Small-area Portable Resistive Plate chambers for Muography

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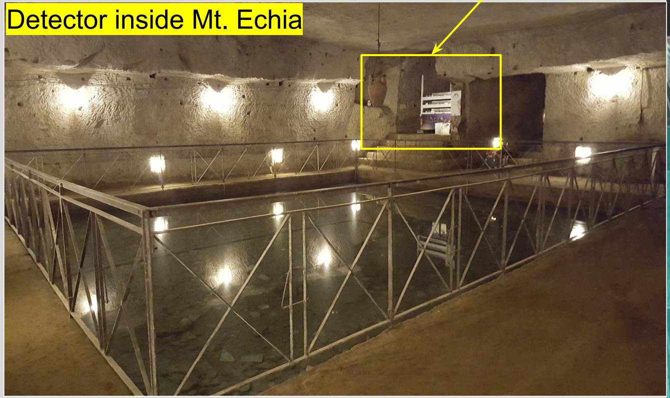
Motivation

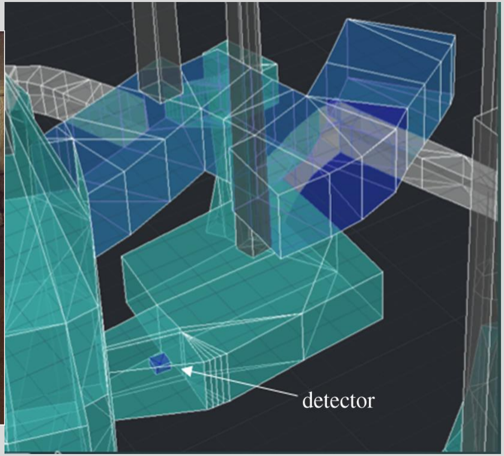
Portable muon telescopes are mainly used to conduct experiments in confined environments

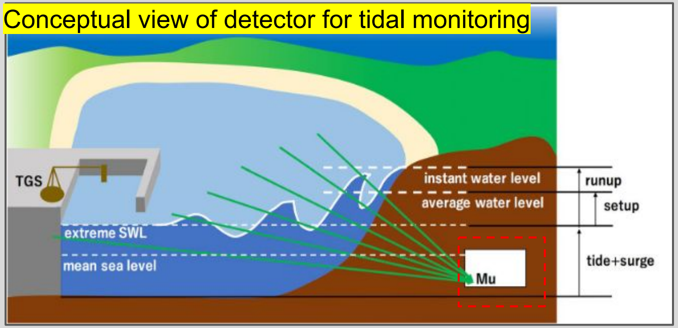
- Limited space to install the experimental setup
- Logistical challenges in terms of power supply, cabling, etc.
- Example applications:

  Archeological and mining explorations, nuclear waste characterisations, underground geophysical experiments



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." *Journal of Instrumentation* 15.05 (2020): C05030

Detector Technologies for Muography

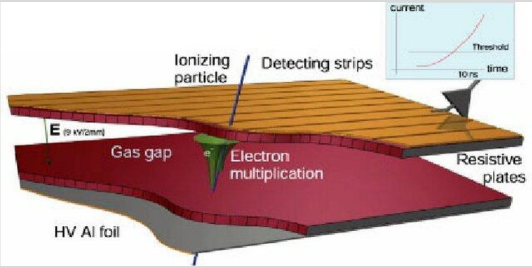
Type	Surface	Resolution	Construction	Readout	Cost
Plastic scintillators					
Square bars	1-4 m^2	>10 mrad	Simple	Simple	Low
Triangular bars	1-2 m^2	<10 mrad	Simple	Medium	Medium
Scintillating fibers	1-2 m^2	0.1 mrad	Medium	Complex	High
Gaseous detectors					
Proportional tubes	1-4 m^2	10 mrad	Simple	Simple	Low
Multi-wire chambers	>4 m^2	<1 mrad	Medium	Simple	Medium
Drift chambers	>4 m^2	0.1 mrad	Complex	Complex	High
Resistive plate chambers	>10 m^2	0.1 mrad	Simple	Medium	Low
Nuclear emulsion detectors	>4 m^2	0.1 mrad	Simple	Complex	Low

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

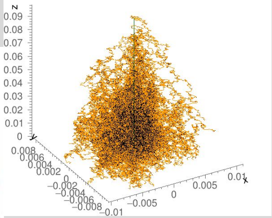
Resistive Plate Chambers (RPCs) are widely used for muon detection in many large-scale and small-scale experiments. Due to their, robustness, portability, low production cost, versatility, etc, it is considered as the optimal choice for our portable muon telescope.

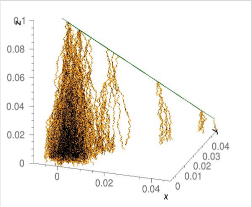
Resistive Plate Chambers

- RPCs can be manufactured at relatively lower cost
- Relatively simple assembly procedure
- Better position resolution (potentially down to ~100 μm)
- Good intrinsic time resolution (~25 ps to~3 ns depending on the technical layout) which can be beneficial for background rejection with time of flight



Avalanche creation in a single gap RPC





- **Gas mixture:** C2H2F4 (~95%)/ C4H10 / SF6

  -**high density**

  -> high detection efficiency

  -**good quenching properties and electronegativity**

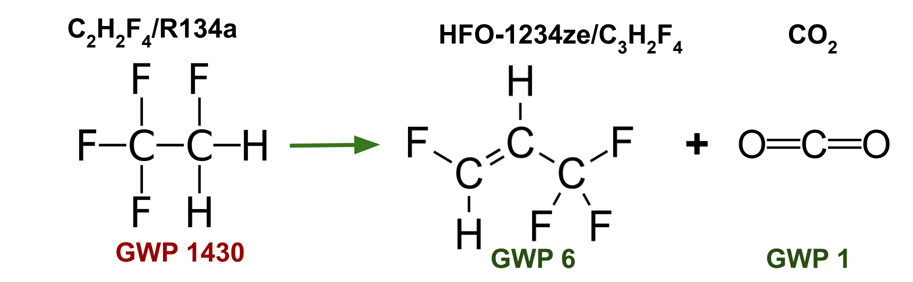
  ->good rate capability and 'slow' detector aging

- European regulations restrict the usage of high Global Warming Potential* (GWP) gases

Gas	GWP* values 100-year time horizon
CO_2	1
CH_2FCF_3	1430
SF_6	22800

*Global Warming Potential :measure of the heat trapped in the atmosphere by a ton of a given gas, if compared to a ton of CO_2

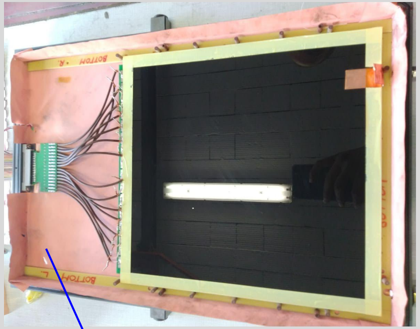
- Gas tight detector design offering operation without a continuous gas flow (sealed system)
- Performance of the detectors with eco-friendly gas mixtures will be conducted



RPC Prototypes

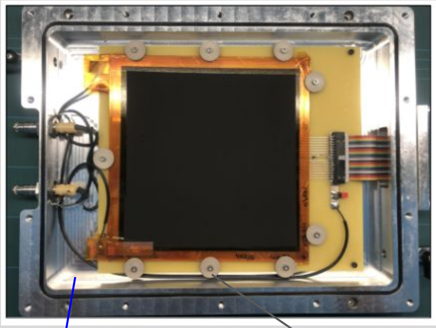
As part of the project, three glass-based RPC prototypes with slightly different characteristics are developed:

Detector	A1	B1	C1
Size	30×30 cm^2	16×16 cm^2	30×30 cm^2
Box type	Honeycomb based	Aluminum casket	Closed with top and bottom PCBs
Readout strips	16-1D	16-1D	32×32 - 2D
Strip pitch	1.5 cm	1 cm	0.8 cm
Gas mixture	95.2% Freon, 0.3% SF6, 4.5% isobutane		
Gas gap	1 mm Single gap	1 mm Single gap	1 mm Double gap
Thickness of electrodes	1.1 mm	1.1 mm	1.1 mm
Resistive coating	Using hand sprayer(~ 650 KΩ/□)	Serigraphy method (~ 4 MΩ/□)	Using hand sprayer(~ 1.5 MΩ/□)
DAQ	NIM + CEAN integrated / custom made		
Portability	No	Yes	Portable (Currently operating in gas flow mode)



gRPC-A1

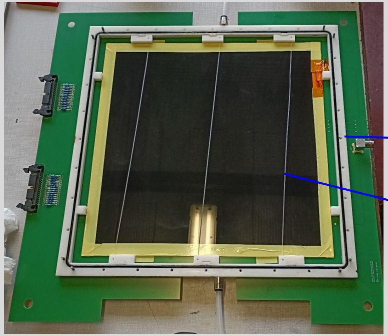
Honeycomb based box with copper foils for Faraday cage



gRPC-B1

Aluminum casket

Round edge spacers



3D printed frame

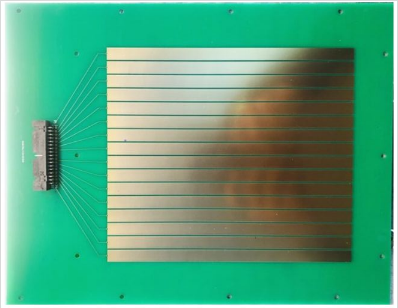
Gas gap with fishline spacers

gRPC-C1

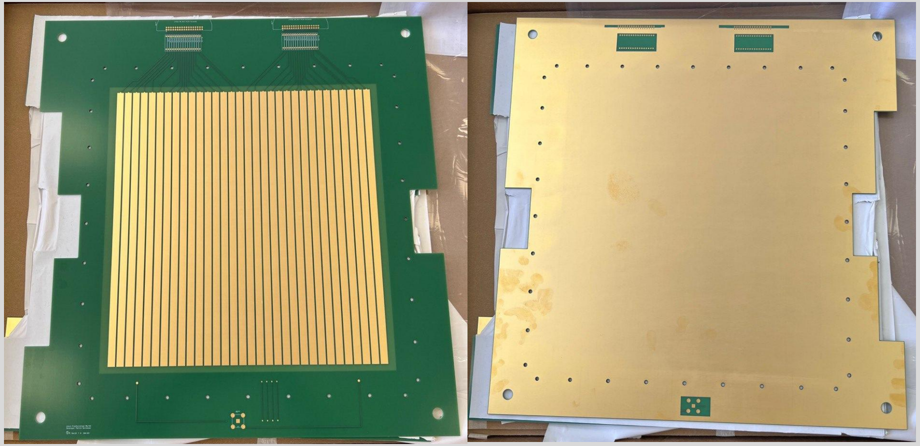
RPC Prototypes: Components

Evolution of strip PCBs

gRPC-A1:
- 16 copper strips (width=1.5 cm) integrated
- Cables soldered on the strips to guide signals to the readout



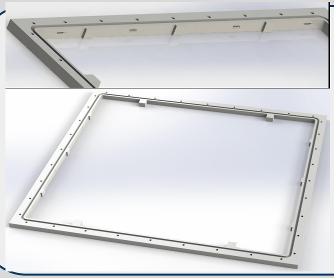
gRPC-B1:
- 16 copper strips (width=1 cm) integrated
- Copper traces integrated on the PCB to guide signals to the readout



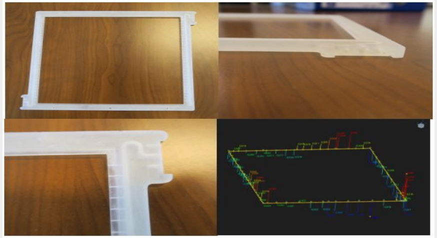
gRPC-C1:
- **32 copper strips** (width=0.8 cm) integrated
- Copper traces integrated on the PCB to guide signals to the readout
- Additional PCB traces for high voltage, ground connection for the glass electrodes, P-T-H sensor
- Slot to mount HV connector
- Two slots to mount 17 pin connector to readout the signals
- 34 slots to add resistors for termination
- Four mounting holes on the corners to mount to the telescope trolley
- Backside coated with copper for Faraday cage
- 36 screw holes to mount the detector frame to the PCB

RPC Prototypes: Components

3D printed detector frames for uniform gas distribution and gas tightness



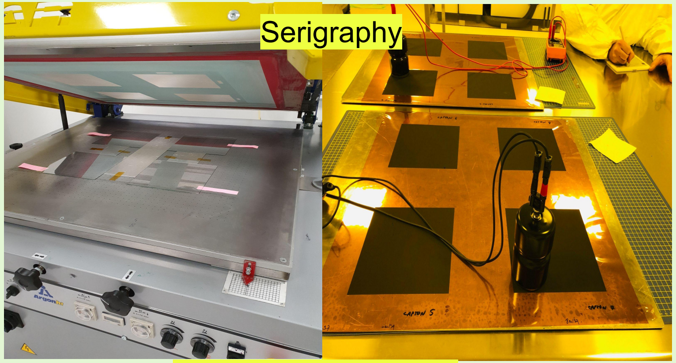
- 3D printed frame with gas distribution slots for uniform distribution of gas
- Consists of screw holes to mount the frame to the PCBs
- Channels for o'rings for gas tightness
- Rectangular blocks to hold glass plates on position
- Currently equipped in gRPC-C1



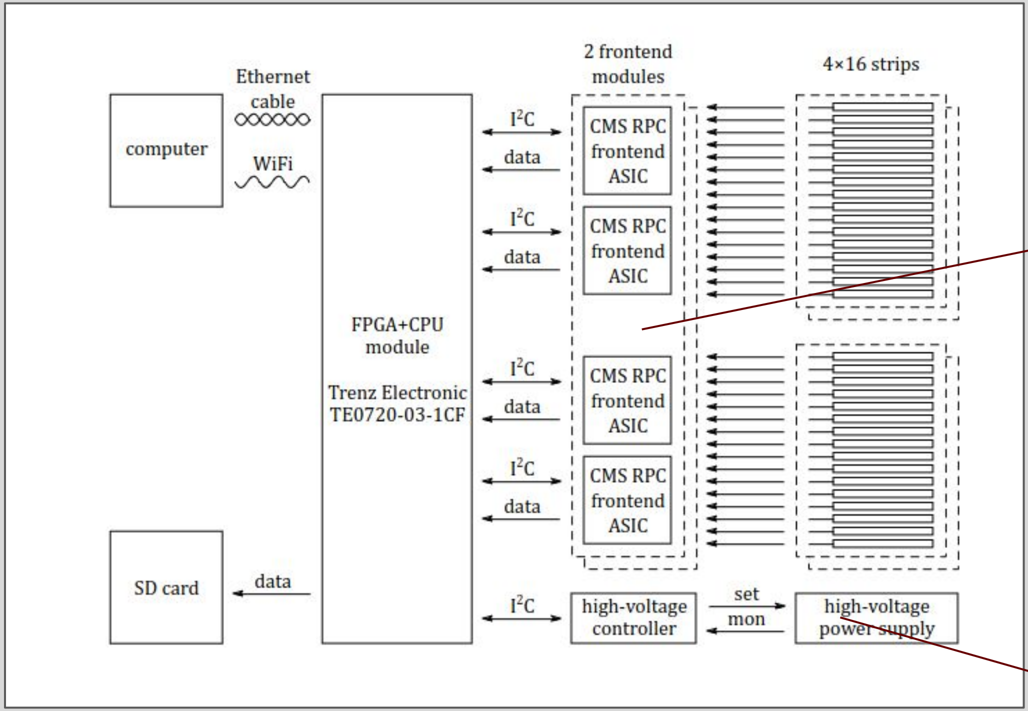
- 3D printed frame to supply gas only between the glass plates and offers uniform gas distribution

Coating techniques

- Serigraphy and hand sprayer coating techniques resulted in uniformity of surface resistivity (up to ~15% variation)
- Resistivity fluctuations were observed in the initial days after painting and after that, it remained stable
- A layer of Urethane spray is applied after coating to protect the plates from effects due to fluctuations in environmental parameters



Custom made DAQ

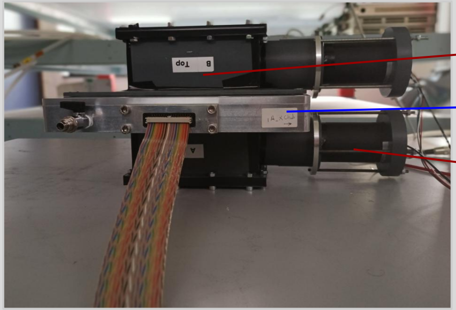


Technical layout of the custom made DAQ

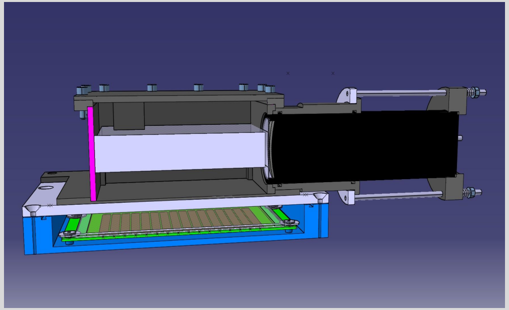
4 × 16 channel CMS electronics used for the DAQ (Add more details)

Iseg DSP mini high voltage supply

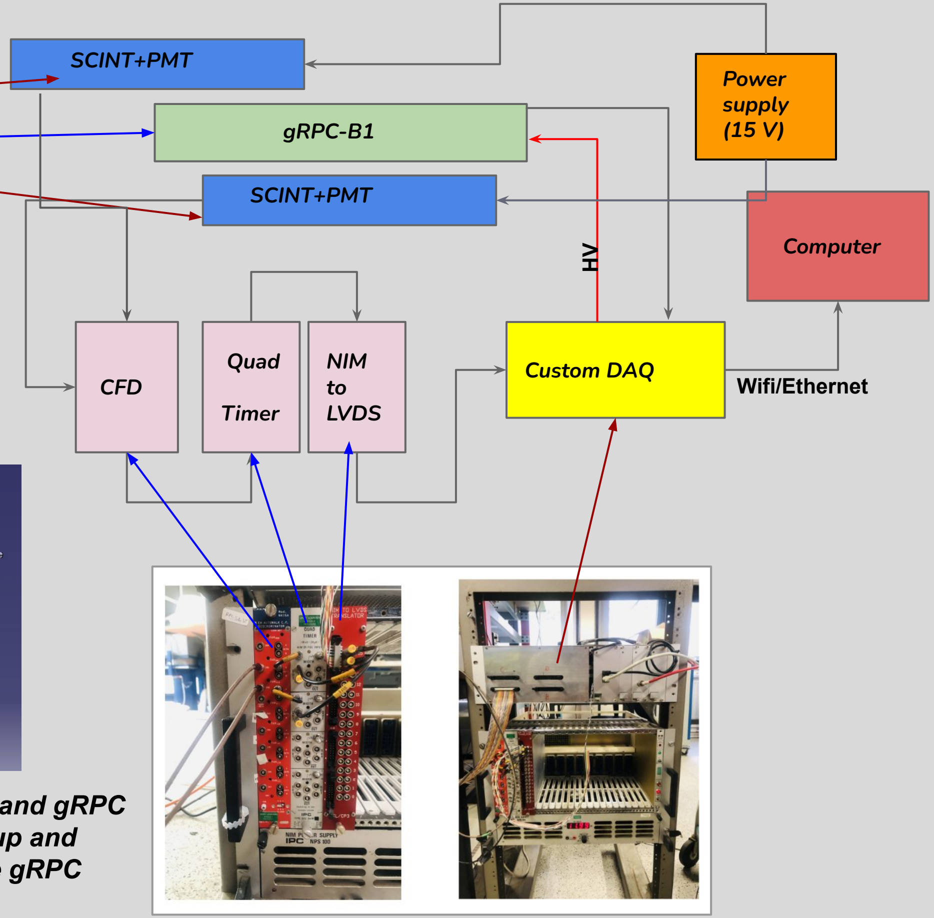
Data taking with custom made electronics



gRPC-B1 aligned with the trigger scintillators

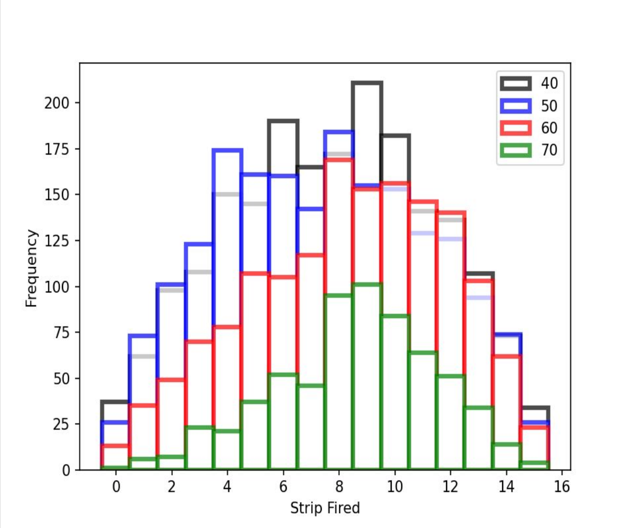


CAD drawings of one of the trigger module and gRPC showing the internal view of the trigger setup and trigger setup covering the active area of the gRPC

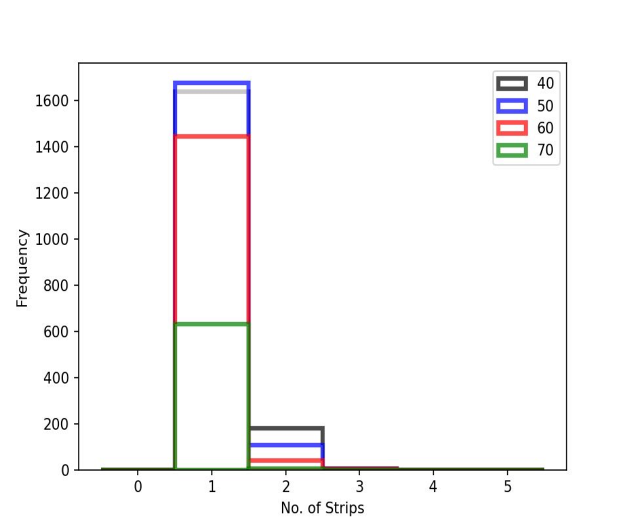


Data taking with custom made electronics: results

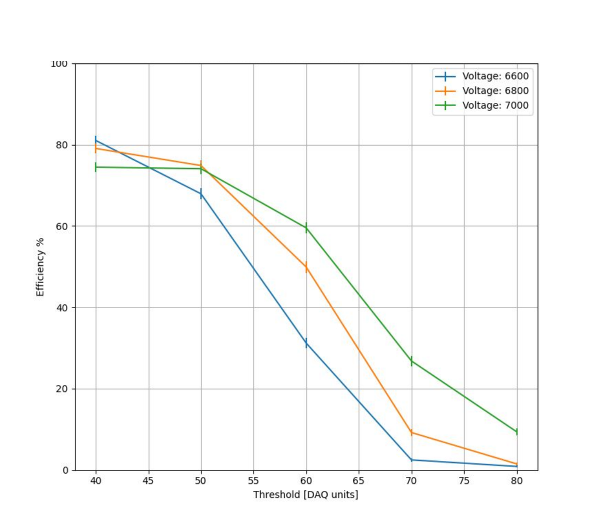
Occupancy distribution at working point HV=7000 V



Cluster Size distributions at 3 different DAQ thresholds applied



Detection efficiency measured with respect to DAQ thresholds applied



Cuts applied for quality event selection:

1)Time: A 10 ns muon time window is fixed for event selection

2)Cluster size: Events are chosen only if the cluster size is <=3

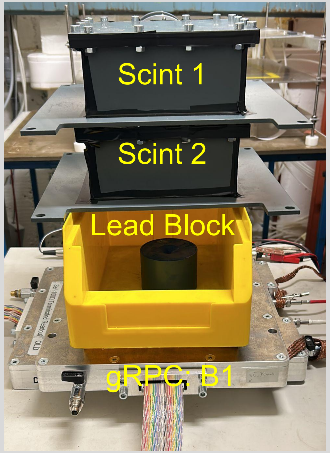
3)Multiplicity: Events are chosen only if the multiplicity =1 (in a 10 ns time window, probability to have more than one muons is very less)

Data taking with custom made electronics:results

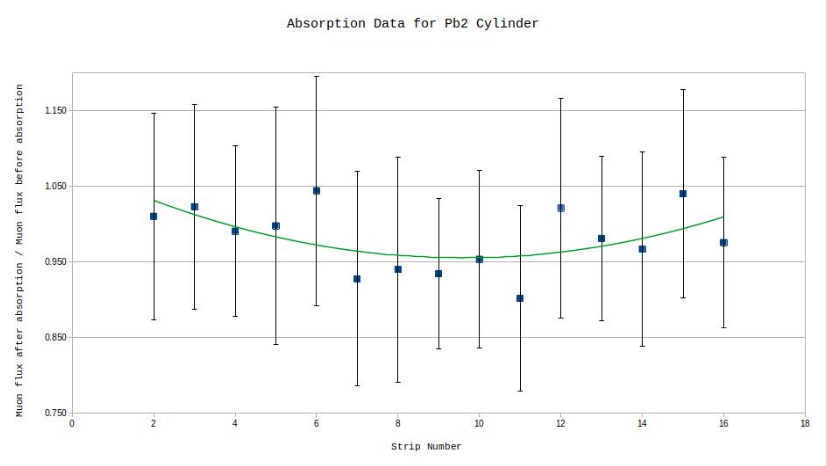
Table summarising the effect of applying cuts on the row data

Threshold	PMT	No Filter	Timing Filter	Cluster size<3	Multiplicity = 1
40	2440	2440 (100.0)	1959 (80.3)	1907 (78.2)	1817 (74.5)
50	2408	2408 (100.0)	1841 (76.4)	1825 (75.8)	1784 (74.1)
60	2491	2185 (87.7)	1516 (60.9)	1511 (60.7)	1483 (59.5)
70	2369	1111 (46.9)	642 (27.1)	642 (27.1)	635 (26.8)
80	2399	878 (36.6)	226 (9.4)	226 (9.4)	225 (9.4)

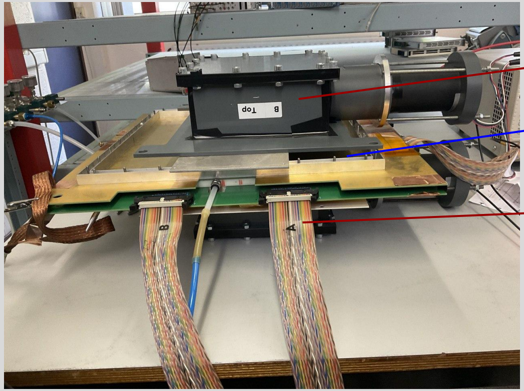
Preliminary results of absorption measurements with cylindrical lead block



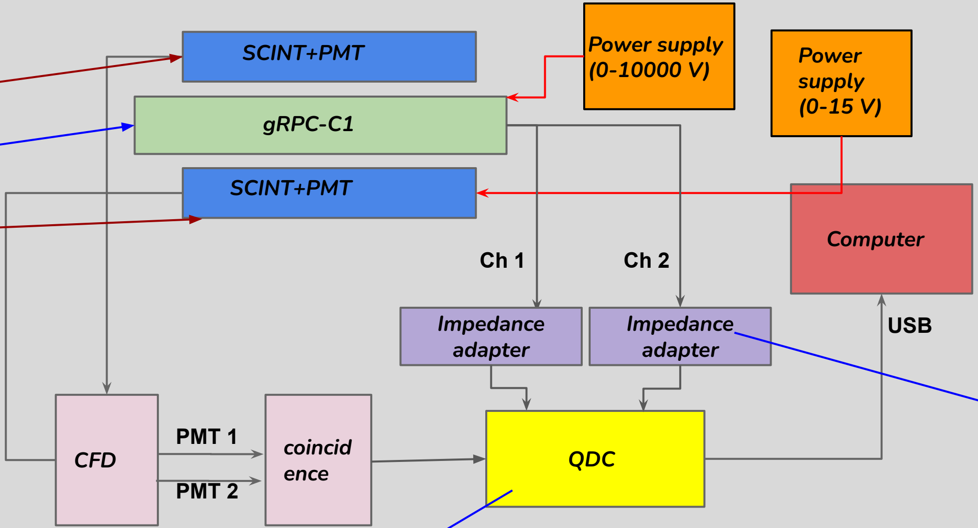
- Configuration: 2 plastic scintillators above and then a lead block before placing the RPC at the bottom
- Although the error in calculation is much higher the reduction is evident as compared to free flux.
- Increase in flux due to scattering in strip no. 6 and 12 are also observed.

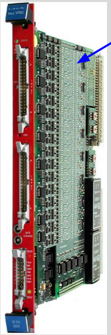


CAEN-QDC based data taking for charge measurements

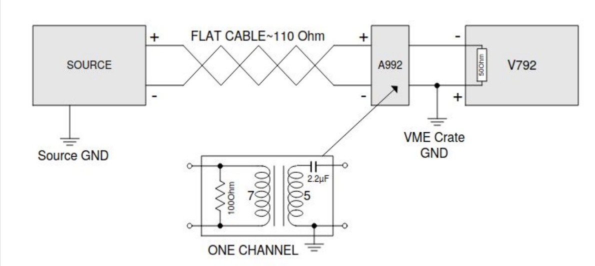


gRPC-C1 aligned with the trigger scintillators





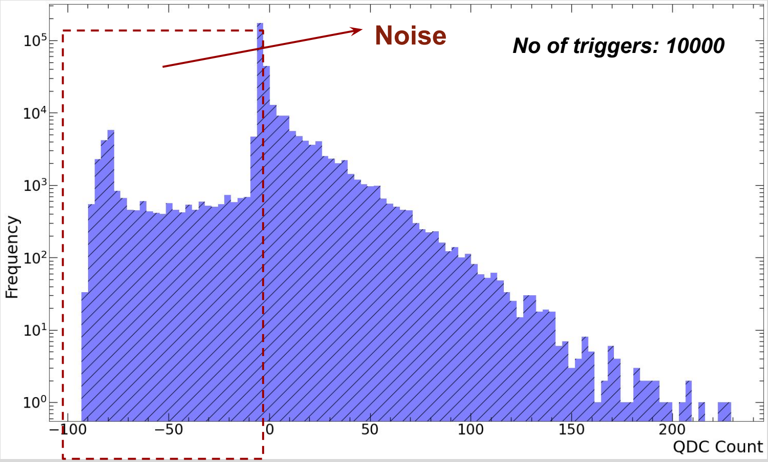
CAEN 32 channel QDC



Connection scheme of source to QDC with impedance adapter

CAEN-QDC based data taking: results

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$_i$)= μ_i+3 σ_i ;

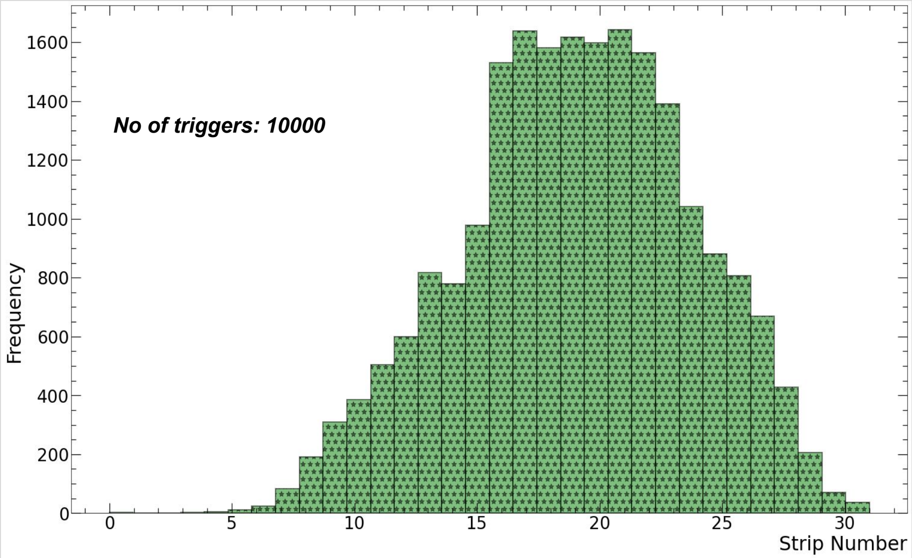
  Where μ_i= Mean ($QDC_{pedestal\_i}$),

  $$\sigma_i = \sqrt{\frac{\Sigma(QDC_{pedestal_i} - \mu_i)^2}{No\ of\ QDC_{pedestal_i}}}$$

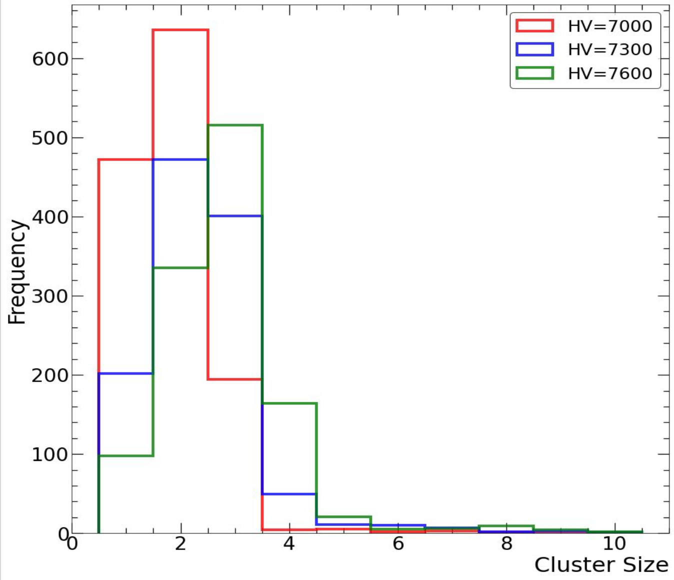
- A strip$_i$ is considered as part of the event only if:

  QDC_{val_i} > QDC_{thr_i}

CAEN-QDC based data taking: results



Occupancy distribution at working point HV=7000 V

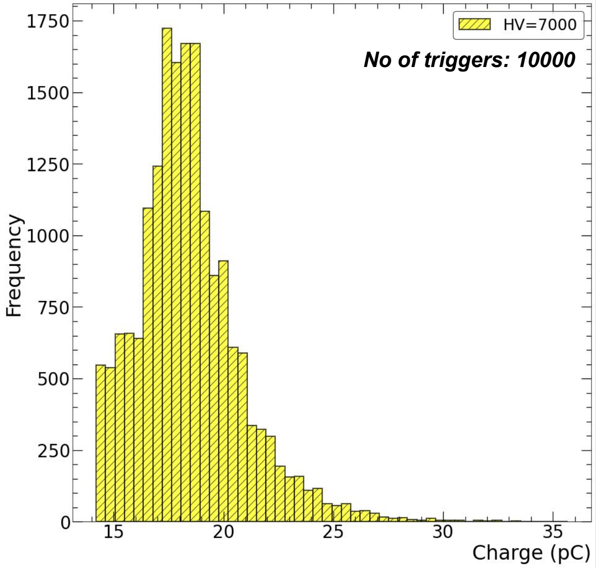


Cluster Size distributions at 3 different HV in the avalanche region (no of triggers in all cases =1000)

- 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

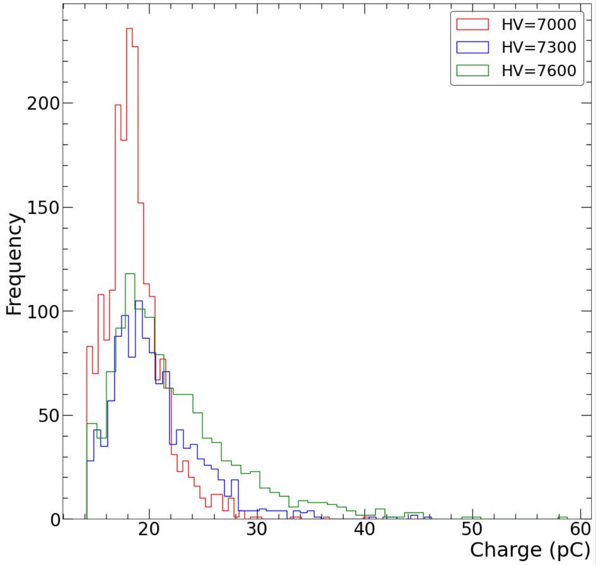
CAEN-QDC based data taking: results

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



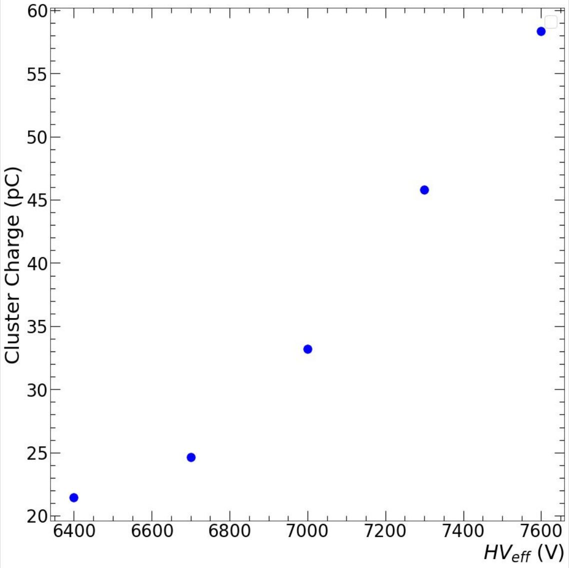
- Charge is calculated by applying the conversion:
  1 QDC count=0.098 pC

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

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

Summary

- **As part of the collaboration of the muography teams in Ghent University and UCL, glass-RPC prototypes are built to explore the feasibility of portable RPCs for muography applications**
- Three glass-based RPC detectors (two single gap and one double gap) of slightly different characteristics are developed in view of gaining construction experience and comparing their performances
- Two of the detectors (gRPC-B1&C1) are completely gas tight and portable
- A portable CMS-electronics based DAQ system is developed and performance of gRPC-B1 was studied with this electronics
- The double gap RPC is built with an improved technical layout which includes a 3D printed detector frame, 2D readout and a PCB based closing system which eliminates the need to external mechanics
- The current status of the project and all the latest results achieved are presented

Upcoming milestones

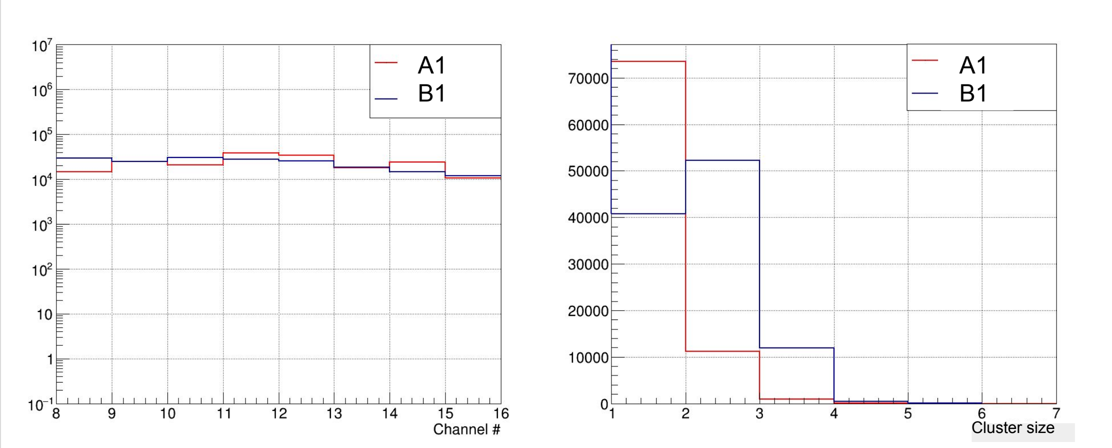
- After the completion of the performance studies, additionion double-gap RPC modules will be developed for the construction of the muon telescope
- To eliminate the usage of high GWP gases, performance studies of the detectors with eco-friendly gas mixtures will be conducted
- A MAROC integrated board is under evaluation to replace the CMS electronics

Thank You

Data taking: 2022

During the data taking conducted in 2022, the performance of the first prototypes: gRPC-A1 and gRPC-B1 were compared.

Occupancy and cluster size of the last 8[1] strips at working point HV = 7 kV and threshold = 90 DAQ units



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

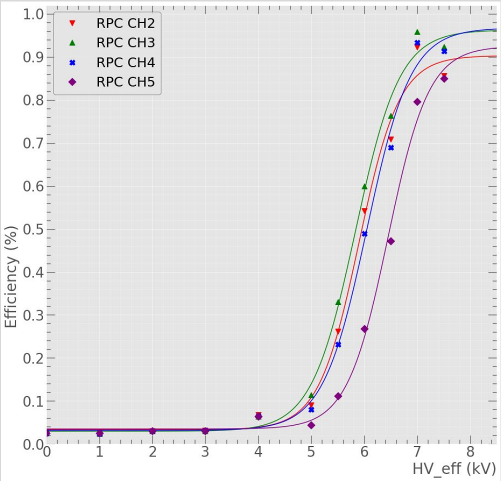
Cluster size distribution : total # of strips fired per event

- Both these distributions are normalized to the active area of B1
- The occupancy distributions of the two prototypes A1 and B1 are in general agreement

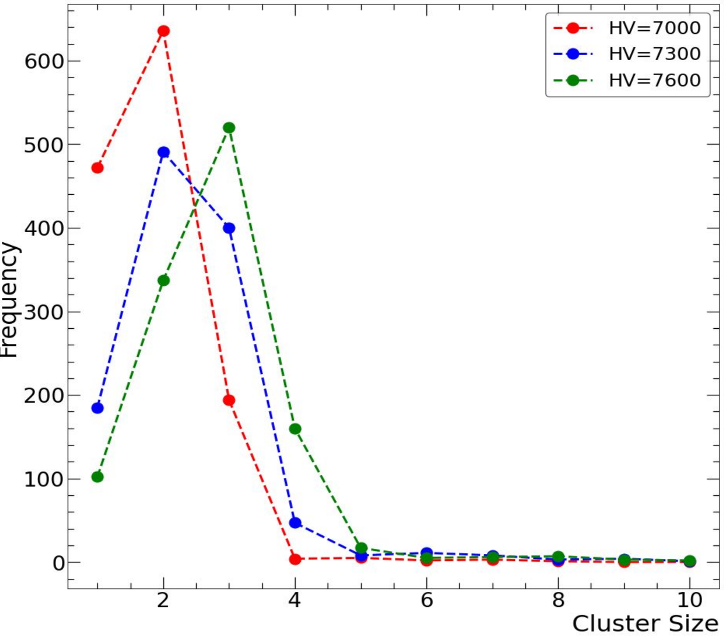
[1]Muoscope A1 had some hardware-related issue with the first 4-5 strips so only last 8 strips were considered for producing these results

Gamage, R. M. I. D., et al. "Portable Resistive Plate Chambers for Muography in confined environments." *E3S Web of Conferences*. Vol. 357. EDP Sciences, 2022.

- Strip efficiency measurement of gRPC-A1 measured using 3 cm × 3 cm trigger scintillators



Cluster size



Trigger time