A portable, gas-tight, and compact glass-RPC telescope for muon imaging

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Outline

1. Introduction
   - Guiding Design Principles
   - General Considerations on Resistive Plate Chambers (RPCs) for Muography
2. First Prototype – Operational experiences and Performance
   - Assembly and Experimental Set-up
   - Data Collection and Analysis
   - Results
3. Outlook
   - Lessons Learnt
   - Future Directions
4. Summary

Muography

Imaging techniques based on the absorption or scattering of cosmic ray muons (μ)[1]

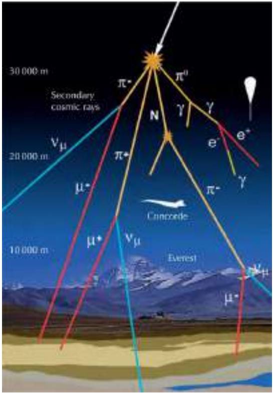


Figure: Atmospheric muon cascade Taken from Forbes article.

Muons (μ)

- Elementary particle – second generation lepton
- Quantum numbers common with electron but 200 times heavier
- Produced in the interaction of primary cosmic rays with the upper atmosphere freely and abundantly

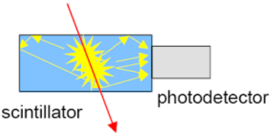
Why cosmic muons?

Most penetrating part of the cosmic shower

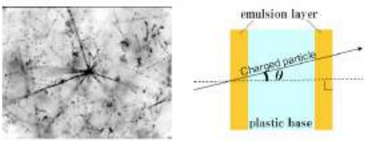
- No strong interaction
- Low probability of generating electromagnetic cascades upto very large momenta
- Minimal energy loss due to ionization

Guiding Design Principles

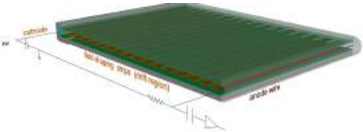
- Use cases (typical e.g. in archaeology):
  - The point of observation closest to the target is in a narrow environment (e.g., narrow tunnel)
    - small volume
    - portable (low weight, incl. electronics)
    - robust
    - easy to assemble/disassemble
  - Logistical challenges (e.g., no power supply)
    - completely autonomous
    - low power consumption
- Other teams are developing portable detectors for the same use cases, based on (but not limited to) scintillating bars



(a) Scintillator detectors



(b) Nuclear emulsion


(c) Gaseous drift chamber

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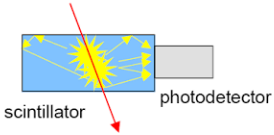
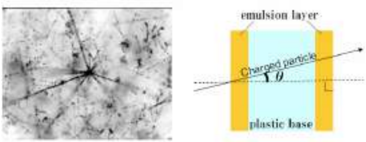


Less portable, temperature dependence of breakdown voltage ⇒ increased power budget **(??)**



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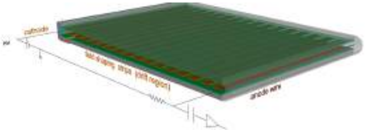

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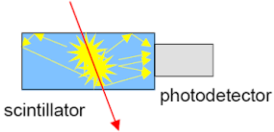

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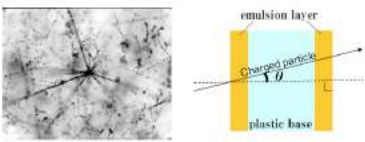
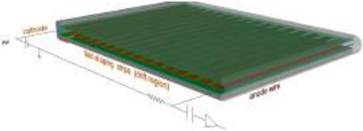


No timing info; resources to analyse plates; issues with start-stop **(??)**



(c) Gaseous drift chamber

General Considerations on RPCs for Muography

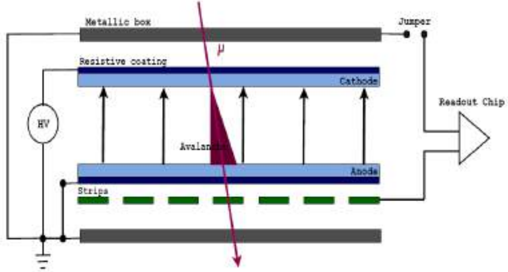
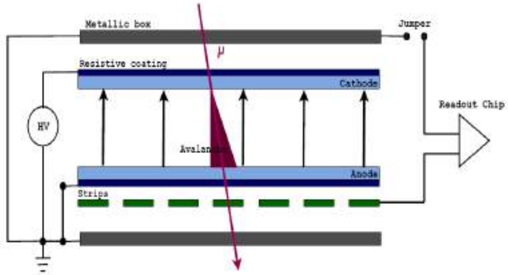


Figure: An ionizing particle (i.e. μ) passing through the gas gap and creating an electron avalanche towards the anode in RPC.

Advantages [1]:

- Large chamber sizes at relatively low price
- Real time information
- Better position resolution ($\sim$100μm)
- Better timing resolution, esp. for multi-gap RPCs ($\sim$50ps - 1ns)

General Considerations on RPCs for Muography



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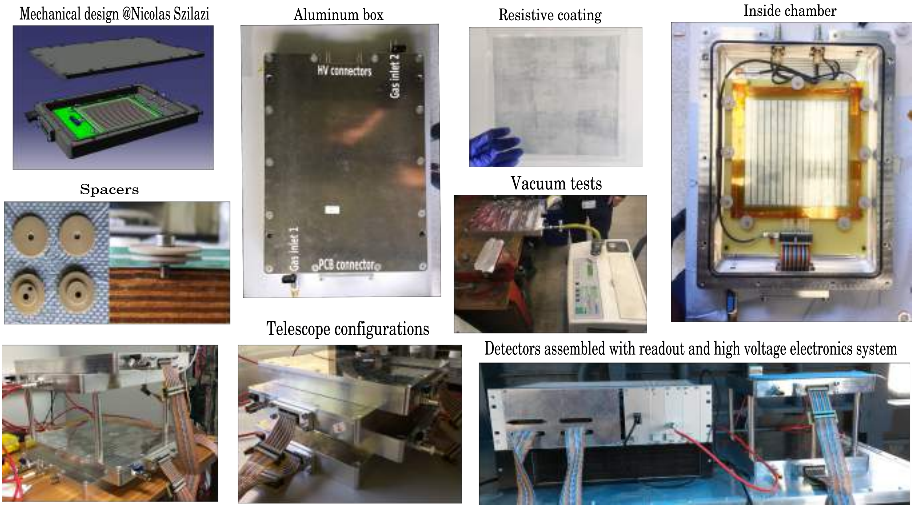
Some issues for muography with RPCs [1]:

- Gas requirements (gas mixtures, logistics, etc)
- Stability in various environmental parameters (temperature, humidity, pressure variations, etc)
- Power consumption for large amount of readout channels

Assembly of the First Prototype Telescope



Few months from end to end (Figure from [2])

Experimental Set-up

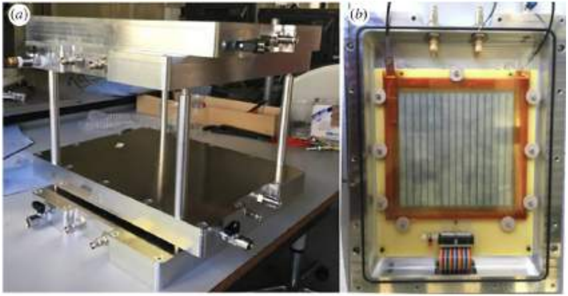


Figure: (a) Muoscope set-up consisting of four gRPC layers. (b) One of the gRPCs inside its casing; consists of 16 sensitive strips, hosted in an air-tight aluminum box. [3]

Design principle: must be **portable**

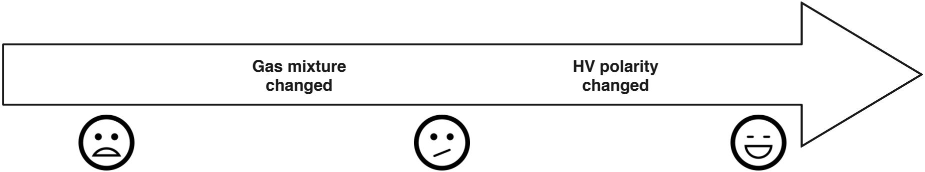
- Sealed; particular care in making gas-tight casings (10^{-9} mbar l/s)
- Small (active area:16X16 cm^2)
- Total weight with electronics ($\sim$50 kg)
- Modular geometry
- Robust and Cheap

Entire fabrication and assembly of first full prototype done locally at UCLouvain with UGent's support

- 4 planes (x_1,y_1,x_2,y_2)
- Gas mixture (95.2% argon, 4.5% isobutane, and 0.3% SF_6) @ 1 atm pressure

Data Collection and Analysis

Purity evolution of events: Trail and Error!



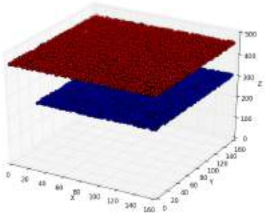


Figure: @MDRS - 4.5kV & th 100

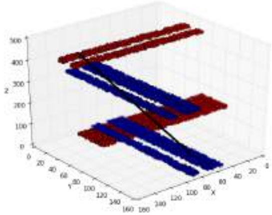


Figure: @UCL with negative HV - 6.8 kV & th 100

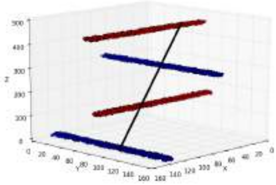


Figure: @UCL with positive HV - 6.6 kV & th 105

Results

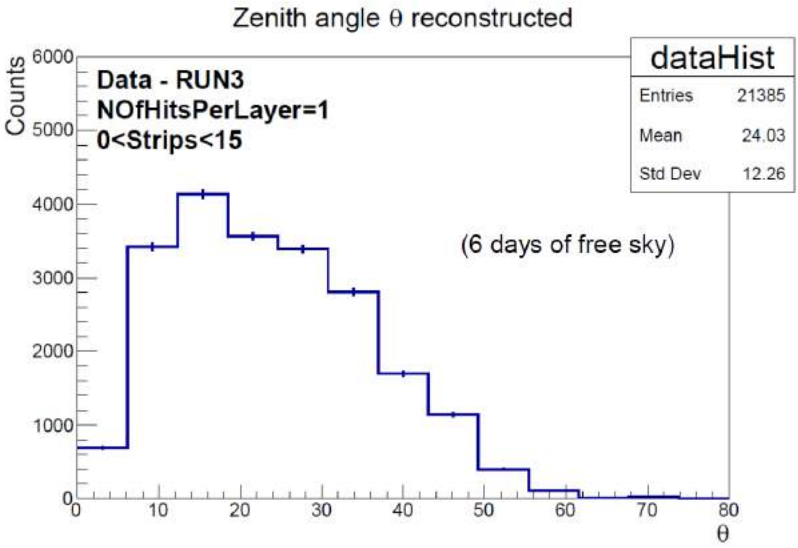


Figure: Preliminary zenith angle (θ) reconstruction with the first prototype [2]

Indoors, and in the wild

First test with real-life logistics at Mars Desert Research Station (MDRS), Utah in 2018-19

- Gas-tightness – no significant loss in gas pressure over time
- Portability and compactness – single person was able to move and operate the detectors
- Robustness – survived round trip between Belgium and the USA

UCLouvain student participating in "UCL to Mars" project in MDRS

Indoors, and in the wild

First test with real-life logistics at Mars Desert Research Station (MDRS), Utah in 2018-19

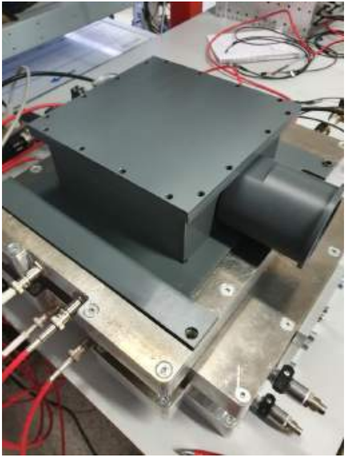
- Only two out of four detector layers were ready
- Different gas-mixture used (freon vs argon)
- SF_6 and isobutane composition in the mixture not as expected
- Large ambient noise picked up from the power generator

Two detector layers at the time of data-taking in MDRS

Future Direction

1. For Current Prototype

- Small gas system now installed locally at Louvain-la-neuve
- Scintillators as external trigger freshly included in the setup for more detailed performance studies and to pin down the spatial resolution
- Inclusion of scintillators data in the current TDAQ system
- Ageing and outgassing tests
- Finally, data-taking of a known structure, Cyclotron building at UCLouvain to perform muon imaging



Setup for trigger with external scintillators

Future Direction

2. For the Next Prototype

- New prototype will have better spatial, **O(1mm)** as well as timing, **O(1ns)** resolutions – this will allows us to perform high resolution muography

1. Replace 16 strips and new electronic chips (MAROC with 64 channels)
2. Multiplexing[4] can also be used to further improve spatial resolution
3. Decreasing the gas volume

Current readout chip (Old CMS FEB)

MAROC 3A chip containing 64 channels

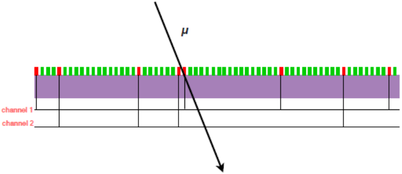


Figure illustrating multiplexing [4]

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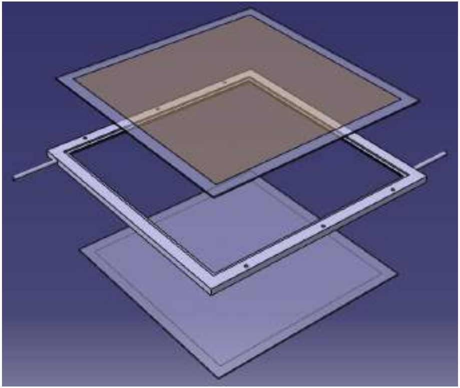


Mechanical design for sealed gas volume

1. Replace 16 strips and new electronic chips (MAROC with 64 channels)
2. Multiplexing[4] can also be used to further improve spatial resolution
3. Decreasing the gas volume
4. Tests with resistive coating using serigraphy at CEA, Saclay in France

Summary

- Muography : imaging with cosmic-ray muons
- Construction of a set of 4 mini-gRPCs (UCL)
- Data collection (Utah Desert + UCL)
  - Modifications of the setup following the problems encountered
- Preliminary data analysis and results

⇒ The **mini-gRPCs prototype works** – first proof of principle!

⇒ It is compact, portable, gas tight and robust

⇒ Improved second prototype R&D currently on-going

References

[1] L. Bonechi, R. D'Alessandro, and A. Giammanco, "Atomspheric muons as an imaging tool", Reviews in Physics, 2019.

[2] S. Wuyckens, "Development of a compact telescope for cosmic muon flux and density measurements", Masters Thesis, UCLouvain, 2018.

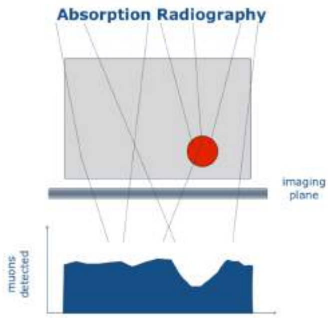
[3] S. Wuyckens, A. Giammanco, E. C. Gil, and P. Demin, "A portable muon telescope based on small and gas-tight resisitive plate chambers", Phil. Trans. R. Soc. A, 377:20180139, 2019.

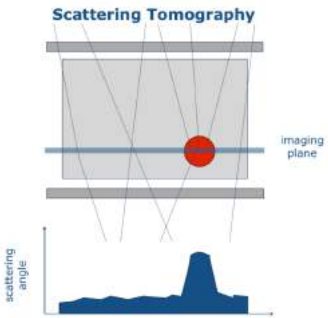
[4] S. Procureur, R. Dupré and S. Aunec," Genetic multiplexing and first results with a 50x50 cm^2 Micromegas", NIM A, 729:888, 2013.

Backup Slides

Absorption vs Scattering muography

Imaging techniques based on the absorption or scattering of cosmic ray muons (μ)





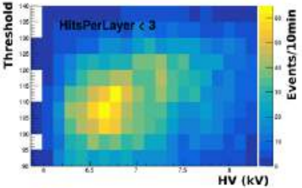
- Transmission of muons through the objects of interest
- "Opacity" along the line of sight
- Slow and applicable mostly for very large targets e.g. volcanoes

- Z measurement via angle of deflection, $\Delta\theta$
- Appropriate for detecting high Z material from a lower Z background
- Fast and applicable for small and medium-sized targets

Data analysis (1/2)

Threshold and HV Scan

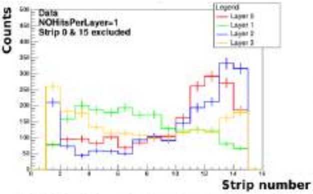
- **Operating voltage and threshold**



HV =6.6 -6.7 kV & TH = 105-110

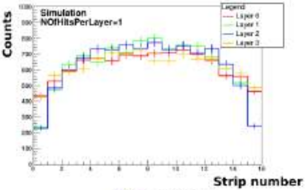
Figure: Scanning in HV (6-8 kV) and TH (90-140) with cut : Number of hits per layer < 3

- **Hits pattern**



(a) Data with cut : Number of hits per layer =1

VS.



(b) Simulation

Figure: Number of hits in each strips for each chamber for HV = 6.6 kV and TH =105

Data analysis (2/2)

Track reconstruction

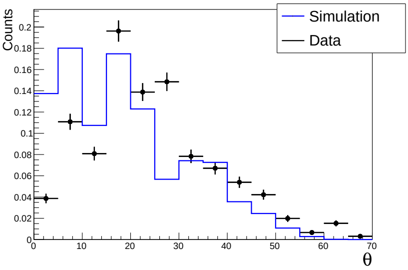
Need : 4 positions to reconstruct angles (x_1, y_2, x_3, y_4)
With $x = x_3 - x_1$; $y = y_4 - y_2$; $z = d$ and $r = \sqrt{x^2 + y^2 + z^2}$, we have :

$$\phi = atan(\frac{y}{x}) \qquad \theta = acos(\frac{z}{r})$$

$\boxdot UCLminigRPCs(16 \times 16 cm^2)$

$\Rightarrow$ 4 planes & height depending on detectors configuration (15-30 cm).

Comparison of zenith angle distribution between simulation and data

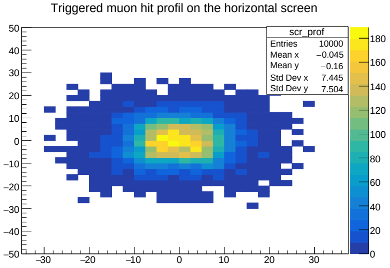


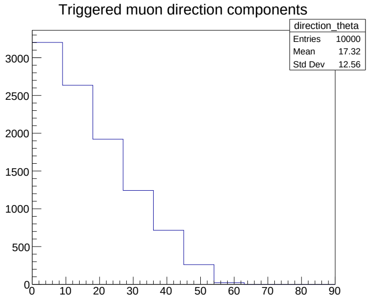
$\Rightarrow$ Expected : $cos^2(\theta)$ distribution.

Simulation

Preliminary Goals :

- Reproduce the 4 detectors configuration
- Generate muon events with respect to $cos^2(\theta)$ distribution
- Distance between detectors dependency
- Triggered muon pattern, efficiency, angular resolution and misalignment.





Plot obtained for a distance between detectors (d) = 3.7 cm.