ePIC MPGD trackers – Current Detector Design

K. Gnanvo on behalf of the MPGD-DSC

EPIC Detector TIC Weekly Meeting

February 26, 2024

Slides from Matt, Annalisa, Seung Joon, Francesco and Andy - Thanks

Outline

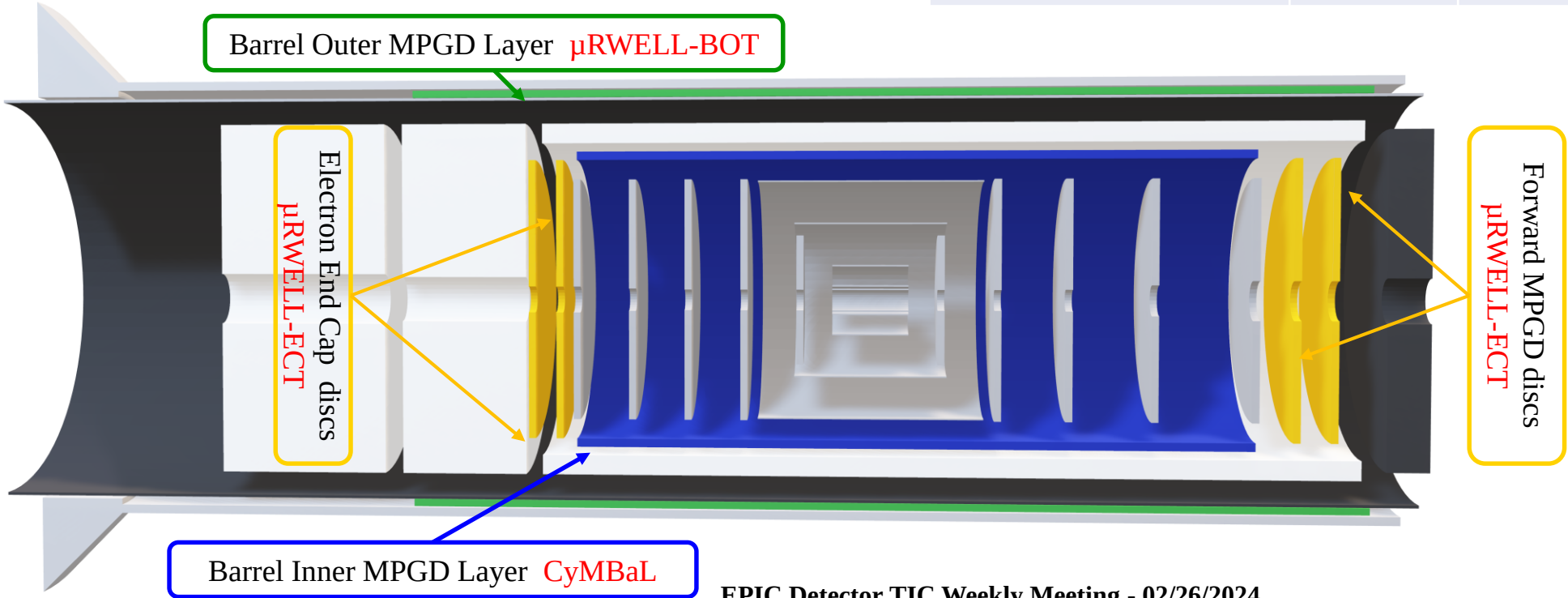
- Inner Barrel: Cylindrical Micromegas Barrel Layer (CyMBaL)
- Thin-gap GEM-µRWELL Barrel Outer Tracker (µRWELL-BOT)
- End Cap Disc: GEM-µRWELL End Cap Tracker (µRWELL-ECT)
- ePIC MPGD Readout Electronics

Overview of ePIC Gaseous Trackers

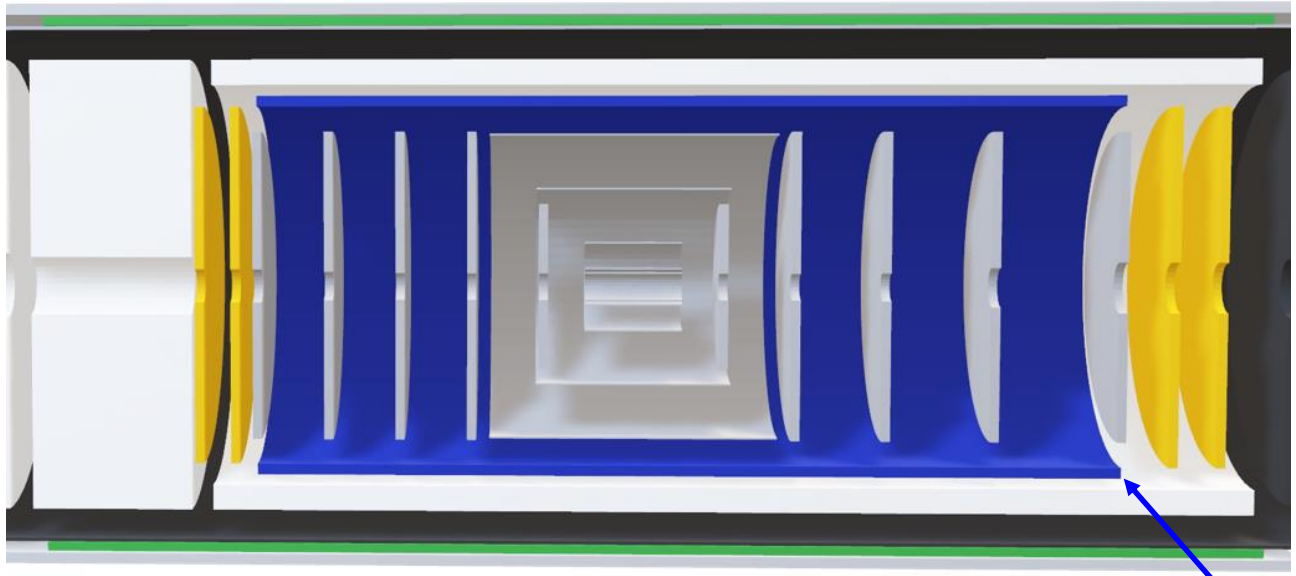
ePIC MPGD trackers

- MPGD trackers in ePIC provide additional hit points and fast timing hit to the core Si trackers for pattern recognition background rejection and hit information to the PID detector in the barrel region
- Two MPGD technologies in ePIC:
  - **Micromegas** (inner barrel tracker)
  - **GEM-µRWELL hybrids** (outer barrel layer and end cap discs)

Detector	Zmin [cm]	Zmax [cm]	Rmin [cm]	Rmax [cm]
CyMBaL	-105	135	50.25	52.25
µRWELL-BOT	-164.5	174.5	72.5	75
µRWELL-ECT 1 (Forward)	148	150.5	7.01	50
µRWELL-ECT 2 (Forward)	161	163.5	7.01	50
µRWELL-ECT 1 (Backward)	-112.5	-110	4.65	50
µRWELL-ECT 2 (Backward)	-122.5	-120	4.65	50



Barrel Inner Layer : Cylindrical Micromegas Barrel Layer (CyMBaL)



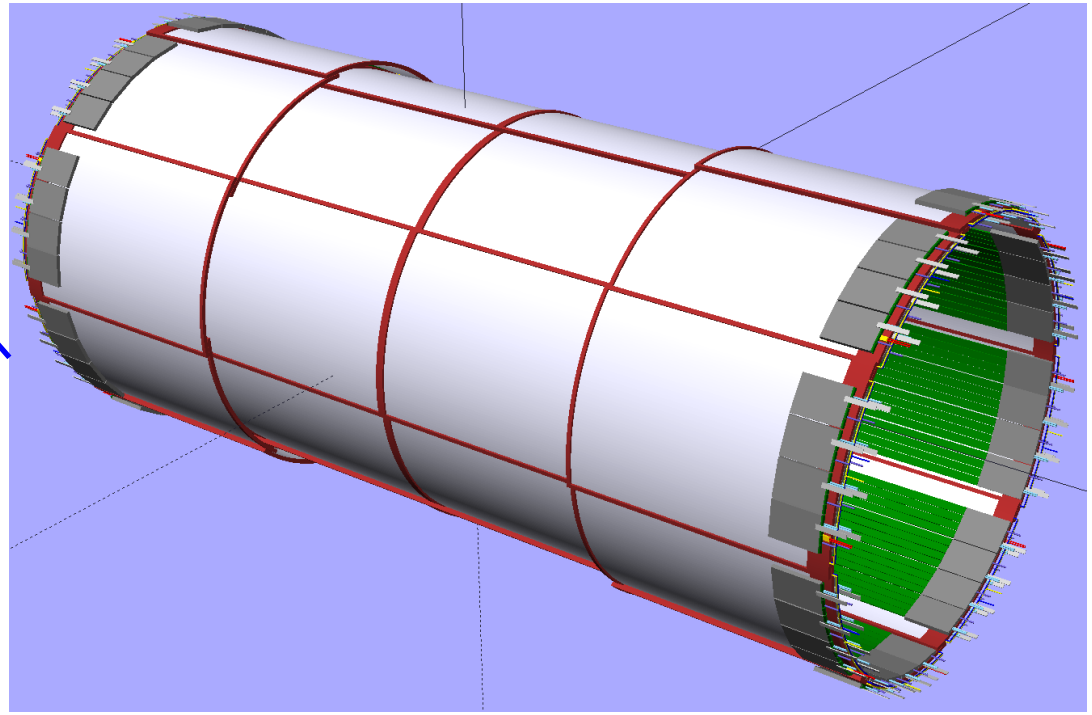
Material from **Francesco's slides** @ Workshop for Inner Detector Support Structures and Cooling

https://indico.bnl.gov/event/22387/contributions/87642/attachments/52775/90266/Inner_detector_workshop_CyMBaL_2024_02_20.pdf

CyMBaL

- Part of the Inner detector (central tracker) with Si trackers and AC-LGAD
- Fast timing and additional hit point to complement the Si tracker for pattern recognition and background rejection
- Single layer based on curved 2D Micromegas modules
- Technology: evolution of the CLAS12 Micromegas, 1D → 2D
- Hermetic in phi and z with 4 cm acceptance gap in the middle ➔ no overlap

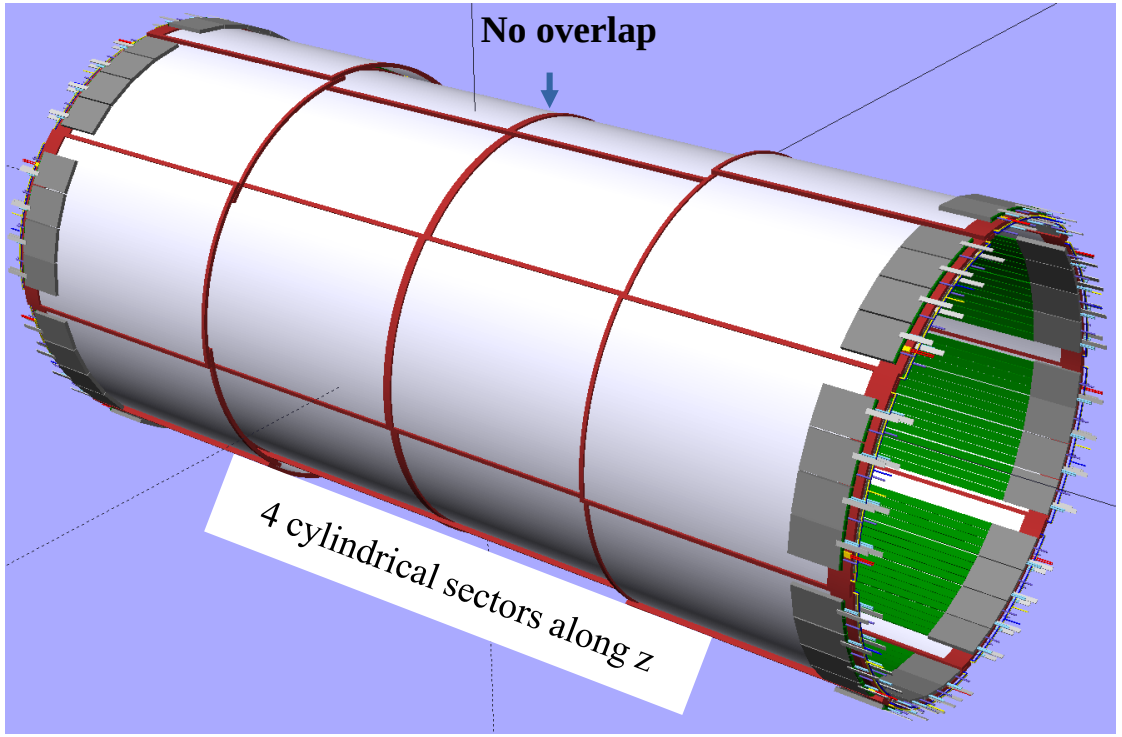
CyMBaL



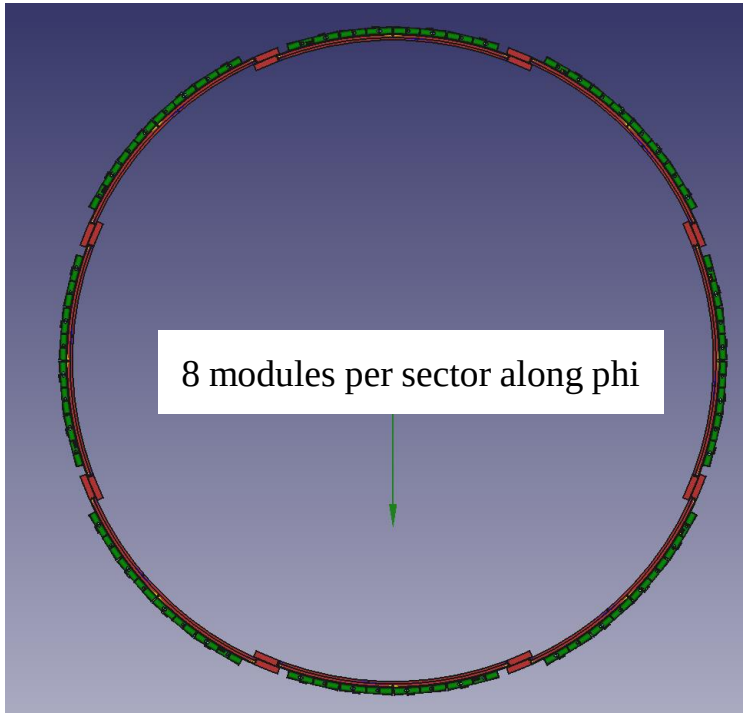
CyMBaL - Overview

CyMBaL : a single layer of curved 2D Micromegas modules

- Length in z -105 cm, 135 cm
- Envelop in radial direction 5 cm ➔ 2 radii layers:
  - 50 cm for two central modules and 52.5 cm for the two outer modules
- Use a single module design to simplify manufacturing and assembly
- Hermetic in phi and z with 4 cm acceptance gap in the middle ➔ no overlap



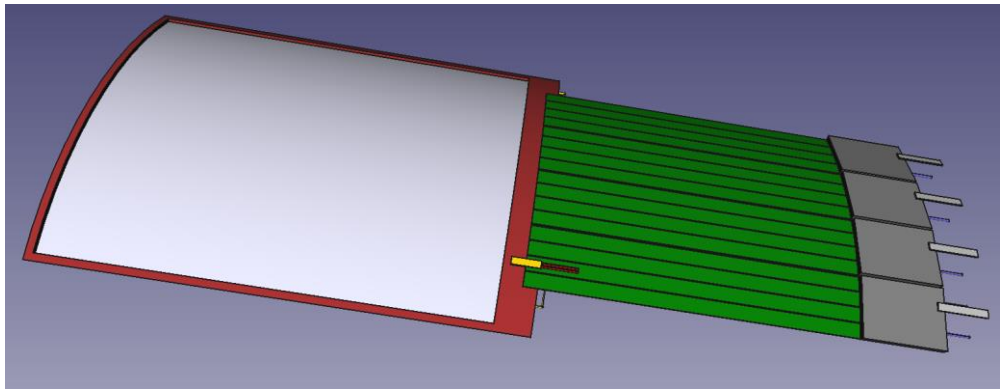
Total of 32 Micromegas tiles



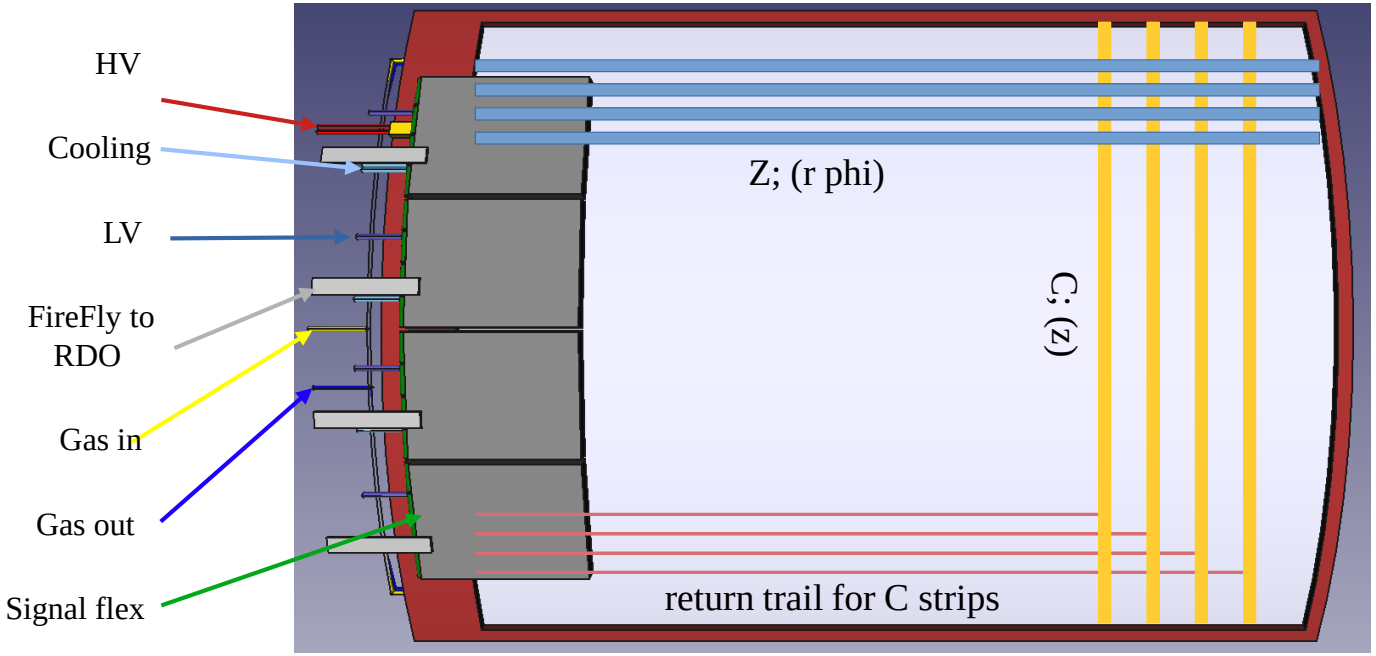
CyMBaL - Basic module

Module characteristics:

- Thickness: 1 cm
- Total Size: **65 × 46 cm²** and active area: **59 × 44 cm²**
- ~1 mm pitch in both directions ➔ 1024 strips per tile
- 32 channels per connector→ 32 connectors

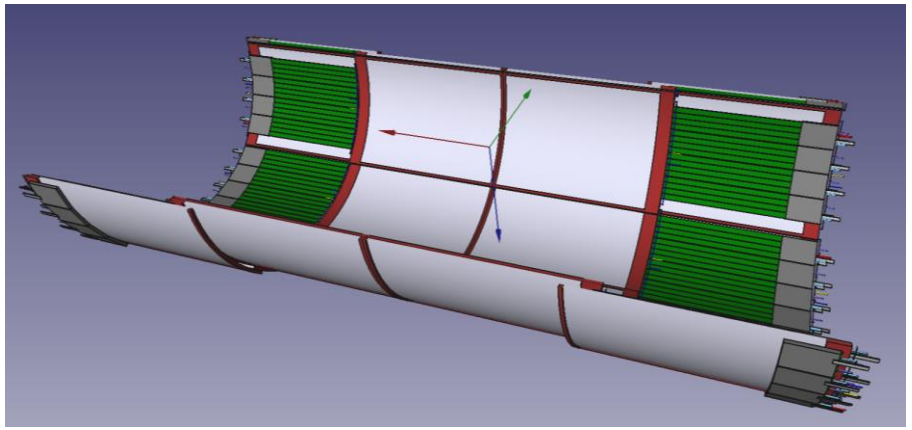


curved Micromegas tile



On-detector front end board (FEBs)

- SALSA chip under development @ Saclay / San Paulo
- 4 FEB per tile assuming 4 ASICs per FEB:
  - Thickness of FEB: ~1cm
  - 1 × 8 ch FireFly per FEB to the RDO
  - 2 flex cables (green) per 64-ch SALSA ASIC ➔ 8 / FEBs
  - LV & Cooling in and out, possibly in series



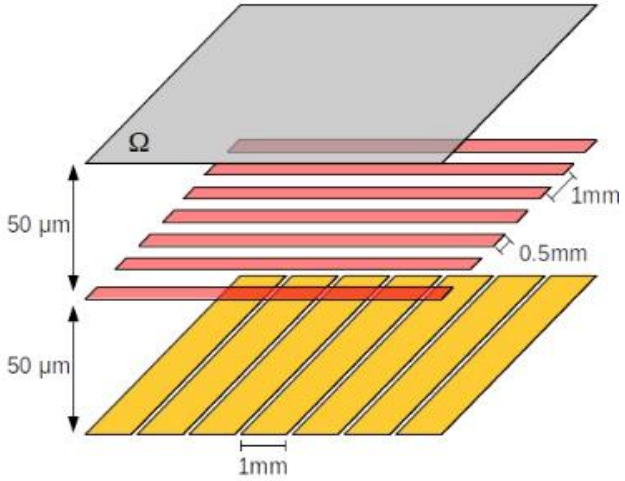
Services:

- HV: 2 channels (drift and resistive layer)
- Gas: 2 tubes (in and out) ➔ Two tiles can be in series

CyMBaL – Ongoing R&D & test beam plans

Development of 2D readout Micromegas for ePIC

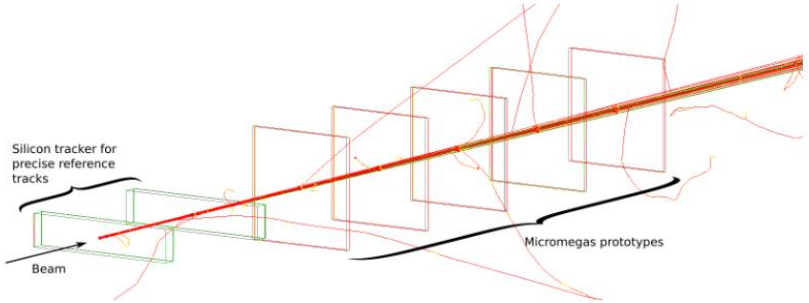
- Study of various 2D strip readout options
- Several 10 cm x 10 cm prototypes tested in beam at MAMI June 2023
- Resistive readout with high surface resistivity ~10 MΩ/□
- X and Y strips on two different layers
  - Straight strips & ASACUSA like pattern

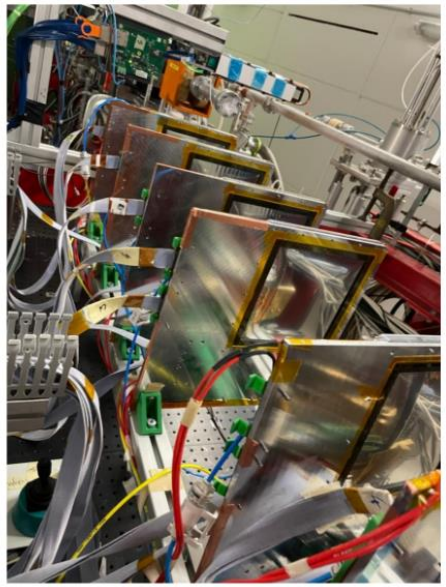


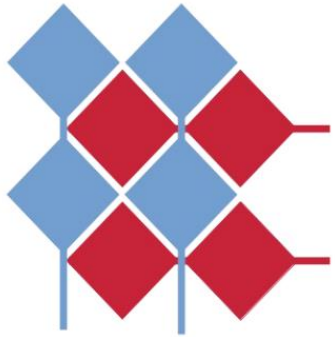
Straight strip pattern

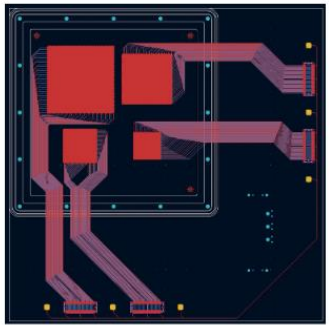
Beam test at MAMI

- In June 2023, beam test on a 880MeV electron beam at MAMI in Mainz.
- We tested prototypes with different variations of readout patterns and resistive patterns.





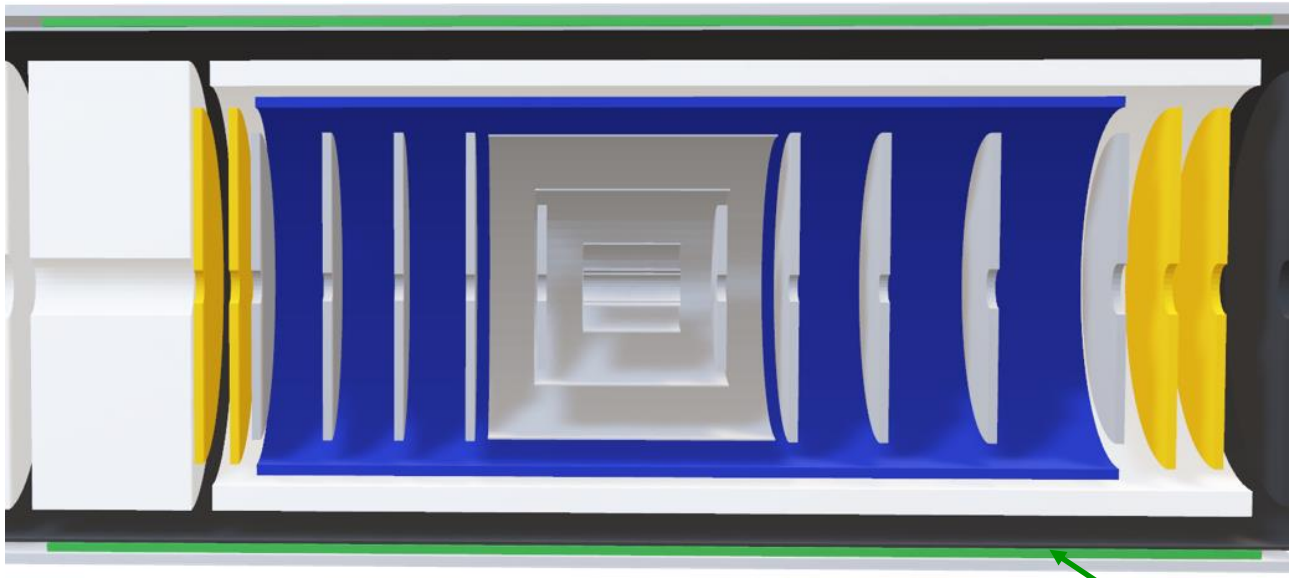




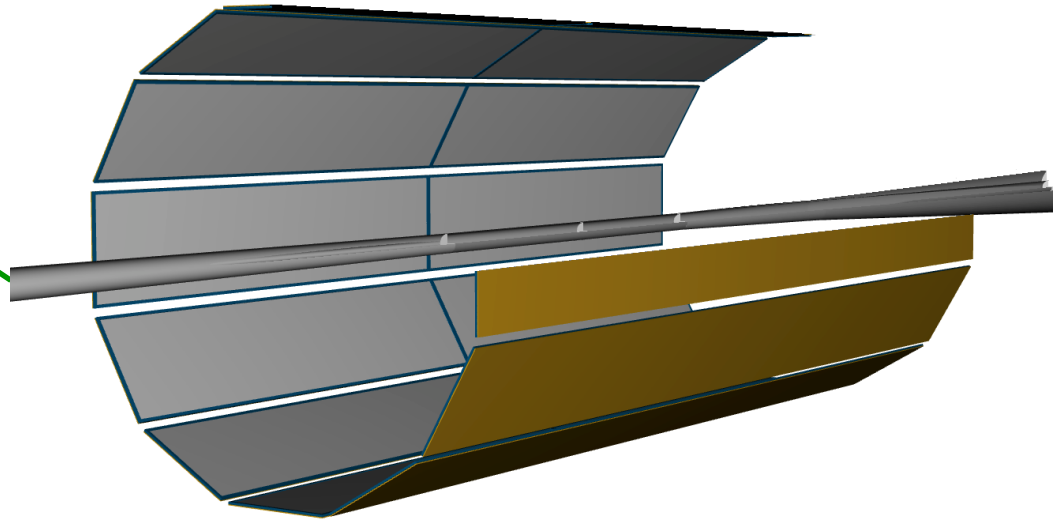
ASACUSA-like pattern

- Plans for beam test at CERN in 2024 with muon beam to minimize multiple scattering
- Mock up for a full size prototype

Barrel Outer Tracker: Thin-gap GEM-µRWELL **(µRWELL-BOT)**



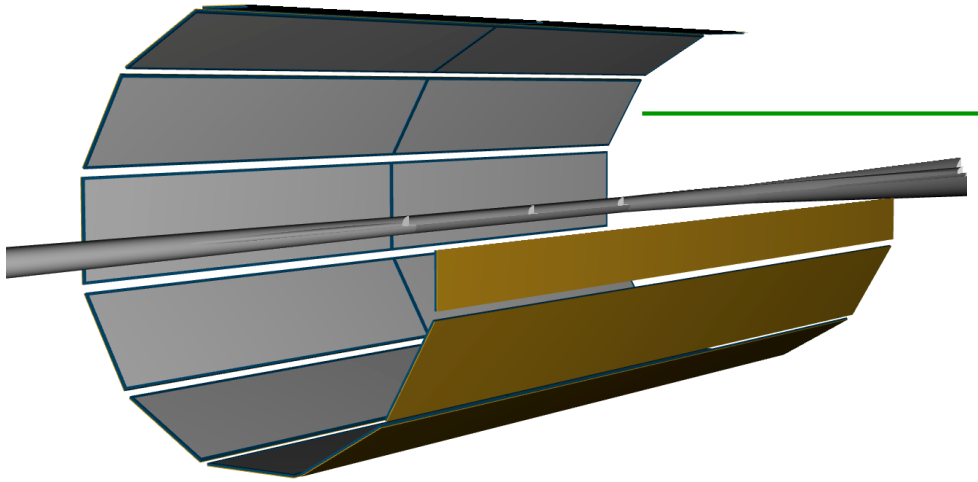
µRWELL-BOT

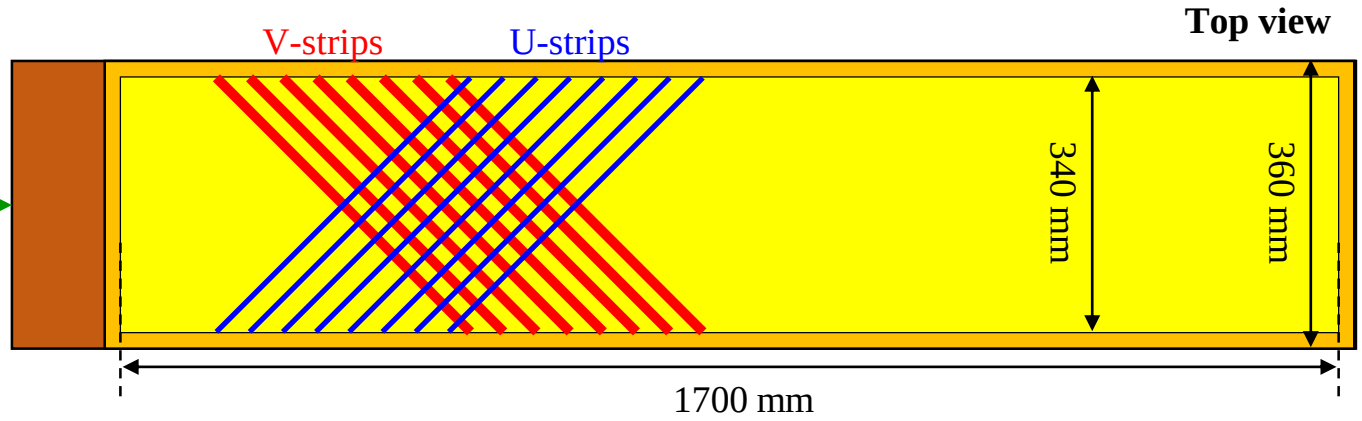


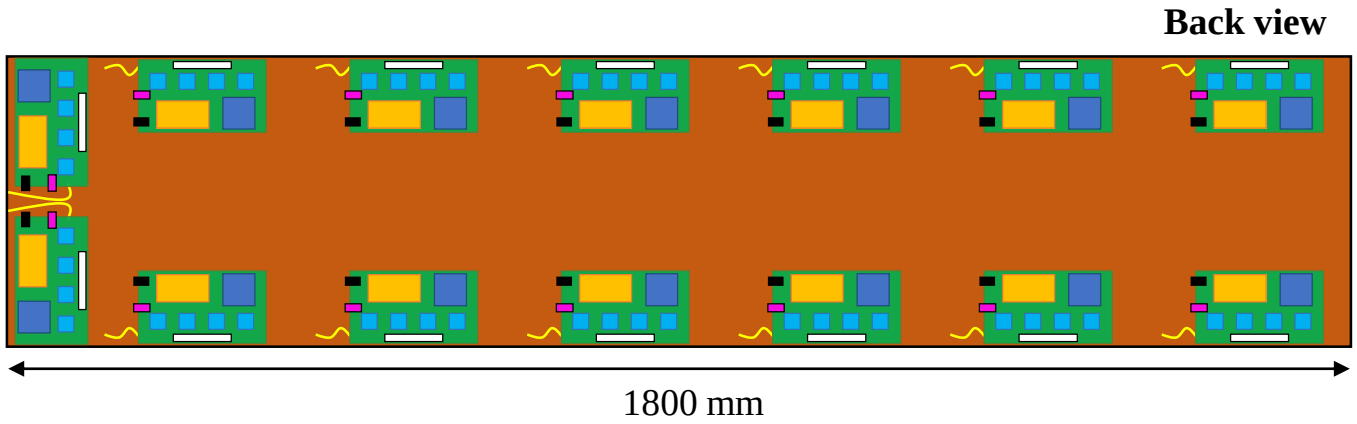
µRWELL-BOT

- Provide hit and directional tracking information for DIRC in addition to pattern recognition and additional timing hit point for central tracker
- Flat long rectangular thin-gap MPGD detector (active area 34 cm × 170 cm)
- 2 modules along z direction and 12 modules along radial axis
- Same segmentation as the DIRC bars in ePIC detector
  - Modules installed in the ECAL support structure under DIRC bars

µRWELL-BOT - Overview







24 uRWELL-BOT modules

- Thin-gap (1-mm drift) hybrid amplification GEM-µRWELL detector
- Capacitive-sharing U-V strips readout layers(45^{O} stereo angle)
- Pitch: ~1.14 mm (1792 U-strips and 1792 V-strips per modules)

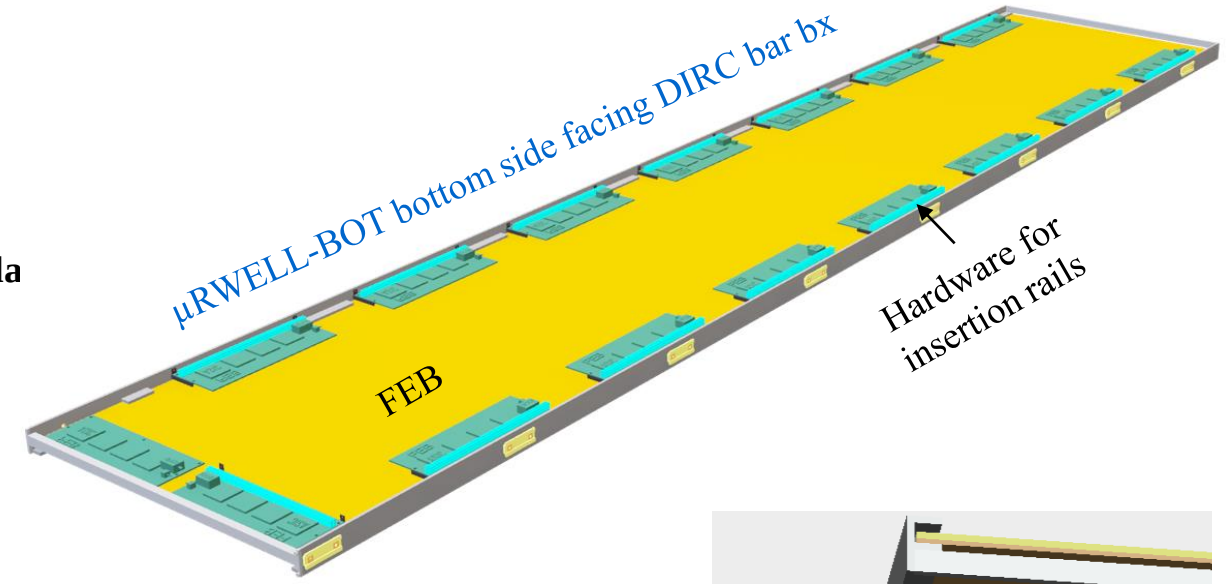
On-detector Front End Boards (FEBs) based on SALSA chips

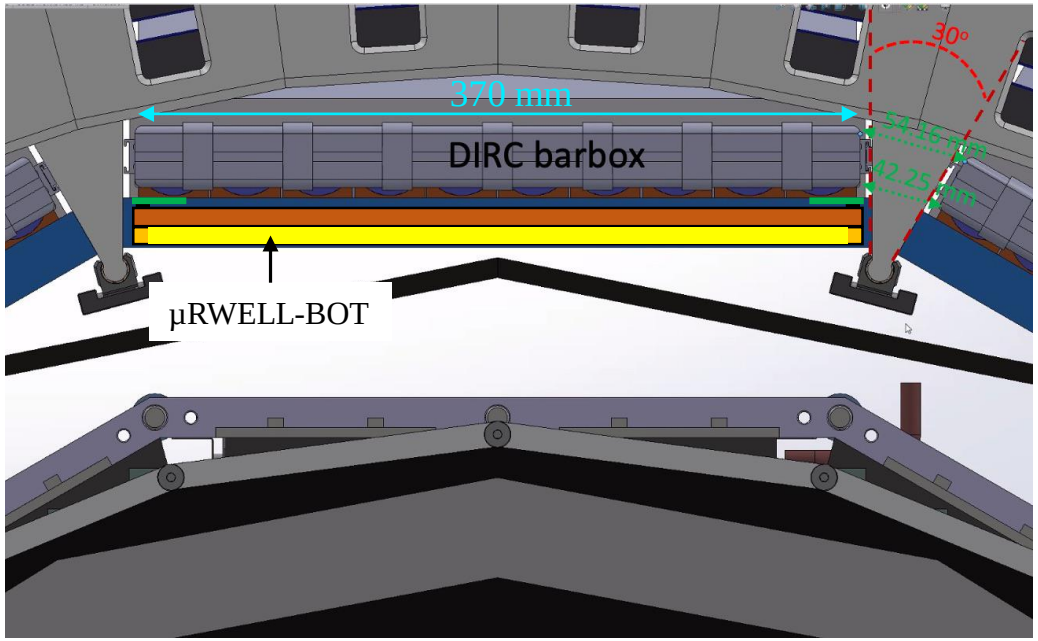
- 14 FEB / modules (assuming 4 SALSA chips i.e 256 e-ch / FEB)
- Total of 336 FEB for the full 24-module µRWELL-BOT
- Direct connection on the back of the modules (no need for flex cables)
- Likely different FEB design than for CyMBAL
  - Driven by space contraints

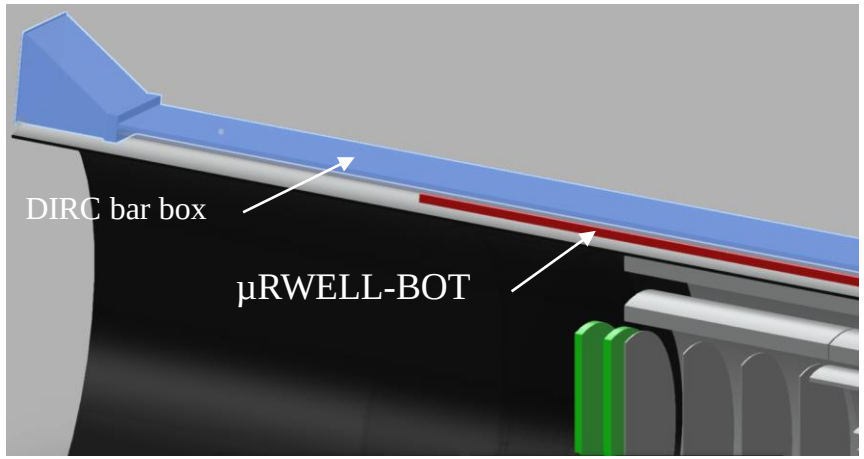
µRWELL-BOT – Integration in ePIC (CAD drawings)

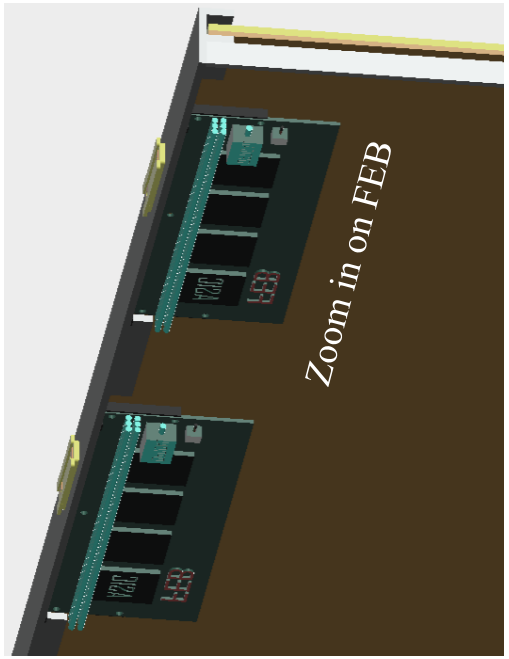
Status of integration of µRWELL-BOT into ePIC

- Installed in the ECAL support structure underneath the DIRC bar boxex
- Working out real estate "conflict" with our DIRC colleagues
- Preliminary design include FEB boards, HV and LV cables, Gas and HV services
- Lots of progress over the past 3 months with the CAD drawings **(Seung Joon @ Jla**
  - Design of the module is in advance stage ➔ still working on final details
- Preliminary design with FEB boards, HV and LV cables, Gas and HV services
- Virtually no space left in the envelop after the integration of the complete module





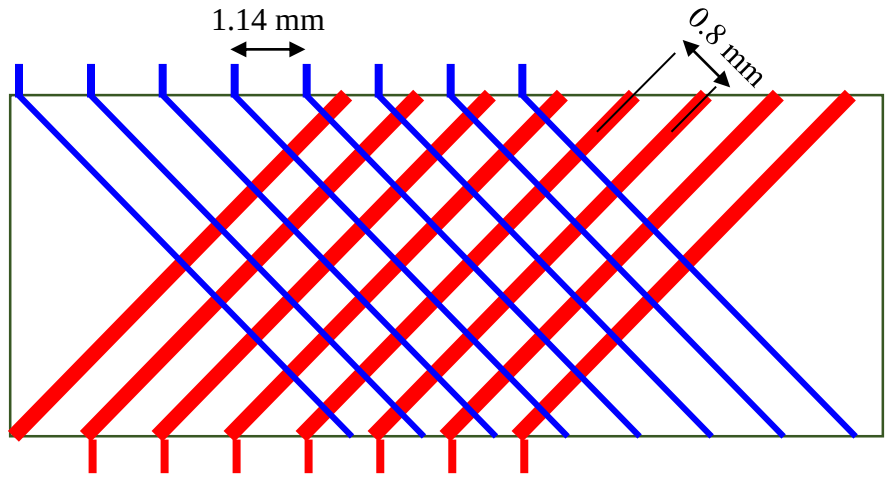




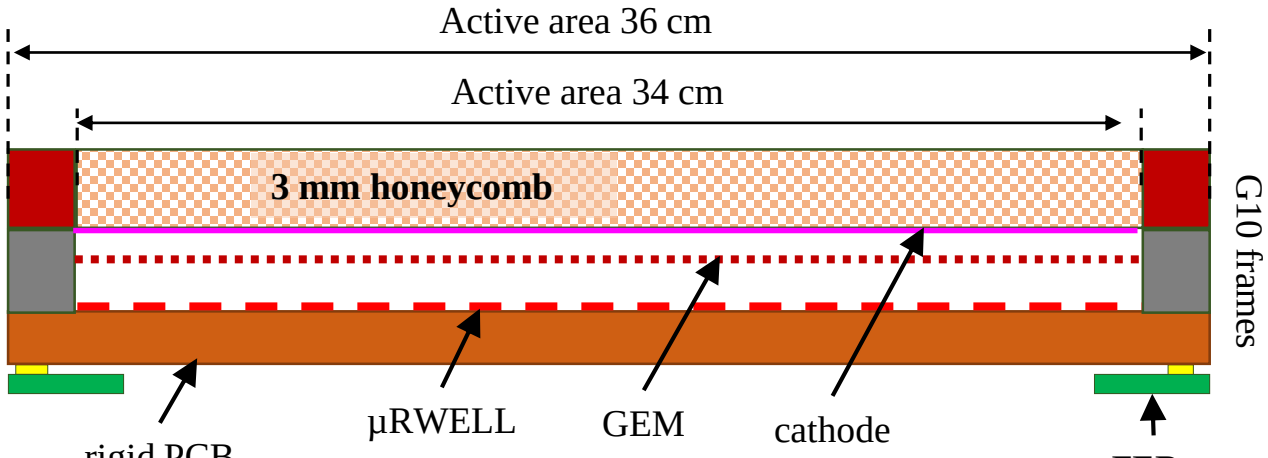
µRWELL-BOT – Technology choice

Thin-gap GEM-µRWELL design (tg-GRWELL)

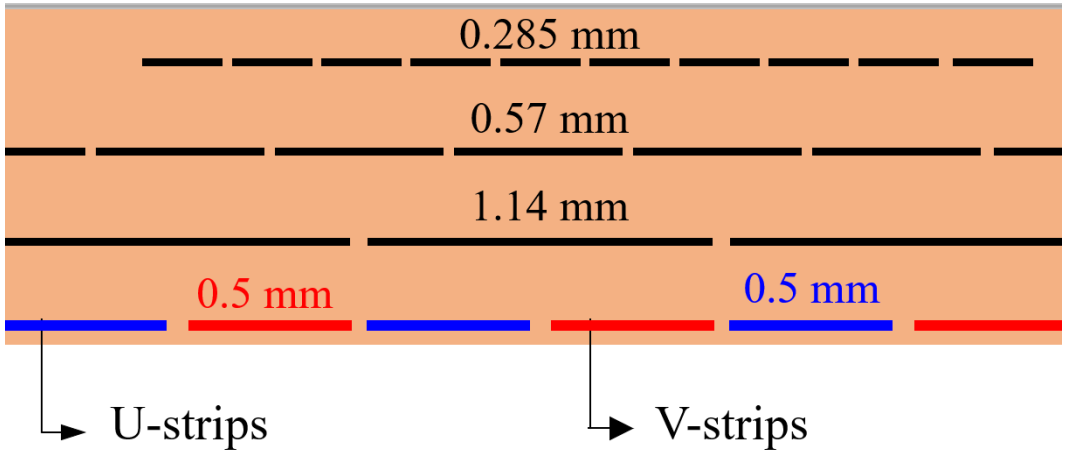
- Double amplification layers: GEM (preamplification) and µRWELL (main amplification)
- Thin gap ionization / drift volume
  - 1 mm ionization gap (GEM to cathode) & 2 mm induction gap (GEM to µRWELL)
- 3-layer capacitive-sharing U-V strip readout
  - Strip pitch: 0.8 mm (along U and V axis)
  - Trace pitch: 1.14 mm along horizontal axis (traces)
- Connectors on the back of the rigid PCB detector ➔ vias connected strips to connectors
- The design of the detector module parts will start in a couple of weeks involving interaction with expert at CERN



U-V strip configuration



cross-section view of thin-gap GRWELL detector

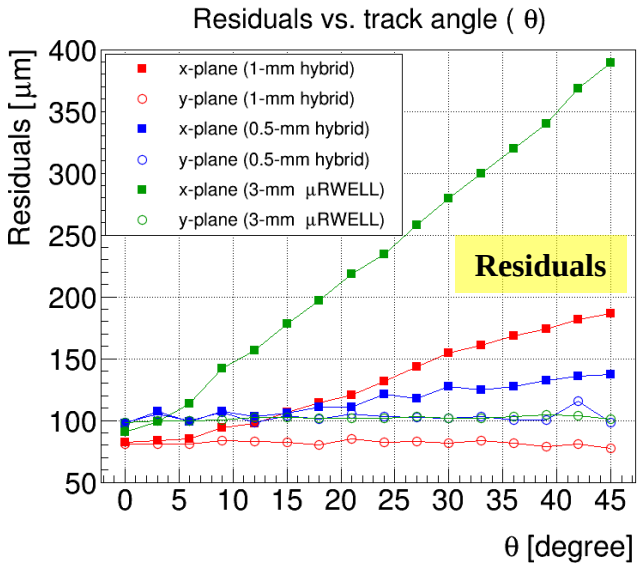


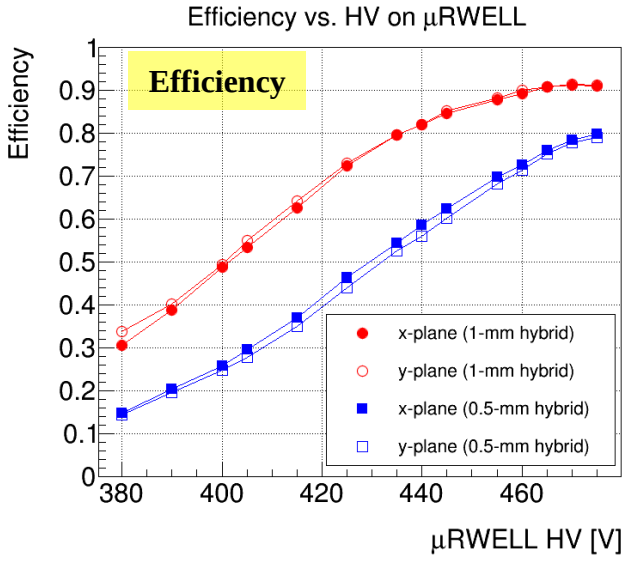
cross-section view of capacitive-sharing U-V readout

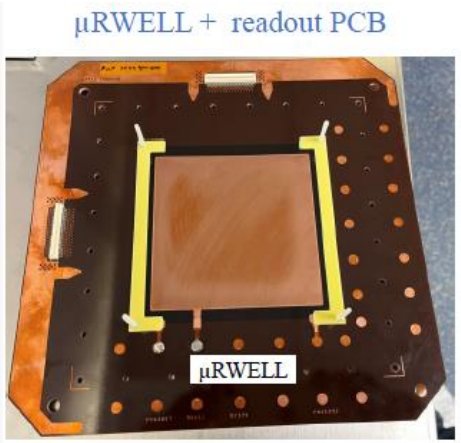
µRWELL-BOT – Performance of thin-gap GEM-µRWELL in test beam

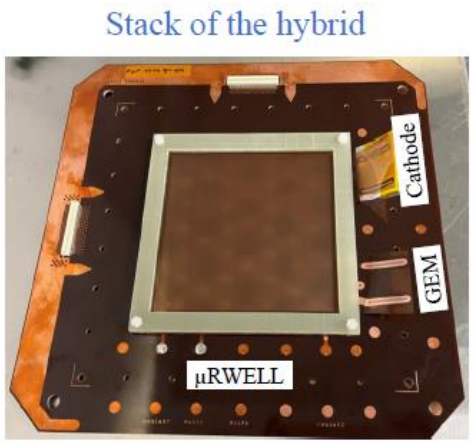
Performance of thin-gap GEM-µRWELL protos with track angle

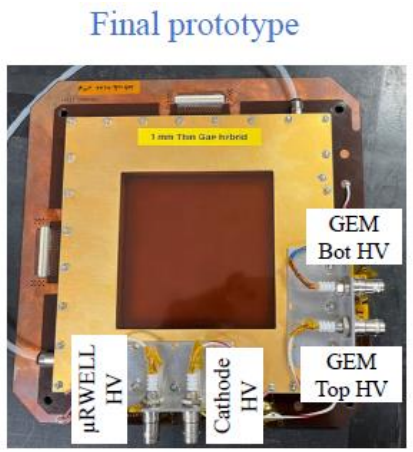
- Position resolution steadily increases with track angle but thin-gap protos shows better performance at large angle than 3-mm protos
- Efficiency **is angle-dependent** and varies from ~90% to ~95% for 1-degree and 45-degres tracks respectively for 1-mm GEM-µRWELL and from ~75% to ~85% for 0.5-mm GEM-µRWELL
- Strip multiplicity is also angle-dependent. Normalized strip multiplicity plot shows 60% and ~22% increase of the strip multiplicity for 3-mm gap uRWELL and 1-mm GEM-µRWELL respectively

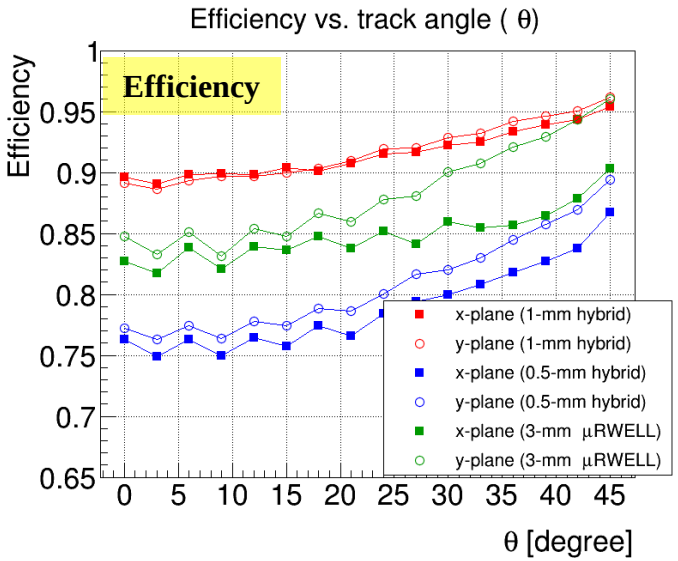








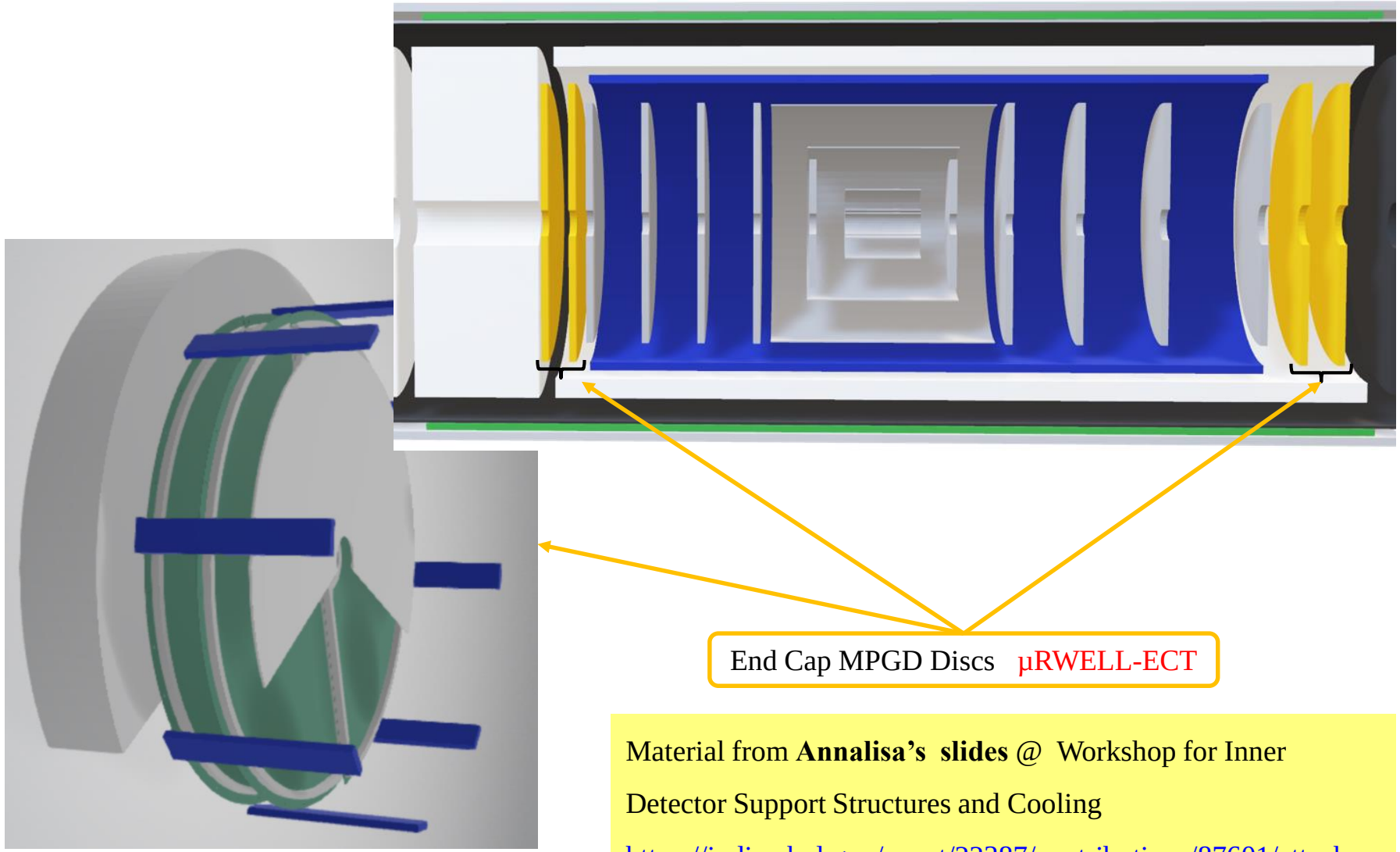




End Cap Disc: GEM-µRWELL End Cap Tracker (µRWELL-ECT)

µRWELL-ECT

- Provide fast timing and additional hit in forward and backward trackers
- Planar GEM-µRWELL discs
  - Both thin gap and standard gap been explored
- 2 discs in either end cap ➔ radius 50 cm
  - 2 semi-circle or 4 quadrants still under consideration
- Design and CAD drawings of implementation in ePIC just started
- Effort led by A. D'Angelo form INFN Roma Tor Vergata
- Jlab helping with CAD design and inetgration



End Cap MPGD Discs µRWELL-ECT

Material from **Annalisa's slides** @ Workshop for Inner Detector Support Structures and Cooling
https://indico.bnl.gov/event/22387/contributions/87601/attachments/52771/90294/EIC_endcaps_Integation_feb_20_2024.pptx

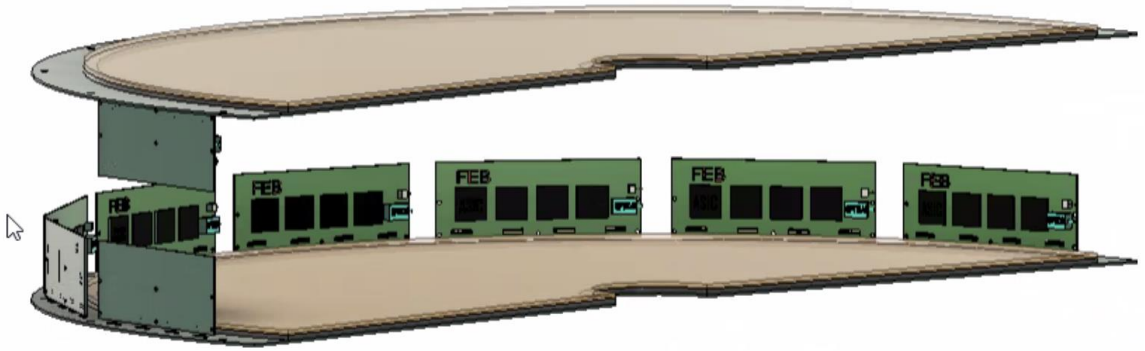
Component	Sub-Component	WBS	Length (cm)	Inner Radius (cm)	Outer Radius (cm)	Offset from Center (cm)	Physical Start (cm)	Physical End (cm)	Volume (m^3)	Weight (kg)	Technology	Notes
HD MPGD 2			2.5	7.014	50	161	161	163.5	0.02	3.85414078		Weight: based on parametric estimate from SBS Gem Offset: measured from face nearest to interaction point
HD MPGD 1			2.5	7.014	50	148	148	150.5	0.02	3.85414078		Weight: based on parametric estimate from SBS Gem Offset: measured from face nearest to interaction point
LD MPGD 1			2.5	4.635	50	-110	-112.5	-110	0.02	3.89772228		Weight: based on parametric estimate from SBS Gem Offset: measured from face nearest to interaction point
LD MPGD 2			2.5	4.635	50	-120	-122.5	-120	0.02	3.89772228		Weight: based on parametric estimate from SBS Gem Offset: measured from face nearest to interaction point

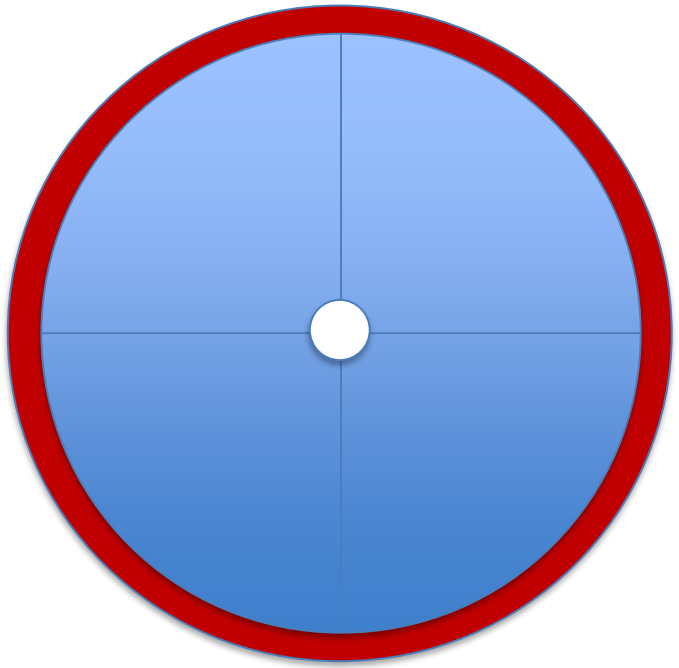
https://eic.jlab.org/Geometry/Detector/Detector-20240117135224.html

Last update: Jan. 17th2024

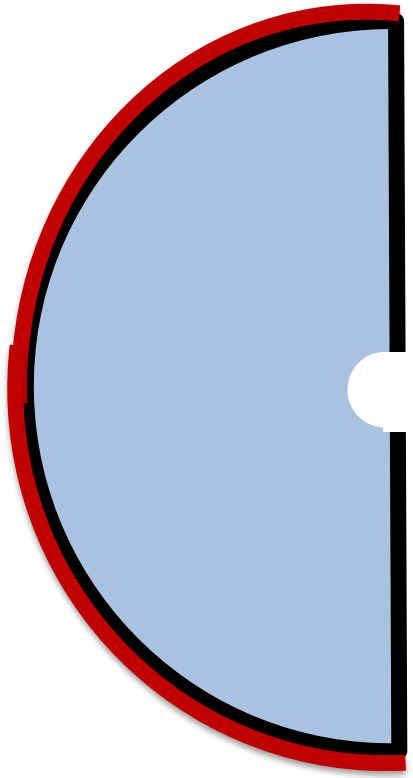
Endcaps - dimensions

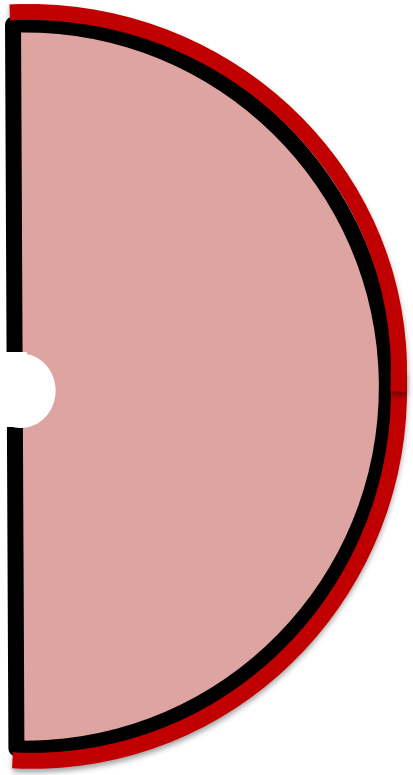
- 50 cm external radius - including frames and services
- 5÷ 8 cm inner radius

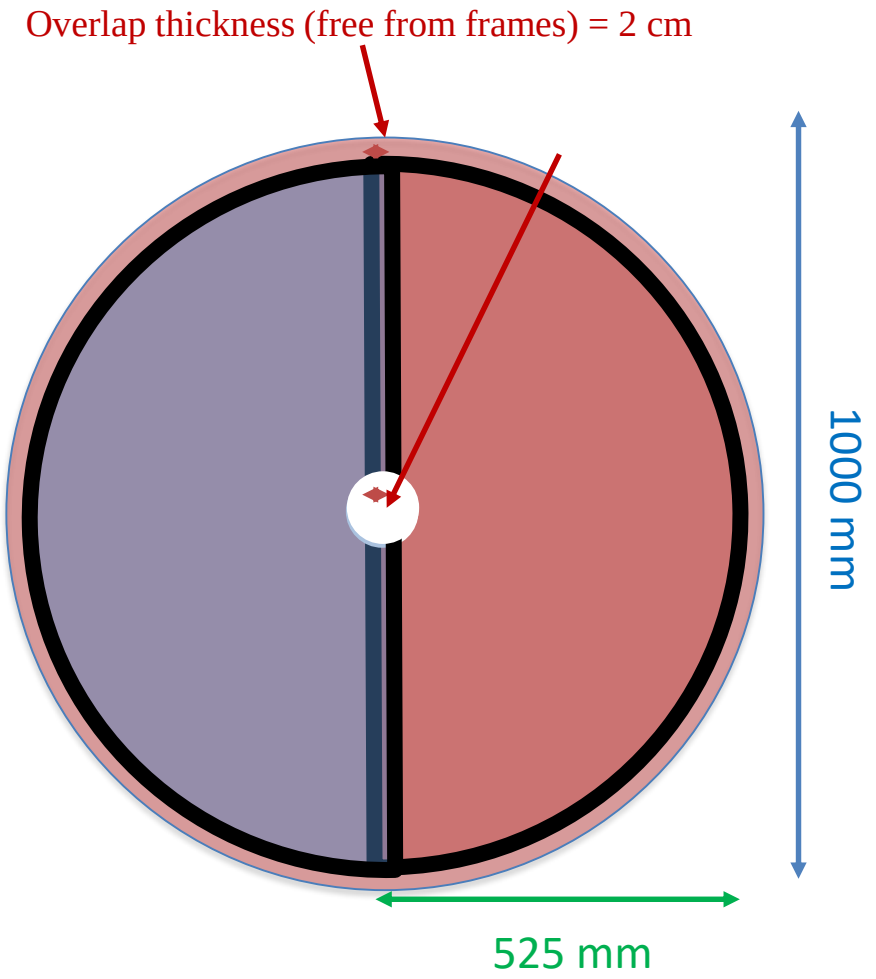




µRWELL-ECT - Overview

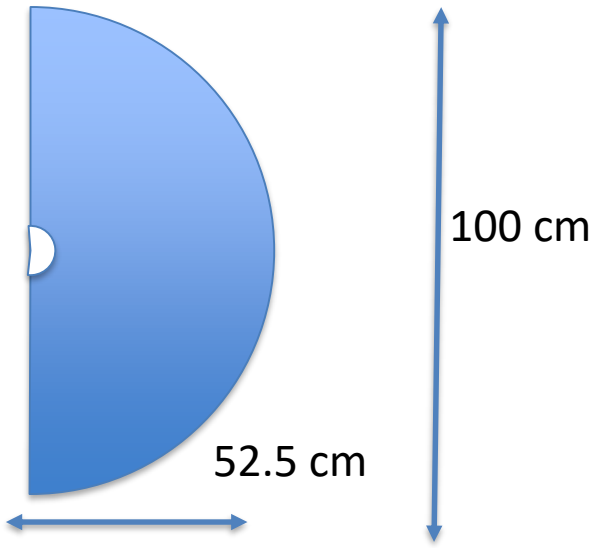






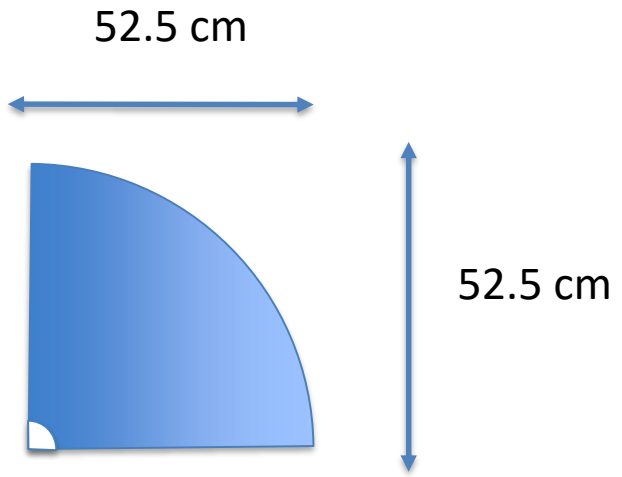
µRWELL-ECT – Disc segmentation options

2 semi-circles



PROs	CONs
One vertical/horizontal overlap only – less material	Larger detector surfaces are more difficult to handle.
The two endcaps may be rotated by 90° one respect to the other to recover overall symmetry	

4 Quadrants

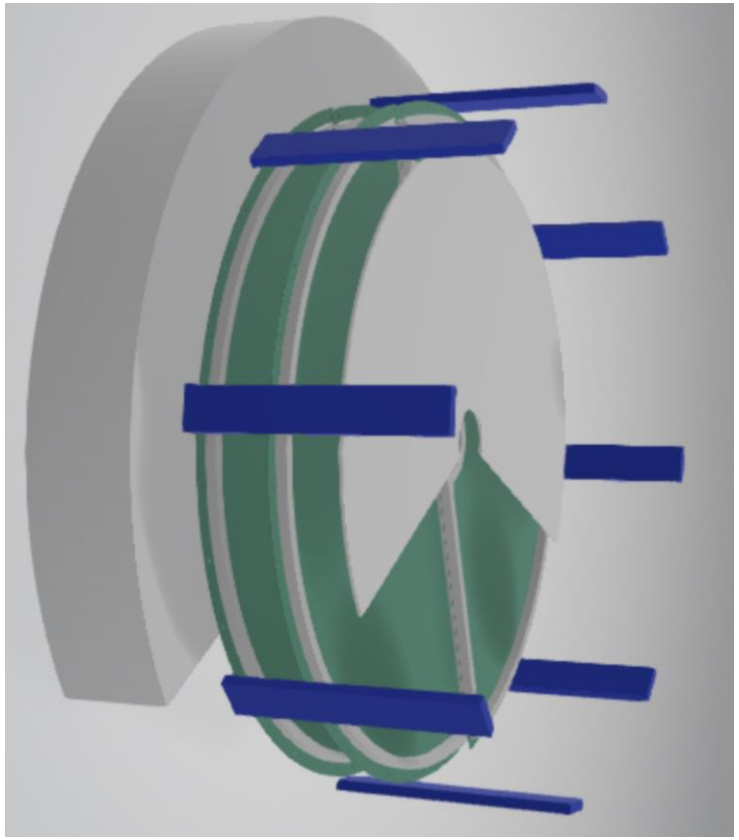


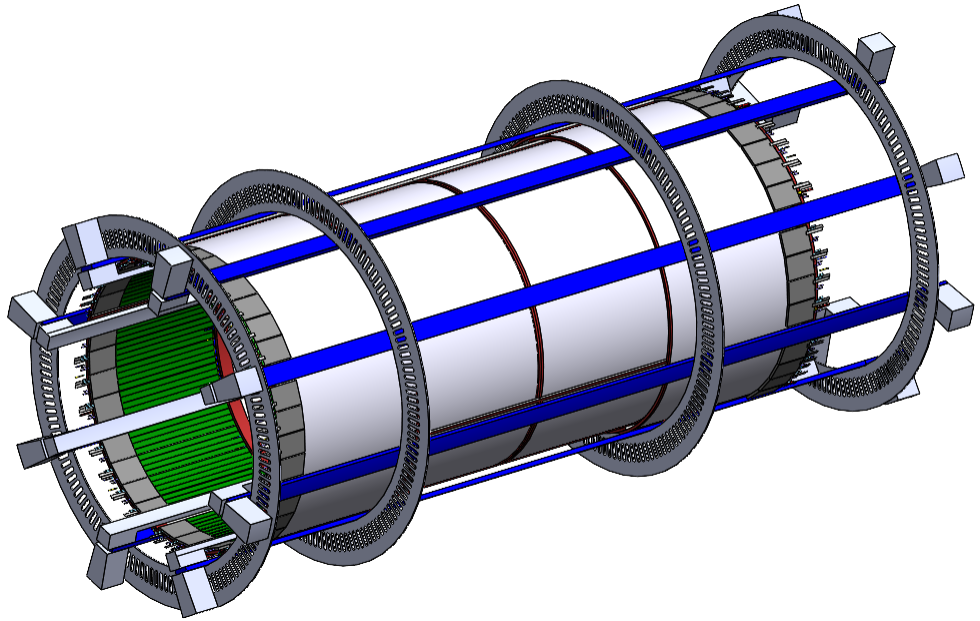
PROs	CONs
Smaller dimensions are easier to handle	Two vertical and horizontal overlapping regions – more material
Each endcap is intrinsically symmetric	

µRWELL-ECT - Integration in ePIC (CAD drawings)

Status of integration of µRWELL-ECT discs into ePIC

- Effort just started with Annalisa for the overall design and Seung Joon for the mechanical drawings and integration into ePIC
- Good understanding of how the end cap discs will be integrated into inner detector support structure (Andy)
- Still need to finalize the envelop of the µRWELL-ECT ➔ will require to increase the radius of CyMBaL to make room for cables and services
- Preliminary design with FEB boards, HV and LV cables, Gas and HV services





For each endcap disk (4 disks in total):

- 16 HV cables
- 4 gas inlets and 4 gas outlets
- 32 data cables
- 32 low voltage cables
- 2 temperature sensors cables
- 2 humidity sensors cables
- 2 dry air inlet and 2 dry-air outlet cooling hoses
- Space for 32 RDO cards

Workshop for Inner Detector Support Structures and Cooling @ BNL - 02/20/2024

Inner Detector Support Structures and Cooling

Tuesday Feb 20, 2024, 8:30 AM → 4:30 PM US/Eastern

Room 2-219 (Bldg 510)

Description Join ZoomGov Meeting
https://bnl.zoomgov.com/j/1609466184?pwd=LzlZRmNyOFZpcnVOWVI2NmlxRVVPQT09

Meeting ID: 160 946 6184
Passcode: 488167

8:30 AM → 9:00 AM	**Inner Detector Support Structures and AC LGAD Overview** Speaker: Andreas Werner Jung (member@cern.ch) Workshop-globalMe...	30m
9:00 AM → 9:30 AM	**SI Detectors Design and Cooling Overview** Speakers: Ernst Sichtermann (Lawrence Berkeley National Laboratory), Mera Horne 20240220 - SVT.pdf	30m
9:30 AM → 10:00 AM	**MPGDs Barrel and Disks Design and Cooling Overview** Speakers: Annalisa D'Angelo (University of Rome Tor Vergata & INFN Roma Tor Vergata), Seung Joon Lee (employee@jlab.org;member@jlab.org) EIC_endcaps_Integ... EIC_InnerBarrel_Inte...	30m
10:00 AM → 10:30 AM	**Design of the Micro Megas** Speakers: Audrey Francisco (CEA-Saclay), Francesco Bossu (CEA-Saclay) Inner_detector_wor...	30m
10:30 AM → 10:45 AM	**DIRC Overview** Speaker: Avishay Mizrahi (MIT LNS) HpDIRC Vs MPGD.p...	15m
10:45 AM → 11:00 AM	**Break**	15m
11:00 AM → 12:30 PM	**Inner Detectors Support Structures Design Details Discussion**	1h 30m
12:30 PM → 1:30 PM	**Lunch**	1h
1:30 PM → 3:00 PM	**SI Detectors and cooling detail design discussion**	1h 30m
3:00 PM → 4:00 PM	**MPGDs Barrel and Disks Details**	1h
4:00 PM → 4:30 PM	**Summary and Steps Forward**	30m

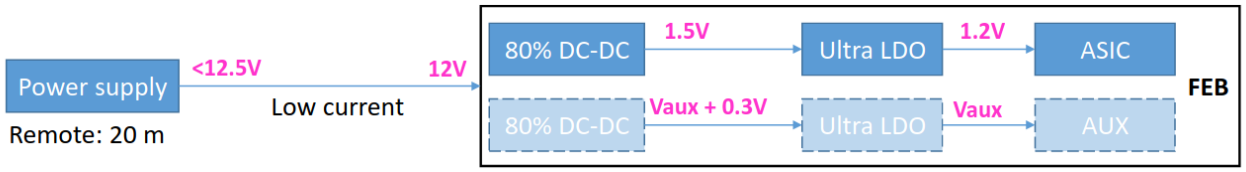
Action items from the workshop - Rahul's email 02/242024

1. Weight estimates for detectors and services:
   - Silicon Detectors : Ernst Sichtermann
   - CyMBaL : Francesco Bossu
   - MPGDs (µRWELL) : Kondo, Seung Joon, Annalisa
2. Services are shown fanned out evenly in the service estimates model. Attachment points for discs and other support features will need space. Extra 25% room should be accounted for that at detector interfaces - Roland
3. Andy and Sushrut will develop conceptual design of support structures to the extent that we can get realistic estimates of detector envelopes to subgroups.
4. 1 cm gap is needed for the adjustment of the inner detectors (CyMBaL and µRWELL-ECT).
5. Subgroups need to work with Andy, Sushrut and Roland if any updates to the service estimates, RDOs etc. is needed in the detector volume.
6. Si group only needs 4 two inch ducts or equivalent coming from both side (8 total) to cool entire Si volume using air. Silicon group will be responsible for the design of the cooling layout within the detector volume. Integration group will look into providing air into that volume and let them know if it's possible.
7. Add North-South, Hadron-Lepton and Forward-Backward on the integration and envelope drawings to avoid confusion.

ePIC Gaseous Trackers – Readout electronics & DAQ

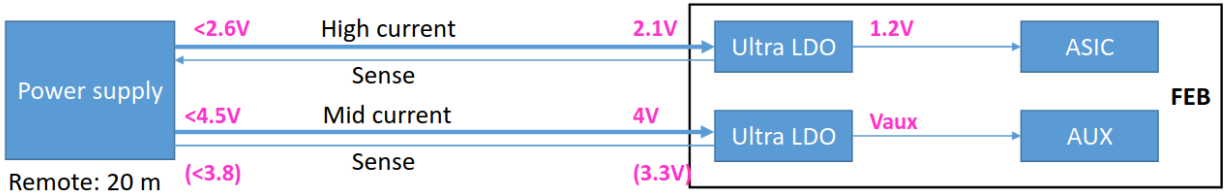
From Irakli's presentation at the DAQ meeting: https://indico.bnl.gov/event/22316/

DCDC on (or close by) FEBs



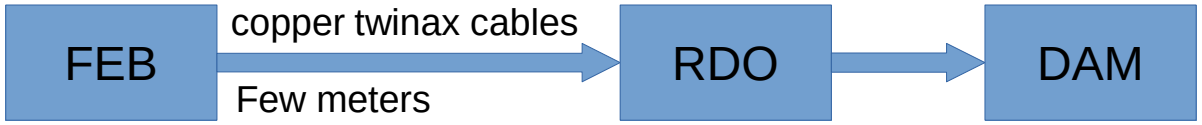
PRO: Small cross section cables
CON: DCDC might be bulky

LDO based powering scheme



PRO: No DCDC on FEBs
CON: Large cross section cables for high current delivery

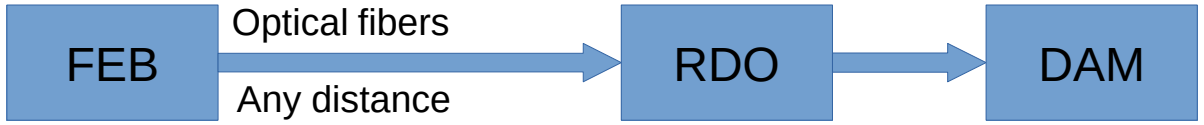
FEB-RDO: on copper twinax cables



PRO: no intelligence on FEBs
CON: RDO MPGD specific, radiation hard, space?

CyMBaL - Inner Detector Workshop

FEB-RDO: on optical fibers



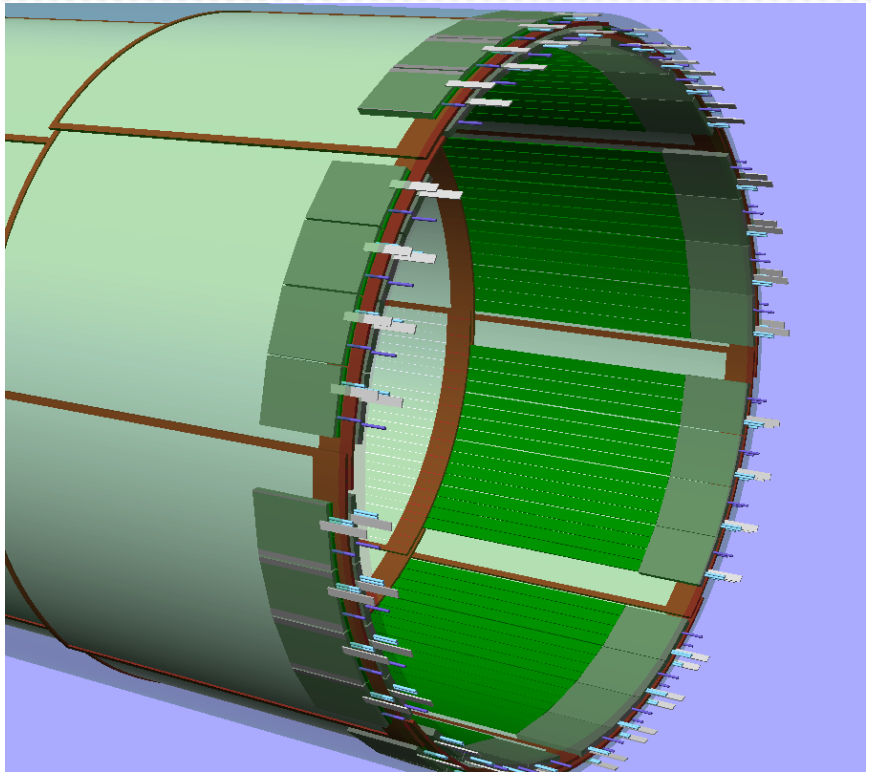
PRO: small cross section for service and no problem of space for RDO
CON: intelligence on FEB, consumption, radiation hardness

Summary

- Design of all three ePIC MPGD tracking layers is ongoing and in good shape
- CAD drawing and integration in ePIC detector made progress with regular meeting with the Integration and support structures groups
- This include our first understanding of the services and cables need for these detectors
- A couple of technical details regarding integration and detector envelops still need to be addressed
- Very productive workshop took place at BNL on 02/20/2024 to discuss issues regarding mechanical support structure and cooling and cabling of the inner detector
- R&D and PED effort of the various technologies ongoing with positive initial performance results from beam test in 2023

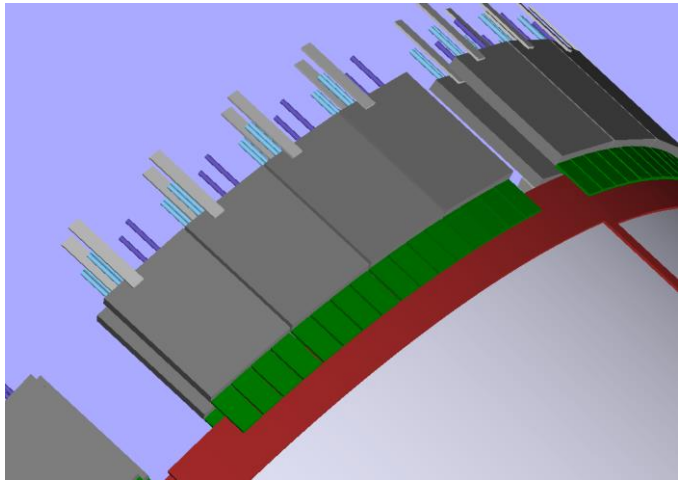
Back up

Inner Barrel: Cylindrical Micromegas Barrel Layer (CyMBaL)



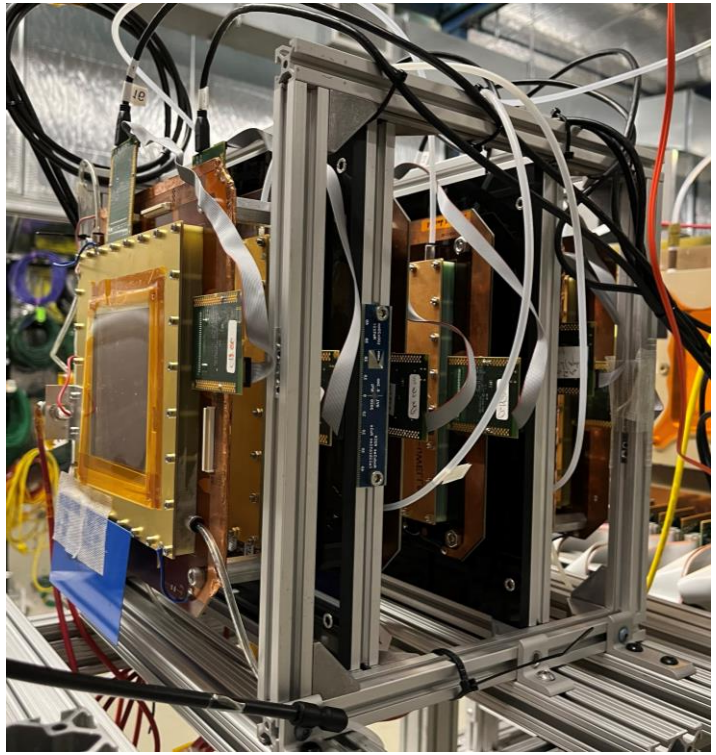
- **Z = [-1050 , 1350] mm**
- **r = [500, 550] mm** (green shade in the picture)
- Assumptions for the radial keeping zone:
  - Thickness of a tile structure ~1cm
  - Thickness of FEB ~1cm
- But this is still a crude (and safe) estimate:
  - We need better estimates for the FEB (see later)
  - Results from the mechanical mock up (later in the year)

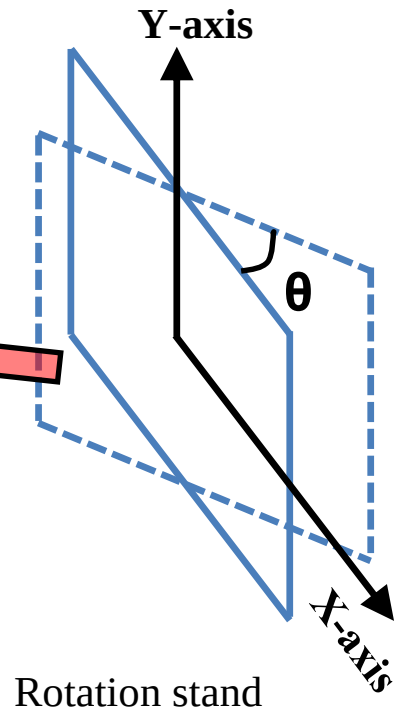
- FEB on the extremities of the system to avoid too much material in the active region
- The inner modules will need longer flex cables (~50cm) to bring the signals to the FEB
- QUESTION: If the 5cm radial keeping zone is not available, we could save some radial space by moving the FEBs close to the modules
- **Is there enough space in z?**



µRWELL-BOT – Thin-gap MPGD test beam @ FNAL June 2023

- All ten various **thin-gap MPGD** prototypes successfully were tested in the 120 GeV proton beam at the Fermilab Test beam Facility (FTBF) in June 2023
- Multi-institution common test beam with two tracking telescopes running simultaneously with 5 prototypes tested for efficiency and position resolution studies
- Several prototypes tested with both Argon and Krypton based gas mixture to study best gas for efficiency
- Test also performed against standard 3-mm gap GEM and µRWELL prototypes for position resolution performance





Rotation stand

Setup I: HV scan setup
- Efficiency with different gas mixtures
- 2 thin-gap prototypes in the stand
- 4 trackers: 2 upstream & 2 downstream

Setup II: Spatial resolution vs. angle scan setup
- Rotation stand rotate the X-Y plane by an angle θ (0 - 45 degrees) w.r.t to Y-axis
- Up to 3 thin-gap prototypes tested in the rotation stand at the time
- 2 trackers upstream and 2 downstream on a fixed separate stand

µRWELL-BOT – Production of components & assembly of modules

Production and procurement of GEM foils and µRWELL PCBs

- GEM foils and µRWELL will be produced by CERN MPT workshop (aka Rui's workshop)
- Production of these components will start after the design is validated with the PED pre-production modules (may need 2 iterations)
- Design validation is expected to be complete by mid 2025
- Korean GEM Production facility express interest in fabricating GEM foils and µRWELL for ePIC MPGDs
  - Facility located at the Korean Institute of Basic Science (IBS) ➔ The group is already member of the ePIC collaboration and just join the MPGD-DSC
  - The equipment were relocated from Mecaro (semi conductor company) that produces large GEM foils for CMS GEMs
  - **Inseok Yoon will present the status of this Korean GEM facility at our next General MPGD-DSC meeting March 07**

Assembly and characterization of µRWELL-BOT module

- Three institutions expresses interest for the assembly, full characterization and QA of the µRWELL-BOT modules
  - JLab, Florida Tech and University of Virginia ➔ all 3 sites have extensive experience with MPGD projects for NP and HEP experiments
    - It is critical to maintain these experience within ePIC MPGD-DSC for MPGD production
- Total of **30 µRWELL-BOT modules** (24 production + 6 spares) for the barrel outer tracker
  - 3 month for the assembly and full characterization and QA of one µRWELL-BOT module
  - Assuming production is conducted in parallel in the 3 assembly sites ➔ 2.5 years for all 30 modules
  - Assuming production start January 2026 ➔ all 30 µRWELL-BOT modules will be on site at BNL July 2028
- We welcome additional institutions interested in joining the ePIC MPGD the effort

µRWELL-BOT – Integration in ePIC (CAD drawings)