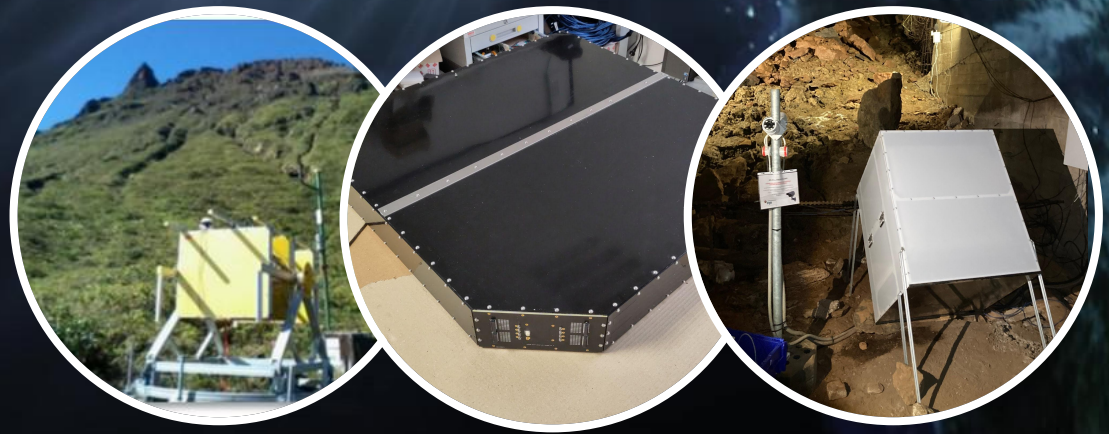
MUODIM

Absorption muography for disused mining site stability

muodim.com

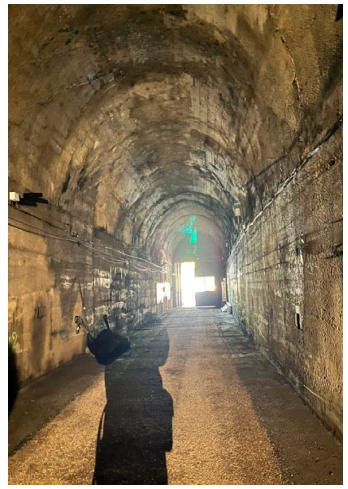


Alistair Boyce | Data Scientist | Muographers 2026

Context and Objectives

Global context:

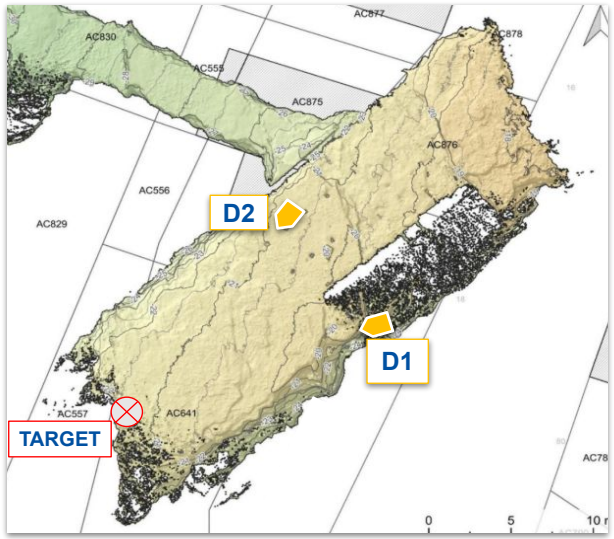
- Client is responsible for monitoring a former iron mine that has long been closed.
- Two significant ground movements (1950s & 2020s): caused localised surface subsidence & roof collapse of principle gallery.
- Inhabited zone, with relatively high land prices.



Outstanding questions:

1. Is the gallery at **risk of future collapse**; is the rock fractured? What is the geology above the area?
2. **Risk mitigation**: Demolish the houses above the area or to reinforce the area with concrete?
3. Can muography map the area between the gallery ceiling and the surface to **map the geological structure** (static).

Position of detectors in the gallery



D1 - Gaseous Detector - MicroMegas - “MM”
D2 - Plastic/Fibre Detector - Scintillator - “SC”

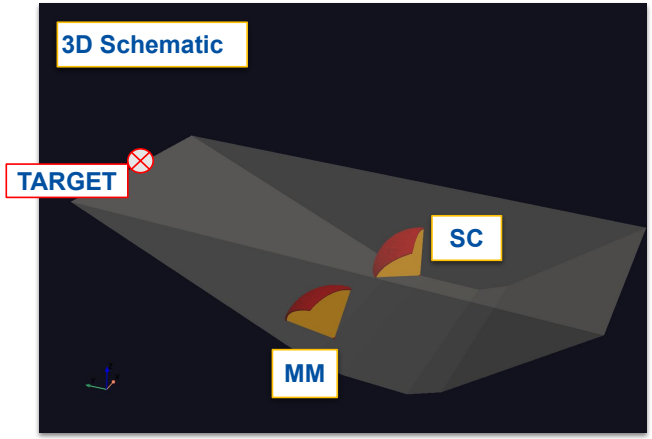
Rear view - D1 - MicroMegas - “MM”

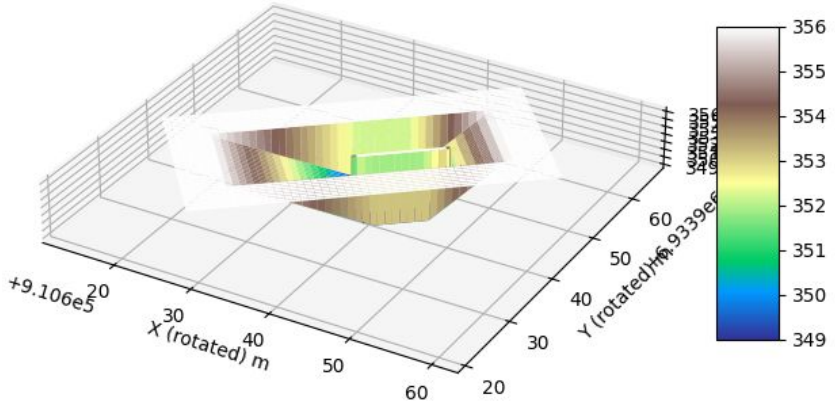
Rear view - D2 - Scintillator - “SC”

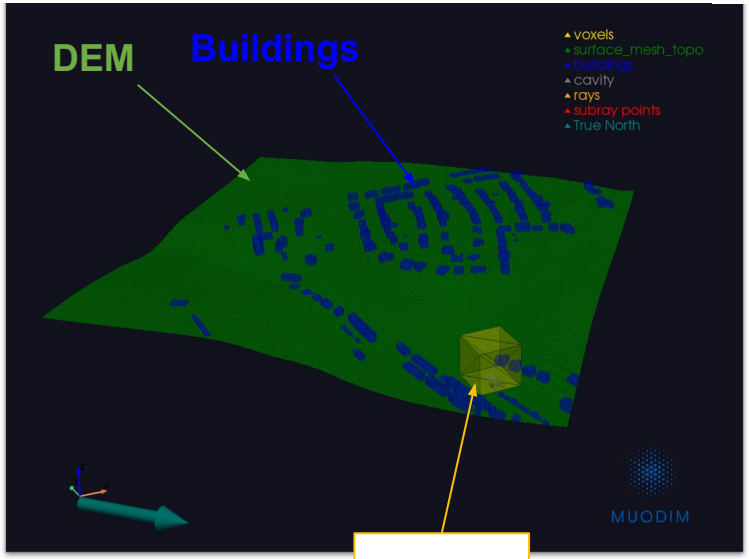
- Two IRIS detectors (MicroMegas – “MM” & Scintillator – “SC”) installed in July 2025, pointing towards the target volume with a “binocular” view.
- To our knowledge, this is the **first combined use** of gas and plastic detectors in 3D muon tomographic imaging.

Inputs to tomographic imaging

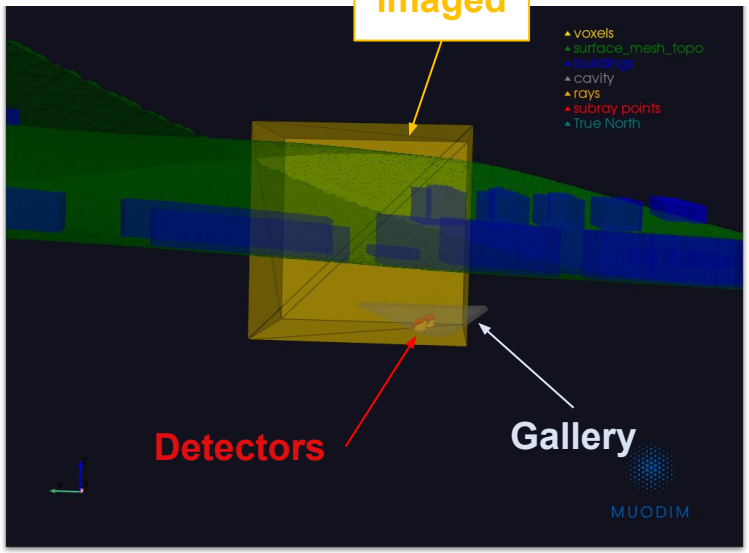
Source: geoservices.ign.fr







Volume imaged



- Digital Elevation Model (DEM) and building height model sourced from geoservices.ign.fr. Geographic Information System (GIS) software used to construct a gallery model.
- The imaged volume (yellow cube) is positioned relative to the sensors, the gallery, the DEM, the buildings and the target.
- Ray tracing used to calculate the distance travelled by the muons within the gallery, DEM, buildings.

Calibration - MicroMegas & Scintillator

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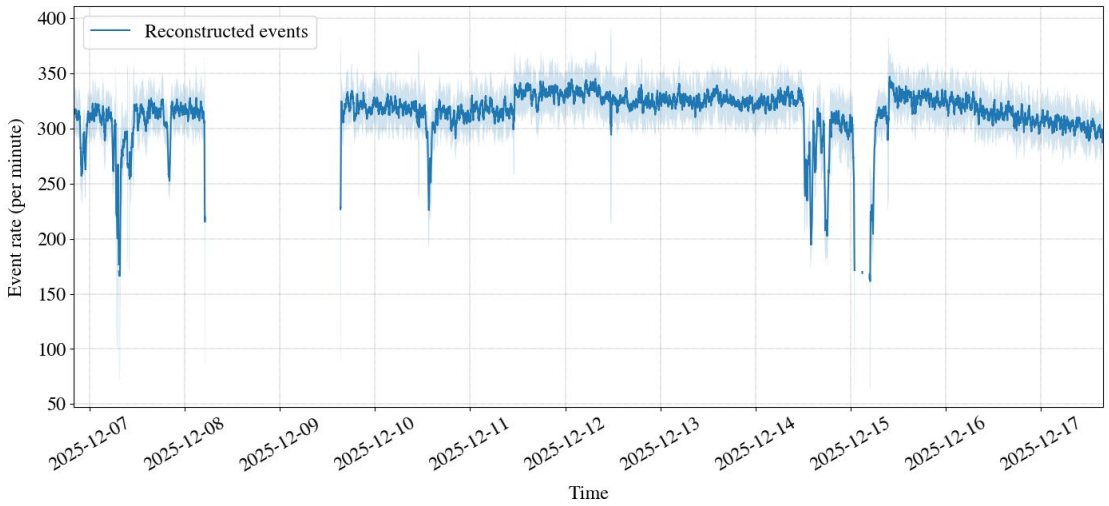
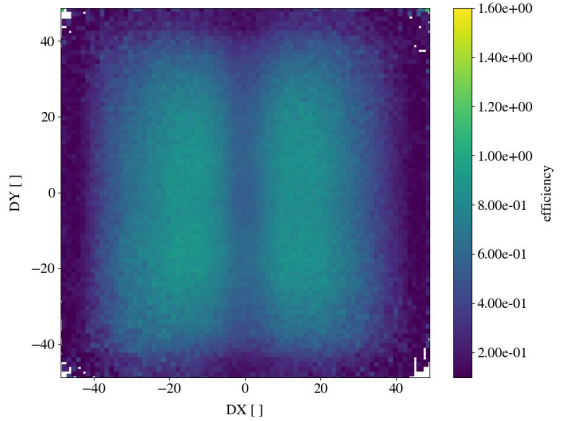
MicroMégas

Muons per minute



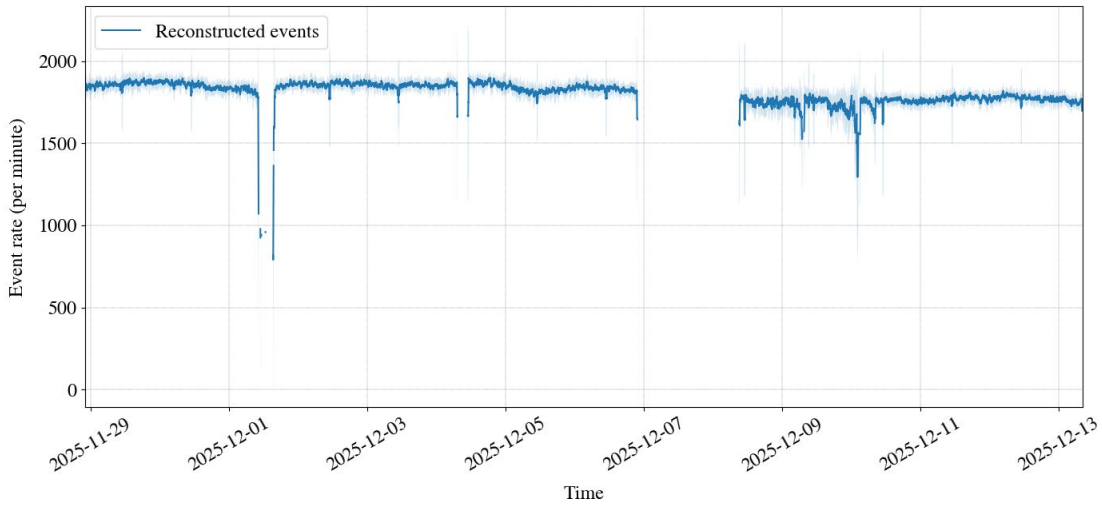
Sensitivity



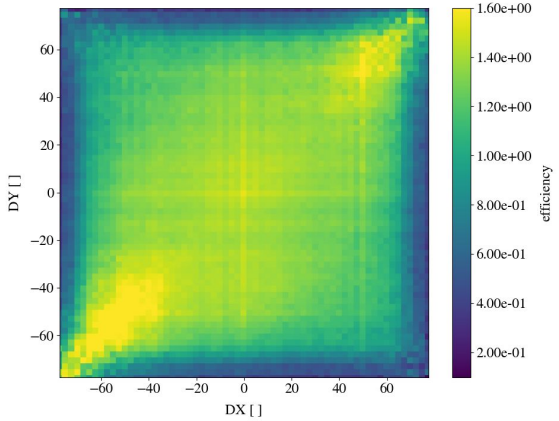
- 50cm x 50cm detection surface
- 9 day duration
- 4 183 777 muons
- Stable flux and sensitivity during calibration

Scintillator

Muons per minute



Sensitivity



- 80cm x 80cm detection surface
- 13.7 day duration
- 32 675 778 muons
- Stable flux and homogeneous sensitivity during calibration

- For operational reasons, final instrument calibration was conducted immediately after the field deployment

Data collection - MicroMegas & Scintillator

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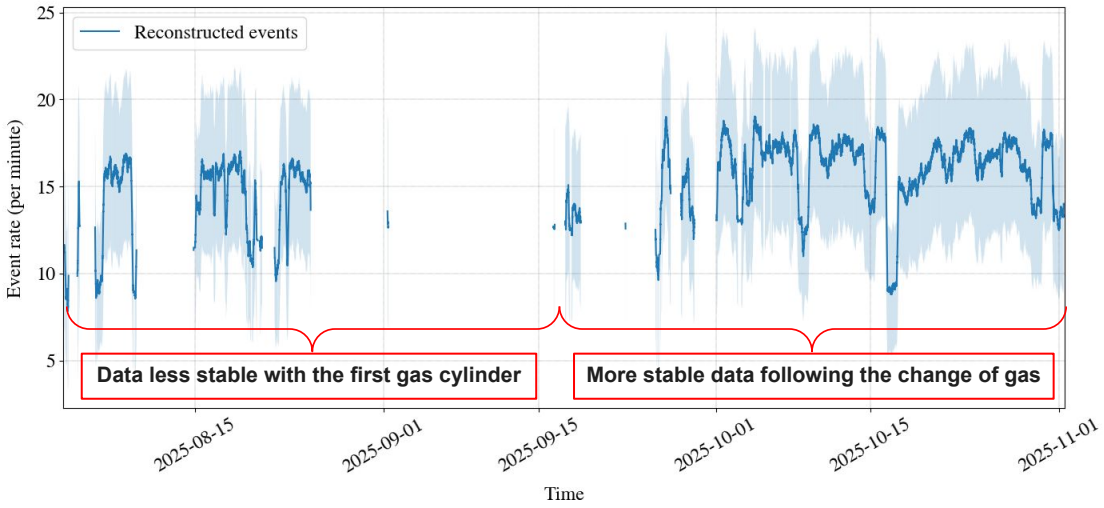
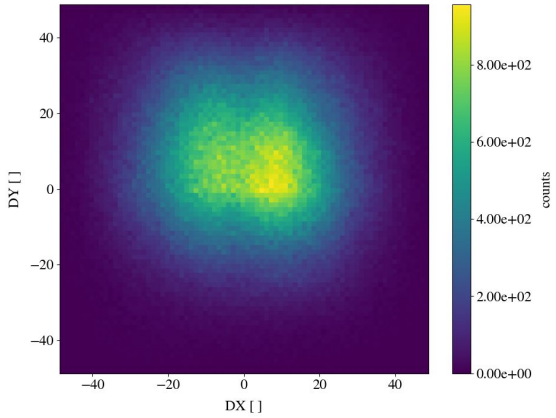
MicroMégas

Muons per minute



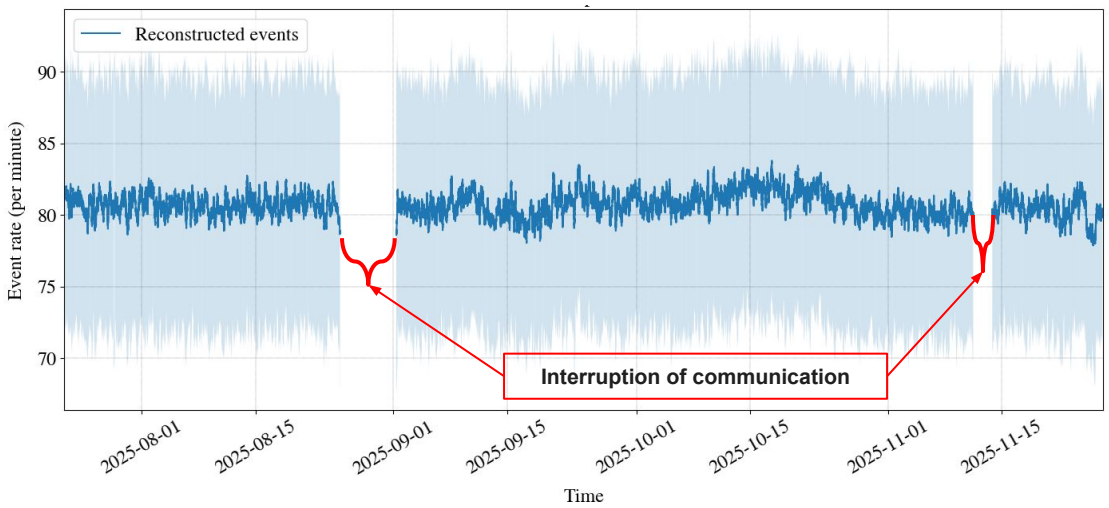
Total muons per direction



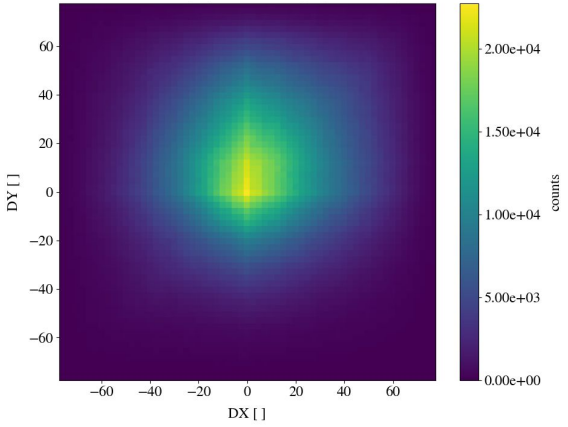
- Duration: ~43 days. 1,060,486 muons, ~16 per minute
- More stable towards the end of the measurement period.

Scintillator

Muons per minute



Total muons per direction

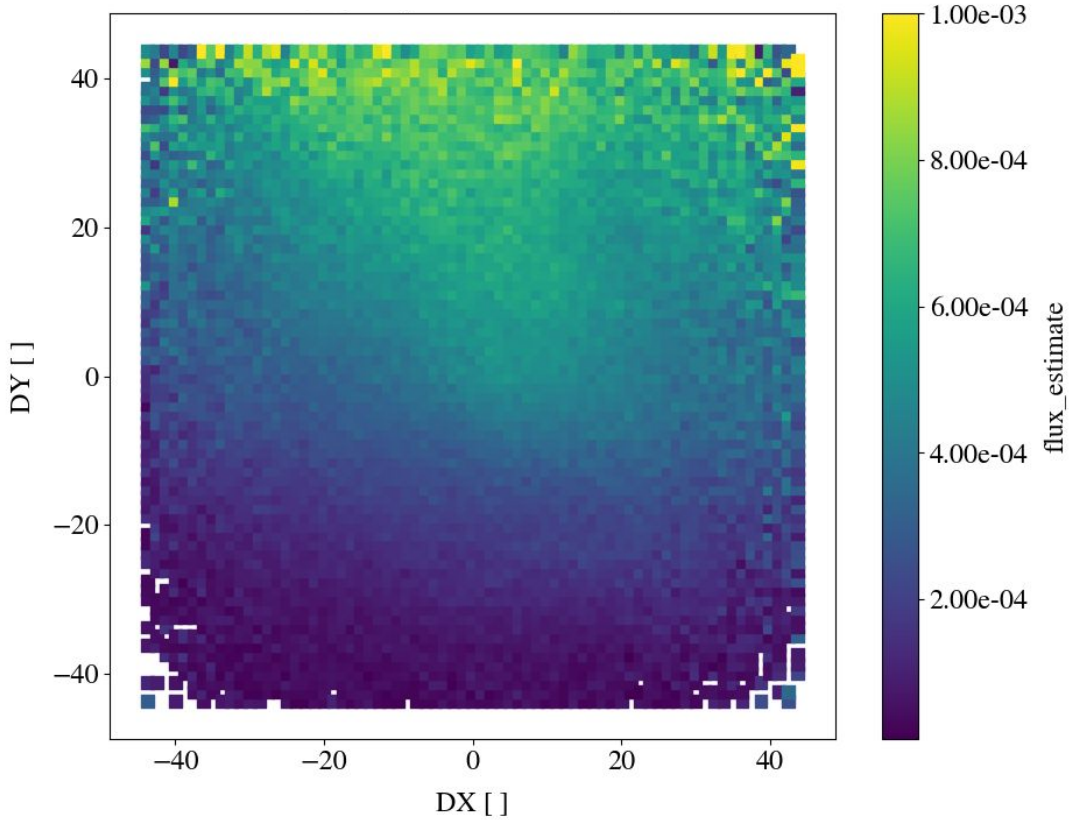


- Duration: ~111 days. 13,784,645 muons, ~81 per minute
- Time-stable data with few interruptions

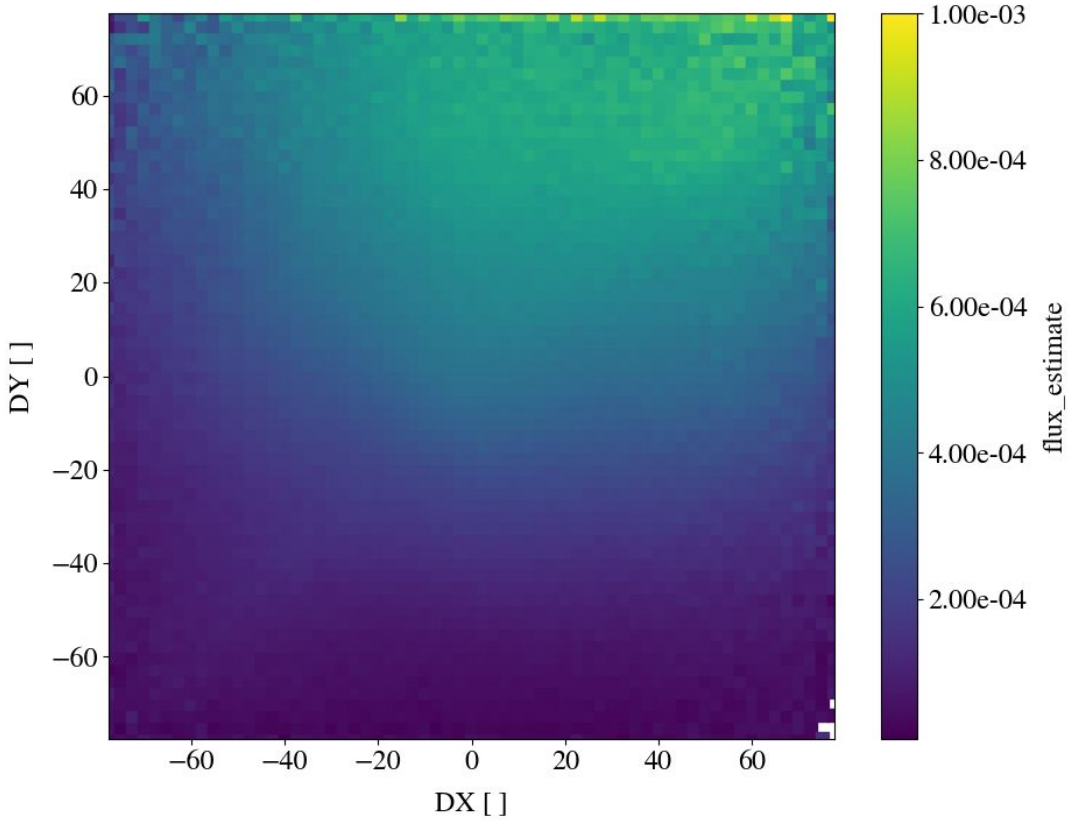
2D flux maps

*For 2D data, muons travel towards the screen

Flux MicroMégas [1/s.cm2.sr]



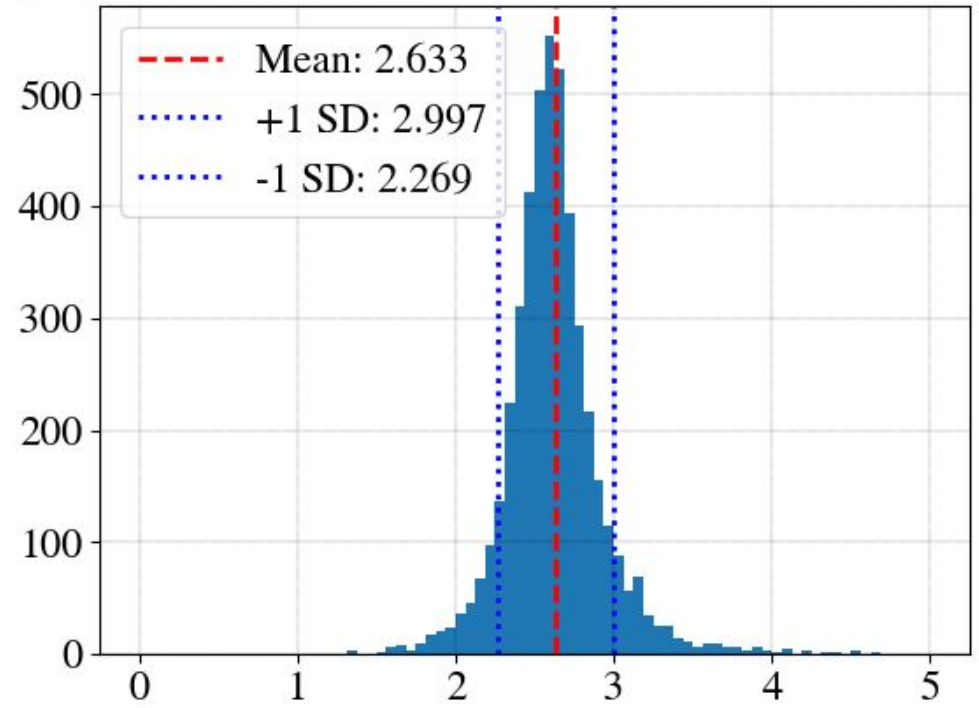
Flux Scintillator [1/s.cm2.sr]



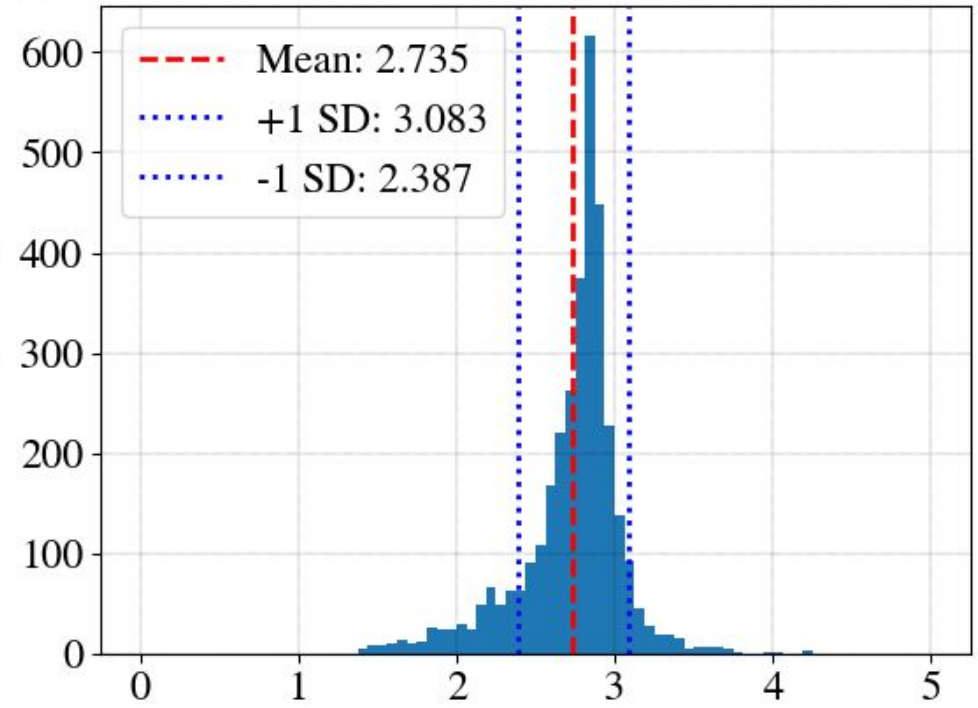
- Muon count data is converted into muon flux: the detectors record a similar flux distribution (accounting for noise).
- Some 2D variations are visible – linked to changes in angle from the vertical, the length of material traversed, or the density of the material.

Density distributions

Density MicroMégas [g/cm³]



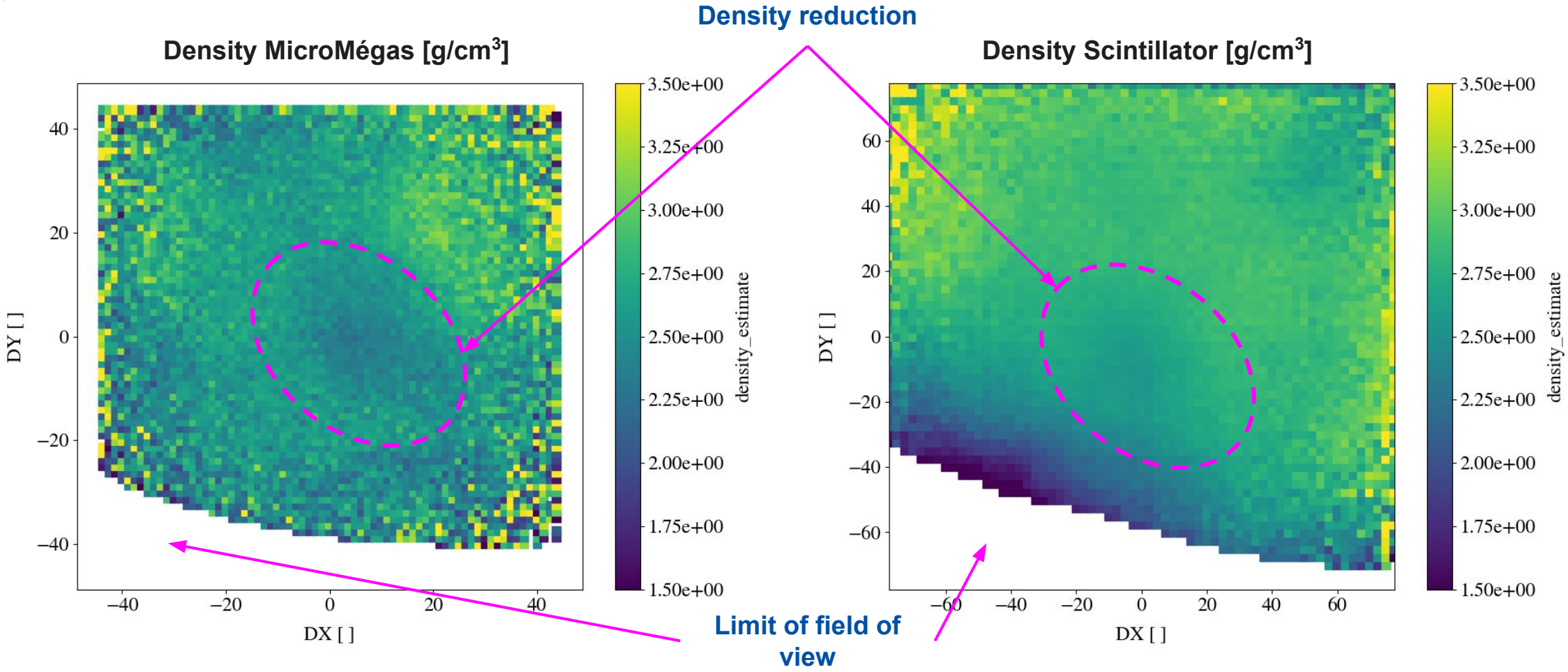
Density Scintillator [g/cm³]



- The histograms show a very similar distribution of densities observed by the two types of detector.
- The average density of the rocks ranges between 2.6 and 2.7 g/cm³ – which is geologically realistic.

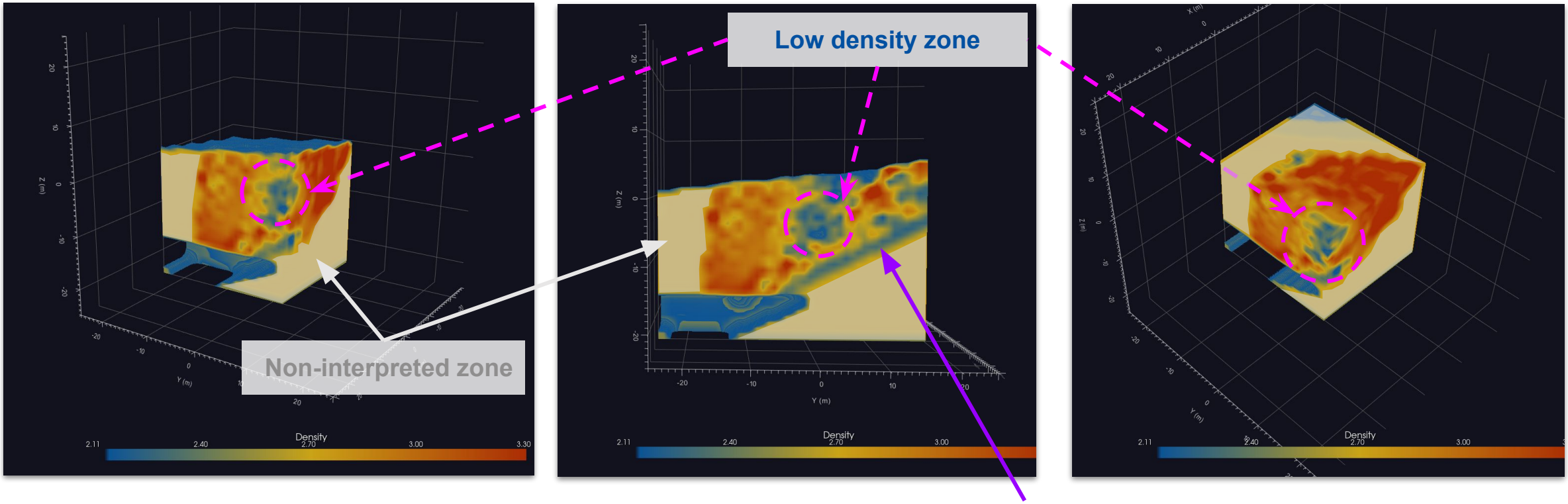
2D density maps

*For 2D data, muons travel towards the screen



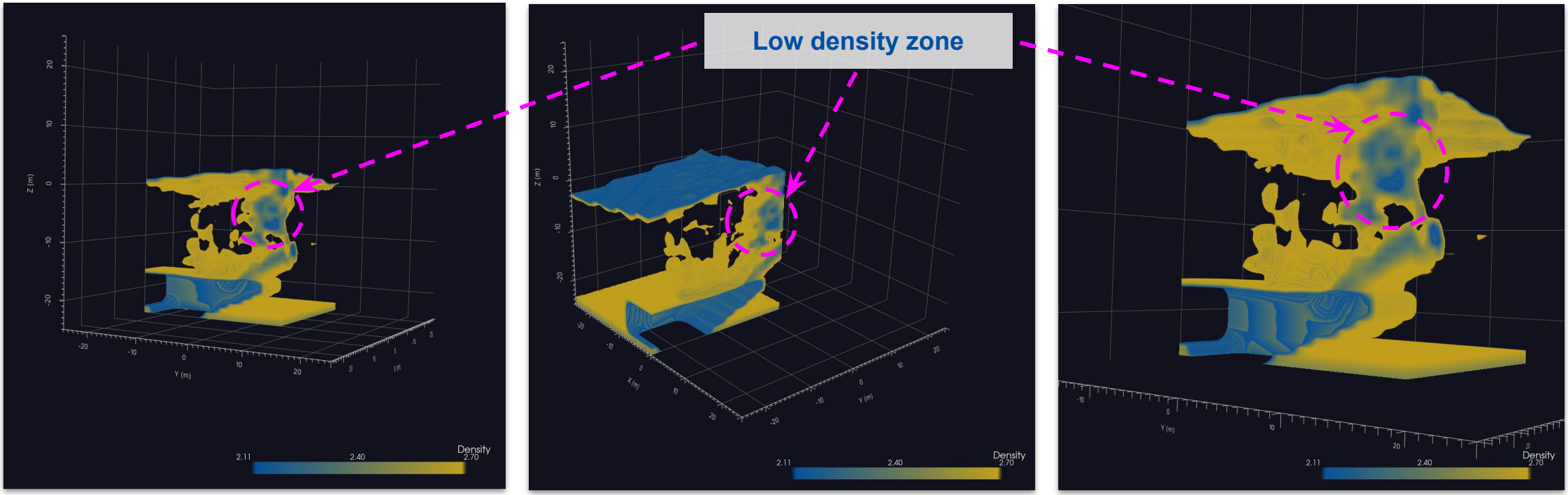
- The Micromégas shows greater uncertainty, but the 2D density profile is similar.
- In the centre of the field of view, both detectors show an area of reduced density.
- Uncertain data have been removed from the field of view.

3D Results



- Focus on density range 2.1–3.3 g/cm³
- A low-density zone (–0.6 g/cm³) measuring 7 x 9 x 9 m appears ~10 m below the surface at the end of the gallery.
- Opaque grey mask applied to invisible areas.

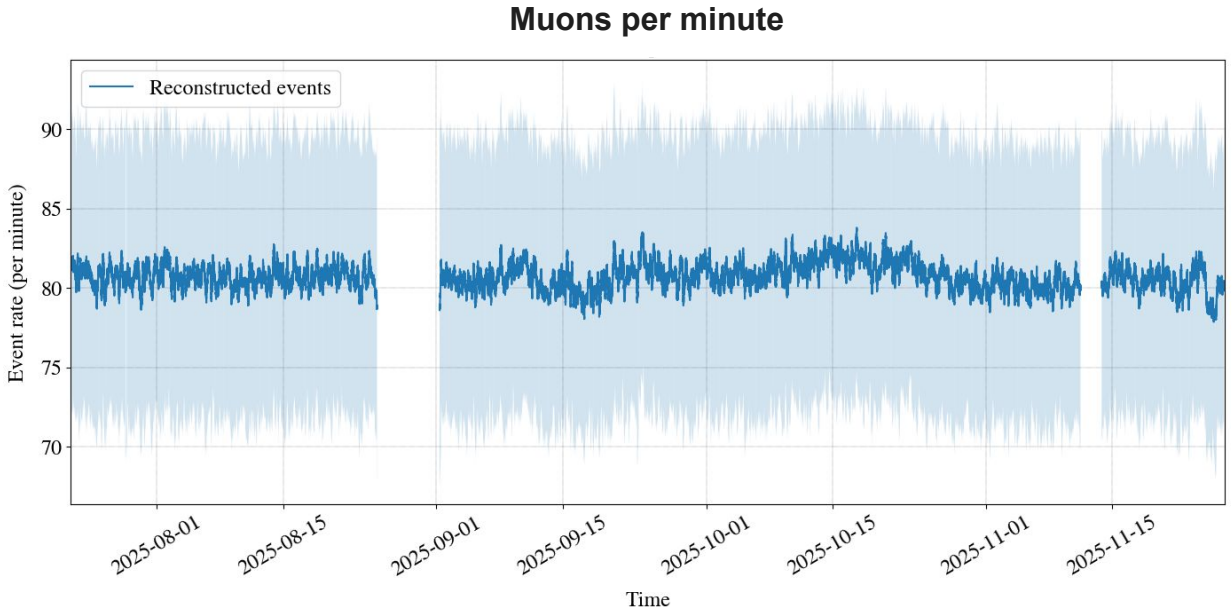
3D results

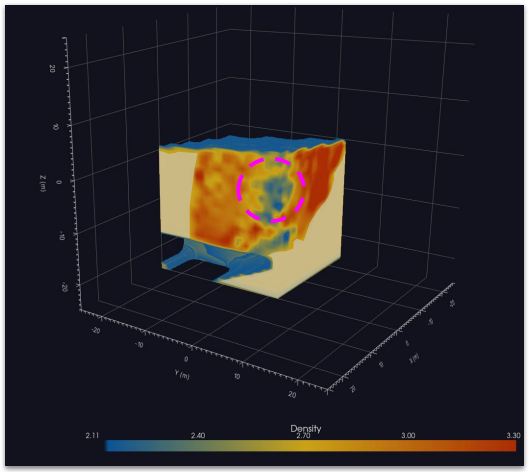


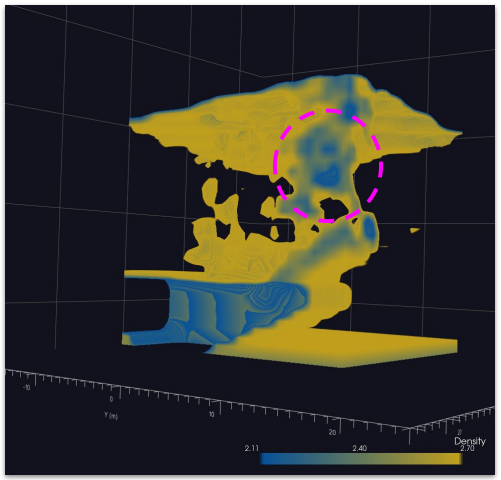
- Isolation of low density regions using contouring.
- The low-density zone is shown above the end of the gallery (pink circle).

Scientific Conclusions

- First successful simultaneous use of gas and plastic detectors for 3D tomographic imaging.
- The muon flux remained very stable for over three months (for SC) – no significant changes were detected in the rock.
- The 2D and 3D density images indicate variations in density, notably significantly reduced densities (-0.6 g/cm³) covering a volume of 7 x 9 x 9 m, which may be concentrated at a depth of approximately 10 m below the surface at the end of the gallery.







Conclusions in context

- Muography provides client results that other existing technologies cannot deliver.
- Just 40 combined-days required to produce a 3D image of a target area (located at a depth of 20 to 30 m).
- The 2D and 3D density images show a decompressed zone, consistent with the location of historical gallery roof collapse…
  - Result immediately informed client decision-making on risk-mitigation strategy to ensure safety of the area.