MPGD ENDCAP Trackers (ECT) for ePIC

GEM–μRWELL technology

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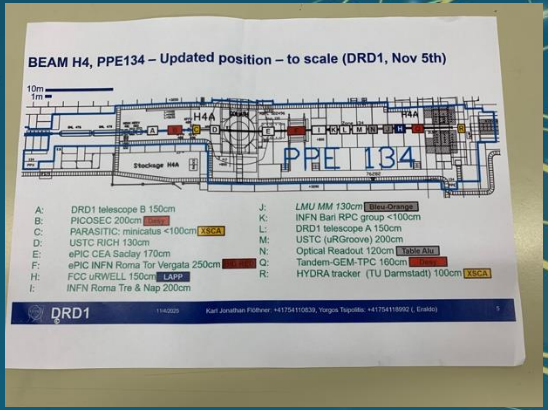
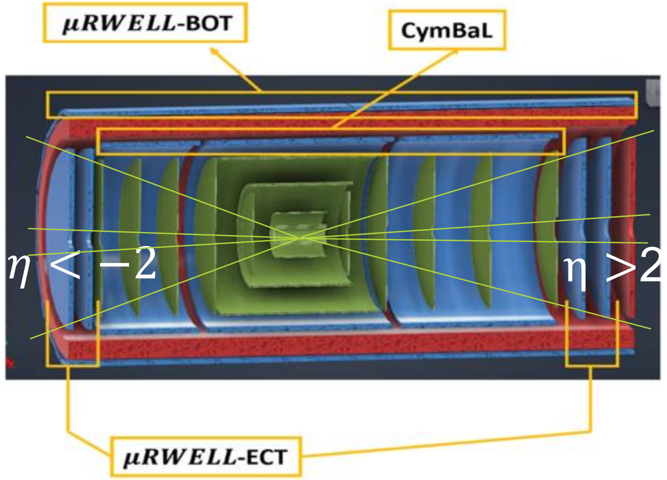
In collaboration with: G. Bencivenni, M. Giovannetti, M. Poli Lener, G. Morello, G. Sekhniaidze

CERN – SPS North Area H4
DRD-1 Test Beam
November 4-23 , 2025

Electron-Ion Collider



GEM-µRWELL ECT Project - The 2025 Test Beam outline



1. **Why: The Scope of the ECT trackers**

   - Scope of the MPGD endcap trackers in the EPIC detector.
   Detector Geometry: Envelope and Active Regions
   Technical performance requirements

   - Detector technology → **PhD Thesis by Elena Sidoretti**, **Master Thesis by Luca Torlai**
   2D – readout challenges
   Hybrid GEM-μRwell technology - μTPC readout

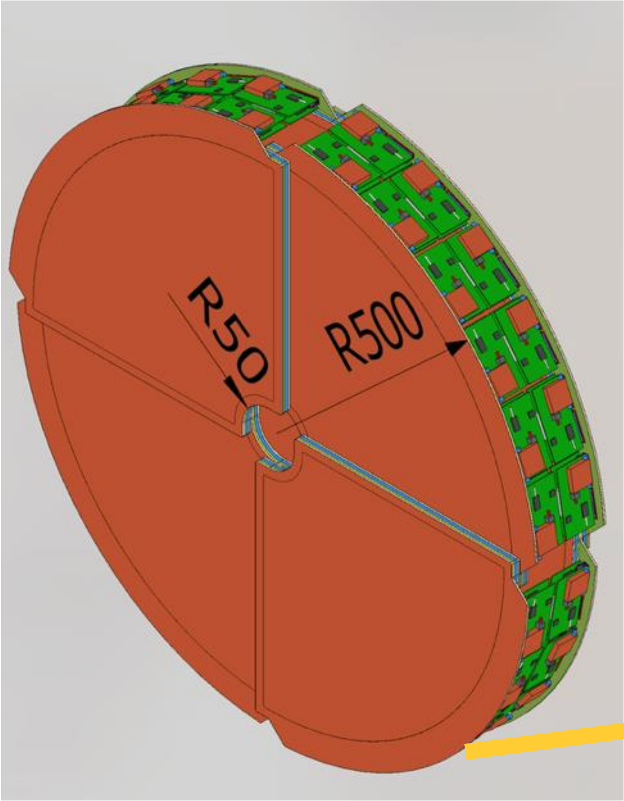
   - Detector Design and Engineering Test Article → **Post Doc: Stefano Gramigna**
   Endcap design: 4 quadrants
   (X,Y) readout – 600 μm pitch

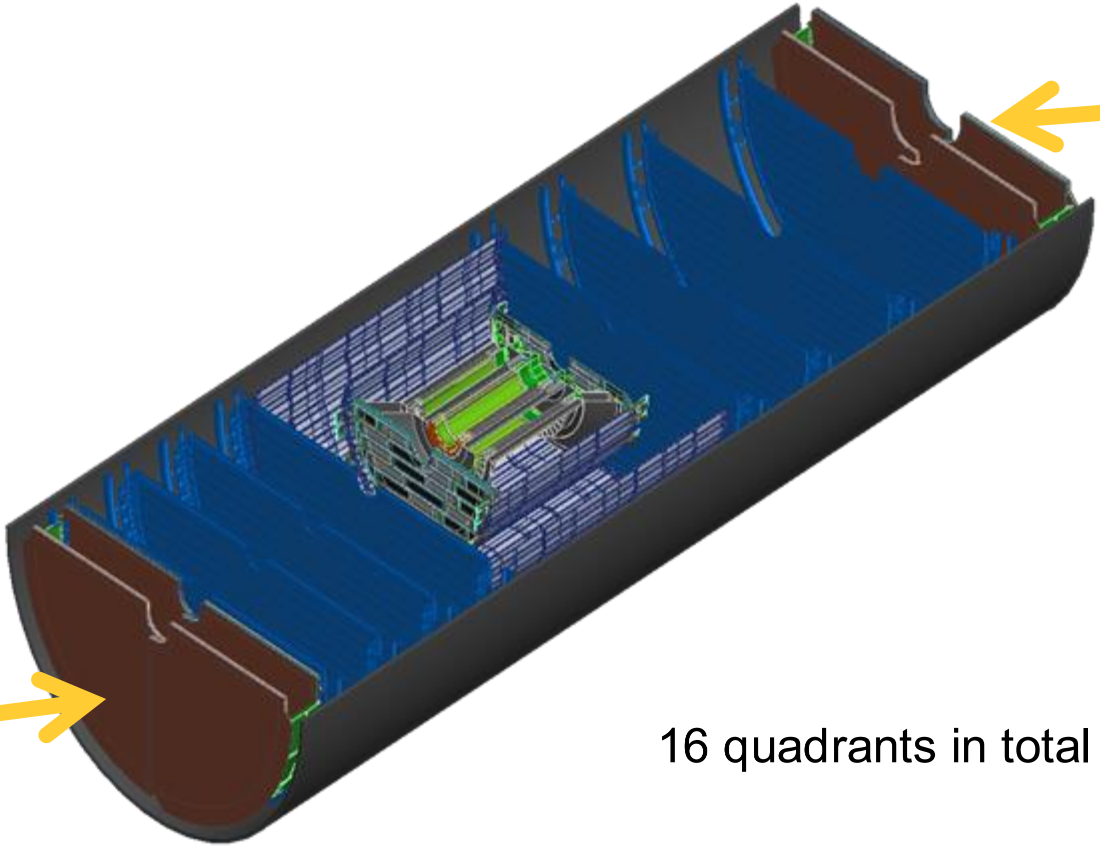
2. **Who: The INFN Roma Tor Vergata group**

3. **What: The set-up and the full-scale prototypes**

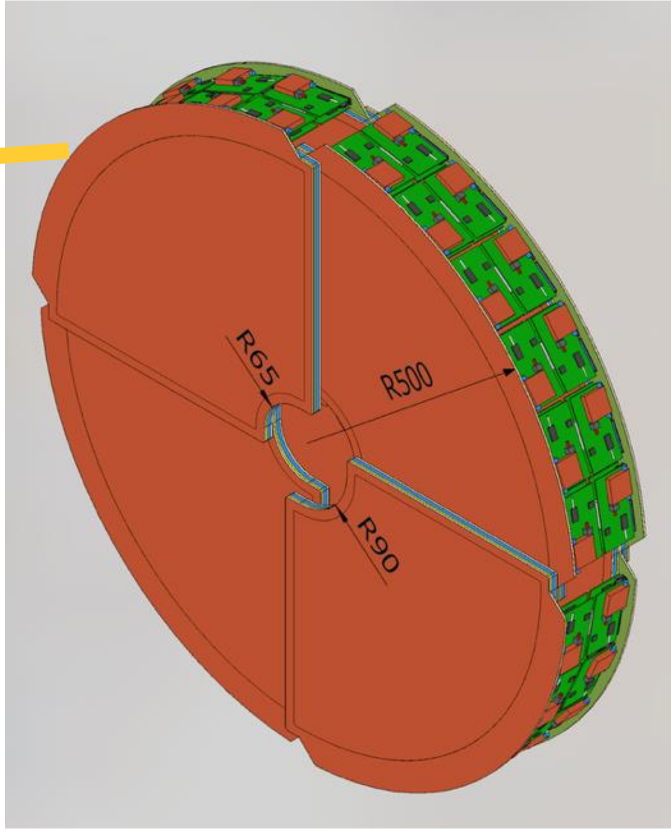
GEM-µRWELL ECT Project - The Endcap Trackers in ePIC

Two endcap tracker disks are required to provide relatively fast trackers hits to complement the SVT information

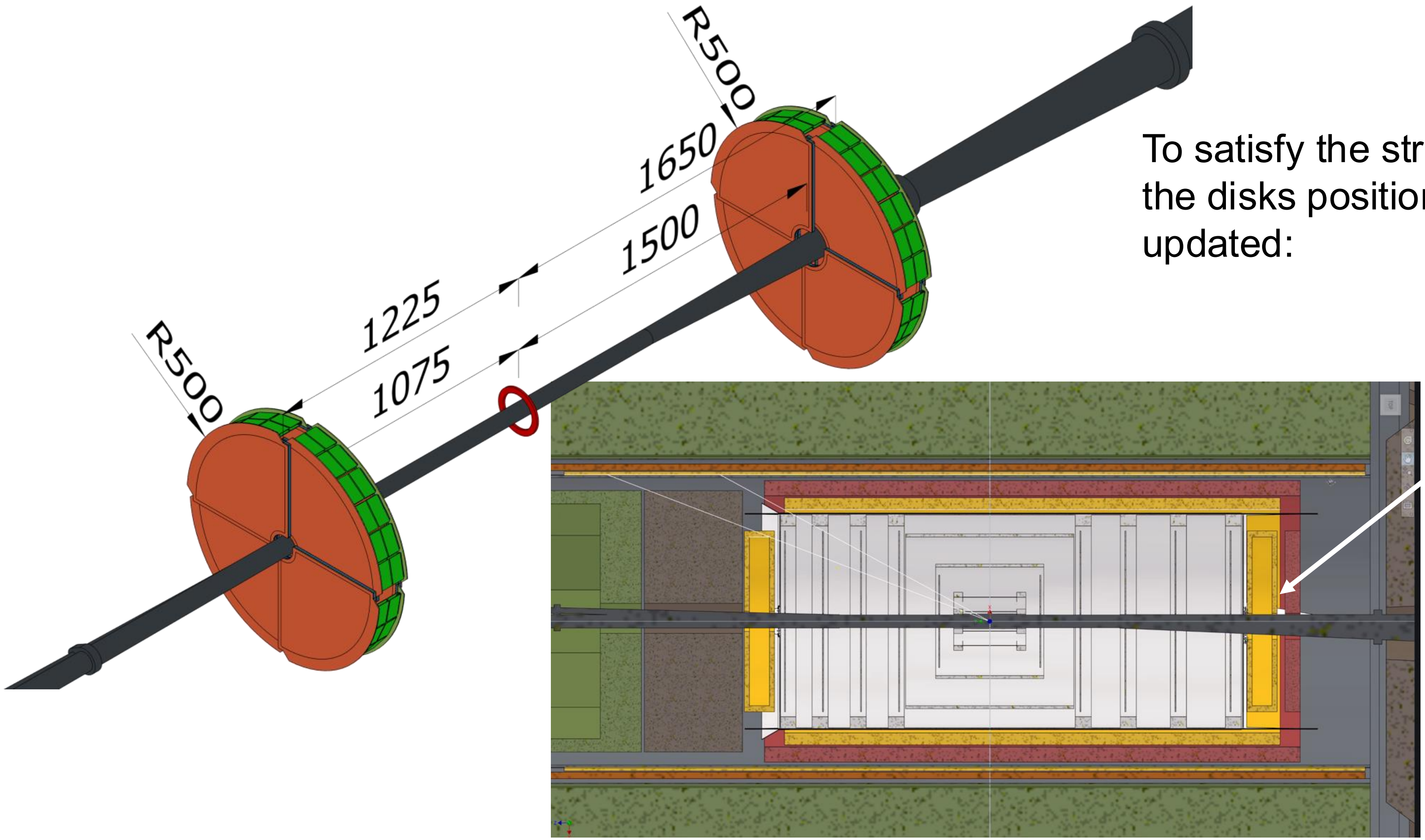




16 quadrants in total



The ePIC MPGD End Cap Tracker Envelope and Active Regions



To satisfy the stringent integration constraints the disks positions and dimensions have been updated:

- Hadron disks are closer to the interaction point

Z_H:1650 mm → 1620 mm

- Disks outer radius have been reduced:

R :500 mm → 450 mm

The ePIC MPGD End Cap Tracker Envelope and Active Regions

Component	Z (cm)	Inner Active Reg. Radius (cm)	$\|\theta\|$ min (deg)	$\|\eta\|$ max	Outer Active Reg. Radius (cm)	$\|\theta\|$ max	$\|\eta\|$ min
HD MPGD 2	162	10.5	3.35	**3.43**	45	15.52	1.99
HD MPGD 1	148	10.5	4.06	**3.34**	45	16.91	1.9
LD MPGD 1	-111	6	3.09	3.61	45	22.07	1.63
LD MPGD 2	-121	6	2.83	3.69	45	20.40	1.72

Component	Z (cm)	Inner Active Reg. Radius (cm)	$\|\theta\|$ min (deg)	$\|\eta\|$ max	Outer Active Reg. Radius (cm)	$\|\theta\|$ max	$\|\eta\|$ min
HD MPGD 2	141	10.5	4.25	**3.29**	40	15.83	1.97
HD MPGD 1	128.5	10.5	4.68	**3.2**	40	17,29	1.88
LD MPGD 1	-107.5	6.5	3.46	3.5	40	20,4	1,71
LD MPGD 2	-120	6.5	3.1	3.6	40	18.43	1.81

$$\mathbf{1.99 < |\eta| < 3.2}$$

MPGD-ECT Technical Performance Requirements

Time resolution ~10 ns or less to provide tracking timing

- Time resolution~ 10 ÷ 20 ns
- Sampling faster than 50 MHz

Low material budget

- <1 % X_0 - it will be the minimum compatible with the chosen technology

Spatial resolution: 150 μm or better

- <150 μm intrinsic spatial resolution for perpendicular tracks
- Technological optimizations to retain 150 μm resolution for inclined/curved tracks → μTPC mode

High Efficiency

- Single detector efficiency ~ 96 –97 % → 92 –94 % combined efficiency for two disks

The MPGD ECT Technology: - GEM-μRWELL Hybrid Detector

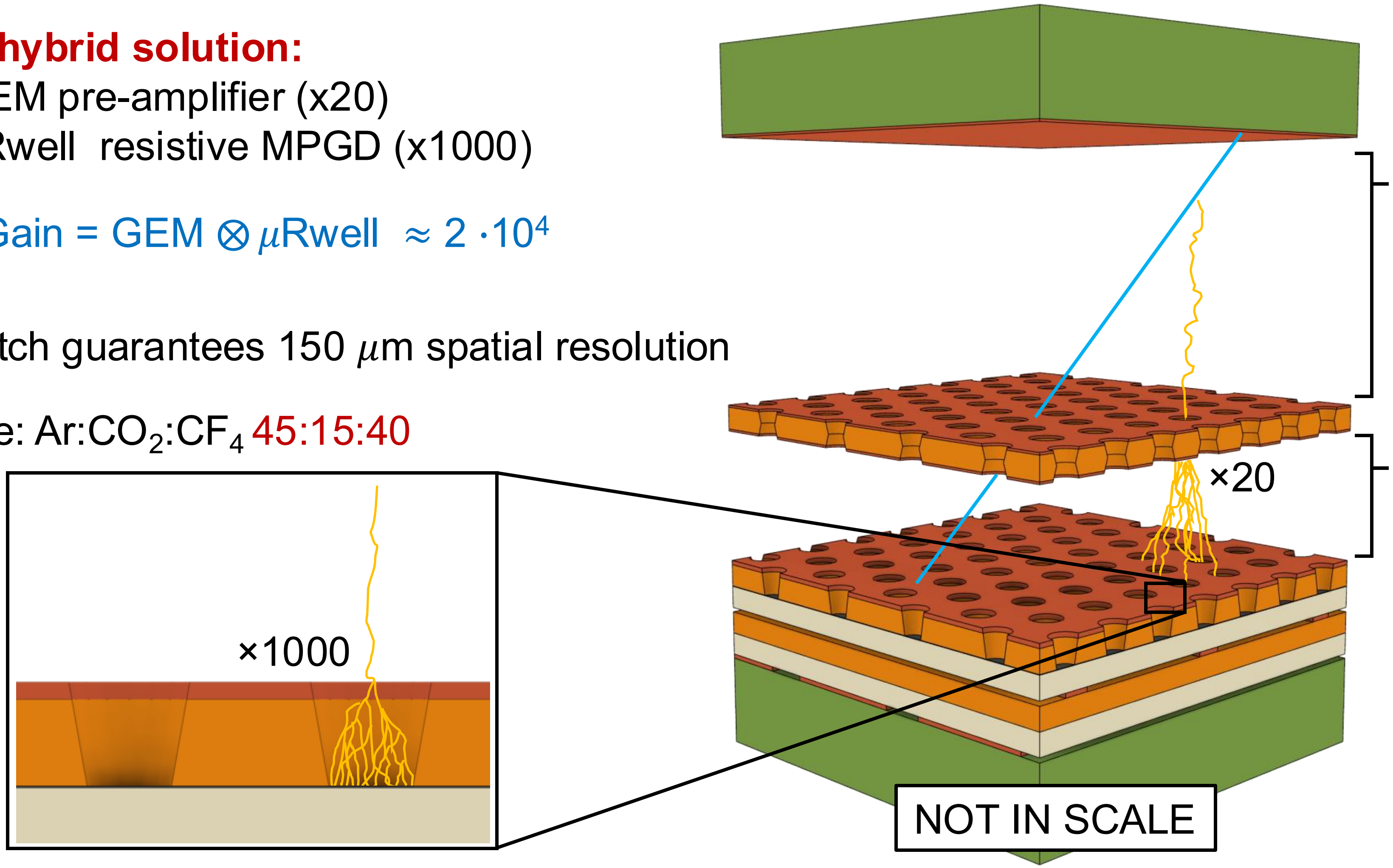
Two stages hybrid solution:

- GEM pre-amplifier (x20)
- μRwell resistive MPGD (x1000)

Total Gas Gain = GEM $\otimes$ μRwell $\approx 2 \cdot 10^4$

- 600 μm pitch guarantees 150 μm spatial resolution

Gas Mixture: Ar:CO_2:CF_4 45:15:40



CATHODE
~ 3 mm lightweight support
5 μm copper

DRIFT
6 mm

GEM
5 μm Copper
50 μm Kapton
5 μm Copper

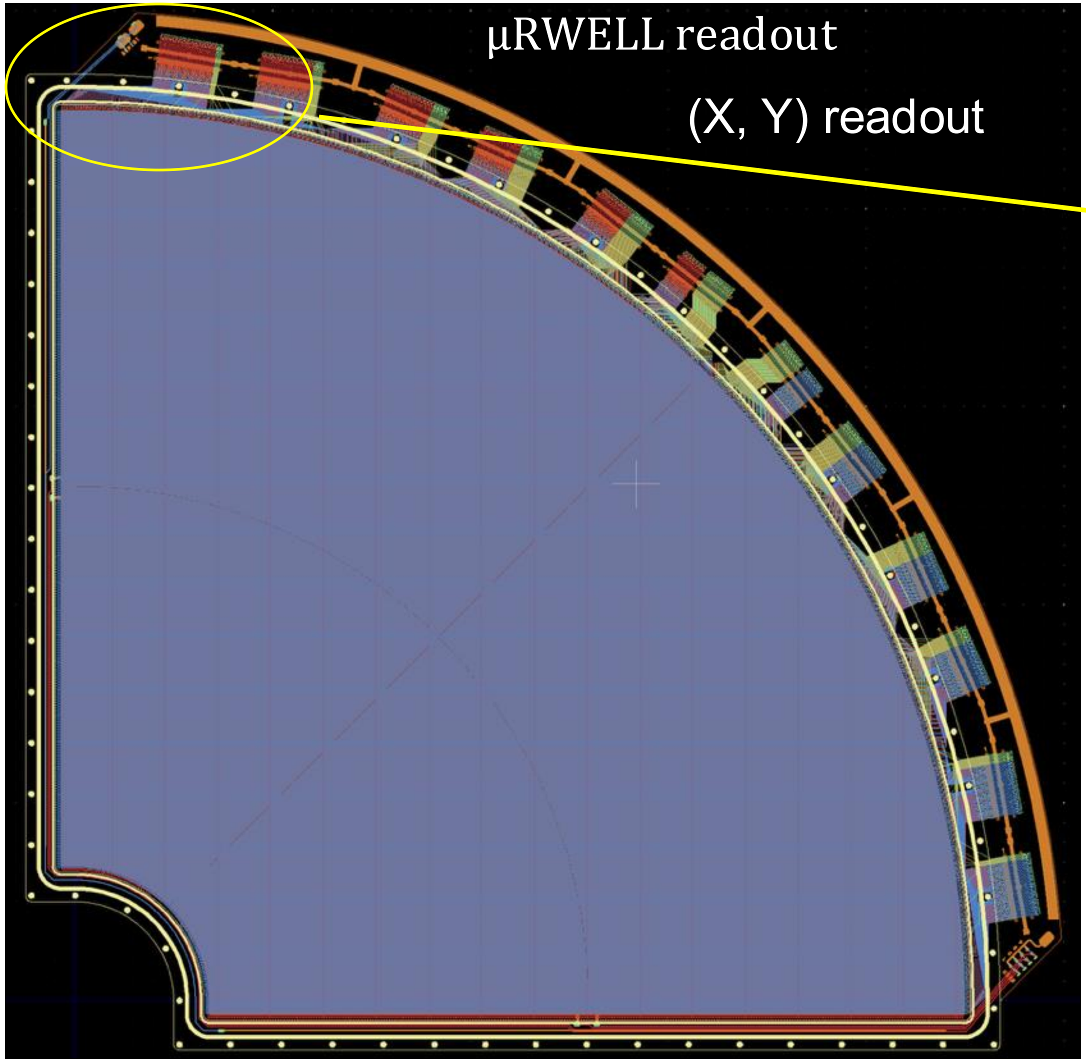
TRANSFER
3 mm → 2 mm in the future?

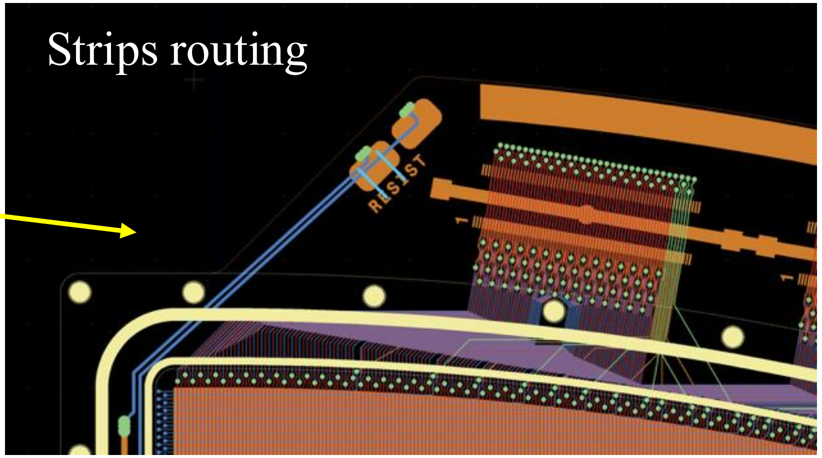
μ-RWELL
10 μm copper
50 μm Kapton
~ 100 nm DLC

R/O
2D strip layout, 600 μm pitch
~ 3 mm lightweight support

All R&D Studies for EIC disks performed in synergic collaboration with INFN-LNF and JLAB

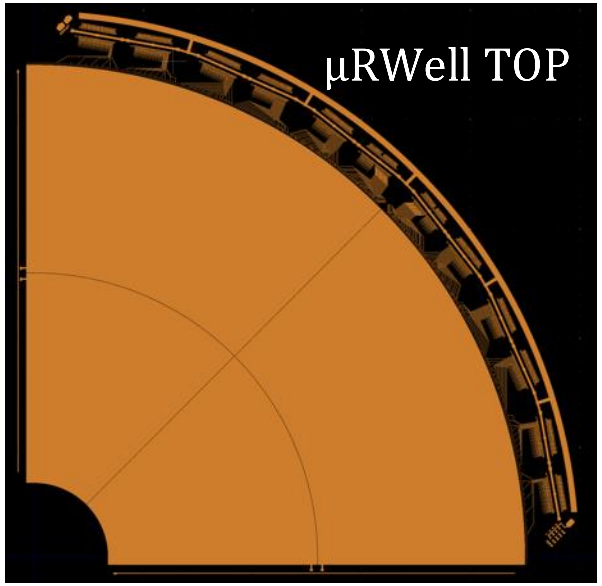
MPGD-ECT: PED Test Article Module

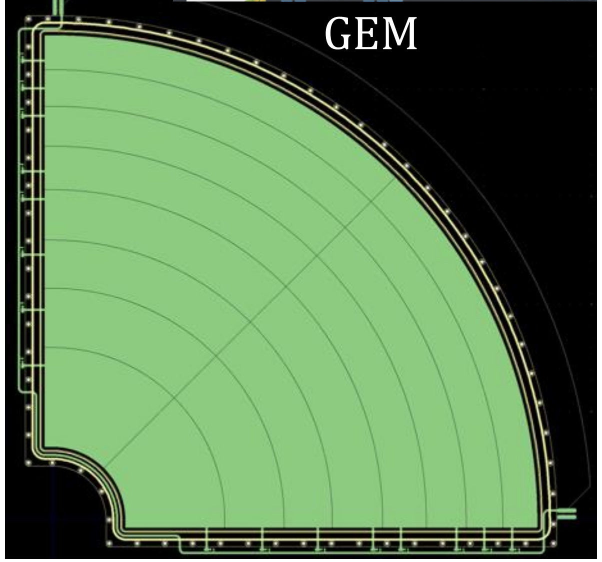




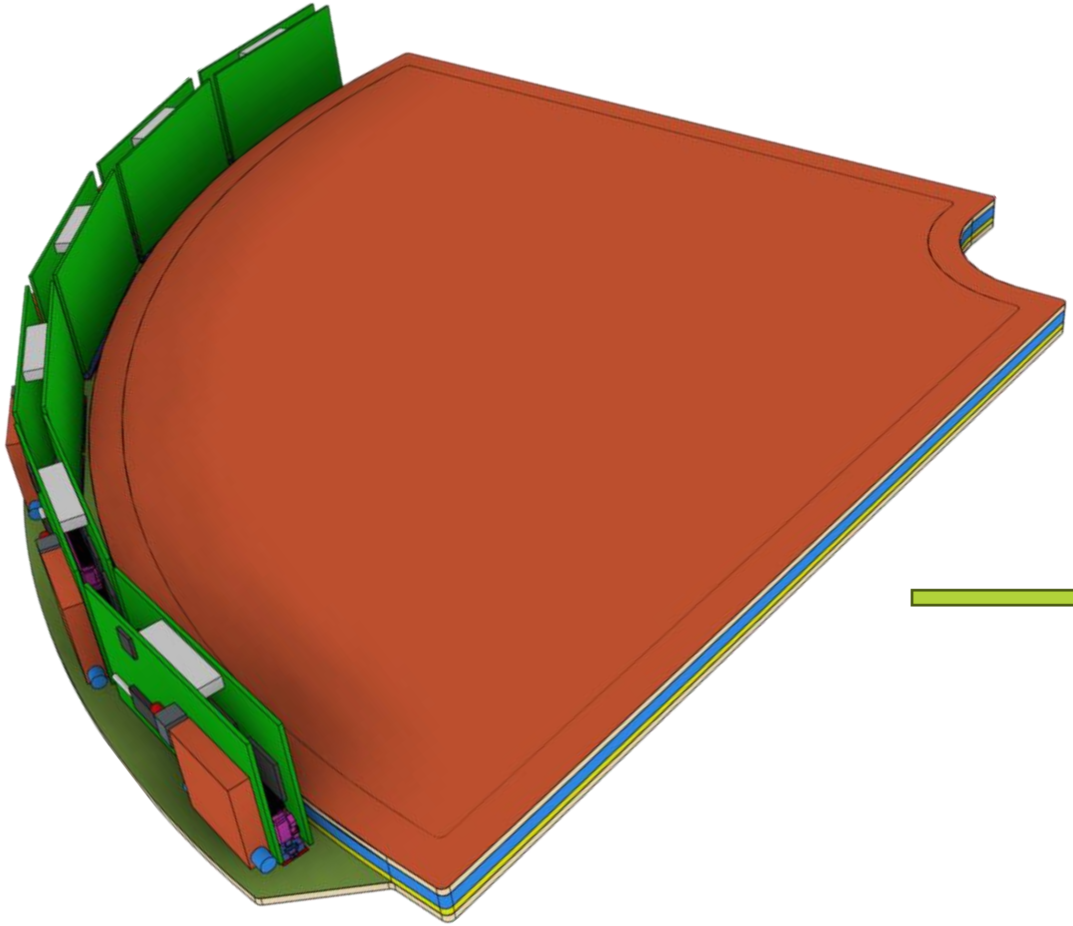
- X/Y strips
- 600 μm pitch
- $90\mu m$ vs $520\mu m$ strips width

Compass-like geometry

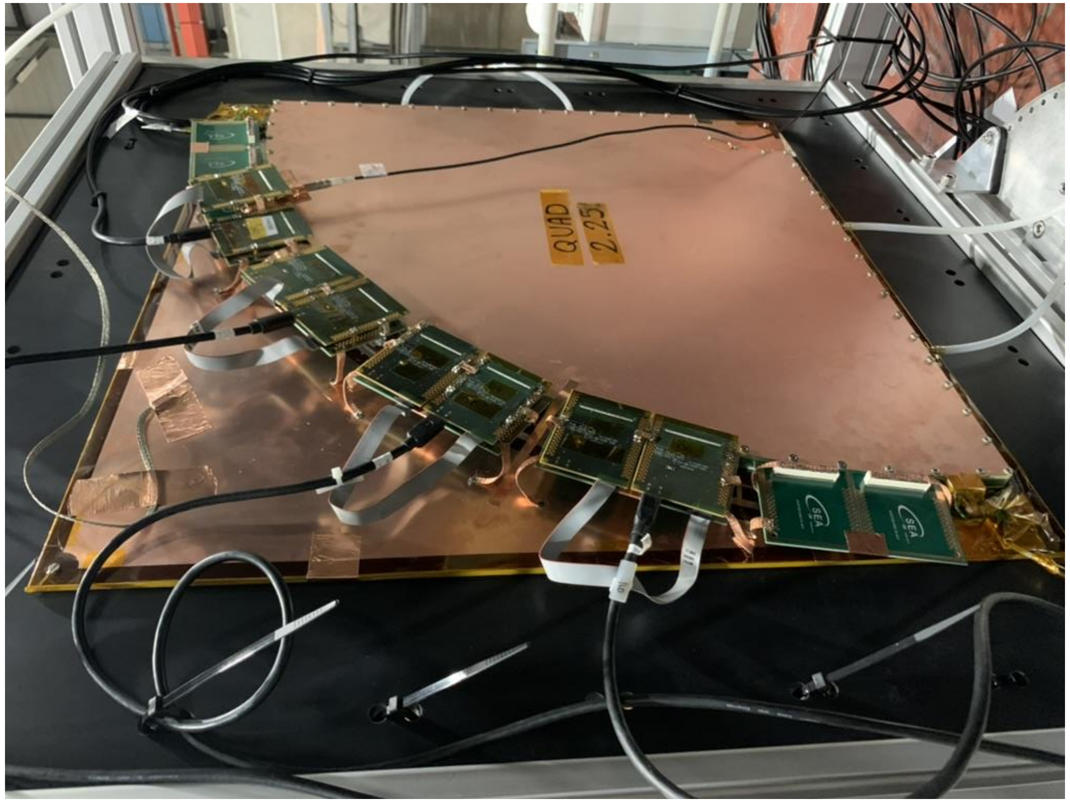




MPGD-ECT: Test Article Module



Engineering Test Article



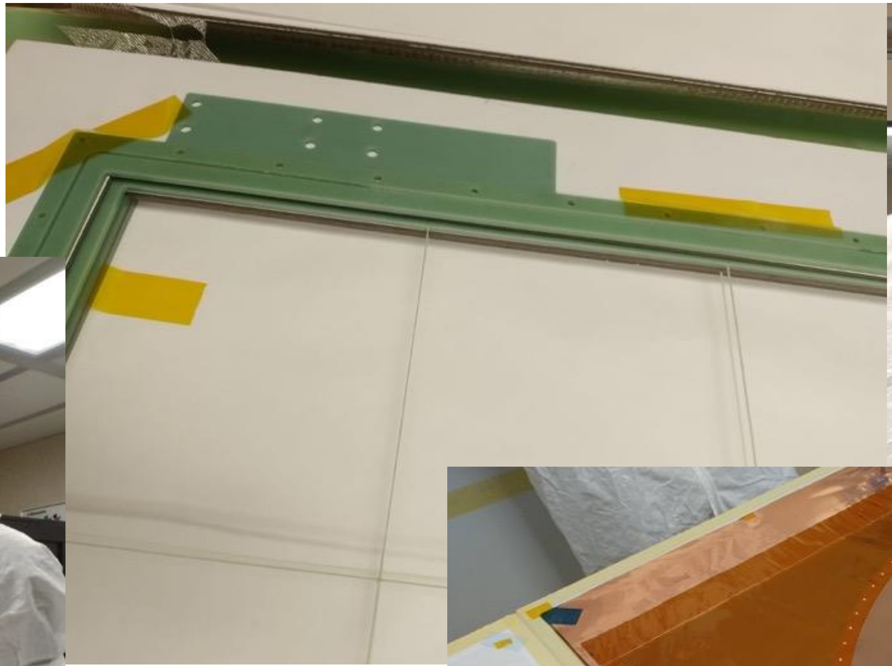
First Large Area Prototype

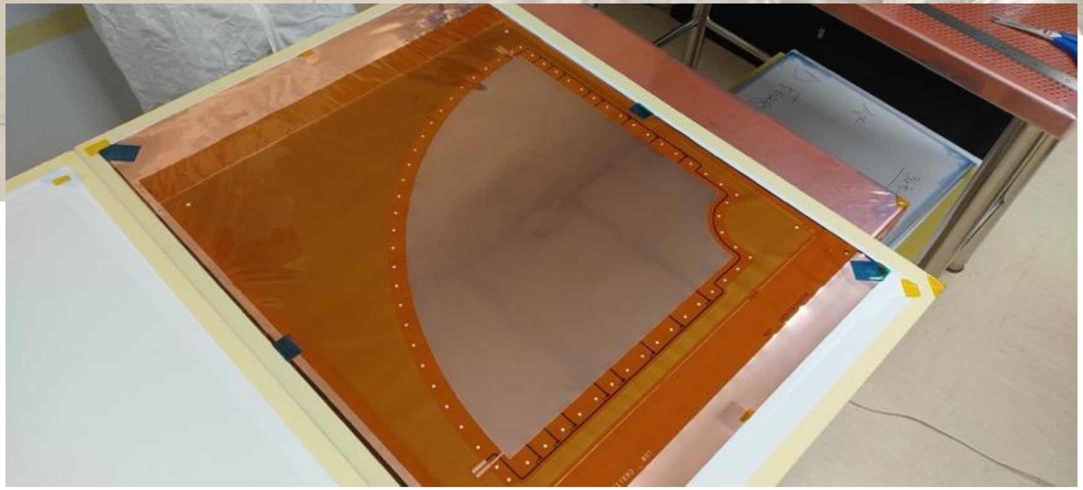
The MPGD ECT GROUP

Chiara Ammendola – PhD Uni& INFN Roma Tor Vergata
Mariangela Bondi' – INFN Catania
Annalisa D'Angelo – Uni & INFN Roma Tor Vergata
Alessia Fantini – Uni & INFN Roma Tor Vergata
Stefano Gramigna –INFN Roma Tor Vergata
Lucilla Lanza – Uni & INFN Roma Tor Vergata
Elena Sidoretti – PHD Uni & INFN Roma Tor Vergata
+ Givi Sekhniaidze and LNF Group: Gianni Bencivenni

Preparation for 2025 Test Beam

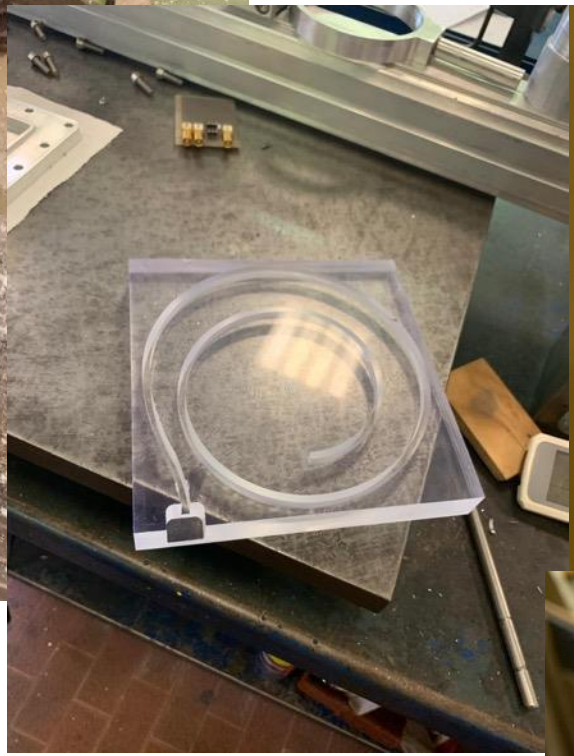
Parts to be Glued

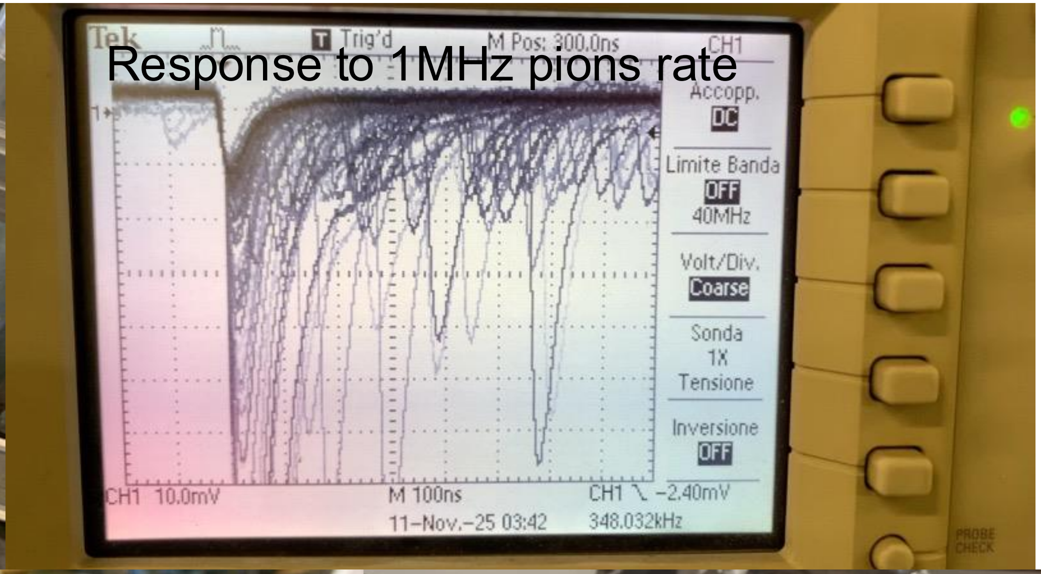


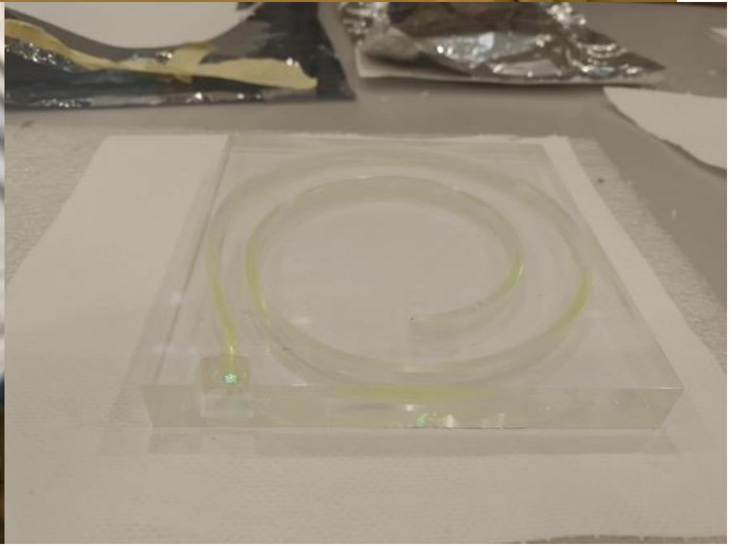


Gluing the GEMS on support in the Clean Room

The Trigger: fast response scintillators



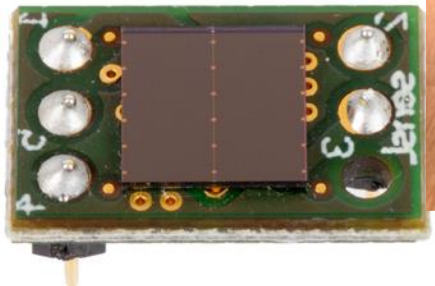




Two 15 cm x15 cm Plastic scintillators

Light collected by a bundle of 9 embedded wavelength shifter fibers

SiPm photosensor: Onsemi J series 3002

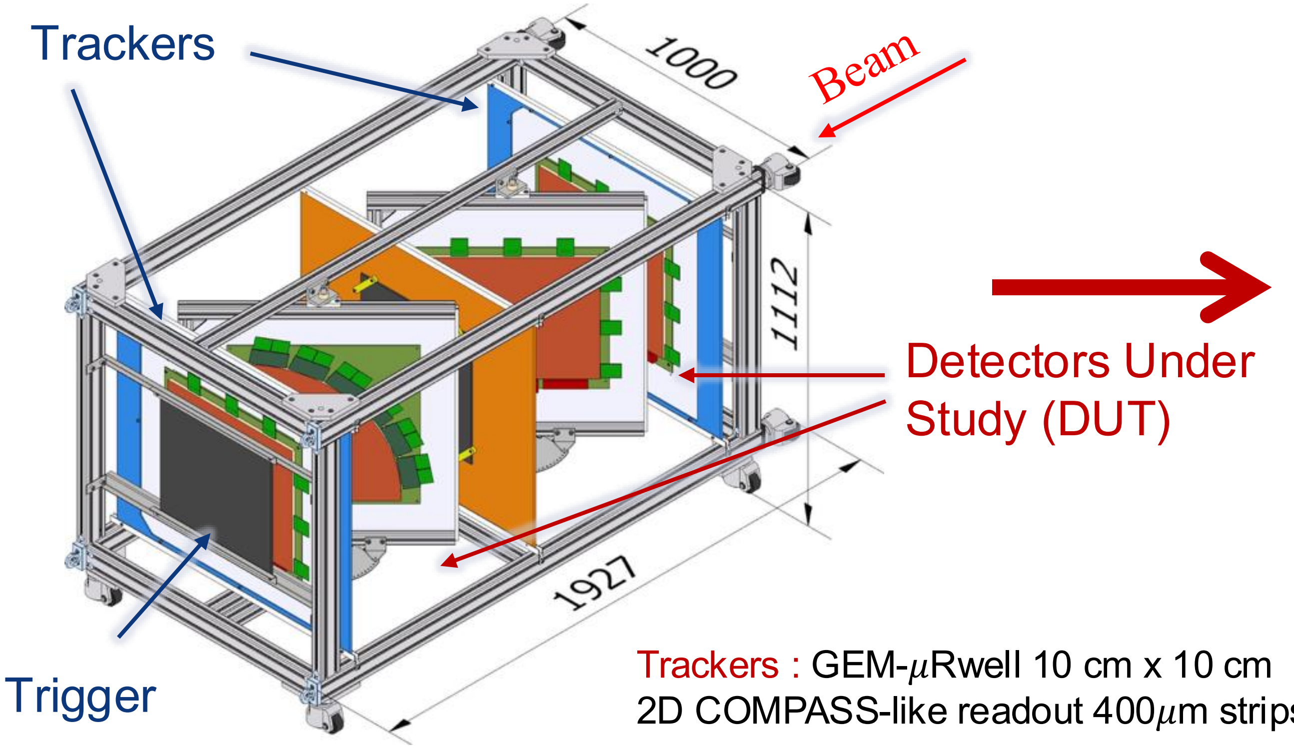


MPGD endcap 2025 test beam scope

Study of the performance of 2D hybrid GEM-μRWELL large area detectors

- DUT with different geometries and readout patterns:
  - two 50 cm radius quadrants – 600 μm strip pitch
  - two 40 cm x 46 cm with 3 layers capacitive sharing readout – 1200 μm strip pitch

- Test at different track angles with μTPC reconstruction (is capacitive sharing compatible with μTPC ?)



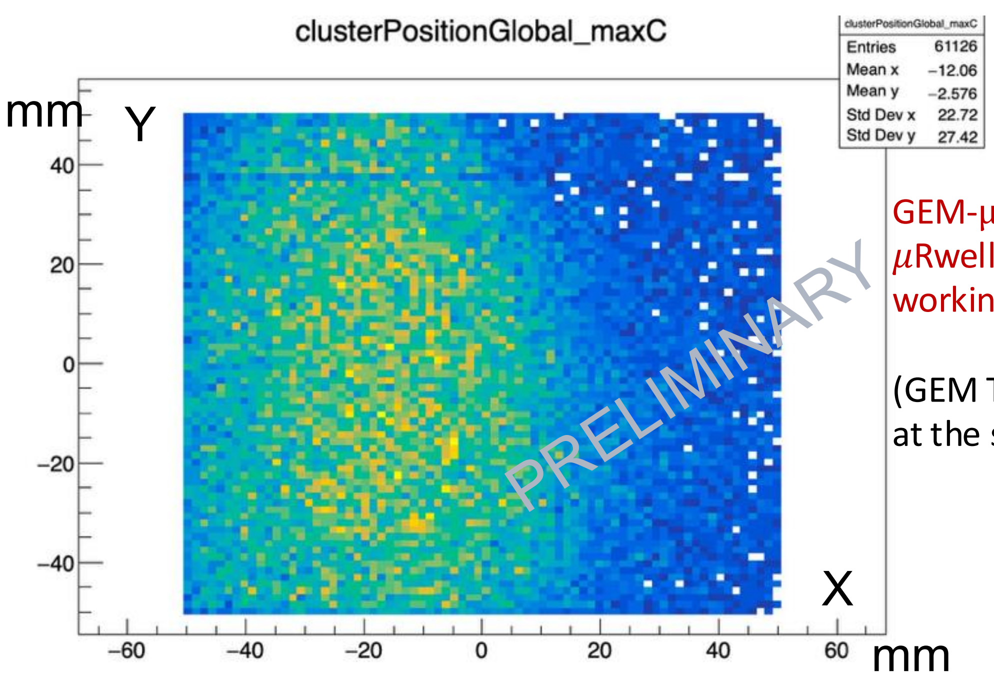
Trackers : GEM-μRwell 10 cm x 10 cm
2D COMPASS-like readout 400μm strips pitch

Gas Mixture: $Ar:CO_2:CF_4$ 45:15:40

MPGD endcap 2025 test beam plan

	Quadrants 50 cm radius	40 cm x 46 cm rectangles
DUT angle = 0°		
ΔV_{GEM}scan	$\Delta V_{Well} = 550$ V, $E_{drift} = 2.5$ KV/cm, $E_{tranfer} = 4.5$ KV/cm	$\Delta V_{Well} = 530$ V, $E_{drift} = 2.5$ KV/cm, $E_{tranfer} = 4.5$ KV/cm
Transfer gap HV scan	$\Delta V_{Well} = 550$ V, $\Delta V_{GEM} = 400$ V, $E_{drift} = 1$ KV/cm	$\Delta V_{Well} = 530$ V, $\Delta V_{GEM} = 490$ V, $E_{drift} = 1$ KV/cm
Drift gap HV scan	$\Delta V_{Well} = 550$ V, $\Delta V_{GEM} = 400$ V, $E_{transfer} = 4.5$ KV/cm	$\Delta V_{Well} = 530$ V, $\Delta V_{GEM} = 400$ V, $E_{transfer} = 4$ KV/cm
μRwell ΔV_{Well}scan	$\Delta V_{GEM} = 430$ V, $E_{drift} = 2.5$ KV/cm, $E_{tranfer} = 4.5$ KV/cm	$\Delta V_{GEM} = 430$ V, $E_{drift} = 2.5$ KV/cm, $E_{tranfer} = 4.5$ KV/cm
DUT angle =20 and 30°	**Quadrants 50 cm radius**	**40 cm x 46 cm rectangles**
ΔV_{GEM}scan	$\Delta V_{Well} = 550$ V, $E_{drift} = 1$ KV/cm, $E_{tranfer} = 4.5$ KV/cm	$\Delta V_{Well} = 530$ V, $E_{drift} = 1$ KV/cm, $E_{tranfer} = 4.5$ KV/cm
Transfer gap HV scan	$\Delta V_{Well} = 550$ V, $\Delta V_{GEM} = 400$ V, $E_{drift} = 1$ KV/cm	$\Delta V_{Well} = 530$ V, $\Delta V_{GEM} = 490$ V, $E_{drift} = 1$ KV/cm
Drift gap HV scan	$\Delta V_{Well} = 550$ V, $\Delta V_{GEM} = 400$ V, $E_{transfer} = 4.5$ KV/cm	$\Delta V_{Well} = 530$ V, $\Delta V_{GEM} = 400$ V, $E_{transfer} = 4$ KV/cm
μRwell ΔV_{Well}scan	$\Delta V_{GEM} = 400$ V, $E_{drift} = 1$ KV/cm, $E_{tranfer} = 4.5$ KV/cm	$\Delta V_{GEM} = 400$ V, $E_{drift} = 1$ KV/cm, $E_{tranfer} = 4.5$ KV/cm

MPGD endcap 2025 – First results: trackers characterization



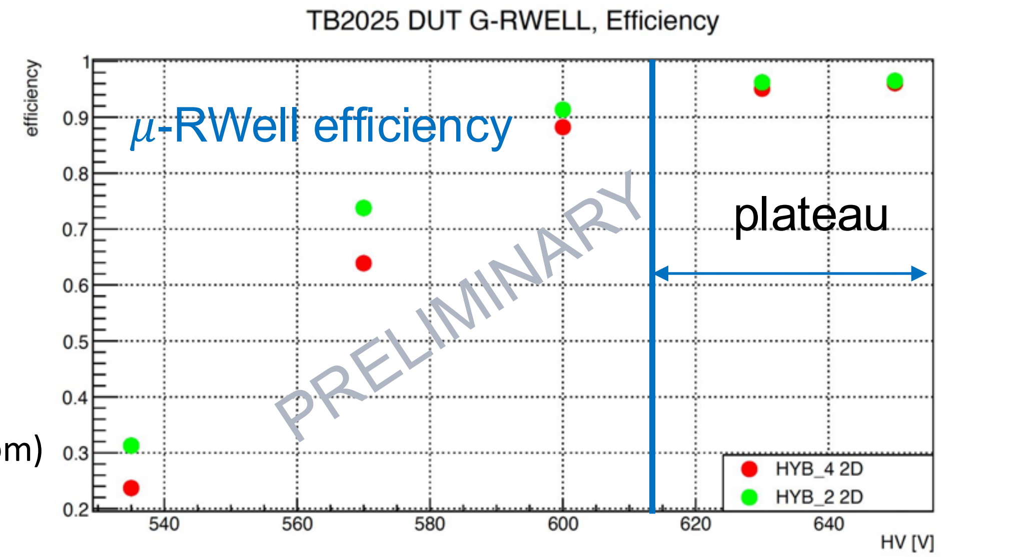
Pion beam hit map (@100 KHz)

GEM-μRwell may also work as μRwell only with GEM bottom working as cathode

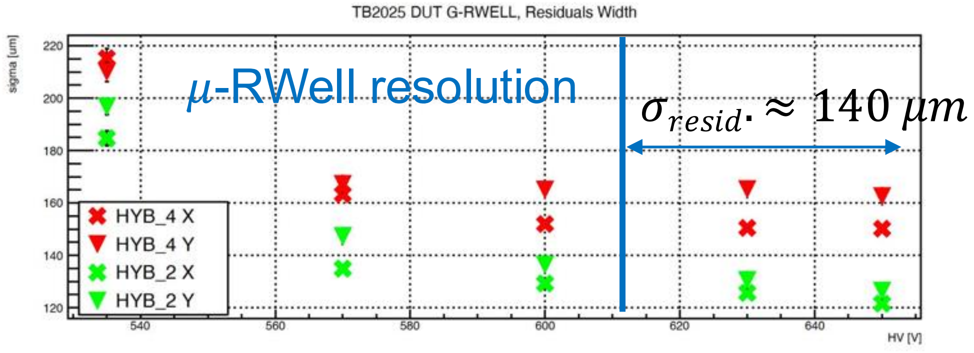
(GEM Top and Cathode
at the same V of the GEM Bottom)

$\Delta V_{\mu Rwell}$= 550 V
$E_{transf.}$ = 4.5 V/cm
$\Delta V_{GEM.}$ = 440 V
E_{drift} = 2.5 V/cm

$\Delta V_{\mu Rwell}$= 550 V
$E_{transf.}$ = 4.5 V/cm
$\Delta V_{GEM.}$ = 0 V
E_{drift} = 0 V/cm



μ-Rwell HV scan



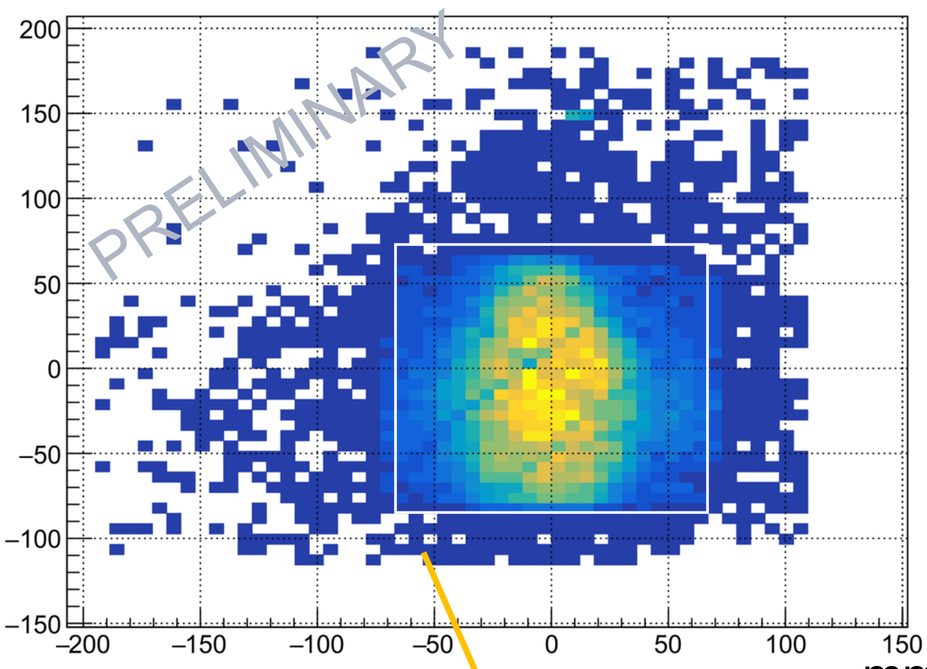
μ-Rwell HV scan

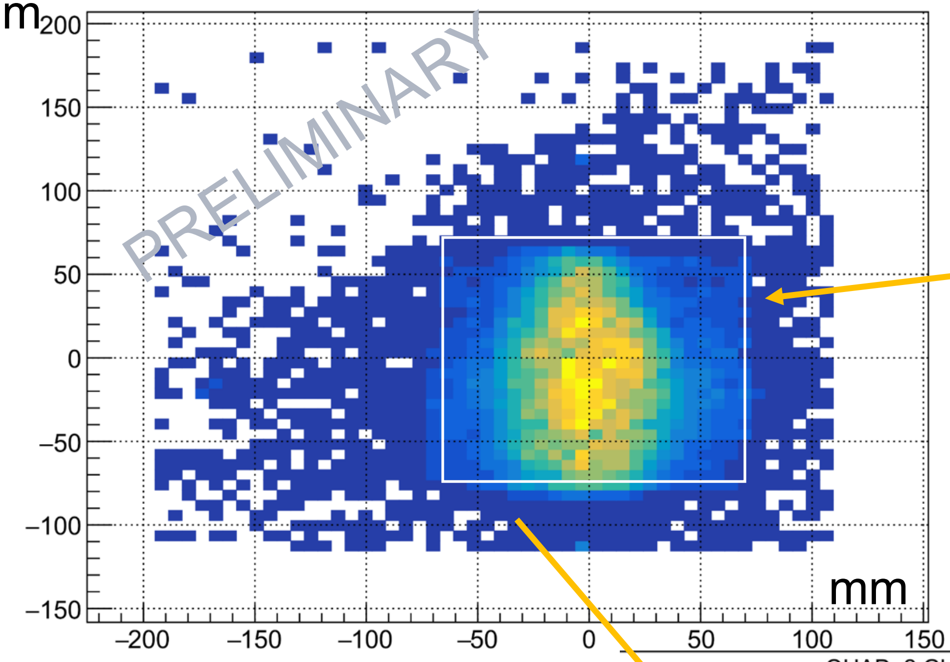
⚠ To be deconvoluted from the tracking resolution

$\sigma_{det} \leq\ 100\ \mu m$

MPGD endcap 2025 – First results: Quadrants Clusters Hit Map

Quadrant 1





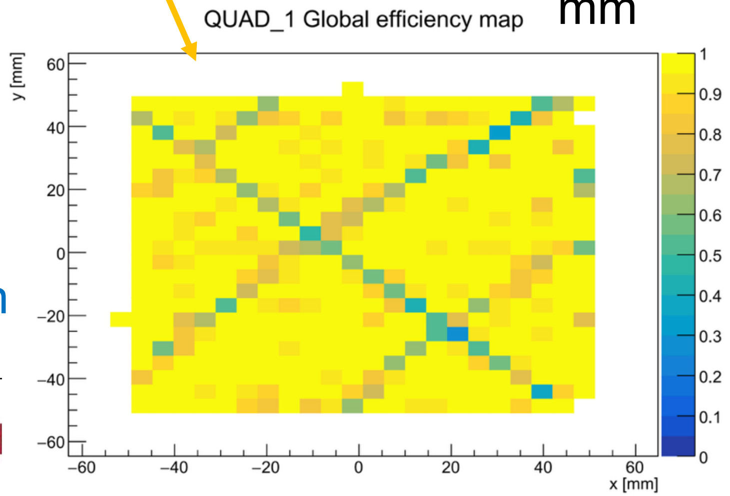
Quadrant 2

Trigger and Trackers geometrical coverage

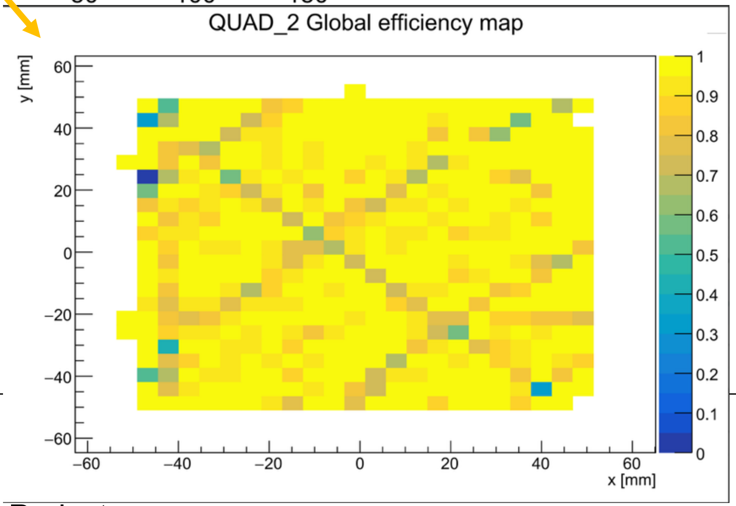
15 x15 cm

Quadrant 2 has no grid to support the GEM

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

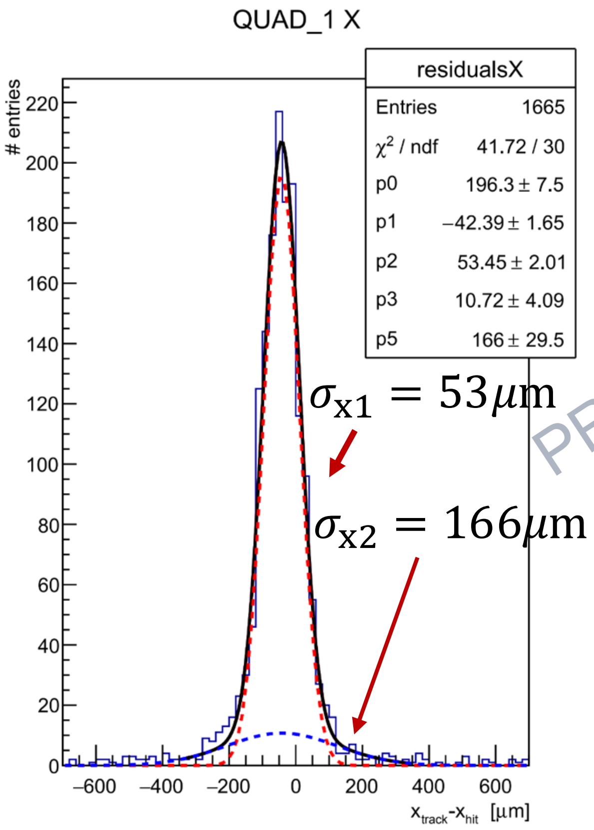


Efficiency maps in the trackers region



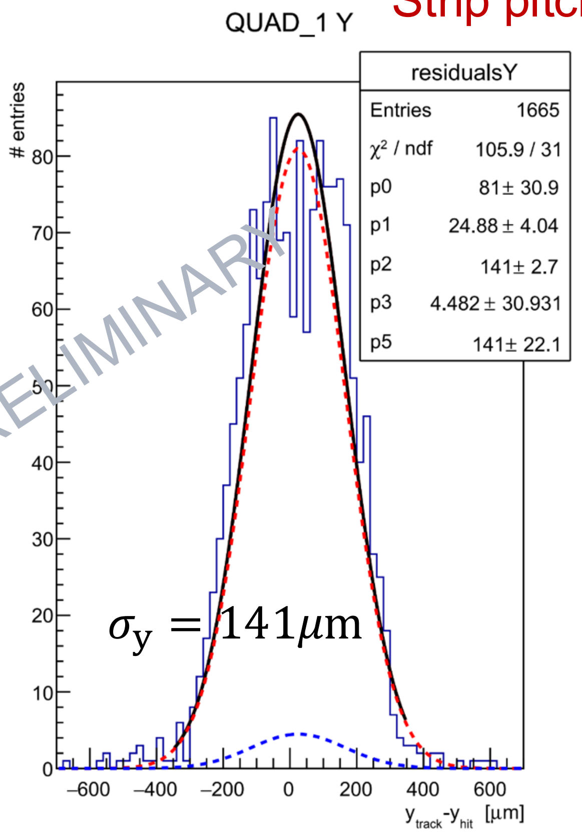
MPGD endcap 2025 – First results: Quadrants Position Resolution

Strip pitch $=600\mu m$



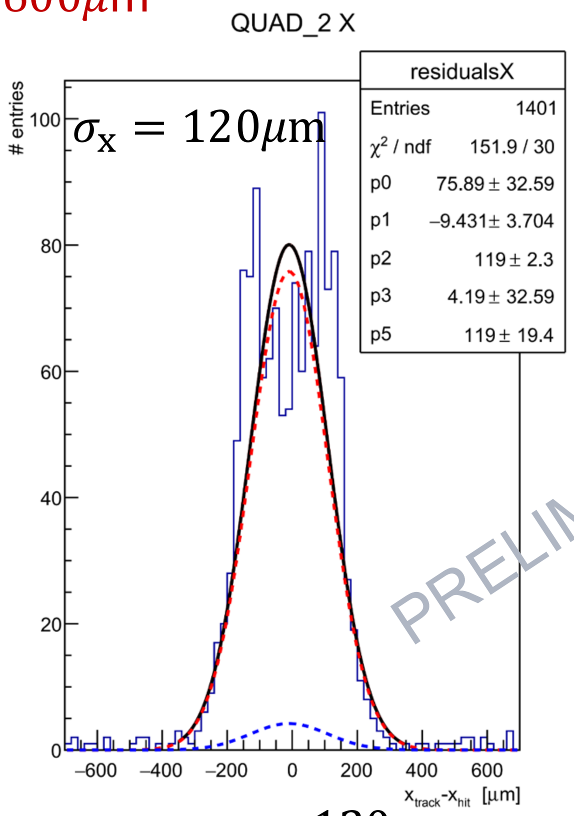
$\sigma_{x\ eff} = 80\mu m$

Lower 520 μm strip width



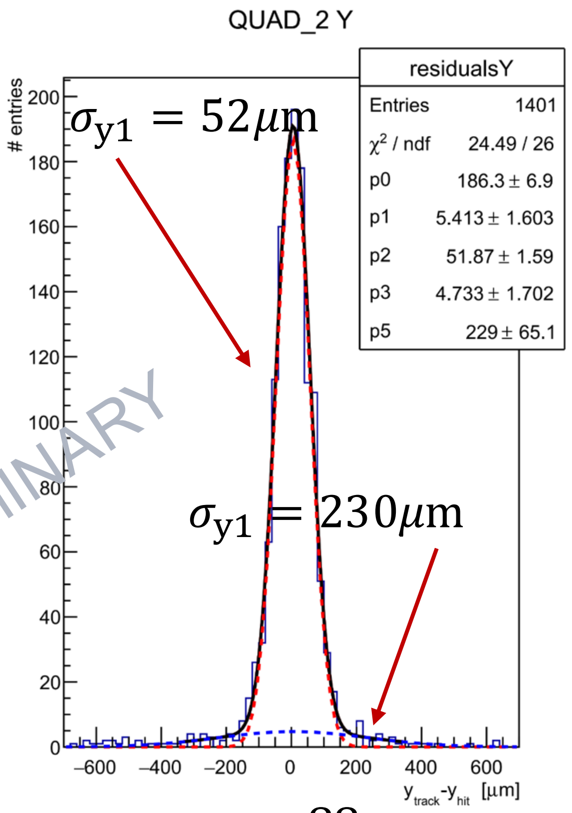
$\sigma_{y\ eff} = 141\mu m$

Upper 90 μm strip width



$\sigma_{x\ eff} = 120\ \mu m$

Upper 90 μm strip width



$\sigma_{x\ eff} = 88\ \mu m$

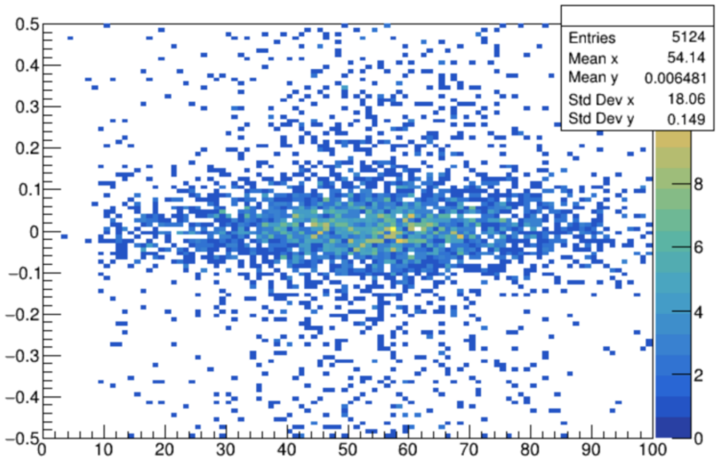
Lower 520 μm strip width

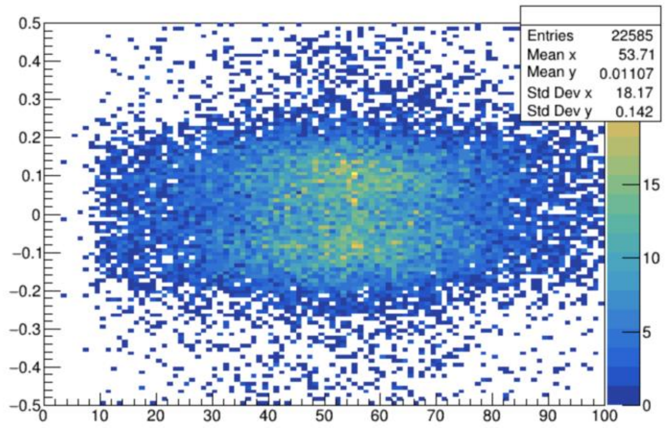
The two quadrants are rotated by 90 degrees with respect to each other

2022 Test Beam – 1D strips 150μm width

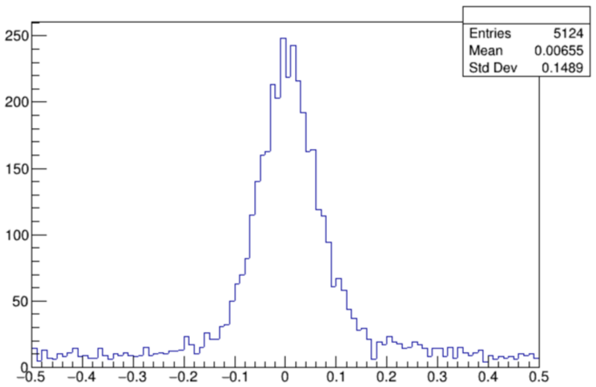
Strip pitch =780 μm

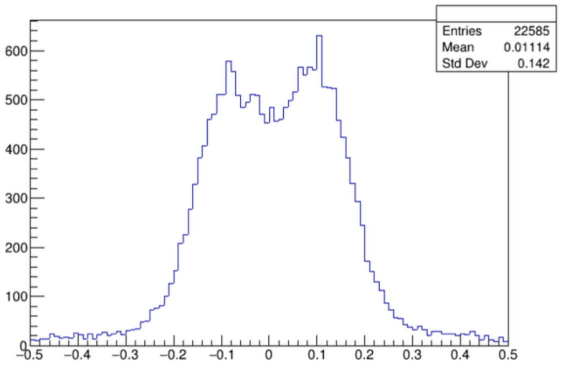
TEST BEAM at CERN 5 – 19 October 2022





4 strips

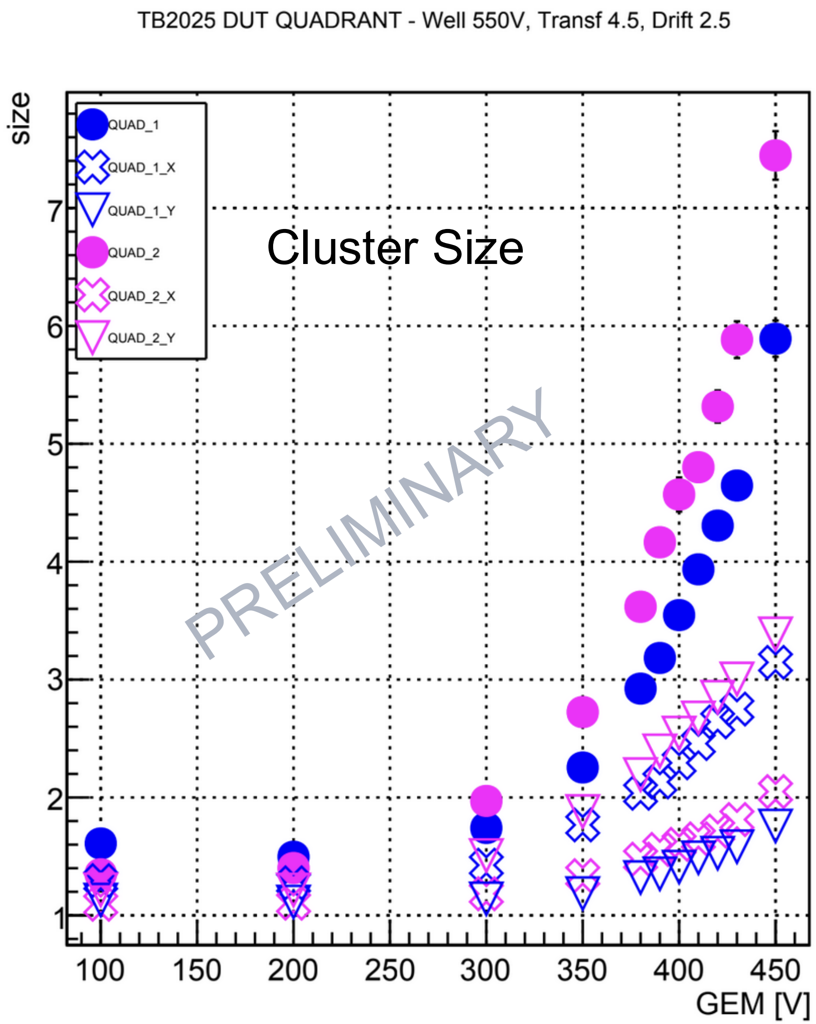


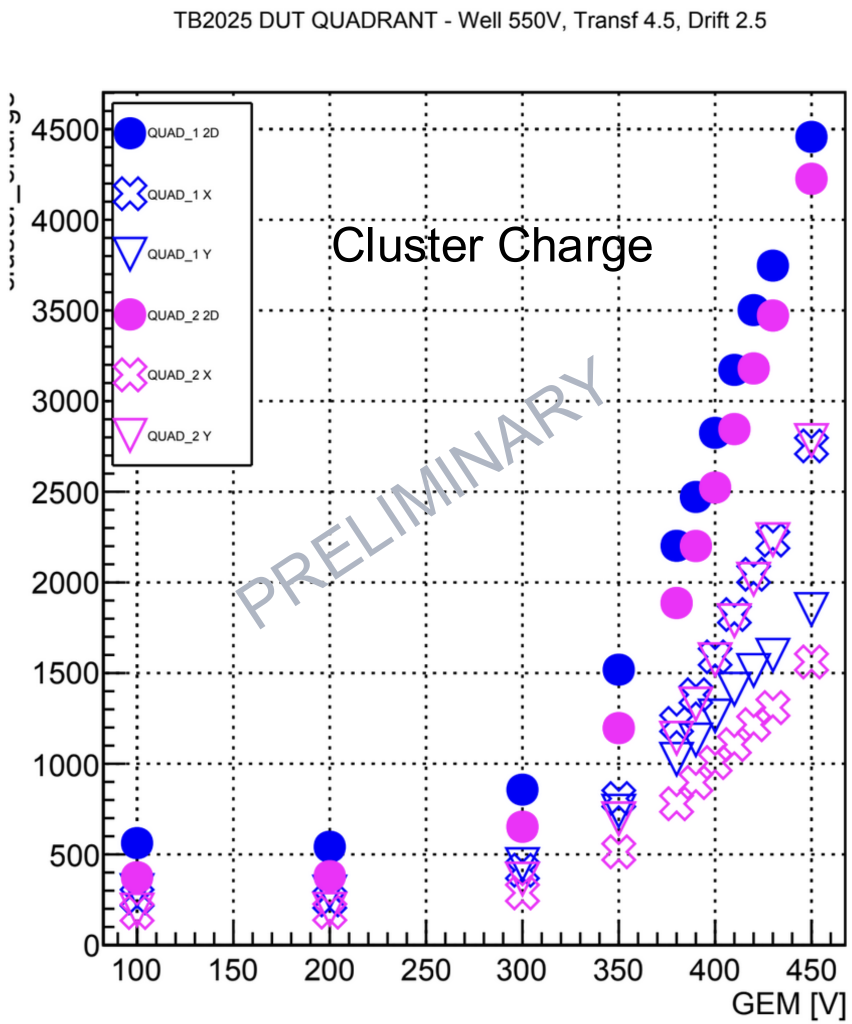


3 strips

December 1st, 2022

MPGD endcap 2025 – First results: Quadrants Cluster charge and size





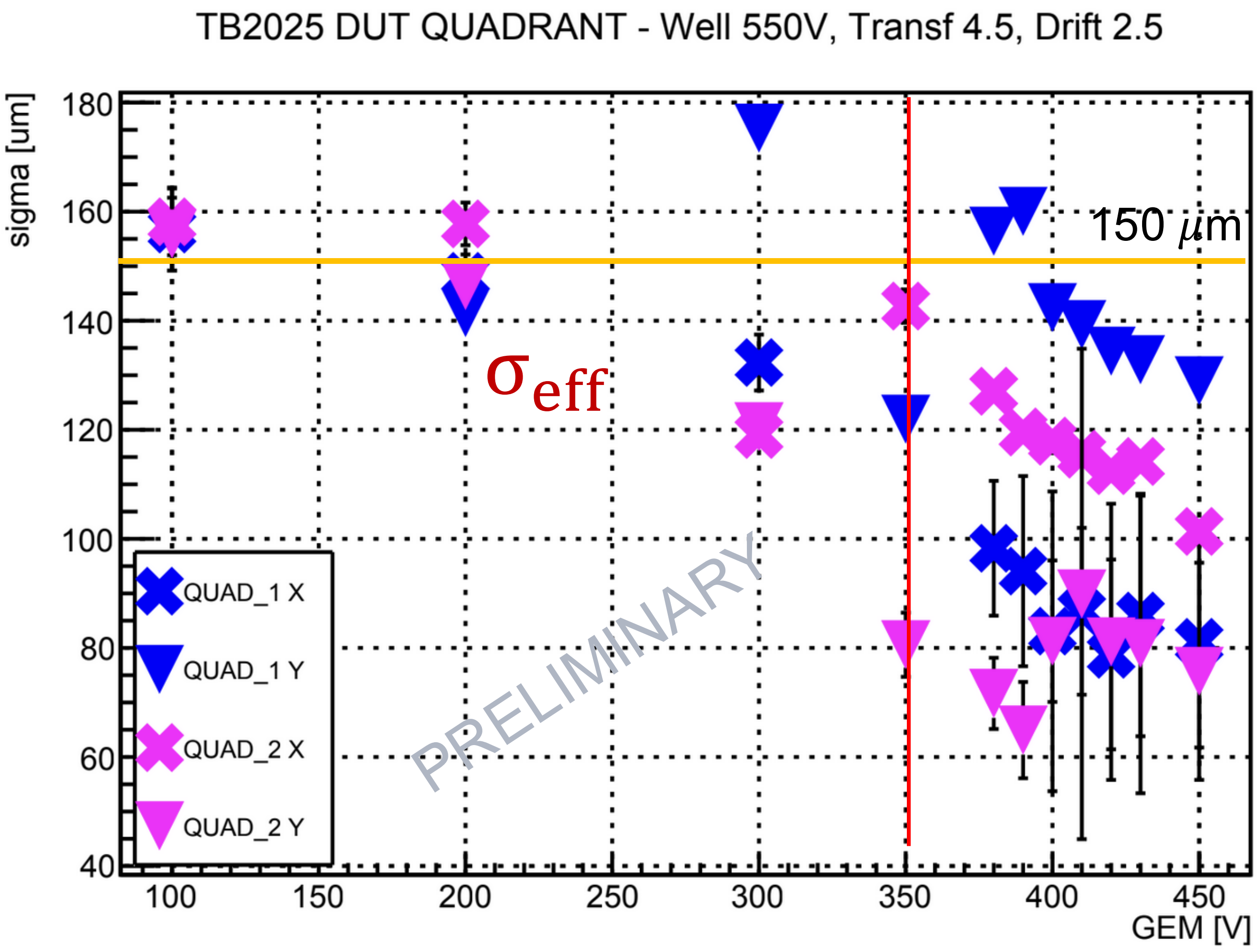
Quadrant 1

Quadrant 2

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

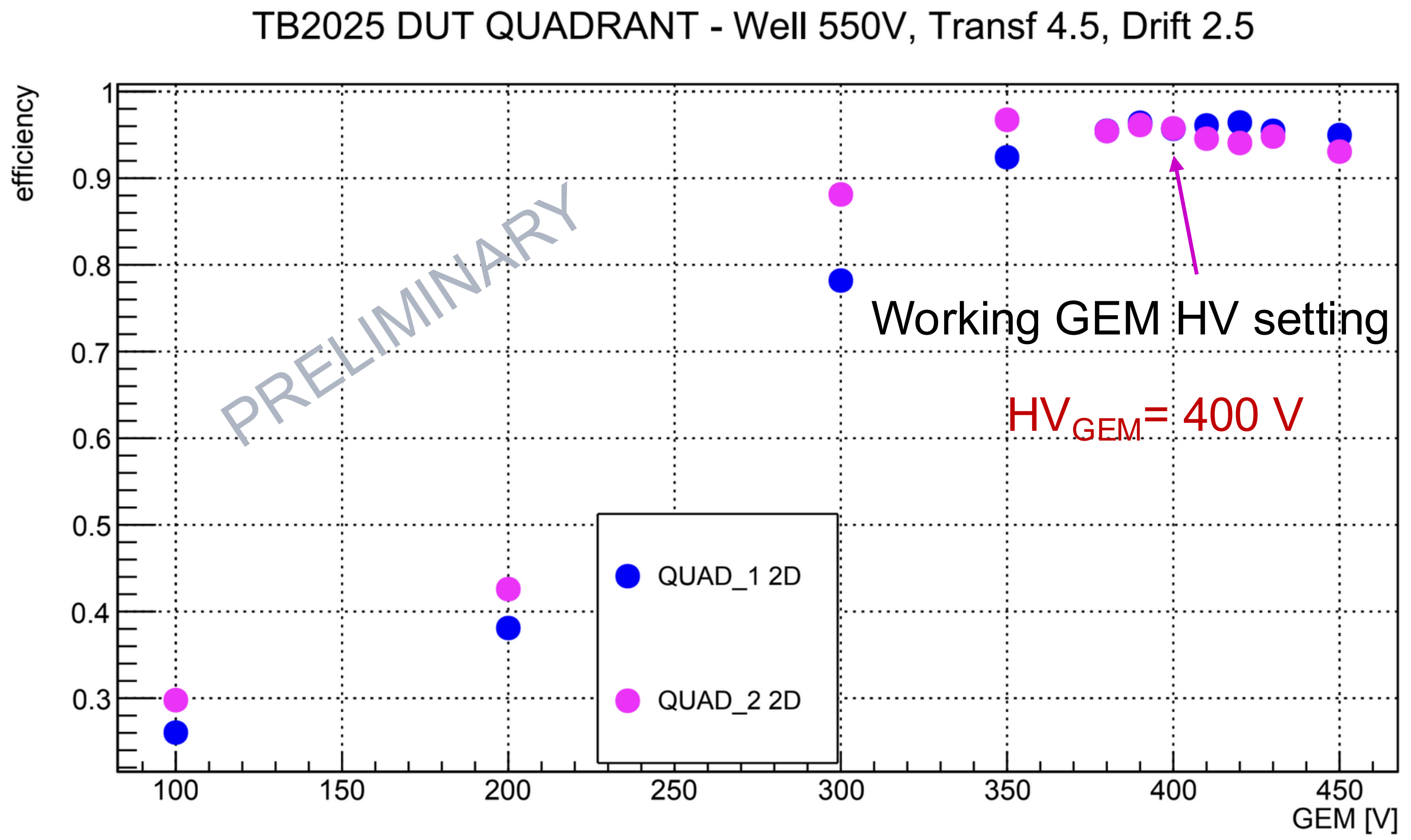
Large lower strips width = 520 μm Small upper strips width = 90 μm

MPGD endcap 2025 – First results: Quadrants Position Resolution



Position Resolution well below specs.

MPGD endcap 2025 – First results: Quadrants Efficiency



Efficiency > 95% @ GEM HV > 350 V

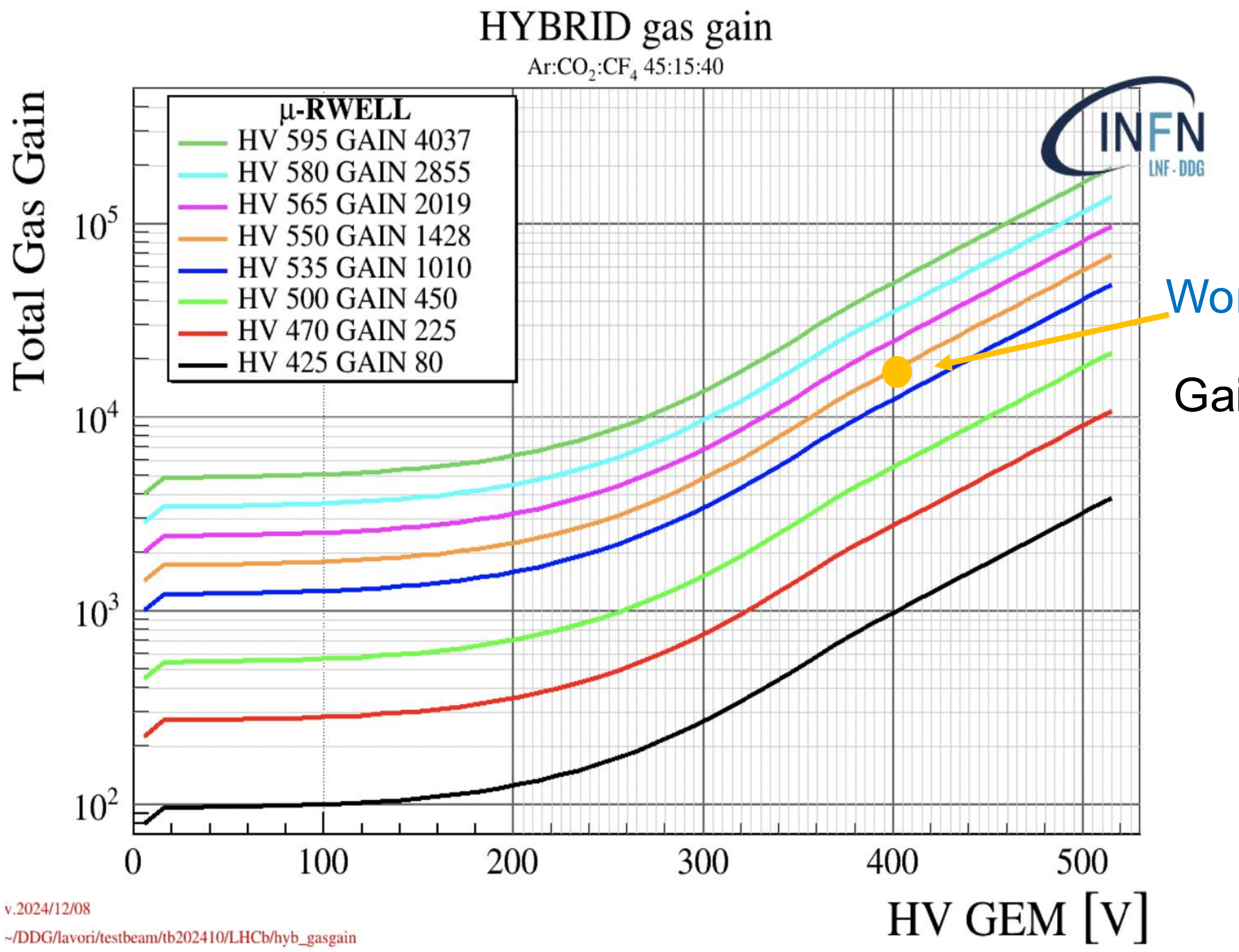
Gas Gain Measurements for GEM-μRwell 10 cm x10cm

by Matteo Giovannetti

Gas Gain plot for GEM- μRWELL
- high gain is reached even for low WELL HV

Gas Gain plot for μRGroove was not performed before the test beam

Fixing the μRwell Gain:
GEM HV ↔ Total gas Gain



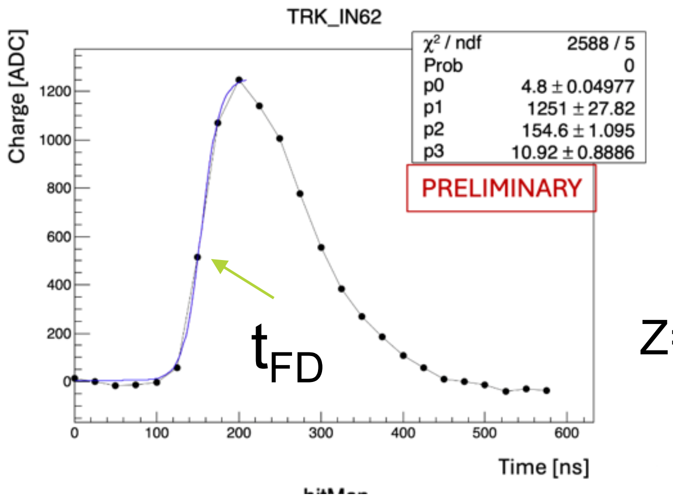
Working point

Gain = $2 \cdot 10^4$

Position resolution optimization - μTPC

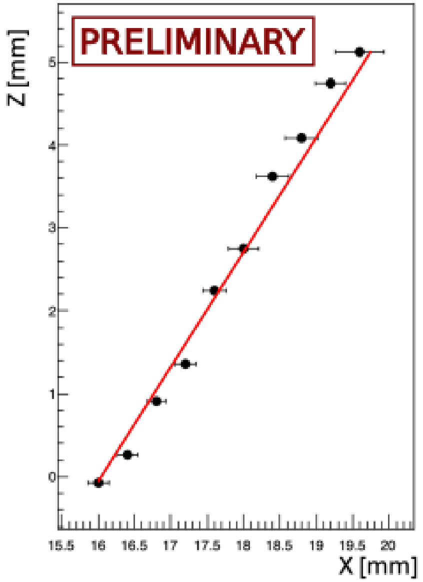
By Elena Sidoretti

- The electrons created by the ionizing particle drift towards the amplification region
- In the μTPC mode from the **knowledge of the drift time** and the **measurement of the arrival time of electrons**, the **track segment in the gas gap is reconstructed**
- The **fit of the analog signal** gives **the arrival time of drifting electrons**.
- By the knowledge of **the drift velocity,** the 3D trajectory of the ionizing particle in the **drift gap** is reconstructed.



Integrated charge as a function of the sampling time

$Z = v_d\, t$

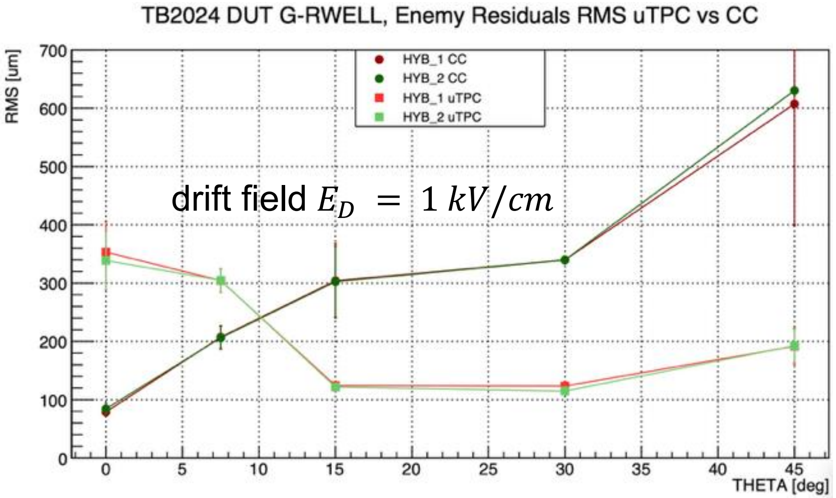


Example of a track reconstruction using the TPC algorithm.

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

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

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



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

MPGD endcap 2025 – First results Summary

GEM-μRwell Technology

- High gas gains are obtained with low (safe) HV GEM and μRwell settings, minimizing current sparks:

  Setting: $\mu\mathrm{Rwell\ HV}$ = 550 V, GEM HV=400 V $\rightarrow$ $\mathrm{Gas\ Gain} = 2 \cdot 10^4$

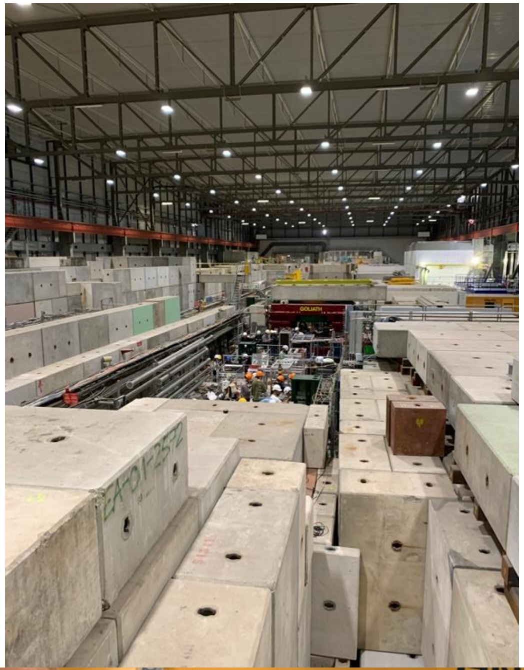
  Transfer Field = 4.5 kV/cm, Drift Field = 1 KV/cm

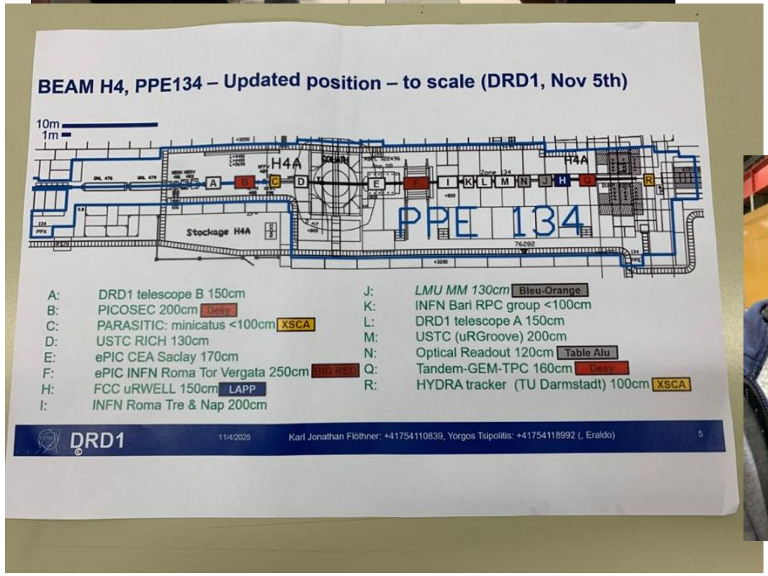
- Same GEM-μRwell Gas Gain curve and performances is obtained the for small and large detectors.

MPGD – ECT status

- Realistic quadrants Engineering Test Articles work as expected
- Position resolution is well below 150 μm, as required
- Detection efficiency > 95 %
- Time resolution under study but expected to be lower 20ns
- Upper strips width may be increased to balance the charge sharing between X and Y

Thank you




BEAM H4, PPE134 – Updated position – to scale (DRD1, Nov 5th)
10m
1m
H4A
H4A
Stockage H4A
PPE 134
A: DRD1 telescope B 150cm
B: PICOSEC 200cm Desy
C: PARASITIC: minicatus <100cm XSCA
D: USTC RICH 130cm
E: ePIC CEA Saclay 170cm
F: ePIC INFN Roma Tor Vergata 250cm BIG RED
H: FCC uRWELL 150cm LAPP
I: INFN Roma Tre & Nap 200cm
J: LMU MM 130cm Bleu-Orange
K: INFN Bari RPC group <100cm
L: DRD1 telescope A 150cm
M: USTC (uRGroove) 200cm
N: Optical Readout 120cm Table Alu
Q: Tandem-GEM-TPC 160cm Desy
R: HYDRA tracker (TU Darmstadt) 100cm XSCA
DRD1
11/4/2025
Karl Jonathan Flöthner: +41754110839, Yorgos Tsipolitis: +41754118992 (, Eraldo)
5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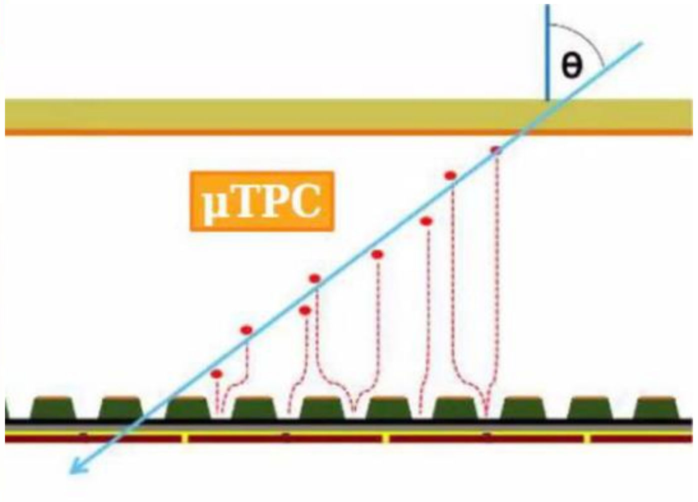
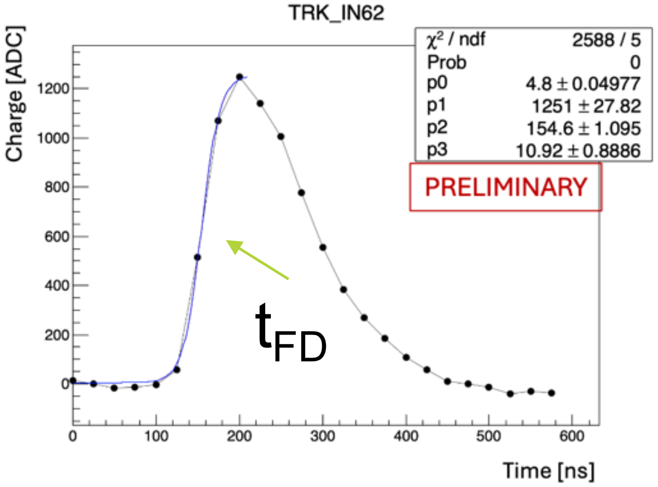
Back-up Slides

GEM-µRWELL-ECT: Hybrid Technology 2024 Test Beam on 10 cm x 10 cm

By Elena Sidoretti



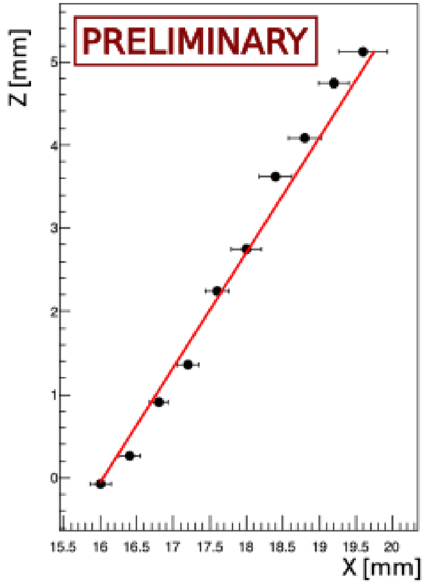


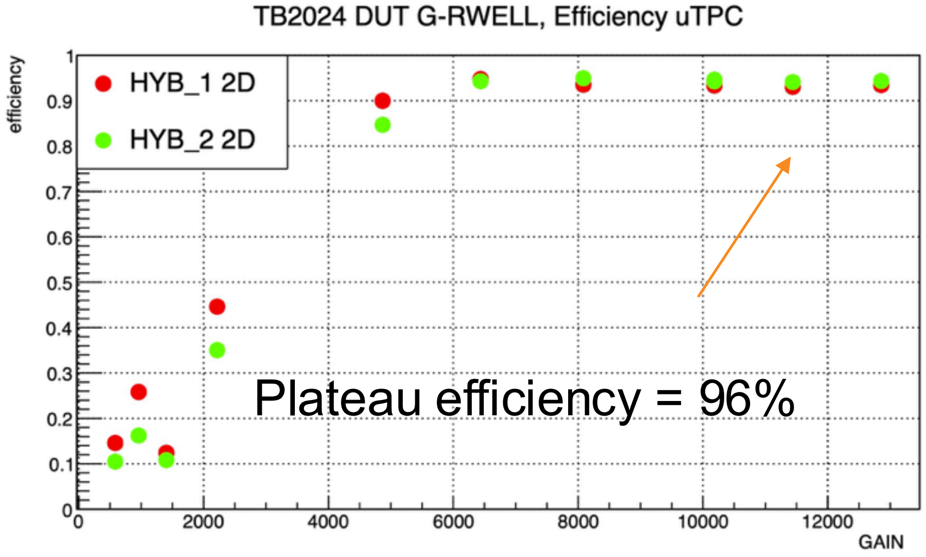
Inclined tracks 30°

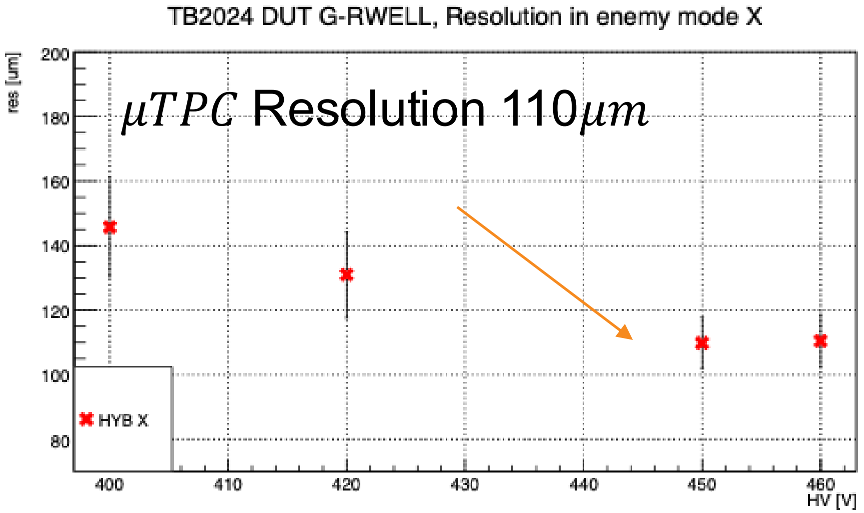
$$t_{hit} = t_0 - t_{FD}$$

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

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



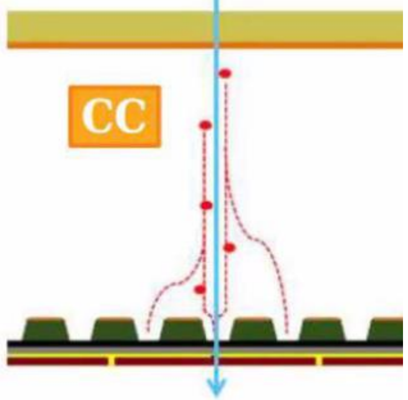




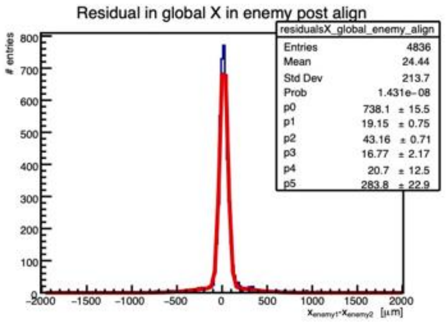
GEM-µRWELL-ECT: Hybrid Technology 2024 Test Beam on 10 cm x 10 cm

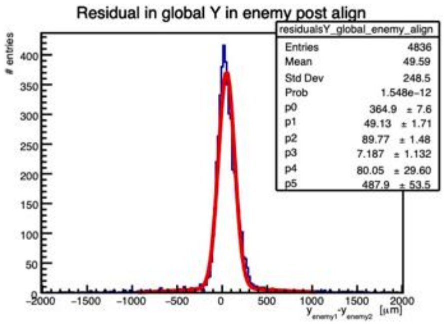
By Elena Sidoretti

Straight tracks 0°

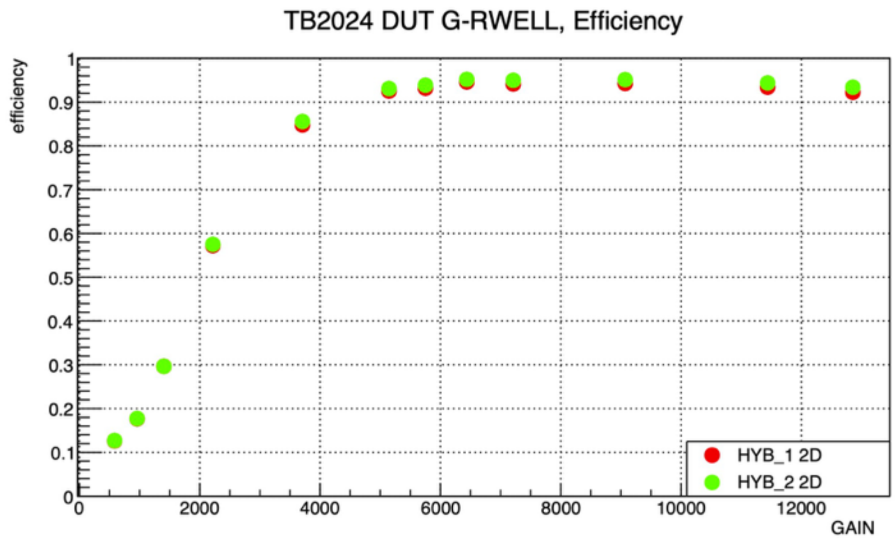


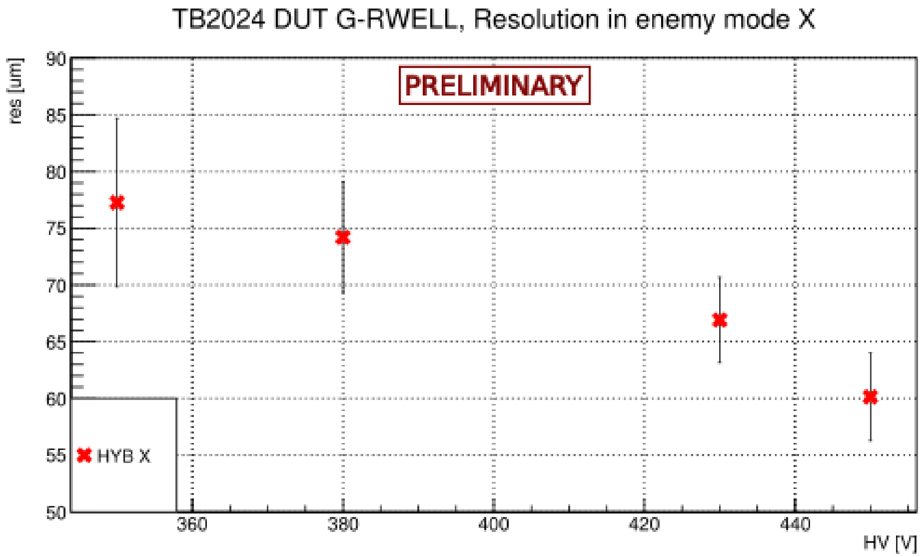
$$x_{cc} = \frac{\sum x_k q_k}{\sum q_k}$$





σ_x = 77.78 ± 5.59 μm σ_y = 123.08 ± 10.73 μm





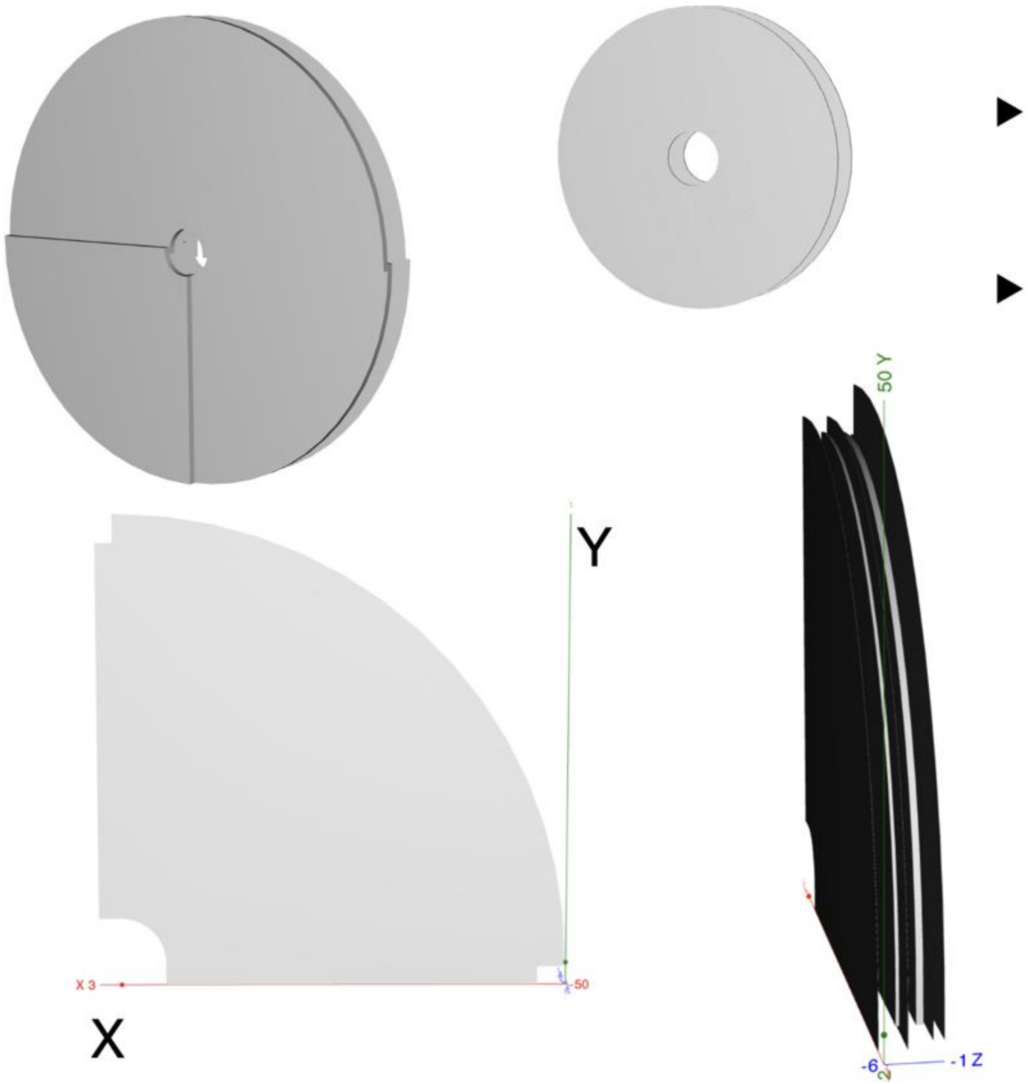
2024 Test Beam assessments

- Efficiency at the plateau > 96%
- Position resolution for straight tracks at the efficiency plateau down to 60 μm
- Projected efficiency for 600 μm pitch better than 150 μm

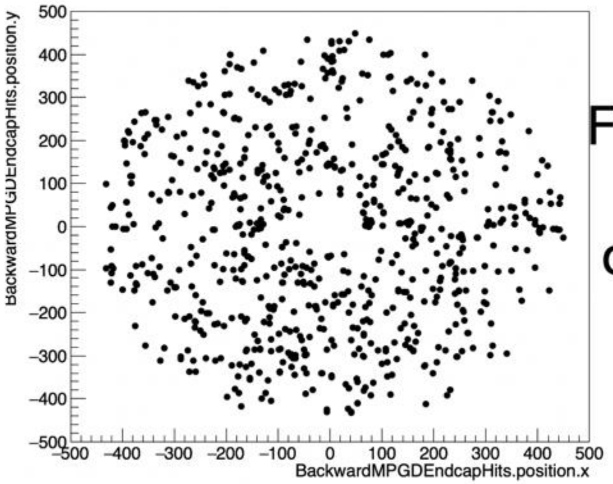
GEM-µRWELL-ECT: Detector Simulation to be updated

By Mariangela Bondì

- A **realistic description** of the geometry and materials of the MPGD disks has been implemented in the detector simulation
- Work is ongoing to enable ACTS tracking with the disks

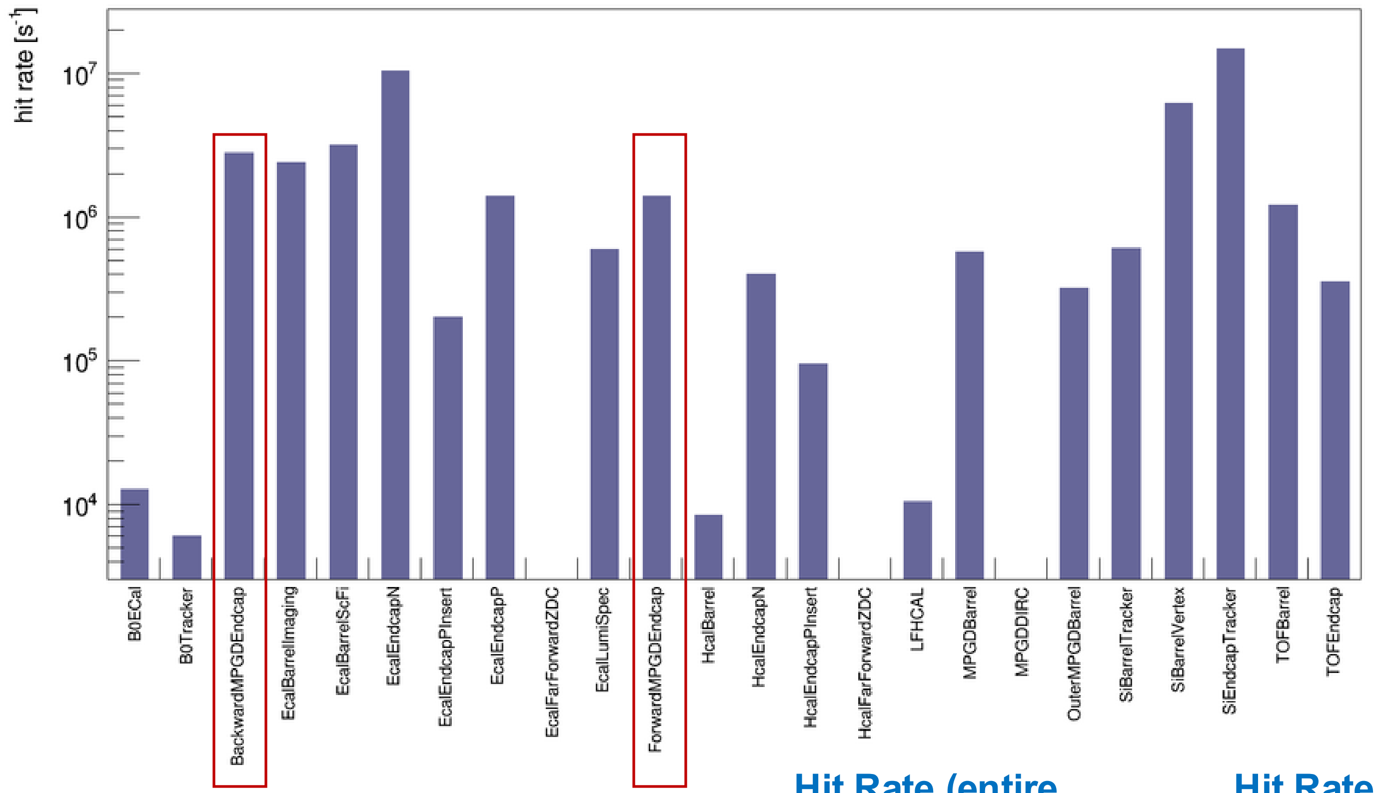


On-going tests



Footprint - ddsim simulation

Background – message by Elke



10 GeV electron energy

Sub-detector	Hit Rate (entire subdetector)	Hit Rate (hottest readout channel)	CellID (hottest readout channel)
BackwardMPGDEndcapRecHits	2.77989e+06	102.08	18324865404498963016
ForwardMPGDEndcapRecHits	1.39517e+06	39.8752	18331339328963305810