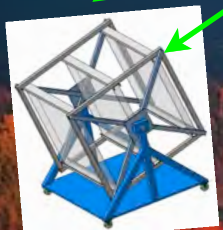
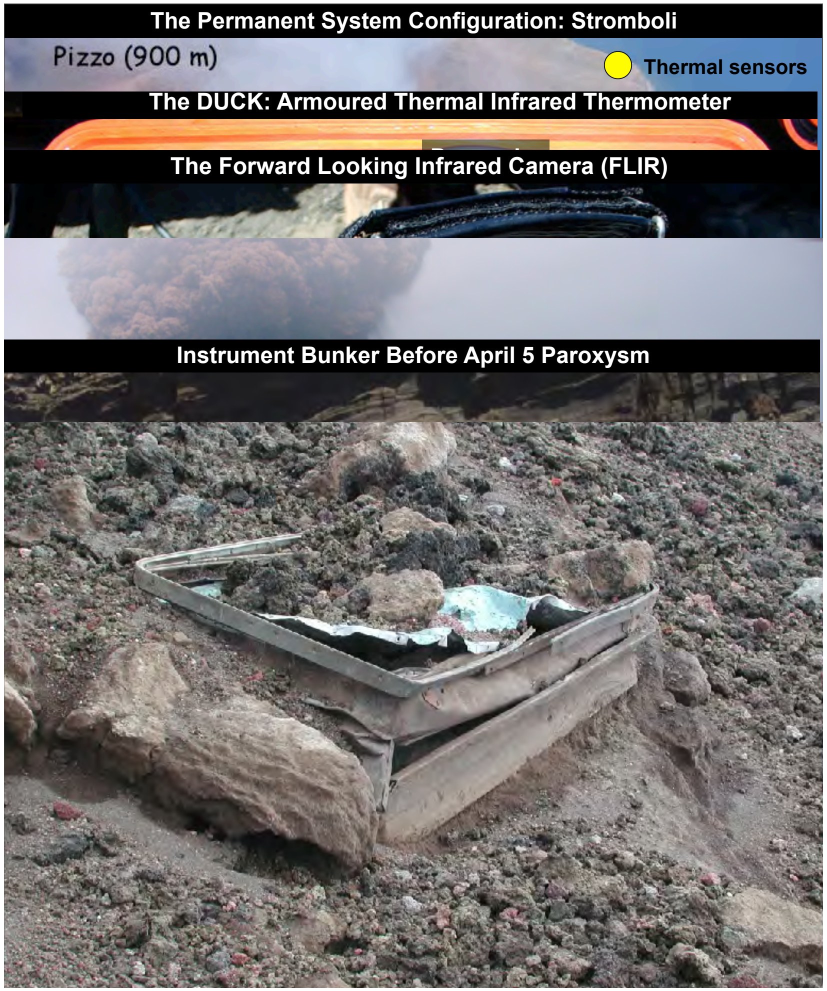
Density Imaging of Volcanoes With Atmospheric Muons using GRPCs

Cristina Cârloganu
LPC/IN2P3/CNRS
on behalf of the
TOMUVOL collaboration

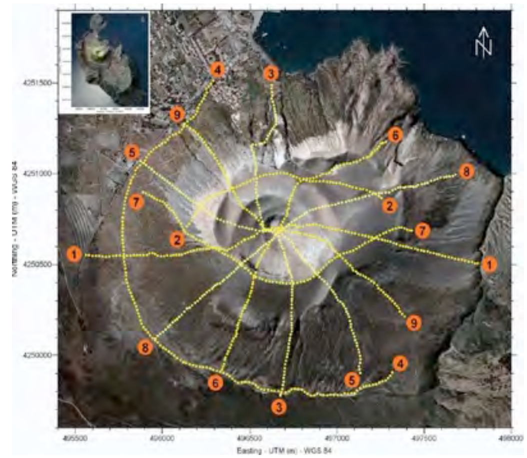


Volcano Density Imaging with Atm Muons: Why ?

Active Volcano Survey
courtesy A Harris (LMV ClFer)

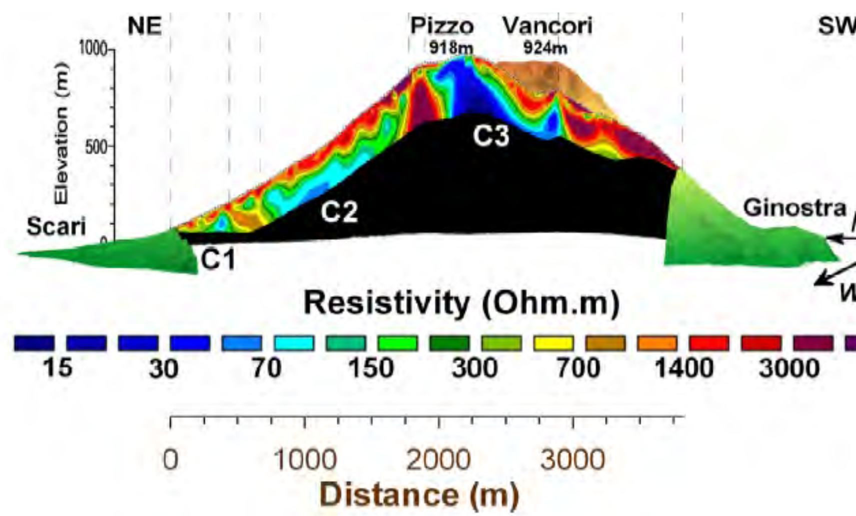


Study of Volcano Structure
courtesy JF Lénat (LMV ClFer)



Vulcano, Stromboli (Iles Eoliennes; Italie)

Finizola et al., GRL (2006, 2009); Revil et al., JGR (2008)



Volcano Density Imaging with Atm Muons: Why ?

Obvious interest in having an additional technique for:

- measuring the volcanos from far away
- probing deep in the edifice structure

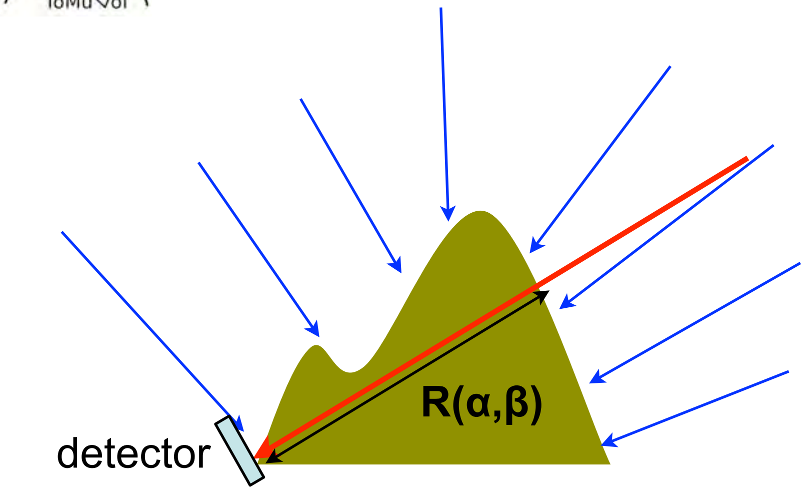
Volcano survey:

- original structure of the volcano not the first priority
- wish: to identify in (almost) real time structure modifications
- the radiographic method preferred
- survey facilitated by the differential “readout” of the data

Structure study of a target volcano:

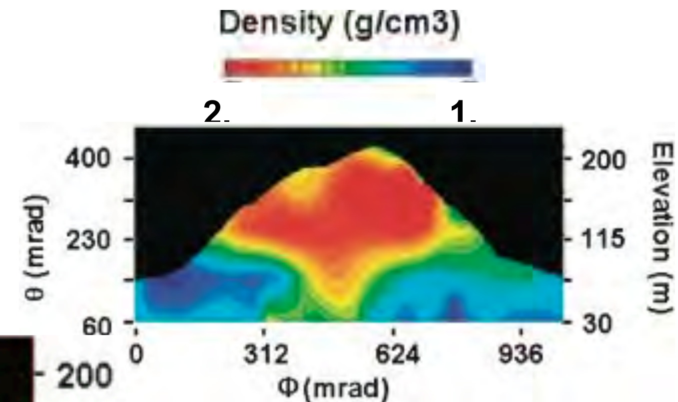
- no temporal constraints
- wish:
  - method without priors
  - 3D mapping of the density structure
- tomographic method preferred

Volcano Density Imaging with Atm Muons: How ?

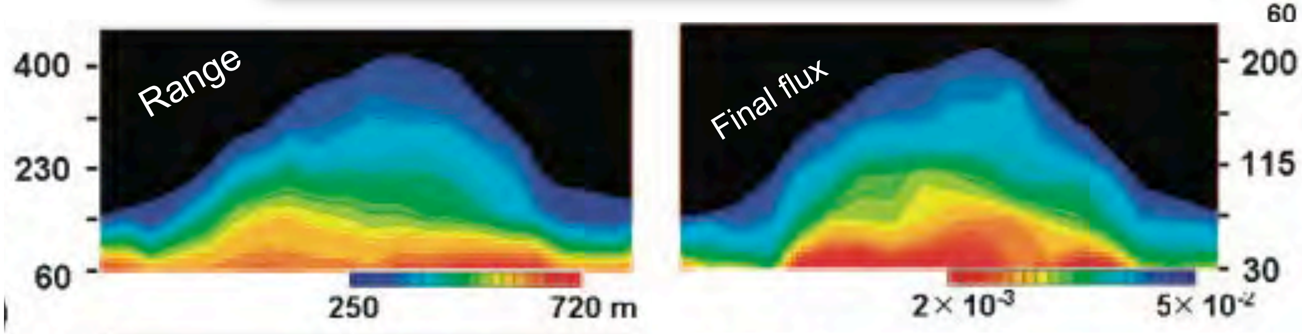


$\Phi_f/\Phi_0(\alpha) = \Im(\alpha,\beta)$

$\Im(\alpha,\beta) \sim R(\alpha,\beta)*\rho(\alpha,\beta)$



Tanaka et al, Proc Jpn Acad, Ser B 84 (2008)



Atmospheric Muons Flux

quite large detectors (>m²) for large targets

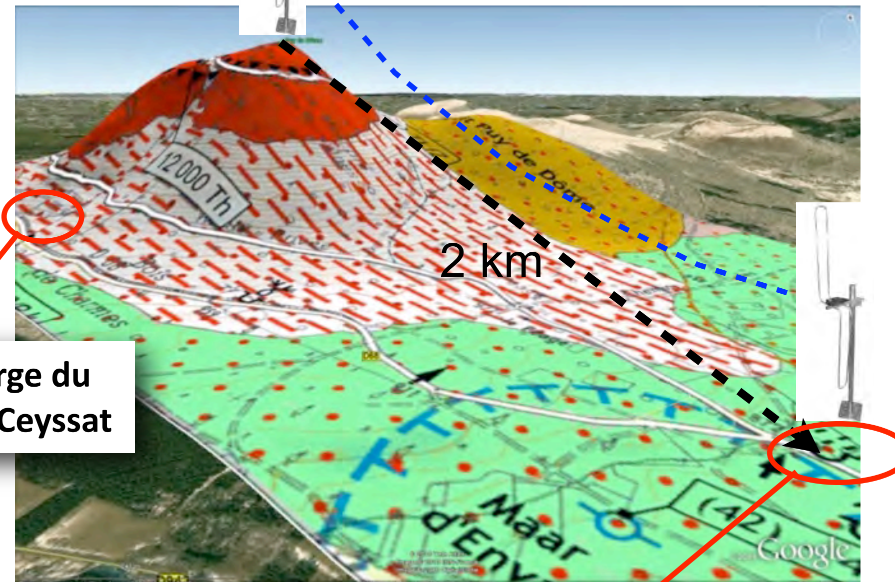
$$\frac{dN_\mu}{dE_\mu d\Omega} \approx \frac{0,14 E_\mu^{-2,7}}{\mathrm{cm}^2\ \mathrm{s}\ \mathrm{sr}\ \mathrm{GeV}} \times \left\{ \frac{1}{1+\frac{1,1 E_\mu cos\theta}{115\ \mathrm{GeV}}} + \frac{0,054}{1+\frac{1,1 E_\mu cos\theta}{850\ \mathrm{GeV}}} \right\}$$

TOMUVOL (2010-2014)

Proof of principle for volcano muon-tomography

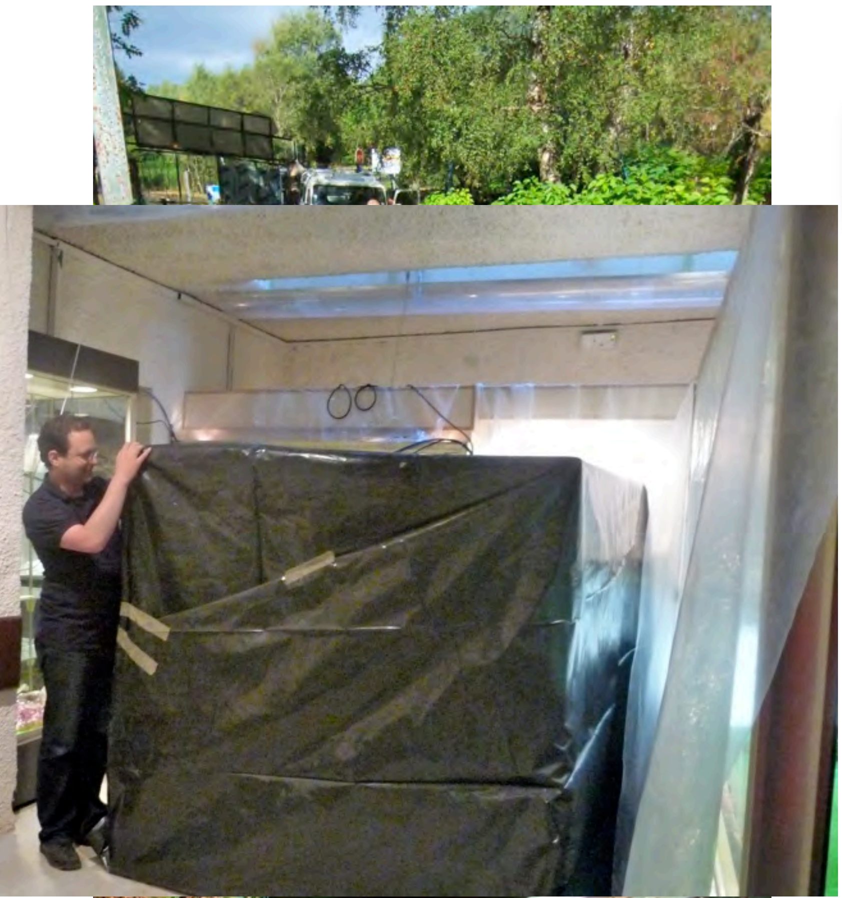
Transform Puy de Dôme in a reference target

- Muon-Radiography (2011)
- Electrical-Resistivity Tomography (2011)
- Muon Tomography (2014)



Auberge du Col de Ceyssat

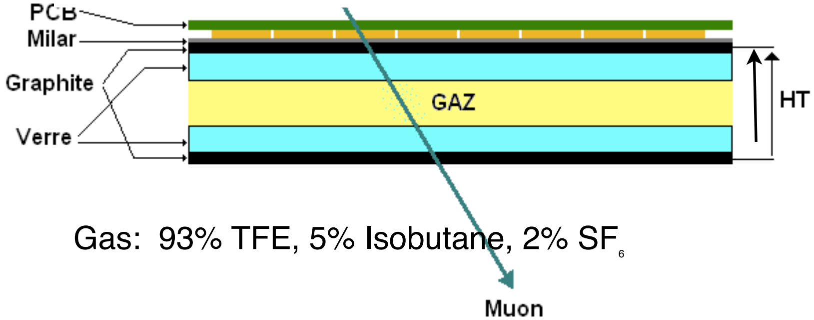
Grotte Taillerie
altitude 872 m



- **Janvier - March 2011 : prototype detector, Grotte Taillerie**
- Avril - beg. May 2011 : enlarged detector, Grotte Taillerie
- May 2011 : First measurements by Electrical-Resistivity Tomography
- September 2011 : prototype detector, Col de Ceyssat

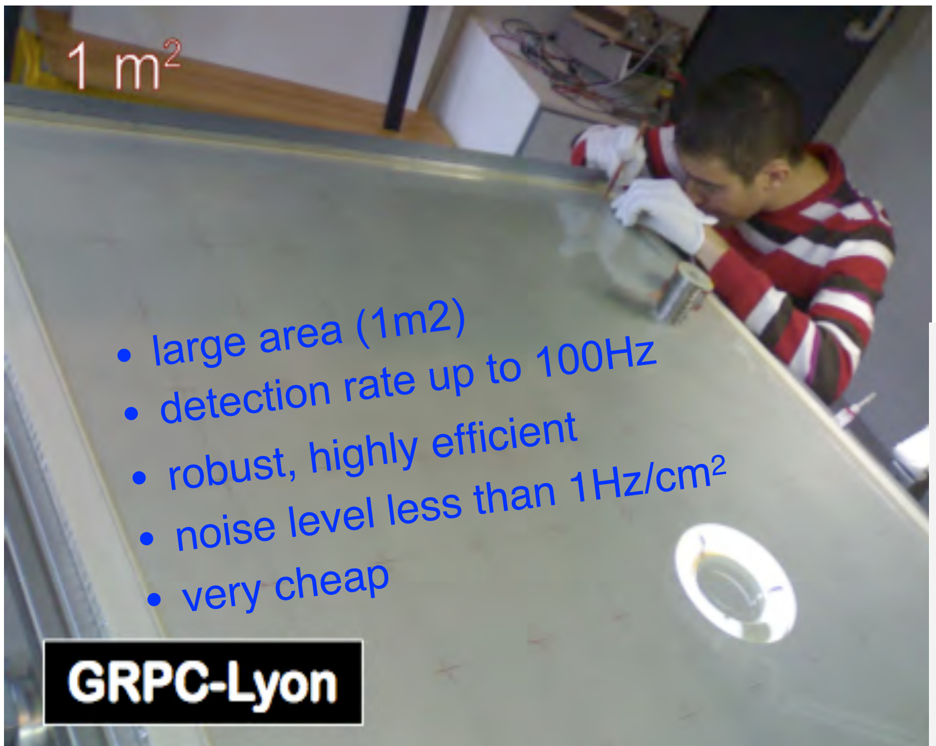
Muon Tracker : CALICE GRPC's

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

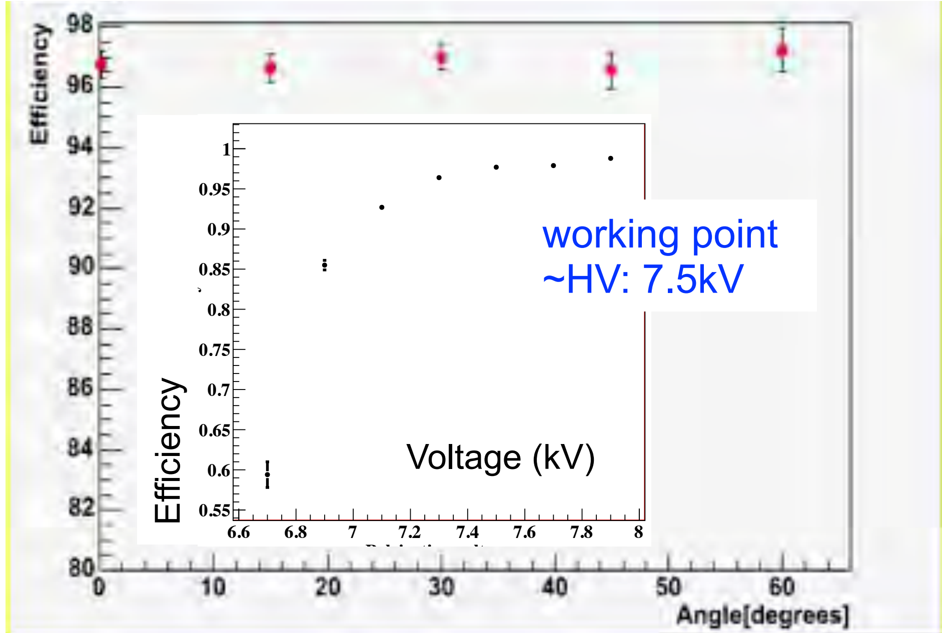


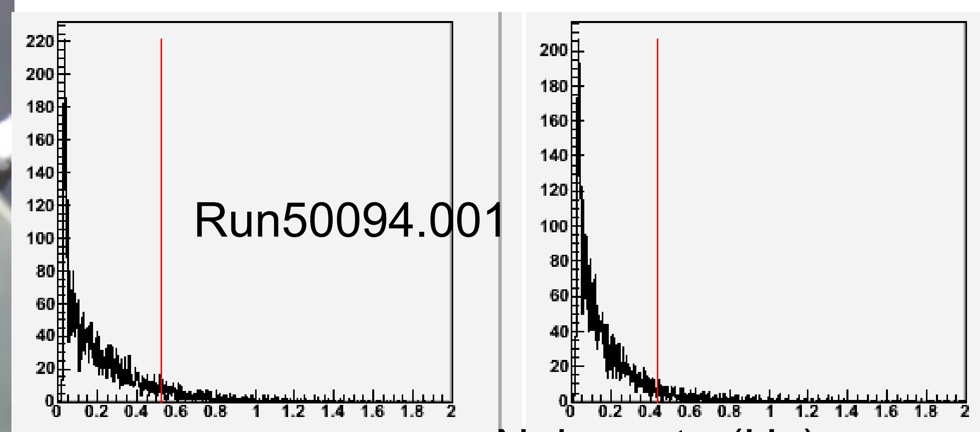
Gas: 93% TFE, 5% Isobutane, 2% SF_6

See Lei Xia's talk in the "Detector R&D" session

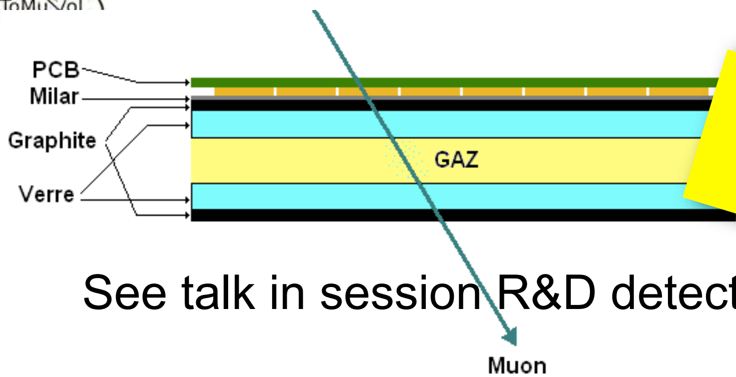


Efficiency vs. HV & track incident angle





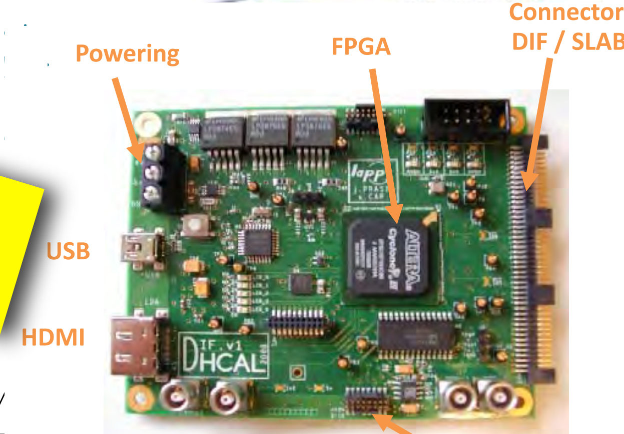
Muon Tracker : CALICE VFE & FE Electronics

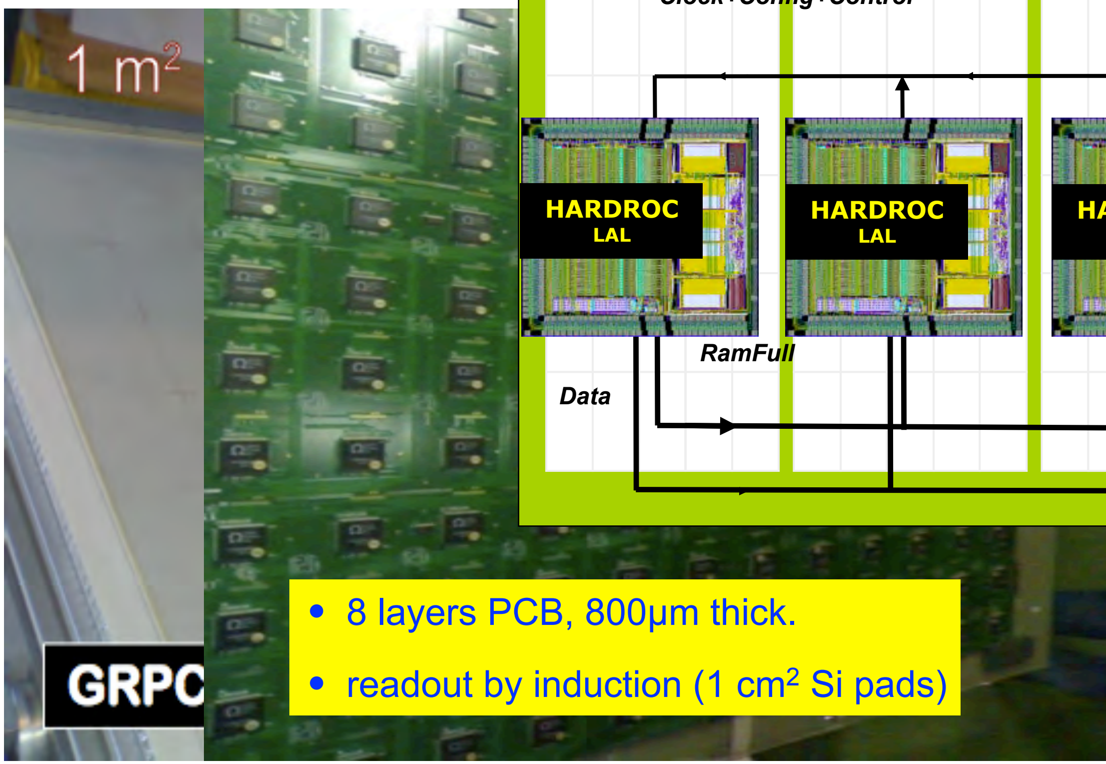


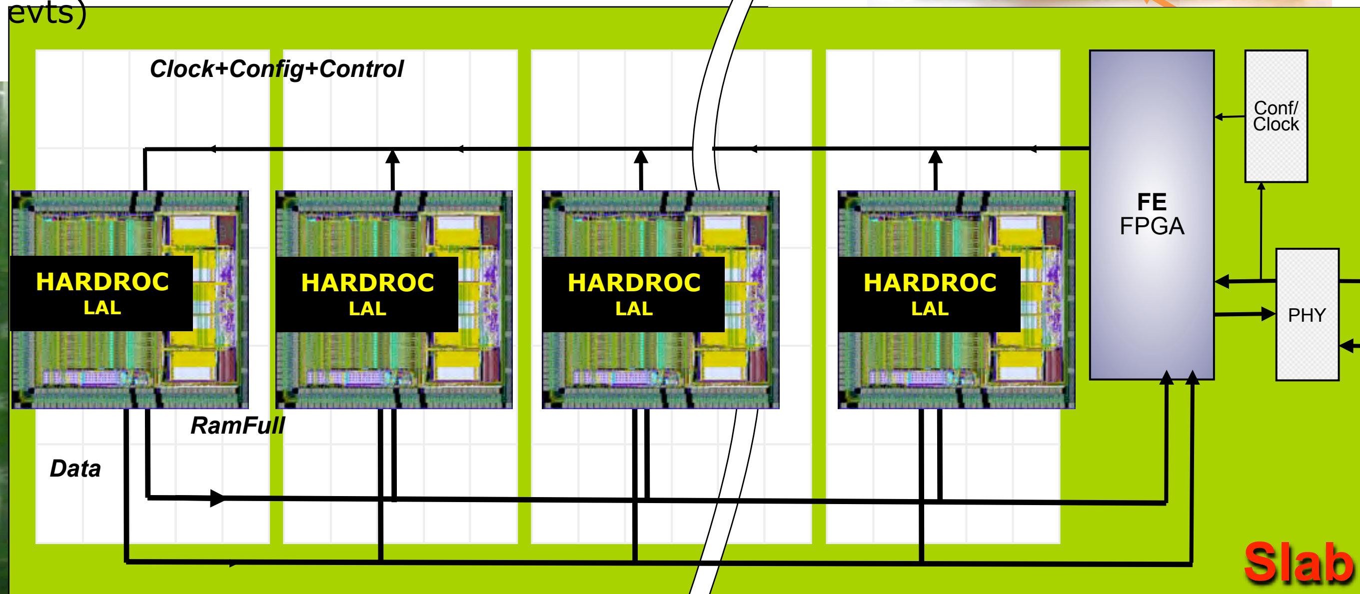
9472 channels/m2
1 hit ≡ time + thresh

See talk in session R&D detector

System clocked @ 200ns
Adjustable periodical trigger emptying the ASIC digital memories (up to 128 evts successive evts)







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

Jan 5 -April 4th, May 3rd-July 13th : prototype detector

secure network @ Taillerie → dedicated server @ LPC
- remote detector control through web interface + env monitoring

Mon compte Exporter les données Déconnexion

Switch #1 on | Switch #1 off | alimentation LV, alimenté

Switch #2 on | Switch #2 off | mélangeur gaz, alimenté

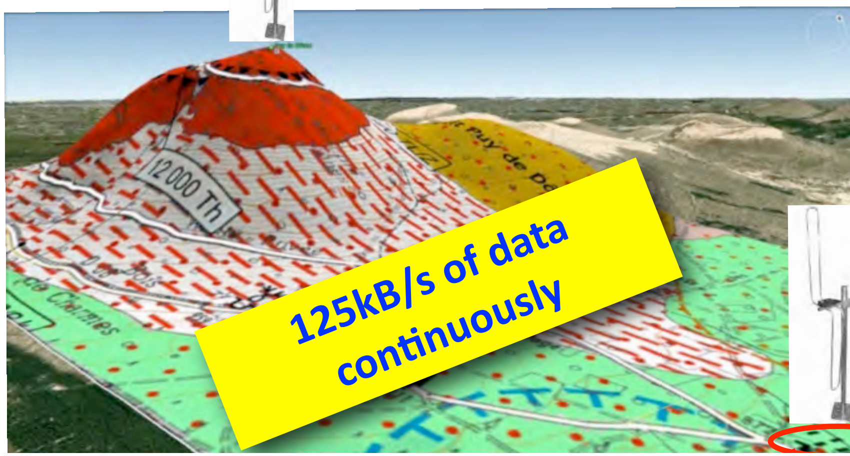
⚠ L'action switch ON doit être accompagnée d'une intervention sur site.

- S'assurer que la HV est en marche,
- Mettre l'interlock du gaz sur OFF,
- Actionner le bouton ARRET puis MARCHE du mélangeur,
- Mettre l'interlock du gaz sur ON.

Switch #3 on | Switch #3 off | alimentation HV, alimenté

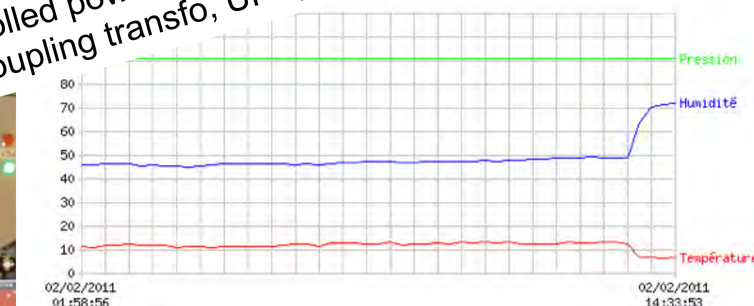
⚠ L'action switch ON doit être accompagnée d'une intervention sur site pour chacune des voies 27, 29 et 31.

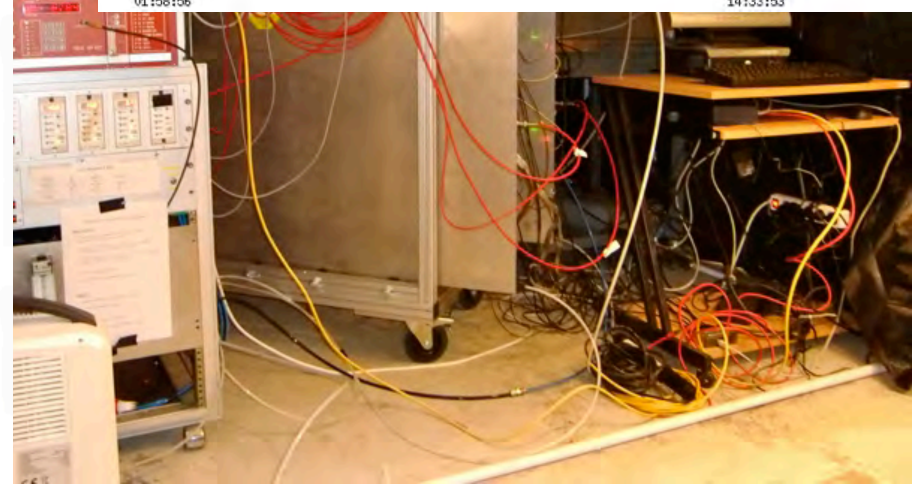
Dernière valeurs obtenues le ... 11 à 14:38:34

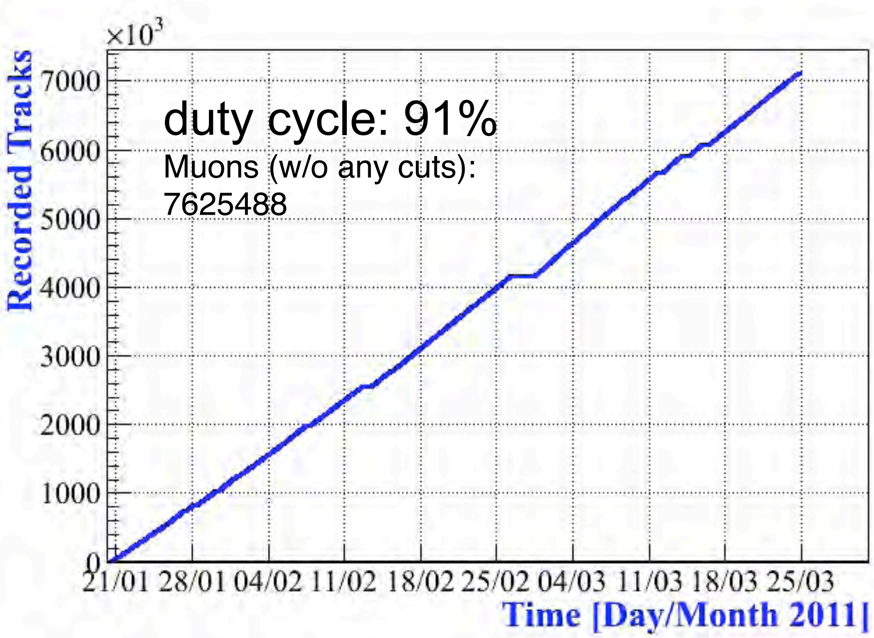


125kB/s of data continuously

Secure, remotely controlled power panel (decoupling transfo, UPS)



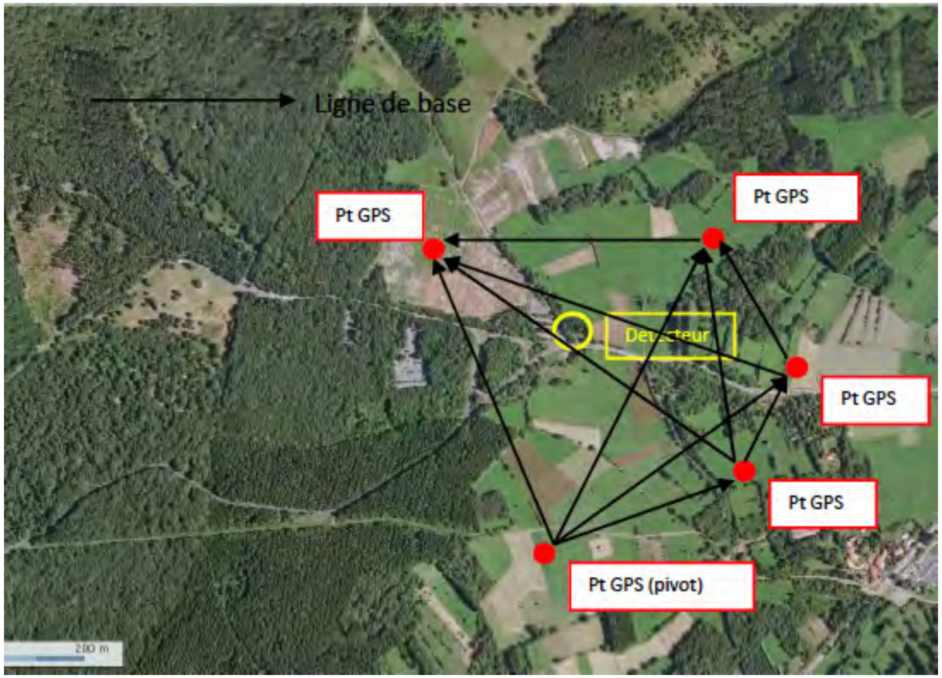




duty cycle: 91%

Muons (w/o any cuts): 7625488

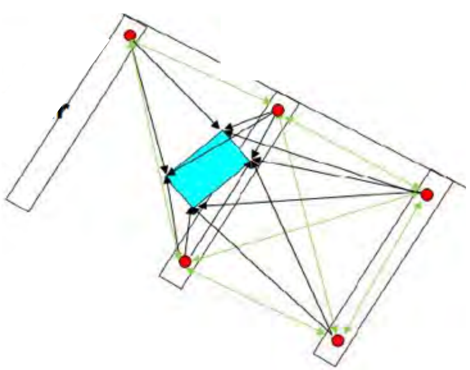
Detector positioning

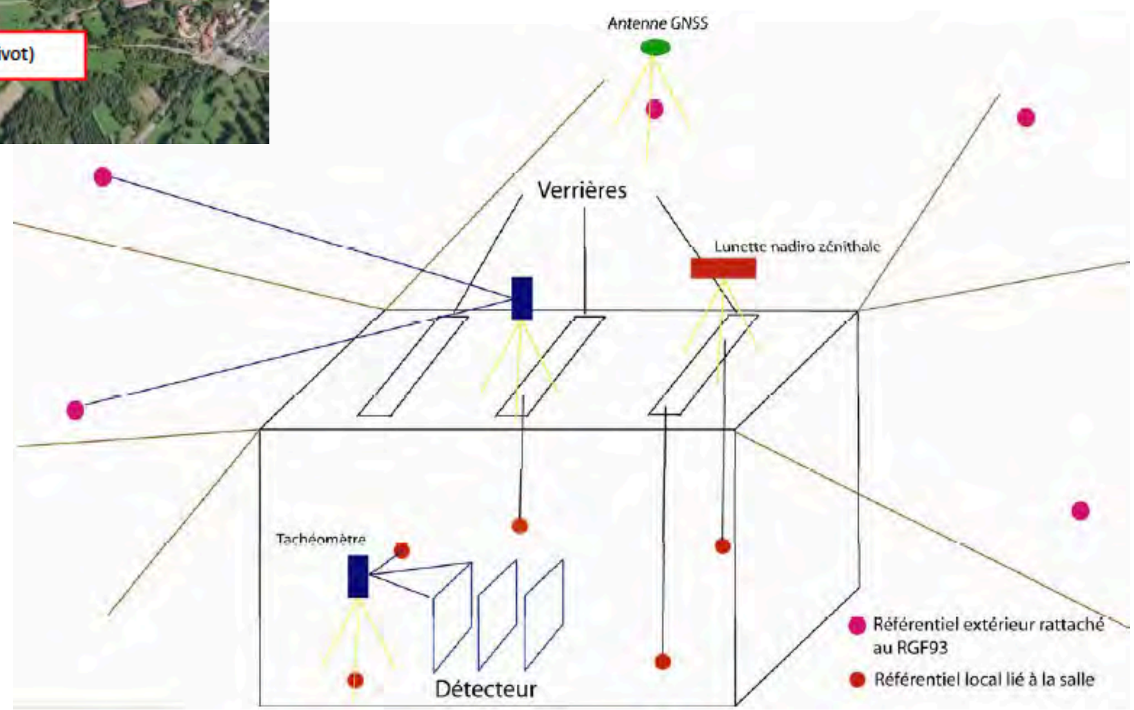


Detector alignment w.r.t target

- GNSS and tacheometric measurements on surface and on detector

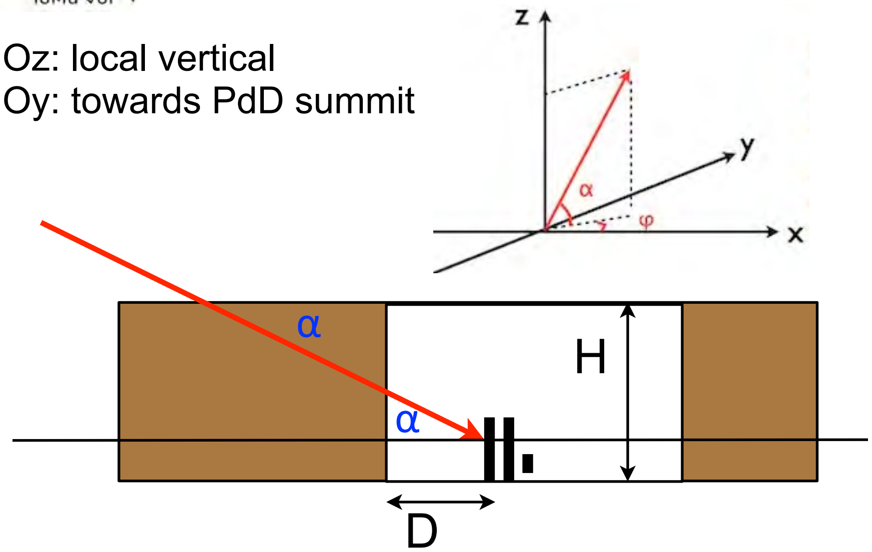
Accuracy better than 5mm

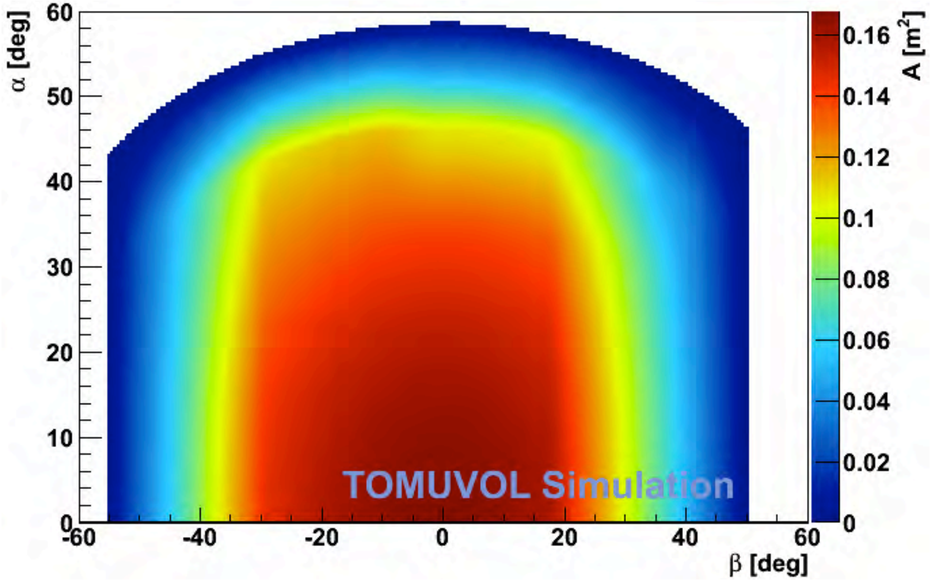




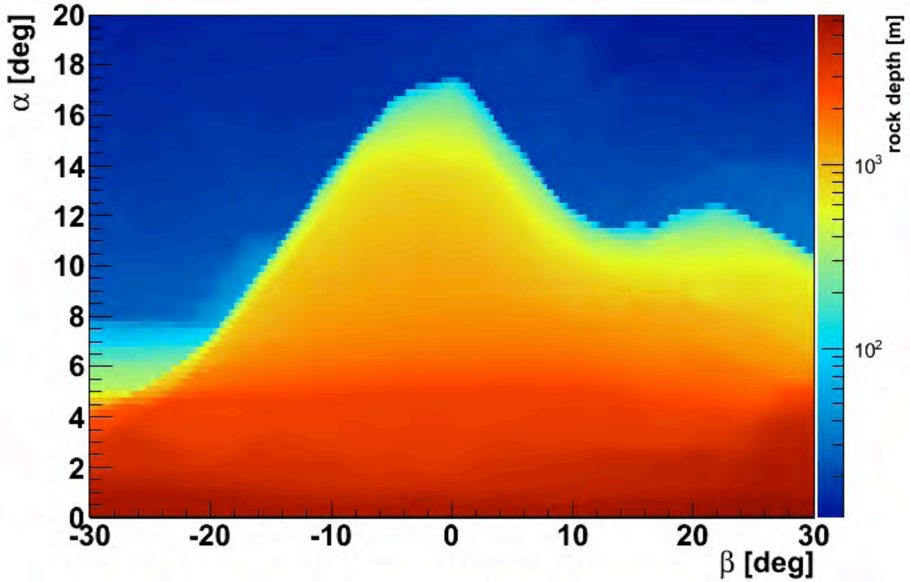
Some site & detector characteristics

Oz: local vertical
Oy: towards PdD summit

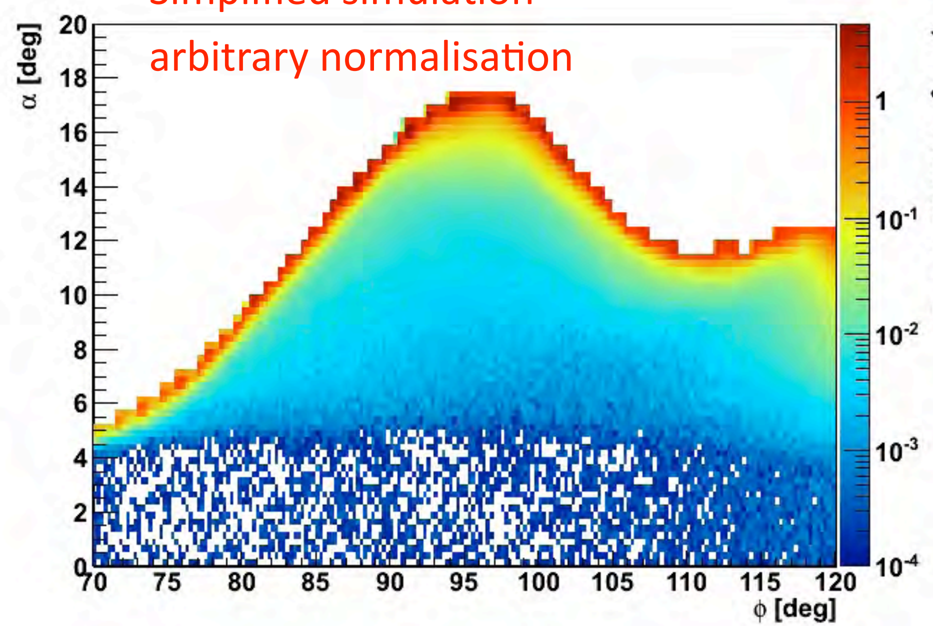




Detector threshold : 4 to 10 GeV
depending on the direction

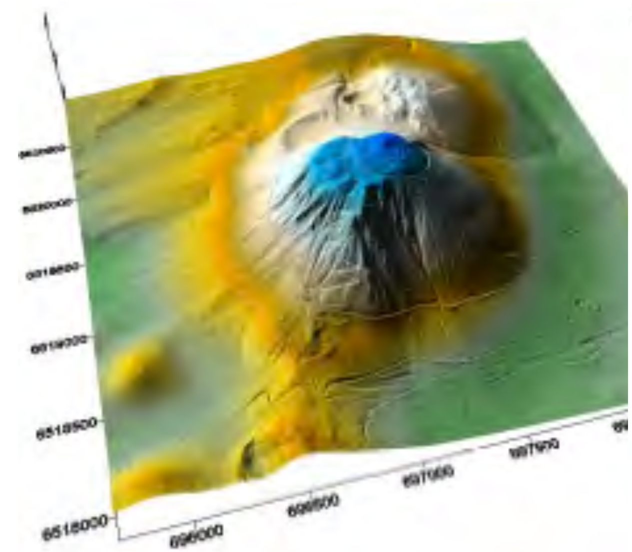


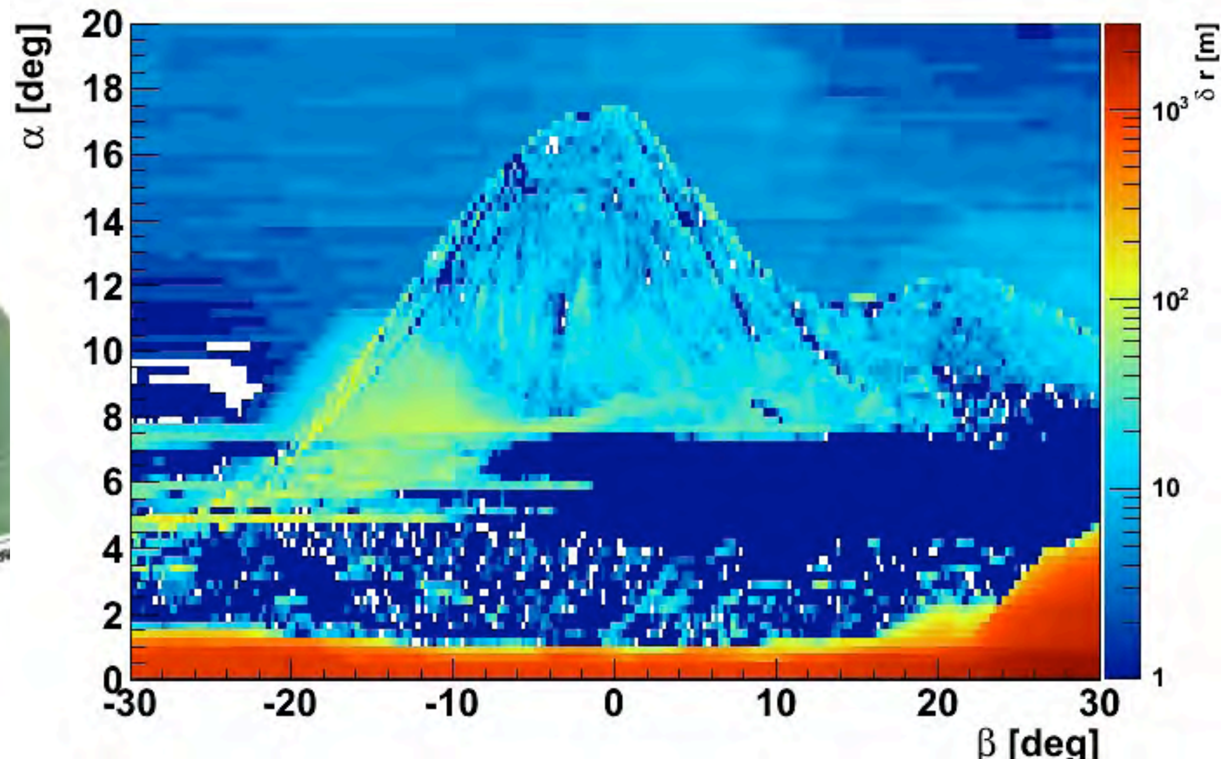
Simplified simulation
arbitrary normalisation



Puy de Dome Topography

- 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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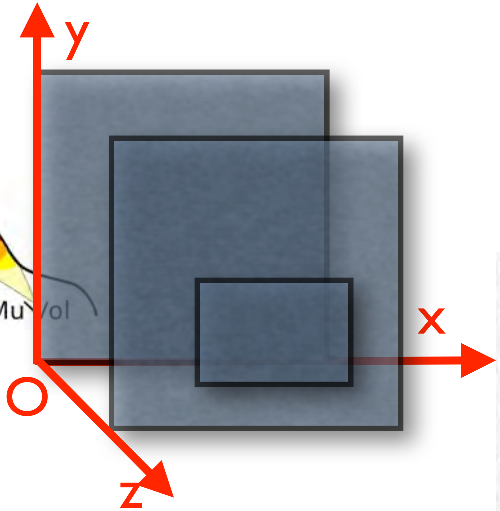
Moulins Communauté Ensemble, construisons notre avenir
Montluçon COMMUNAUTÉ D'AGGLOMÉRATION
Vichy Val d'Allier

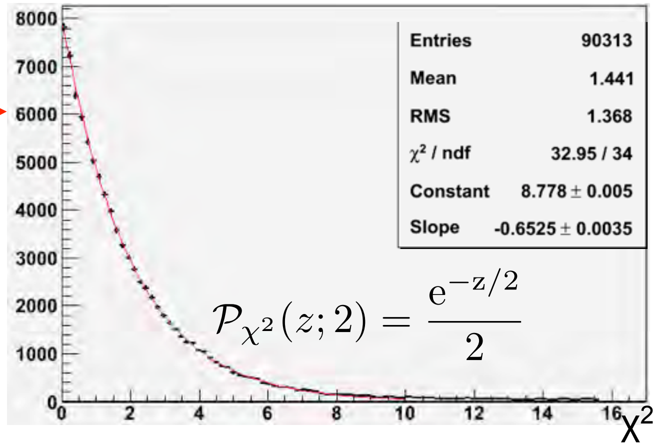
Chamber Inter-alignment & Track Fit

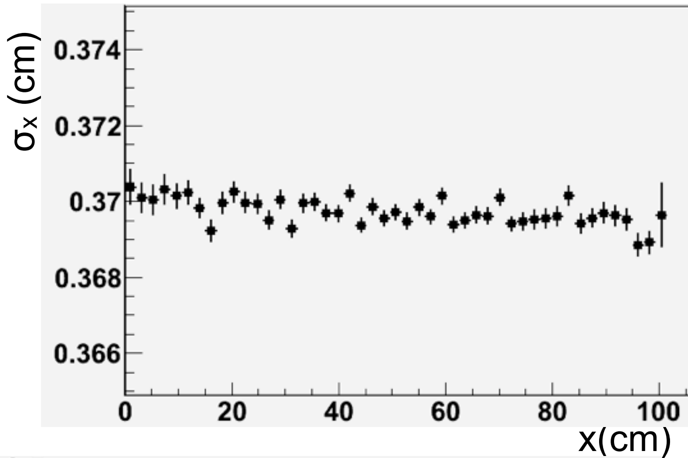


Track reconstruction

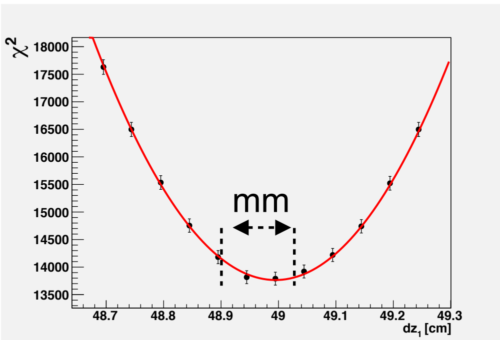
Clusterise the coincident hits in the three chambers

Analytically minimise χ^2 w.r.t. 4 track parameters using the 3 cluster barycentres

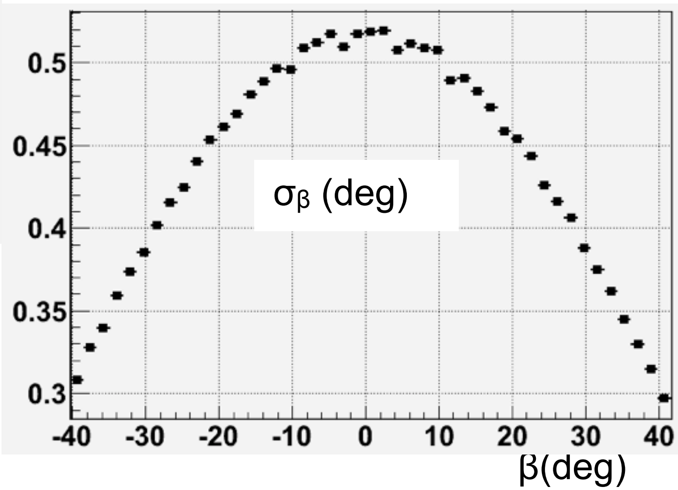


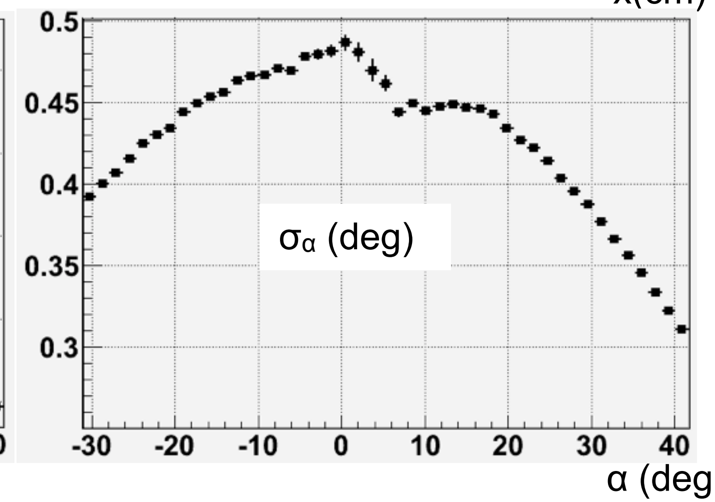


Detector inter-alignment

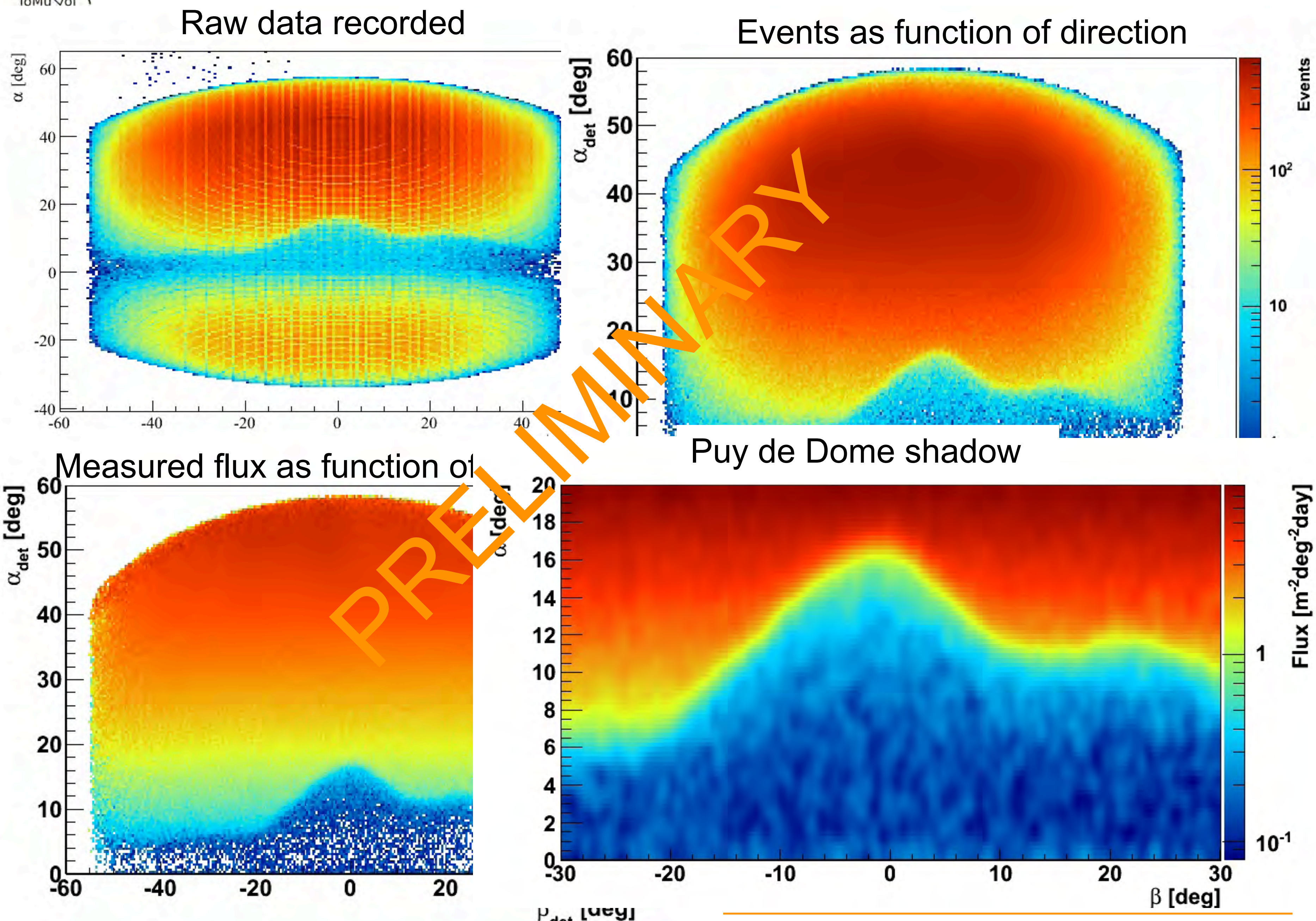


Track χ^2 optimal when detector well aligned





The very first data



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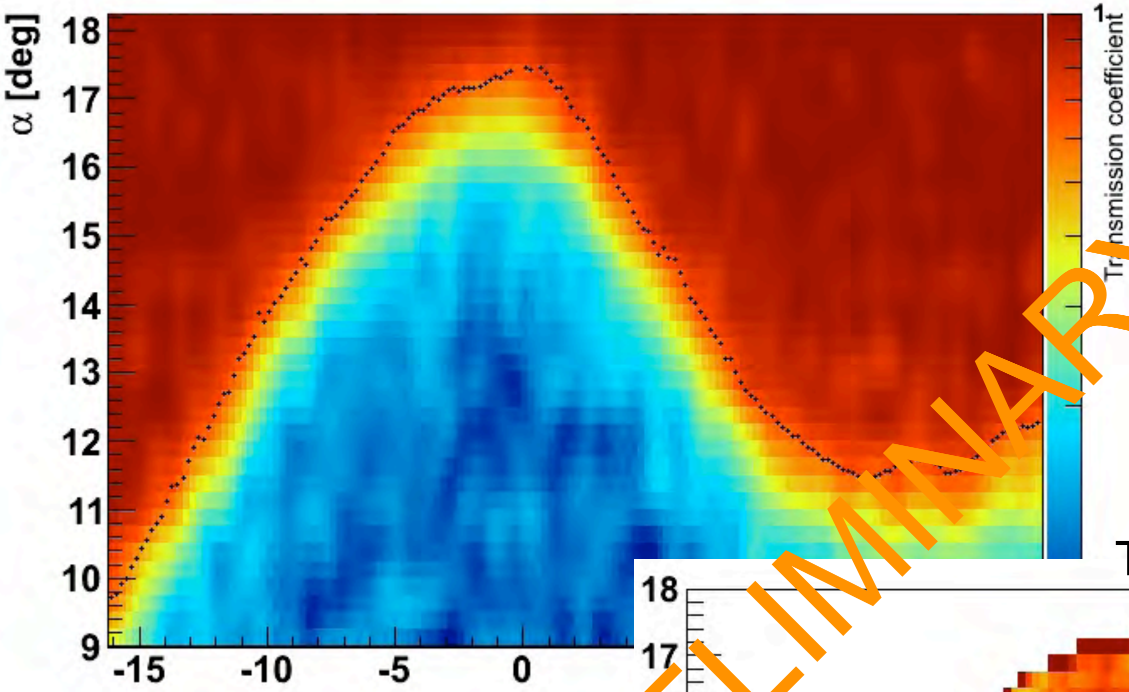
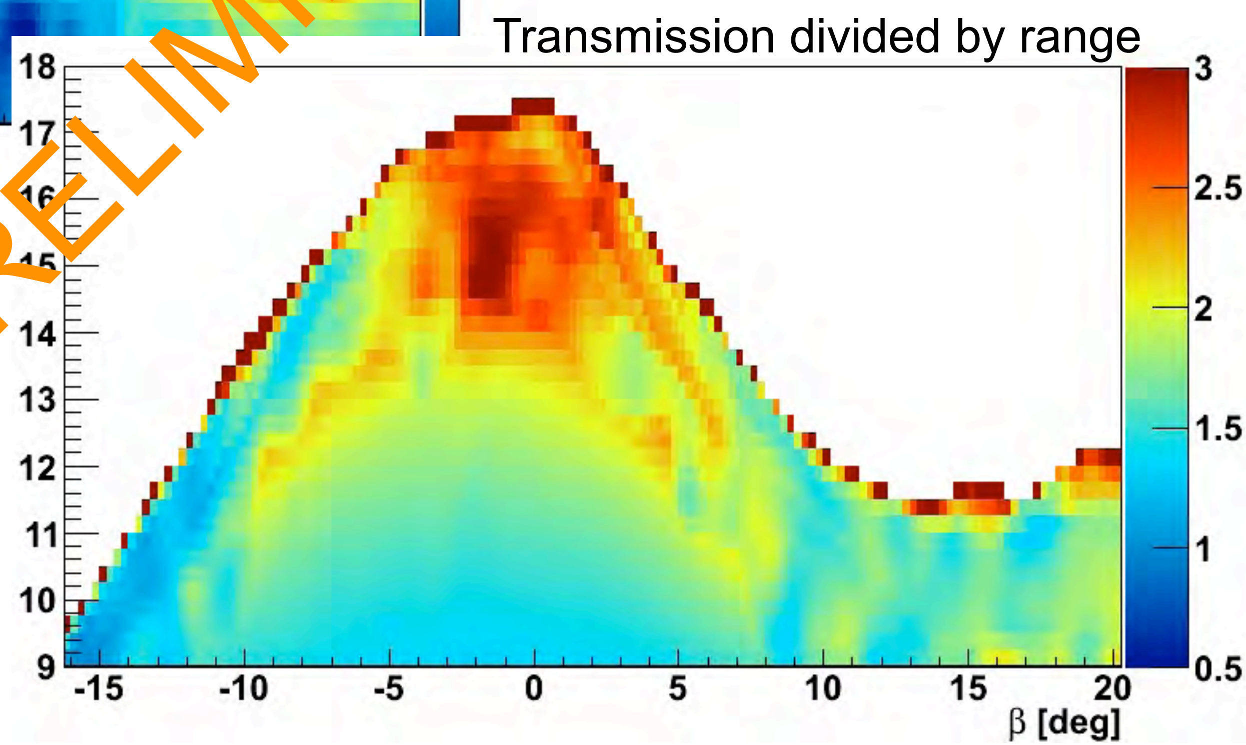


$\Phi_f/\Phi_0(\alpha) = \Im(\alpha,\beta)$

$\Im(\alpha,\beta) \sim R(\alpha,\beta)*\rho(\alpha,\beta)$



Conclusion

Detector functioning very well in an out-of-laboratory environment

First data confirm the potential of the method

... time to go in a more appropriate (physics viewpoint) site, ie closer to the target)

... time for heavy work on flux and detector simulation to fully exploit the potential of the radiography

Present + new experimental site (col de Ceyssat) provide two planar images

start to think about muon tomography!