eRD108: MPGDs for ePIC

FY23 Progress Report & FY24 Proposal

EIC Project R&D and DAC Meeting

M. Posik on behalf of eRD108 consortium

eRD108 Consortium

The eRD108 Consortium

Project ID: eRD108

Project Name: Development of EIC ePIC MPGD Trackers.

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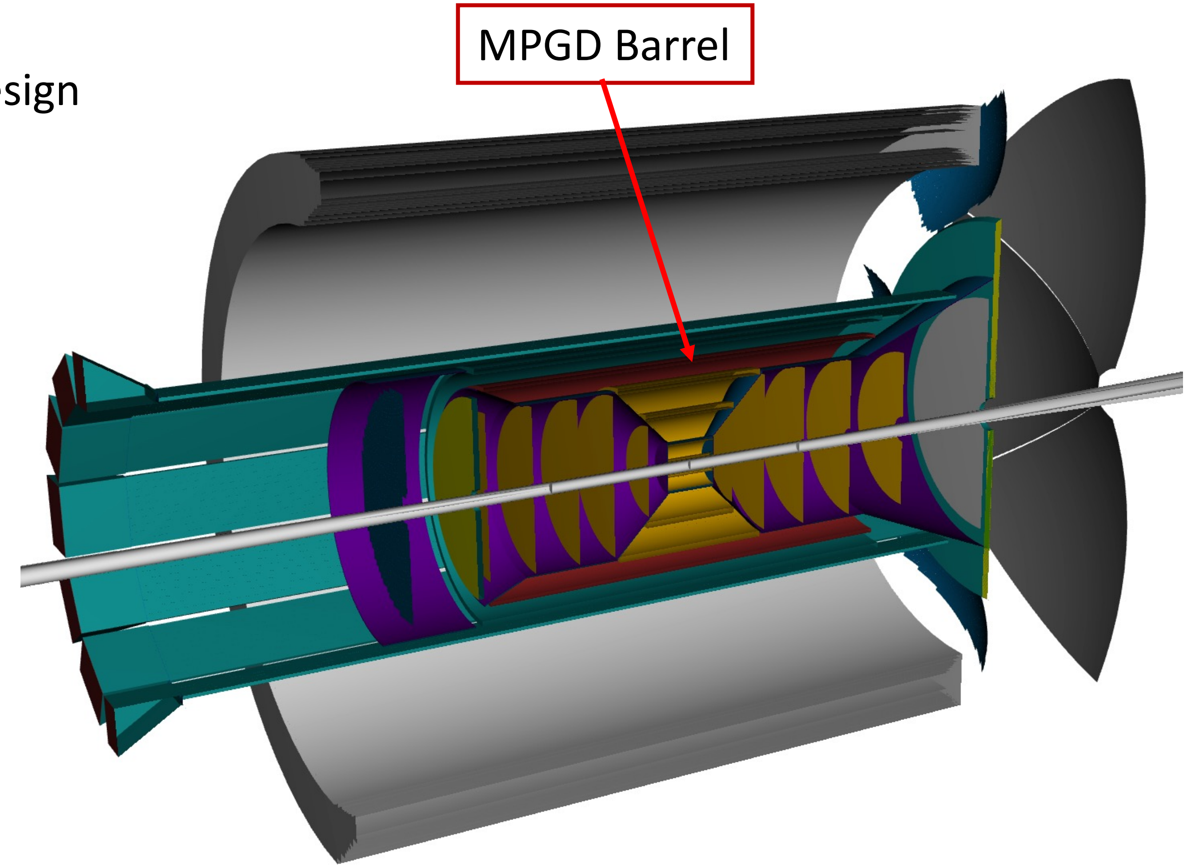
Report on FY23 Activity

- FY23 activity driven by now outdated detector reference design
  - Consisted of a single cylindrical MPGD layer
  - Reference detector was redesigned this past June



Previous reference tracker (pre-June)

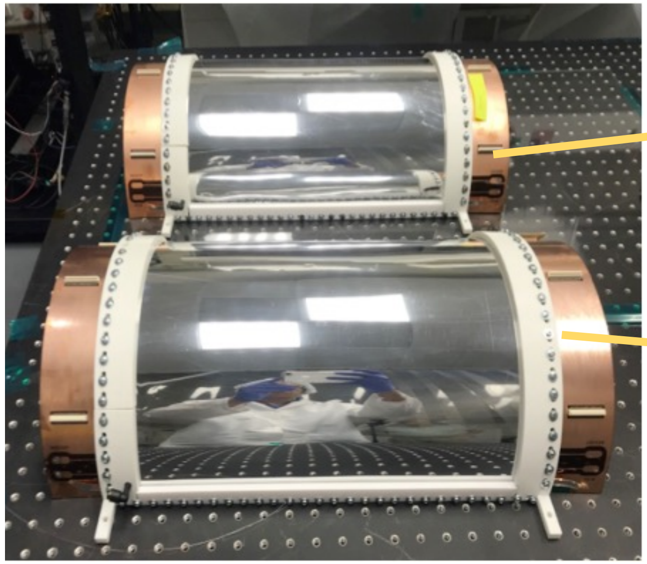
Report on FY23 Activity

- Planned to build **cylindrical $\mu RWELL$ prototype** as risk mitigation for cylindrical MicroMegas barrel.
  - Design of two composite $\mu RWELL$/2D-readout flexible PCBs (BNL, JLab)
  - Detector (active area)
    - Length = 38 cm,
    - Diameter = 26 cm
  - 3D print mechanical frame parts (FIT)
  - Final assembly of cylindrical prototype
  - Test beam at Fermilab
- Executed as planned

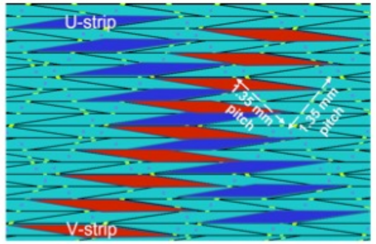
- Planned **cylindrical MicroMegas** R&D to upgrade the CLAS12 Micromegas technology to be 2D readout
- 2D readout optimization:
  - Design and build several small prototypes with different 2D-readout motives and different resistivity
  - Test beam at MAMI (Mainz)
  - Executed as planned
- Full scale prototype
  - Design, build and test a ~50x50cm^2 cylindrical prototype with the optimal 2D readout
  - Design and build a mock-up for a longer detector
  - Ongoing

Cylindrical $\mu RWELL$ Prototype: Assembly

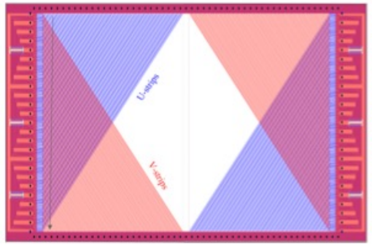
- Each half cylinder used capacitive-sharing readout strips with U-V geometry.
  - One with zigzag strips (BNL) and another with straight strips (JLab)
  - 3D-printed PLA mechanical support parts (FIT)



2D zig-zag U-V strip



2D Straight U-V strip



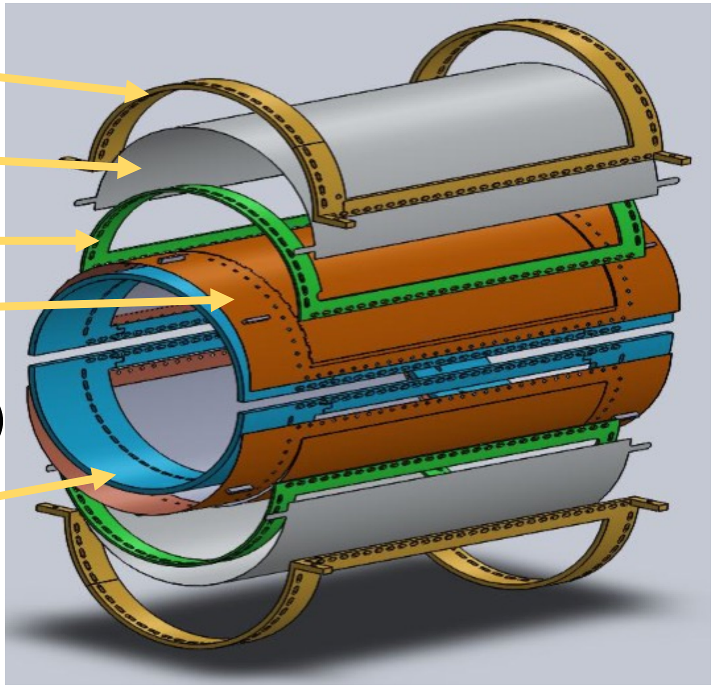
Outer Clamp

Cathode Foil

Main Frame

$\mu RWELL$-RO composite foil (w/FE connectors)

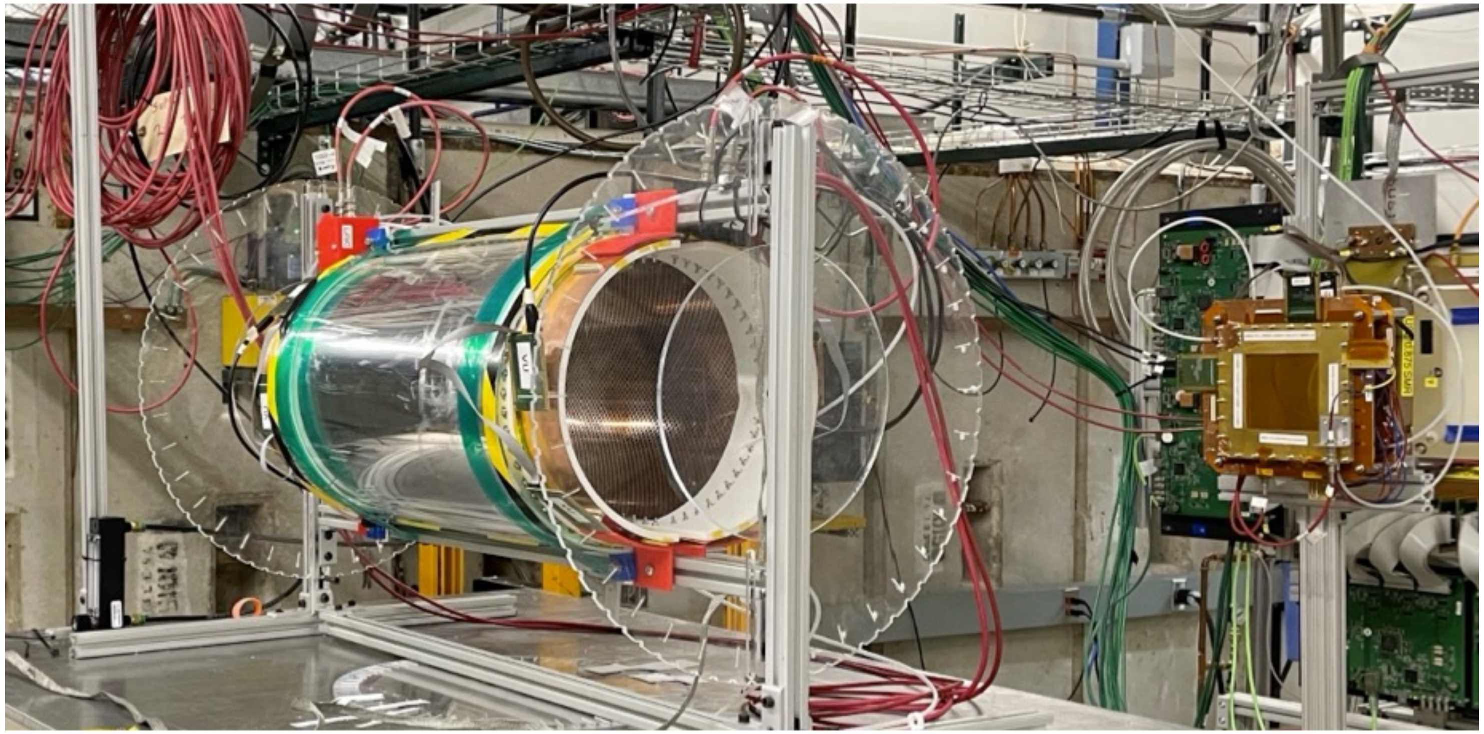
Inner Clamp



Cylindrical $\mu RWELL$ Prototype: Beam Test

- **June 2023 Fermilab Test Beam**
  - Two detector halves installed on a rotational mount
  - Placed in 120 GeV proton beam
  - 10 cm x 10 cm triple-GEM trackers upstream and downstream of cylinder to create a tracking telescope

- **Unable to collect data**
  - Discovered dents in drift foil, leading to compromised integrity of the drift gap.
  - Worked around this issue by increasing flow rate of the gas.
  - FNAL shut down beam activities (due to safety/security issues elsewhere at the lab) shortly after implementing the fix.
  - Assigned beam test period ended before beam could return

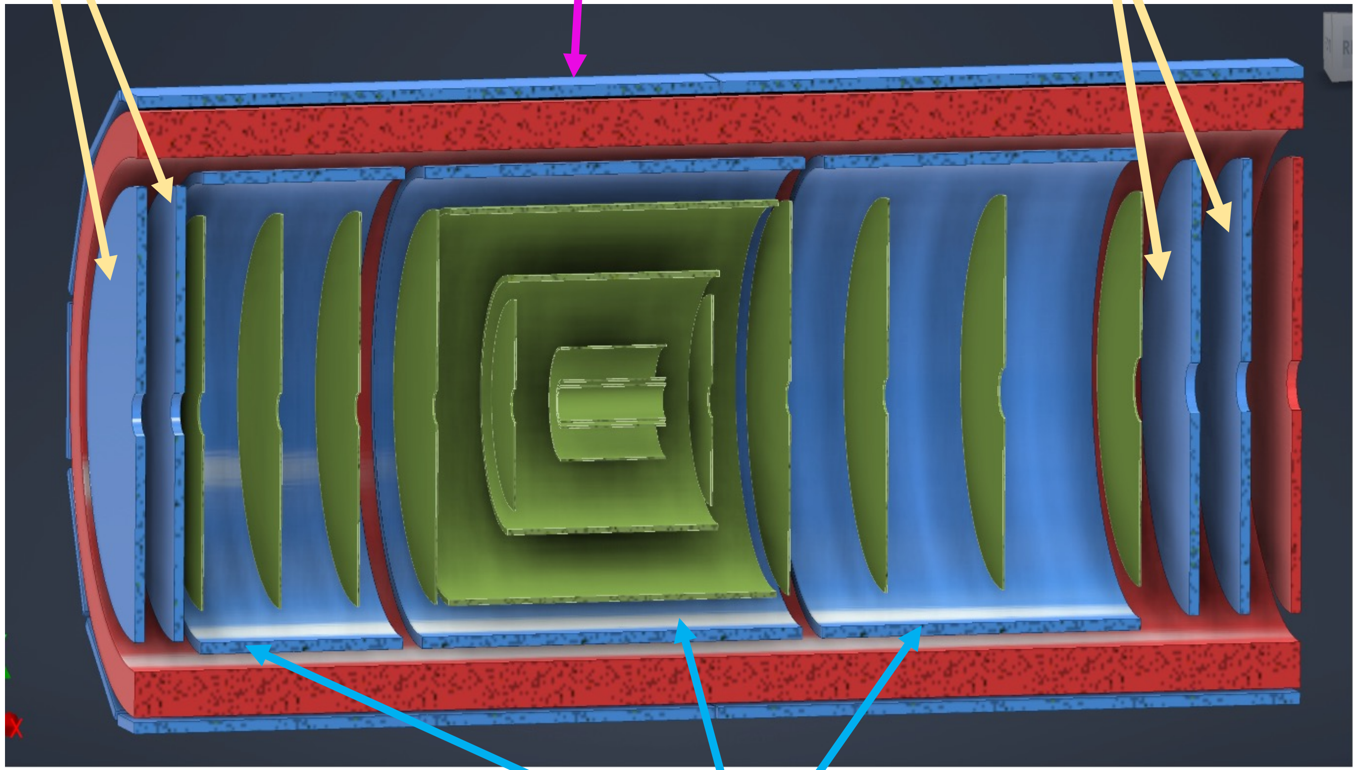


Cylindrical $\mu RWELL$ prototype installed in June 2023 test beam at Fermilab.

New ePIC Reference Detector

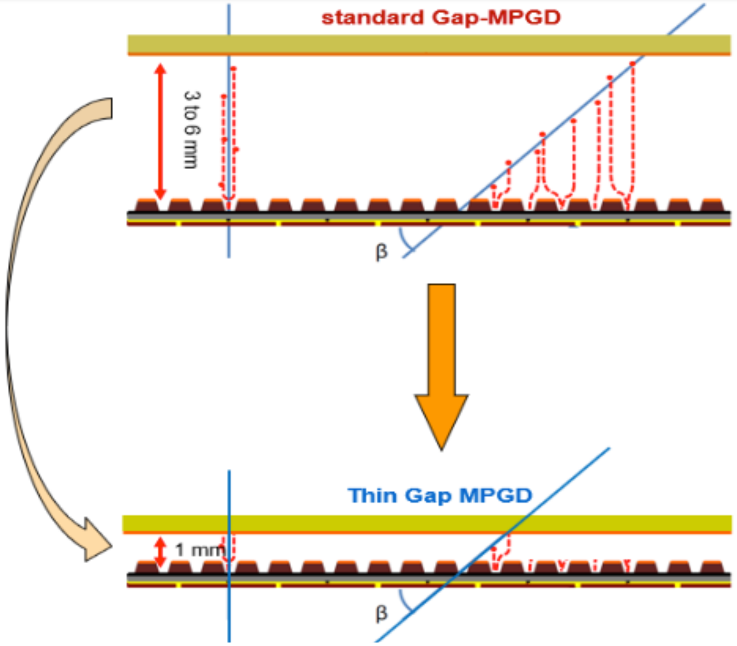
❑ Role of MPGDs in ePIC

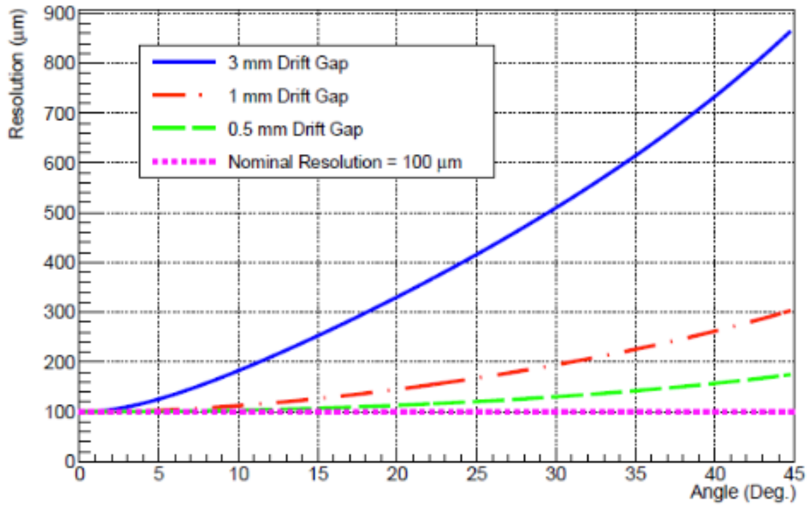
- Additional hit points for pattern recognition in track reconstruction
- Fast timing hits for signal/background discrimination (~10 ns)
- Implement enough fast-timing layers to form fast tracklets
- Provide precision hit point over large angular range in front of DIRC



Thin Gap Motivation

- **Motivation**
  - Incoming track at large angle: Ionization in drift volume generates signal on too many strips → spatial resolution limited by drift gap d for large angle tracks
  - Lorentz angle in high B field: Another source of degradation of the spatial resolution performance that depends on the drift volume
  - General issue for $\mu RWELL$ **and** Micromegas detectors
- **Proposed Solution**
  - Reducing the drift gap from 3 mm to $\lesssim$ 1mm is one approach to recover spatial resolution performance
  - Thin-Gap hybrid GEM-$\mu RWELL$ good candidate



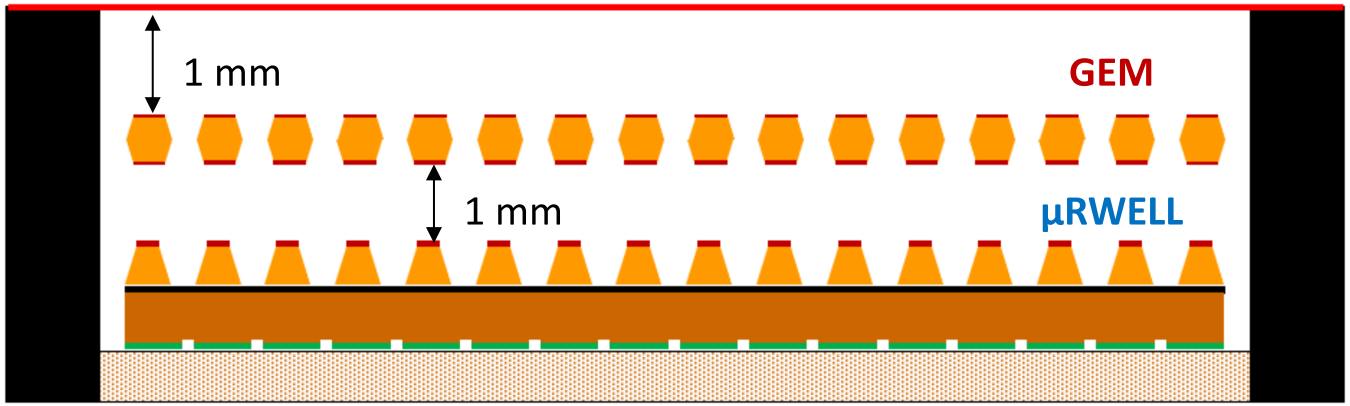


Spatial resolution v.s. track angle for various drift gaps

Thin-Gap Hybrid GEM-$\mu RWELL$

- Hybrid amplification (GEM+uRWELL) with GEM pre-amplification:
  - Large S/N to compensate for small number of primaries
  - Each device at lower HV ➔ safer operation voltage point
  - Safety margin for HV for unexpected issue with large detectors

Single hybrid thin-gap GEM-µRWELL



Options for Thin-Gap Hybrid GEM-$\mu RWELL$

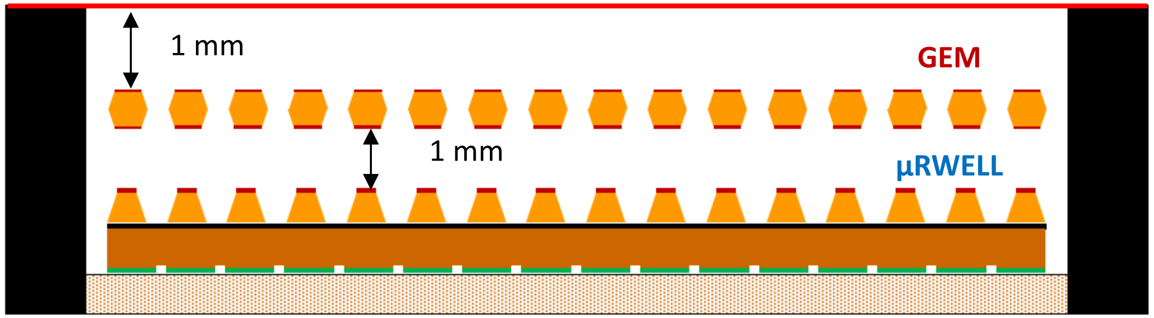
Hybrid thin-gap GEM-μRWELL with Xe-CO_2 mixture

- ❑ Single detector module but with hybrid amplification:
  - No need for double-sided detector
  - Single hit detection efficiency > 95% for 1 mm thin gap
  - No benefit for 2-hit capability

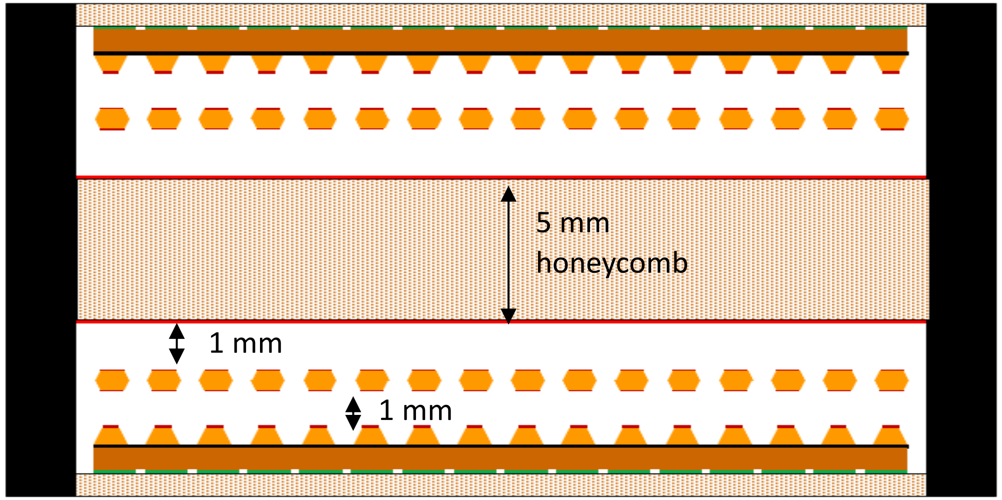
Double-sided hybrid thin-gap GEM-μRWELL with Ar-CO_2 gas

- ❑ Double-sided detector with common cathode support structure:
  - An OR of the two layers ensures a single hit detection efficiency > 98% despite short drift gap
  - An AND of the two layers gives a 2-hit detection efficiency ~ 72% ➔ tracklet for pattern recognition

Single hybrid thin-gap GEM-μRWELL (Xe/CO_2 mixture)

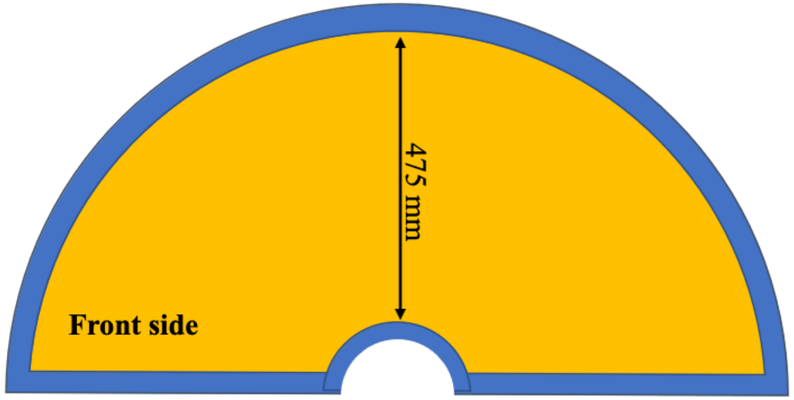


Double-sided hybrid Thin-Gap GEM-μRWELL (Ar/CO_2 mixture)



Endcap $\mu RWELL$

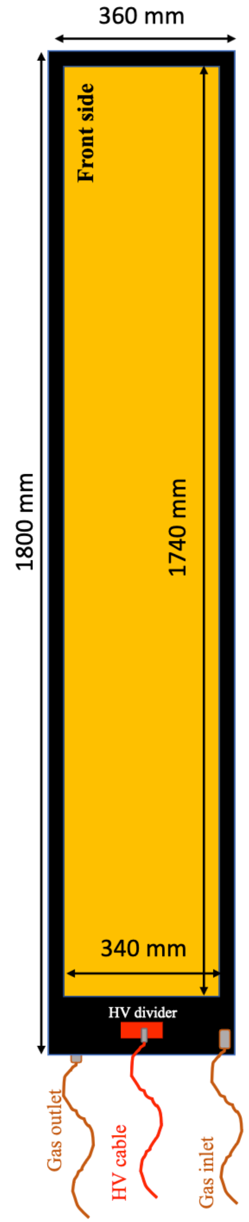
- **Endcap $\mu RWELL$ Readout Design (INFN and TU)**
  - Design a low-channel-count-2D readout for half-circular disk geometry
  - Investigate strip geometry and electronics location (on or off detector)
  - Perform circuit layout work for readout design



- **Endcap $\mu RWELL$ Mechanical Design (FIT and VU)**
  - Design, build, and test full-size ($R \approx 50\ cm$) mock-up prototype gas-envelope/foil support structures from light materials and test them for robustness.
    - Investigate how carbon fiber (CF) material can be used and how charging up of conductive CF material near HV electrodes can be avoided or mitigated and study stretching techniques (FIT).
    - Explore use of very thin FR4 with honeycomb sandwich and Delrin as gas enclosure and study stretching techniques (VU).

Outer Barrel $\mu RWELL$

- **Outer Barrel $\mu RWELL$ Design (JLab and UVa)**
  - Develop a full-size (30 cm x 150 cm) low-mass planar detector aimed at achieving high spatial resolution and efficiency using the hybrid GEM-$\mu RWELL$ technology.
  - Two main focuses:
    - Design and build a full-size mock-up prototype to address challenges related to stability of a large-size detector, while maintaining thin gaps ($\lesssim 1mm$) between drift, GEM, and $\mu RWELL$ layers.
    - Design a 2D $\mu RWELL$ readout that conforms to the mechanical design of the mock-up prototype.



Planar MPGD: Plan for FY24 and Outyears

- **Year #1: Targeted R&D – eRD108 FY24**
  - Design of the 2D readout structure of large thin-gap hybrid GEM-µRWELL prototype
  - Fabrication of mock-up prototypes to study mechanical structures, HV stabilities, gap uniformity, gas flowing structure
    - Full-size Outer Barrel Module and end cap disc with Cu-clad Kapton foils instead of uRWELL, GEM and readout foils
    - Investigate mechanical structures of support frame options (honeycomb, carbon fiber / FR4, w/ or w/o spacer …)
    - Perform HV stress test for 1 mm ionization and transfer gap with mock-up prototypes
  - Join the heavy gas (Xe, Kr) purification / recirculation effort by EIC Generic MPGD-TRD R&D consortium
    - Participate in joint beam test at Fermilab with TRD effort to test small scale gas recirculation system

- **Year #2: PED – Design and procurement of the parts for pre-production of full-size thin-gap hybrid GEM-µRWELL prototypes**
  - Design of all parts (2D readout structure, GEM and µRWELL foils) for large thin-gap hybrid GEM-µRWELL prototype
  - Design of the mechanical structure / support frames for the prototypes (End cap discs and Outer barrel modules)
  - Procurement of the uRWELL-R/O PCBs, GEM foils from CERN and the support frames from commercial vendors

- **Year #3: PED – Assembly and test of the pre-production full-size thin-gap hybrid GEM-µRWELL prototypes**
  - Assembly of the full-size (180 cm × 40 cm) Outer Barrel module prototype
  - Assembly of the full-size (100 cm × 50 cm) end cap half disc prototype
  - Test and characterization of the prototypes in institution labs (x-ray and cosmic tests, HV setting and gas system optimization)
  - Final test in beam test at Fermilab for efficiency / position resolution studies with various gas mixtures

Cylindrical Micromegas – Motivation

CyMBaL: Cylindrical Micromegas Barrel Layer

Motivation

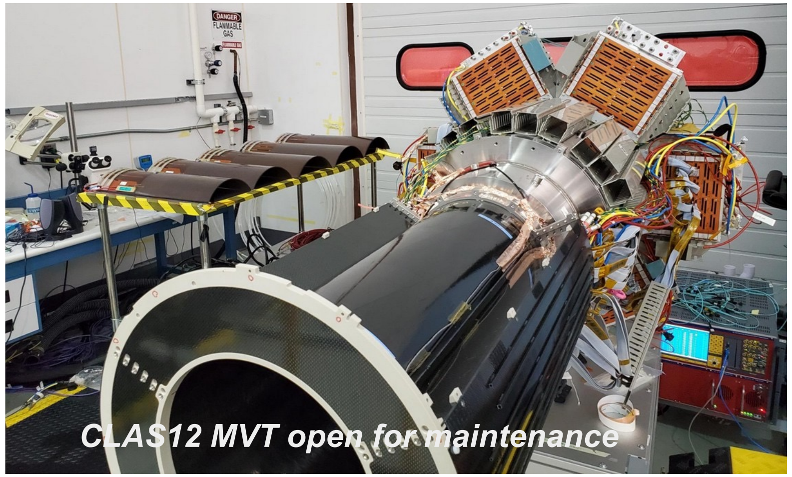
- Build a full (no acceptance gaps) light-weight modular Micromegas barrel layer to complement the silicon vertex detector

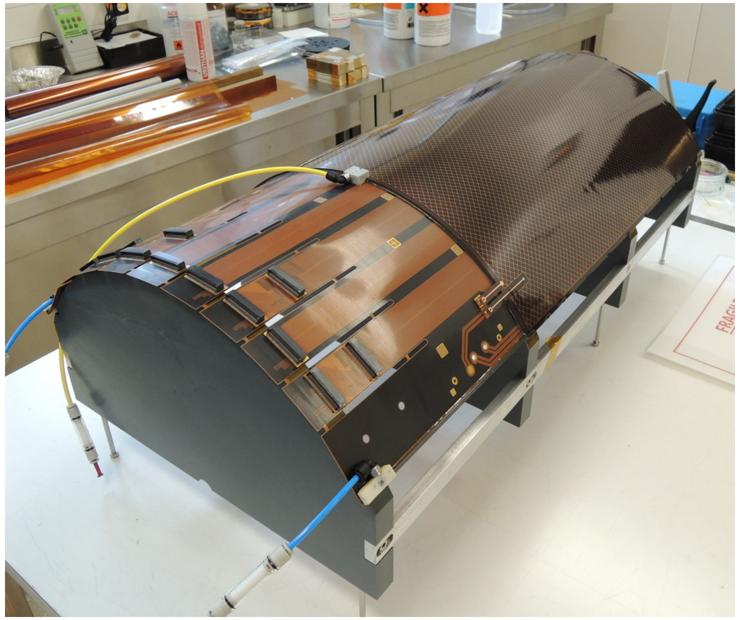
CLAS12 MM Technology

- Compact cylindrical tracker in a **B=5T solenoid**, total active area ~4m^2.
- Light cylindrical tiles (**~0.4% X0 per layer**)
- 1D readout per tile (either phi or z coordinates)
- Six layers in about 10 cm of space with **tiles of different size,** active area ~40x40cm^2
- **Taking data since 2017**

Upgrades to fit the EIC needs:

- **Simpler construction:**
  - Few basic small modules, possibly **just one module**
  - overlap tiles for no acceptance gaps
- **2D readout**
  - Resolutions ~150 µm, on both directions
  - Keeping the channel count as low as possible

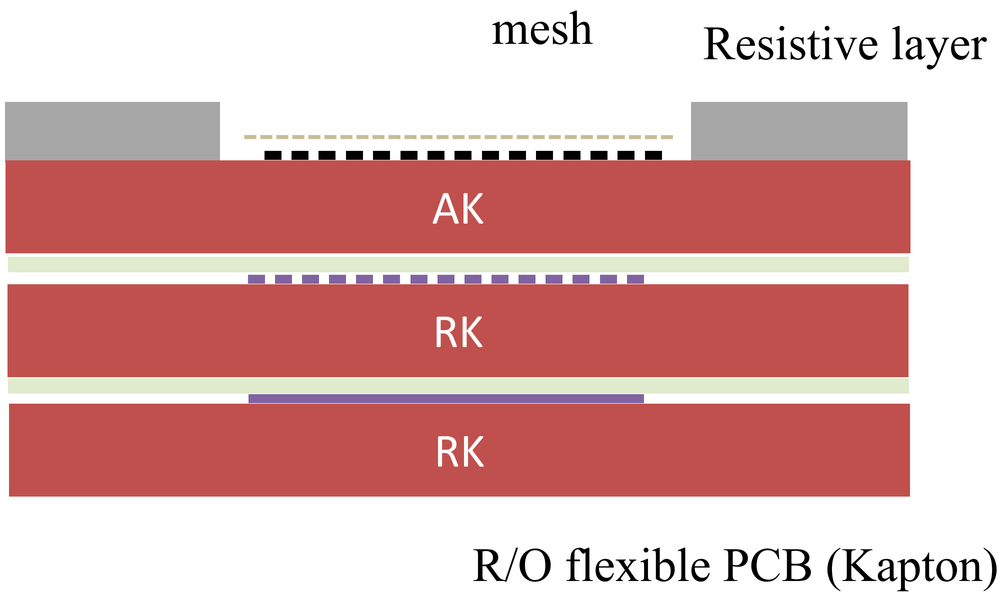


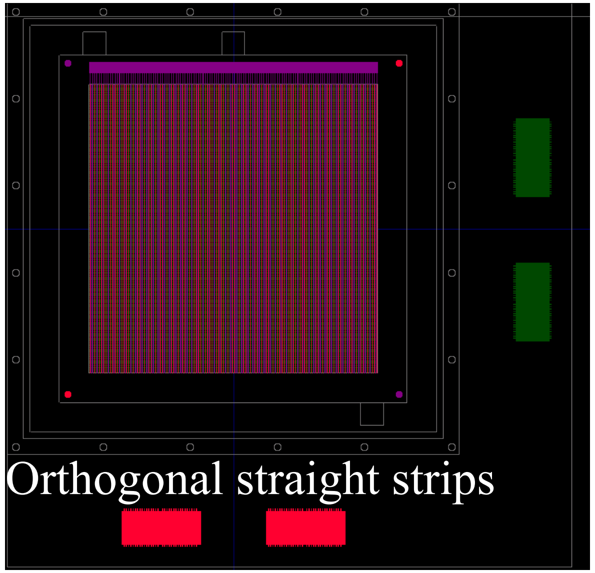


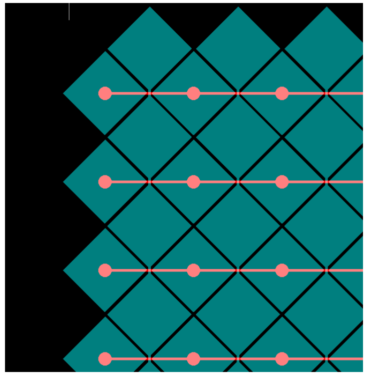
Cylindrical Micromegas – 2D R&D

R&D 2D readout

- Built several small prototypes ~12x12 cm^2
- Multi stack for easy combination of different options:
  - AK: Amplification Kapton
    - Vary the resistivity, the shape, …
  - RK: Readout Kapton
    - Different strip pitch and patterns
- Stretched Kapton MM bulk
  - Very low material budget (~0.2% X0)

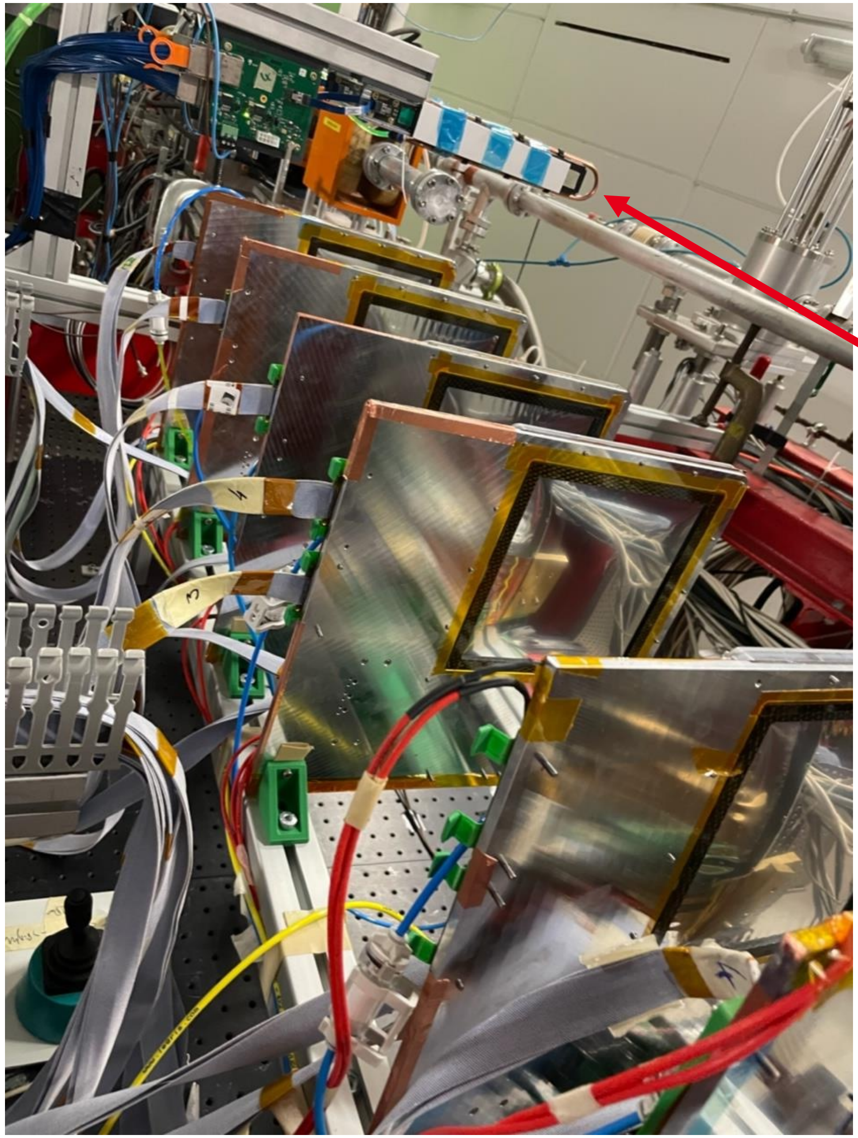




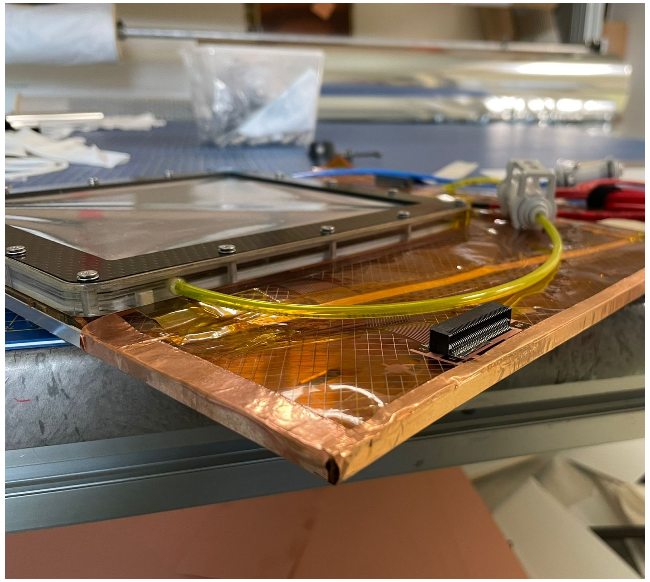


2D ASACUSA-like

Cylindrical Micromegas – 2D R&D

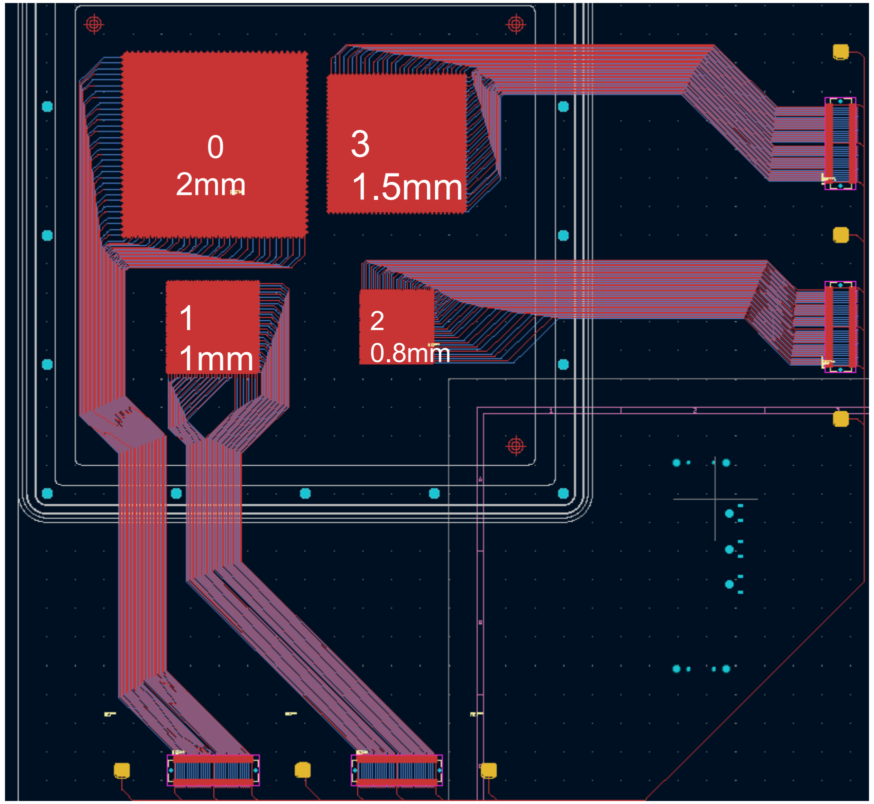


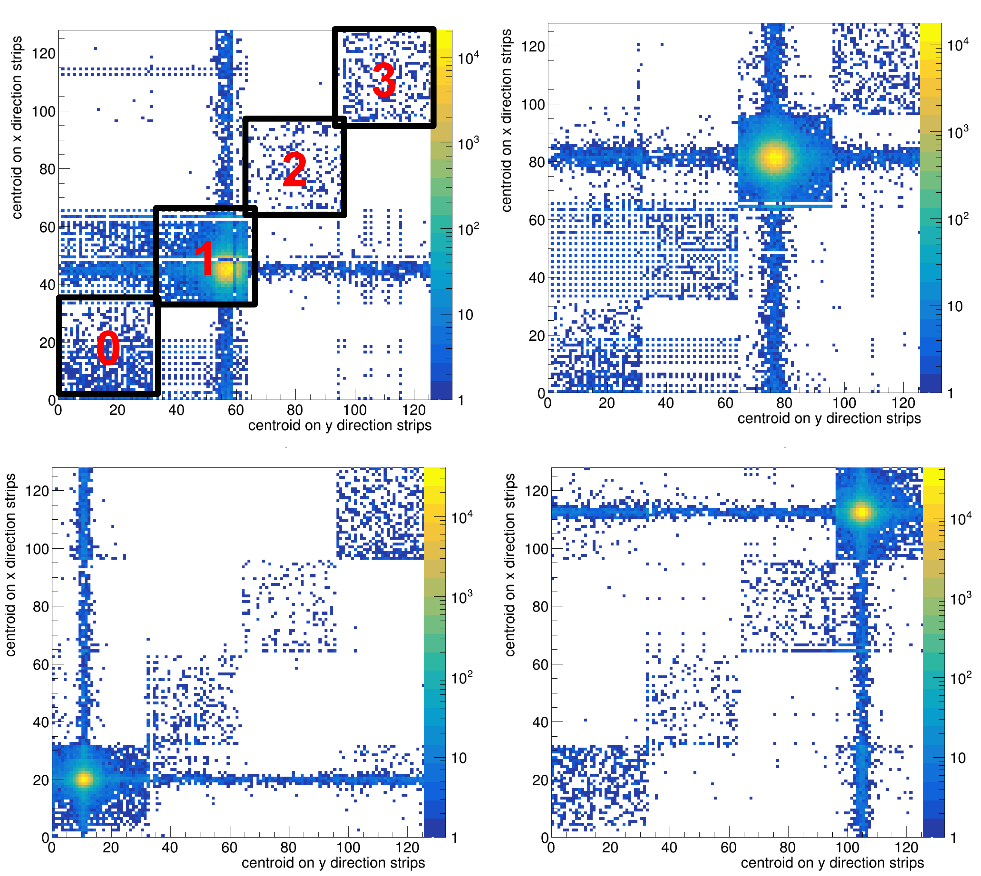
- Beam test of about one week in June ‘23 in Mainz at MAMI
- In synergy with the R&D for the P2 experiment
- Tested several small Micromegas and µRWELL prototypes
- Low material budget: ~0.2% X0 in the active region
- Reference tracker: 4 layers of ALPIDE sensors (from ALICE MFT) assembled in Saclay
- Analysis is ongoing

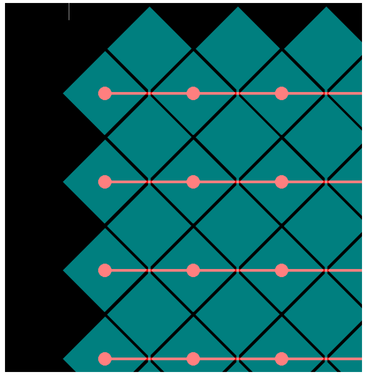


Cylindrical Micromegas – 2D R&D

- Analysis of the beam test data ongoing
- Here, just an example of the ASACUSA pattern data during the beam position scan







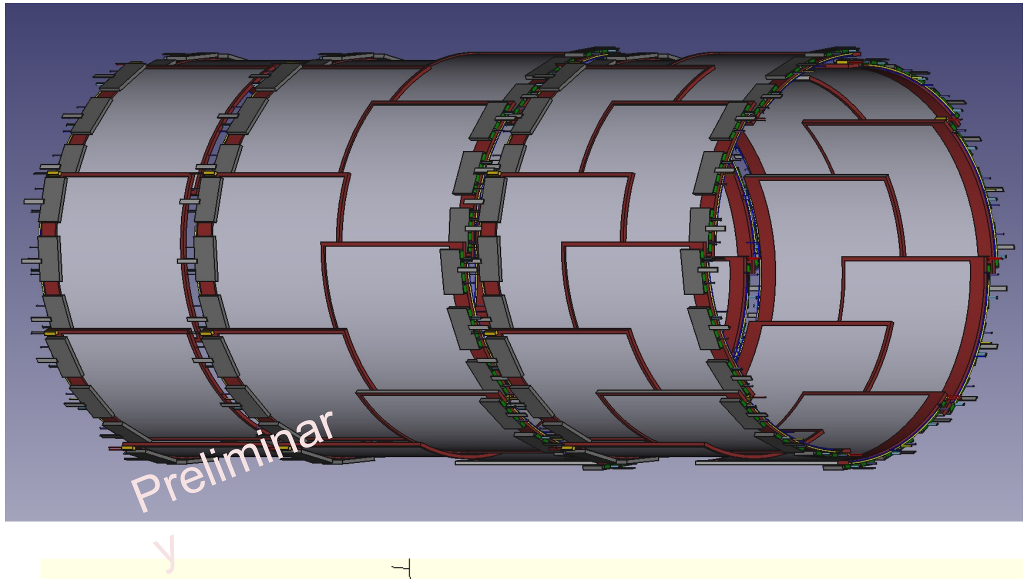
Cylindrical Micromegas – Full scale prototype

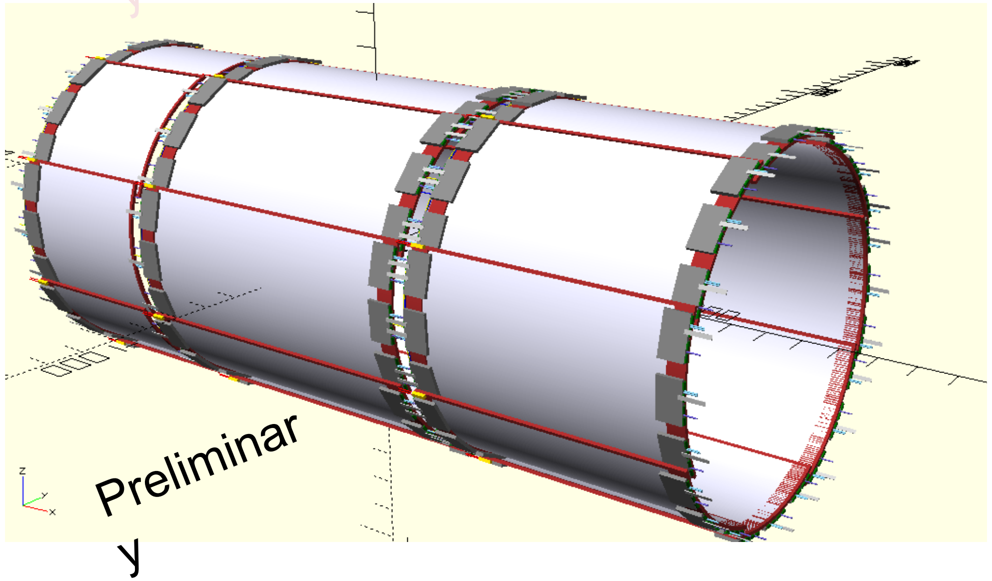
- ❑ With the new ePIC MPGD configuration, the cylindrical barrel can either be tiled with one ~50x50 cm^2 module or with longer modules that fit individually the three regions

- ❑ **Full scale prototype:**
  - Build and test a 2D readout prototype with an active area ~50x50 cm^2
  - Reuse CLAS12 CAD designs to minimize effort
  - Refurbishment of tooling ongoing, in particular the tensioning system for the mesh

- ❑ **Longer mock-up:**
  - Design ongoing to build a mechanical mock-up with dimensions ~50x90 cm^2, with radius of 50 cm
  - Tests with gas

- ❑ Completion expected by mid 2024

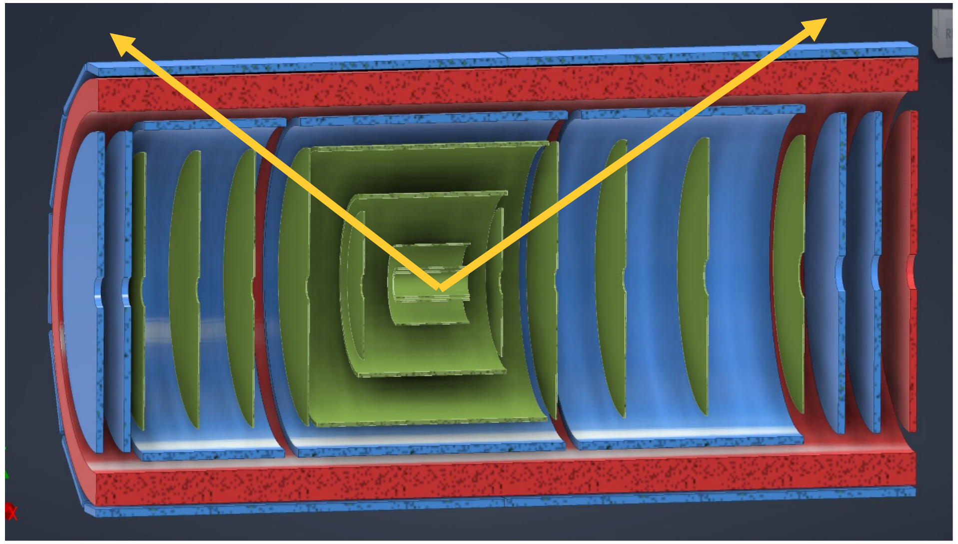




Cylindrical Micromegas – FY24 requests

Motivation:

- ❑ Particularly in the forward and backward section of the cylindrical MPGD layer, particles will cross with large angles (> 45deg)
- ❑ **Consequences:**
  - Degradation of the spatial resolution
  - Larger multiple scattering
- ❑ **Mitigation strategy:**
  - Recover the spatial resolution with a small conversion gap of ~1 mm
  - Reduce the material budget of the support
- ❑ **Proposed R&D:**
  - Build a small prototype with a 1 mm gap to test different gas mixtures (in collaboration with Yale U.)
  - Design and test a light carbon fiber structure as a replacement of the FR4 component of the readout PCB



FY24 Budget Request

Budget Request Justification

- **Endcap $\mu RWELL$ half-disc mock-up:**
  - Material costs
  - Partial support of graduate student (for INFN and FIT)
- **Outer Barrel $\mu RWELL$ mock-up:**
  - Material costs
  - Support of graduate student (UVa)
  - Labor (JLab)
- **Inner Barrel:**
  - Material costs

Includes overheads and IDCs Detailed Breakdown

Institution	Endcap	Inner Barrel	Outer Barrel	Total per institution
BNL	-	-	-	$0
FIT	$36,218	-	-	$36,218
INFN	$25,000	-	-	$25,000
JLab	-	-	$22,500	$22,500
Saclay	-	$35,000	-	$35,000
TU	-	-	-	$0
UVA	-	-	$46,515	$46,515
VU	$14,925	-	-	$14,925
TOTAL	$76,143	$35,000	$69,015	$180,158