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

Proposal to the FY23 EIC generic detector R&D program

K. Gnanvo*[1], S. Lee[1], M. Hohlmann[2], P. Iapozzuto[2], X. Bai[3], N. Liyanage[3], H. Nguyen[3], M. Posik[4], V. Greene[5], S. Tarafdar[5], J. Velkovska[5], and N. Smirnov[6]

[1]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[2]Florida Institute of Technology, APSS Dept., Melbourne, FL 32901, USA
[3]University of Virginia, Department of Physics, Charlottesville VA 22903, USA
[4]Temple University, Philadelphia, PA 23606, USA
[5]Vanderbilt University, Department of Physics and Astronomy, Nashville, TN 37240, USA
[6]Yale University, Physics Department, New Haven, CT 06520, USA

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.

The Thin Gap MPGD (tg-MPGD) Consortium

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

Project Period: from 10/1/2023 to 09/30/2024

PI & Contact Person: Kondo Gnanvo; kagnanvo@jlab.org

Project Members:

FIT: Marcus Hohlmann, Pietro Iapozzuto
JLab: Kondo Gnanvo, Seung Joon Lee
Temple: Jae Nam, Matt Posik, Bernd Surrow
UVa: Huong Nguyen, Nilanga Liyanage
VU: Sourav Tarafdar, J.Velkovska, V.Greene
Yale U.: Nikolai Smirnov

*kagnanvo@jlab.org

Contents

1 Introduction **3**

1.1 Physics motivation . . . 3

2 Summary of FY22 R&D effort - RD2223 **4**

2.1 Thin-Gap µRWELL prototypes assembled at JLab . . . 4

2.2 Thin-Gap µRWELL and Micromegas prototypes assembled at VU. . . . 5

2.3 Thin-Gap triple-GEM prototypes assembled at UVa . . . 6

3 Proposal:
Medium-size double thin-gap GEM-µRWELL hybrid trackers **7**

3.1 Introduction of R&D plans at UVa . . . 7

3.2 R&D timeline and funding request . . . 8

3.3 Introduction of the R&D plans at VU . . . 8

3.4 R&D timeline and funding request . . . 8

3.5 Introduction of the R&D plans at FIT . . . 9

3.6 R&D timeline and funding request . . . 10

4 Proposal:
Small-size thin-gap GEM-µRWELL for tracking in high-η region **10**

4.1 Introduction of the R&D plans at JLab . . . 10

4.2 Design and fabrication of the prototype . . . 11

4.3 Performance studies of the prototype . . . 11

4.4 R&D timeline and funding request . . . 12

5 FY23 Funding request **13**

5.1 Money matrix and split among participating institutions . . . 13

5.2 Three budget funding scenarios . . . 13

6 Personnel **13**

7 Diversity, Equity and Inclusion **14**

1 Introduction

We propose to explore the development of Thin-Gap Micro-Pattern Gaseous Detectors (tg-MPGDs) as part of the generic detector R&D for EIC detector 2 and for future upgrades of the ePIC detector. These tg-MPGDs are gaseous detector with MPGD amplification structures such as GEM, Micromegas and µRWELL but where the thickness of the gas volume for primary ionization is significantly reduced ($<$ 1mm gap) to minimize the impact of incident track angle and Lorentz angle on the position resolution performance of the detector. It is well known that the position measured in an MPGD detector for a track impinging at a large angle from the normal is no longer determined by the detector structure (MPGD amplification, readout strip or pad segmentation, etc.) but rather by the gap for the primary ionization gas volume that the particle traverses before reaching the amplification stage.

1.1 Physics motivation

Excellent particle identification (PID) and momentum resolution are important requirements for a successful EIC physics program as discussed in the Yellow Report [1]. On one hand, measurement of open charm is important for probing the distribution of gluons in protons and nuclei while, on the other hand, tagging the flavor of quarks in semi-inclusive DIS can provide information about transverse momentum distributions of the strange sea quarks.

Quarkonia measurements, e.g. exclusive J/ψ measurements, will be key to understanding the gluon distribution in nuclei as they are only coupled to gluons and not light mesons. Measurement of exclusive J/ψ decays in the barrel region requires tracking detectors that can provide excellent momentum resolution above 2 GeV. MPGD-based trackers in the barrel region are potential candidates for providing the required momentum resolution for measurement of both exclusive J/ψ decays and other heavy quarkonia.

Heavy flavor and heavy-flavor tagged jets are other crucial physics observables for EIC physics. While nuclear parton distribution functions (nPDFs) influence initial state modification of jets and open heavy flavor production, the interaction of jets and open heavy flavor with cold nuclear matter gets manifested as final-state effects. Measurements of the modification of jet and open heavy flavor yields provide the opportunity to disentangle initial-state and final-state effects due to nuclear matter. For both open heavy flavor and heavy-flavor tagged jets, vertex and momentum reconstruction needs to be done with utmost precision.

While Si detectors are good candidates for providing vertexing information on heavy flavor, the overall momentum reconstruction requires excellent momentum resolution along with track efficiency and high track purity. MPGD tracking layers are excellent candidates for providing the required momentum resolution along with pattern recognition and track purity in the barrel region. Thus the focus of the proposed R&D will be to develop MPGD-based trackers to provide the required momentum resolution and pattern recognition.

2 Summary of FY22 R&D effort - RD2223

A total of ten small size (10 cm × 10 cm) Thin-Gap MPGD prototypes were constructed and tested as part of the EIC FY22 Generic Detector R&D program RD2223 [2]. The prototypes were based on all three MPGD main amplification technologies (GEM, Micromegas and μRWELL), including the combination of different technologies into hybrid configuration to provide two-stage electron amplification. Several 2D strip readout patterns were also explored. After a preliminary test of each prototype in various detector labs at the participating institutions (JLab, UVa and VU), the prototypes were brought to Fermilab and installed on two dedicated setups at the Fermilab Test Beam facility (FTBF) in June 2023 for more advanced characterization studies of the position resolution and efficiency performance as a function of the track angle of incoming 120 GeV protons and with both Ar/CO_2 and Kr/CO_2 gas mixtures. Pictures of the two MPGD setups at the

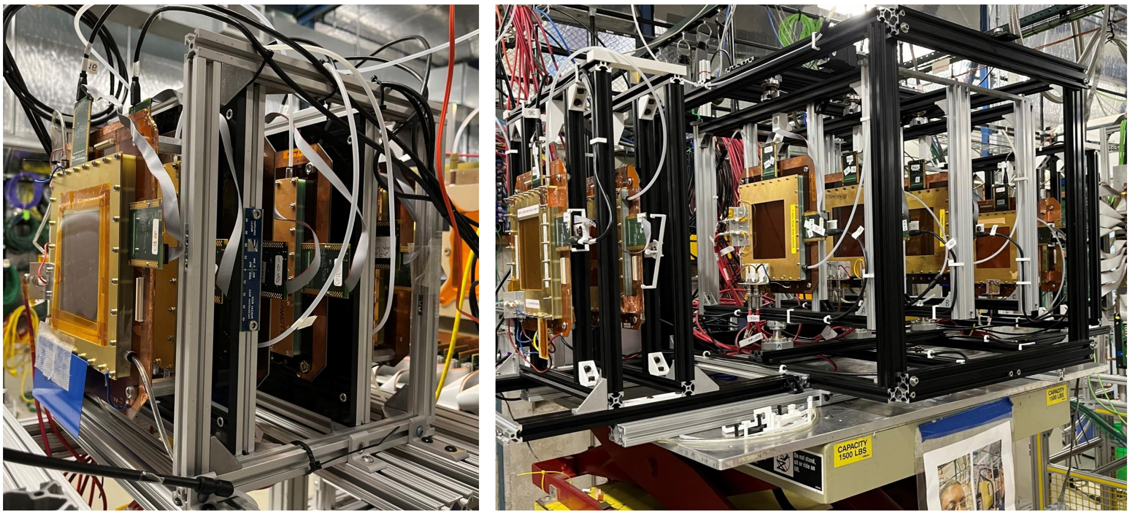


Figure 1: Picture of thin gap prototype setups in MT6.2b at the FTBF *Left:* Upstream setup for efficiency study with HV scan; *right:* Downstream setup for position resolution study with track angle scan.

MT6.2b beam test area of the FTBF are shown in Fig. 1. The setups allowed for simultaneous studies of the efficiency of two prototypes as a function of the applied voltages (left picture) and the position resolution of three other prototypes as a function of the track angle (right picture). The position resolution setup included a plane rotation stand that allows to rotate all three prototypes under test around a vertical axis up to 45° in both directions. Each of the two setups included a set of two trackers (standard 10 cm × 10 cm triple-GEMs and μRWELL with 3 mm drift gap) in front and behind the prototypes under test. Two APV25-based SRS DAQ systems were used to read out all thirteen MPGD detectors (eight trackers and five Thin-Gap prototypes during the beam test. All thirteen detectors were successfully operated at any given time in the two setups during the week-long beam test.

2.1 Thin-Gap μRWELL prototypes assembled at JLab

Three 10 cm × 10 cm thin-gap prototypes based on μRWELL technology were assembled in the Radiation Detector and Imaging Group (RD&I group) at Jefferson Lab. The first prototype is a single amplification μRWELL detector with 1-mm gap between the cathode and the μRWELL foil (left in Figure 2). The other two are hybrid thin-gap MPGD prototypes with a GEM foil used as pre-amplification stage above the μRWELL amplification. The gaps in the drift region, between the cathode and the top of the GEM foil and in the induction region, between the bottom of the GEM foil and the μRWELL foil are 1 mm for one of the hybrid prototype and 0.5 mm for the second (right).

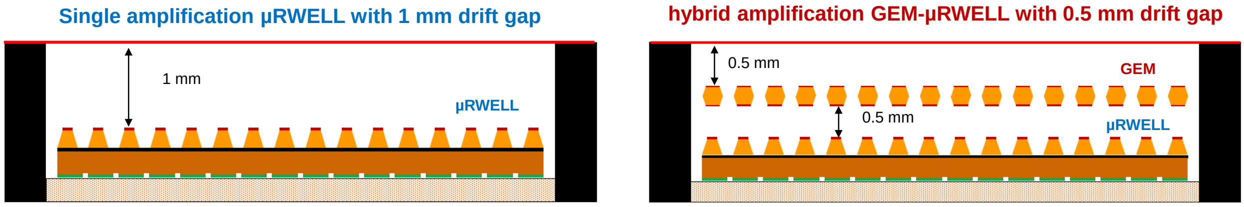
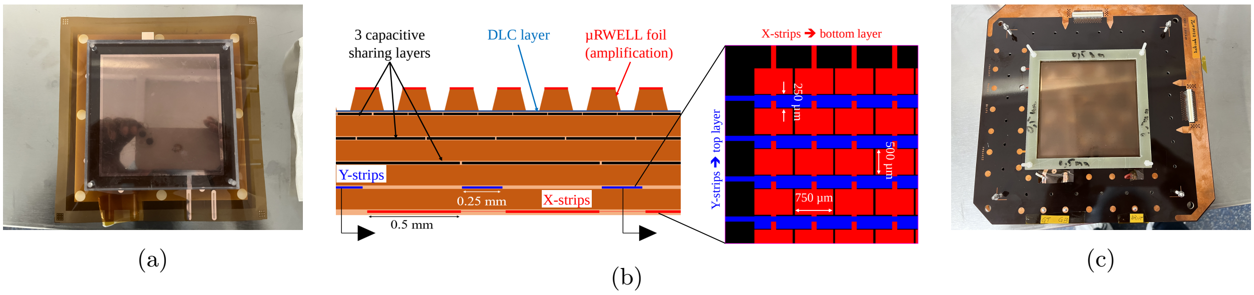


Figure 2: *Left:* Cross sectional view of 1 mm gap tg-µRWELL; *Right:* Cross section of a 0.5 mm gap hybrid tg-GEM-µRWELL detector.



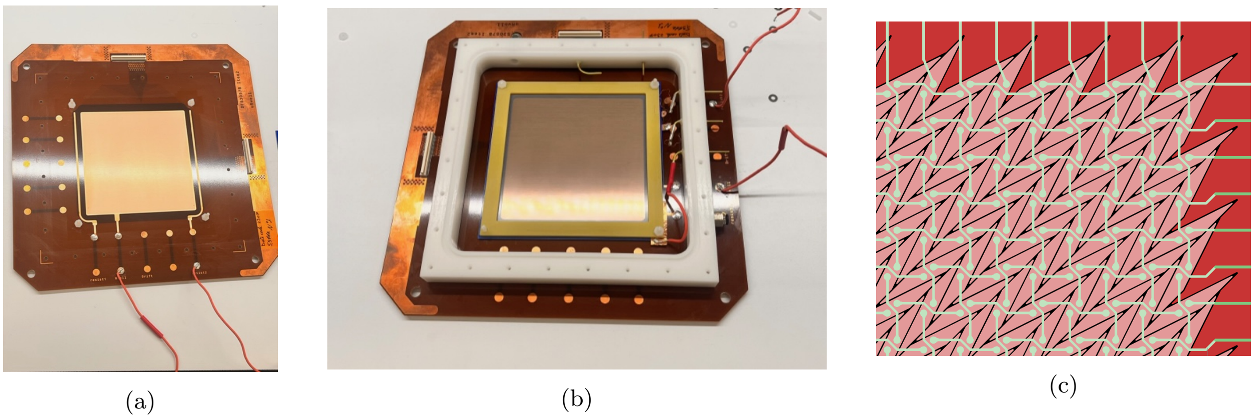
(a) (b) (c)

Figure 3: a) Stack of the cathode and GEM pre-amplification foils; b) Cross-section view of the µRWELL foil on top of the X-Y capacitive-sharing readout PCB; c) Assembled thin-gap hybrid-GEM-µRWELL

All three prototypes share the capacitive-sharing X-Y strip readout structure [3] with a strip pitch equal to 800 µm. A picture of the stack composed of the stretched GEM foil glued to the drift cathode frame is shown on the left of Figure 3. In the middle, a cartoon view of the stack composed of the µRWELL amplification foil on top of the X-Y capacitive-sharing readout PCB is shown. The picture on the right shows the two stacks mounted into the chamber. The detailed analysis of data from Fermilab test beam using these prototypes to extract efficiency and effect of track angle on spatial resolution is ongoing.

2.2 Thin-Gap µRWELL and Micromegas prototypes assembled at VU.

The Vanderbilt gaseous detector lab assembled three 10 cm × 10 cm thin-gap prototypes based on both µRWELL and Micromegas (MMG) technology. All three prototypes were based on 2D X-Y Chevron readout



(a) (b) (c)

Figure 4: a) µRWELL foil on PCB for the purpose of thin-gap hybrid (GEM-µRWELL) protoype; b) Assembled thin gap hybrid prototype; c) 2D X-Y chevron readout.

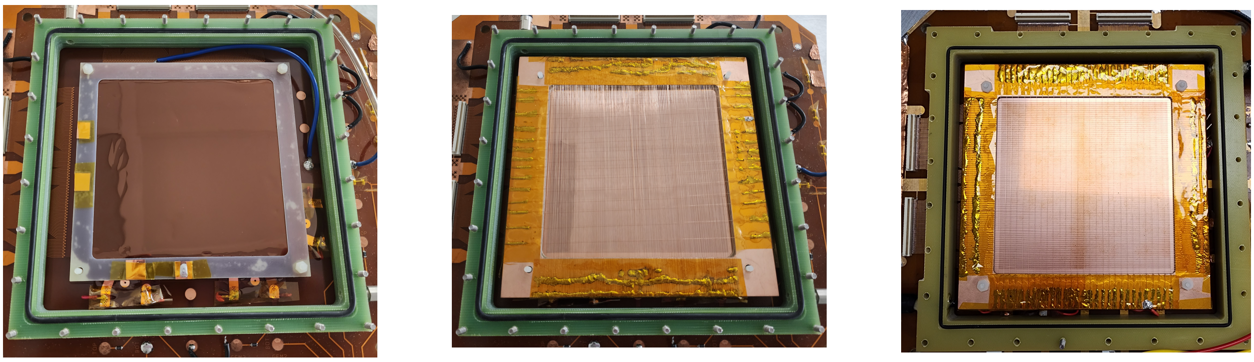
strips of 1.6 mm pitch and have the same type of mesh drift cathode. Below are the specifications of the three prototypes in terms of various gas gaps:

1. **GEM-µRWELL hybrid prototype:** Drift gap of 1 mm, transfer gap between GEM foil and µRWELL of 0.5 mm.
2. **Single amplification µRWELL prototype:** Drift gap of 1 mm.
3. **GEM-MMG hybrid prototype:** Drift gap of 1 mm, transfer gap between GEM foil and MMG of 1.0 mm.

Fig. 4 shows the µRWELL PCB along with the assembled GEM-µRWELL thin-gap prototype with 2D X-Y Chevron readout board used in the FNAL test beam. The detailed analysis of Fermilab test beam data from these prototypes to extract efficiency in both Ar and Kr based gas mixtures along with the effect of track angle on spatial resolution is ongoing.

2.3 Thin-Gap triple-GEM prototypes assembled at UVa

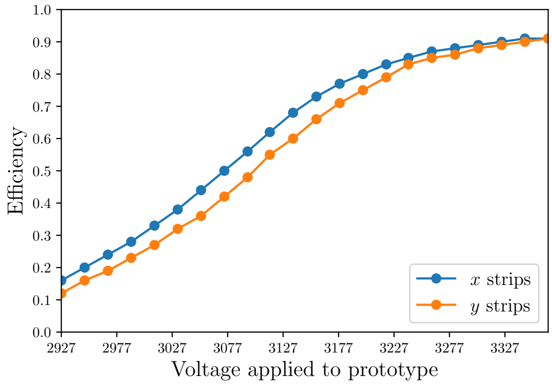
As with any gaseous detector, the spatial resolution of a triple-GEM detector degrades significantly when a track incident at a large angle from the normal traverses a greater distance in the ionization gas volume. Conversely, if the ionization region is too thin, it may not produce a sufficient number of primary electrons, resulting in reduced detection efficiency. To mitigate the impact of the incident angle on the spatial resolution and maintain high efficiency and stability in triple-GEM detectors, we have constructed four 10 cm × 10 cm Thin-Gap triple-GEM prototypes. These prototypes feature a drift gap that is significantly thinner than the typical 3mm gap in standard triple-GEM detectors, achieved through different configurations of the cathode layer. The first two prototypes utilize cathode layers made of standard Copper-kapton foil and have a drift gap between the cathode and the uppermost GEM foil measuring 1.5mm and 1.0mm, respectively. The third and fourth prototypes employ cathodes made of fine wires with wire pitches of 400μm and 800μm, maintaining a drift gap of 1.5mm. Fig. 5 displays images of these triple-GEM prototypes with different cathode configurations.



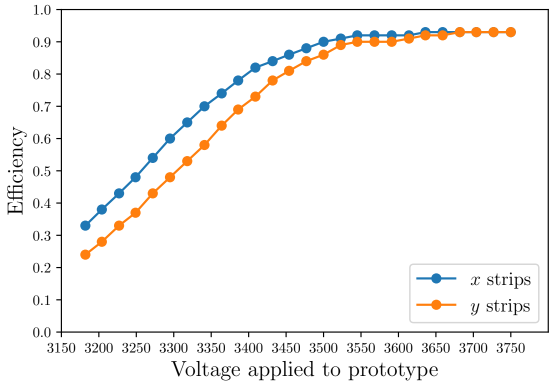
(a) (b) (c)

Figure 5: (a) Prototype with standard Copper-kapton foil; (b) Prototype with 400μm wire-pitch cathode; (c) Prototype with 800μm wire-pitch cathode.

The performance of these triple-GEM prototypes has been evaluated in beam studies using the Fermilab Test Beam Facility. Our preliminary results obtained with four prototypes in a beam of 120 GeV protons show that the Thin-Gap Triple-GEM prototypes operated in a gas mixture of 80% Argon and 20% CO_2 are able to reach a detection efficiency above 90% and have excellent high voltage stability (Fig. 6.) Detailed analysis of the spatial resolution and efficiency of all four triple-GEM prototypes is ongoing.



(a)



(b)

Figure 6: Efficiency for the detection of charged particles in Ar/CO_2 (80:20) gas as a function of the overall applied voltage of (a) prototype with cathode made of Copper-kapton foil and 1mm drift gap, (b) prototype with 400μm wire-pitch cathode and 1.5 mm drift gap

3 Proposal: Medium-size double thin-gap GEM-µRWELL hybrid trackers

3.1 Introduction of R&D plans at UVa

We plan to develop and build a low-mass, medium-size double-sided thin-gap detector [2] with an active area of 30 cm × 30 cm based on the hybrid amplification GEM-µRWELL technology. Each side of the detector will incorporate a standard Copper-kapton drift foil, a GEM foil, and a composite µRWELL/2D-readout foil with capacitive-sharing readout strips [3] in U-V and X-Y geometry, designed by JLab and Vanderbilt groups. To maintain mechanical stability and achieve uniform thin gaps between adjacent layers within the detector, low-mass honeycomb structures are utilized as the primary support frames, as well as to join the two sides of the detector. A conceptual design of the detector is depicted in Fig. 7.

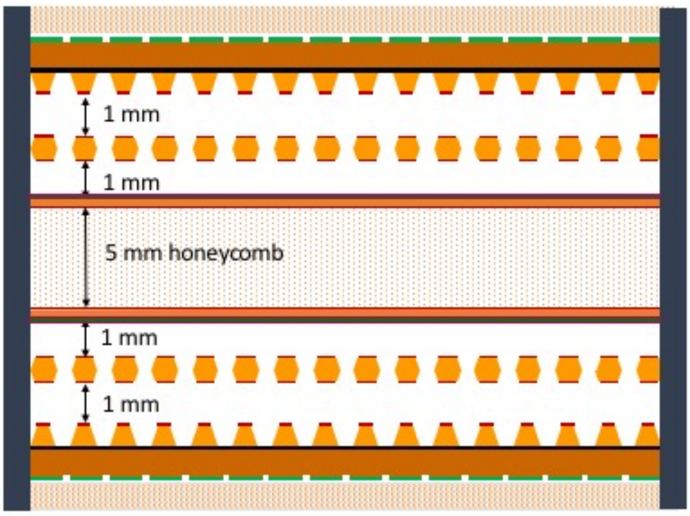


Figure 7: Conceptual design of the double-sided thin-gap hybrid GEM-µRWELL detector (not to scale).

With their expertise in developing large-sized gaseous detectors and designing full-size μRWELL/2D-readout foils, JLab, Vanderbilt, and UVA will collaborate on the design, construction, and characterization of the detector. We will examine the gain structure of the hybrid amplification configuration, as well as the high voltage stability and mechanical stability of the detector under X-ray radiation at the UVA detector lab.

3.2 R&D timeline and funding request

The proposed timeline for this R&D from the University of Virginia is as follows

- **10/2023 - 01/2024:** Design components of the prototype (GEM and cathode foils, honeycomb and spacer frames) and parts for the foil-stretcher and assembly system.
- **02/2023 - 05/2024:** Procurement of µRWELL, GEM foils, cathode foils, and frames for prototype as well as parts for the foil-stretcher and 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.

Table 1: UVA FY24 Funding Request

	Request	**-20%**	**-40%**
PhD student support	$19,271	$15,419	$12,563
GEM & Cathode foils	$12,000	$11,000	$9,000
Honeycomb and spacer frames	$10,000	$9,000	$7,000
Materials for foil-stretcher & assembly system	$7,000	$5,000	$4,000
Supplies for Prototype testing	$3,000	$3,000	0
Travel	$3,000	0	0
Overhead	$14,382	$11,505	$8,629
Total	**$68,653**	**$54,925**	**$41,192**

3.3 Introduction of the R&D plans at VU

The Vanderbilt group will procure two planar µRWELL PCBs with 30 cm $\times$ 30 cm active area. The readout structure for these two µRWELL PCBs will be based on capacitive sharing strip-pad readout with two different 2D-strip patterns designed by both the Vanderbilt and JLab groups. The advantage of having two different readout patterns on either side of double-sided thin-gap GEM-µRWELL hybrid detector will be to reject ghost tracks arising from real events.
After procuring µRWELL PCBs from CERN, Vanderbilt will participate in the assembly of the complete detector in collaboration with other institutions in the proposal. Apart from assembly, testing of detectors for HV stability and basic QA will be also done on an X-ray test bench.

3.4 R&D timeline and funding request

The proposed timeline for this R&D from Vanderbilt is as follows:

- **10/2023 - 05/2024:** Design and procurement of 30 cm × 30 cm active area tg-μRWELL PCB.
- **06/2024 - 08/2024:** Assembly and test of double-sided thin-gap GEM-μRWELL detector in collaboration with other institutions in the proposal.

Table 2: VU FY23 Request.

	Request	**-20%**	**-40%**
μRWELL PCB	$40,000	$40,000	$40,000
Travel	$2,000	$2,000	$2,000
Supplies	$1,000	$0	$0
Overhead	$1,145	$560	$560
Total w/ Overhead	**$44,145**	**$42,560**	**$42,560**

During FY24 Vanderbilt University is requesting funding associated with two 30 cm × 30 cm active area μRWELL PCB during FY24. The funding also includes travel to collaborating institutes in the proposal for assembling the final detector. Tab. 2 summarizes the Vanderbilt University funding request for FY24. If the original funding request is reduced by 20%, then there will be reduction in travel to fit into the budget. If the funding is reduced by 40%, μRWELL PCBs cannot be procured for the project.

3.5 Introduction of the R&D plans at FIT

The FIT group will investigate the feasibility of implementing a double-sided thin-gap GEM-μRWELL hybrid detector of medium size (30 cm × 30 cm active area) in a frame structure that allows for purely mechanical stretching of GEM foils and drift foils and assembly with minimal application of glue. The advantage of this approach is that the foil tensions can be adjusted as needed to ensure a correct drift gap size and that it allows re-opening of the detector to fix any problems or to swap out components. This represents the next step up from the small (10cm × 10cm active area) prototype detectors developed and successfully tested in the previous grant period. The assembly concept builds on our previous development of a mechanically stretched large trapezoidal Triple-GEM detector [4] for the eRD6 program, which in turn is based on the mechanical stretching design of the CMS forward muon upgrade with over a hundred large Triple-GEM detectors currently in operation in CMS and 500 more currently in production [5].

Fig. 8 shows a conceptual design of such a detector. The μRWELLs are supported by the same low-mass honeycomb structure that UVa and UV will develop. The GEM foils and the drift foils will be sandwiched between insulating spacer frame pieces that provide the proper spacing between electrodes. T-nuts are embedded into the central spacer frame part; screws that are inserted into the nut are tightened to pull against "pull-out" posts, which in turn stretches the foil assembly to make the foils taut. The pull-outs are mounted on a rigid carbon-fiber frame that surrounds the foils. An outer frame surrounds the pull-outs to close the gas volume.

We will first produce a technical design for this detector with 30 cm × 30 cm active area and construct a mechanical mock-up. Instead of actual μRWELL and GEM foils, we will use basic copper-clad kapton foils of the same thickness as the base material for drift and GEM foils. We will study how well this approach can ensure the envisioned very small 0.5 mm gap sizes between foils over this medium-sized active area. We will flush counting gas into the detector and apply high voltage to the foils to test the robustness of this design with respect to discharges.

If successful, we will design and produce actual GEM foils and drift foils and plan to use them with existing μRWELL foils from a previous project (if available) to construct an operational prototype and test it. The frame mechanics from the mock-up will be reused for this prototype.

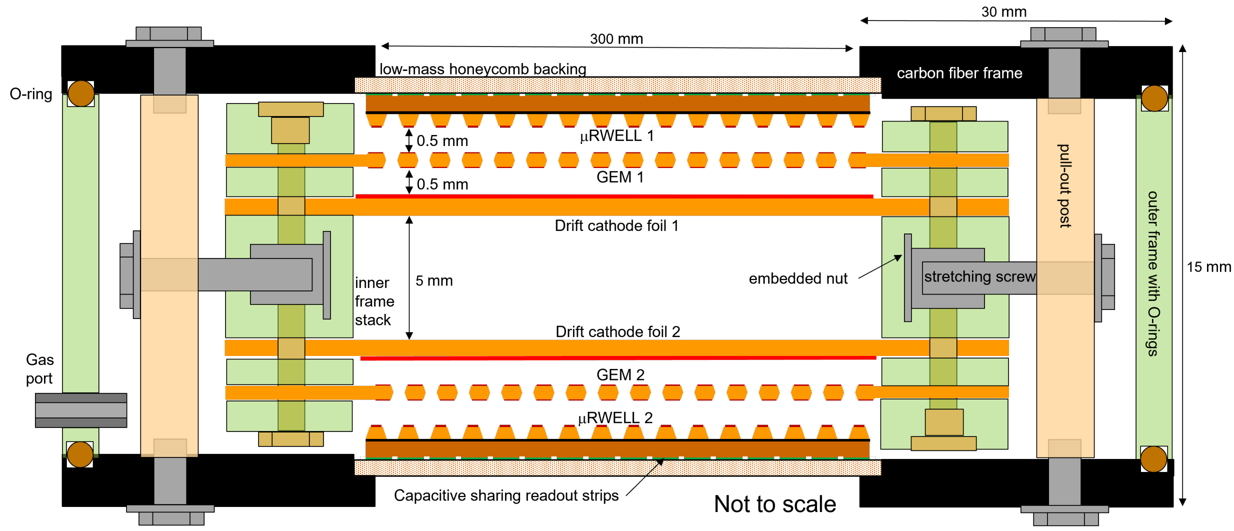


Figure 8: Conceptual design of a mechanically stretched double thin-gap GEM-µRWELL hybrid detector.

3.6 R&D timeline and funding request

- **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.

Table 3: FIT FY23 Request.

	Request	**-20%**	**-40%**
Ph.D. student	$17,000	$17,000	$12,000
Mock-up construction	$10,000	$9,000	$8,000
GEM foils and drift foils	$6,000	$0	$0
Gas and Supplies	$2,000	$2,000	$1,000
Overhead (44.87%)	$15,705	$12,564	$9,423
Total w/ Overhead	**$50,705**	**$40,564**	**$30,423**

4 Proposal: Small-size thin-gap GEM-µRWELL for tracking in high-η region

4.1 Introduction of the R&D plans at JLab

The JLab group will develop a small-size, high-performance double thin-gap GEM-µRWELL hybrid detector [2] for precision tracking in the high pseudorapidity region in the endcap region of a detector at the EIC collider. The proposed detector will be optimized to operate in the higher-η area of the end cap tracking disks or as a standalone high-precision tracker for the far forward detectors. Because of the higher rate requirement in these regions due to both high machine background and scattered particles, hexagonal pad readout structures will be implemented instead of strip readout to better cope with multiple-hit (ghost hits) ambiguity issues. Adopting the capacitive-sharing readout technology [3] will allow to maintain excellent spatial resolution performance with a minimum number of pads to read out. The prototype will have a 0.5 mm gaps in the drift region between the cathode and the top of the pre-amplification GEM foil, and in the transfer region between the bottom of the GEM and the μRWELL foil. A double-sided detector in a single module will guarantee full efficiency for single-hit detection despite the small gaps, and moderate efficiency for two-hit detection. A conceptual design of the high-performance prototypes is shown in the cartoons of Fig. 9.

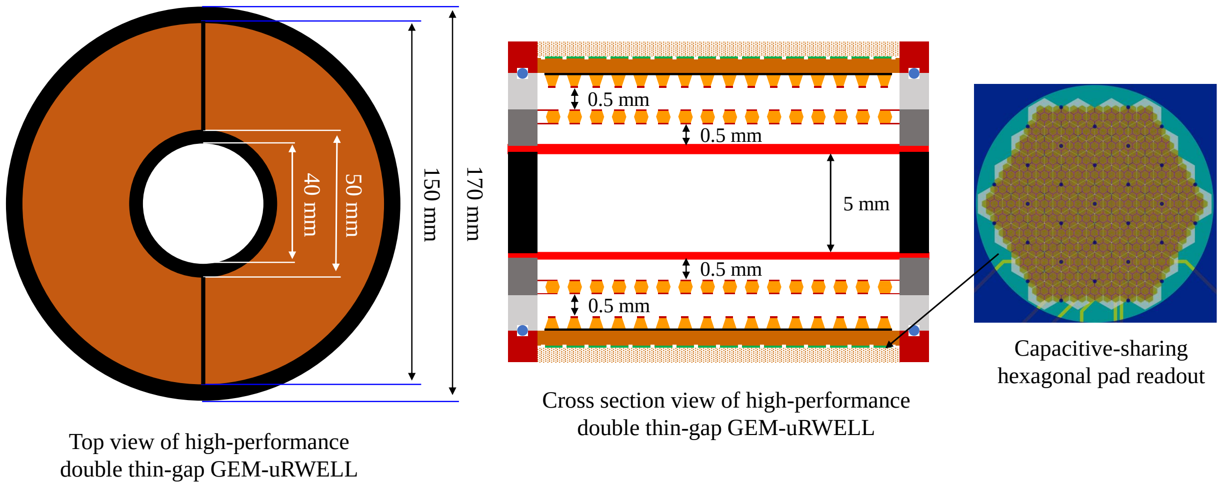


Figure 9: Conceptual design of the high-performance double thin-gap GEM-μRWELL hybrid detector for high-rate tracking. *Left:* Top view of the prototype tg-μRWELL. *Center:* Cross-sectional view with 0.5mm gap. *Right:* Design of the capacitive-sharing hexagonal pad readout.

4.2 Design and fabrication of the prototype

The design of the prototype which includes the GEM foil, the μRWELL PCB with capacitive-sharing pad readout, the cathode foil, and the mechanical support frames will all be done at JLab in collaboration with the technical expertise in the MPGD workshop at CERN. Procurement of the GEM, cathode foils and μRWELL PCBs will be placed at CERN; the mechanical support structures will be fabricated in the machine shop at JLab. To develop the high-rate capability of the μRWELL amplification structure, we will investigate the available options such as a vertical evacuation grounding scheme or lateral draining of charges through DLC segmentation. The readout PCB of the prototype will implement the capacitive-sharing technology with $\sim$ 5mm hexagonal pads not only for the sharing layers, but also for the readout pads. The very narrow gaps between layers, 0.5 mm in both amplification and transfer region, remain as the principal challenge during the assembly of such a prototype. The design of the mechanical support structures will reflect our solution for how to address that issue.

4.3 Performance studies of the prototype

The prototype will be assembled in the MPGD lab of the RD&I Group at JLab and preliminary tests and characterization studies of the chamber will be carried out in the cosmic setup of the MPGD lab. These tests include:

- Voltage scan in Ar/CO_2 mixture to study efficiency for single-hit and two-hit efficiency of the double-sided hybrid detector
- Optimization study for the voltage setting between pre-amplification GEM and second amplification µRWELL structures for stability and performance

In parallel, we plan to evaluate the impact of the capacitive-sharing readout technology on detector signal amplitude as seen by the frontend electronics (FE). We will compare the signal of several readout PCBs with same strip (or pads) pattern, but different numbers of capacitive-sharing layers and look for potential correlation between the number of capacitive layers and signal amplitude. To do so, we will use the same amplification structure (triple-GEM detector) for all the PCBs tested. Finally, we will seek any opportunity for parasitic beam test at JLab to evaluate high-rate capability and spatial resolution performance of the prototype.

4.4 R&D timeline and funding request

- **10/01/2023 - 05/30/2024:** Design and procurement of µRWELL and GEM and cathode foils.
- **05/01/2024 - 07/30/2024:** Assembly and characterization of the prototype in the MPGD Lab at JLab.
- **07/01/2024 - 08/30/2024:** Data analysis of performance results and preparation of the Progress Report.
- **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.

Table 4: JLAB FY23 funding request table

	Full request	**-20% request**	**-40% request**
Labor cost	\$28,000	\$21,000	\$14,000
2 µRWELL PCBs	\$20,000	\$20,000	\$20,000
GEM & drift foils	\$5,000	\$3,000	\$ 3,000
Support frames	\$4,000	\$3,000	\$2,000
Travel	\$1,500	\$1000	\$0
Overhead	\$15,000	\$10,000	\$7,000
Total	**\$73,500**	**\$58,000**	**\$46,000**

5 FY23 Funding request

5.1 Money matrix and split among participating institutions

Tab. 5 shows a **money matrix** itemizing the budget allocations to the individual institutions.

In the case of university requests, fringe and indirect costs are included in the numbers in the table. A detailed breakdown of the request for each institution can be found in an excel sheet available at this link: Detailed Budget Breakdown (Google spreadsheet).

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**

5.2 Three budget funding scenarios

Tab. 6 shows **three budget scenarios** for the individual institution.

Table 6: **FY23 Budget request** – Three budget scenarios per institution.

	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**

6 Personnel

Jlab charges partial salary for staff scientist efforts. Other labor costs are budgeted to support Ph.D. students at contributing universities. None of the FIT, UVA, or Vanderbilt senior team members are to be funded by EIC R&D; all contributions are in kind. Below we list the FTE percentages planned for this effort.

Jefferson Lab (JLAB):

- K. Gnanvo, Staff Scientist 5%
- S. Lee, Staff Scientist 5%

Florida Institute of Technology (FIT):

- M. Hohlmann, Professor 10%
- P. Iapozzuto, Ph.D. student 50%

University of Virginia (UVa):

- N. Liyanage, Professor 15%
- H. Nguyen, Senior Research Scientist 15%
- X. Bai, Postdoc 15%
- B. Purijjala, PhD student 60%

Vanderbilt University (VU):

- S. Greene, Professor 5%
- S. Tarafdar, Research Scientist 25%
- J. Velkovska, Professor 5%

7 Diversity, Equity and Inclusion

The authors involved in this proposal have diverse background in terms of gender, ethnicity and social status. Institutions involved in this proposal are committed to include under-represented minority communities. Also we are committed to work together to create an inclusive space where everyone irrespective of their gender identity, ethnicity, color, race, sexual orientation can express their views and be heard by the rest of the collaborators.

Different universities in this proposal have different programs to train students to be future scientists. Vanderbilt University has a Bridge program to include students from under-represented minor communities in various research activities in different labs within the University. Vanderbilt Physics department gaseous detector lab already had a student under this Bridge program to work on MPGD project and this R&D proposal will focus on training more students from under represented minority to be future scientists. FIT brought a female undergraduate student from an ethnic group that is underrepresented in physics to an EIC R&D beam test effort in summer 2023. Furthermore, close collaboration of universities in this proposal with Jefferson Lab will provide experience to students to work in large laboratories.

This proposal includes scientists and researchers of vast expertise either in the form of detector hardware or in the form of software development and simulation. Furthermore, the proposal has members who have experience working in large collaborations and also members who has leadership roles in APS committee of Status of Women, DNP Allies, and institutional/collaboration DEI committees.

References

[1] R. Abdul Khalek et al. *Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report*. 2021. DOI: 10.48550/ARXIV.2103.05419. URL: https://arxiv.org/abs/2103.05419.

[2] Kondo Gnanvo et al. *Development of Thin Gap MPGDs for EIC Trackers*. https://www.jlab.org/sites/default/files/eic_rd_prgm/files/2022_Proposals/20220725_eRD_tgMPGD_Proposal_final_EICGENRandD2022_23.pdf. Generic EIC-related Detector R&D Program. 2022.

[3] Kondo Gnanvo et al. "Performance of a resistive micro-well detector with capacitive-sharing strip anode readout". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* (2022), p. 167782. ISSN: 0168-9002. DOI: https://doi.org/10.1016/j.nima.2022.167782.

[4] Marcus Hohlmann et al. "A Low-mass GEM Detector with Radial Zigzag Readout Strips for Forward Tracking at the EIC". In: *Proc., 2017 IEEE Nuclear Science Symposium and Medical Imaging Conference*. Oct. 2017. DOI: 10.1109/NSSMIC.2017.8532722. arXiv: 1711.05333 [physics.ins-det].

[5] D. Abbaneo et al. "Layout and Assembly Technique of the GEM Chambers for the Upgrade of the CMS First Muon Endcap Station". In: *Nucl. Instrum. Meth. A* 918 (2019), pp. 67–75. DOI: 10.1016/j.nima.2018.11.061. arXiv: 1812.00411 [physics.ins-det].