An advanced gaseous detector based telescope for muography

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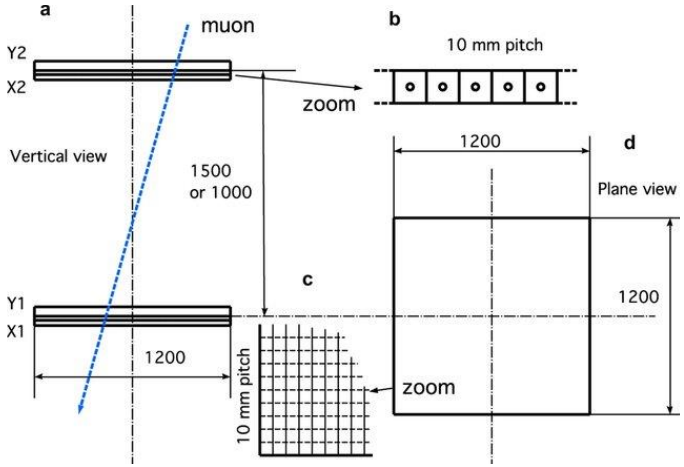
Introduction

- Traditional muography telescope technology: emulsions, scintillators or gaseous detectors

- Each of these types comes with its own set of features and advantages; selection may depend on specific application, target object and its environment, available budget …

Micromegas telescope outside pyramid (CEA/irfu/SPhN)



Layout of the ScanPyramids scintillator hodoscope (KEK)

Emulsion film muons detectors observing SP-North Facing Corridor inside the pyramid (Nagoya U.)

Introduction

- Our team has been focusing on gaseous detectors for ~15 years:
  - Resistive Plate Chambers (RPCs) & Gas Electron Multipliers (GEMs) for Muon system of CMS@LHC experiment; RPC-based calorimetry (CALICE SDHCAL)
  - Muography with standard RPCs: portable RPC-based muoscope project in collaboration with UCLouvain [see e.g. S. Basnet et al., *Towards a Portable High-Resolution Muon Detector Based on Resistive Plate Chambers*, *JAIS* (2022) 299 (Muography2021) and talk on Wednesday]
- Adaption of gaseous detectors for (remote) muography applications
  - Mitigate the need for large gas refresh rates and complex gas mixtures
- Application of high-time precision in muography telescopes
  - Suppression of out-of-time background, i.e. reduction of combinatorics during muon track reconstruction
  - Removal of backward going muons
  - Muon momentum estimation from time-of-flight ??

[High-time precision is a central theme in the ECFA Detector R&D Collaborations that are currently put in place]

Introduction

→ Study of two different gaseous detector types for muography

- Multi-gap Resistive Plate Chambers (mRPC), compared to standard RPCs:
  - Similar characteristics in terms of stability, spatial resolution, gas mixtures
  - Superior time resolution down to ~50ps
  - But, higher chamber voltage required

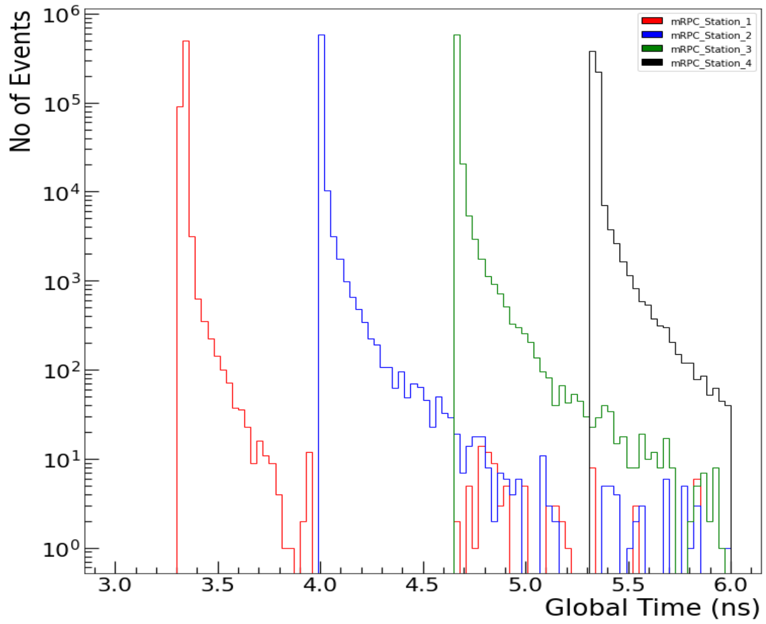
- Thick Gas Electron Multipliers (THGEM), compared to standard RPCs:
  - Stabler operation, i.e. less affected by environmental parameters
  - Lower chamber voltage levels required
  - Simpler gas mixtures, e.g. Ar/CO_2 or monogases, e.g. Xe …
  - But, higher cost (GEM PCB fabrication)

[A. Samalan *et al*., Exploring Advanced Detector Technologies for Muon Radiography Applications, 2022 IEEE Nucl. Sci. Symp. and Med. Imag. Conf. Rec. (NSS/MIC) (accepted)]

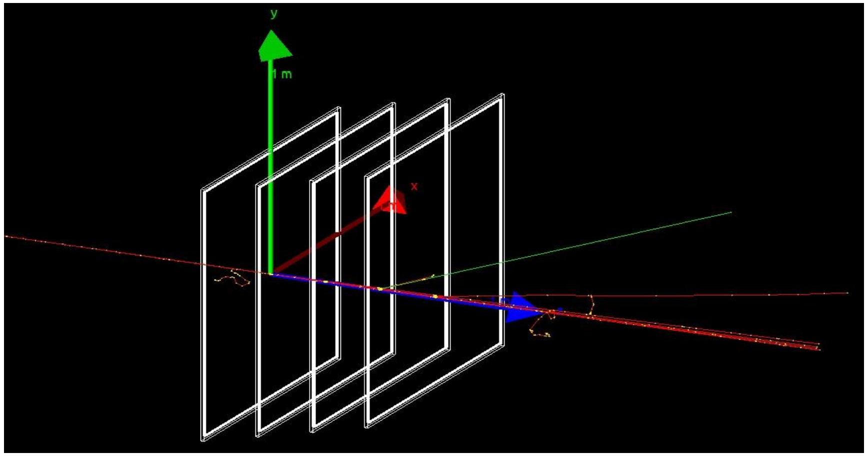
Timing in muography

A toy Geant4-based simulation of a 4-plane mRPC telescope is under development to

- study the effectiveness of improved time information
- tune muon telescope layout



4 planes separated by 20cm
(→ sub-ns timing required …)



Time-of-flight momentum estimation ?
Assume typical telescope of 1m (+-1mm) and time resolution of 50ps

$$pc = \frac{L(m_0c^2)}{\sqrt{t^2c^2 - L^2}}$$

$$\sigma_p^2 = \frac{t^2c^4(m_oc^2)^2}{(t^2c^2 - L^2)^3}[L^2\sigma_t^2 + t^2\sigma_L^2]$$

σ_p(1 GeV muon) = 1.35 GeV already
→ cannot do much above ~1 GeV

Multi-gap RPC Prototyping

General design aims:
- Low volume, gas tightness (RPC has complex mixture of greenhouse gases …)
- No glueing which allows re-opening and disassemble chamber in case of issues
- Easily adaptable in terms of readout board
- Time resolution of O(<100ps)

→ Same design concept applied to one of our standard double-gap RPCs in portable muoscope project (See talk A. Samalan, Small-area portable resistive plate chambers for muography, on Wednesday)

⇨ **Specifications of initial prototype**

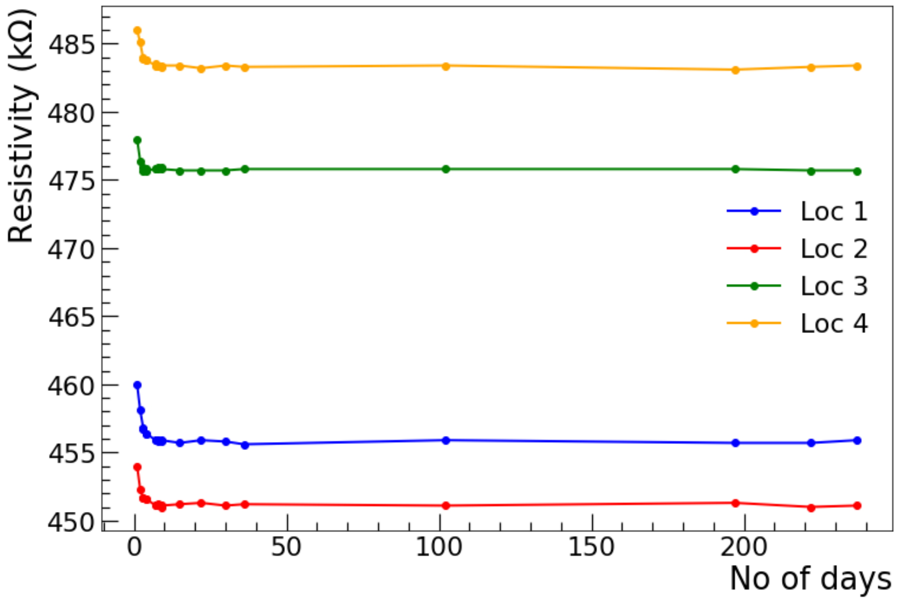
- Active area of 30x30cm^2
- *Stack of 7 glass plates* → top and bottom with resistive coating (1.1 mm) and thin glass plates in between (0.55 mm)
- *Resistive coating* → using spray gun @ 5bar
- *Gas gap construction* → circular Mylar spacers (h=250 μm; d=4mm)
- *2D readout* → two 32-strip PCBs on top and bottom (XY orthogonal)

Glass Resistive Coating

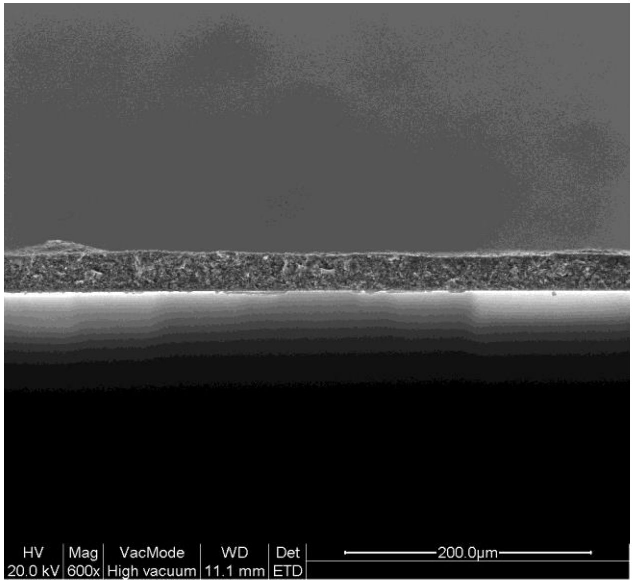
Resistive coating on glass plates:

- Paint mixture of EDAG 6017SS conductive and PM404 resistive paint; tunable resistivity values
- Manual coating procedure with a 5mbar spraying gun
- Curing of coating inside oven at 110°C

Resistivity values stable over several months



Uniform surface (30-35μm measured with SEM)

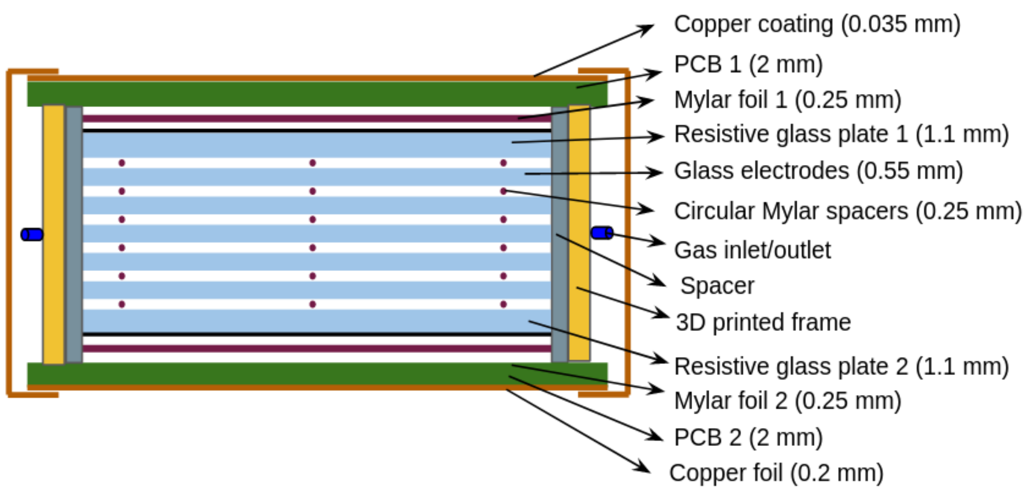


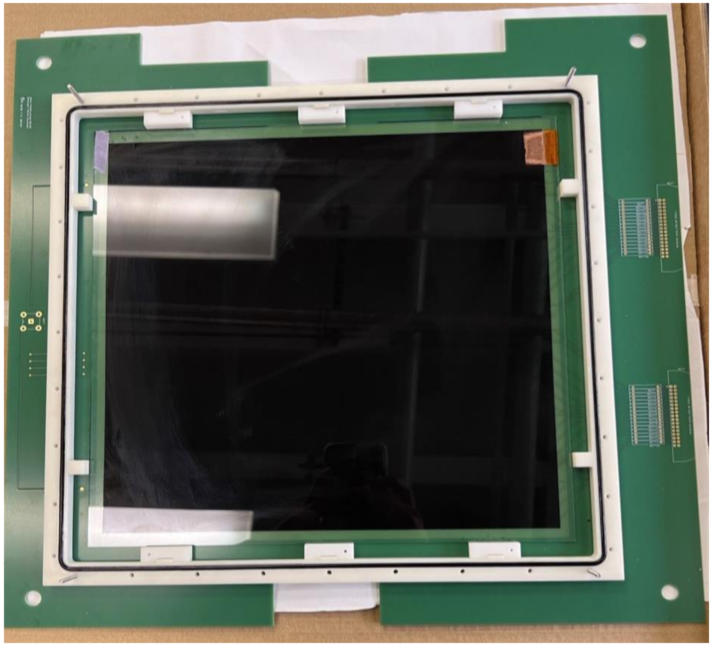
mRPC prototype design

Gas-tight, low volume design:

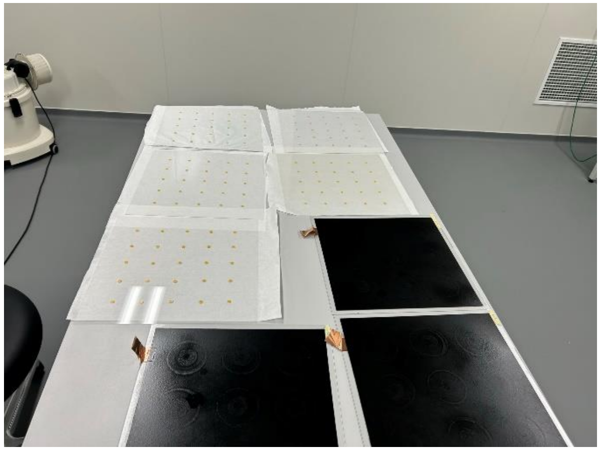
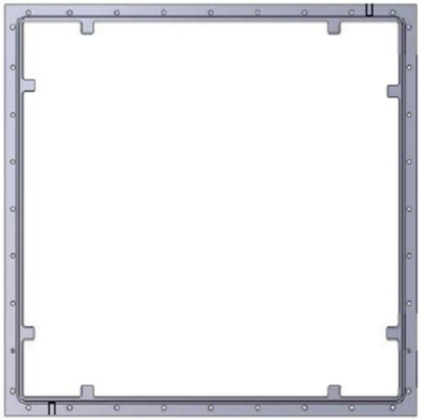
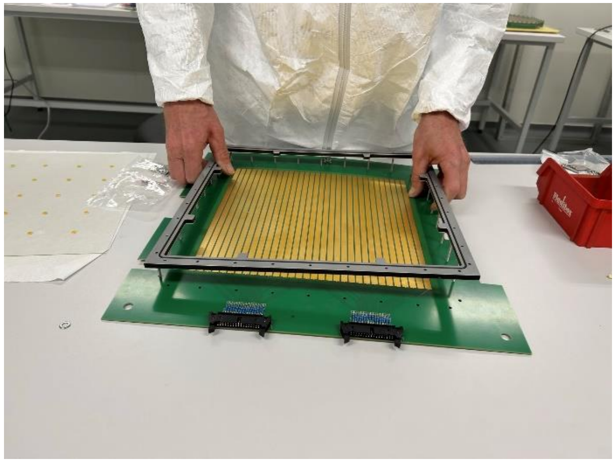
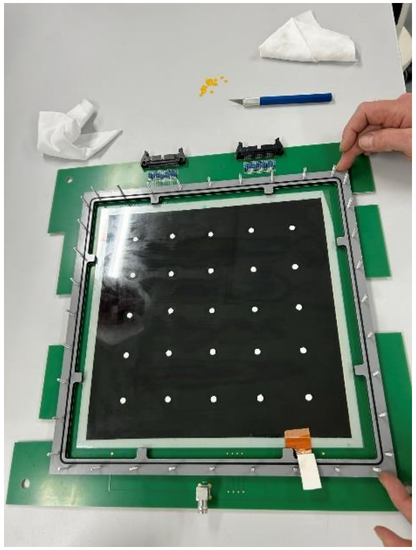
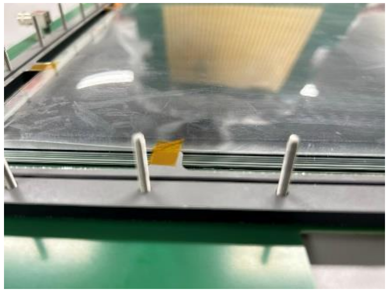
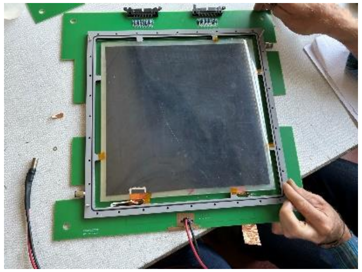
- Gas volume contained inside gas-tight metallic frame, sandwiched between 2 Printed Circuit Boards containing strip pattern, connection to readout electronics and services (HV, T-H sensors)

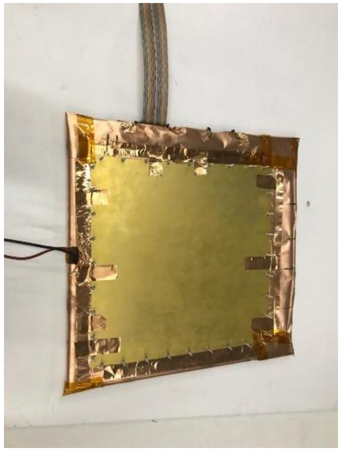
- Simplified mRPC glass stack assembly following new idea from CALICE SDHCAL project





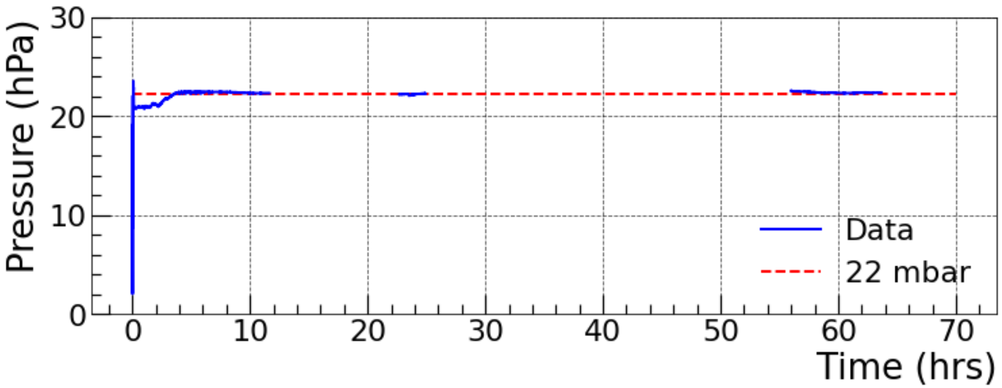
mRPC prototype assembly



mRPC prototyping

Verifying leak tightness



Performance tests with cosmic inside scintillator telescope ongoing … stay tuned

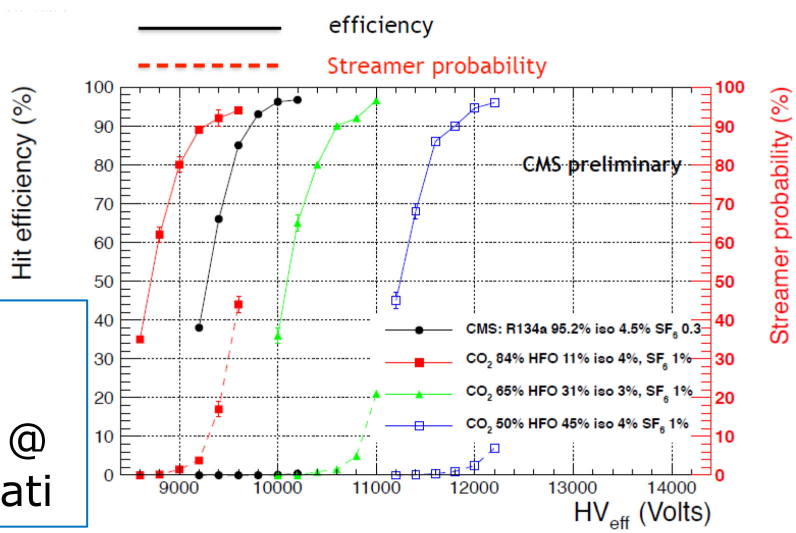
RPC Ecogas Issue

- Standard RPC gas mixture consists of **$C_2H_2F_4$ (R134a) / SF_6 / C_4H_{10}**

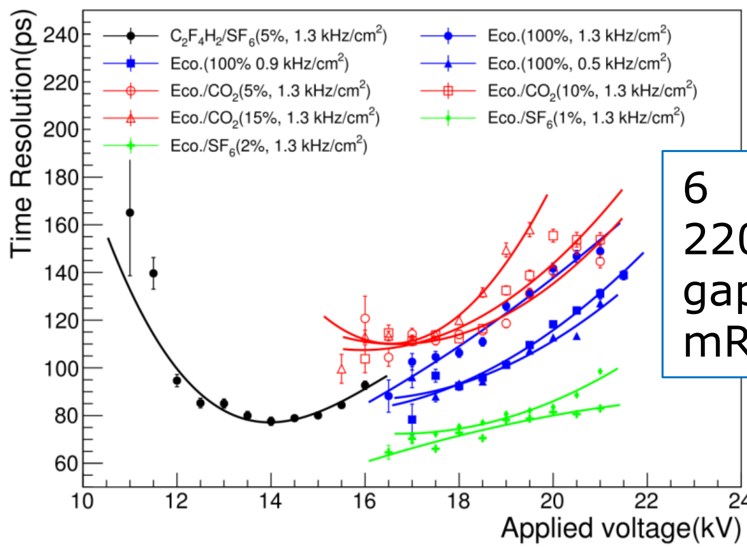
→ R134a and SF_6 are greenhouse gases, whose usage is being phased out following European regulations (causing limited availability and huge cost increase …)

→ Current efforts mostly focus on replacing $C_2H_2F_4$ (GWP=1430) by $C_3H_4F_4$ze (GWP=4) + CO_2 (GWP=1) or He (GWP<1) to reduce the operating voltage

CMS RPC tests @ Frascati



[Y. Baek *et al*, Nucl.Instrum.Meth.A 927 (2019) 366-370]



6 220µm gap mRPC

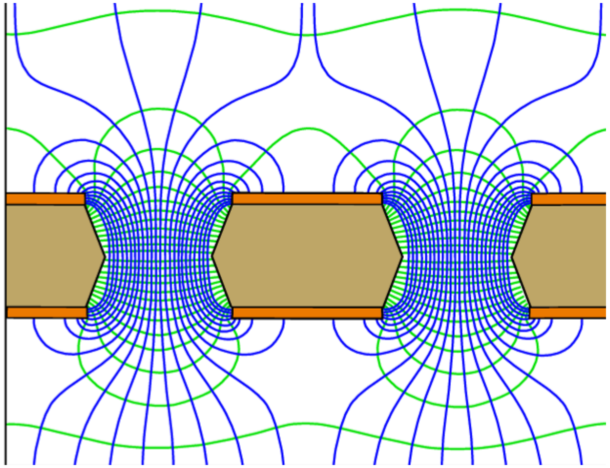
Ecogas mixtures tend to increase operating voltage and shorten the efficiency plateau (due to increased amount of streamers); efficiency and time resolution performance can be maintained; detailed studies ongoing …

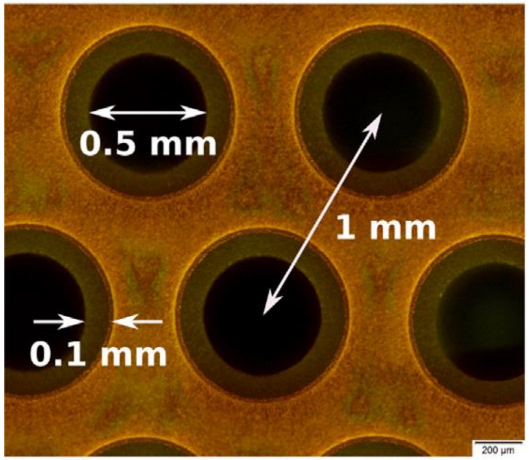
Thick-GEMs

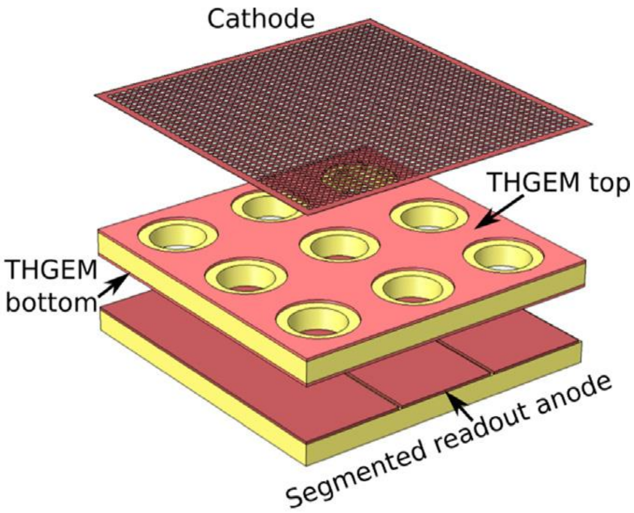
Similar to standard GEMs, but with dimensions of order mm instead of µm, i.e. stable operation, with excellent position resolution of ~100µm

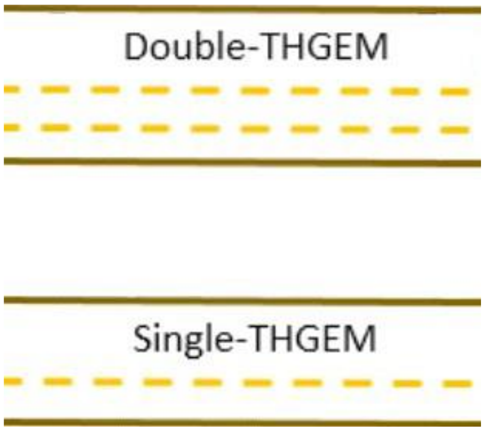
Compared to regular GEMs, THGEMs are:

- More robust and simpler assembly (PCB instead of flexible foils)
- Cheaper construction (mechanical drilling in PCB instead of chemical etching of foils)





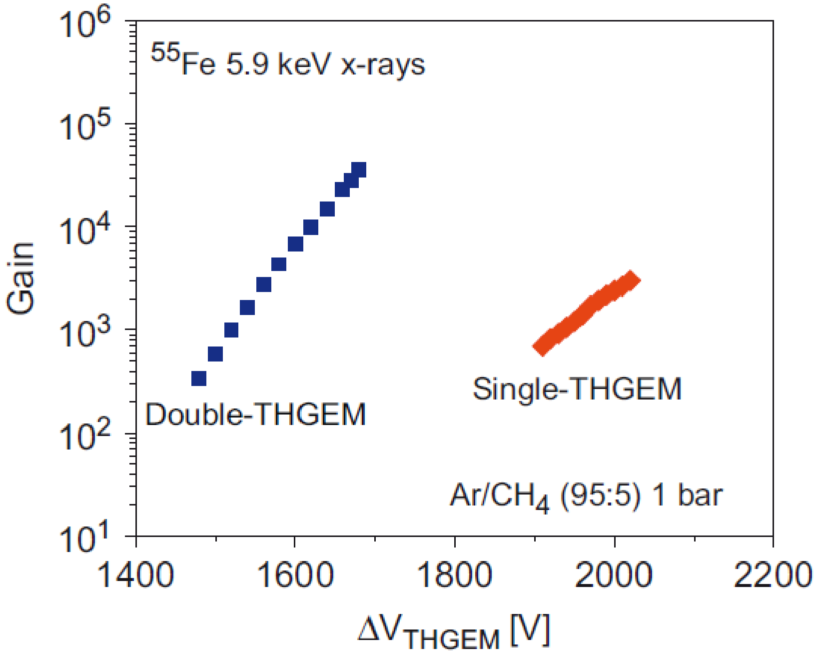


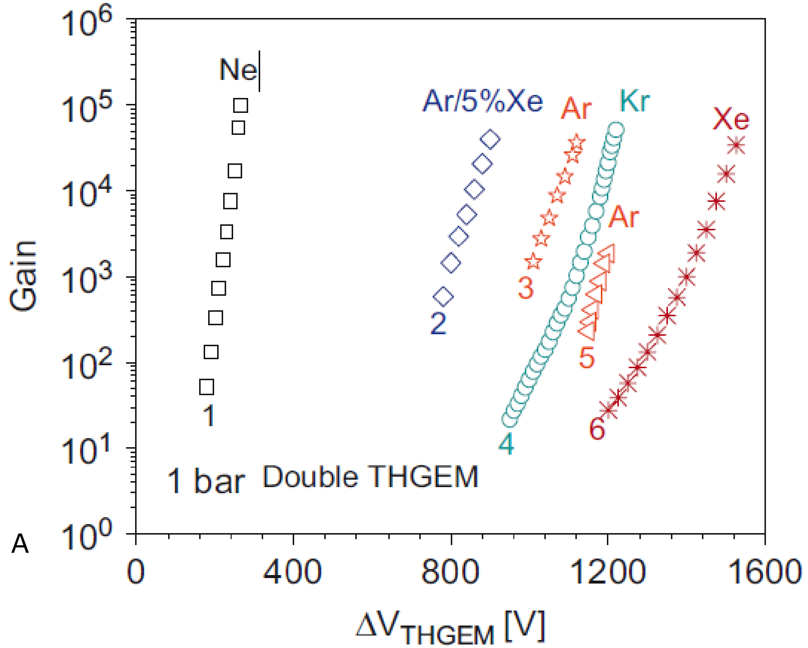


[Figure from S. Bressler *et al*, Progress in Particle and Nuclear Physics (2023)]

Thick-GEMs

- Double or triple-THGEMs yield similar gain as single-THGEMs, but at lower voltages leading to more stable performance
- Typical values of ΔV_{THGEM} = 1-2kV, E_{ind} = 1 kV/cm, and E_{drift} = 0.5 kV/cm
- Operation possible with noble mono-gases, which simplifies logistics for outdoor muography
- Efficiencies up 98%
- Spatial resolution down ~100µm
- Time resolution ~5-10ns





[A. Breskin *et al*, Nucl. Instr. Meth. A 598 (2009) 107–111

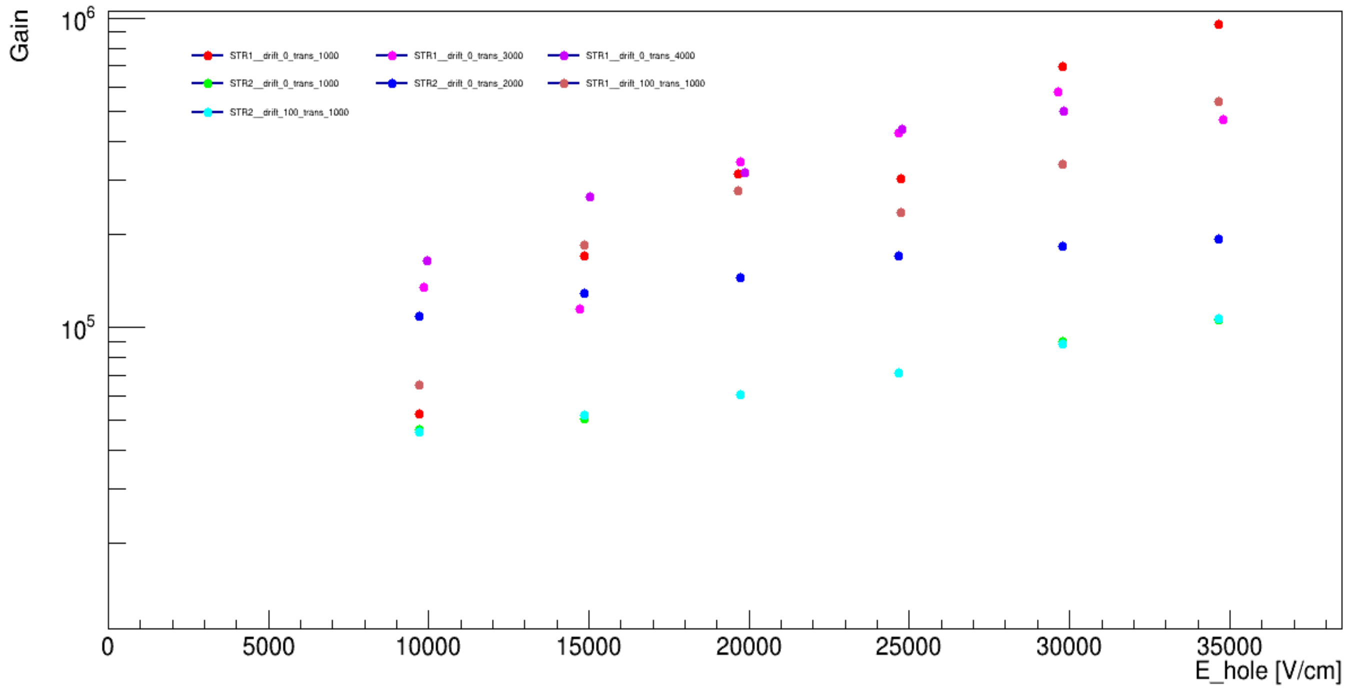
Design Optimization Study

Ongoing optimization study via Garfield++ / ANSYS simulations

- Gas composition, i.e. mixtures and mono-gases
- GEM layout, i.e. hole density, hole diameter, rim size
- Field configuration, i.e. drift, GEM, transfer, induction

Example of

single THGEM gain
vs.
E-field inside GEM hole
for different drift and induction fields

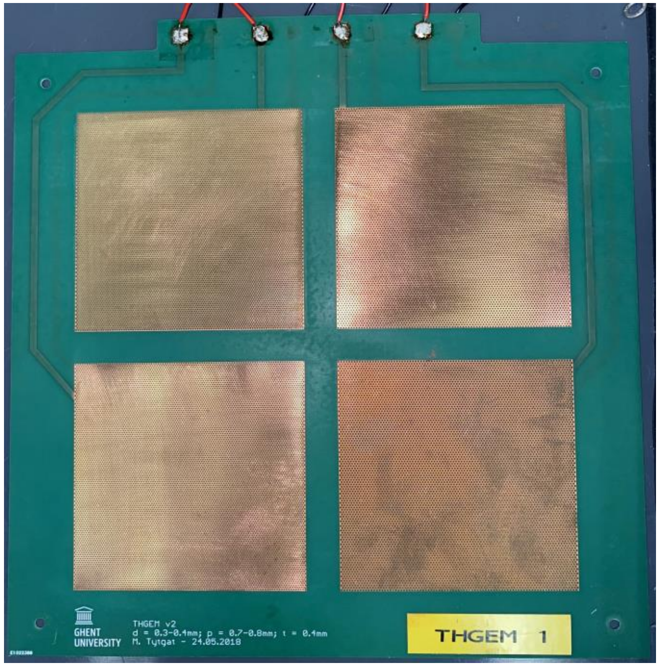


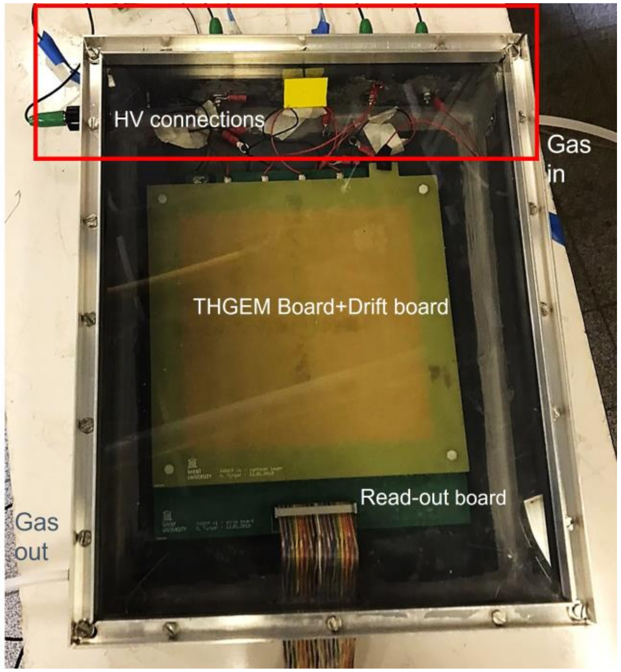
Thick-GEM Prototyping

Test PCBs with multiple 7x7cm^2 GEM patterns:

- Commercially produced (Eurocircuits); quality issues with drilled GEM holes
- Initial prototype with single/double THGEM; adjustable gap sizes

thickness=0.4mm;
hole diameter= 0.3-0.4mm;
rim size = 0.1mm;
pitch=0.7-0.8mm



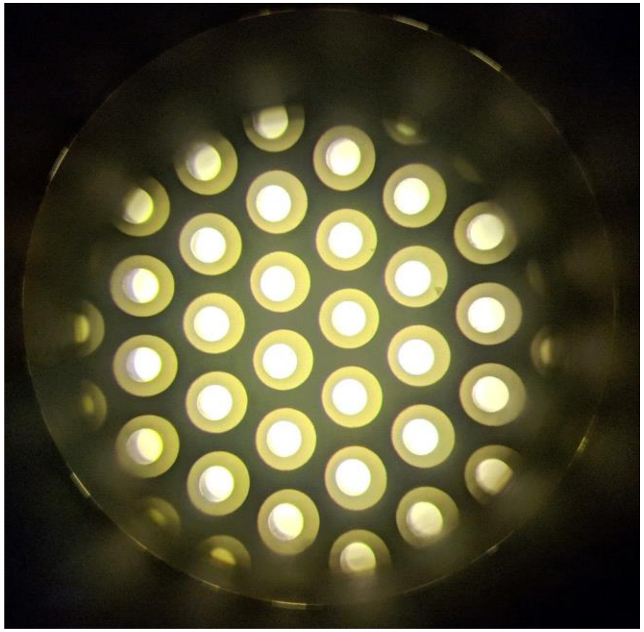


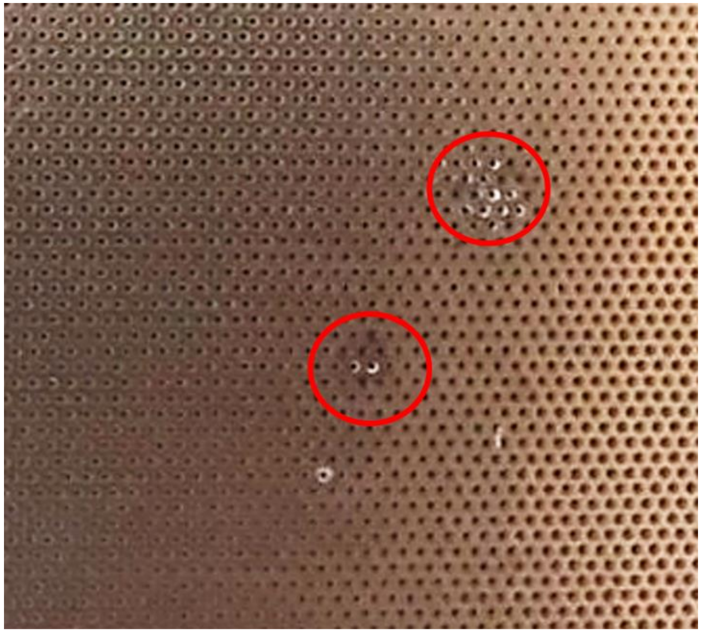
→ test different configurations (efficiency, cluster size, spatial resolution …) following results of optimization simulation studies

Thick-GEM Prototyping

- Quality issues with commercially produced THGEM PCB:
  - Hole/rim pattern alignment
  - Drilling residues inside holes
  - Resin-like depositions

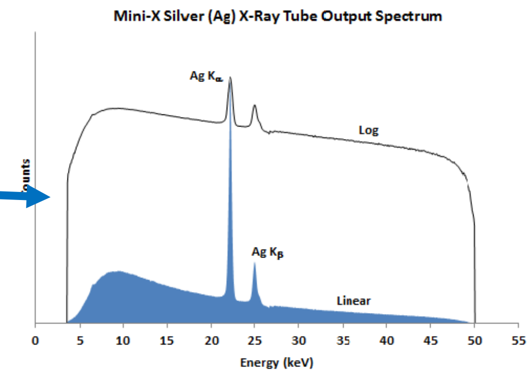
→ Inspection and cleaning of hole through microscope …





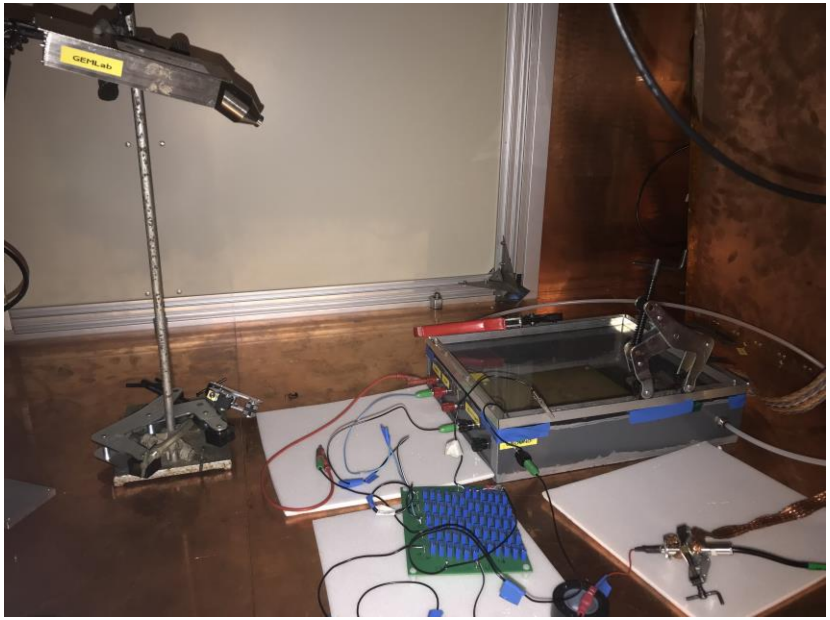
- Maximum size limited by PCB technology (~0.5-1m)
- GEM segmentation studies to be done (stability against discharges, reduce losses of surface area in case of shorts in individual holes)

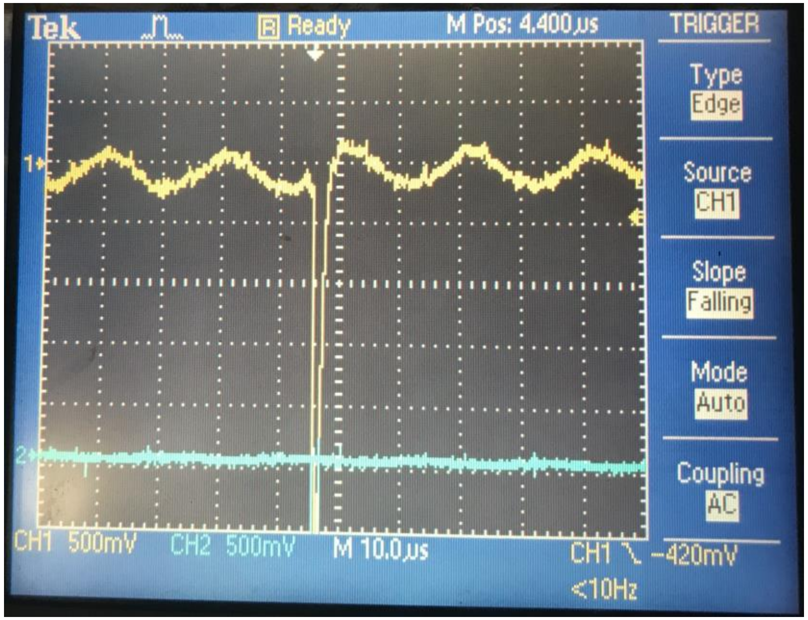
Initial Lab Tests



Initial studies ongoing:

- Amptek Mini-X X-ray gun (Ag target)
- Cosmic muons and scintillator paddles for more detailed performance studies





First detector signals observed with X-rays; setup to be optimized in terms of noise

Summary & Outlook

- Considering the usage of advanced gaseous detectors for muography, i.e.
    - mRPC for high precision timing, to improve background rejection and tracking, and crude momentum estimation
    - THGEM, for high resolution, stable operation with mono-gases
- Initial prototyping studies ongoing along with accompanying simulation studies in Geant4 and Garfield++, i.e.
    - mRPC: low volume, gas-tight chamber design; performance to be determined
    - THGEM: initial, small-size single/double THGEM studies ongoing; basic detector configuration and performance to be determined
- DAQ electronics to be addressed (Weeroc-based, i.e. Petiroc ?)

[A. Samalan *et al*., Exploring Advanced Detector Technologies for Muon Radiography Applications, 2022 IEEE Nucl. Sci. Symp. and Med. Imag. Conf. Rec. (NSS/MIC) (accepted)]