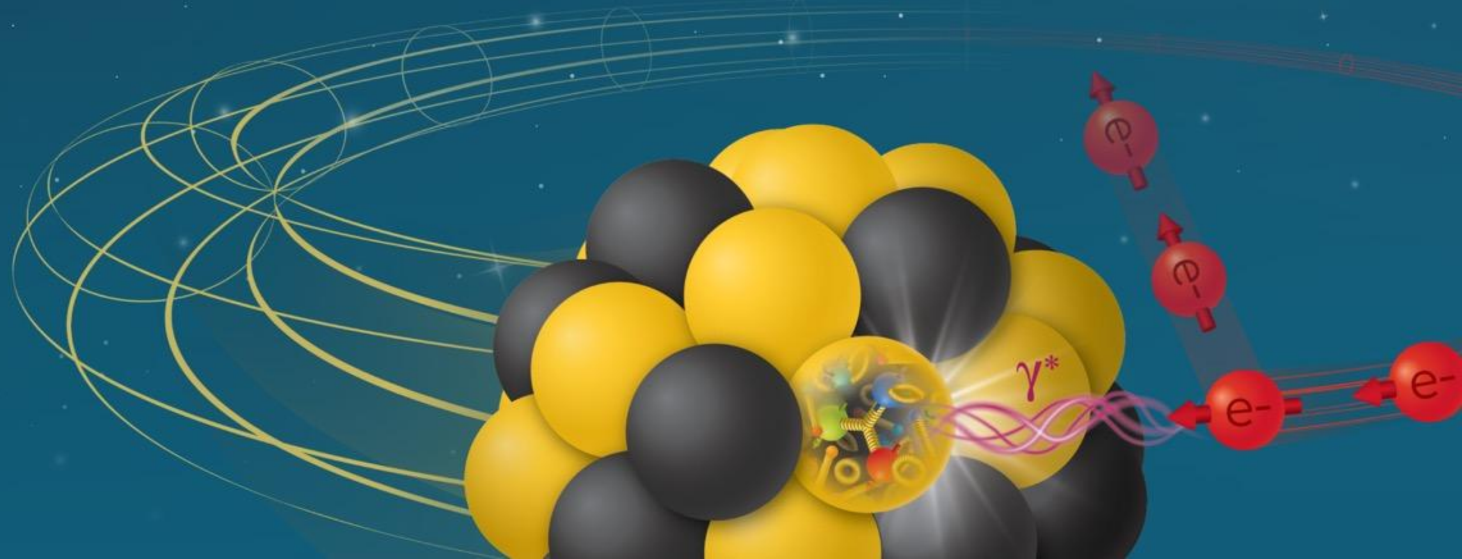
Summary of MPGD beam test campaign at CERN SPS

Kondo Gnanvo *On behalf of MPGD-DSC*

ePIC TIC Meeting, August 24, 2026

Electron-Ion Collider



Outline

- ❖ MPGD-BOT in 2026 DRD1 Beam Test @ the CERN SPS H4 Beam Line
- ❖ MPGD ENDCAP Trackers (ECT) for ePIC - Test Beam 2026 @H4 CERN

ePIC MPGD Barrel Outer Tracker (MPGD-BOT)

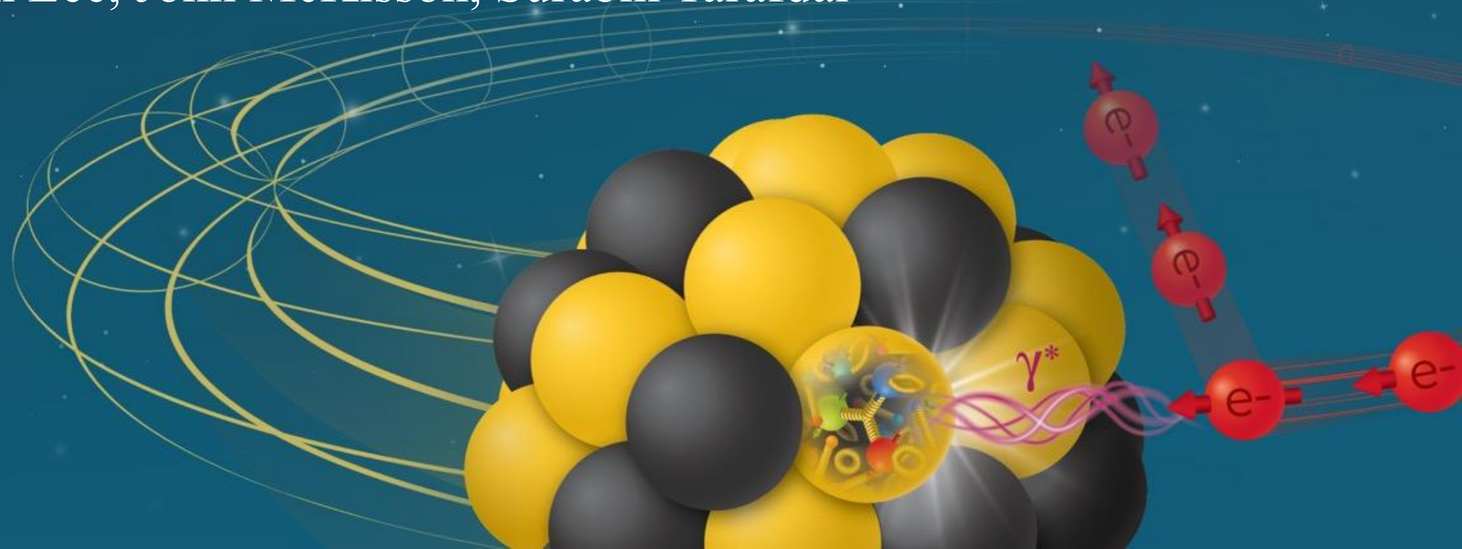
MPGD-BOT in 2026 DRD1 Beam Test @ the CERN SPS H4 Beam Line *(sort of…)*

Crew @ 2026 DRD1 beam test

JLab: Xinzhan Bai, Kondo Gnanvo, Seung Joon Lee, John McKisson, Surabhi Tarafdar

UVa: Jacob McMurtry, Huong Nguyen

ePIC TIC Meeting, August 24, 2026



Electron-Ion Collider

ePIC Gaseous Barrel Outer Tracker (MPGD-BOT): Thin Gap GEM-µRWELL Hybrid

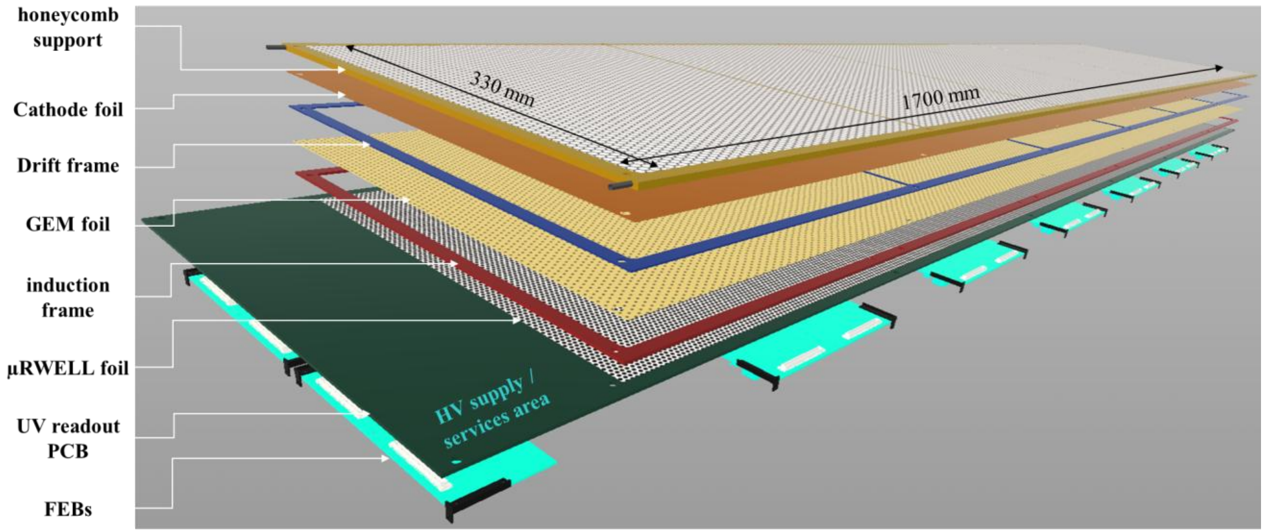
MPGD-BOT module:

- **Technology:** Thin-gap GEM-µRWELL hybrid detector
- **Active area:** 1700 mm × 330 mm
- **Double amplification:** hybrid GEM & µRWELL
- **Gas gaps:** drift gap: 1.5 mm & transfer gap: 2.5 mm
- **Readout plane:** Capacitive-sharing 2D strips readout
  - X & Y strips rotated 45° strip pitch = 0.8 mm

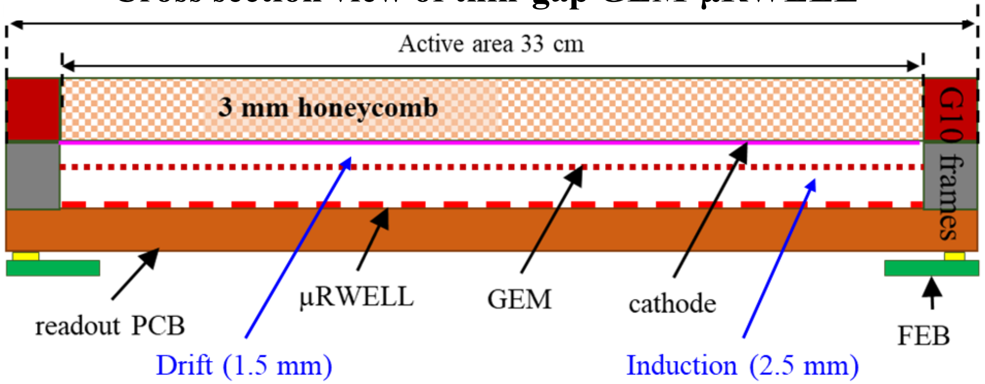
Readout electronics:

- Front End Boards (FEBs) based on SALSA chips
- 14 FEBs / module (4 SALSA chips i.e 256 e-ch / FEB)

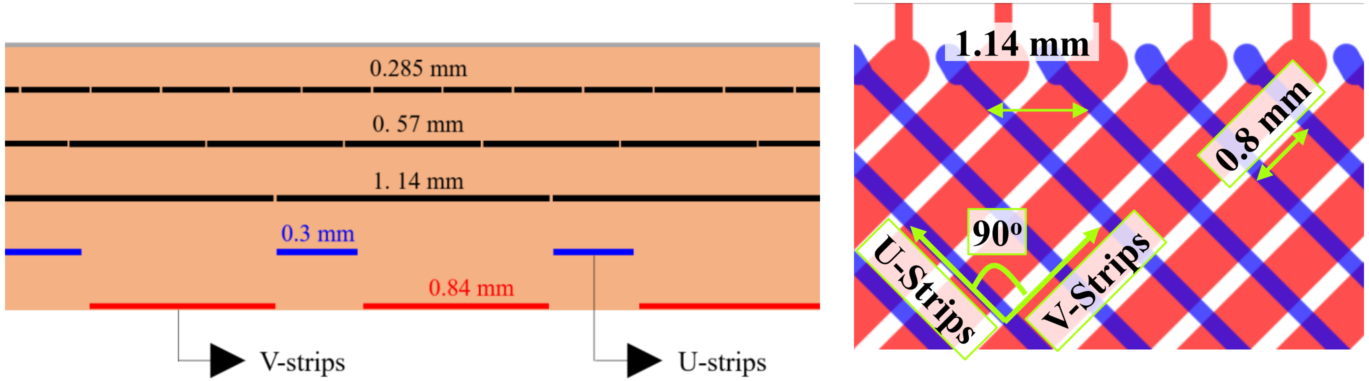
CAD design of the MPGD-BOT module



Cross section view of thin-gap GEM-µRWELL



Capacitive-sharing U-V strip readout – baseline design



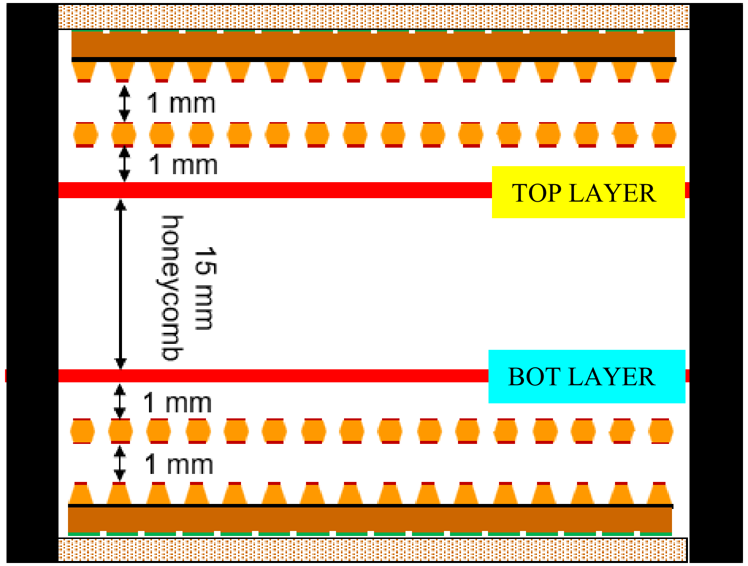
https://doi.org/10.1016/j.nima.2022.167782

Development of Double Thin Gap GEM-µRWELL Hybrid Detectors (DTGH)

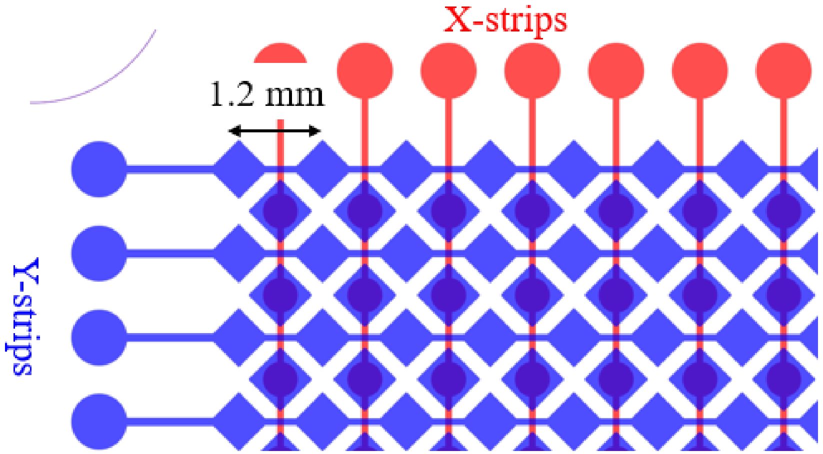
EIC Generic Detector R&D Program: https://wiki.bnl.gov/eic/index.php?title=File:20230714_eRD_tgMPGD_Proposal_FY23_Final.pdf

Medium size (30.72 cm x 30.72 cm) **DTGH prototype:** Two sensitive volume with 2D readout each sharing one gas volume

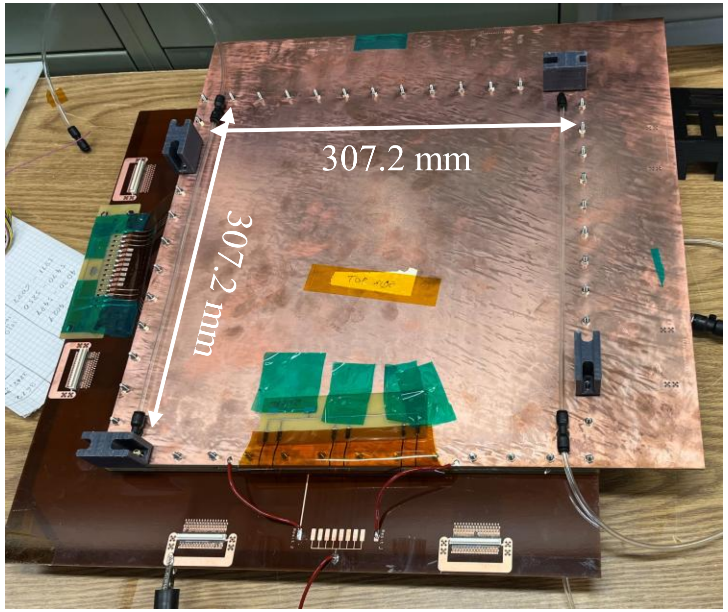
- **Detector sensitive volume:** hybrid GEM & µRWELL amplification with 1 mm drift gap & 2 mm transfer gap
- **2D readout strips:** 1.2 mm pitch 256 X-strips and 256 Y-strips ➔ Only 512 total channels for the two detectors
  - Strip has ASACUSA pattern ➔ ensure de facto equal X/Y charge sharing
  - 3 Capacitive layers ➔ to maintain good position resolution with large pitch strip readout



Cross sectional view of DTG Hybrid



X-Y strips ASACUSA pattern



30 cm x 30 cm DTGH prototype

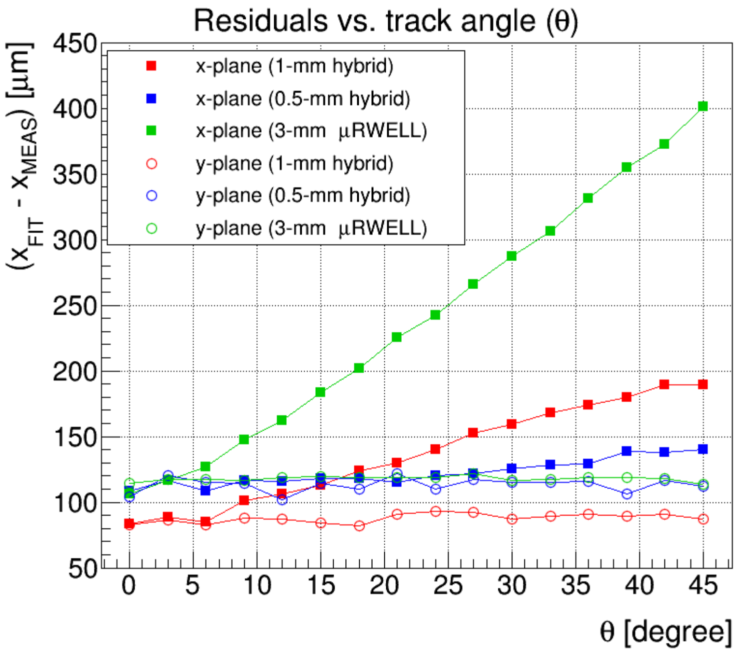
Synergy between DTGH prototype and ePIC MPGD-BOT test article

	30 × 30 DTGH prototype	ePIC MPGD-BOT module	Comment
Technology	**Double** thin gap GEM- μRWELL hybrid	**Single** thin gap GEM- μRWELL hybrid	
Gap in gas volume	Drift: 1 mm – transfer: 2 mm	Drift: 1.5 mm – transfer: 2.5 mm	
Active area	307.5 mm × 307.5 mm	1700 mm × 330 mm	
2D strip readout scheme	X-Y: • Pitch 1.2 mm • ASACCUSA design • 3 capacitive layers	X-Y: • Pitch 0.8 mm • COMPASS design • 3 capacitive layers • Strips 45^{O} w,r,t detector sides	• DTGH: Larger pitch = less readout channels • DTGH: ASACUSA design: de facto X / Y equal charge sharing but more challenging to manufacture
@ July Beam test	Serves as a proxy for MPGD-BOT performance study	MPGD-BOT module not ready ➔ Assembly was delayed	• DTGH performance directly applicable to MPGD-BOT • DTGH total active area is ~ ¼ of MPGD-BOT • Good performance with ASACUSA readout will be implemented in MPGD-BOT subsequent versions

Small Thin-gap GEM-μRWELL Hybrid prototypes in past beam test

FNAL 2023 beam test results

Significant improvement of spatial resolution for large angle tracks with thin-gap GEM-μRWELL hybrid detector



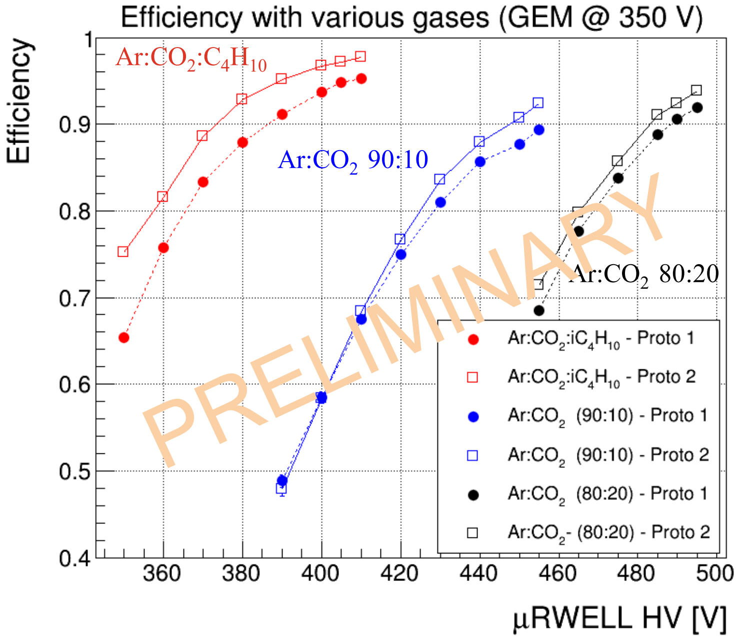
Position resolution vs. track angle

https://doi.org/10.1016/j.nima.2025.170791

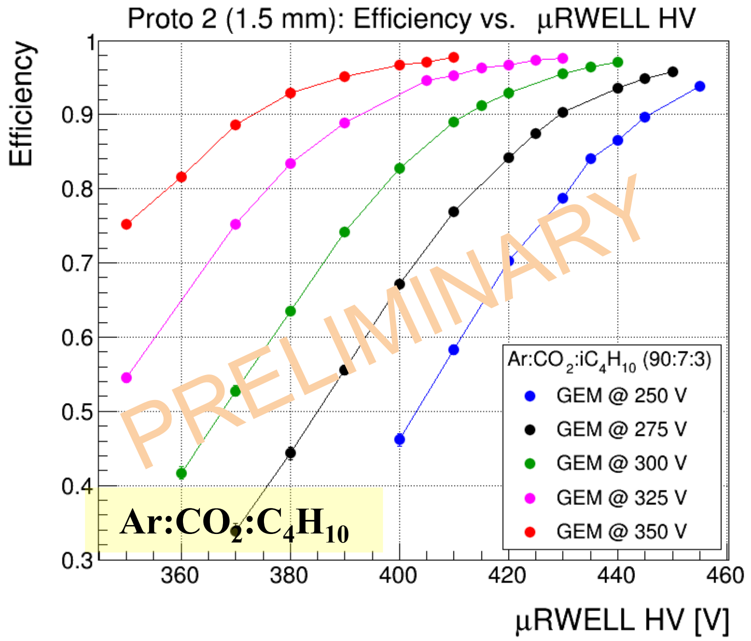
JLab 2025 beam test with small prototypes

- Proto-1 (1-mm) proto 2 (1.5 mm) gap
- With $Ar:CO_2:C_4H_{10}$, full efficiency is achieved at lower voltages on both GEM and μRWELL

- Hybrid GEM & μRWELL allows flexibility on operation working point
- Full efficiency reached at different GEM & μRWELL HVs combination



Efficiency vs. HV for different gas mixtures



Efficiency vs. HV with $Ar:CO_2:C4H_{10}$

DTGH setup in GOLIATH Magnet @ CERN SPS H4 – Beam test goals

The two main motivations for DTGH prototype (aka ePIC MPGD-BOT proxy) at the July DRD1 beam test

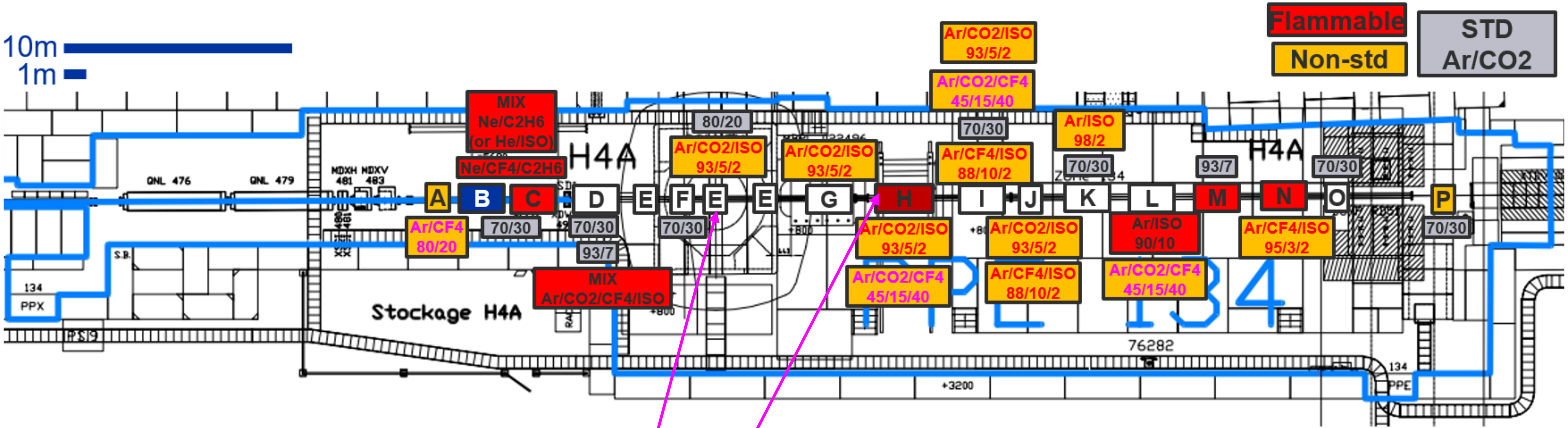
- Performance and operation stability of Thin-Gap GEM-μRWELL detectors with Ar:CO_2:iC_4H_{10} gas mixture
  - Demonstrate that the ePIC MPGD-BOT could operate with the same gas mixture used by CyMBaL and MPGD-ECT
  - Optimization of position, time resolution and efficiency through HV scans in different regions of the detector
- Study the performance and operation stability in a magnetic field up to 1.5 T field (similar to ePIC B-field)
  - Dedicated runs in the GOLIATH magnet with pion beam ➔ scan from 0 to 1.5 T with different gas mixtures

We were able to successfully complete the beam test program which includes various the HV scans, B-field scan for different gas studies during the two and half weeks of the beam test.

Large amount of data (> 200kEvts) were collected for each data point to allow clean data analysis with small statistical error

DRD1 Beam Test Layout – July 15th to August 3rd

BEAM H4, PPE134 – PRELIMINARY overview gas (DRD1, July 15th)



A: Optically read out MPGDs XSCA
B: PICOSEC A LAPP
C: PICOSEC B Desy
D: µRwell CF4 Replacement Studies
E: EIC - JLab & UVa - Thin Gap MPGD Setup
F: MM in magnetic field
G: EIC - MPGDs - CyMBaL
H: EIC - MPGD-ECT BIG RED (with yellow support)

I: RHUM
J: PADME MM with VMM
K: DRD1 telescope A
L: USTC
M: MICROMEGAS TRACKER Pisa/Siena Desy
N: HYDRA-TPC TEST Desy
O: GEM TPC
P: CERN - McWellPix XSCA

16 setups
2 ePIC related

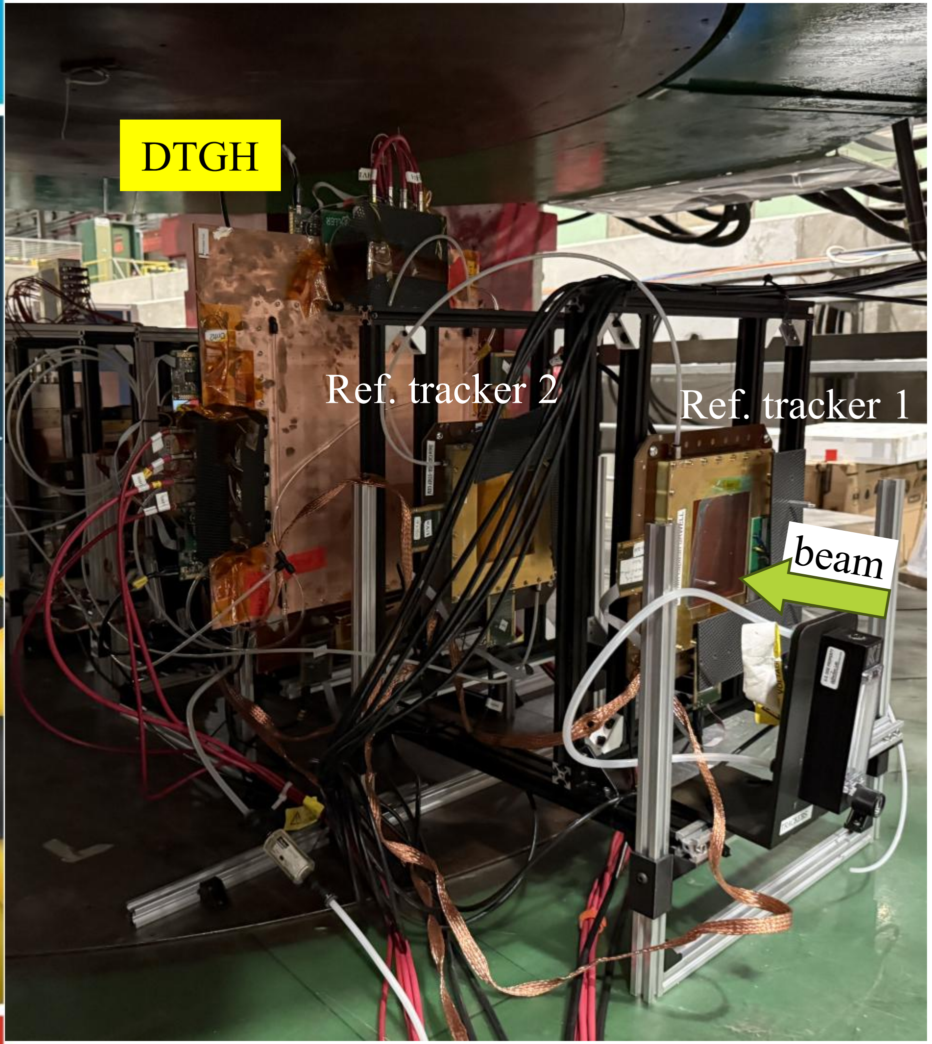
DRD1 Beam Test @ CERN SPS H4 Beam Line (PPE134): July 15th to Aug. 3rd

H2/H4 General Information

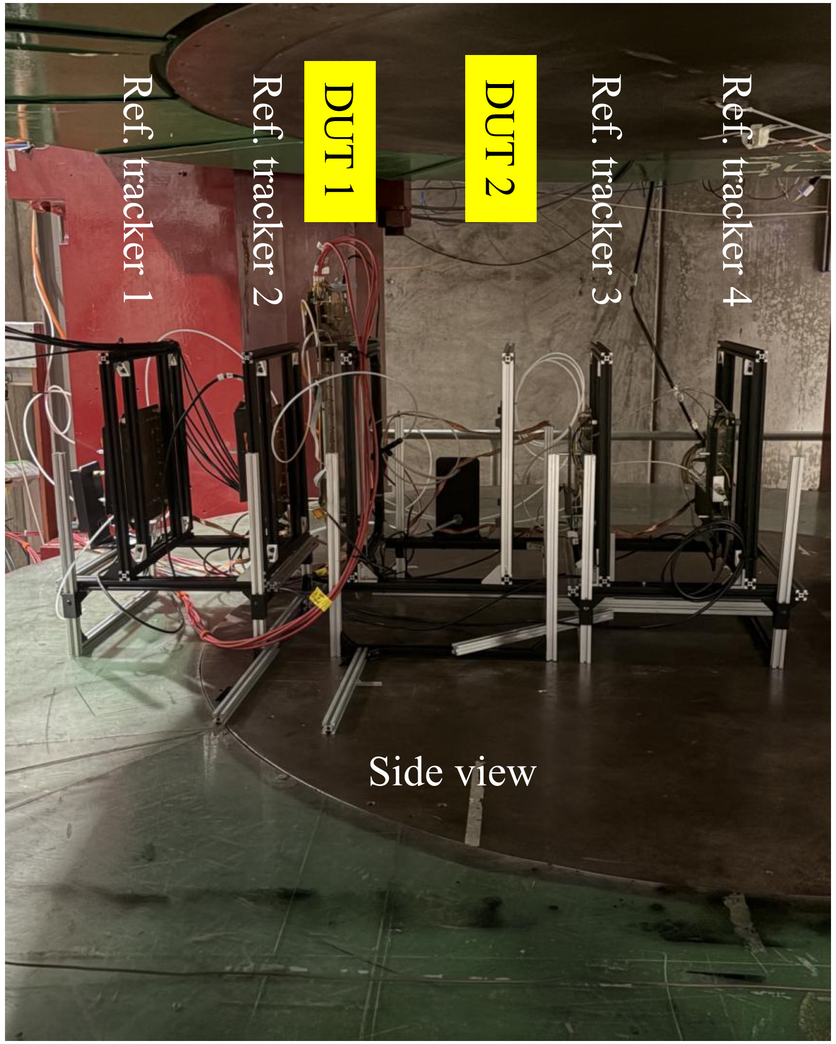
- **Two unique experimental beam lines**
  - Magnetic spectrometers with maximum dp/p : 2%
    - Separating **momenta** and not particle **species** !
- **Available momenta : 20 – 400 GeV/c**
  - Mixed hadron or pure electron modes
    - Purity variable with momentum/intensity and (both) beam lines configuration
- **Spill duration: ~4.8 s flat-top, 1-2 spills / supercycle, ~3000 spills / day**
  - Rates @ your detector : a few hundred particles/spill – 1E7 particles /spill
    - RP and other limitations may apply
- **Very dynamic facilities**
  - Modifiable, easily accessible, and adaptable to user needs….within limits.

Contact Persons: Yorgos Tsipolitis, Karl Flöthner

Double Thin Gap GEM-μRWELL Hybrids (DTGH) setup in GOLIATH Magnet



- DUTs: **DTGH** prototypes
- Trackers: 2 upstream & 2 downstream
  - Downstream trackers: small Thin-Gap GEM-μRWELL Hybrids
- APV-SRS readout + CODA (DAQ)
- Ar:CO_2 (80:20) & Ar:CO_2:iC_4H_{10} (93:5:2)
- & Ar:CO_2:iC_4H_{10} is the adopted common gas mixture by all 3 ePIC MPGD trackers



DTGH setup in GOLIATH Magnet - $ArCO_2$ (80:20) runs

https://docs.google.com/spreadsheets/d/18fzHT8VrBVvGst_2utNJ0KWm9WRms5FTCQ0ZwbAe5EM/edit?gid=18034894#gid=18034894

Date	Runs	Beam	Magnet	Comment
07 / 25 07 / 23 07 / 24	µRWELL scan (400 V – 485 V) @ GEM 350 V µRWELL scan (380 V – 470 V) @ GEM 360 V µRWELL scan (400 V – 480 V) @ GEM 370 V	Muon	OFF	Drift field 2kV /cm; transfer field 2.5 kV / cm
07 / 20	GEM scan (250 V – 400 V) @ µRWELL 450 V	Muon		
07 / 21	Transfer field scan 1 kV / cm – 2.5 kV / cm	Muon		Drift 2 kV /cm; GEM @ 360 V; µRWELL @ 460 V
07 / 22	Drift field scan 1 kV / cm – 6 kV / cm	Muon		Transfer 2.5 kV /cm; GEM @ 360 V; µRWELL @ 460 V
07 / 23	B field scan from 0 to 1T (1.5 T to be confirmed)	Pion	ON	Drift 2 kV /cm; GEM @ 360 V; µRWELL @ 460 V; Transfer @ 3 kV / cm
07 / 24	µRWELL scan (410 V – 480 V) @ GEM 360 V µRWELL scan (410 V – 480 V) @ GEM 370 V µRWELL scan (410 V – 480 V) @ GEM 360 V	Pion	OFF	Drift field 2kV /cm; transfer field 2.5 kV / cm Drift field 2kV /cm; **transfer field 3 kV / cm**

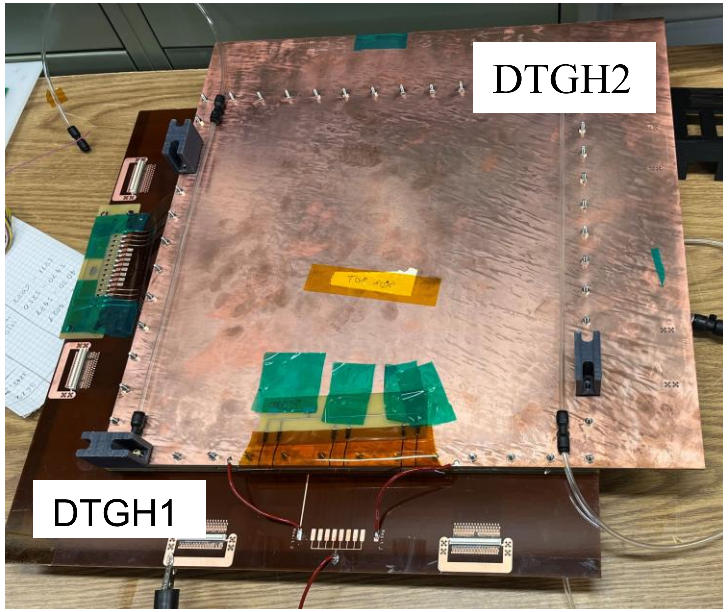
DTGH setup in GOLIATH Magnet – $Ar:CO_2:iC_4H_{10}$ (93:5:2) runs

https://docs.google.com/spreadsheets/d/18fzHT8VrBVvGst_2utNJ0KWm9WRms5FTCQ0ZwbAe5EM/edit?gid=18034894#gid=18034894

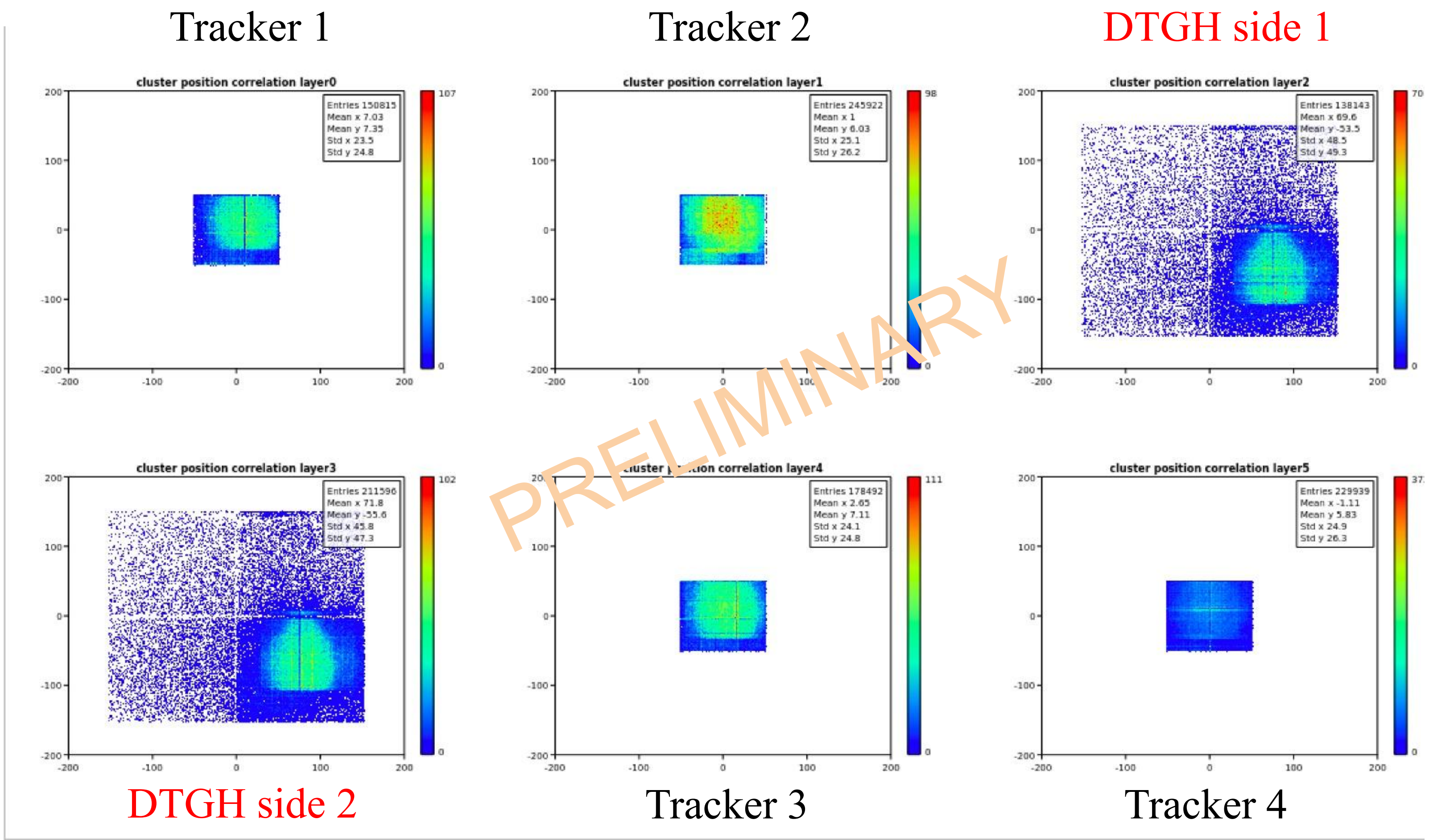
Date	Runs	Beam	Magnet	Comment
07 / 25 07 / 26 07 / 27 **08 / 02**	µRWELL scan (300 V – 400 V) @ GEM 325 V µRWELL scan (300 V – 400 V) @ GEM 340 V µRWELL scan (300 V – 390 V) @ GEM 350 V µRWELL scan (300 V – 420 V) @ GEM 340 V	Muon	OFF	Drift field 2kV /cm; transfer field 2.5 kV / cm Drift field 2kV /cm; transfer field **3** kV / cm
07 / 26	Transfer field scan 1 kV / cm – 4.2 kV / cm	Muon		Drift 2 kV /cm; GEM @ 325 V; µRWELL @ 390 V
07 / 26	Drift field scan 1 kV / cm – 4.2 kV / cm	Muon		Transfer 2.5 kV /cm; GEM @ 325 V; µRWELL @ 390 V
07/ 27 **08 / 02**	GEM scan (260 V – 370 V) @ µRWELL 360 V GEM scan (260 V – 360 V) @ µRWELL 370 V GEM scan (260 V – 360 V) @ µRWELL 385 V	Muon		Drift field 2kV /cm; transfer field 2.5 kV / cm Drift field 2kV /cm; **transfer field 3 kV / cm**
07 / 27	B field scan from 0 to 1.55 T	Pion	ON	Drift 2 kV /cm; GEM @ 340 V; µRWELL @ 490 V; Transfer @ 3 kV / cm
07 / 28	Drift field scan 2 kV / cm – 4 kV / cm	Pion	OFF	Transfer 2.5 kV /cm; GEM @ 325 V; µRWELL1 @ 390 V and µRWELL @ 370 V

Preliminary results – 2D hit Map

- **DTGH2 -** DLC resistivity: 40 - 55 MΩ
- μRWELL hole
  - Pitch = 100 μm
  - OD = 70 μm
  - ID = 40-50 μm



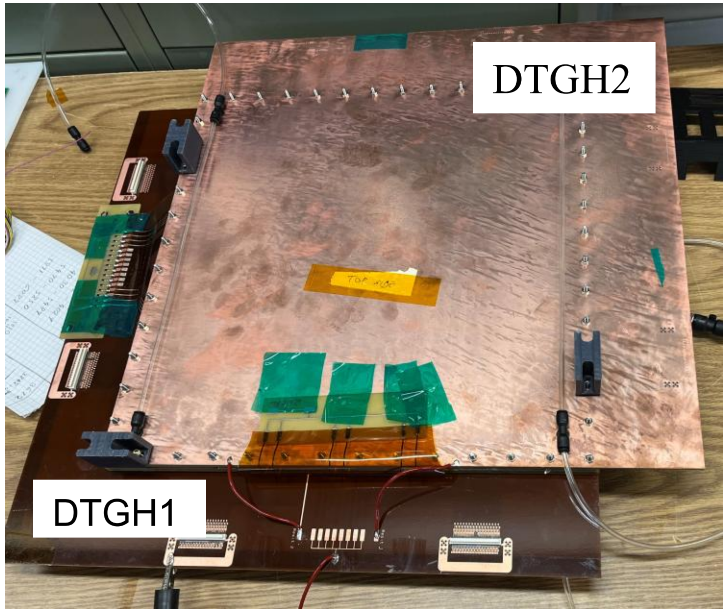
- **DTGH1 -** DLC resistivity: 70 - 95 MΩ
- μRWELL hole
  - Pitch = 100 μm
  - OD = 70 μm
  - ID = 40-50 μm



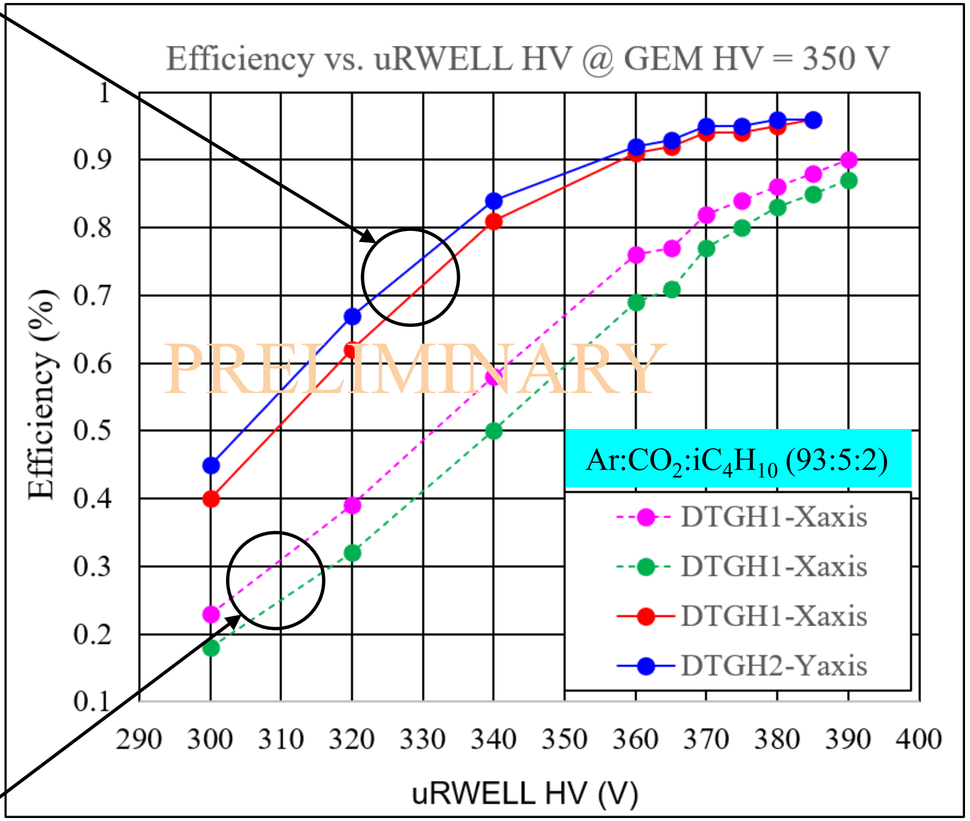
Reconstructed 2D muon beam profile in each detector in the setup

Preliminary results – Efficiency plots

- **DTGH2** - DLC resistivity: 40 - 55 MΩ
- μRWELL hole
  - Pitch = 100 μm
  - OD = 70 μm
  - ID = 40-50 μm

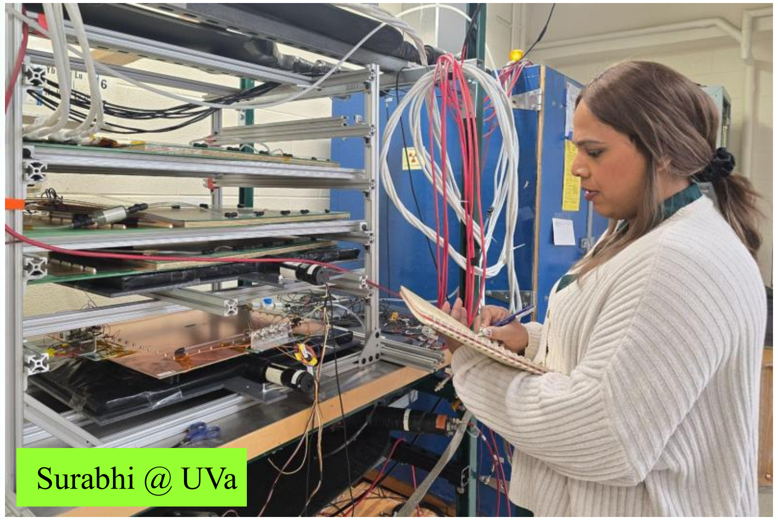


- **DTGH1** - DLC resistivity: 70 - 95 MΩ
- μRWELL hole
  - Pitch = 100 μm
  - OD = 70 μm
  - ID = 40-50 μm



- μRWELL parameters (i.e. DLC resistivity, hole parameters, thicknesses etc …) all critically impact detector performance.
- This prototype has a different DLC resistivity for each side.
- DTGH1 resistivity higher than DTGH2 but the two μRWELLs have the same hole parameters
- Preliminary results shows that DTGH2 with lower resistivity has a significantly higher gain than DTGH1
- DTGH2 efficiency ~97% while DTGH1 ~89%

DTGH Team



Surabhi @ UVa

Kondo Jacob & Seungjoon

Jacob, Huong & Kondo

Seungjoon, Jacob, John & family, Huong & Kondo

DRD1 Group @ CERN + 16 participating groups @ End of beam test barbecue

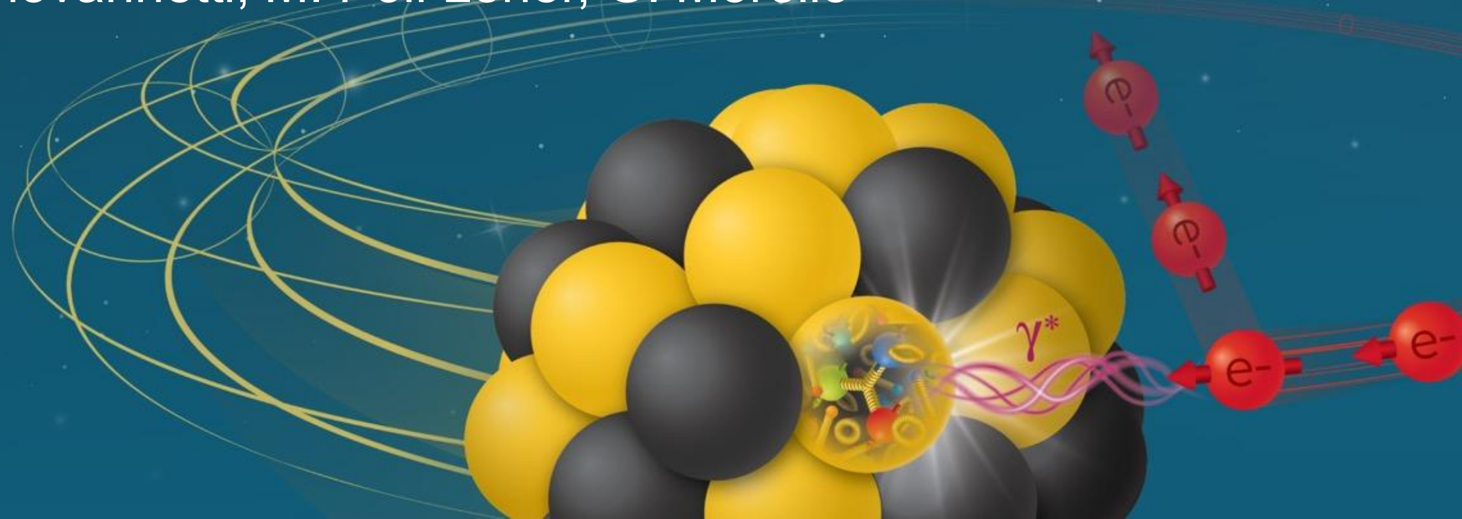
MPGD ENDCAP Trackers (ECT) for ePIC

Test Beam 2026 @H4 CERN

On behalf of the **ECT project group**: C. Ammendola, R. Ammendola, M. Bondì, A. D’Angelo, R. Di Salvo, A. Fantini, S. Gramigna, L. Lanza, G. Nobili, E. Sidoretti, E. Tusi

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

Temple University: M. Posik, B. Surrow



Electron-Ion Collider

MPGD-ECT Technical Performance Requirements

Time resolution

- Time resolution~ 10 ÷ 20 ns or less to provide timing able to discriminate among different bunches

Low material budget

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

Spatial resolution: ~ 150 μm

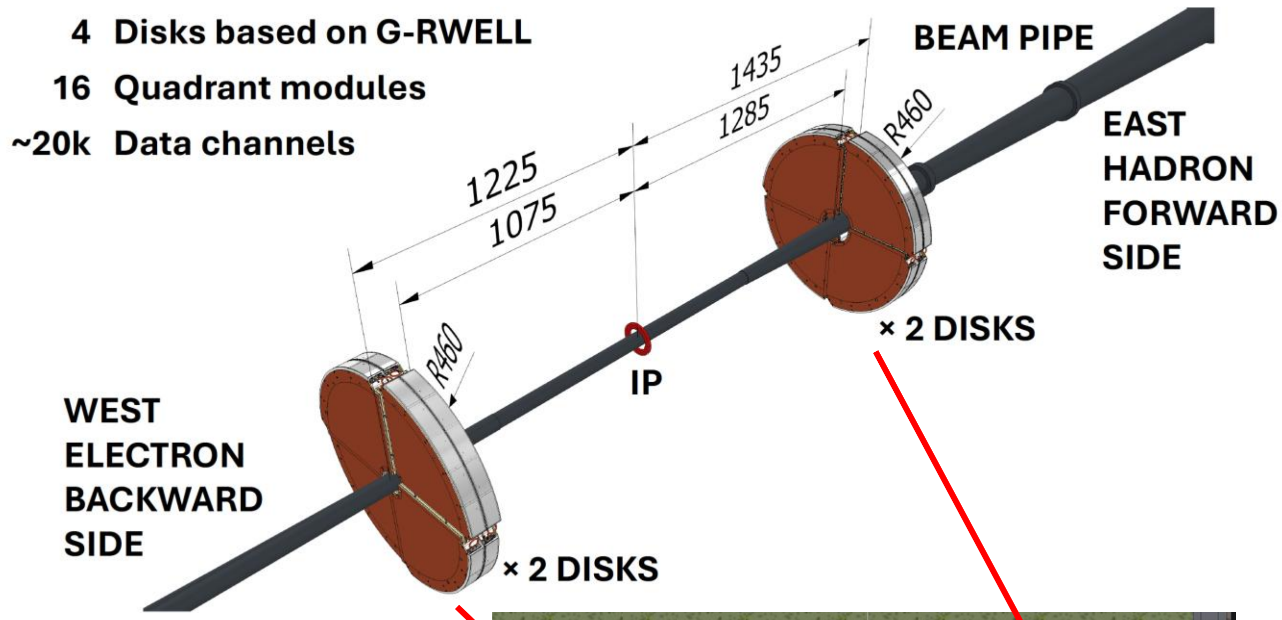
- <150 μm intrinsic spatial resolution for perpendicular tracks
- Technological optimizations to retain 150 μm resolution for inclined/curved tracks → μTPC mode

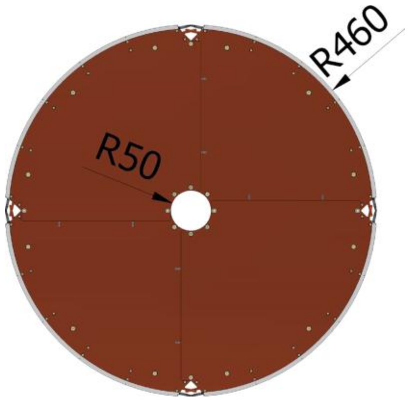
High Efficiency

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

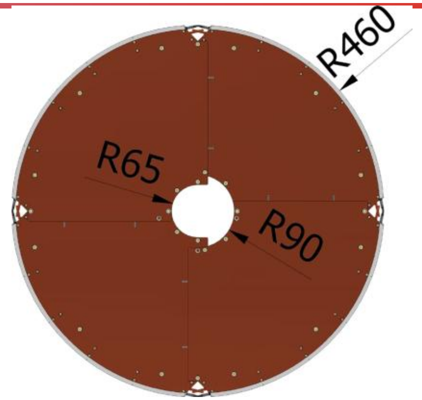
GEM-µRWELL ECT Project Update: updated geometry

Quadrants envelope updated to optimize integration



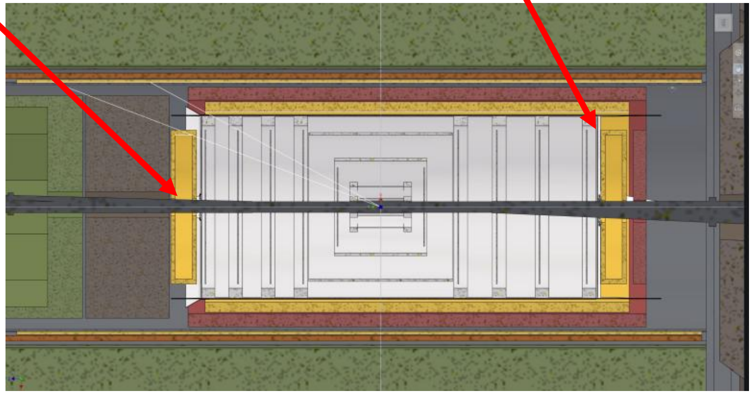


Lepton disks



Hadron disks

- Hadron disks have been located closer to the IP
- Outer radius has been reduced: 50 cm to 46 cm to leave space for SVT services



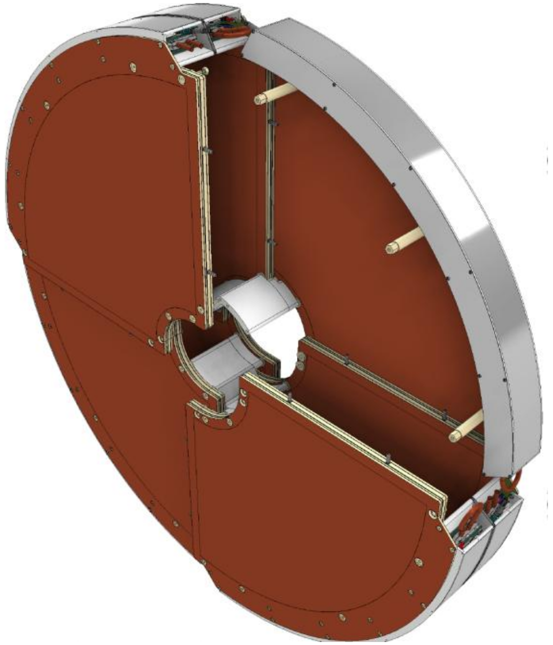
3 quadrant designs overall:

Electron side
  1 design → 8 quadrants

Hadron side
  2 designs → 4 + 4 quadrants

Quadrants **overlap** to achieve total azimuthal coverage

Different inner radii of the hadron side modules to cope with **beam pipe asymmetry**



By Stefano Gramigna

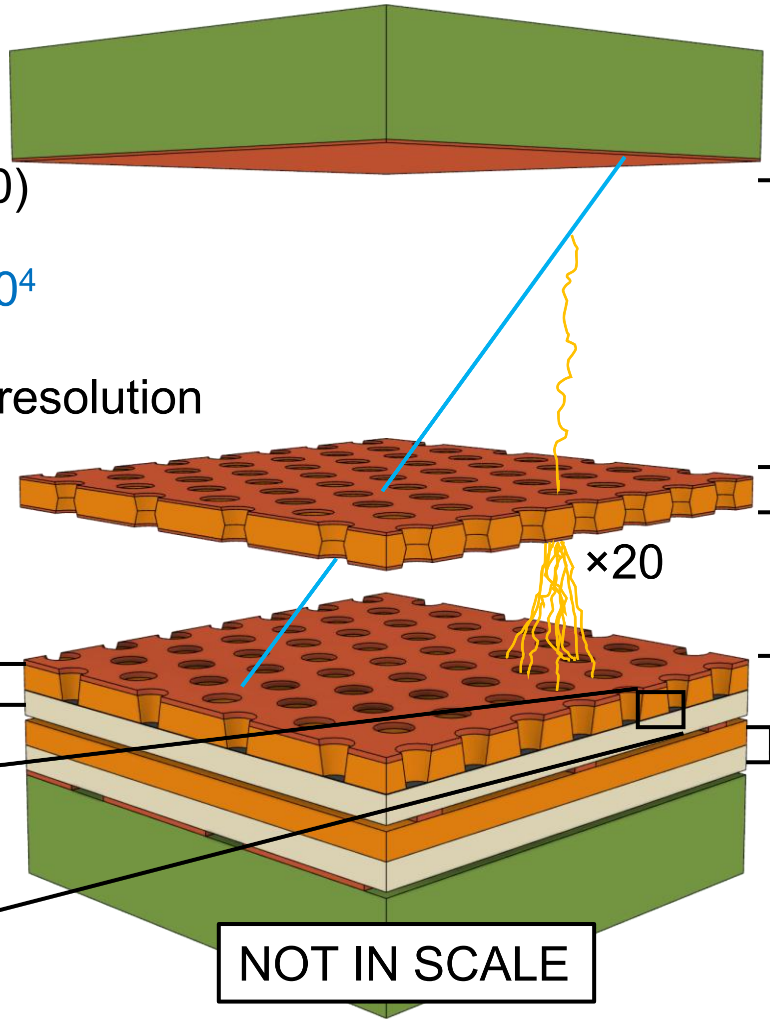
New MPGD Technology: - GEM-µRWELL Hybrid Detector

Two stages hybrid solution:

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

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

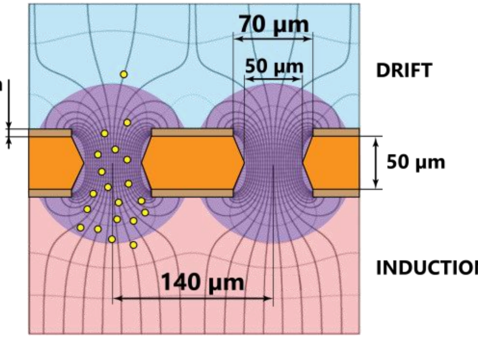
600 μm pitch guarantees 150 μm spatial resolution



CATHODE
~ 3 mm lightweight support
5 µm copper

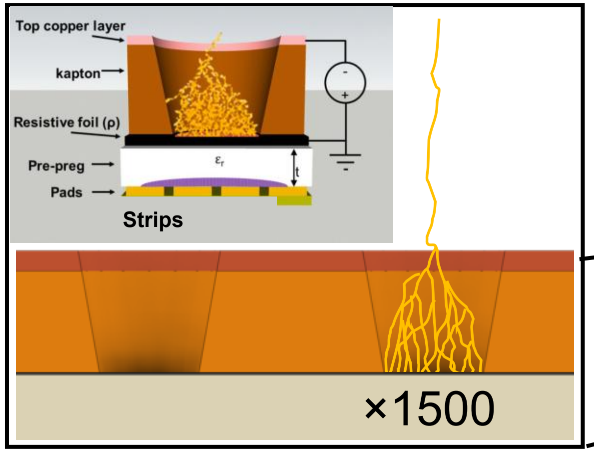
DRIFT
6 mm

GEM
5 µm Copper
50 µm Kapton
5 µm Copper



TRANSFER
3 mm

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



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

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

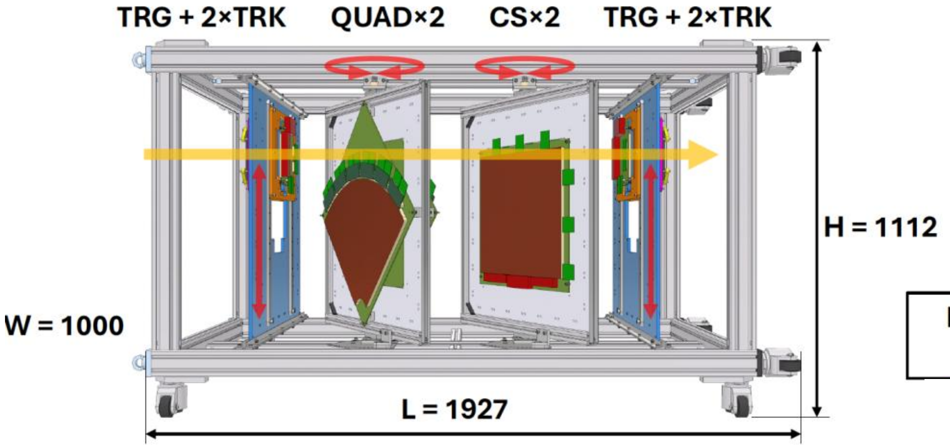
MPGD endcap - 2026 Test Beam

Scope:

- Study detectors performances (position and time resolutions, efficiency) using different gas mixtures
- Optimization of the drift gap
- Uniformity studies

Understand if all MPGD detectors can find a common gas mixture

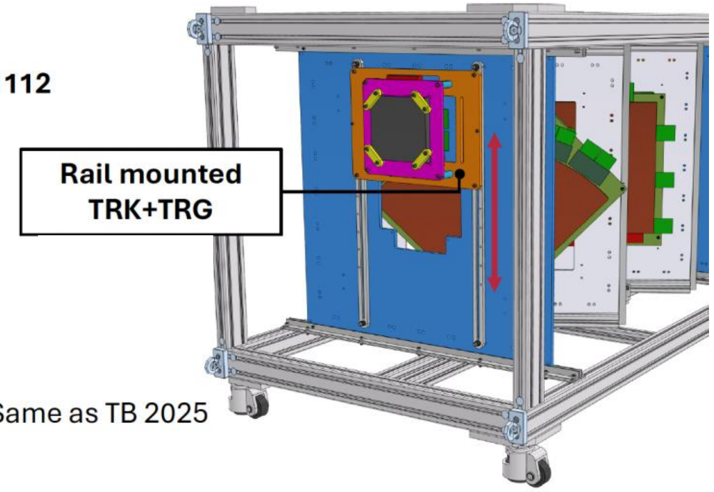
Mixture	Ar	CO2	iC4H10	CF4	Max Flow (sccm)	Max Flow (l/h)	Limiting Gas	Min Flow (sccm)	Min Flow (l/h)	Limiting Gas
Ar:CO2	70%	30%			167	10.0	CO2	28.6	1.7	Ar
Ar:CO2	80%	20%			250	15.0	CO2	25.0	1.5	Ar
Ar:iC4H10	90%		10%		500	30.0	iC4H10	22.2	1.3	Ar
Ar:CO2:CF4	45%	15%		40%	217	13.0	CF4	44.4	2.7	Ar
Ar:CO2:iC4H10	93%	2%	5%		1000	60.0	iC4H10	50.0	3.0	CO2
Ar:CO2:iC4H10	93%	5%	2%		1000	60.0	CO2	50.0	3.0	iC4H10



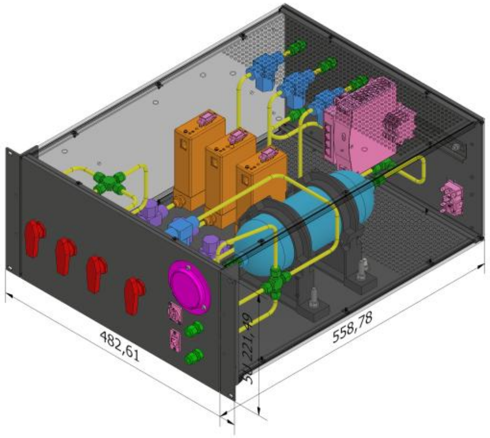
DET	Pitch (µm)	Active Area	Readout	Capacitive Sharing
TRK	400	10x10 cm^2	2D XY	No
QUAD	600	R = 45 cm	2D XY	No
CS	1200	46x40 cm^2	2D XY	3 Layers (300µm)
TRG	NA	15x15 cm^2	SiPM	NA

Same as TB 2025

@ CERN SPS H4 Beam Line 15/7-3/8

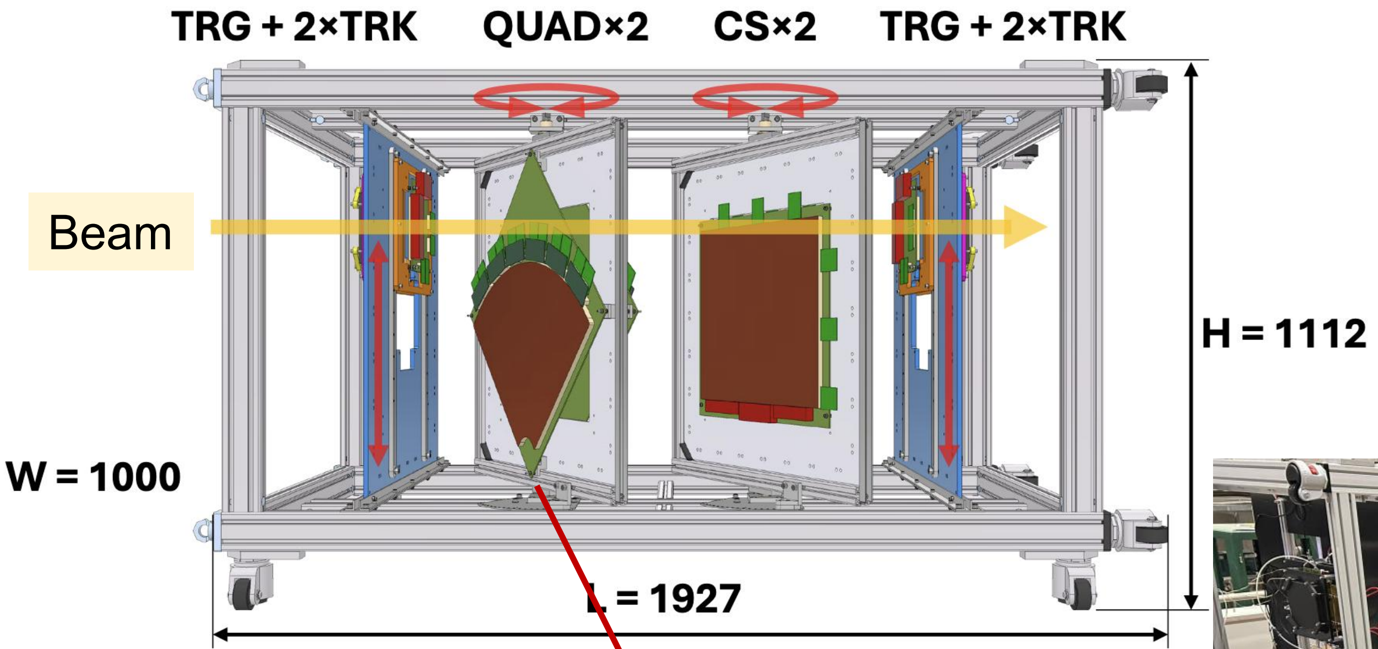


Gas mixing unit

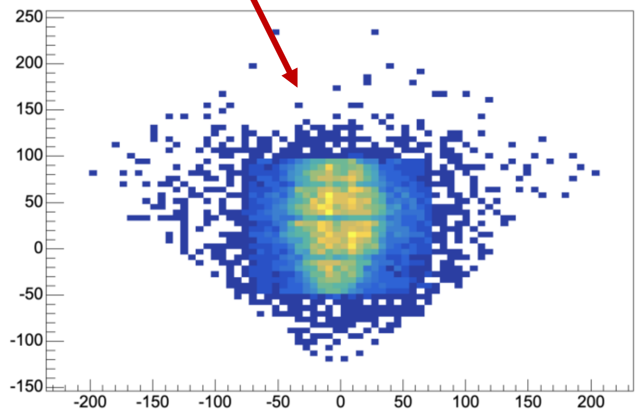


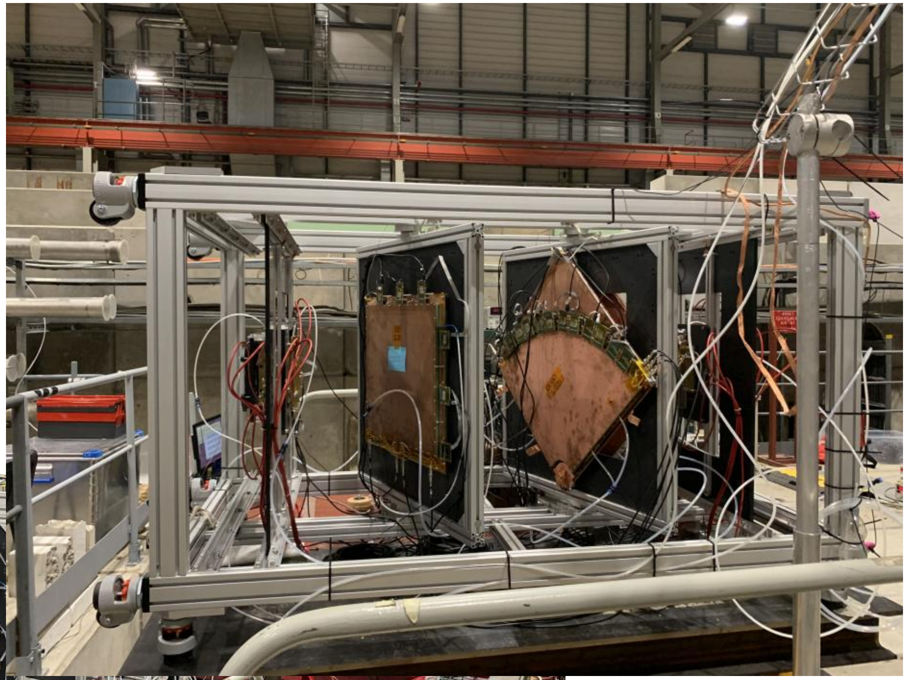
By Stefano Gramigna

GEM-µRWELL ECT- ETA 2026 Test Beam



Hit Map
2026





Here We Are!!

Data taking plan

Gas mixture 1: Ar:CO_2:CF_4 (45:15:40)

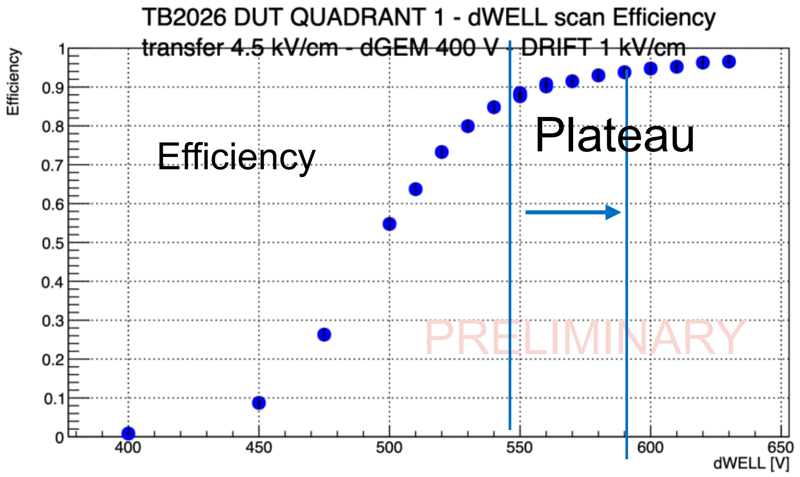
DUT angle = 0° and 20°		
	Quadrants 45 cm radius	40 cm x 46 cm rectangles
ΔV_{GEM}scan	$\Delta V_{Well} = 550$ V, $E_{drift} = 1$ KV/cm, $E_{tranfer} = 4.5$ KV/cm	$\Delta V_{Well} = 550$ V, $E_{drift} = 1$ KV/cm, $E_{tranfer} = 4.5$ KV/cm
Transfer gap HV scan	$\Delta V_{Well} = 550$ V, $\Delta V_{GEM} = 400$ V, $E_{drift} = 1$ KV/cm	$\Delta V_{Well} = 550$ V, $\Delta V_{GEM} = 400$ 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	$\Delta V_{Well} = 550$ V, $\Delta V_{GEM} = 400$ V, $E_{transfer} = 4.5$ KV/cm
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

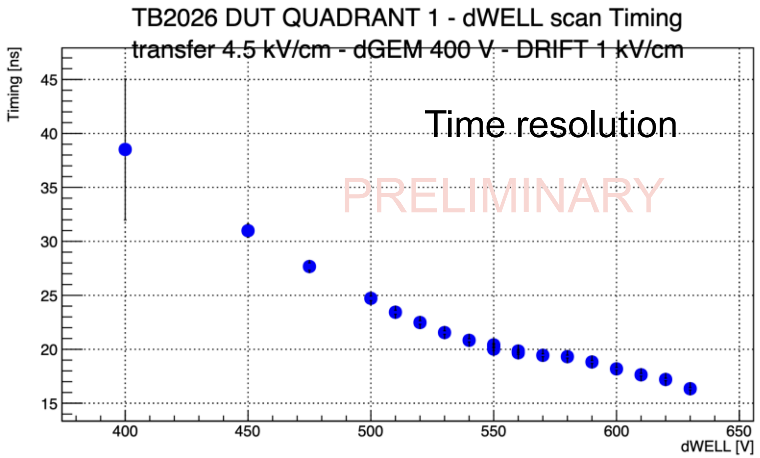
Similar scans were taken with gas mixture 2 Ar:CO_2 :iC_4H_{10} (93:5:2)
The data analysis is ongoing!

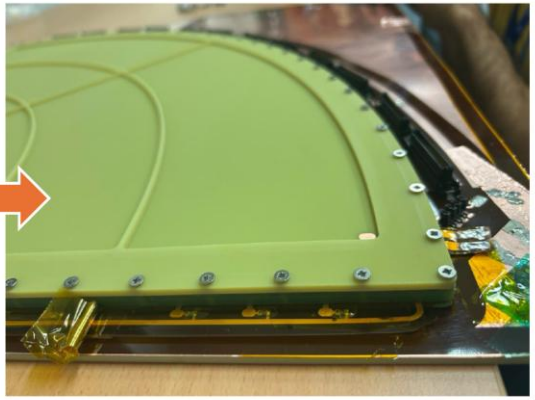
GEM-µRWELL ECT- ETA 2026 Test Beam: On-line results!

Preliminary Results: QUAD1 – reduced drift gap 6 mm → 3 mm

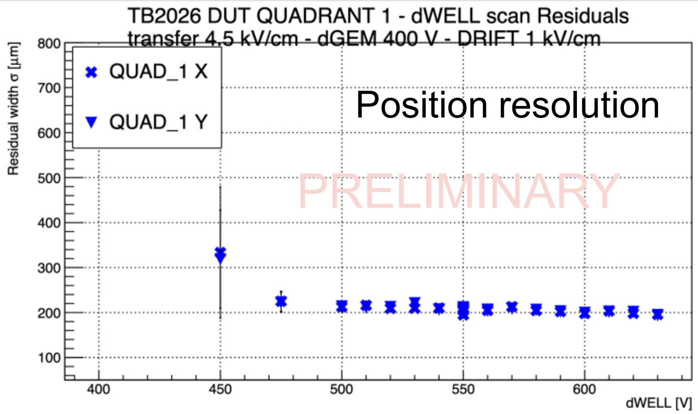
Gas Mixture: Ar:CO_2:CF_4 45:15:40







Modified QUAD1
Drift Gap: 3 mm

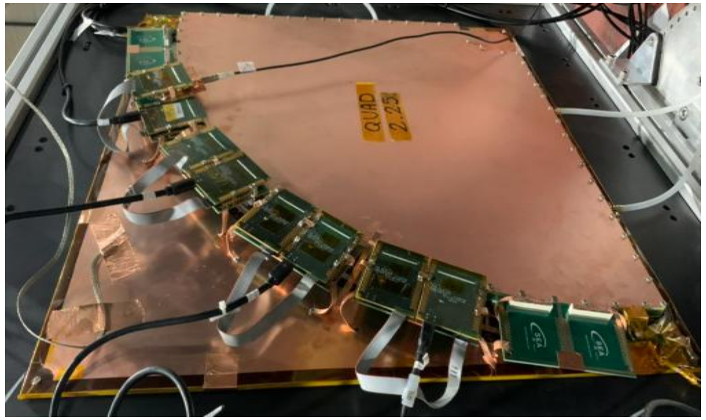


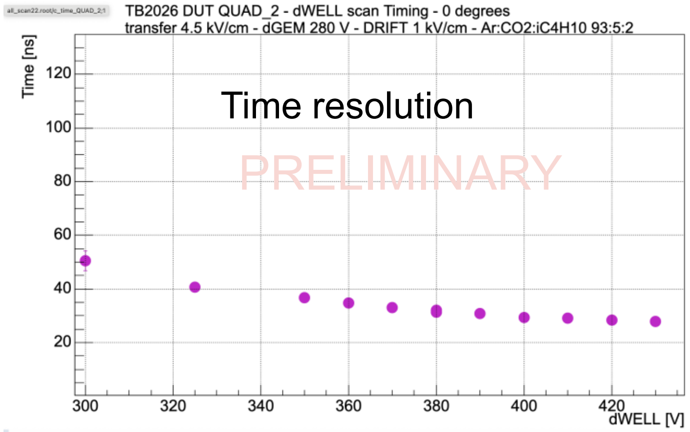
- Detector performances in the rotated reference frame Is compatible with the average performances for X and Y strips obtained in 2025.
- The Plateau is shifted at higher HV working point

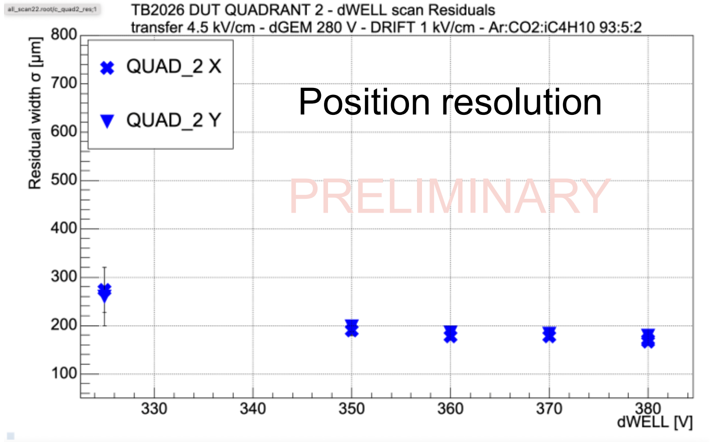
By Elena Sidoretti

GEM-µRWELL ECT- ETA 2026 Test Beam: On-line results!

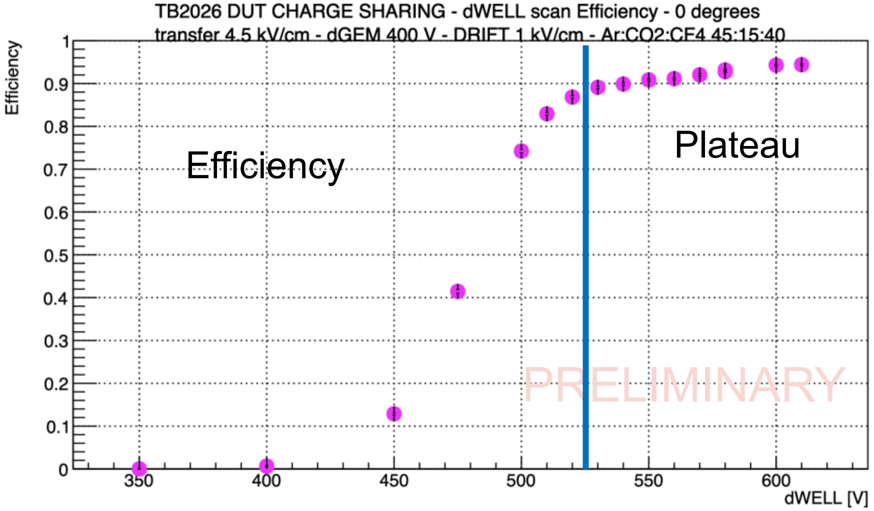
Preliminary Results: QUAD2 – 6 mm drift



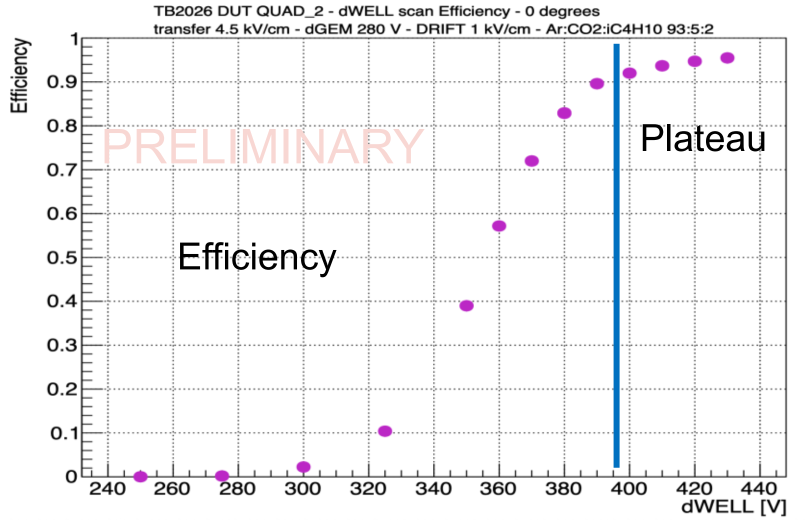




Gas Mixture: Ar:CO_2:CF_4 45:15:40



Gas Mixture: Ar:CO_2:iC4H_{10} 93:5:2



- Timing detector performances reduced with Ar:CO_2:iC4H_{10} compared with Ar:CO_2:CF_4
- Position resolution performances are comparable
- The Plateau is shifted at lower HV working point

By Elena Sidoretti


Thank you!

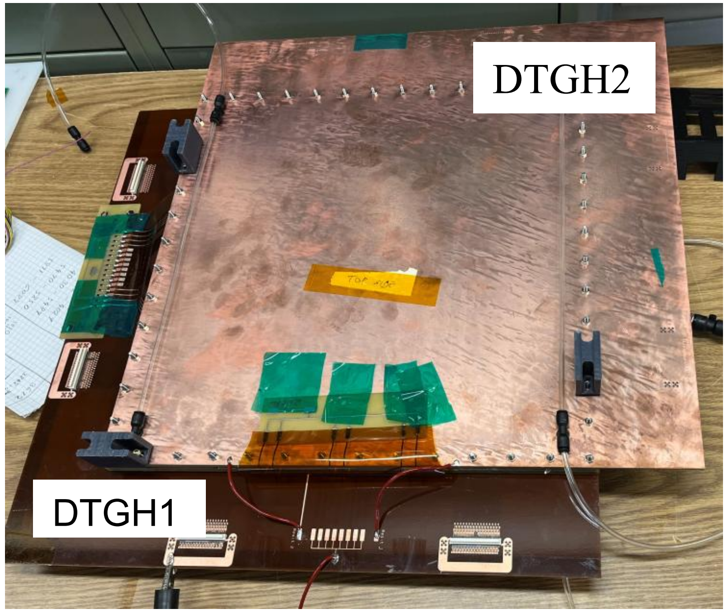
Summary - What's next

- ePIC MPGD Trackers beam test program at CERN I July 2025 was very successful
- Both MPGD-BOT and MPGD-ECT were able to complete their program and achieve their goals with large statistic data
- We demonstrate that the two subsystem could operate with the same gas mixture anticipated to be used by CyMBaL
- Thin Gap Hybrid Detectors operates flawlessly in 1.5T field in the GOLIATH magnet providing a critical information for the MPGD in ePIC magnetic field
- The data analysis will take over now in the next few months and we anticipate to publish the beam test results in a peer-review journal with one year
- Great thanks for all the CERN DRD1 colleagues for the wonderful organization and execution of the beam test campaign accommodating 16 different program

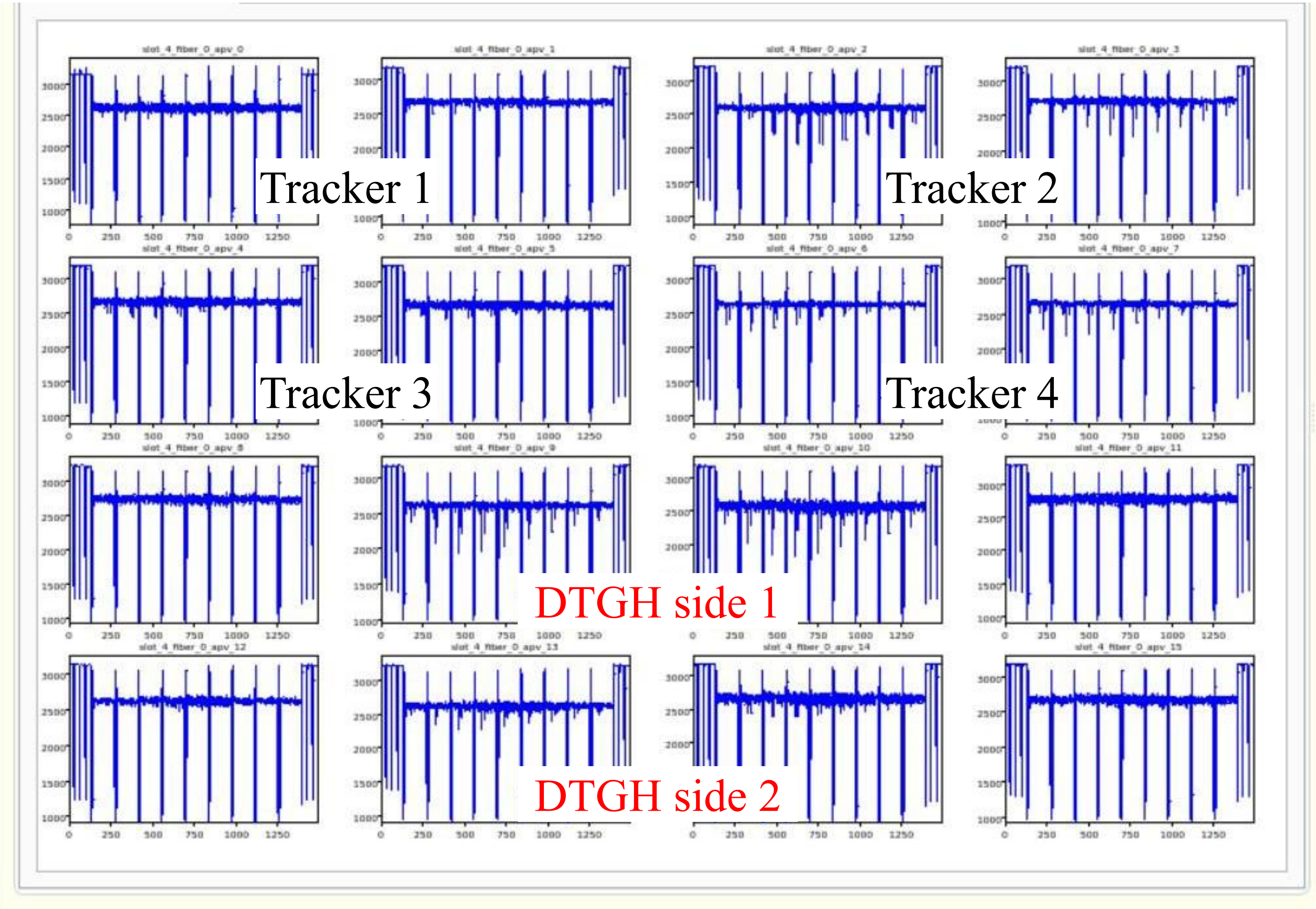
Backup

Preliminary results – APV-SRS raw data

- **DTGH2** - DLC resistivity: 40 - 55 MΩ
- µRWELL hole
  - Pitch = 100 µm
  - OD = 70 µm
  - ID = 40-50 µm



- **DTGH1** - DLC resistivity: 70 - 95 MΩ
- µRWELL hole
  - Pitch = 100 µm
  - OD = 70 µm
  - ID = 40-50 µm



Raw hit in the APV25 frame of each detector in the setup