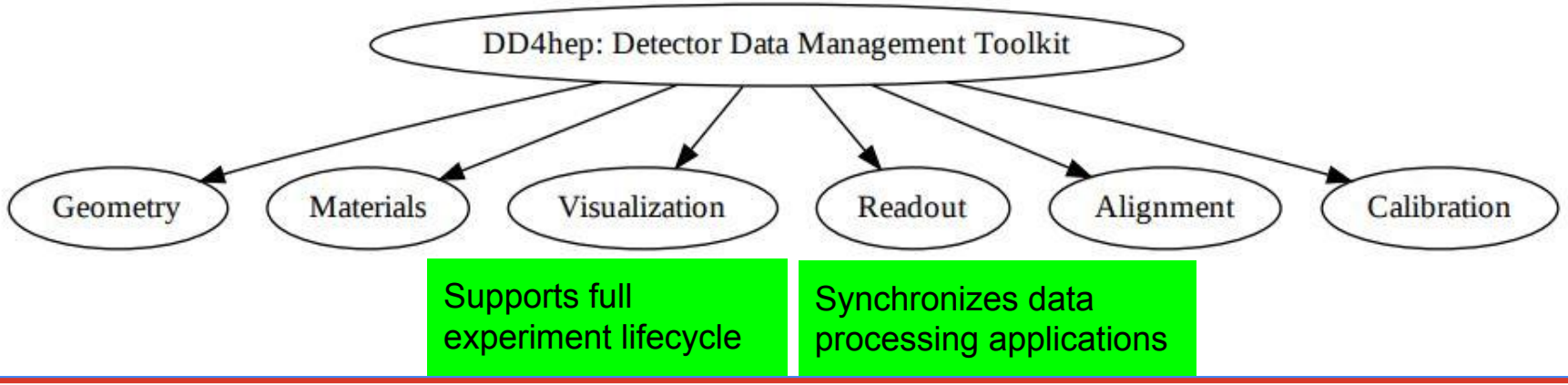
DD4hep-ACTS interface for ePIC simulation and B0 tracker implementation

Sakib Rahman
University of Manitoba

EPIC Collaboration Meeting
January 10, 2023

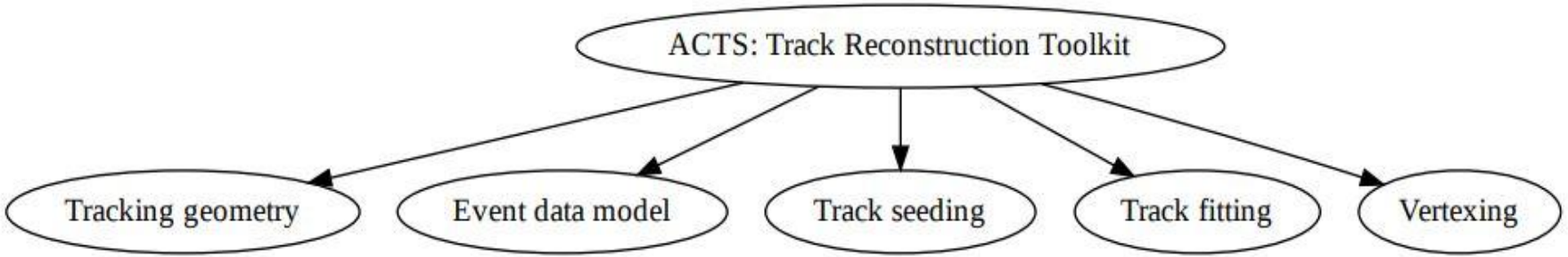
ACTS and DD4hep overview

More details on collaboration with ACTS in Shujie Li's talk in COMP SW session [Jan 9, 12:15 pm]



Supports full experiment lifecycle

Synchronizes data processing applications



Easy interface with dd4hep

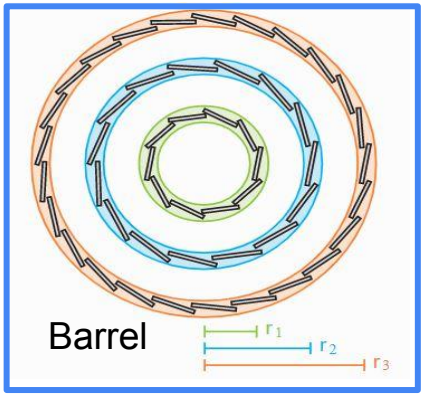
Provides common and state-of-the-art algorithms

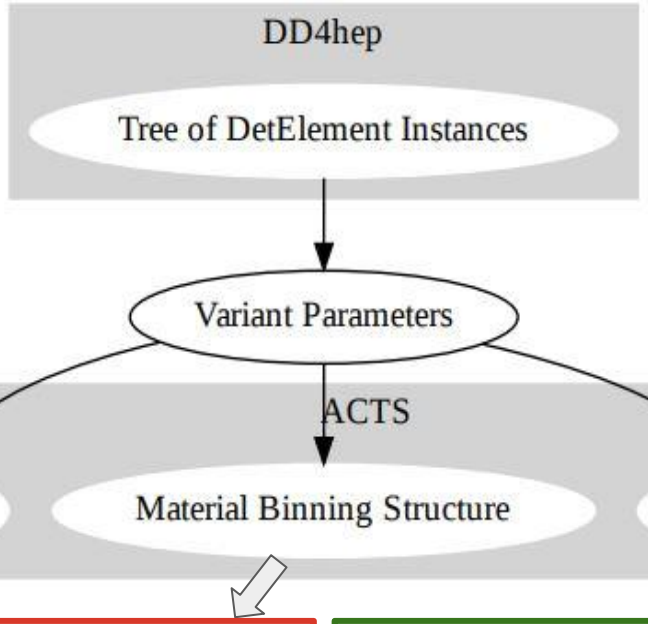
Combines experience from multiple experiments

Responsive developers

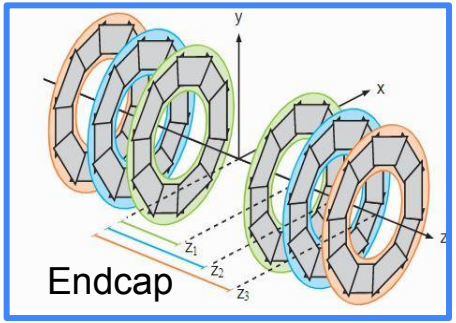
DD4hep-ACTS Integration

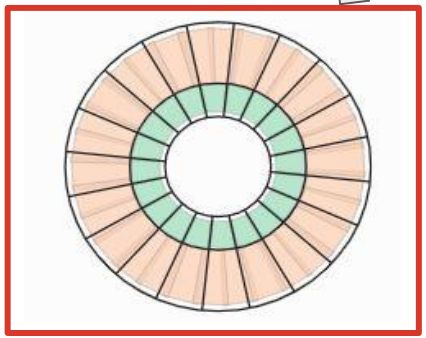
Source: ACTS documentation

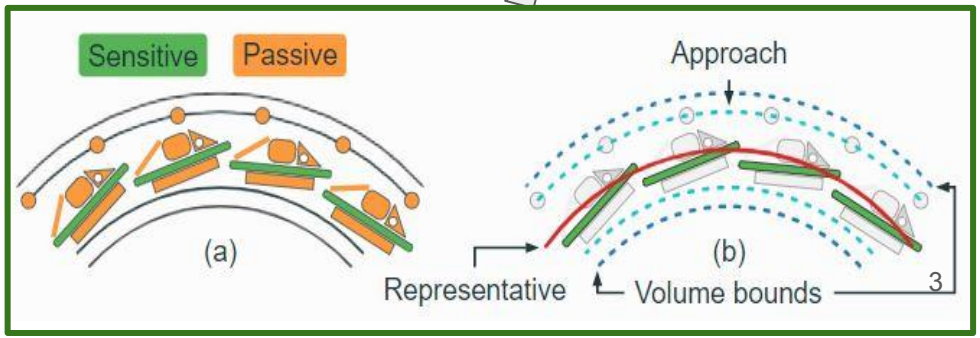




ACTS Tracking geometry: A collection of volumes glued together with adjacent volumes sharing boundaries
Volume: A collection of layers
Layer: A collection of sensitive surfaces



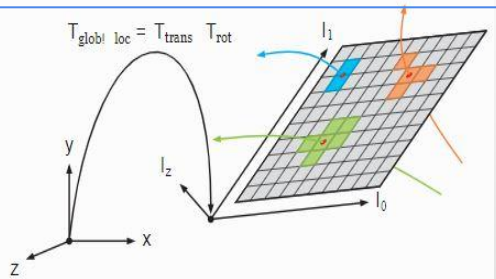




ACTS Tracking and Reconstruction

Source: ACTS documentation

Clustering and Space Point Formation

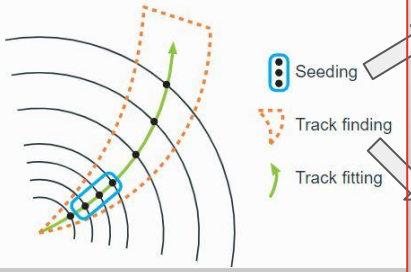


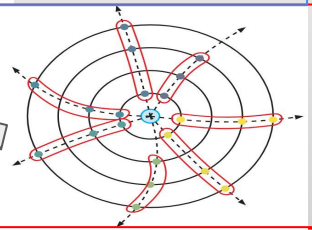
Local to Global Transform

Track seeding

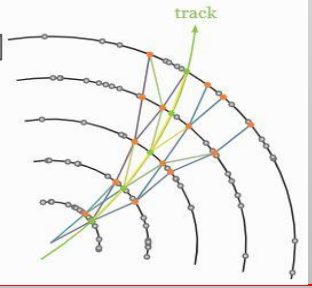
Track finding and fitting

Vertex Reconstruction



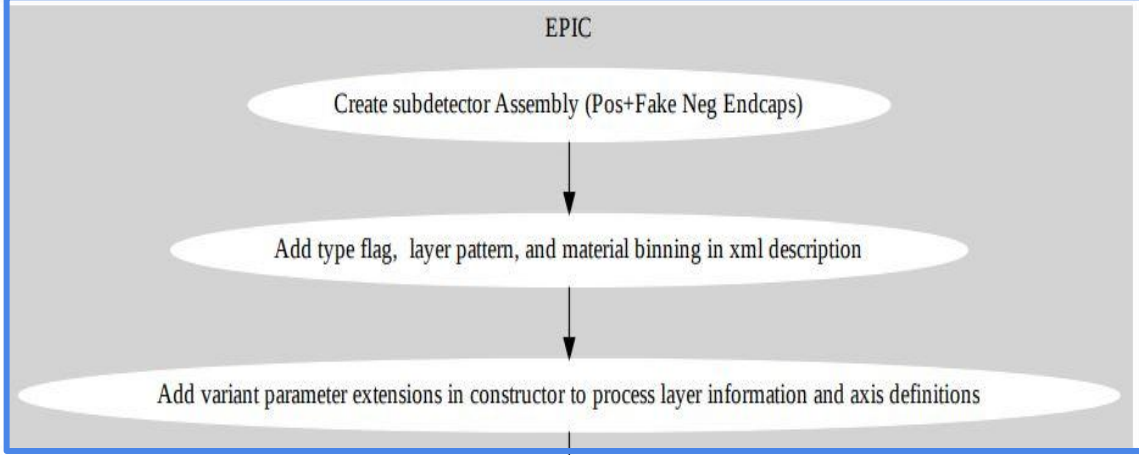


Hit Triplet Search

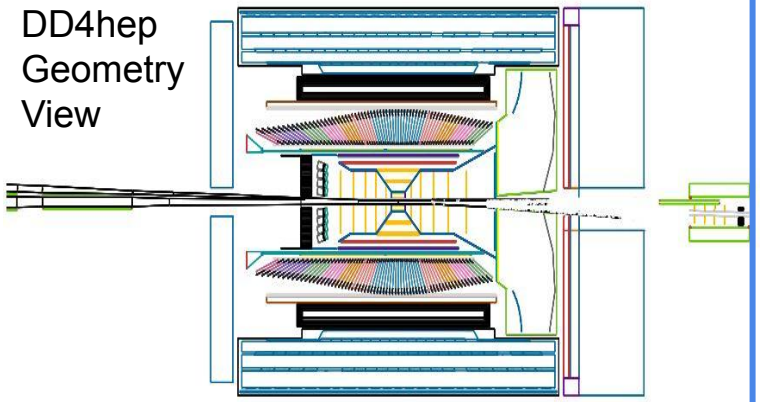


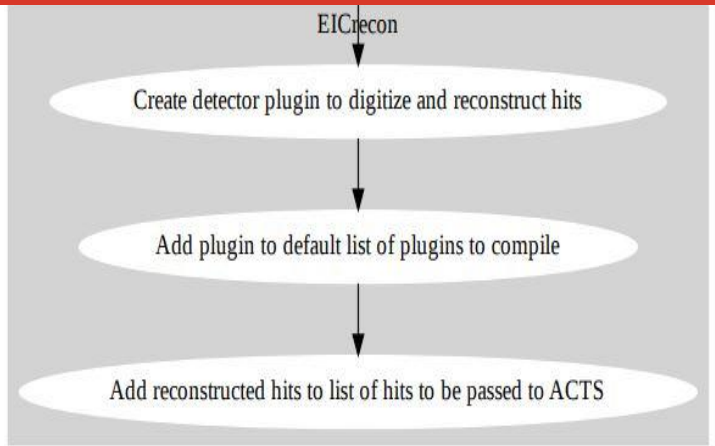
Combinatorial Kalman Filtering

Integrating the B0 Trackers into ACTS tracking for EPIC

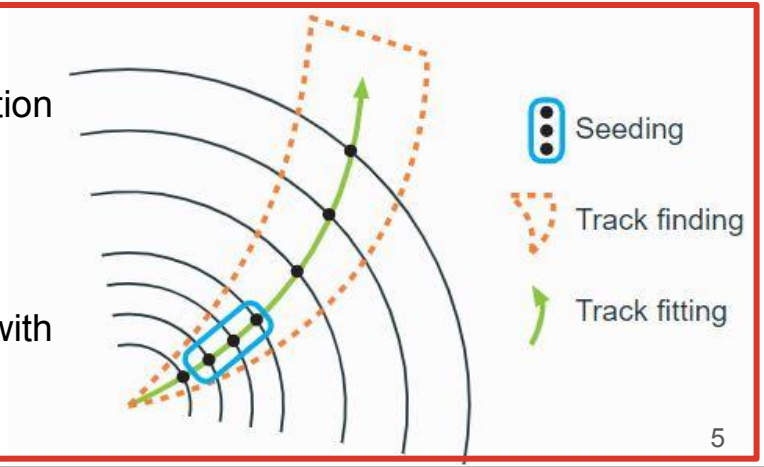


DD4hep Geometry View

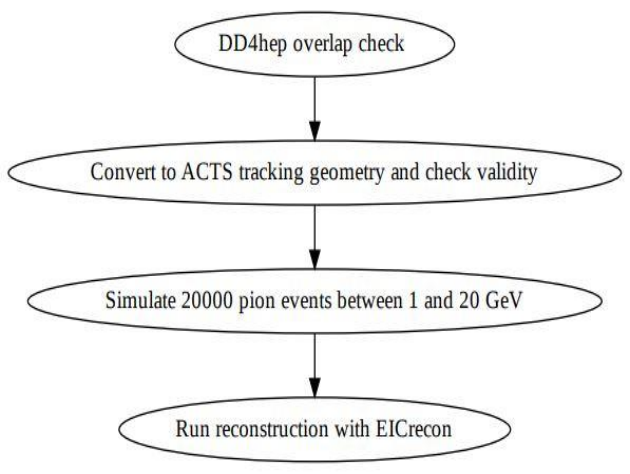




Reconstruction chain abstracted away within EICrecon interfacing with ACTS



Test simulation and reconstruction chain

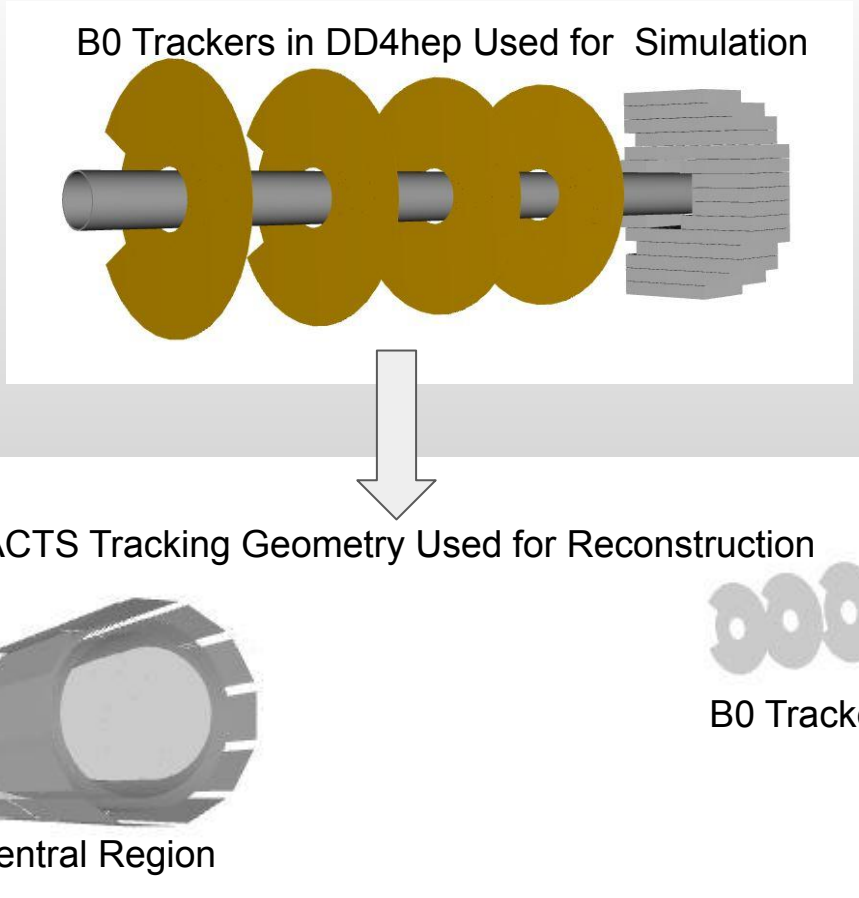


Challenges to integrating B0

Off-axis and at an angle

Simple cylindrical layer envelopes cannot be defined explicitly (DD4hep overlap)

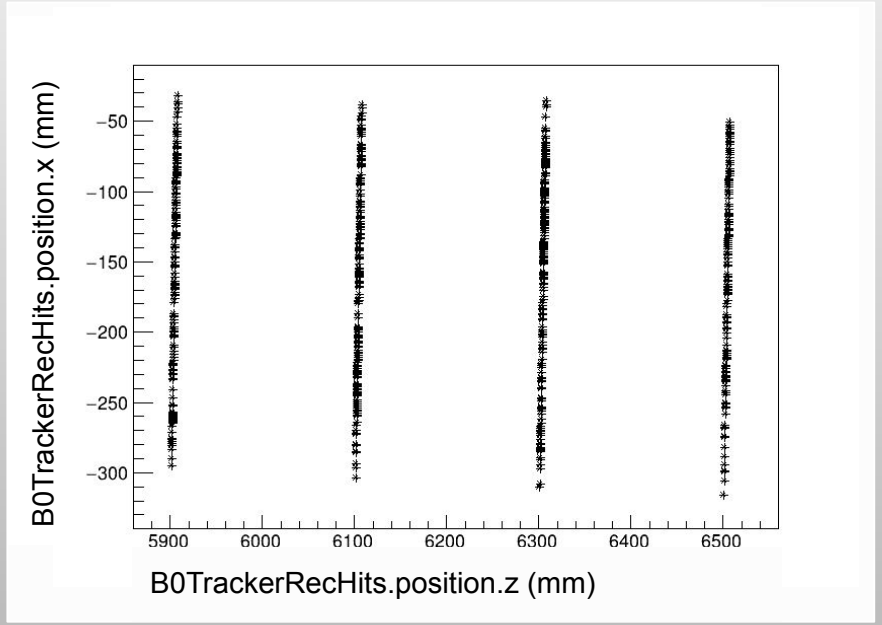
Define material layers for ACTS more carefully

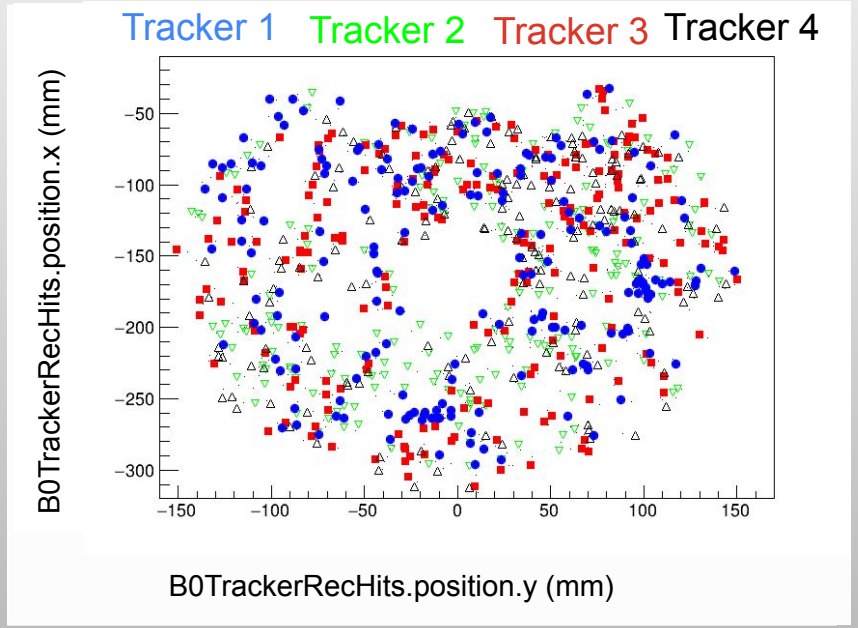


Results

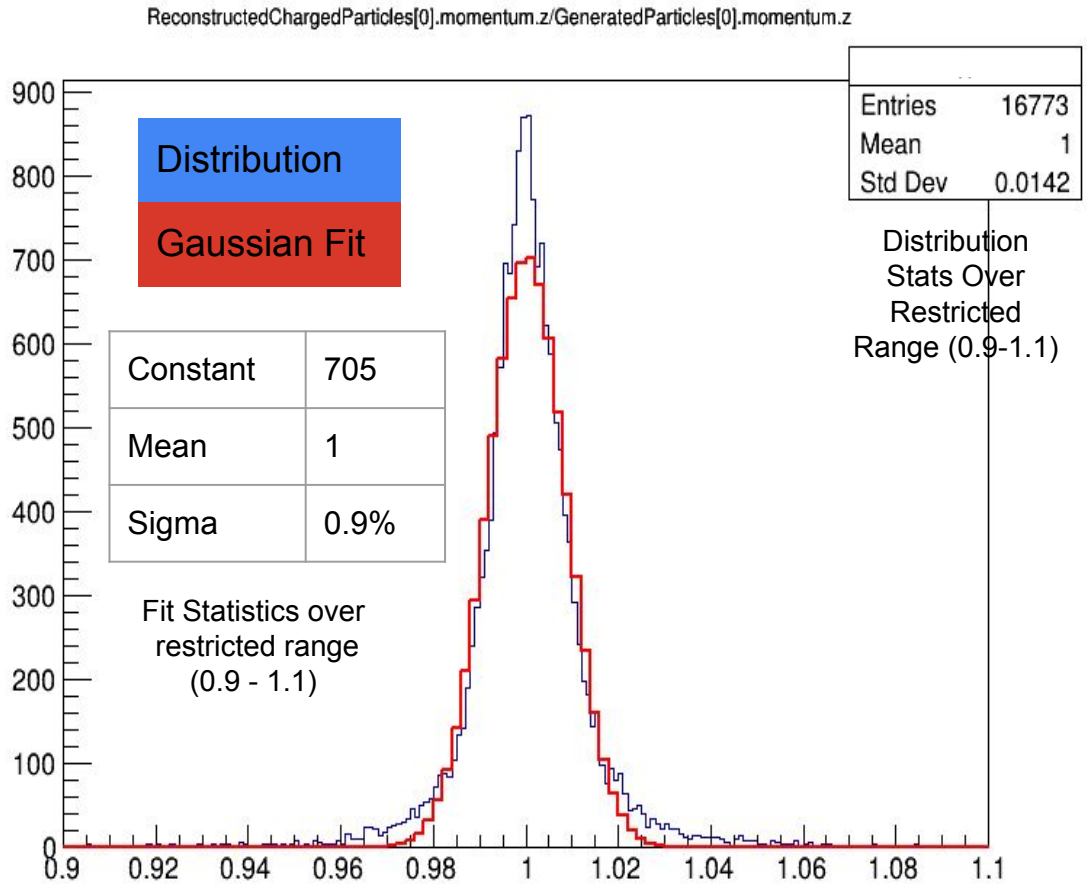
20000 pion events
1-20 GeV

Digitised and Reconstructed B0TrackerHits





Results



Overall reconstruction seems to produce reconstructed momentum fit with reasonable width but fails for events recording hits on B0

B0TrackerHits not recognized to be "On Surface" by ACTS resulting in zeroed out reconstructed momentum.

Summary and To Do List

Overall EPIC dd4hep description updated to take advantage of latest interface with ACTS.

Central region integrated. Moving onto trackers in the far forward region starting with the B0.

Acknowledgements

Supervisors: Juliette Mammei and Wouter Deconinck (University of Manitoba)

Special thanks to ACTS and EICrecon experts for helping with implementation and debugging.

Special thanks to the collaborators in the far forward working group for providing their comments and suggestions on the slides.

Backup Slides

ACTS and DD4hep overview

DD4hep is a toolkit to manage the data describing the detector geometry, the materials used when building the structures, visualization attributes, detector readout information, alignment, calibration and environmental parameters

Key features:

- Gathers all information necessary to interpret event data from collisions
- Supports full experiment lifecycle-concept, optimization, construction and operation
- Synchronizes detector information for data processing applications such as simulation, reconstruction, online trigger and data analysis

ACTS is an experiment-independent toolkit for (charged) particle track reconstruction in (high energy) physics experiments implemented in modern C++.

Key features:

- **A tracking geometry description which can be constructed manually or from TGeo and DD4hep input.**
- Simple event data model to describe track parameters and measurements.
- Implementations of common algorithms for track propagation and fitting.
- Implementations of basic seed finding algorithms.
- Implementations of common vertexing algorithms.

DD4hep-ACTS integration

DD4hep Detector Element Tree

Detector descriptions in xml format parsed by C++ constructors.

Forms a tree of instances of the det element class.

Each detector is associated with a det element containing readout segmentation, geometrical information, and environmental conditions.

Extensions can be added to the det element to add specific features or access specific information

Variant Parameters Plugin Mechanism

The variant parameters plugin mechanism is used to pass relevant information from DD4hep description to ACTS

- Detector type flags
- Layer patterns
- Boundary material binning
- Layer material binning
- Axis definitions

ACTS Tracking Geometry

ACTS expects the whole detector to be segmented into barrel-endcap structures

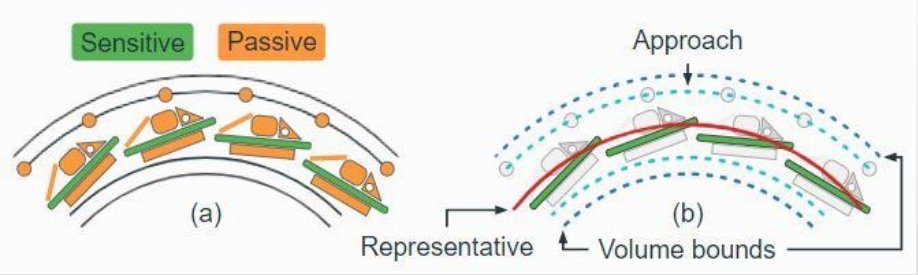
Inspects the geometry hierarchy and searches for sensitive detector elements and passive material structures

The ACTS tracking geometry is simplified-a compromise between modelling accuracy and speed

ACTS Tracking and Reconstruction

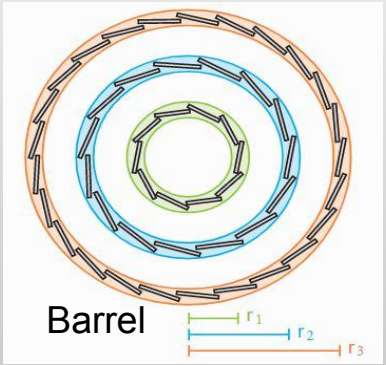
ACTS uses simplified surface-based description of simulation geometry

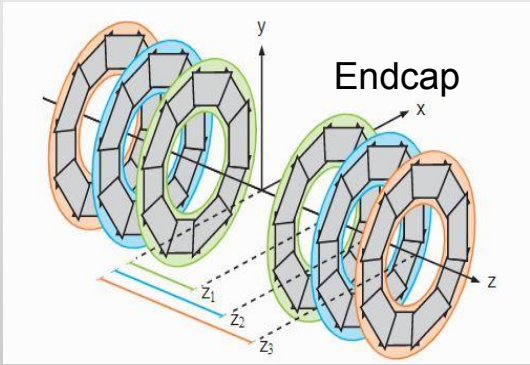
Tracking geometry = A collection of volumes glued together with adjacent volumes sharing boundaries
Volume = A collection of layers
Layer = A collection of sensitive surfaces

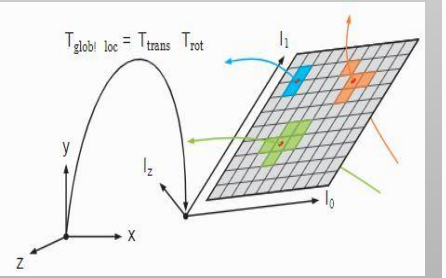


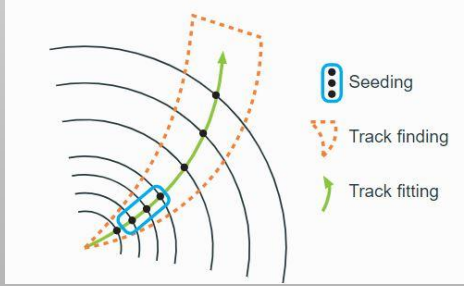
Real material information is averaged and encoded onto approach surfaces of each layer to approximate interaction effects.

A binned structure is imparted to layers to ensure fast retrieval of sensitive surfaces associated with any given bin during particle propagation.









Numerical integration with RKN method is used to estimate particle propagation under magnetic fields.

Reconstruction = Space point formation (Local to global transform) => Seeding (Hit triplet search filtered by momentum and impact parameters) => Track Finding and Fitting (Combanitorial Kalman Filtering)

Integrating the B0 Trackers into ACTS tracking for EPIC

Step 1:
Add B0 tracker subsystem as a dd4hep subdetector assembly

(positive endcap+fake negative endcap each with their own xml description and constructor)

compact/tracking/definitions.xml

```
<detectors>
-------------------------------------------------
   <detector id="B0TrackerSubAssembly_ID"
             name="B0TrackerSubAssembly"
             type="DD4hep_SubdetectorAssembly"
             vis="TrackerSubAssemblyVis">
             <composite name="B0Tracker"/>
             <composite name="B0TrackerCompanion"/>
   </detector>
-------------------------------------------------
</detectors>
```

Integrating the B0 Trackers into ACTS tracking for EPIC

Step 2:
Set detector type flag

B0Tracker.xml

```
<detectors>
 <detector
     id="B0Tracker_Station_1_ID"
     name="B0Tracker"
     type="ip6_B0Tracker"
     readout="B0TrackerHits"
     vis="FFTrackerVis">
     <type_flags type=
                "DetType_TRACKER +
                DetType_ENDCAP"/>
-----------------------------------
 </detector>
-----------------------------------
</detectors>
```

B0Tracker_geo.cpp

```
static Ref_t create_B0Tracker(Detector& description, xml_h e,
SensitiveDetector sens)
{
  xml_det_t      x_det    = e;
  DetElement     sdet(x_det.nameStr(), x_det.id());
  Volume         motherVol = description.pickMotherVolume(sdet);

-----------------------------------------------------------------

  dd4hep::xml::setDetectorTypeFlag(x_det, sdet);
  auto &params = DD4hepDetectorHelper::ensureExtension
                 <dd4hep::rec::VariantParameters>(sdet);

  for (xml_coll_t bmat(x_det, _Unicode(boundary_material));
       bmat; ++bmat) {
    xml_comp_t x_boundary_material = bmat;
    DD4hepDetectorHelper::xmlToProtoSurfaceMaterial(
                            x_boundary_material, params,
                            "boundary_material");
  }
-----------------------------------------------------------------

}


DECLARE_DETELEMENT(ip6_B0Tracker, create_B0Tracker)
```

Integrating the B0 Trackers into ACTS tracking for EPIC

Step 3:
Set layer parameters

B0Tracker.xml

```
<detectors>
 <detector
     id="B0Tracker_Station_1_ID"
     name="B0Tracker"...>

-------------------------------------------------------------------------------
      <layer id="4">
        <envelope rmin_tolerance=.../>
        <ring phi0 =...
              dphi =...
              r    =...
              zstart = ...
              nmodules=...
              dz=...
              module="Module1" />
        <layer_material surface="inner"
                        binning="binPhi,binR"
                        bins0=...
                        bins1=.../>
      </layer>
-------------------------------------------------------------------------------
 </detector>
-------------------------------------------------------------------------------
</detectors>
<plugins>
    <plugin name="DD4hep_ParametersPlugin">
      <argument value="B0Tracker"/>
      <argument value="layer_pattern:
                       str=B0Tracker_layer\d"/>
    </plugin>
</plugins>
```

B0Tracker_geo.cpp

```
static Ref_t create_B0Tracker(Detector& description, xml_h e, SensitiveDetector
sens)
{
-------------------------------------------------------------------------------
 for (xml_coll_t li(x_det, _U(layer)); li; ++li) {
  xml_comp_t x_layer(li);
  string layer_name = det_name + std::string("_layer") +
                      std::to_string(x_layer.id());
  xml_comp_t l_env      = x_layer.child(_U(envelope));
  double layer_rmin_tolerance  = l_env.attr<double>(_Unicode(rmin_tolerance));
-------------------------------------------------------------------------------
  DetElement layer_element(sdet, layer_name, x_layer.id());
  auto &layerParams = DD4hepDetectorHelper::ensureExtension
                      <dd4hep::rec::VariantParameters>(layer_element);
  layerParams.set<double>("envelope_r_min", layer_rmin_tolerance);
-------------------------------------------------------------------------------
  for (xml_coll_t lmat(x_layer, _Unicode(layer_material)); lmat; ++lmat) {
      xml_comp_t x_layer_material = lmat;
      DD4hepDetectorHelper::xmlToProtoSurfaceMaterial(x_layer_material,
                                                      layerParams, "layer_material");
  }
 }
-------------------------------------------------------------------------------
}
```

Integrating the B0 Trackers into ACTS tracking for EPIC

Step 4:
Set axis definitions of sensitive elements

B0Tracker.xml

```
<detectors>
 <detector
     id="B0Tracker_Station_1_ID"
     name="B0Tracker"...>

-------------------------------------------------------------------------------
    <module name="SmallModule4"
            vis="FFTrackerModuleVis">
        <trd x1="B0TrackerMod1_x1/2.0"
             x2="B0TrackerMod4Small_x2/2.0"
             z="B0TrackerMod4Small_y/2"/>
        <module_component
             thickness="0.12*mm"
             material="CarbonFiber"
             vis="FFTrackerSupportVis" />
        <module_component
             thickness="0.3*mm"
             material="SiliconOxide"
             vis="FFTrackerSurfaceVis"
             sensitive="true"/>
    </module>

-------------------------------------------------------------------------------
 </detector>
-------------------------------------------------------------------------------
</detectors>
```

B0Tracker_geo.cpp

```
static Ref_t create_B0Tracker(Detector& description, xml_h e, SensitiveDetector
sens)
{
-------------------------------------------------------------------------------

  for (xml_coll_t ri(x_layer, _U(ring)); ri; ++ri) {      -
  ------------------------------------------------------------------------------
    for (int k = 0; k < nmodules; ++k) {
      DetElement module(layer_element, m_base + "_pos", det_id);
      -----------------------------------------------------------------------
      for (size_t ic = 0; ic < sensVols.size(); ++ic) {
        PlacedVolume sens_pv = sensVols[ic];
        DetElement   comp_elt(module, sens_pv.volume().name(), mod_num);
        comp_elt.setPlacement(sens_pv);
        auto &params = DD4hepDetectorHelper::ensureExtension
                       <dd4hep::rec::VariantParameters>(comp_elt);
        params.set<std::string>("axis_definitions", "XZY");
        volSurfaceList(comp_elt)->push_back(volplane_surfaces[m_nam][ic]);
      }
    }
  }
-------------------------------------------------------------------------------
}
```

Integrating the B0 Trackers into ACTS tracking for EPIC

Step 5: Activating the tracker in EICrecon

Add B0tracker detector plugin to digitise and reconstruct hits with detector info

```
void InitPlugin(JApplication *app) {
    InitJANAPlugin(app);
    using namespace eicrecon;
    app->Add(new JChainFactoryGeneratorT<SiliconTrackerDigi_factory>
          ({"B0TrackerHits"}, "B0TrackerRawHits"));
    app->Add(new JChainFactoryGeneratorT<TrackerHitReconstruction_factory>
    ({"B0TrackerRawHits"},"B0TrackerRecHits"));
}
```

```
std::vector<std::string> EICRECON_DEFAULT_PLUGINS = {
...
“B0TRK”
...
}
```

Add B0tracker plugin to default list of plugins to activate in src/utilities/eicrecon/eicrecon.cc

Add B0TrackerRecHits to be used in src/global/tracking/tracking.cc

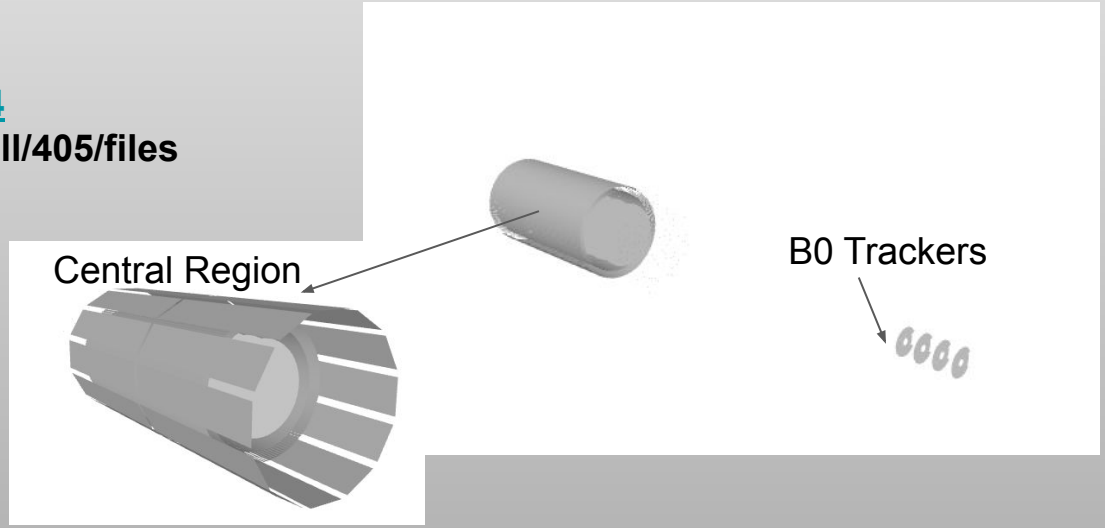
```
app->Add(new JChainFactoryGeneratorT<TrackerHitCollector_factory>(
                        {
                           "SiBarrelTrackerRecHits",
                           "SiBarrelVertexRecHits",
                           "SiEndcapTrackerRecHits",
                           "TOFBarrelRecHit",
                           "TOFEndcapRecHits",
                           "MPGDBarrelRecHits",
                           "MPGDDIRCRecHits",
                           "B0TrackerRecHits"
    },
                        "CentralTrackingRecHits"));
```

Test simulation and reconstruction chain

ddsim –compactFile epic_tracking_only.xml -G –gun.particle “pi-” –gun.momentumMin “1*GeV” –gun.momentumMax “20*GeV” –gun.distribution “uniform” -N 2000 –outputFile sim_pi-_1GeV_20GeV_tracking_only.edm4hep.root

install/bin/run_eicrecon_reco_flags.py sim_pi-_1GeV_20GeV_tracking_only.edm4hep.root rec_result -Pplugins=dump_flags,janadot -Pdump_flags:json=tracking_only_flags.json

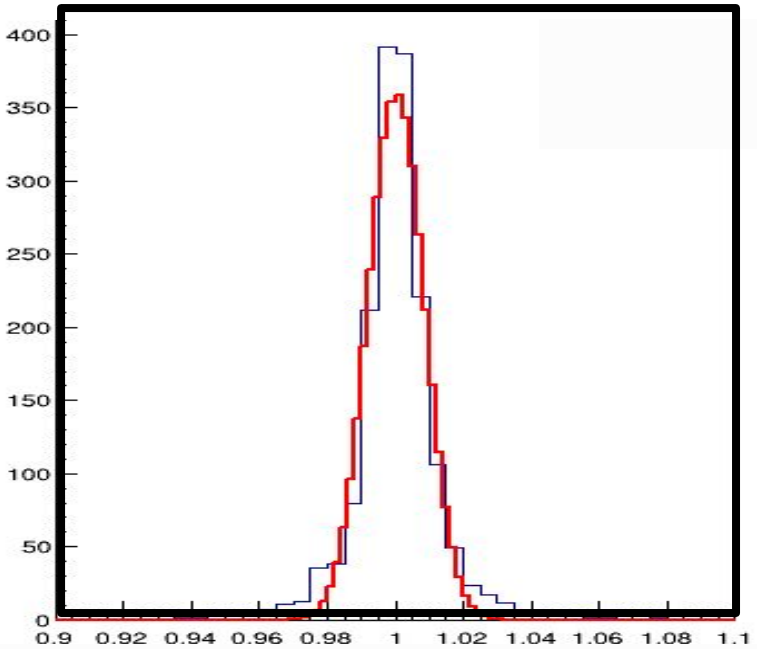
https://github.com/eic/epic/pull/344
https://github.com/eic/EICrecon/pull/405/files



Overall reconstruction seems to produce reconstructed momentum fit with reasonable width but fails for events recording hits on B0

Warning indicates that no surface in the acts tracking geometry can be associated with hits on B0. Currently debugging this issue with help from ACTS and EICrecon experts.

ReconstructedZMomentum/TruthZMomentum



B0TrackerRecHits