



MUOGRAPHY AT THE LOW BACKGROUND NOISE UNDERGROUND RESEARCH LABORATORY OF RUSTREL

Ignacio LÁZARO ROCHE

On behalf of T2DM2 project for Muographers 2021

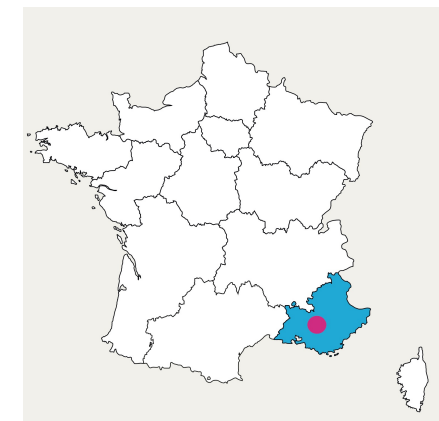
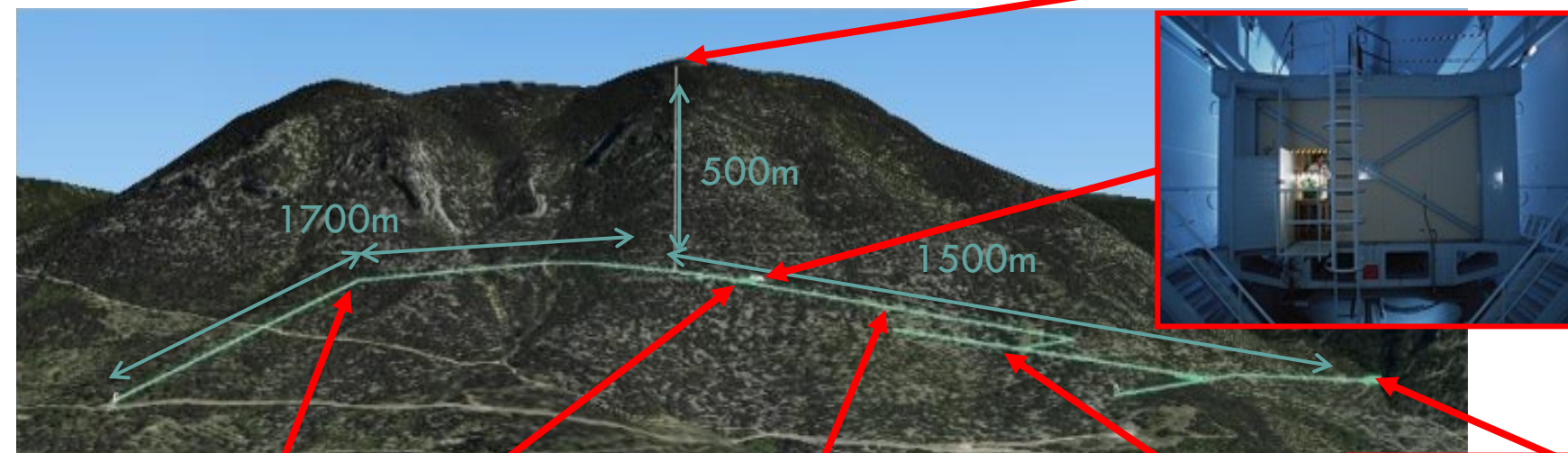


LOW BACKGROUND NOISE UNDERGROUND LABORATORY

- Underground **and** surface unique facilities
- 4.3km of galleries
- 53 ha of surface



- Permanent network of detectors
- Periodical campaigns
- >20 years of environmental data
- Over 60 PhD thesis



MULTIDISCIPLINARY AND WELCOMING

Resources

- Karst
- **Underground Water Resources**
- Carbonated platform

Environment/ fluid interactions

- Processes and thermo-hydro-mechanical couplings
- Poroelasticity
- **Geomechanics**

Waves, radiation and astrophysics

- Seismology
- Magnetism
- Gamma
- Neutrons
- **Muons**
- WIMPs (DM)
- Atmospheric electrical phenomena

Instrumentation and metrology

- Magnetometry
- Gravimetry
- Densitometry
- Seismometry
- Rotation
- Clinometry
- Optic fiber
- Electronics characterization
- **New tools development**

Life

- Geobiology
- Brain imaging

Human science & society

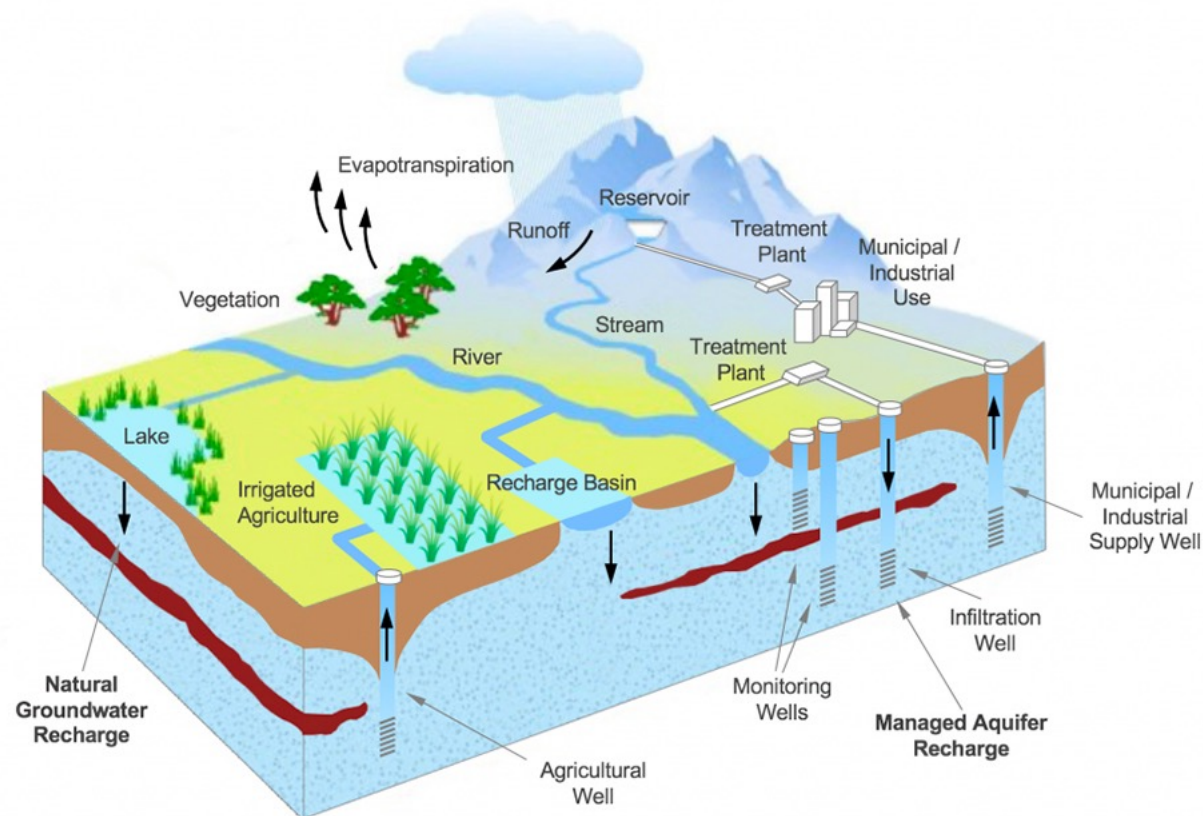
- Contemporary History vs Cold War
- Anthropization vs Global Changes

Open to everyone, specially muographers

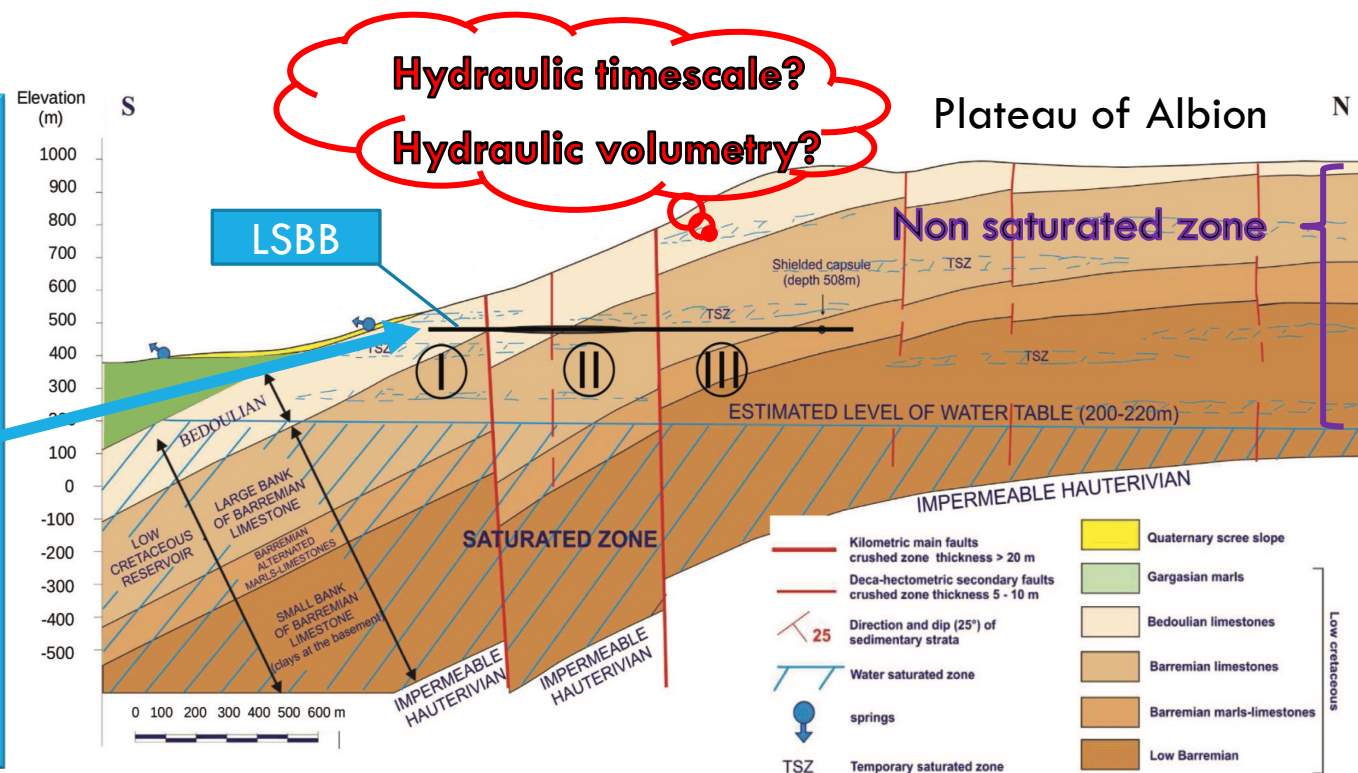
ORIGIN OF THE PROJECT – WATER MANAGEMENT, A SOCIETAL CHALLENGE

- Karst covers ~15% of the Earth's surface distributed in over 50 countries.
- 25% of the world's population relies on water supplies coming from karst reservoirs for drinking water.
- Additional stress due to climate change require more intense exploitation of karst water resources.
- Water-triggered geohazards are common in karst environments (sinkholes, landslides, flooding, water contamination...).

The **complexity** of karst hydro-systems makes sustainable water exploitation and management difficult.

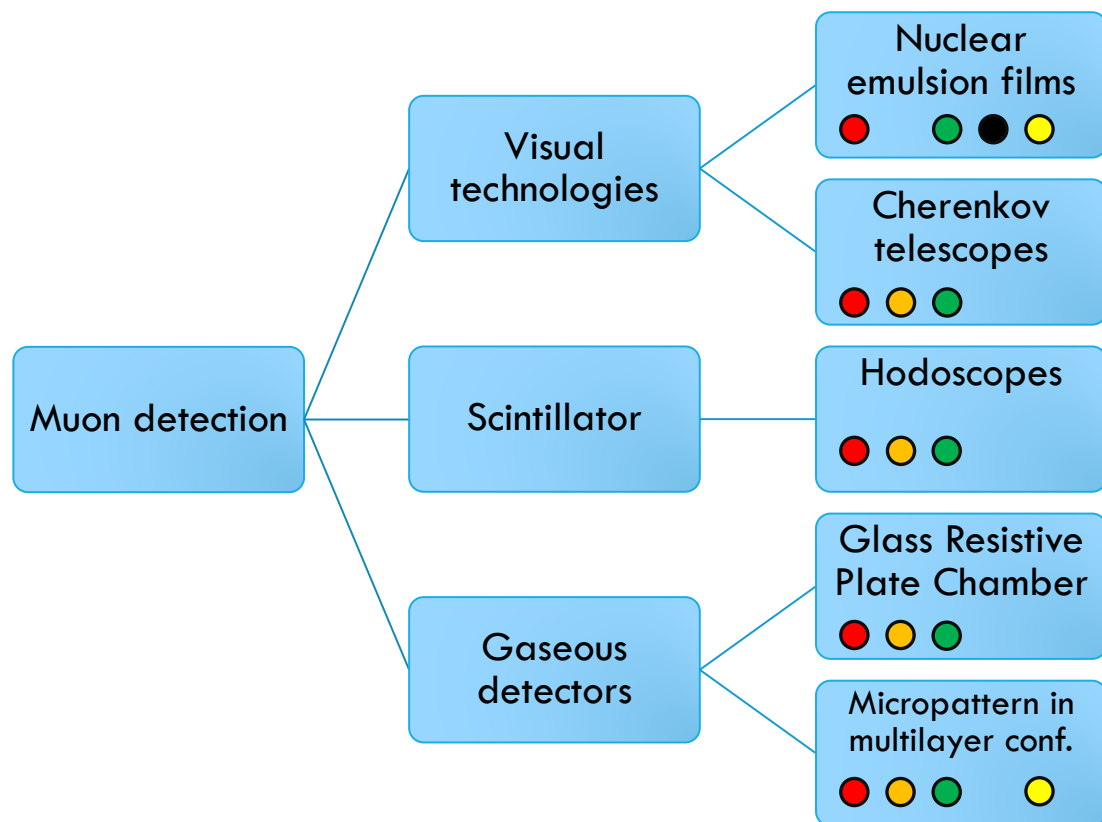


ORIGIN OF THE PROJECT – A CONVENIENT LOCATION



- Goal : map the presence and movement of groundwater in a highly dynamic and heterogeneous environment.
- Challenges : Up to 500m deep, underground operation, broad field of view required, temporal information...

IN NEED OF A NEW SOLUTION

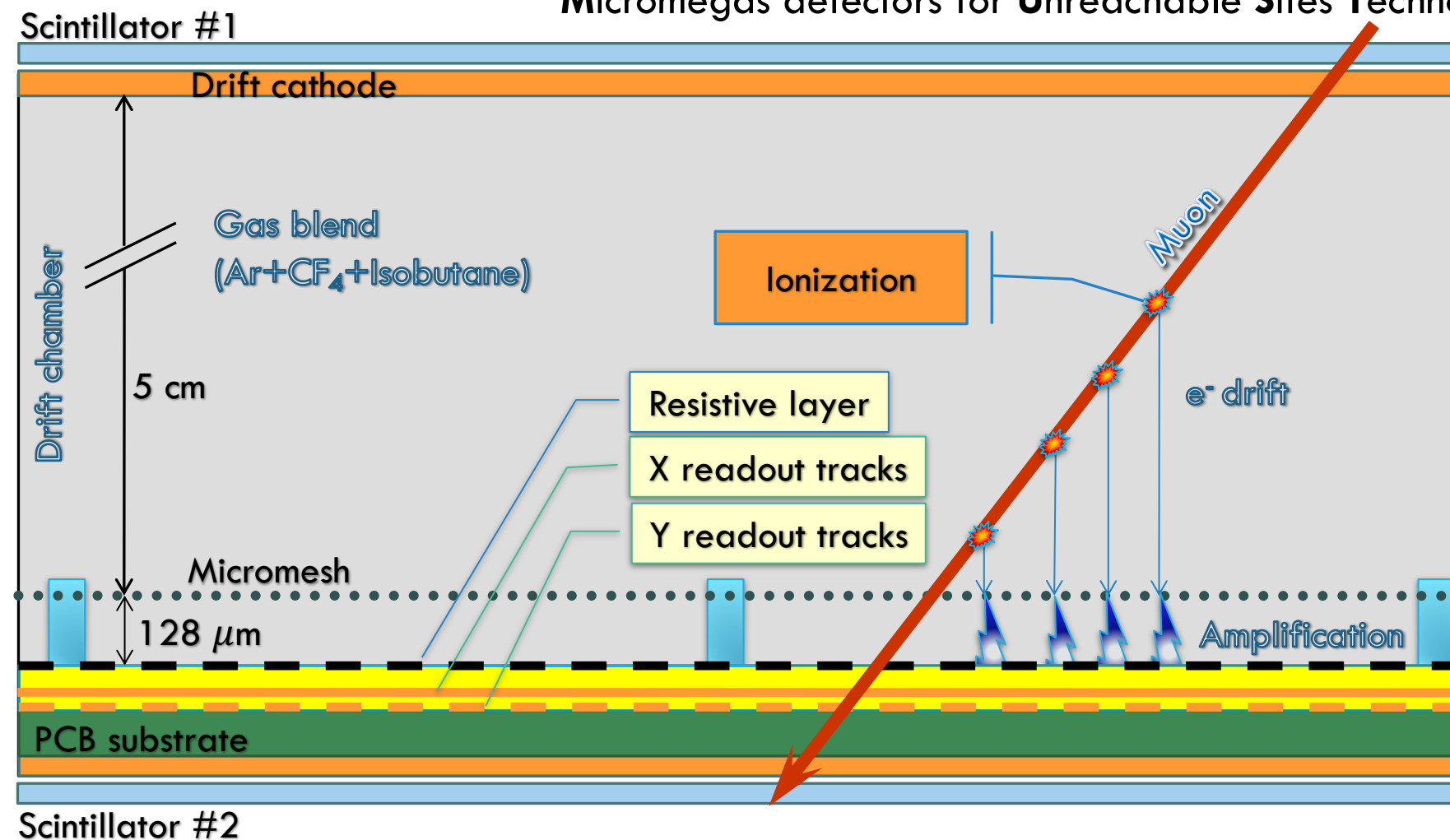


- Requirements for the targeted application back in 2012:
 - Retrieve the particle trajectory (zenith and azimuth angles)
 - Temporal information of the detected muons
 - Angular resolution compatible with geophysical techniques
 - Big angular acceptance
 - Compact and transportable for narrow operation

Need for a new technology

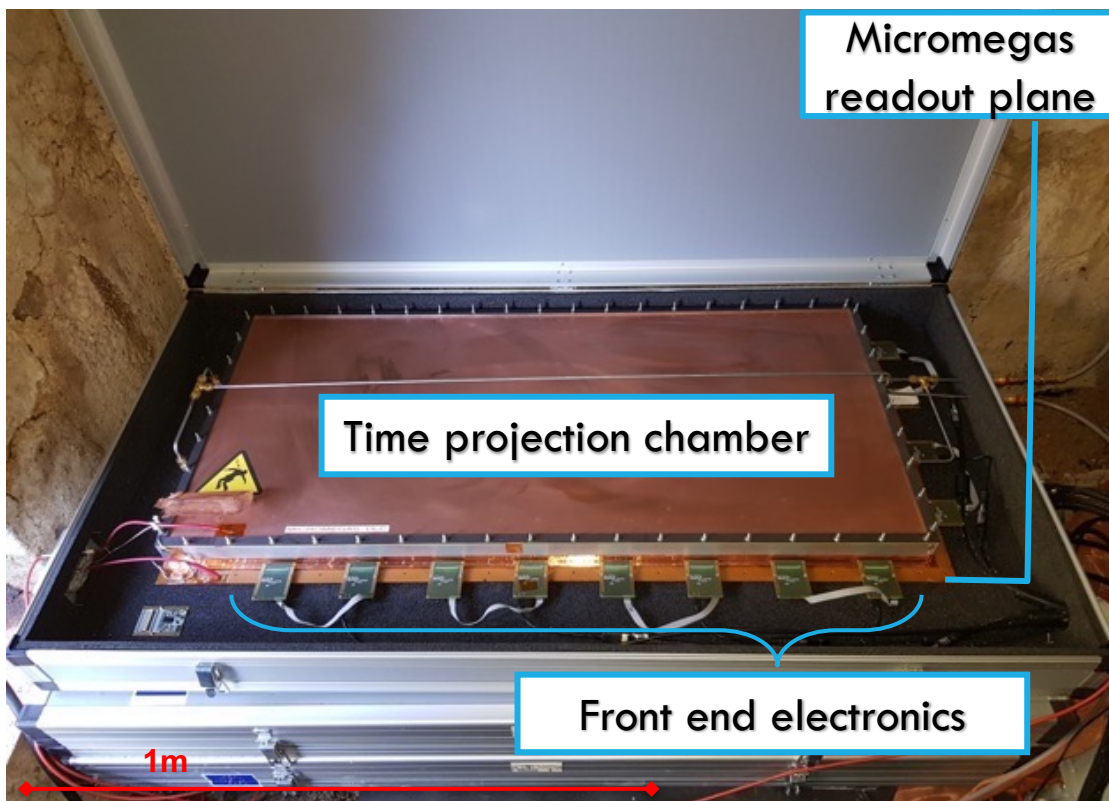
MUST² CAMERA – Principle

MUon **SUR**vey **TOM**ography based on
MICromegas detectors for **UN**reachable **SIT**es **TE**chnology



- Thin time projection chamber
- Bulk Micromegas with resistive layer
- Accessory scintillators for triggering

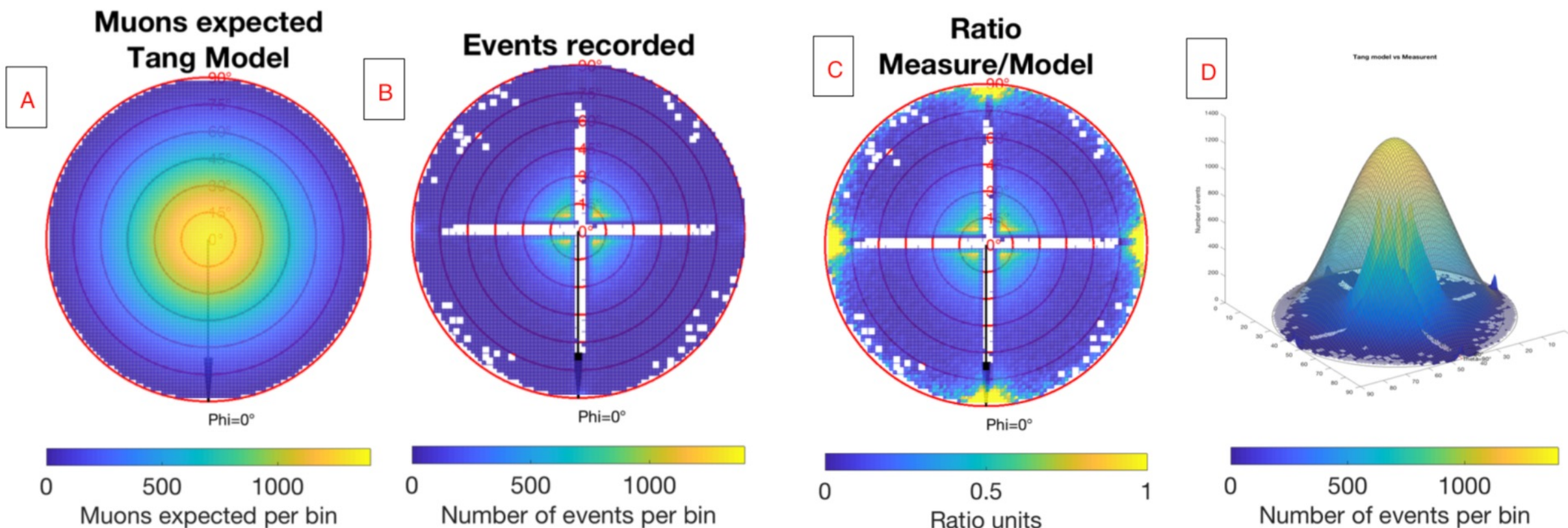
MUST² CAMERA – Principle



- Max. external dimensions 144 x 79 x 12 cm
- Weight ~28 kg
- Angular acceptance up to 80° when triggered with external scintillators
- Angular resolution better than 1° for particles with angles of incidence over 17°
- Patented along with the gas conditioning system

EXPERIMENTAL RESULTS – Calibration tests : response characterization

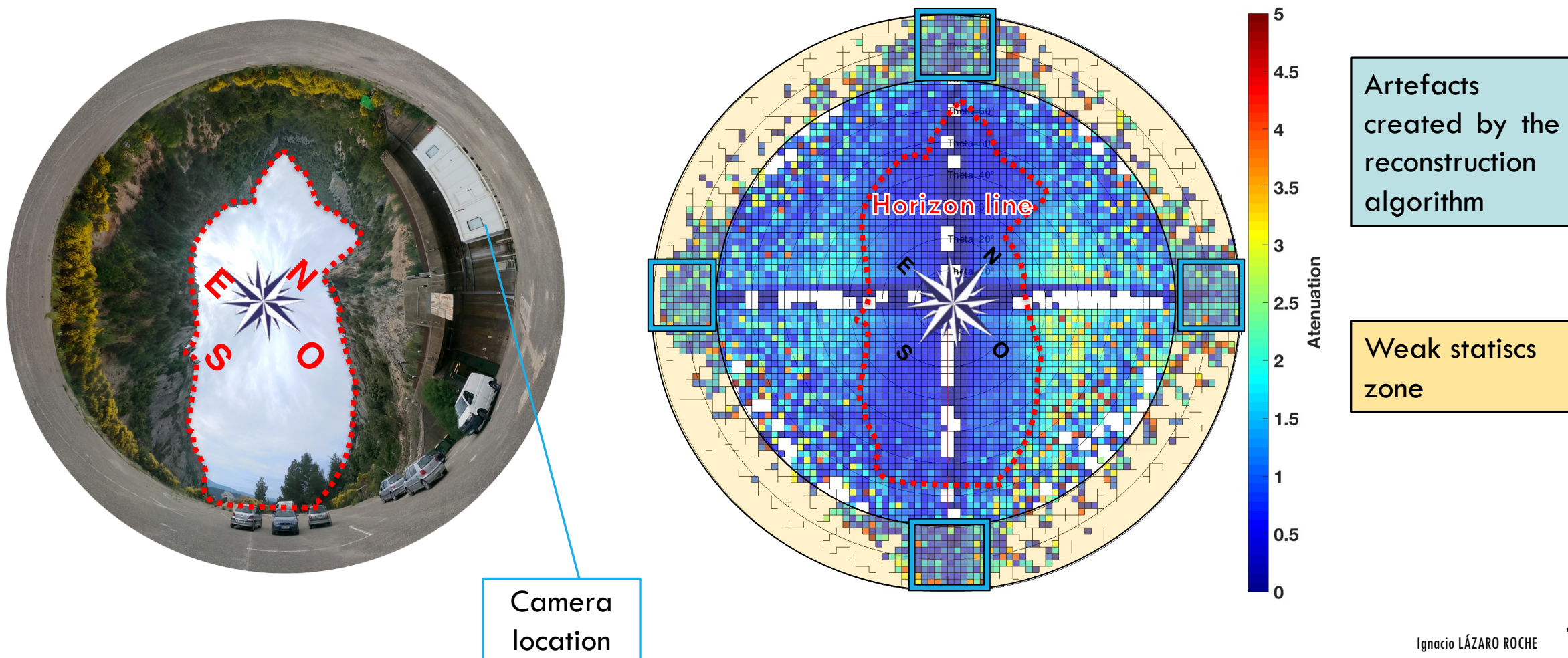
Polar chart of the muon arrival distribution for the Tang* model and experimental measurements.



*[Tang, 2006]

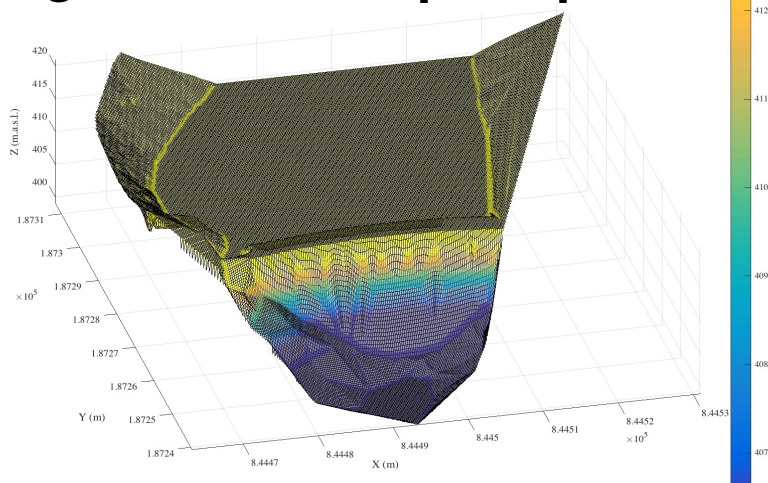
EXPERIMENTAL RESULTS – Calibration tests : first qualitative measurements

360° view around the camera

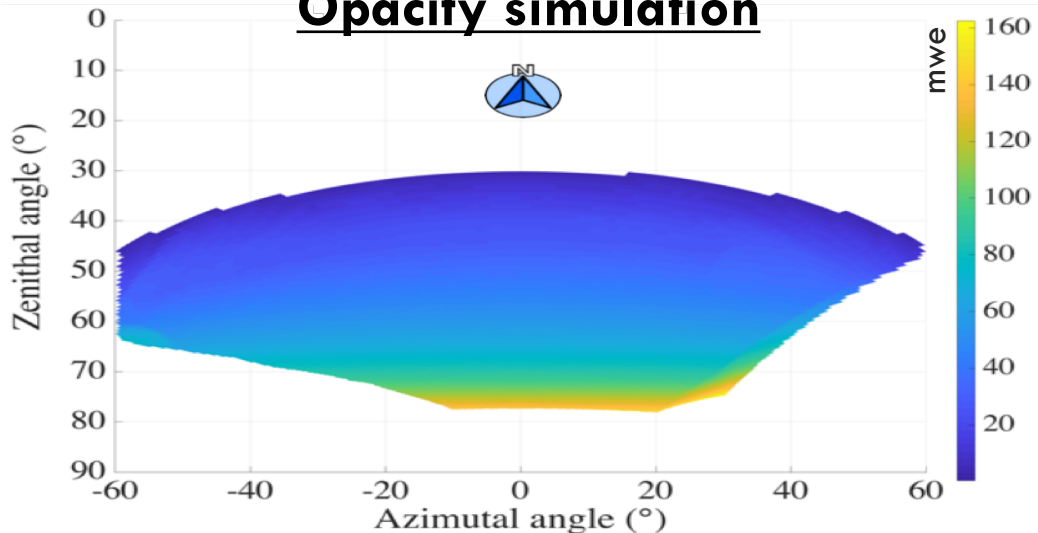


EXPERIMENTAL RESULTS – Study case

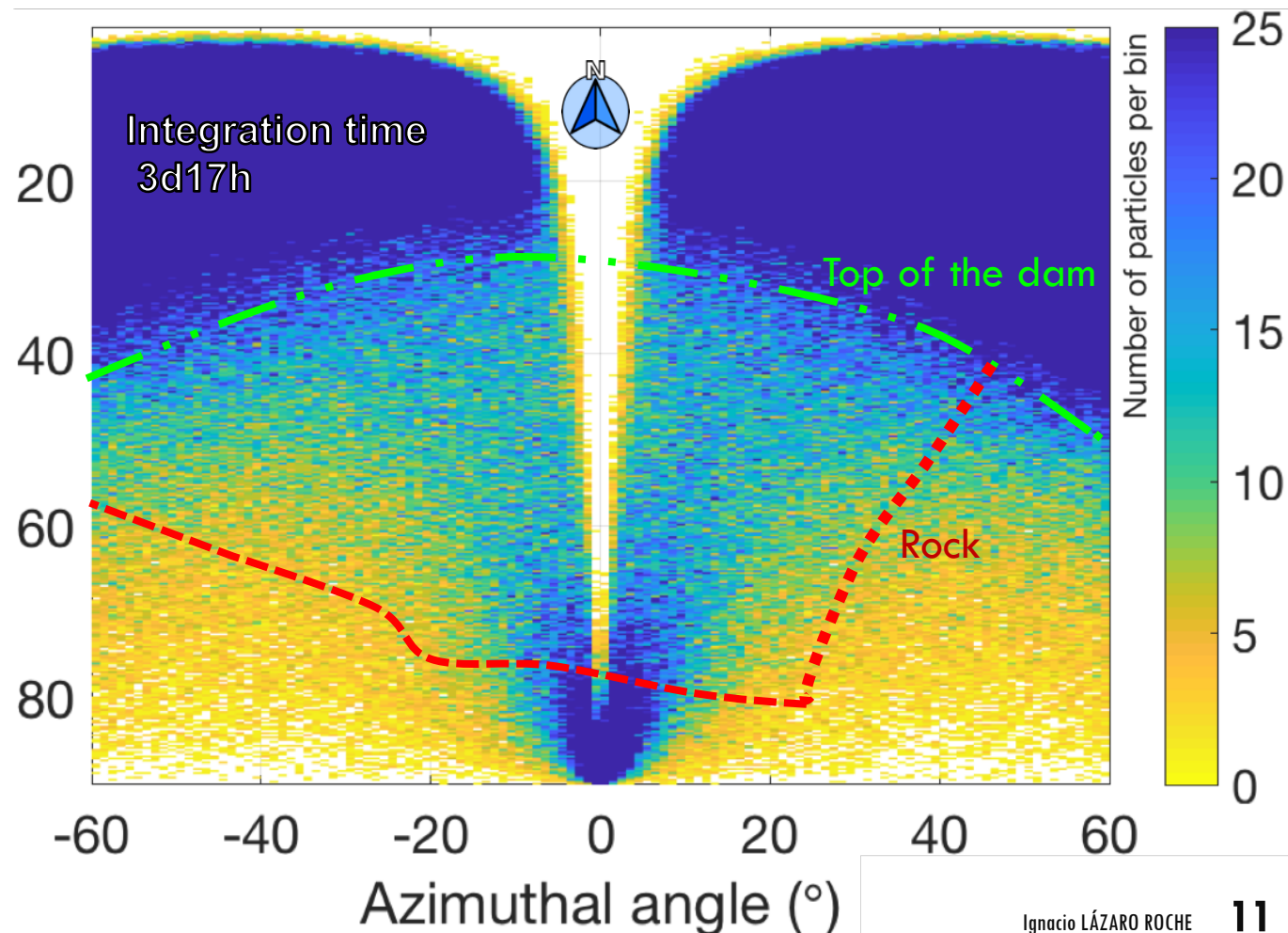
2 digital models superimposed:



Opacity simulation

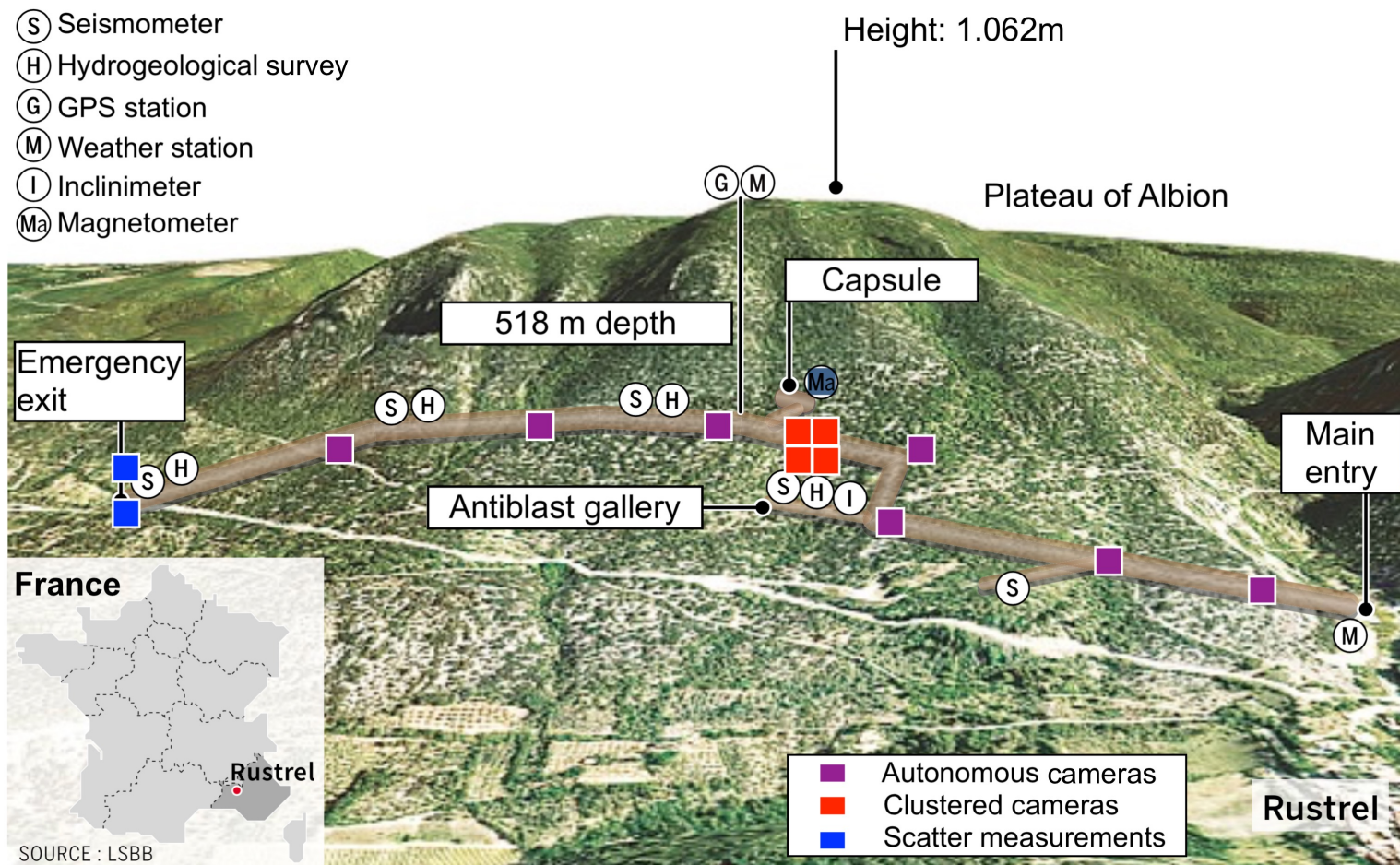


Experimental measurement



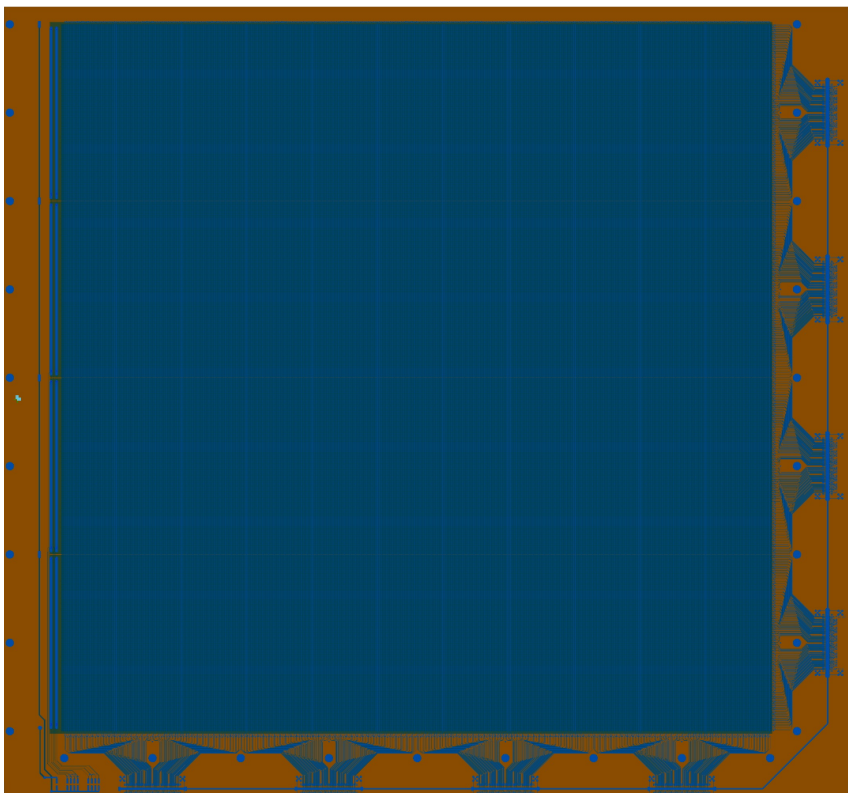
SCALING UP THE DETECTOR NETWORK

- Ⓢ Seismometer
- Ⓜ Hydrogeological survey
- ⓐ GPS station
- Ⓜ Weather station
- Ⓡ Inclinator
- Ⓜa Magnetometer



- ✓ Construction and deployment at the LSBB of a network of 20 autonomous cameras, 5m² active surface
- ✓ Meant for the LSBB, but possibility to deploy them elsewhere
- ✓ Funded by FEDER LSBB2020 (400k€)
- ✓ Versatile setup configurations for experiments

TECHNOLOGY UPGRADE — HARDWARE IMPROVEMENTS



- Pioneers in the use of DLC-RL
- New readout layout, better charge ratio between XY layers
- New shape: reduce signal heterogeneity
- New HV, automatic temperature compensation
- New interface: compatible with new electronics, reduces noise

TECHNOLOGY UPGRADE – ELECTRONICS

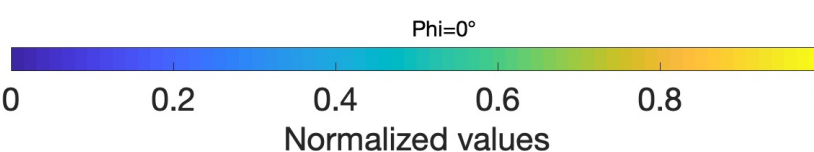
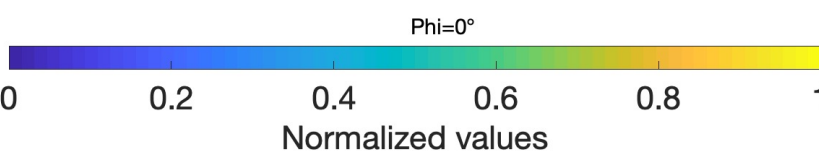
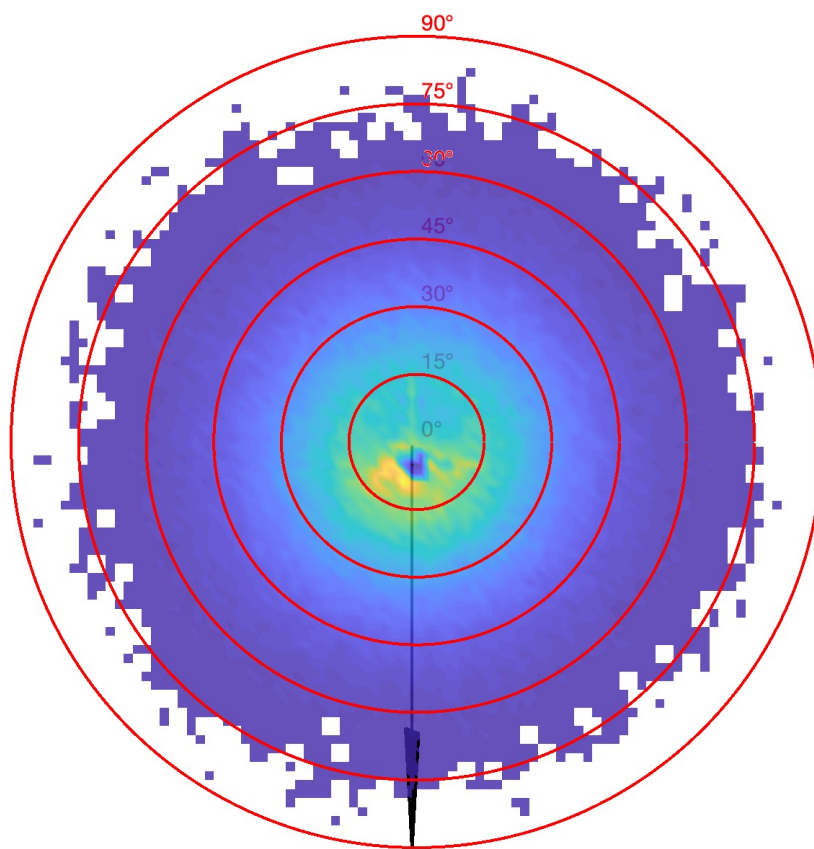
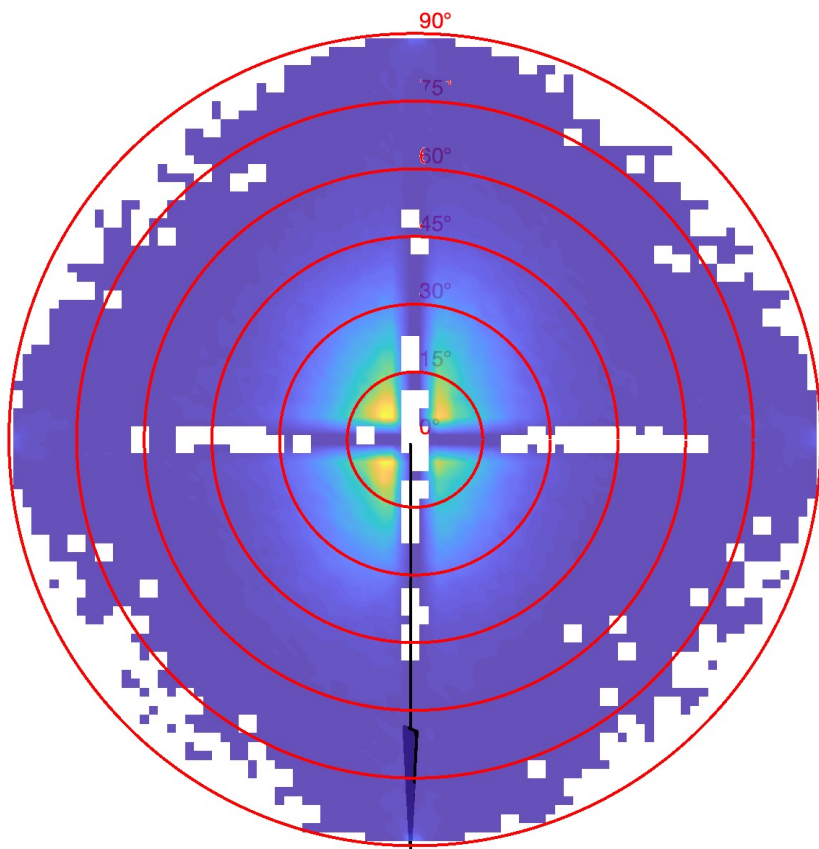
New data acquisition electronics

Feature	Former (APV25)	Current (VMM v4)
Off-the-self product	No	Yes
Need of auxiliary detectors	Yes	No
Self-trigger	No	Yes
Zero suppression	No	Yes
Custom gain	No	Yes
Time resolution	25ns	1 ns

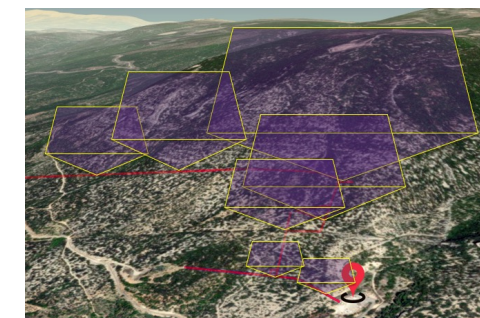
TECHNOLOGY UPGRADE – DATA ANALYSIS

Early reconstruction algorithm

New reconstruction algorithm



- New approach to minimize the blind zones
- More reliable reconstruction
- Every event is calculated with a quality factor (Q)
- Ongoing work:
 - Multi-POV data analysis



MUOGRAPHY TEAMS AND LSBB

T2DM2 (from 2012)



Micromegas
in TPC +
plastic
scintillators

CPPM (2012-2015)



Liquid
scintillators

Onera (2012-2016)



CEA/Iris Inst (2015-2018)



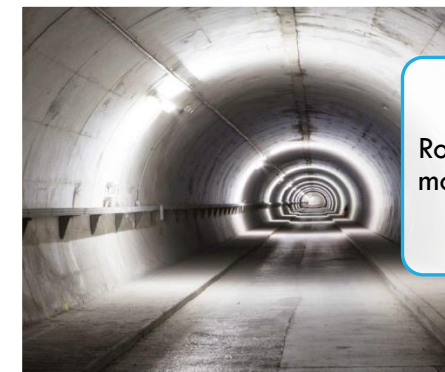
Genetic
Micromegas
in multilayer
configuration

DIAPHANE (2018-2019)



Plastic
scintillators

APOGEIA (2022 ???)



Room for
more

MULTI-TECHNIQUE APPROACH – THE BUISSONNIÈRE EXPERIMENT

Project funded with 20k€ during 2018 and 2019



CRITEX

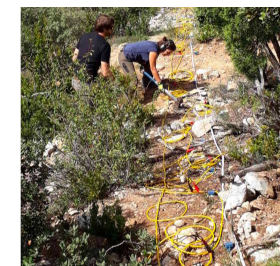
Innovative equipment for the critical zone

Couple **muon densitometry** measurements with state-of-the-art **geophysical methods** to characterize the near-surface environment (Critical Zone) to monitor the hydrodynamics.

High-resolution imaging of the CZ structure with muon 3D tomography (continuous measurements) to monitor density variations associated to changes in the water content.



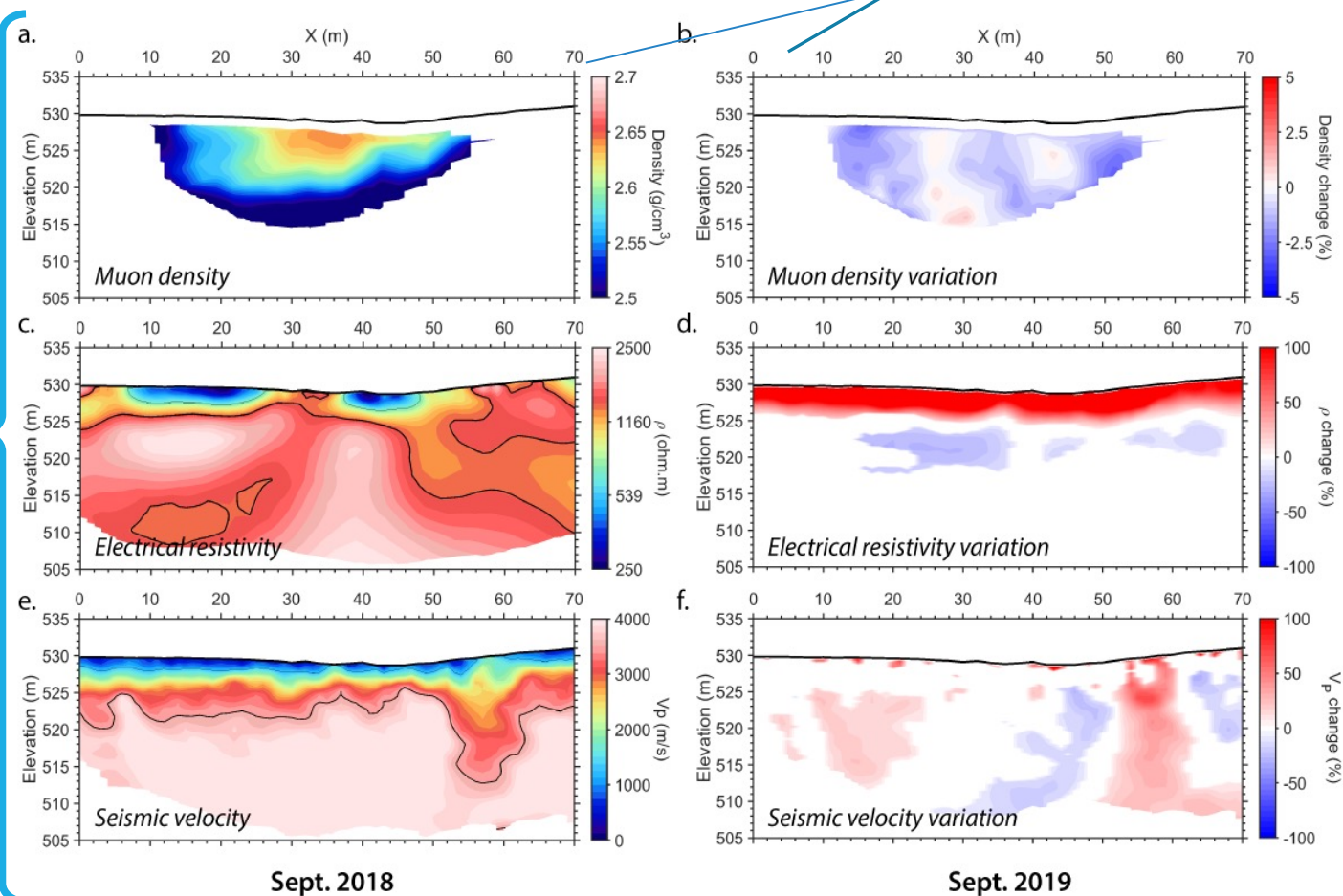
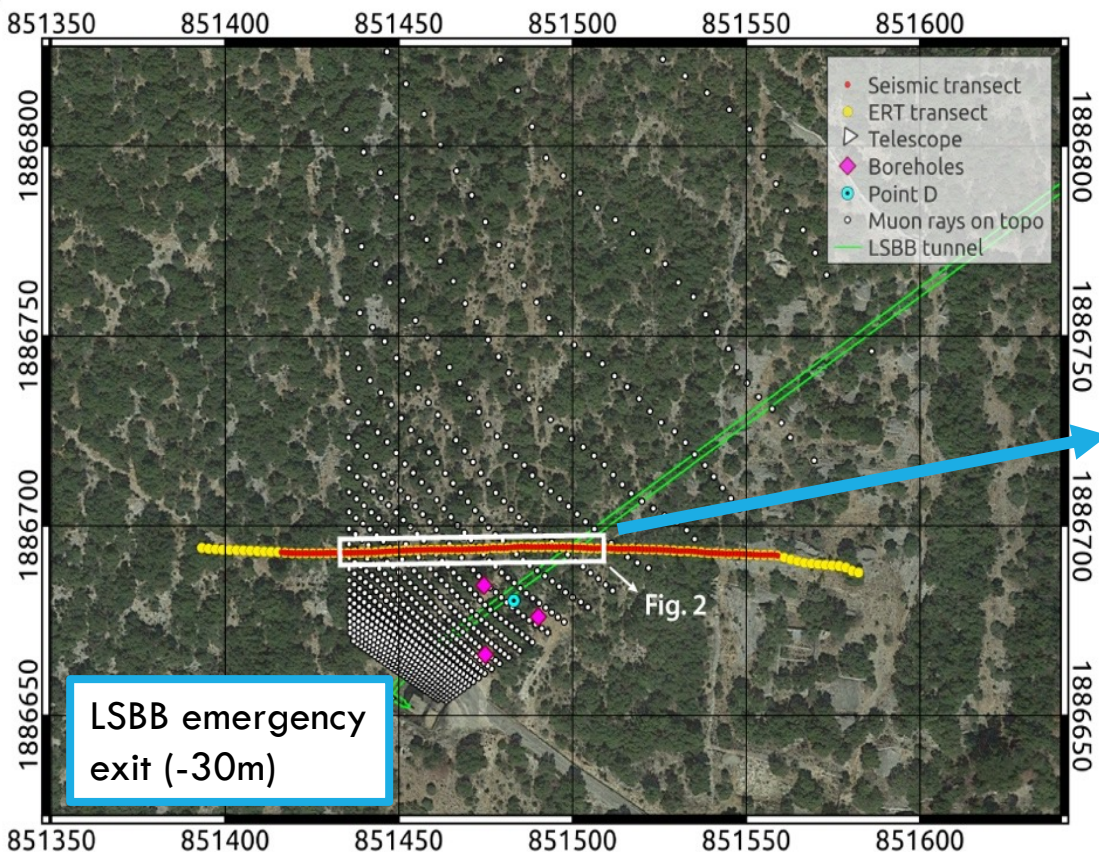
Continuous recordings of seismic ambient noise and superconducting gravimetry, supplemented with repeated surveys of microgravimetry, seismics, electrical resistivity tomography and NMR.



These **methodologies** are **highly complementary** since they are sensitive to water content, either directly or through different physical parameters (e.g. density, seismic velocity, electrical conductivity) with different spatial resolutions.

MULTI-TECHNIQUE APPROACH – THE BUISSONNIÈRE EXPERIMENT

Obtained with
DIAPHANE equipment

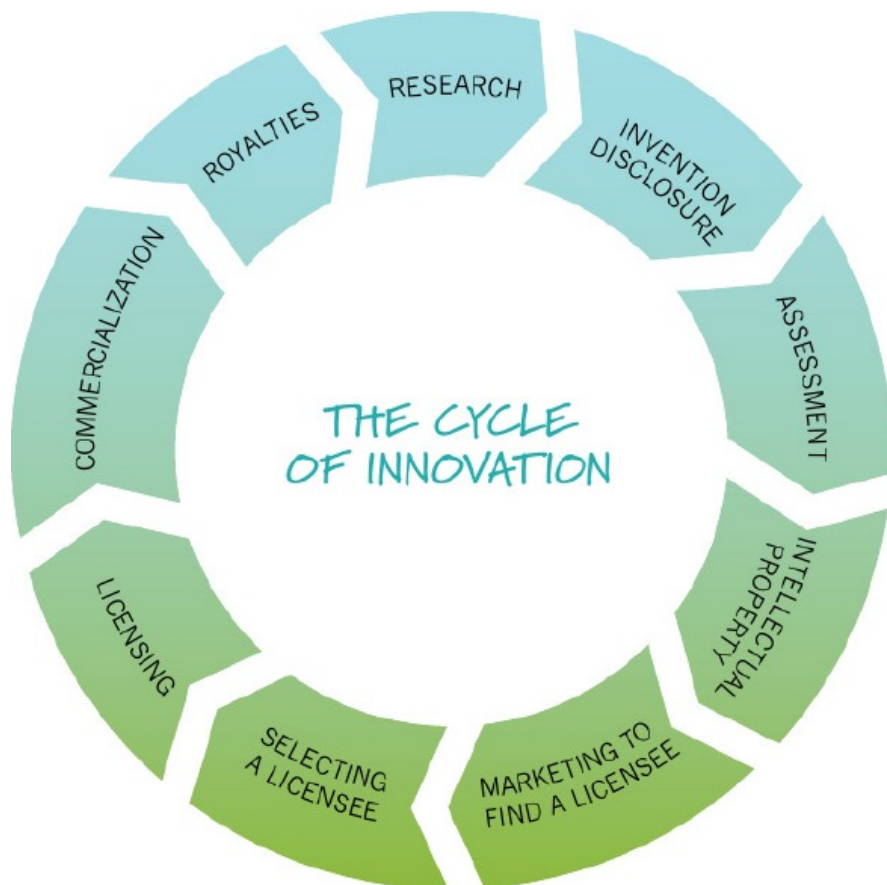


Ref: Lázaro Roche, I.; Pasquet, S.; Chalikakis, K.; Mazzilli, N.; Rosas-Carbajal, M.; Decitre, J.B.; Batiot-Guilhe, C.; Emblanch, C.; Marteau, J.; et al.

Water resource management: The multi-technique approach of the Low Background Noise Underground Research Laboratory of Rustrel, France, and its muon detection projects.

In Muography: Exploring Earth's Subsurface with Elementary Particles. **2021**, Geophysical Monograph Series; Olah, L., Tanaka, H., Varga, D., Eds. American Geophysical Union, USA. DOI:10.1002/9781119722748.ch10

BEYOND FUNDAMENTAL RESEARCH



- IP: 2015 Patent of “Method and device for determining the density of rocky volumes or artificial buildings”
- 2021 Spin-off Project: Tomographic Research of Underground and large Structures with Muographic Expertise (TRUST-ME)
 - Awarded as “Innovative Young PhD” (55,5k€ for HHRR)
 - Currently in final selection phase of CNRS prématuration program (150k€ for HHRR, materials and field campaigns)

WE ARE HIRING




Information and application: ignacio.lazaro@lsbb.eu

- 2 years position at CNRS
 - Research engineer or postdoc profiles
 - With possibility of extension
 - To work at the LSBB (in Provence, South-East France)
- Required competences
 - Data analysis and image reconstruction
 - Simulation tools and studies
 - Computer network and programming
 - Geophysics

CONCLUSIONS

- ❑ The LSBB is an underground multidisciplinary platform with low background noise
 - ❑ With an inhouse muography technology
 - ❑ Whose main target is groundwater monitoring and large infrastructures survey
 - ❑ Current developments focused on data analysis from new generation detectors
 - ❑ Deploying a network of 20 autonomous muon trackers for the study of the Critical Zone
 - ❑ Spin-off project: TRUST-ME, now hiring.
- ❑ **Plenty of room for other members of the community to come**

A photograph of a lavender field with a stone building in the background. The lavender plants are in full bloom, creating a vibrant purple color. The stone building has a small arched entrance and a larger arched opening on the roof. The background shows a line of trees and a clear sky.

Thank you for your attention