ACTS in ePIC at the future EIC

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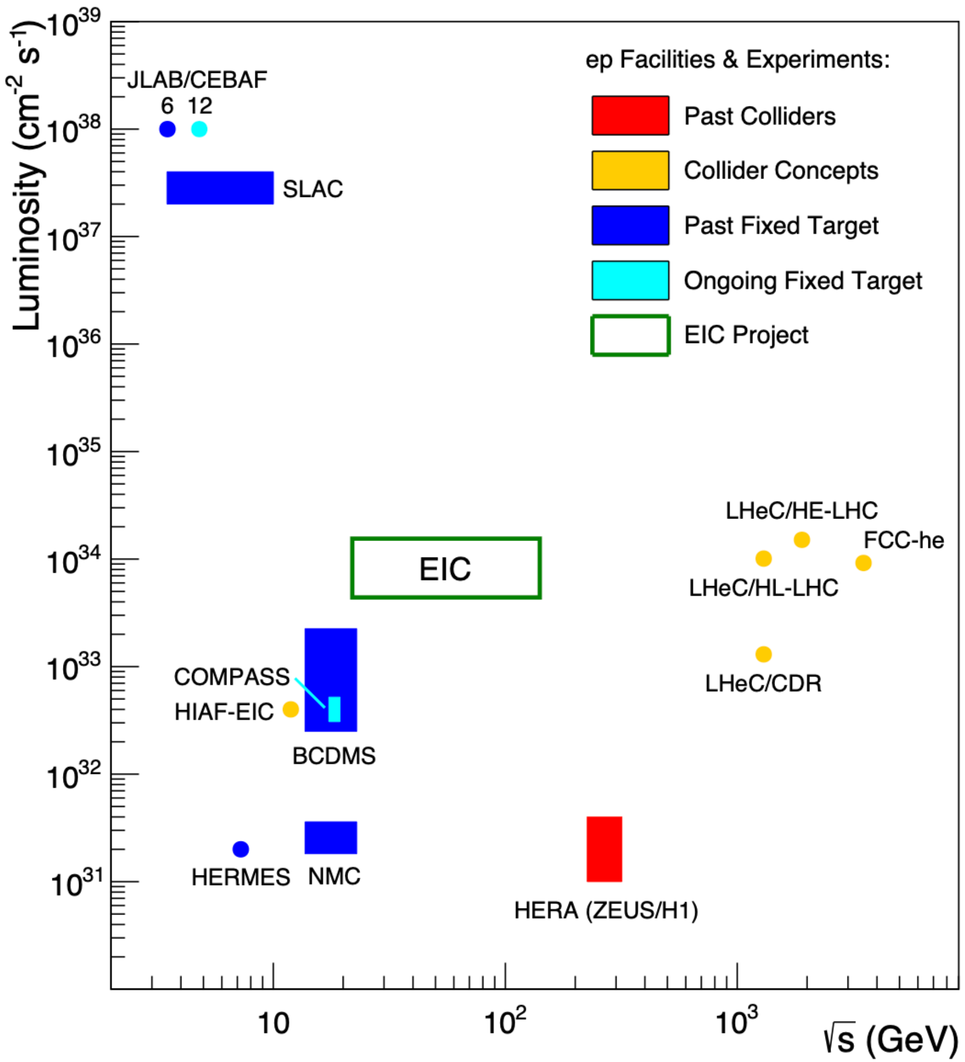
On behalf of the ePIC track reconstruction working group

The Electron-Ion Collider (EIC)



The EIC will be the first

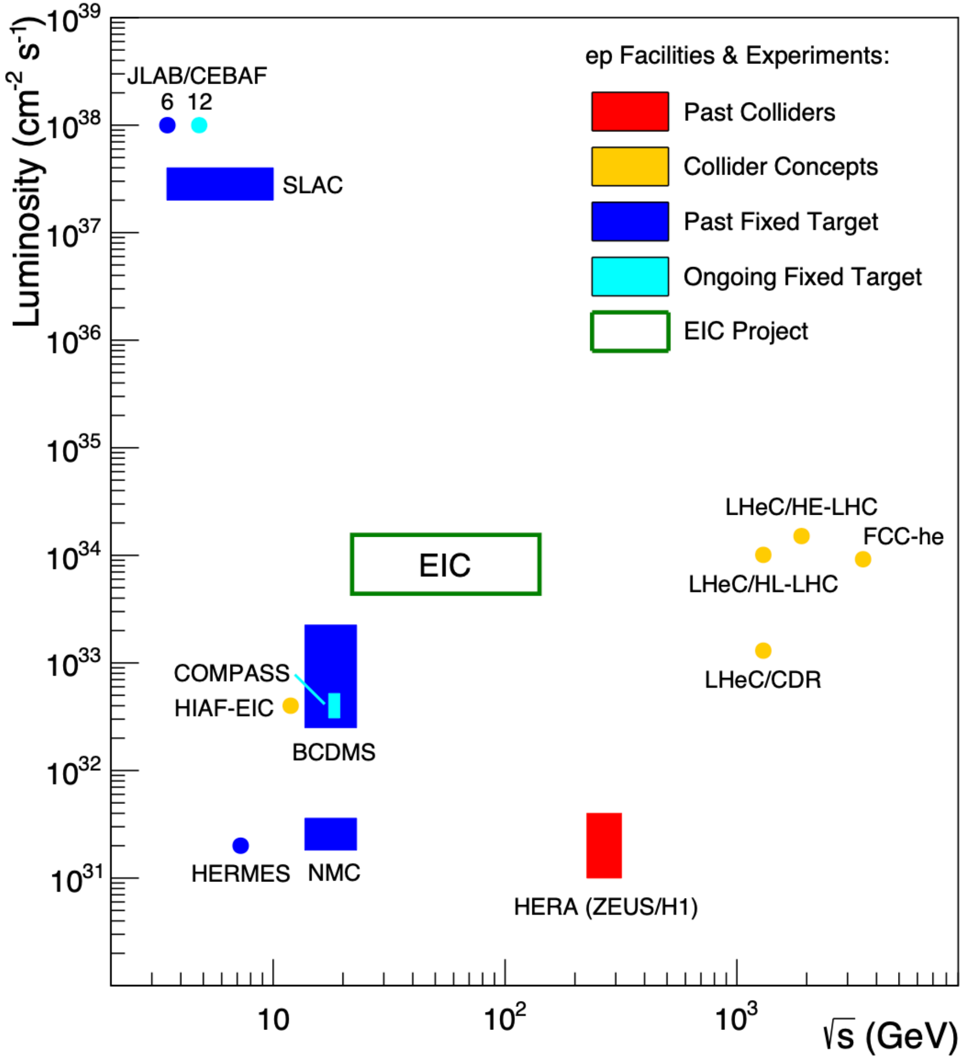
- High-luminosity e-p collider
- Polarized target collider
- Electron-nucleus collider

EIC energy range: $29 < \sqrt{s} < 141\ GeV$

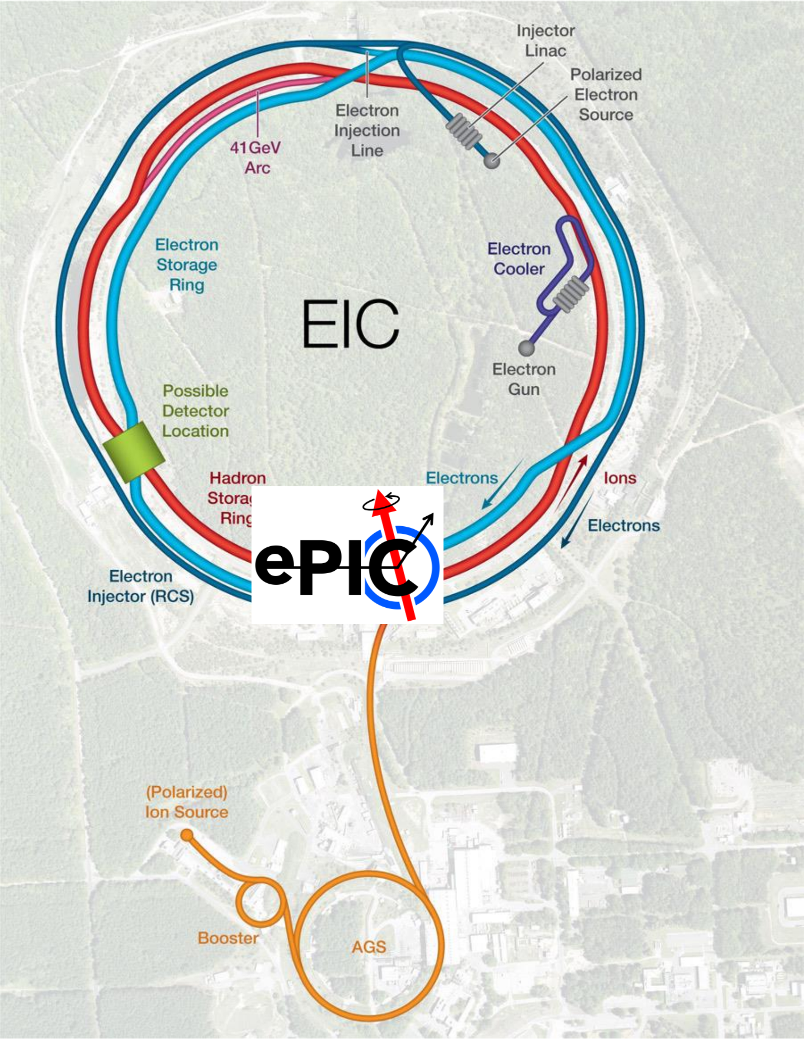
<u>Main physics topics to be explored at the EIC</u>

- Nucleon structure – full three-dimensional momentum and spatial structure, as well as spin structure
- Origin of nucleon (hadron) mass – how is the nucleon's mass generated by the underlying internal partonic interactions
- Dense partonic systems in nuclei
- Science beyond the 2018 National Academies of Science (NAS) report

The Electron-Ion Collider (EIC)



Start date: Early 2030s
Location: BNL
Budget: ~$2.4 billion



ePIC central detector design

Magnet

- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking

- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (µRWELL, MMG) cylindrical and planar

PID

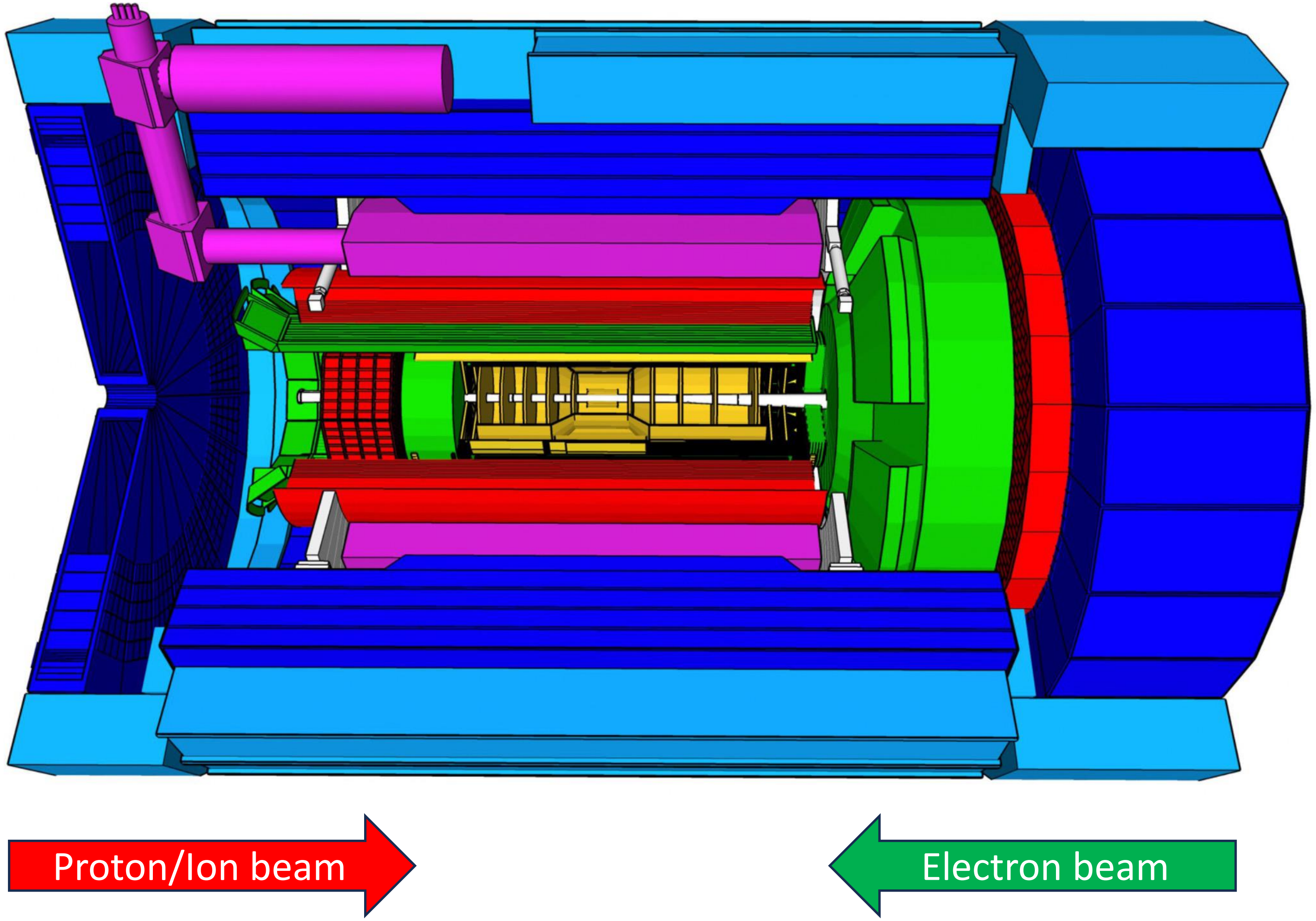
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry

- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

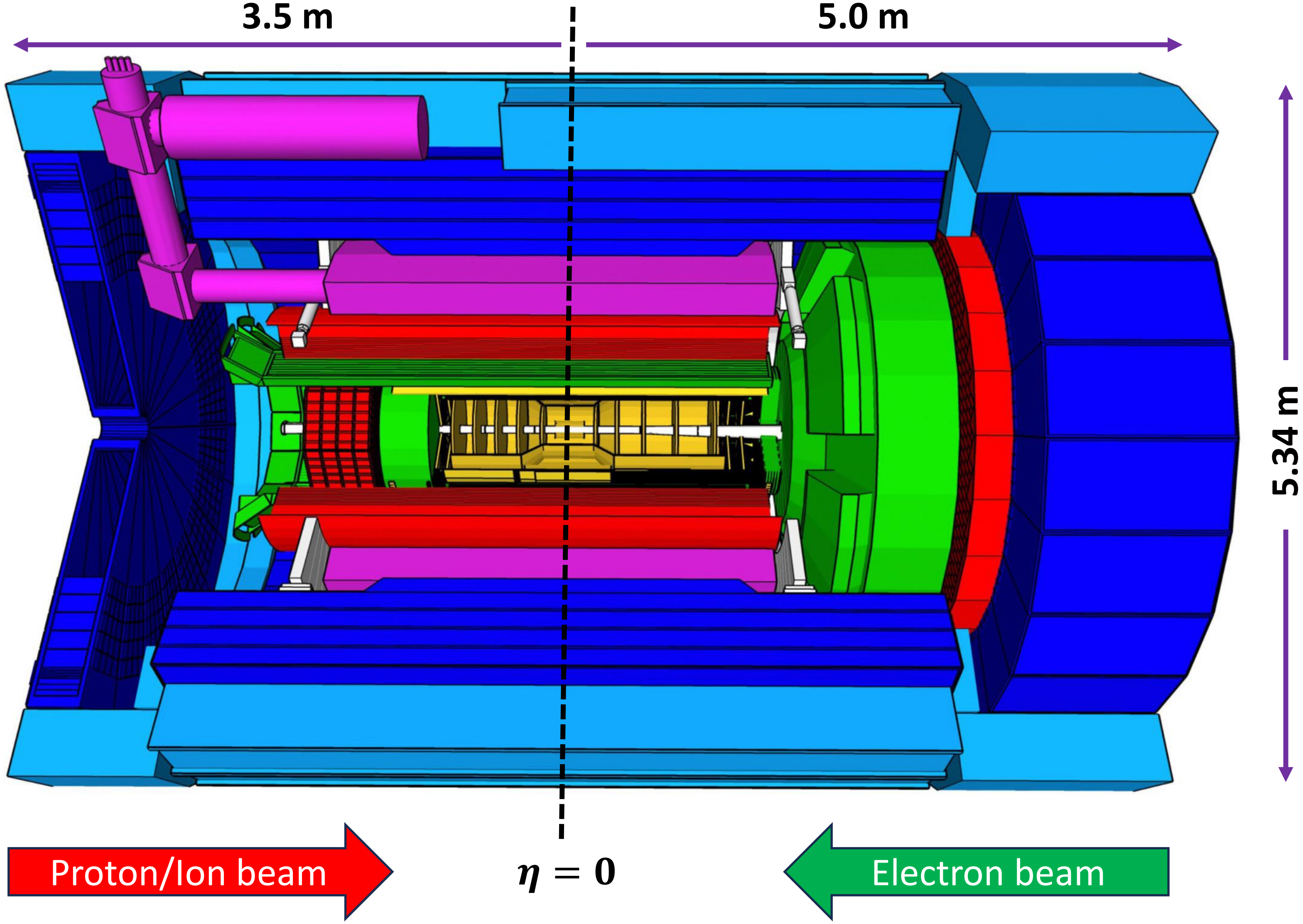
Hadron calorimetry

- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



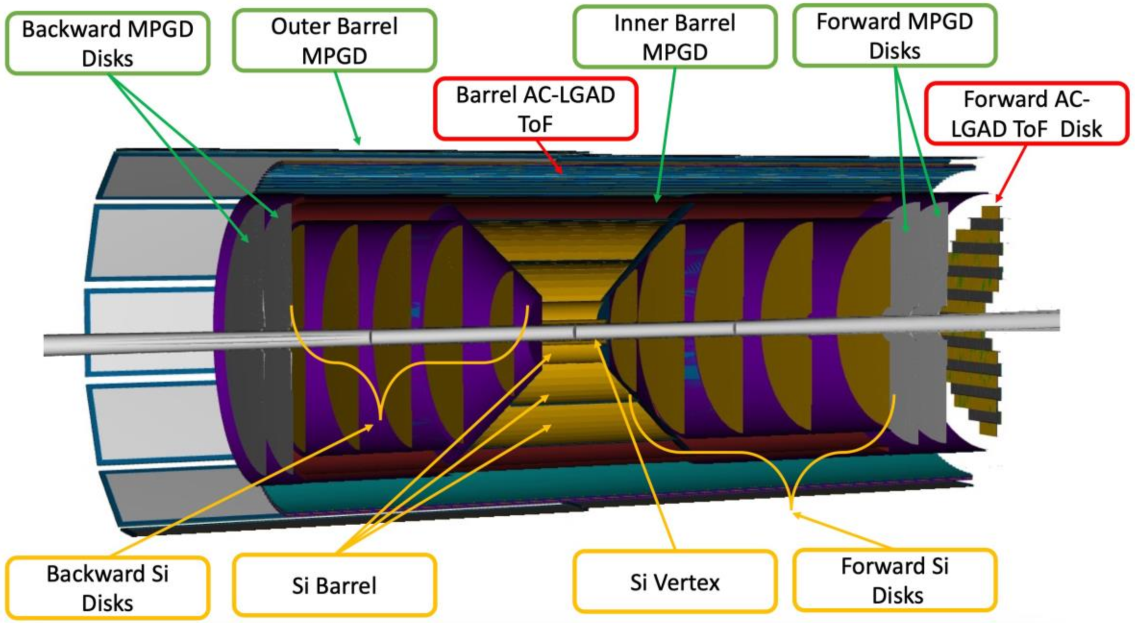
ePIC central detector design

- Central detector is ~9m long – compactness comes from IR design allowing high luminosity
- Solenoidal field – magnet won't affect the electron beam
- Combines > 16 subsystems for tracking, vertexing, PID, EM calorimetry, and hadronic calorimetry
- Substantial challenges to integrate power, cooling, and data services, while also maintaining as hermetic a detector as possible
- Detector will use streaming-readout approach



ePIC central detector design – tracking

Full tracking system: Silicon Vertex Tracker (SVT) + MPGDs + AC-LGAD TOFs detectors



MPGDs and **AC-LGADs** provide

- additional hit points for track reconstruction
- fast timing hits for background rejection (~10-20 ns)

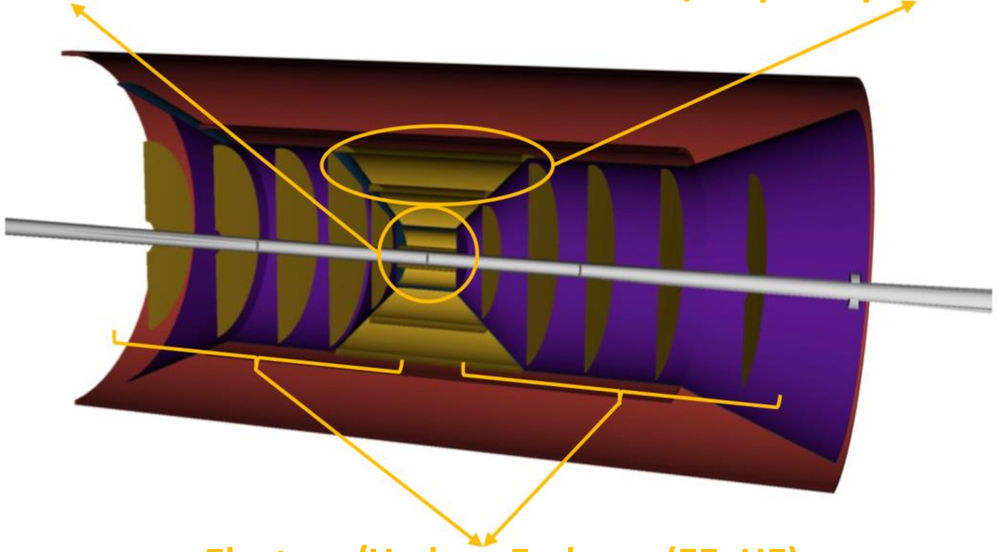
SVT

Inner Barrel (IB)

- **Two curved silicon vertex layers**
- **One curved dual-purpose layer**
- **0.05% X/X0 per layer**

Outer Barrel (OB)

- **One stave-based sagitta layer**
- **One stave-based outer layer**
- **0.55% X/X0 per layer**



Electron/Hadron Endcaps (EE, HE)

- **Five disks on either side of the Interaction Region**
- **0.24% X/X0 per layer**

65 nm MAPS technology (ALICE ITS3)
O(20x20 μm^2) pixel size
Total active area of 8.5 m^2

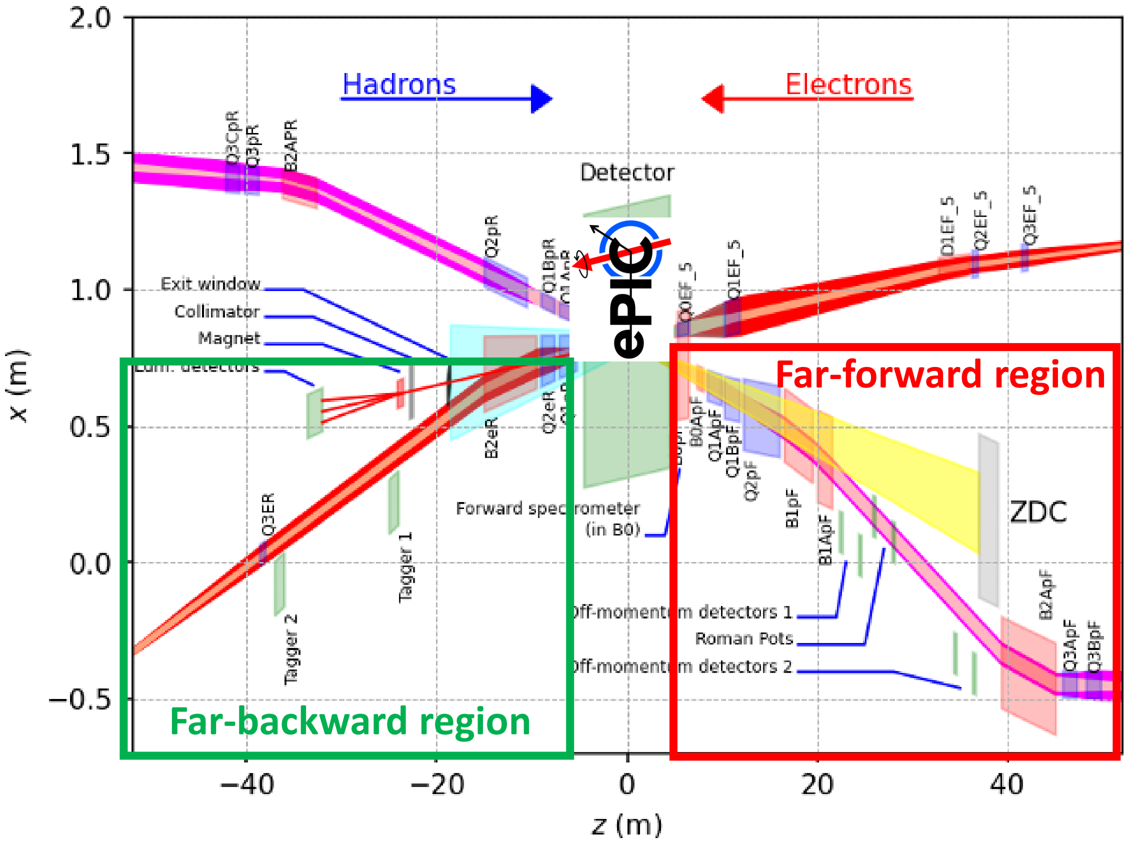
ePIC detector design – some unique features

- The full detector design is integrated over the entire 90m long EIC interaction region.

- The central (tracking) detector has an asymmetric design, due to the larger hadron beam energy relative to the electron beam energy.
- The beams have a large (25 mRad) crossing angle, which leads to an asymmetry in the horizontal direction.
- The ePIC detector will use a streaming readout mode (time slices). The time component for tracking and vertexing will be important.

- ACTS track reconstruction is being used in the central and far-forward (B0 detector) regions. For the B0 detector, thank you to the ACTS developers for adding geometry support for an off-axis detector.
- Focus of this presentation will be on tracking in the central detector region.

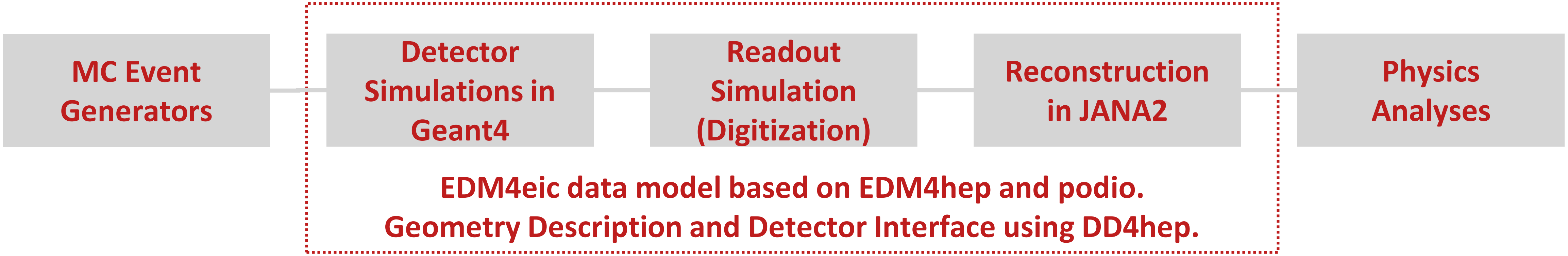
Interaction region (IR) design



ePIC software for the realization of the ePIC experiment

Our software design is based on **lessons learned in the worldwide NP and HEP community** and a **decision-making process** involving the whole community. We will continue to work with the worldwide NP and HEP community.

Modular Simulation, Reconstruction, and Analysis Toolkit using tools from the NP-HEP community



MC Event Generators

Detector Simulations in Geant4

Readout Simulation (Digitization)

Reconstruction in JANA2

Physics Analyses

EDM4eic data model based on EDM4hep and podio.
Geometry Description and Detector Interface using DD4hep.

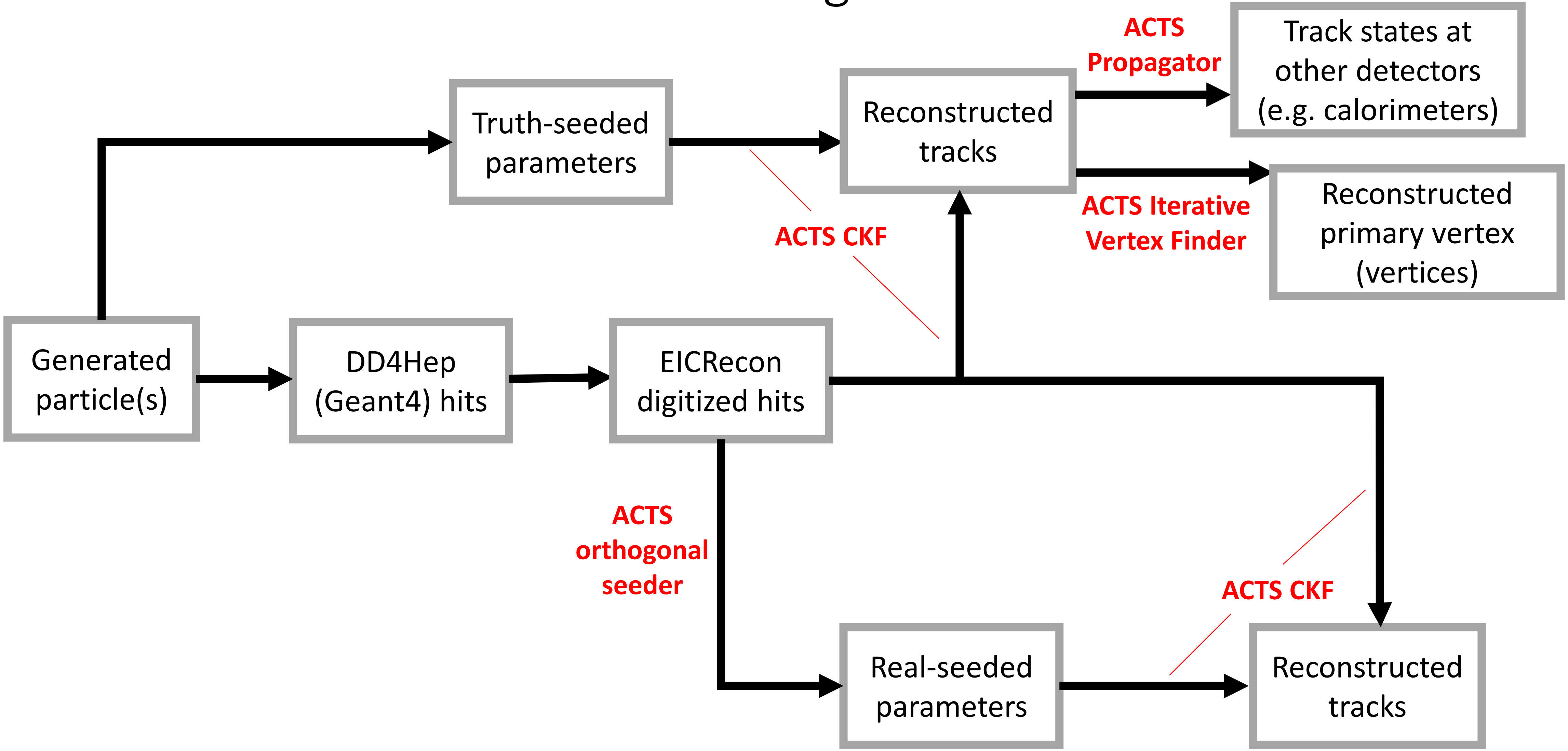
Continuous Integration for Detector and Physics Benchmarks and Reproducibility

We are providing a production-ready software stack throughout the development:

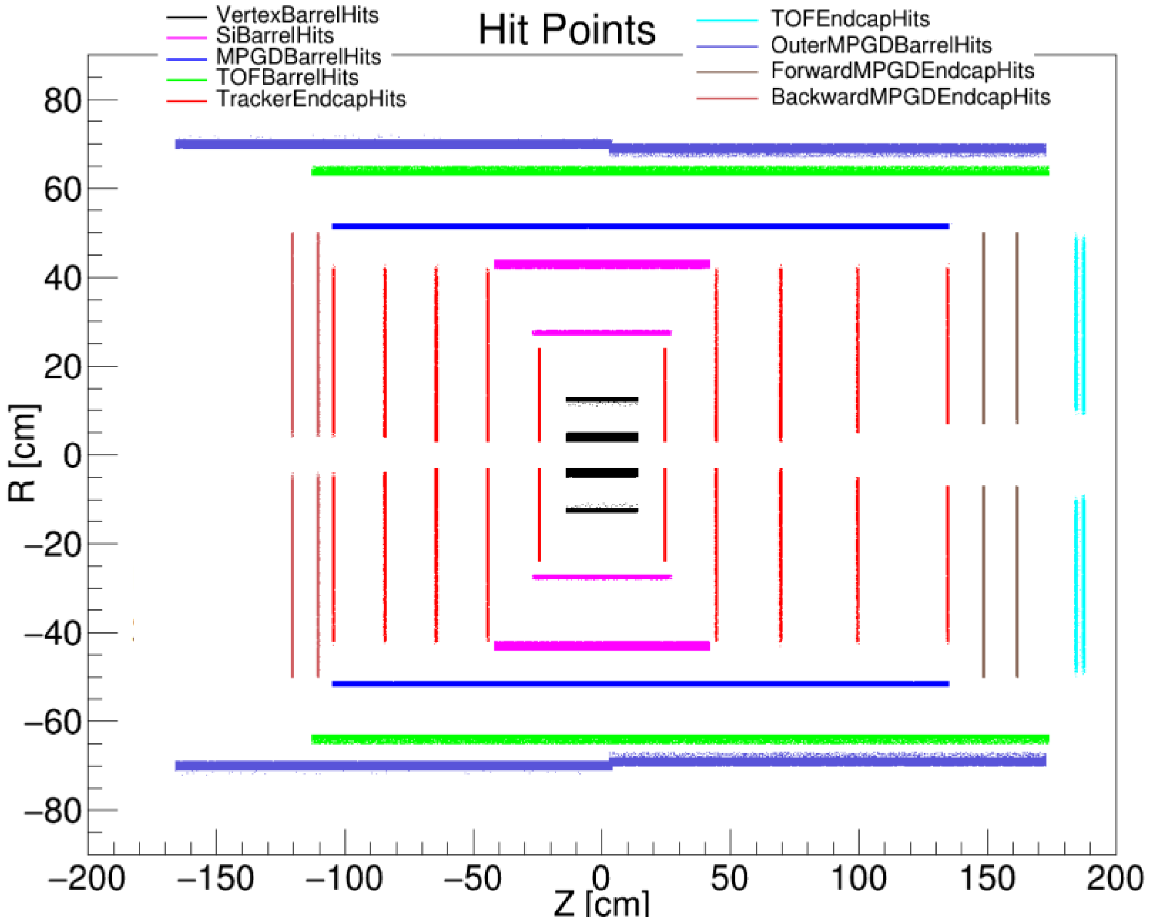
- **Milestone**: Software enabled first large-scale simulation campaign for ePIC.

We have a good foundation to meet the near-term and long-term software needs for ePIC.

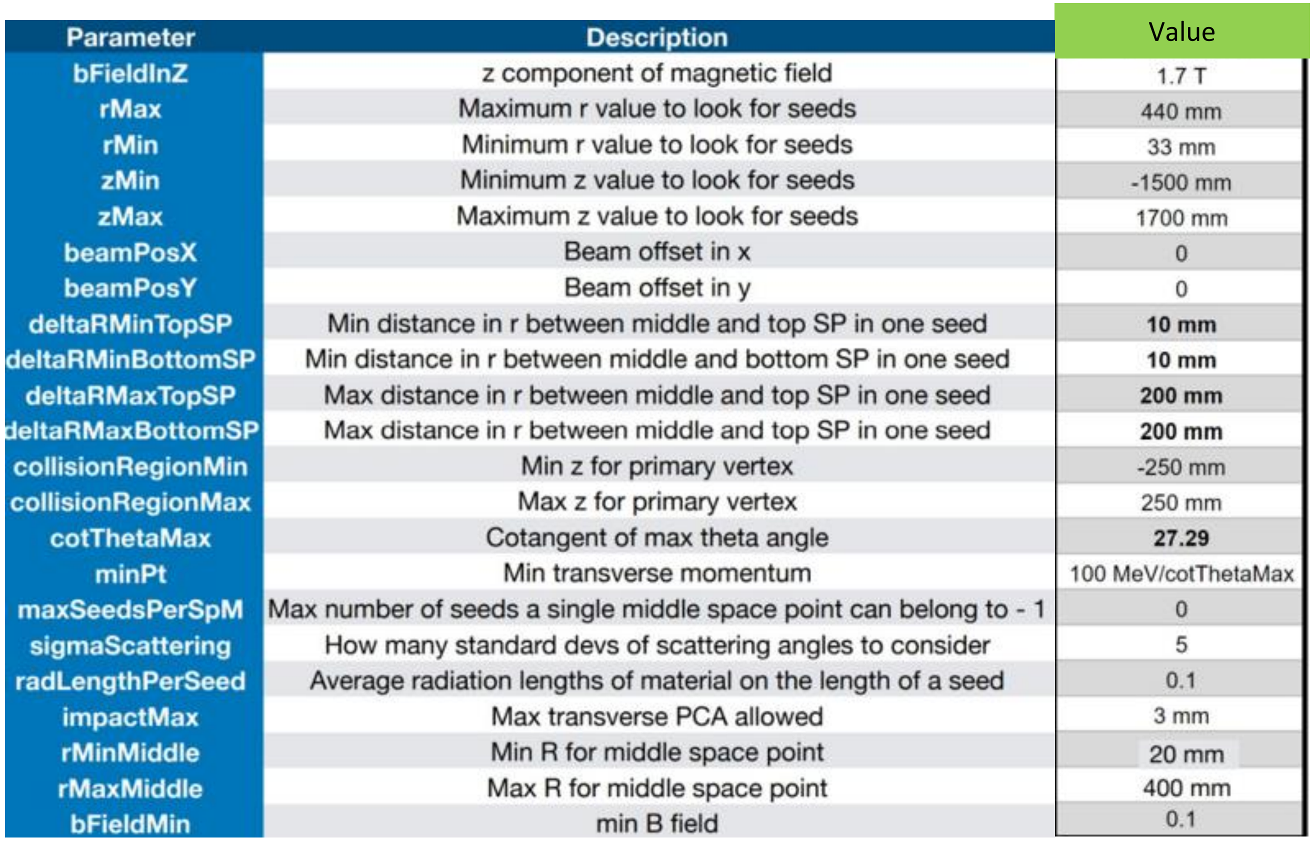
Tracking workflow



Seed finding using the ACTS orthogonal seeder



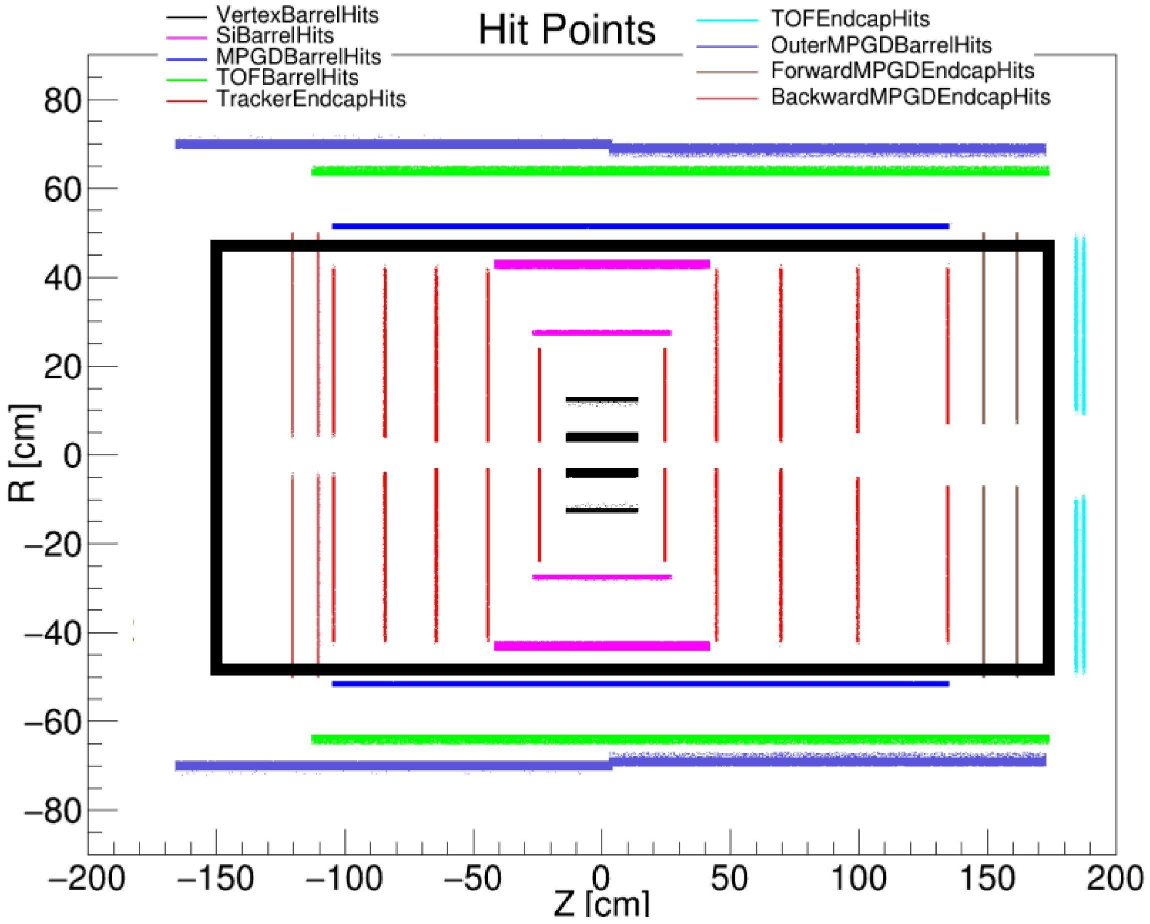
ACTS seed finder and filter parameters



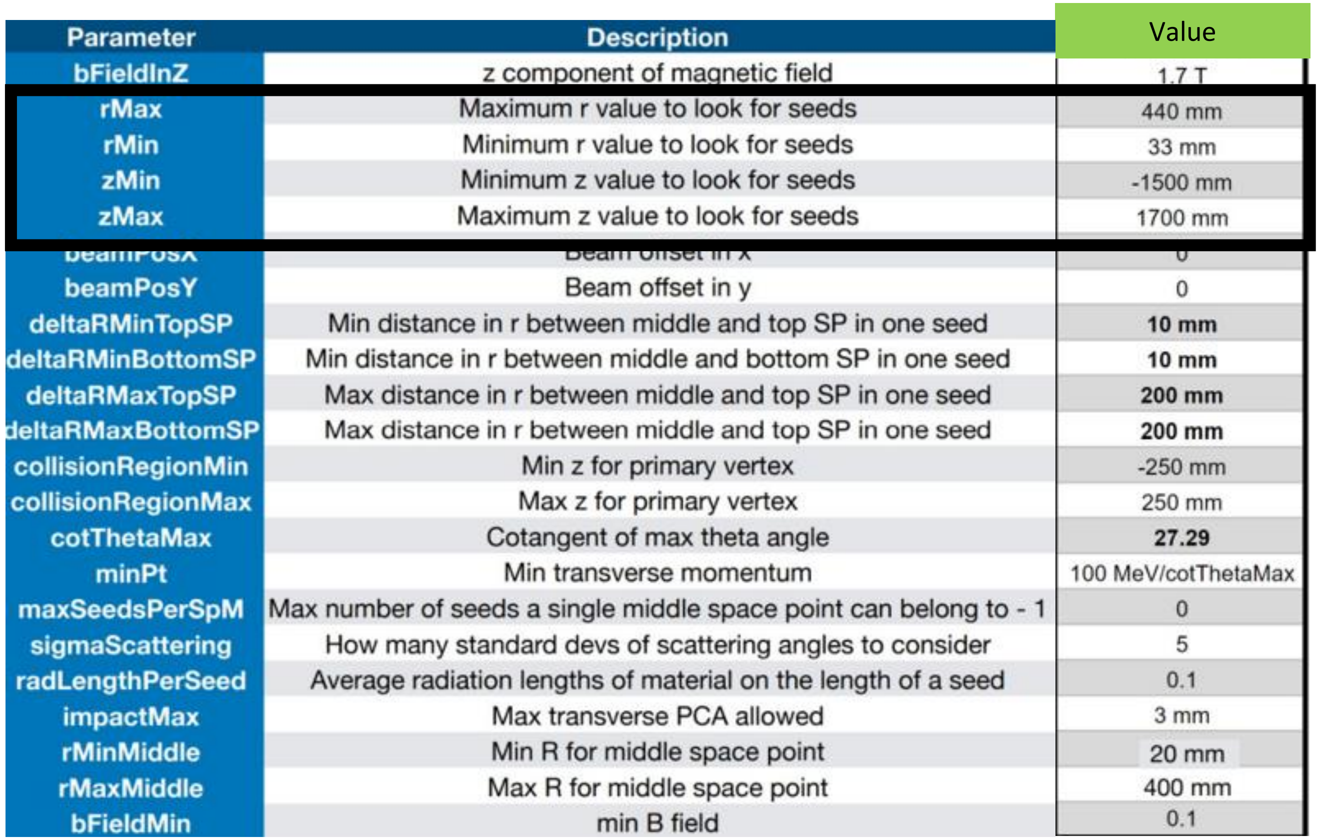
Parameter	Description	Value
bFieldInZ	z component of magnetic field	1.7 T
rMax	Maximum r value to look for seeds	440 mm
rMin	Minimum r value to look for seeds	33 mm
zMin	Minimum z value to look for seeds	-1500 mm
zMax	Maximum z value to look for seeds	1700 mm
beamPosX	Beam offset in x	0
beamPosY	Beam offset in y	0
deltaRMinTopSP	Min distance in r between middle and top SP in one seed	**10 mm**
deltaRMinBottomSP	Min distance in r between middle and bottom SP in one seed	**10 mm**
deltaRMaxTopSP	Max distance in r between middle and top SP in one seed	**200 mm**
deltaRMaxBottomSP	Max distance in r between middle and top SP in one seed	**200 mm**
collisionRegionMin	Min z for primary vertex	-250 mm
collisionRegionMax	Max z for primary vertex	250 mm
cotThetaMax	Cotangent of max theta angle	**27.29**
minPt	Min transverse momentum	100 MeV/cotThetaMax
maxSeedsPerSpM	Max number of seeds a single middle space point can belong to - 1	0
sigmaScattering	How many standard devs of scattering angles to consider	5
radLengthPerSeed	Average radiation lengths of material on the length of a seed	0.1
impactMax	Max transverse PCA allowed	3 mm
rMinMiddle	Min R for middle space point	20 mm
rMaxMiddle	Max R for middle space point	400 mm
bFieldMin	min B field	0.1

Seed finding using the ACTS orthogonal seeder

We search for seeds in part of our tracking volume – that is in our MAPS silicon pixel detectors.



ACTS seed finder and filter parameters



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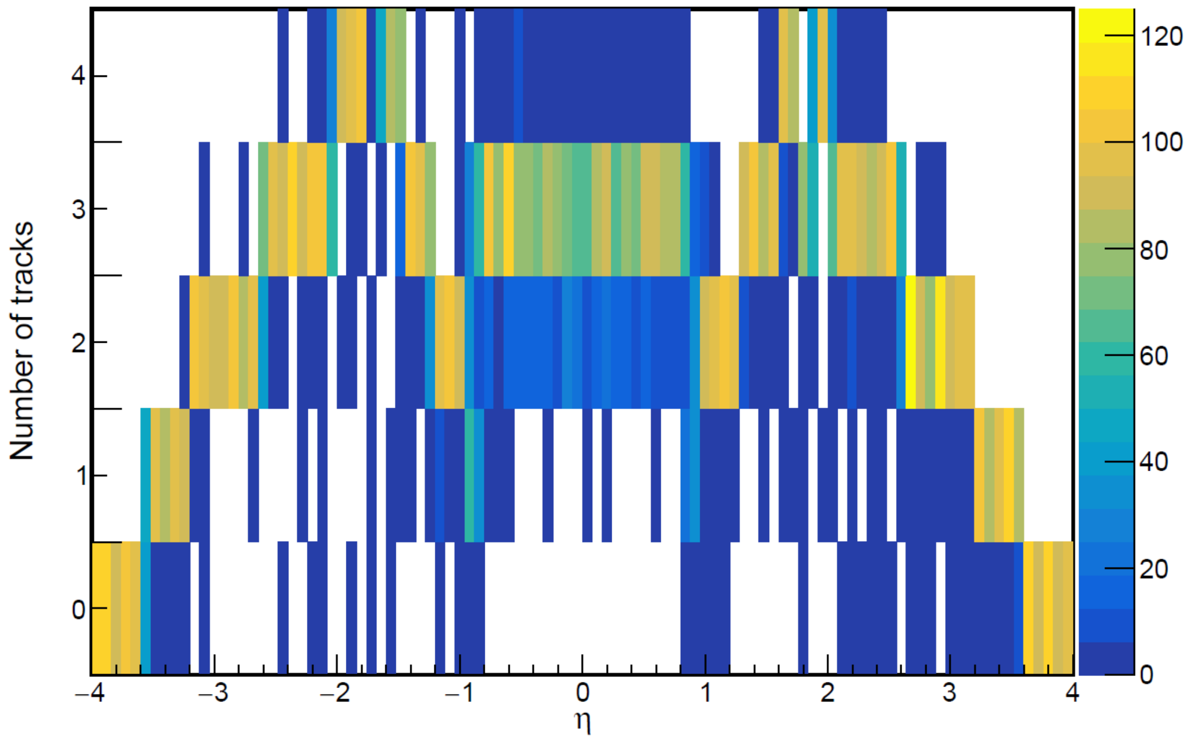
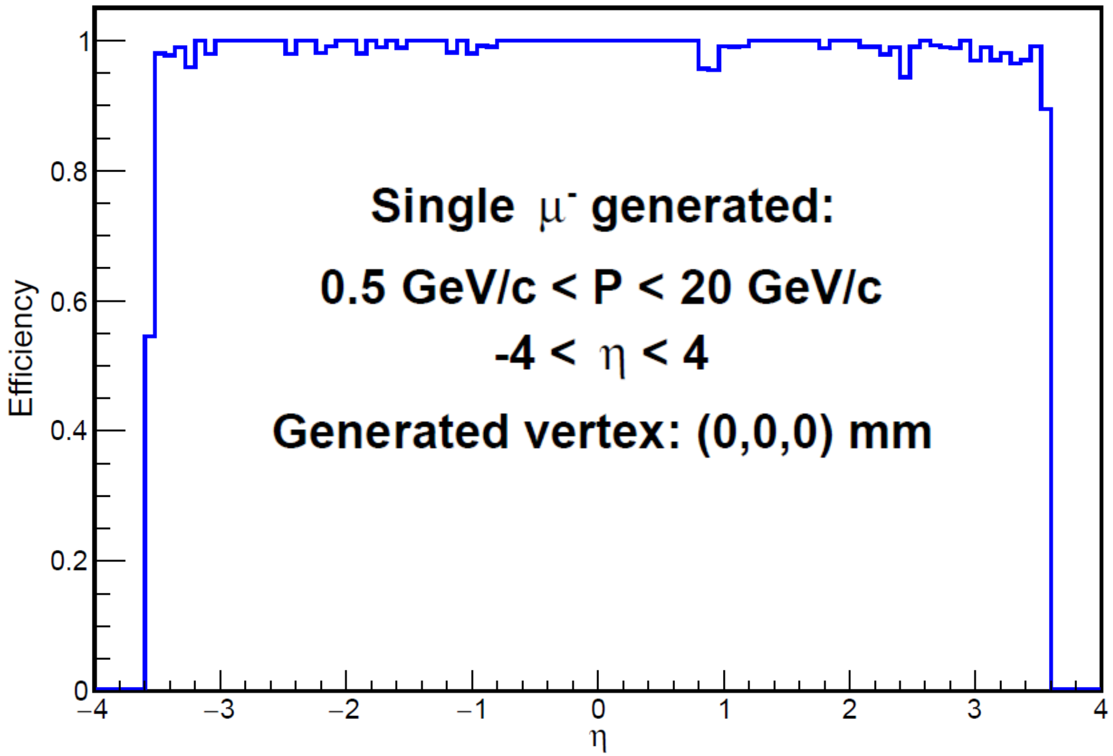
Single-particle tracking efficiency/multiplicity


Number of tracks vs. generated particle η


Tracker Efficiency vs. generated particle η

Single μ^- generated:

0.5 GeV/c < P < 20 GeV/c

$-4 < \eta < 4$

Generated vertex: (0,0,0) mm

An efficient event is defined as one where at least one track is found. We (almost) always get a single track per seed in our setup right now. This is because we only save the trajectory with the longest branch (i.e. the *trackTips.front()*).

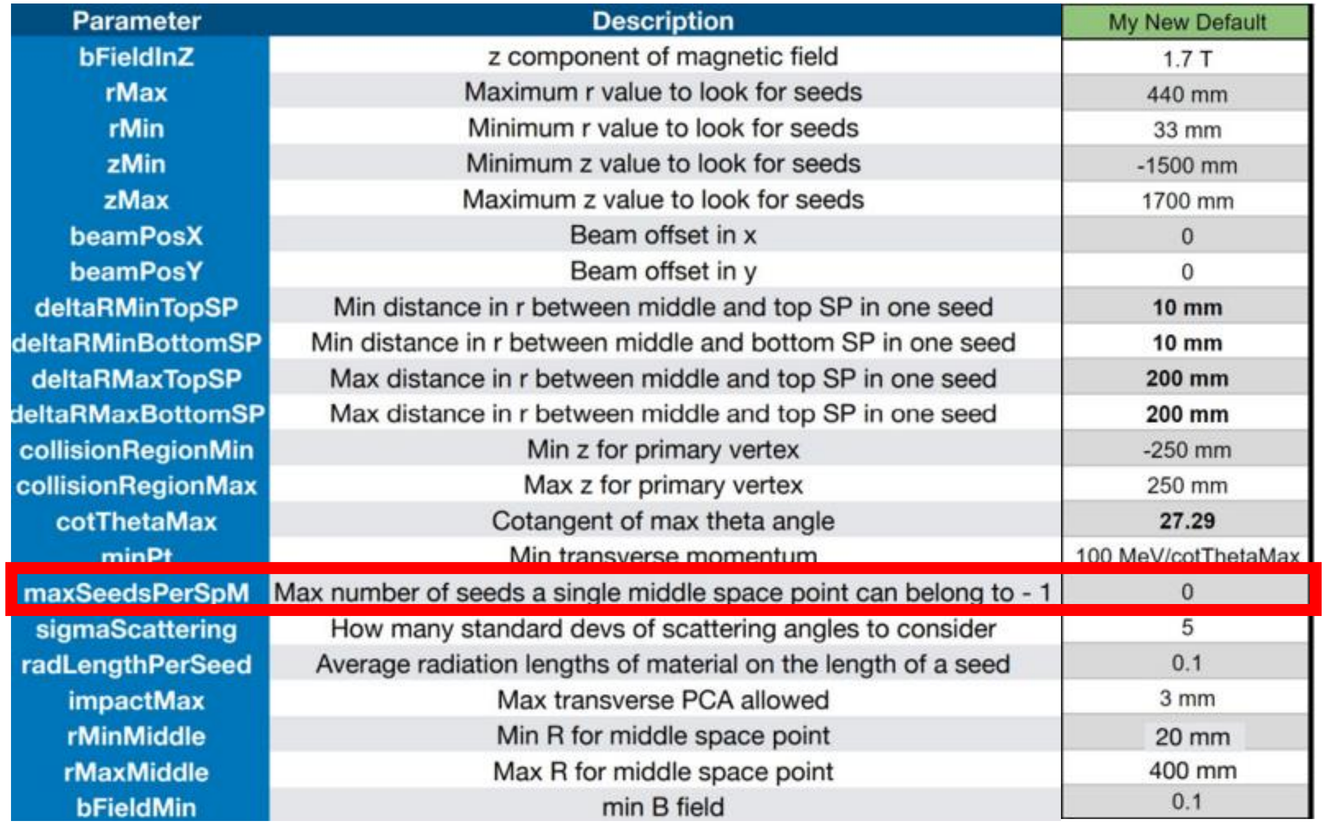
Seed duplicates – particles have multiple seeds

If we have a particle at mid-rapidity which hits layers L0, L1, L2, L3, and L4, then we can make the following combinations:

1. L0,L1,L2
2. L0,L2,L3
3. L0,L3,L4

✖ 4. L0,L1,L3
✖ 5. L0,L1,L4
✖ 6. L0,L2,L4
✖ 7. L1,L2,L3
✖ 8. L1,L2,L4
✖ 9. L1,L3,L4
✖ 10. L2,L3,L4

ACTS seed finder and filter parameters



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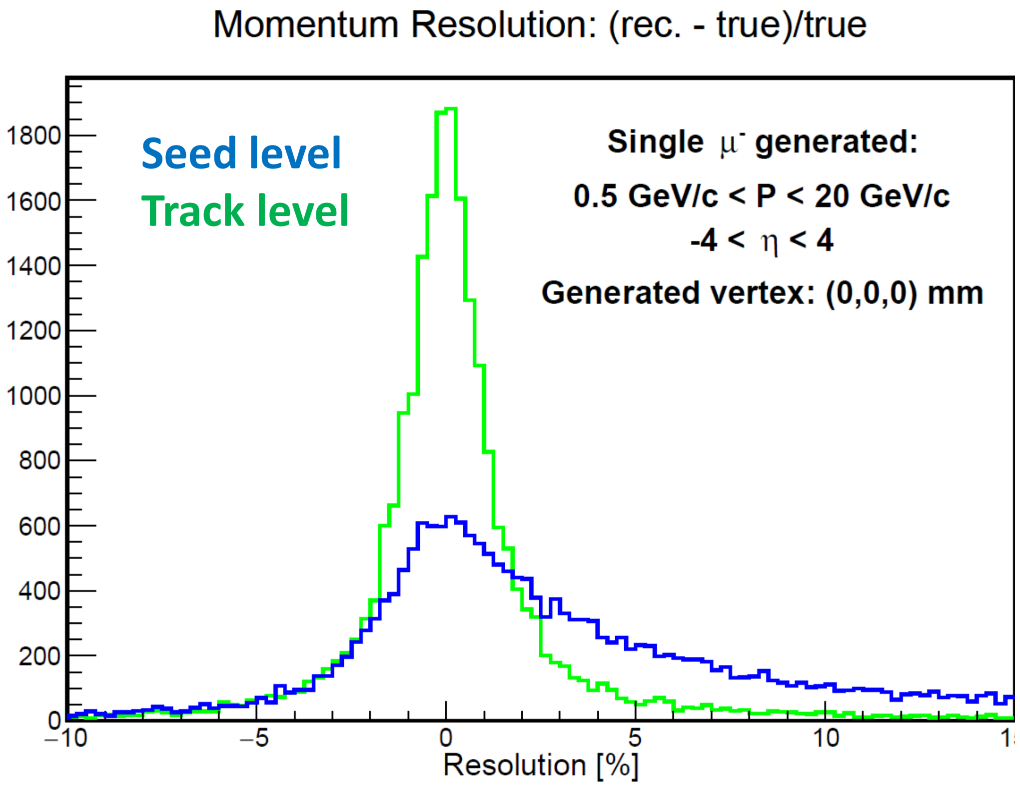
bFieldMin	min B field	0.1

Tracking performance

Real-seeded tracking


Momentum Resolution: (rec. - true)/true

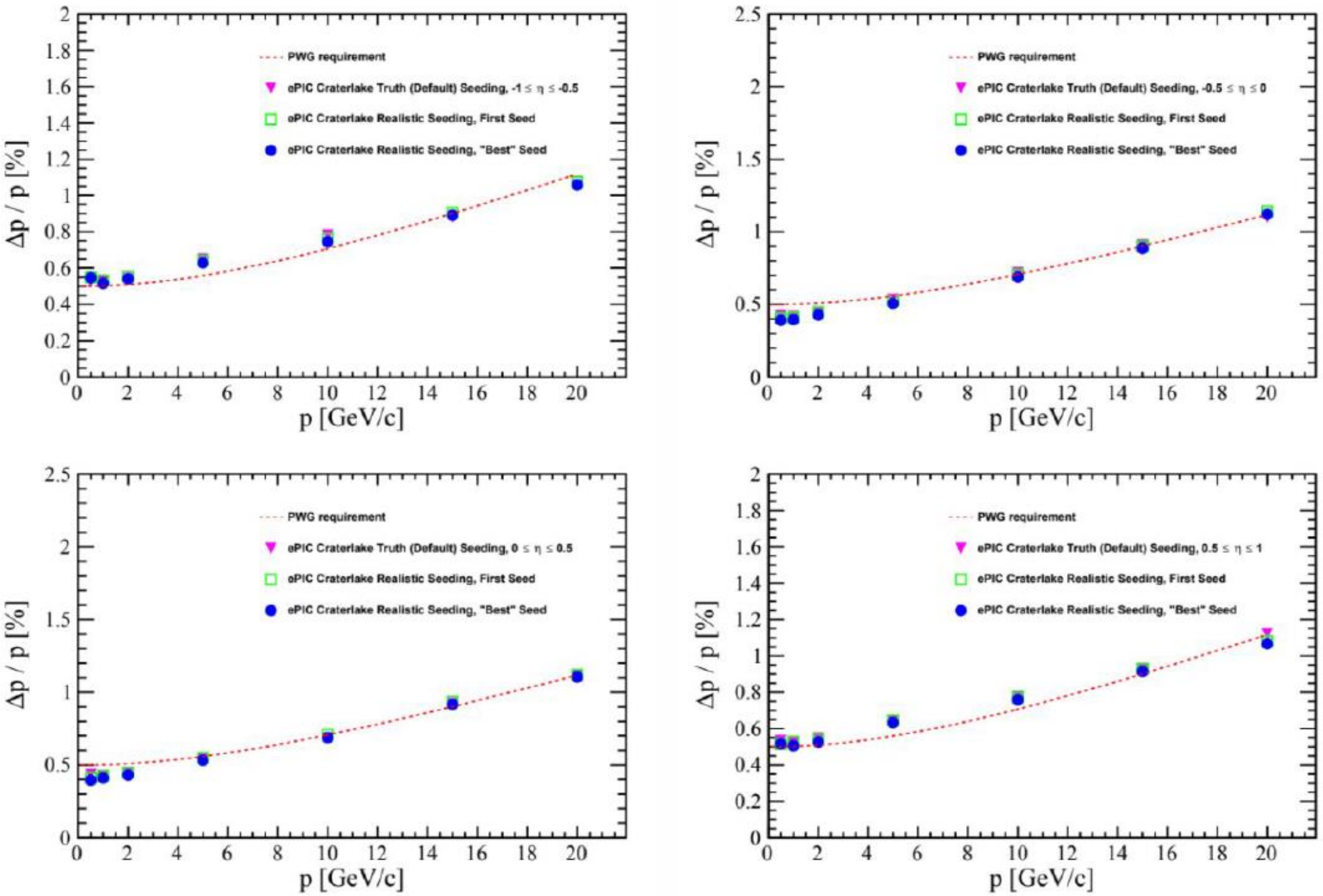
Single μ^- generated:

0.5 GeV/c < P < 20 GeV/c

-4 < η < 4

Generated vertex: (0,0,0) mm

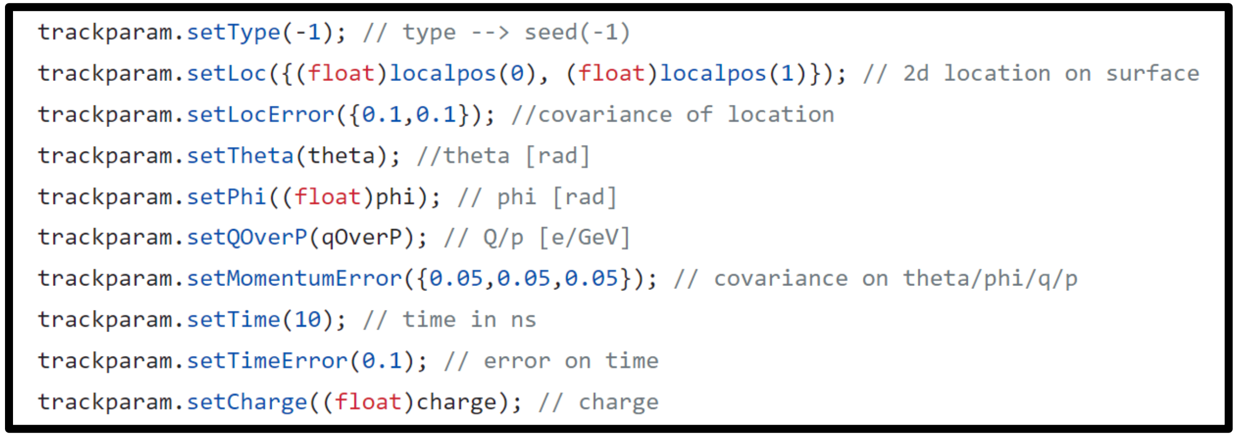
Comparison of truth-seeded and real-seeded tracking



Some seeding-related questions we are working on

- We are trying to implement removal of the duplicate seeds/tracks using the seed filter/confirmation, as well as by matching the hits used in the final set of tracks. Are there other ambiguity tools that exist in ACTS?
- After running the seeder and fitting the three seed points for a given seed, we have the initial set of parameters that are fed into the CKF. We also provide the CKF a covariance matrix corresponding to the initial track parameters. Right now, these parameters are set to fixed numbers. We are looking into the affect of varying these parameters.

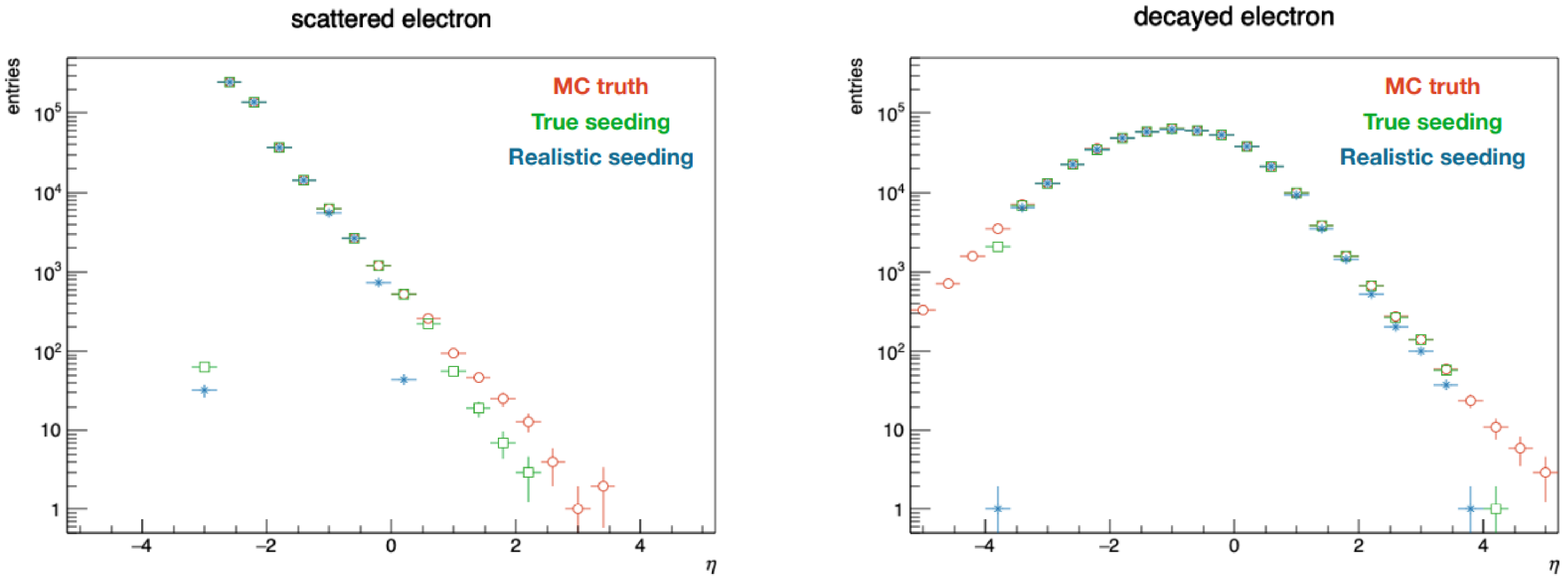
Initial set of track parameters and errors that are given to the CKF



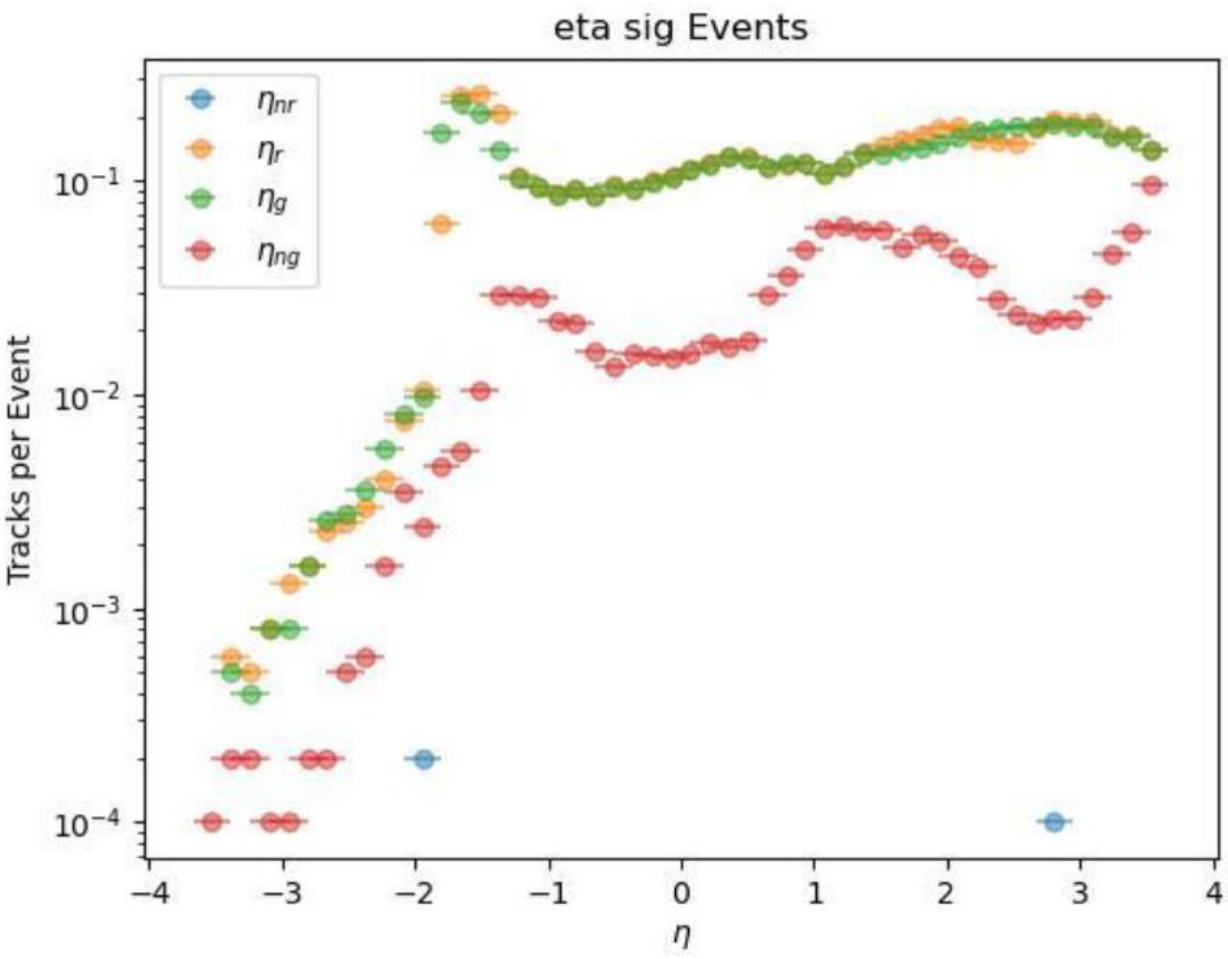
```
trackparam.setType(-1); // type --> seed(-1)
trackparam.setLoc({(float)localpos(0), (float)localpos(1)}); // 2d location on surface
trackparam.setLocError({0.1,0.1}); //covariance of location
trackparam.setTheta(theta); //theta [rad]
trackparam.setPhi((float)phi); // phi [rad]
trackparam.setQOverP(qOverP); // Q/p [e/GeV]
trackparam.setMomentumError({0.05,0.05,0.05}); // covariance on theta/phi/q/p
trackparam.setTime(10); // time in ns
trackparam.setTimeError(0.1); // error on time
trackparam.setCharge((float)charge); // charge
```

Track Reconstruction for physics events

J/ψ electroproduction: 5 GeV^2 < Q^2 < 10 GeV^2
Three particles detected in the final state: 2 electrons + positron



Track Reconstruction for physics events



Inclusive DIS w/real-seeded tracking : $Q^2 > 10\ GeV^2$

Monte Carlo (MC) charged particles that get Reconstructed
Reconstructed tracks that get matched to an MC charged particle after duplicates removed
MC charged particles that do not get reconstructed
Reconstructed tracks that do not get matched to an MC charged particle

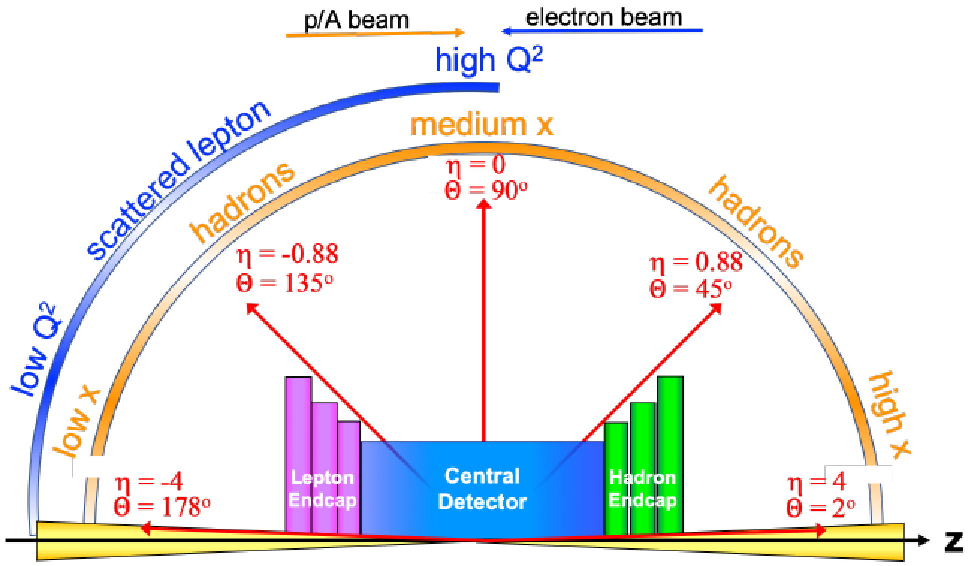
Summary / ongoing work

- The EIC project is on schedule. ePIC is a new collaboration formed last year to build the first EIC detector and realize the science potential of the EIC.
- Ongoing track-related work with ACTS:
  1. Filtering seed/track duplicates either with the seed filter and/or on the track level
  2. More systematic studies of multi-particle events, including DIS events and events with embedded background
  3. Vertex finding/fitting studies
  4. Including the detector time information in the track fit
  5. Track fitting with the far-forward B0 detector
  6. ACTS version update from v21.1
- Thank you to the ACTS developers for all the help with track reconstruction development in ePIC.

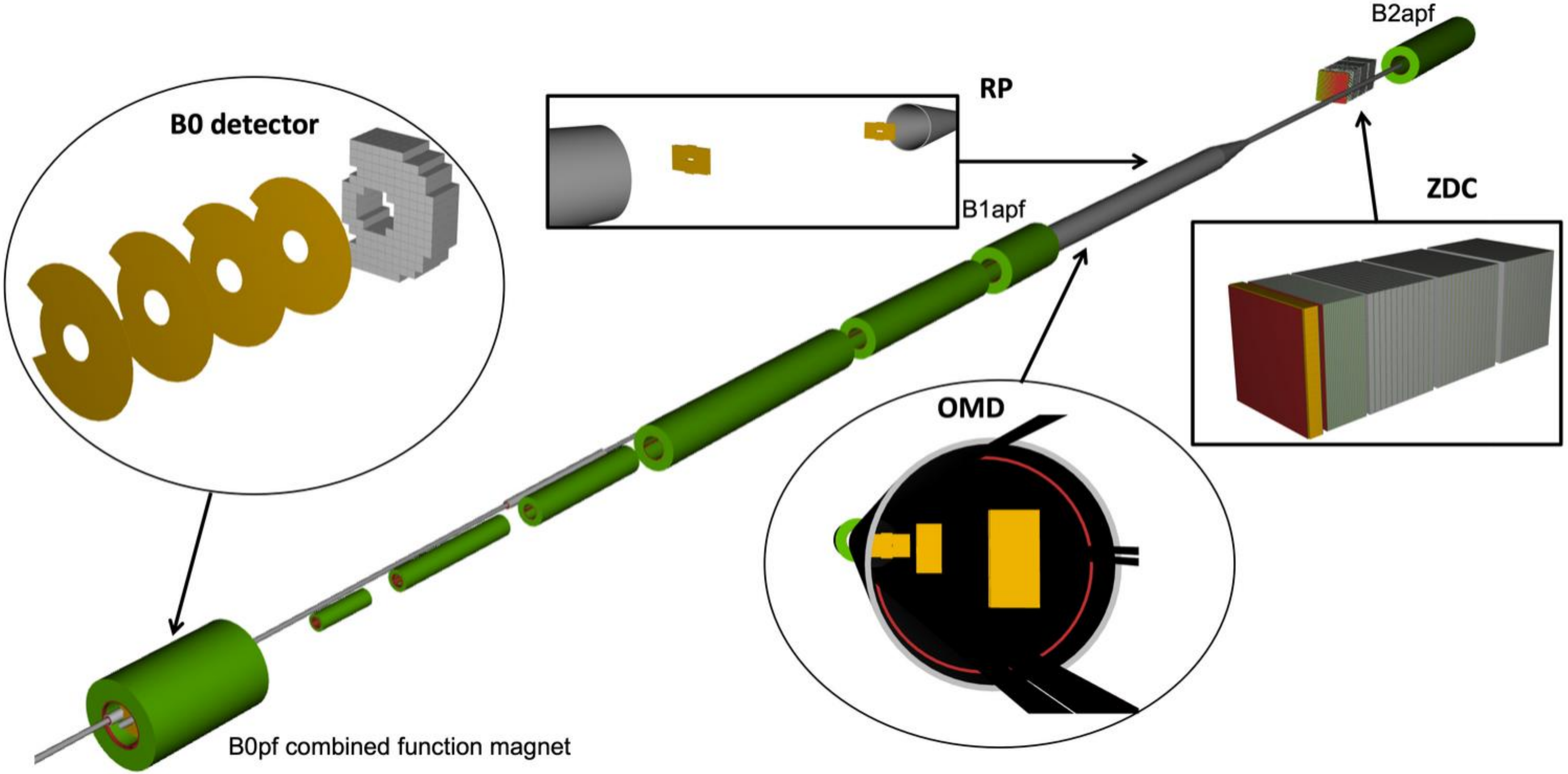
Backup

General EIC detector requirements

Detector requirement	Associated challenge
Hermetic coverage for the scattered electron	Leave no gaps in EMcal coverage while also incorporating PID readout
Good momentum resolution over the entire detector acceptance, including for the endcap regions	Design trackers to optimize momentum resolution when the particle has a large component parallel to the solenoid field
High scattered electron purity in the backwards direction and barrel	Require high-precision EMcals and additional detectors for low momentum
PID for π/K/p separation down to very low momenta	Combine multiple technologies to obtain continuous coverage from high to low momentum
Good forward calorimetry and PID	Need good energy resolution for hadronic final state; space is constrained for PID detector placement



Far-forward region



The ePIC Collaboration

171 institutions
24 countries

500+ participants

A truly global pursuit for a new experiment at the EIC!