Mahmoud Ali

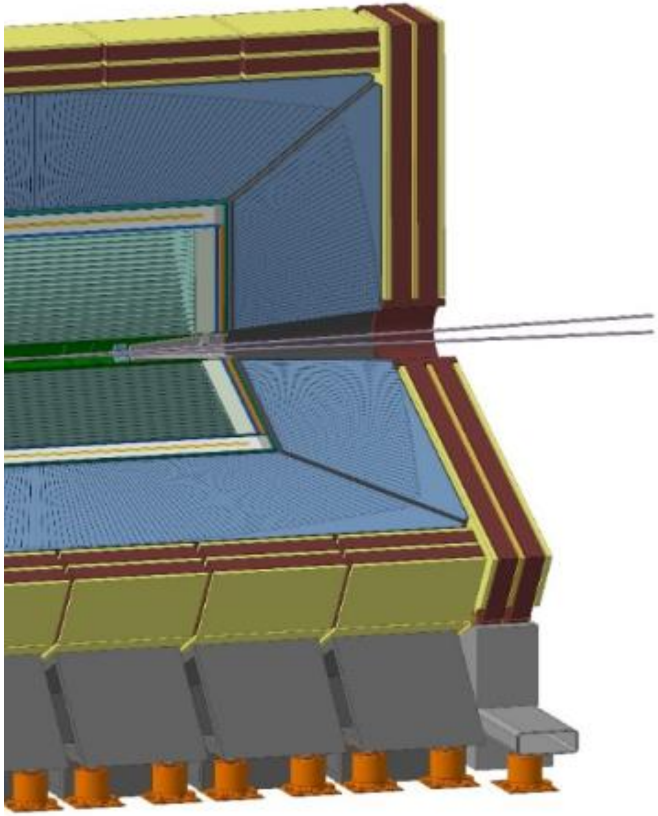
FULL SIMULATION OF IDEA MUON SYSTEM

R&D-FCC Meeting, 15 Febraury 2024.

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

INFN Istituto Nazionale di Fisica Nucleare

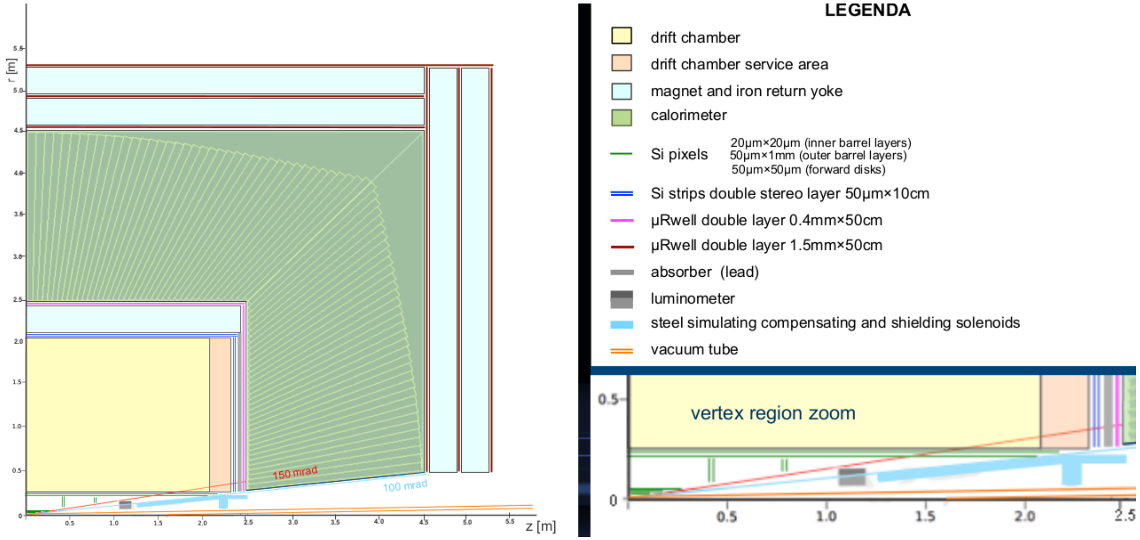
FUTURE CIRCULAR COLLIDER



IDEA Detector:

IDEA detector concept foresees a **muon detection system** and **pre-shower** that would be realized using the μRWELL[1] technology.

Each station will consist of a large mosaic of 50 × 50 cm^2 μRWELL detectors.



IDEA detector layout

[1]JINST 10 (2015), P02008.

Full simulation:

Full simulation of IDEA is being done using two software packages:

Standalone **GEANT4**:

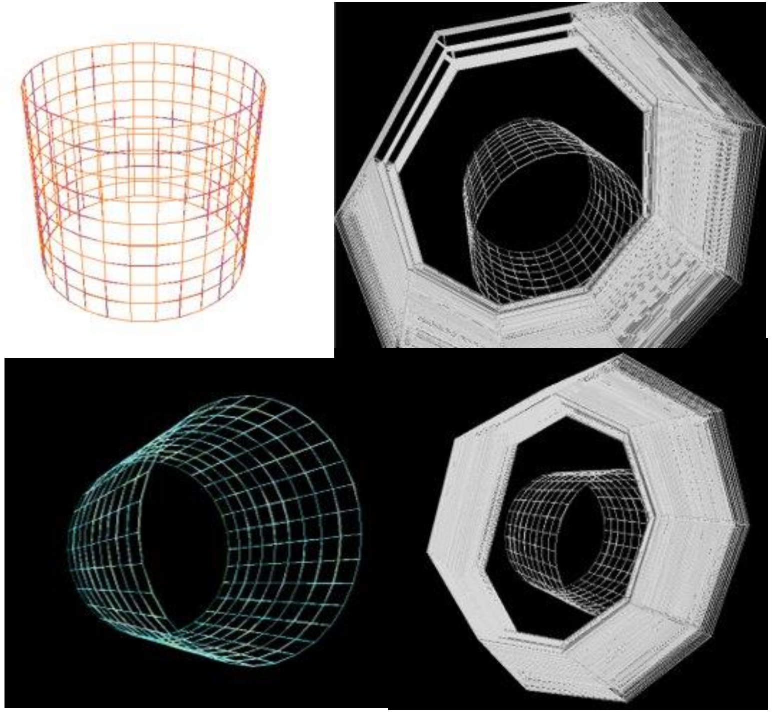
- Where all the work started, but;
- **No more development is supported.**

KEY4HEP framework:

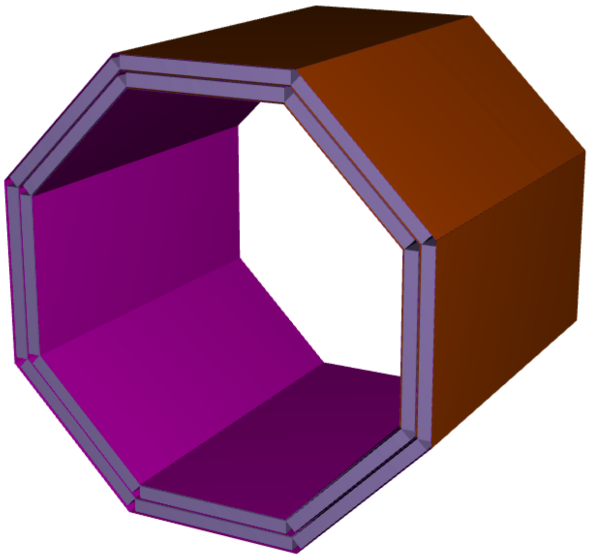
- The FCC collaboration has decided to use KEY4HEP toolkit -which **DD4HEP** is part of its framework- in the simulation and analysis of all the experiments included within the collaboration.

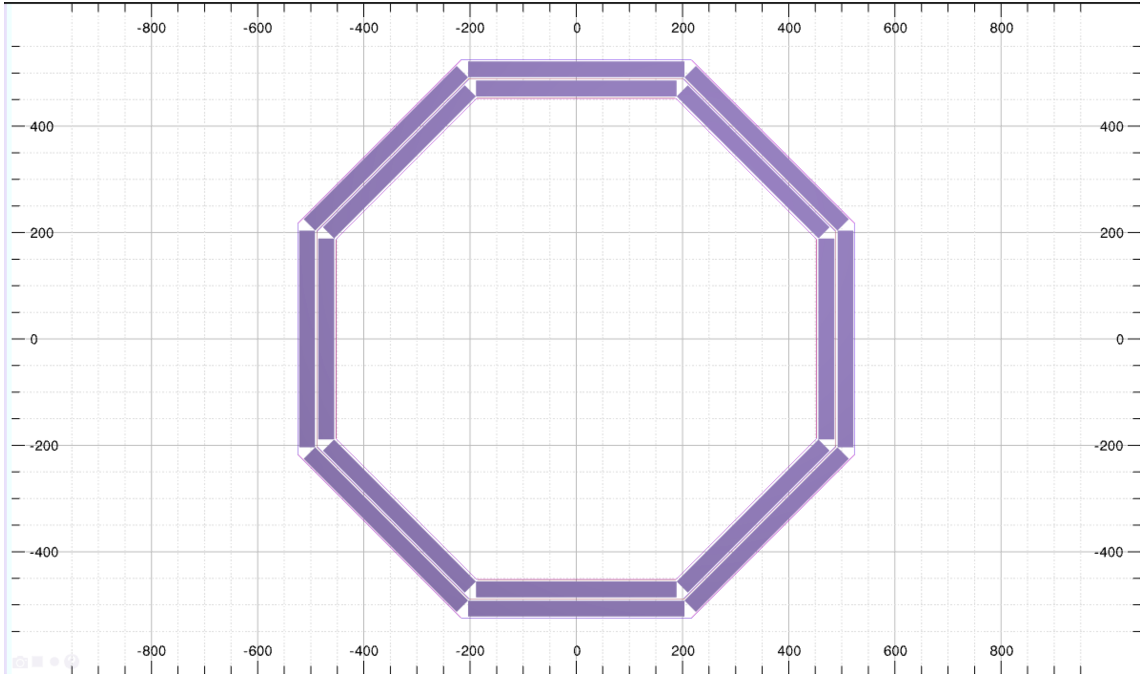
IMPLEMENTATION OF THE MUON SYSTEM IN GEANT4

- The muon system of the IDEA detector concept is composed of three layers of μRWELL gas detectors as sensitive layers, and two layers of Iron as radiators.
- The μRWELL geometery and materials have been successfully implemented into the full simulation with GEANT4 of IDEA. The same has been done with the pre-shower subdetector too, which is composed of one layer of μRWELL.
- The preshower starts at a radius of 2440 mm and is made of an almost cylindrical shape of mosaics of 50 * 50 cm^2 of μRWELL chambers.
- The muon system starts at a radius of 4500 mm, and has an octagon shape. Each radiator layer has a thickness of 300 mm of Iron.



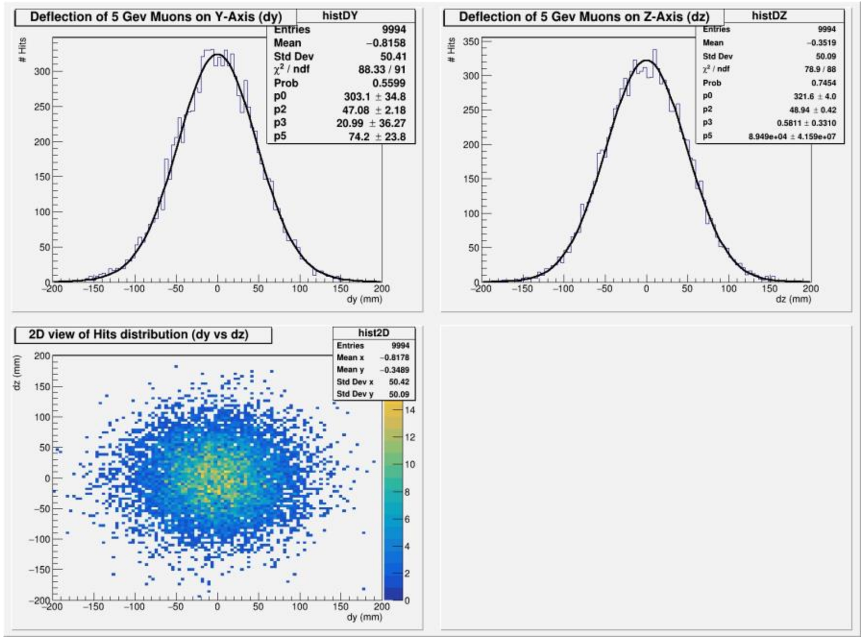
The following figures shows the **barrel** muon system as it appears in GEANT4 visualization.

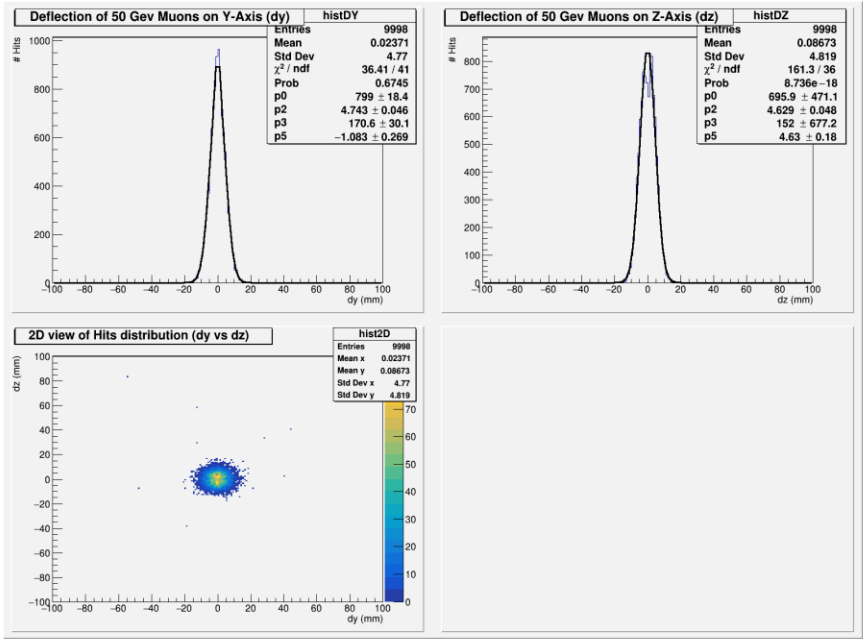




Study of the Muon Track Deflection at IDEA

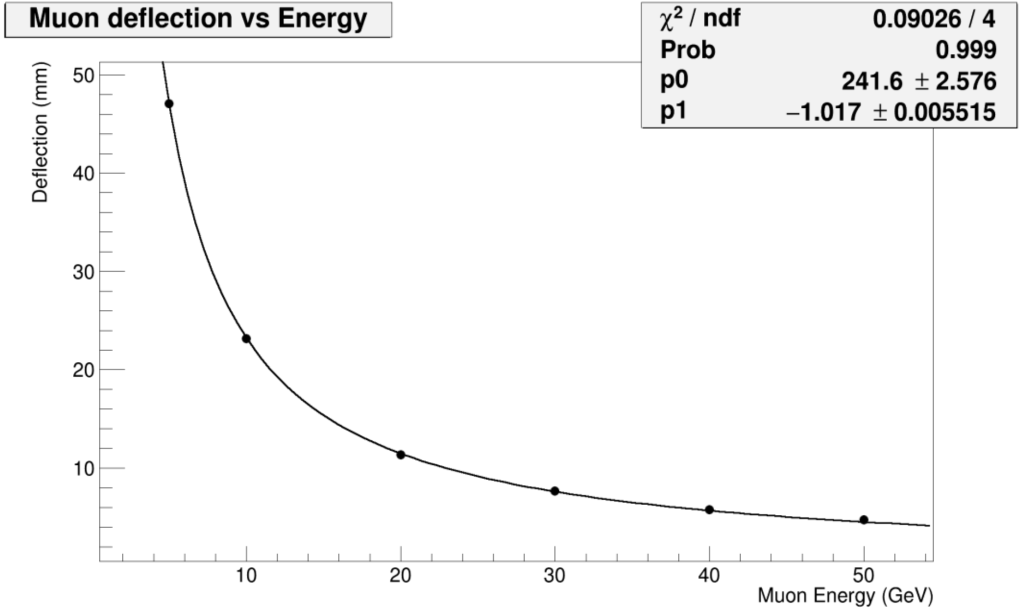
As performing simulation tuning with test beam data. The calculation of the effect of multiple scattering as a function of the momentum of muons caused by their interaction with the IDEA implemented material (all sub-detectors before the muon system) is crucial. This analysis aids in understanding the deviation of particle tracks and determining the required space resolution for muon detector.

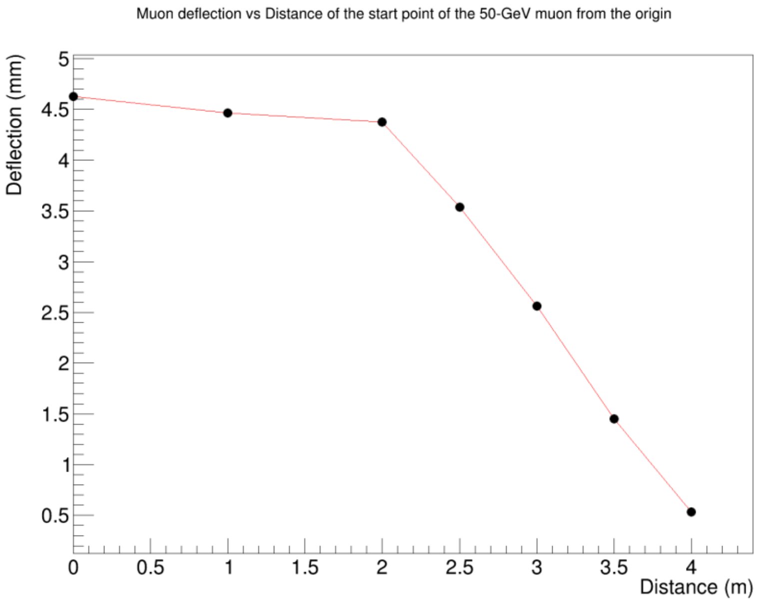




Study of the muon track deflection at IDEA detector environment

A full scan of the muon different energies starting from 5 GeV up to 50 GeV has been calculated, and the result is briefed in the following figure (left). Right: The relation between the track deflection and the distance between the muon vertex and the muon system. As we can see from the deflection-distance relation, the deflection falls rapidly after distance = **2140 mm**, which is the start of the magnet volume. At this distance the material density is much larger than before, because of the presence of the magnet, calorimeter's passive material, and muon system return yokes.





IMPLEMENTATION OF THE MUON SYSTEM IN DD4HEP

The implementation of the muon system has been through two tracks:

1. As a first approach as a **simple cylindrical shaped**, which describe the muon system as layers of cylinders contains the different materials of our detector.
2. Then gradually a description of more complex and **detailed muon system**, which describe the mosaics of 50 × 50 cm^2 detailed μRWELL chambers.

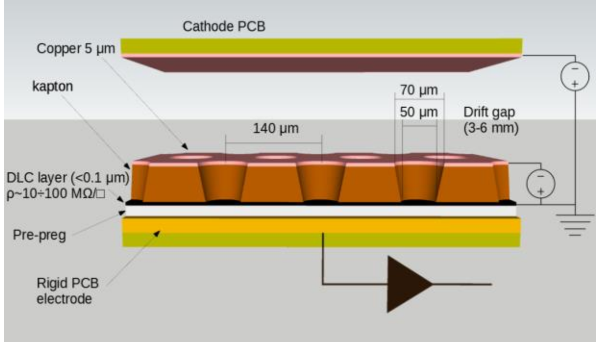
The advantage of a simple description approach is to provide us with:

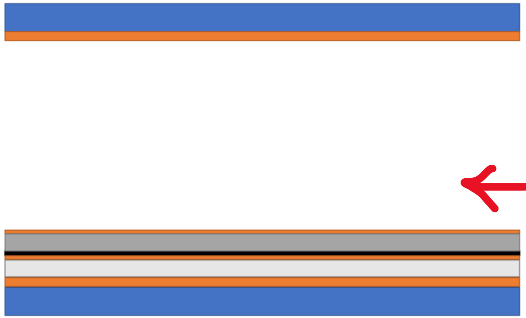
- A functional version in a short time, facilitating numerous pertinent physics investigations.
- It offers great adaptability, considering that the muon chamber, being the final detector in the sequence, is susceptible to adjustments necessitated by alterations in other sub-detectors.

SIMPLE CYLINDRICAL SHAPED

A complete description of the materials of the μRWELL and the geometry of the system has been done.

Component	Thickness of each layer	Material
	1.6 mm	FR_4
Cathode	35 μm	Copper
Gas gap	6 mm	$ArCO_2CF_4$
	5 μm	Copper
	50 μm	Kapton
	0.1 μm	DLC
μ-RWELL + readout PCB	35 μm	Copper
	100 μm	Film glue (same DLC density)
	35 μm	Copper
	1.6 mm	FR_4



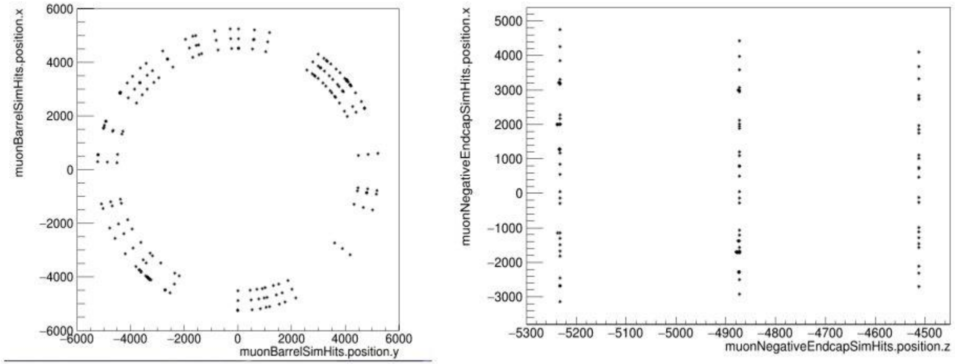


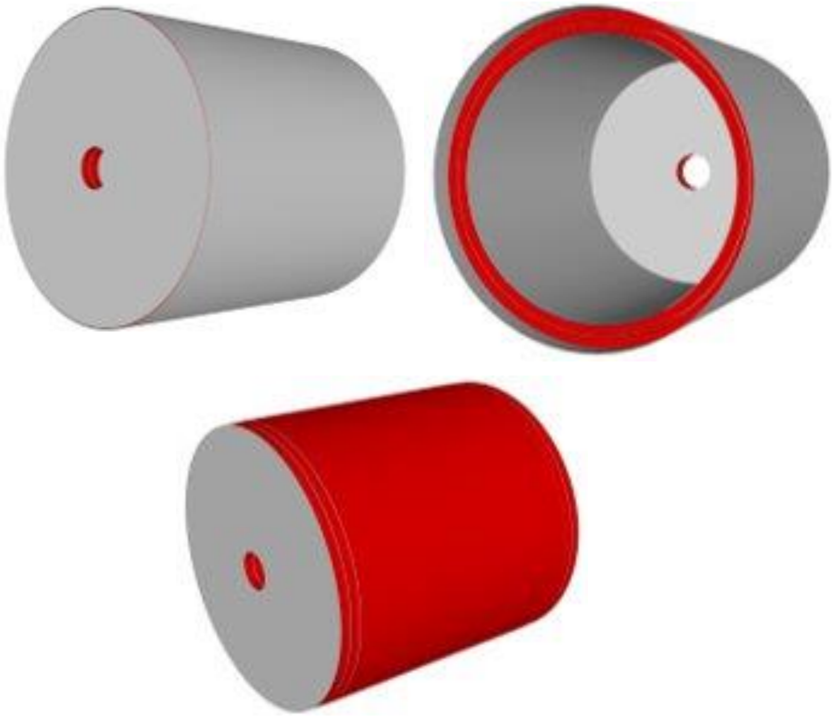
The sensitive area

A schematic view of the various layers involved in the description of the μ-RWELL detector

SIMPLE CYLINDRICAL SHAPED

- A complete description of the muon system as a simple cylindrical shape has been done.
- A readout system has been implemented for the cylindrical shape, with a segmentation in ϕ and θ direction to match the foreseen strip pitch.

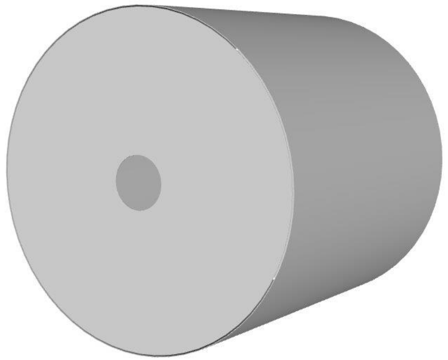




Left: SimHits from the barrel muon system. **Right:** SimHits from one of the endcap muon system.

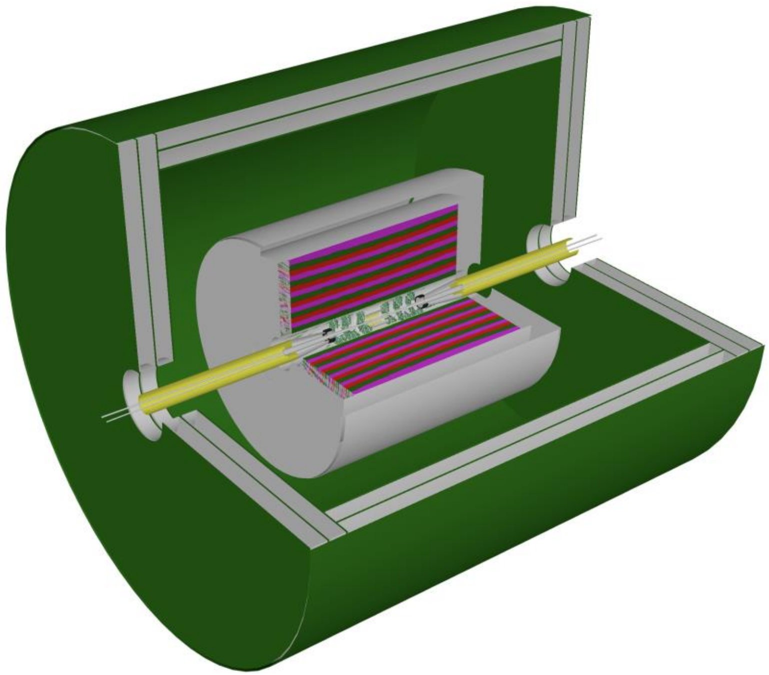
SIMPLE CYLINDRICAL SHAPED

- Since the Preshower will be built with the same technology, the same code of the muon system can be used to describe the Preshower.
- A complete description of the Preshower as a simple cylindrical shape has been done.



SIMPLE CYLINDRICAL SHAPED

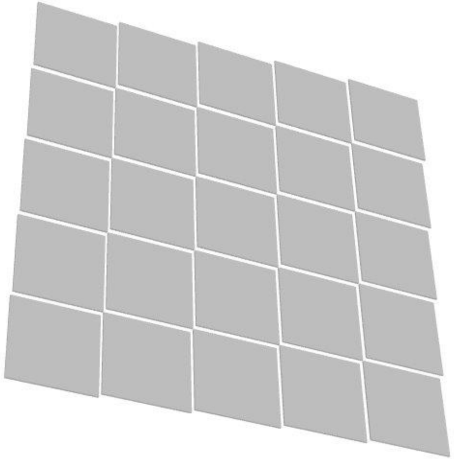
- The simple Muon System and Pre-shower have been included in the full IDEA DD4hep implementation.
- The full implementation now on k4geo



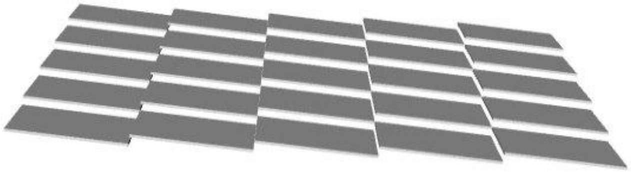
DETAILED VERSION OF THE MUON SYSTEM

The aims:

- Building the muon system based on 50 × 50 cm^2 μRWELL chambers.
- Taking into account the overlap between the chambers in 2 dimensions (to minimize the dead area as much as possible).
- A readout system for every single chamber has been created (CartesianGridXY).



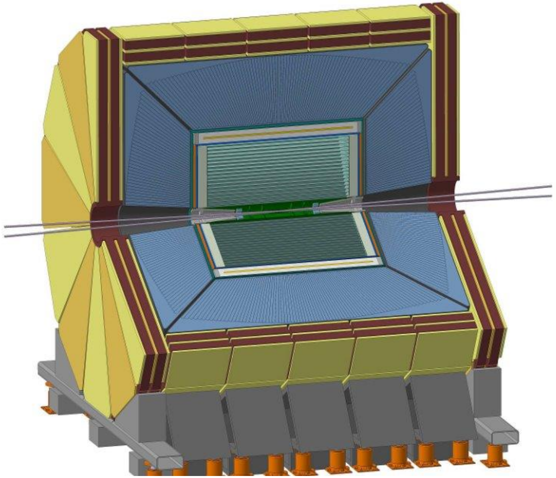
- **The structure of the detector starting from creating an envelope for the side volume, which contains an array of our μRWELL chambers.**
- **Then the envelope will be copied in different rotation angles to create the barrel part.**



DETAILED VERSION OF THE MUON SYSTEM

The aims:

- Making the design flexible, where the user can choose the number of sides of the shape (hexagon, octagon, ….), and automatically the builder will calculate the number and places of the copied chambers.



DETAILED VERSION OF THE MUON SYSTEM

The aims:

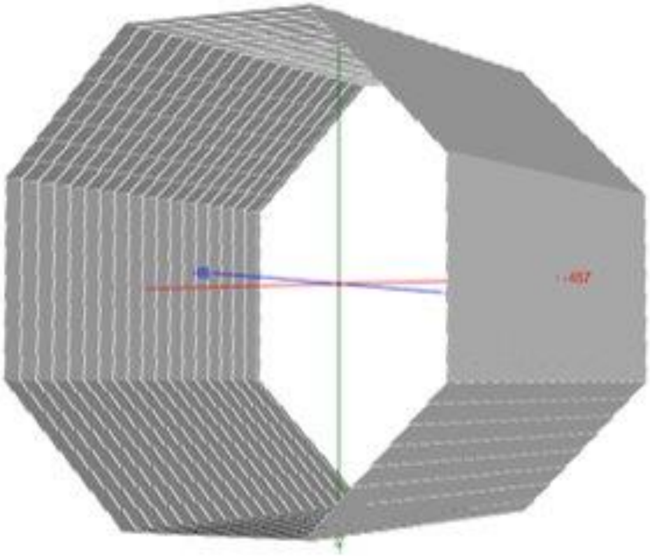
- Making the design flexible, where the user can choose the number of sides of the shape (hexagon, octagon, ….), and automatically the builder will calculate the number and places of the copied chambers.

```
<!-- Specify the detector paramenters and the overlap -->
<detectorParameters radius="4520*mm" barrelLength="9000*mm" numSides="8" overlapY="1*cm" overlapZ="1*cm" />
```

The user only needs to enter in the xml file: the **inner radius**, his detector **barrel length**, and the **number of the detector sides** and his detector barrel will be ready.

OCTAGON SHAPE AS AN EXAMPLE:

- An Octagon shaped **barrel** part of the muon system depending on 50*50 cm^2 chambers.

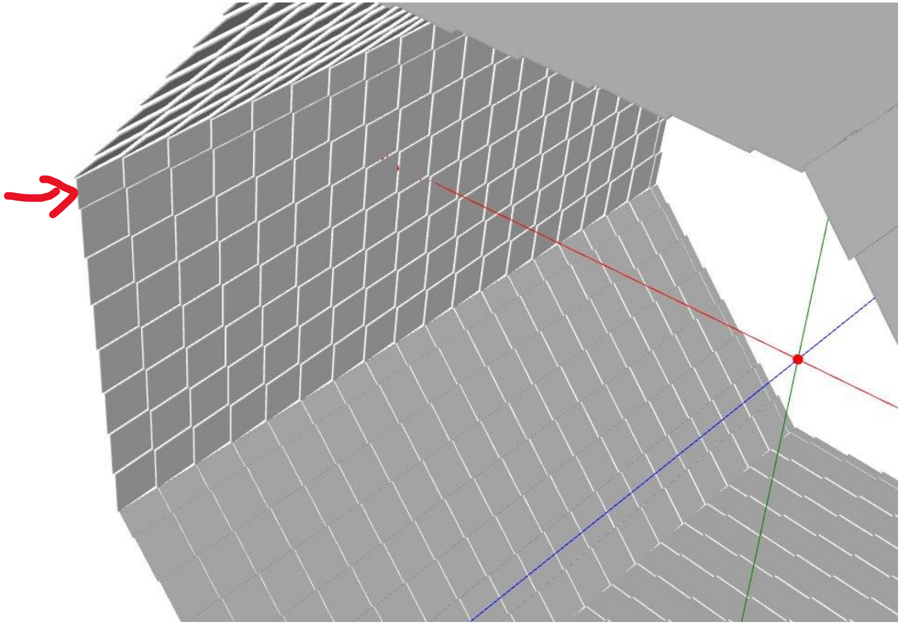


OCTAGON SHAPE AS AN EXAMPLE:

- An Octagon shaped **barrel** part of the muon system depending on 50*50 cm^2 chambers.

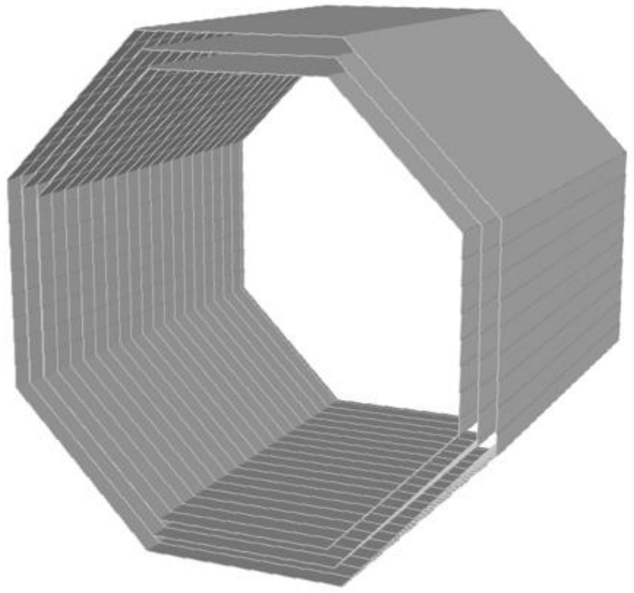
- If the side length do not fit with an integer number of 50 × 50 cm^2 , the builder can make a chamber with unusual dimensions, which can fit the excess area at the end of the side.

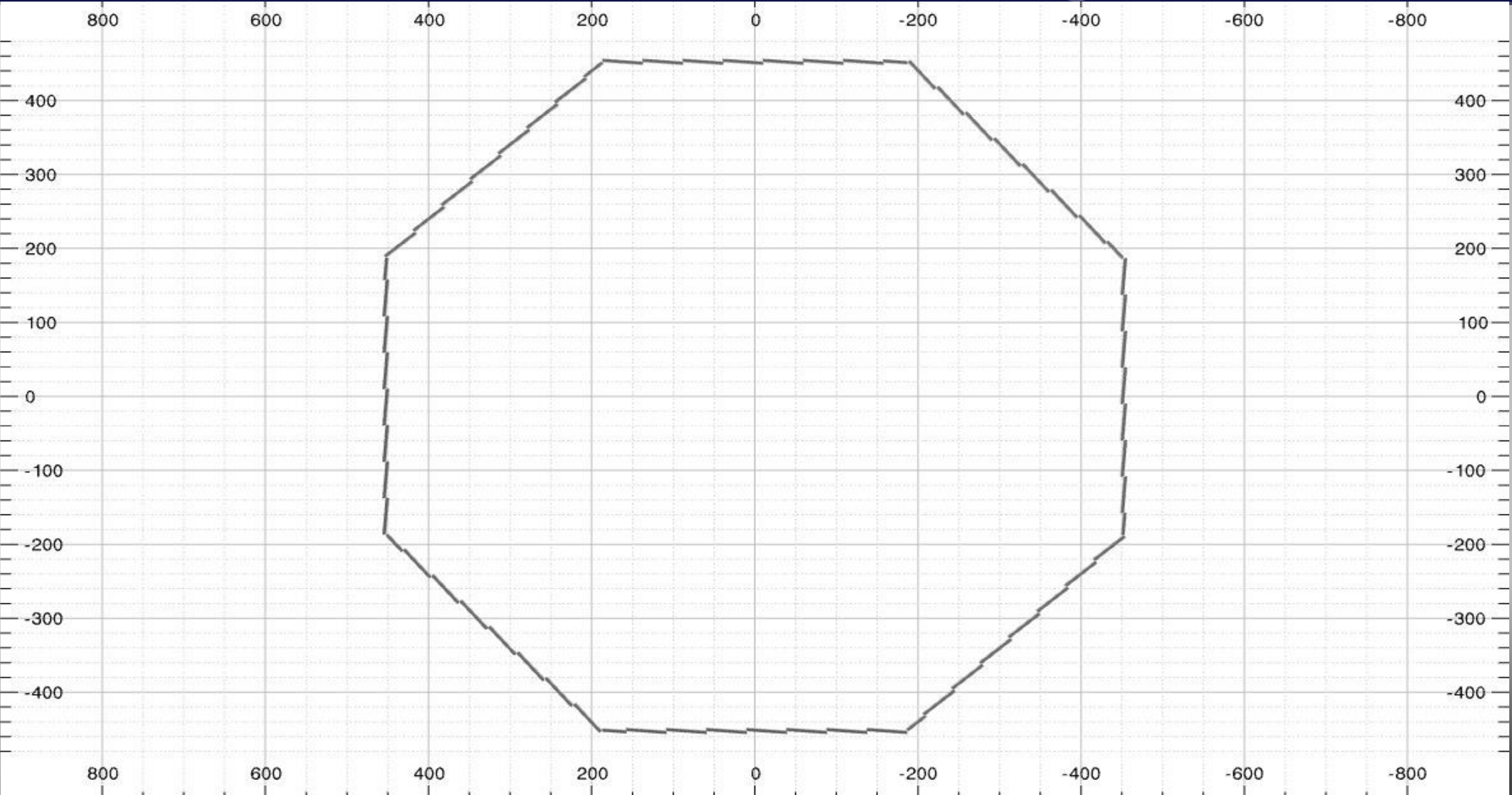
- There is another idea of keeping the same chamber (PCB) size but changing (automatically) the overlapping area (Still not implemented).



OCTAGON SHAPE AS AN EXAMPLE:

- An Octagon shaped **barrel** part of the muon system depending on 50*50 cm^2 chambers.
  - The availability to make multiple layers with different **inner radius** and **barrel length**.

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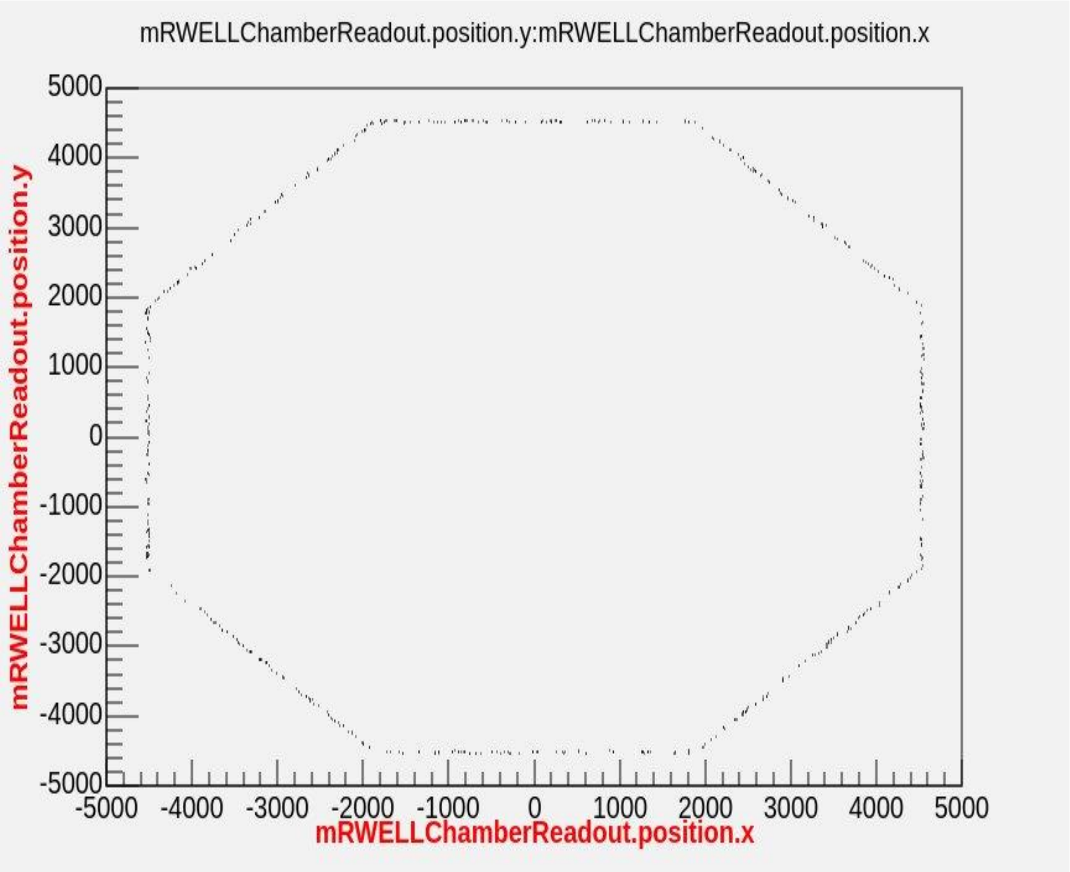
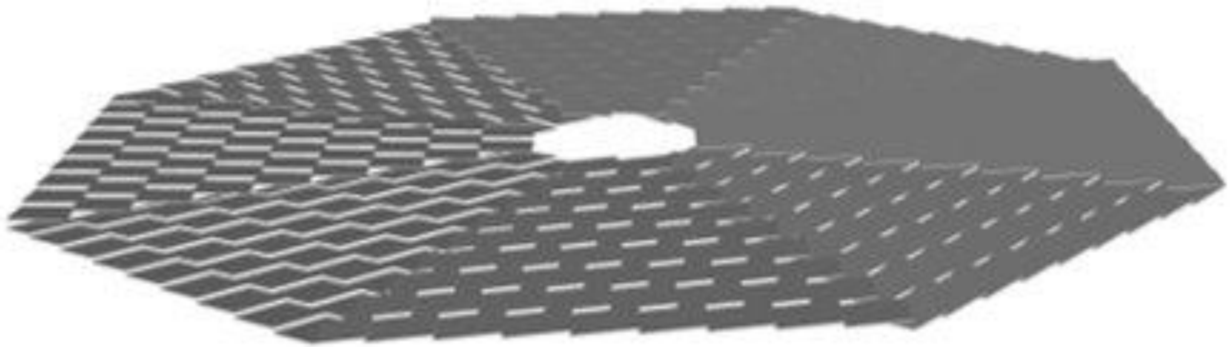
OCTAGON SHAPE AS AN EXAMPLE:

Simulation of 1000 muon hits as it appears in our chambers sensitive area for a single layer taking the octagon shape.



OCTAGON SHAPE AS AN EXAMPLE: ENDCAP

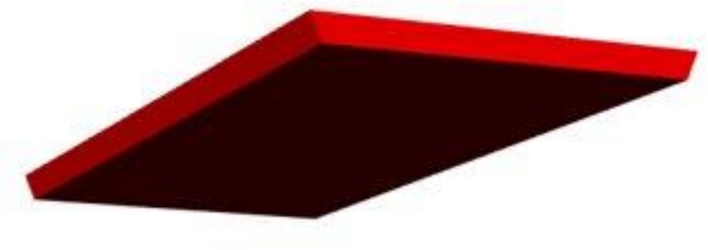
- An Octagon shaped **endcap-**part of the muon system depending on 50*50 cm^2 chambers.
- Divided into 8-sides overlapping over each other.
- The same properties like the barrel: Creating chambers of unusual dimensions to fill the gaps.

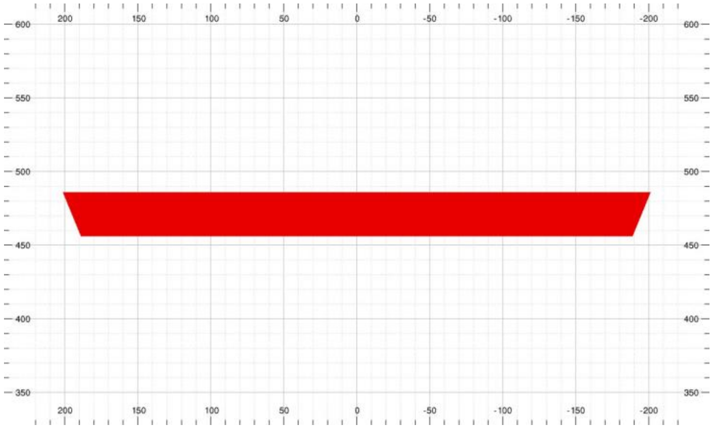


The code is very general, which can be used to describe any detector system made from repeated tiles, with having the capability to fill the gaps with unusual dimensions tiles.

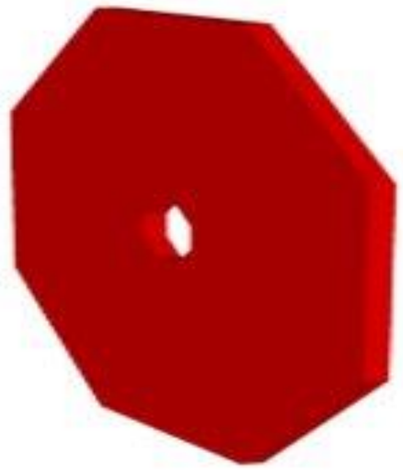
IMPLEMENTATION OF THE IRON YOKES:

- I have described the yokes on the shape of trapezoid along Z-axis, taking the full length of the detector.
- The angle of the trapezoid is the same angle of the detector shape (octagon , hexagon, ...). That will assure they will perfectly meet at the corner without intersections.



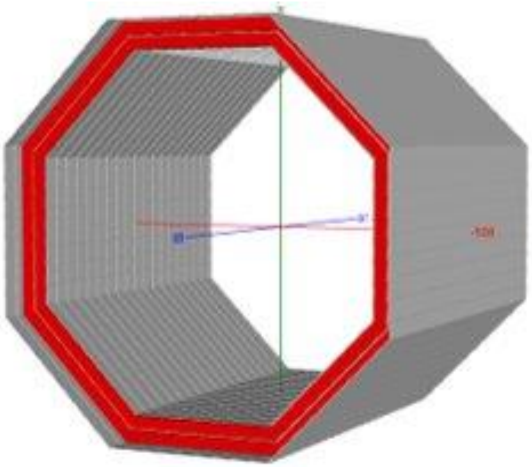


IMPLEMENTATION OF THE IRON YOKES:

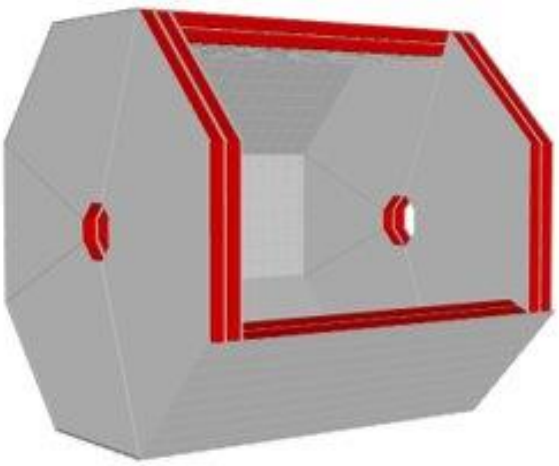


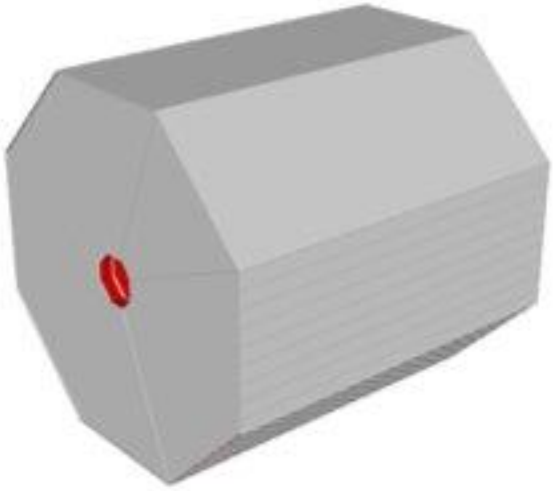
- In the **endcap**, I divided the yoke into # of parts = # of the shape sides.
- The angle of the trapezoid is the same angle of the detector shape (octagon , hexagon, ...). That will assure they will perfectly meet at the corner without intersections.

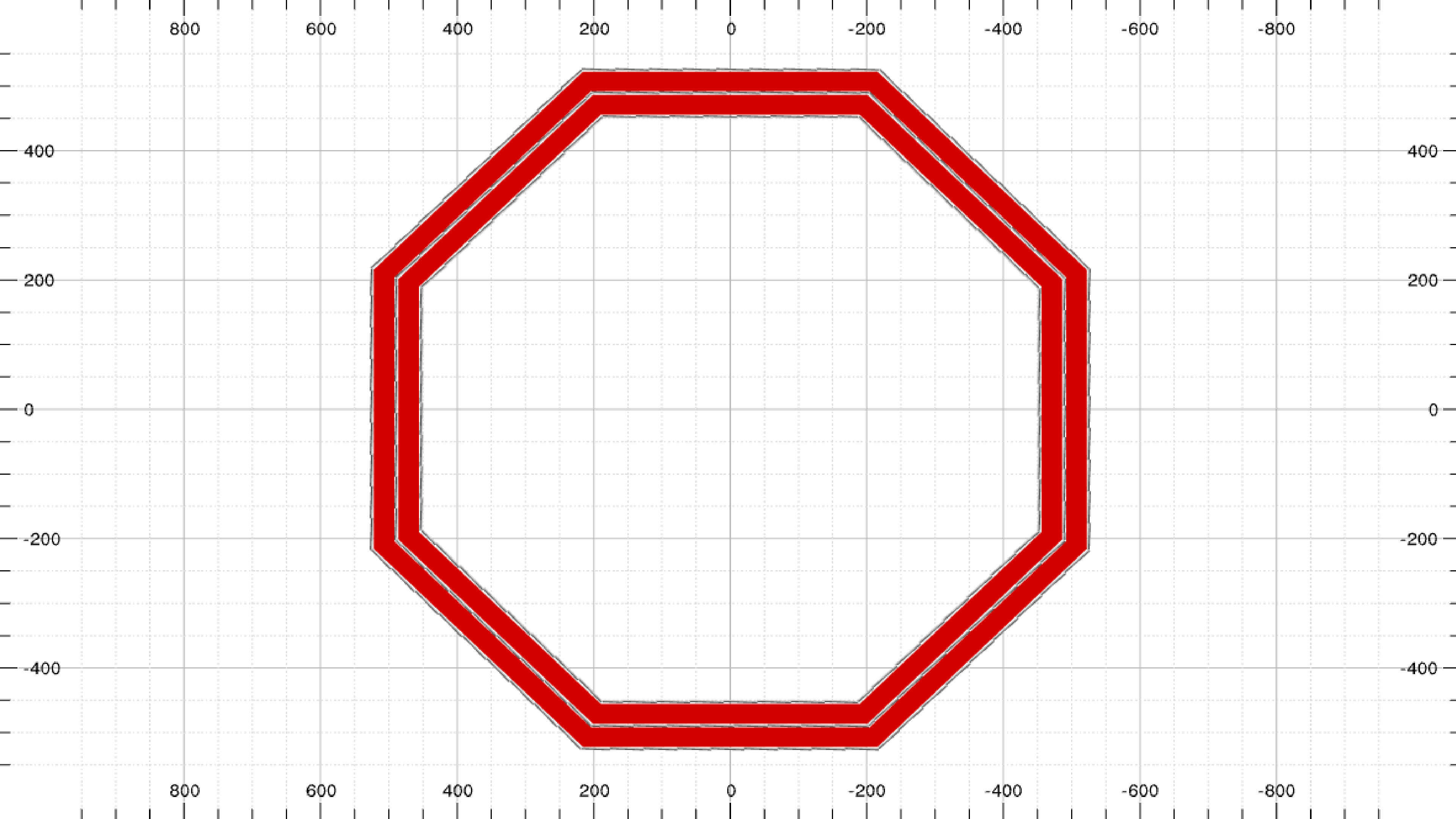
FULL MUON SYSTEM GEOMETRY



- A first draft of the **detailed version of the muon system** geometry implementation is ready.



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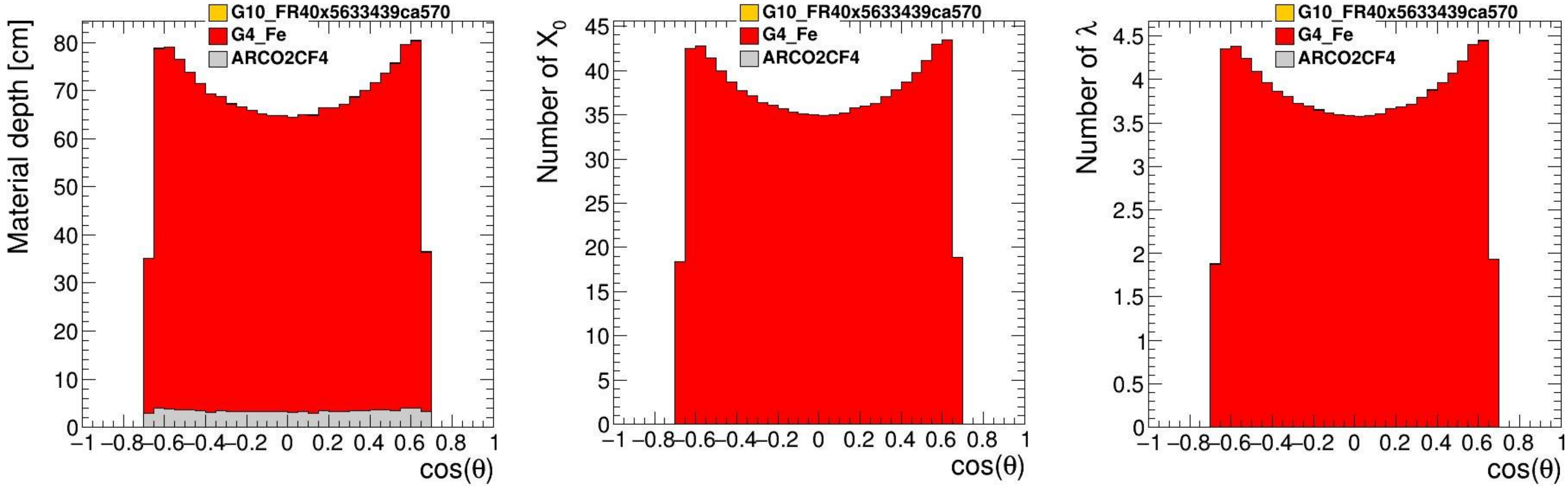
STUDY OF THE MATERIAL BUDGET OF THE MUON BARREL SYSTEM



Left: The depth of the material. **Middle:** # of interaction lengths. **Right:** # of radiation lengths.

DETAILED VERSION OF THE MUON SYSTEM

Recall

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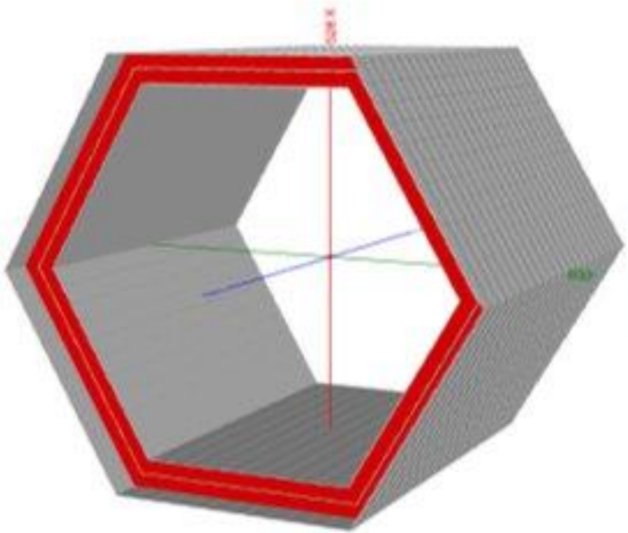
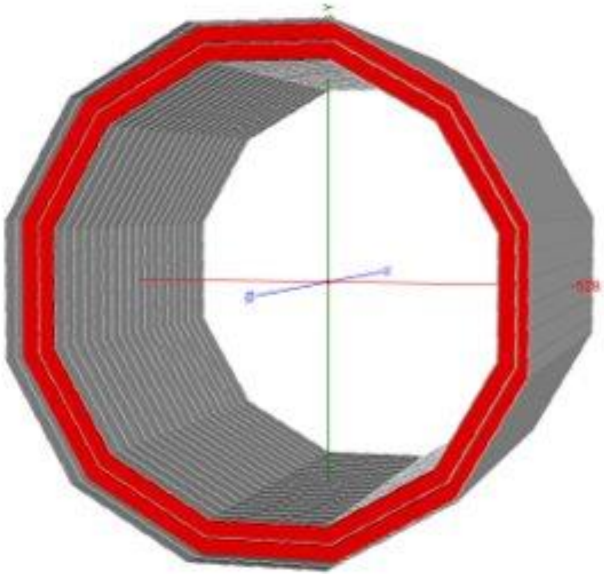
```

The user only needs to enter in the xml file: the **inner radius**, his detector **barrel length**, and the **number of the detector sides** and his detector barrel will be ready.

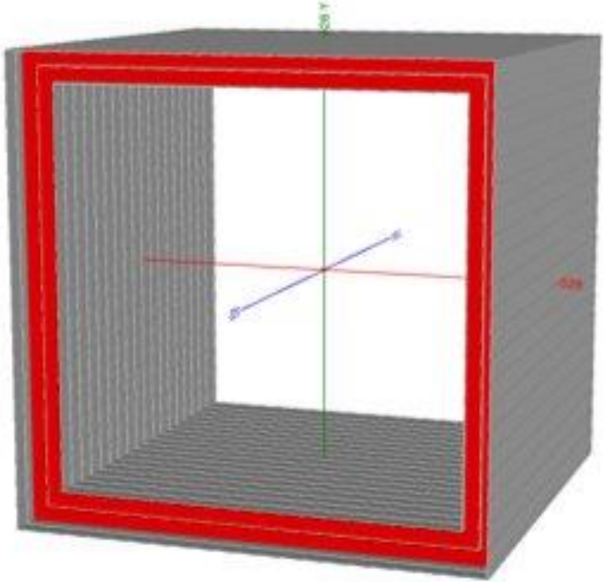
MORE DIFFERENT GEOMETRIES MADE BY THE SAME BUILDER (C++ CODE)



Hexagon



Dodecagon



Quadrilateral

Conclusion:

- The simple geometry description of the muon system and Preshower has been done, and both have been included in full IDEA DD4hep implementation.
- A detailed version of the muon system has been done.

Further developments:

- Implementation of a digitization algorithm(ongoing).
- Implementation of a muon reconstruction algorithms with and without the usage of the tracking system.
- Evaluation of the IDEA muon reconstruction performance.
- Evaluation of the physics reach for highly displaced "muon-like" signatures.

Thank you for your attention.

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