Changing Geometry in DD4hep

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CERN-EP-SFT

FCC Software Hands-on Tutorial
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Scope and Goals

Changing DD4hep Geometries

In this set of tutorials you will learn how to

- simulate an existing detector model
- modify its XML files
- check for overlaps with Geant4
- get a better understand of what DD4hep does under the hood
- Write your own c++ detector constructor and run with it

Setup and Requirements

Setup

Assuming you are on some CentOS7 machine, lxplus, VM, Docker with CVMFS

```
source /cvmfs/sw.hsf.org/key4hep/setup.sh
mkdir mydd4heptutorial
cd mydd4heptutorial
cp -r $LCGEO/FCCee/compact/FCCee_o1_v05 .
pip install --user uproot3
```

You should now see something like this when listing the current working directory

```
ls -ltra
total 8
drwxr-xr-x. 28 sailer zf 4096 Oct 14 11:29 ..
drwxr-xr-x.  3 sailer zf   26 Oct 14 11:30 .
drwxr-xr-x.  2 sailer zf 4096 Oct 14 11:30 FCCee_o1_v05
```

Show Some Distribution Script

Save this a `showPlots.py`, with `uproot3` this can draw histograms in the terminal

```
#!/bin/env python
import sys, ROOT, uproot3 as uproot
from ROOT import TFile, TTree
ROOT.gROOT.SetBatch(True)
if len(sys.argv) < 2:
  print("Please specify input file"); sys.exit(1)
inputFile = sys.argv[1]; print("Reading:", inputFile)
tfile = ROOT.TFile.Open(inputFile)
myTree = tfile.Get("events")
myTree.Draw("ECalEndcapCollection.position.z>>zHist(100, 2300, 2510)",
            "ECalEndcapCollection.position.z > 0")
myTree.Draw("ECalEndcapCollection.energy>>eHist(30, 0, 0.002)")
zHist = tfile.Get("zHist")
eHist = tfile.Get("eHist")
oFile = ROOT.TFile.Open("temp.root", "RECREATE")
eHist.Write(); zHist.Write(); oFile.Close()
uFile = uproot.open("temp.root")
uFile["zHist"].show()
uFile["eHist"].show()
```


Simulate some Muons in CLD

Simulation of 100 Muons

Let's use this detector model to simulate a couple of Muons

```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --enableGun \
      --gun.distribution uniform \
      --gun.energy "10*GeV" \
      --gun.particle mu- \
      --numberOfEvents 100 \
      --outputFile Step1_edm4hep.root
...
DDSim INFO DDSim INFO  Total Time:   152.55 s (User), 0.98 s (System)
DDSim INFO DDSim INFO  StartUp Time: 136.30 s, Event Processing: 16.25 s (0.16 s/
```

And plot the distribution with `showPlots.py`

```
python showPlots.py Step1_edm4hep.root
```

Removing an Included XML file

Removing an Include

The Silicon Tracker has a lot of volumes, for the next important bit (overlap checking) we will remove those sub-detectors, because we are on a schedule.

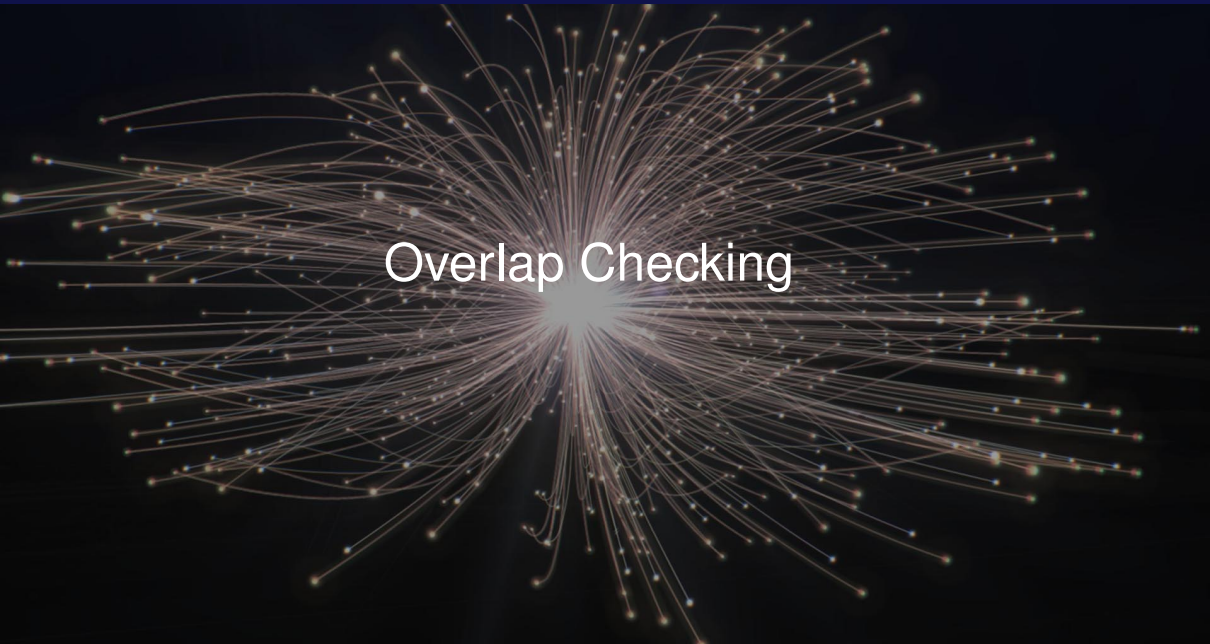
1. Open `FCCee_o1_v05/FCCee_o1_v05.xml`
2. Find
```
<include ref="InnerTracker_o2_v06_02.xml"/>
<include ref="OuterTracker_o2_v06_02.xml"/>
```
3. And replace, or delete
```
<!-- <include ref="InnerTracker_o2_v06_02.xml"/> -->
<!-- <include ref="OuterTracker_o2_v06_02.xml"/> -->
```
4. Comment out the `<plugins> ... </plugins>` in the same file
   - They use some constants defined in the commented files
   - We don't need them for the simulations today

Simulate the model without the Tracker

```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --enableGun \
      --gun.distribution uniform \
      --gun.energy "10*GeV" \
      --gun.particle mu- \
      --numberOfEvents 100 \
      --outputFile Step2_edm4hep.root
...
DDSim INFO DDSim INFO  Total Time:   7.79 s (User), 0.46 s (System)
DDSim INFO DDSim INFO  StartUp Time: 2.71 s, Event Processing: 5.08 s (0.05 s/Eve
```

Fast enough for repeated testing

The distributions should not have noticeably changed



Overlap Checking

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Whenever you change the geometry in a non-trivial way there are the possibilities of overlaps and the following things should be kept in mind

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Whenever you change the geometry in a non-trivial way there are the possibilities of overlaps and the following things should be kept in mind

1. There are no trivial changes
2. See point 1
3. Run the overlap check

Running the Geant4 Overlap Check

Create the following file as `overlap.mac`

```
/geometry/test/run
exit
```

And then we run `ddsim` with this macro file, and dump the output to a text file for easy browsing

```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --runType run \
      --macroFile overlap.mac > overlapDump &
```

- With the full detector model including the tracker this would take about 30 minutes

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- There are some exceptions. . . someone didn't follow step 3?

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  - The exceptions about the VertexEndcapModule are due to a too small envelope, and could be easily fixed

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- With the full detector model including the tracker this would take about 30 minutes
- There are some exceptions. . . someone didn't follow step 3?
  - The exceptions about the VertexEndcapModule are due to a too small envelope, and could be easily fixed
  - The exceptions about the Boolean Volume are more vexing. . . , let's ignore those for now. Maybe drop the HOMAbsorber include as well

Modifying the ECal

Modifying the ECal

- Now let's do some "real" modifications to the detector model
- Let's change the number of layers and silicon thicknesses of the ECal Endcap
- Open the file `FCCee_o1_v05/ECalEndcap_o2_v01_03.xml`
- Find this block:

```
<layer repeat="40" vis="ECalLayerVis">
  <slice material = "TungstenDens24" thickness = "1.90*mm" vis="ECalAbsorberVis" radiator="yes"/
  <slice material = "G10"            thickness = "0.15*mm" vis="InvisibleNoDaughters"/>
  <slice material = "GroundOrHVMix"  thickness = "0.10*mm" vis="ECalAbsorberVis"/>
  <slice material = "Silicon"        thickness = "0.50*mm" sensitive="yes" limits="cal_limits"
        vis="ECalSensitiveVis"/>
  <slice material = "Air"            thickness = "0.10*mm" vis="InvisibleNoDaughters"/>
  <slice material = "siPCBMix"       thickness = "1.30*mm" vis="ECalAbsorberVis"/>
  <slice material = "Air"            thickness = "0.25*mm" vis="InvisibleNoDaughters"/>
  <slice material = "G10"            thickness = "0.75*mm" vis="InvisibleNoDaughters"/>
</layer>
```

Modifying the ECal

- Now let's do some "real" modifications to the detector model
- Let's change the number of layers and silicon thicknesses of the ECal Endcap
- Open the file `FCCee_o1_v05/ECalEndcap_o2_v01_03.xml`
- and change the number of layers and the silicon thickness:

```
<layer repeat="20" vis="ECalLayerVis">
  <slice material = "TungstenDens24" thickness = "1.90*mm" vis="ECalAbsorberVis" radiator="yes"/
  <slice material = "G10"            thickness = "0.15*mm" vis="InvisibleNoDaughters"/>
  <slice material = "GroundOrHVMix"  thickness = "0.10*mm" vis="ECalAbsorberVis"/>
  <slice material = "Silicon"        thickness = "1.00*mm" sensitive="yes" limits="cal_limits"
        vis="ECalSensitiveVis"/>
  <slice material = "Air"            thickness = "0.10*mm" vis="InvisibleNoDaughters"/>
  <slice material = "siPCBMix"       thickness = "1.30*mm" vis="ECalAbsorberVis"/>
  <slice material = "Air"            thickness = "0.25*mm" vis="InvisibleNoDaughters"/>
  <slice material = "G10"            thickness = "0.75*mm" vis="InvisibleNoDaughters"/>
</layer>
```

Simulate with the new ECal

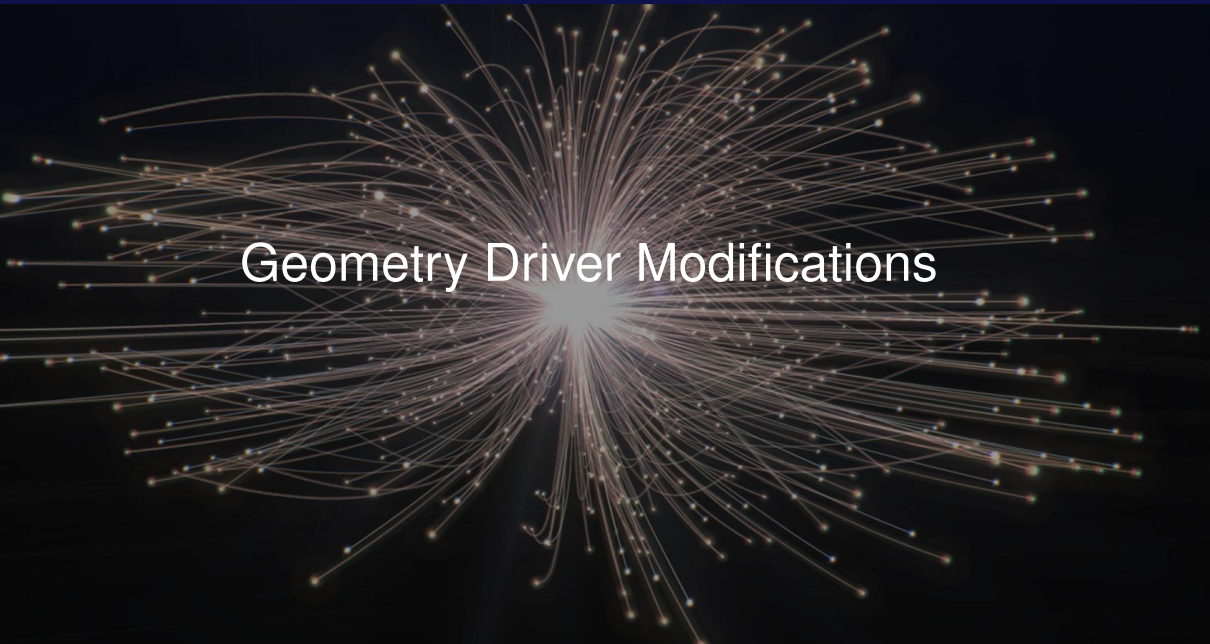
```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --enableGun \
      --gun.distribution uniform \
      --gun.energy "10*GeV" \
      --gun.particle mu- \
      --numberOfEvents 100 \
      --outputFile Step3_edm4hep.root
```

Compare the distributions

- Now compare the output of showPlots for Step2 and Step3
- Note how the distributions changed?

Congratulations

You are now an expert in modifying detector geometries!



Geometry Driver Modifications

DD4hep Plugin Basics

- You just saw how changing the XML file changes the detector geometry, but how does this work under the hood?
- The `type` attribute of the detector tag tells DD4hep which detector constructor to load

```
<detector name="ECalEndcap"
          type="GenericCalEndcap_o1_v01"
          id="DetID_ECal_Endcap"
          readout="ECalEndcapCollection"
          vis="ECALVis" >
  <!-- more XML -->
</detector>
```

- DD4hep's plugin service will look in the `components` files it finds via the LD_LIBRARY_PATH (or DD4HEP_LIBRARY_PATH on macOS because of SIP) environment variables, and load the library on-demand, and then instantiate the function
- How can we know which library contains the `GenericCalEndcap` plugin?

```
for DIR in $(echo $LD_LIBRARY_PATH | tr ":" " ") ; do
  grep GenericEndcap $DIR/*.components 2> /dev/null;
done
```

Boilerplate Project

Usually we would add our detector to an existing project, but because overwriting existing libraries in the environment is a bit of a pain, we start with a new project

```
mkdir MyFirstDetector
cd MyFirstDetector
git init
touch CMakeLists.txt
mkdir src
touch src/MyFirstDetector.cpp
```

CMakeLists.txt

In `MyFirstDetector` create a `CMakeLists.txt` file with this content

```
cmake_minimum_required(VERSION 3.12 FATAL_ERROR)

set(PackageName MyFirstDetector)
project(${PackageName})

find_package(DD4hep REQUIRED COMPONENTS DDG4)

# our sources
set(sources ./src/MyFirstDetector.cpp)

# create our library and make the components file
add_dd4hep_plugin(${PackageName} SHARED ${sources})

# link it with DDCore, or whatever you need
target_link_libraries(${PackageName} DD4hep::DDCore)

# Create this_package.sh file, and install
dd4hep_instantiate_package(${PackageName})
```

MyFirstDetector.cpp

```cpp
#include "DD4hep/DetFactoryHelper.h"
#include "XML/Layering.h"
#include "XML/Utilities.h"
#include "DDRec/DetectorData.h"
static dd4hep::Ref_t create_detector(
 dd4hep::Detector& theDetector,
 xml_h entities,
 dd4hep::SensitiveDetector sens)  {
  // XML Detector Element (confusingly also XML::DetElement)
  xml_det_t x_det = entities;
  // DetElement of our detector instance, attach additional information, sub-elements...
  // uses name of detector and ID number as defined in the XML detector tag
  std::string detName  = x_det.nameStr();
  sens.setType("calorimeter");
  dd4hep::DetElement sdet (detName, x_det.id());
  return sdet;
}
DECLARE_DETELEMENT(MyFirstDetector,create_detector)
```

Overall Dimensions, and First Cylinder

Add this just before the `return`:

```
//get the dimensions tag
xml_dim_t dim = x_det.dimensions();
//read its attributes
double rmin = dim.rmin();
double rmax = dim.rmax();
double zmax = dim.zmax();

//Make a Cylinder
dd4hep::Tube envelope(rmin, rmax, zmax);
dd4hep::Material air = theDetector.air();
dd4hep::Volume envelopeVol(detName+"_envelope",
                           envelope,
                           air);
dd4hep::PlacedVolume physvol =
  theDetector.pickMotherVolume(sdet).placeVolume(envelopeVol);
  // add system ID and identify as barrel (as opposed to endcap +/-1)
physvol.addPhysVolID("system", sdet.id()).addPhysVolID(_U(side),0);
sdet.setPlacement(physvol);
```

Compile

We are still in the `MyFirstDetector` directory

```
mkdir build install
cd build
cmake -D CMAKE_INSTALL_PREFIX=$PWD/../install ..
make install
source ../install/bin/thisMyFirstDetector.sh
```

Look at `$PWD/../install` and note the content of the `bin`, `lib` directories, have a look at the `components` file

Use It

1. In the `FCCee_o1_v05` directory, create a `mydetector.xml` file
2. Modify the `FCCee_o1_v05/FCCee_o1_v05.xml` and replace the include for the ECalBarrel with `mydetector.xml`

MyDetector.xml

Fill `mydetector.xml` with

```
<lccdd>
  <!-- Constants, Readout, VIS goes here -->
  <detectors>
    <detector name="MyDetectorName"
              type="MyFirstDetector"
              id="1234"
              readout="MyReadout"
              vis="MyVis" >
      <dimensions
          zmax="ECalBarrel_half_length"
          rmin="ECalBarrel_inner_radius"
          rmax="ECalBarrel_outer_radius"/>

    </detector>
  </detectors>
</lccdd>
```

and also see next page

XML: Constants, Readout, Visualisation

Add to the `mydetector.xml` file:

```
<define>
  <constant name="ECal_cell_size" value="5.1*mm"/>
</define>

<readouts>
  <readout name="MyReadout">
    <segmentation type="GridRPhiEta"
                  grid_size_eta="ECal_cell_size"     phi_bins="360"
                  offset_r="ECalBarrel_inner_radius"
                  grid_size_r="1*cm" />
    <id>system:5,side:2,module:8,stave:4,layer:9,submodule:4,r:32:10,eta:-11,phi:-11</id>
  </readout>
</readouts>

<display>
  <vis name="MyVis" alpha="0.1"
       r="0.1" g=".5" b=".5"
       showDaughters="true"
       visible="false"/>
</display>
```

Check for Overlaps

Go back to the base folder, or change the path to the XML file.

```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --runType run \
      --macroFile overlap.mac > overlapDump &
```

Layers in the XML

```
<!-- In the <detector></detector> -->

<layer repeat="10" vis="MyVis">
  <slice material="Iron"     thickness="1*cm" />
  <slice material="G10"      thickness="1*mm" />
  <slice material="Silicon"  thickness="1*mm" sensitive="true" />
  <slice material="G10"      thickness="1*mm" />
</layer>
```

Add interpretation of the layers to `MyFirstDetector.cpp`

```
double currentInnerRadius = rmin; // running inner radius
dd4hep::Layering layering(x_det); // convenience class
int layerNum = 0;
for(xml_coll_t c(x_det,_U(layer)); c; ++c, ++layerNum) {
  xml_comp_t x_layer = c;
  const dd4hep::Layer* lay = layering.layer(layerNum); // Get the layer from the layering engine.
  const double layerThickness = lay->thickness();
  //loop over the number of repetitions
  for(int i=0, repeat=x_layer.repeat(); i<repeat; ++i, ++layerNum)  {

    std::string layerName = detName + dd4hep::_toString(layerNum,"_layer%d");
    //make a volume for the layer
    dd4hep::Tube layerTube(currentInnerRadius,
                           currentInnerRadius + layerThickness, zmax);
    dd4hep::Volume layerVol(layerName, layerTube, air);
    dd4hep::DetElement layerElement(sdet, layerName, layerNum);
    dd4hep::PlacedVolume layerVolPlaced = envelopeVol.placeVolume(layerVol);
    layerVolPlaced.addPhysVolID("layer",layerNum);
    //loop over slices
  } //repetitions
 }//layers
```

Add interpretation of the slices to `MyFirstDetector.cpp`

```
int sliceNum = 0;
for(xml_coll_t slice(x_layer,_U(slice)); slice; ++slice, ++sliceNum)  {
  xml_comp_t x_slice = slice;
  double sliceThickness = x_slice.thickness();
  dd4hep::Material sliceMat  = theDetector.material(x_slice.materialStr());
  std::string sliceName = layerName + dd4hep::_toString(sliceNum,"slice%d");
  dd4hep::Tube sliceTube(currentInnerRadius,
                         currentInnerRadius + sliceThickness, zmax);
  dd4hep::Volume sliceVol(sliceName, sliceTube, sliceMat);
  if ( x_slice.isSensitive() ) {
    sliceVol.setSensitiveDetector(sens);
  }
  //place the slice in the layer
  layerVol.placeVolume(sliceVol);

  currentInnerRadius += sliceThickness;
 } // slices
```

Check for Overlaps

- Compile your detector again
- Go back to the base folder, or change the path to the XML file.

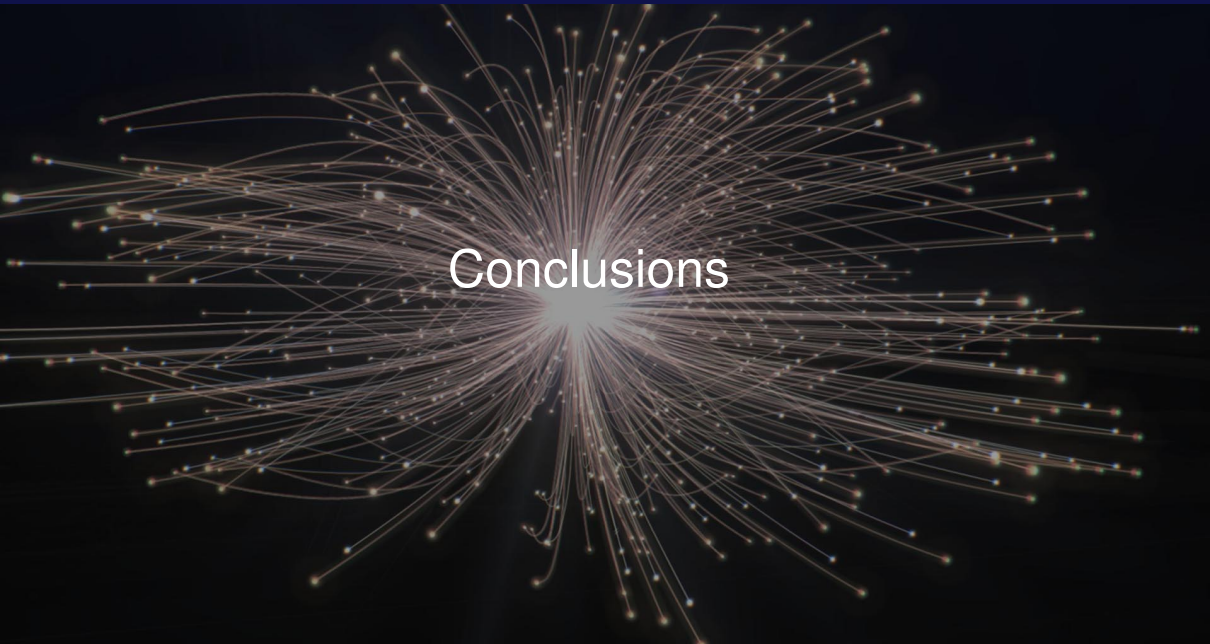
```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --runType run \
      --macroFile overlap.mac > overlapDump &
```

Simulate

Go back to the base folder, or change the path to the XML file.

```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --enableGun \
      --gun.distribution uniform \
      --gun.energy "10*GeV" \
      --gun.particle mu- \
      --numberOfEvents 100 \
      --outputFile Step4_edm4hep.root
```

Modify `showPlots.py` to display properties from this collection (MyReadout)



Conclusions

Conclusions

- Changing geometries with DD4hep can range from trivial to sophisticated
- use the overlap checker
- When you have questions:
  1. Browse the **DD4hep documentation**
  2. Ask us at **https://github.com/aidasoft/dd4hep**