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U.S. DEPARTMENT OF ENERGY
Office of Science

ePIC Tracking Software and Plans

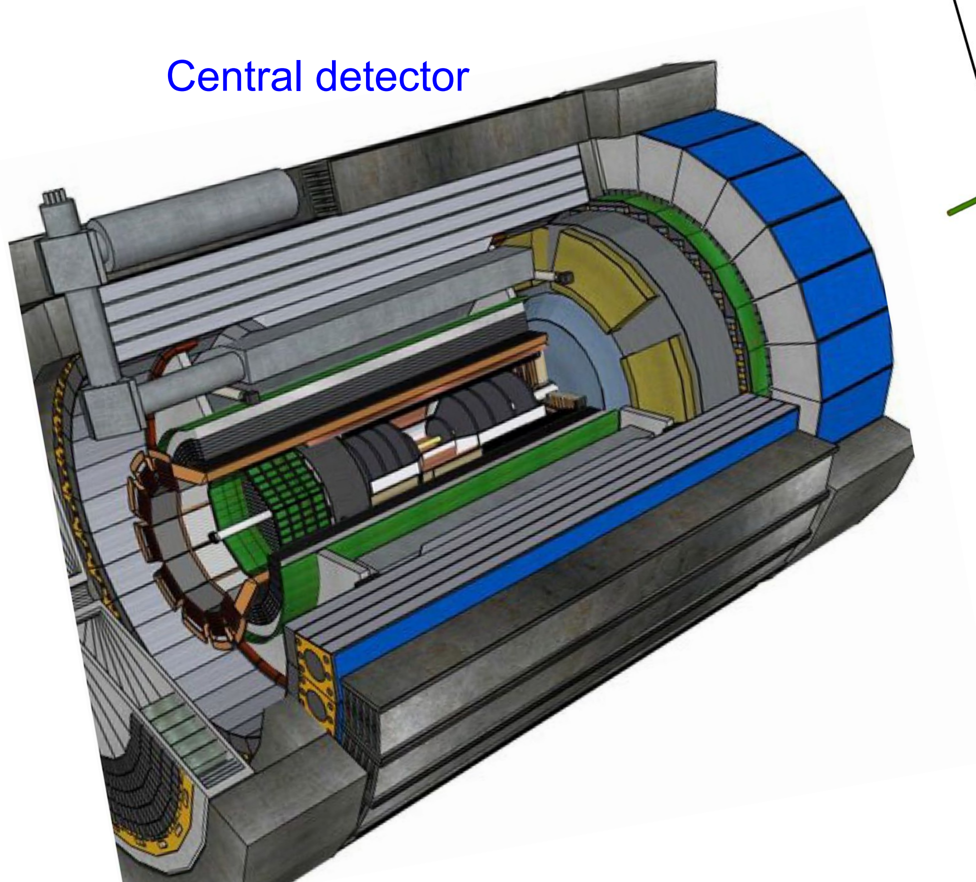
Shujie Li

UC EIC Consortium Meeting

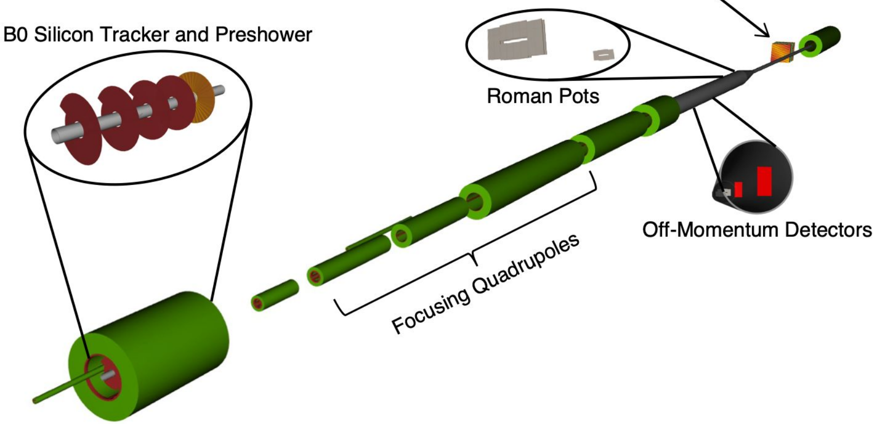
August 22nd, 2023

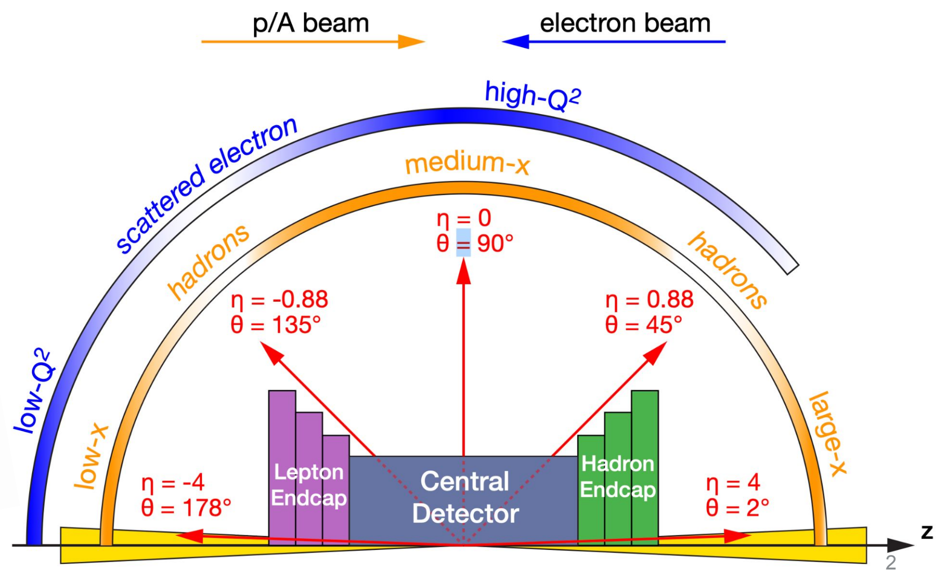
ePIC Tracking System

Central detector

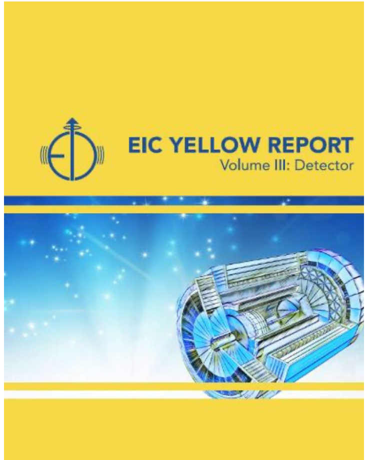


Far-forward detector





Central Tracker Design



- Yellow Report
- Detector One proposals
- ePIC:
  - Arches
  - Brycecanyon
  - Craterlake
  - ...

Requirements:

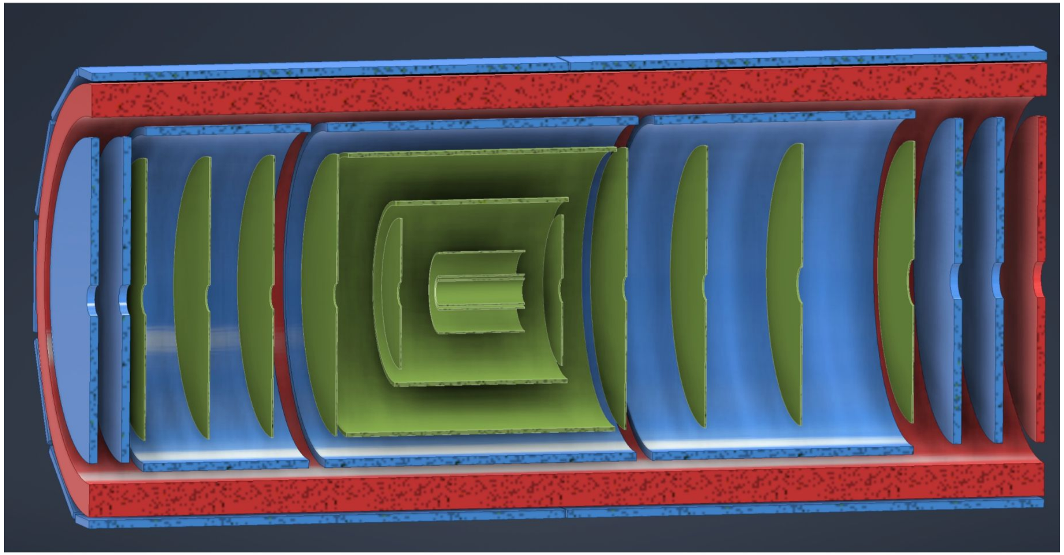
- High pattern recognition efficiency
- High spatial resolution
- Low material budget
- Good time resolution

Technologies:

- Monolithic Active Pixel Silicon (MAPS)
- MicroPattern Gaseous Detector layers (MPGD)
- AC-LGAD ToF

Current Tracking Configuration
“Craterlake”

Ernst Sichtermann and Matt Posik, ePIC tracking WG, June 2023
https://indico.bnl.gov/event/19854/



SVT MPGDs ToF (fiducial volume)

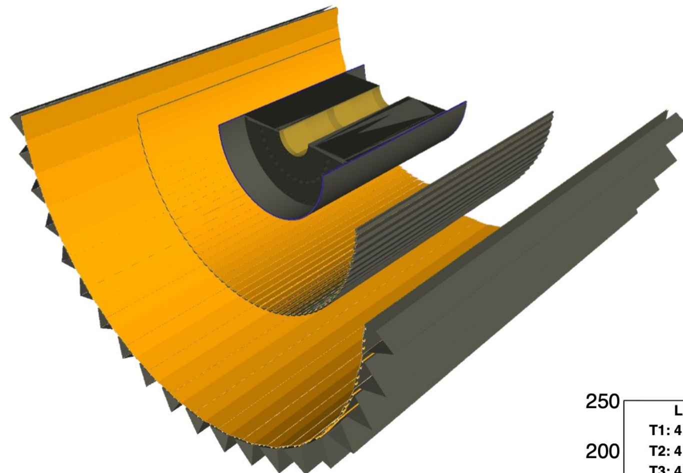
Silicon trackers:
- 3 vertex barrels
- 2 outer barrels
- 5 disks (forward/backward)

MPGDs:
- Inner barrel (forward/central/backward)
- Outer barrel (MPGD+DIRC)
- 2 disks (forward/backward)

AC-LGAD ToF:
- 1 forward disk
- 1 barrel

Silicon Vertex Tracker (SVT)

High spatial resolution for charged particle tracking
Low material budget

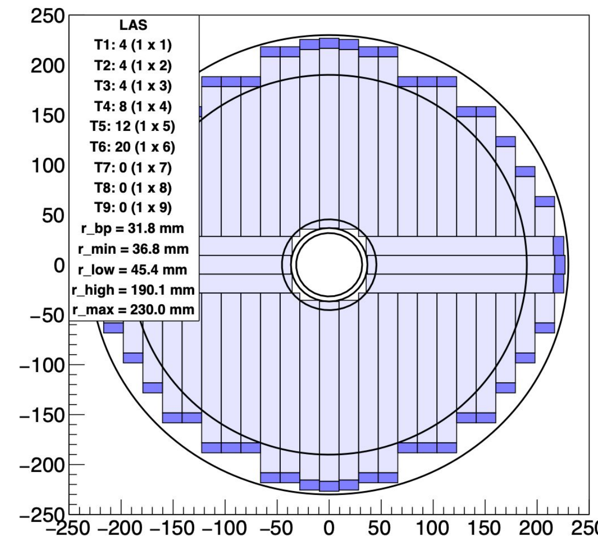


Ongoing R&D:

- eRD104: readout and power
- eRD111: mechanical structure and cooling
- eRD113: sensor characterization

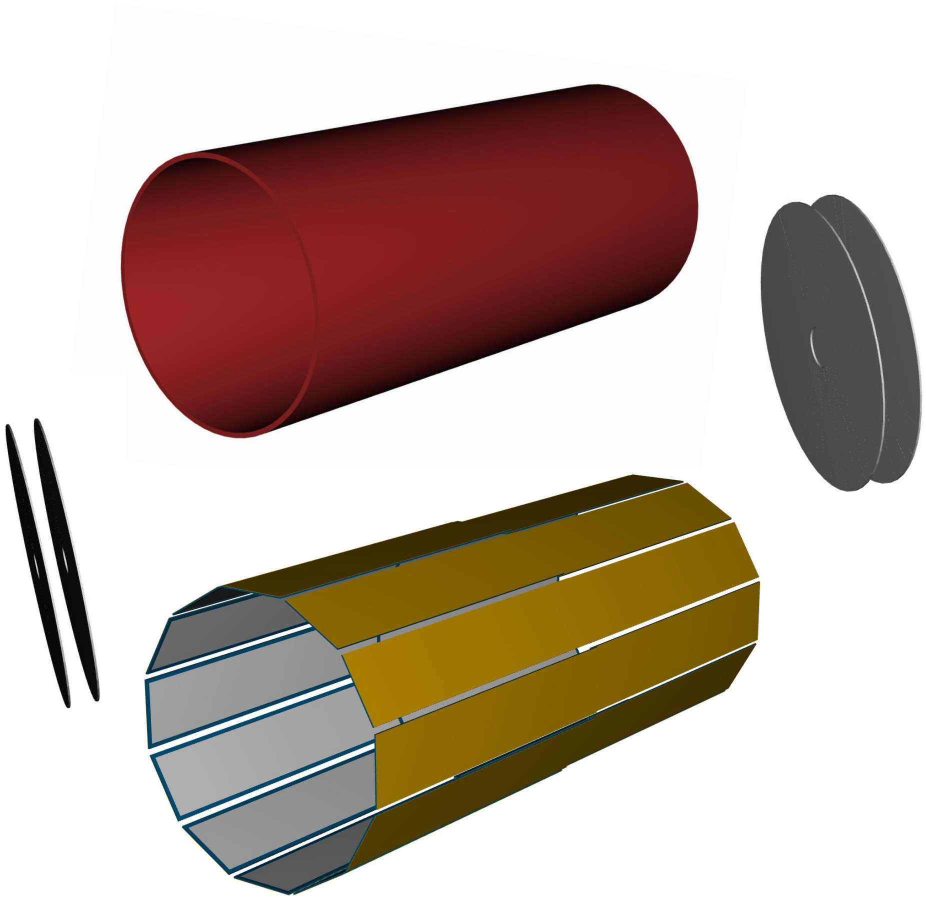
- 3 inner vertex barrels
  - ITS3, 65nm MAPS sensor
  - 20x20um pixels
  - 0.05% X/X0
- 2 outer barrels
  - ITS2 staves
  - 0.55% X/X0
- 5 disks (forward/backward)
  - ITS2
  - 0.24% X/X0

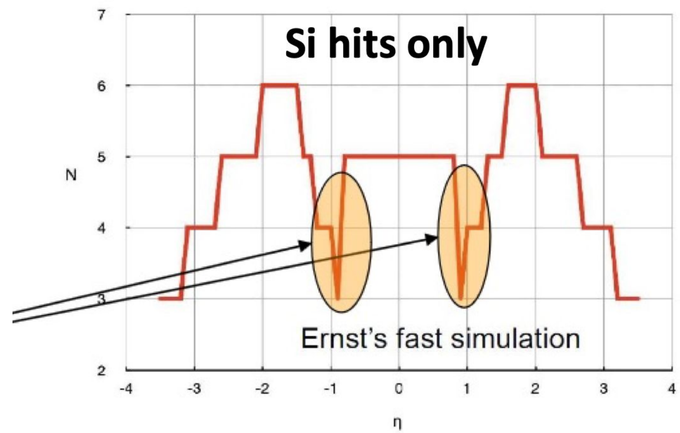
Example: ED0/HD0

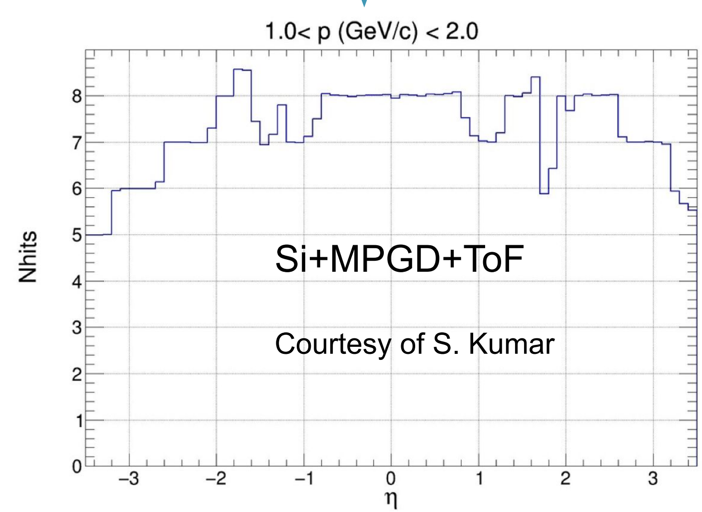


MPGD

Additional hits for pattern recognition
Fast timing info for signal/background separation

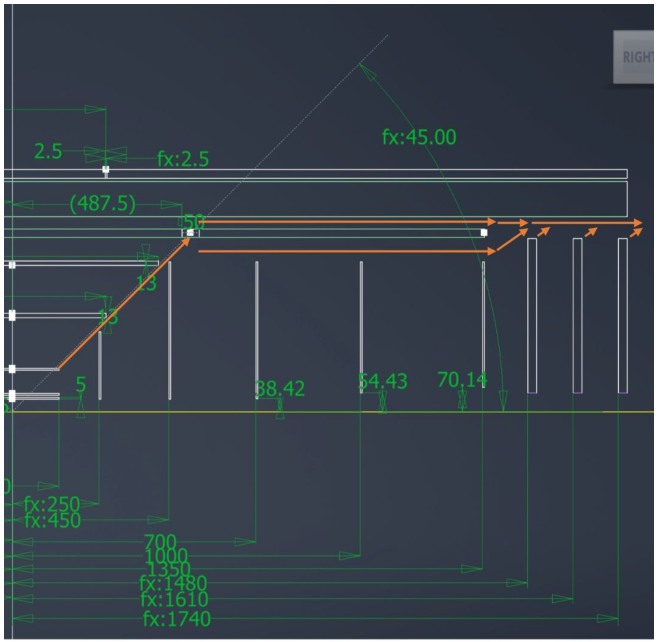






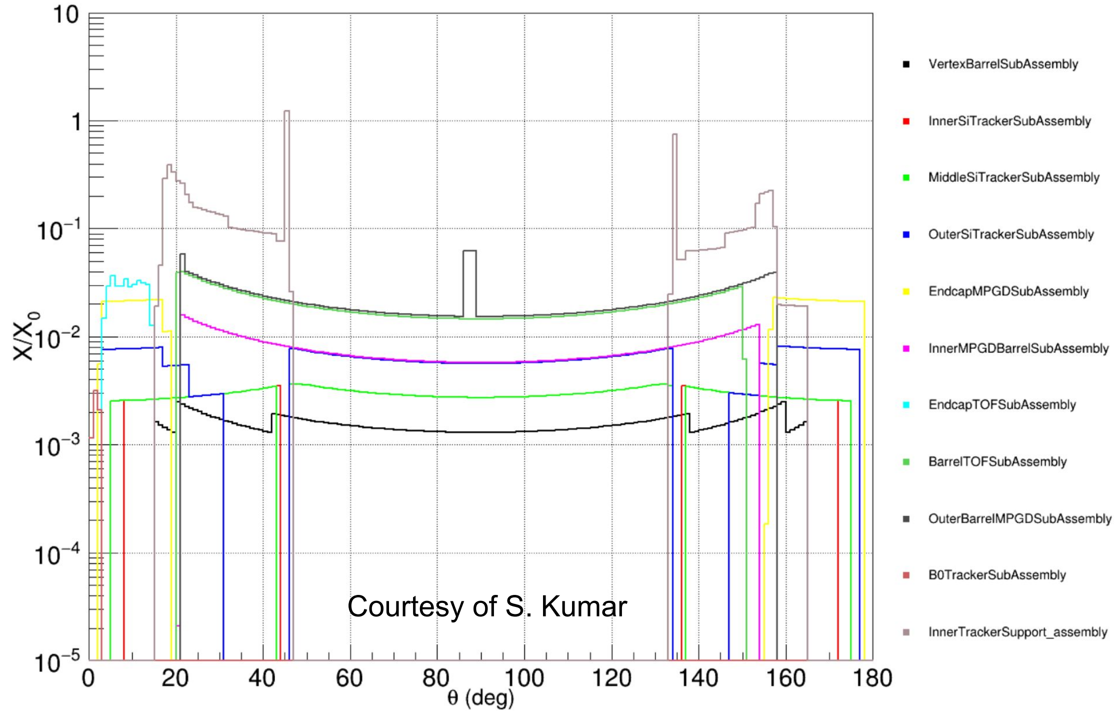
Services and Materials

Cables guided out along the carbon supporting cone



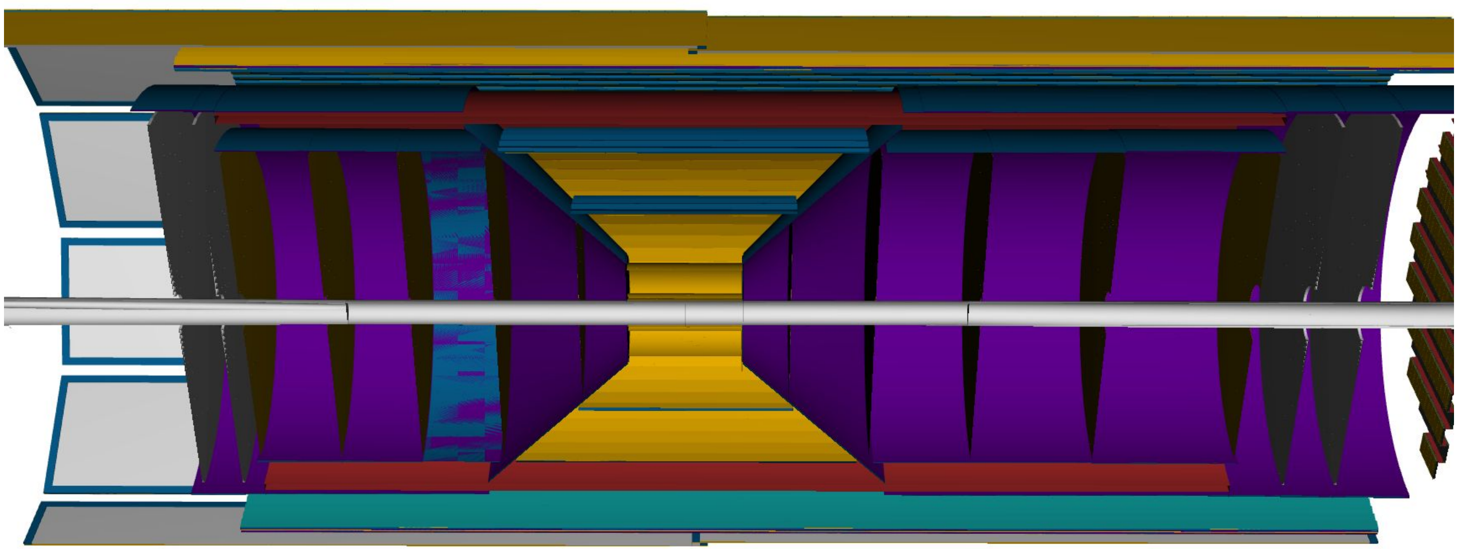
Courtesy of E. Sichtermann

Material Scan



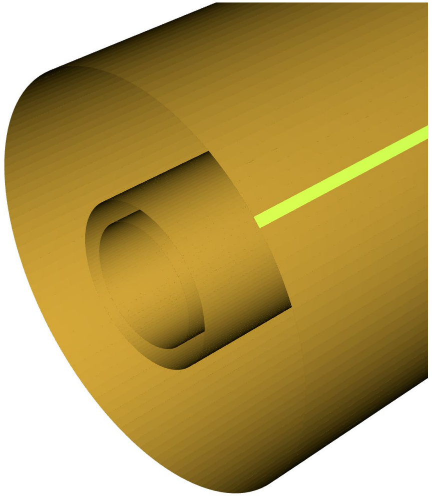
Tracking Geometry in DD4hep Simulation

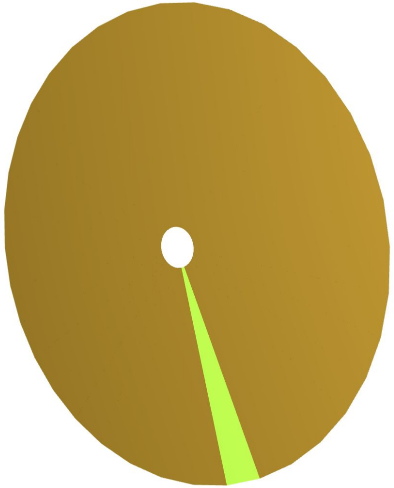
- Version 23.07 (Craterlake) for July simulation campaign
  https://github.com/eic/epic/tree/main
- Up-to-date geometry with detailed material descriptions

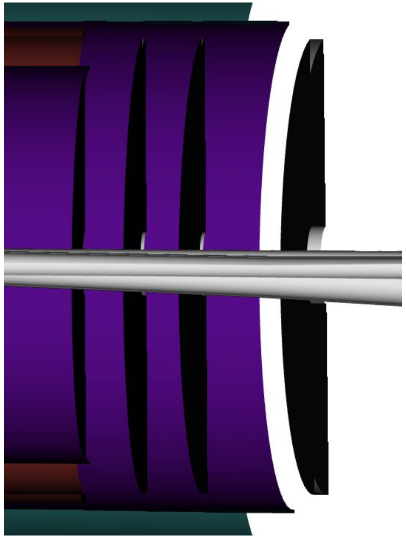


Tracking Geometry in DD4hep Simulation

- Version 23.07 (Craterlake) for July simulation campaign
  https://github.com/eic/epic/tree/main
- Up-to-date geometry with detailed material descriptions
- Approximated cylinder (staves) and disks (trapezoids)
- Use effective thickness of cables assuming uniform azimuthal distribution

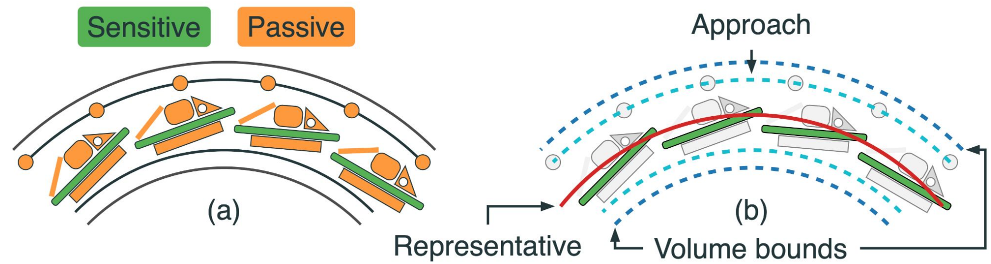




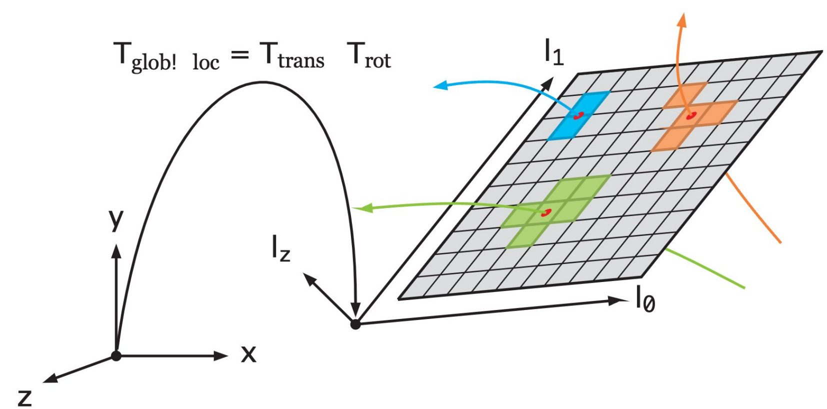


Track Reconstruction

- **Data structure:** EDM4eic https://github.com/eic/EDM4eic/tree/main
- **Reconstruction framework:** **EICrecon** http://eicrecon.epic-eic.org/)
  - Space point formation



- Global / local coord. transformation
- Digitization:
  - Raw hits -> Surface and cell ID
  - Energy deposit threshold
  - Hits clustering



* Material map

arXiv:1910.03128

A Common Tracking Software

Track Reconstruction

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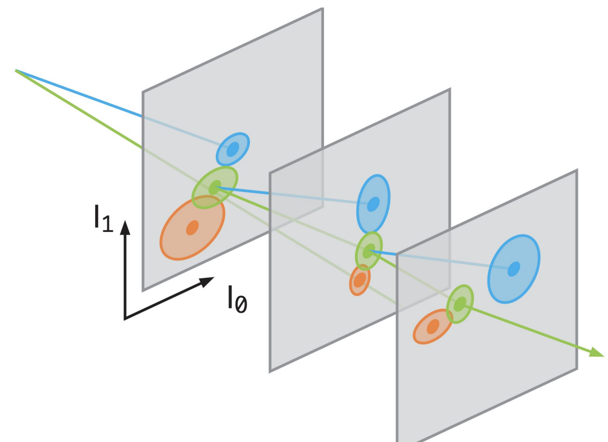
  - Space point formation
  - Track finding/fitting

Combinatorial Kalman Filter (CKF)

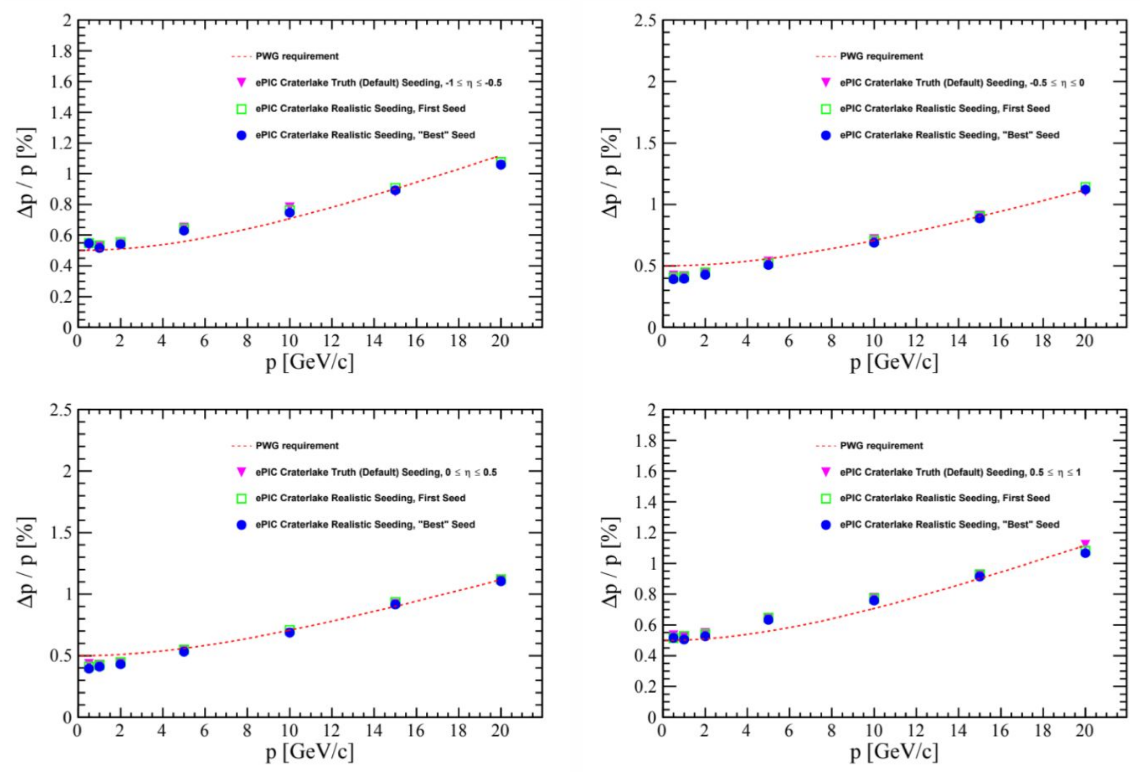
- combine track finding and fitting
- allows track branching
  - → user-defined measurement selector (number, chi2)
- high efficiency
- **Need a reasonable "initial guess"**
  - → Realistic seeding implemented by YueShi, Ray, Wenqing, Barak, etc …



Performance Study

Mid-rapidity: eta bins: -1, -0.5, 0, 0.5, 1

- Single pion events to study the momentum resolution dp/p
- no background
- Realistic seeding v.s. Truth seeding



Courtesy of S. Maple

See https://indico.bnl.gov/event/20126/ for details arXiv:1910.03128

A Common Tracking Software

Track Reconstruction

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- **Reconstruction framework:** **EICrecon** http://eicrecon.epic-eic.org/)
  - Space point formation
  - Track finding/fitting

Reconstruction Priorities

The Physics Working Groups (PWGs) have identified four key priorities for the ePIC Reconstruction effort (https://docs.google.com/document/d/1y2zb3x7rUp9jO63uE5PBMpfs-1dAGWyn-77UbUQ0VP8/edit)

1. **Electron Finder (Daniel Brandenburg)**: Developing an efficient and accurate algorithm for identifying electrons and identifying the scattered electron of the DIS process.
2. **Vertexing and PID (Shujie Li)**: Enhancing the vertexing capabilities and particle identification techniques to study heavy flavor physics.
3. **Particle Flow (Derek Anderson)**: Improving the jet reconstruction using particle flow information.
4. **Low-Q^2** (**Simon Gardner**): Integration of the low-Q2 tagger into the reconstruction framework for precise measurements of photo production and vector mesons.

CD3 Goal: Demonstrate ePIC tracking is able to efficiently and accurately reconstruct tracks embedded in a background environment.

Tasks needed to complete CD3 Goal:

Weekly track recon meeting at 10am ET on Thursdays https://indico.bnl.gov/event/20315/

— geometry—

1. Eliminate any acceptance holes in tracking geometry Stephen Maple (Birmingham)
2. Mechanism to propagate tracks to calorimeters (and PID?) to allow accurate track-cluster matching
3. Bring barrel calorimeter tracking layers into track reconstruction Sylvester Joosten (ANL)
4. Create an ACTS surface at the calorimeter to allow track projection with proper material information Tyler Kutz (MIT)

—algorithm/data structure—

5. Separate digitization and EICrecon (may work already, need verify, ask Markus for candidates)
6. Timing information from detector hits implemented into track reconstruction Kolja Kauder (BNL)
   a. Add time info as an extra dimension to hits - Dmitry Romanov
   b. Covariance matrix
7. Hits clusterization
8. Detector noise needs be implemented
9. Implementation of vertex reconstruction Xin Dong (LBL), Sooraj Radhakrishnan(LBL), Lokesh Kumar(Panjab University)

—-validation—-

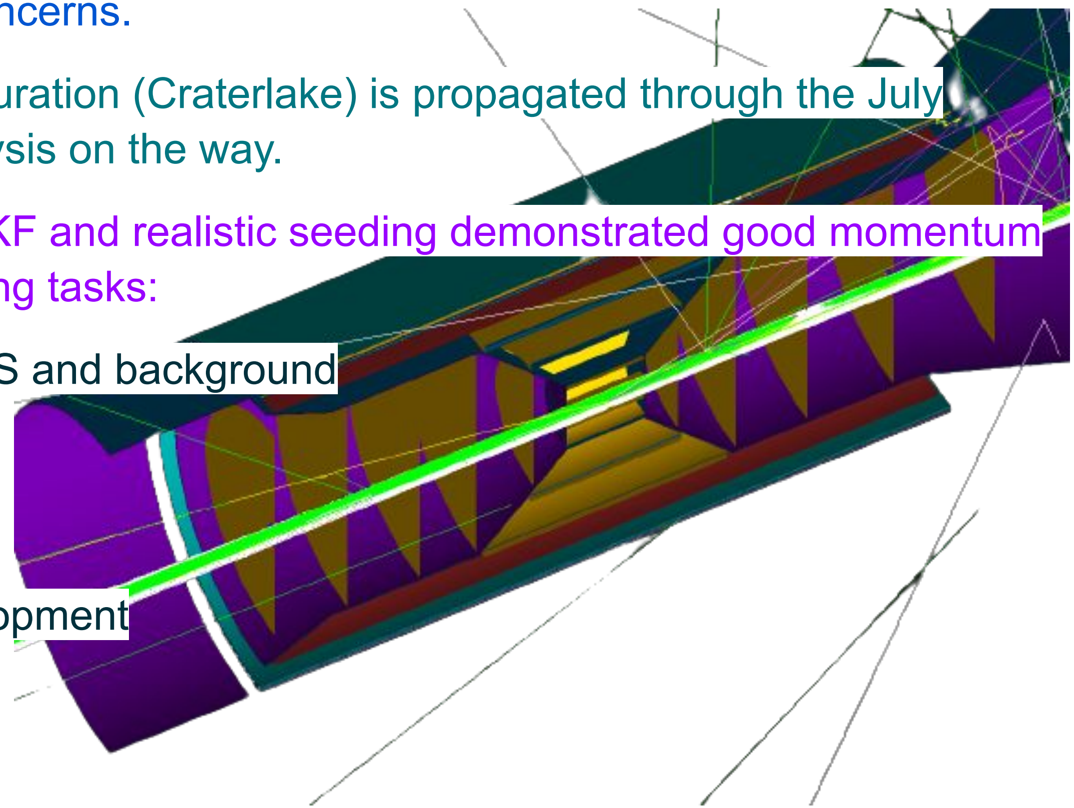
10. Realistic seeder
    a. Realistic seeder demonstrated in DIS Mingjun Kim (LBL), Barak Schmookler(LBL)
    b. Realistic seeder demonstrated in singles + background Barak(LBL), Kolja(BNL), Benjamen Sterwerf(LBL), Shyam
    c. Realistic seeder demonstrated in DIS + background Mingjun (LBL), Barak(LBL)
11. Far-forward B0 tracking performance study Sakib Rahman(U. of Manitoba)
12. Setup automatic benchmarks (Nhits vs eta, recon track eff, track acceptance, dp/p,...)

—-software—-

13. Compile ACTS updates with EICrecon Dmitry Romanov(JLab), Shyam (after Aug 25)
14. Trajectory and other tracking info to rootfiles Barak

Summary

- ePIC tracking system combines MAPS and gas detector technologies to fulfill EIC physics requirements. The actual configuration is under development, with several R&D projects to address technical concerns.
- The most recent tracking configuration (Craterlake) is propagated through the July simulation campaign, data analysis on the way.
- The track reconstruction with CKF and realistic seeding demonstrated good momentum and angular resolutions. Ongoing tasks:
  - Performance study with DIS and background
  - Vertexing and PID
  - Use timing information
  - Far-forward tracking development



Backups

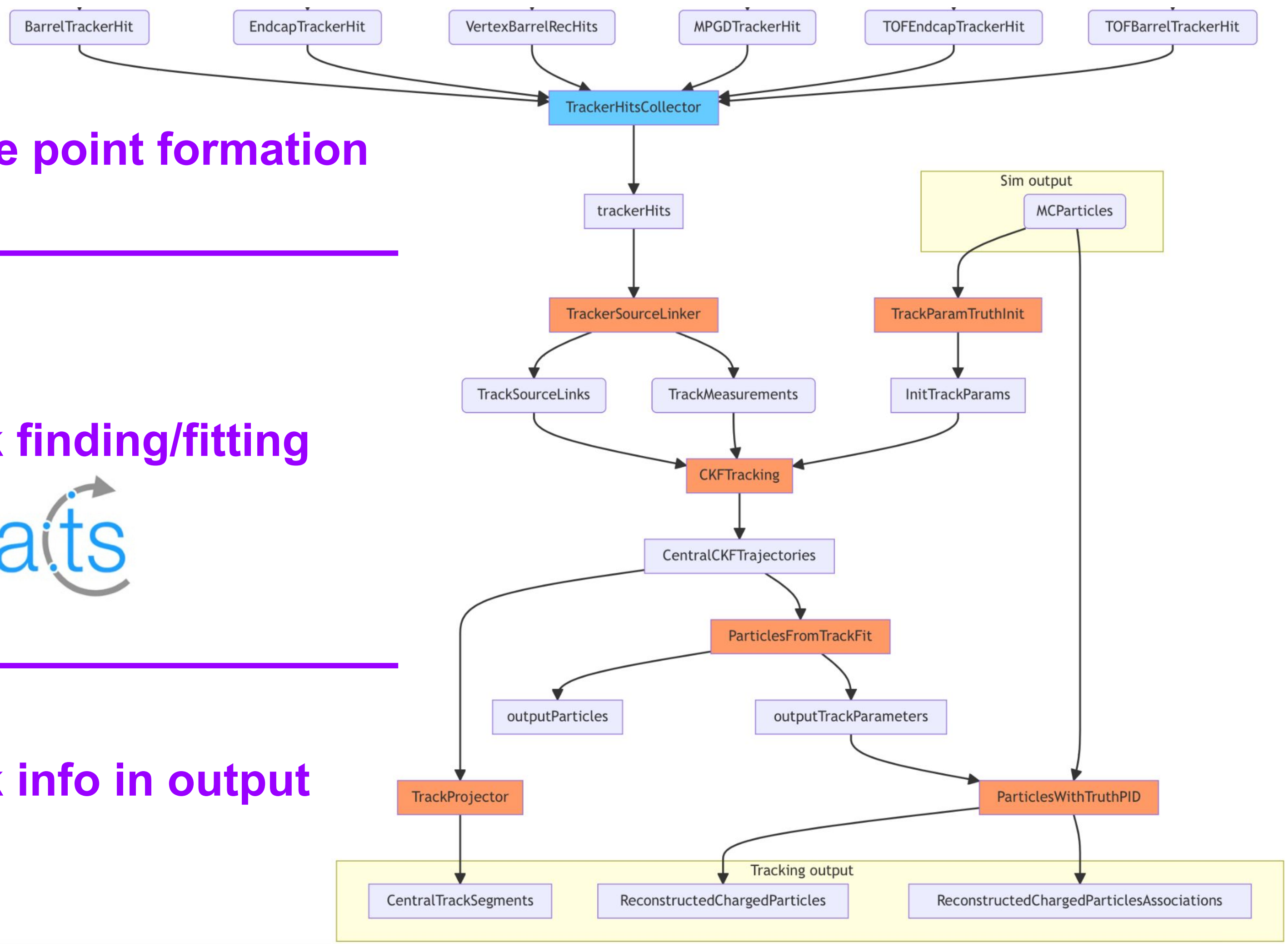
Track Reconstruction in EICrecon

Full diagram at https://eic.github.io/EICrecon/#/design/tracking?id=full-diagram

Space point formation

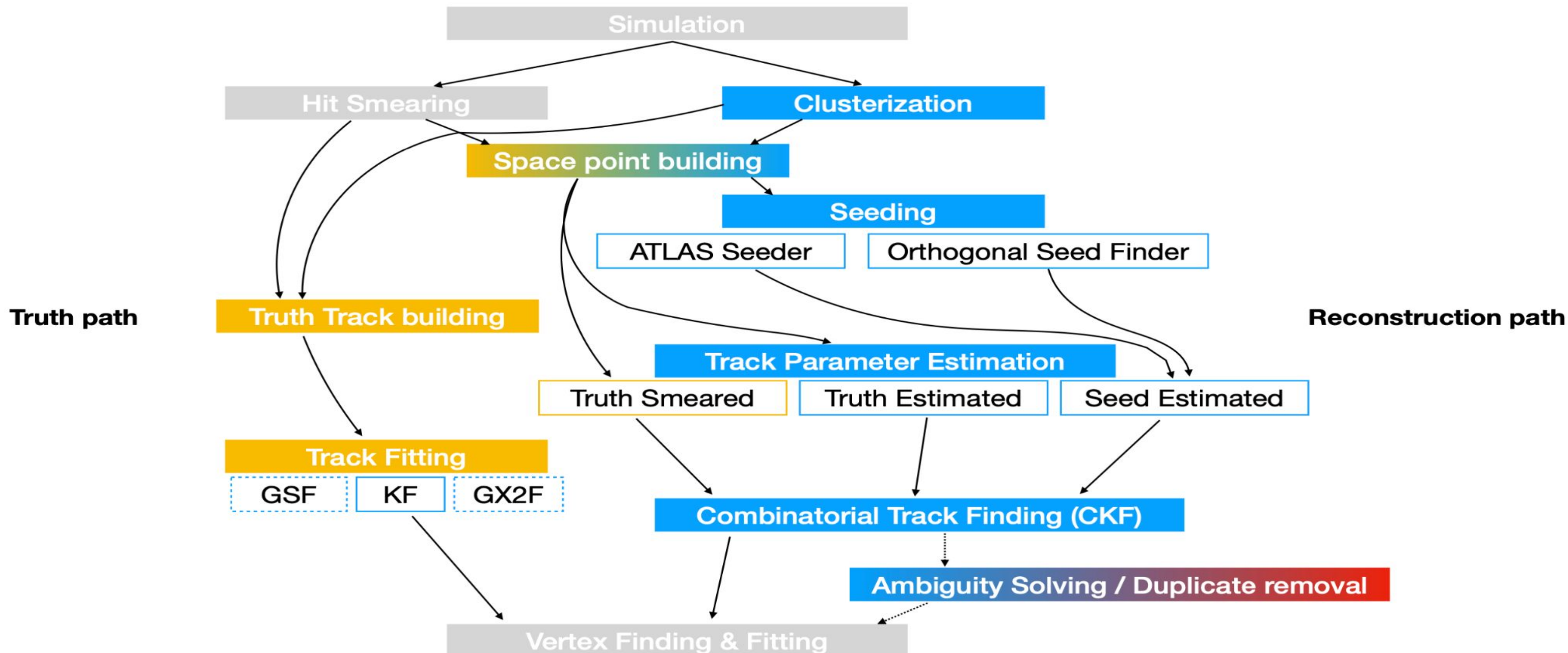
Track finding/fitting with

Track info in output



ACTS: Core Functionality

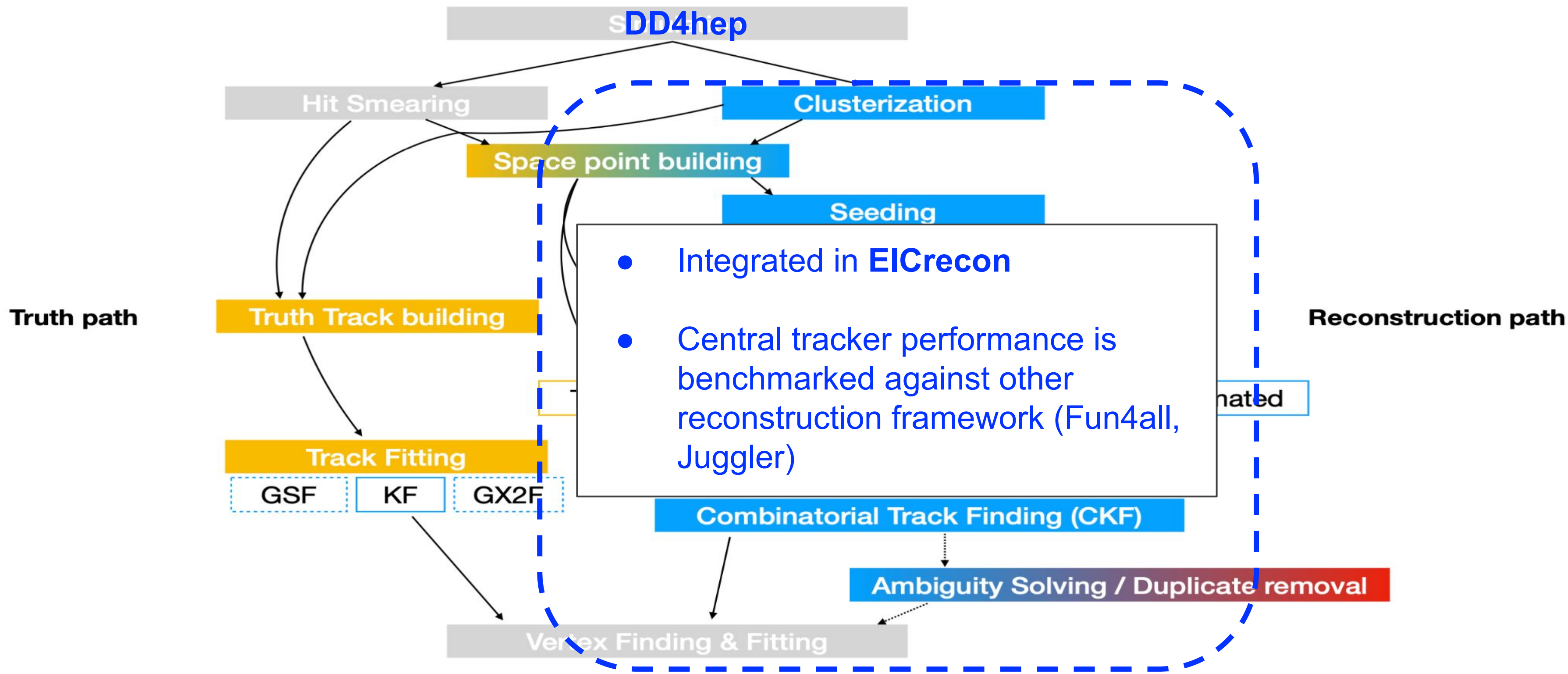
https://acts.readthedocs.io/en/latest/index.html



courtesy of A. Salzburger

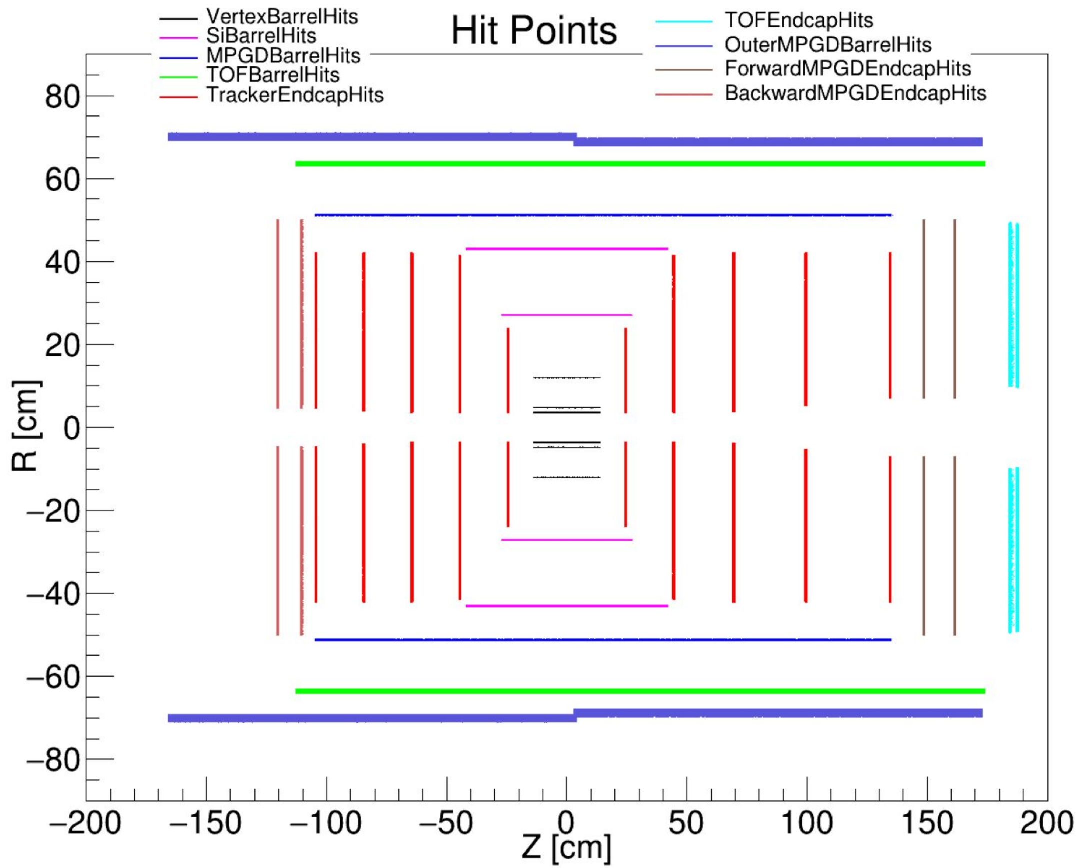
ACTS for ePIC

https://github.com/eic/EICrecon



- Integrated in **EICrecon**
- Central tracker performance is benchmarked against other reconstruction framework (Fun4all, Juggler)

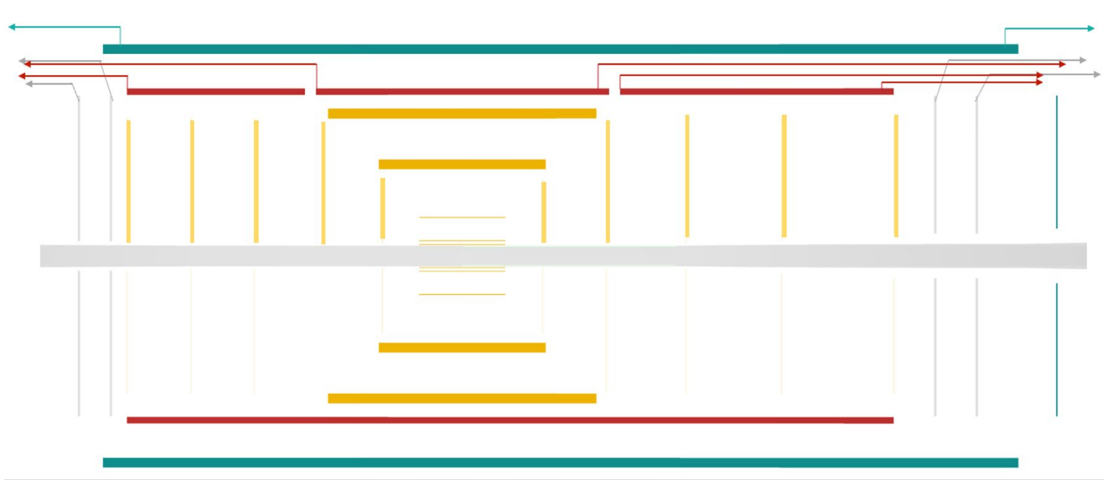
courtesy of A. Salzburger



Hit Points
VertexBarrelHits
SiBarrelHits
MPGDBarrelHits
TOFBarrelHits
TrackerEndcapHits
TOFEndcapHits
OuterMPGDBarrelHits
ForwardMPGDEndcapHits
BackwardMPGDEndcapHits
R [cm]
Z [cm]
80
60
40
20
0
−20
−40
−60
−80
−200
−150
−100
−50
0
50
100
150
200

MPGD Services

	Al Thickness (cm)
(BE1 + BE2 + IB1 + IB2 + OB1) z < -167.5	0.850
(BE1 + BE2 + IB1 + IB2) -167.5 < z < -120	0.574
(BE1 + IB1 +IB2) -120 < z < -110	0.443
(IB1 +IB2) -110 < z < -105	0.312
(IB2) -105 < z < -48.75	0.156
() -48.75 < z < 48.75	0.000
(IB3) 48.75 < z < 53.75	0.156
(IB3 + IB4) 53.75 < z < 135	0.312
(IB3 + IB4+IB5) 135 < z < 148	0.468
(IB3 +IB4 +IB5 + FE1) 148 < z < 161	0.599
(IB3 +IB4 +IB5 + FE1 +FE2) 161 < z < 174	0.730
(IB3 +IB4 +IB5 + FE1 +FE2 + OB2) 174 < z	1.006



https://indico.bnl.gov/event/20126/contributions/78817/attachments/48721/82868/GeometryandSevices.pdf

Crater Lake (23.07.2)

Negative Endcap Region

	Z-position	Rmin	Rmax
Si Disk (1)	-250 mm	36.76 mm	240 mm
Si Disk (2)	-450 mm	36.76 mm	415 mm
Si Disk (3)	-650 mm	36.76 mm	421.4 mm
Si Disk (4)	-850 mm	40 mm	421.4 mm
Si Disk (5)	-1050 mm	46.35 mm	421.4 mm
MPGD Disk (1)	-1100 mm	46.5 mm	500 mm
MPGD Disk (2)	-1200 mm	46.5 mm	500 mm

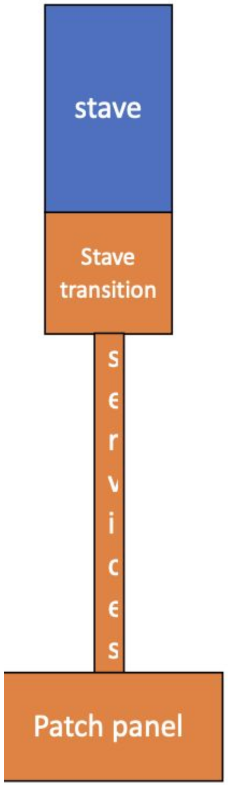
Central Region

Detector	Z min	Z max	R
Si Vertex (1)	-240 mm	240 mm	36 mm
Si Vertex (2)	-240 mm	240 mm	48 mm
Si Vertex (3)	-240 mm	240 mm	120 mm
Si Barrel (1)	-260 mm	260 mm	270 mm
Si Barrel (2)	-420 mm	420 mm	430 mm
Inner MPGD Barrel	-1050 mm	1350 mm	510 mm
Barrel ToF	-1125 mm	1740 mm	630 mm
Outer MPGD Barrel	-1740 mm	1675 mm	695 mm

Positive Endcap Region

	Z-position	Rmin	Rmax
Si Disk (1)	250 mm	36.76 mm	240 mm
Si Disk (2)	450 mm	36.76 mm	415 mm
Si Disk (3)	700 mm	38.46 mm	421.4 mm
Si Disk (4)	1000 mm	53.43 mm	421.4 mm
Si Disk (5)	1350 mm	70.14 mm	421.4 mm
MPGD Disk (1)	1480 mm	70.14 mm	500 mm
MPGD Disk (2)	1610 mm	70.14 mm	500 mm
ToF Disk	1870 mm	85 mm	500 mm

Summary of ITS3 like Si tracking



	Stave X/X0	Stave transition (per 100 cm^2 of Si surface)*	Services (per 100 cm^2 of Si surface)*	Patch panel (per 100 cm^2 of Si surface)*
ITS3 like vertexing	~0.1%	6.66 cm^3 of material with X/X0 of 0.0684 per traversed cm	2.96 cm^2 cross section with X/X0 of 0.022 per traversed cm	4.32 cm x 1cm x 1 cm with 0.102 X/X0 per traversed cm
ITS3 like barrel (up to 1.5m length)	0.55 %	4.286 cm^3 of material with X/X0 of 0.0684 per traversed cm	1.905 cm^2 cross section with X/X0 of 0.022 per traversed cm	2.778cm x 1cm x 1 cm with 0.102 X/X0 per traversed cm
ITS3 like disc (up to 60 cm diameter)	0.24%	6.66 cm^3 of material with X/X0 of 0.0684 per traversed cm	2.96 cm^2 cross section with X/X0 of 0.022 per traversed cm	4.321 cm x 1cm x 1 cm with 0.102 X/X0 per traversed cm

* Corrected 2021_03_13