MUOGRAPHERS 2014 - International Workshop on Muon & Geo-Radiation Physics for Earth Studies
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Muography applied to Archaeology
(and other fields)

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on behalf of the MURAVES collaboration

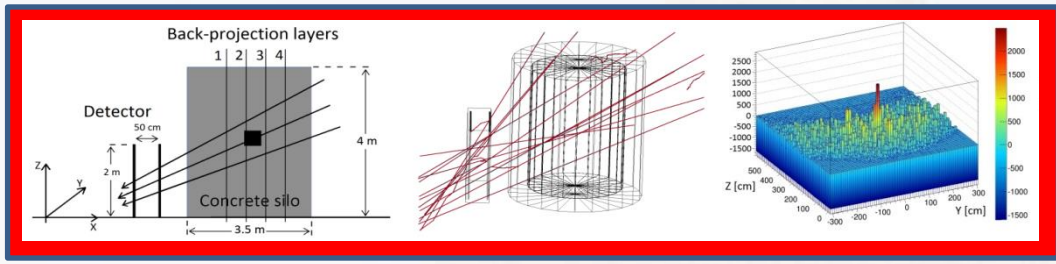
Outline

- 1-slide non-exhaustive summary on some applications of Muon Radiography to fields other than Volcanology
- Applications in Archaeology
  - Example: interesting case studies in Italy
- Preliminary simulations
- Small detector under construction
- Conclusions

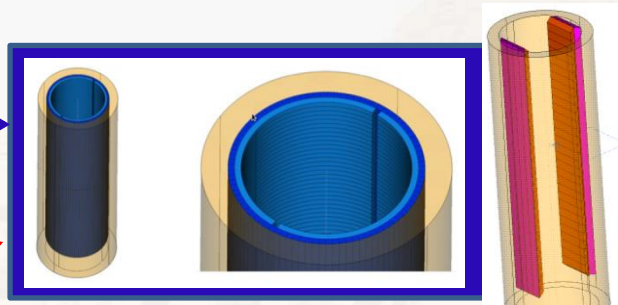
Applications of Muon Absorption Radiography in fields other than volcanology

Many possible fields of applications (only some example shown here)

- **Characterization of nuclear reactors (?)** (currently it is mainly done by MS)
- **Characterization of nuclear waste** → (previous presentation by R. D'Alessandro)

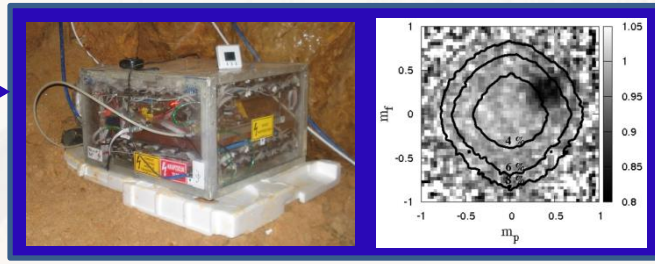


- **Archaeology and preventive archaeology** (this presentation) →



Small detectors to be dropped in a borehole or installed in a gallery

- **Civil engineering** (check of status of ground before beginning construction and check of the status of historical buildings)
- **Geophysical prospections and survey of mines and caves** →



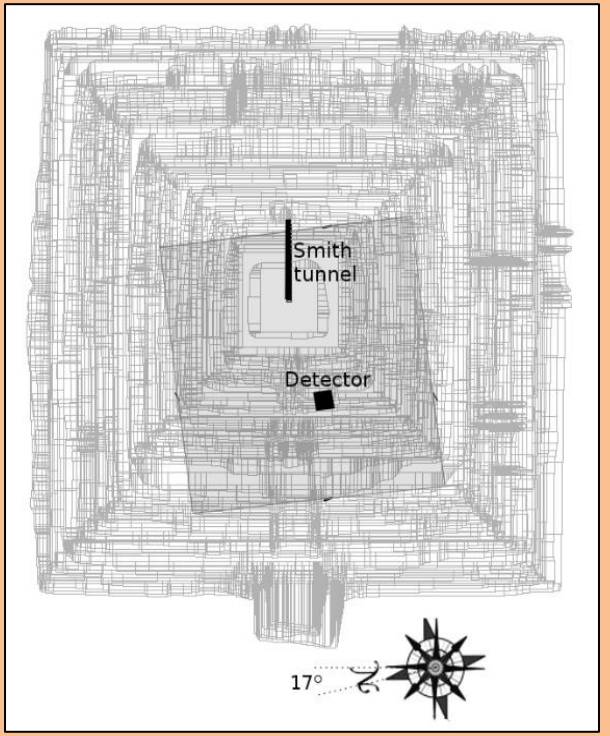
For example: CCC-based Muontelescope (Hungary)

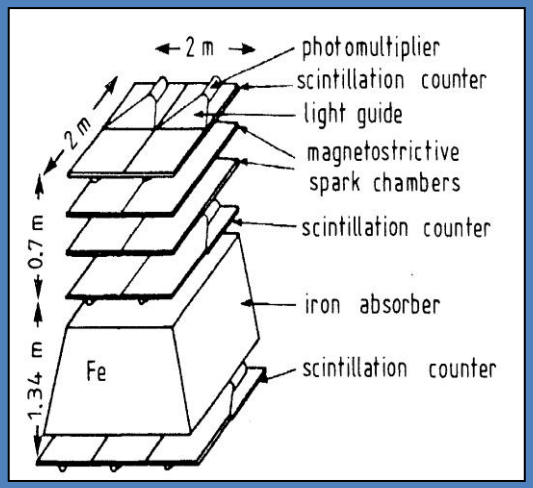
Muon absorption radiography in archaeology

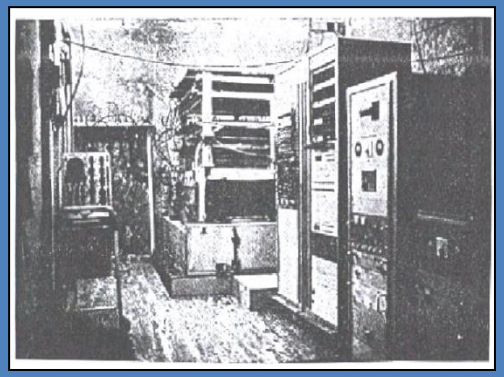
Two important examples:

- Pyramid of Chephren (Egypt)
- Pyramid of the Sun (Mexico)

S. Aguilar et al., *Search for cavities in the Teotihuacan Pyramid of the Sun using cosmic muons: preliminary results*, 33rd ICRC (2013), Rio de Janeiro, Brasil





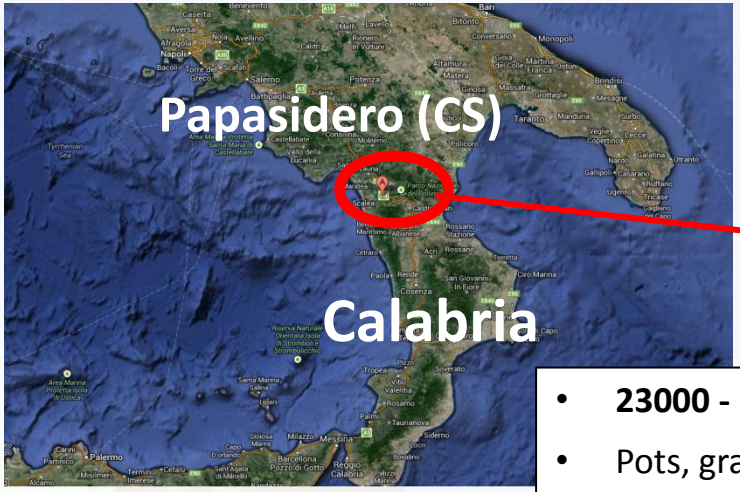


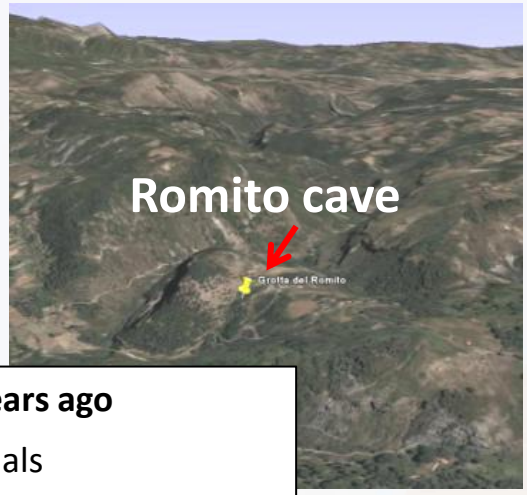
L.W. Alvarez et al., *Search for Hidden Chambers in Pyramids using Cosmic Rays*, **Science** 167, 832-839 (1970)

Muon absorption radiography in archaeology

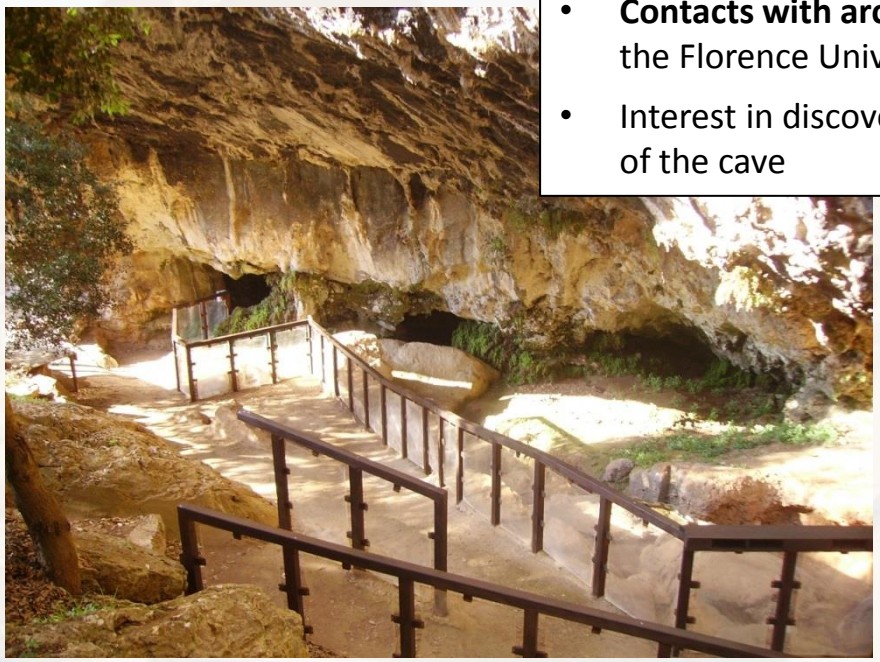
- Many possible locations to investigate around the world
  - Several cases in Italy: from prehistoric times
  - Examples of prehistoric sites in Italy:
    - Grotta d'Oriente in the Favignana island (Sicily); 14000 – 7500 years ago
    - Grotta del Romito near Papasidero (Cosenza, Calabria) one of the oldest evidences of prehistoric art in Italy and one of the most important in Europe
  - Example of a more recent site:
    - Tharros ruins and necropolis in the Sardinia island; Punic-Roman town
- Possible discovery of hidden chambers or tombs
  - Survey of unexplored parts of known sites
  - Useful especially when other common techniques cannot be exploited
  - Muon radiography makes possible looking for underground empty cavities

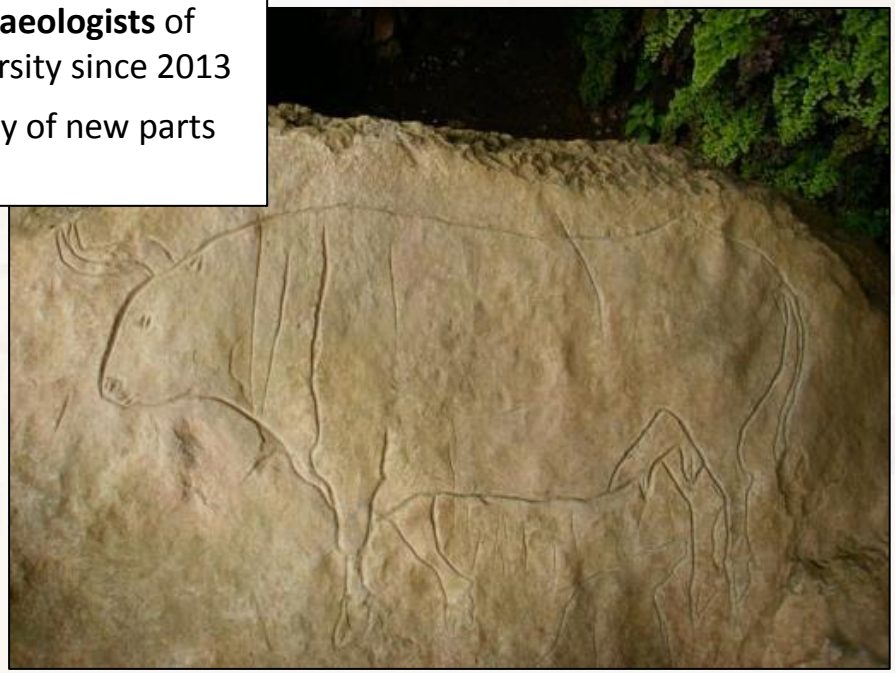
Grotta del Romito – Romito cave





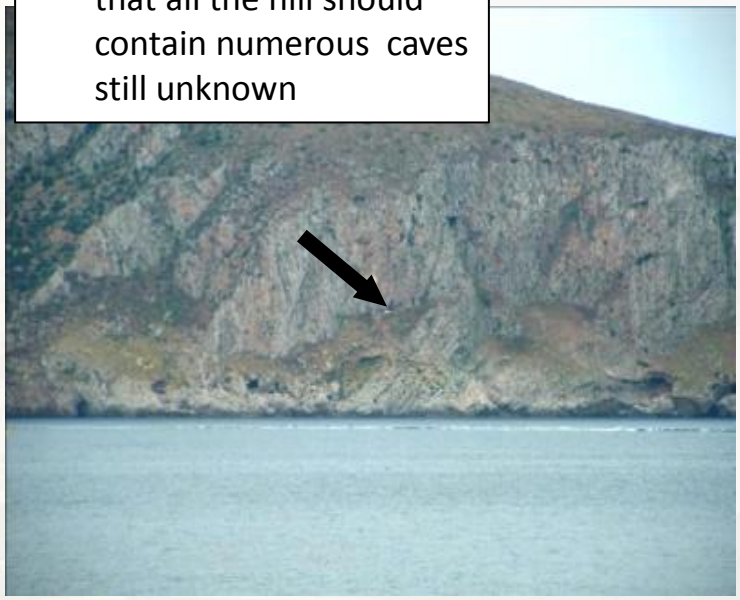
- **23000 - 10000 years ago**
- Pots, graffiti, burials
- **Contacts with archaeologists** of the Florence University since 2013
- Interest in discovery of new parts of the cave



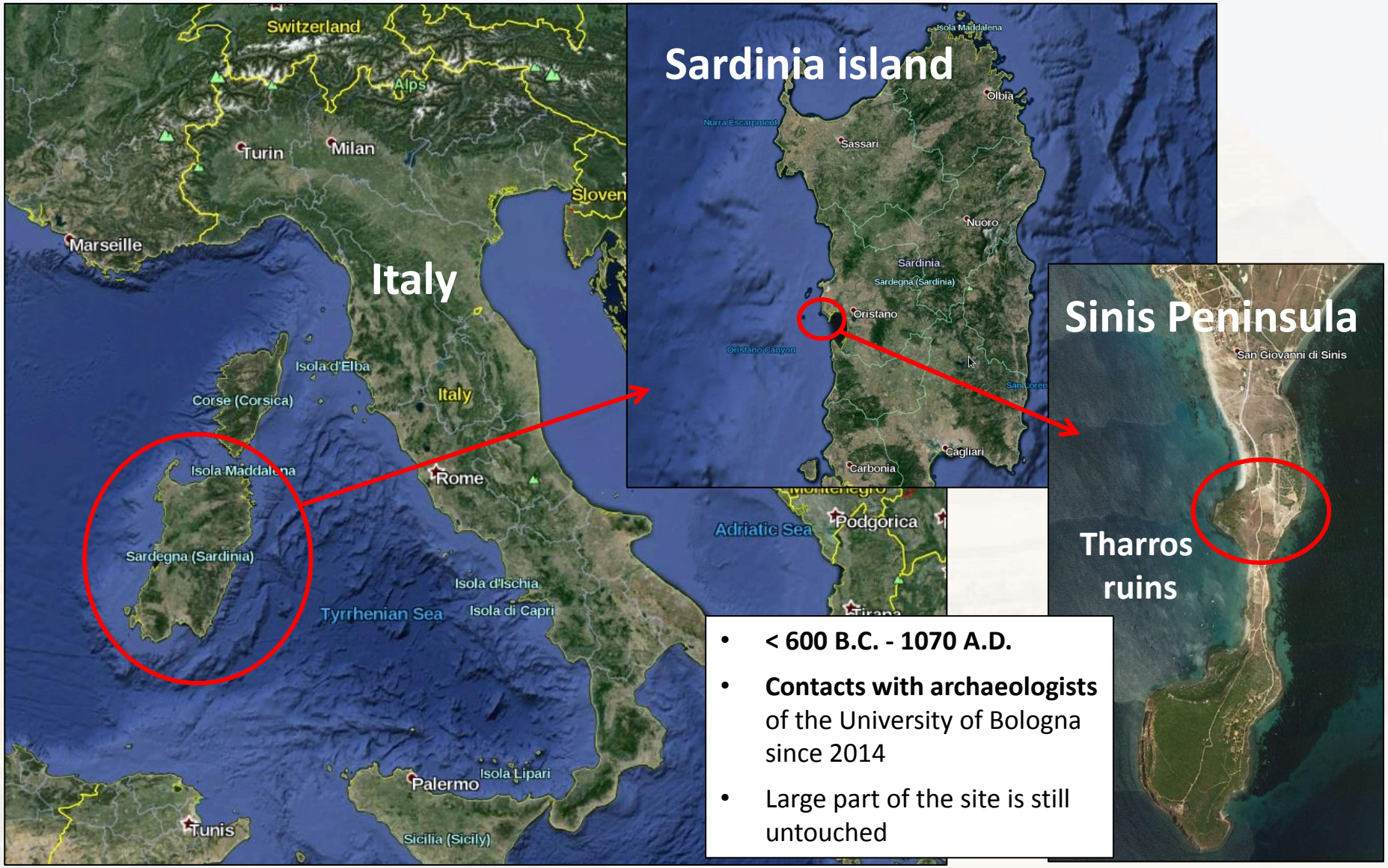


Grotta d'Oriente – Cave of the Orient

- **14000 - 7500 years ago**
- Burials
- Archaeologists think that all the hill should contain numerous caves still unknown



Location of the site of Tharros

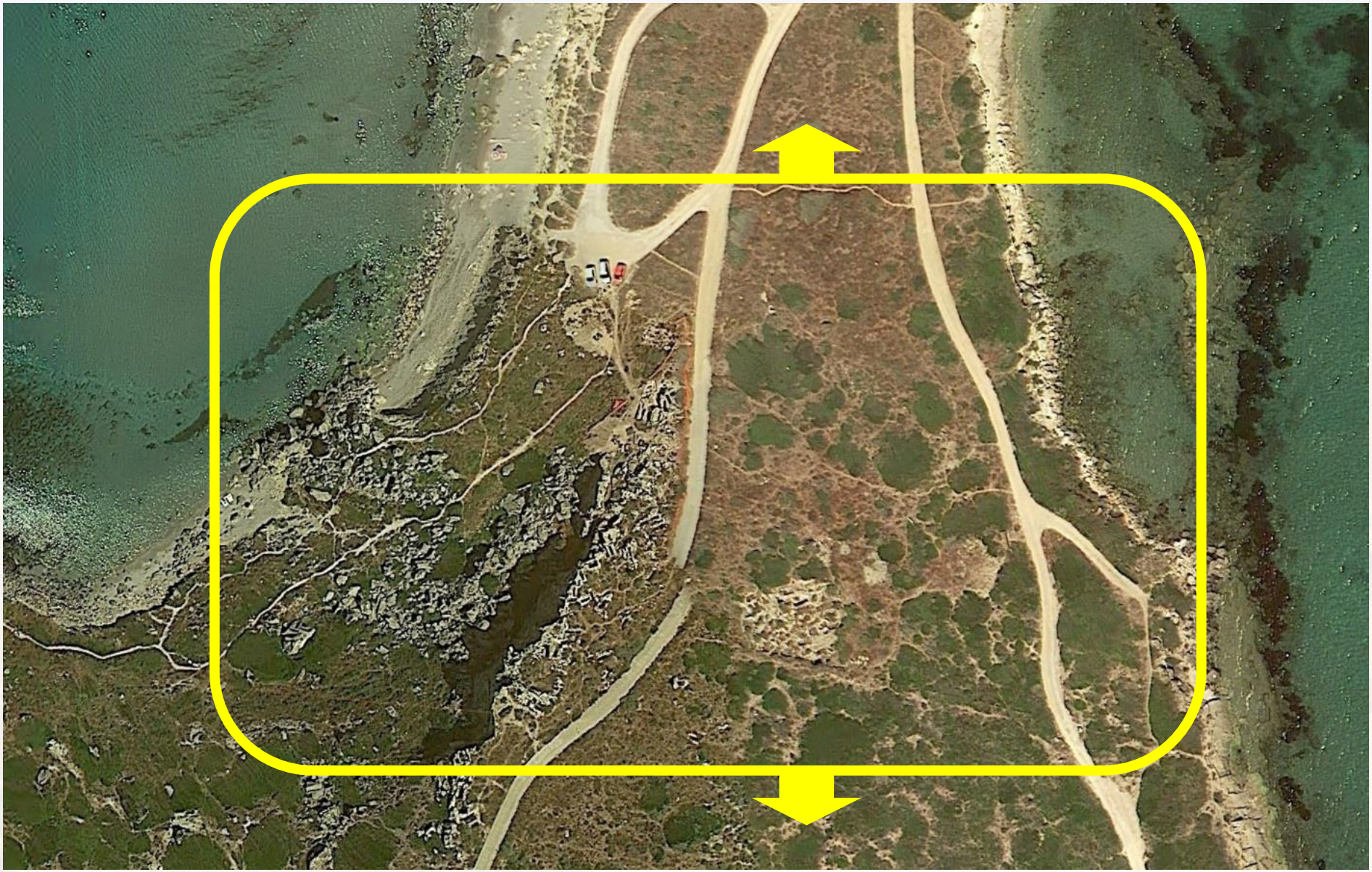


- **< 600 B.C. - 1070 A.D.**
- **Contacts with archaeologists** of the University of Bologna since 2014
- Large part of the site is still untouched

The Tharros ruins

This town was definitively abandoned around 1070 A.D. probably because the ground is subject to landslides

Unexplored parts



Motivations for muon radiography in Tharros

- Archaeology: necropolis of Punic age
  - Large parts of this location are not known and are thought to contain many **undiscovered tombs** (hopefully not looted by grave robbers)
  - Important information can be deduced by the **content of the tombs**

- Method: why using Muon Radiography
  - **Impossibility to use standard survey methods** like GPR (Ground Penetrating Radar) due to the vegetation (Mediterranean scrubs) that is safeguarded by the Italian law
  - **Empty tombs** with a volume of several cubic meters to be found in a few tens of meters thick soil

GPR in use

Examples of tombs in the Necropolis of Tharros

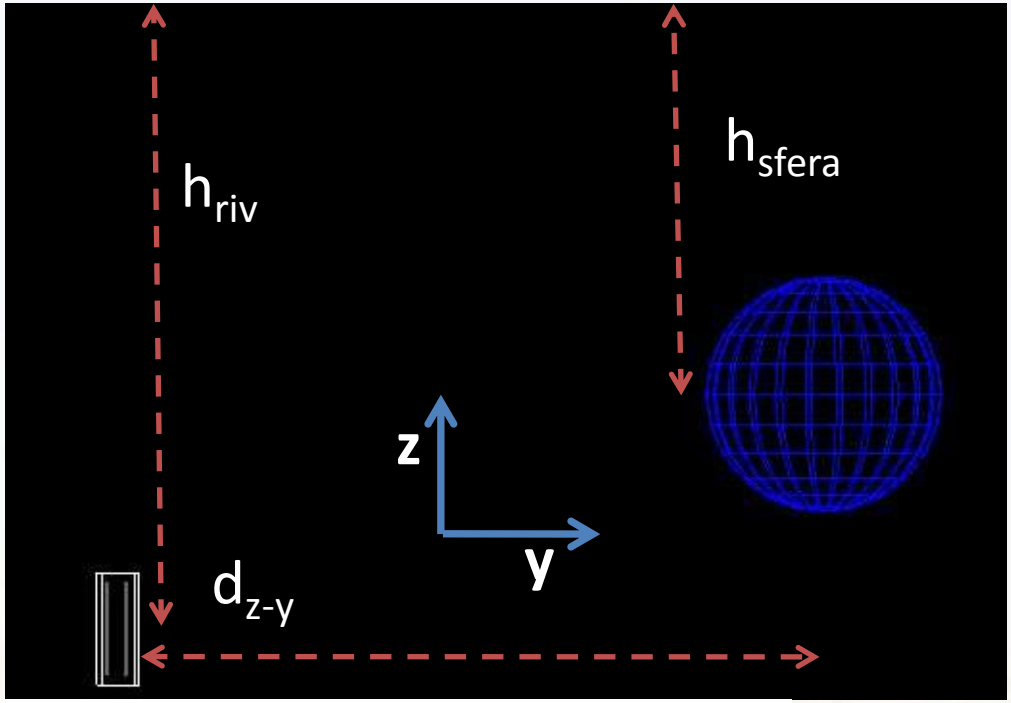
Location for the installation of a muon detector

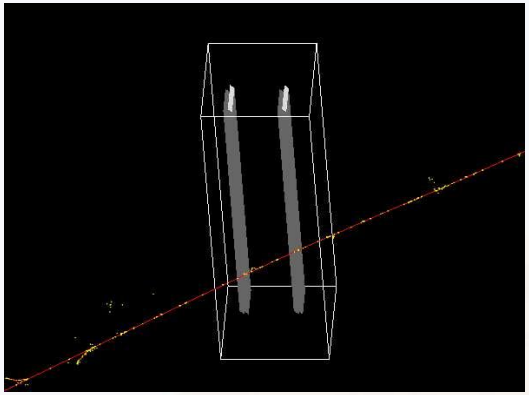
A closer inspection

First simplified simulations

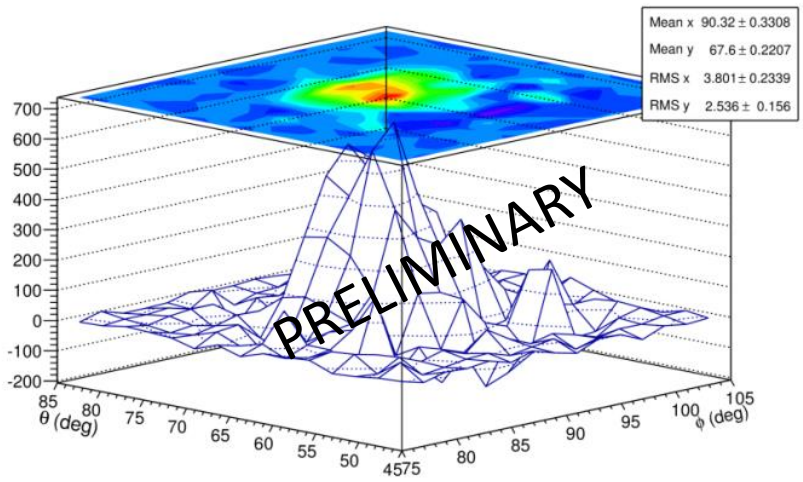
- Based on the GEANT4 package
  - Simplified implementation of detector geometry
    - Only acceptance has been considered
  - Realistic soil composition
    - Uniform density has been simulated up to now
  - Cubic or spherical cavities
    - 1 m^3 volume, 10 m far from detector
  - Realistic cosmic ray flux
    - analytic formula by prof. H. Tanaka
    - measurement at low energy by means of the ADAMO detector
  - Comparison of simulations with/without cavity

Very preliminary results





- h_{riv} = 10 m
- h_{sfera} = 7.5 m
- $d_{z\text{-}y}$ = 7.5 m
- R_{sfera} = 1.25 m (8m^3)
- ρ_{soil} = 1.5 g/cm^3

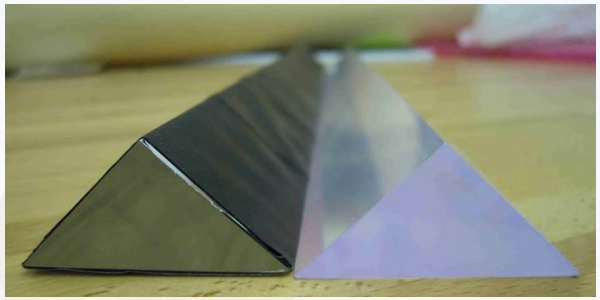


Preliminary result of the simulation of a 1 m^3 cubic cavity. The statistic is equivalent to a 90 days data acquisition.

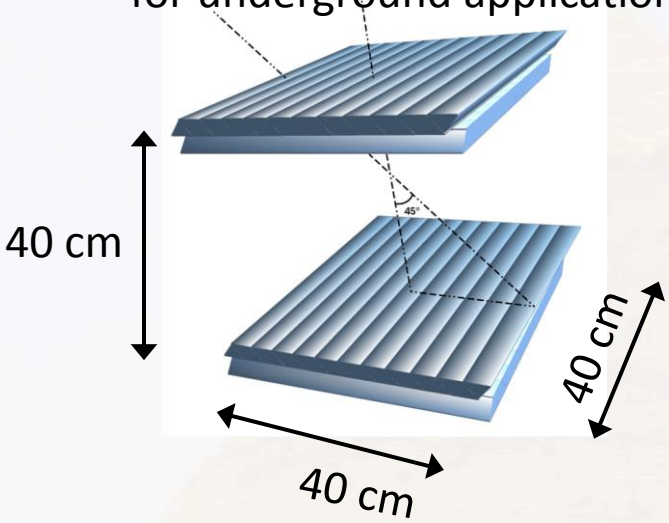
Small detector under development

Based on the Mu-Ray experience.

40 cm long triangular bars read by SiPMs, which are directly coupled to the good-quality scintillator.



Small size detector to be used for underground applications.



New 4x4 mm2 SiPM optimized for UV
(420 nm peak sensitivity) by AdvanCiD.
SMD package with protective epoxy glue layer.

ASD-NUV4S-P

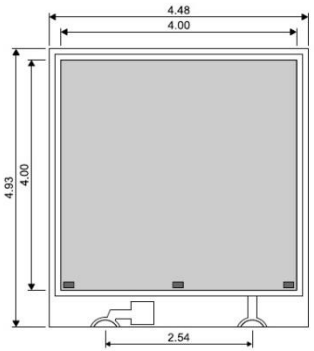
SMD package

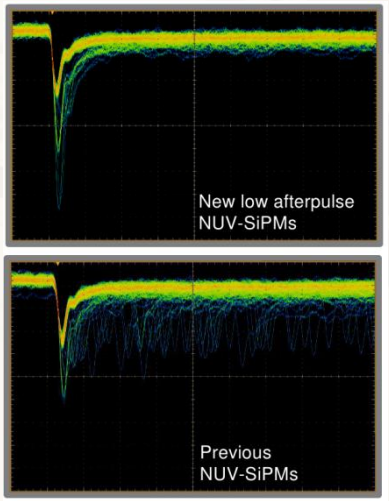
for SiPM 4x4 mm^2 active area size

Material: Black FR4 + transparent epoxy layer

SLIM PACKAGE

9440 cells





Conclusions

- Many possible applications of muon radiography in fields other than volcanology
- Some important cases in archaeology
  - In Italy: highlight → Tharros necropolis in the Sardinia island
- Preliminary simplified simulations
  - Based on GEANT4
  - Encouraging results
- Contacts with Italian archaeologists are well established
  - They are really interested to this tentative and can be ready to drill a real borehole in a short time!
  - A small cubic prototype detector is under development