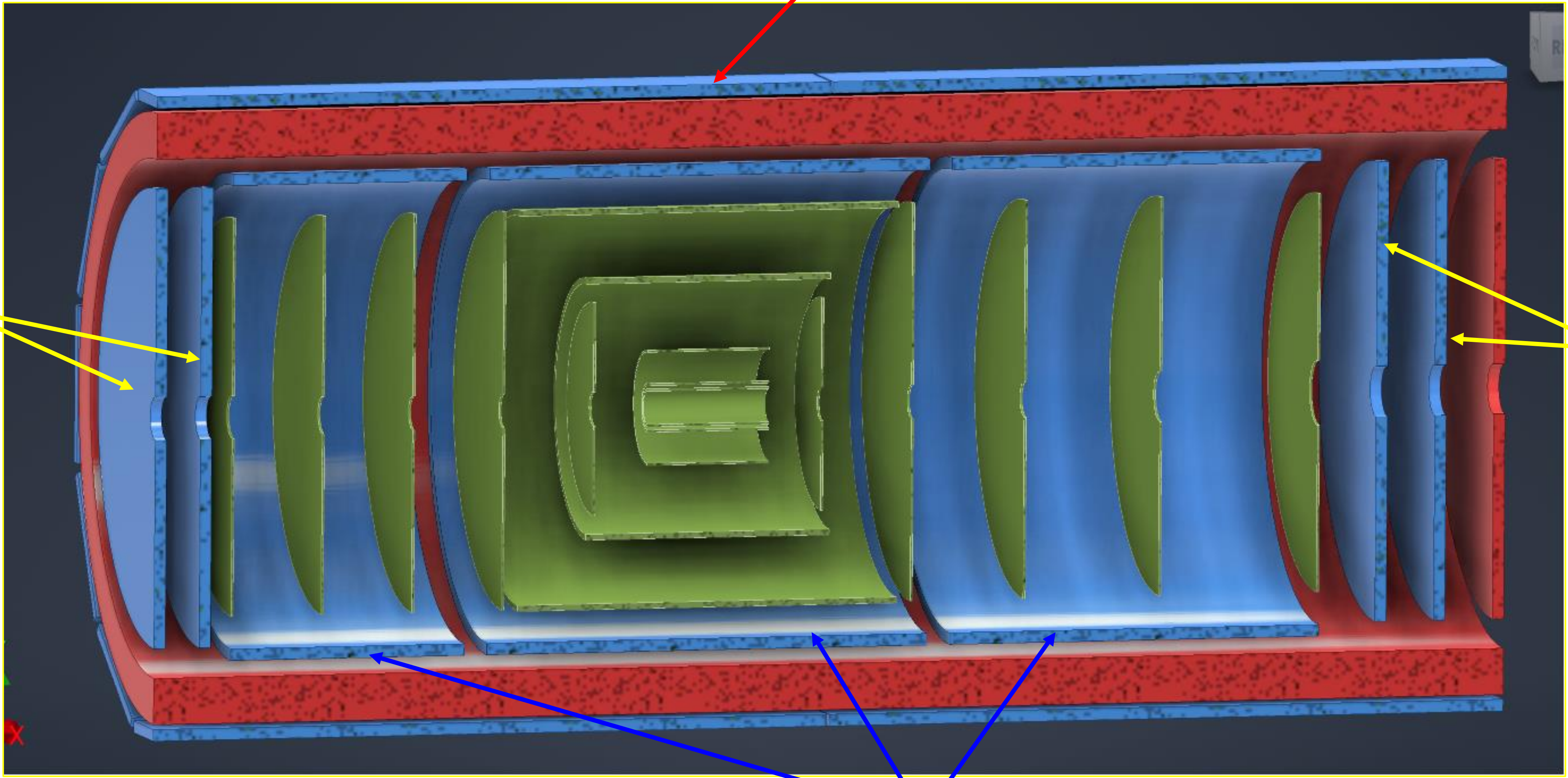
Perspectives, Status and Timelines for thin-gap MPGDs for ePIC

Kondo Gnanvo

On behalf of the eRD108 Consortium / DSC Gaseous Trackers

TIC weekly Meeting - 09/18/2023

Overview of MPGD Trackers in ePIC



ePIC µRWELL trackers

Endcap µRWELL disc module:

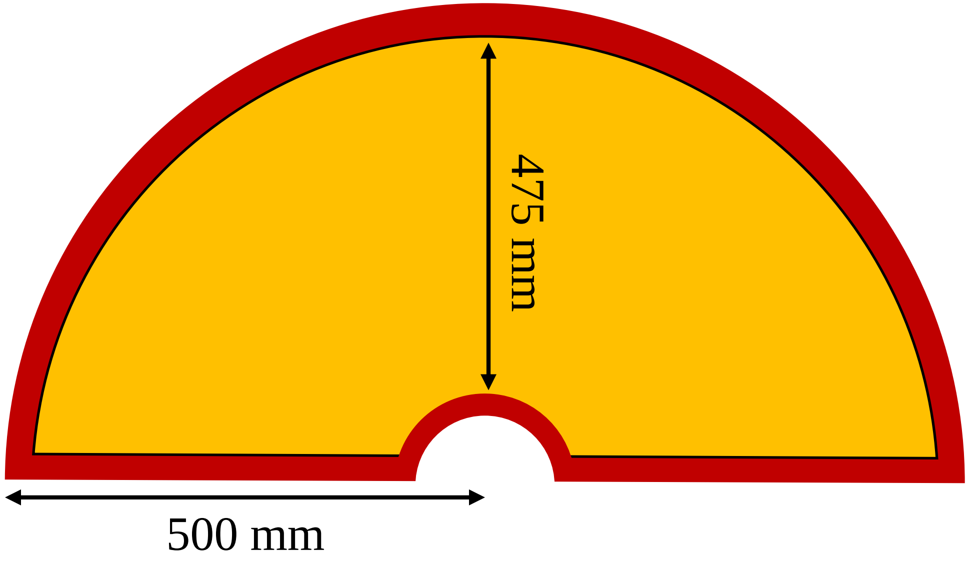
- Half disk (radius 50 cm) twin (double-sided) hybrid GEM-µRWELL thin gap detector
- 2D (r-phi)-strip capacitive-sharing readout: pitch ~1.2 mm (low capacitance)

Barrel Outer µRWELL Tracker:

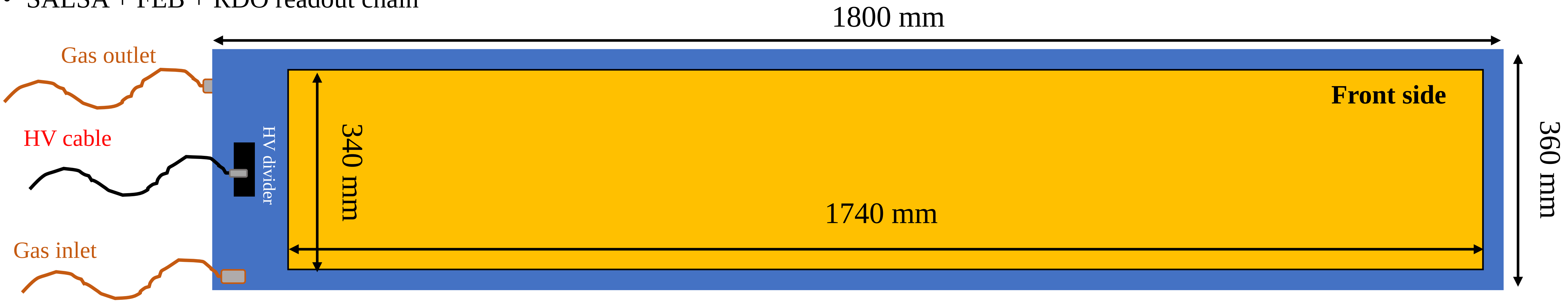
- 180 cm × 36 cm planar twin (double-sided) hybrid GEM-µRWELL thin gap detector
- 2D (diagonal X-Y)-strip capacitive-sharing readout: pitch ~1.2 mm (low capacitance)

Readout electronics for all ePIC µRWELL trackers:

- Same readout electronics as for ePIC barrel inner Micromegas tracker (CyMBal)
- SALSA + FEB + RDO readout chain



End cap µRWELL disk module

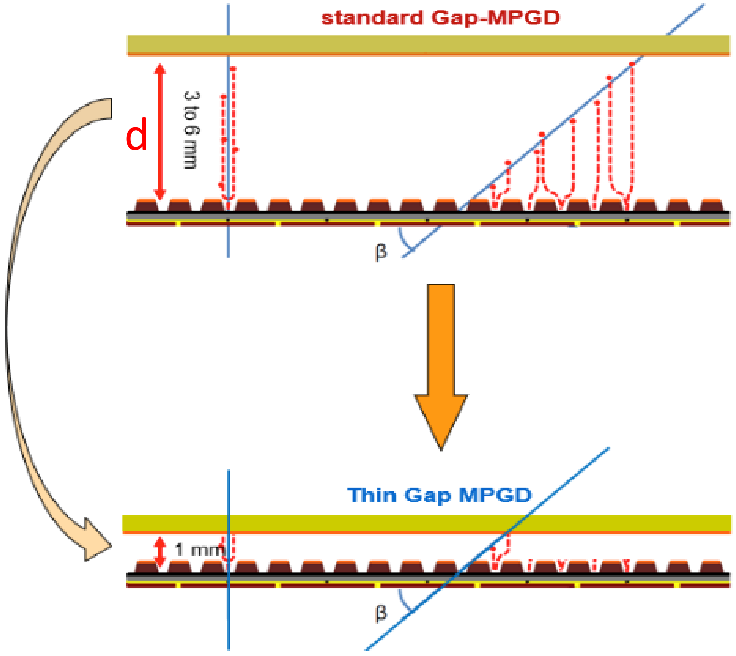


Barrel Outer µRWELL Tracker

Why developing thin-gap MPGDs for ePIC

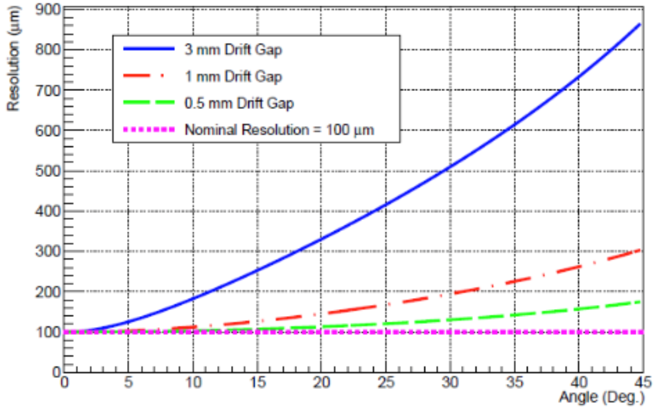
❖ Motivation

- 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 with MPGDs i.e. GEM, µRWELL and Micromegas detectors



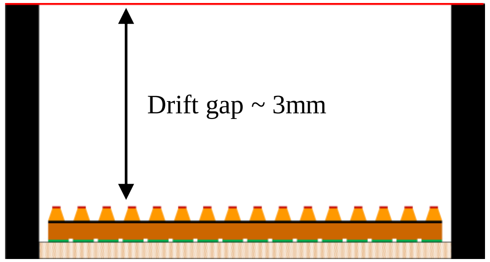
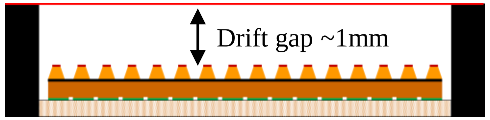
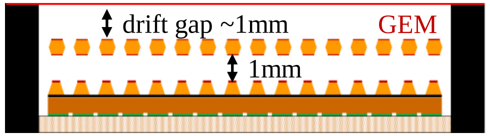
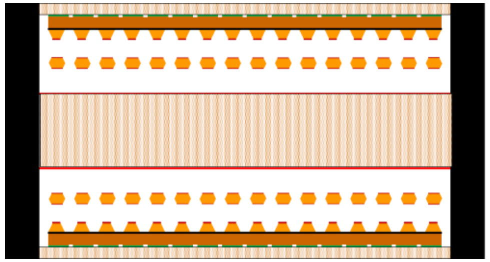
❖ Proposed Solution

- Reducing the drift gap from 3 mm to < 1mm is one approach to recover at least to some degree good spatial resolution performance
- Address both large angle tracks and E × B effect simultaneously
- Bonus advantage ➔ time resolution inversely proportional to drift gap
- Thin-gap & Hybrid GEM-µRWELL technology seems the best candidate



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

Pros and cons of thin gap µRWELL technology options

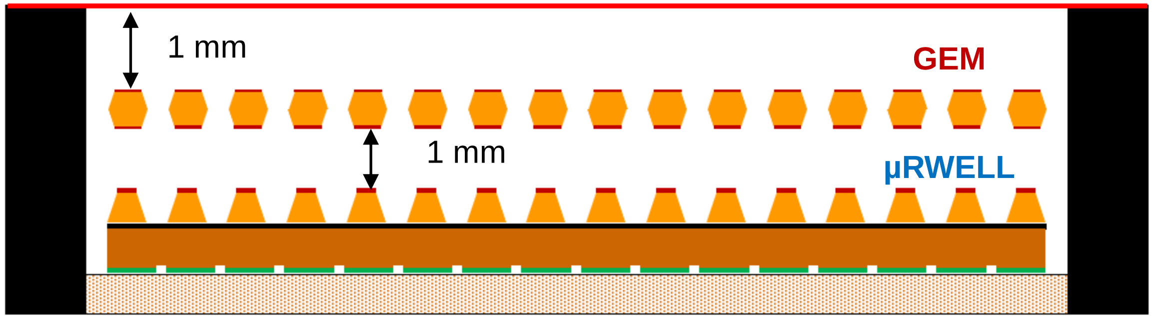
	Standard µRWELL - 2D strip readout 	Thin-gap µRWELL - 2D strip readout 	Hybrid thin-gap GEM-µRWELL - 2D strip readout - GEM pré-amplification - µRWELL amplification 	Twin (double-sded) hybrid thin-gap GEM-µRWELL × 2 
Nominal spatial resol. (perpendicular tracks)	Excellent ~70 µm	Excellent < 70 µm	Excellent < 70 µm	• Excellent < 70 µm
Position resol. @ large angle	Really poor	Good, can be limited by S/N	Good	Good
Timing resolution	10 - 20 ns	**< 10 ns**	**< 10 ns**	**< 10 ns**
Detector efficiency	Full efficiency > 97%	• ~ 75% with Ar-mixture • ~ 90% with Xe-mixture?	• ~ 85% with Ar-mixture • > 95% with Xe-mixture	• 98% 1-hit with Ar mixture • 72% 2-hit with Ar mixture
Pros	Simple structure	• Simple structure • Good position resolution possible @ large angle • Excellent time resolution	• Good position resolution @ large angle • Excellent time resolution • Robustness & stability	• Same as for hybrid thin gap GEM-µRWELL + • Full efficiency (Ar mixture) • 2-hit capability • Compact detector
Con	• Poor position resol. • average time resol.	• limited efficiency • High gain with single amplification ➔ Possible stability issues	• limited efficiency (with Ar-based mixture) • Complex structure • Assembly challenges	• Even more complex structure • Assembly challenges

eRD108 choice: Thin Gap hybrid GEM-µRWELL

Hybrid thin-gap GEM-µRWELL (with Xe-based mixture)

- Hybrid amplification (GEM-µRWELL) with GEM pre-amplification:
  - Large S/N to compensate for small number of primaries
  - HV on each device at low / safe operation voltage point
  - Safety margin for HV for unexpected issue with large detectors
- Single detector module but with hybrid amplification:
  - Single hit detection efficiency > 95% for 1 mm thin gap
  - No benefit for 2-hit capability
  - Xe gas cost and availability (Kr gas an alternative option)
  - Gas purification / recirculation system needed
  - Xe slower gas than Ar ➔ time resolution ~ 2 times worse

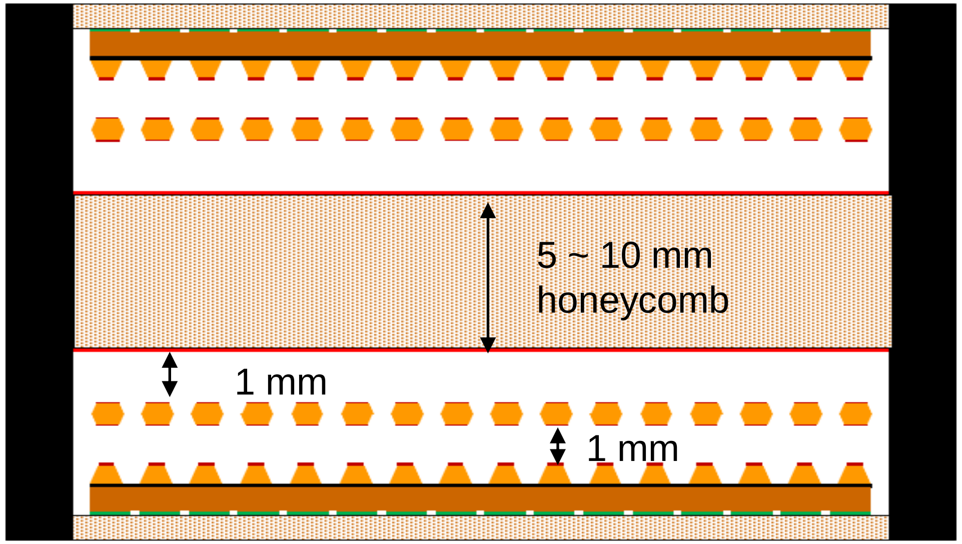
Single hybrid thin-gap GEM-µRWELL



Twin (double-sided) hybrid thin-gap GEM-µRWELL (with Ar-based gas mixture)

- Same technology choice as hybrid thin-gap GEM-µRWELL but
  - Double-sided detector with shared cathode support structure:
  - Compact 2-detector-in-one approach ➔ will fit the ePIC envelop
- Full efficiency with Ar-based gas mixture
  - An **OR** of the two layers ensures a single hit detection efficiency ~98%
  - An **AND** gives a 2-hit efficiency ~72% ➔ tracklet for pattern recognition

Twin Hybrid Thin-Gap GEM-µRWELL



Timeline for ePIC thin-gap hybrid GEM-µRWELL R&Ds

- **Year #1: Targeted R&D – eRD108 FY24:**
  - Design of the 2D readout structure of large thin gap hybrid GEM-µRWELL prototype
  - Design & 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 for µRWELL, 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 with EIC Generic MPGD-TRD R&D consortium
    - Participate to joint beam test at Fermilab with TRD effort to test small scale gas recirculation system
- **Year #2: PED – Design and procurement of the parts of pre-production full-size thin-gap hybrid GEM-µRWELL prototypes:**
  - Design of all parts (2D readout structure, GEM and µRWELL foils) of large thin gap hybrid GEM-µRWELL prototype
  - Design of the mechanical structure / support frames the prototypes (End cap discs and Outer barrel modules)
  - Procurement of the µRWELL-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 × 360 cm) Outer Barrel hybrid Thin Gap GEM-µRWELL module prototype
  - Assembly of the full-size (100 cm × 50 cm) end cap Thin Gap GEM-µRWELL 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

Ongoing R&D on thin-gap hybrid GEM-uRWELL

2 EIC related- R&D programs for the development thin Gap Hybrid GEM-uRWELL technology

- EIC FY24 Project - eRD108 Proposals: Design of full-size modules and construction and test of mock-up prototypes
  - Mock-up prototypes to investigated mechanical issues associated with large area. We can not complete the design, fabrication and characterization of full-size working prototypes in a 1-year time frame - **This is a 3-year thin-gap MPGD development program**
- EIC FY23 Generic R&D – Thin Gap Consortium proposal: Medium-size prototypes to fully investigate all challenges related new approach

➔ **we want to concentrate on Ar-CO2 gas mixture**

EIC Detector R&D Proprosal

The eRD108 Consortium

July 10, 2023

The eRD108 Consortium

Project ID: eRD108

Project Name: Development … MPGD Trackers.

Brookhaven Natior… …ry (BNL): Craig Woody
CEA Saclay: … …ossù, Maxence Vandenbroucke
Florida … Technology (FIT): Marcus Hohlmann
Ist… …ale di Fisica Nucleare (INFN Roma Tor Vergata): Annalisa D'Angelo
…y of Virginia (UVa): Huong Nguyen, Nilanga Liyanage
…nple University (TU): Matt Posik, Bernd Surrow
Thomas Jefferson National Accelerator Facility (JLab): Kondo Gnanvo
Vanderbilt University (VU): Sourav Tarafdar

https://wiki.bnl.gov/eic/upload/ERD108_Proposal_FY24_Final.pdf

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

Proposal to the FY23 EIC generic detector R&D pro…

The Thin Gap MPGD (tg-MPGD)…

Project Name: Development of D… …M-µRWELL for Tracking at the EIC
Project Period: from 10/1…
PI & Contact Pers… …anvo@jlab.org
Project Mem…
F… …ietro Iapozzuto
…, Seung Joon Lee
…am, Matt Posik, Bernd Surrow
…ong Nguyen, Nilanga Liyanage
… Sourav Tarafdar, J.Velkovska, V.Greene
Yale U.: Nikolai Smirnov

https://wiki.bnl.gov/eic/index.php?title=File:20230714_eRD_tgMPGD_Proposal_FY23_Final.pdf

Comments from DAC – Project R&D meeting closeout section

eRD108 –MPGD: Outer Barrel µRWELL Layer

- A layer of planar detectors using hybrid GEM-µRWELL technology, arranged in a circle is proposed for the outer barrel tracking layer in front of the hpDIRC.
- Provide fast timing hits as an aid to pattern recognition and improve the determination of the angles of charged particles entering the hpDIRC.
- A full-size prototype is planned to address stability issues albeit with a mock µRWELL foil.
- Many technical challenges (foil stretching, low mass materials, HV stability) must be overcome in a short time to create a reliable final design.
- There is a risk posed by using a Ph.D. student to design and fabricate the prototype.
- Explore the possibility of employing professional design engineers.

eRD108 –MPGD: Endcap µRWELL Layers

- To provide additional tracking hits in the endcap regions of ePIC two planar MPGD disks at each end were added to the baseline design. An additional benefit would be providing fast hit points for background rejection.
- One year is a very short time to accomplish the design and development of new large-area µRWELL chambers particularly given the issue of charge-up and chamber integrity using light-weight materials.
- Reliance on students for design tasks poses a risk.
- The anticipated one-year needed for the CERN workshop to fabricate large-area µRWELL foils pushes chamber construction and testing well into FY25.
- No beam testing of large area µRWELL chambers poses a risk.
- What is the proposed strategy and impact of the services for the forward disks?
- Explore the possibility of employing professional design engineers.

Groups involved in the realization?

Institutions	Contacts	Expressed interest	Anticipated contribution (Here, I am speculating)	Past and present experience in MPGD for NP and HEP experiments
University of Virginia	N. Liyanage, H. Nguyen	Barrel Outer μRWELL Trackers	Design, assembly, commissioning, Installation?	SBS GEMs, PRad GEMs, MOLLER GEMs, CLAS12 μRWELL, EIC R&Ds
Jefferson Lab	K. Gnanvo, Seung Joon Lee, D. Weisenberger	Barrel Outer μRWELL Trackers	Design, assembly, commissioning, Installation?	SBS GEMs, PRad GEMs, CLAS12 μRWELL, CLAS12 Micromegas, BoNuS and BoNuS12 rTPC GEMs
Florida Tech	M. Hohlmann	Hadron end cap μRWELL discs	Design, assembly, commissioning, Installation?	CMS GEMs, EIC R&Ds
BNL	C. Woody, A. Kiselev, B Azmoon	Electron end cap μRWELL discs	Design, assembly, commissioning, Installation?	PHENIX HBD, sPHENIX TPC, EIC R&Ds …
INFN (Roma Tor Vergata)	A. D'Angelo	end cap μRWELL discs	Design, assembly …?	CLAS12 μRWELL, EIC R&Ds
Vanderbilt U.	S. Tarafdar	end cap μRWELL discs	Design, assembly, commissioning, Installation?	sPHENIX TPC GEM readout, EIC R&Ds …
Temple U.	M. Posik, B. Surrow	end cap μRWELL discs Barrel Outer μRWELL	Will let Matt comments	STAR FGT, sPHENIX TPC GEM readout, EIC R&Ds
Korean Institutions contribution	I. Yoon	Production of GEM and μRWELL foils	In kind contribution (GEM foils and μRWELL PCBs)?	CMS GEMs foil production

Summary

- **Twin (Double-sided) Thin Gap Hybrid GEM-µRWELL is eRD108 preferred option for ePIC µRWELL trackers**
  - Same technology and configuration will be developed for both Barrel Outer Tracker and Endcap discs
  - Only detector size / shape and strip readout geometry and segmentation will differ
  - Full efficiency, good timing and spatial resolution, stable operation configuration, redundancy and double-hit capability with standard non-flammable and cheap Ar-CO2 gas mixture

- **Need a sustained & dedicated R&D & PED effort**
  - We estimate a 3-year R&D (and /or PED) effort to complete a full-size working prototypes for both barrel and end cap trackers
  - No show-stopper or serious concerns with the technology choice but a few challenges need to be addressed

- **ePIC µRWELL trackers instrumented with SALSA electronics**
  - Use same readout electronics and DAQ scheme as CyMBaL
  - Only minor difference in the implementation between subsystems

- **Large MPGD community in ePIC Coll. interested in the effort**
  - Several US institutions with proven experience in MPGD tracking systems for large scale NP & HEP experiments
  - EU (INFN Roma) and Asia (Korean MPGD consortium) institutions

Backup

µRWELL Technology: Maturity for ePIC Trackers

Is the technology mature for ePIC? Yes and No

The answer below to this question are only my personal but I hope unbiased opinion based on my experience with the technology so far

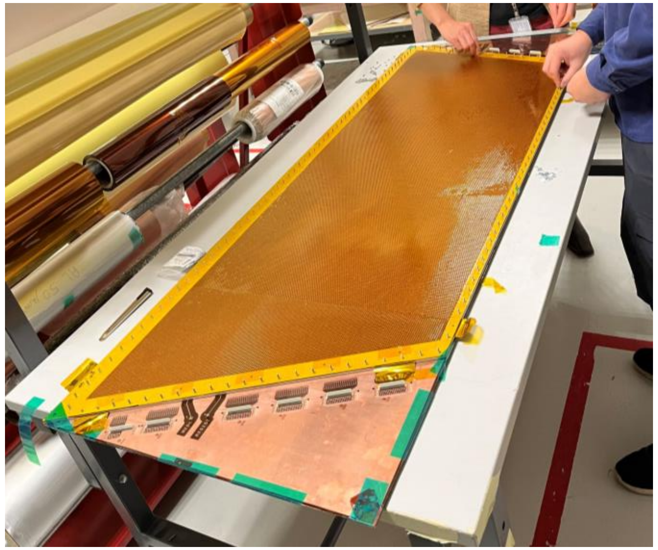
- **Is µRWELL mature for ePIC? Yes**
  - µRWELL as MPGD technology is not fundamentally different from the other 2 mature MPGDs (GEM and Micromegas)
  - Amplification structure (µRWELL foil) is based on the same concept and base material as a GEM foil
  - Operating concept of µRWELL detector is very similar to Micromegas (single amplification stage) detector unlike triple-GEM
  - Concept of resistive MPGD (with DLC) to ensure stable operation of single-stage amplification was pioneered for Micromegas detector (ATLAS Small Well MM, T2K TPC MM readout, CLAS12 MVT…) ➔ so there is nothing fundamentally
  - There is a lots of effort **in MPGD community in EU, US and Asia** to bring the technology to maturity level for large scale experiments

- **Is µRWELL mature for ePIC? No**
  - Has never been used in an experiment so far so the community can feel a little bit nervous about investing in this option for ePIC
  - Challenges and issues are expected, specially for large area devices because it is new ➔ but this is the case for every technology
  - Thought there is no show-stopper that needs to cause concerns

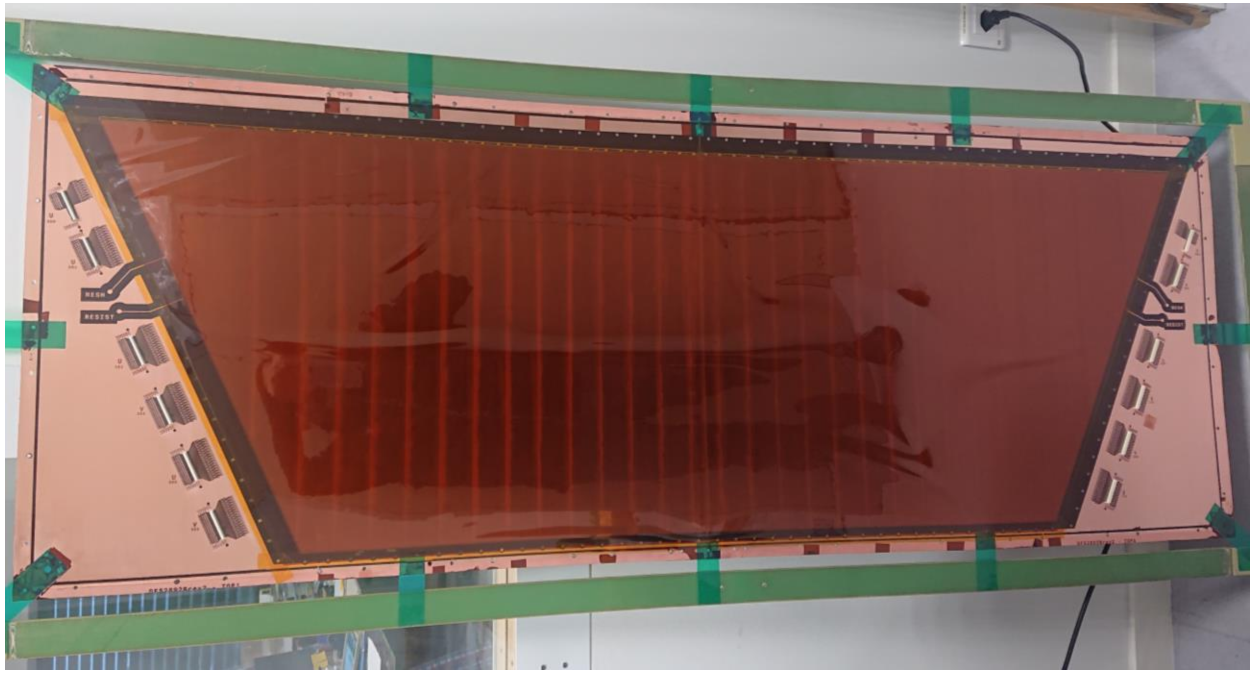
µRWELL technology: Recent experience

Is the technology mature for ePIC? Yes and No

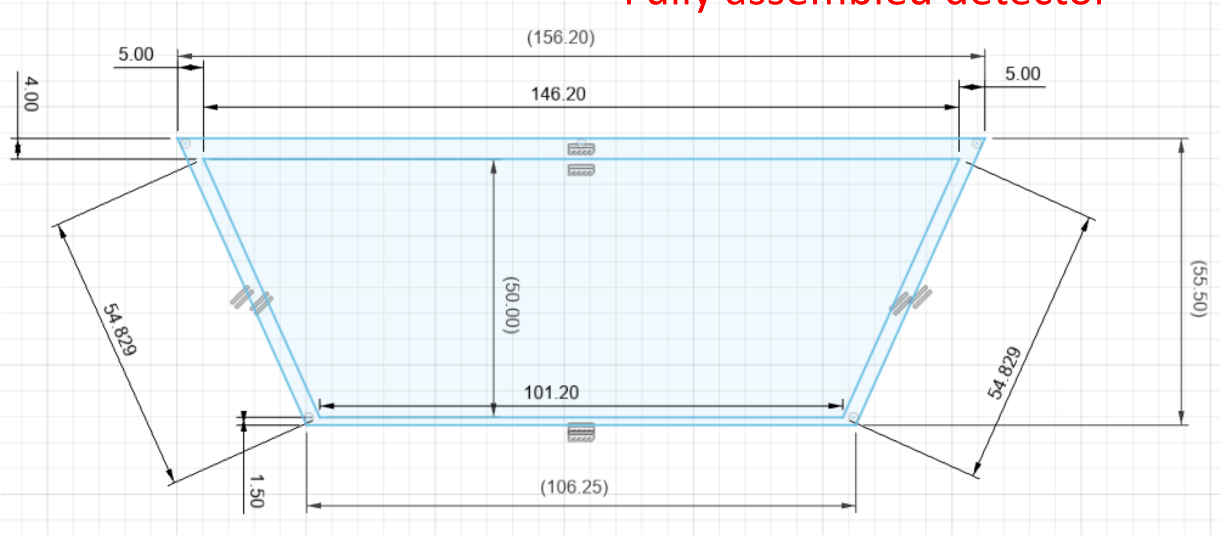
- ❖ CLAS12 recently built a large µRWELL prototype for High Lumi Upgrade of its forward tracker
  active area: Trapezoid [146 cm – 101 cm] × 54 cm
- ❖ The dimension are similar to the largest module needed for ePIC Barrel Outer Tracker
- ❖ The prototype has been under test at JLab since early 2023
- ❖ As expected, some issues with this first attempt for large area ➔ the collaboration is investigating



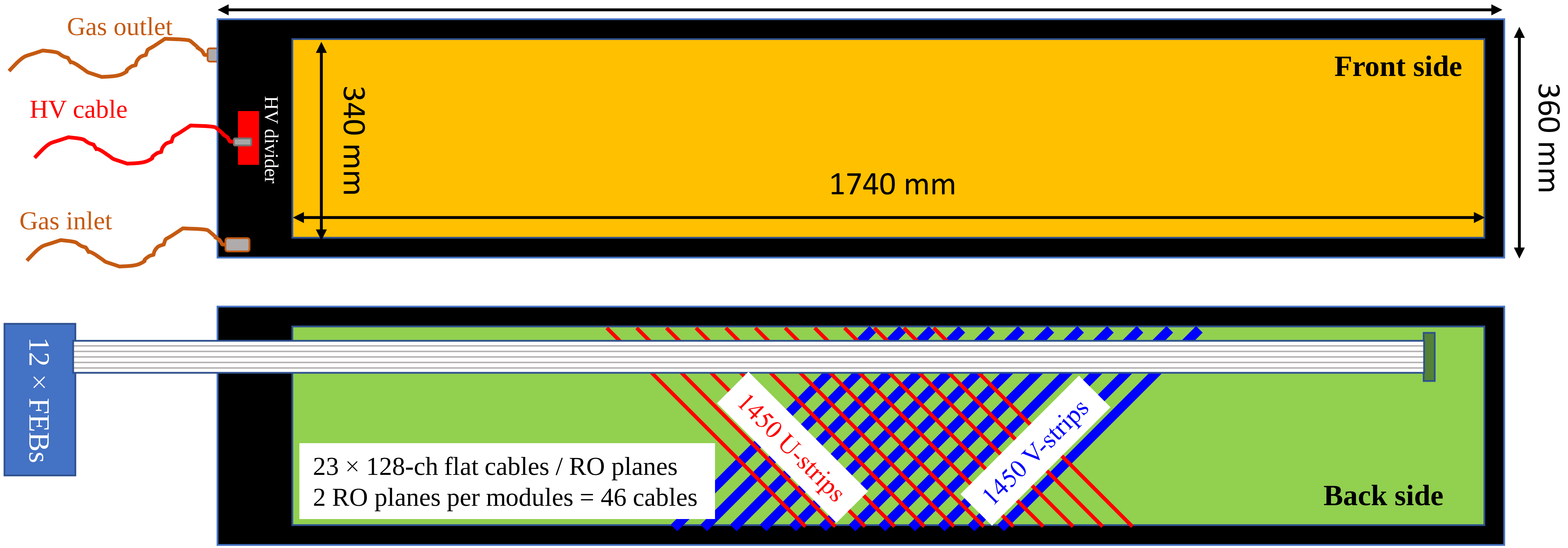
Fully assembled detector



µRWELL + capaSh RO PCB



ePIC Outer µRWELL Barrel Tracker



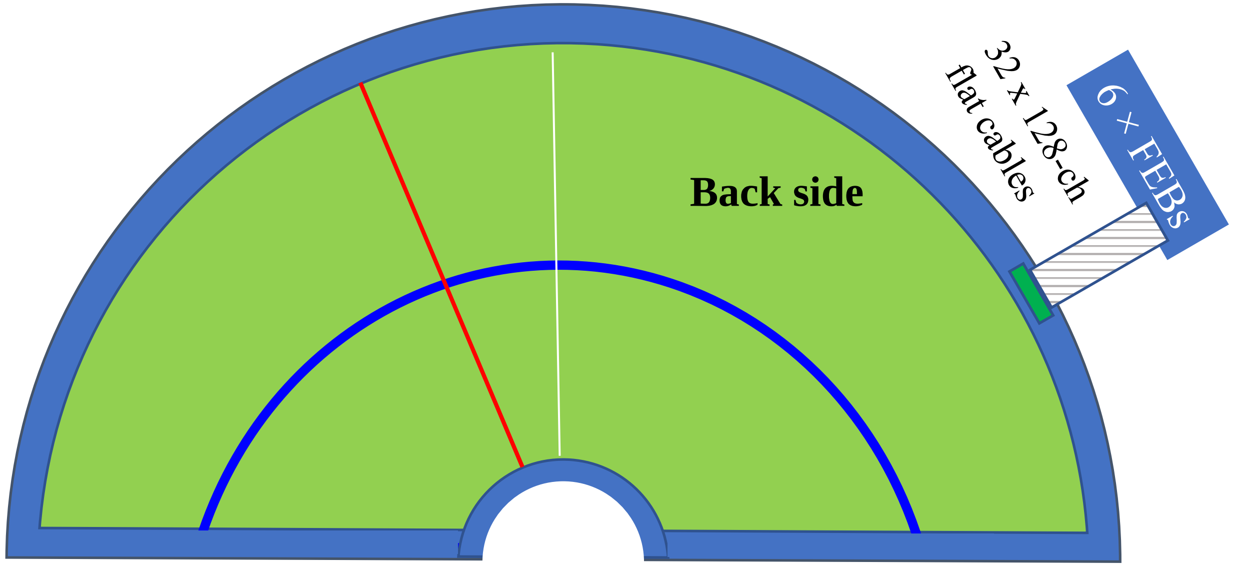
Outer µRWELL module:

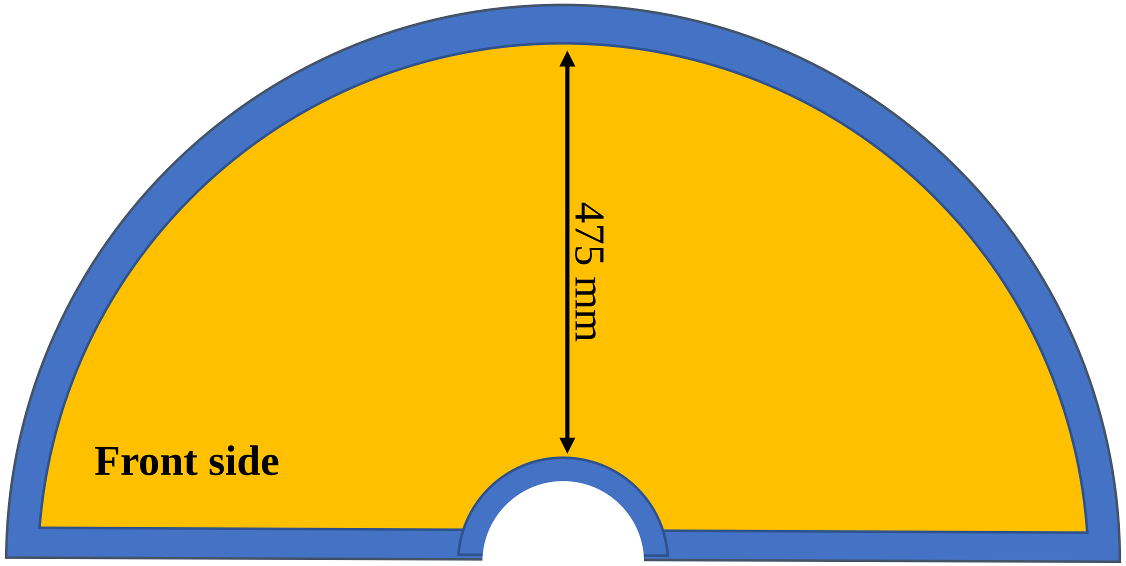
- Readout strips: Capacitive-sharing 45-degree U-V strips
- Pitch: 1.2 mm pitch
- 2 (double-sided modules) × 2 × 1450 U-V strips = **5800 strips**
- 46 × 128-pins flat cables + connectors on the back of the chamber
- 12 FEBs (assuming 8 SALSA chips / FEB) ➔ ~ 6000 channels
- 2 gas lines (inlet and outlet)
- 1 × HV cable for (2 kV, 1 mA)

Outer µRWELL tracker: ➔ 2 × 12 modules (24 modules)

- 2 × 12 ×12 ×FEBs = 288 FEBs
- 2 × 12 × 46 **= 1104 × 128-pins flat cables** / connectors
- **142,312 readout channels**
- 48 gas lines
- 24 HV cables

ePIC End Cap μRWELL discs





Endcap μRWELL disc module: (double-sided hybrid)

- Readout strips: Capacitive-sharing 45-degree r-phi strips
- Pitch: 1.2 mm pitch
- ~2 × 1570 phi-strips + ~ 2 × 400 r-strips = ~**4k strips**
- 32 (2 × 16) 128-pins flat cables + connectors on the back of the chamber
- 2 × 4 FEBs (assuming 8 SALSA / FEB) ➔ ~ 4 kch
- 2 gas lines (inlet and outlet)
- HV cable for (2 kV, 1 mA)

2 × ePIC Endcap μRWELL disc trackers: EE (2 × 2 half-discs)

- 2 × 2 × 8 × FEBs = 32 FEBs
- 2 × 2 × 32 = **128 × 128-pins flat cables** + connectors
- **~16k readout channels**
- 8 gas lines
- 4 HV cables

Are there any remaining R&Ds? Yes

3 thin-gap hybrid GEM-µRWELL prototypes already successfully tested in beam

- ❖ Proto #1, (#2): 1-mm, (0.5-mm) drift) / 1-mm induction with capacitive-sharing X-Y strip readout
- ❖ Proto #3: 1-mm drift / 0.5-mm induction with 2D zigzag strip readout

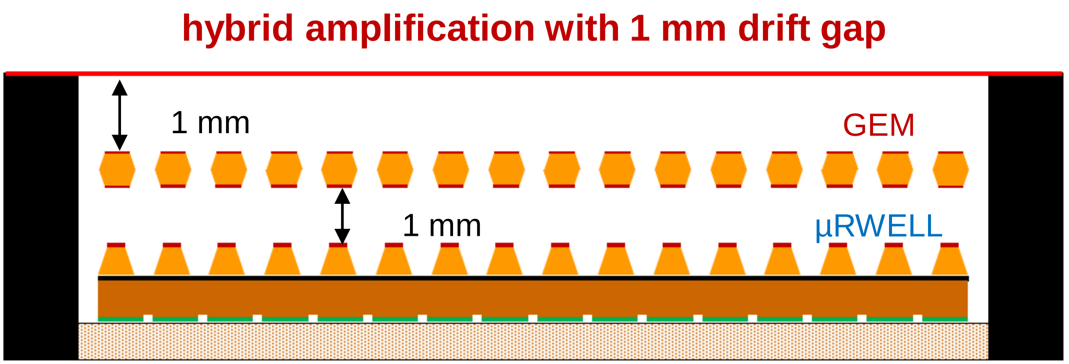
Preliminary results:

- ❖ Good efficiency in Ar/CO_2 ➔ 85% for 1-mm drift prototypes and ~ 75% for 0.5-mm drift
- ❖ Good S/N was easily achievable ➔good spatial resolution performance expected

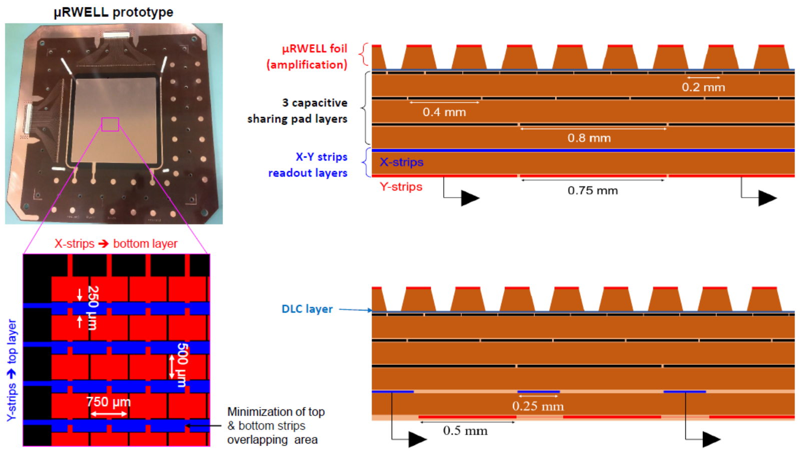
Test in beam at CERN in a couple of weeks

- Impact of B-field (1.5 T) on spatial resolution performance

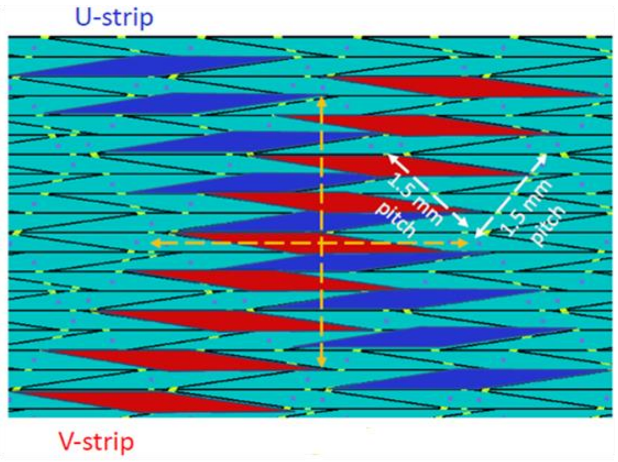
This R&D effort need to be supported in a sustained way for the next couple of years for the technology to be ready for ePIC



Two configurations for amplification



µRWELL with capacitive-sharing strip readout



2D zigzag strip readout

R&D on thin-gap MPGDs – (EIC FY22 Generic R&D)

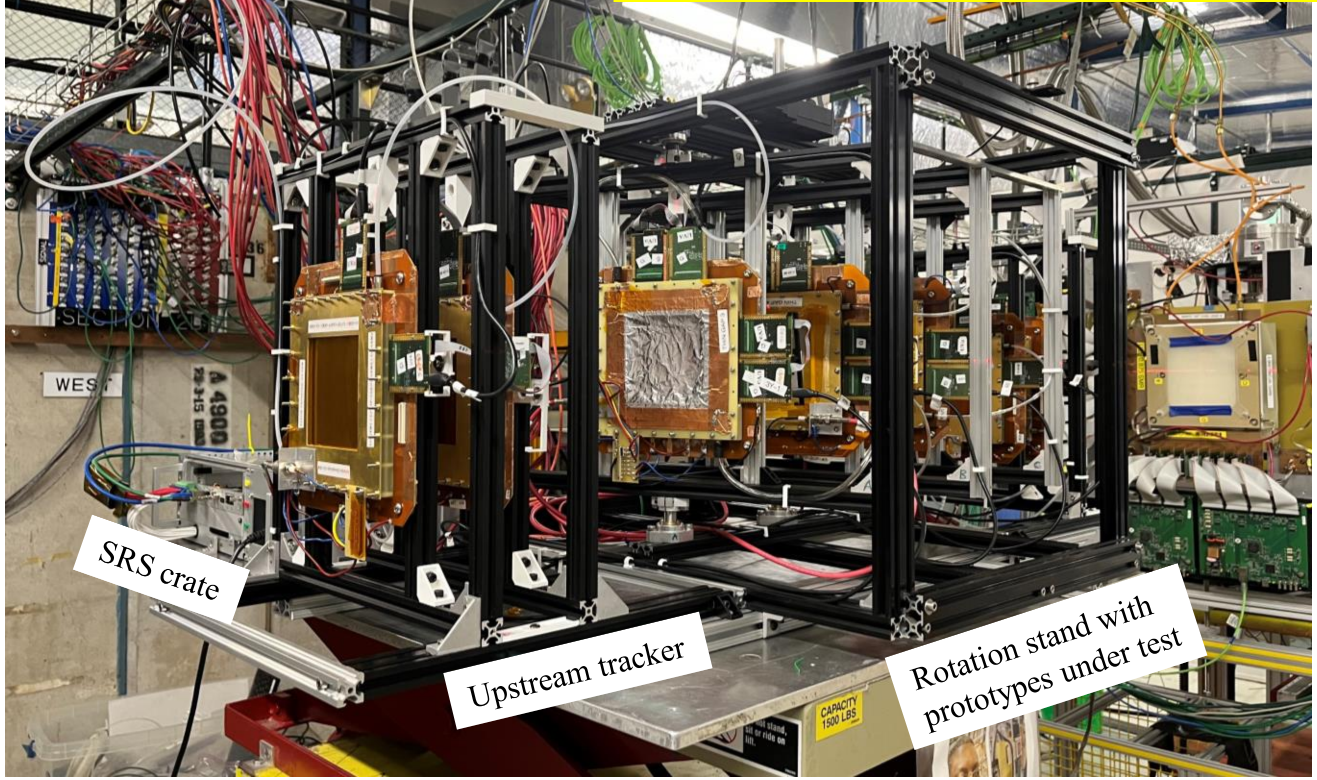
Development of Thin Gap MPGDs for EIC Trackers

K. Gnanvo*[1], S. Greene[4], N. Liyanage[2], H. Nguyen[2], M. Posik[3], N. Smirnov[5], B. Surrow[3], S. Tarafdar[4], and J. Velkovska[4]

[1]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[2]University of Virginia, Department Of Physics, Charlottesville VA 22903, USA
[3]Temple University, Philadelphia, PA 23606, USA
[4]Vanderbilt University, Department of Physics and Astronomy, Nashville, TN 37240, USA
[5]Yale University, Physics Department, New Haven, CT 06520, USA

https://www.jlab.org/sites/default/files/eic_rd_prgm/files/2022_Proposals/20220725_eRD_tgMPGD_Proposal_final_EICGENRandD2022_23.pdf

Are there any remaining R&Ds? **Yes**



Fermilab beam test (June 07 – 13, 2023)

- 10 Thin Gap MPGD prototypes tested
  - All three technologies: µRWELL, Micromegas, GEMs
  - Single amplification vs. hybrid amplification
  - Capacitive-sharing R/O vs. zigzag structures

CERN beam test (August 30 – September 06, 2023)

- Test in B field at CERN for E × B measurement :
- B-Field up to 1.5 T

Test beam team:

- Jefferson Lab: Kondo Gnanvo, Seung Joon Lee
- Temple U: Jae Nam
- Vanderbilt U: Sourav Tarafdar
- UVa: Huong Nguyen, Minh Dao, Xinzhan Bai
- Yale U: Nikolai Smirnov

R&D needs for ePIC μRWELL trackers

Any issue with the foreseen ASIC FEE SALSA? ➔ NO

- **SALSA electronics will be used for both CyMBaL and all ePIC μRWELL Trackers**
  - The readout electronics is being developed jointly by Saclay and San Paolo groups
  - Don’t anticipate any significant difference in the implementation system used by all ePIC MPGD trackers
    - Details like numbers of chips / FEB or needs for long micro-coax flat cables etc … will be decided based on specific needs and constraints of each sub tracker system i.e. Outer barrel will likely used long micro-coax flat cables, CyMBaL likely not

- **We had a very productive meeting with DAQ colleagues on Friday 11th to discuss ePIC MPGD readout and DAQs**
  - Indico link: https://indico.bnl.gov/event/20280/
  - Also see Marco talk on SALSA for MPGDs
  - We don’t see any issue on this area

- **Need to clarify the space availability for ePIC MPGD trackers cables and services in the forward backward of the detector**
  - Looks like very tight space that will make it difficult to integrate all the cables and FEB boards
  - First naïve assumption on next slides assume FEB board ➔ red boxes are place holders for that
  - If not, we wll have to rethink a number of assumption in term of volume and material thickness to have FEB on the back of the chambers

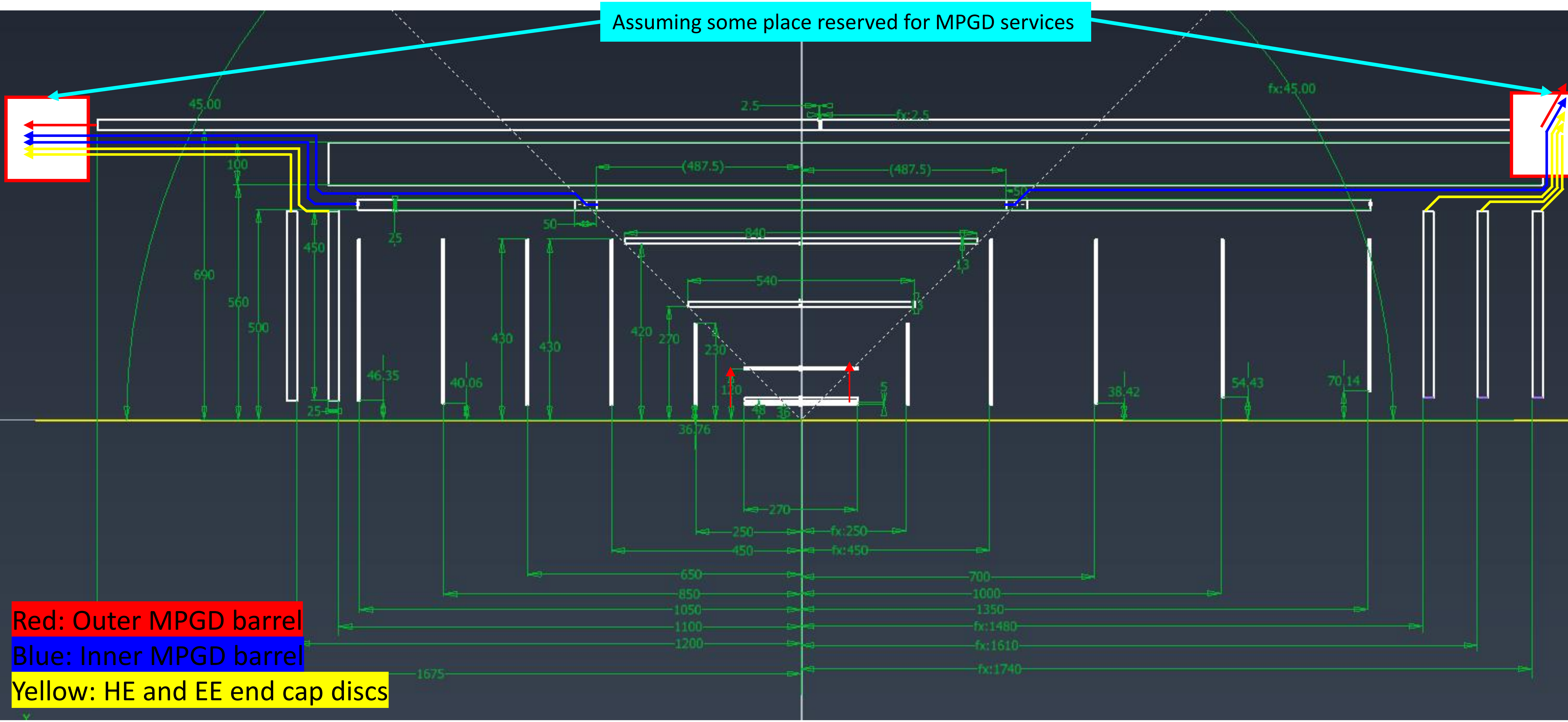
Summary

	Barrel Outer µRWELL Tracker	HE µRWELL tracker	HE µRWELL tracker
Technology	Double Thin Gap Hybrid µRWELL	Double Thin Gap Hybrid µRWELL	Double Thin Gap Hybrid µRWELL
2D R/O	2D Capacitive-sharing diagonal X-Y strips	2D Capacitive-sharing diagonal r-phi or U-V strips	2D Capacitive-sharing diagonal R-PHI or U-V strips
Spatial resolution	150 µm for 0 – 45^{o} tracks in 2T	150 µm for 0 – 45^{o} tracks in 2T	150 µm for 0 – 45^{o} tracks in 2T
Timing resolution	~10 ns	~10 ns	~10 ns
Efficiency	98% single hit 70% double hit	98% single hit 70% double hit	98% single hit 70% double hit
Material budget	1 – 2 % X_o/X	1 – 2 % X_o/X	1 – 2 % X_o/X

ePIC µRWELL Tracker

	Barrel Outer µRWELL tracker	Hadron end cap µRWELL disc	Electron end cap µRWELL disc	Total
Number of modules	24	4	4	
R/O channels (pitch 1.2 mm)	140k (24 × 6000)	16k (4 × 4000)	16k (4 × 4000)	**172k**
Number of FEBs (8 SALSA / FEB)	288 (24 × 12)	32 (4 × 8)	32 (4 × 8)	**352**
Micro-coax flex 128-pins flat cables (> 2.5 m)	1104 (24 × 46)	128	128	**1360**
LV lines	288 (24 × 12)	32 (4 × 8)	32 (4 × 8)	**352**
Firefly per FEB to RDO (12-pairs cables)	288 (24 × 12)	32 (4 × 8)	32 (4 × 8)	**352**
Gas lines (inlet and outlets)	48 (24 × 2)	8	8	**64**
HV (distribution through resistive divider)	24	4	4	**64**

ePIC MPGD cables & services routing



Technology of choice for ePIC µRWELL trackers:

Thin-Gap Hybrid GEM-µRWELL

- **Default configuration will have:**
  - GEM for pre-amplification and µRWELL amplification
  - 1-mm drift gap (cathode to GEM) and 1-mm induction gap (GEM to uRWELL/RO PCB)
  - 0.5 mm gap will also be explored
  - Double-sided amplification structures.
  - 2D capacitive-sharing strips
- **Large area capability:**
  - Length of barrel outer module ➔ up to 180 cm
  - Radius of end cap disc module ➔ ~50 cm
  - ➔ minimize dead area and material thickness
- **Same technology for the barrel outer layer and EE and HE discs**
  - Only shape and strip arrangement will be different