Test beam first preliminary results on the GEM- μRWELL prototypes for ePIC endcap tracking

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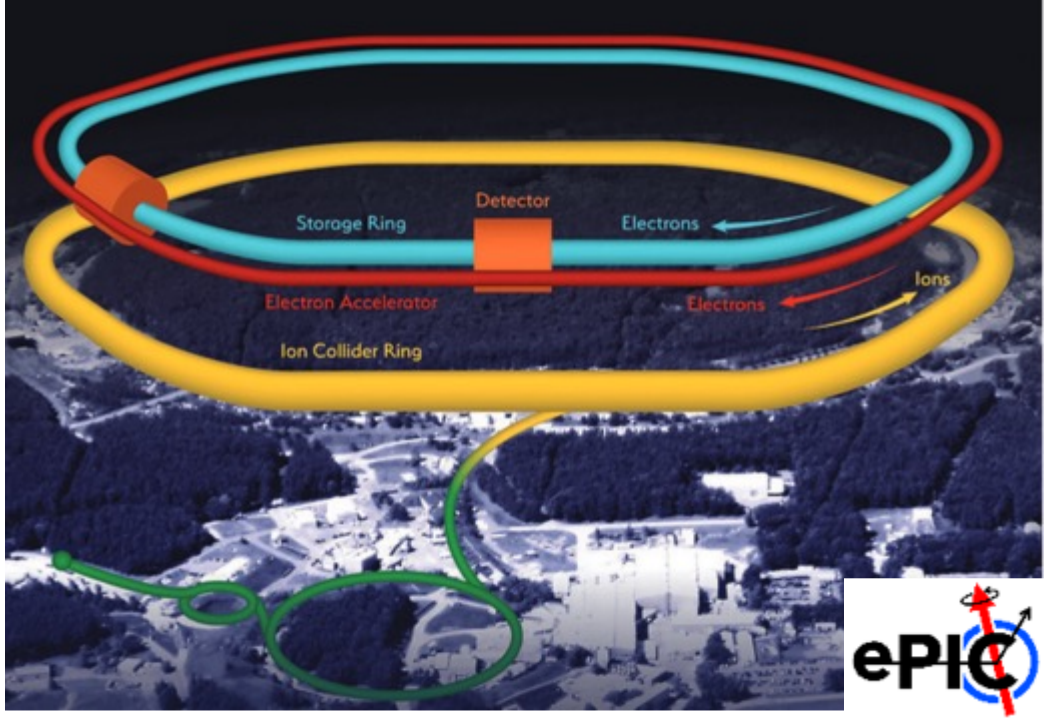
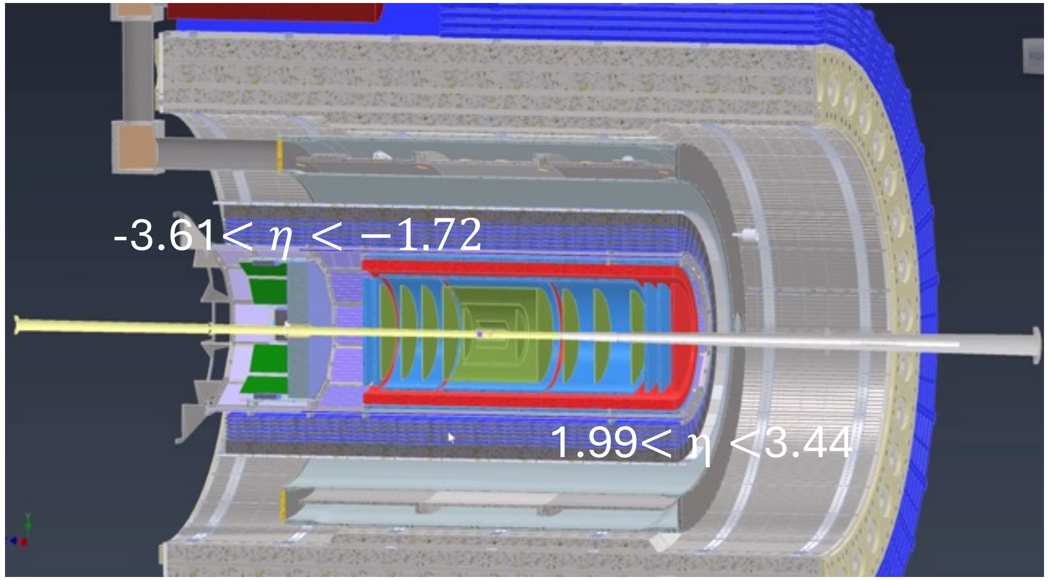
3rd DRD1Collaboration Meeting – December 2024

Electron Ion Collider

The **Electron Ion Collider**[1] (EIC) will be built at Brookhaven National Laboratory and is designed to study the **nuclear structure** with an unprecedented precision, shading light on confinement and on the intriguing behavior of QCD in the non-perturbative regime





Colour code:
green → silicon trackers
light blue → MPGDs
red → Time of Flight
purple → DIRC

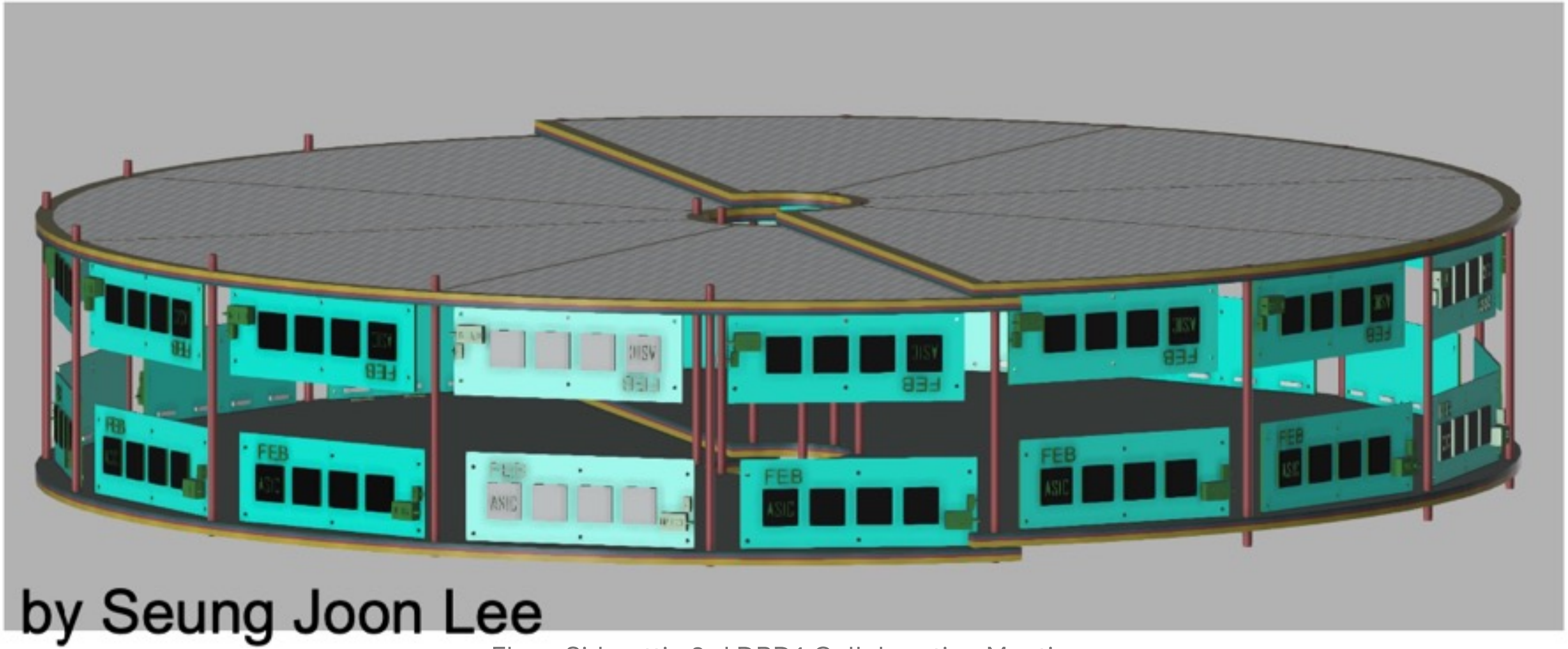
ePIC detector tracking – MPGD endcap trackers

The trackers covering the area of the detector with pseudo-rapidity **|η| > 2** include the Endcap Tracker: two pairs of GEMμ-RWELL disks, one in the leptonic region and one in the hadronic region.

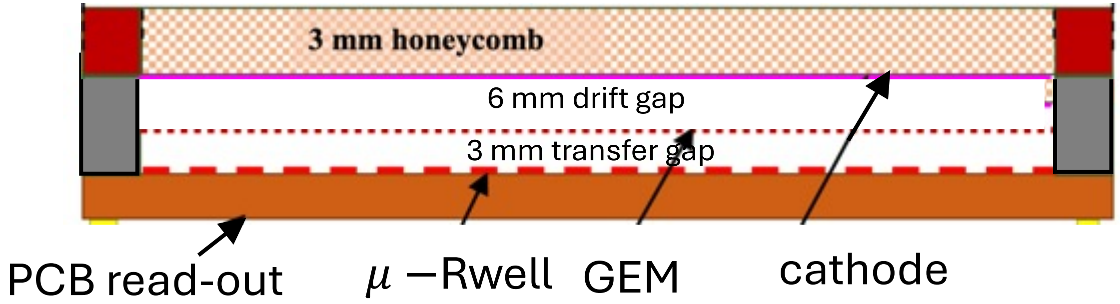
[1]R. Abdul Khalek et al. Nuclear Physics A, 1026:122447, 2022.

ePIC MPGD endcaps

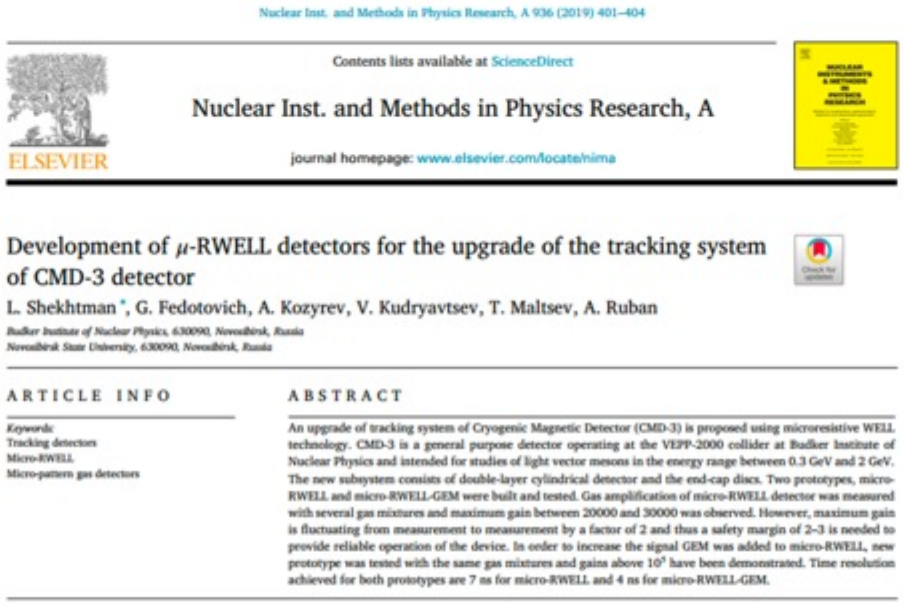
The active region of the disks is drawn with an external radius of 45 cm and internal radius of 6 cm (leptons region) or 9.5 cm (hadrons region) and divided in four quadrants. The detector should provide a **time resolution** of 10-20 ns, **low material budget** ($\simeq 1\ \% X_0$), **spatial resolution** of 150 μm, **2D readout**, and single detector **efficiency** of 96 – 97% (corresponding to 92 – 94% combined efficiency)



GEM- μRWELL hybrid ePIC Requirements



- GEM- μRwell hybrid configuration has been chosen to have safe operation at a gain larger than 10 000
- 2D strip read-out using a "COMPASS-like" scheme
- 500-600 μm pitch corresponding to a spatial resolution ~150 μm
  (with 650 μm pitch, in 5 mm drift gap, spatial resolution better than 150 μm has been reached for incident angles up to 30° using CC and μTPC reconstruction methods combined [1])
- A drift gap larger than 3 mm is compatible with single detector efficiency larger than 96%


Nuclear Inst. and Methods in Physics Research, A 936 (2019) 401–404

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Development of μ-RWELL detectors for the upgrade of the tracking system of CMD-3 detector

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ARTICLE INFO

Keywords:
Tracking detectors
Micro-RWELL
Micro-pattern gas detectors

ABSTRACT

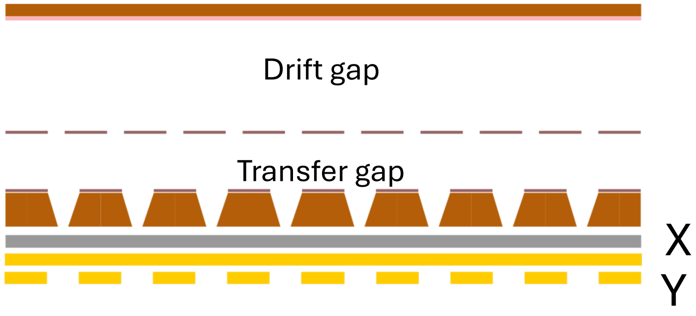
An upgrade of tracking system of Cryogenic Magnetic Detector (CMD-3) is proposed using microresistive WELL technology. CMD-3 is a general purpose detector operating at the VEPP-2000 collider at Budker Institute of Nuclear Physics and intended for studies of light vector mesons in the energy range between 0.3 GeV and 2 GeV. The new subsystem consists of double-layer cylindrical detector and the end-cap discs. Two prototypes, micro-RWELL and micro-RWELL-GEM were built and tested. Gas amplification of micro-RWELL detector was measured with several gas mixtures and maximum gain between 20000 and 30000 was observed. However, maximum gain is fluctuating from measurement to measurement by a factor of 2 and thus a safety margin of 2–3 is needed to provide reliable operation of the device. In order to increase the signal GEM was added to micro-RWELL, new prototype was tested with the same gas mixtures and gains above 10^5 have been demonstrated. Time resolution achieved for both prototypes are 7 ns for micro-RWELL and 4 ns for micro-RWELL-GEM.

L. Shekhtman et al 10.1016/j.nima.2018.11.033

[1]M. Alexeev *et al* 2019 *JINST* **14** P08018

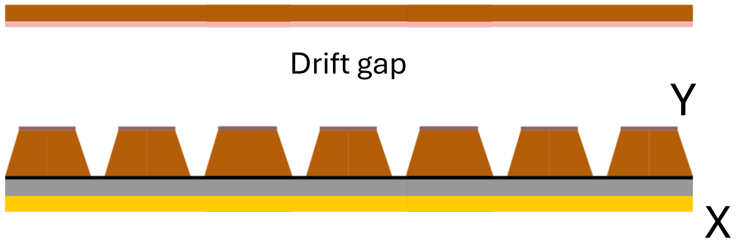
Detector Under Test 2D layout

GEM- μRWELL



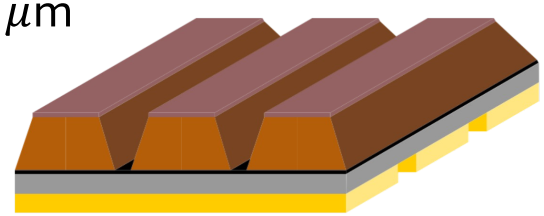
- Active area 100x100 mm^2
- Readout à la COMPASS 2D
  - Bottom strip pitch 400 μm, width 300 μm
  - Top strip pitch 400 μm, width 60 μm
- 6 mm drift gap
- 3 mm transfer gap

μRGroove[1]



On behalf of INFN LNF DDG group

- Active area 100x100 mm^2
- Readout 2D
  - Groove width 70 μm
  - Top width 70/140 μm
  - Strips as clusters of 2 or 3 grooves
  - Final pitch 400 or 420 μm
- 6 mm drift gap



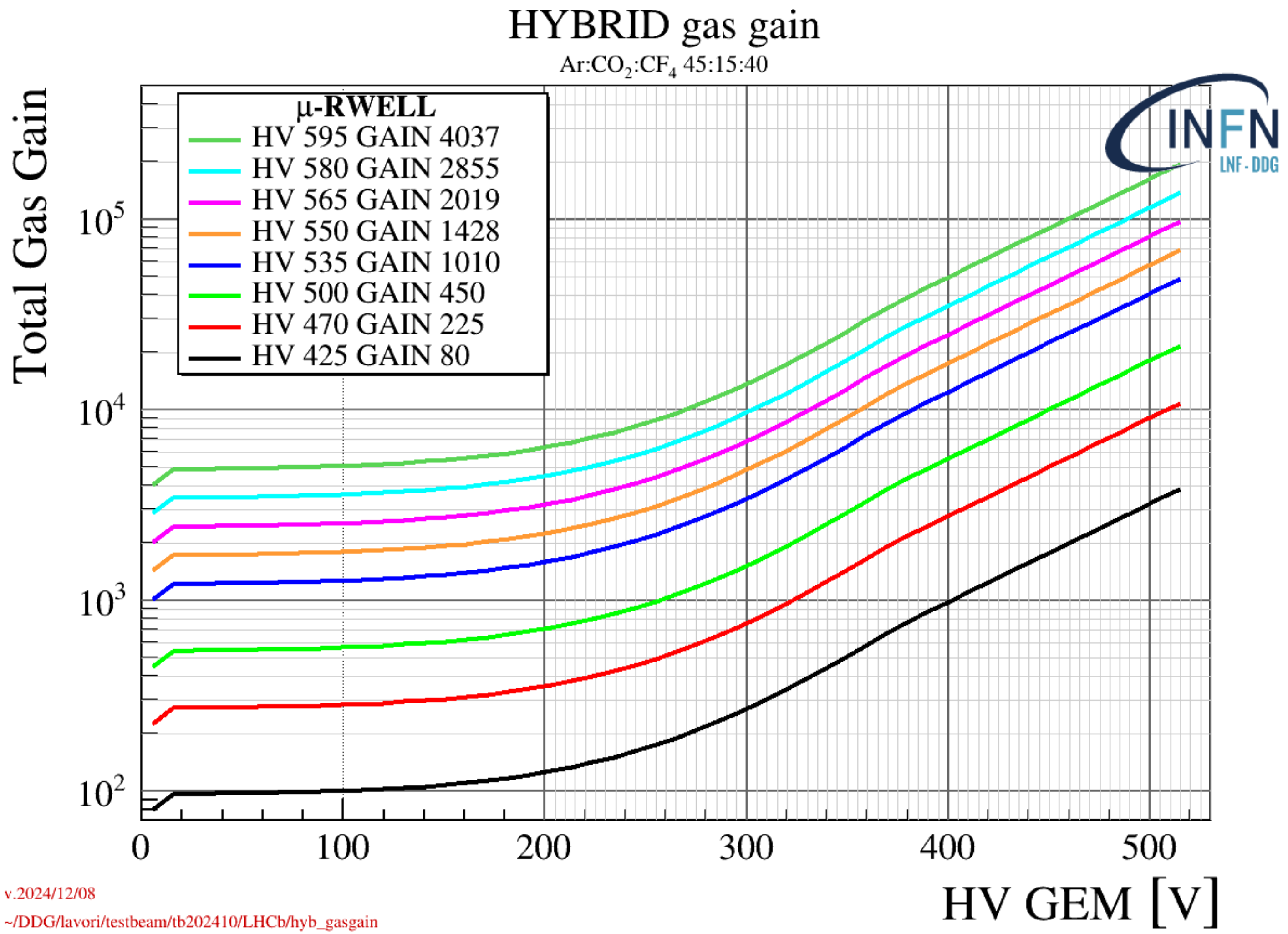
[1]Xiangqi Tian *et al* 2024 *JINST* **19** P07031

Gas Gain – X Ray gun study

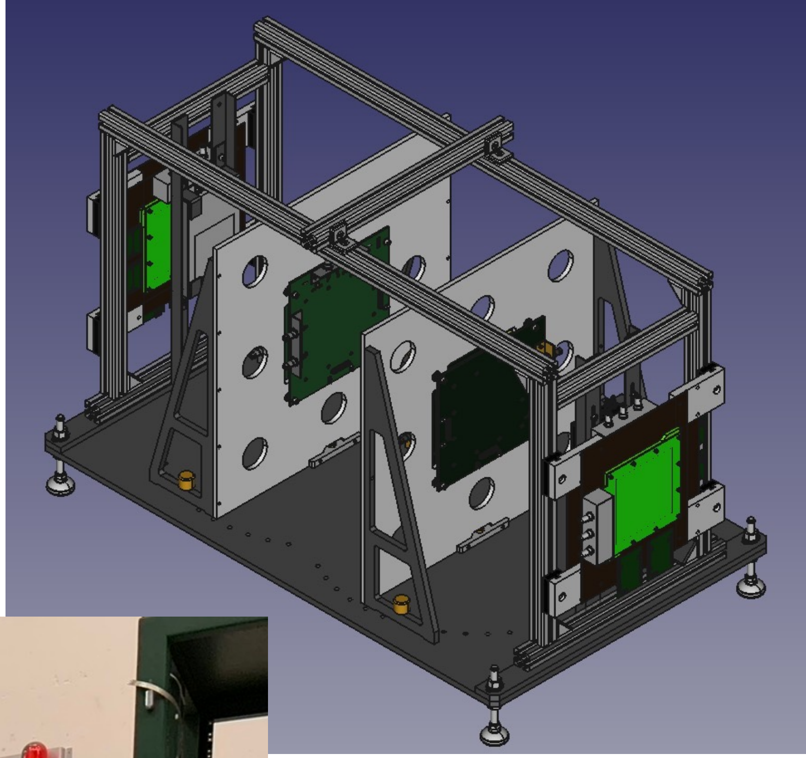
Gas Gain plot for GEM- μRWELL

- high gain is reached even for low WELL HV

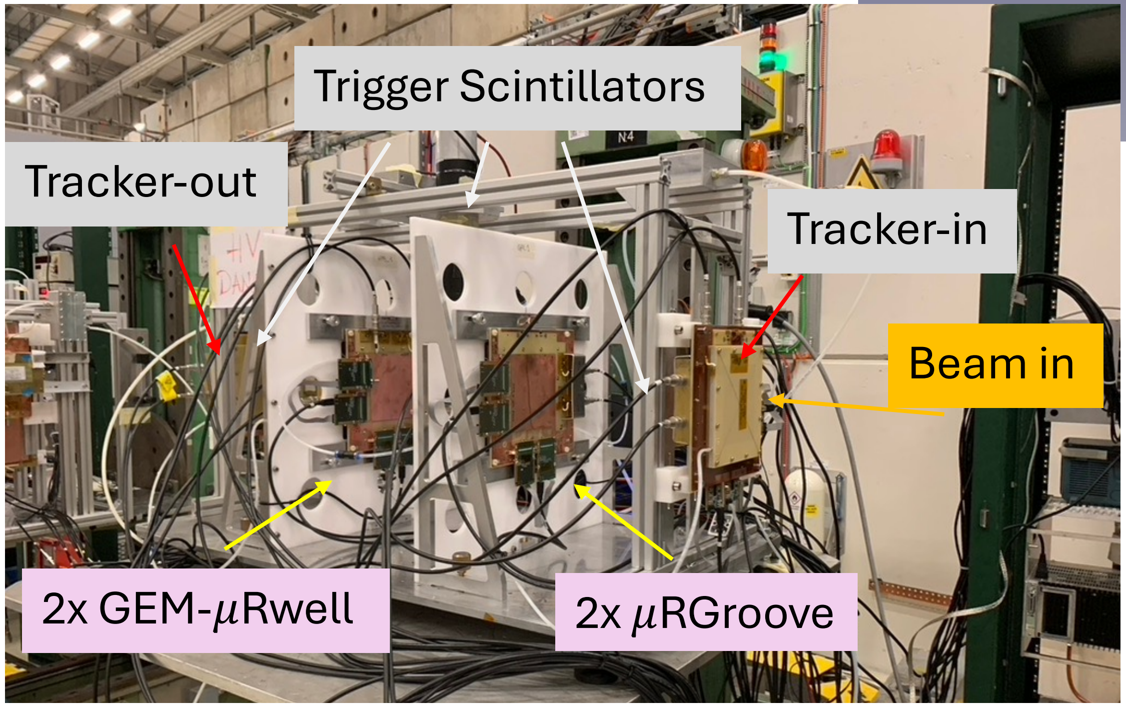
Gas Gain plot for μRGroove was not performed before the test beam



Test Beam @PS T10
13 -27 November 2024



- **Gas mixture**: Ar:CO_2:CF_4 45:15:40
- **Tracking**:
  - hybrid GEM- μRWELL with 2D Compass like readout and
  - μRWELL with 2D Compass like readout
- **Detectors Under Test**:
  - 2 hybrid GEM- μRWELL with 2D Compass like readout
  - 2 μRGroove with 2D readout



Trackers set-up & backup solutions

The goal was to use two hybrid GEM-μRWELL as trackers. Since one of the GEM broke during the test beam, one of the trackers was used as a standard μRWELL with 3 mm gas gap

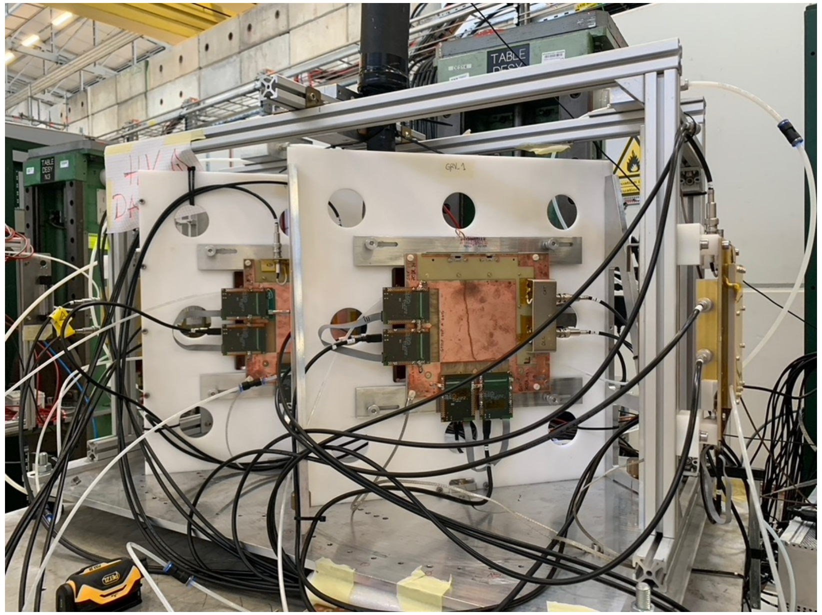
	GEM-μRWELL hybrid	μRWELL
Drift field	2.5 kV/cm in 6 mm gas gap	OFF
ΔV_{GEM}	400 V (gas gain ~10)	OFF
Transfer field	4.5 kV/cm in 3 mm gas gap	3.5 kV/cm in 3 mm gas gap (as Drift)
ΔV_{WELL}	550 V (gas gain ~1500)	630 V (gas gain ~8000)
Gas gain	~15000	~8000

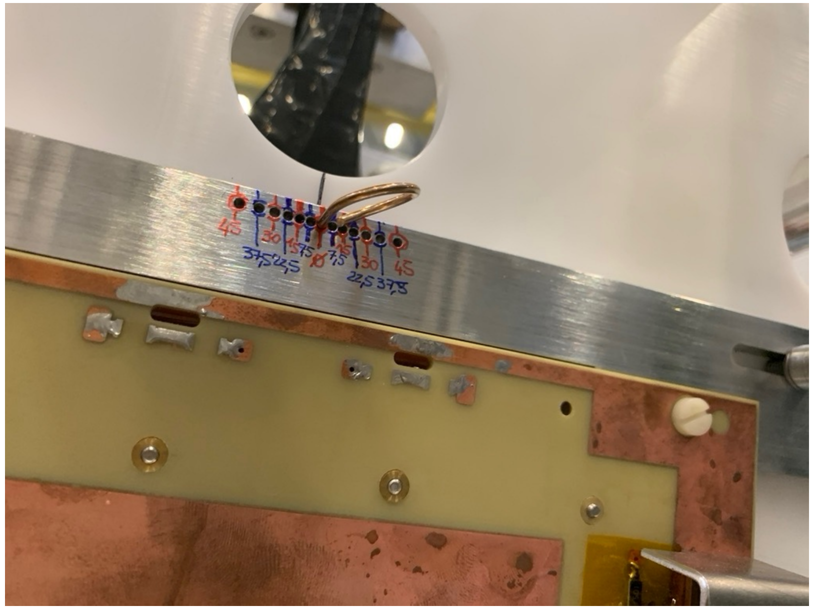
Note: we realized that also during the experiment the GEM-μRWELL may still be used as a standard μRWELL, with efficiency higher than 90%, should the GEM stage show problems and must be disconnected.

DUT set-up

- Each pair of identical DUT are positioned in a mirror configuration with facing cathodes, also called “**Enemy**" mode. This will allow to directly compare the relative measured hit position with minimum systematic uncertainties.

- DUT may be rotated to study their characteristics for inclined tracks.
  - θ= 0°, 7.5°, 15°, 30°, 45°





Data Acquisition and Analysis

- The used data acquisition system is the **Scalable Readout System** (SRS[1])+**APV25[2]** read by **mmDAQ3[3]**
  - Two FECs are used
  - 24 APV25 in total
- The data analysis is performed using the **Corryvreckan**[4] framework

Corryvreckan

The Maelstrom for Your Test Beam Data

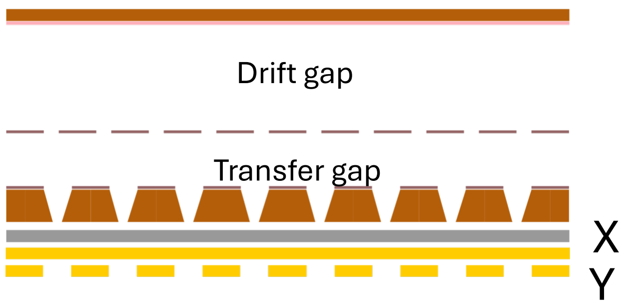
E. Sidoretti at WG7
https://indico.cern.ch/event/1442324/contributions/6262062/

Thanks to Givi for his fundamental help

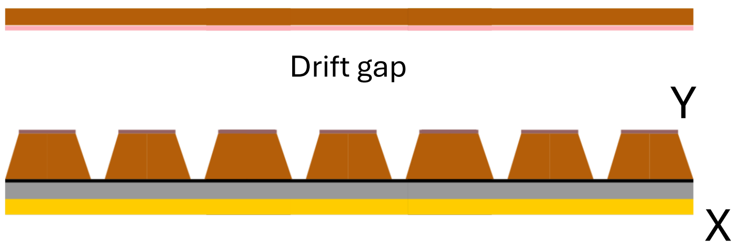
[1]S. Martoiu et al. JINST, 8:C03015, 2013.
[2]M. French et al. NIM A, 466(2):359–365, 2001
[3]M. e. a. Bianco. PoS, TIPP2014:202, 2015
[4]D. Dannheim *et al* 2021 *JINST* **16** P03008

Studied parameters

GEM- μRWELL



μRGroove



	GEM-μRWELL	**μRGroove**
SCAN HV 0°	ΔV_{GEM} scan ΔV_{WELL}= 550 V, E_{drift}= 1 kV/cm, $E_{transfer}$= 4 kV/cm	ΔV_{WELL} scan E_{drift}= 1 kV/cm
SCAN HV 30°	ΔV_{GEM} scan ΔV_{WELL}= 550, V E_{drift}= 1 kV/cm, $E_{transfer}$= 4 kV/cm	ΔV_{WELL} scan E_{drift}= 1 kV/cm
SCAN gap field 30°	E_{drift} and $E_{transfer}$ scan ΔV_{WELL}= 550 V, ΔV_{GEM} = 440 V	E_{drift} scan ΔV_{WELL}= 670 - 720 V
SCAN θ	θ scan ΔV_{WELL}= 550 V, ΔV_{GEM} = 440 V, E_D= 1 kV/cm, E_T= 4 kV/cm	θ scan ΔV_{WELL}= 670 - 720 V, E_{drift}= 1 kV/cm

We studied the performance of the μRWELL when the GEM is turned off at different angles to check if it is possible to still perform μTPC calculations with 3 mm gas gap.

Preliminary results HV scan at 0°

Efficiency is calculated as:

$$\frac{\#\ tracks\ with\ associated\ cluster\ on\ the\ DUT}{\#\ tracks\ passing\ trought\ the\ DUT}$$

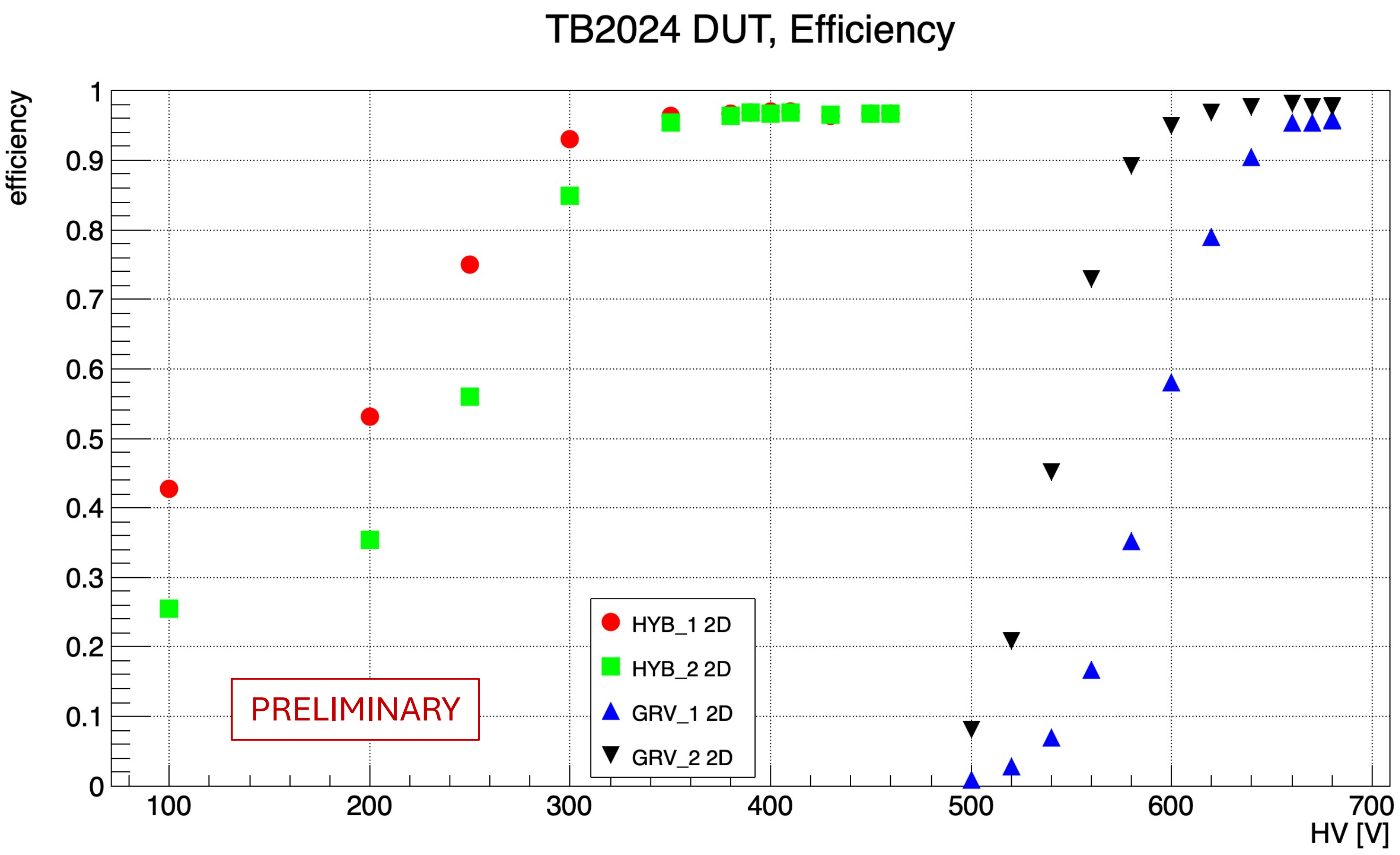
with cluster association performed for a 1 cm x 1 cm window.

GEM-μRWELL

- The hybrids' WELL is set to have gain ~1500 (ΔV_{WELL}= 550 V), high efficiency are reached even for low GEM gain (~3.5), ΔV_{GEM} ~380 V (eff ~97%)

μRGroove (2 groove connected, 400 μm total pitch)

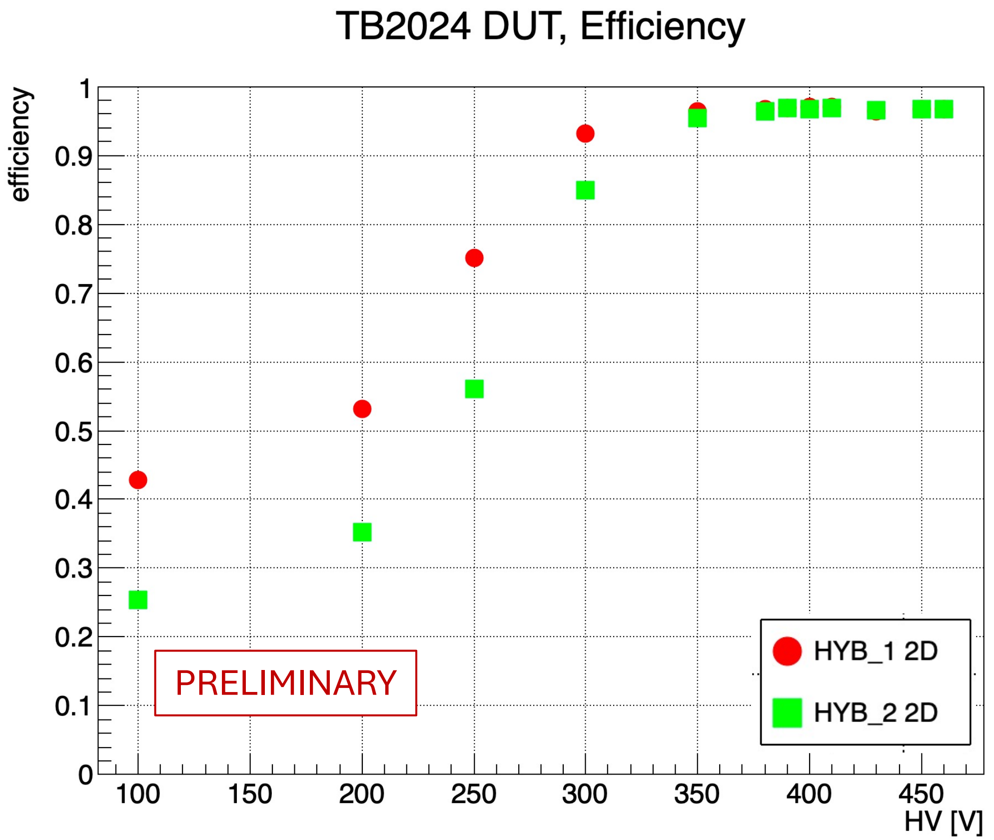
- Efficiency plateau is reached for HV ~ 680 V (eff ~96%)
- The reason of the HV shift between them is under investigation



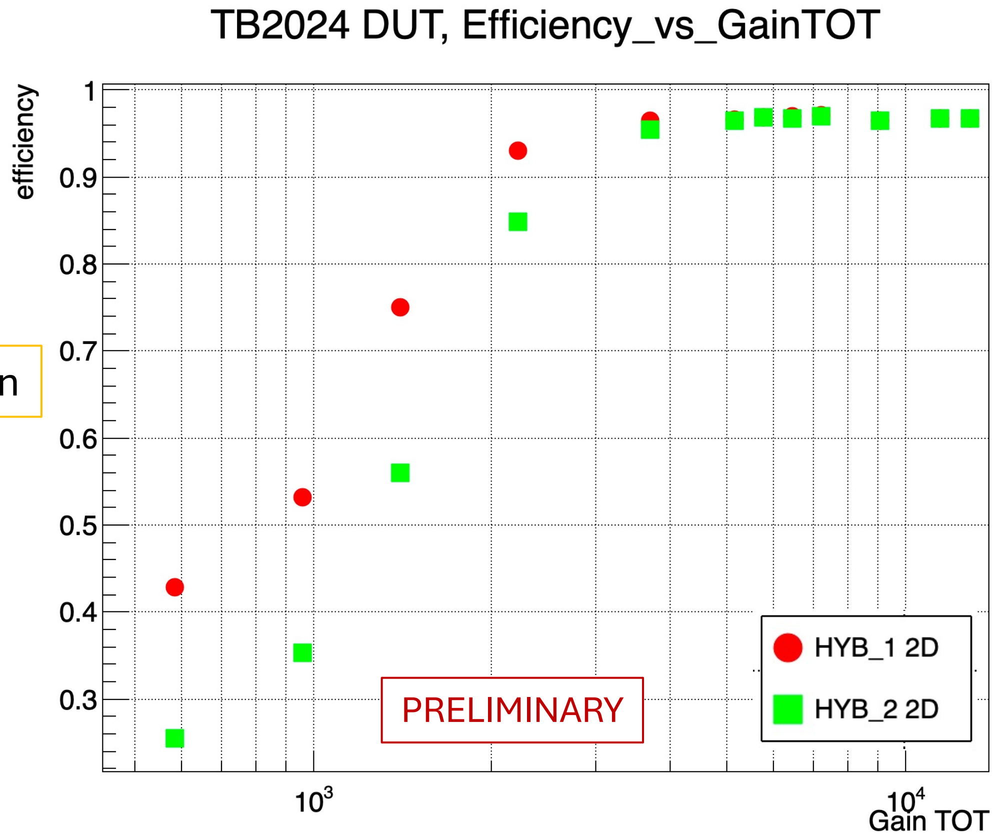
Preliminary results
HV scan at 0°

GEM-μRWELL

- ΔV_{WELL}= 550 V corresponding to ~1500 gas gain in the WELL
- high efficiency are reached for ΔV_{GEM} ~380 V (eff 97%) corresponding to ~5200 gas gain in total



HV → Gain



Preliminary results HV scan at 0°

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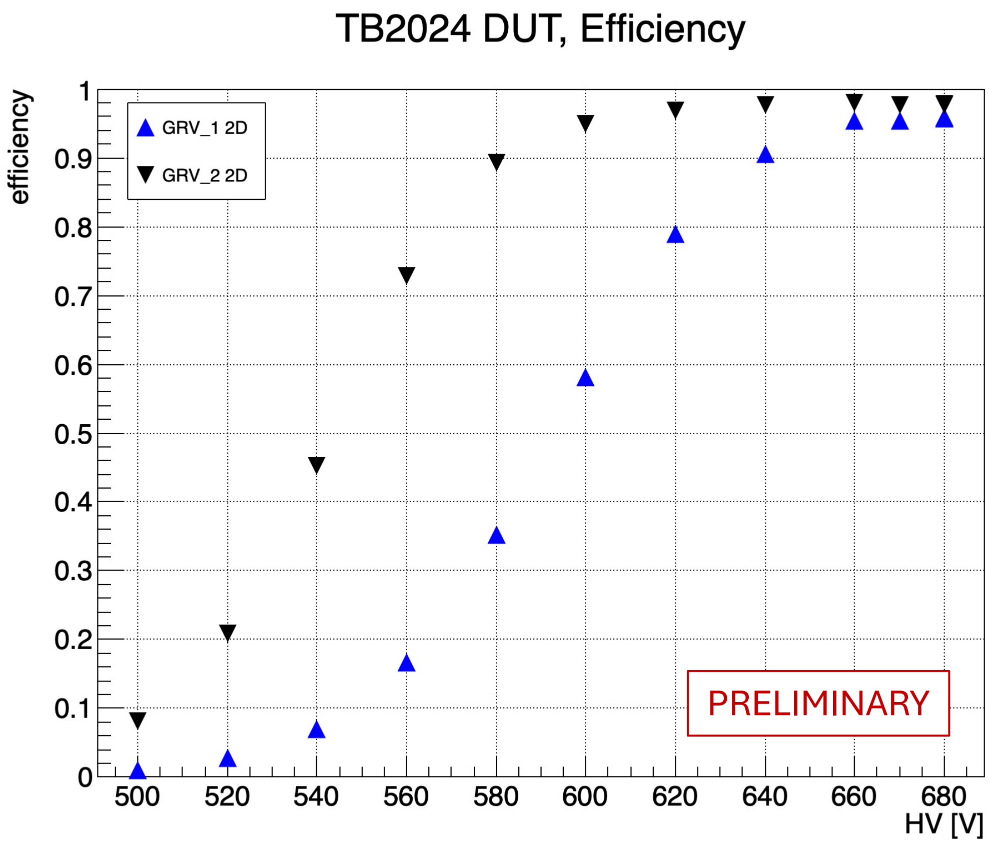
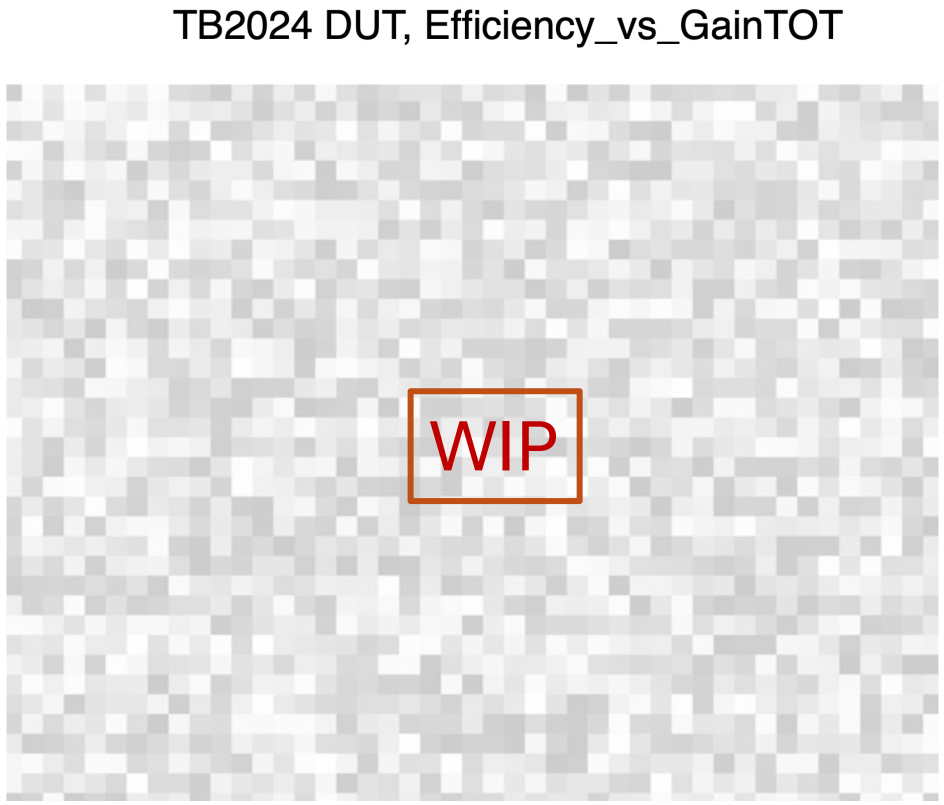
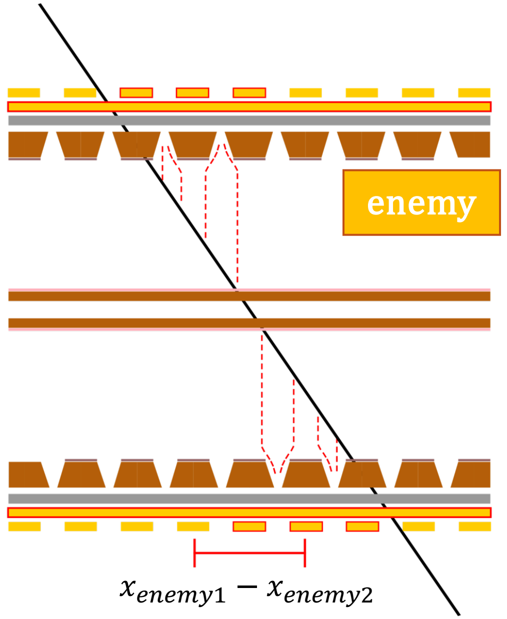


HV → Gain



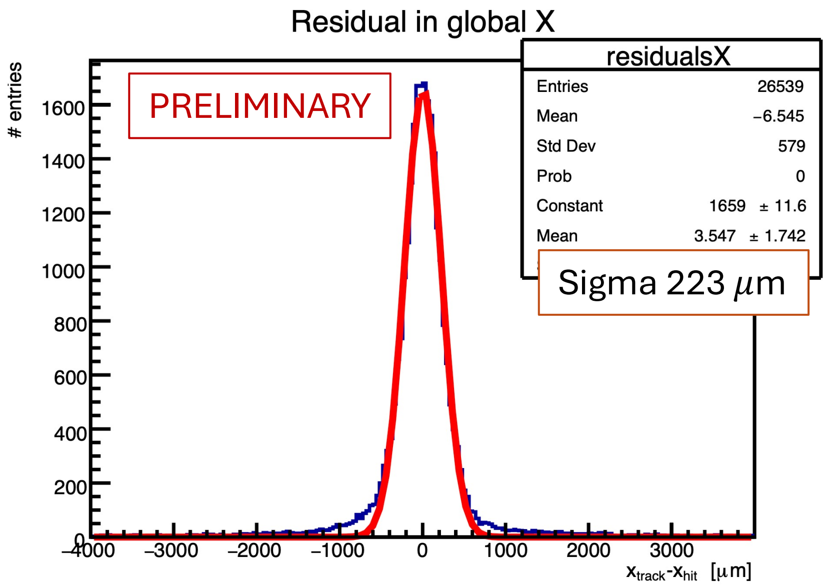
Analysis ongoing

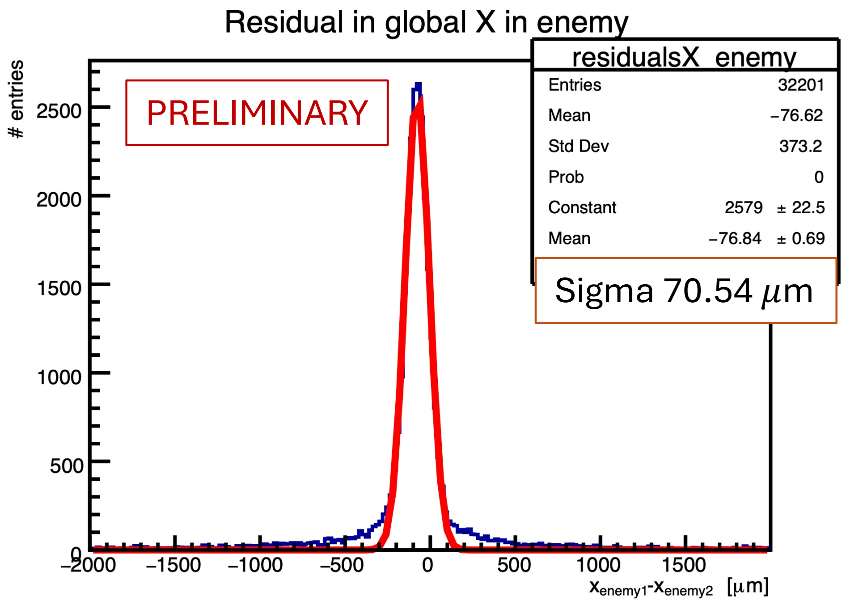


Charge Centroid method is currently used as the first step of spatial resolution study.

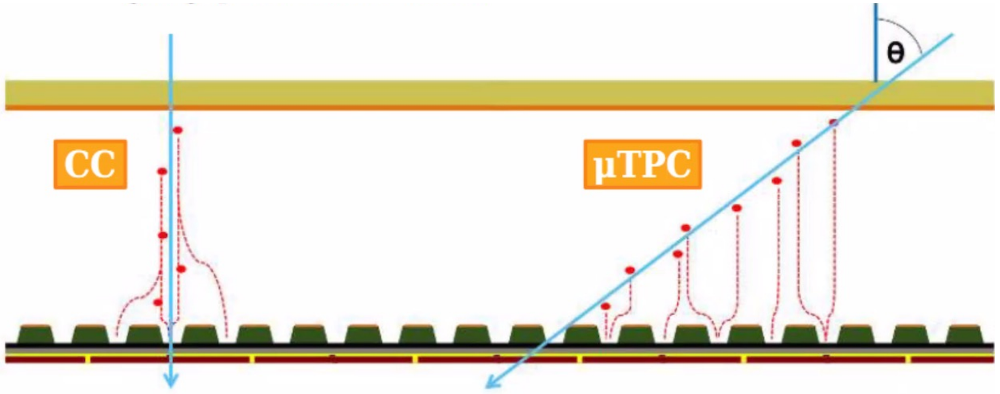
On-going data analysis implementations:

- The "**enemy**" method
  - calculates the distance between the clusters' centre on each readout as residual





Analysis ongoing



Thanks to Riccardo Farinelli (INFN Bologna)

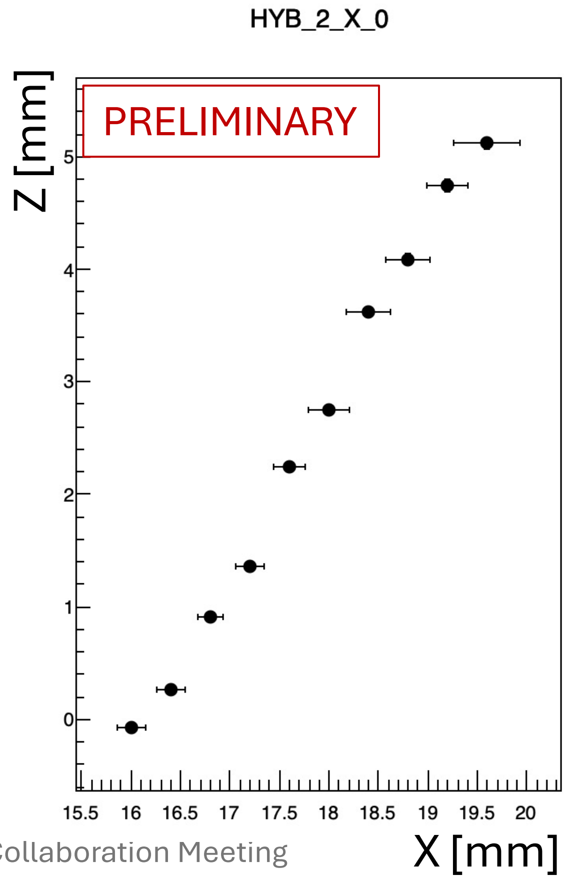
Charge Centroid method is currently used as the first step of spatial resolution study.

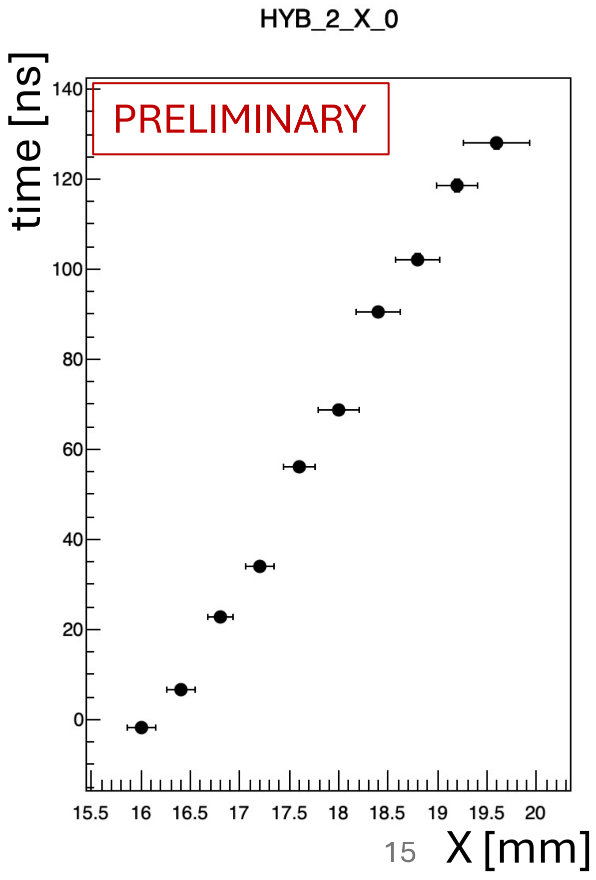
On-going data analysis implementations:

- The "**enemy**" method
  - calculates the distance between the clusters' centre on each readout as residual

Implementation to study **inclined tracks:**

- The "μ**TPC**" method
  - time of the hit on the strip is used with the drift velocity in the gap, to perform μTPC and select the position along z in the gas gap in which the particle passed

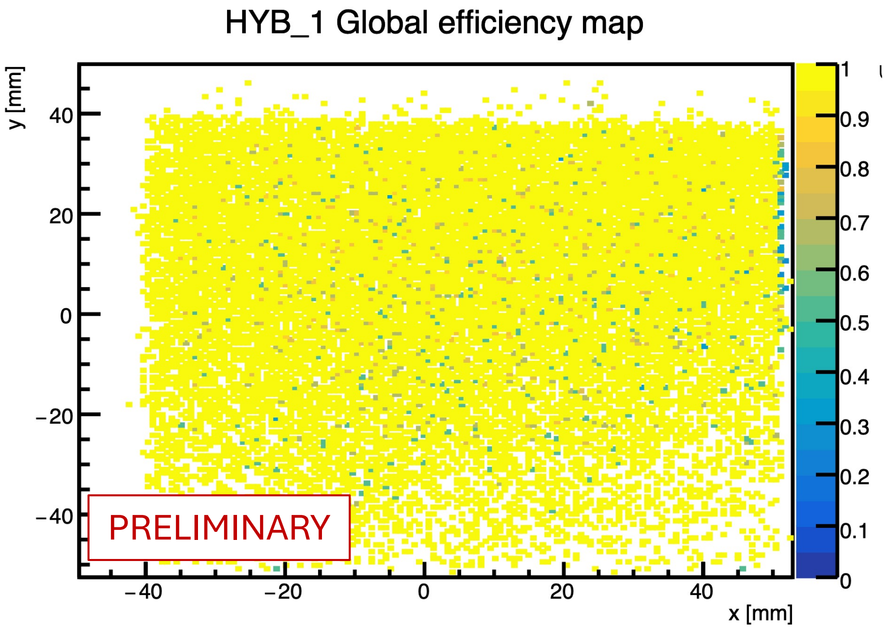




Effects under study

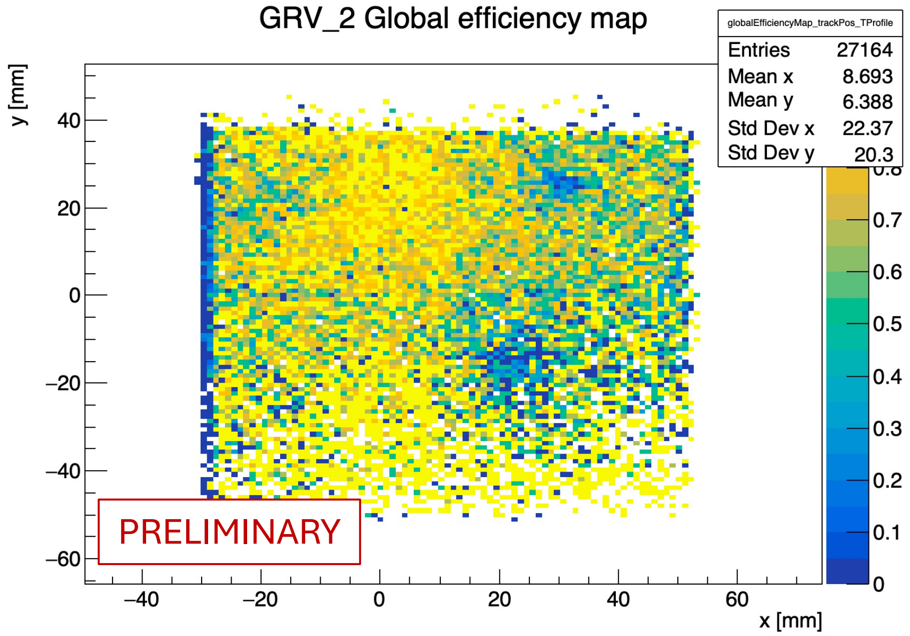
Efficiency 2D map:

GEM-μRWELL in HV plateau (ΔV_{GEM} = 430 V)



Average efficiency ~97%

μRGroove (ΔV_{WELL} = 590 V)

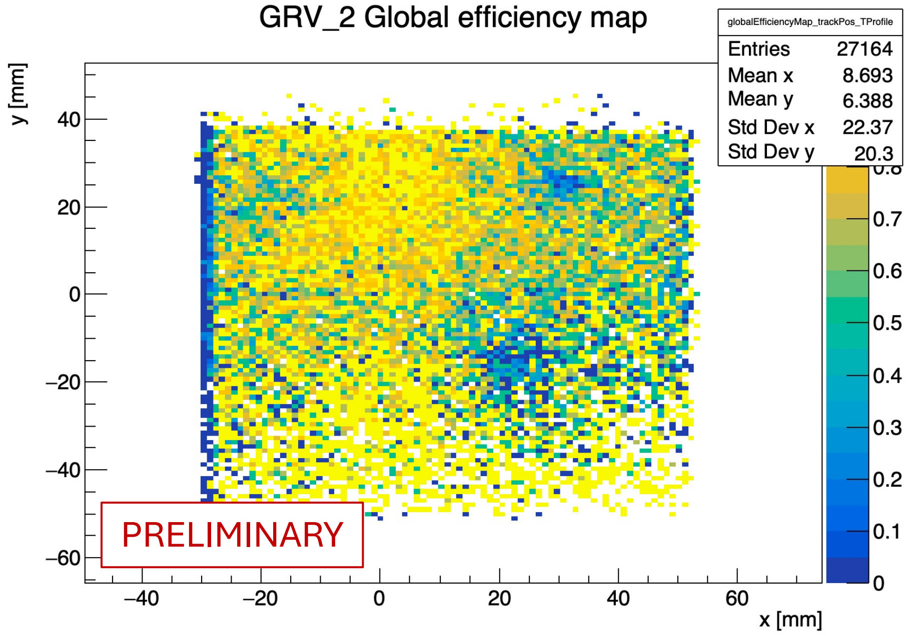


Average efficiency ~71%

Effects under study

- after a few days of data taking, for one of the two μRGroove the current on electrodes reached ~800 nA (HV filter on the TOP with resistivity of 2 MΩ)
- The detector is still operational with only a relatively small inefficient region in the efficiency map (an effect also reported by Kondo Gnanvo with μRWELL)
- Efficiency lowers from ~94 % to ~71 %

μRGroove (ΔV_{WELL} = 590 V)



Average efficiency ~71%

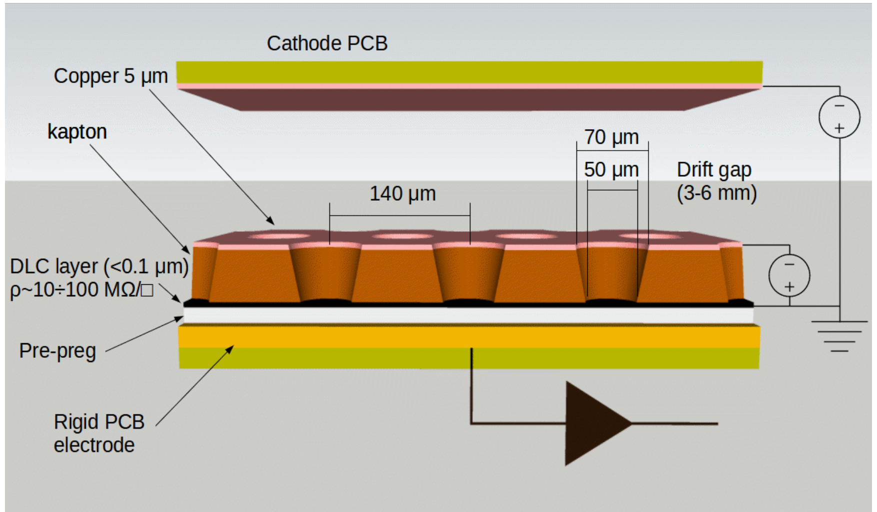
Next steps

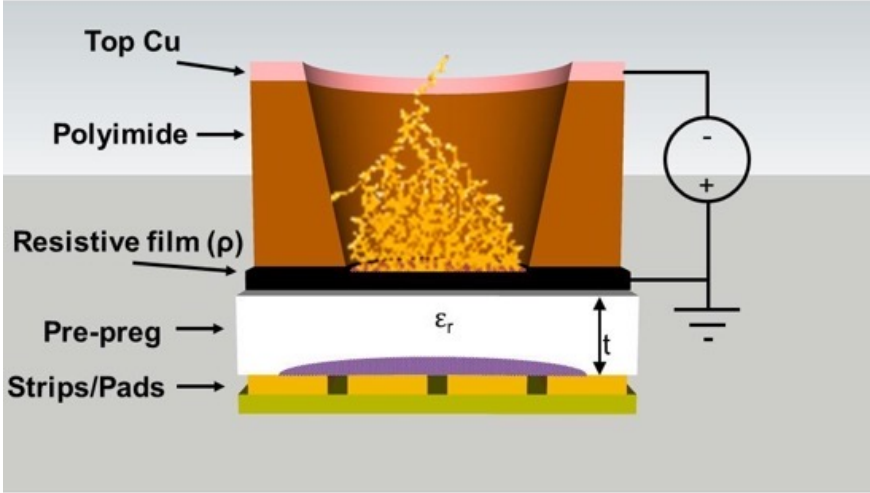
- Implementation and finalization of the spatial resolution analysis for angular tracks
- Stay tuned…

Thank you

Spare

The μ-RWELL



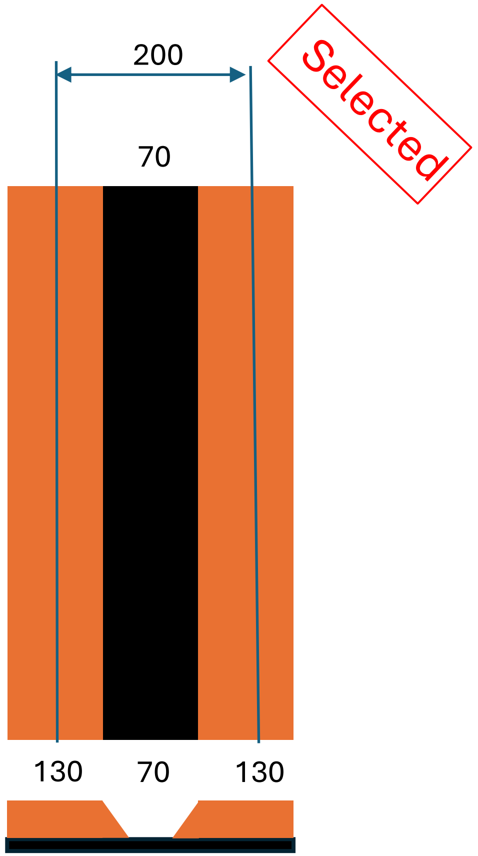


Resistive MPGD composed of:
PCB cathode (gas detector gap)
μ-RWELL_PCB anode (electron amplification + readout stages)

– a WELL patterned kapton foil (w/Cu-layer on top) acting as amplification stage
– a resisitive DLC layer w/ ρ~50÷100 MΩ/□
– a standard readout PCB with pad/strip segmentation

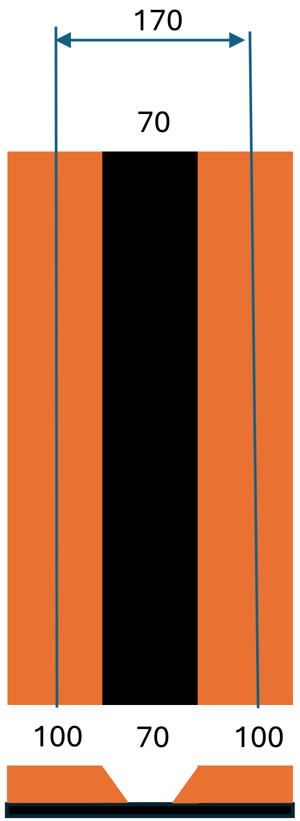
The “WELL” acts as a **multiplication channel** for the ionization produced in the drift gas gap.
The resistive stage ensures the **spark amplitude quenching,** allows to achieve large gains > 10^4.
Drawback: capability to stand high particle fluxes reduced, but largely recovered with appropriate grounding schemes of the resistive layer.

Pitch 200 um
Width 130 um



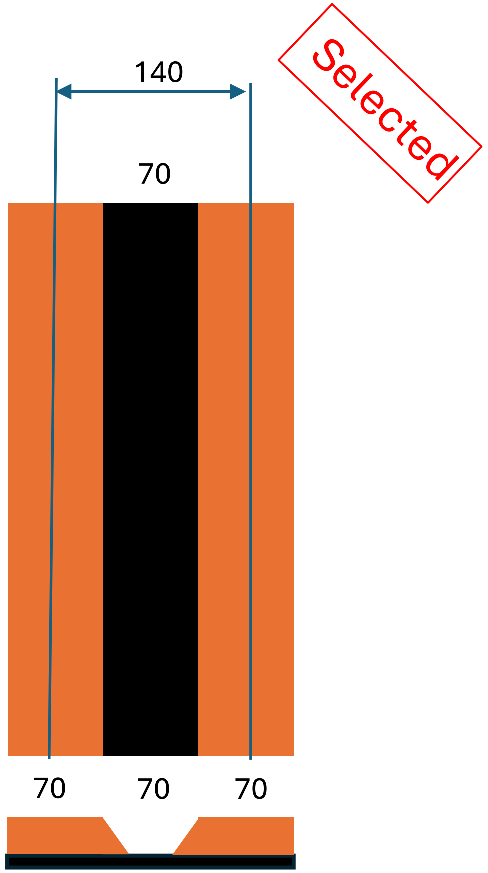
Pitch R/0→
2 strips OR conneted
= 400 um
(0.4*256 ch)= 102.4

Pitch 170 um
Width 70 um



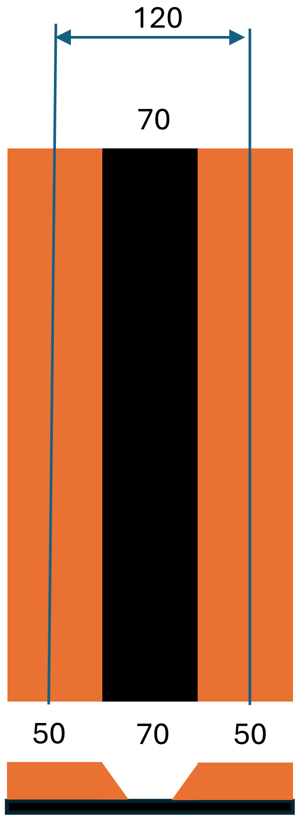
Pitch R/0→
2 strips OR conneted
= 340 um
(0.34*256 ch)= 87.04

Pitch 140 um
Width 70 um



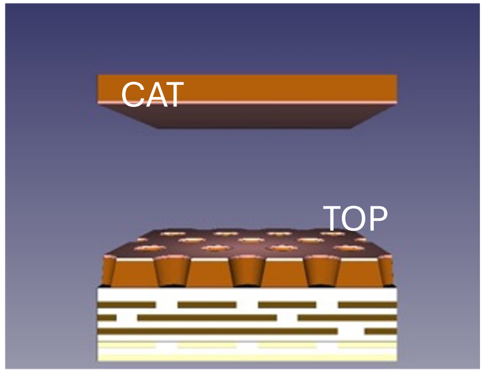
Pitch R/0→
3 strips OR conneted
= 420 um
(0.42*244 ch)= 102.4

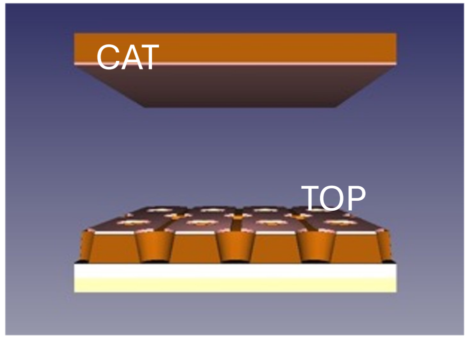
Pitch 120 um
Width 50 um



Pitch R/0→
3 strips OR conneted
= 360 um
(0.36*256 ch)= 92.2

Test Beam 2023 @ CERN



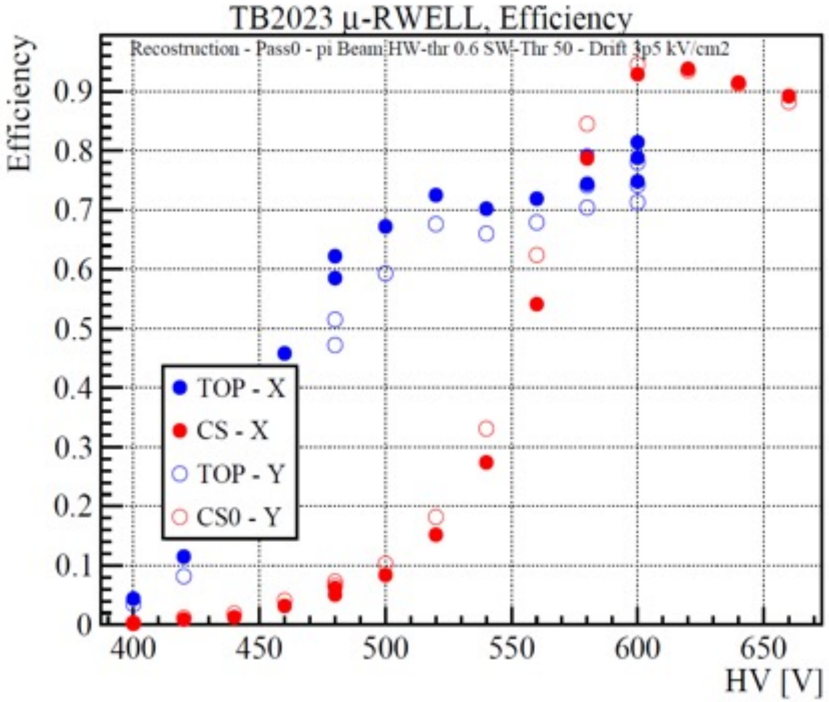


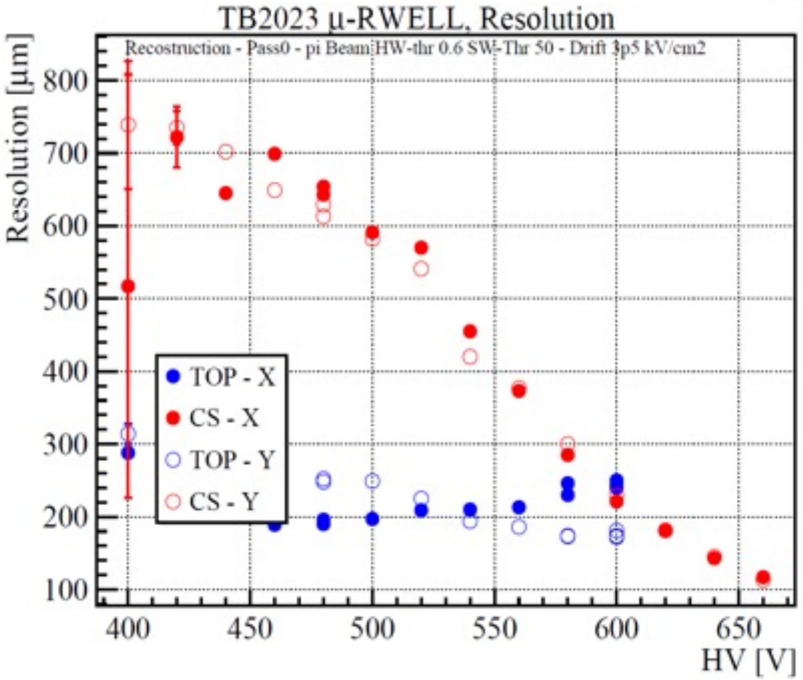
CS pitch 1.2 mm

- The charge is **split** between X and Y → the **working point is shifted** to high voltage/gain
  - Common to every detector with the "COMPASS" readout
- Efficiency knee @ 600 V and plateau ~95%
- Spatial Resolution improves with gain → <150μm

Top R/O pitch 0.8 mm

- The charge is **NOT split** between X and Y → the working point is similar to the 1D μ-RWELL
- **Low efficiency** due to the segmentation of the amplification stage (dead zone between the top strips)
- Efficiency knee @ 500 V and plateau ~70%





The ePIC detector acceptance

ePIC is the first large acceptance detector that will be located at the Interaction Point (IP6).