CLD detector with ARC

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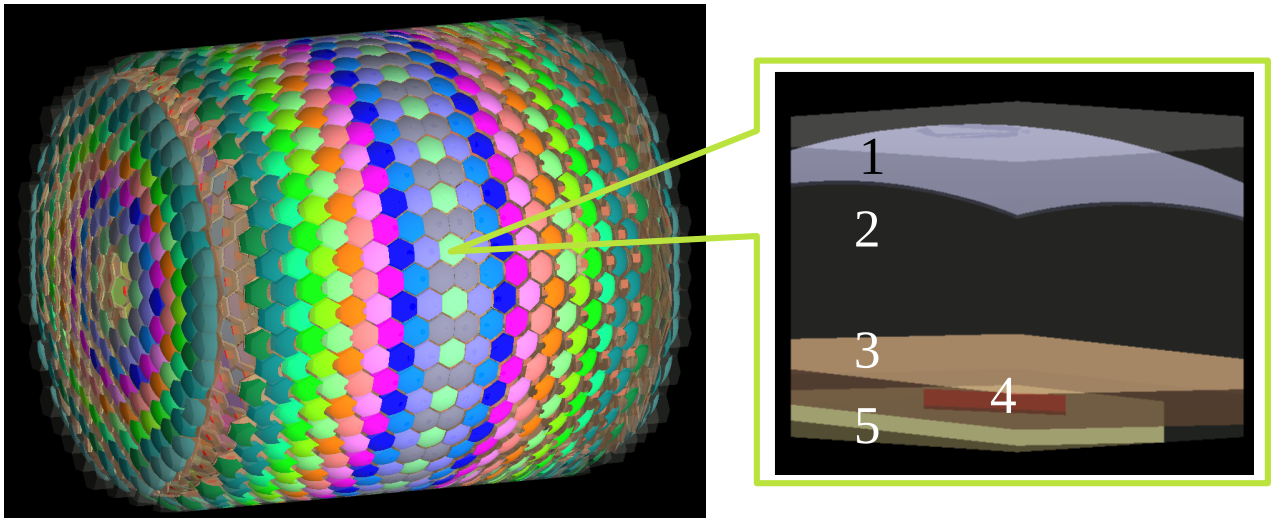
Detector Concept meeting

Sept. 18th, 2023 (updated Sept. 20th)

What is the Array of RICH Cells (ARC) detector

- It is a Ring-Imaging Cherenkov detector for particle identification
- Current implementation concept was developed by Roger Forty, Guy Wilkinson, and Martin Tat
- The detector was presented by Roger at FCC Week 2021 and the Kickoff Detector Concepts workshop June 2022, and later by Martin at ECFA October 2022 and Krakow January 2023

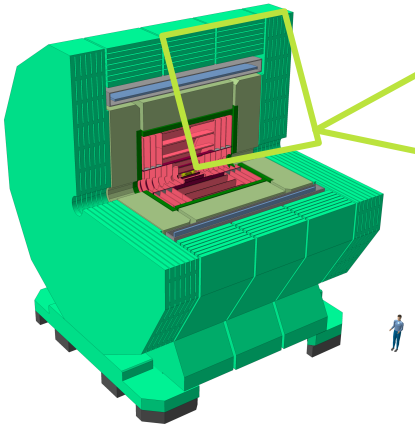


1. Spherical mirror
2. Radiator gas C4F10
3. Aerogel
4. Light sensor
5. Cooling plate

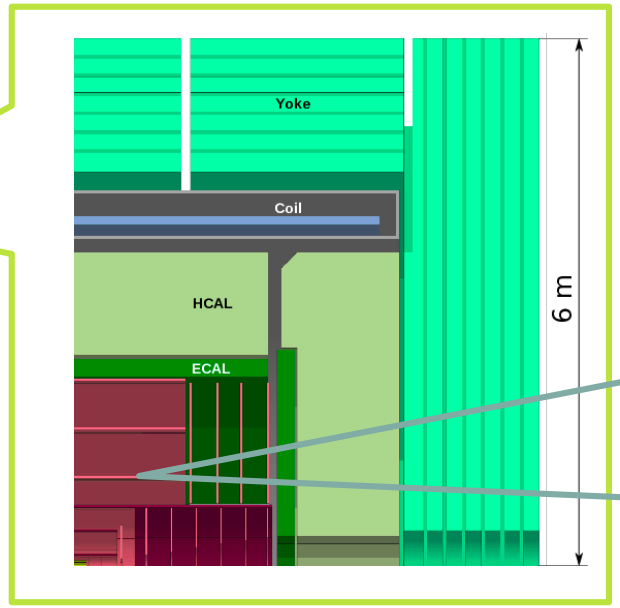
Design of Array of RICH Cells (ARC)

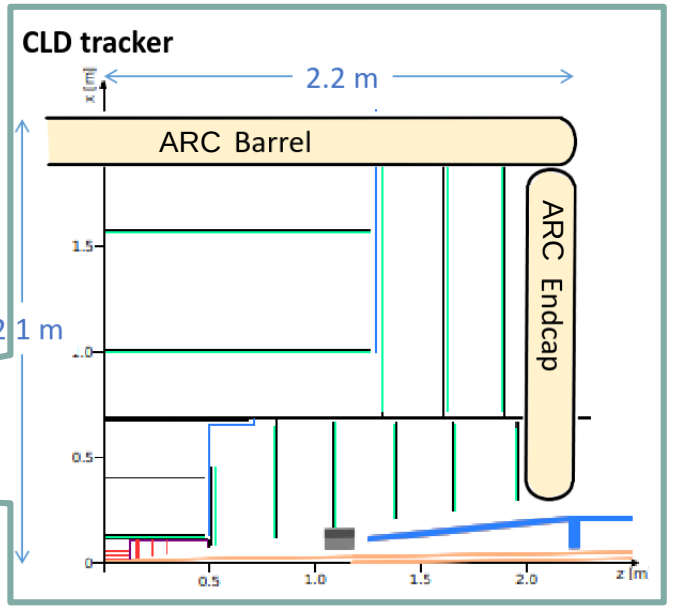
- The ARC was designed to be integrated with the CLD detector, between the tracker and the ECAL

- The ARC thickness is 20 cm, the barrel length is 4.4 m and the endcaps are placed as the bases of the barrel

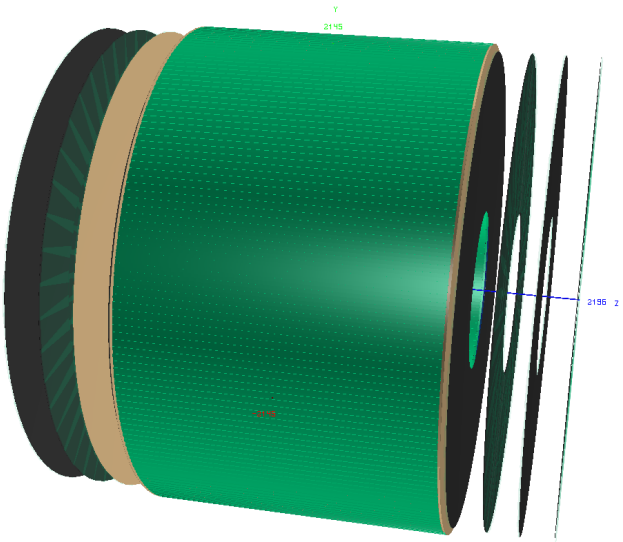


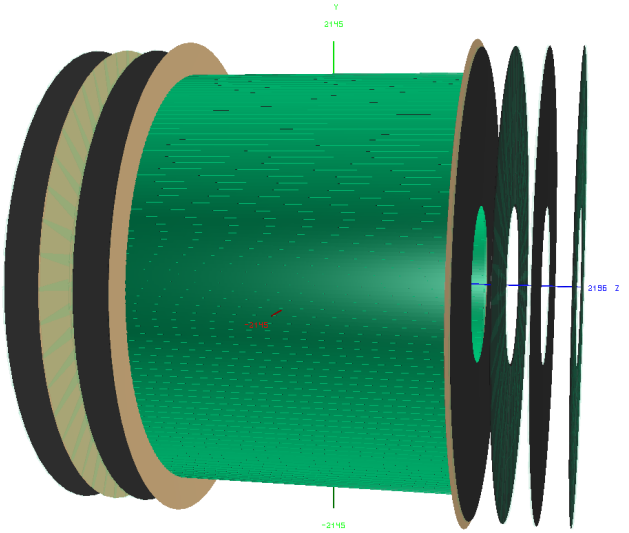
CLD detector





CLD outer tracker barrel shrinking





Original size:

Z_out/2 = 220 cm

R_out = 215 cm

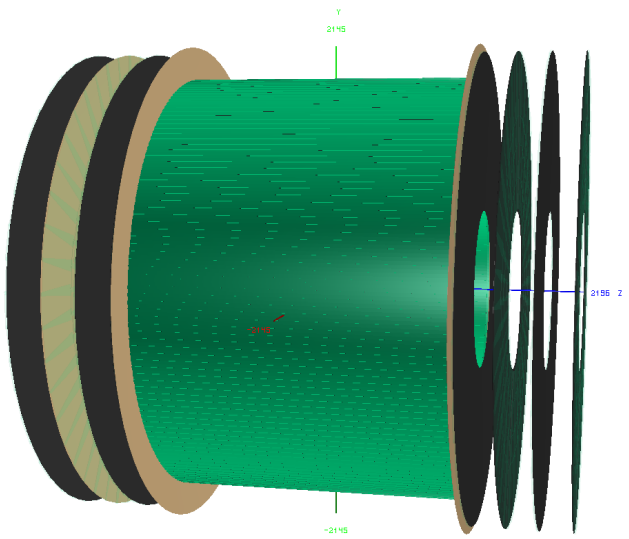
Reduce the radius of layers #2 and #3 of OT,

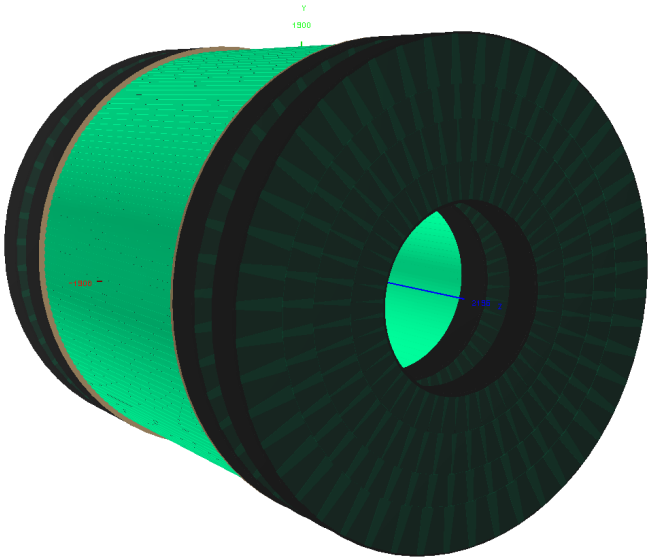
Number of modules per layer reduced accordingly

Goal:

Z_out/2 = 200 cm
R_out = 190 cm

CLD outer tracker endcap shrinking





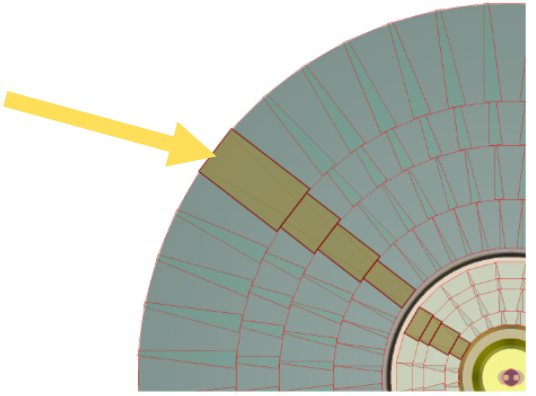
Original size:

Z_out/2 = 220 cm

R_out = 215 cm

Reduce the radius of envelope and support structure

Reduce Y-size of last ring module



Goal:

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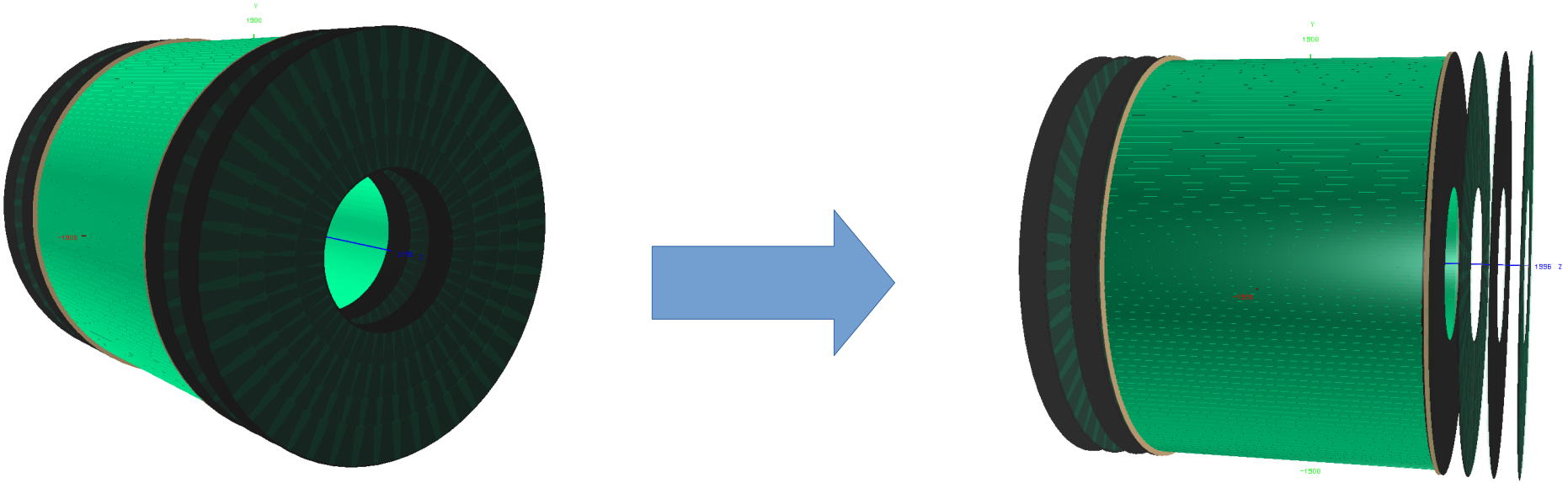
R_out = 190 cm

CLD outer tracker endcap shrinking



Original size:

Z_out/2 = 220 cm

R_out = 215 cm

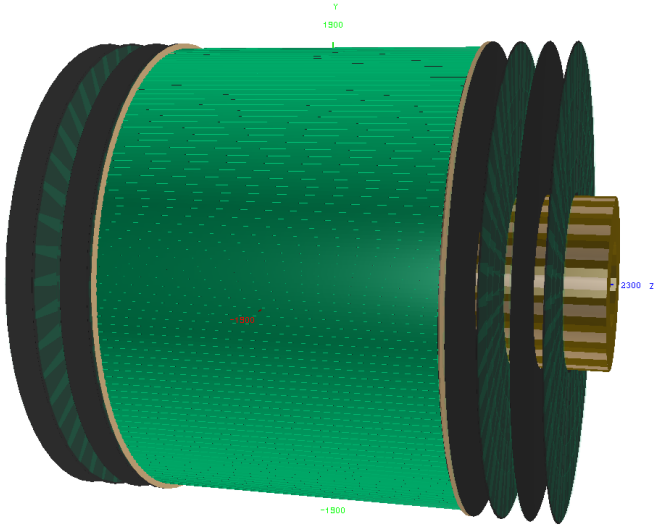
Reduce 23% the inter-layer spaces

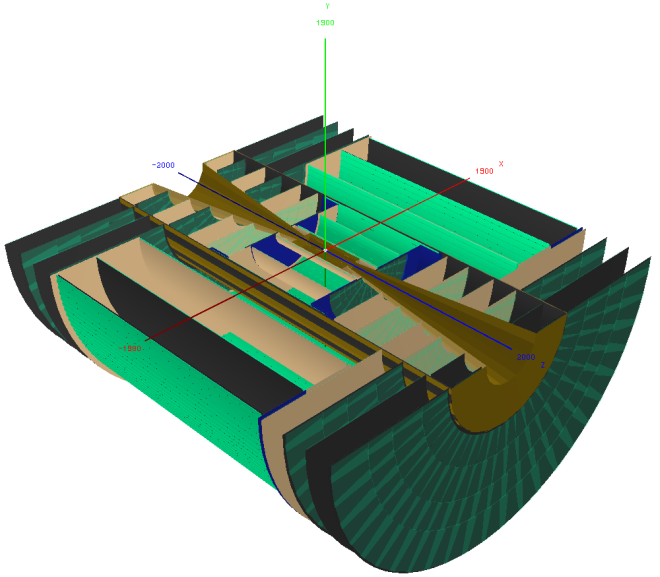
Reduce global length of the tracker

Goal:

Z_out/2 = 200 cm
R_out = 190 cm

CLD inner tracker endcap shrinking





Original size:

Z_out/2 = 220 cm

R_out = 215 cm

Reduce 13% the inter-layer spaces

Reduce inner radius, so the geometrical coverage is kept at 150 mrad (thanks Andre)

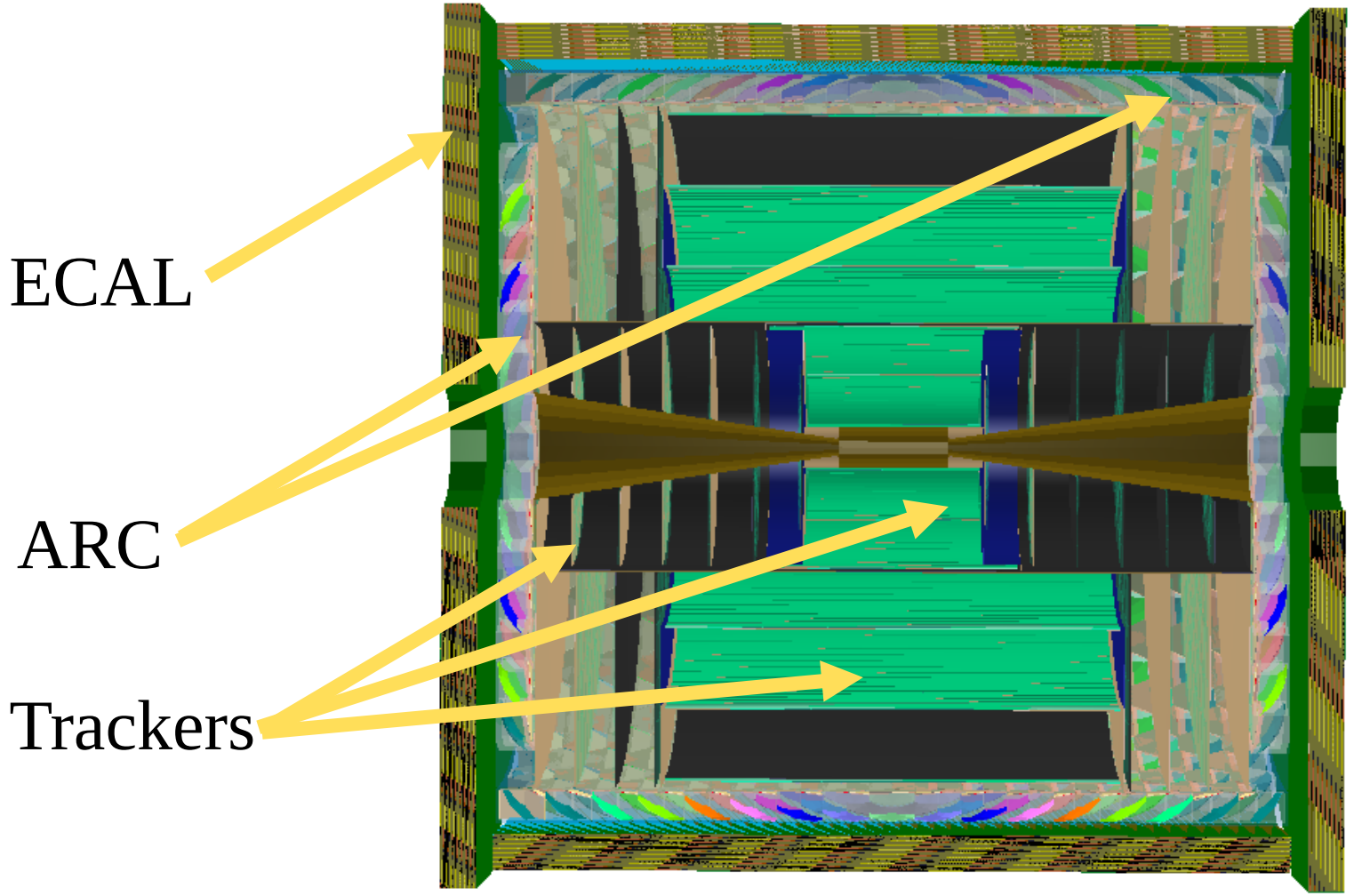
Reduce length of support structure

Goal:

Z_out/2 = 200 cm
R_out = 190 cm

CLD for ARC

CLD is ready to accommodate the ARC detector between the trackers and the ECAL, lets use it in fullsim...



Fullsim of CLD with ARC compared to baseline

Full simulation of the CLD baseline and CLD+ARC was performed using ddsim application provided by DD4hep.

Each simulation output correspond to of 10k events with 1 μ^- @ 1GeV, for different fixed theta angles, as primary particle

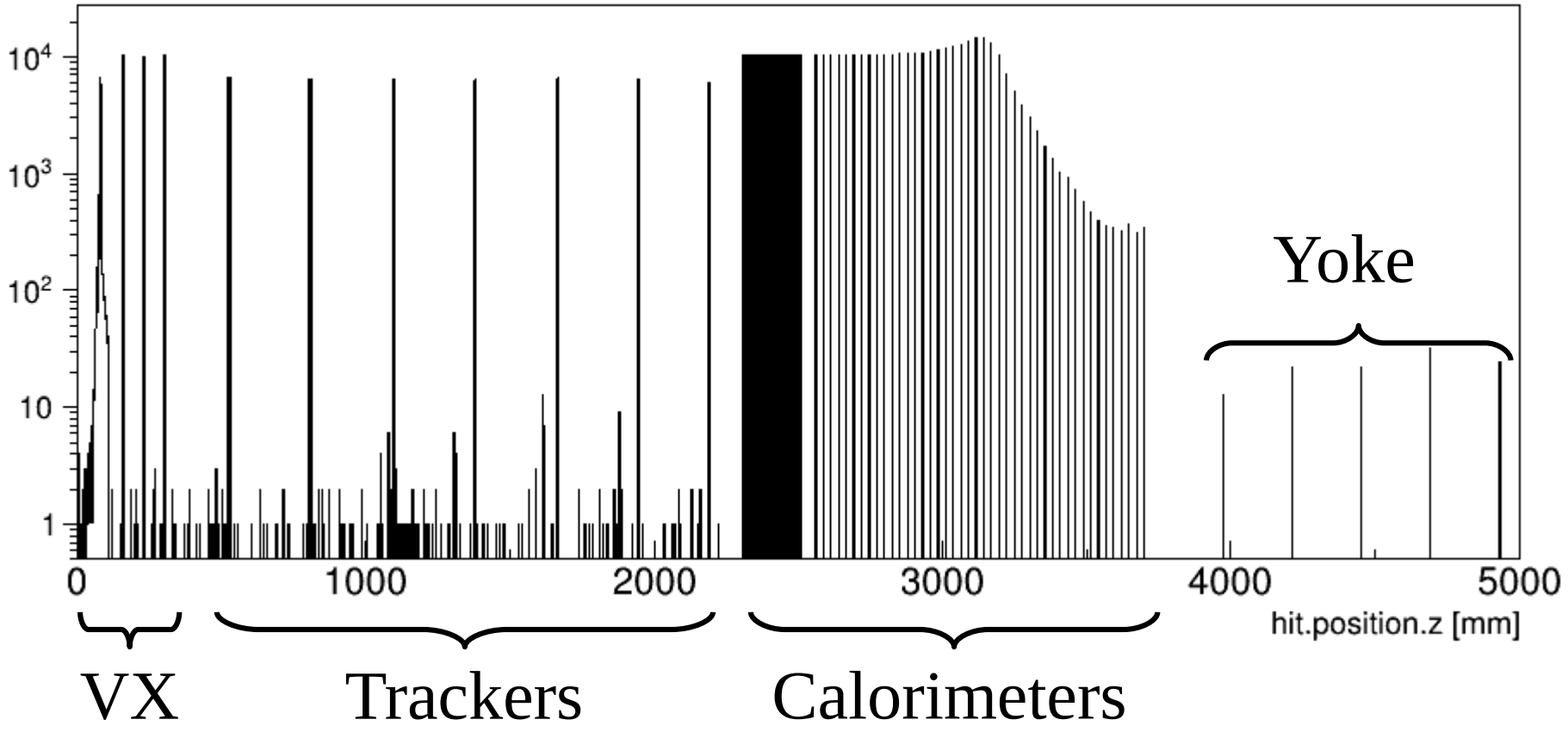
The following slides show the results for θ=10° and θ=90°

The optical photon physics lists was not included, so any hit recorded by ARC corresponds to direct energy deposit into the light sensors

Fullsim of CLD with ARC compared to baseline

Fullsim of CLD baseline (CLD_o2_v05), 10k μ^- @ 1GeV @ θ=10°

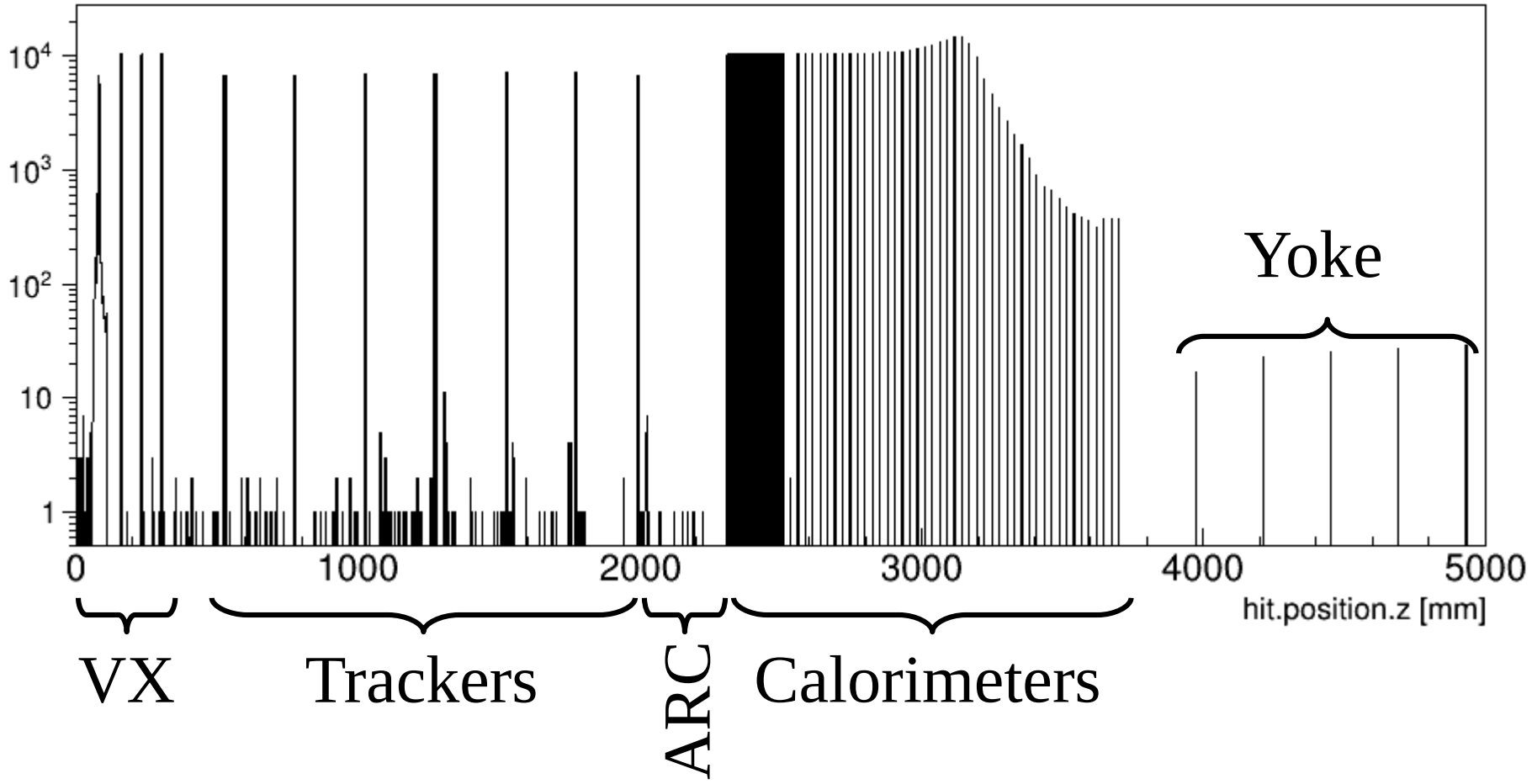
The plot show the Z-position of all hits



Fullsim of CLD with ARC compared to baseline

Fullsim of modified CLD with ARC (CLD_o3_v01), 10k μ^- @ 1GeV @ θ=10°.

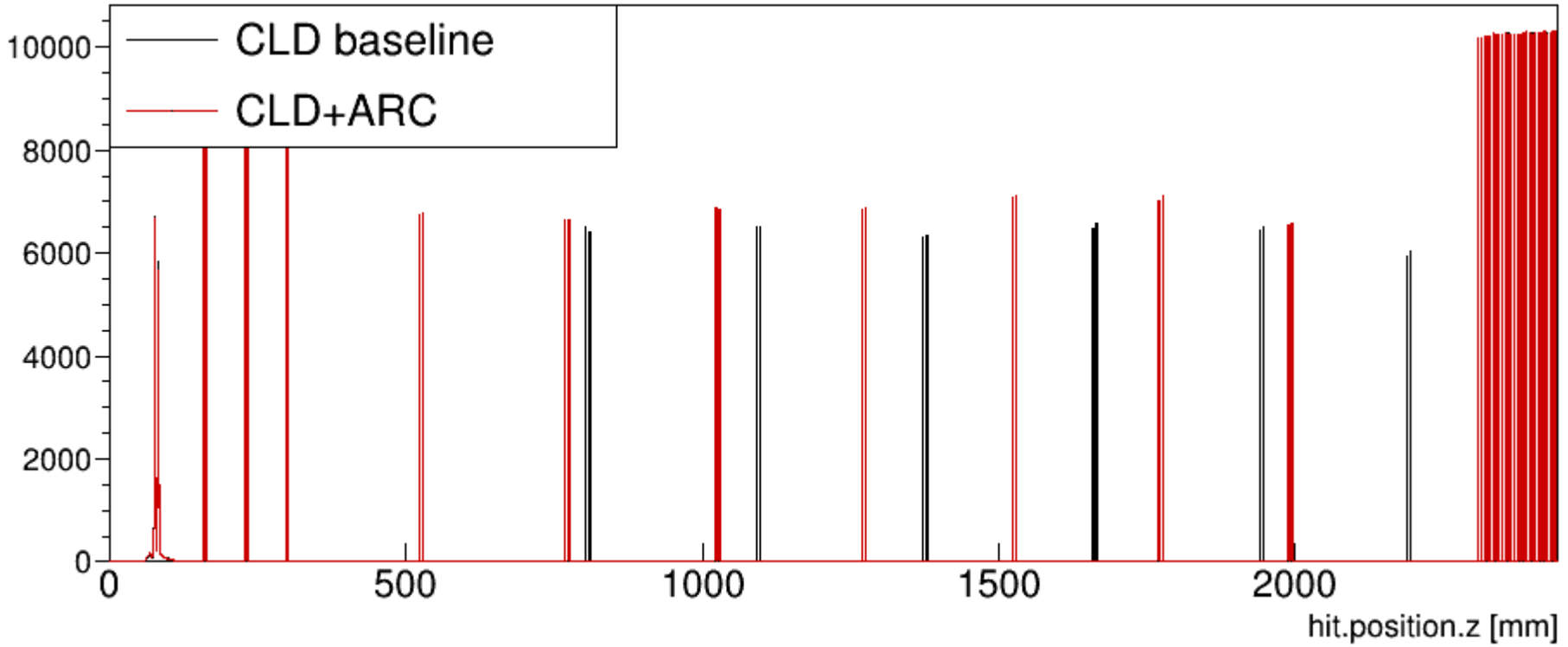
The plot show the Z-position of all hits



Fullsim of CLD with ARC compared to baseline

Open questions:

1. Different number of hits in tracker region. To be checked if it is related to lack of geometrical coverage in trackers after modification to accommodate ARC

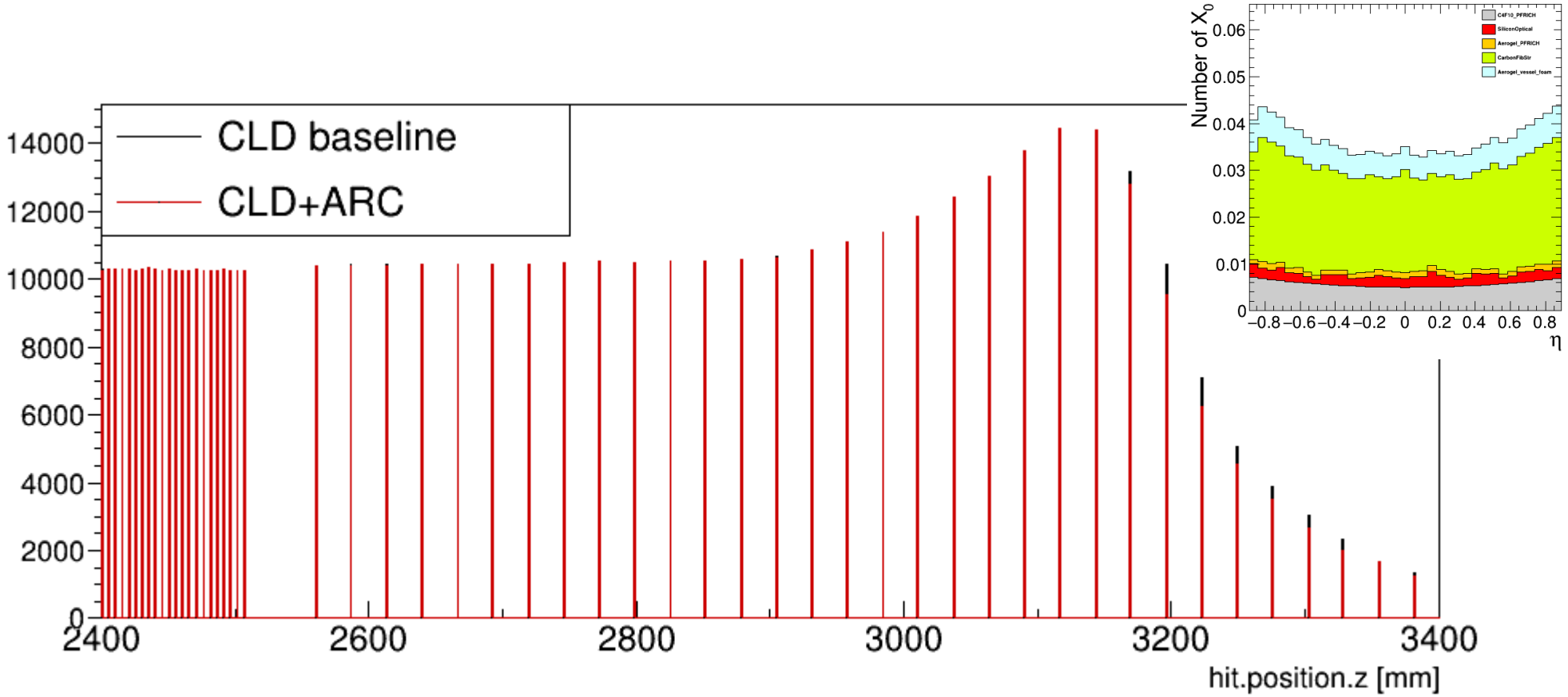


Particle gun: 10k μ^- @ 1GeV @ θ=10°

Fullsim of CLD with ARC compared to baseline

Open questions:

2. Different number of hits in calorimeter region. A comparison with/without ARC showed that this change is caused by a shift in the Bragg peak (see backup slides)

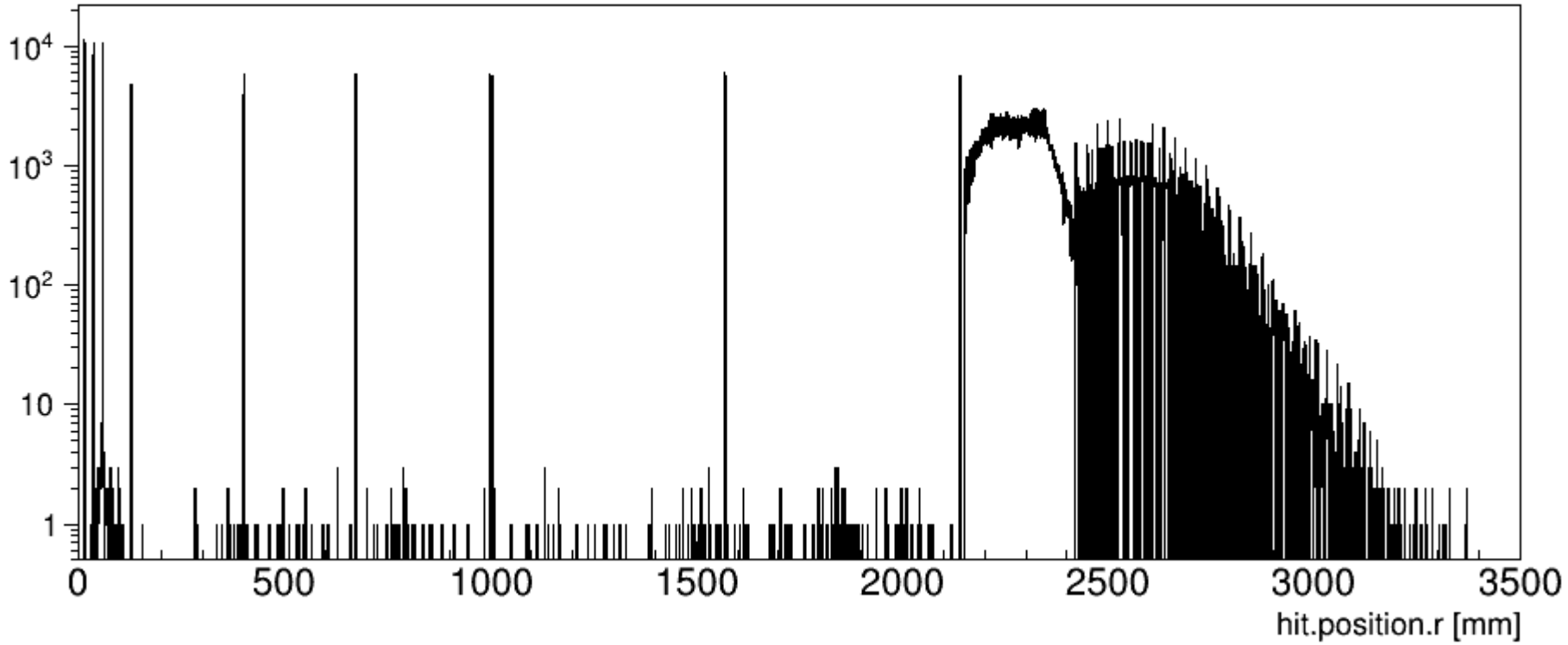


Particle gun: 10k μ^- @ 1GeV @ θ=10°

Fullsim of CLD with ARC compared to baseline

Fullsim of CLD baseline (CLD_o2_v05), 10k μ^- @ 1GeV @ θ=90°

The plot show the distance to Z-axis of all hits

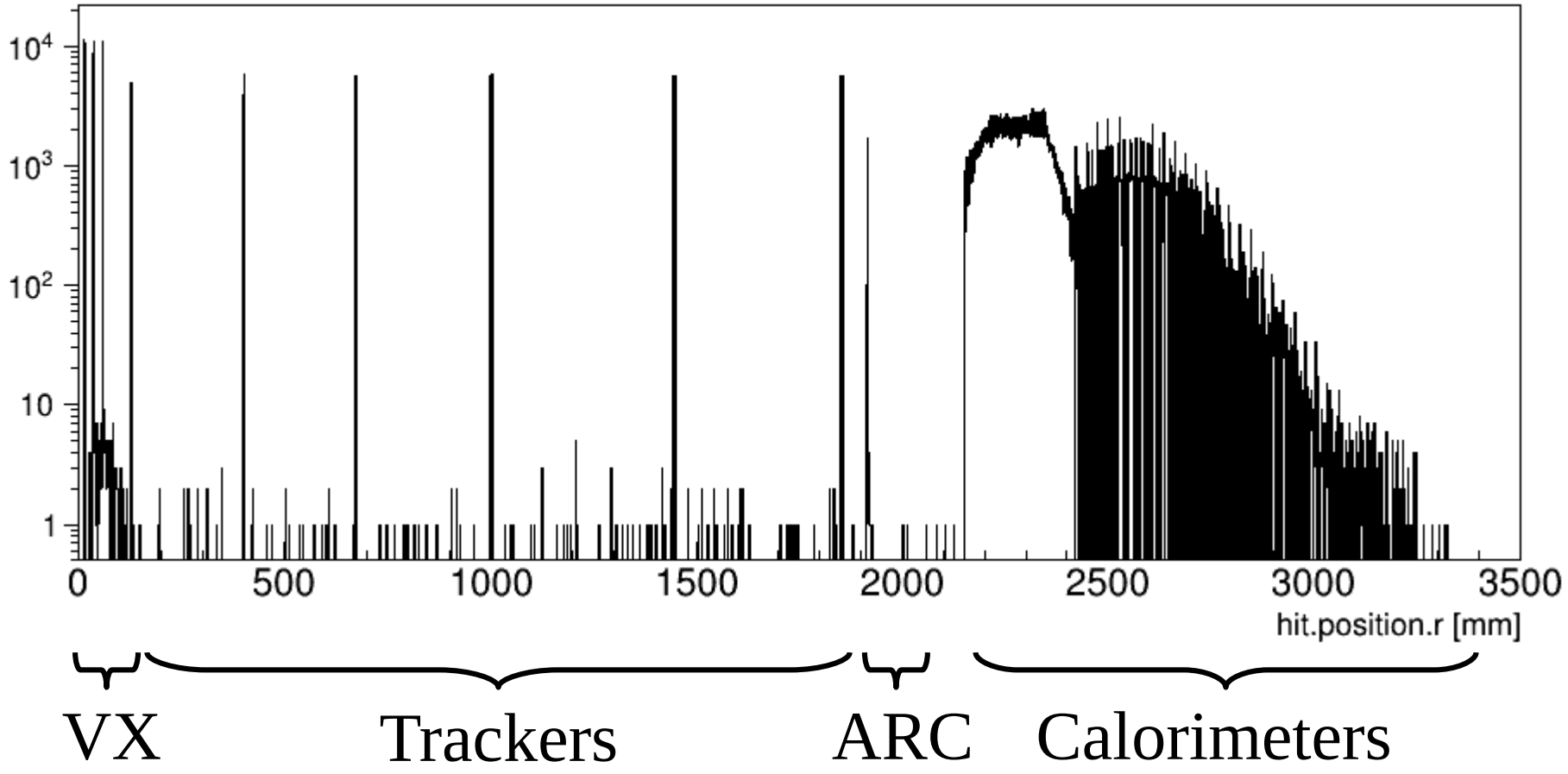


VX Trackers Calorimeters

Fullsim of CLD with ARC compared to baseline

Fullsim of modified CLD with ARC (CLD_o3_v01), 10k μ^- @ 1GeV @ θ=90°

The plot show the distance to Z-axis of all hits



Fullsim of CLD with ARC

Modified CLD with ARC (CLD_o3_v01) is tested by full simulation

Some subtle differences with respect the CLD baseline should be understood before releasing the model, particulary at low θ

Next step is evaluating the PID efficiency of current implementation of ARC

Q: the number of options and versions of detector models is expected to grow, would it be good idea to run systematically simple tests that measure some detector features and prevent unnoticed failures? (a detector that pass the geometrical overlap check still may have a problem) Which features would you suggest to measure systematically?

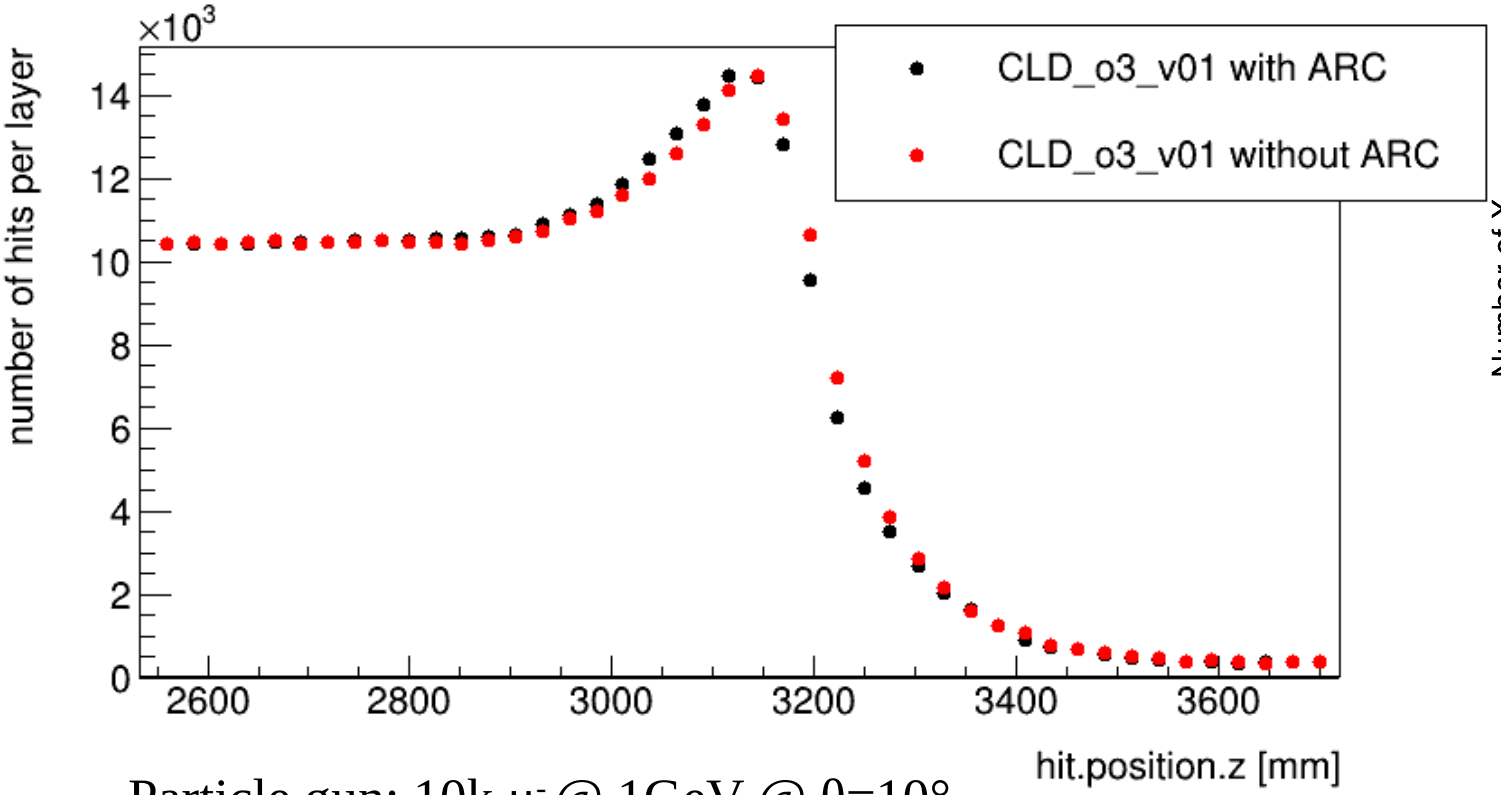
Backup

Effect of ARC in the calorimeters

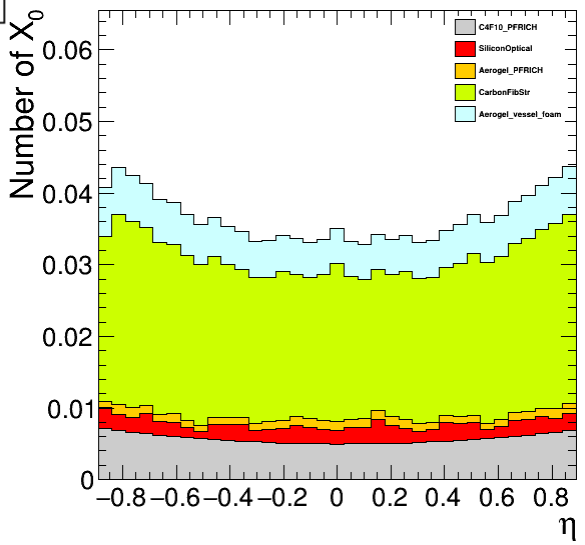
Fullsim of CLD with ARC compared to baseline

The number of hits per layer of the H-Cal Endcap is shown below. The detector concept is in both cases the modified CLD. The difference is the presence/absence of the ARC detector.

The Bragg peak peak shifts 1 layer because of the presence of the ARC



Particle gun: 10k μ^- @ 1GeV @ θ=10°



ARC material budget

Remarks about the detector repository

Detector concepts are stored in k4geo repository

Each concept is described by DD4hep compact files, fully contained inside a directory, named by the concept, option and version

The master compact file has the same name as the directory (+ .xml extension)

The master XML file calls every subdetector compact file

Subdetectors should be implemented in such a way they can be replaced in the master XML file without (big) modifications

Global variables must be placed in the main compact file (not always the case in the current repo, to be improved...)

Envelope geometry of each subdetector (eg, inner/outer radius) must be defined by global constants in the main compact file

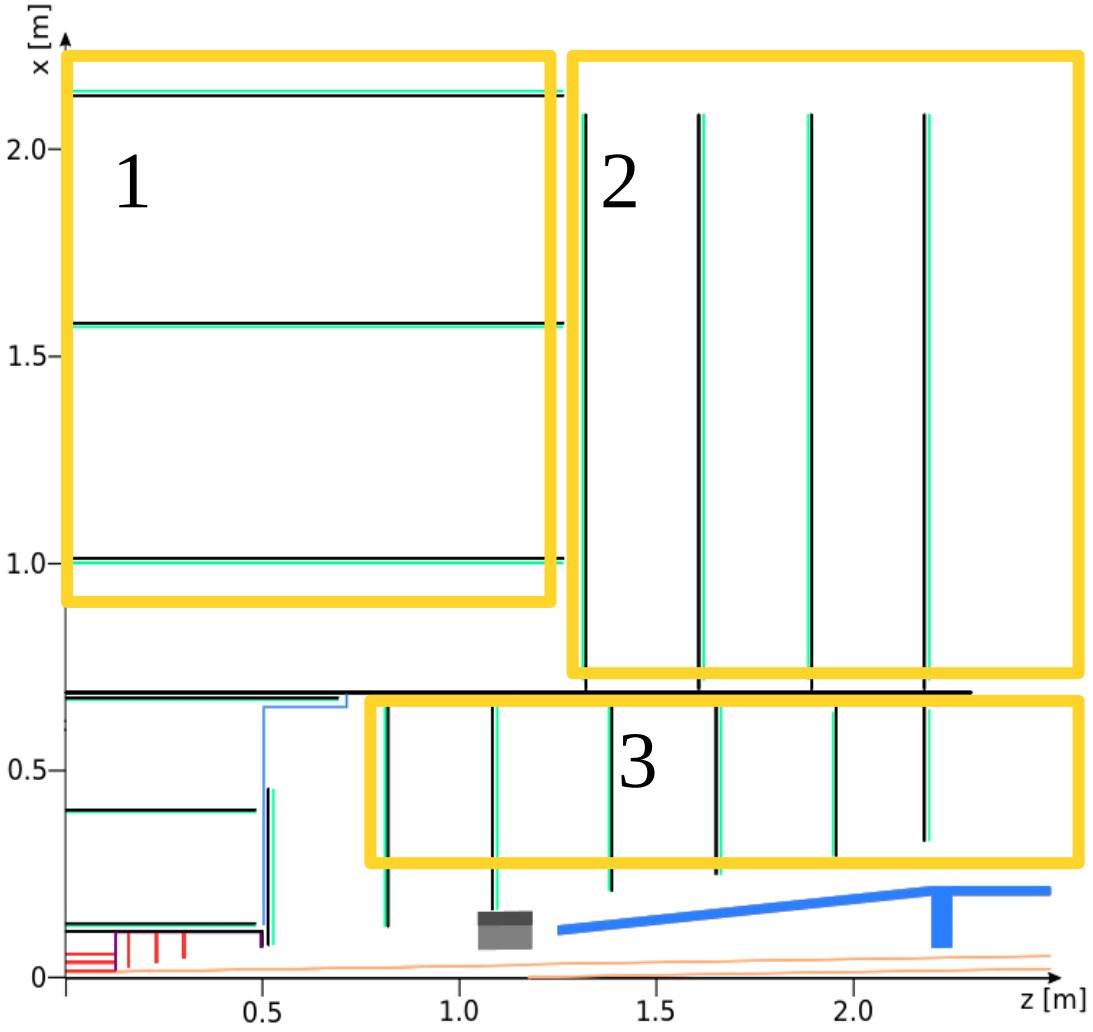
How to adapt CLD to accommodate the ARC detector

CLD tracker parts

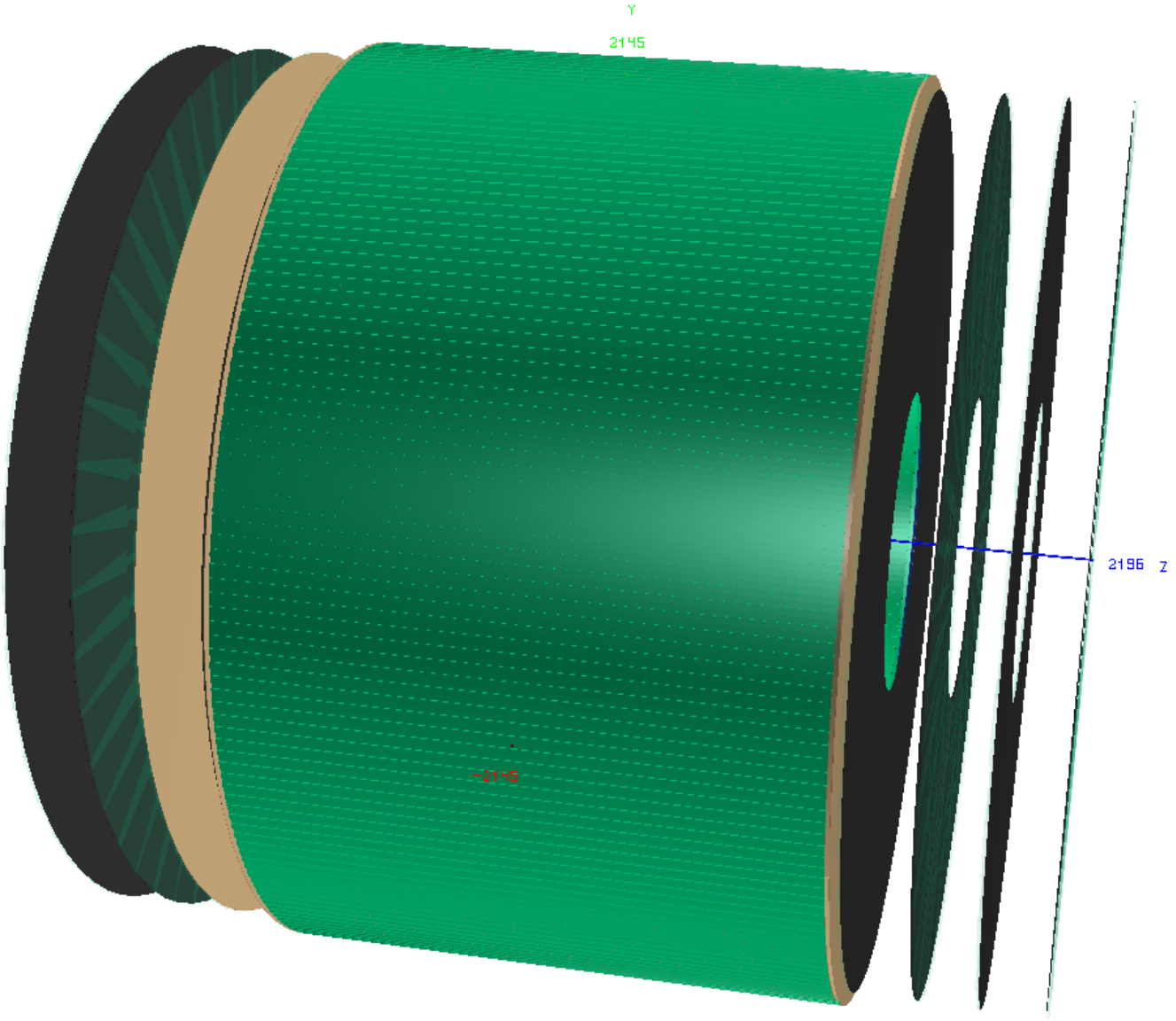
CLD o2 v05 is taken as starting point

The following parts have to be shrunk by 20 cm inwards:

1. Outer tracker barrel
2. Outer tracker endcap
3. Inner tracker endcap



CLD outer tracker original



Original size:

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Goal:

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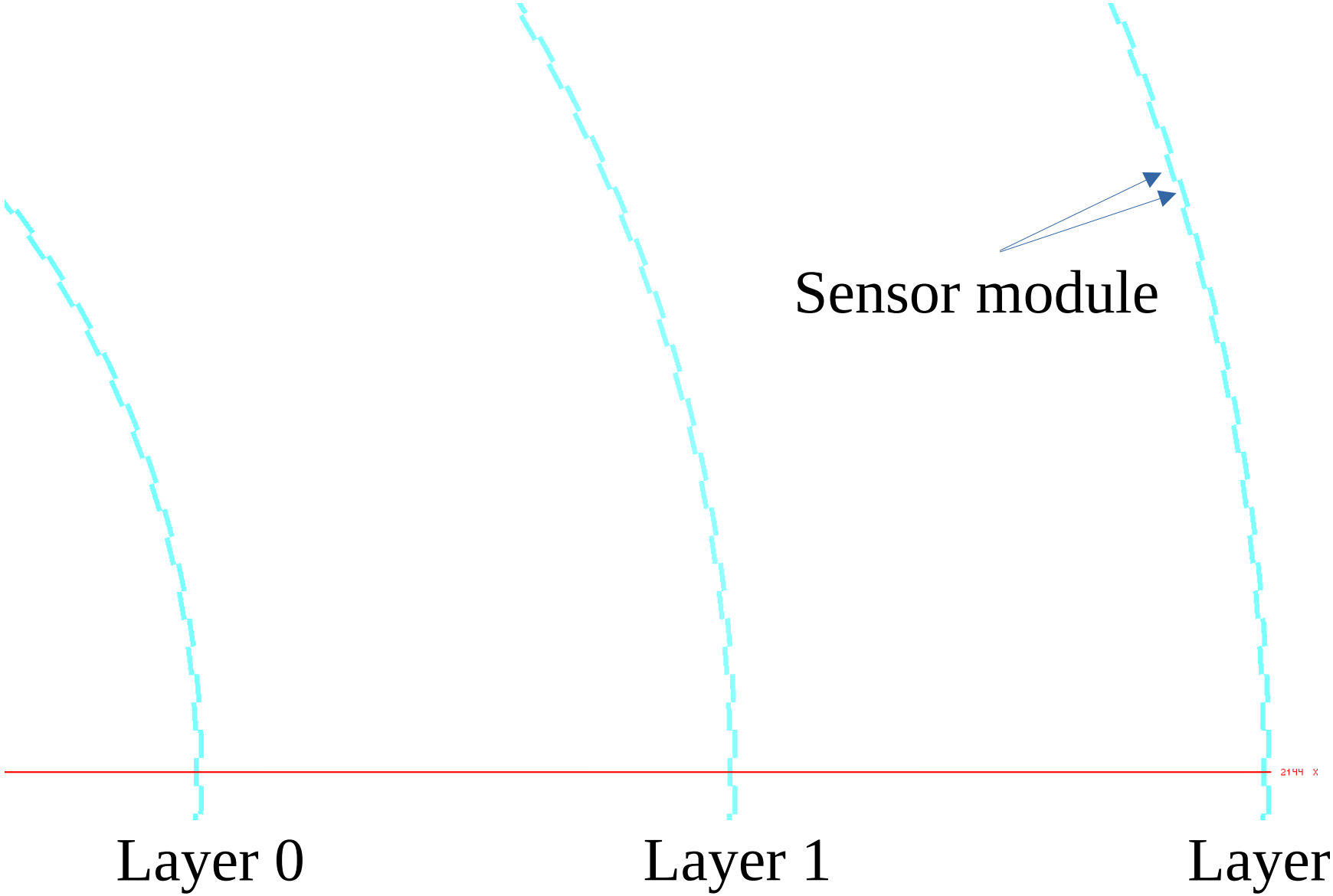
CLD outer tracker barrel



CLD outer tracker barrel

How to determine the number of sensors for a given radius? My approach (not consistent with previous work): change slightly the radius so an integer number of sensors can be fitted inside the ring without overlaps/gaps

```
double sideXY = 30.1; //mm

void OT_bestRadius(double Rin /*in mm*/ ) // return in mm

{std::cout << "nphi = " << floor(2*3.141592*Rin/sideXY) << "\t R = " <<
floor(2*3.141592*Rin/sideXY)*sideXY/(2*3.141592) << "*mm" << std::endl;}
```

OT_bestRadius(1450 /*mm*/)

nphi = 302 R = 1446.75*mm

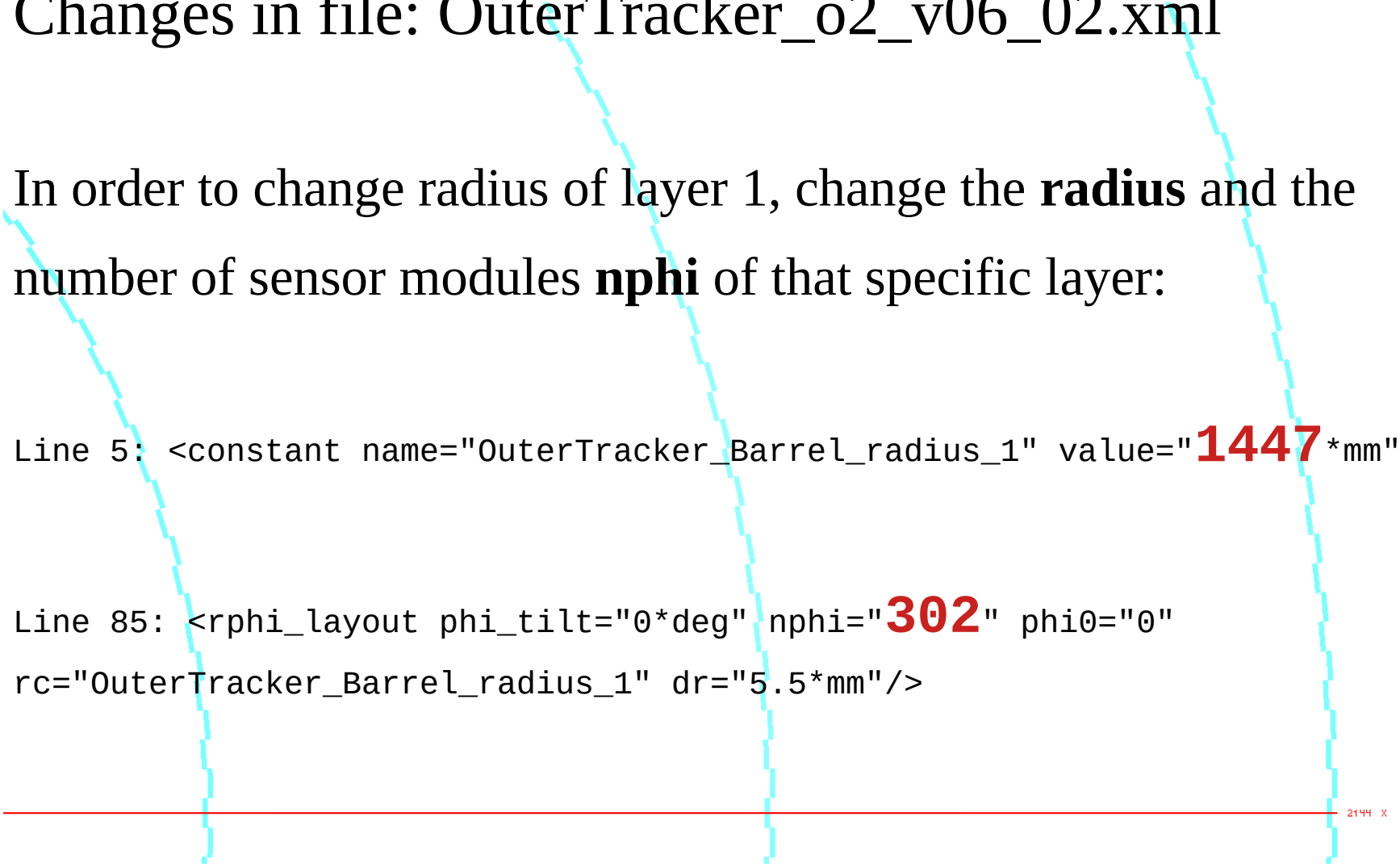
CLD outer tracker barrel

Changes in file: OuterTracker_o2_v06_02.xml

In order to change radius of layer 1, change the **radius** and the number of sensor modules **nphi** of that specific layer:

```
Line 5: <constant name="OuterTracker_Barrel_radius_1" value="1447*mm"/>

Line 85: <rphi_layout phi_tilt="0*deg" nphi="302" phi0="0"
rc="OuterTracker_Barrel_radius_1" dr="5.5*mm"/>
```



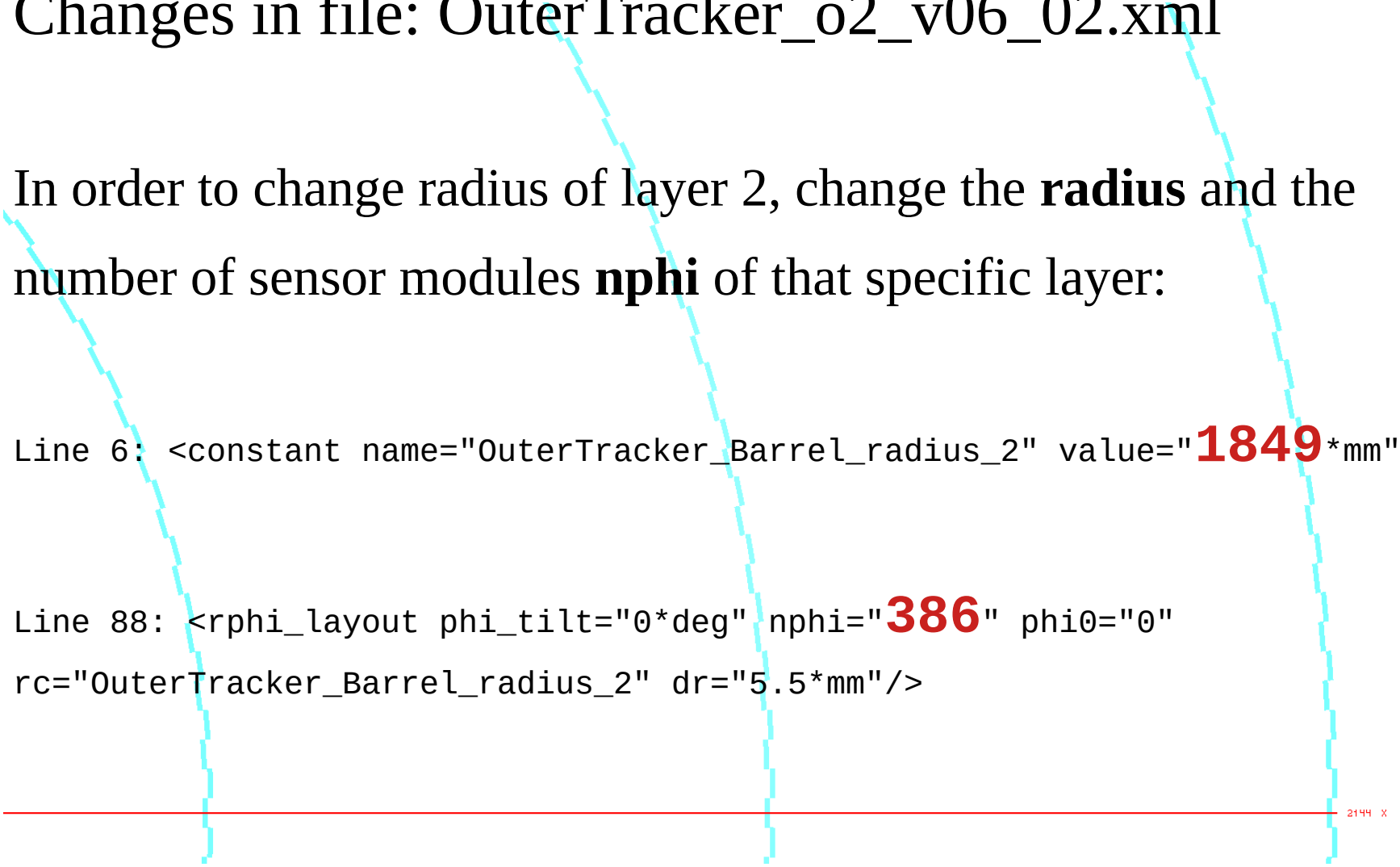
CLD outer tracker barrel

Changes in file: OuterTracker_o2_v06_02.xml

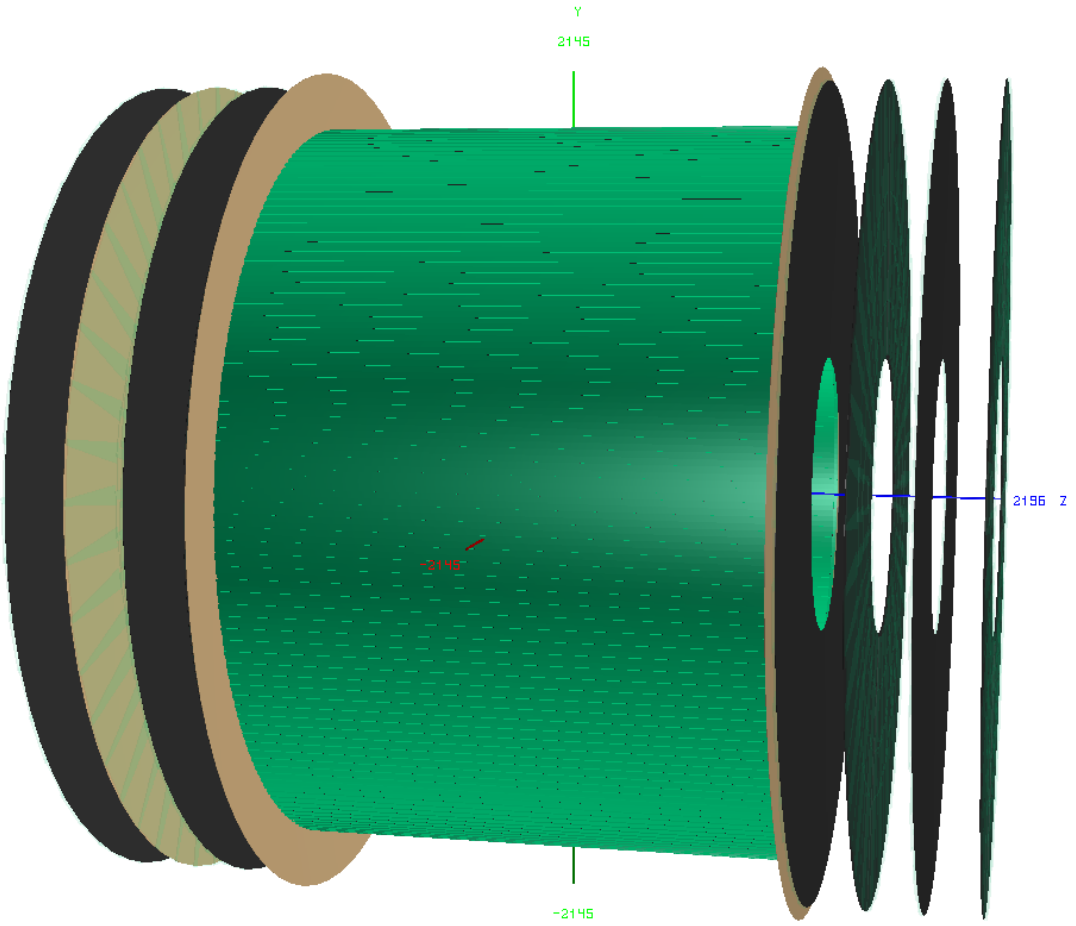
In order to change radius of layer 2, change the **radius** and the number of sensor modules **nphi** of that specific layer:

```
Line 6: <constant name="OuterTracker_Barrel_radius_2" value="1849*mm"/>

Line 88: <rphi_layout phi_tilt="0*deg" nphi="386" phi0="0"
rc="OuterTracker_Barrel_radius_2" dr="5.5*mm"/>
```



CLD outer tracker barrel



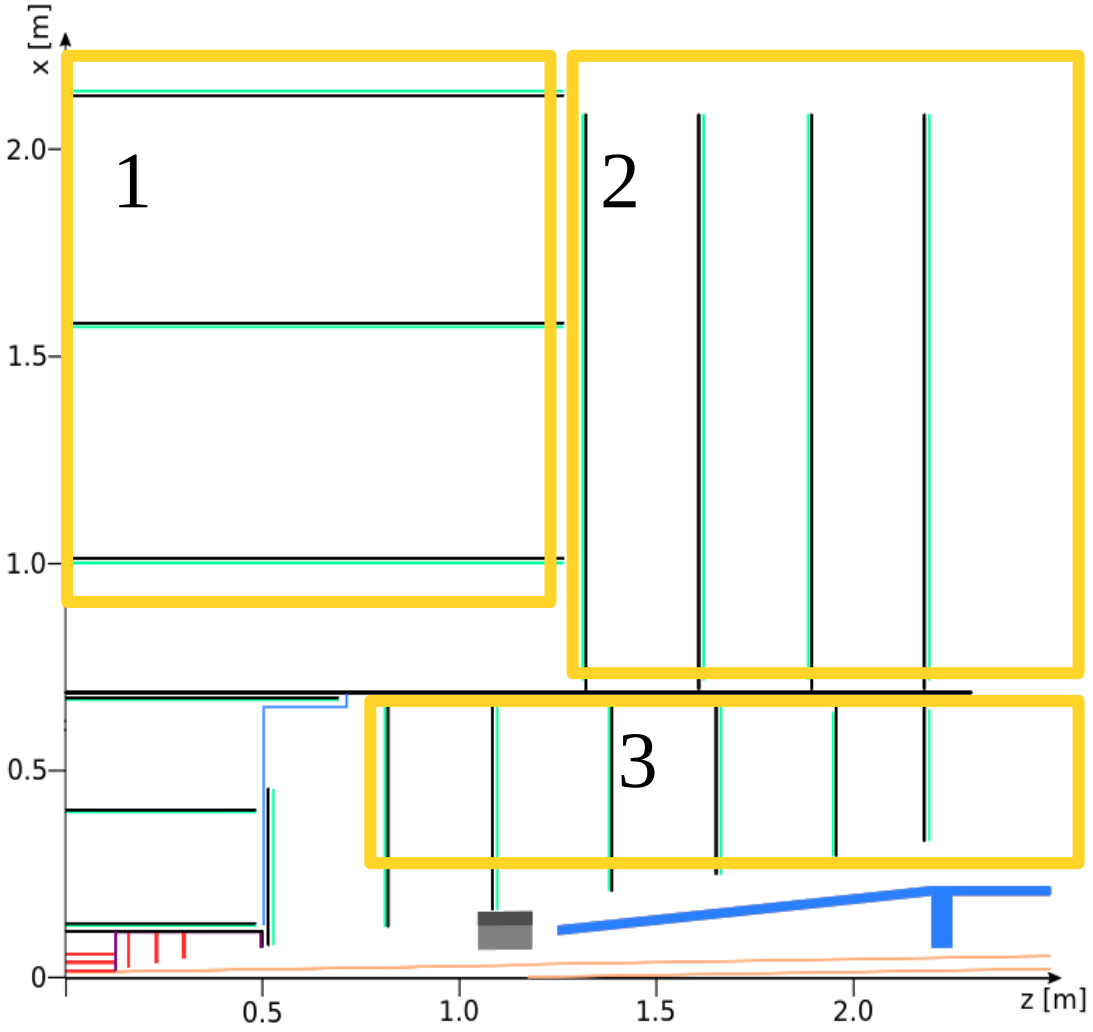
After shrinking the OT barrel...

CLD tracker parts

CLD o2 v05 is taken as starting point

The following parts have to be shrunk by 20 cm inwards:

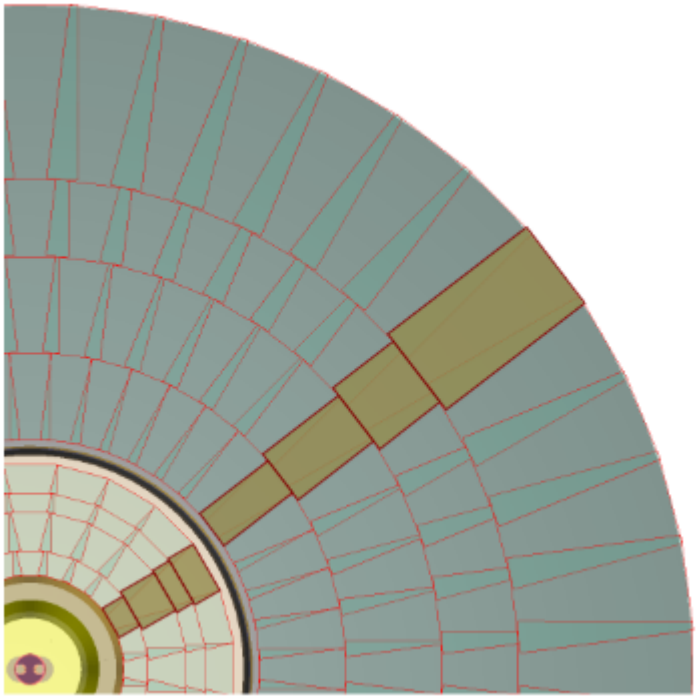
1. Outer tracker barrel
2. **Outer tracker endcap**
3. Inner tracker endcap

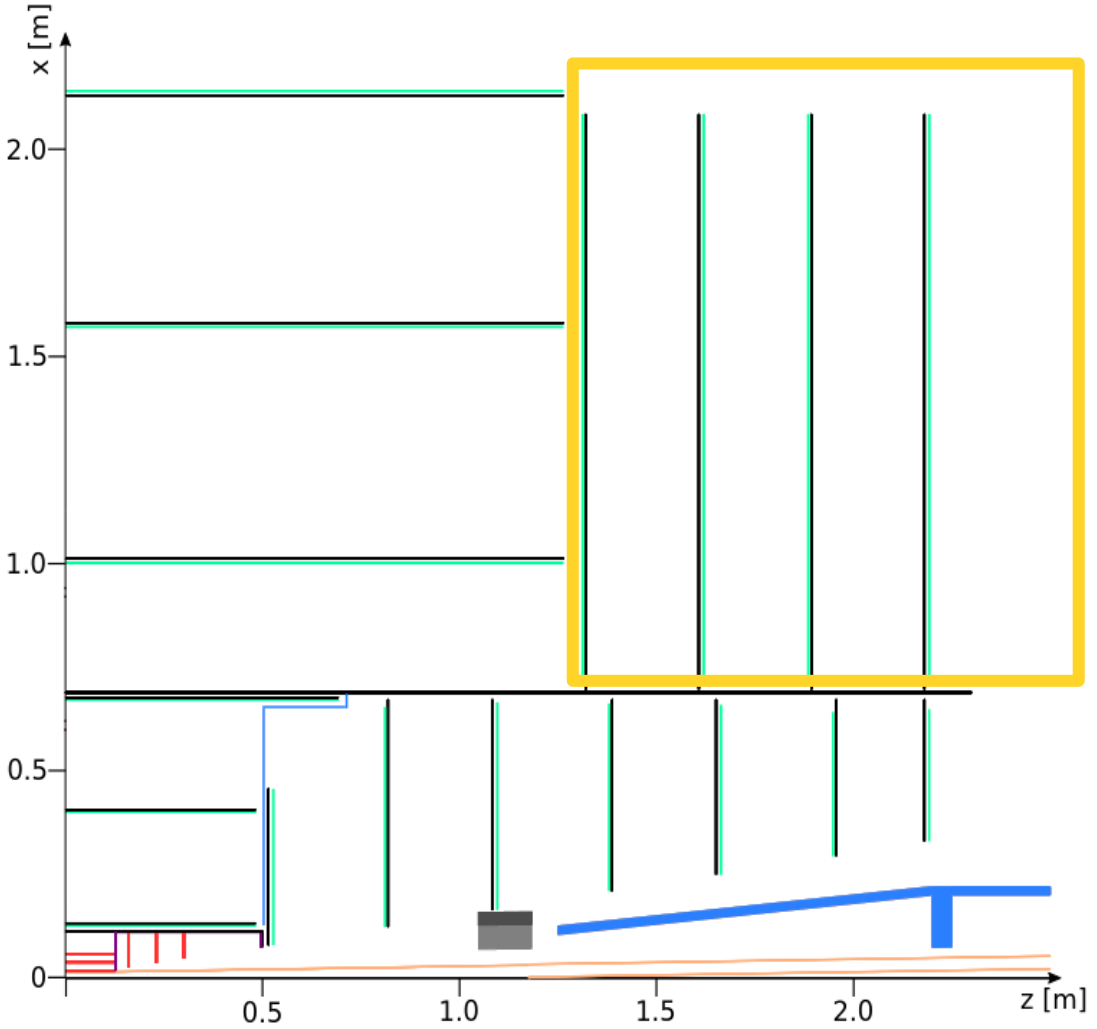


CLD outer tracker endcap

The radius of outer tracker endcap must be reduced by 20 cm

Layer z position must move closer to z=0





CLD outer tracker endcap

The radius of outer tracker endcap must be reduced by 20 cm

|→ Solution: reduce outer tracker envelope radius

In main compact file, CLD_oX_v0Y.xml:

```
        <constant name="OuterTracker_outer_radius" value="1900*mm" />  <!-- to avoid overlap with
```

CLD outer tracker endcap

The radius of outer tracker endcap must be reduced by 20 cm

|→ Solution: reduce outer tracker envelope radius

|→ Solution: reduce support structure radius

In tracker compact file:

Change support structure radius

```
<constant name="OuterTracker_Endcap_outer_radius" value="1900*mm"/>
```

CLD outer tracker endcap

The radius of outer tracker endcap must be reduced by 20 cm

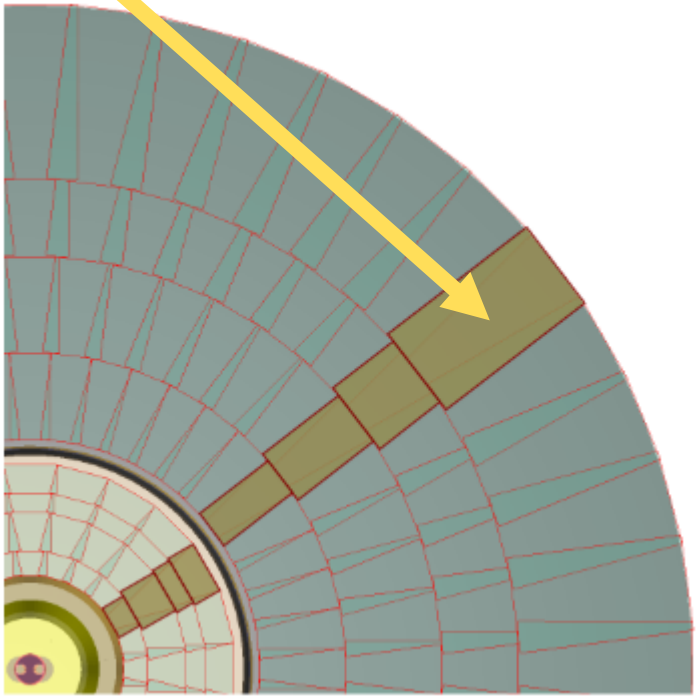
|→ .....

|→ Solution: reduce Y-size of the last ring module

In tracker compact file:

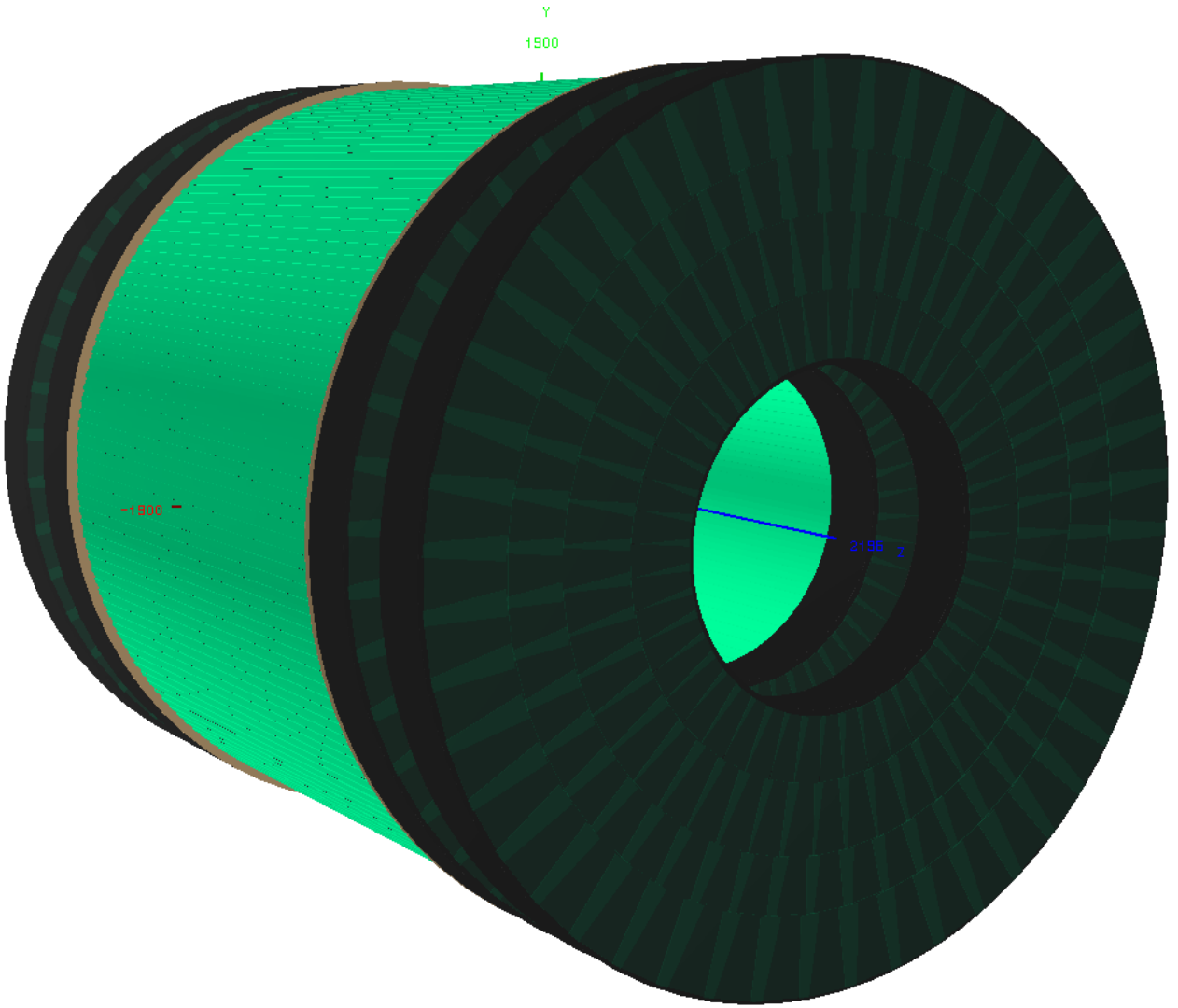
```
 <module name="OuterTrackerEndcapModule_3_In"
vis="OuterTrackerModuleVis"> <trd x="300*mm"
y="349.4*mm"/> <include
ref="TrackerDiskModuleIn.xml"/> </module>

<module name="OuterTrackerEndcapModule_3_Out"
vis="OuterTrackerModuleVis"> <trd x="300*mm"
y="349.4*mm"/> <include
ref="TrackerDiskModuleOut.xml"/> </module>
```



CLD outer tracker endcap

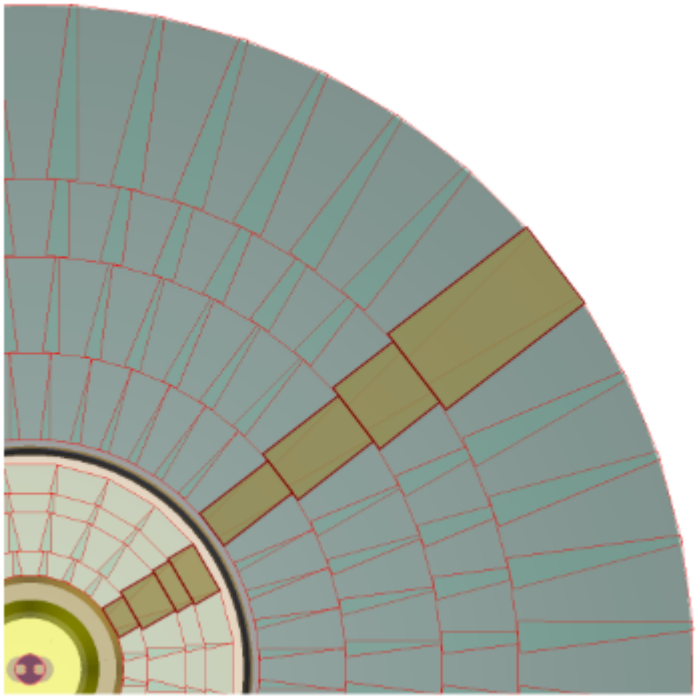
Resulting radius: 190 cm

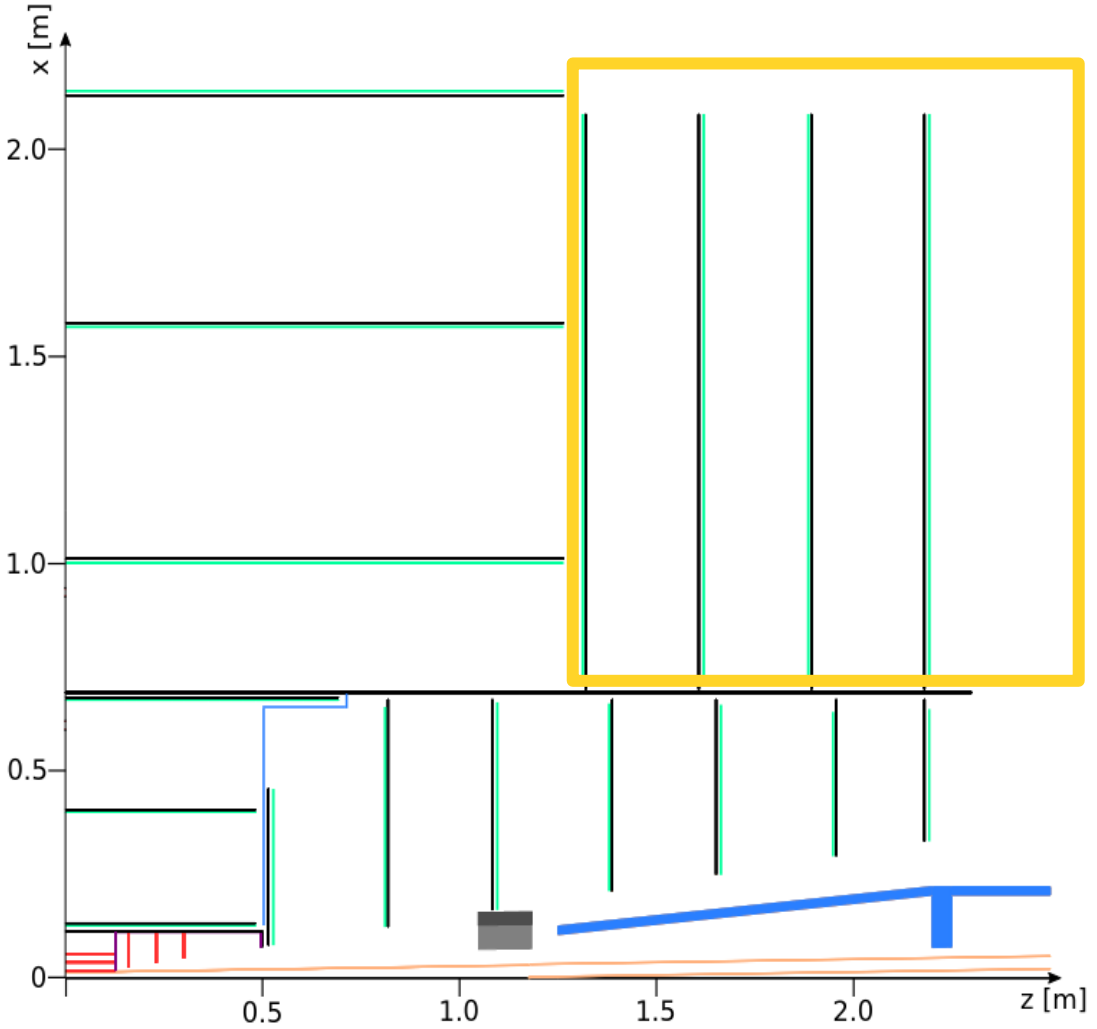


CLD outer tracker endcap

The radius of outer tracker endcap must be reduced by 20 cm

Layer z position must move closer to z=0





CLD outer tracker endcap

Layer z position must move closer to z=0 by 20cm

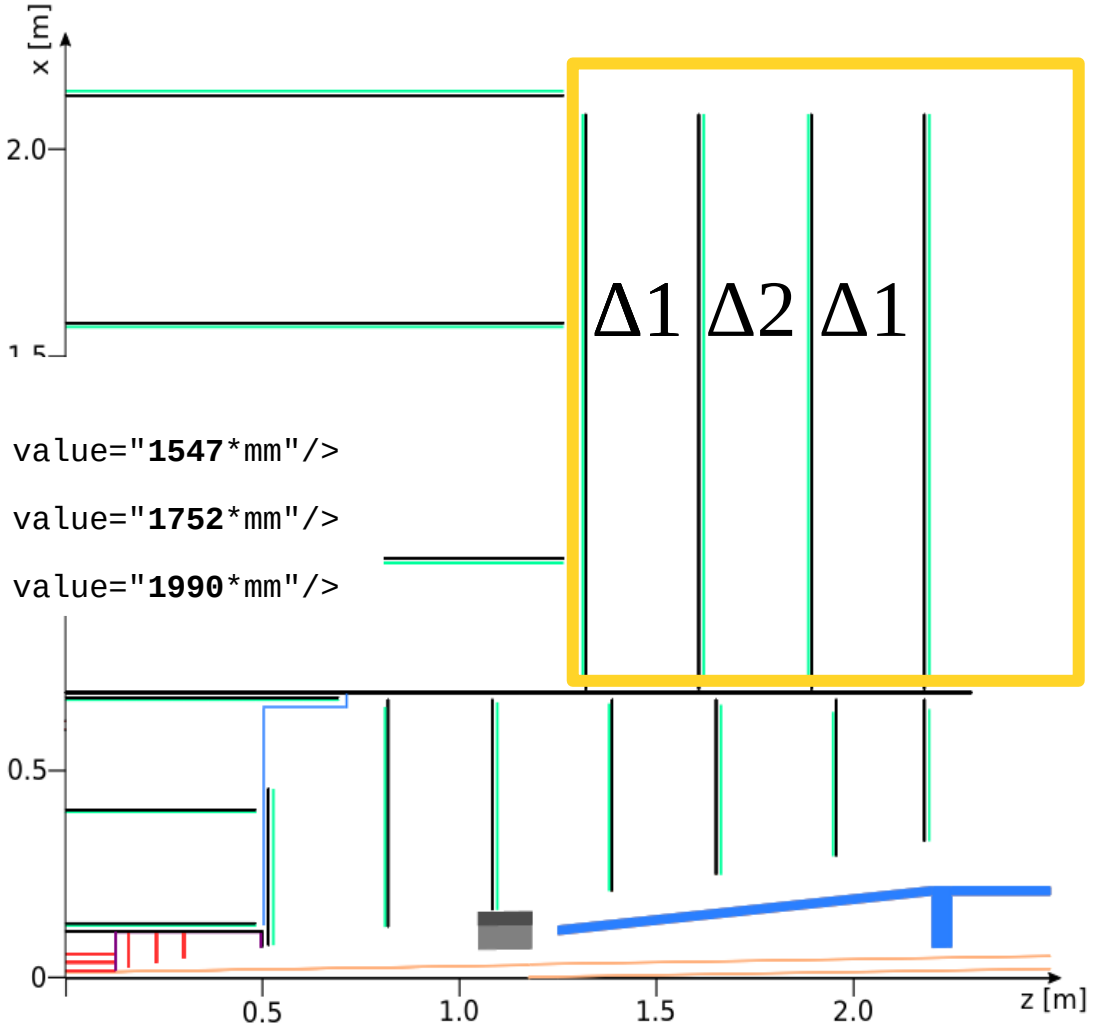
|→ Solution: reduce 23% the inter-spaces Δ1 and Δ2,

by changing the position

Of layer 1,2,3 (0 stays)

In the outer tracker compact file:

```
<constant name="OuterTracker_Endcap_z_1" value="1547*mm"/>
<constant name="OuterTracker_Endcap_z_2" value="1752*mm"/>
<constant name="OuterTracker_Endcap_z_3" value="1990*mm"/>
```



CLD outer tracker endcap

Layer z position must move closer to z=0 by 20cm

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Of layer 1,2,3 (0 stays)

In the outer tracker compact file:

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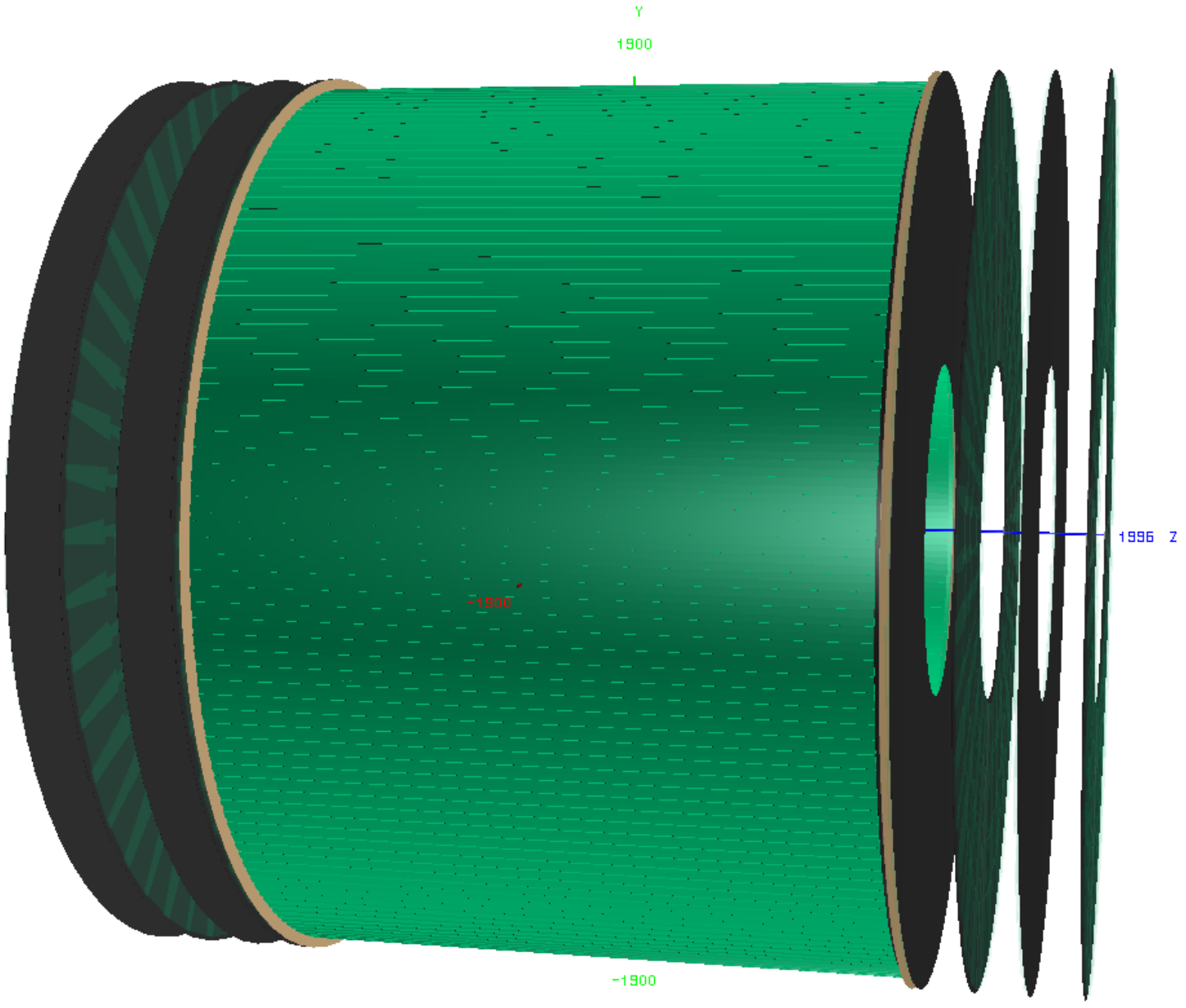
<constant name="OuterTracker_Endcap_z_2" value="1752*mm"/>
<constant name="OuterTracker_Endcap_z_3" value="1990*mm"/>
```

|→ And reduce the global length of the outer tracker

In the main compact file:

```
<constant name="OuterTracker_half_length" value="2000*mm" />
```

CLD outer tracker after these changes



CLD tracker parts

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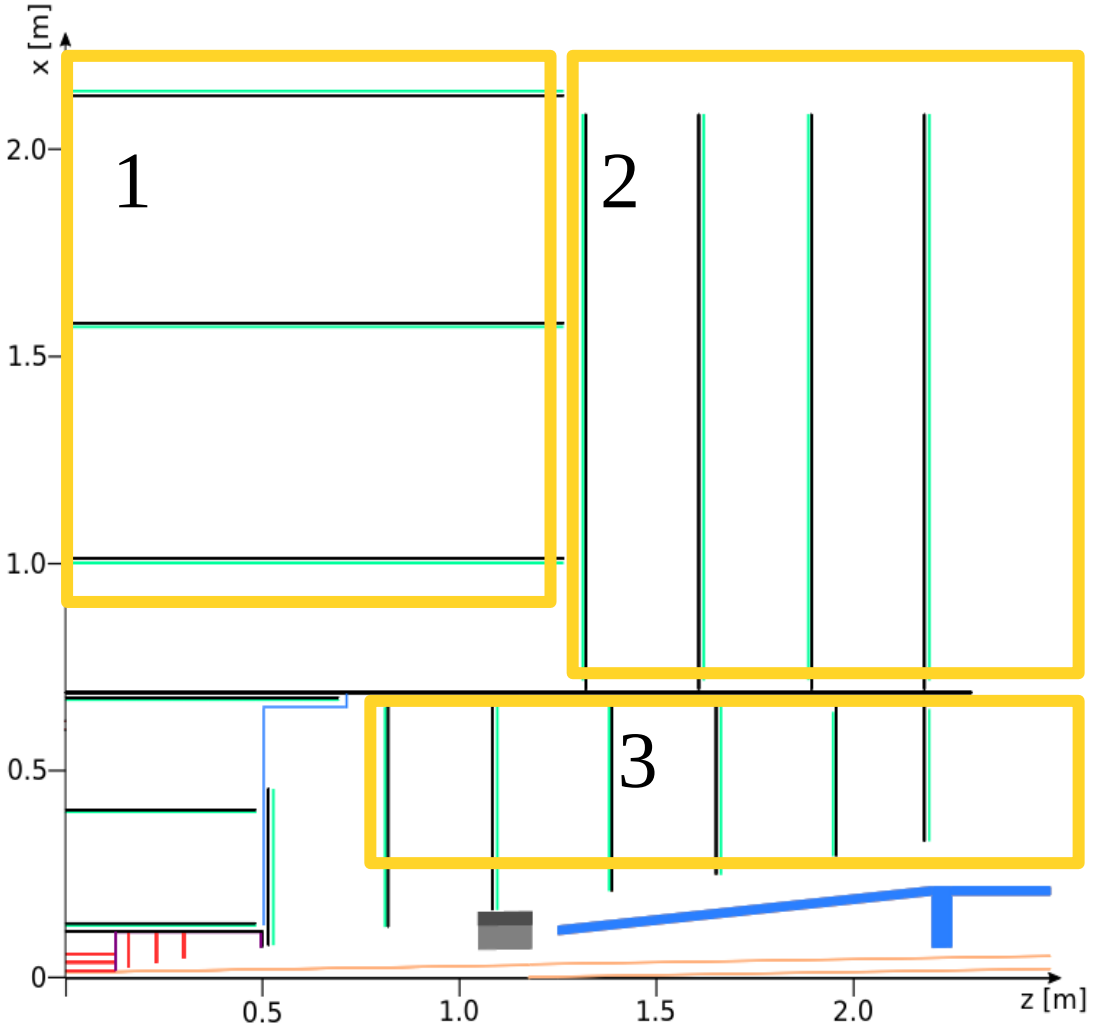
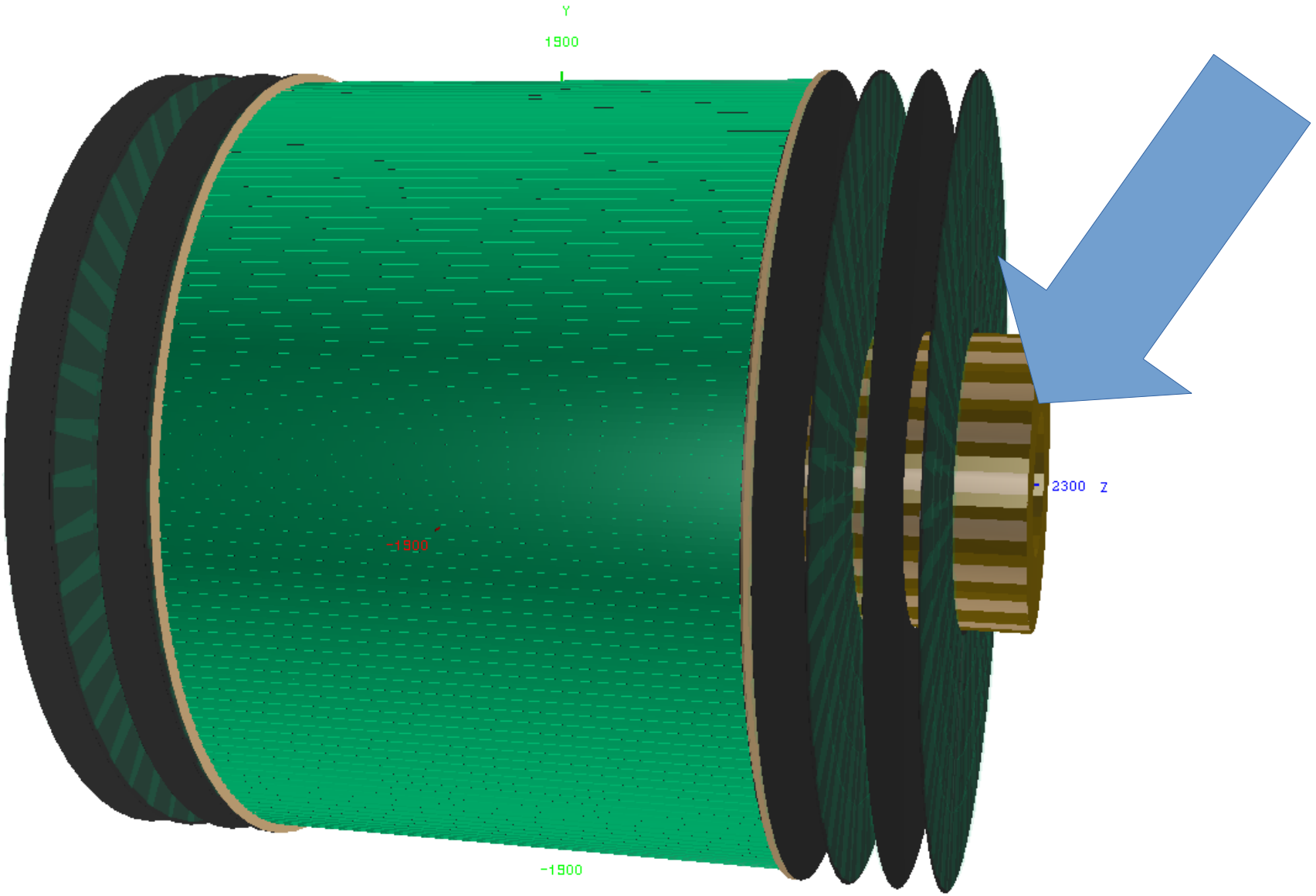
2. Outer tracker endcap
3. **Inner tracker endcap**



CLD inner tracker endcap



CLD inner tracker endcap

Layer z positions must move closer to z=0
|→ Solution: reduce the inter-space by 13%

In the inner tracker compact file change:

<constant name="InnerTracker_Endcap_z_0" value="524*mm" />

<constant name="InnerTracker_Endcap_z_1" value="773*mm" />

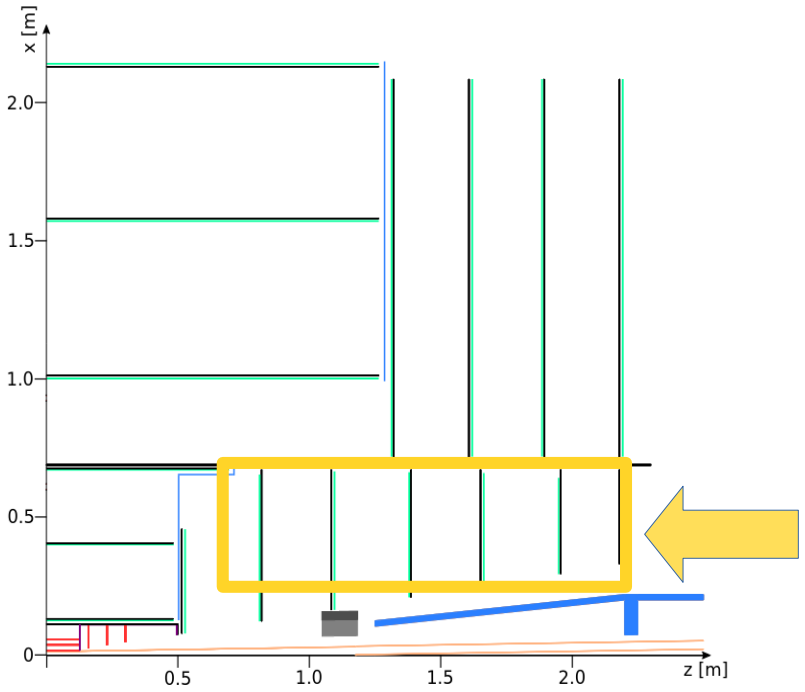
<constant name="InnerTracker_Endcap_z_2" value="1024*mm" />

<constant name="InnerTracker_Endcap_z_3" value="1274*mm" />

<constant name="InnerTracker_Endcap_z_4" value="1524*mm" />

<constant name="InnerTracker_Endcap_z_5" value="1775*mm" />

<constant name="InnerTracker_Endcap_z_6" value="1990*mm" />



CLD inner tracker endcap

Layer z positions must move closer to z=0

|→ Solution: reduce the inter-space by 13%

|→ Along with the z position change we would need to reduce the inner radius accordingly to stay close to the 150 mrad coverage

In the inner tracker compact file change:

<constant name="InnerTracker_Endcap_radius_1" value="117*mm" />

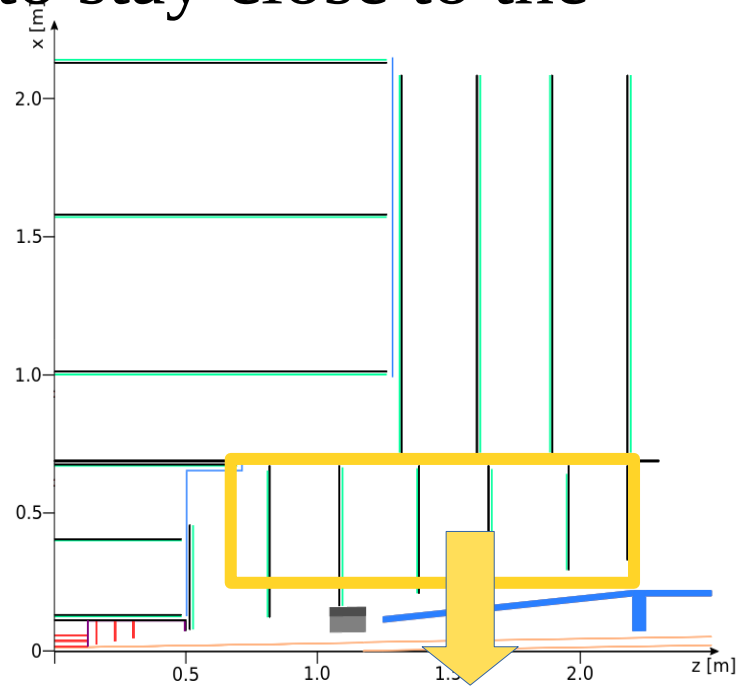
<constant name="InnerTracker_Endcap_radius_2" value="154.6*mm" />

<constant name="InnerTracker_Endcap_radius_3" value="192.4*mm" />

<constant name="InnerTracker_Endcap_radius_4" value="230.1*mm" />

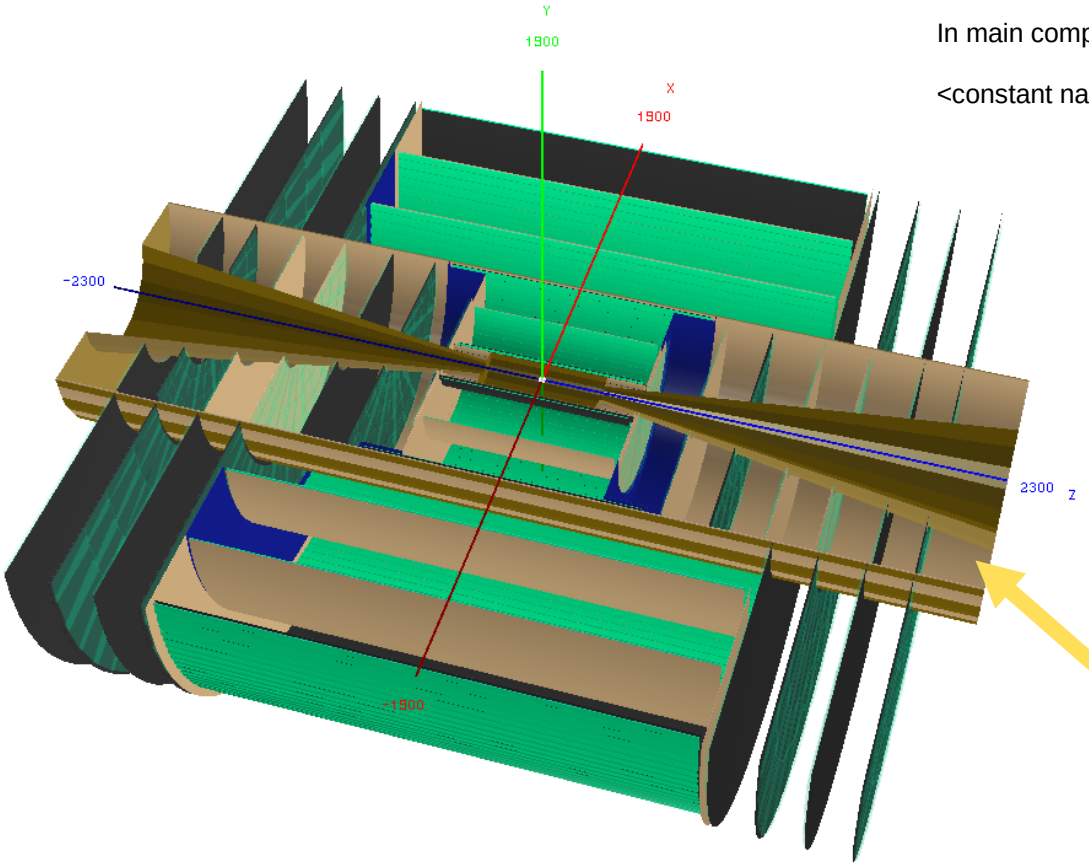
<constant name="InnerTracker_Endcap_radius_5" value="268*mm" />

<constant name="InnerTracker_Endcap_radius_6" value="300.5*mm" />



CLD inner tracker endcap

The support structure still extends for z>2m



In main compact CLD_oX_v0Y file, change

<constant name="InnerTracker_half_length" value="2000*mm" />

Support structure

CLD for ARC

After these modifications, CLD is ready to accommodate the ARC detector between the trackers and the ECAL