Gas-Tight Portable RPC for Muography Applications

On behalf of the UCLouvain, VUB and NISER groups
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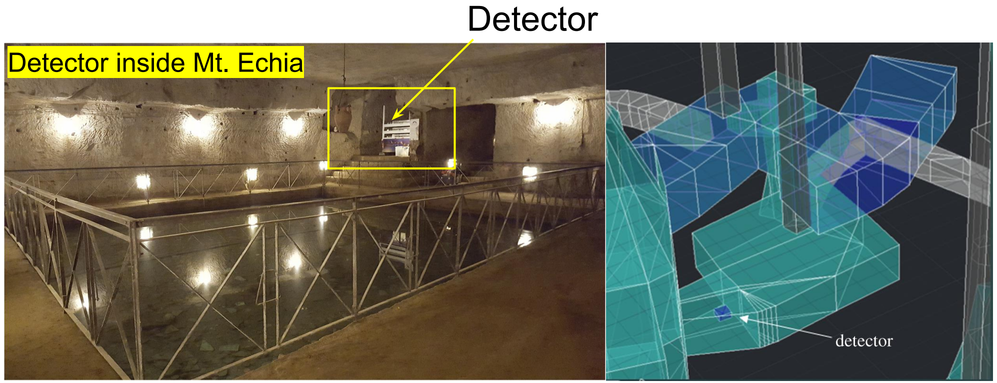
2nd DRD1 Collaboration Meeting

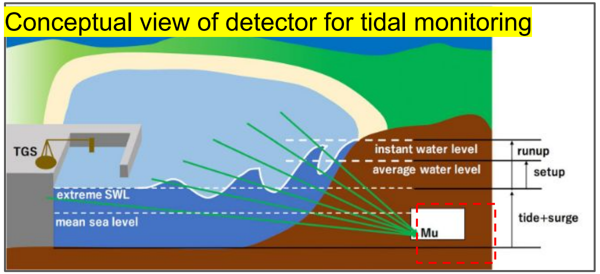
Motivations

Portable muon telescopes are mainly used to conduct experiments in confined environments

- Limited space to install the experimental setup
- Logistical challenges in terms of power supply, cabling, gas cylinder, etc.
- In confined spaces gas detectors have an additional challenge: the presence of gas bottles poses hazard issues (anoxia, explosion, etc.)
- Example applications: Archeological and mining explorations, underground geophysical surveys, civil infrastructure integrity checks



Saracino, G., et al. "Applications of muon absorption radiography to the fields of archaeology and civil engineering." *Philosophical Transactions of the Royal Society A* 377.2137 (2019): 20180057.



Tanaka, Hiroyuki KM. "Muography for a dense tide monitoring network." *Scientific Reports* 12.1 (2022): 6725.

Bonechi, L., et al. "Multidisciplinary applications of muon radiography using the MIMA detector." *JINST* 15.05 (2020): C05030

Gas-Tight RPC

The concept of a gas-tight Resistive Plate Chamber (RPC) is relatively novel and introduces several challenges:

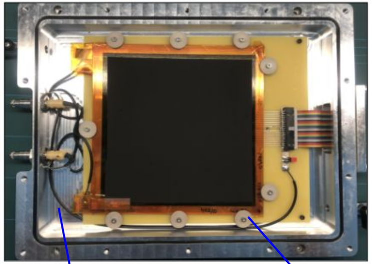
- The absence of gas flow within the RPC can potentially result in variations in the homogeneity of the gas mixture over time.
- This, in turn, can cause an increased discharge probability, reducing the detector performance with time.
- Furthermore, the stationary/static state of gas mixture within the chamber may contribute to acceleration in polymerization on the detector surface.

However, these detectors are economical, easily fabricated and transported, have reasonable efficiency and spatial resolution.

RPC Prototypes

As part of the project, three glass-based RPC prototypes with slightly different characteristics are developed:

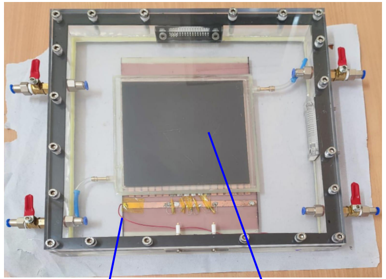
Detector	A	B	C
Size	16 × 16 cm^2	16×16 cm^2	30×30 cm^2
Box type	Aluminum casket	Standalone RPC housed in acrylic casket	Closed with top and bottom PCBs
Readout strips	16-1D	16 × 16 - 2D	32×32 - 2D
Strip pitch	1 cm	1 cm	0.8 cm
Gas mixture	95.2% Freon, 0.3% SF6, 4.5% isobutane		
Gas gap	1 mm Single gap	2 mm Single gap	1 mm Double gap
Thickness of electrodes	1.1 mm	3.0 mm	1.1 mm
Resistive coating	Serigraphy Method (~ 4 MΩ/□)	Using paint spray gun (~ 1 MΩ/□)	Using hand sprayer(~ 1.5 MΩ/□)
DAQ	NIM + CEAN integrated / custom made and ASIC + FPGA		
Portability	Yes	Yes (Currently operating in gas flow mode)	Yes (Currently operating in gas flow mode)



gRPC-A

Aluminum casket

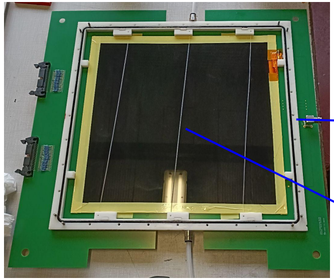
Round edge spacers



gRPC-B

Acrylic casket

RPC



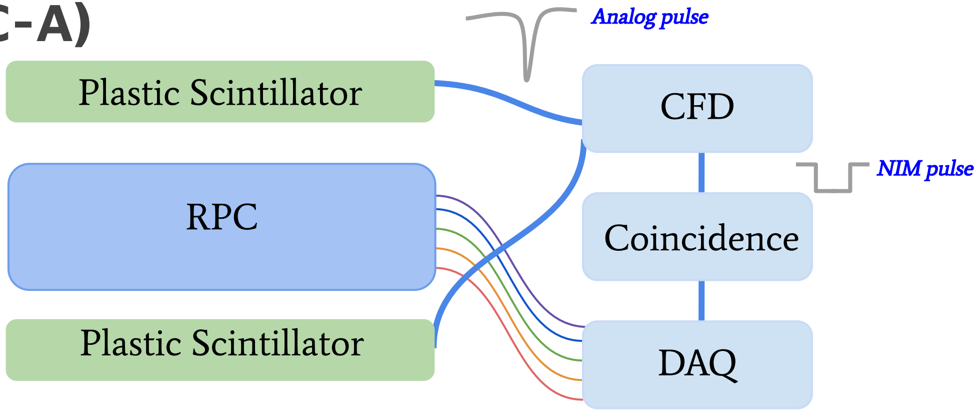
3D printed frame

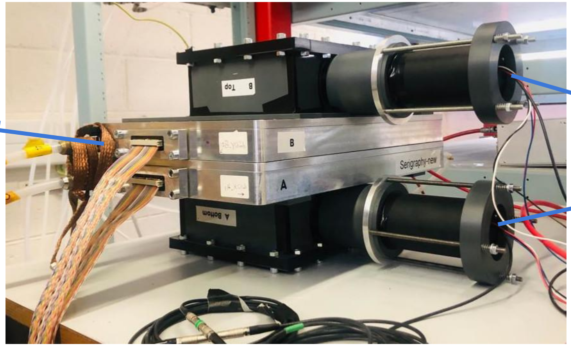
Gas gap with fishline spacers

gRPC-C

Experimental setup
(efficiency test for gRPC-A)

- Trigger signal from plastic scintillators
- Signals are collected in parallel with all 16 readout strips (Pre-trigger)
- DAQ consists of CMS's RPC Front End Board that has charge sensitive preamplifiers and discriminators
- The digital discriminator pulse is processed by FPGA for data collection
- The data are collected from pre-trigger as the scintillators signals are delayed with respect to RPC

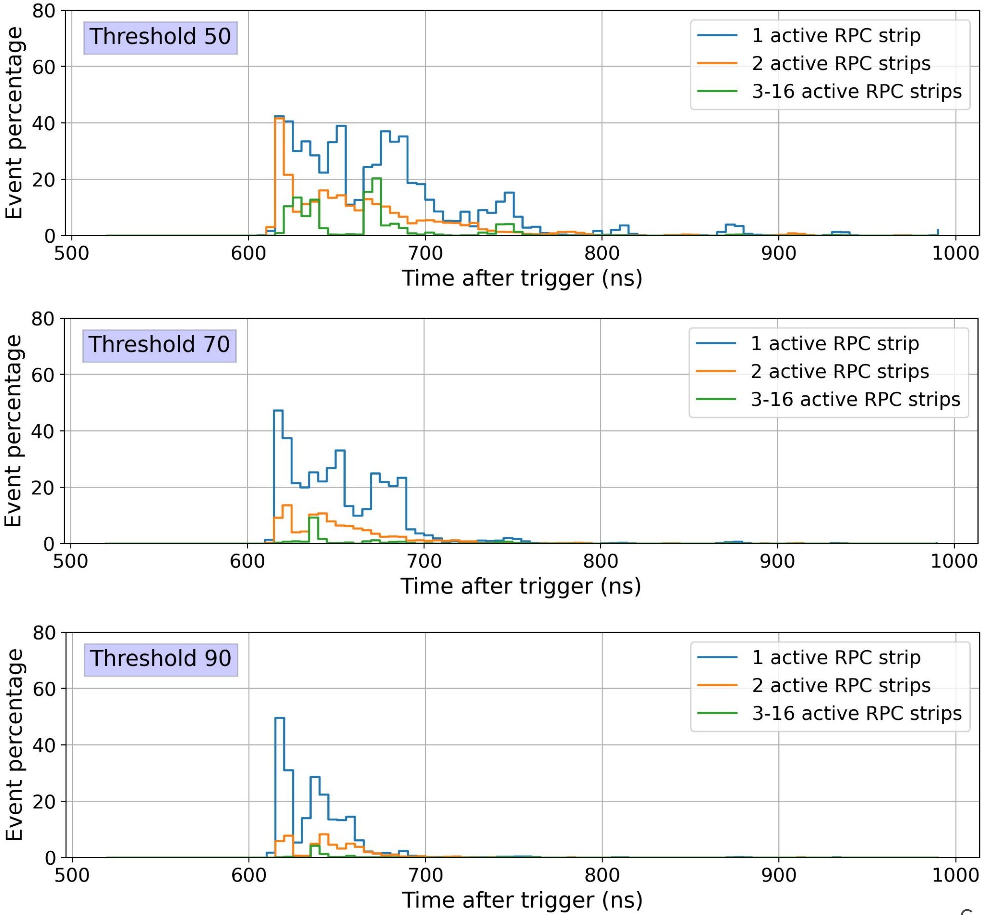




Lab setup with two RPCs

Noise analysis (gRPC-A1)

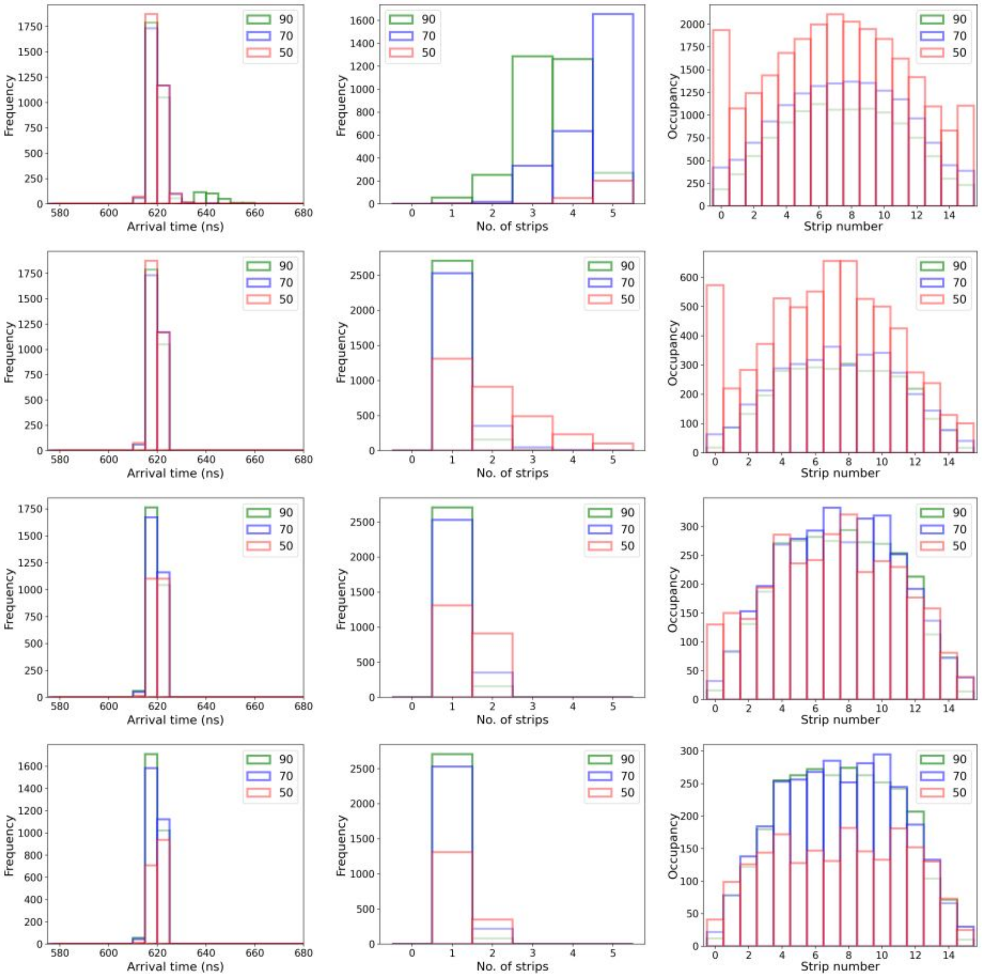
- The RPC signal is delayed to save pre-trigger data
- The noise appears after RPC signal
    - Parasitic capacitance
    - Cross-talk
    - Reflection from strip and cable ends due to impedance mismatch



Filters for offline noise reduction (gRPC-A1)

- Time filter
- Strip multiplicity
- No. of muons per event

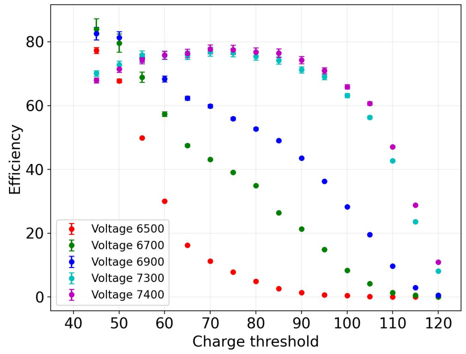
Threshold No. of events in PMTs	50 3479	70 3298	90 3483
No filter	93.4 ± 0.4 %	93.5 ± 0.4 %	93.7 ± 0.4 %
Time filter (610-625 ns)	89.7 ± 0.5 %	89.7 ± 0.5 %	83.2 ± 0.6 %
No. of strips ≤2	63.8 ± 0.8 %	87.5 ± 0.6 %	82.3 ± 0.6 %
No. of clusters = 1	47.7 ± 0.8 %	83.4 ± 0.6 %	80.0 ± 0.7 %



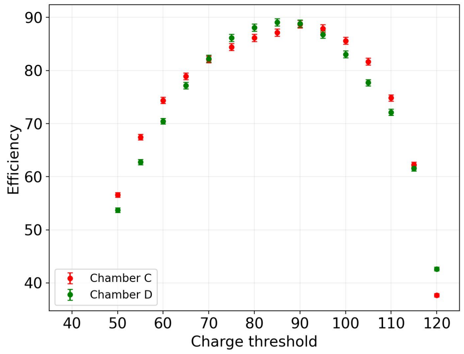
Detector optimization (gRPC-A)

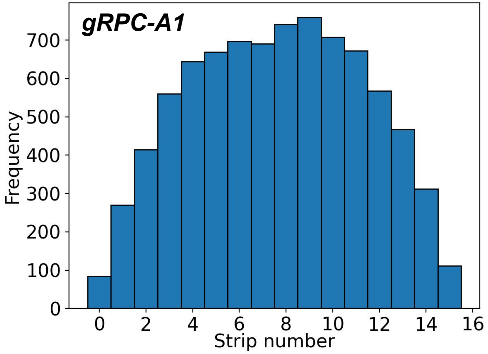
- Efficiency decreases with increasing charge threshold values for lower voltages.
- The efficiency is lower for low threshold at higher voltage due to suppression of signal along with the noise at higher voltage values.
- The efficiency and occupancy for two identical chamber follows same trend after optimization.
- The strip occupancy shows the acceptance for efficiency measurement setup.

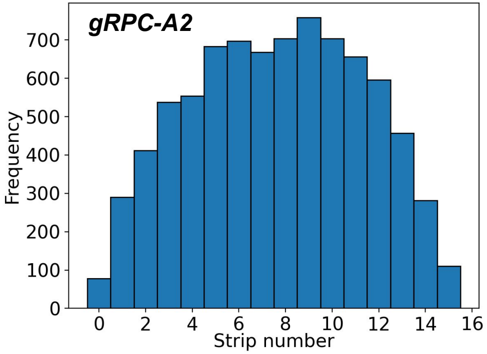
Testing before optimization



After optimization

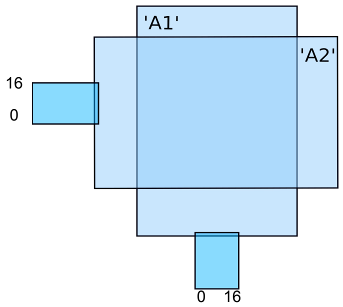


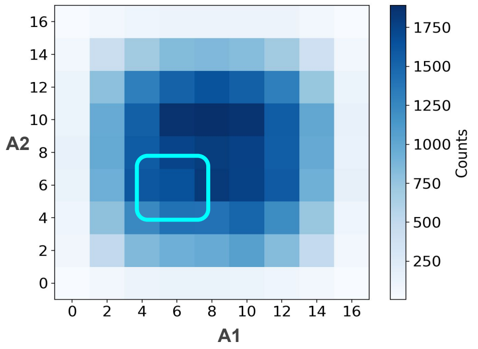


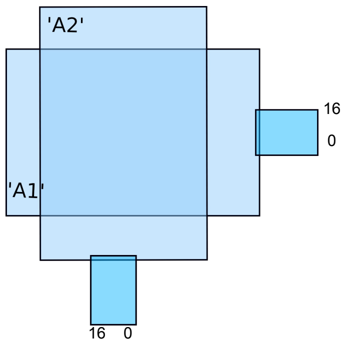


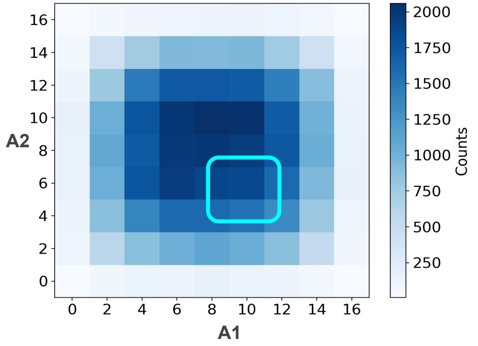
Muon flux distribution (gRPC-A)

- Detectors are placed orthogonally to obtain a 2D muon flux map
- Setup is rotated 90^0 counter-clockwise to check the discrepancy in muon flux
- The discrepancy is not due to the detector but to the distribution of matter above it, as the low muon region shifts from (6,6) to (10,6).



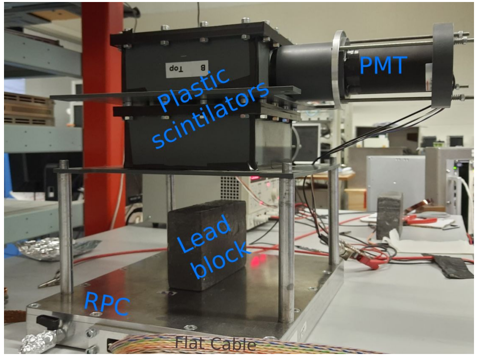




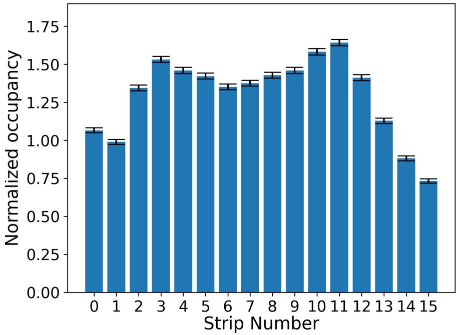


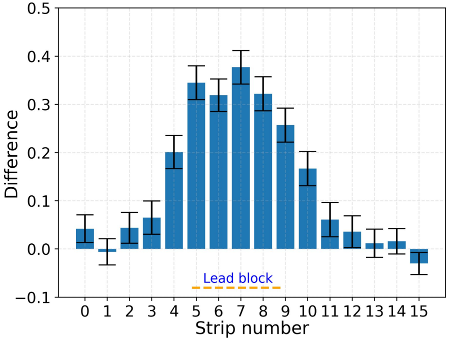
Absorption muography (gRPC-A1)

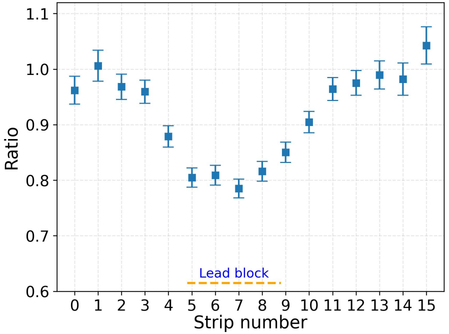
- The muon absorption setup with two plastic scintillators on top and RPC at the bottom
- A lead block in the region between the scintillators and RPC
- The flux difference and ratio plots depicts the reduction in muon flux due to absorption



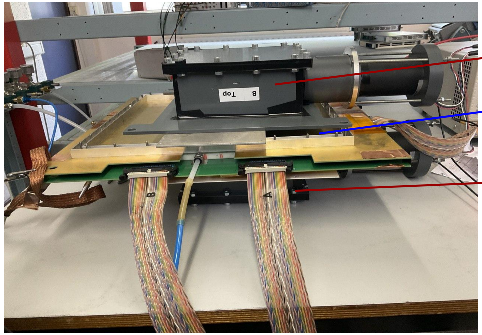
Occupancy after absorption



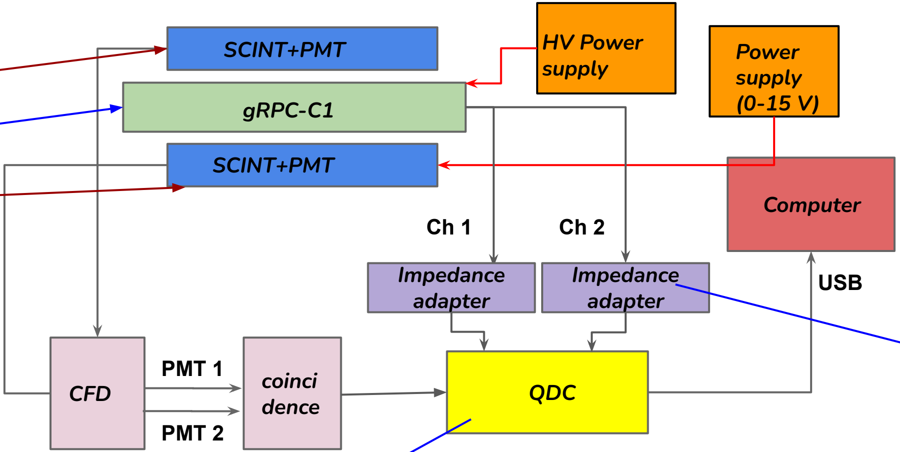


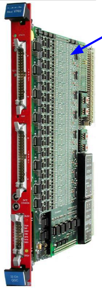


CAEN-QDC based data taking for charge measurements (gRPC-C)

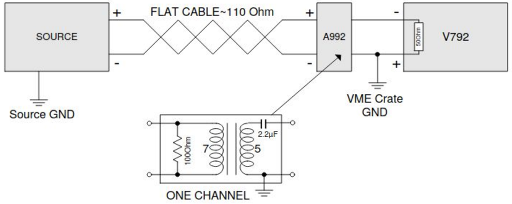


gRPC-C1 aligned with the trigger scintillators





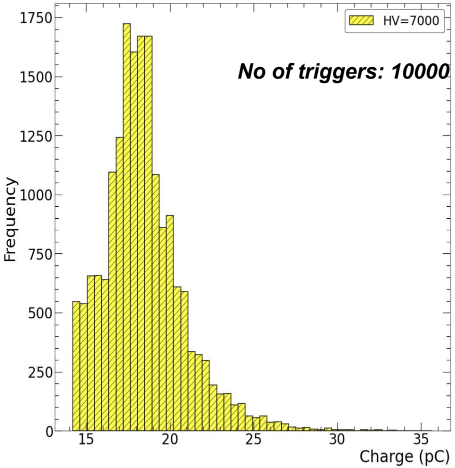
CAEN 32 channel QDC



Connection scheme of source to QDC with impedance adapter

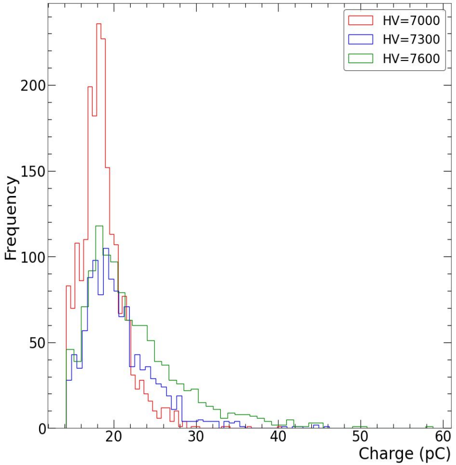
CAEN-QDC based data taking: results

Distribution of pulse charge acquired from the strips at operating voltage (7000 V)



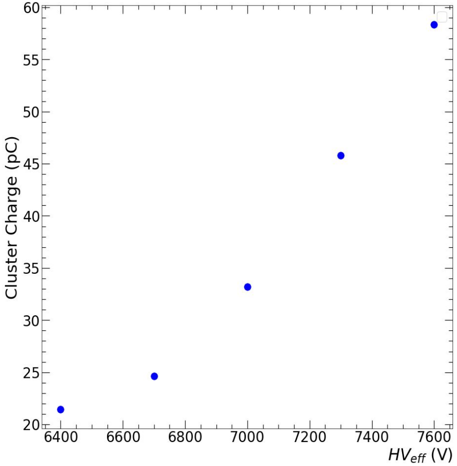
- Charge is calculated by applying the conversion:
  1 QDC count=0.098 pC

Distribution of pulse charge acquired from the strips at 3 different voltages in the avalanche region



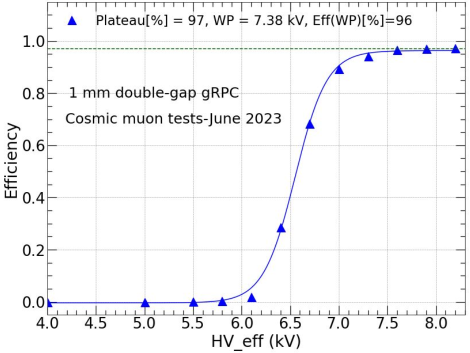
- As expected, pulse charge increases as the HV increases

Distribution of average cluster charge of clusters with respect to the high voltage



- Cluster charge = sum of the charge collected from the strips involved in the cluster
- Average cluster charge = Average of the charge of all clusters in the data collected at each HV points

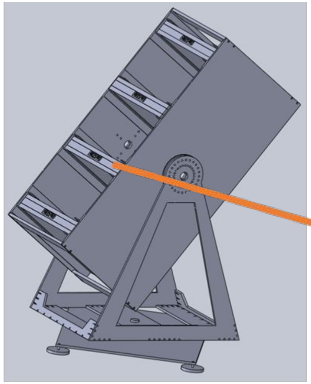
Working voltage test



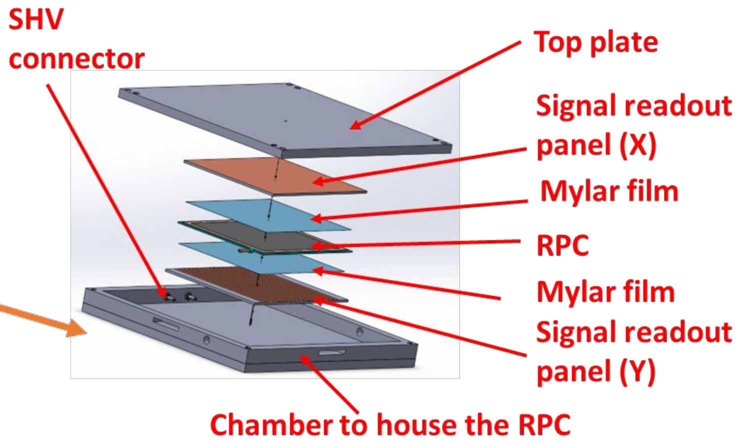
Cuts applied for event selection: 1) QDC count > channel threshold, 2)Cluster multiplicity <3, 3) Cluster size<4

A modular muon telescope with gRPC-B

- A portable muon telescope is being developed using four RPC modules.
- Each module houses a glass RPC of active area 16 × 16 cm^2 active area. The RPC is sandwiched between two strip readout panels, placed orthogonally to each other to record (x,y) information of muon hit.

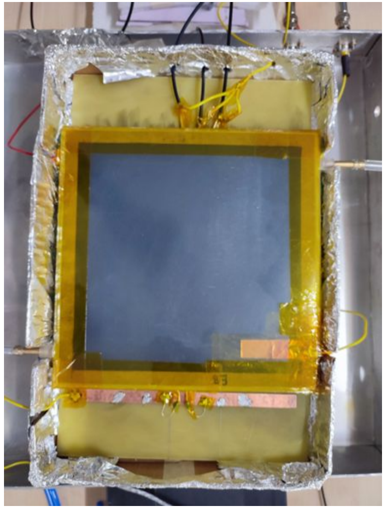


A modular muon telescope with four modules

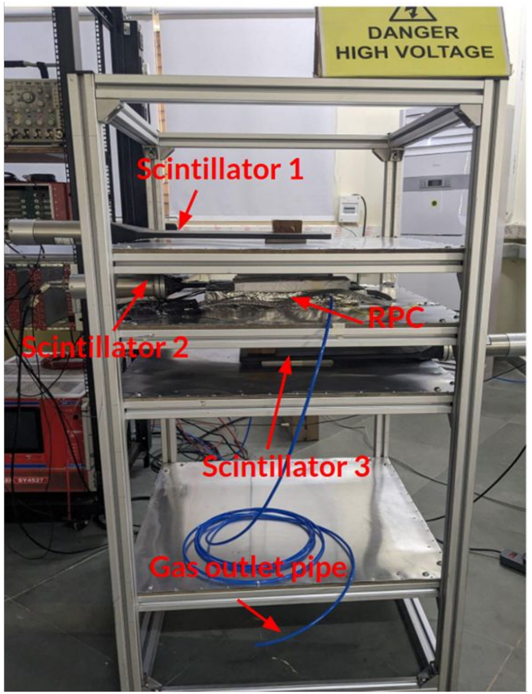


Schematic of an acrylic module housing an RPC and signal readout panels

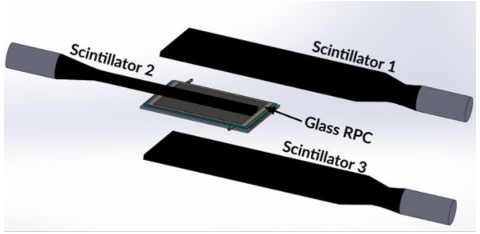
Efficiency tests for the gRPC-B



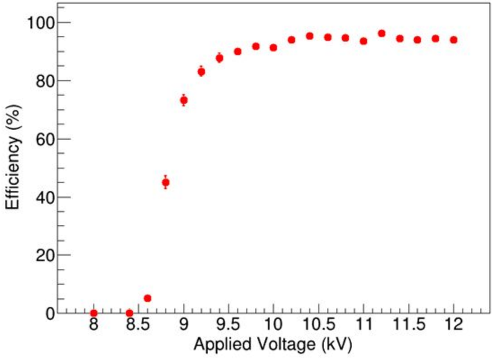
RPC placed in a Faraday cage



A muon trigger system developed to study the performance of RPCs



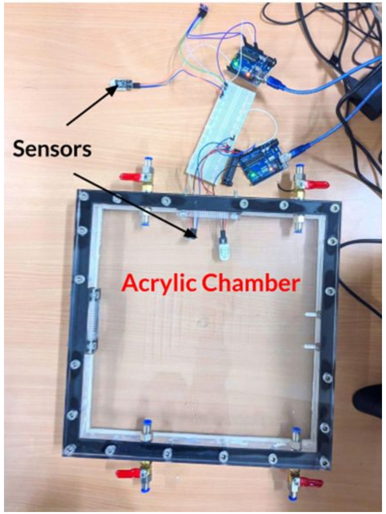
A schematic view of trigger system

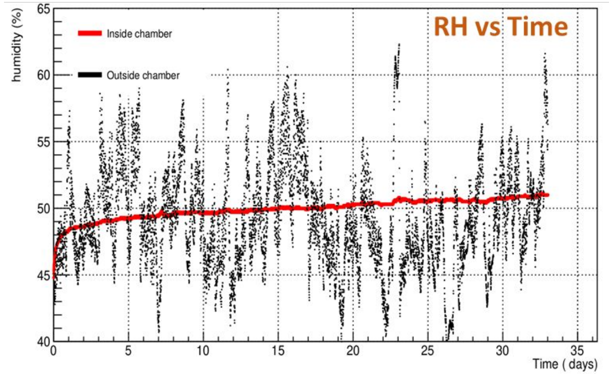


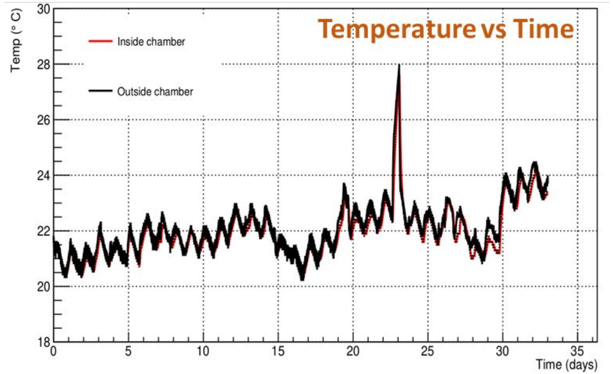
Efficiency of the RPC is 95% on the plateau

Air tightness studies to the acrylic chamber

- Using DHT22 sensors the Relative Humidity (RH) and Temperature (T) are measured inside and outside the acrylic chamber for a month.
- Arduino UNO R3 board is used to record the RH and T data from the DHT22 sensors.
- RH is consistent inside the chamber.
- Temperature inside the chamber is varied as outside the chamber.







Future plans and challenges

- Long term stability test for efficiency
- Ageing of resistive coating with time
- Gas stability with time and if required providing gas circulation system
- Testing new prototypes having lower gas volume and better modular design with reduced casket size
- Muon telescope for tracking with two vertical and two horizontal coordinates (improving DAQ to have 2D information from same RPC)
- Optimize the telescope modules to function in the outdoor conditions, like temperature, relative humidity and pressure.
- Testing ecogas with gas-tight environment
- Developing MAROC 3A based DAQ to increase the readout granularity.

Collaborators

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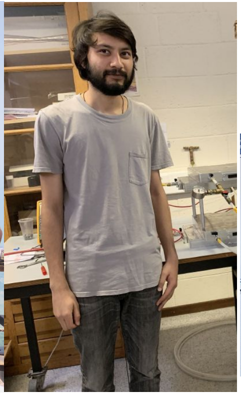

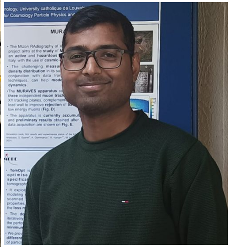

References

- Performance testing of gas-tight portable RPC for muography applications / V. Kumar et al., Proceedings of the 16th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD23), 25-29 September 2023, Siena, Italy. arXiv:2312.07204 [physics.ins-det], JINST 19 C04027.
- Small-area Portable Resistive Plate Chambers for Muography / A. Samalan et al., Proceedings of the International Workshop on Cosmic-Ray Muography (Muographers 2023). arXiv:2311.11451 [physics.ins-det], accepted by Journal for Advanced Instrumentation in Science
- Portable Resistive Plate Chambers for Muography in confined environments / R.M.I.D Gamage et al., Proceedings of the inter-Disciplinary Underground Science and Technology conference (i-DUST 2022). arXiv:2209.09560 [physics.ins-det], E3S Web of Conferences 357 (2022) 01001
- Towards a portable high-resolution muon detector based on Resistive Plate Chambers / S. Basnet et al., Proceedings of the International Workshop on Cosmic-Ray Muography (Muographers 2021). arXiv:2202.01084 [physics.ins-det], Journal for Advanced Instrumentation in Science, 1 (2022) 299
- A portable muon telescope for multidisciplinary applications / R.M.I.D. Gamage et al., Proceedings of the XXII International Workshop on Radiation Imaging Detectors - iWoRiD 2021, 27 June- 1 July 2021, Ghent (Belgium). arXiv:2109.14489 [physics.ins-det]; JINST 17 (2022) C01051
- A portable muon telescope for exploration geophysics in confined environments / M. Moussawi et al., Proceedings of the First International Meeting for Applied Geoscience & Energy, 26 September - 1 October 2021, Denver (USA). SEG Technical Program Expanded Abstracts, First International Meeting for Applied Geoscience & Energy Expanded Abstracts, 3034-3038
- Towards portable muography with small-area, gas-tight glass Resistive Plate Chambers / S. Basnet et al., Proceedings of the XV Workshop on Resistive Plate Chambers and Related Detectors, 10-14 February 2020, Rome (Italy) RPC2020. arXiv:2005.09589 [physics.ins-det]; JINST 15 (2020) C10032
- A portable muon telescope based on small and gas-tight Resistive Plate Chambers / S. Wuyckens et al., Proceedings of the "Cosmic-Ray Muography" meeting of the Royal Society, 14-15 May 2018 at the Kavli Royal Society Centre, Chicheley Hall, Newport Pagnell (UK). arXiv:1806.06602 [physics.ins-det], Phil. Trans. R. Soc. A 377 (2018) 20180139

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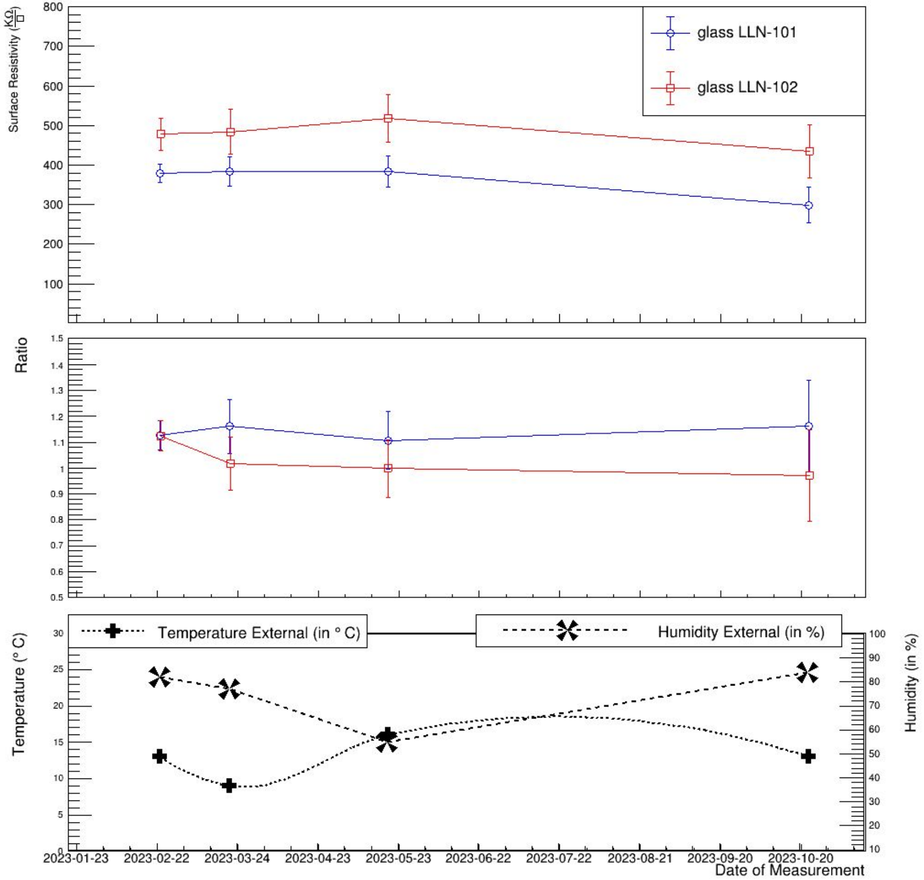
Backup

Paint sprayed on plate

Top: surface resistivity measurements over time for two plates manufactured using the spray-gun-based technique.

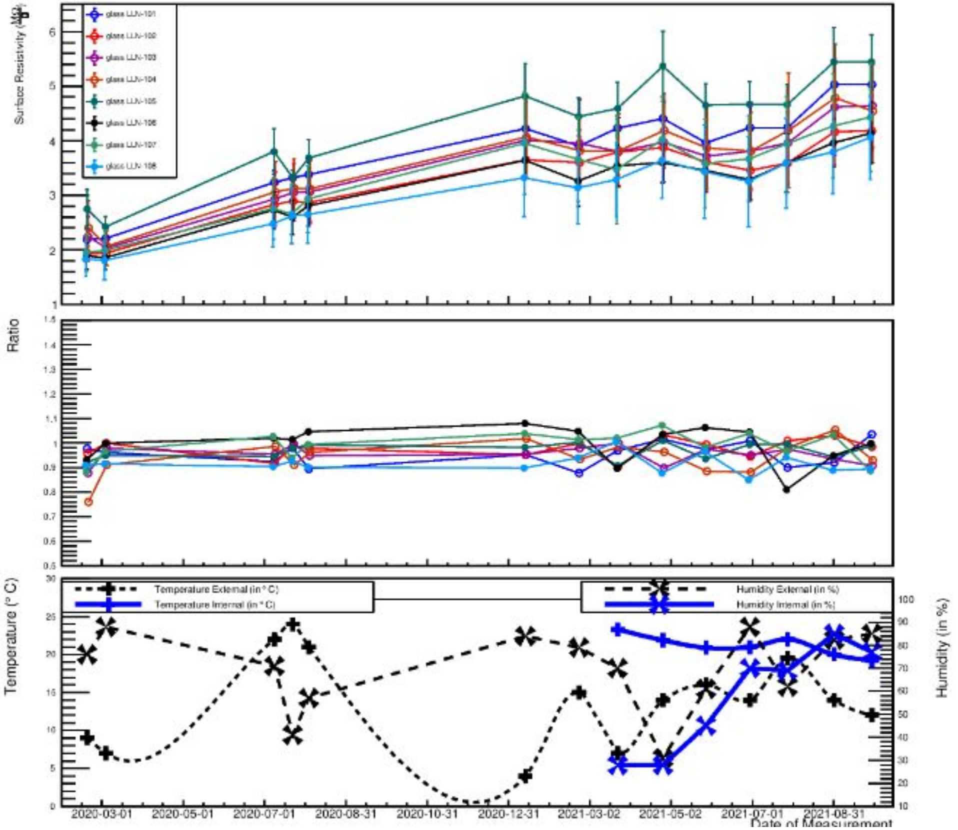
Middle: The ratios of the surface resistivity measurement taken at two different locations (center vs. average of the edges) of both plates as a function of the measurement date.

Bottom: data on temperature and humidity recorded during the measurement period. Fluctuations in surface resistivity measurements can be attributed to variations in these environmental parameters.

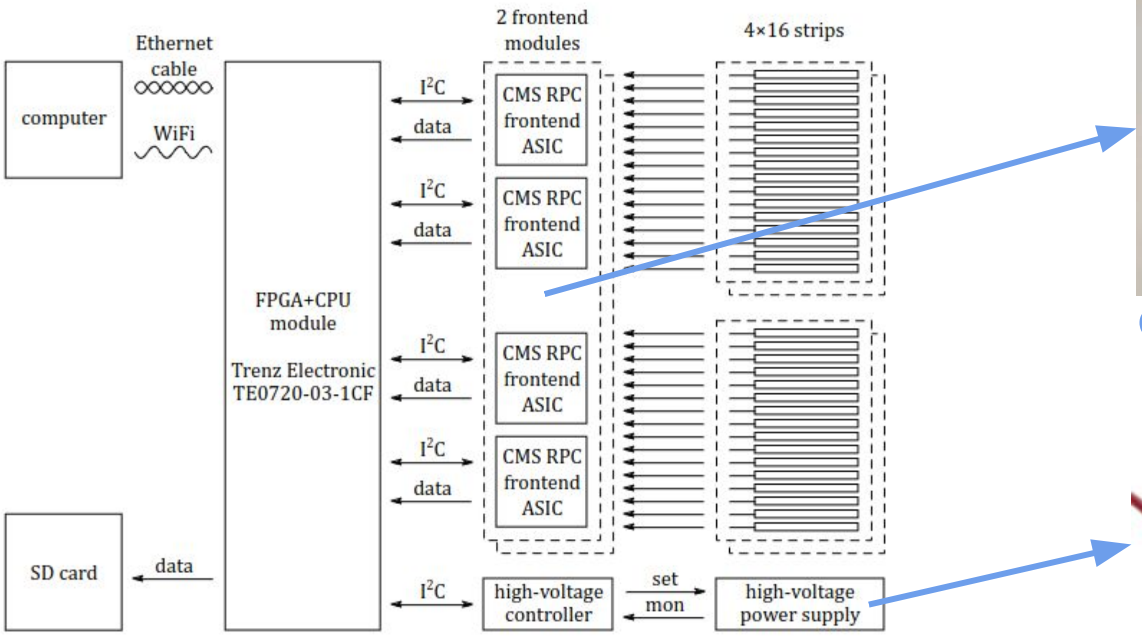


Serigraphy

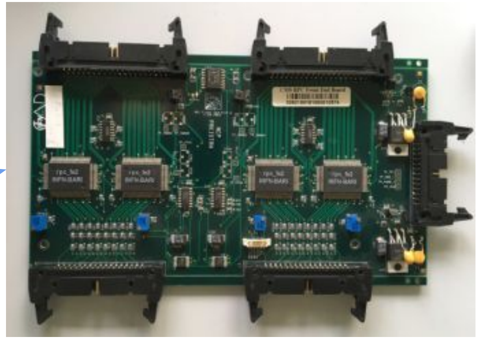
Evolution with time of the following observables of interest. Top: average surface resistivity of eight selected glass plates. The vertical bars represent the standard deviations of the measurements at nine different locations on the same plate. Middle: ratio, for each of the same glass plates, between the resistivity at the center and the average resistivity of the other eight locations. Bottom: temperature and humidity as measured externally (i.e. data from the local weather casting) and internally (i.e. data from an internal Arduino-based sensor)



DAQ system used for gRPC - A



Technical layout of the custom made DAQ



CMS RPC Front End Board

Iseg DSP mini
High Voltage Supply

PCB