Development of Double-Sided Thin-Gap GEM-µRWELL hybrid Detector for Tracking at the EIC

FY22 Progress Report & FY23 Proposal

EIC GENERIC R&D REVIEW MEETING

Kondo Gnanvo on behalf of Thin-Gap MPGD Consortium

October 31, 2023

Outline

- Responses to Reviewers Written Questions
- FY22 Progress Report
  - Development of Thin-Gap MPGDs
  - FNAL 2023 Test Beam Results
- FY23 Proposal
  - Double-Sided Thin-Gap GEM-µRWELL Hybrids
  - Timeline & Budget

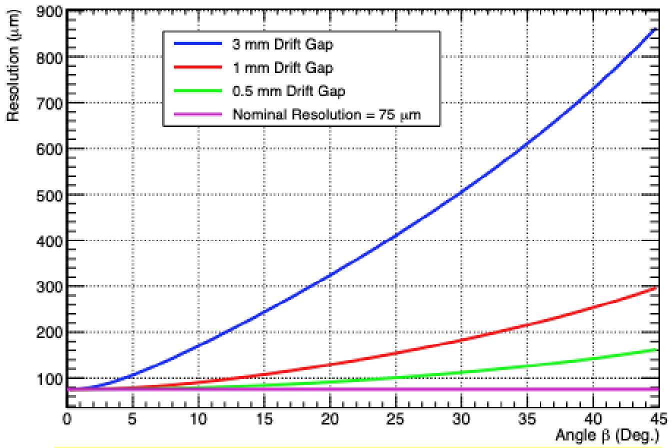
FY22 Proposal: Generic Thin Gap MPGD Proposal

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

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

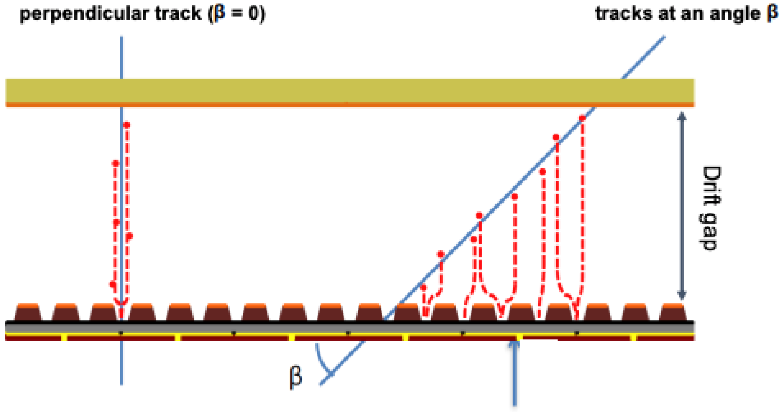
Development of Thin-gap MPGDs:

- Smaller drift gap to reduce the dependence of resolution
- Smaller gaps ➔ minimize E × B effect in magnetic field
- Improve the detector timing performance

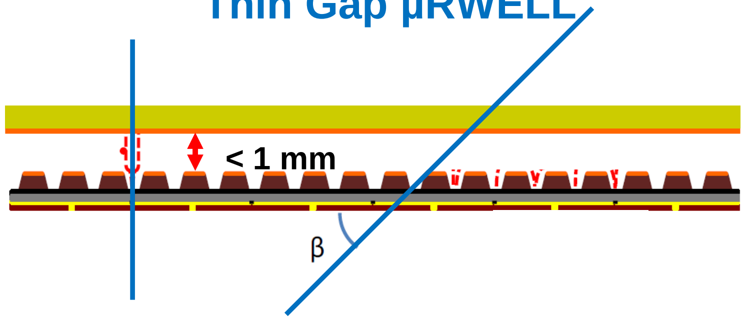


parametrization from *EPJ Web of Conferences* ***174***, *06005 (2018)*

standard Gap µRWELL



Thin Gap µRWELL



Development of Thin Gap MPGDs for EIC Trackers

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Questions from reviewers

QUESTION 1: Please summarize what has been done in the last year and what remains to be done

RESPONSE:

What was achieved:

- ❖ Design and fabrication of 10 small (10 cm × 10 cm) thin-gap MPGD prototypes to demonstrate the viability of thin gap concept to recover spatial resolution over a wide range of incoming track angles
- ❖ All prototypes based on 3 amplification structures (GEM, Micromegas and µRWELL) or a combination of them **(hybrids)**.
- ❖ The prototypes were all successfully tested in beam at Fermilab in June 2023 to study efficiency with HV scans and spatial resolution performance with angle scan with ArCO2 and KrCO2 based gas mixture

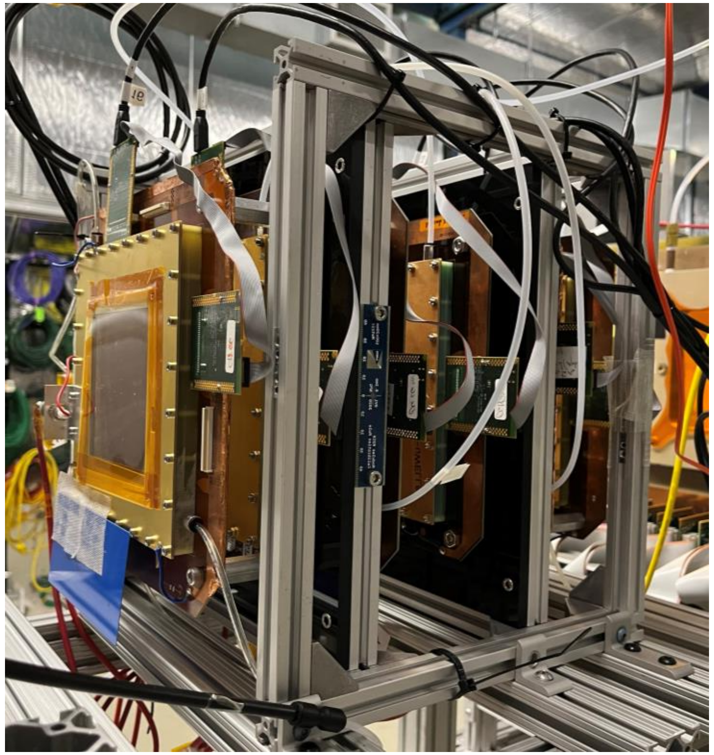
What remains to be done:

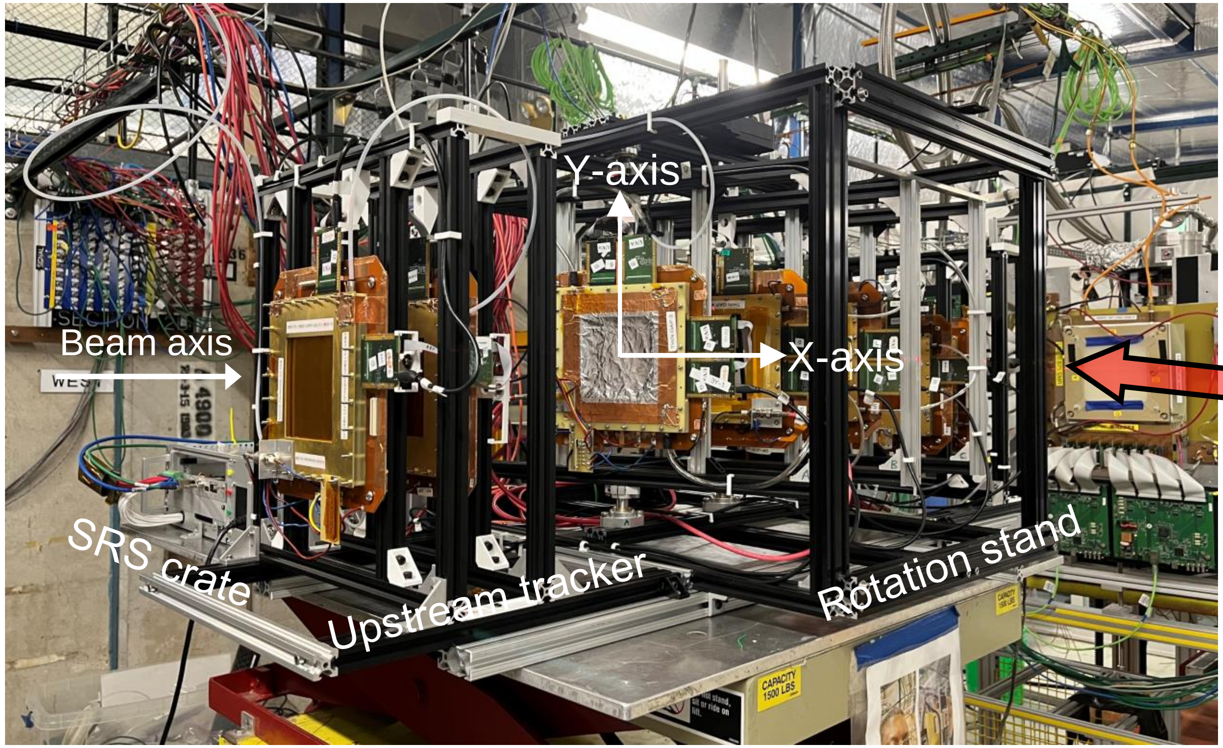
- ❖ Data with Kr-based gas are missing for several prototypes (1 week beam time at FNAL for 10 prototypes was not enough) ➔ Need to complete this test in opportunistic beam test in 2024
- ❖ Unsuccessful attempt for spatial resolution in magnetic field (CERN RD51 beam test August 2023), A few of hours in parasitic test was not ideal ➔ Need to complete this test in opportunistic beam test in 2024

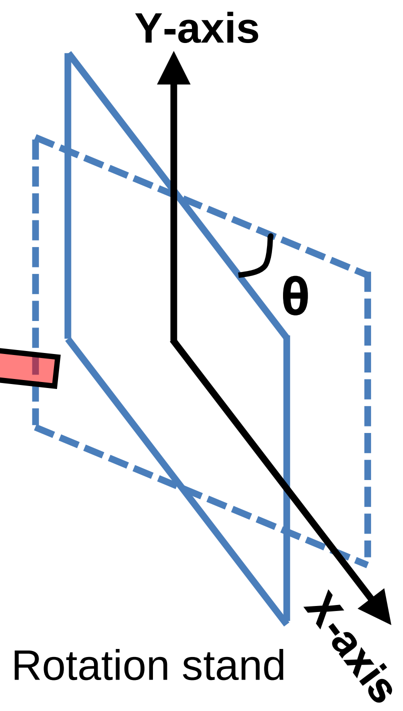
Questions from reviewers

QUESTION 1: Please summarize what has been done in the last year and what remains to be done

Fermilab Test Beam (June 2023): Study of the thin-gap MPGDs







Setup I: HV scan setup

- Efficiency measurement with different gas
- 2 thin-gap prototypes installed 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, to +- 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

Questions from reviewers

QUESTION 2: How does your collaboration share expertise during the year?

RESPONSE:

- ❖ All institutions of the Thin-Gap MPGD consortium are active members of eRD108 and of the ePIC Detector Subsystem Collaboration (DSC)
- ❖ We have bi-weekly meeting during the design phase of the prototypes as well as the ongoing analysis of the test beam data to discuss issues and share experience ➔ This collaborative effort will continue
- ❖ Organize a common beam test campaign (Thin Gap MPGD @ FTBF @ FNAL) ➔ Share test beam setup and equipment i.e., detector stand, DAQ, gas system
- ❖ We plan to submit 2 to 3 manuscripts for peer-review journal (NIM A, TNS…) on the June 2023 beam test results with common authorship of Thin-Gap MPGD consortium
- ❖ The Thin Gap MPGD consortium have been reinforced with Florida Tech joining the FY23 proposal for the development of thin-gap GEM-uRWELL hybrid detector

Questions from reviewers

QUESTION 3: Do you develop complementary infrastructure to share during the development of different MPGD prototypes?

RESPONSE:

- All institutions of the thin-gap MPGD consortium have infrastructures for the development of MPGD technologies
  - Class 1000 clean rooms facilities for the assembly of large MPGDs (Florida Tech, UVa, JLab)
  - MPGD Detector test labs with cosmic bench (all institutions) for basic prototype characterizations
  - UVa and Florida Tech has X-ray test bench for high-rate test of large prototypes (~1 m)
  - JLab is also setting up an X-ray scanner (X-Y) for gain characterization of large MPGD detector
- A plane rotation stand was fabricated at JLab the prototypes of the FY22 program was used / shared at the FNAL 2023 beam test and will be upgraded for the next beam test campaign as part of the continuation of the program,.
- **The infrastructures and equipment of detector labs at the various institutions will be made available during the development of the thin-gap MPGD prototypes of FY23 proposal.**

Questions from reviewers

QUESTION 4: Where do you see a potential µRWELL in the EIC detector, and what would be its advantage?

RESPONSE:

µRWELL trackers in ePIC detector (EIC project detector):

- µRWELL Barrel Outer Tracker (µRWELL-BOT) consisting of 24 planar modules (active area ~170 cm x 34 cm) in the barrel tracker to provide fast hits for pattern recognition that complement slower hits from the Si trackers and to assist hpDIRC with directional information and hit position for the Cerenkov ring seeding.
- µRWELL Discs (2 layers in each Electron & Hadron end caps) provide fast hits that complement slower hits from the Si trackers.
- **The baseline ePIC µRWELLs has 3-mm drift but we (eRD108) believe that thin-gap GEM-µRWELL hybrid is the best approach to address the spatial resolution concerns and satisfy the requirements for ePIC gaseous trackers**

Potential use of Thin-gap GEM-µRWELL hybrid in EIC Detector II or ePIC detector Upgrade:

- Large muon trackers, large and low mass tracking layers in central region
- Precision and high-rate trackers in far forward (FF) region of an EIC detector

Questions from reviewers

<u>QUESTION 5</u>: To follow up on the previous question: does your collaboration have access to simulations which can show how improved position resolution in a thin-gap gaseous detector in the outer part of the detector leads to improved momentum and angle resolution of tracks?

RESPONSE:

Angular resolution studies are ongoing in ePIC which will address what resolution is needed in the outer MPGD layer. Two methods are being applied to estimate the angular resolution, which are giving different results. Investigation within ePIC is ongoing to determine the source of the difference between the two methods. Once the difference is understood the needed MPGD resolution can be determined

.

Questions from reviewers

QUESTION 6: To what extent does your collaboration have the capability to simulate the performance of new designs?

RESPONSE:

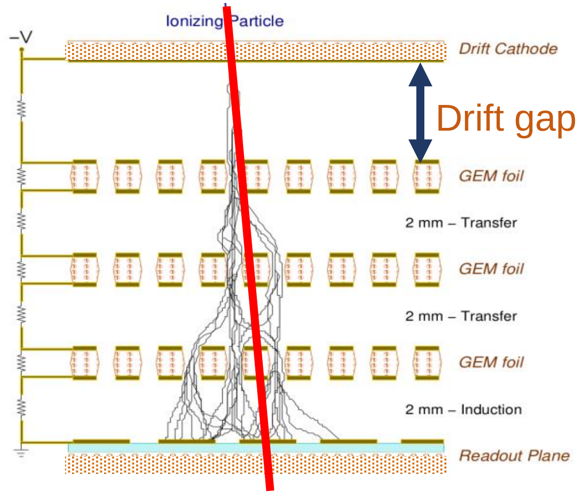
- The simulation of the detector performance using a “standalone simulation” and compare to test beam results. Person power to implement the standalone simulation is needed.
- Implement the spatial resolution obtained from test beam into the ePIC simulation framework to estimate the tracking performance. If part of the ePIC reference detector, the tracking working group can help analyze the impact on tracking performance. However, specific subsystem personal cannot be pointed out at this time.

FY22 Progress report:

Development of Thin-Gap MPGDs for EIC Trackers

FY22 Progress Report – Thin-gap Triple-GEMs @ UVa

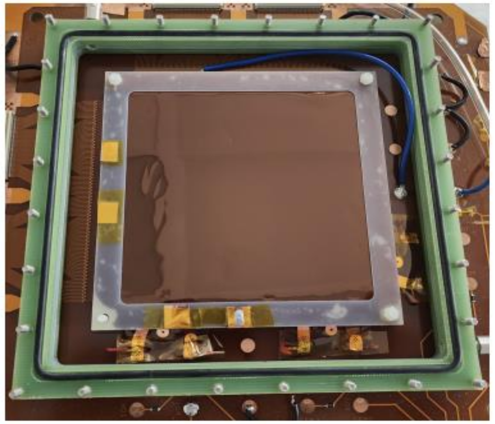
Structure of UVA Triple GEM Prototypes



	Cathode	Drift Gap	Tested at FNAL in June 2023
Proto I	Copper-Kapton foil	1.0 mm	ArCO2, HV & Angle Scan
Proto II	Copper-Kapton foil	1.5 mm	ArCO2 & KrCO2, HV & Angle Scan
Proto III	Copper-Kapton foil	3.0 mm	ArCO2, Angle Scan
Proto IV	400 µm-pitch fine Copper wire	1.5 mm	ArCO2, HV & Angle Scan
Proto V	800 µm-pitch fine Copper wire	1.5 mm	ArCO2, HV & Angle Scan

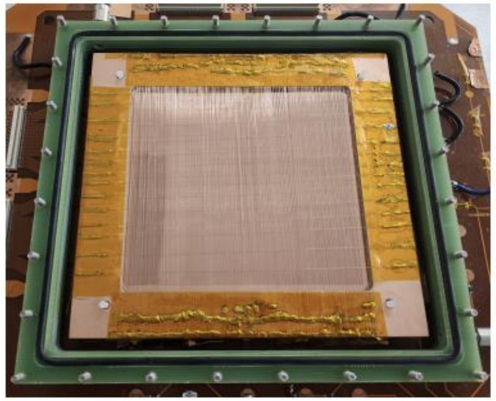
- ❖ **UVA Tripple GEM Prototypes**:
  - Amplification: 3 GEM foils
  - RO plane: 400 µm-pitch X-Y strips
  - Three prototypes having different drift gaps (1.0 mm, 1.5 mm, 3.0 mm), the same cathode
  - Three prototypes having different Cathode structures, the same drift gap (1.5 mm)

(a) Copper-Kapton Cathode



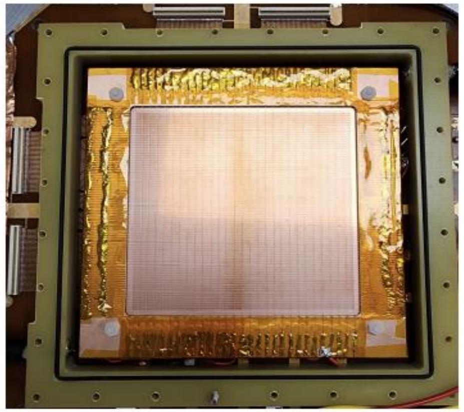
(a)

(b) 400 µm wire-pitch cathode



(b)

(c) 800 µm wire-pitch cathode



(c)

FY22 Progress Report – Thin-gap Triple-GEMs @ UVa

Efficiency vs. Gas mixture studies

- Investigated efficiency of **Proto II** (1.5 mm drift gap) with two different gas mixtures KrCO2 and ArCO2. **Proto II** reaches 94% efficiency in ArCO2 at HV GEM significantly lower than in KrCO2 **(355V vs. 390V)**

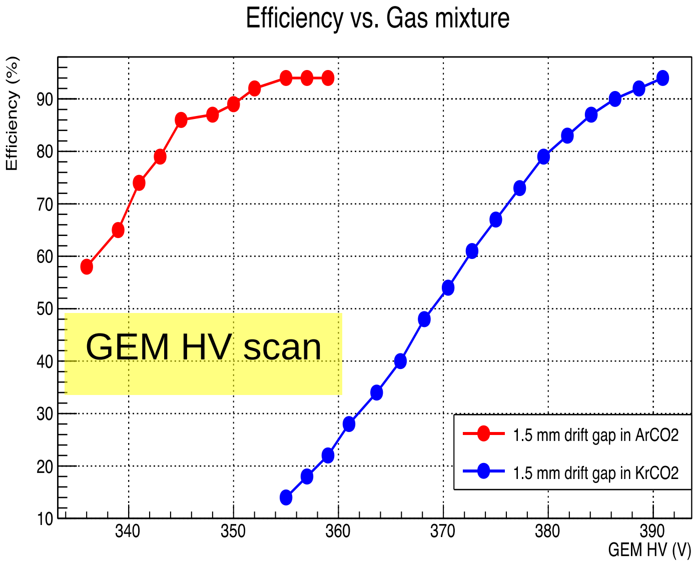
Efficiency vs. Drift Gap studies

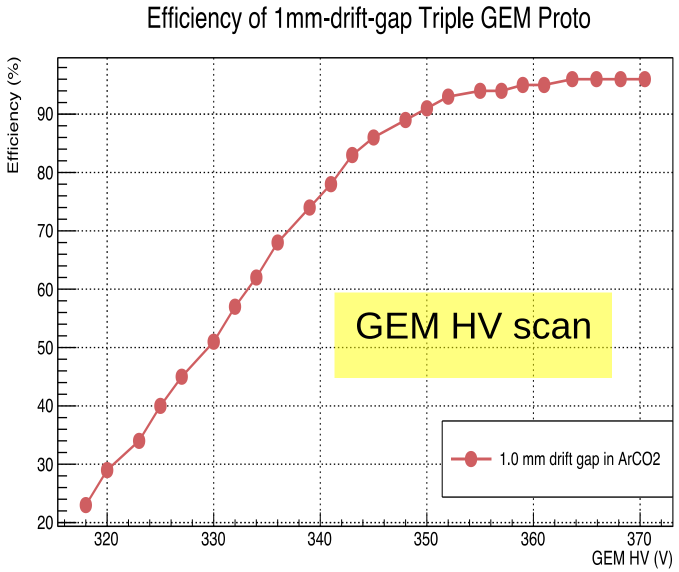
- Efficiency of **Proto I** (1.0 mm drift gap) in ArCO2 (80%/20%).
- **Proto I** achieves a high **efficiency of 96%** similar to a standard 3 mm drift gap triple GEMs

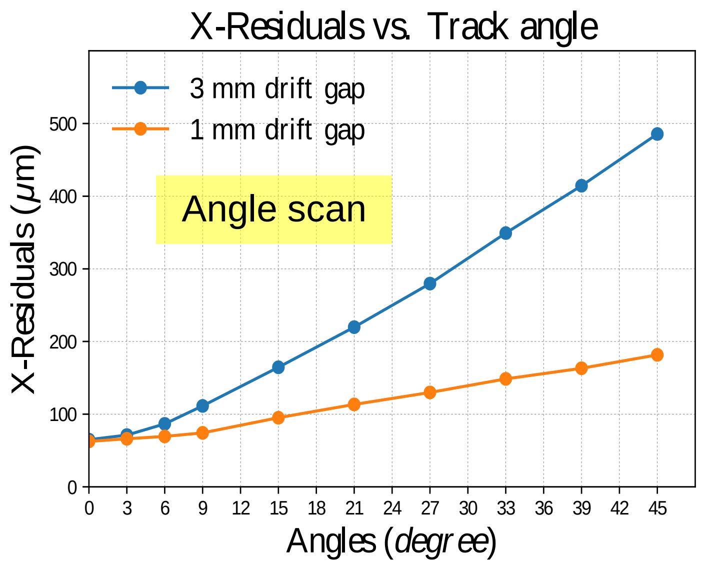
Spatial resolution vs. track angle studies

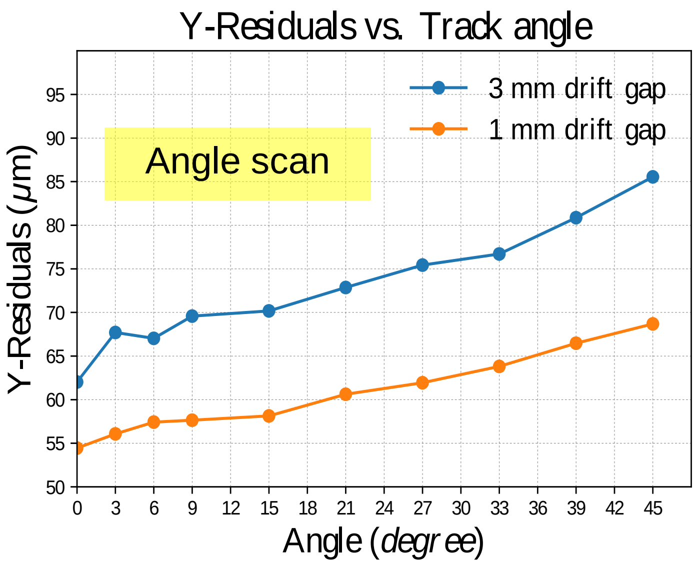
- Investigated spatial resolution of **Proto I** (1 mm drift) and **Proto III** (3mm drift) in ArCO2 with track angle from 0º to 45º
- At large track angle, spatial resolution of **Proto I** significantly better than **Proto III**

Drift Gap	Resolution in Y-plane @ 45º	Resolution in X-plane @ 45º
1 mm	69 µm	182 µm
3 mm	86 µm	486 um







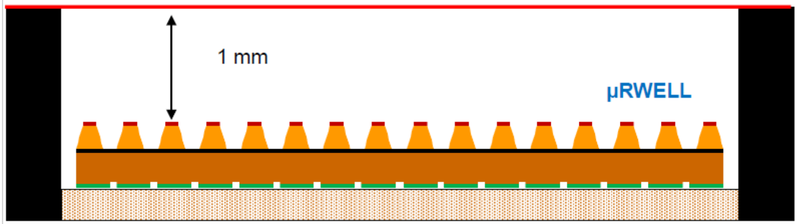


FY22 Progress Report – Thin-gap GEM-µRWELL hybrids @ JLab

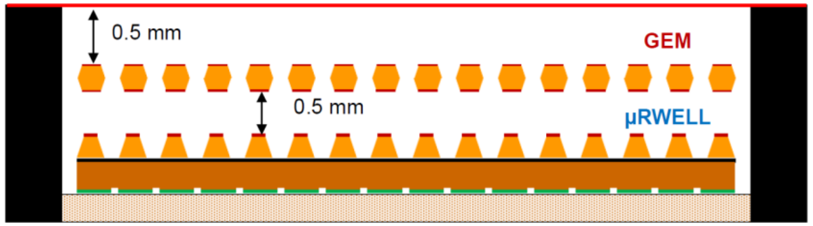
- 1 thin gap uRWELL:1-mm gap (**not tested**)
- 2 hybrids GEM-µRWELL: 1-mm and 0.5-mm
- 1 standard 3-mm gap µRWELL for reference
- R/O: Capacitive-sharing X-Y strip (0.8 mm)
- Tested at FNAL, June 2023 - HV & angle scan
  - Only Ar/CO_2 with JLab prototypes
  - No opportunity for data with $KrCO_2$

	amplification	technology	Drift gap	Transfer gap	Beam test @ FNAL 06/2023
Proto I	Single	µRWELL	1 mm	N/A	No data taken
Proto II	hybrid	GEM+µRWELL	1 mm	1 mm	ArCO2 & HV angle scans
Proto III	hybrid	GEM+µRWELL	0.5 mm	1 mm	ArCO2 & HV angle scans
Ref	Single	µRWELL	3 mm	N/A	ArCO2 & HV angle scans

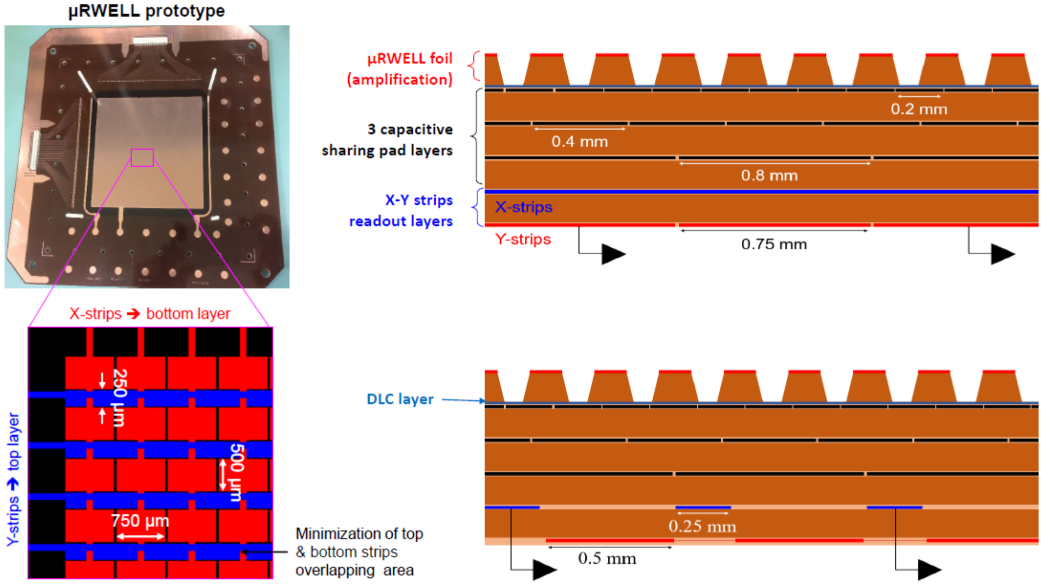
Single amplification µRWELL with 1 mm drift gap



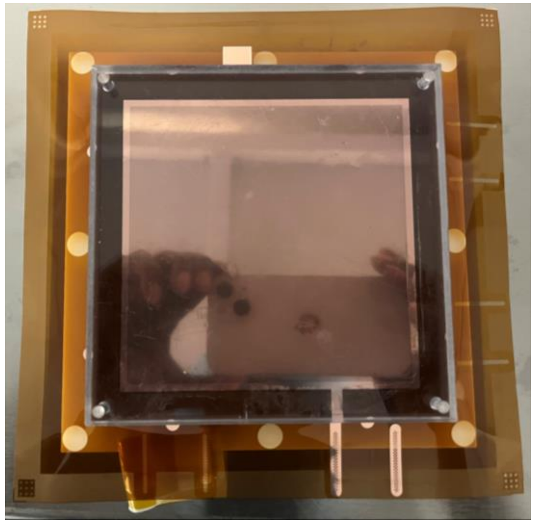
hybrid amplification GEM-µRWELL with 0.5 mm drift gap



Two configurations for amplification



µRWELL with capacitive-sharing strip readout



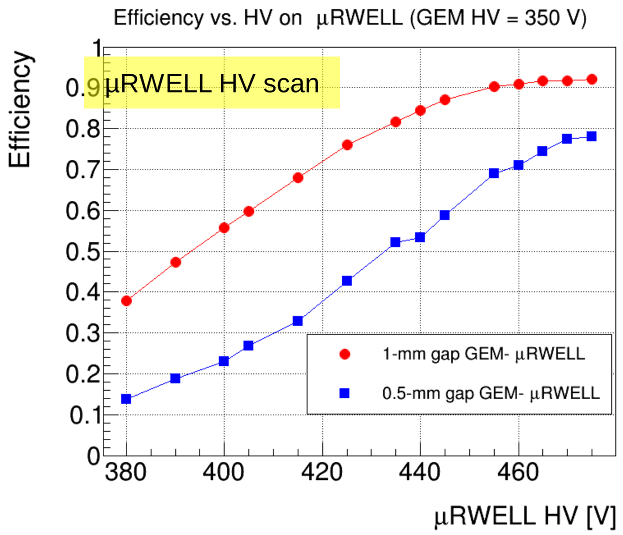
GEM pre-amplification

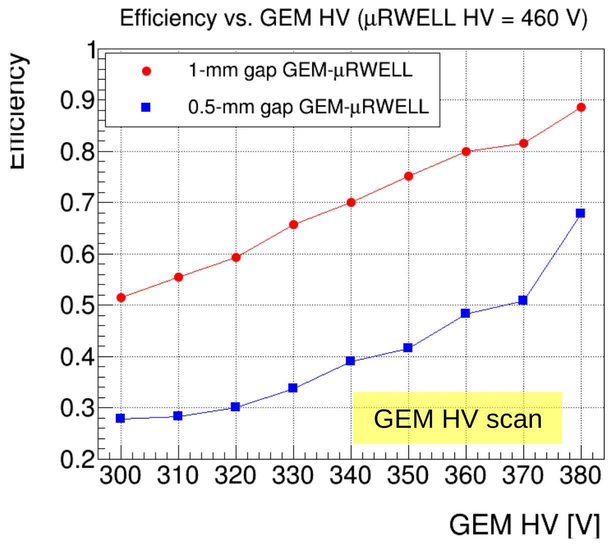
Jefferson Lab

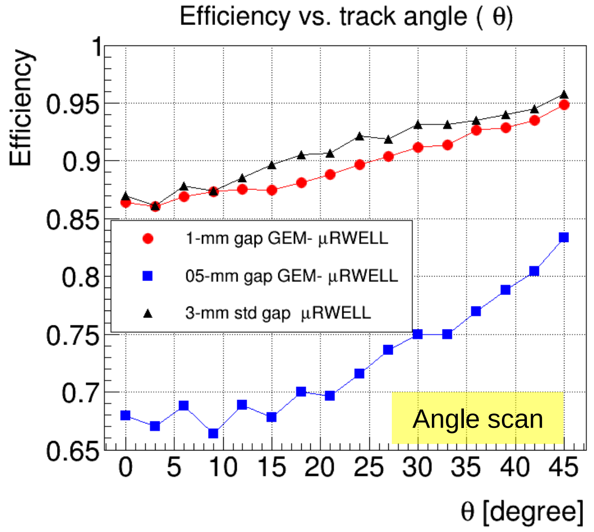
FY22 Progress Report – Performance of GEM-μRWELL hybrids

Efficiency studies

- JLab protos with Ar/CO2 – 80/20 only
- Linear increase of spatial resolution with track angle
- Thin-gap protos: better performance at large angle than 3 mm protos
- Efficiency **(angle-dependent)** ~ 95% 1-mm GEM-μRWELL at 45 degree
- GEM-μRWELL hybrid is optimal for performance and operation stability

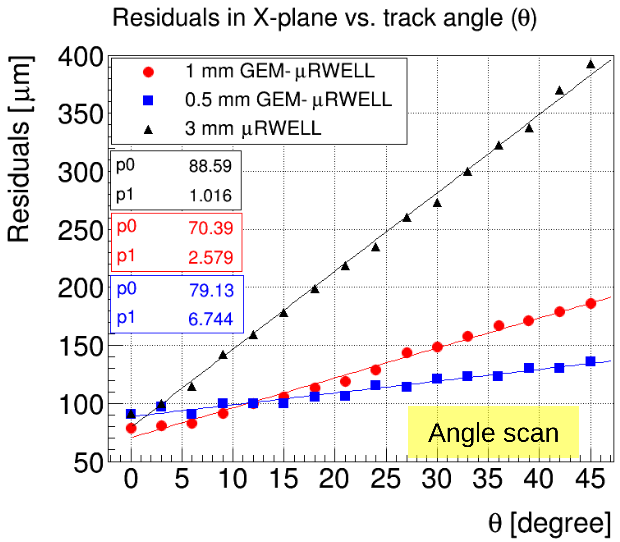


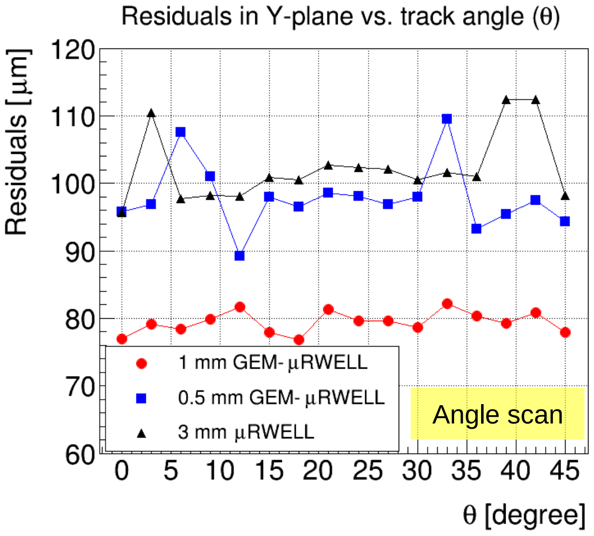




Spatial resolution vs. track angle studies

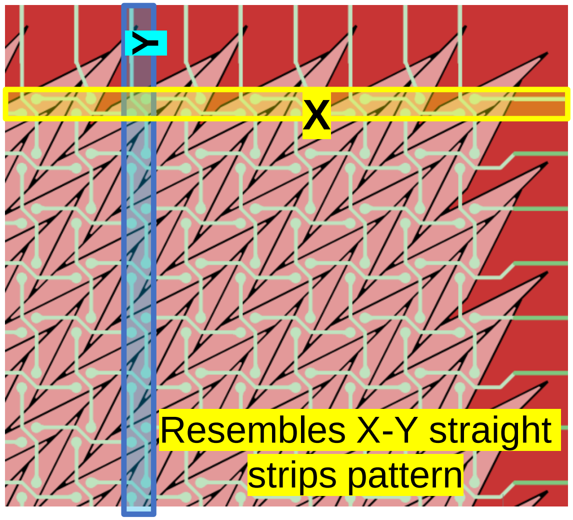
	resolution @ 0 degree	resolution @ 45 degree	Efficiency @ 30 degree
1-mm hybrid thin gap GEM-μRWELL	79 μm	**185 μm**	>90%
0.5-mm thin gap hybrid GEM-μRWELL	90 μm	**137 um**	~75%
3mm std μRWELL	90 μm	**390 um**	>90%

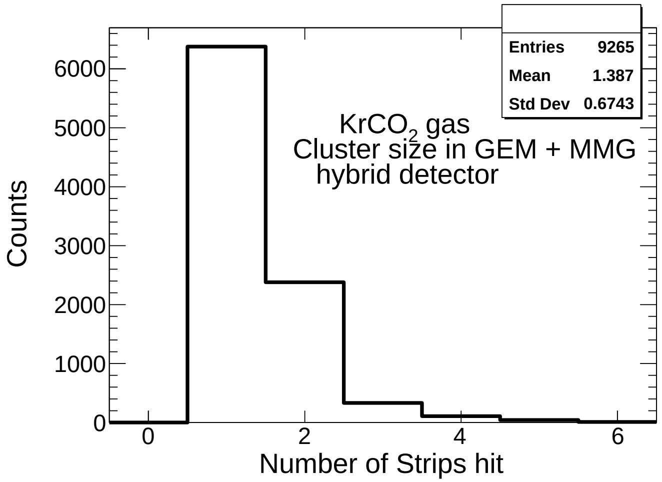


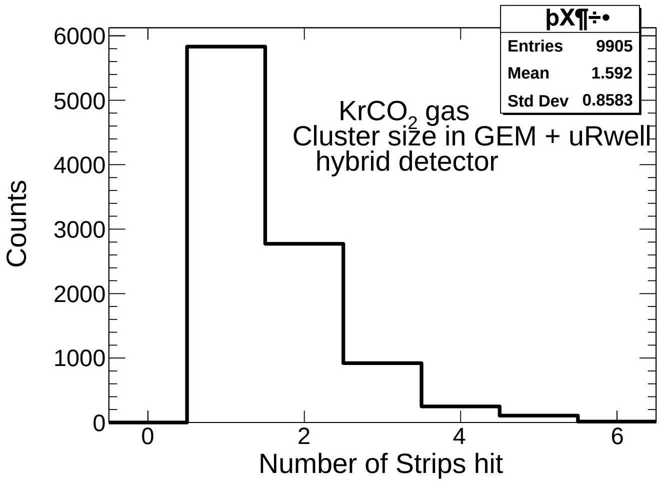


FY22 Progress Report - Thin-gap MPGDs @ Vanderbilt

Prototypes	Specifications	Data taken (Fermilab test beam)
GEM +MMG	• Active area = 10 cm x10 cm • Drift gap = 1 mm • Transfer gap = 1 mmm • 2D chevron R/O with 1.6 mm pitch	• ArCO2 gas (HV scan + track angle scan) • KrCO2 gas (HV scan + track angle scan)
GEM + µRWELL	• Active area = 10 cm x10 cm • Drift gap = 1 mm • Transfer gap = 0.5 mm • 2D chevron R/O with 1.6 mm pitch	• ArCO2 gas (HV scan + track angle scan) • KrCO2 gas (HV scan + track angle scan)
µRWELL	• Active area = 10 cm x10 cm • Drift gap = 1 mm • 2D chevron R/O with 1.6 mm pitch	No data taken



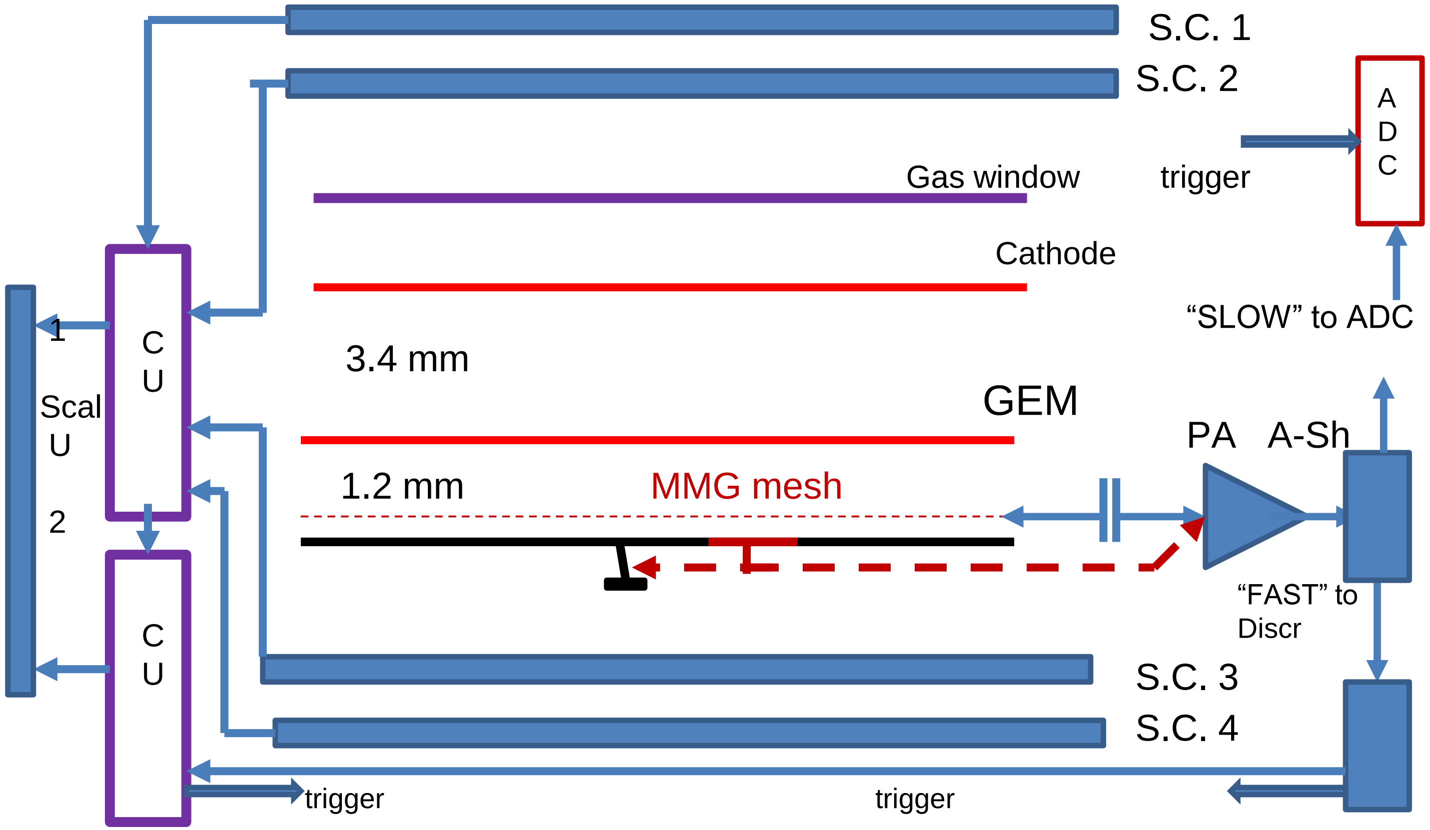




- Mostly single strips are getting fired most of the time
- Challenging to decipher hot channel with real hit
- Ongoing analysis

FY22 Progress Report – Thin-gap MicroMegas @ Yale

- Measure tracking efficiency using Cosmic. and participates in the at FNAL test-beam in June 2023.
- Combine two (10 x10 cm2) MMG chambers (one on a top on another, second one with 1. mm gap), and using OR signal, tracking efficiency was measure as 95%.(Ar+CO2(20%)) and 97.5% (Ar+isoButane(10%)).
- Setup with an additional GEM foil was prepared but both CO2 and isoButane cylinders were found « empty » . New bottles have been ordered, but delivery time is unknown.



Procedure:

- GEM Top & Bottom –same voltage. Cathode: -10 V.
- With Fe55 source and connect small number of MMG pads to PA select Mesh Voltage to set MM gain ~2.e4
- Reconnect PA to Mesh, check Discriminator Threshold for "FAST" signal.
- Measurement SC1 & Sc2 ratio with statistics ~ 1000.
- Reduce MMG Voltage, tune GEM and Cathode voltages to return to the same gain.
- Measurement SC1 & SC2 ratio with statistics ~ 1000.

$$\frac{\text{Counts ratio Scal2 / Scal1 (1.2 mm)}}{\text{Counts ration Scal2 / Scal1 (3.4 mm)}} = 0.87$$

FY22 Progress Report - Summary

QUESTION1: Please summarize what has been done in the last year and what remains to be done

What was achieved:

- Design and fabrication of 10 small (10 cm × 10 cm) thin-gap MPGD prototypes to demonstrate the viability of thin gap concept to recover spatial resolution over a wide range of incoming track angles
- The prototypes are based on 3 MPGD amplification structures (GEM, Micromegas and µRWELL) and / or a combination of them **(hybrids)** were fabricated and tested.
- The prototypes were all successfully tested in beam at Fermilab in June 2023 to study efficiency with HV scans and spatial resolution performance with angle scan with $ArCO_2$ and $KrCO_2$ based gas mixture

What remains to be done:

- Data with Kr-based gas are missing for several prototypes (1 week beam time at FNAL for 10 prototypes was not enough) ➔ Need to complete this test in opportunistic beam test in 2024
- Unsuccessful attempt for spatial resolution in magnetic field (CERN RD51 beam test August 2023), A few of hours in parasitic test was not ideal ➔ Need to complete this test in opportunistic beam test in 2024

FY23 Proposal - EICGENR&D2023_16

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

Jefferson Lab
Florida Tech
University of Virginia
Yale University
Vanderbilt University
Temple University

FY23 Proposal: R&D Motivation and Goals

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

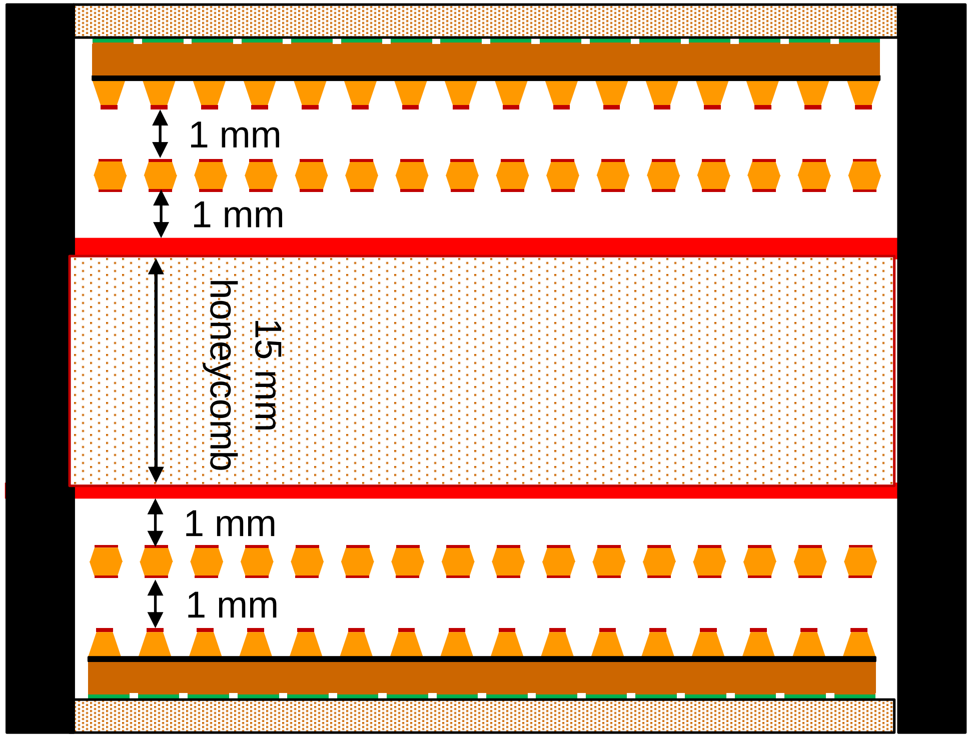
The EIC physics program requires precision tracking over a large kinematic acceptance, as highlighted in the EIC Yellow Report [1]. MPGDs are able to provide space point measurements for track pattern recognition and momentum measurement. These MPGD detectors will span a large pseudorapidity range and 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.

- **Double-sided thin-gap GEM-µRWELL hybrid**
  - Continuation of FY22 Thin Gap MPGD development
  - Double amplification with hybrid GEM-µRWELL is a promising approach for thin-gap MPGD
  - Double-sided allows full detector efficiency
  - Minimize Lorentz angle effect on resolution in B field
- **Operation with Argon based gas mixture**
  - Affordability and availability than Xe / Kr
  - Reduction of background rate in the detector
  - Better timing resolution (~ 2 ns) for 0.5 mm gap
- **Large-area, low-mass and compact detector modules**
  - Outer tracker layer / disc of EIC central tracker
  - Large acceptance muon chambers
  - High performance trackers in high-η and FF regions

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

FY23 Proposal: UVa & Vanderbilt

R&D1 - Medium-size Double-sided Thin-gap GEM-µRWELL Hybrid Trackers



- Development of low mass, low channel count, double-sided thin-gap 30 cm x 30 cm active area GEM- µRWELL hybrid trackers with capacitive-sharing readout board. Two sides of detector have:
- The same structure of Cu-Kapton drift foil and a GEM foil
- Different strip structure of RO board: X-Y strip & U-V strip
- **Applications:** Muon trackers, outer layers of an EIC central tracker

- Vanderbilt in collaboration with JLab will design capacitive sharing readout PCBs
- Procurement of both µRWELL layers will be done by Vanderbilt.

- UVa will develop stretcher system and honey-com support to maintain mechanical stability and to achieve uniform thin gaps between adjacent layers of detectors
- Design and procurement of drift foils and GEM foils will be done by UVa
- Assembly of prototype and study of gain structure and high voltage stability of the detector under X-ray radiation will be at UVA with collaboration of other participating institutes

FLORIDA TECH

FY23 Proposal: Florida Tech

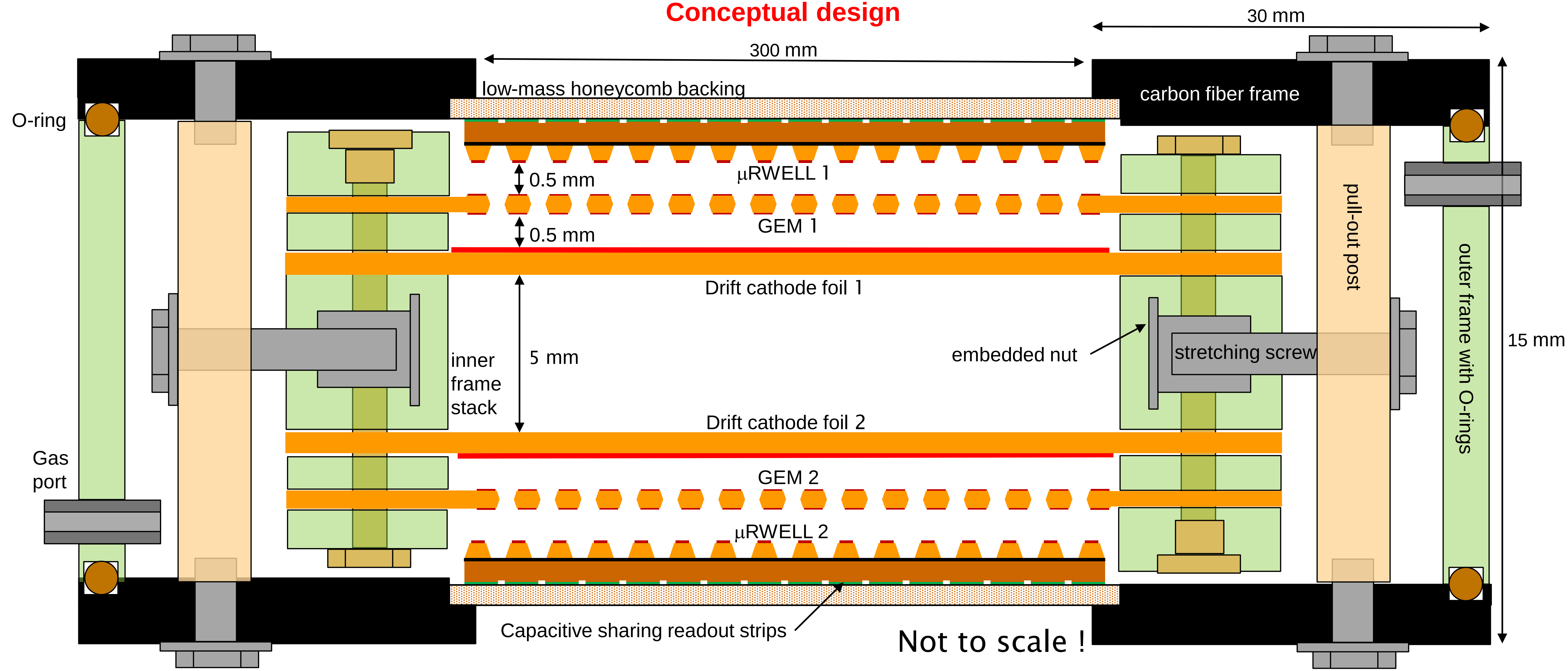
R&D2 - Mechanically Stretched Double Thin-Gap GEM-µRWELL Hybrid

- Double-sided and **low-mass** thin-gap GEM-µRWELL hybrid detector of medium size (30 cm $\times$ 30 cm active area)
- Frame structure allows purely mechanical stretching of GEM foils and drift foils and assembly with minimal application of glue
  - ⇒ Foil tension can be adjusted during assembly to ensure uniformity of small drift gap (0.5-1mm)
  - ⇒ Detector can be re-opened to access or swap out components
- Use carbon fiber (CF) to provide a stiff outer frame
- Build on experience with mechanically stretched Triple-GEMs from past eRD6 program & CMS mass production
- **Approach:**
  - ⇒ Produce technical design and construct a mock-up of the mechanics
  - ⇒ Use Cu-clad Kapton foils as stand-ins for μRWELL and GEM foils
  - ⇒ Investigate and mitigate possible charging up of conductive CF frame with foils under HV

FY23 Proposal: Florida Tech

R&D2 - Mechanically Stretched Double Thin-Gap GEM-µRWELL Hybrid

Conceptual design



FY23 Proposal: JLab

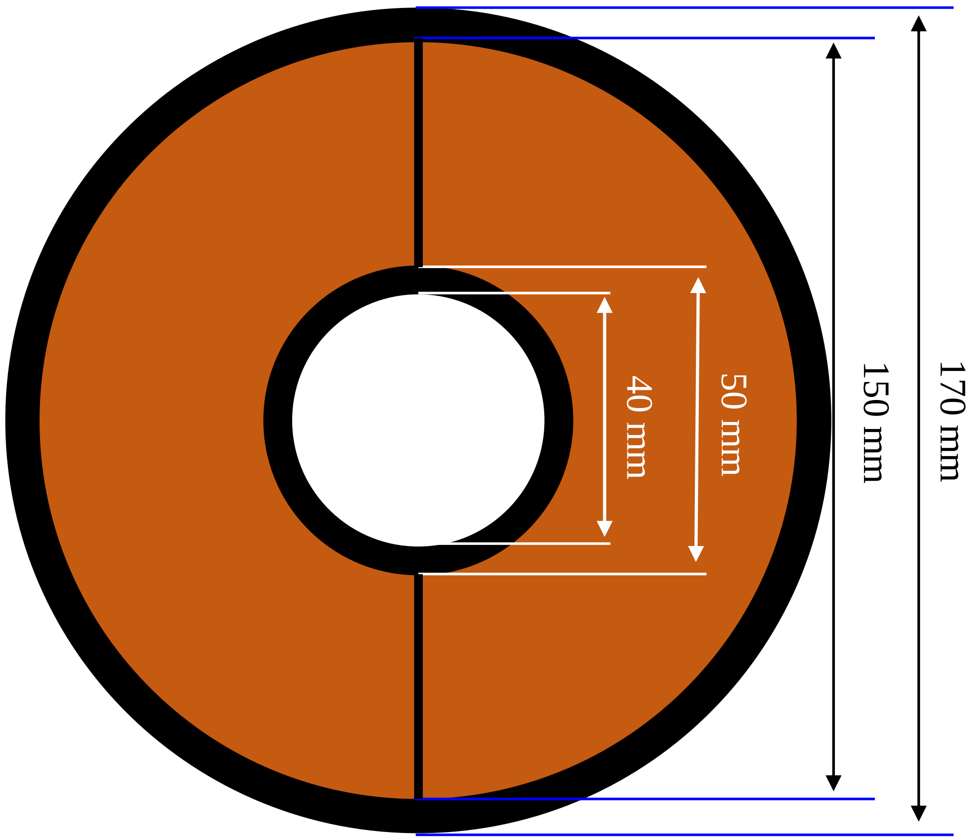
R&D3 - Double-Sided Thin-Gap GEM-µRWELL Hybrid for Tracking in High-η

- Small-size double-sided thin-gap GEM-µRWELL hybrid with capacitive-sharing pad readout structures
- The focus of the thin gap R&D is to improve spatial and timing resolution for normal tracks but rather by minimizing both the transverse diffusion and drift time
- Improve spatial resolution (< 50 µm) and high-rate for tracking in high-η region of an EIC detector
  - ⇒ Capacitive-sharing pad readout ➔ reduced readout channel
  - ⇒ 0.5 mm drift gap / 0.5 mm induction detector ➔ improve position & time resolution, reduce background
- Investigate different support materials for support frame: carbon fiber (CF), PEEK and G10 fiberglass
- Build on experience with prototypes from FY22 EIC Generic R&D program
- **Approach:**
  - ⇒ Build two half-disc prototypes (~15 cm outer diameter) with ~4mm hexagonal and / or squared pads)
  - ⇒ Prototypes will be design to be re-opened to access or swap out components

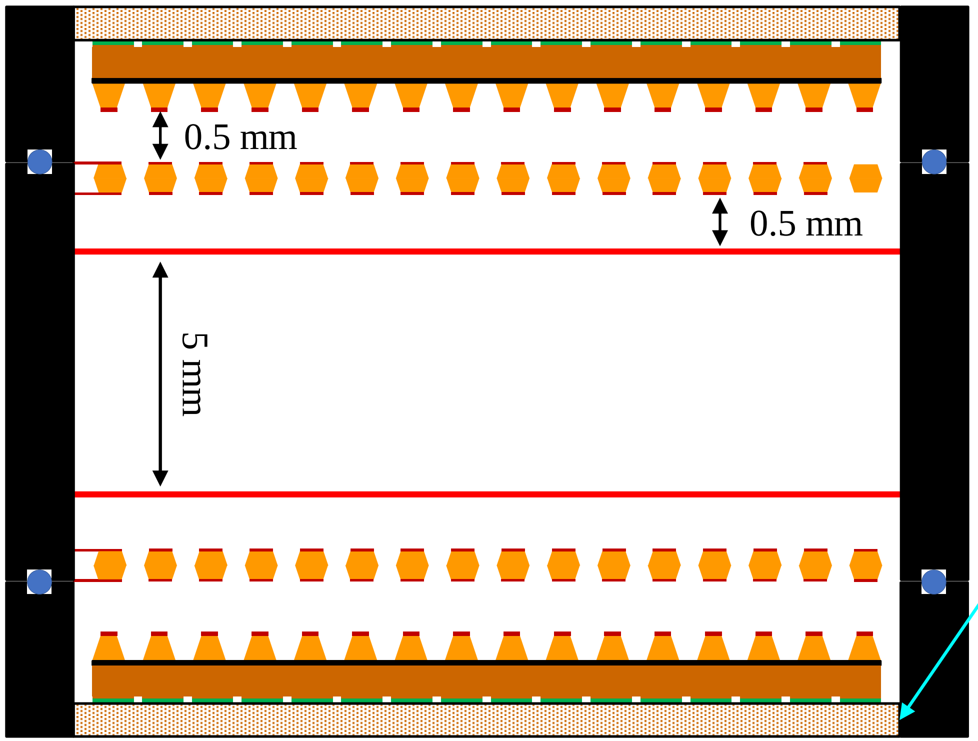
FY23 Proposal: JLab

R&D3 - Double-Sided Thin-Gap GEM-µRWELL Hybrid for Tracking in High-η

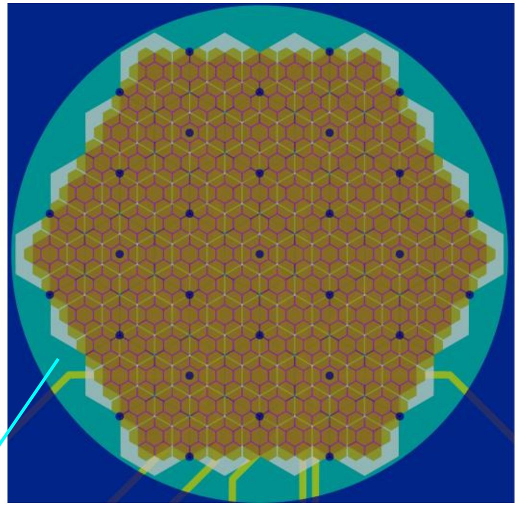
Conceptual design



Top view of high-performance double thin-gap GEM-uRWELL



Cross section view of high-performance double thin-gap GEM-uRWELL



Capacitive-sharing hexagonal pad readout

FY23 Proposal: Timeline

R&D1 - Medium-size Double-sided Thin-gap GEM-μRWELL Hybrid Trackers

- **10/2023 - 05/2024:** Design of the prototype components: GEM, μRWELL PCB, cathode foils, support frames & parts for assembly stretcher
- **02/2023 - 05/2024:** Procurement of μRWELL, GEM foils, cathode foils, and frames for prototype as well as parts of assembly system.
- **06/2024 - 08/2024:** Assembly prototype, characterizing and optimizing the gain structure of the prototype with X-ray beams at the UVA Detector lab.
- **09/2024 - 10/2024:** Data analysis on performance of prototype and preparation of progress report.

R&D2 - Mechanically Stretched Double Thin-Gap GEM-μRWELL Hybrid

- **10/2023 - 1/2024:** Technical design of double-sided thin-gap GEM-μRWELL hybrid detector with mechanical stretching and procurement of components for mock-up.
- **2/2024 - 4/2024:** Assembly and test of the mock-up in FIT gaseous detector lab.
- **5/2024 - 9/2024:** Design and procurement of 30cm × 30cm GEM and drift foils.

R&D3 - Double-Sided Thin-Gap GEM-μRWELL Hybrid for Tracking in High-η

- **10/01/2023 - 07/30/2024:** Design and procurement of μRWELL and GEM and cathode foils and assembly of the prototype
- **07/01/2024 - 08/30/2024:** characterization of the prototype in the MPGD Lab at JLab.
- **09/01/2024 - 12/30/2024:** Presentation of the results at conferences and in peer-reviewed journal.
- **01/01/2025 -:** Preparation for full characterization of the prototype in beam at FNAL in 2025.

FY23 Proposal: Budget Request

Table 5: **FY23 Budget request Money matrix (includes overheads and IDCs).**

	GEM & Drift foils	µRWELL PCBs	Mechanical & Mock-up	Gas and Supplies	Labor	Travel	Overhead /IDC	Total Request
JLAB	$5,000	$20,000	$4,000	$1,500	$28,000	$1,500	$15,000	$75,000
FIT	$6,000	$0	$10,000	$2,000	$17,000	$0	$15,704	$50,705
UVA	$12,000	$0	$10,000	$10,000	$19,271	$3,000	$14,382	$68,643
VU	$0	$40,000	$0	$1,000	$0	$2,000	$1,145	$44,145
Total	$23,000	$60,000	$24,000	$14,500	$64,271	$6,500	$46,231	**$238,502**

Three budget scenarios per institutions

	Request	-20%	-40%
JLAB	$75,000	$59,000	$47,000
FIT	$50,705	$40,564	$30,423
UVA	$68,643	$54,925	$41,192
Vanderbilt	$44,145	$42,560	$42,560
Total	**$238,502**	**$197,049**	**$161,175**

Detailed budget breakdown:

https://docs.google.com/spreadsheets/d/1W36ZnVjbVYADVRYbL8Wm7LLN0h3I4bAg/edit#gid=125710836

FY23 Proposal: Summary

- **Development of double-sided thin-gap GEM-µRWELL hybrid technology**
  - Very promising approach for thin-gap MPGD technology
  - Optimization for operation with Ar-based gas mixture and allow full detector efficiency even with 0.5 mm drift gap
  - double-sided thin-gap is ideal for minimizing Lorentz angle effect, improving background rejection and timing resolution
- **Development of dedicated prototypes for diverse applications in future EIC detectors:**
  - Tracking layers in central region
  - Large area muon chambers,
  - High performance trackers in high-η & FF regions

Back up