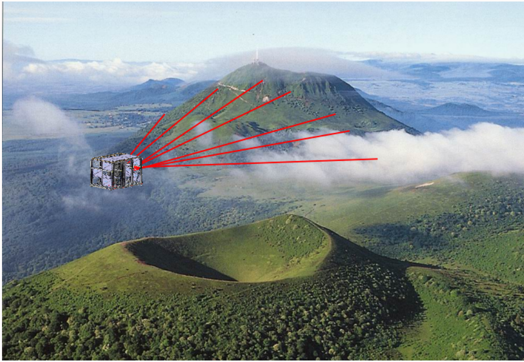
RPC application in muography and specific developments

Eve Le Ménédeu (LPC)
on behalf of the TOMUVOL collaboration

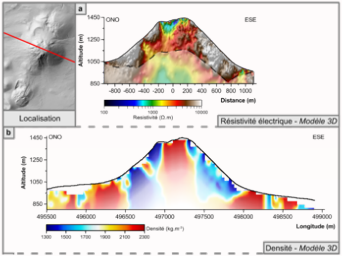


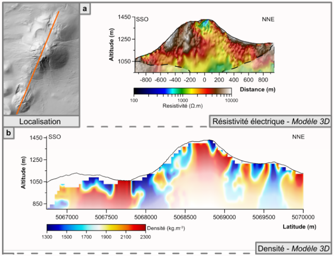
RPC 2016 conference
21-26 February 2016, Gent

Outline

Imaging volcanoes

- Goals: volcanic hazard mitigation, prediction of their future behaviour from internal structure and past activity
- Several methods are usually used to study the inner structure of volcanoes:
  - electrical resistivity tomography → (fluids, alteration, nature of rocks)
  - gravimetry → density
  - magnetization → local variation of magnetic field induced by rocks
  - seismic tomographies → elasticity and seismic waves velocity
- Difficult to access large depth, complex, ill-posed inverse problem and usually on the volcano itself (resistivity and gravimetry)

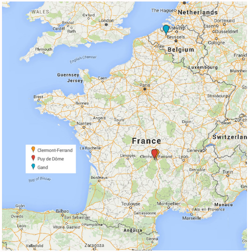


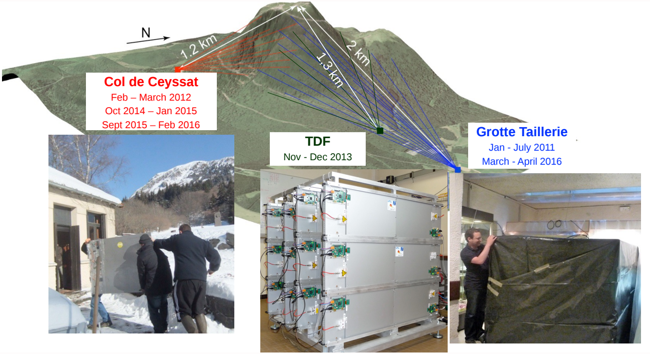


Ref: Portal et al., 2015, JVGR, submitted

Tomuvol experiment

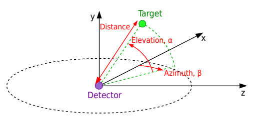
- Goal: Proof of principle for imaging volcanoes with atmospheric muons (muography) using the Puy de Dôme volcano.
- Collaboration: LPC, LMV, IPNL, ESGT
- Steps
  - 2011-2012: Preliminary campaigns with CALICE GRPCs
  - 2012: Building and commissionning a dedicated detector
  - 2013-2016: Data-taking campaigns with the Tomuvol chambers on Puy de Dôme

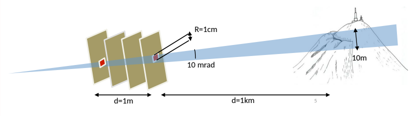


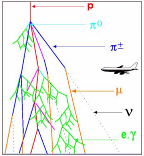


Muography

- Principle same as for radiography: a radiation passes through a target and we build a 2D image from its transmittance
- As target is huge (volcano) → use atmospheric muons
  - Cross kms before decaying
  - Large energy spectrum: 100 MeV → PeV
  - Simple trackers and no direct measurement of incoming flux





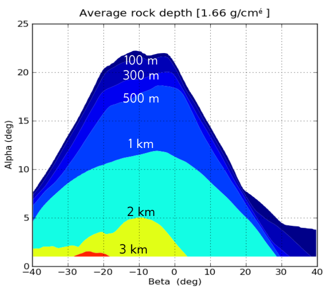


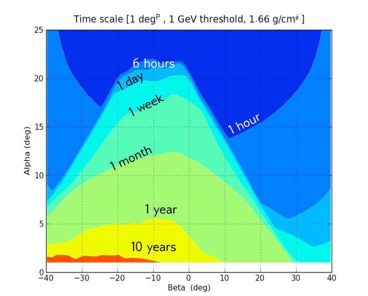
$$\mathcal{T}_\rho(\alpha, r(\alpha,\beta)) = \frac{\phi(\alpha, r(\alpha,\beta))}{\phi_0(\alpha)} \qquad \text{with} \qquad \int \rho(\alpha,\beta)dr = \mathcal{F}(\mathcal{T}_\rho)$$

ρ: density to be determined through integrated density over a direction where $\mathcal{F}$ is a bijection (unique solution)

- Advantages:
  - Complementary to other, already existing, methods
  - Remote imaging
  - Good spatial resolution; well-defined inverse problem
- But (very) high energy muons are rare, in particular for the interesting directions

Objectives





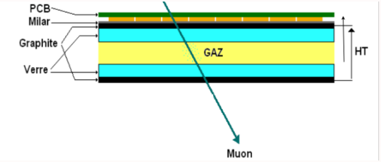
- If high resolution wanted, high exposure ($S_{det} \times Time$) needed
- Possible compromise between density resolution and angular resolution depending on physics goal
- Gaseous detectors: reasonable price for large areas

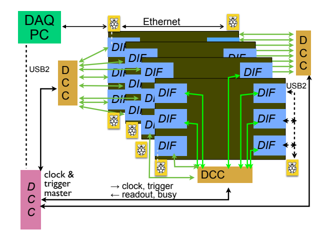
Tomuvol detector

Highly segmented tracker without energy measurement and particle identification capabilities

Tomuvol detector

- 4 layers of 6 GRPCs made at IPNL, following CALICE SDHCAL GRPCs
  - 1 layer $\sim$ 1 m^2
  - readout cells of 1 cm^2 ($\sim$ 40000 cells)
  - 1.2 mm gap
  - Gas: 93.0% $C_2H_2F_4$, 5.5% C_4H_{10} and 1.5% SF_6
  - Nominal HV: $\sim$ 7.5 kV @ P = 1.013 hPa and T = 20 °C
- Electronics:
  - synchronous at 5 MHz, auto-triggered
  - very front end: semi-digital Hardroc2 ASICs from Omega (Palaiseau), 64 channels, low power consumption (3.5 mW/channel), 3 thresholds
  - front end: DIF board from LAPP (Annecy)
- Slow control:
  - PLC (gas, HV, LV, environmental conditions)
  - remotely monitored from web interface



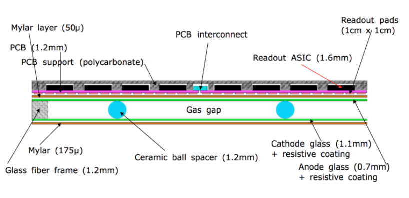


Zoom on GRPCs

1st try with GRPCs from CALICE collaboration for SDHCAL before customization

CALICE SDHCAL GRPCs

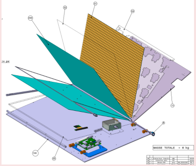
- 1 m^2 chambers
- 6 PCB of 50 $\times$ 33 cm^2
- Float glass: 0.7 and 1.1 mm
- Independent gas circuit
- 1 DIF for 2 PCB
- Iron cassette

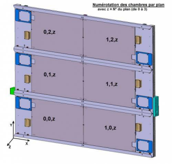


Ref: Beaulieu et al., JINST 10 (2015) 10, P10039

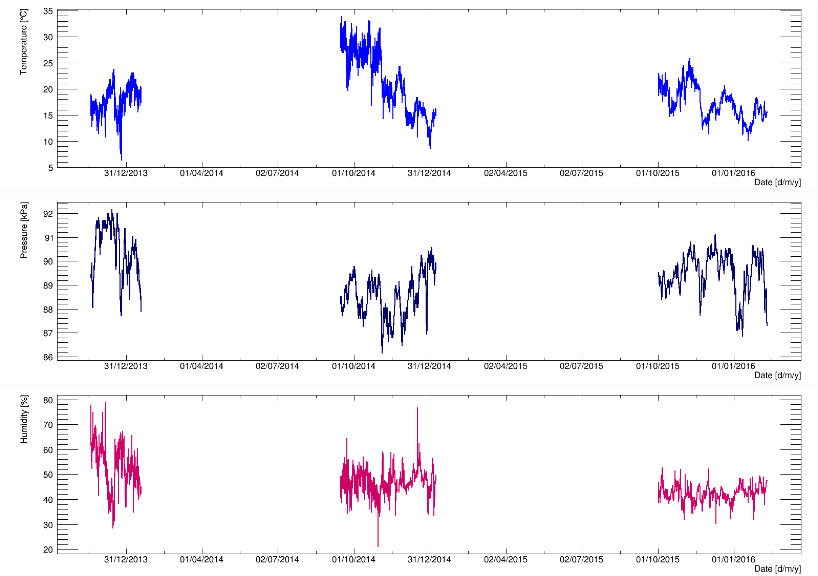
TOMUVOL GRPCs

- 50 $\times$ 33 cm^2 chambers following the existing PCB geometry
- 1 PCB of 50 $\times$ 33 cm^2 per chamber
- Float glass: 2 $\times$ 1.1 mm
- Chambers chained by 3 for gas circulation
- 1 DIF for each PCB
- Aluminium cassette

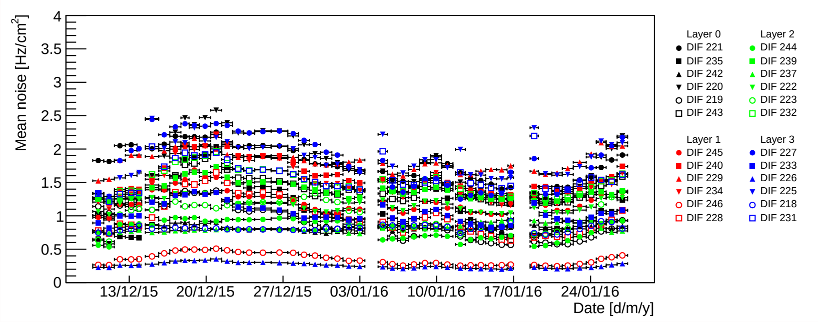


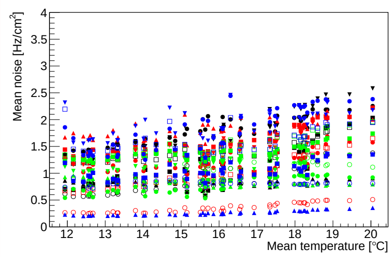


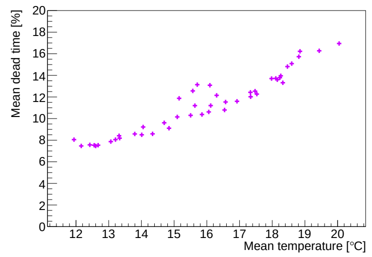
Atmospheric conditions



CDC 2015-2016: noise and dead time (1)

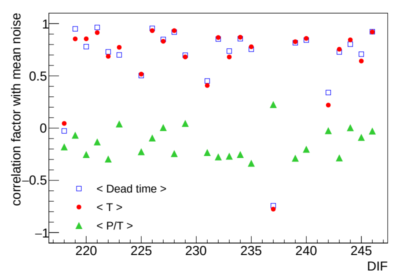






CDC 2015-2016: noise and dead time (2)

DAQ is limited by the USB protocol used for reading the FE boards → important dead time when the noise is increasing



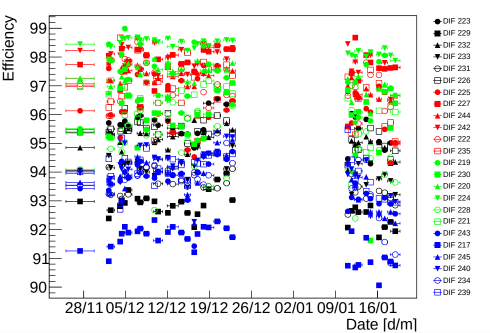
HV corrected for P/T:

$$HV_{eff} = HV \times f_{corr} \qquad \text{with} \qquad f_{corr} = \frac{P}{P_{ref}} \frac{T_{ref}}{T} \qquad (P_{ref} = 1.013\,\text{hPa},\ T_{ref} = 293.15\,\text{K})$$

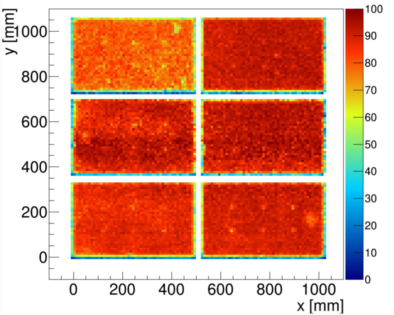
→ still a correlation with temperature.
Ethernet FE board under development

Efficiency

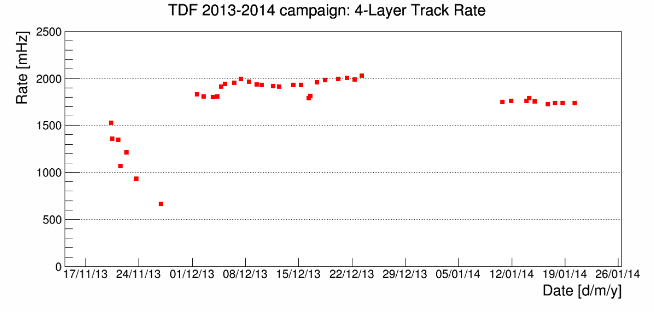
Stability of efficiency over the TDF campaign in 2013

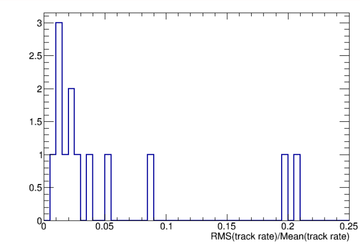


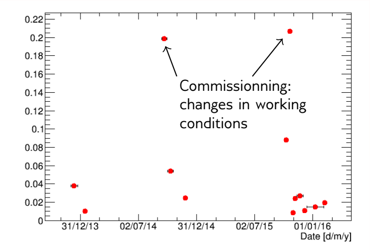
Efficiency in layer 0 during the CDC campaign in 2015 - 2016



Rates stability

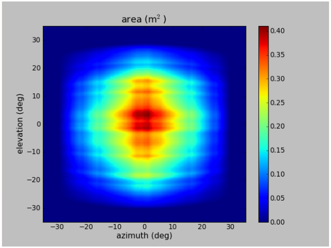


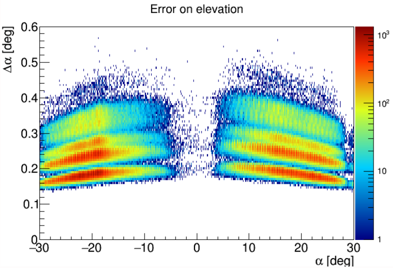




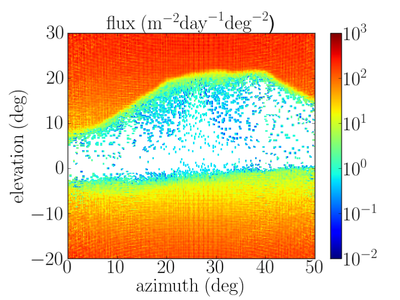
Final analysis

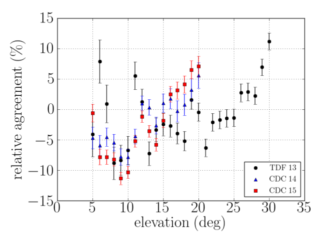
- Alignment of the detector (February 2016)
- Very preliminary results on the CDC 2015-2016 campaign



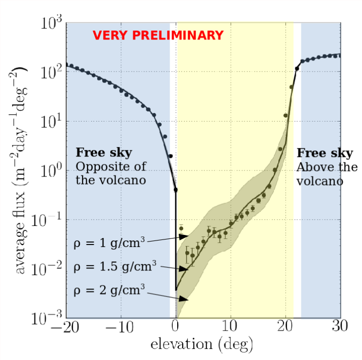


Flux through the Puy de Dôme





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

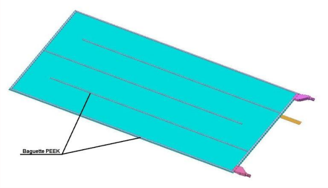


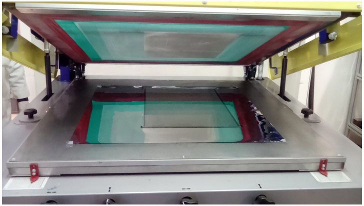
Flux integrated over β

Ref: D. Chirkin, arxiv:hep-ph/0407078

R&D for building new chambers

- Goals
  - Improving spatial and temporal resolution by factor 10 → multi-gap GRPC
  - Reducing cost, electrical consumption and complexity → readout by strips
- Glass and coated electrodes characterization (serigraphy with CEA-Saclay, AIDA 2020)
- New scheme for gas circulation and new gas inlets/outlets
- Gas tightness





Conclusion

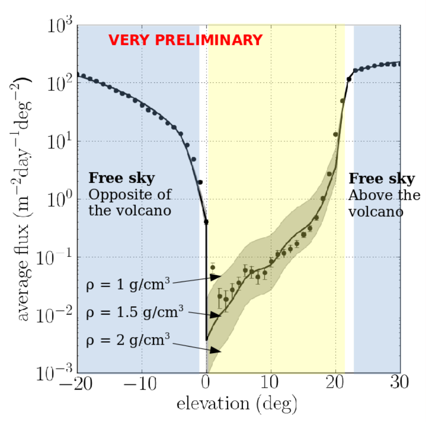
- RPC can be successfully used for muography :-)
- Sensible to atmospheric conditions $\rightarrow$ corrections
- Improvements foreseen to optimize (Multi-gap)GRPC to our application, low consumption, portability, autonomy in energy, etc.

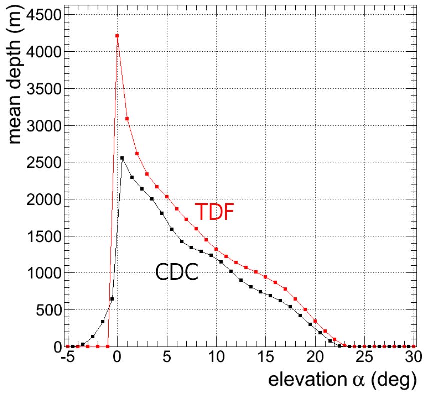
Thank you for your attention

References

- Inner structure of the Puy de Dôme volcano: cross-comparison of geophysical models (ERT, gravimetry, muon immaging), A. Portal et al, Geosci. Instrum. Method. Data Syst., 2, 47-54, 2013
- Towards a muon radiography of the Puy de Dôme, C. Cârloganu et al., Geosci. Instrum. Method. Data Syst., 2, 55-60, 2013
- Joint measurement of the atmospheric muon flux through the Puy de Dôme volcano with plastic scintillators and Resistive Plate Chambers detectors, F. Ambrosino et al., J. Geophys. Res. Solid Earth, 120, doi:10.1002/2015JB011969, 2015 (MU-RAY and TOMUVOL collaborations)

Puy de Dôme thickness





Estimation of α and β