# Development of Thin-Gap MPGDs

Preliminary Results from Fermilab June 2023 Test Beam


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*on behalf of Thin-Gap MPGD Consortium*


RD15 Collaboration Meeting - Dec 4 – 8, 2023, CERN

# Outline

- Motivation for thin-gap MPGDs
- Prototypes & Preliminary Results
- Ongoing R&D efforts & Challenges
- Summary and Perspectives

# Motivation for Thin-gap MPGDs

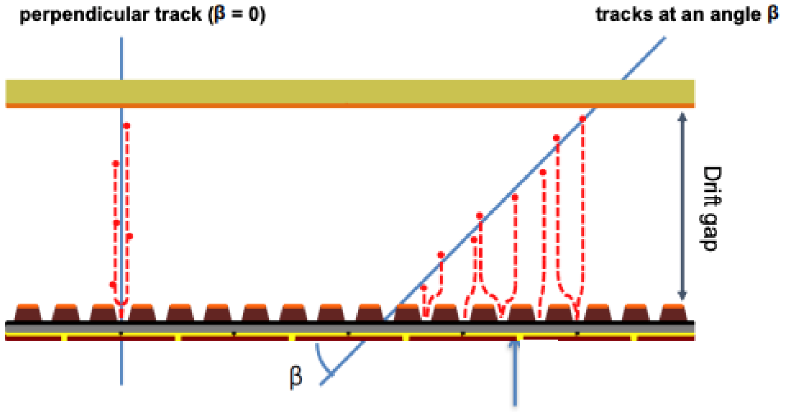
## MPGD with standard drift gap

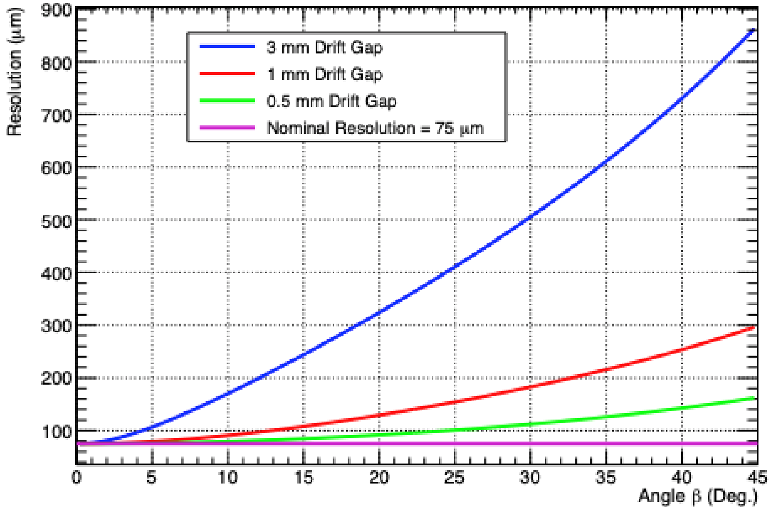
- ❖ Typically, 3 mm or larger drift gap to allow enough primary ionization for full efficiency
- ❖ For relativistic charged particles (MIPs) ionization happen along the track of the particle
- ❖ Perpendicular track particles to the detector plane hit a limited number of readout strips to provide precise position reconstructed using center of gravity (COG) algorithm
- ❖ For tracks coming at an angle θ with respect the normal axis of the detector, too many strips along the ionization trail are hit ➔ COG no longer ensure good spatial resolution.
  - ▪ Spatial resolution is severe degraded increasing with the incoming particle angle

## Two approach to partially recover spatial resolution performance at large angle

- ❖ Operate MPGD detector in mini-drift / µTPC mode
  - ▪ Does require fast front end readout electronics with large dynamic range
  - ▪ Has not been tested in magnetic field environment
- ❖ Develop thin-gap MPGD to minimize the ionization trail even at large angle
  - ▪ No need for fast front end readout electronics with large dynamic range
  - ▪ Will also minimize ExB effect on spatial resolution performance
  - ▪ Smaller drift gap will provide improve timing resolution

**standard Gap µRWELL**



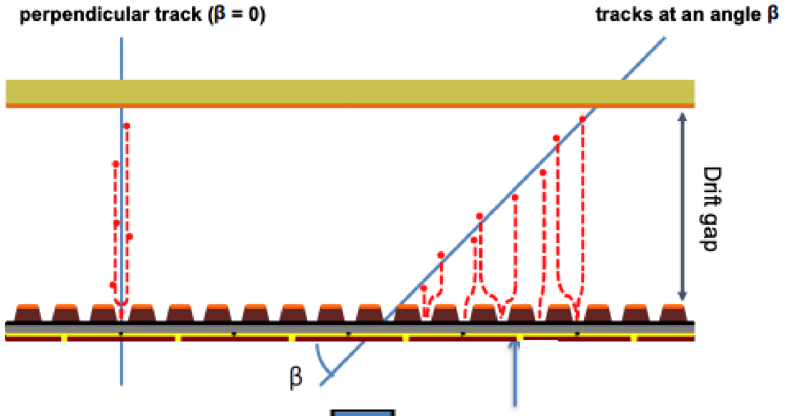




parametrization from *EPJ Web of Conferences* ***174***, *06005 (2018)*

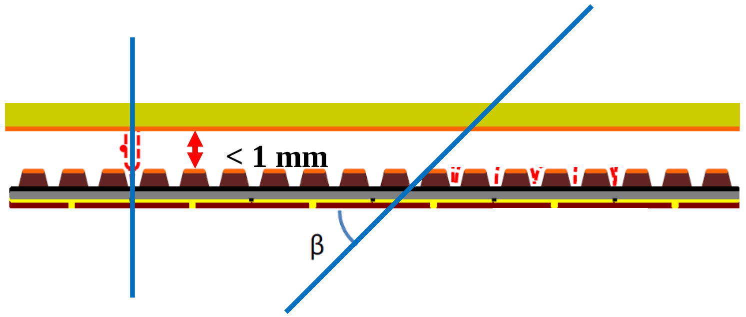
# Motivation for Thin-gap MPGDs

- **Thin-gap MPGDs has a drift gap of 1 mm or smaller compared to standard MPGD:**
  - minimize the impact large track angles on spatial resolution
  - minimize E × B effect in magnetic field on spatial resolution
  - Improve the detector timing performance
- **Challenges associated to thin-gap MPGD development**
  - Mechanical support structures for large area detector ➔ Need to maintain uniform 1-mm gap
  - Efficiency drop due to smaller ionization gap ➔ Single amplification structure will be challenging
- **Thin-gap MPGD consortium:**
  - formed US institutions involved in development of MPGD trackers for EIC detectors
  - R&D on thin-gap MPGD As part of EIC Generic R&D for future Detector II or EPIC Upgrade

**standard Gap µRWELL**




**Thin Gap µRWELL**




## Development of Thin Gap MPGDs for EIC Trackers

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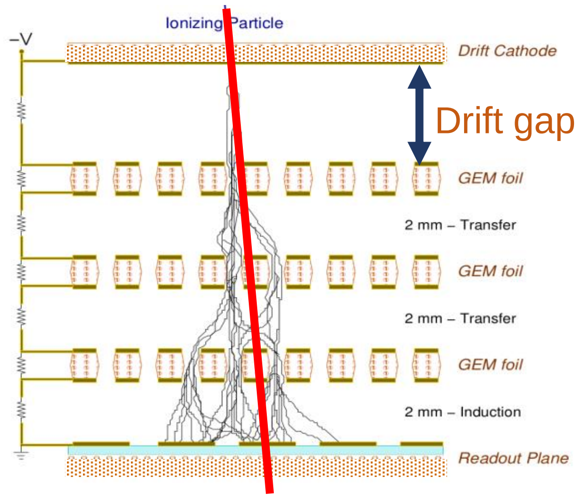
# UVa thin-gap triple-GEM Prototypes

**UVA triple-GEM Prototypes:**

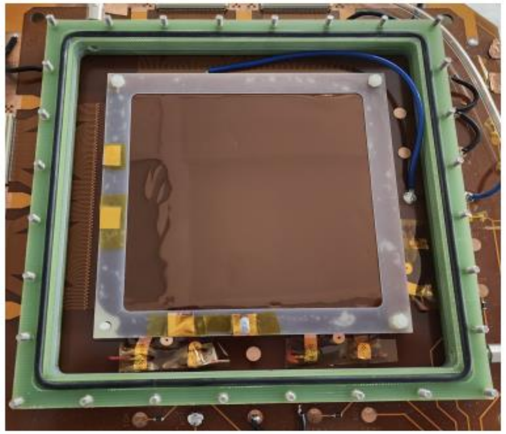
- Amplification: 3 GEM foils
- RO plane: 400 μm-pitch X-Y strips
- Three prototypes having different drift gaps (1.0 mm, 1.5 mm, 3.0 mm), the same cathode
- Three prototypes having different Cathode structures, the same drift gap (1.5 mm)

| | 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 |

**Structure of UVA Triple-GEM Prototypes**

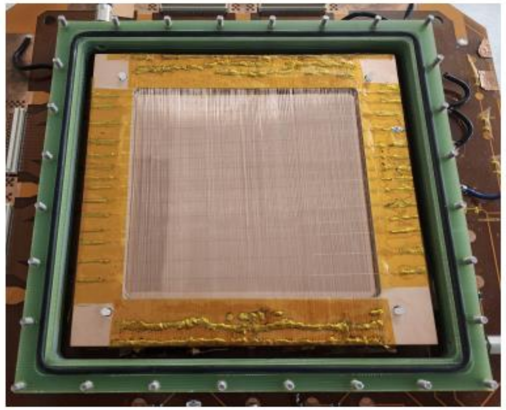



**(a) Copper-Kapton Cathode**



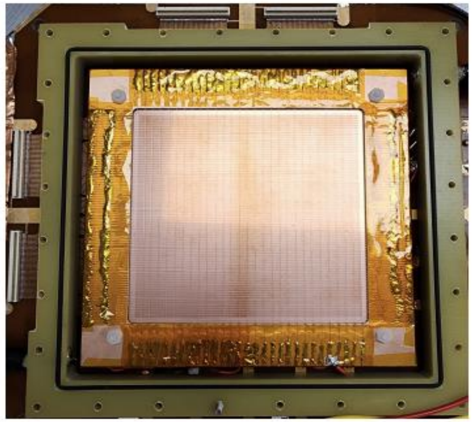
(a)

**(b) 400 μm wire-pitch cathode**



(b)

**(c) 800 μm wire-pitch cathode**



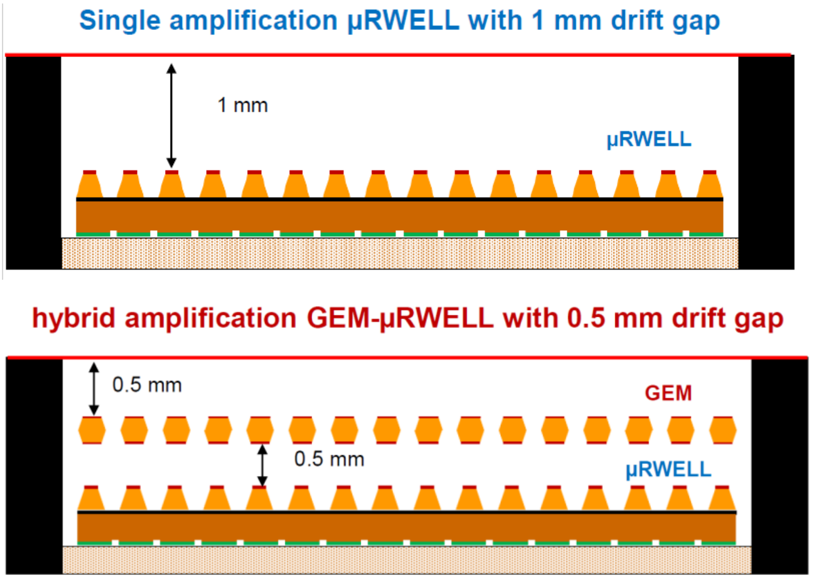
(c)

# JLab thin-gap GEM-µRWELL hybrid Prototypes

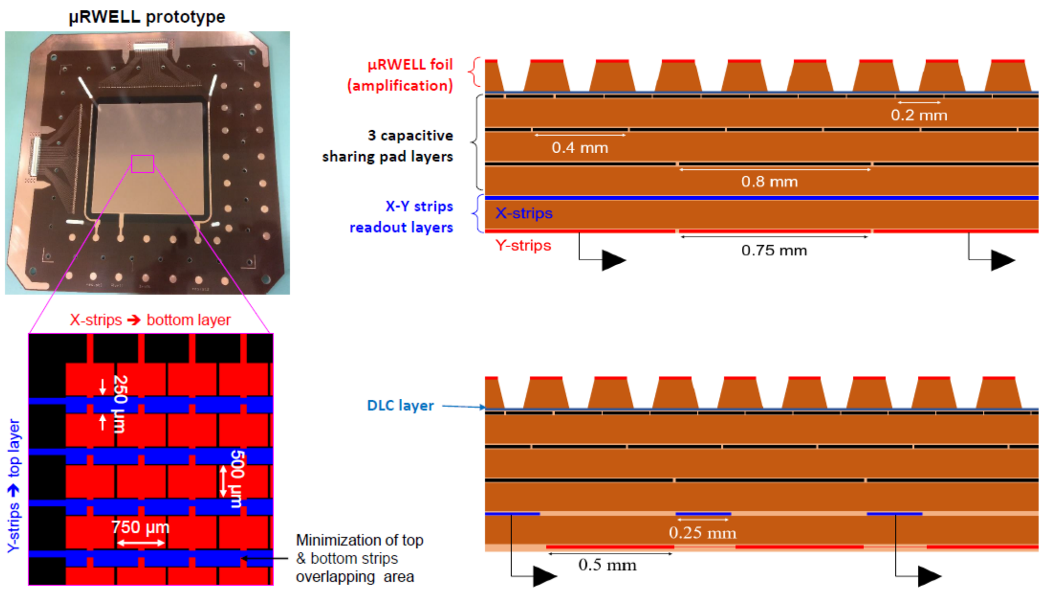
**JLab Prototypes:**

- ❖ One thin gap uRWELL:1-mm gap (not tested)
- ❖ Two 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/CO2 80/20 with JLab prototypes**
  - No opportunity for data with KrCO2

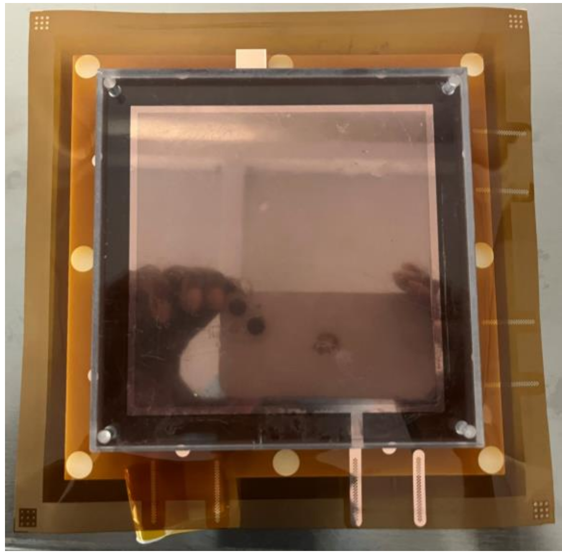
| | amplification | technology | Drift gap | Transfer gap | Beam test @ FNAL 06/2023 |
|---|---|---|---|---|---|
| Proto I | Single | µRWELL | 1 mm | N/A | Not tested in beam |
| Proto II | hybrid | GEM+µRWELL | 1 mm | 1 mm | HV angle scans |
| Proto III | hybrid | GEM+µRWELL | 0.5 mm | 1 mm | HV angle scans |
| Ref | Single | µRWELL | 3 mm | N/A | angle scans |




**Two configurations for amplification**




**µRWELL with capacitive-sharing strip readout**



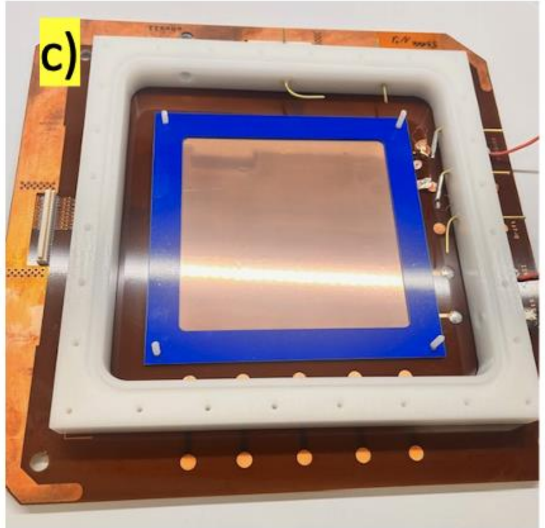
**GEM pre-amplification**

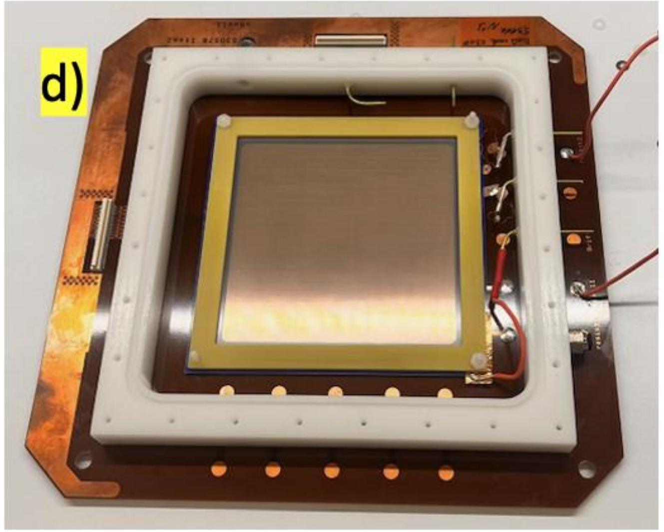
# Vanderbilt thin-gap hybrids MPGD Prototypes

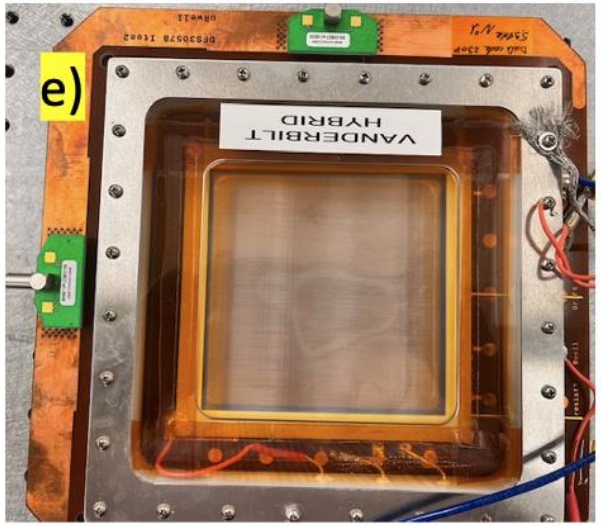
**Vanderbilt Prototypes:**

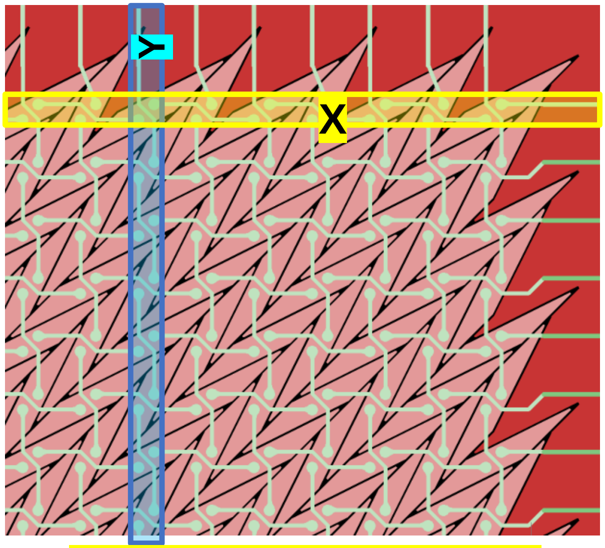
- 1 thin gap uRWELL:1-mm gap (**not tested**)
- hybrids GEM-µRWELL & GEM-MMG hybrids
- 2D zigzag R/O with 1.6 mm pitch
- Tested at FNAL June 2023 – HV scan & track angle scan with Ar/CO2 80/20 and KrCO2 80/20 gas mixtures

| Prototypes | Specifications | Tested at FNAL in June 2023 |
|---|---|---|
| GEM +MMG | • Drift gap = 1 mm<br>• Transfer gap = 1 mm | • ArCO2 (HV & track angle scan)<br>• KrCO2 (HV & track angle scan) |
| GEM + µRWELL | • Drift gap = 1 mm<br>• Transfer gap = 0.5 mm | • ArCO2 (HV & track angle scan)<br>• KrCO2 (HV & track angle scan) |
| µRWELL | • Drift gap = 1 mm | No data taken |



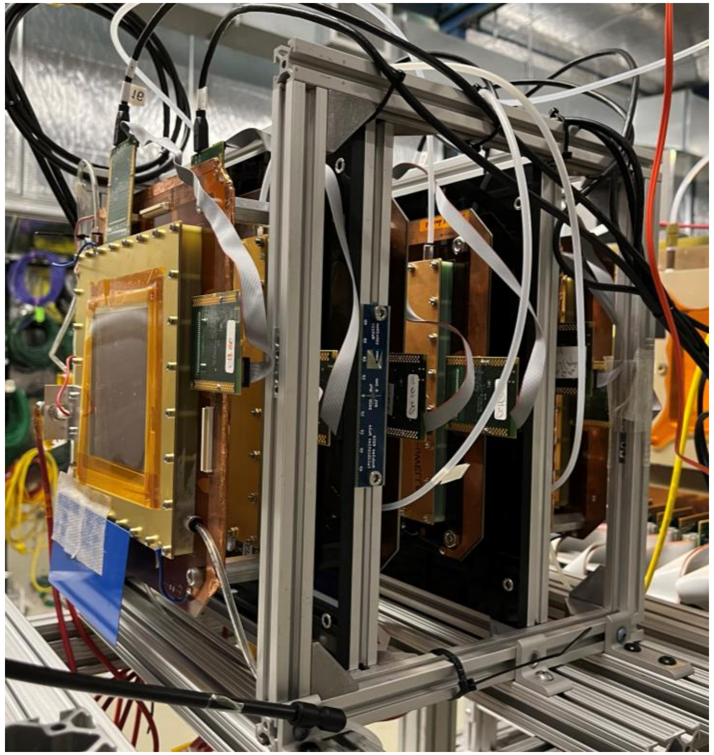



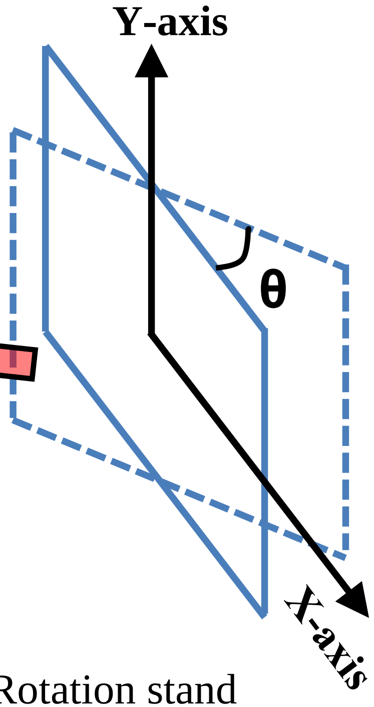




2D X-Y zigzag strip pattern

# Thin-gap MPGD prototypes in Test Beam at FNAL (June 2023)

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




Rotation stand

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

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

# UVa prototypes: Thin-gap triple-GEMs

## 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)**

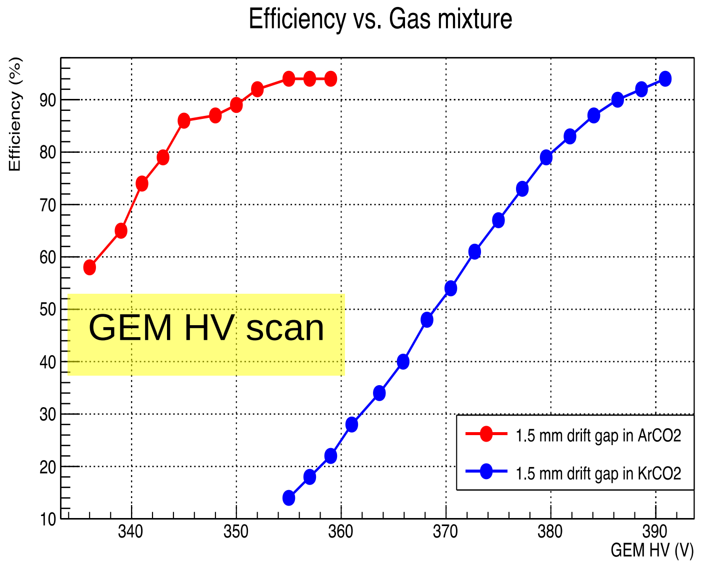
## Efficiency vs. Drift Gap studies

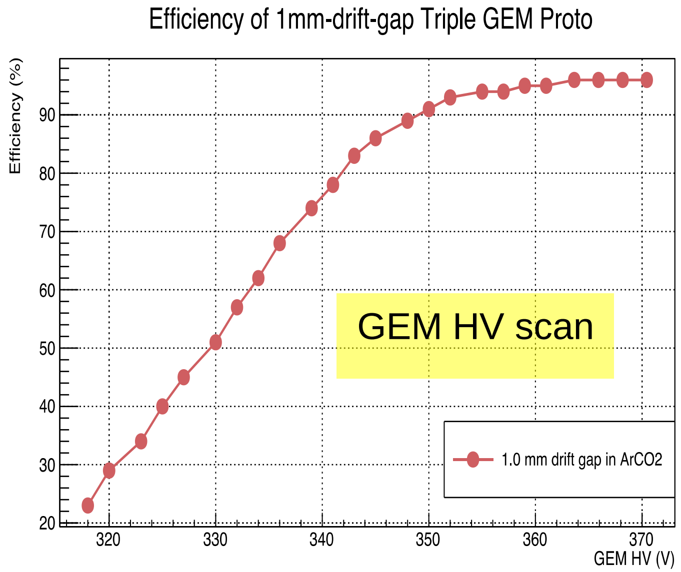
- Efficiency of **Proto I** (1.0 mm drift gap) in ArCO2 (80%/20%).
- **Proto I** achieves a high **efficiency of 96%** similar to a standard 3 mm drift gap triple GEMs

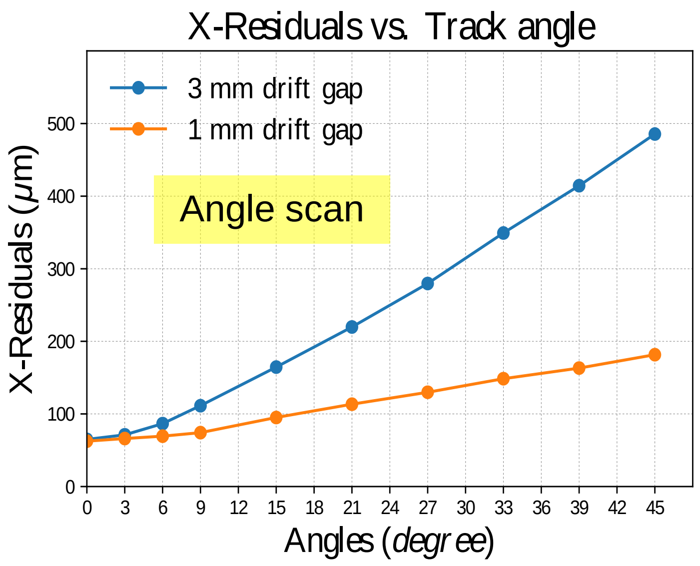
## Spatial resolution vs. track angle studies

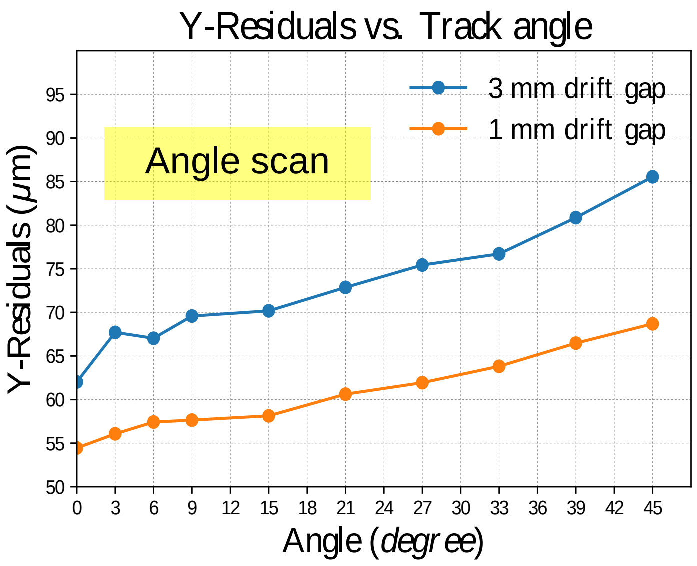
- Investigated spatial resolution of **Proto I** (1 mm drift) and **Proto III** (3mm drift) in ArCO2 with track angle from $0^o$ to $45^o$
- At large track angle, spatial resolution of **Proto I** significantly better than **Proto III**

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



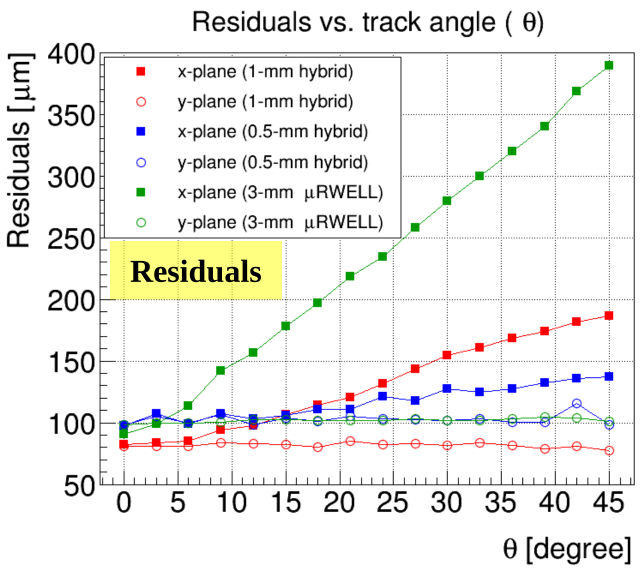



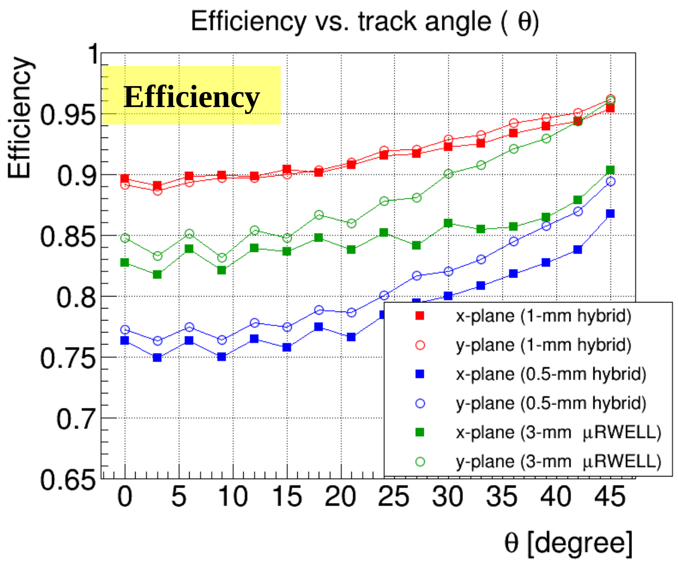
# JLab prototypes: Thin-gap GEM-µRWELL hybrids

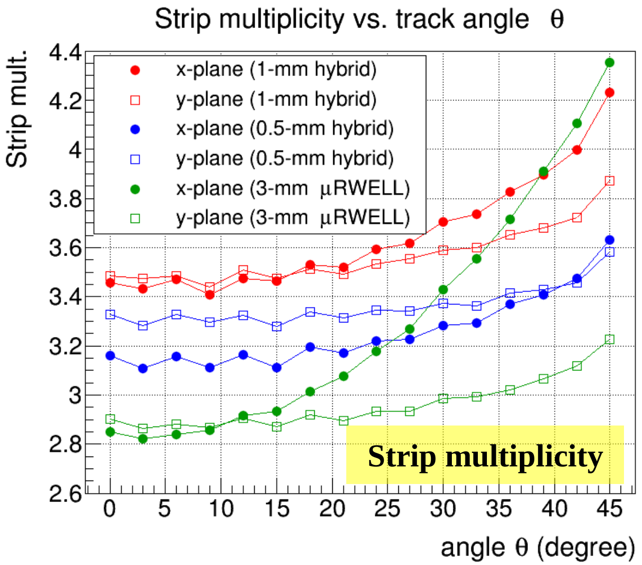
**Performance of thin-gap GEM-µRWELL protos with track angle**

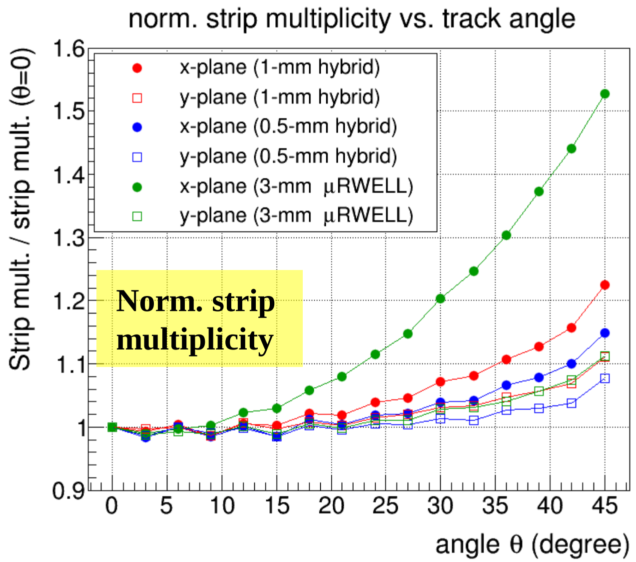
- Position resolution steadily increases with track angle but thin-gap protos shows better performance at large angle than 3-mm protos
- Efficiency **is angle-dependent** and varies from ~90% to ~95% for 1-degree and 45-degres tracks respectively for 1-mm GEM-µRWELL and from ~75% to ~85% for 0.5-mm GEM-µRWELL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

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



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# JLab prototypes: Thin-gap GEM-µRWELLs

**Efficiency performance of thin-gap GEM-µRWELL hybrid prototype**

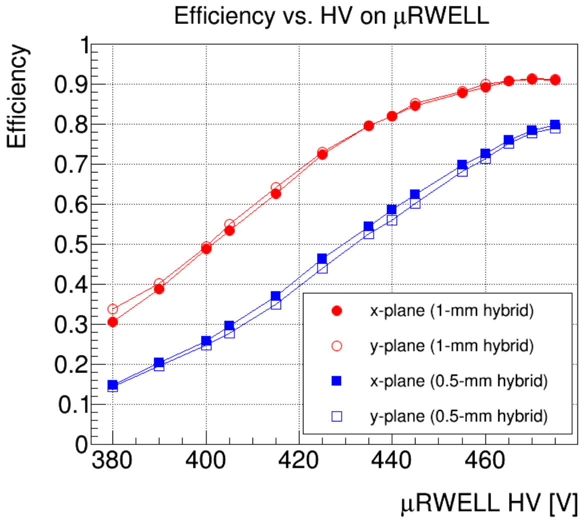
- Efficiency in Ar/CO2 reaches 80% and ~90% for 0.5-mm gap and 1-mm gap GEM-µRWELL protos respectively at the plateau when a 5×σ pedestal rms cut is applied and single strip cluster is included.
- Overall efficiency depends on several parameters of the detectors the HV applied on GEM preamplification 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

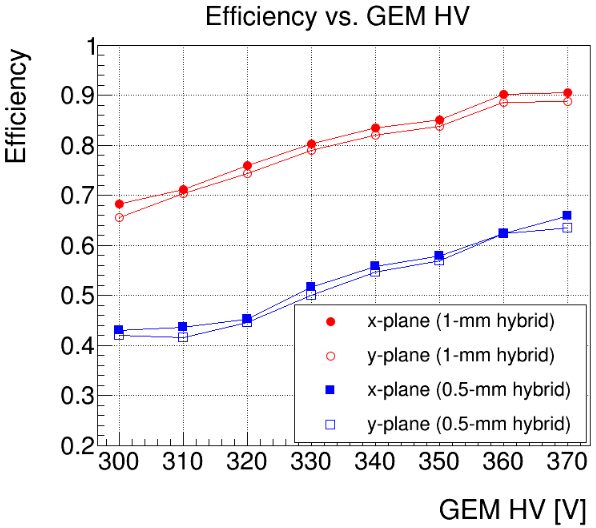
**µRWELL HV scan**
- GEM HV: 350 V
- Drift E-field: 2 kV / cm
- Induction E-field: 2kV / cm

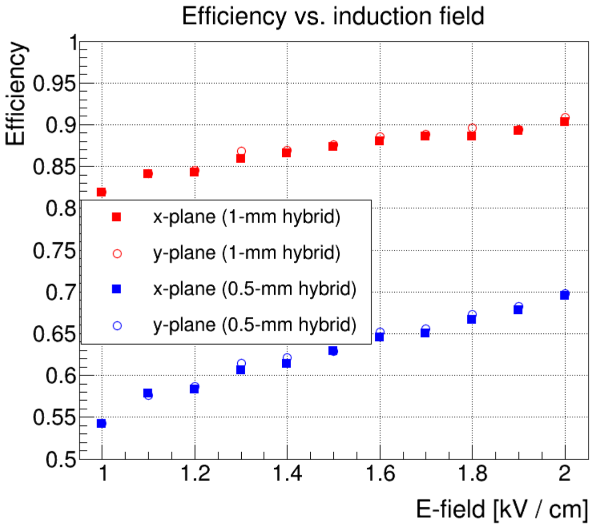
**GEM HV scan**
- µRWELL HV: 460 V
- Drift E-field: 2 kV / cm
- Induction E-field: 2kV / cm

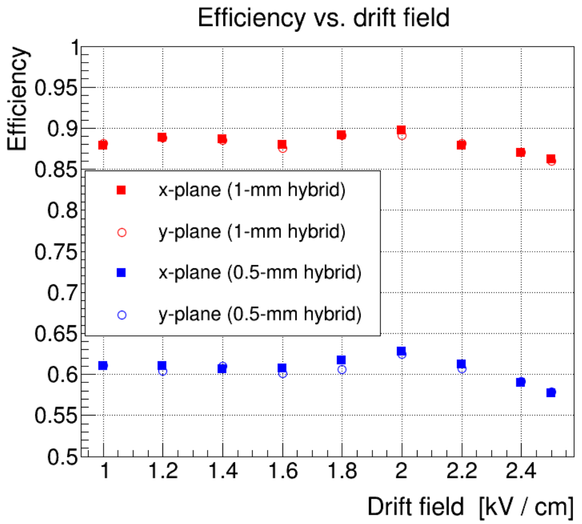
**Induction E-field scan**
- GEM HV: 350 V
- µRWELL HV: 460 V
- Drift E-field: 2kV / cm

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



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# EIC Generic R&D – Double thin-gap GEM-μRWELL hybrid detectors

## 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]

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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 acceptance 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

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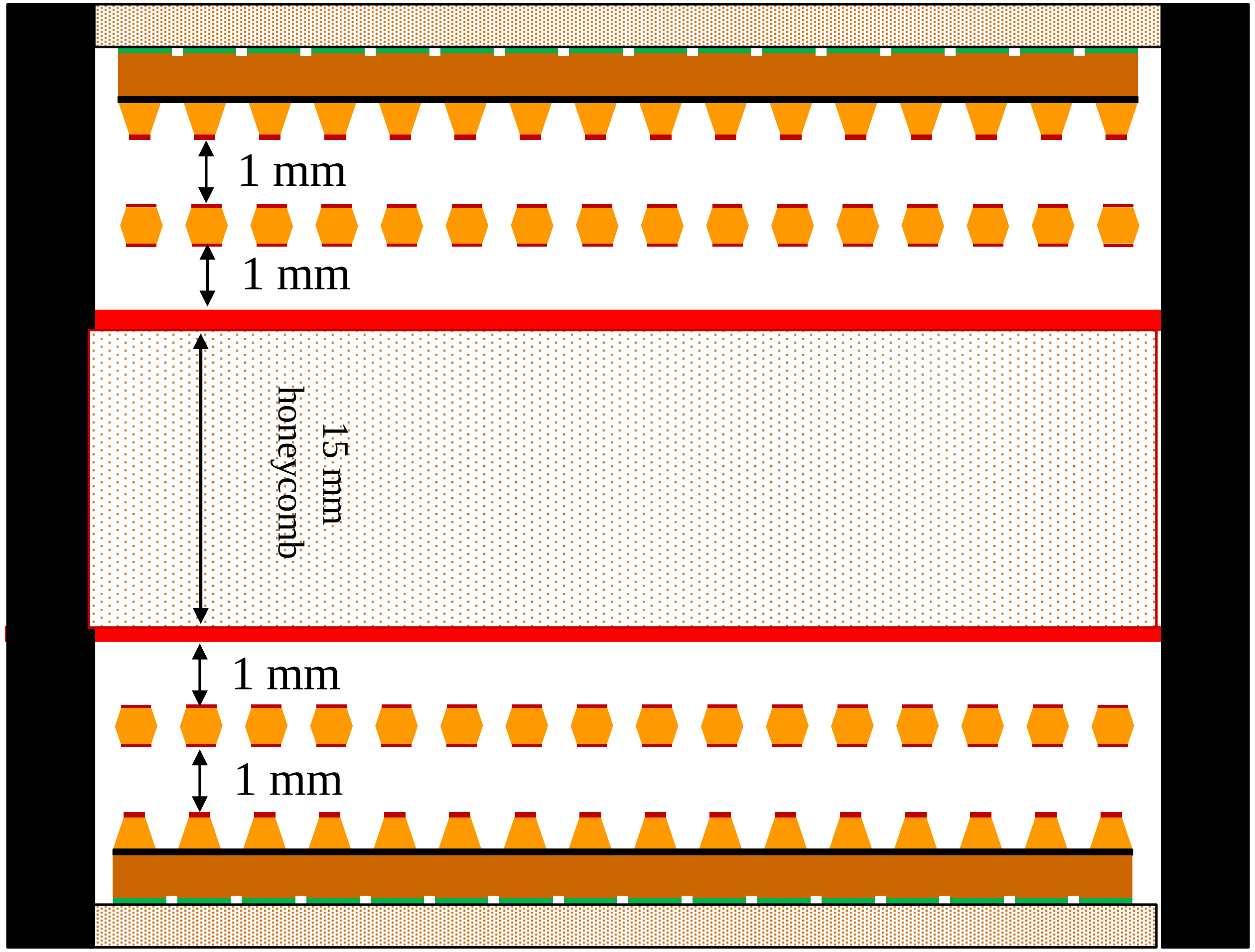
# Large-size double thin-gap GEM-µRWELL Hybrid

## Medium-size double thin-gap GEM-µRWELL prototype

- Development of low channel count, double thin-gap ~30 cm x 30 cm active area GEM- µRWELL hybrid detector with capacitive-sharing readout board. Two sides of detector have
- Stepping stone for larger detector 1-m scale ➔ will study various challenges associated with mechanical and electrical stability
- Single honeycomb support frame for Cu-Kapton drift foil and a pre-amplification GEM foil
- Explore different strip structure of RO board: X-Y strip & U-V strip coupled with capacitive-sharing structure
- **Applications**: Muon trackers, large area trackers e.g. outer tracking layers of an EIC central trackers

**UVa, Vanderbilt & JLab conceptual design**

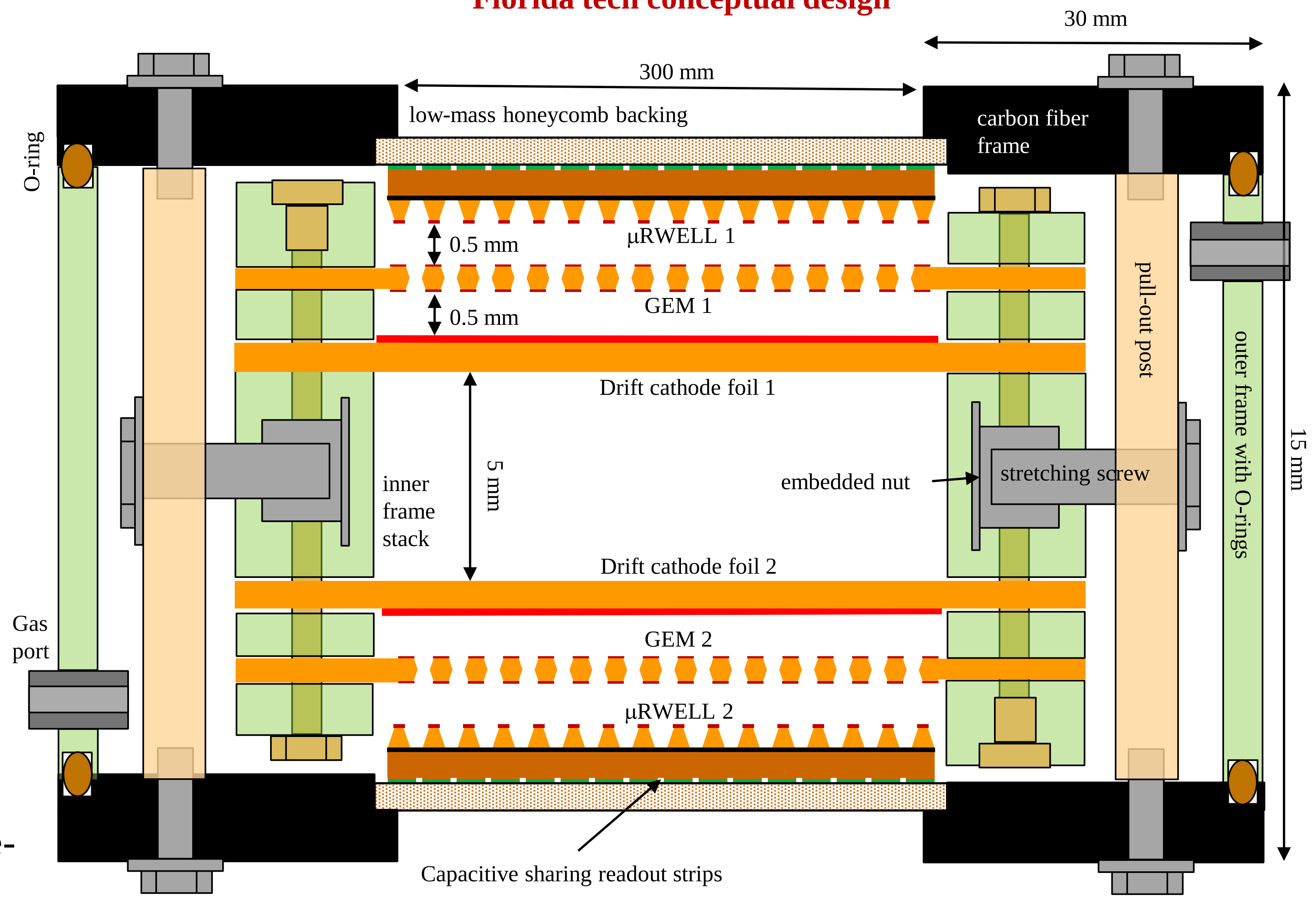


# Mechanically Stretched Double Thin-Gap GEM-µRWELL Detector

## Double & low-mass thin-gap GEM-µRWELL detector

- Medium size (30 cm ╳ 30 cm active area) with capacitive-sharing strip readout structures
- 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 stiff outer frame
- Build on experience with mechanically stretched Triple-GEMs from eRD6 program & CMS mass production

**Florida tech conceptual design**




**Not to scale !**

# High-performance Double Thin-Gap GEM-µRWELL Hybrid

## Thin-gap MPGDs for tracking at high-η in an EIC detector

❖ Small-size double thin-gap GEM-µRWELL hybrid with capacitive-sharing pad readout (~5 mm pads) structures

❖ The focus is to improve spatial and timing resolution for normal tracks by minimizing both the transverse diffusion and drift time

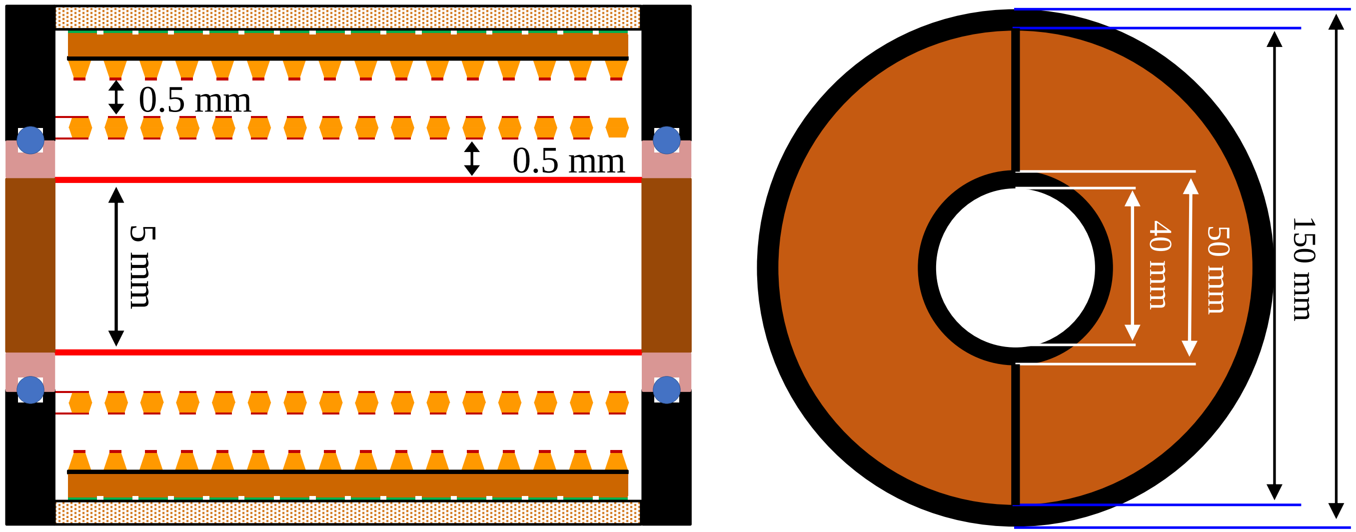
❖ We expect achieve below 50-µm resolution with 5 mm-pad R/O for high-rate tracking in high-η region of an EIC detector

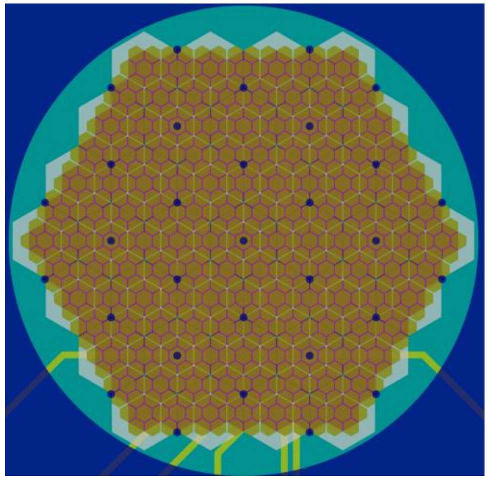
⇒ Capacitive-sharing pad R/O ➔ reduced readout channel

⇒ 0.5 mm drift gap / 0.5 mm induction detector ➔ improve position & time resolution, reduce background

❖ We will explore new type of mechanical support structures, carbon fiber, PEEK etc …

**JLab conceptual design**



CapaSh hexagonal pad

# Summary

- Spatial resolution performance of standard gap MPGDs started degrading for track at an angle higher than 10-degree or for curved track in a strong magnetic field ➔ reducing the drift gap (thin-gap) of these detectors to mitigate the degradation.
- Proof of concept of thin-gap MPGD with amplification structures has been established ➔ Up to 10 prototypes with triple-GEM and hybrid GEM-uRWELL, GEM-MMG amplifications were built and successfully tested in beam at Fermilab in June 2023
- Significant improvement of spatial resolution performance of thin-gap MPGDs compared to standard 3-mm gap detectors was demonstrated for track at large angle with test beam data
- Efficiency above 90% was reached for 1-mm thin gap detectors with Ar/CO2 gas mixture ➔ triple-GEM or hybrid GEM-µRWELL thin-gap detectors allow high gain, optimization of the spatial resolution performance and stable operations.
- 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

# The Thin-gap MPGD (tg-MPGD) Consortium

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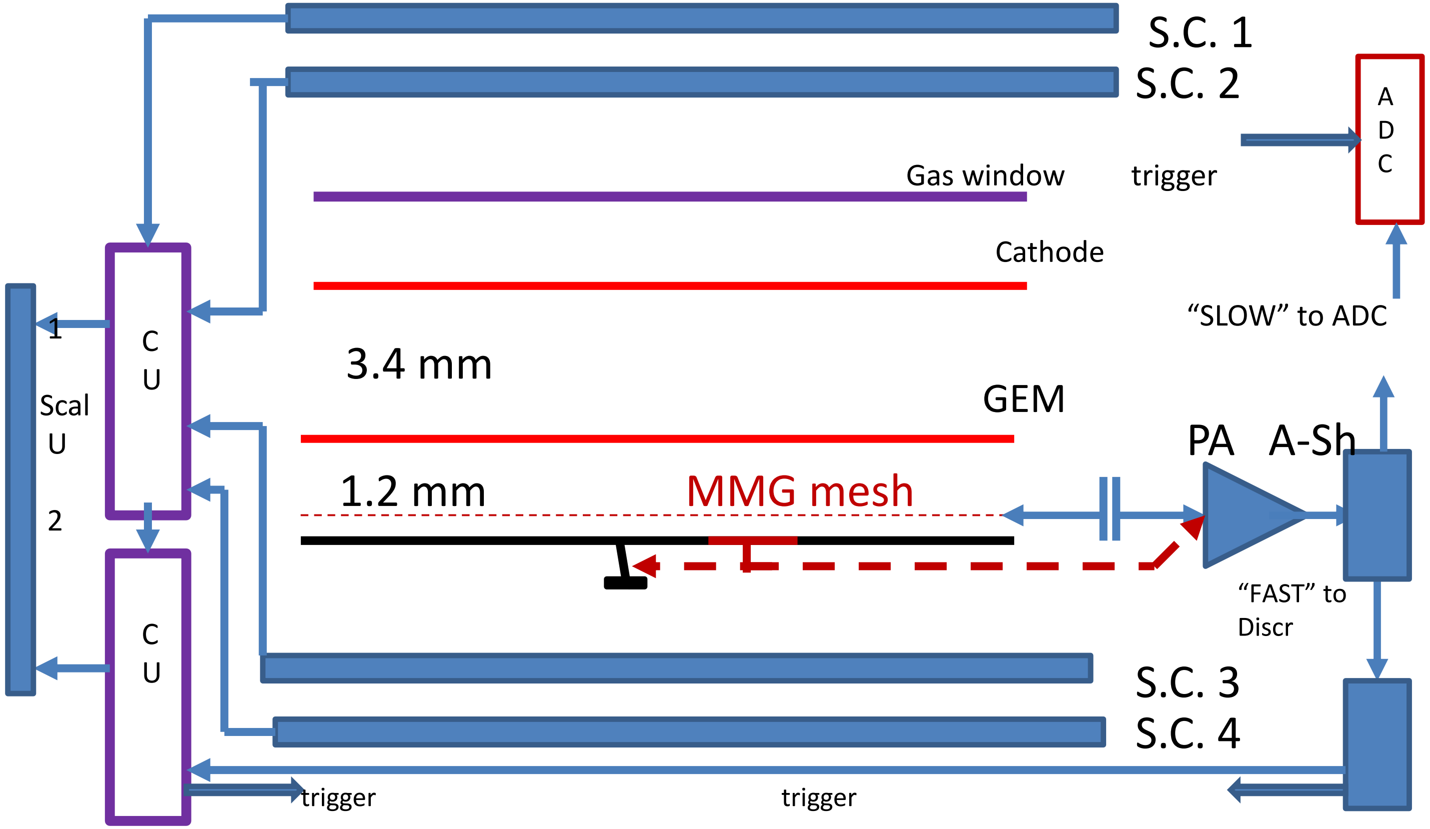
# Back up slides

# Yale prototype: Thin-gap Micromegas

- 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.

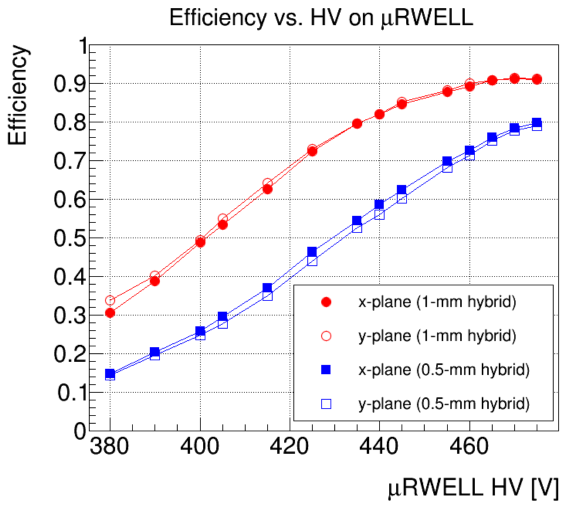
$$\frac{\text{Counts ratio Scal2 / Scal1 (1.2 mm)}}{\text{Counts ration Scal2 / Scal1 (3.4 mm)}} = 0.87$$

# JLab prototypes: Thin-gap GEM-µRWELLs

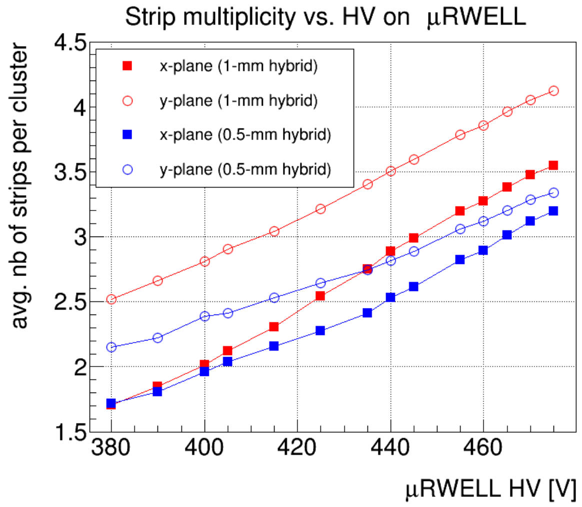
## µRWELL HV scan

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

**Efficiency**



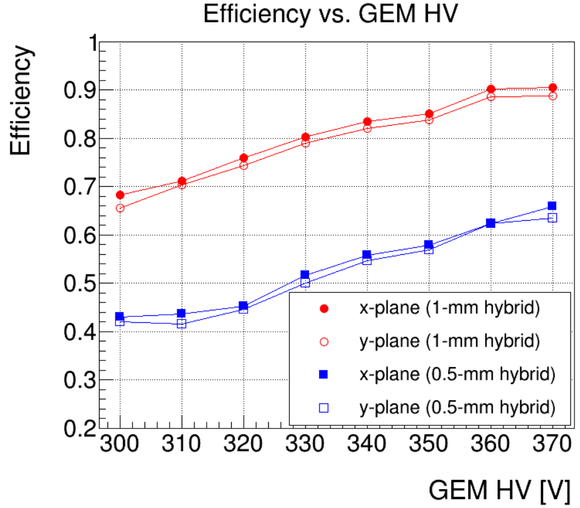

**Strip multiplicity**




## GEM HV scan

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

**Efficiency**

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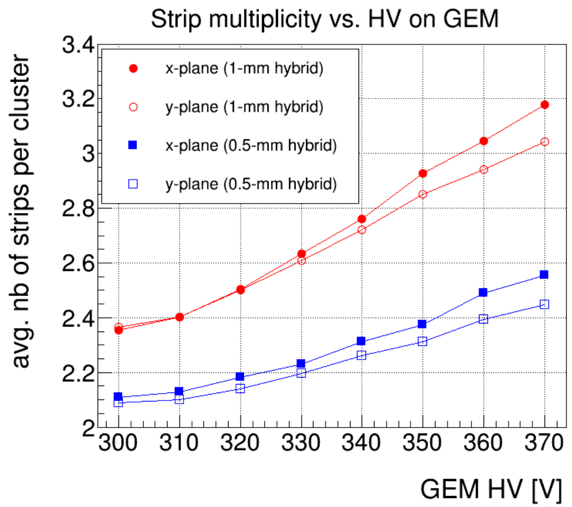
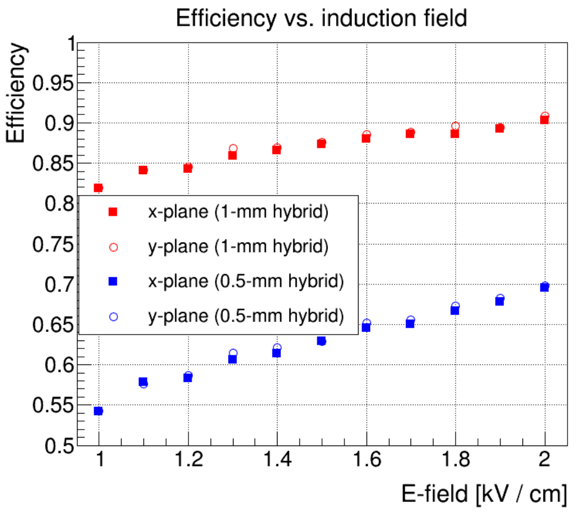


# JLab prototypes: Thin-gap GEM-μRWELLs

## Induction E-field scan

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

**Efficiency**

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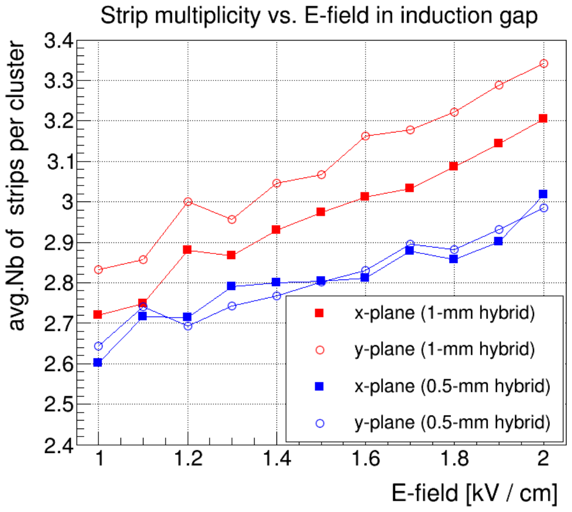
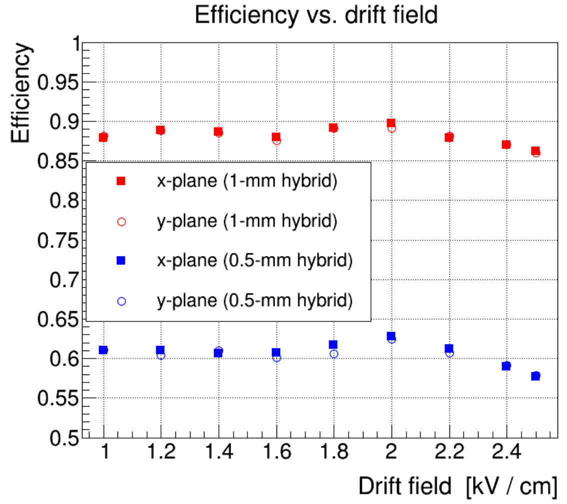



## Drift E-field scan

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

**Efficiency**




**Strip multiplicity**