Measuring Length of Electron Bunches With Optics In LCLS-II

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Introduction

The main goal of this project is to design an optics obstacle course in order to measure electron bunches from the LINAC Coherent Light Source II (LCLS-II). The LCLS-II builds from the success of the LCLS, which was the world's first hard X-ray free-electron laser. The LCLS-II will add a superconducting accelerator, using one - third of SLACs original 2-mile long linear accelerator tunnel. Creating the optics obstacle course, or optics box, will provide feedback from the radiation sent from the electrons that will help ensure a more coherent beam.

Figure 1. Linear Accelerator at SLAC National Lab

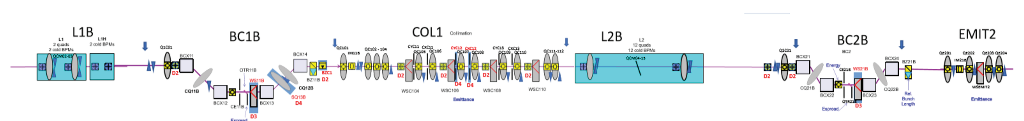

Figure 2. Inside the LCLS-II

Background

Imagine a sine wave with bunches of electrons at the peaks. They distribute themselves just like in Figure 3. Electrons further ahead of the pack have higher energy levels compared to the electrons that are at the back. The end goal is to achieve coherence in the beam, which requires much calibration. In order to do this, we have two chicanes with four dipole magnets each, which are designated as bunch compressors (BC1 and BC2), a monitor of the average energy of the beams (Collimation Diagnostics), and a beam chirper that controls the energy put into the electrons. The dipole magnets are used to bend electron around the serpentine curve. At each bend, edge radiation is emitted from the electron beam. This radiation is what is sent into the optics box and is then used to measure the diagnostics of the beam coherence and strength.

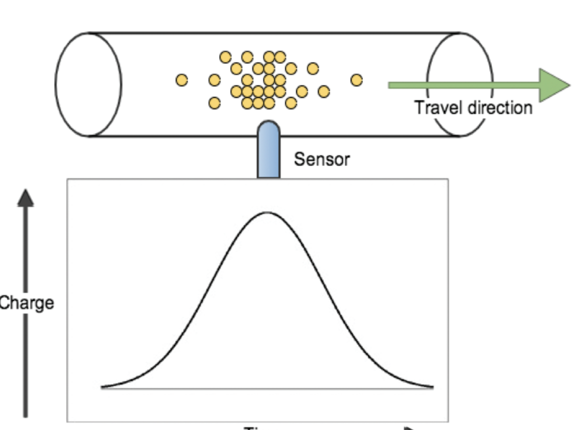

Figure 3. Electron Bunch and Gaussian

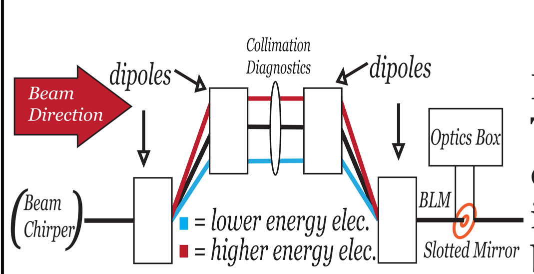

Figure 4. Bunch Compressor Chicane

Imagine a race track like Figure 5. The shortest distance around a curve is the inner most path. Thus, in order to compress our electron beams in the bunch compressor, we send electrons with lower energy along the shorter path (blue) and higher energy electrons on the longer path (red). Observe Figure 4. Doing this allows the electrons to meet at the same time resulting in a shorter length. This is done twice, with BC1 and BC2.

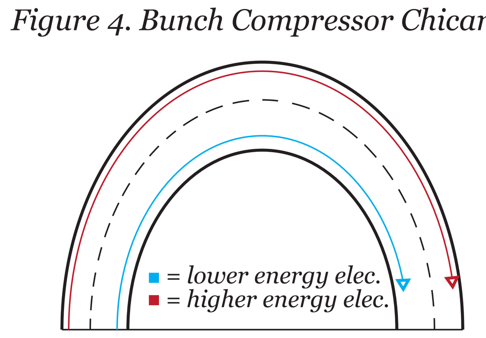

Figure 5. Race Track Analogy

Methods

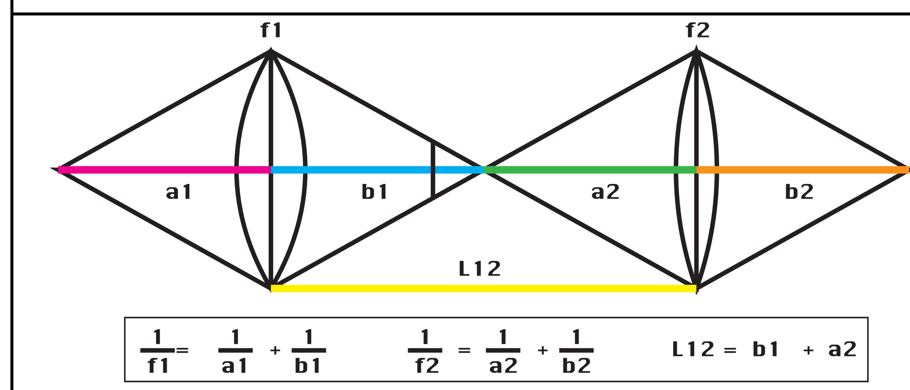

Figure 6. Double Lens Set-Up

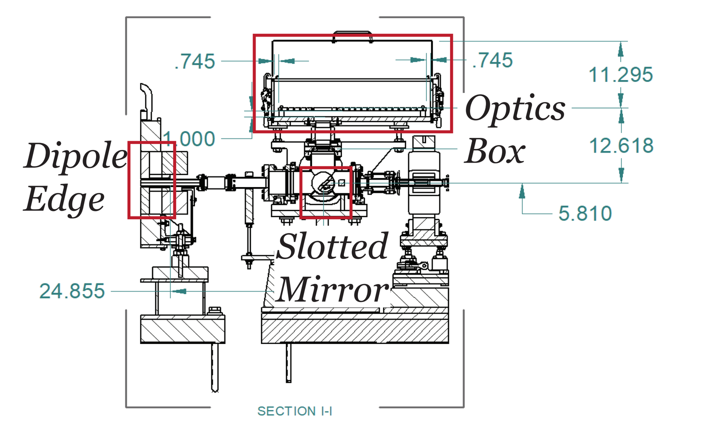

Figure 7. Bunch Length Monitor CAD Design from Engineers[1]

We worked collaboratively with engineers to produce constraints while designing the Optics Box. The constraints, labeled from the Thin Lens Formula as seen in Figure 6., are:

BC1:
- a1 = 28.34"
- f1 = 177.8 mm
- Box = 48" x 36"
- M < 1/2

BC2:
- a1 = 40.31"
- f1 = 228.6 mm
- Box = 48" x 36"
- M < 1/2

These constraints were used to find the unknown distances and focal length:
- b1
- b2
- a2
- f2

Then, we searched for THz filters that have:
- Cut-on Wavelength at 50 um
- Durable Materials
- High Transmittance Over Time

Results

Manipulating the Thin Lens Formula from Figure 6., we were able to calculate the optimal distances and focal lengths for BC1 and BC2, while using off-the-shelf products. This ensures a lower cost and delivery time. You can see in Table 1 the values that were calculated, and then used to design the Optics Boxes in Figure 8 and Figure 9 using Adobe Illustrator.

		f1	f2	a1	b1	a2	b2	L12	m1	m2	M
BC1	mm	177.8	101.6	719.7344	236.133333	185	225.371703	421.133333	0.32808399	1.21822542	0.39968026
	inch	7	4	28.336	9.29658793	7.28346457	8.87290168	16.5800525			
BC2	mm	228.6	101.6	1023.823	294.31485	185	225.371703	479.31485	0.28746653	1.21822542	0.35019904
	inch	9	4	40.3079921	11.5871988	7.28346457	8.87290168	18.8706634			

Table 1. BC1 and BC2 Calculated Data

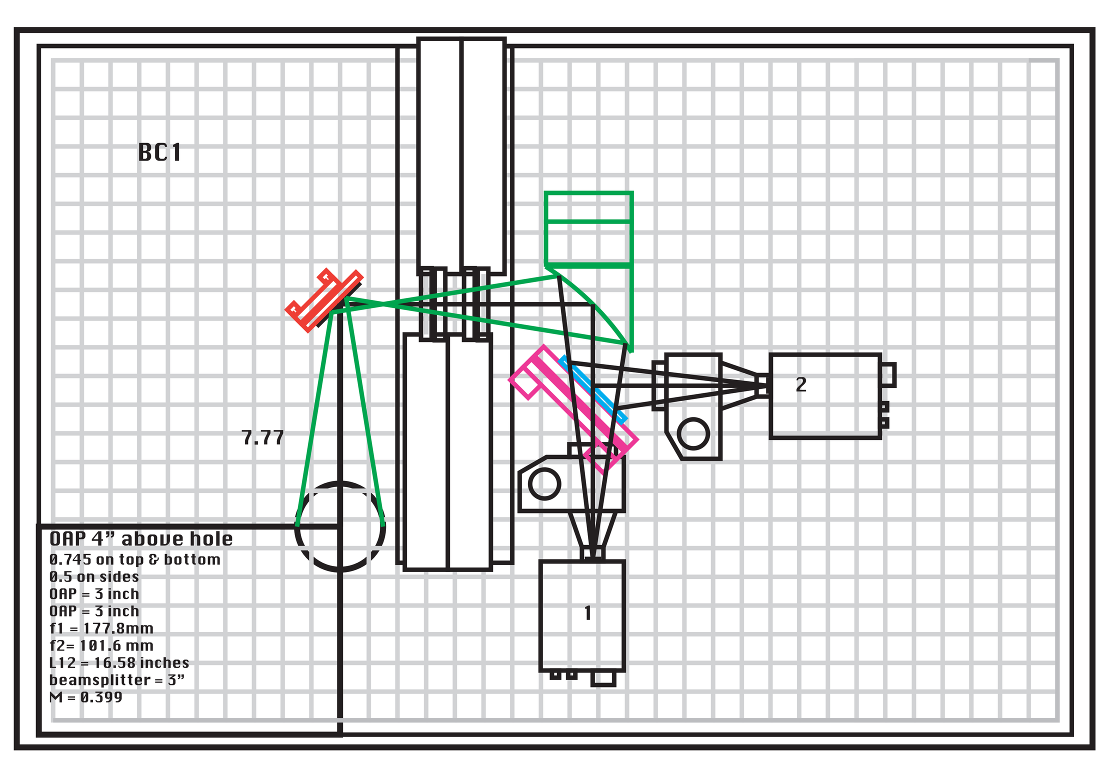

Figure 8. BC1 Optics Box Layout

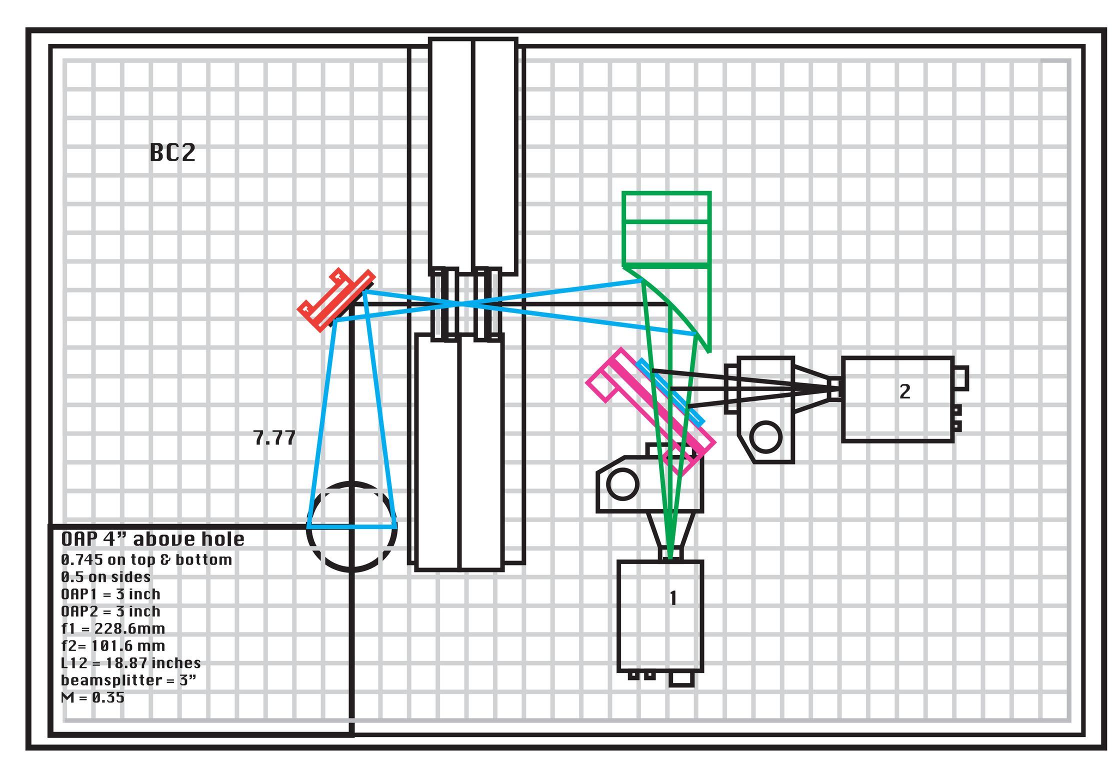

Figure 9. BC2 Optics Box Layout

After finalizing the Optics Box Layouts for BC1 and BC2, we were then able to find a company that produced THz filters with the majority of the specifications that were needed.

Conclusion

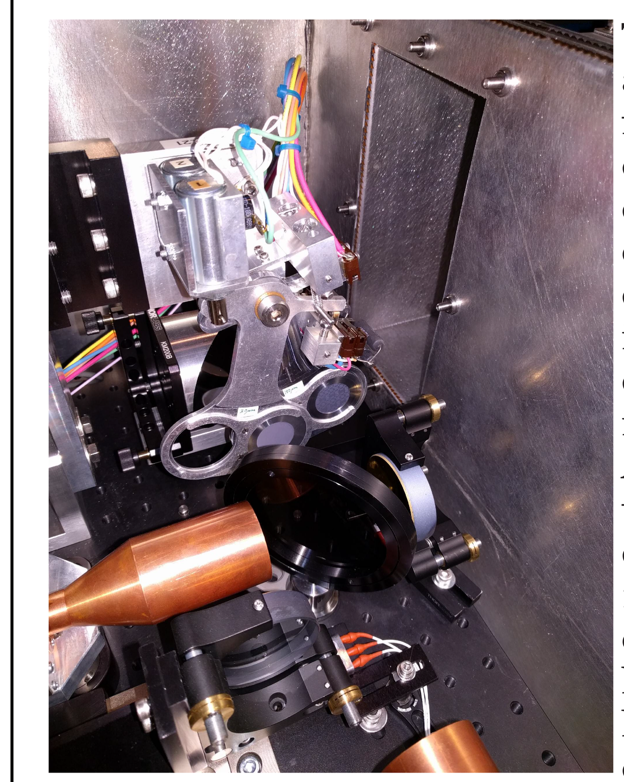

Figure 10. Optics Box Interior in LCLS

The designs in Figure 8. and Figure 9. are potential final layouts, however, the designs can be subject to change due to a number of reasons. One factor that could change the designs is the availability of components for the interior mechanics of the box. Another factor could be that a more feasible design could be achieved. Figure 10. depicts what the interior of a built Optics Box would look like and is currently housed in the LCLS. The design for each component is different, which has been re-designed for the LCLS-II.

Things to consider for the future are the limitations to modeling softwares. This project used Adobe Illustrator as mentioned before, but limited perspective because a 2D design lacks a z-plane. Other modeling softwares to consider would be:
- Autodesk
- Houdini
- Cinema 4D

A final thing to consider would be the time it takes to coordinate with international companies that specialize in optics. Emailing over international time zones complicated communication and can often take weeks. This is something that should be prioritized in the future.

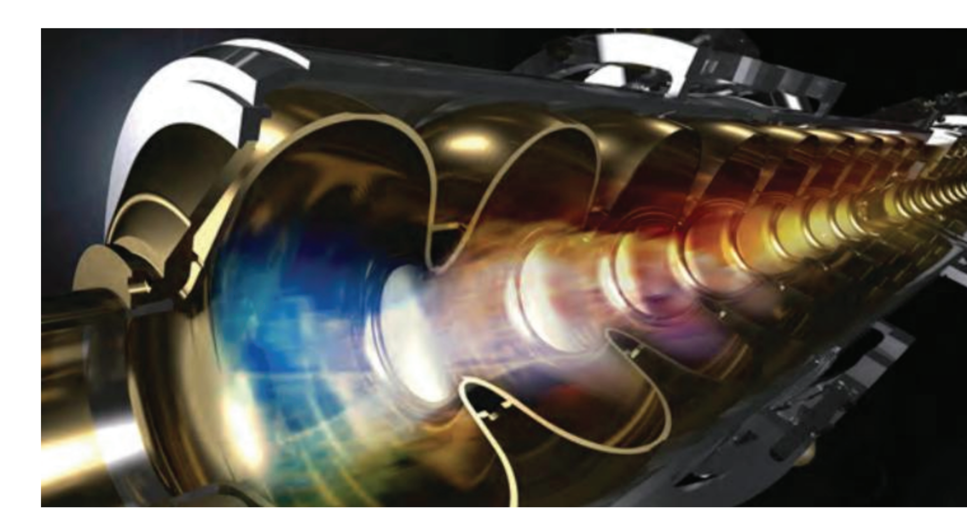

Figure 11. Render of LCLS-II Beam

[1] Tien Tan from Private Communication.

Acknowledgements

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