# ePIC Tracking System Overview and Performance

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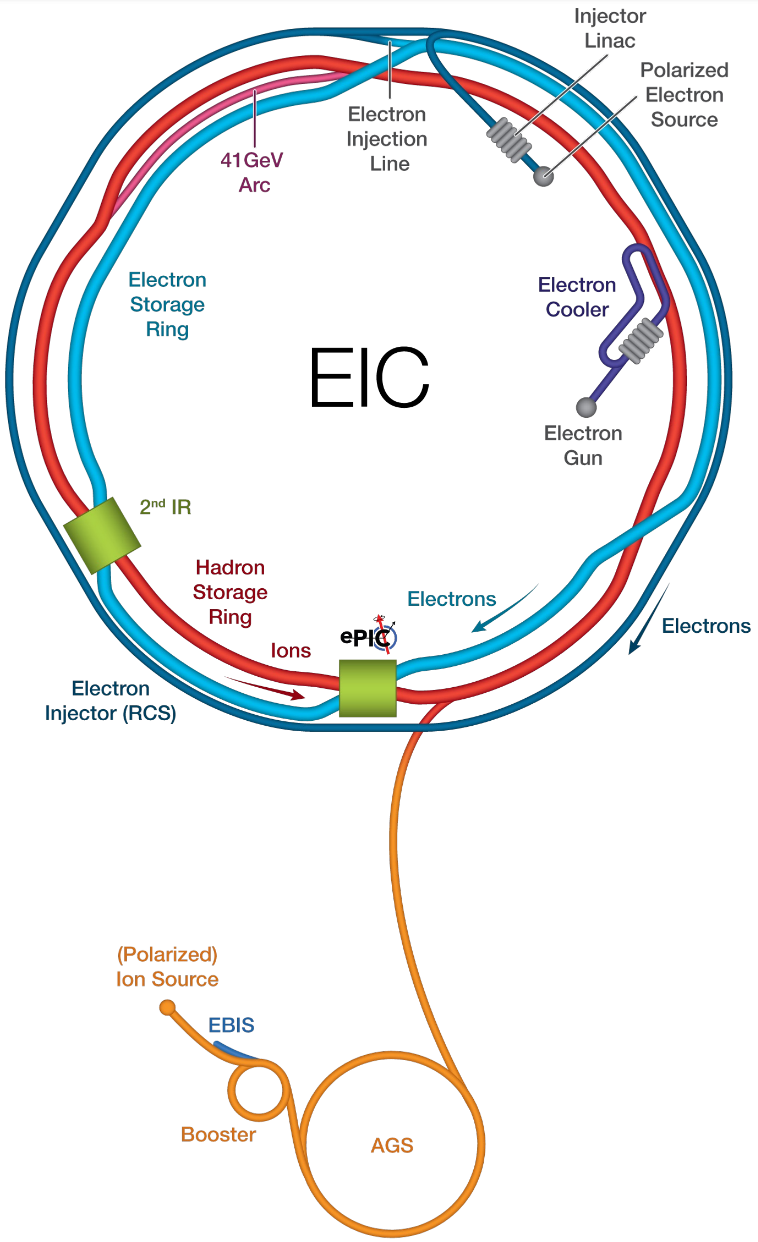
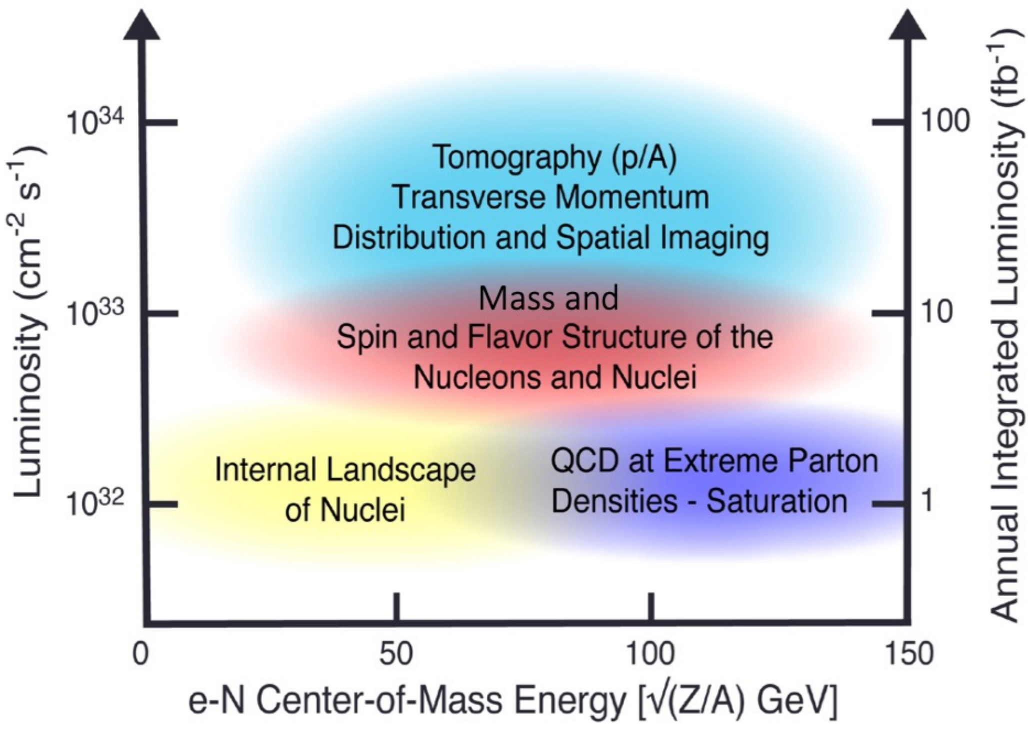
# Electron-Ion Collider




| | |
|---|---|
| Center of Mass Energies | 30GeV – 140GeV |
| Luminosity: | $10^{33}$-$10^{34}$cm$^{-2}$s$^{-1}$ / 10-1000fb$^{-1}$/year |
| Highly Polarized Beams | 70% |
| Large Ion Species Range | P to U |
| Number of Interaction Regions | Up to 2 |



# Electron-Ion Collider Detector Requirements

Internal Landscape of Nuclei

QCD at Extreme Parton Densities Saturation

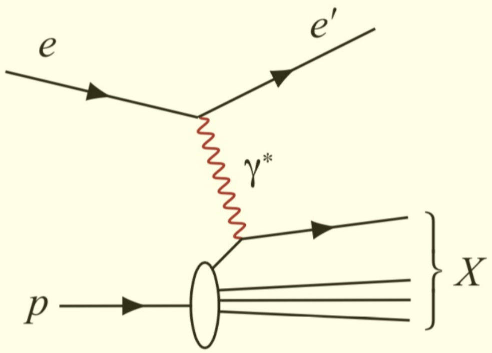
Mass, Spin, Flavor Structure of the Nucleons and Nuclei

Tomography Transverse Momentum Distribution Spatial Imaging

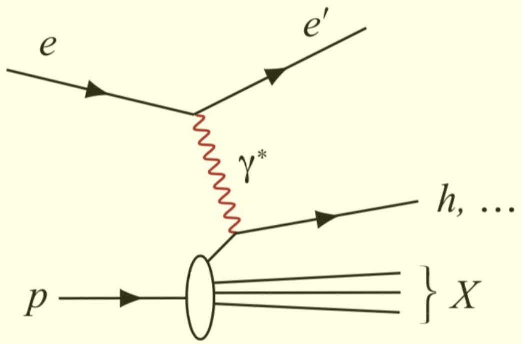
QCD at Extreme Parton Densities Saturation

Tomography Transverse Momentum Distribution Spatial Imaging

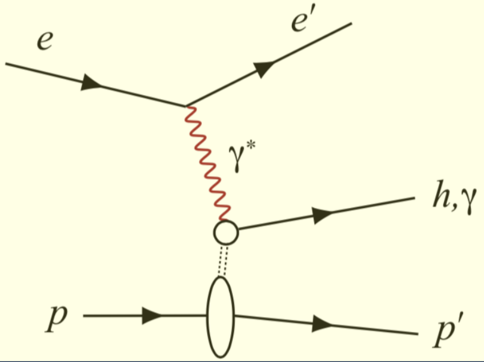
## Inclusive DIS




## Semi-inclusive DIS




## Exclusive DIS




- ❑ High performance electron identification and reconstruction

- ❑ Tracking and hadronic calorimetry
- ❑ Heavy flavor identification via vertexing
- ❑ Light flavor identification from PID detectors

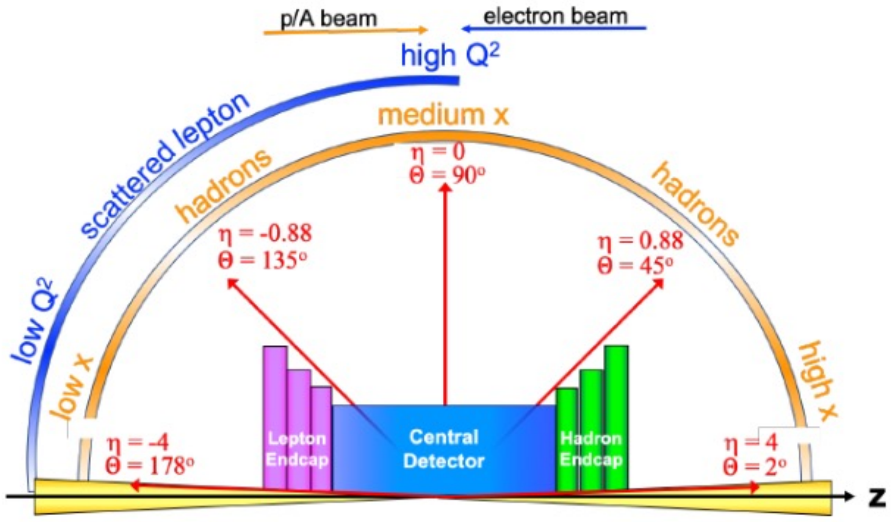
- ❑ Efficient proton tagging
- ❑ Cover full acceptance

# Electron-Ion Collider Tracking Requirements

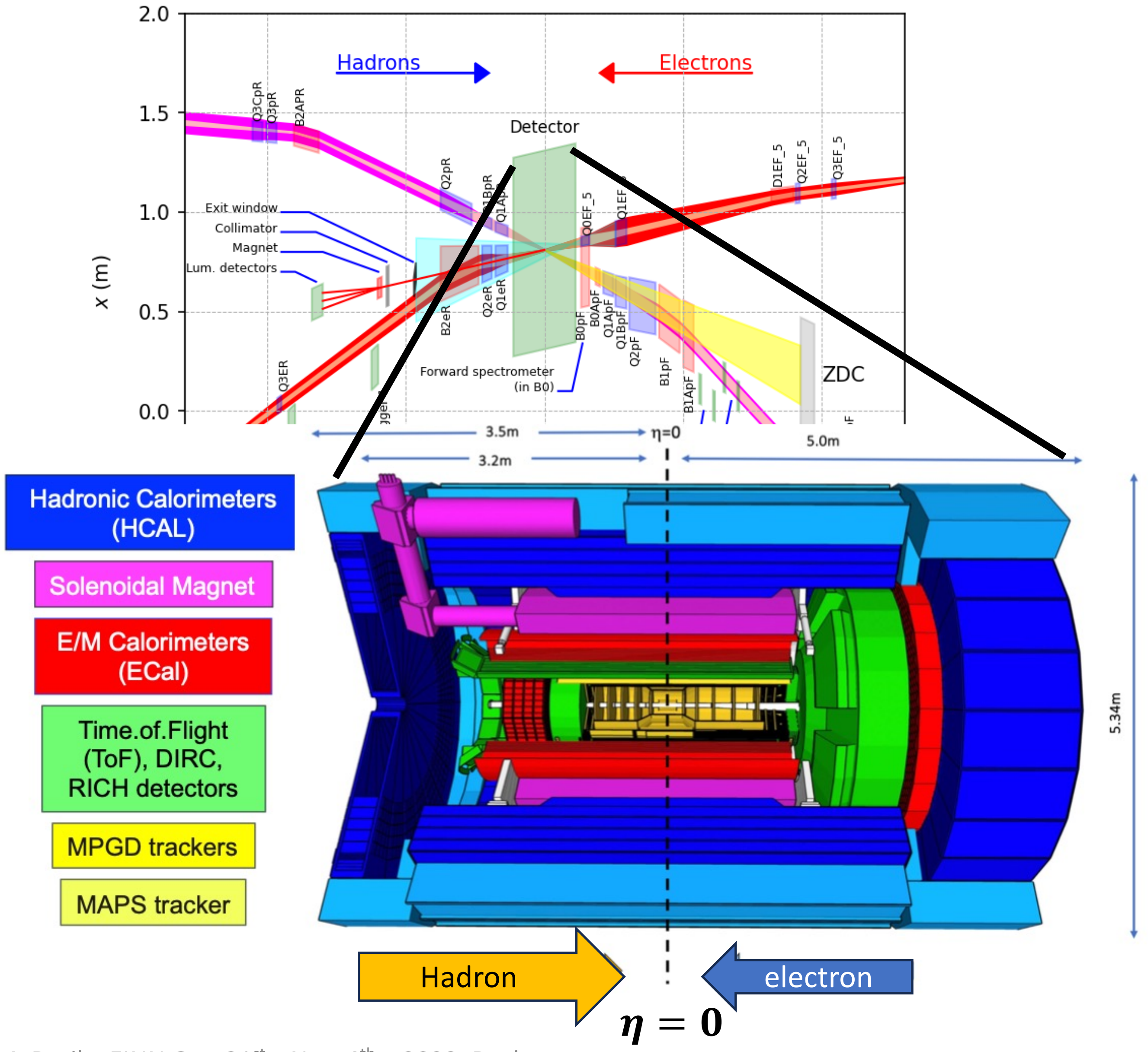
- High point resolution and low material budget are critical to meeting physics requirements.
- Most challenging requirements
  - High granularity
  - Minimal material from mechanics, cooling, power, and data distribution

| Tracking requirements from PWGs | | | | | | |
|---|---|---|---|---|---|---|
| | | | Momentum res. | Material budget | Minimum pT | Transverse pointing res. |
| η | | | | | | |
| -3.5 to -3.0 | Central Detector | Backward Detector | σp/p ~ 0.1%×p ⊕ 0.5% | ~5% X0 or less (~MAPS + MPGD trackers) | 100-150 MeV/c | |
| -3.0 to -2.5 | | | | | 100-150 MeV/c | dca(xy) ~ 30/pT µm ⊕ 40 µm |
| -2.5 to -2.0 | | | σp/p ~ 0.05%×p ⊕ 0.5% | | 100-150 MeV/c | dca(xy) ~ 30/pT µm ⊕ 20 µm |
| -2.0 to -1.5 | | | | | 100-150 MeV/c | |
| -1.5 to -1.0 | | | | | 100-150 MeV/c | |
| -1.0 to -0.5 | | Barrel | σp/p ~ 0.05%×p ⊕ 0.5% | | 100-150 MeV/c | dca(xy) ~ 20/pT µm ⊕ 5 µm |
| -0.5 to 0 | | | | | | |
| 0 to 0.5 | | | | | | |
| 0.5 to 1.0 | | | | | | |
| 1.0 to 1.5 | | Forward Detector | σp/p ~ 0.05%×p ⊕ 1% | | 100-150 MeV/c | dca(xy) ~ 30/pT µm ⊕ 20 µm |
| 1.5 to 2.0 | | | | | 100-150 MeV/c | |
| 2.0 to 2.5 | | | | | 100-150 MeV/c | |
| 2.5 to 3.0 | | | σp/p ~ 0.1%×p ⊕ 2% | | 100-150 MeV/c | dca(xy) ~ 30/pT µm ⊕ 40 µm |
| 3.0 to 3.5 | | | | | 100-150 MeV/c | dca(xy) ~ 30/pT µm ⊕ 60 µm |

YR, Table 11.2



# The ePIC Detector




- ❑ Far Forward detector to measure very forward neutral and charged particles
- ❑ Far Backward detector to measure luminosity and low-$Q^2$ events
- ❑ **Central detector**
  - Integrates tracking, vertexing, PID, EM and hadronic calorimetry
  - Asymmetric beam energies
- ❑ 1.7 T solenoidal magnetic field (~2.8 m bore)
- ❑ Streaming readout

# Operational Environment: Backgrounds

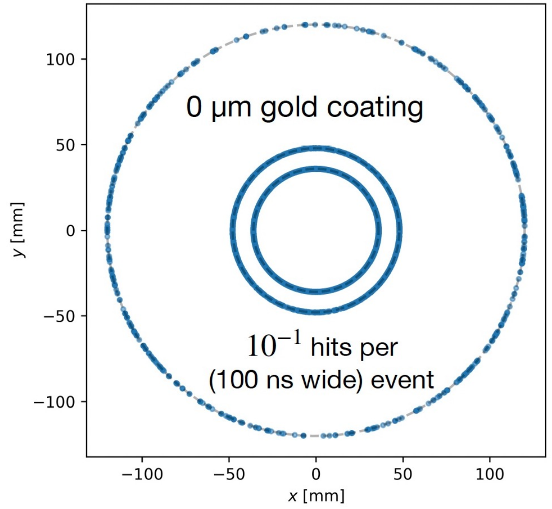
- EIC bunch crossing frequency 98.5 MHz
  - Interaction frequency much lower
- Rates for DIS ep events up to ~500 kHz, $L = 10\times10^{33} cm^{-2}s^{-1}$
- Main background sources, up to O(MHz) rate
  - Hadron and electron beam gas

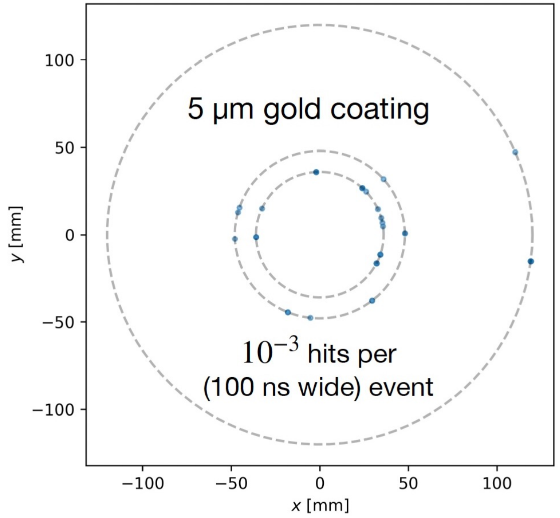
[ePIC Background Wiki page](#)

| Rates | 10 GeV x 275 GeV | Vacuum | Region |
|---|---|---|---|
| DIS ep | 500 kHz | -- | -- |
| Hadron Beam Gas | 32.6 kHz | 1000 Ahr | -5.5 m < IP < 5 m |
| Electron Beam Gas | 3.18 MHz | 1000 Ahr | -5 m < IP < 15 m |

  - Synchrotron radiation – reduced by about 2 orders of magnitude with 5 $\mu m$ gold coating of the beam pipe

SR hits in innermost silicon tracker layers

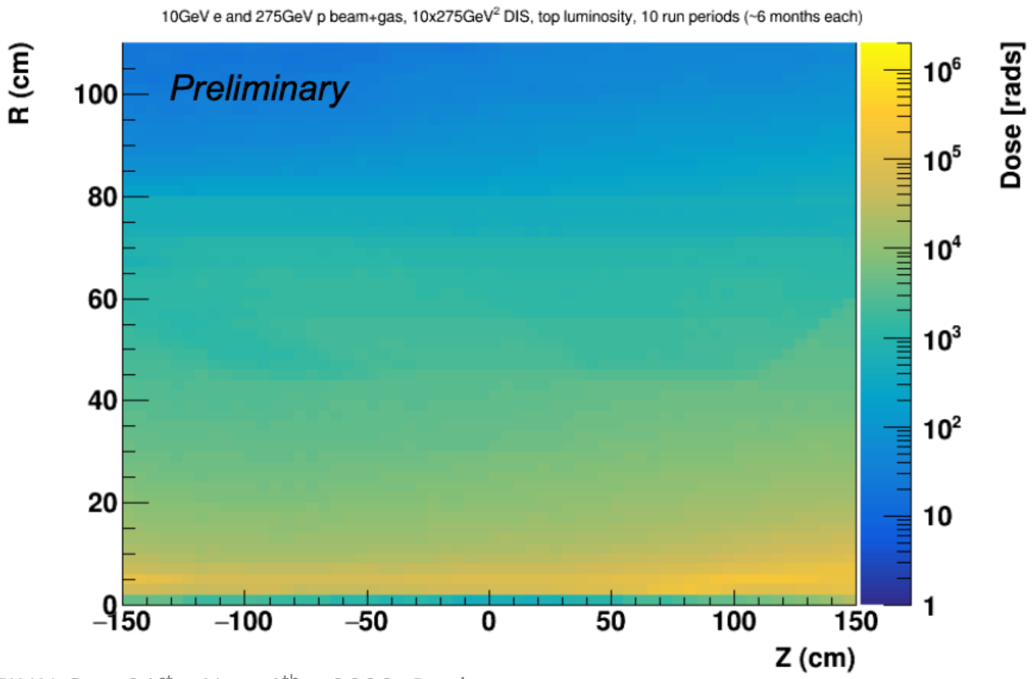


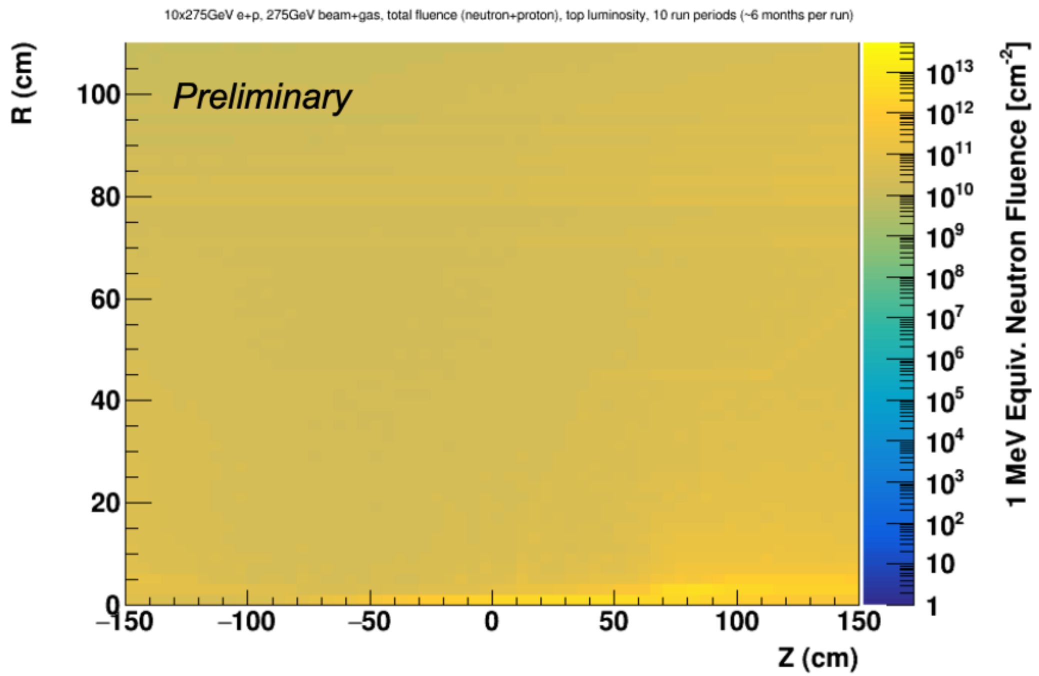



# Operational Environment: Radiation

- Low-moderate radiation levels
  - Much lower than those seen at LHC
- Example study: 10x275 GeV DIS ep events + beam gas backgrounds
  - Upper bound estimate: top luminosity, 10 six month run periods at 100% run time
    - Total ionizing dose < 1 Mrad
    - Fluence below $5\times10^{13}\ n_{eq}/cm^2$

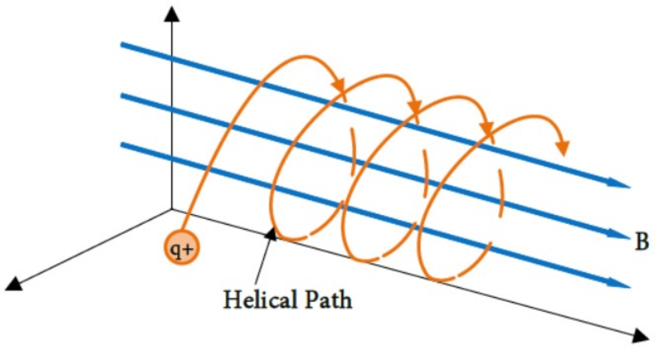
Maps of fluence and dose
over the silicon tracker envelop



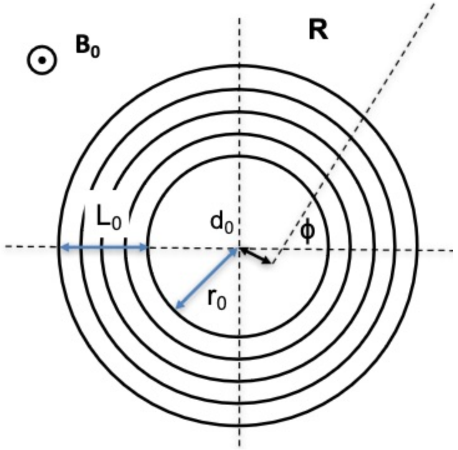



# Momentum Resolution

- Charged particle in a magnetic field:



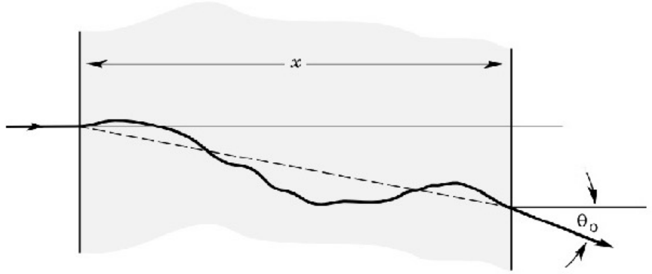

$$p_T[\mathrm{GeV}] = 0.3 \cdot \mathrm{B[T]} \cdot \mathrm{r[m]}$$




N equal and equidistant layers

arXiv:1805.12014

- Two contributions to determining momentum resolution
  - Spatial resolution (res)
  - Multiple scattering (ms) through materials




Multiple scattering through a material

$$\left(\frac{\sigma_{pT}}{p_T}\right)_{res} = \frac{\sigma_{r\phi} p_T}{0.3\, B_0 L_0^2} \sqrt{\frac{720 N^3}{(N-1)(N+1)(N+2)(N+3)}}$$

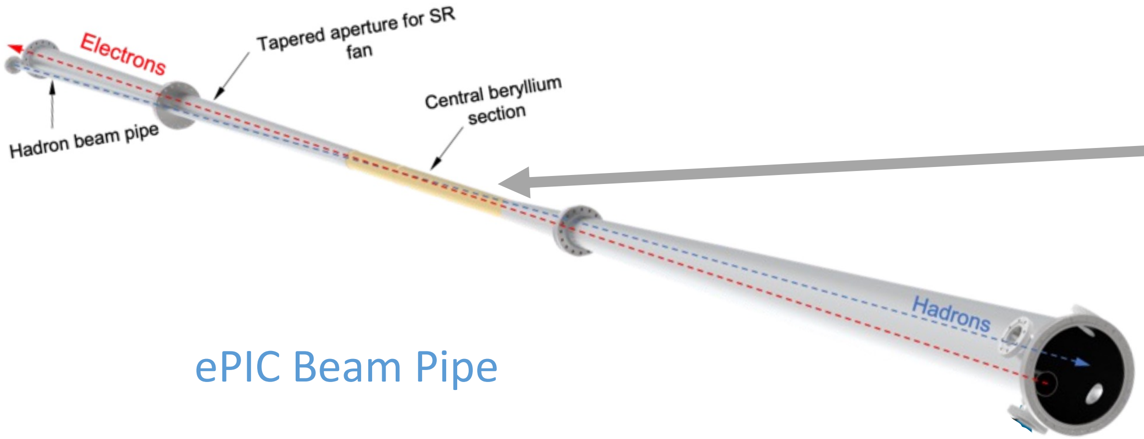
$$\left(\frac{\sigma_{pT}}{p_T}\right)_{ms} = \frac{N}{\sqrt{(N+1)(N-1)}} \frac{0.0136\, GeV/c}{0.3 \beta B_0 L_0} \sqrt{\frac{d_{tot}}{X_0 sin\theta}} \left(1 + 0.038 \ln \frac{d}{X_0 sin\theta}\right)$$

$$\frac{\sigma_{pT}}{p_T} = \sqrt{\left(\frac{\sigma_{pT}}{p_T}\right)_{res}^2 + \left(\frac{\sigma_{pT}}{p_T}\right)_{ms}^2}$$

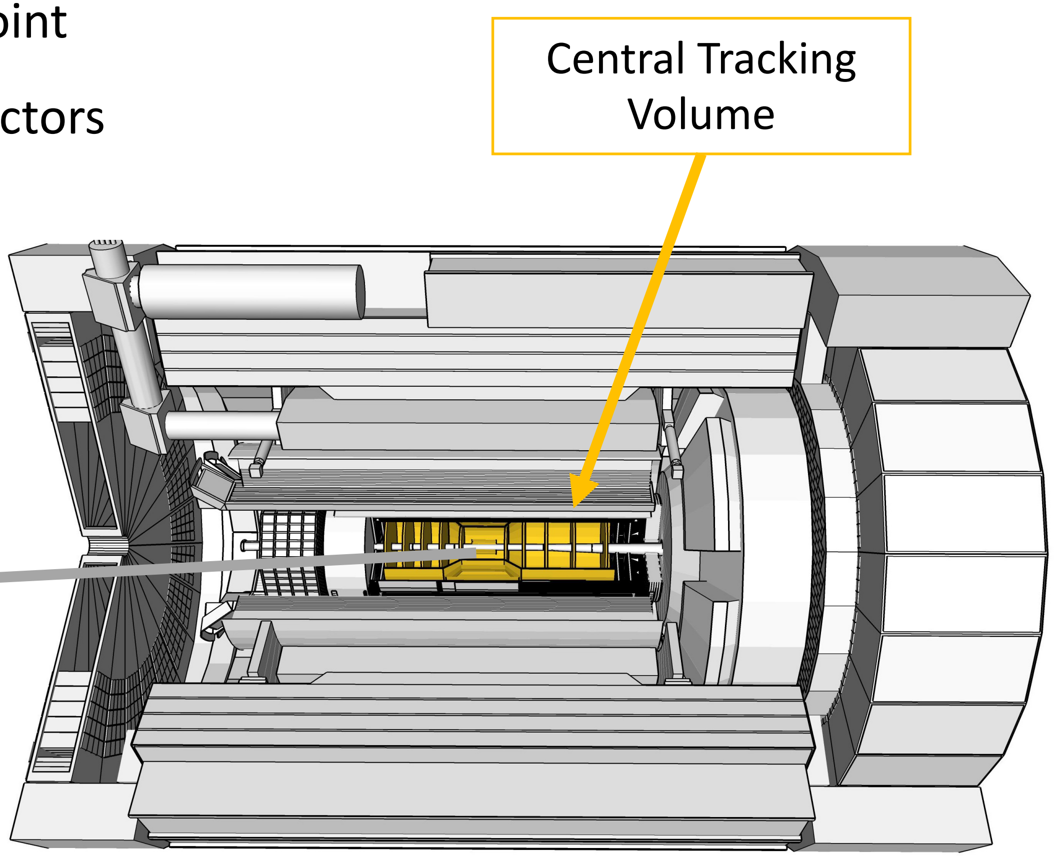
arXiv:1805.12014

Detector Integration and Constraints

- Large beam pipe diameter, 31.8 mm radius
    - More challenging required vertexing precision
- Beam pipe diameter increases away from the interaction point
- Tracking volume constrained by magnet and other sub detectors
    - Tracking volume radius: $R \lesssim 70\ cm$
    - Tracking volume length: $-124\ cm \lesssim z \lesssim 180\ cm$

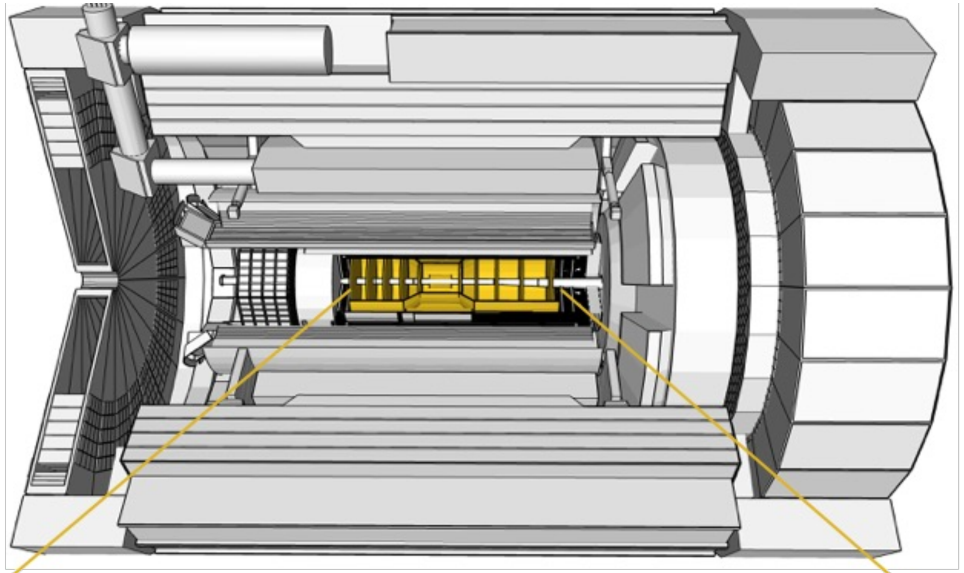


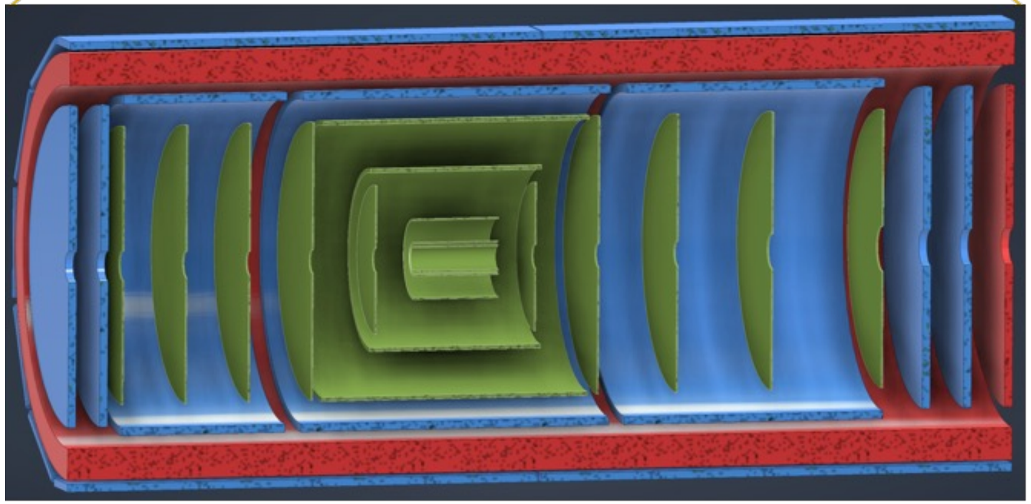

ePIC Beam Pipe

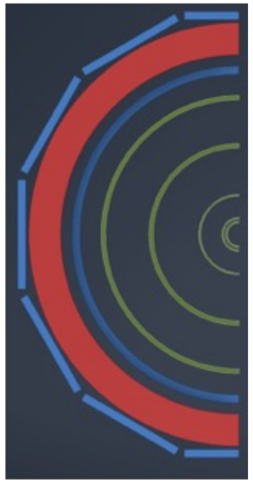



ePIC Central Detector

# ePIC Central Tracking Layout Overview







■ MAPS Barrel + Disks ■ MPGD Barrels + Disks ■ AC-LGAD based ToF

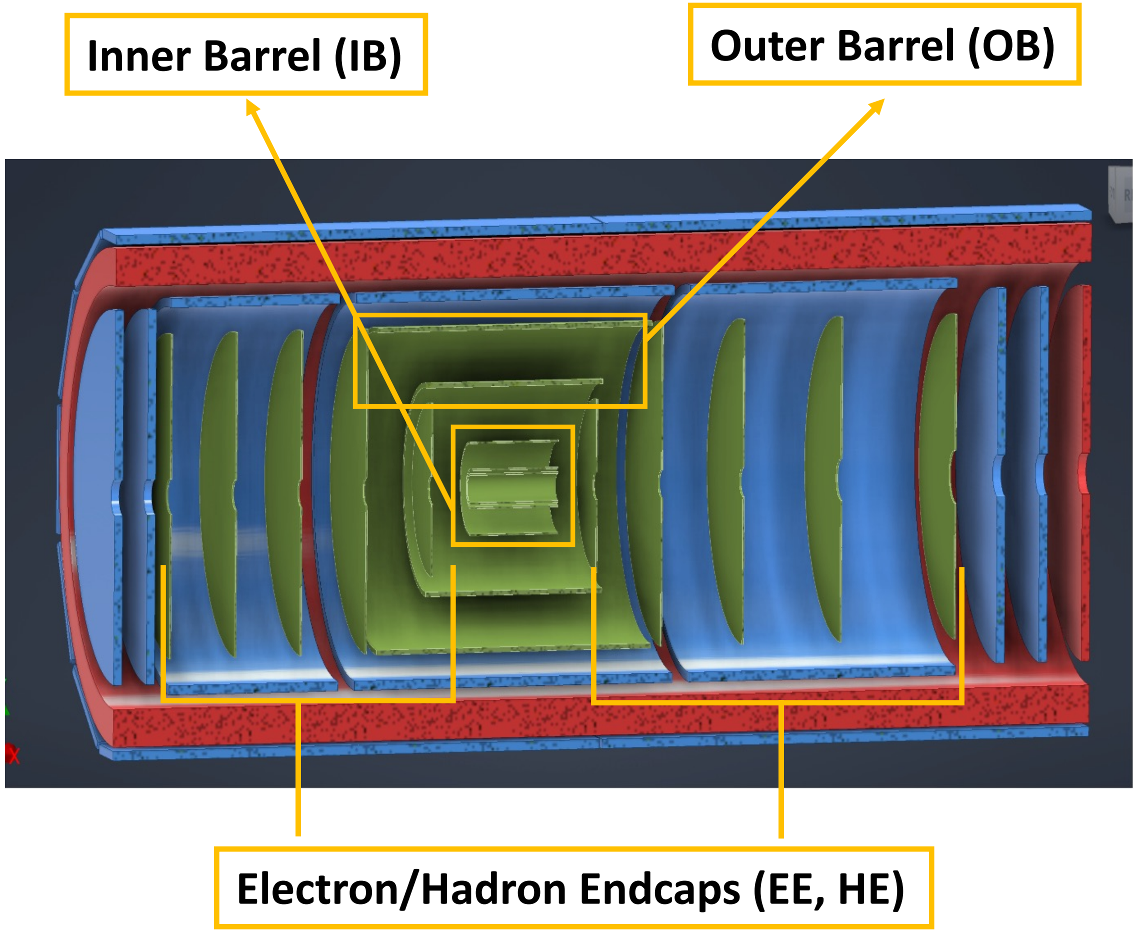
- ePIC tracking system is a hybrid of silicon and gaseous technologies

- **MAPS Layers**
  - Make up inner tracking volume
  - Highly granular and low mass layers to provide excellent momentum resolution and precision pointing resolution

- **MPGD Layers**
  - Large area detectors are instrumented in the outer tracking volume
  - Provide timing and pattern recognition
  - Planar detectors can provide impact point and direction for PID seeding

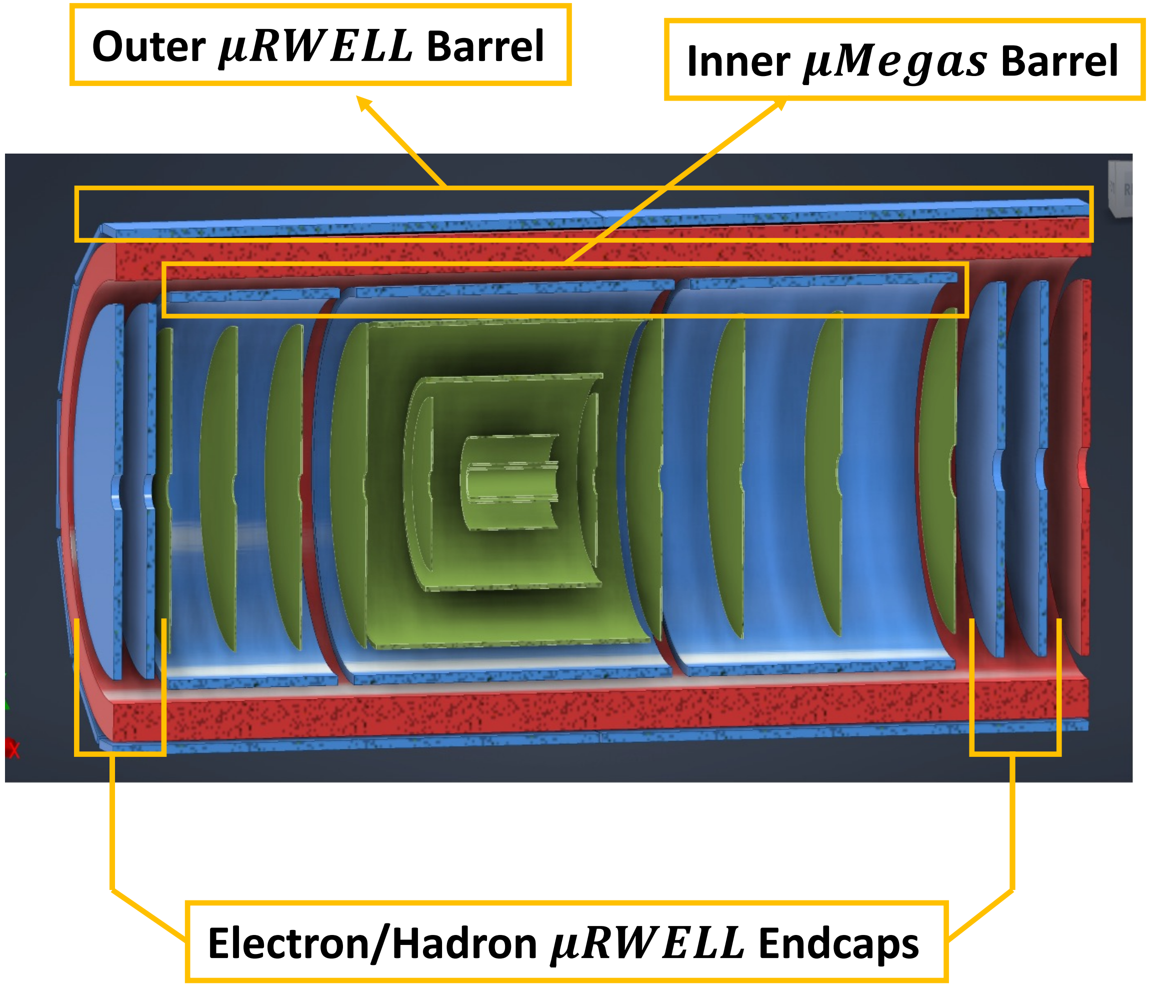
- **AC-LGAD**
  - Fast detector to provide low momentum PID.
  - Can provide an additional space point for pattern recognition/redundancy

# ePIC Silicon Vertex Tracker (SVT)




- SVT based on MAPS 65 nm CMOS imaging technology
  - Total (active) area $\sim 8.5\ m^2$
  - Small pixels ($20\ \mu m$) provide excellent resolution
  - Low power consumption ($< 40\ mW/cm^2$)
  - Low material budget ($0.05\%$ to $0.55\%\ X/X_0$) per layer
  - Frame rate $\approx 2\mu s$

# ePIC MPGD Trackers

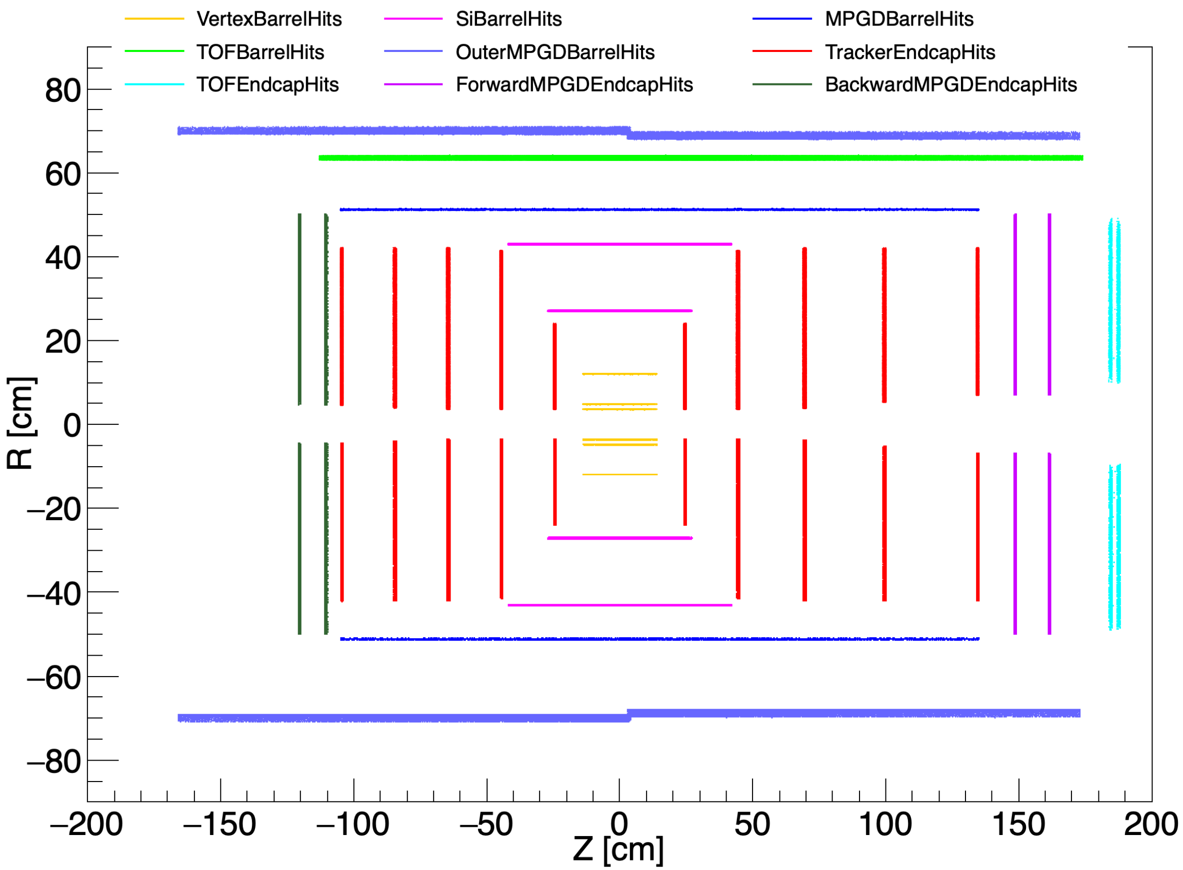



- MPGD detectors based on two technologies:
  - $\mu Megas$ (curved layers) and
  - $\mu RWELL$ (planar layers)
- Total (active) area $\sim 26\, m^2$
- Provide $\sim 10 - 30\, ns$ timing resolution
- Mean spatial resolution $\sim 150^{*}\, \mu m$
- Streaming readout capable SALSA FEE being developed by CEA Saclay IRFU and Sao Paulo Universities for ePIC MPGDs

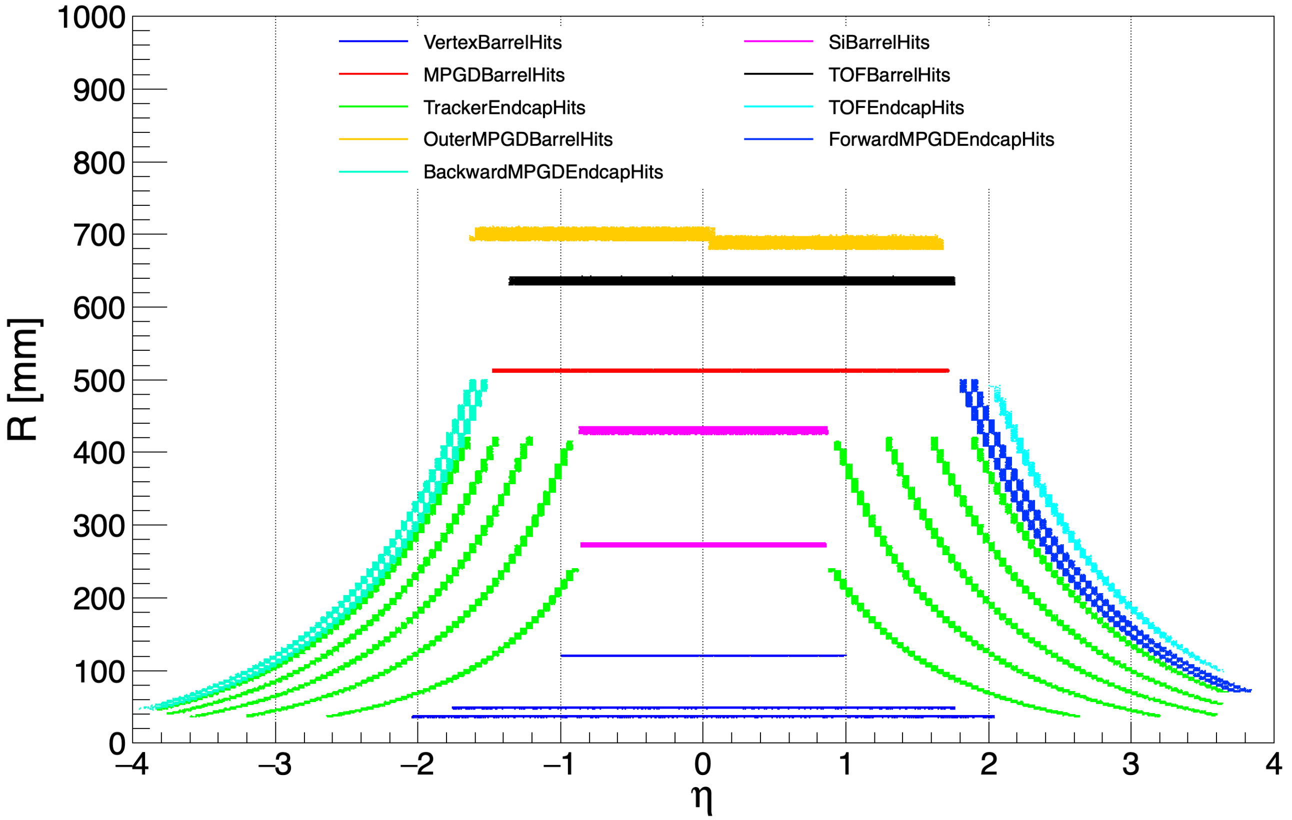
* Depends on track angle relative to readout plane

# ePIC Tracker Layout and Covrage

## Layout

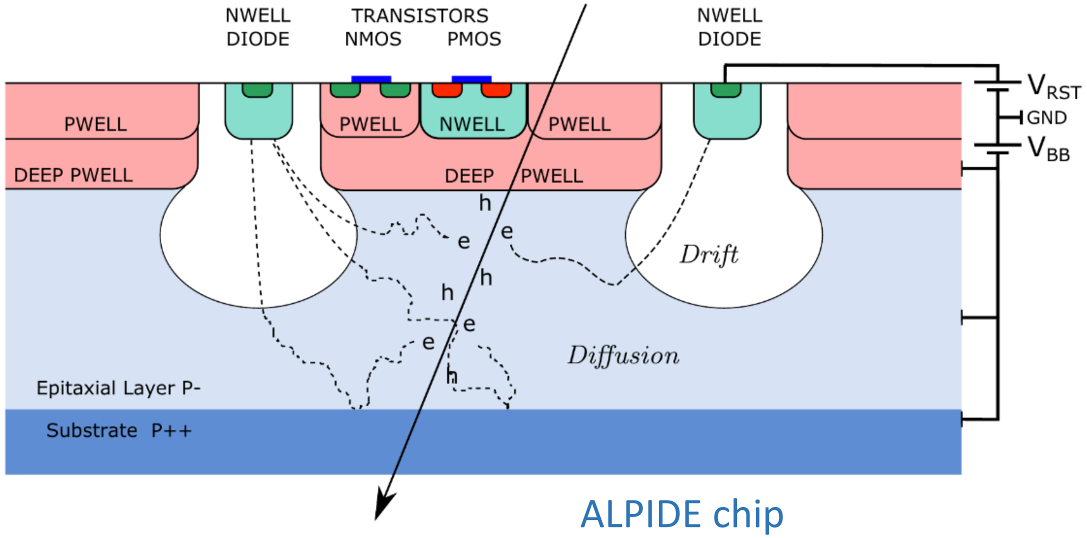



## $\eta$ Coverage



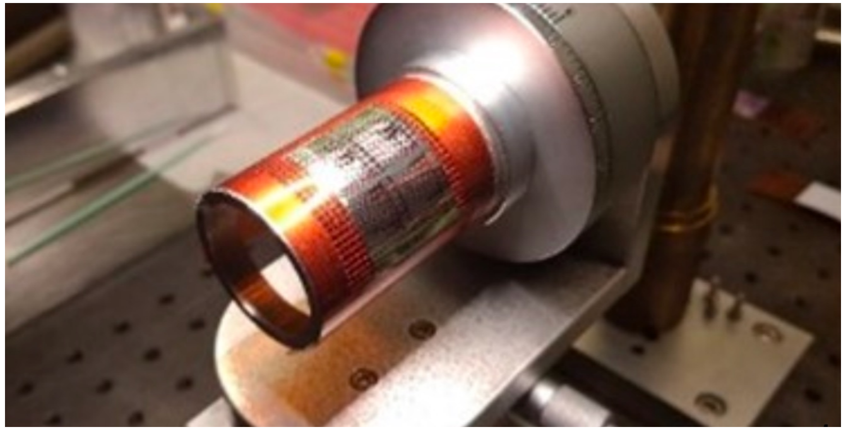
# Tracking Detector Technology: Silicon

- **Monolithic Active Pixel Sensor** (MAPS) : Contain sensor and signal processing integrated on the same chip
  - Particle traversing the silicon forms signal in the Epitaxial Layer (creates electron-hole pairs)
  - Each pixel has a *collection diode* (NWELL DIODE)
  - Induced electrical signal can be processed by the integrated CMOS transistor network
  - Metalized layers are produced on the very top of the chip to interconnect the electronic devices making up the in-pixel and chip circuity




ALPIDE chip

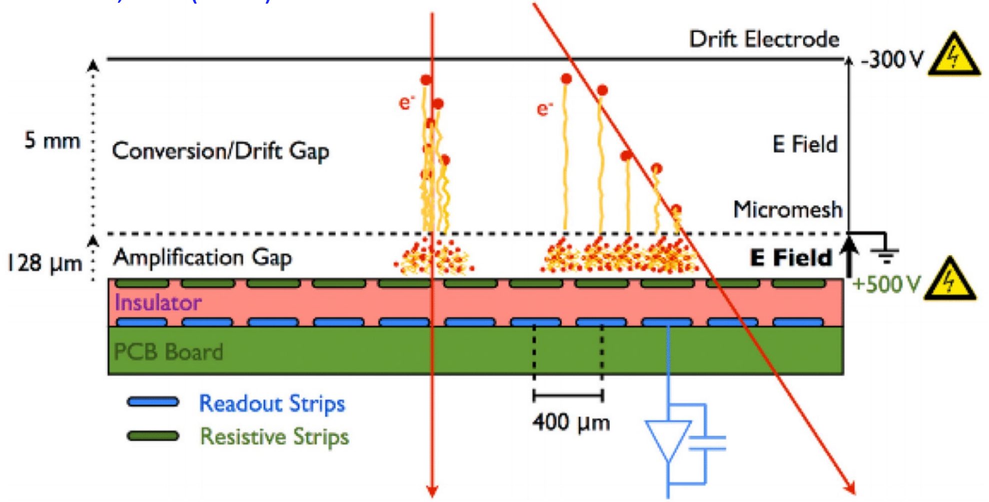
Curved DPTS chip



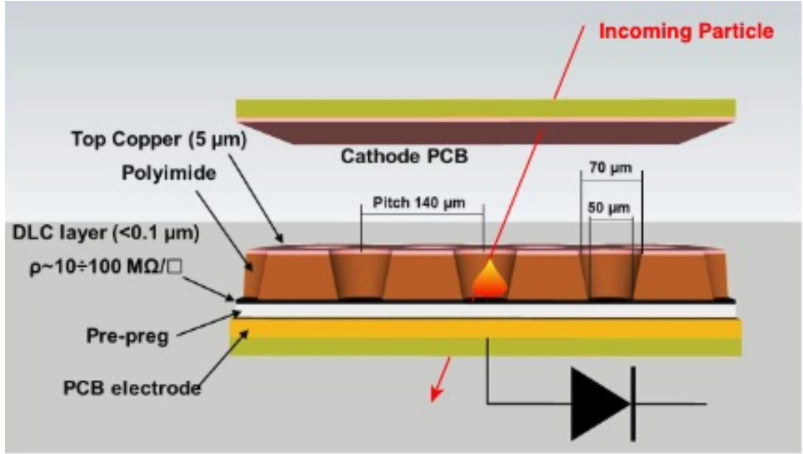
# Tracking Detector Technology: MPGDs

## CLAS12 Micro Megas ($\mu Megas$) and image

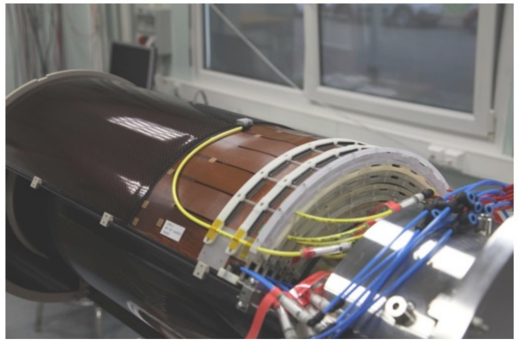
NIM A, 957 (2020) 163423



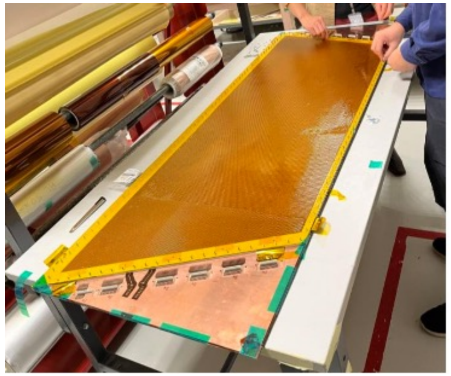

## Micro Resistive Well ($\mu RWELL$) and image




- Working Principle:
  - Incident particles ionize gas atoms. The resulting secondary electrons then drift to the mesh where they initiate an electron cascade, producing a measurable signal on the readout strips.
- $\mu Megas$ and $\mu RWELL$ MPGDs consist of:
  - Cathode
  - Conversion/Drift gap
  - Amplification gap
  - Readout PCB (resistive layer, readout strips)



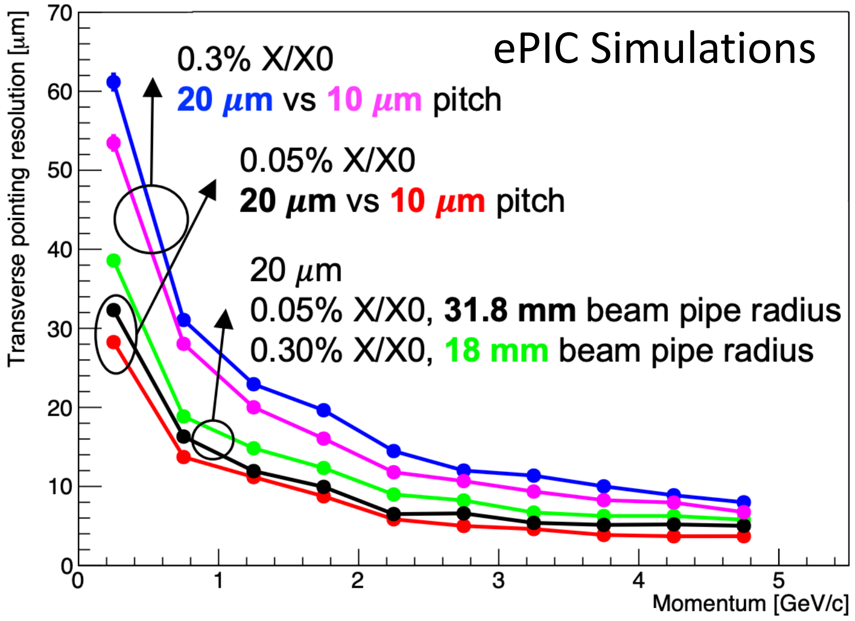
CLAS12 $\mu Megas$

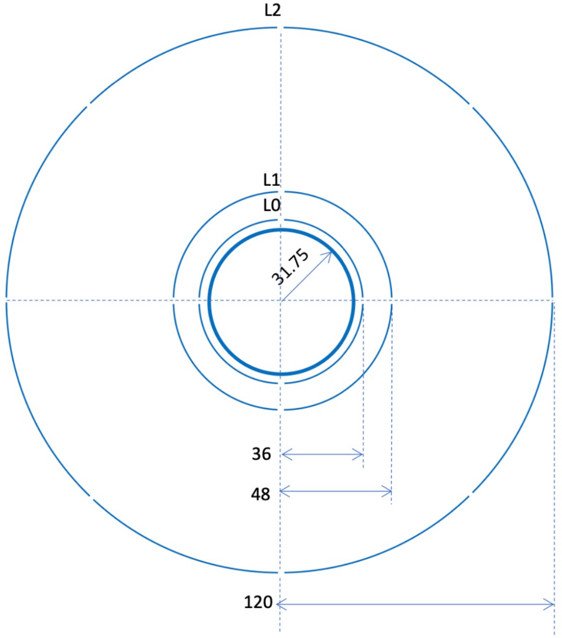


CLAS12 $\mu RWELL$ prototype [146-101]cm x 54

# SVT: Inner Barrel

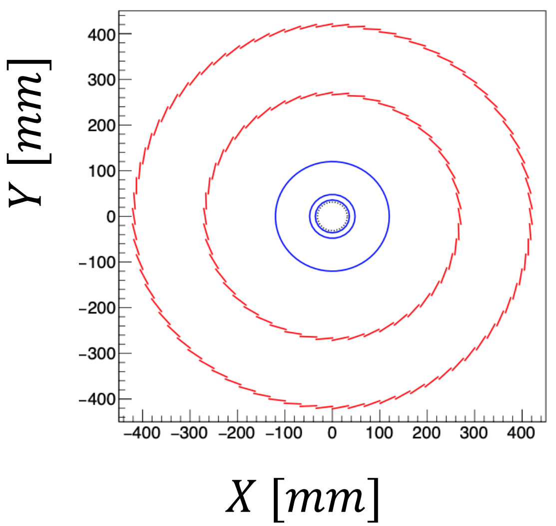
- Transverse pointing resolution is dominated by multiple scattering
- The inner barrel will adopt the ALICE ITS3 wafer scale and ultra-thin detector concept
  - Three layers of thin, bent silicon sensors
  - Minimal mechanical support, air cooling, and no services in active area
- Layers positioned to optimize transverse pointing resolution within operational constraints
  - L0 ($R = 36\ mm$), L1 ($R = 48\ mm$): large beam pipe diameter ($R = 31.75\ mm$), beam pipe bake-out ($5\ mm$ clearance)
  - L2 ($R = 120\ mm$): dual purpose vertexing and sagitta layer, without increase in material

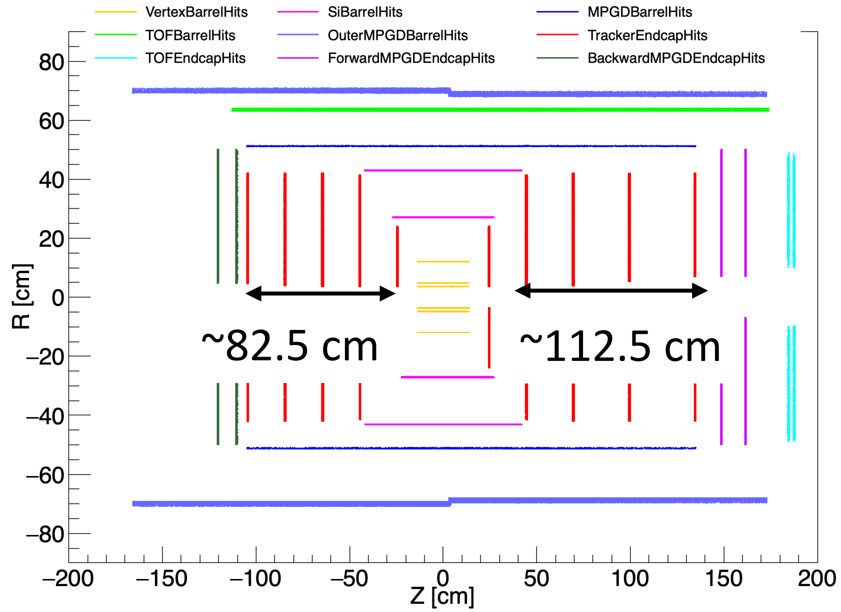


# SVT: Outer Barrel and Endcaps

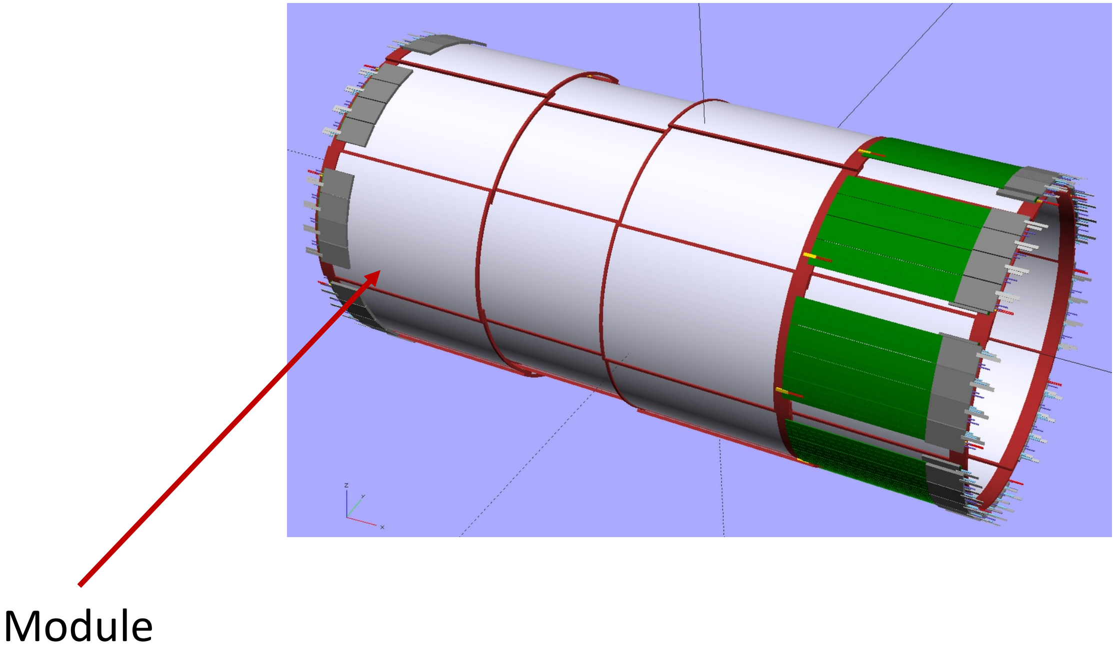
- EIC Large Area Sensor (LAS) optimized for high yield, low cost, large area coverage
  - Modification of the ITS3 sensor; LAS stitched but not wafer scale; possible modifications in the periphery to reduce number of readout links.
- Lightweight mechanical support with integrated cooling and electrical interfaces.
- Large lever arm with high precision measurements
  - Improve momentum resolution
  - Maximize acceptance at large $\eta$
- Disk inner opening defined by beam pipe bake-out constraints and off-centered where beam pipe diverges



- **Preliminary** Curved $\mu Megas$ Inner Barrel Tracker Concept
  - Module size $\sim 46\ cm \times 65\ cm$
  - 32 modules to complete barrel tracker
  - Can bring FEB connections from center tiles to edges via flex cables
  - Hermeticity in $R, \phi$ being explored

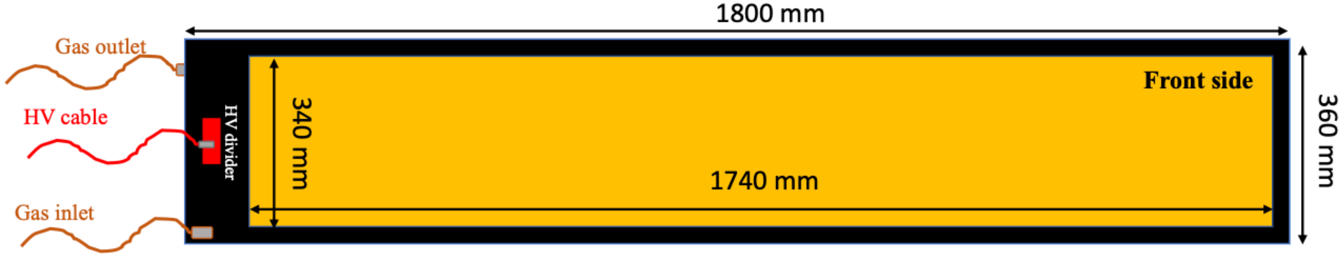
**Preliminary Concept**: Curved $\mu Megas$ Inner Barrel Module



# $\mu RWELL$ Outer Barrel and Endcap Disks

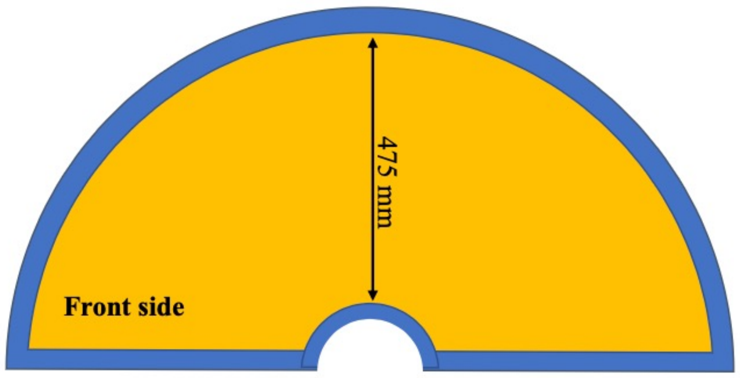
- **Preliminary** Outer $\mu RWELL$ Barrel Tracker Concept
  - Constrained by DIRC PID system → shares support structure
  - Gas and HV connections made at one end of module
  - 2D U-V strip readout and connections on back side
  - 2 modules needed to cover 360 cm length in z
  - 12 x 2 modules needed to cover azimuth ($\phi$)
  - Can be designed with overlap in z

**Preliminary Concept**: $\mu RWELL$ Outer Barrel Module

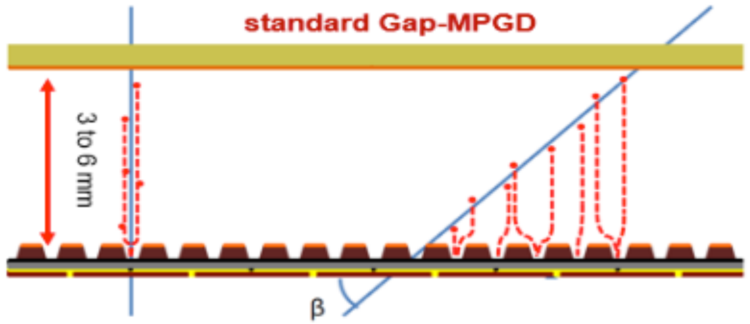


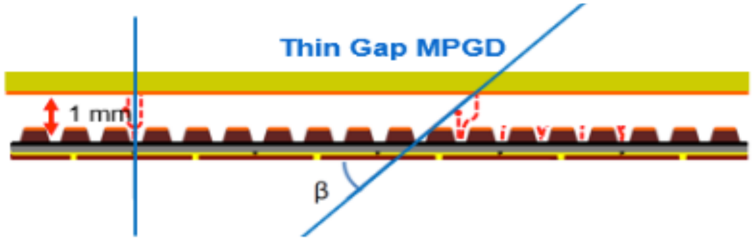

- **Preliminary** Endcap $\mu RWELL$ Tracker Concept
  - Inner radius constrained by beam pipe and will be off-center
  - Gas and HV connections made on outer radius
  - 2D $R - \phi$ strip readout with connections made along outer radius
  - 4 half disk modules needed for each End cap tracker
  - Can be designed with overlap in $\phi$

**Preliminary Concept**: Endcap $\mu RWELL$ Half Disk Module

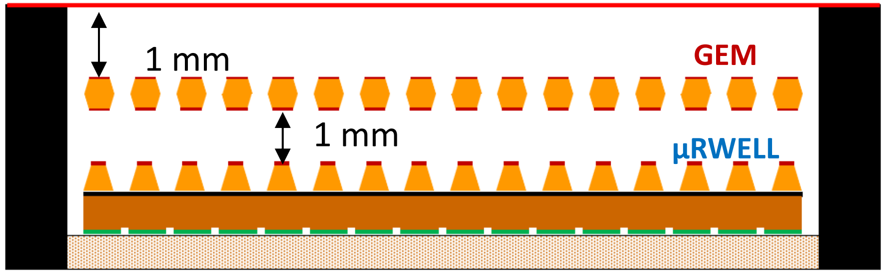


- Motivation
  - Incoming track at large angle: Ionization in drift volume generates signal on too many strips → spatial resolution limited by drift gap for large angle tracks
  - Lorentz angle in high B field: Another source of degradation of the spatial resolution performance that depends on the drift volume
  - General issue for $\mu RWELL$ **and** $\mu Megas$ detectors
- Exploring thin gap implementation in both $\mu RWELL$ and $\mu Megas$ technologies

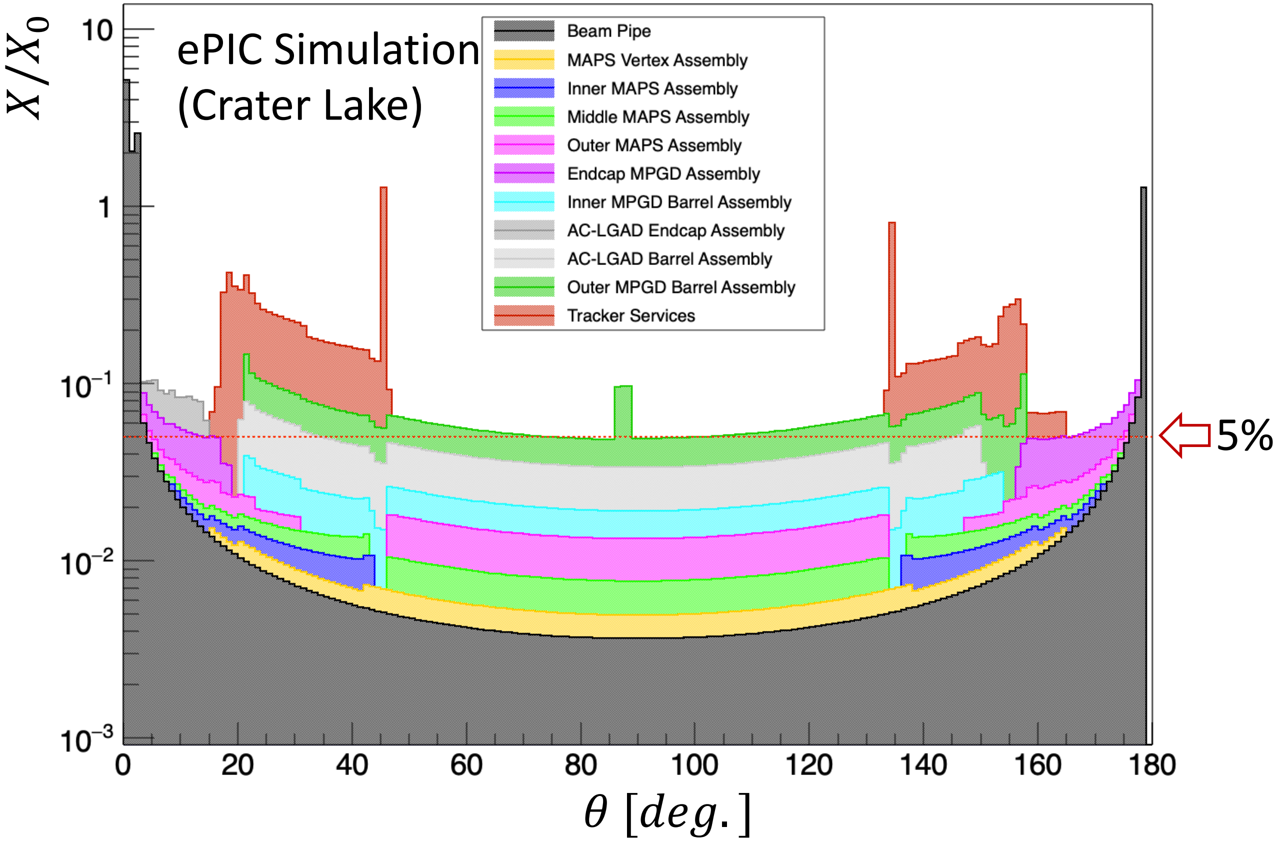


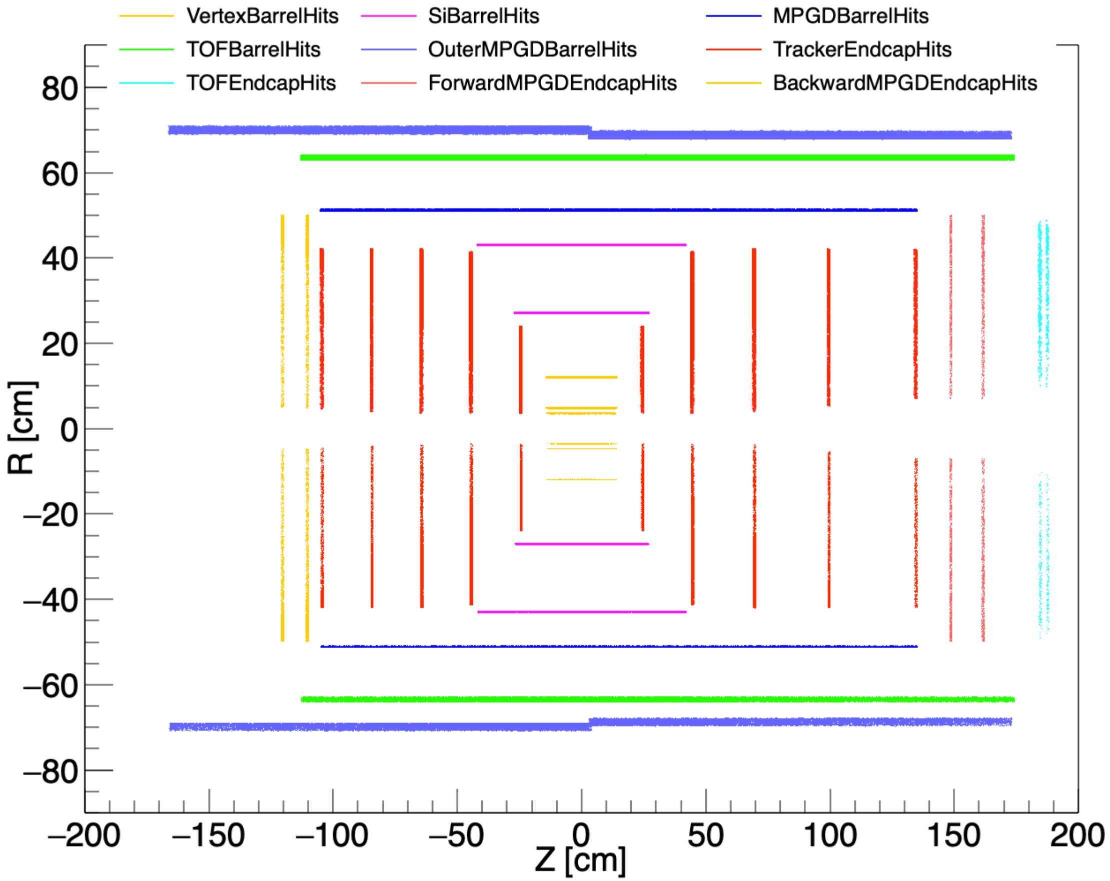




Single hybrid thin-gap GEM-µRWELL



# ePIC Tracking: Material Budget



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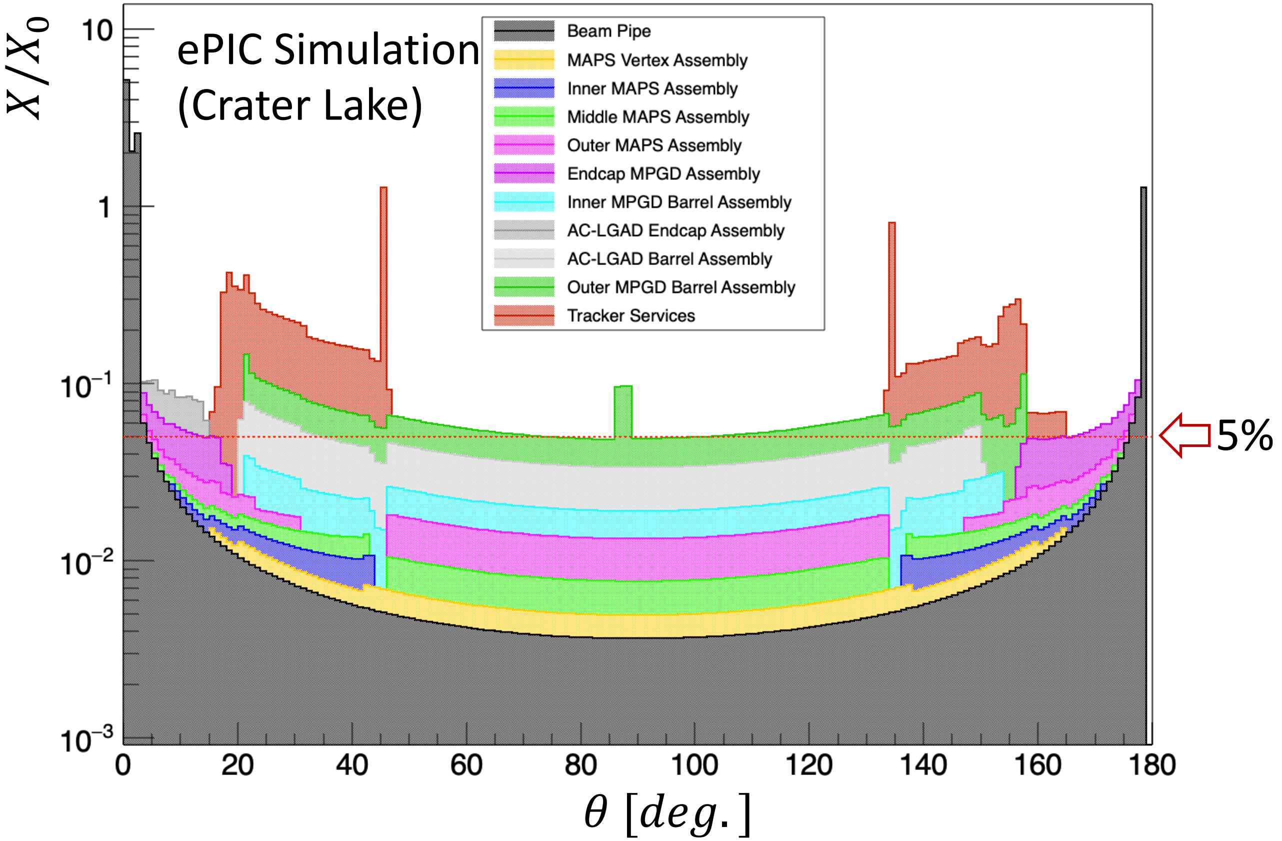
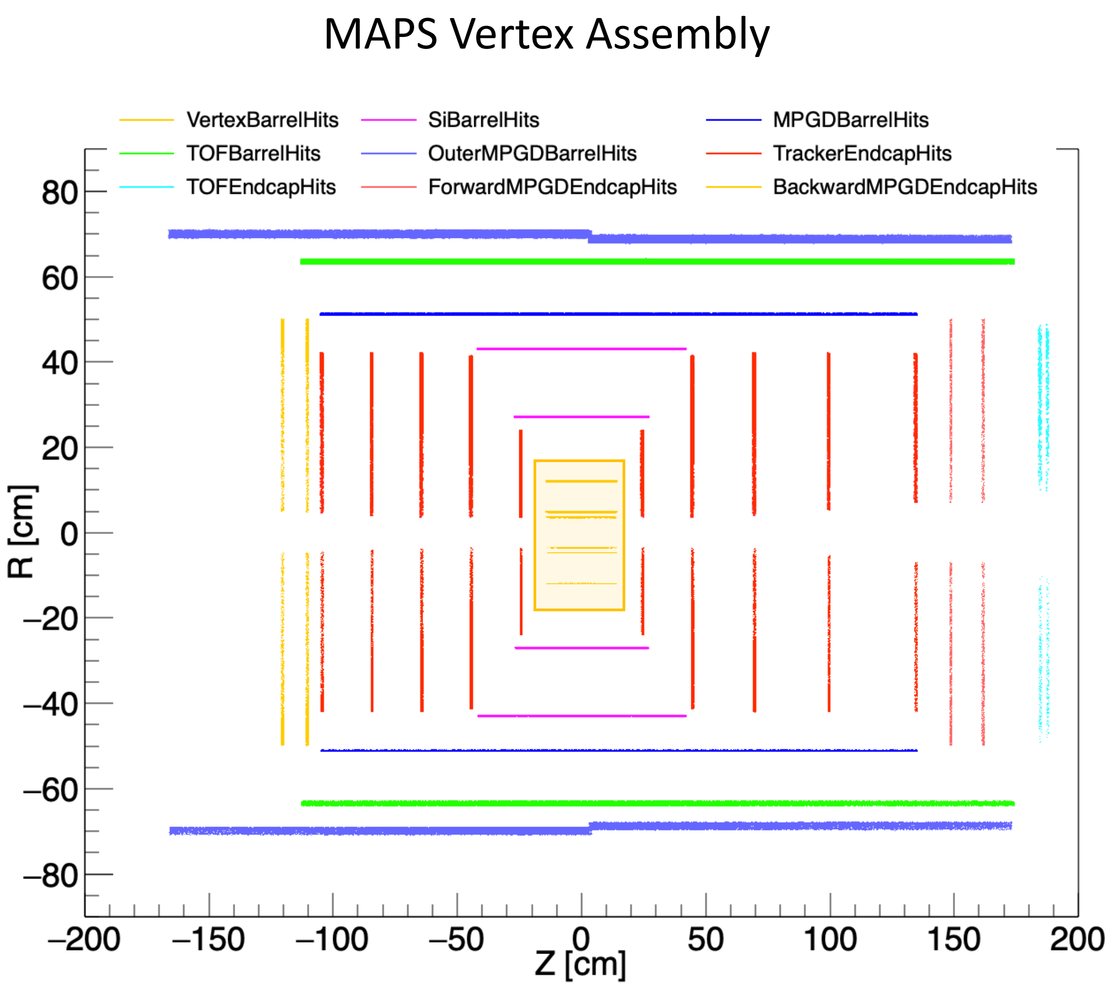
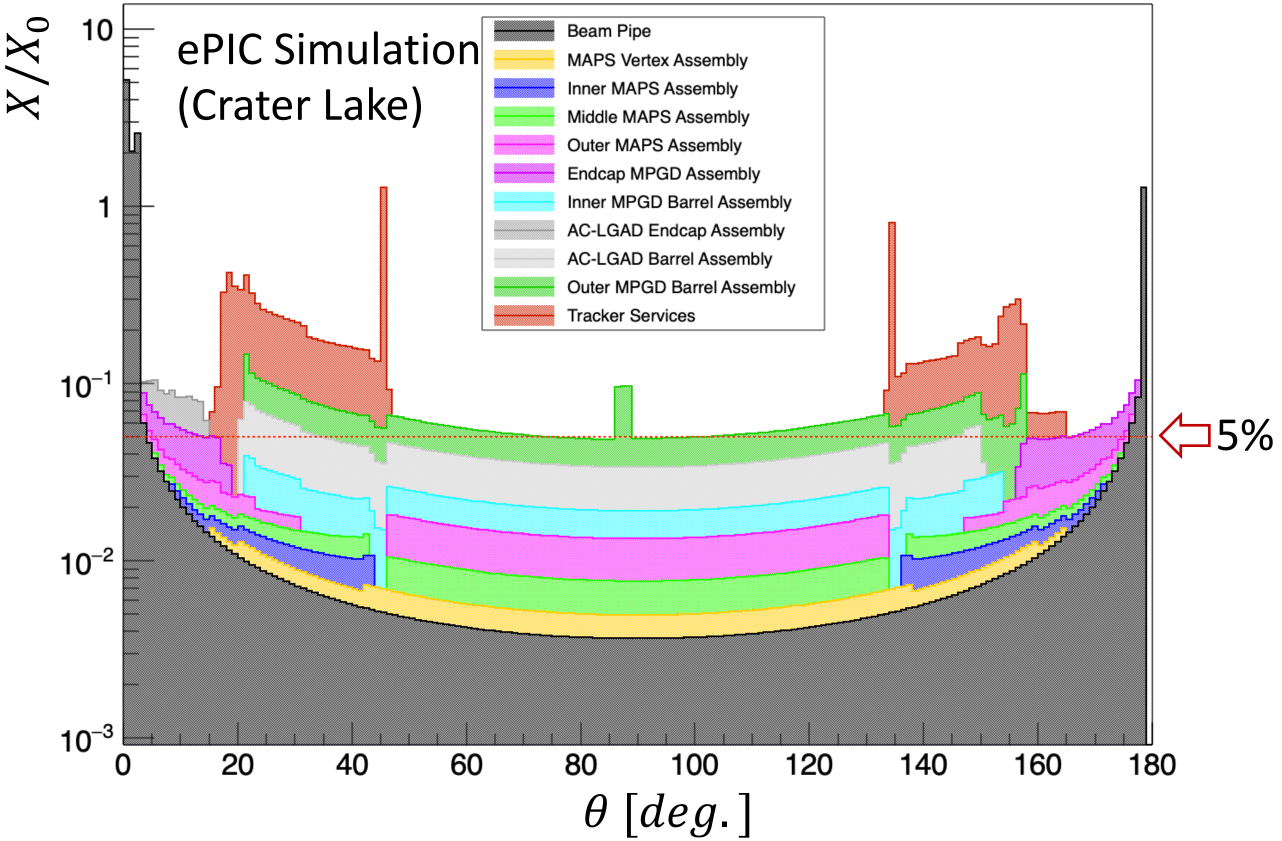
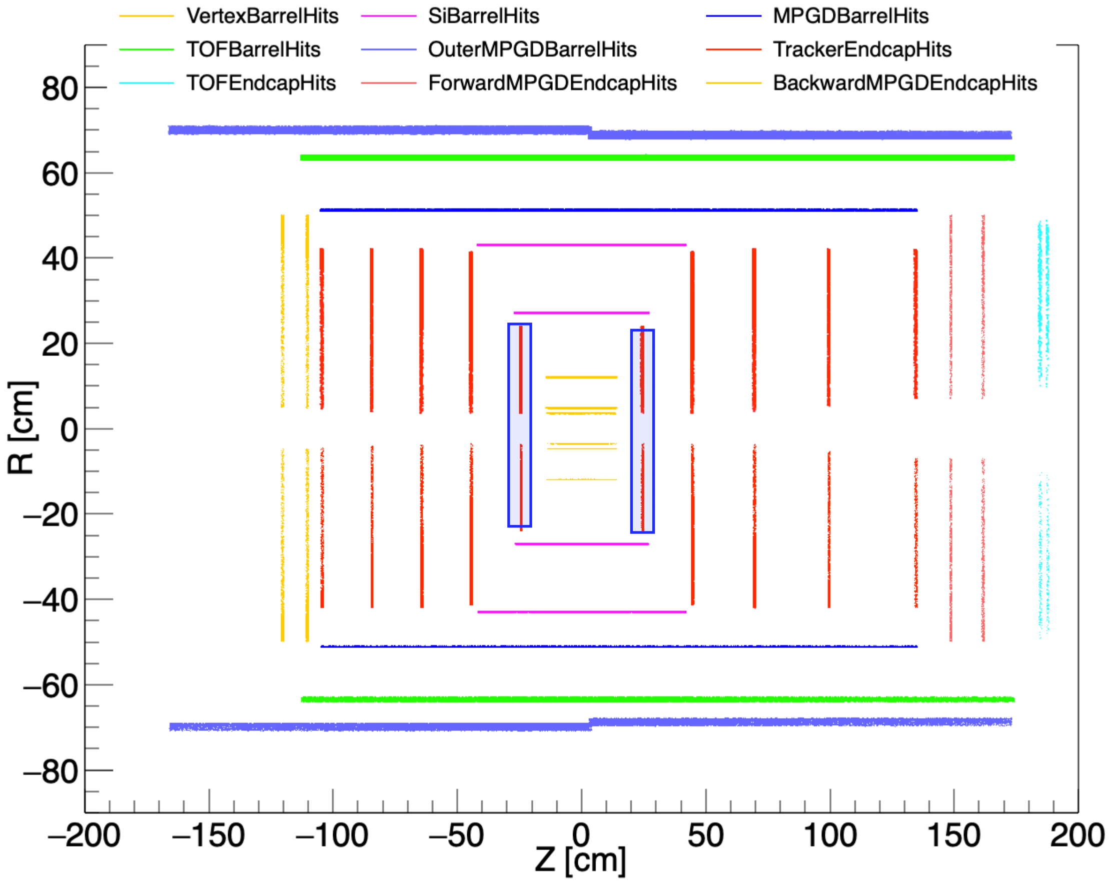


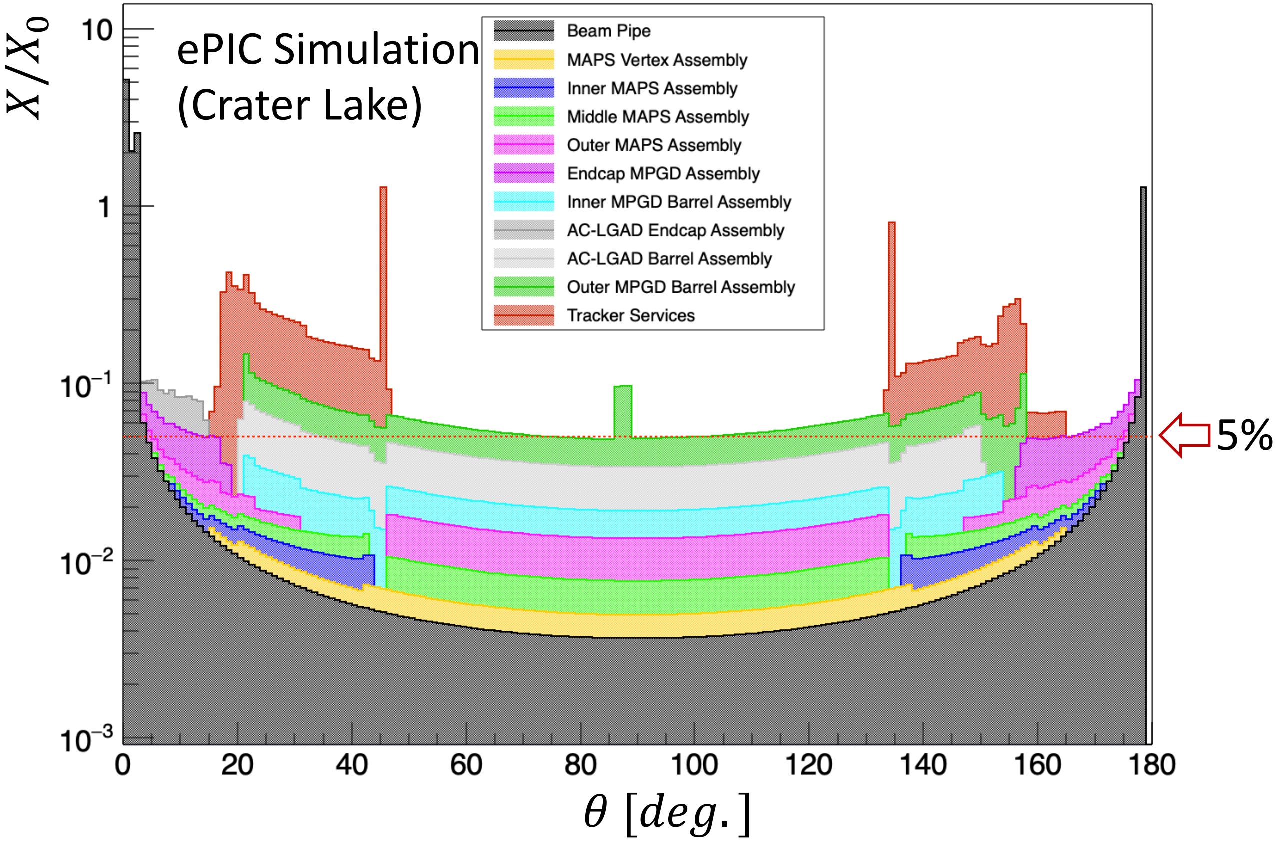
# ePIC Tracking: Material Budget



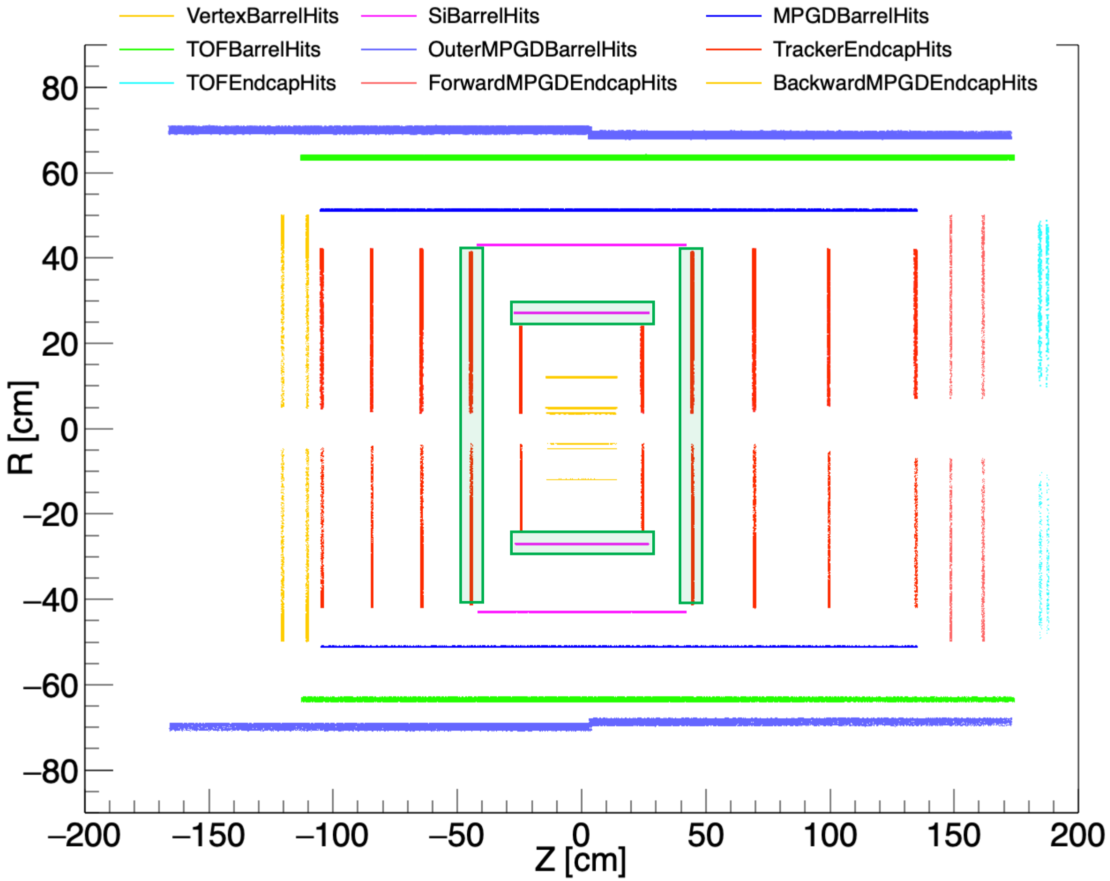

Inner MAPS Assembly



# ePIC Tracking: Material Budget




Middle MAPS Assembly



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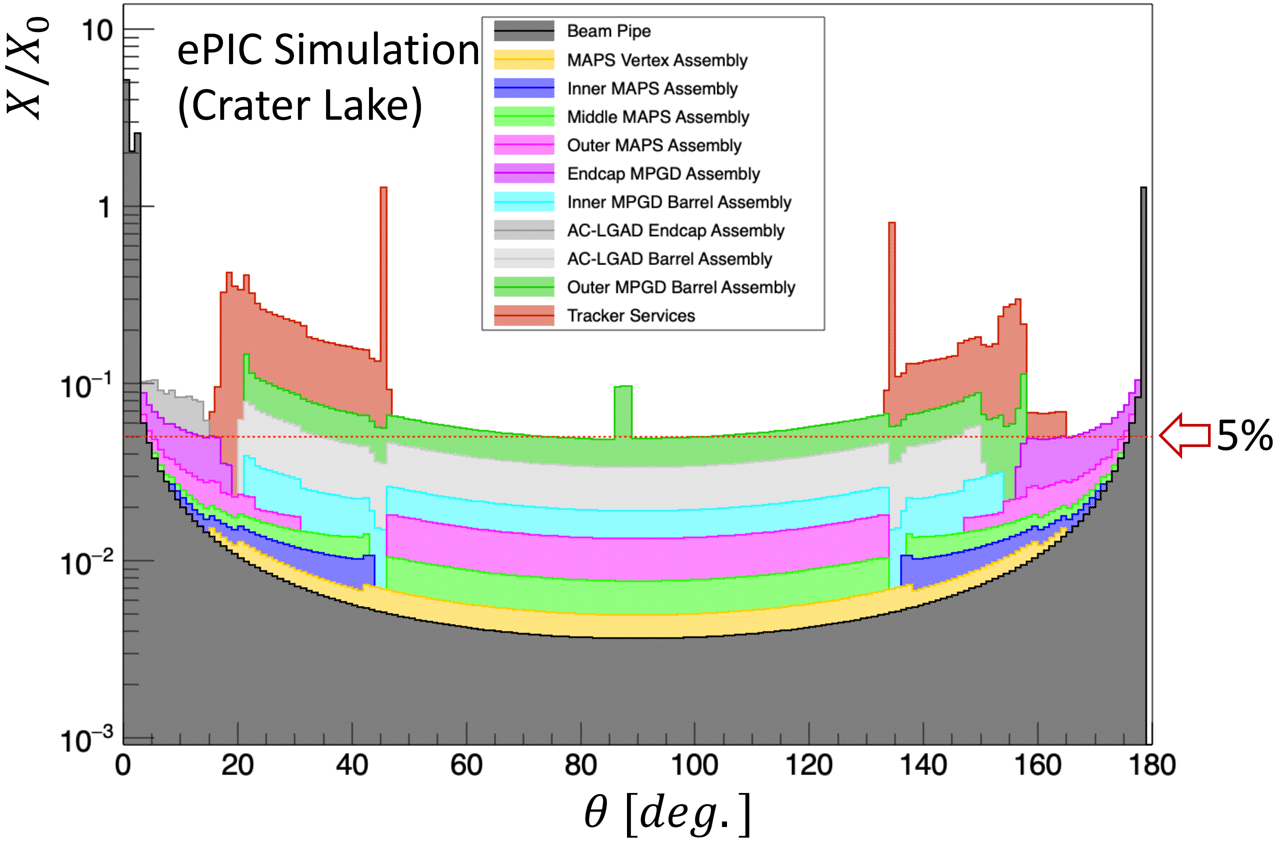
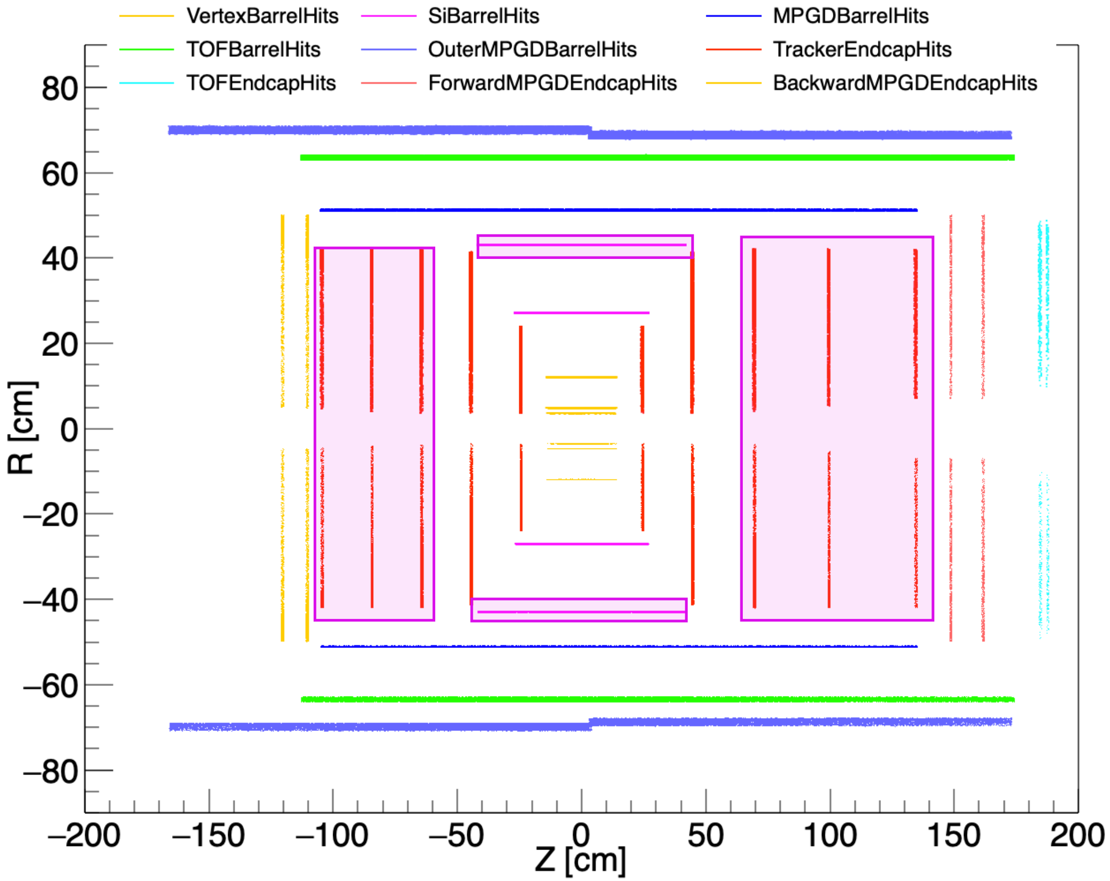
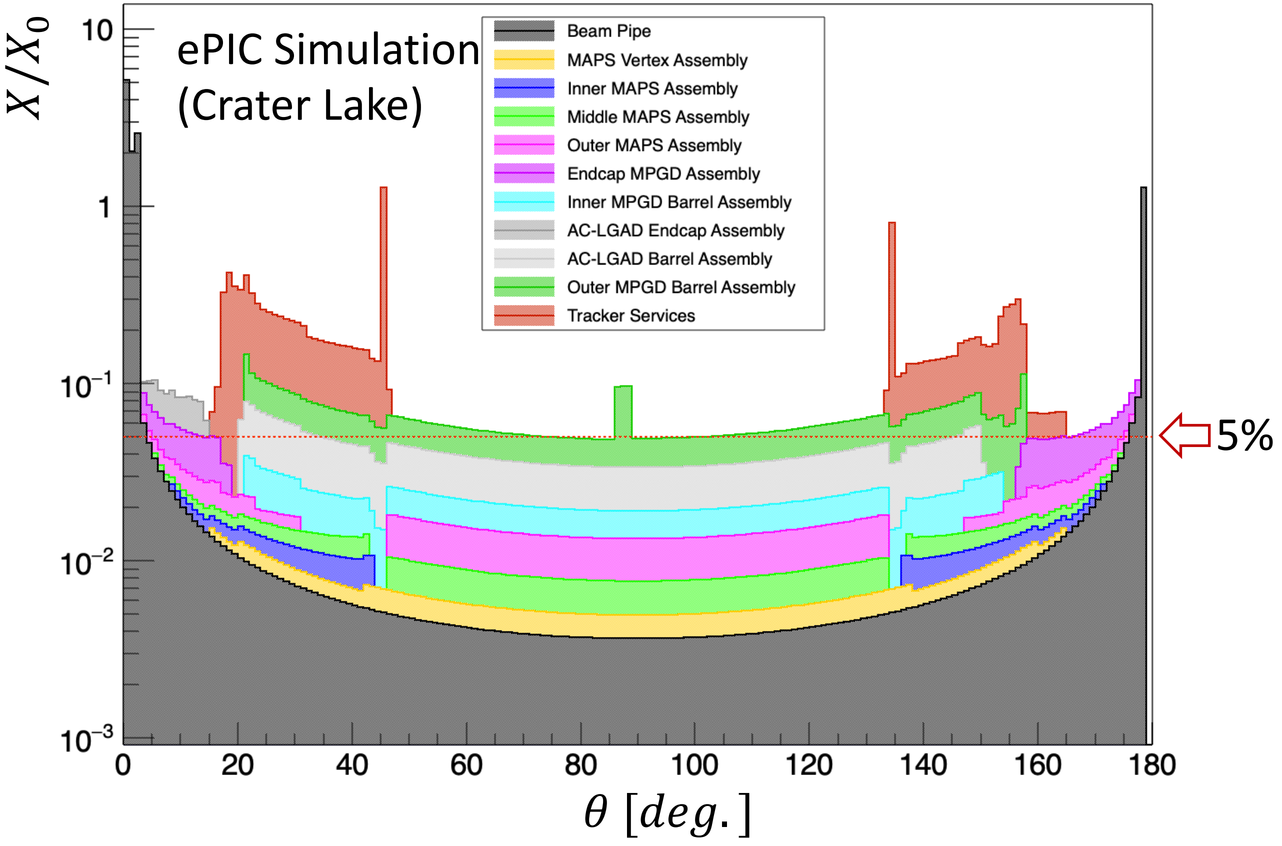


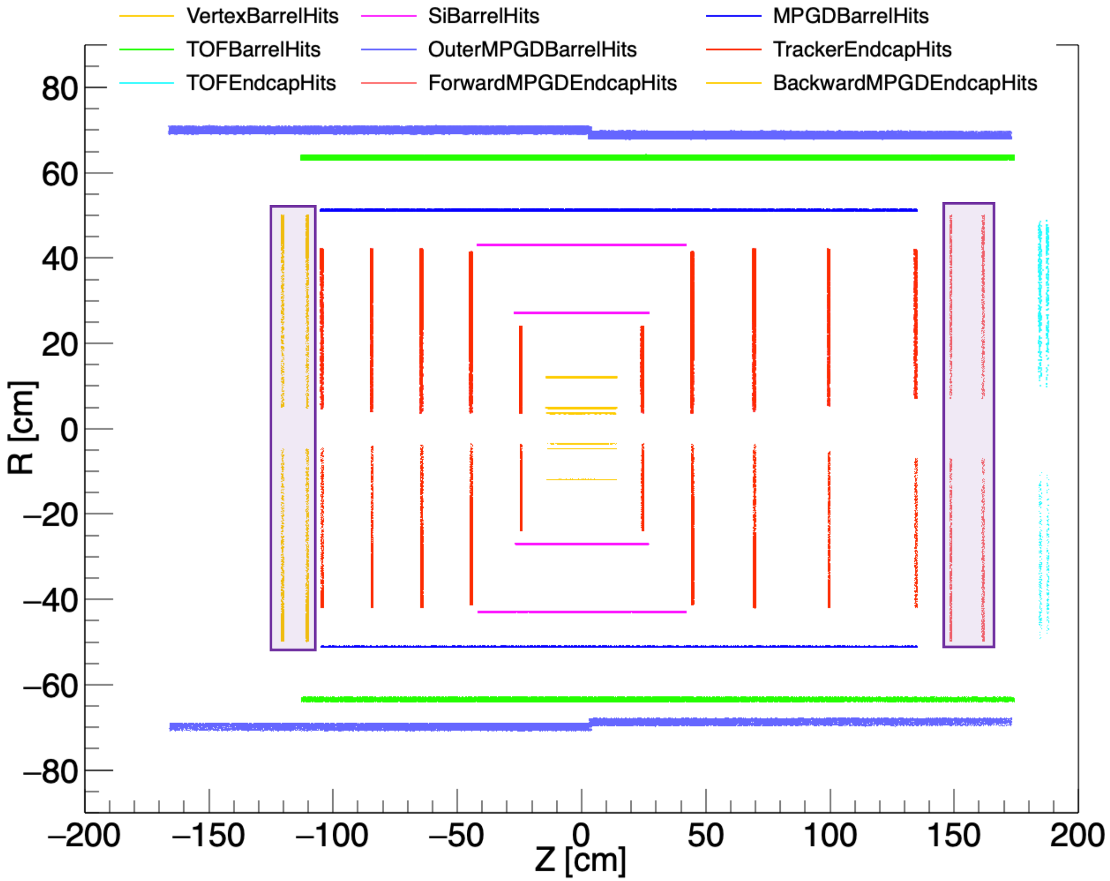

Outer MAPS Assembly



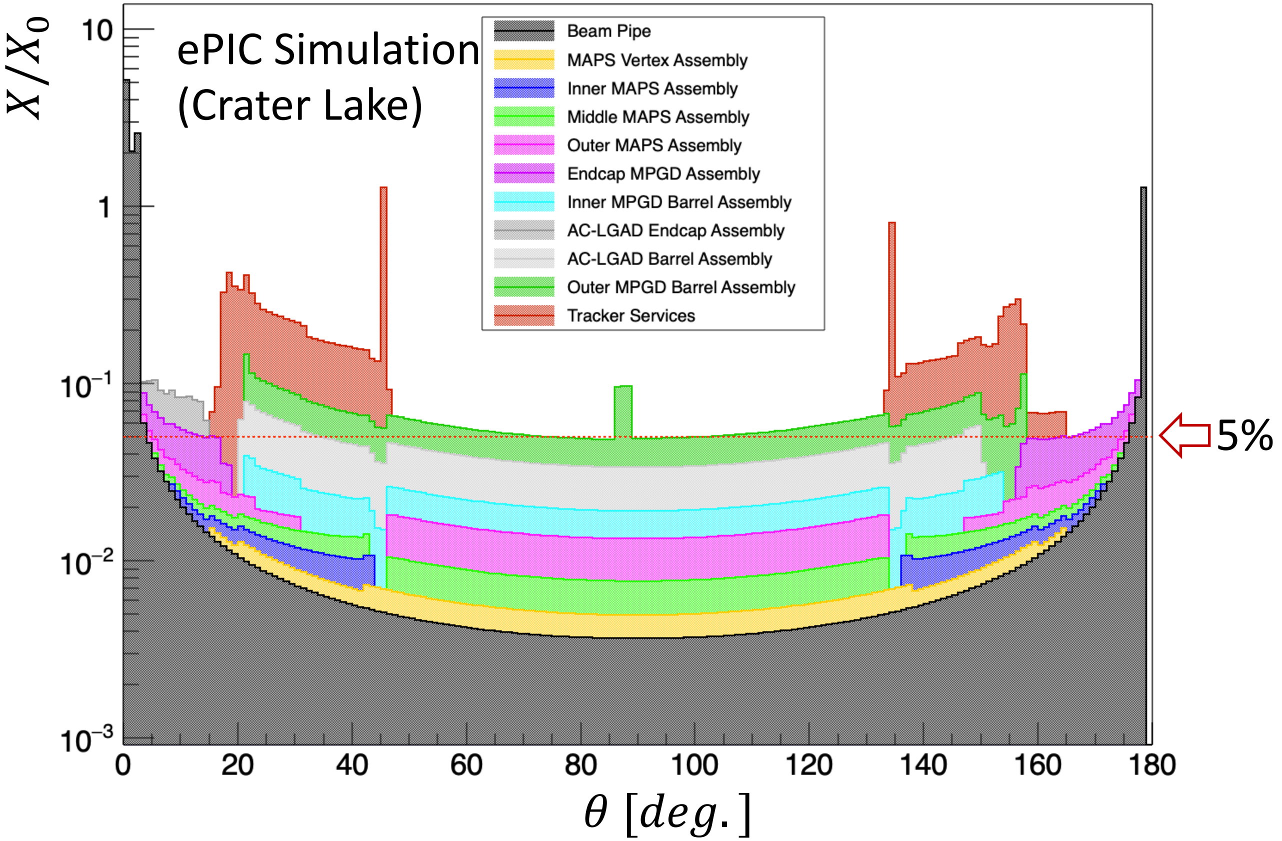
# ePIC Tracking: Material Budget



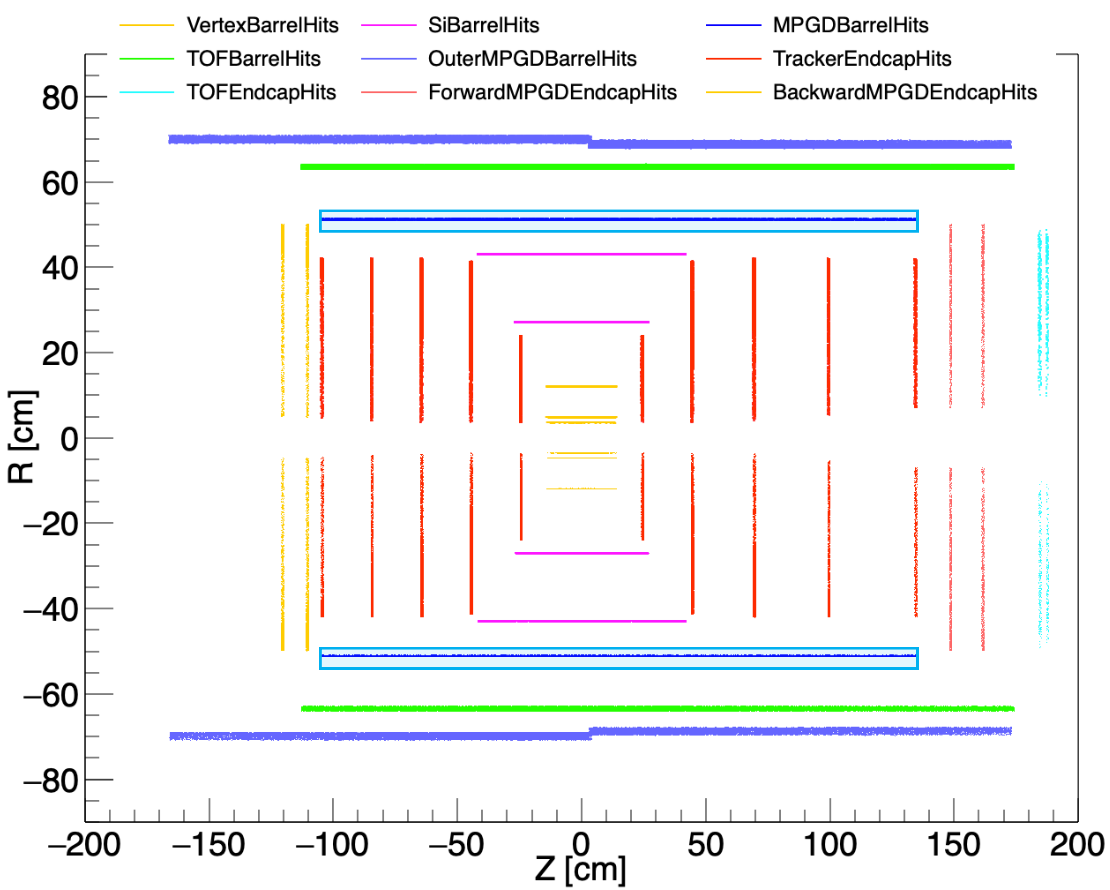

Endcap MPGD Assembly



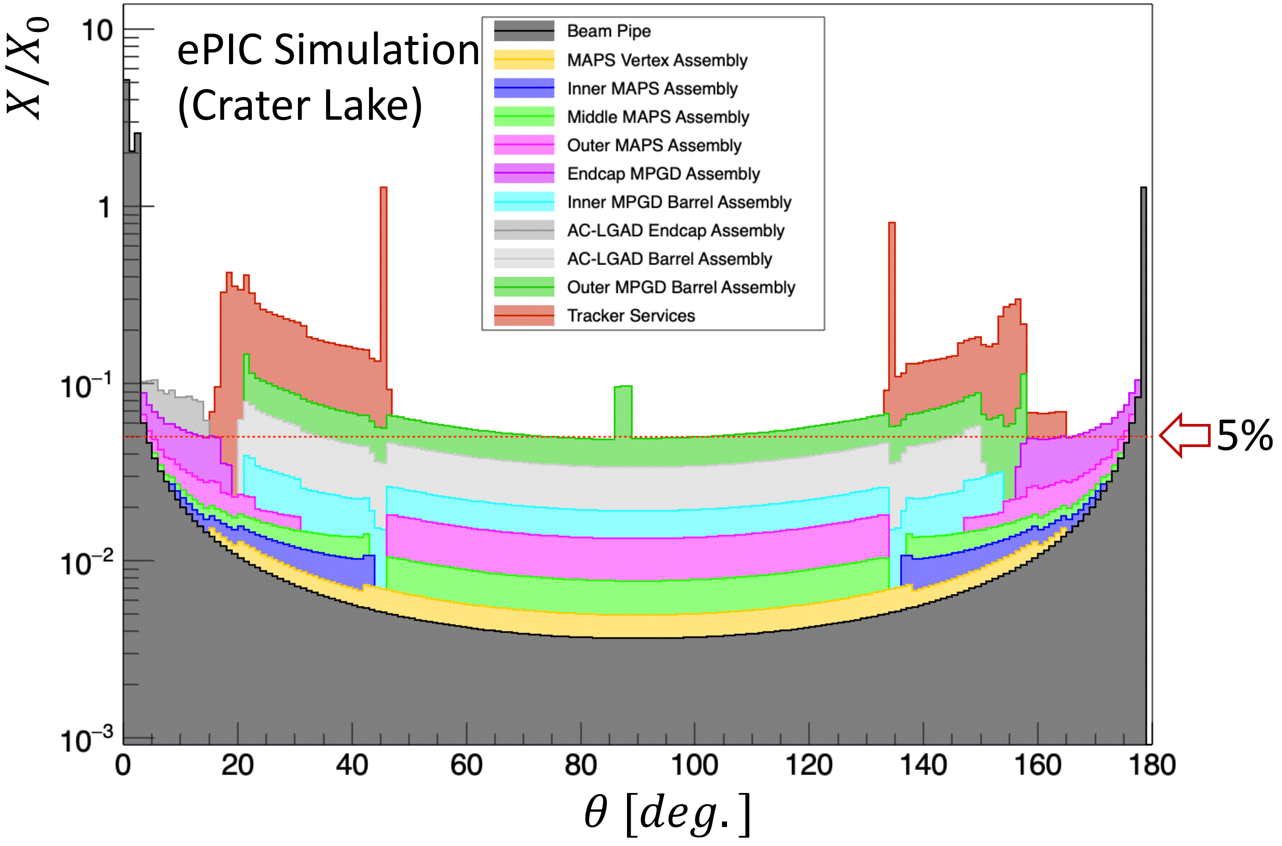
# ePIC Tracking: Material Budget



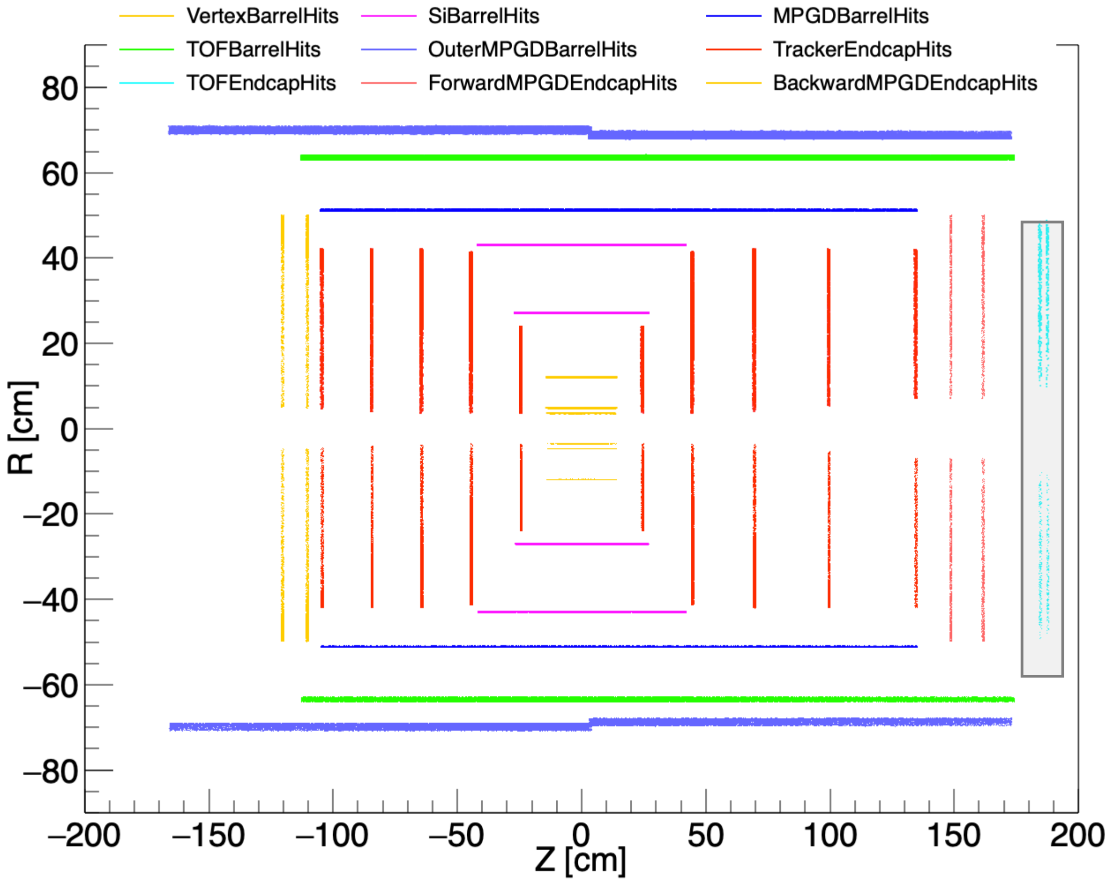

Inner MPGD Barrel Assembly



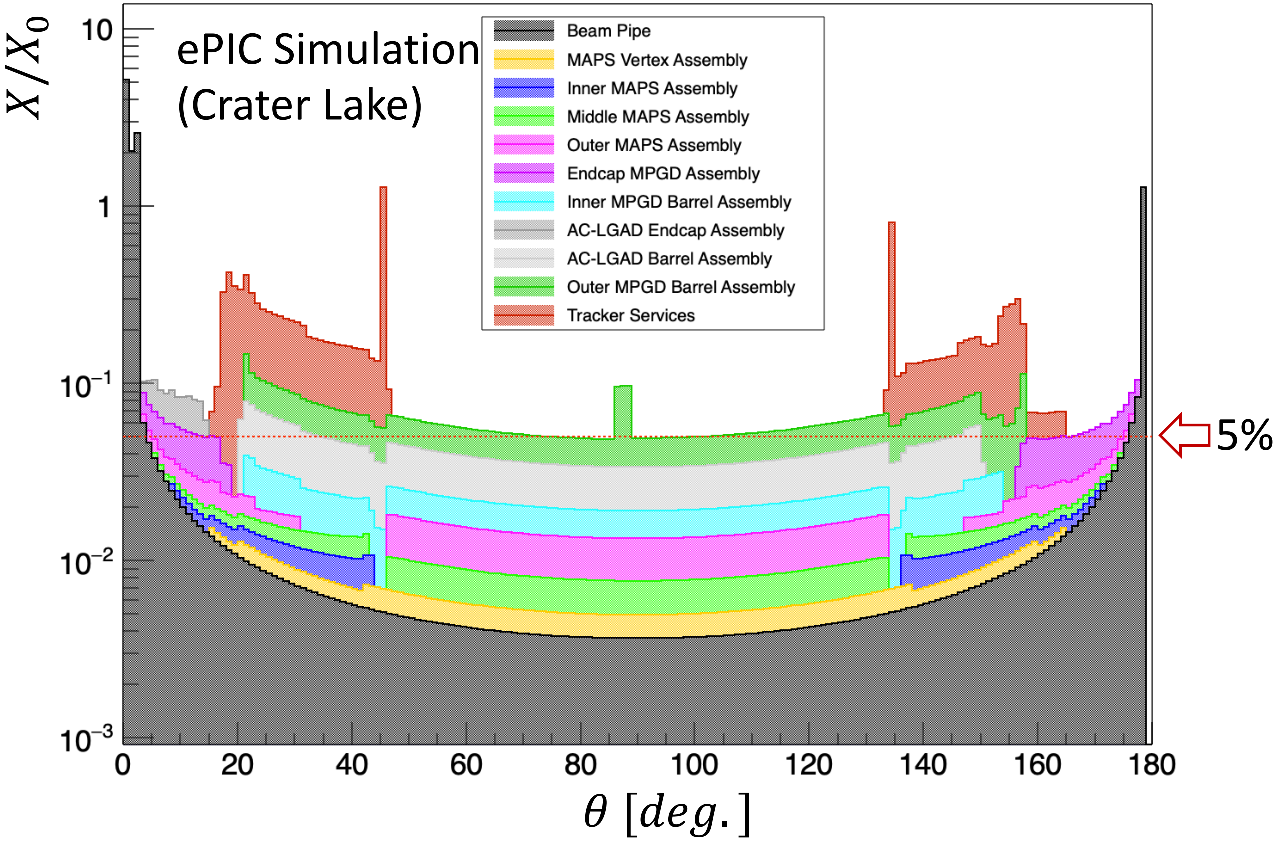
# ePIC Tracking: Material Budget



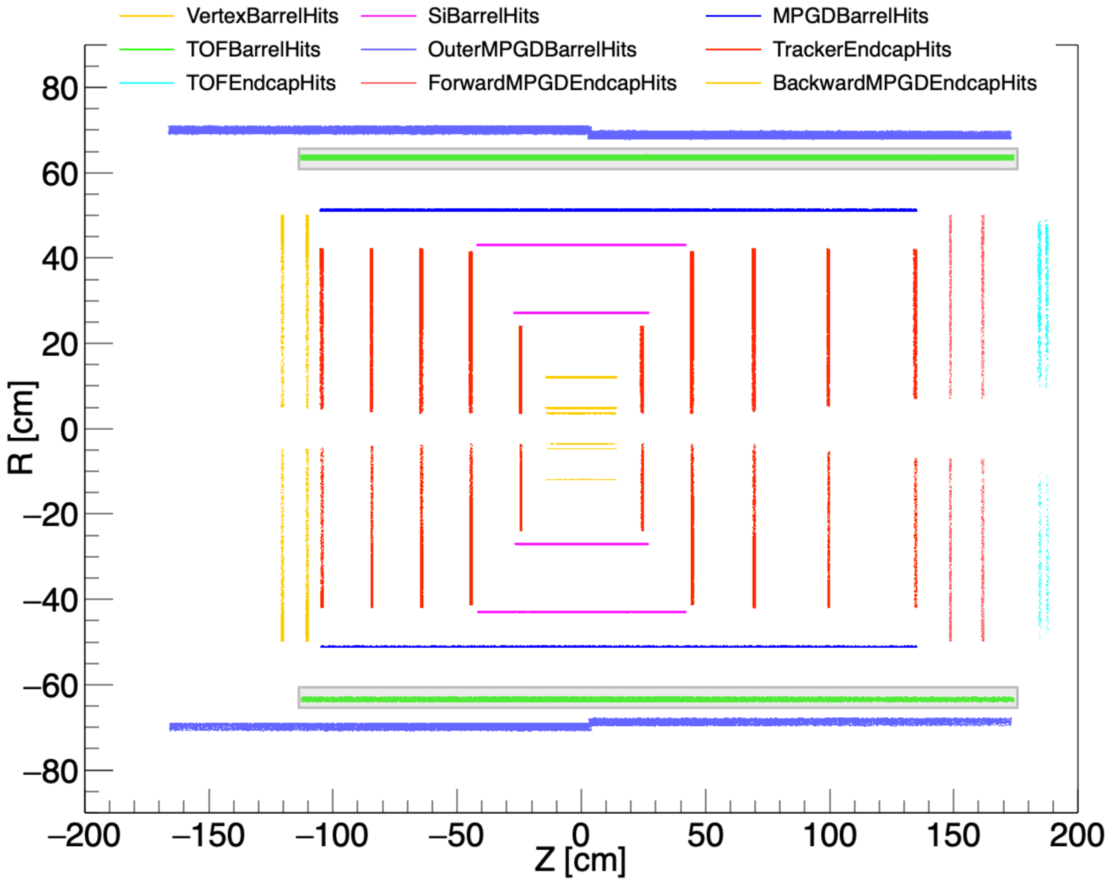

AC-LGAD Endcap Assembly



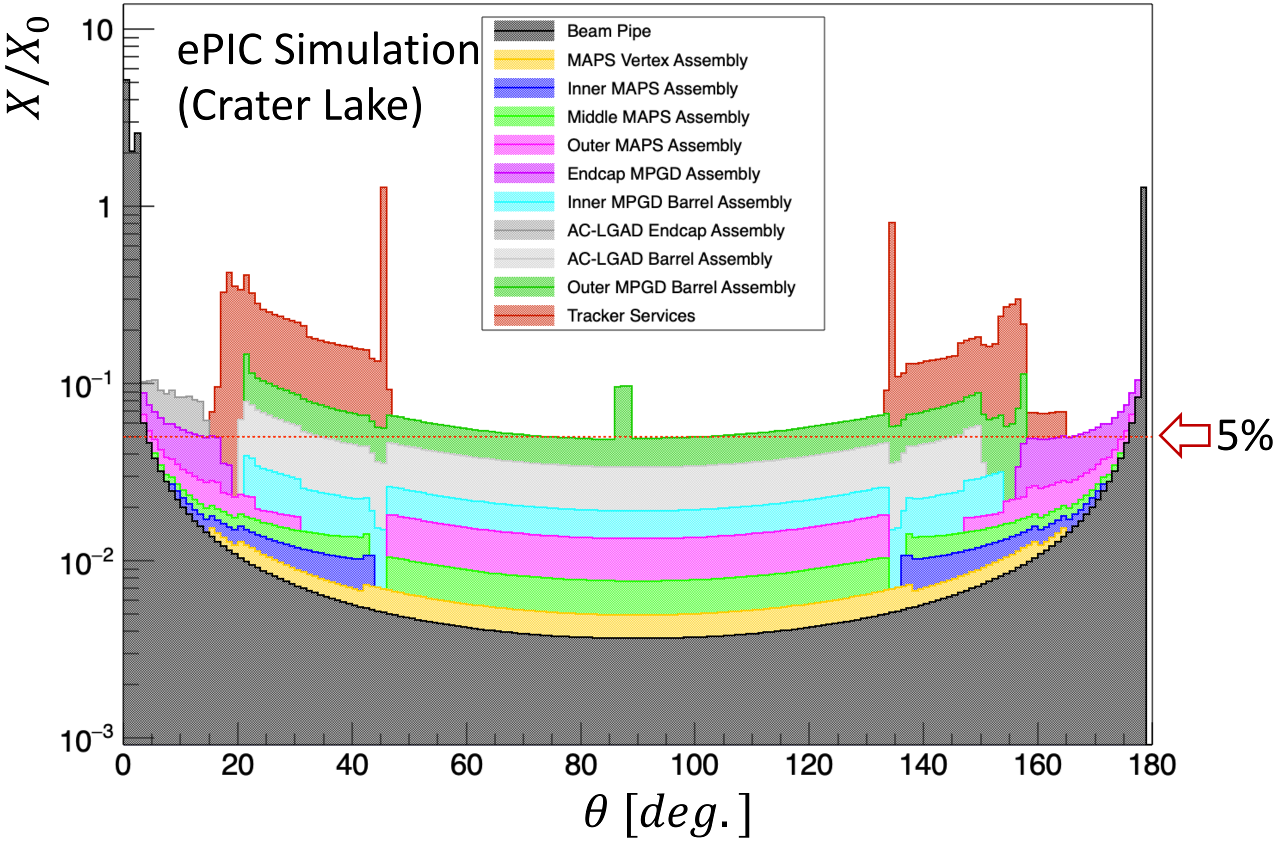
# ePIC Tracking: Material Budget



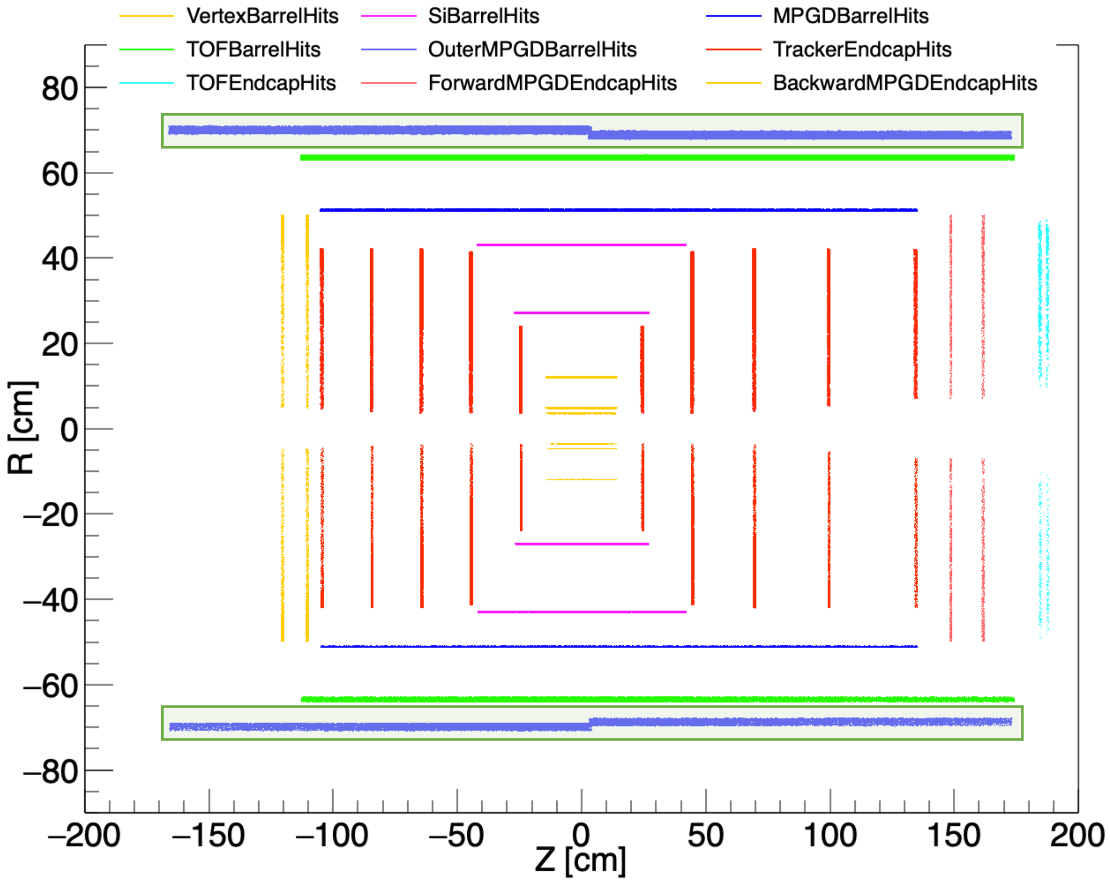

AC-LGAD Barrel Assembly



# ePIC Tracking: Material Budget



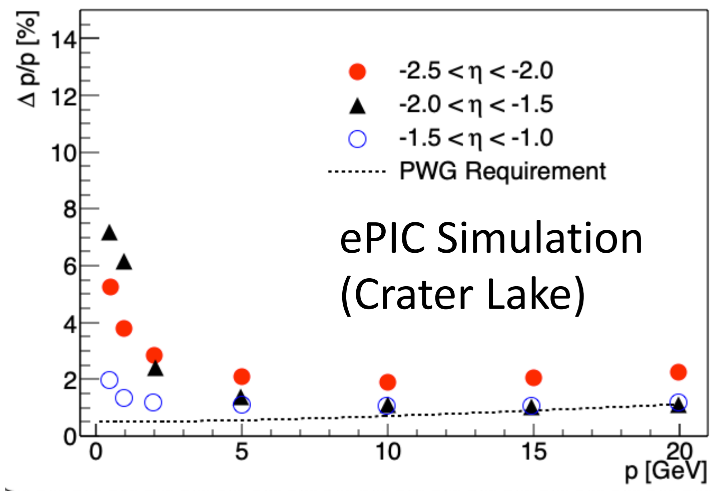

Outer MPGD Barrel Assembly

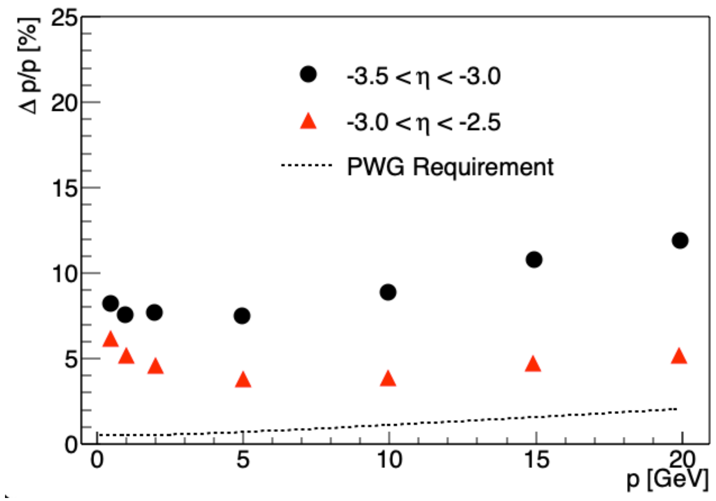


# Simulated Tracking Performance: Momentum Resolution

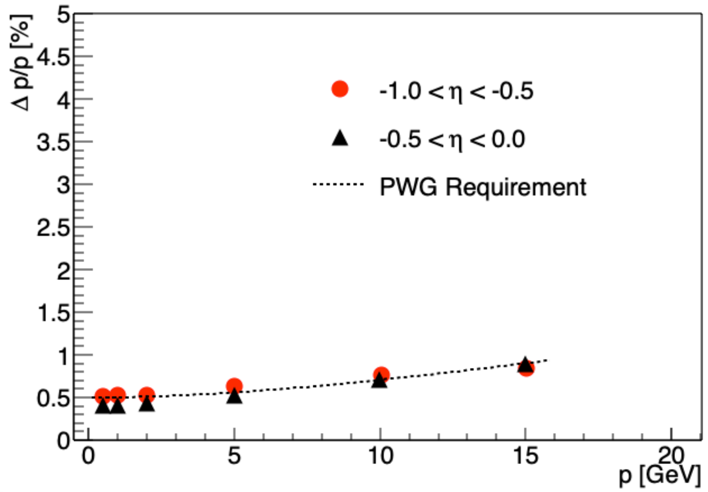
- Simulated performance: Truth Seeding (ePIC Simulation, Crater Lake) -- Pions

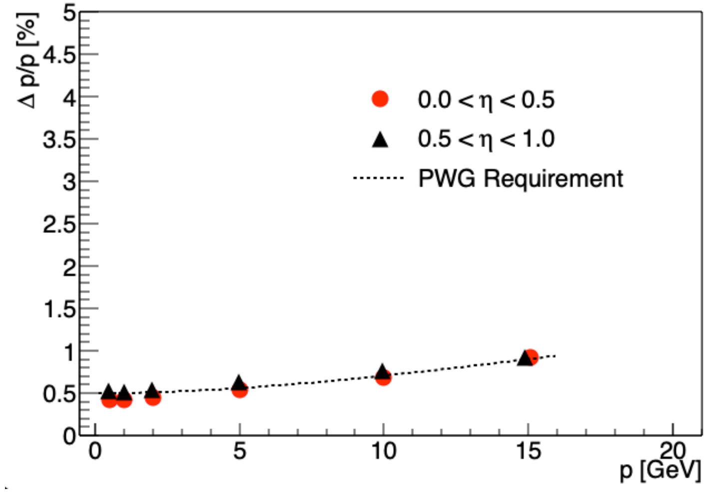
## Backward



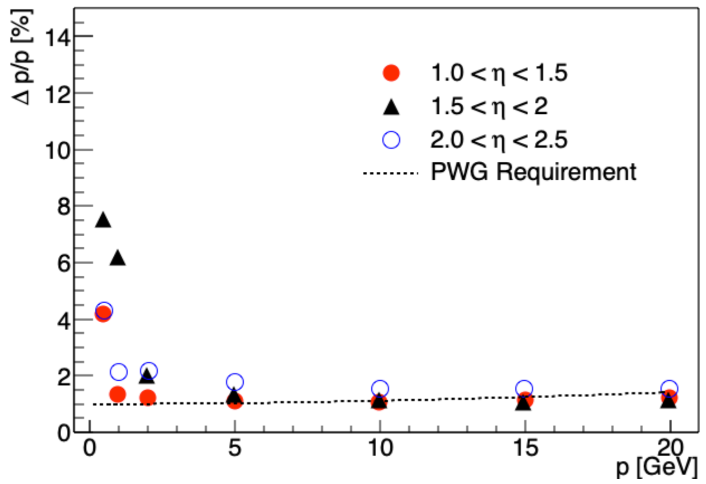



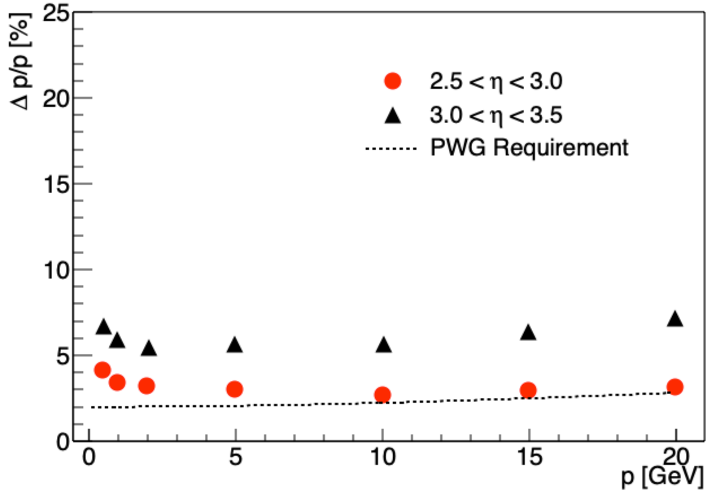

## Central




## Forward

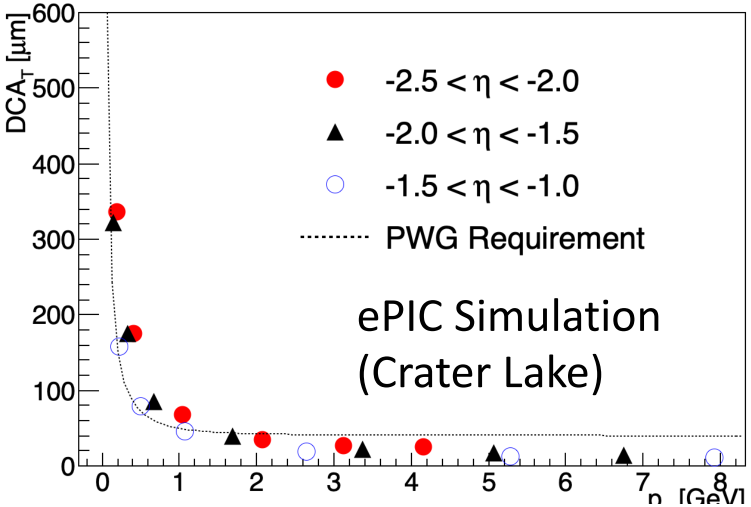


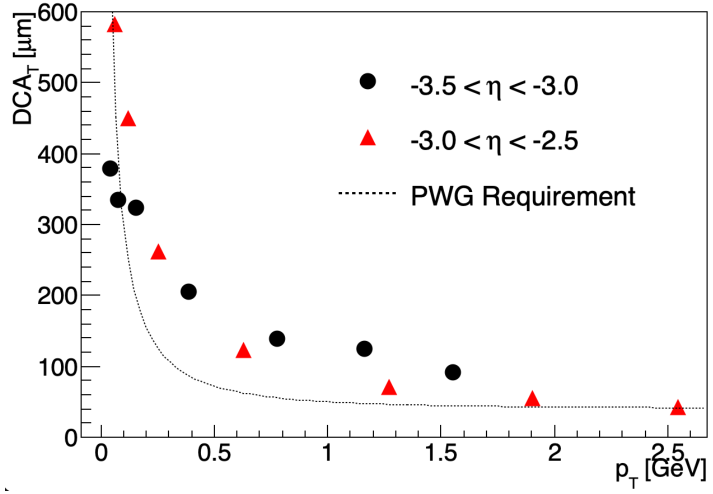



# ePIC Simulated Tracking Performance: DCA

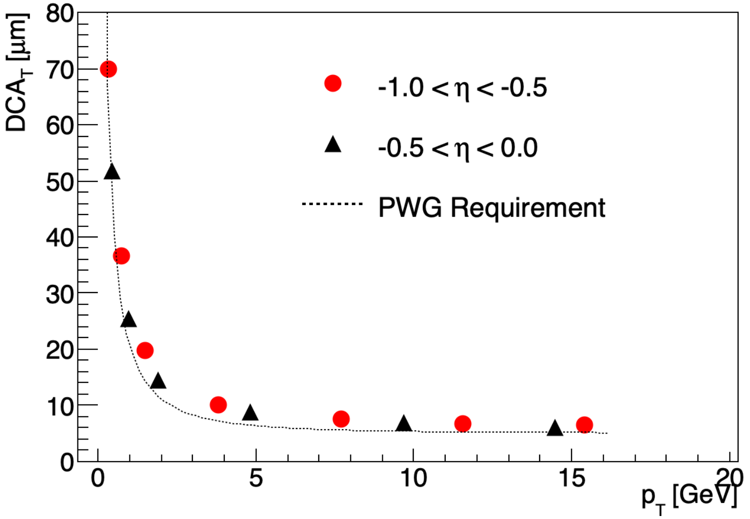
- Simulated performance: Truth Seeding (ePIC Simulation, Crater Lake) -- Pions

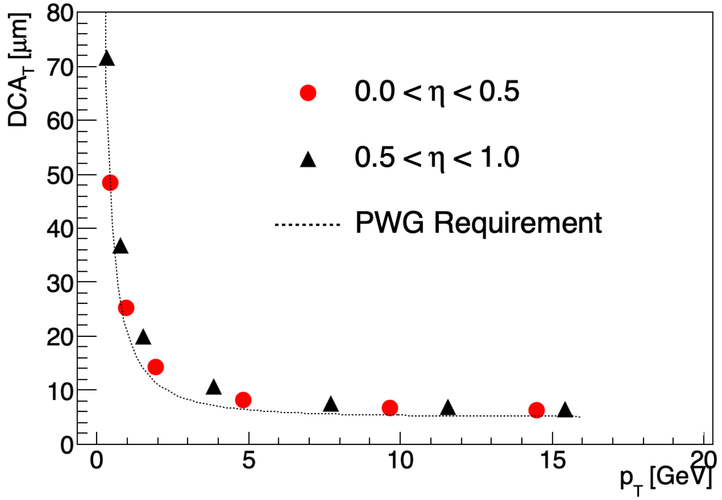
**Backward**



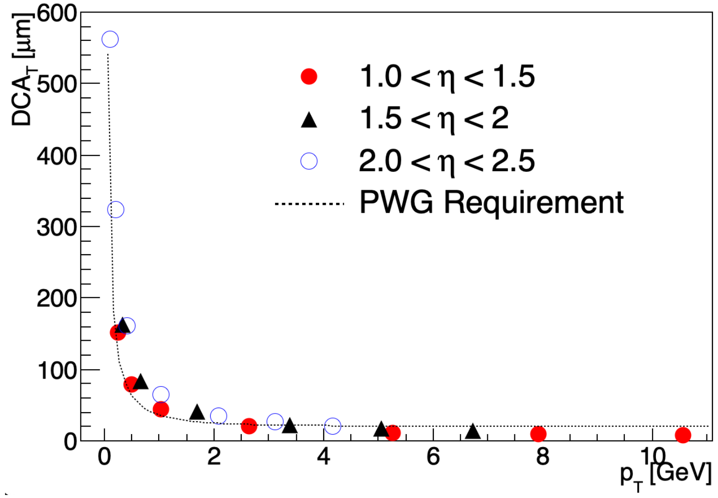



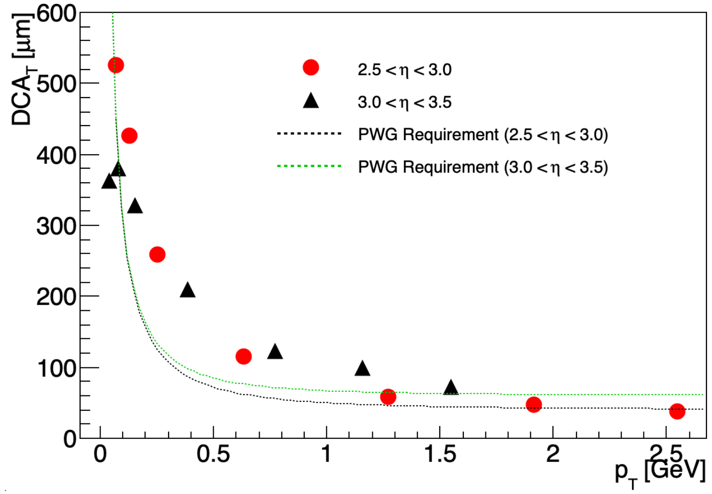

**Central**




**Forward**



# Summary

- ePIC central tracking system integrates both state of the art silicon and gaseous detector technologies
- Silicon based MAPS detector provides precision momentum resolution and excellent pointing resolution
- $\mu RWELL$ and $\mu Megas$ MPGD based tracking detectors provide good space point and timing resolution over a large area in the outer tracking volume aiding in pattern recognition and informing seeding for PID
- Yellow Report requirements met in most regions
- Integration of other detector information (e.g. EM calorimeter) should help with overall performance, in particular the backward region.

# Backup

# Outer MPGD Barrel: Material Budget