ePIC µRWELL Barrel Outer Tracker (µRWELL-BOT)

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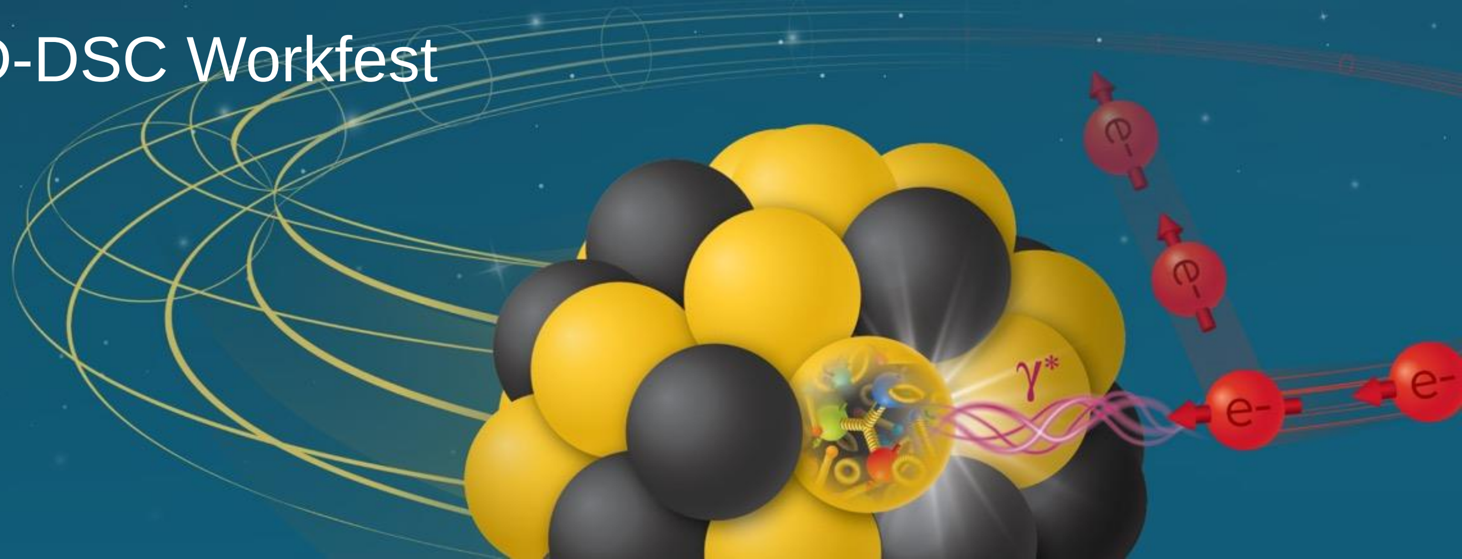
On behalf of the ePIC MPGD DSC

ePIC Collaboration Meeting - MPGD-DSC Workfest

Lehigh University, Bethlehem PA

July 25, 2024

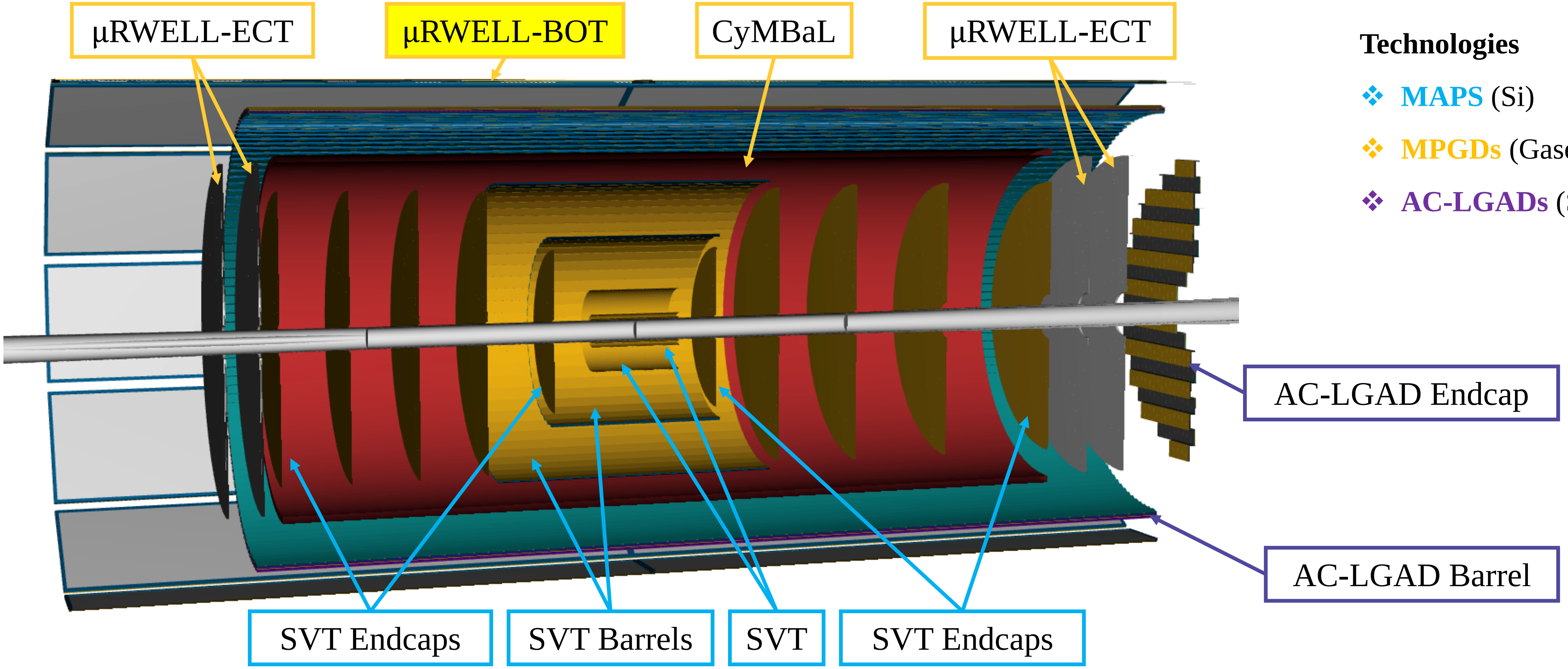
Electron-Ion Collider



Outline

- ❖ Requirements
- ❖ µRWELL-BOT Detector Layout
- ❖ Technology Choice & Design Considerations
- ❖ PED - Engineering Test Article
- ❖ Assembly Schedule
- ❖ Summary

Overview of ePIC Tracking Detector

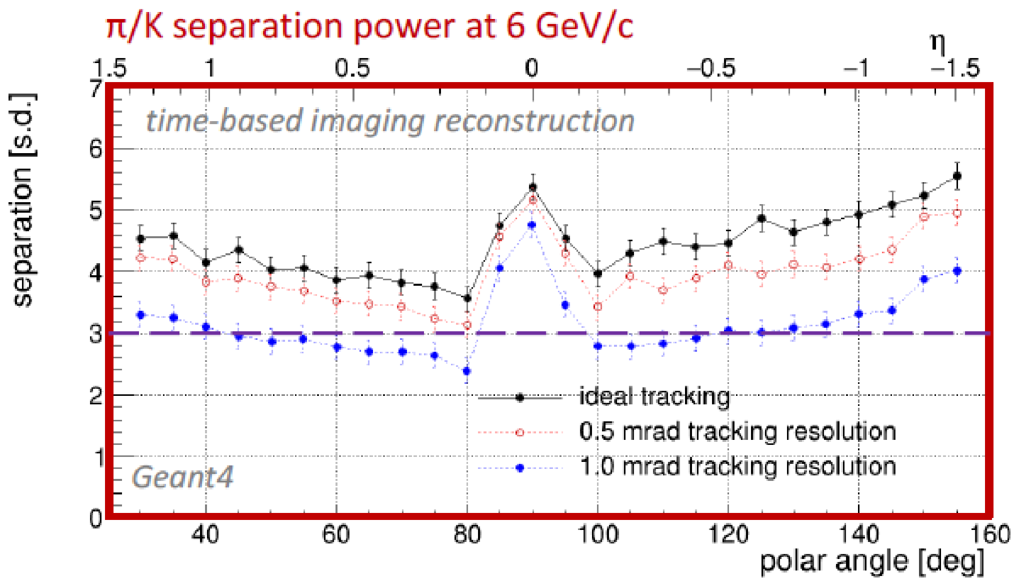


Technologies

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

Requirements for µRWELL-BOT: Tracking needs from hpDIRC in the barrel

Impact of tracking angular resolution on hpDIRC performance



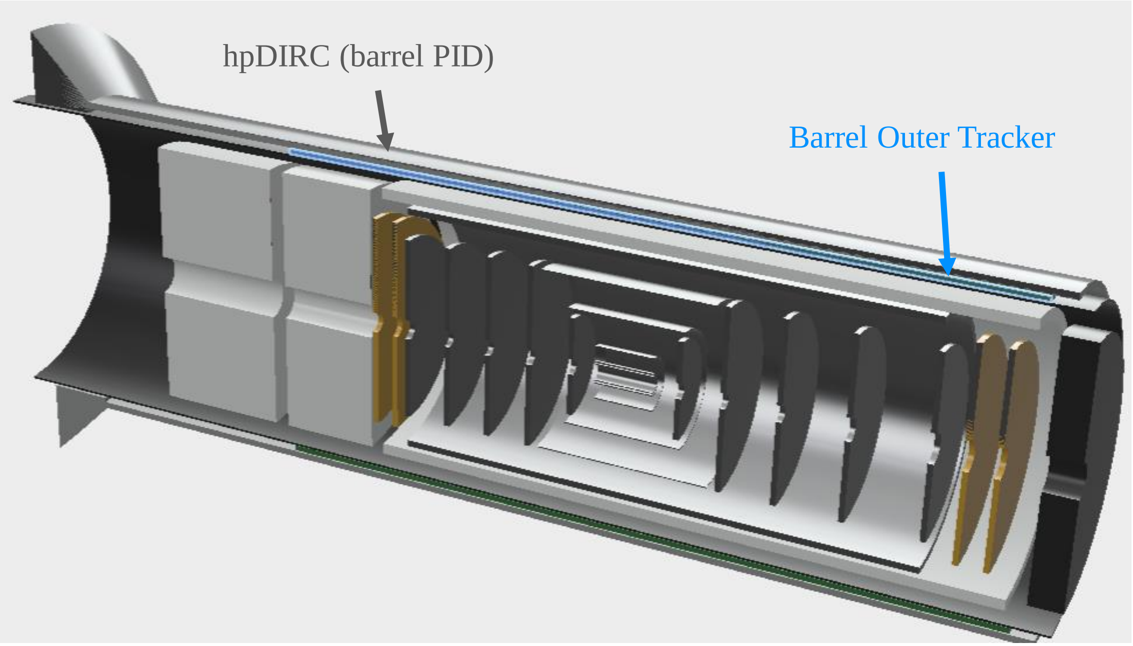
Simulation studies performed with

- 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)

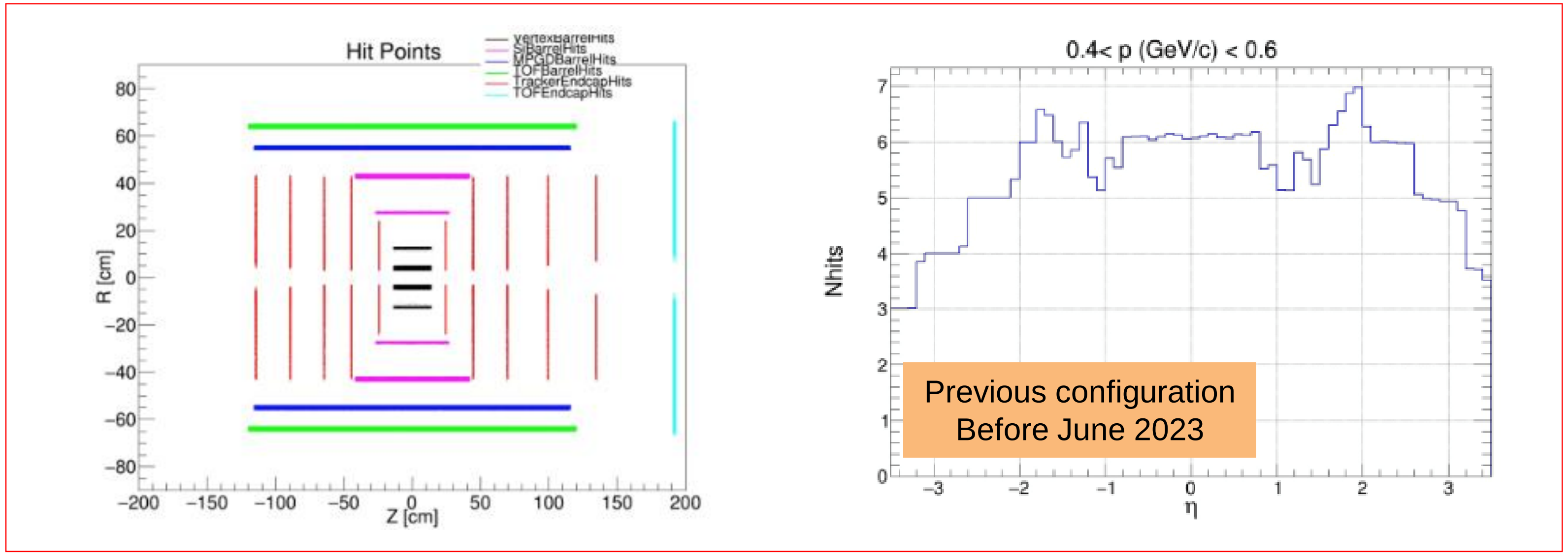
- Tracking layer close to hpDIRC detector
- improved and angular and space point resolution at the DIRC level
- Acceptance matching with hpDIRC bars
- Spatial resolution: better than150 µm on average over the full eta range in barrel region

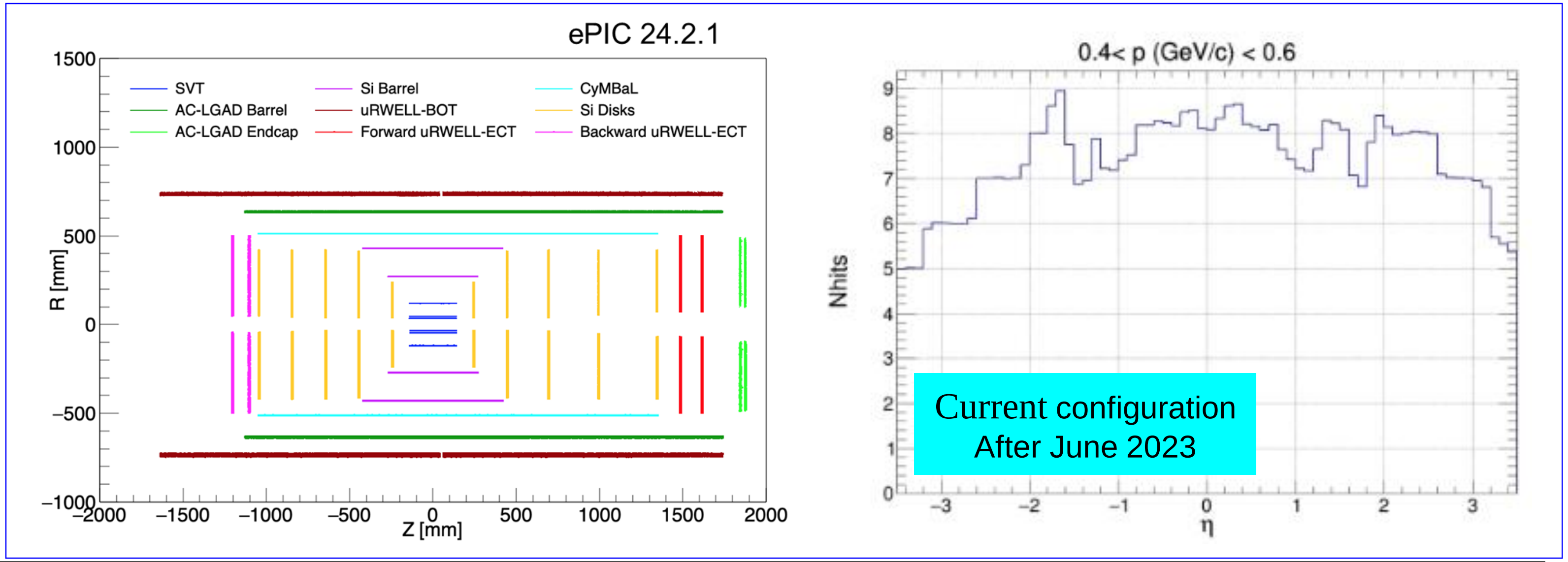


Requirements for µRWELL-BOT : Pattern recognition & tracking redundancy

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 capability (~10 ns) to help the slow Si trackers with pattern recognition in high background.
- Provide additional hit point to tracking for redundancy

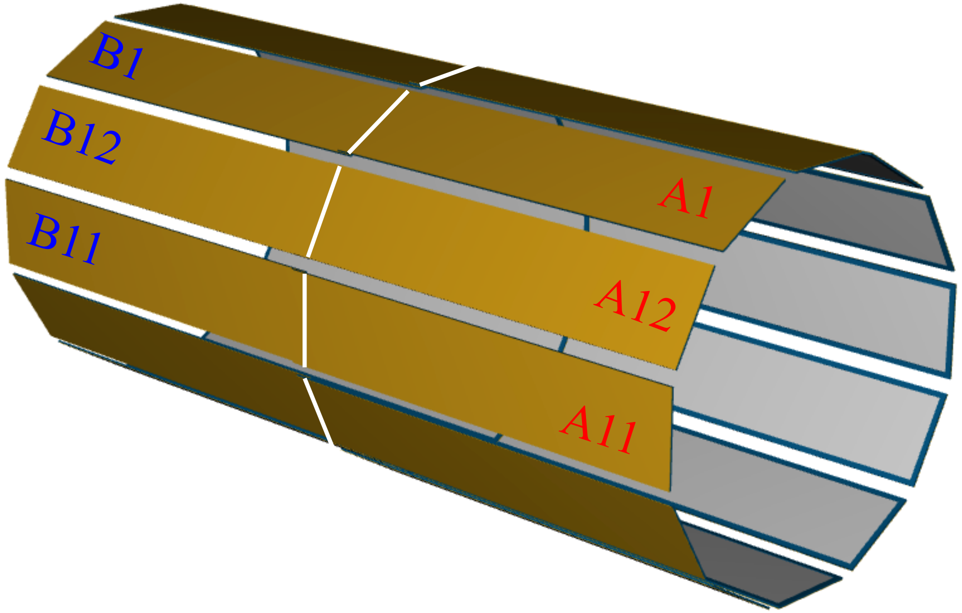


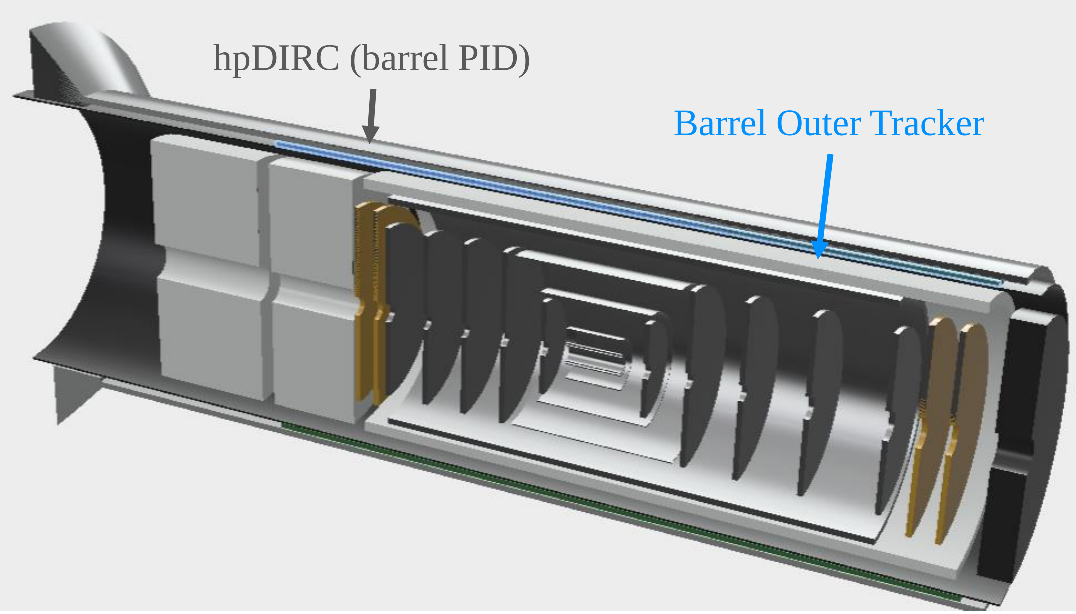


µRWELL-BOT Layout

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

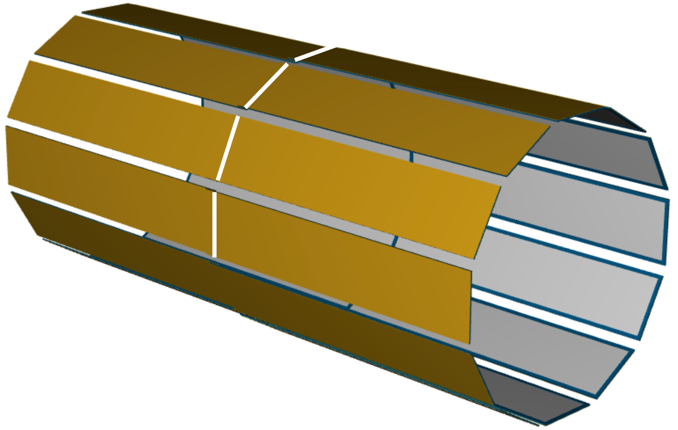


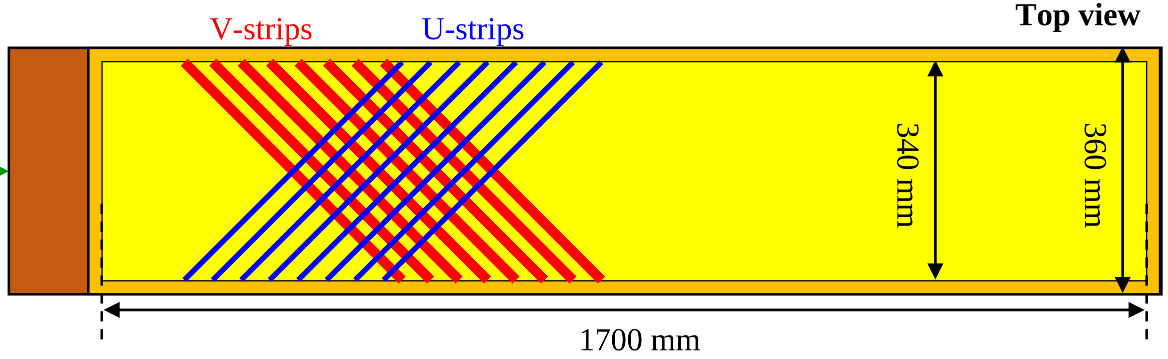


µRWELL-BOT specifications

- 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

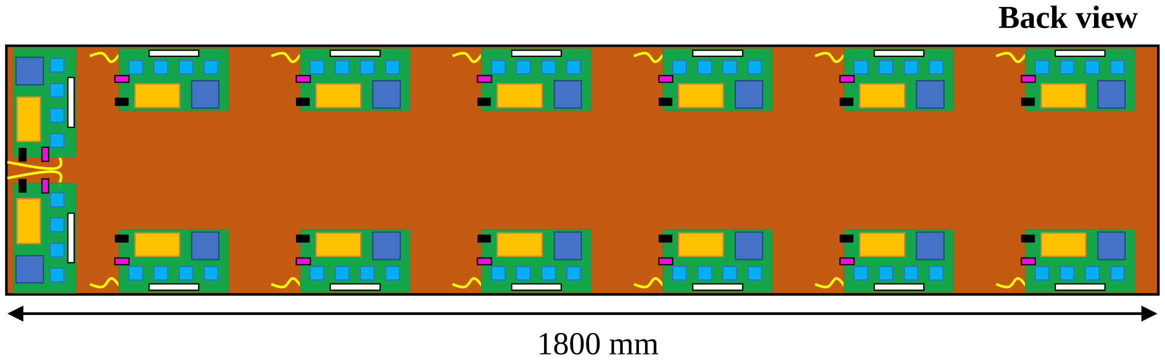
µRWELL-BOT Module:





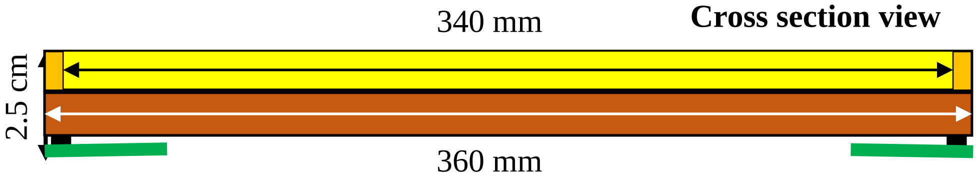
µRWELL-BOT module

- ❖ 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)

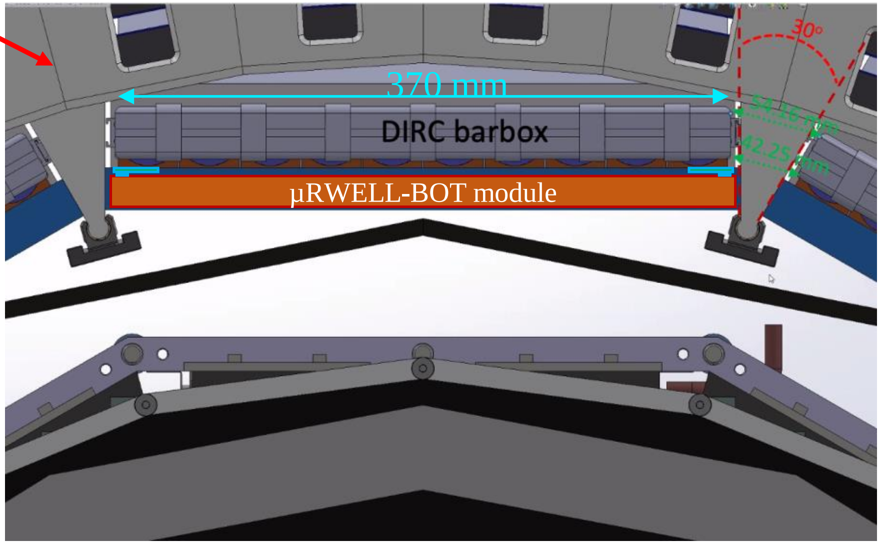


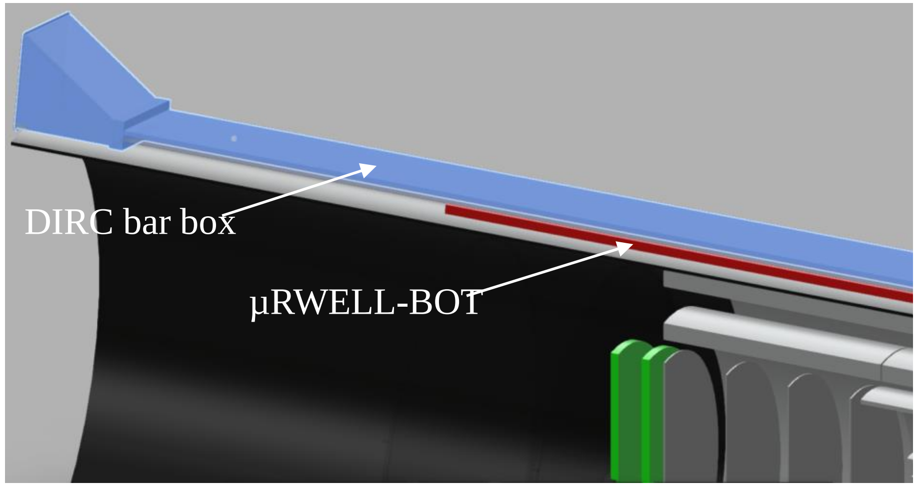
µRWELL-BOT Module: Integration considerations

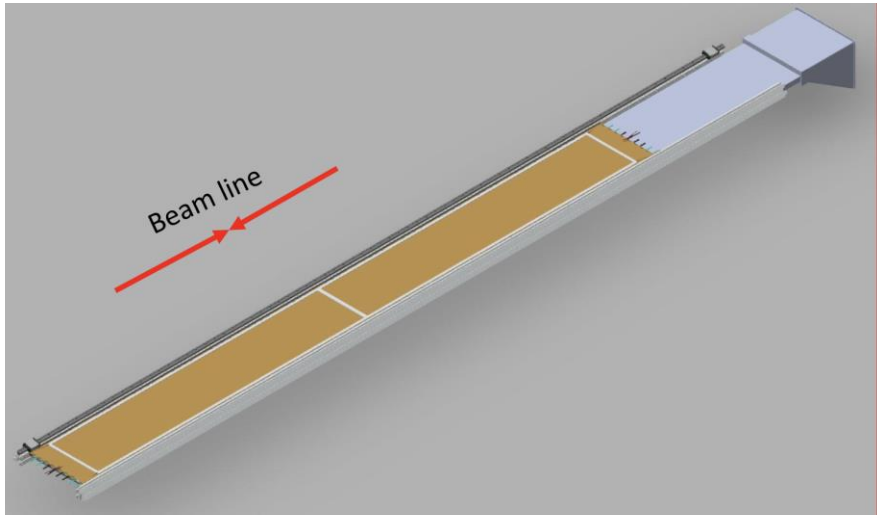
Main integration challenges: Space limitation in ePIC detector environment

- 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







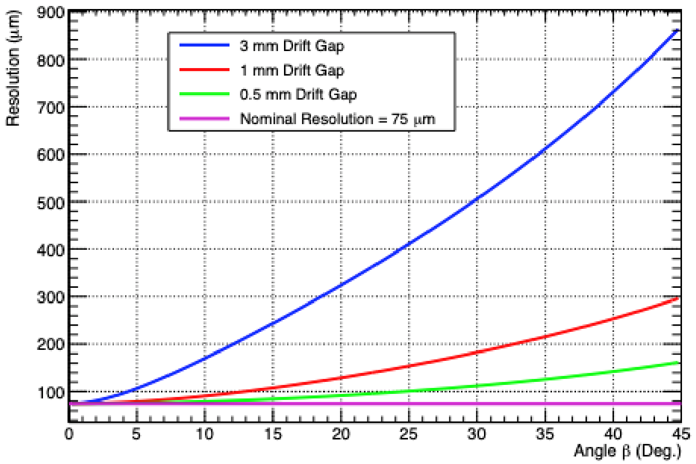
Technology choice: Thin-gap GEM-μRWELL Hybrid Detector

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:

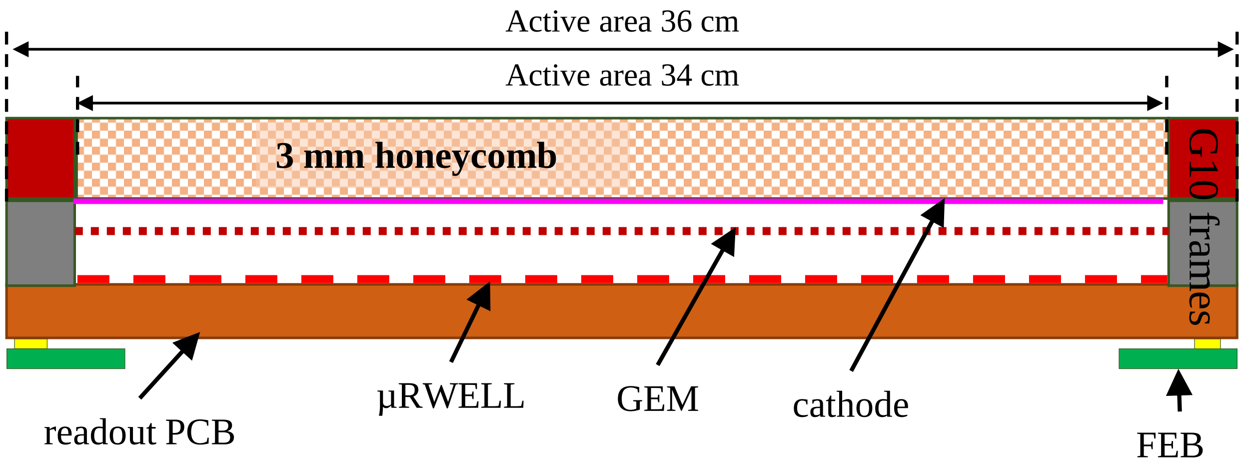
- Small drift gap improve spatial resolution at large angle
- Small gap ➔ minimize E × B effect in magnetic field
- Improve the detector timing performance



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



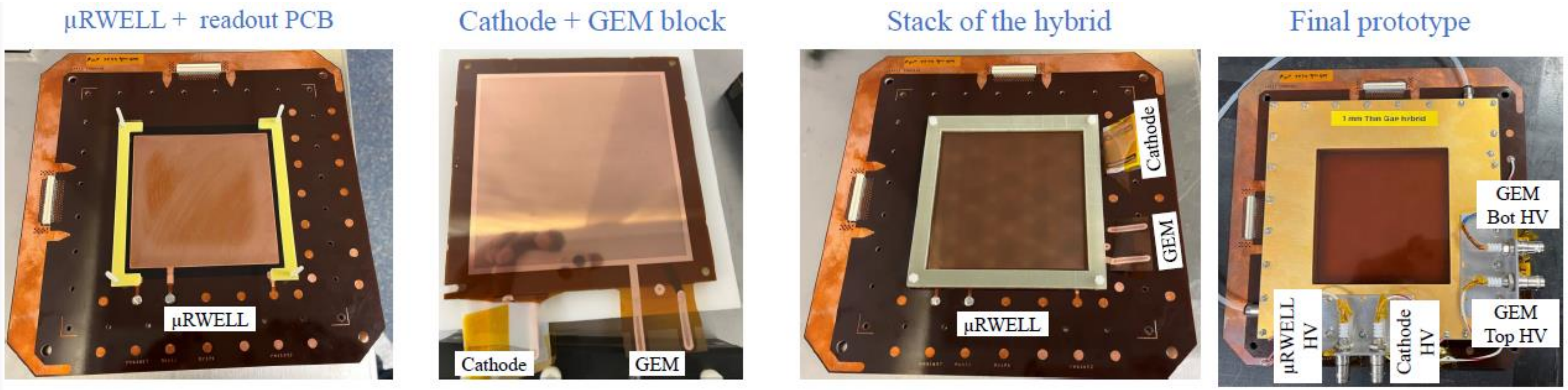
cross-section view of thin-gap GEM-μRWELL detector

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

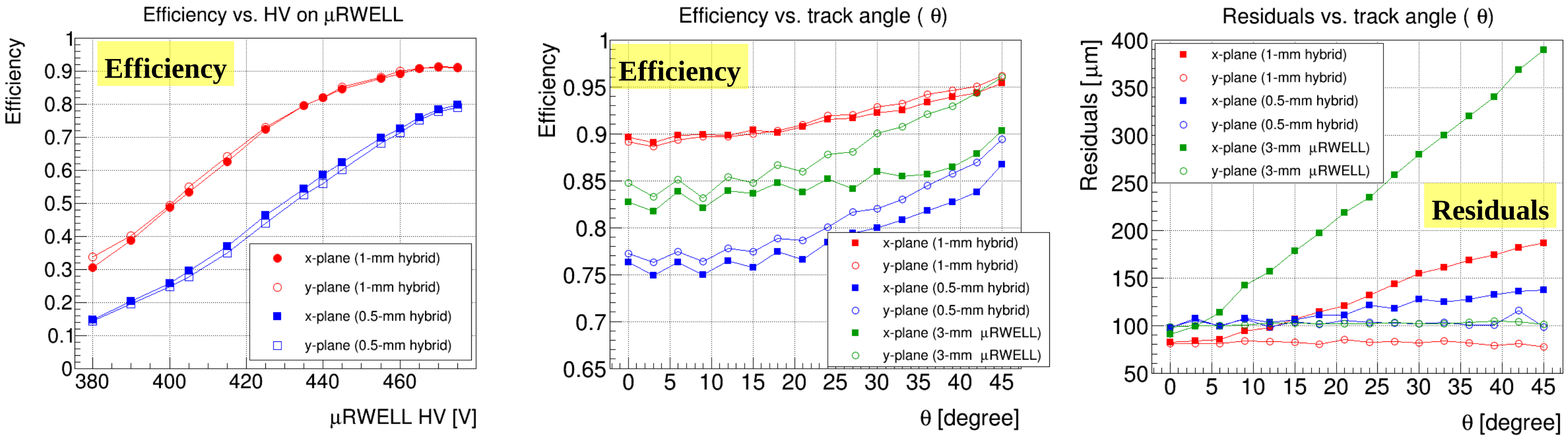
Technology choice: Thin-gap GEM-µRWELL Hybrid Detector

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



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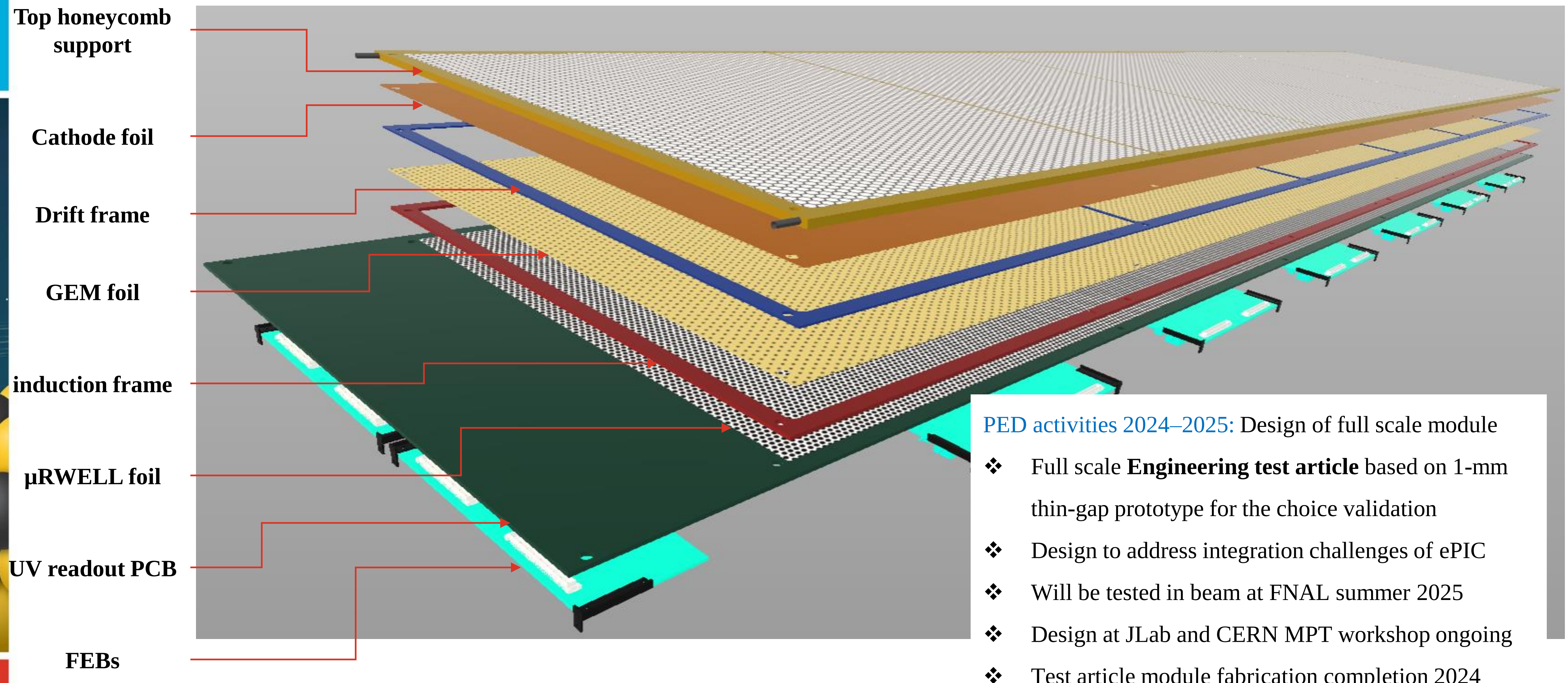
Design consideration: Breakdown of µRWELL-BOT module



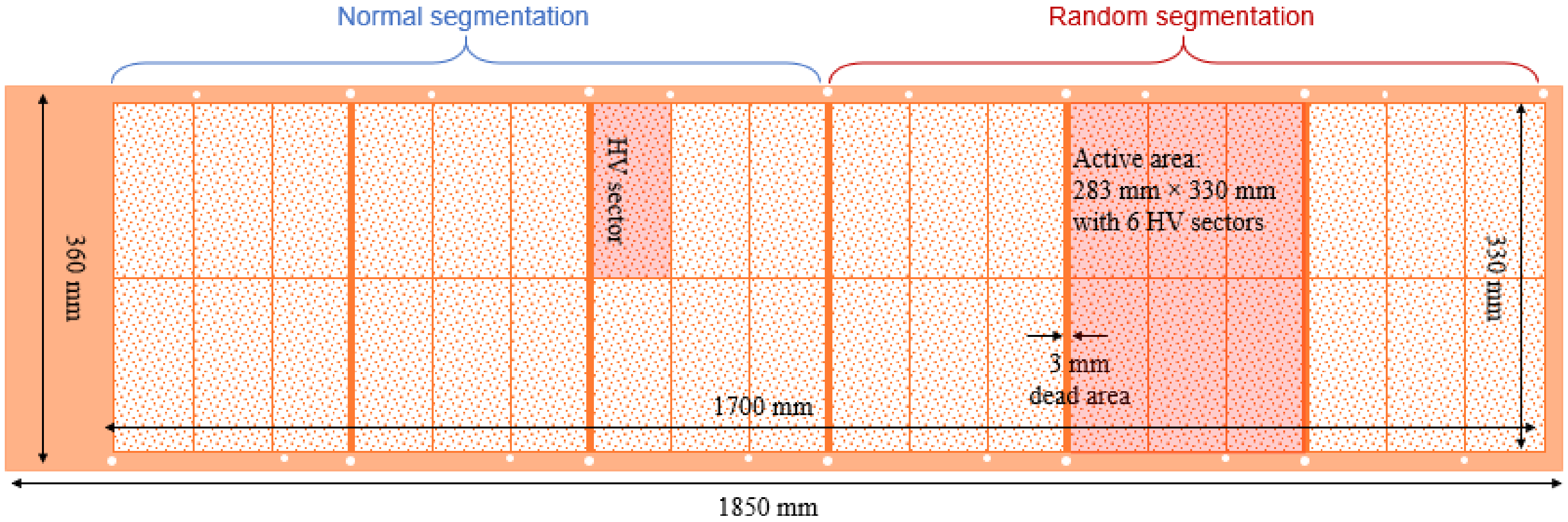
PED activities 2024–2025: Design of full scale module

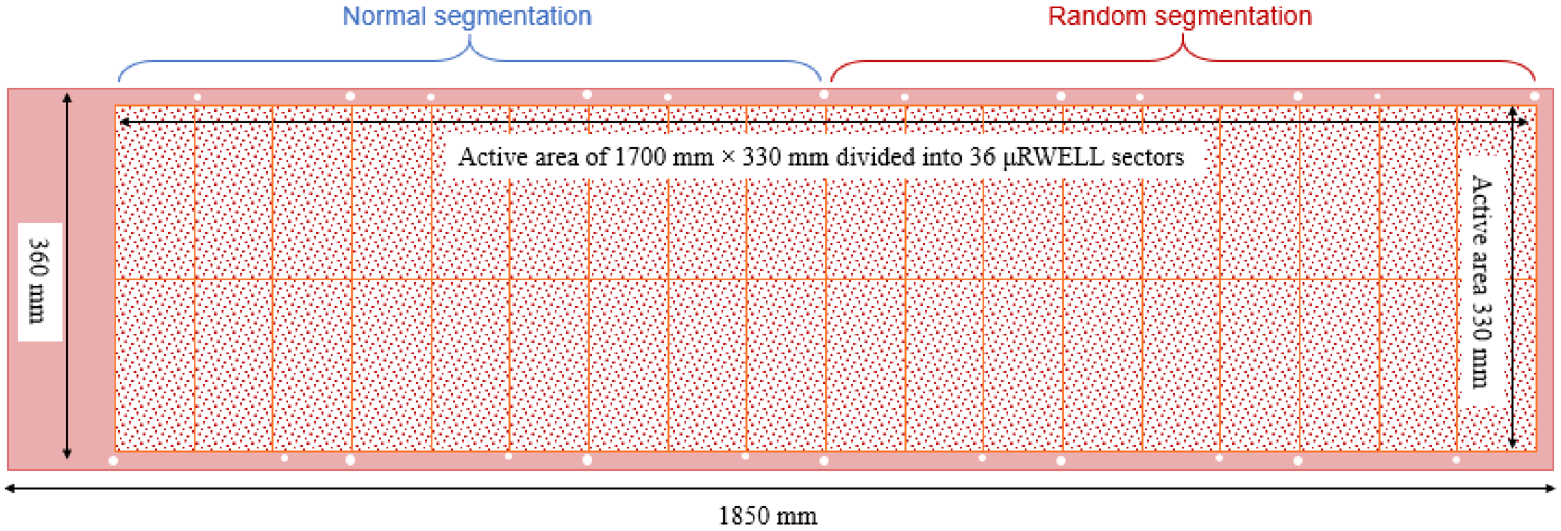
- Full scale **Engineering test article** based on 1-mm thin-gap prototype for the choice validation
- Design to address integration challenges of ePIC
- Will be tested in beam at FNAL summer 2025
- Design at JLab and CERN MPT workshop ongoing
- Test article module fabrication completion 2024
- Will be tested in beam at FNAL summer 2025

Design consideration – µRWELL and GEM foil design

GEM foil:

- foil divided into 36 HV sector ~ 156 cm^2
- Trade-off between active-to-dead area ratio for gap uniformity (~1% dead area)
- Final design ongoing in collaboration with CERN MPT workshop experts
- Procurement expected by 12/24





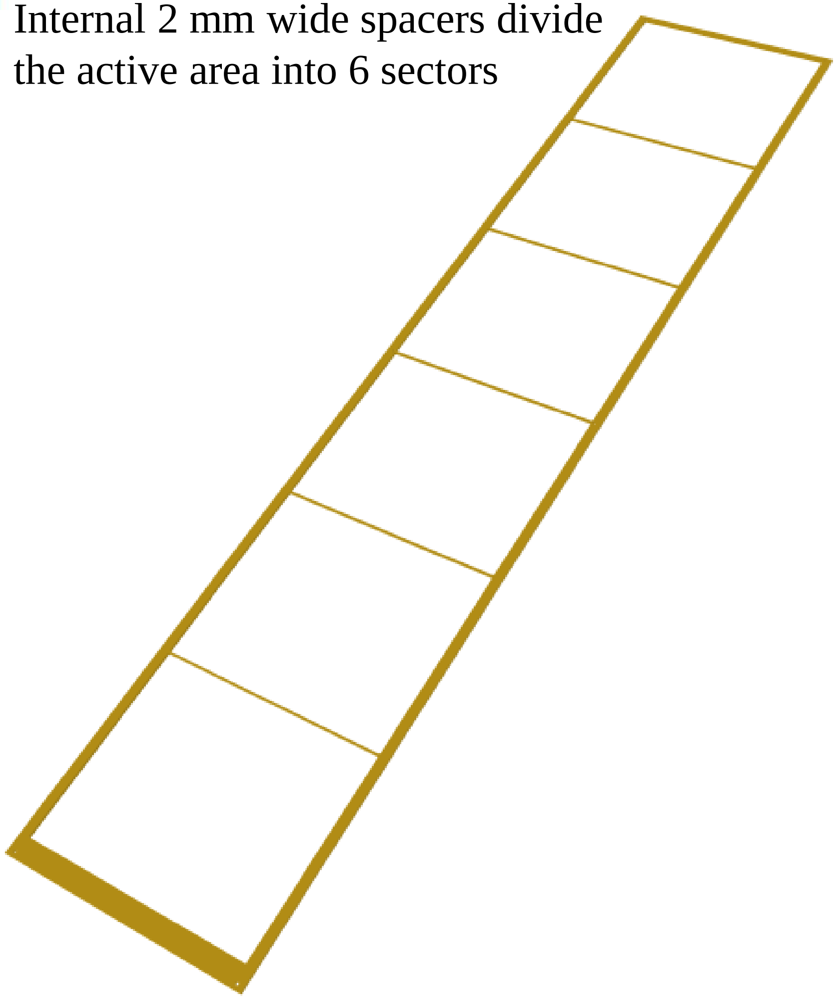
µRWELL PCB:

- Foil divided into 36 HV sectors ~ 156 cm^2
- Final design ongoing in collaboration with CERN MPT workshop experts
- Procurement by 12/24

Design consideration – Various frame designs

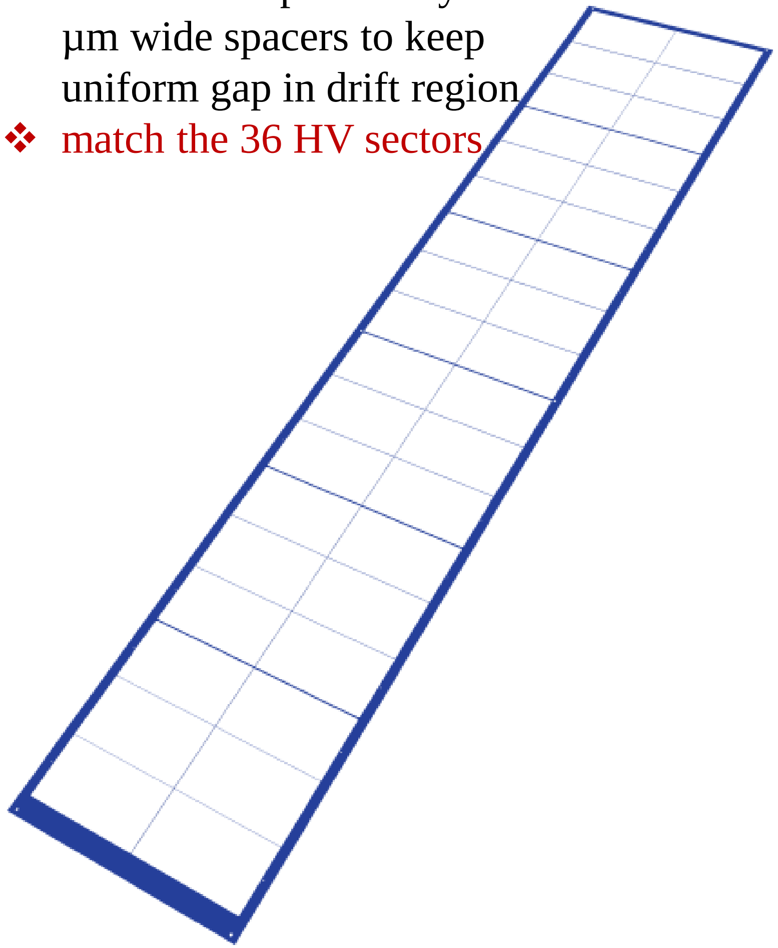
Top honeycomb frame

Internal 2 mm wide spacers divide the active area into 6 sectors



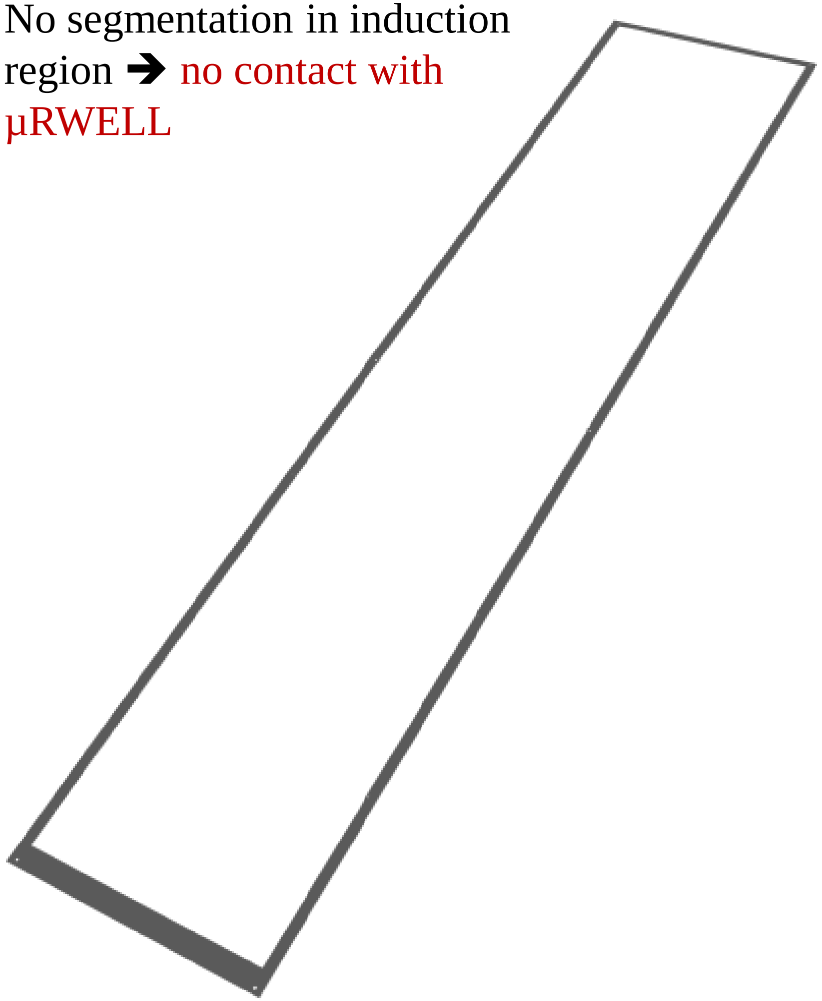
GEM top support – drift region

- ❖ 36 sectors separated by 500 µm wide spacers to keep uniform gap in drift region
- ❖ match the 36 HV sectors



GEM bottom support – induction region

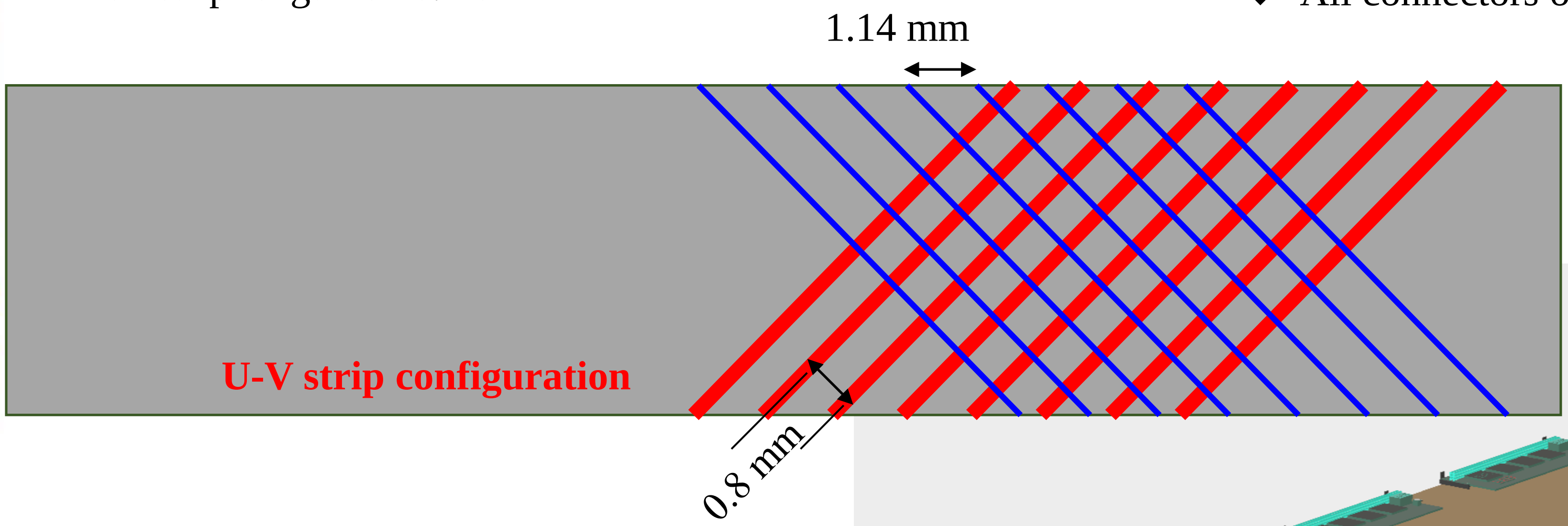
No segmentation in induction region ➔ no contact with µRWELL

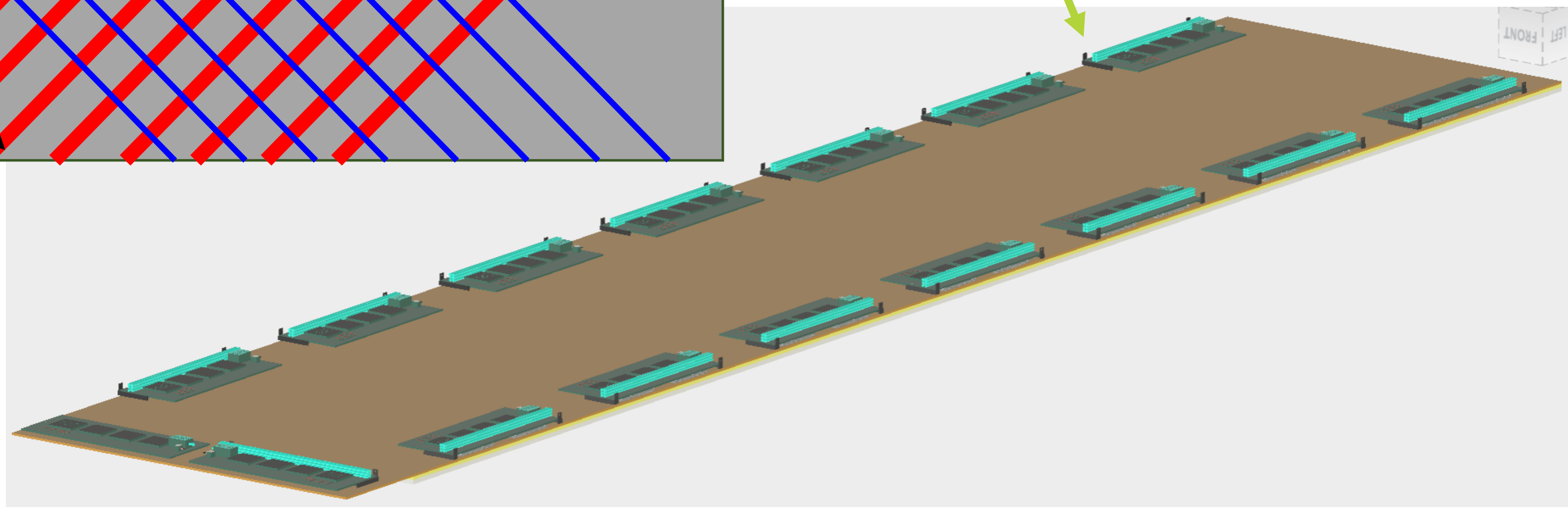


Design consideration: 2D (U-V)-strip readout layer

- 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(
- Max strip length is 46.7 cm

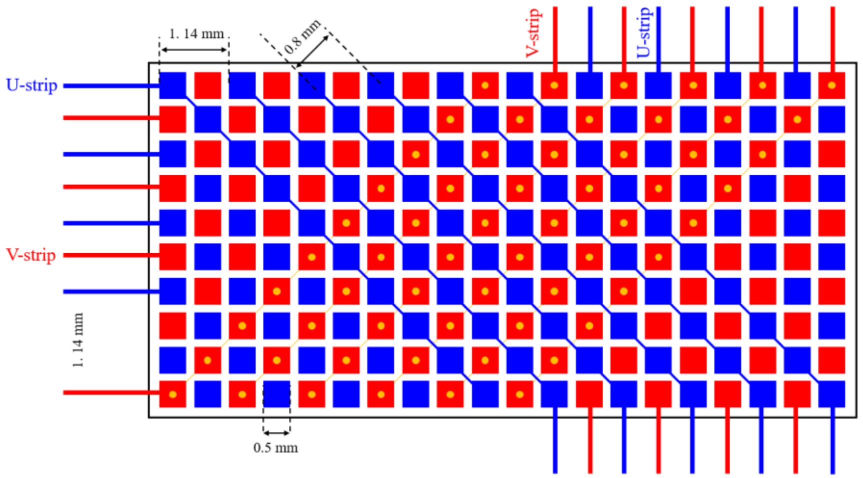
- 1780 U-strips + 1780 V-strips
- 7 FEBs / U (V) planes ➔ 14 FEBs / µRWELL-BOT modules
- 140-pins Hirose connectors
- All connectors on the back of the rigid µRWELL / readout PCB



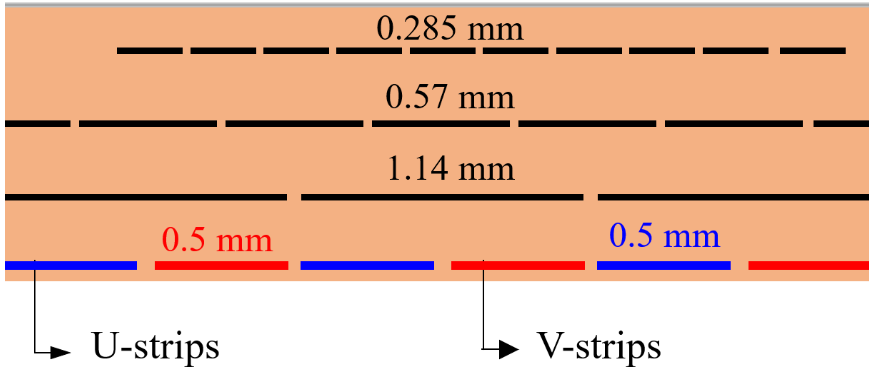


Design consideration: 2D (U-V)-strip capacitive-sharing readout options

ASACUSA-like design R/O



cross-section view of 3-layers capaSh readout



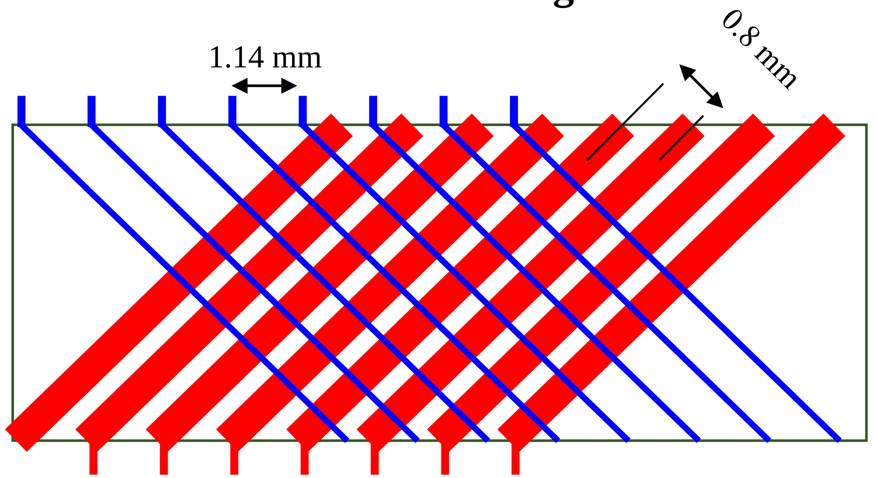
ASACUSA-like design: preferred option

- Equal U-V charge sharing guaranty
- Perfect one-to-one matching with pads capacitive sharing layer 3 pad
- But large number of vias ➔ challenging fabrication issues.

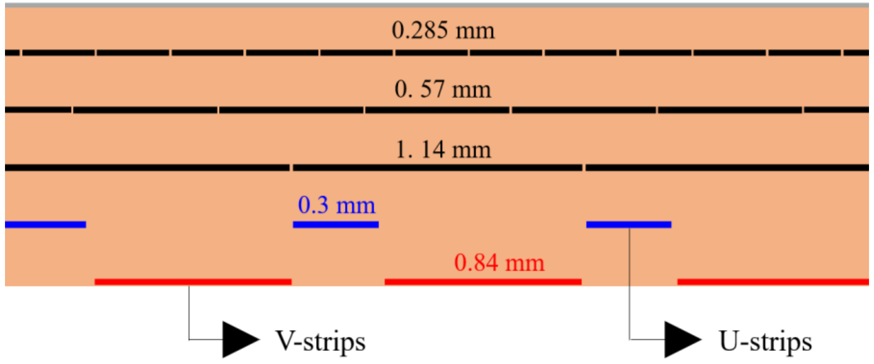
COMPASS-like design: alternative option

- Fabrication easier for Rui's workshop
- Need to fine tune parameter for equal U-V sharing ➔ width of top and bottom strips
- Might require a couple of iteration
- No vias in the active area

COMPASS-like design R/O

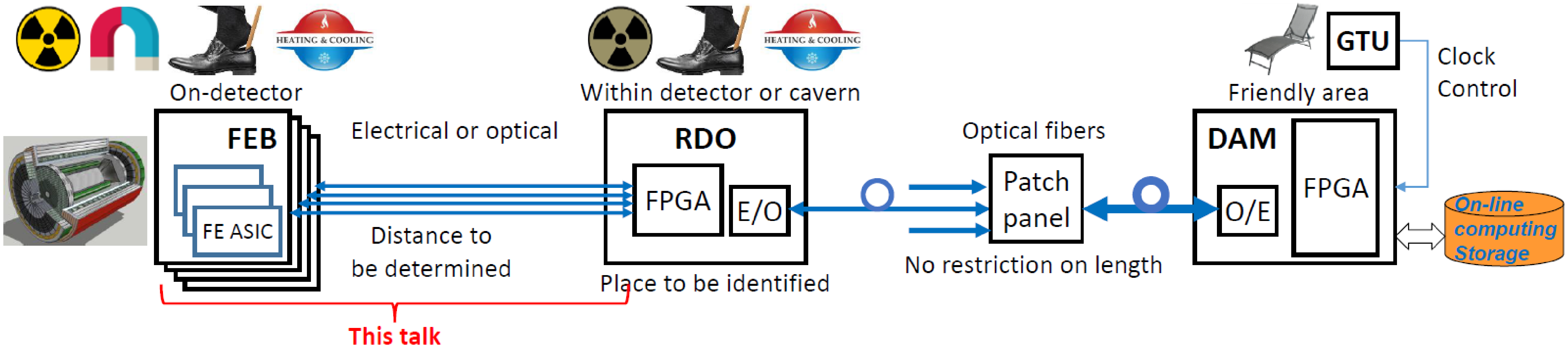


cross-section view of 3-layers capaSh readout



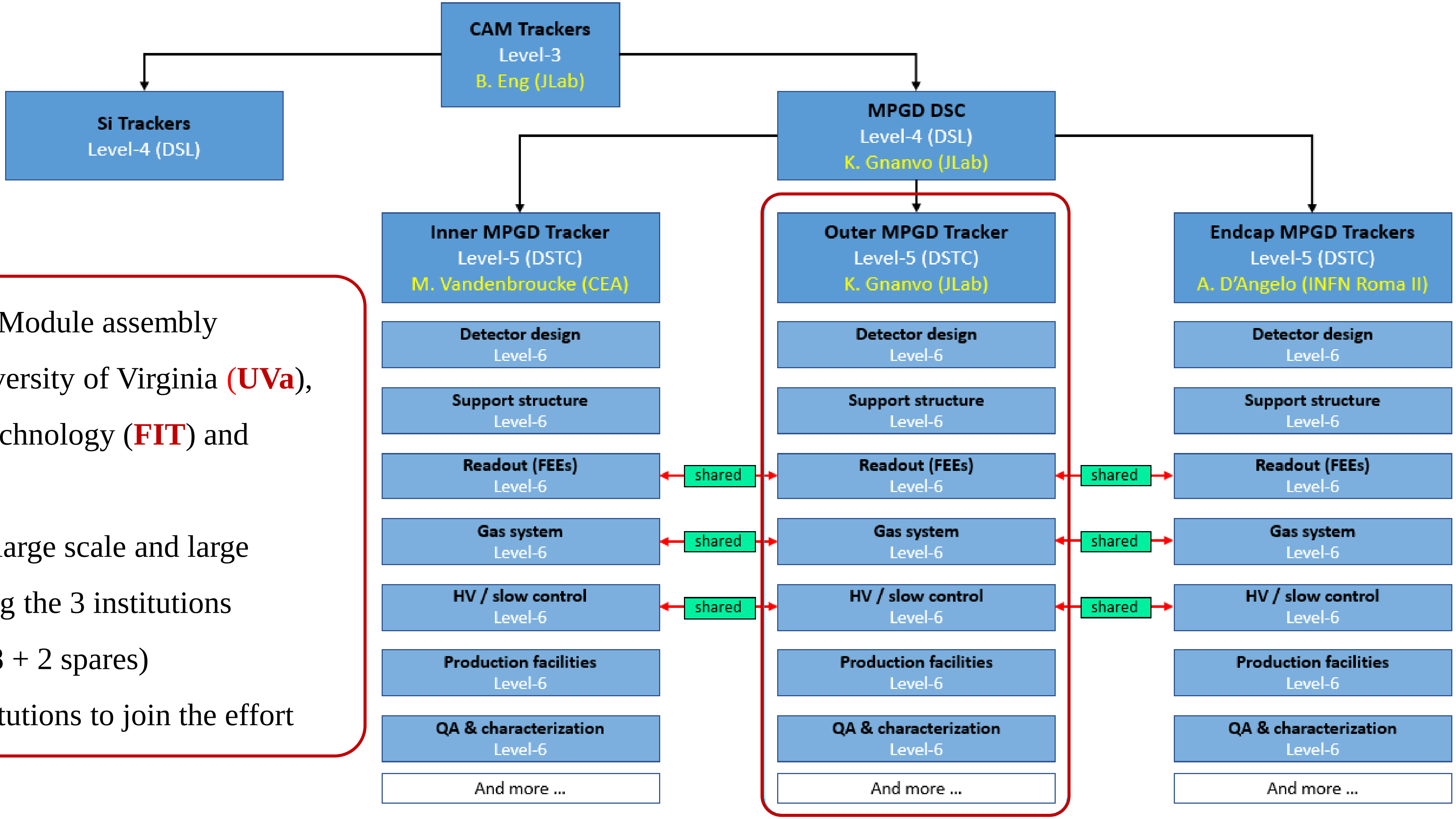
https://doi.org/https://doi.org/10.1016/j.nima.2022.167782

Design consideration: µRWELL-BOT Readout Electronics



- 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

MPGD-DSC: Organization of ePIC MPGD Subsystem Collaboration



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: Planning & schedule

PED & validation (06/2025)	Pre-production (06/2026)	Production (04/2029)	Shipment to JLab (06/2029)	Commissioning & Installation
▪ 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**	▪ Assembly of one pre-production module (**module#0**) ▪ Setup of infrastructure and equipment in assembly sites	▪ 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 of all 24 modules to BNL ▪ Commissioning at BNL cosmic test stand of all µRWELL-BOT as well as µRWELL-ECT	▪ Commissioning ▪ Installation

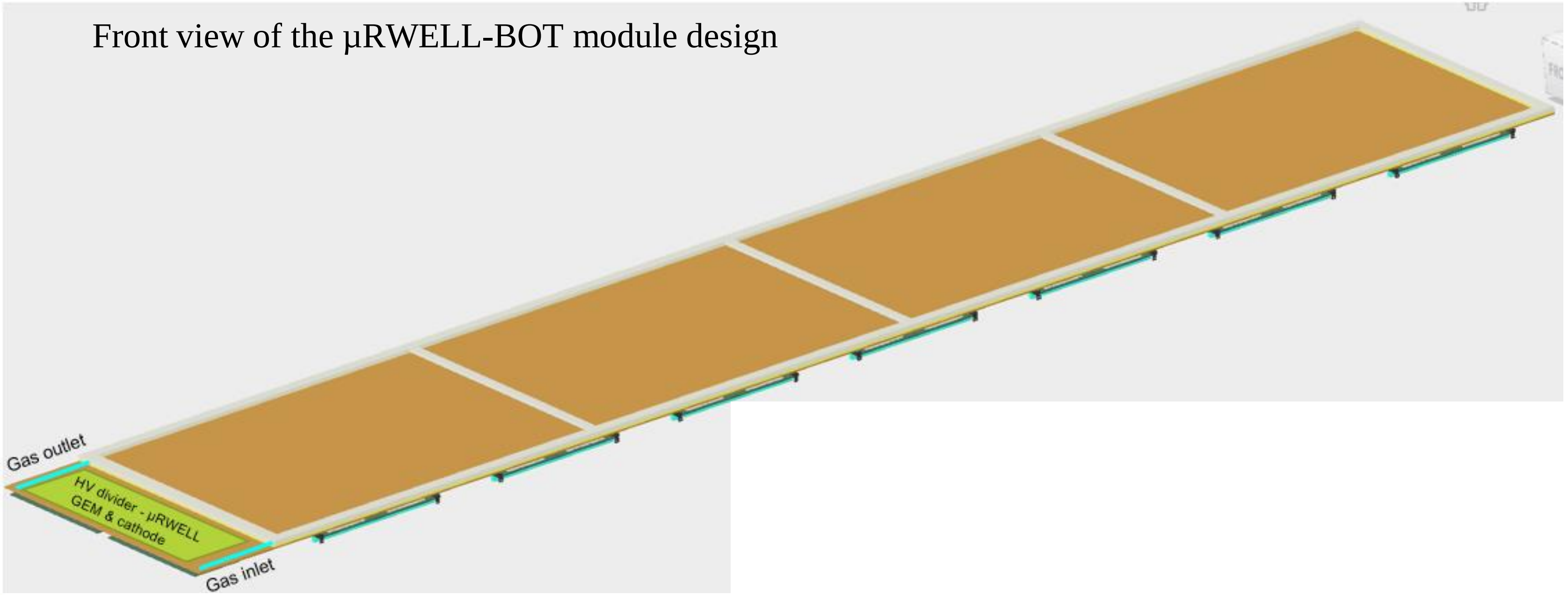
Summary

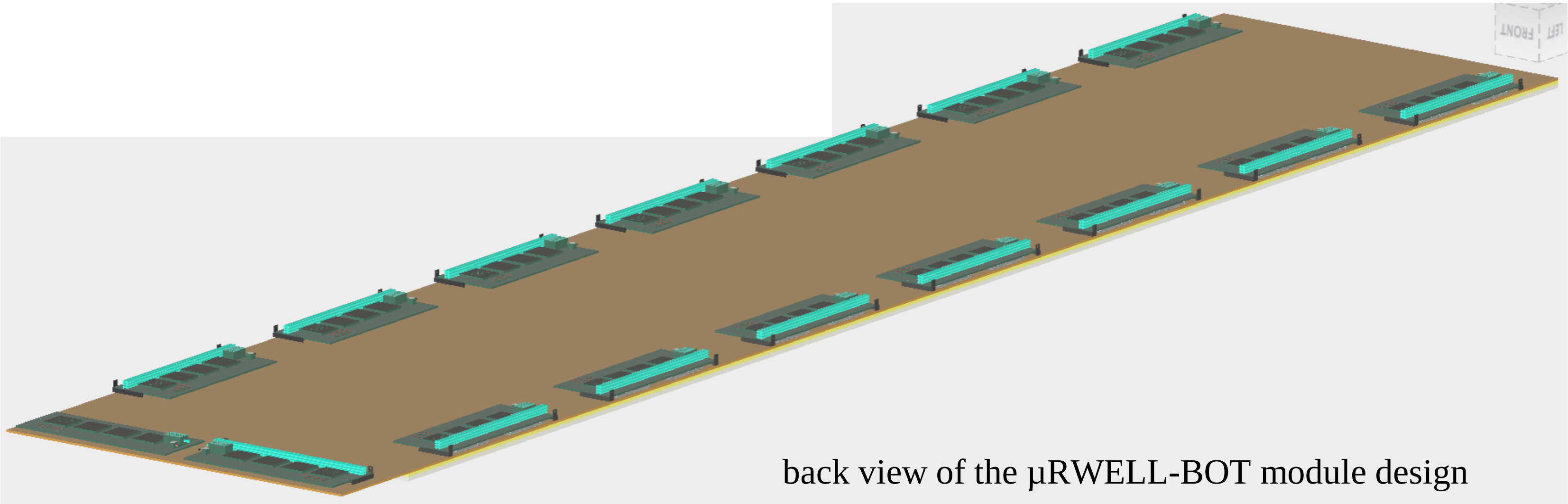
- ❖ The ePIC **B**arrel **O**uter MPGD **T**racker (µRWELL-BOT) is based on thin-gap GEM-µRWELL amplification technology
- ❖ µRWELL-BOT provides improved tracking option to the hpDIRC and pattern recognition with fast timing hit to Si tracker in the barrel
- ❖ Design of the µRWELL-BOT is well advanced 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: µRWELL-BOT module

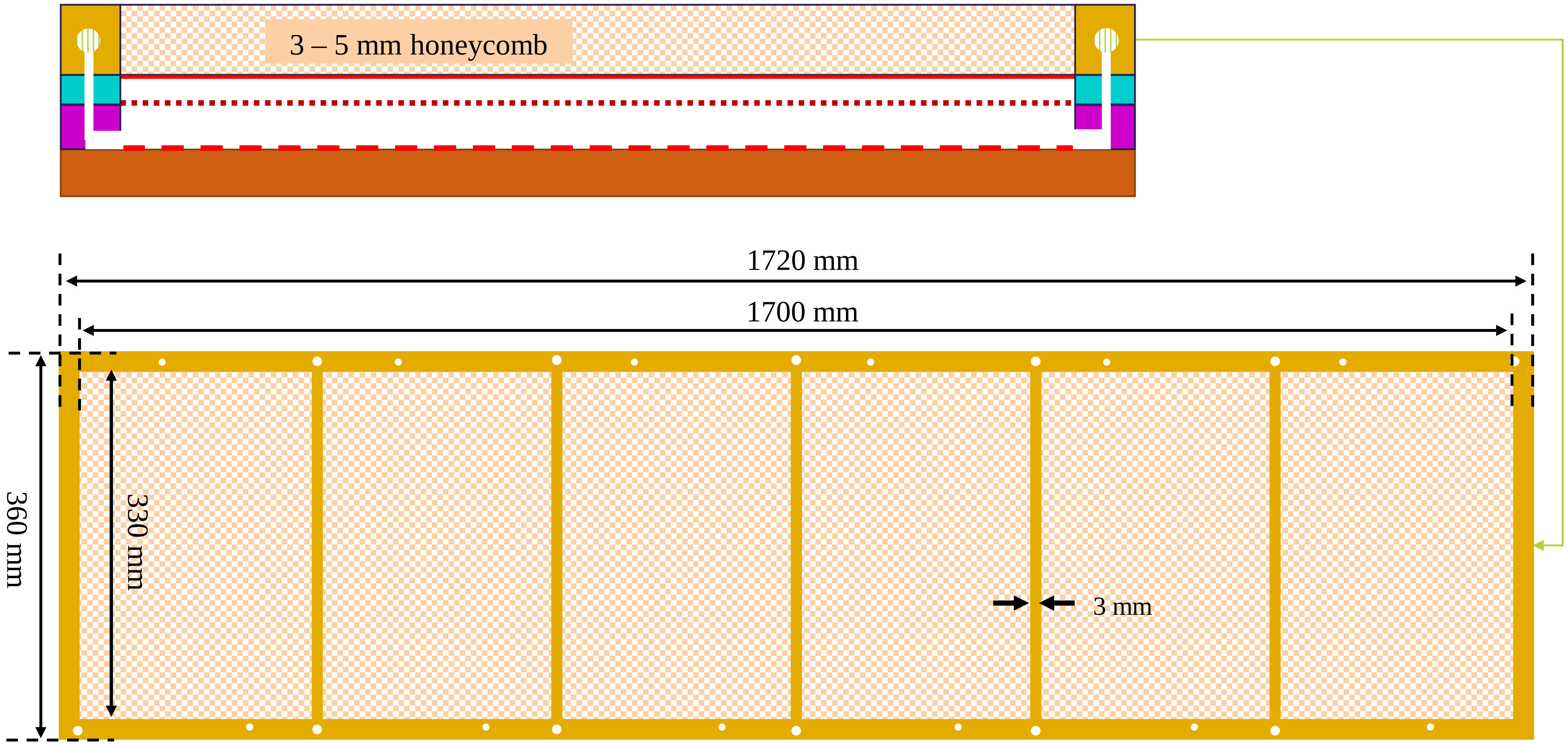
Front view of the µRWELL-BOT module design



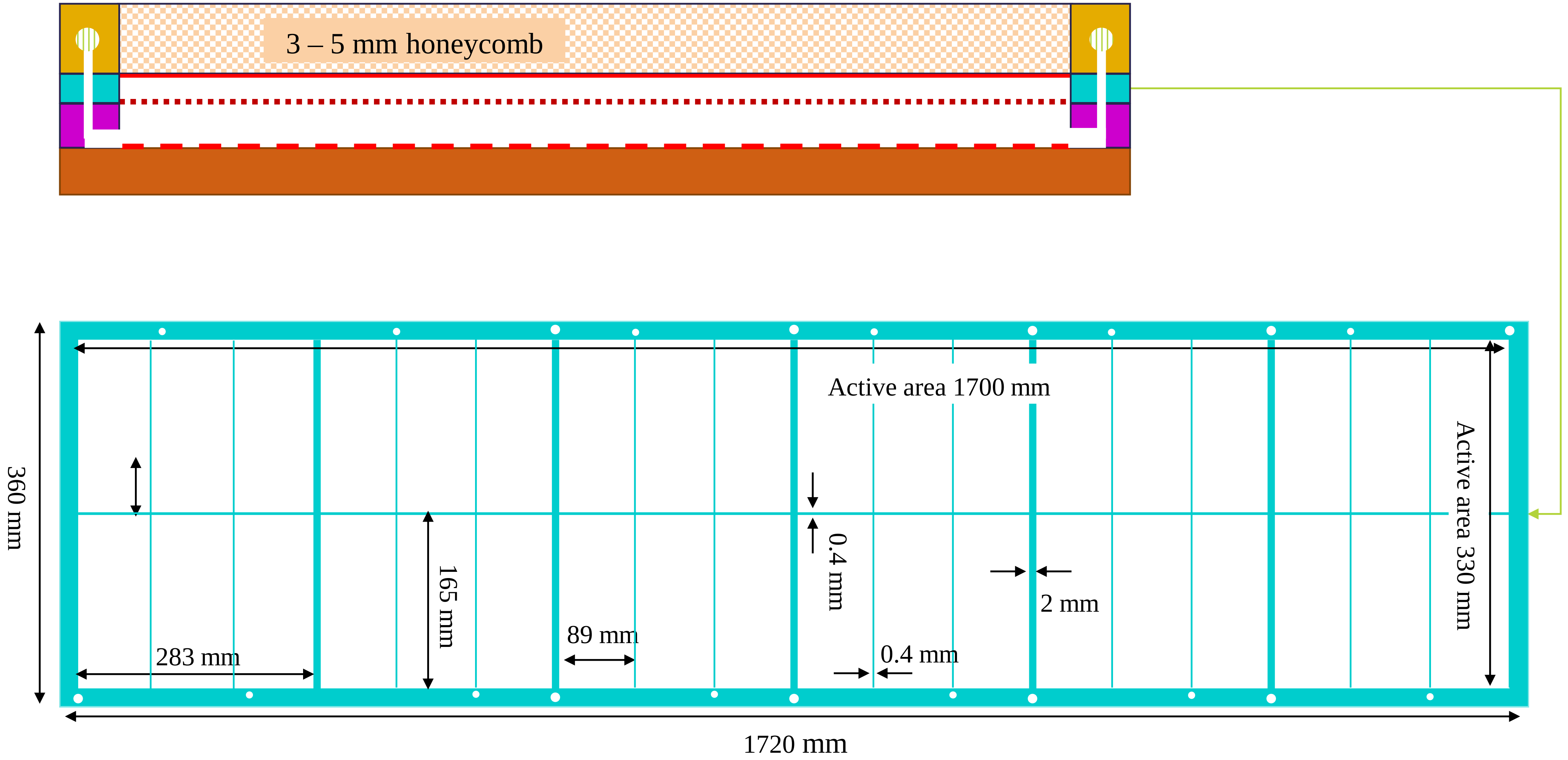


back view of the µRWELL-BOT module design

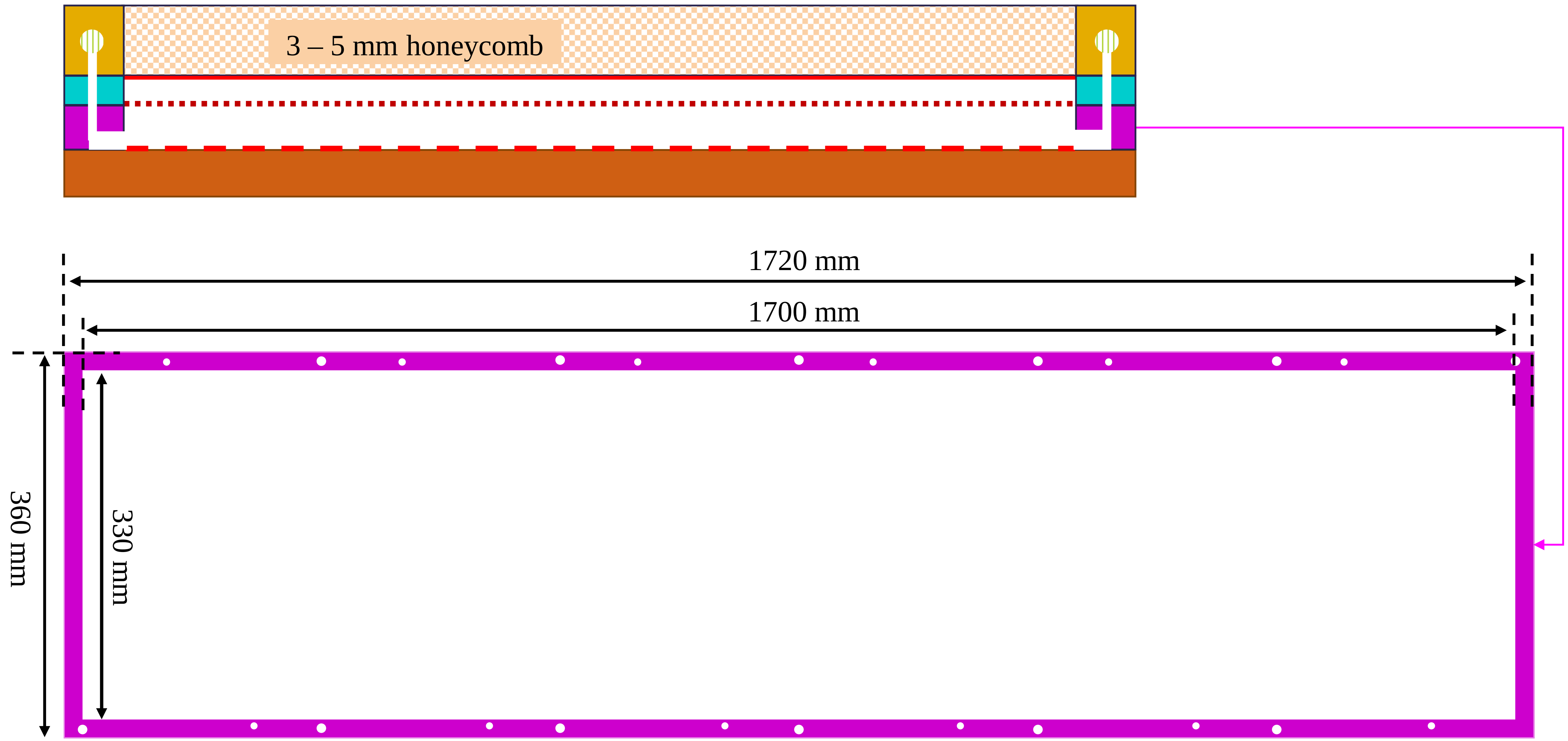
Design consideration: Honeycomb frame



Design consideration: Drift frame



Design consideration: Induction frame



Assembly plans: ES&H

- 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: Quality Assurance (QA)

❖ 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: Equipment at the assembly sites

- 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

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