NPdet

Release 0.9

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CONTENTS:

CHAPTER

ONE

INTRODUCTION

NPdet is detector toolkit for full simulations of Nuclear Physics experiments.

This site is currently under construction. Come back later!!!

1.1 Overview

A detector library for simulation and reconstruction based on [DD4hep](https://github.com/AIDAsoft/DD4hep). This library makes full detector simulation and reconstruction easier by providing a set of flexible **parameterized detectors**. From these detectors, a full blown concept-detector can be created.

CHAPTER

TWO

GETTING STARTED

2.1 Installation

2.1.1 Singularity Container

The easiest way to use this library is the with the eic_container.

> **Warning:** need to add brief instructions here.

2.1.2 Building from source

The following are needed before building *NPDet*

- DD4hep
- ROOT
- GEANT4

```
git clone https://eicweb.phy.anl.gov/EIC/NPDet.git
mkdir npdet_build && cd npdet_build
cmake ../NPDet/. -DCMAKE_INSTALL_PREFIX=$HOME # or where ever
make -j4
make install
```

2.2 Development

> **Warning:** need to add brief how to for container development.

CHAPTER

THREE

DETECTORS

NPdet is detector toolkit for full simulations of Nuclear Physics experiments.

This site is currently under construction. Come back later!!!

3.1 Calorimeters

3.1.1 Crystal Calorimeters

For the backward electron direction

From Tanja Horn's talk at 1st EIC Yellow Report Workshop at Temple University. The title of talk is Electromagnetic calorimetry technologies for EIC. The presentation file can be found (Page 4 Electron Endcap EMCAL).

- Homogeneous calorimetry (inner part)
  1. PbWO4 $(12\text{cm} < R < 60\text{cm})$
  2. Dimension: $2 \times 2 \times 20\text{cm}^3$
  3. Performance: $\sim 2\%/\sqrt(E) + 0.7\%$
  4. Estimated # of blocks for EIC: 2500
- Implemeted in
  1. GenericDetectors/calorimeters/compact/CrystalEndcapECAL_example.xml
  2. GenericDetectors/calorimeters/src/CrystalEndcapECAL_geo.cpp

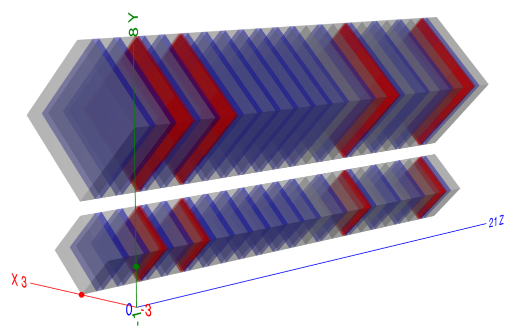
3.1.2 Zero Degree Calorimeters

For neutrons and photons

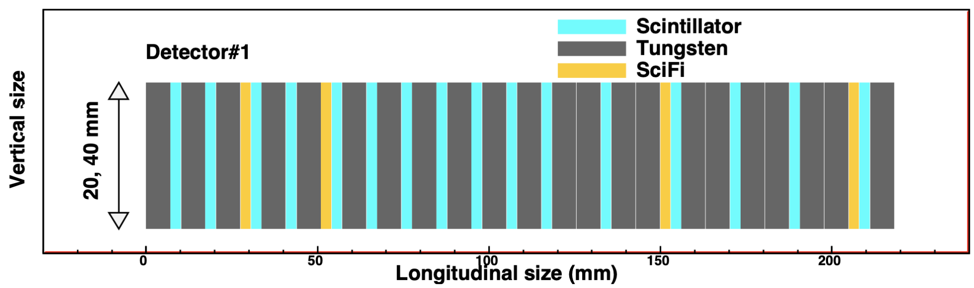
Form Yuji Goto (RIKEN)'s talk at 1st EIC Yellow Report Workshop at Temple University. The title of talk is Zero Degree Calorimetry. The presentation can be found.

Detector configuration of RHICf detector

- Tungsten (Grey)
- Scintillator (Blue)
- Scintillator position (Red)



Longitudinal structure



Detector Description

- Two towers with the same layer structure
  1. Small tower: 20mm x 20 mm
  2. Large tower: 40mm x 40 mm
  3. Tungsten absorbers, Plastic Scintillators, and Scintillator position layers

Define section:

```
<define>
        <constant name="offset_ZDC"    value="5.0*mm"/>
        <constant name="st_length"     value="20.0*mm"/>
        <constant name="lt_length"     value="40.0*mm"/>
        <constant name="st_ZDC_x_pos"  value="0.0*m"/>   <!-- value="0.60*m"  -->
        <constant name="st_ZDC_y_pos"  value="0.0*m"/>
        <constant name="st_ZDC_z_pos"  value="1.0*m"/>   <!-- value="34.0*m"  -->
        <constant name="lt_ZDC_x_pos"  value="0.0*m"/>   <!-- value="0.60*m"  -->
        <constant name="lt_ZDC_y_pos"  value="offset_ZDC + (st_length+lt_length)/sqrt(2)
↪"/>
        <constant name="lt_ZDC_z_pos"  value="1.0*m"/>  <!-- value="34.0*m"  -->
</define>
```

Detector section:

```
<detector id="1" name="smallZDC" type="ZDC" readout="ZDCHits" vis="RedVis">
        <position x="st_ZDC_x_pos" y="st_ZDC_y_pos" z="st_ZDC_z_pos"/>
        <dimensions x = "st_length" y = "st_length"/>
        <layer repeat="2">
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
                <slice name="Scint_slice"    material="PlasticScint"   thickness="3*mm"␣
↪vis = "BlueVis" sensitive = "true"/>
        </layer>
        <layer repeat="1">
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
                <slice name="SciFi_belt"     material="PlasticScint"   thickness="1*mm"␣
↪vis = "RedVis"  sensitive = "true"/>
                <slice name="SciFi_belt"     material="PlasticScint"   thickness="1*mm"␣
↪vis = "RedVis"  sensitive = "true"/>
        </layer>
        <layer repeat="2">
                <slice name="Scint_slice"    material="PlasticScint"   thickness="3*mm"␣
↪vis = "BlueVis" sensitive = "true"/>
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
        </layer>
        <layer repeat="2">
```

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```
                <slice name="SciFi_belt"     material="PlasticScint"    thickness="1*mm"␣
↪vis = "RedVis"  sensitive = "true"/>
        </layer>
        <layer repeat="7">
                <slice name="Scint_slice"    material="PlasticScint"    thickness="3*mm"␣
↪vis = "BlueVis" sensitive = "true"/>
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
        </layer>
        <layer repeat="1">
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
                <slice name="Scint_slice"    material="PlasticScint"    thickness="3*mm"␣
↪vis = "BlueVis" sensitive = "true"/>
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
        </layer>
        <layer repeat="2">
                <slice name="SciFi_belt"     material="PlasticScint"    thickness="1*mm"␣
↪vis = "RedVis"  sensitive = "true"/>
        </layer>
        <layer repeat="3">
                <slice name="Scint_slice"    material="PlasticScint"    thickness="3*mm"␣
↪vis = "BlueVis" sensitive = "true"/>
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
        </layer>
        <layer repeat="2">
                <slice name="SciFi_belt"     material="PlasticScint"    thickness="1*mm"␣
↪vis = "RedVis"  sensitive = "true"/>
        </layer>
        <layer repeat="1">
                <slice name="Scint_slice"    material="PlasticScint"    thickness="3*mm"␣
↪vis = "BlueVis" sensitive = "true"/>
                <slice name="Tungsten_slice" material="TungstenDens24" thickness="7*mm"␣
↪vis = "GrayVis"/>
        </layer>
</detector>

<detector id="2" name="largeZDC" type="ZDC" readout="ZDCHits" vis="RedVis">
        <position x="lt_ZDC_x_pos" y="lt_ZDC_y_pos" z="lt_ZDC_z_pos"/>
        <dimensions x = "lt_length" y = "lt_length"/>
        <layer>

        </layer>
</detector>
```

Access Variables

- Volume ID that obtained from Cell ID using dd4hep::VolumeManagerContext.identifier

```
auto volID = [&] (const std::vector<dd4hep::sim::Geant4Calorimeter::Hit*>& hits) {
      std::vector<double> result;
      for(const auto& h: hits) {
              auto volcontext = cellid_converter.findContext(h->cellID);
              result.push_back(volcontext->identifier);
      }
return result;
};
```

- Volume ID that obtained from Cell ID using dd4hep::VolumeManagerContext.element and Readout/Segmentation

```
auto volID = [&] (const std::vector<dd4hep::sim::Geant4Calorimeter::Hit*>& hits) {
      std::vector<double> result;
      for(const auto& h: hits) {
              auto volcontext = cellid_converter.findContext(h->cellID);
              dd4hep::Readout r = cellid_converter.findReadout(volcontext->element);
              dd4hep::Segmentation seg = r.segmentation();
              result.push_back(seg.volumeID(h->cellID));
      }
return result;
};
```

3.1.3 SoLID ElectroMagnetic Calorimeter

A electromagnetic calorimeter for the SoLID detector. It is a ring-shape detector with hexgonal modules.

Example use:

```
<detector id="3" name="LAECPreShower" type="EMCalorimeterSoLID" readout="LAEC_PrShHits"␣
↪vis="PurpleVis" >
  <comment>Large Angle Electromagnetic Calorimeter (LAEC) Preshower for SIDIS</comment>
  <dimensions rmin="83*cm" rmax="140*cm" z0="-65*cm" rmod="6.25*cm" rtol="1.0*cm" />
  <layer repeat="1" vis="InvisibleWithDaughters">
    <slice material = "Lead"  thickness = "1.12*cm" vis="BlueVis"/>
    <slice material = "EJ204" thickness = "6.25*cm" vis="PurpleVis" sensitive="yes"/>
  </layer>
</detector>

<detector id="4" name="LAECShower" type="EMCalorimeterSoLID" readout="LAEC_ShHits" vis=
↪"PurpleVis" >
  <comment>Large Angle Electromagnetic Calorimeter (LAEC) Shower for SIDIS</comment>
  <dimensions rmin="83*cm" rmax="140*cm" z0="-57*cm" rmod="6.25*cm" rtol="1.0*cm" />
  <layer repeat="194" vis="GreenVis">
    <slice material = "Lead"  thickness = "0.05*cm"/>
    <slice material = "EJ204" thickness = "0.15*cm" sensitive="yes" limits="cal_limits"/>
    <slice material = "Air"   thickness = "0.012*2*cm"/>
  </layer>
</detector>
```

Detector description variables

dimensions Dimensions of the sensitive detector

- **rmin** Inner radius of the detector
- **rmax** Outer raidus of the detector
- **z0** Z position (along the beam line) of the front surface of the detector
- **rmod** Outer radius (side length) of the hexgonal module
- **rtol** Extrusion Tolerance for putting modules inside the detector ring

layer Layer definition of the hexgonal modules

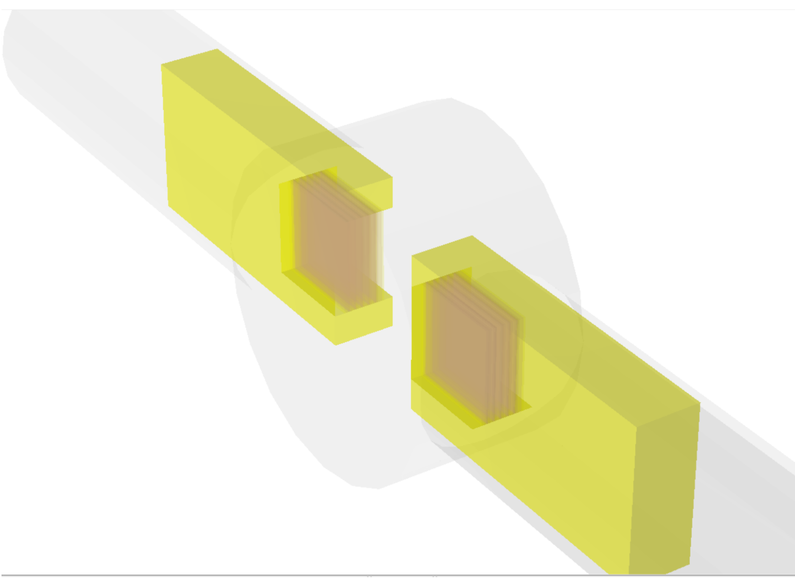
- **repeat** Number of the same slices to stack along z
- **slice** Slice definition in the layer
  - **material** slice material
  - **thickness** slice thickness

3.2 Trackers

3.2.1 Roman Pot

A pair of Roman Pot-style detectors for detection of particles scattered by very small angles, typically in forward and far-forward regions.

Generic information about design of Roman pot detectors can be found in references describing units used at LHC ref 1 and ref 2.



Example use:

```
<detector id = "1" name = "MyRomanPot" type = "RomanPot" readout =
            "ForwardRomanPotHits" vis = "RedVis">
   <dimensions x = "3.0*cm" y = "3.0*cm" delta = "0.005*cm" />
```

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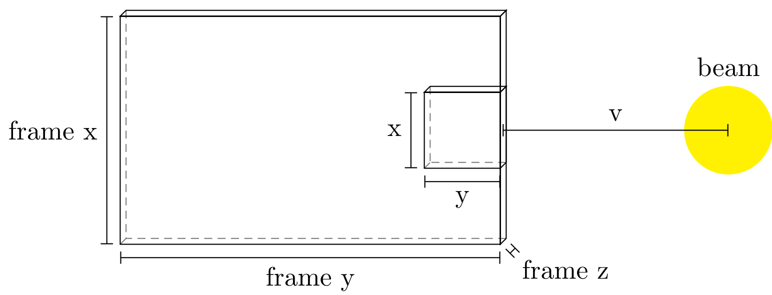
```
  <frame x = "10.0*cm" y = "5.0*cm" z = "2*cm" />
  <position z_offset = "0.0*m" rotation = "false" vmax = "10*cm" v = "2.0*cm" />
  <layer repeat = "5">
    <slice material = "Carbon"  thickness = "0.5*mm"  vis = "BlueVis" />
    <slice material = "Silicon" thickness = "0.03*cm" vis = "GreenVis" sensitive = "true
↪"  />
    <slice material = "Carbon"  thickness = "0.5*mm"  vis = "BlueVis" />
    <slice material = "Vacuum"  thickness = "1.0*mm"  vis = "InvisibleWithDaughters" />
  </layer>
</detector>
```

Detector description variables



dimensions Dimensions of the sensitive detector.

x Width of the detector.

y Height of the detector.

delta Separation gap - the distance between the inner edges of the active area substrate.

frame Dimensions of the frame that houses the sensitive detector.

x Width of the frame.

y Height of the frame.

z thickness of the frame.

position Positioning of the whole detector pair relative to the beamline.

z_offset Distance along the beamline.

rotation Boolean which determines whether the detector pair is horizontal (false) or vertical (true).

vmax Furthest distance of the detector from the beam (used to create the full unit unclosure).

v Current insertion depth of the detectors (distance of the inner edge relative to the beam axis).

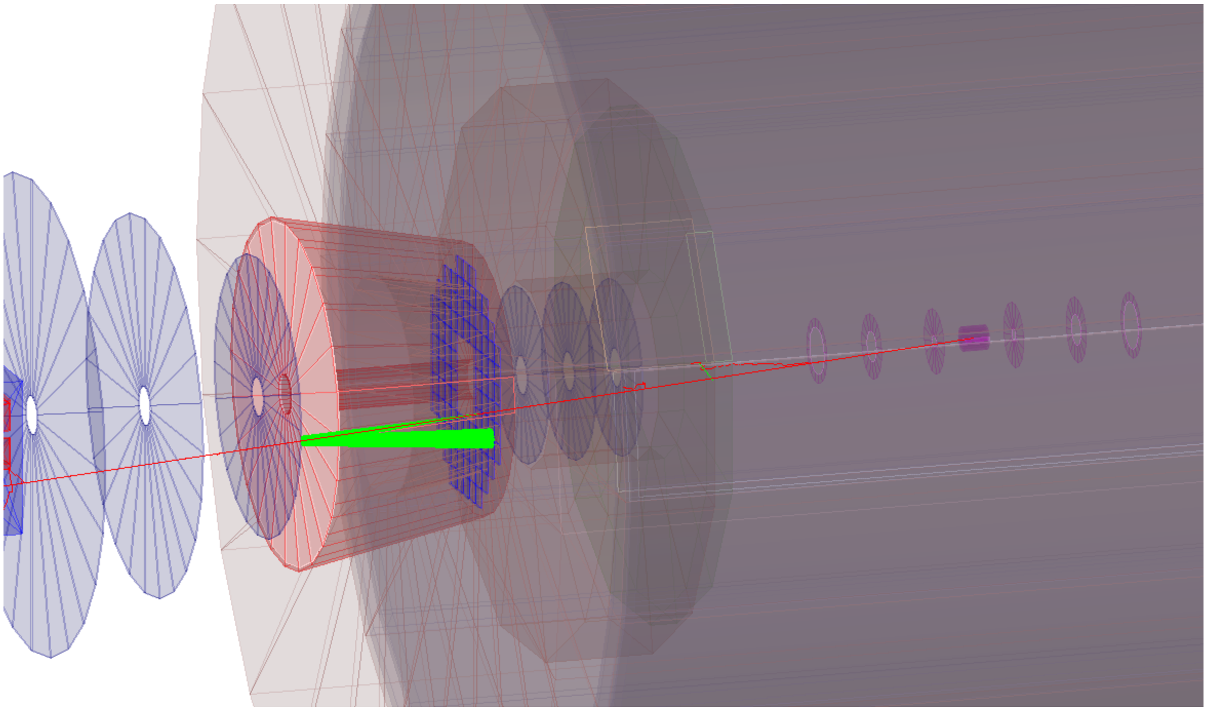
layer Material stack used for the sensitive detector.

repeat Number of layers in a single detectors.

3.3 Particle Identification (PID)

3.3.1 Generic Gaseous RICH

A generic gas RICH detector for hadron PID in the forward dectection is shown in the figure below. The simple design uses a plane mirror to reflect cherenkov photons (green) onto an array of MCP-PMT detectors (blue). The optical properties of the mirror are defined in a properites block as shown here.



```
<detector id="1" name="ForwardRICH" type="GenericRICH"
          readout="ForwardRICHHits" vis="RedVis" material="N2cherenkov">
  <dimensions rmin1="30*cm" rmin2="30*cm" rmax1="80*cm" rmax2="80*cm" zmin="20*cm"  zmax=
↪"120*cm"/>
</detector>
```

Optical surfaces are defined in the detector construction. Their optical properites of surfaces are defined in the detector description:

```
<surfaces>
  <opticalsurface finish="polished" model="glisur" name="MirrorOpticalSurface" type=
↪"dielectric_metal" value="0">
    <property name="REFLECTIVITY" ref="REFLECTIVITY_mirror"/>
    <property name="RINDEX"       coldim="2" values="1.034*eV  1.5   4.136*eV  1.5"/>
  </opticalsurface>
</surfaces>
```

CHAPTER

FOUR

BEAMLINE MAGNET ELEMENTS

These detector elements don't directly serve a role in particle detection, but have to be included to accomodate for particle-matter interactions. The provided magnet types are *dipole* and *quadrupole* magnets and *spin rotators*.

4.1 Dipole magnets

Magnets generating dipole field used for beam steering and spectrometry.

example use:

```
<detector id="3" name="B0PF_BeamlineMagnet" type="B0pFMag">
  <placement x="B0PF_XPosition" y="0*m" z="B0PF_CenterPosition" theta="B0PF_RotationAngle
↪" />
  <dimensions x="B0PF_InnerRadius*4" y="B0PF_InnerRadius*4" z="B0PF_Length*0.5" />
  <apperture x="B0PF_InnerRadius*2" y="B0PF_InnerRadius*2" />
  <coil dx="0.1*m" dy="0.03*m" />
</detector>
```

4.2 Quadrupole magnets

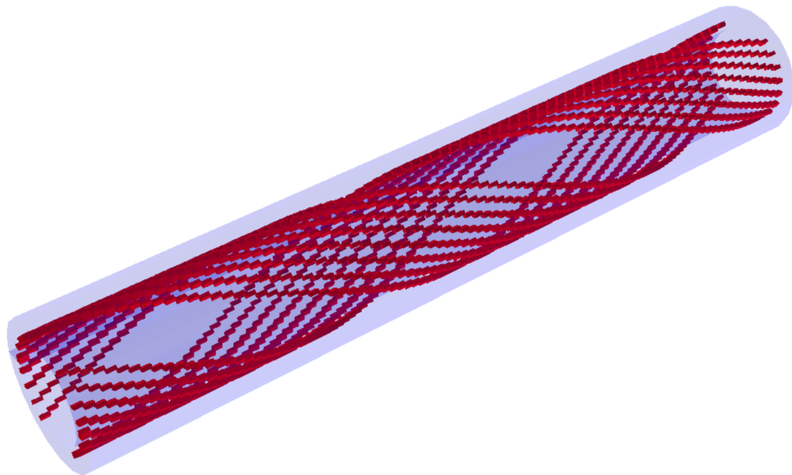
Magnets used for bea focusing, loosely based on design shown here. More information can be also found at reference discussing the EIC design.

example use:

```
<detector id="1" name="quad_example" vis="RedVis" type="QuadMagnet">
   <placement x="0*m" y="0*m" z="0*m" theta="0.0" />
   <dimensions r="0.2*m" z="3.8*m" />
   <coil dx="8*cm" dy="2.5*cm" />
   <apperture r="0.131*m" />
 </detector>
```

4.3 Helical dipole magnets

These beamline elements are used for spin rotation. See this reference for more information.



example use:

```
<detector id="1" name="spinp_example" vis="RedVis" type="HelicalDipole">
   <placement x="0*m" y="0*m" z="0*m" theta="0.0" psi="0.0" />
   <dimensions r="0.2*m" z="2.3*m" />
   <coil dy="2.5*cm" />
   <apperture r="0.131*m" />
 </detector>
```

CHAPTER FIVE

INPUT EVENT FORMAT

Use Hepmc3

CHAPTER

SIX

TIPS AND TRICKS

6.1 Code Snippets

6.1.1 Access Variables

Volume ID from Cell ID

- Volume ID that obtained from Cell ID using dd4hep::VolumeManagerContext.identifier

```
auto volID = [&] (const std::vector<dd4hep::sim::Geant4Calorimeter::Hit*>& hits) {
      std::vector<double> result;
      for(const auto& h: hits) {
              auto volcontext = cellid_converter.findContext(h->cellID);
              result.push_back(volcontext->identifier);
      }
return result;
};
```

- Volume ID that obtained from Cell ID using dd4hep::VolumeManagerContext.element and Readout/Segmentation

```
auto volID = [&] (const std::vector<dd4hep::sim::Geant4Calorimeter::Hit*>& hits) {
      std::vector<double> result;
      for(const auto& h: hits) {
              auto volcontext = cellid_converter.findContext(h->cellID);
              dd4hep::Readout r = cellid_converter.findReadout(volcontext->element);
              dd4hep::Segmentation seg = r.segmentation();
              result.push_back(seg.volumeID(h->cellID));
      }
return result;
};
```

6.2 FAQ

6.2.1 DD4hep

What is the difference between Volume ID and Cell ID?

Both are unique IDs, but in the case of volume ID, it is associated with a physical placement of a volume (in G4 or tgeo). The cell ID is used to further identify the subgeometry allocated to a volume through a segmentation. The volume ID is related to the cell ID through the readout's `id` tag.

See dd4hep CellID Descriptors documentation

What is a segmentation?

A segmentation is a virtual geometry that is used to subdivide a volume. This avoids creating many small volumes to uniquely identify sensitive elements of a volume. An example would be a silicon detector with many channels at a fine pitch. Instead of create each pixel as a box of silicon, one silicon box is logically divide through the segmentation mechanism of DD4hep.

For a list of segmentations look at the headers in DDSegmentation.

What is a readout?

A readout is associated with a senstive detector in DD4hep and is used by setting the `detector`'s `readout` attribute. The attribute value is the name of a readout defined in the `readouts`.

```
<readouts>
  <readout name="ECalHits">
    <segmentation type="CartesianGridXY" grid_size_x="10.0*cm" grid_size_y="10.0*cm" />
    <id>system:5,layer:9,module:8,x:32:-16,y:-16</id>
  </readout>
</readouts>
```

How do I run the GEANT4 simulation?

todo

How can I visualize the GEANT4 simulation?

todo

How can I visualize the detector geometry?

todo

CHAPTER

SEVEN

TOPSIDE

This site is currently under construction. Come back later!!!

7.1 Tracking

7.1.1 Vertex Trackers

Silicon Vertex Tracker Barrel

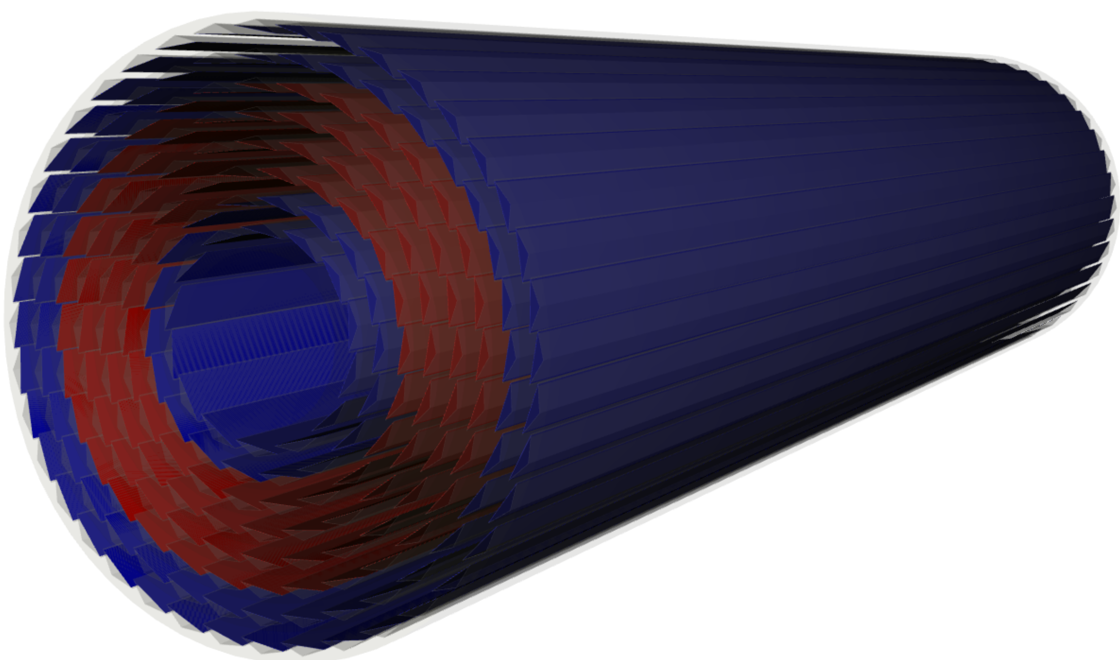
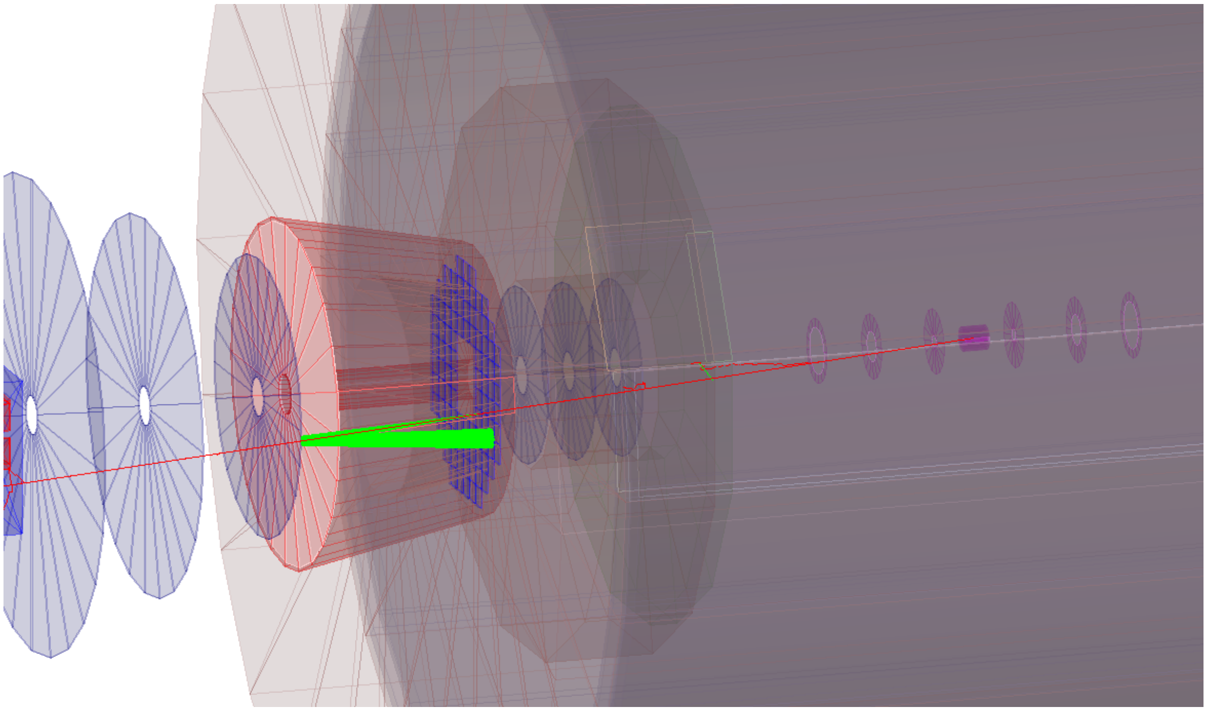


Fig. 1: Silicon vertex tracker barrel with soi and usfd detectors and a simple stave.

7.2 Particle Identification (PID)

7.2.1 RICH



```
<detector id="1" name="ForwardRICH" type="GenericRICH"
          readout="ForwardRICHHits" vis="RedVis" material="N2cherenkov">
  <dimensions rmin1="30*cm" rmin2="30*cm" rmax1="80*cm" rmax2="80*cm" zmin="20*cm"  zmax=
↪"120*cm"/>
</detector>
```

Optical surfaces are defined in the detector construction. Their optical properites of surfaces are defined in the detector description:

```
<surfaces>
  <opticalsurface finish="polished" model="glisur" name="MirrorOpticalSurface" type=
↪"dielectric_metal" value="0">
    <property name="REFLECTIVITY" ref="REFLECTIVITY_mirror"/>
    <property name="RINDEX"       coldim="2" values="1.034*eV  1.5   4.136*eV  1.5"/>
  </opticalsurface>
</surfaces>
```

CHAPTER

EIGHT

INDICES AND TABLES

- genindex
- modindex
- search