Test beam analysis results on G-RWELL prototypes

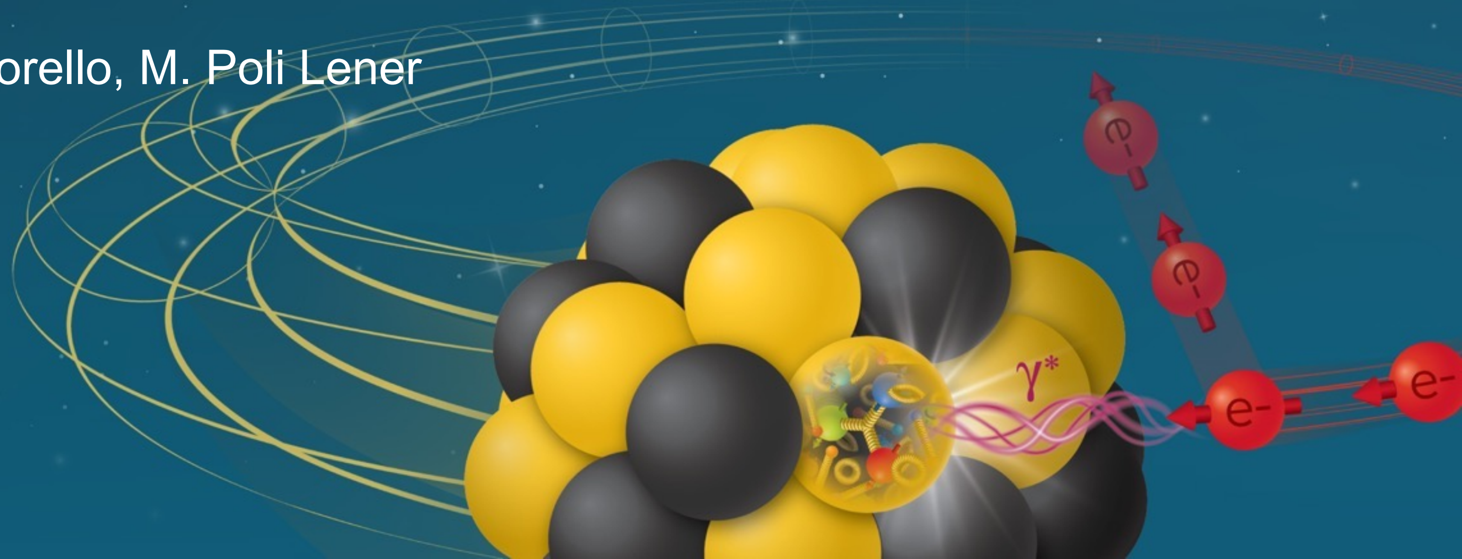
Elena Sidoretti (INFN): elena.sidoretti@roma2.infn.it

On behalf of the ePIC ECT group:
C. Ammendola, R. Ammendola, M. Bondì, A. D’angelo, R. Di Salvo, A. Fantini, S. Gramigna, L. Lanza, G. Nobili, L. Torlai

With the support of INFN LNF DDG:
G. Bencivenni, G. Felici, M. Giovannetti, G. Morello, M. Poli Lener

Giornate Nazionali ePIC Italia
Padova, Italy
Jun 16-18, 2025

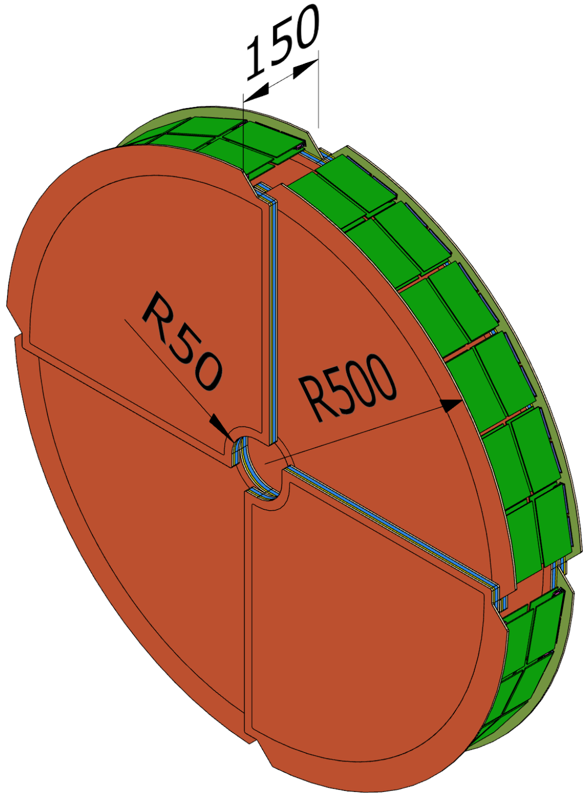
Electron-Ion Collider



ePIC MPGD endcap trackers

Design parameters (using G-RWELLs):

- **2D strip read-out** using a “*COMPASS-like*” scheme
- 600 μm pitch to guarantee a **spatial resolution** ~150 μm
- A drift gap larger than 3 mm allows to perform μ-TPC reconstruction algorithm, keeping high **efficiency**



Performance Requirements	
Time resolution	10 -20 ns
Material budget	$\simeq$ 1 % X_0
Spatial resolution	150 μm
Readout	2D (X-Y)
Single detector efficiency	96 − 97%

Test Beam @PS T10 CERN – November 2024

5 GeV muons beam

Gas mixture:

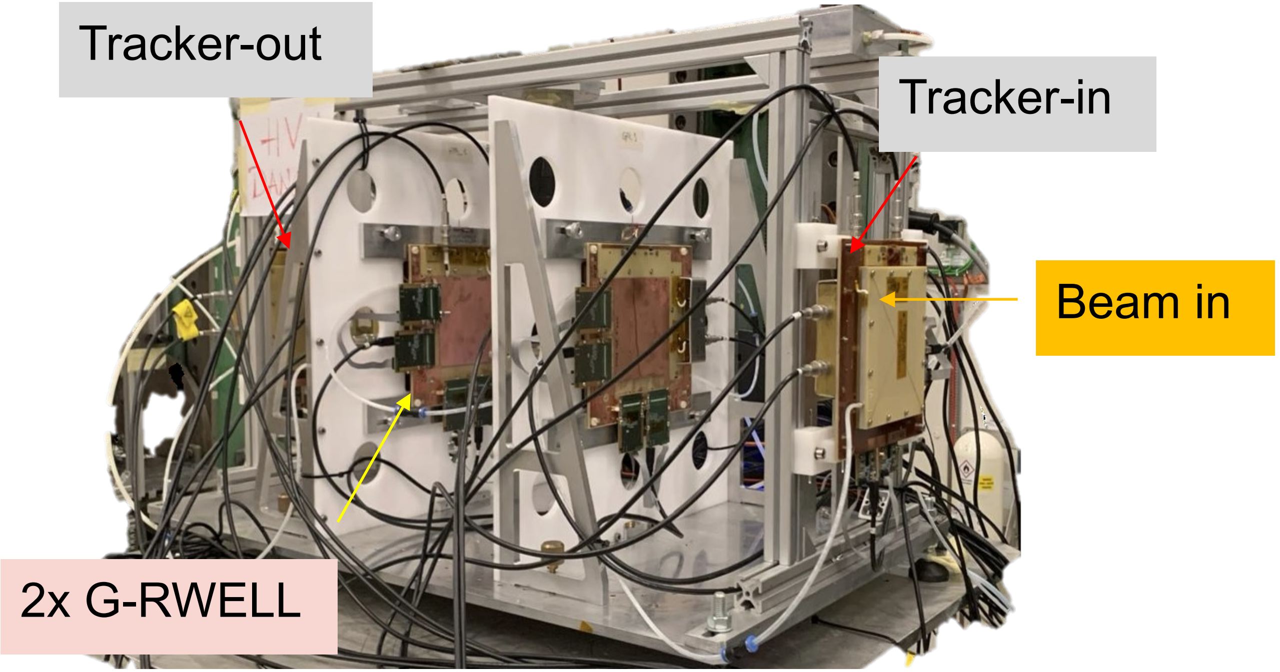
- $Ar:CO_2:CF_4$ 45:15:40

Tracking:

- hybrid G-RWELL with 2D R/O and μ-RWELL with 2D R/O

Detectors Under Test:

- 2 hybrid G-RWELL with 2D R/O



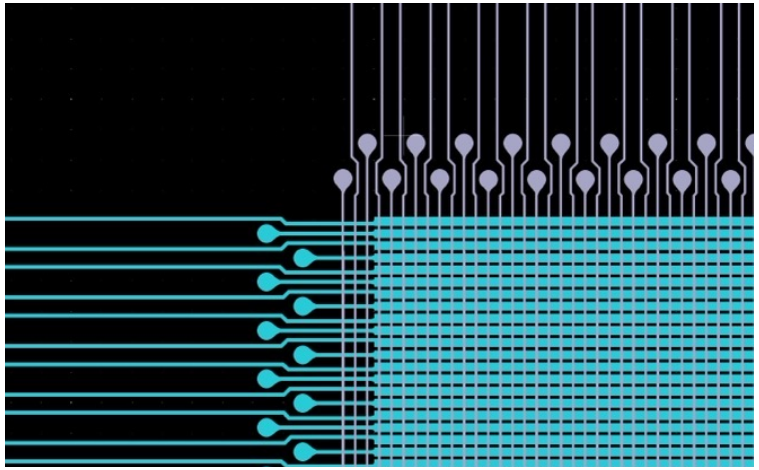
The pair of identical DUT is positioned in a mirror configuration with facing cathodes, allowing to use the “**enemy**" mode for spatial resolution analysis, comparing the relative measured hit position with minimum systematic uncertainties

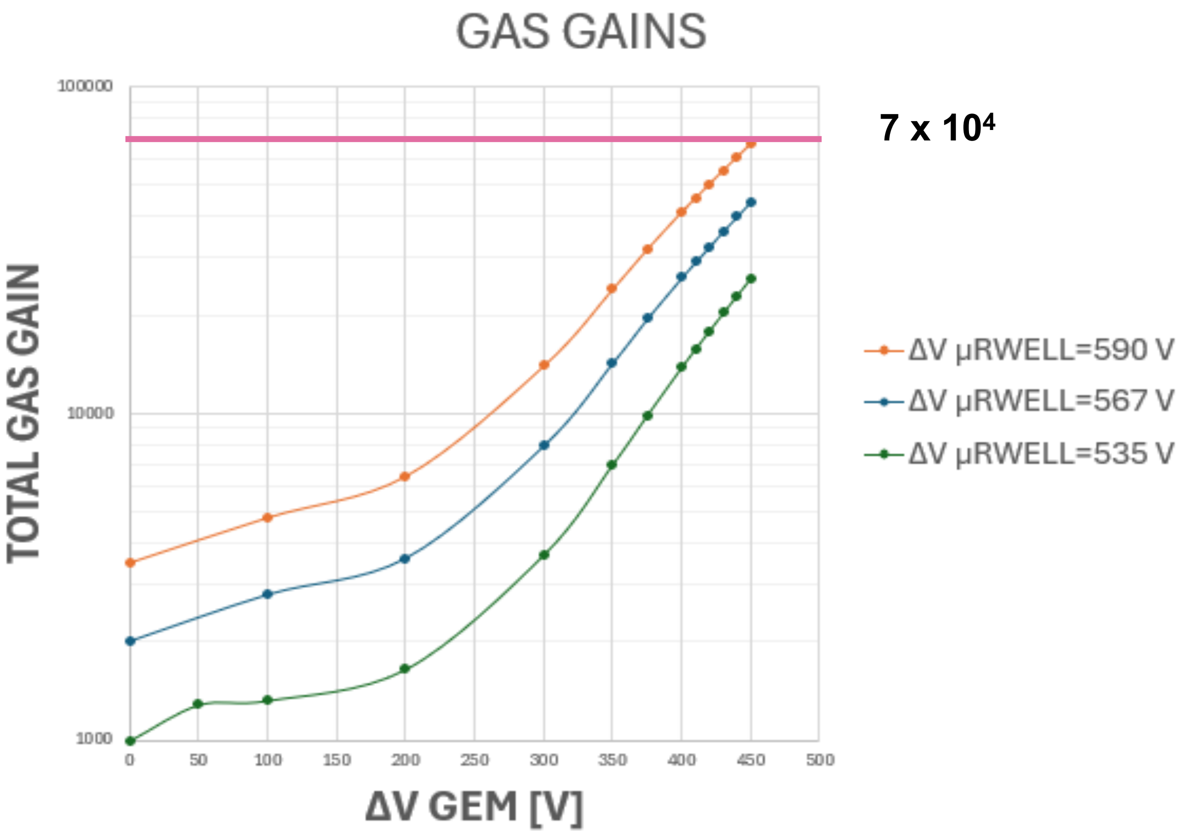
DUT may be rotated to study their performance with for inclined tracks

- θ= 0°, 7.5°, 15°, 30°, 45°

G-RWELL prototypes

Detectors Under Test:
- 2 hybrid G-RWELL
  - Active area 10x10 cm^2
  - Read-out 2D "*COMPASS-like*"
    - Bottom strip pitch 400 μm, width 300 μm
    - Top strip pitch 400 μm, width 60 μm
  - 6 mm drift gap
  - 3 mm transfer gap





Gas Gain – X Ray gun study
($Ar:CO_2:CF_4$ 45:15:40)
Gas Gain plot for G-RWELL
- high gain is reached even for low WELL HV

$$G_{\text{G-RWELL}} = G_{\text{GEM}} \otimes G_{\mu\text{-RWELL}}$$

Trackers set-up & backup solutions

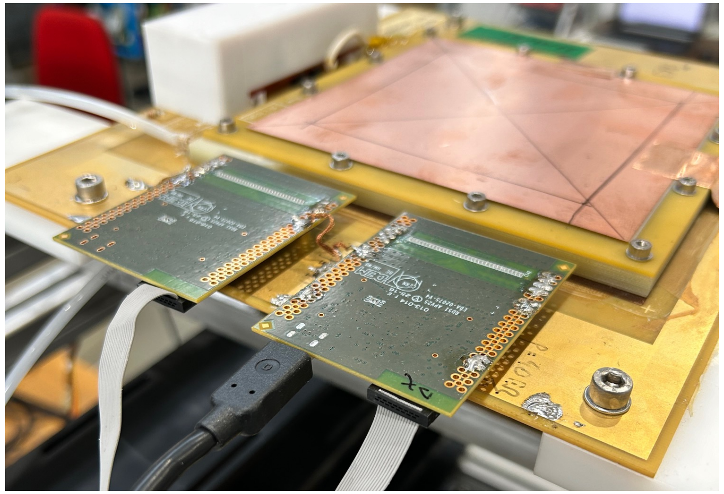
The goal was to use two hybrid G-RWELL as trackers. Since one of the GEM broke during the test beam, one of the trackers was used as a standard μRWELL with 3 mm gas gap

	G-RWELL 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

The G-RWELL may still be used as a standard μRWELL, with efficiency higher than 90%, should the GEM stage show problems and must be disconnected.

Data acquisition

Test Beam Goal
Evaluation of the tracking performance for various:
- angles of incidence
- ΔV applied
- drift/transfer field values



Data acquisition System
- The used data acquisition system is the **Scalable Readout System** (SRS)+**APV25**
  - 2 FECs + 2 ADCs are used with 1 CTGF module
  - 24 hybrid APV25 in total
- Data acquisition was handled by the **mmDAQ3** software
  - 24 bins x 25 ns time window

Data analysis

Data analysis performed using the Corryvreckan framework.

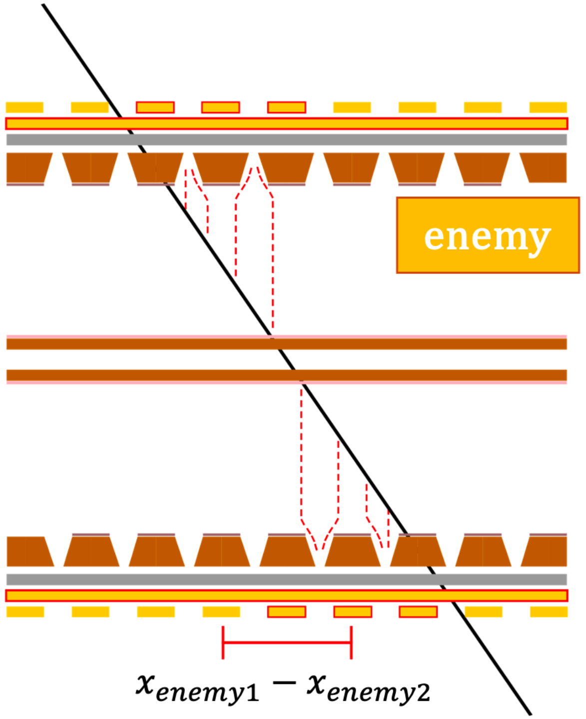
SCAN HV 0° and 30° incidence:

- ΔV_{GEM} variable
- ΔV_{WELL}= 550 V (~1500 gas gain)
- 35k events per run

Spatial resolution study

"Enemy mode": evaluates the residual as the distance between the position of the cluster detected by the two adjacent DUTs minimizing the systematic contribution of the tracking devices

$$\sigma = \frac{\sigma_{res}}{\sqrt{2}}$$



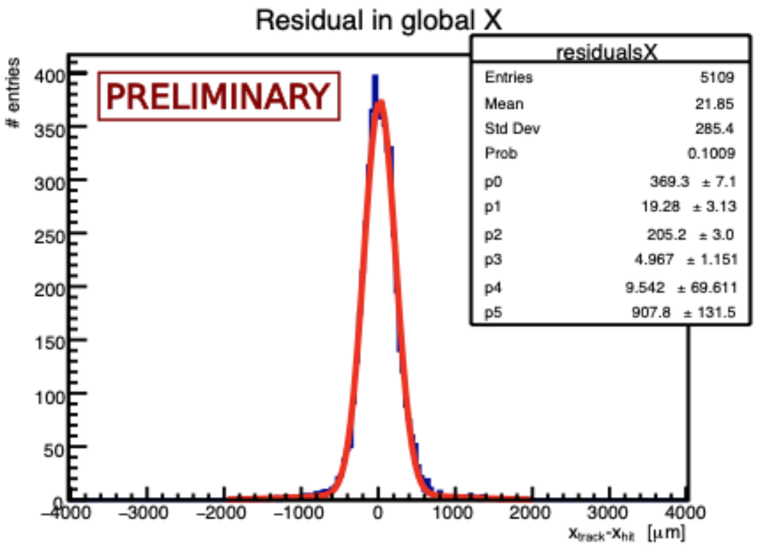
Data analysis

Spatial resolution study at 0°

- **Charge Centroid:** calculates the position of ionization clusters based on mean position weighted on measured charge

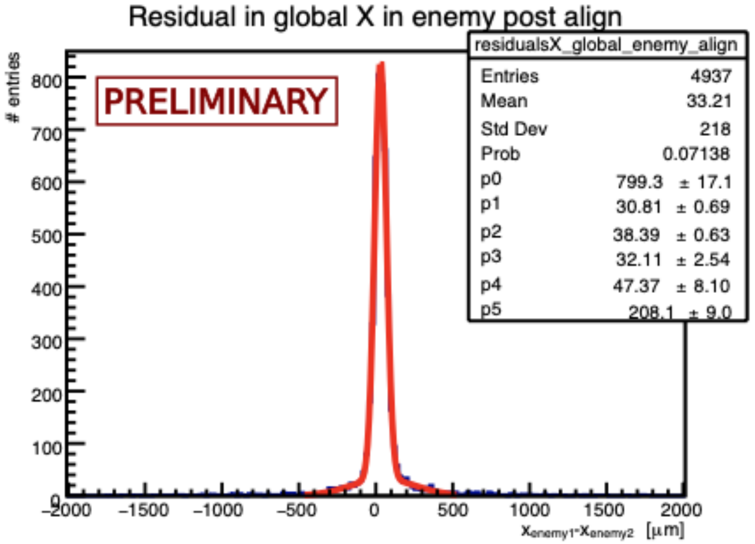
$$x_{cc} = \frac{\sum x_k q_k}{\sum q_k}$$

CC - Tracking system dependent

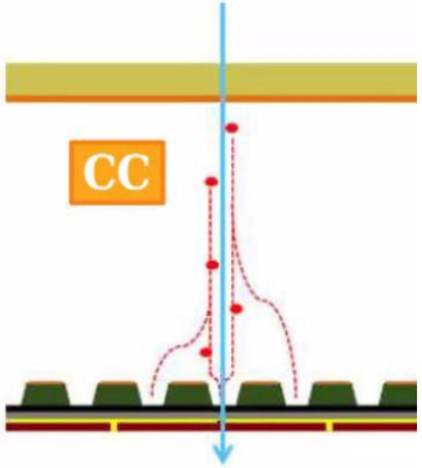


$\sigma_{res\_x} = 293 \pm 24\ \mu m$

CC-Enemy mode



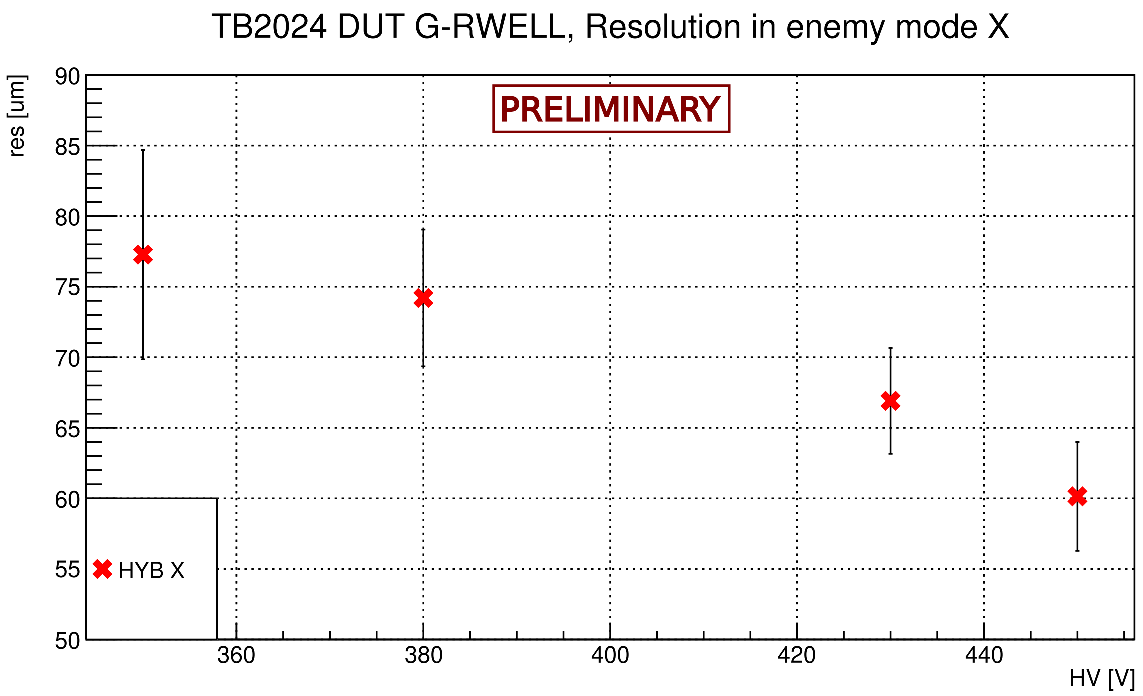
$\sigma_{res\_x} = 94.6 \pm 3.7\ \mu m$



ΔV_{GEM} = 430 V
$\Delta V_{\mu RWELL}$ = 550 V

Data analysis

Spatial resolution study at 0°



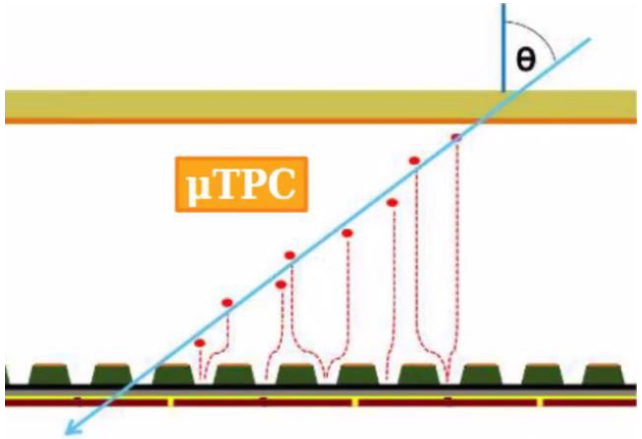
Resolutions for the ΔV_{GEM} scan at 0°
X coordinate evaluated with the CC method in enemy mode

Spatial resolution
down to ~ 60 μm

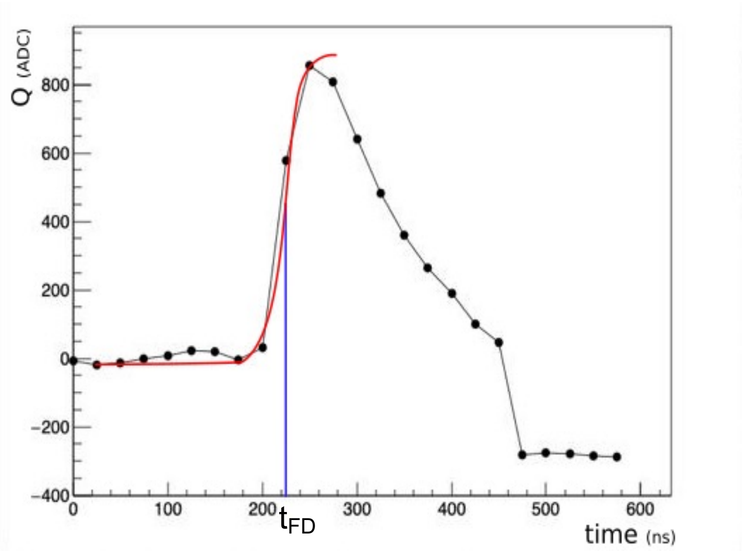
Data analysis

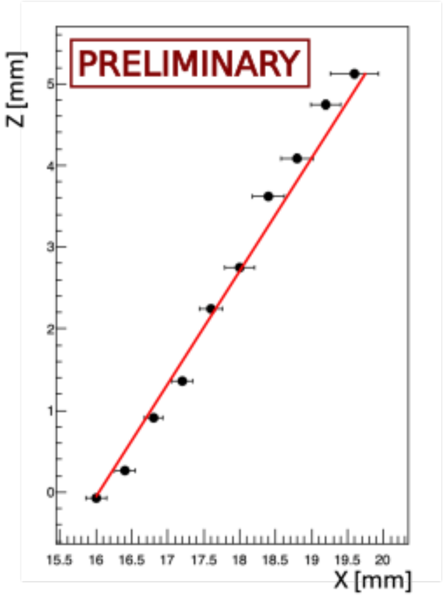
Spatial resolution study at 30°

- **µTPC:** tracks are reconstructed with the time of arrival of hits and the drift velocity, the cluster's position is the intercept with a plane parallel to the readout
- Time of hit is defined as the inflection point of the Fermi-Dirac function fitting the rising edge of the signal of each strip



Signal sampling for each APV25 channel





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

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

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

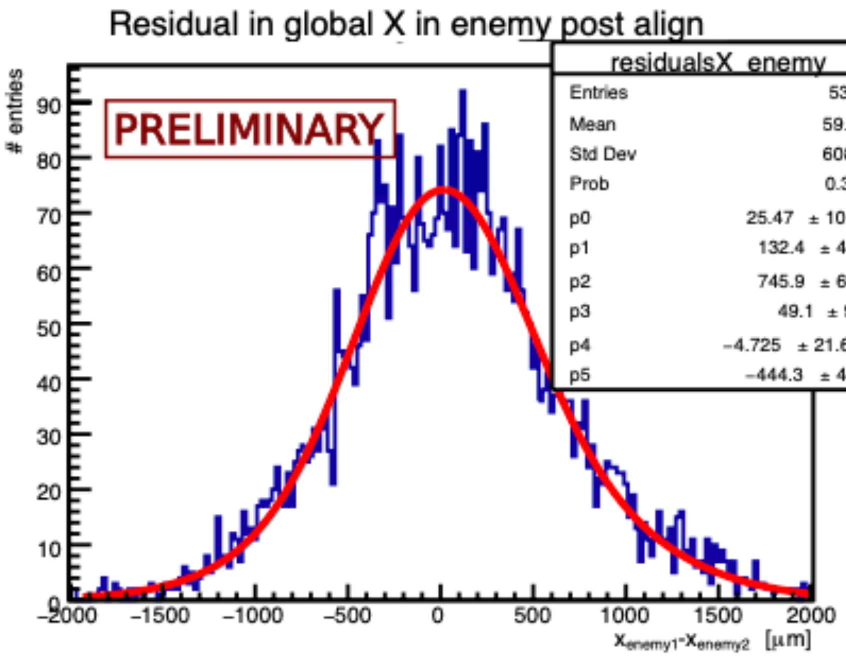
Custom made card to provide the time t_0 of the event

Data analysis

Spatial resolution study at 30°

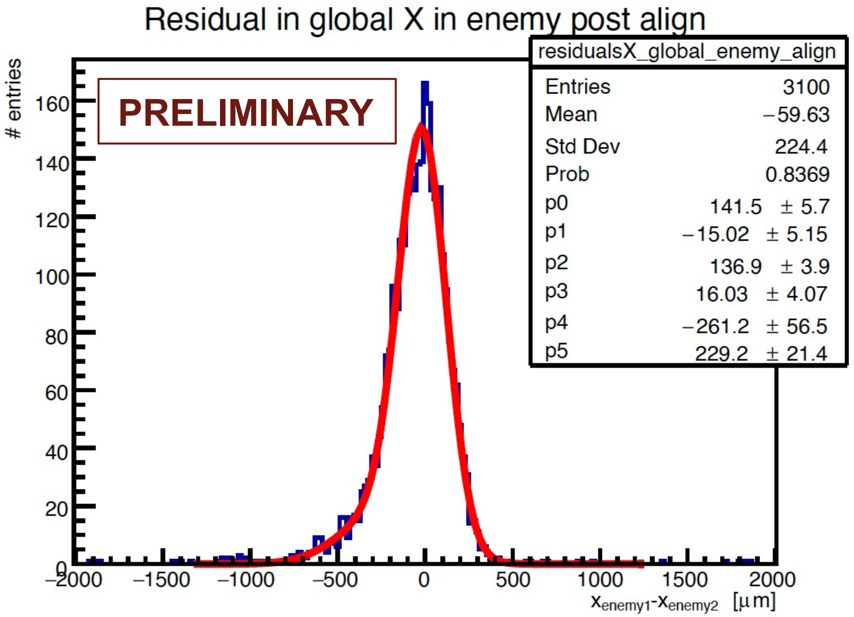
ΔV_{GEM} = 450 V
$\Delta V_{\mu RWELL}$ = 550 V

CC - Enemy mode



$\sigma_{res\_x} = 571 \pm 8\ \mu m$

μTPC - Enemy mode

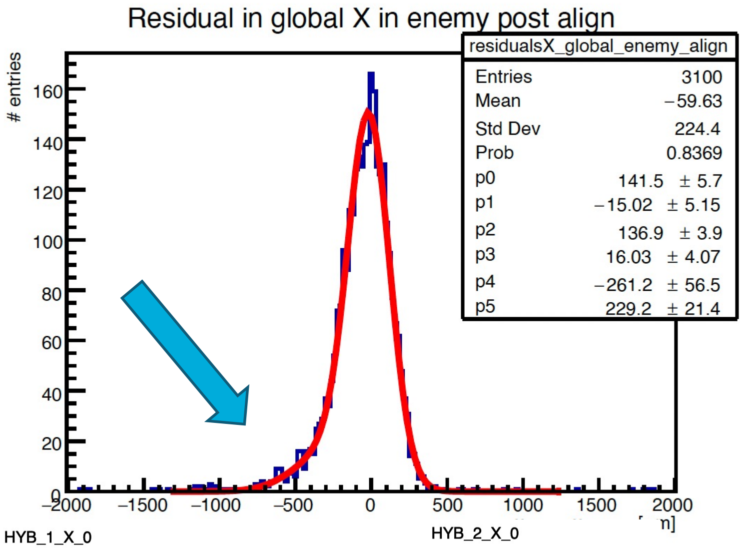


$\sigma_{res\_x} = 155.32 \pm 7.91\ \mu m$

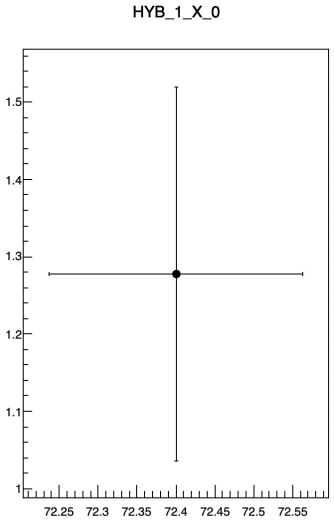
Data analysis

Spatial resolution study at 30°

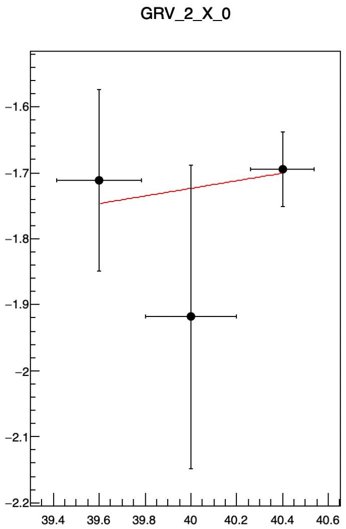
- μTPC fails when not performing the linear fit in the gas gap:
  - Angular coefficient == 0
  - Cluster size < 4
  - $\chi^2/_{Ndof}$ > 4



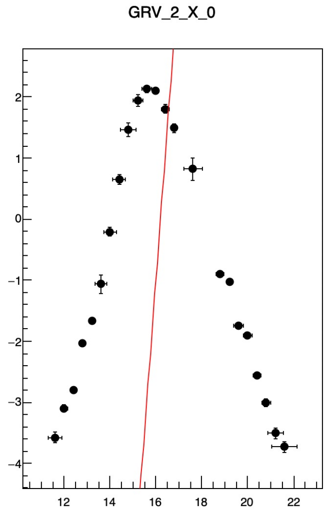
b == 0



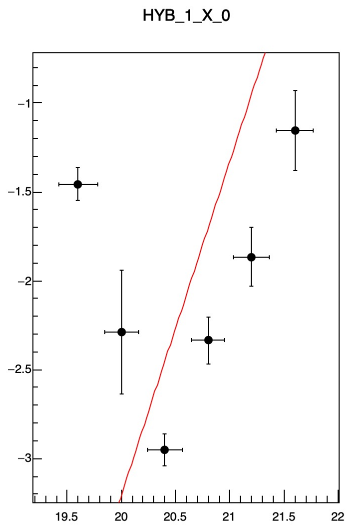
Size < 4



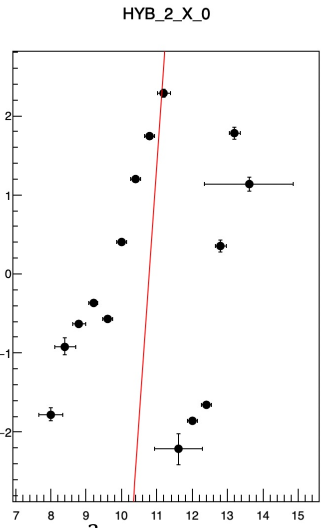
$\chi^2/_{Ndof}$ > 4



$\chi^2/_{Ndof}$ ~ 306



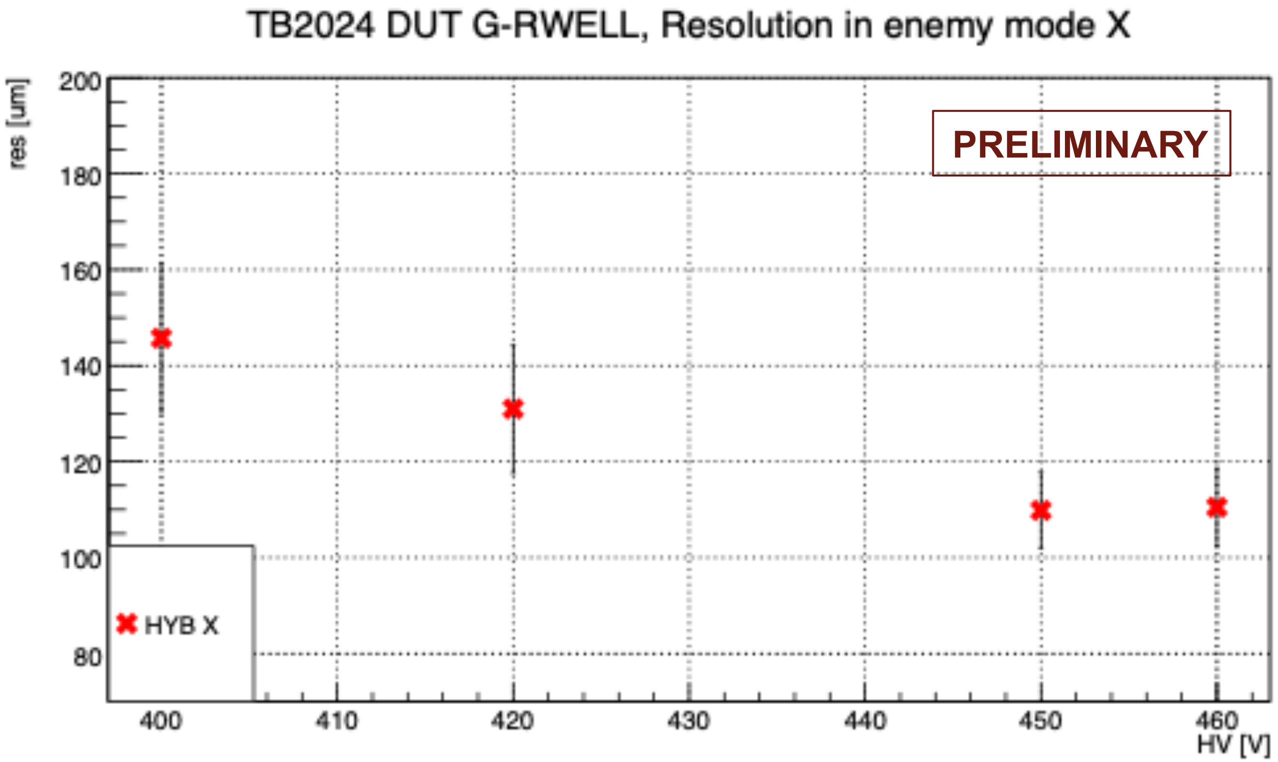
$\chi^2/_{Ndof}$ ~ 18,8



$\chi^2/_{Ndof}$ ~ 83

Data analysis

Spatial resolution study at 30°



Resolutions for the ΔV_{GEM} scan at 30°

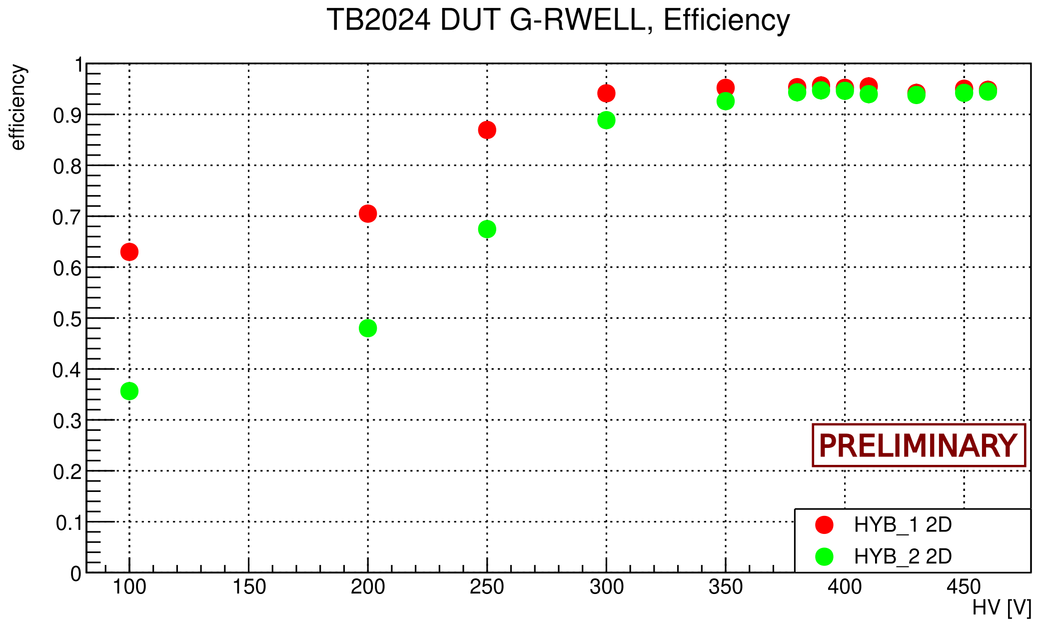
X coordinate evaluated with the

µTPC method in enemy mode

Spatial resolution
down to ~ 110 μm

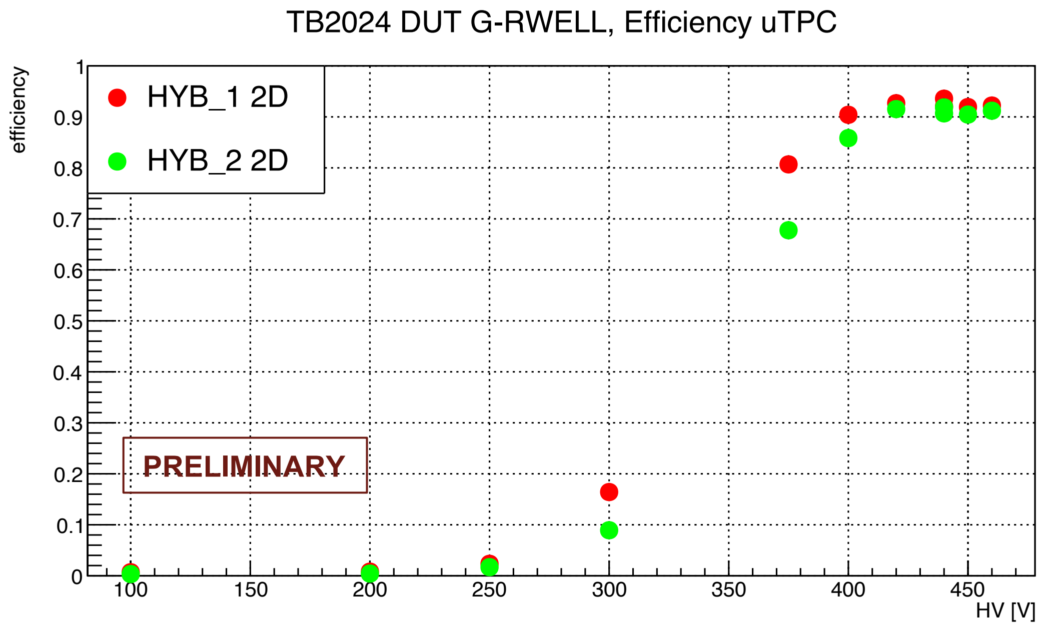
Data analysis

Efficiency as a function of different ΔV_{GEM} for the two G-RWELL under test at 0°



Efficiency at 10σ ~ 96%

Efficiency as a function of different ΔV_{GEM} for the two G-RWELL under test at 30°



Efficiency at 10σ ~ 92%

Lower efficiency due to reconstruction algorithm failures

Summary and outlook

The **G-RWELL** is a hybrid detector based on the μ-RWELL, with a GEM preamplification:

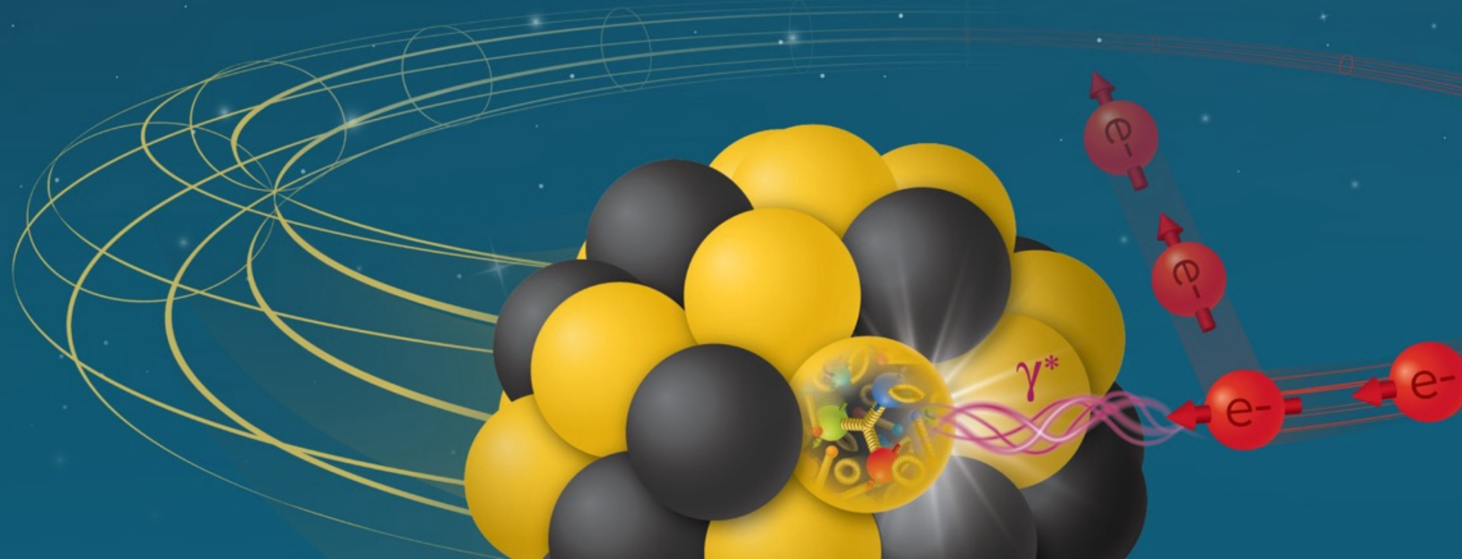
- Max gas gain ≈ 10^5
- **Fine 2D tracking** for non-orthogonal tracks, (INFN Roma2).
  - **Spatial resolution < 100 μm** for perpendicular tracks
  - **Spatial resolution < 150 μm** for inclined tracks
  - Single-layer **efficiency ~96 %**

The requirements for the ECT were satisfied at 400 μm strip pitch

The next steps foresee the construction and test of large area G-RWELL prototypes: a quadrant with 50 cm radius (600 μm strip pitch)

Gas mixture optimization, μTPC reconstruction in a magnetic field and integration with SALSA will represent the major effort in the upcoming years

Backup slides

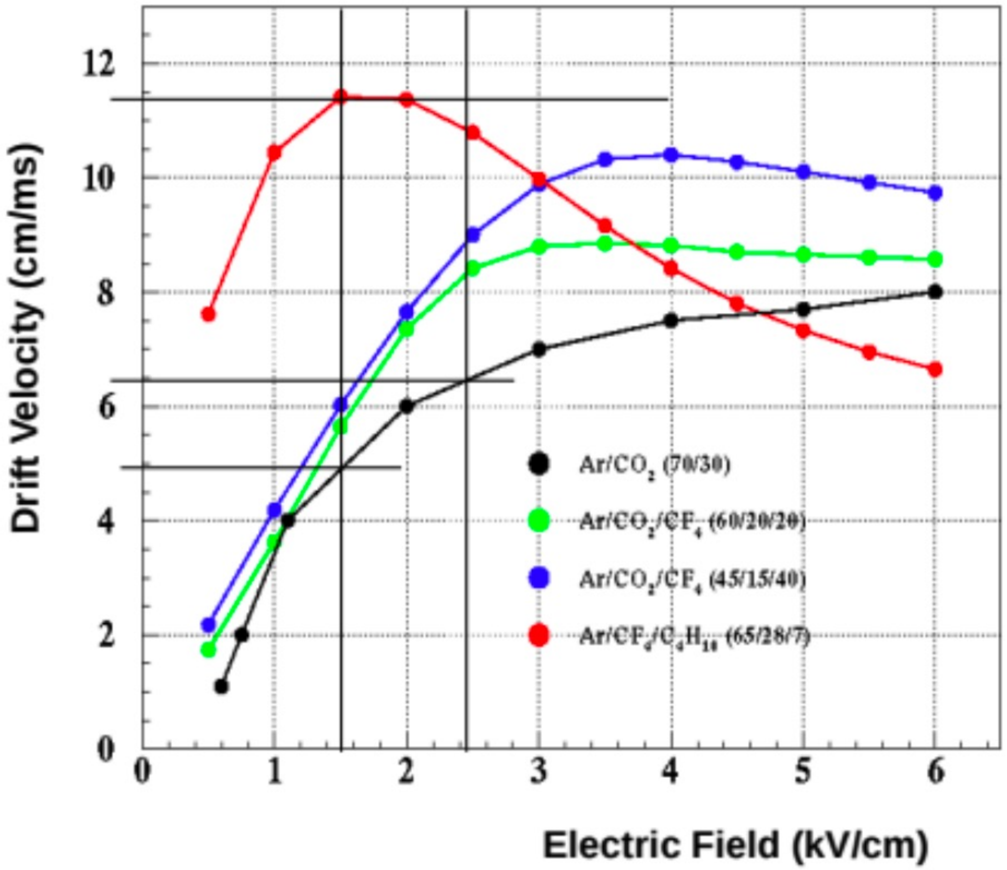


Electron-Ion Collider

Drift velocity

Calculated using Garfield++ simulations

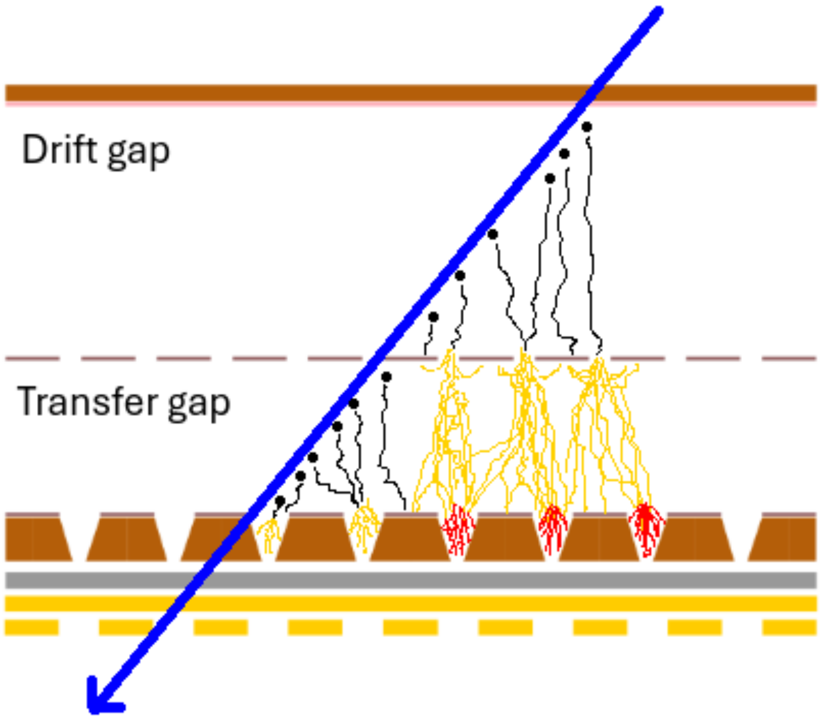
- Ar:CO_2:CF4 (45:15:40) v_{drift} = 4 cm/ms ($E_d = 1$ KV/cm)



Bi-WELL effect

Ionization produced in the drift gap: double amplification
Ionization produced in the transfer gap: single amplification

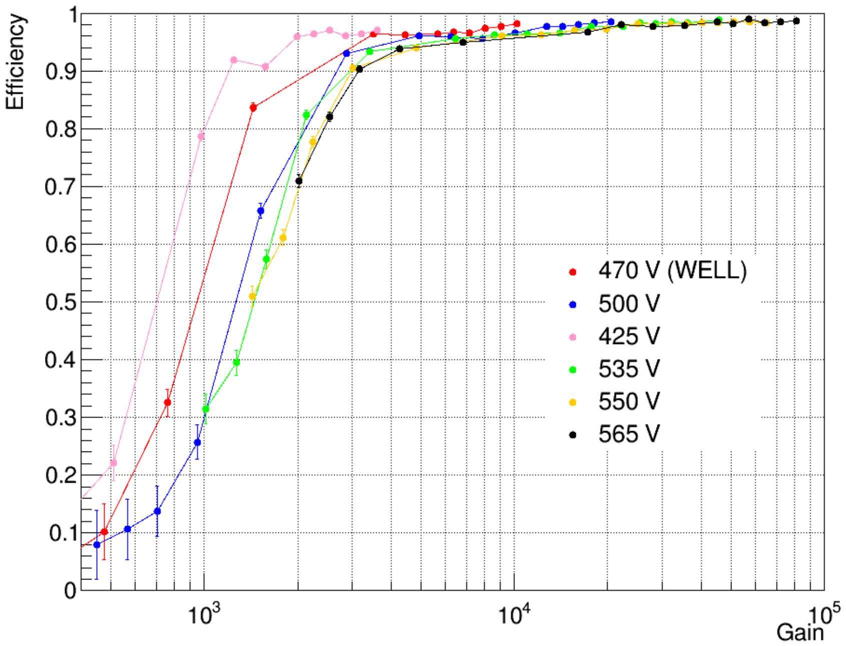
If the μ-RWELL amplification is set too high, due to amplification fluctuations in the gas (which can reach up to 100%), the signal generated by the transfer ionization may exceed the electronic threshold and arrive approximately 30 ns earlier than the main signal (a timing consistent with the gas mixture used).
The distribution of the time resolution is negatively affected, resulting in a deterioration of the detector's time resolution.



To be minimized:

- minimizing the transfer gap without compromising the stability of the detector
- keeping the μ-RWELL amplification as low as possible, without having to excessively increase the GEM gain

Timing Performances



Efficiency plateau >98% at gas gain above 6000

Work from the **DDG INFN-LNF** group

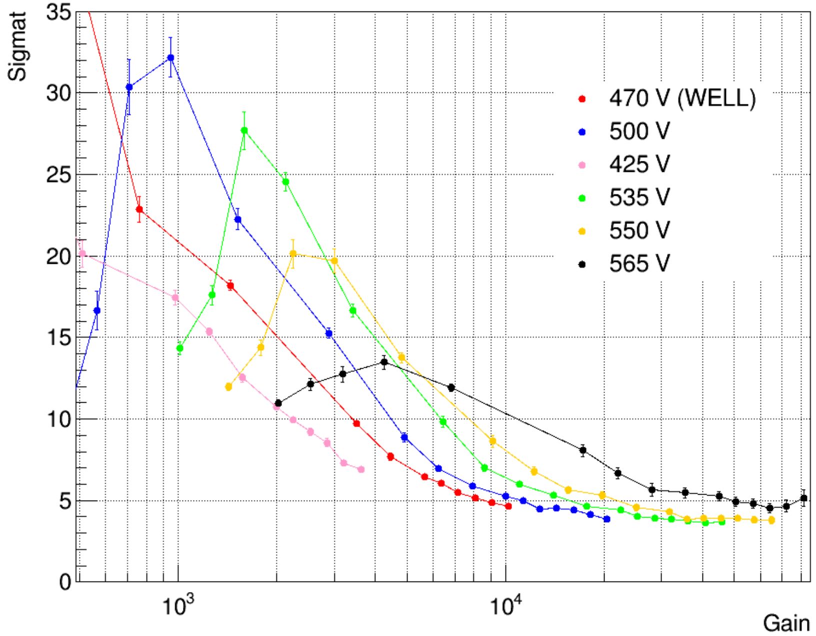
Test beam @PS T10 November 2024

- muon beam 5GeV/c

Gas mixture	$Ar:CO_2:CF_4$ 45:15:40
FEE	FATIC3 ASIC chip (**INFN Bari**)
THR	6 fC for efficiency, 5fC for timing

2 G-RWELL prototypes	
Active area	10 x 10 cm^2
Pad Readout	9×9 mm^2
Drift gap	6 mm
Transfer gap	3 mm

Multiple time resolution curves corresponding to different settings of μ-RWELL amplification stage



time resolution 3.8 ns
G_{TOT} ~3 − 4 x 10^4
$G_{\mu\text{-RWELL}}$ ~1.5 x 10^3
G_{GEM} ~20–25

Differences between different HV_WELL values can be attributed to a well-known effect typical of multi-step amplification stage layouts, commonly referred to as the “bi-WELL effect”