Muon tomography of rock density using Micromegas – TPC telescope

HIVERT Fanny[1,2,3], LAZARO ROCHE Ignacio[1], BUSTO José[2], ERNENWEIN Jean-Pierre[2], BRUNNER Jürgen[2], DECITRE Jean-Baptiste[1], MARTIN Xavier[3] and GAFFET Stéphane[1,3]

Contact: hivert.fanny@lsbb.eu

[1] LSBB, University of Nice, University of Avignon, CNRS, Aix-Marseille University, OCA; Rustrel, France

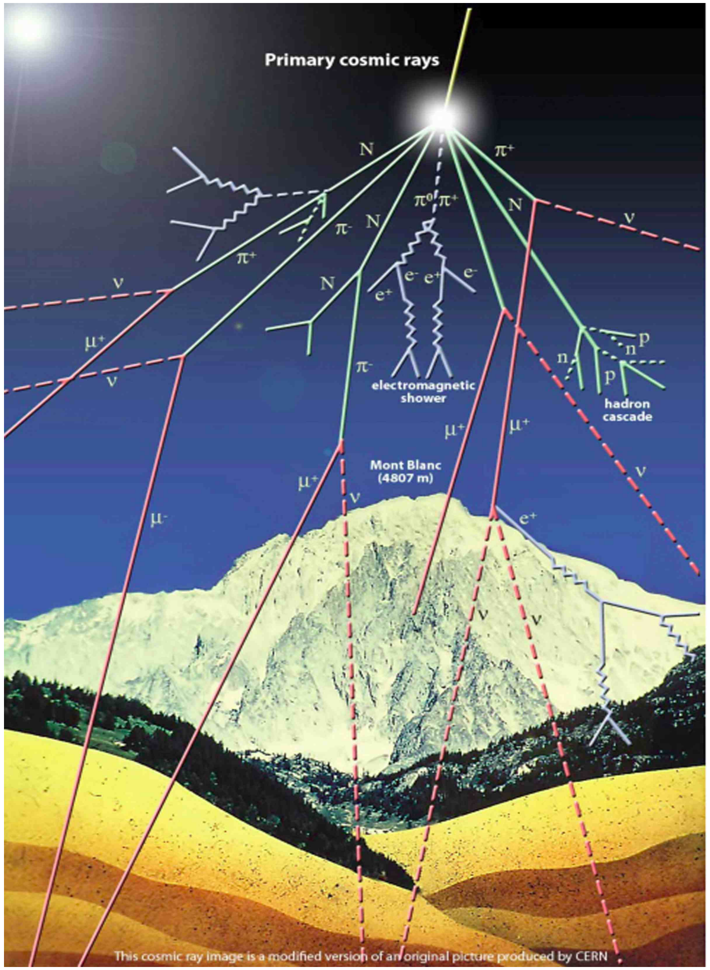
[2] CPPM, Aix-Marseille University, CNRS/IN2P3

[3] GEOAZUR, University of Nice, CNRS, IRD, OCA

Inter-Disciplinary Underground Science and Technology 2014

May 6th, 2014

Muons: from the atmosphere to the few hundred of meters of the crust



Cosmic rays showers,
Image source: CERN

➡ Muons are particles produced in the atmosphere

➡ Very penetrating for shallow depth

➡ Until few hundred of meters below surface

► *Charged particle*

► *200 times the electron mass*

► *Muon flux varies with the quantity of matter*

Multiple fields of applications

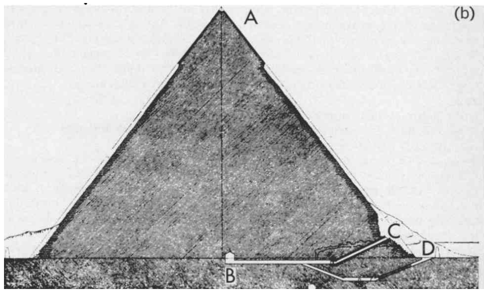
1955 -> Study of a tunnel overburden
(George, 1955)

1970 -> Archeology
(Alvarez et al., 1970)

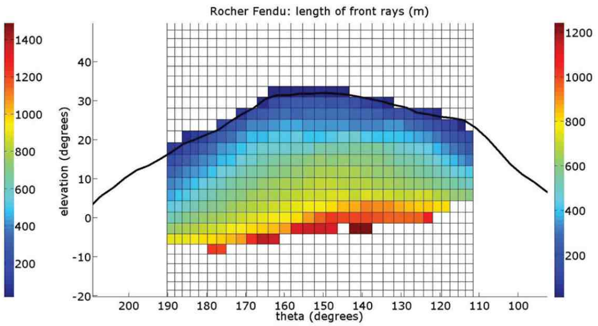
1995 -> Volcanology
(Nagamine et al., 1995; Tanaka et al., 2007)

2010's -> CO_2 storage, Mars exploration
(Kudryavtsev et al., 2012; Kedar et al., 2013)

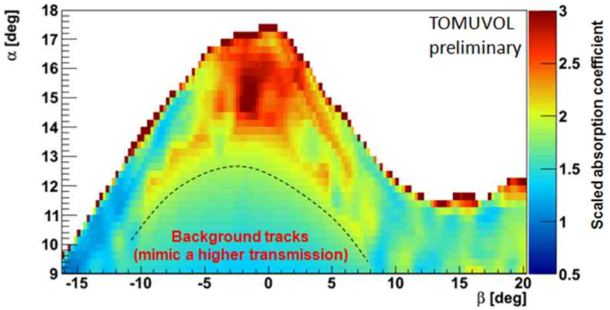
Open methodology for future applications ...



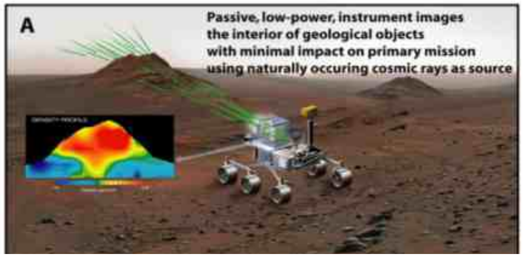
Chephren Pyramid
Alvarez et al., 1970



La Soufrière volcano,
Lesparre et al., 2012



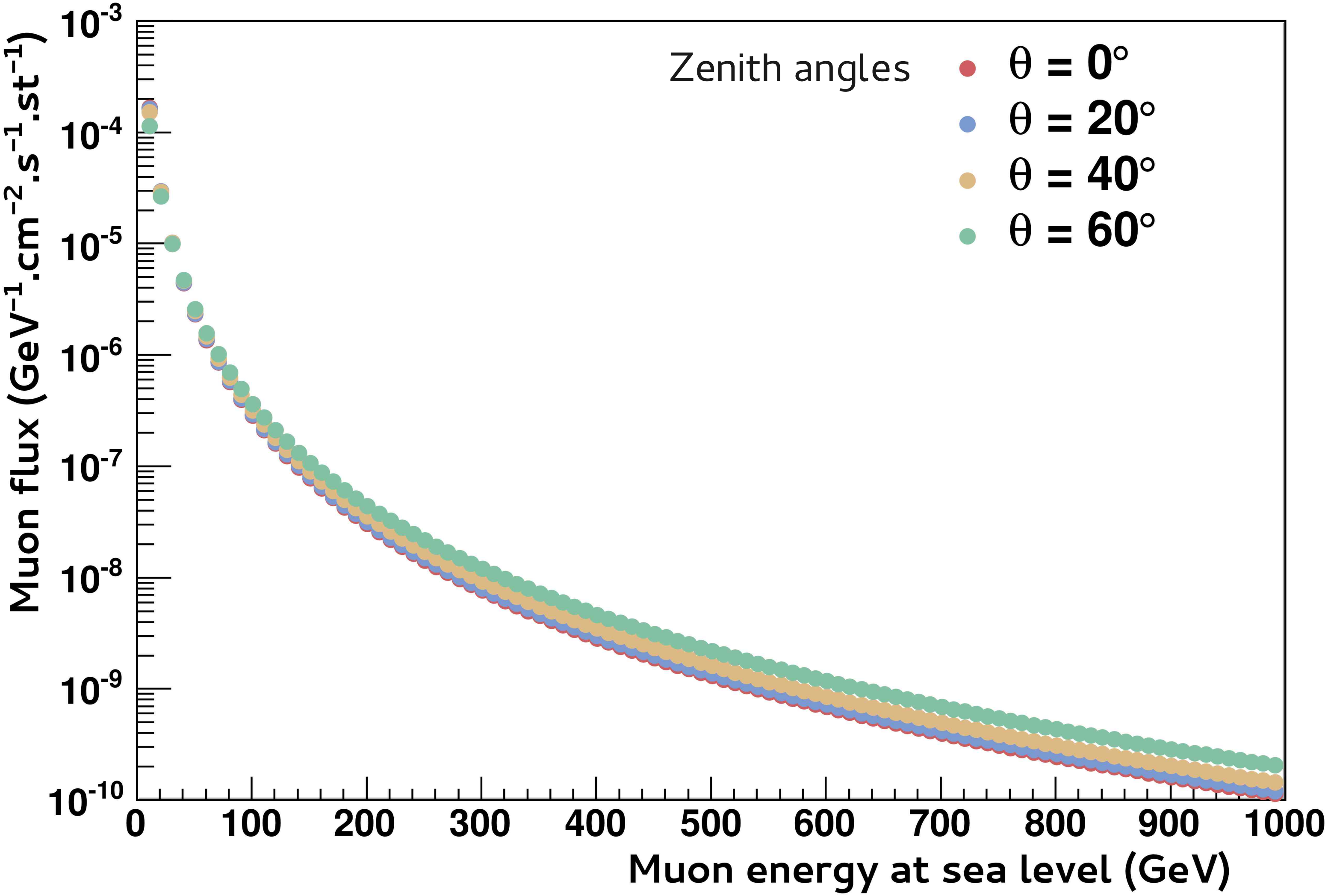
Puy de Dôme volcano,
Carloganu et al., 2013



Kedar et al., 2013

Surface muon flux

Surface muon flux calculated from Gaisser model (1990)

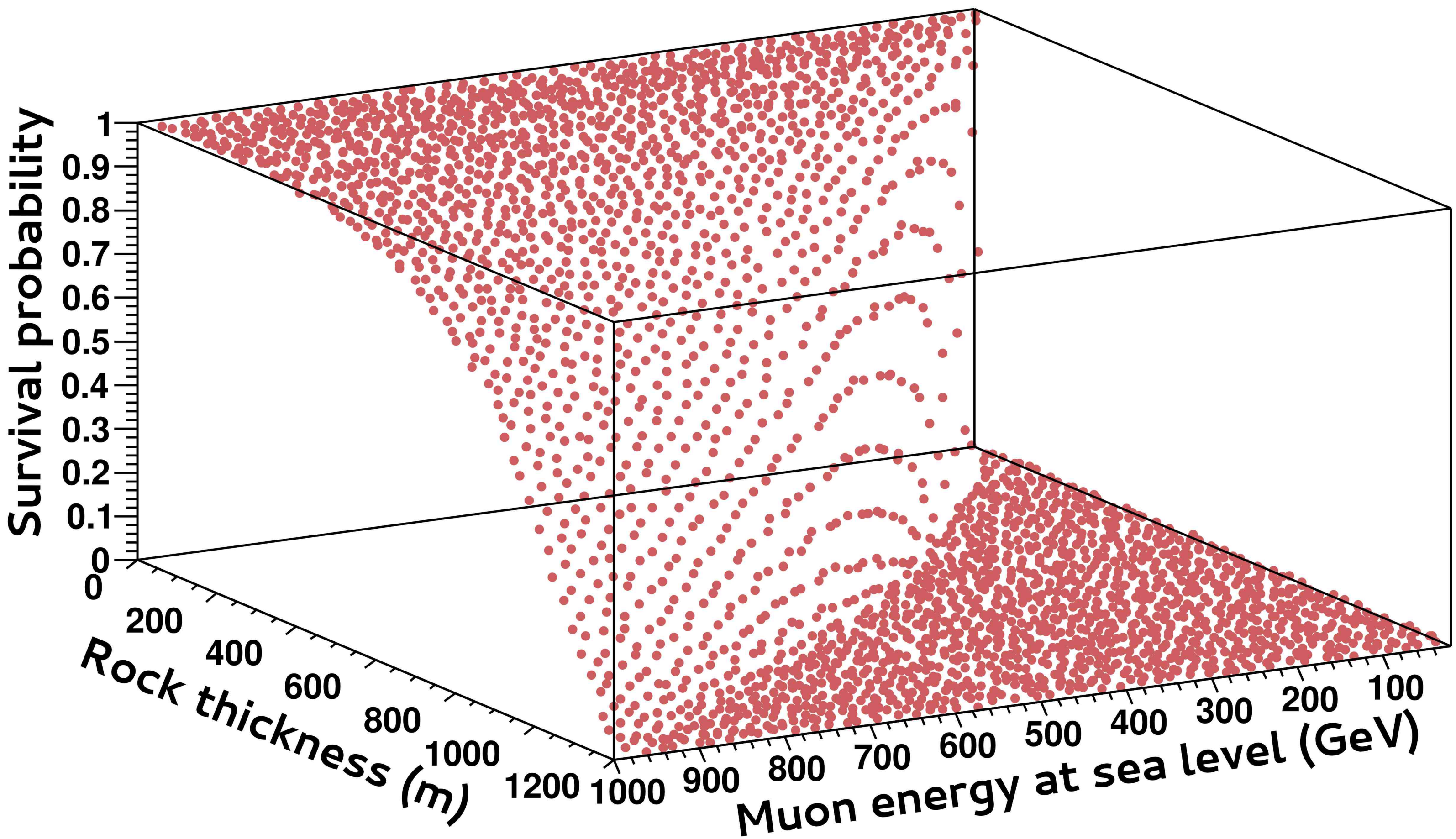


➡ The flux strongly decreases for high muon energies

➡ Slight dependence to the zenith angle

Depth muon flux

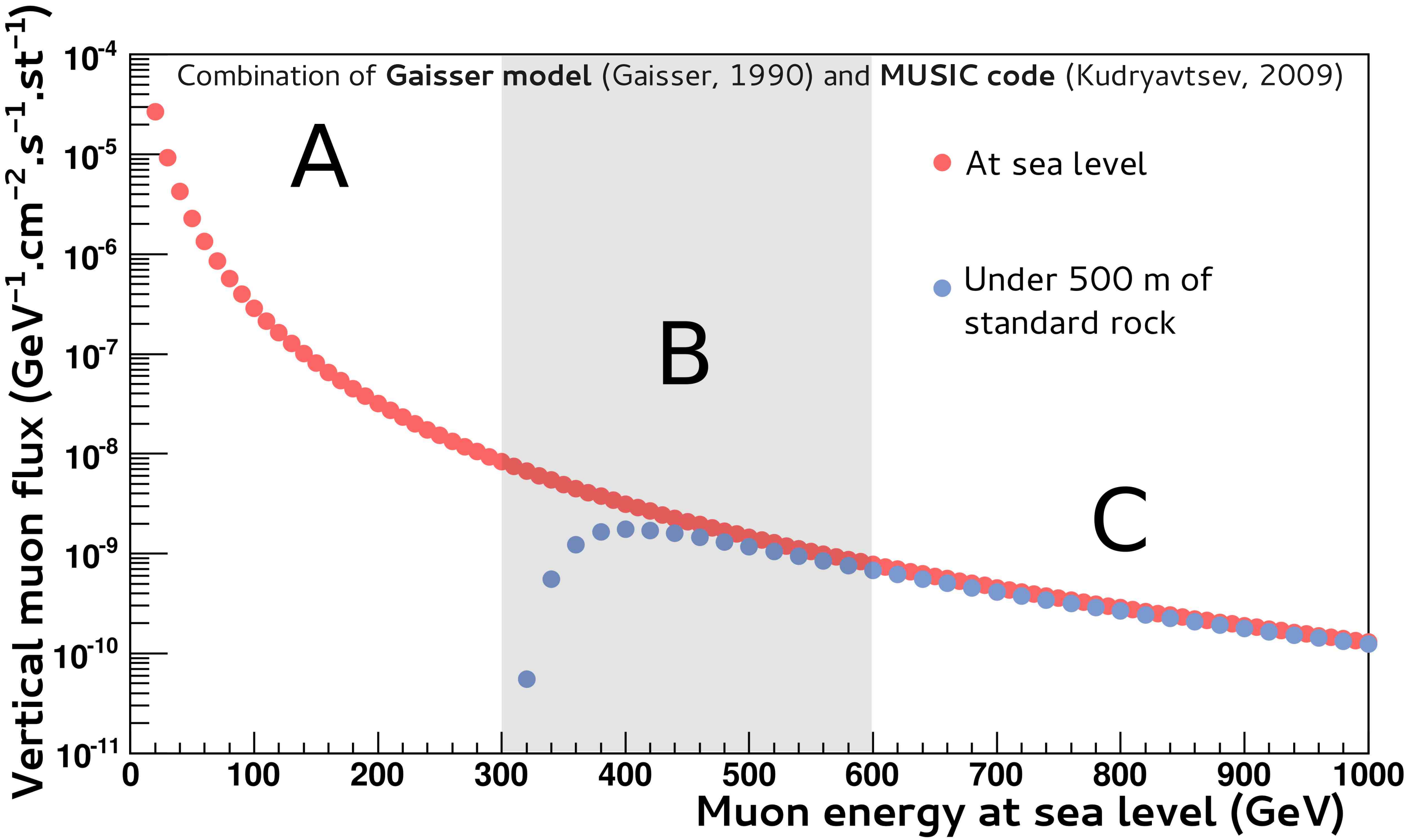
Muon survival probabilities for a standard rock density (2.65 g cm^{-3})
Simulated from MUSIC code (Kudryavtsev, 2009)



➡ Muon survival probabilities decrease with the increase of rock thickness

Vertical muon flux at sea level compared to 500 m below surface

Surface muon flux times Muon survival probabilities for a standard rock density



A ➡ Muon energies too low to pass through 500 m of rocks

B ➡ Partly reach the desired depth

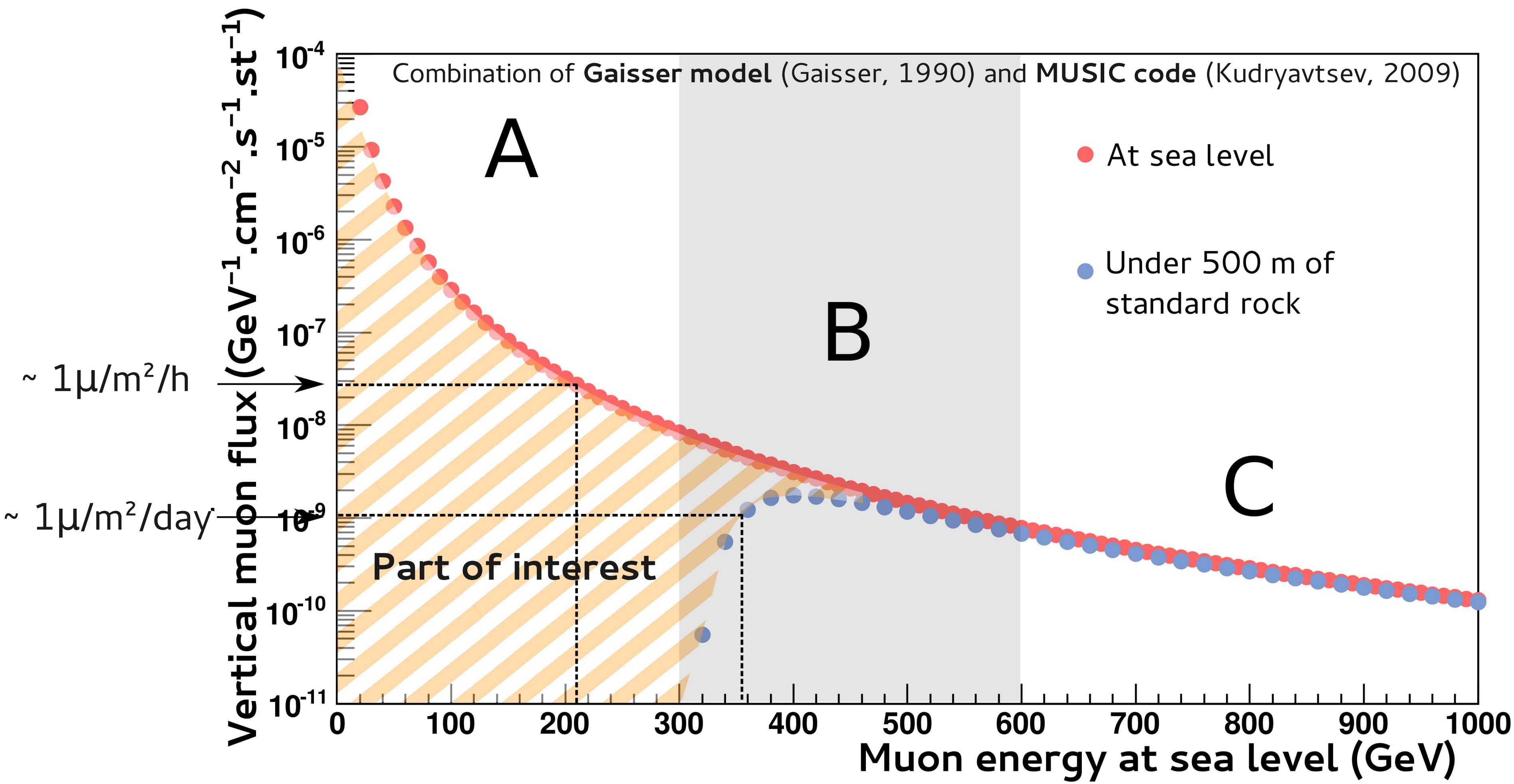
C ➡ High energy muons that almost all pass through the rock thickness

Statistic representativity of the flux measurements

Solid angle: 1 sr
half sphere ⇔ 2π sr

Vertical muon flux at sea level compared to 500 m below surface

Surface muon flux times Muon survival probabilities for a standard rock density



A ➡ Muon energies too low to pass through 500 m of rocks

B ➡ Partly reach the desired depth

C ➡ High energy muons that almost all pass through the rock thickness

A + B Muon energies of interest

Statistic representativity of the flux measurements

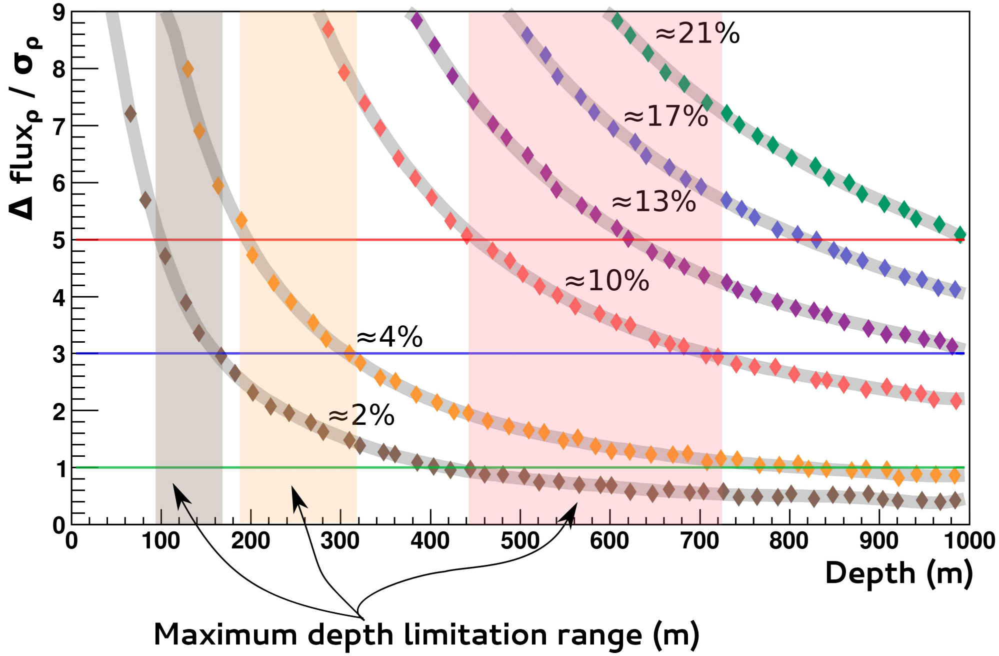
Solid angle: 1 sr
half sphere ⇔ 2π sr

Flux differences linked to rock density and rock atomic composition

➡ **Rock composition influence on muon flux is negligible compared to the density effect**

Sensitivity to density variations of rocks

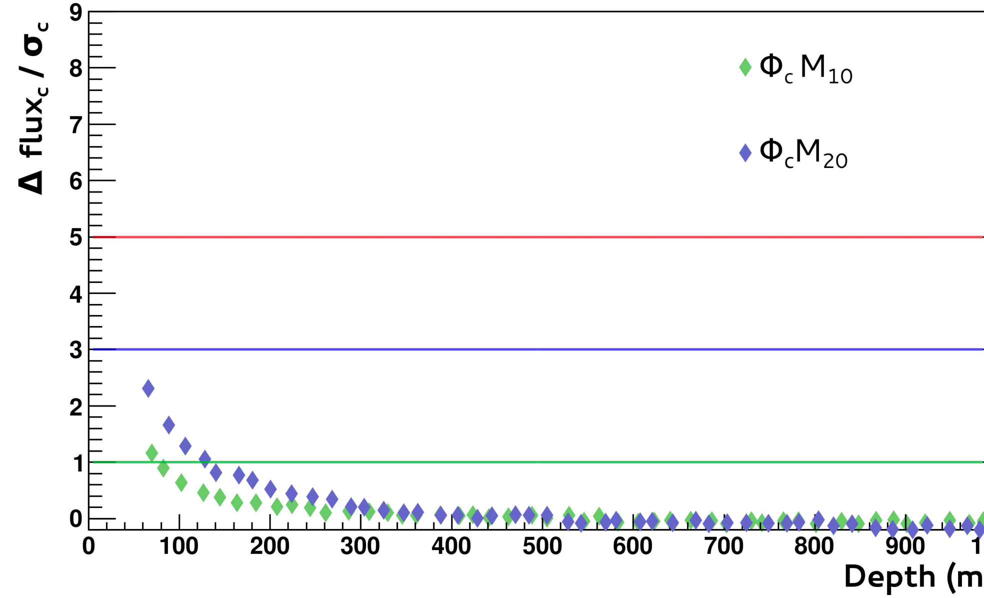
$$\Phi_\rho = \frac{\Delta(Flux_\rho)}{\sigma_\rho} = \frac{N_{standard} - N_{\Delta\rho}}{\sqrt{\sigma_{standard}{}^2 + \sigma_{\Delta\rho}{}^2}},$$



2% ➡ ~ 100 – 160 m
4% ➡ ~ 180 – 320 m
10% ➡ ~ 440 – 720 m

Unsensitivity to slight variations of the atomic composition

$$\Phi_C = \frac{\Delta(Flux_C)}{\sigma_C} = \frac{N_{dry} - N_{10/20}}{\sqrt{\sigma_{dry}{}^2 + \sigma_{10/20}{}^2}},$$



3 rock compositions with a constant density of 2.40 g cm-3

-> dry rock (Z=11.39; A=22.82): M_{dry}

-> dry rock + 10% H_2O (Z=11.66; A=23.43) : M_{10}

-> dry rock + 20% H_2O (Z=11.97; A=24.13) : M_{20}

Green line -> 1 σ; Blue l. -> 3 σ; Red l. -> 5 σ

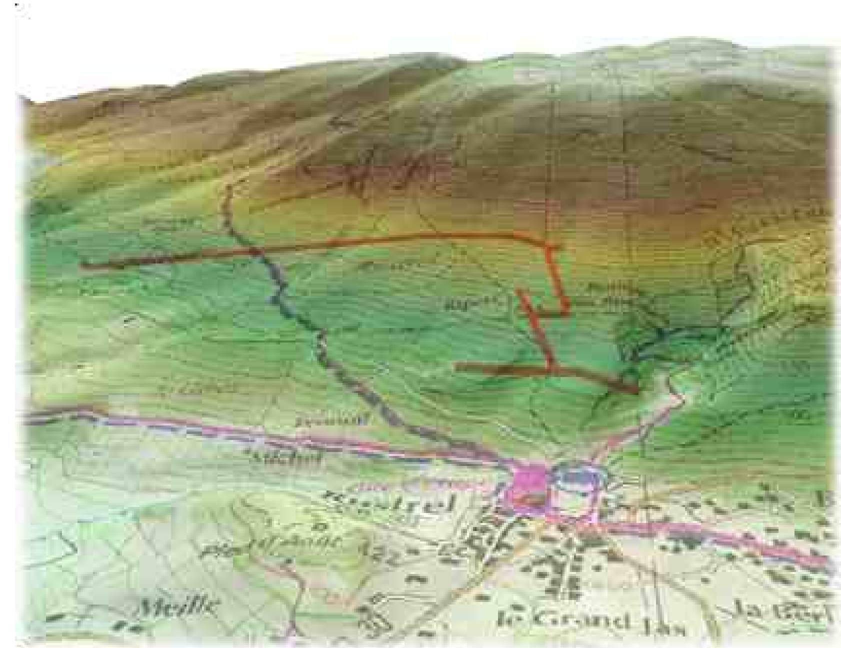
Normalization: 1month / 1m² / 10°

Test site: low noise Underground Research Laboratory (LSBB URL)

Temporal & spatial characterization of the transfer in the unsaturated zone of reservoir

www.geoportail.gouv.fr

LSBB galleries



- **Access to the unsaturated area of Fontaine de Vaucluse carbonate reservoir (LSBB URL)**
- **Depth range: 0 to 500 m**

Spatial heterogeneity of reservoir

- **Rock permeability:**
  characteristic times of transfer from days to several months
  (Garry , 2007)

- **Rock porosity:**
  from 0% to 25% (fractures and pores) *(Fournier, 2013)*
  Δρ from 0% to 10% (dry vs saturated rock)

Micromegas – TPC telescope

Observation of thin geological structures

→ Development of Micromegas – TPC (Time Projection Chambers)

Gaseous detectors
(6 detectors under construction)

→ With spatial and angular very high resolutions

- *Spatial resolution: ~ 12 μm*
- *Angular resolution (at 10 cm): ~ 0.3 mrad*
- *Time resolution: ~ 25 ns*

Conclusions and prospects

Muon tomography

➡ Suitable to image spatial and temporal density variations caused by water transfer

Micromegas – TPC detectors

➡ High resolutions to image thin geological structures

Application field is not limited to hydrogeology.

➡ Muon tomography is used in archeology, volcanology, security...
And a lot of others are expected