Designing a Gamma-Ray Collimator

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Background

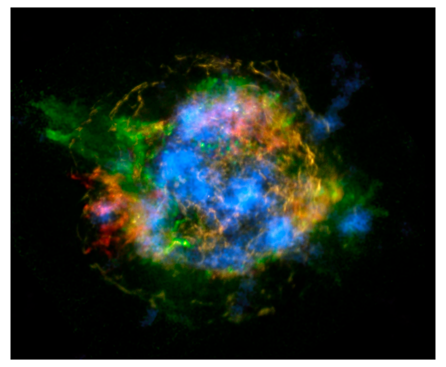

Figure 1: Cassiopeia A, each color represents a different element [1].

The elements that we are made of, specifically those heavier than iron, can be formed in supernova explosions and observing these environments will tell us more about how those elements are created. The Superconducting Titanium Imager (SCOTTI) has a goal to map the 68 and 78 keV emission from decays of ^{44}Ti and hopes to obtain an order of magnitude improvement in spectral resolution using Transition Edge Sensor (TES) detectors. To optimize the spectral resolution, we will look at the uniformity across a detector. This project presents the design for a gamma ray collimator that will allow us to study uniformity with a known isotope source by hitting a small spot on the detector.

TES Detectors

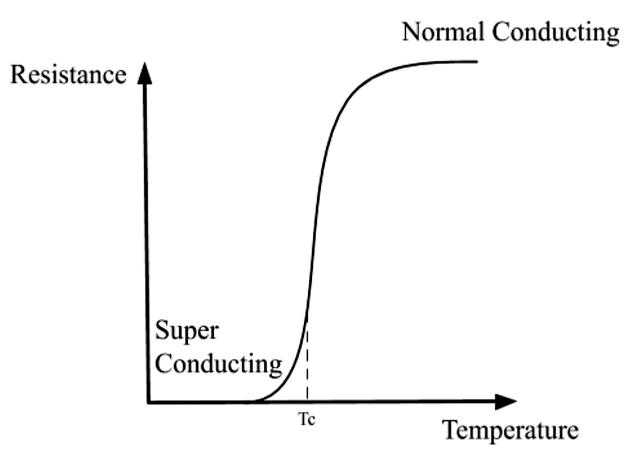

Figure 2: TES biased at superconducting transition temperature.

A TES detector is a superconducting film that is kept at the critical temperature between superconducting and normal conducting. Thermally coupled to the detector is a tin absorber and when a photon strikes this absorber and the temperature changes, there is an increase in resistivity and a drop in current. This current drop is what is related back to the photon energies of our isotope source.

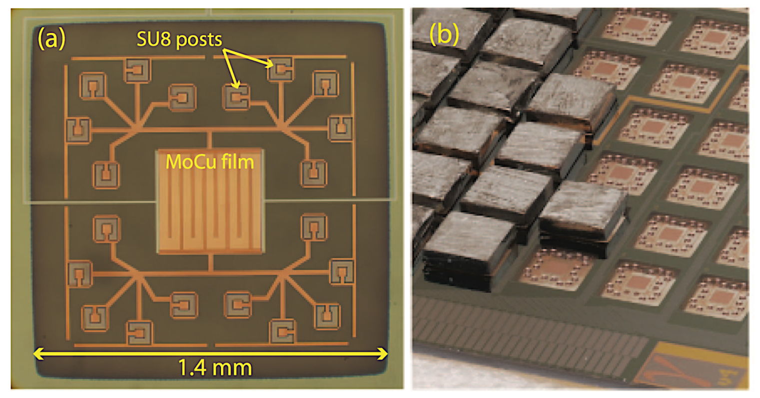

Figure 3: a) TES detector, labeled MoCU film b) Array of detectors and TESs [2].

Design Parameters

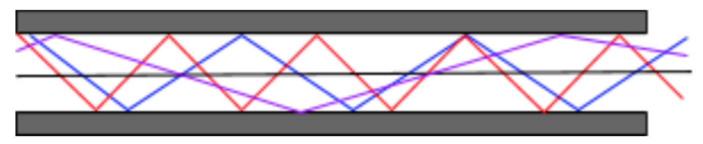

Figure 4a. 2D view of photon scattering in collimator with one long hole.

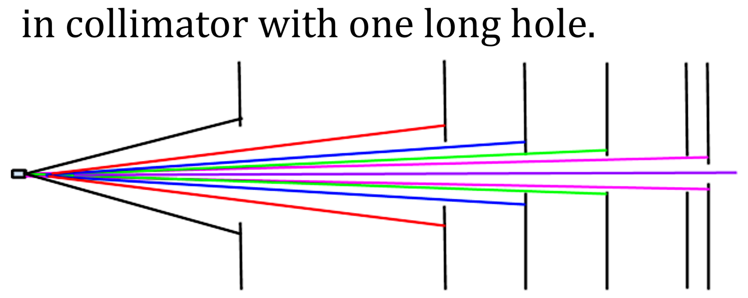

Figure 4b. 2D view of collimation using multiple slits with small pin holes.

Pictured left we can see that having several disks rather than one long tube with a small hole is better for collimating photons. Having vertical slits prevents the photons from scattering off the inside of the collimator like in 4a. The design in 4a would also be difficult to fabricate, as it requires cutting an extremely small hole in a long and thick piece of material.

- Detectors located inside cryostat, 30cm from window.
- Radiation Safety – Thickness of shielding.
- Source with energy lines of interest: 50-100keV.
- 0.2mm spot size on the detector

Source and Collimation

We used ref. [3] to help us select a source with multiple high intensity lines in our range of interest, making sure there aren't any high energies that are too intense to shield. 25mCi of ^{241}Am was chosen because of its favorable gamma-ray lines and this amount will give us approximately 1 billion decays per second. The table below shows the most intense emission lines, what kind of particles are emitted, and their energies. The α particles will not be an issue because they are easily shielded.

Energy (keV)	Intensity (%)	Type	Origin*	Levels Start*	Levels End*	Possible coincidence with (keV) / Possible sum of (levels)
5 485.56 (12)	84.45 (10)	α	Am-241	0	2	
59.5409 (1)	35.92 (17)	γ	Np-237	2	0	
16.96 (-)	18.58 (13)	$X_{L\beta}$	Np-237			
5 442.86 (12)	13.23 (10)	α	Am-241	0	4	
13.852 (-)	13.02 (10)	$X_{L\alpha}$	Np-237			
21.16 (-)	4.83 (3)	$X_{L\gamma}$	Np-237			
26.3446 (2)	2.31 (8)	γ	Np-237	2	1	

Table 1: ^{241}Am alpha, gamma-ray, and x-ray lines [3].

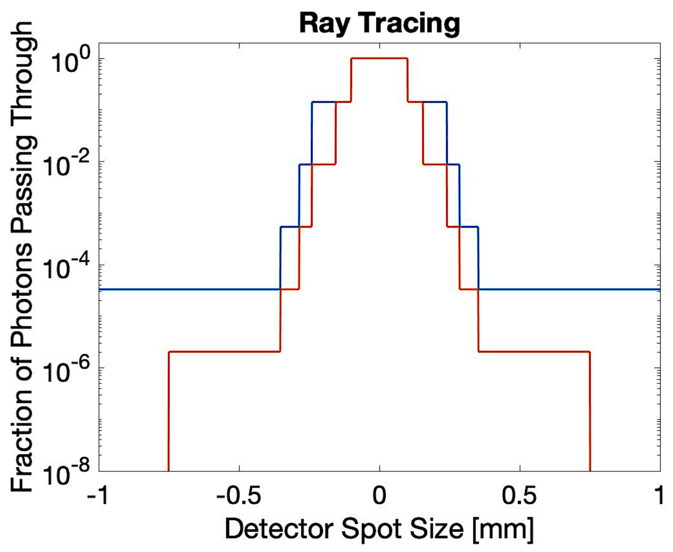

Figure 5: This graph is from a ray tracing code designed to simulate a collimator with slits of different thicknesses and diameters. The code calculates the thickness of Tungsten along each line of sight. Using absorption data from NIST XCOM [4] we calculated the fraction of 60 keV photons transmitted along each line in order to calculate the shape of the spot on the detector.

Shielding

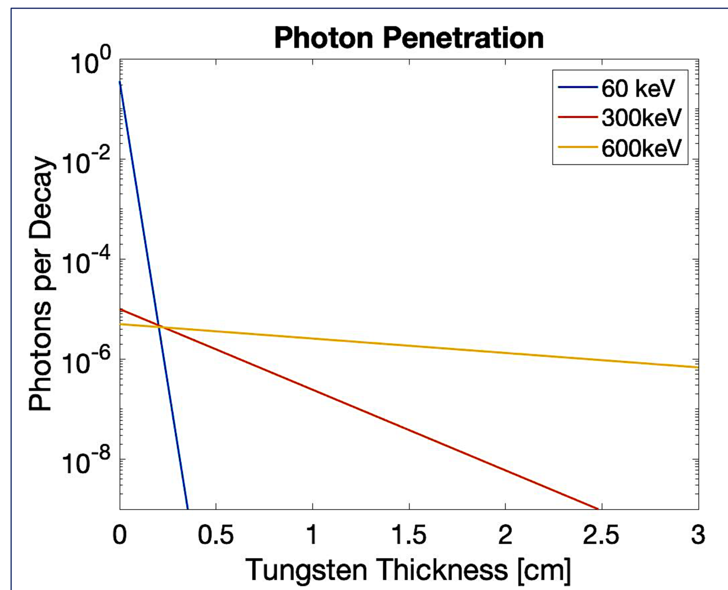

Figure 6: This graph shows the effectiveness of tungsten in shielding photons of 3 different energy levels and intensities. We chose tungsten because it has a high density and a high atomic number which makes it good for shielding. Unlike lead, it is non-toxic and has mechanical properties similar to steel. Using NIST XCOM [4] and a specific Tungsten alloy from ref. [5] we were able to calculate how much tungsten we would need to shield the strongest high energy lines.

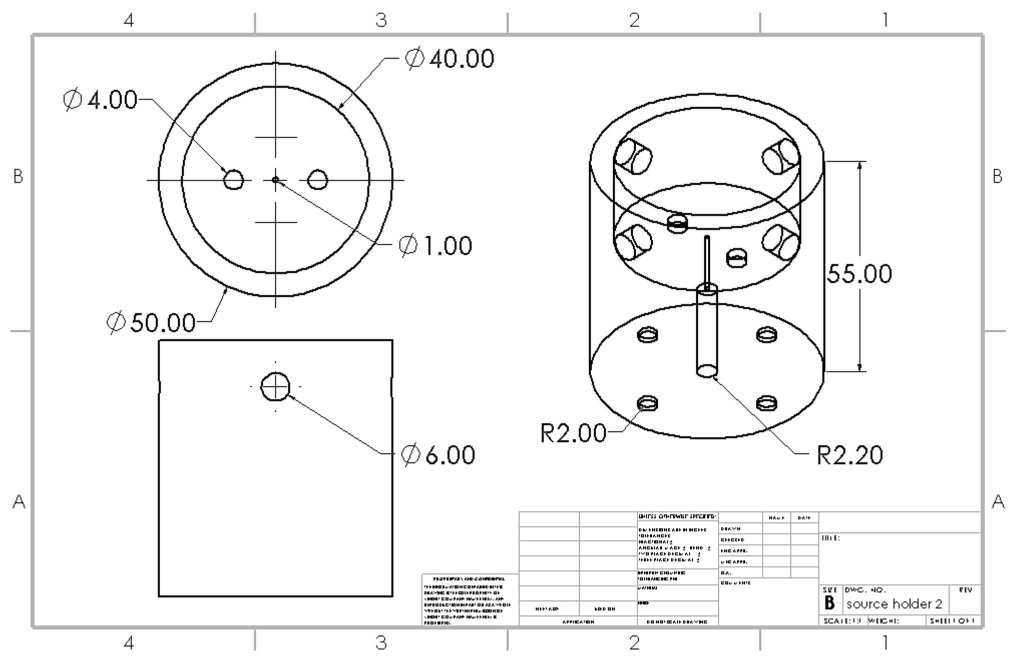

Figure 7: Dimensioned drawing of the source holder made of tungsten with 2cm shielding the source in all directions.

Collimator Assembly

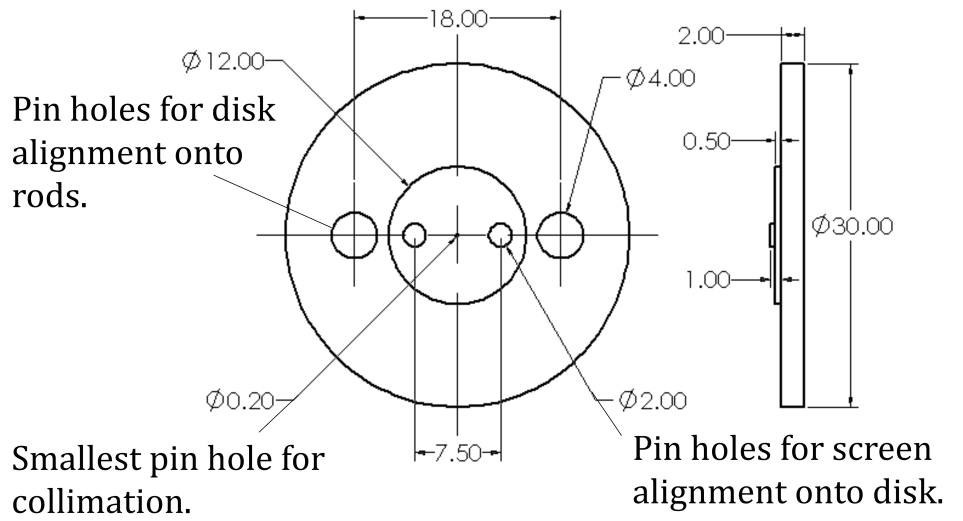

Figure 8: Dimensioned drawing of screen and disk assembly. Figure 5 helped determine how many of these subassemblies we would need, their thicknesses, and center hole diameters to produce a 0.2mm spot size. We chose to make these two separate parts, so we could have a thick supporting disk and still be able to get the small center pin hole we need. The screen is aligned onto the disk using two pins and will be attached using epoxy.

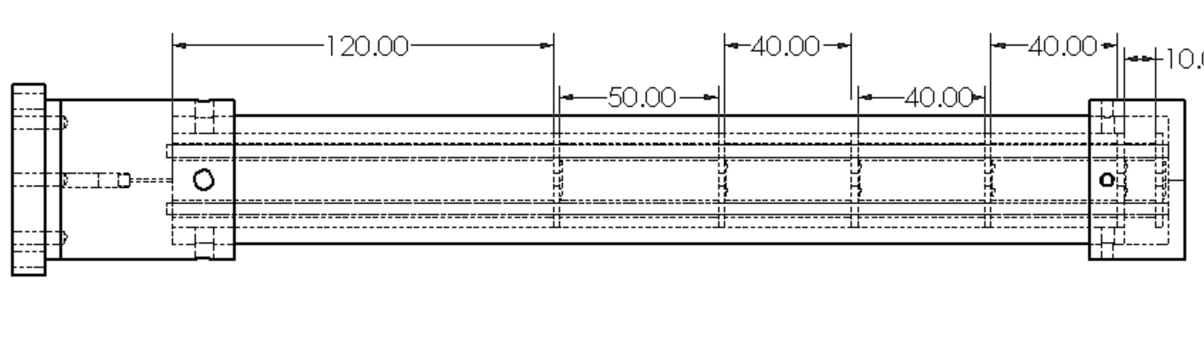

Figure 9: Collimator assembly with dimensioned separations between collimation elements. Separation and alignment of these slits is extremely important in achieving the desired spot size. Each slit is aligned with one another by two stainless steel pins, being kept a specific distance apart with separators. Because our goal is a spot size of 0.2mm, we had to ensure we would be able to fabricate these parts and create the hole sizes we needed. This type of precision can be achieved with laser cutting, which cuts features as small as 15 microns on thicknesses as large as 635 microns [6].

Results

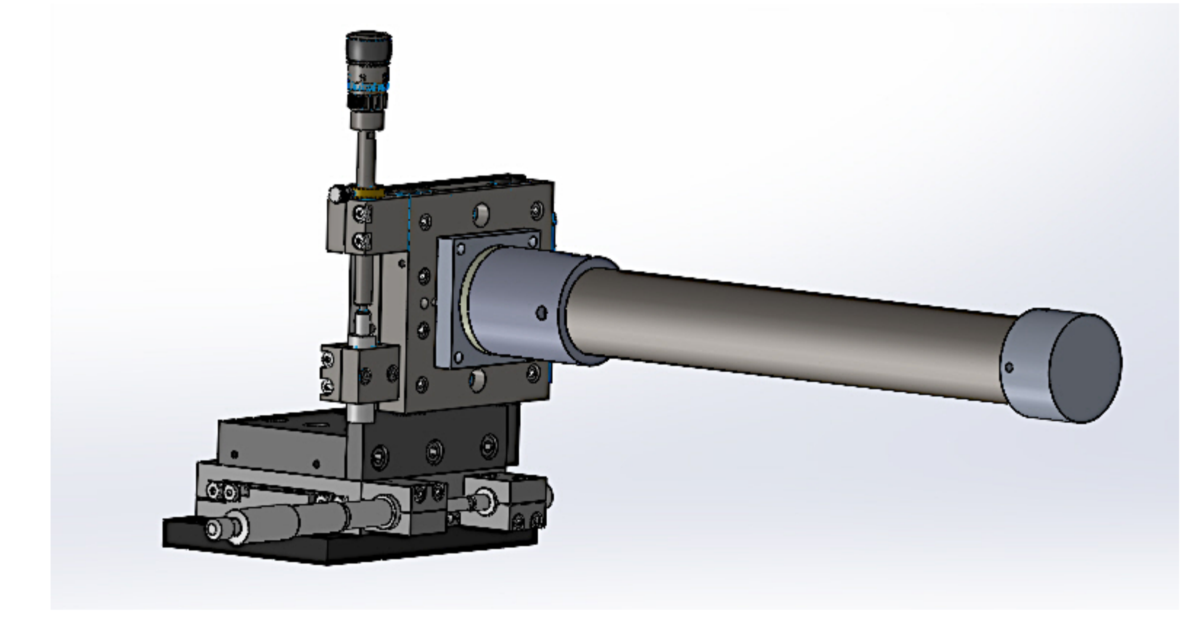

Figure 10: Isometric view of collimator attached to Thor Labs Linear XZ stage Assembly [7]. The vertical stage has a maximum vertical load of 10 kg, which is a factor of 3 larger than the weight of the collimator assembly which is 3387 grams.

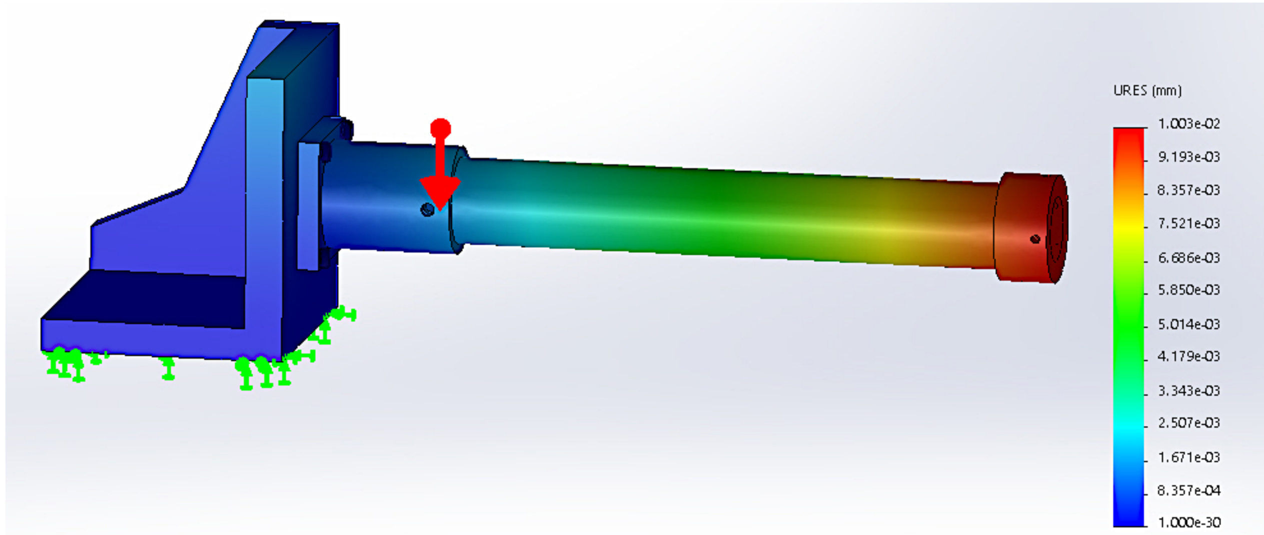

Figure 11: This figure shows the deformation of the collimator while it is attached to a part intended to act as the XZ stage. The calculation shows a maximum sag of the the collimator to be 0.01mm , an order of magnitude smaller than the pinhole size. Having such a wide range of feature sizes made it difficult to run the simulation so the deformation test was done not including the collimation elements, however they only accounted for ~100g out of the overall ~3kg weight so it is likely their weight will not have a large impact.

Acknowledgements & Future Work

I would like to acknowledge my advisor, Fabian Kislat, for his guidance throughout the year while working on this project.

In the future, this design will be used by the machine shop at UNH to build the collimator.

References

[1] B.W. Grefenstette et al. Nature 506 (2014) 339.

[2] D. Bennett et al. Rev. Sci. Inst. 83 (2012) 093113

[3] *NUCLÉIDE-LARA on the Web (2018)*, www.nucleide.org/Laraweb/index.php.

[4] *NIST XCOM: Element/Compound/Mixture*, physics.nist.gov/PhysRefData/Xcom/html/xcom1.html.

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