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U.S. DEPARTMENT OF ENERGY
Office of Science

Track Reconstruction at the Electron-Ion Collider

An effort from the ATHENA detector proposal collaboration, with much appreciated contributions and help from the Acts group

Shujie Li
Berkeley Lab

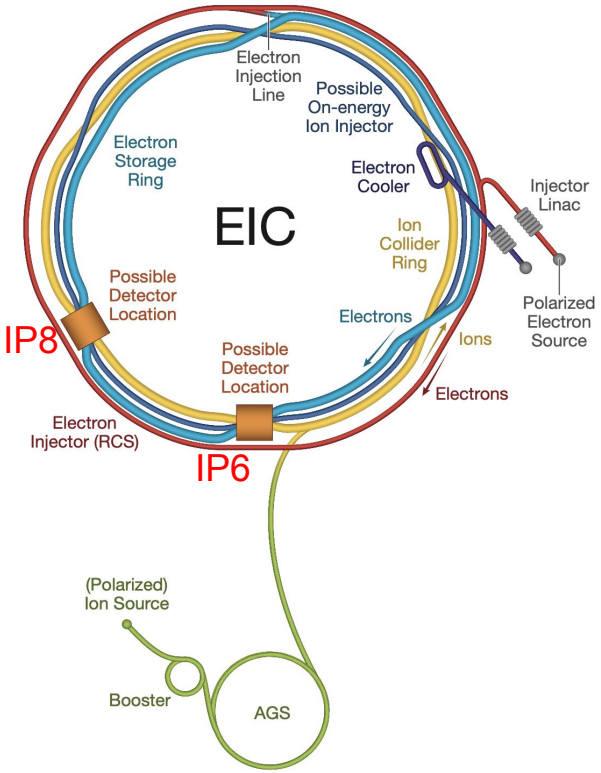
June 2nd @ CTD 2022

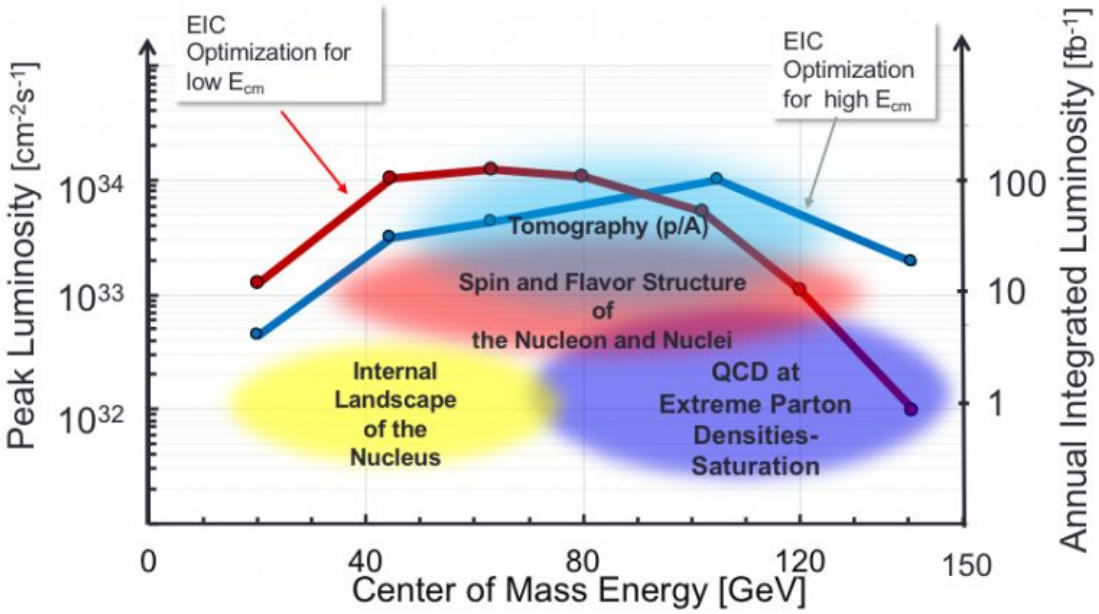
ATHENA

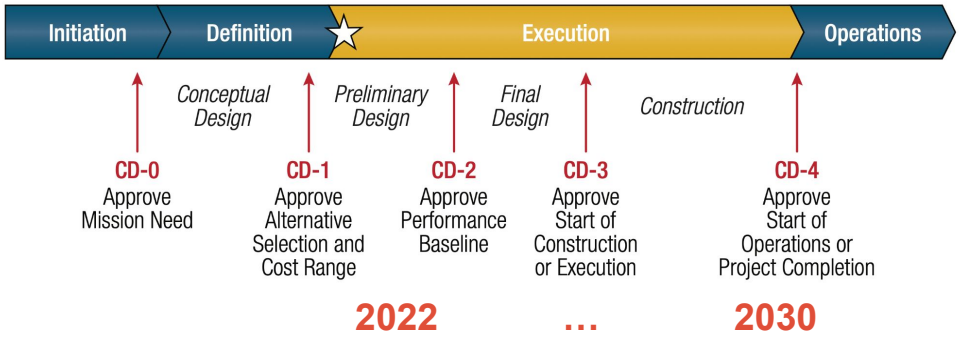
EIC Overview

https://www.bnl.gov/eic/
http://eicug.org

- Beam properties:
  - Electron: 2.5 - 18 GeV
  - Hadron: 40 - 275 GeV
  - Crossing angle: 25 mrad
  - Collision rate: 500 kHz - 1 MHz



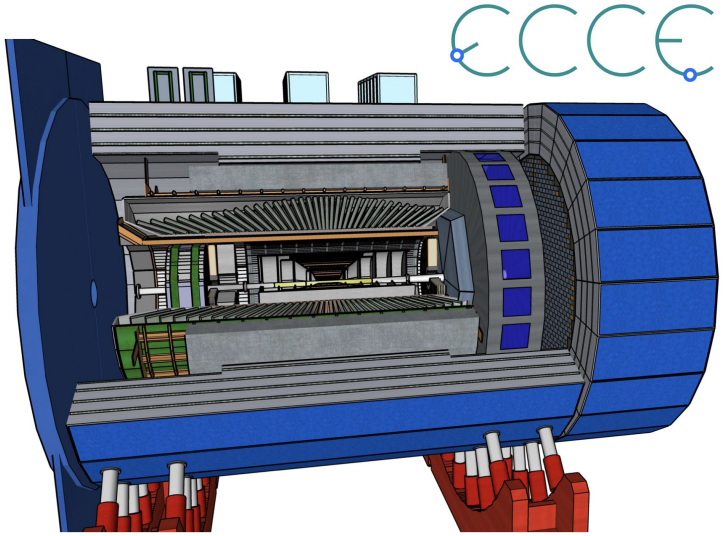




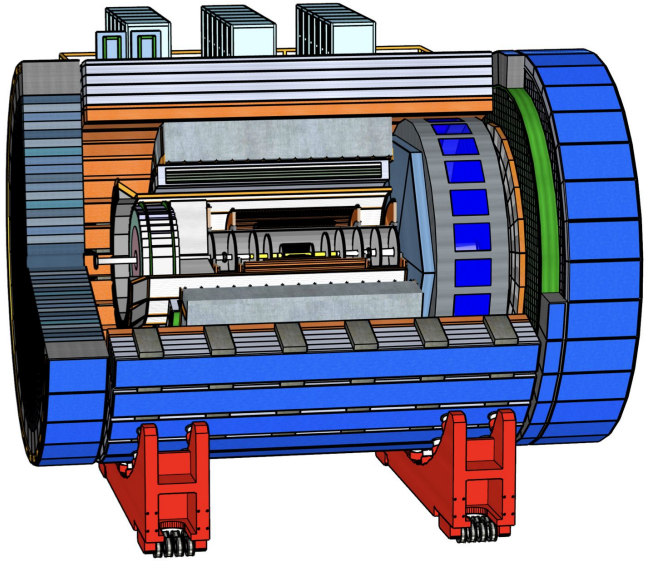
EIC Detector 1 Proposals

- Call for proposal: https://www.bnl.gov/eic/cfc.php
- Detector Proposal Advisory Panel meeting: https://www.bnl.gov/dpapanelmeeting/

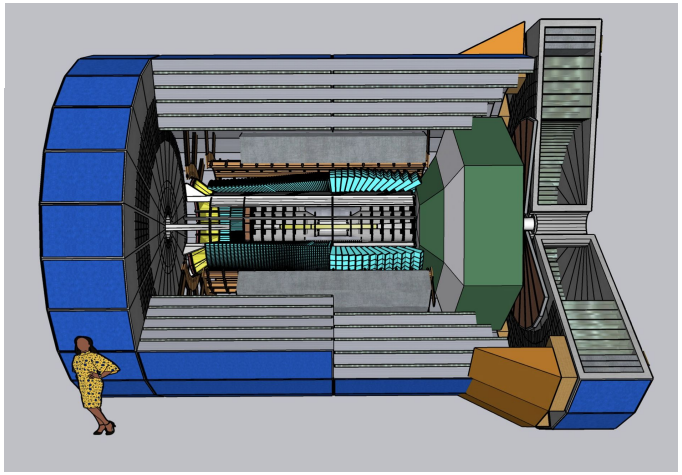
- Meet physics requirements as listed in the EIC yellow report (arxiv: 2103.05419)
- Cost, schedule, and risk



1.5T magnet from BaBar/sPHENIX.
Suggested as the reference design



designed for IP8 with second focus for far-forward physics



ATHENA

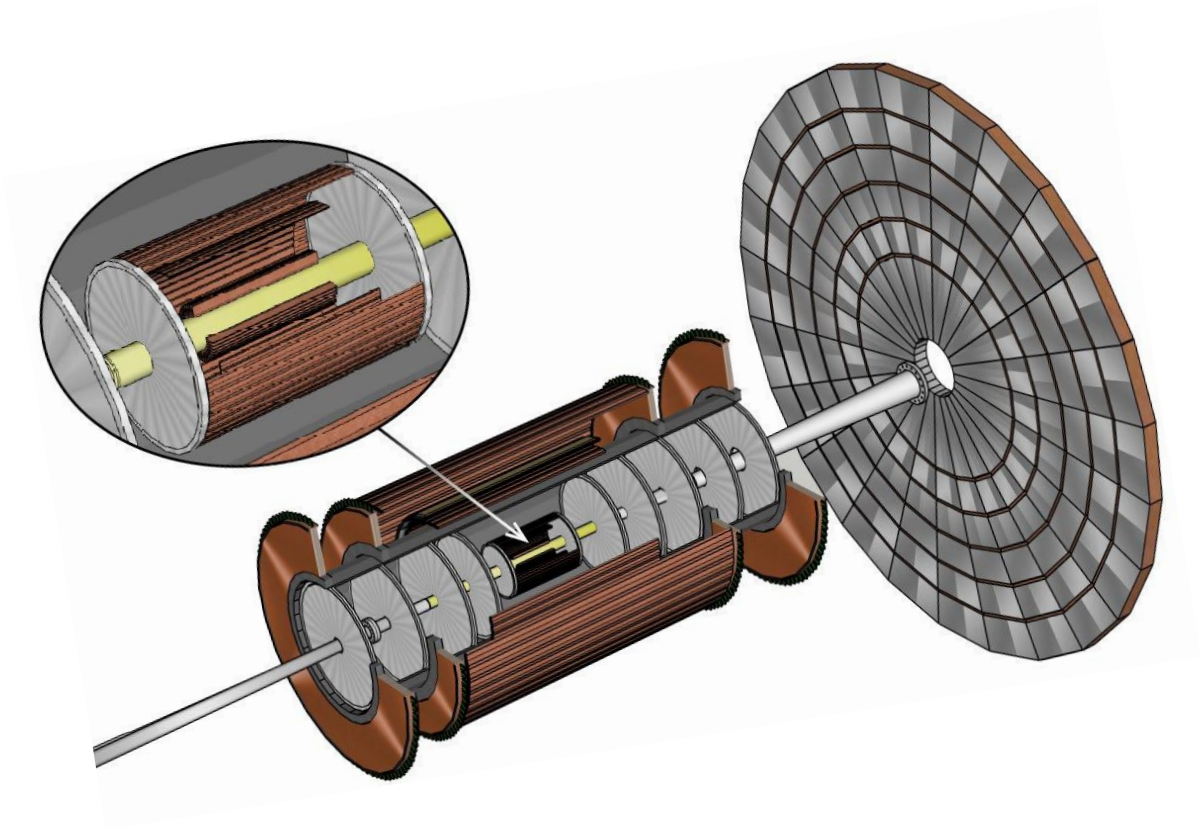
3T new solenoid magnet

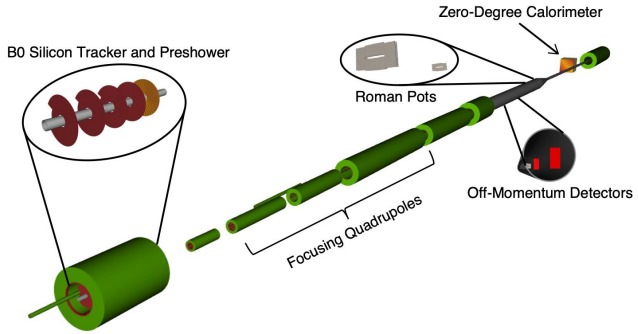
- Homepage: https://sites.temple.edu/eicatip6/
- the rest of this presentation will **ONLY** cover studies during ATHENA proposal studies.

ATHENA Tracking System

Central detector:

- Compact - total length limited to approx. 9.5 m for luminosity reasons
- Low-mass, high granularity - monolithic active pixel sensor (MAPS) based inner tracker
- Large acceptance covering both the electron and the ion hemisphere : -3.8 < eta < 3.8



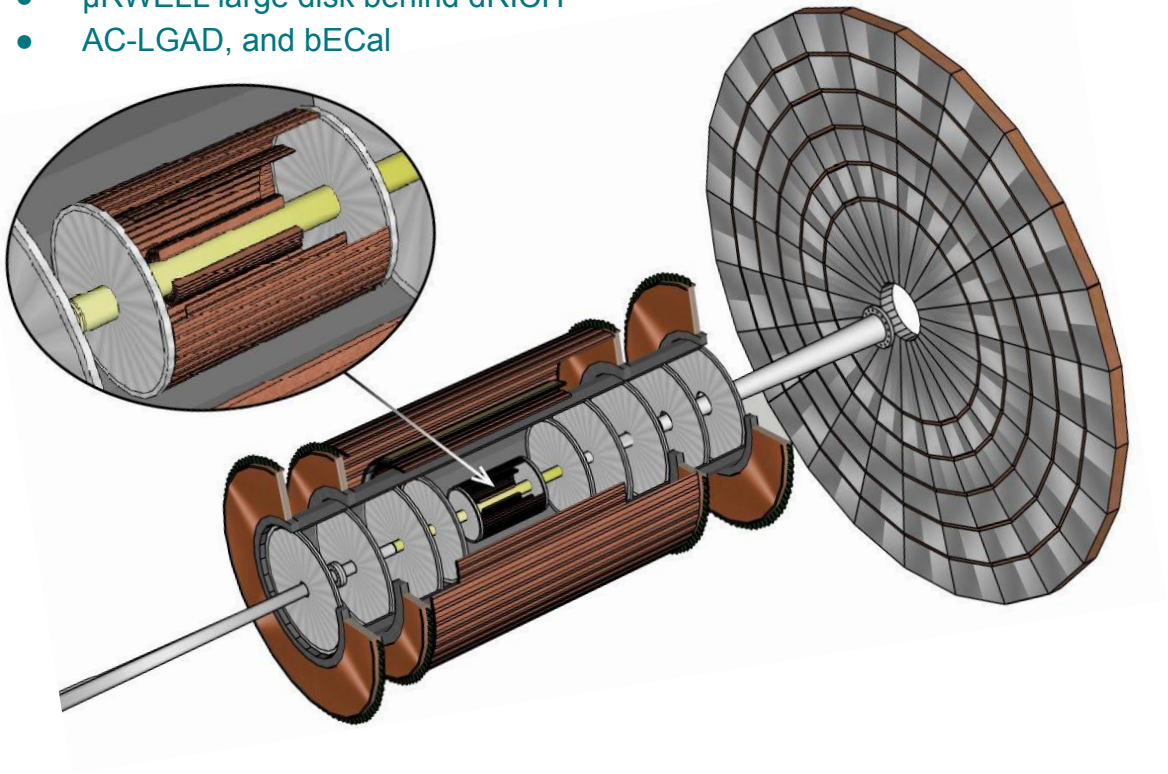


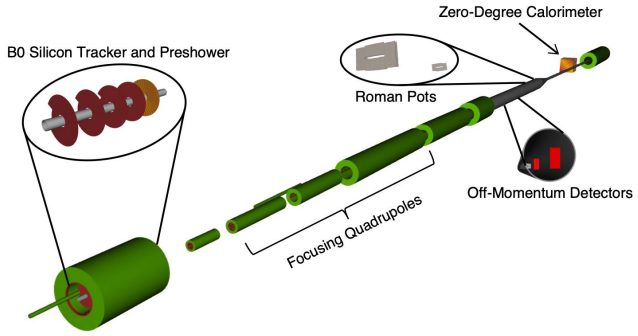
Far-forward subsystem(s)
tag the forward-going particles for various physics processes (e.g. pion form factor, deuteron offshell effect, …)

ATHENA Tracking System

Central detector:

- Silicon tracker:
  - Three inner vertex barrel layers
  - Two sagitta barrel layers
  - disks (six in the forward (ion-going) direction + five in the backward (electron-going) direction
- Micromega outer barrels (two barrels, each has two layers)
- GEM rings
- µRWELL large disk behind dRICH
- AC-LGAD, and bECal





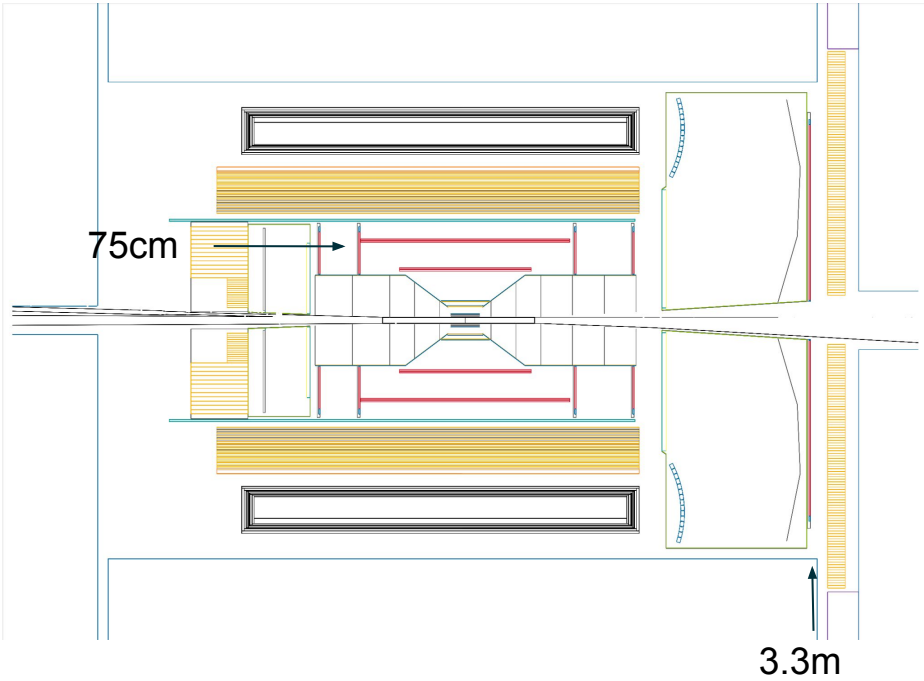
Far-forward subsystem(s)
Silicon disks inside B0 beamline magnet to track charged particles, e.g. tag the proton from $e^- + p \rightarrow e^- + p + \pi^0$

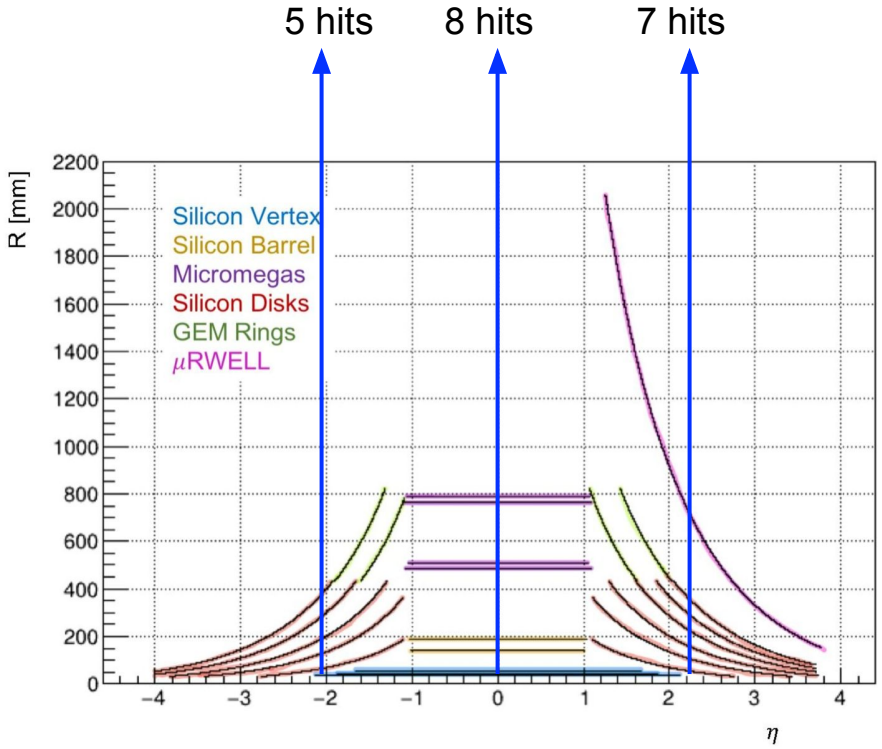
Central Tracker

Central detector:

- Silicon barrels (vertex + sagitta) and disks (Forward + Backward)
- Micromega outer barrels
- GEM rings
- μRWELL large disk behind dRICH
- AC-LGAD, and bECal

included in this tracking study





Simulation Framework

a new design for the ATHENA proposal

homepage: https://eic.phy.anl.gov/ip6/index.html

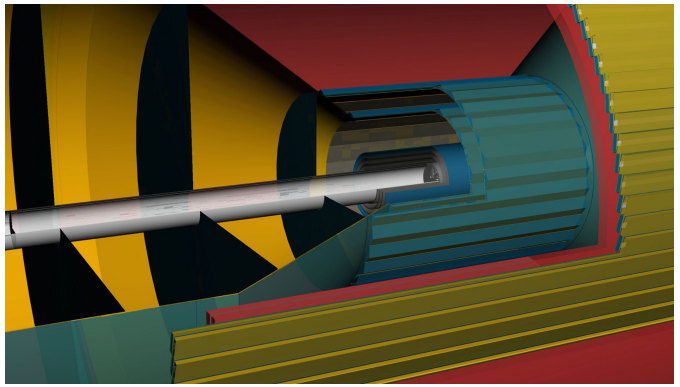
gitlab: https://eicweb.phy.anl.gov/EIC

ATHENA software WG: W. Armstrong, S. Joosten, W. Deconinck, et. al.

DD4Hep:

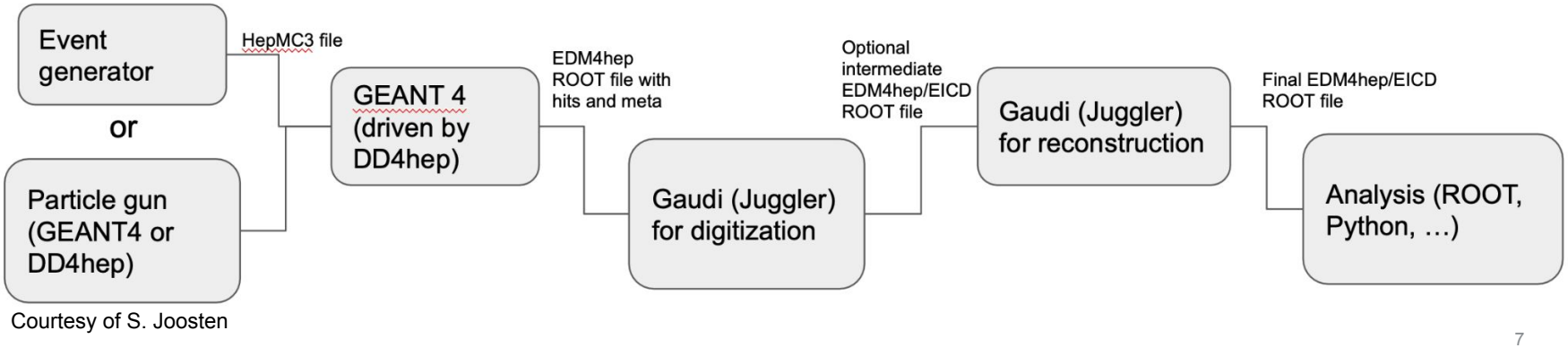
- Geant4-based full detector description
  - detailed beampipe, supporting structures, and material budget
  - use segmentation to handle pixel sensor resolutions
  - detector volumes are constructed for later use (by Acts).

detailed view of inner silicon layers



Juggler:

- Gaudi-based digitization and reconstruction
- **Acts** for track finding/reconstruction

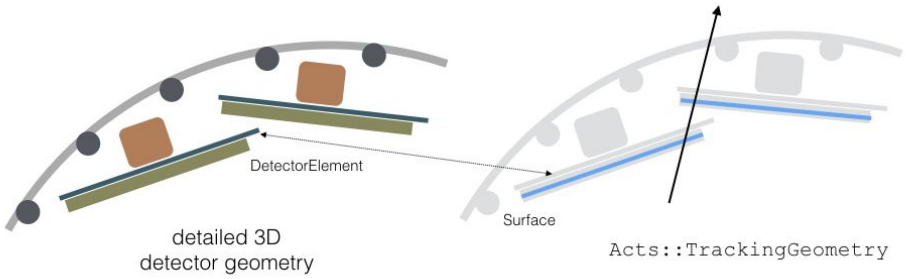


Courtesy of S. Joosten

Tracking with Acts

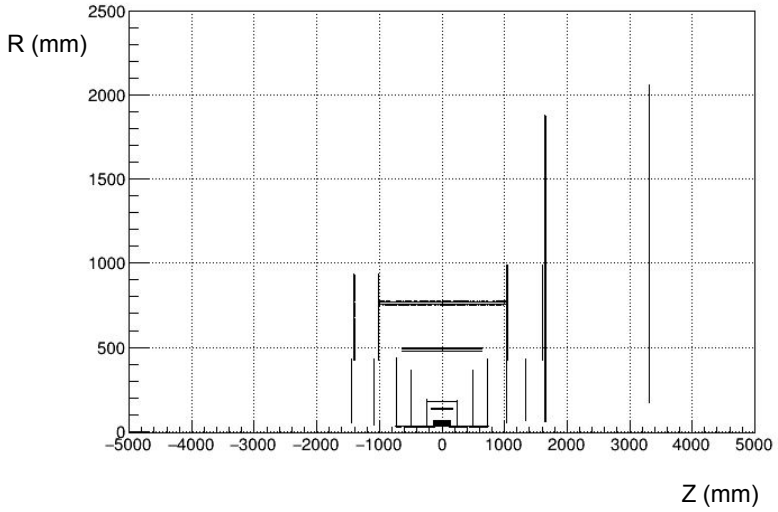
https://acts.readthedocs.io/en/latest/index.html

- Combinatorial Kalman Filter (CKF)
  - default **truth seeding**, realistic seeding under development (Yue-Shi Lai)

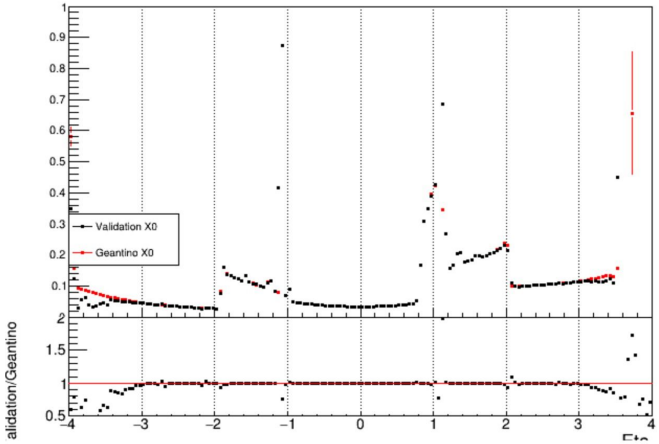


- Map materials to chosen surfaces to simplify track propagation (thanks Corentin Allaire for his help!)

material map for the central tracker



material scan: X/X0 v.s. eta

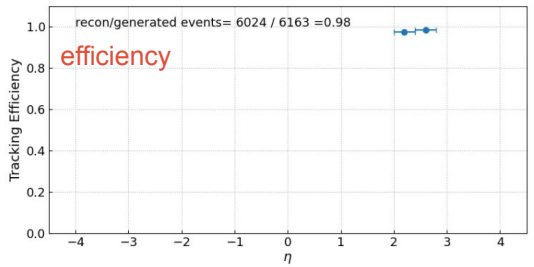


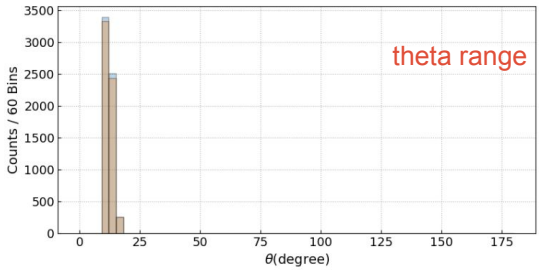
Single Particle Track Reconstruction

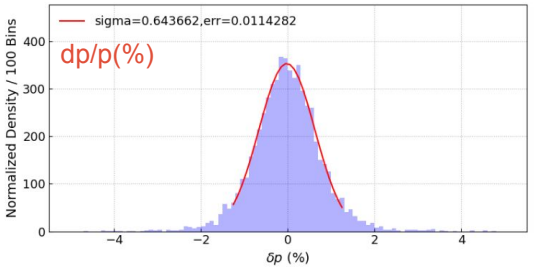
- single pion events
- vertex at 0
- CKF with truth seeding

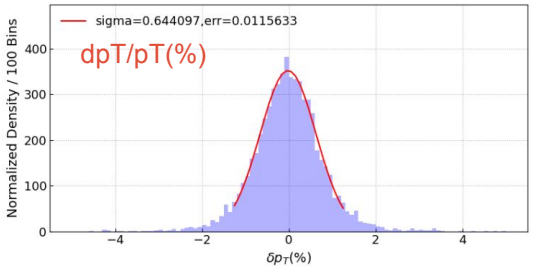
resolution = (init - rec) / init

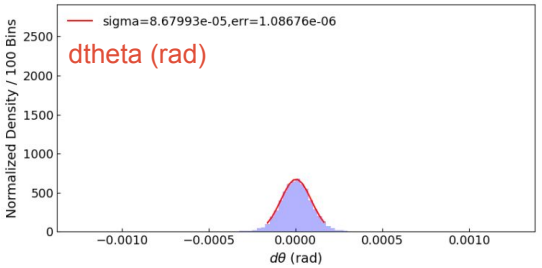
efficiency cuts:
dpp: 5%
theta: 0.005 rad
phi: 0.03 rad
DCA: 3 mm

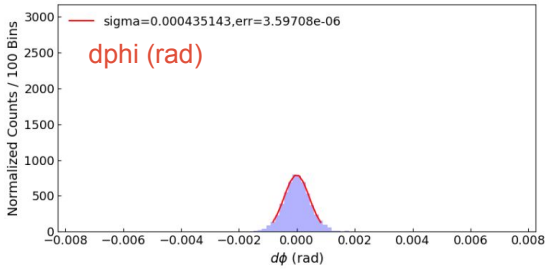


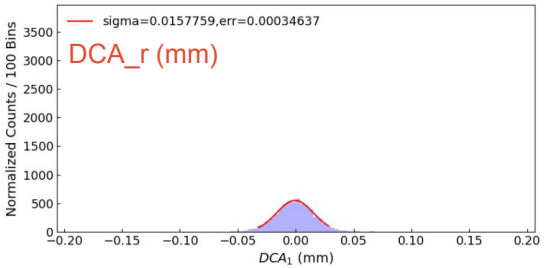


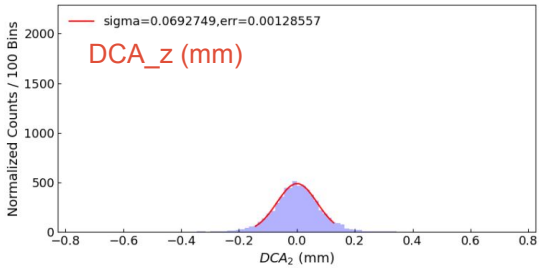








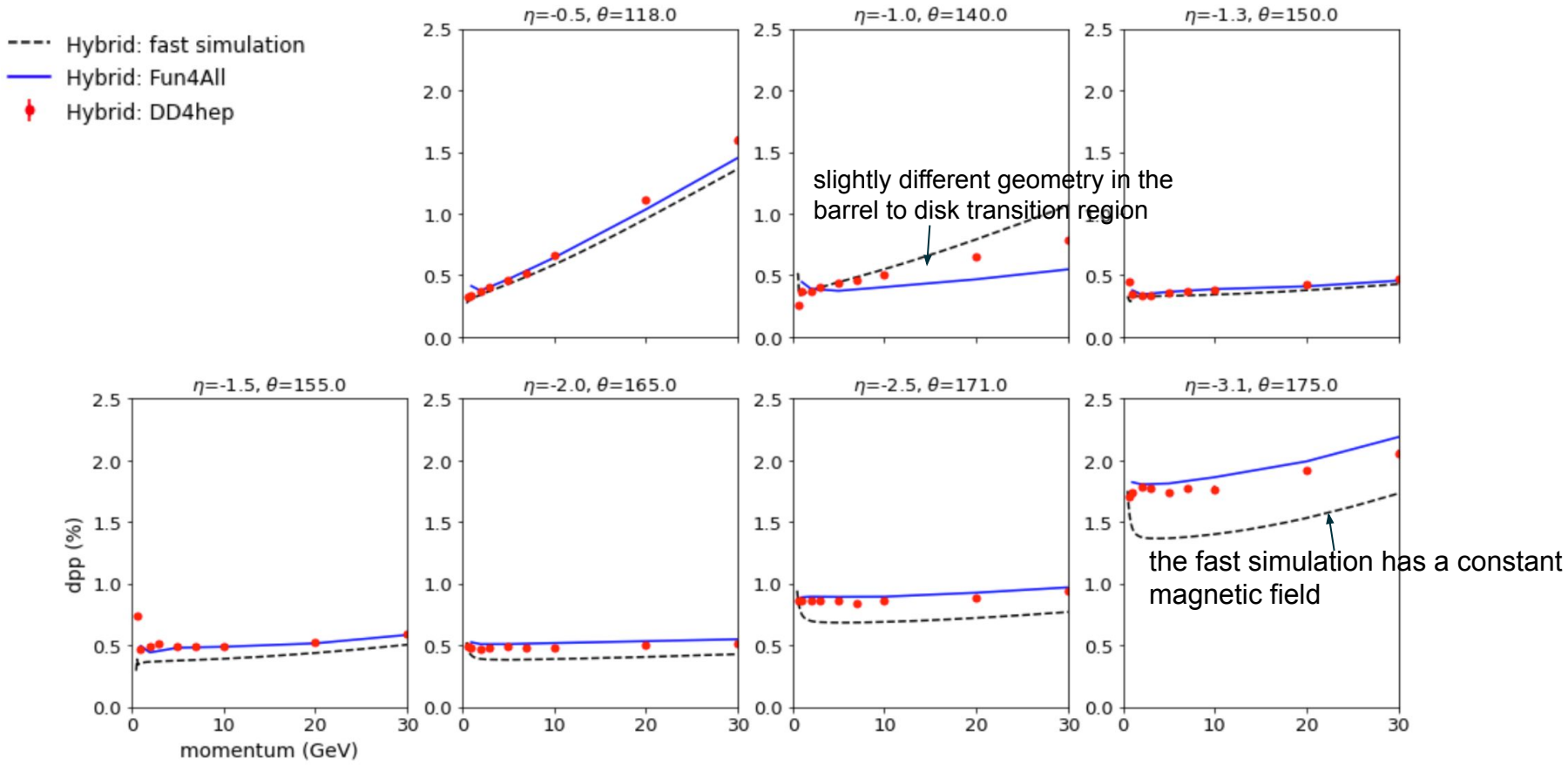




Single Particle Track Reconstruction

Simulation benchmark examples:

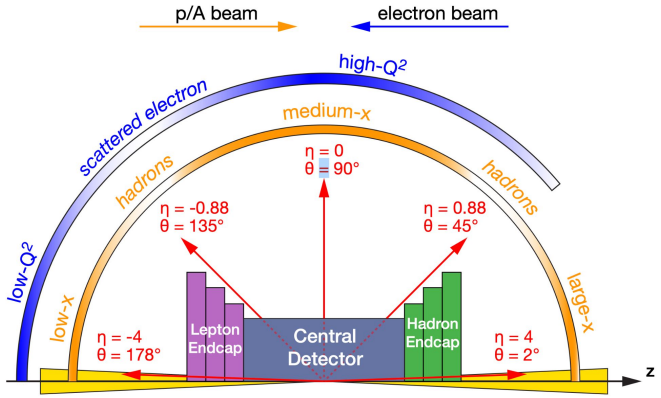
- dp/p at backward region
- comparing between 3 simulation packages:
  - fast simulation: LDT https://inspirehep.net/literature/811906
  - Fun4ALL: Geant4 + GenFit (and Acts later) from sPHENIX
  - DD4hep: this study

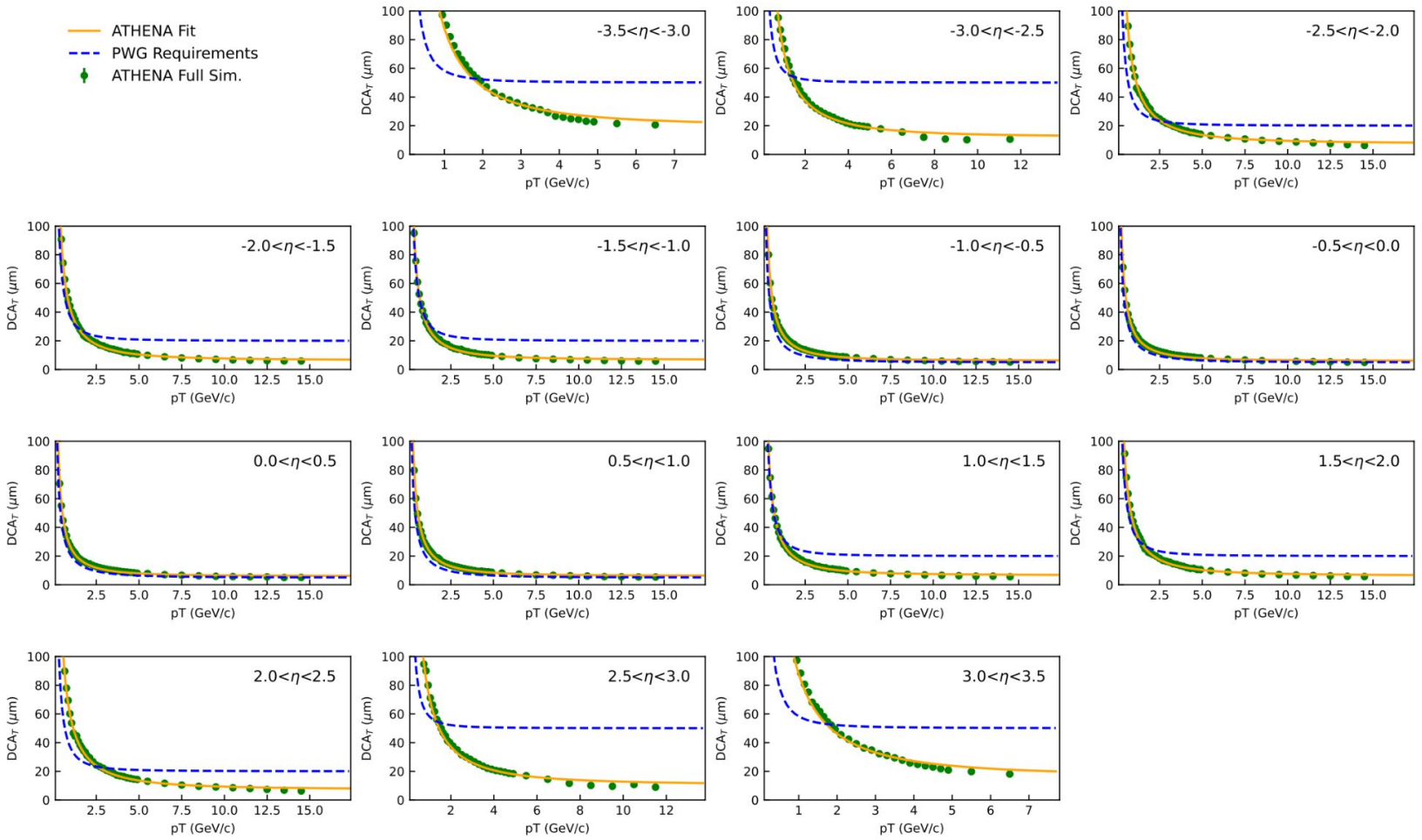


Single Particle Track Reconstruction

Performance check against physics requirements from the EIC Yellow Report

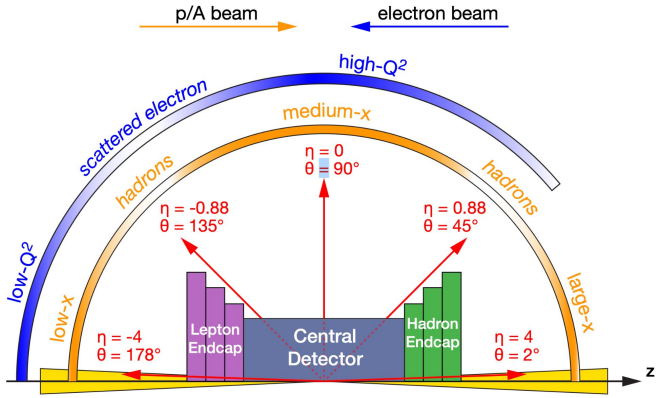
Transverse DCA (mainly for hadron decays):



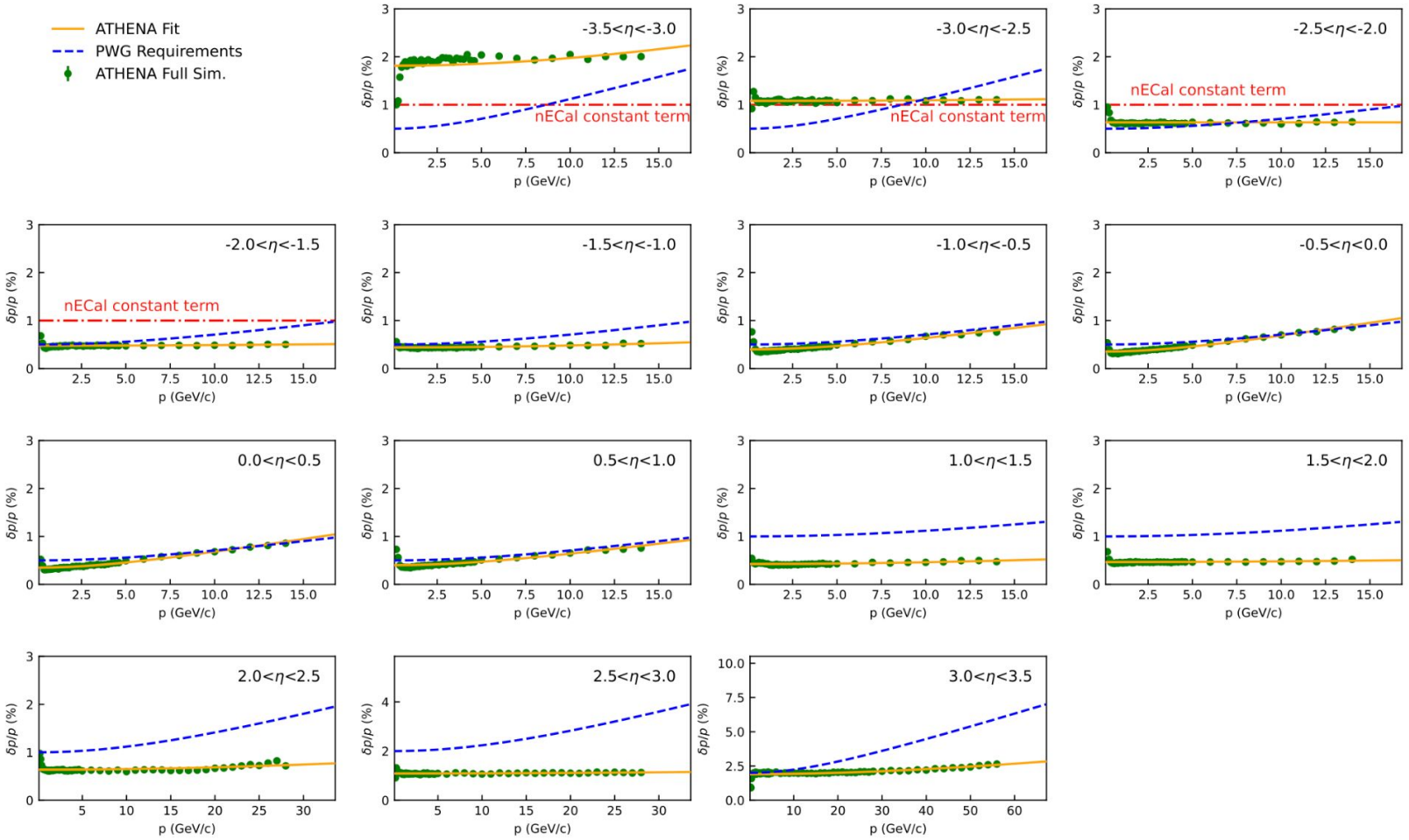


Single Particle Track Reconstruction

Performance check against physics requirements from the EIC Yellow Report

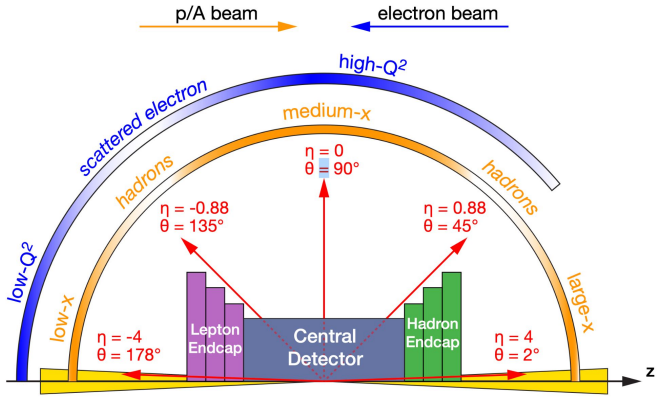


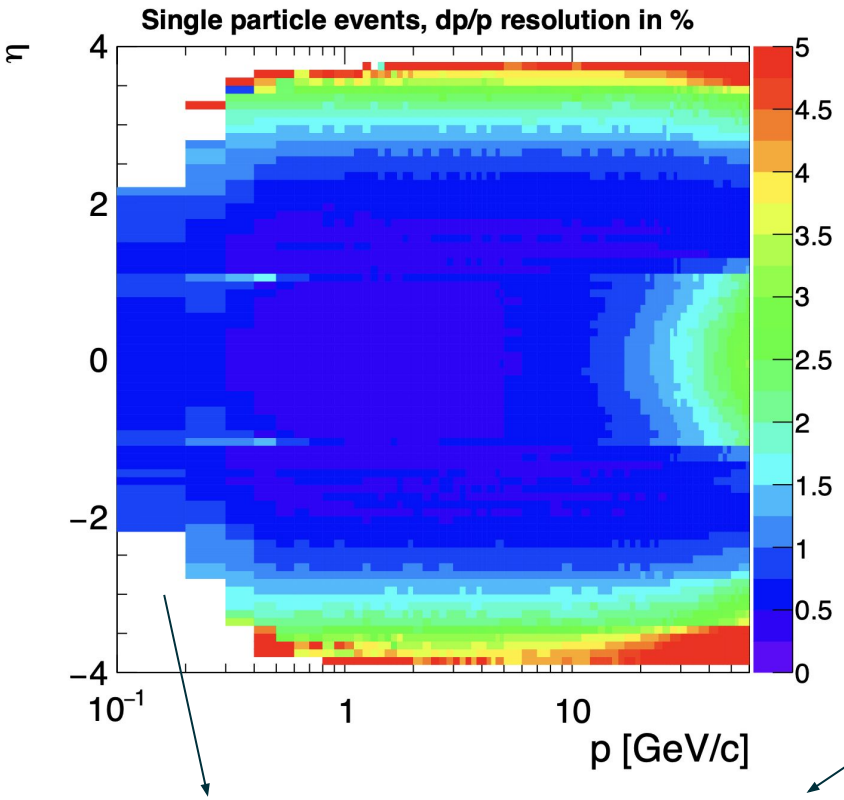
dp/p:

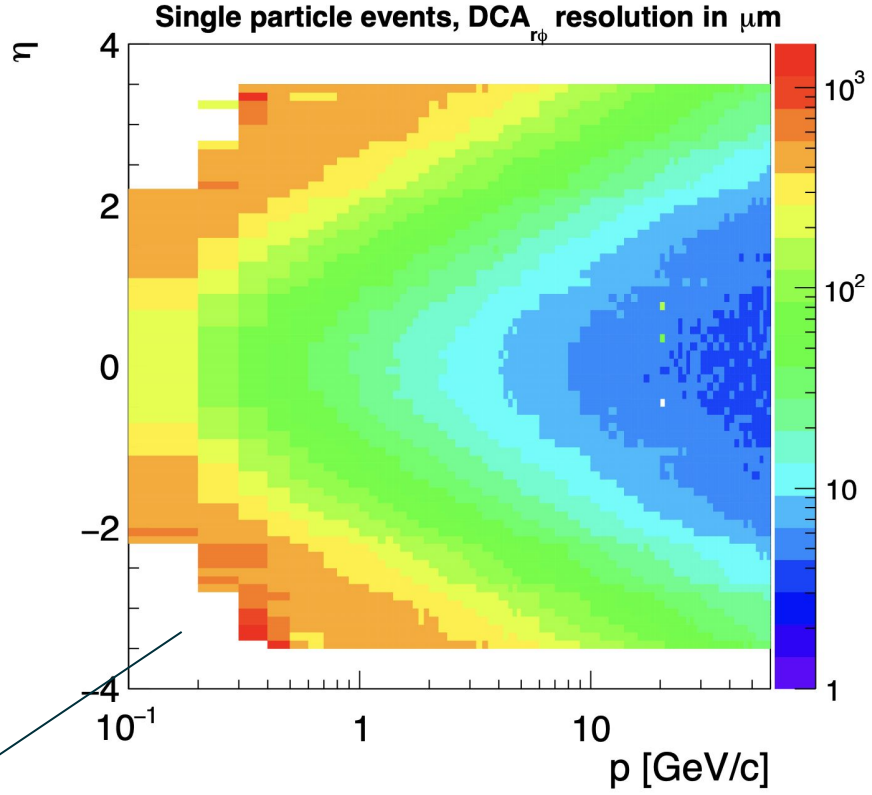


Single Particle Track Reconstruction

Performance check against physics requirements from the EIC Yellow Report





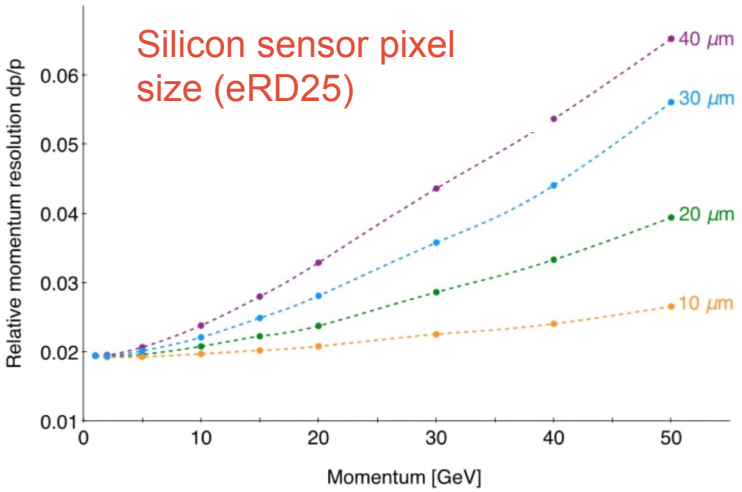


inefficiency at small pT: few hits, multiple scattering

Towards a Realistic Tracking Solution

Detector design optimization by LBL group

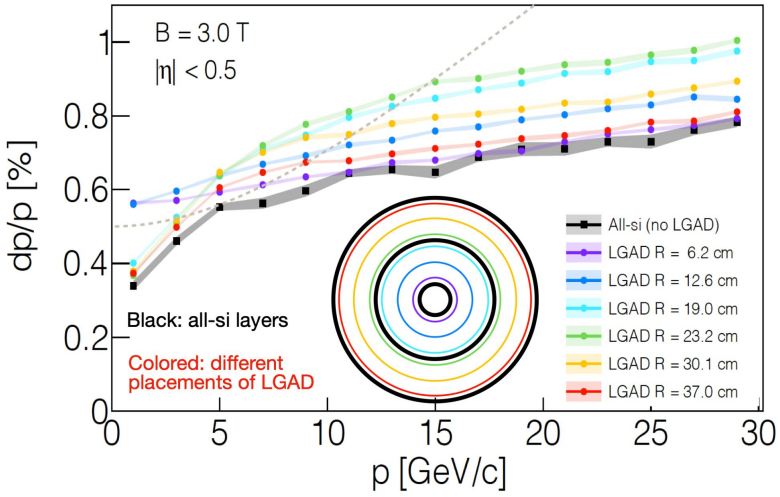
Figure by E. Sichtermann



Equidistant disks, 0.25 < z < 1.21m, 3T field (open), eta =3

LGAD location

Figure by R. Cruz Torres



momentum resolution is very sensitive to material near sagitta

Silicon tracker R&D (eRD111)

- sensor layout, cooling and support (N. Apadula)

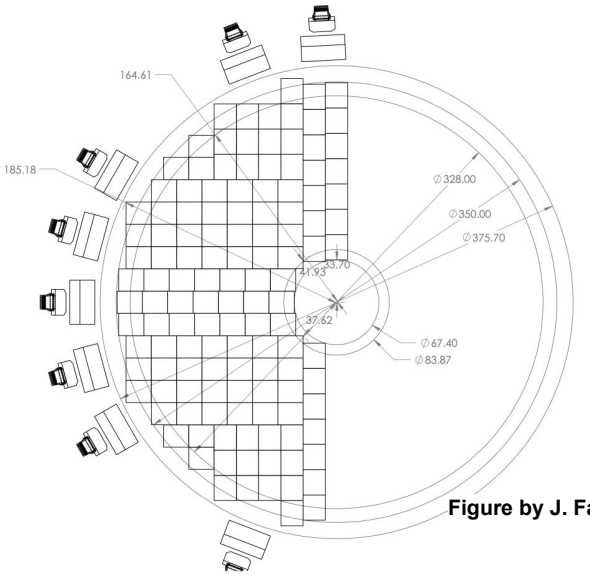
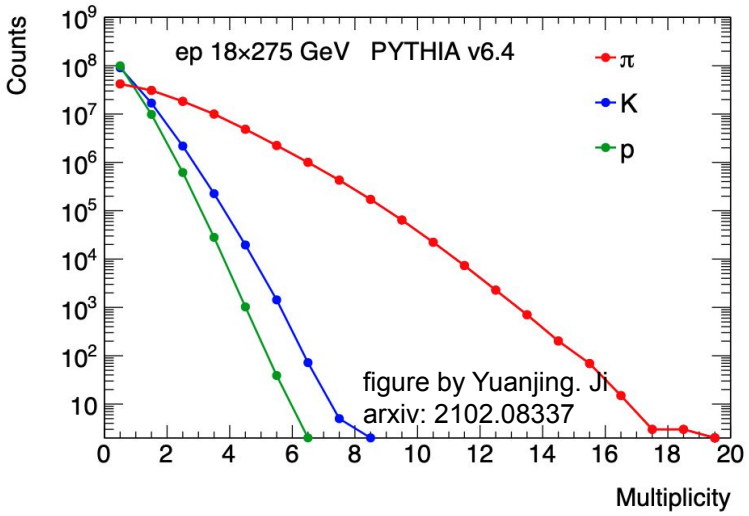


Figure by J. Fast

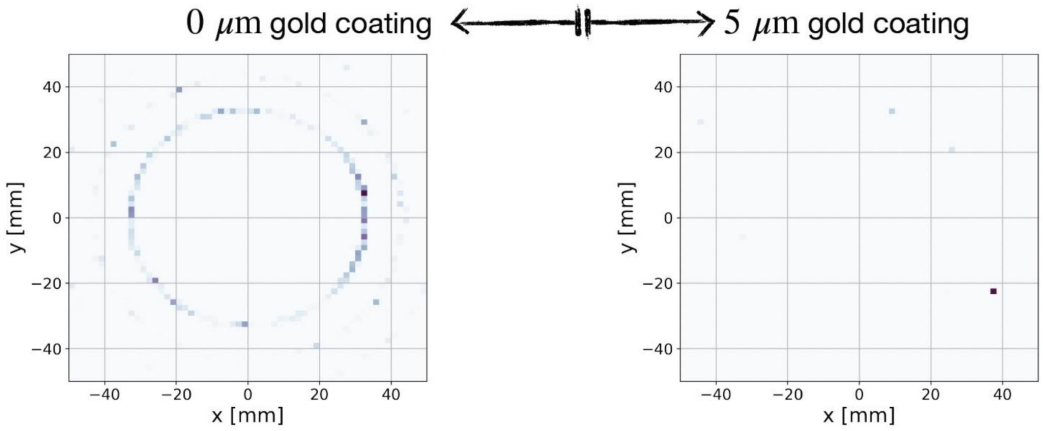
Towards a Realistic Tracking Solution

Realistic track reconstruction

- DIS event multiplicity:



- Background Study:
  - synchrotron radiation (R. Cruz Torres)



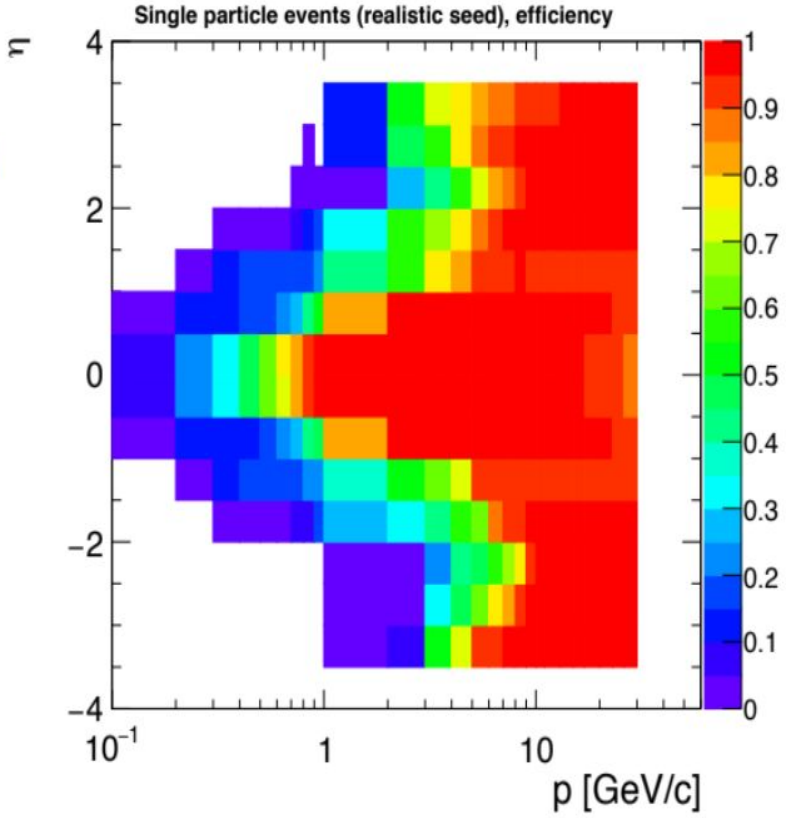
Towards a Realistic Tracking Solution

Realistic track reconstruction

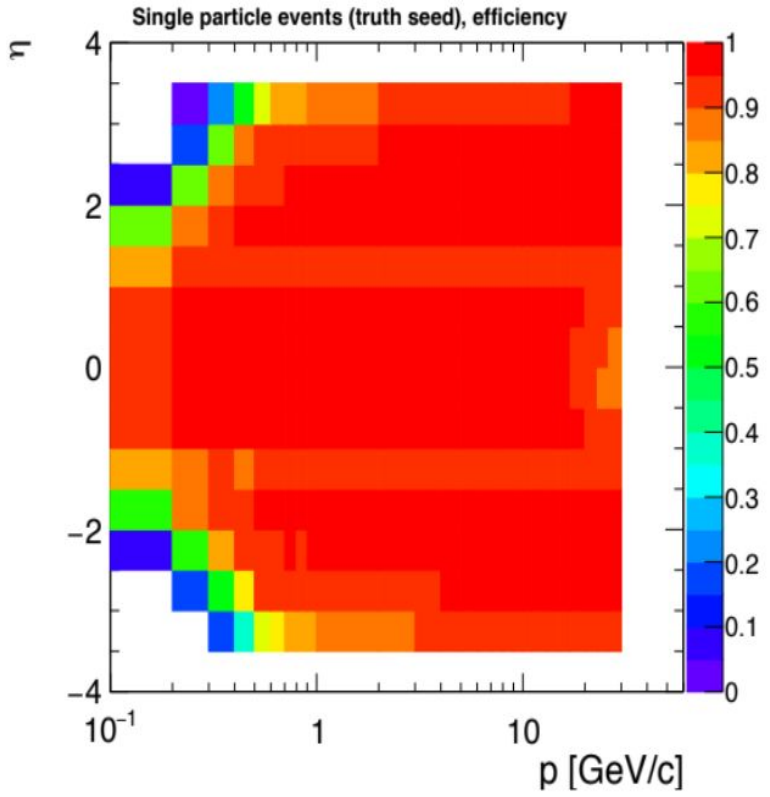
ongoing effort with the Acts group

- CKF with Realistic seeding (Y. Lai and W. Fan)
  - seeds filter
  - low momentum, large-eta: low efficiency, more fake tracks

Realistic seeding



Truth seeding



Towards a Realistic Tracking Solution

Realistic track reconstruction

ongoing effort with the Acts group

Development for far-forward tracking

- Special cylinder geometry for the electron beam pipe inside B0 tracker (S. Rahman)

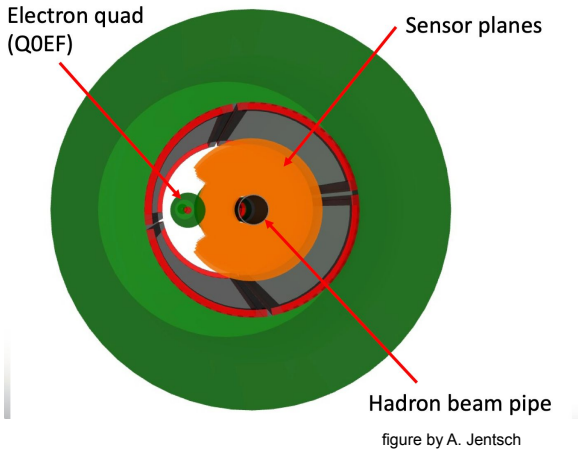
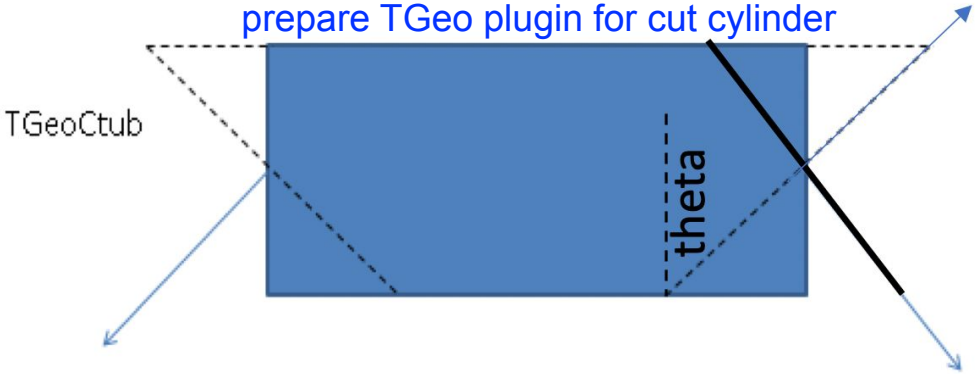
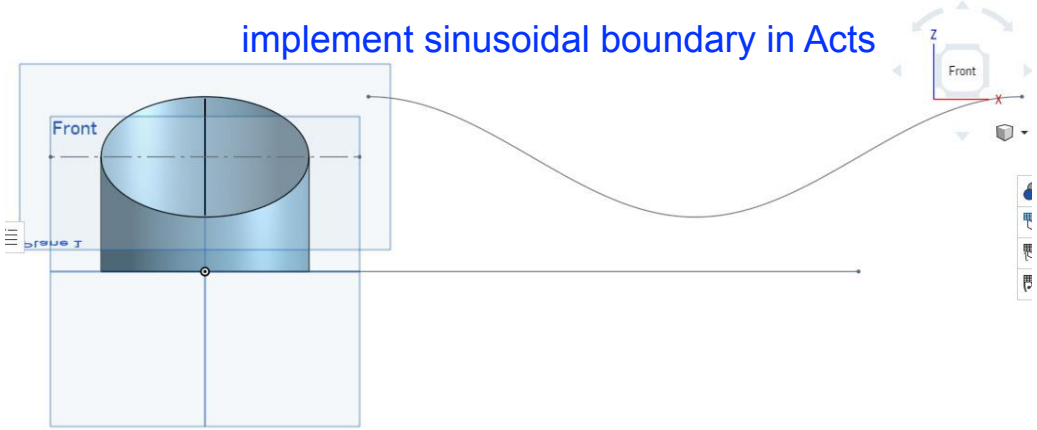


figure by A. Jentsch

prepare TGeo plugin for cut cylinder



implement sinusoidal boundary in Acts



Summary

The DD4Hep + Acts simulation/reconstruction framework has been successfully developed and benchmarked at the EIC detector 1 proposal stage for ATHENA.

With ECCE being selected as the reference design concept, the software/simulation working groups from the different proposal communities are being merged. Discussions on software choices are on-going: Software decision schedule

Further simulations will be performed to verify and optimize the current detector reference design towards a detector baseline.

We work closely with the Acts group to continue track reconstruction development under ATHENA framework, while preparing for transferring this effort into the formal detector 1 framework and the EIC community as a whole.

Questions to the experts:

What do Acts developers plan to do with two key EIC technologies, streaming readout (and analysis) and machine learning?

With streaming readout, there will be partial information, not whole event information. Can we run track reconstruction with sub-event level info, potentially on partially overlapping patches of detectors?

Thank you !