23 April 2024

Experience with muon radiography in the mining field. Preliminary ideas for the MUSTAR POC

Lorenzo Bonechi (INFN – Florence)
on behalf of the INFN and UNIVERSITY muon radiography team in Florence (Italy)
lorenzo.bonechi@fi.infn.it

Topics

Muon, muography and activities of the Florence team

- Introduction
- Study of a mine: the MIMA-SITES project

The PoC for MUSTAR

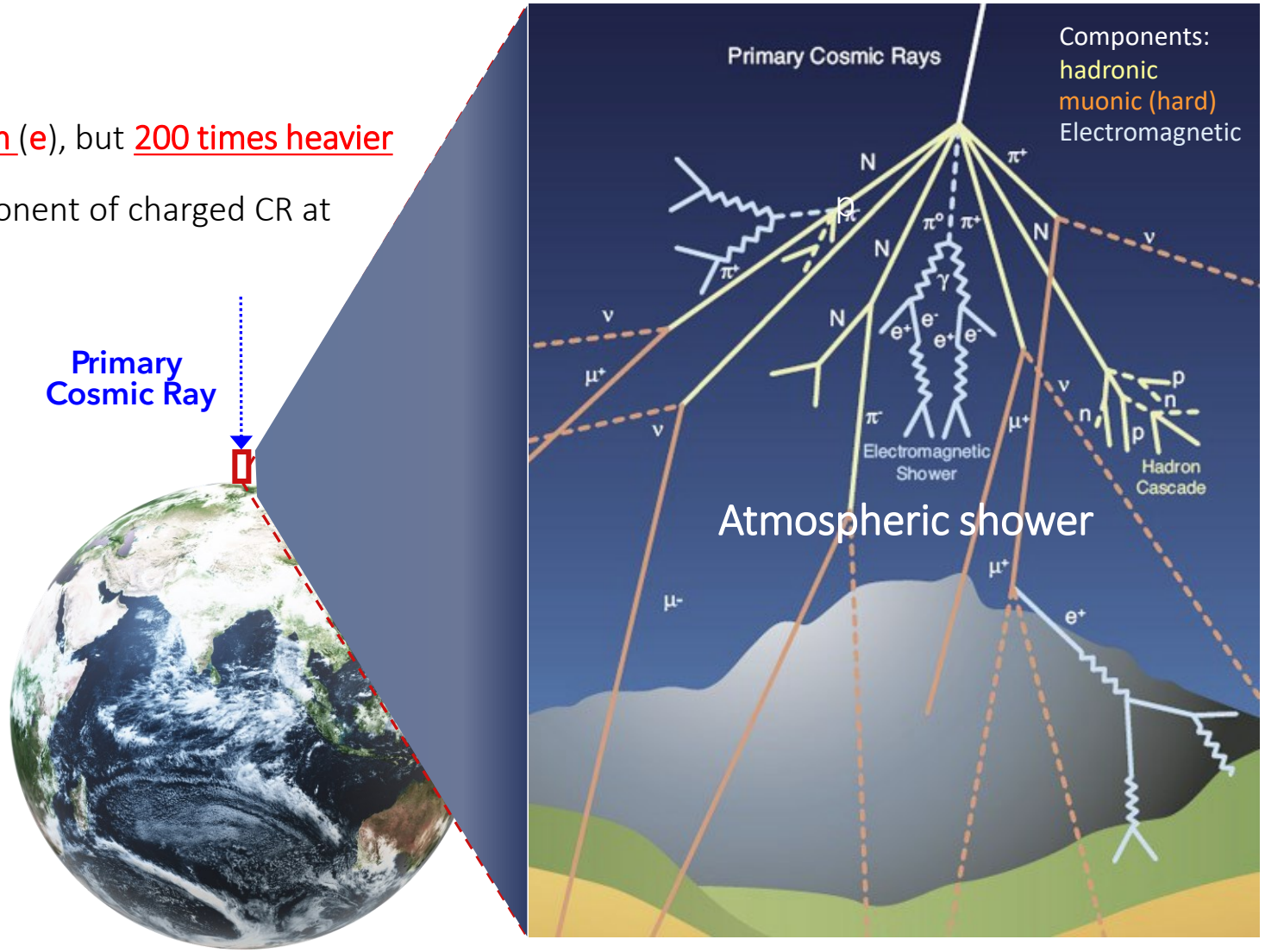
- Possible development of activities
- Status of preparation of the muographic apparatus

Introduction

Atmospheric muons

Muon (μ^+ and μ^-)

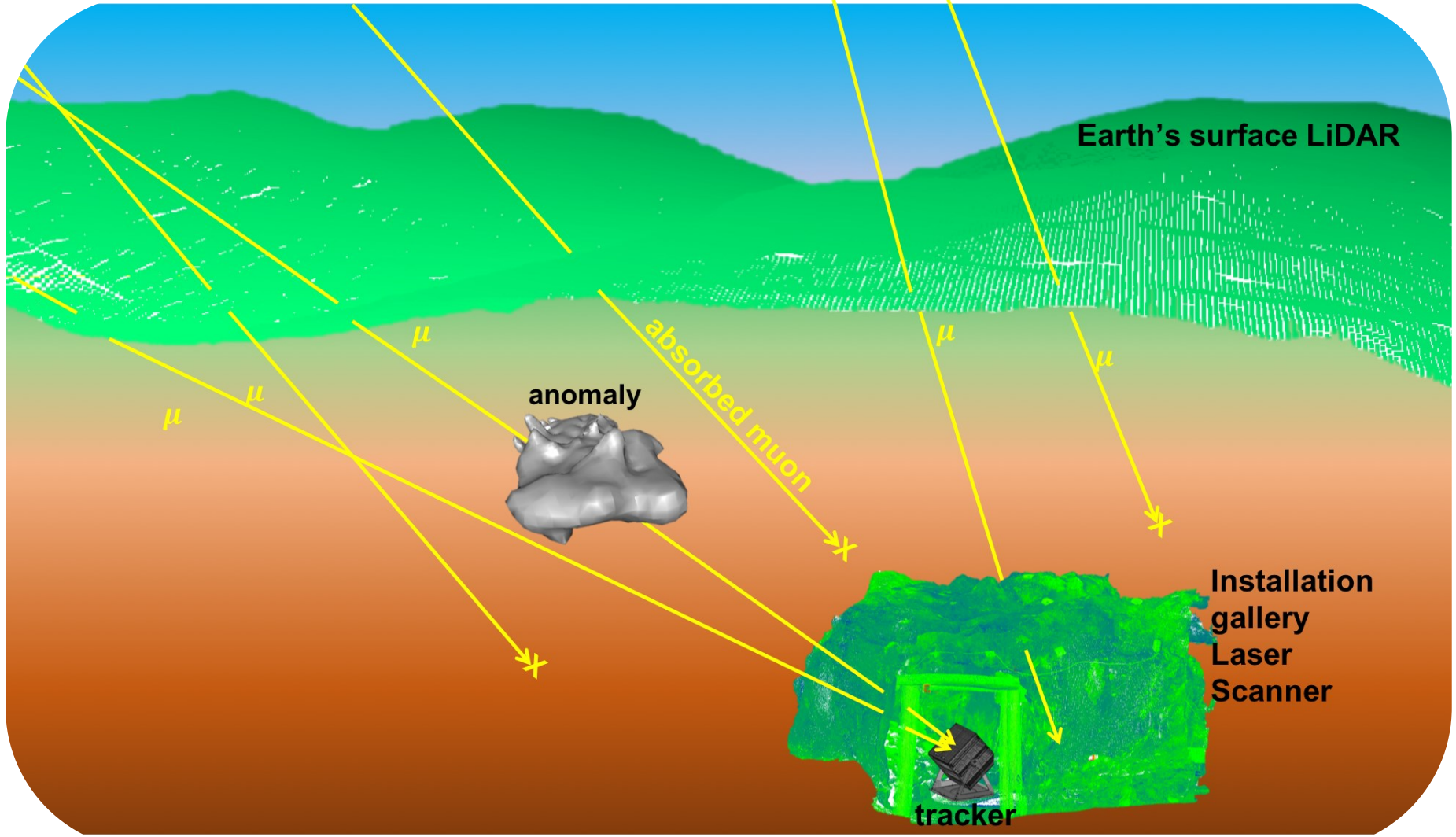
- Elementary particle similar to electron (e), but 200 times heavier
- It is the most abundant natural component of charged CR at ground level
  - ~150 $m^{-2}s^{-1}$ at Italian latitudes
- High energy
- Very penetrating natural radiation
- Not isotropic flux



Spark Chamber for outreach @ INFN Firenze

Introduction

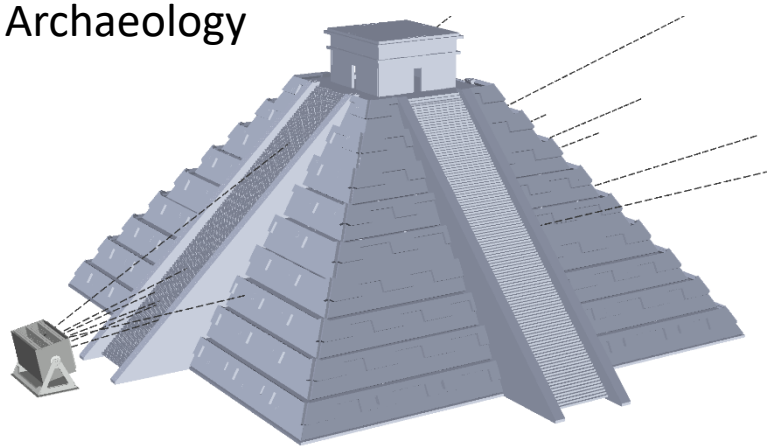
Large-volume radiographs using muons



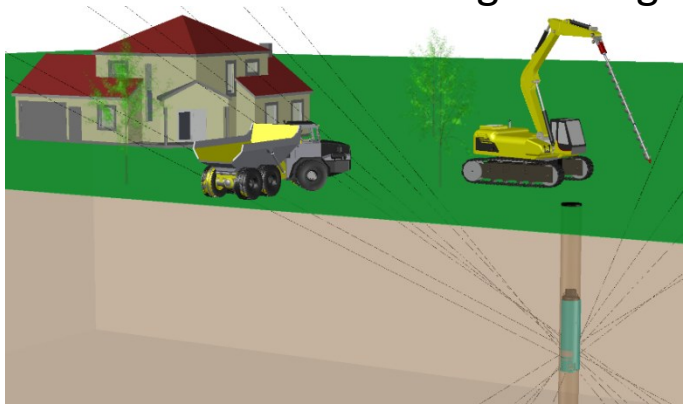
Introduction

Applications of muon trasmission radiography

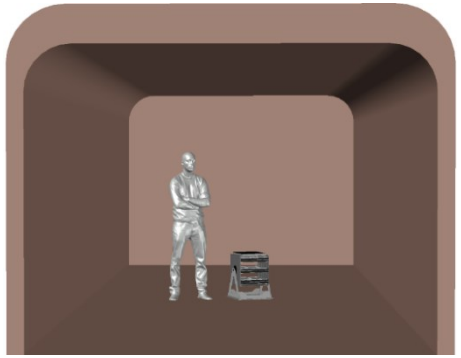
Archaeology



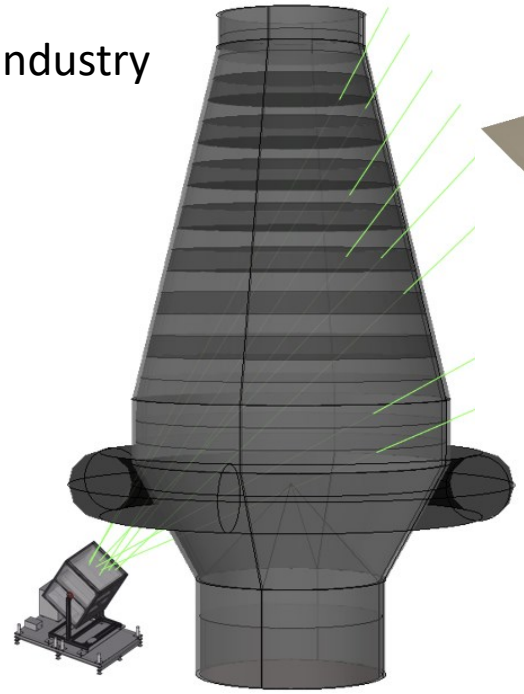
Civil engineering



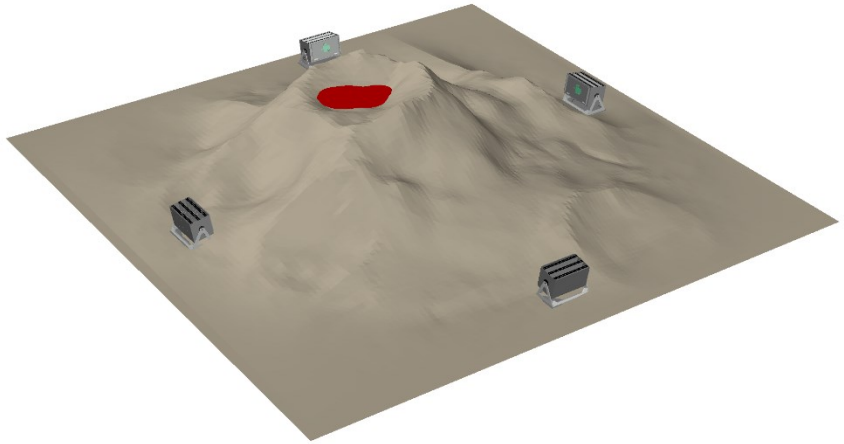
Tunnels/buildings



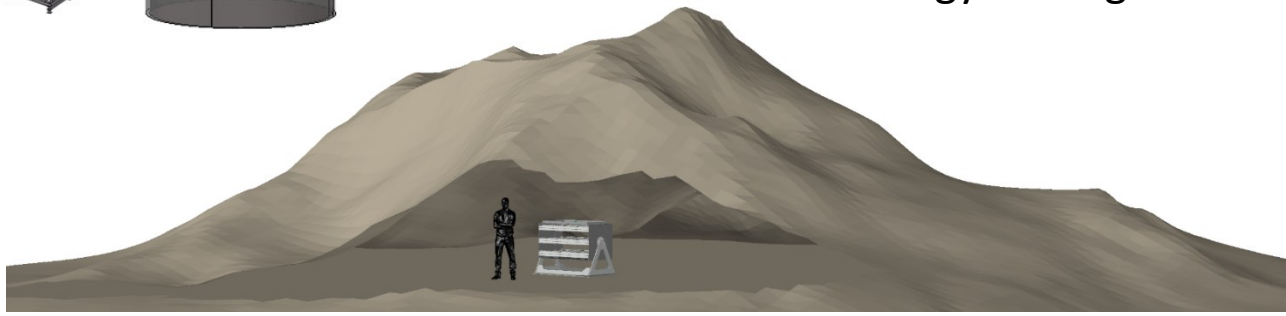
Industry



Volcanology



Geology-mining



Some experiences of the Florence team

Measurements and HW development

ON-SITE MEASUREMENT CAMPAIGNS

- MINING: 7 measurements carried out inside of a mine
- CULTURAL HERITAGE/ARCHITECTURE: 1 test measurement in a historical building
- CIVIL ENGINEERING: 3 measurements carried out inside the inspection tunnel of a dam
  2 in front of river embankments
- INDUSTRY: 2 detectors currently measuring in an industrial site in Europe
  1 measurement carried out outside of Europe
- VOLCANOLOGY: on-going measurement
- ARCHAEOLOGY: 1 measurement completed in an Etruscan necropolis

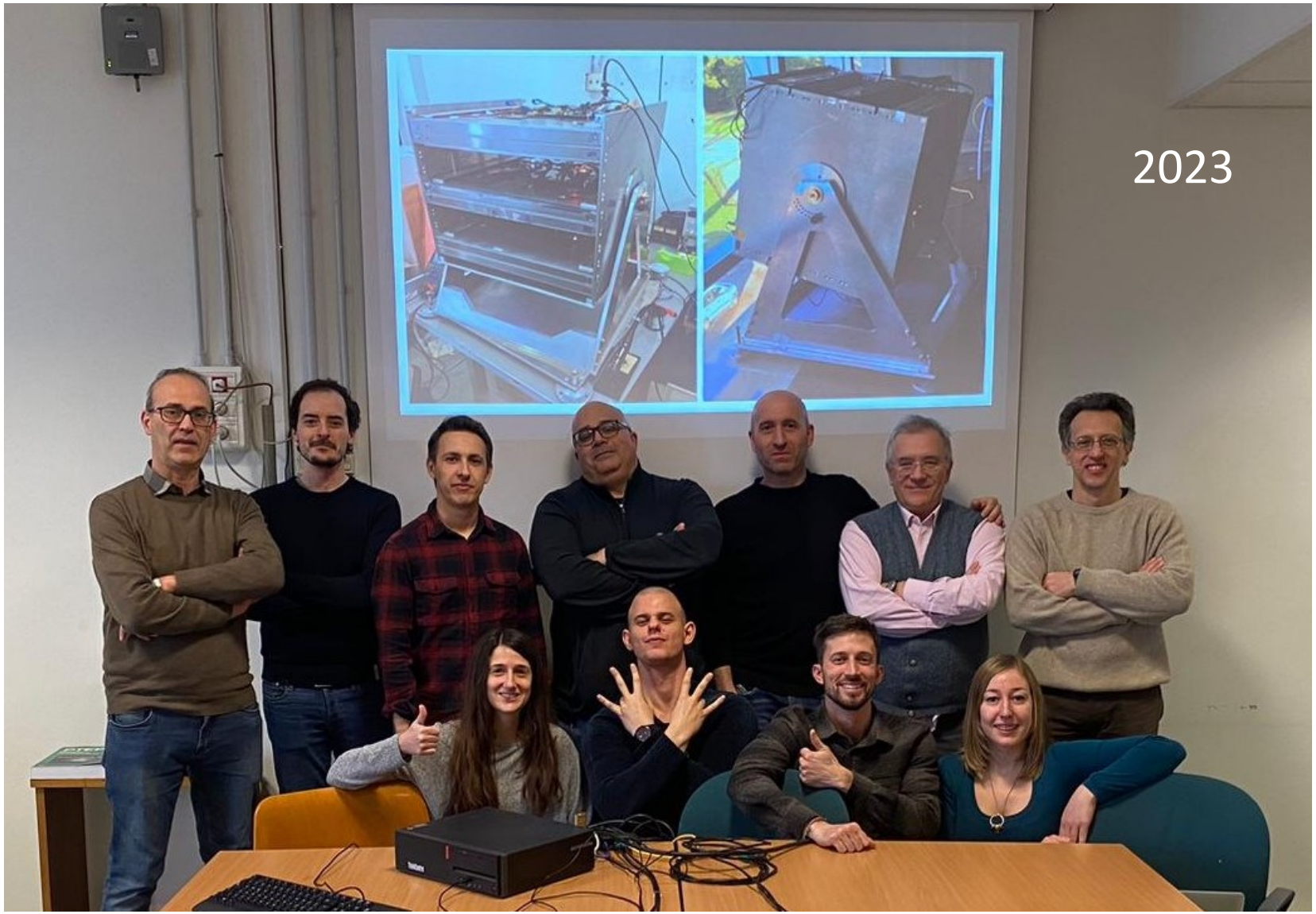
DETECTOR DEVELOPMENT

- S : 40x40 cm^2 (in use)
- M : 64x64 cm^2 (in use)
- L : 80x80 cm^2 (in use)
- XL : 100x100 cm^2 (in use)

- Low power (<100W)
- Low Voltage
- Light and rugged
- Remotely controllable
  - Real time analysis

Some experiences of the Florence team

The Florence INFN-UNIFI muography team



Study of a mine

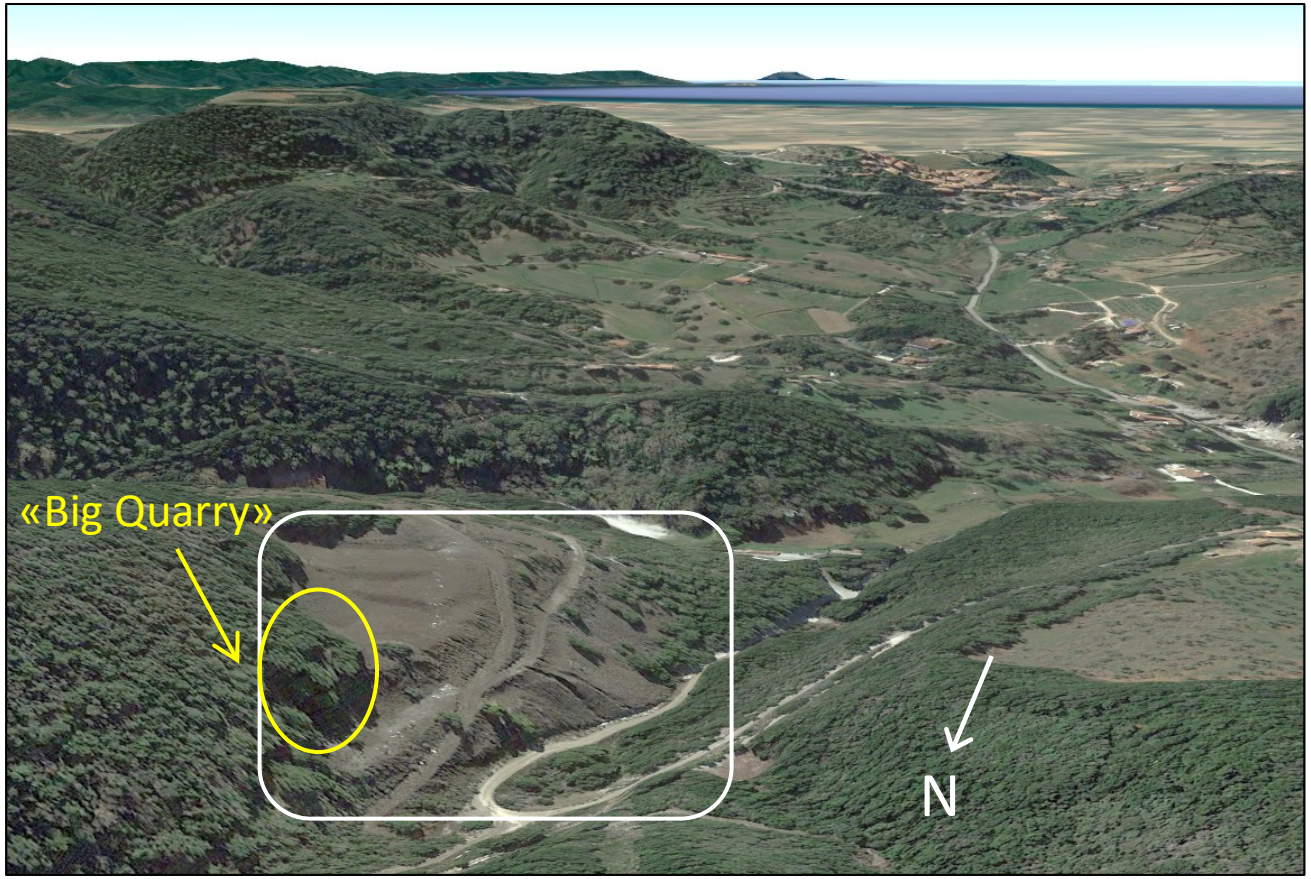
Activities and results from a similar application: the MIMA-SITES project

The MIMA-SITES project @ the Temperino mine

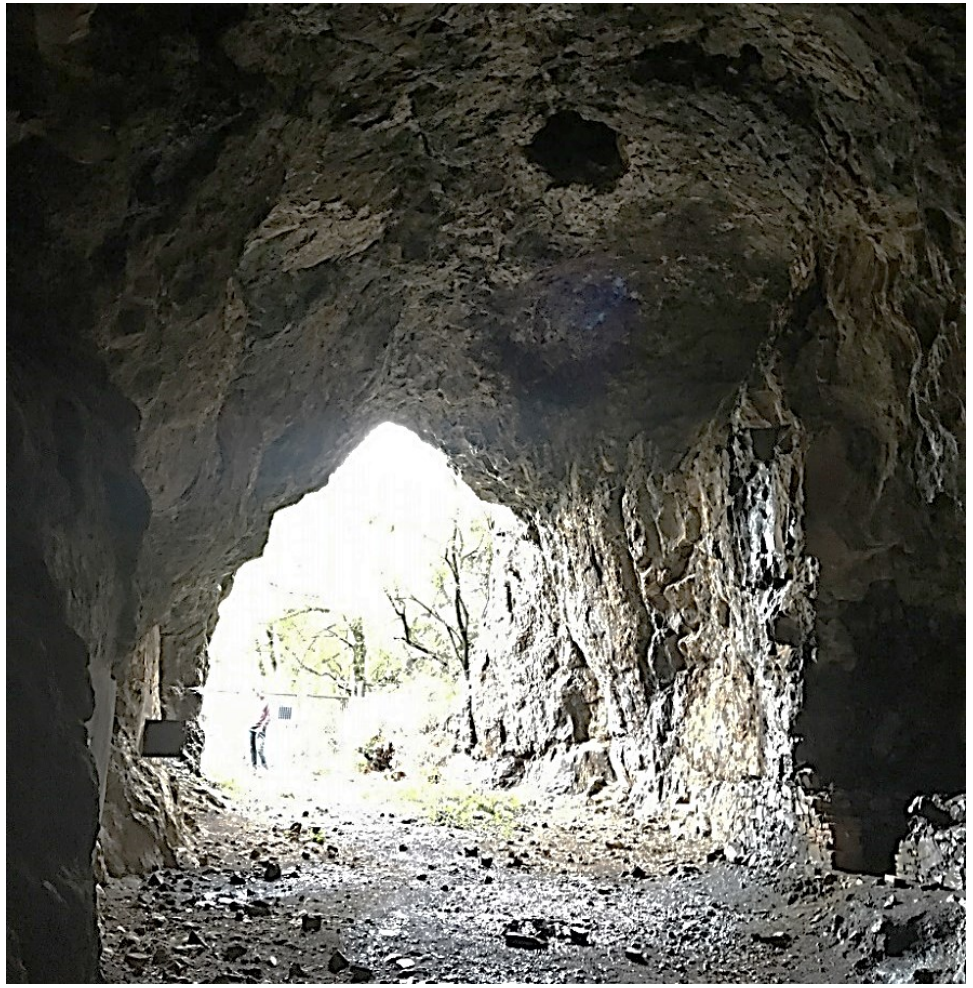
*Application of the **M**uon **IMA**ging technique in archaeological and mining **SITES** of touristic and historical interest for the evaluation of cultural and safety aspects*

The MIMA-SITES project

View of the site – Temperino mine

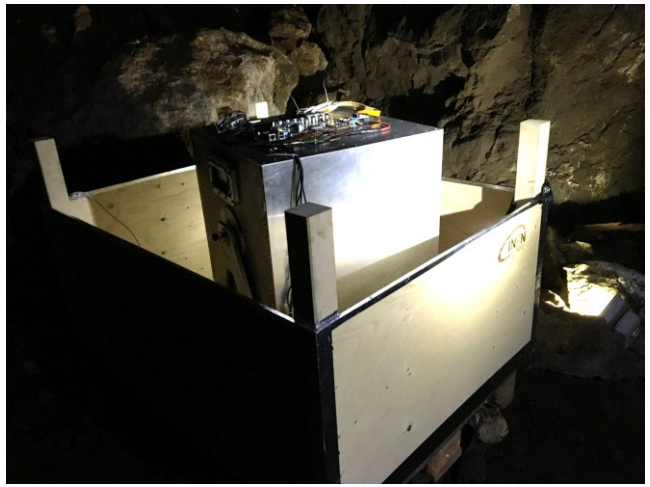


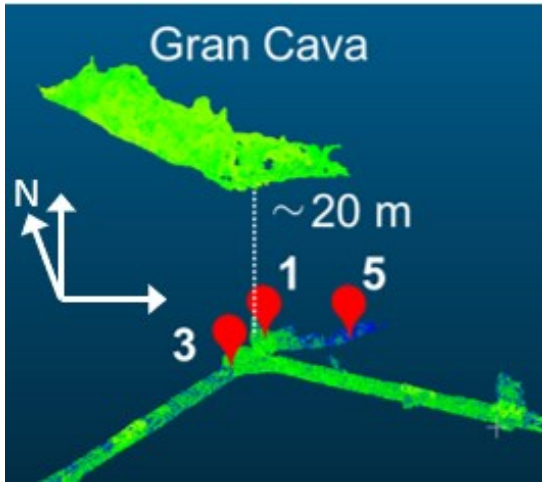
The «Big Quarry» (Gran Cava in italian)

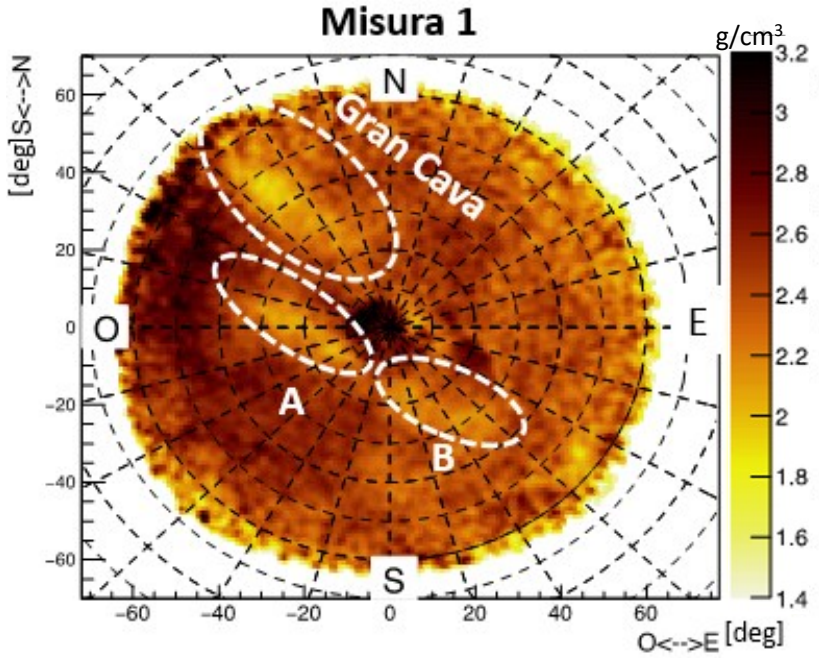


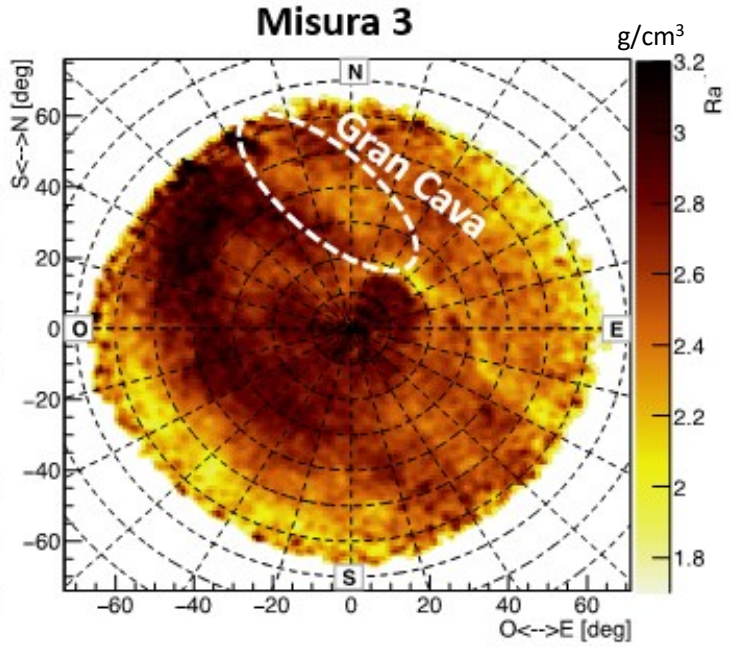
The MIMA-SITES project

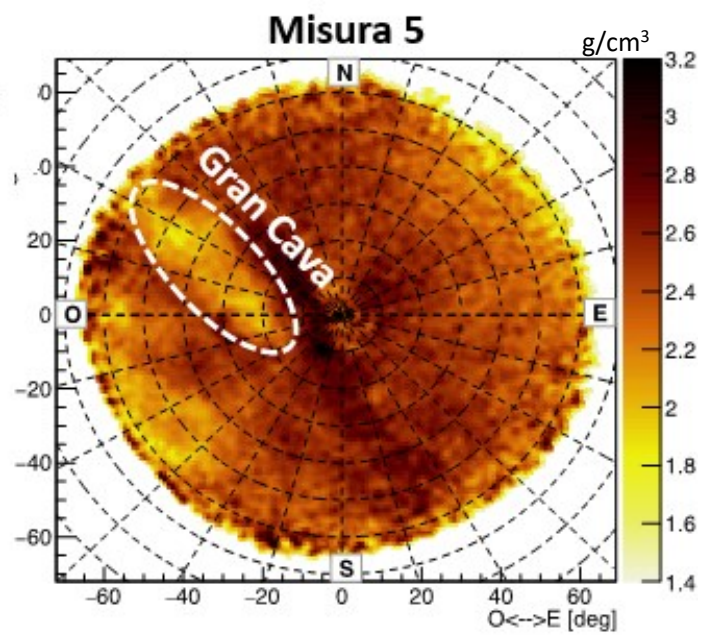
Results: 2D angular distribution of the average density from three points of view





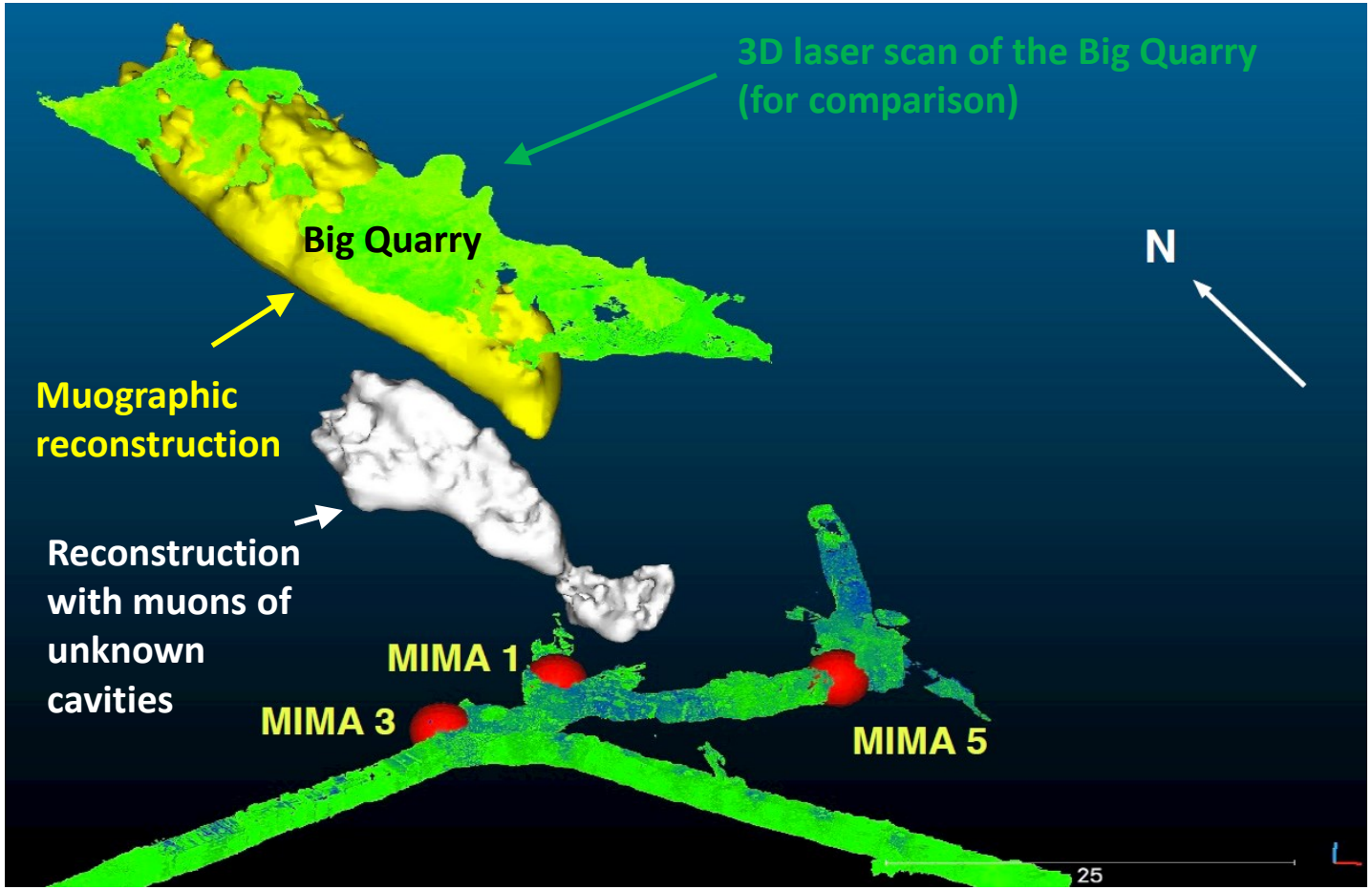




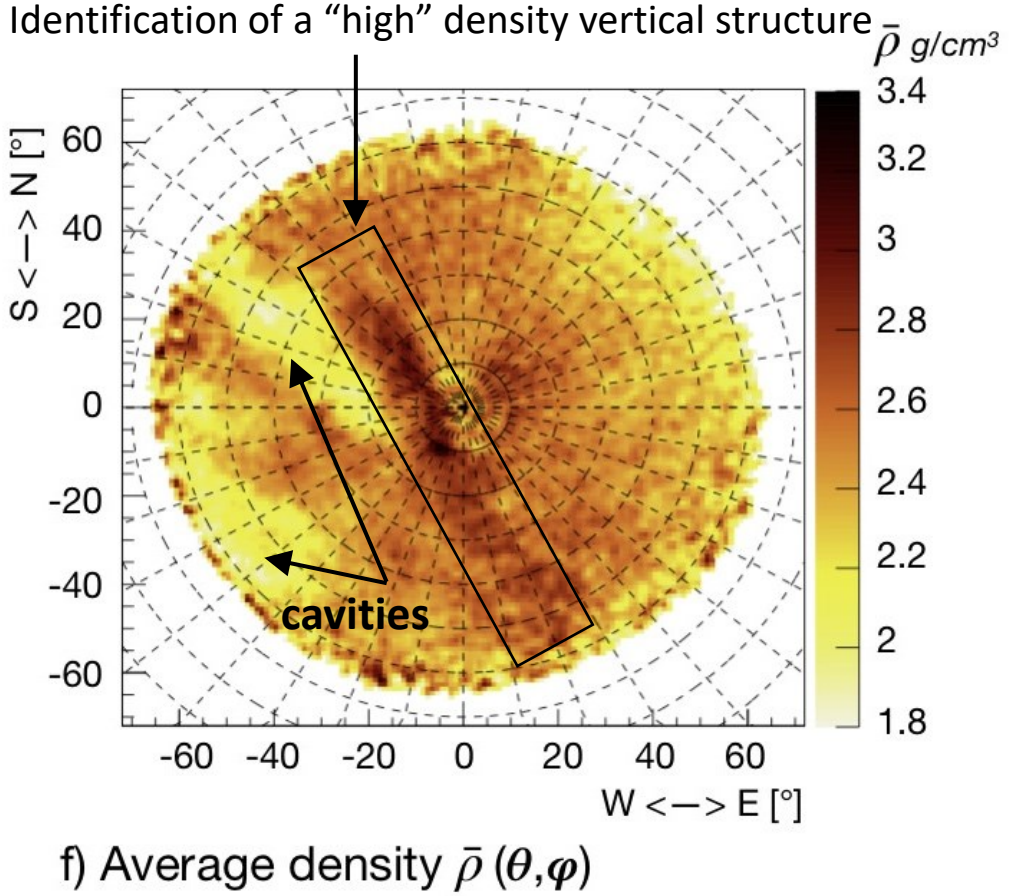


The MIMA-SITES project

From 2D to 3D: cavities and «high» density deposits

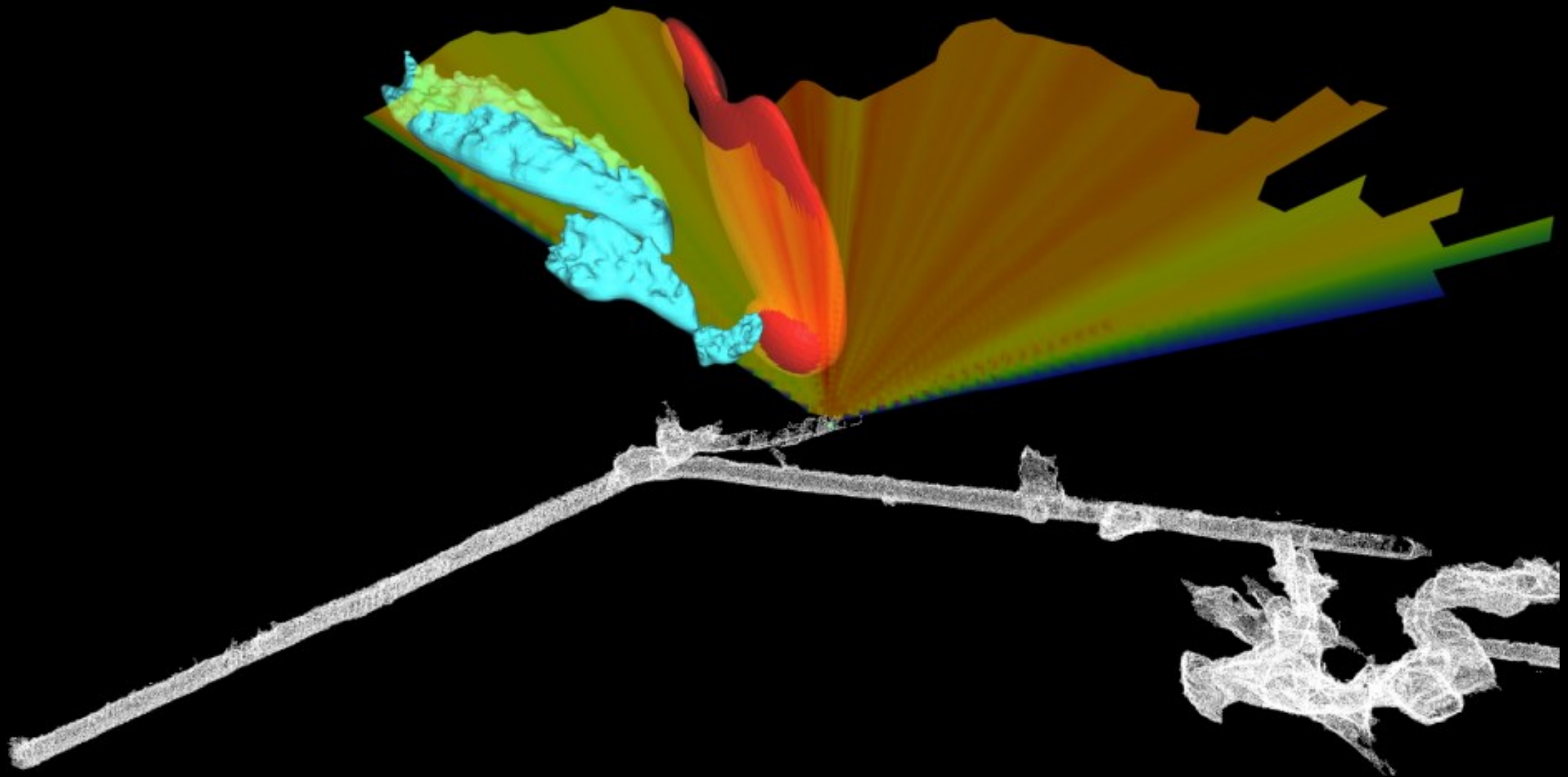


Identification of a “high” density vertical structure

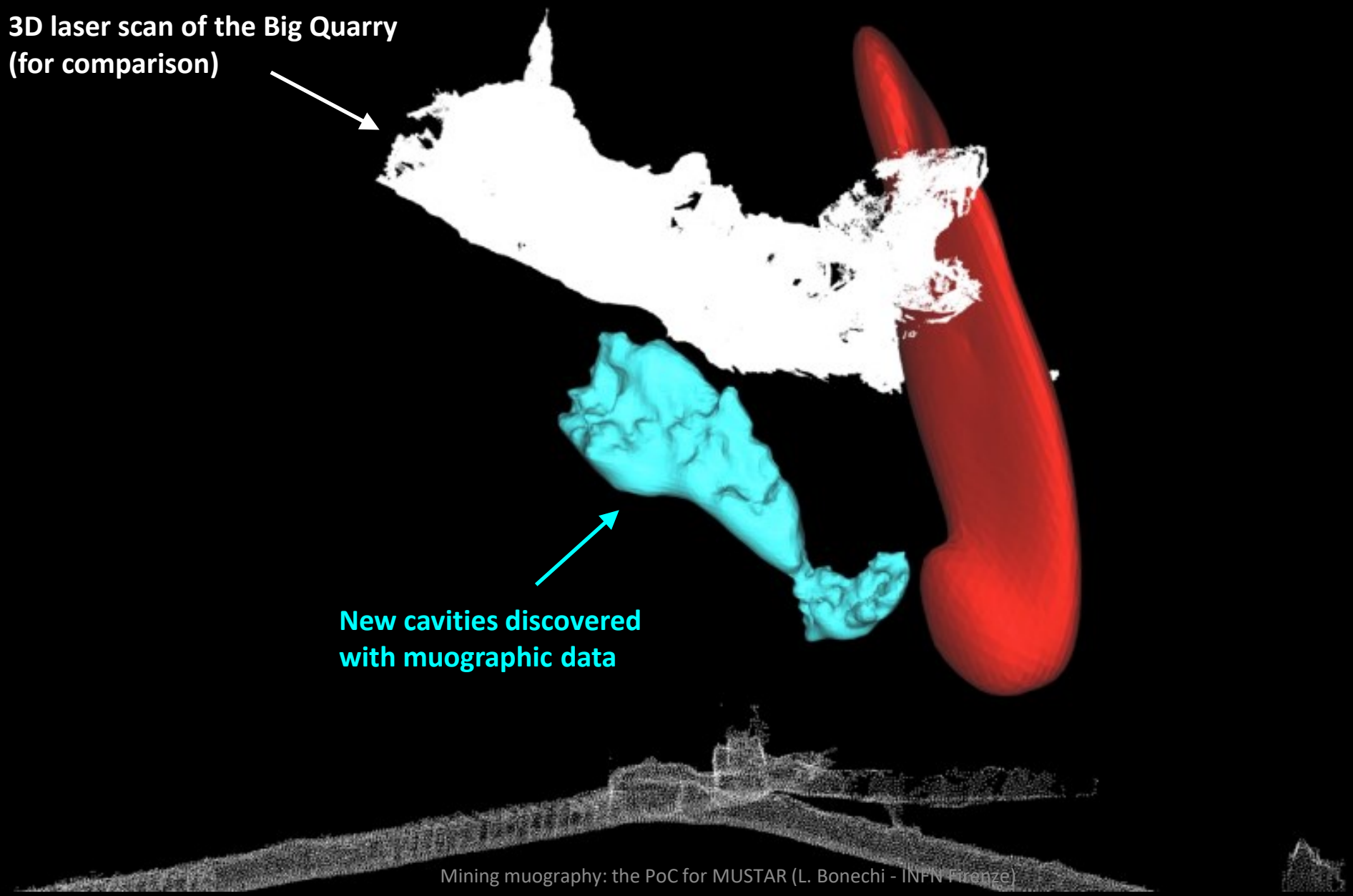


f) Average density $\bar{\rho}\,(\theta,\varphi)$

3D reconstruction of a (sub)vertical dense material deposit located over the detector’s istallation point (red volume)

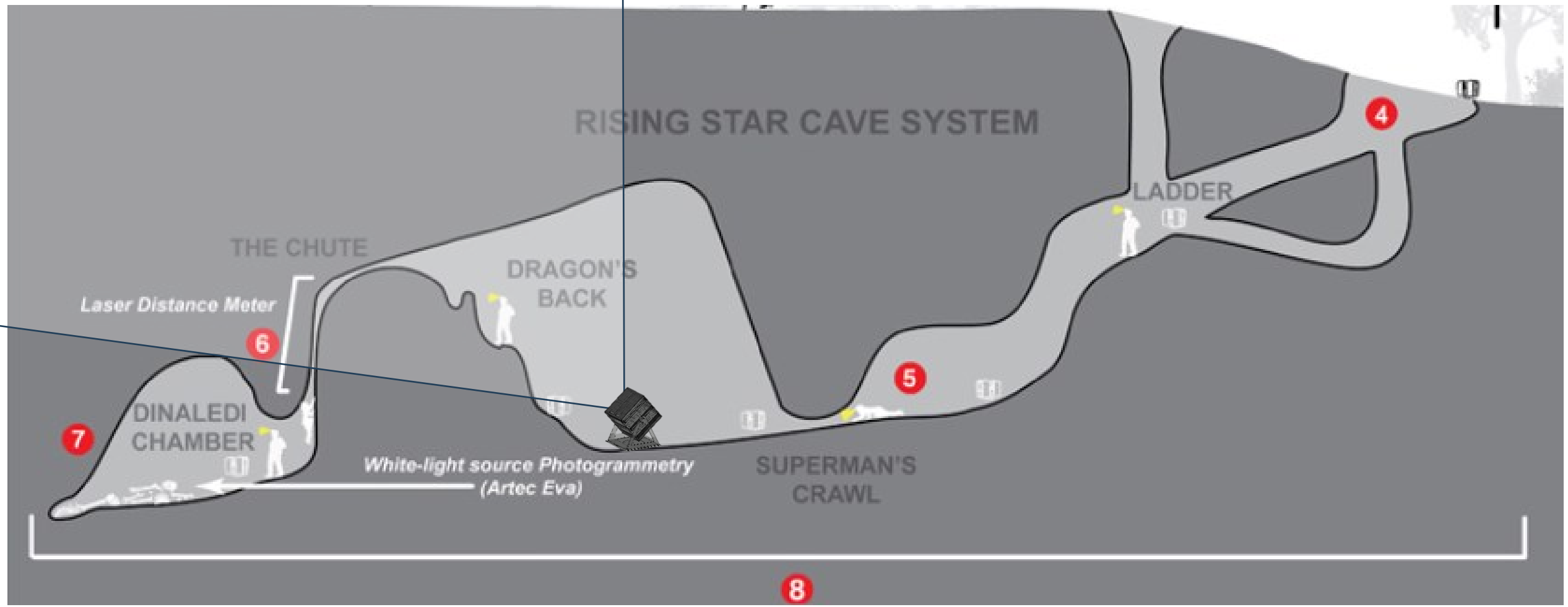


3D reconstruction of a (sub)vertical dense material deposit located over the detector's istallation point (red volume)



Analogies with the MUSTAR project

Survey at the Rising Star cave in the Cradle of Humankind



The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

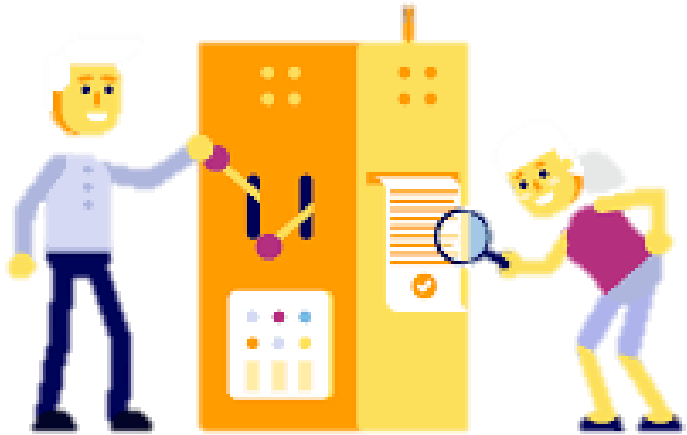
1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy



The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

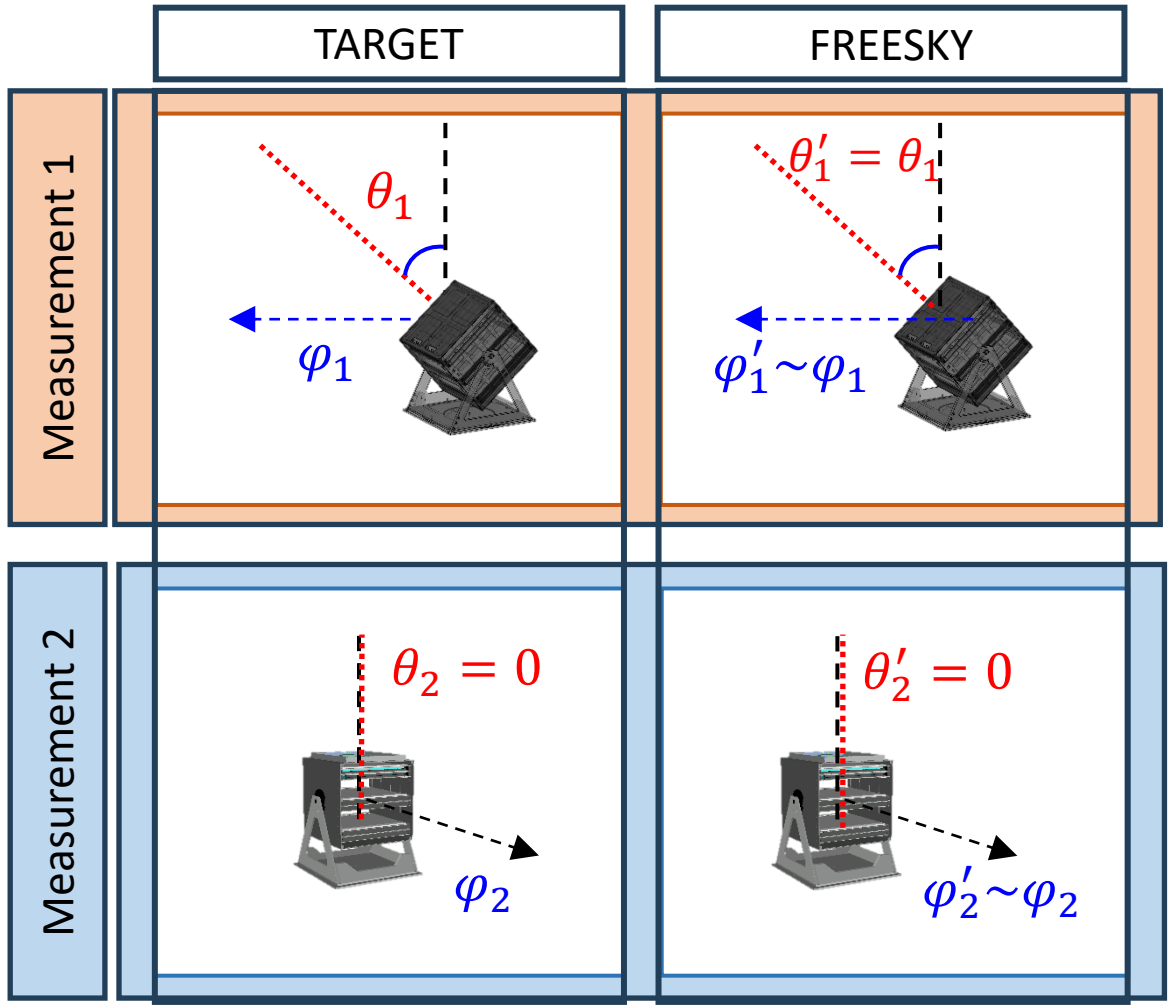
1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy



The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Preliminary evaluation of the necessary steps

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits
3. Test of detector and training of operators at iThemba Labs or Wits
   - Two people from Italy for 1 week
4. Implementation of two free sky measurements
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration
5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. Implementation of two measurements
   - One oriented towards the lateral wall
   - One oriented along the vertical direction
7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

The PoC for MUSTAR

Estimation of the duration of activities

Hypothetical development of activities:

1. Delivery of instrumentation to South Africa
2. Arrival of instrumentation to iThemba Labs or Wits

→ 2 weeks ??

3. **Test of detector and training of operators at** iThemba Labs or Wits
   - Two people from Italy for 1 week

→ 2 weeks

4. **Implementation of two free sky measurements**
   - Selection of appropriate installation points
   - One reference measurement for each foreseen measurements at Rising Star, in the same geometrical configuration

→ (3 weeks) × 2

5. Transportation of the instrumentation to the site
   - Three people from Italy for 1 week to coordinate and help with 1st installation
6. **Implementation of two measurements**
   - One oriented towards the lateral wall
   - One oriented along the vertical direction

→ (6 weeks) × 2

7. Transportation of the instrumentation back to iThemba Labs or Wits
8. Delivery of the instrumentation to Italy

→ 2 weeks ??

→ 24 weeks → 6 - 8 months

The PoC for MUSTAR

Status of the instrumentation

Previous situation ….

… and current situation

The PoC for MUSTAR

Status of the instrumentation