

Collimator2 Redesign

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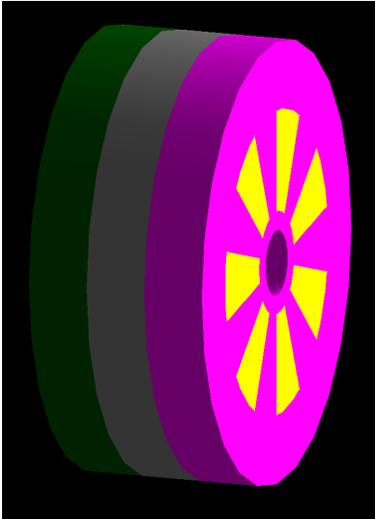
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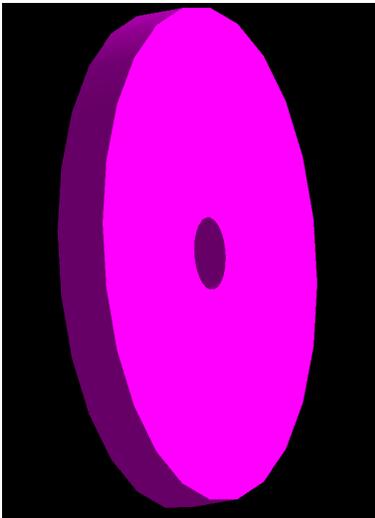
1 Current Design of Collimator 2

How is collimator 2 constructed. There are three pieces along z. 50mm each.



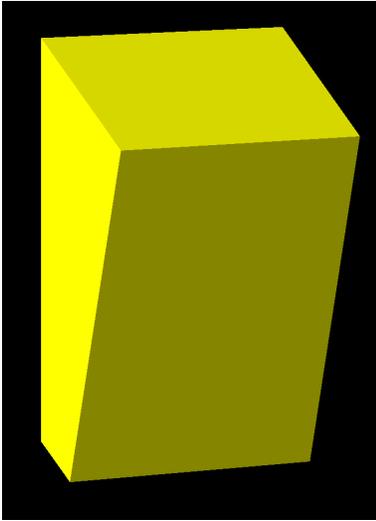
The first two pieces are tungsten and the third is Copper. Each of the three pieces are cylindrical (of length 50mm) with inner radius of 25mm and outer radius of 150mm.

Lets look at the last Copper piece for example.

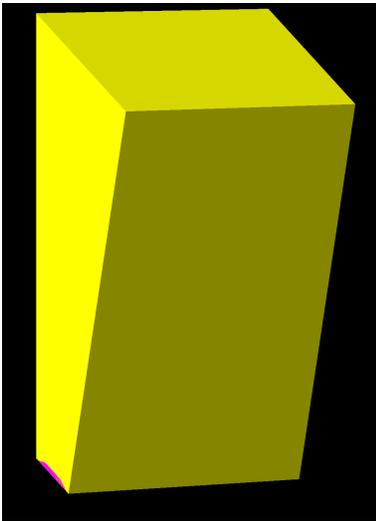


To create the sector holes the sector holes are not cut out of this solid. Instead a new solid is made using vacuum material and overlapped with this solid.

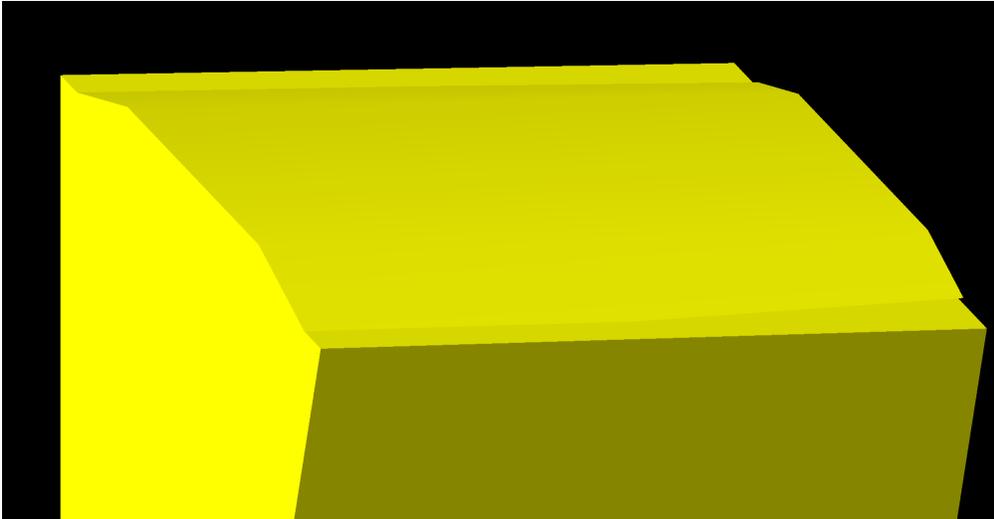
An arb8 solid of vaccum is made first.



The top and bottom face of this solid are flat planes. But we want them curved with Inner Radius and Outer Radius of the sector. To achieve the curved part. On top of this vacuum arb8 volume, a new conical section is yet again overlapped on the bottom of this but made of Copper.

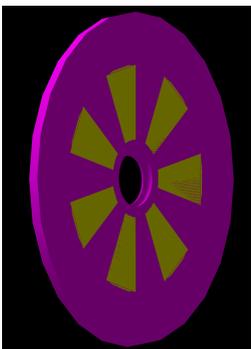


Similarly for the top curved part, a new conical section is put on the top of this sector made up of vacuum material.



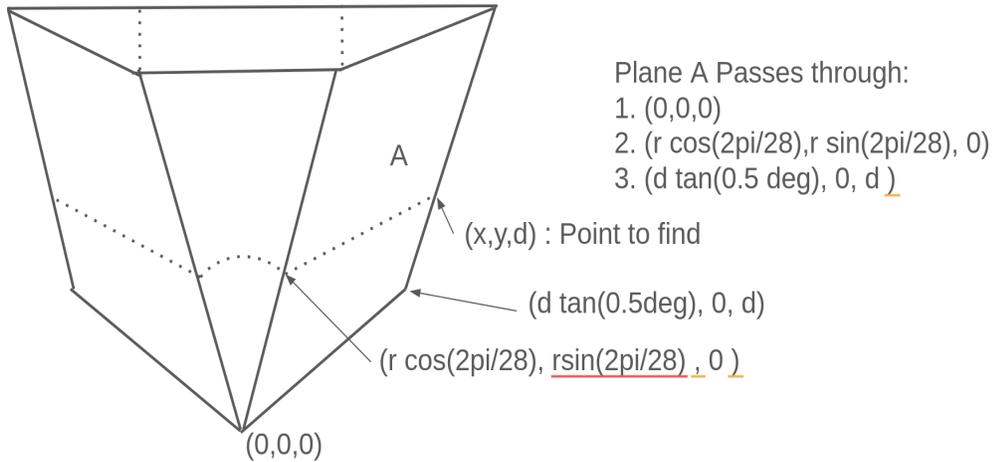
This shows that the top vacuum curve is not the same “size” (azimuthally) as the arb8 solid (the sector hole). The top curved part has increase in the radius by 1.5degrees corresponding to 1.5deg radial taper. This is tru for the second tungsten layer and the third copper layer.

Combining all these it looks like:



The top curved vacuum solid (yellow) is not precisely placed so there is a visible gap with the arb8 solid.

1.1 How is tapered arb8 made?



Plane A passes through

1. (0, 0, 0)
2. $(r \cos(\frac{2\pi}{28}), r \sin(\frac{2\pi}{28}), 0)$
3. $(d \tan(0.5^\circ), 0, d)$

The point to find is a general point (x, y, d) where d is 0 or 50; the width of the piece.

So:

The general equation of plane is $ax + by + cz = d$ since this passes through origin we have $d = 0$.

Rescaling the variables the updated equation of plane passing through origin is:

$$x + by + cz = 0$$

The plane passes through the 2nd point so

$$r \cos\left(\frac{2\pi}{28}\right) + br \sin\left(\frac{2\pi}{28}\right) = 0$$

$$\Rightarrow b = -\tan\left(\frac{2\pi}{28}\right)$$

Now the third point satisfying the plane gives

$$d \tan(0.5^\circ) + cd = 0$$

$$\Rightarrow c = -\tan(0.5^\circ)$$

So the general equation of plane is:

$$x - \tan\left(\frac{2\pi}{28}\right)y - \tan(0.5^\circ)z = 0$$

Now we are ready to calculate (x, y) at various z given that $x^2 + y^2 = R_{\min|\max}^2$.

At $z = 0$:

$$\begin{aligned}x - \tan\left(\frac{2\pi}{28}\right)y &= 0 \\x^2 + y^2 &= R^2\end{aligned}$$

Solving these two gives

$$y = R \cos\left(\frac{2\pi}{28}\right)$$

At $z = h$ where $h = 50$ for now.

$$x - \tan\left(\frac{2\pi}{28}\right)y - h \tan(0.5^\circ) = 0$$

Assume $A = -\tan\left(\frac{2\pi}{28}\right)$ and $B = -h \tan(0.5^\circ)$

$$\begin{aligned}x + Ay + B &= 0 \\x^2 + y^2 &= R^2\end{aligned}$$

Solving these two yields:

$$y = \frac{-2AB \pm \sqrt{4A^2B^2 - 4(A^2 + 1)(B^2 - R^2)}}{2(A^2 + 1)}$$

Writing a cute julia code for this

$$x(z,R,B) = (-2*A*B*z + \sqrt{4*A^2*B^2*z^2 - 4(A^2 + 1)*(B^2*z^2 - R^2)}) / (2*(A^2 + 1))$$

$$y(z,R,B) = \sqrt{R^2 - (x(z,R,B))^2}$$

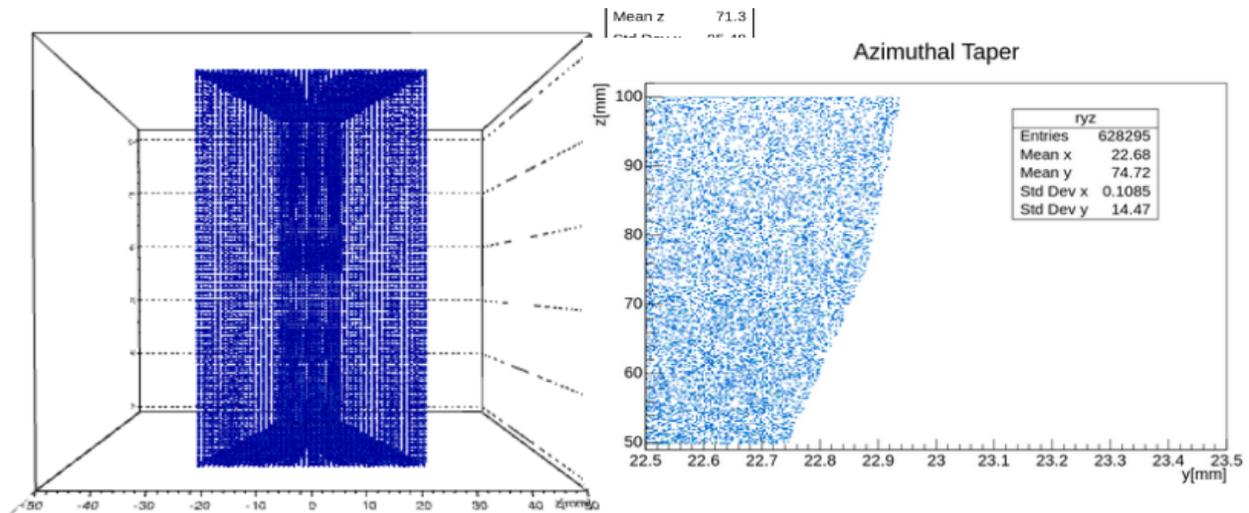
```
zr = [(0,35),(0,101),(50,35),(50,101+50*tan(1.5deg)),(100,35),(100,101+100*tan(1.5deg))]
```

```
for (z,R) in zr
    B = tan(0.25deg)
    xx = x(z,R,B); yy = y(z,R,B)
    println(" ($z,$R) => ($xx, $yy) ")
end
```

For $B = \tan(0.5^\circ)$ we get:

```
(z,R) => (x, y)
(0,35) => (34.122476926363824, 7.788232688471012)
(0,101) => (98.46771913036419, 22.47461432958776)
(50,35) => (34.02529524308769, 8.202394992970913)
(50,102.30929607845934) => (99.64866502604377, 23.180500913422396)
(100,35) => (33.923071377212594, 8.615406452195954)
(100,103.6185921569187) => (100.82792996779968, 23.886003830493234)
```

1.2 Issues with this design



1. *Inconsistent azimuthal angle*: The left plot is the top view of 3D xyz plot of one sector opening. The right plot is the right top edge the azimuthal opening piece. There is a change in azimuthal angle midway and not sure why this happens. My guess is that the subtraction of geometry is somehow wrong.
2. *Overlapping Volumes*: As explained before, to make the opening, a vacuum material is overlapped with a copper base. And then again to make the curved inner opening, a copper piece is again overlapped with the vacuum material. This seems *unnecessarily complicated*.
3. *GDML implementation error prone*: The GDML implementation of this geometry is error prone.

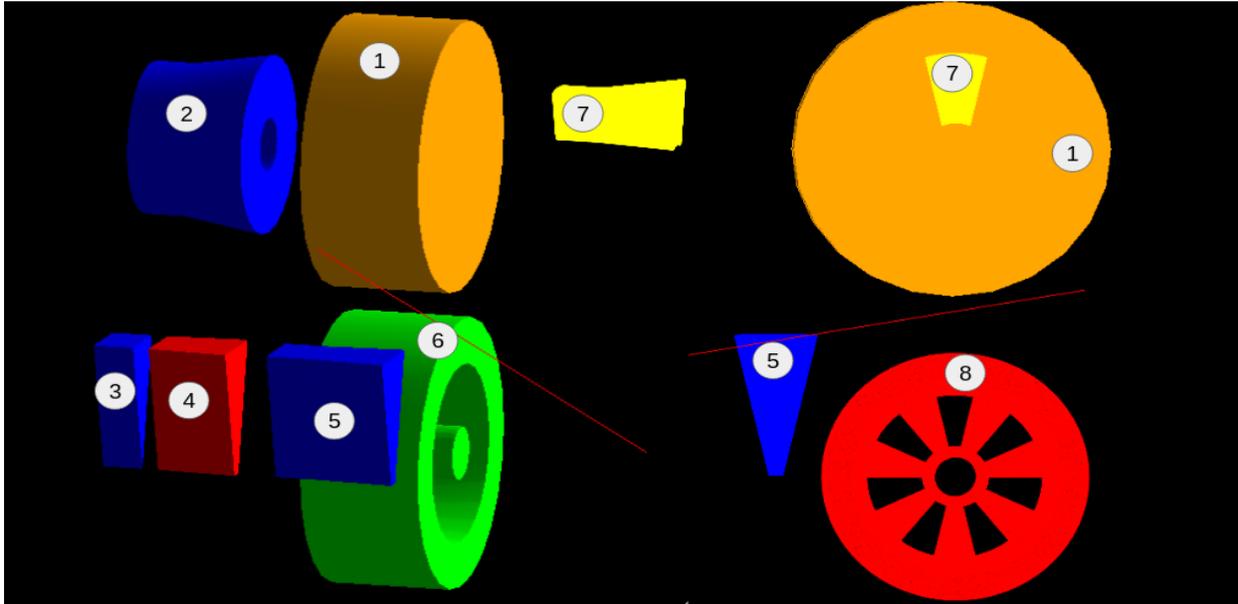
Because we have to externally solve non linear equation to get the arb8 volume parameters. Change in IR, for example, requires recalculation of these parameters, this process is error prone.

2 Redesign

I propose a new collimator 2 design, where we make a single piece for the final collimator 2 piece. I have used series of boolean operation with primitive volumes to obtain the final collimator 2 piece. This avoids geometry overlaps and the necessity of calculating parameters externally.

The only parameters that are input to these are the design parameters,

1. inner radius,
2. outer radius,
3. azimuthal taper angle and
4. radial taper angle



2.1 Summary of these design

Make cylindrical shape(1), and subtract a polycone (2) to make a taper envelope (6). Make a union(5) of first untapered prism(3) and azimuthally tapered trapezoid volume(4), which makes the opening along z . Now subtract (6) from (5) to make radial taper in OR and parallel IR opening (7). Then finally subtract the opening (7) seven times around the azimuth to make the final piece (8).

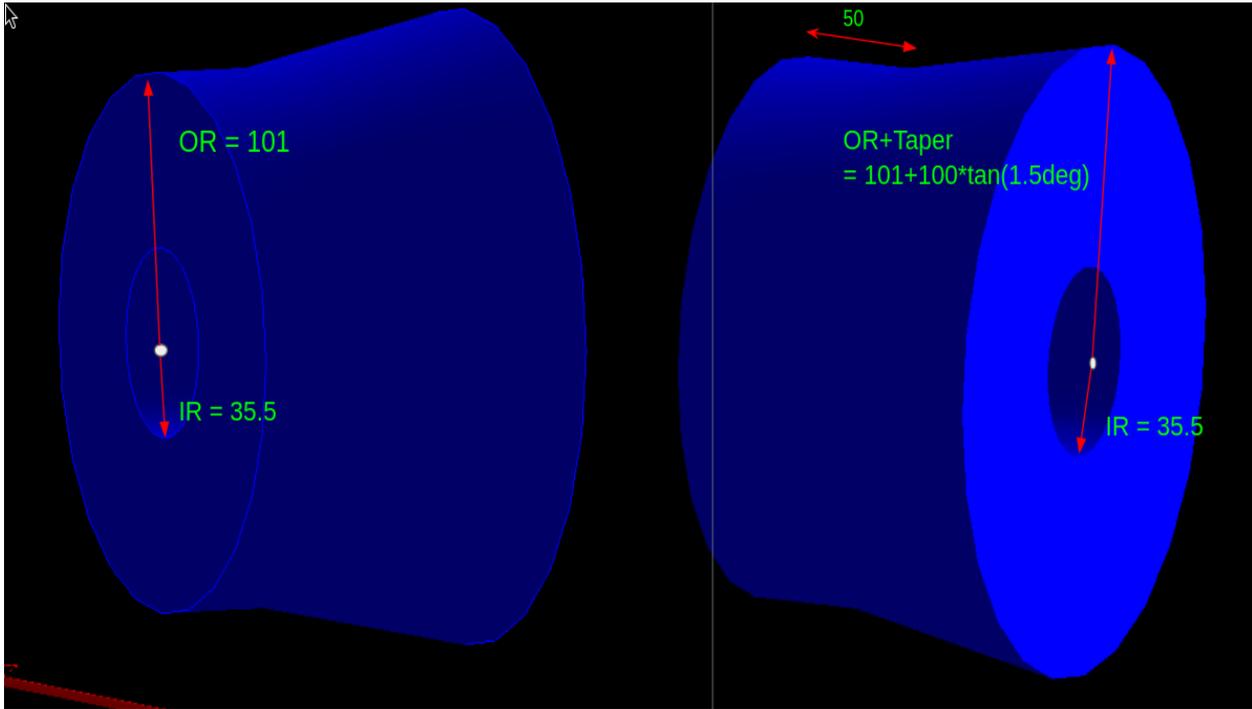
The description of each of the shapes is given below.

2.2 The description of each of the shapes

2.2.1 Shape 1

Shape 1 is a solid cylinder of $l = 150\text{mm}$ and $r = 150\text{mm}$ which makes the actual collimator 2.

2.2.2 Shape 2

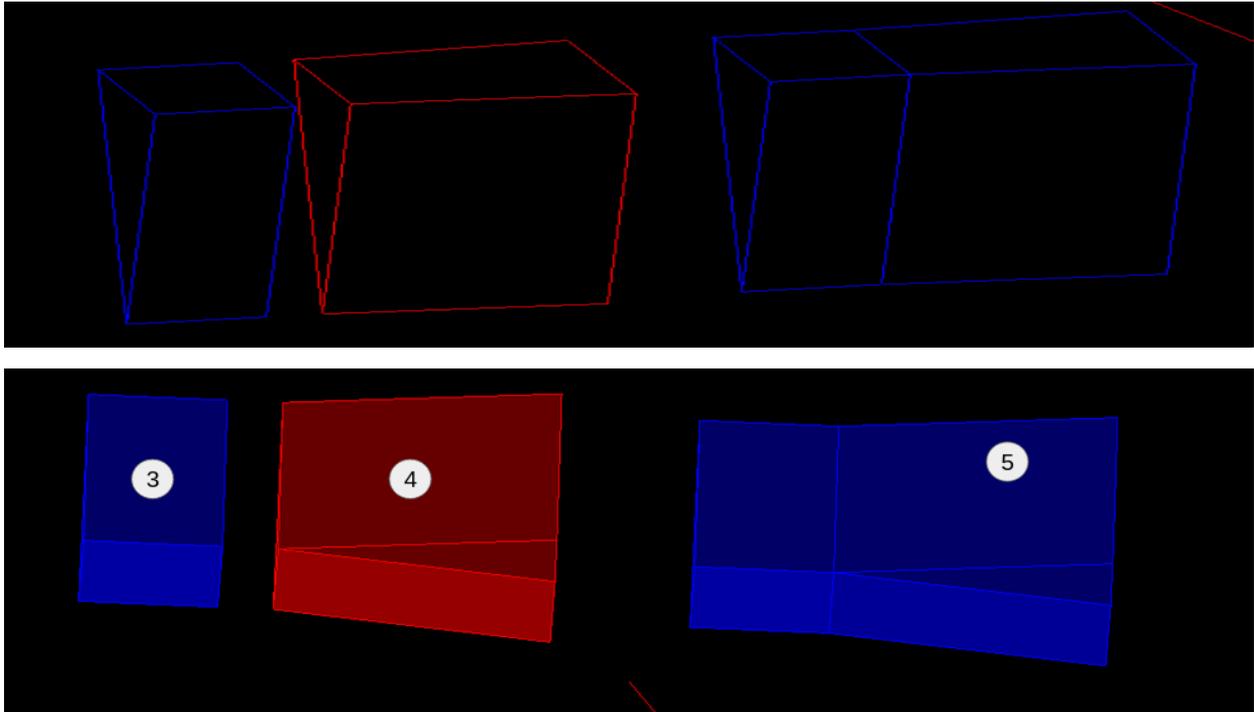


Shape 2 is a polycone.

1. First face: $z=0$, $IR=35.5\text{mm}$, $OR=101\text{mm}$
2. Second face: $z=50$, $IR=35.5\text{mm}$, $OR=101\text{mm}$
3. Third face: $z=150$, $IR=35.5\text{mm}$, $OR=101 + 100 \cdot \tan(1.5^\circ)\text{mm}$

To create outer envelope, make a polycone with front face of $IR=35.5\text{mm}$ and OR (101mm) and back face of $IR=35.5$ and $OR + 1.5\text{deg}(\text{taper})$ only on the last 100mm.

2.2.3 Shapes 3, 4 and 5



Shape 3 is a prism of half angle equal to $\frac{2\pi}{28}$. Its uniform of length 50mm. This makes first 50mm of untapered part of collimator 2.

Shape 4 is arb8 volume of following 8 coordinates.

1. $(0, 0)$
2. $(0, 0)$
3. $(r \sin(\frac{2\pi}{28}), r \cos(\frac{2\pi}{28}))$
4. $(-r \sin(\frac{2\pi}{28}), r \cos(\frac{2\pi}{28}))$
5. $(-h \tan(\alpha), 0)$
6. $(h \tan(\alpha), 0)$
7. $(r \sin(\frac{2\pi}{28}) + h \tan(\alpha), r \cos(\frac{2\pi}{28}))$
8. $(-r \sin(\frac{2\pi}{28}) - h \tan(\alpha), r \cos(\frac{2\pi}{28}))$

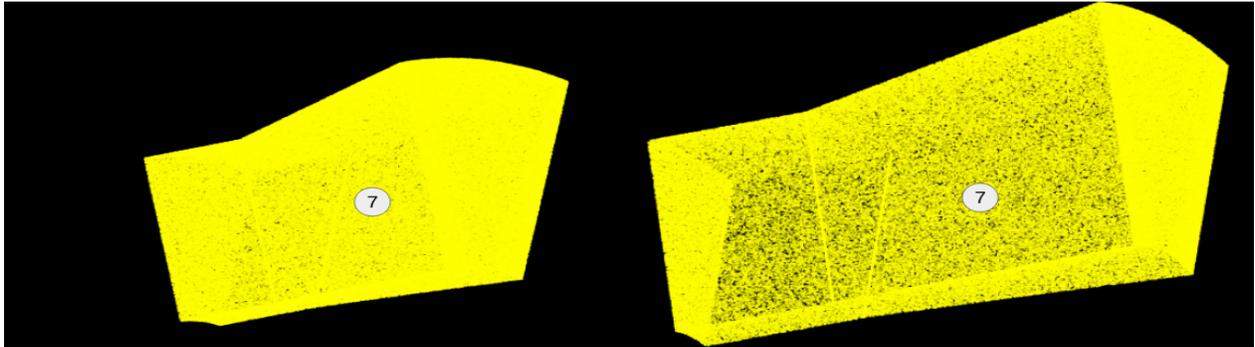
Here r is a number greater than outer radius of the open sector. And h is the width of the piece and α is azimuthal taper angle 0.5° . The first four coordinates make the triangular face at the start of azimuthal opening. At $h = 100$ downstream of that, we increase the x coordinate by $h \tan(\alpha)$

Shape 5 is the union of shape 3 and shape 4.

2.2.4 Shape 6

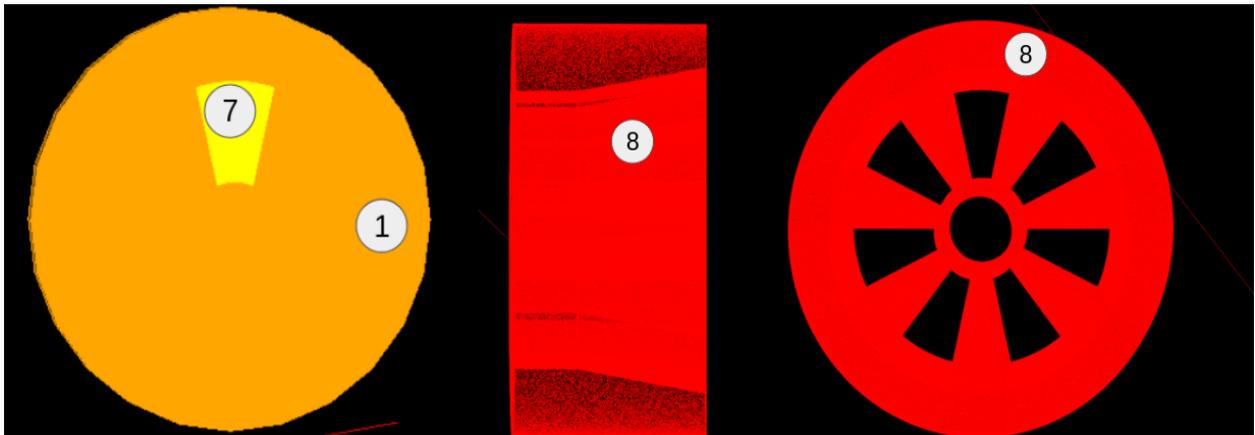
Shape is subtracting 2 from 1. So Shape6 = Shape 1 - Shape 2

2.2.5 Shape 7



Shape 7 is obtained by subtracting shape 6 from shape 5. The height of shape 5 is made sure to be larger than IR OR (101mm). This is the actual opening shape of collimator where first third is taper free both radially and azimuthally and the last 2/3rds are tapered azimuthally 0.5 deg and radially 1.5 deg.

2.2.6 Shape 8

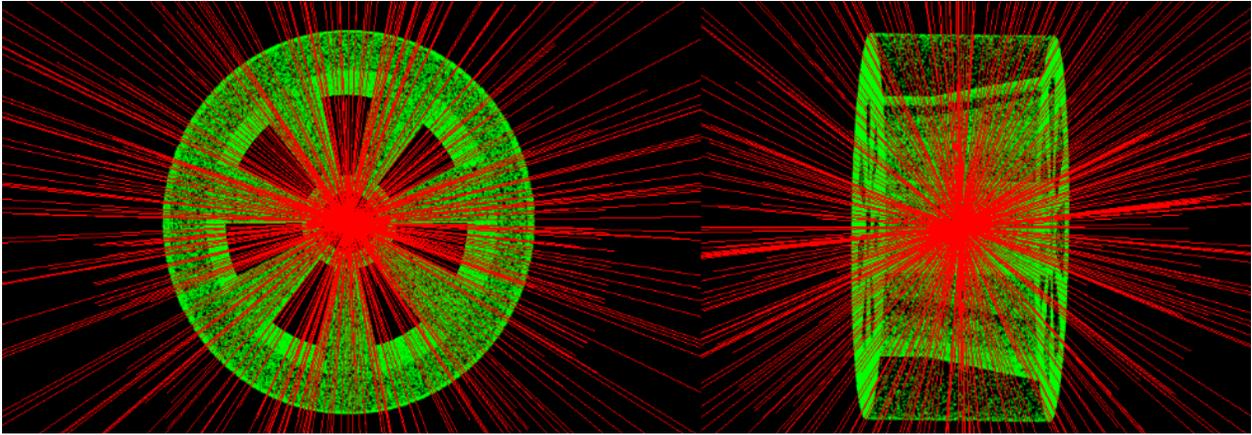


Subtracting the piece 7 from shape 1 (cylindrical) 7 times, each time rotating by $\frac{2\pi}{7}$ gives the Shape 8 which is the final collimator piece.

Now subtract this shape from the cylinder to make the inverted solid. Again subtract that inverted solid from the opening piece to make the opening hole.

3 Simulation

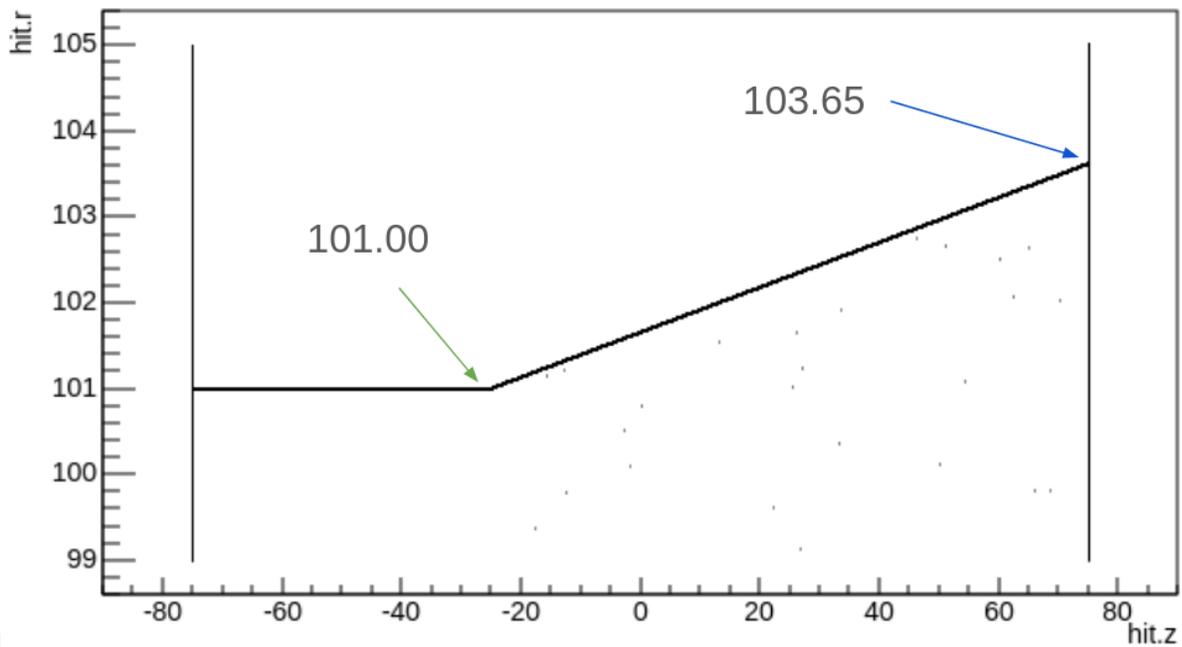
Simulation is done with a new toy-geant4 simulation. In this toy simulation, the object is placed at the origin. The generator is a particle generator that shoots uniformly generated particles from an arbitrary spherical surface, radially towards the center. This ensures uniform hit distribution on each of the boundaries. The test object is made of vacuum material so no particles attenuates.



3.1 Radial taper

The radial taper is very clearly obtained to be 1.5deg from simulation.

```
T->Draw("hit.r:hit.z", "hit.r > 99 && hit.r < 105")
```



The radial taper is clearly seen as expected to be 1.5deg.

$$\tan^{-1} \left(\frac{103.65 - 101.00}{100} \right) = 1.5^\circ$$

3.2 Azimuthal taper

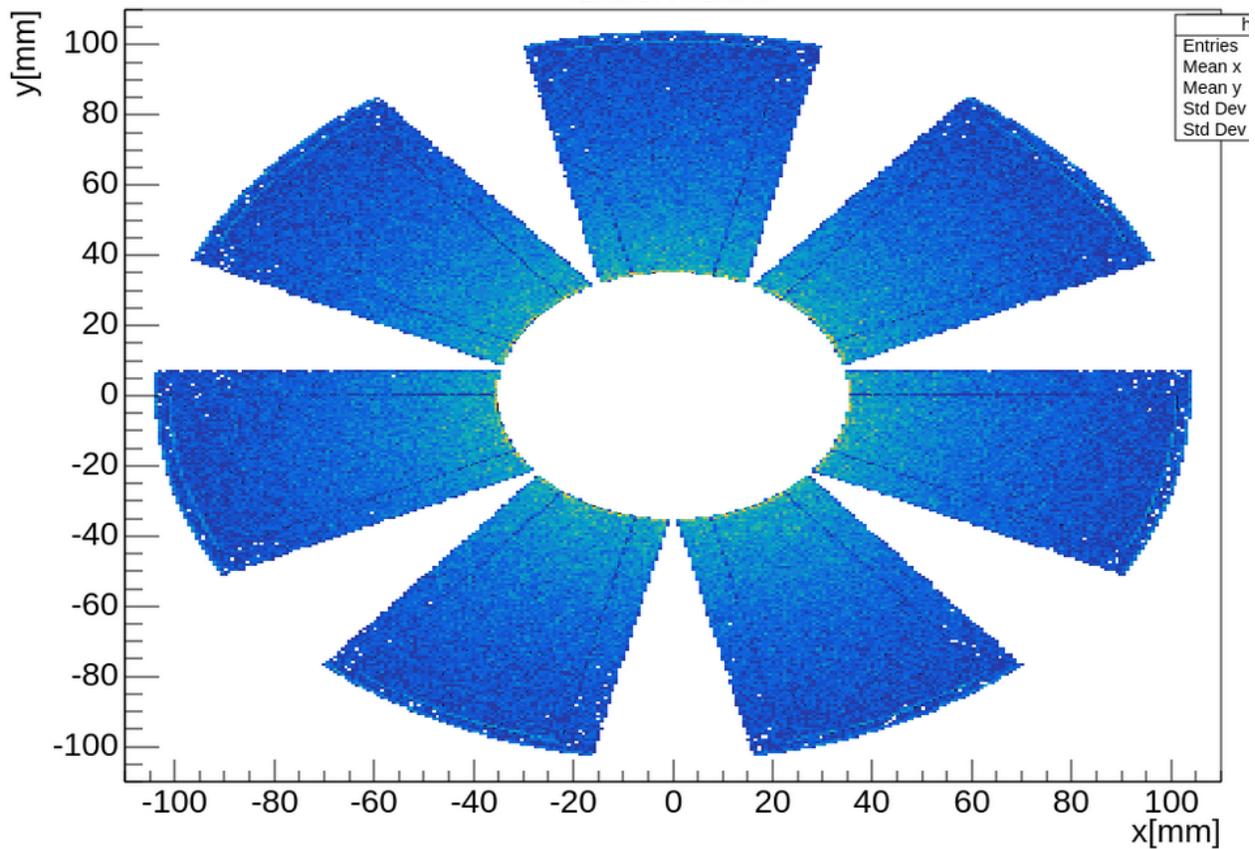
To get the azimuthal taper first I select events in narrow band of front face. And narrow band in back face.

```

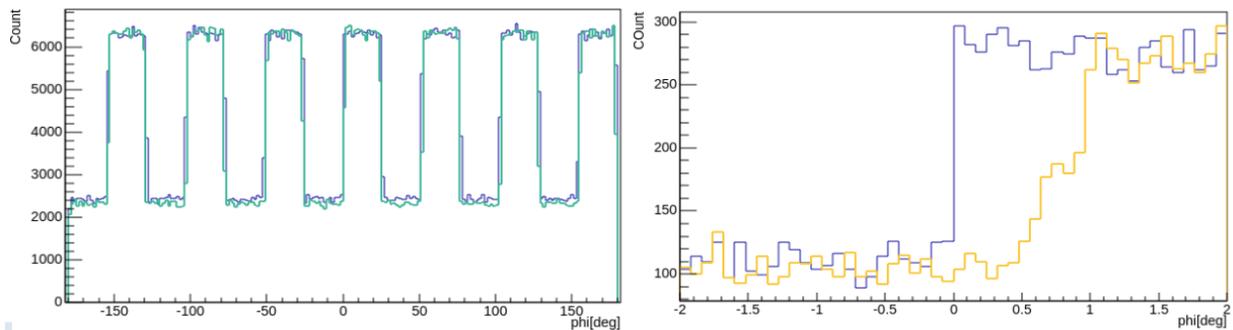
auto h1 = new TH2D("h2f","Front face; x[mm]; y[mm]",900,-110,110,300,-110,110)
auto h2 = new TH2D("h2b","Back face; x[mm]; y[mm]",900,-110,110,300,-110,110)
T->Draw("hit.y:hit.x>>h2b","(75-hit.z) < 0.001")
T->Draw("hit.y:hit.x>>h2f","(hit.z+75) < 0.001")

```

Since we have enough statistics, we can limit the faces to within $1\mu\text{m}$ of the faces. This gives us very clean separation of hits in the faces. Plot below shows the overlaid version of back vs front faces. The azimuthal taper is *exaggerated* to make it clearly visible.



For each of the faces, if we plot the azimuthal angles of the hits we will see clear azimuthal angle differences. This is shown in the figure below.

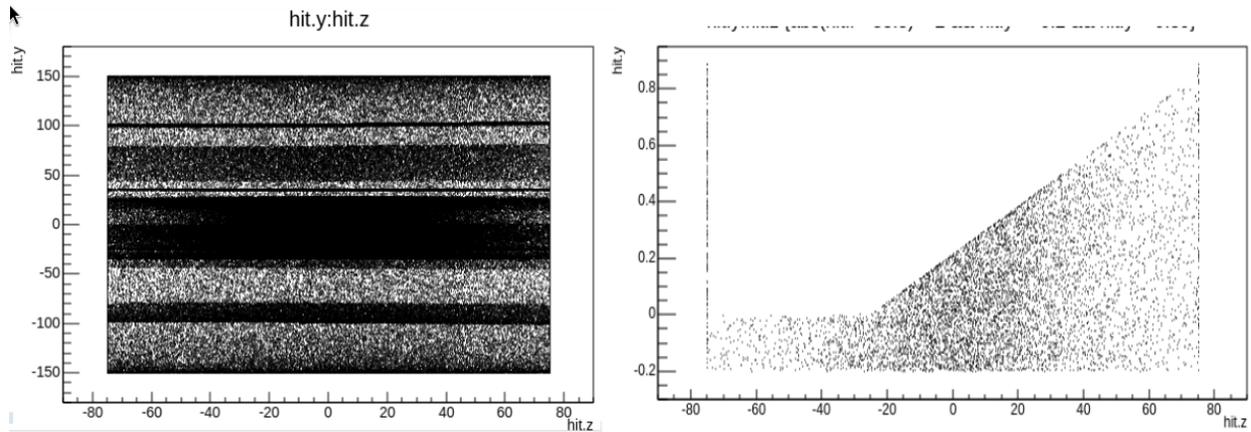


The right plot clearly shows that the back face (yellow) has larger azimuthal edge. The edge is at 0.5deg

larger than the front face, verifying the taper.

There is another way of verifying the azimuthal taper.

```
T->Draw("hit.y:hit.z","abs(hit.r - 35.5) < 2 && hit.y > -0.2 && hit.y < 0.89")
```

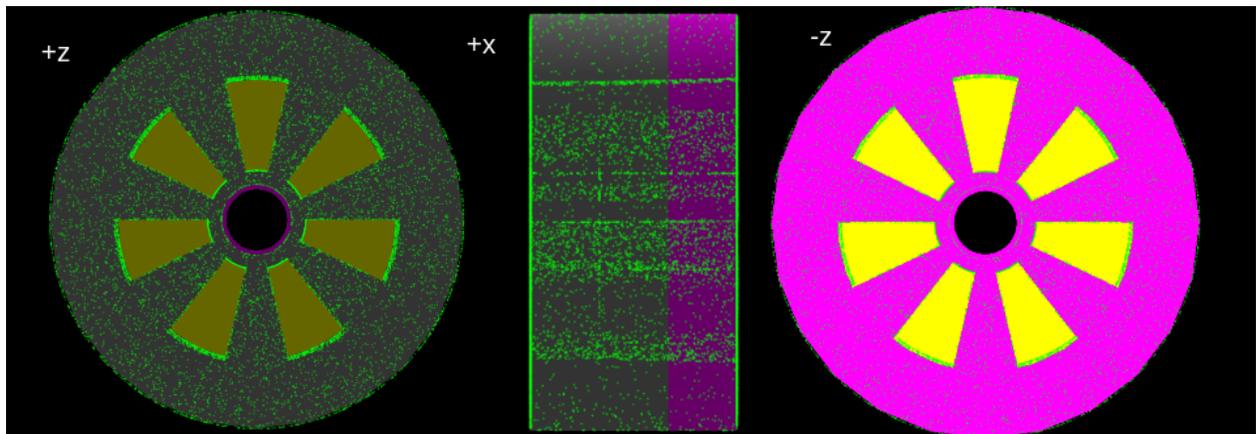


If we plot hit.y vs hit.z, we can see (among others) the edges of IR at 35.5. If we select that edge:

$$\tan^{-1} \left(\frac{0.86 - 0.00}{100} \right) = 0.49\text{deg}$$

4 Remoll Simulation

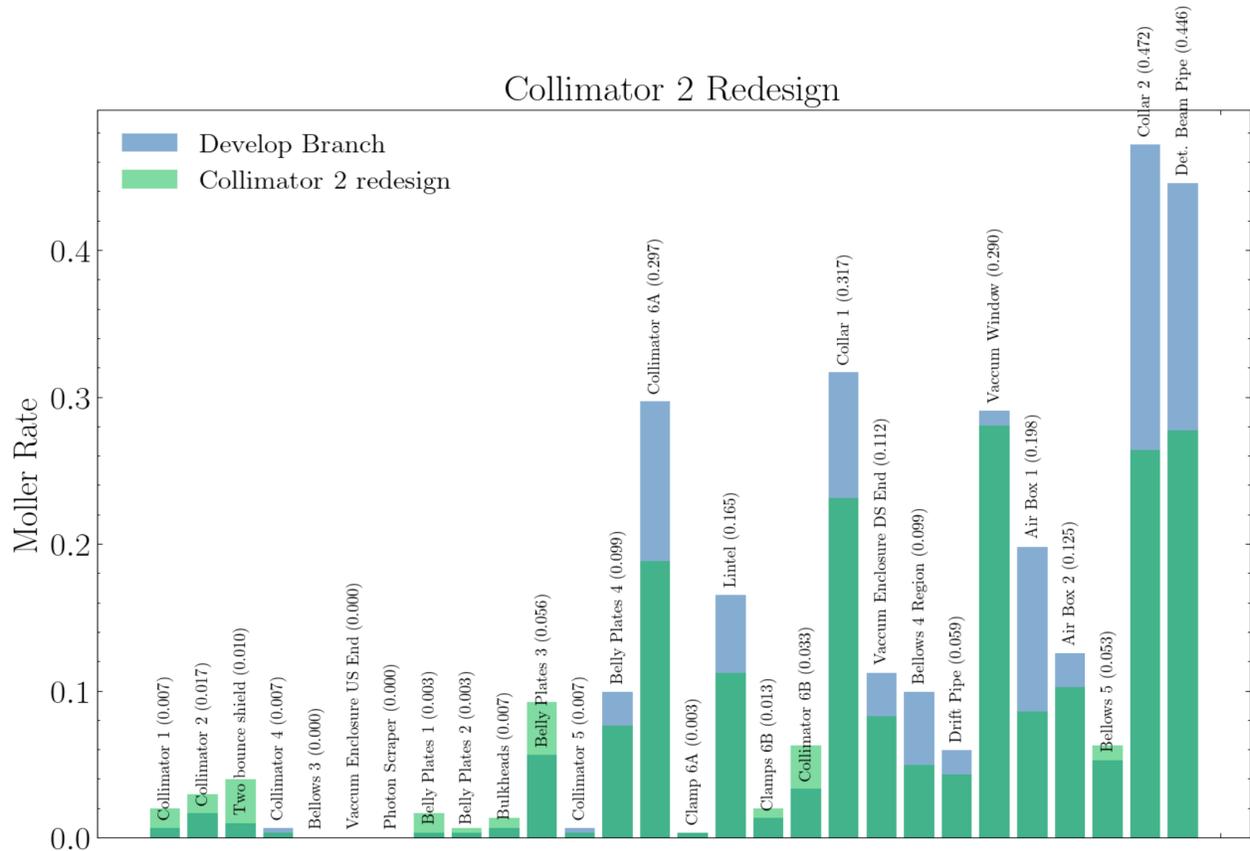
Implementating this goemtry in remoll



The new collimator2 solid is made of cloud points in geant4 which allows us to see the overlap between the new and the existing collimator2 geometry(from develop branch). On this view there is a little bit of pink geometry visible in the first +z view which is because the last 3rd in the original implementation has non uniform bore hole. Which I have to implement in this implementation as well. But for current simulation we will just take this and run the simulation.

4.1 All edges background comparison

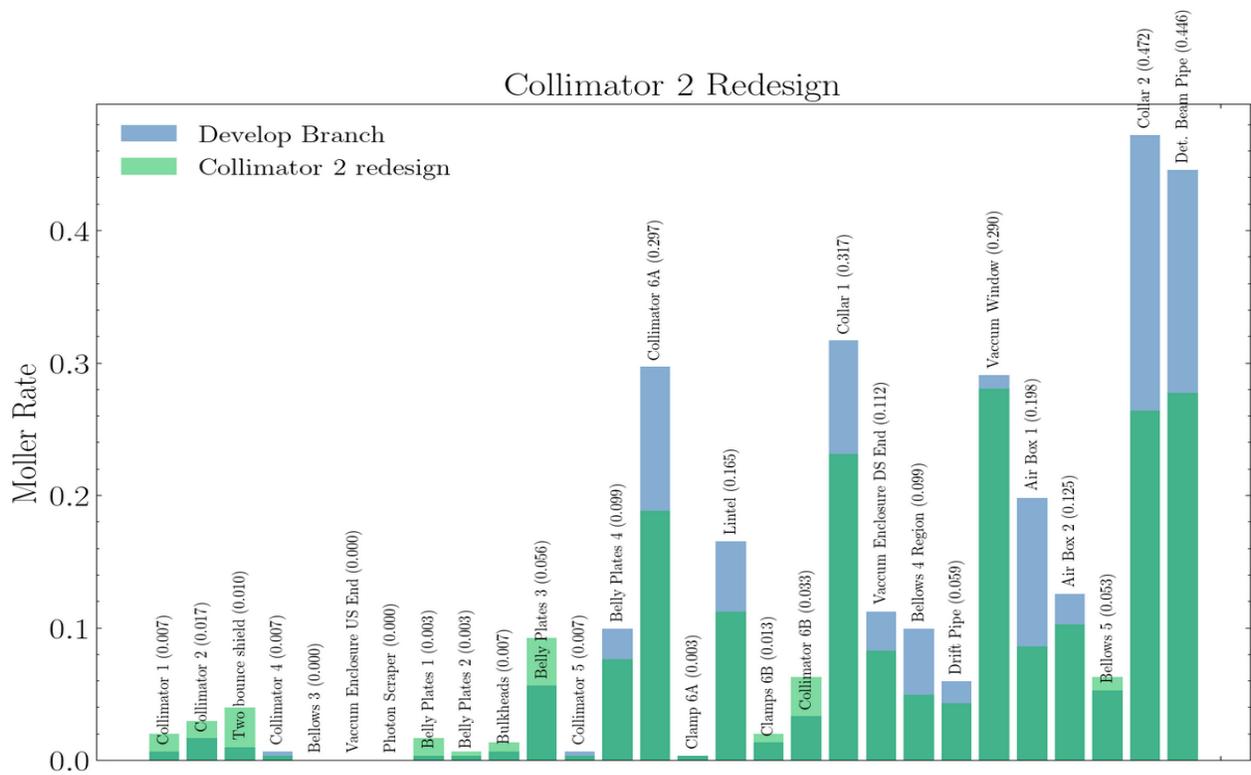
With the new gdml design of collimator 2, a new 1×10^8 beam simulation was done. I had a previous beam simulation with develop branch done a few months back.



This is a plot of background of all edges(ref. DCDB-1159). This is comparison of background from all edges in the spectrometer. The dataset labelled “Develop Branch”, is develop branch which has old collimator 2 design. The dataset labelled “Collimator 2 redesign” is new collimator 2 redesign.

It looks there is a slight increase in collimator 2 background (could be statistical) but looks like significant improvement in collimator 6A, Collar2 and Det. beampipe. This is a bit confusing. I wasn't expecting this much change.

I am going to do a new simulation with the develop branch again with same setting again to make sure that the last simulation did not have anything out the ordinary. So I just ran the simulation, and we have the result.

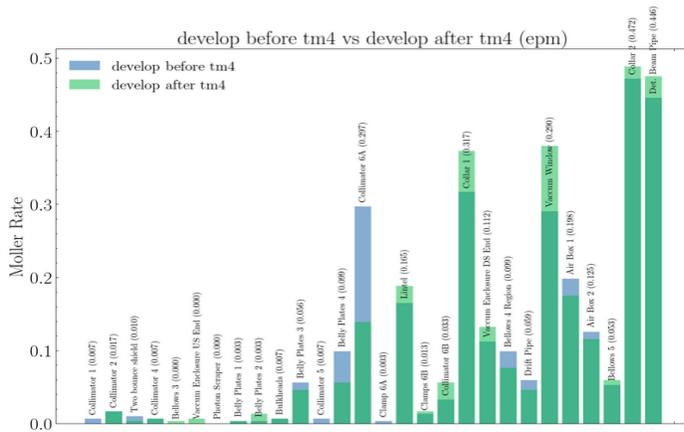


This again confirms the previous observation. There is significant improvement in Collimator 6A, Collar 2 and detector beam pipe.

There needs to be more tests done to make sure that this is infact the case.

4.2 Redo the develop again with asymmetric field

So I did the simulation with develop branch (old coll2 design) with asymmetric field. Because after the last TM4 assembly movement I had not done asymmetric field simulation.

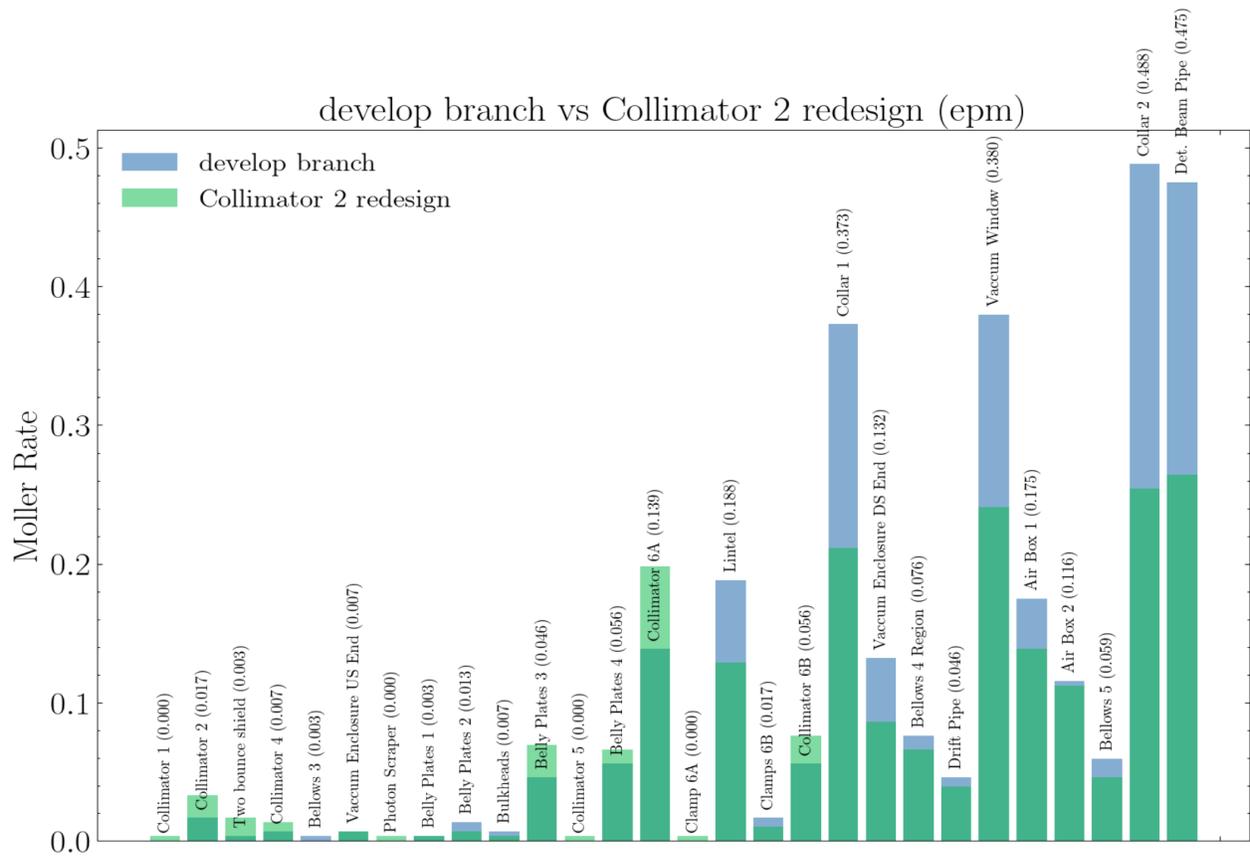


So, for the comparison of asymmetric field map before and after th TM4 move. This shows that there is decrease in the background from Collimator 6A, which was also seen in the last study comparing with develop branch but only with symmetric field.

4.3 Compare again the asymmetric field with Collimator2 redesign

So I redid the collimator 2 redesign simulation with asymmetric field. The field used are:

1. US Field: V2U.1a.50cm.parallel.real_asymmetric.txt
2. DS Field: DS_TM1-4_Coila-G_ll_TM2-4_out3mm_asym_case_II.txt



This plot again shows same result as I saw last with naive comparison without TM4 move; that there is significant reduction in backgrounds in collar2 and det. beam pipe.

I have to think more about what this could mean.