

μ – Rwell for HI-LUMI

2025 Test beam for MPGD development
4 – 23 November 2025

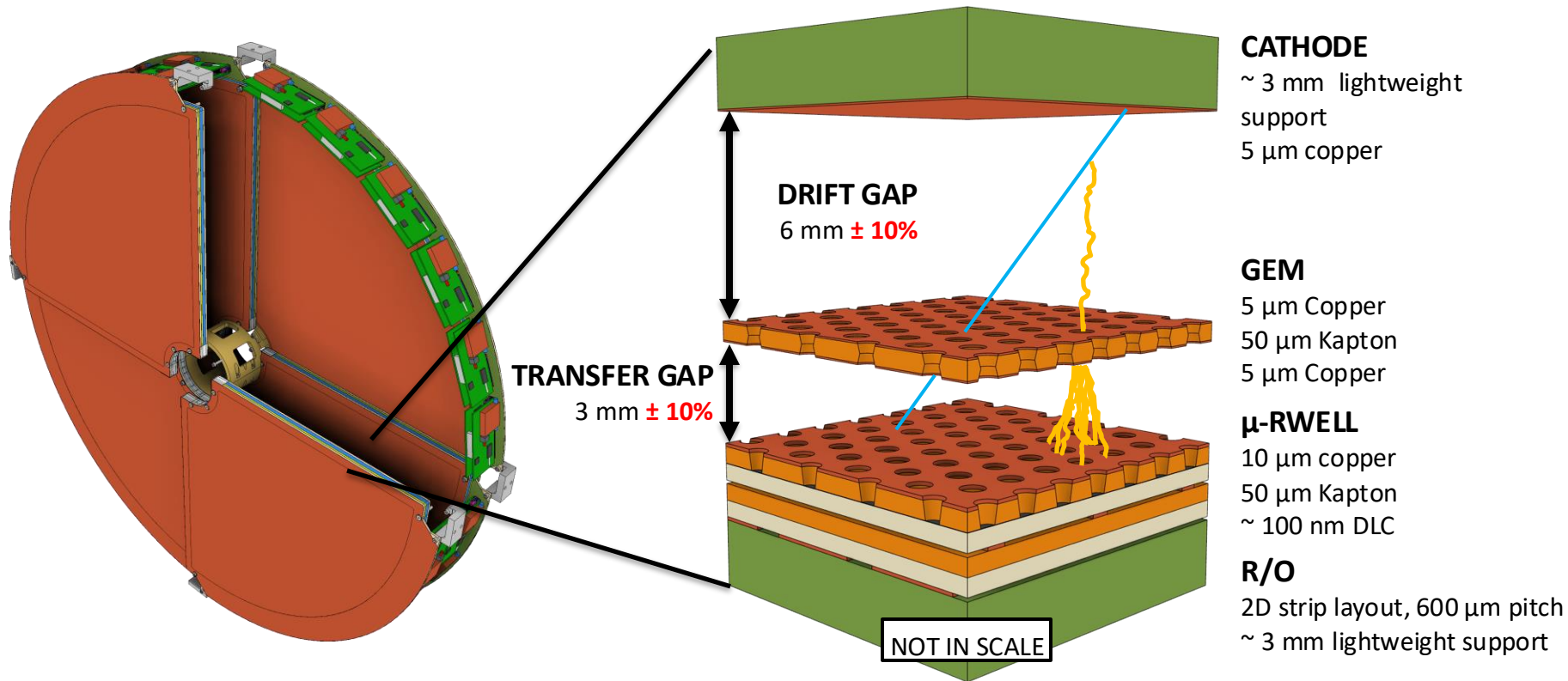
C. Ammendola, R. Ammendola, M. Bondì,
A. D'Angelo, R. Di Salvo, A. Fantini, S. Gramigna,
L. Lanza, S. J. Lee, G. Nobili, E. Sidoretti



In collaboration with:

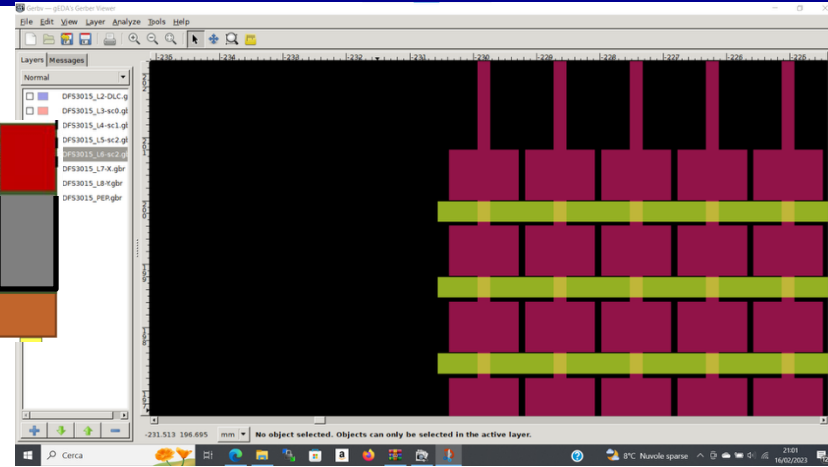
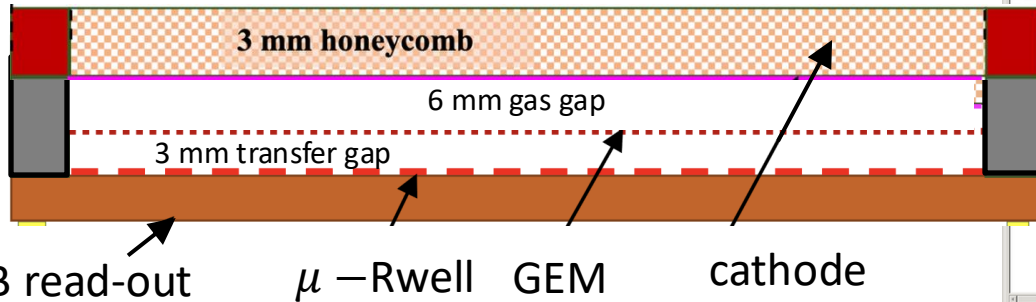
G. Bencivenni, G. Felici, M. Gatta, M.
Giovannetti, G. Morello, M. Poli Lener,
G. Sekhniaidze, L. Torlai, G. Zunica

GEM – μ Rwell Hybrid Technology



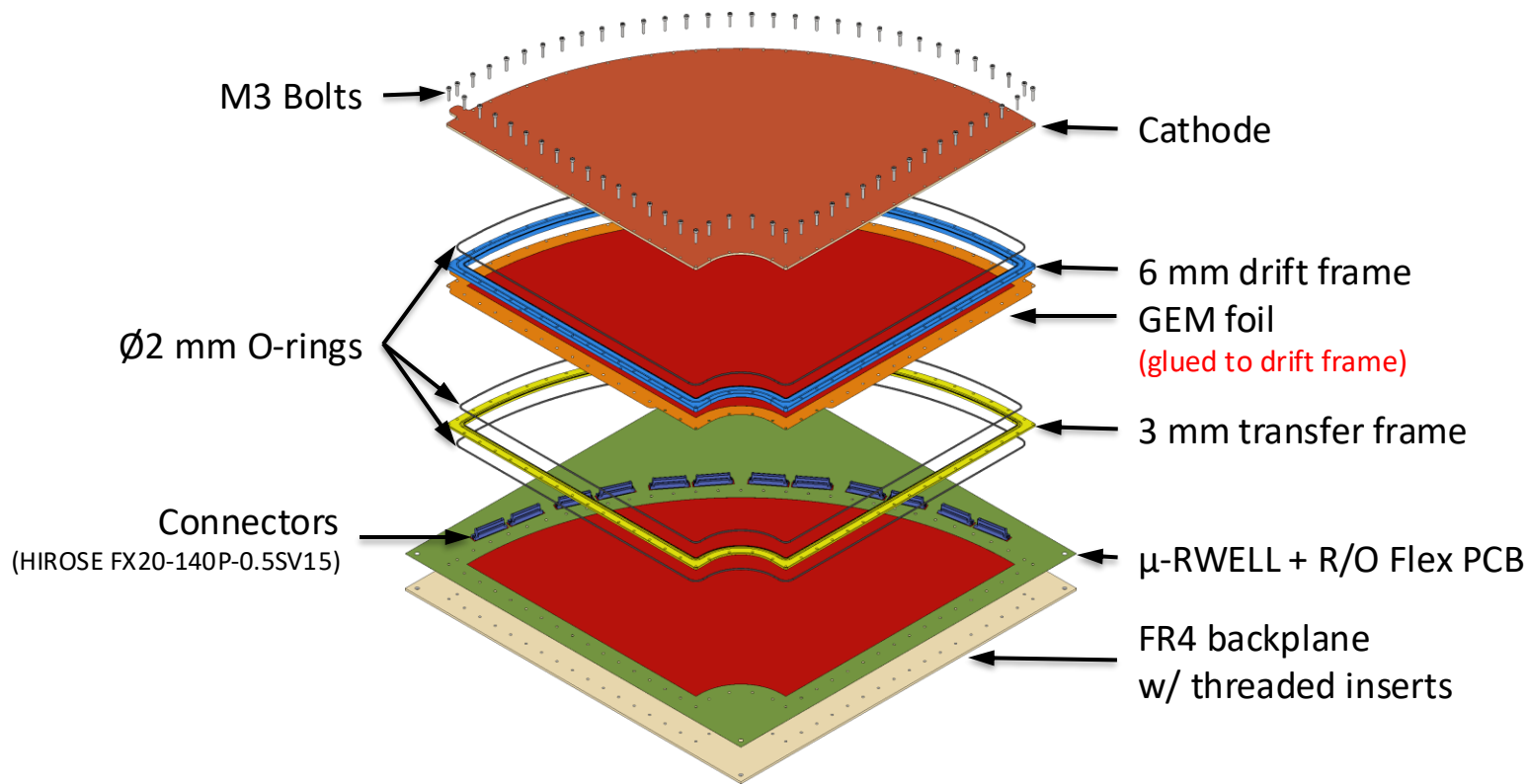
Detector Technology Choices: GEM+ μ Rwell

GEM - μ Rwell Technology



- 2D CS readout reduces the **gain** from 10^4 to $3-4 \cdot 10^3$ → the detector stability is put at risk
- GEM- μ Rwell hybrid configuration has been chosen to increase the gain in the $10\,000 \div 20\,000$ range
- 2D strip read-out using a “COMPASS-like” scheme
- $600\ \mu\text{m}$ pitch guarantees a spatial resolution better than $150\ \mu\text{m}$
- A gas gap larger than 3 mm is compatible with single detector efficiency larger than 96%

ETA Main Components and Assembly



GEM Stretching Tool

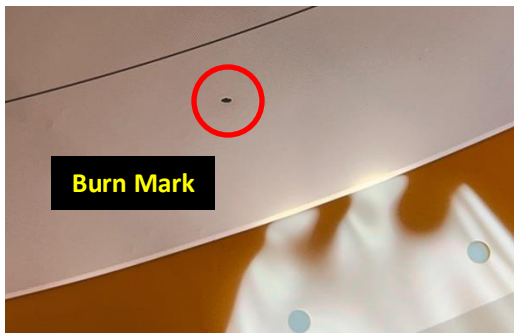


+10kg tension

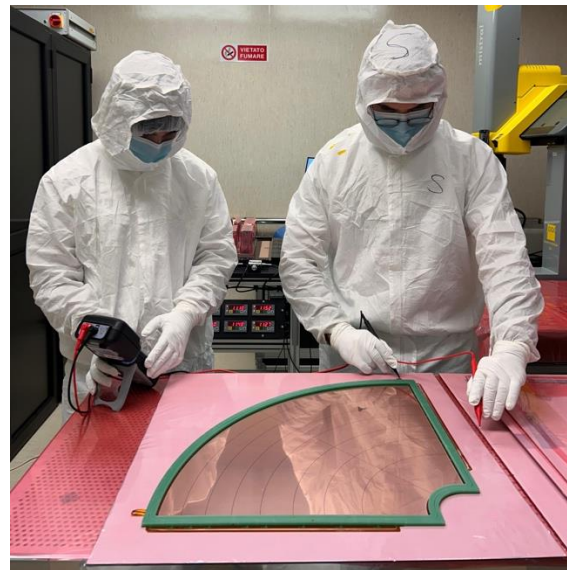
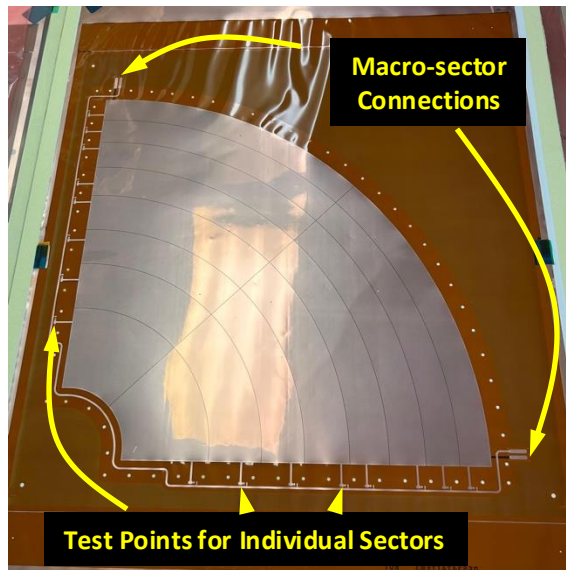


Equipment tested with success, stretching technique consolidated

Quality Control of the GEM Foils



- Optical inspection
- Capacitance measurement
- Resistance measurement
- Insulation test up to 500v
(Requires N2 enclosure)

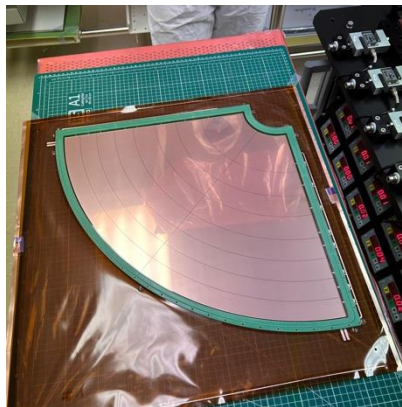
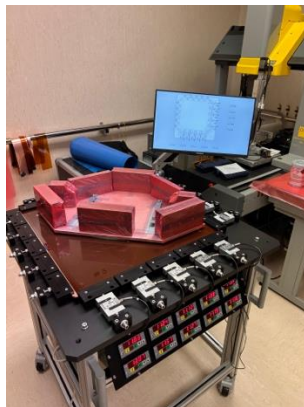
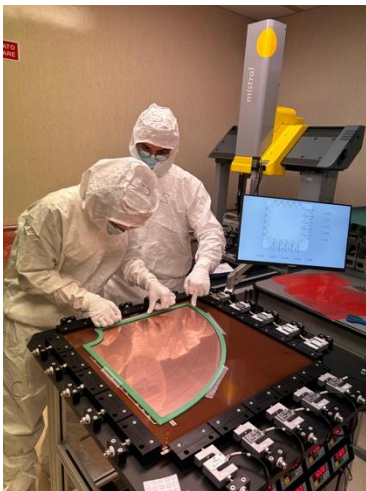


Performed on arrival and after the gluing, before shipping the foils back to CERN

One sector already shorted on arrival, **no new sectors were damaged in the operations**

The gluing procedure is "clean"

GEM Gluing



Araldite AY103 epoxy deposited in a 3 mm wide strip

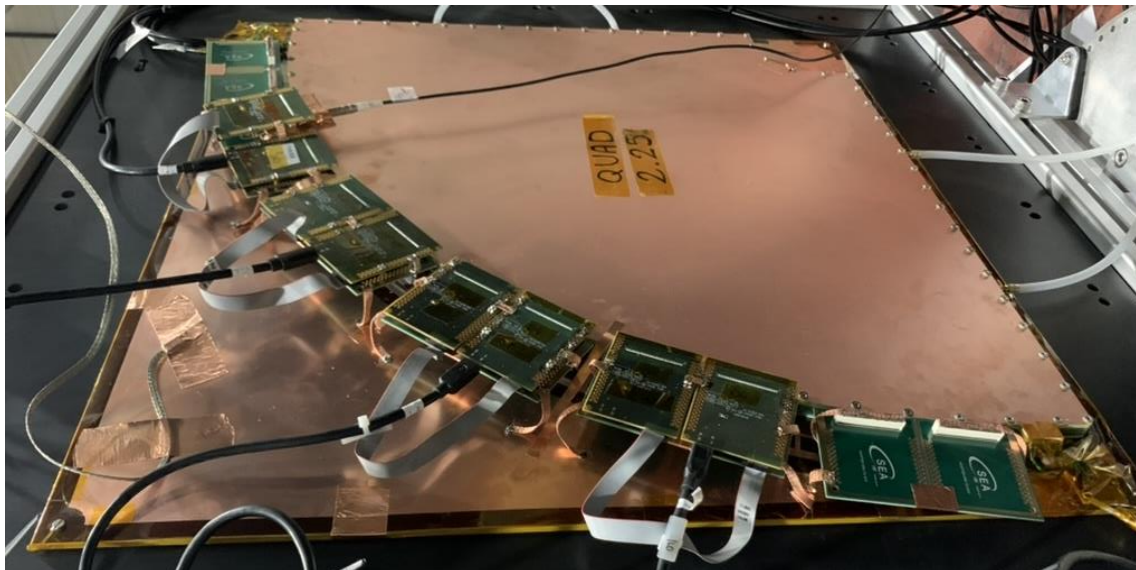
GOOD for mechanical stability, no overflow, no holes occluded

BAD for gas tightness, internal sealing with Araldite 2011 required

4 GEMs Glued in total (2x ETA Quadrants, 2x CS prototypes)

The technique is serviceable, there is room for improvement

Assembly and First Conditioning

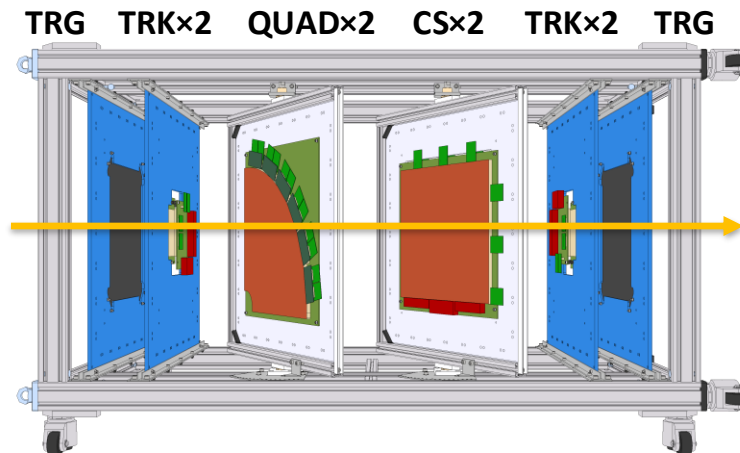
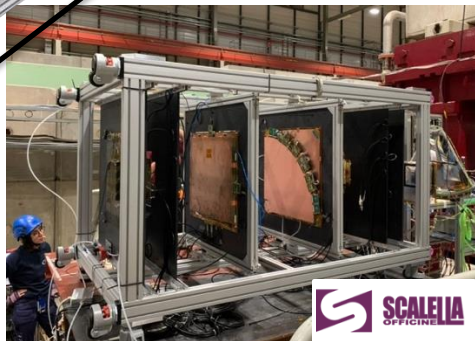
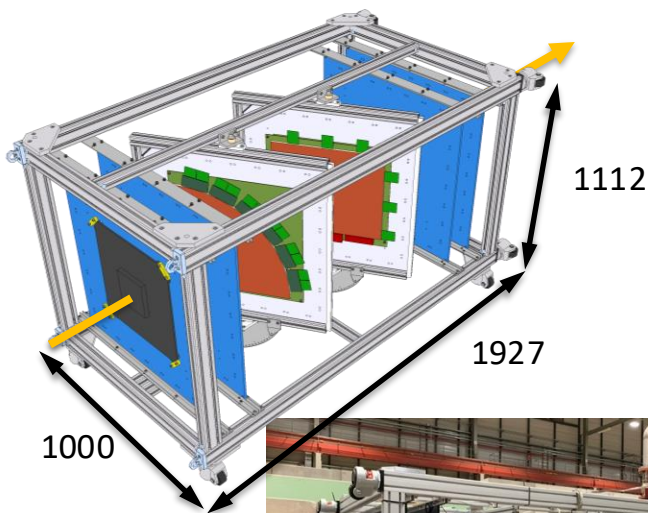


μ -RWELL + R/O PCB Manufactured at CERN MPT Workshop

Final assembly and first detector conditioning also performed at CERN

Nr. 2 detectors ready for the second week of the test beam (1 w/ grids and 1 w/o)

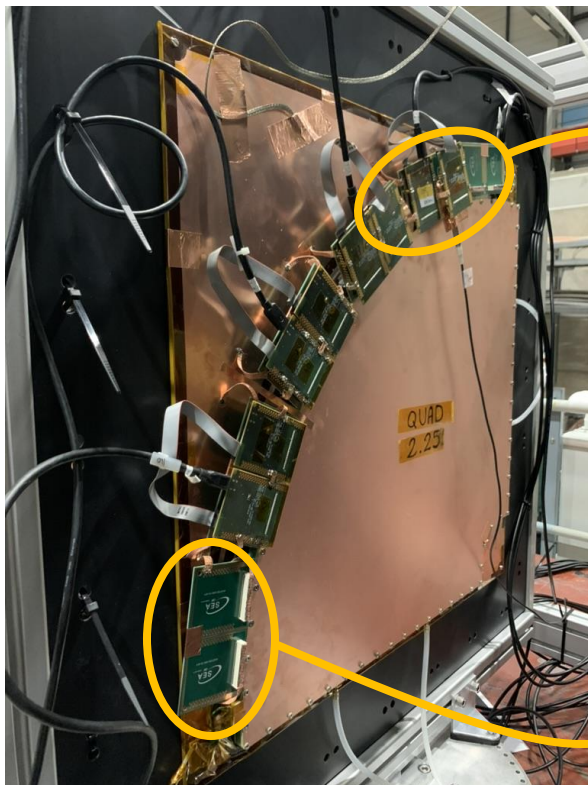
Setup and Detector Arrangement



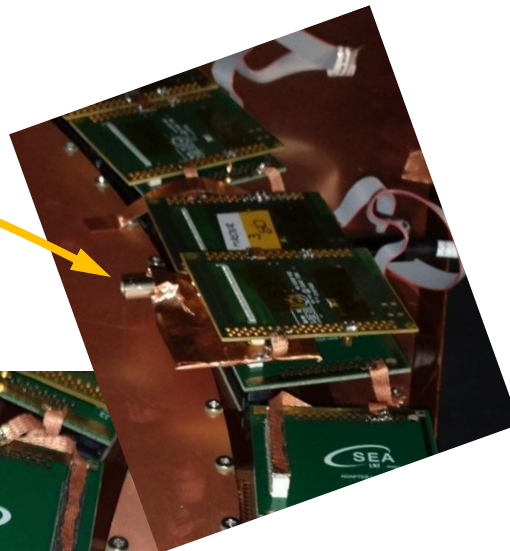
| DET | Pitch (μm) | Active Area | Readout | Capacitive Sharing |
|------|-------------------------|-----------------------------|---------|--------------------------------|
| TRK | 400 | $10 \times 10 \text{ cm}^2$ | 2D XY | No |
| QUAD | 600 | $R = 45 \text{ cm}$ | 2D XY | No |
| CS | 1200 | $46 \times 40 \text{ cm}^2$ | 2D XY | 3 Layers ($300 \mu\text{m}$) |
| TRG | NA | $15 \times 15 \text{ cm}^2$ | SiPM | NA |

All MPGDs operating with $\text{Ar}:\text{CO}_2:\text{CF}_4$ (45:15:40)

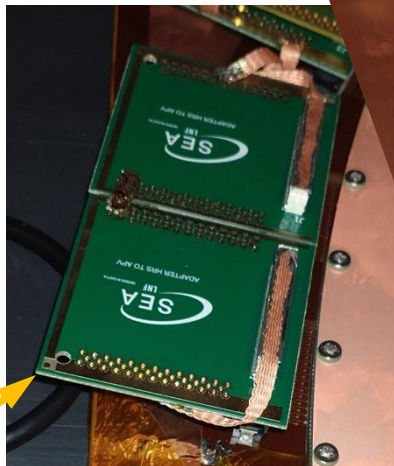
DAQ



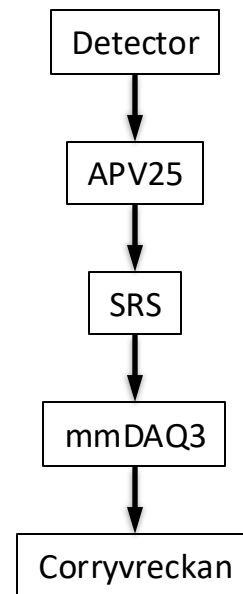
Trigger Signal Injection Board



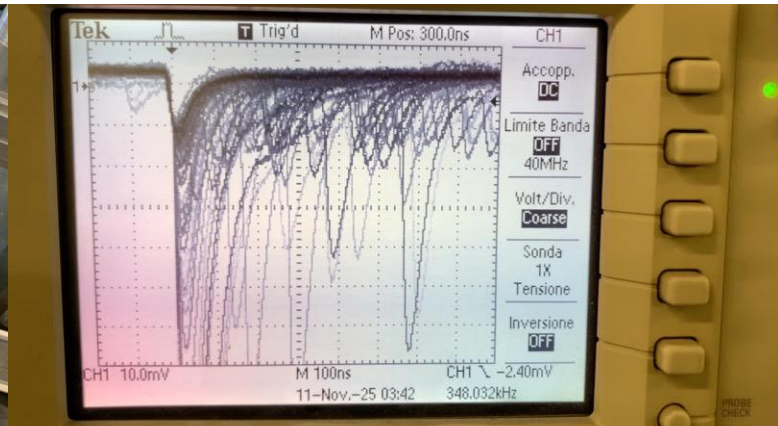
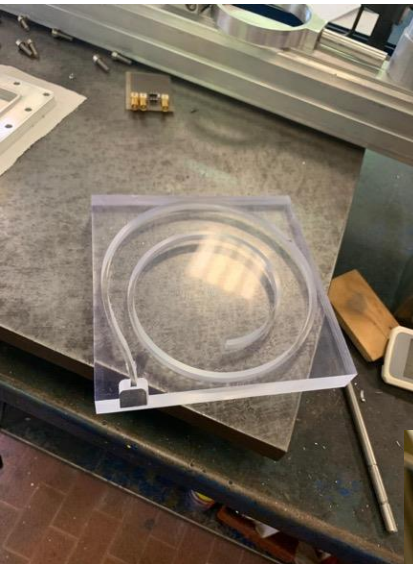
HIROSE to Panasonic Transition Board



Data Pipeline



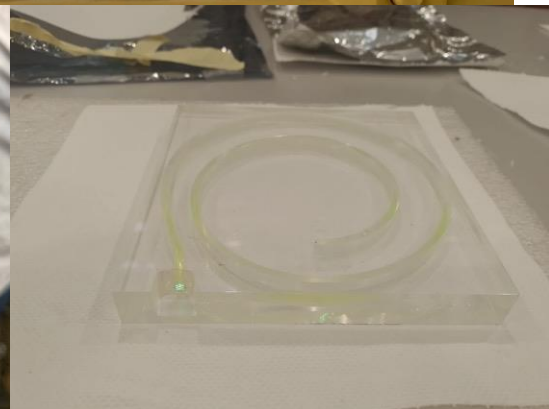
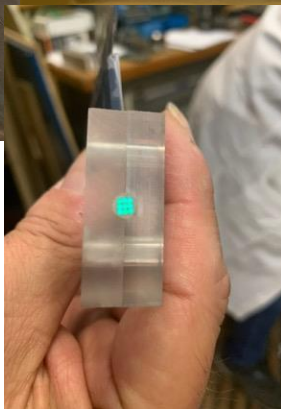
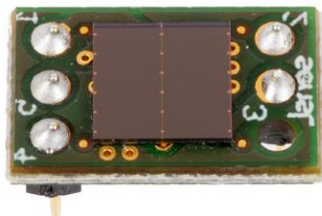
The Trigger: fast response scintillators



Two 15 cm x15 cm Plastic scintillators

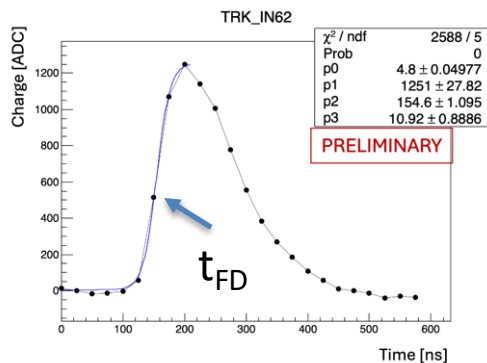
Light collected by a bundle of 9 embedded wavelength shifter fibers

SiPm photosensor: Onsemi J series 3002

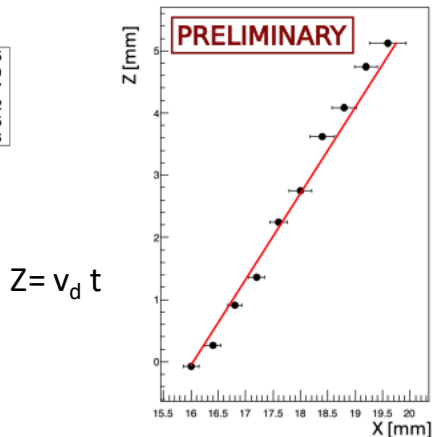


Time and Position resolution optimization - μ TPC

- The electrons created by the ionizing particle drift towards the amplification region
- The **fit of the analog signal** gives the **arrival time of drifting electrons**.
- By the knowledge of **the drift velocity**, the longitudinal position of the primary ionization in the **drift gap** is reconstructed.
- In the μ TPC mode the **track segment in the gas gap is reconstructed** obtaining the **3D trajectory** of the ionizing particle in the **drift gap**.
Position resolution for inclined tracks is reduced compared to Charge Centroid method



Integrated charge as a function of the sampling time

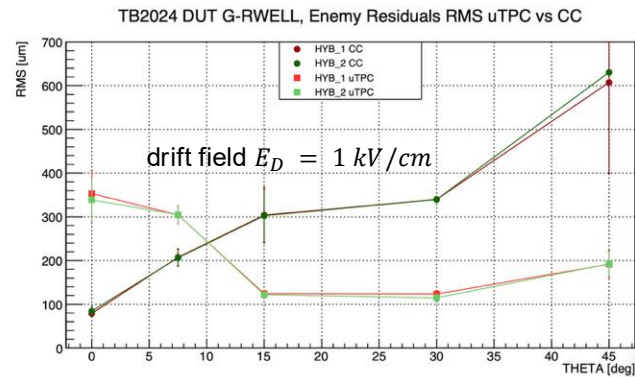


Example of a track reconstruction using the TPC algorithm.

$$t_{hit} = t_0 - t_{FD}$$

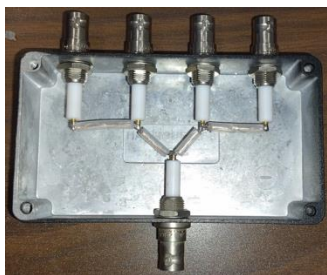
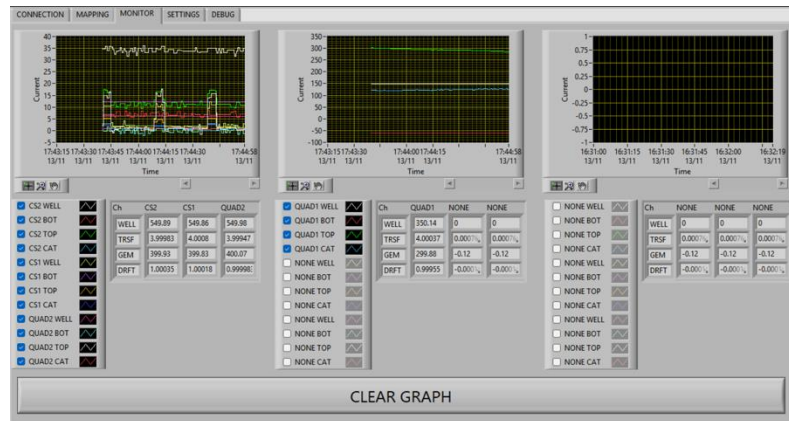
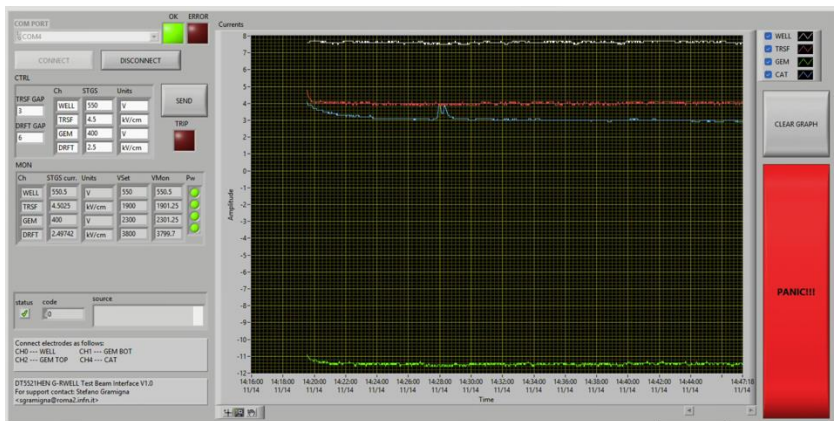
$$z_{hit} = v_{hit} t_{hit}$$

$$x_{\mu TPC} = \frac{z_{rout} - b}{a}$$



Comparison of the **CC** and **μ TPC** reconstruction algorithms in function of the impinging angle

HV Slow Control and Current Monitor



Trackers powered in parallel

1 HV Channel per type of electrode

Same electrodes of different detectors grouped together

4 HV channels in total

DUT's electrodes powered individually

1 HV Channel per electrode per detector

16 HV channels in total

Finer diagnostics and HV regulation

2025 test beam plan

DUT angle = 0°

Quadrants 50 cm radius

40 cm x 46 cm rectangles

| | | |
|---|--|---|
| $\Delta V_{\text{GEMscan}}$ | $\Delta V_{\text{Well}} = 550 \text{ V}, E_{\text{drift}} = 2.5 \text{ KV/cm}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ | $\Delta V_{\text{Well}} = 530 \text{ V}, E_{\text{drift}} = 2.5 \text{ KV/cm}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ |
| Transfer gap HV scan | $\Delta V_{\text{Well}} = 550 \text{ V}, \Delta V_{\text{GEM}} = 400 \text{ V}, E_{\text{drift}} = 1 \text{ KV/cm}$ | $\Delta V_{\text{Well}} = 530 \text{ V}, \Delta V_{\text{GEM}} = 490 \text{ V}, E_{\text{drift}} = 1 \text{ KV/cm}$ |
| Drift gap HV scan | $\Delta V_{\text{Well}} = 550 \text{ V}, \Delta V_{\text{GEM}} = 400 \text{ V}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ | $\Delta V_{\text{Well}} = 530 \text{ V}, \Delta V_{\text{GEM}} = 400 \text{ V}, E_{\text{transfer}} = 4 \text{ KV/cm}$ |
| $\mu\text{Rwell } \Delta V_{\text{Wellscan}}$ | $\Delta V_{\text{GEM}} = 430 \text{ V}, E_{\text{drift}} = 2.5 \text{ KV/cm}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ | $\Delta V_{\text{GEM}} = 430 \text{ V}, E_{\text{drift}} = 2.5 \text{ KV/cm}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ |

DUT angle = 20 and 30°

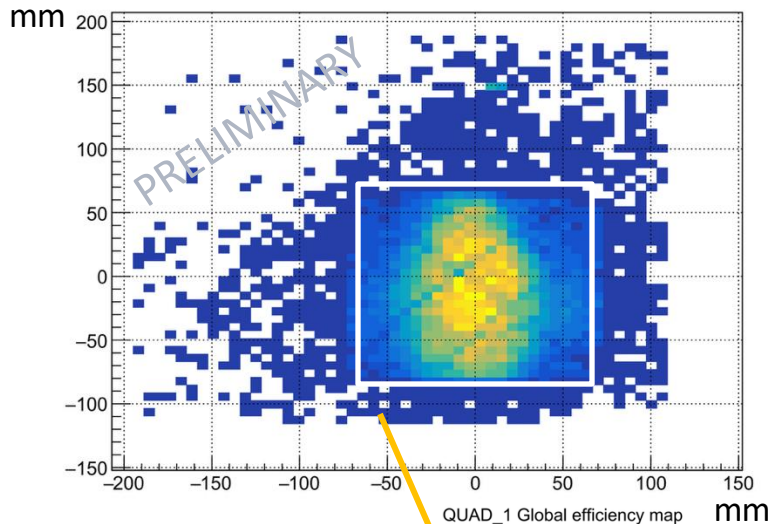
Quadrants 50 cm radius

40 cm x 46 cm rectangles

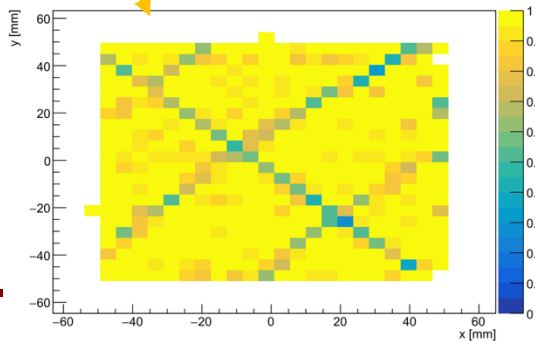
| | | |
|---|--|--|
| $\Delta V_{\text{GEMscan}}$ | $\Delta V_{\text{Well}} = 550 \text{ V}, E_{\text{drift}} = 1 \text{ KV/cm}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ | $\Delta V_{\text{Well}} = 530 \text{ V}, E_{\text{drift}} = 1 \text{ KV/cm}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ |
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| $\mu\text{Rwell } \Delta V_{\text{Wellscan}}$ | $\Delta V_{\text{GEM}} = 400 \text{ V}, E_{\text{drift}} = 1 \text{ KV/cm}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ | $\Delta V_{\text{GEM}} = 400 \text{ V}, E_{\text{drift}} = 1 \text{ KV/cm}, E_{\text{transfer}} = 4.5 \text{ KV/cm}$ |

First results: Clusters Hit Map

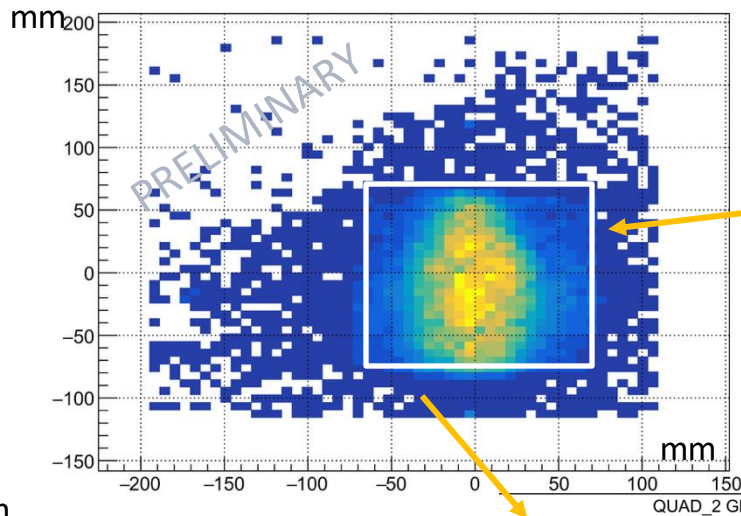
Quadrant 1 clusterPositionGlobal_maxC



Quadrant 1 has a grid to support the GEM, overlapping with the HV sectors



clusterPositionGlobal_maxC



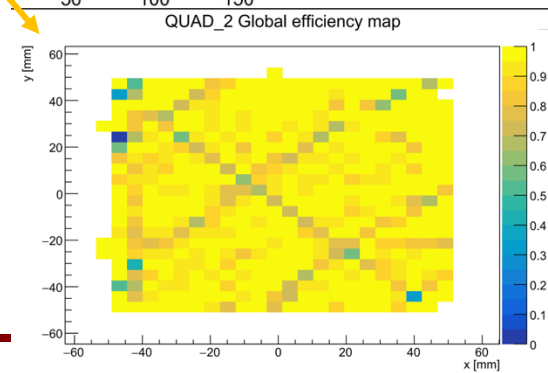
Quadrant 2

Trigger and Trackers geometrical coverage

15 x 15 cm

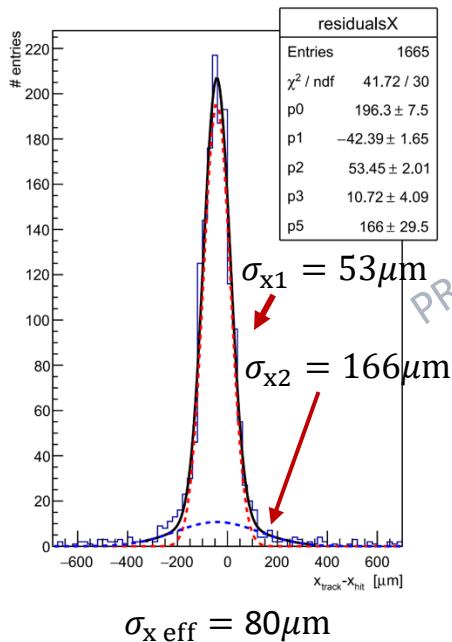
Quadrant 2 has no grid to support the GEM

Efficiency maps in the trackers region



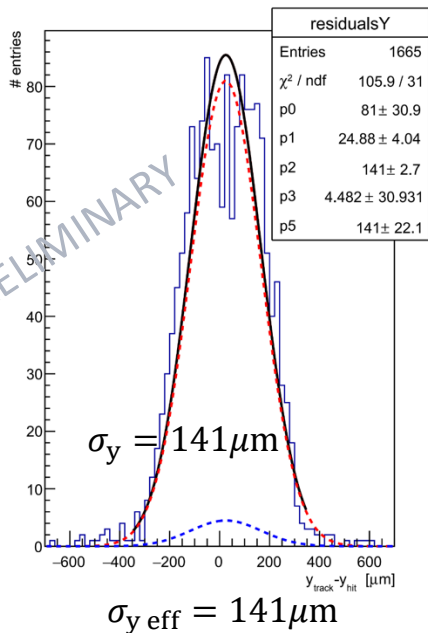
First results: Position Resolution

QUAD_1 X



Lower 520 μm strip width

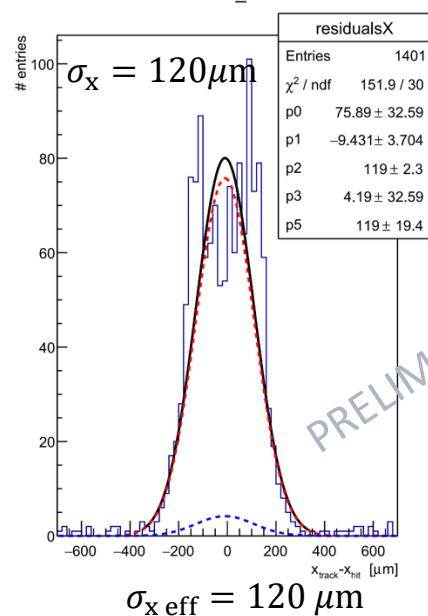
QUAD_1 Y



Upper 90 μm strip width

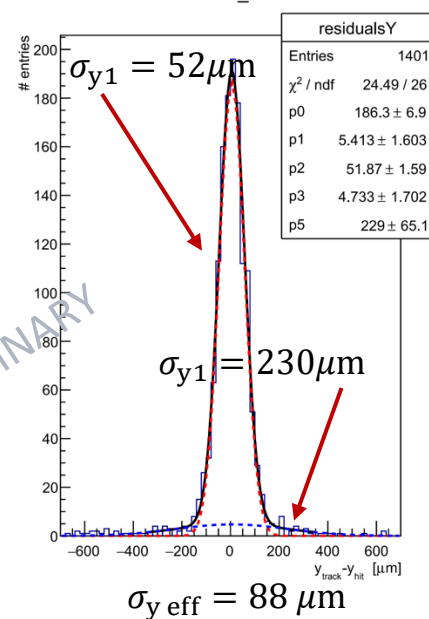
Strip pitch = 600 μm

QUAD_2 X



Upper 90 μm strip width

QUAD_2 Y

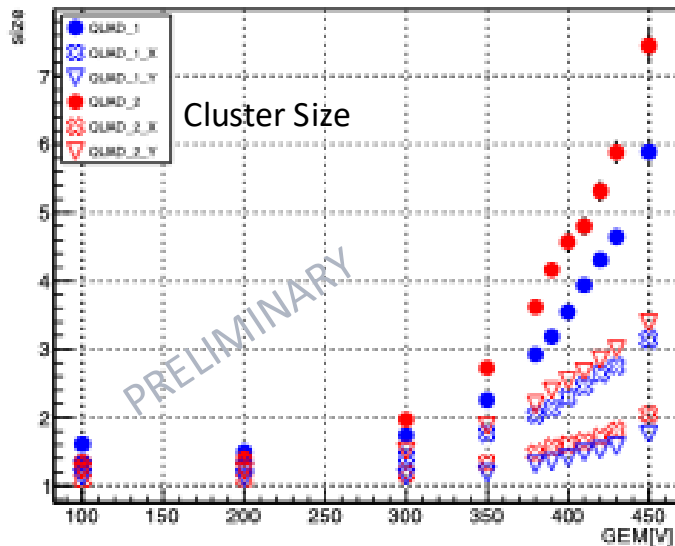


Lower 520 μm strip width

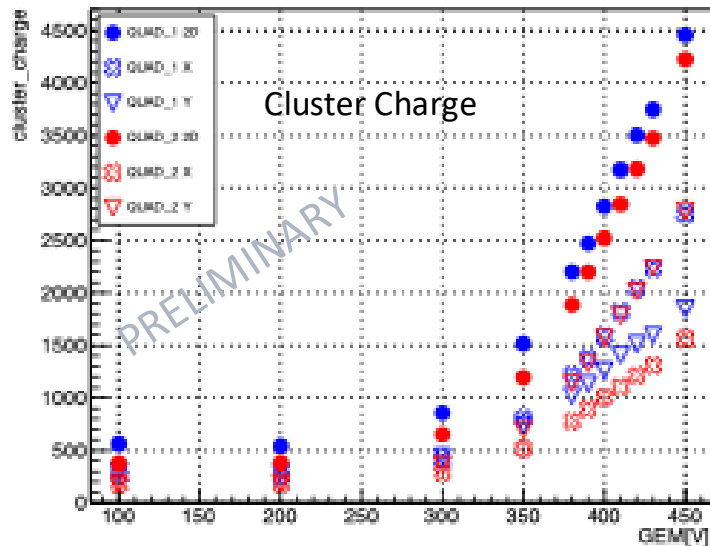
The two quadrants are rotated by 90 degrees with respect to each other

First results: Cluster charge and size

TB2025 DUT QUADRANT - Well 550V, Transf 4.5 [kV/cm], Drift 2.5[kV/cm]



TB2025 DUT QUADRANT - Well 550V, Transf 4.5 [kV/cm], Drift 2.5[kV/cm]



- Quadrant 1
- Quadrant 2

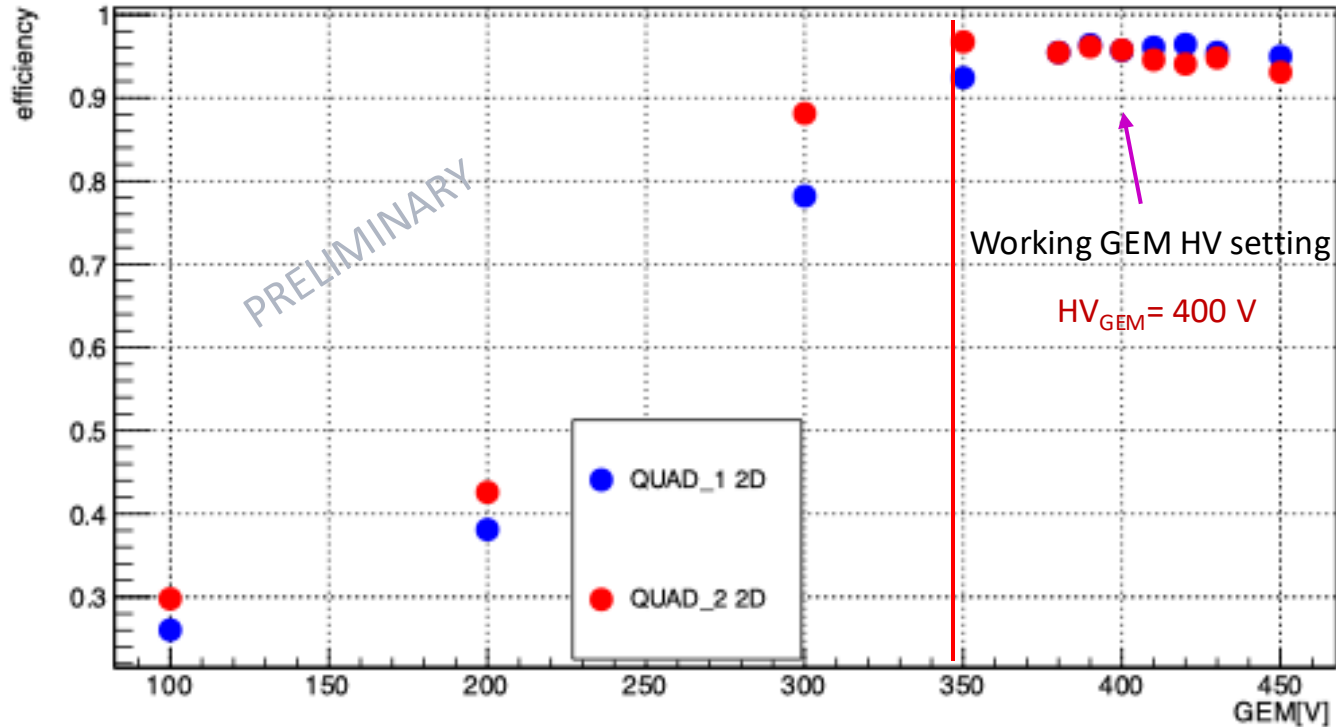
Large lower strips width = $520 \mu\text{m}$

Small upper strips width = $90 \mu\text{m}$

The larger strips collect higher cluster charge and their cluster size is larger

First results: Efficiency

TB2025 DUT QUADRANT - Well 550V, Transf 4.5 [kV/cm], Drift 2.5[kV/cm]

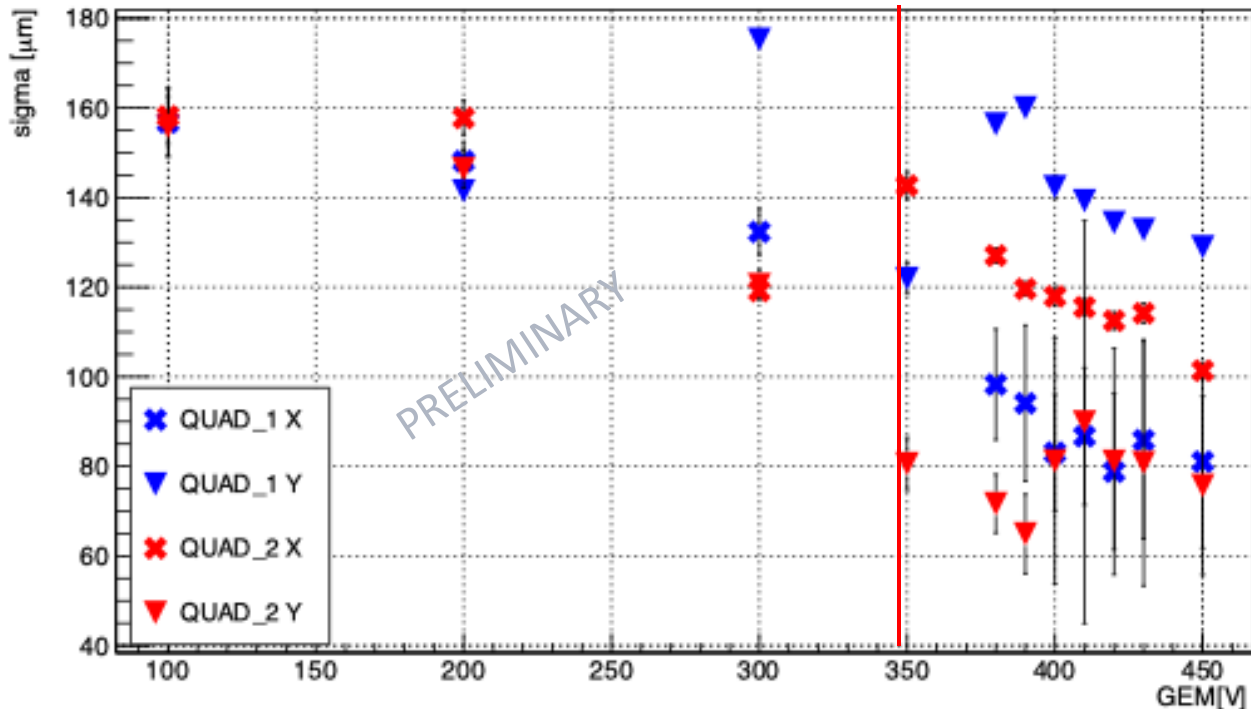


Efficiency > 95% @ GEM HV > 350 V

First results: Position Resolution

TB2025 DUT QUADRANT - Well 550V, Transf 4.5 [kV/cm], Drift 2.5[kV/cm]

σ_{eff}



Position Resolution lower than 150 μm at plateau.

Gas Gain Measurements for GEM- μ Rwell 10 cm x10cm

by Matteo Giovannetti

Gas Gain plot for GEM- μ RWELL

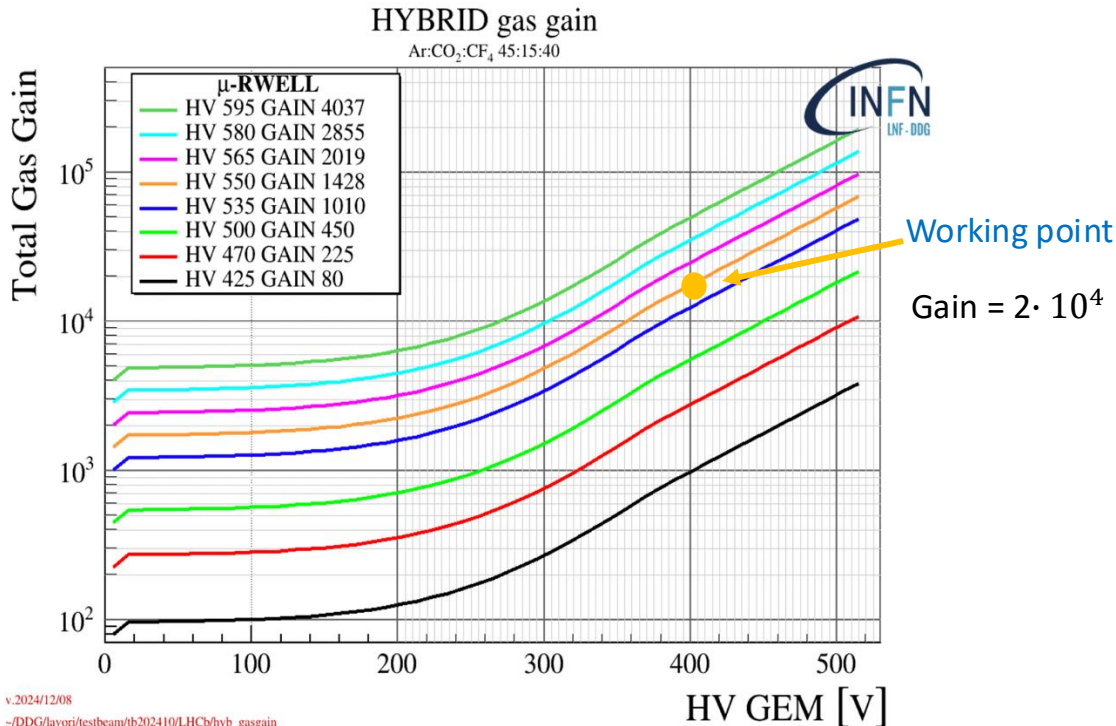
- high gain is reached even for low WELL HV

Gas Gain plot for μ RGroove was not performed before the test beam



Fixing the μ Rwell Gain:

GEM HV \leftrightarrow Total gas Gain

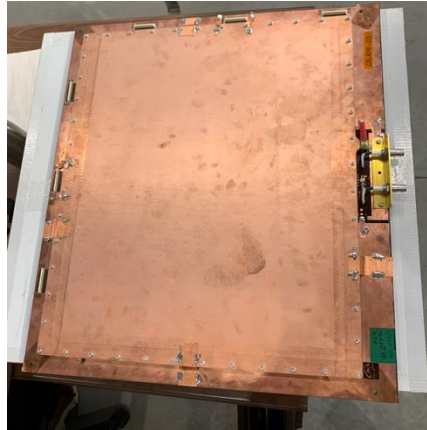


Status of 40x46 cm Detectors

Test of Large Area Prototype steps @ LNF: CS - 40x46 cm²

Data analysis is ongoing

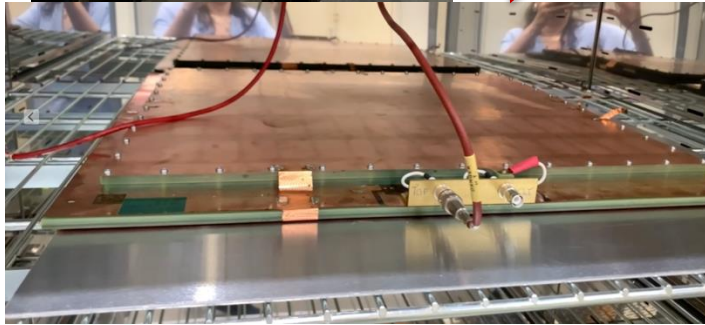
LT Thesis of Gabriele Trifiro'



HV filter on



Conditioning
In the Oven



X-Ray characterization

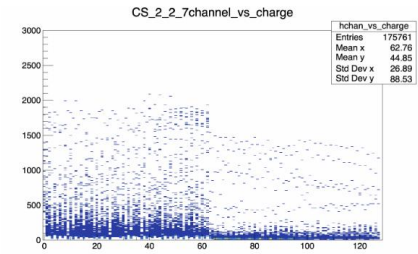
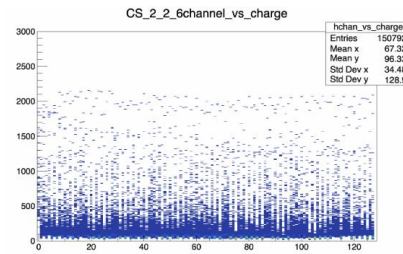
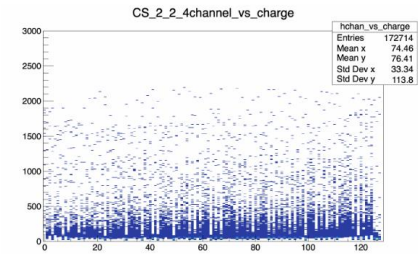
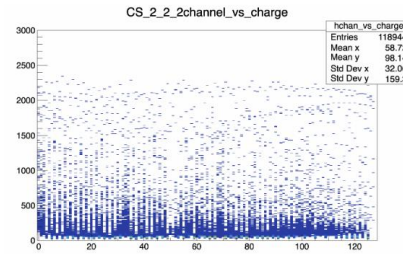
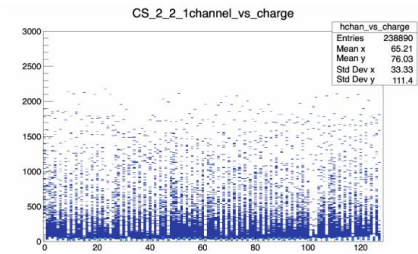
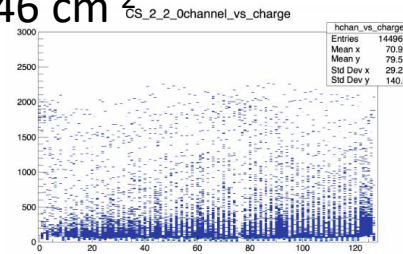


Cosmic-rays Data Acquisition

Status of 40x46 cm Detectors

Test of Large Area Prototype steps @ LNF: CS - 40x46 cm²

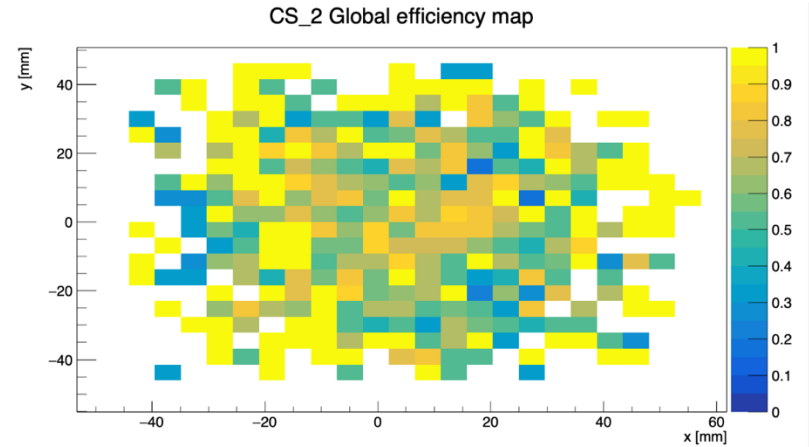
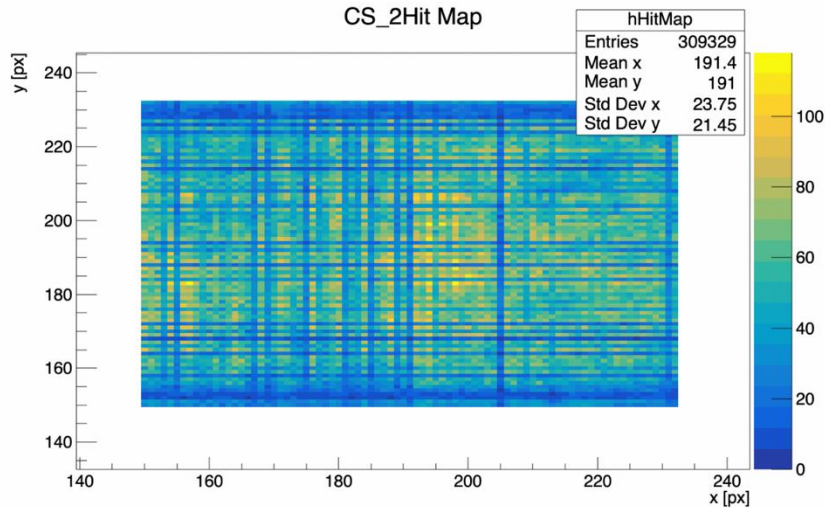
Mapping of the channels has shown applying Silver glue is not a final solution: many channels are still disconnected



Status of 40x46 cm Detectors

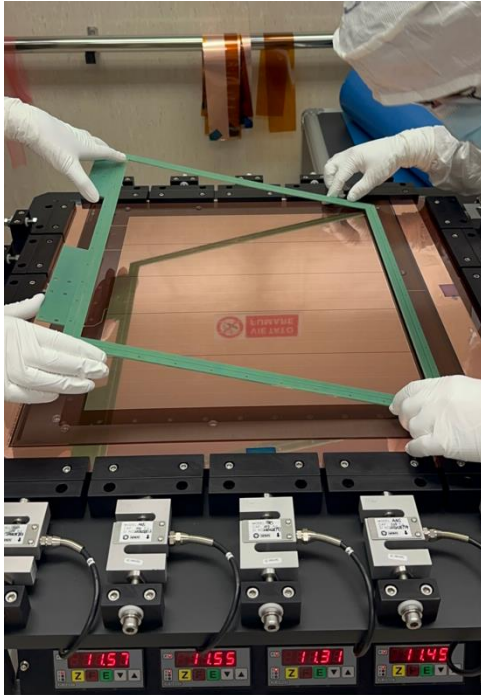
Test of Large Area Prototype steps @ LNF: CS - 40x46 cm²

Mapping of the channels has shown applying Silver glue is not a final solution: many channels are still disconnected



Status of 40x46 cm Detectors

Test of Large Area Prototype steps @ LNF: CS - 40x46 cm²



Following Steps:

- Adding the GEM – Preamplifier
- Data from 2025 Test Beam
- New μ Rwell foil will be produced at CERN
- New test beam in 2026

2025 Test Beam – First results Summary

GEM- μ Rwell Technology

- High gas gains are obtained with **low (safe) HV** GEM and μ Rwell settings, minimizing current sparks:
Setting: μ Rwell HV = 550 V, GEM HV=400 V \rightarrow Gas Gain = $2 \cdot 10^4$
Transfer Field = 4.5 kV/cm, Drift Field = 1 KV/cm
- Same GEM- μ Rwell Gas Gain curve and performances is obtained the for small and large detectors.
- GEM- μ Rwell detectors with capacitive sharing are also being studied

MPGD – Large Area Detectors status

- Large Area Detectors work as expected
- Position resolution is well below 150 μ m from 600 μ m pitch without capacitive sharing
- Detection efficiency > 95 %
- Time resolution under study but expected to be lower than 20ns
- Upper strips width may be increased to balance the charge sharing between X and Y