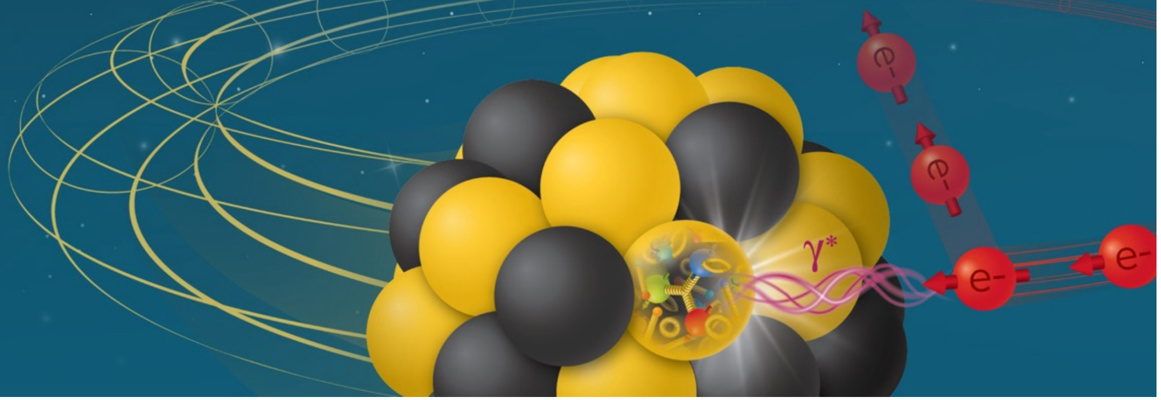
MPGD ENDCAP Trackers (ECT) for ePIC

GEM−μRWELL technology

Annalisa D'Angelo – ePIC ECT project coordinator

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

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



INFN ePIC Referee Meeting
Torino, July 35, 2025

Electron-Ion Collider

GEM-μRWELL ECT Project Update: OUTLINE

Scope of the MPGD endcap trackers in the EPIC detector.
- Detector Geometry: Envelope and Active Regions
- Pseudo-rapidity coverage: effective η ranges
- Technical performance requirements

Detector technology
- 2D – readout challenges and test beam results
- Hybrid GEM-μRwell technology - μTPC readout

→ **PhD Thesis by Elena Sidoretti**
Master Thesis by Luca Torlai

Detector Design and Engineering Test Article
- Endcap design: 4 quadrants
- (X,Y) readout – 600 μm pitch
- Integration of MPGD endcap trackers in the ePIC detector

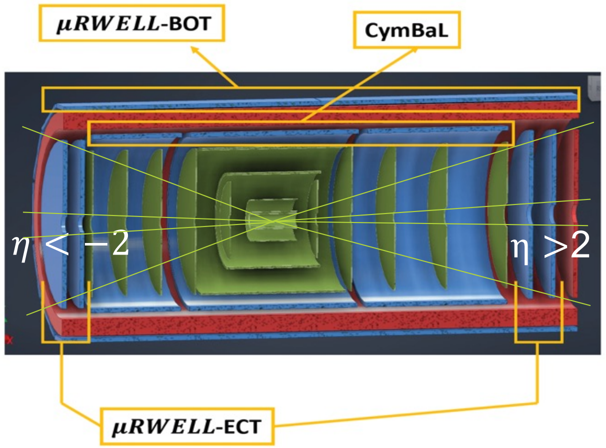
→ **Post Doc: Stefano Gramigna**

INFN Involvement
- Readout Electronics and FEB form factor
- Detector Simulation
- Fabrication and Assembly Plans Timeline & Workforce

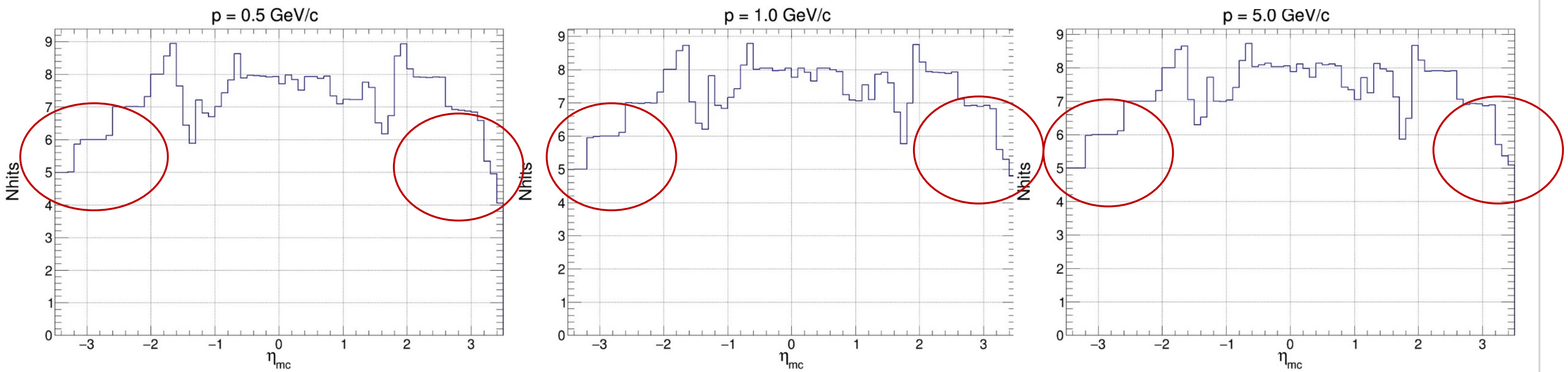
→ **CT: Mariangela Bondì**

MPGD-ECT: the scope of the endcaps in ePIC detector tracking

- Adding **two MPGD Endcap Tracking (ECT) disks** both in the **hadronic** and in the **leptonic regions** increases the number of hits in the $|\eta| > 2$ region to improve pattern recognition.



Source: ePIC Tracker Simulation by Shyam Kumar



The ePIC MPGD End Cap Tracker Envelope and Active Regions

The geometrical envelopes are available at: https://eic.jlab.org/Geometry/Detector/Detector-20240117135224.html → will be updated

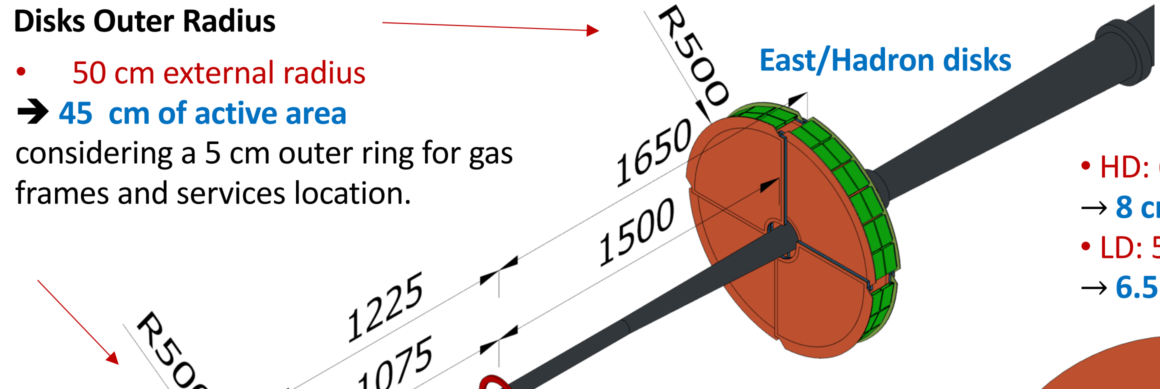
Disks Outer Radius

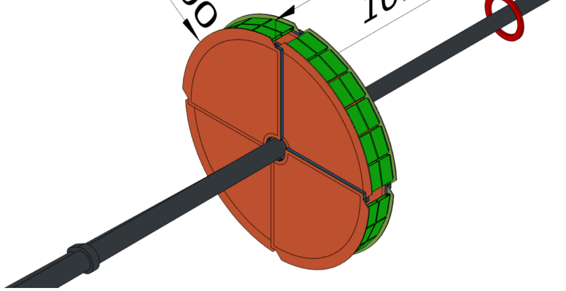
- 50 cm external radius

➔ **45 cm of active area**

considering a 5 cm outer ring for gas frames and services location.

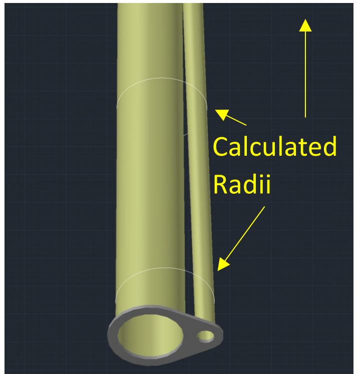
East/Hadron disks





West/Lepton disks

Quadrants **overlap** to achieve total azimuthal coverage



Diverging beam pipes

Disks Inner Radii

different for the two LD and HD regions to accommodate the beam pipe shape

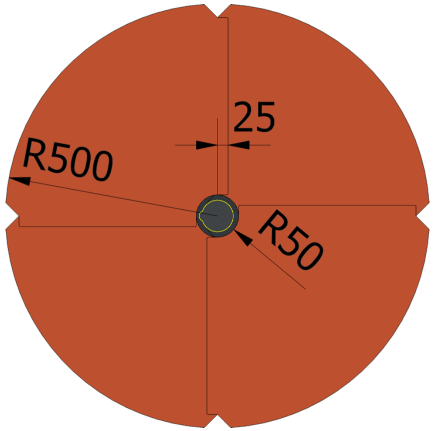
- HD: 6.5 cm & 9 cm inner radii

→ **8 cm & 10.5 cm active area radii**

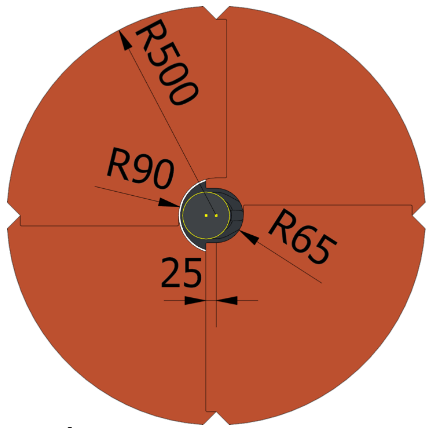
- LD: 5 cm inner radius

→ **6.5 cm radius of active area**

considering 1.5 cm gas frame



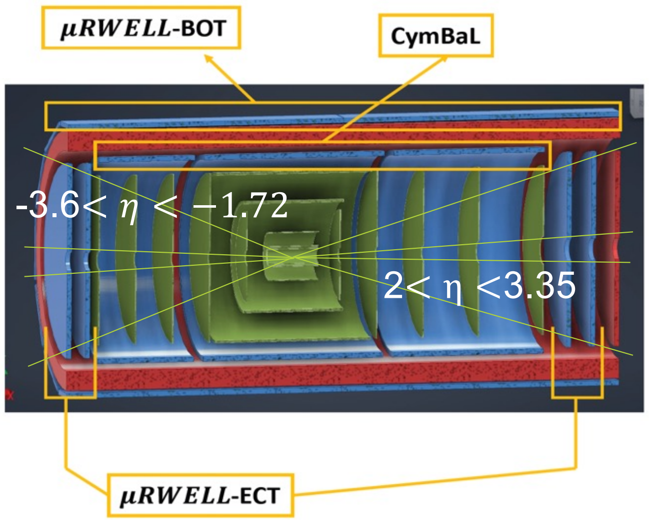
West/Lepton Disk Backward side



East/Hadron Disk Forward side

Pseudo-rapidity coverage: effective η ranges

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	166	8.0/10.5	2.76/3.62	3.73/3.45	45	15.17	2.0
HD MPGD 1	150	8.0/10.5	3.05/4.00	3.62/3.35	45	16.70	1.9
LD MPGD 1	-107	6.5	3.47	3.49	45	22.80	1.6
LD MPGD 2	-122	6.5	3.04	3.62	45	20.24	1.72



- The minimum $|\eta|$ value is not larger than 2
it is limited by the outer HD disk location/dimensions

- The maximum $|\eta|$value is not less than 3.35
it is limited by the inner HD disk location/dimensions

The η **range** covered by the MPGD Endcap tracking disks is **compliant** with requirements.

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

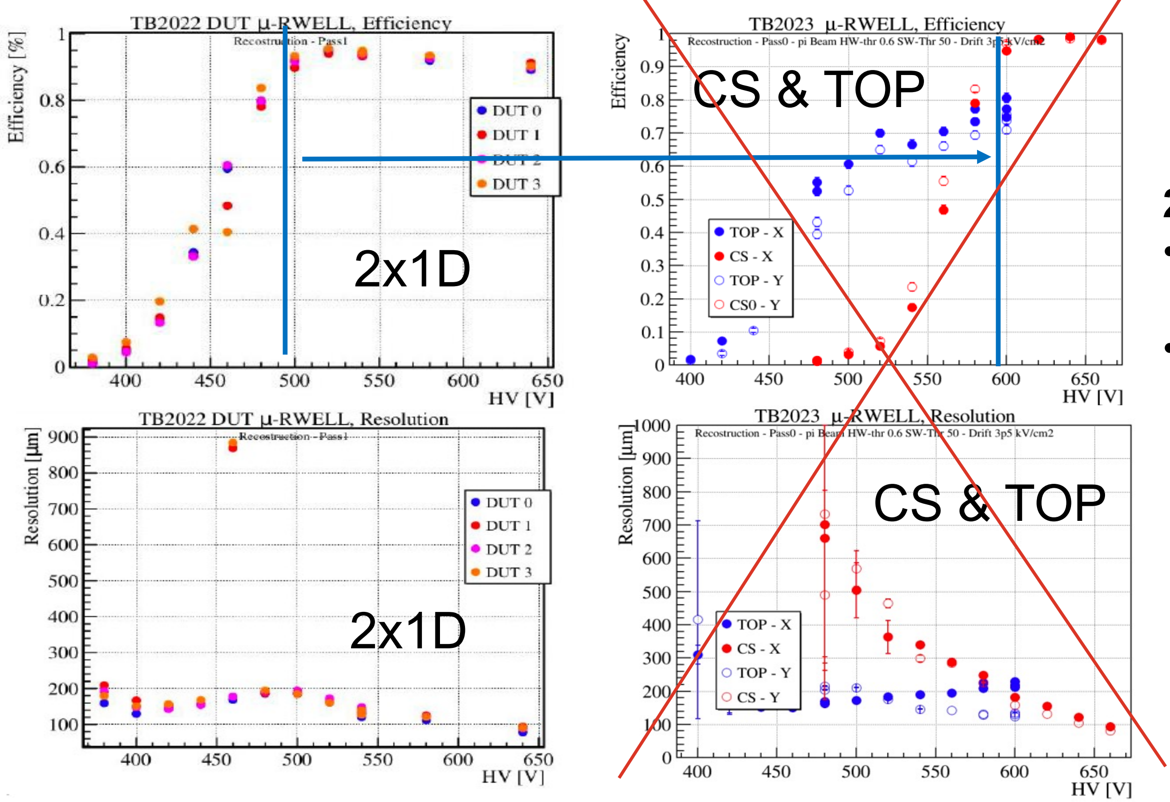
- <150 μm intrinsic spatial resolution for perpendicular tracks
- Technological optimizations to retain 150 μm resolution for inclined/curved tracks → μTPC mode

High Efficiency

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

MPGD Technology: µRWELL from 1D to 2 D

October 2022 test beam | **June 2023 test beam**



1D pitch 0.78 mm

Reference performances:

- 96% efficiency
- 120 μm resolution

2D CS pitch 1.2mm

- Due to the charge spread the working point is shifted to high voltage/gain
- Spatial resolution improves at high gain reaching 150 μm with a strip pitch of 1.2 mm

2D Top-r/out pitch 0.78 mm

- low-voltage/gain operation but low efficiency level (80%) due to the geometrical dead zone on the segmented amplification stage

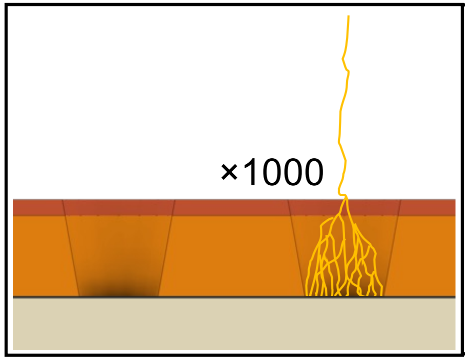
New MPGD Technology: - GEM-μRWELL Hybrid Detector

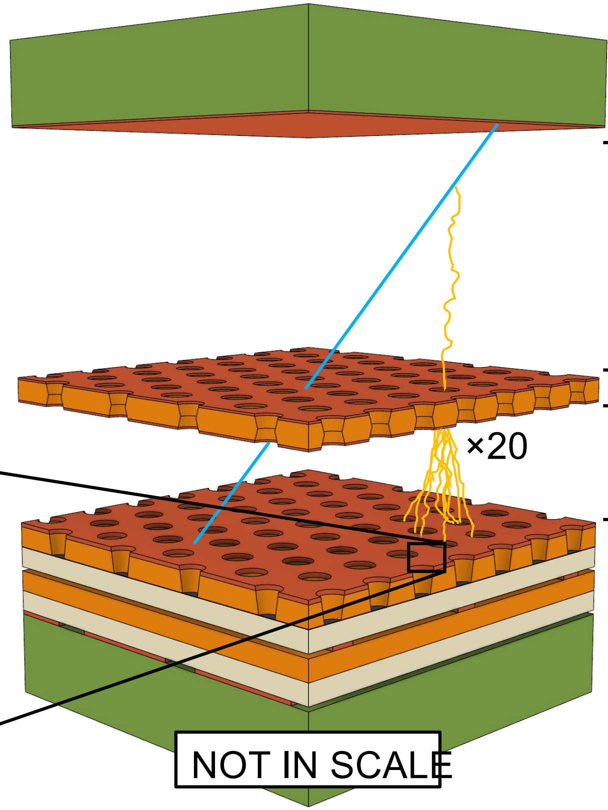
Two stages hybrid solution:

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

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

- 600 μm pitch guarantees 150 μ 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 → 2 mm in the future?

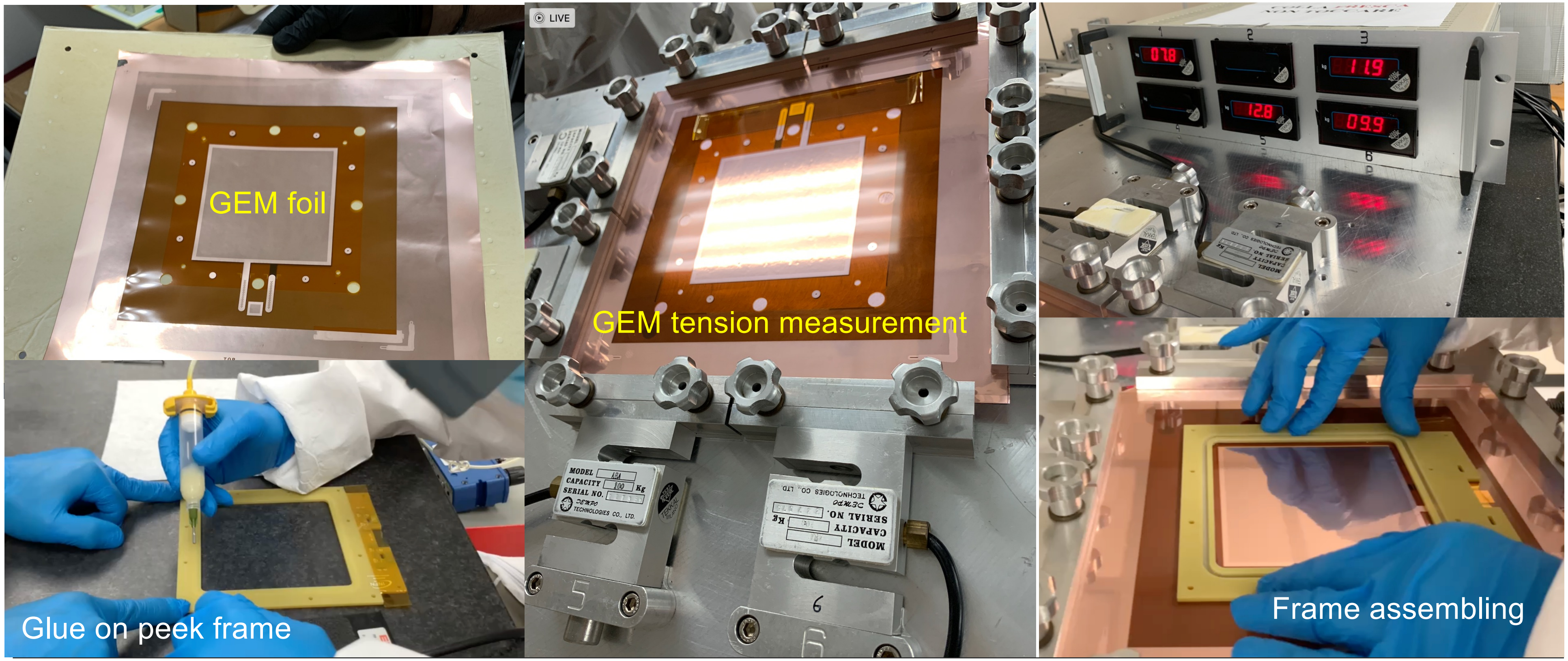
μ-RWELL
10 μm copper
50 μm Kapton
~ 100 nm DLC

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

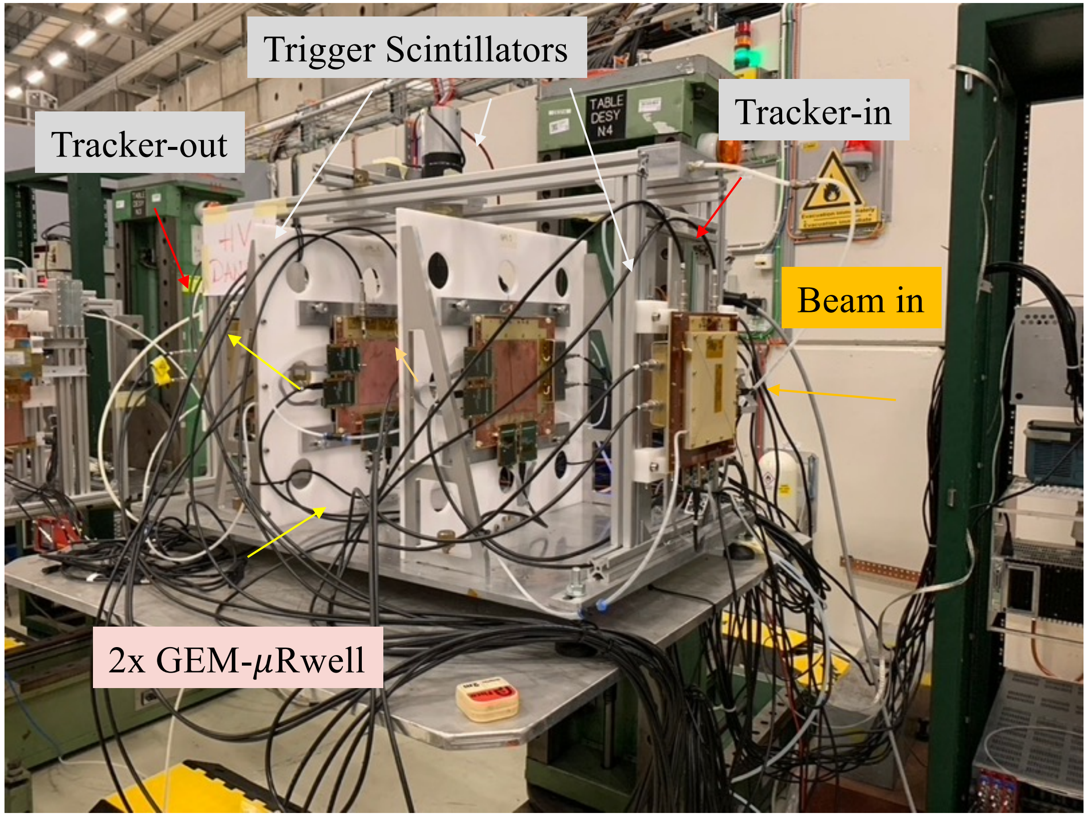
All R&D Studies for EIC disks performed in synergic collaboration with INFN-LNF and JLAB

New MPGD Technology: - GEM-μRWELL Hybrid Detector

GEM 10x10 cm^2 layer assembly



GEM-μRWELL Hybrid Technology 2024 Test Beam



All detectors :
2D COMPASS-like readout
400 μm pitch

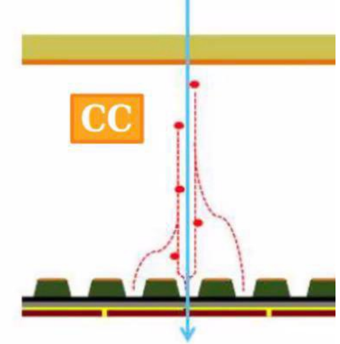
Tracker-In : μRwell – 3 mm drift gap

Tracker-Out : GEM-μRwell
6 mm drift + 3 mm transfer gaps

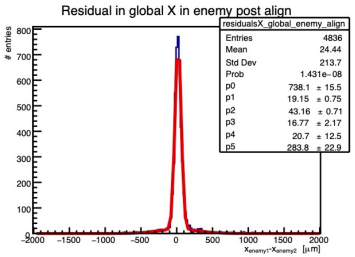
Detectors Under Study (DUT)
- 2 x GEM-μRwell prototypes
- 6 mm drift + 3 mm transfer gaps

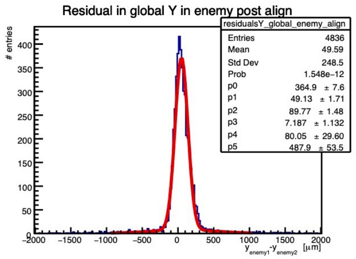
GEM-µRWELL-ECT: Hybrid Technology 2024 Test Beam

By Elena Sidoretti



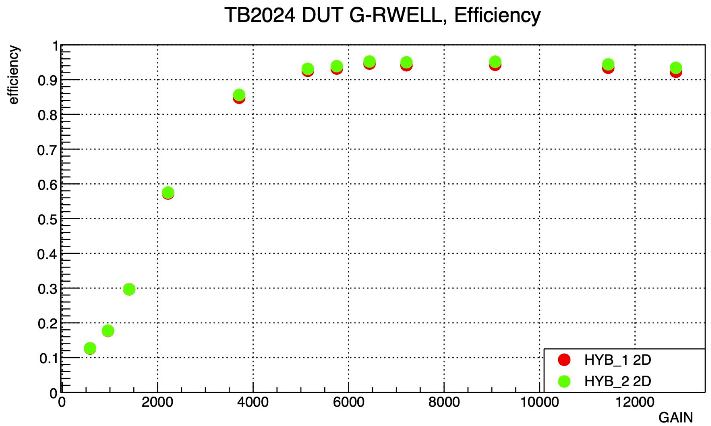
Straight tracks 0°

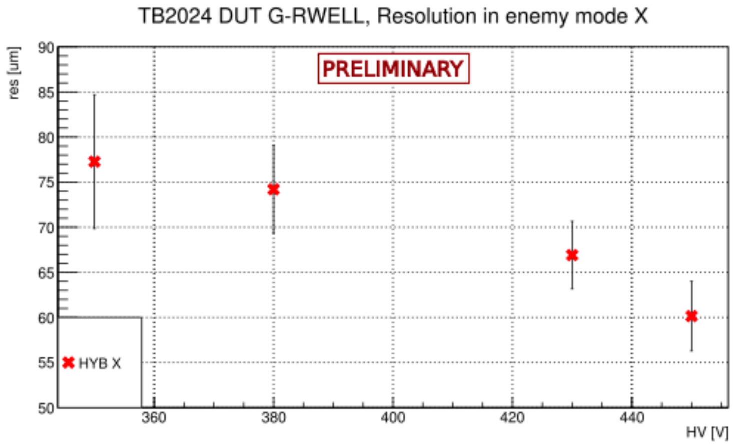




$$x_{cc} = \frac{\sum x_k q_k}{\sum q_k}$$

$\sigma_x = 77.78 \pm 5.59\ \mu m$ $\sigma_y = 123.08 \pm 10.73\ \mu m$



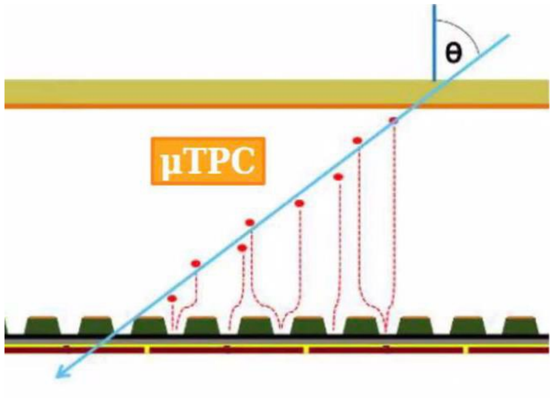


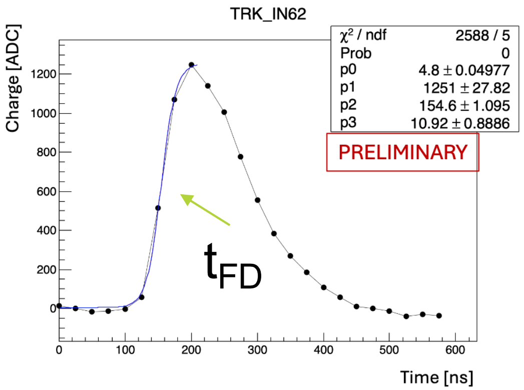
2024 Test Beam assessments

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

GEM-µRWELL-ECT: Hybrid Technology 2024 Test Beam

By Elena Sidoretti



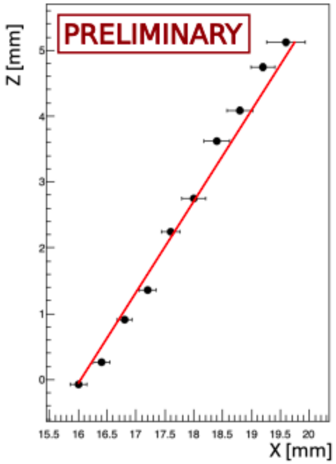


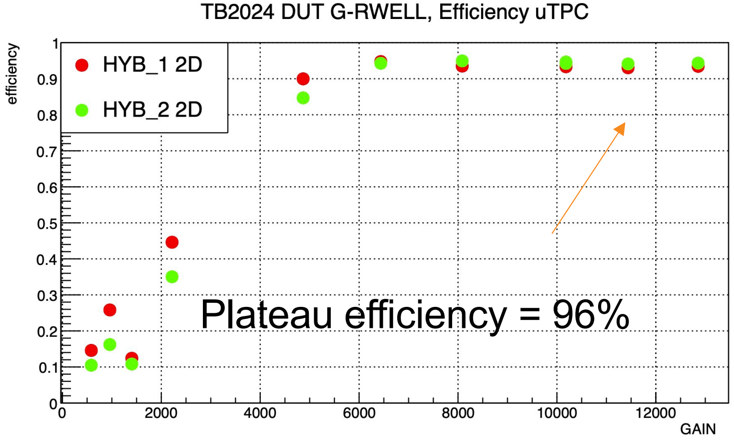
Inclined tracks 30°

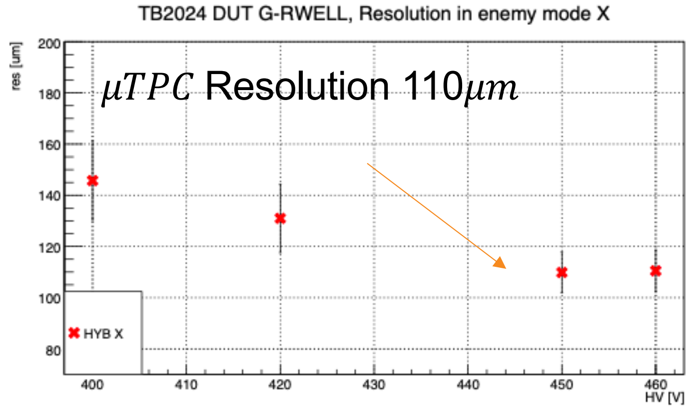
$$t_{hit} = t_0 - t_{FD}$$

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

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

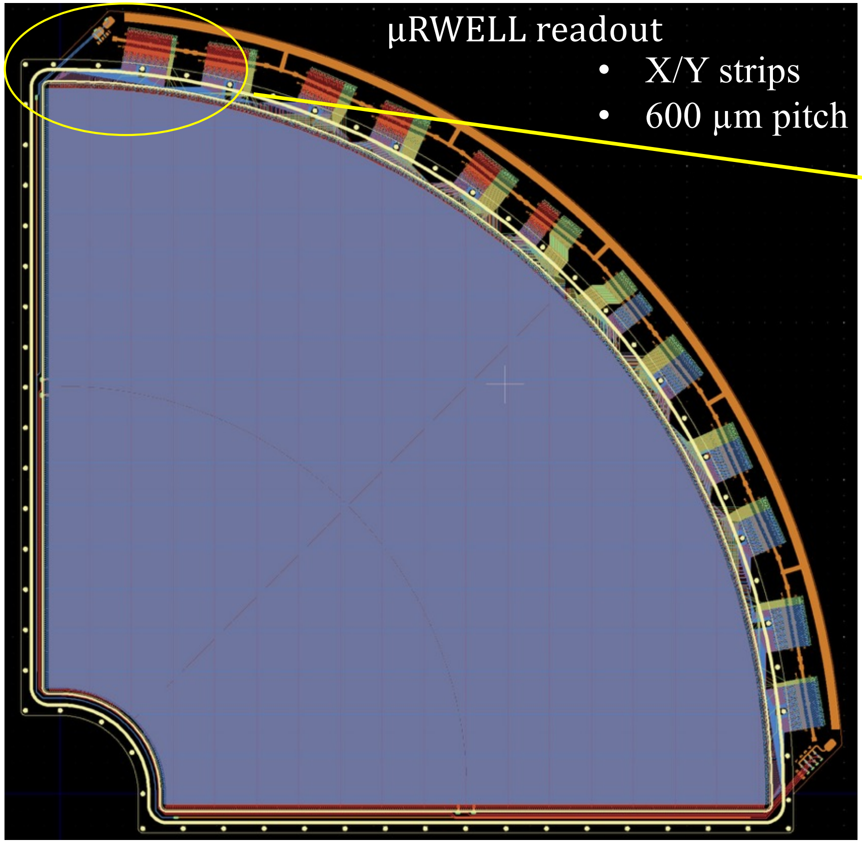


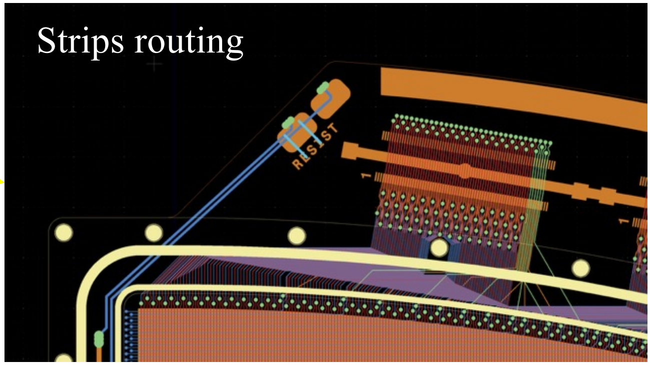




MPGD-ECT: PED Test Article Module

By Stefano Gramigna

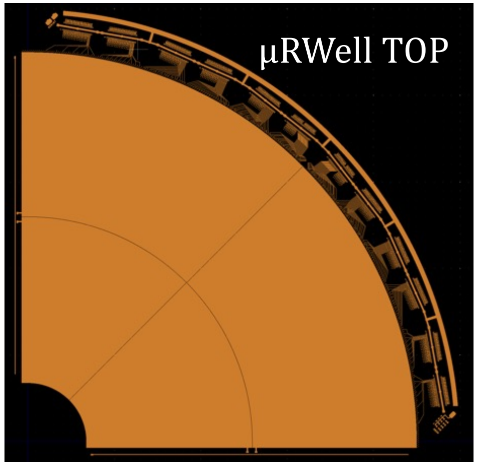


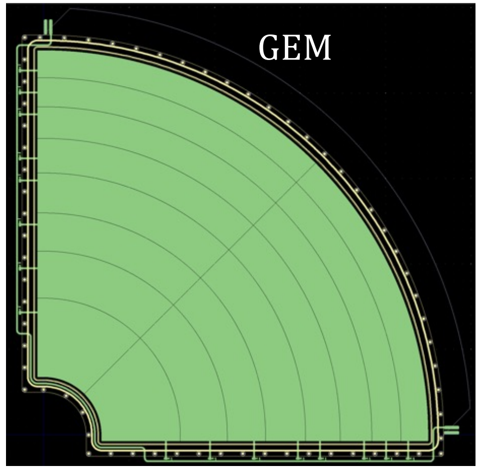


(X, Y) readout

→ no FEB in the active area

Detector delivery expected by Oct. 2025





MPGD-ECT: PED Test Article Module

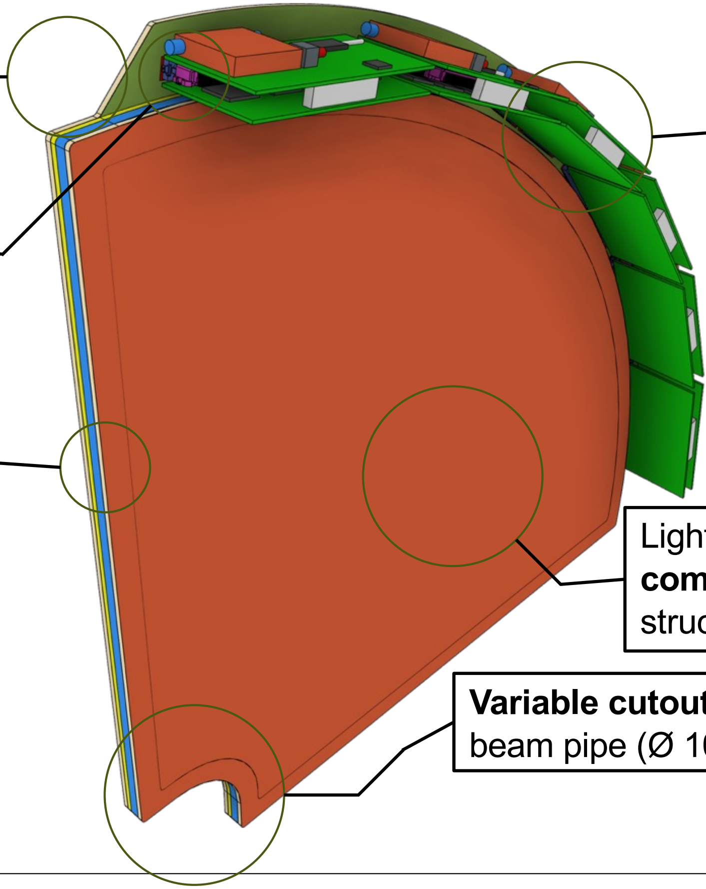
Refer to Stefano's presentation for more details

Cutouts for services
At 0°, 90°, 180°, and 270°

4x **SALSA** ASICs per FEB
2x **Hirose FX20-140P** Connectors per FEB

15 mm wide **Fiberglass** frames to define gas gaps
Fiberglass frames for outer support structures

Still to implement:
- HV distribution
- Gas distribution
- Interconnection framing
- Integration with GST



6 **FEBs** per quadrant located in the service rim

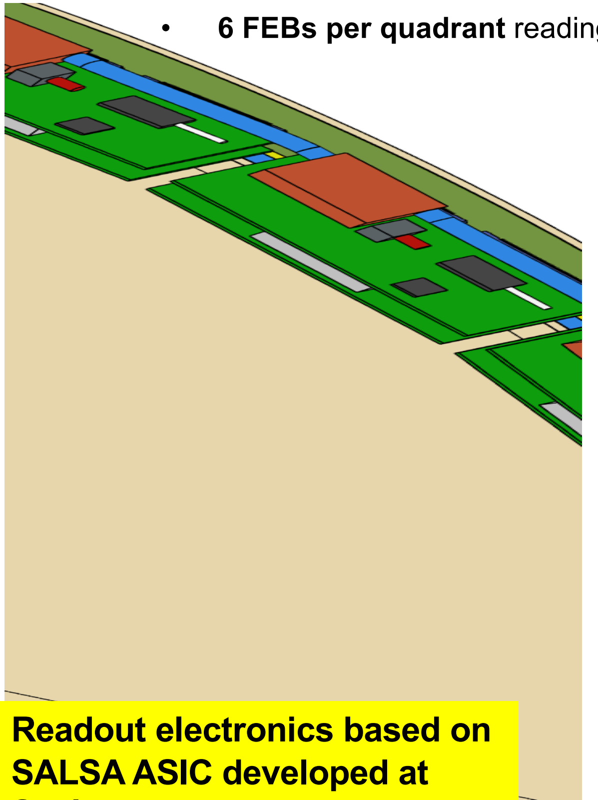
Lightweight **sandwich-structured composites** for anodes/cathodes' structural supports

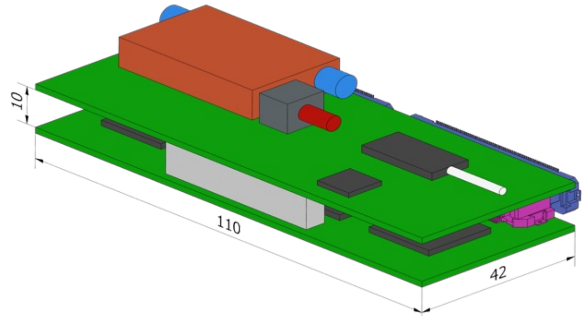
Variable cutout to cope with the asymmetric beam pipe (Ø 100, 130, and 180)

By Stefano Gramigna

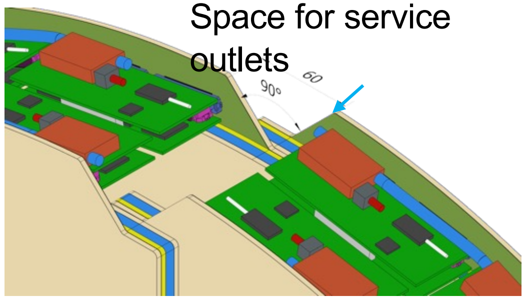
GEM-µRWELL-ECT: Front End Boards (FEB) & Services

- The service rim can accommodate **12 FX20-140P connectors**
- **6 FEBs per quadrant** reading **1524 channels**





Two FEBs in mezzanine configuration separated by 10 mm



Readout electronics based on SALSA ASIC developed at Saclay

All the service requirements have been communicated to the Integration group

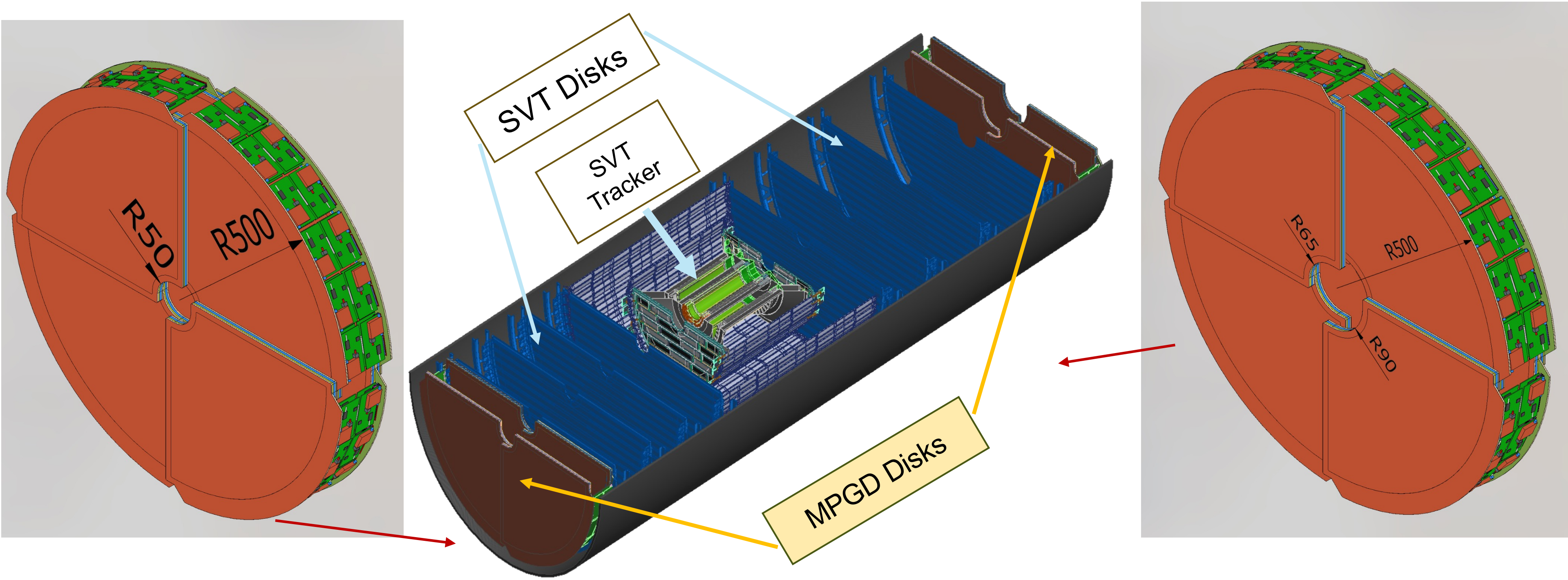
For each endcap disk (4 disks in total):

- 16 HV cables
- 4 gas inlets and 4 gas outlets
- 24 data cables
- 24 low voltage cables
- 2 temperature sensors cables
- 2 humidity sensors cables
- 2 inlet and 2 outlet cooling hoses (H_2O) 210 W cooling dissipation

GEM-µRWELL-ECT: Integration in ePIC Detector

The assigned envelope will include the detectors and the FEB electronics.

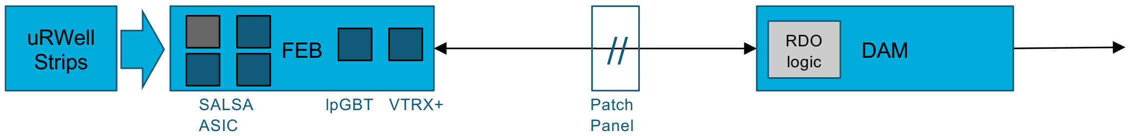
The disks will be attached to the support frame under design.



GEM-µRWELL-ECT: DAQ Scheme and Figures

By Roberto Ammendola

- Readout based on SALSA ASIC developed at Saclay (CEA Irfu)
- Front End boards will host 4 64 channel SALSA chips
- FE Boards modular development in common with other MPGD detectors
- Each detector will work in a specific FEB form factor
- Actual DAQ scheme foresees lpGBT and VTRX+ on FEB and no RDO stage



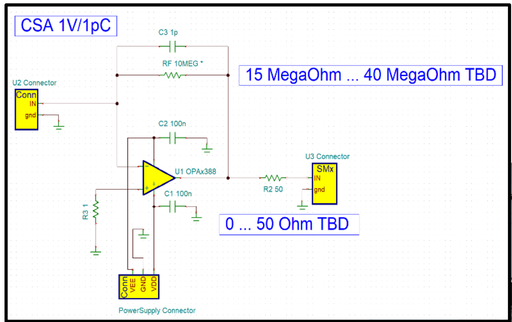
Number of urwell strips per quadrant per dimension	768
Number of channels per SALSA ASIC	64
Number of SALSA ASICs per FEB	4
Number of quadrants per disk	4
Number of channels per DAM	48

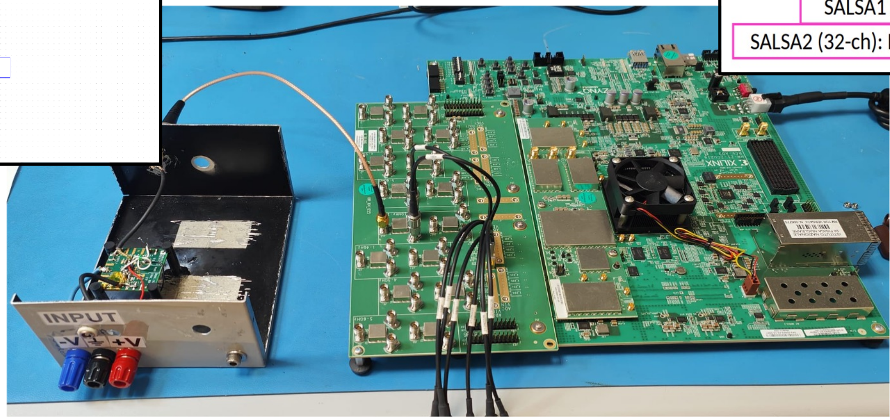
4 disks

	per quadrant	per disk	ECT total
Number of SALSA ASICs	24	96	384
Number of FEBs	6	24	96
Number of DAMs		0.5	2

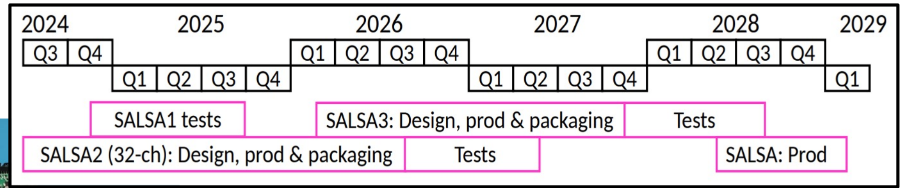
GEM-µRWELL-ECT: Front End and Readout Chain Emulation

- SALSA chip could be available in 2027 for first integration in Front-End boards
- In the meanwhile, we are preparing a testbed to exercise the complete readout chain interfacing with real detector
- Using development board with multi-channel, high sampling rate integrated ADCs FPGAs (AMD Xilinx ZCU216)
- Developing custom charge amplifier (CSA) mimicking SALSA analog stage
- Adding more SALSA features in firmware and coupling with VLDB+ board to implement lpGBT + VTRX+ layer





SALSA Roadmap

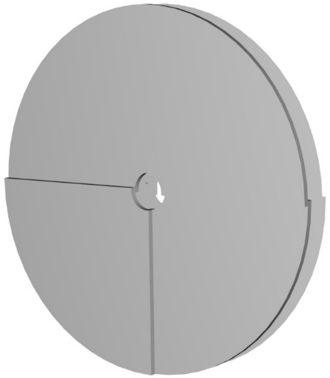


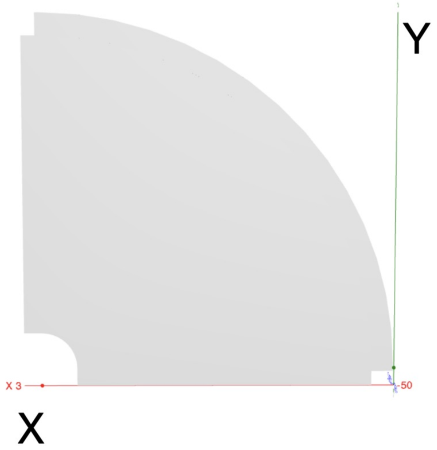
By Roberto Ammendola

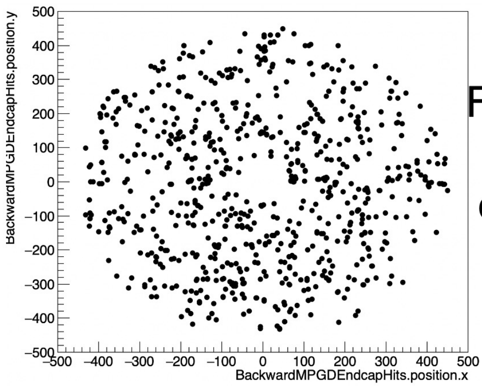
GEM-µRWELL-ECT: Detector Simulation

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

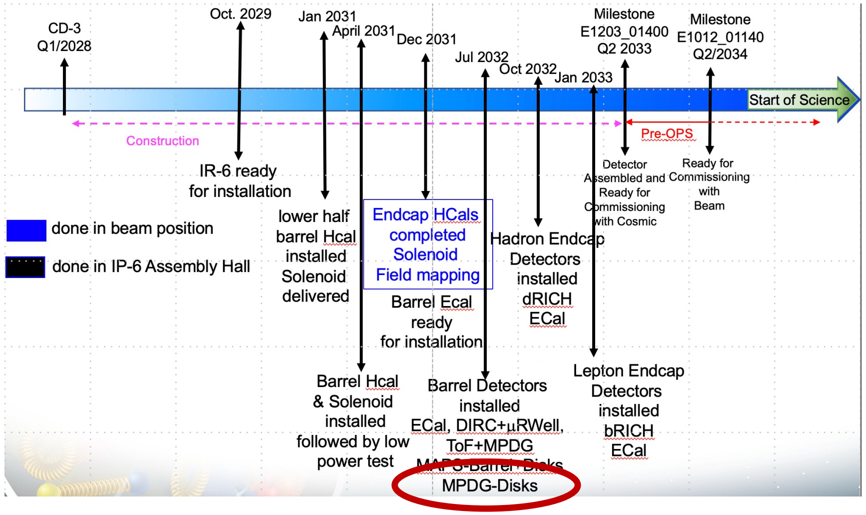
Footprint -

ddsim simulation

Fabrication / Assembly Plans & Timeline / Workforce

MPGD ECT Timeline

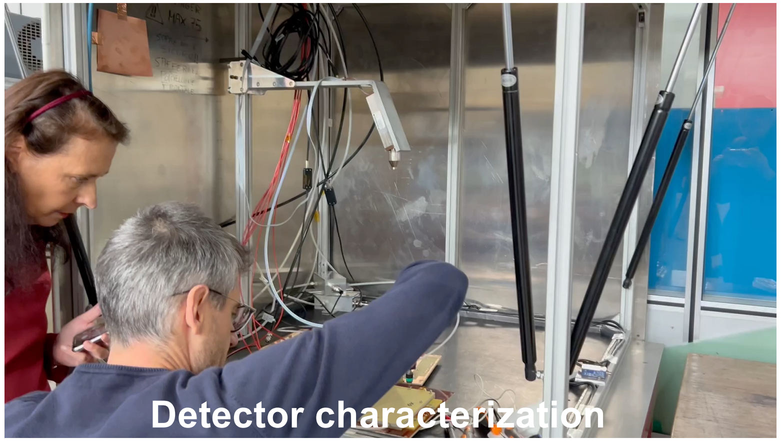
YEAR	INFN R&D K Euro	INFN IN-KIND K Euro	DESCRIPTION
2025	**27**	**15**	**Pre-Production**
2026	30	40	Pre-Production
2027	-	100	Production
2028	-	100	Production
2029	-	100	Production
2030	-	55	Electronics, QA, Commissioning
2031		50	Electronics, QA, Commissioning
2032		40	Installation
TOT	**57**	**500**	

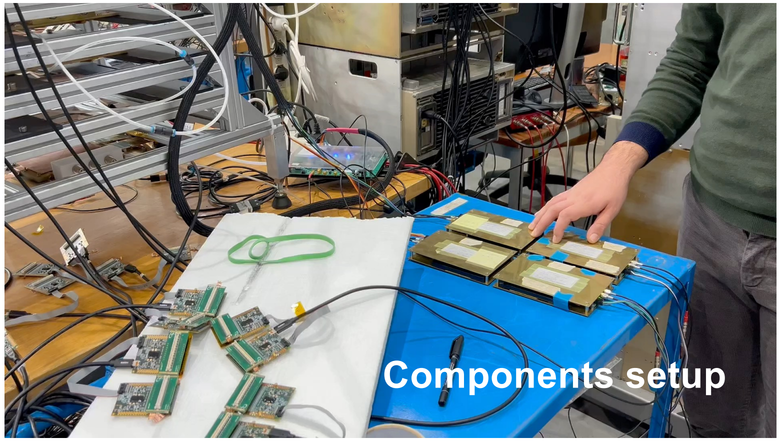


Workforce

- **INFN Groups:**
  - Roma Tor Vergata
  - Catania
  - LNF
  - Genova
- JLab
- Temple University
- Seul University

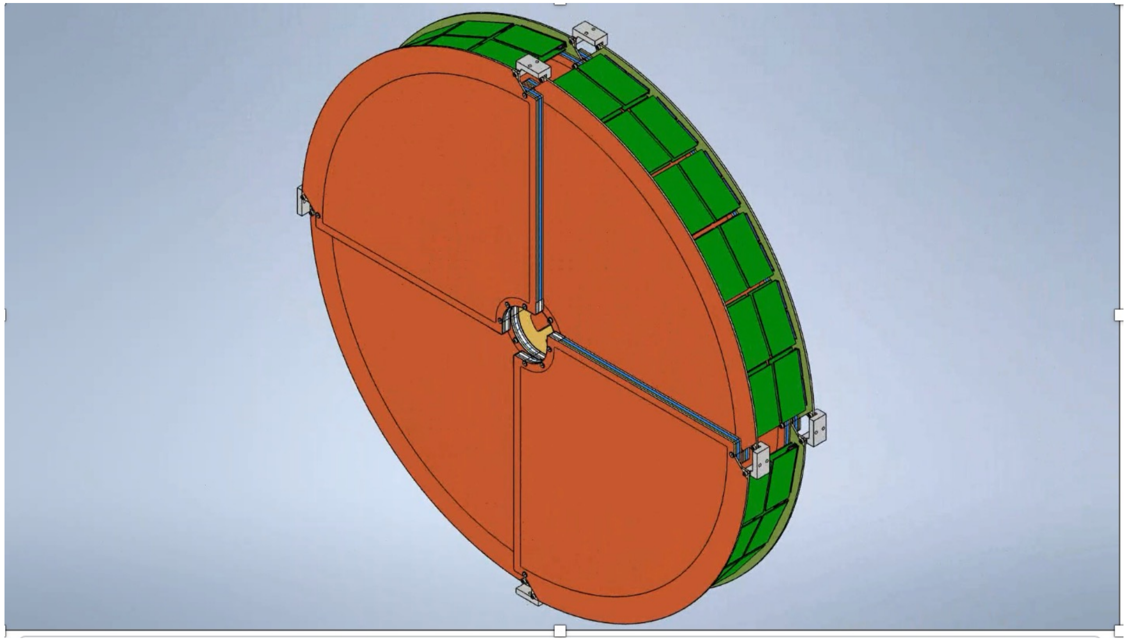
Workforce: Setting up the Test Beam @LNF



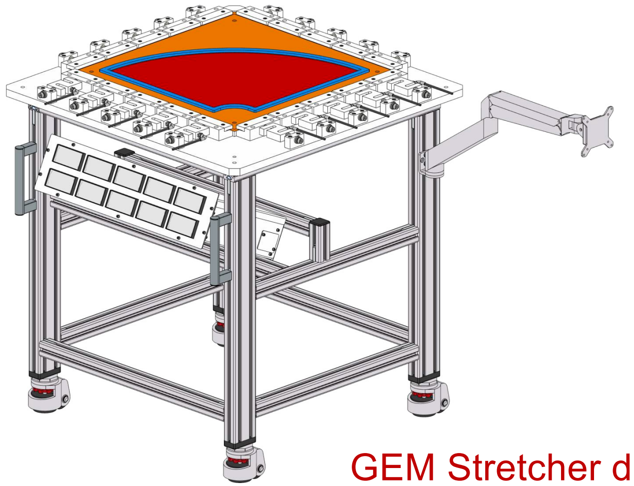


2025 On-Going Activities:

Integration Studies



- GEM Stretcher realization
- MPGD-ECT Integration Studies
- First Engineering Test Articles (ETA) design and procurement
- Test Beam at CERN: November 2025 to characterize the ETA



GEM Stretcher design

2026 Activity Plans

Milestones 2025

30/06/2025 - Studio ricostruzione tracce " μTPC" nei prototipi GEM-uRwell (MPGD-ECT)

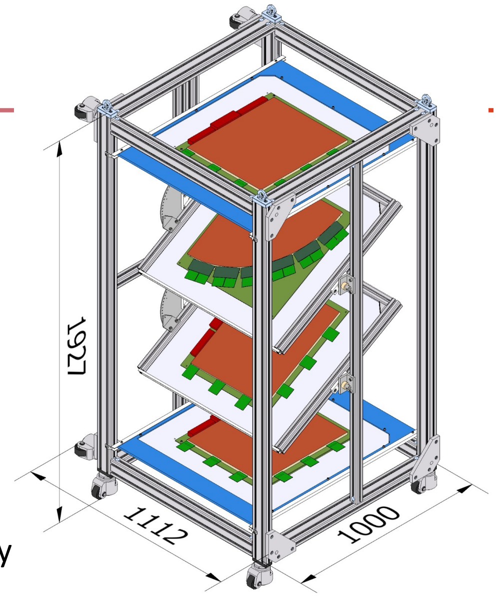
Stato di completamento: **100%**

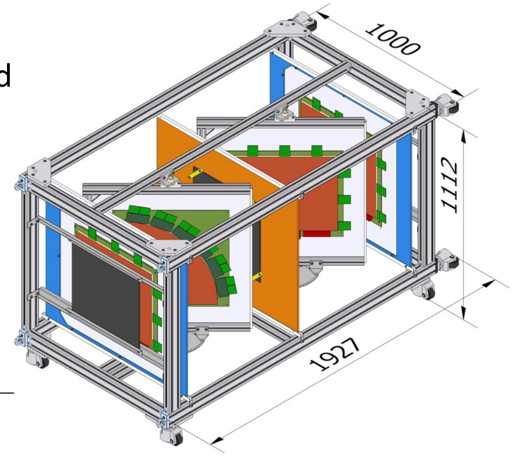
31/12/2025 - Disegno e ordine di produzione del "First Engineering Test Article"

Ordine sottomesso. Stato di completamento: **75%**

NEXT STEPS:

- November 2025 Test-Beam data analysis
- Design and procurement of Light-Weight final version of ECT disk (II Engineering Test Article)
- Completion of the MPGD laboratory at Roma Tor Vergata, by procuring a second CAEN HV supply module
- Emulation of the the GEM-μRwell charge signals acquisition using SALSA chips.
- Procurement and assembly of a detector mechanical support for large area detectors to be used for both cosmic-rays and test beam (compatible with Goliath at CERN.





Proposed Milestones 2026:

31/12/2026 – Caratterizzazione del primo set dei " First Engineering Test Article"

31/12/2026 –Disegno e ordine di produzione di un secondo set di "Engineering Test Article" su supporti a bassa massa ed ottimizzati per l'integrazione nel rivelatore ePIC.

2026 Financial Requests to INFN

Richieste Roma Tor Vergata	
Item	**Costo Totale IVA inclusa k€**
2 set di Engineering test articles light weight a forma di quadrante ottimizzati per la loro integrazione in ePIC → IN-KIND	40
Supporto meccanico per rivelatori a grande area per test con raggi cosmici e test beam → R&D	7
2 moduli CAEN A1561HDN - SYx527 H.V. channels -6 KV 20 uA SHV (12ch) - 50pA res. → R&D	13.5
Gas box per Quality Assurance GEM → R&D	3.5
KIT di elettronica di backend basato su VLDB+ per acquisizione dei segnali delle MPGD in emulazione del chip SALSA e della DAQ prevista in ePIC → R&D	4.5
Sostituzione Filtri EPA per camera pulita (50% del costo)	12
Materiali di consumo per accesso in camera pulita (tute, calzari, cuffie, materiale per incollaggio..)	4
Licenza Autodesk Inventor per disegni meccanici	3
Totale	**87,5**

A financial travel request of **17.5 K€** for the RM2 participation to Test Beam (**10 K€ s.j)**, collaboration meetings and exchanges with Catania and Genova groups.

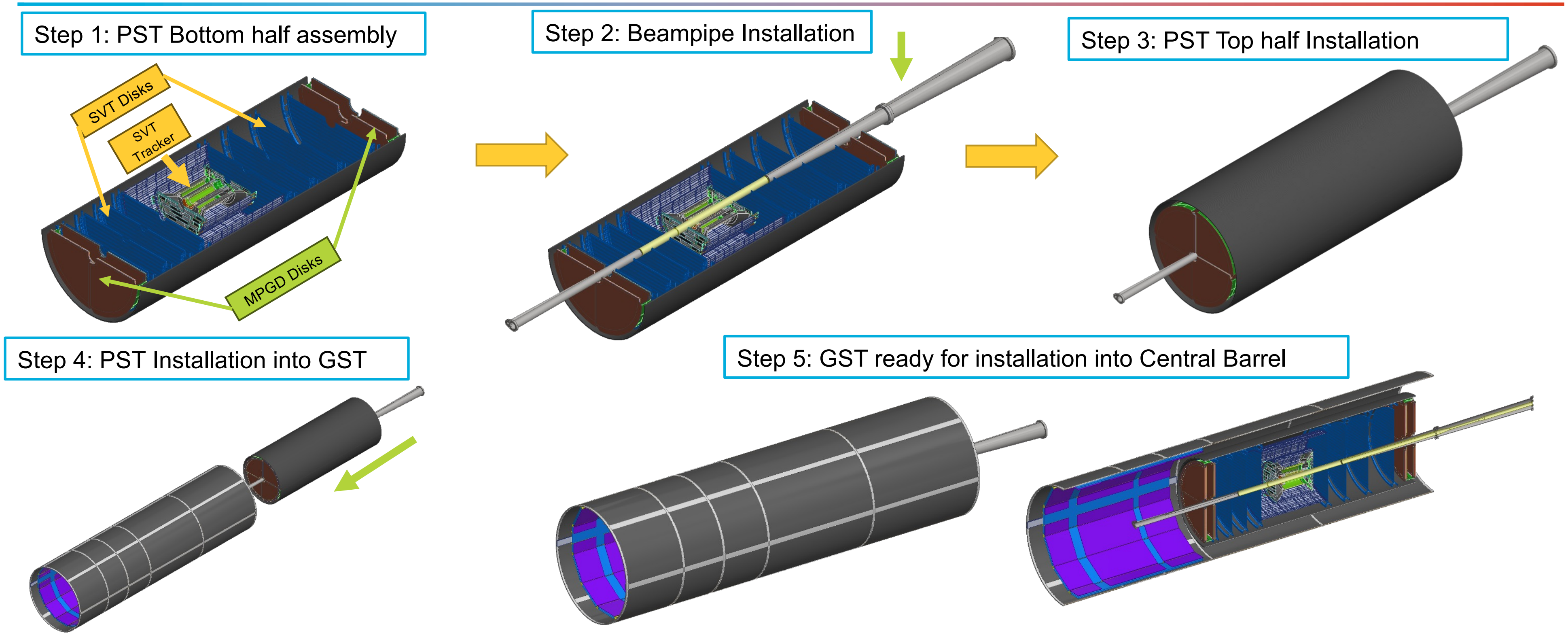
Total Request 105 K€

GEM-µRWELL ECT: Summary

- Geometrical Acceptance and Technical Performances of hybrid GEM-μRwell endcap trackers have been assessed.
- A detector layout compliant with position resolution and tracking efficiency requirements has been identified.
- The disks are segmented into four quadrants, connected and attached to the inner tracker support, maximizing the azimuthal and polar acceptances. Integration studies are on-going
- Readout Electronics is based on SALSA ASIC, being developed at Saclay. A SALSA ASIC emulator is being designed at INFN Roma Tor Vergata to test the final electronics chain.
- Workforce is available to meet the timeline of the production and assembly plans.
- Production timeline is consistent with the overall ePIC detector schedule.
- INFN – In kind financial support has been re-modulated accordingly.

Thank you

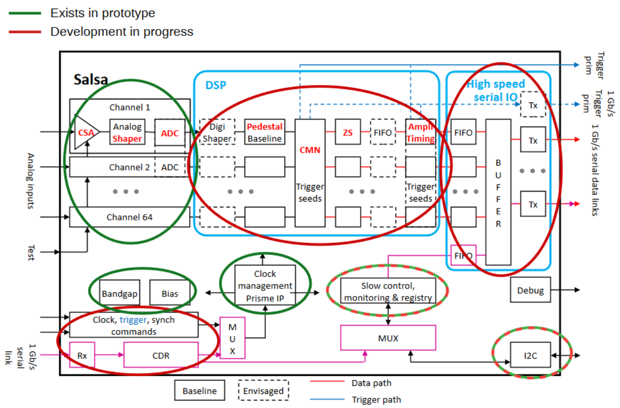
ECT Integration - Global Support Tube (GST) Assembly



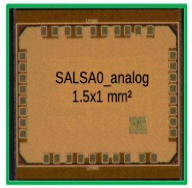
- Global Support Tube (GST) is the Carbon fiber support structure for inner detectors.

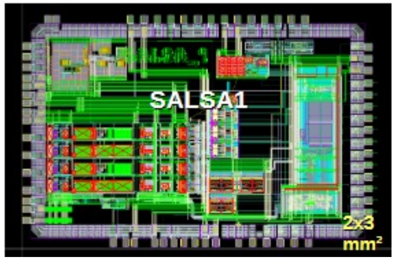
FY25 Status & Progress – Cont.

MPGD – SALSA (CEA-Saclay, U. Sao Paulo)



- 64 Ch
- 65 nm CMOS
- Peaking time: 50 – 500 ns;
- Inputs: Cdin<200 pF; Dual polarity; Q: 3 – 250 fC
- ADC: 12 bits, 5 – 50 MSPS.
- Extensive data processing capabilities
- I2C configuration.
- Triggerless and triggered operation;
- Several 1 Gbps links.
- Power: 15 mW/Ch
- Radiation tolerant.



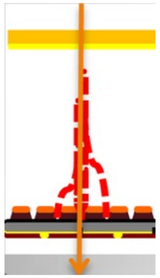


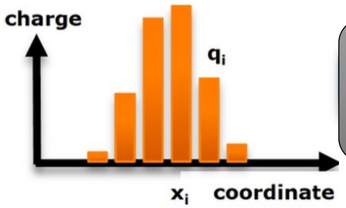
❑ Progress Summary:

- SALSA0_analog and SALSA0_digital blocks fully characterized.
- PLL block + services prototyped under PRISME. PRISMEv1 – April 2025.
- SALSA1 (full frontend and ADC chain) – under tests.
- SALSA2 (32 ch fully featured with DSP) design in progress for submission in October 2025.
- Tests in 2026, available to users.

- SALSA0 (IP blocks): FY23
- SALSA1: FY23 – FY24
- SALSA2: FY23 – FY25
- SALSA3: FY25 – FY26
- SALSA: FY27 – FY28 Production

Possible position resolution improvement - μTPC



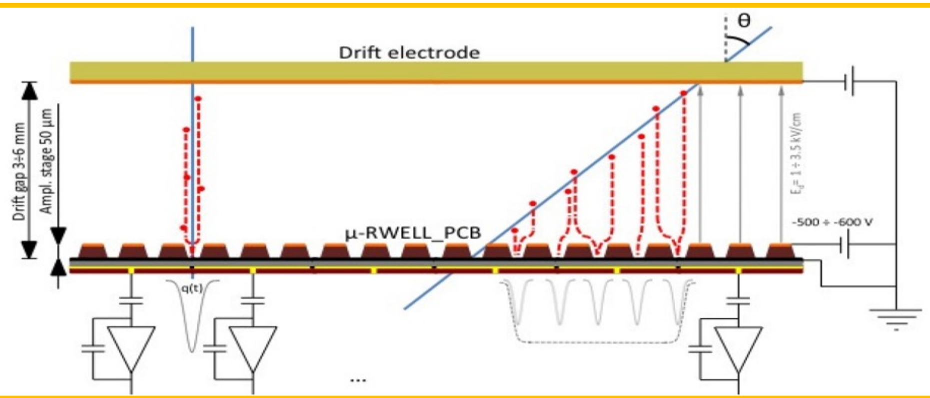


$$x_{hit} = \frac{\sum x_i \cdot q_i}{Q_{tot}}$$

Charge Centroid (CC)reconstruction method

The track position is determined as a weighted average of fired strips

GOOD FOR ORTHOGONAL TRACKS



Bended tracks

the Charge Centroid method gives a very broad spatial distribution on the anode-strip plane.

μTPC reconstruction

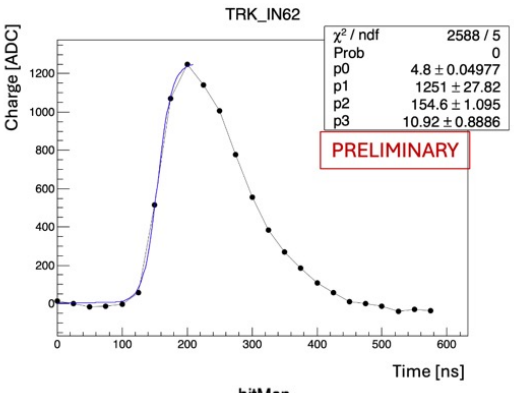
The spatial resolution is strongly dependent on the impinging angle of the track =>

A not uniform resolution in the solid angle covered by the apparatus => Large systematical errors.

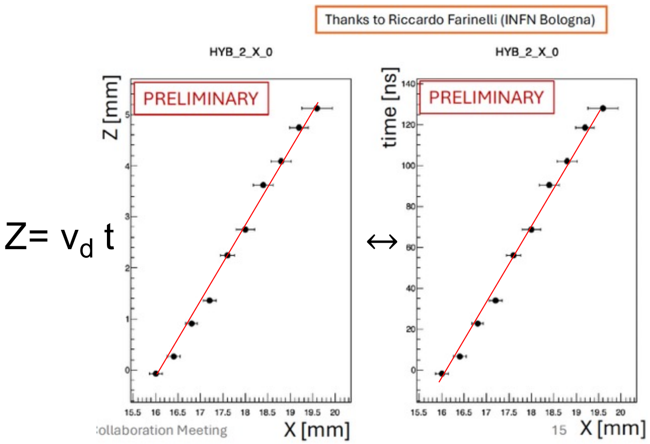
Possible position resolution improvement - µTPC

A possible solution :

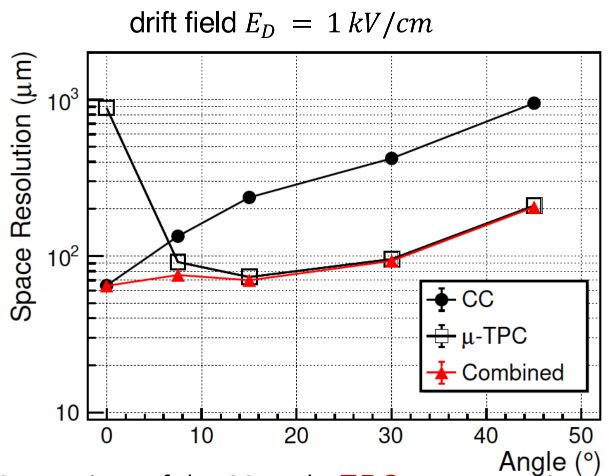
- The electrons created by the ionizing particle drift towards the amplification region
- In the µTPC mode from the **knowledge of the drift time** and the **measurement of the arrival time of electrons**, the **track segment in the gas gap is reconstructed**
- The **fit of the analog signal** gives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



Example of a track reconstruction using the TPC algorithm.



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