Towards a Muon Radiography of the Puy de Dôme

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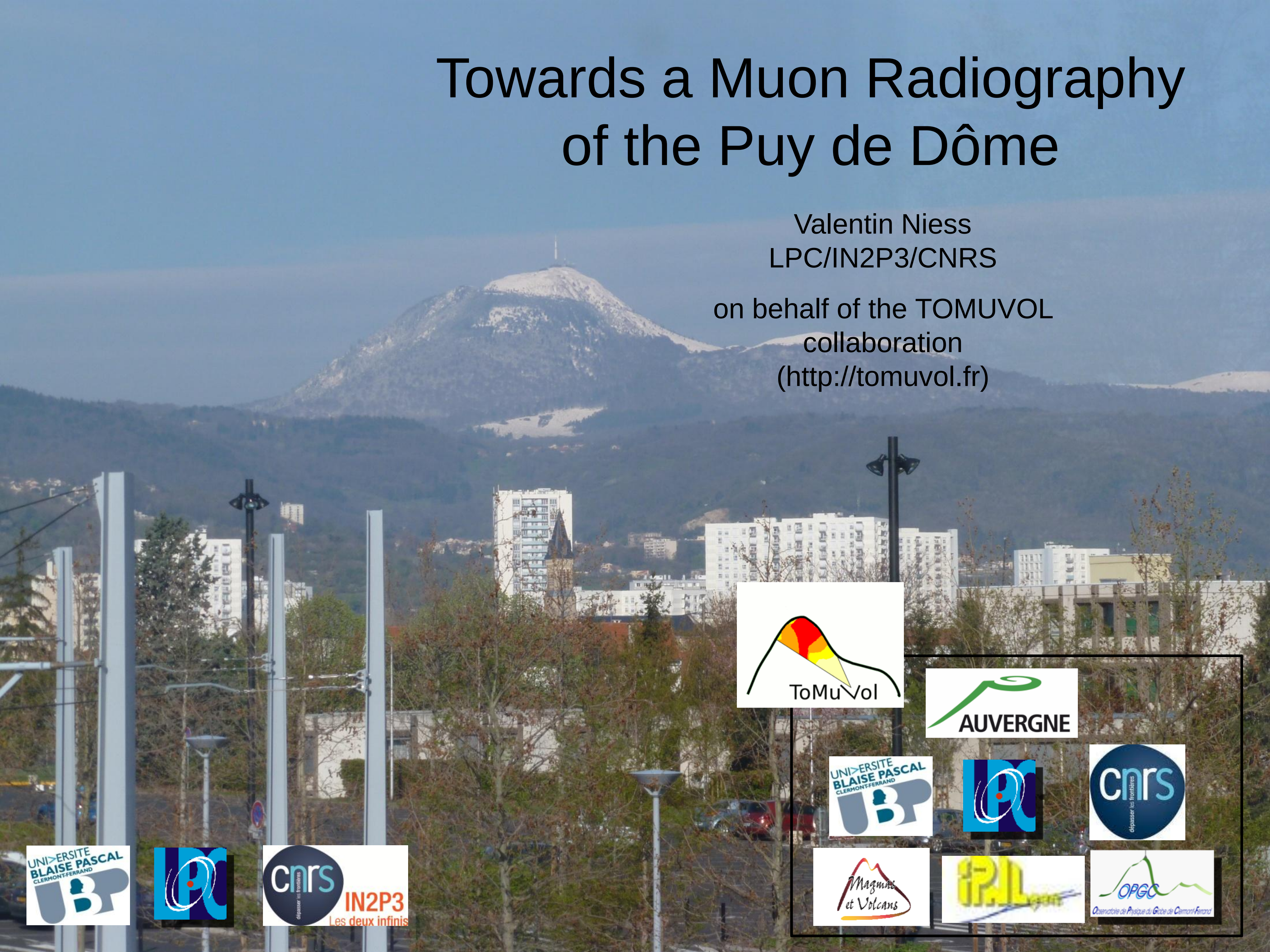
LPC/IN2P3/CNRS

on behalf of the TOMUVOL collaboration
(http://tomuvol.fr)



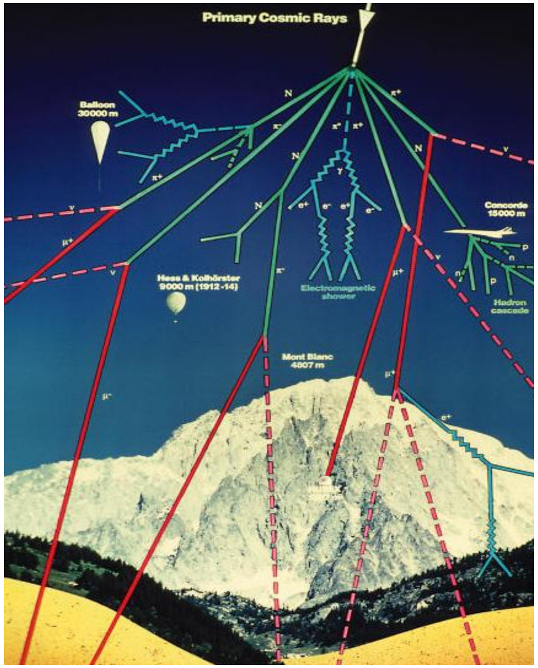
Density Imaging With Cosmic Ray Muons

❑ **Transmission measurement** using the **natural cosmic ray μ flux** through dense targets:

- **Cosmic rays** are a natural -but scarce- **source of high energy μ secondaries**: ϕ ~1-10 m^{-2} day^{-1} deg^{-2} close to the horizontal.

- **High energy μ** (E ~0.1-1TeV) **are very penetrating**. They can pass through ~0.1-1 km of rocks, which make them suitable to probe structures of such extent.

$\Rightarrow$ Allows **radiography of volcanoes and tomographic 3D imaging** from multiple view points.



❑ **Pros**: provides access to the **integrated density** along the line of sight with a typical **~0.5 deg resolution** and **from a remote** ~few km **position**.

❑ **Cons**: the **cosmic ray flux** down to the horizontal and the **μ propagation through the rocks** have to be well understood $\Rightarrow$ introduces **model dependent systematics**.

Timescale: ~month / $(L / 1\ m)^2$

For a L ~5 m detector monitoring of daily structural modifications feasible.

The Tomuvol Collaboration

Proof of principle for `**TO**mographie **MU**onique des **VOL**cans`

❑ **Interdisciplinary collaboration,** emerged in 2009, and grouping Particle Physicists (IPNL, LPC) and Volcanologists (LMV, OPGC). - some of which actually share the same building :P

❑ **Phase 1**: 2011-2014

- **Extensive radiographic studies** of the Puy de Dôme using an **existing detector** developed for Particle Physics R&D (CALICE collaboration).

- **Comparison to other techniques**: Electrical resistivity measurements, Gravimetry measurements ⇒ *See Angelie Portal's talk on Wednesday 18*.

⇒ **Turn the Puy de Dôme into a reference site.**

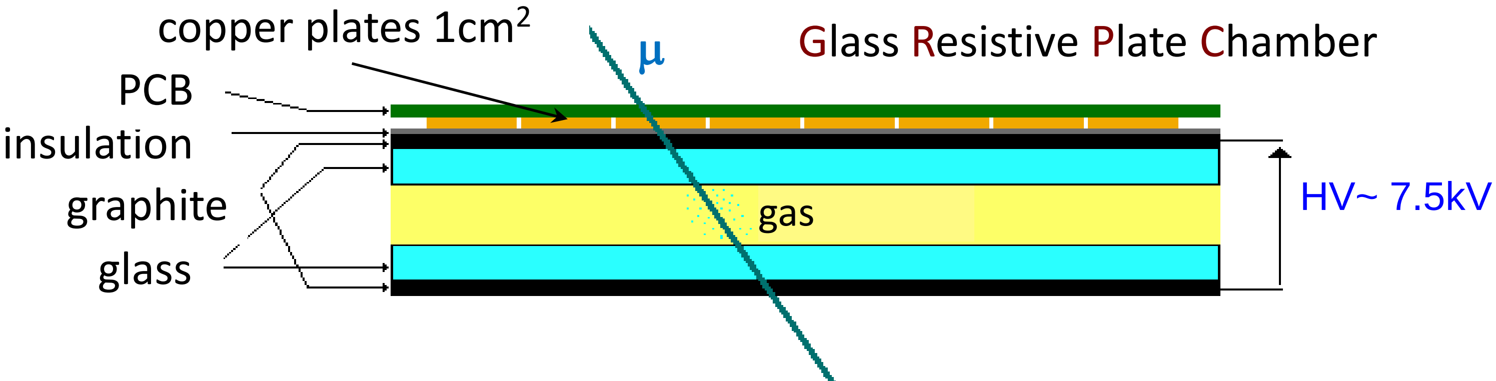
❑ **Phase 2**: 2014 →

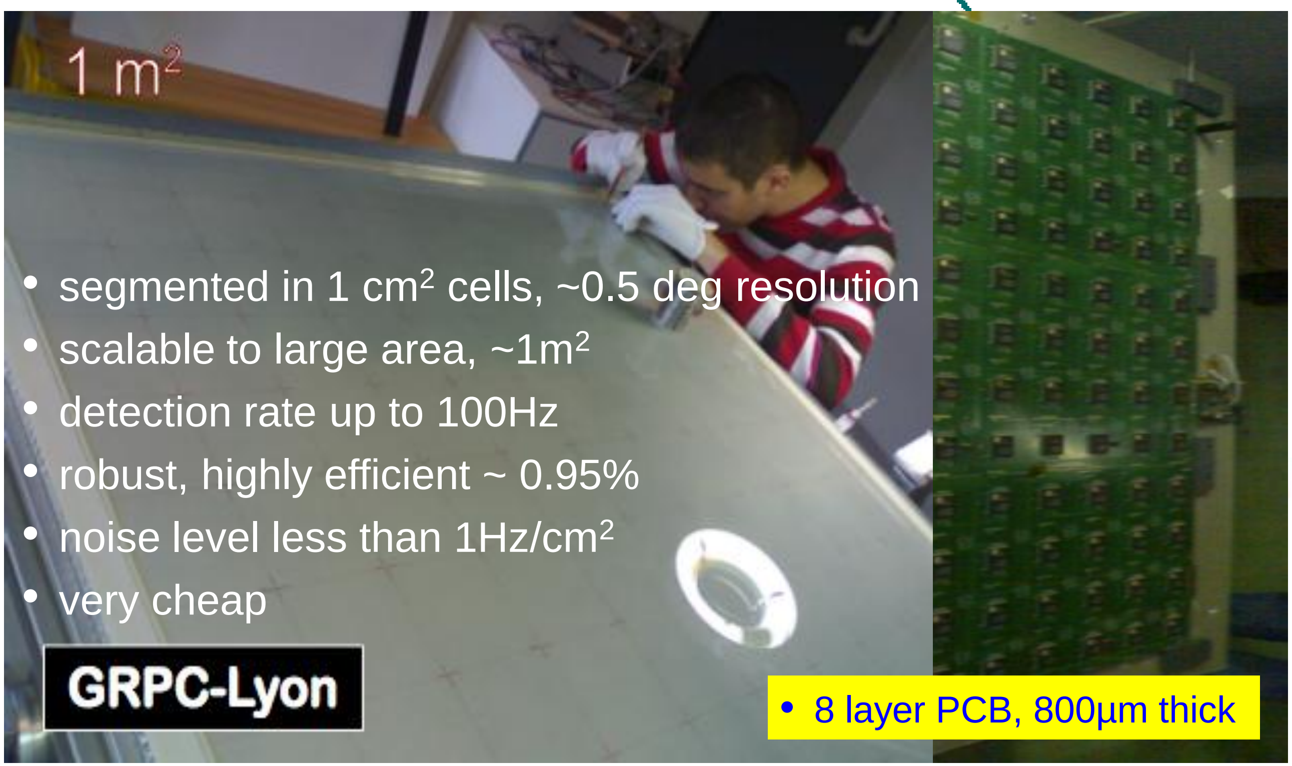
- Design, construction and validation of an **autonomous and portable radiographic device** for volcanoes tomography. ⇒ *See Philippe Labazuy's talk on Thursday 19*.

Grail: tomographic 3D reconstruction
from multiple directions of observation.

The GRPC Detector Used as a Muon Tracker

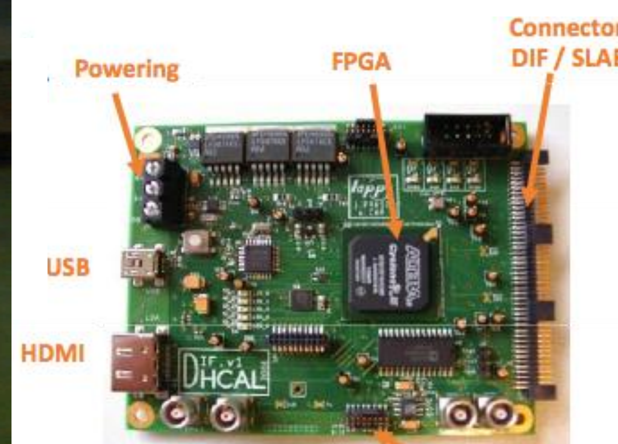
See Imad Laktineh's talk on Thursday 19





- segmented in 1 cm² cells, ~0.5 deg resolution
- scalable to large area, ~1m²
- detection rate up to 100Hz
- robust, highly efficient ~ 0.95%
- noise level less than 1Hz/cm²
- very cheap

- 8 layer PCB, 800µm thick



Detector InterFace Board
Readout via USB or HDMI

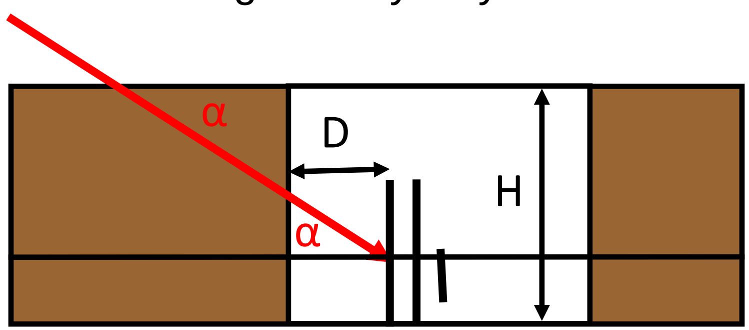
The Simulation Tools

See Samuel Béné talk on Thursday 19

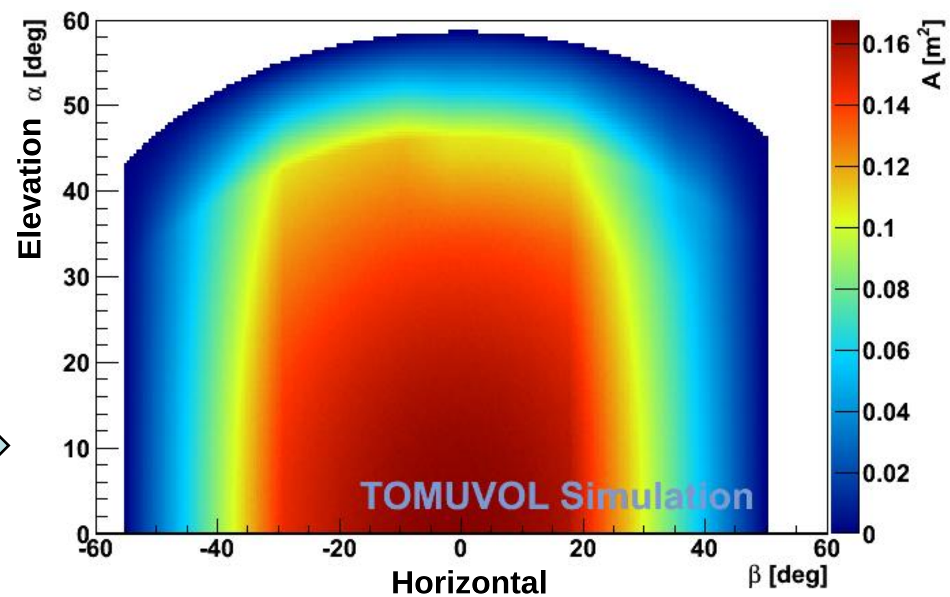
- Detailed **air shower simulations studies** (CORSIKA, GEANT4):
  - Secondary **μ fluxes** from primary cosmic rays.
  - **Contamination from vertical showers** reconstructed as ~horizontal tracks.

- **Detector simulation** (GEANT4, Custom):
  - Detection **efficiency**, accounting for dead cells.

- **Full simulation** (Python+Java):
  - Based on atmospheric **μ flux measurements + modeling** for zenith angles (S.Matsuno *et. al*., Phys. Rev. D. 29 No.1 (1984), G.Parente *et al*., Astroparticle Physics 3 (1995) 17-28).
  - **Propagation of muons** with dedicated propagation code (**MMC**).
  - Uses **topographical** precision data from **LiDAR** survey.
  - Detector geometry fully customizable.

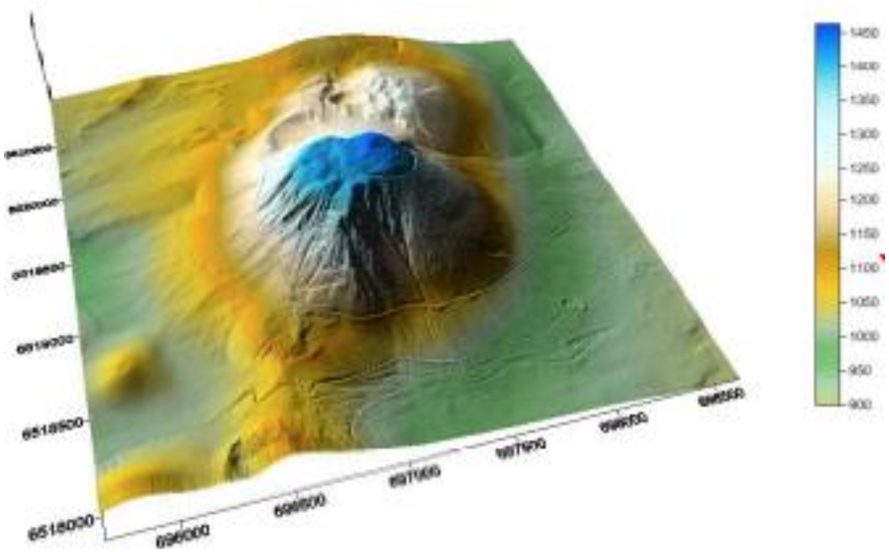


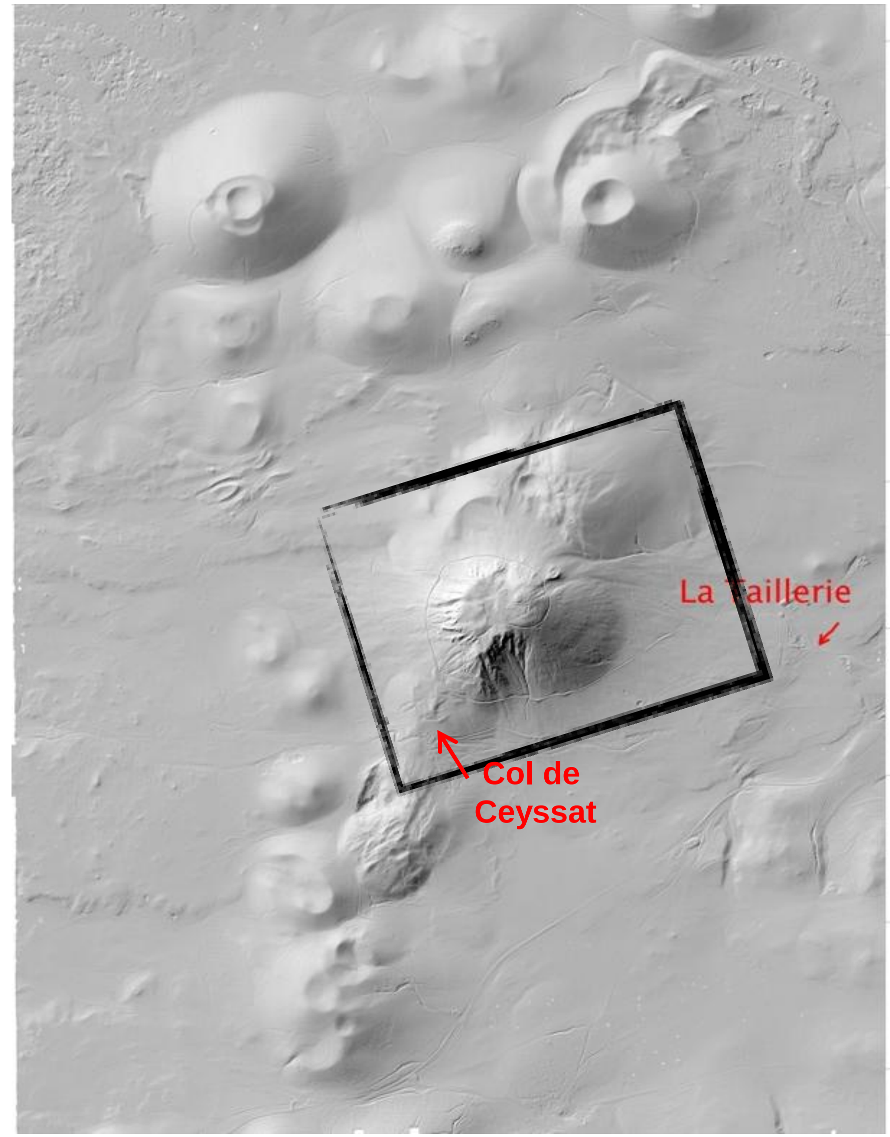
Detector acceptance
ray-tracing simulation taking masked cells into account
0.16 m^2 x 1 m total spacing



LiDAR survey of Puy de Dome

- LiDAR survey realised in March 2011
- Digital Elevation Model available since end of June (0.5 m grid, accuracy better than 10cm on the grid)





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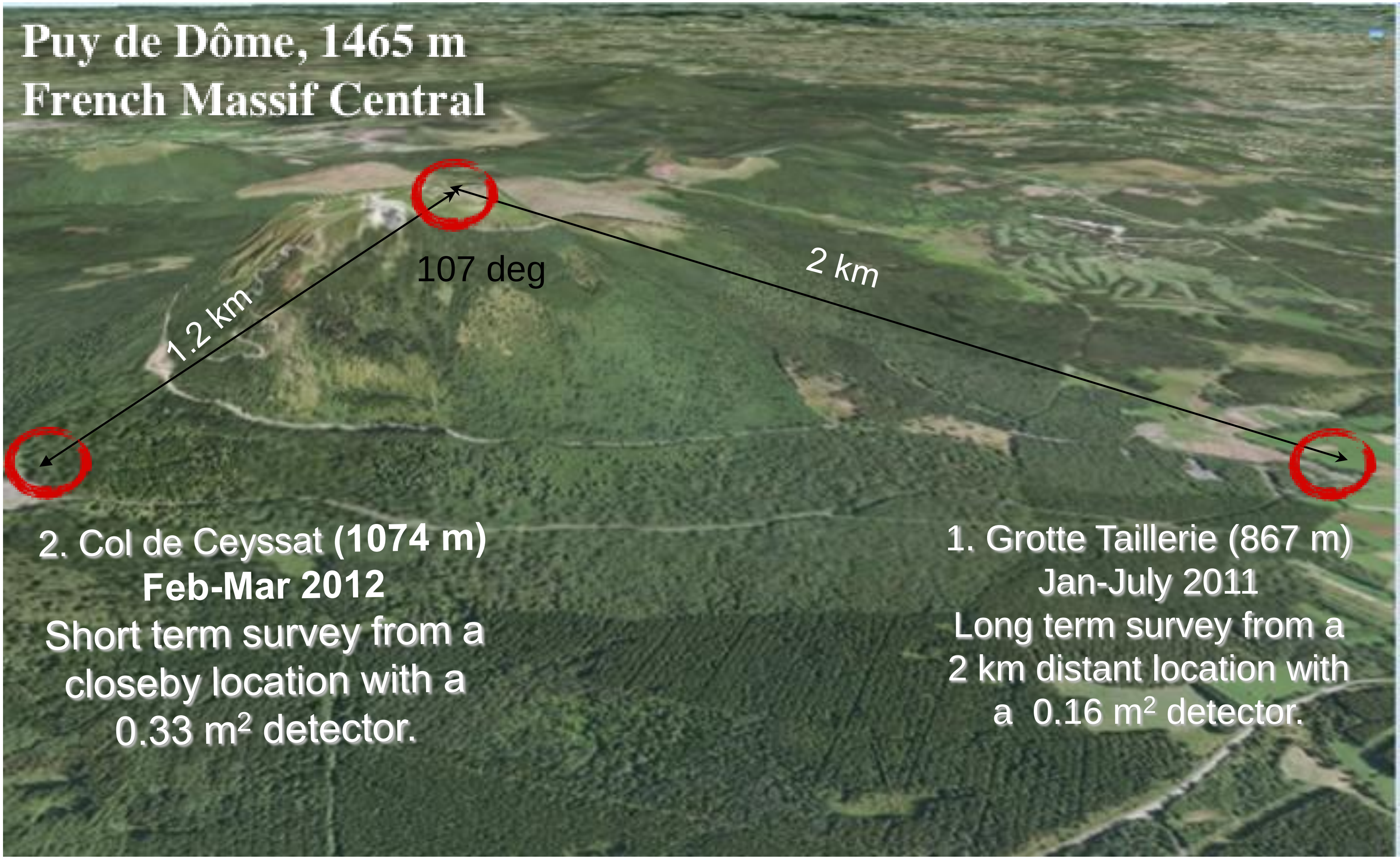
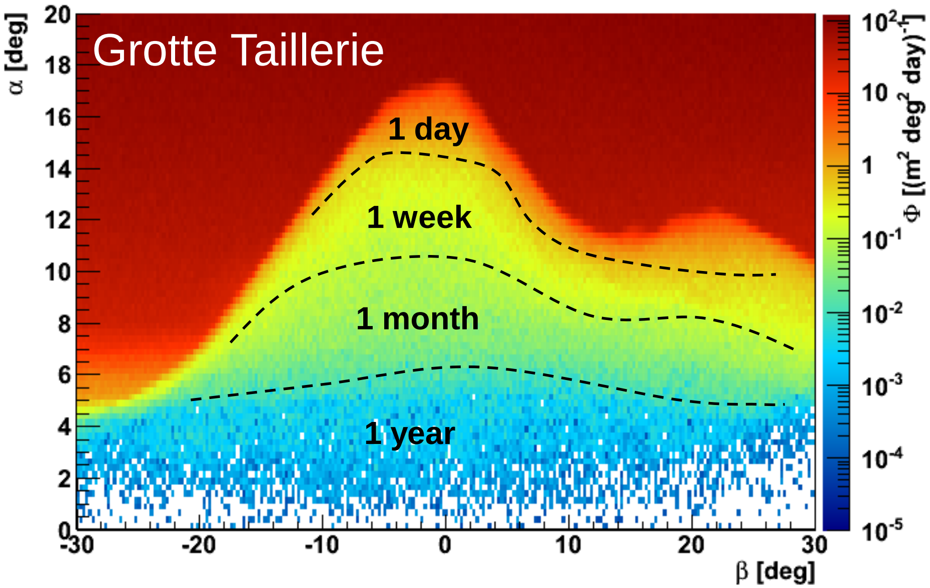
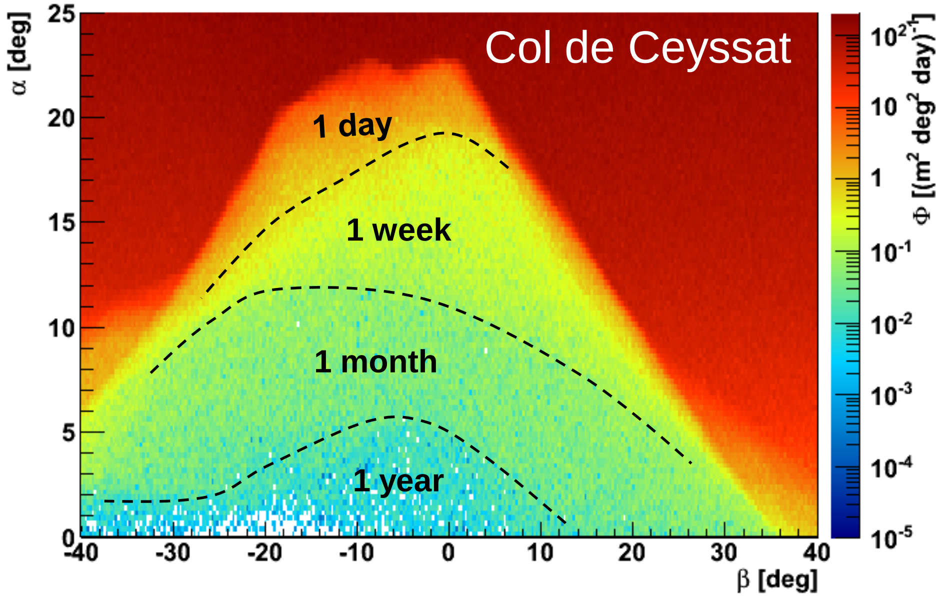
The Radiography Measurements Campaigns



Estimated Muon Flux From Simulation

Simulation for a uniform target with ρ=1.66g/cm3, **1m²** detector





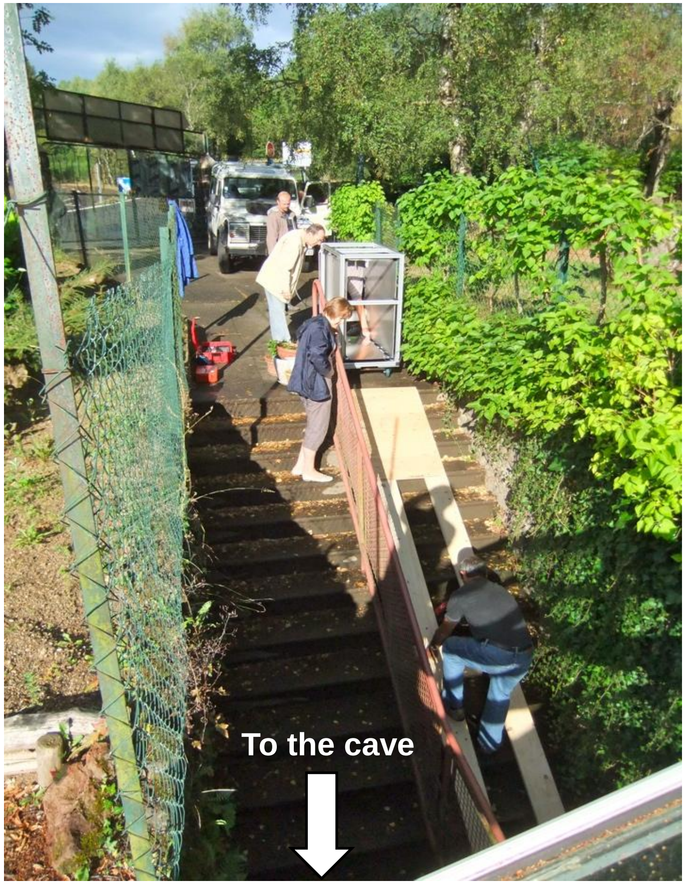
- The **Puy de Dôme inner structure** should be accessible within a **timescale of ~month** using a **1m²** detector, provided that the **fake tracks** noise level is **controlled at the level** of **1 per month per deg²** for a 1 m² area.

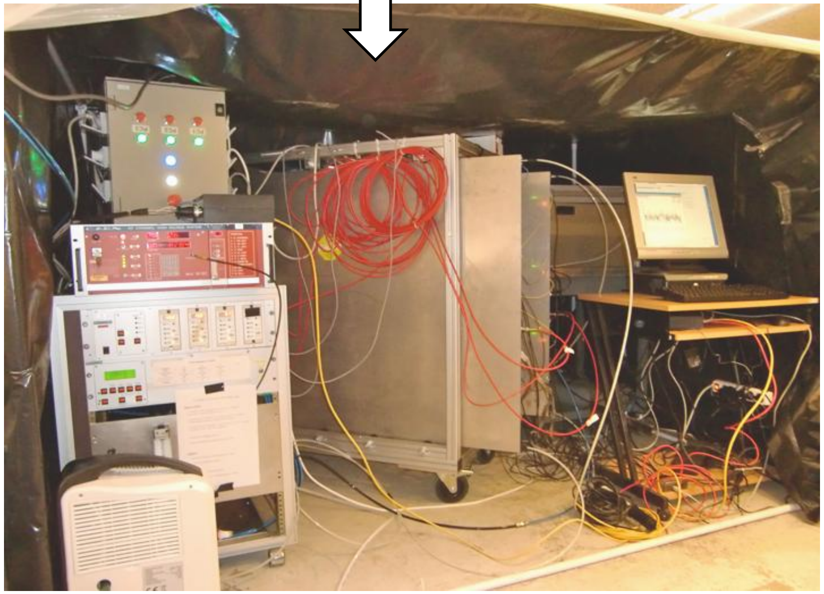
- A radiography of the **base** below would require a very **high level of control** over the background **fake tracks** at the level of **1 per year per deg²** for a 1 m² area.

Campagne de la Taillerie

Jan-July 2011

Detector installation





- ❑ **Three vertical detector plans** of 1m^2 x 1m^2 x **0.16 m^2 or 1 m^2** with 0.5 m (Jan-May) and 1 m (May-July) max spacing.

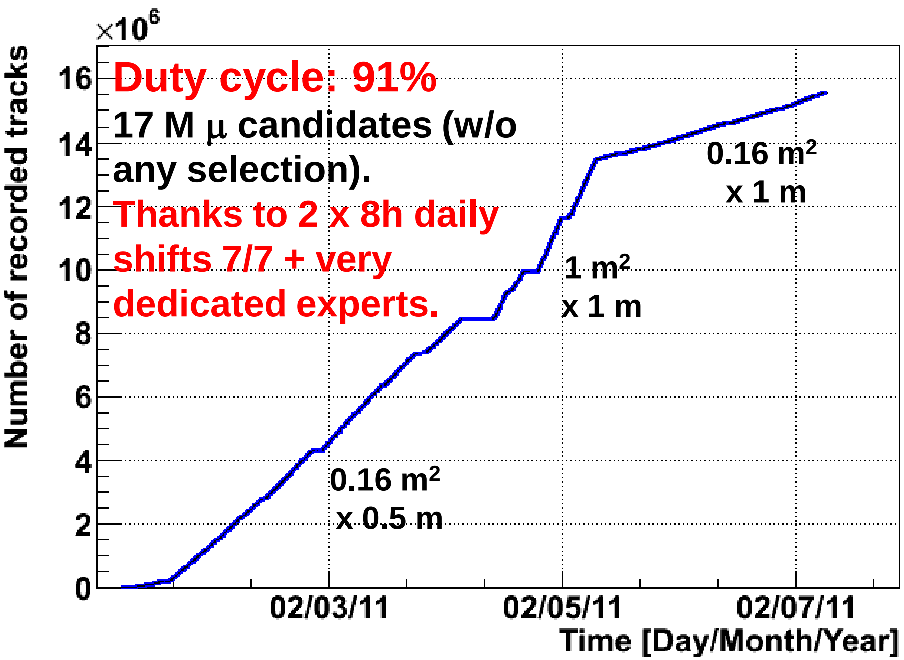
- ❑ **Detector in** an artificial **cave**. Shielded by **~60 cm concrete**. Though not from everywhere.

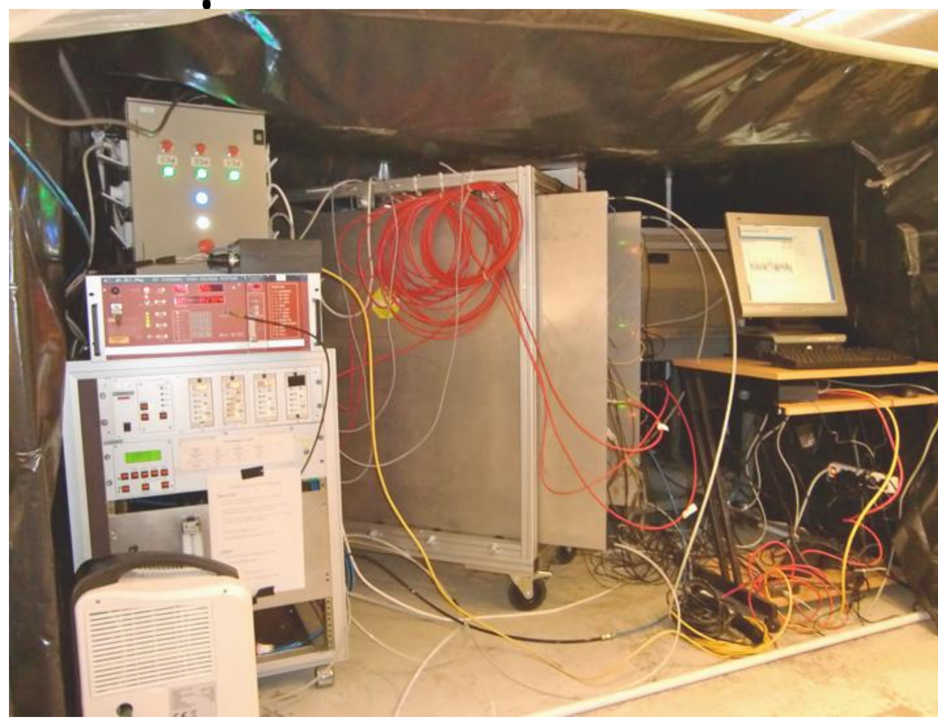
Remote Control and Data Taking

125kB/s of data continuously

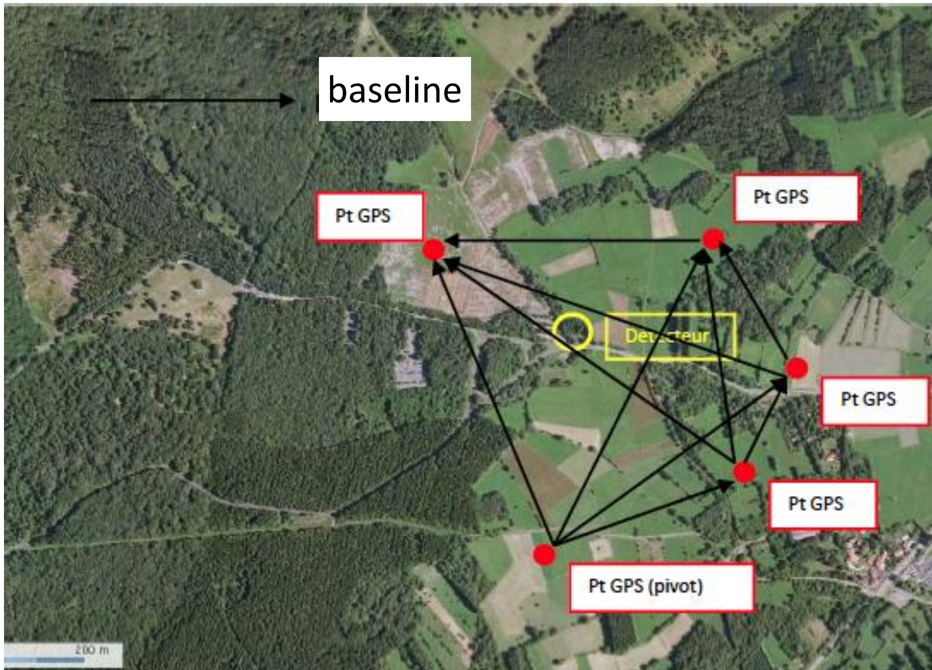
secure network @ Taillerie
→ dedicated server @ LPC

Remote detector control (VNC) + environment monitoring





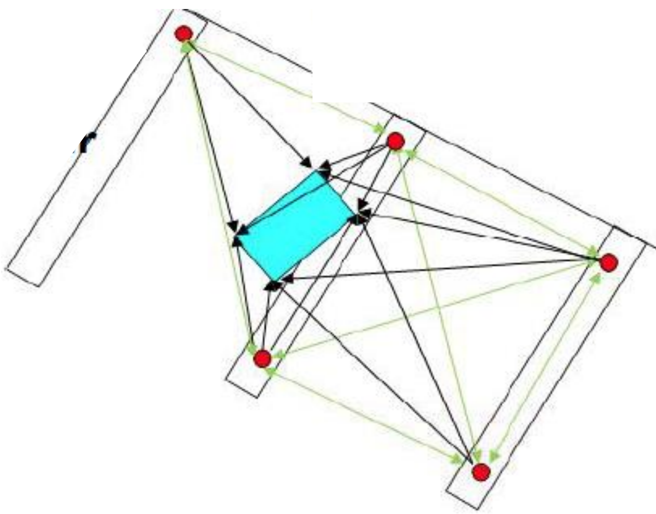
Absolute Detector Positioning

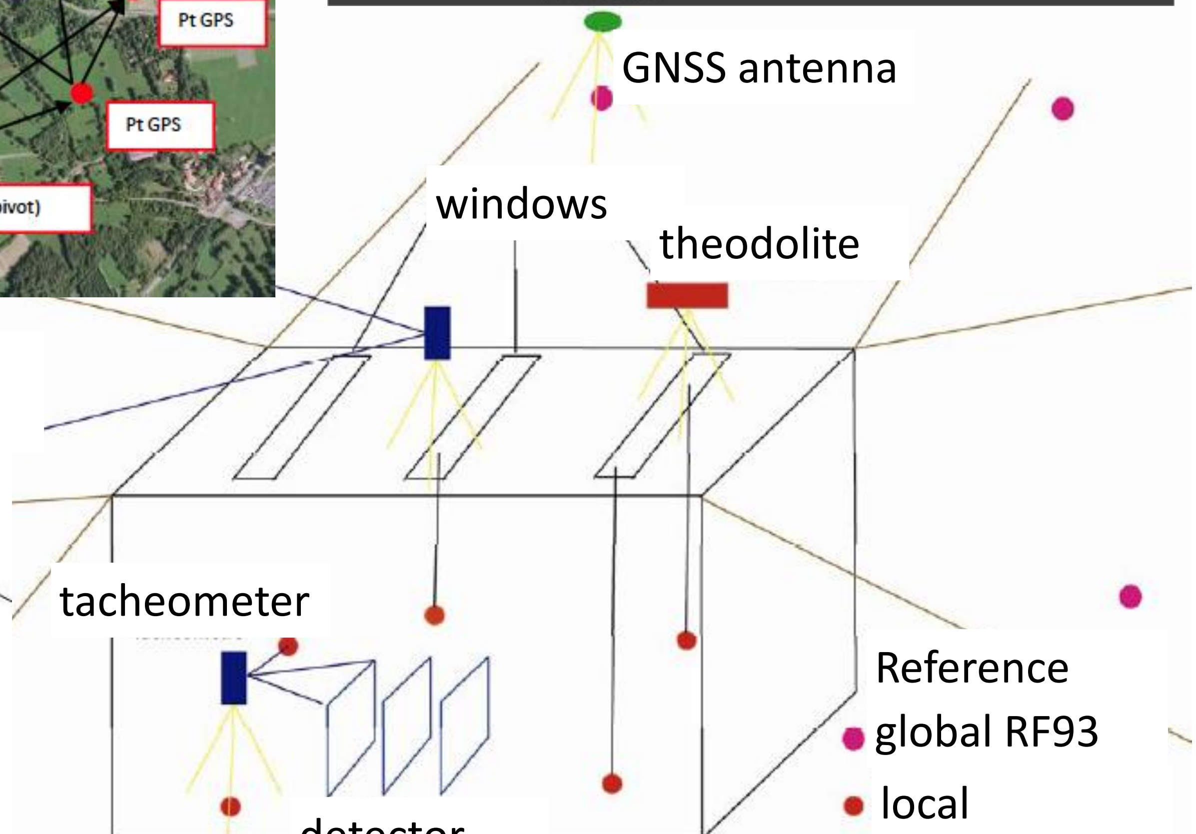


GNSS and **tacheometric** measurements of surroundings and basement thanks to a collaboration with `**E**cole **S**uperieure des **G**eometres et **T**opographes`, Le Mans (**ESGT**).

provide high precision reference frame

⟹ Accuracy better than 5 mm

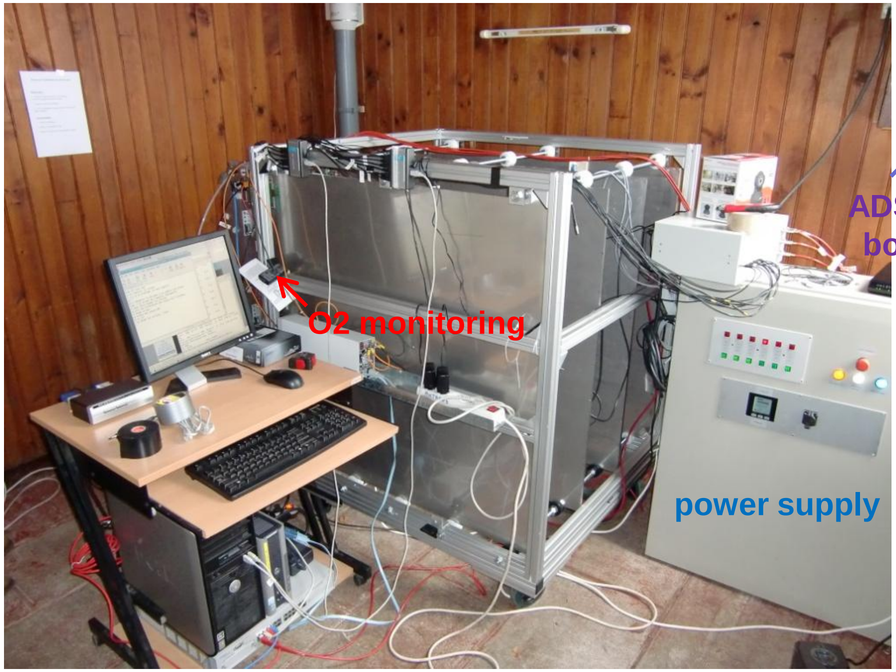




Campagne du Col de Ceyssat

Feb-Mar 2012

The `Col de Ceyssat` Setup

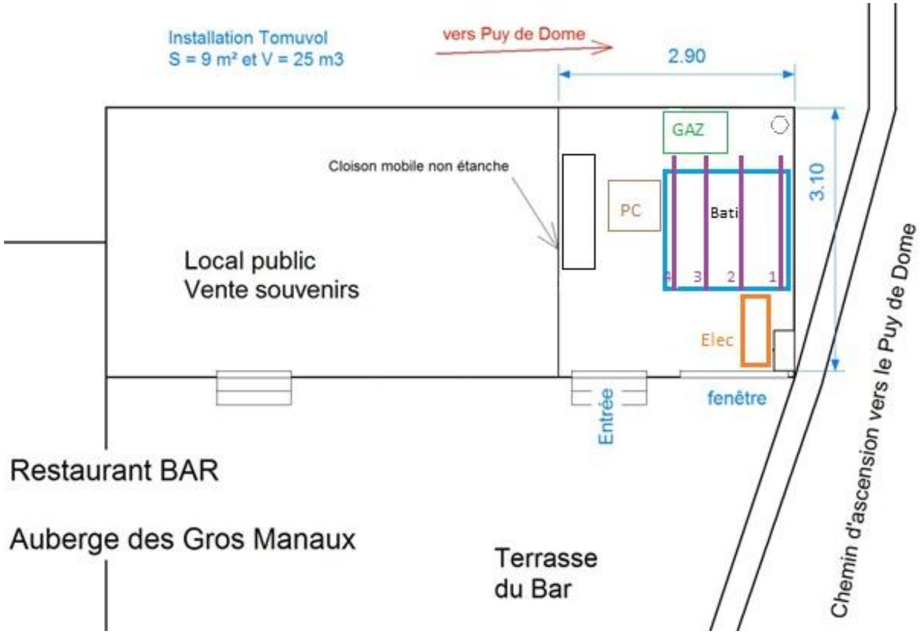


Remote detector control (VNC) + environment monitoring by subscribing a contract to a private I.P.

Positioning in collaboration with ESGT. **Measurements more difficult** than in `la Taillerie` due to the detector location within a small room with little to no openings …

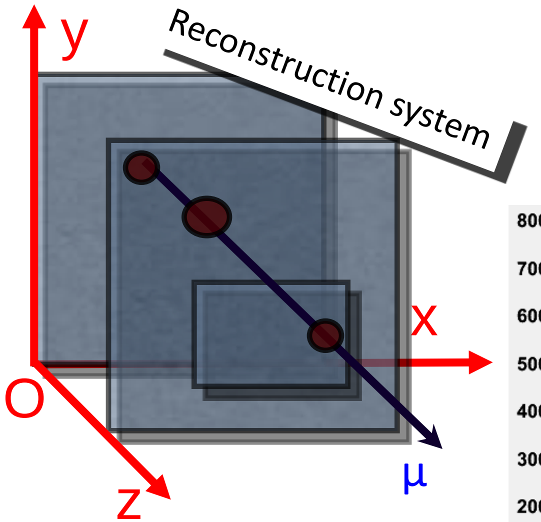
⟹ Expected accuracy : ~1 cm.

- ❑ **Four vertical detector plans** of $1m^2$ x $1m^2$ x $1m^2$ x **$0.33\ m^2$** with 1 m max spacing.
- ❑ **Detector** installed **in** `Auberge des Gros Manaux` **building**. **Partial shielding** from buildings around.
- ❑ 11 M candidate tracks recorded. Analysis ongoing …



Data Processing & Analysis

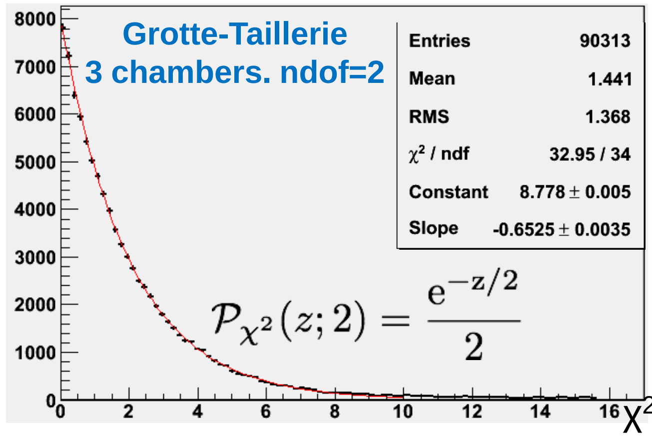
Track Fit and Chambers Inter-alignment

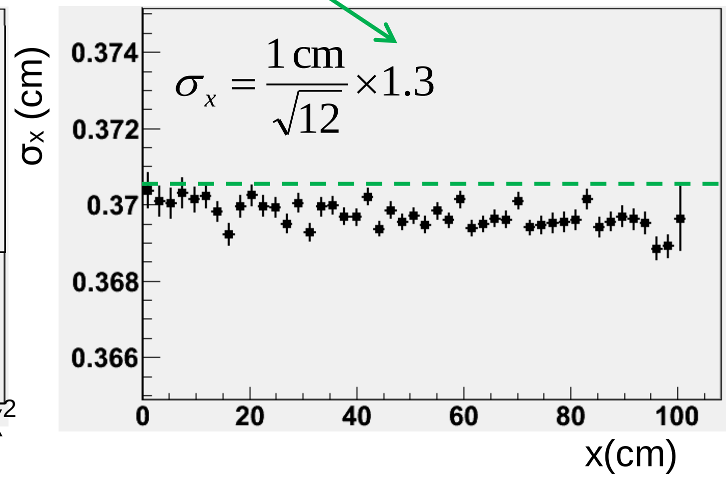


Track reconstruction

Clusterise the coincident hits in the chambers

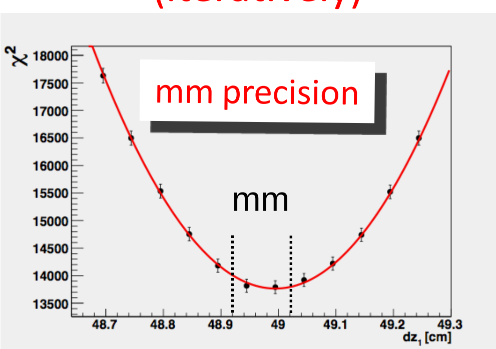
Analytically minimise χ^2 w.r.t. 4 track parameters using the cluster barycentres in each chamber. N.B.: the **average cluster** size is **1.3 cell**.



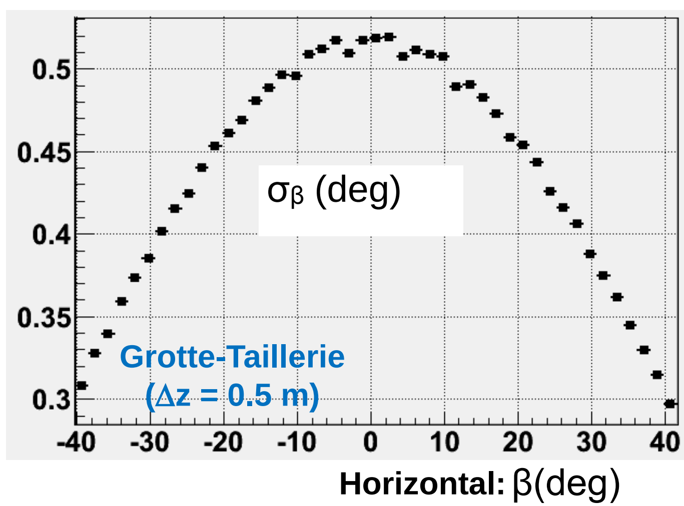


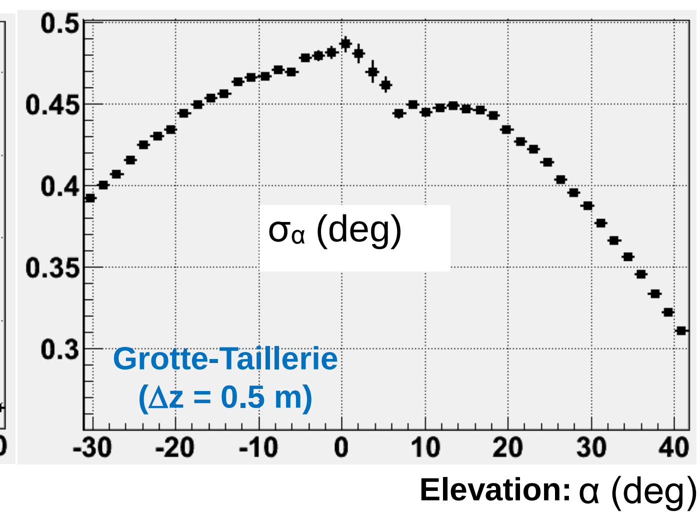
⇒ Detector inter-alignment

Performed from the Track Fit (iteratively)



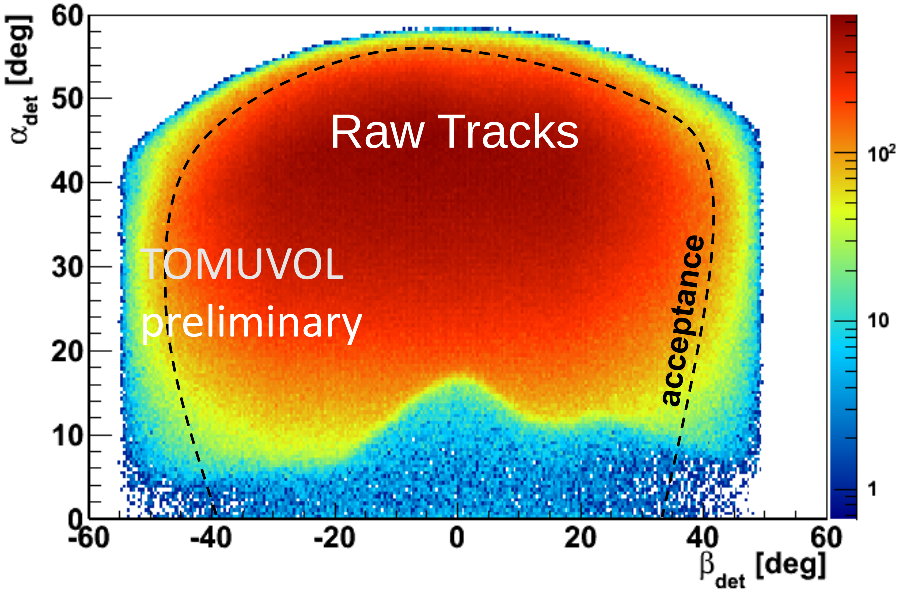
Track χ^2 optimal when detector well aligned

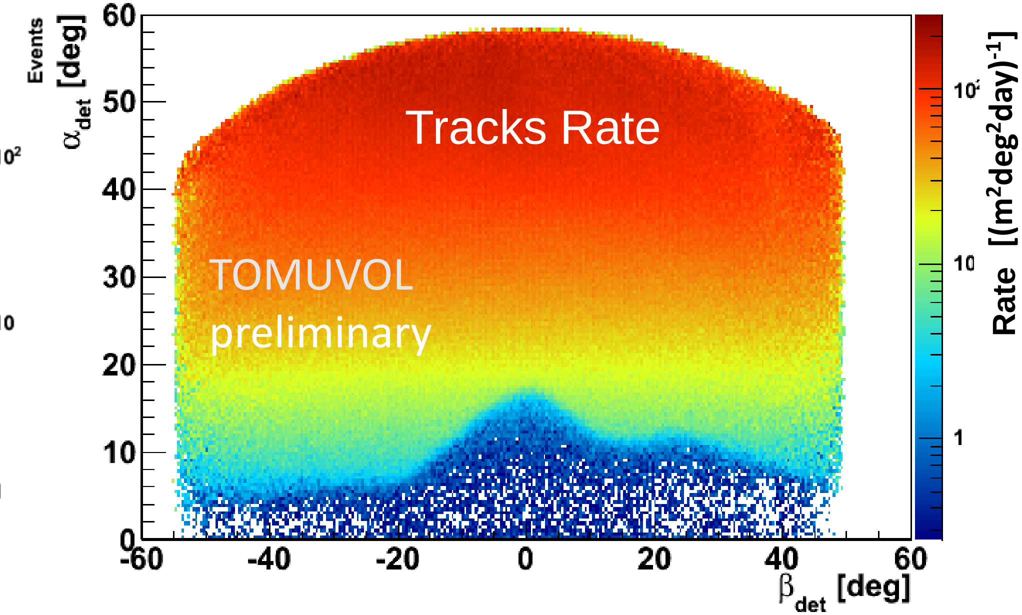




Track Rates

Grotte Taillerie: 21/01/2011 - 06/04/2011, 65.8 days of data taking, 0.16 m^2 x 0.5 m

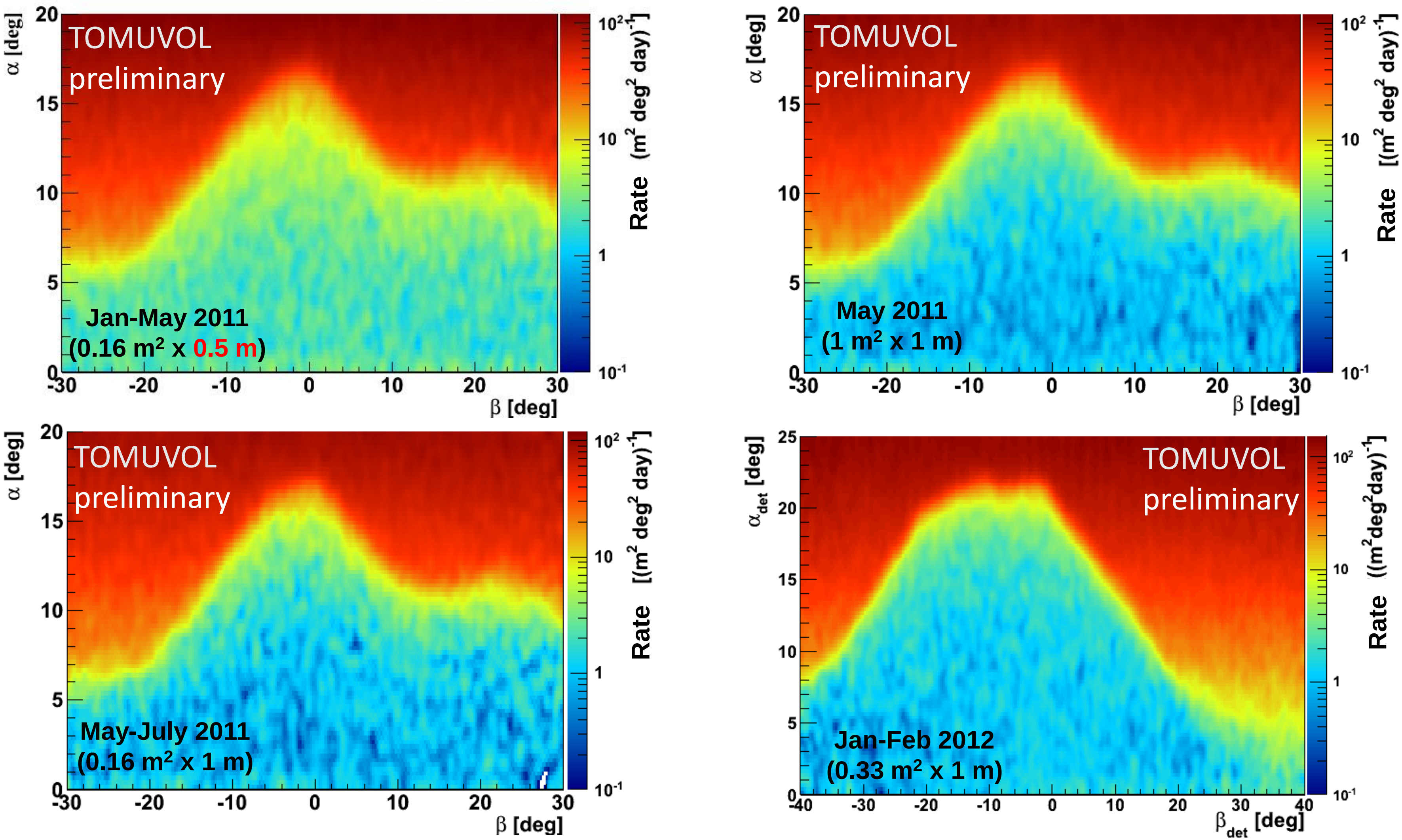




❑ **Preliminary map** by converting the aligned tracks to **a track rate** per m^2 per solid angle and unit time.

- **Correct** for the detector geometrical **acceptance** and dead cells.
- **No correction** from individual chambers detection **efficiency** yet. Additional factor ~$(0.90\text{-}0.95)^{N=3,4}$.

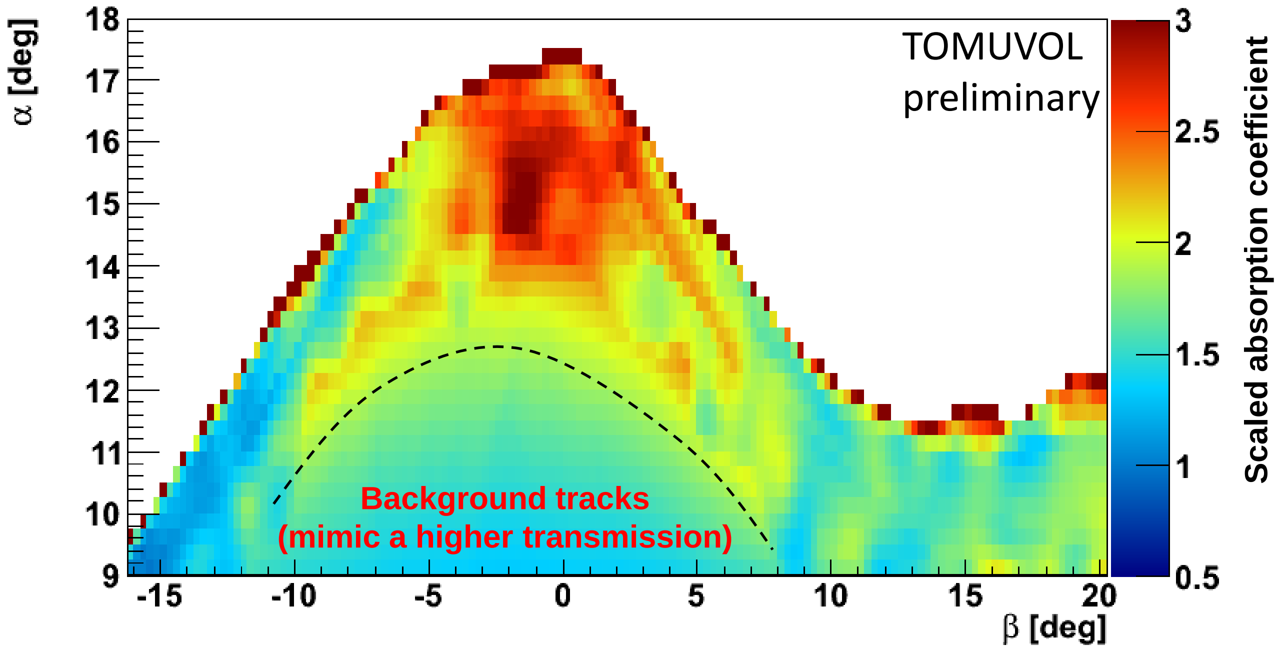
Comparison of Background Track Rates

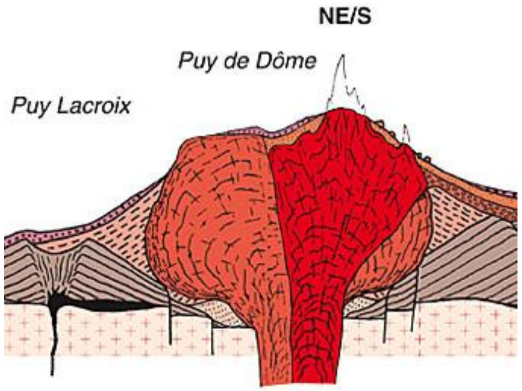


❑ The **background track** rate seems to decrease by a factor of ~2 when increasing the chambers spacing from 0.5 m to 1 m.

⇒ **Contamination** from low energy components of **down going showers**?

Scaled Absorption Coefficient





Artiste view `Volcanologie de la chaine des Puys`, EAVUC

❑ Scaled transmission coefficient:

- Compute the transmission through the rocks normalised by the measured open sky flux.
- Report the **absorption coefficient divided by the rock depth** for each line of sight as given by the topography (LiDAR measurements).

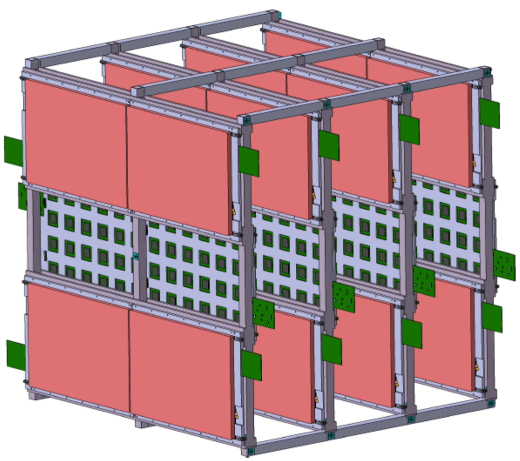
❑ **Hints** of a structural contrast in the **somital area**. In the **base**, **background tracks mimic a higher transmission**.

Perspectives

❑ **First μ flux** measurements **through the Puy de Dôme**:

- Encouraging results with **17+11 M tracks** candidates at ~orthogonal positions.
- **Detector working well** in an out-of-the-lab environment.
- **Analysis work** ongoing for **quantitative results** with systematics estimates.
- Pollution from **background tracks needs to be controlled**.

⇒ Time for **tentative 3D tomographic** reconstruction.



❑ **New detector** with 1 m^2 x 1 m to be deployed **January 2013**.

- 4 chambers modular design with GRPCs.
- Should provide the **ultimate radiographic and tomographic imaging of the Puy de Dôme**.

❑ Design, construction and validation of an **autonomous and portable radiographic device** for volcanoes tomography would follow.