Development and Performance Evaluation of a Compact Portable Glass-RPC Muon Telescope for Muography Applications

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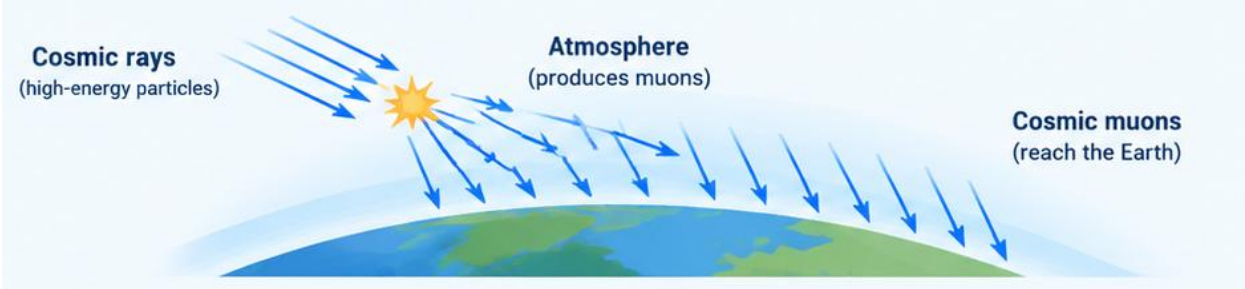


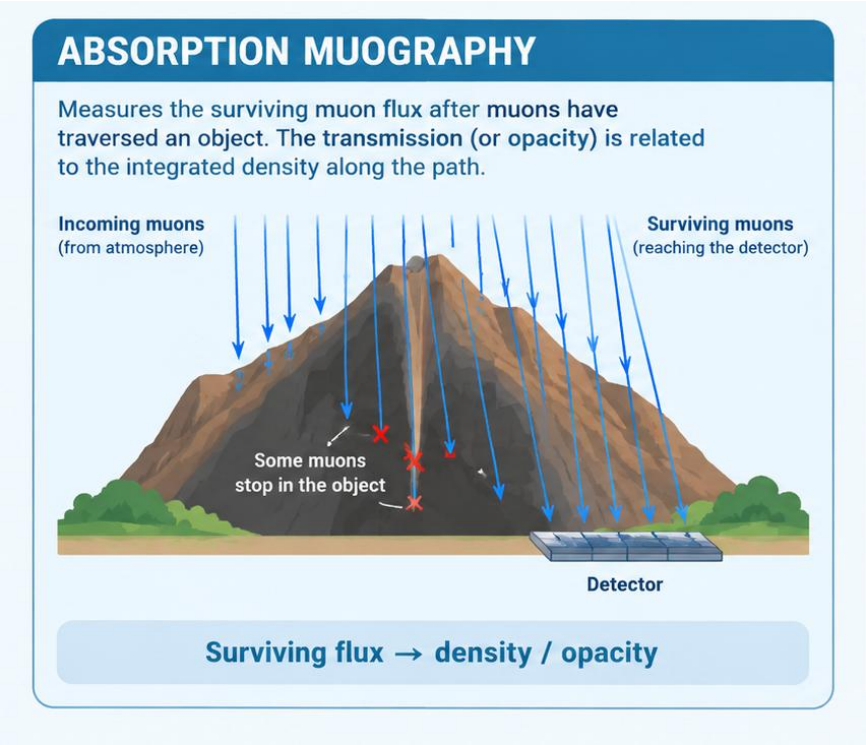
XVIII Conference on Resistive Plate Chambers and Related Detectors,
Rio De Janeiro, Brazil, Sept. 14-18, 2026

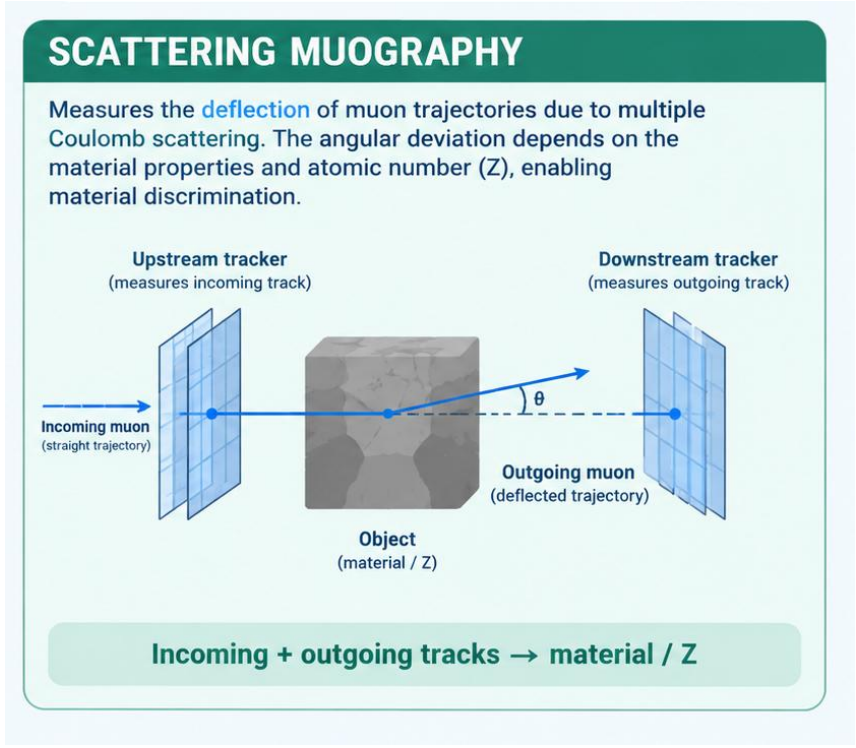
1. Motivation
2. Portable RPCs
3. Performance Tests in Lab
4. Initial Deployments
5. Summary & Outlook

1a. Muography – Imaging the Hidden with Cosmic-Ray Muons

Cosmic-ray muons provide a naturally occurring, penetrating probe; muography uses cosmic-ray muons to look inside large and dense objects, i.e. it is a versatile imaging technique with applications in many fields from Earth sciences to industry and security







- *Key advantages*: passive, non-destructive, naturally available radiation source, but … low count rates
- *Common detector technologies*: scintillator counters, nuclear emulsions, gaseous detectors
- Field logistics may be complicated

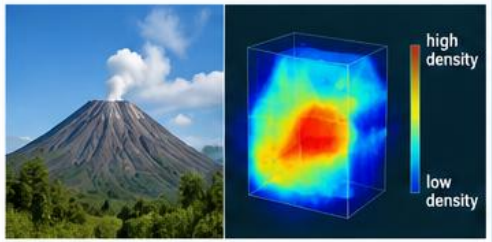
Mostly large, thick targets
2D images; 3D images with multiple viewpoints
Long exposure time for sufficient statistics

Small/medium size targets
3D images
Relatively fast, but needs tracking on both sides of the target

1b. Muography applications and portable muon telescopes

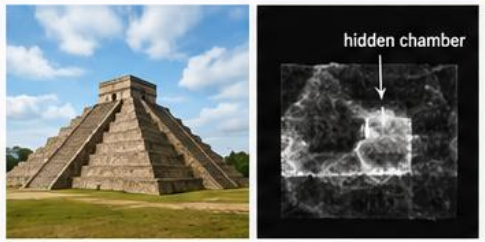
Illustrative pictures and graphs generated with OpenAI, 2026

Volcanoes & geology



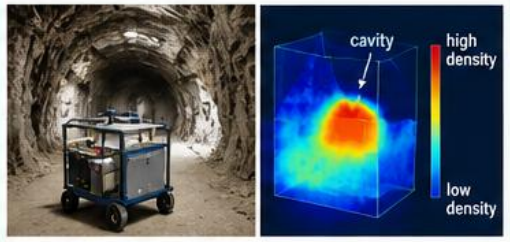
- Map internal density structures
- Identify magma conduits and chambers
- Monitor volcanic activity

Archaeology & cultural heritage



- Detect hidden chambers and voids
- Explore archaeological structures
- Study historical monuments (e.g. pyramids)

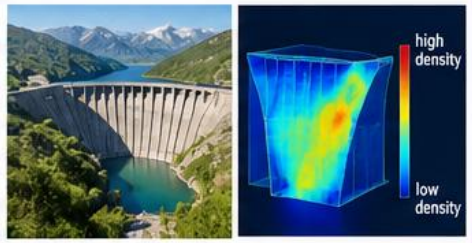
Mining & underground



- Locate cavities, faults and ore bodies
- Improve safety and resource management

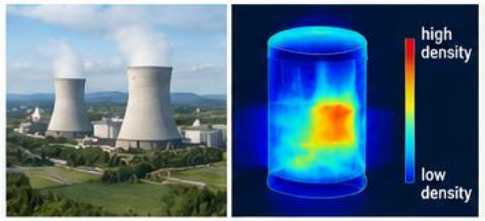
→ **Portable detectors are particularly valuable in underground and confined environments.**

Civil engineering



- Inspect bridges, dams and concrete structures
- Detect voids, cracks and deterioration
- Monitor long-term stability

Nuclear applications



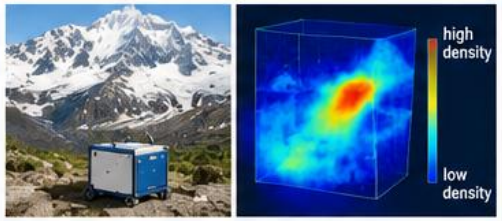
- Inspect spent fuel and reactor components
- Detect high-Z materials
- Support non-destructive evaluation

Security & cargo inspection



- Detect concealed high-Z materials
- Inspect cargo, vehicles and buildings
- Support border and critical infrastructure security

Extreme & remote environments



- Study inaccessible or remote locations
- Operate in harsh environments
- Enable measurements where large systems are impractical

Portability expands the reach of muography

- ✓ Bring the detector to the object
- ✓ Enable underground, confined, remote and difficult-to-access locations
- ✓ Open new possibilities beyond large, fixed installations

Our design target: compact + light + gas-tight + robust + autonomous + low-cost

1c. Why muography with gaseous detectors / RPCs?

Pros:

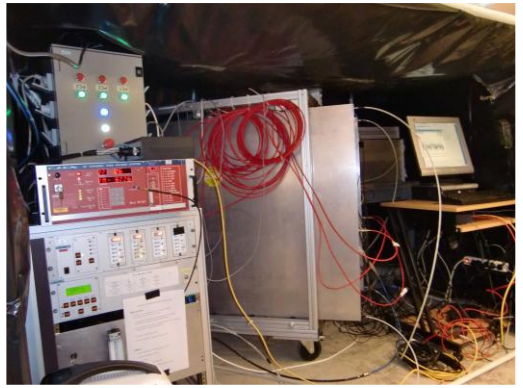
- High positional and temporal resolution (~300μm-mm; ~100ps-ns)
- Surface area easily tunable (cm^2 to m^2), without compromising performance in terms of e.g. position resolution or homogeneity
- Relatively cheap and robust, simple construction
- Triggerable data-acquisition system (live monitoring)

Cons:

- They need gas … often mixtures, with safety or environmental issues (flammability, toxicity, greenhouse gases …)
- Large power consumption (HV of ~3-10kV depending on chamber type)
- Environmental sensitivity (T, H, p) in uncontrolled, outdoor setups and long-term stability

Examples of muography with gaseous detectors

$1m^2$ gRPCs @ TOMUVOL, Puy de Dôme, France



[Fehr et al., J. Phys. Conf. Ser. 375 (2012) 052019]

$50x50cm^2$ Micromegas @ ScanPyramids, Khufu Pyramid, Egypt



[K. Morishima et al., Nature 552 (2017) 386-390]

$1m^2$ double-gap gRPCs @ Lousal mine, Portugal



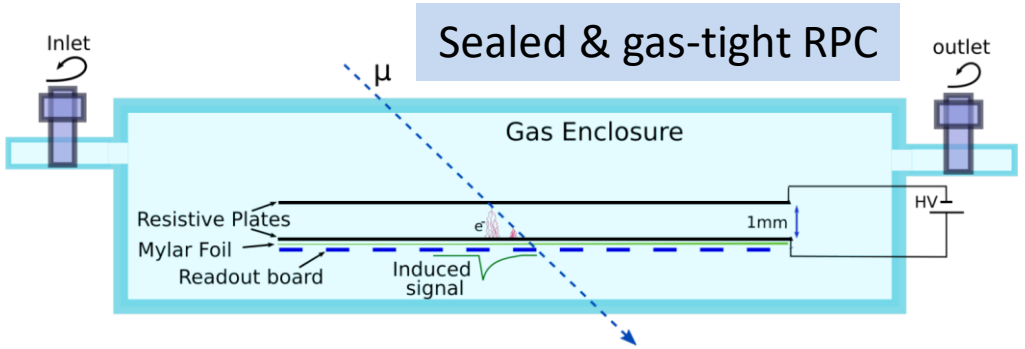
[R. Sarmento et al., NIM-A 1060 (2024) 169031]

$0.5m^2$ MWPCs @ Sakurajima volcano, Japan



[L. Oláh et al., Journal of the Society of Photographic Science and Technology of Japan 81 (2018) 269–274]

2a. Our Current 3-Prototype Landscape



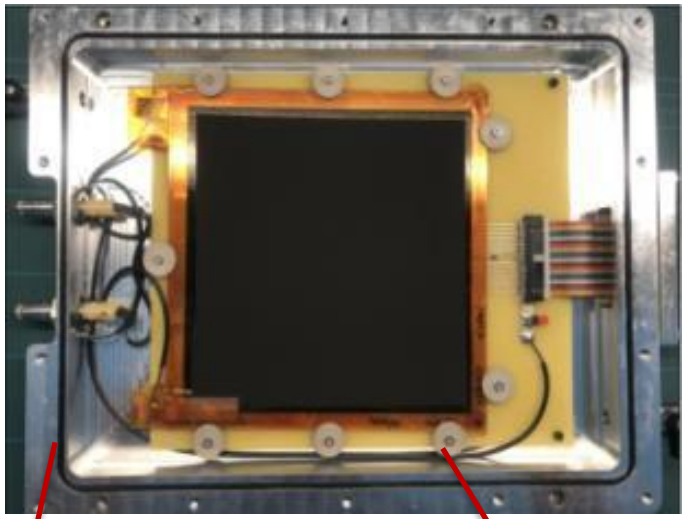
Our hopes/goals:

- Low/zero gas flow during operation (i.e. sealed systems)
- Portable (i.e. light-weight), autonomous, and modular system, suitable for confined or remote field locations (i.e. no mixing units or large gas bottles on-site, simplified logistics)
- Low power consumption DAQ and services

	Prototype A	Prototype B	Prototype C
Electrode material/thickness	Float glass / 1.1 mm	Float glass / 3 mm	Float glass / 1.1 mm
Resistive coating	Serigraphy (~ 4 MΩ/□) Hand-painted (0.5-1 MΩ/□)	Spray gun (~ 1 MΩ/□)	Spray gun (~ 1.5 MΩ/□)
Electrode active area	16 × 16 cm^2	16 × 16 cm^2	28 × 28 cm^2
Gas gap	1 mm, single gap	2 mm, single gap	1 mm, double gap
Readout strips/strip pitch	16 - 1D / 1 cm	16 × 16 - 2D / 1 cm	32 × 32 - 2D / 0.8 cm
Outer casing	Aluminium box	Acrylic box	Gas volume sandwiched between top and bottom PCBs
Gas mixture	$C_2H_2F_4/C_4H_{10}/SF_6$ = 95.2/4.5/0.3		
DAQ	NIM and ASIC + FPGA		
Sealed mode	Yes	Yes (Currently open loop)	Yes (Currently open loop)

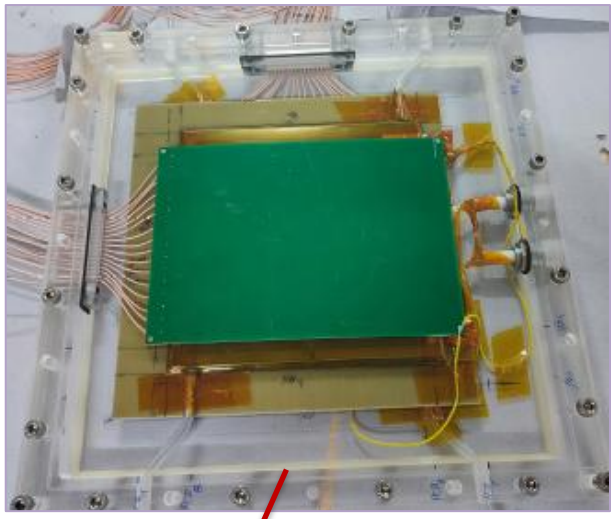
2b. Detector Layouts: Mini-gRPCs

Prototype A



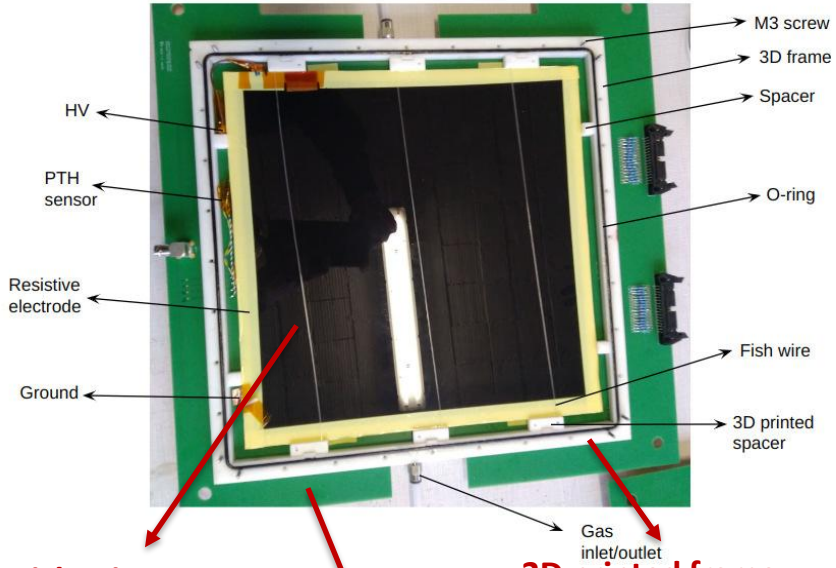
Aluminium gas box **Circular spacers**

Prototype B



Acrylic gas box

Prototype C

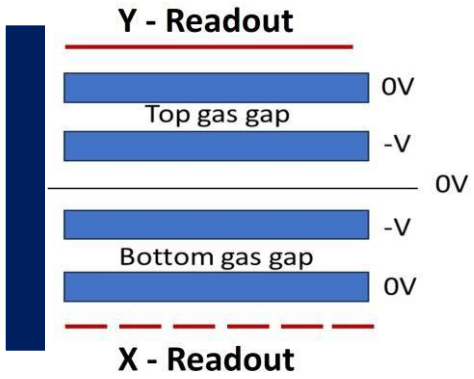


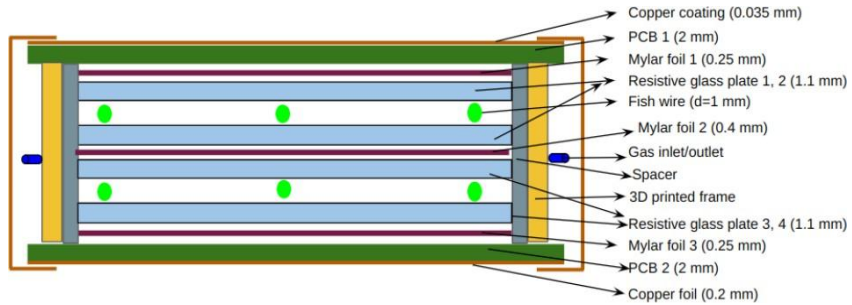
Fish wire spacers **3D printed frame defining gas volume**

PCBs closing gas volume

Various small-area prototypes built over the years, going from:

- single to double gap configs (→ efficiency)
- 1D to 2D readout strip boards (→ tracking)
- Large external gas cover box to internal, cable-free gas volume (→ low volume, gas-tightness, light-weight)





2c. Detector Construction: Glass Electrode Coating

Electrode coating:

- 2-component semi-conductive paint (Electrodag 6017SS conductive and PM-404 resistive paint)

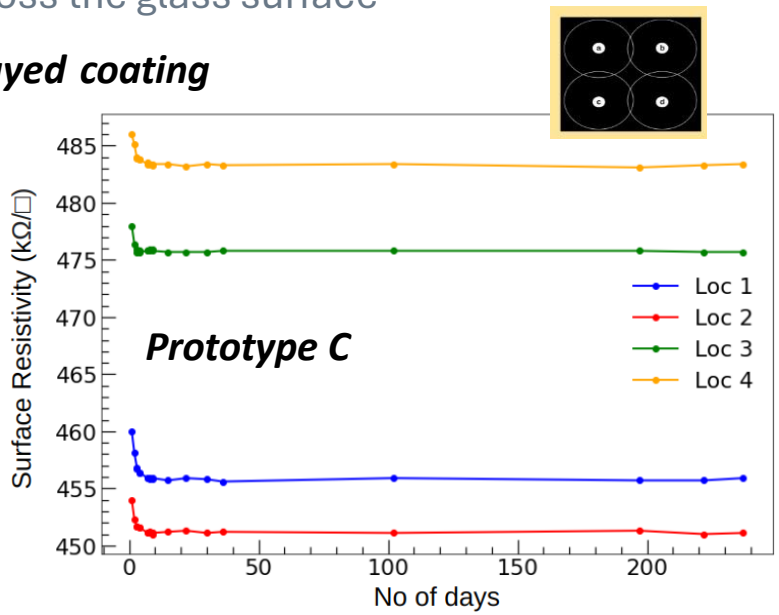
Various coating methods have been applied:

- Manual paint roller
- Manual spray painting
- Manual and automated serigraphy

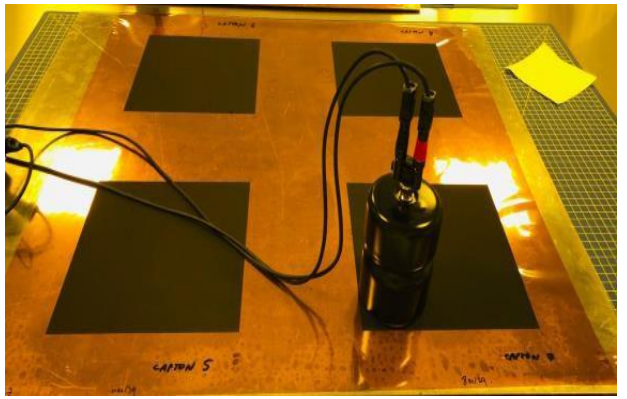
Surface resistivity (in the range ~ 0.5-1.5 MΩ/□) appears stable over time, homogenous (down to ~10%) and uniform thickness across the glass surface

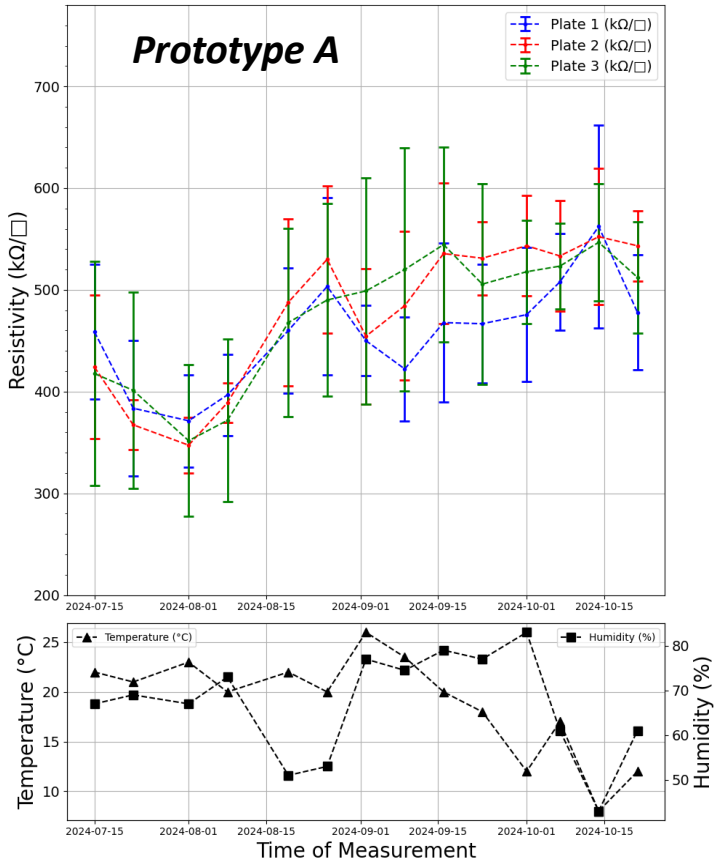
Hand sprayed coating





Serigraphy

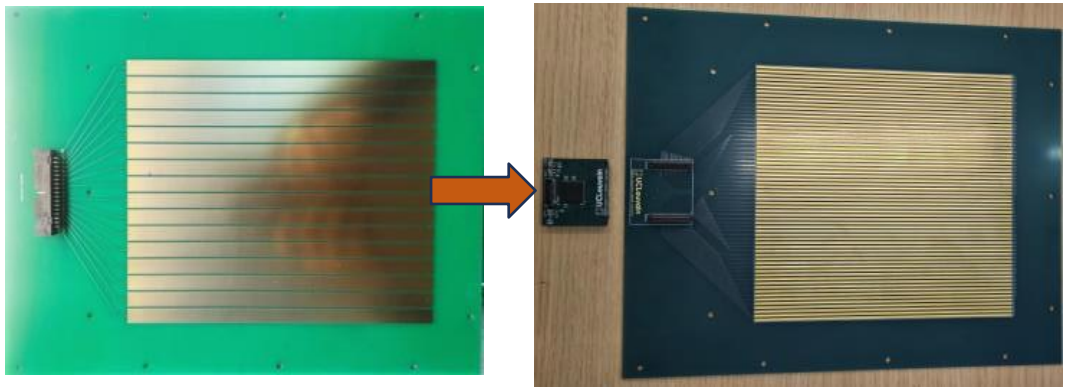


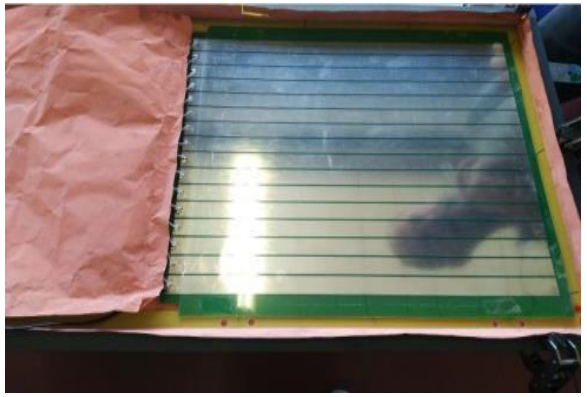


2d. Detector Construction: Readout Boards

Prototype A:

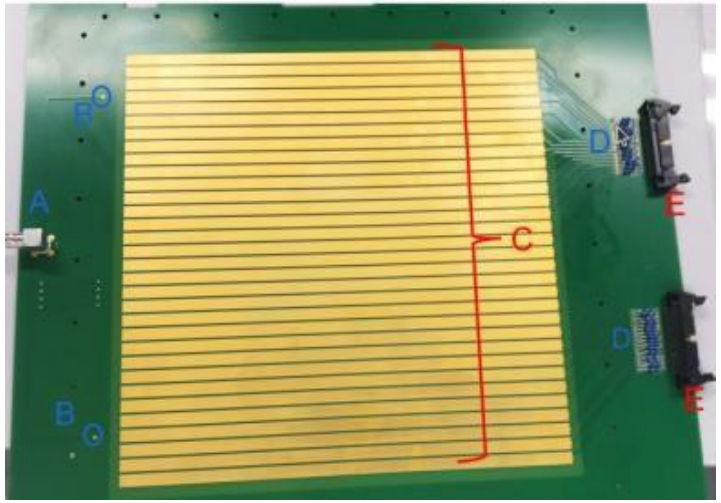
- Incorporates 16 copper strips (1cm width) embedded in the PCB
- Copper traces are integrated to route signals to the readout electronics
- Currently upgrading from 16 to 64 strips





Prototype B:

- 16 copper strips (strip pitch 1 cm) integrated in PCB
- Cables soldered on the strips to guide signals to the readout



Prototype C:

- BNC connector for HV connection
- Flat cable connectors for signal collection
- Traces for HV/grounding/PTH sensor going into gas volume
- 32 readout strips integrated in the PCB; 50 Ω termination resistors
- Screw holes to fix the 3D printed gas volume frame
- PCB backside coated with 35 µm Copper layer to construct Faraday cage

2e. Detector Construction: Low-Volume, Leak-Tightness

In case of glass electrodes, how to keep gas volume limited and leak-tight ?

Prototype C

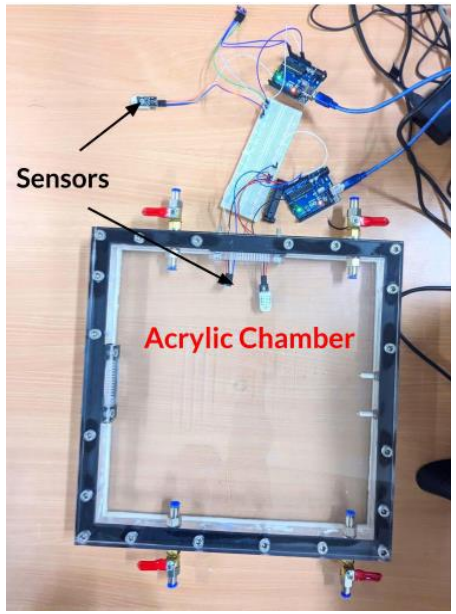
- **3D printed frame (single piece) enclosing glass stack**; fixed with screws to top and bottom PCBs that close the gas volume
- Gas distribution slots built into the 3D frame ensure uniform gas flow
- O-rings provide sufficient gas-tightness
- 3D printed spacer blocks to fix fish wires and keep glass stack in place
- **Cable-free gas volume** (all connections via embedded traces in PCB)
- **Glue-free design**, i.e. detector can be re-opened in case of failure or reconfiguration
- Gas T, P, H monitored with internal sensors





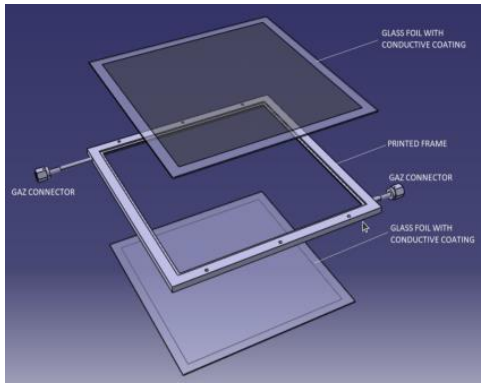
Prototype B

- Acrylic (PMMA) chamber housing glass stack and readout panel
- RH and T monitored with DHT22 sensors and Arduino UNO R3



Prototype A

- Currently adopting the 3D printed frame solution



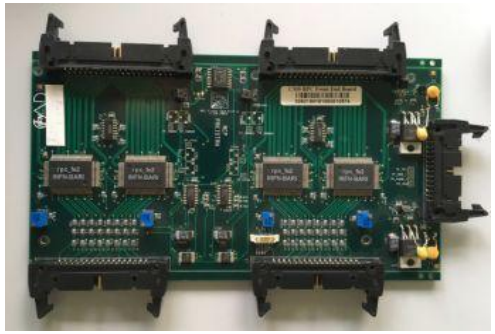


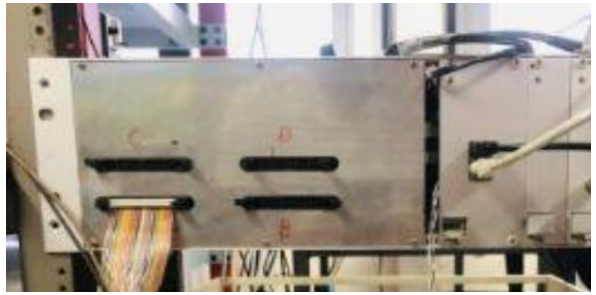
2d. DAQ Systems and Power Supplies

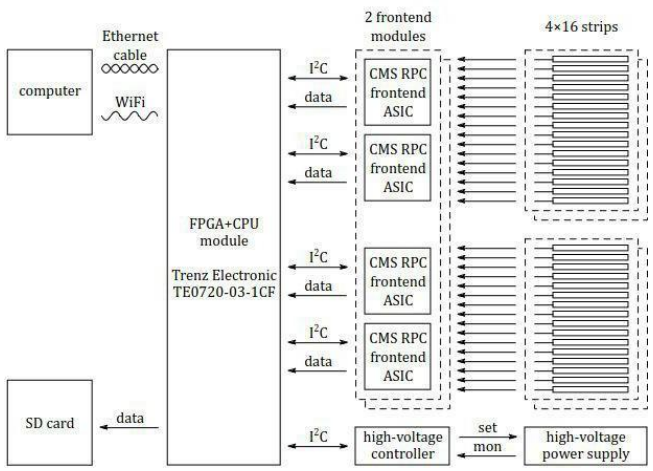
Prototype A

- Front-end boards from CMS Muon-RPC system (charge sensitive preamplifiers plus discriminators) in combination with FPGA

[M. Abbrescia et al., NIM-A 456 (2000), 143–149]







Prototype B

- CAEN DT5550W DAQ platform with programmable FPGA plus PETIROC-2A ASIC piggyback board is being tested
- CAEN A7512DB single channel portable power supply module to power all RPCs



PETIROC-2A ASIC:

- Input channels: 32 inputs **(Four ASICs have 128 inputs)**
- Signal polarity: positive or negative
- Dynamic range: 160 fC up to 480 pC
- 32 trigger outputs
- 40 ps bin TDC

ISEG DPS DC/DC mini HV power supply:

- Single output channel
- Up to 10kV output
- Input 24V
- Max current 1mA





CAEN A7512DN single channel power supply module:

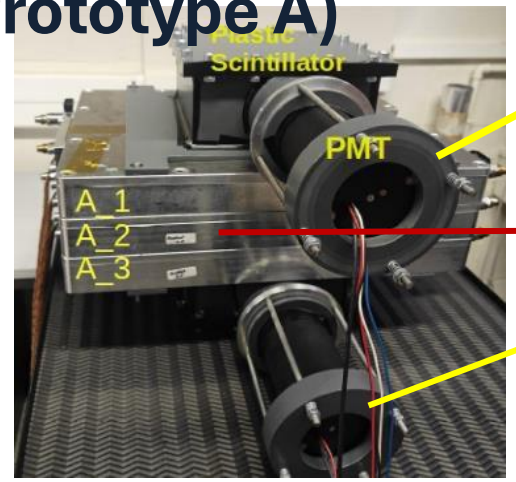
- Single output channel
- Maximum output voltage = 12 kV
- 200 mV monitor resolution
- Maximum current = 20 µA
- 500 pA monitor resolution

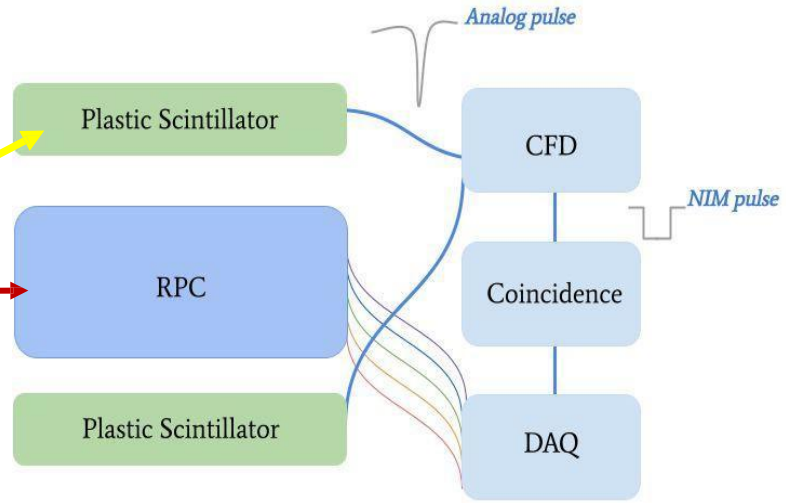
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3a. Performance Tests in the Lab (Prototype A)

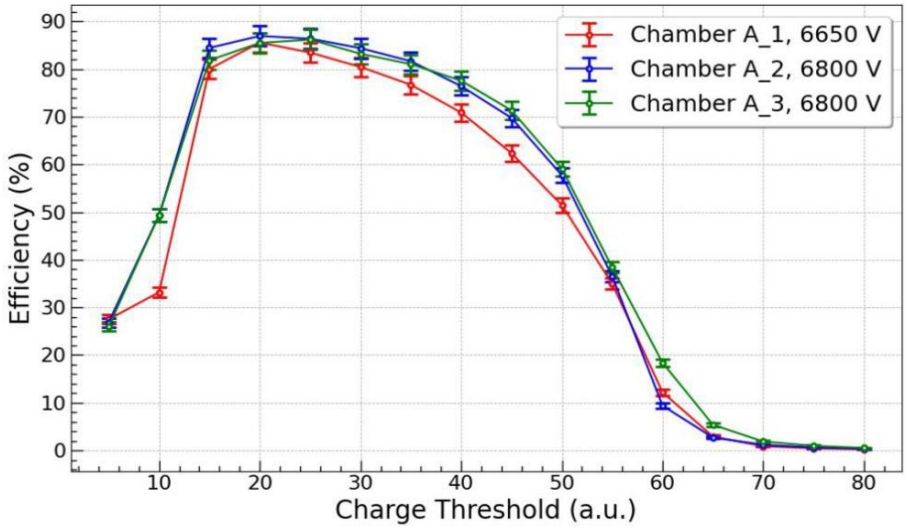
- Plastic scintillators/PMTs for external triggering (same active area as RPCs)

$$\varepsilon = \frac{N\left(\text{RPC hit after filters} \wedge \text{scintillator hit after coincidence}\right)}{N\left(\text{scintillator hit after coincidence}\right)} \times 100$$



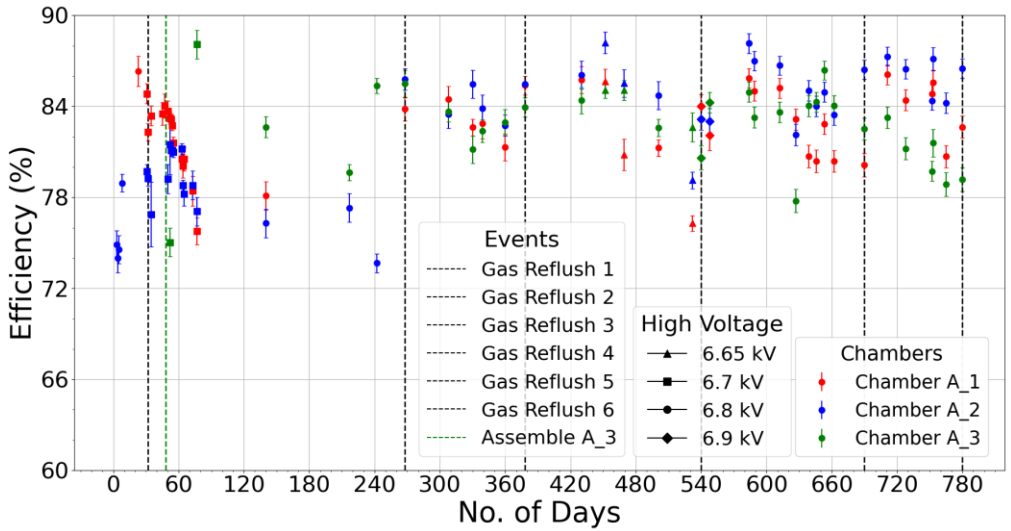


Efficiency vs. charge threshold



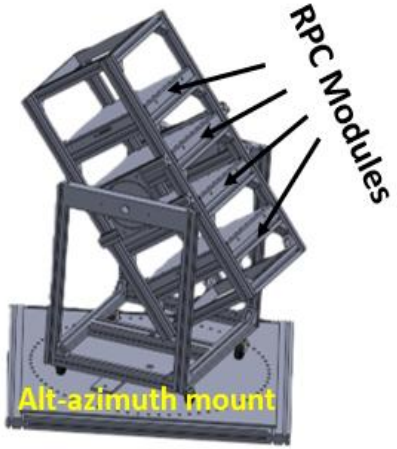
- 3 identical chambers (A_1–A_3); HV: 6.65 vs 6.8 kV
- Higher efficiency at 6.8 kV (optimal working point)
- Maximum efficiency ~85% at threshold 30 a.u.

Efficiency vs. time

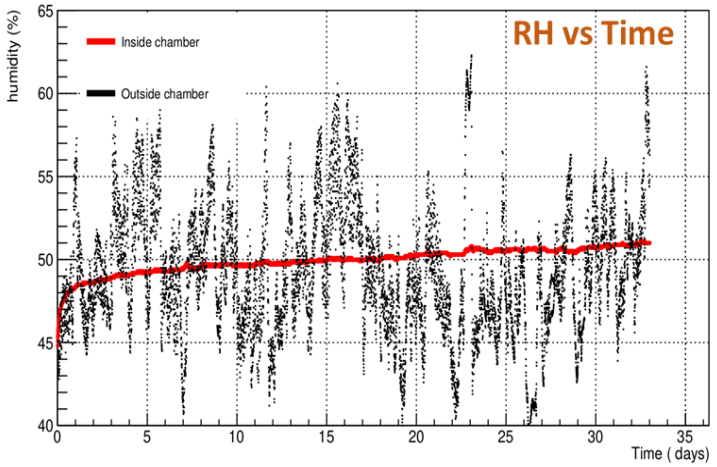


- Long term stability of a few chambers monitored during >2 years
- Periodic gas flushing restores efficiency after gradual decline
- Stable good performance maintained for over 2 years

3b. Performance Tests in the Lab (Prototype B)



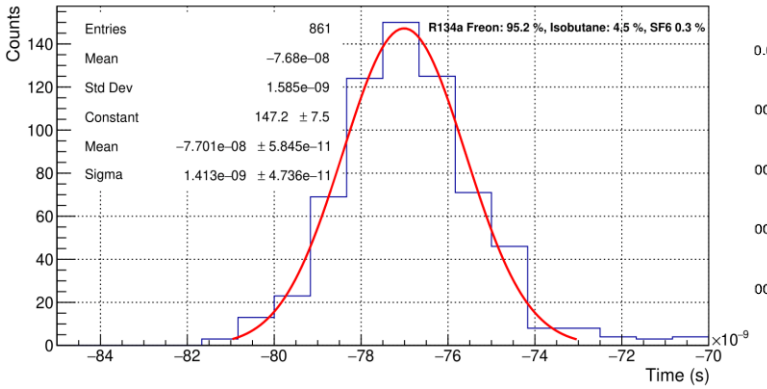
- A three-layer muon telescope is built with standalone glass RPC modules
- Each module houses two RPCs sandwiched between two orthogonally placed strip readout boards enabling bidirectional (X,Y) tracking



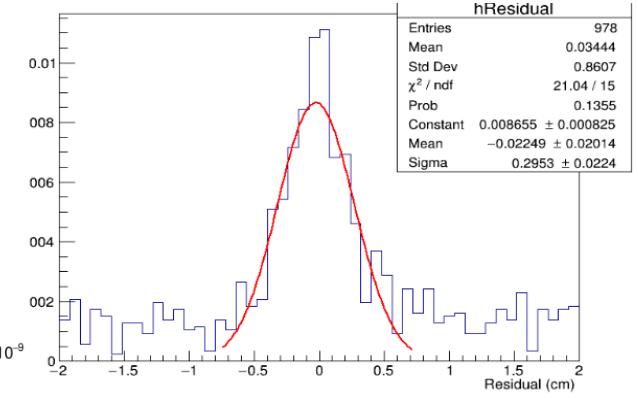
- Internal RH remains stable, despite fluctuations in atmospheric humidity, for over a month



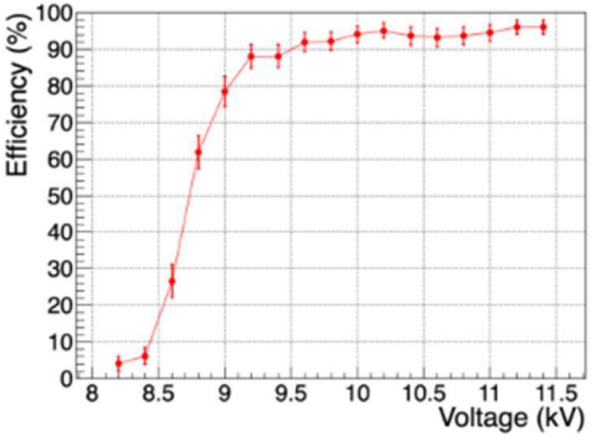
Time resolution



Position resolution

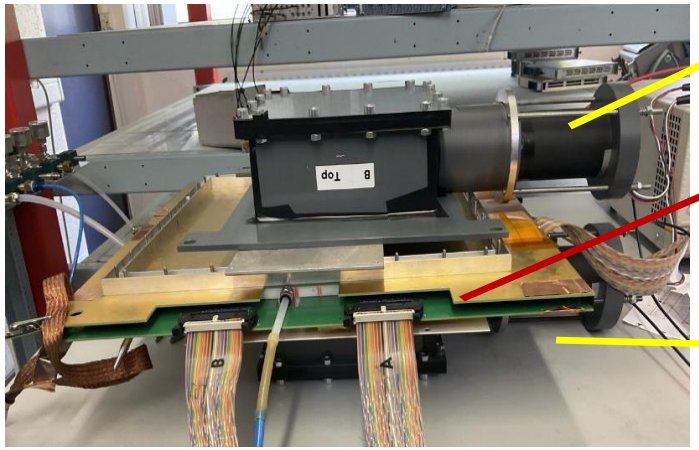


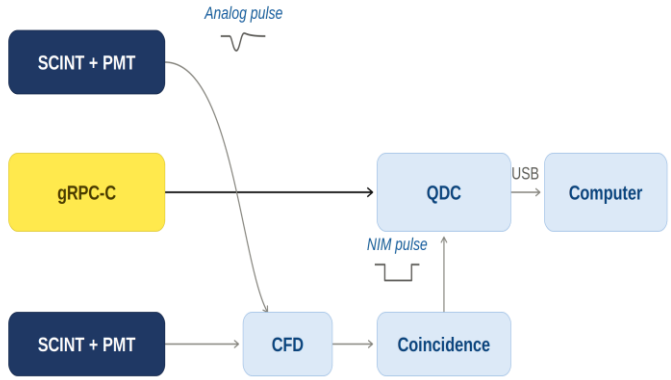
Muon detection efficiency



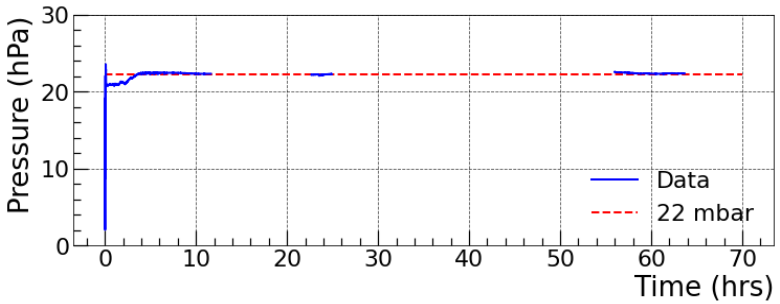
- Time resolution ~1.4ns
- Strip multiplicity of 1-2 for cosmic-ray muons; position resolution ~3mm
- RPC detection efficiency for cosmic-ray muons is ≥95% above 10 kV applied HV

3c. Performance Tests in the Lab (Prototype C)



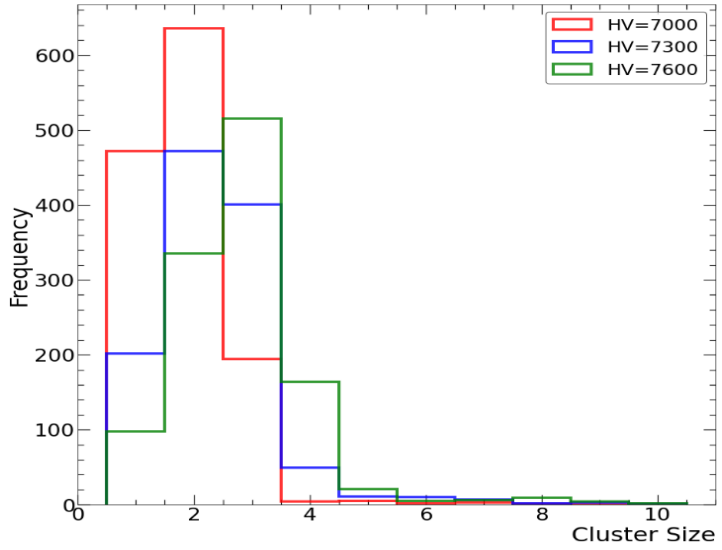


- Double-gap gRPC, positioned between two 16x16cm^2 trigger scintillators (i.e. only 18/32 strips read out)
- NIM/VME QDC/CFD based DAQ



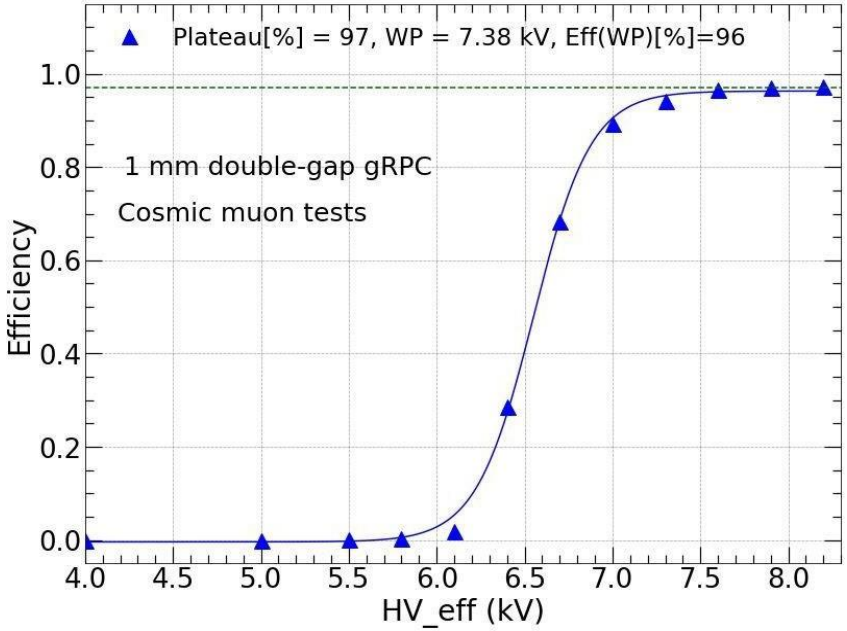
- Gas leak test with Argon @ 22mbar overpressure (validating leak-tight 3D printed frame design)

Muon cluster size



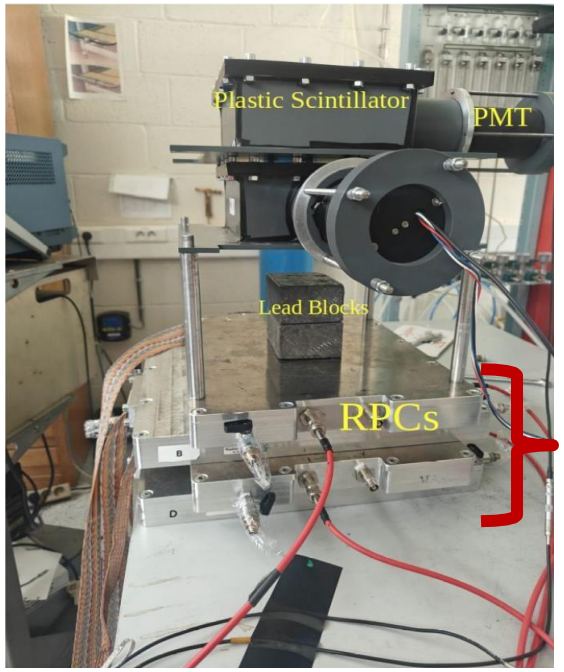
- Marginal rise in cluster size with increased applied voltage
- Average cluster size ~2 strips

Muon detection efficiency

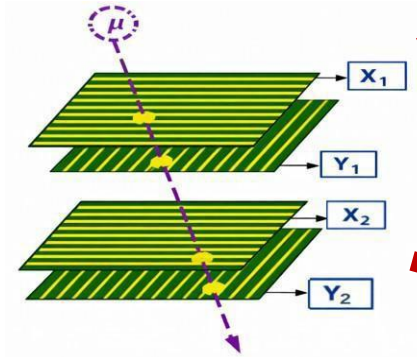


- Efficiency plateau at ~98% above ~7.5 kV

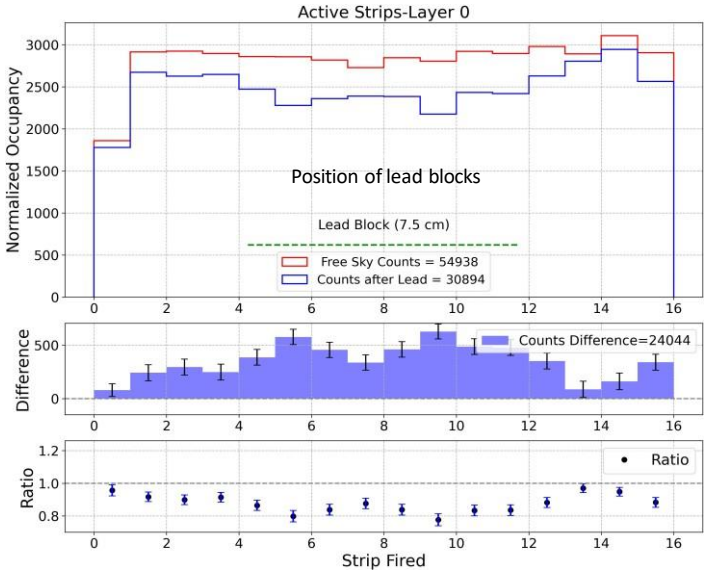
3d. Simple Muography-like Absorption Test



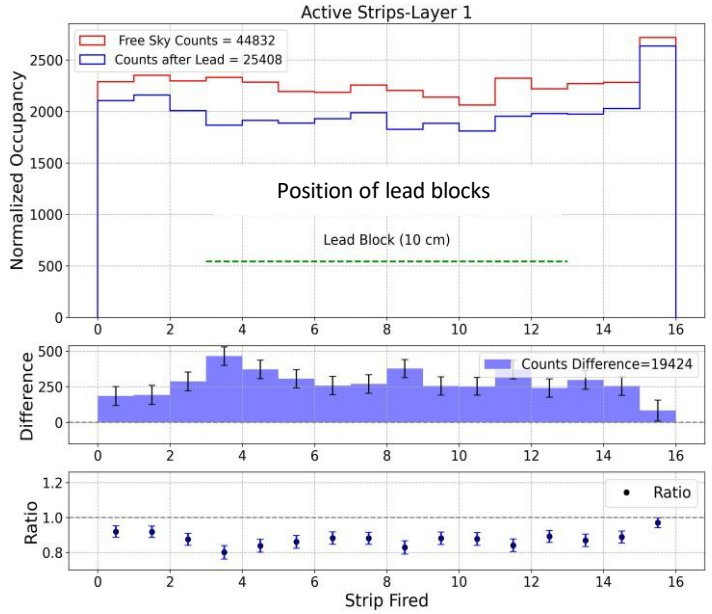
Prototype A



Top RPC Layer



Bottom RPC Layer



- Two plastic scintillator trigger detectors plus two layers of 4 RPCs (XY-readout)
- 2 lead blocks ($10 \times 7.5 \times 4.5$ cm^3) as absorbers placed between scintillators and RPCs
- Measurements without (“free sky”) and with lead blocks
- Count rate decrease due to lead blocks clearly visible

4a. Initial Deployments: ELI Beamlines

Compact (<100m^2) GeV muon production driven by laser electron acceleration at ELI (Extreme Light Infrastructure) Beamlines laser center

- Muon telescopes consisting of 3 prototype A chambers operating in sealed mode
- **Apr.-May & Aug. 2025 (and Sep. 2026) @ ELI Beamlines near Prague, Czech Republic**

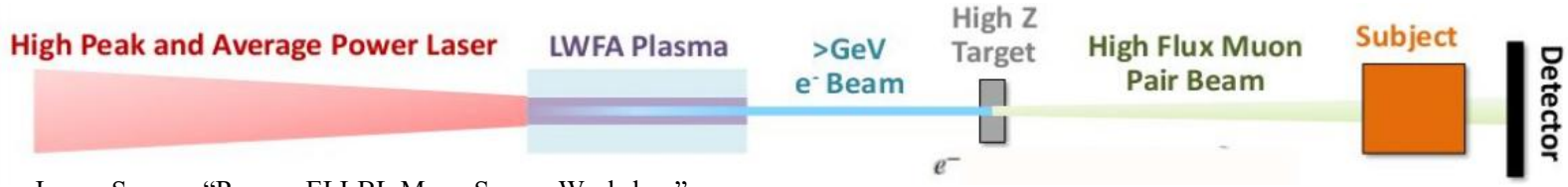


Image Source: "Reagan ELI-BL Muon Source Workshop"

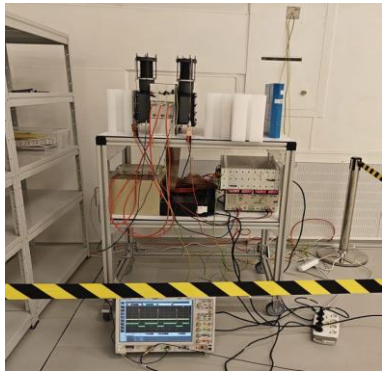
ELI Beamlines:

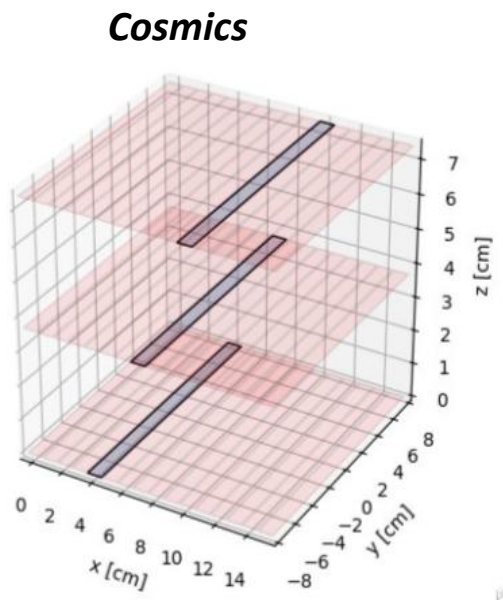
- ELBA ("High energy", ~0.5-5 GeV, ~10's-100's pC) Laser Wakefield Accelerator (LWFA): ultra-short (30 fs), single-shot or pulsed (3.3 Hz) and high-power (1 PW) plasma-laser interactions
- GAMMATRON ("Low energy", ≤1 GeV): negligible amount of muons, i.e. beam-induced background study
- Highly penetrating secondary charged particles (including muons) are produced at the beam dump
- Can we detect these muons with our RPCs ? Analysis still ongoing …

[S. Ikram et al., arXiv: 2605.13118 [physics.ins-det], under review in MDPI Appl. Sci.]







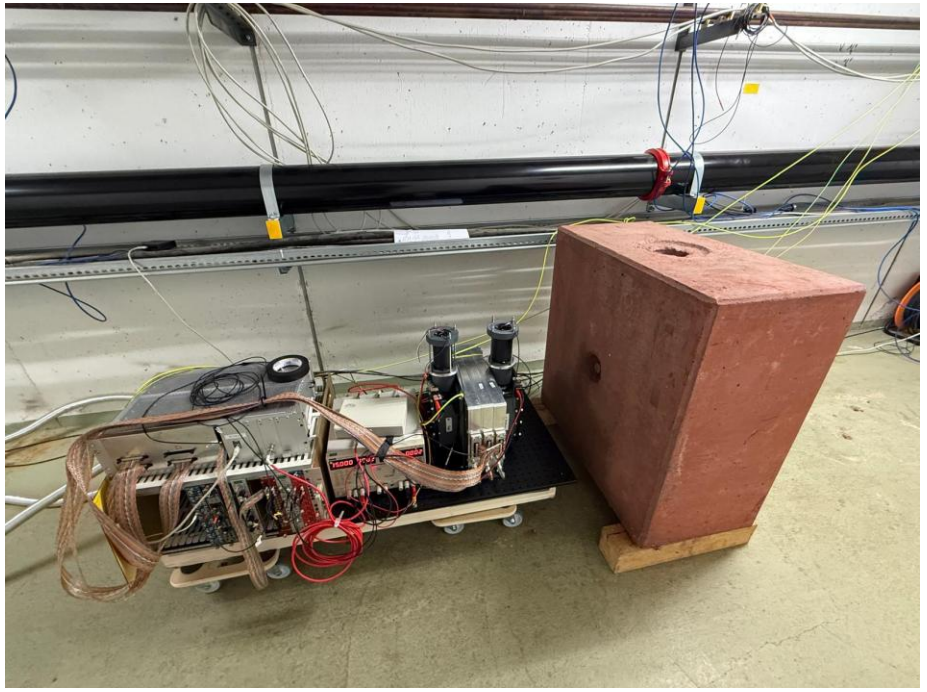


4b. Initial Deployments: DESY-II

- **Aug. 2026**: 3 chambers (prototype A) operating in sealed mode for a week @ DESY-II synchrotron, Hamburg, Germany
- 4 GeV electron beam; bunches of 1.9x10^9 electrons; 4 µs pulse duration; 160ms bunch spacing
- Muon telescope placed behind Tungsten target and concrete beam dump







- Data analysis ongoing …

5. Summary and Next Steps

- ❑ Targeting muography applications in remote outdoor locations or confined spaces with glass-RPCs
- ❑ Several mini-gRPC prototypes with various configurations have been built and characterized; aim to have a modular, mechanically robust but light-weight construction, suitable for low-gas flow or sealed mode operation
- ❑ Leak-tight design and operation in sealed mode seems to work
- ❑ Initial muon absorption measurements performed in the lab
- ❑ Ongoing campaigns with a first version of a sealed, portable muon telescope at ELI Beamlines and DESY

To be done

- ❑ Higher granularity readout
  - potentially with MAROC3A ASIC (under development)
  - optimization (multiplexing) of readout board
- ❑ Switch to more eco-friendly RPC gas mixtures to eliminate high-GWP gases
- ❑ Move to outdoor applications … and solve the corresponding logistics issues …

Muography | **Glass RPCs** | **Portability** | **Sealed Operation**

Selected Publications

D. Ahmadi[1], H. Basiri[2], A. Biolchini[2], E. Cortina Gil[2], P. Demin[2], A.Giammanco[2], S. Ikram[2], R. Karnam[3], V. K. S. Kashyap[3,4], B. Mohanty[3,4], G. Nyitrai[2], M. Tytgat[1]

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[2]Centre for Cosmology, Particle Physics and Phenomenology, UCLouvain, Louvain-la-Neuve, Belgium
[3]Centre for Medical and Radiation Physics, National Institute of Science Education and Research Bhubaneswar, An OCC of HBNI, Jatni, Khurda 752050, Odisha, India
[4]School of Physical Sciences, National Institute of Science Education and Research Bhubaneswar, An OCC of HBNI, Jatni, Khurda 752050, Odisha, India

- S. Basnet et al., “Towards portable muography with small-area, gas-tight glass Resistive Plate Chambers,” JINST 15 (2020) C10032
- R. M.I.D. Gamage et al., “Portable Resistive Plate Chambers for Muography in confined environments,” E3S Web of Conferences 357, 01001 (2022)
- A. Samalan et al, “Small-Area Portable Resistive Plate Chambers for Muography”, JAIS 2024 (2024) 489
- V. Kumar et al., “Performance testing of gas-tight portable RPC for muography applications”, JINST 19 (2024) 04, C04027
- S. Ikram et al., “Development and performance analysis of glass-based gas-tight RPCs for muography applications”, J.Appl.Phys. 138 (2025) 174502
- R. Karnam et al., “A portable glass-RPC based muon tracking system for muography applications,” TIPP2026
- S. Ikram et al., “RPC Telescope Tests for Muon Detection at Laser-Plasma Accelerators”, arXiv: 2605.13118 [physics.ins-det], under review MDPI Appl. Sci.

Thank you

BACKUP