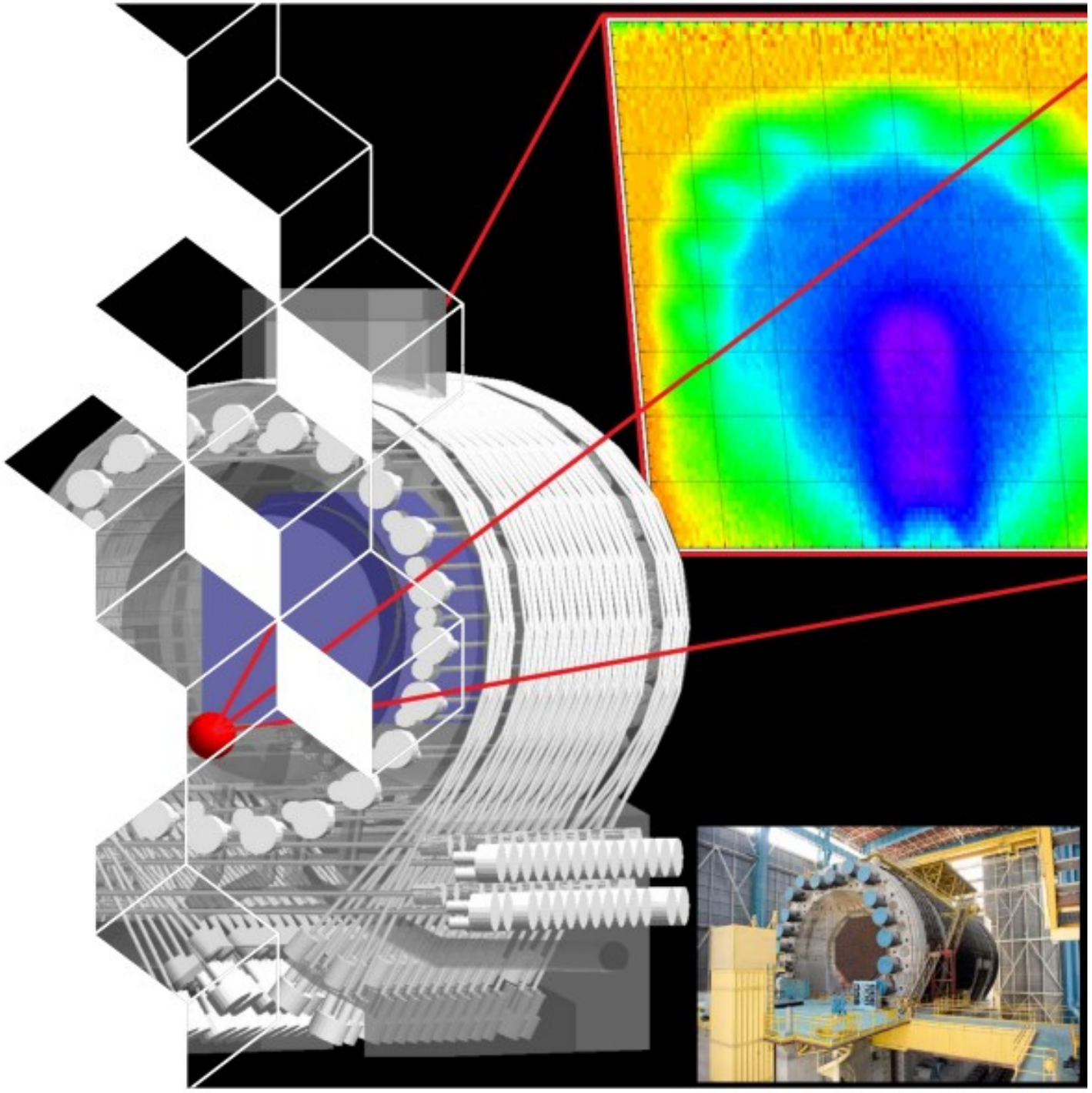
Muography @ CEA

Simulations and analysis ...

Héctor Gómez (CEA – Irfu) – hector.gomez@cea.fr



… or the history of the Giomataris Axion – Muon coupling

A Sunday Evening in August 2004

First meet with Ioannis:

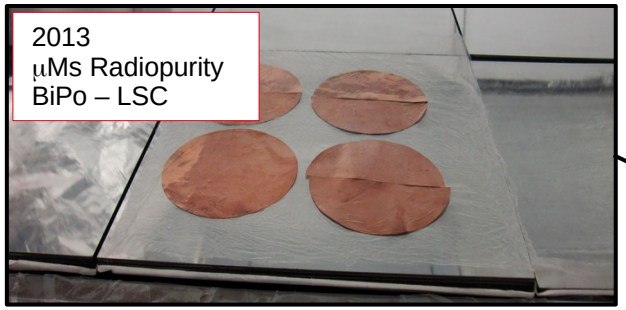
- A CAST evening shift

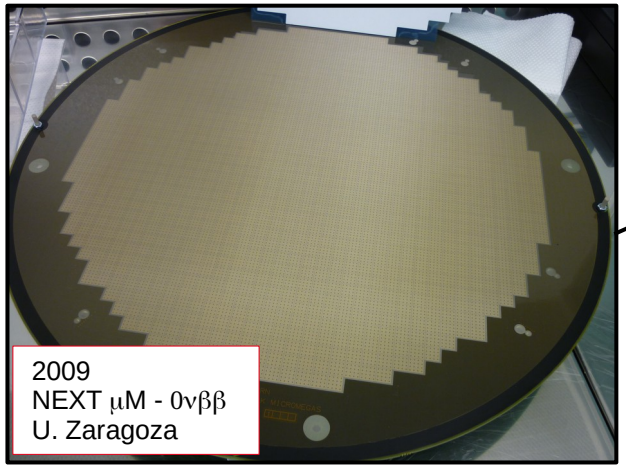
- Looking for **axion** – photon coupling

No pictures together (we were supposed to be working!!)

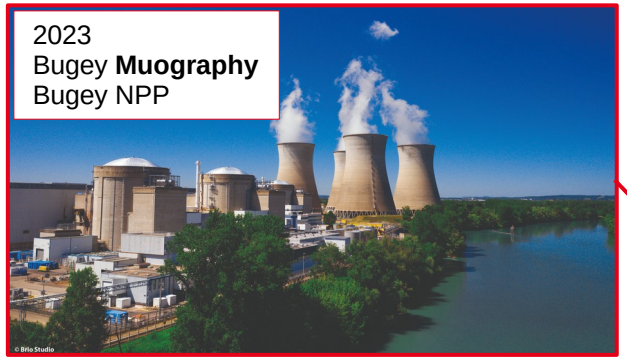
Since then, Micromegas were always present …

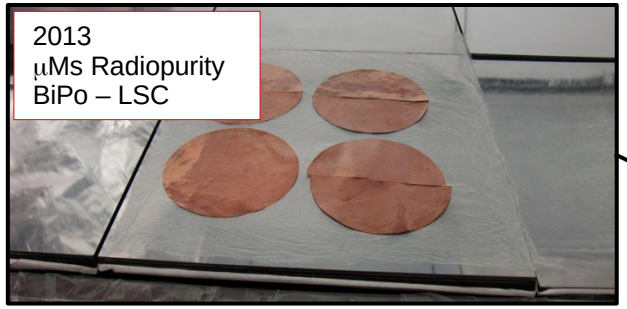

2004
Axion Detection
CAST - CERN


2013
μMs Radiopurity
BiPo – LSC


2009
NEXT μM - 0νββ
U. Zaragoza

Since then, Micromegas were always present …


2023
Bugey **Muography**
Bugey NPP


2013
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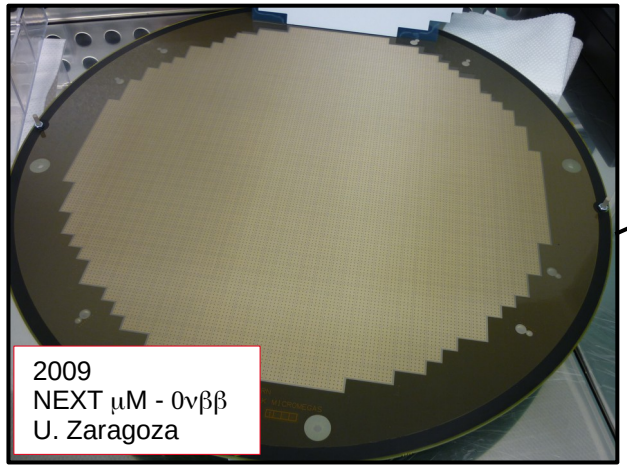
BiPo – LSC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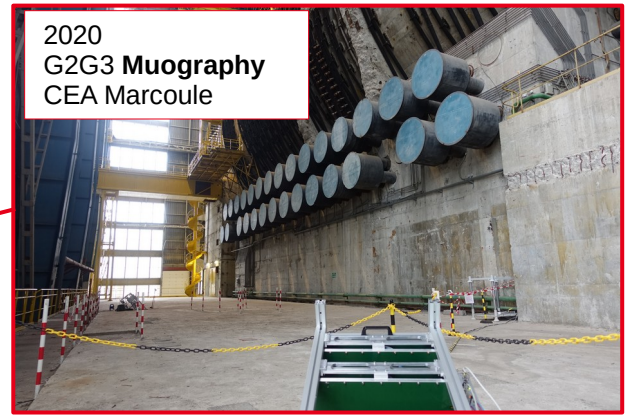
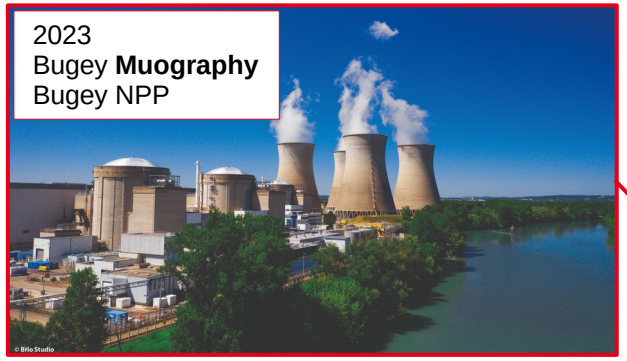
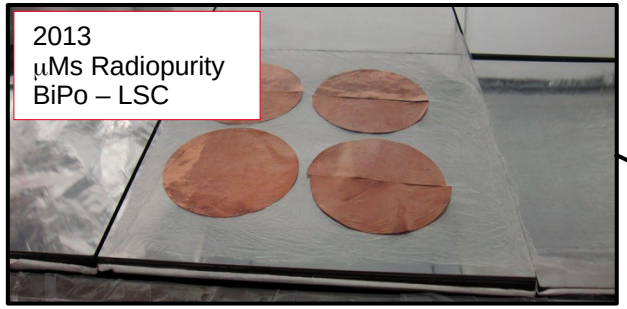
2004
Axion Detection
CAST - CERN

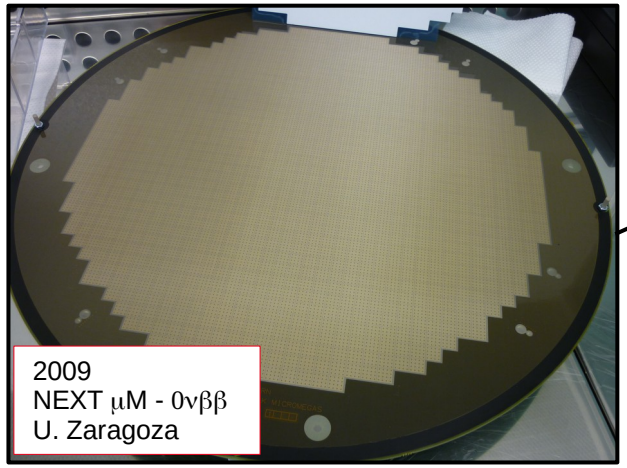

2020
G2G3 **Muography**
CEA Marcoule

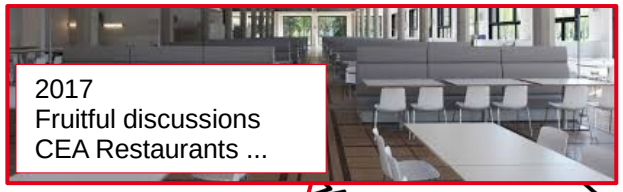

2018
Khufu **Muography**
Cairo

Since then, Micromegas were always present ...

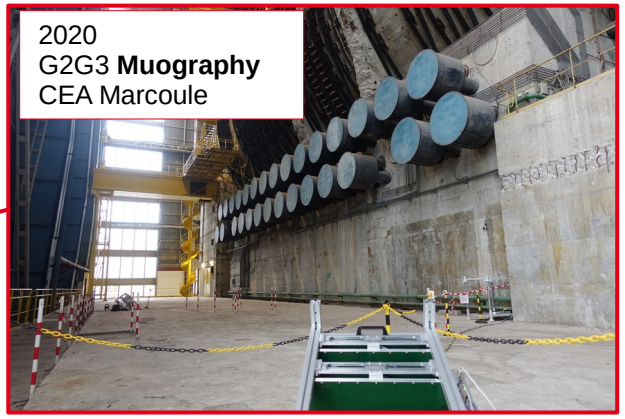

2023
Bugey **Muography**
Bugey NPP


2013
μMs Radiopurity
BiPo – LSC


2009
NEXT μM - 0νββ
U. Zaragoza


2017
Fruitful discussions
CEA Restaurants ...


2004
Axion Detection
CAST - CERN

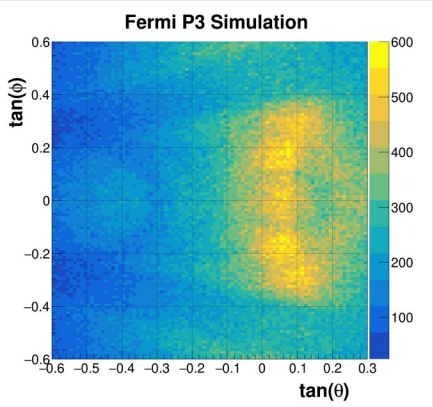

2020
G2G3 **Muography**
CEA Marcoule

2018
Khufu **Muography**
Cairo

Muography Simulations and Data Analysis

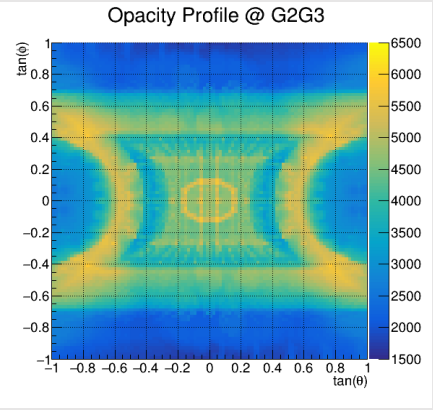
Goal: Optimize and generalize tools for their use independently on the muography application

Detailed Simulation



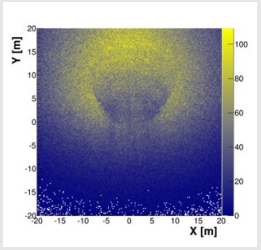
- Modular (Geant4 + Root)
- Precise implementation of geometry (imported from 3D CAD models)
- All particles and physics processes included (if needed → Backgrounds …)
- Telescopes definition: Hodoscopes, TPCs
- Production of muographies, feasibility studies, distance/opacity maps, ...

Simplified Simulation



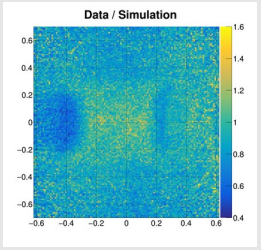
- Faster simulations from opacity maps or simple geometries
- Quite compatibles with detailed simulations (ScanPyramids, G2G3)
- Several simulations on a short time scale (different muographies → 3D Tomography)

2D Analysis (based on Data)



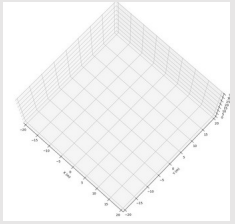
- Structures Evolution (**WatTo**, EDF)
- Defects identification (IZEN, D3DT)
- Metrology (POMME, CITERE)

2D Analysis (Data / Simulation comparison)



- Unknown Structures (**ScanPy**)
- Anomalies identification (G2G3)

3D Analysis (Muography → Muon Tomography)



- 2D muographies combination
- Reconstruction based on SART
- ScanPy NFC, G2G3, ...

Demultiplexing → Muon Selection → Track Reconstruction

Transmission, Absorption and Deviation Muography

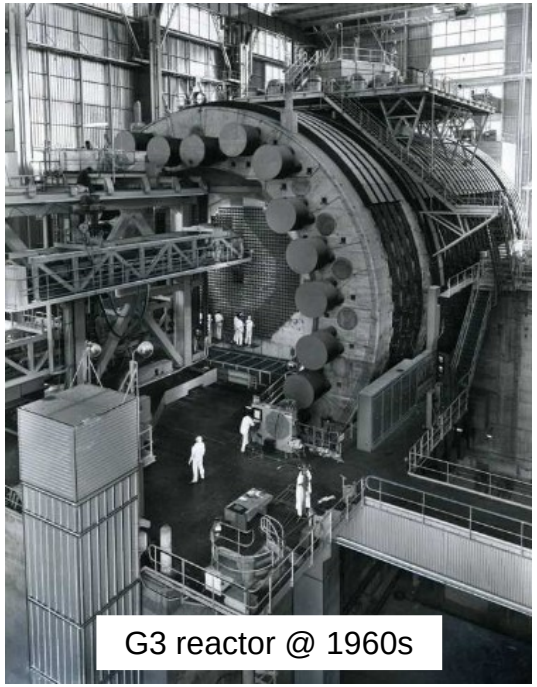
The G2G3 Project

Main Goal:

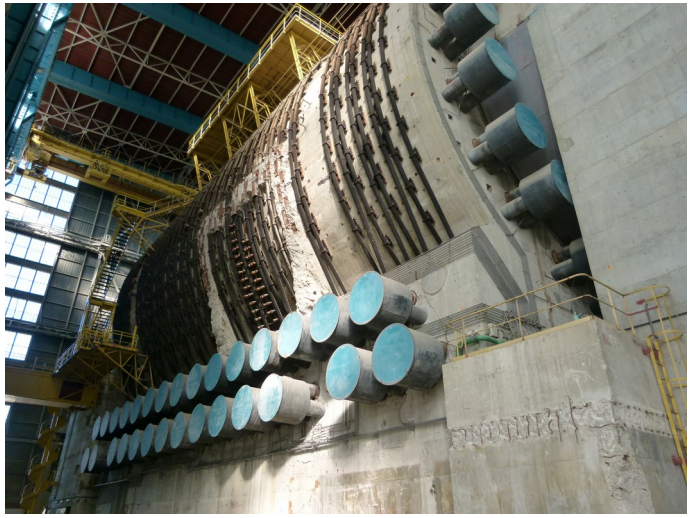
- Monitoring of the G2 and G3 nuclear reactors, located at CEA – Marcoule (South France), by muon tomography to:
  - Cross-check the validity of the existing plans / designs (they date from the 60's)
  - Check the internal structure and ageing of the reactors → Reactor Body
  - Look for possible damages (e.g. fissures) inside the concrete (is it possible?)

Ready for dismantling

G2 – G3 buildings @ CEA Marcoule



G3 reactor @ 1960s



G2 reactor @ 2018

The G2G3 Project

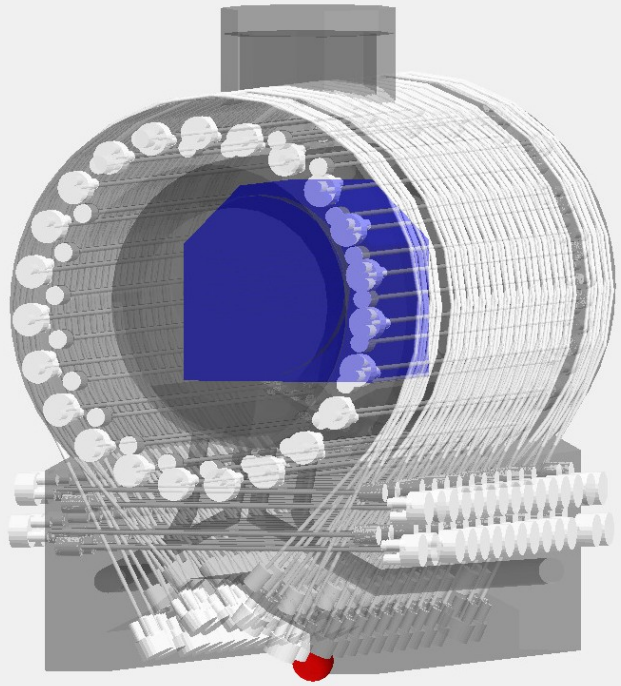
First analysis: Look for disagreements Reality – CAD Model

- Data / Monte Carlo comparison
  - Monte Carlo generated with the geometry from the 3D - CAD model
    - Any anomaly will imply differences between the model and the real structure

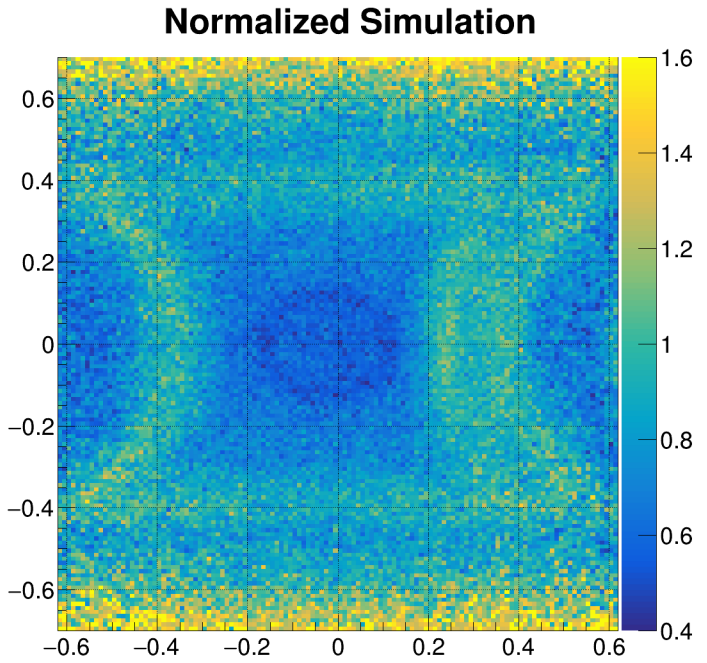
GDML Reactor Geometry (interpretable by Geant4):

>22000 Geometry files

~3.4 GB



Geant4 - GDML Model



The G2G3 Project

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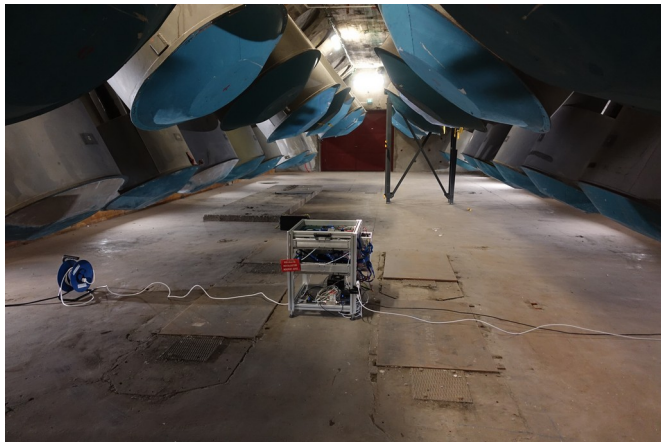
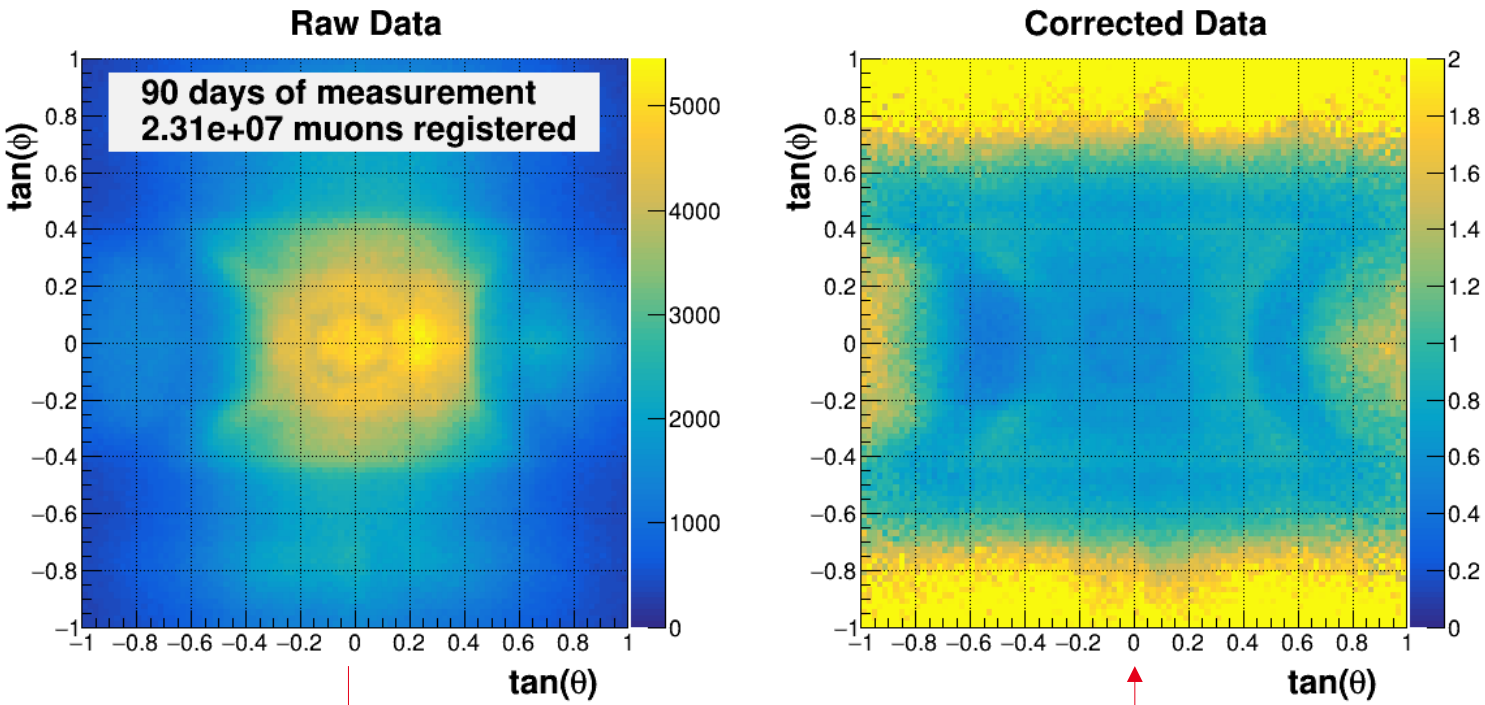


- Detector placed at the centre of the reactor (level – 0)
- Optimal position for a first overall image

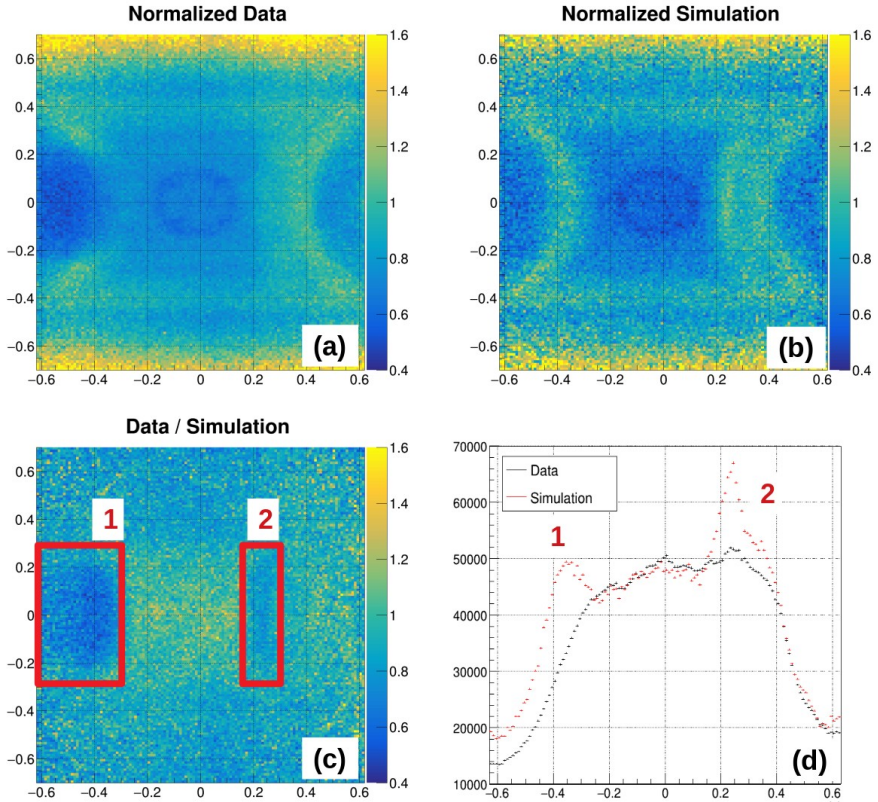


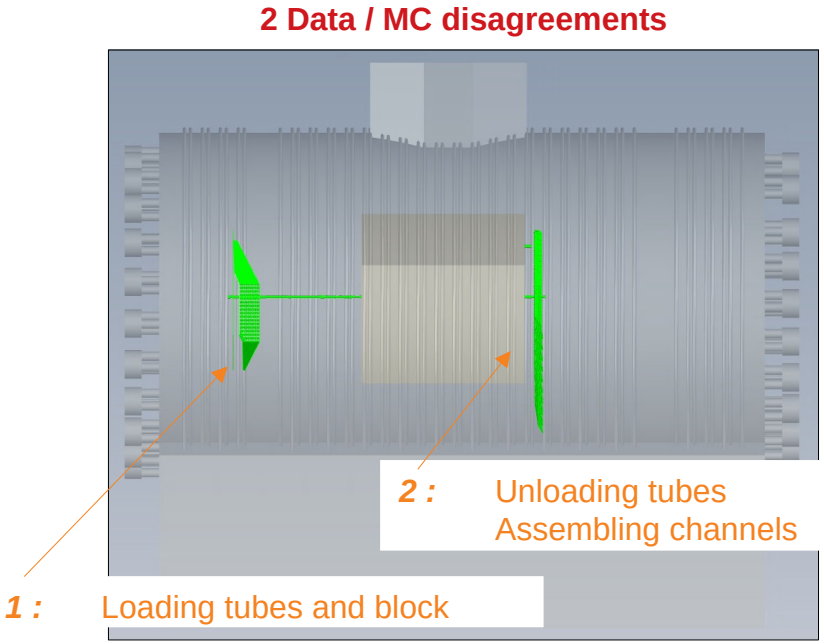
The G2G3 Project

First analysis: Look for disagreements Reality – CAD Model

https://irfu.cea.fr/en/Phocea/Vie_des_labos/Ast/ast.php?t=fait_marquant&id_ast=4888

- Data / Monte Carlo comparison
  - Monte Carlo generated with the geometry from the 3D - CAD model
    - Any anomaly will imply differences between the model and the real structure

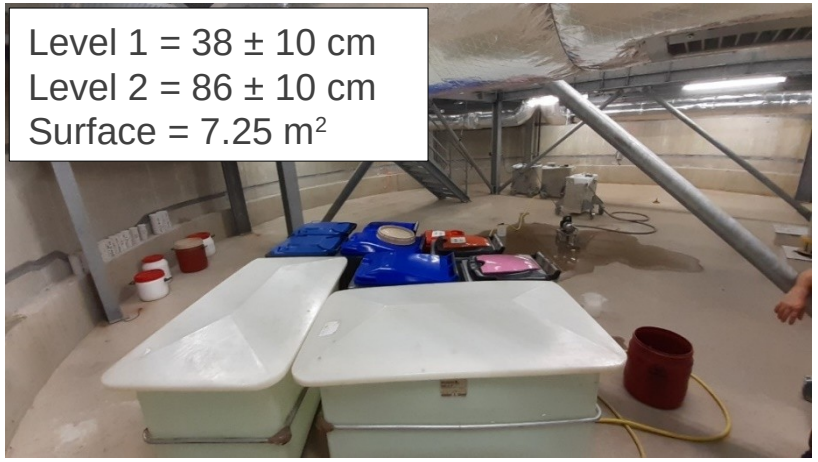




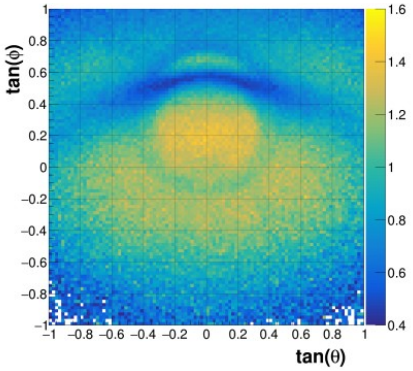
EDF Project

Study of the evolution of the water level inside a PWR Reactor Building in accidental case

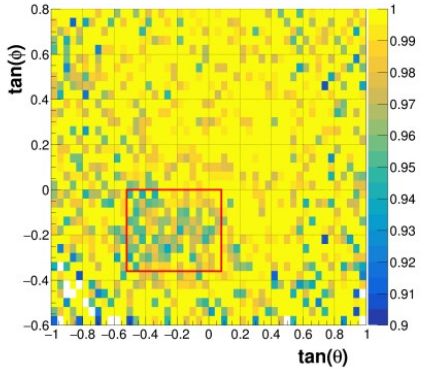
- Proof of concept in a Reactor Mockup



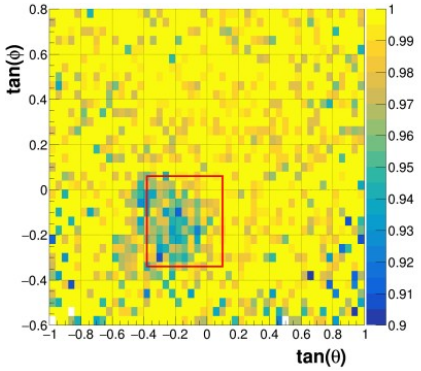
Experimental Data



Reference Muography



Level 1 / Reference

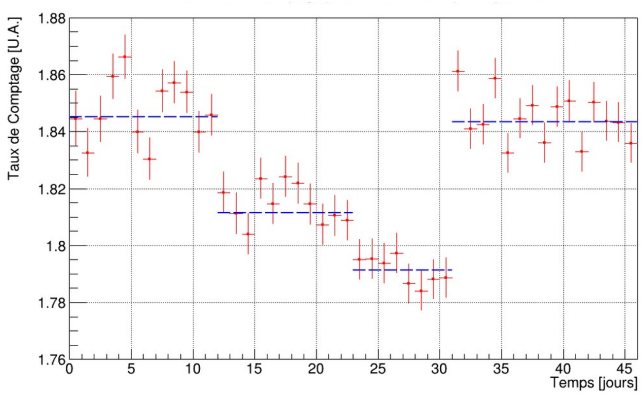


Level 2 / Reference

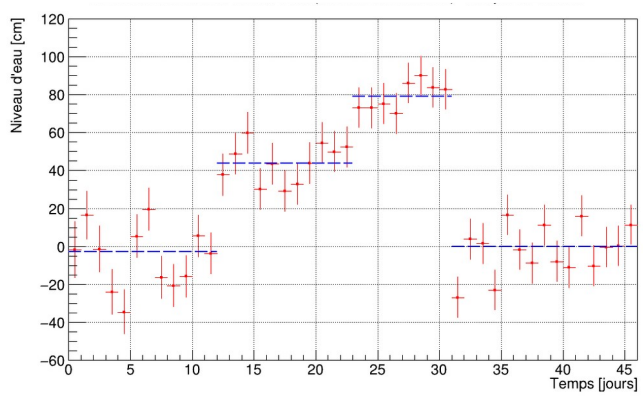
We are able to identify water volumes inside the BR and see differences depending on the water quantity

EDF Project

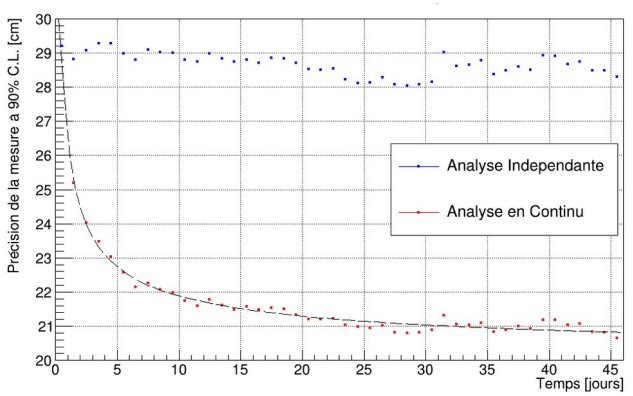
Study of the evolution of the water level inside a PWR Reactor Building in accidental case



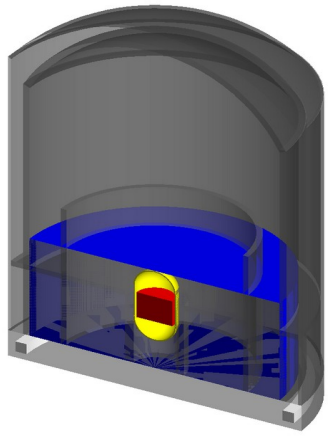
RoI Muon Rate (one meas. per day)

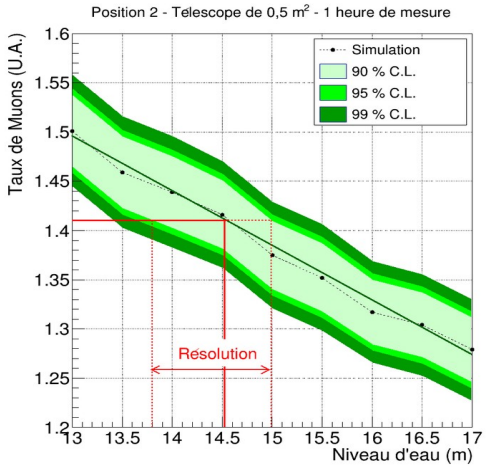


Water Level (After Calibration)



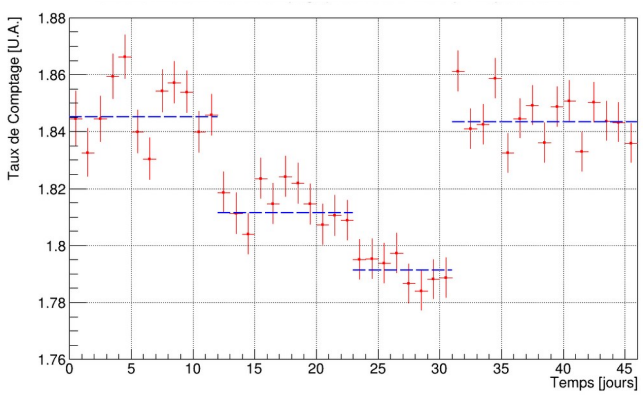
Measurement Precision





EDF Project

Study of the evolution of the water level inside a PWR Reactor Building in accidental case



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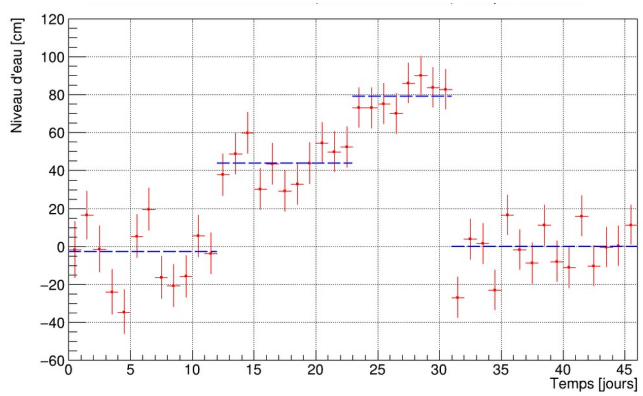

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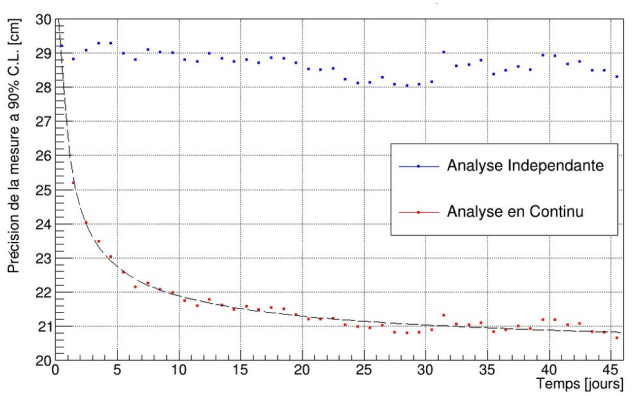
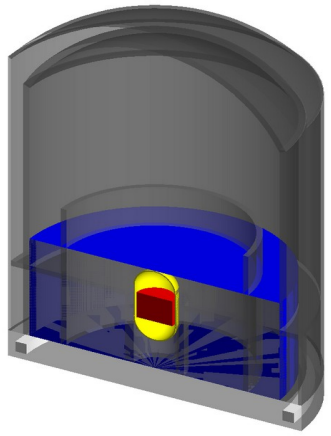
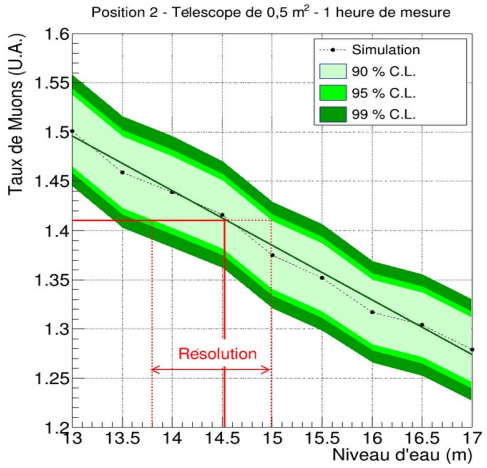


Measurement Precision





Here are some examples about how muography with Micromegas motivated a full simulation development, being a key-tool for data analysis and interpretation ...

… but this was only the beginning