Thin Gap GEM-μRWELL Hybrid MGPDs for EIC

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on behalf of the ePIC MPGD-DSC Collaboration

DRD1 Collaboration Meeting - June 17 – 21, 2024, CERN

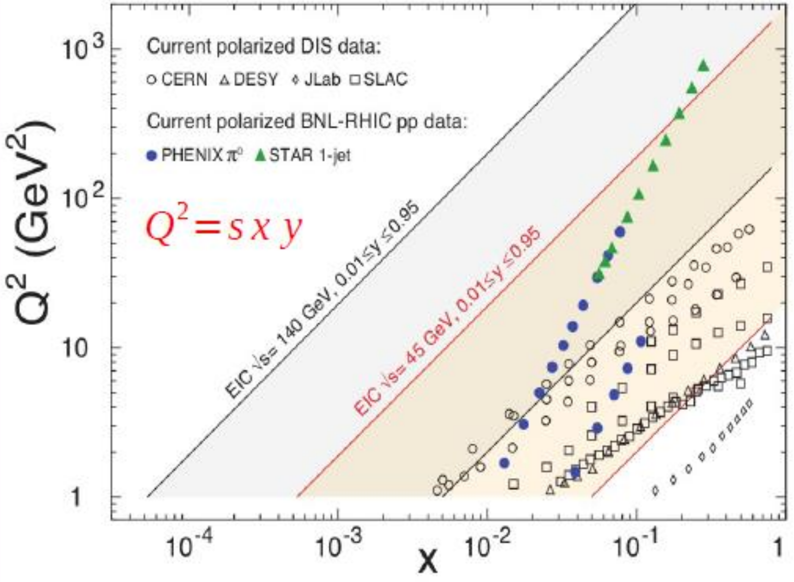
Outline

- The MPGD Barrel Outer Tracker in the ePIC Detector at the EIC
- Motivation for the Thin Gap GEM-μRWELL Hybrid Detector Concept
- Design considerations of the ePIC μRWELL-BOT Detector
- Ongoing R&D efforts on thin gap MPGDs
- Summary

The ePIC Detector @ the EIC

- Why ePIC Experiment ?
  - Electrons mainly interacts with electroweak interaction using Deep Inelastic Scattering (DIS): high precision
  - Polarized protons and light ions to study spin/structure physics
  - Collider to achieve wide x and Q^2 range to probe extreme gluon density regime

Wide x and Q^2 range

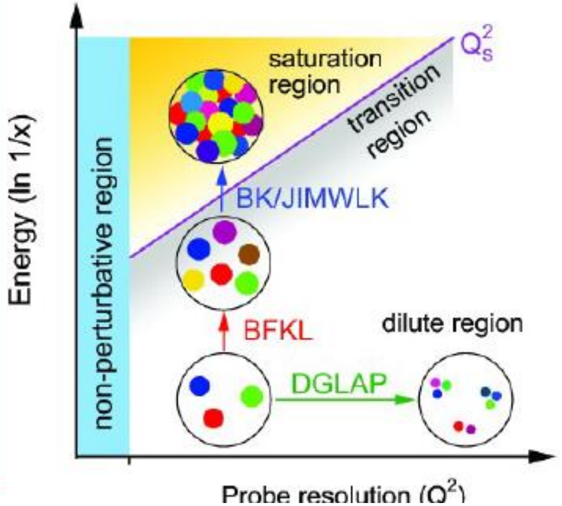


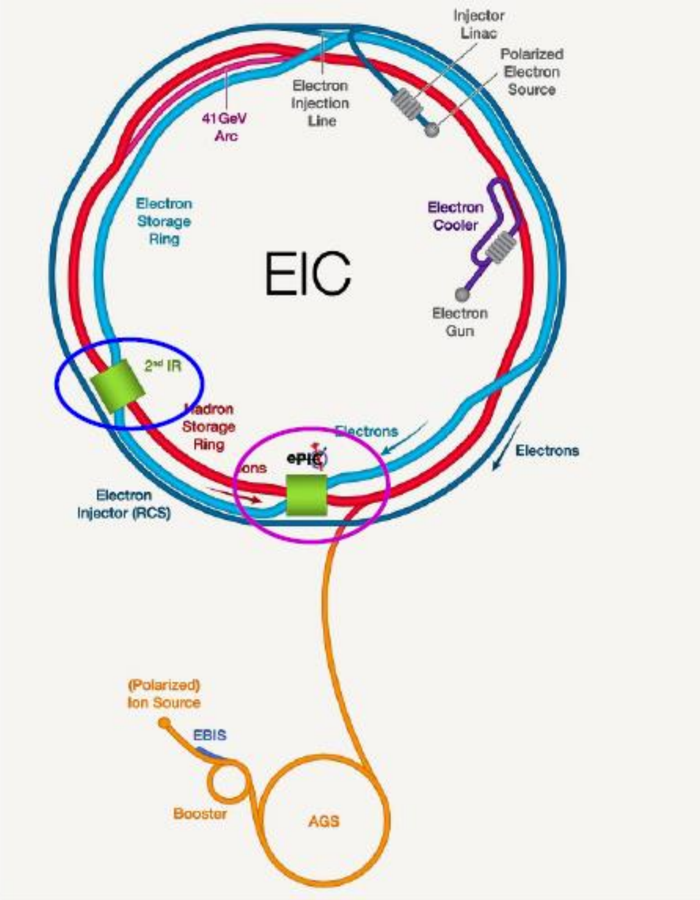
For e-N collisions at the EIC:

- ~70% polarized beams: e, p, d/^{3}He
- Electron beam (5-18 GeV)
- $\sqrt{s_{ep}}$ = 20-140 GeV (Variable)
- L_{ep} ~10^{33}-10^{34} $cm^{-2}sec^{-1}$ ~100-1000 times higher than HERA using crab cavities

For e-A collisions at the EIC:

- Wide range of nuclei
- Variable center-of-mass energy
- Luminosity per nucleon same as ep collisions





ePIC (electron-Proton/Ion Collider) experiment at Brookhaven National Laboratory (BNL), USA

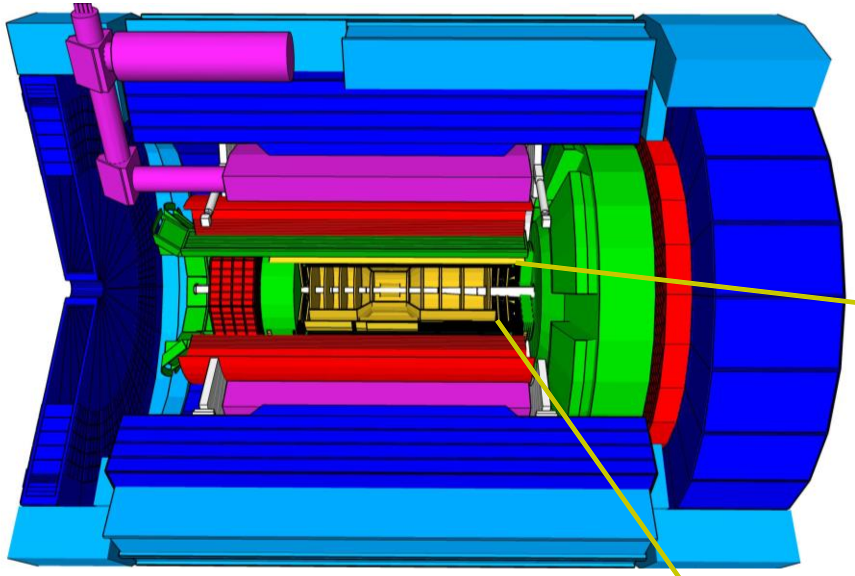
More than one interaction region

Detector II (not yet scheduled in time)

Overview of the ePIC Tracking Detector

ePIC Detector@ EIC

e/m calorimeters | solenoid coils | ToF, DIRC, RICH

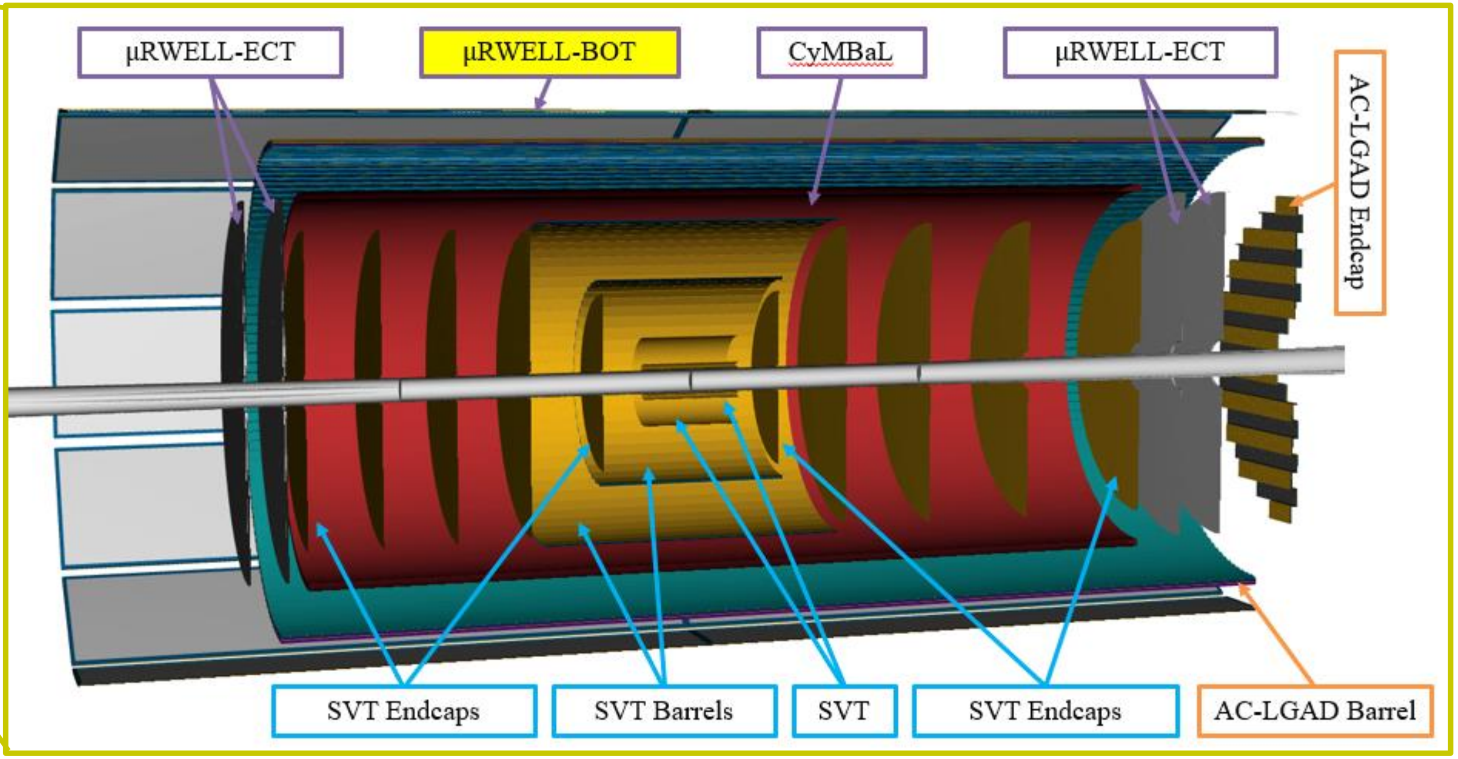


hadronic calorimeters | Central trackers

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

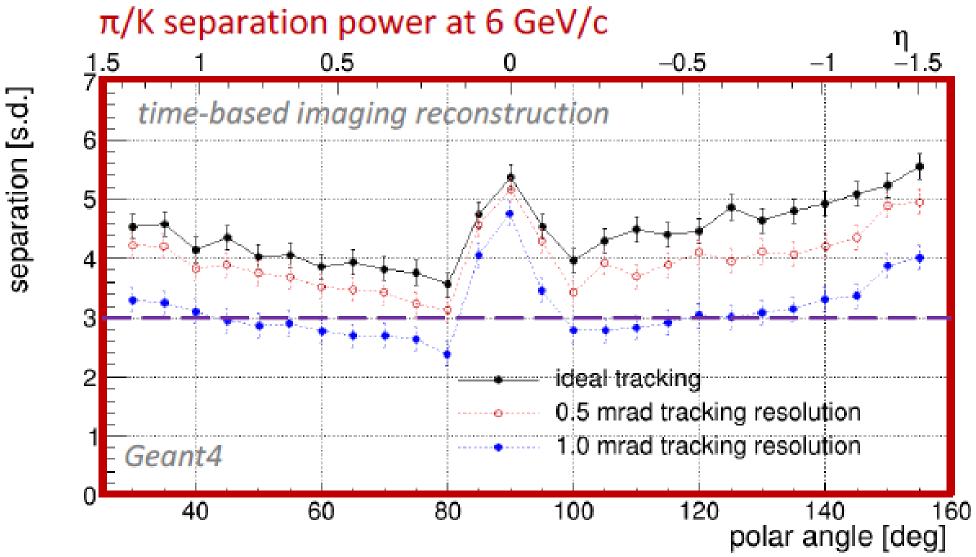
Tracking requirement for hpDIRC in barrel region

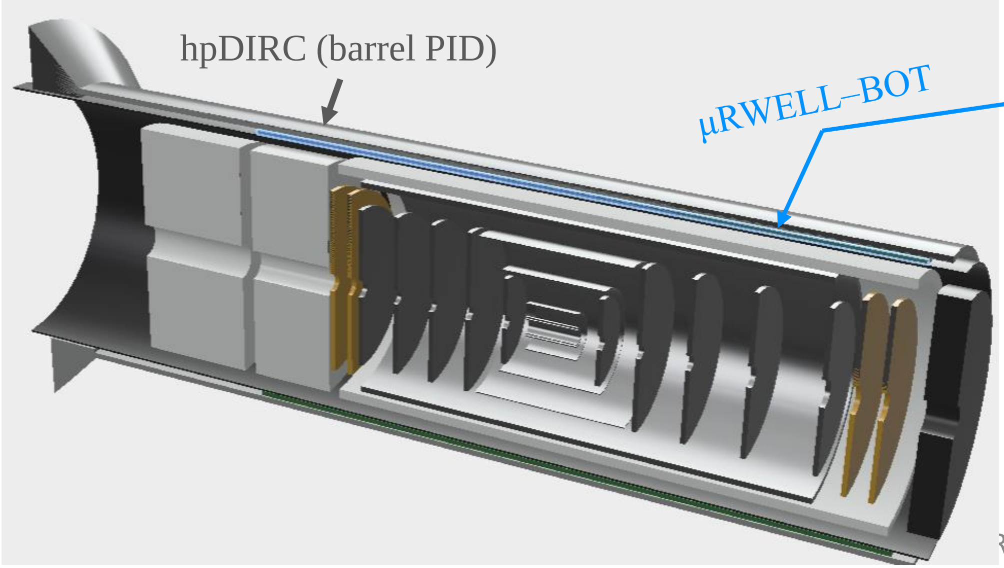
- ❖ Vertex detector → Identify primary and secondary vertices,
  - Low material budget: 0.05% X/X_0 per layer;
  - High spatial resolution: 20 µm pitch CMOS Monolithic Active Pixel Sensor
- ❖ Central tracker → Measure charged track momenta
  - MAPS – tracking layers in combination with micro pattern gas detectors
  - MPGD: µRWELL and Micromegas technologies



μRWELL Barrel Outer Tracker (μRWELL–BOT) in ePIC Detector

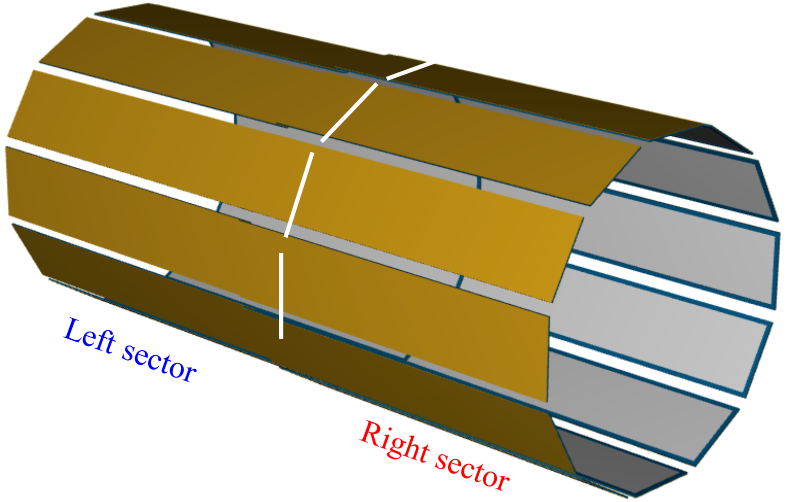
Tracking requirement for hpDIRC in barrel region





ePIC Barrel Outer Tracker (μRWELL-BOT)

- ❖ Improved angular and space point resolution at the hpDIRC level
  - Acceptance matching with hpDIRC bars
  - **Spatial resolution: ~150 μm on average in the full eta range**
- ❖ Pattern recognition combination with Micromegas layers & AC-LGAD
  - Timing layers (~10 ns) to help the slow MAPS trackers in the barrel
  - Additional hit point to tracking for redundancy



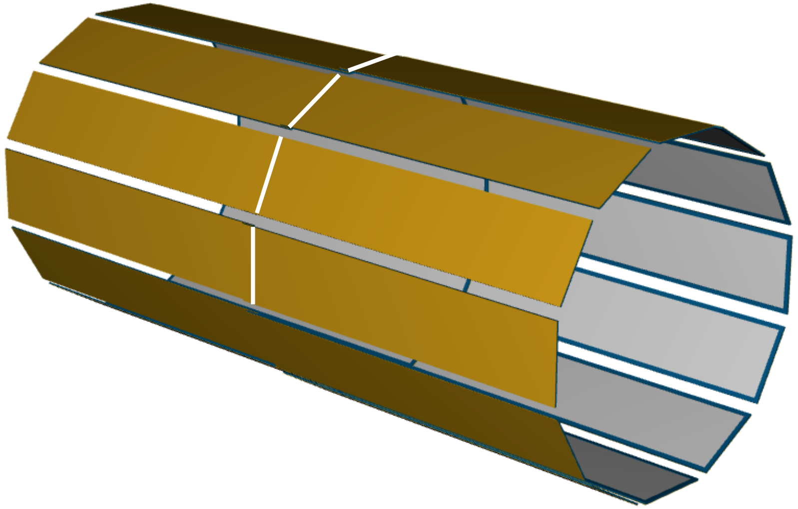
μRWELL-BOT Tracker in ePIC

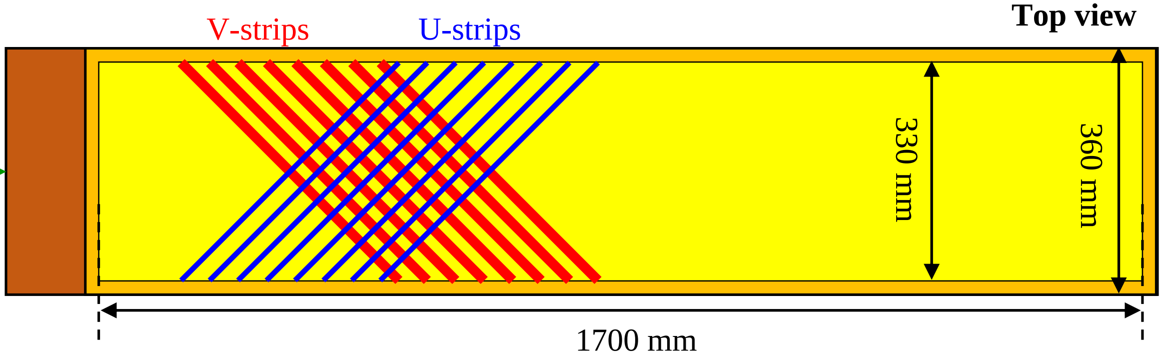
- ❖ 2 sectors (left & right) along **z**
- ❖ Each made of 12 planar modules in φ in a dodecagon shape
- ❖ Length = 340 cm
- ❖ Radius = 72.5 cm

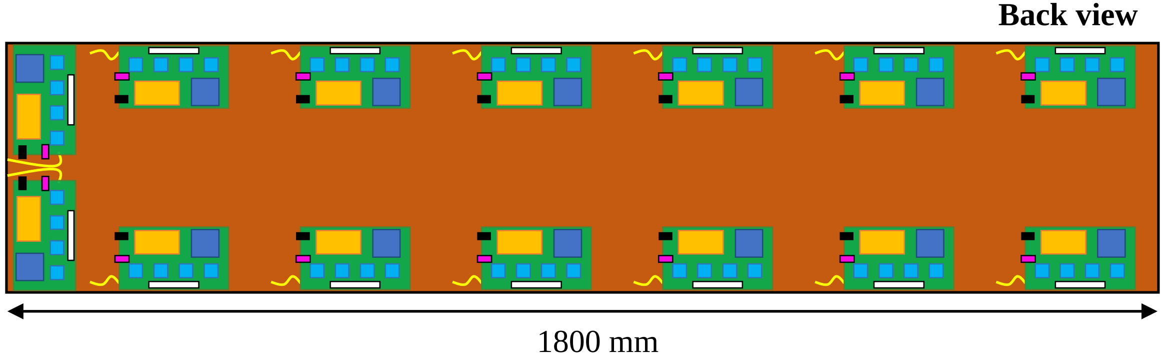
μRWELL–BOT Module: Design Considerations

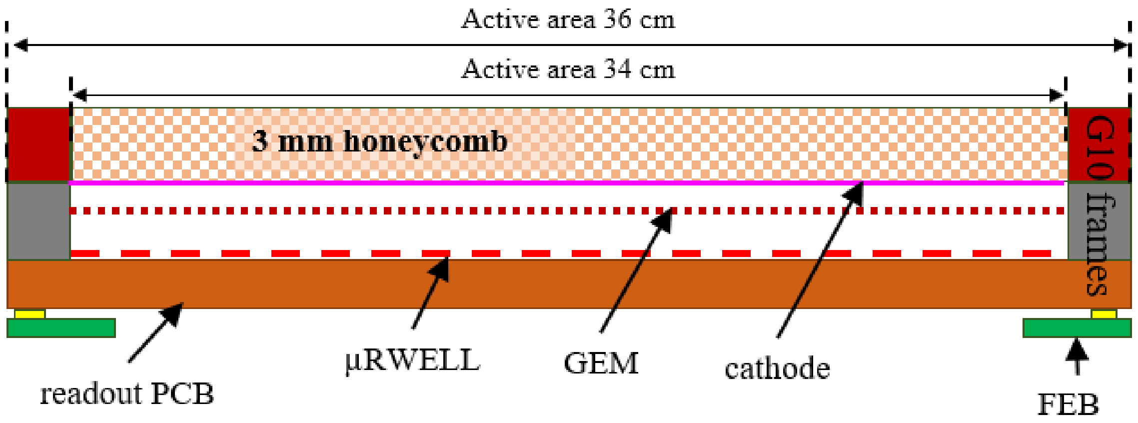
μRWELL-BOT module

- ❖ Thin drift gap (**1 mm**) & hybrid amplification (GEM-μRWELL) detector
- ❖ Dimensions: 1850 mm × 360 mm × 25 mm
  - ▪ Active area: 1700 mm × 330 mm
- ❖ Capacitive-sharing U-V strips readout layers(45^{O} stereo angle)
  - ▪ Pitch: 1.14 mm (1790 U-strips and 1790 V-strips per modules)









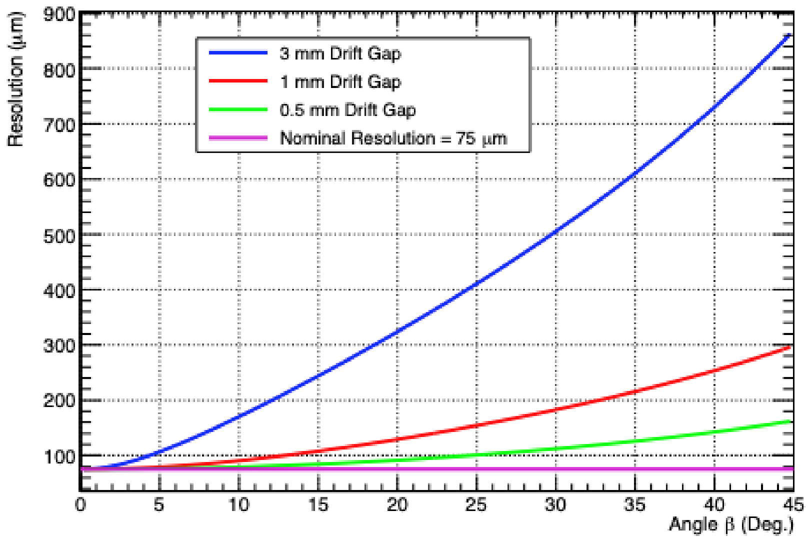
On-detector Front End Boards (FEBs) based on SALSA chips

- ❖ 14 FEB / modules (assuming 4 SALSA chips i.e 256 e-ch / FEB)
- ❖ Direct connection on the back of the modules (no need for flex cables)

Motivations for ePIC Thin Gap GEM-μRWELL Outer Tracker

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

- ❖ Degradation of the spatial resolution with track angle .
- ❖ E × B in magnetic field negatively impact resolution
- ❖ Detector performance in the barrel region will be very poor
- ❖ Negatively impact the performance of hpDIRC in the barrel



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

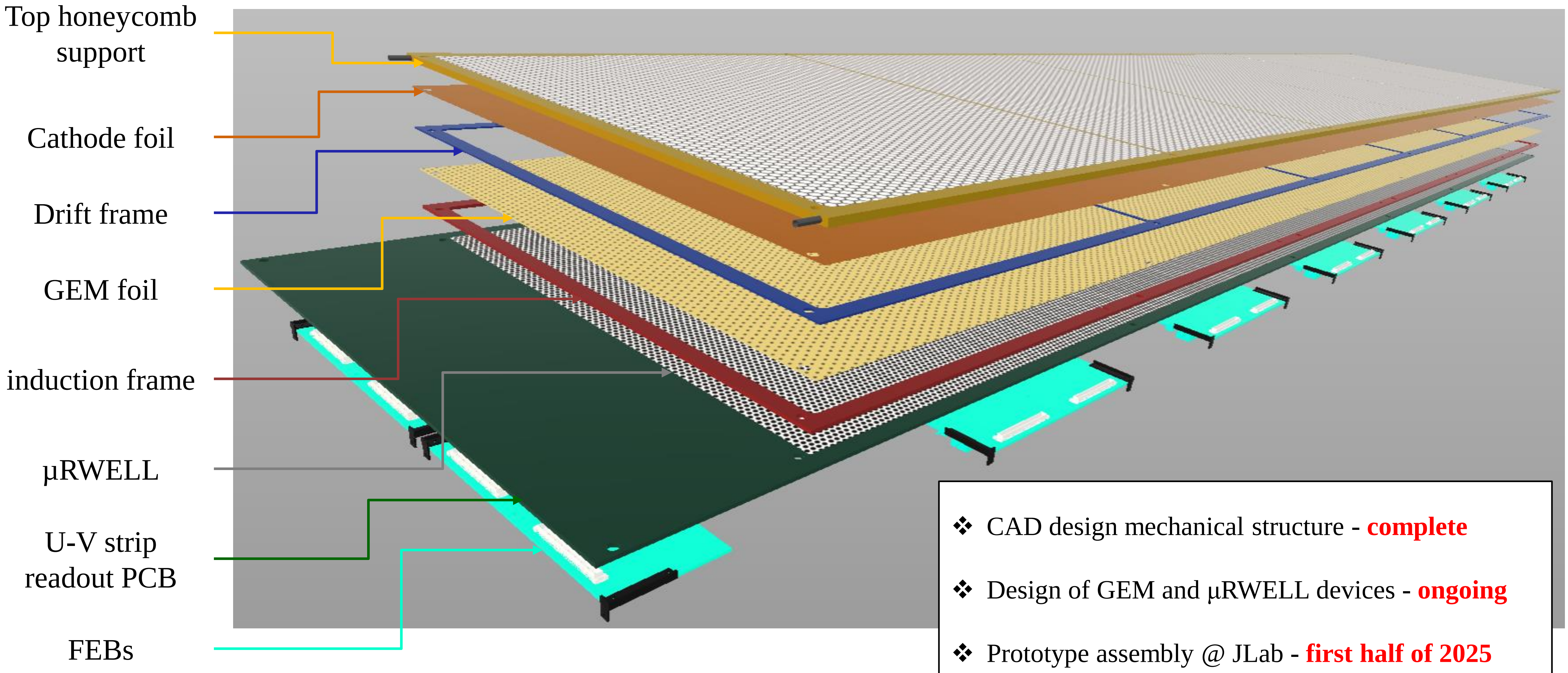
https://wiki.bnl.gov/eic/upload/ERD_tgMPGD_FY22_endOfYearReport_final.pdf

https://wiki.bnl.gov/eic/index.php?title=File:20230714_eRD_tgMPGD_Proposal_FY23_Final.pdf

Features of ePIC Thin Gap GEM-μRWELL Outer Tracker

- ❖ **Thin gas volume (~ 1mm) in the ionization (drift) gap gap**
  - ▪ Reduce the length of the ionization trail of the incoming charge particles and thus minimize its impact in position reconstruction
  - ▪ Minimize E × B effect in strong magnetic field
- ❖ **Double amplification MPGD:**
  - ▪ Hybrid GEM (preamplification) and μRWELL (second amplification) ➔ Compensate for reduced primaries in the ionization gap
  - ▪ HV setting flexibility to allow high gain and stable operation
- ❖ **Capacitive-sharing strip readout**
  - ▪ Strip charge sharing quasi independent of electron cloud size
  - ▪ Strip multiplicity > 3 easily achievable for 2D readout with 800 um strip pitch ➔ critical feature for thin gap to maintain excellent spatial resolution

µRWELL–BOT Module: Full Scale Engineering Test Article

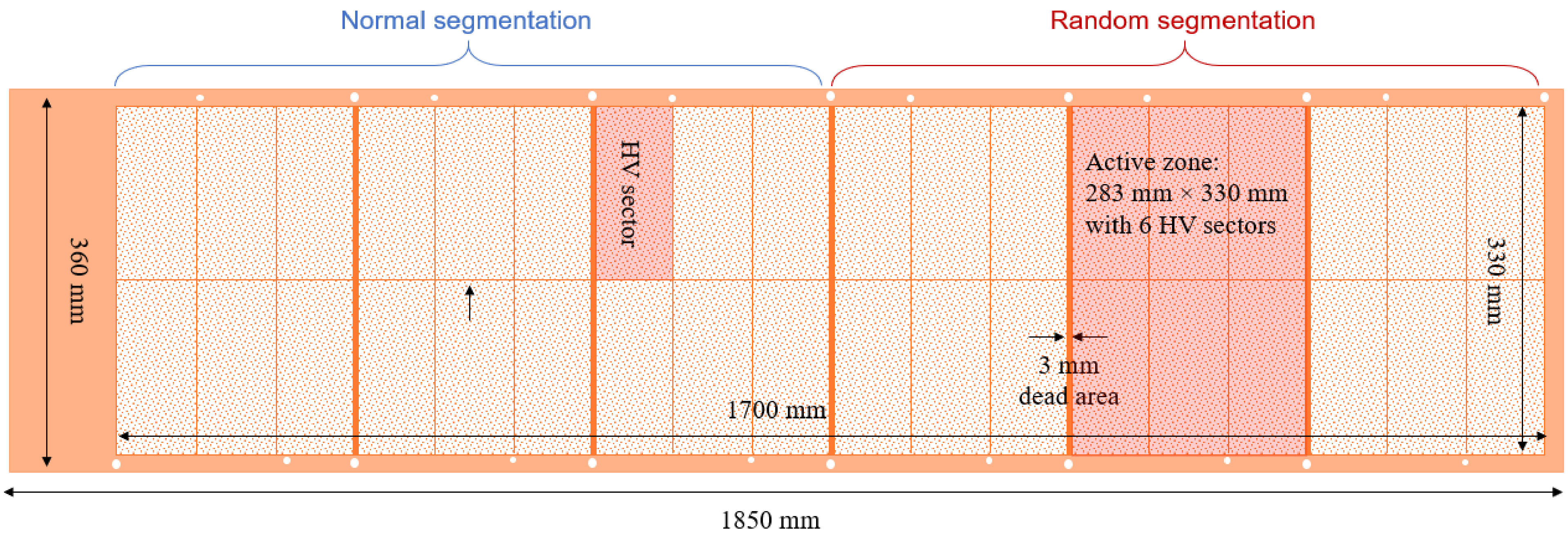


- ❖ CAD design mechanical structure - **complete**
- ❖ Design of GEM and µRWELL devices - **ongoing**
- ❖ Prototype assembly @ JLab - **first half of 2025**
- ❖ Performance test in beam - **second half of 2025**

μRWELL–BOT Module: GEM foil design

Pre-amplification GEM foil: active area ~1700 mm × 33 mm

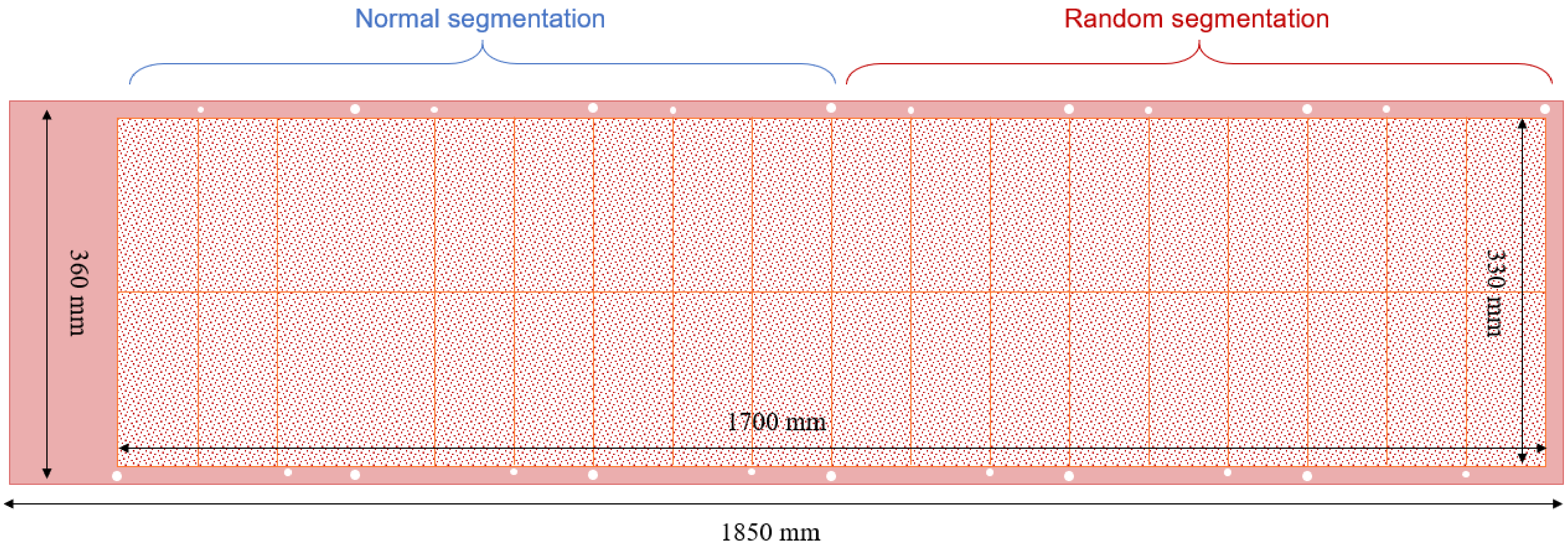
- Higher hole density: **Pitch** 100 μm; **hole diameter** 70 μm; **inner diameter** 70 μm ➔ We expect higher gain at lower HV setting
- The active area of the foil is divided in 6 active zones of an area ~283.33 mm × 33 mm separated by 3 mm dead area
  - The 3 mm dead areas of GEM foil are glued to the support frame to maintain gap uniformity
  - Each active zone is subdivided into 6 HV sectors of area ~9.45 mm × 165 mm
- Half (18) of the HV sectors on the left side of the foil with random segmentation ➔ minimize dead area around HV sector boundaries
  - Will compare left and right sides to evaluate impact of random segmentation on efficiency and spatial resolution



μRWELL–BOT Module: μRWELL foil design

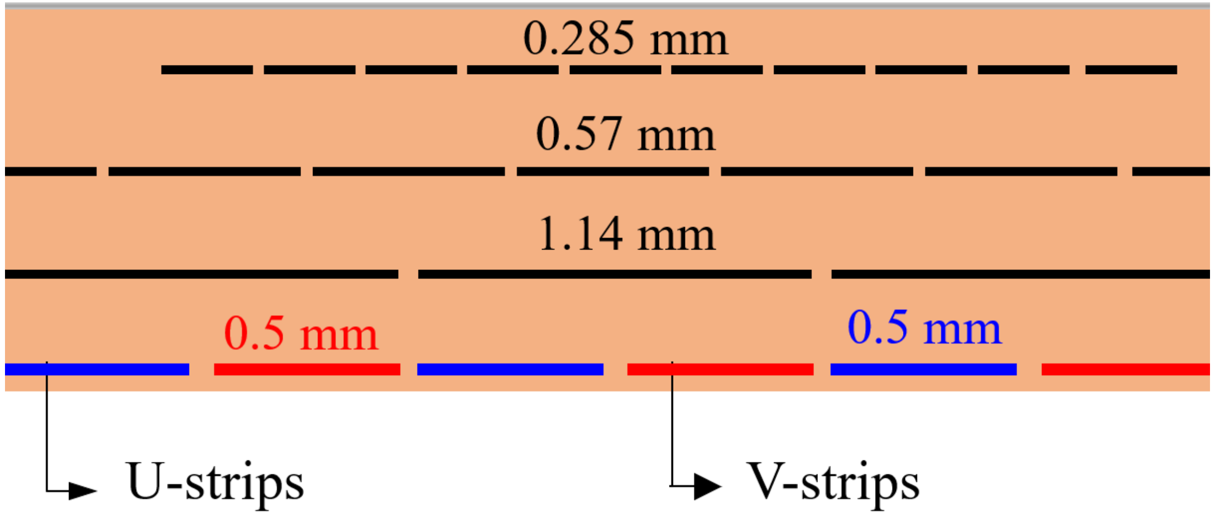
Second amplification μRWELL design: active area ~1700 mm × 33 mm

- Higher hole density: **Pitch** 100 μm; **hole diameter** 70 μm; **inner diameter** 70 μm ➔ We expect higher gain at lower HV setting
- The active area of the foil is divided into 36 HV sectors (~9.45 mm × 165 mm)
- Half (18) of the HV sectors on the left side of the foil with random segmentation ➔ minimize dead area around HV sector boundaries
  - Same idea than with GEM foil ➔ randomly segmented sectors of GEM and μRWELL stacked
  - Will compare left and right sides to evaluate impact of random segmentation on efficiency and spatial resolution

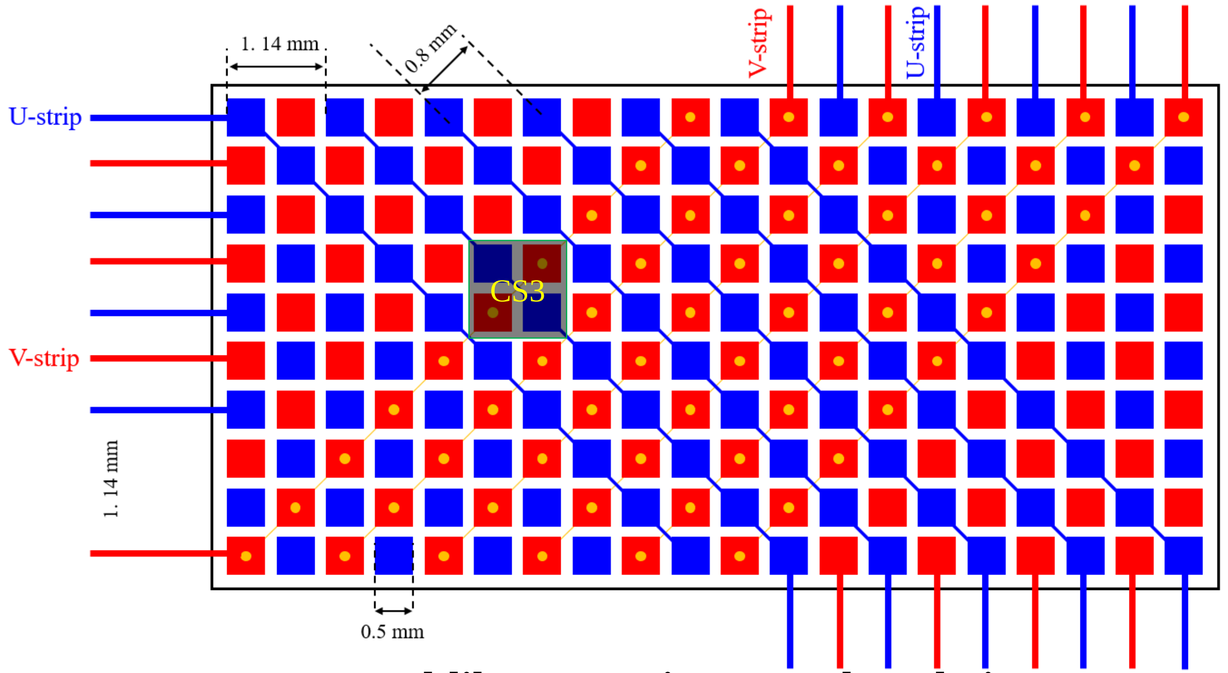


µRWELL–BOT Module: Capacitive-sharing U-V strip readout layer

- U-V strip design ➔ Optimize for equal sharing between U and V strips:
  - U-strips: pad-like strips with the pad directly connected along one diagonal axis
  - V-strips: pad-like strips with the pads interconnected along the other diagonal into traces on a layer underneath through vias.
- Capacitive sharing layers ➔ Optimize for a strip multiplicity per event > **3** for each readout plane (U or V)
  - 3 capacitive sharing layers: first layer (top) pad size 285 µm and last layer pad size of 1.14 mm
  - 3rd capacitive-layer (CS3) covers one U-strip and one V-strip (2 pads each



cross-section view – capacitive sharing readout structure



Pad-like U-V strip 2D readout design

Assembly sites for ePIC µRWELL–BOT Modules

- Procurement of GEM and µRWELL parts from CERN MPT workshop
- 3 assembly sites: Florida Tech, University of Virginia & Jefferson Lab
- have fully equipped MPGD Detector Lab
  - Fully equipped CLASS 1000 Clean rooms for module assembly
  - Cosmic tracking telescope setup with coincidence trigger counters 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

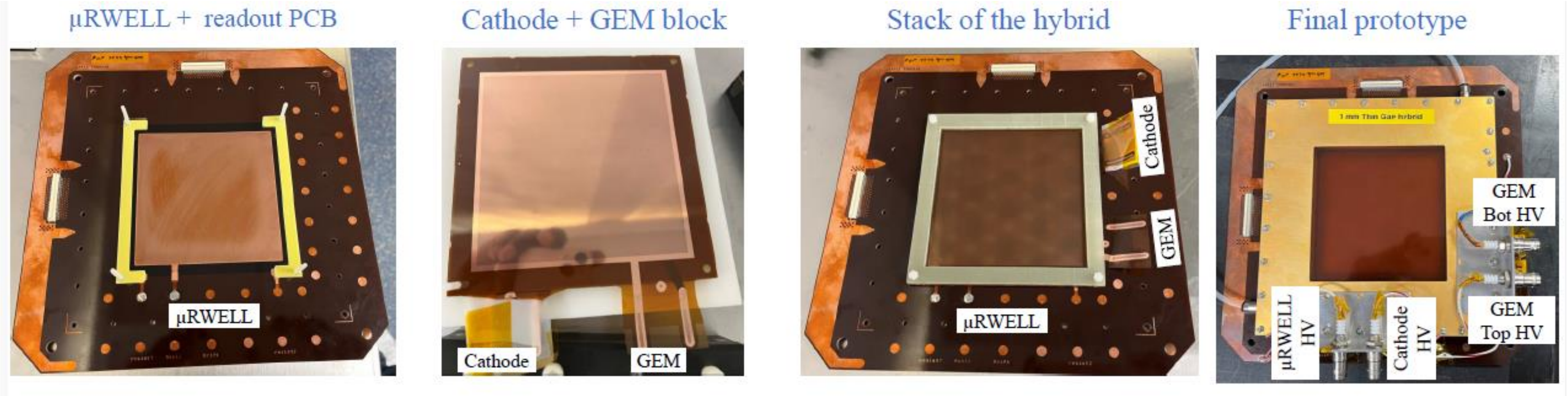
UVa Clean Room: SBS GEMs, MOLLER GEMs, PRad GEMs, CLAS12 µRWELL, Hall D GEM-TRD prototype

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

Small Thin Gap GEM-µRWELL Hybrid Prototype

Proof of concept in beam test

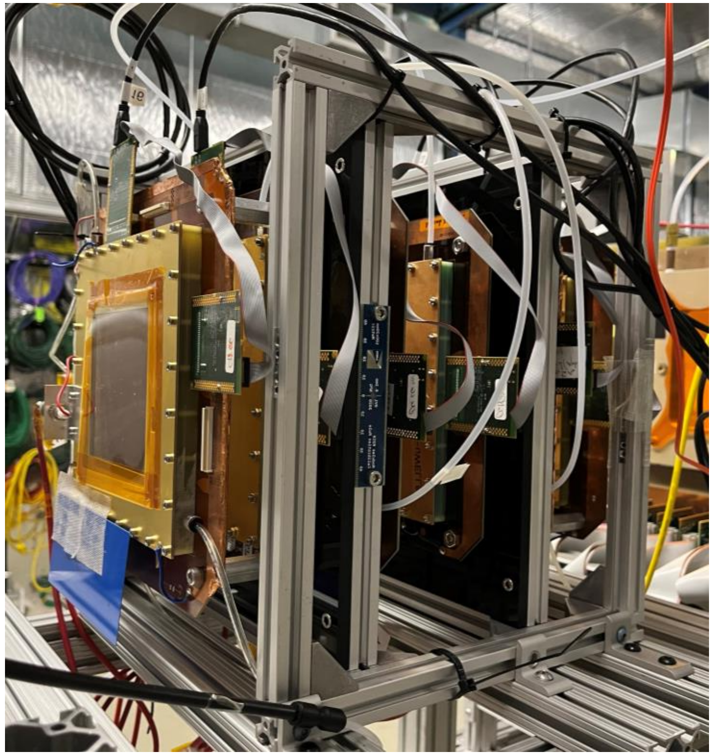
- Concept of thin-gap GEM-µRWELL hybrid prototype demonstrated in beam at Fermilab Test Beam Facility (June 2023)
- Space resolution < 150 µm and efficiency of 92% on average for 1-mm thin-gap GEM-µRWELL prototype and for track in an range [0 – 45] degrees.
- **Baseline technology for ePIC outer MPGD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

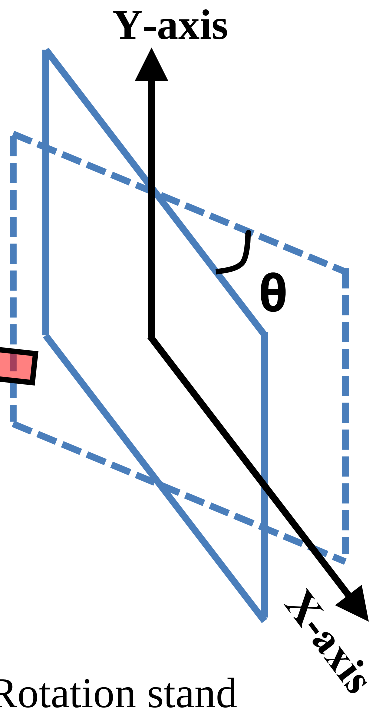


R&D funded by JLab administered DOE EIC Generic R&D Program as EICGENRandD_2022_23

Thin-gap MPGD prototypes in Test Beam @ Fermilab (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

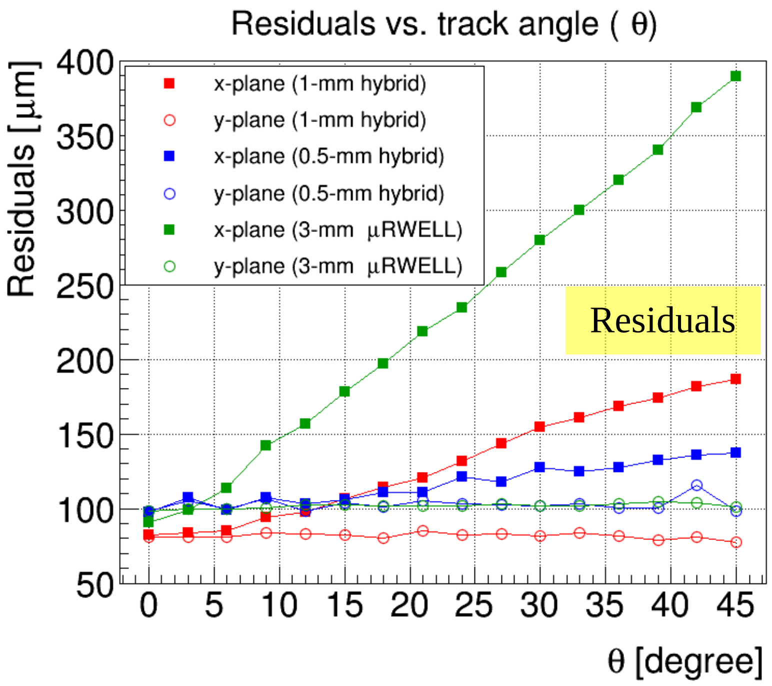
Setup II: Spatial resolution vs. angle scan setup

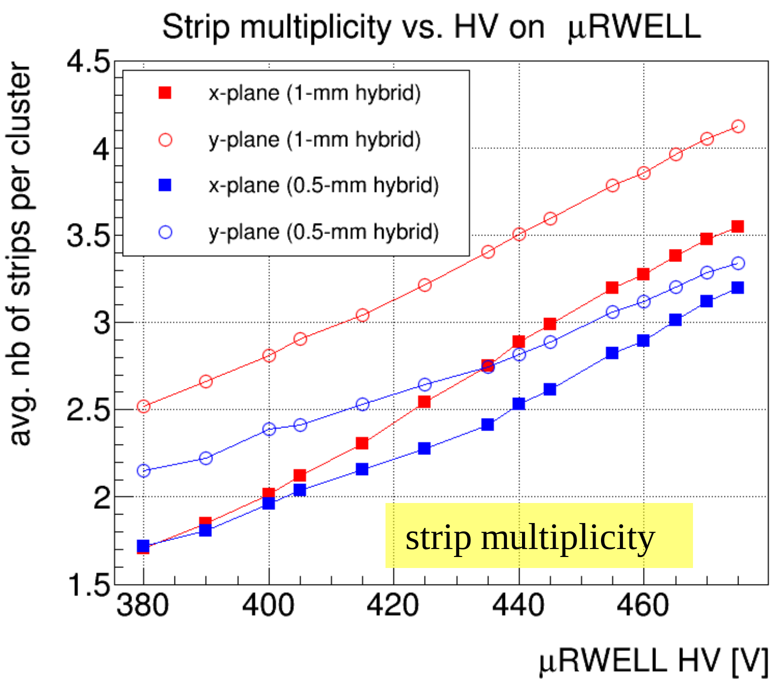
- ❖ Rotation stand rotate the X-Y plane by an angle θ (0 - 45 degrees) w.r.t to Y-axis
- ❖ Up to 3 thin-gap prototypes tested in the rotation stand at the time
- ❖ 2 trackers upstream and 2 downstream on a fixed separate stand

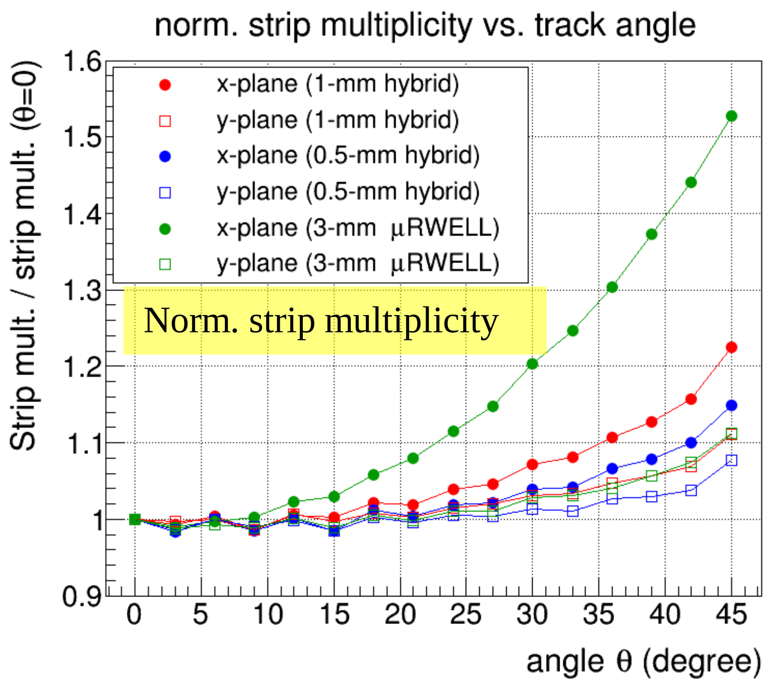
Preliminary results of thin gap GEM-µRWELL Hybrid

Tracking residuals vs. track angle

- Concept of thin-gap GEM-µRWELL hybrid prototype demonstrated in beam at Fermilab Test Beam Facility (June 2023)
- 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 range [0 – 45] degrees.
- Baseline technology for ePIC outer MPGD tracker







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

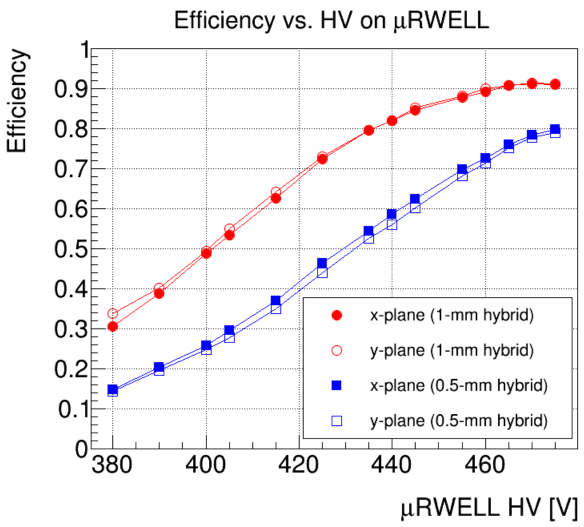
Preliminary results of thin gap GEM-µRWELL Hybrid

Efficiency vs. HV scans

- Efficiency in Ar/CO2 reaches 80% and ~90% for 0.5-mm gap and 1-mm gap GEM-µRWELL protos respectively at the plateau when a 5×σ pedestal rms cut is applied and single strip cluster is included.
- Overall efficiency depends on several parameters of the detectors the HV applied on GEM preamplification as well as the electric field in the induction region and is optimized around 2kV/cm in the drift region
- Optimization of the detector HV setting for maximum efficiency at a stable operating will be studied in more details in the future

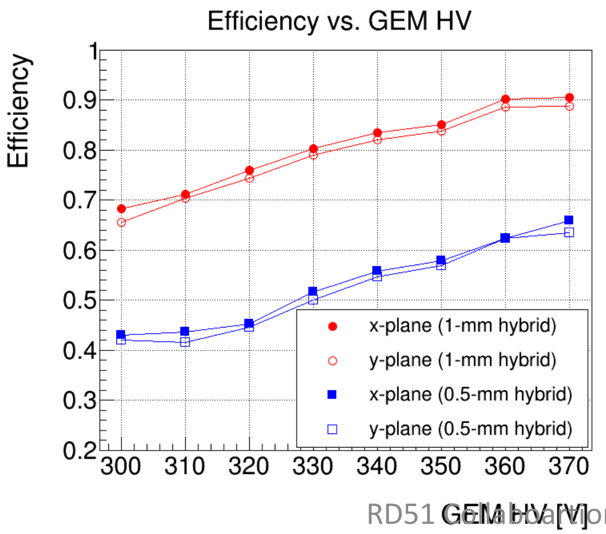
µRWELL HV scan

- GEM HV: 350 V
- Drift E-field: 2 kV / cm
- Induction E-field: 2kV / cm



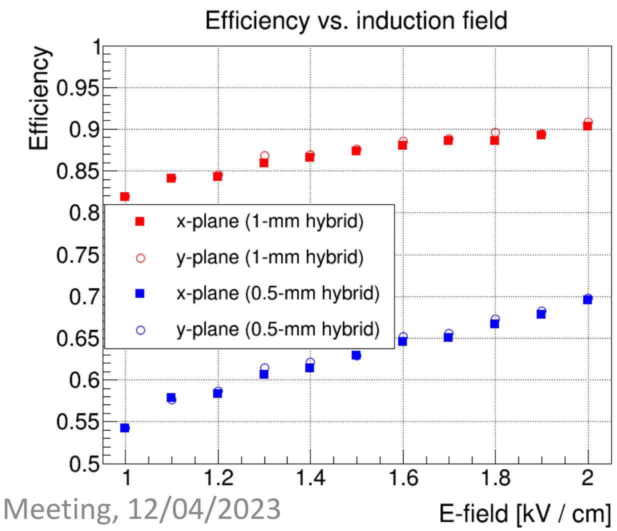
GEM HV scan

- µRWELL HV: 460 V
- Drift E-field: 2 kV / cm
- Induction E-field: 2kV / cm



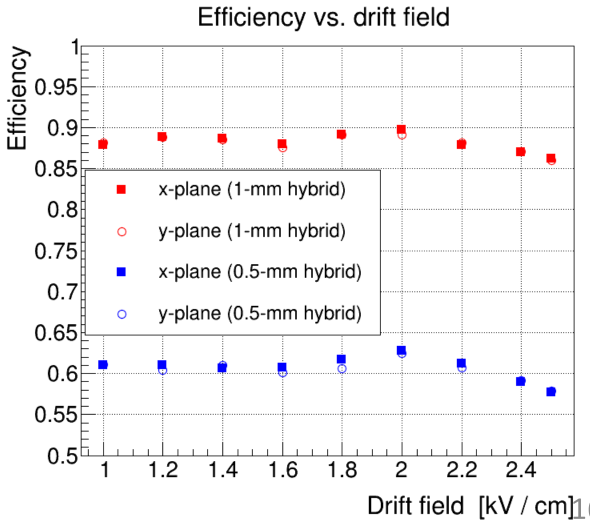
Induction E-field scan

- GEM HV: 350 V
- µRWELL HV: 460 V
- Drift E-field: 2kV / cm



Drift E-field scan

- GEM HV: 350 V
- µRWELL HV: 460 V
- Induction E-field: 2kV / cm



EIC Generic R&D: Double Thin Gap GEM-µRWELL Hybrid

Development of Double-sided Thin-Gap GEM-µRWELL for Tracking at the EIC

Proposal to the FY23 EIC generic detector R&D program

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July 14, 2023

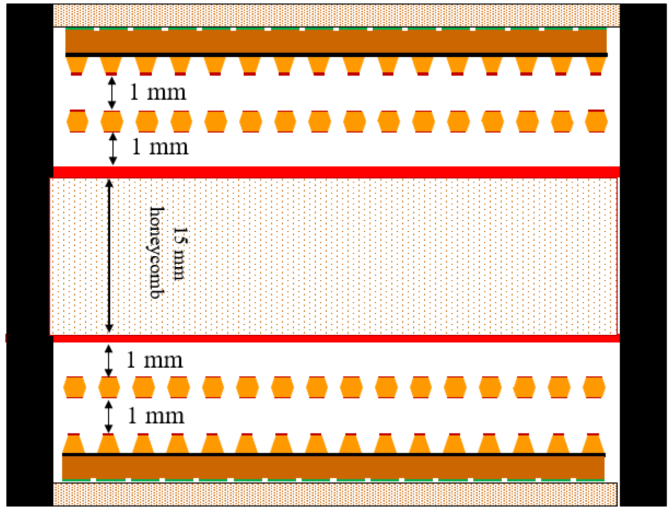
Abstract

The EIC physics program requires precision tracking over a large kinematic acceptance, as highlighted in the EIC Yellow Report [1]. MPGDs are able to provide space point measurements for track pattern recognition and momentum measurement. These MPGD detectors will span a large pseudorapidity range and will see tracks entering over a large range of incidence angles, in addition to tracks bending due to magnetic fields. The position measured by a standard MPGD structure for a track impinging at a large angle from the normal is no longer determined by the detector readout structure, but instead by the gap in the ionization gas volume that the particle traverses before reaching the amplification stage, leading to a deterioration in the spatial resolution that grows with the incidence angle relative to the normal. To minimize the impact of the track angle on the resolution, several medium-size prototypes with double layers of thin-gap MPGDs, where the ionization gas volume is significantly reduced with respect to typical MPGD detectors and that can be operated with standard Ar/CO_2 gas mixtures at high efficiency, will be designed, built, and tested.

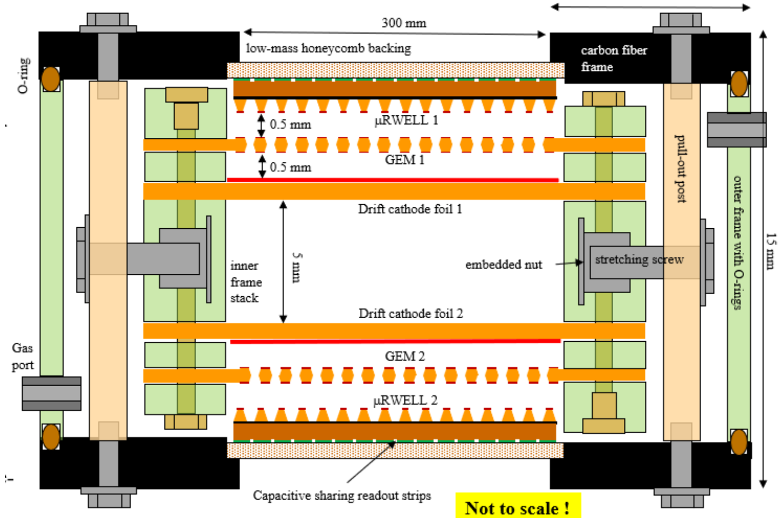
- **FY23 Thin-gap MPGD R&D Focus**
  - Large ara for outer and muons tracking layers
  - Mechanically stretched & low mass thin-gap MPGDs
  - High-performance tracking in high-η & far forward regions
- **Double thin-gap GEM-µRWELL hybrid detector**
  - Continuation of FY22 Thin Gap MPGD development
  - Double amplification with hybrid GEM-µRWELL
  - Double-sided to achieve full detection efficiency
  - Minimize Lorentz angle effect on resolution in B field
- **Optimization with Argon-based gas mixture**
  - Affordability and availability compared to Xe / Kr
  - Higher gain at lower bias voltage
  - Better timing resolution (~ 2 ns) for 0.5 mm gap
  - Reduction of background rate in the detector

1mm gap medium size prototypes

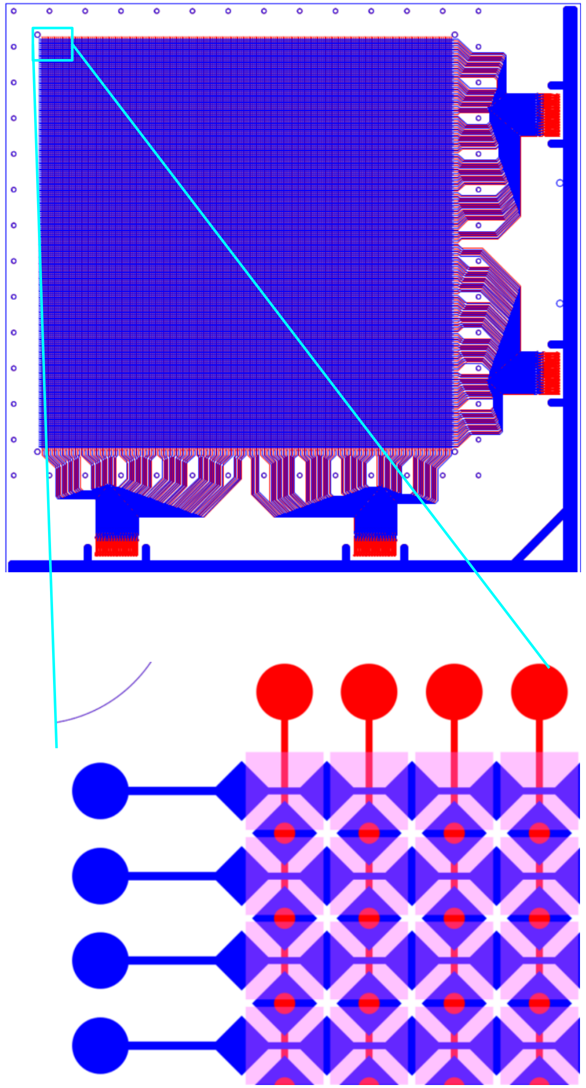
30 cm × 30 cm "glued option" prototype



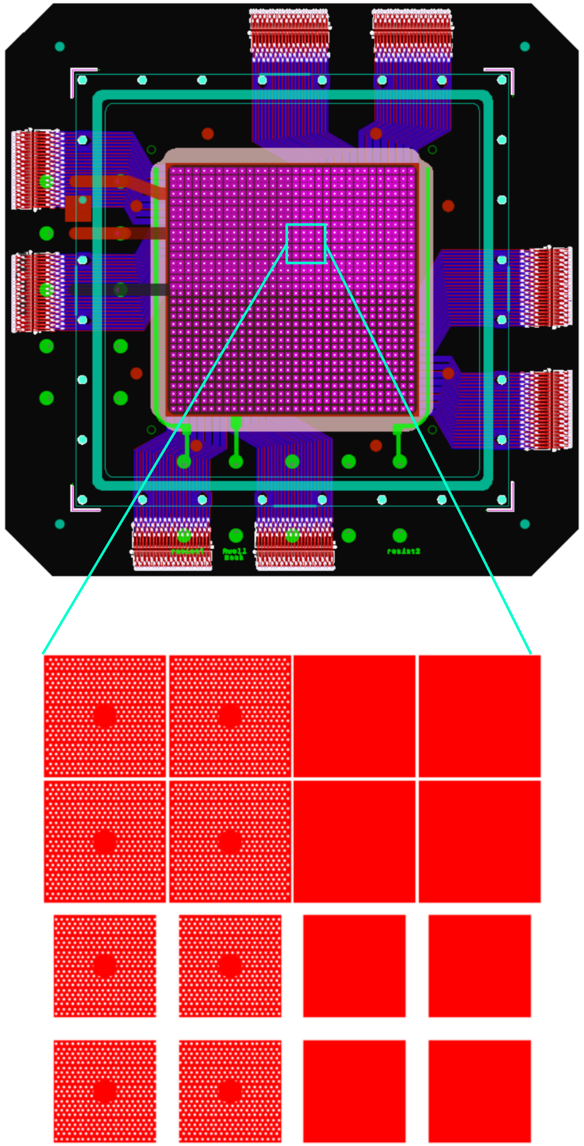
30 cm × 30 cm "self stretched option" prototype



1mm gap medium size prototype with ASACUSA-like X-Y strip readout



0.5 mm gap small prototype with 3.2 mm x 3.2 mm pad readout:



Summary

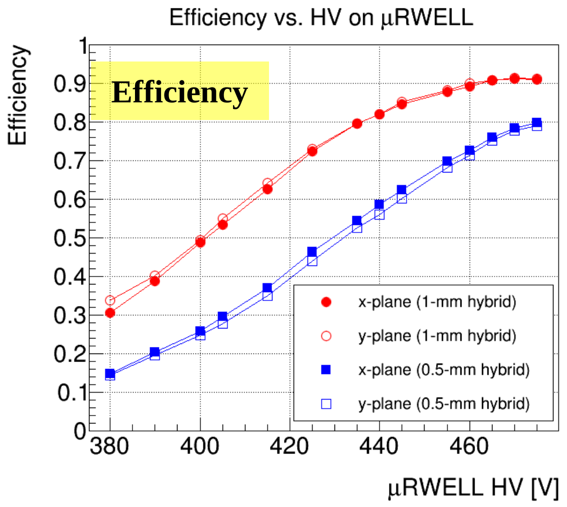
- Micro Pattern Gas Detectors (Micromegas, GEM and µRWELL) are part of the tracking system of the ePIC detector @ EIC
- The outer tracking layer in the barrel region of ePIC is based on large area planar thin gap GEM-µRWELL hybrid technology
- A small size prototype 1-mm thin gap GEM-µRWELL hybrid was developed and tested in beam at Fermilab in June 2023
- Efficiency above 90% was reached with Ar-CO2 gas mixture for 1-mm thin gap GEM-µRWELL hybrid detectors
- Design of the full scale engineering test article (aka prototypes) of the µRWELL-BOT modules is ongoing and the prototype is expected to be assembled and tested in beam by end 2025
- Ongoing R&D effort aims at the development of large-area, high-performance double thin-gap GEM-µRWELL detector for various application in tracking system for future colliders detectors

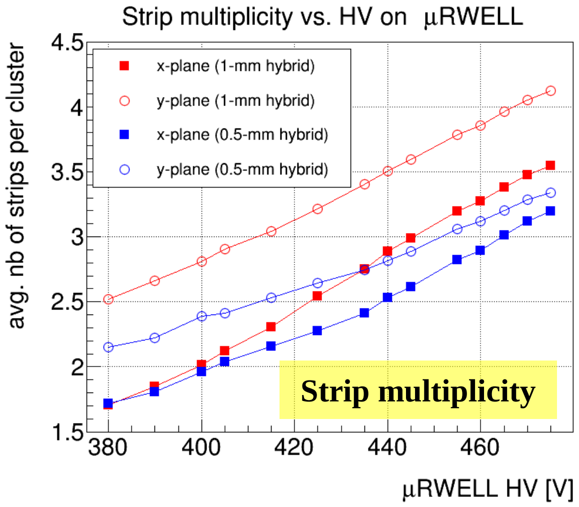
Backup

JLab prototypes: Thin-gap GEM-µRWELLs

µRWELL HV scan

- GEM HV: 350 V
- E-field in drift gap: 2 kV / cm
- E-field induction gap: 2kV / cm

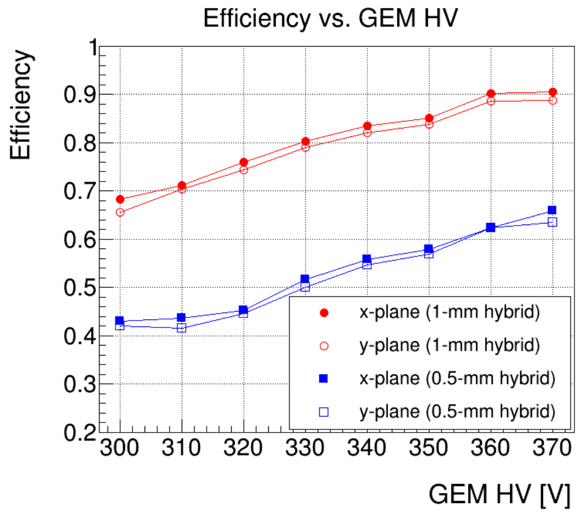




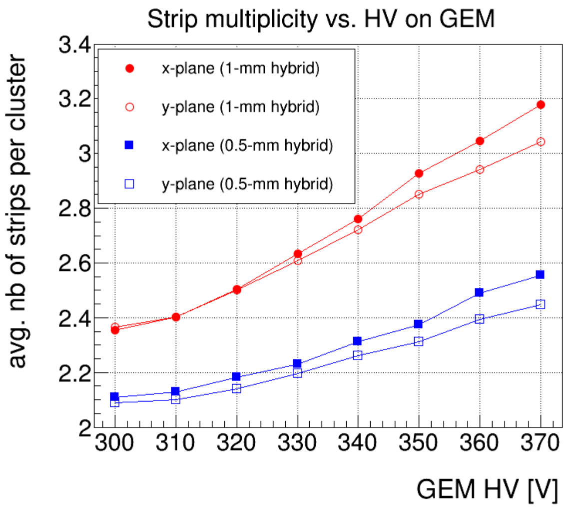
GEM HV scan

- µRWELL HV: 460 V
- E-field in drift gap: 2 kV / cm
- E-field induction gap: 2kV / cm

Efficiency



Strip multiplicity

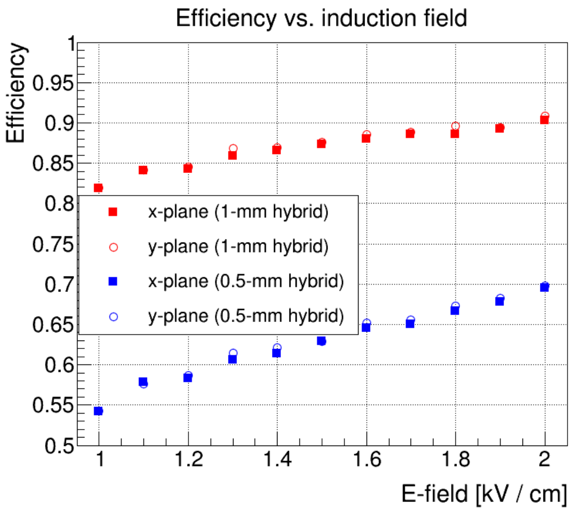


JLab prototypes: Thin-gap GEM-μRWELLs

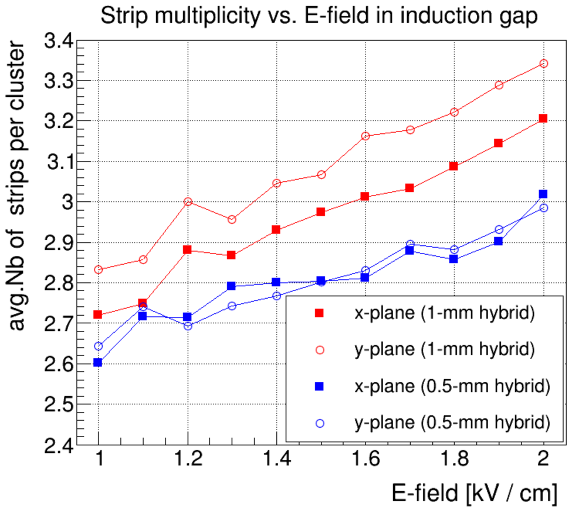
Induction E-field scan

- ❖ GEM HV: 350 V
- ❖ μRWELL HV: 460 V
- ❖ Drift E-field: 2kV / cm

Efficiency



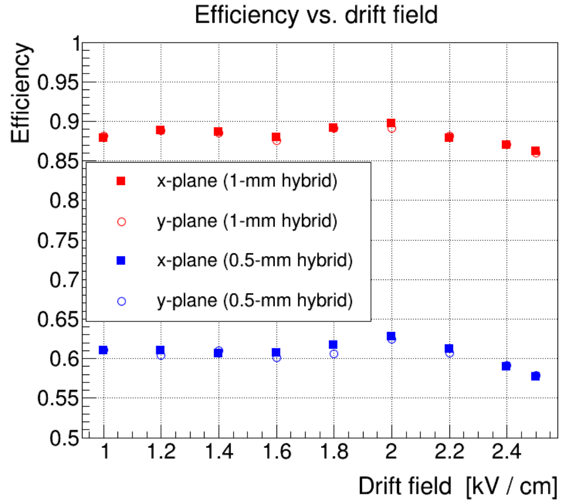
Strip multiplicity



Drift E-field scan

- ❖ GEM HV: 350 V
- ❖ μRWELL HV: 460 V
- ❖ Induction E-field: 2kV / cm

Efficiency



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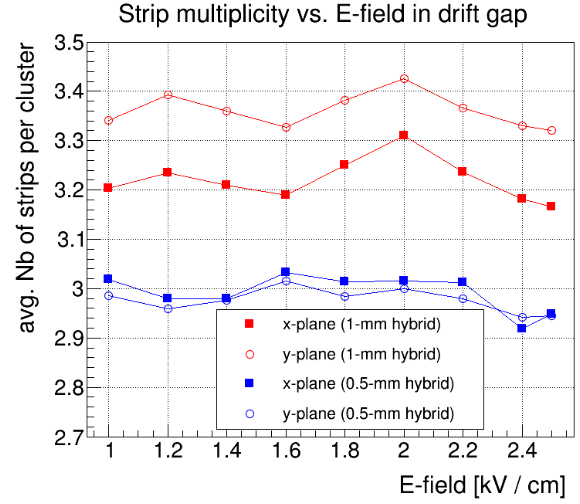

Preliminary results of thin gap GEM-µRWELL Hybrid

Strip multiplcity