# Development of gaseous detectors for muography at LSBB: the TRUST-ME project

Tomographic **R**esearch of **U**nderground and large **ST**ructures with **M**uographic **E**xpertise (**TRUST-ME**)

- **Muography** project of the Low-Background Noise Underground Laboratory (**LSBB**)

- Tomography of large structures (buildings) and medium with **cosmic muons** as a source

- Use of **MUST²**, a novel compact, wide-angle Micromegas detector designed for underground use (patented 2015)

- Targets **sustainable water management** in monitoring of large structures and underground aquifers

- Aims to develop and improve **detector networks** for real-time, 4D monitoring

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18-20 juin 2025

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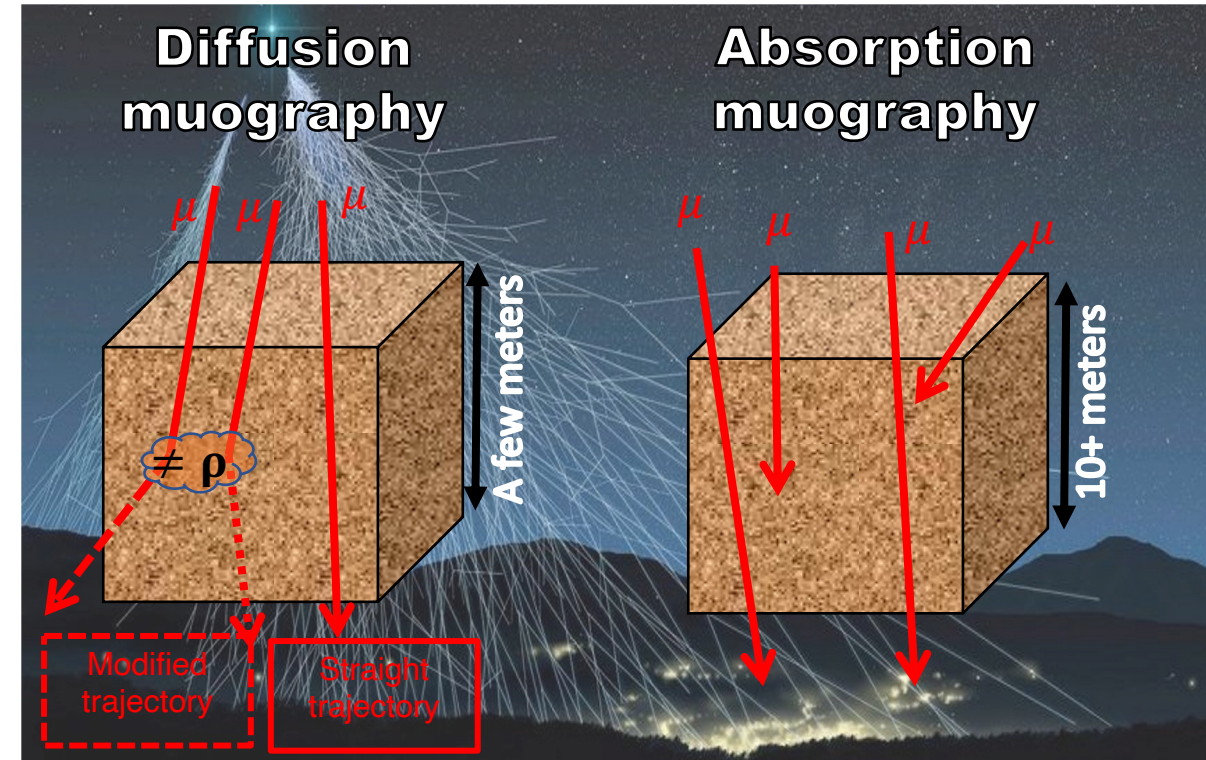
Project centered on sustainable water management in two main axes:
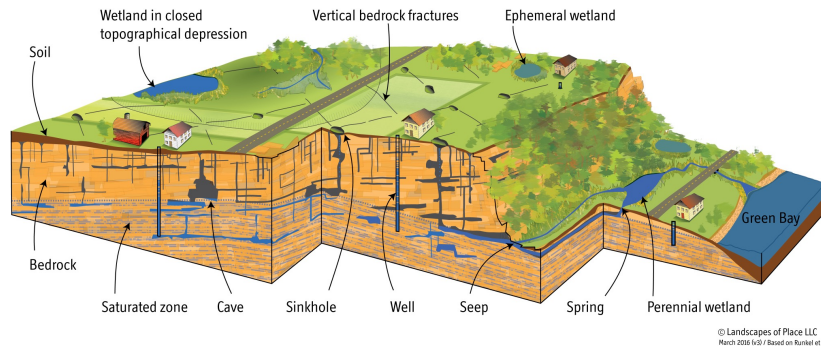
- **Survey of groundwater in aquifers**
  - 25% of world population depends on groundwater from karstic reservoirs
  - Climate change, demographic growth cause increasing need for water
  - Karst aquifers are complex and heterogeneous
  - Existing monitoring techniques are limited (*e.g.* low spatial resolution)

- **Hydraulic structures**
  - Water management and electricity production
  - 85% of dams have reached the end of their lifespan
  - 200 dam failures between 2000 and 2009
  - Aging causes lower yield and increased servicing costs

Malpasset dam collapse
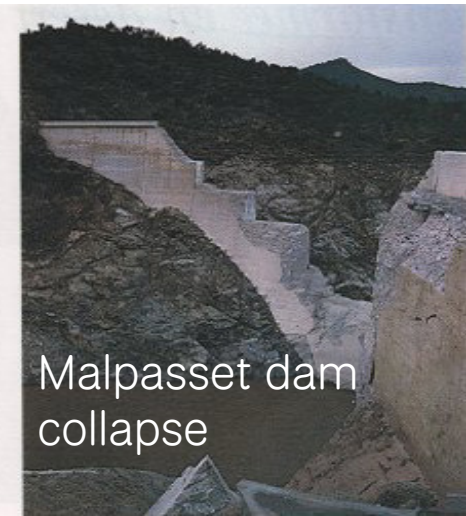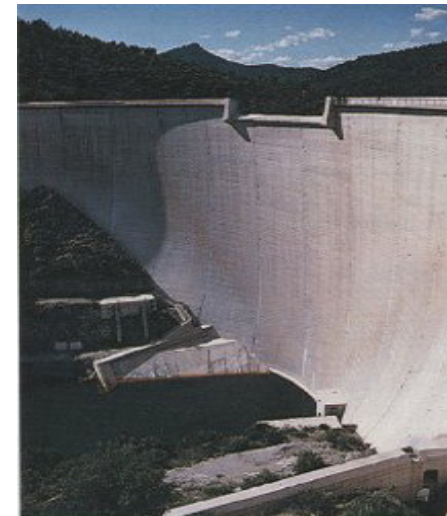
ac-aix-marseille.fr

→ Development of muography as a non-invasive technique for groundwater and hydraulic structure monitoring
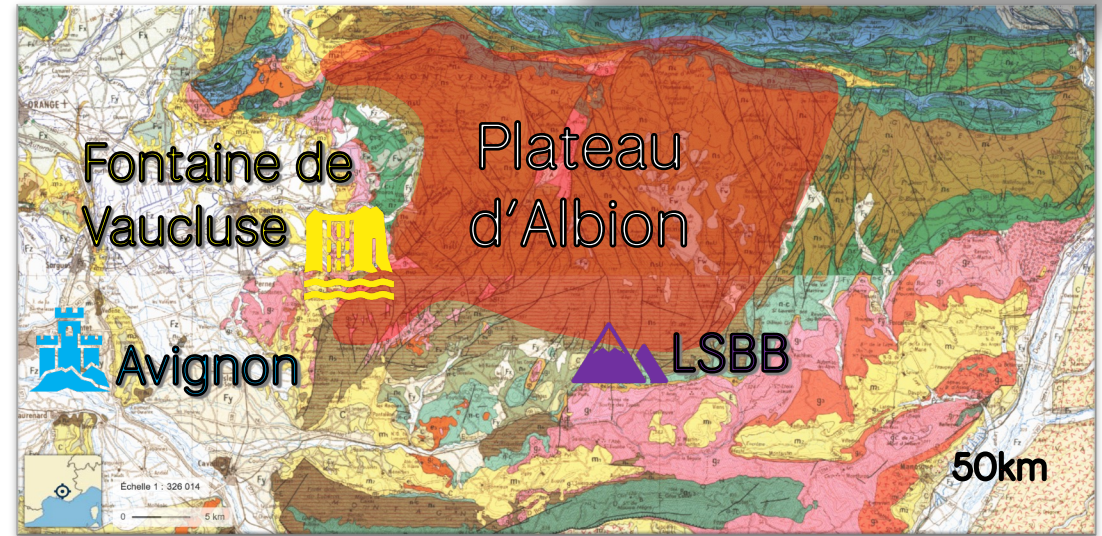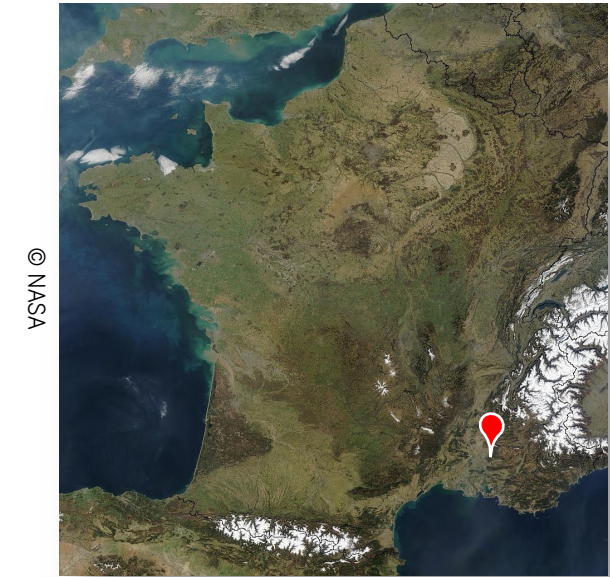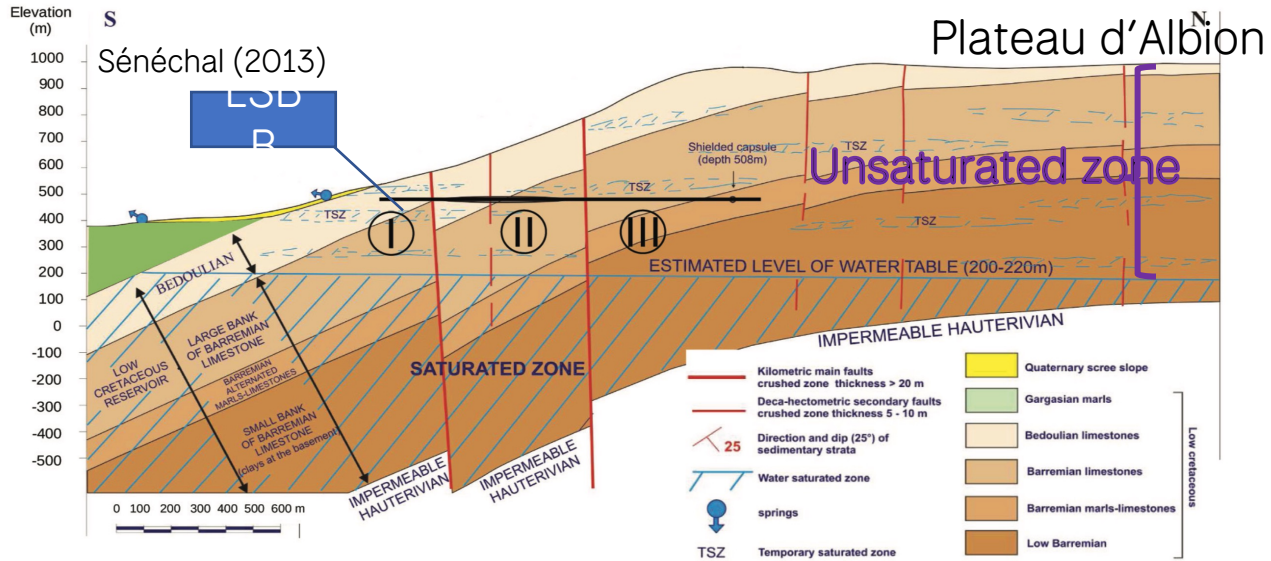
- Low background noise interdisciplinary above-ground and under-ground research laboratory (CNRS – Avignon University UAR3538)

- Large scientific network with ultra-sensitive multiphysics instrumentation

- International academic and industrial collaborations

- Strengths in geological, electromagnetic and hydrogeological research fields

- 4.3 kilometers long tunnel, 14,000 m² of underground installations

- Low-background noise from lack of industrial activity, rock thickness and metallic shielding

- Depth ranging from 0 to 518 meters
- Access to a 500-meter-deep metal-shielded room
- Measurements possible at different depths and altitudes
- Located in the unsaturated zone of the Fontaine de Vaucluse aquifer
- Years of scientific data in numerous domains (gravimetry, magnetometry...)

→ LSBB is an ideal site for the development of muon detectors

© NASA

Sénéchal (2013)

Plateau d'Albion

Unsaturated zone

LSBB

ESTIMATED LEVEL OF WATER TABLE (200-220m)

IMPERMEABLE HAUTERIVIAN

SATURATED ZONE

Kilometric main faults crushed zone thickness > 20 m	Quaternary scree slope
Deca-hectometric secondary faults crushed zone thickness 5 - 10 m	Gargasian marls
Direction and dip (25°) of sedimentary strata	Bedoulian limestones
Water saturated zone	Barremian limestones
springs	Barremian marls-limestones
Temporary saturated zone	Low Barremian

Fontaine de Vaucluse

Plateau d'Albion

Avignon

LSBB

50km

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- New version of the **MU**on **S**urvey **T**omography based on **M**icromegas detectors for **U**nreachable **S**ites **T**echnology (**MUST²**) detector

- Compact, thin TPC Micromegas detector suited for underground use (60 × 70 × 10 cm)

- Working principle: events excite gas, signal is amplified and read on a detector plane in X and Y

- New features, improved cost efficiency

- Wide FOV (~170° zenith and 360° azimuth)

- Designed for a network configuration : simultaneous acquisition of several points of view for 4D tomography
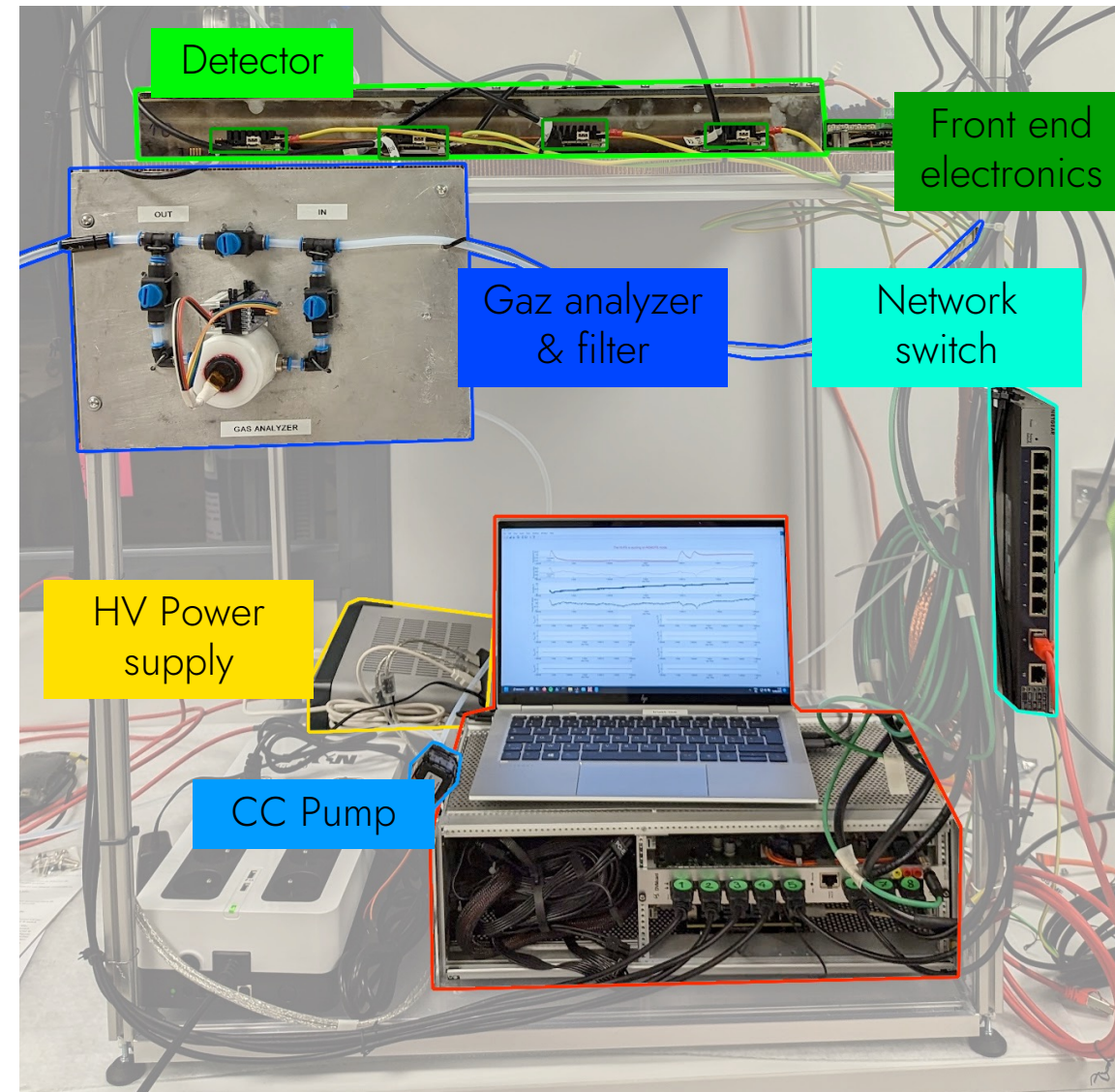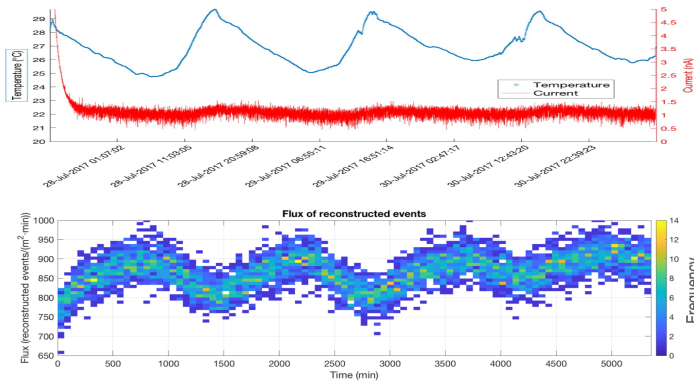
- Electronics and software provided by CERN RD51/DRD1
- Micromegas data read from VMM3a ASIC cards and Front-End Concentrator
- Passive cooling
- Auto-triggering from muon detection
- 1ns time resolution
- Remote operation of the detector network possible

VMM-3a

Visualisation des hits en coordonnées sphériques

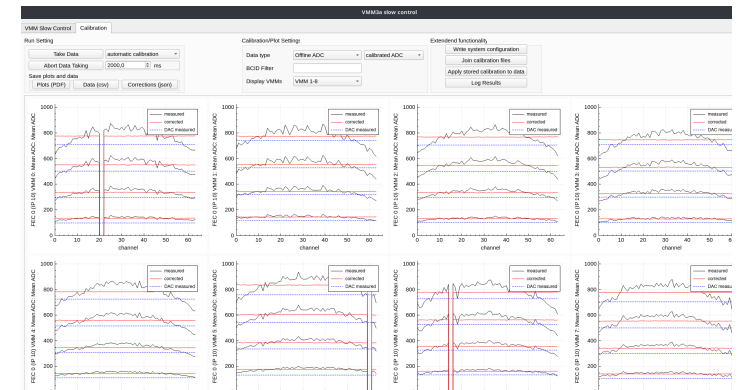Heatmap des hits en coordonnées θ-φ
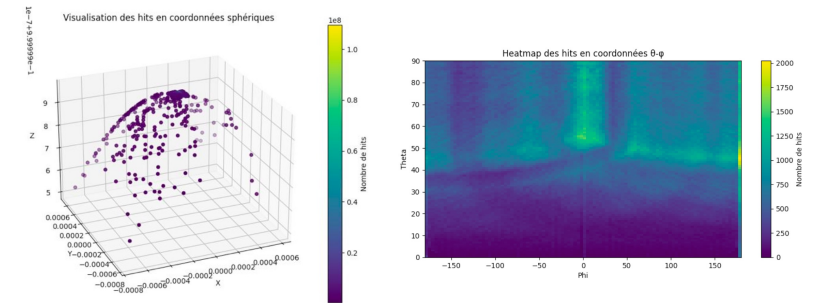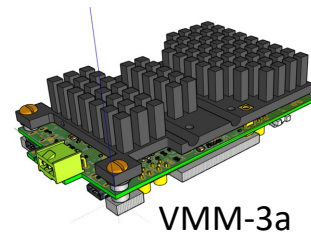
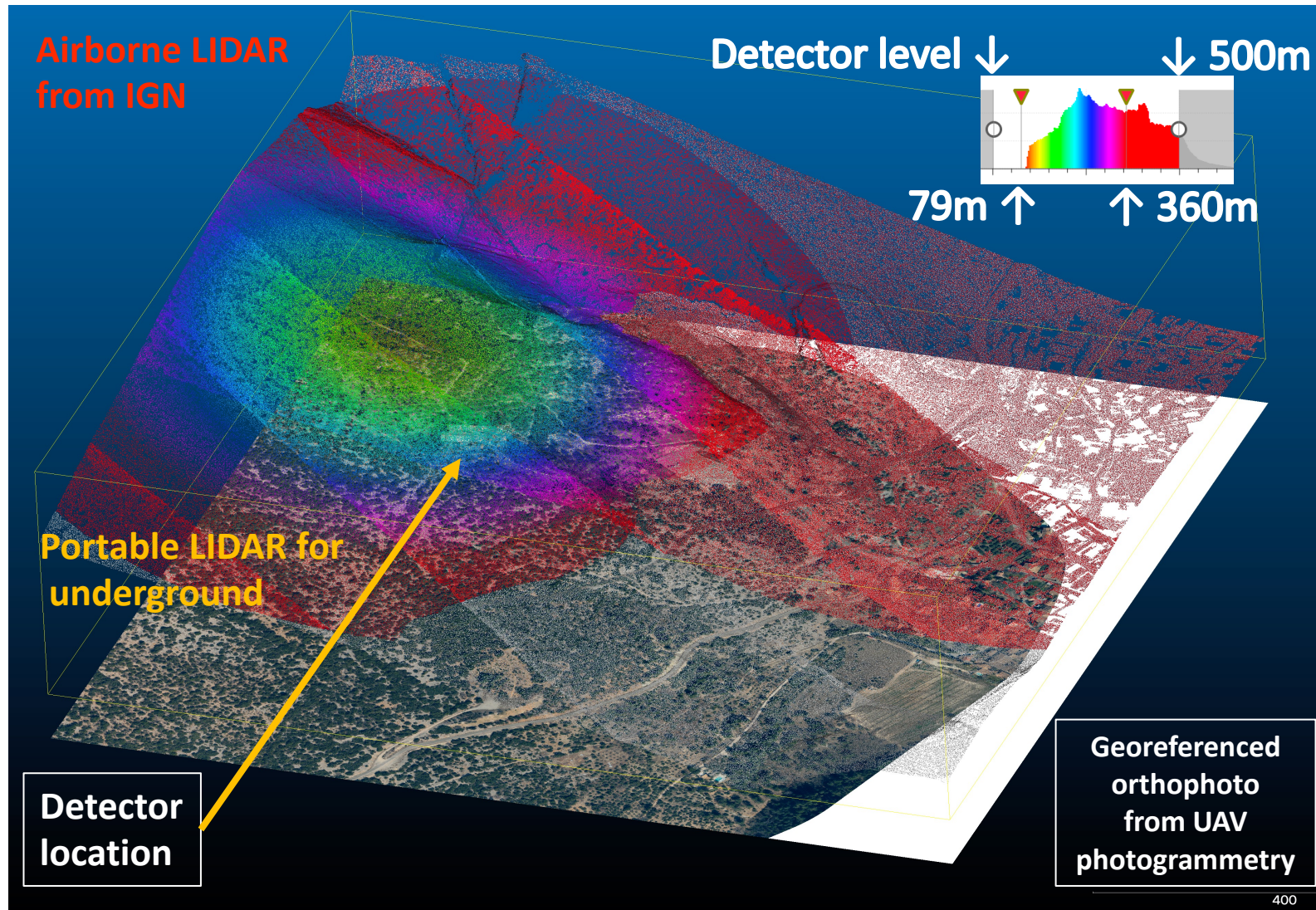Combined use of in-house and manufacturer-issued software for detector operation and data analysis

Real-time gas analysis and filtering, adaptative micromesh gain with HV power supply

→ Correction of variations due to temperature

Coupling muon detector data with photogrammetry & LIDAR

Airborne LIDAR from IGN

Detector level ↓   ↓ **500m**

79m ↑   ↑ 360m

Portable LIDAR for underground

Detector location

Georeferenced orthophoto from UAV photogrammetry

400

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- Using photogrammetry / LIDAR to complement muography

- Drone photogrammetry to generate surface / terrain models

- Calculation of distances from detector to surface (1cm accuracy in length)

- Accurate thickness data allows for precise detector calibration
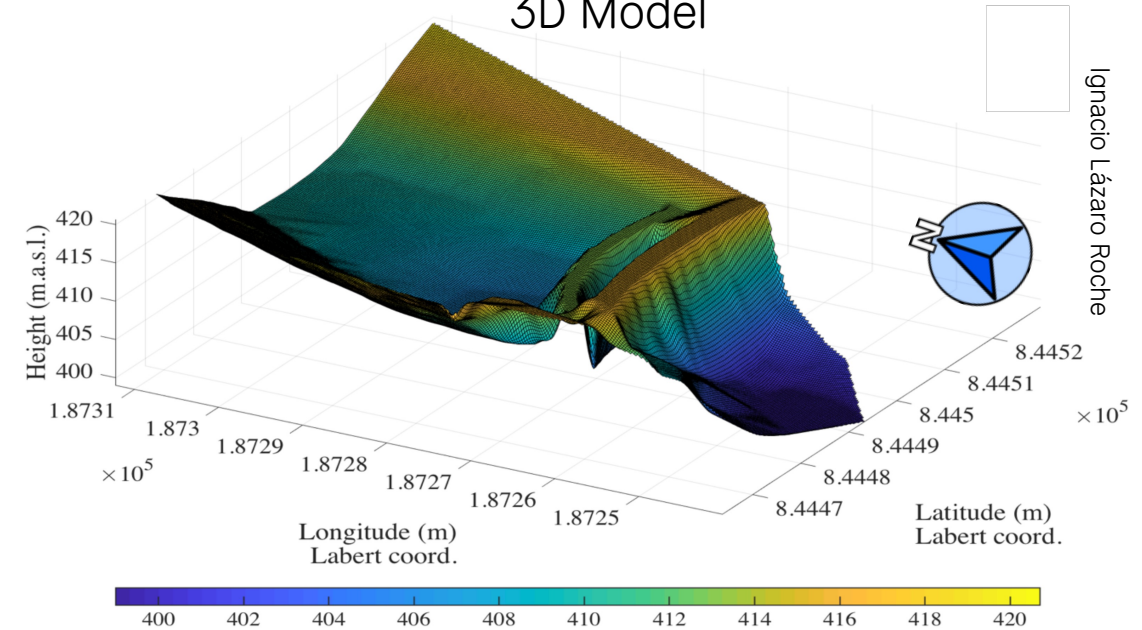
- Allows georeferencing

- Site close to the LSBB (~10 km)

- Muon tomography of a historic double dam structure for concrete quality monitoring

- 3D model of the water reservoir needed to calibrate the MUST^2 detector

- Original model made from topographic data

Topographic survey
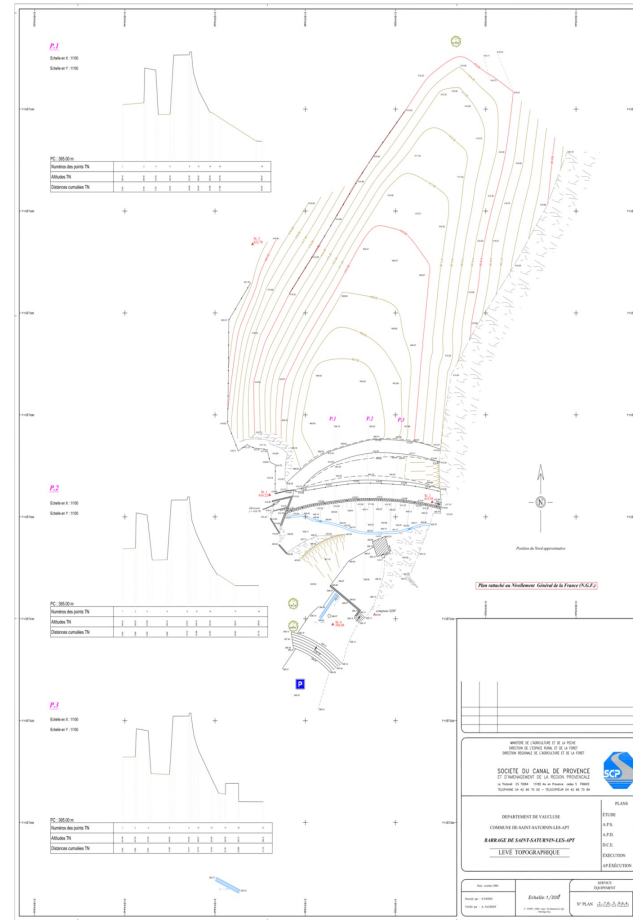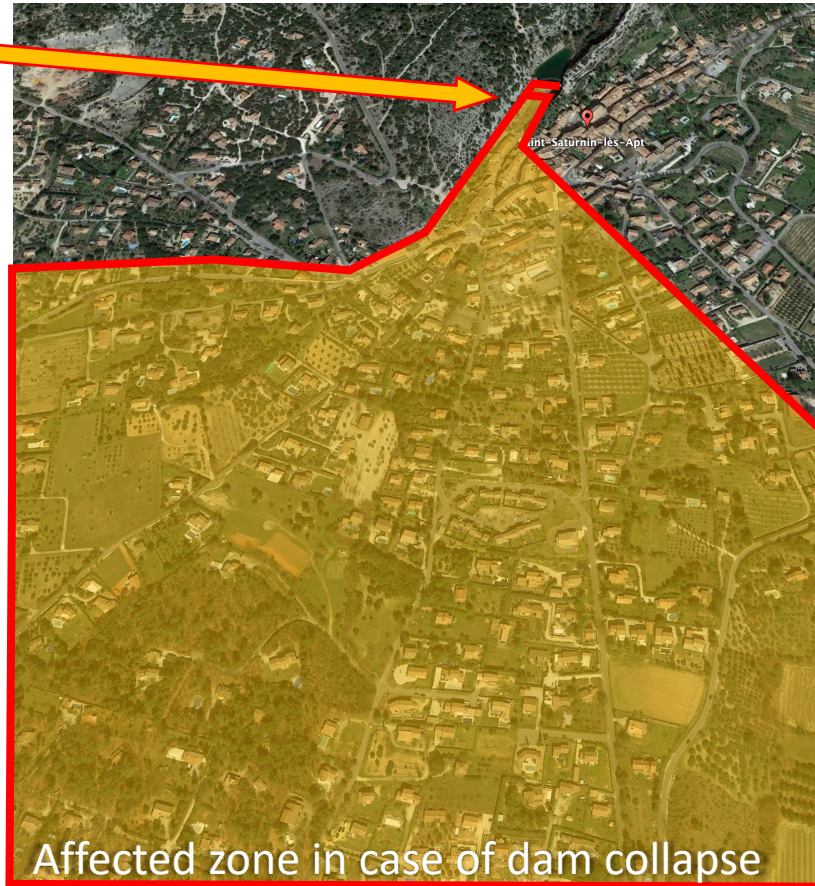

October 2006
Unknown accuracy

3D Model

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October 2017
Based on the topographic survey
Resolution 1 point/m^2
Size 297x441m
Interpolation artifacts

February 2023: Dangerous incident during dam monitoring

Affected zone in case of dam collapse

- Periodical dam monitoring is required by regional agency
- Borehole operation with no plan is carried out to sample concrete
- Borehole damages the dam exhaust, water starts leaking
- Emptying the dam is not possible due to sediments
- High risk of ram effect and dam collapse
- Reservoir is emptied using pumps to prevent catastophic failure

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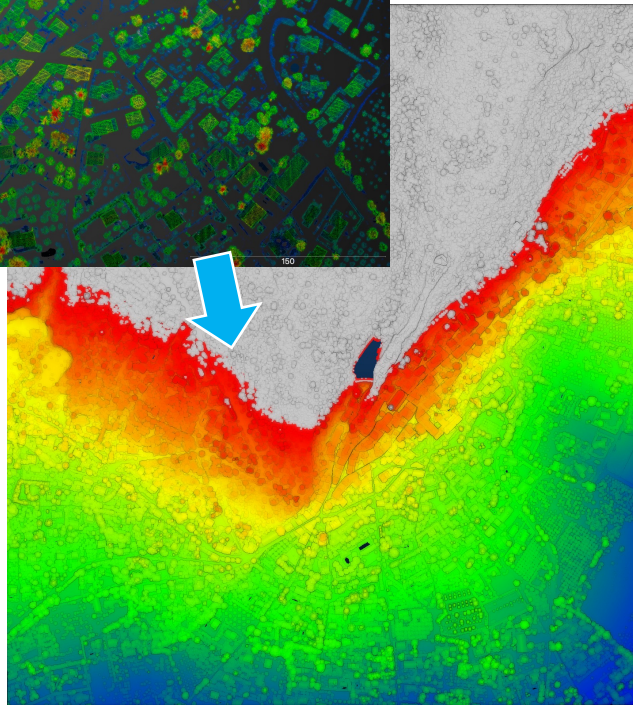# Study case: dam of Saint-Saturnin-lès-Apt
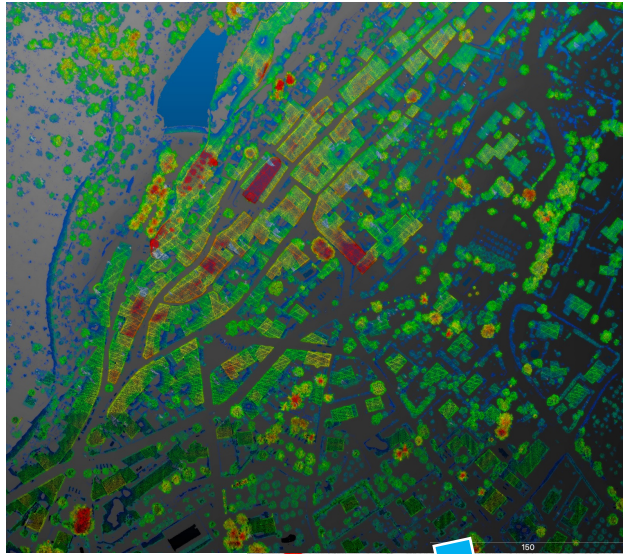
Airborne LIDAR for village (IGN)
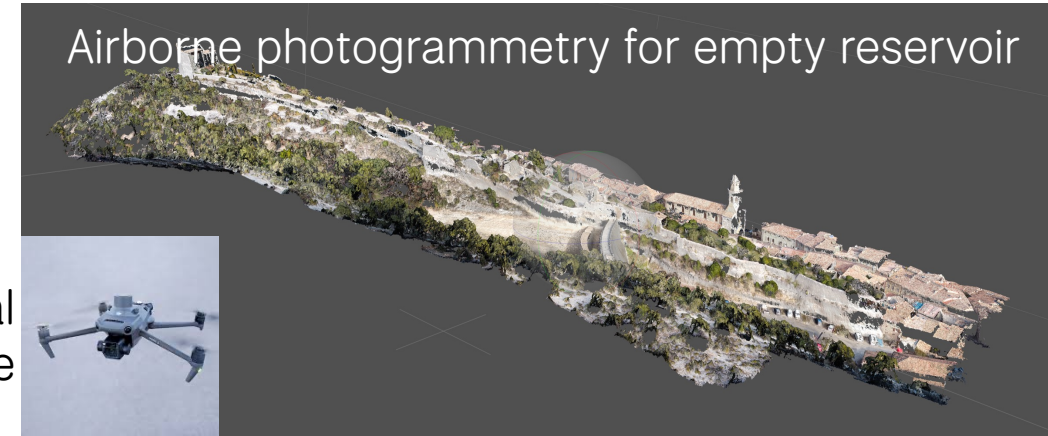
Airborne photogrammetry for empty reservoir

Commercial drone

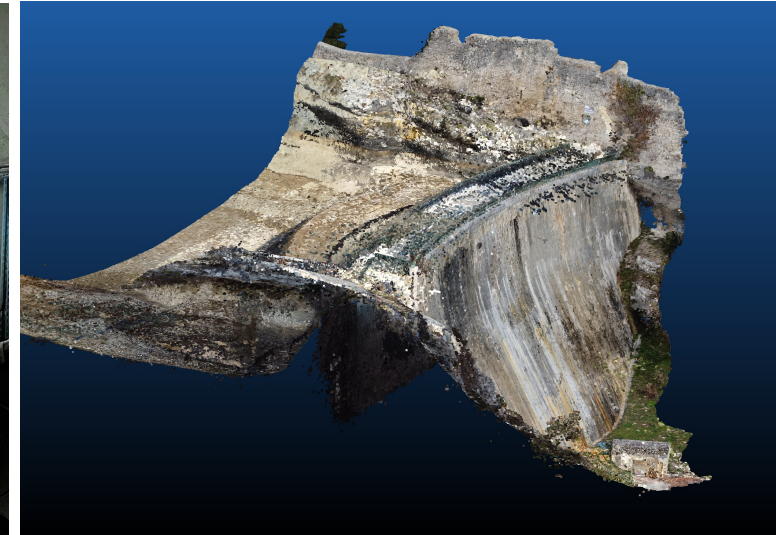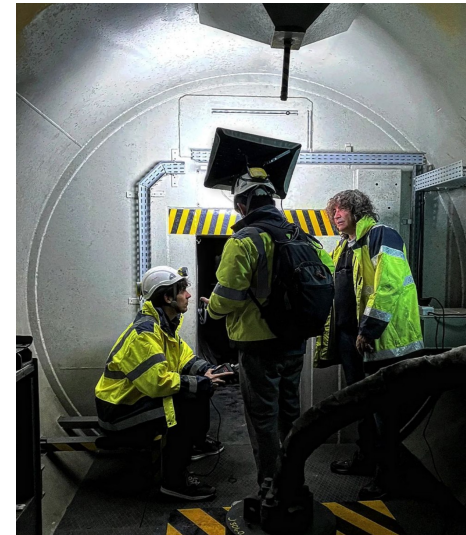- Using LIDAR & photogrammetry to model the area
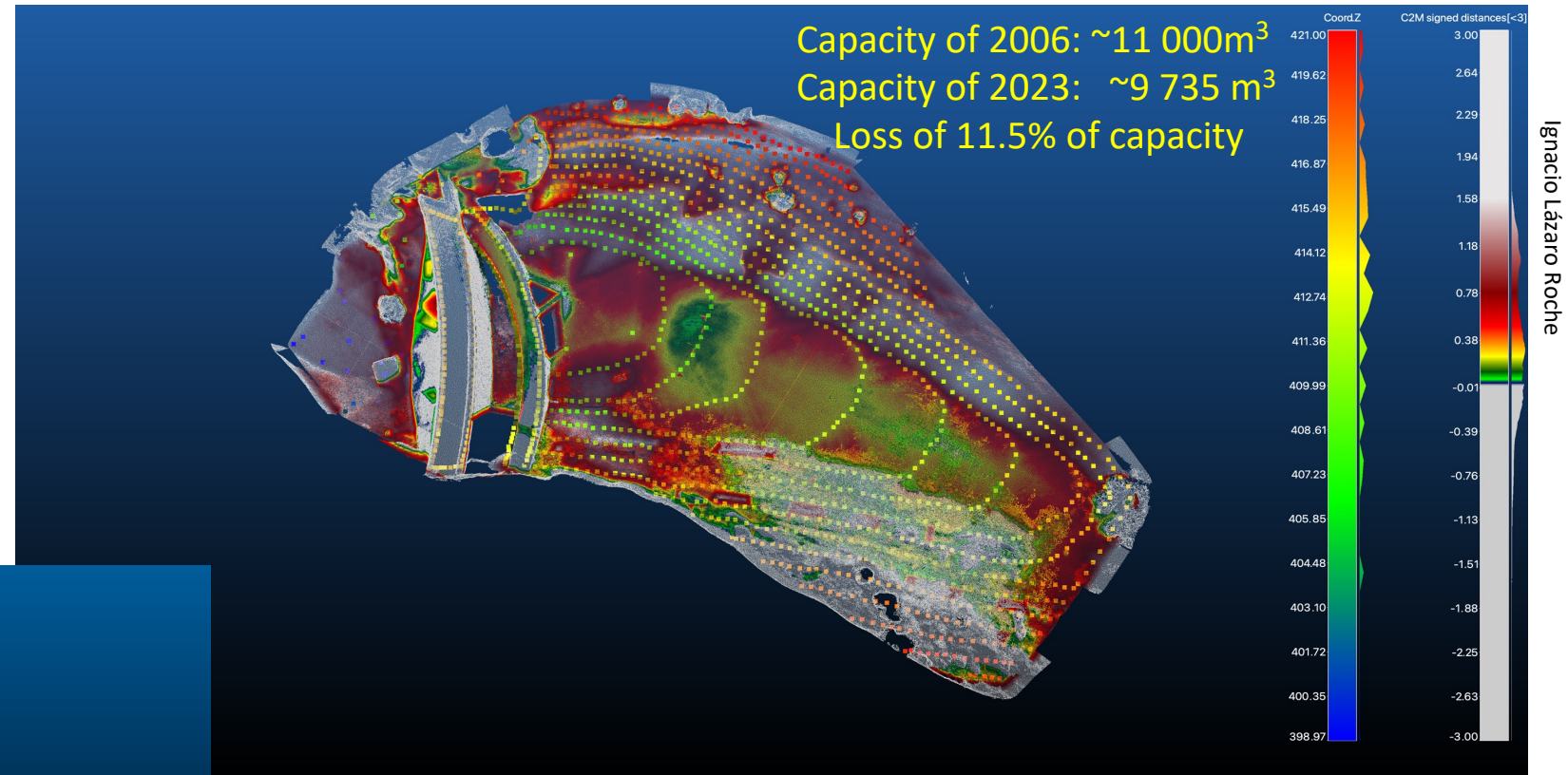
2021 : Raw data by IGN
https://geoservices.ign.fr/lidarhd

Mobile LIDAR for dam & underground spaces

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Map of sedimentation between 2006 and 2023

Capacity of 2006: ~11 000m^3
Capacity of 2023:   ~9 735 m^3
Loss of 11.5% of capacity

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Cross-section of the dams

2.5 m of sediment over the drain
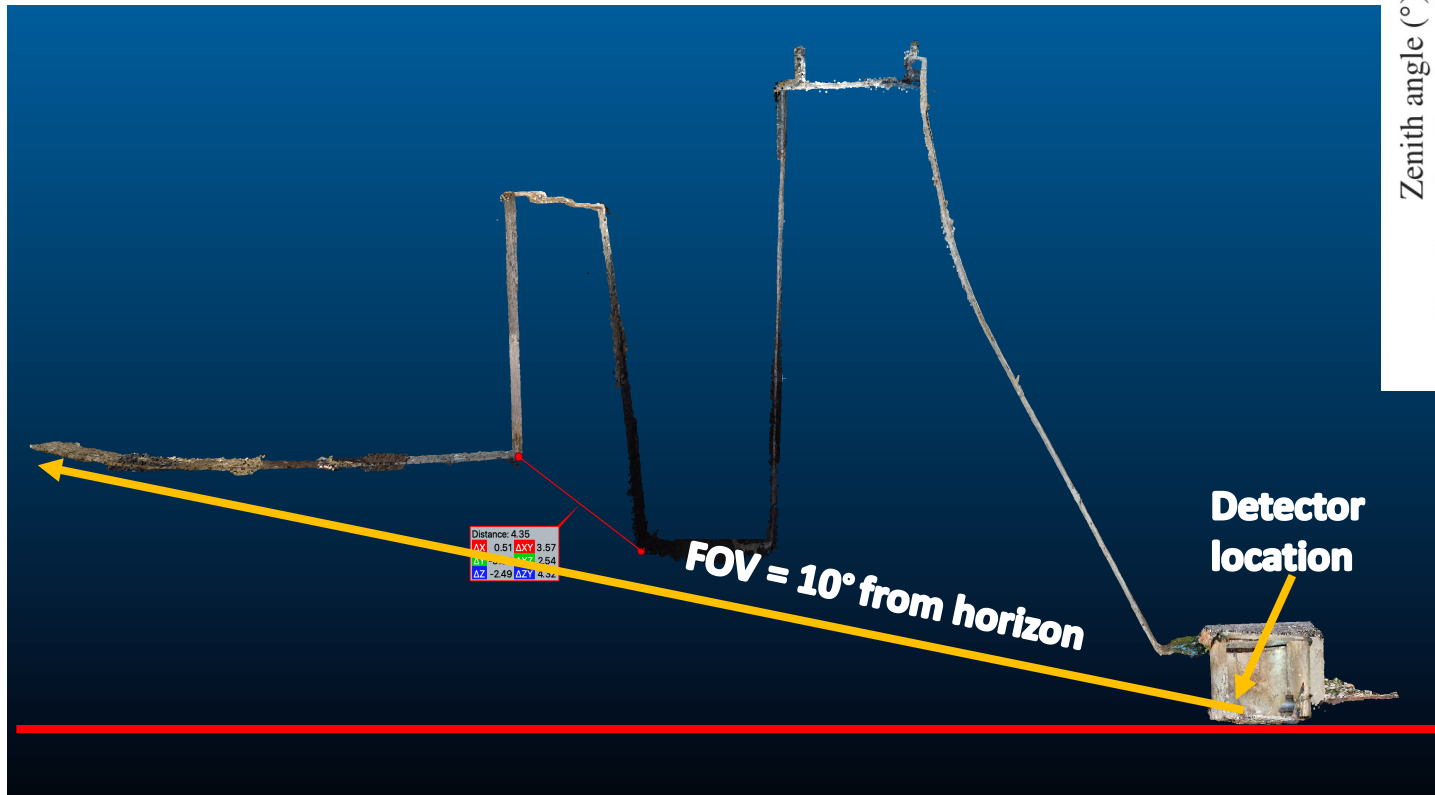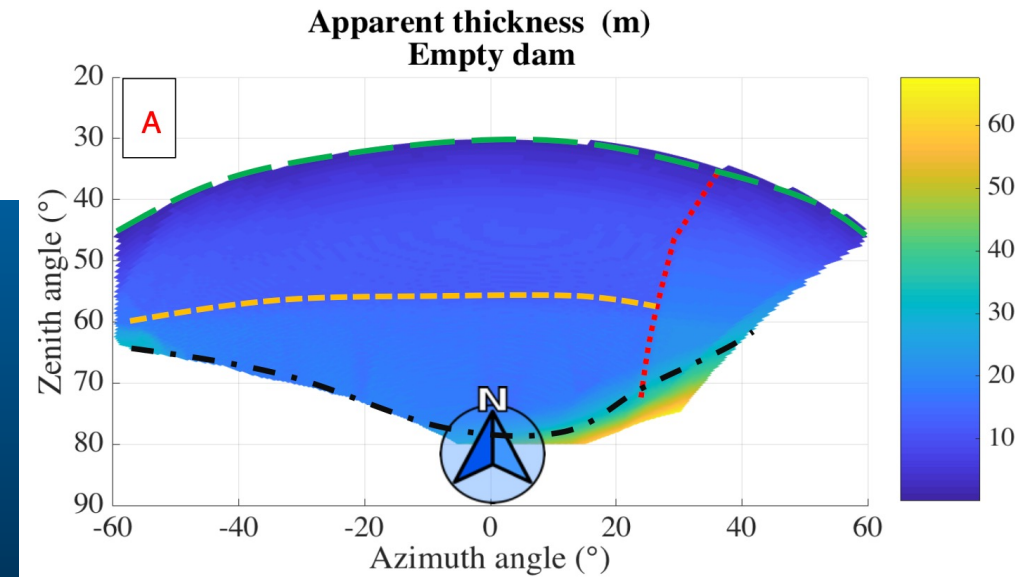
→ Insight on water capacity, concrete thickness and sediment depth

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**Apparent thickness (m)
Empty dam**

Cross-section of double dam system

Simulated apparent thickness of the dam from the detector location

Lázaro Roche, I. A Compact Muon Tracker for Dynamic Tomography of Density Based on a Thin Time Projection Chamber with Micromegas Readout. Particles 2021, 4, 333–342.
https://doi.org/10.3390/particles4030028

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Detector location

FOV = 10° from horizon

Conclusion

- Muon tomography: non-invasive monitoring technique for hydraulic structures, underground aquifers

- New version of MUST^2 detector: compact, lightweight detector designed for underground

- LSBB is an ideal pilot platform for detector development

- Combined use of muography, LIDAR and photogrammetry facilitates calibration and improves tomography data

- Ongoing developments: reducing instrument noise for better S/N ratio; muon track reconstruction

- Further development needed for network operation

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Thank you for your attention - Acknowledgements

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