Updates on Corryvreckan integration modules for MPGDs

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6th DRD1Collaboration Meeting – October 2025

Part I – code updates
Part II – uTPC implementation

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Overview

Corryvreckan's **modular approach** simplifies the process of adapting it to various types of detectors and enhances the efficiency of data analysis by providing a streamlined, **user-friendly** interface.

- Built to reconstruct and analyse **pixel R/O**
- Modular structure
- Highly flexible and configurable

… now also **strips**, combining X and Y

Goal:
adapt Corryvreckan to MPGDs
(including strip readouts, 1D→2D)

Corryvreckan

The Maelstrom for Your Test Beam Data

Recap from last DRD1 collaboration meeting

Data sources (SRS + APV25/mmDAQ3):
- event IDs, SRS time stamp, FEC/Chip/Channel, **raw_q** (25 ns waveform)

Geometry (key fields):
- Size, position, pitch, number of pixels, type, APV chip number
- **new flags**: *FEC number*, *2D readout type* (Compass, Top, PAD), *gas gap*, *enemy role*

Workflow:

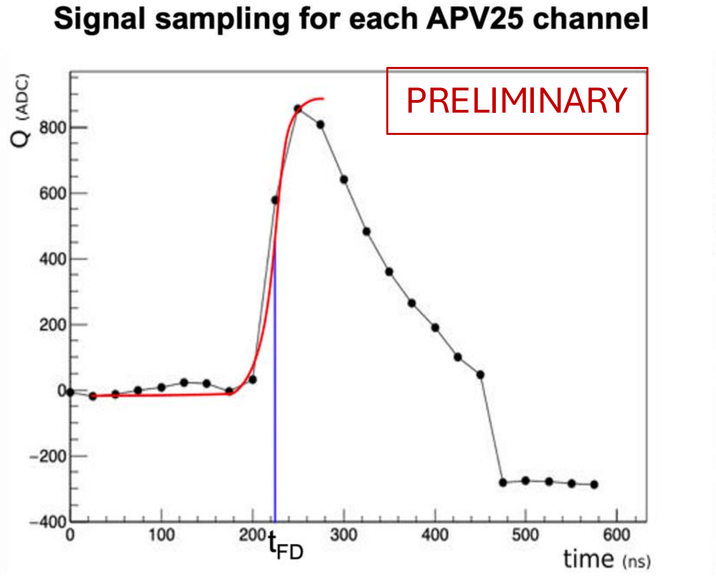
Event Loader → Clustering → Tracking → DUT Association → DUT Analysis

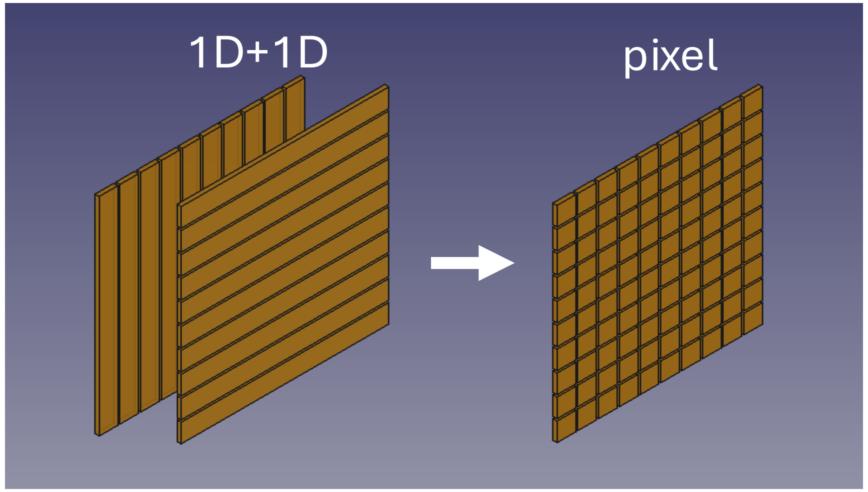
Recap from last DRD1 collaboration meeting

EventLoader:

- Pixel charge when **COMPASS-like** uses $\mathbf{Q = q_x + q_y}$ (single-view events discarded)
- Pixel charge when **TOP** uses $\mathbf{Q = (q_x + q_y)/2}$
- Per-strip **charge vs time** <u>can be</u> fitted with **Fermi–Dirac** to take the hit time at the rising-edge inflexion point → **T0** chip and strip number to be set in the code
- **New Pixel**: stores charge and time **separately** for X and Y strips, plus a pixel charge and time stamp

→ info on the strips' data is not lost when creating the 2D pixel!

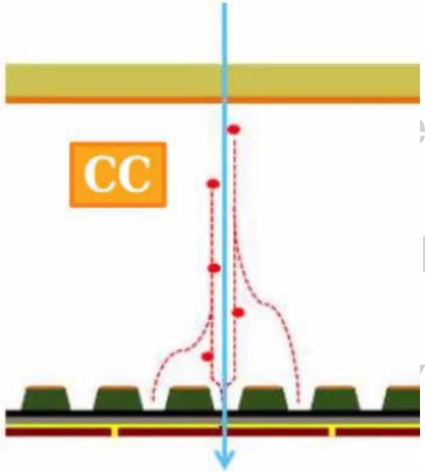





```
[EventLoadermmDAQ3]
input_directory = "run/"
charge_cut_x = 50
charge_cut_y = 50
time_cut = 100
#fit = true
```

Recap from last DRD1 collaboration meeting

EventLoader:
- Pixel charge when **COMPASS-like** use … -view events discarded)
- Pixel charge when **TOP** uses **Q = (q_x +**
- per-strip **charge vs time** fitted with **Fe** … he hit time point
- **New Pixel**: stores charge and time **se** … strips, plu … amp
  → **info on the strips' da** … **creating t**




```
[ClusteringStrips]
charge_weighting = true
neighbor_radius_col = 2
neighbor_radius_row = 2
time_cut_abs = 1000
time_cut_col = 100
time_cut_row = 100
time_cut_pixel = 100
```

ClusteringStrips:
- allows ≤1 empty neighbouring strip
- **time window** cut (configurable, reduce ghost hits)
- position of the cluster is calculated with the **Charge Centroid** using X and Y separately

Tracking4D:
- builds tracks with **Golden Clusters** (max-charge)

Analysis:
- resolution with "**enemy**" analysis is implemented

Recap from last DRD1 collaboration meeting

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  → **info on the strips' data is not lost when creating the 2D pixel!**

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- allows ≤1 empty neighbouring strip;
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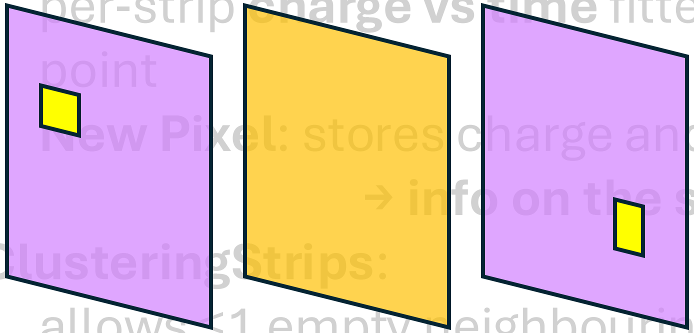
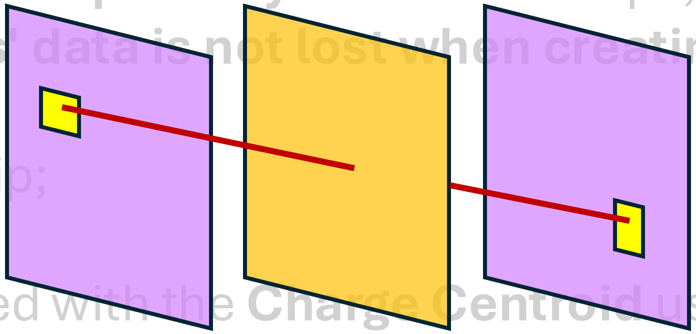
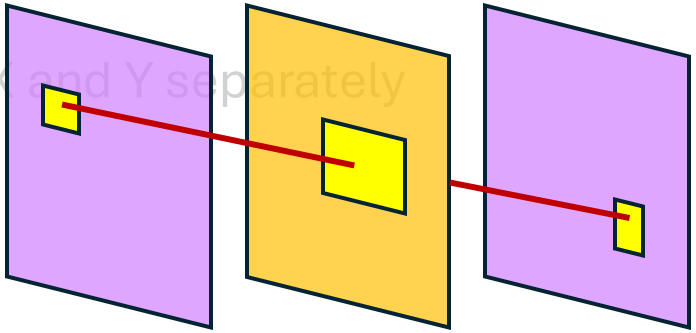






```
[Tracking4D]
spatial_cut_rel = 300
exclude_dut = true
time_cut_abs = 50
min_hits_on_track = 2
require_detectors = "TRK_IN","TRK_OUT"
unique_cluster_usage = true
OnlyGoldCluster = true
max_plot_chi2 = 500.5
reject_by_roi = true
```

Recap from last DRD1 collaboration meeting

EventLoader:

- Pixel charge when **COMPASS-like** uses **$Q = q_x + q_y$** (single-view events discarded)
- Pixel charge when **TOP** uses **$Q = (q_x + q_y)/2$**
- p... take the hit time at the rising-edge inflexion
- N... and Y strips, plus a pixel charge and time stamp **when creating the 2D pixel!**

If the detector has the flag «enemy» true, the module will calculate the Residuals also with the enemy method:
The enemy method calculates the distance between the clusters' centres on each readout of two identical DUTs

Clus...

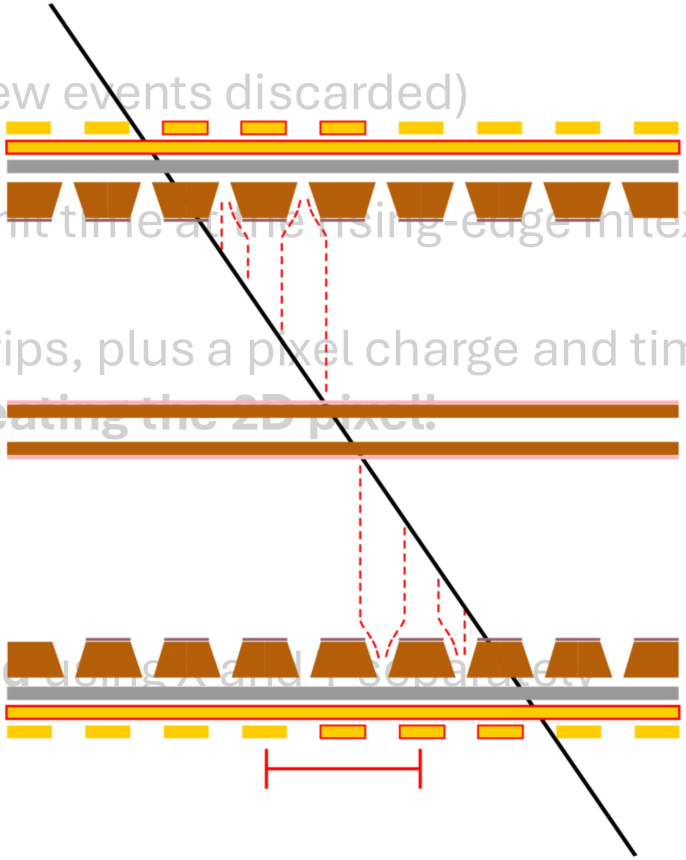
- a...
- **ti...**
- position of the cluster is calculated with the **Charge Centroid** using X and Y separately

Tracking4D:

- builds tracks with **Golden Clusters** (max-charge)

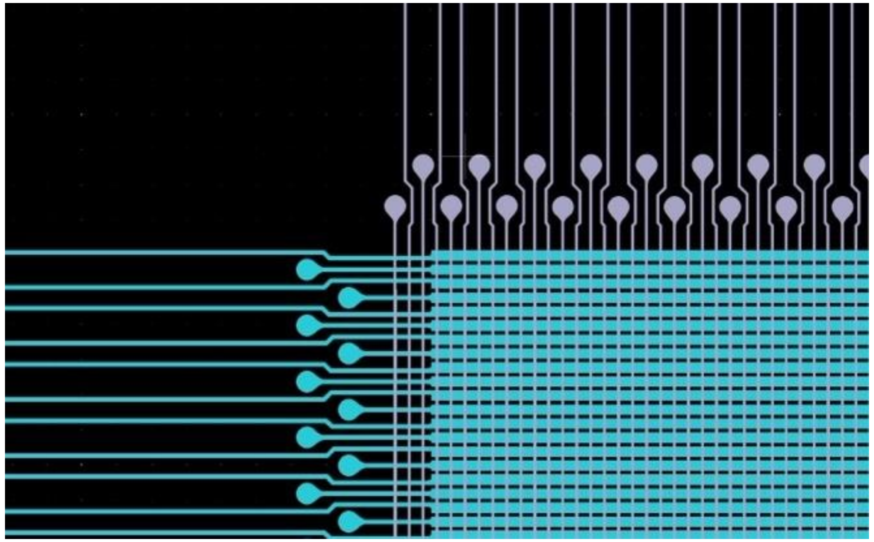
Analysis:

- resolution with "**enemy**" analysis is implemented



Recap from last DRD1 collaboration meeting

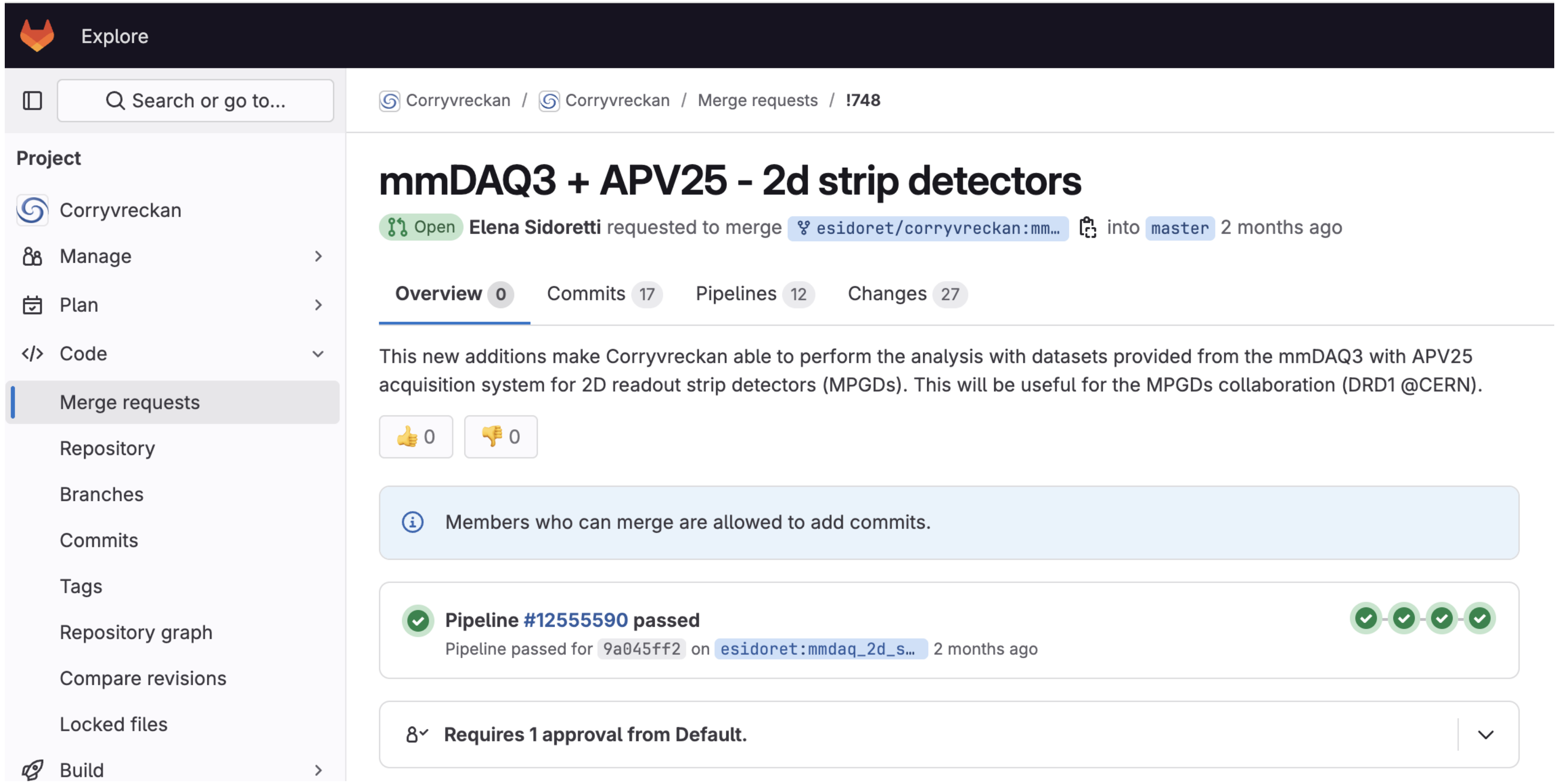
Example of Geometry file



```
[HYB_1]
number_of_pixels = 256,256
mask_file = "../mask_files/mask_HYB_1.conf"
orientation = 0deg,-30deg,0deg
orientation_mode = "xyz"
pixel_pitch = 400um,400um
position = 0cm,0cm,614mm
spatial_resolution = 100um,100um
time_resolution = 10ns
m_fec = 1
apv_1 = 0
apv_2 = 2
readout = "compass"
enemy = "true"
gas_gap = 6
type = "APV252D"
role ="dut"
```

The code can be found as a merge request in the Corryvreckan GitLab

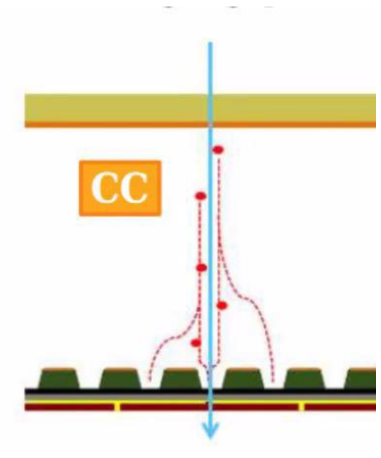
https://gitlab.cern.ch/corryvreckan/corryvreckan/-/merge_requests/748



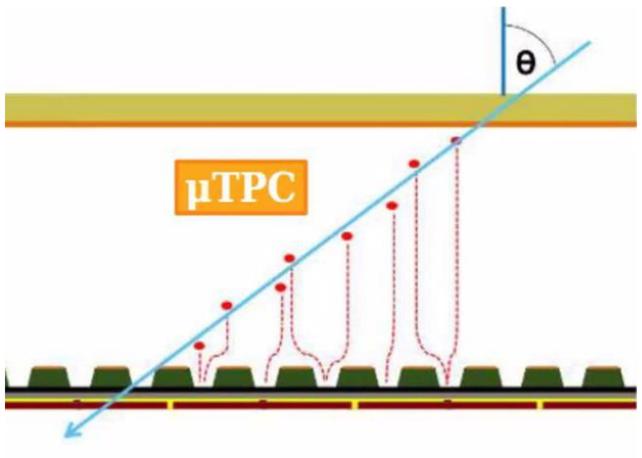
WIP: Analysis µTPC

Analysis performed for G-RWELL prototypes tested in November 2024 @CERN T10 with X axis rotated w.r.t. the incident beam

Spatial resolution reconstruction methods



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



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

µTPC

The "**µTPC**" method for inclined tracks

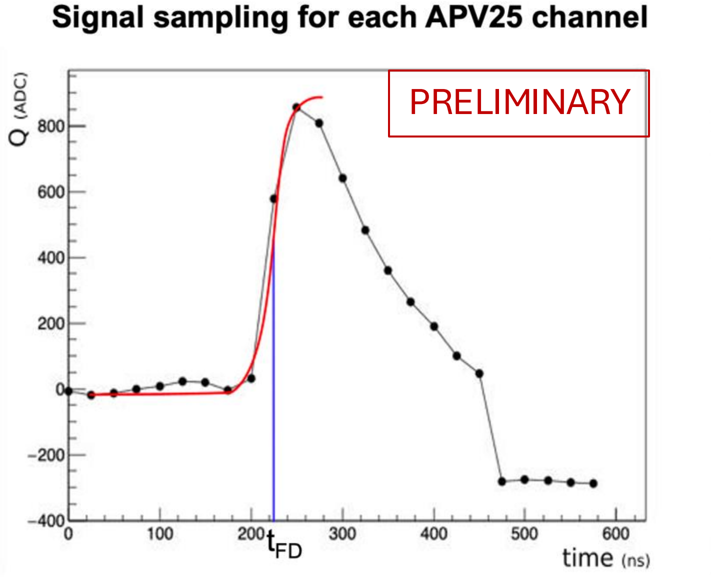
- The time of arrival of the hits and the drift velocity in the gap are used to reconstruct the track segment.
- The cluster's position is determined by the intercept with an arbitrary plane parallel to the readout
  → **half gas gap in my module**

A linear fit on position/time to get track slope and offset is performed:

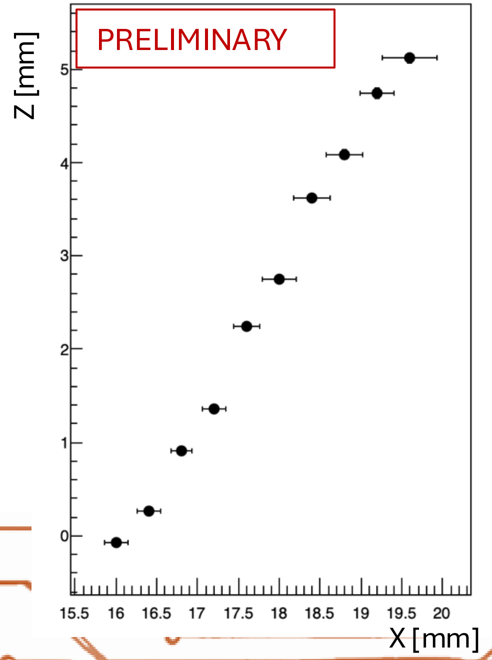
- The input is the X position of the strips and their time, all with respective errors
- The Z position is computed with $z = t\ v_{drift}$ (with v_{drift} = 0.04 mm/ns)
- The vectors are sorted by position and fitted **z = a + b x**

The data extrapolated: the intercept (a), the slope (b) and the χ^2/NDF.

Thanks to Riccardo Farinelli (INFN Bologna)

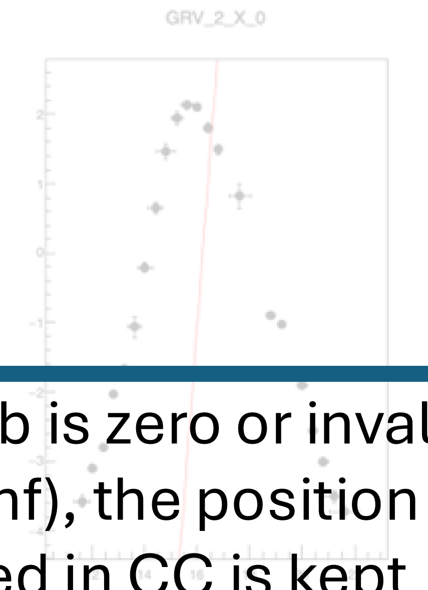


$Z = v_d\ t$

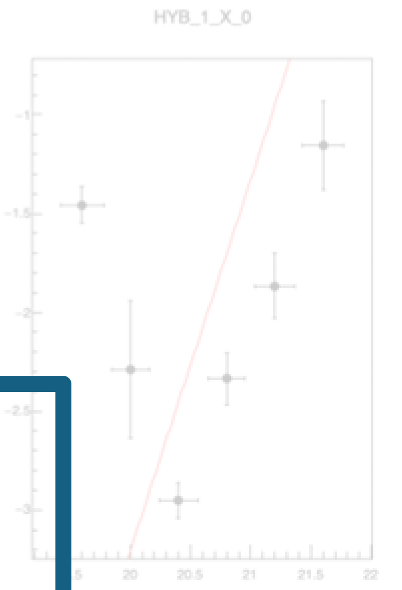


µTPC fit checks

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



Chi2/Ndf = 6442/21 = 306

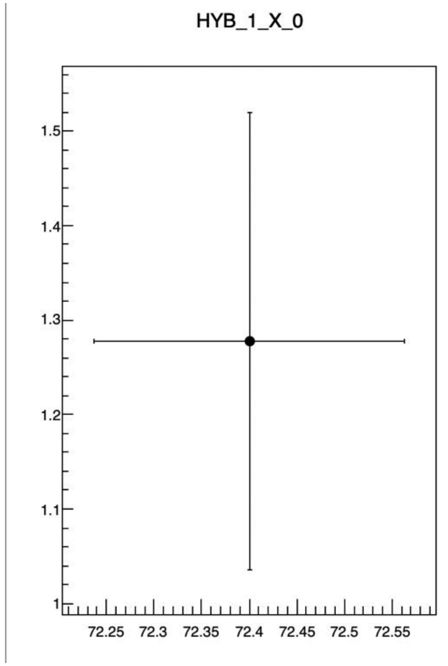


Chi2/Ndf = 74/4 = 18,8

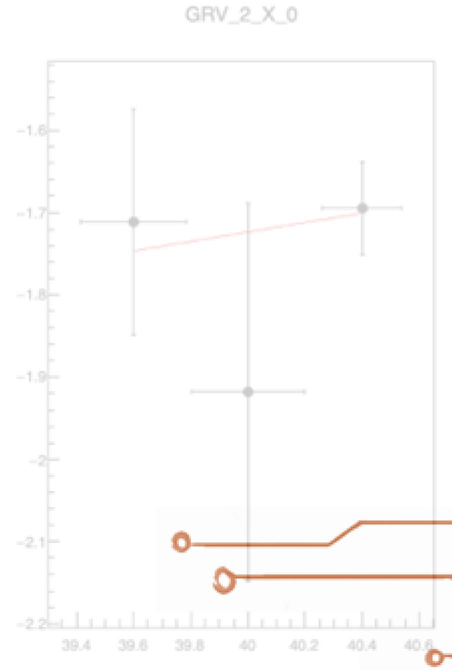
Chi2/Ndf = 1081/13 = 83

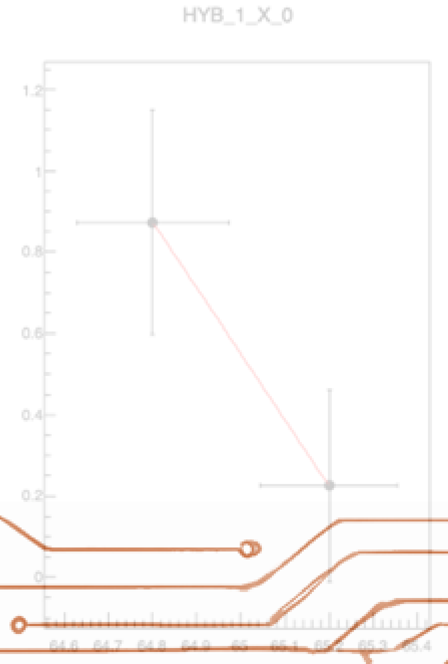
if the slope b is zero or invalid (NaN or Inf), the position calculated in CC is kept

b == 0



Size < 4





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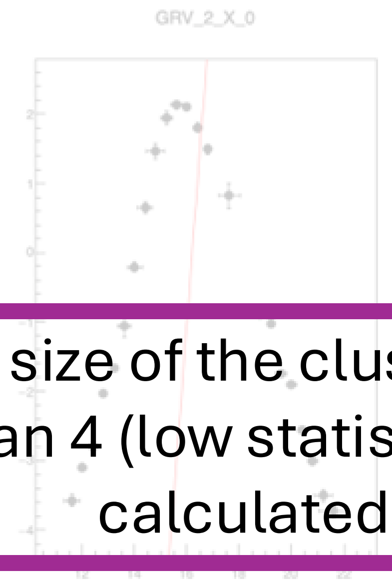

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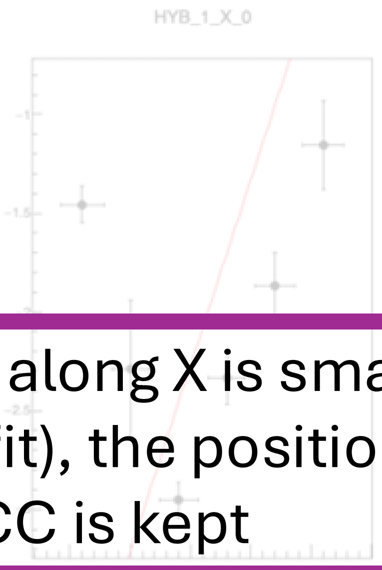


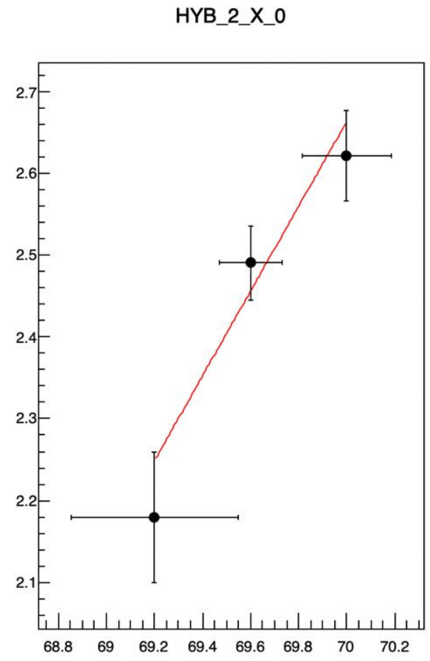
Chi2/Ndf = 74/4 = 18,8

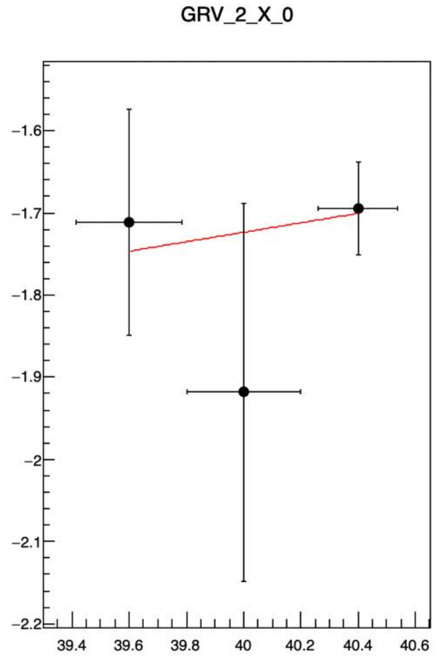
Chi2/Ndf = 1081/13 = 83

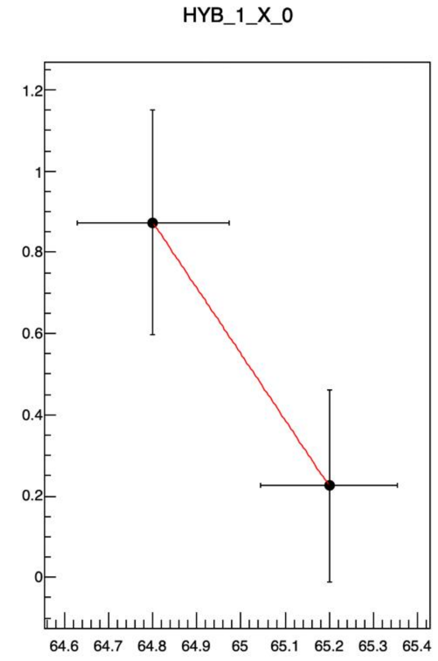
if the size of the cluster along X is smaller than 4 (low statistic fit), the position calculated in CC is kept

b == 0

Size < 4







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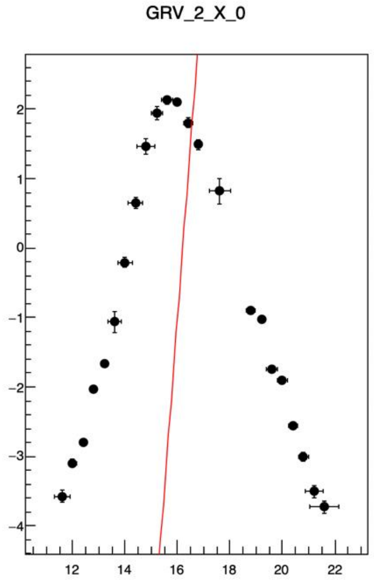

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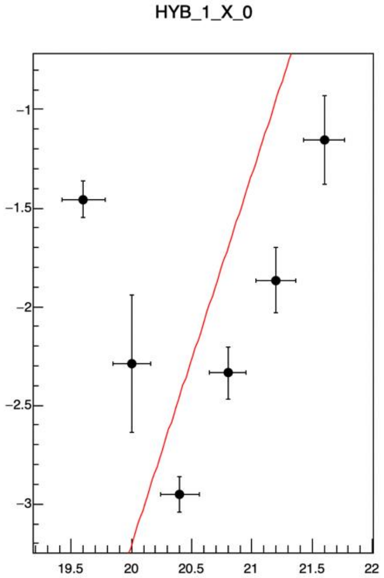

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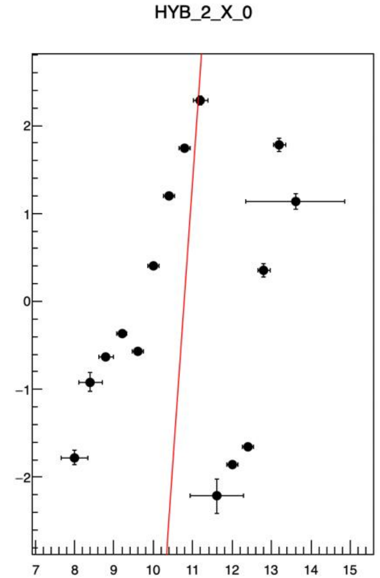
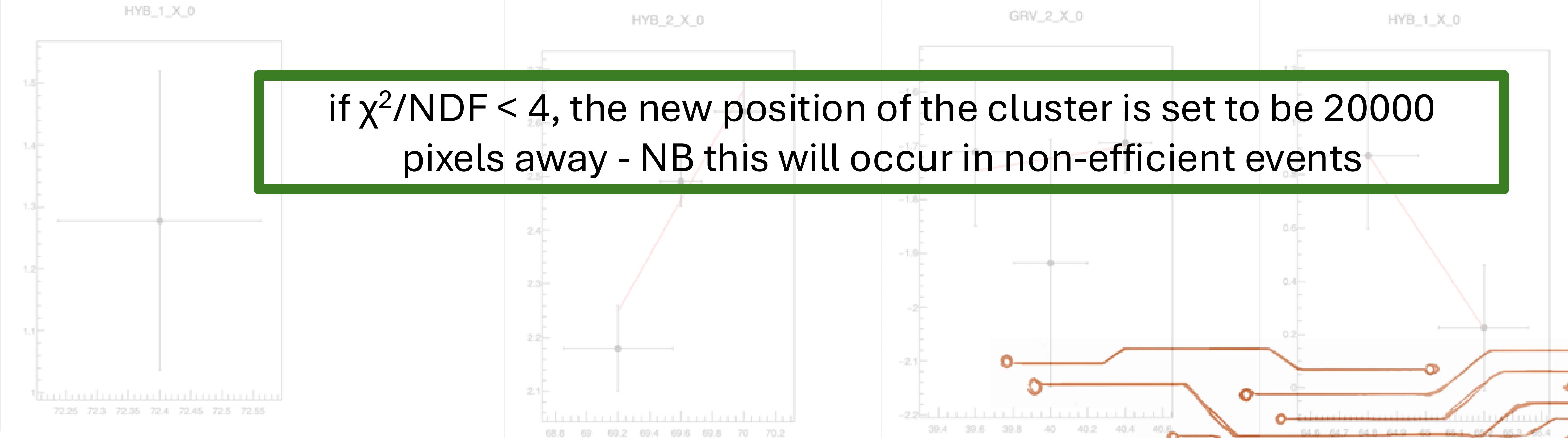


Chi2/Ndf = 1081/13 = 83

b == 0

Size < 4



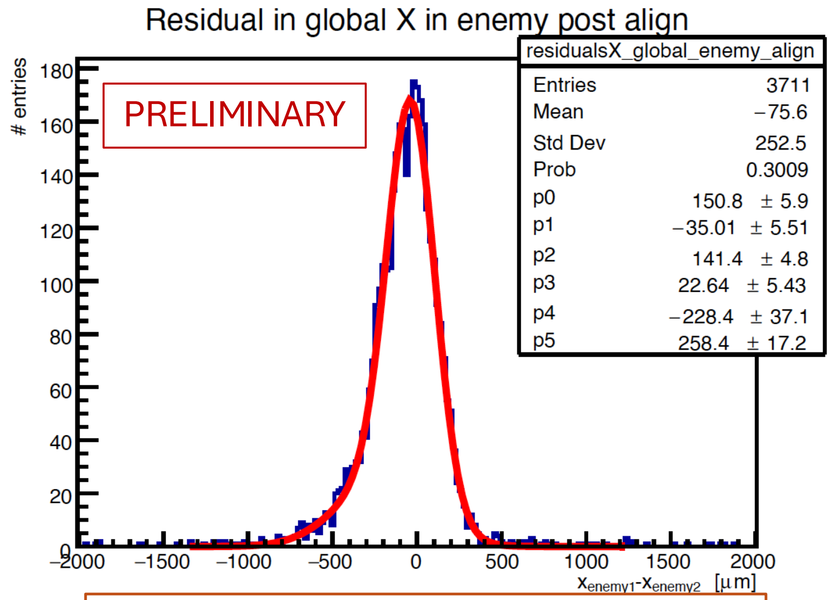
if χ^2/NDF < 4, the new position of the cluster is set to be 20000 pixels away - NB this will occur in non-efficient events

µTPC residuals

The fits that pass all the checks are intercepted on a plane parallel to the readout plane, at half gap distance (along Z).

→ The interception point is set to be the **new centre** of the cluster

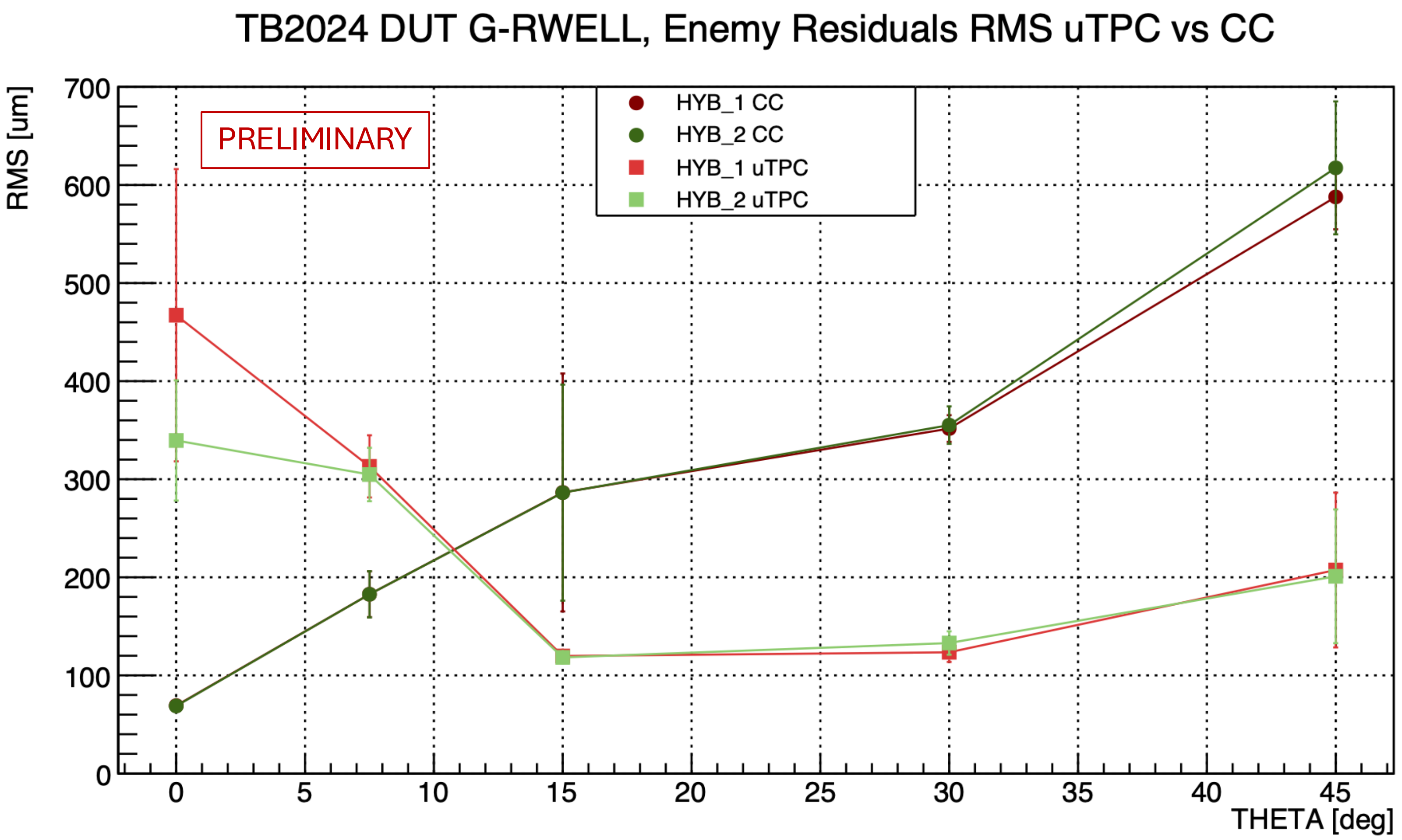
Tracking and DUT Association follow.



Sigma 177 μm
Resolution in enemy mode 125 μm

µTPC angle scan

The efficiency of all the runs is ~ 95%, except for the one at 45° in CC, having ϵ = 88% and the one at 0° in µTPC, having ϵ = 82%



μTPC notes

Usage:

- The uTPC Analysis module is added right after the Clustering module
- For the alignment procedure, the position of the DUT will be moved at half its gas gap, and the uTPC will be performed discarding also the clusters with b=0 and size < 4
- The χ^2/NDF cut can be set from the configuration file

Implementation ongoing:

For the "in gas gap" fit:

- The last point closer to the readout may be "doubled" due to crosstalk between adjacent strips. In that case, depending on the slope, the fit should discard it

2-Dimensional μTPC

Thank you!

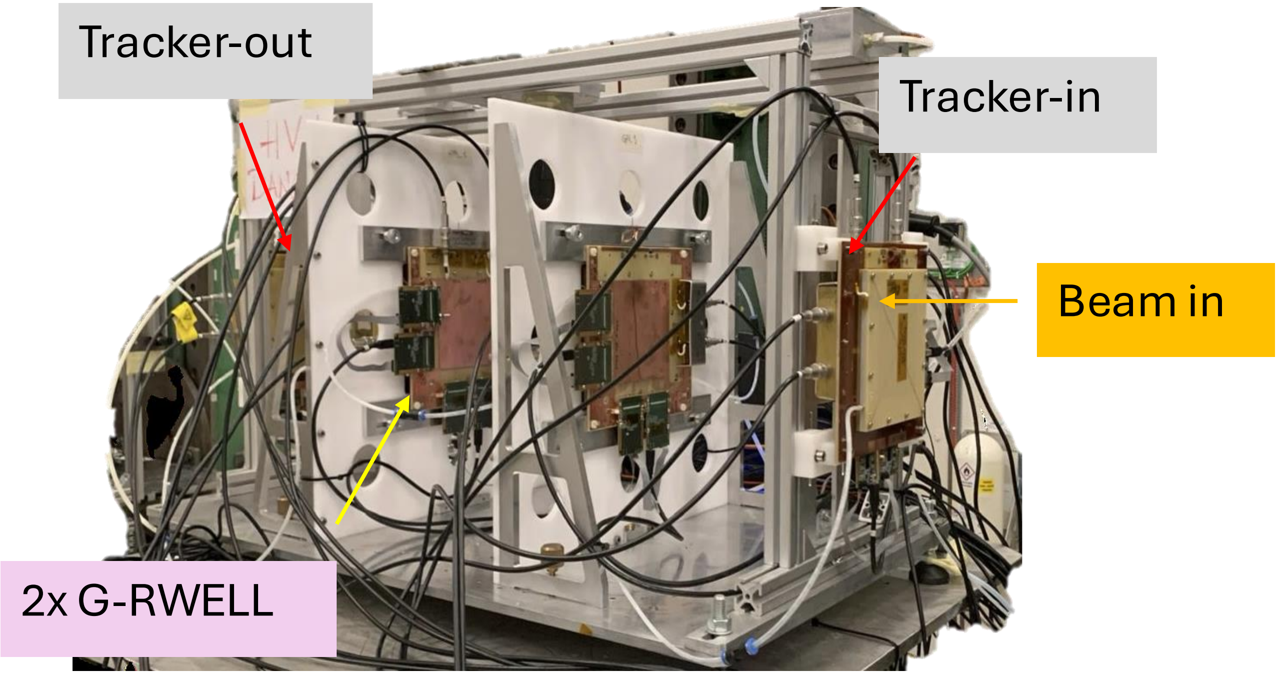
Thanks to

Marinagela Bondì, Annalisa D’Angelo, Riccardo Farinelli, Matteo Giovannetti, INFN-Roma 2 & INFN-LNF w.g.

Backup

Data taking @CERN

2 G-RWELL prototypes	
Active area	10 x 10 cm^2
Pitch	400 μm
Drift gap	6 mm
Transfer gap	3 mm



Test beam @PS T10 November 2024

- muon beam 5GeV/c

GOAL:
The aim of the test beam was to evaluate the performance regarding spatial resolution as a function of:

- various angles of incidence
- various ΔV GEM applied
- different values of drift and transfer fields

Gas mixture	$Ar:CO_2:CF_4$ 45:15:40
Acquisition system	SRS + APV25 + mmDAQ3
Data analysis	Corryvreckan framework

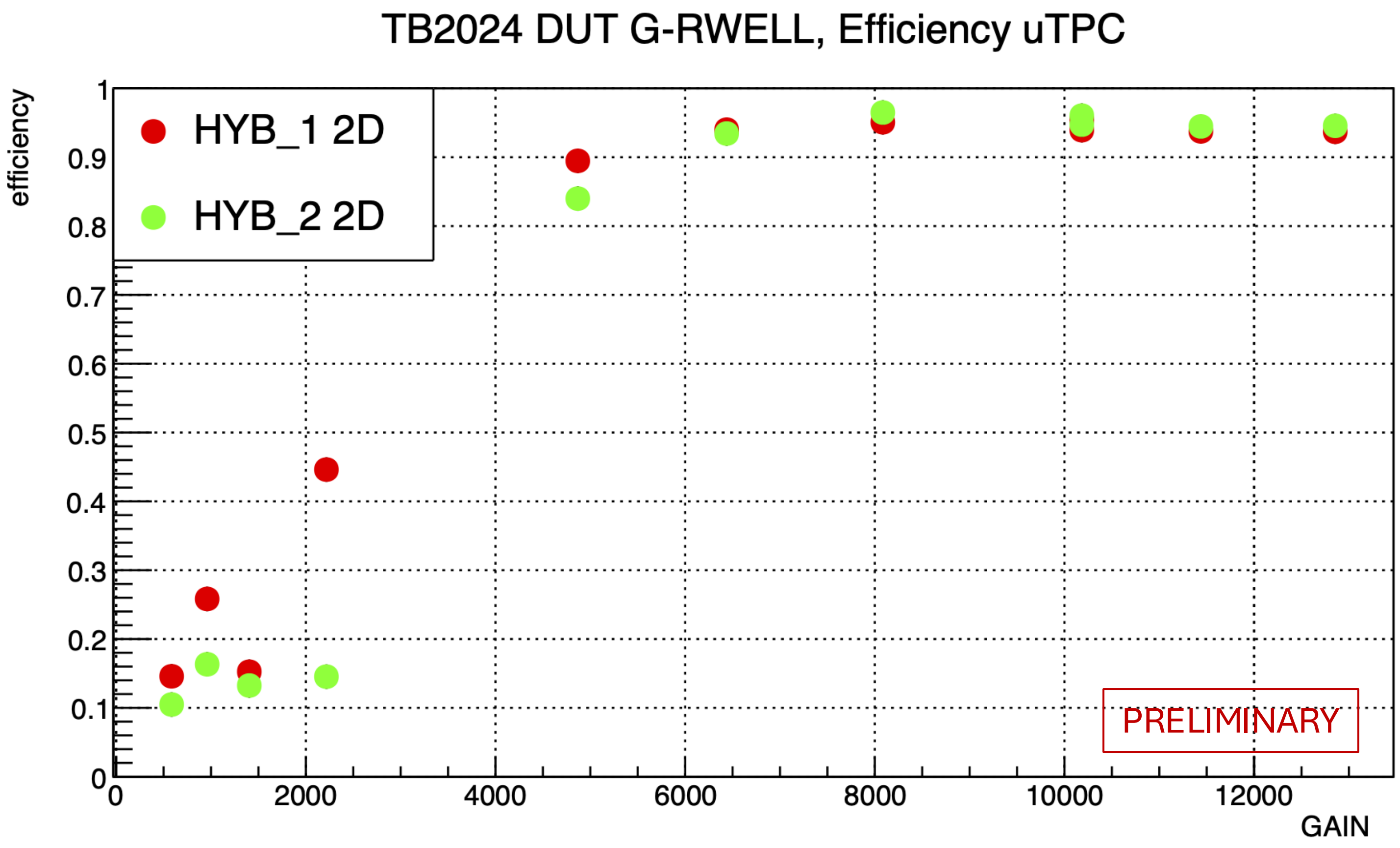
Trackers set-up & backup solutions

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

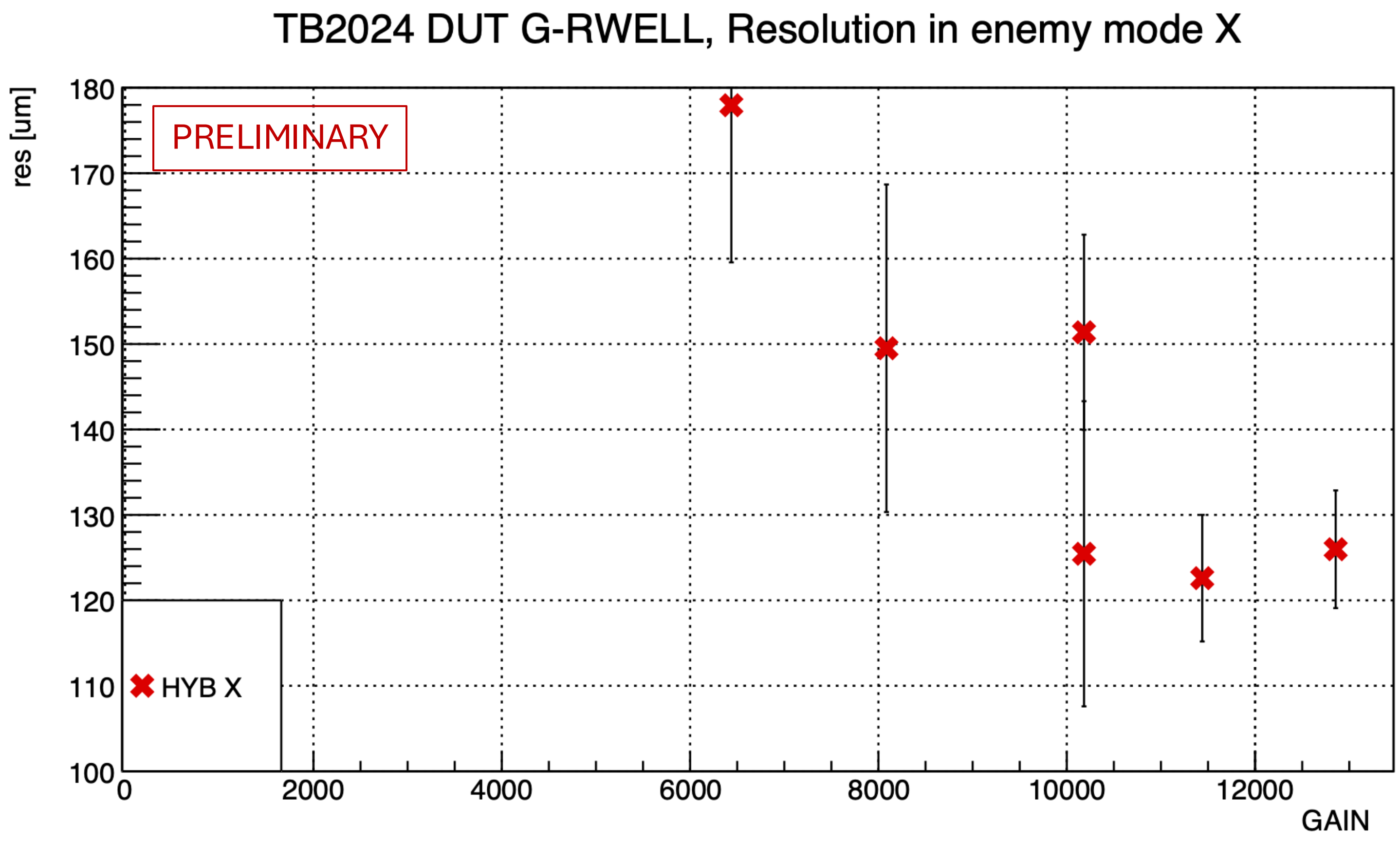
	G-RWELL hybrid	**μRWELL**
Drift field	2.5 kV/cm in 6 mm gas gap	OFF
ΔV_{GEM}	400 V (gas gain ~10)	OFF
Transfer field	4.5 kV/cm in 3 mm gas gap	3.5 kV/cm in 3 mm gas gap (as Drift)
ΔV_{WELL}	550 V (gas gain ~1500)	630 V (gas gain ~8000)
Gas gain	~15000	~8000

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.

µTPC results - efficiency



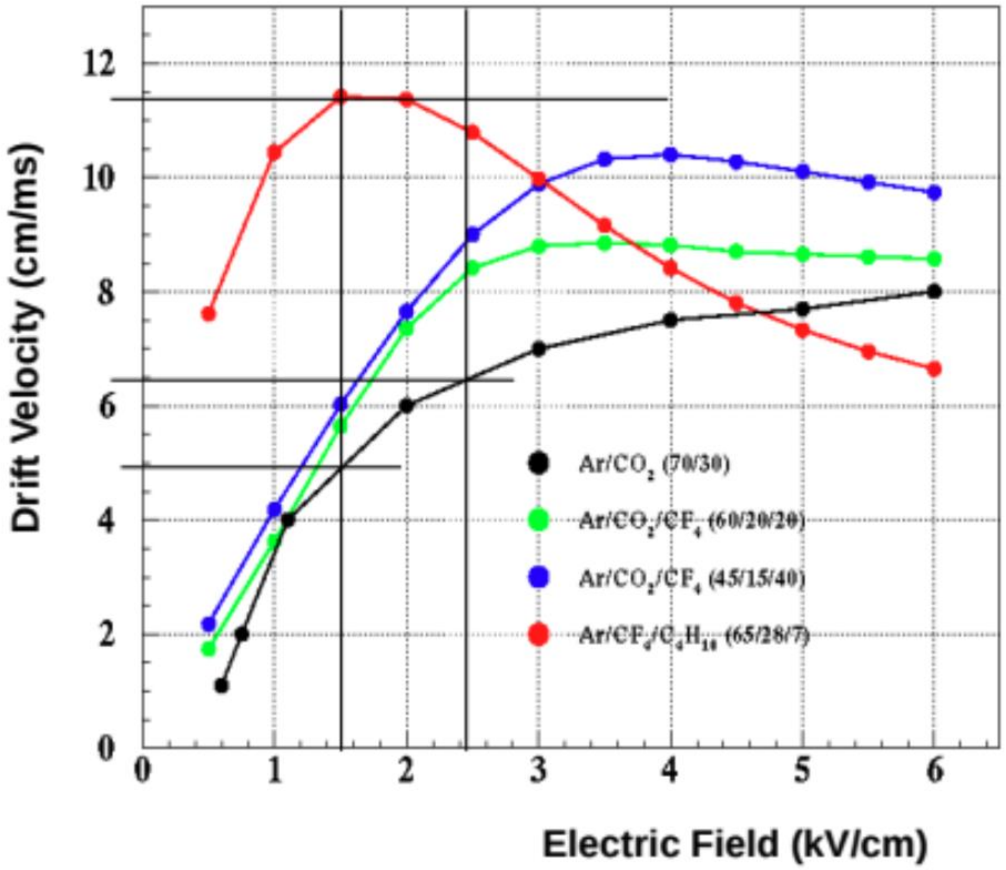
µTPC results - resolution



Drift velocity

Calculated using Garfield++ simulations

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



µTPC angle scan