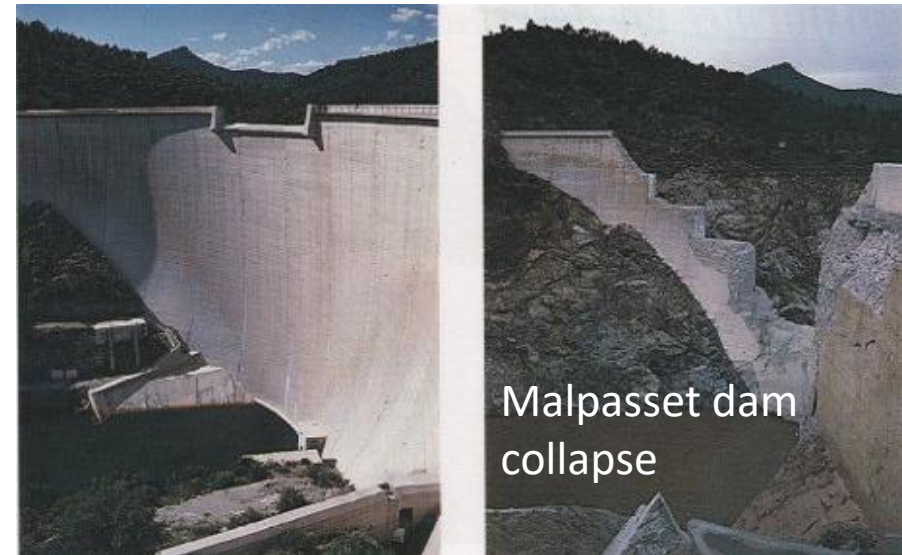
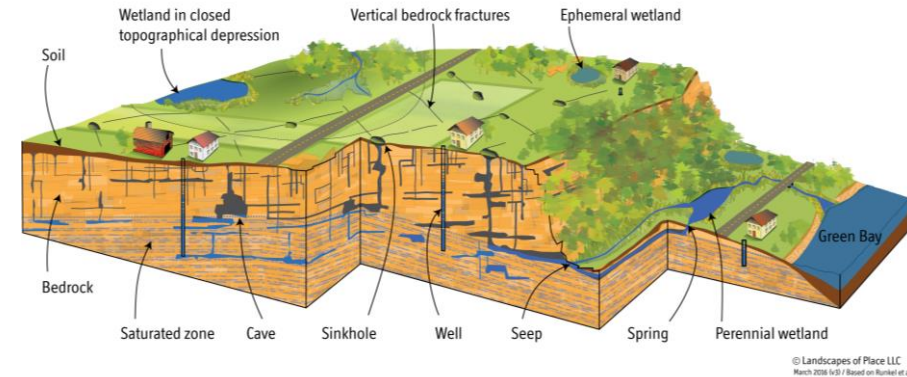


Advancement on Tomographic Research of Underground and large Structures with Muographic Expertise project (TRUST-ME)

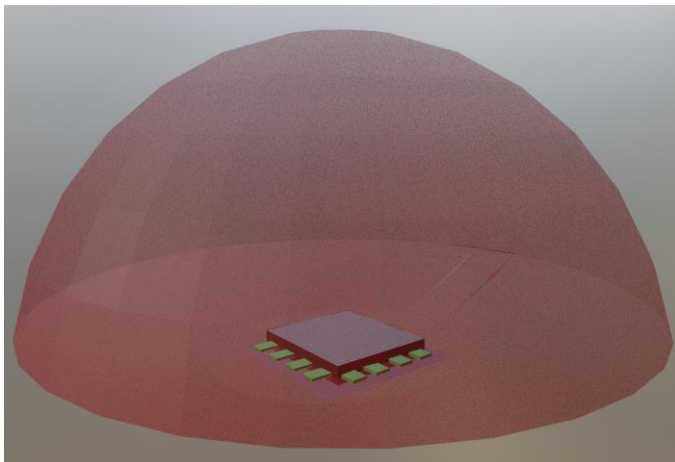
Project centered on sustainable water management

- Survey of groundwater in aquifers
 - Climate change, demographic growth cause increasing need for water
 - 25% of world population depends on groundwater from karstic reservoirs
- Hydraulic structures
 - 85% of dams have reached the end of their lifespan
 - 200 dam failures between 2000 and 2009
 - Existing monitoring techniques are limited
- Project focuses on muography to complement existing geophysics imaging techniques

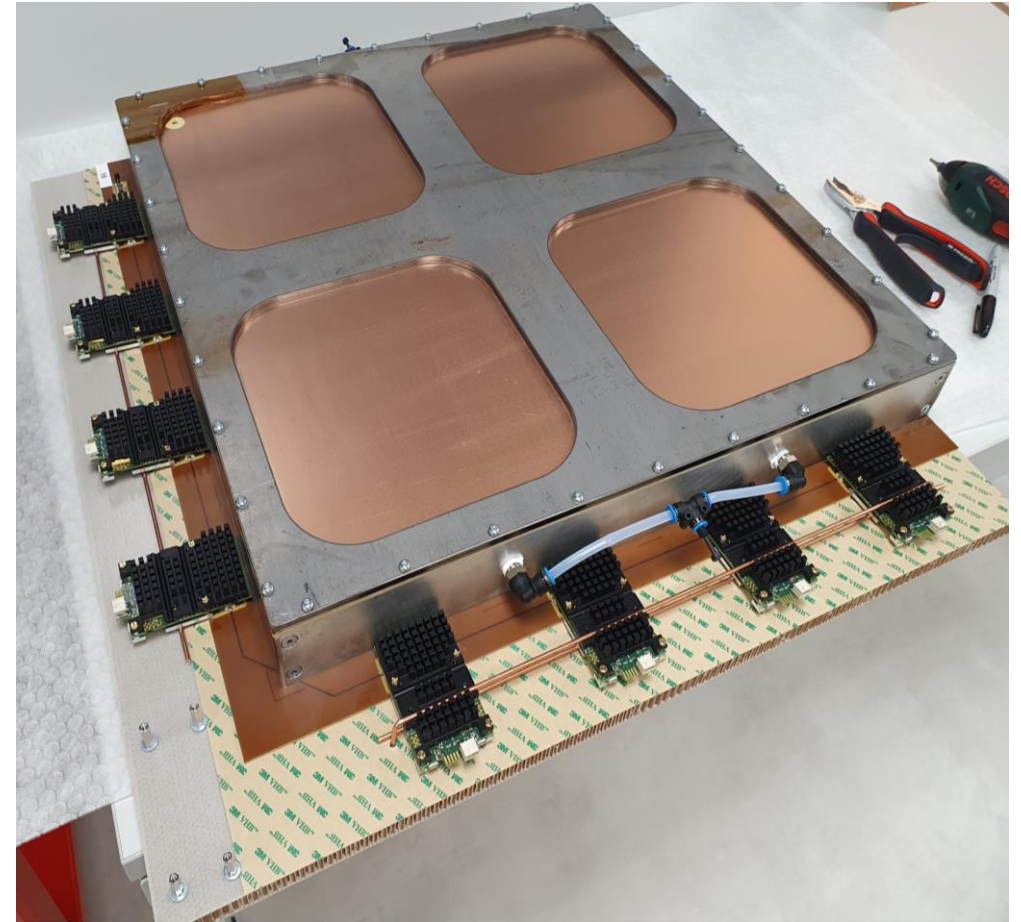


MUST² detector upgrade

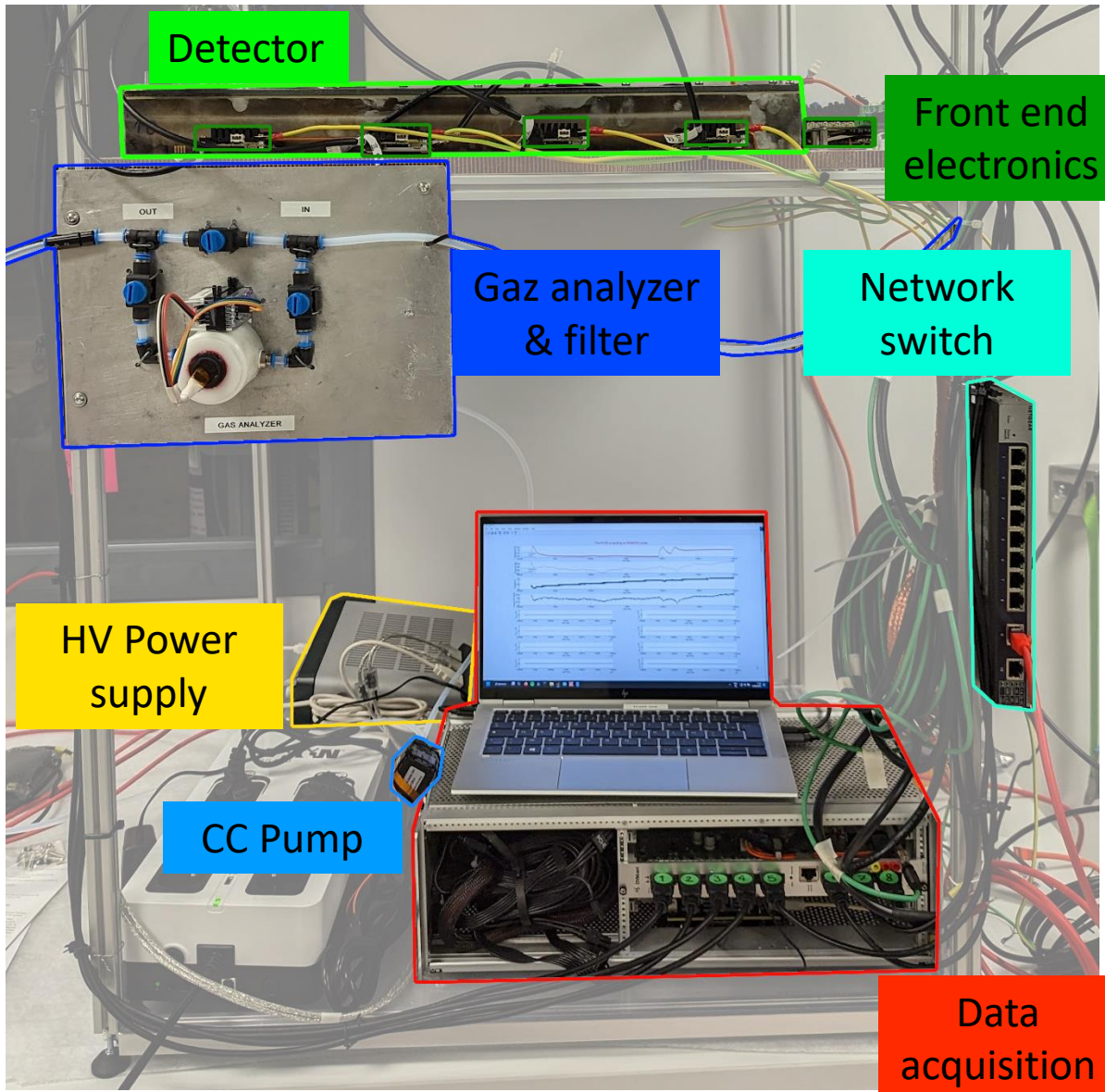
- New version of the *MUon Survey Tomography based on Micromegas detectors for Unreachable Sites Technology* muon tracker (MUST², patented in 2015)
- Improved angular resolution, new features, more cost-efficient
- Network configuration capable
- Simultaneous acquisition of several points of view for 4D tomography
- Wide FOV ($\sim 170^\circ$ zenith and 360° azimuth)



FOV of the detector

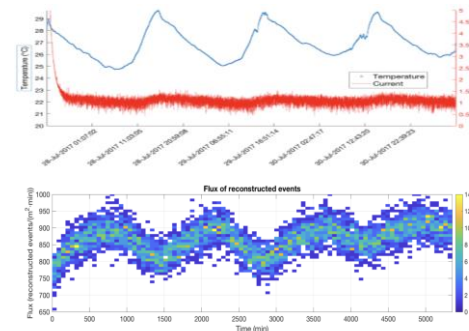


MUST² detector upgrade

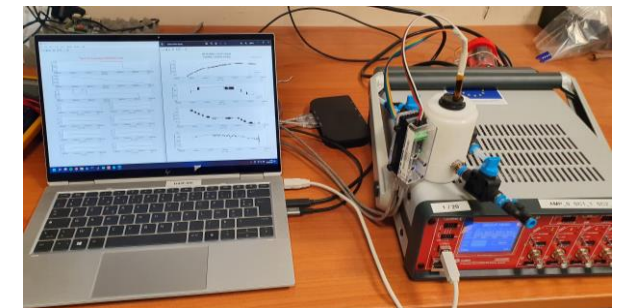


- Lightweight detector, 60 × 70 × 10 cm, 20 kg
- Peripherals are remote-capable
- Versatile, autonomous, compact and scalable
- Real-time gas analysis to adjust voltage

Gas analyzer system: reads temperature and gas quality in the closed circuit, then allows real-time gain and gas control



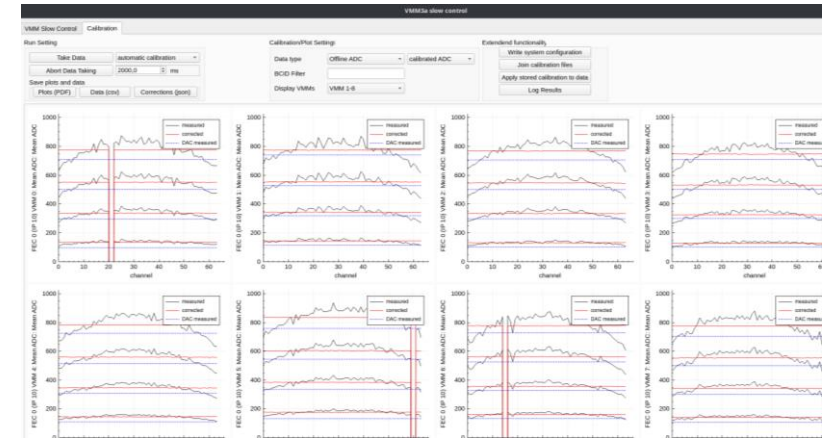
Reconstructed events from gas monitoring



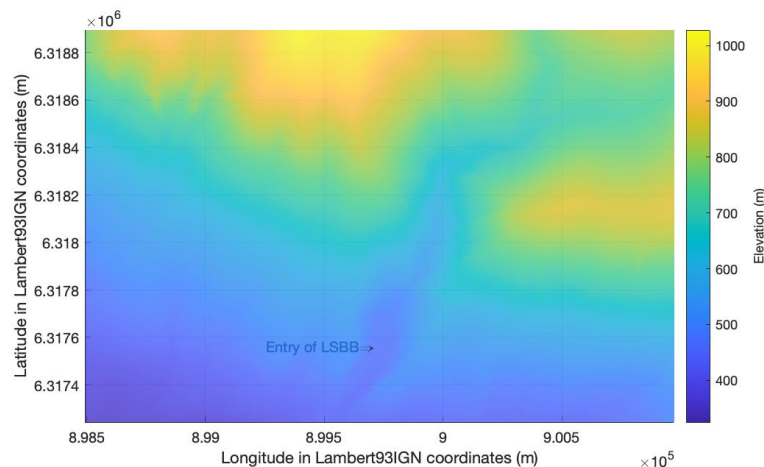
Gain of high-voltage power supply adjusted automatically

Software aspect of the project include:

- Calibration and configuration of the detector using RD51 software
- Reconstruction of muon trajectories inside the detector
- Network configuration of the detector and acquisition system
 - Use of multiple detectors for temporal 3D imaging
- Modeling of mid-sized targets for detector characterization
 - Topographic, 3D models generated using photogrammetry & LIDAR

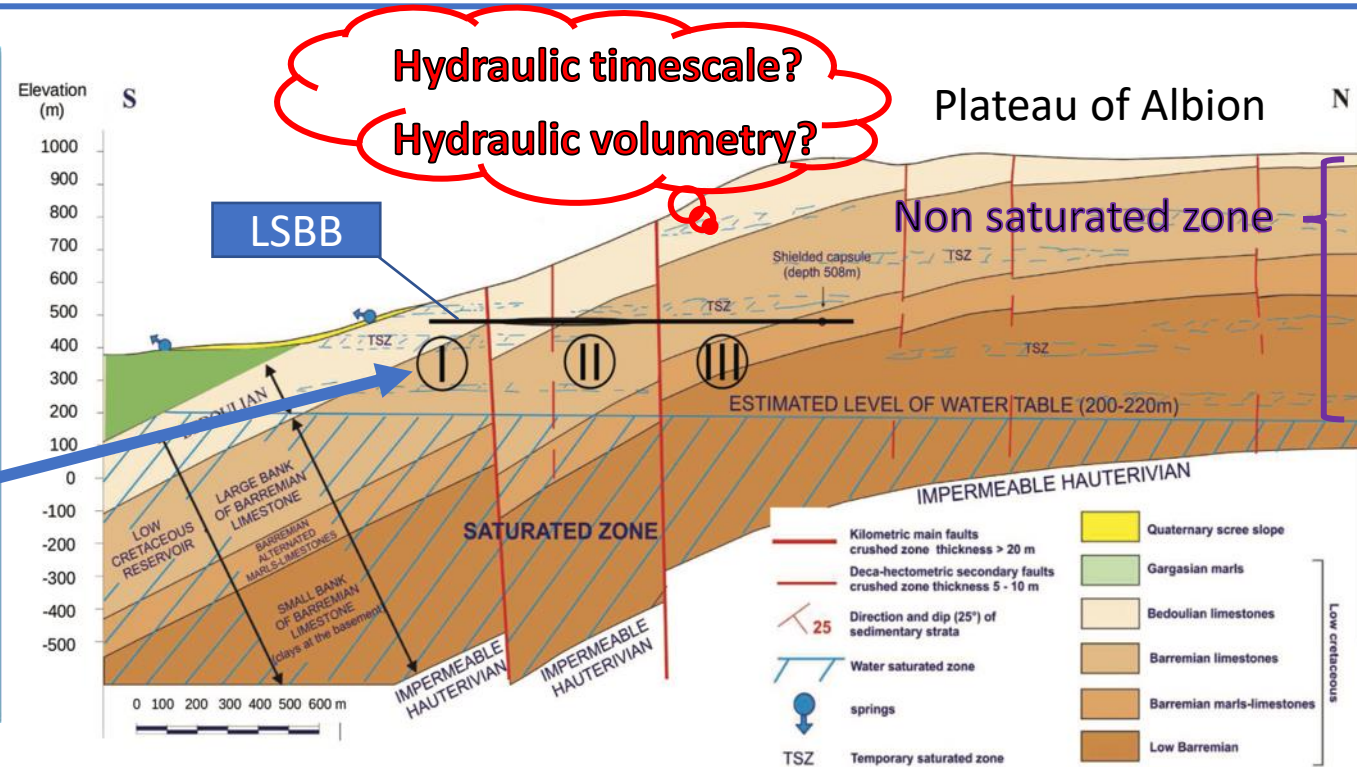


Calibration of VMM3a cards using Slow Control software
 Dorothea Pfeiffer – Lucian Scharenberg



Elevation map of LSBB from airborne LIDAR

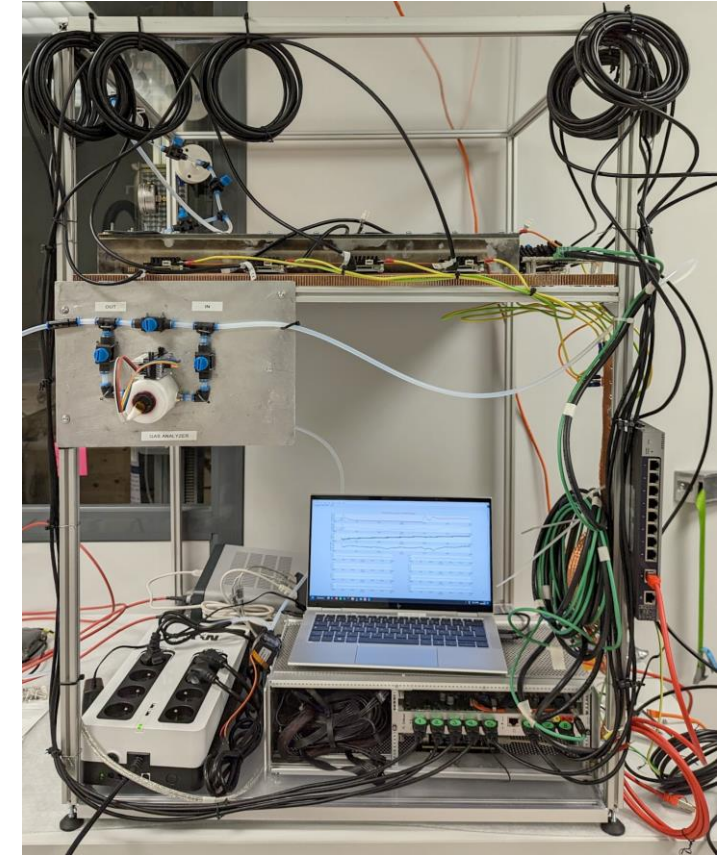
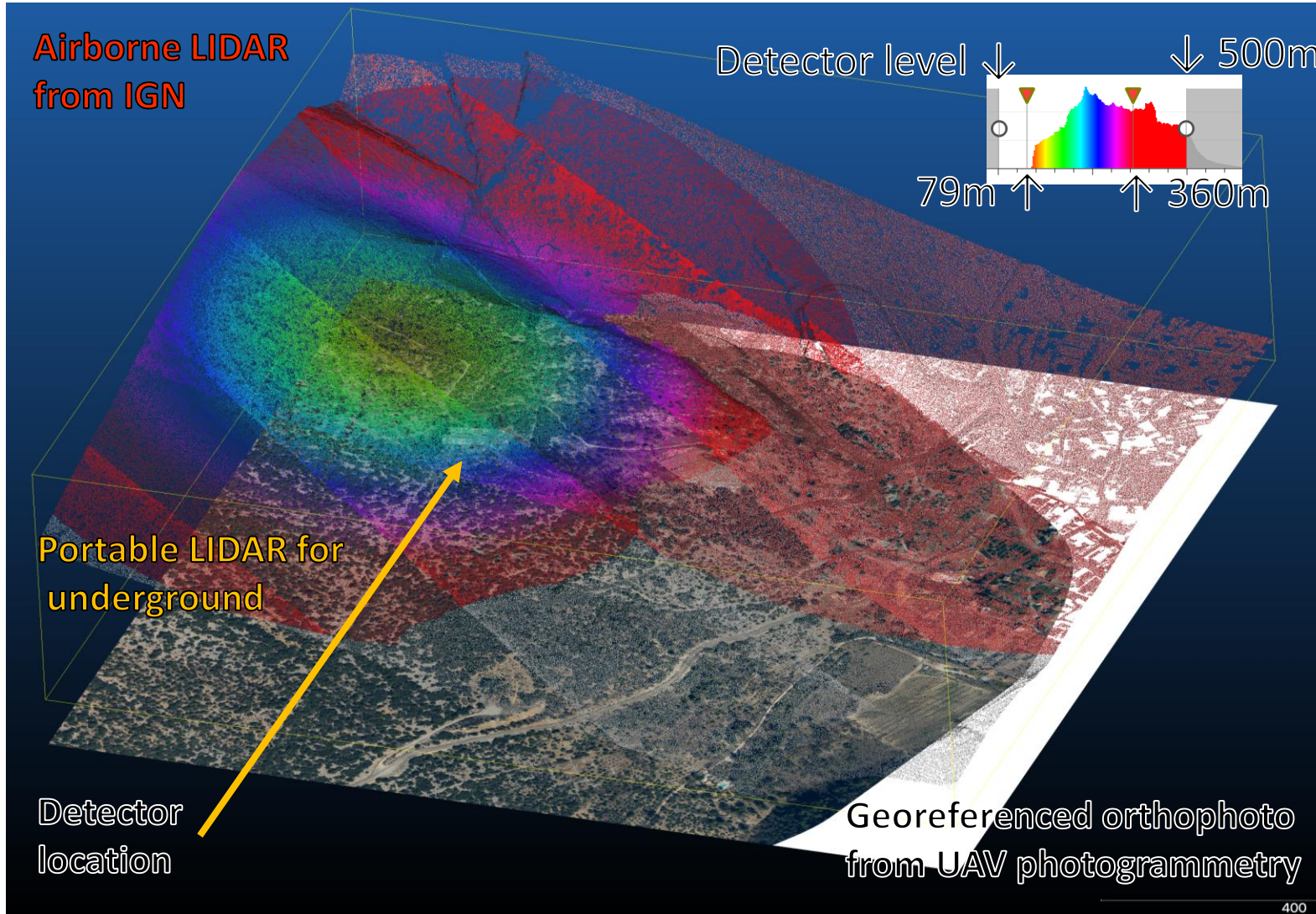
Study case: underground monitoring



- Low background noise underground laboratory: pilot site of the project, possibility to deploy detectors elsewhere
- LSBB located in the non-saturated zone above water table
- Rainwater collected by Plateau of Albion feeds Fontaine de Vaucluse
- Underground muon tomography gives insight about aquifers

Study case: underground monitoring

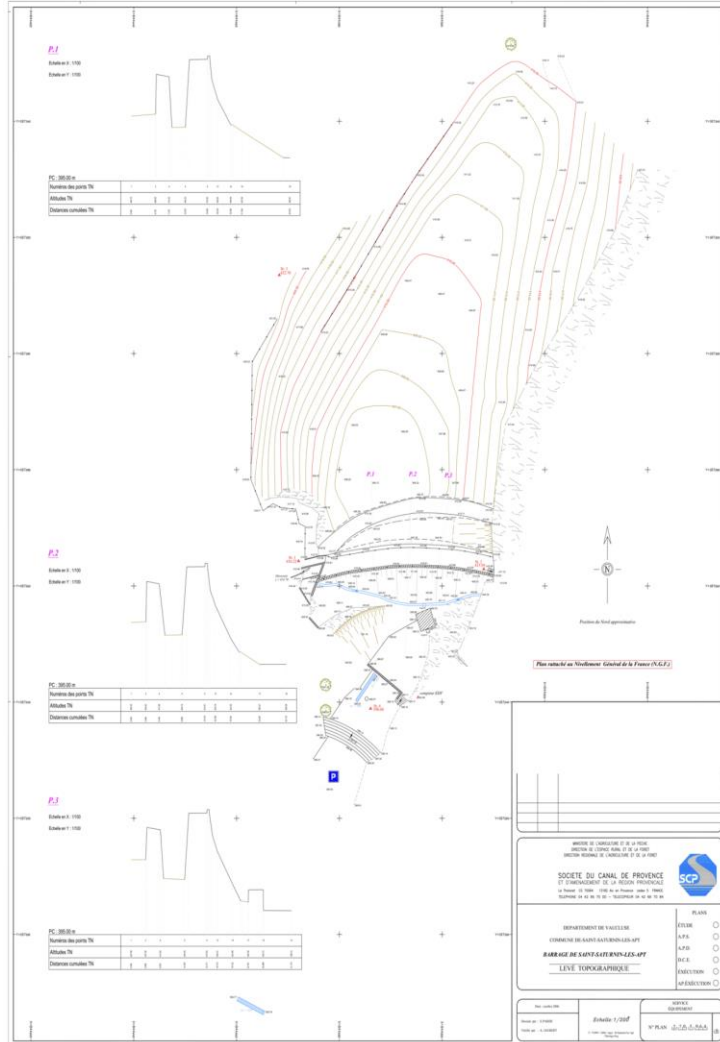
- Distances from detector to surface (1cm accuracy in length)
- Off ground points classified



Necessary for accurate modeling of muon flux attenuation on detector location

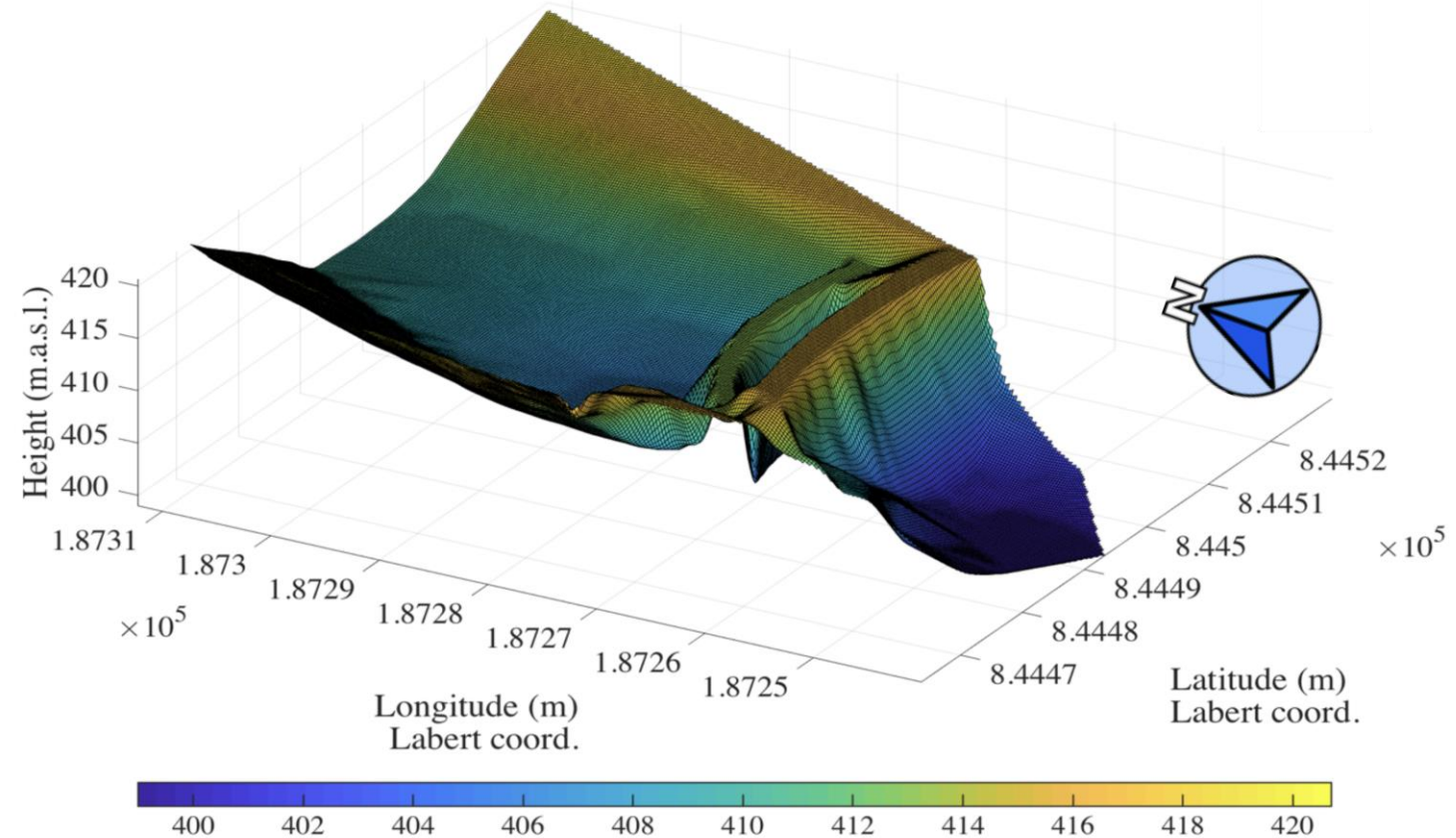
Study case: dam

Topographic survey



October 2006
 Unknown accuracy

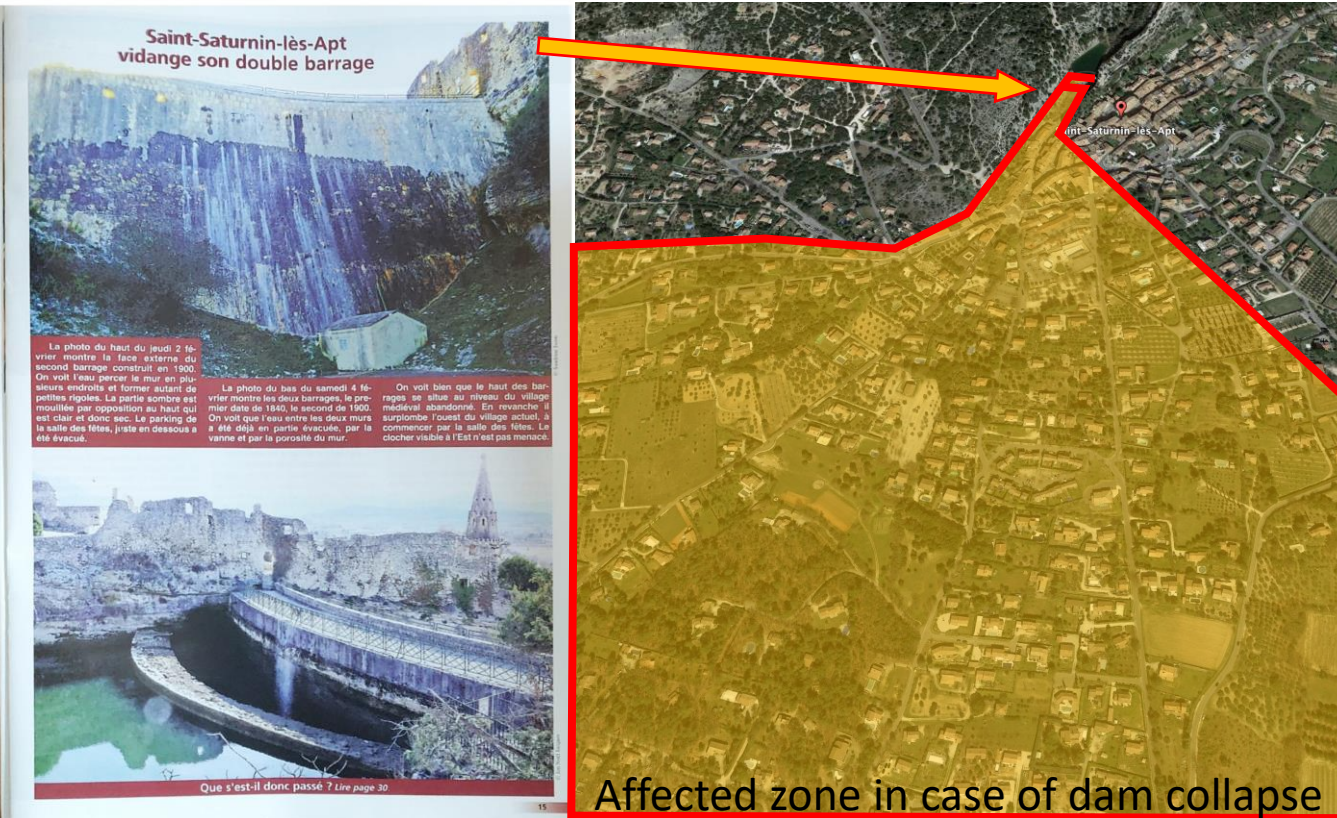
3D Model



October 2017
 Based on the topographic survey
 Resolution 1 point/m²
 Size 297x441m
 Interpolation artifacts

Study case: dam

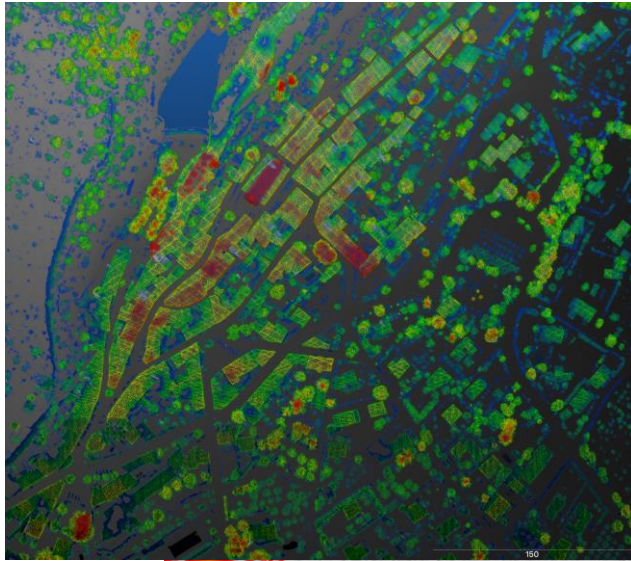
February 2023: Dangerous incident during the dam monitoring



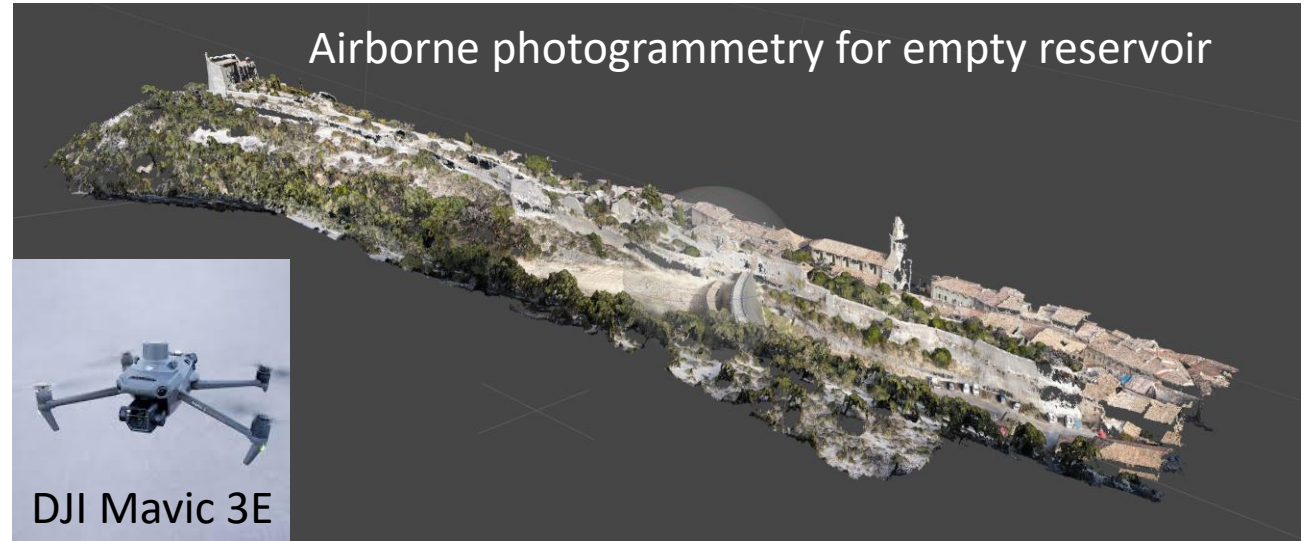
- Periodical dam monitoring required by regional agency.
- Local council (owner) commissions the monitoring to the concession holder.
- Concession holder outsources a borehole drilling for structure analysis.
- Borehole technicians ask for dam plans, they do not exist as the double dam structure is over 200 years old.
- Owner authorizes the drilling as the monitoring is legally enforced.
- Borehole damages the dam exhaust and the dam front starts to leak, weakening the whole structure.
- Emergency procedure triggered to empty the reservoir.
- Emptying doesn't work as sediment has clogged the drain system.
- The old submerged dam holds the water weight and can cause a hydraulic ram.
- Firefighters deploy motor pumps to empty reservoir (3 days).



Study case: dam

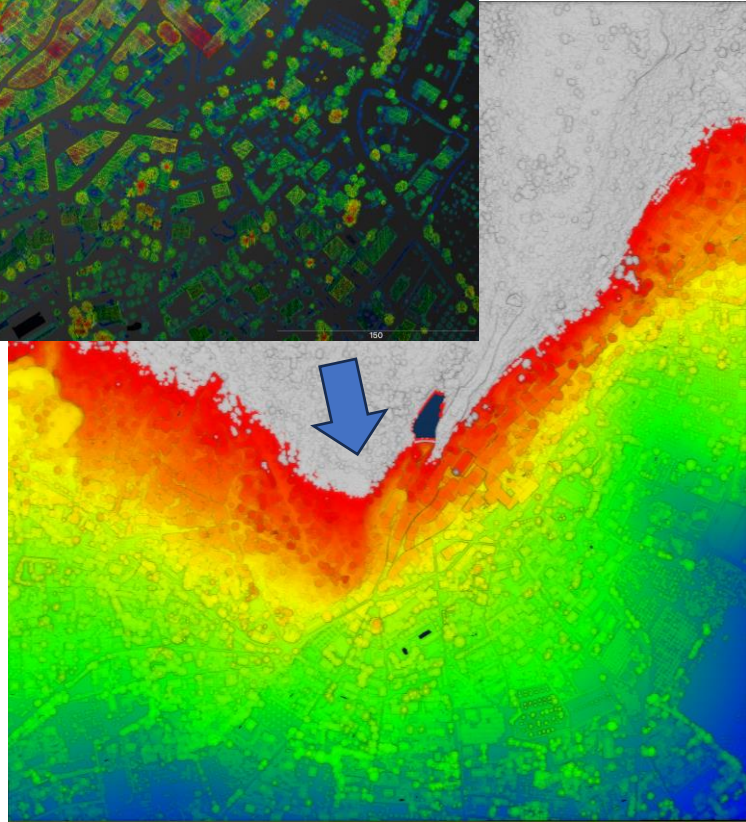


Airborne LIDAR
for village



Airborne photogrammetry for empty reservoir

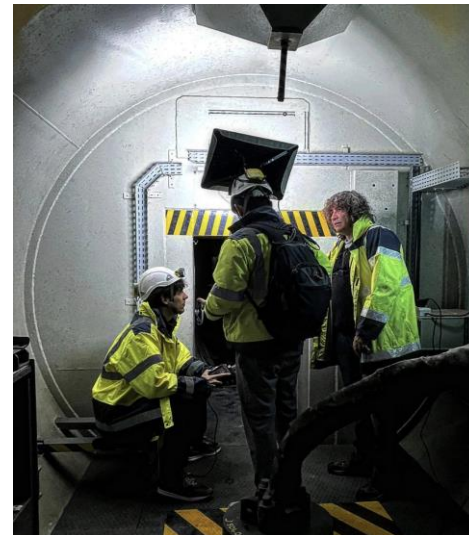
DJI Mavic 3E



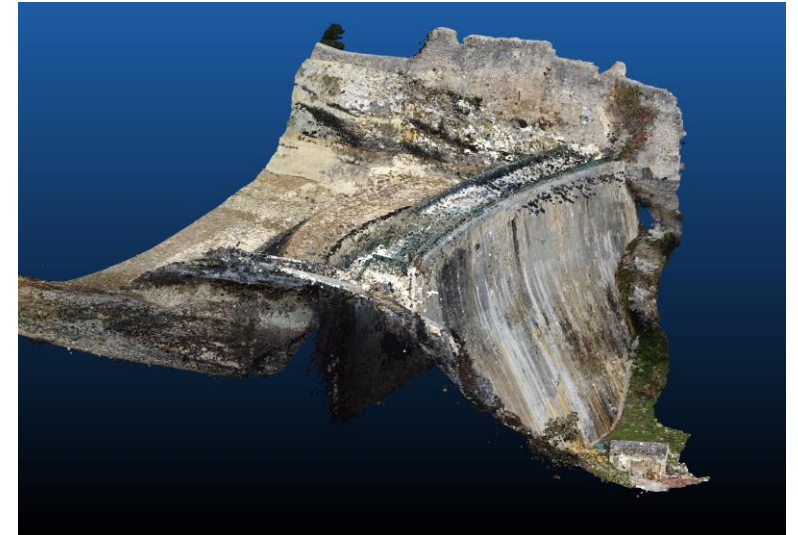
2021

Raw data by IGN

<https://geoservices.ign.fr/lidarhd>



Mobile LIDAR for dam &
underground spaces

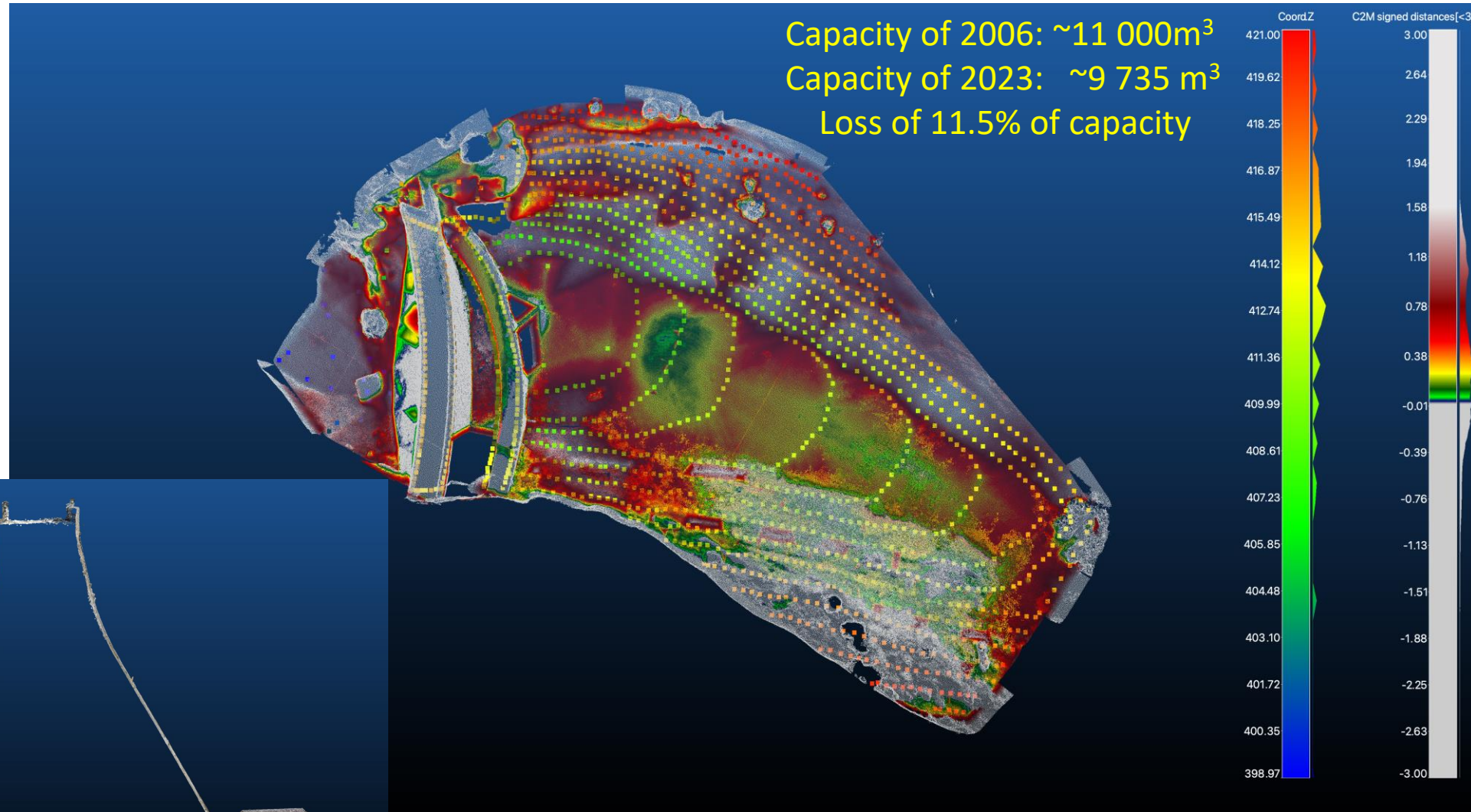


Clément Risso
Ignacio Lázaro Roche

TRUST-ME | Muographers 2023

Study case: dam

Map of sedimentation
 between 2006 and 2023

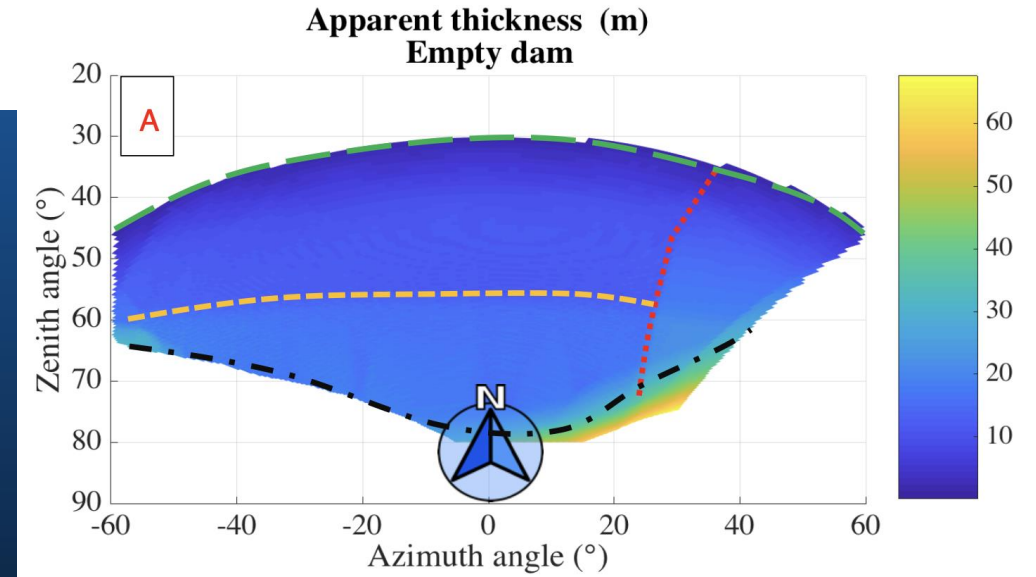
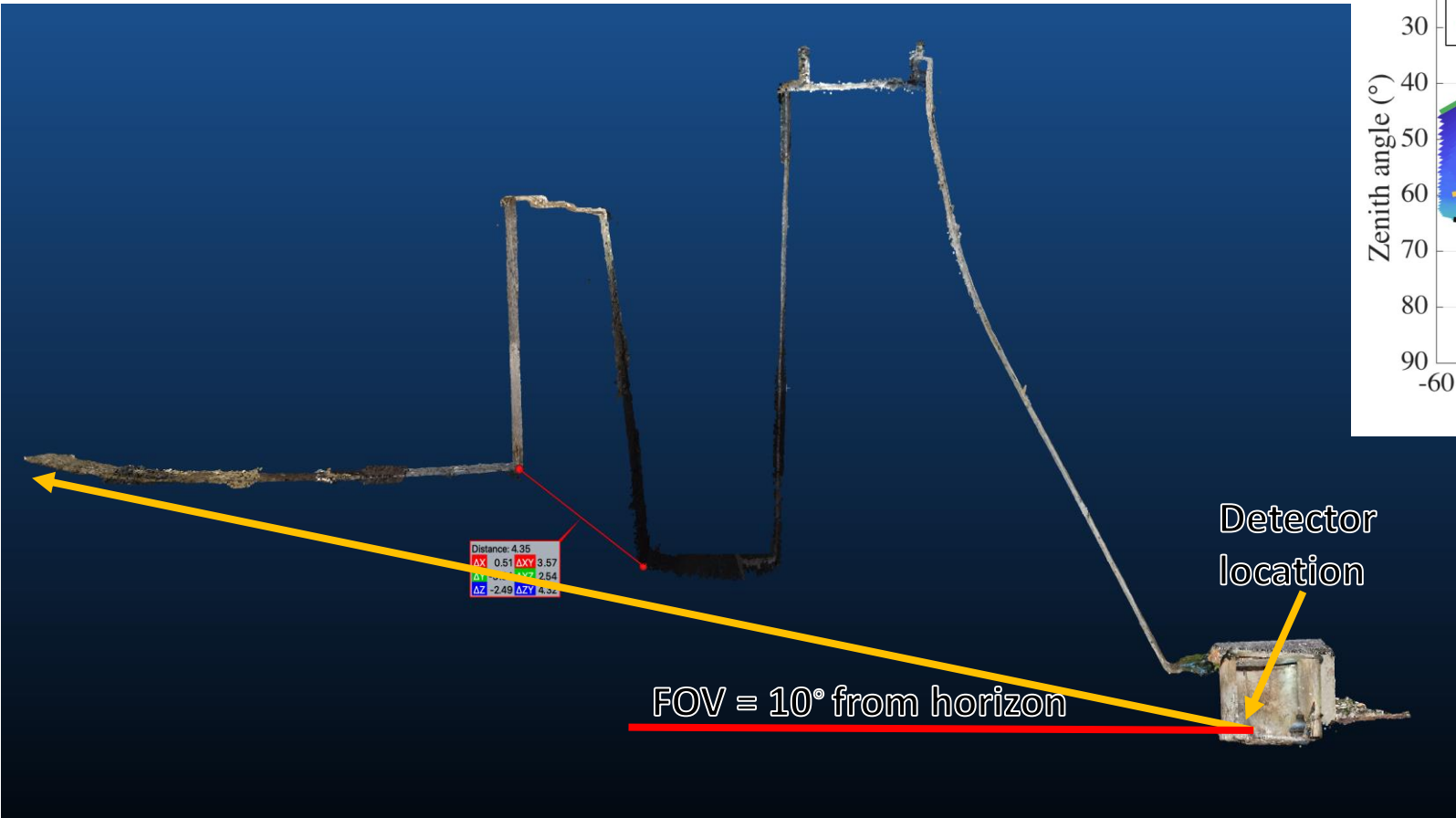


Cross-section of the dams



Study case: dam

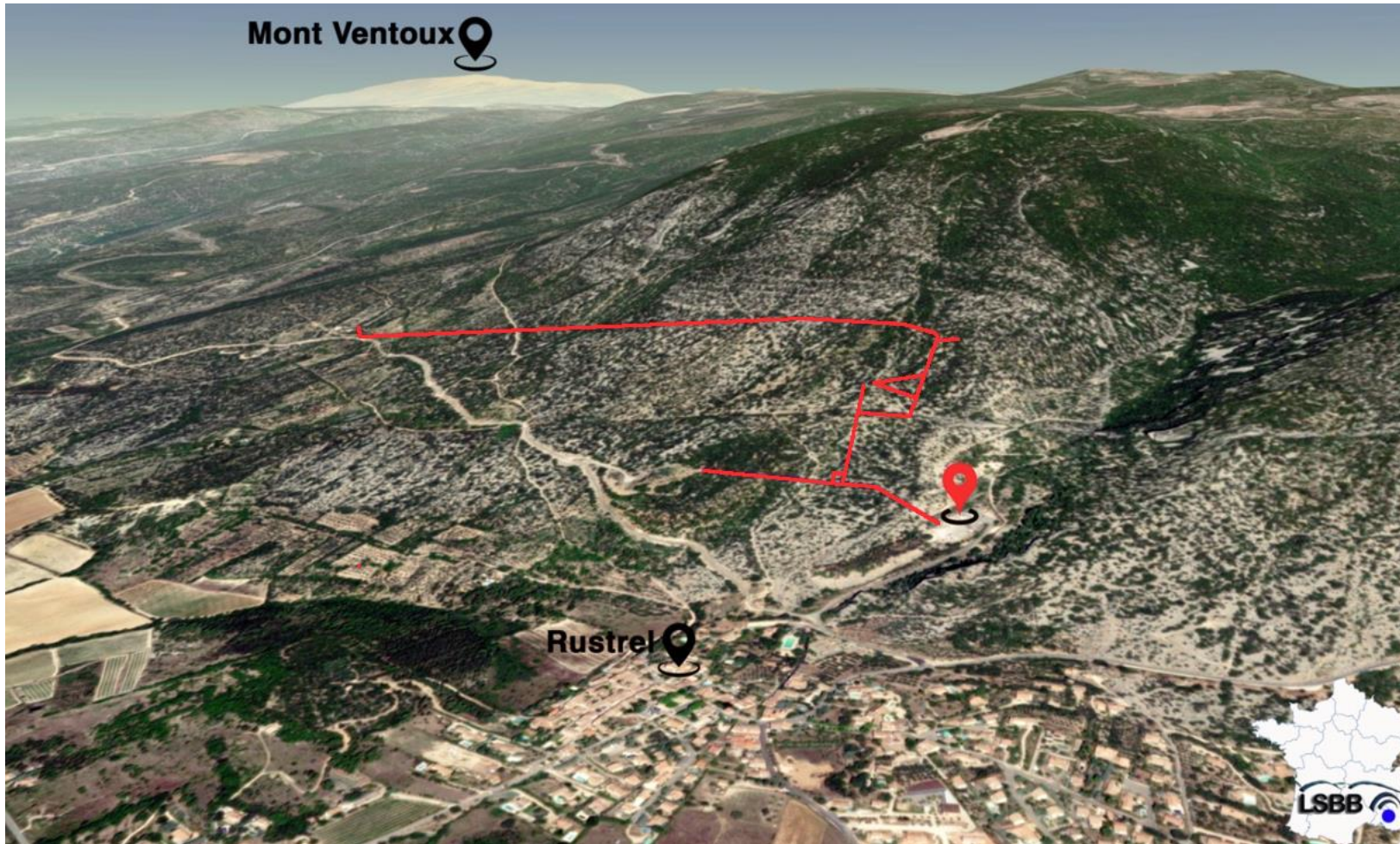
New data campaign using photogrammetry



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>

Cross-section of double dam



Funding agencies



Acknowledgements



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