Overview of ePIC Tracking System

Francesco Bossù (CEA), Kondo Gnanvo (JLab), Laura Gonella (U. of Birmingham), Xuan Li (LANL).

On behalf of EIC ePIC Detector Tracking Working Group

ePIC Collaboration Meeting

Jefferson Lab, January 09 – 11, 2023

Outline

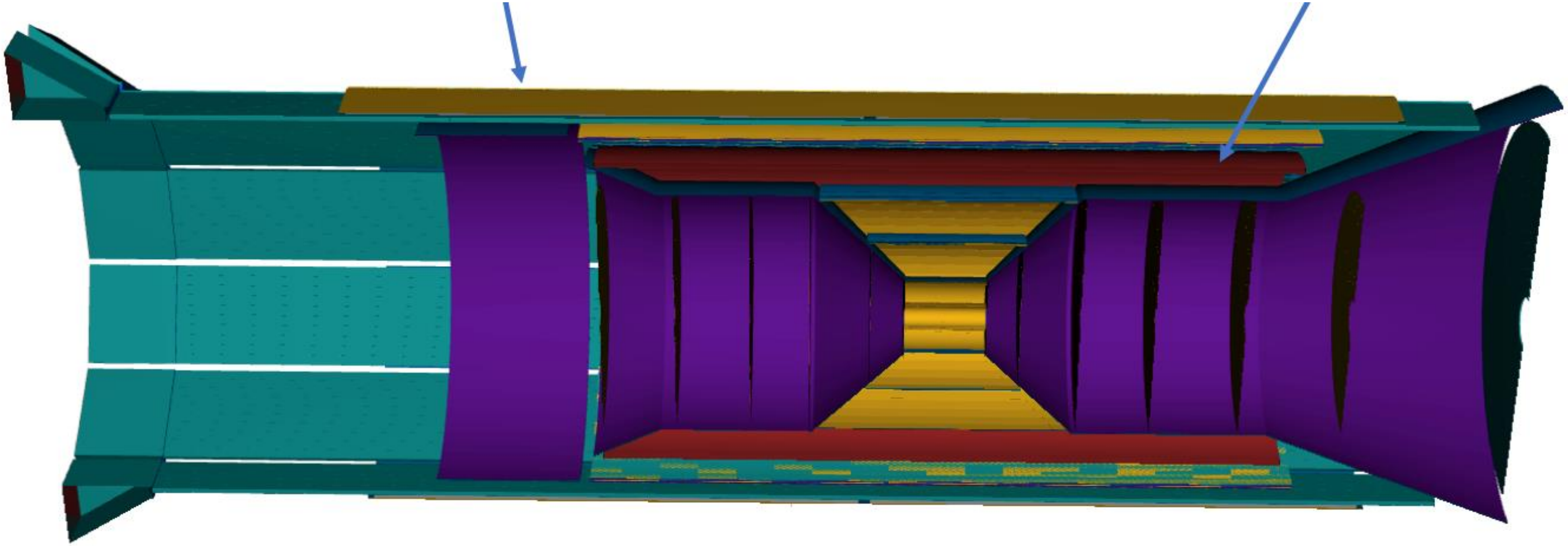
- Overview of ePIC tracking detector
  - Current design geometry
  - Tracking performance
- Update on tracking detector technologies
  - ESC Consortium – Si R&D effort
  - eRD108 Consortium – MPGD R&D effort
- Remaining issues
  - Background simulation
  - Further detector geometry Optimization
  - Integration & services

ePIC Tracking Detector WG

- ePIC Tracking working group:
  - Conveners: Xuan Li (xuanli@lanl.gov), Kondo Gnanvo (kagnanvo@jlab.org), Laura Gonella (laura.gonella@cern.ch), Francesco Bossu (francesco.bossu@cea.fr)
  - Email mailing list: eic-projdet-tracking-l@lists.bnl.gov
  - We have weekly meetings scheduled at 11:00AM US eastern time every Thursday and the meeting indico link: https://indico.bnl.gov/category/404/
  - Mattermost channel: https://eic.cloud.mattermost.com/main/channels/tracking
  - WIKI page: https://wiki.bnl.gov/EPIC/index.php?title=Tracking#Tasks_list
- ESC : EIC Silicon Consortium
  - Mailing list: https://lists.bnl.gov/mailman/listinfo/eic-rd-silicon-l
  - Indico: https://indico.bnl.gov/category/386/
  - Contacts: Laura Gonella (laura.gonella@cern.ch), Giacomo Contin (giacomo.contin@ts.infn.it), Ernst Sichtermann (epsichtermann@lbl.gov)
- eRD108: EIC MPGD Consortium
  - Contacts: Kondo Gnanvo (kagnanvo@jlab.org), Francesco Bossu (francesco.bossu@cea.fr)
  - Bi-weekly meetings on Wednesday at 1:30PM EST - indico link: https://indico.bnl.gov/category/425/
  - WIKI page: https://wiki.bnl.gov/eic/index.php/Eic-rd-meeting

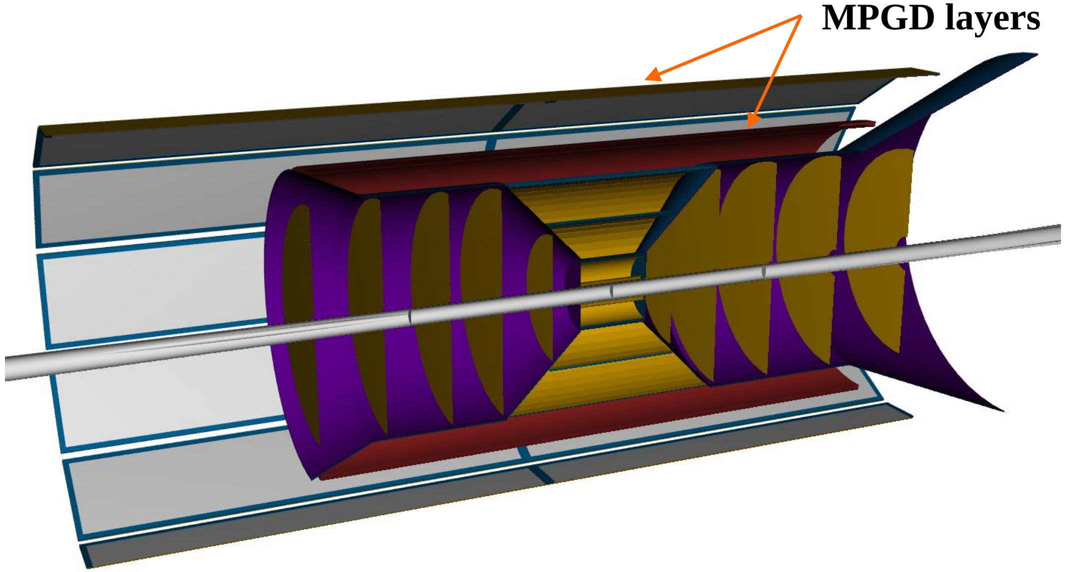
ePIC Barrel tracker: Current configuration

- The EPIC tracking detector consists of the MAPS, MPGD and AC-LGAD layers/disks. Latest geometry has been implemented in the default simulation configuration.
  - MAPS: 5 barrel layers (3 vertex layers and 2 sagitta layers), 5 hadron-endcap disks, 5 electron-endcap disks.
  - MPGD: 1 MPGD Barrel layer in the “Bryce Canyon” tag, 1 MPGD Barrel layer and 1 MPGD DIRC layer in the “Arches” tag.
  - AC-LGAD: 1 AC-LGAD barrel layer and 1 AC-LGAD hadron endcap disk



Barrel tracker: Current configuration

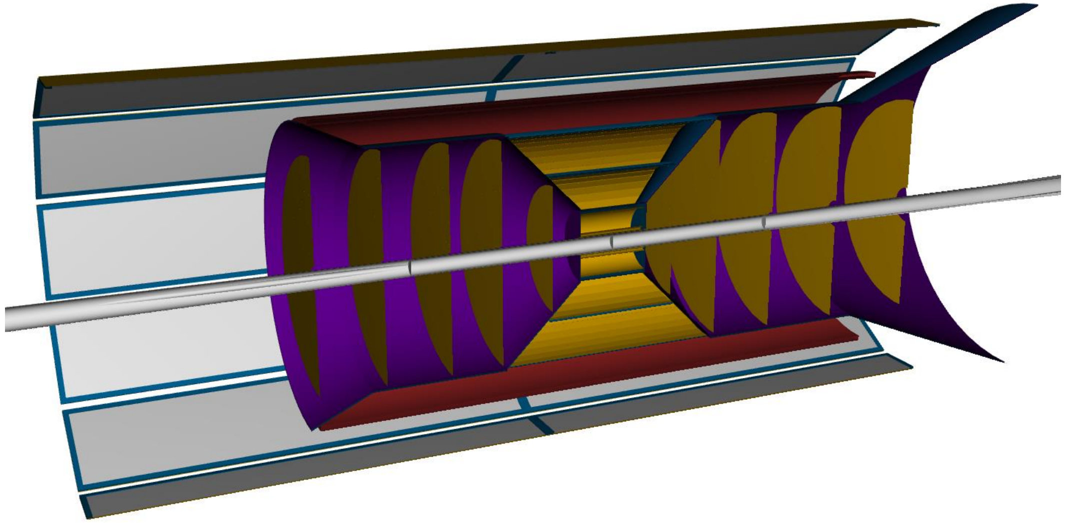
- Vertex layers:
  - Radii of two innermost vertex layers optimised for beam pipe bake out (5 mm clearance) and ITS3 sensor size.
  - 3rd vertex layer at r = 120 mm, dual purpose vertexing & sagitta layer, without increase in material (i.e. 0.05% X/X0, bent layer).
- Sagitta layers:
  - Moved at larger radii to increase lever arm with high precision measurements to improved momentum resolution.
  - Layer at 27 cm made two halves of 0.25% X/X0.
- Cyl. Micromegas & AC-LGAD layers:
  - Additional space point for pattern recognition / redundancy
  - Ongoing geometry optimization
- µRWELL planar layer behind hpDIRC
  - Impact point and direction for the ring seeding of hpDIRC
  - Additional space point for pattern recognition / redundancy
  - Not be required if imaging calorimeter is used



BARREL	r [mm]	l [mm]	X/X0 %
Si vertex layer 0	36	270	0.05
Si vertex layer 1	48	270	0.05
Si layer 2	**120**	270	**0.05**
Si sagitta layer 3	**270**	540	**0.25**
Si sagitta layer 4	**420**	840	0.55
Cyl.Micromegas layer	550	2300	0.5
AC-LGAD layer	640	2400	1.0
µRWELL behind DIRC	**730**	3420	~1.0%

See talk by Stephen & Ernst at https://indico.bnl.gov/event/16261/
See talk by Laura & Ernst at https://indico.bnl.gov/event/16582/

ePIC end cap trackers: Current configuration



- ❖ Number of disks in the electron direction increased to improve acceptance at high eta/increase number of points on track.
  - At |eta| >= 3 in the electron going direction, hits on three disks only in reference detector. Insufficient considering noise and inefficiency.
- ❖ Use all available space in z to increase lever arm.
  - The table below show the current layout implemented in simulation. This is the envelop assuming the pfRICH in the electron going direction. The disk design can be symmetric if the mRICH is used (i.e. envelop on electron side up to ~1350 mm).

DISKS	+z [mm]	-z [mm]	X/X0 %
Disk 1	250	-250	0.24
Disk 2	450	-450	0.24
Disk 3	700	-650	0.24
Disk 4	1000	-900	0.24
Disk 5	**1350**	**-1150**	0.24

See talks by Ernst at https://indico.bnl.gov/event/16582/ and https://indico.bnl.gov/event/17348/

Tracking performance

- Performance studies of the current ePIC tracker configuration are presented in detail in next three talks by **Stephen, Wenqing and Rey** https://indico.bnl.gov/event/17621/

- Will just present two slides that highlight the areas to focus our next effort for the ePIC detector geometry optimization
  - Studies of the average number of hits per track for performance optimisation
  - Study of the role of the MPGD and AC-LGAD layers in the barrel tracker

Tracking WG 1h

Speakers: Francesco Bossu (CEA-Saclay), Kondo Gnanvo (Jefferson Lab), Laura Gonella (University of Birmingham), Xuan Li (Los Alamos National Laboratory)

Tracking overview 20m

Speaker: Kondo Gnanvo (Jefferson Lab)

Tracking momentum and spatial resolution (online) 10m

Speaker: Stephen Maple (University of Birmingham)

Track angular resolution and magnetic field dependence 10m

Speaker: Wenqing Fan (Lawrence Berkeley National Laboratory)

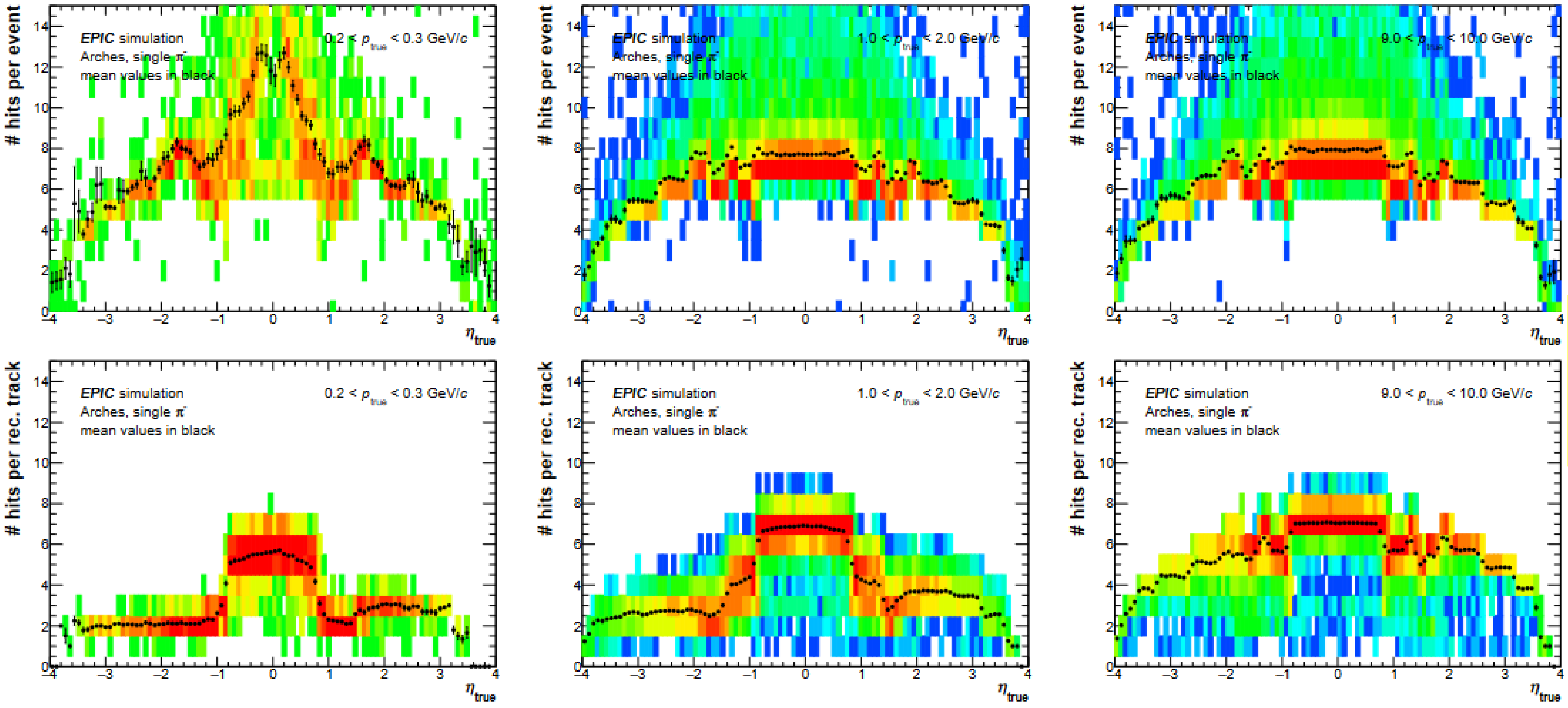
Background and track reconstruction software (online) 15m

Speaker: Reynier Cruz-Torres (Lawrence Berkeley National Lab)

Tracking performance: Average number of hits per track

EPIC detector performance studies with DD4hep and eicrecon: Average number of reconstructued hits per tracks vs. eta and p

Hits per event and per rec. track with ACTS

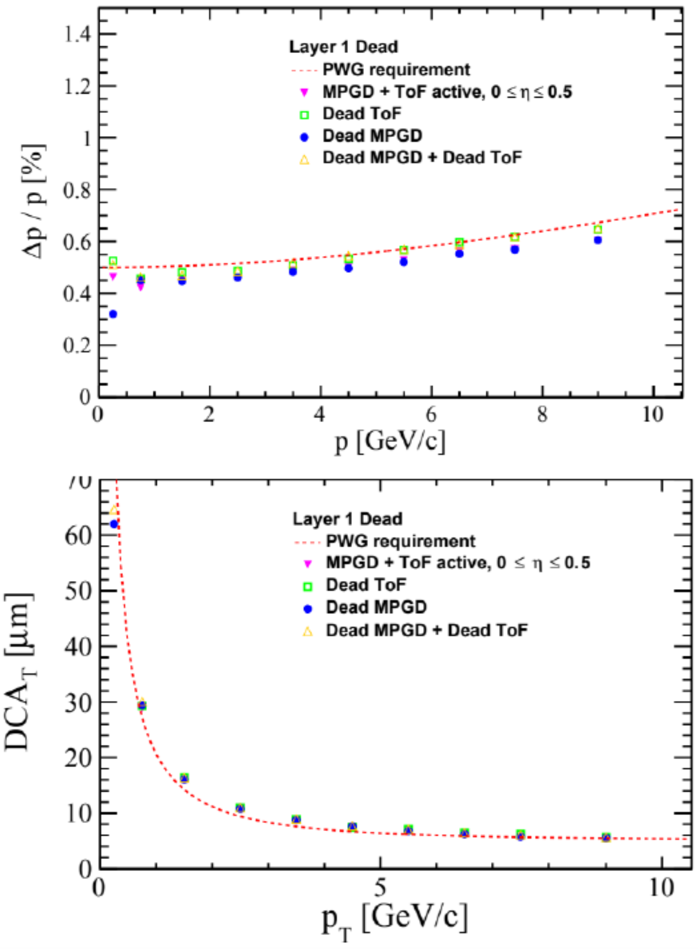


See talk by Nicolas Schmidt at https://indico.bnl.gov/event/17752/

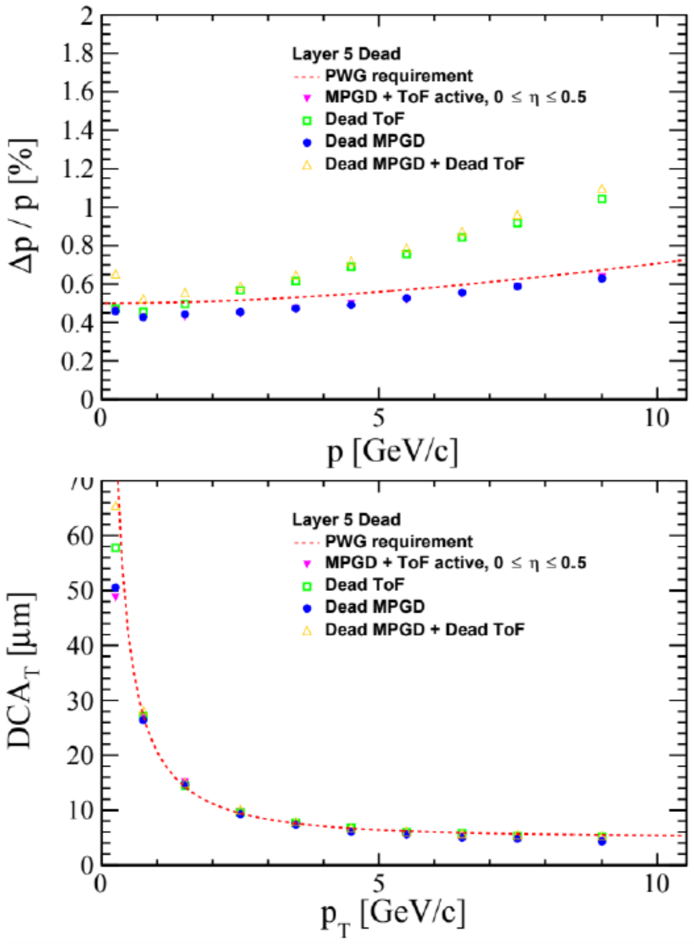
Tracking performance: Role of MPGD & AC-LGAD layers

Simulations in Fun4All to study the contribution of the barrel MPGD and AC-LGAD layers to momentum and DCA resolutions

Missing hit in inner Si layer



Missing hit in outer Si layer



See talk by Stephen Maple at https://indico.bnl.gov/event/17752/

Hits in all 5 Si layers:

- Momentum & DCA resolutions dominated by Si layers
- Small improvement of momentum resolution with ToF
- Negligible contribution by MPGD or ToF to either p or DCA measurement

Hits missing in one of the 5 Si layers:

- Negligible impact on momentum and DCA resolution, except for Si layer 5
- Improvement to momentum resolution by ToF layer if missing hit from outer Si layer (layer 5).
- MPGD helps improve performance at low momentum only when hits are missing in both Si and ToF layers

To summarize:

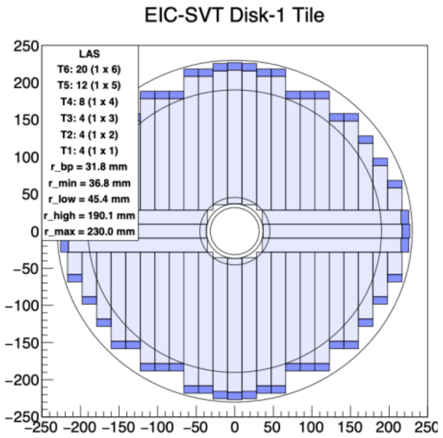
- Barrel MPGD has minimal impact on performance even for redundancy when hit are missing in Si layers
- Performance improvement by ToF layers when single hit missing in Si layers
- MPGD will be mostly needed for pattern recognition
- **Very important study for further optimization of tracking detector geometry**

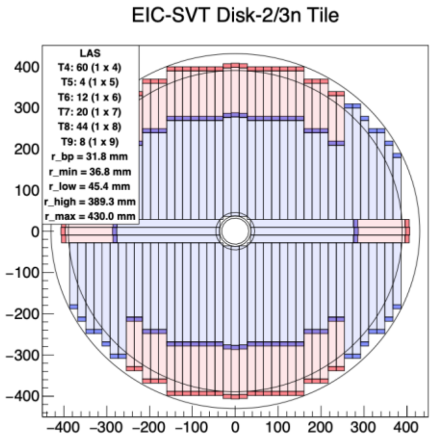
EIC Silicon Consortium – R&D effort

- Overarching goal is the development and construction of a full tracking and vertexing detector subsystem for the EIC detector(s) based on 65 nm Monolithic Active Pixel Sensors (MAPS),
- Consortium grew out of the previous Generic EIC Detector R&D program; eRD16, eRD18, and eRD25 (2015—2021), contributed to all detector proposals, and many members are active within ePIC,
- Open to collaborators new to the effort,
  - Mailing list: https://lists.bnl.gov/mailman/listinfo/eic-rd-silicon-l
  - Indico: https://indico.bnl.gov/category/386/
  - Contacts: Laura Gonella, Giacomo Contin, Ernst Sichtermann
- Two streams of R&D:
  - Targeted R&D for the ePIC detector:
    - eRD104 – services reduction aims to significantly reduce the all-important services (powering; readout)
    - eRD111 – development of tracking and vertexing solution (modules; barrel and disks; mechanics, integration, cooling)
    - eRD113 – development of the EIC MAPS sensor (sensor design; sensor characterization)
  - Generic R&D for ePIC improvements and upgrades, or for a future second detector

EIC Silicon Consortium – R&D effort (eRD111)

- The EIC science program requires a well-integrated, large acceptance tracking and vertexing solution designed with high-granularity and minimized material (including services),
- 65 nm MAPS technology – being spearheaded by the ALICE ITS3 project – choice and focus was a carefully considered outcome from a broad survey, see e.g. Laura Gonella’s talk at the 1st Yellow Report Workshop, https://indico.bnl.gov/event/7449/
- The path to ePIC / an EIC detector based on 65 nm MAPS thus requires us to develop:
  - ITS3-like vertex layers re-using the ITS3 large-area sensor (LAS) as is in a configuration adapted to the larger EIC radii (R&D)
  - EIC variant optimized for large area coverage for outer barrels and disks – that is high yield, cost, etc. This sensor will have the same interfaces as ITS3 and will be stitched, but not to wafer scale (R&D). More conventional carbon fiber support structures with integrated cooling (R&D).
- Ongoing studies on tiling of staves and disks, illustrated on the right for two representative disks, to inform the EIC LAS formats (stitching plan, digital periphery).

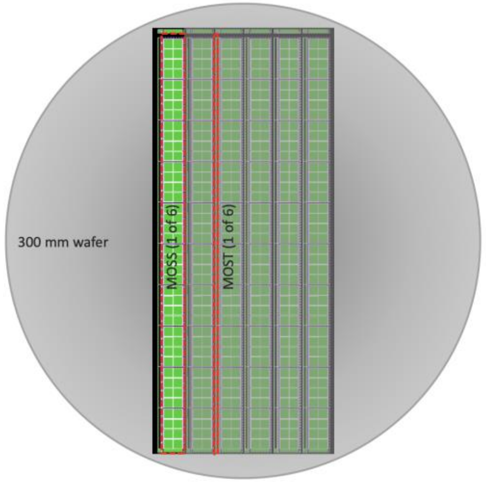




EIC Silicon Consortium – R&D effort

Sensor design (eRD113) - Current EIC SC designer groups: RAL and (new) BNL and LBNL,

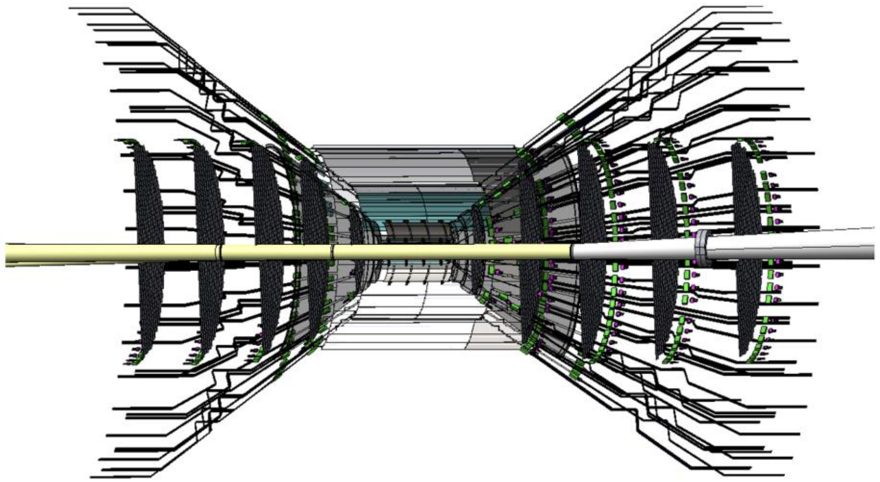
- MLR1 – Q4 2020
  - First submission in Towerjazz 65 nm; scoped within CERN EP R&D WP1.2, significant drive from ITS3, important contributions from many groups,
  - Scope: Technology exploration and prototype circuit blocks for future sensors,
  - Large number of test structures included,
  - RAL contributions: high-speed data transmission IP blocks (LVDS receiver, CML transmitter),
- ER1 – Q4 2022
  - First Engineering Run, driven by ITS3 stitched sensor prototype,
  - Scope: learning about stitching and yield of LAS
  - Two large stitched sensor chips (MOSS, MOST) plus small test and development chips,
  - RAL contributions: high-speed data transmission IP blocks (PLL, CML receiver); on-chip signal transmission I2C block; DFM cell improvements.



EIC Silicon Consortium – R&D effort

- Sensor characterization efforts gearing up **(eRD113),**
  - INFN groups leading tests of DPTS circuits,
  - INFN and Berkeley groups participated in test beams,
  - Test setups received and being commissioned (and produced) – currently LBNL, ORNL, UK groups,
  - Characterization of the MLR1 RAL IP blocks – UK groups,

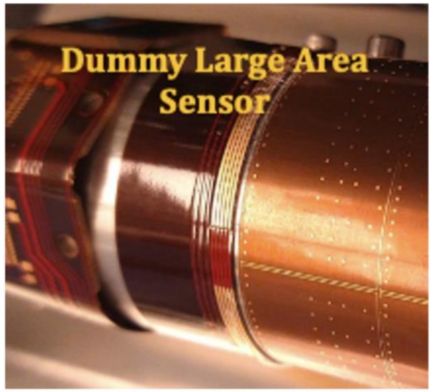
- Power and Readout are integral to service reduction **(eRD104)**,
  - Powering – as the outcome of a survey, serial powering and DC-DC conversion with integrated regulator is currently being considered as the most promising candidate for the ePIC MAPS-based tracking and vertexing subsystem – pursued by UK groups,
  - Readout – ongoing exercises to estimate and refine hit loads; candidates for radiation tolerant FPGA and optical interconnect, and electrical / optical interface being identified – pursued by ORNL,

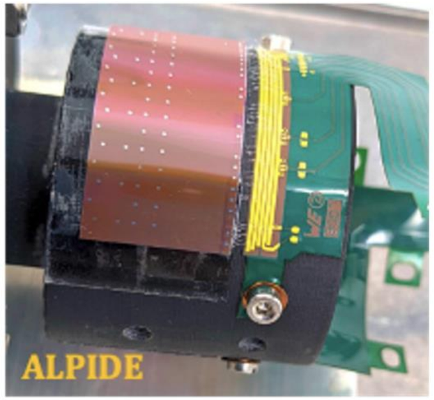


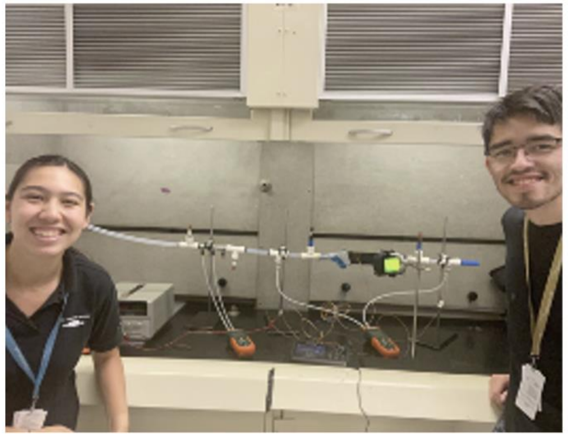
- CAD modeling continues from the effort for the initial detector proposals at JLab and LANL,

EIC Silicon Consortium – R&D effort

- Mechanical studies on single-reticle and large-size MAPS are ongoing at INFN,
  - Bending, thinning, and interconnection,
  - Characterization in flat and curved geometries,
  - Bending and wire-bonding have been successfully exercised at EIC vertex-layer radii,
- Studies of cooling option for staves and disks – for example, air cooling internal to the mechanical structures – are ongoing at LBNL,
- Starting assessments of materials to construct disks and supports at LANL, LBNL.







MPGD - Barrel Cylindrical Micromegas

Motivation

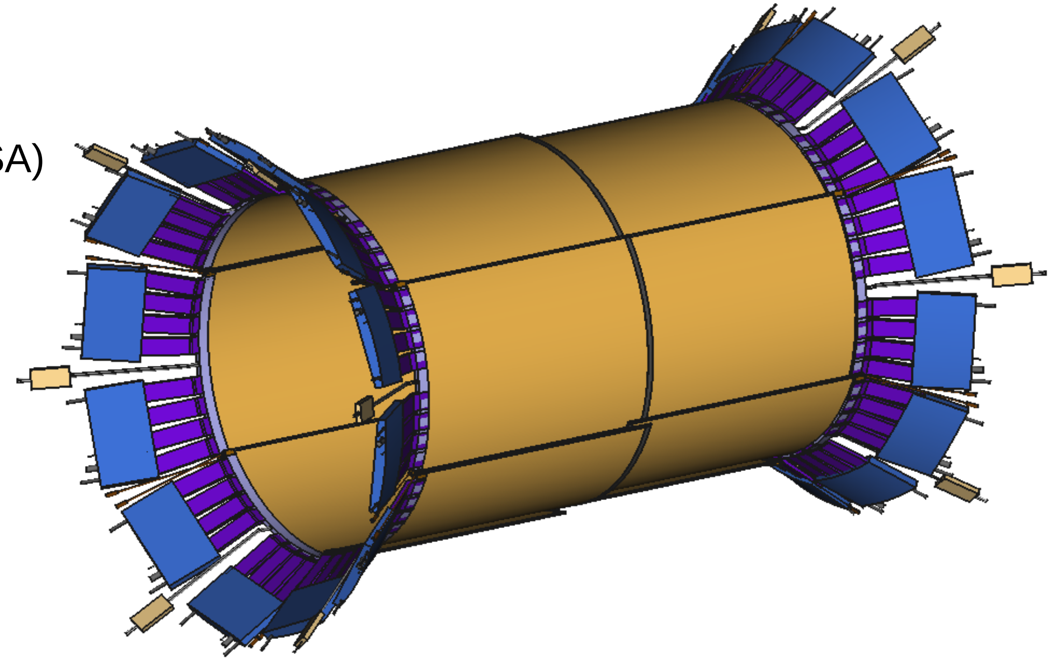
- ❖ Build a full acceptance light-weight modular MPGD barrel tracker to complement the silicon vertex detector
- ❖ Due to space limitations and material budget limits: cylindrical tiles
- ❖ Light cylindrical Micromegas technology is already in use (CLAS12 and ASACUSA)
- ❖ Cylindrical µRWELL is viewed as back up technology for Micromegas

Objectives

- ❖ Resolutions of ~150µm
- ❖ Fewest possible number of channels to limit the material budget
- ❖ Keep the material budget at ~0.5% X0 per layer

R&D ongoing within eRD108

- ❖ 2D readout, with large strips (~1mm)
  - 2022–2023: optimization and choice of the 2D pattern on small prototypes
- ❖ Optimize the production by limiting the number of types of modules:
  - 2023-2024: production of full scale tile (50x70cm^2) and a mockup of longer size



CAD design of one layer of overlapping cylindrical tiles with FEE and services

R ~ 50cm, L ~ 140cm

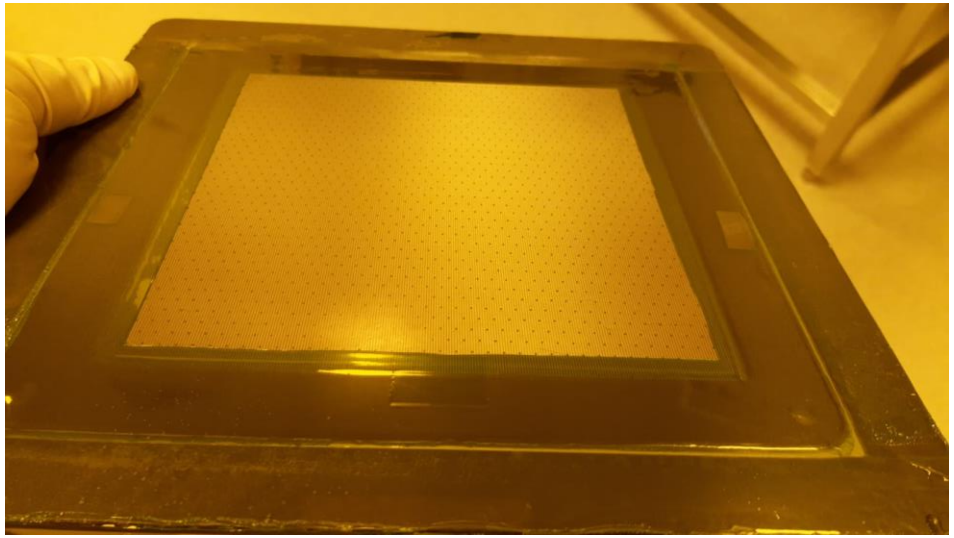
MPGD - R&D effort (eRD108)

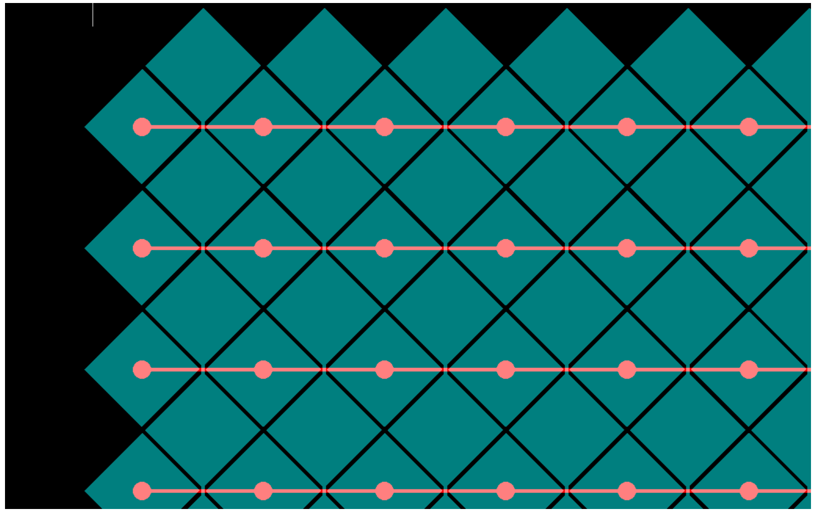
2022 – 2023: 2D readout optimization on small prototypes

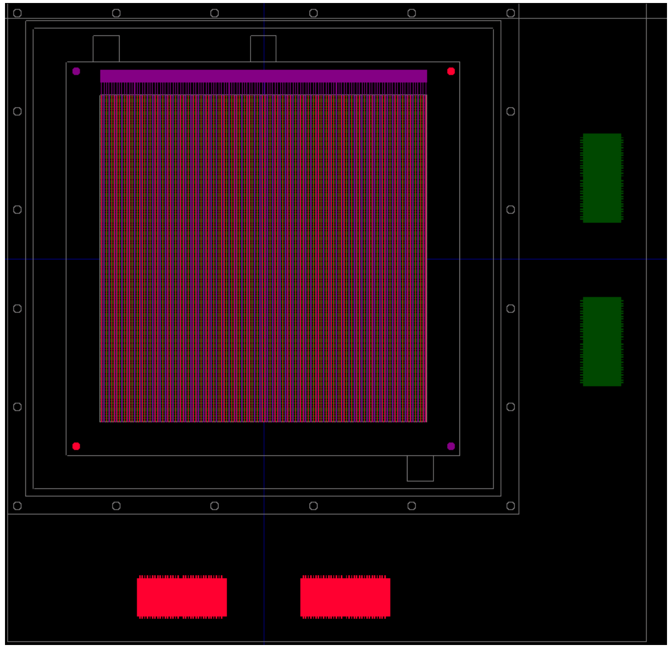
❖ **Amplification Kapton (AK):** a Kapton foil with resistive paste stretched on a carbon fiber frame and then bulk with a micromesh
- AKs with different resistivity will be glued together with Kapton foils with 2D readout patterns

❖ **Readout pattern design:**
- Several design 2D patterns:
  - Orthogonal strips
  - ASACUSA like readout

❖ **Tests:**
- **Beam test in June 23**





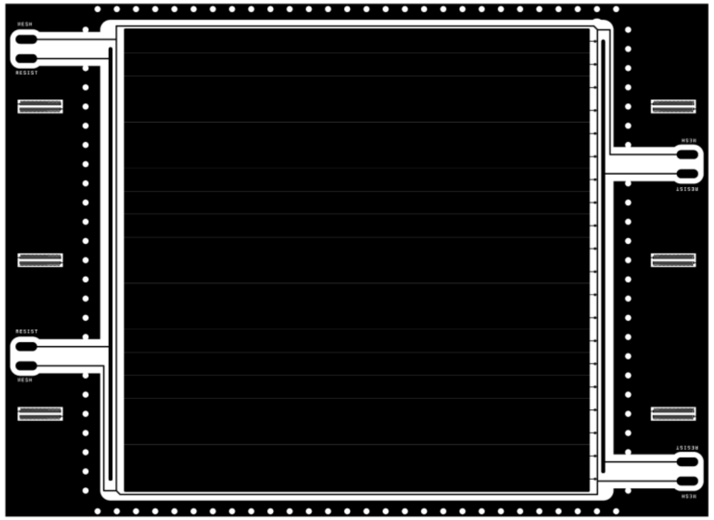


MPGD - R&D effort (eRD108)

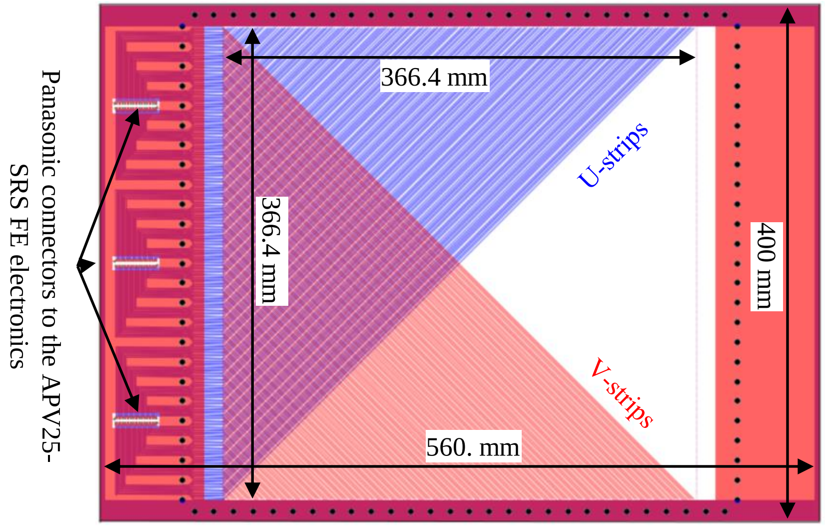
Development of cylindrical µRWELL prototype: (BNL, Florida Tech, JLab, Temple U.)

- Prototype consists of 2 half-cylinder chambers with different readout structures
  - **CapaSh-uRWELL:** uRWELL/readout foil with U-V capacitive-sharing readout
  - **Zigzag-uRWELL:** uRWELL/readout foil with U-V :zigzag" readout structure
- Design of all parts (2 uRWELL/RO foils) and mechanical structure are completed,
- Fabrication at CERN assemblyt of the prototype at Florida Tech ➔ **April 2023**
- Tests in hadron beam at FNAL ➔ **June 2023**
- Data analysis, report / presentation at DAC committee meeting and preparation for publication in peer-review journal ➔ **June – December 2023**

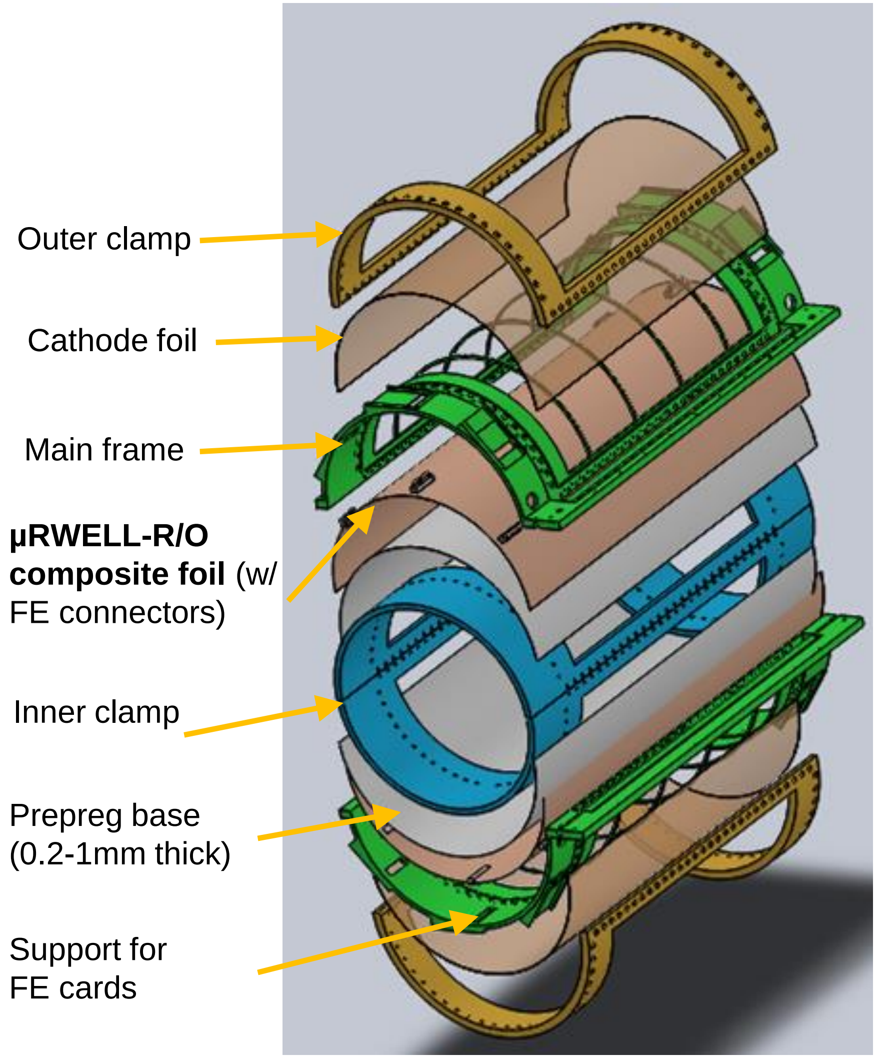
uRWELL foil design completed



U-V strip readout design completed

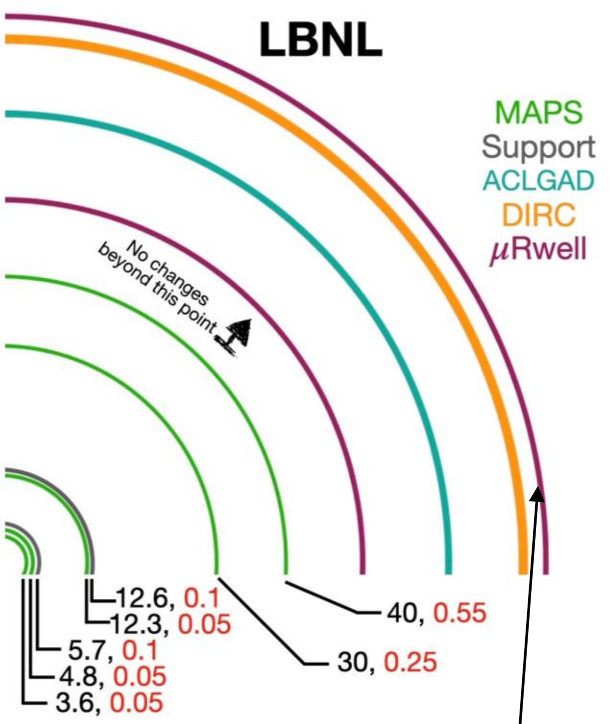


CAD drawing / mechanical design completed



https://wiki.bnl.gov/eic/upload/ERD108_Proposal_FY23.pdf

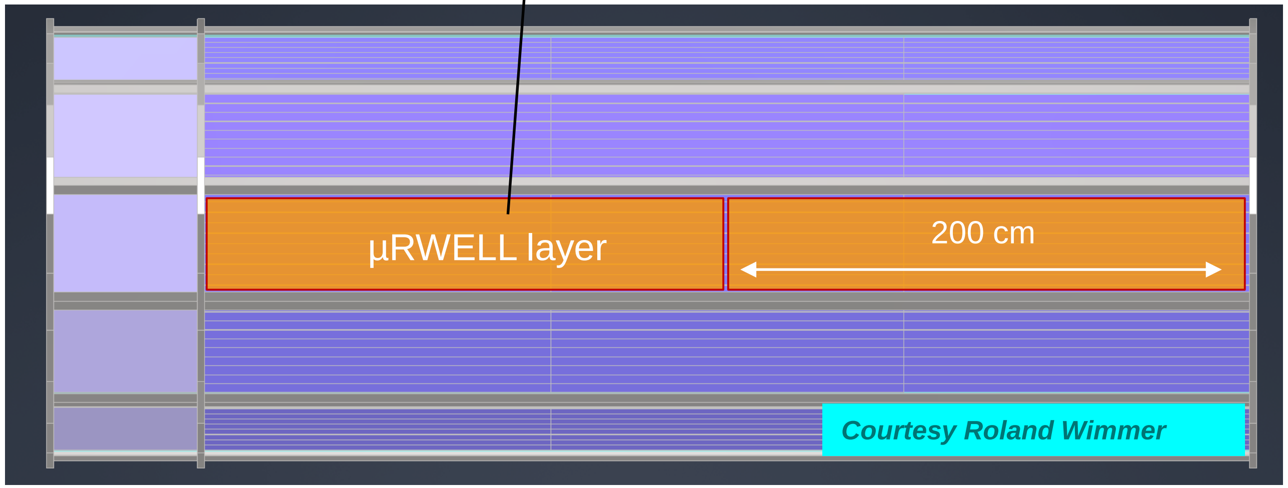
MPGD - Planar μRWELL layers



Requirements & expectations from YR & various detector proposals:

- Low mass (< 1% X0) not justified here ➔ **1% to 2% X0** in front of EM Cal. is not an issue
- But space limitation for layer behind hpDIRC ➔ 2 cm thick box space for MPGD layer
- Spatial resolution (50 - 100 μm) in both phi and z

μRWELL layer behind hpDIRC



EIC Detector Generic R&D - EICGENRandD_2022_23

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]

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[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

July 25, 2022

Abstract

The EIC physics program requires precision tracking and PID over a large kinematic acceptance, as highlighted in the Yellow Report [1]. MPGDs are able to provide space point measurements to aid in both tracking and PID. These MPGD detectors will span a large pseudorapidity range (e.g. angular acceptance) and will see tracks entering over a large angular range, in addition to tracks bending due to the EIC's magnetic field. The position measured by an MPGD structure for a track impinging at a large angle is no longer determined by the detector structure (e.g. readout structure) but the gap in the ionization gas volume that the particle traverses before reaching the amplification stage, leading to a deterioration in the spatial resolution that grows with the angle. To minimize the impact of the track angle on the resolution, several prototype thin gap MPGDs (tg-MPGDs), where the ionization gas volume is significantly reduced with respect to typical MPGD detectors, will be built and tested in beam. In addition various gas mixtures will be studied within simulation to identify optimal mixtures for future use.

https://www.jlab.org/research/eic_rd_prgm/receivedproposals

Remaining tasks / issues

- Implementation of the background in simulation for tracking performance studies
  - MPGD trackers for pattern recognition
    - How many barrel MPGD layers are required, what is the best configuration (radii and size …) for optimal configuration
    - Do we need additional Si disks in the forward and backward regions to increase the number of hits in background environment
- Optimization of the interface between barrel MPGD layer and the Si support structure
  - Do we need barrel MPGD layers to cover an eta range > 1.1? or rather increase the Si disks radii in the end cap
  - Complement with MPGD rings instead
- MPGD layer behind dRICH
  - Simulation studies is needed to evaluate the impact dRICH ring reconstruction and overall tracking performance
- Integration & Services
  - More realistic evaluation of the services (cables, FE cards, HV …) and integration issues only after new geometry optimization phase
- Technology review:
  - Complete review of the choice of tracking technologies.
  - Identify risks & fallback solutions for each technology.
  - Close coordination with the detector consortia (EIC Silicon consortium, MPGD consortium)

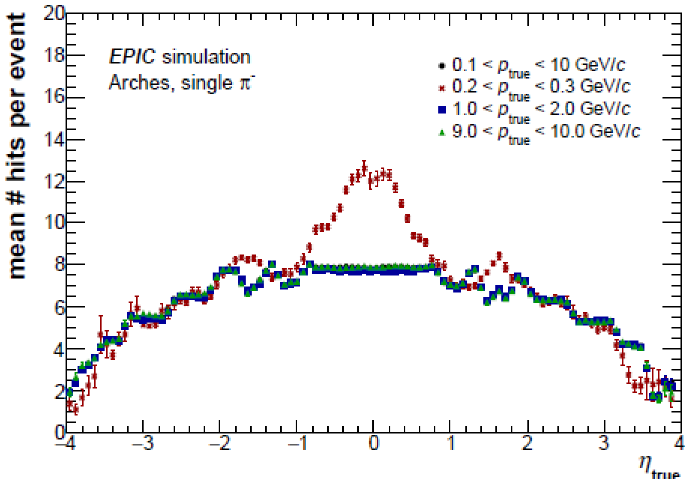
Backup

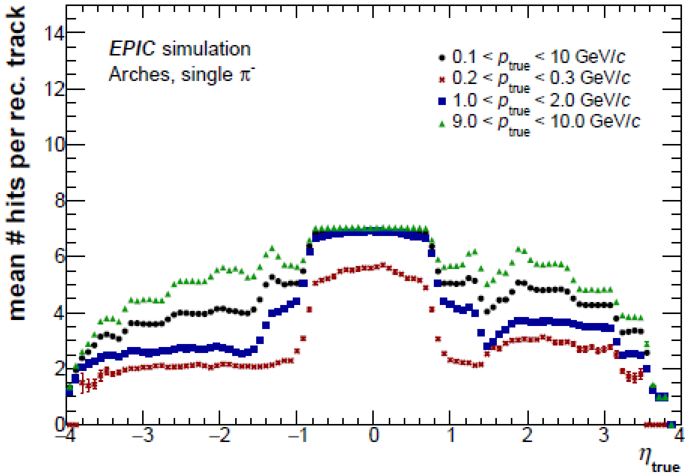
Tracking performance: Average number of hits per track

EPIC detector performance studies with DD4hep and eicrecon: Average number of reconstructued hits per tracks vs. eta and p

Hits per event and per rec. track with ACTS

See talk by Nicolas Schmidt at https://indico.bnl.gov/event/17752/



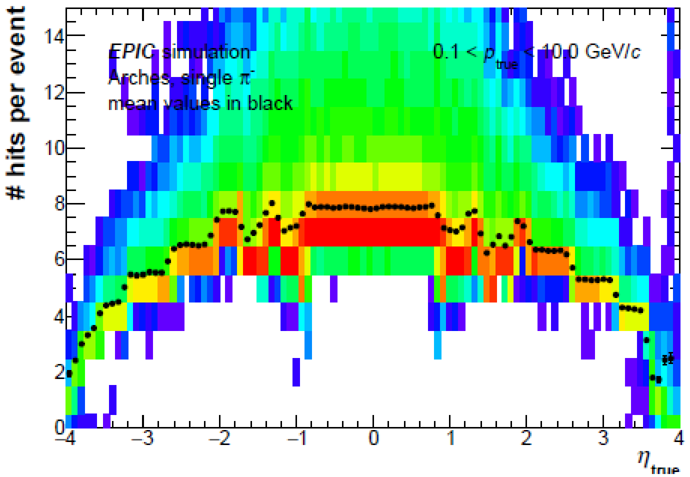


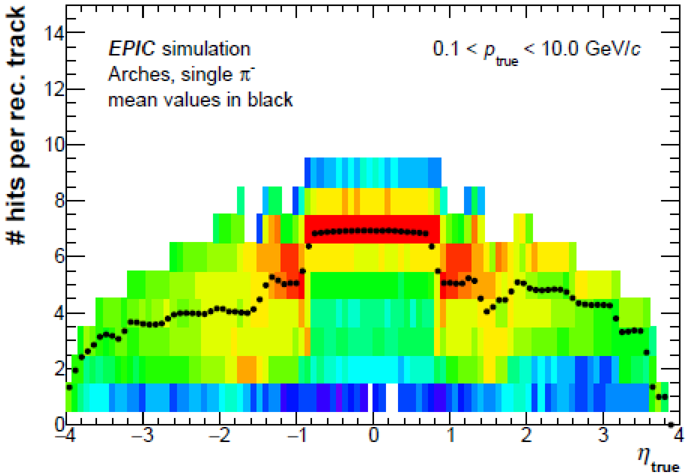
Information shown in plots:

- Hits per event:
  → all hits saved for "SiBarrelHits", "MPGDBarrelHits", "VertexBarrelHits", "TrackerEndcapHits", "TOFEndcapHits", "TOFBarrelHits", "MPGDDIRCHits"
- Hits per track:

```
auto acts_results = event->Get<eicrecon::TrackingResultTrajectory>("CentralCKFTrajectories");
for (const auto& traj : acts_results) {
    const auto &mj = traj->multiTrajectory();
    const auto &trackTips = traj->tips();

    const auto &trackTip = trackTips.front();
    auto trajState = Acts::MultiTrajectoryHelpers::trajectoryState(mj, trackTip);
    if (traj->hasTrackParameters(trackTip)) {
        int  m_nMeasurements = trajState.nMeasurements;
    }
}
```





MPGD – Generic R&D: Thin Gap MPGDs

Proposal - EICGENRandD_2022_23

Development of Thin Gap MPGDs for EIC Trackers

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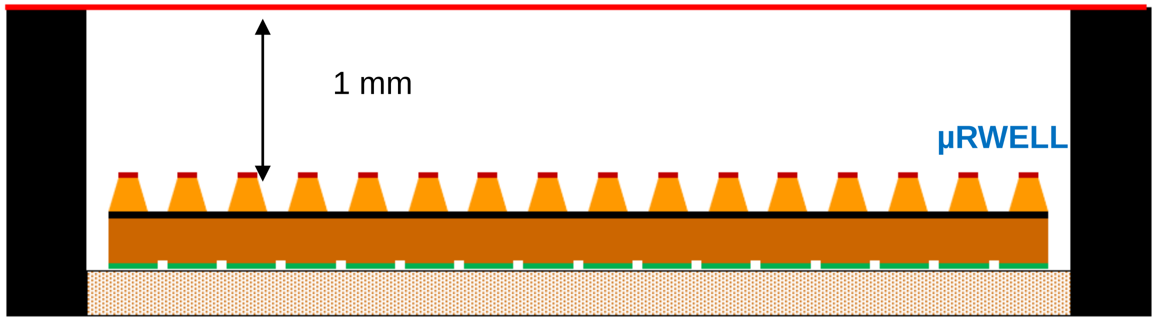
Abstract

The EIC physics program requires precision tracking and PID over a large kinematic acceptance, as highlighted in the Yellow Report [1]. MPGDs are able to provide space point measurements to aid in both tracking and PID. These MPGD detectors will span a large pseudorapidity range (e.g. angular acceptance) and will see tracks entering over a large angular range, in addition to tracks bending due to the EIC's magnetic field. The position measured by an MPGD structure for a track impinging at a large angle is no longer determined by the detector structure (e.g. readout structure) but the gap in the ionization gas volume that the particle traverses before reaching the amplification stage, leading to a deterioration in the spatial resolution that grows with the angle. To minimize the impact of the track angle on the resolution, several prototype thin gap MPGDs (tg-MPGDs), where the ionization gas volume is significantly reduced with respect to typical MPGD detectors, will be built and tested in beam. In addition various gas mixtures will be studied within simulation to identify optimal mixtures for future use.

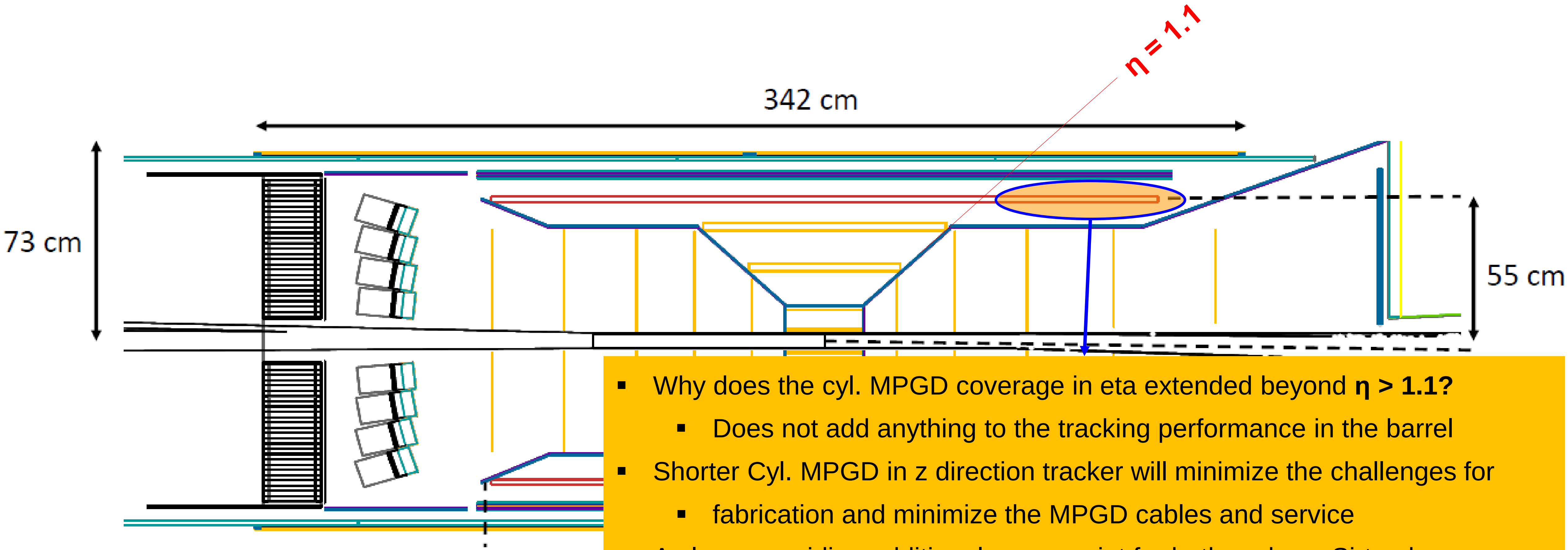
https://www.jlab.org/research/eic_rd_prgm/receivedproposals

Motvation for thin gap MPGDs

- **Limitation with standard gap MPGDs (~ 3mm):**
  - deterioration of spatial resolution with track angle .
  - Degradation spatial resolution due to E x B effect inside magnetic field.
- **Thin Gap MPGDs** will address the above issues ➔ Reduce drift gap (< 1mm)
  - Improve spatial resolution over a large angle range
  - Minimize E × B effect on resolution dependence
  - Improve timing resolution by a factor > 2
- **Challenges:**
  - affect detector efficiency ➔ use heavier gas
  - Mechanical stability for large area detector
- **EICGENRandD_2022_23 Proposal:**
  - Multi institution protosal
  - Prototypes with all 3 MPGDs technologies (MM, GEM, µRWELL)
  - Explore single and double amplification stages to recover efficiency
  - **Will directly benefit ePIC MPGD tracking layers.**

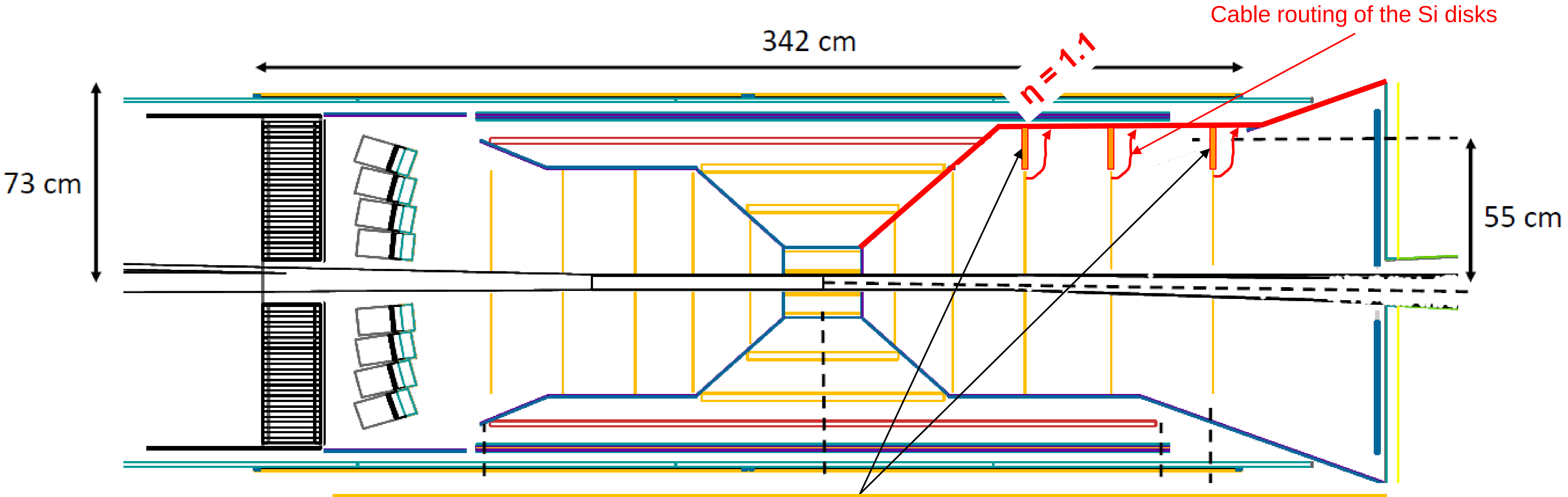


EPIC reference detector: Question 2



- Why does the cyl. MPGD coverage in eta extended beyond **η > 1.1?**
  - Does not add anything to the tracking performance in the barrel
- Shorter Cyl. MPGD in z direction tracker will minimize the challenges for
  - fabrication and minimize the MPGD cables and service
- As layer providing additional space point for both end cap Si-trackers
  - Poor space point resolution ➔ because of large track angles (> 45^{o})
  - Material of the Si support cone structure in front of the layer …
- **Similar argument can be held for the AC-LGAD disk**
  - **But this is a discussion for another day**

EPIC reference detector: Possible option to question 2



- Complement the Si disks with thin gap MPGD rings (or extending Si disks radius)
- Optimizing the Si-layer cable and services "cone" support ➔ (red lines)
- Could the cables of the Si-disks be routed vertically up to the cone structure?
  - This will be optimal for performances