# EIC Detector R&D Proprosal

The eRD108 Consortium

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**Project ID:** eRD108

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

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# 1 Introduction

We propose R&D on Micro-Pattern Gaseous Detectors (MPGDs) for the tracking system of the EIC project detector ePIC. One type is the micro-Resistive-Well (μRWELL) detector, the second is the micromegas (MM) detector. Gas Electron Multiplier (GEM) technology is also under consideration. We propose to:

1. Continue with the development of cylindrical μRWELL technology and we plan to investigate the operation of such detector in the μ-TPC mode for pattern recognition in the central barrel tracker.
2. Alternatively, we plan to pursue the study of multiple Cylindrical Micromegas detector layers in the central barrel tracker for pattern recognition.
3. Explore the novel concept of thin GEM-μRWELL hybrid detector (tg-GEM-μRWELL) to improve spatial resolution performance at large angle and in high B field.
4. Characterize the μRWELL detectors performance with VMM ASIC electronics.

## 1.1 Risks addressed

The proposed R&D addresses various risks in the development of a Day-1 detector for the EIC project:

- Particle ID under-performs because reconstruction in DIRC and RICH devices suffer as the impact point and direction of the charged particle producing the Cerenkov radiation are not known precisely enough.
- Central track finding and reconstruction based on Si detectors alone will be difficult for the limited number of silicon layers.
- Pattern recognition in high background environment in the barrel tracker requires additional tracking layers at larger radius.

## 1.2 Risk mitigation approach in proposed R&D

**Cylindrical μRWELL in μ-TPC configuration:** The recent discussions in EIC ePIC detector Tracking Working Group on the optimization of the barrel tracker configuration suggest the needs for additional tracking layers at larger radius to assist the Si-Tracking layers with the pattern recognition in the high background environment. The upcoming simulation studies will determine the tracking requirements for the pattern recognition. Multiple layers of cylindrical μRWELL could be used to produce the matching tracks with the Si-trackers for pattern recognition. Alternately, one can develop a single MPGD layer with larger drift gap that operates in μ-TPC mode to measure the tracklet direction with a directional resolution of order of 1 mrad or better to match the track measured by the Si-tracker in the central tracking. The R&D is necessary because nobody has yet constructed and operated a large cylindrical μRWELL in a μ-TPC mode to the best of our knowledge.

**Cylindrical Micromegas:** The MM detector layers aim at being a low-mass tracking detector that complements a silicon vertex tracker. A Si-MPGD hybrid design is currently under consideration for the ePIC detector concept. The curved MM design will leverage the already existing low material budget of CLAS12 MM technology, with the requirement that the detectors for EIC must have a 2D readout. The R&D will focus on the choice of the 2D readout patterns and the production of a full size prototype.

**Planar Thin Gap MPGDs:** MPGD layer with spatial resolution of the order of 100 μm will vastly improve the measurement of direction and impact position of charged particles that hit the Cerenkov detectors (the hpDIRC in the barrel region, dRICH in the Hadron endcap) of ePIC detector by measuring a hit after the particles have traversed all material in the central tracker and its support structure. This information, that is little compromised by multiple scattering in material, can be used to seed the Cerenkov ring reconstruction. However, it is well known that spatial resolution of standard MPGDs rapidly degrades with particles crossing the detector at large angle due to the long ionization charge trail produced these particles along their path in the gas volume. Moreover, the Lorentz force effect of the magnetic field of the solenoid also adversely impact the spatial resolution. In both cases, the degradation of spatial resolution performance is proportional to the ionisation gap of the chamber.
Our approach to recover the spatial resolution performance, at least partially is to explore the concept of a thin gap μRWELL detector with GEM pre-amplification, (tg-GEM-μRWELL). The ionization volume between the drift cathode and the amplification structure of such detectors has a smaller gap ($\leq$ 1 mm) compared to the typical 3 mm for standard MPGD tracker. The expected result is an improvement of the spatial resolution from $\sim$400 to $\sim$150 μm or better for track crossing the detector at an angle of 20°.

# 2 μRWELL Trackers

## 2.1 Progress report on Cylindrical μRWELL prototype

### 2.1.1 What was planned for FY22?

We proposed to design, build, and commission a functional small (20 cm diameter, 55 cm length) cylindrical μRWELL detector in FY22. The main objectives are to demonstrate that a cylindrical μRWELL detector indeed works and to quantify its tracking performance. This μRWELL prototype is to be equipped with a composite foil that integrates the μRWELL amplification structure either with a capacitive charge-sharing readout or with a 2D zigzag readout. Both types of readouts minimize the number of readout channels. Half of the detector cylinder is to be read out by one of the structures and the other half by the other.
We proposed to develop a design that uses thin rigid materials, e.g. carbon fiber pre-preg material, to create a rigid but low-mass inner main cylinder for the detector. A composite μRWELL/readout foil is to be attached to the outside of this cylinder.

### 2.1.2 What was achieved in FY22?

Funding for this project R&D did not arrive at the collaborating institutions until about mid-August 2022, i.e. only six weeks before the submission of this proposal. Consequently, the achievements so far are limited to the first steps in the process, which are the design work and initial investigations into support materials and DAQ system.

**Design of the detector mechanics:** The FIT team has produced a first complete design of the cylindrical detector frame (Fig.1 left). The design features two independent half-cylindrical symmetrical sections that can be attached to each other to form a complete cylinder. Each section contains an inner clamp (blue), a thin but rigid composite support base for the μRWELL/readout foil (gray), a main frame with support for front-end electronics cards (green), a drift foil made from a copper-clad Kapton sheet (gold), and a clamp for the drift foil (orange). The main frame (56 cm length, 13 cm radius) provides a 3 mm drift gap space

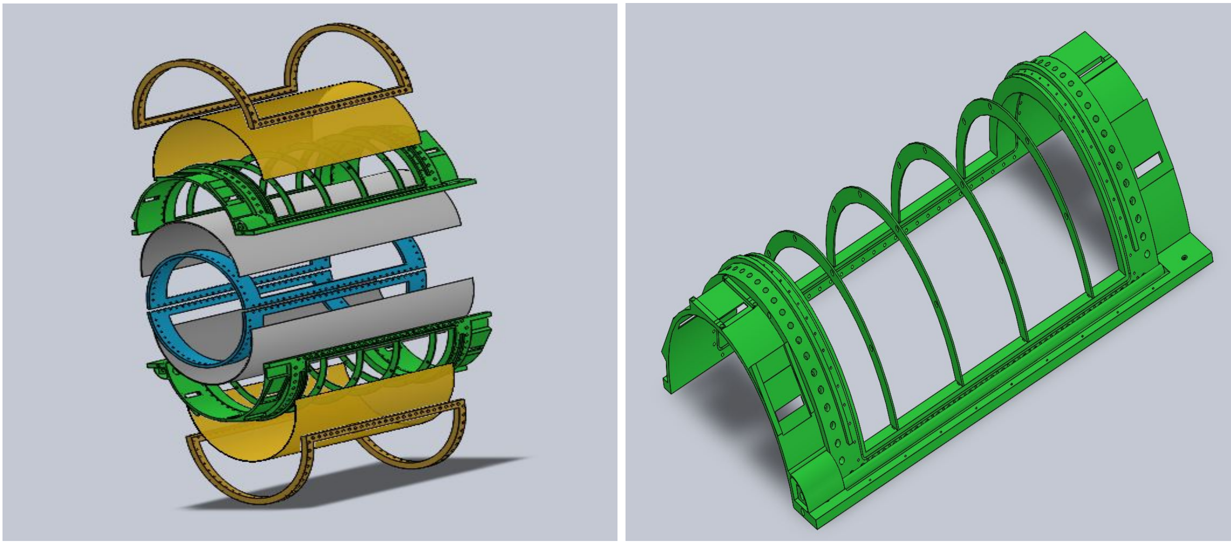

Figure 1: Left: Expanded assembly of the cylindrical μRWELL prototype design. The blue frame is the inner clamp; the gray sheet is the composite μRWELL/readout foil mounted on a thin rigid support; the green frame is the main frame; the gold sheet is the drift foil; the orange frame is the outer clamp for the drift foil. Right: Zoomed view of the main frame with ribs that support the drift foil and endcap rings that support the front-end electronics cards.

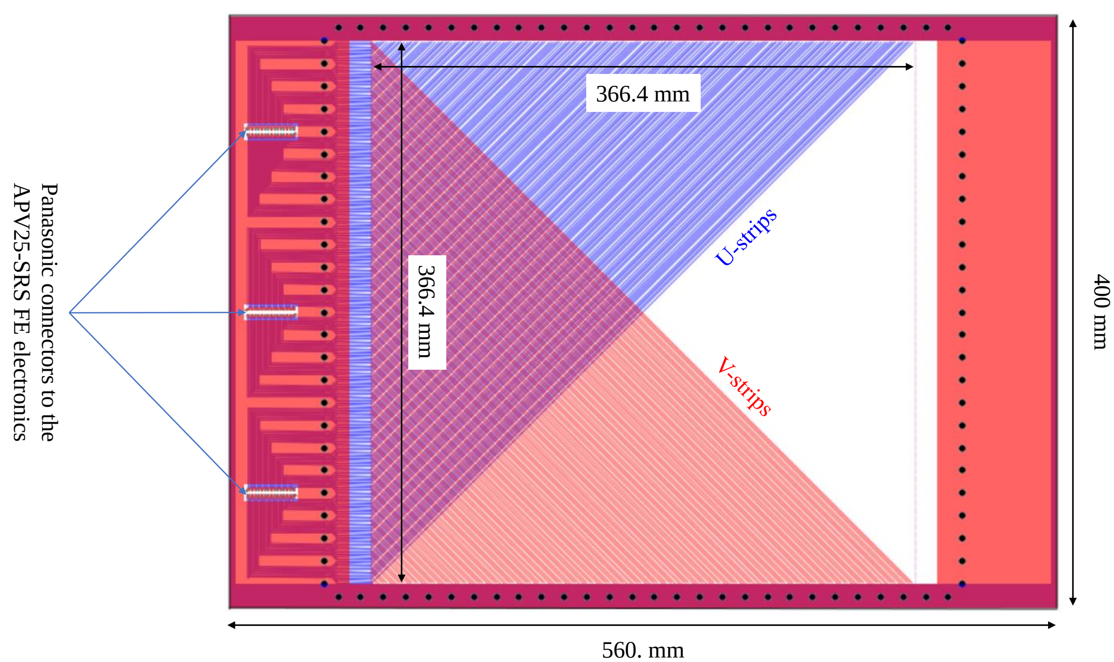


Figure 2: Design template of the U-V strip readout component of the μRWELL/readout composite foil. The overall dimensions and the dimensions of the active area are indicated. Due to the square design, the strips cross at a right angle. The traces and connectorization on the right are a mirror image of those on the left, but are not shown here.

between the Kapton foil and the μRWELL/readout foil (Fig. 1 right). The drift gap will contain a gas mixture of Argon/$CO_2$ for the ionization process. Two O-rings running each along the inner and outer side

of the main frame will seal the gas in the drift space. Two end holes will provide the gas inlet and outlet to the drift volume. The supporting central arches act as support ribs for the Kapton foil that goes on top of the main frame. A dowel located in the base on the right will facilitate azimuthal stretching of the Kapton foil. The structures with rectangular slots on the outer edge will house the APV or VMM front-end cards for the scalable readout system (SRS). We are designing a modular mount that can accommodate both types of cards. The inner clamp (blue) and the drift foil clamp (orange) compress the O-rings in the main frame and seal the gas into the drift space. The inner clamp also fastens the composite base to the main frame while the drift foil clamp fixates the drift foil to the main frame after it is stretched over the ribs.
The FIT team plans to 3D-print all structural elements out of high-density PLA or ABS filament except for the thin rigid support for the µRWELL/readout foil, which will be made from 0.2 mm pre-preg fiber-glass/epoxy composite or 1 mm thermoplastic. We have already investigated various methods to produce half-cylinders from these materials that are sufficiently smooth and rigid.

**Design and procurement of the µRWELL/readout composite foils from CERN:** The preliminary template of the U-V strip readout layer, one of the component of the composite foil has been designed at BNL. Figure 2 shows a Gerber view of the readout template with the routing of half of the U-strips (blue) and V-strips (red) to three Panasonic connectors on the left of the figure. The remaining half of the two set of strips (not shown in the figure) have a symmetric routing scheme to three connectors on the right side of the readout foil. Both U- and V-planes have a pitch of 1.35 mm. The overall size of readout foil is 560 mm $\times$ 400 mm. The active area has a size of 366.4 mm $\times$ 366.4 mm. The same template will be used for the anode U-V strip readout of both half-cylinders prototypes with only the strip pattern in the active area i.e. capacitive-sharing straight strips and 2D zigzag geometry being different between the two prototypes. The final readout design will be completed together with the µRWELL design in collaboration with experts at the CERN PCB workshop.

**Implementation and testing of VMM ASICs:** TU and BNL have acquired and assembled all electronic components needed to commission a small DAQ system consisting of an SRS minicrate, FEC, DVM and four VMM hybrid cards. Communication between the DAQ software, RCDAQ, and the VMM-SRS setup has been established and efforts are underway to configure the settings of the setup using the RCDAQ software.

## 2.2 R&D Plans and Funding Request for FY23

### 2.2.1 Cylindrical µRWELL prototype

**Production, assembly, and initial testing:** In late 2022, we plan to produce the components for the two half-cylindrical µRWELL prototypes. The current plan is to 3D-print the mechanical frame parts. The design of the composite µRWELL / 2D readout flexible PCBs will be done in collaboration with experts of the MPT PCB workshop at CERN and is expected to be completed by the end of October 2022, with the production to start in early November 2022. The fabrication of the two composite PCBs is expected to be completed and shipped to FIT in early April 2023 for the final assembly into two half-cylinders. Once assembled, we will subject the two half-cylinders separately to basic functionality tests on a bench-top. This includes pressure and gas leak testing, HV testing, determination of noise levels, and establishment of a signal using radioactive sources and cosmics.

**Configuring and commissioning the VMM3a-SRS DAQ:** The VMM3a ASIC has been developed for the readout of the ATLAS Muon New Small Wheels upgrade at CERN [1]. The RCDAQ data acquisition system [2] and the SRS system with the well-known APV25 ASICs have long been one of most commonly used readout systems in R&D projects and test beams. Drawing on the existing general SRS system support in RCDAQ, we will implement the readout of the new VMM3a hybrids. Each hybrid holds two VMM3a chips and provides 128 readout channels. Fig. 3 shows a picture of our current VMM3a-SRS system. Shown here is the special readout card mounted in the back of the SRS crate that interfaces with up to 8 hybrids. Two hybrids are connected here and are used in test-pulse mode during the development of the readout support. During the beam test we will partially equip the cylindrical µRWELL prototype with the VMM3a ASICs. This will allow us to compare the detector performance of the ASICs and determine if it could serve

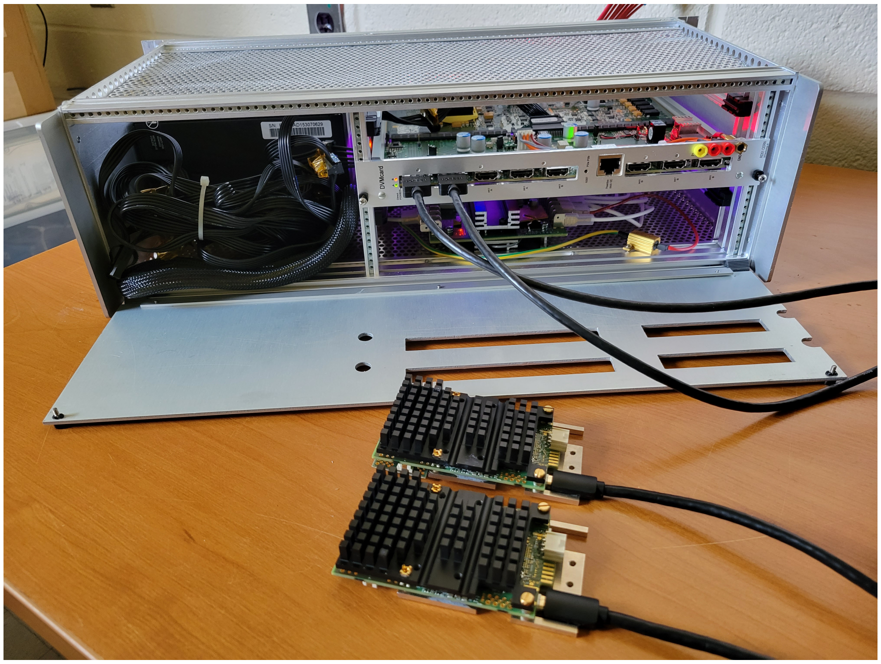

Figure 3: A picture of the VMM3-SRS system. It consists of the SRS crate with a special card (visible in the back) that interfaces with up to 8 VMM3 hybrids. Two connected hybrids are shown here.

as a fall-back option for the EIC MPGD readout ASIC.

**Beam test:** We have reserved one week of beam time at the FNAL test beam facility in June 2023. We plan to test the performance of the prototype with the two readout options in the 120 GeV proton beam. If funding is not received in time to organize the June 2023 campaign, then the beam test will have to be delayed until 2024 because all others slots for beam time in 2023 are already reserved by other groups.

### 2.2.2 Cylindrical μRWELL operating in μ-TPC mode

We propose to construct an additional half-cylinder μRWELL prototype which will be optimized to operate in μ-TPC mode with a larger drift gap of 10 - 15 mm and with a standard 400 μm-pitch U-V strip readout. In this design we will have to accommodate 3.5 times the number of electronic readout channels compared to the initial design. We will leverage the development effort already made for the mechanical support structure and the μRWELL/readout foil developed for the capacitive-sharing prototype to reduce design and production cost of this μ-TPC prototype. We aim to bring the prototype to the beam test at Fermilab in June 2023 together with the two other half-cylinders single-point prototypes to investigate the angular resolution of track stubs as a function of the incoming track angle that the detector can achieve.

### 2.2.3 Thin gap GEM-μRWELL hybrid structures (tg-GEM-μRWELL).

A proposal for the development of thin gap MPGD (tg-MPGD) technologies [3] has been submitted in the context of the EIC Detector Generic R&D FY22 call proposal, including hybrid tg-GEM-μRWELL approach with a GEM pre-amplification. One of the expected downside of tg-MPGDs, if operated with the standard Ar-$CO_2$ gas mixture, is a significant drop of the detector efficiency because of the reduced probability for primary ionization charges. To achieve the full detector efficiency, it is necessary to operate these novel detectors with heavier gas mixtures.
In the current eRD108 FY23 proposal, we will request a modest funding for the procurement and assembly of two small tg-GEM-μRWELL prototypes with capacitive-sharing X-Y strip readout. One prototype will

have 1-mm gap between the cathode and the GEM foil and the second, 0.5 mm gap. The gap between the GEM and the µRWELL / readout composite PCB will be 1 mm for both prototypes. Study of the efficiency and spatial resolution performance with different gas mixtures will be conducted in the June 2023 during the Fermilab beam test campaign of the cylindrical prototypes. The selection of heavier gas such as Xe-$CO_2$ or Kr-$CO_2$ will be made based on funding availability and heavy gas supply situation. The bulk of the funding request is allocated to the procurement of the heavy gas mixtures.

### 2.3 Person-power required and available for FY23

- Designer of composite µRWELL/readout foil - JLab staff Kondo Gnanvo, will also participate in 2023 beam test (10% FTE, available) & BNL staff Alexander Kiselev (10% FTE, available)
- Assembler of cylinder mechanics, tester, data analyzer - FIT Ph.D. student Pietro Iapozzuto (100% FTE, available; the student has designed the detector mechanics; he will test the detector on the benchtop and participate in the beam test and in the data analysis.)
- Tester for electronics & DAQ - TU Matt Posik (10% FTE), post-doc (20% FTE, TBD) & BNL staff Martin Purschke (10% FTE)
- Coordinators & Managers - Senior personnel from all institutions (unfunded)

### 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

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

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

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

The main task for FY23 will be to get the prototype ready for the beam test at FNAL, conduct the test there, and analyze the data afterwards. The group will conduct these tasks jointly. 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 the beam test. Any delay of the funding availability will also result in a minimum one year delay for the beam test campaign into 2024.

We aim at performing a preliminary test of a cylindrical μRWELL prototype operating in μ-TPC mode even though we are aware that getting the μ-TPC prototype and operational for the June 2023 beam test will be extremely challenging. This is the part of the R&D on μRWELL trackers that will certainly not be completed in the current FY23 timescale but with an aggressive effort and timely funding availability, we expect to be ready by the end of 2024 in time for the CD-3.

Similarly, the concept of thin gap MPGD with heavier gas can be demonstrated during the beam test in Jun 2023 if the funding is awarded in a timely manner. This preliminary R&D result will drive the need for a proposal to develop a full size prototype (hpDIRC MPGD module) in FY24 for a full validation of the tg-GEM-μRWELL technology for EPIC detector in time for CD-3. A delay in funding will equally affect the timeline for completion of this critical R&D program.

## 3 Micromegas Barrel Tracker

### 3.1 What was proposed for FY22

Simulations performed for the EIC Yellow Report have shown that a cylindrical 2D readout MPGD technology with material budget and geometry similar to the MM detectors in use in the CLAS12 experiment would meet the requirements of the EIC detector in terms of spatial resolution and material budget. The CLAS12 cylindrical MM tiles, in use since 2017, are read out with 1D strips. Therefore, we proposed to focus on the optimization of the 2D readout patterns.

The main objective of the R&D is to chose the 2D readout pattern that allows us to achieve the best resolutions while minimizing the number of readout channels and the amount of copper in the active region. We planned to design and build small scale prototypes with 2D readout patterns zigzag as well as orthogonal strips. We planned to produce separately the amplification Kapton layer (i.e. the layer with the resistive paste bulked with a micromesh) and the readout foils and then press them together: this technique allow us to test several combination of different resistive layers with different readout strip layouts. It was planned These detectors will be tested with cosmic rays and in beam tests.

### 3.2 What was achieved in FY22

The signing of the contract for funding has been finalized only in August 2022, delaying the acquisition of some materials for the construction of the prototypes. Therefore, the person power has been partially redirected on simulation studies.

**Bulk of a stretched resistive Kapton foil:** This part of the R&D focuses on the preparation of the readout and amplification parts of the 2D detectors as a stack of Kapton foils stretched on a carbon fiber support. The two readout layers made of Kapton foils with copper strips (readout kapton, RK) will be glued together to the amplification Kapton (AK). The AK consists of a 50μm Kapton foil prepared with the resistive paste layer and stretched on a carbon fiber frame that will be bulked with a stainless steel micromesh at 128μm distance from the foil. The process of stretching and bulking AKs has been tested and some of the samples are shown in Figure 4. The samples have been also tested electrically and it was possible

Figure 4: Examples of stretched Kapton foils with a resistive layer that have been bulked.

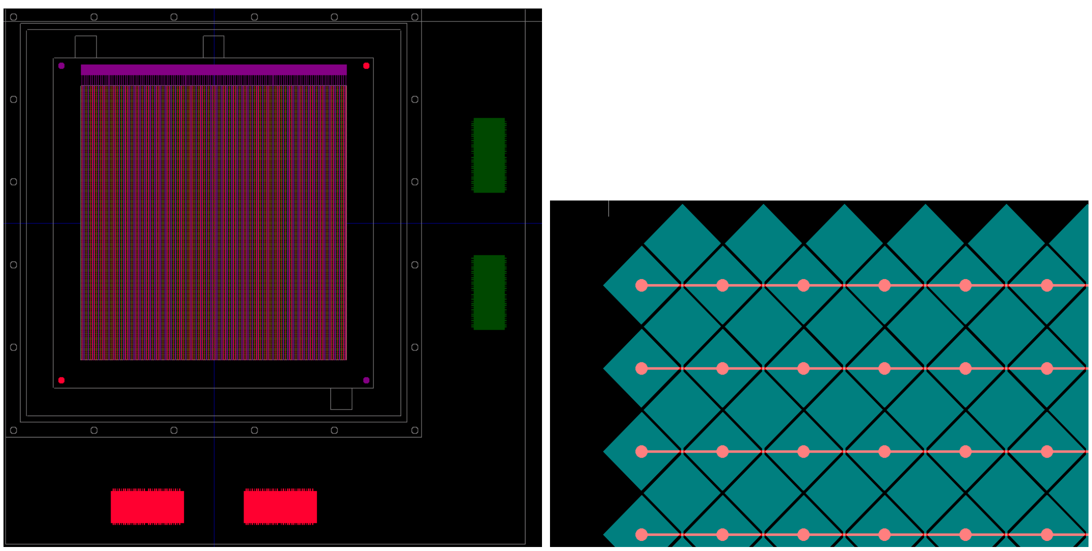

Figure 5: Examples of Gerber files for the 2D readout prototypes. (Left) full view of the 2D orthogonal strips option. (Right) Zoomed view of the ASACUSA-like readout pattern.

to set potential differences of up to 900V between the mesh and the resistive layer in air with currents below 1$\mu$A, values that are typical for a standard MM.

**Design of readout Kapton foils (RKs):** Several designs for the RK foils have been prepared. A couple of examples are shown in Figure 5. In particular, Gerber files have been prepared for different motives including, straight orthogonal strips, zigzag strips and ASACUSA-like pattern (see the right Figure 5). Also Gerber files for different strip pitches have been prepared.

**Simulations of a resistive MM detector:** The signal formation in gaseous detectors is simulated with the Garfield++ library, but this library cannot simulate the signal formation and propagation in the resistive layers of MPGD detectors. Therefore, the work of an internship student was dedicated to couple the output of Garfield++ simulations with finite element analysis of the signals in the resistive layer. The resistive layer has been implemented using the Telegraphist's equations that, considering the inductance negligible, reduce to diffusion's equations. The diffusion coefficient is proportional to $1/RC$, where $R$ is the resistance and

$C$ the capacitance. Preliminary results show that it is possible to obtain position resolutions of less than $100\mu$m with a strip pitch of 1mm. The simulations will be calibrated, in particular the diffusion coefficient, once the results of the prototypes will be available. We plan to use the simulations to optimize the final choice of the readout pattern.

## 3.3 R&D plans and funding requests for FY23

### 3.3.1 Small scale 2D prototypes

**Production:** We plan to finalize the integration of several prototypes. The readout PCBs will be the result of the integration of the AKs with different RKs. The active area of the prototypes will be about 12x12cm$^2$. The prototypes will have two 64-channels connectors for each readout direction. We plan to use RKs with straight and zigzag orthogonal strips and ASACUSA-like layouts. Each RK will have small variation of the readout motives, in order to test the performance with different pitch choices: as an example, the RK with straight strips, will have strips with 1mm and 2mm pitches. The mechanics will be 3D printed and its design is being finalized. We are planning to produce mechanics with 1mm and 3mm drift gaps in order to test the resolutions and efficiencies for shallow angle tracks. We will also have AKs with different values of resistivity between 1M and 100M$\Omega/\square$: this will allow us to chose the optimal value of resistivity for the position resolution and the cluster size desired.

**Testing:** We plan to use the cosmic test bench in Saclay to perform efficiency and resolutions studies. In particular, an ongoing effort in Saclay aims at integrating few MAPS sensors to the cosmic test bench to improve the track resolution and to allow for precision studies of the prototypes. We plan also to participate in a beam test in MAMI (PSI) in the first quarter of 2023.

### 3.3.2 Full size prototype design and construction:

We propose to build a full scale prototype with the chosen 2D readout pattern. Although, the size and radii of the MPGD layers in the EPIC detector are not currently defined, previous studies have shown that barrel layers could be more than two meters long at radii between 40cm and 80cm. The proposed design for a MM barrel tracker for the EIC detector is based on two main concepts: 1) having only a single module design that can be curved at different radii, 2) avoiding acceptance gaps by overlapping modules both in azimuth and longitudinal dimensions. Having only one module design will simplify production and integration.

**Full scale prototype.** Modules with active area of about 50x70cm$^2$ will allow us to fulfill the requirements stated above. Since the size of a CLAS12 MM tile is of a similar size, we propose to reuse the CAD designs of CLAS12 tiles and adapt them to fit the 2D readout. Although the curvature of the CLAS12 tiles is smaller (radius $\approx$20cm) compared to the EIC ones, we propose to reuse the mechanics and the tooling to curve the PCBs that have been used for the CLAS12 production in order to save time and costs in the design. The active region of the prototype will be longer (50x70cm$^2$) with respect to the CLAS12 MM ($\approx$50x50cm$^2$), but the number of readout channels is similar since we are proposing to use readout pitches larger than 1mm, thanks to the developments int charge sharing through the resistive layer and zigzag patters. Reusing the CLAS12 geometry will allow us also to reuse the tooling to curve the detector.

We propose to perform tests for gas tightness, HV stability, efficiency and resolution measurements with cosmic rays and in test beam.

**Longer mechanical mock-up.** Since the EIC MPGD barrel layers can be longer than 2 meters, longer detector modules can minimize the number of detectors to be produced. Thus, we propose to design, build and test a mechanical model of a detector of dimensions 50x100cm$^2$. This mechanical model will be equipped with the gas piping to test the mechanical deformation with pressure. We also plan to equip this mock-up with electrodes for the readout and the drift to be able to evaluate the impact of the electrical forces on the drift geometry.

### 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

#### 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

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

The main task for the FY23 is to build one full scale curved MM tile (50 cm × 70 cm) with the final choice of the 2D readout.

Before CD-3, the module geometry will be optimized to fit the final decision for the EPIC barrel MPGD layers. The main task will be to find industrial partners for the production phase and perform the pre-production R&D with them.

## 4 Funding profile and split among the institutions for FY23

### 4.1 Money matrix and split among participating institutions

In the case of university requests, fringe and indirect costs are included in the numbers in the table.

### 4.2 Three budget funding scenario

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 (excel Sheet).

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 |

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