INFN

Brookhaven National Laboratory

Jefferson Lab

U.S. DEPARTMENT OF ENERGY

MPGD ENDCAP Trackers (ECT) – Project Update

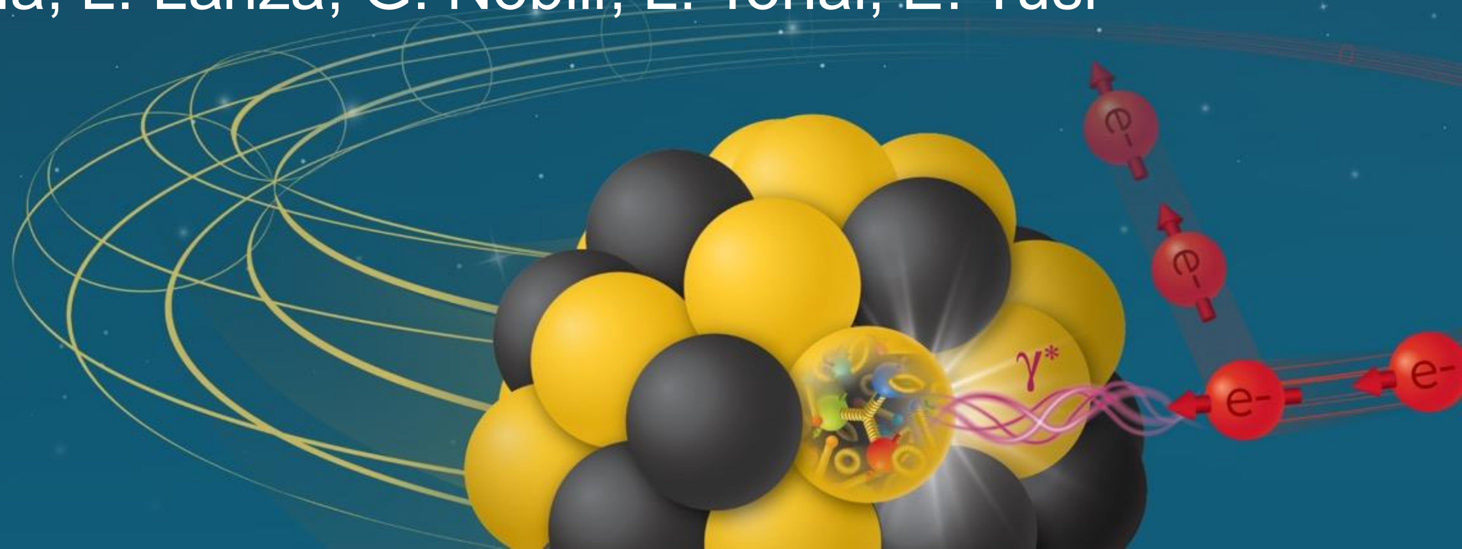
GEM–μRWELL technology

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

Giornate Nazionali ePIC Italia
Padova, June 16-18, 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

→ Talk by Elena Sidoretti

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

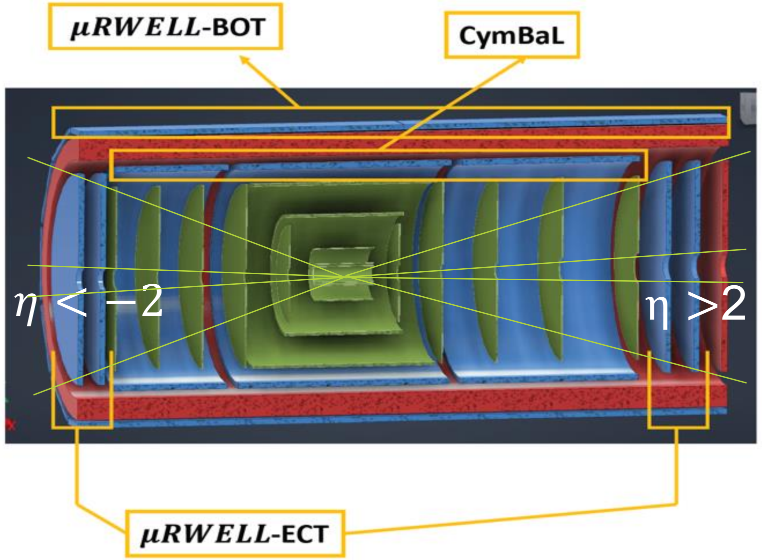
→ Talk by Stefano Gramigna

INFN Involvement

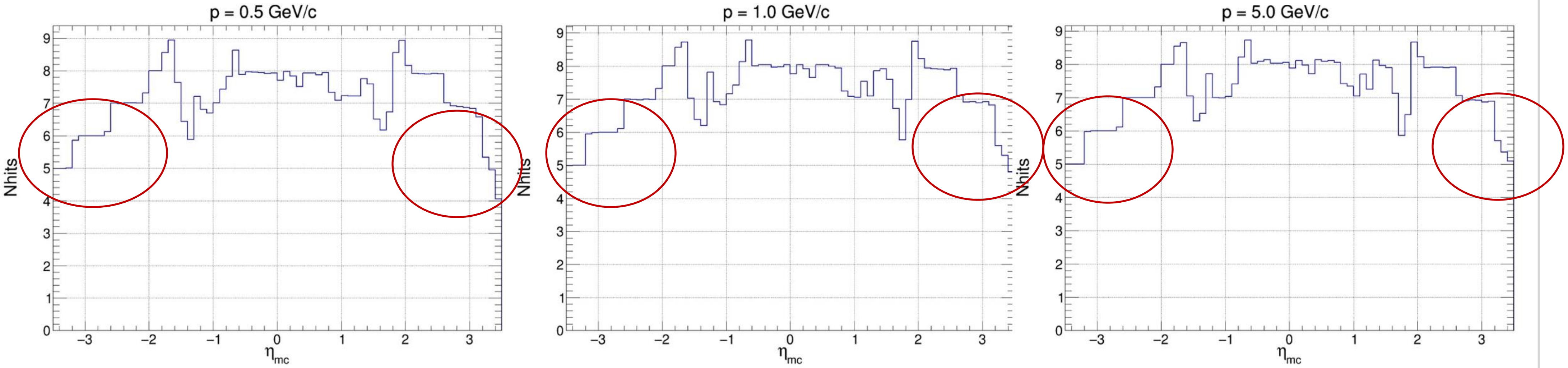
Readout Electronics and FEB form factor
Detector Simulation
Fabrication and Assembly Plans Timeline & Workforce

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

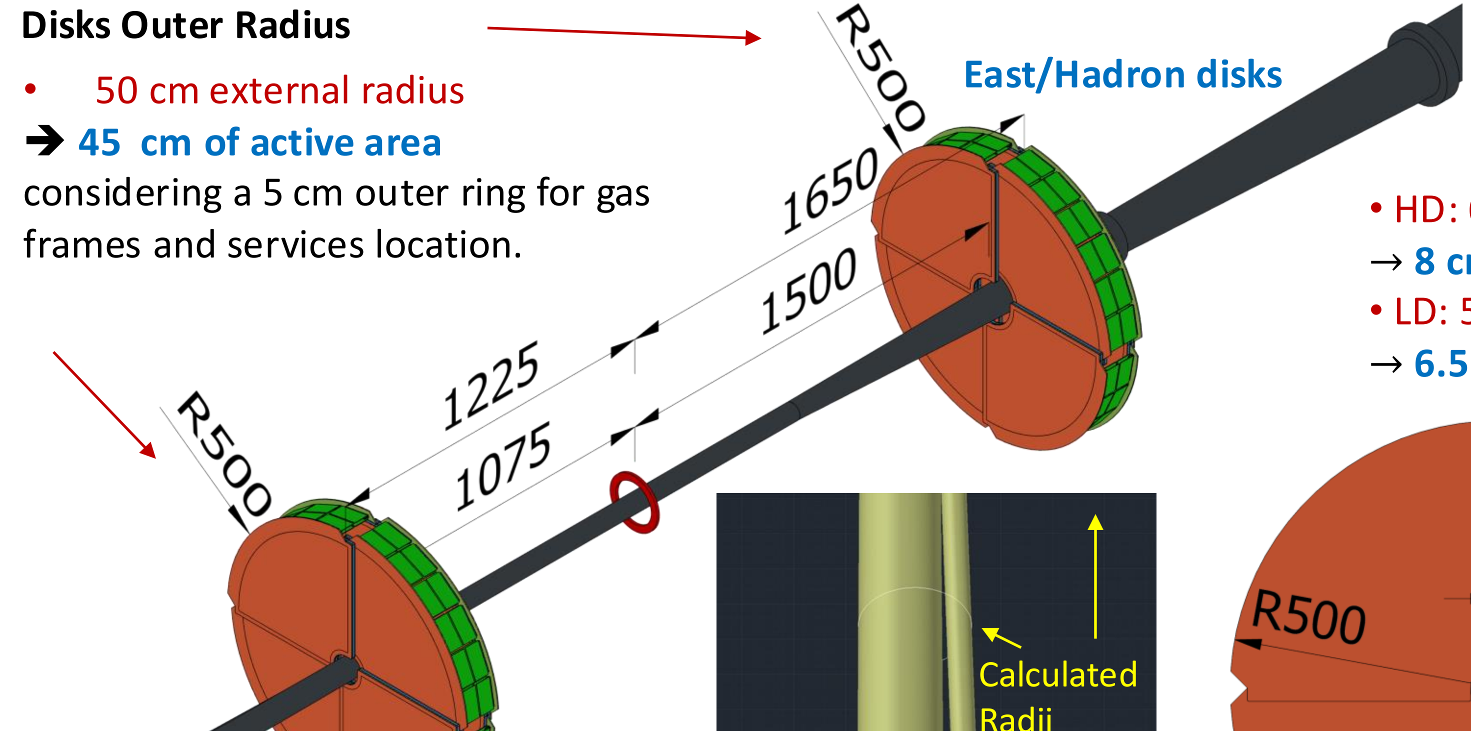
The geometrical envelopes are available at: https://eic.jlab.org/Geometry/Detector/Detector-20240117135224.html

Disks Outer Radius

- 50 cm external radius

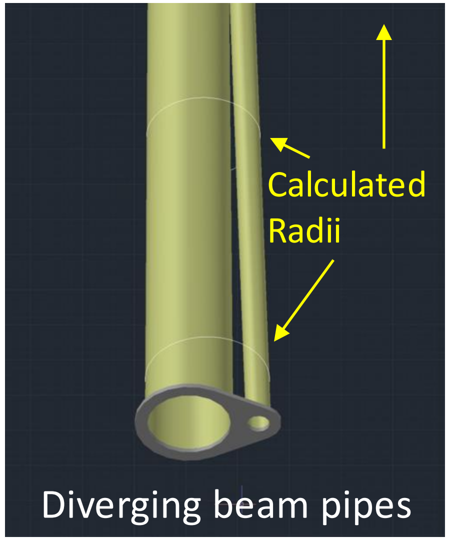
➔ **45 cm of active area**

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



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

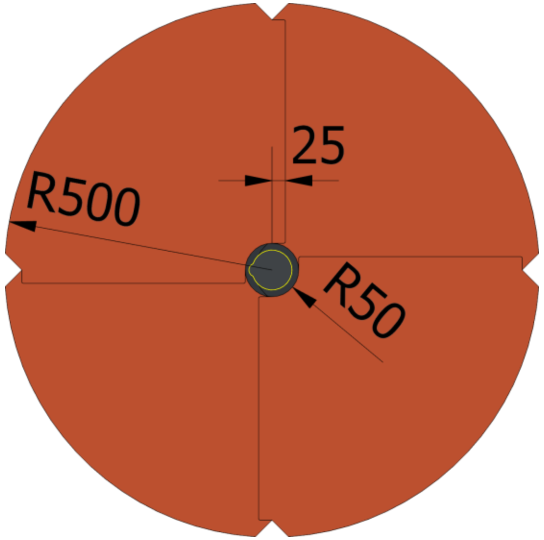
- HD: 6.5 cm & 9 cm inner radii

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

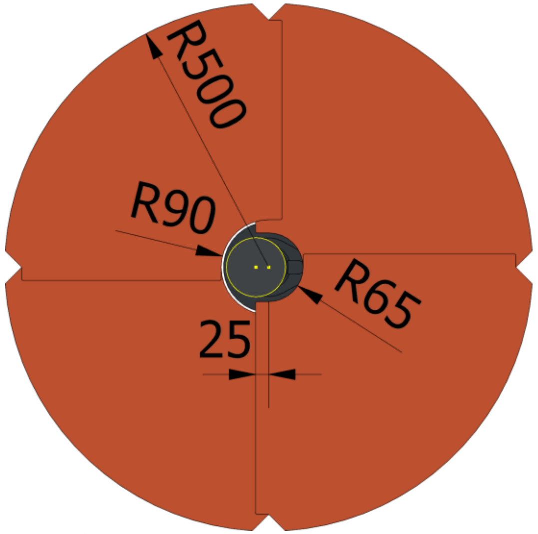
- LD: 5 cm inner radius

→ **6.5 cm radius of active area**

considering 1.5 cm gas frame



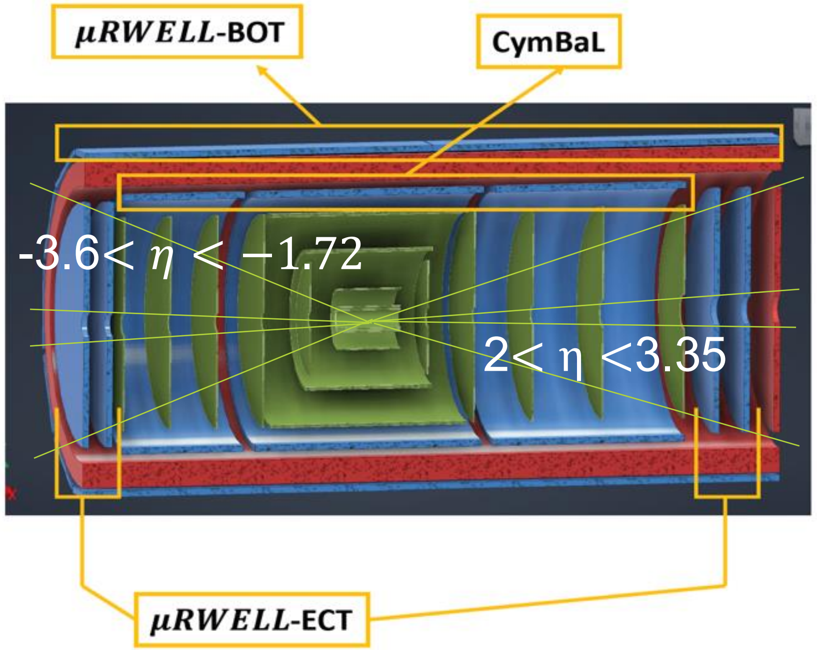
West/Lepton Disk Backward side



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

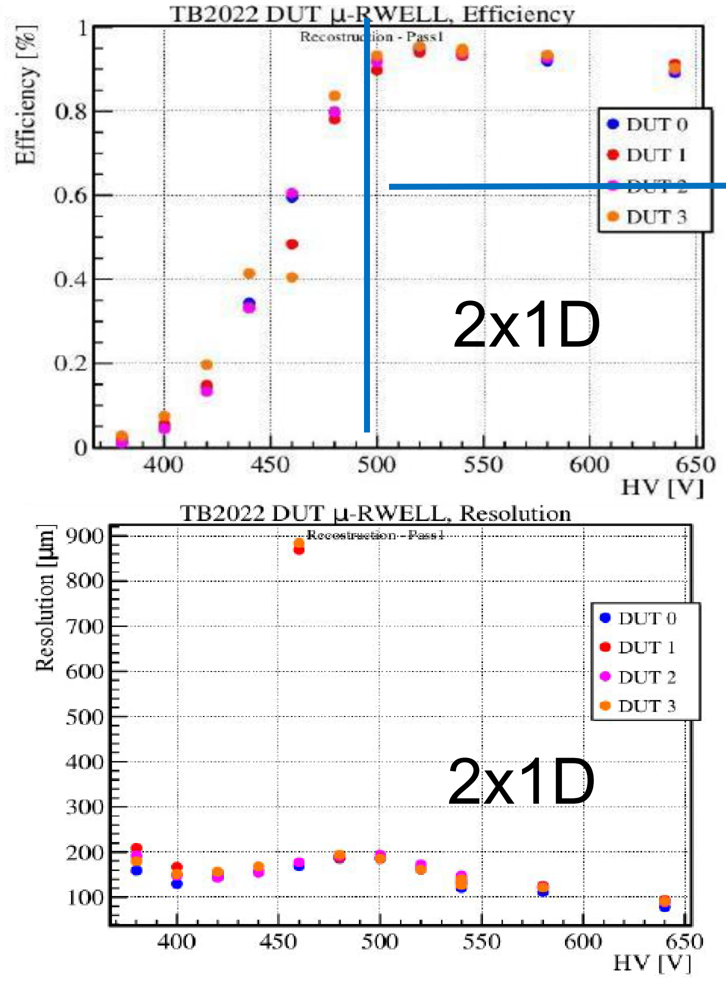
- <150 μm intrinsic spatial resolution for perpendicular tracks
- Technological optimizations to retain 150 μm resolution for inclined/curved tracks → μTPC mode

High Efficiency

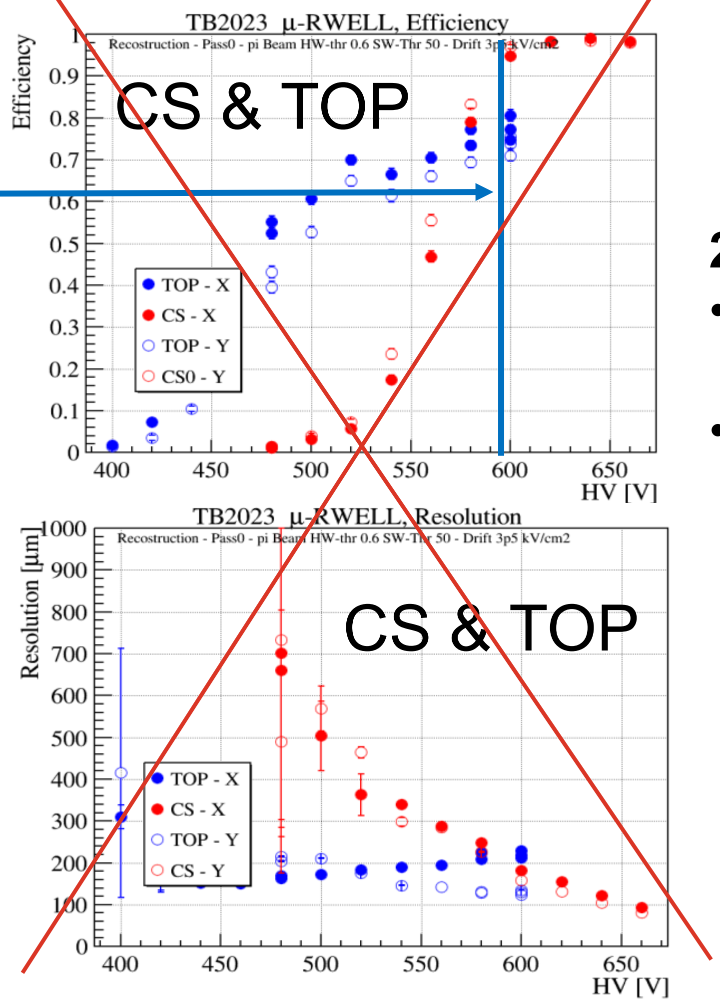
- Single detector efficiency ~ 96 –97 % → 92 –94 % combined efficiency for two disks

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

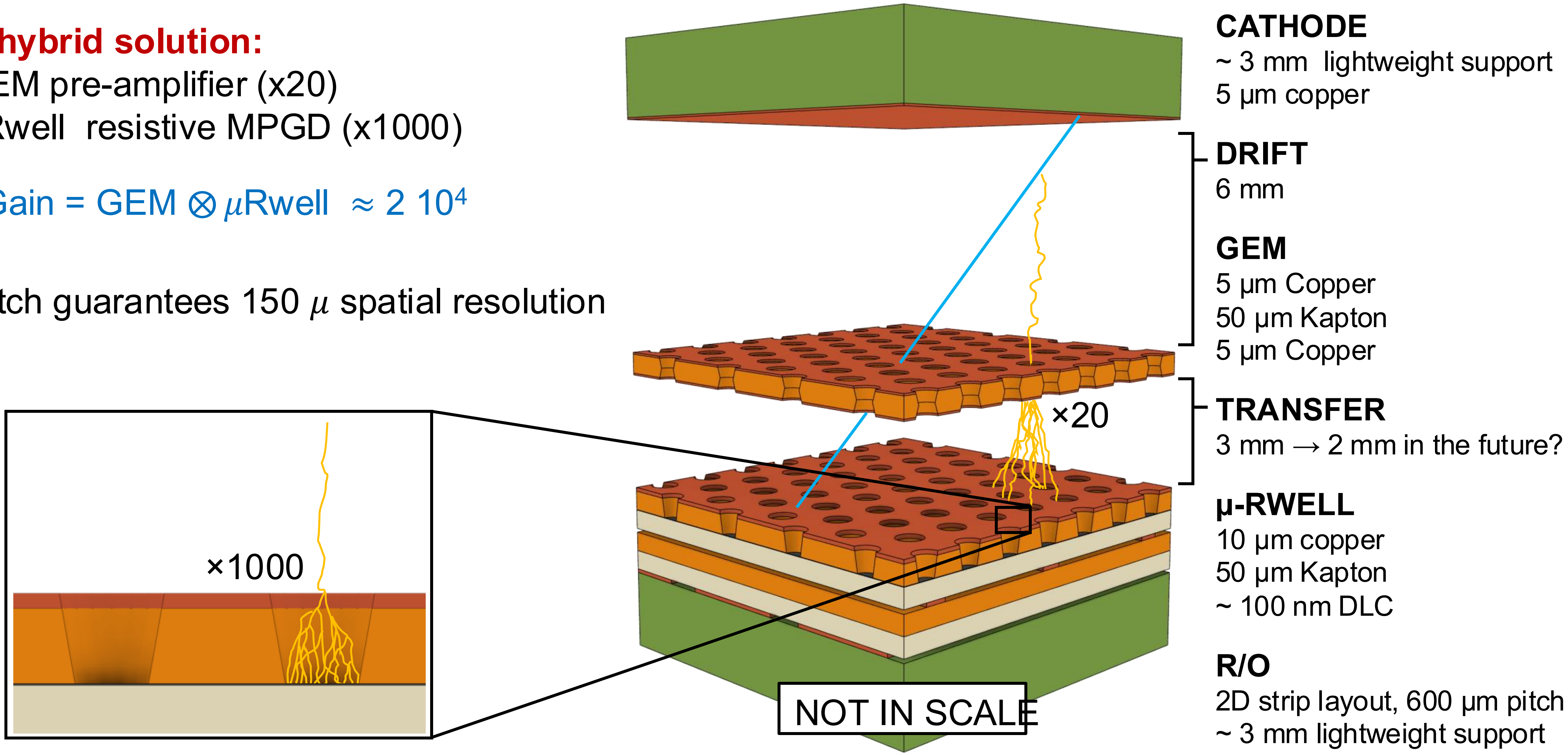
New MPGD Technology: - GEM-µRWELL Hybrid Detector

Two stages hybrid solution:

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

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

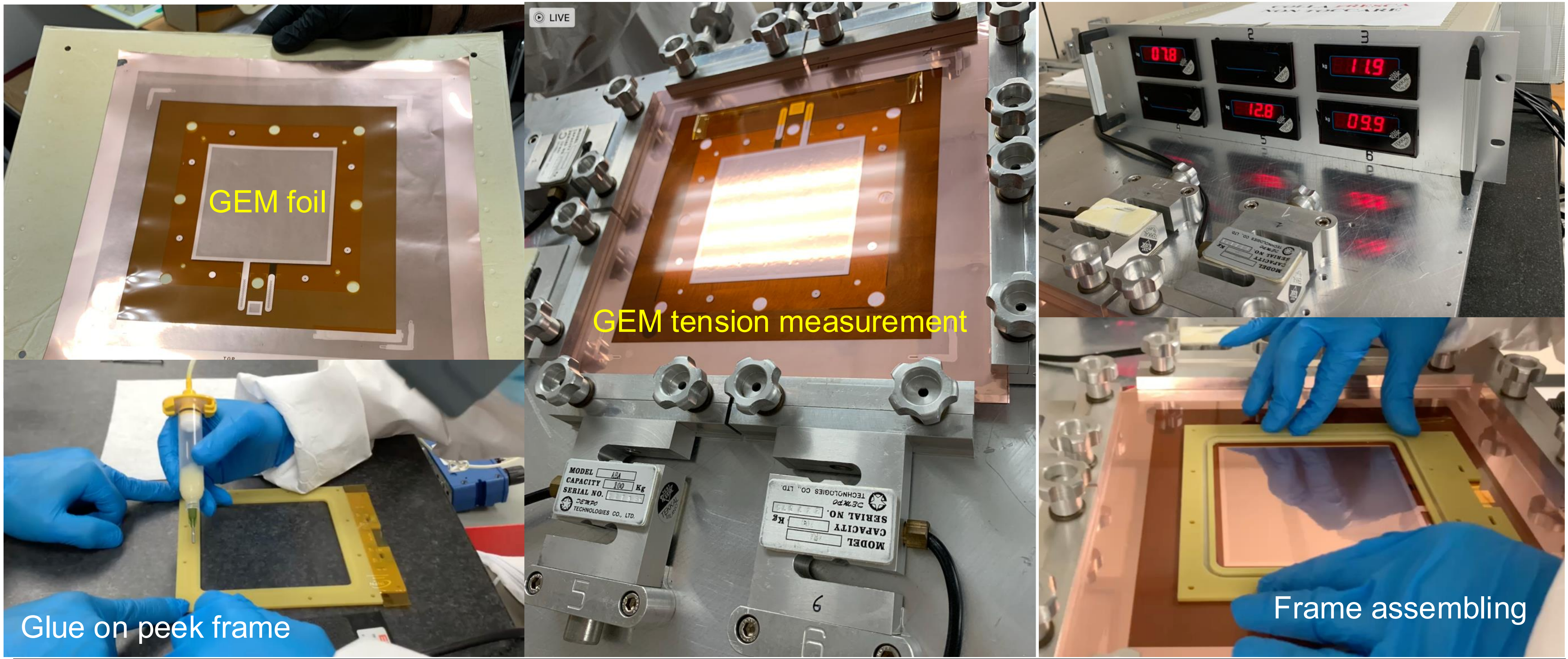
- 600 μm pitch guarantees 150 μ spatial resolution



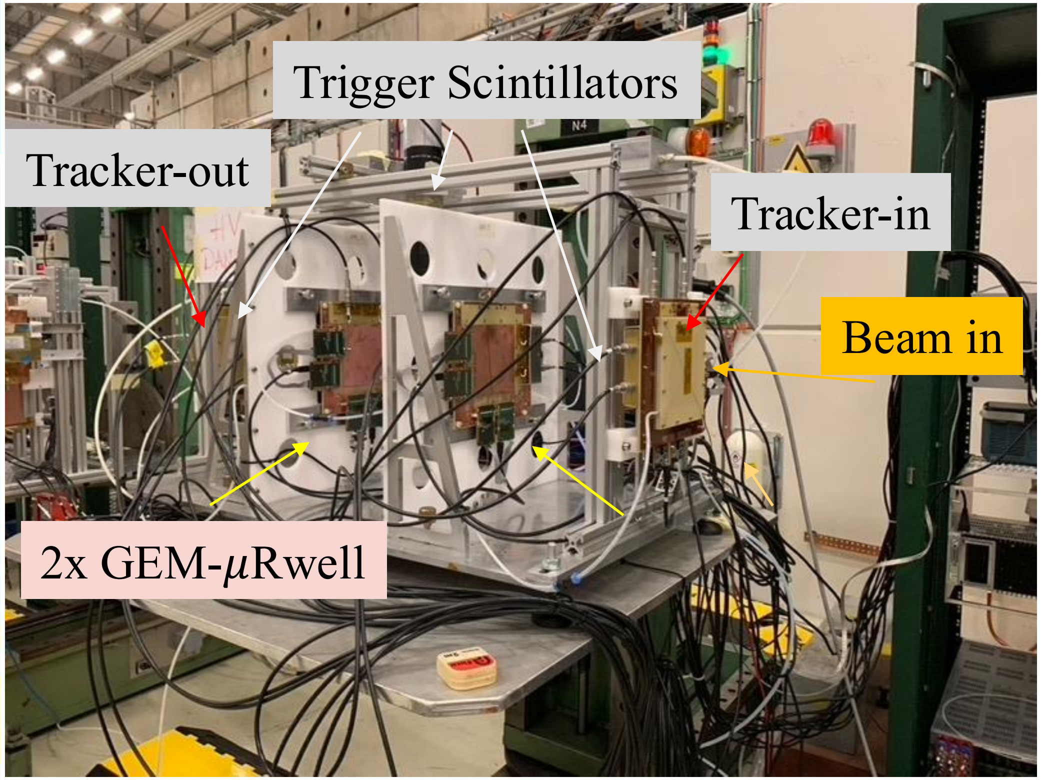
All R&D Studies for EIC disks performed in synergic collaboration with INFN-LNF and JLAB

New MPGD Technology: - GEM-μRWELL Hybrid Detector

GEM 10x10 cm^2 layer assembly



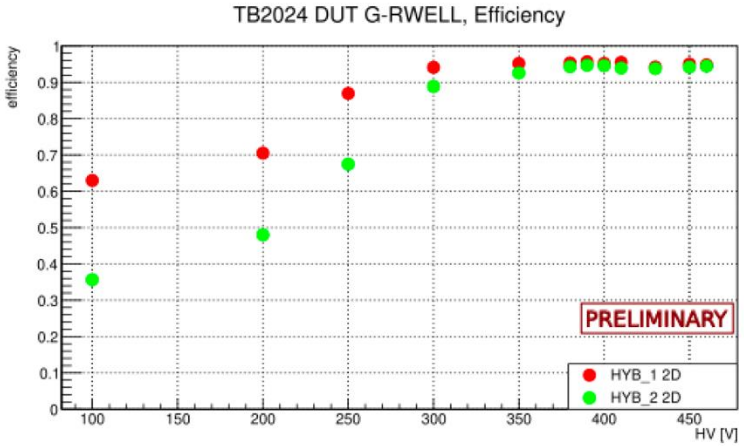
GEM-µRWELL Hybrid Technology 2024 Test Beam

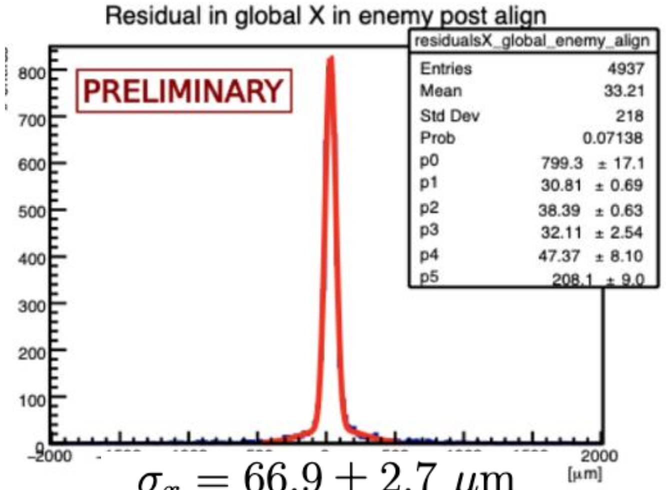


Tracker-In : μRwell – 3 mm drift gap
Tracker-Out : GEM-μRwell 6 mm drift + 3 mm transfer gaps

Detectors Under Study (DUT)
- 2 x GEM-μRwell prototypes 2D COMPASS-like readout 400 μm pitch

By Elena Sidoretti





$\sigma_x = 66.9 \pm 2.7\ \mu m$

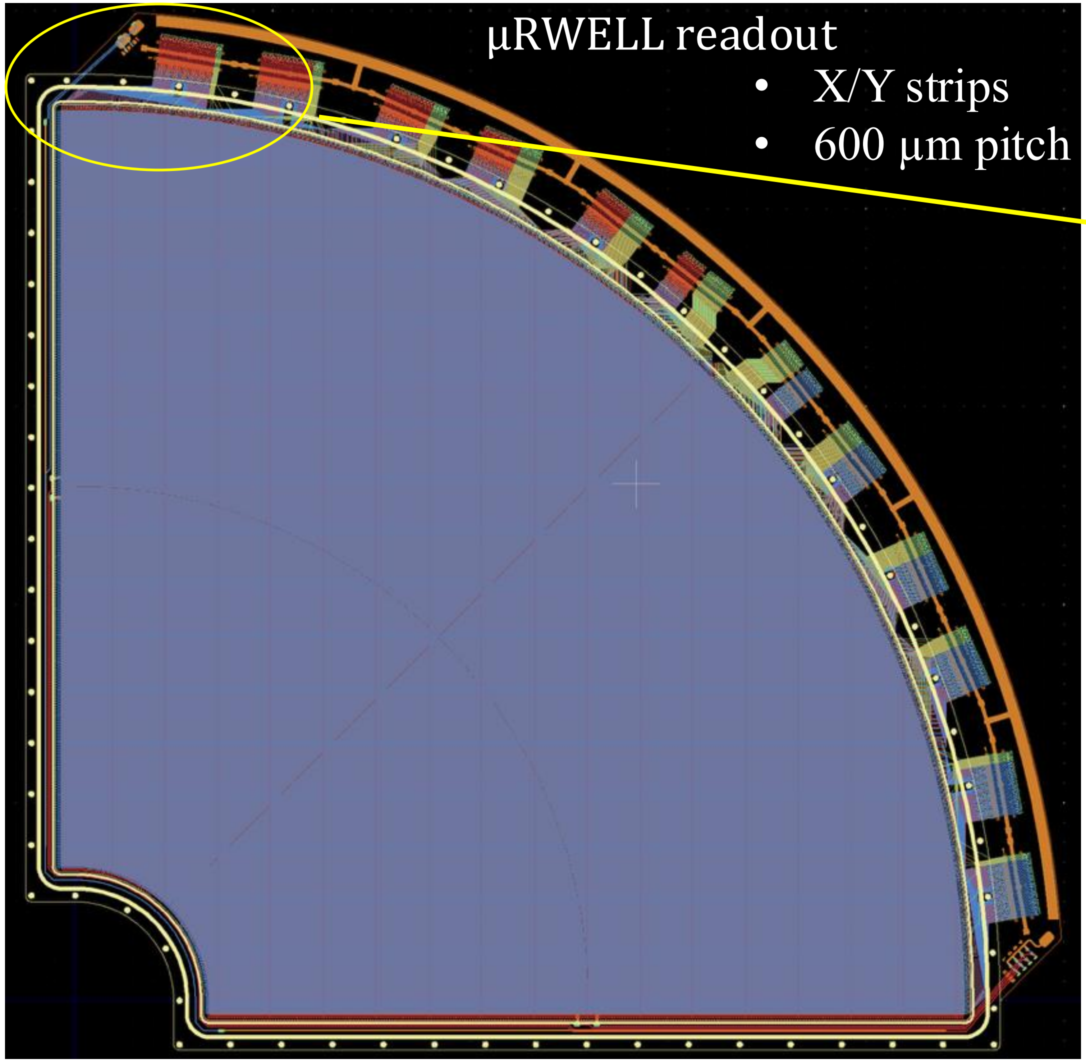
2024 Test Beam assessments

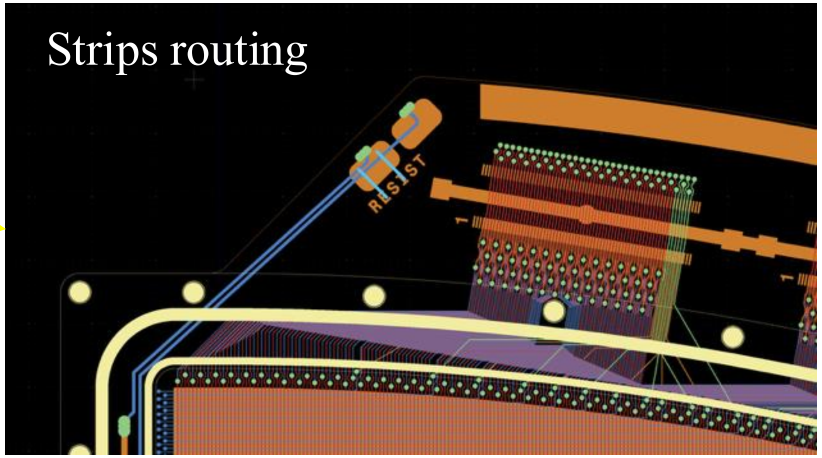
Refer to Elena's presentation for more details

- 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

MPGD-ECT: PED Test Article Module

Refer to Stefano's presentation for more details

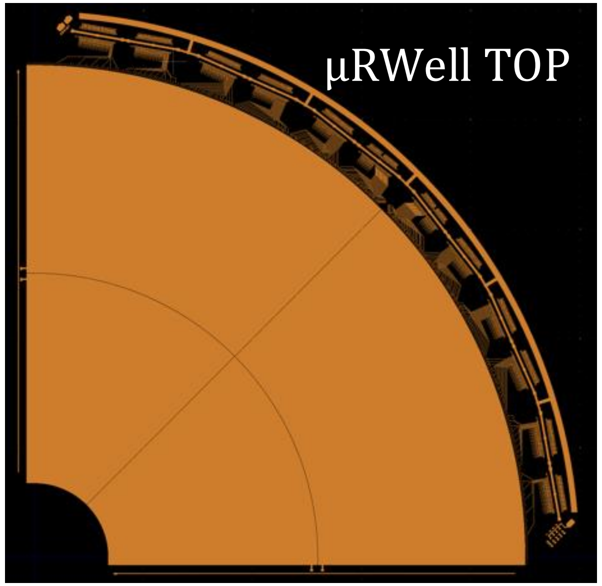


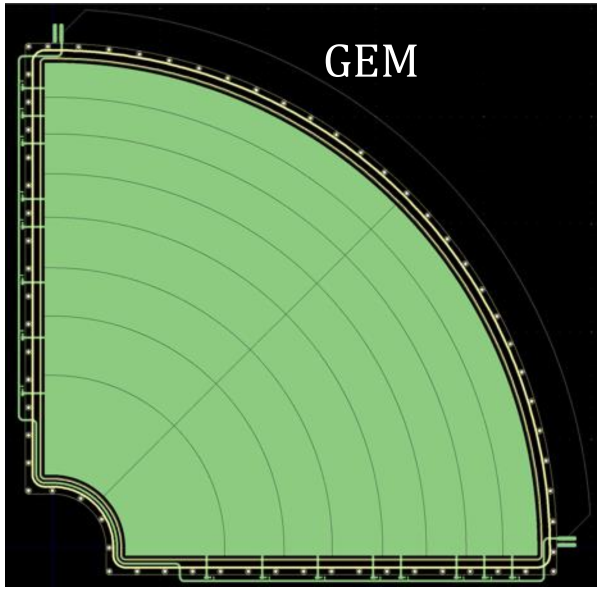


(X, Y) readout

→ 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

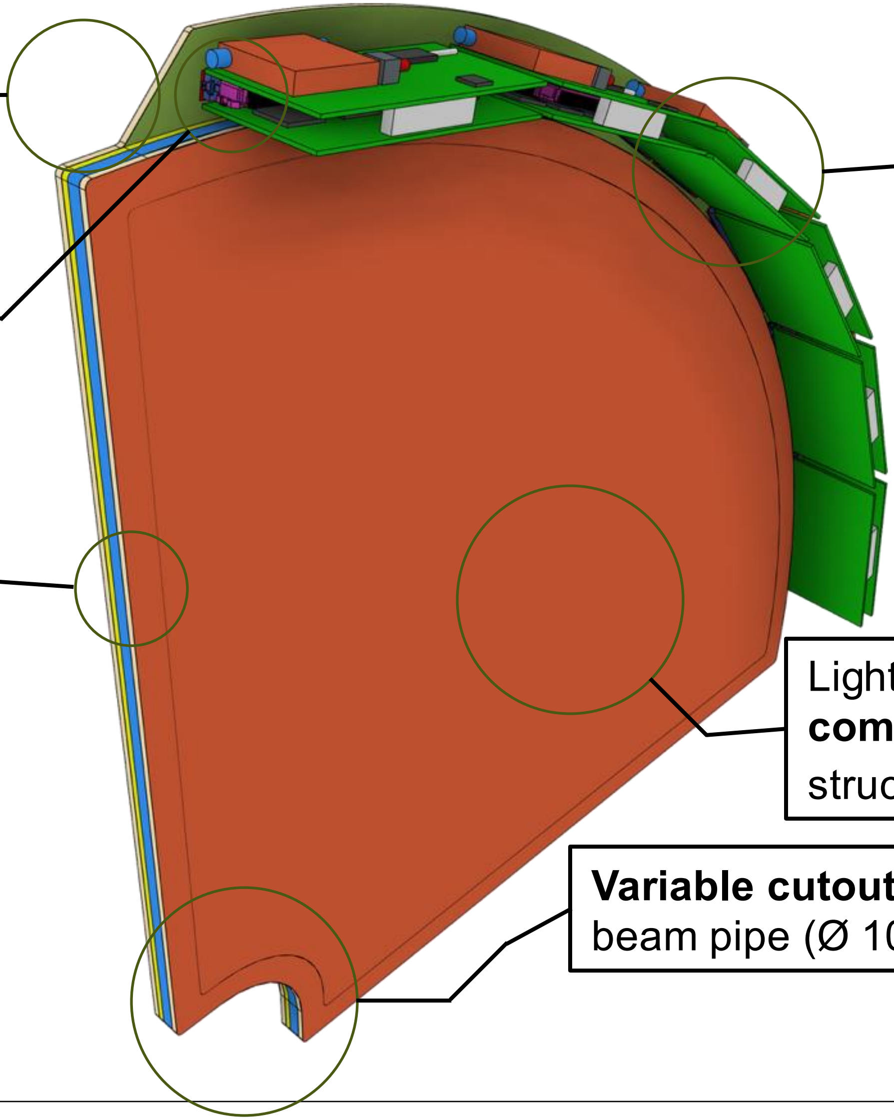
2x **Hirose FX20-140P** Connectors per FEB

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

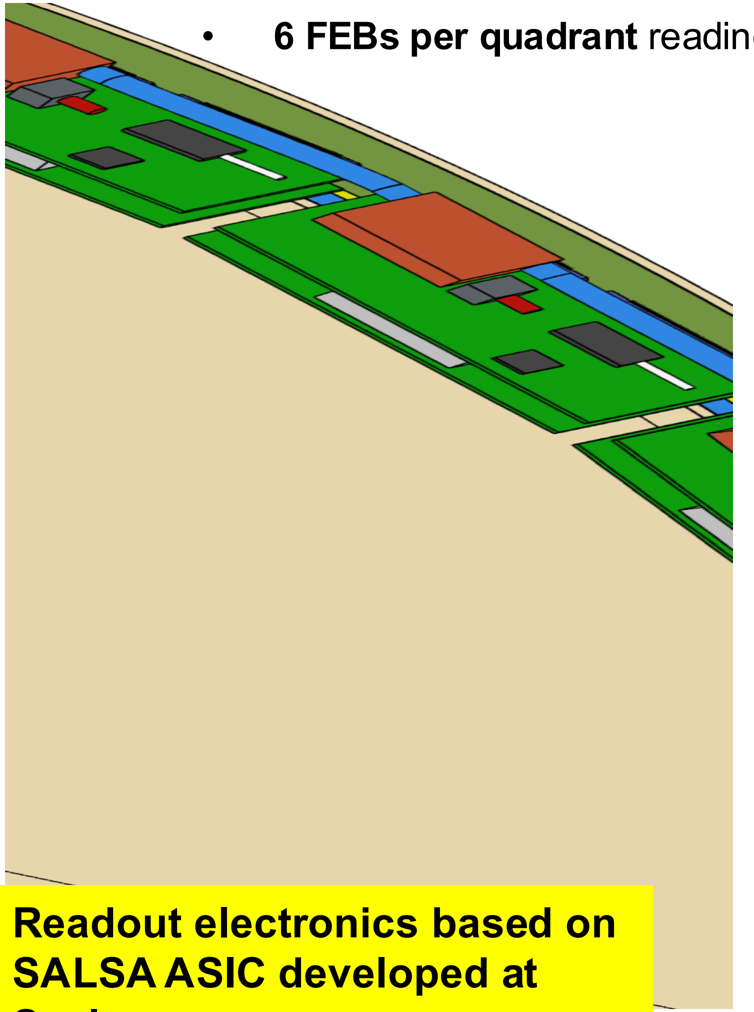
Lightweight **sandwich-structured composites** for anodes/cathodes' structural supports

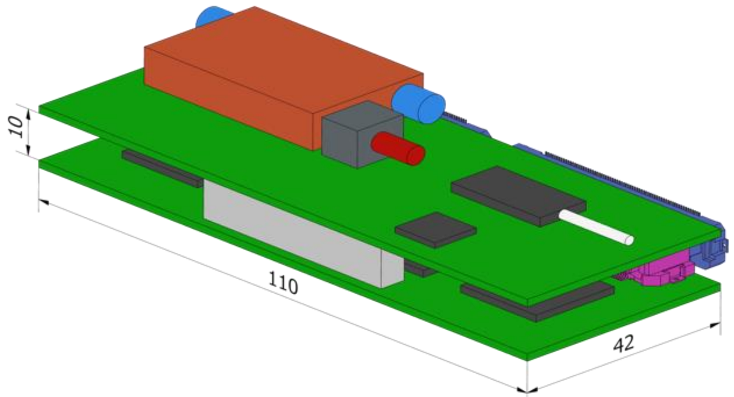
Variable cutout to cope with the asymmetric beam pipe (Ø 100, 130, and 180)

By Stefano Gramigna

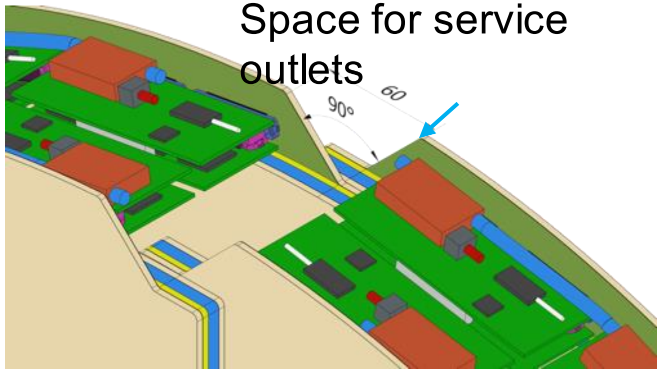
GEM-µRWELL-ECT: Front End Boards (FEB) & Services

- 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



All the service requirements have been communicated to the Integration group

For each endcap disk (4 disks in total):

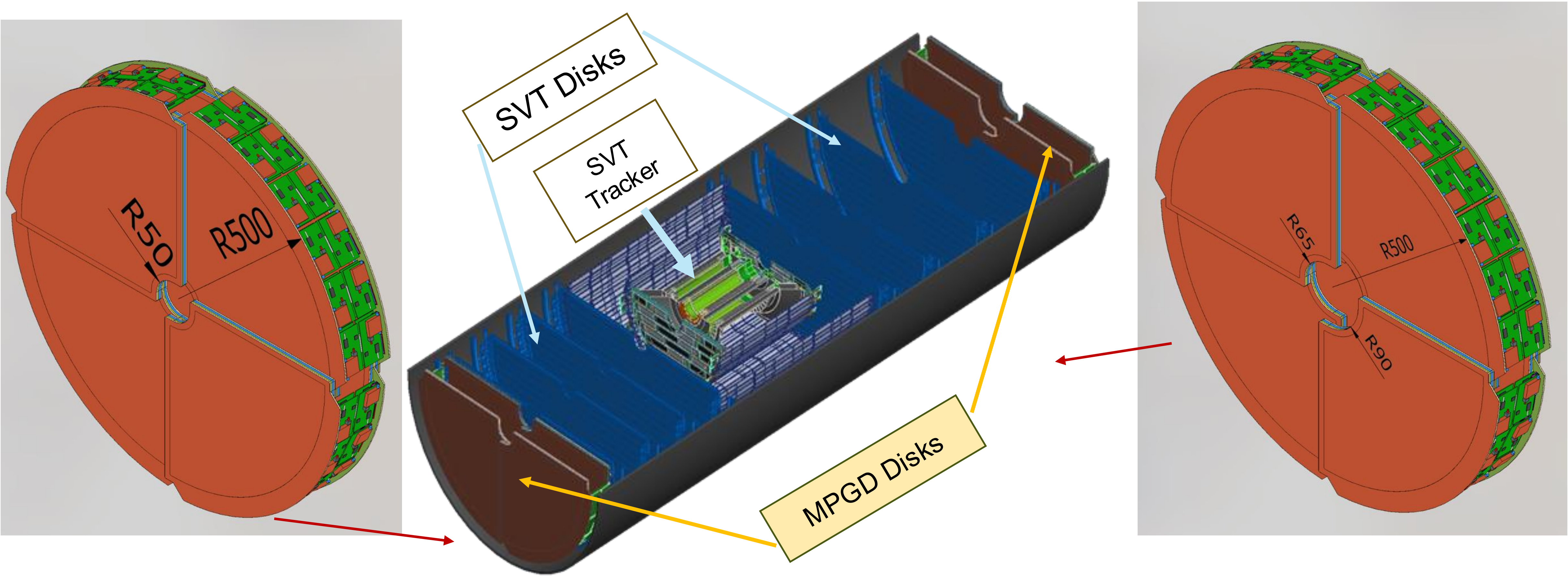
- 16 HV cables
- 4 gas inlets and 4 gas outlets
- 24 data cables
- 24 low voltage cables
- 2 temperature sensors cables
- 2 humidity sensors cables
- 2 inlet and 2 outlet cooling hoses (H_2O) 210 W cooling dissipation

Readout electronics based on SALSA ASIC developed at Saclay

GEM-µRWELL-ECT: Integration in ePIC Detector

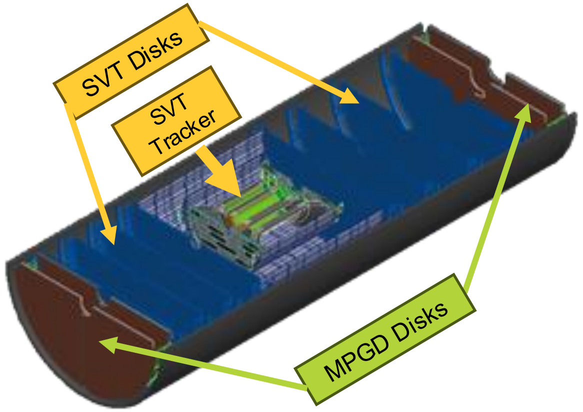
The assigned envelope will include the detectors and the FEB electronics.

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

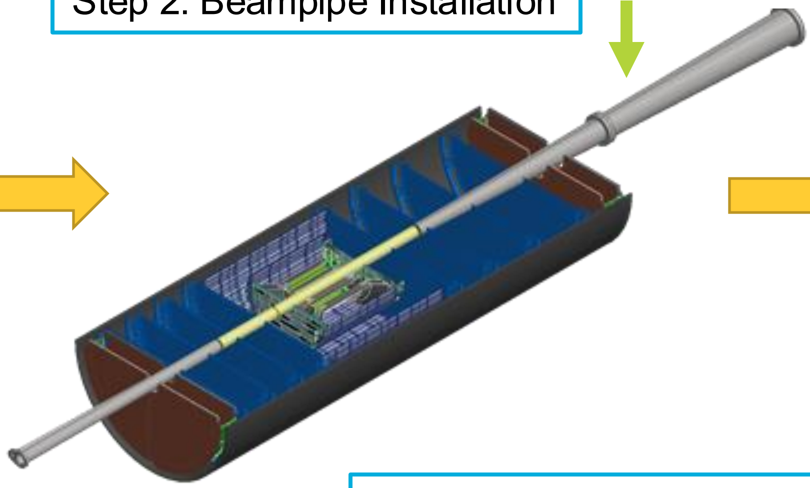


ECT Integration - Global Support Tube (GST) Assembly

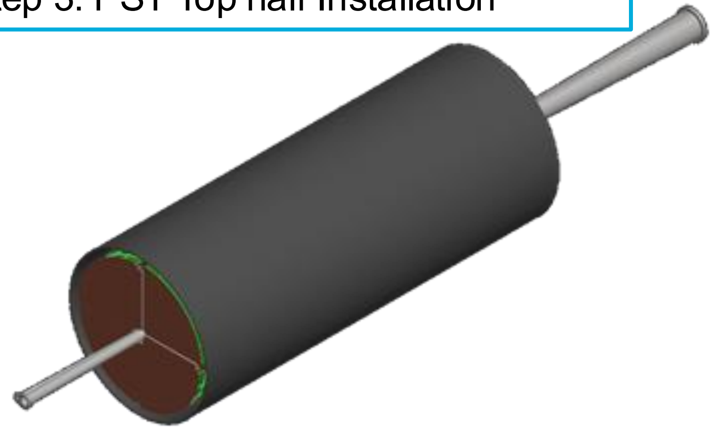
Step 1: PST Bottom half assembly



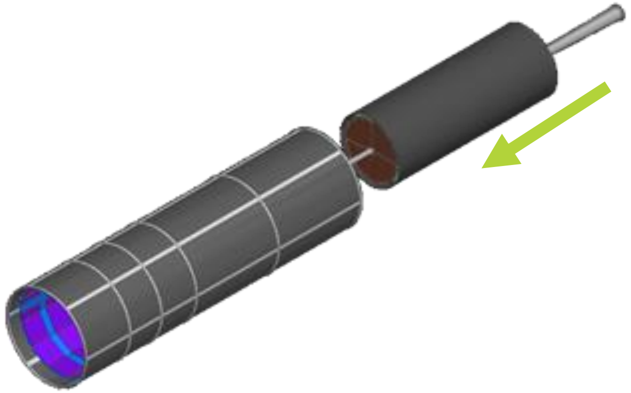
Step 2: Beampipe Installation



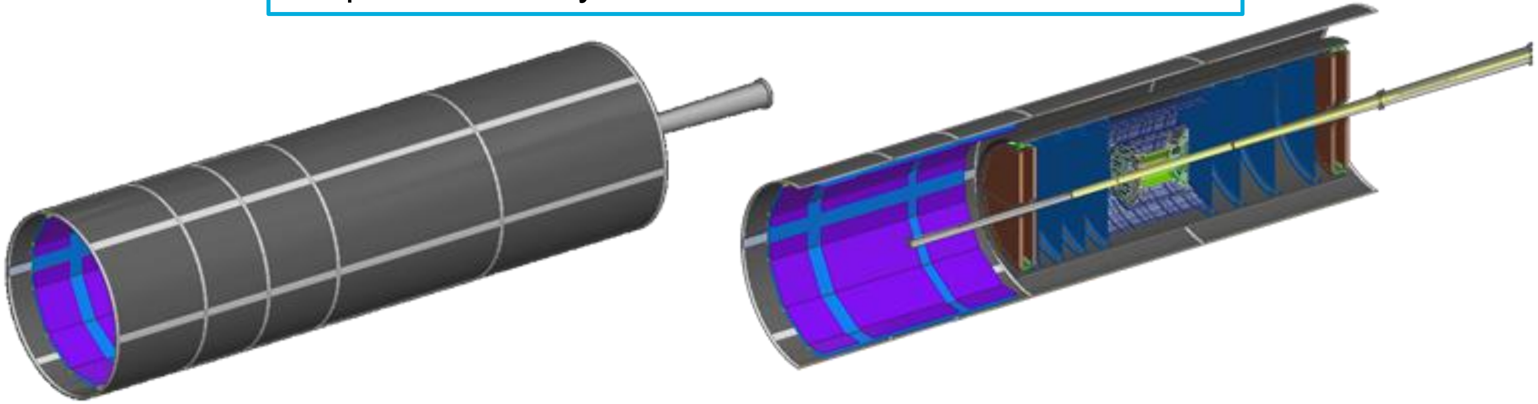
Step 3: PST Top half Installation



Step 4: PST Installation into GST



Step 5: GST ready for installation into Central Barrel

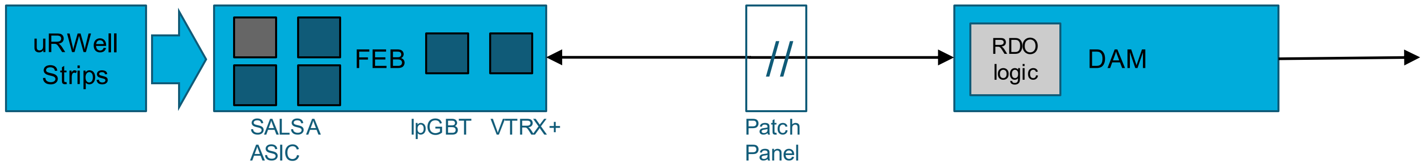


- Global Support Tube (GST) is the Carbon fiber support structure for inner detectors.

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



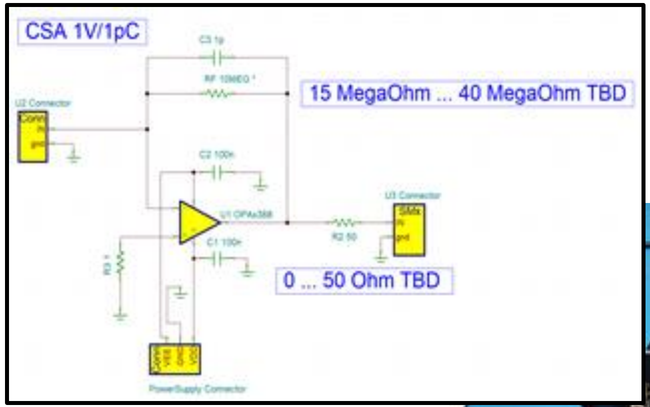
Number of urwell strips per quadrant per dimension	768
Number of channels per SALSA ASIC	64
Number of SALSA ASICs per FEB	4
Number of quadrants per disk	4
Number of channels per DAM	48

4 disks

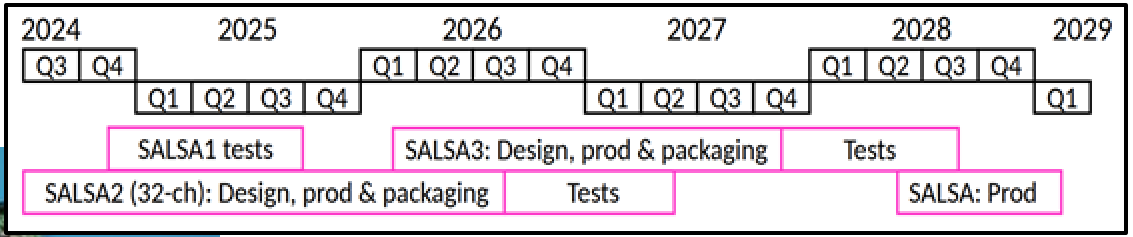
	per quadrant	per disk	ECT total
Number of SALSA ASICs	24	96	384
Number of FEBs	6	24	96
Number of DAMs		0.5	2

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

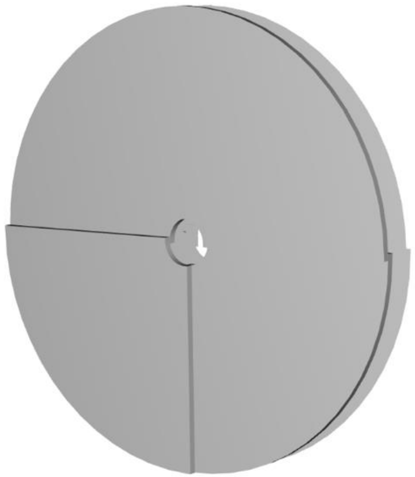
- SALSA chip could be available in 2027 for first integration in Front-End boards
- In the meanwhile we are preparing a testbed to exercise the complete readout chain interfacing with real detector
- Using development board with multi-channel, high sampling rate integrated ADCs FPGAs (AMD Xilinx ZCU216)
- 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

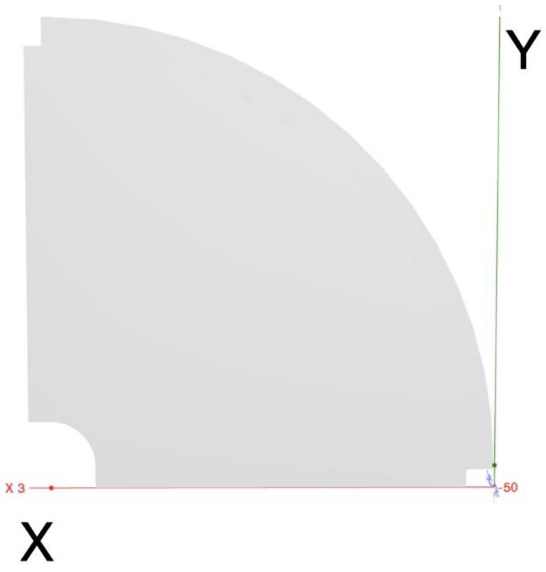


GEM-μRWELL-ECT: Detector Simulation

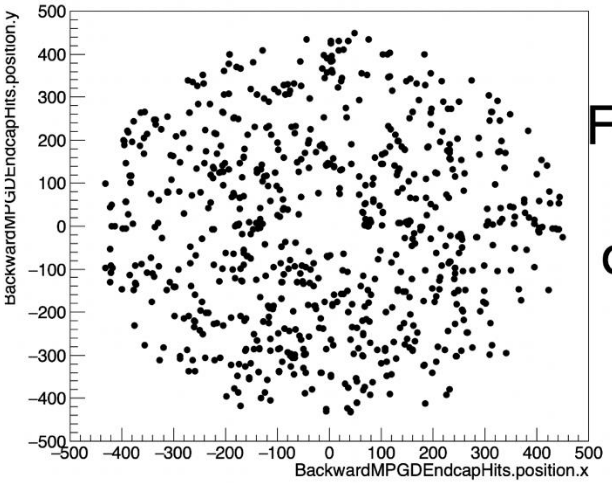


By Mariangela Bondì

- 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



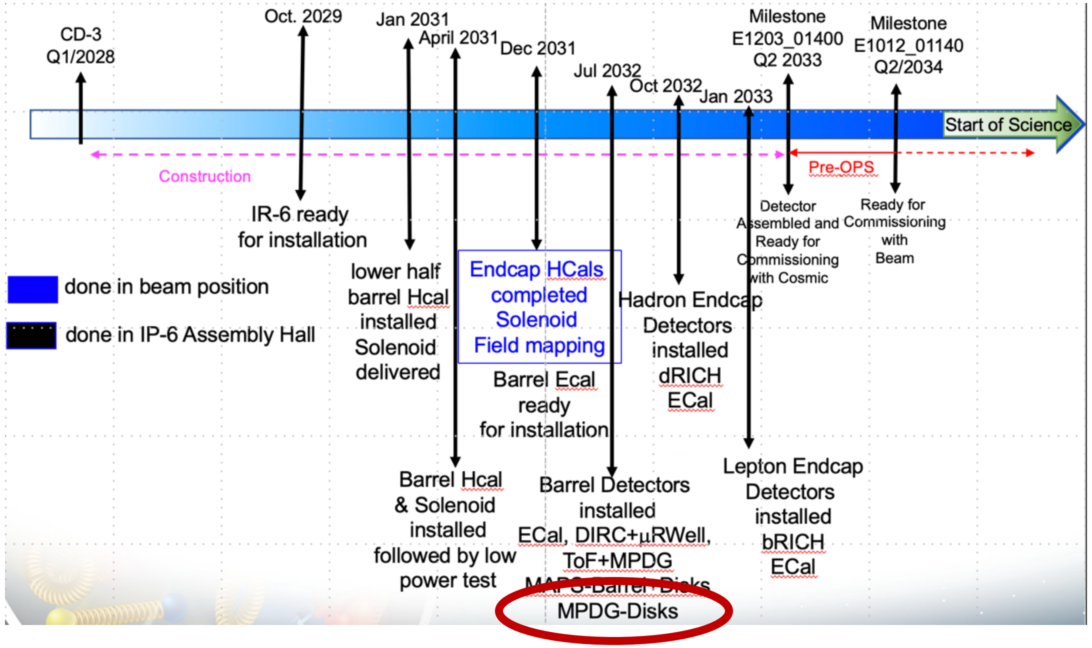
Footprint -

ddsim simulation

Fabrication / Assembly Plans & Timeline / Workforce

MPGD ECT Timeline

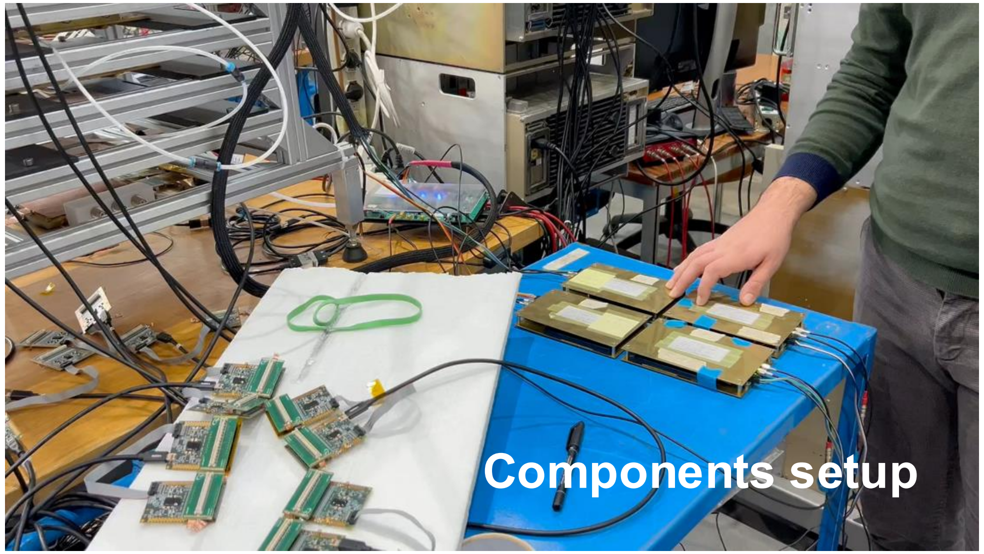
YEAR	INFN R&D K Euro	INFN IN-KIND K Euro	DESCRIPTION
2025	**27**	**15**	**Pre-Production**
2026	30	40	Pre-Production
2027	-	100	Production
2028	-	100	Production
2029	-	100	Production
2030	-	55	Electronics, QA, Commissioning
2031		50	Electronics, QA, Commissioning
2032		40	Installation
TOT	**57**	**500**	



Workforce

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

Workforce: Setting up the Test Beam @LNF



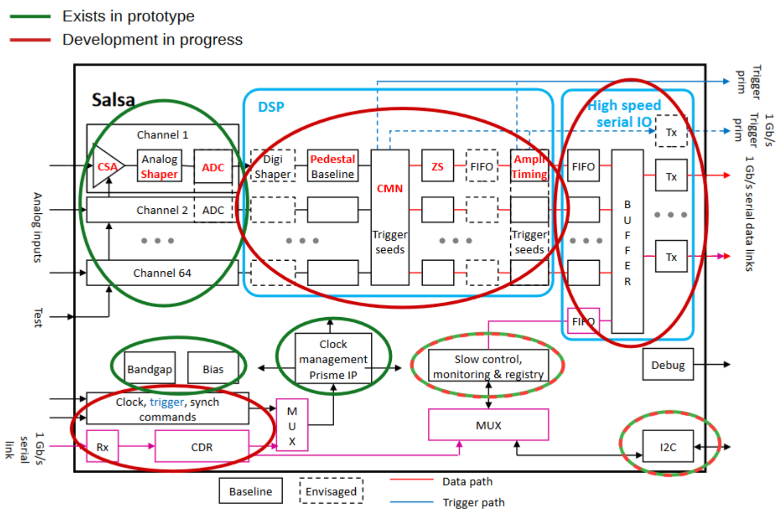
GEM-μRWELL ECT: Summary

- 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.
- 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 PED .
- 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.

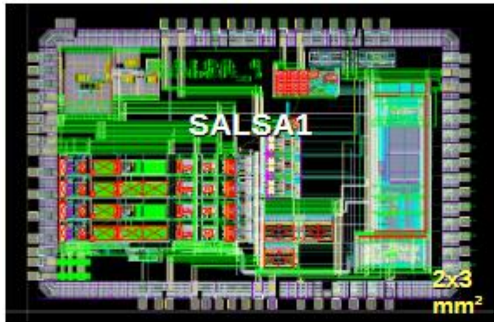
Thank you

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

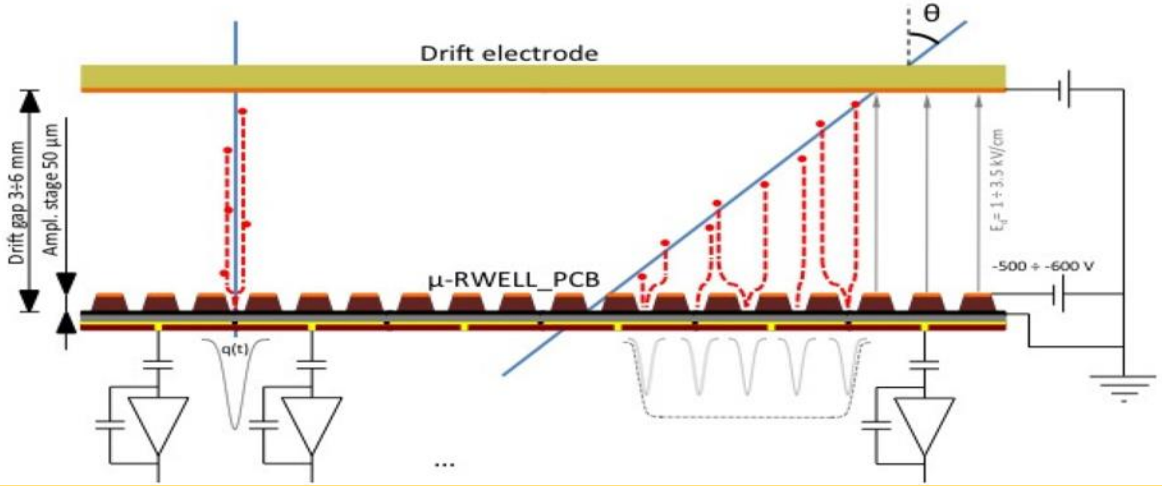
Possible position resolution improvement - μTPC

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

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

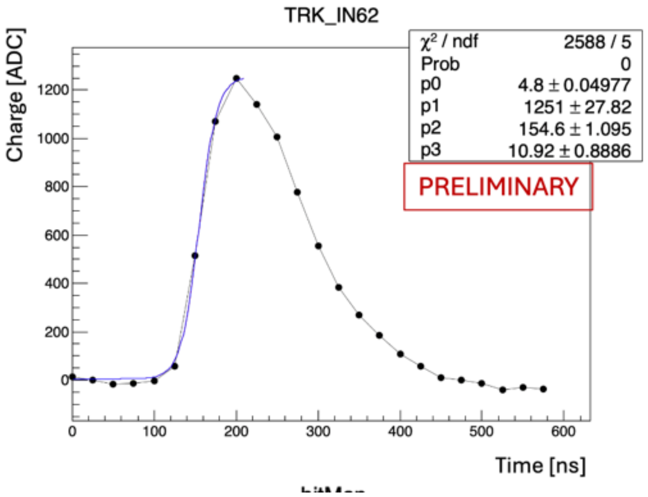
The spatial resolution is strongly dependent on the impinging angle of the track =>

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

Possible position resolution improvement - μTPC

A possible solution :

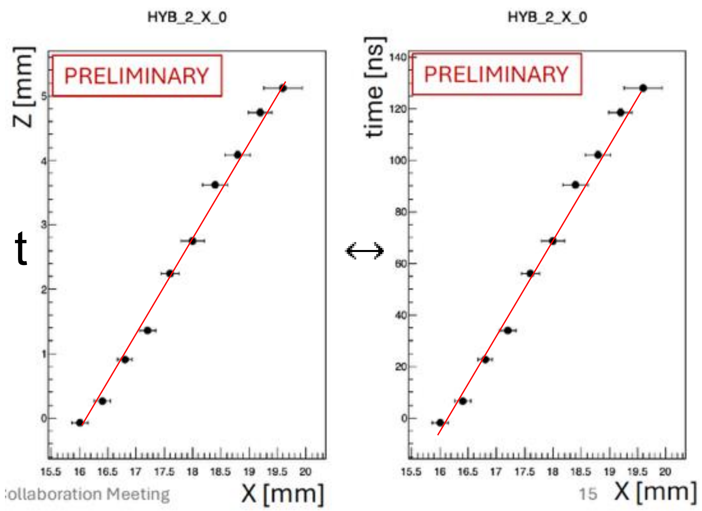
- The electrons created by the ionizing particle drift towards the amplification region
- In the μTPC mode from the **knowledge of the drift time** and the **measurement of the arrival time of electrons**, the **track segment in the gas gap is reconstructed**
- The **fit of the analog signal** gives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

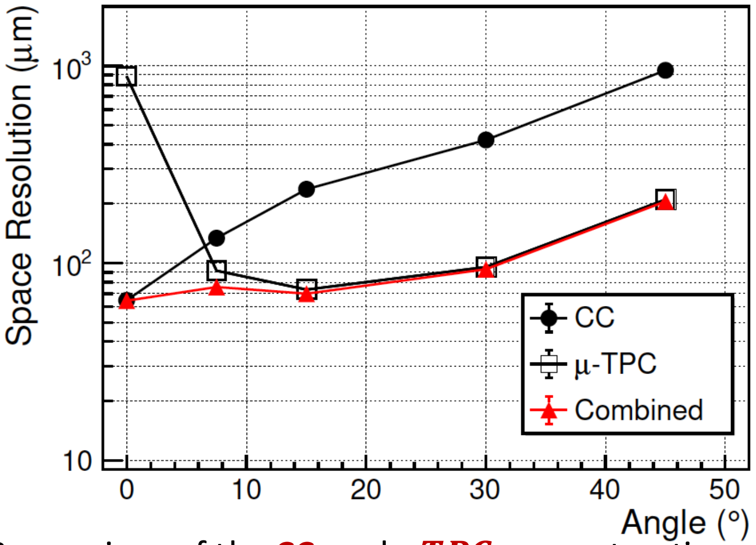
$Z = v_d\, t$

Thanks to Riccardo Farinelli (INFN Bologna)



Example of a track reconstruction using the TPC algorithm.

drift field $E_D = 1\ kV/cm$



Comparison of the **CC** and $\boldsymbol{\mu TPC}$ reconstruction algorithms in function of the impinging angle