The µRWELL Trackers for ePIC

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On behalf of the eRD108 Consortium / DSC Gaseous Trackers

TIC weekly Meeting - 08/12/2023

Questions from TIC (Silvia 08/08/2023's email)

- **Is the technology mature for ePIC? Yes and No**
- **Are there any remaining R&Ds? Yes**
- **Groups involved in the realization?**
- **Any issue with the foreseen ASIC FEE SALSA? → NO**

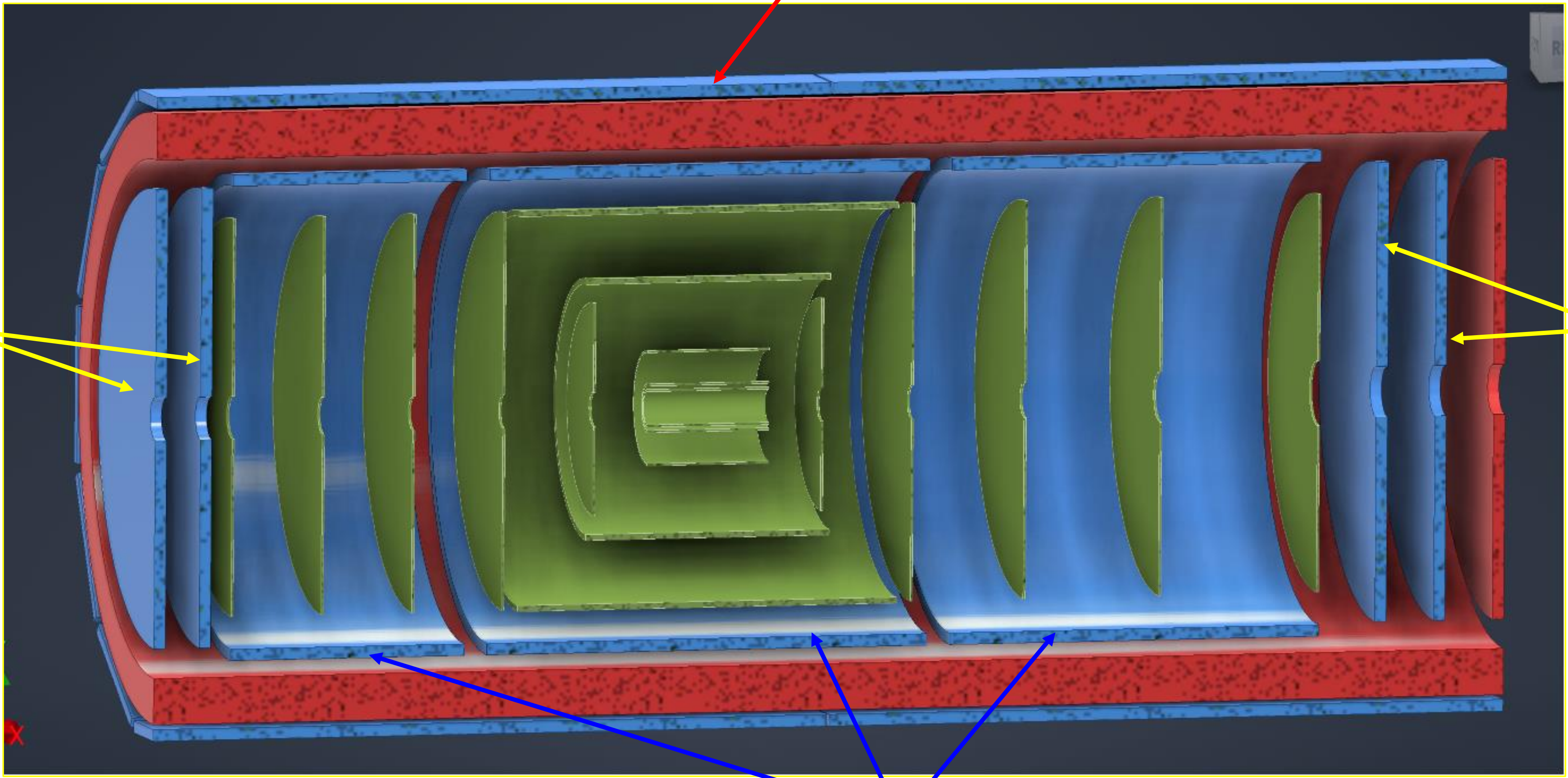
Outline

- Overview of µRWELL Trackers in ePIC
  - Outer µRWELL Barrel Tracker
  - Electron and Hadron End Cap µRWELL discs
  - Institutions with expressed interest in ePIC µRWELL trackers
- R&D needs for ePIC µRWELL trackers
  - The uRWELL technology R&D needs
  - Targeted R&D effort to achieve ePIC requirements

Overview of MPGD Trackers in ePIC

Barrel Outer µRWELL Layer

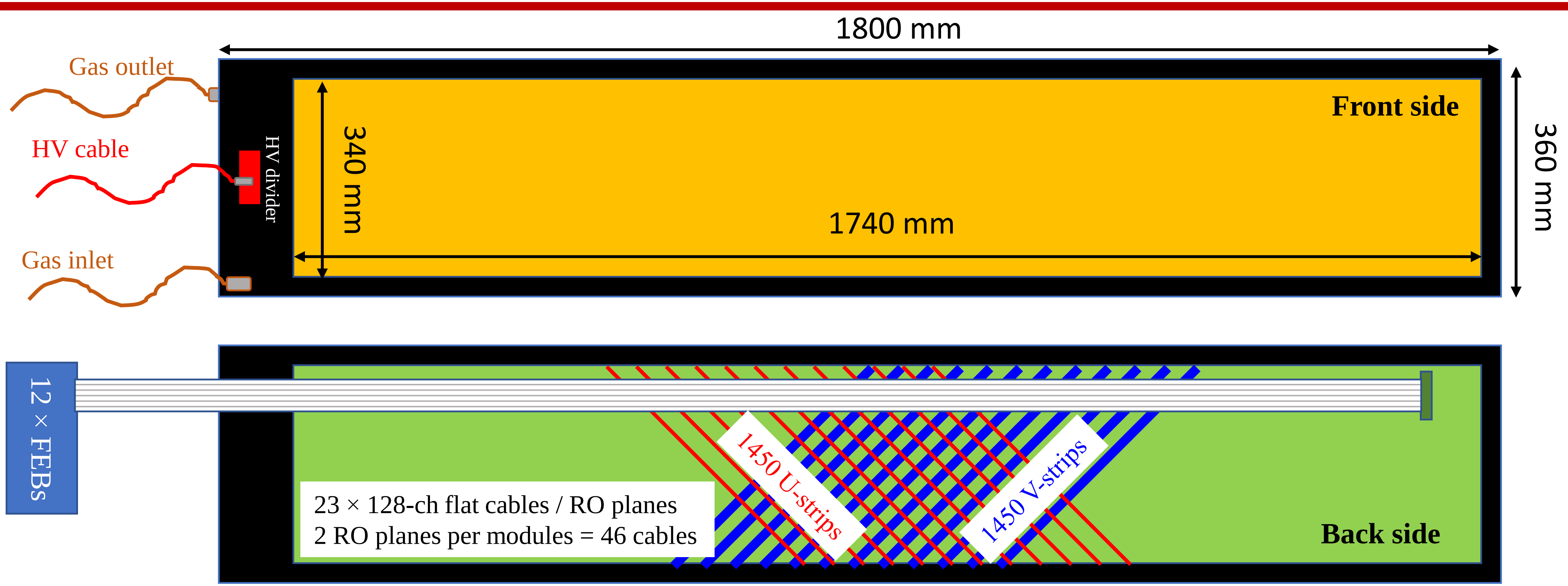
Backward µRWELL Disks



Forward µRWELL Disks

Inner Cyl Micromegas Barrel Layer CyMBaL

ePIC Outer µRWELL Barrel Tracker



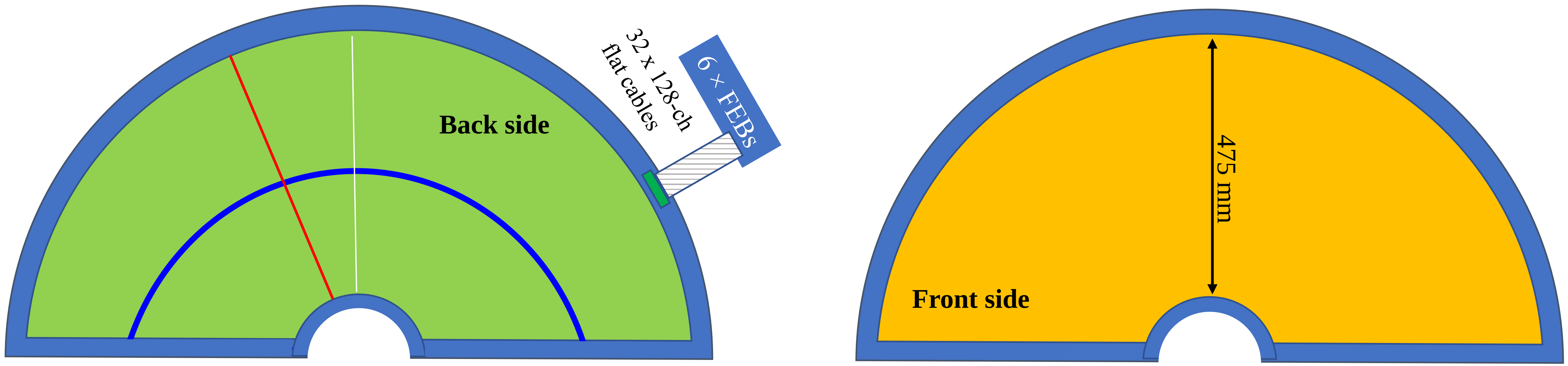
Outer µRWELL module:

- 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

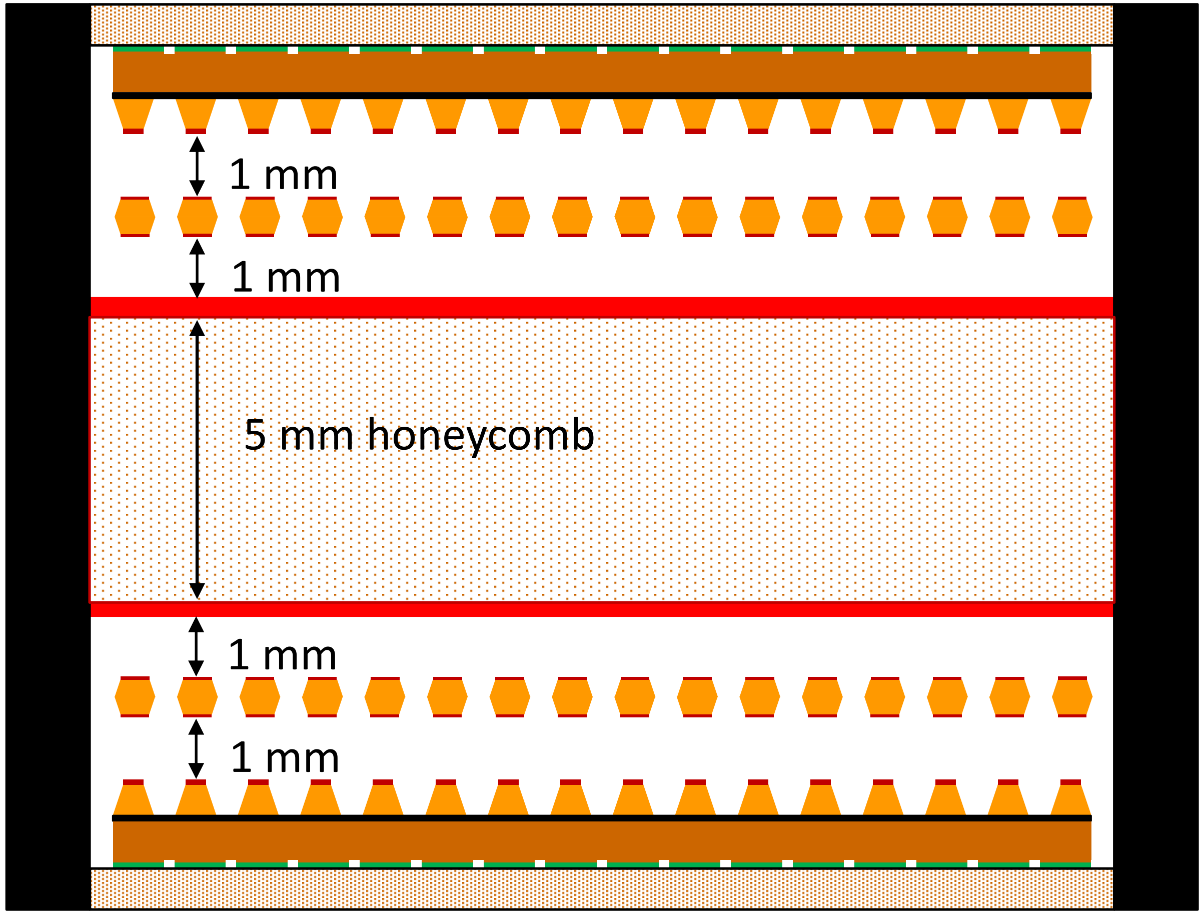
ePIC µRWELL Tracker

	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**

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



Groups involved in the realization?

Institutions	Contacts	Expressed interest	Anticipated contribution (Here, I am speculating)	Pas and present experience in MPGD
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, 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

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

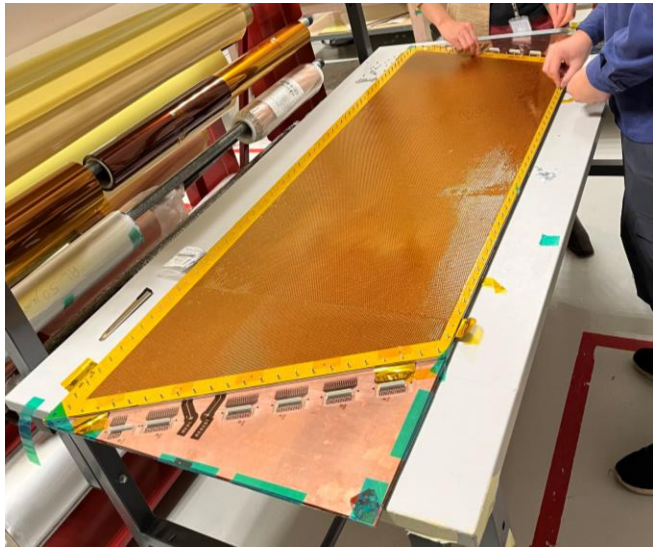
- **Is µRWELL mature for ePIC? No**
  - Has never been used in an experiment so far so the community can feel a little bit nervous about investing in this option for ePIC
  - Challenges and issues are expected, specially for large area devices because it is new ➔ but this is the case for every technology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

µRWELL technology: Recent experience

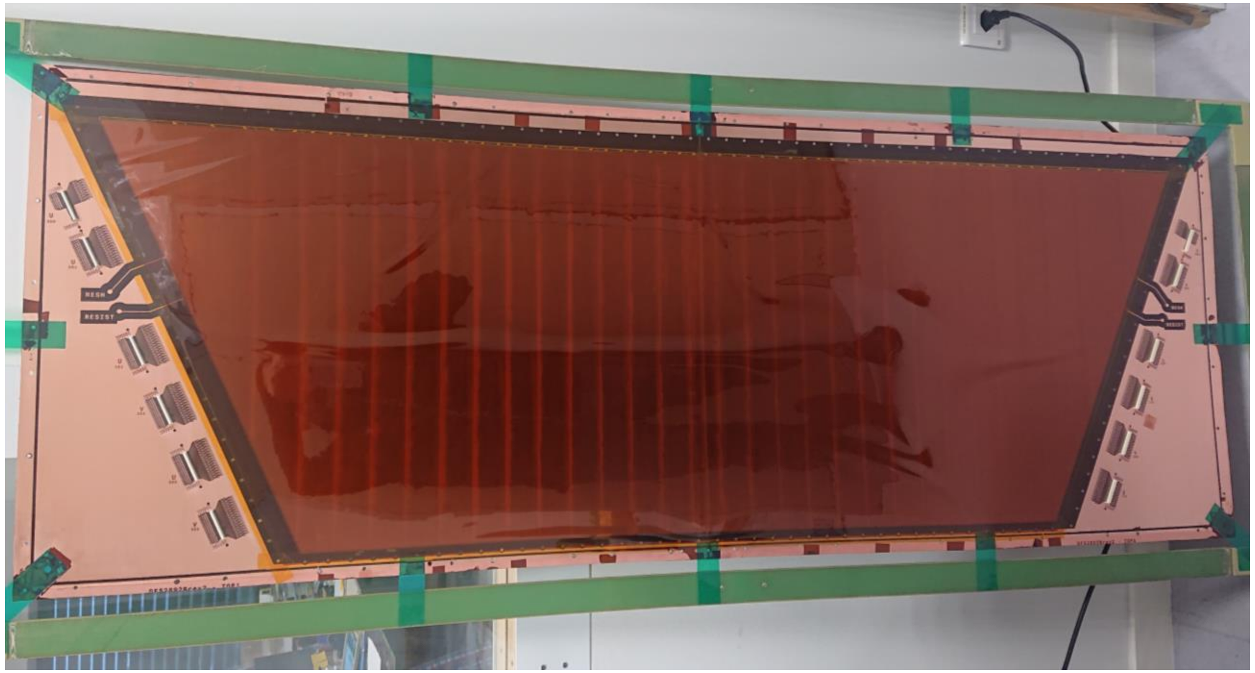
Is the technology mature for ePIC? Yes and No

- CLAS12 recently built a large µRWELL prototype for High Lumi Upgrade of its forward tracker

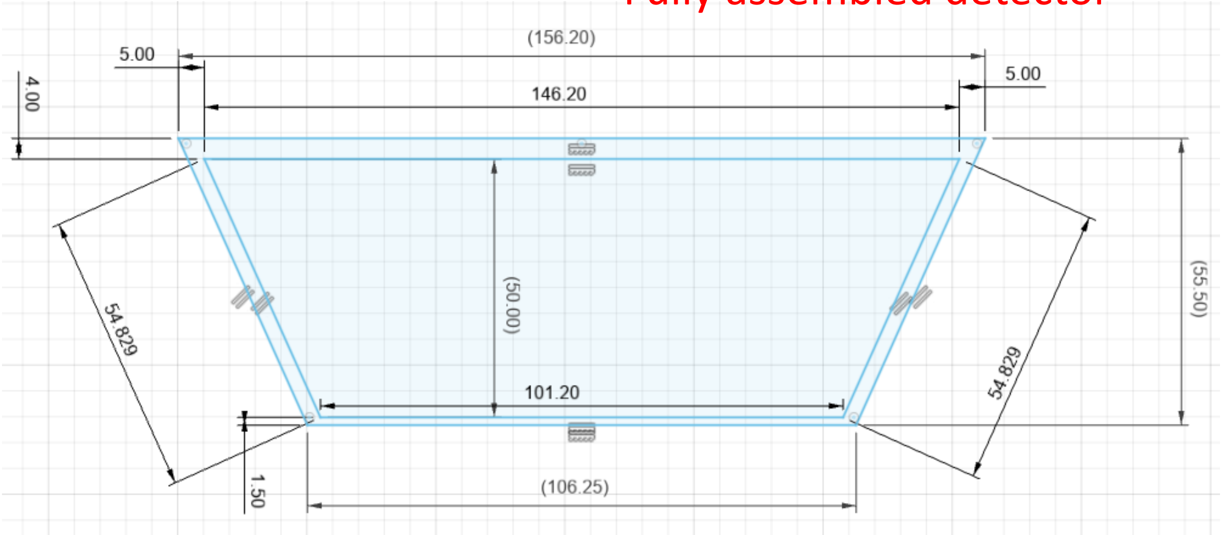
  active area: Trapezoid [146 cm – 101 cm] × 54 cm
- The dimension are similar to the largest module needed for ePIC Barrel Outer Tracker
- The prototype has been under test at JLab since early 2023
- As expected, some issues with this first attempt for large area ➔ the collaboration is investigating



Fully assembled detector



µRWELL + capaSh RO PCB



R&D needs specific to ePIC tracking requirements

Are there any remaining R&Ds? Yes

We propose to develop double-sided thin-gap hybrid GEM-µRWELL for ePIC?

- **Why Thin-Gap MPGD:**
  - MPGD still need decent spatial resolution over a wide range of particle's track angle
    - ➔ This is particularly critical for hpDIRC that requires good tracking input parameters
  - Limit negative impact of B-field on the position resolution
  - Assumption in Crater Lake simulation are not compatible with standard (> 3-mm) gap MPGDs

- **Why hybrid GEM-µRWELL:** Two stage amplifications with GEM pre-amplification
  - To increase detection efficiency of a 1-mm gap detector to > 85%
  - improve signal to noise ratio to achieve spatial resolution even with large pitch readout structures
  - allow very stable operation at large detector gain (far away from the critical voltage limit of each amplification structure)

- **Why double-sided Thin Gap GEM-µRWELL:**
  - Single hit per module efficiency ~98% with cheap, easily available and non-flammable gas mixture (Ar-CO2)
  - Will also provide 72% double-hit efficiency per module ➔ help with track angular resolution for the hpDIRC seed finding
  - Compact detector will fit the 25 mm tight envelope allocated for the barrel outer MPGD layer

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

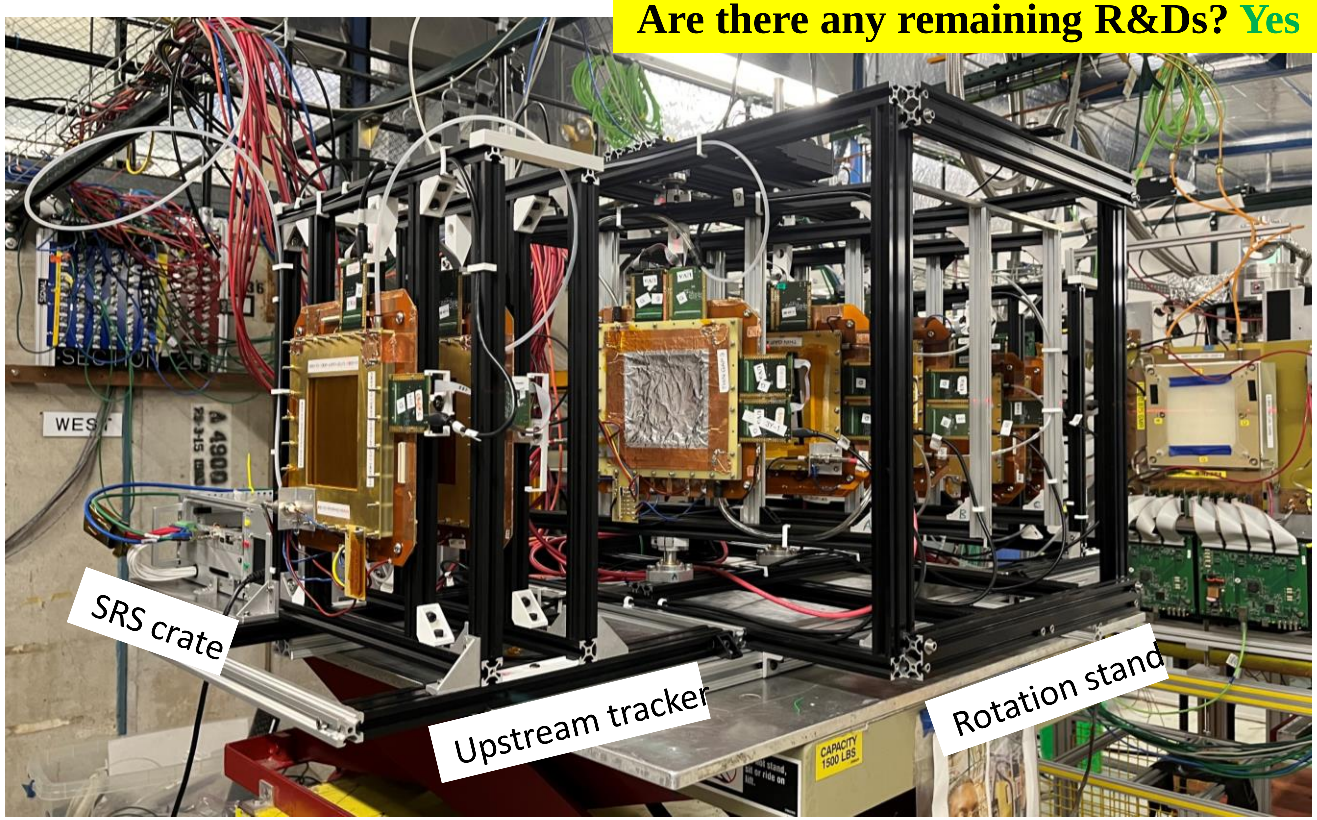
Development of Thin Gap MPGDs for EIC Trackers

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*
- ***And the very nice Test beam Facility crew:*** *Todd, JJ, Mandy, Evan, Joe …*

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

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:

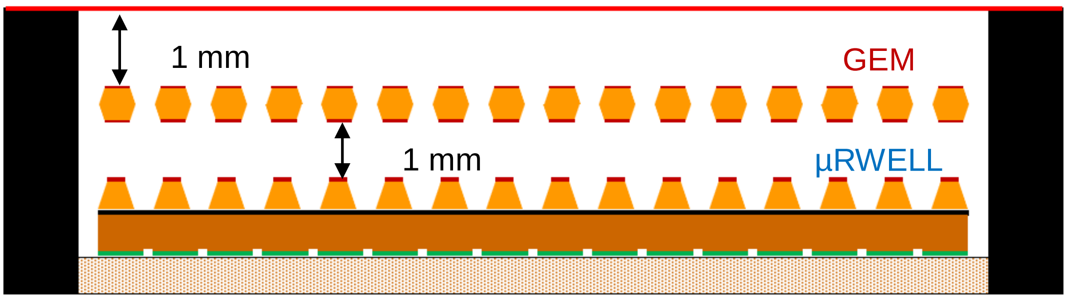
- ❖ Good efficiency in Ar/CO2 ➔ 85% for 1-mm drift prototypes and ~ 75% for 0.5-mm drift
- ❖ Good S/N was easily achievable ➔good spatial resolution performance expected

Test in beam at CERN in a couple of weeks

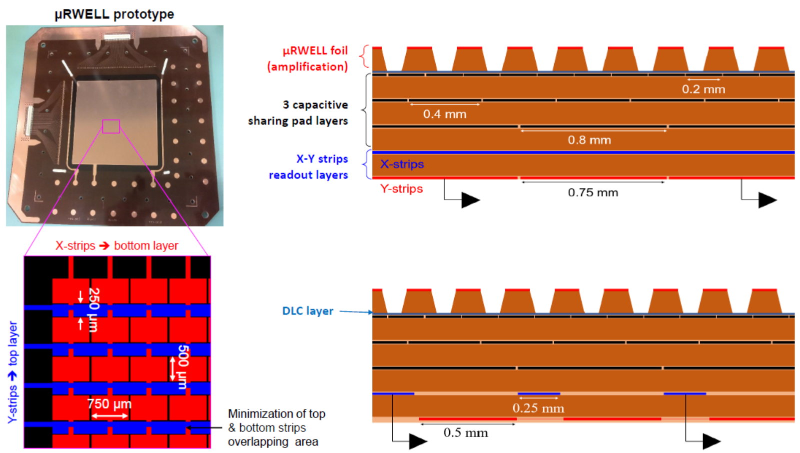
- Impact of B-field (1.5 T) on spatial resolution performance

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

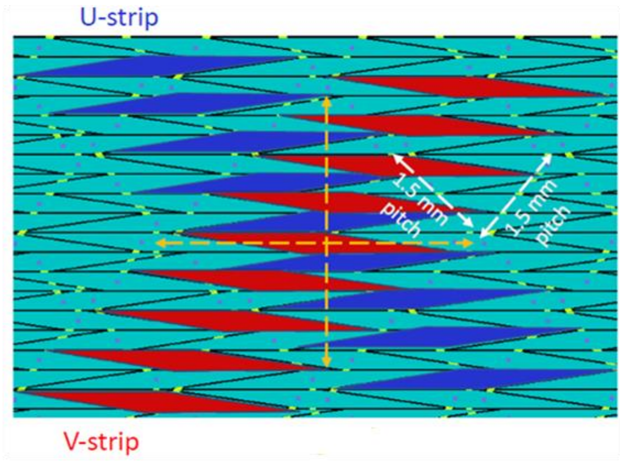
hybrid amplification with 1 mm drift gap



Two configurations for amplification



µRWELL with capacitive-sharing strip readout



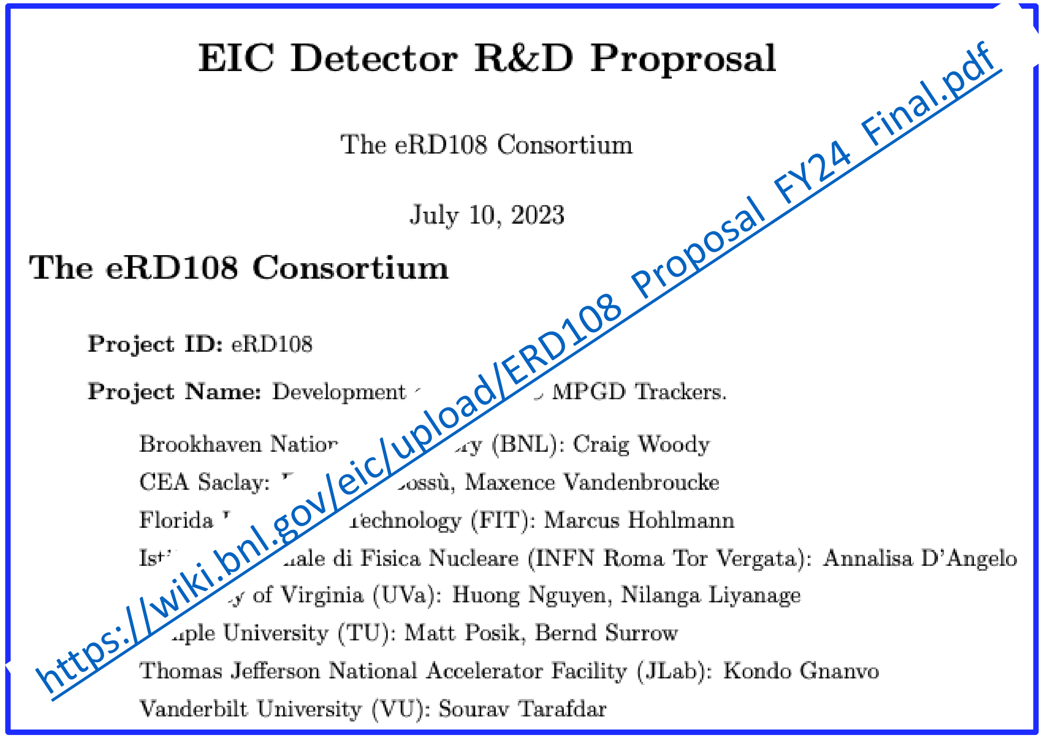
2D zigzag strip readout

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

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

Are there any remaining R&Ds? Yes

- **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 minimum 3-year R&D 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

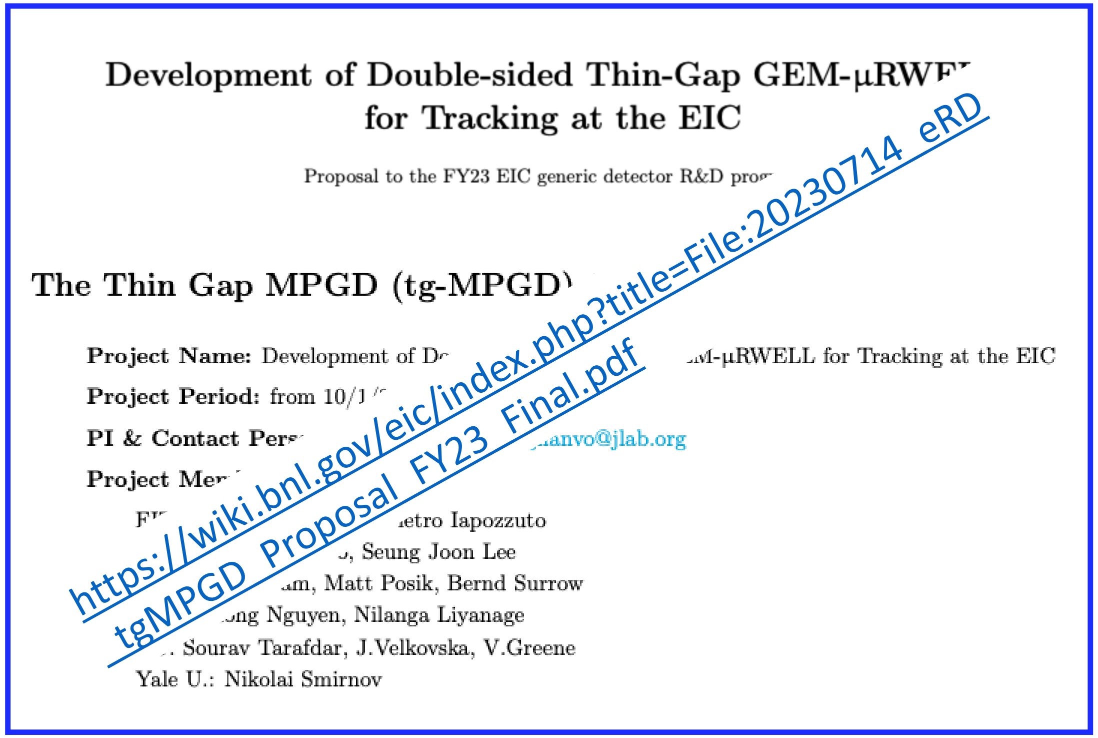
The eRD108 Consortium

Project ID: eRD108

Project Name: Development ... MPGD Trackers.

Brookhaven Natior... (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
...ple 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-µRWE... 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 Me...
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

R&D needs for ePIC µRWELL trackers

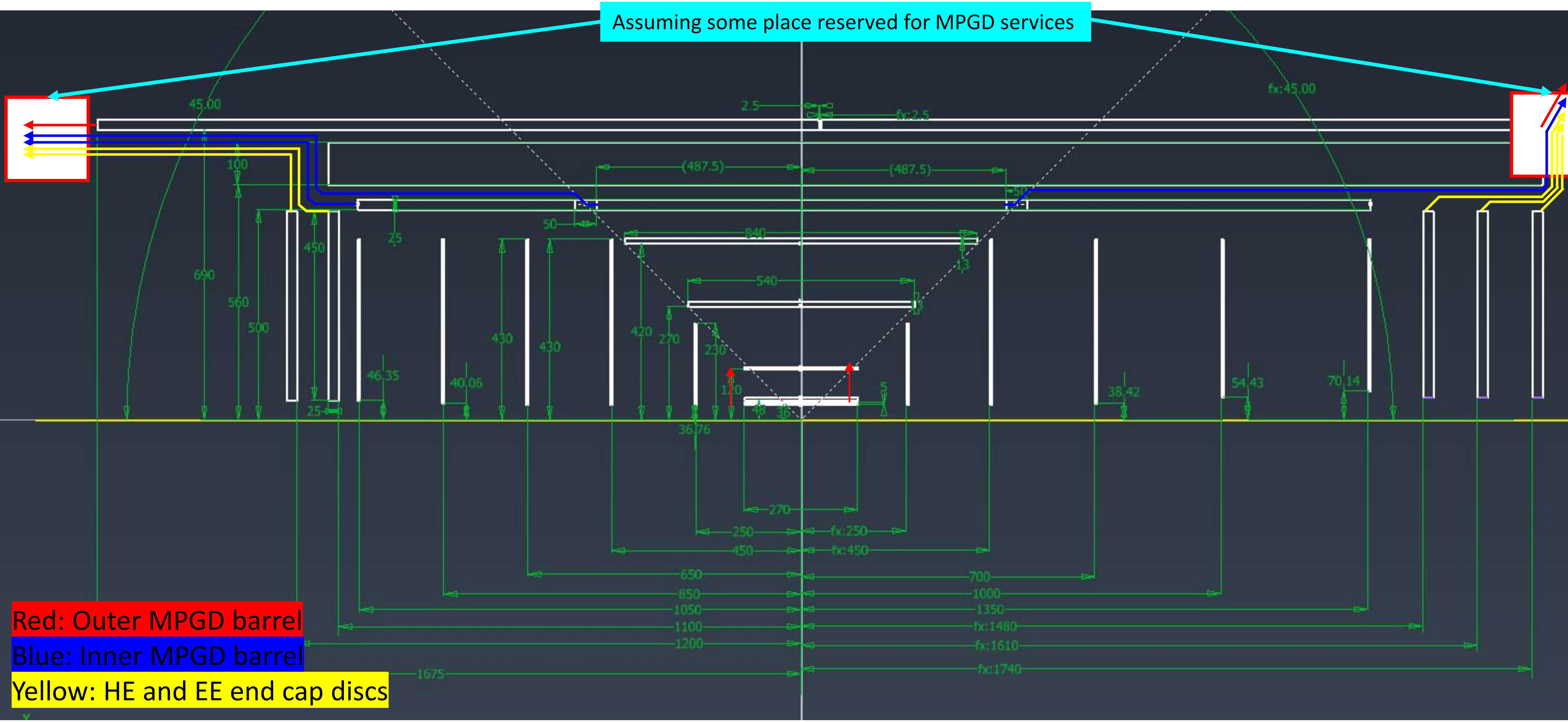
Any issue with the foreseen ASIC FEE SALSA? ➔ NO

- **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

ePIC MPGD cables & services routing



Summary

- **Double-sided Thin Gap Hybrid GEM-µRWELL is the best technology candidate for ePIC µRWELL trackers**
  - Same technology for Barrel Outer Tracker and Endcap discs
  - Full efficiency, good timing and spatial resolution, stable operation configuration, redundancy and double-hit capability.
- **Need a sustained & dedicated R&D effort to validate the approach**
  - Estimate 3-year effort to demonstrate full size working prototypes for both barrel and end cap trackers
  - No show-stopper or any serious concern with the technology.
- **ePIC µRWELL trackers instrumented with SALSA electronics**
  - Use same readout electronics and DAQ scheme as CyMBaL
  - Only minor difference in the implementation between subsyetms
- **Large MPGD community in ePIC Coll. interested in the effort**
  - Several US institutions with proven experience in MPGD tracking systems for large scale NP experiments
  - EU (INFN Roma) and Asia (Korean MPGD consortium) institutions

	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