Straw tracker simulation

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On behalf of the UM group

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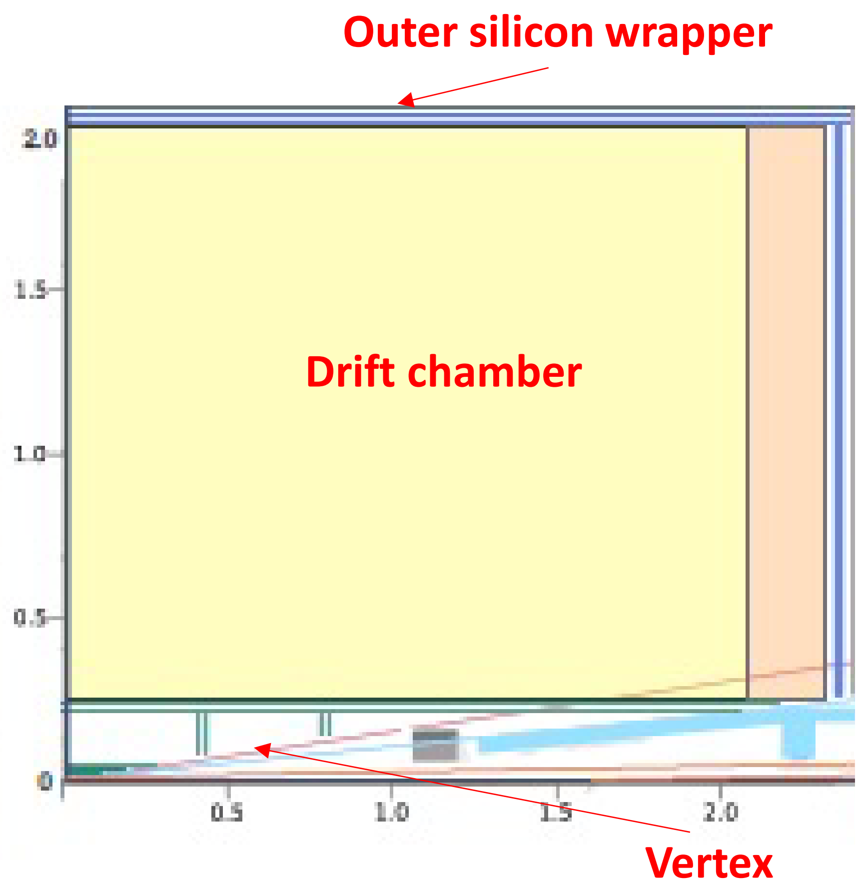
Inner tracker for FCC-ee

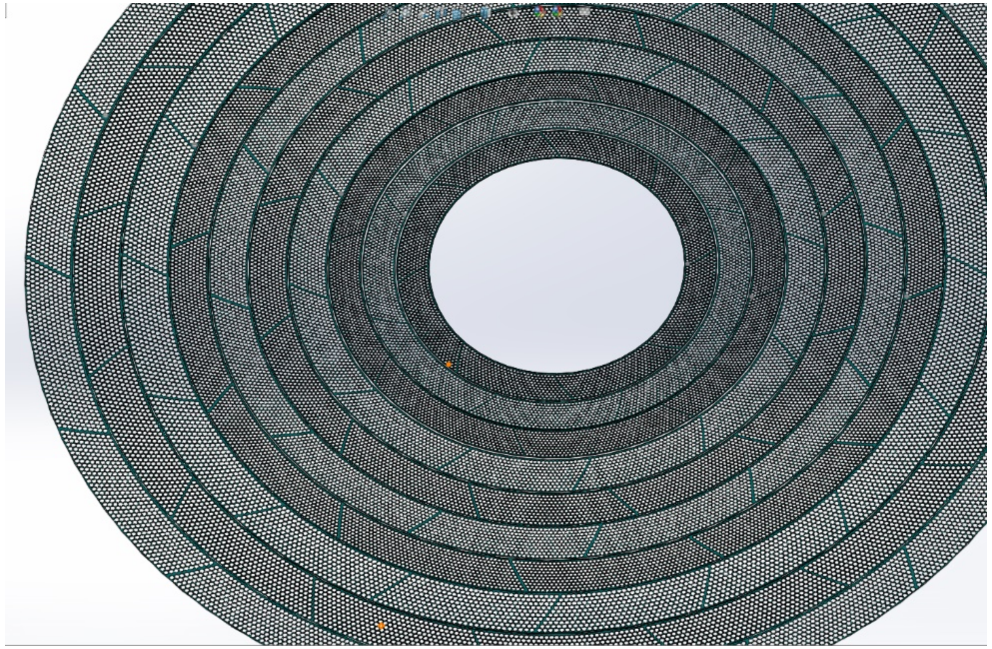
- Momentum resolution is an important requirement for the FCC-ee tracker
  - σ_{p_T}/p_T ~0.2% at 45 GeV
  - A factor of 5-10 better than the current ATLAS and CMS inner tracker
- Current proposals for FCC-ee inner tracker
  - CLD: full silicon pixel + strip (TPC under consideration)
  - IDEA/ALLEGRO: silicon pixel + drift chamber + outer silicon wrapper
- We propose to have an ultra-light weight straw tracker (Combined with pixel and silicon wrapper)
  - Single hit resolution: $100{\sim}130\ \mu m$
  - Low material and less multiple scattering with thin-wall straws
  - Capable of triggering
  - Particle identification (π-K, K-p identifications)
  - …



Inner tracker of the IDEA detector concept. Propose to replace the drift chamber with straws.

A potential layout

- Between the vertex detector and the silicon wrapper
- 10 multilayers and 10 layers per multilayer
- Three different sizes of tubes
  - 3 MLs of 10 mm tubes
  - 4 MLs of 12 mm tubes
  - 3 MLs of 15 mm tubes
- Tungsten wire: 20 μm, straw wall thickness: 12 μm, Aluminum coating inside tube: 50 nm
- Cover $R = 35.1$ cm to 184.2 cm, $z = -225$ cm to 225 cm
- Optimize the design in simulation (DD4hep & ACTS)



DD4hep

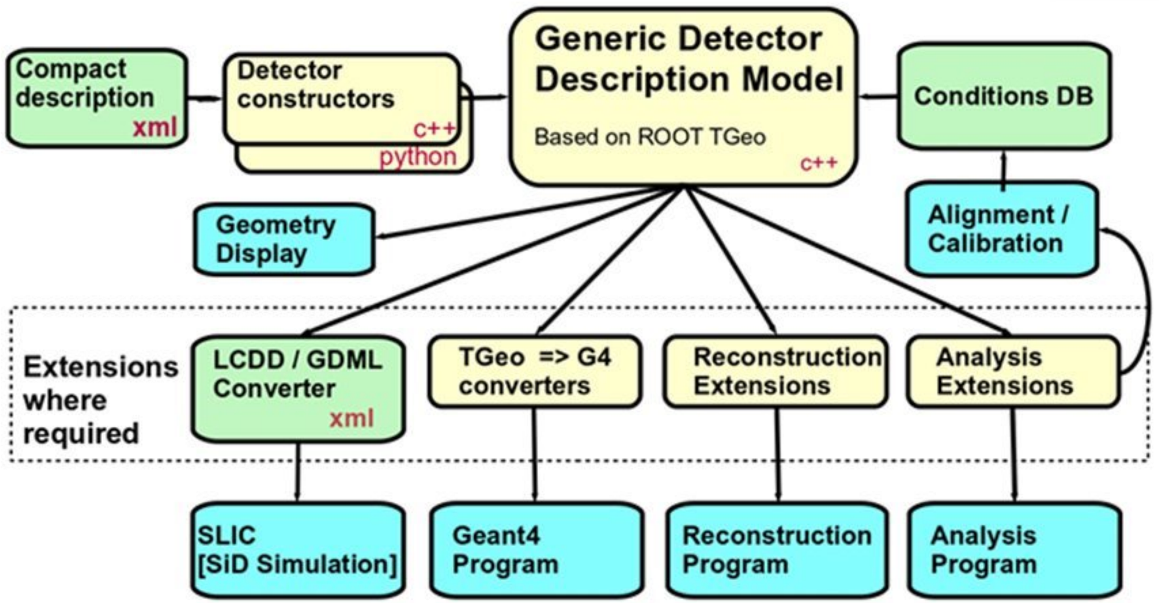
Detector Description Toolkit for High Energy Physics (DD4hep)

acts

A Common Tracking Software (ACTS)

Introduction to DD4hep

- Detector construction and simulation
- Reuse the existing software components
  - ROOT geometry package
  - Geant4
  - …
- Build interfaces to user-application: Visualization, Simulation, Calibration, Reconstruction



Straw tracker construction

fcc-straw-tracker > IDEA_o1_v03 > StrawTubeTracker_o1_v01.xml

```xml
<lccdd>
    <detectors>
        <detector name="MyStrawTubeTracker"
            <!-- 12 mm tube layers -->
            <layer thickness="12.8*cm" repeat="30" vis="MyVis">
                <slice material="W" thickness="0.001*cm"/>
                <slice material="He" thickness="0.597*cm" sensitive="true"/>
                <slice material="Al" thickness="0.000005*cm"/>
                <slice material="Mylar" thickness="0.0012*cm"/>
            </layer>

            <layer thickness="12.8*cm" repeat="35" vis="MyVis">
                <slice material="W" thickness="0.001*cm"/>
                <slice material="He" thickness="0.597*cm" sensitive="true"/>
                <slice material="Al" thickness="0.000005*cm"/>
                <slice material="Mylar" thickness="0.0012*cm"/>
            </layer>

            <layer thickness="12.8*cm" repeat="40" vis="MyVis">
                <slice material="W" thickness="0.001*cm"/>
                <slice material="He" thickness="0.597*cm" sensitive="true"/>
                <slice material="Al" thickness="0.000005*cm"/>
                <slice material="Mylar" thickness="0.0012*cm"/>
            </layer>
```

fcc-straw-tracker > StrawTubeTracker > src > StrawTubeTracker.cpp

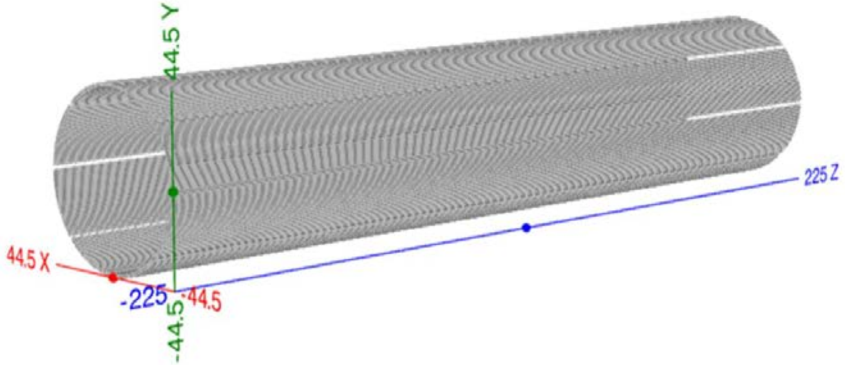
```cpp
static dd4hep::Ref_t create_detector(dd4hep::Detector &theDetector,
  for (xml_coll_t c(x_det, _U(layer)); c; ++c, ++MLNum) {
    for (int j = 0; j < layer_num; ++j, ++tubeNum)
    {
      for (int l = 0; l < sector_num[tubeType]; ++l, ++tubeNum)
      {
        for (int i = 0, repeat = x_layer.repeat(); i < repeat; ++i,
        ++tubeNum) {
          // tube volume
          std::string tubeName = MLName + dd4hep::_toString(l, "sector%d")
          + dd4hep::_toString(j, "layer%d") + dd4hep::_toString(i,
          "tube%d");

          dd4hep::Tube singleTube(0, tubeThickness/2, zmax);
          dd4hep::Volume singleVol(tubeName, singleTube, gas);
          dd4hep::DetElement tubeElement(sdet, tubeName, tubeNum);
          double phi = l*2*dd4hep::pi/sector_num[tubeType] + (j+2*i)
          *delta_phi;
          // dd4hep::Position tubePosition = (layerRadius*sin(phi),
          layerRadius*cos(phi),0);
          // dd4hep::PlacedVolume tubePlacedVolume = MLVol.placeVolume
          (singleVol,tubePosition);
          dd4hep::PlacedVolume tubePlacedVolume = MLVol.placeVolume
          (singleVol,dd4hep::Position(layerRadius*sin(phi),layerRadius*cos
          (phi),0));
```

Compact files: .xml

- Defining materials, geometry parameters, sensitive parts

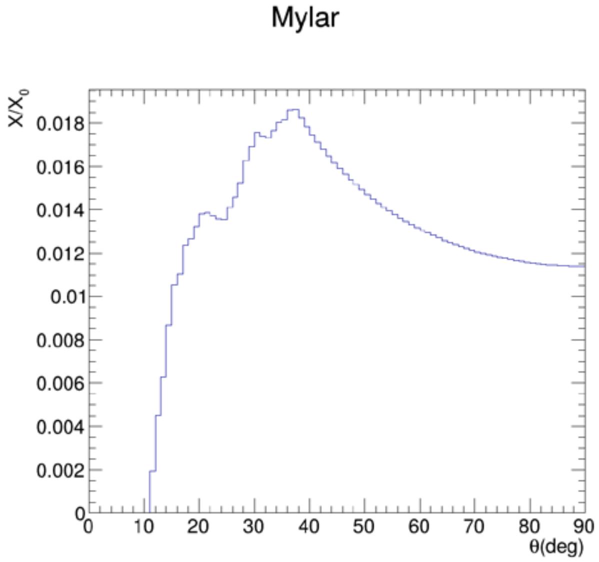
Constructor: .cpp

- Defining tube structure, detector geometry

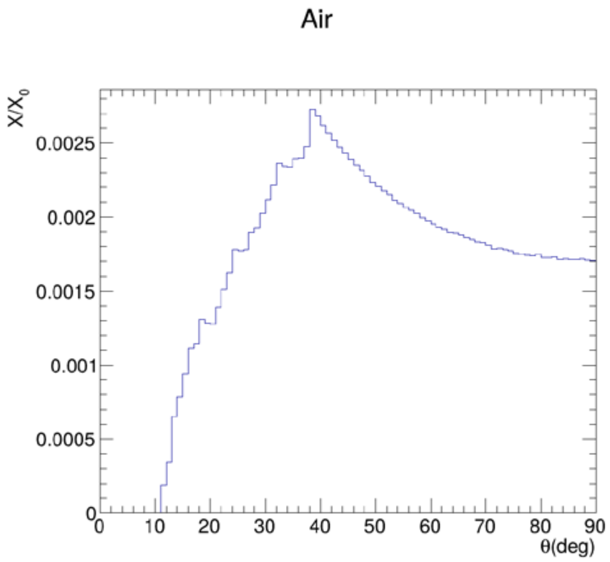


Material budget for straw only

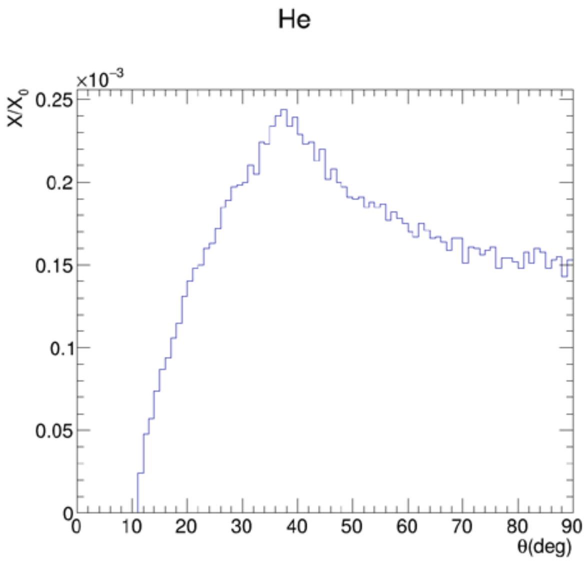
Using the Geant4 simulation to collect the material inside the detector from the detailed geometry. (~1.35% X_0 at $\theta = 90°$, not including any mechanical structure. Mainly contributed by the mylar walls)



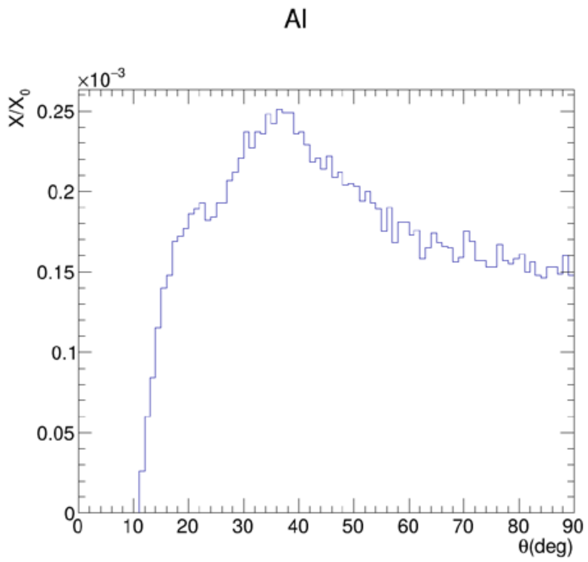
Mylar wall (12 μm)



Gap-filled air

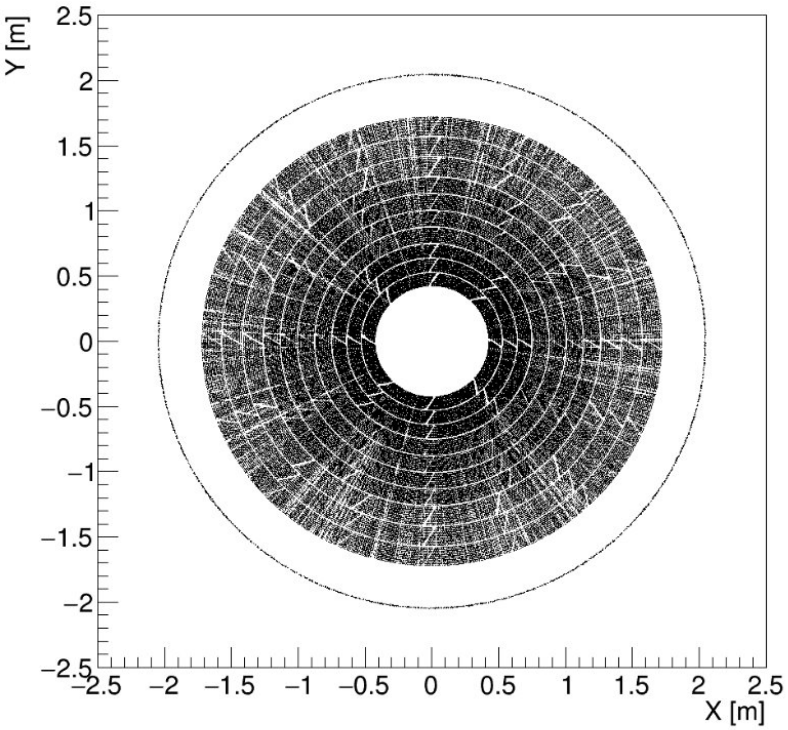


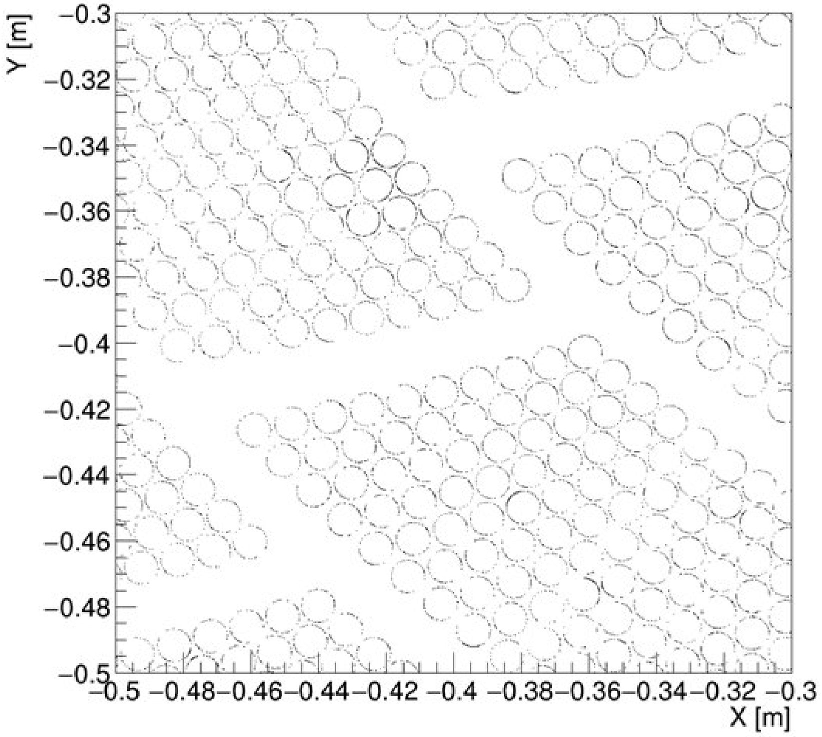
Helium gas

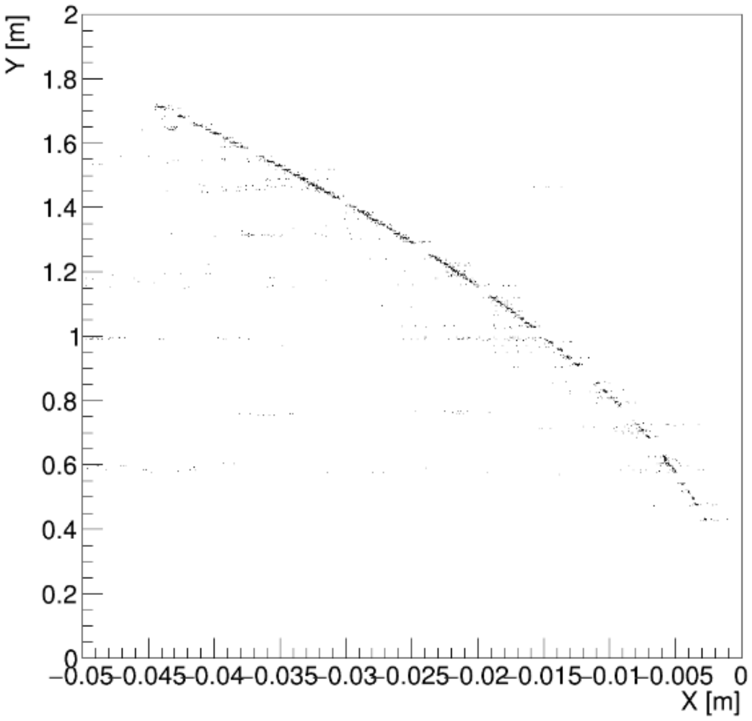


Aluminum coating (50 nm)

Geant simulation





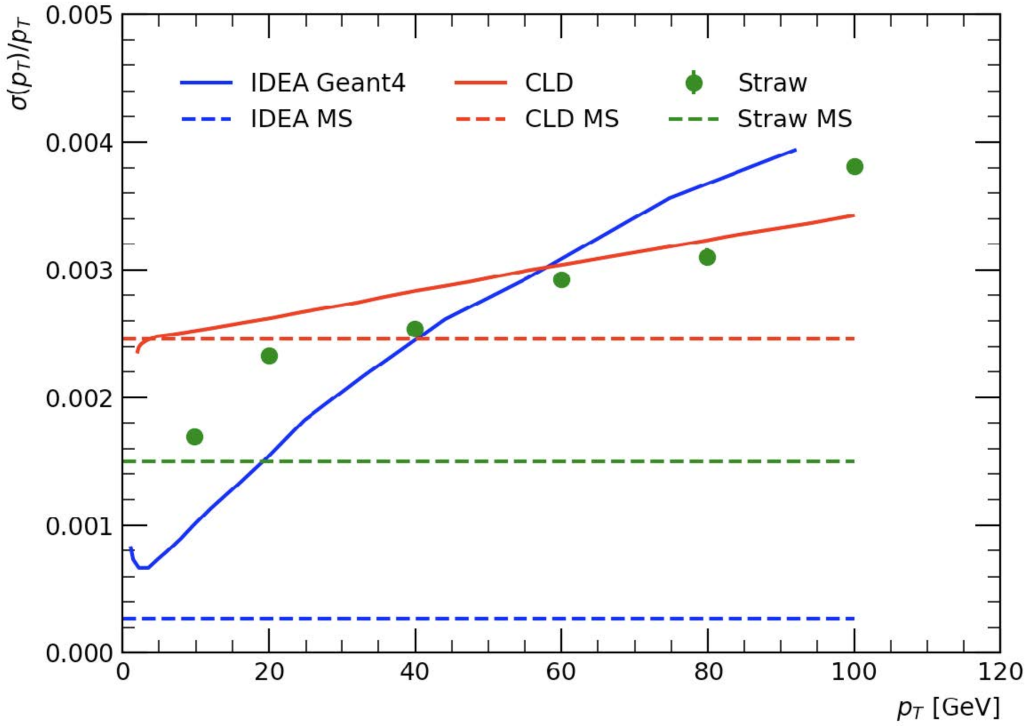


5000 muons with $p_T = 20$ GeV. Hits on the straw walls and silicon wrapper

1000 muons with $p_T = 20$ GeV. Hits inside tubes

Momentum resolution

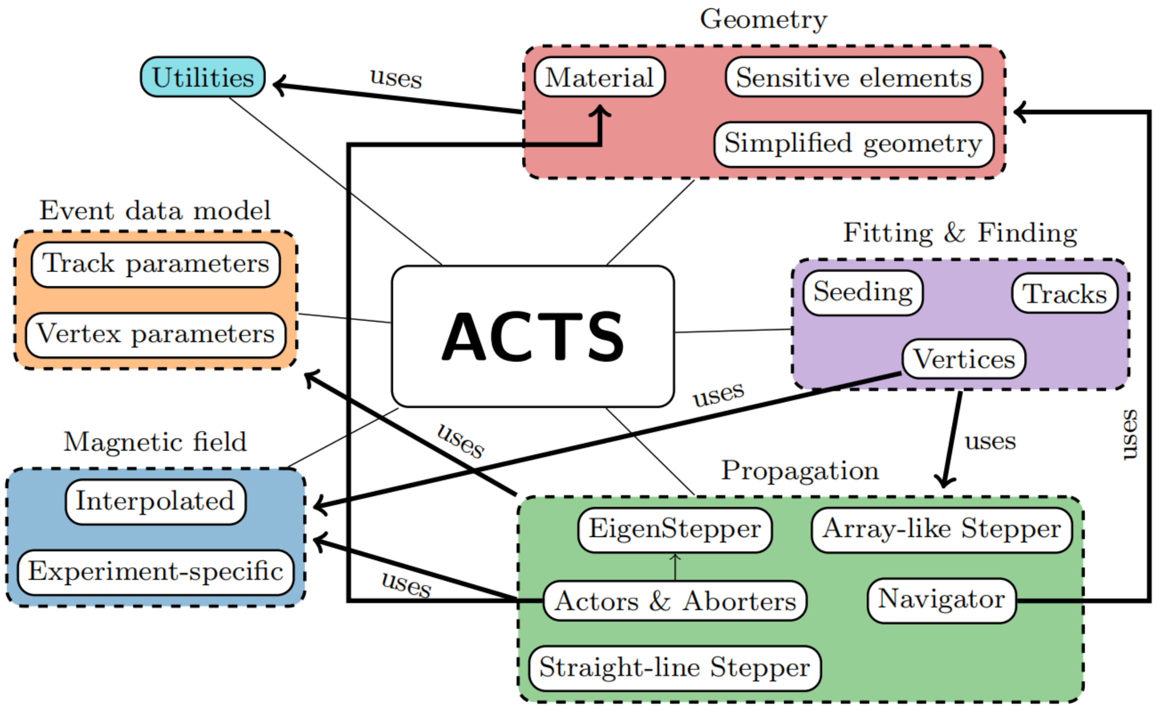
- Using the simulated hits from Geant4 to estimate the track momentum resolution
- Magnetic field: 2T
- Assumptions on resolution for the straw tracker
  - Pixel: 5 μm
  - Straw tube: 120 μm (Conservative estimation)
  - Silicon wrapper: 15 μm
- Straws are competitive with drift chamber
- Results of straws are from simple scripts to minimize the ChiSquare to find the measured track p_T. Move to the actual track fitting.



CLD: analytical estimates
IDEA: Geant simulation
Straw: semi-Geant simulation

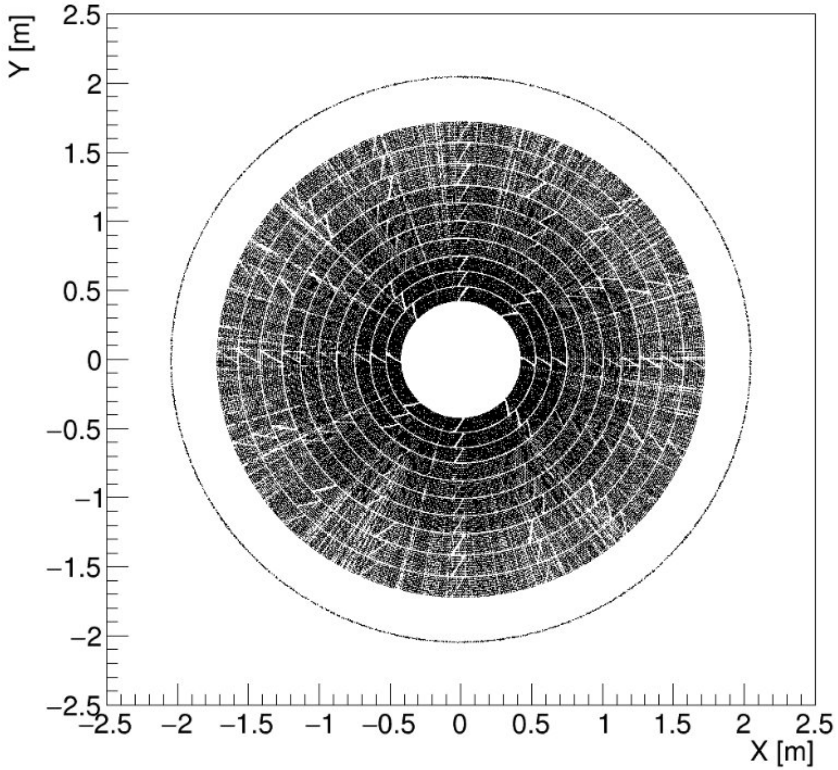
Introduction to ACTS

- Tracking geometry
  - Keep sensitive parts and simplify passive parts simplified with material mapping
- Particle propagation
  - Numerical integration in non-homogeneous magnetic field
  - Material effects
- Finding and fitting
  - Iteratively calculate a track estimate
  - Track fit to extract the best estimate of the track



Tracking geometry transformation

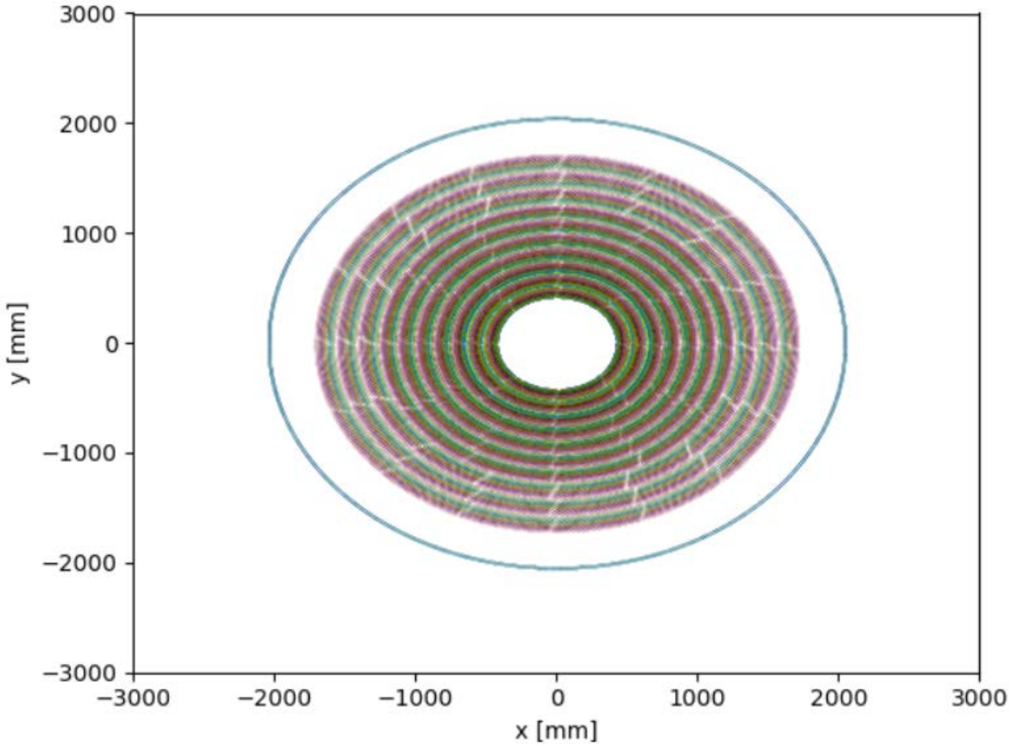
DD4hep geometry: .xml, .cpp



Detailed geometry: Helium, wire, mylar wall, Al coating, silicon…

ROOT geometry (TGeo): .root

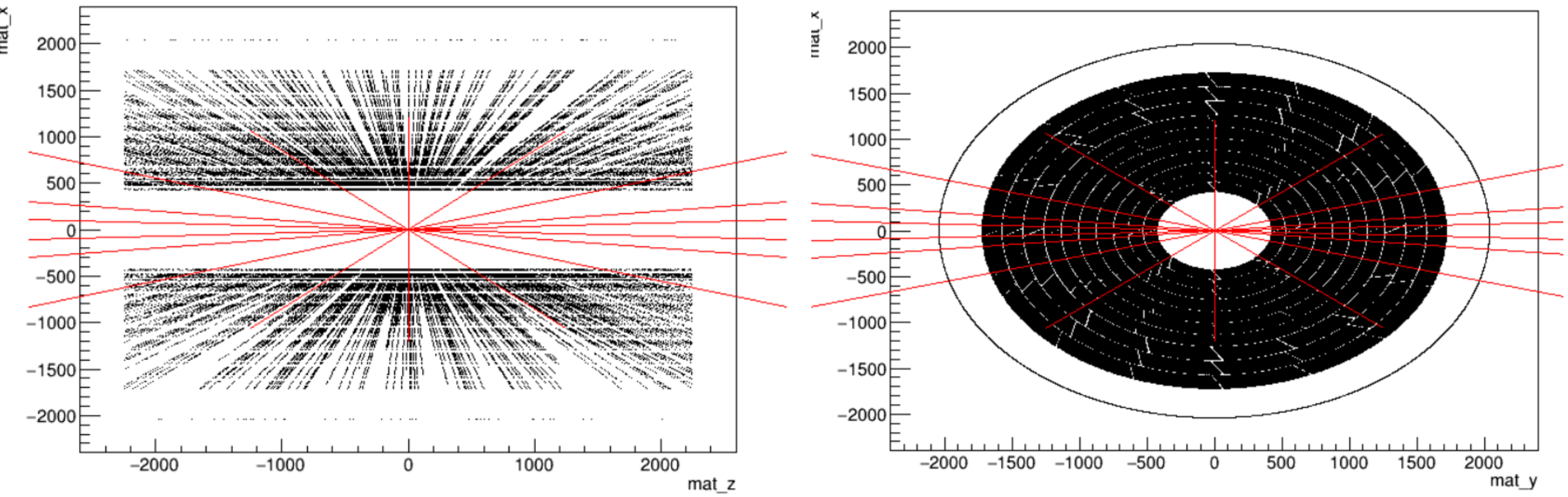
ACTS geometry: .json



Tracking geometry: Simplifying the passive part (wire, mylar wall, Al coating) and keep the sensitive part (Helium, silicon)

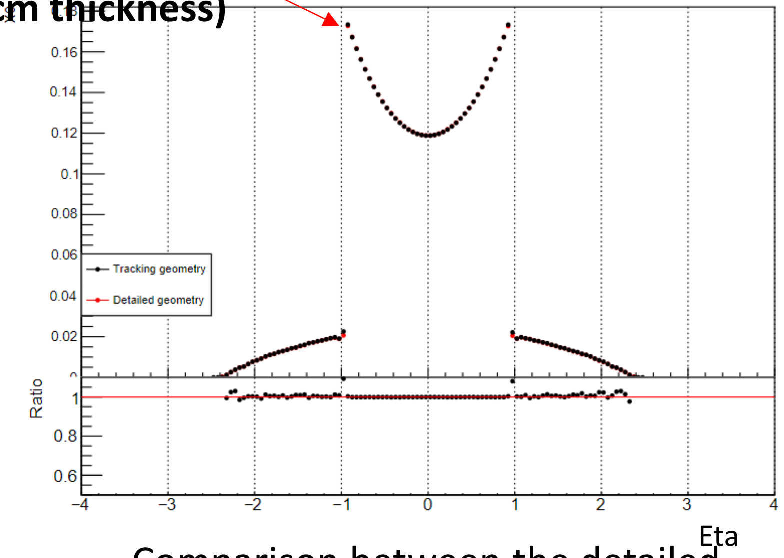
Material mapping

- To count the material effects, i.e. multiple scattering and energy loss, material samples are assigned or projected onto the closest surface in the tracking geometry
- Using the Geant4 simulation to collect material in the detailed geometry and tracking geometry. Mapping results are consistent.



Material map in tracking geometry

End of the silicon wrapper
(1 cm thickness)

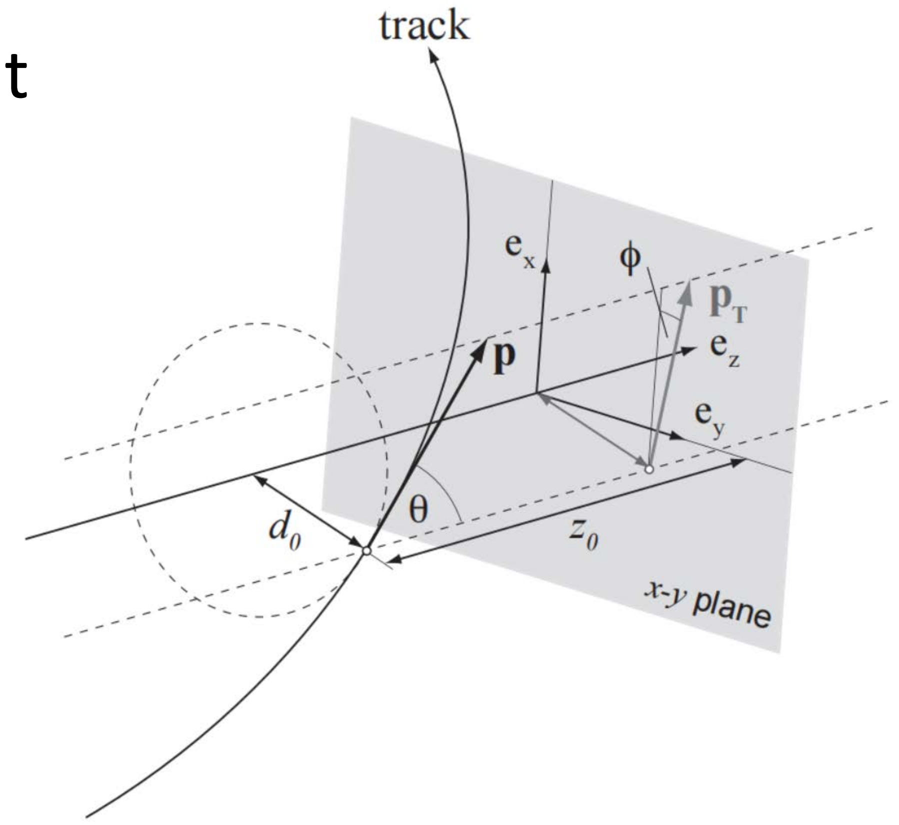


Comparison between the detailed geometry and tracking geometry

Tracking parametrization

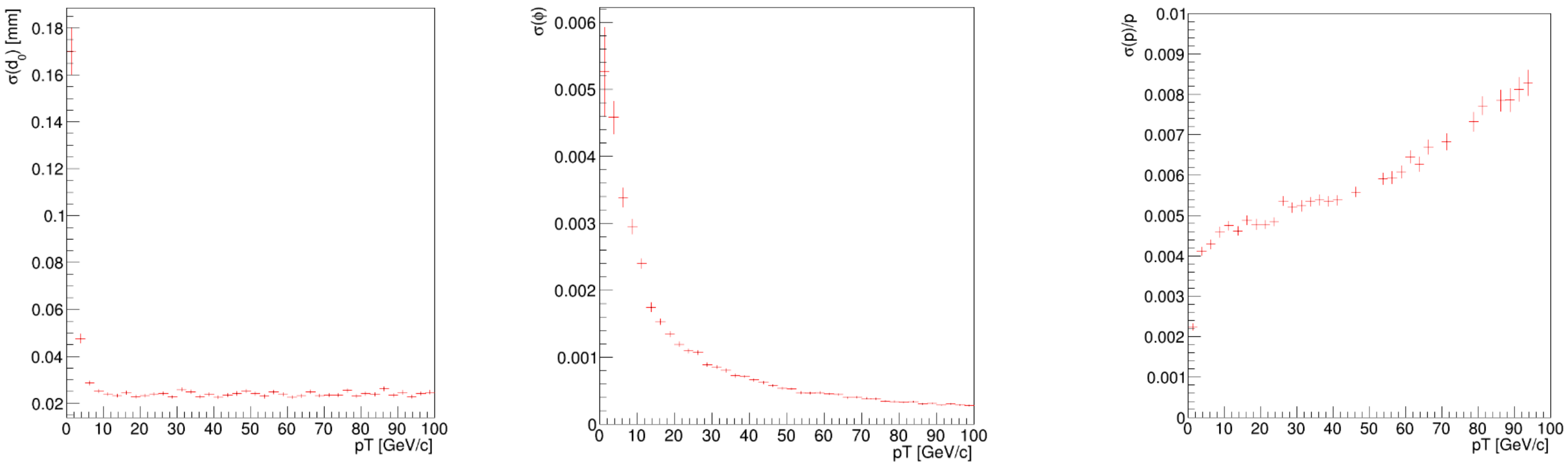
$$(d_0, z_0, \phi, \theta, \frac{q}{p})$$

- d_0: the signed distance of closest approach point from track to z axis.
- z_0: the z distance of closest approach point.
- ϕ: the azimuth angle of momentum at closest approach point.
- θ: the polar angle of momentum at closest approach point.
- q/p: charge over momentum



Tracking results

- Geant4 simulation using the tracking geometry
  - Magnetic field: 2T
  - Straw resolution: 120 μm
  - Silicon wrapper resolution: 15 μm
  - $|\eta| < 0.5$
- Stereo-view layers will be introduced to study the resolution of the z coordinate.



Summary

- We propose to have a straw tracker for an FCC-ee inner tracker.
- A potential layout has been successfully implemented in DD4hep, and full detector simulation is performed using Geant4.
- Simplified tracking has been used compare the performance with the drift chamber. We also setup the workflow to perform actual tracking with ACTS.
- Plan:
  - Optimize the number of tubes and their radii
  - Introduce stereo layers and optimize stereo angle
  - Get the energy deposition and numbers of clusters from the Geant4 simulation for dE/dx and dN/dx studies.

Thank you!

Back up

Parameters

```
<!-- 12 mm tube layers -->
<layer thickness="12.8*cm" repeat="30" vis="MyVis">
    <slice material="W" thickness="0.001*cm"/>
    <slice material="He" thickness="0.597*cm" sensitive="true"/>
    <slice material="Al" thickness="0.000005*cm"/>
    <slice material="Mylar" thickness="0.0012*cm"/>
</layer>
```

```
<define>
    <!-- <constant name="ECal_cell_size" value="5.1*mm" /> -->
    <constant name="ML1_gap" value="1*mm" />
    <!-- <constant name="ML1_alpha" value="1.013*degree" /> -->
    <constant name="LayerNum" value="10" />
    <constant name="ML1_SectorNum" value="8" />
    <constant name="ML2_SectorNum" value="12" />
    <constant name="ML3_SectorNum" value="16" />
</define>
```

For straws:

- Sense wire: 20 um Tungsten
- Gas: Helium (Radii vary for 10 mm, 12 mm, 15 mm tubes)
- 0.05 um Aluminum coating
- Straw wall: 12 um Mylar

For multi-layers:

- Num. of layer per multi-layer: 10
- Num. of sector per multi-layer (Vary for 10 mm, 12 mm, 15 mm tubes)
- Num. of tube per layer in each sector (Vary for different MLs)
- Gap between tubes: 1 mm

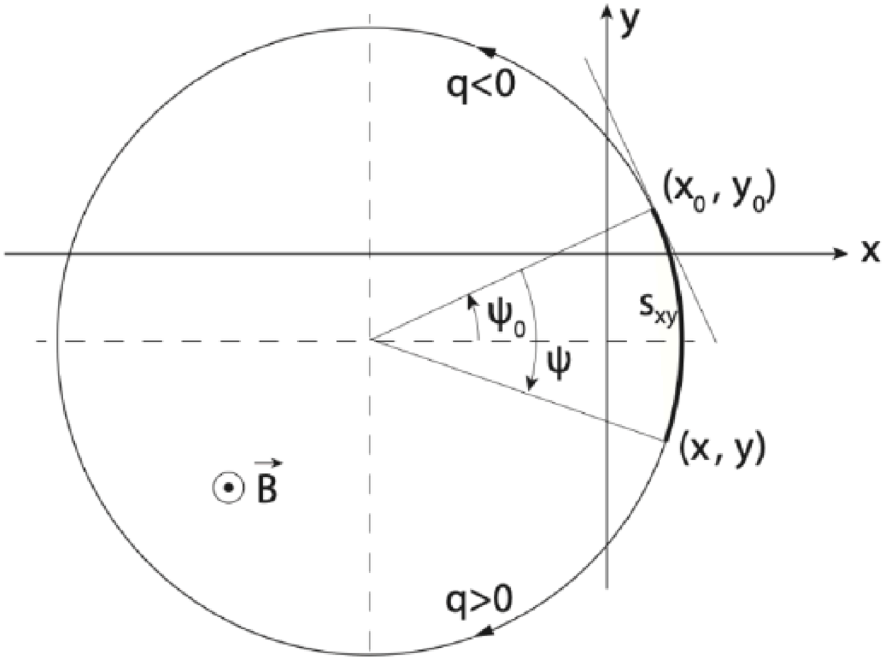
Simplified tracking

- **The simplified simulation we developed performs tracking in 2D**
  - Simulate monochromatic muons initially pointed in the positive y dir.
  - Vary muon energy to measure resolution as a function of p_T at $\theta = 90^o$

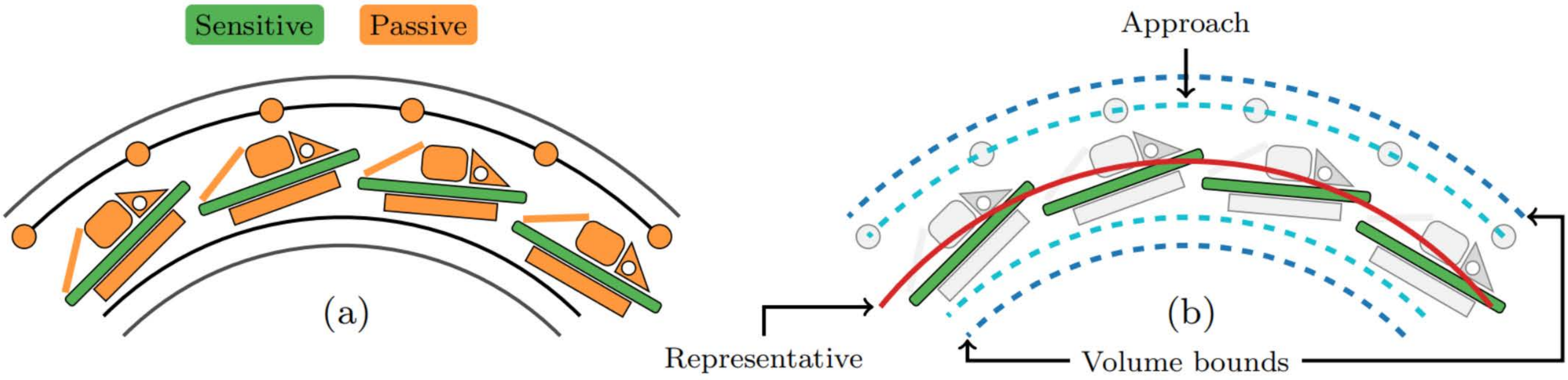
- **Rather than 6 parameters only 4 are required**
  - (x_0, y_0) initial position
  - Initial p_T
  - Initial angle ψ_0

  - Excluded for 2D tracking: z_0, θ

- **Intrinsic detector resolution:**
  - Smear truth hits (from Geant4) in various detector subsystems by gaussian distributions:
    - Straw tube: 120 microns
    - Pixel: 5 microns
    - Silicon wrapper: 15 microns



Geometry simplifying

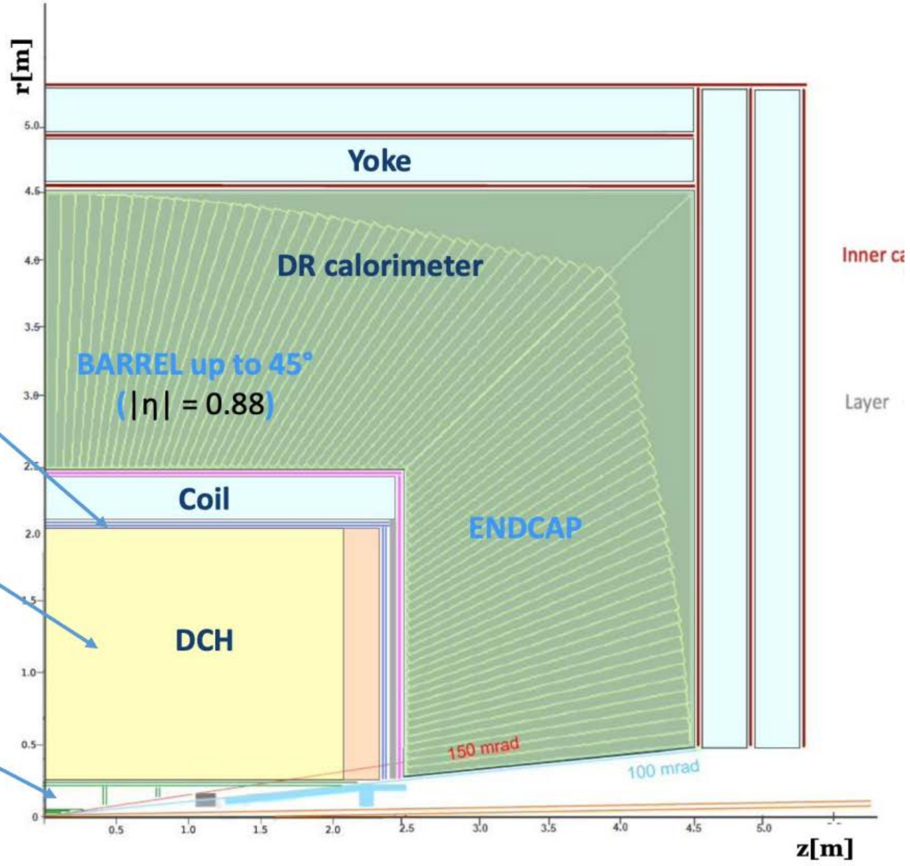


The IDEA detector concept

Outer Silicon wrapper:
Si strips

Drift Chamber: 112 layers
4 m long, R = 35-200 cm

Vertex:
5 MAPS layers
R = 1.37-31.5 cm



Material mapping validation

Using the Geant4 simulation to collect material in the detailed geometry and tracking geometry (10 mm tube only). Mapping results are consistent.