Portable Resistive Plate Chambers for Muography in confined environments

R.M.I.D. Gamage[1] S. Basnet[1] E. Cortina Gil[1] P. Demin[1] A. Giammanco[1] R. Karnam[1] M. Moussawi[1] A. Salaman[2] M. Tytgat[2] A. Youssef[3]

[1]Université Catholique de Louvain,Louvain-la-Neuve, Belgium

[2]Ghent University, Ghent, Belgium

[3]Lebanese University, Beirut, Lebanon

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Outline

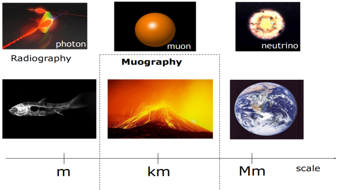
Muon Radiography

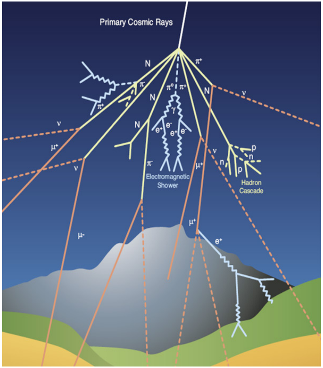
- Muon Tomography (Muography) is an imaging technique based on the absorption or scattering of the cosmic-ray mouns (μ).

Specialties of Muons

- No strong interaction.
- Produced from the collisions of cosmic rays with the upper atmosphere.
- Minimal energy loss due to ionization.
- Have a high penetration power.

Visible Scales





Cosmic Muon cascade*.

(∗) Source: CMS Knowledge Transfer, Cosmic rays

Detectors in Muography

- There are many different detectors/technologies used in Muography. Optimal choice mostly depends on the application.

Type	Surface	Resolution	Construction	Readout	Cost
Plastic Scintillators					
square bars	1-4m^2	$>$ 10 mrad	Simple	Simple	Low
Triangular bars	1-2m^2	$<$10 mrad	Simple	Medium	Medium
Scintillating Fibres	1-2m^2	0.1 mrad	Medium	Complex	High
Gaseous detectors					
Proportional tubes	1-4m^2	10 mrad	Simple	Simple	Low
Multi-wire chambers	$>$4m^2	$<$ 1 mrad	Medium	Simple	Medium
Drift Chambers	$>$4m^2	0.1 mrad	complex	Complex	High
Res. Plate Chambers	$>$10m^2	0.1 mrad	Simple	Medium	Low
Nuclear Emulsion	$>$4m^2	0.1 mrad	Simple	Complex	Low

- Resistive plate chambers (RPC) are typically chosen when large surfaces must be instrumented. However, in our project we are exploring the feasibility of Mini-RPCs for portable detectors.

Resistive plate Chambers (RPC)

The active component of a RPC is the gas mixture contained in the thin gap between two parallel plates of high resistivity. And High voltage is applied to parallel plates while operating.

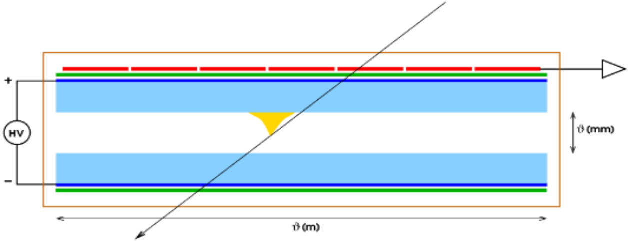


Diagram of a single-gap RPC**

Strengths

- Low cost, low complexity
- Good position and time resolutions achievable

Weaknesses

- Gas: logistics and hazard issues
- Performance stability

(∗∗) from A. Giammanco, S. Andringa, E. Cortina, M. Tytgat, DOI: 10.1002/9781119722748.ch18

RPC based detectors for confined environments

Challenges that drive our detector design choices

Optimal point of observation may be located in confined environments. This implies:

- Limited room available → **small size RPCs**
- Potentially no power available → **low power consumption, to be able to operate on batteries**
- Safety: toxic or flammable gas, anoxia → **sealed detectors**

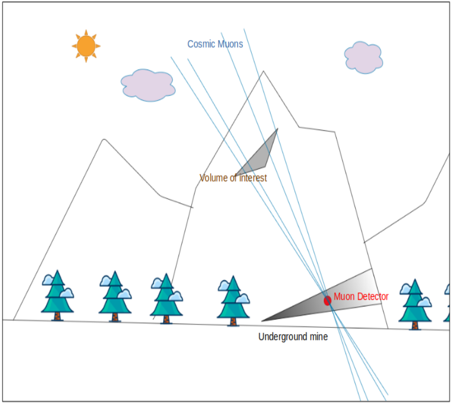


Illustration of Muography for a mining survey

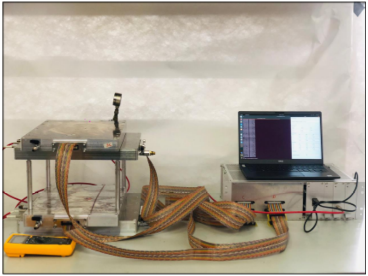
RPC Detectors at UCLouvain and UGent

We are developing two sets of RPCs with slightly different characteristics, cross-validating them towards a future co-developed prototype for Muography applications.

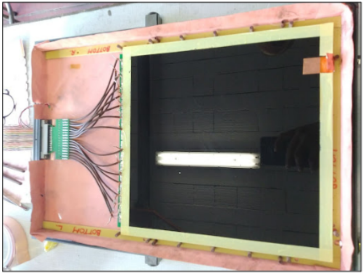
Property	UGent (Prototype 1.G)	UCLouvain (Prototype 1.L)
Size	30×30 cm^2	16×16 cm^2
Gas Flow	Continuous	Sealed
Gas Mixture	95.2% Freon, 0.3% SF_6 4.5% isobutane	95.2% Freon, 0.3% SF_6 4.5% isobutane
Readout	1.5cm width Cu strip	1cm width Cu strip
Semi-resistive coating	Using hand sprayer ($\sim$ 650 K$\Omega/\square$)	Seriagraphy method ($\sim$ 4 M$\Omega/\square$)
DAQ	NIM + CEAN integrated	Custom made
Portability	Not yet	Portable

Table : Properties of two RPC's detectors

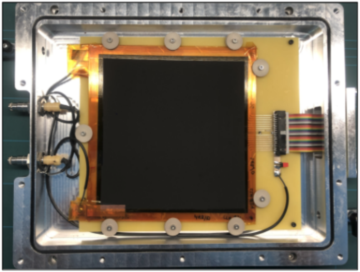
Prototype 1.G



Prototype 1.L



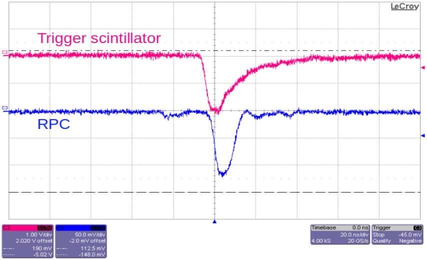
RPC inside its casing @ Prototype 1.G



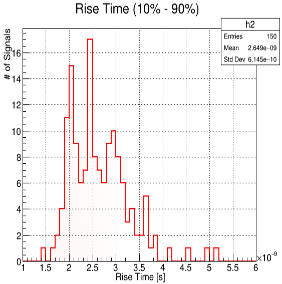
RPC inside its casing @ Prototype 1.L

Experimental Results of Protype 1.L

The signal from one strip of the RPC and the rise time of the RPC signal from Muoscope is shown below.



Signal from 1 Channel(strip) of the RPC

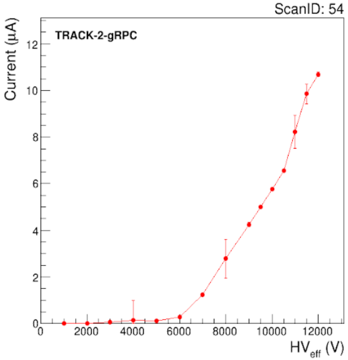


The signal:

- Amplitude $\simeq -160mV$
- Rise time $\simeq 3ns$

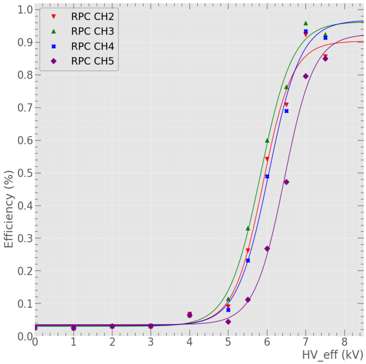
- Rise time of the signal is in the order of 2ns.
- High rise times are due to double signals

Experimental Results of Protype 1.G



Ohmic behavior of the RPC

- This plot shows the current drawn by the RPC while it working in different HVs.
- For the avalanche mode it behaves linearly so the working voltage is between 6kV and 8 kV

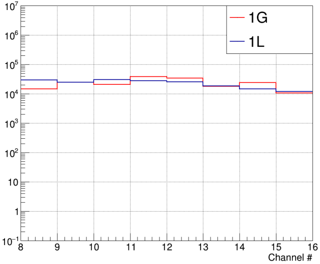


Efficiency Vs high Voltage

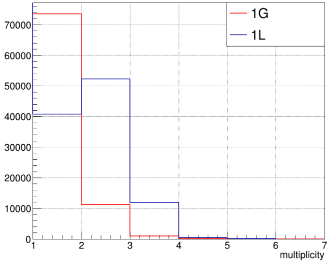
- This plot shows the the efficiency of 4 strips triggered with in the RPC
- The working point(high voltage) of the Detector can be estimated by this plot

Joint Data taking of 1.L and 1.G

- The occupancy and multiplicity of the last 8 strips[1] at our fist estimate of working point of HV = 7 kV and threshold = 90 DAQ units.



Occupancy distribution : # of times each strip fired throughout the data-taking run



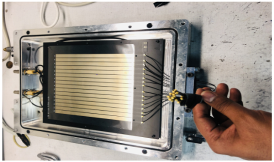
Multiplicity distribution : total # of strips fired per event

- Both these distributions are normalized to the 1.L active area
- The occupancy distributions of the two prototypes 1.L and 1.G are in general agreement
- A difference in the multiplicity distribution could be related to the difference in the resistivity of the glass plates between the two prototypes (1.G resistivity was less than 1.L).
- Coincidence events between the two RPCs will be closely examined to further fine-tune the working points for both chambers

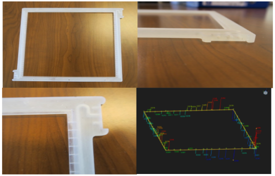
[1] Muoscope 1.G had some hardware-related issue with the first 4-5 strips so only last 8 strips were taken into consideration for producing these results

Towards Prototype 2.L

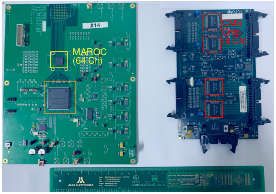
In the meantime we are working on the next prototype (2.L)



Readout board with coaxial cable connected to strip



3D Printed frame for new RPC



CMS RPC chip replaced by MAROC chip

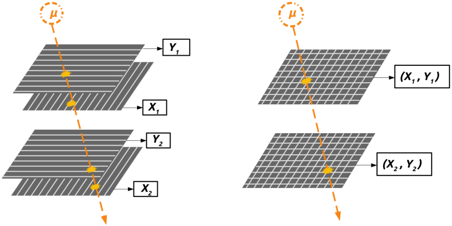
- The current readout is with copper track after the strips.
- In this board, coaxial cables are connected directly to the strip.
- The tests are already started with new readout.

- In 1.L, the whole Aluminum chamber is filled with gas.
- in 2.L,Gas is only filled between the glass plates
- We expect uniform distribution of gas between 2 plates

- Old CMS electronics is replaced by MAROC intergrated board.
- Currently testing with MAROC evaluation board

Multiplexing

- Our next steps aim at eventually performing high resolution (spatial:**O(mm)**; timing:**O(ns)**) muography, requiring an increased number of sensitive units
- In addition, we are considering switching the sensitive units from strips to pixels



A illustrative setup with 4 layers of strips (left) and one with 2 layers of pixels (right) providing the same x, y information at the same two positions in z.

Pros and Cons

Pros: Need half the number of layers (n)

- Weight of the setup is roughly reduced to the half
- Higher efficiency ($\epsilon^n < \epsilon^{n/2}$, where ϵ is single-RPC efficiency), and less material

Cons: Cost and power consumption

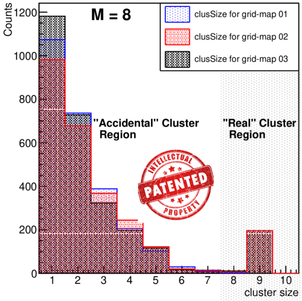
- With pixels, both cost and power consumption (few mW/channel) of electronics scale quadratically instead of linearly with N, the number of units in X and Y
- Number of electronic channels is 4 × N with strips and 2 × N^2 with pixels

With our current resolution, opting for the pixel options (2×16^2=512 readout channels) would be roughly 10 times pricey both in terms of cost and power consumption compared to the strip option (4×16=64 channels)

Multiplexing

- The cost of electronics is the main counter-argument against the pixels option (= too many pixels).
- An appropriate solution, is reading out several units with just one electronic channel, i.e **2D multiplexing**.
- De-multiplexing introduces ambiguities, but thanks to the low cosmic rate they are manageable.
- Standard multiplexing approaches are thought for 1D, we are developing a 2D-specific algorithm[4].

- The readout matrix of pixels (64×64) are divided into sub-grids, based on multiplexing factor, M, (i.e., # of pixels to be connected to a single readout channel)
- The pixels labels that satisfy a set of rules [4] are randomly generated in each sub-grid
- A simulation using an arbitrary expected signal size 3×3 pixels, a simulation was performed



Cluster size distribution for $M = 8$ comparing three different grid-maps. Clear separation between "real" and "accidental" cluster regions when noise is not taken into account

Summary

- A collaboration established between the muography teams in Louvain-la-Neuve and Ghent ("RPCBel") to explore the feasibility of portable RPCs for muography applications
- Two prototypes built with slightly different characteristics, to gain construction experience and compare the performances
- Current detector performances are encouraging
- Planning towards the next steps: exploring the move from strips to pixels, which will imply an explosion of channels and the need for a dedicated multiplexing scheme

References

1. Resistive Plate Chambers in Muography / A. Giammanco, S. Andringa, E. Cortina and M. Tytgat, DOI: 10.1002/9781119722748.ch18, in "Muography: Exploring Earth's Subsurface with Elementary Particles" (Wiley's Geophysical Monograph Series, ISSN: 0065-8448)
2. A portable muon telescope based on small and gas-tight Resistive Plate Chambers / S. Wuyckens, A. Giammanco, P. Demin, E. Cortina, arXiv:1806.06602 [physics.ins-det], Phil. Trans. R. Soc. A 377 (2018) 20180139
3. A portable muon telescope for multidisciplinary applications / R.M.I.D. Gamage, S. Basnet, E. Cortina Gil, P. Demin, A. Giammanco, R. Karnam, M. Moussawi, M. Tytgat, arXiv:2109.14489 [physics.ins-det], JINST 17 (2022) C01051
4. Radiographic imaging based on detection of ionizing particles / Eduardo Cortina Gil, Andrea Giammanco, Samip Basnet, Sophie Wuyckens. Application number: EP21201857.6, submitted in the European Union on Oct. 11, 2021

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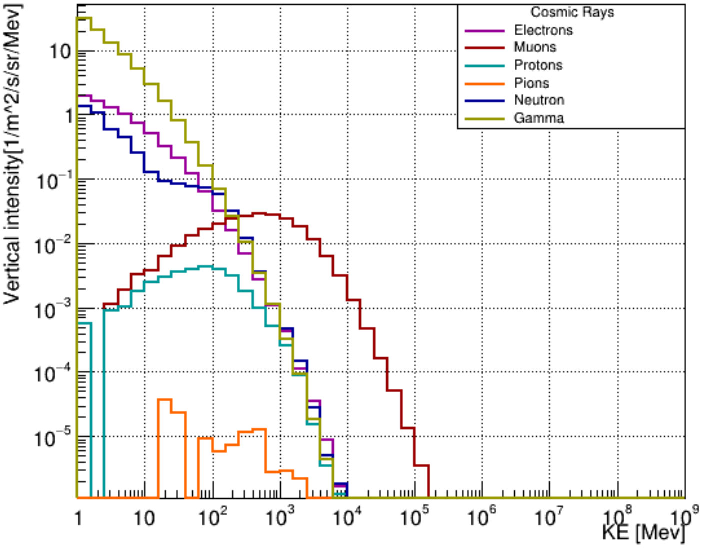
Thank you!

Backup Slides

Secondary Cosmic ray flux



Cosmic ray flux at sea level

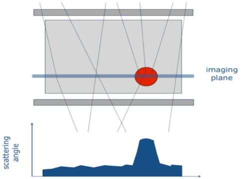
Scattering Vs Absorption Muography

Scattering Muography

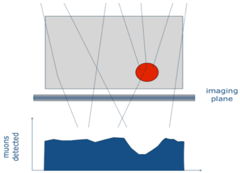
- Scattering position and angular shift.
- Smaller Masses and shorter exposure times.
- At least two detectors are needed.
- Applications: security, nuclear reactor and waste monitoring, etc.

Absorption Muography

- Muon flux measured as a function of the direction.
- Need Large Masses and Long exposure times.
- Only one detector needed.
- Applications: underground measurements, geology, archaeology, vulcanology, etc.

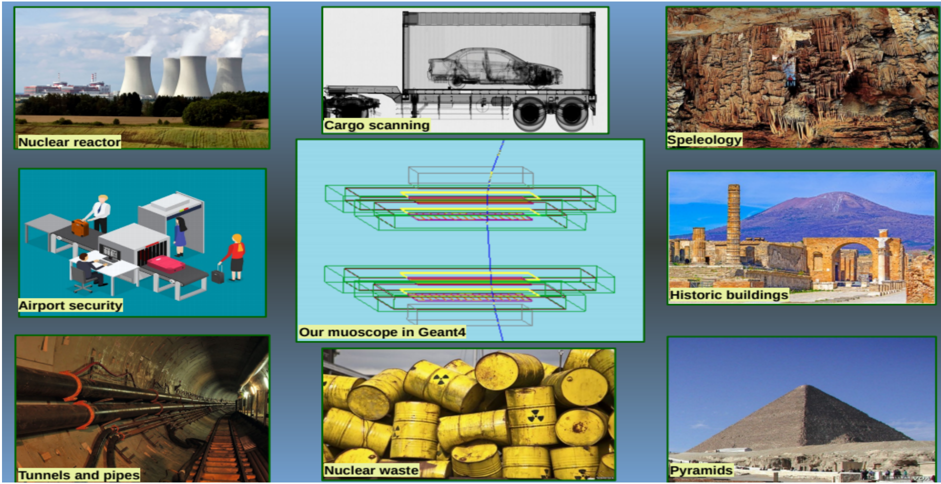


Scattering technique.



Absorption technique.

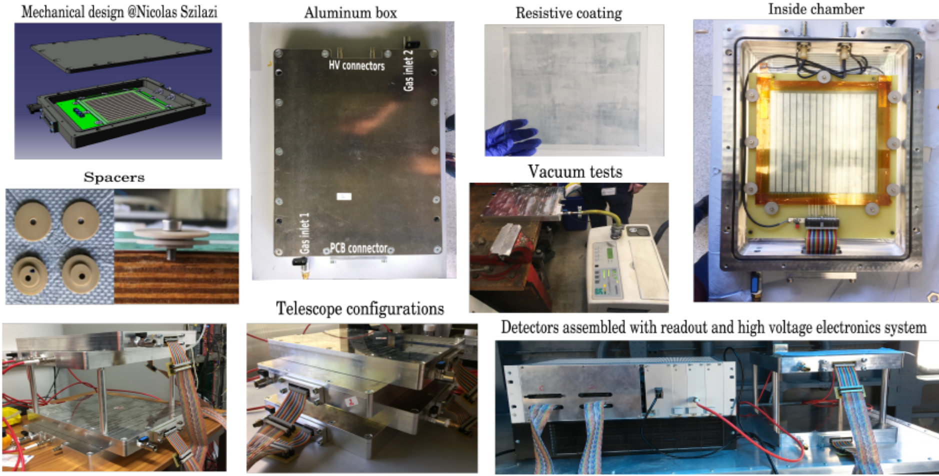
Use cases of Muography



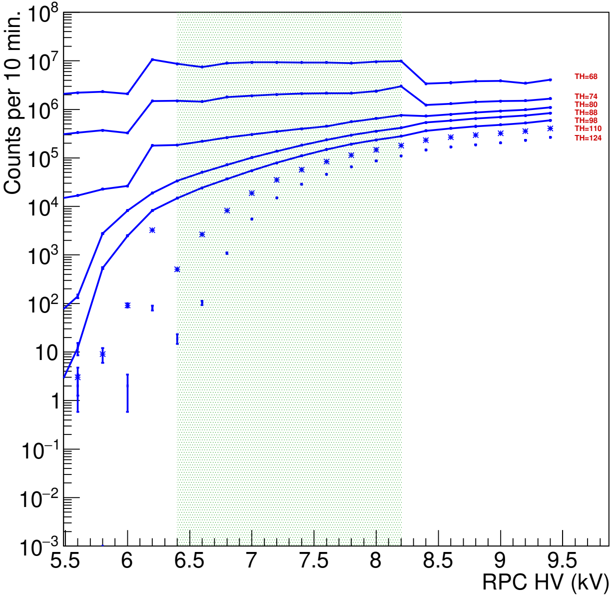
[2] Applications of MUography

2

Experimental setup from end to end



From end to end (source: S. Wuyckens' MSc thesis)



Counts per 10 min.
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
5.5
6
6.5
7
7.5
8
8.5
9
9.5
RPC HV (kV)
TH=68
TH=74
TH=80
TH=88
TH=98
TH=110
TH=124