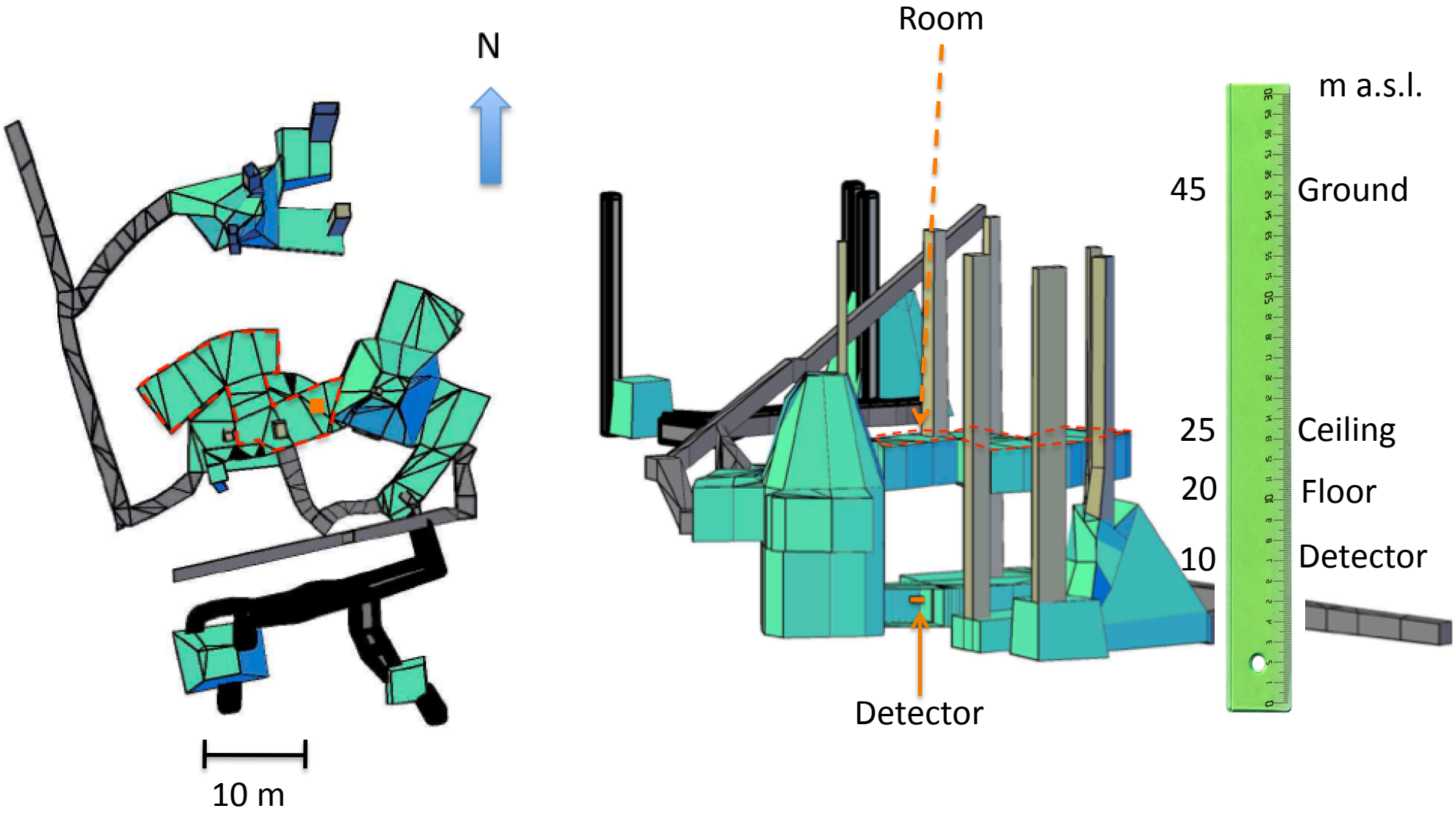
# The site

12 m a.s.l.

35 m to the ground

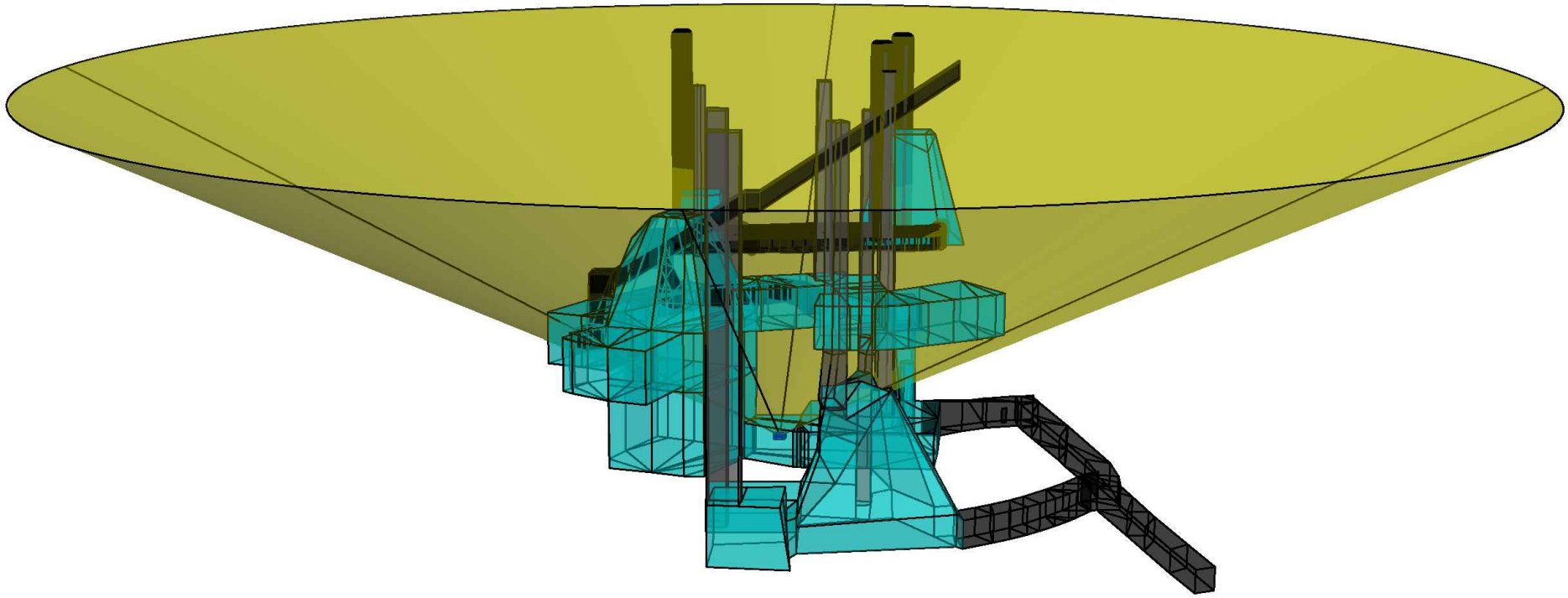
# The test

find a room above the detector



# Other known structures inside acceptance

Detector acceptance: 63° angle cone



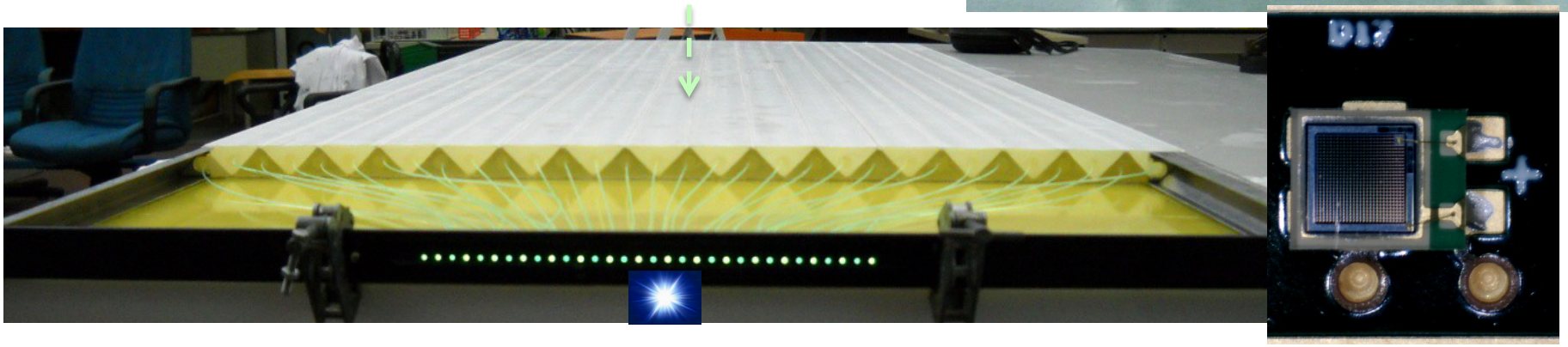
# The detector

Muray up-graded detector prototype:
Plastic scintillators with triangular shape
WLS fibers
Silicon photomultiplier
Easiroc1B F.E.E.  chip
Three X-Y planes 1 $m^2$ sensitive surf.

2 mm x and y resolution
4 mrad angular resolution (0.25° re-binned to 3°)

0.5 m distance between planes
63° zenith acceptance

Four detectors under construction for the MURAVES experiment at Vesuvius.

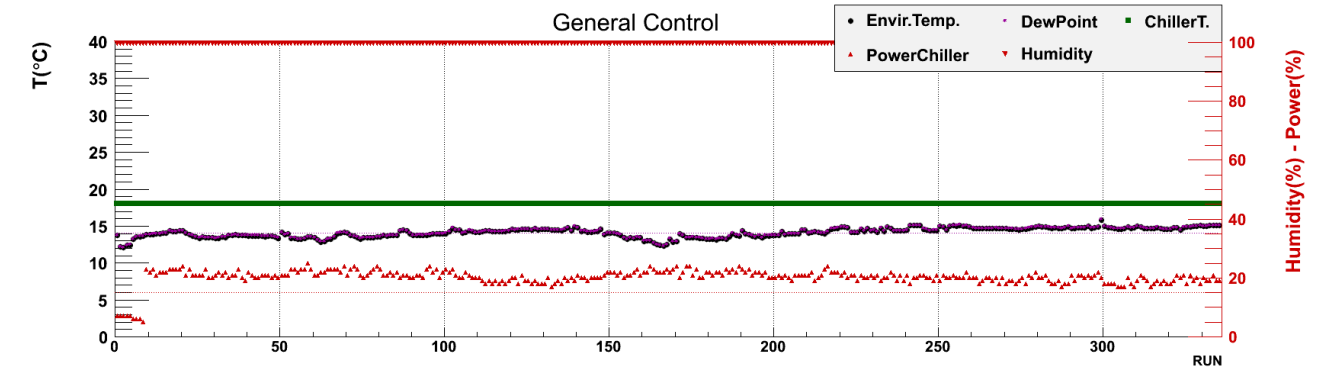


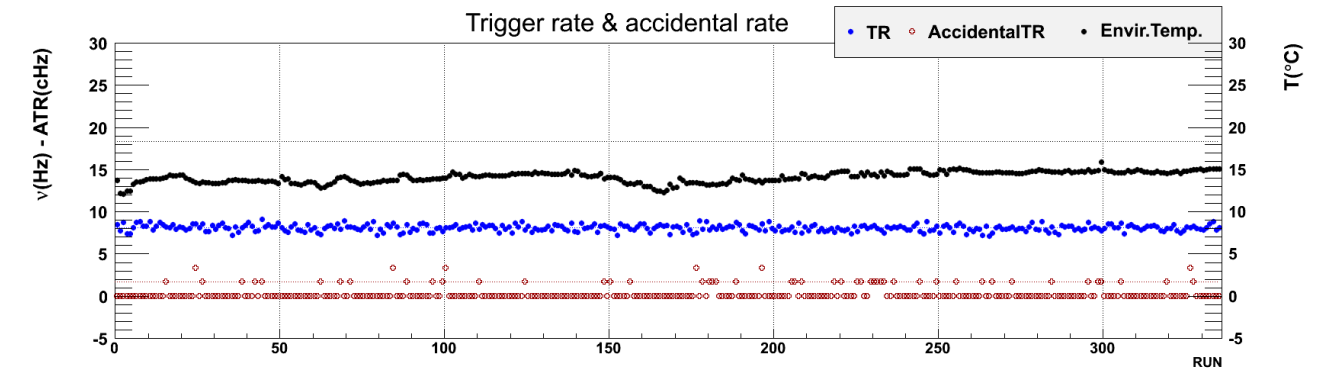
# Data Taking

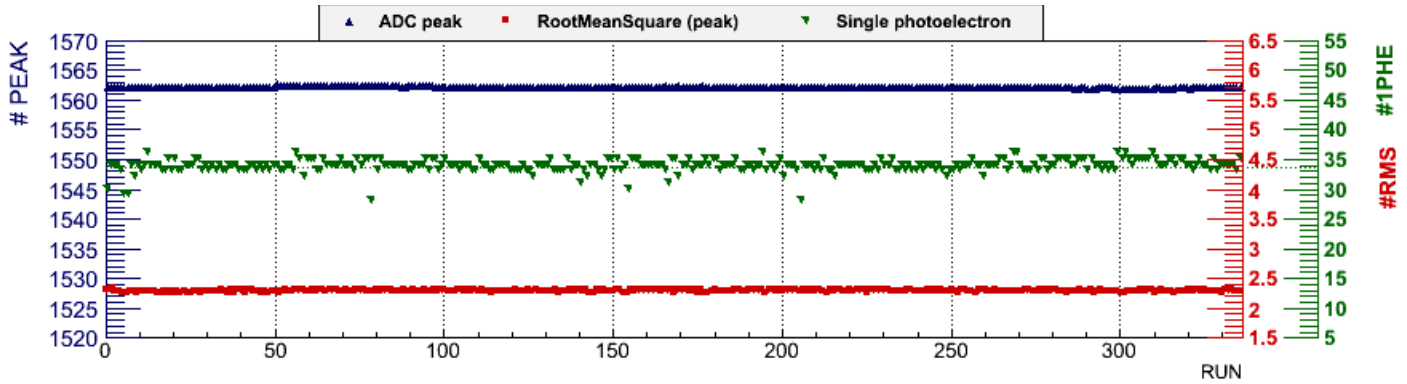
Gallery : 14x$10^6$ events in 26 days

Laboratory : 12x $10^6$ events of "free SKY"

Environment and detector Monitoring



# Data analysis: relative transmission

We define

$$T^m(\alpha,\phi) = \frac{1}{C}\frac{N^u(\alpha,\phi)}{Nfs(\alpha,\phi)}$$

Measured transmission

corrected for the different time acquisition

$$T(\rho,\alpha,\phi) = \frac{\int_{E_{min}}^{\infty}\Phi(\alpha,\phi,E)\,\mathrm{d}E}{\int_{E_0}^{\infty}\Phi(\alpha,\phi,E)\,\mathrm{d}E}$$

Expected transmission

calculated in the NO cavities hypothesis

As first approximation ρ =1.2 g/cm$^3$ was used (sample measurement)

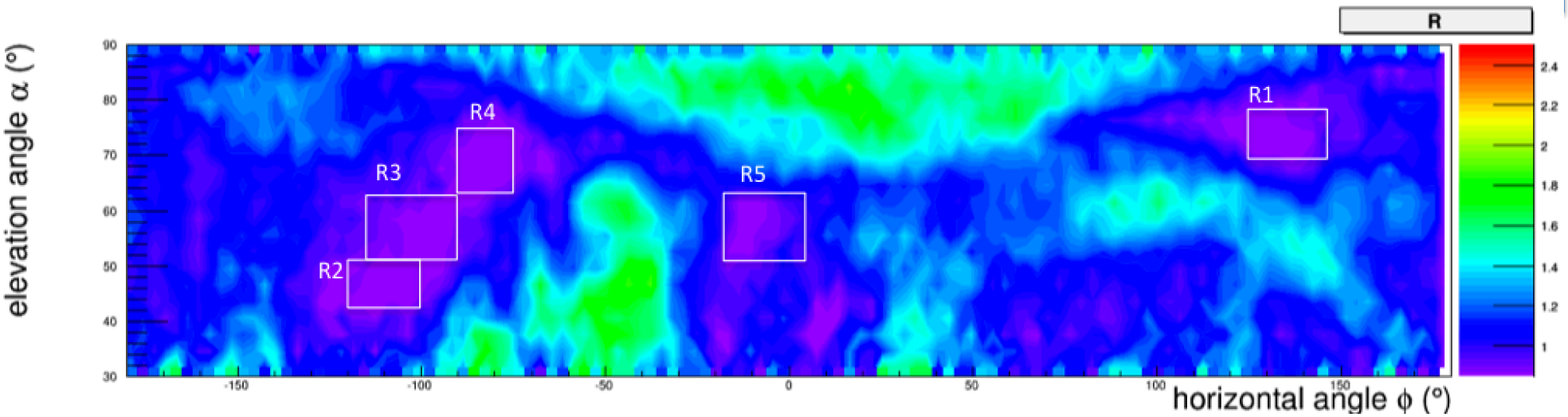
$$R(\rho,\alpha,\phi) = \frac{T^m(\alpha,\phi)}{T(\rho,\alpha,\phi)}$$

Relative transmission:

≅ 1 if no cavities are present and correct density

*R(α,φ)* > 1 -> mean density lower than expected -> cavity

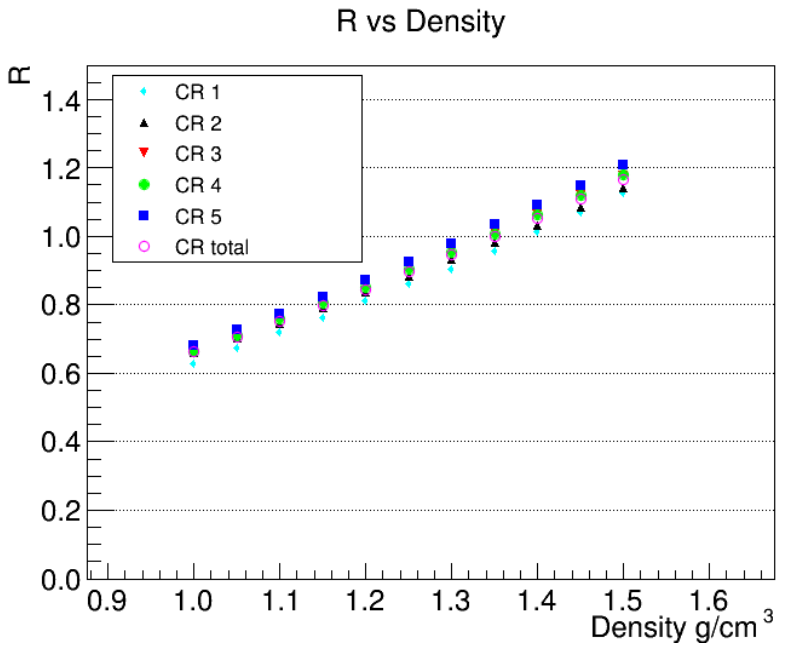
# Relative transmission with $\rho = 1.2$ g/cm$^3$



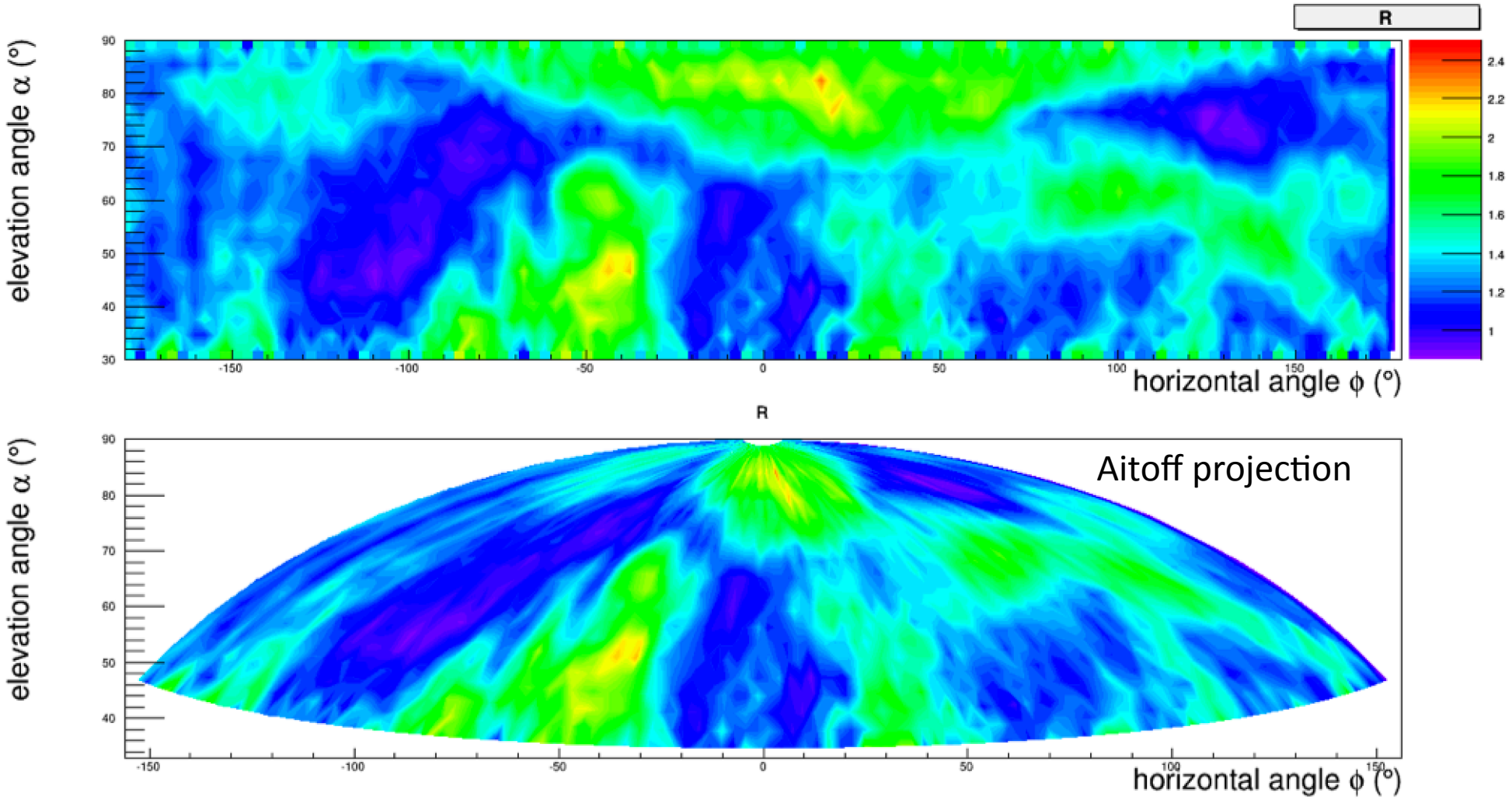

Clear evidence of structures with R > 1 (green)

To improve R we estimated the best density value using five control regions where R is at the minimum.

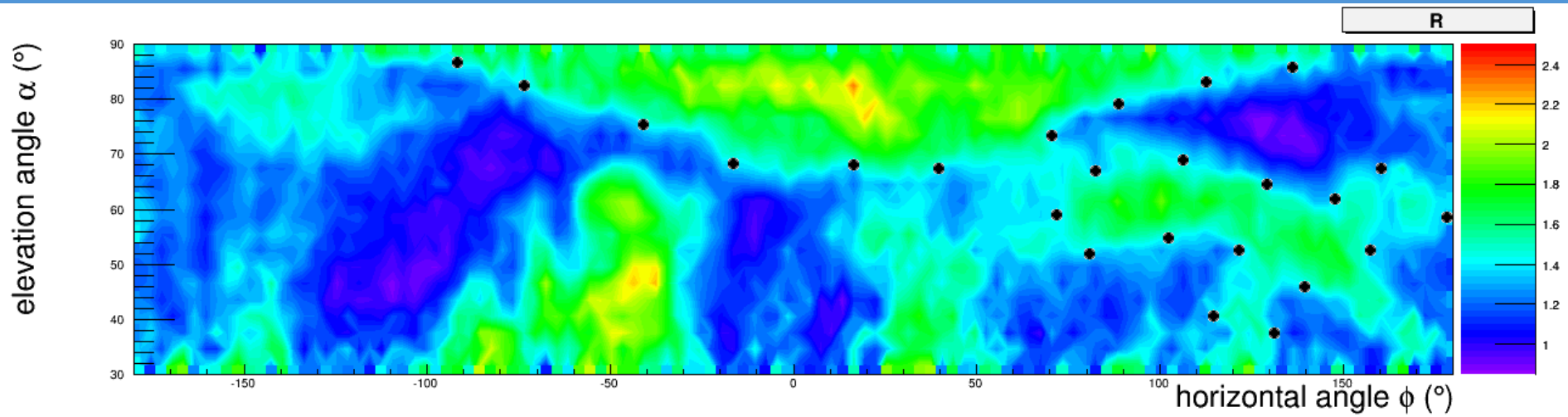
$\rho_{bes}$ = 1.35 g/cm$^3$ gives R = 1
in the control regions



# Relative transmission with $\rho = 1.35\ g/cm^3$



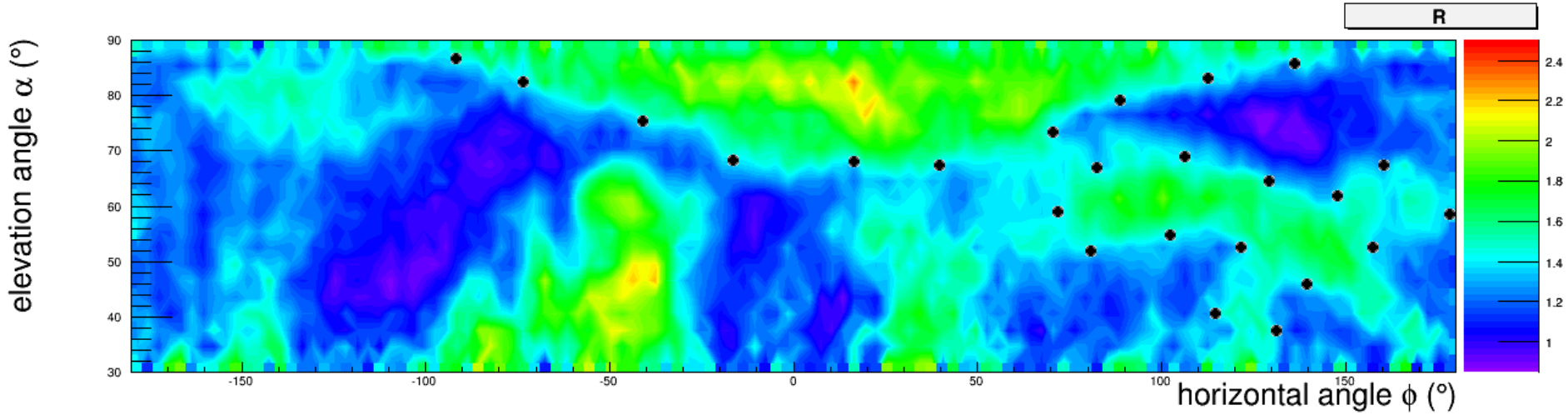
# The room above the detector

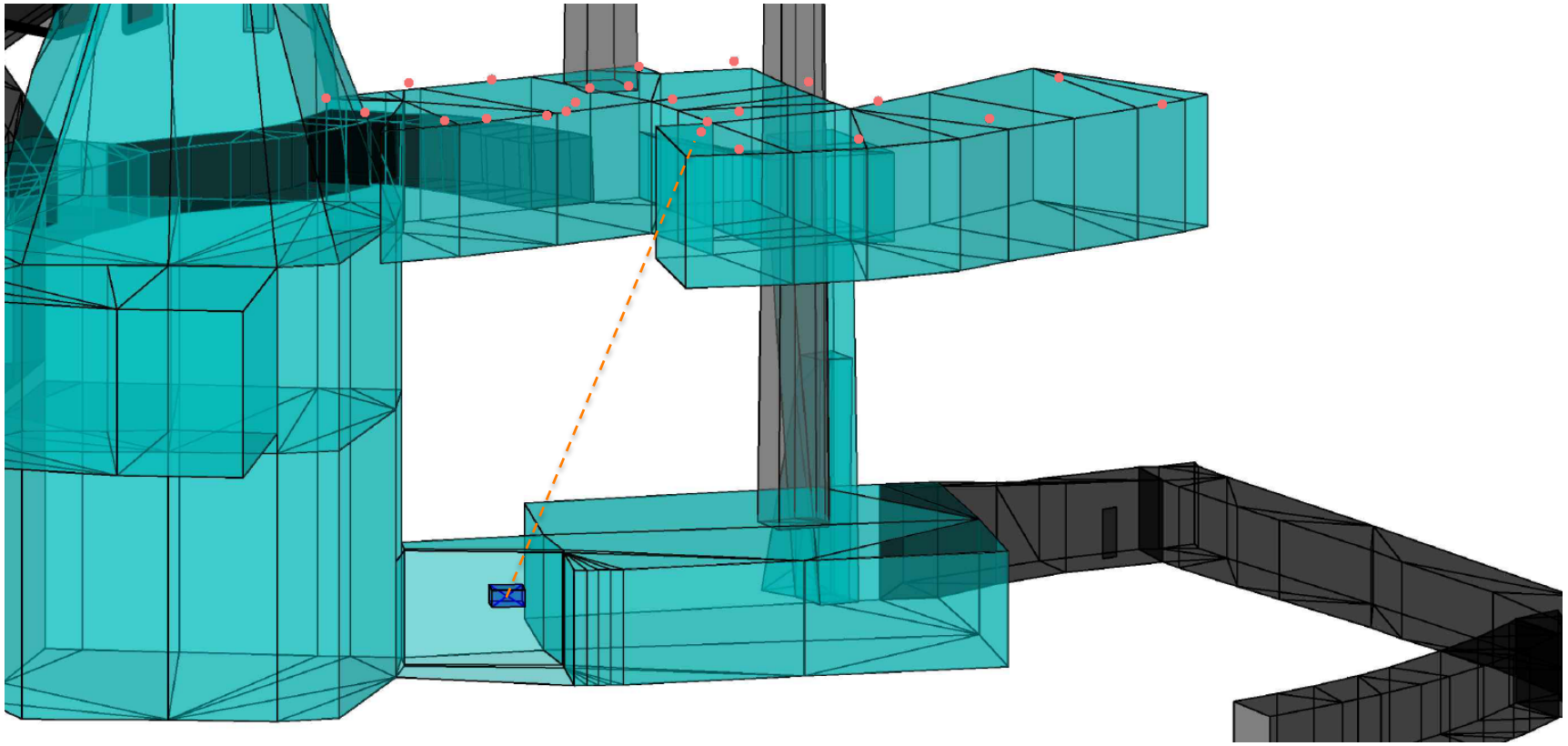



The points define the angular region of the room above the detector.

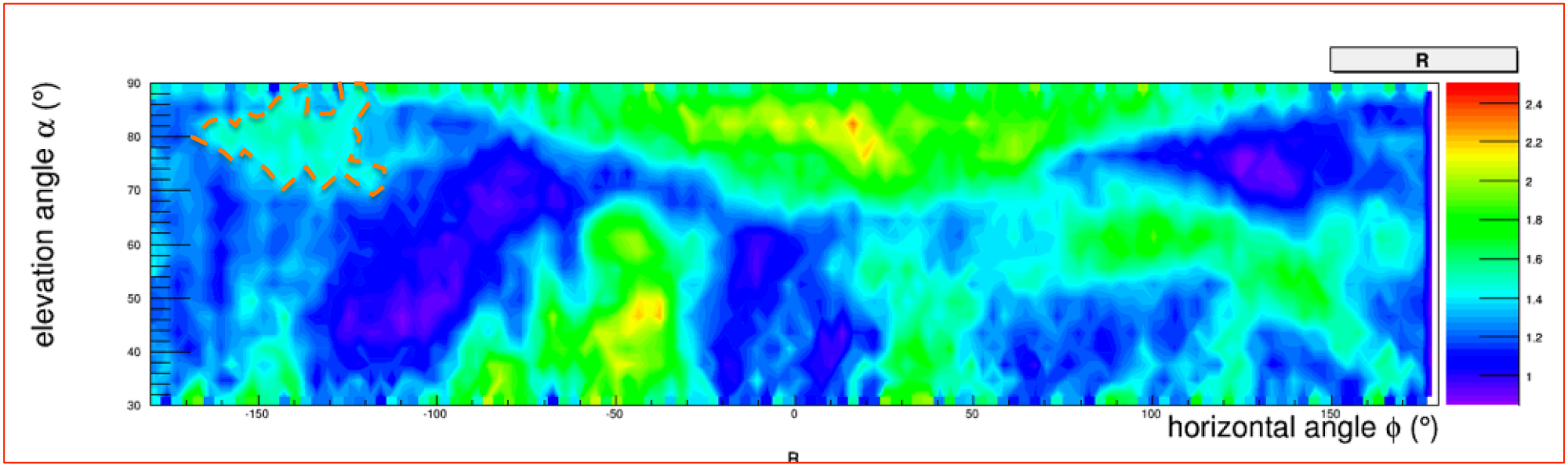
Intersections of lines starting from the detector and with the points directions with the plain  of the ceiling of the chambers were evaluated.

# Clear correspondence



# Comparison with structures

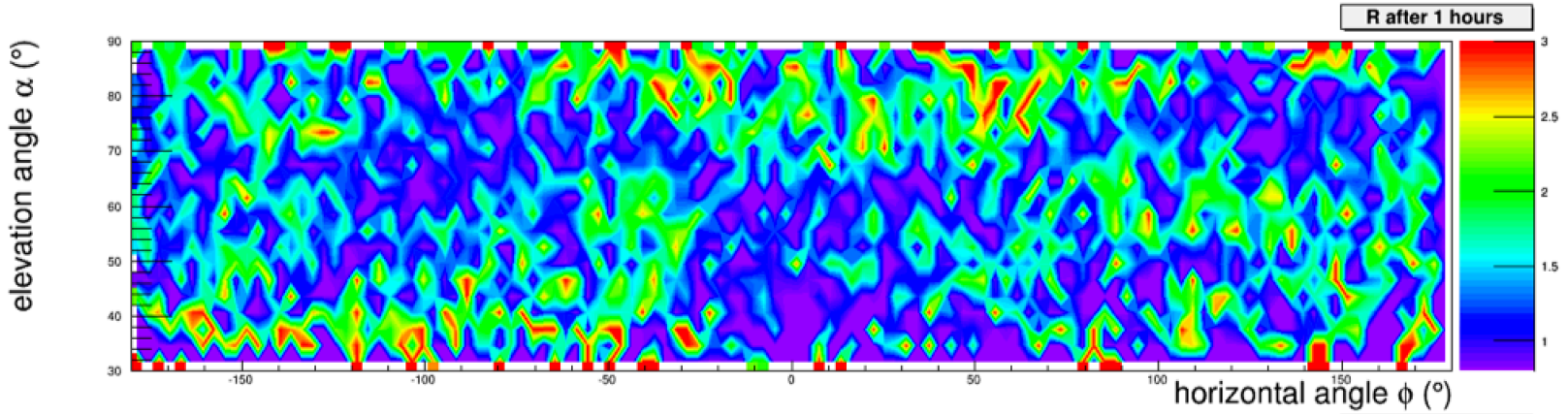



Most of the green area  correspond to known structures

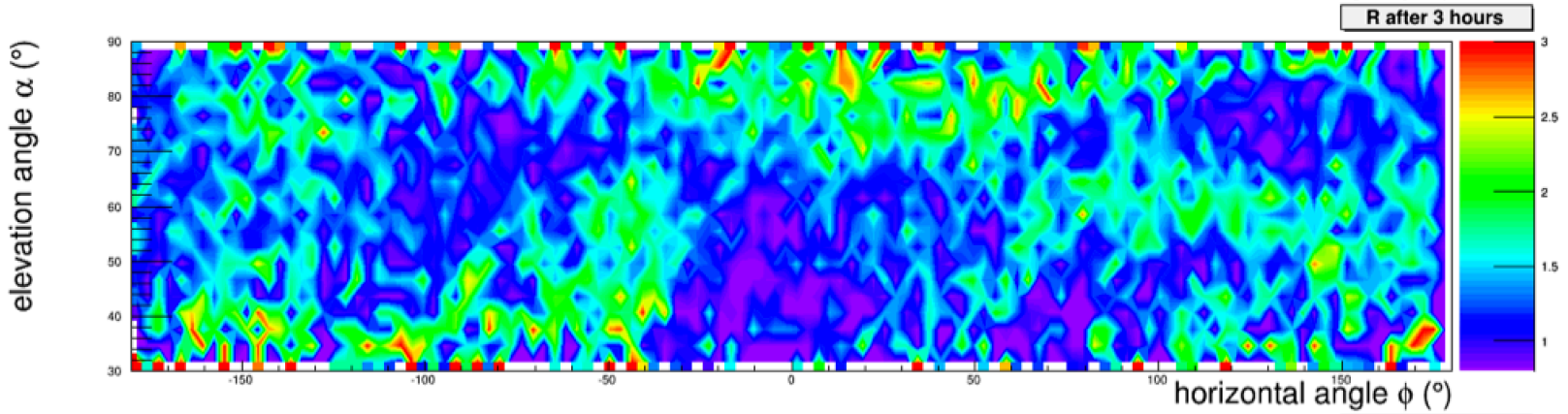
Hints of an unknown chamber ( dashed line)

# Time resolution

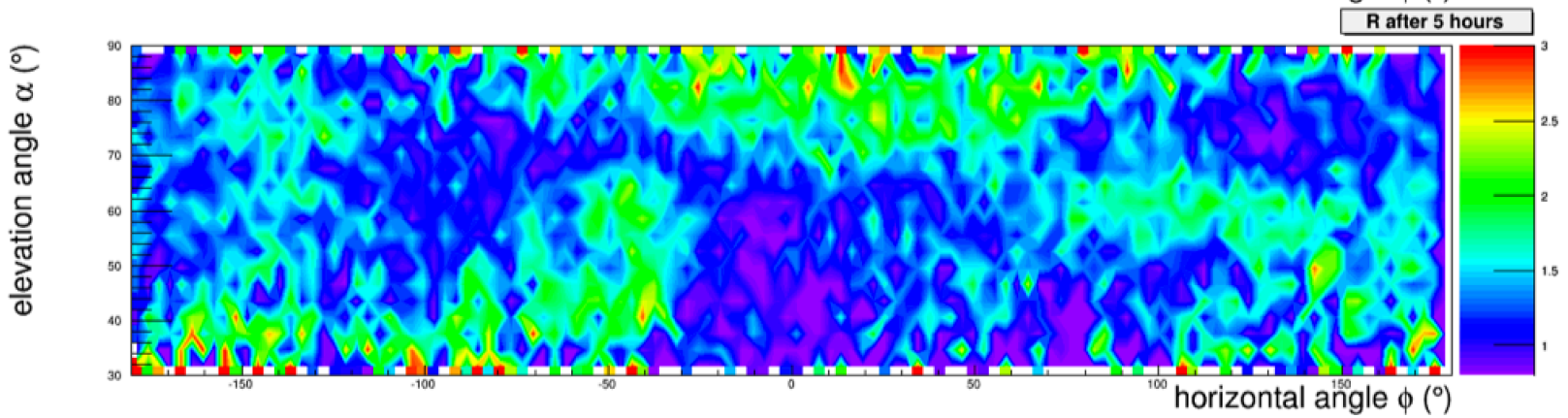
1 h




3 h




5 h



# Conclusions

- We started a research program about muography applications in geological survey of cavities.

- A sample of 14x10^6 trigger was acquired under Mt. Echia

- Evidence of known structures

- Hints of a hidden chamber

- A second muon sample was acquired in a different position: analysis in progress

- A cylindrical detector for bore-hole is under construction

# THE END

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