MPGD Barrel Outer Tracker (MPGD-BOT)

Kondo Gnanvo, Jefferson Lab – RD&I Group

ePIC MPGD Detector Subsystem Leader (MPGD DSL)

Incremental Design and Safety Review of the ePIC MPGD Trackers
December 15th, 2025

JLab Team:
Xinzhan Bai, Seungjoon Lee on behalf of MPGD DSC

Electron-Ion Collider

Charge Questions Addressed

1. Are the technical performance requirements appropriately defined and complete for this stage of the project?

2. Are the plans for the various sub-systems appropriately documented and complete for this stage of the project?

3. Are the current plans for the detector likely to achieve the technical performance requirements, with a low risk for cost increases, schedule delays, and technical problems?

4. Are the schedule assumptions for the fabrication of the various sub-systems and assembly plans reasonable and consistent with the overall detector schedule?

5. Have ESH&Q and QA considerations been adequately incorporated into the plans at their present stage?

6. Have the recommendations from previous reviews been adequately addressed

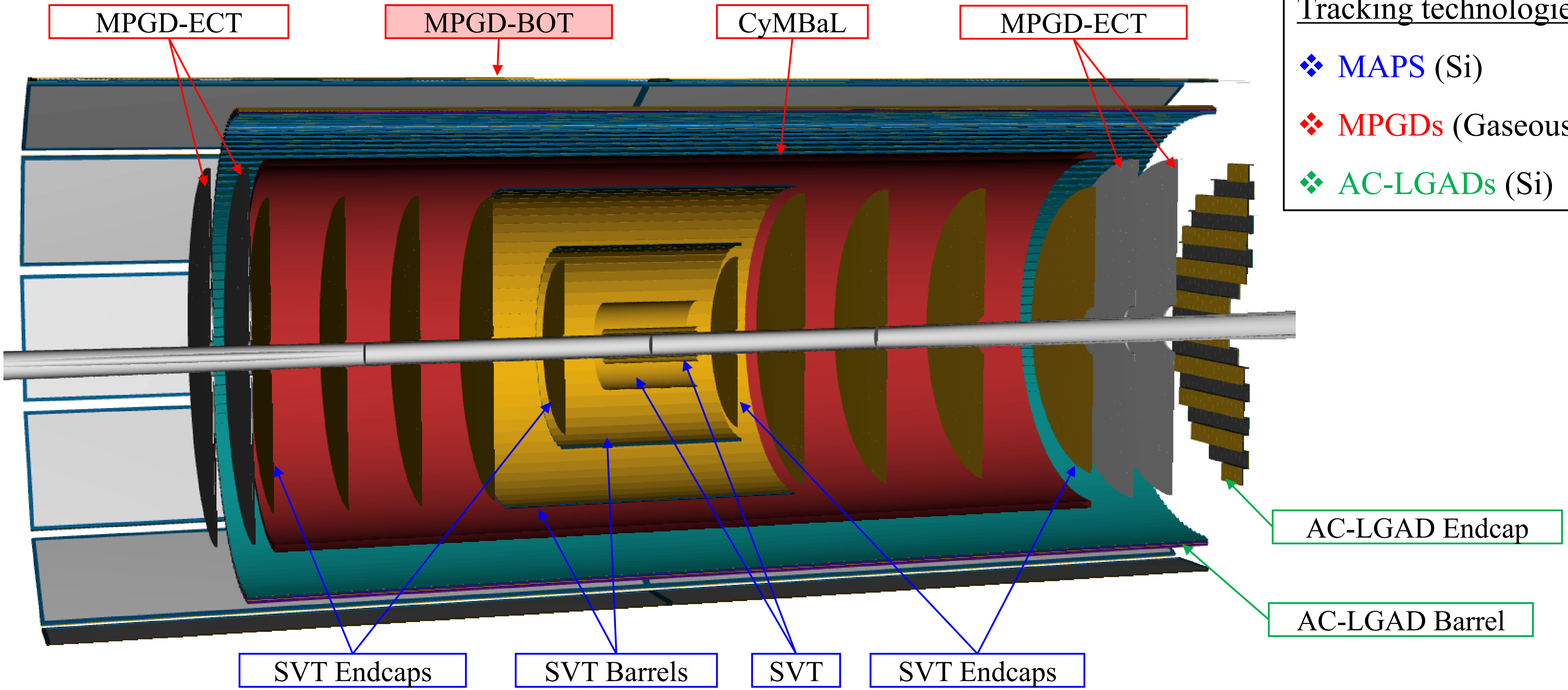
Outline

- ❖ Roles & Requirements — Charge 1
- ❖ MPGD-BOT Layout — Charge 1,3
- ❖ Technology & Performances — Charge 3
- ❖ PED - Engineering Test Article — Charge 3, 4, 6
- ❖ Assembly Schedule, QA & ES&H — Charge 4, 5
- ❖ Summary

Roles & Requirements

Overview of ePIC Central Tracker

Charge 1



Tracking technologies

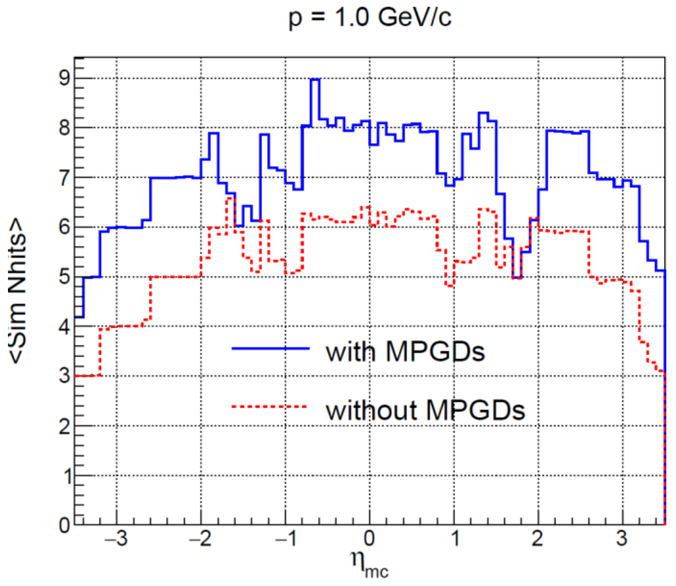
- MAPS (Si)
- MPGDs (Gaseous)
- AC-LGADs (Si)

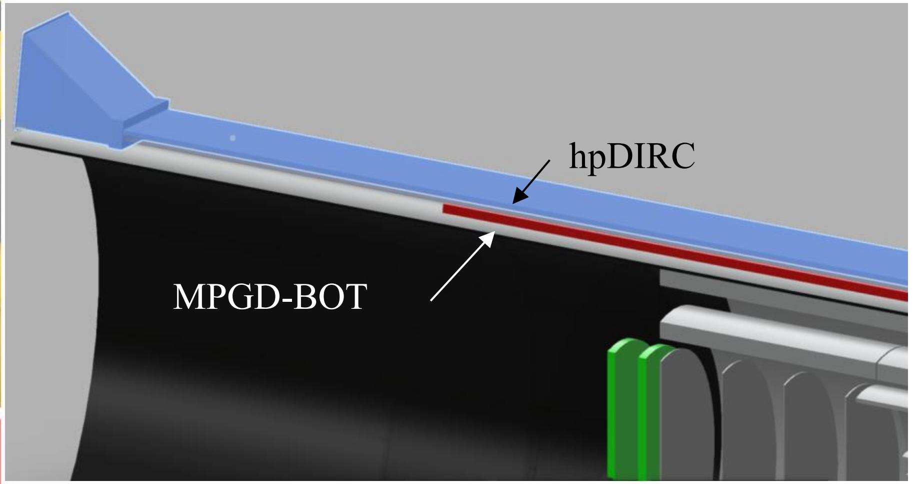
Roles of MPGD-BOT in ePIC Barrel Tracker

Charge 1

Primary role: Pattern recognition, additional hit point & redundancy

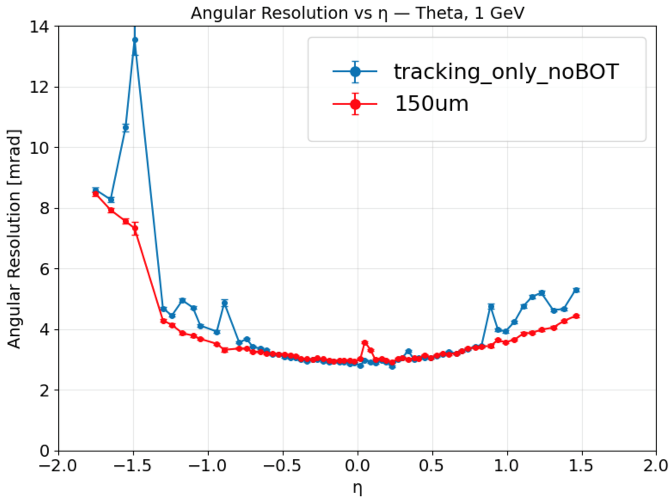
- MPGD-BOT fast timing capability will help with the pattern recognition to discriminate between physics and background signals during track reconstruction.
  - Expected timing resolution ~10 ns ➔ achievable with thin-gap hybrid MPGDs
- Will provide additional hit for robust track reconstruction and for redundancy
  - Expected spatial resolution:
    - ✓ **~70 µm** for perpendicular tracks
    - ✓ **~150 µm** for inclined tracks [0, 45°] ➔ achievable with thin-gap hybrid MPGDs





Additional role: Enhance hpDIRC performance

- MPGD-BOT close to hpDIRC detector with acceptance matching
- Improved angular and space point resolution at the hpDIRC level



See Matt's talk on Tracking

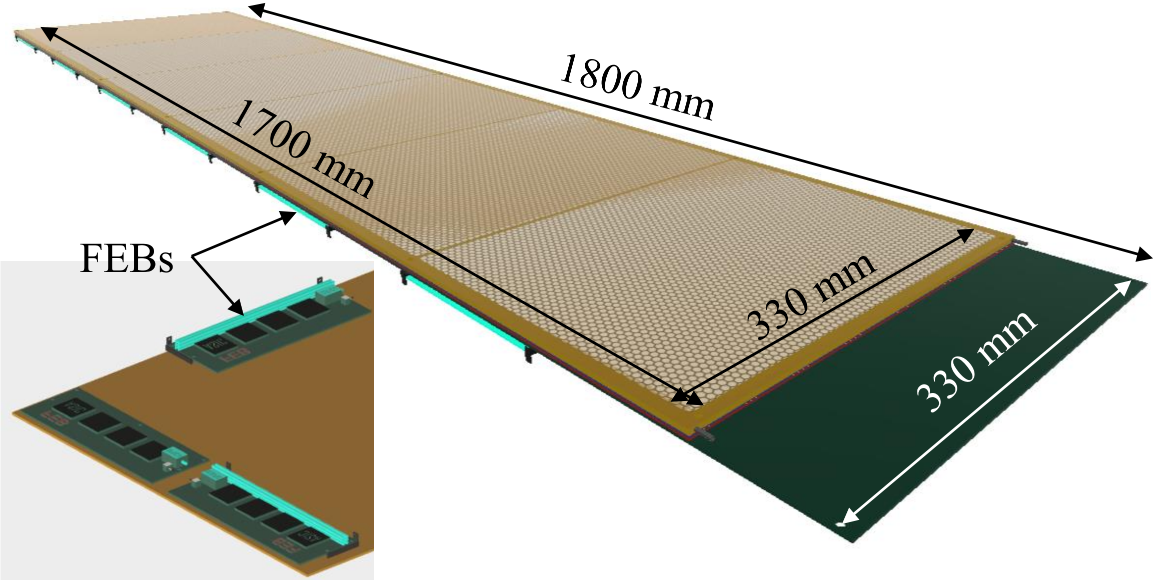
MPGD-BOT Layout

MPGD-BOT Layout

Charge 1,3

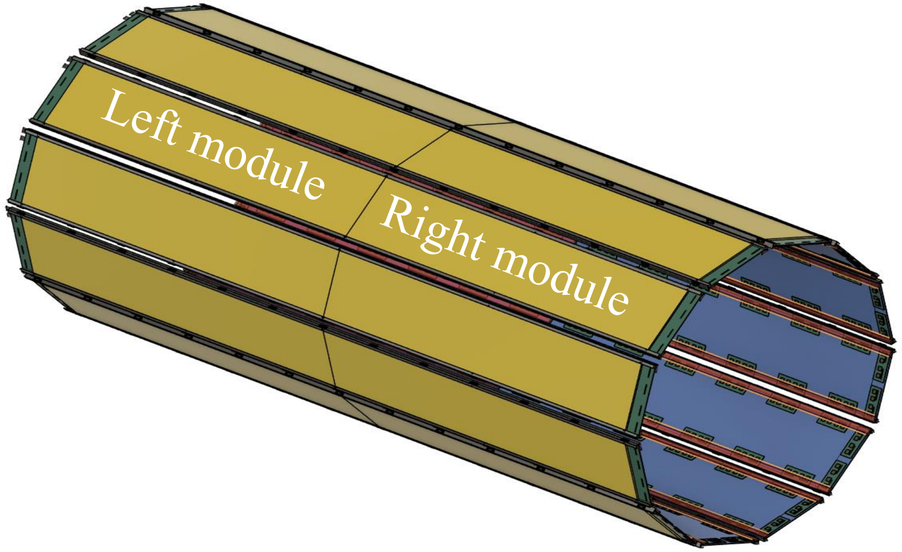
24 planar detector modules

- 2 sectors in z made of left and right planar modules
  - Keeping zones: z = [-164.5 cm, 174.5 cm]
- 12 modules in (r × φ) arranged in dodecagon geometry
  - Keeping zones: r = [73.5 cm, 76 cm]
  - No overlaps in r × φ ➔ ~12 % acceptance gap
- Total readout electronic channels ~86K

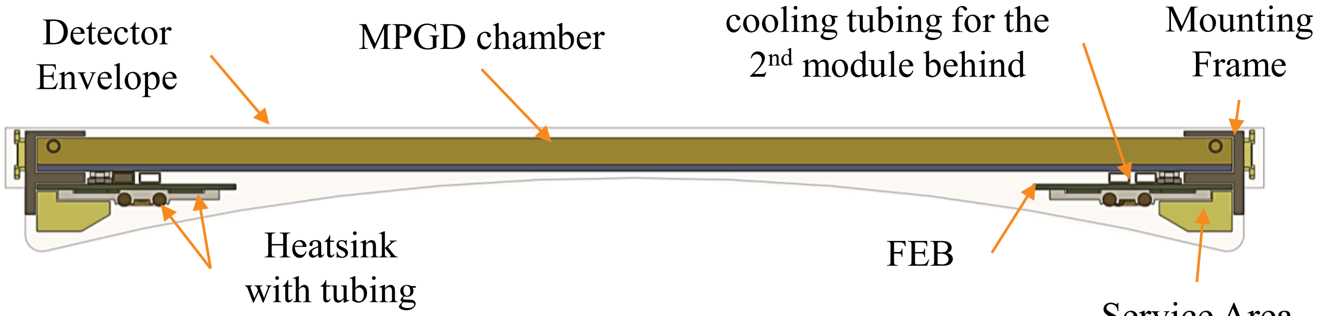


MPGD-BOT module

https://eic.jlab.org/Geometry/Detector/Detector-20240515102931.html



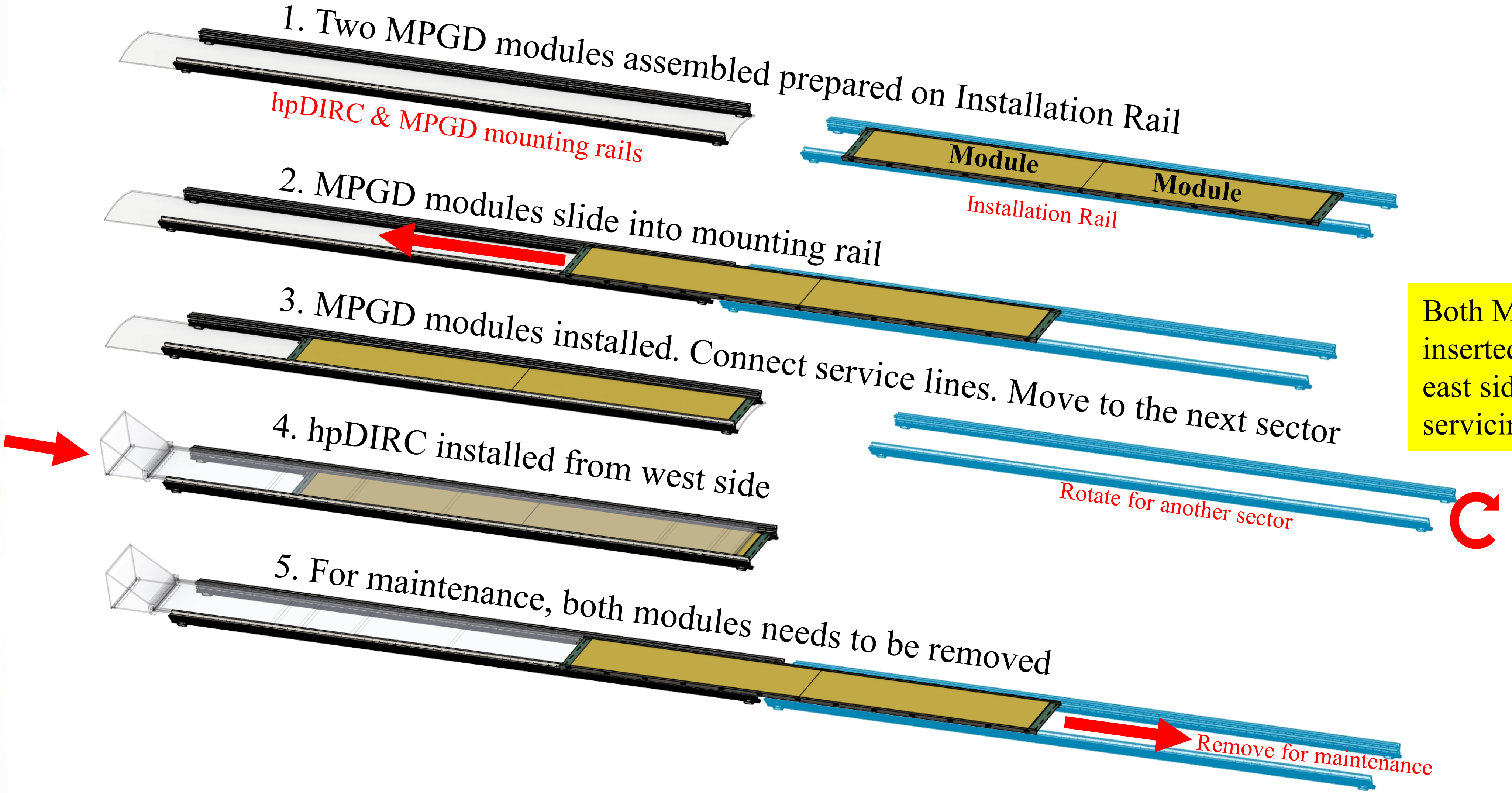
MPGD Barrel Outer Tracker (MPGD-BOT)



MPGD-BOT module cross sectional view

MPGD-BOT: Integration, Installation & Maintenance

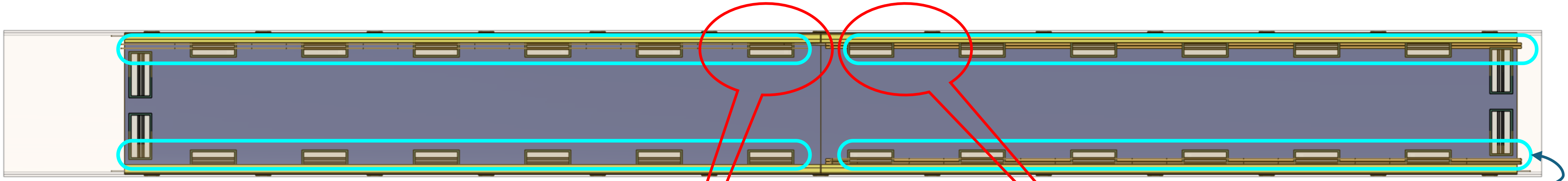
Charge 3



Both MPGD modules must be inserted and removed from the east side for maintenance and servicing

MPGD-BOT module: FEB cooling design

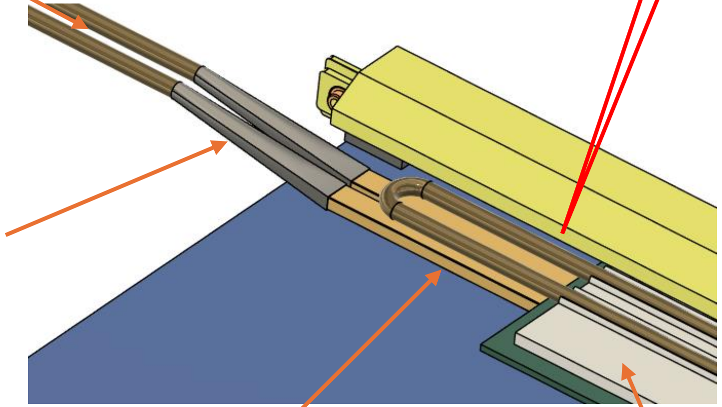
Charge 3



Service Area for
4 ×cooling loop

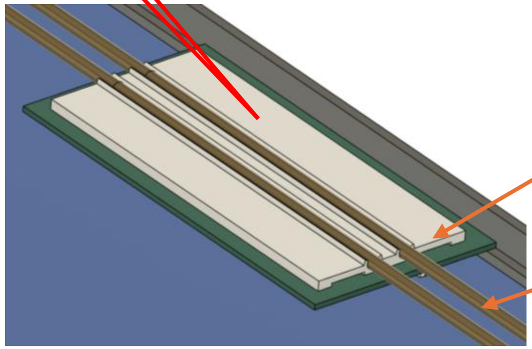
Cooling line
(left module)

Custom
adapter



Rectangular Tubing
under FEB (low profile)

Cooling line
(right module)



Aluminum
Heat Sink

Cooling Pipe

Expected Cooling Parameters

Total power: 240W = 60W × 4 cooling lines

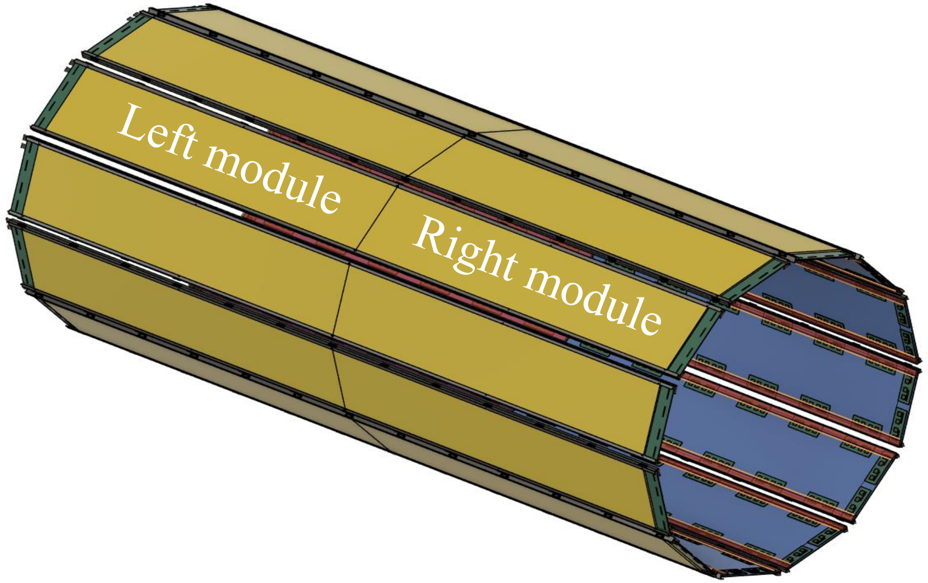
Flow rate: 0.6 L/min

Flow speed: ~ 1 m/s (OK for 3.5 mm ID pipe)

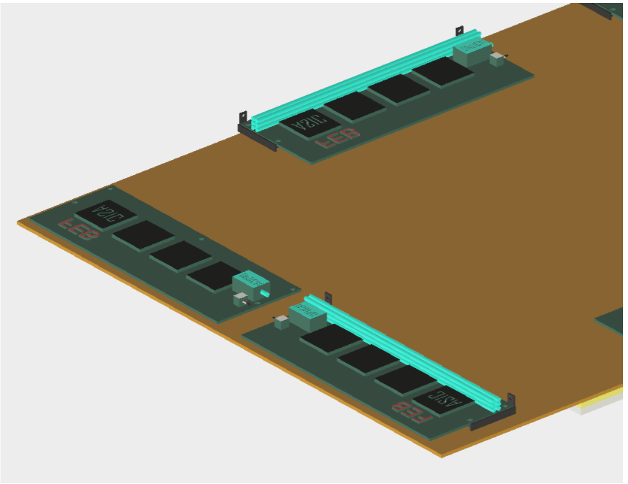
T_{in} = 20 °C, dT < 3 °C

MPGD-BOT: Services

Charge 3



Service/Parts	Per Module	Total	Parameter
Frontend Boards (FEBs)	14	336	256 Channel / FEB
High Voltage	1 (through divider)	24	3.2 mm OD
Low Voltage	14	336	6 mm OD
Gas lines	2	48	3 mm ID, 4 mm OD
Cooling	4	96	6 mm ID, 8 mm OD
Data Cable	14	336	Optical Fiber
Environment Sensor	2	48	Temp. & Humidity
Ground			Depends on grounding plan



- ❖ Parameters of service line are subject to change as FEB design progresses.
- ❖ The cooling requirement has not yet been finalized.
- ❖ The current cooling approach utilizes water cooling with a heatsink.
- ❖ MPGD-BOT, MPGD-ECT & CyMBaL will collaborate on cooling system design.

Technology & Performances

MPGD-BOT module: Thin-gap GEM-µRWELL Technology

Charge 1, 3

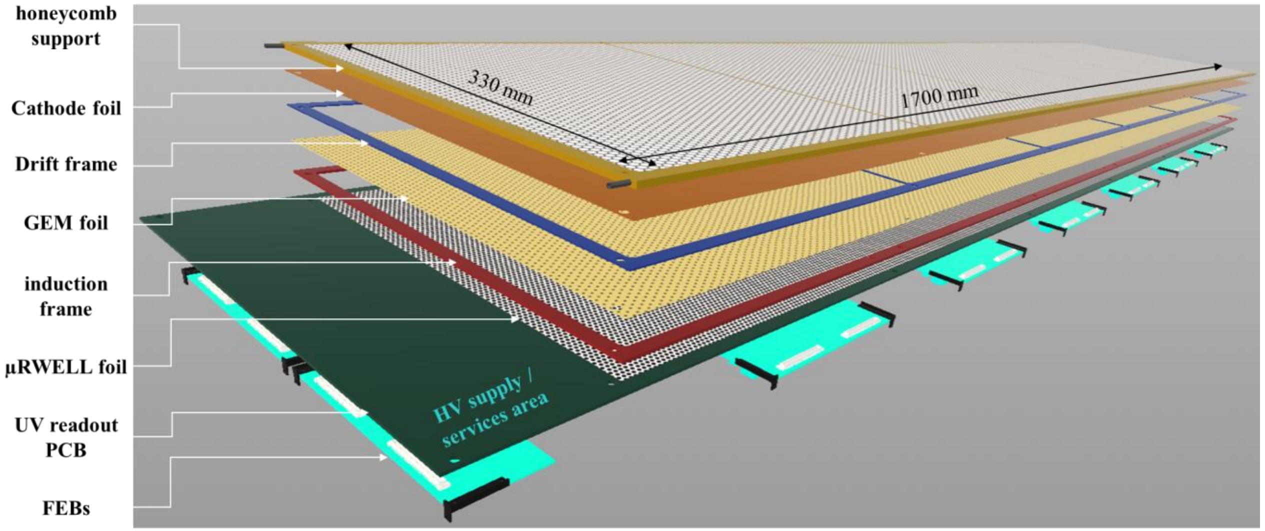
Thin-gap GEM-µRWELL hybrid detector

- Drift gap: 1.5 mm & transfer gap: 2.5 mm
- Double amplification stage (GEM & µRWELL)
- Capacitive-sharing U-V strips readout layers
  - Pitch: 0.8 mm (3580 U & V strips / module)
- https://doi.org/10.1016/j.nima.2025.170791

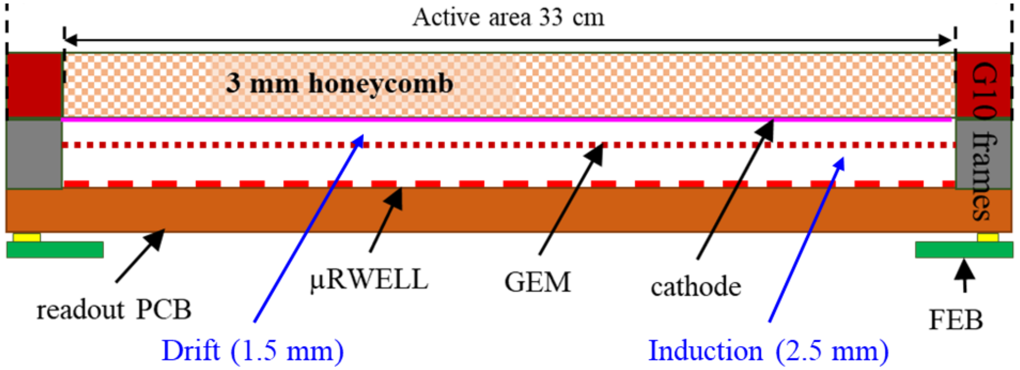
Readout electronics:

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

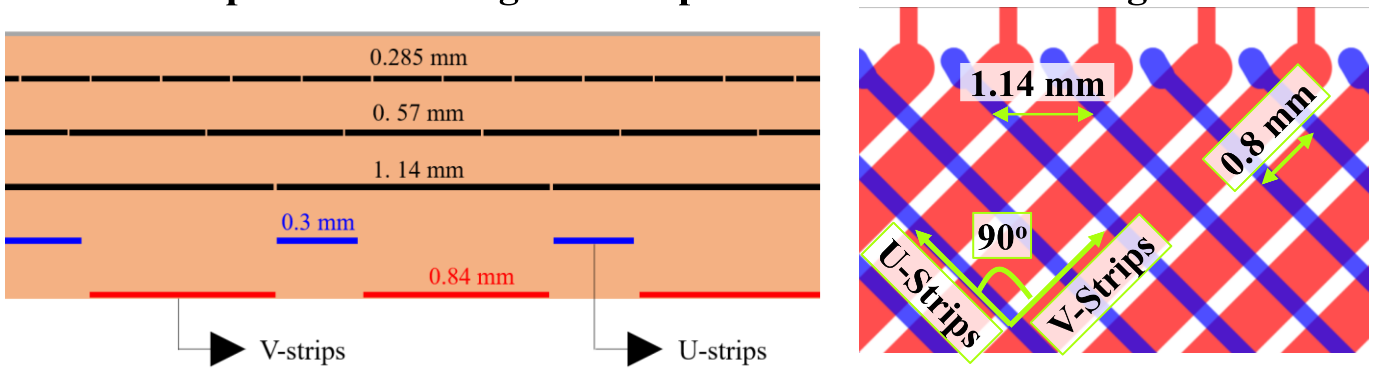
CAD model of thin-gap GEM-µRWELL hybrid



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

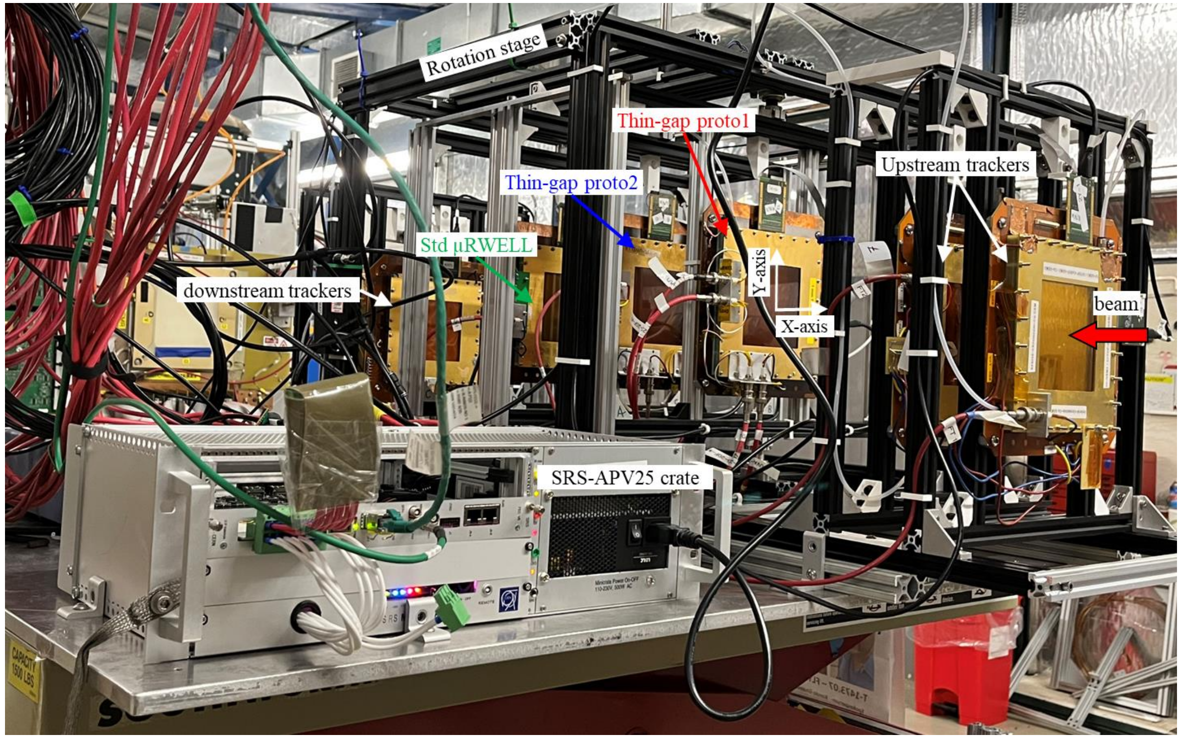
Thin-gap GEM-µRWELL: Performance studies in test beam

Charge 1, 3

Test beam @ FNAL (2023) and @ JLab (2025) for performance study and optimization of thin-gap GEM-µRWELL prototypes

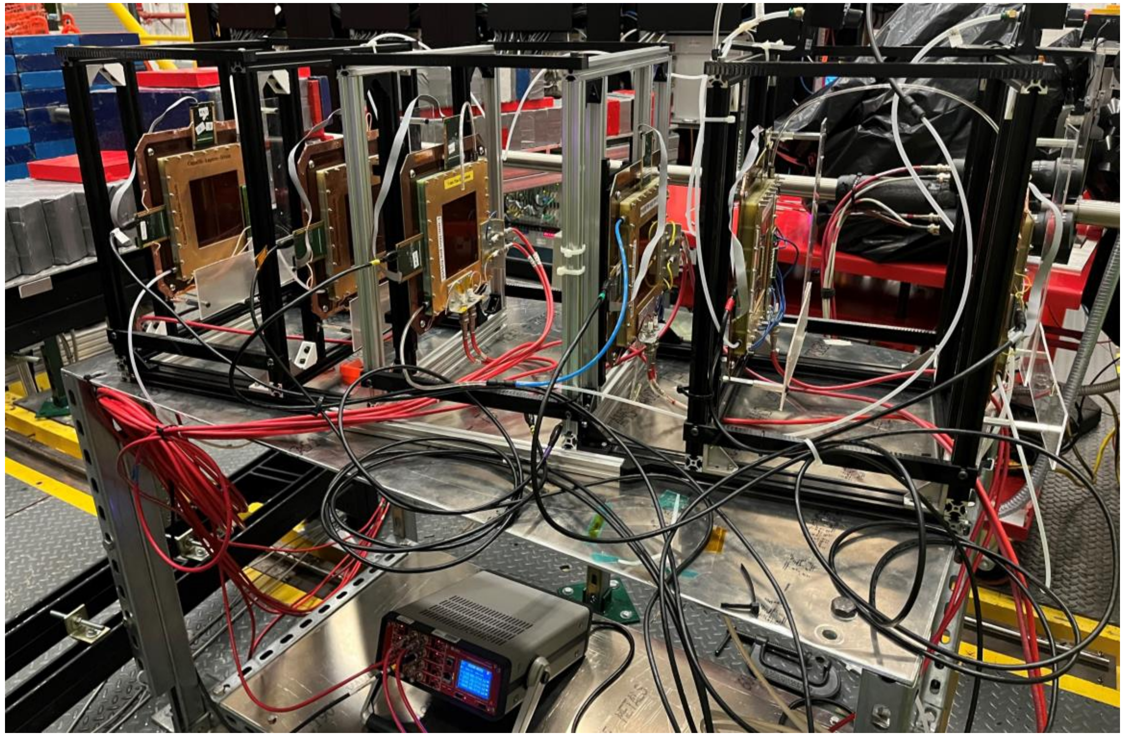
FNAL test beam (06/2023): **Position resolution vs. track angle**

- 3 protos: 0.5 & 1 mm thin-gap GEM-µRWELL, 3-mm std µRWELL
- 4 HV scans for efficiency study with $Ar:CO_2$ (80:20) gas mixture
- Track angle scan (0 – 45^O) for position resolution comparison studies



JLab Hall D test beam (06/2025): **Efficiency vs. gas mixtures**

- 2 protos: 1-mm and 1.5-mm thin-gap GEM-µRWELLs
- HV scan for efficiency study various Ar-based mixtures
- Argon gas mixture: $Ar:CO_2$ & $Ar:CO_2:iC_4H_{10}$

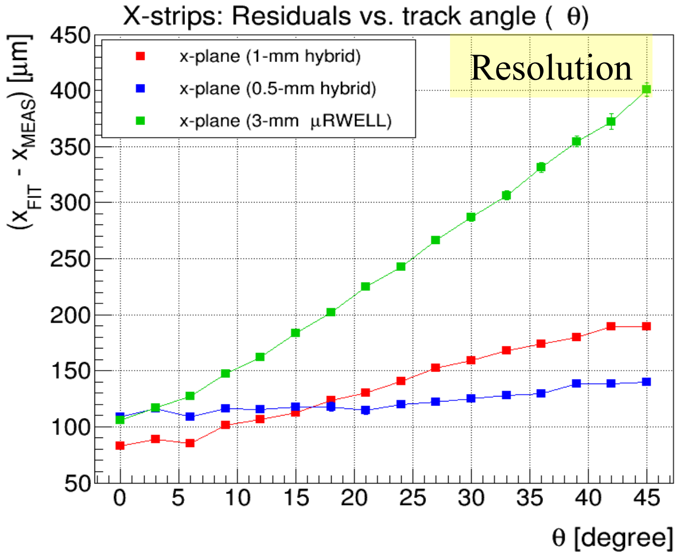


EIC Generic Detector R&D Program: https://wiki.bnl.gov/eic/index.php?title=File:ERD_tgMPGD_FY22_endOfYearReport_final.pdf

Thin-gap GEM-µRWELL: Performance studies in test beam

Charge 1, 3

- Spatial resolution improved by 2 w.r.t to standard gap MPGD.
- Efficiency: ~98% with proper choice of gas mixture
  - **$Ar:CO_2:iC_4H_{10}$ (90:7:3)** is the baseline choice.
- High degree of flexibility and versatility on HV settings
  - GEM, the µRWELL, drift and transfer field
  - Guaranteed operation stability at high performance



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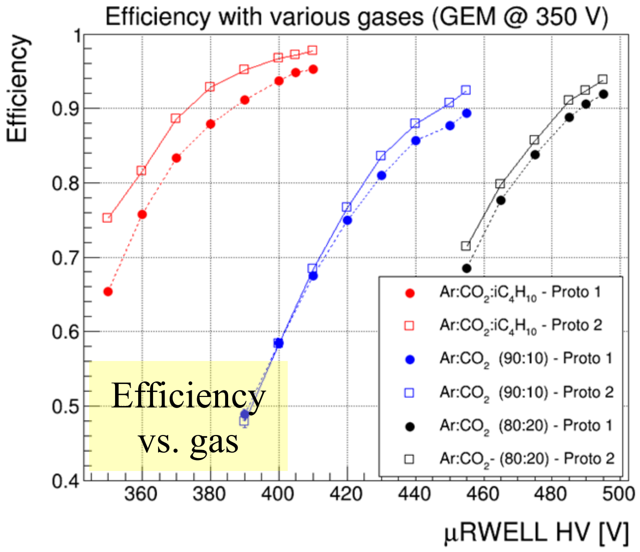
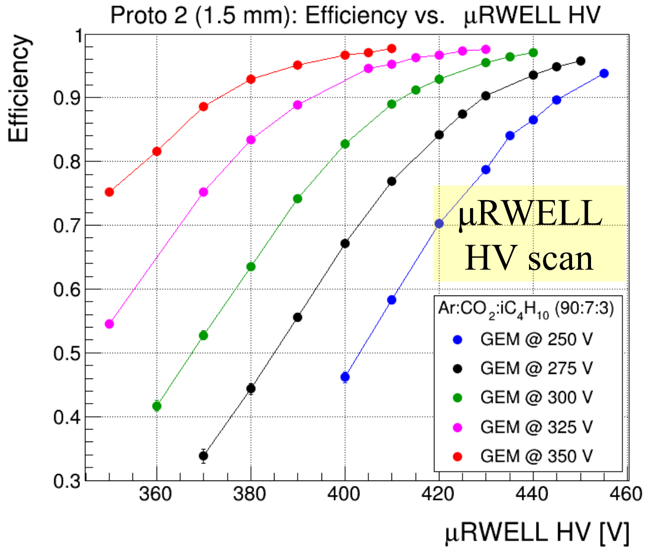
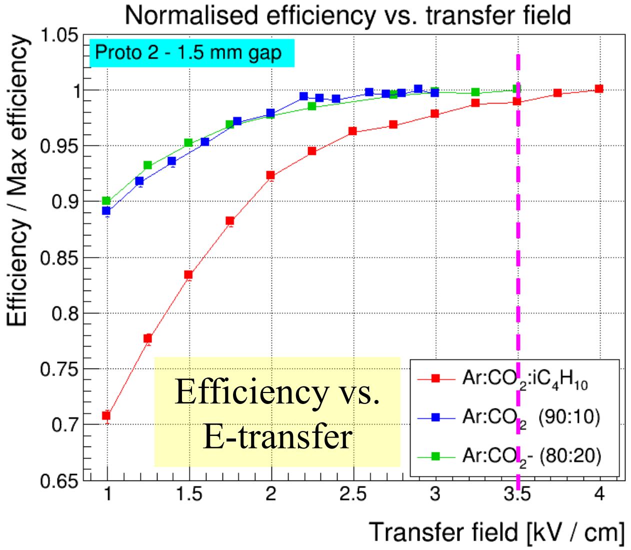
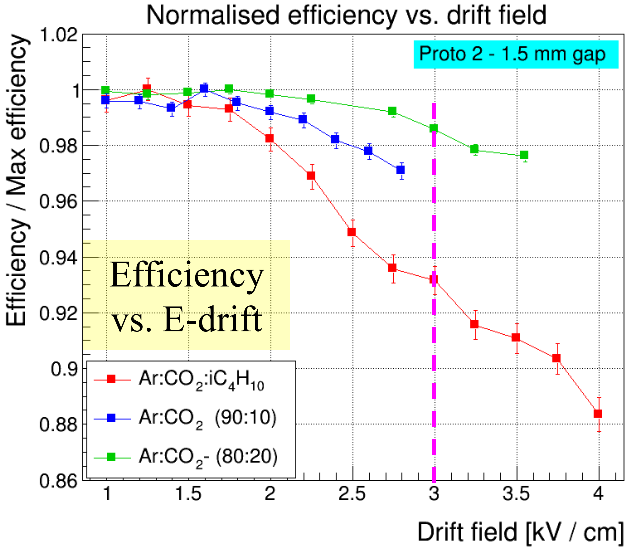




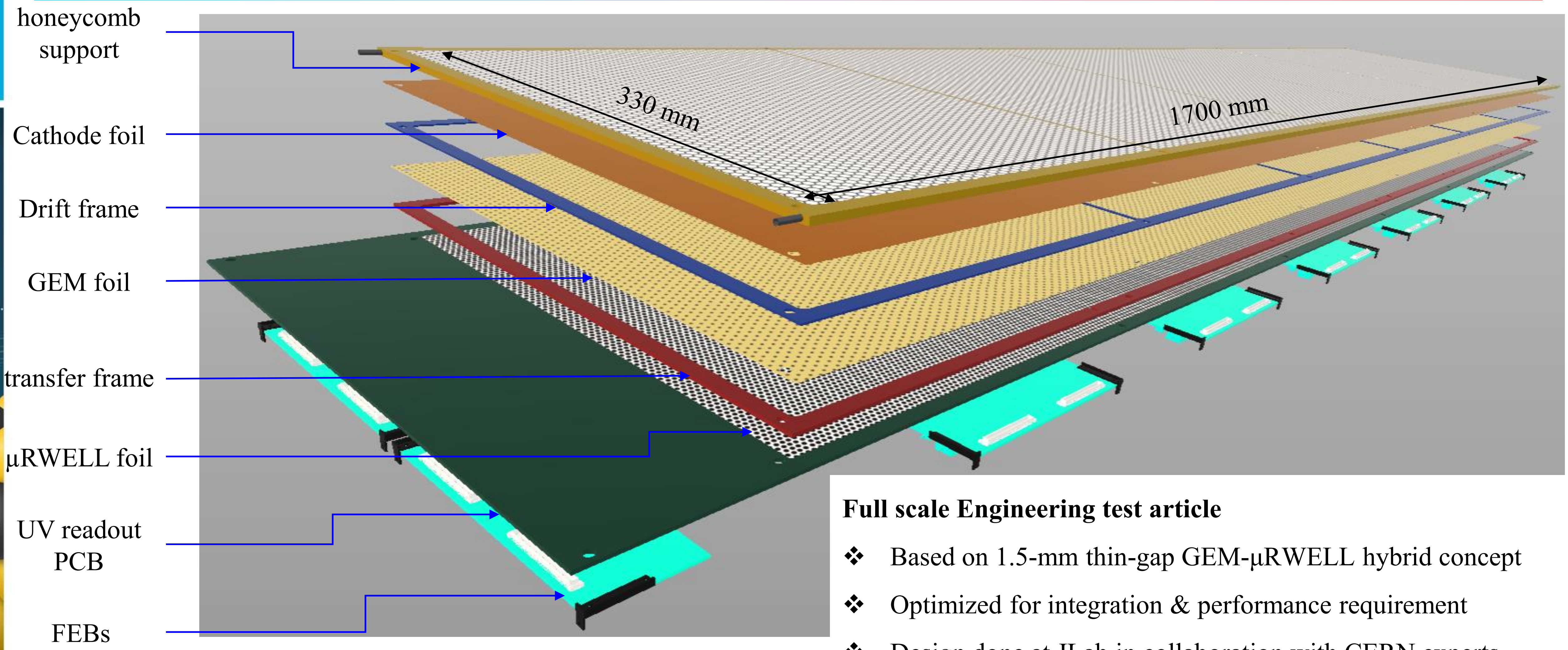




PED: Engineering Test Article

MPGD-BOT module: Project Engineering Design Test Article

Charge 3



Full scale Engineering test article

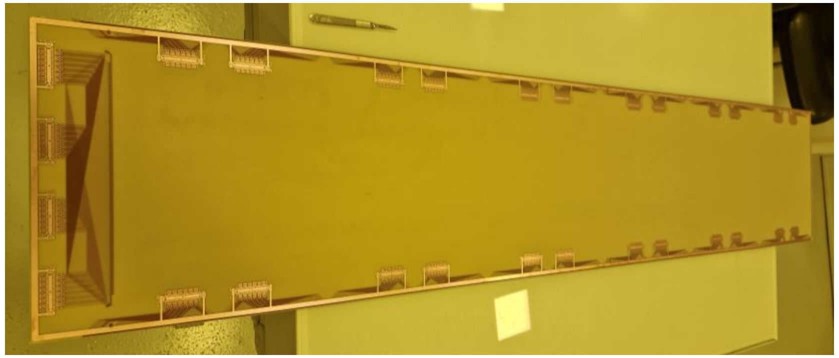
- Based on 1.5-mm thin-gap GEM-µRWELL hybrid concept
- Optimized for integration & performance requirement
- Design done at JLab in collaboration with CERN experts
- Final assembly Q1 - 2026 & tests in beam at CERN Q2 -2026

MPGD-BOT module: Project Engineering Design Test Article

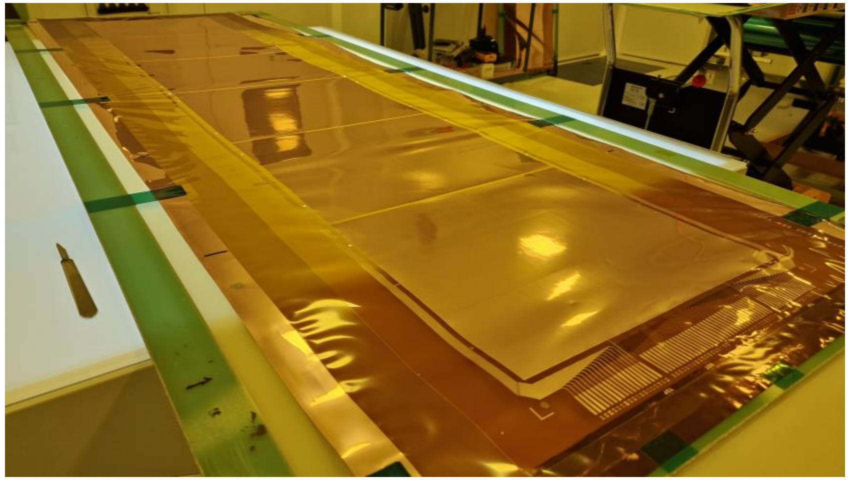
Charge 3, 6

- All essential detector parts have been produced and are in hand at JLab
  - GEM & cathode foils
  - µRWELL + U-V strip readout PCB
  - Cathode and GEM Support frames
  - 30 Panasonic-to-Hirose connectors
- Next step: preparation for assembly
  - GEM HV sectors tests setup
  - GEM stretcher device
  - Assembly flow hood space
  - Cleaning & coating of the frames

µRWELL PCB front view



µRWELL PCB back view



GEM foil

Support frames

Preliminary Design and Safety Review of the EIC Tracking Detectors – Mar 20-21, 2024

MPGDs **Comment about charge 4**

- The production of the moderately high number of MPGD structures should not pose a major risk for the project. Still, the full-size structures (1800 mm long) should be produced as soon as possible, and the prototypes should be constructed to ensure timely realization of the prototyping and production plans.

PED Test Article: Module Assembly @ JLab

Charge 3,6

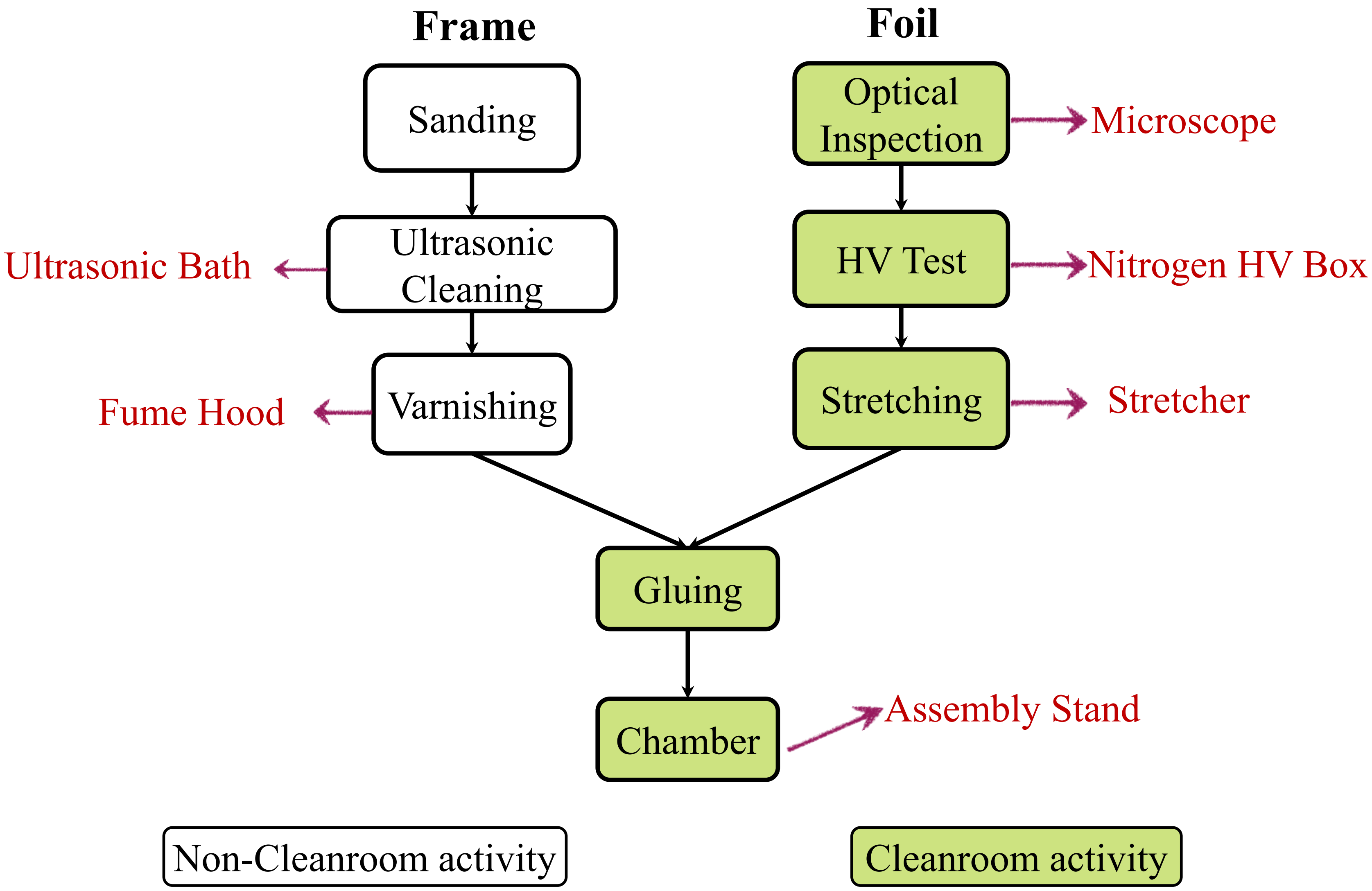
Workflow for the Assembly

Components:

- Detector Frame
- GEM Foil
- μRWELL Foil

Includes cleanroom activity and non-cleanroom activity

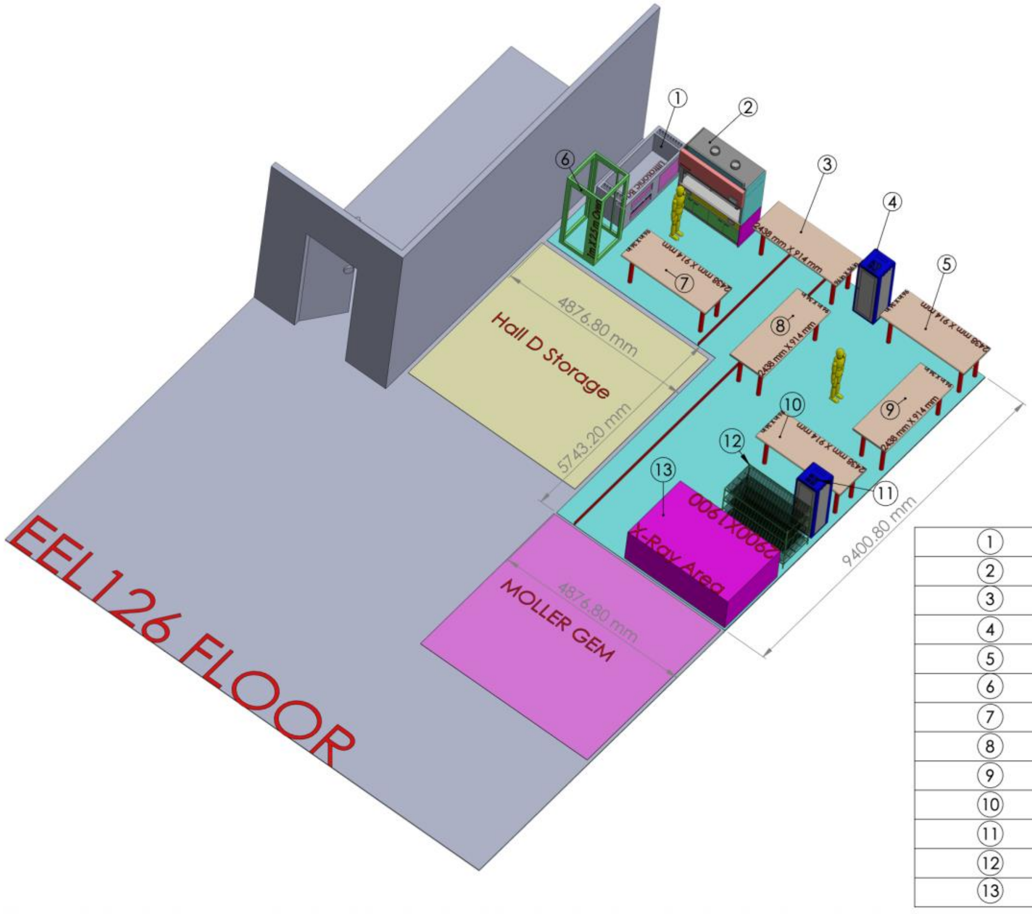
Highly customized instruments – tailored to detector size and shape



PED Test Article: Assembly Clean room & Testing lab

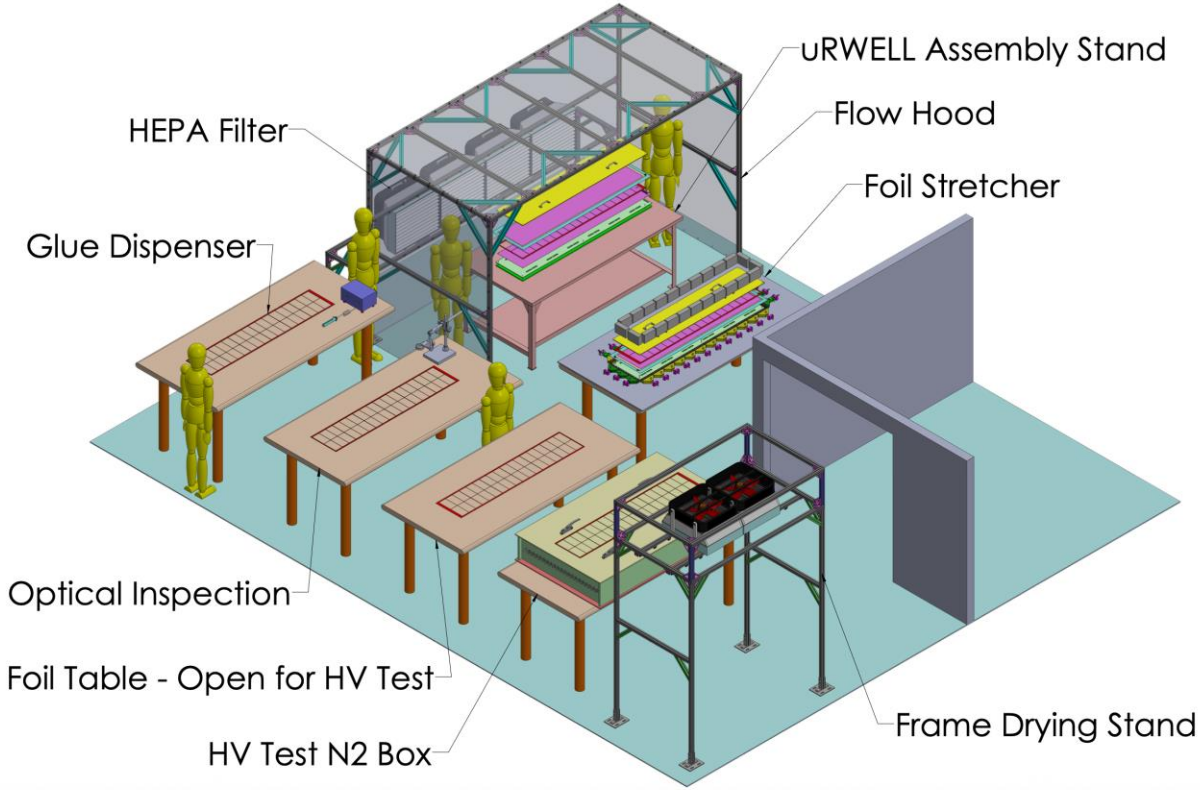
Charge 3,6

MPGD test lab (EEL-126 @ JLab)



1	Ultrasonic Bath
2	Fume Hood
3	Sanding Stand
4	Electronics Rack
5	Eric's Test Stand
6	Oven Space
7	Clean Hood
8	Workbench
9	PICOSEC
10	Flow Hood
11	Electronics Rack
12	Cosmic Stand
13	X-Ray Area

Clean room layout (EEL-122 @ JLab)

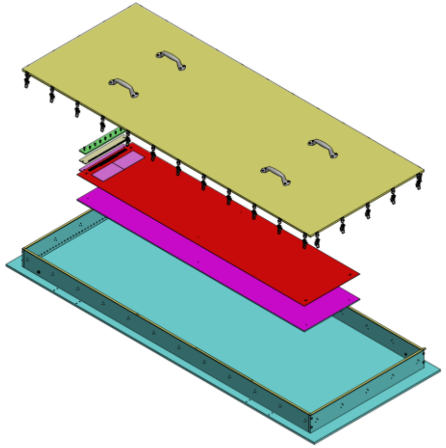


Both areas are tightly packed with equipment & instruments

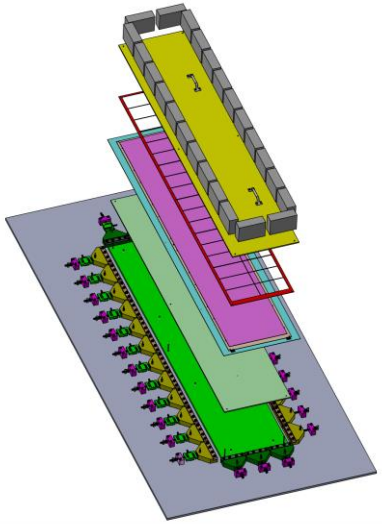
PED Test Article: Clean room assembly stations

Charge 3,6

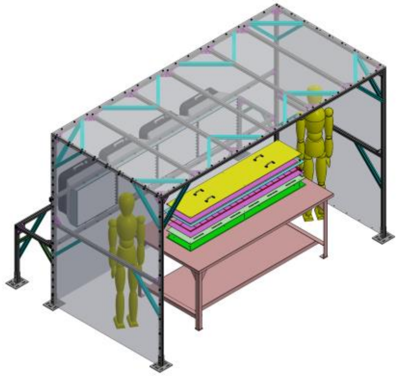
GEM Foil HV Nitrogen Test Box
- HV test of unframed GEM
- HV test of Framed GEM
- HV test of the GEM after glued onto cathode



Stretch GEM Foil mechanical
- GEM glued to support frame
- Frame GEM glued to cathode / honeycomb



Detector assembly stand
- Glue framed GEM to µRWELL PCB
- Require a very clean space
- Laminar flow hood inside clean room



PED Test Article: Frames - Sanding, Cleaning & Coating

Charge 3, 6

Large ultrasonic tank for frame cleaning

- After sanding the frames
- Ultrasonic bath to clean the frame filled with de-ionized water
- Large volume ultrasonic thank
- Pending installation in EEL-126

Fume hood for frame coating

- Apply a thin film of varnish to protect the spacers after sanding and ultrasonic bath cleaning
- Varnish work requires a fume Hood
- Pending installation in EEL-126

Frame storage and dryer in clean room 121

- Dry the frames after USB cleaning
- Process needs 48 hours

PED Test Article: Preparation of top honeycomb cathode frame

Charge 3, 6

Cutting the honeycomb to size

Inserting the honeycomb in the frame

Sandwich the honeycomb b/w G10 skins

Assembly Plans, ES&H & QA

MPGD-BOT: Assembly Plans, Sites & Workforce

Charge 5

Module production sites:

- Jefferson Lab (**JLab**)
- University of Virginia (**UVa**)
- Florida Institute of Technology (**FIT**)

Vast experience with large scale and large MPGD projects among the 3 institutions

- 10 modules per site (8 + 2 spares)
- Overall effort under JLab supervision
- Common QA / QC procedures for all sites

Activities / schedule	**01/2024 - 01/2025**	**01/2025 – 06/2026**	**03/2026 – 12/2026**	**01/2027 – 01/2028**	**01/2028 – 01/2031**	**01/31 -**
PED Test article design	JLab					
PED Test article I		JLab				
PED Test article II			JLab			
Pre-production				JLab, UVa, FIT		
Production modules					JLab, UVa, FIT	
Commissioning @ BNL						JLab, UVa, FIT

MPGD-BOT: Assembly Plans, Sites & Workforce

Charge 3,4

All 3 assembly sites have fully equipped MPGD Detector Lab

- ❖ Fully equipped CLASS 1000 Clean rooms for module assembly
- ❖ Cosmic tracking telescope setup with coincidence trigger counters and readout & DAQ system
- ❖ X-ray setup for high-rate studies and long-term stability …
- ❖ Will setup DAQ and readout system for SALSA – MPGD readout system

JLab MPGD Clean Room: New capacity for large MPGD module assembly

UVa Clean Room: SBS GEMs, MOLLER GEMs, PRad GEMs, CLAS12 µRWELL, Hall D GEM-TRD prototype

FIT Clean Room: assembly of CMS GE1/1 GE2/1 and ME0 GEMs

MPGD-BOT: Quality Assurance (QA) – ES&H

Charge 5

- **QA / QC:**
  - HV test in N_2 of GEM and μRWELL sectors before, during and after assembly (in clean room)
  - Gas leak test and sealing after module assembly
  - Electrical & capacitance test of the connectors: (QA at CERN), additional check at production sites
  - Check of the pedestal noise and offset of all U & V strips after FEB connections
  - Tag dead strips and replace FEB cards with dead readout channels
  - Efficiency and relative gain uniformity studies with cosmic setup
  - Absolute gain measurement with Fe55 (local measurement)

- **ES&H:**
  - Assembly will follow guidelines in compliance with ES&H requirements at JLab and the production sites
  - Flammable gas $Ar:CO_2:iC_4H_{10}$ ➔ Safety concern or implementation procedure will be implemented
  - HV supply via simple passive divider ➔ Procedure to isolate any electric point on the detector
  - The ES&H procedures will be documented in the ePIC documentation database
  - BNL ES&H procedures will be implemented during commissioning and installation in ePIC at BNL

Common gas mixture for all 3 MPGD subsystems: What does it take

Charge 3, 4

Current gas mixture choice for the baseline detectors:

- MPGD-BOT baseline gas mixture: $Ar:CO_2:iC_4H_{10}$ (90:7:3)
  - Open to explore different ratio i.e.. 93:2:5 ➔ will be studied in test beams at JLab & CERN in 2026
- CyMBaL baseline gas mixture: $Ar:CO_2:iC_4H_{10}$ (93:5:2) under consideration ➔ likely not an option for MPGD-BOT
- MPGD-ECT is has been experimenting with $Ar:CO_2:CF_4$ (45:10:45)
  - CF_4 based gas mixture not under consideration for MPGD-BOT ➔ not required to achieve good timing

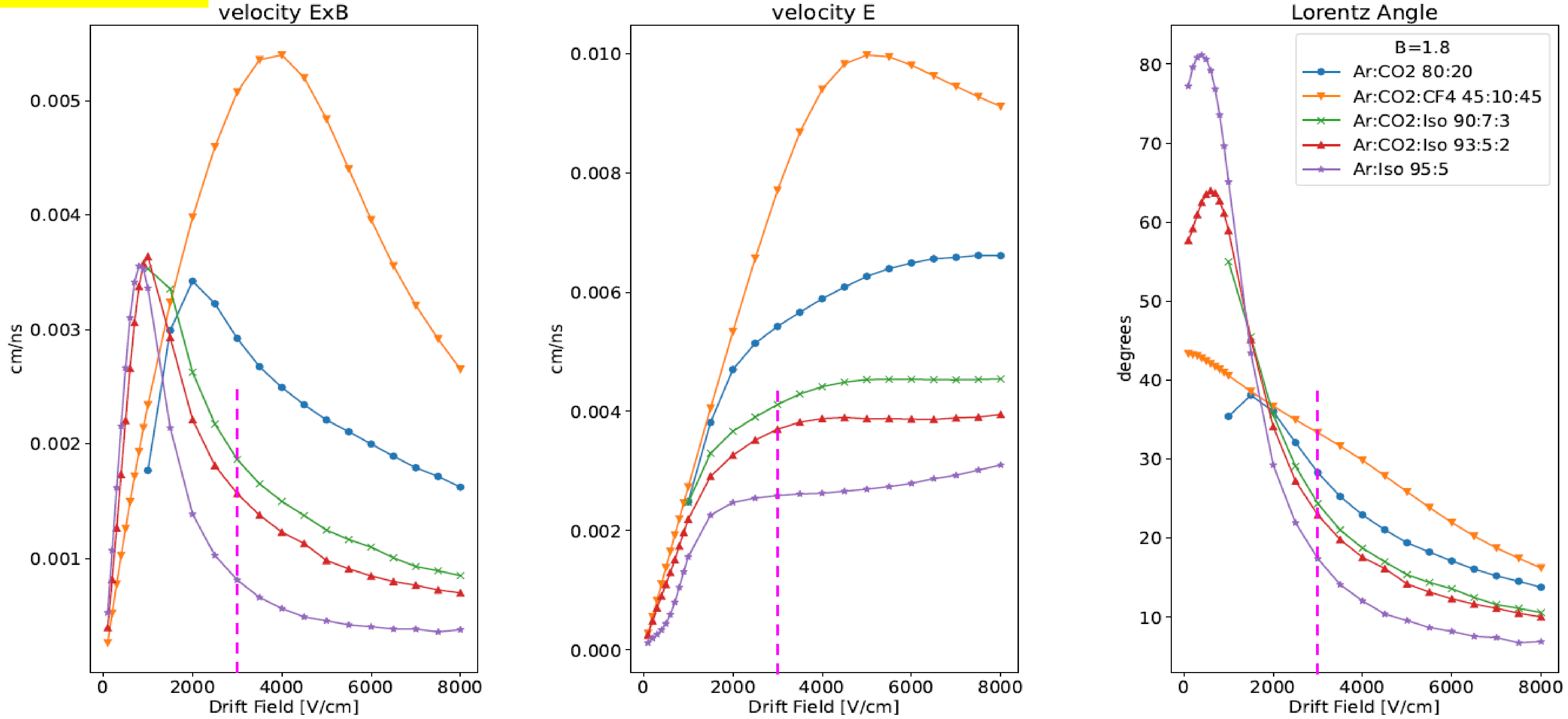
The Goal is to operate all three gaseous trackers with the same gas mixture

- We will agree on a mixture and ratio that satisfies all 3 trackers if achievable ➔ $Ar:CO_2:iC_4H_{10}$ mixture is a good starting point
- Several performance parameters need to be optimized simultaneously and sometimes they are contradictory
  - Fast gases (CF4-based) are **good for timing** but **bad for Lorentz effect** which also affects position & timing ➔ see next slide
  - Large fraction of Ar is **good for gain** (critical for CyMBaL) but one must be careful about **stability** (i.e., increase discharge rate)
- More studies of different gas mixture with all 3 subdetectors will be performed in test beams in 2026 to **converge to a common** choice

Gas Selection: Garfield simulation of various gas mixtures

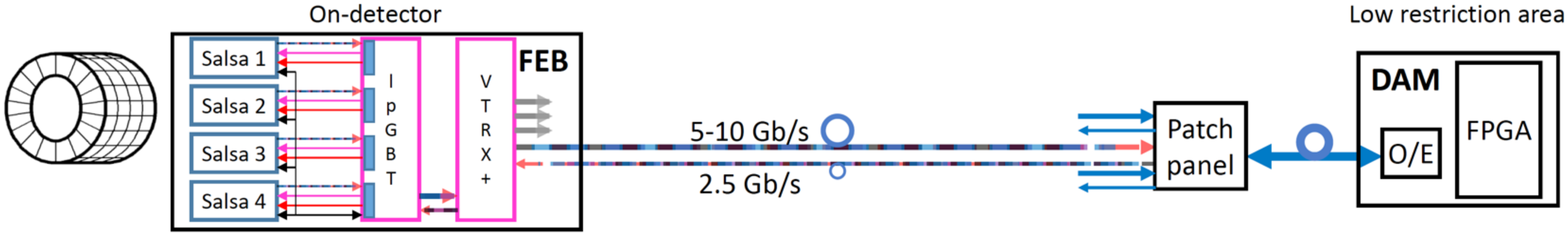
Charge 3, 4

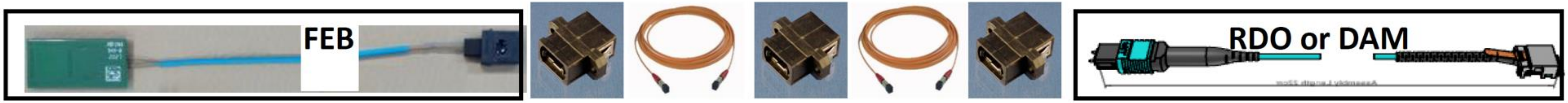
Courtesy F. Bossu



MPGD-BOT: Readout Electronics based on SALSA ASIC

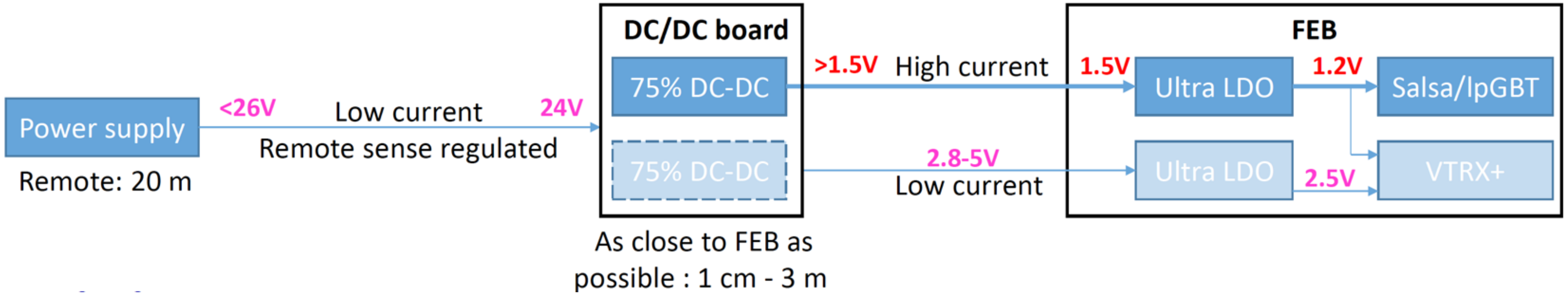
Charge 1,3





Short pigtail / on board | Fibers of adapted length between patch panels | Short pigtail / on board

FEB LV Powering scheme



- ❖ SALSA ASIC ➔ same readout & DAQ as CyMBaL & MPGD-ECT
- ❖ Form factors of the on-detector FEB, DC-DC board, cooling scheme … are subsystem specific
- ❖ JLab Electronics group will adapt FEB, DC-DC boards from CEA Saclay to MPGD-BOT specific needs

MPGD-BOT: Assembly plans & schedule

Charge 3, 4

12/2025	01/2027	01/2028	01/2031	03/2031

PED & validation → **Pre-production** → **Production** → **Shipment to BNL** → **Commissioning & Installation**

PED & validation
- full size MPGD-BOT Test article modules
- Procurement of GEM foils, µRWELL **06/2025**
- Assembly @ JLab &Test in beam @ CERN **- 06/2026**
- Have time for a second test article if needed before 2027

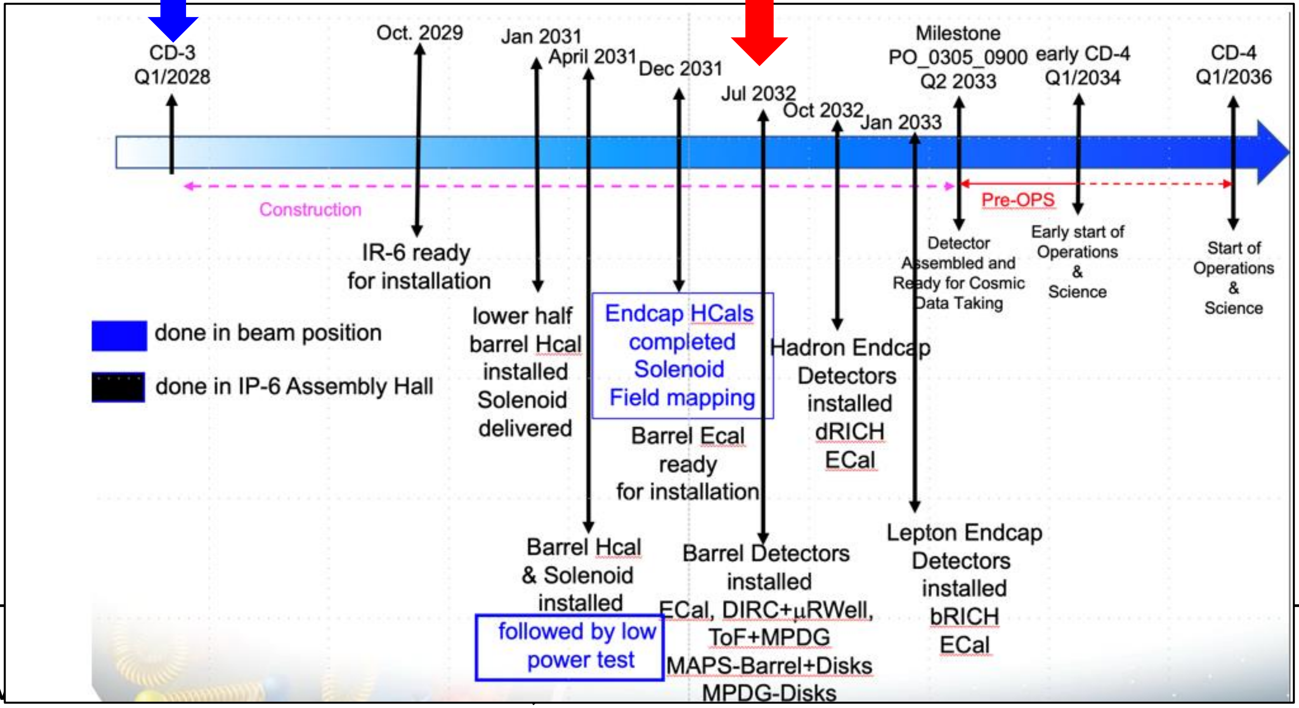
Pre-production
- Assembly of one pre-production module **module#0** by each production site
- Setup of infrastructure and equipment in production sites

Production
- Assembly and QA of 9 production modules at assembly sites
- Characterization with cosmic and radioactive sources

Shipment to BNL
- Shipment of all 24 modules to BNL
- Commissioning at BNL with cosmic of all modules

Commissioning & Installation
- Commissioning
- Installation

High Level Installation Schedule
From Elke's talk

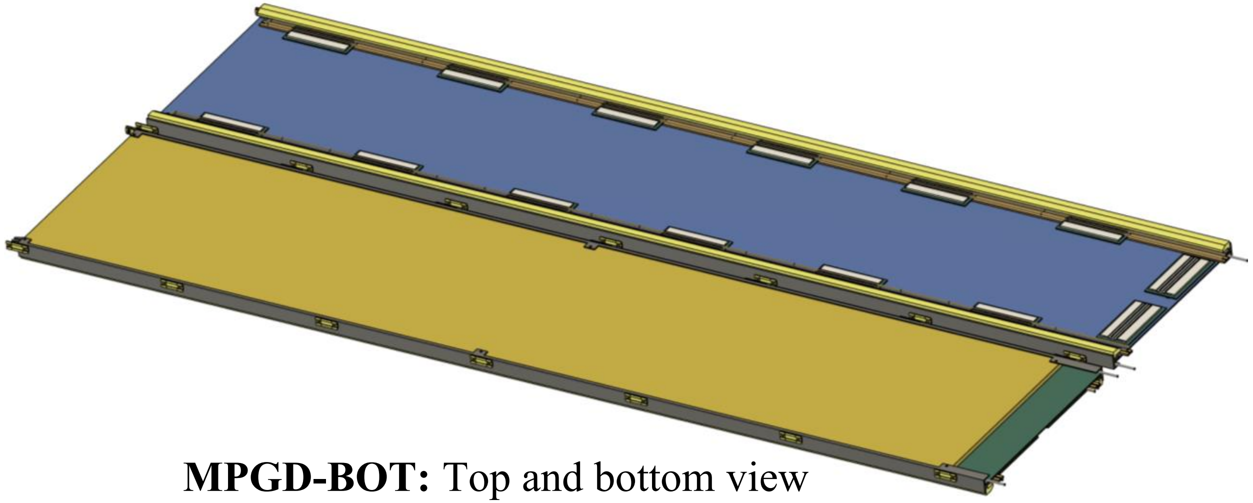


Summary

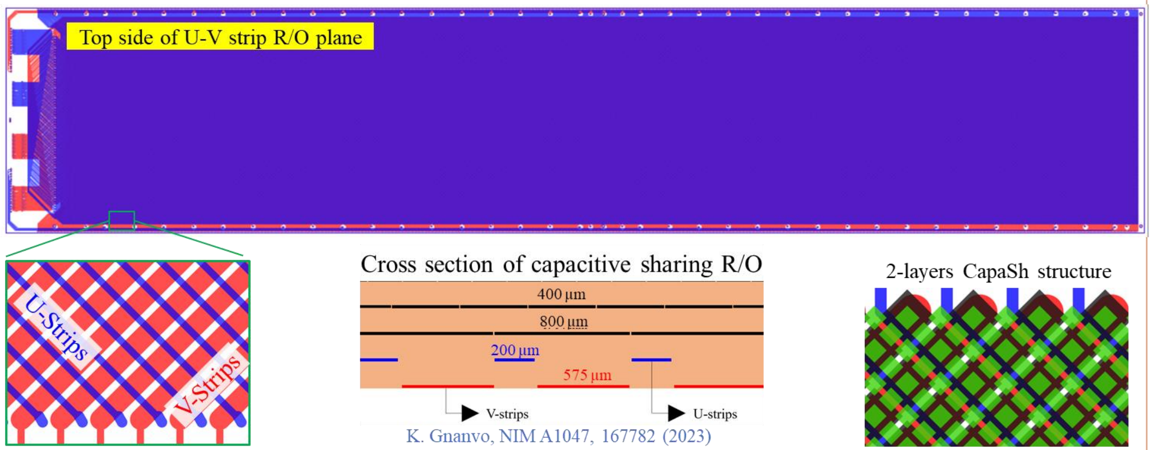
- ePIC MPGD-BOT Tracker will provide fast timing information for pattern recognition to support Si trackers in the barrel
- MPGD-BOT also provides hit redundancy capability and improved angular resolution to enhance hpDIRC performance
- MPGD-BOT is based on thin-gap GEM-µRWELL hybrid detector technology
- Design of the full scale MPGD-BOT first test article module and procurement of essential parts are complete
- Setup of the clean room infrastructure for the assembly of the first test article at JLab is ongoing
- Assembly is scheduled for the first quarter of 2026 and characterization in beam and with cosmic for summer 2026
- Plans and schedule for MPGD-BOT pre-production & production modules at the 3 assembly sites is scheduled for early 2027

Backup

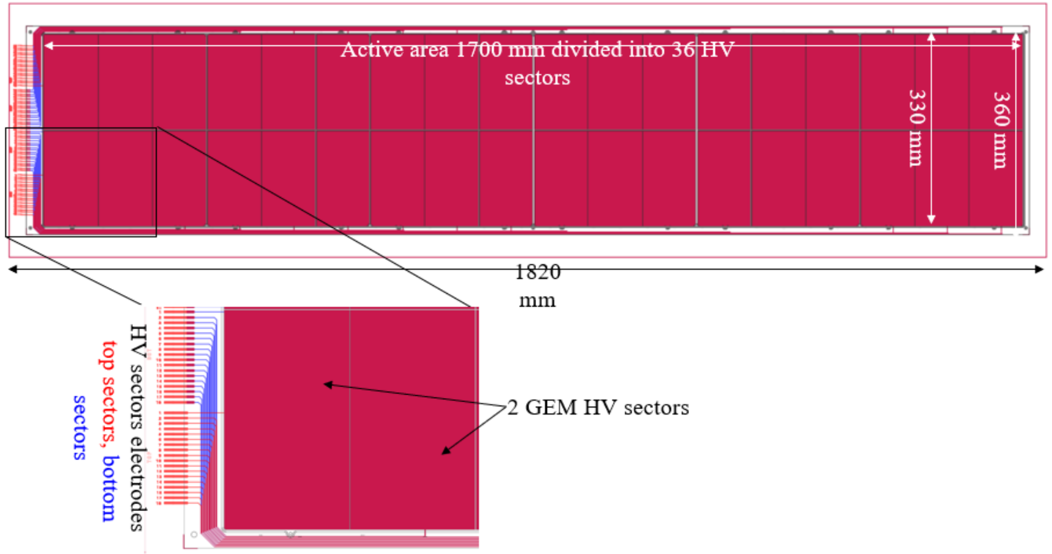
MPGD-BOT module: Project Engineering Design Test Article



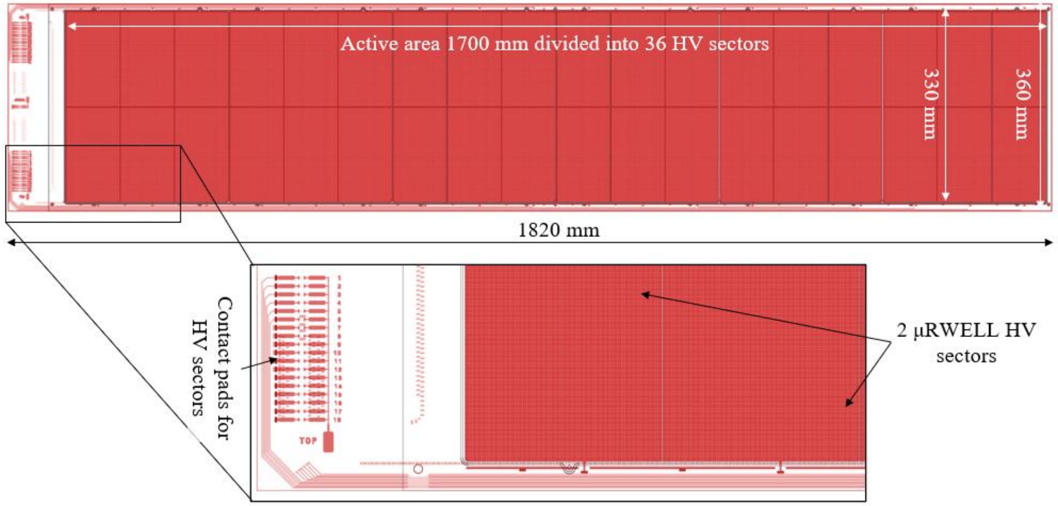
MPGD-BOT: Top and bottom view



Capacitive sharing readout with orthogonal U-V strips

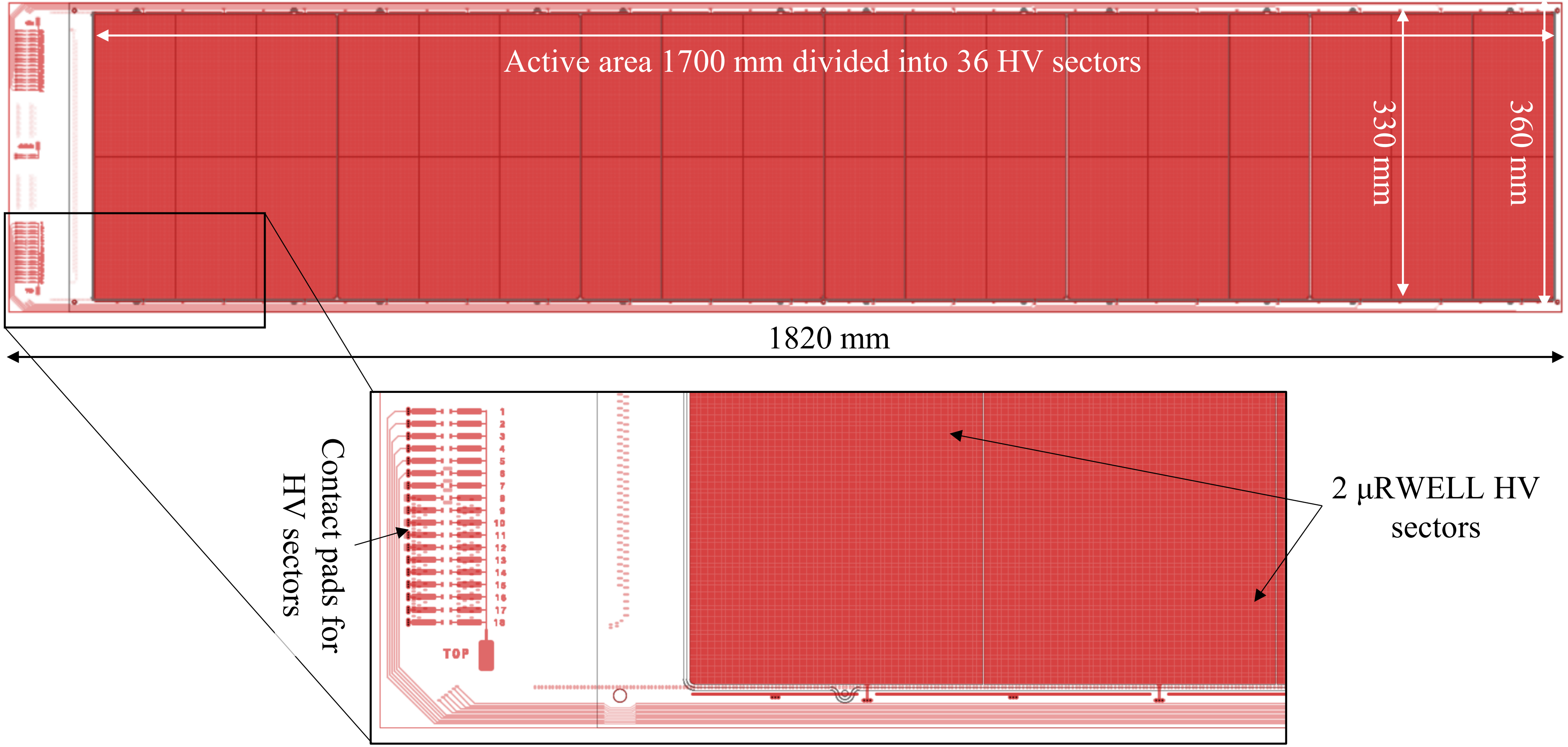


GEM foil design: 36 HV sectors

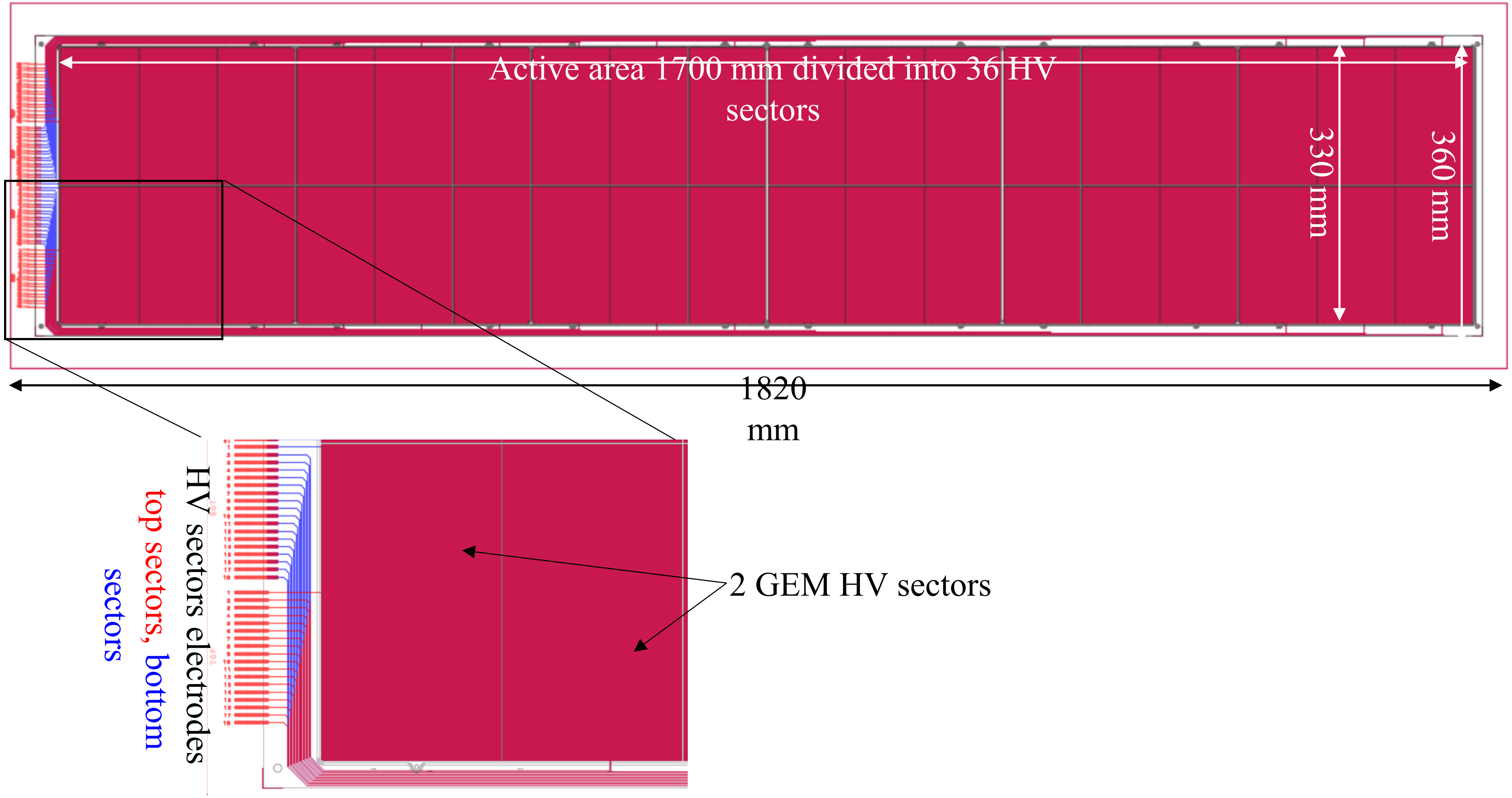


µRWELL foil design: 36 HV sectors

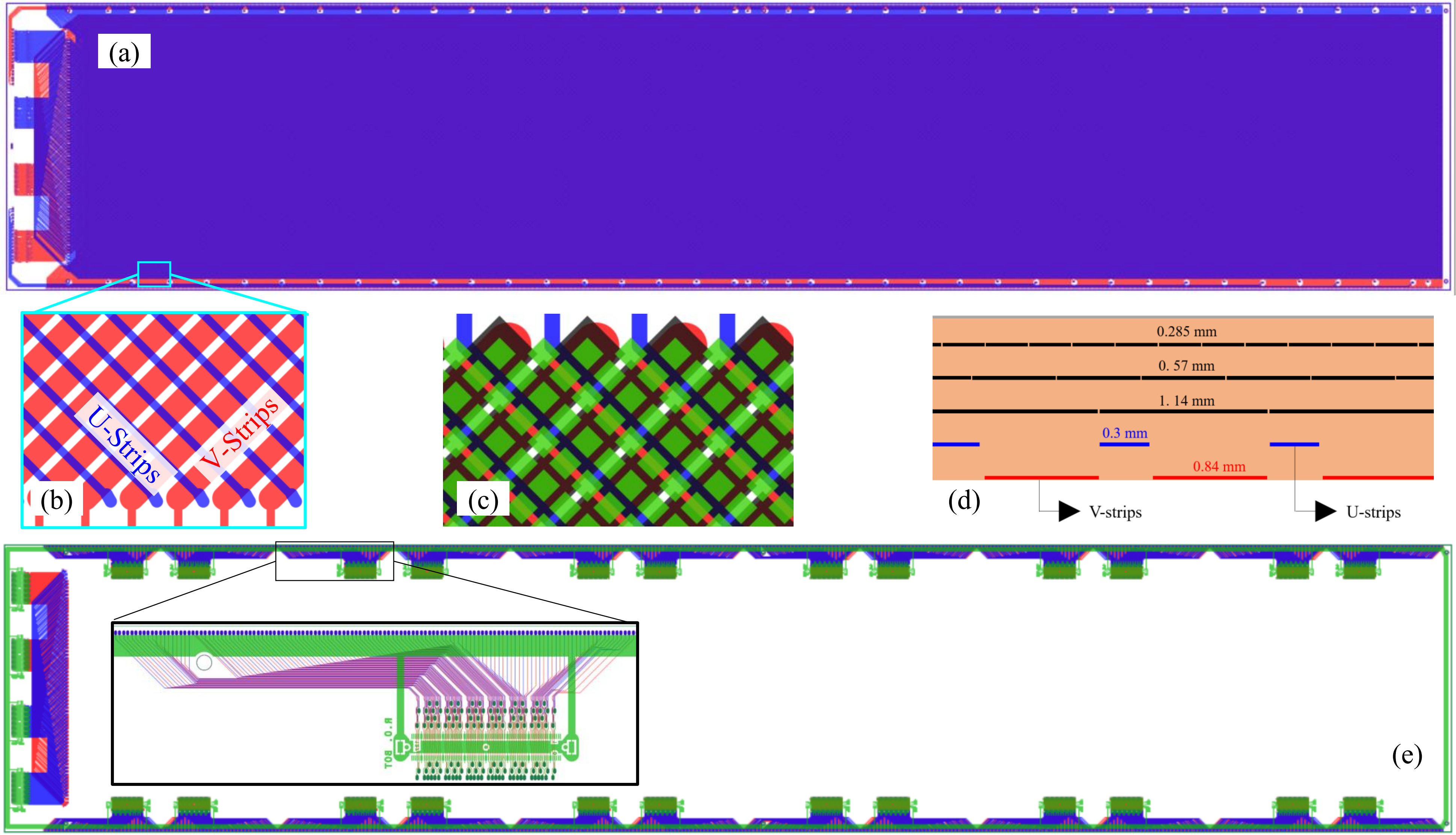
MPGD-BOT Parts: µRWELL foil design



MPGD-BOT Parts: GEM foil design



MPGD-BOT Parts: U-V strip readout PCB design



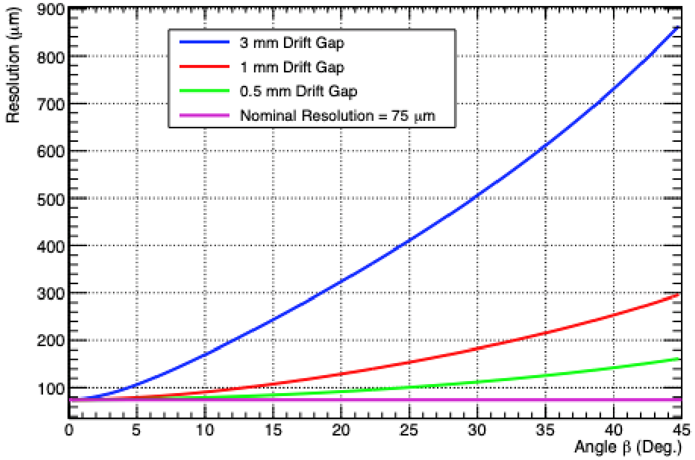
Technology choice: Thin-gap GEM-µRWELL Hybrid Detector

Challenges with standard (> 3-mm drift gap) MPGD

- ❖ Degradation of the spatial resolution with track angle .
- ❖ E × B in magnetic field negatively impact resolution

Development of Thin-gap MPGDs:

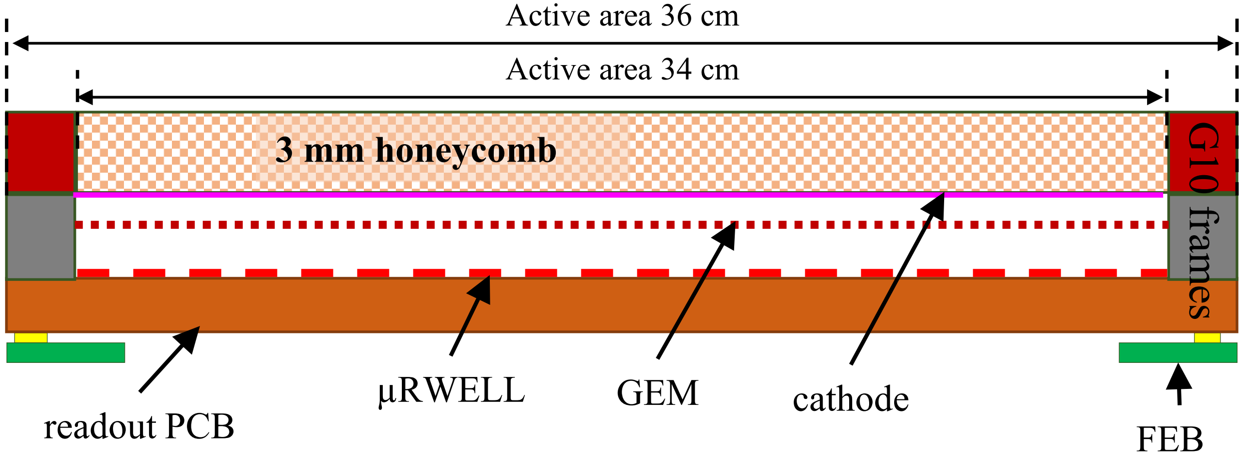
- ❖ Small drift gap improve spatial resolution at large angle
- ❖ Small gap ➔ minimize E × B effect in magnetic field
- ❖ Improve the detector timing performance



parametrization from *EPJ Web of Conferences* ***174****, 06005 (2018)*

Thin-gap GEM-µRWELL detector concept

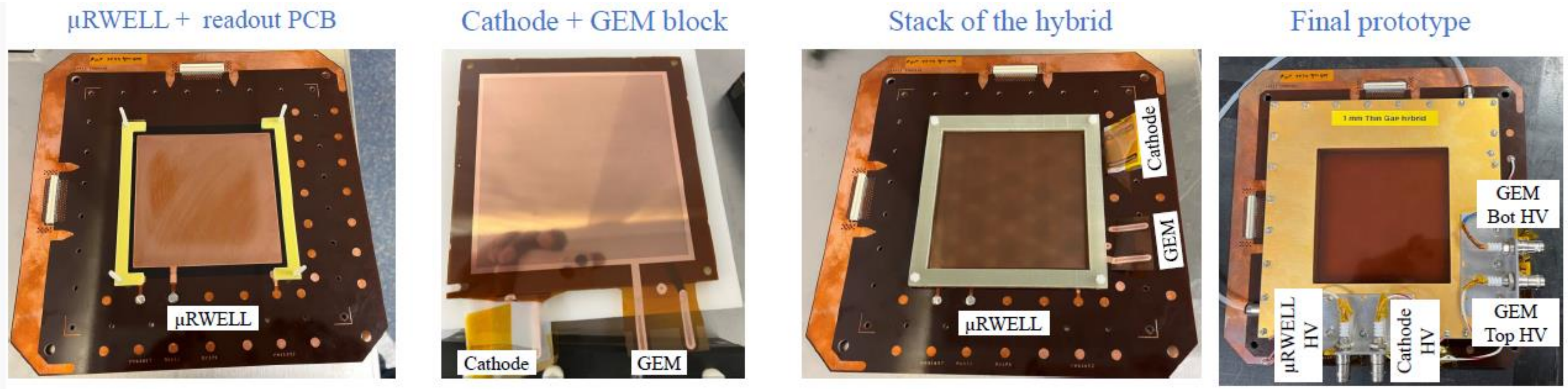
- ❖ hybrid amplification MPGD:
  - ▪ GEM (preamplification) and µRWELL (main amplification)
  - ▪ Allow large detector gain and stable operating HV
- ❖ Readout layer: 3-layer capacitive-sharing U-V strip readout
  - ▪ Achieve excellent spatial resolution with thin gap detector



cross-section view of thin-gap GEM-µRWELL detector

https://wiki.bnl.gov/eic/upload/ERD_tgMPGD_FY22_endOfYearReport_final.pdf

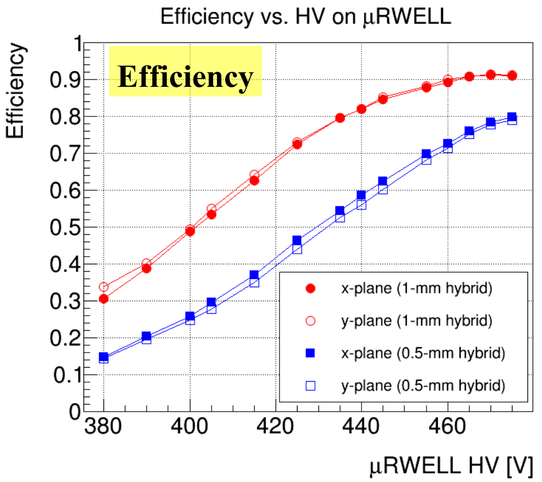
Technology choice: Thin-gap GEM-µRWELL Hybrid Detector

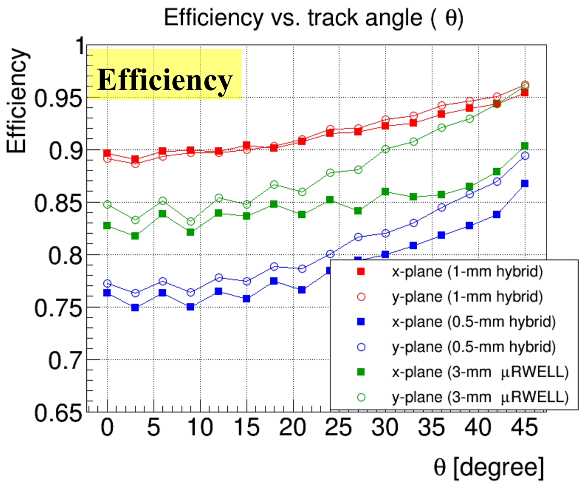


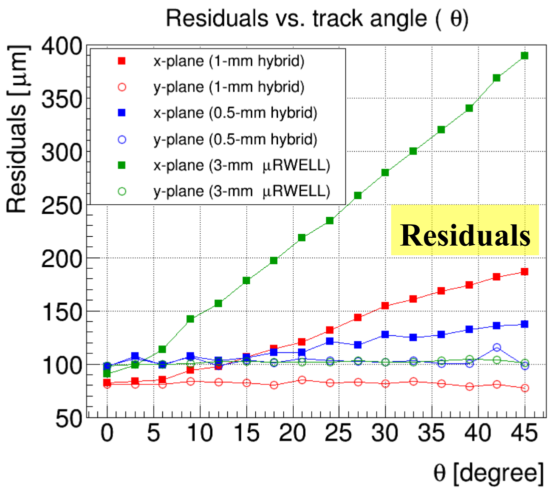
Proof of concept

- Concept of thin-gap GEM-µRWELL hybrid prototype demonstrated in beam test at the Fermilab Test beam Facility in Summer 2023 (red plots)
- Space resolution < 150 µm and efficiency of 92% on average for 1-mm thin-gap GEM-µRWELL prototype (red dots) and for track in an angle range between 0 – 45 degrees.
- **Baseline technology for ePIC outer MPGD tracker**

R&D funded by JLab administered DOE EIC Generic R&D Program as EICGENRandD_2022_23







https://wiki.bnl.gov/eic/upload/ERD_tgMPGD_FY22_endOfYearReport_final.pdf

Design consideration: Some General considerations

- ❖ Rate Capability
  - Not critical ~ 1 kHz/cm² or less
- ❖ Radiation Hardness
  - Not critical for the detectors
  - Important for FEBs and RDO electronics boards
- ❖ Temperature Stability
  - Not critical for the detector performances
  - Detector calibration should consider gas pressure variations
- ❖ Electronics power consumption and cooling
  - SALSA ASIC consumption ~ 15 mW/ channel at 1.2V
  - Air vs liquid cooling is under study at Saclay – see Irakli's talk