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U.S. DEPARTMENT OF ENERGY
Office of Science

ePIC Track Reconstruction Status

Shujie Li
ePIC tracking WG meeting

Feb 23, 2023

ePIC

Summary

works

- Generate test particles
- GEANT simulation
  - Detailed geometry
  - Digitization at pixel level*
- Hit info to ACTS
- Initial guess for CKF
  - truth params smeared
  - seeding to init params
- CKF track finding/fitting algorithm
- Track params from fit
- Event display
  - root script available on github (Shyam)
  - HSF/Phoenix online server (Sakib)

To finish

- Hit clustering (Shujie)
  - Smearing at hit rather than pixel level to resolve multi hits
  - *clusterization algorithm*
- ACTS Seed finding/filter (Rey, Barak)
- Track info from ACTS
  - Raw hits → primary particle association (Barak)
  - Hits used w/track association
  - χ^2, # of measurements to rootfile (Shyam)
- Optimize track quality cuts (Beatrice)
  - χ^2 , # of measurements
- Validation plots
- Background embedding (Kolja)

Track Reconstruction in EICrecon

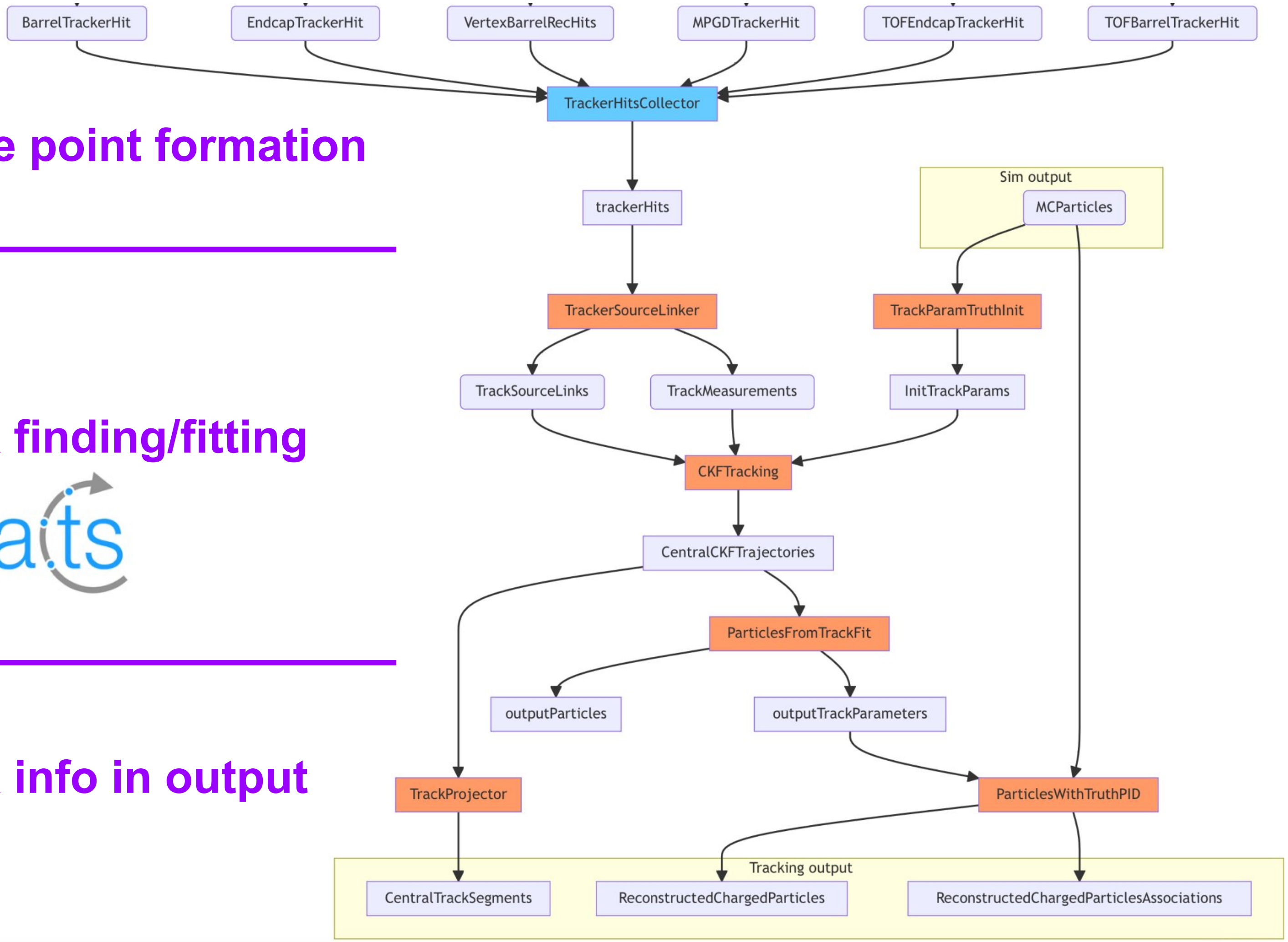
contact: Dmitry Romanov

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

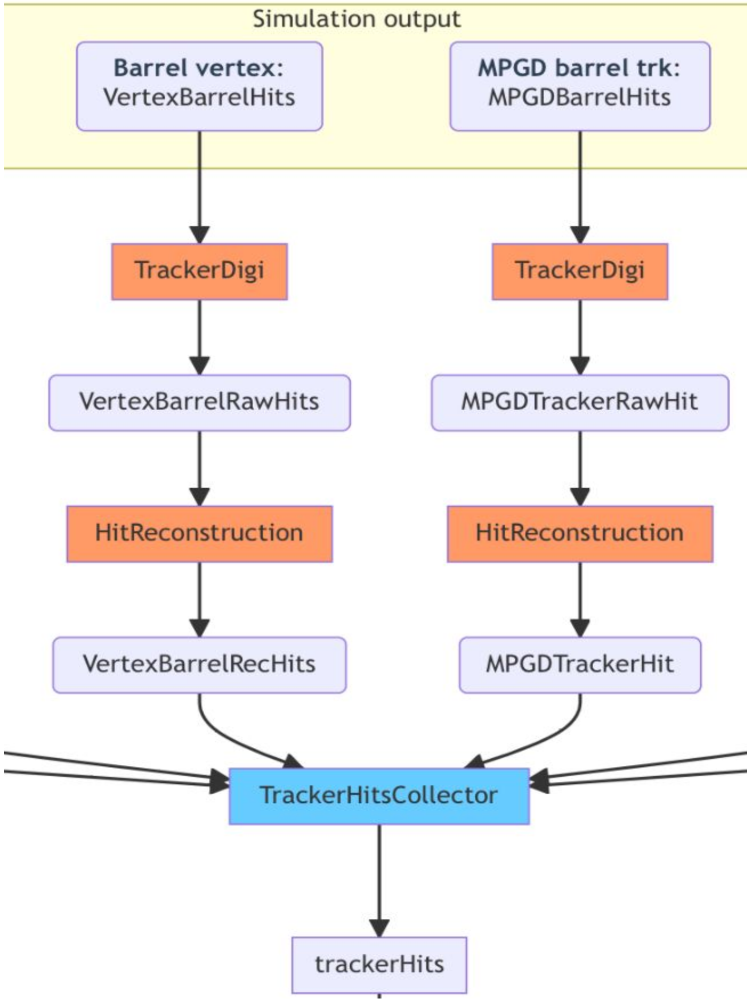
Space point formation

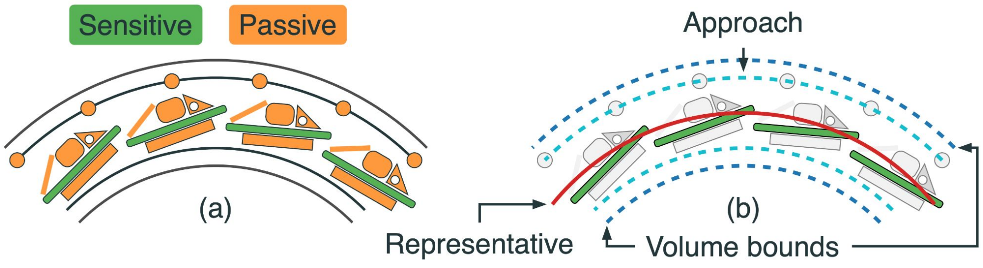
Track finding/fitting with acts

Track info in output

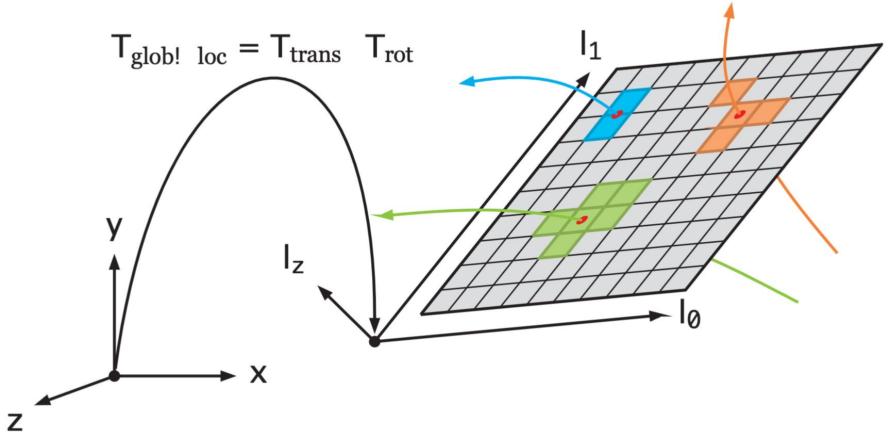


Space Point Formation

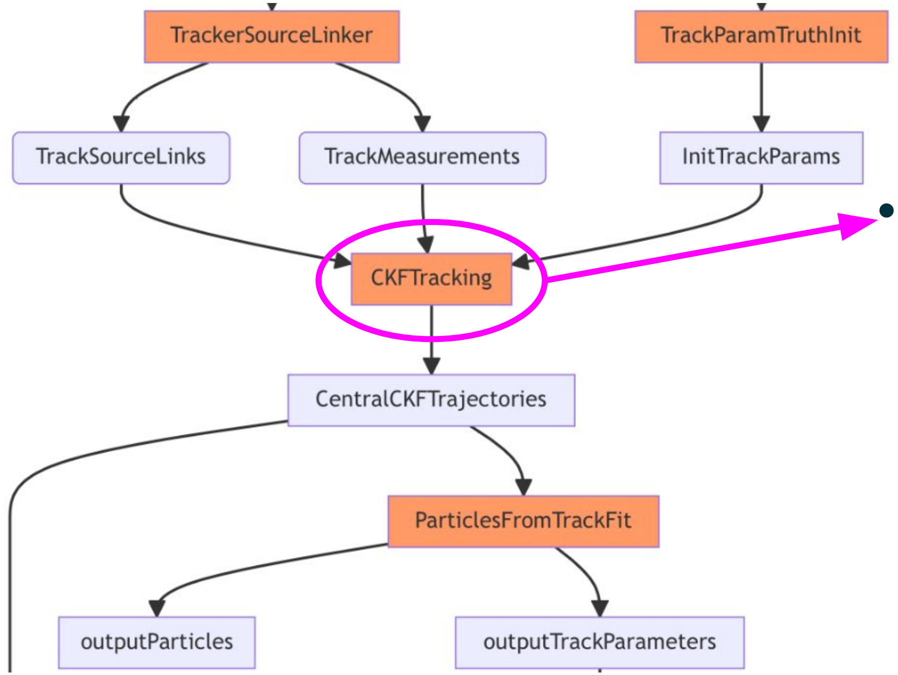




- Global / local coord. transformation
- Digitization:
    - Raw hits -> Surface and cell ID
    - Energy deposit threshold:
        - Now: 0, to use : 110 electrons
    - Clustering algorithm available at https://github.com/acts-project/acts/pull/1190 (Louis-Guillaume Gagnon, March 9th)


$T_{\text{glob!}\ \text{loc}} = T_{\text{trans}}\ \ T_{\text{rot}}$
l_1
y
l_z
l_0
x
z

Track Finding/Fitting with ACTS



TrackerSourceLinker

TrackParamTruthInit

TrackSourceLinks

TrackMeasurements

InitTrackParams

CKFTracking

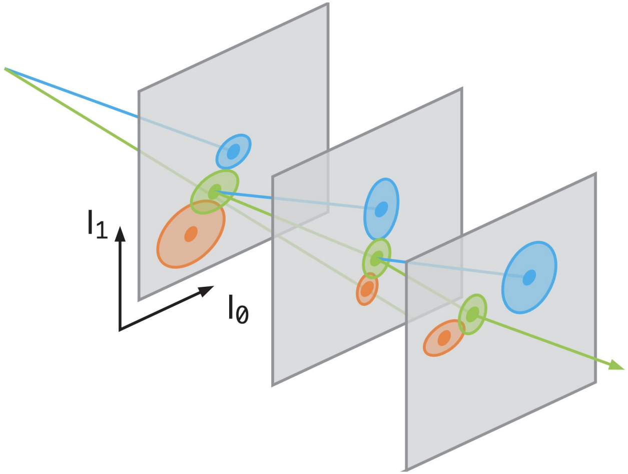
CentralCKFTrajectories

ParticlesFromTrackFit

outputParticles

outputTrackParameters

- **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”**



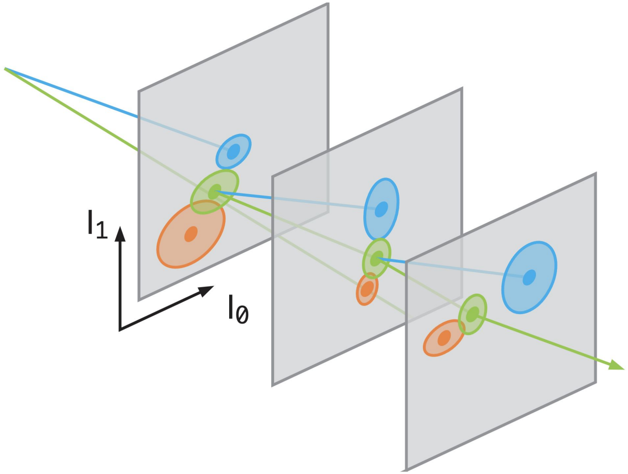
EICrecon: JANA2 based recon framework

EICrecon factory (interface)

ACTS: CKF Algorithm

Hits selection

acts/Core/include/Acts/TrackFinding/MeasurementSelector.hpp



CKF:

if no hits on surface→ **nHoles++**

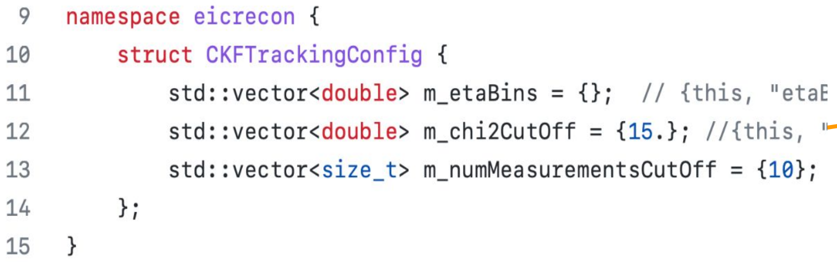
for (track state : track state candidates):

    Track state → hits on surface

    Calculate chi2 of all hits and rank, find chi2min

    if chi2min >chi2CutOff → save chi2min as **outlier**

    <chi2CutOff → save up to num**Measurements**CutOff candidates



```
namespace eicrecon {
    struct CKFTrackingConfig {
        std::vector<double> m_etaBins = {};  // {this, "etaB
        std::vector<double> m_chi2CutOff = {15.}; //{this, "
        std::vector<size_t> m_numMeasurementsCutOff = {10};
    };
}
```

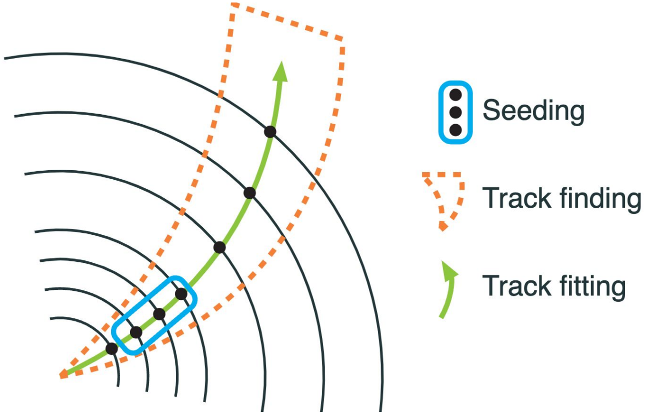
optimize cuts (Beatrice)

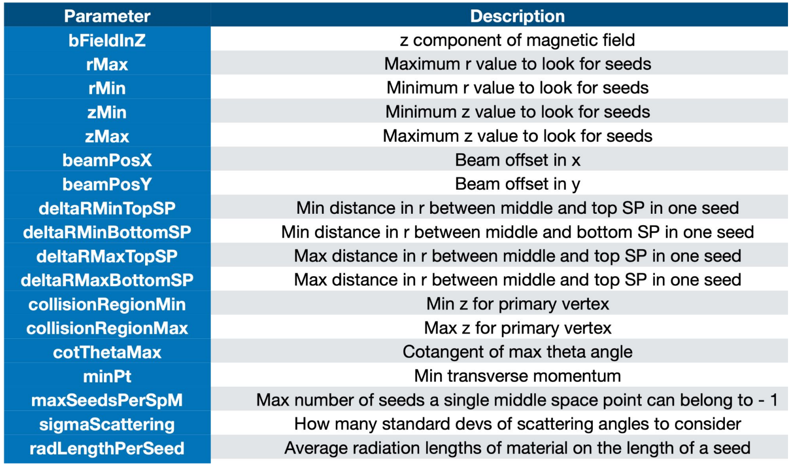
# of sensitive surfaces = nHoles + nMeasurements + nOutliers

Initial Guess for CKF: 2. realistic seeding

Seeder: a set of three space points to estimate initial track parameters

- **Binned seeder**: loop over φ-z binning to try all combinations. Slow at large η
  - tested and bugs fixed. See YueShi Lai's work
- **Orthogonal seed finder**: can efficiently search for space points within a given range.
  - Initial implementation in EICrecon - Joe Osborn
  - Seeder configuration:
    - default parameters from binned seeder
    - parameter optimization - See Rey Cruz-Torres's work
  - Seeder confirmation/filter





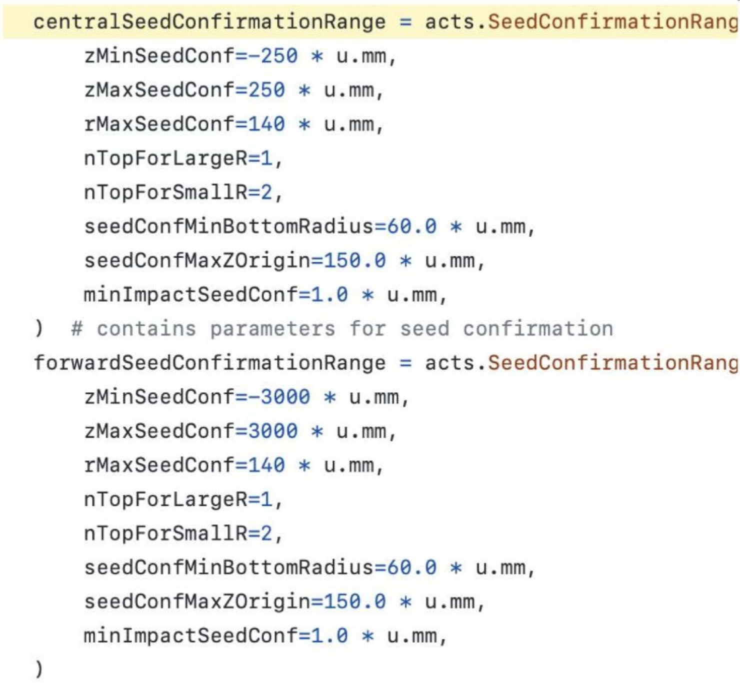
Parameter	Description
bFieldInZ	z component of magnetic field
rMax	Maximum r value to look for seeds
rMin	Minimum r value to look for seeds
zMin	Minimum z value to look for seeds
zMax	Maximum z value to look for seeds
beamPosX	Beam offset in x
beamPosY	Beam offset in y
deltaRMinTopSP	Min distance in r between middle and top SP in one seed
deltaRMinBottomSP	Min distance in r between middle and bottom SP in one seed
deltaRMaxTopSP	Max distance in r between middle and top SP in one seed
deltaRMaxBottomSP	Max distance in r between middle and top SP in one seed
collisionRegionMin	Min z for primary vertex
collisionRegionMax	Max z for primary vertex
cotThetaMax	Cotangent of max theta angle
minPt	Min transverse momentum
maxSeedsPerSpM	Max number of seeds a single middle space point can belong to - 1
sigmaScattering	How many standard devs of scattering angles to consider
radLengthPerSeed	Average radiation lengths of material on the length of a seed

Initial Guess for CKF: 2. realistic seeding

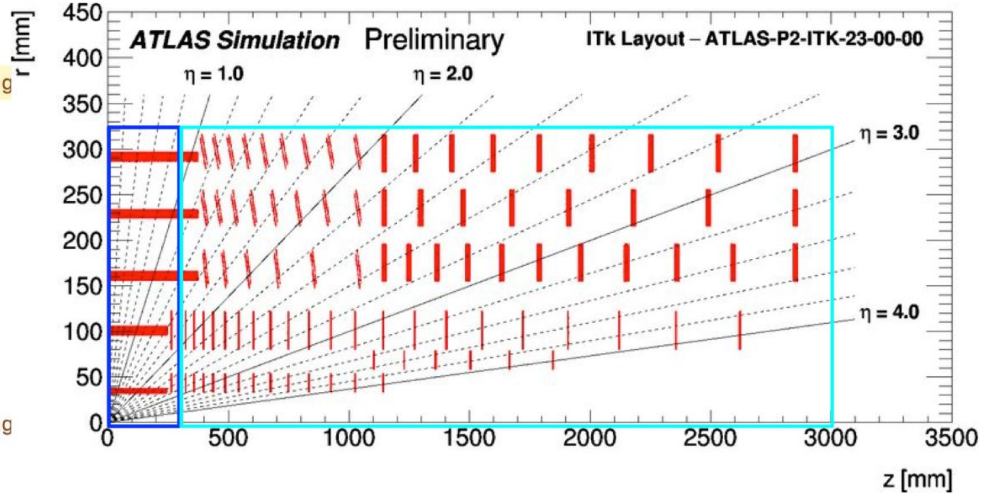
Seed Confirmation/Filter

Individual filter settings for each geometry region.

- Experience from ATLAS-ITK , see Luis Falda Coelho's work
- implementation in EICrecon, **TBD** - Rey, Barak Schmookler



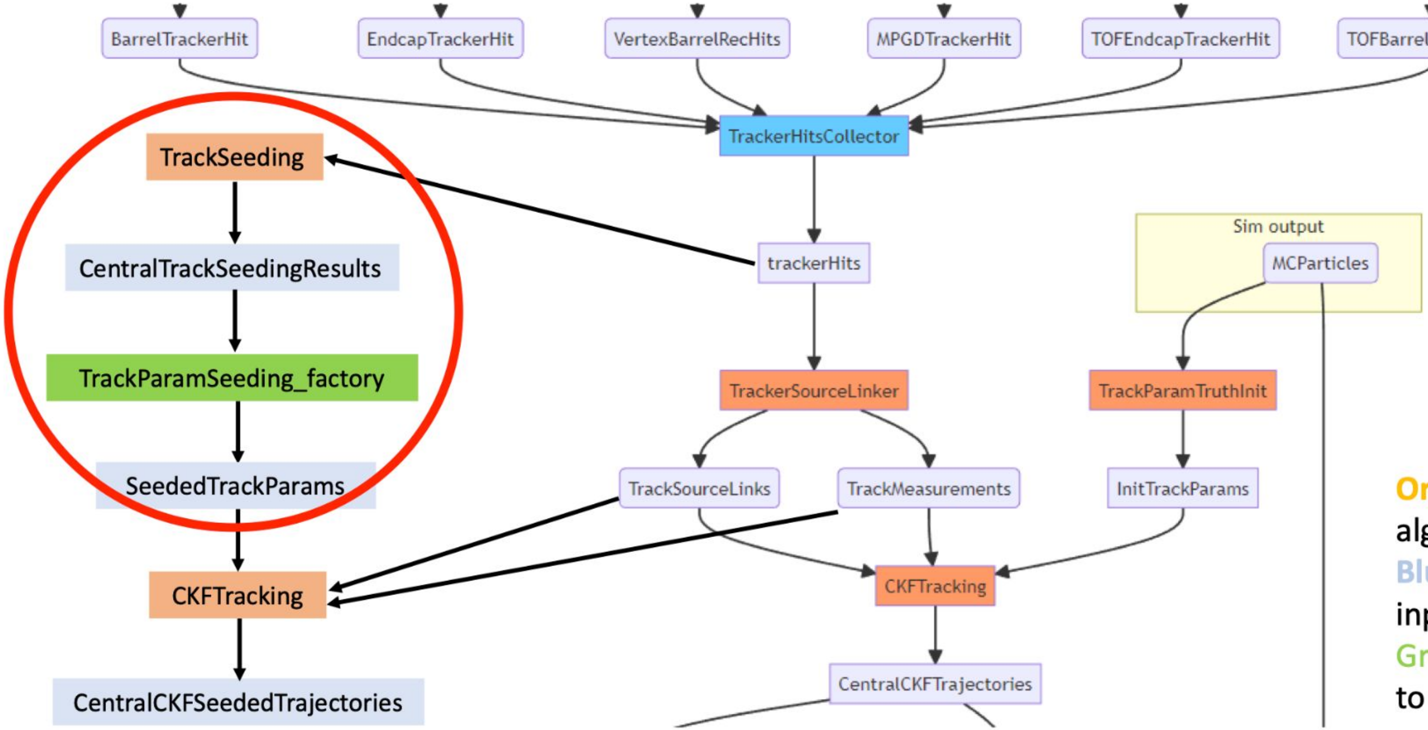
```
centralSeedConfirmationRange = acts.SeedConfirmationRang
    zMinSeedConf=-250 * u.mm,
    zMaxSeedConf=250 * u.mm,
    rMaxSeedConf=140 * u.mm,
    nTopForLargeR=1,
    nTopForSmallR=2,
    seedConfMinBottomRadius=60.0 * u.mm,
    seedConfMaxZOrigin=150.0 * u.mm,
    minImpactSeedConf=1.0 * u.mm,
)  # contains parameters for seed confirmation
forwardSeedConfirmationRange = acts.SeedConfirmationRang
    zMinSeedConf=-3000 * u.mm,
    zMaxSeedConf=3000 * u.mm,
    rMaxSeedConf=140 * u.mm,
    nTopForLargeR=1,
    nTopForSmallR=2,
    seedConfMinBottomRadius=60.0 * u.mm,
    seedConfMaxZOrigin=150.0 * u.mm,
    minImpactSeedConf=1.0 * u.mm,
)
```



Initial Guess for CKF: 2. realistic seeding

Supply realistic init parameters to CKF

- CKF with realistic seeding in addition to truth seeding. See Barak’s work
  - retain data structure for current downstream analysis
- Switch between truth / realistic seeding. TBD. See Dmitry’s work



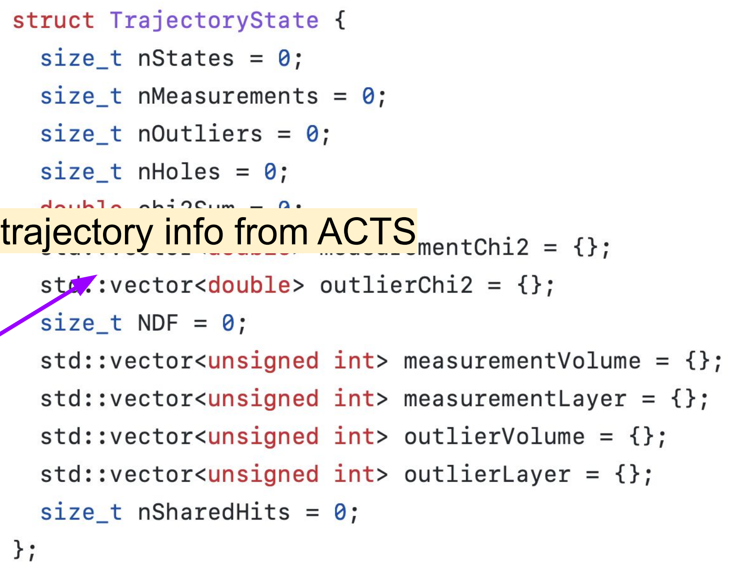
Orange boxes are algorithms. Blue/Grey boxes are input/output data. Green box is a factory to reformat data type.

Track Info in Output

- Track parameters from fit - Done
- Track projection - Done

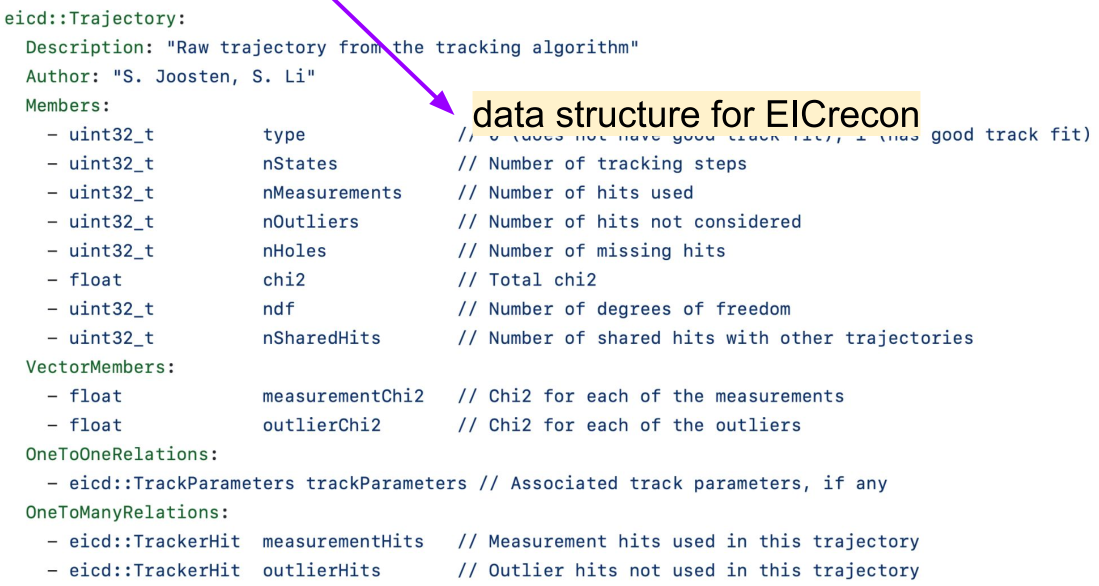
- Trajectory info (chi2, number of hits …)
  - save to histograms with EICrecon plugins
  - save to output rootfile:
    - **TBD**: write an EICrecon factory to write trajectory info into data structure

- **TBD:** Hits associated with tracks



trajectory info from ACTS

```
struct TrajectoryState {
  size_t nStates = 0;
  size_t nMeasurements = 0;
  size_t nOutliers = 0;
  size_t nHoles = 0;
  double chi2Sum = 0;
  std::vector<double> measurementChi2 = {};
  std::vector<double> outlierChi2 = {};
  size_t NDF = 0;
  std::vector<unsigned int> measurementVolume = {};
  std::vector<unsigned int> measurementLayer = {};
  std::vector<unsigned int> outlierVolume = {};
  std::vector<unsigned int> outlierLayer = {};
  size_t nSharedHits = 0;
};
```



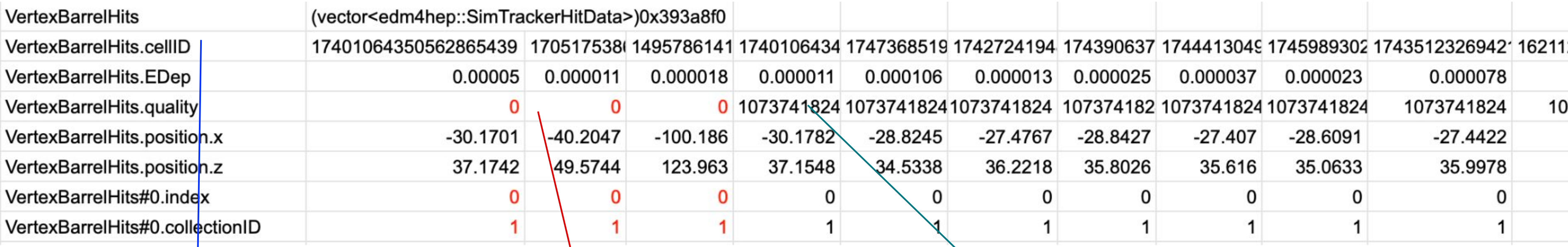
data structure for EICrecon

```
eicd::Trajectory:
  Description: "Raw trajectory from the tracking algorithm"
  Author: "S. Joosten, S. Li"
  Members:
    - uint32_t         type              // 0 (does not have good track fit), 1 (has good track fit)
    - uint32_t         nStates           // Number of tracking steps
    - uint32_t         nMeasurements     // Number of hits used
    - uint32_t         nOutliers         // Number of hits not considered
    - uint32_t         nHoles            // Number of missing hits
    - float            chi2              // Total chi2
    - uint32_t         ndf               // Number of degrees of freedom
    - uint32_t         nSharedHits       // Number of shared hits with other trajectories
  VectorMembers:
    - float            measurementChi2   // Chi2 for each of the measurements
    - float            outlierChi2       // Chi2 for each of the outliers
  OneToOneRelations:
    - eicd::TrackParameters trackParameters // Associated track parameters, if any
  OneToManyRelations:
    - eicd::TrackerHit  measurementHits   // Measurement hits used in this trajectory
    - eicd::TrackerHit  outlierHits       // Outlier hits not used in this trajectory
```

MCParticle-Hits Association

https://github.com/AIDASoft/DD4hep/issues/126
https://github.com/AIDASoft/DD4hep/pull/145

See Barak’s work

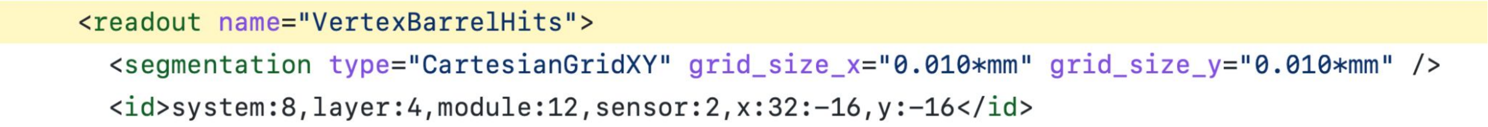


VertexBarrelHits	(vector<edm4hep::SimTrackerHitData>)0x393a8f0										
VertexBarrelHits.cellID	17401064350562865439	170517538	1495786141	1740106434	1747368519	1742724194	174390637	1744413049	1745989302	1743512326942	16211
VertexBarrelHits.EDep	0.00005	0.000011	0.000018	0.000011	0.000106	0.000013	0.000025	0.000037	0.000023	0.000078	
VertexBarrelHits.quality	0	0	0	1073741824	1073741824	1073741824	107374182	1073741824	1073741824	1073741824	10
VertexBarrelHits.position.x	-30.1701	-40.2047	-100.186	-30.1782	-28.8245	-27.4767	-28.8427	-27.407	-28.6091	-27.4422	
VertexBarrelHits.position.z	37.1742	49.5744	123.963	37.1548	34.5338	36.2218	35.8026	35.616	35.0633	35.9978	
VertexBarrelHits#0.index	0	0	0	0	0	0	0	0	0	0	
VertexBarrelHits#0.collectionID	1	1	1	1	1	1	1	1	1	1	

segmentation defined in each detector xml file

3 primary hits on 3 vertex layers with quality = 0

quality>0 means hits from secondaries **BUT** those secondaries didn’t pass dd4hep cut **10 MeV**, so the are **NOT** saved in MCparticle.
⇒Those hits are linked back to primary (parent) particles.



```
    <readout name="VertexBarrelHits">
      <segmentation type="CartesianGridXY" grid_size_x="0.010*mm" grid_size_y="0.010*mm" />
      <id>system:8,layer:4,module:12,sensor:2,x:32:-16,y:-16</id>
```

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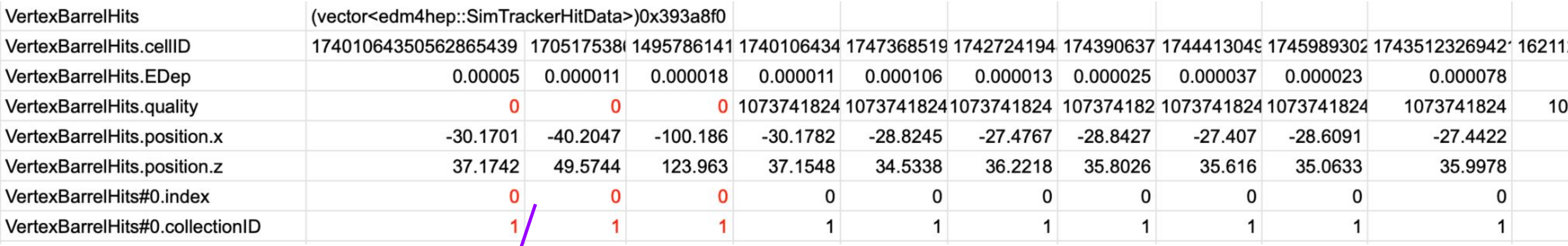
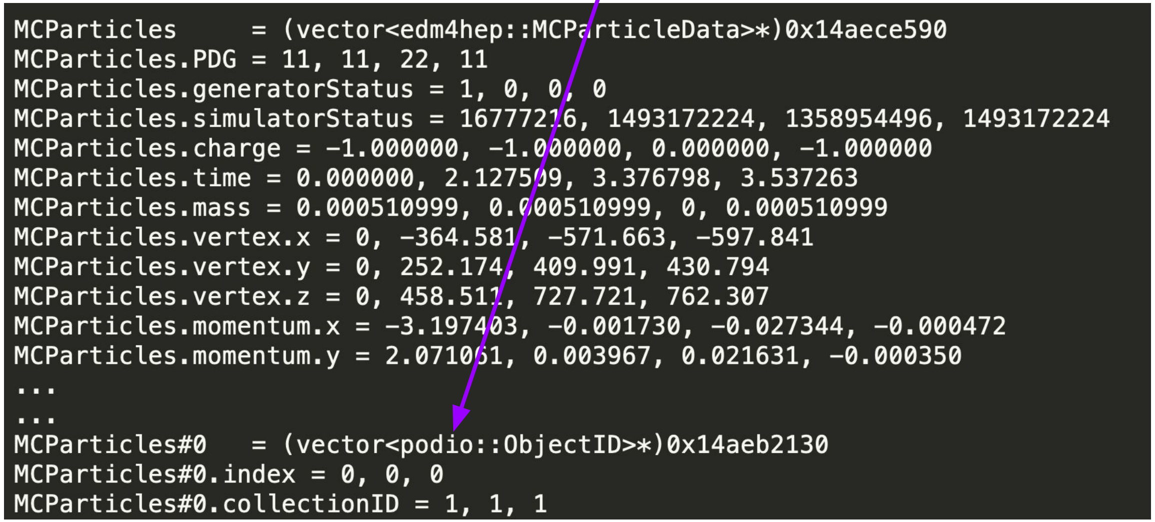
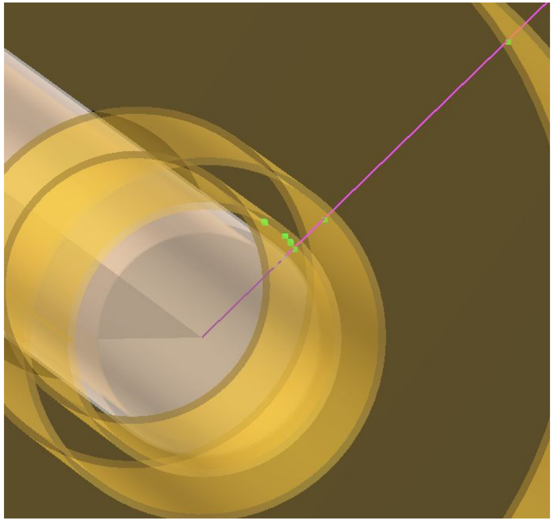


VertexBarrelHits	(vector<edm4hep::SimTrackerHitData>)0x393a8f0										
VertexBarrelHits.cellID	17401064350562865439	170517538	1495786141	1740106434	1747368519	1742724194	174390637	174441304	174598930	174351232694	16211
VertexBarrelHits.EDep	0.00005	0.000011	0.000018	0.000011	0.000106	0.000013	0.000025	0.000037	0.000023	0.000078	
VertexBarrelHits.quality	0	0	0	1073741824	1073741824	1073741824	107374182	1073741824	1073741824	1073741824	10
VertexBarrelHits.position.x	-30.1701	-40.2047	-100.186	-30.1782	-28.8245	-27.4767	-28.8427	-27.407	-28.6091	-27.4422	
VertexBarrelHits.position.z	37.1742	49.5744	123.963	37.1548	34.5338	36.2218	35.8026	35.616	35.0633	35.9978	
VertexBarrelHits#0.index	0	0	0	0	0	0	0	0	0	0	
VertexBarrelHits#0.collectionID	1	1	1	1	1	1	1	1	1	1	

use index to access associated particle/initial track



```
MCParticles     = (vector<edm4hep::MCParticleData>*)0x14aece590
MCParticles.PDG = 11, 11, 22, 11
MCParticles.generatorStatus = 1, 0, 0, 0
MCParticles.simulatorStatus = 16777216, 1493172224, 1358954496, 1493172224
MCParticles.charge = -1.000000, -1.000000, 0.000000, -1.000000
MCParticles.time = 0.000000, 2.127509, 3.376798, 3.537263
MCParticles.mass = 0.000510999, 0.000510999, 0, 0.000510999
MCParticles.vertex.x = 0, -364.581, -571.663, -597.841
MCParticles.vertex.y = 0, 252.174, 409.991, 430.794
MCParticles.vertex.z = 0, 458.511, 727.721, 762.307
MCParticles.momentum.x = -3.197403, -0.001730, -0.027344, -0.000472
MCParticles.momentum.y = 2.071061, 0.003967, 0.021631, -0.000350
...
...
MCParticles#0   = (vector<podio::ObjectID>*)0x14aeb2130
MCParticles#0.index = 0, 0, 0
MCParticles#0.collectionID = 1, 1, 1
```



MCParticle-Hits Association

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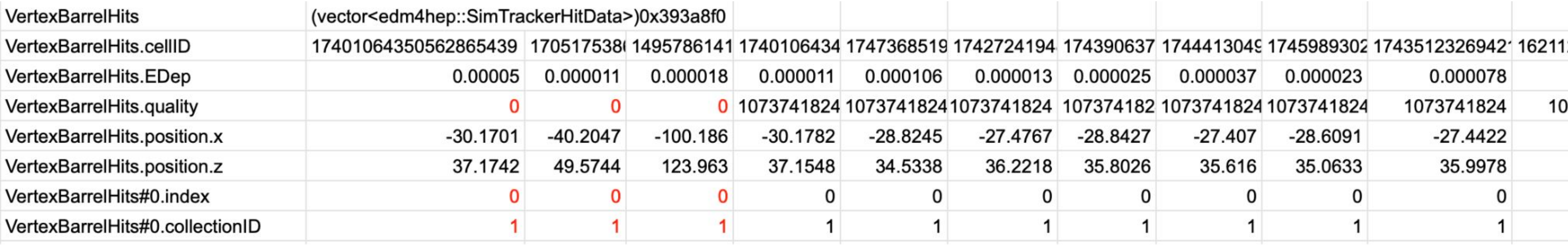
See Barak's work



VertexBarrelHits	(vector<edm4hep::SimTrackerHitData>)0x393a8f0										
VertexBarrelHits.cellID	17401064350562865439	170517538	1495786141	1740106434	1747368519	1742724194	174390637	1744413049	1745989302	1743512326942	16211
VertexBarrelHits.EDep	0.00005	0.000011	0.000018	0.000011	0.000106	0.000013	0.000025	0.000037	0.000023	0.000078	
VertexBarrelHits.quality	0	0	0	1073741824	1073741824	1073741824	107374182	1073741824	1073741824	1073741824	10
VertexBarrelHits.position.x	-30.1701	-40.2047	-100.186	-30.1782	-28.8245	-27.4767	-28.8427	-27.407	-28.6091	-27.4422	
VertexBarrelHits.position.z	37.1742	49.5744	123.963	37.1548	34.5338	36.2218	35.8026	35.616	35.0633	35.9978	
VertexBarrelHits#0.index	0	0	0	0	0	0	0	0	0	0	
VertexBarrelHits#0.collectionID	1	1	1	1	1	1	1	1	1	1	

Solutions to multi-hits:

1. reject secondaries by quality and index values
2. clusterization algorithm in ACTS https://github.com/acts-project/acts/blob/main/Core/include/Acts/Clusterization/Clusterization.hpp