eRD108: MPGDs for ePIC

FY22 Progress Report & FY23 Proposal

EIC PROJECT R&D AND DETECTOR ADVISORY COMMITTEE (DAC) MEETING

Kondo Gnanvo on behalf of eRD108 Consortium

October 19, 2022

Outline

- Progress report on ongoing activities
- R&D focus of FY23 proposal
- Timeline & Milestone
- Open R&D questions toward CD-3

The eRD108 Consortium

Project ID: eRD108

Project Name: R&D on cylindrical and planar MPGDs towards an EIC detector

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EIC requirements for MPGDs: FY22 vs. FY23 proposals

MPGDs requirements	3 EIC detector proposals – (then in 09/2021)	EPIC detector (now in 09/2022)
Barrel Trackers	Cylindrical MPGDs - Curve tiles modules • Micromegas for ATHENA (70 µm) • µRWELL for ECCE (55 µm) • Multiple layers • **Low mass critical for momentum resolution**	Cylindrical Micromegas - Curve tile modules • Multiple layers • **Pattern recognition layer** • Fallback option: MPGD in **µ-TPC mode**
hpDIRC layer	Cylindrical µRWELL (ATHENA, ECCE) • Spatial resolution (<100 µm) • No low mass requirement	Planar µRWELL (Micromegas) • Spatial resolution (< 100 µm) • **Thin gap MPGD ➔** hybrid µRWELL-GEM? • No low mass requirement
dRICH layer	Planar µRWELL disks / GEM (ATHENA, CORE) • Trapezoidal modules • Spatial resolution (100 µm) • No low mass requirement	Planar µRWELL disks (GEM / Micromegas) • Trapezoidal modules • Spatial resolution (100 µm) • **Thin gap MPGD ➔** hybrid µRWELL-GEM? • No low mass requirement
Hadron endcap layer	Planar µRWELL disks / GEM (ATHENA) • Trapezoidal modules • Spatial resolution (70 µm) • **Low mass critical**	**N/A**

eRD108 - FY22 proposal: Development of Cylindrical MPGDs

https://wiki.bnl.gov/conferences/images/c/c9/ERD108_Proposal_update20210918.pdf

- **Two very distinct motivations for cylindrical MPGD R&D for EIC detector:**
  1. a single cylindrical µRWELL layer directly in front of (and behind) the DIRC subdetector
     - Provide precise directional information to help seed the DIRC Cherenkov ring reconstruction
     - Tracking layer needed in all 3 EIC detector concepts **(ECCE, CORE & ATHENA-all-Si)**
  2. several cylindrical Micromegas (MM) detector layers to create a central barrel tracker
     - This is a MPGD of choice for the **ATHENA-Hybrid Tracking** subdetector in the barrel region
     - Development of low mass detector (< 0.5% r.l.) is critical.
- **Different applications & different R&D focus**
  - The R&D focus mean that the two technologies are not to be considered interchangeable
  - Both R&D projects share common goal for development / optimization of 2D readout patterns for MPGDs.

Funding delay and its impact on FY22 R&D progress:

- The scope and progress of our R&D program for FY22 has been severely impacted by the late availability of the funding in **mid-August 2022**
- This has delayed the various efforts by an equal amount of time and limited them to design work only so far
- **The delay affected even more the timely funding for grad students who are critical for the successful outcome of the R&D effort**

eRD108 - FY23 proposal : **ePIC** focused R&D on MPGDs

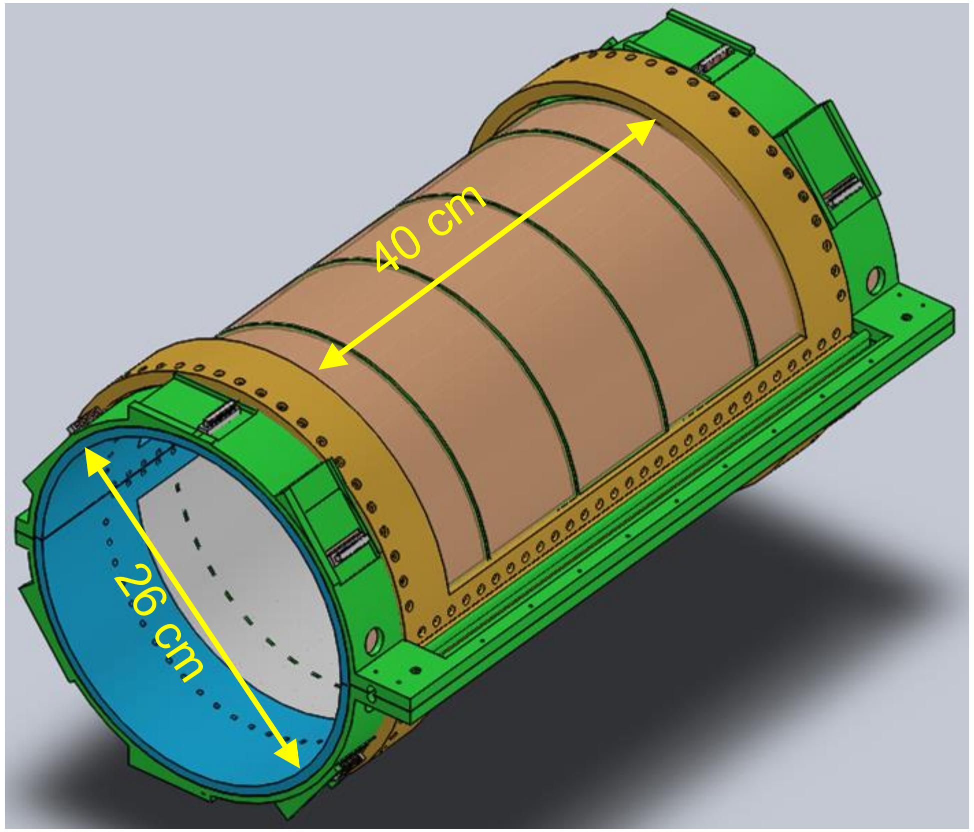
https://wiki.bnl.gov/eic/upload/ERD108_Proposal_FY23.pdf

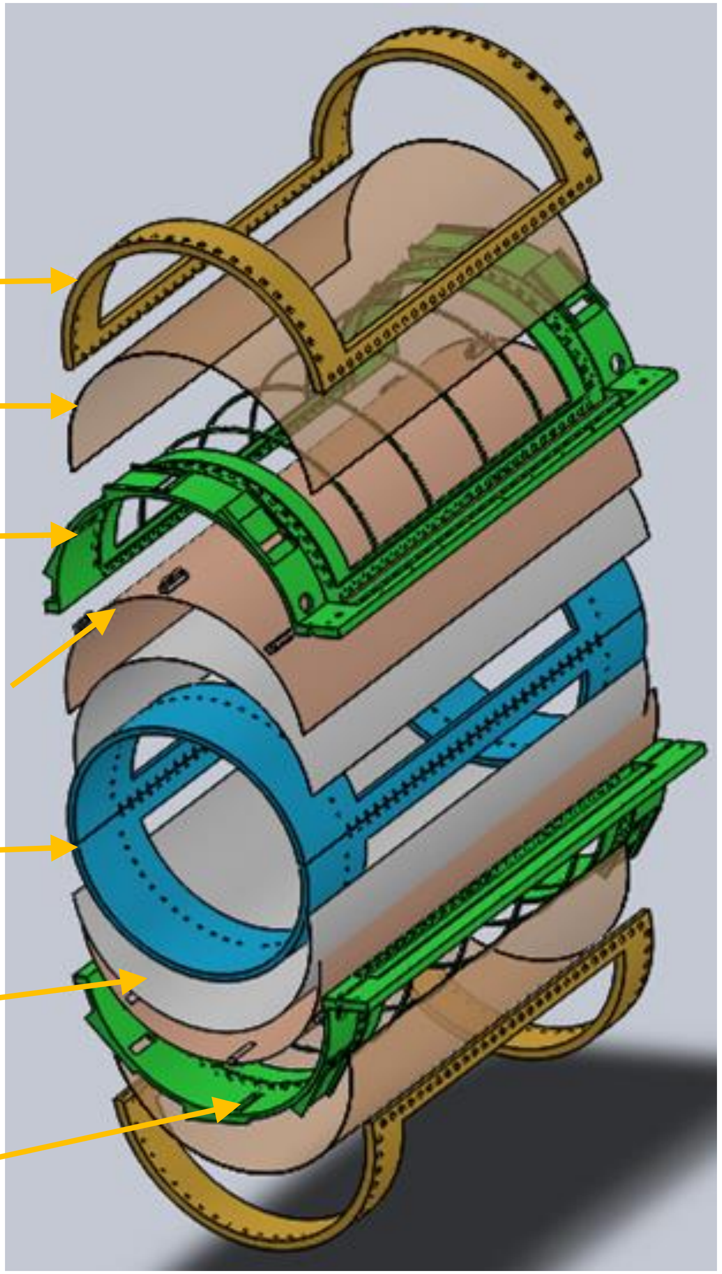
1. **Development of cylindrical MPGD for ePIC central tracker:**
   - ❖ **Ongoing effort:** Standard cylindrical MPGD with ~3 mm drift gap ➔ single space point detector
     - ▪ Technology of choice: Micromegas (CEA Saclay, Yale U. BNL)
     - ▪ Fall back technology: µRWELL (Florida Tech, BNL, JLab, Temple U)
     - ▪ R&D focus: Large area, low mass, 2D readout structures, full cylindrical / curved tiles modules
   - ❖ **Alternative approach:** Cylindrical MPGD in µ-TPC mode ➔ vector information of the track
     - ▪ Attractive option for the pattern recognition layer in the central barrel tracker
       - ➔ Single detector provide vector information of the track rather than single point
     - ▪ R&D focus: Demonstrate the proof of concept with a small cylindrical prototype
2. **Development of planar Thin Gap MPGDs (tg-MPGDs) for hpDIRC tracking layer**
   - ❖ Address the issue of degradation of MPGD spatial resolution for large angle tracks and in high magnetic field
   - ❖ Technology of choice: µRWELL, hybrid amplification GEM-µRWELL (JLab, Temple U., Vanderbilt U., UVa)
   - ❖ Fall back option: Micromegas (Yale U.)
   - ❖ R&D focus: Proof of concept with single and hybrid amplification tg-MPGDs with various gas mixtures
   - ❖ Same technology will be proposed for potential layers behind dRICH or mRICH in the end cap regions

Progress Report: R&D on Cylindrical µRWELL

Design of mechanical support of the cylindrical µRWELL prototype with 3mm drift gap

- Prototype consists of 2 half-cylinder chambers with different readout structures
  - **CapaSh-uRWELL:** uRWELL/readout foil with U-V capacitive-sharing readout
  - **Zigzag-uRWELL:** uRWELL/readout foil with U-V :zigzag" readout structure
- Design of mechanical structure completed with a set of 3 of frames per chamber





Outer clamp

Cathode foil

Main frame

µRWELL-R/O composite foil (w/ FE connectors)

Inner clamp

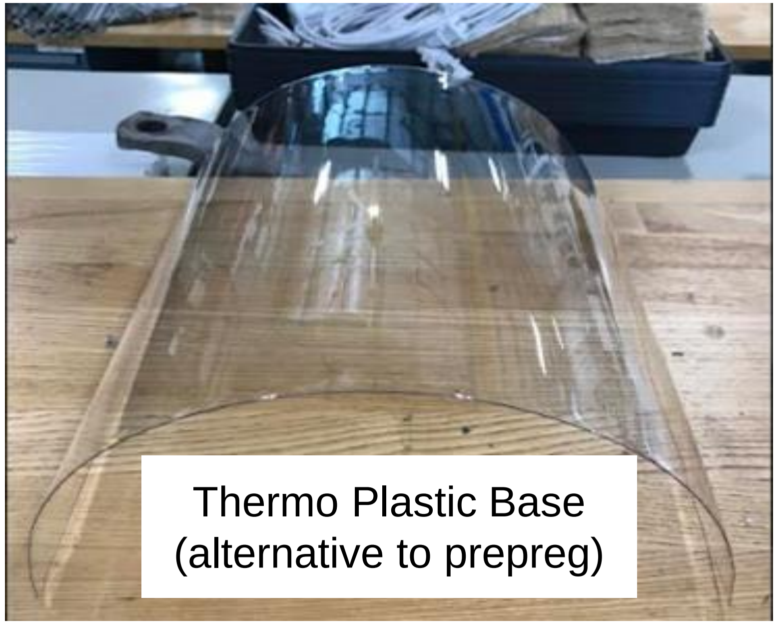
Prepreg base (0.2-1mm thick)

Support for FE cards

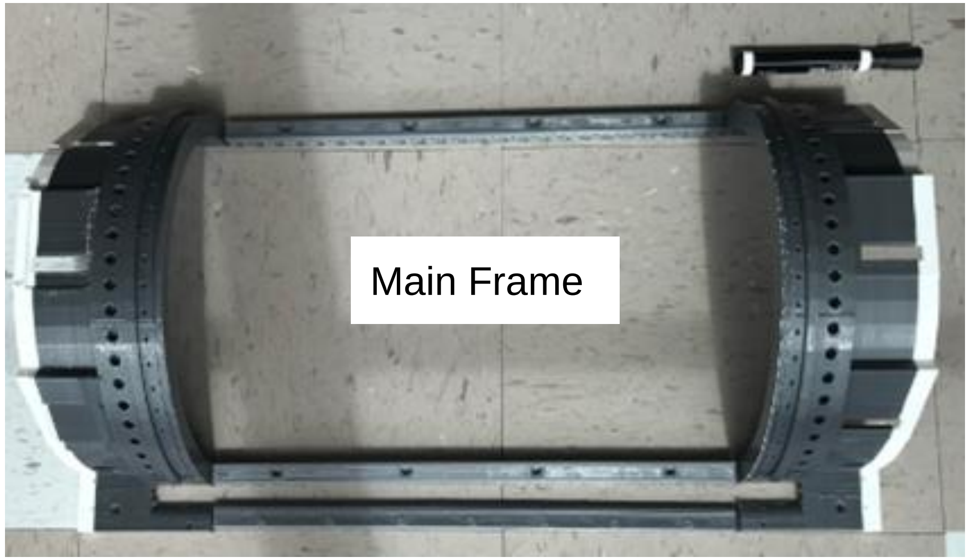
Progress Report: R&D on Cylindrical µRWELL

Very Early 3D-Printed Prototypes

Mock-up assembly of a half-cylinder with the inner & outer clamps, the main frame, and a Kapton “drift” foil



Thermo Plastic Base (alternative to prepreg)



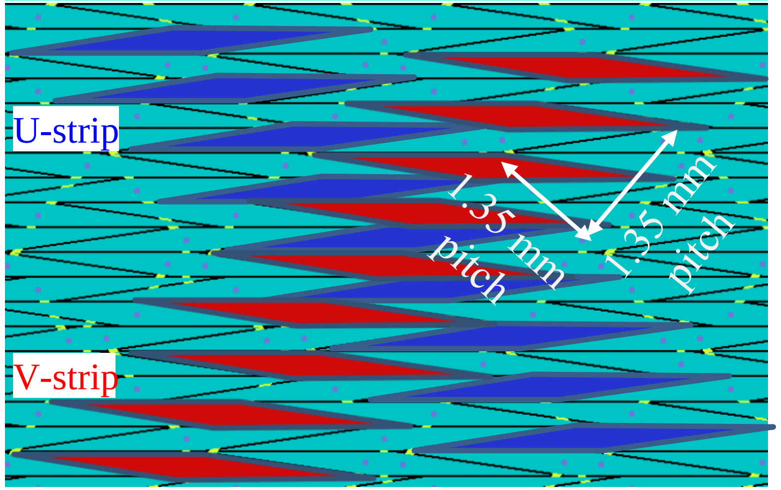
Main Frame

Progress Report: R&D on Cylindrical µRWELL

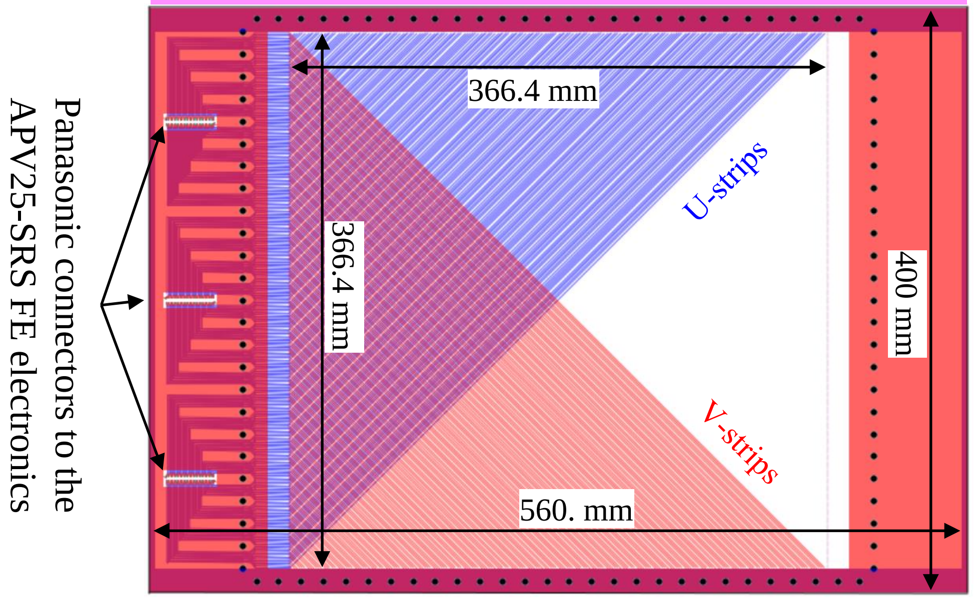
Design of uRWELL / 2D readout composite foil structures

- Single foil design, same µRWELL amplification, two different U-V readout structures
  - 2D zigzag readout @ BNL and
  - Capacitive-sharing straight strip @ JLab
- Common readout template design ➔ only U-V strip structures in active area is different
  - Strip pitch: 1.35 mm ➔ total of 768 strips / half cylinder
  - **Target**: Nominal space point resolution **better than** 100 µm for perpendicular tracks
- Each µRWELL-R/O composite foil to instrument half of the cylindrical µRWELL prototype

U-V zigzag readout concept (BNL)



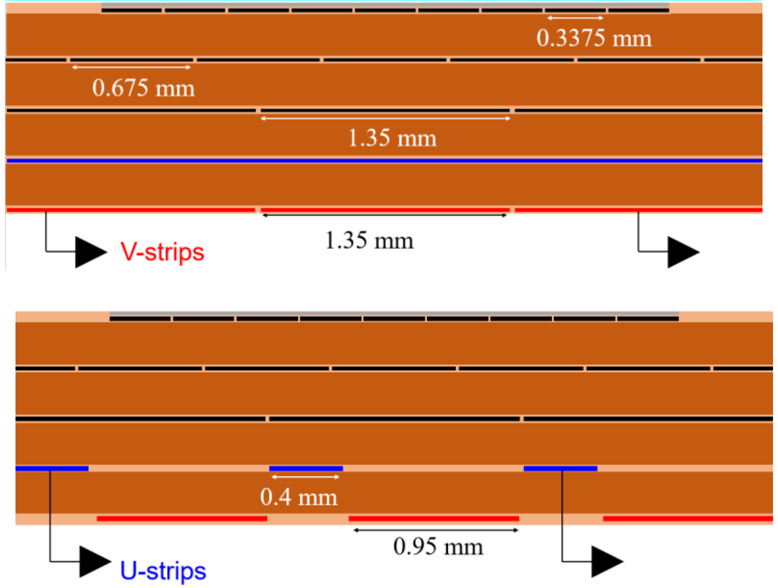
common U-V readout template design



Status & timeline

- Pre-design of the template completed
- Design of full uRWELL / readout started (completed by **11/15/2022)**
- Production of the two foils at CERN **(delivery expected by 04/2023)**
- Assembly and preliminary test of the cyl. prototype **(Florida Tech – 05/2023)**
- Final tests in beam at **FNAL in 06/2023**

capacitive-sharing readout concept (JLab)



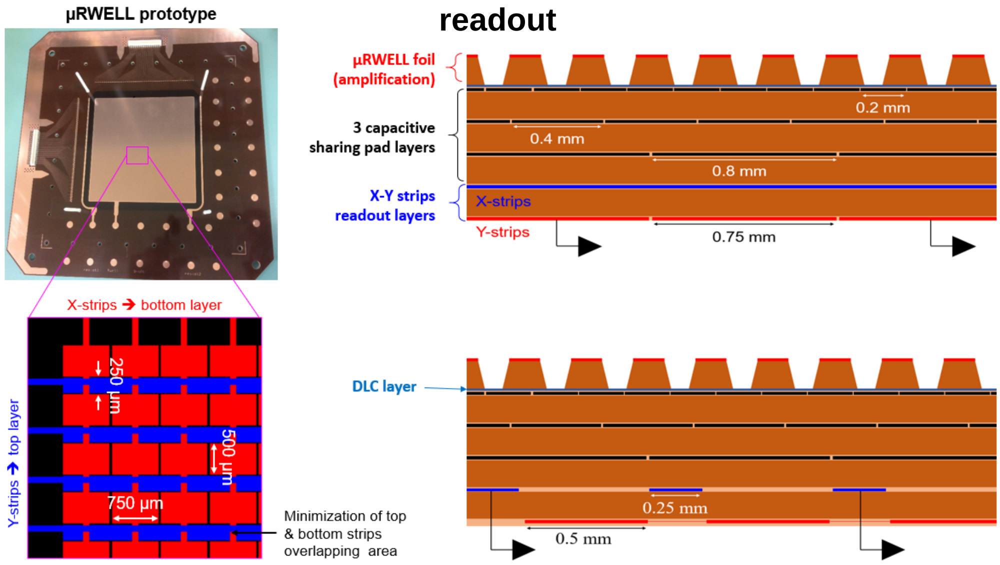
Progress Report: R&D on small µRWELL prototype

Jefferson Lab

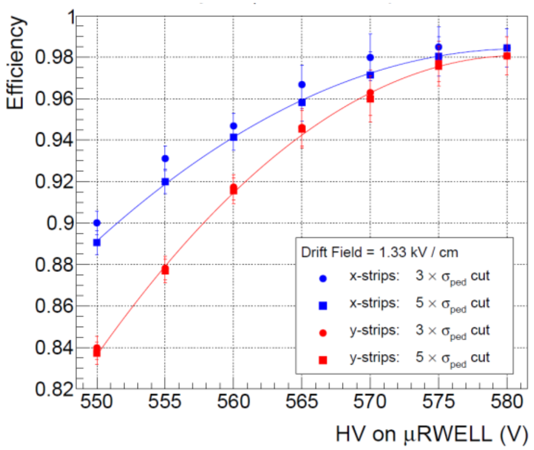
Performance of small µRWELL prototype with capacitive-sharing readout

- Small 10 cm x 10 cm CapaSh-µRWELL prototype with 3 mm drift
- 3-layer stack capacitive sharing strip readout ➔ black pads on cross-section view
- X-strips and Y-strips on different layers separated by 50 µm. Kapton foil ➔ Signal on top and bottom strip collected through capacitive coupling: strip pitch = 800 µm
- Beam test in Hall D Pair Spectrometer electron arm @ JLab with 3 – 6 GeV electrons
- Spatial resolution performances
  - Tracking residuals in x and y **before** track fit correction. $\sigma^{res}_{X(Y)}$ = 63 µm
  - Spatial resolution **after** track fit corrections in x and y **$\sigma_{X(Y)}$ = 59 µm**
- Efficiency ~98% at 575 V in Ar-CO2 70/30
- Cluster multiplicity > 3 in both x and y in large HV range (550V to 580 V)

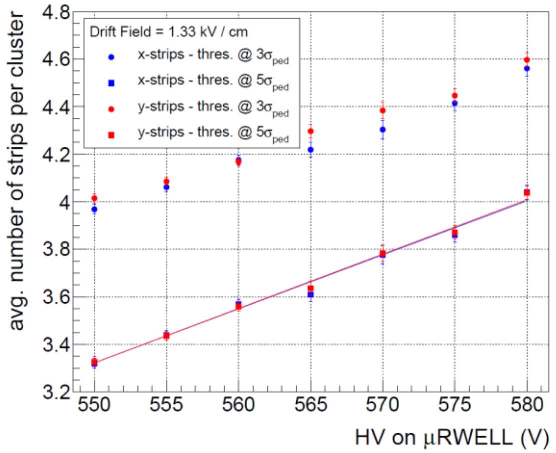
capaSh-uRWELL prototype with 800 µm pitch X-Y strip readout



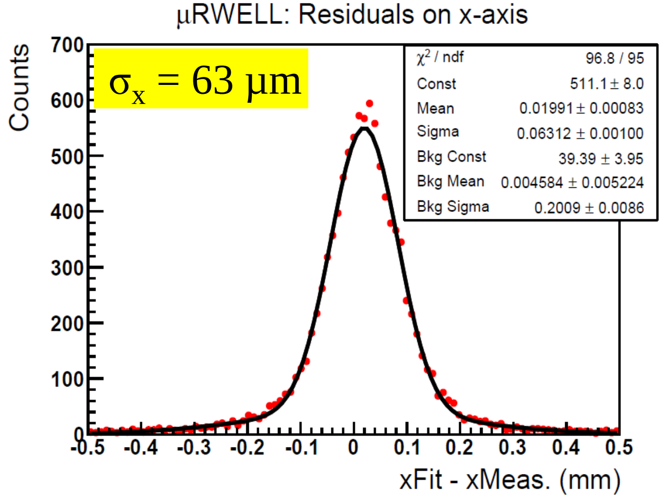
Efficiency vs. HV in x and y

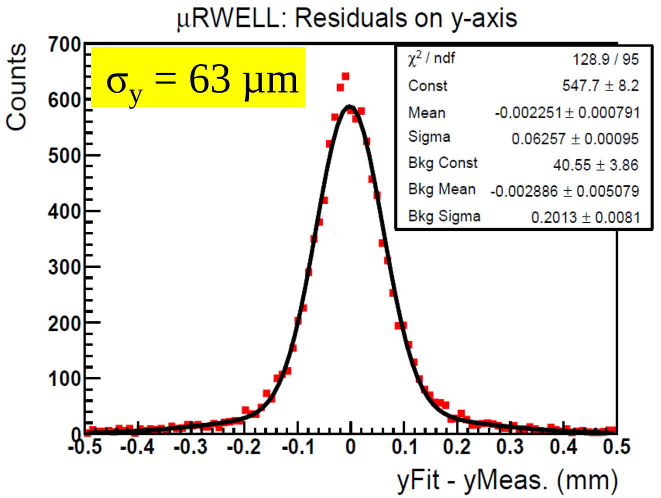


Strip multiplicity vs. HV in x & y



Track fit residuals distribution before correction in x and y





Progress Report: Cylindrical Micromegas

Motivation

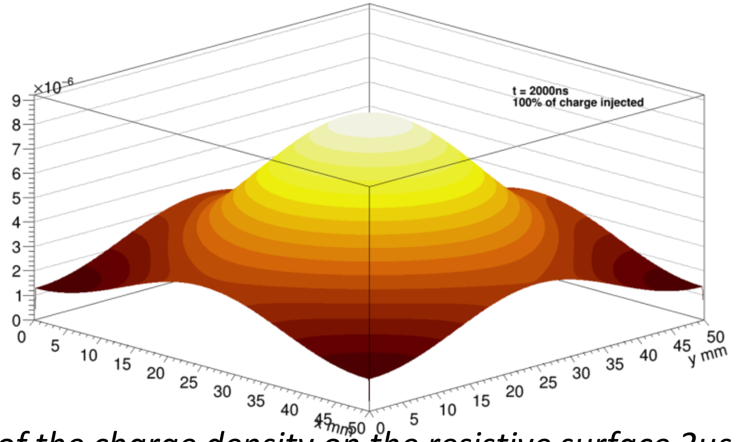
- ❖ Build a full (no acceptance gaps) light-weight modular Micromegas barrel tracker to complement the silicon vertex detector
- ❖ Take the existing 1D MM technology from CLAS12 and upgrade it to be **2D readout**

Objectives

- ❖ FY22: Optimization of the 2D readout to reach resolutions of ~150um with the fewest possible number of channels on small prototypes
- ❖ Design and construction of several small prototypes with different r/o patterns and different resistivity values

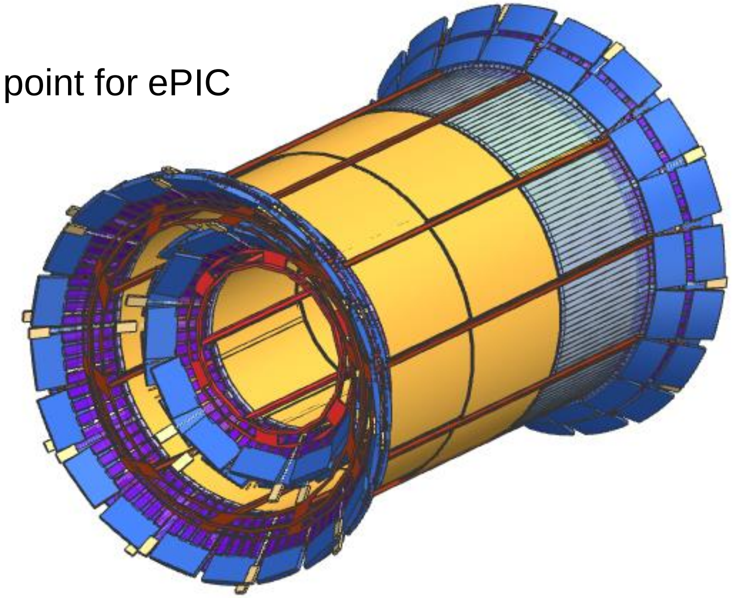
Main activities

- **Finite difference element simulation of the resistive layer** coupled with Garfield++ output
- This tool will be calibrated with prototype results



Example of the charge density on the resistive surface 2µs after injection

- First **CAD design** of the whole Micromegas tracker for the ATHENA proposal
- Being used also as starting point for ePIC

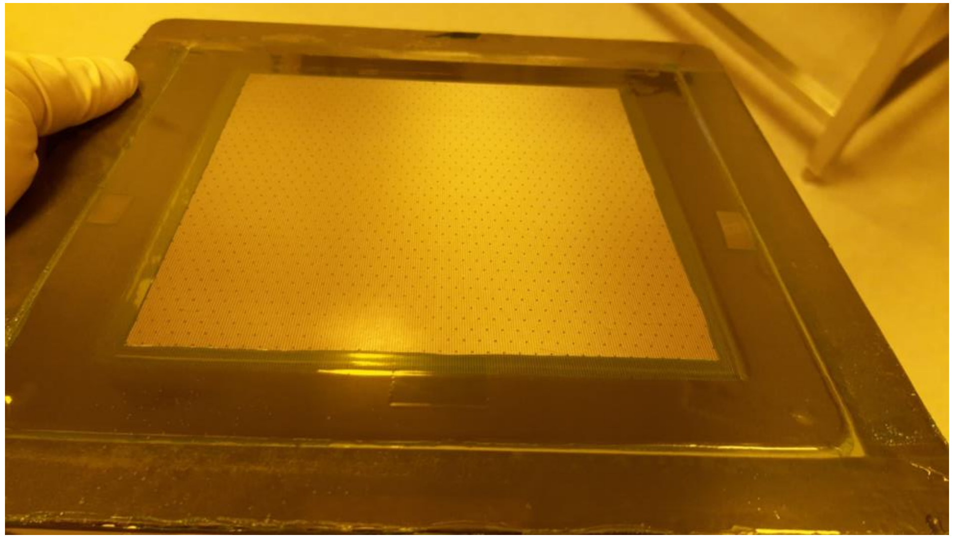


Progress Report: Cylindrical Micromegas

Prototype design and R&D

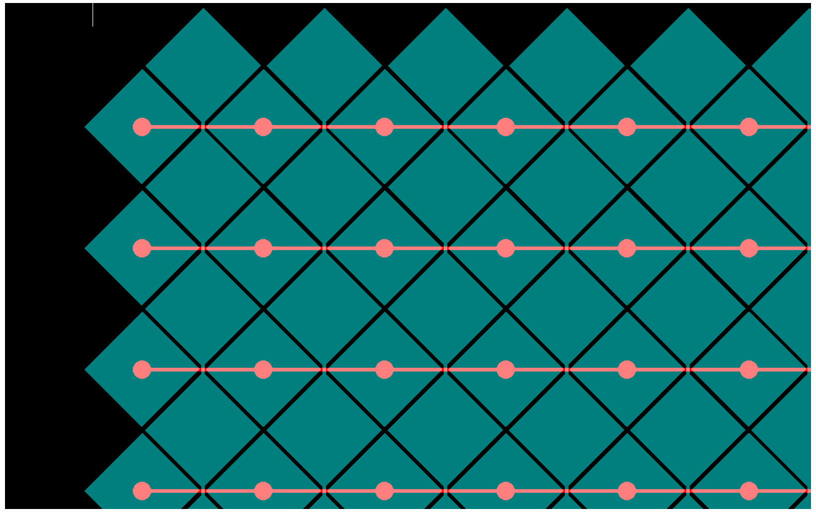
Amplification Kapton (AK): a Kapton foil with resistive paste stretched on a carbon fiber frame and then bulk with a micromesh

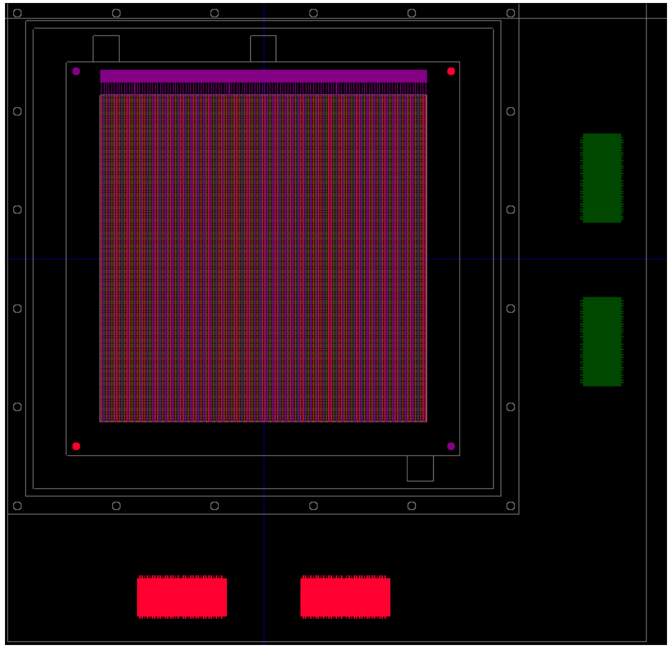
- AKs with different resistivity will be glued together with Kapton foils with 2D readout patterns
- First tests of assembly of AK are promising: holding up to 900V between the resistive layer and the mesh in air.



Readout pattern design:

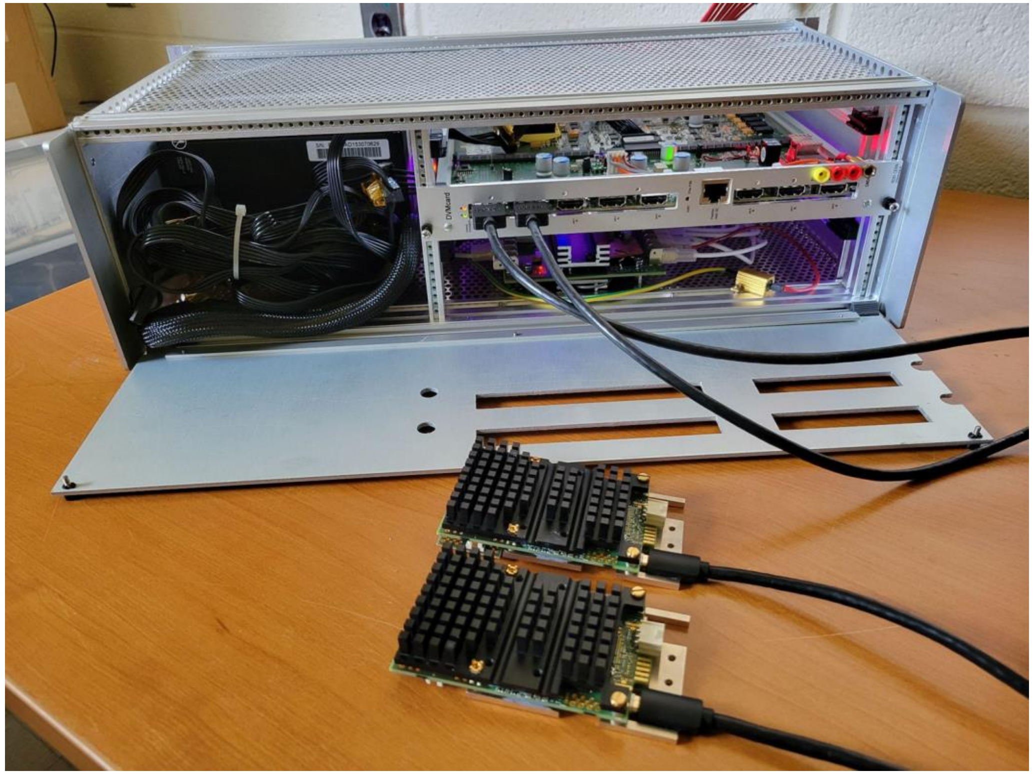
- Several design 2D patterns:
  - Orthogonal strips
  - ASACUSA like readout





Progress Report: VMM3a-SRS readout

- **Goal:** Assess cylindrical µRWELL performance using VMM3a electronics
  - During beam test cylindrical µRWELL will be partially equipped with VMM3a ASICs to validate it as a potential fallback option
- **Progress:**
  - All components of the VMM3a-SRS system have been acquired and assembled:
    - SRS mini-crate, FEC, DVM, and 4 VMM3a hybrid cards (512 channels total)
  - The RCDAQ data acquisition software will be used to with the VMM3a-SRS system. Communication with the DAQ system via RCDAQ software has been established.
  - Additional configuration and bench top testing (via VMM test pulses) are underway.

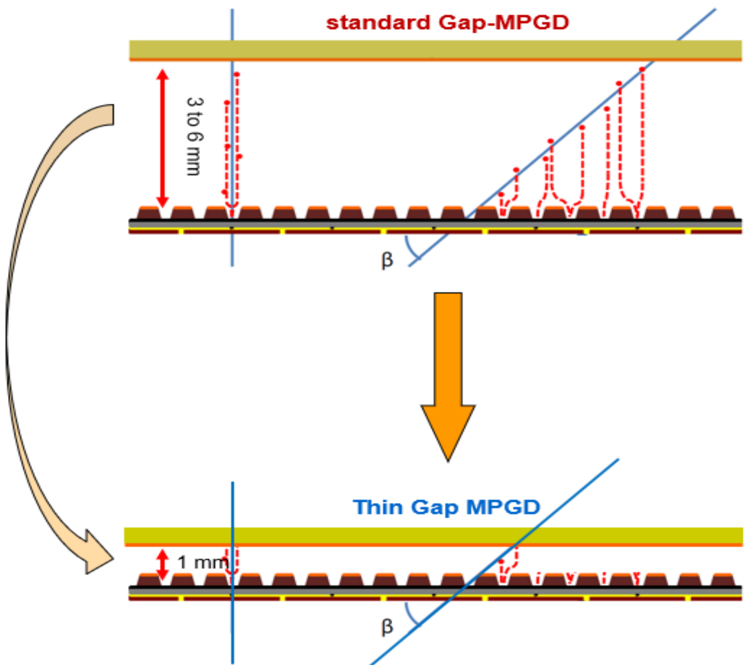


FY23 Proposal: R&D on Thin Gap MPGDs (tg-MPGDs)

Jefferson Lab

Motivation

- **Incoming track at large angle:** Ionization in drift volume generates signal on too many strips ➔ spatial resolution (**~ d/**$\sqrt{12}$) 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 thickness **d** of the drift volume



Proposed solutions:

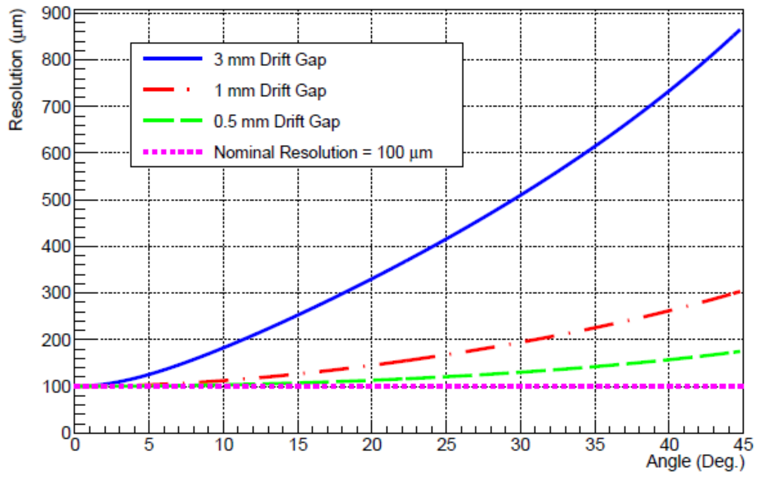
- Two approaches to recover spatial resolution performance under consideration
  - MPGD in µ-TPC mode ➔ increase drift gap from 3 to ~20 mm; **does not address Lorentz angle issue.**
  - Thin gap MPGDs ➔ reduce drift gap (from 3 to < 1 mm) ➔ **Improve both large track angle high B field impact on spatial resolution**
- We will investigate the thin gap MPGD approaches and test two prototypes:

R&D goal and timeline for FY23

- Procure µRWELL PCBs and prototypes parts from CERN **(03 / 2023)**
  - Thin gap µRWELL (tg-µRWELL) and hybrid tg-GEM-µRWELL➔ for large amplification
- Investigate and procure new gas mixtures for performance optimization **(05 / 2023)**
- Beam test at FNAL of the two prototypes **(06 / 2023)**

FY24 R&D program toward CD3 timeline

- Full validation of thin gap MPGDs with the selection of the gas mixture for full efficiency
- Develop full size (200 cm × 40 cm) hpDIRC tg-MPGD layer prototype
- Final beam test campaign at FNAL of the large prototype **(2024 -)**



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

FY23 Proposal: R&D on MPGD in μ-TPC mode

Motivation

- Single MPGD layer with larger drift gap that operates in μ-TPC mode
- Measure the tracklet direction and provide directional resolution of order of 1 mrad or better
- Ideal for **pattern recognition** to match the track measured by the Si-tracker in the central tracking
- Smaller detector envelop than multiple MPGD pattern recognition layers – Lower detector cost – minimum services and cablings
- No one has ever constructed and operated a large cylindrical μRWELL in a μ-TPC mode yet
- R&D needed to validate the concept.

R&D goal and timeline

- Construct a third half cylinder μRWELL prototype base on the same design and mechanical structure
- Modify the drift gap from 3-5 mm to 15 mm and reduce strip pitch to 400 μm
- Aim to have the prototype ready in time for the June 2023 FNAL beam test

FY23 Proposal: Milestones for µRWELL

2.4 Milestones and Timeline for FY23 - Cylindrical µRWELL prototypes

- Mechanical assembly completed (FIT) - 01/2023
- µRWELL / readout PCB design completed (JLab & BNL) - 11/2022
- Procurement µRWELL / Readout PCB from CERN (JLab & BNL) - 03/2023
- VMM-SRS front-end electronics & DAQ tested (TU & BNL) - 10/2022 to 04/2023
- **Major Milestone:** Detector assembled at FIT - 04/2023
- Preliminary bench testing completed (FIT) - 05/2023
- Front-end electronics & DAQ configuration (TU & BNL) - 05/2023
- **Major Milestone:** Beam Test at FNAL (All & contingent availability of FY23 funding) - 06/2023
- Data analysis completed (All) - 12/2023

- A timely completion of this part of R&D program is contingent to funding for travel and support funding for grad student at FIT made available in time for us to be ready for the June 2023 beam test campaign
- Funding availability after 03/2023 will severely compromise plans for travel to FNAL for beam test and delay the program by a year ➔ due mostly to the lead time for procurement of new type gas mixture)

FY23 Proposal: Milestones for Micromegas

3.4 Milestones and Timeline for FY23

3.4.1 Milestones for the 2D readout optimization:

- Design of the 2D readout PCBs – 09/2022
- Procurement of readout boards – 12/2022
- Major milestone: Bulk and assembly of prototypes – 04/2023
- Major milestone: Beam test – Spring 2023
- Data analysis completed – Summer 2023

Continuation of FY22 program

3.4.2 Milestones for full size prototype:

- Design of 2D full scale prototype reusing CLAS12 design - DBNLFR + 3 months
- Design of the longer (50x100cm^2) mock-up - DBNLFR + 3 months
- Readout and drift foils received - DBNLFR + 6 months
- Assembly of the longer mock-up - DBNLFR + 7 months
- Major milestone: Bulk and assembly of the prototype - DBNLFR + 9 months
- Tests using the cosmic test bench - DBNLFR + 10 months
- Beam test - DBNLFR + 11 months

FY23 proposal

Path towards CD3:

- Follow the needs of the ePIC detector
- Finalize the design of the tracker
- Find an industrial partners
- Pre-production iterations with industrial partners

FY23 Proposal: Milestones for Thin Gap MPGDs

2.5 Milestones and Timeline for FY23 - Thin Gap GEM-μRWELL prototypes

- Procurement of μRWELL / readout PCB from CERN (JLab) - DBNLFR + 3 months
- <u>**Major Milestone:**</u> Detector assembly & preliminary bench tests (JLab) - DBNLFR + 4 months
- Procurement of Xe- or Kr-based gas mixture (JLab) - DBNLFR + 6 months ???
- <u>**Major Milestone:**</u> Beam test at FNAL (JLab) contingent FY23 funds availability - 06/2023
- Data analysis completed (JLab) - 12/2023

- The first phase of this R&D effort will be completed in FY23 if funding is available in time for the June 2023 beam test campaign
- If not, we will seek funding for beam test in FY24 to conclude the R&D before we proceed to second phase of large area tg-GEM-uRWELL prototype

FY23 Proposal: Budget Request

Table 1: **FY23 Budget request Money matrix (includes overheads and IDCs).**

Institution	Cylindrical	Planar Thin Gap	Total per institution
BNL	$16,000	-	$16,000
FIT	$60,000	-	$60,000
JLab	$28,980	$35,880	$64,860
Saclay	$41,000	-	$41,000
TU	$7,925	-	$7,925
TOTAL	$153,905	$35,880	$189,785

Table 2: **FY23 Budget request** Three budget scenario per institution.

Institution	100% scenario	80% scenario	60% scenario
BNL	$16,000	$12,800	$9,600
FIT	$60,000	$48,000	$36,000
JLab	$64,860	$50,560	$36,680
Saclay	$41,000	$32,000	$25,000
TU	$7,925	$4,755	$0
TOTAL	$189,725	$148,115	$107,280

Budget request justification

- **Cylindrical µRWELL prototype:**
  - Support for beam test at FNAL (multiple institutions)
  - Support for FIT grad student
  - Prototype for operation in u-TPC mode (materials)
- **Cylindrical Micromegas R&D:**
  - Materials for various 2D readout PCBs
  - Large (full size) mock-up prototype
  - Support for beam test
- **Thin gap MPGDs**
  - Materials for two small prototypes
  - Procurement of alternative gas mixture

Detailed budget breakdown spreadsheet

https://docs.google.com/spreadsheets/d/122FEJfwMi8SaeWPJbFHG1pWAH-f5mC91/edit#gid=698221693

Open questions to complete the R&D program before CD-3

Technology	**Layer in ePIC detector**	**Detector configuration**	**Leading institution,** Participating institutions	**R&D open questions and performance validation**
Cylindrical MPGD: ❖ standard drift gap ❖ Low channel count - large pitch Micromegas as default option ❖ µRWELL as fallback option	**Pattern recognition** layers in barrel region	❖ Multiple layers (min 3) ❖ Curved tiles module ❖ Full cylindrical layer with µRWELL?	❖ Micromegas: **Saclay,** Yale, BNL ❖ µRWELL: **Florida Tech,** Vanderbilt, BNL, Temple U	❖ Mechanical stability of large modules ❖ Spatial resolution performance ❖ Routing of services along z ❖ Acceptance optimization - (frame material vs. dead area) ❖ Choice of number of tiles along z
Cylindrical MPGD in µ-TPC mode: ❖ large drift gap 10 to 20 mm ❖ Narrow pitch (~500 um) ❖ Micromegas as default option ❖ µRWELL as fallback option	**Pattern recognition** layers in barrel region	❖ Single layer (or 2 for enhanced performance) ❖ Curved tiles modules with up to 20 mm gap	❖ Micromegas: **Saclay,** Yale, BNL ❖ µRWELL: **Florida Tech,** Vanderbilt, BNL, Temple U	❖ Mechanical stability of large modules ❖ Tracklet reconstruction in µ-TPC mode ❖ Mechanical support & detector stability ❖ Acceptance optimization - (frame material vs. dead area) ❖ Choice of number of tiles along z
Thin Gap MPGD (tg-MPGD): ❖ Narrow drift gap < 1 mm ❖ Low channel count – large pitch ❖ High density high-z gas mixture ❖ µRWELL as default option ❖ Micromegas as fallback option	**Precision tracker** behind hpDIRC Option for tracker behind dRICH and mRICH	❖ Single planar layer (or 2 for enhanced performance) ❖ Compact detector : thickness < 2 cm	❖ µRWELL: **JLab,** Vanderbilt, UVa ❖ Micromegas: **Yale U,** Saclay	❖ Mechanical stability of large modules ❖ Detector efficiency ❖ Spatial resolution performance ❖ Routing of services along z ❖ Choice of number of tiles in z direction ❖ Cost of gas

Open questions to complete the R&D program before CD-3

FY23 R&D effort:

- Choice of optimal 2D readout structure for each detector technology between capacitive-sharing, zigzag, resistive etc …
- Demonstrate basic performance of MPGD in µ-TPC mode ➔ track stub reconstruction, angular resolution
- Complete the construction and tests of cylindrical µRWELL
- Proof of concept of thin gap tg-µRWELL (also hybrid amplification tg-GEM-µRWELL) ➔ Optimal gas mixture for optimal efficiency

FY24 – FY25 R&D program:

We will focus the R&D effort into developing full size prototypes to address all the open questions identified in the table of the previous slide.

The choices for the full-size prototypes will be eductated by the lessons learned from the R&D outcome of eRD108 FY22 – FY23 programs

- Full-size barrel MPGD curved module prototypes:
  - one uRWELL prototype with selected R/O structure and one Micromegas prototype with the selected R/O structure
  - Comparison of the performances, detector stability, material thickness and mechanical structure …
- Full-size planar tg-MPGD module: tg-µRWELL and tg-MM prototypes
  - one uRWELL prototype with selected R/O structure and one Micromegas prototype with the selected R/O structure
  - Comparison of the performances, detector stability, material thickness and mechanical structure

The aim is to ensure that MPGD technologies for ePIC are in mature level of readiness for construction by the CD-3 timeline

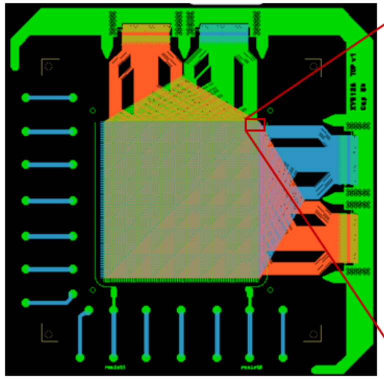
Back up

Progress Report: Cylindrical µRWELL

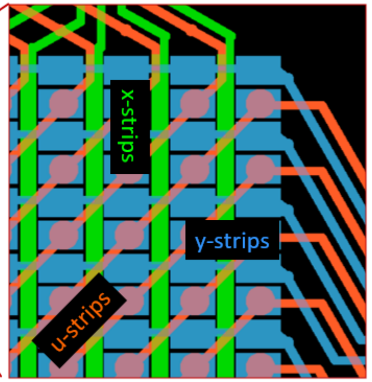
3-coordinate (XYU)-strip capacitive-sharing readout

- Small 10 cm x 10 cm CapaSh-µRWELL prototype with 3 mm drift
- 2-layer stack capacitive sharing strip readout ➔ black pads on the cross-sectional view
- 3-coordinates XYU-strip readout PCB with 800 µm pitch ➔ two layers
  - Top layer: X-strips - vertical / green strips
  - Bottom layer: Y-strips - horizontal / blue pad-like strips
  - Bottom layer: U-strips - pads diagonally connected (red lines)
- Mounted with standard triple-GEM amplification
- Prototype in beam test in Hall D @ JLab
- Preliminary results ➔ good charge-sharing X/Y, X/U & Y/U;
- average hit multiplicity > 3 for all 3 strips

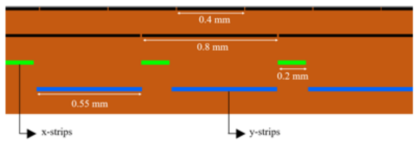
Capacitive-sharing (XYU) strip readout PCB for triple GEM



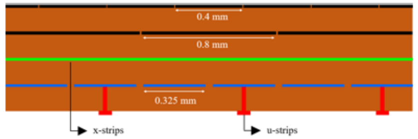
Gerber view of X-Y-U strips design



Zoomed view of X-Y-U strip design

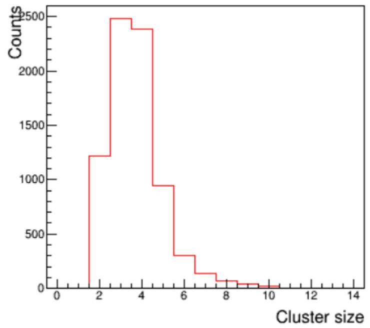


cross section view of X and Y strips

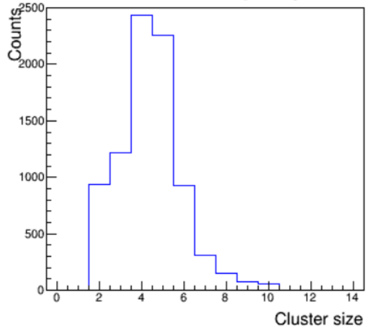


cross section view of X and U strips

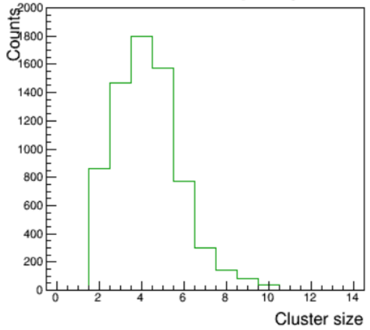
XYUGEM: Hit multiplicity in X



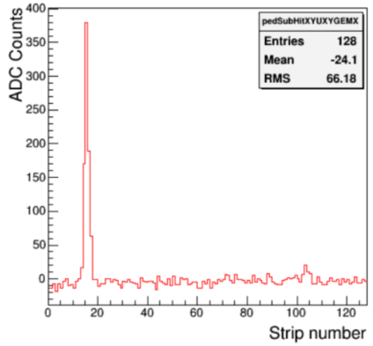
XYUGEM: Hit multiplicity in Y



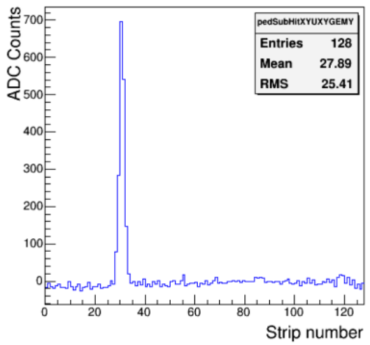
XYUGEM: Hit multiplicity in U



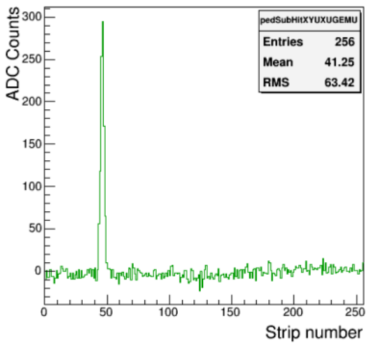
XYUGEM: Hit in X



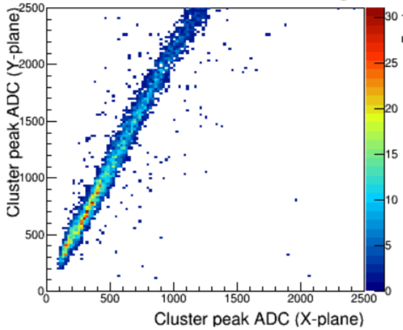
XYUGEM: Hit in Y



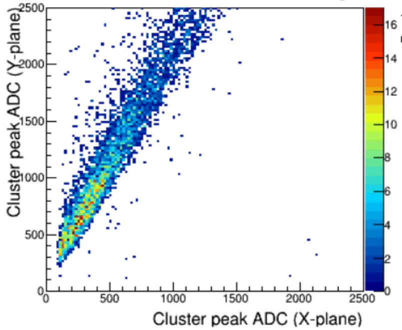
XYUGEM: Hit in U



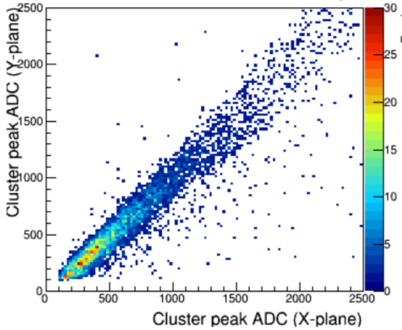
XYUGEM: Y-X ADC sharing



XYUGEM: Y-U ADC sharing

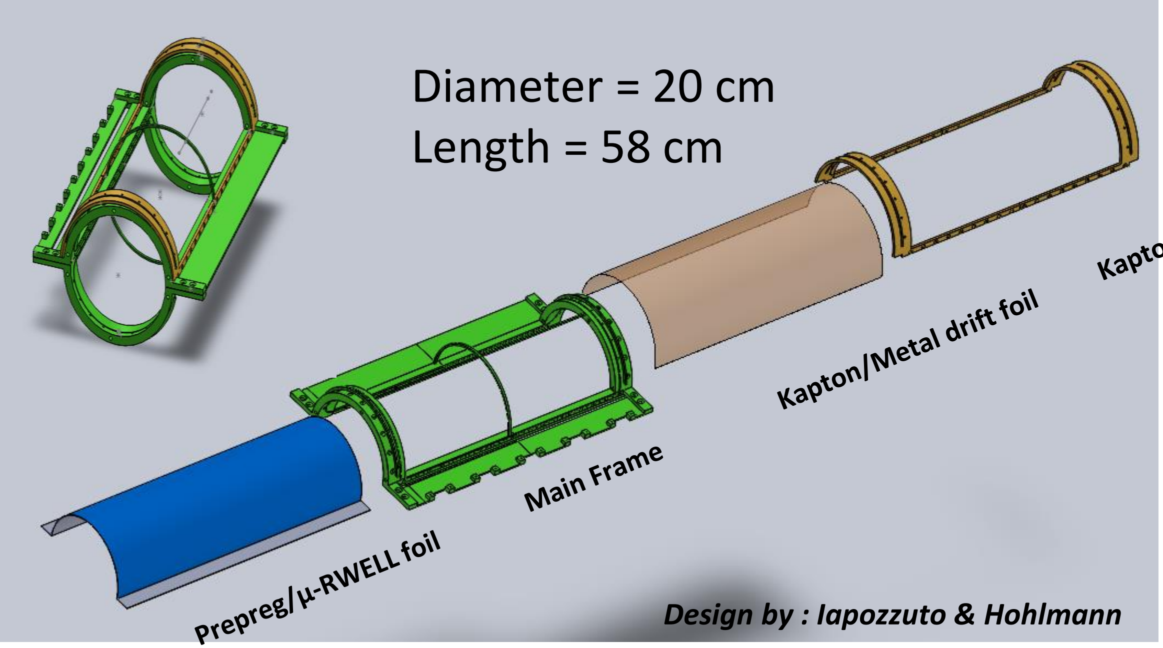


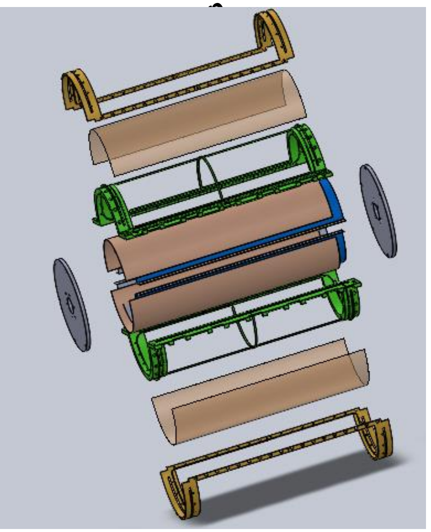
XYUGEM: X-U ADC sharing



Mechanical structure of cylindrical µ-RWELL

FLORIDA TECH





PETG

Currently preferred candidate

300microns

Material considerations for µ-RWELL foil support base

Base Material	Thickness (mm)	Radiation Length (cm)	% of Radiation Length
Epoxy Resin…	0.3	41.6	0.07
Prepreg Fiberglass	0.2	25.0	0.08
Carbon Fiber	0.1	42.7	0.02
PETG Thermo	0.5	28.5	0.17
PETG Thermo	1.0	28.5	0.35
Styrofoam	5.0	1,375.0	0.04
Styrofoam	2.6	1,375.0	0.02
Styrofoam	1.3	1,375.0	0.01

Materials/ Prototypes:



Prepreg in oven

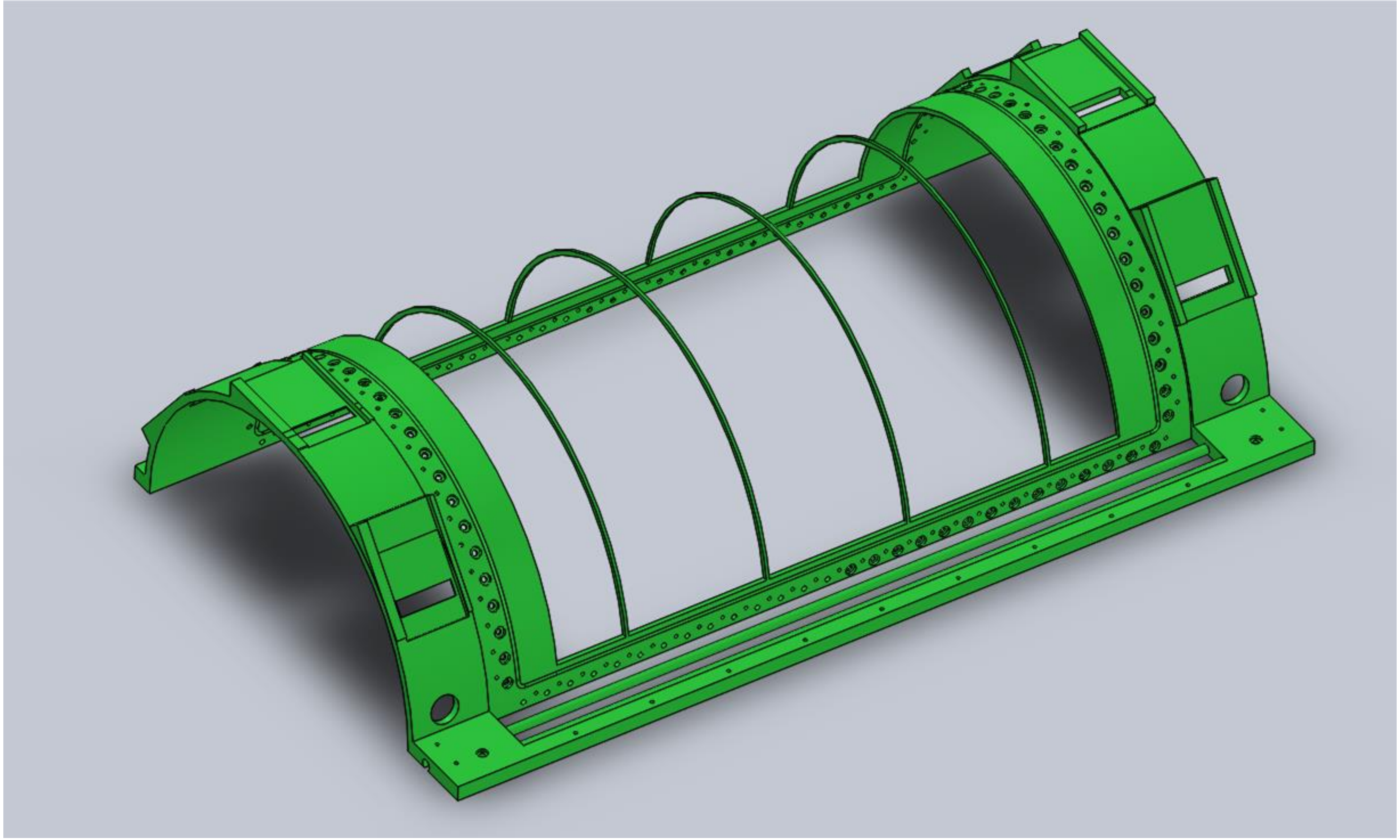

Smooth Prepreg Base Prepreg w/ vacuum method


Thermo Plastic Base


Main Frame

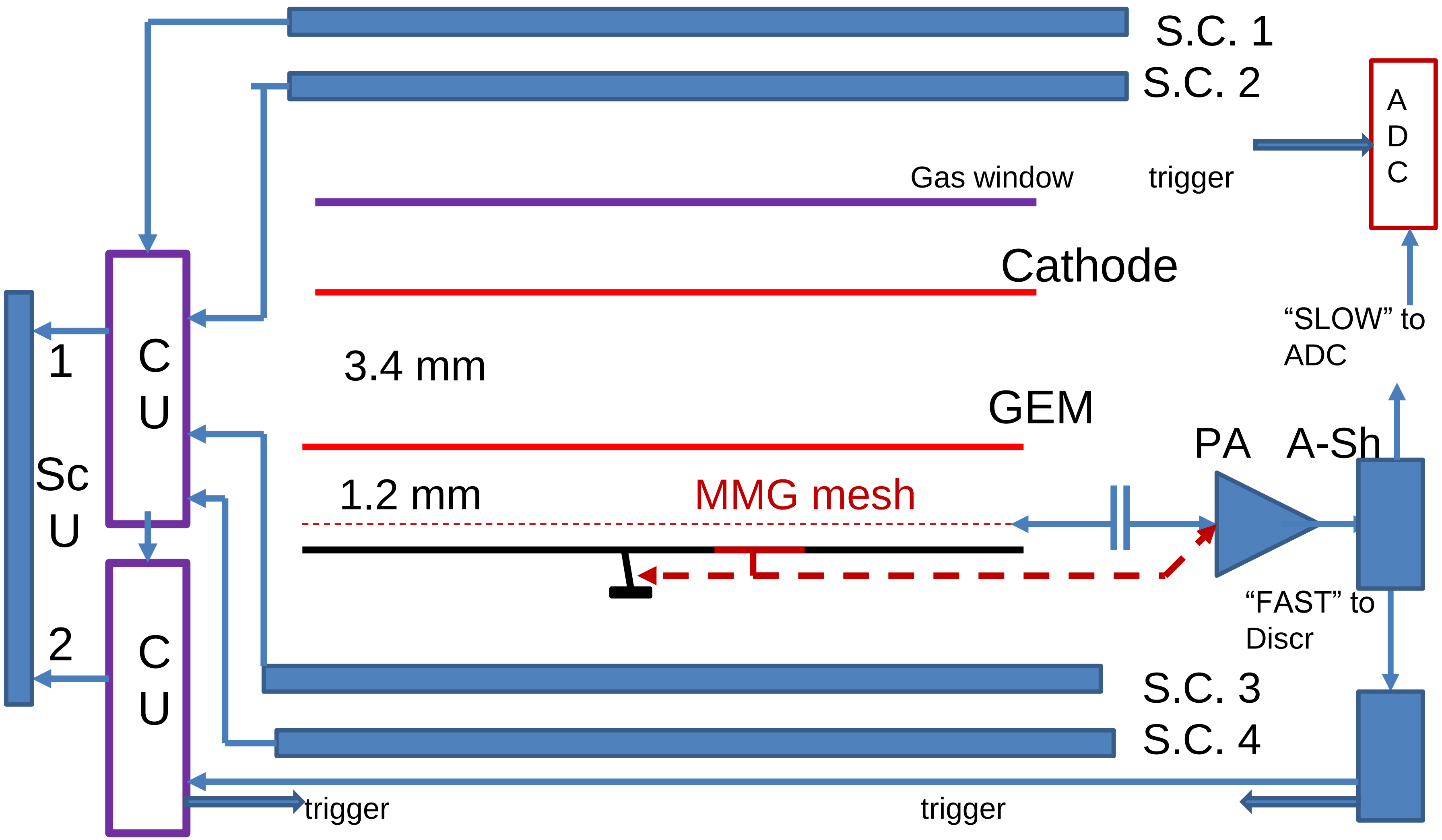

Assembly with Inner frame, Main frame,Outer clamp & Kapton Foil

Early 3D Printed Prototypes




cmsgem011

Thin gap gas tracking chamber, MMG, Ar + isobutane (9.7%)



Preliminary result

Procedure:

1. GEM Top and Bottom – the same voltage. Cathode: -10 V.
   With Fe55 source and connect small number of MMG pads to PA select Mesh Voltage to get the MMG gain ~ 2. e4
   Reconnect PA to Mesh, check Discriminator Threshold for "FAST" signal.
   Measurement Sc1 and Sc2 ratio with statistics ~ 1000.

2. Reduce MMG Voltage, Tune GEM and Cathode voltages to return to the same gain.
   Measurement Sc1 and SC2 ratio with statistics ~ 1000.

$$\frac{\text{Counts ratio Sc2 / Sc1 (1.2 mm)}}{\text{Counts ration Sc2 / Sc1 (3.4 mm)}} = 0.87$$