RPC 2024
Santiago de Compostela (Spain)

Developmental Studies on the Performance Enhancement of Gas-Tight Resistive Plate Chambers (RPCs) for Muography Applications

9-13 September, 2024

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Centre for Cosmology, Particle Physics and Phenomenology (CP3), UCLouvain
On behalf of the UCLouvain, VUB/UGent and NISER groups

European Commission | Horizon 2020 European Union funding for Research & Innovation
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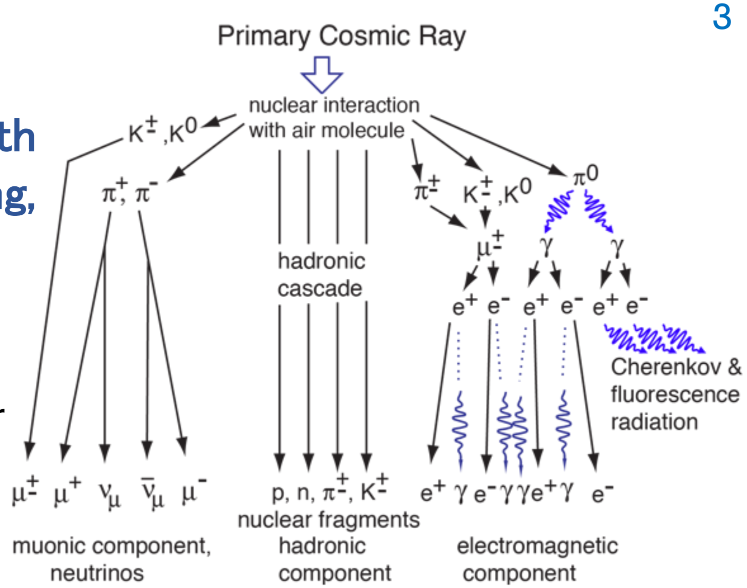
OUTLINE

- Background and Motivation
- Overview of RPC prototypes at all three institutes
- Detector Efficiency
- Surface Resistivity Monitoring Comparing Two Different Coating Methods
- Charge Distribution Measurement
- Absorption Muography Feasibility Test
- Future Outlook and Prospects

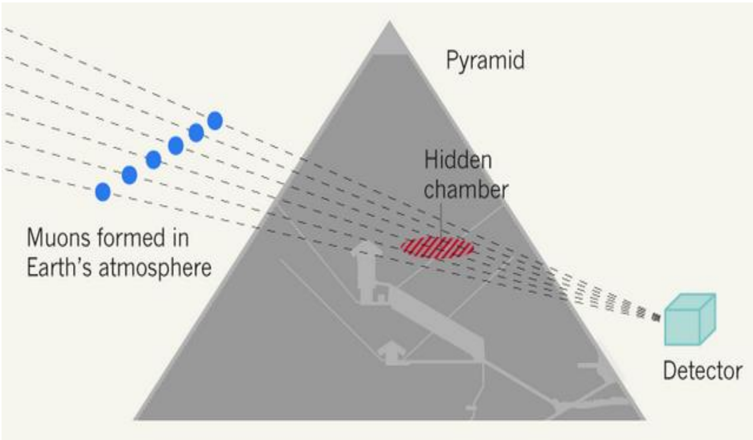
MUOGRAPHY

❖ **Imaging technique based on absorption and scattering of cosmic ray muons, with multidisciplinary applications spanning volcanology, archeology, civil engineering, nuclear waste characterization etc.**



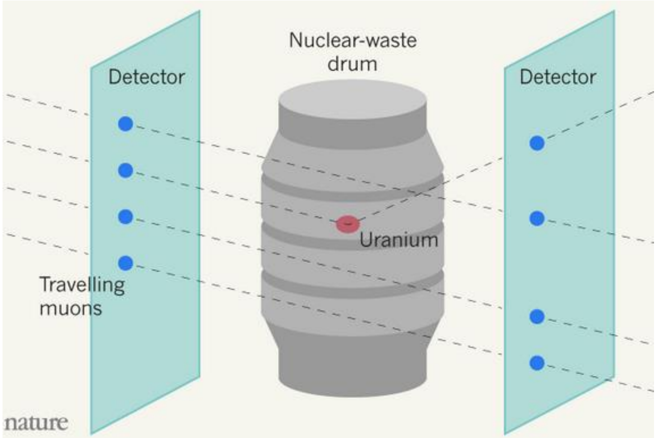
WHY COSMIC μ FOR IMAGING?

- Produced freely and abundantly in the interaction of primary cosmic rays with the upper atmosphere
- Most penetrating part of the cosmic shower
  - Not involved in the strong interaction
  - Low probability of generating electromagnetic cascades up to very large momenta
  - Minimal energy loss due to ionization
- At sea-level, cosmic muons have an average energy of roughly 4 GeV and their flux is around 1 muons per sr. per cm^2 per minute (much lower rate compared to most HEP use cases)



Slow and applicable for very large targets such as volcanoes, pyramids, tunnels overburden, etc.

ENERGY LOSS → ABSORPTION/TRANSMISSION MUOGRAPHY



Fast and applicable for small and medium-sized targets such as nuclear waste monitoring, border safety and homeland security, etc.

COULOMB SCATTERING → SCATTERING MUOGRAPHY

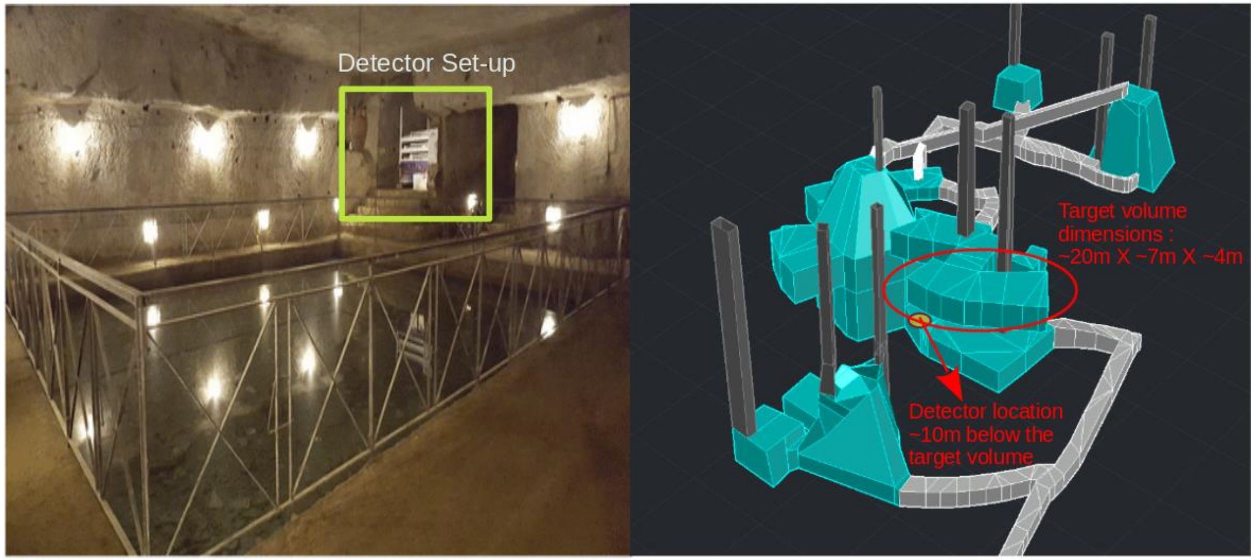
MOTIVATION

- **Typical use cases in muography involves challenging logistics and confined environments**
  - ✓ For example, archaeological and mining explorations, nuclear waste characterizations etc.
  - ✓ The point of observation closest to the target of interest is often located in narrow and confined areas
  - ✓ Limited room for instrumentation and other logistical challenges such as lack of power-supply

SPECIFIC DESIGN GOALS

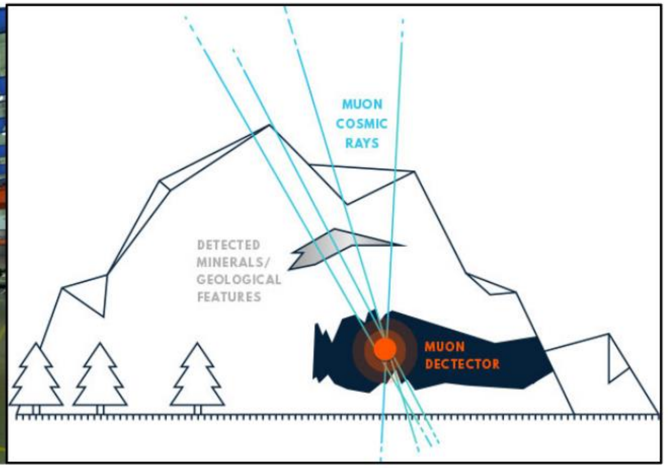
- Modular Geometry
- Gas Tightness
- Portability
- Versatility
- Robustness
- Autonomous Operation
- Safe and Cheap

With these design goals, our detector set-up can be optimized to a wide array of muography applications



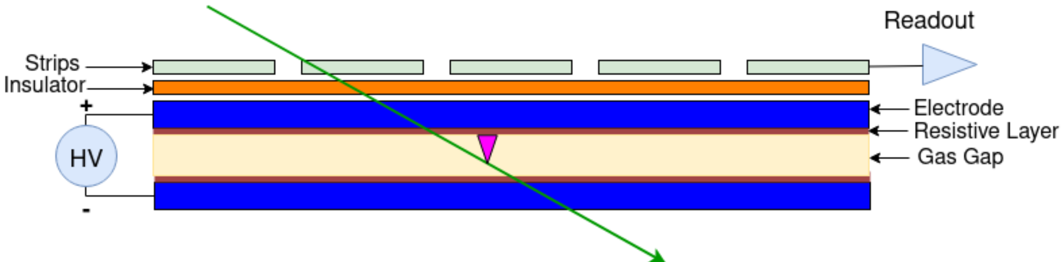
Figures from https://doi.org/10.1098/rsta.2018.0057

Typical nuclear spent-fuel storage.
(https://doi.org/10.1007/978-981-13-9901-5_6)



Demanding logistics for muon detector location for mining exploration.
(Lingacom Muon Systems : https://lingacom.com/)

RESISTIVE PLATE CHAMBERS (RPCs) FOR MUOGRAPHY



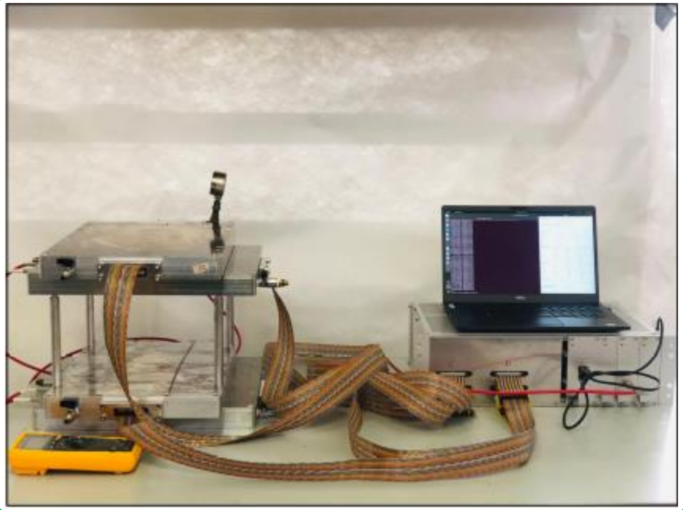
An ionizing particle passing through the gas gap and creating an electron avalanche towards the anode in RPC

Active Detection Component
CMS Gas mixture ($C_2H_2F_4$ – 95.2%, SF_6 – 0.3% and i-C_4H_{10} –4.5%)

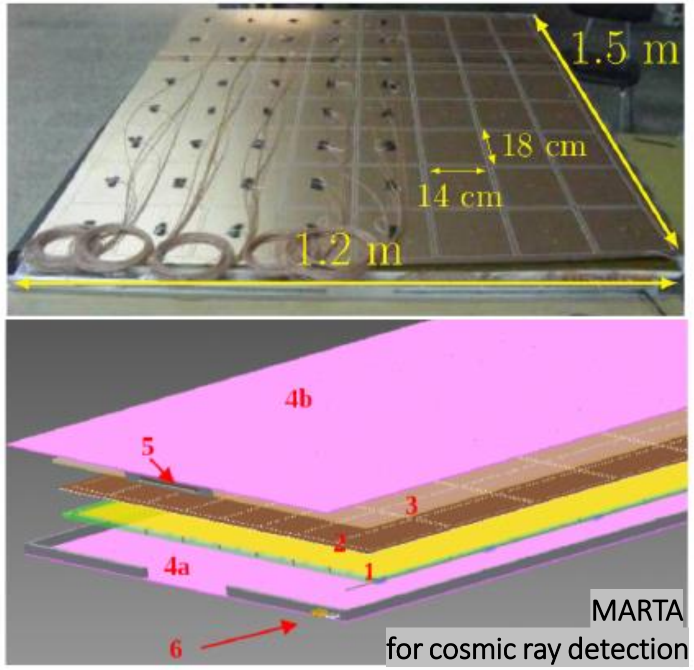
- **ADVANTAGES :**
  - Large chamber sizes at relatively low price
  - Good intrinsic spatial resolution (potentially <100 μm)
  - Excellent timing resolution (<50 ps) that can be used for better background rejection
  - Large area usage popular in muography (volcanology)

- **SOME CONSIDERATIONS:**
  - Gas mixture requirements (esp. in challenging logistics)
  - Conventionally operated with continuous gas flow to ensure homogeneity of the gas mixture over time
  - Stationary/static state of gas mixture inside the chamber may contribute to acceleration in polymerization on the detector surface
  - Stability in various environmental parameters such as temperature, humidity, pressure variations etc.
  - Power consumption for large amount of readout channels


TOMUVOL Collaboration
Béné, S. et al. TOMUVOL Collaboration (2013)
DOI: 10.13140/RG.2.1.3776.6161




University of Bristol
Baesso, P. et al. (2013)
DOI: 10.1088/1748-0221/8/08/p08006

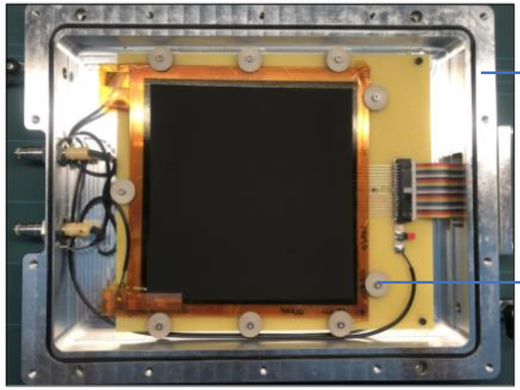


MARTA
for cosmic ray detection
Abreu, P. et al. (2018)
/https://doi.org/10.1140/epjc/s10052-018-5820-2

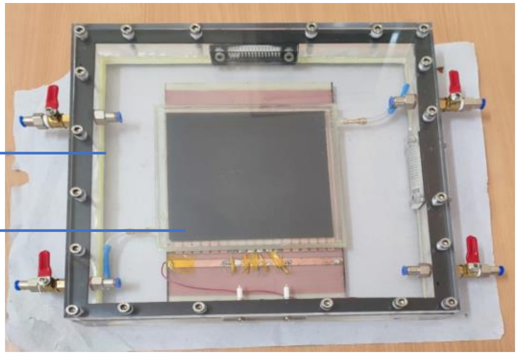
RPC PROTOTYPES

As part of the project, three small scale glass-based RPC prototypes with slightly different characteristics have been developed independently at three different institutes.

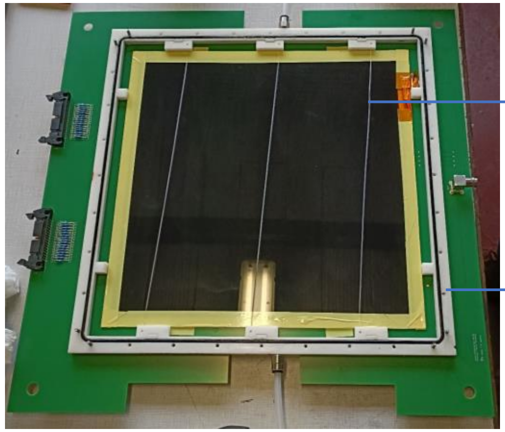
Detector	A	B	C
Institute	UCLouvain	NISER	UGent/VUB
Size	16 × 16 cm^2	16 × 16 cm^2	28 × 28 cm^2
Outer Casing	Aluminum casing	Standalone RPC housed in acrylic casing	Closed with top and bottom PCBs
Readout Strips	16-1D	16 × 16 – 2D	32 × 32 – 2D
Strip Pitch	1 cm	1 cm	0.8 cm
Gas mixture	95.2% Freon, 0.3% 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 (~ 4 MΩ/☐) and Hand-painted (0.5-1.0 MΩ/☐)	Spray gun (~ 1 MΩ/☐)	Spray gun (~ 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



gRPC-B



gRPC-C

RPC PROTOTYPES

As part of the project, three small scale glass-based RPC prototypes with slightly different characteristics have been developed independently at three different institutes.

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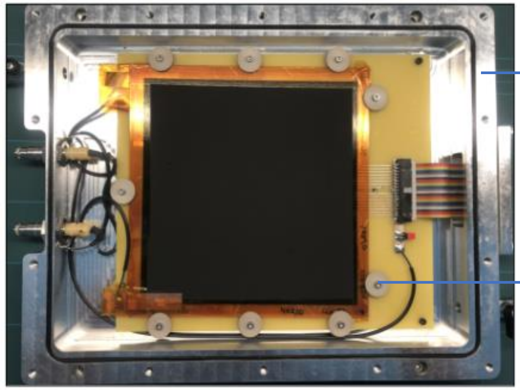
Strip Pitch	1 cm	1 cm	0.8 cm
Gas mixture	95.2% Freon, 0.3% SF6, 4.5% isobutane		
Gas Gap	1 mm Single gap	2 mm Single gap	[illegible] Double gap
Thickness of Electrodes	1.1 mm	[illegible] mm	1.1 mm
Resistive coating	[illegible]aphy (~ 4 MΩ/□) and Hand-painted (0.5–1.0 MΩ/□)	Spray gun (~ 1 MΩ/□)	Spray gun (~ 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)

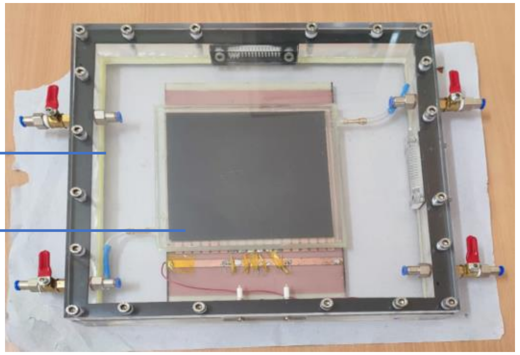
More details about this prototype in Raveendra's talk!!



Aluminum Casing

Round Edge Spacers

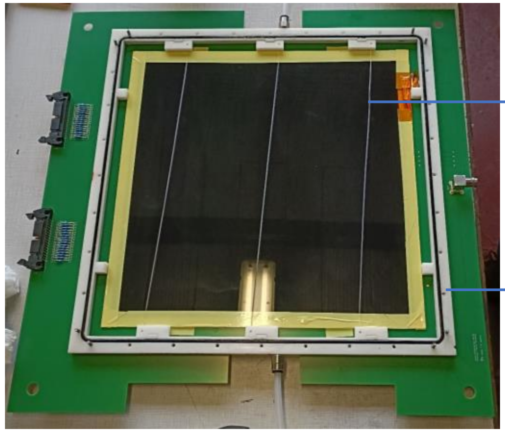
gRPC-A



Acrylic Casing

RPC

gRPC-B

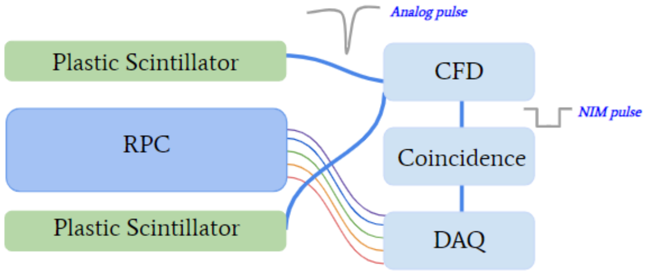


3D Printed Frame

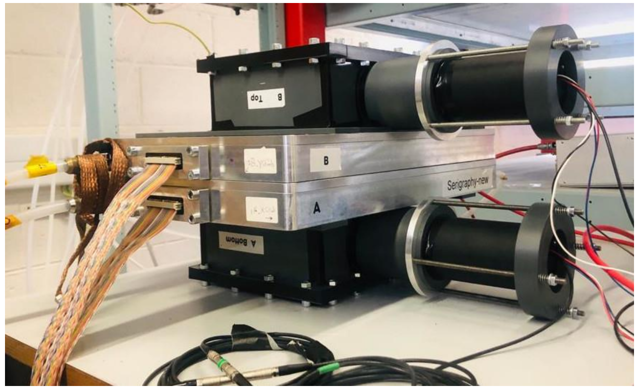
Fishline Spacers

gRPC-C

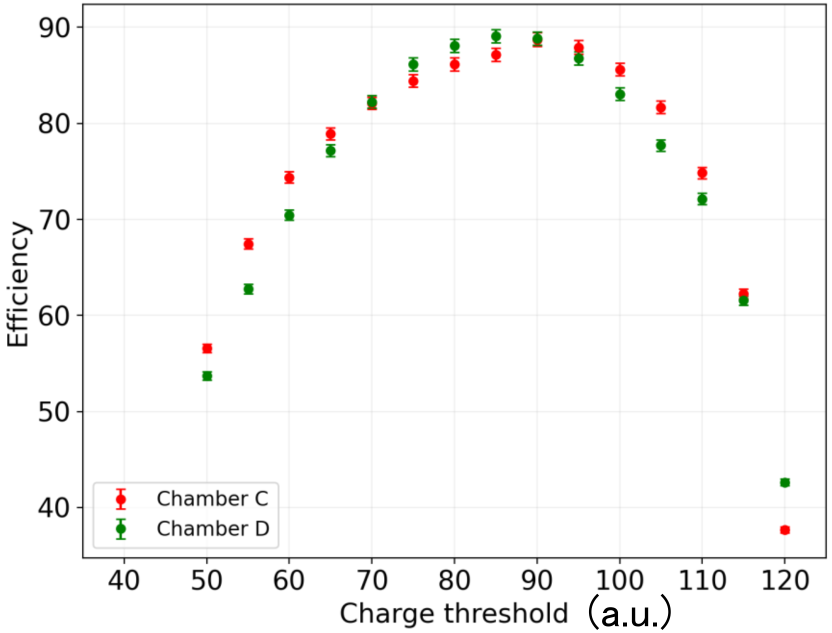
EFFICIENCY TEST FOR gRPC-A

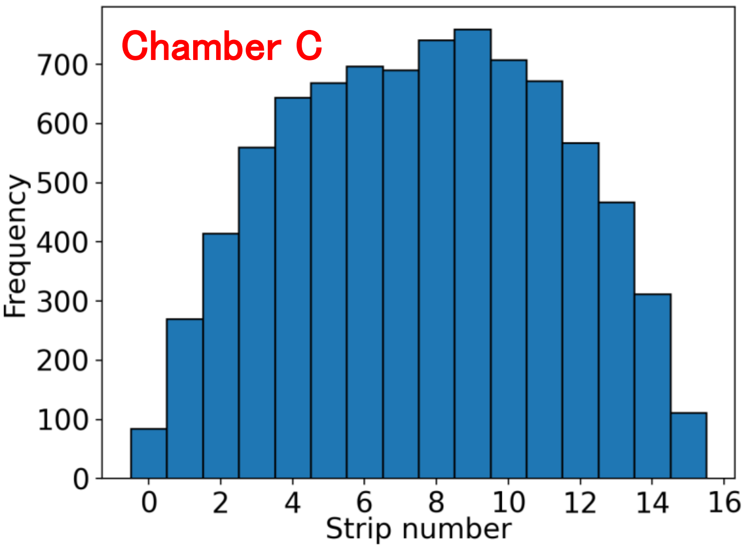


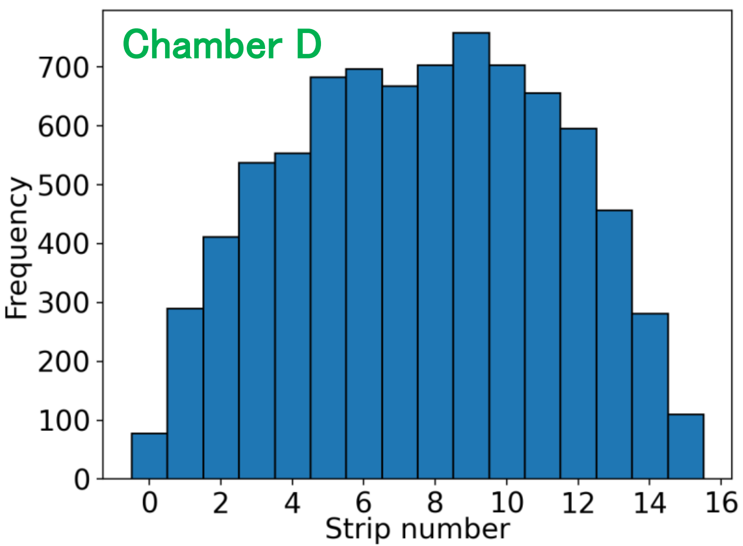
Schematics and Lab Set-up



- Plastic scint. pads with the same active area as the RPC coupled to PMTs used as external trigger to study the detector performance
- RPC pre-trigger signals from the logical OR of all 16 strips are collected in parallel as the coincident scint. trigger signal
- DAQ uses old CMS RPC FEB consisting charge sensitive preamplifiers and discriminators that are processed by FPGA for data-collection

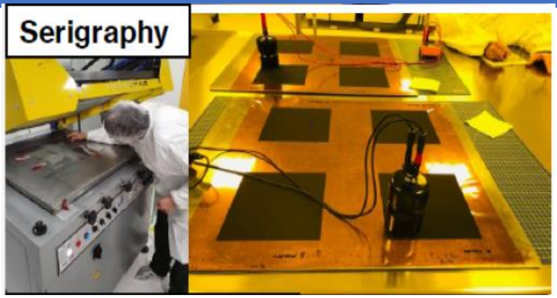




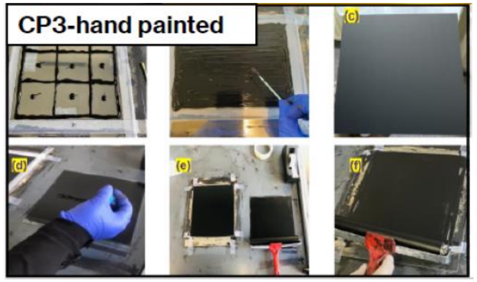


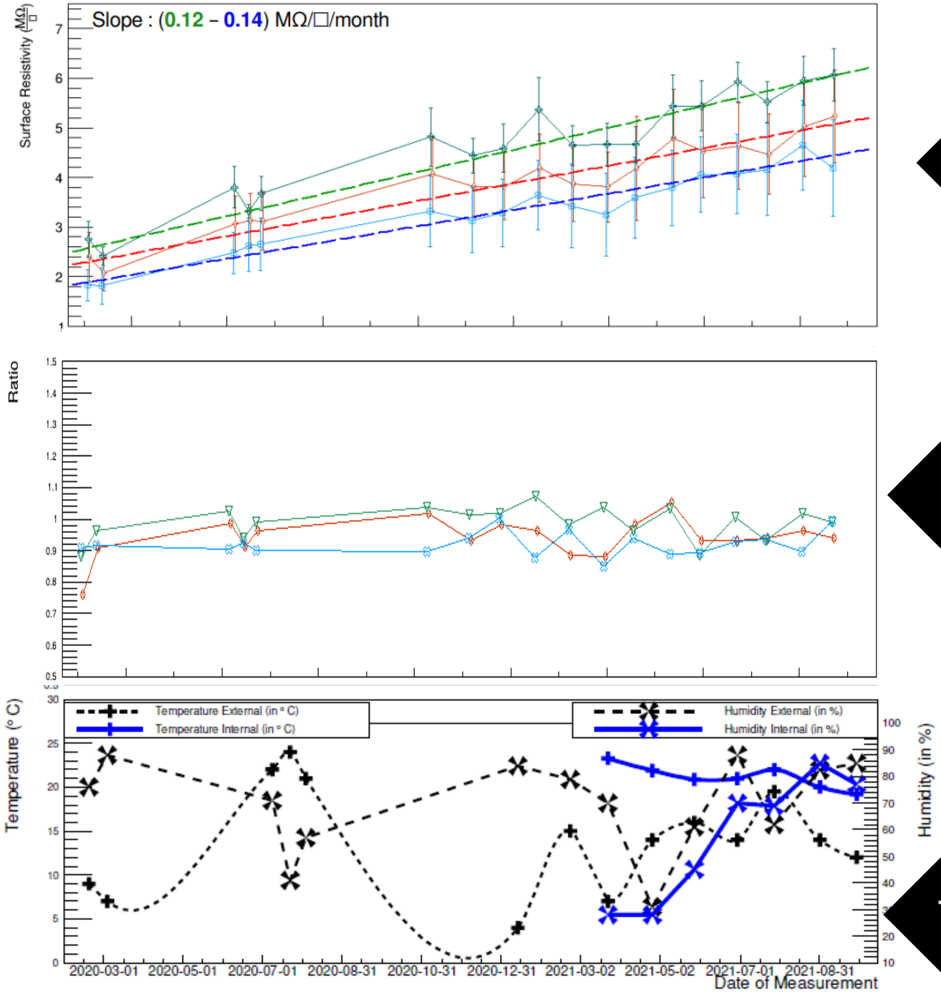
- In general, efficiency decreases with increasing charge threshold values for lower voltages
- However, because of the suppression of signal and higher noise, the efficiency is lower for low threshold values
- The efficiency and occupancy for two identical chamber in the same orientation follows the same trend with both reaching efficiency of roughly 90%

gRPC-A SURFACE RESISTIVITY OVER TIME



Stable surface resistivity and the uniformity of the resistive layer made at CP3 (inspired by UGent/VUB group) in comparison to serigraphy plates which showed an increase in avg. surface resistivity in the range 0.12–0.14 MΩ/□ per month



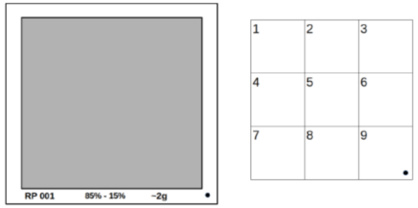


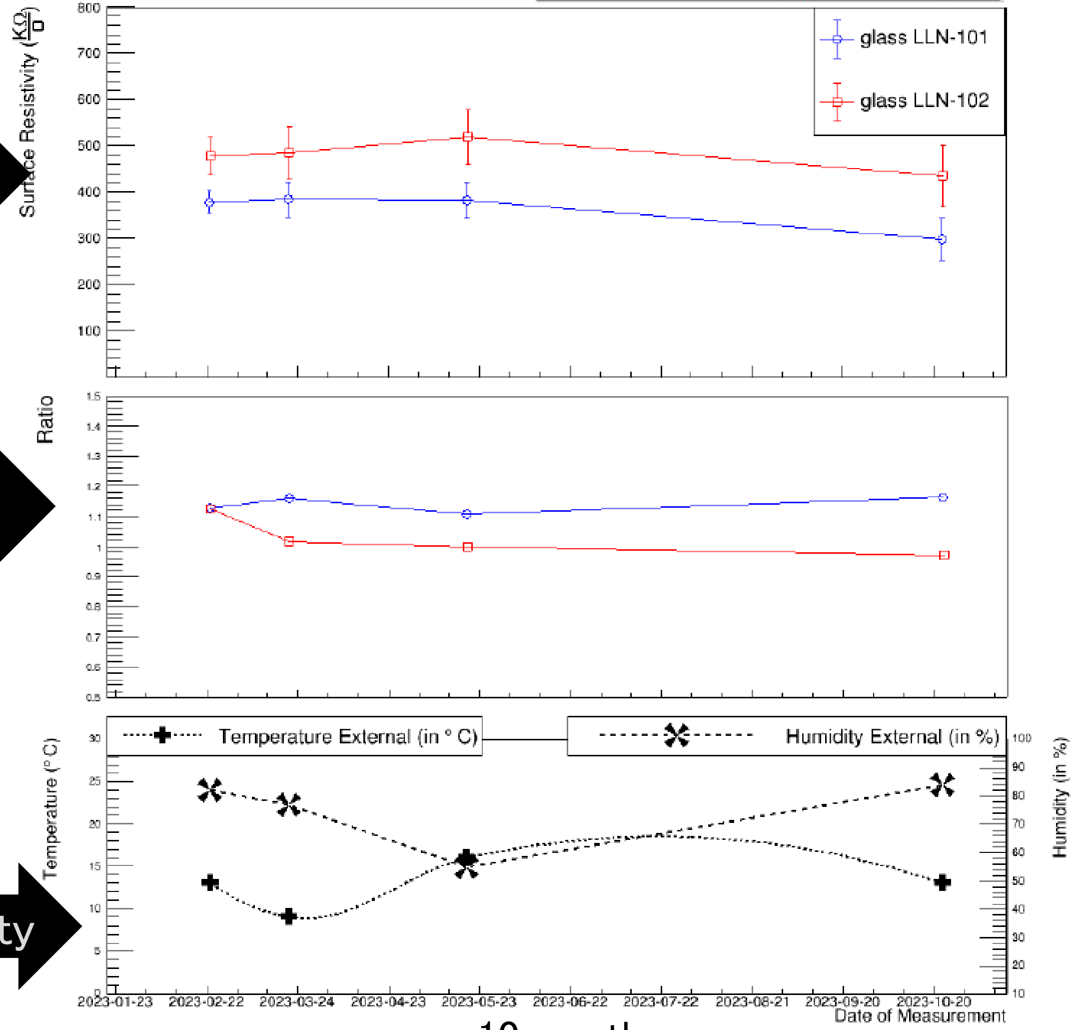
1.5 years

Avg. surface resistivity

Surface resistivity ratio

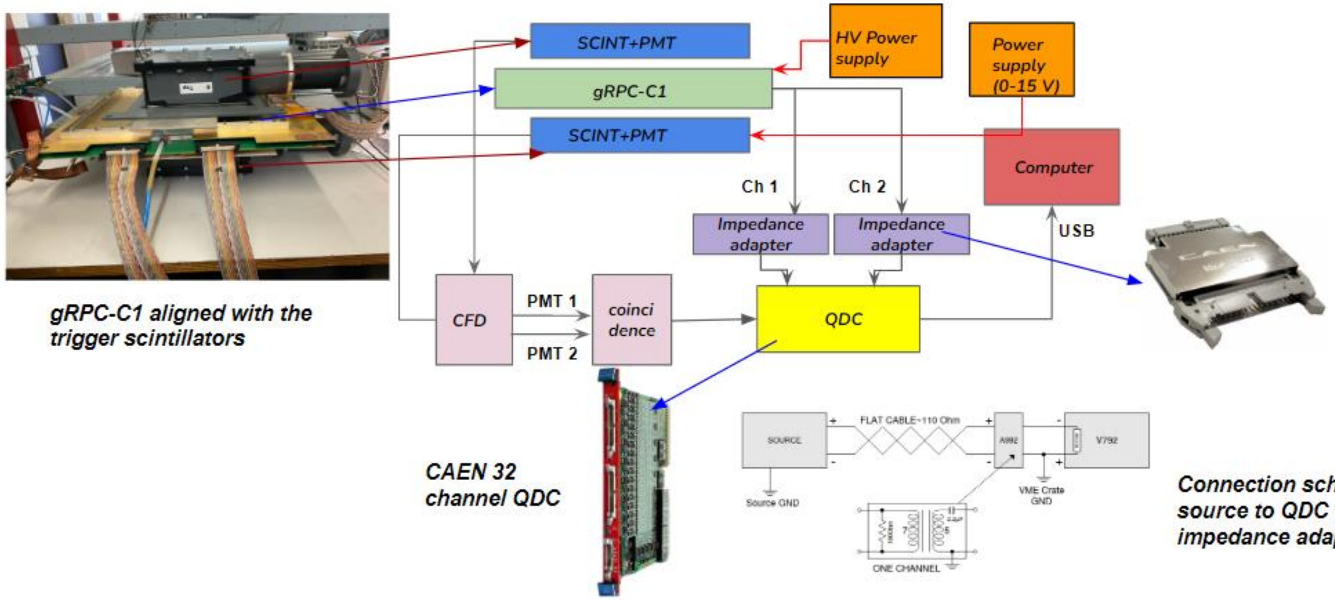
Temperature and Humidity





10 months

CHARGE DISTRIBUTION MEASUREMENT FOR gRPC-C

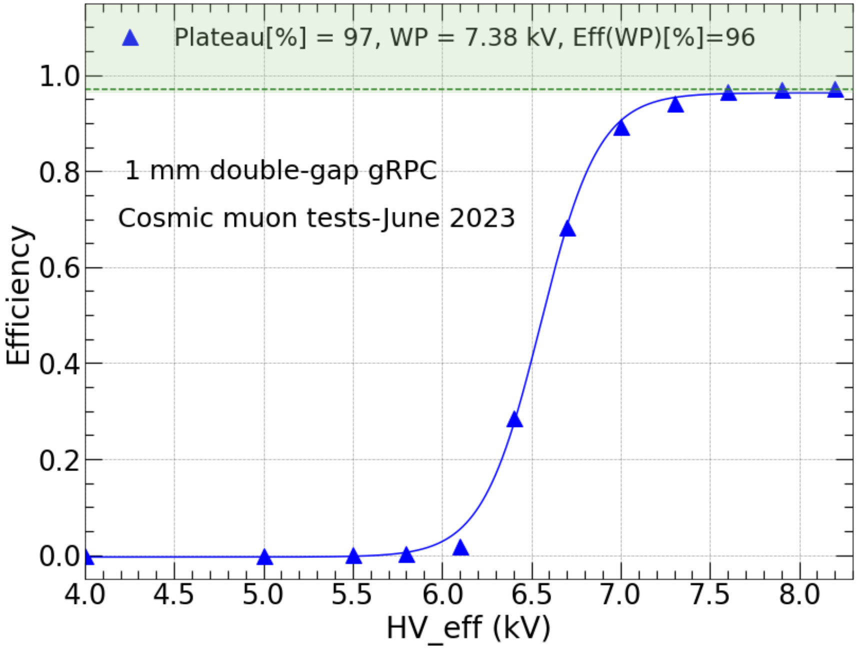


gRPC-C1 aligned with the trigger scintillators

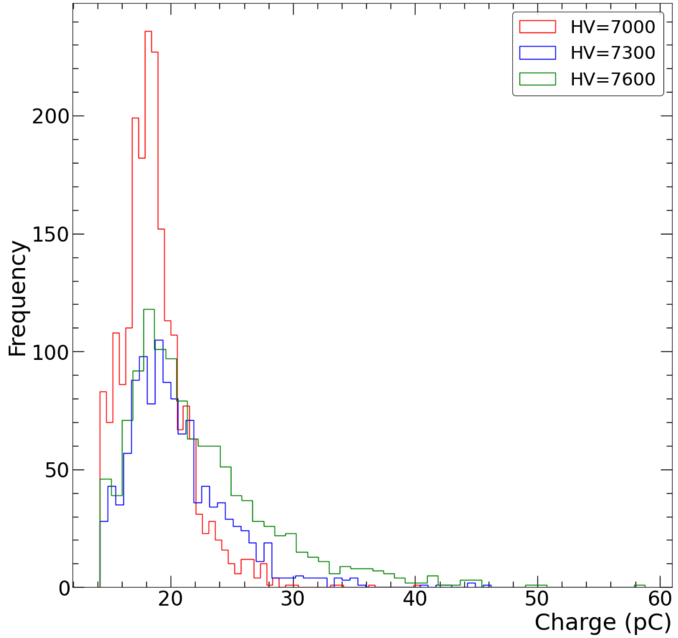
CAEN 32 channel QDC

Connection scheme of source to QDC with impedance adapter

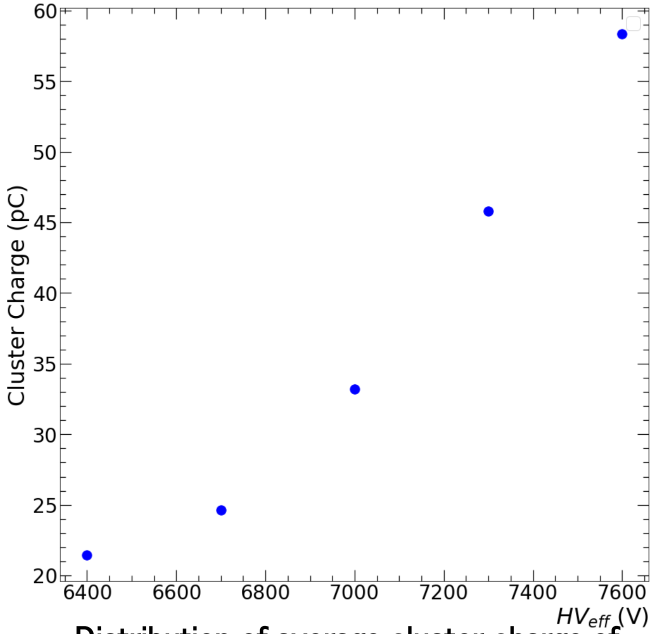
- Charge distribution was measure for gRPC-C using the CAEN QDC, with the conversion factor: ***1 QDC count = 0.098 pC***
- Event selection criteria used for this measurement: 1) QDC count > channel threshold, 2) Cluster multiplicity < 3 and 3) Cluster size < 4
- Cluster charge is the sum of charge collected from all the strips in a cluster while avg. cluster charge is the avg. charge of all clusters in the data collected at each HV points
- As expected, pulse charge increases as the HV increases, ranging from 22 pC at 6.4 kV to 58 pc at 7.6 kV



Operating high voltage



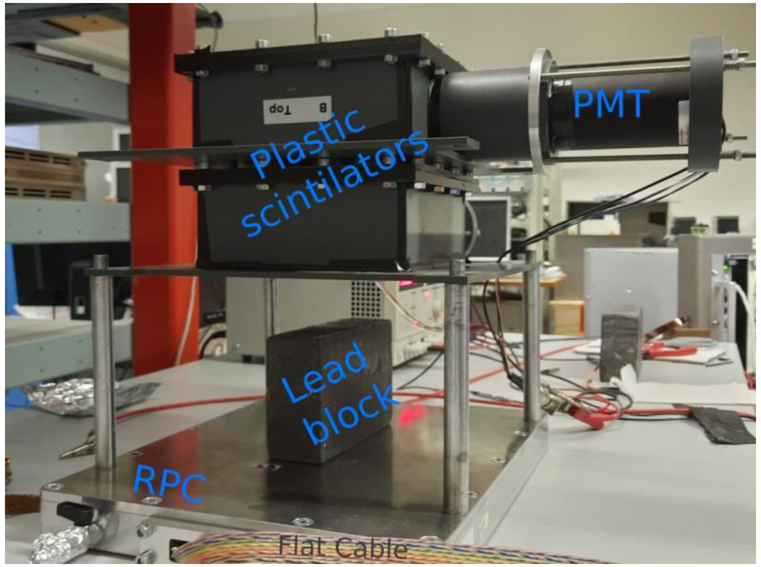
Distribution of pulse charge acquired from the strips at 3 different voltages in the avalanche region

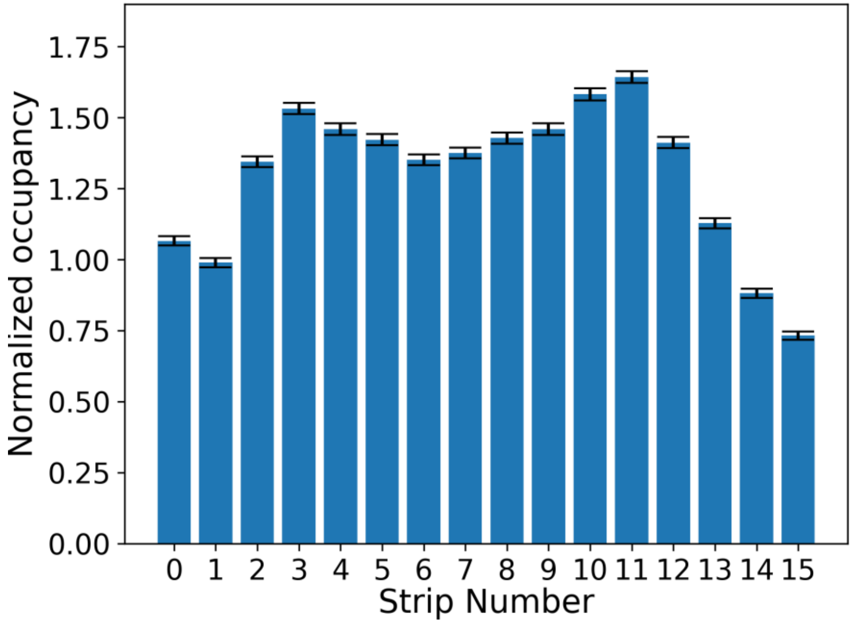


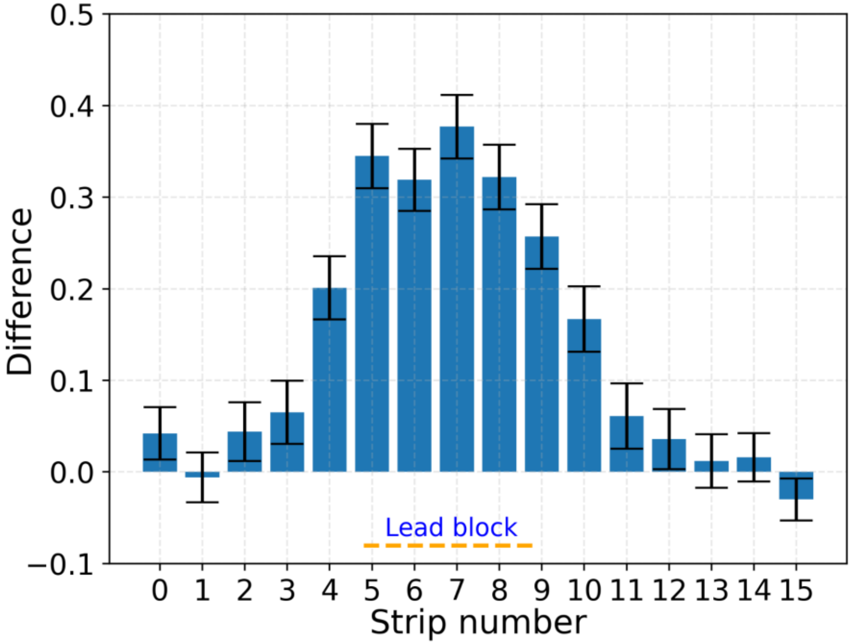
Distribution of average cluster charge of clusters with respect to the high voltage

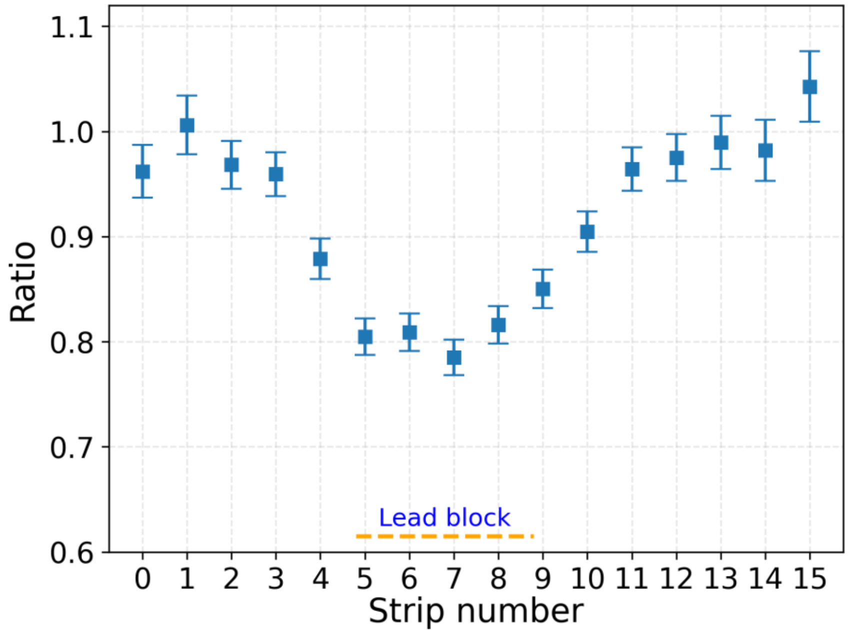
ABSORPTION MUOGRAPHY WITH gRPC-A1

- A small scale muon absorption feasibility study was carried in the lab
- The experimental setup consists of two plastic scintillators on top and only **ONE** 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 (as expected!!)**
- Scattering based muography use case have also been explored with Geant4 simulated data of our RPCs



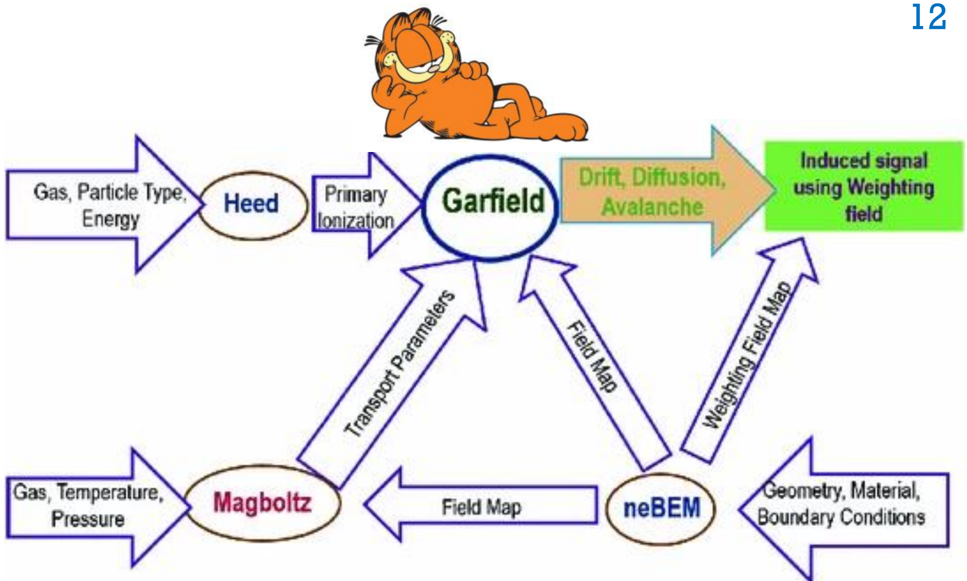






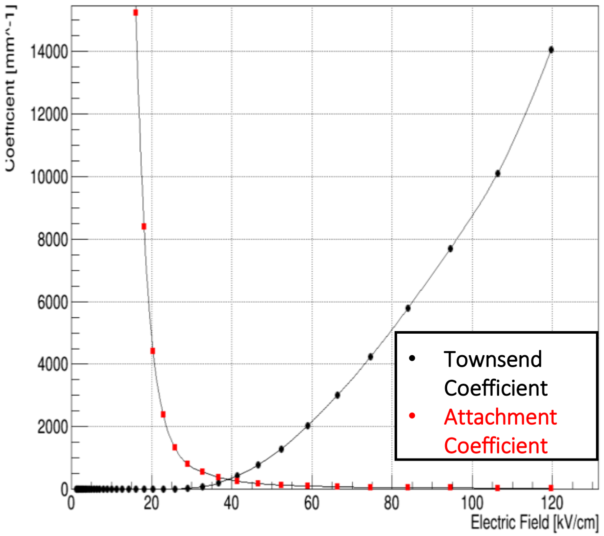
FUTURE OUTLOOK AND PROSPECTS

- Garfield++ based simulation framework has been developed and is currently in the testing and validation phase; we intend to use the simulation to guide our detector optimization. In particular, we plan to study:
  - ✓ Study the dependence of RPC response (signal-to-noise ratio) on strips width and pitch sizes
  - ✓ Effects of external parameters (temperature and pressure), which is crucial in outdoor detector use, typical for most muography applications
  - ✓ Possibility of switching to eco-gas mixture based on RPC performance with new gas mixture



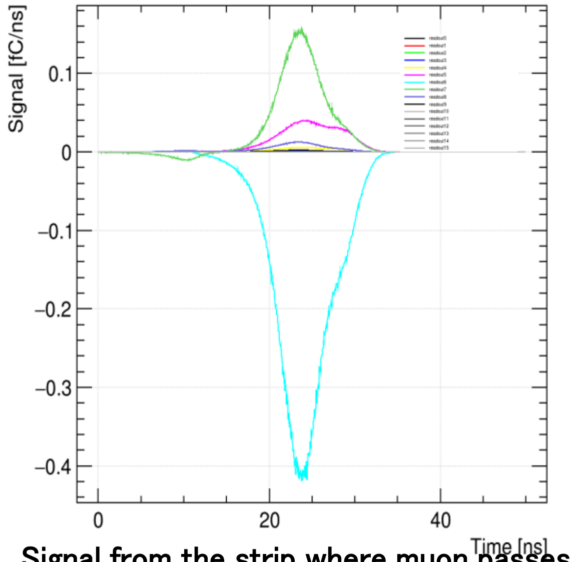
Mukhopadhyay, S. (2018). Device Physics Simulation of Gaseous Ionization Detectors. DOI : 10.1007/978-981-10-7665-7_6

- Switching from CMS RPC FEB to MAROC 3A and PETIROC based DAQ to increase the readout granularity
- Testing new prototypes requiring lower gas volume and better modular design with reduced casket size
- Long term stability test for efficiency, and ageing of resistive coating over time
- Muon telescope for tracking with two vertical and two horizontal coordinates (improving DAQ to have 2D information from same RPC)



Townsend and Attachment Coefficients for our gas mixture as a function of applied electric field

Simulated Induced RPC signals



Signal from the strip where muon passes shown in cyan, and the cross-talk signal in the two neighboring strips on either side shown in green and magenta

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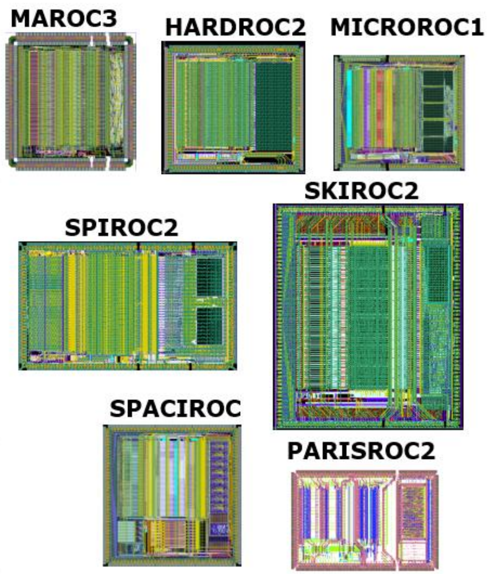
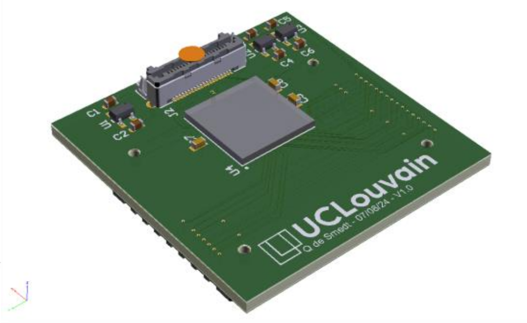
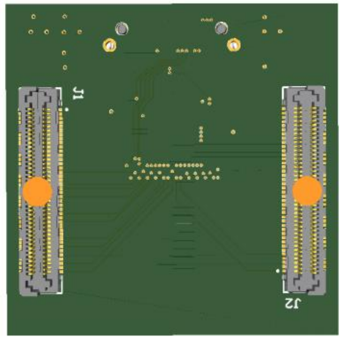
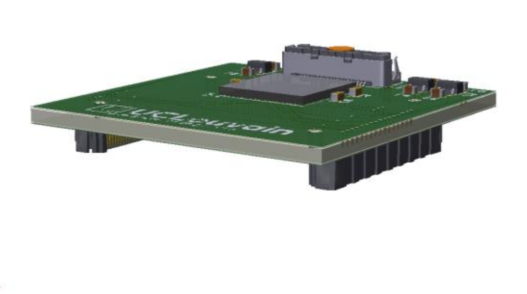
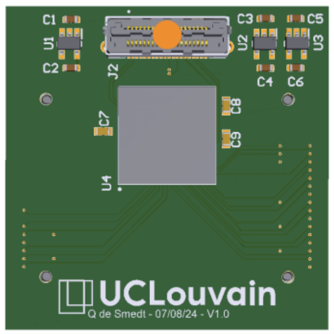
Chip	Detector	CH#	DR (Q)
MAROC	PMT	64	-2f-50pC
SPIROC	SiPM	36	+10fC-200pC
SKIROC	Si	64	+0.3fC-10pC
HARDROC	RPC	64	-2fC-10pC
PARISROC	PM	16	-5fC-50pC
SPACIROC	PMT	64	-5fC-15pC
MICROROC	μMegas	64	-0.2fC-0.5pC
PETIROC	SiPM	32	50fC-300pC



http://omega.in2p3.fr



MACROC based DAQ design and development started at CP3, UCLouvain

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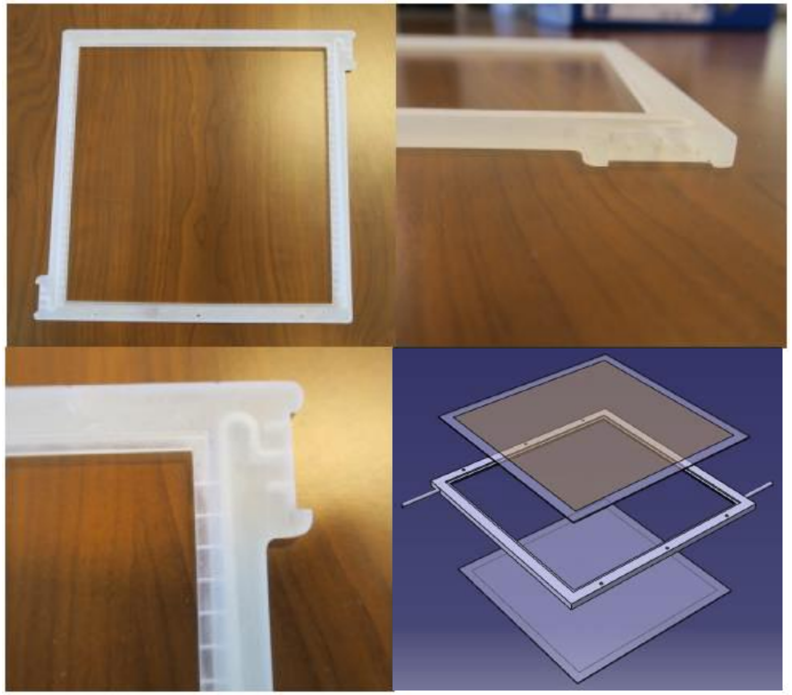
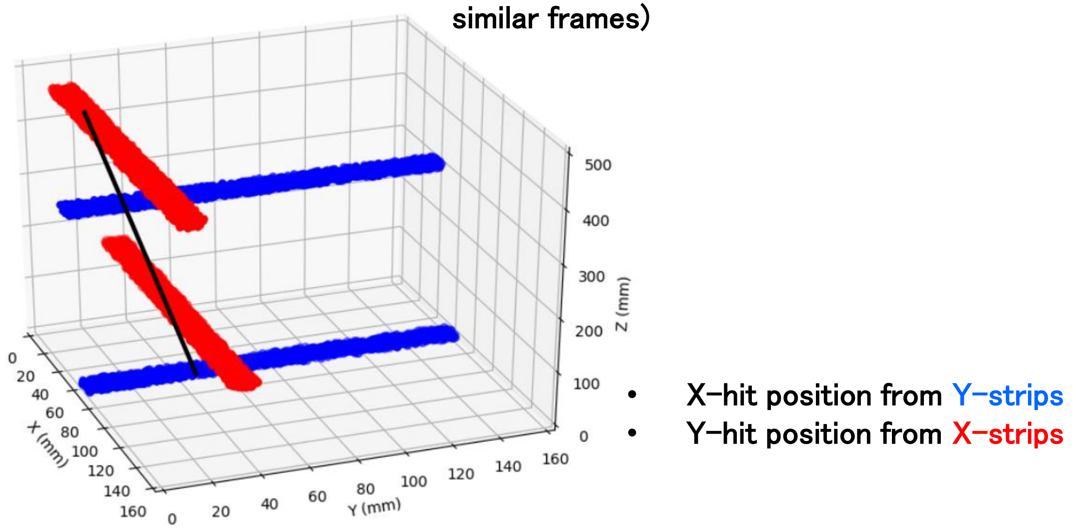


3D printed frame that requires lower gas volume only in the gas gap instead of the entire outer casing in the current version (for gRPC-A but gRPC-C is already using similar frames)



At least, 4 working RPC layers required in order to reconstruct the muon tracks with current prototypes (2 layers if bi-dimensional info can be obtained from one RPC layer)

COLLABORATION

VUB

- M. Tytgat
- A. Salaman (Former member @ UGent)

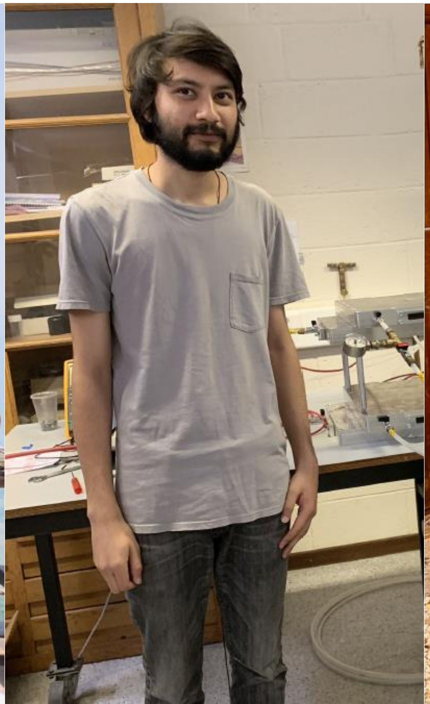
UCLouvain

- A. Giammanco
- E. Cortina Gil
- S. Basnet
- M. Al-Moussawi
- V. Kumar
- S. Ikram
- R. M. I. D. Gamage (Former Member)

NISER

- R. Karnam
- V. K. S. Kashyap
- B. Mohanty
- A. Chauhan (Former Member)

We also acknowledge the help and support of electronics technicians and machinists at all three institutes.

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THANK YOU FOR YOUR ATTENTION!

Back-up Slides

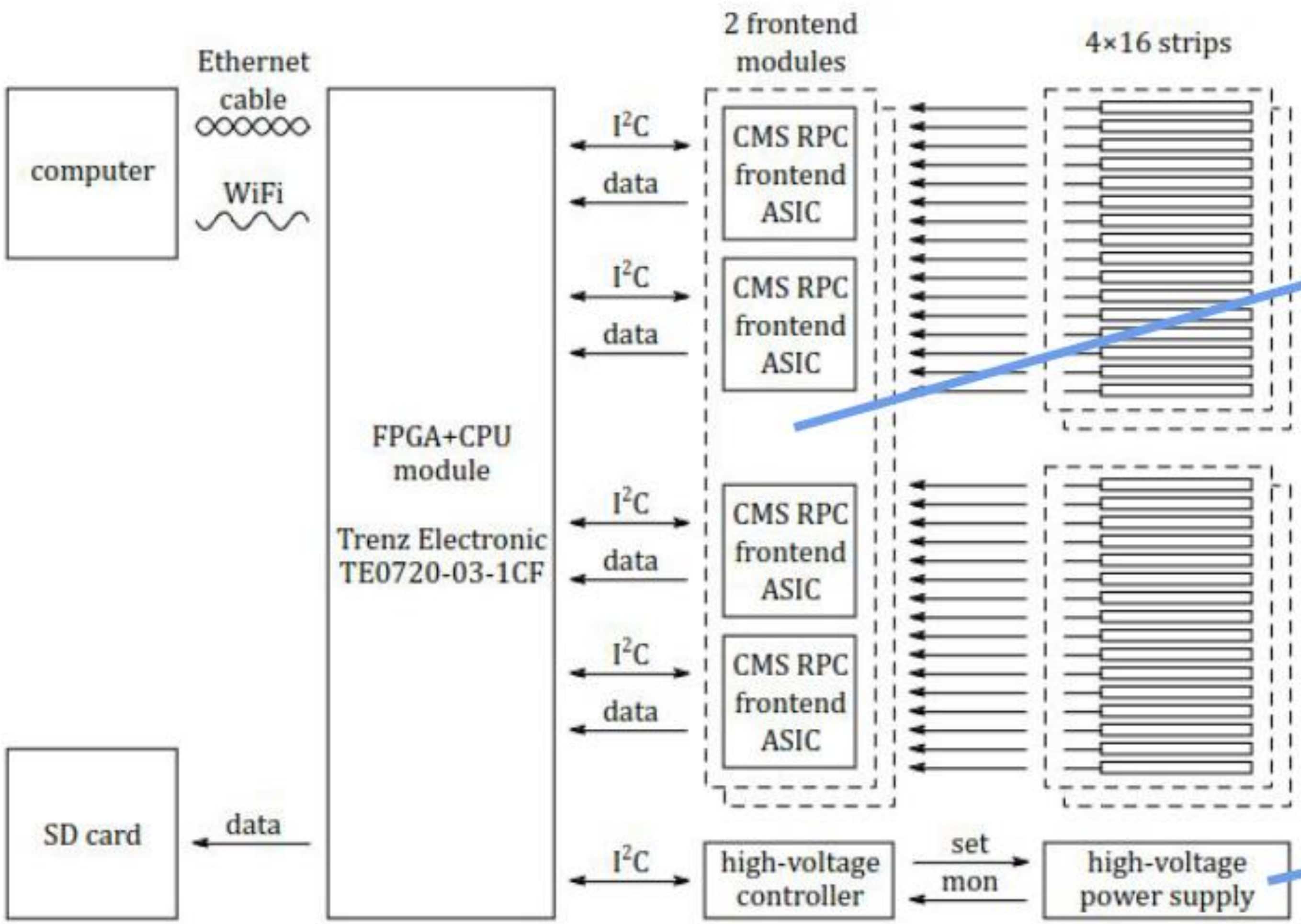
POPULAR DETECTOR TECHNOLOGIES IN MUOGRAPHY

Type	Surface Area	Resolution	Construction	Readout	Cost
Plastic Scintillators					
Square Bars	1–4 m^2	>10 mrad	Simple	Simple	Low
Triangular Bars	1–2 m^2	<10 mrad	Simple	Medium	Medium
Scintillating Fibers	1–2 m^2	0.1 mrad	Medium	Complex	High
Gaseous Detectors					
Proportional Tubes	1–4 m^2	10 mrad	Simple	Simple	Low
Multi-wire Chambers	>4 m^2	<1mrad	Medium	Simple	Medium
Drift Chambers	>4 m^2	0.1 mrad	Complex	Complex	High
Resistive Plate Chambers (RPCs)	>10 m^2	0.1 mrad	Simple	Medium	Low
Nuclear Emulsion Detectors	>4 m^2	0.1 mrad	Simple	Complex	Low

Lorenzo Bonechi, Raffaello D’Alessandro, and Andrea Giammanco. "Atmospheric muons as an imaging tool." *Reviews in Physics* 5 (2020): 100038.

Resistive Plate Chambers (RPCs) are popular for muon detection in many large and small scale conventional HEP experiments. Due to their ease of assembly, low production cost, versatility and good resolution, it was chosen as the optimal choice for our portable muography detectors

DAQ system used for gRPC – A



Technical layout of the custom made DAQ

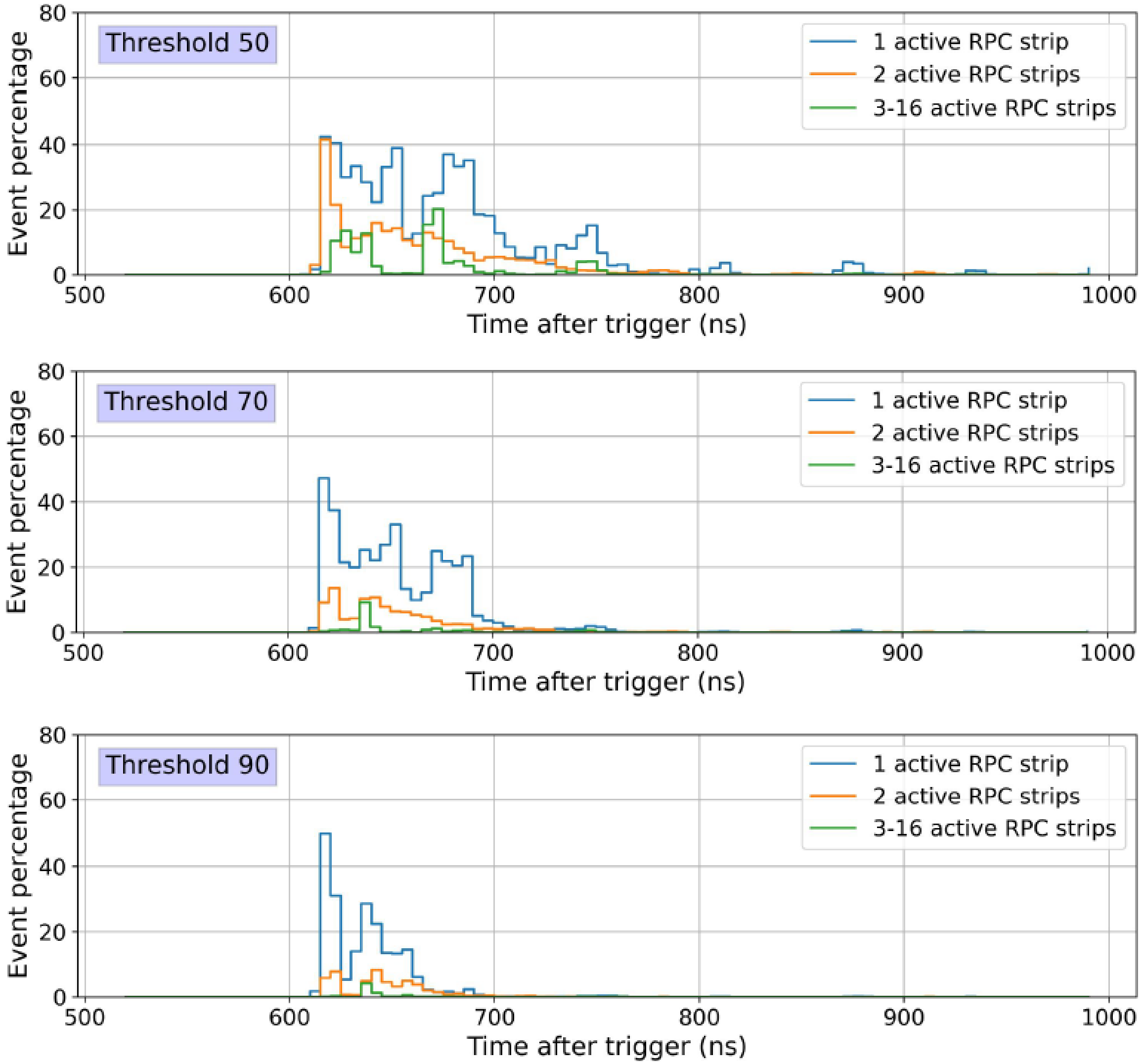
CMS RPC Front End Board

Iseg DSP mini
High Voltage Supply

Noise analysis

(gRPC-A)

- ➢ 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

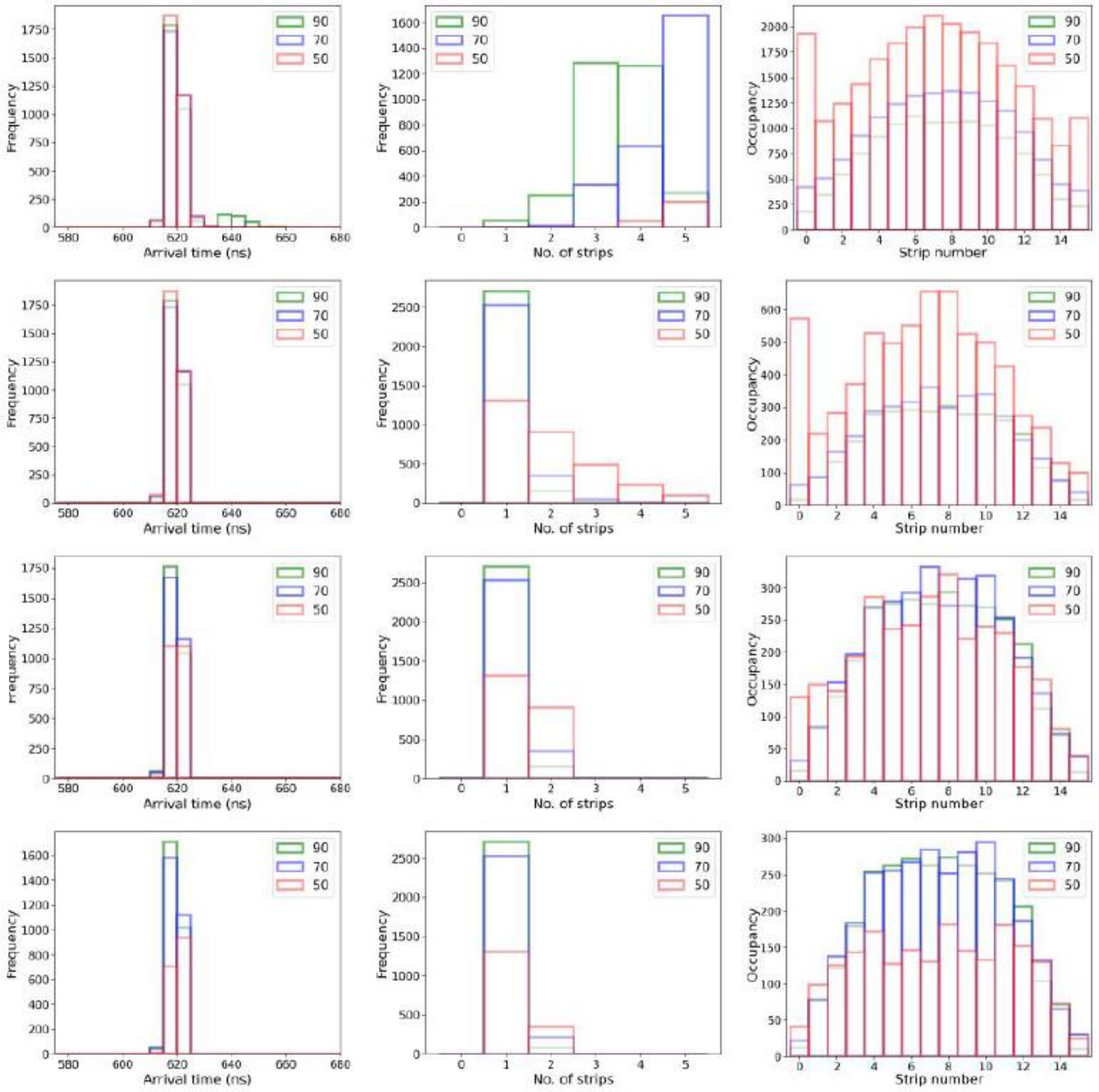


gRPC-A @ UCLouvain

Filters for offline noise reduction (gRPC-A1)

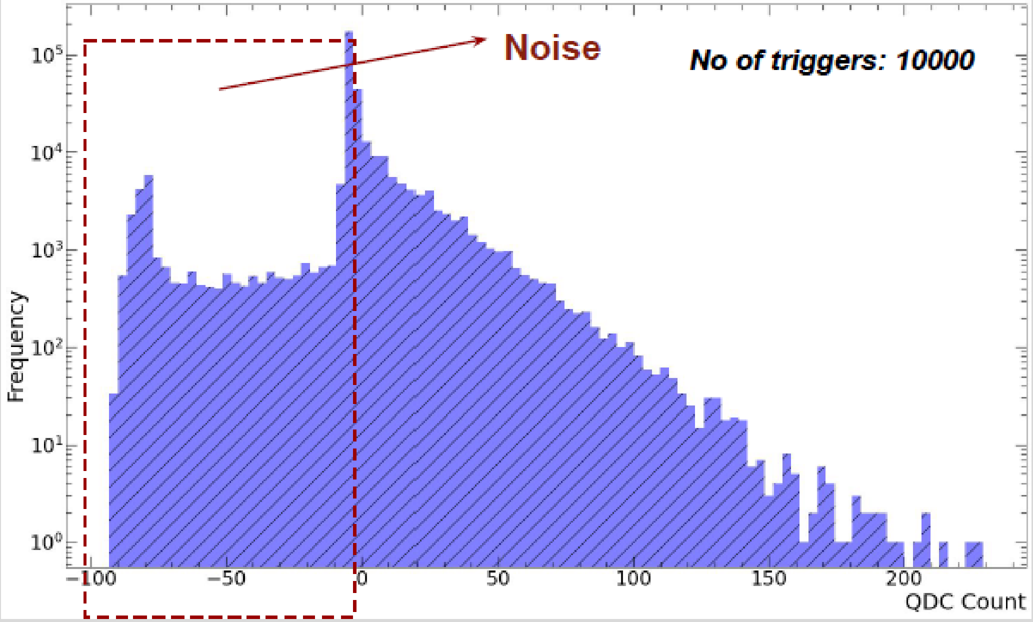
- Time filter
- Strip multiplicity
- No. of muons per event

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 %



CAEN-QDC based data taking: results

Results of the performance studies of the double gap chamber gRPC-C1 obtained from the data collected using the CAEN QDC:



Distribution of QDC_{val_i}-QDC_{thr_i}
Where i= 0 to 31

- For event selection, a threshold (QDC_{thr}) is applied to the data collected from each QDC channel
- QDC_{thr} is estimated from the Pedestal data collected :
  QDC_{thr} (Channel$_i$)= $\mu_i + 3\,\sigma_i$;

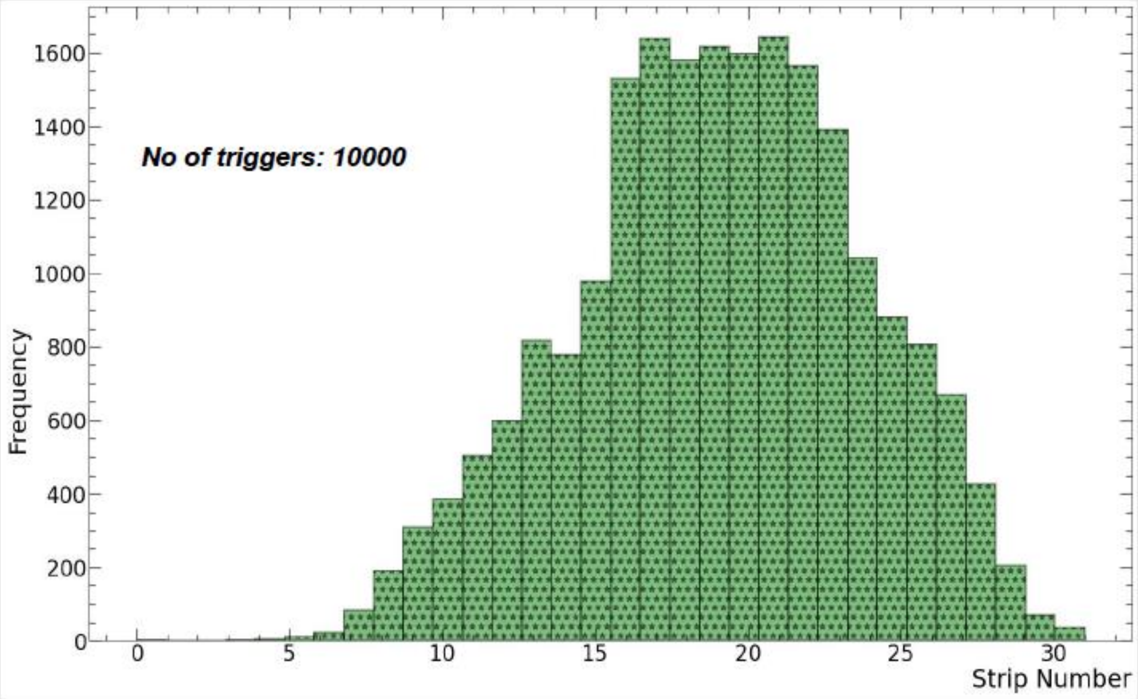
  Where μ_i= Mean ($QDC_{pedestal\_i}$),

  $$\sigma_i = \sqrt{\frac{\Sigma(QDC_{pedestal_i} - \mu_i)^2}{No\ of\ QDC_{pedestal_i}}}$$
- A strip$_i$ is considered as part of the event only if:

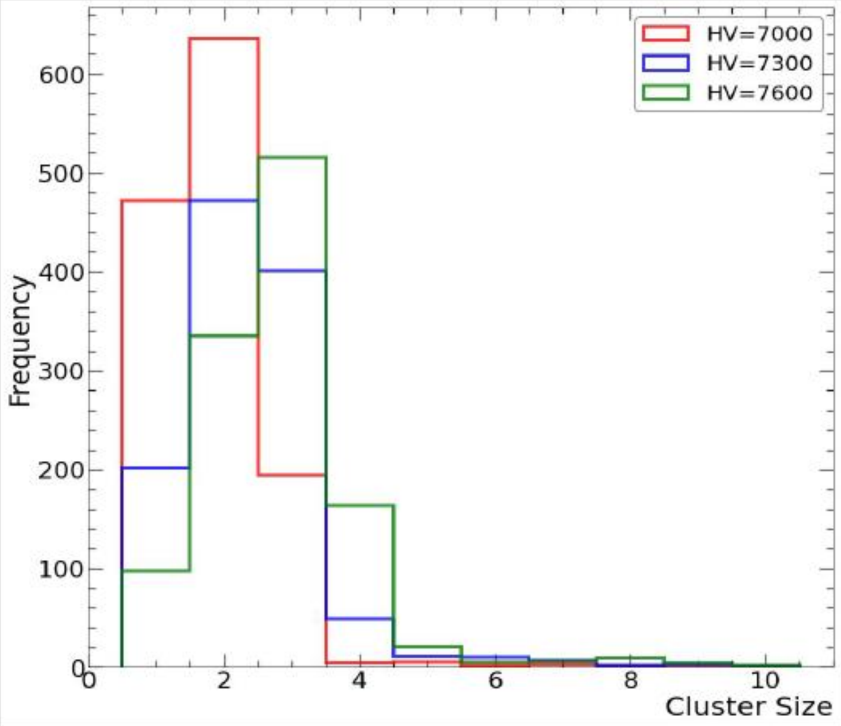
  $QDC_{val\_i} > QDC_{thr\_i}$

Work done by A. Samalan et al.

CAEN-QDC based data taking: results



Occupancy distribution at working point HV=7000 V



Cluster Size distributions at 3 different HV in the avalanche region (no of triggers in all cases =1000)

- The observed shift to the right is attributed to the off-center placement of trigger scintillators.
- The small size of the scintillators (16x16 cm) in comparison to the RPC active area (28x28 cm) results in a reduction in statistics across approximately 16 strips

Work done by A. Samalan et al.