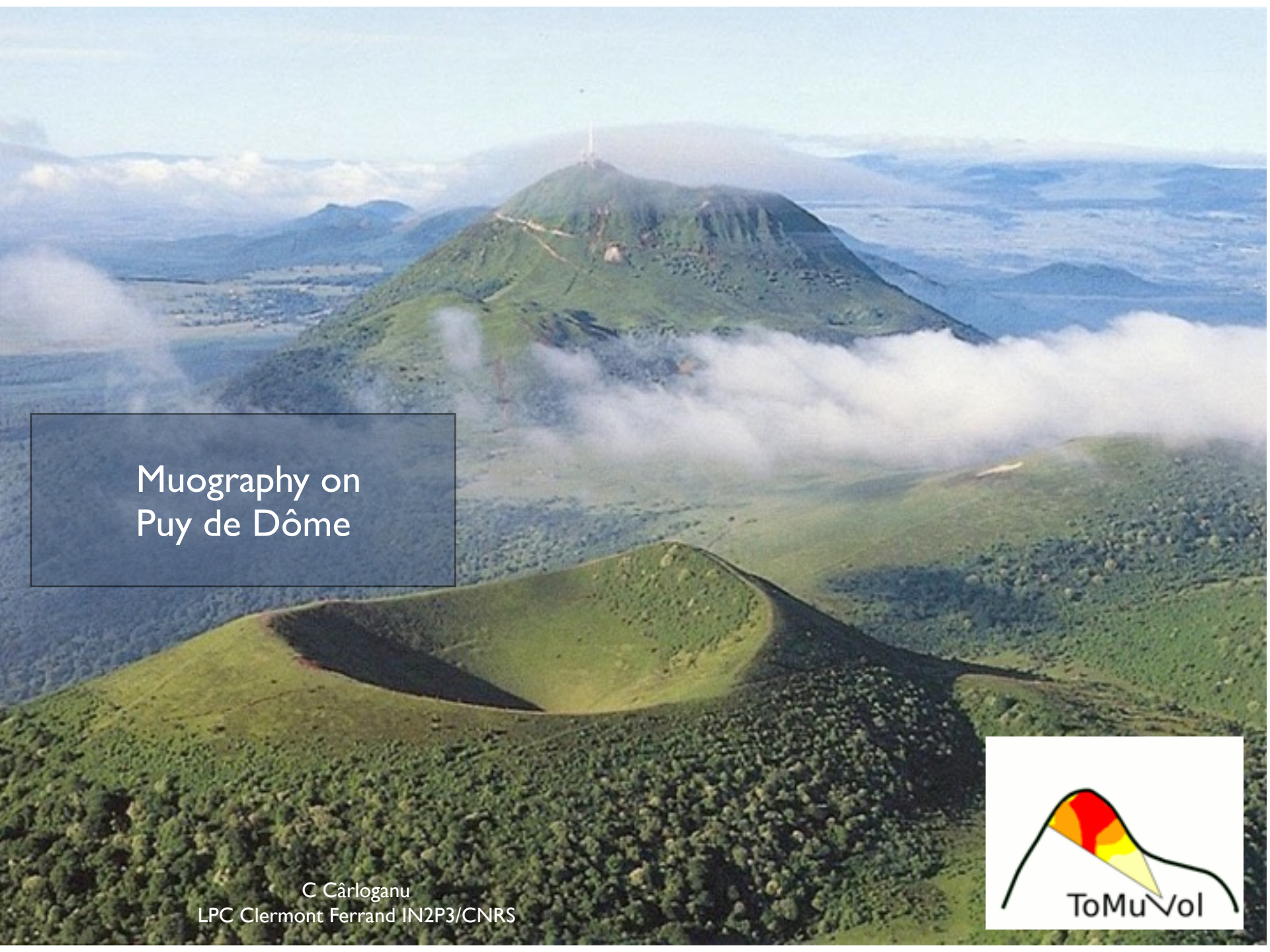
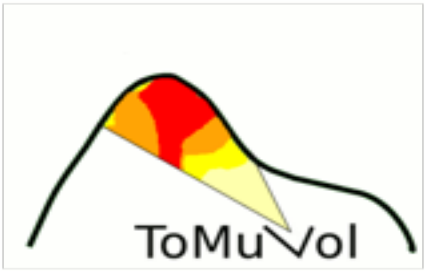


C Cârloganu
LPC Clermont Ferrand IN2P3/CNRS

Laboratoire de Physique de Clermont

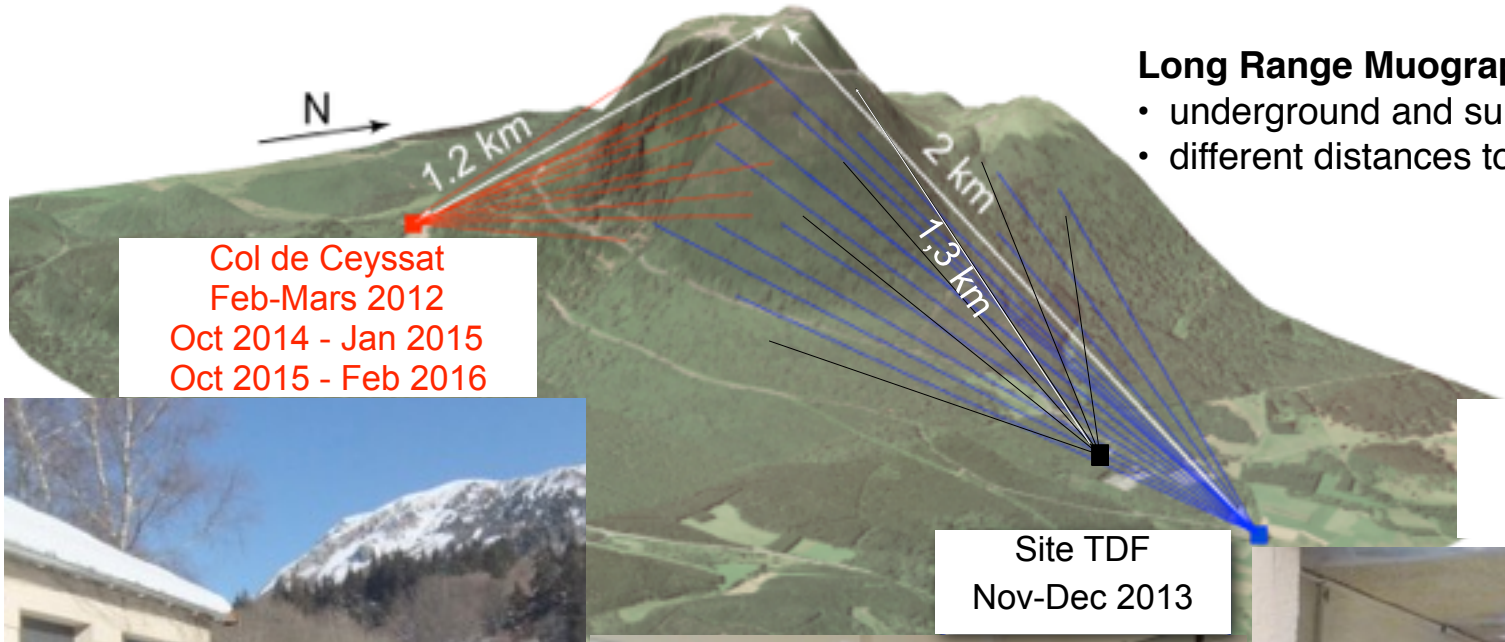
Institute of Nuclear Physics of Lyon



Proof of principle of muography on km sized volcanoes

Puy de Dôme muography reference site

Proof of Principle for Muographic Imaging of Volcanoes



Long Range Muography

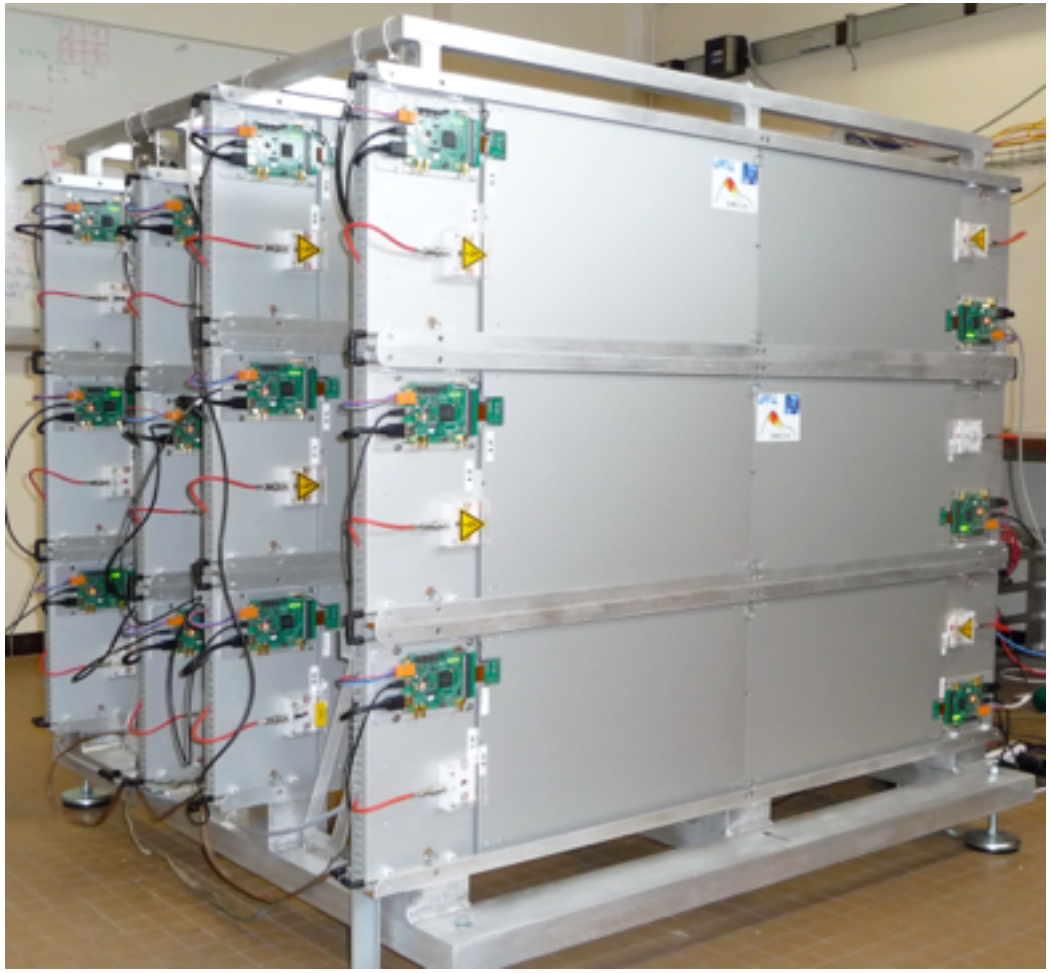
- underground and surface deployment sites
- different distances to the target

Col de Ceyssat
Feb-Mars 2012
Oct 2014 - Jan 2015
Oct 2015 - Feb 2016

Site TDF
Nov-Dec 2013

Grotte Taillerie
Jan-Juillet 2011
March-April 2016

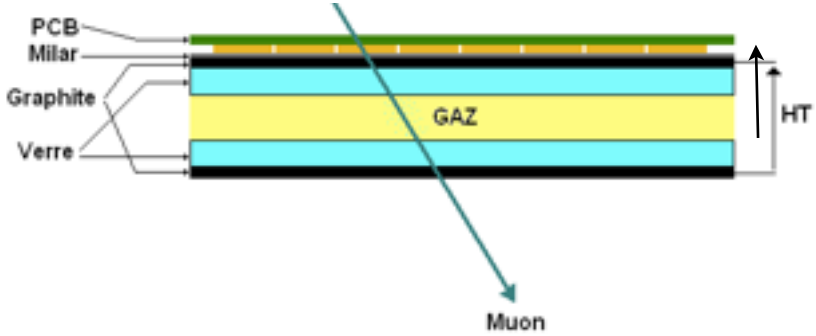
Tomuvol: a 4-layer muon telescope



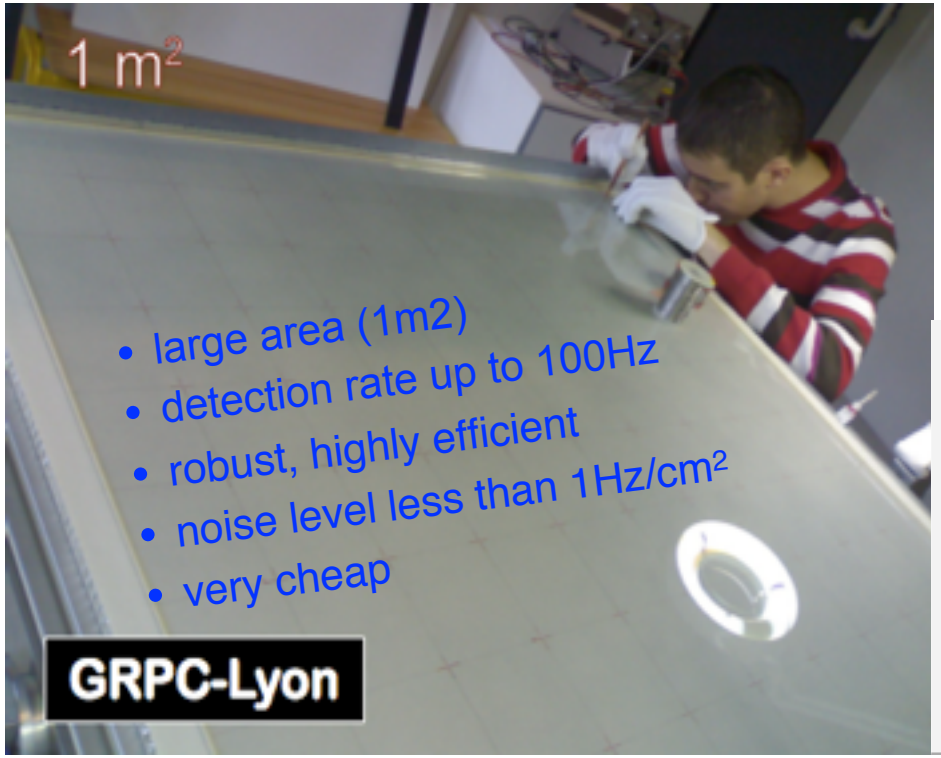
- 4 layers of 6 Glass Resistive Plate Chambers (GRPC)
- GRPC: gaseous detector with glass electrodes
- Applied voltage: 7.5 kV
- 1.2 mm gap filled by a gas mixture chosen for its ionizations properties
- 1layer:~1m^2
- Readout cells of 1 cm^2 (~ 40000 cells in total)
- Using a 5 MHz clock and auto-triggered
- Remotely monitored from web interface

Muon Tracker : CALICE GRPC's

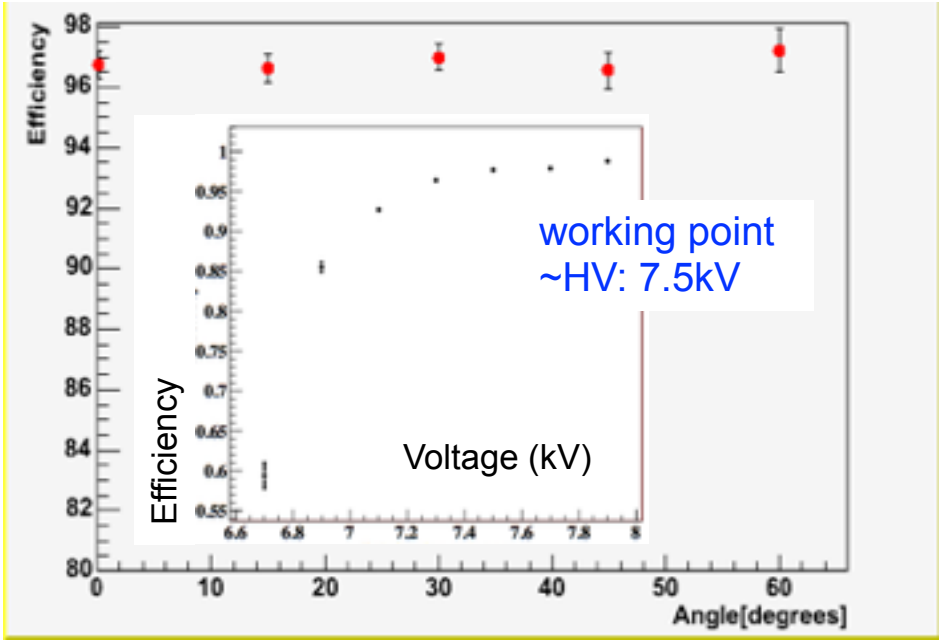
Avalanche mode: mean MIP charge 2.6pC, RMS: 1.6pC



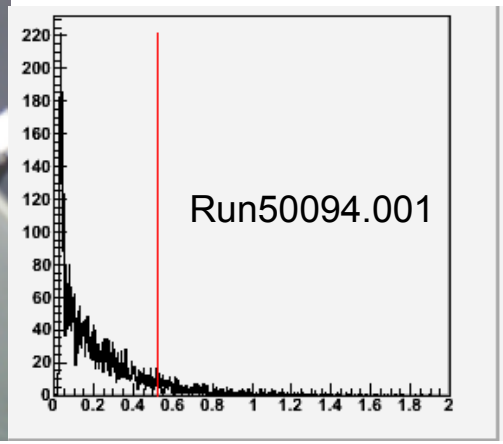
M. Bedjidian et al, "Performance of Glass Resistive Plate Chambers for a high granularity semi-digital calorimeter", JINST 6:P02001,2011

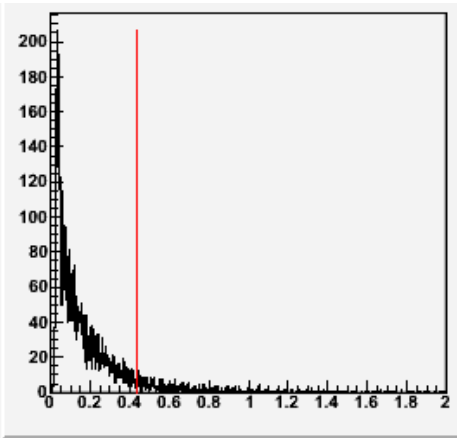


Efficiency vs. HV & track incident angle

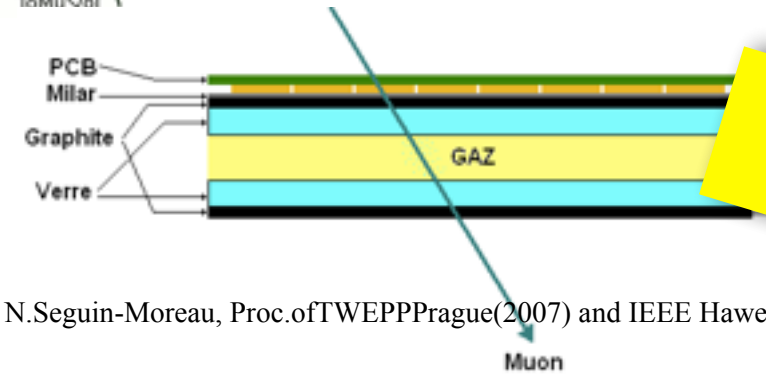


Noise rate (Hz)



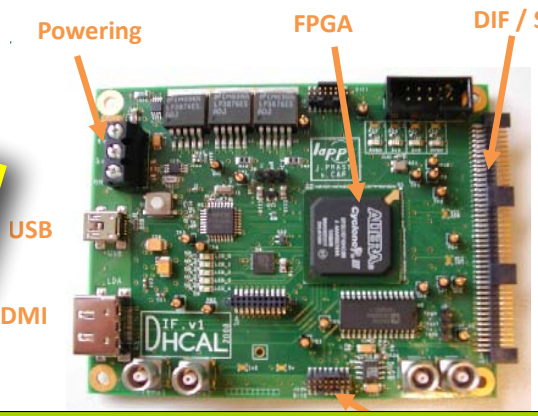


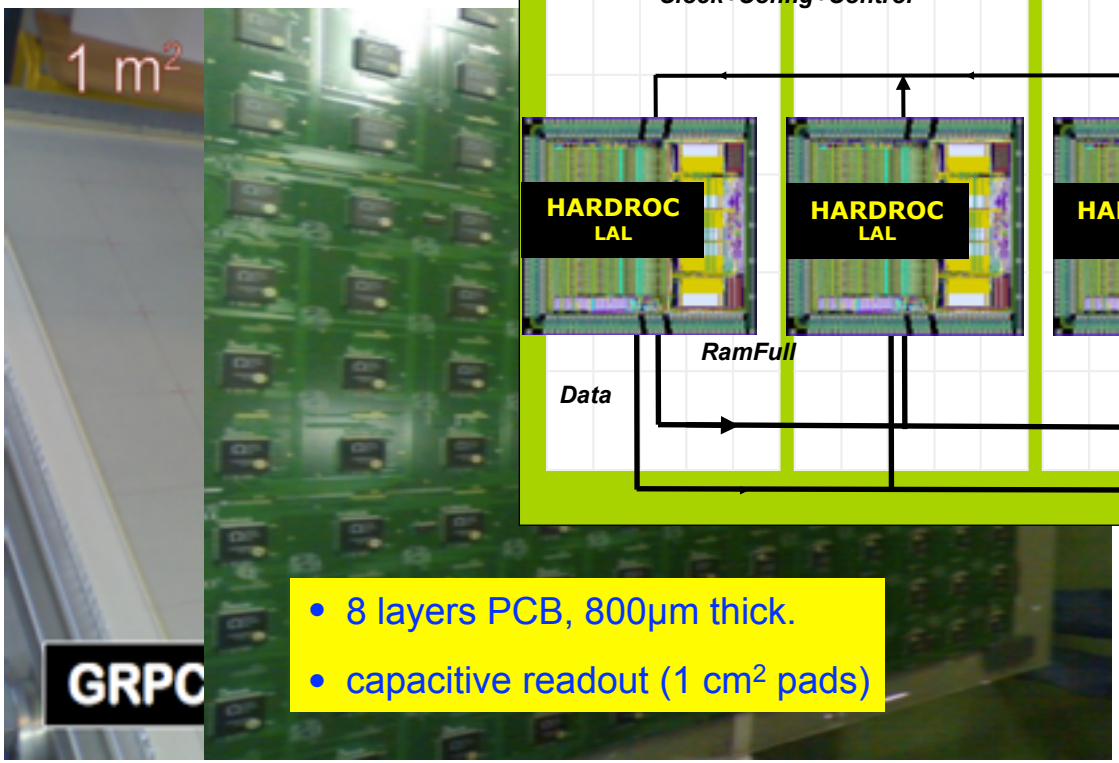
Muon Tracker : CALICE Electronics



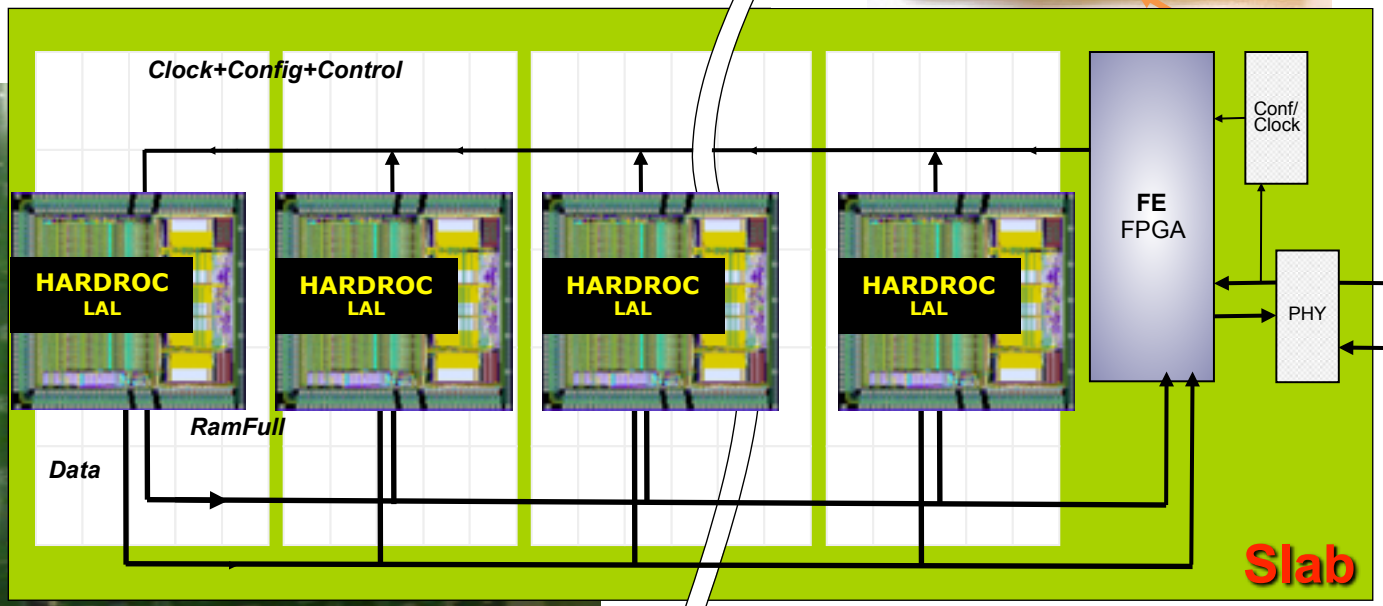
9472 channels/m2
1 hit ≡ time + thresh

N.Seguin-Moreau, Proc.ofTWEPPPrague(2007) and IEEE Hawei (2007)



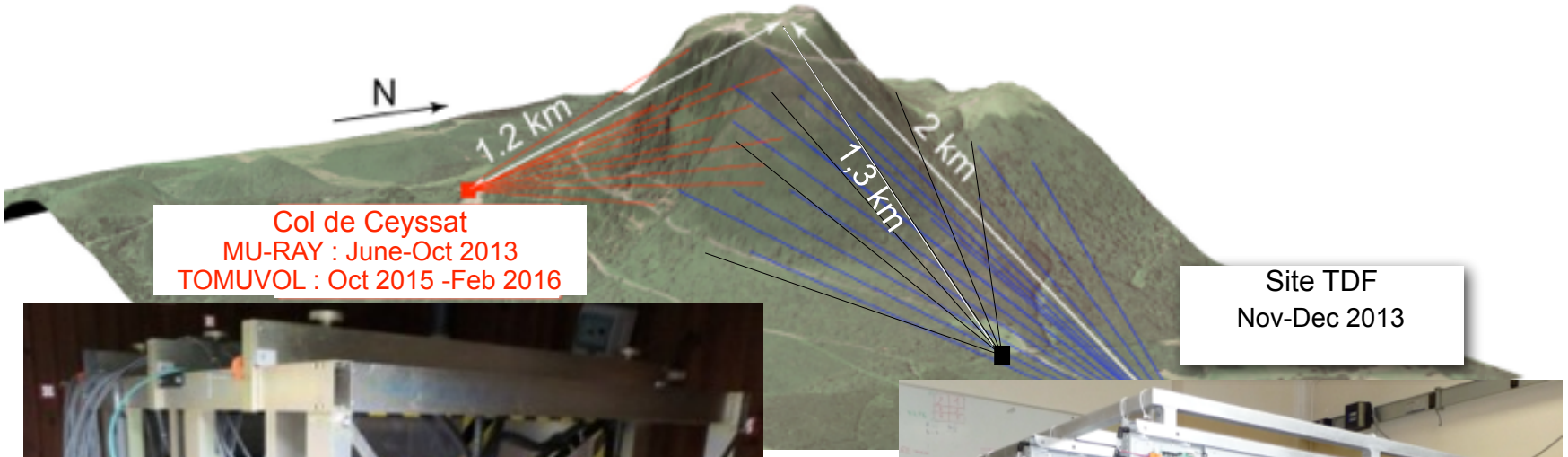


- 8 layers PCB, 800µm thick.
- capacitive readout (1 cm² pads)



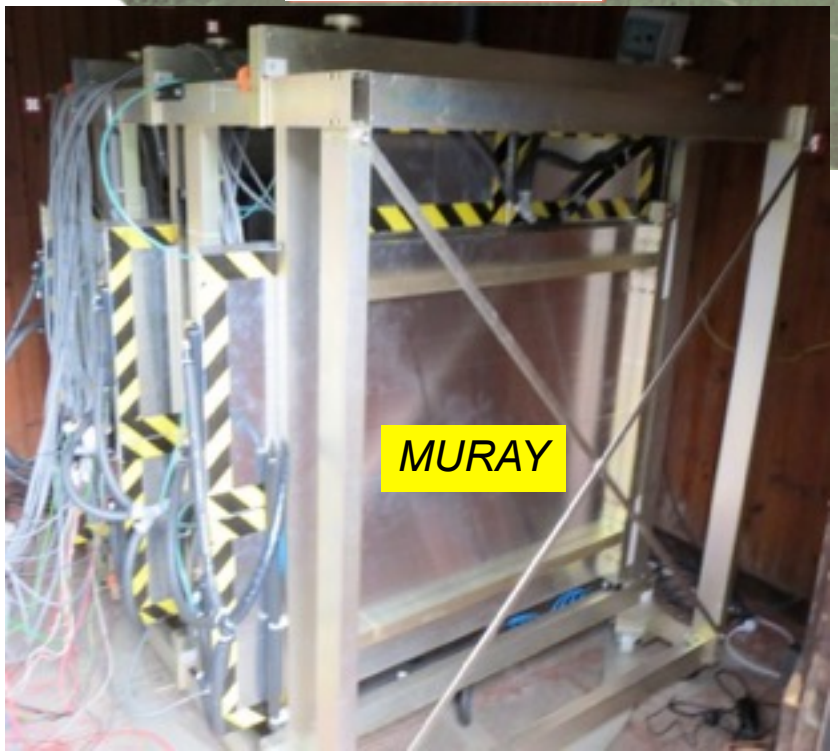
64 channels, 16 mm²
- digital output (2 adjustable thrs)
- low power consumption
- large gain range
- xtalk <2%
- ajustable gain for each channel

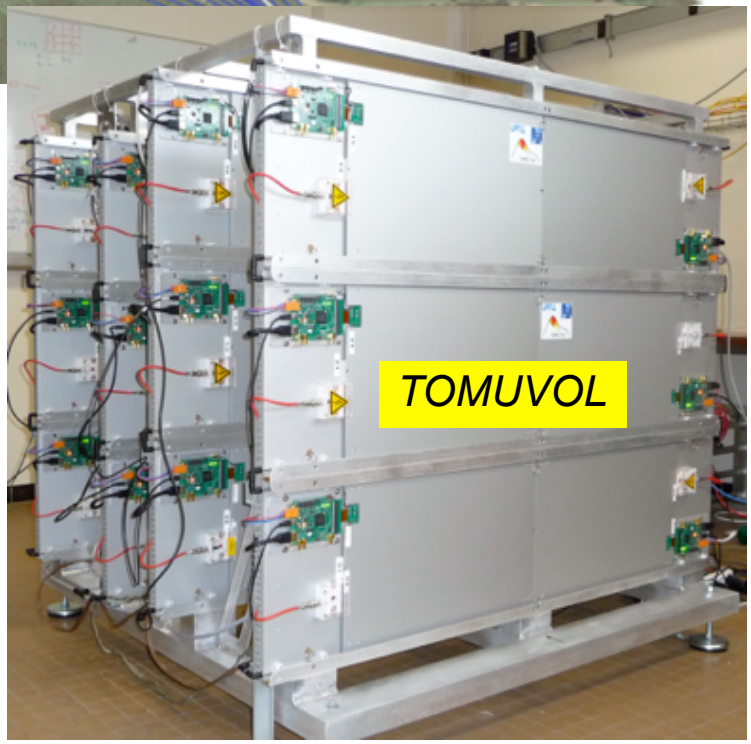
MURAY-TOMUVOL 2013 campaign on Puy de Dôme



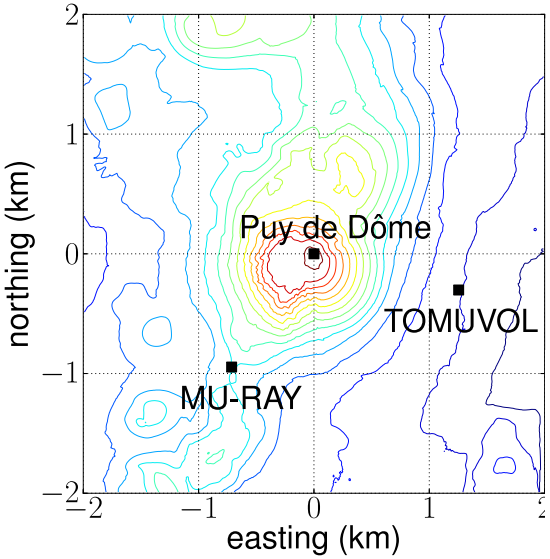
Col de Ceyssat
MU-RAY : June-Oct 2013
TOMUVOL : Oct 2015 -Feb 2016

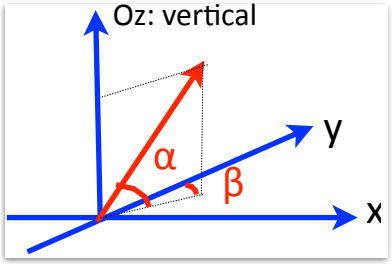
Site TDF
Nov-Dec 2013

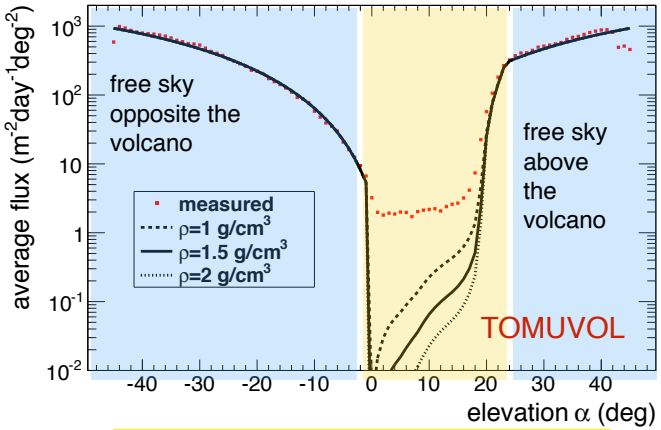


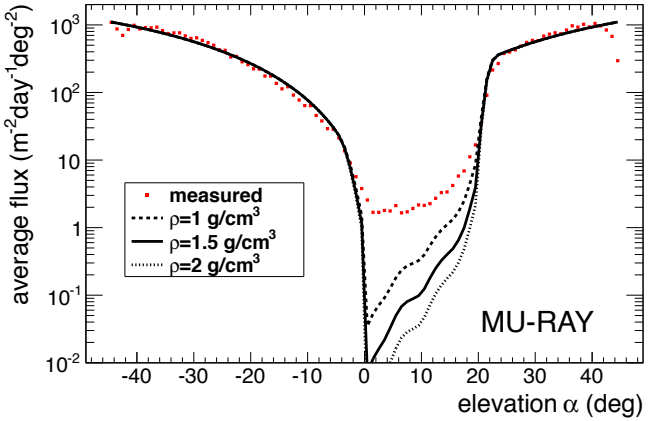


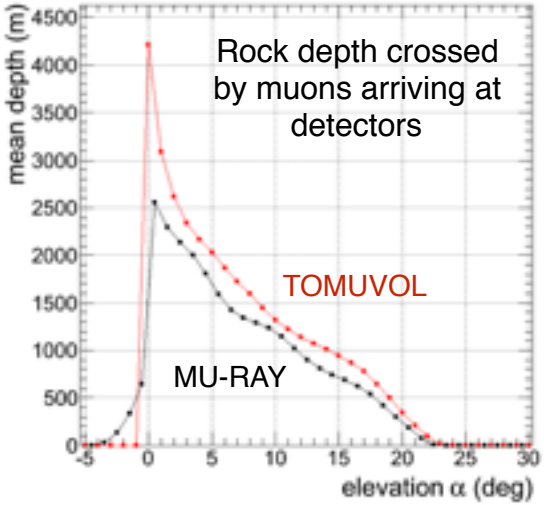
MURAY-TOMUVOL 2013 campaign on Puy de Dôme









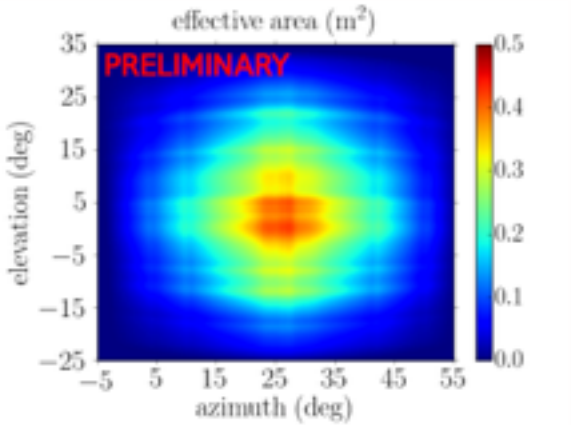


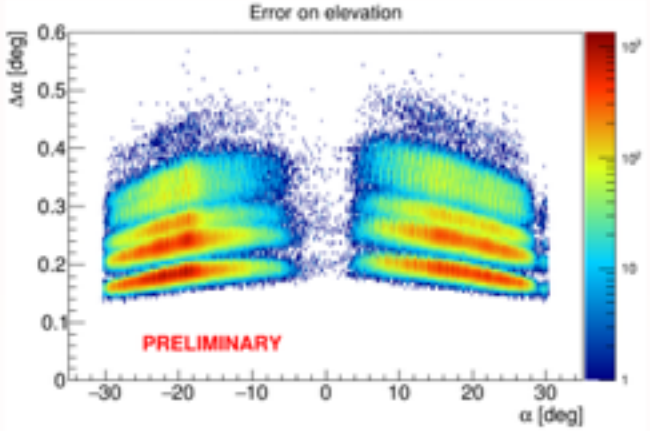
Data/flux model agreement:
~5% for free sky

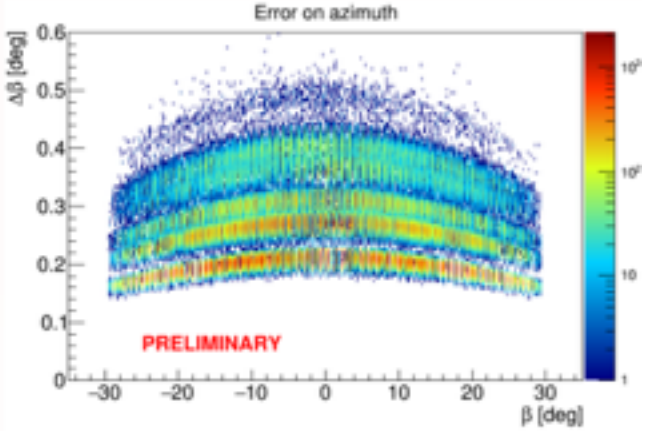
J. Geophys. Res. Solid Earth, 120,
doi:10.1002/2015JB011969

TOMUVOL 2015-2016 campaign on Puy de Dôme

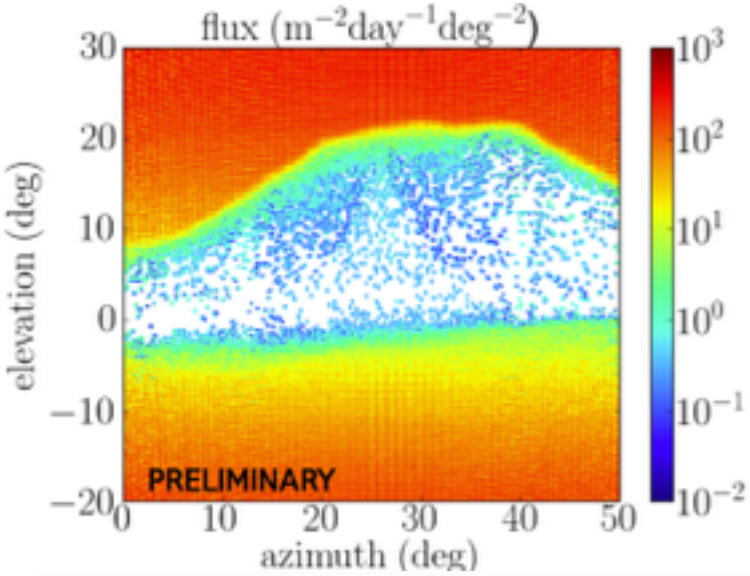
- Very preliminary results on the CDC 2015-2016 campaign
- 99.6 effective days of data taking
- 1 m^2 detector



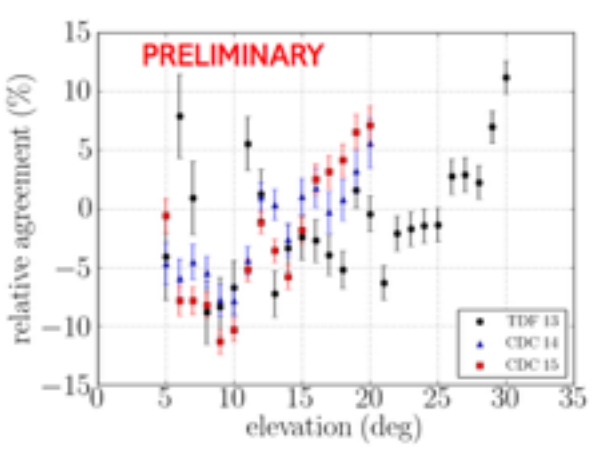




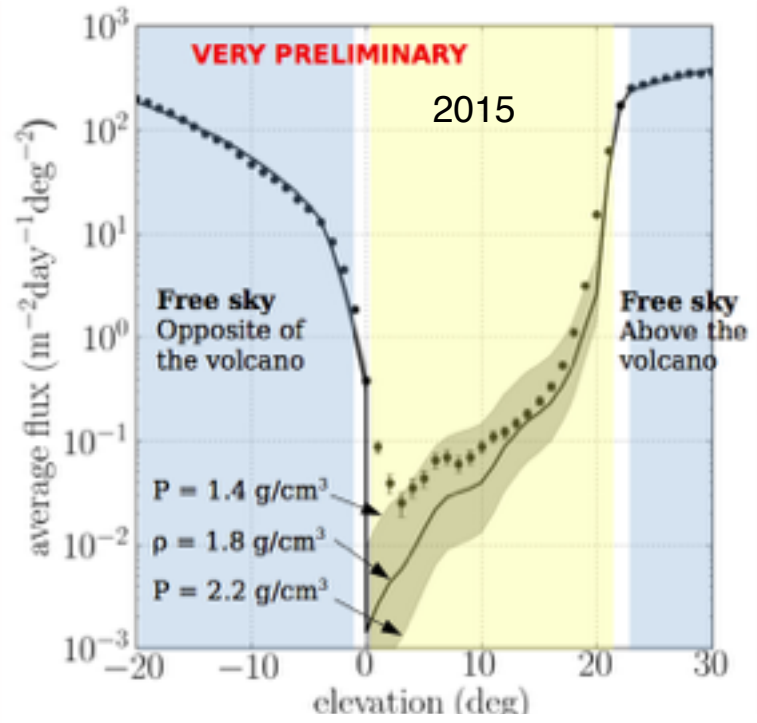
TOMUVOL 2015-2016 campaign on Puy de Dôme

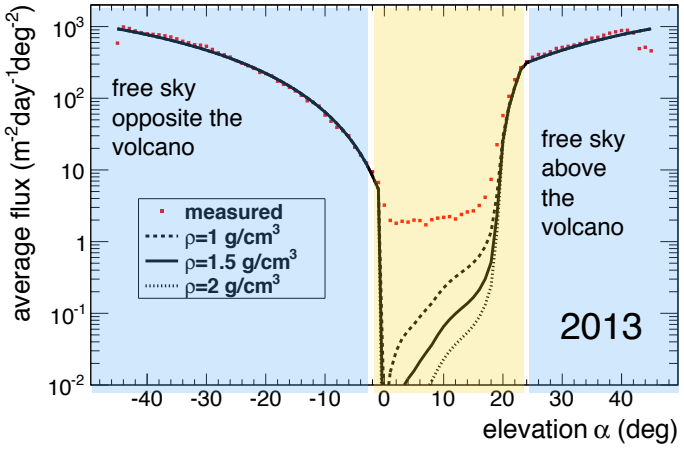


For the moment, systematic uncertainty estimated from comparison between data and model in the free sky



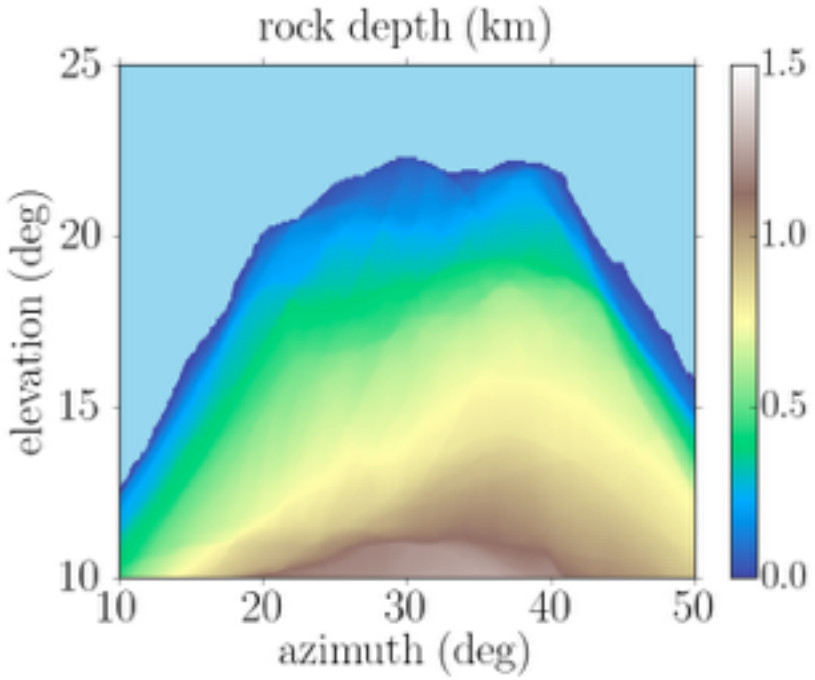
$$rel.\ agreement = 100 \times \left(\frac{data}{pred} - 1\right)$$

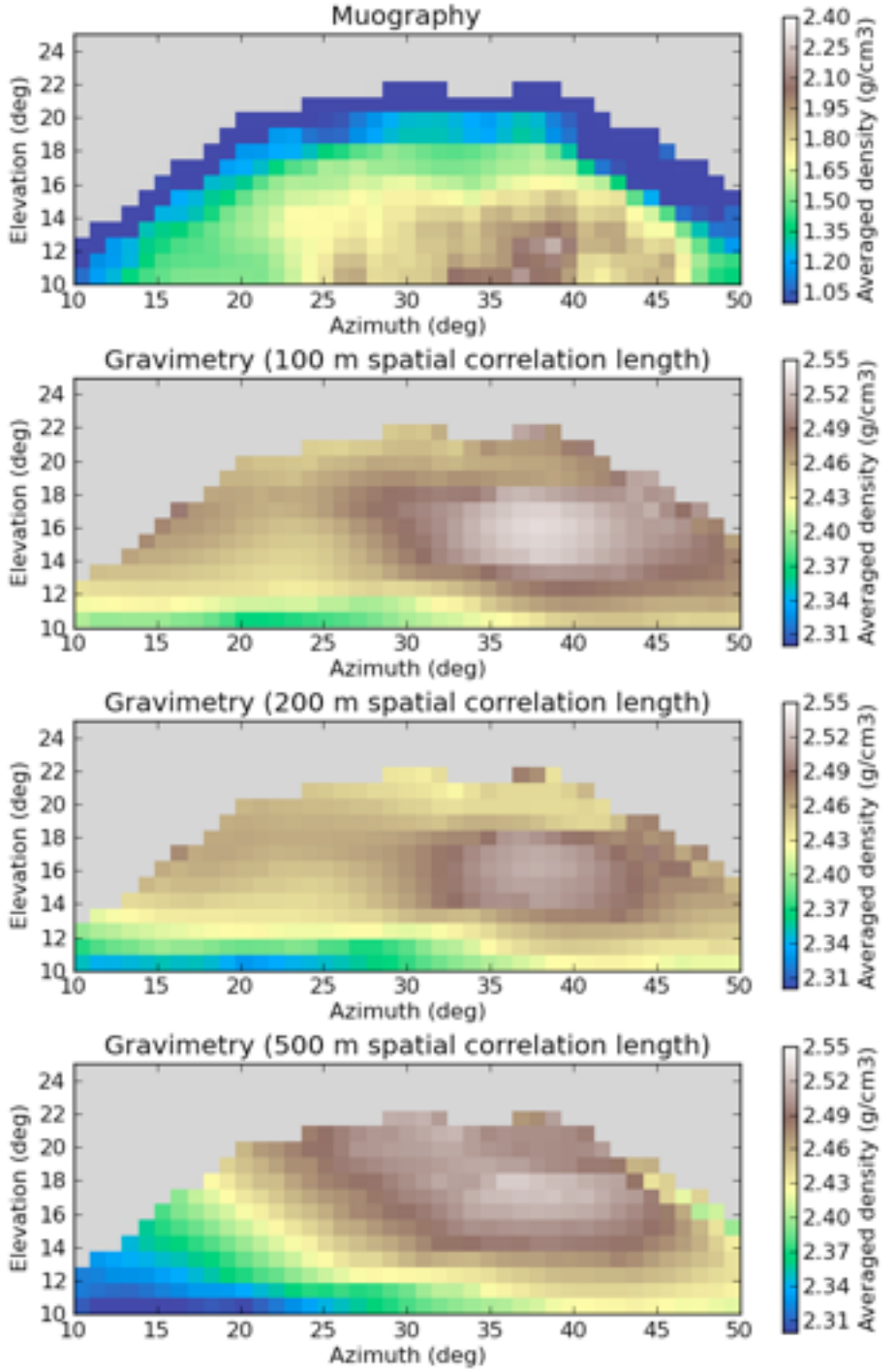




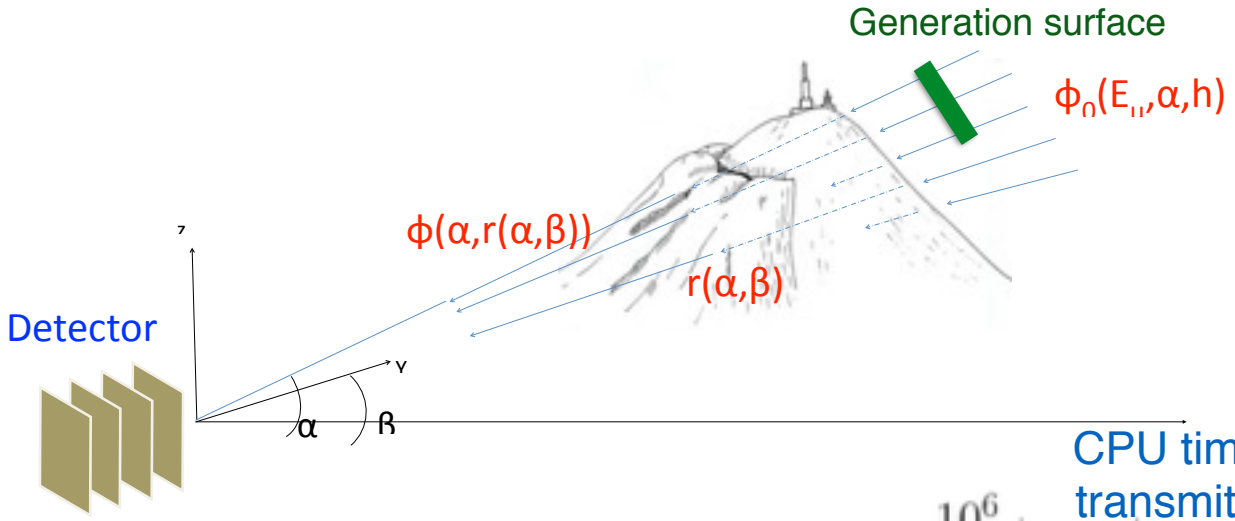
Puy de Dôme

Inner structure

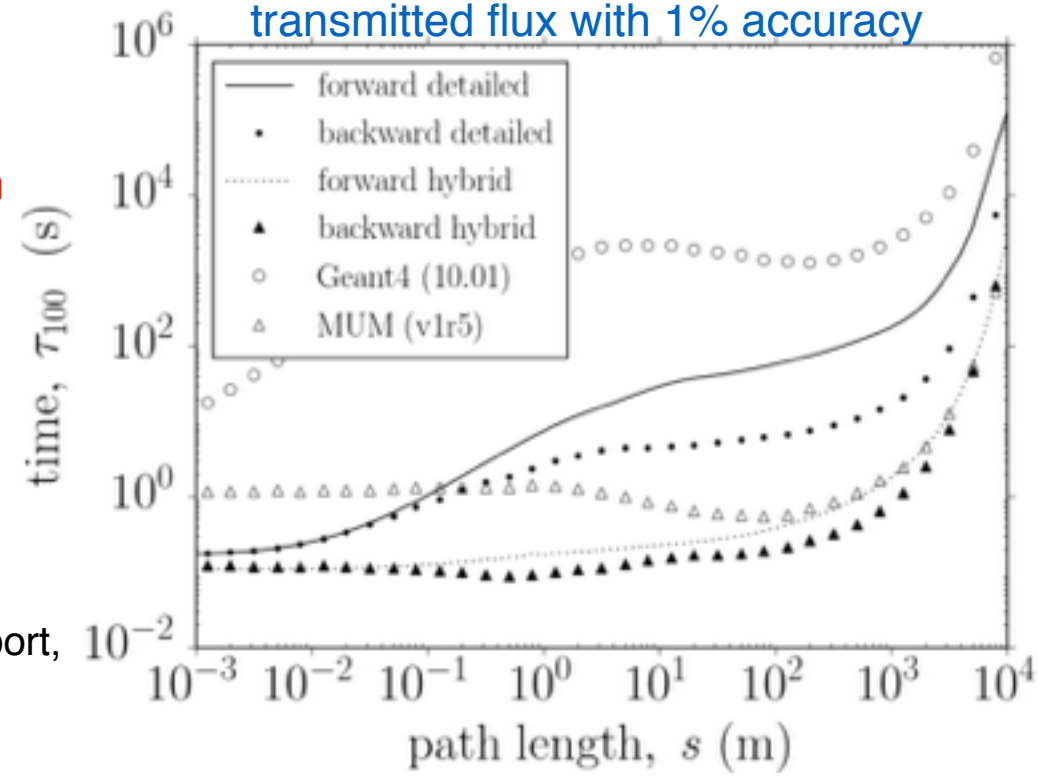




A methodological development: inverse tracking



CPU time needed to simulate the transmitted flux with 1% accuracy

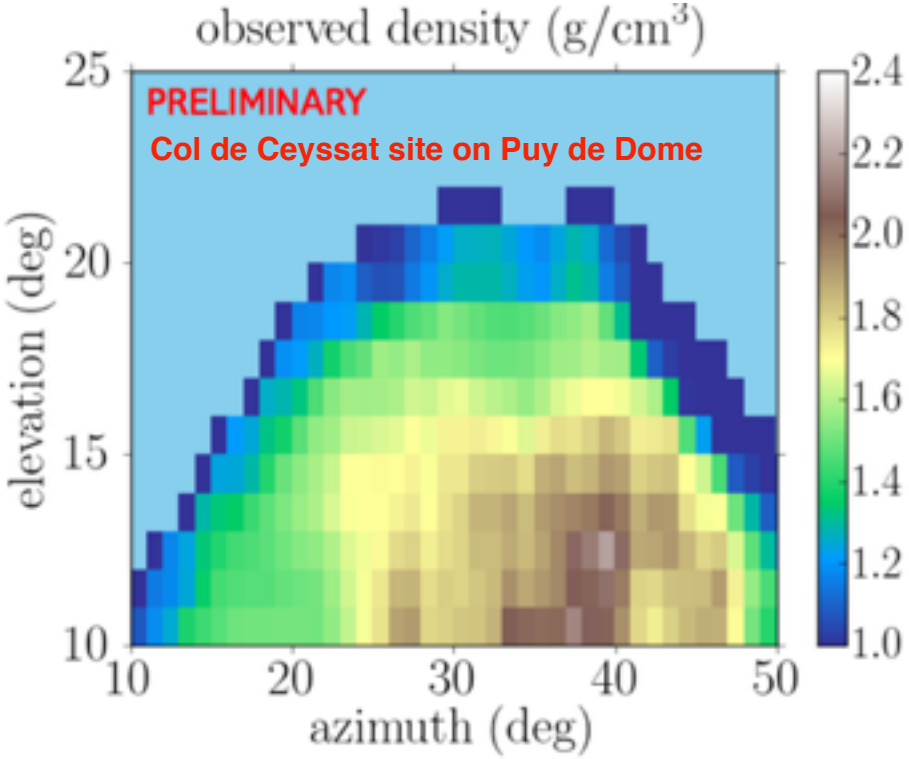


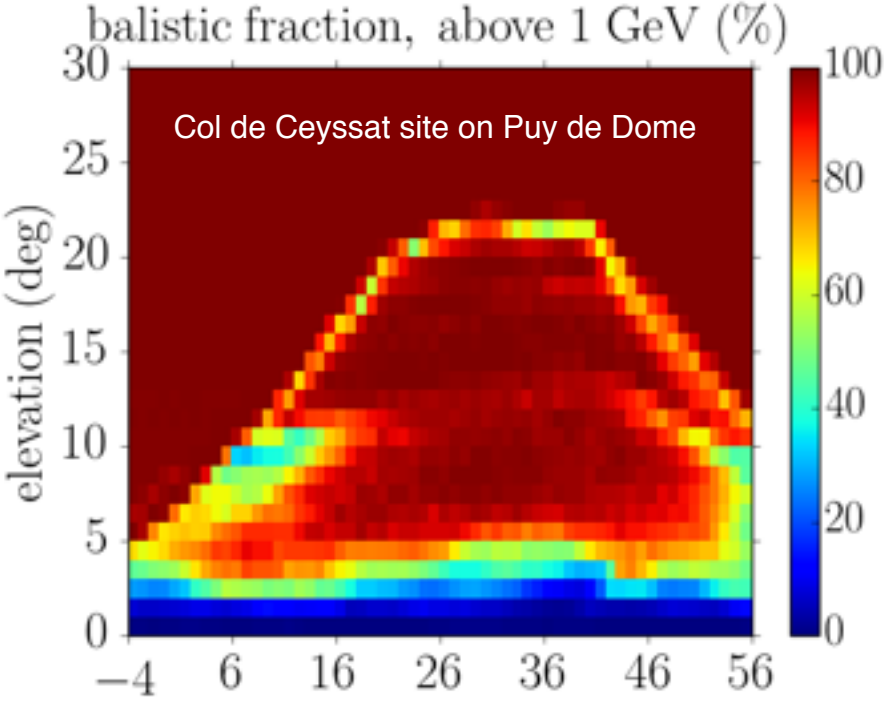
Solution: sample the muons backwards in time, from the detector to the atmosphere

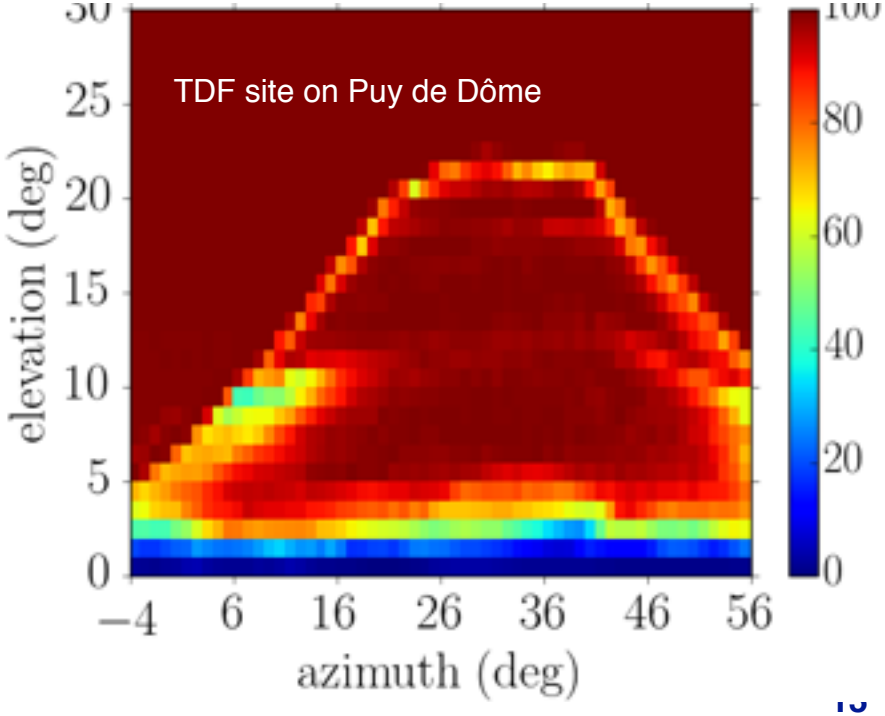
Backward Monte Carlo applied to muon transport, submitted to CPU,
https://arxiv.org/abs/1705.05636

First results from MC

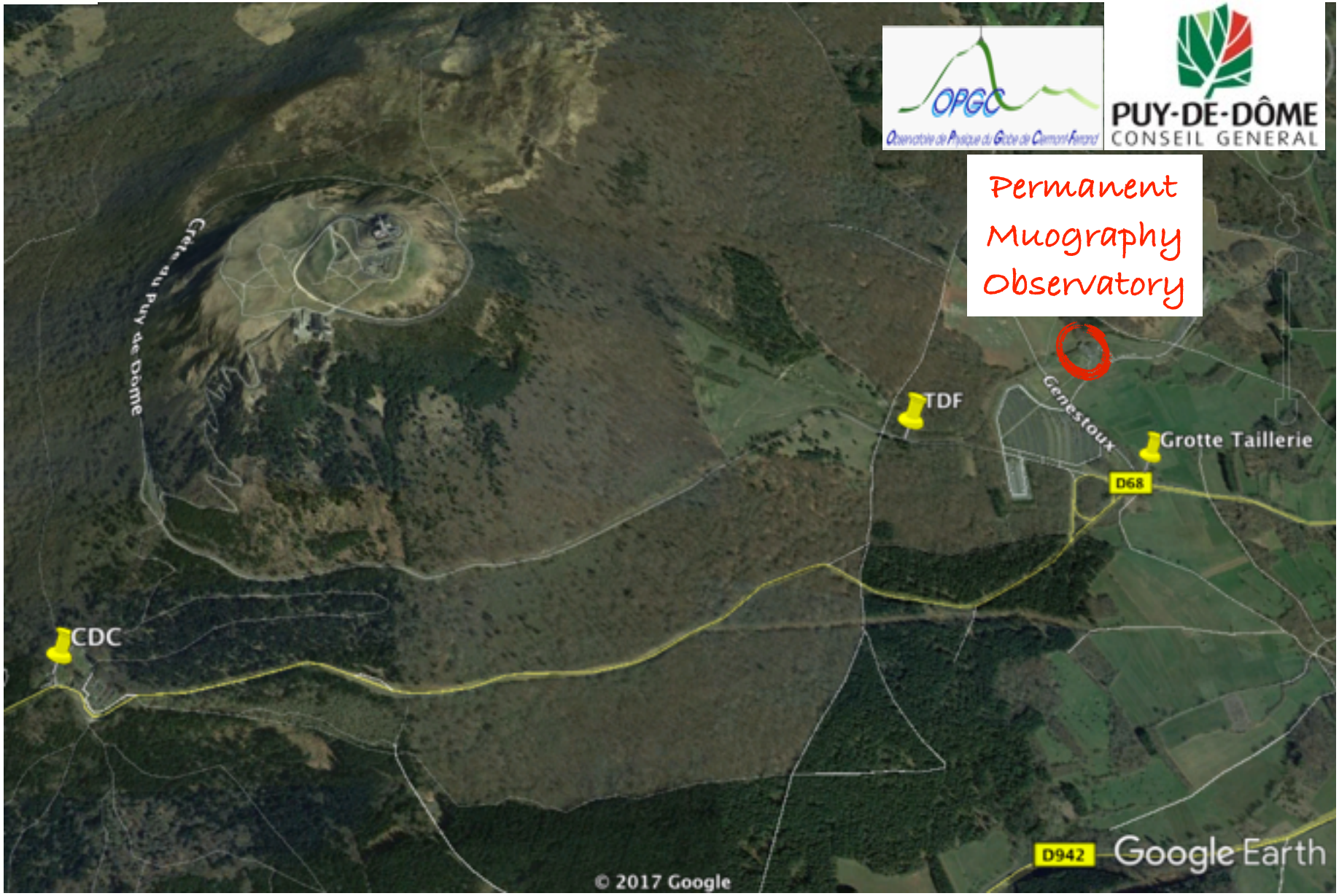
Background depends on volcano topography close to detector

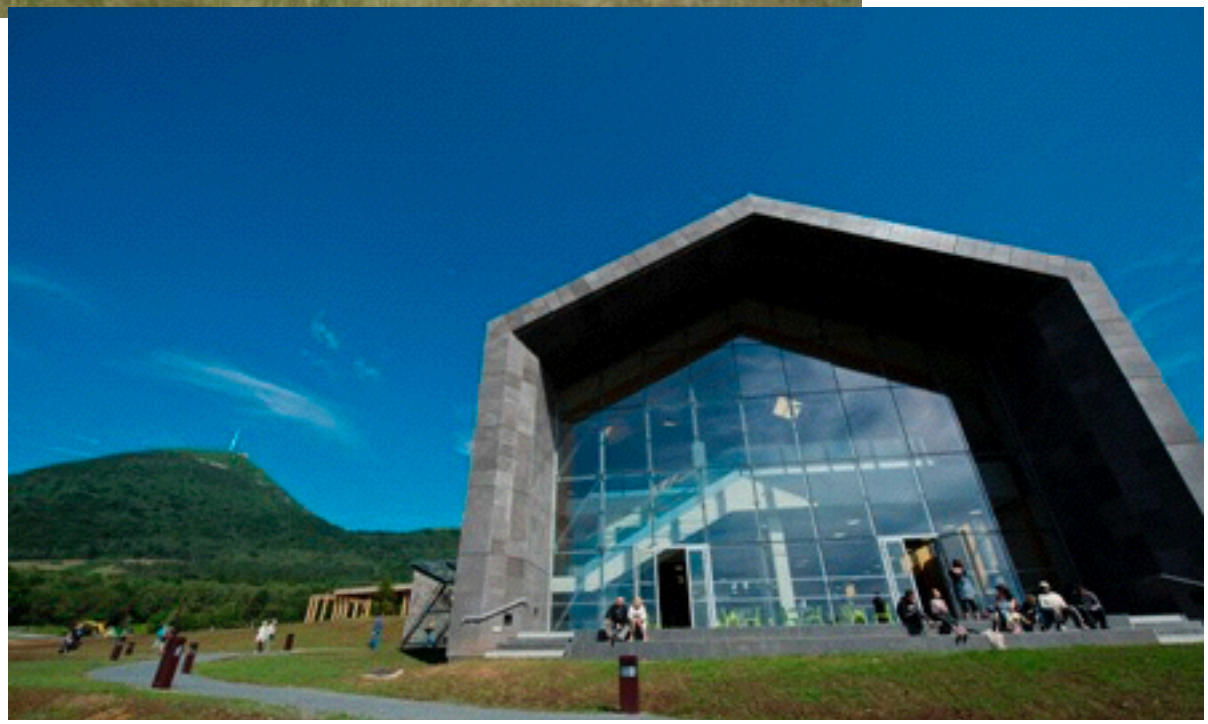




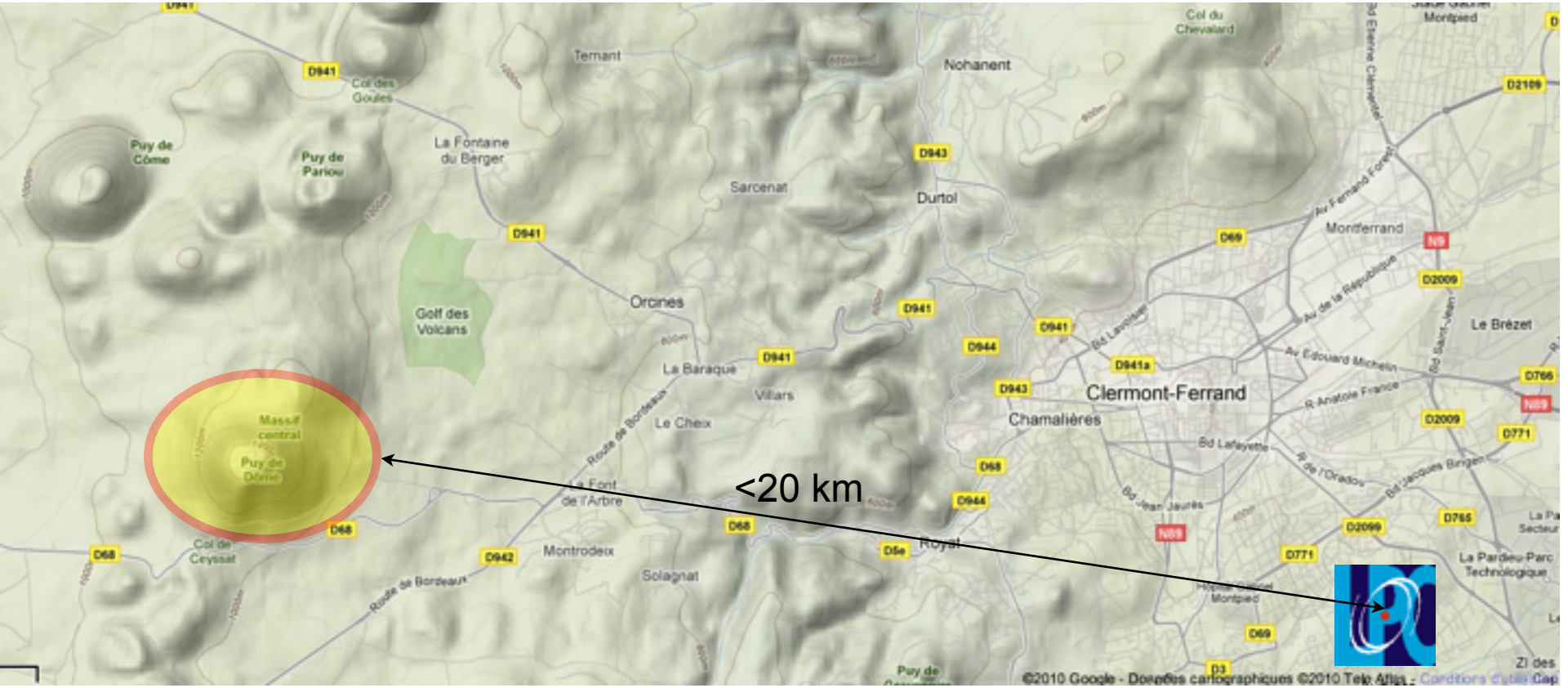


Puy de Dôme as reference site for muography and beyond





Experimentation site with
- electricity
- network
- easy to host researchers
- easy to access
- close to Clermont labs


Puy de Côme
Puy de Pariou
Col des Goules
Ternant
La Fontaine du Berger
Nohanent
Col du Chevalard
Montpied
Sarcenat
Durtol
Montferrand
Orcines
Golf des Volcans
La Baraque
Villars
Le Cheix
Clermont-Ferrand
Chamalières
Le Brézet
Massif central
Puy de Dôme
Col de Ceyssat
Montrodeix
Solagnat
Royat
La Pardieu Parc Technologique
<20 km
©2010 Google - Données cartographiques ©2010 Tele Atlas -

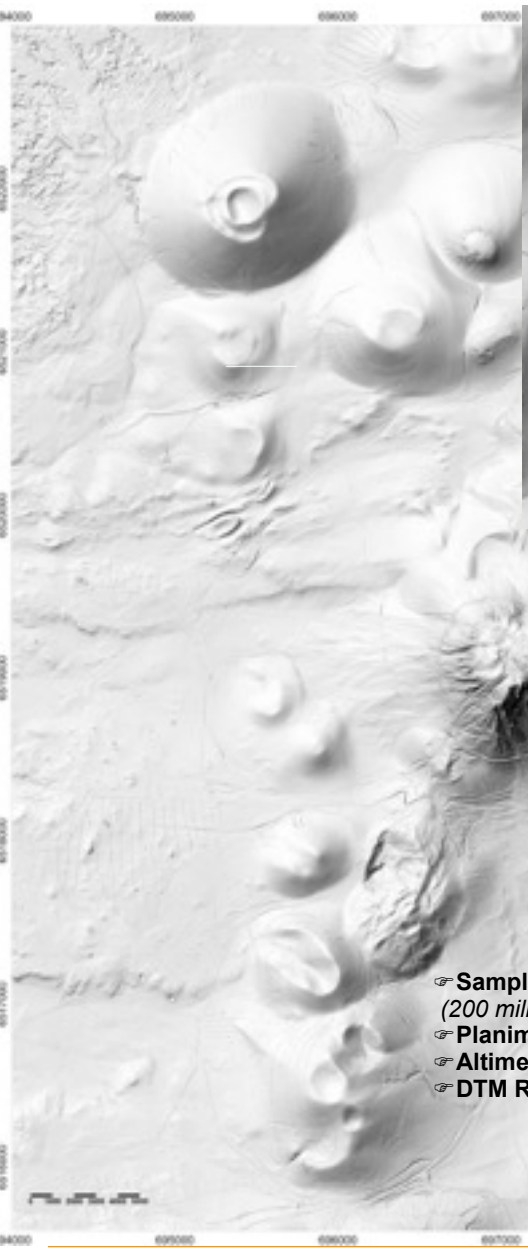
Puy de Dôme – a well "calibrated volcano"

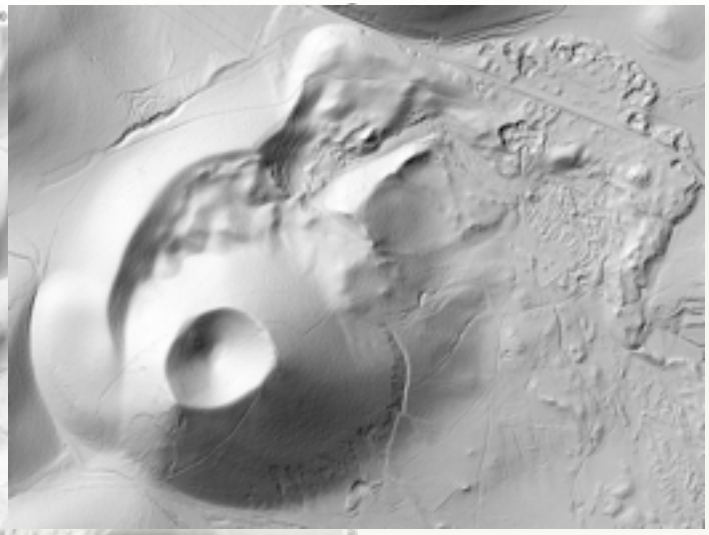
- very detailed muon flux estimates available
- reference set of muographic data

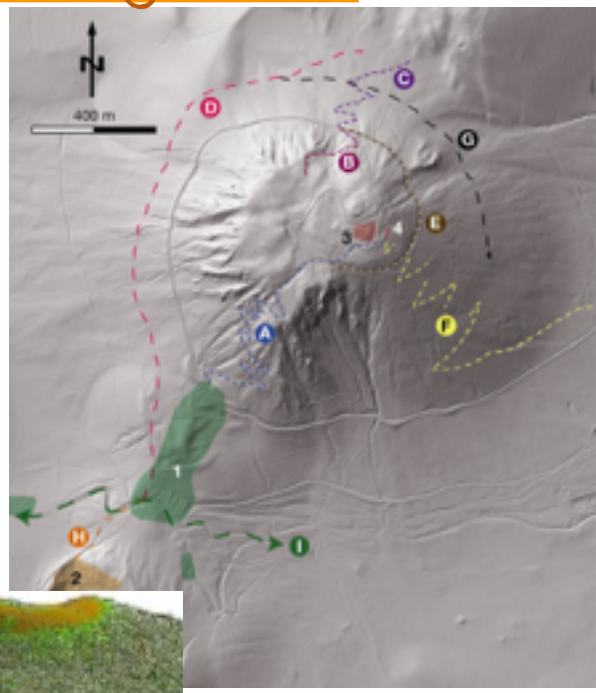
- topography well known (LIDAR)

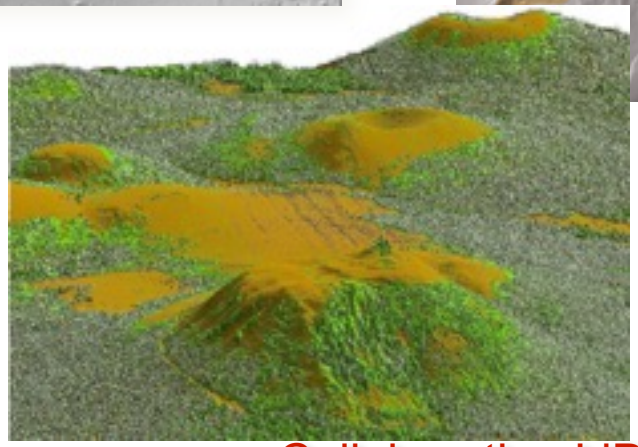
High Resolution Airborne LiDAR Survey

(Puy de Dôme and central part of the Chaîne des Puys)









- **Sampling: 10 points/m²**
  (200 millions of ground échoes)
- **Planimetric Precision: 10 cm**
- **Altimetric Precision: 10 cm**
- **DTM Resolution: 50 cm**

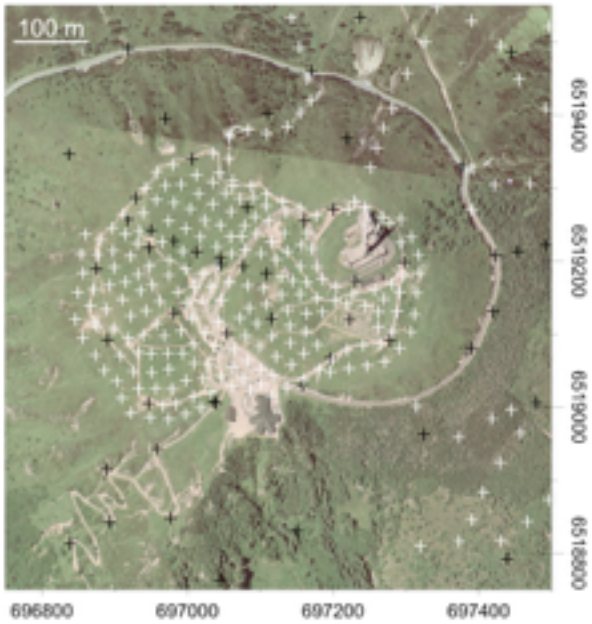
Collaboration LiDARverne (2011)

Puy de Dôme – a well "calibrated volcano"

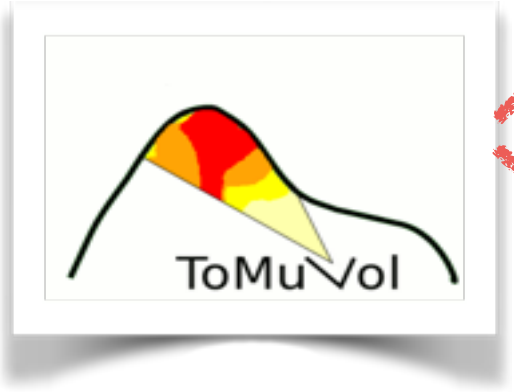
- very detailed muon flux estimates available
- reference set of muographic data
- topography well known (LIDAR)

- gravimetric measurements available
- electrical resistivity measurements available (and more to come, see Catherine's talk tomorrow)

- around 2500 relative gravity measurements
- High resolution differential GPS positioning at the gravimeter tripod center average accuracy: **1.6 cm** in planimetry and **2.3 cm** in altimetry



Conclusion



Proof of principle of muography on km sized volcanoes

Updated results expected to be released for beginning 2018 (joint inversion of muography + gravimetry)

Puy de Dôme muography reference site

- permanent muography observatory; external collaborators more than welcomed
- reference site for developing joint, multi-probe imaging