Barrel Outer MPGD Tracker (BOT)

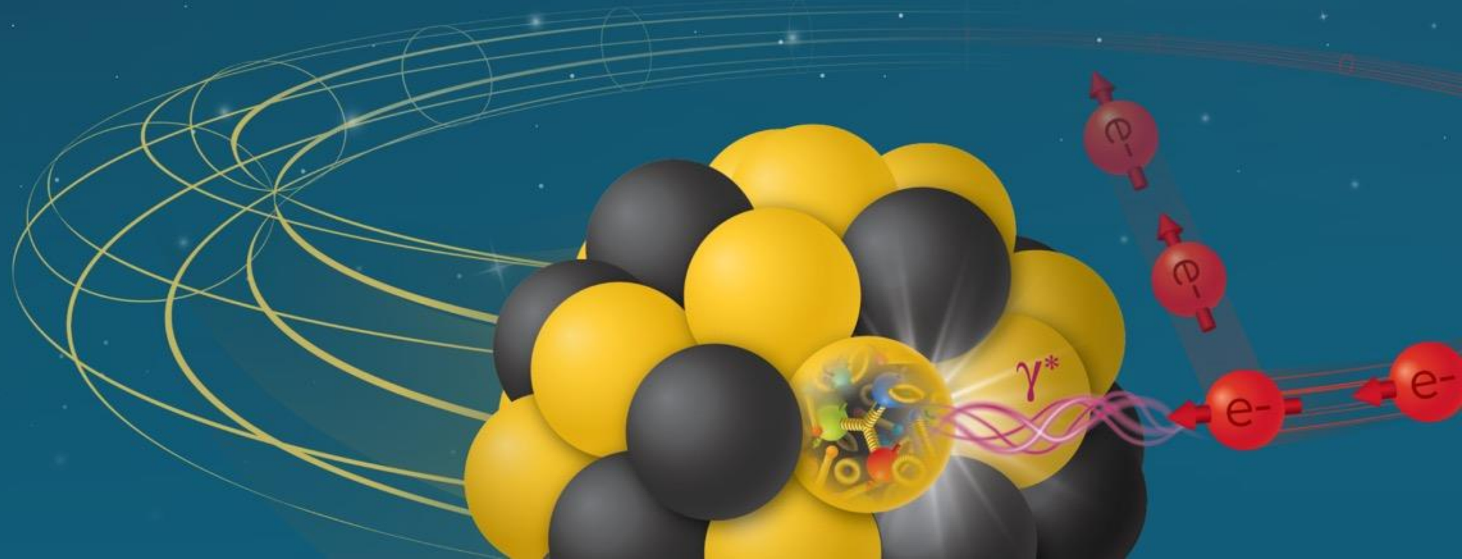
Thin-gap GEM-µRWELL hybrid Detector

Kondo Gnanvo, Jefferson Lab

ePIC MPGD DSL

Incremental Design and Safety Review
of the EIC Tracking Detectors
March 20-21, 2024

Electron-Ion Collider



Charge Questions Addressed

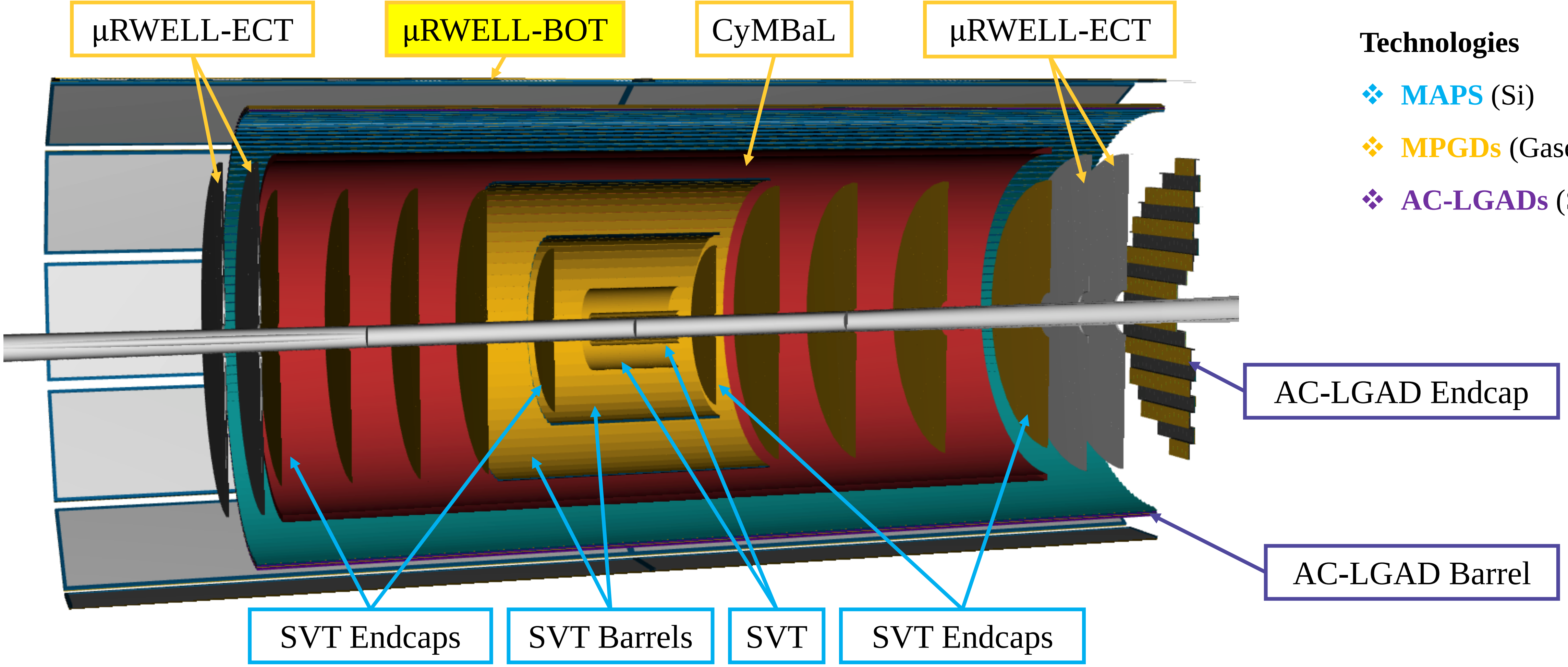
1. Are the technical performance requirements appropriately defined and complete for this stage of the project?
2. Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?
3. Are the current designs and plans for detector, electronics readout, and services sufficiently developed to achieve the performance requirements?
4. Are plans in place to mitigate risk of cost increases, schedule delays, and technical problems?
5. Are the fabrication and assembly plans for the various tracking detector systems consistent with the overall project and detector schedule?
6. Are the plans for detector integration in the EIC detector appropriately developed for the present phase of the project?
7. Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?

Outline

- Requirements
- µRWELL-BOT Detector Layout
- Technology Choice & Design Considerations
- PED - Engineering Test Article
- Assembly Schedule, ES&H & QA
- Summary

Overview of ePIC Tracking Detector

Charge 1



Technologies

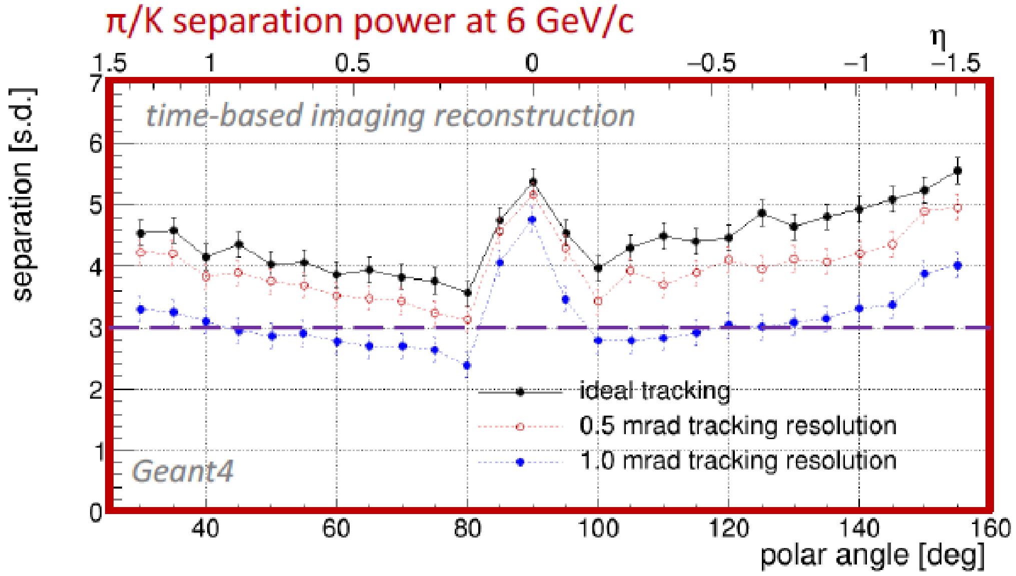
- **MAPS** (Si)
- **MPGDs** (Gaseous)
- **AC-LGADs** (Si)

Requirements

Requirements: Tracking needs from hpDIRC in the barrel

Charge 1

Impact of tracking angular resolution on hpDIRC performance



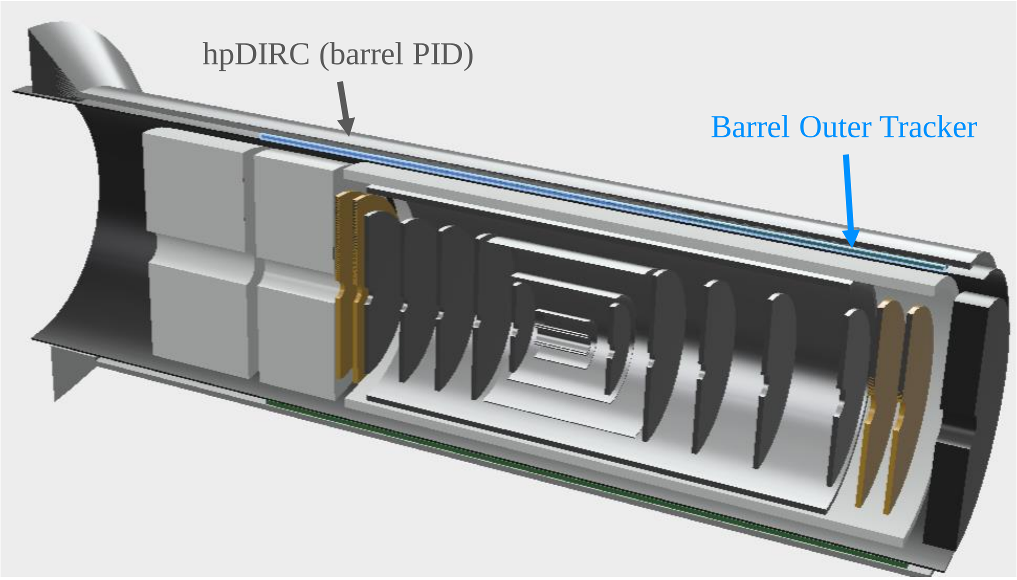
Simulation studies performed with

- Stand-alone Geant4 simulation
- Single particles from particle gun
- 6 GeV/c momentum
- No magnetic field, no other ePIC subsystems

Studies from ePIC PID Detector Subsystem Collaboration

ePIC Barrel Outer Tracker (μRWELL-BOT)

- Tracking layer close to hpDIRC detector
- improved and angular and space point resolution at the DIRC level
- Acceptance matching with hpDIRC bars
- Spatial resolution: better than150 μm on average over the full eta range in barrel region



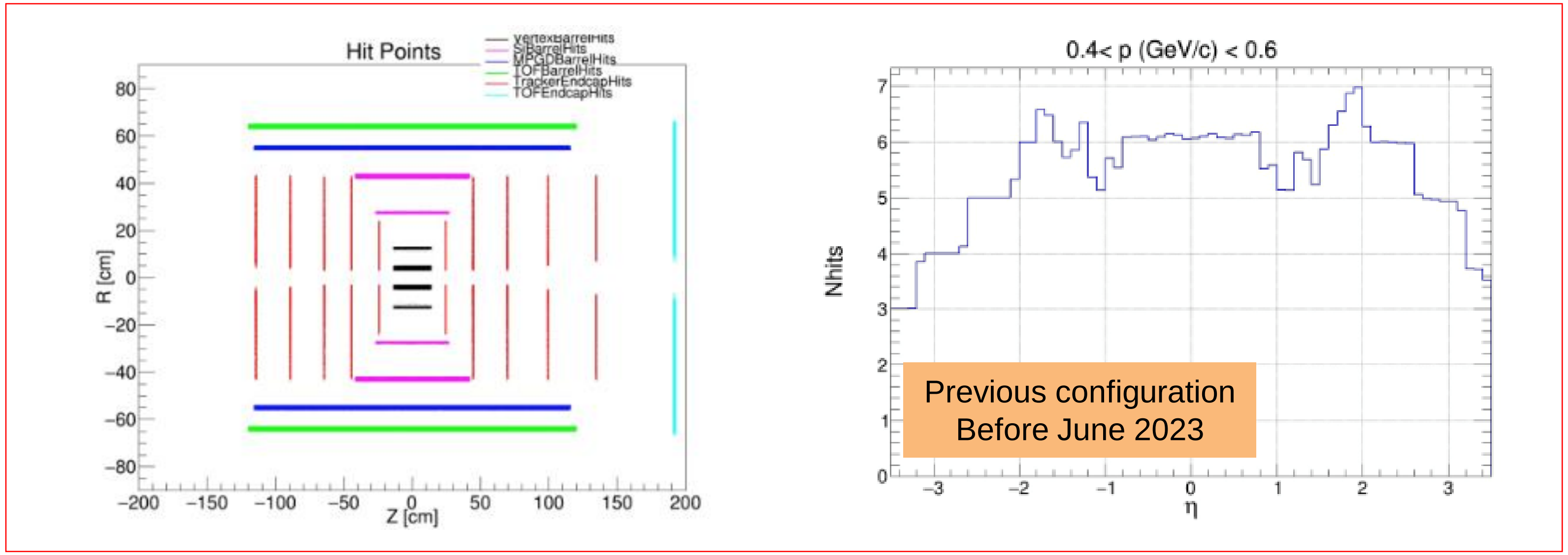
Requirements: Pattern recognition & tracking redundancy

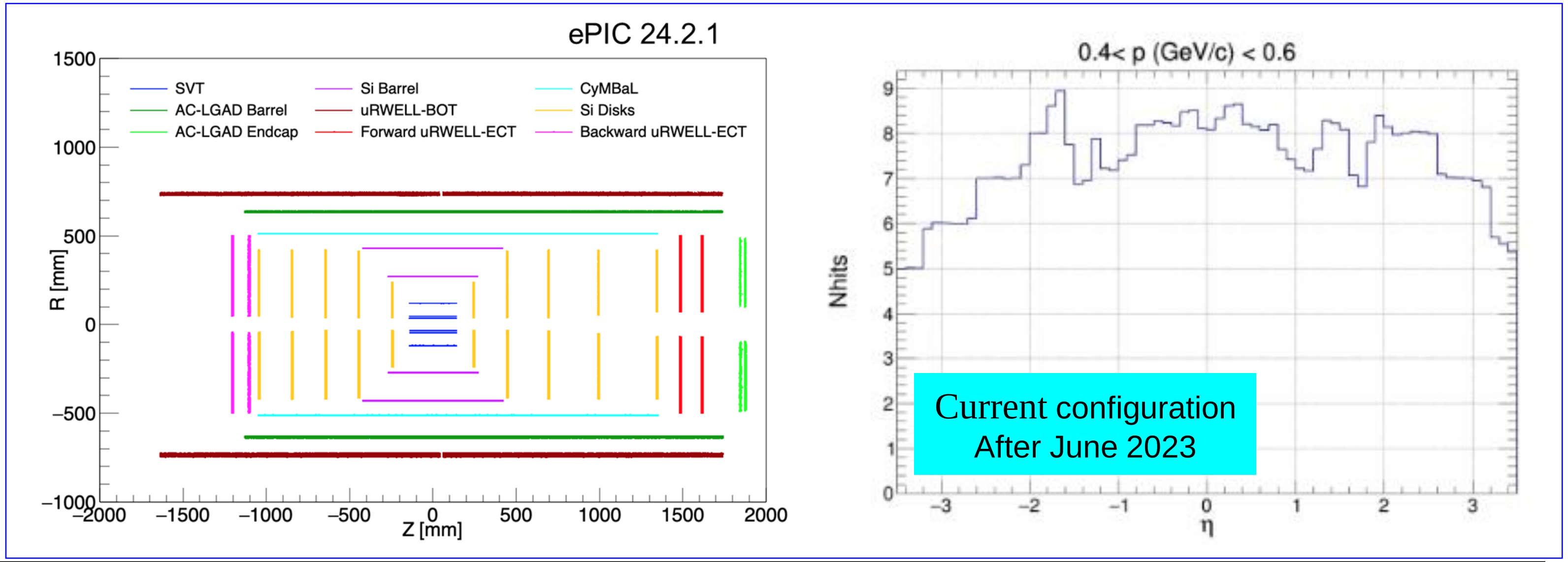
Charge 1

ePIC Barrel Outer Tracker (μRWELL-BOT)

- Outer layer for pattern recognition together with the TOF (AC-LGAD) and Inner barrel layer (CyMBaL) trackers
- Provide fast timing capabilitiy (~10 ns) to help the slow Si trackers with pattern recognition in high background.
- Provide additional hit point to tracking for redundancy

See Matt's presentations
Tracking simulation and reconstruction





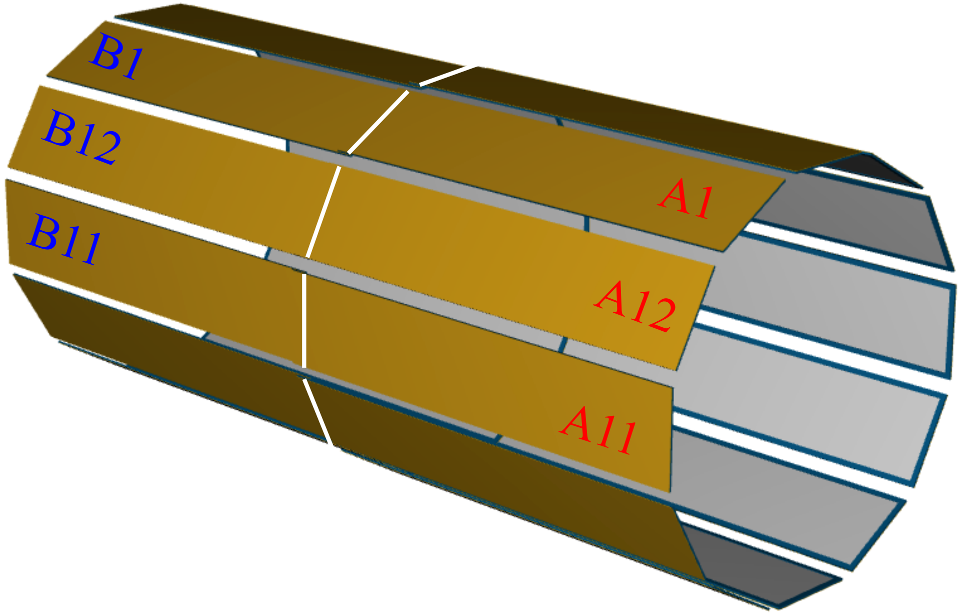
µRWELL-BOT Detector Layout

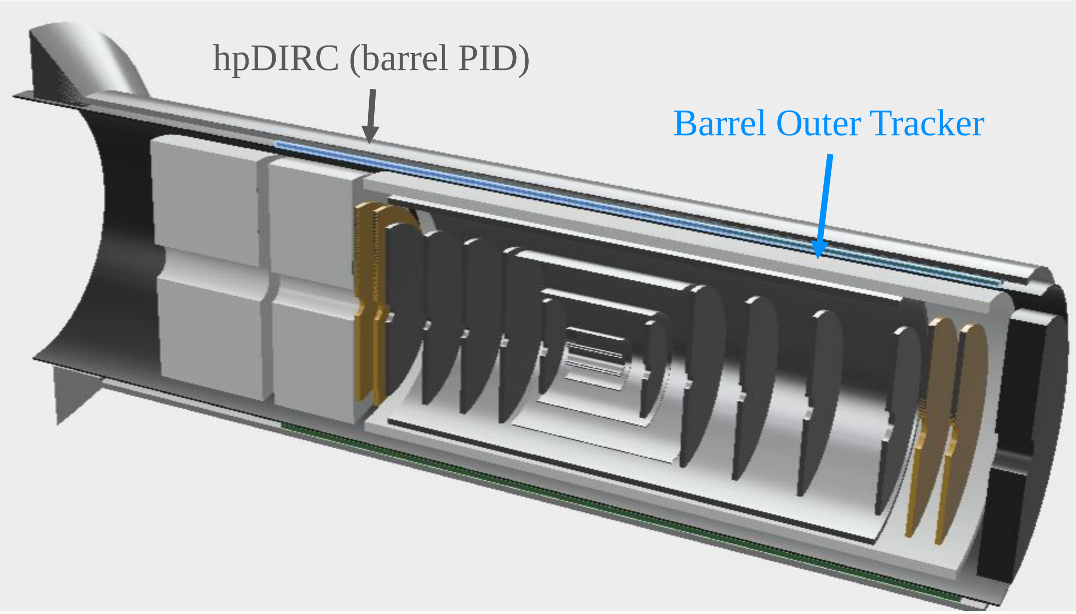
μRWELL-BOT Layout

Charge 2,3

μRWELL-BOT Layout

- 24 planar modules arrange in 12-sided polygon shape
  - L = 340 cm (-165 cm $\leq Z \leq 175$ cm)
  - R = 72.5 cm
- Segmented into
  - 2 sectors (A & B) in **z** along beam axis
  - 12 modules in phi azimuthal direction



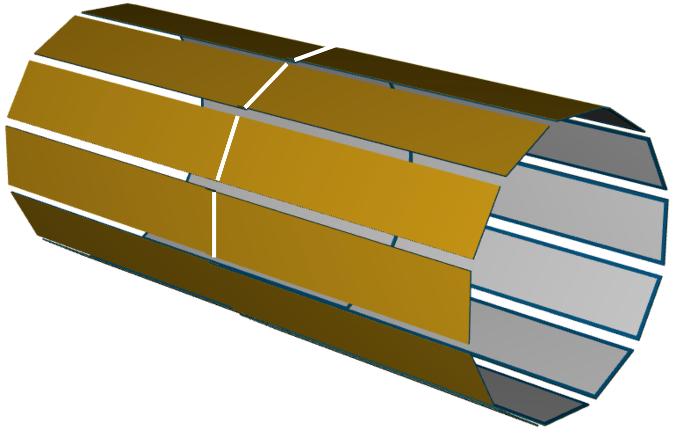


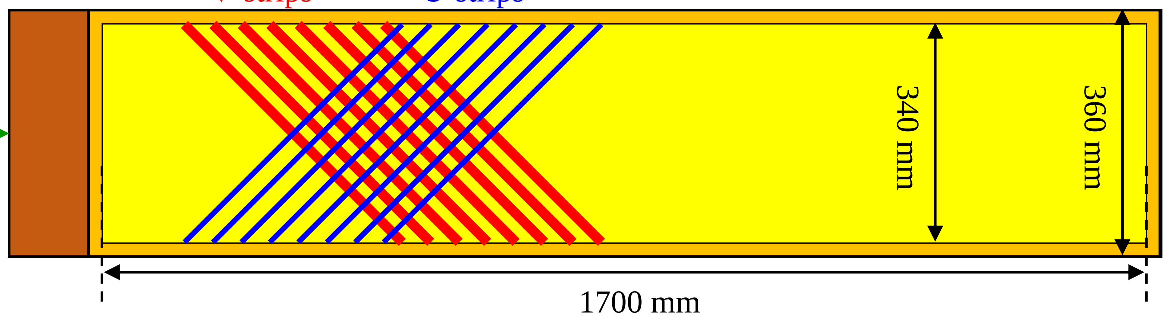
μRWELL-BOT specifications

- Thin-gap & double amplification (GEM & μRWELL)
- 2D-strip readout
  - Nominal 70 μm (perpendicular tracks)
  - On average 150 μm on for tracks in angle range [0, 45 degrees]
- Fast timing layer ~ 10 ns
- Radiation length < 2% in active area

µRWELL-BOT Module:

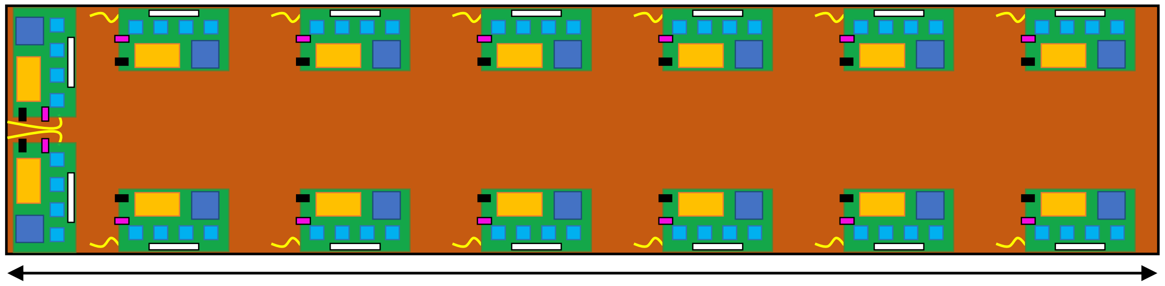
Charge 2,3





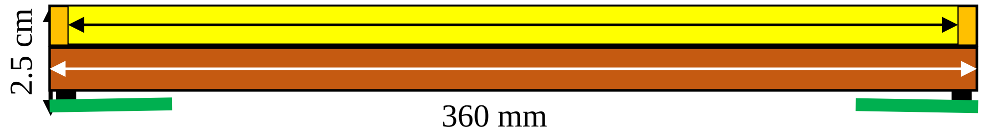
µRWELL-BOT module

- ❖ Thin-gap (1-mm drift) hybrid amplification GEM-µRWELL detector
- ❖ Capacitive-sharing U-V strips readout layers(45^{O} stereo angle)
- ❖ Pitch: 1.14 mm (1790 U-strips and 1790 V-strips per modules)



On-detector Front End Boards (FEBs) based on SALSA chips

- ❖ 14 FEB / modules (assuming 4 SALSA chips i.e 256 e-ch / FEB)
- ❖ Direct connection on the back of the modules (no need for flex cables)



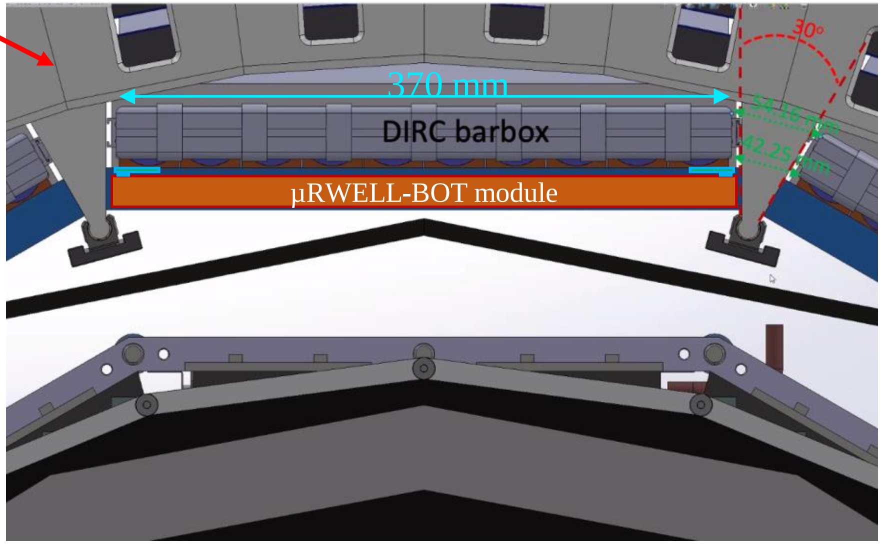
μRWELL-BOT Module: Integration considerations

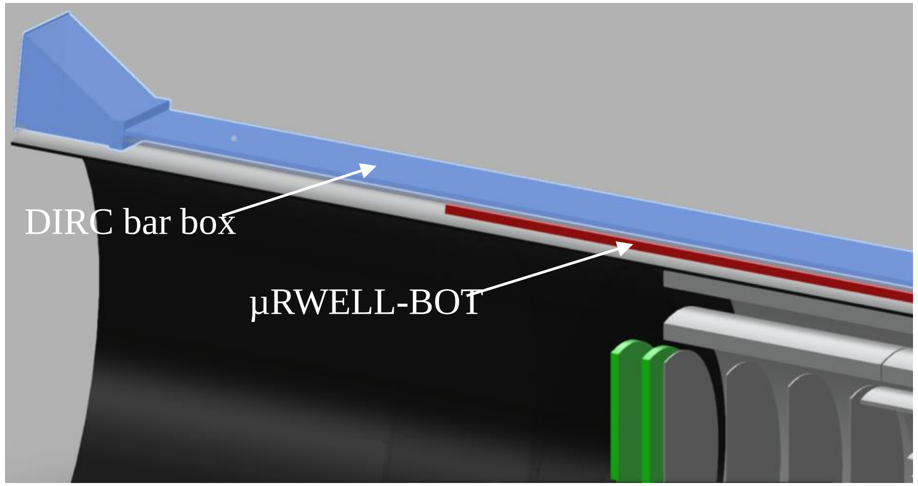
Charge 6

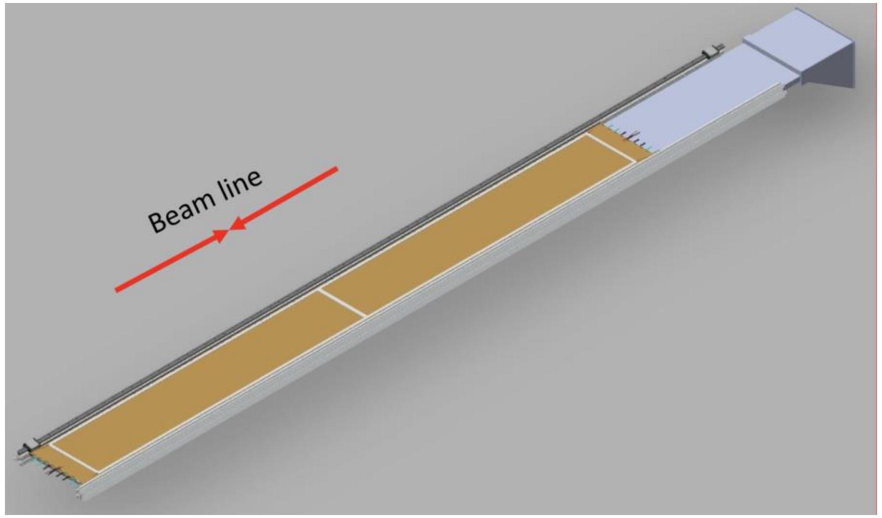
Main integration challenges: Space limitation in ePIC detector environment

- μRWELL-BOT detector envelop in ePIC
  - In radial direction: 2.5 cm
  - Azimuthal direction: 36 cm
- Installed in support structure of barrel ECAL in front (from IP) of hpDIRC bar
- Optimization of the acceptance matching with hpDIRC
- Implications in the design of the μRWELL-BOT module
  - FEB cards on the back of the modules ➔ material budget
  - Carefully consider how services, cables choices affect maintenance in the future

Barrel ECAL support structure







Technology Choice & Design Considerations

Technology choice: Thin-gap GEM-μRWELL Hybrid Detector

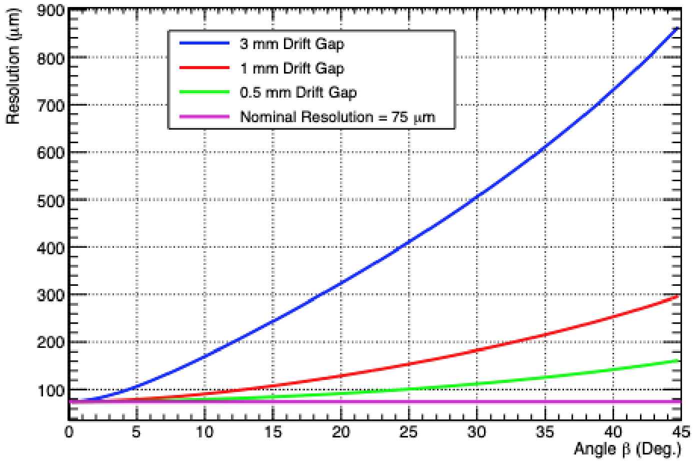
Charge 2,3

Challenges with standard (> 3-mm drift gap) MPGD

- ❖ Degradation of the spatial resolution with track angle .
- ❖ E × B in magnetic field negatively impact resolution

Development of Thin-gap MPGDs:

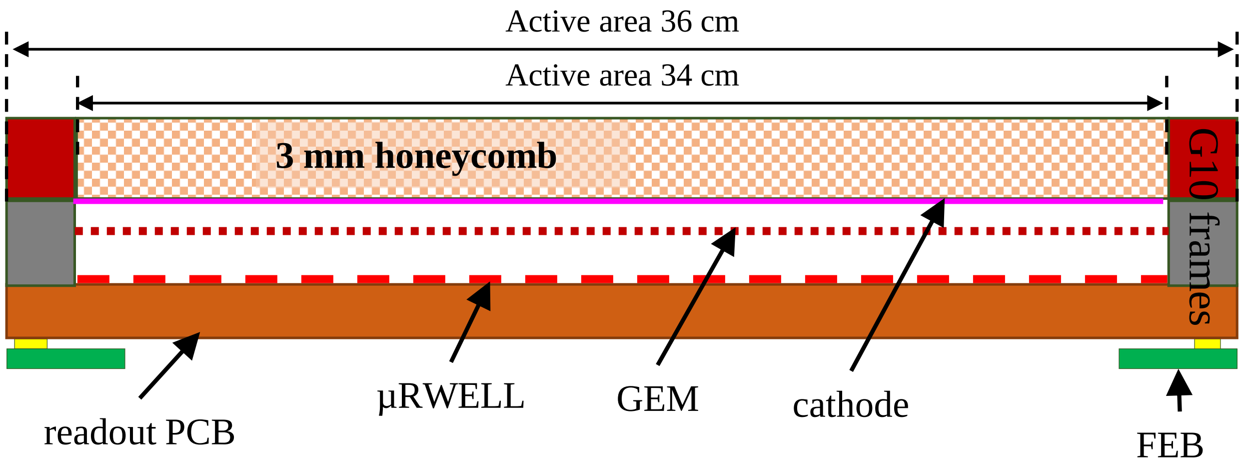
- ❖ Small drift gap improve spatial resolution at large angle
- ❖ Small gap ➔ minimize E × B effect in magnetic field
- ❖ Improve the detector timing performance



parametrization from *EPJ Web of Conferences* ***174****, 06005 (2018)*

Thin-gap GEM-μRWELL detector concept

- ❖ hybrid amplification MPGD:
  - GEM (preamplification) and μRWELL (main amplification)
  - Allow large detector gain and stable operating HV
- ❖ Readout layer: 3-layer capacitive-sharing U-V strip readout
  - Achieve excellent spatial resolution with thin gap detector



cross-section view of thin-gap GEM-μRWELL detector

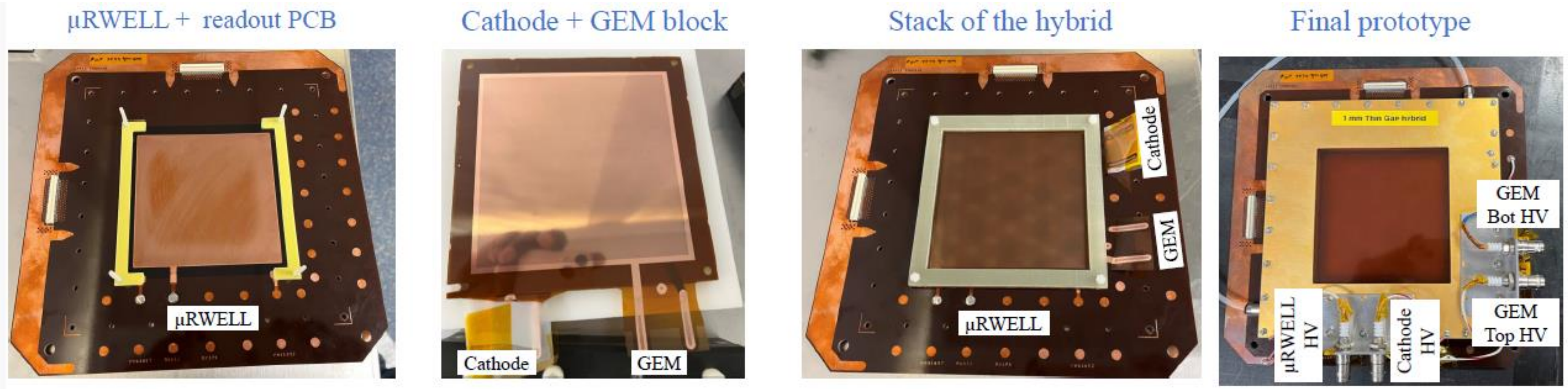
https://wiki.bnl.gov/eic/upload/ERD_tgMPGD_FY22_endOfYearReport_final.pdf

Technology choice: Thin-gap GEM-µRWELL Hybrid Detector

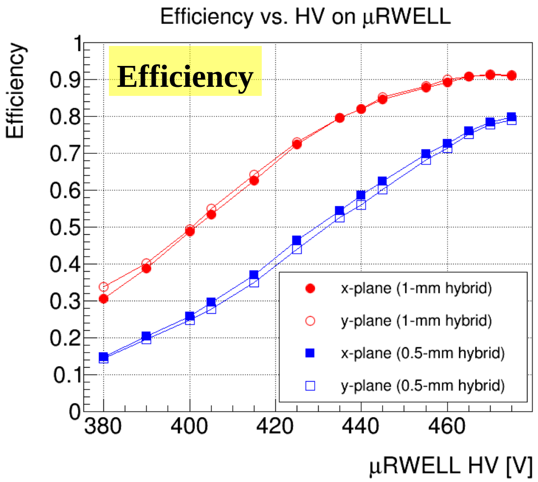
Charge 2,3

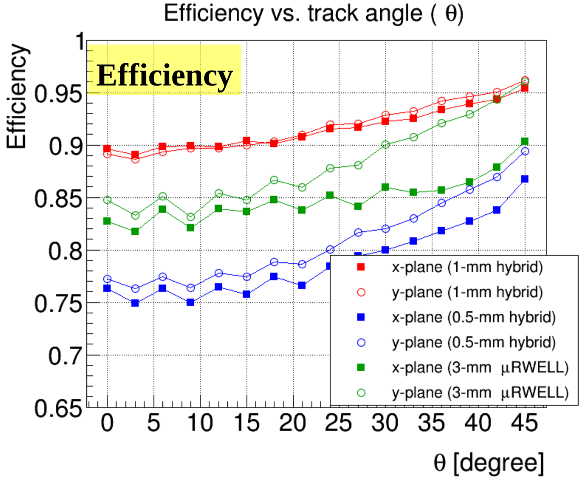
Proof of concept

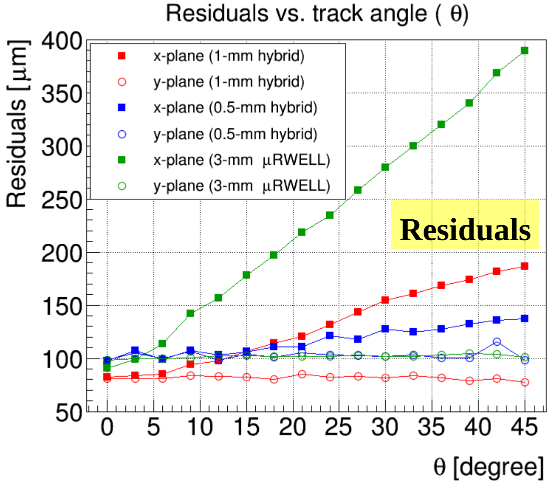
- Concept of thin-gap GEM-µRWELL hybrid prototype demonstrated in beam test at the Fermilab Test beam Facility in Summer 2023 (red plots)
- Space resolution < 150 µm and efficiency of 92% on average for 1-mm thin-gap GEM-µRWELL prototype (red dots) and for track in an angle range between 0 – 45 degrees.
- **Baseline technology for ePIC outer MPGD tracker**



R&D funded by JLab administered DOE EIC Generic R&D Program as EICGENRandD_2022_23





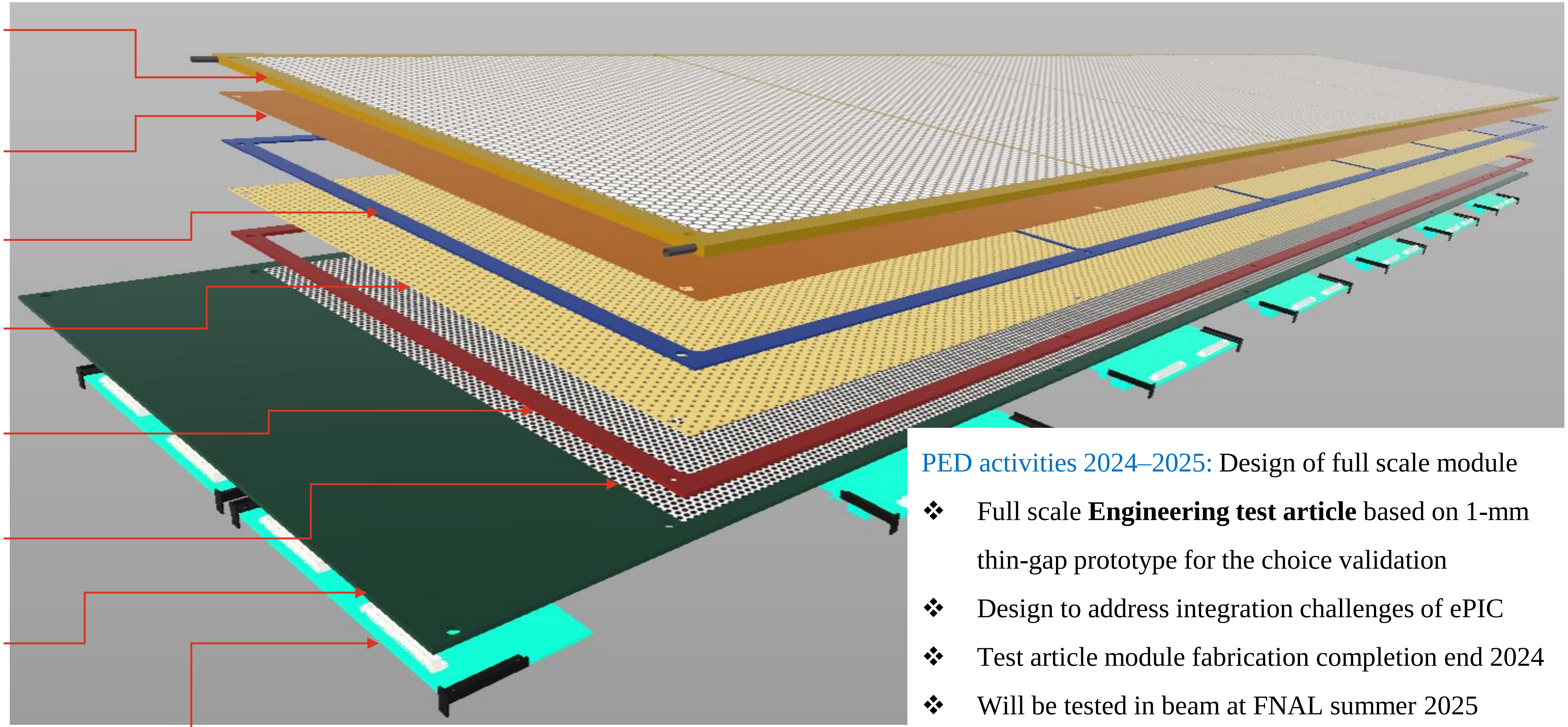


https://wiki.bnl.gov/eic/upload/ERD_tgMPGD_FY22_endOfYearReport_final.pdf

PED: Engineering Test Article

Design consideration: Breakdown of µRWELL-BOT module

Charge 2,3

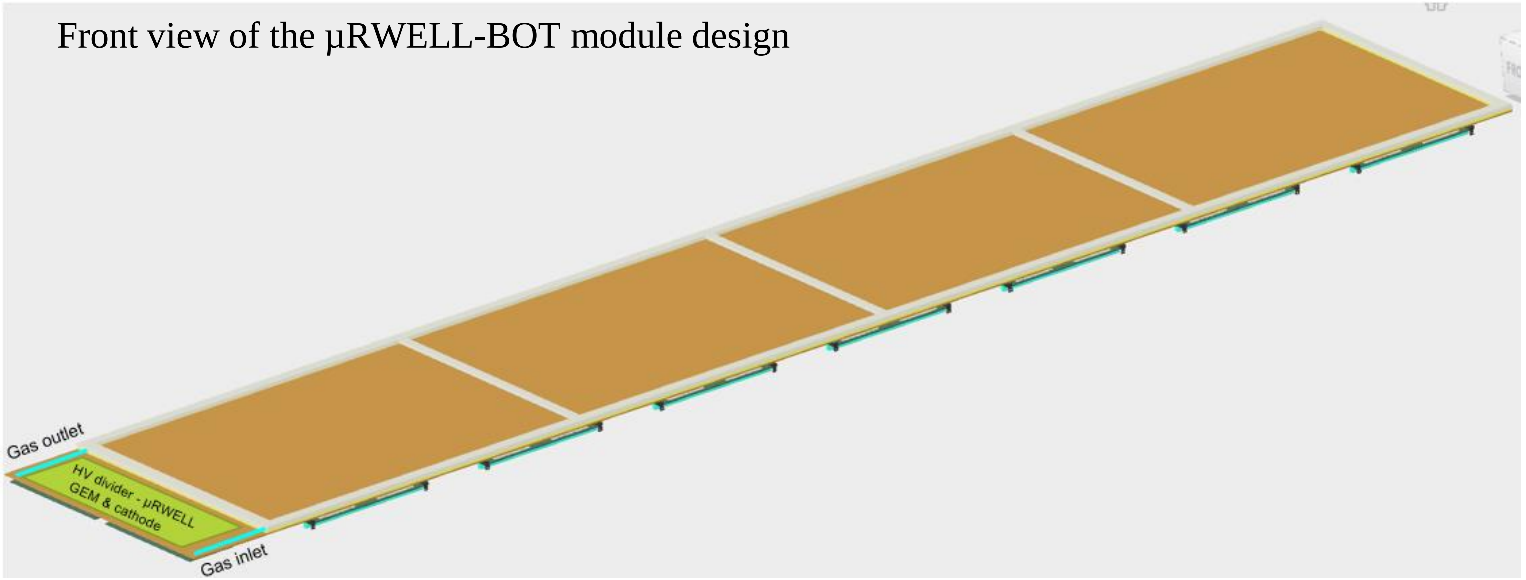


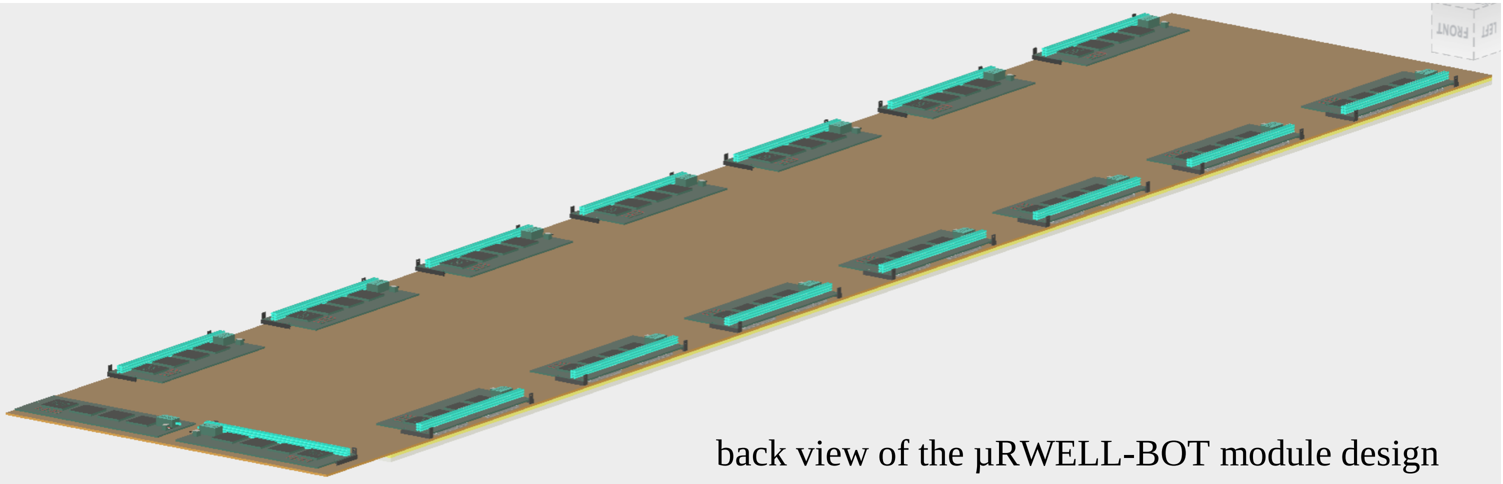
PED activities 2024–2025: Design of full scale module

- Full scale **Engineering test article** based on 1-mm thin-gap prototype for the choice validation
- Design to address integration challenges of ePIC
- Test article module fabrication completion end 2024
- Will be tested in beam at FNAL summer 2025
- Design by the RD & I Group at JLab

Design consideration: µRWELL-BOT module

Charge 2,3



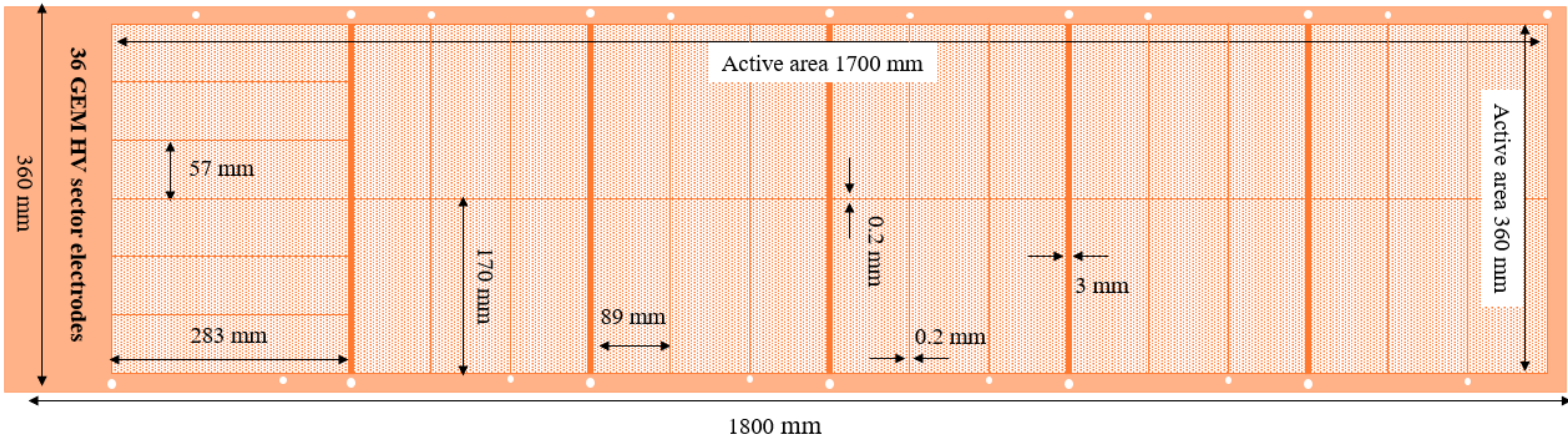


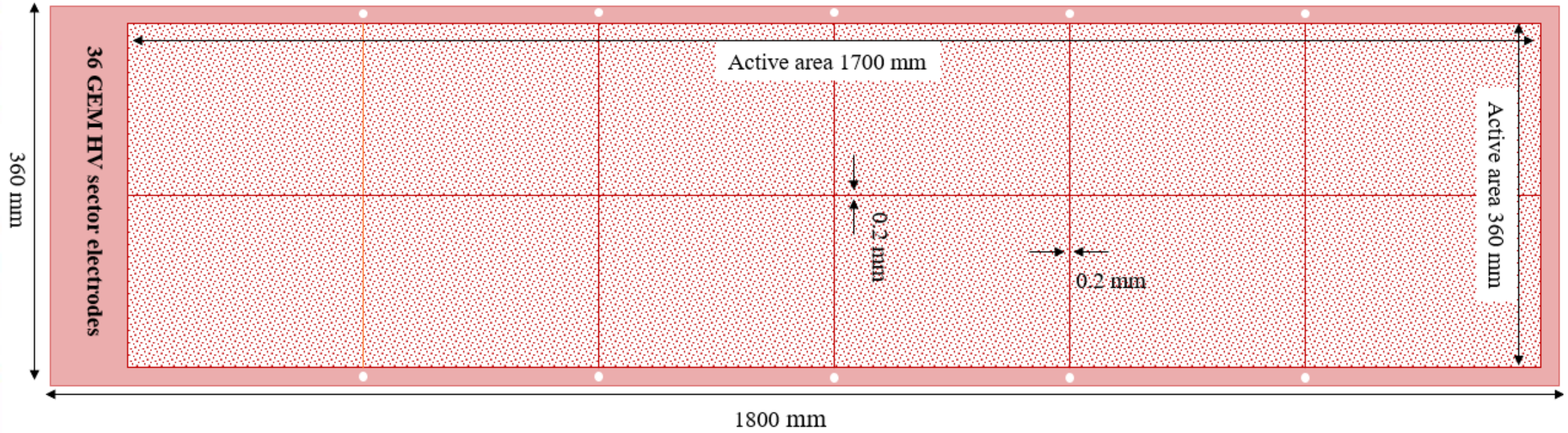
Design consideration – µRWELL and GEM foil design

Charge 2,3

GEM foil: Conceptual design

- foil divided into 36 HV sector ~ 160 cm^2
- Optimization trade-off between active-to-dead area ratio for gap uniformity
- Final design with input from GEM experts at CERN MPT workshop - 06/24
- Procurement by 12/24





µRWELL foil: Conceptual design

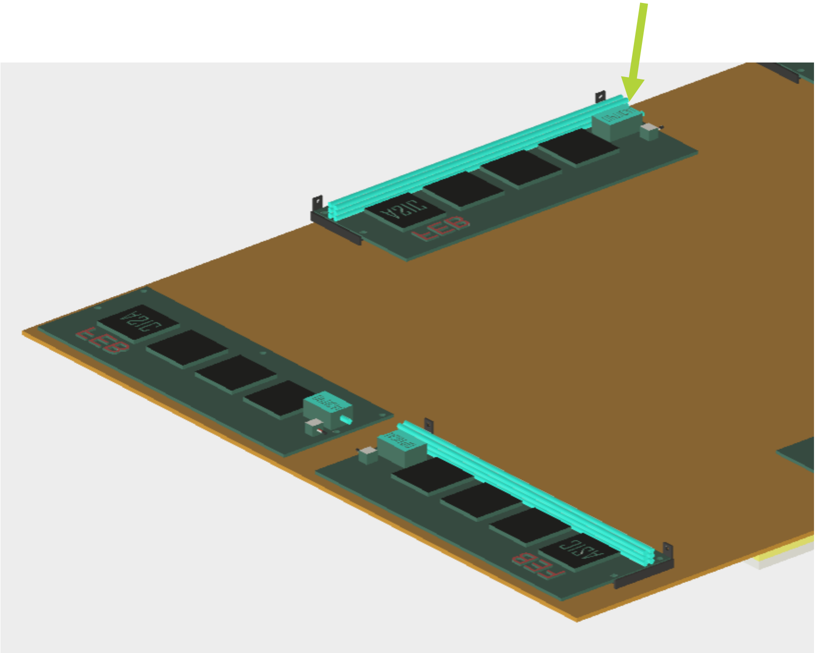
- Foil divided into 12 HV sector ~ 480 cm^2
- Final design with input from GEM experts at CERN MPT workshop - 06/24
- Procurement by 12/24

Design consideration: 2D (U-V)-strip readout layer

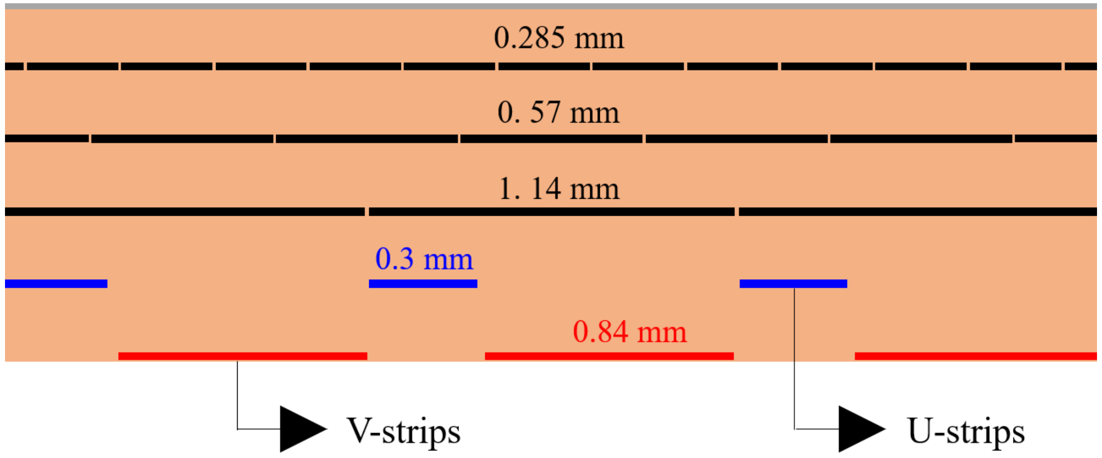
Charge 2,3

Readout strip layers

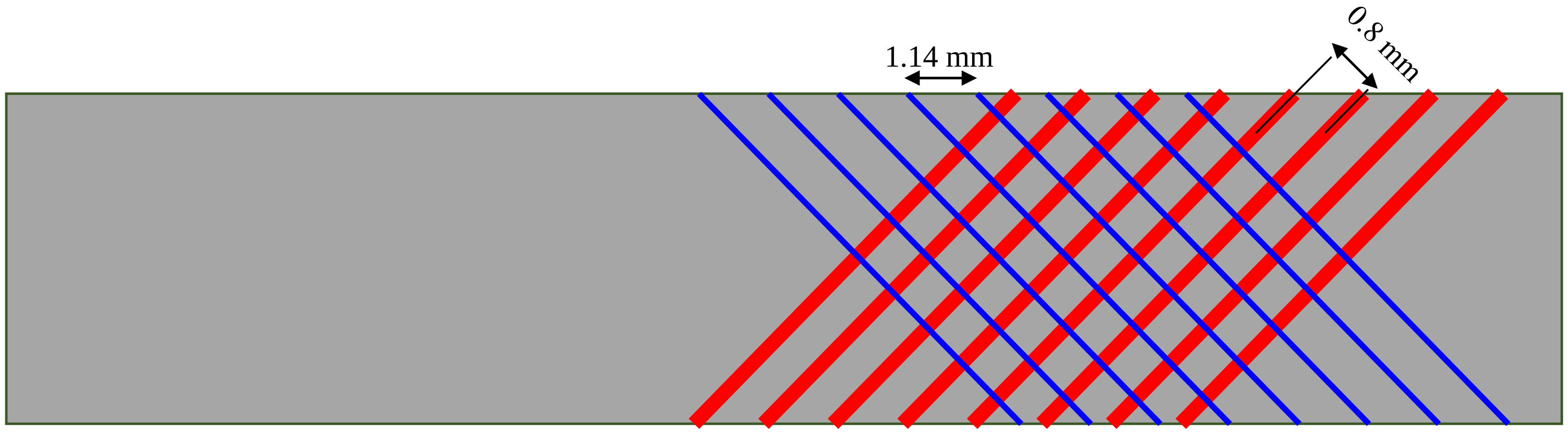
- 3-layer capacitive-sharing U-V strip readout
  - Strip pitch: 0.8 mm (along U and V axis)
  - Trace pitch: 1.14 mm along horizontal axis (traces)
- All connectors on the back of the rigid µRWELL / readout PCB



cross-section view of 3-layers U-V strip capacitive-sharing readout



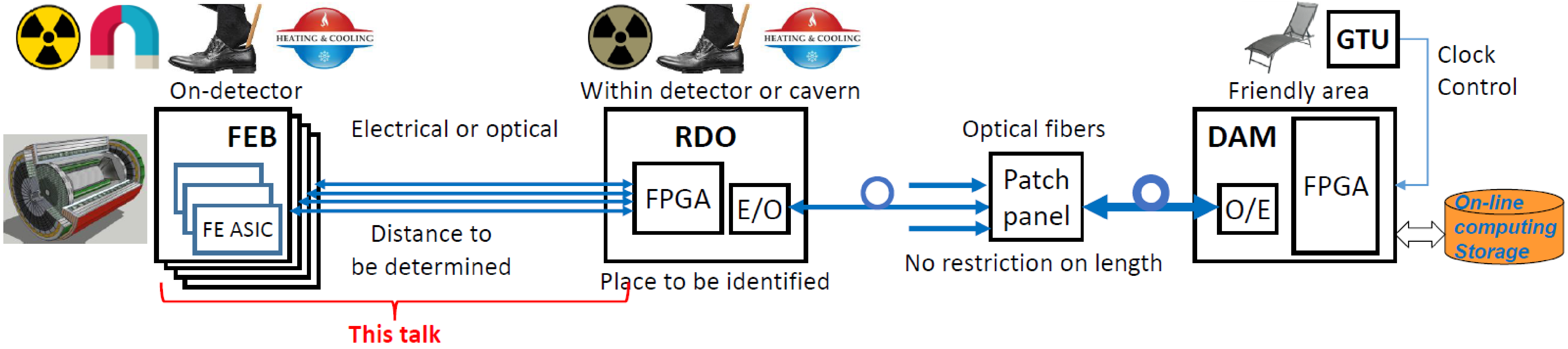
https://doi.org/https://doi.org/10.1016/j.nima.2022.167782



U-V strip configuration

Design consideration: µRWELL-BOT Readout Electronics

Charge 2,3



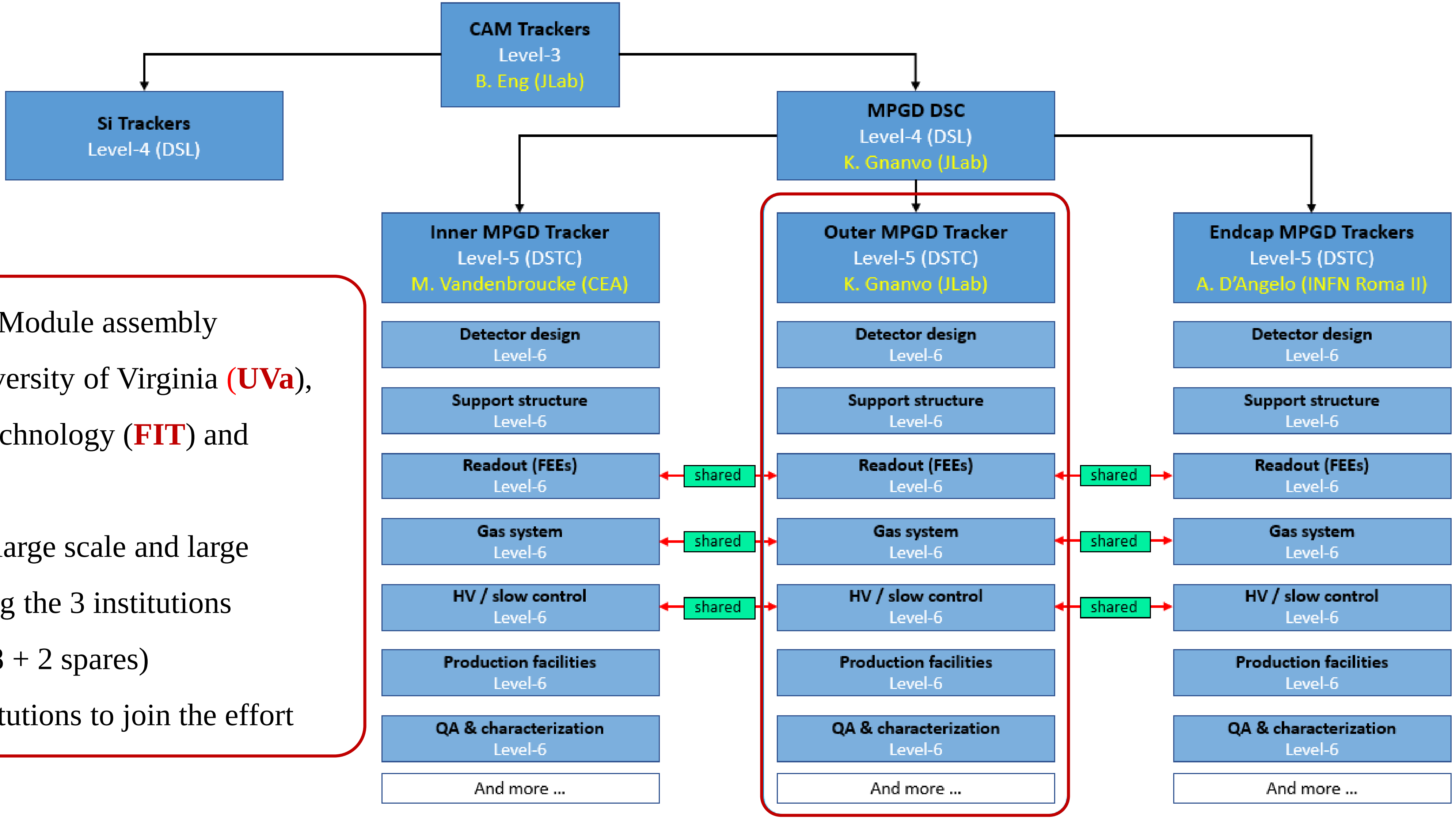
- FEB – frontend board with readout ASICs
  → Sub-detector specific
- RDO – readout module – first stage of FEB data aggregation, last stage to dispatch clock & control
  → Common design between sub-detectors, different form factor
- DAM – data aggregation module – interface with computing and global timing and control unit (GTU)
  → Common design for all sub-detectors
- Downstream towards detector : clock, control, monitoring
- Upstream towards storage : physics, calibration, monitoring data

See Irakli's presentations
MPGD Readout Electronics

Assembly plans, ES&H & QA

MPGD-DSC: Organization of ePIC MPGD Subsystem Collaboration

Charge 5



Outer MPGD Tracker: Module assembly

- Production sites: University of Virginia (**UVa**), Florida Institute of Technology (**FIT**) and Jefferson Lab (**JLab**)
- Vast experience with large scale and large MPGD projects among the 3 institutions
- 10 modules per site (8 + 2 spares)
- Welcome to new institutions to join the effort

Assembly plans: Equipment at the assembly sites

Charge 6

- All 3 assembly sites have fully equipped MPGD Detector Lab
  - Fully equipped CLASS 1000 Clean rooms for module assembly
  - Cosmic tracking telescope setup with coincidence trigger counters and readout & DAQ system
  - X-ray setup for high rate studies and long term stability …
  - Will setup DAQ and readout system for SALSA – MPGD readout system

JLab MPGD Clean Room: New capacity for large MPGD module assembly

UVa Clean Room: SBS GEMs, MOLLER GEMs, PRad GEMs, CLAS12 μRWELL, Hall D GEM-TRD prototype

FIT Clean Room: assembly of CMS GE1/1 GE2/1 and ME0 GEMs

Assembly plans: Quality Assurance (QA)

Charge 7

- Test and characterization of µRWELL-BOT modules
  - HV test in N_2 of GEM and µRWELL sectors before, during and after assembly (in clean room)
  - Gas leak test and sealing after module assembly
  - Electrical connection capacitance and pedestal noise test of all U & V and strips
  - Tag dead strips and replace FEB cards with dead readout channels
  - Efficiency and relative gain uniformity studies with cosmic setup
  - absolute gain measurement with radioactive source (local measurement)
  - Large 2D X-Ray scanner for absolute gain uniformity (JLab)

Assembly plans: ES&H

Charge 7

- ES&H procedure will derived from past experience in each assembly site with similar system
  - Non flammable operation gas mixture Ar / CO2 ➔ no special safety concern or implementation procedure needed
  - HV supply via simple passive divider ➔ Procedure to isolate any electric point on the detector
  - Will follow JLab ES & H procedures for handling radiation sources during QA at the lab
  - Similar procedures will be implemented in the various institutions
  - Will have all these procedure documented in the appropriate ePIC documentation database (for example EICLOG @ JLab)

Assembly plans: Planning & schedule

Charge 6

PED & validation	Pre-production	Production	Shipment to JLab	Commissioning & Installation
06/2025	**06/2026**	**04/2029**	**06/2029**	

PED & validation

- Ongoing design of full size µRWELL-BOT module
- Procurement of GEM foils, µRWELL PCB – **12 / 2024**
- Assembly at JLab test in at FNAL **- 06/2025**

Pre-production

- Assembly of one pre-production module (**module#0**)
- Setup of infrastructure and equipment in assembly sites

Production

- Assembly and QA of 9 production modules at assembly sites
- Full characterization at assembly sites of each module on cosmic stand and with radioactive sources

Shipment to JLab

- Shipment of all 24 modules to BNL
- Commissioning at BNL cosmic test stand of all µRWELL-BOT as well as µRWELL-ECT

Commissioning & Installation

- Commissioning
- Installation

Summary

- The ePIC **B**arrel **O**uter MPGD **T**racker (µRWELL-BOT) is based on thin-gap GEM-µRWELL amplification technology
- µRWELL-BOT provides improved tracking option to the hpDIRC and pattern recognition with fast timing hit to Si tracker in the barrel
- Design of the µRWELL-BOT is well advanced and integration issues and mechanical constraints are being addressed in the design
- The engineering test article pre-production module is under development and expected to be validated by Summer 2025
- Preliminary plans and schedule for the production of µRWELL-BOT modules in assembly sites is initiated
- The ePIC MPGD DSC is established and very active with several institutions with vast experience with large MPGD productions

Backup

Design consideration: Some General considerations

Charge 2,3

- Rate Capability
  - Not critical ~ 1 kHz/cm^2 or less
- Radiation Hardness
  - Not critical for the detectors
  - Important for FEBs and RDO electronics boards
- Temperature Stability
  - Not critical for the detector performances
  - Detector calibration should consider gas pressure variations
- Electronics power consumption and cooling
  - SALSA ASIC consumption ~ 15 mW/ channel at 1.2V
  - Air vs liquid cooling is under study at Saclay – see Irakli's talk