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Scattering from the DarkLight target in the e-Linac

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Abstract: The DarkLight experiment is moving forward at TRIUMF with the recent installation of the target module in the e-Linac beamline. The resulting scattering from the electron beam on the proposed 1 µm tantalum target foil is modeled. It is shown that the effect of this scattering on the beam envelope vastly exceeds the beam loss tolerance of 1 W/m in the beamline. Therefore, a maximum target thickness is calculated using this constraint. It is found that a 10 kW beam could tolerate the scattering from a target with a maximum thickness of 7 nm.

1 Introduction

The DarkLight experiment is moving forward at TRIUMF, with the experimental apparatus currently being integrated into the e-Linac beamline. This experiment will be run parasitically alongside the e-Linac's other operations, notably the ARIEL rare isotope facility. The DarkLight target module was recently installed downstream of the acceleration cryomodule. In order to finalize the target design, it is essential to quantify the effect that the proposed 1 μm tantalum foil would have on the beam. The following sections will detail how this is accomplished.

2 TRANSOPTR envelope simulation

The first step to quantifying the effect of the DarkLight target foil on the beamline is to identify its exact location and add it as an element in the acc database. This is obtained from the installation drawings, and the arrow in figure 1 indicates this location in the full e-Linac beamline.

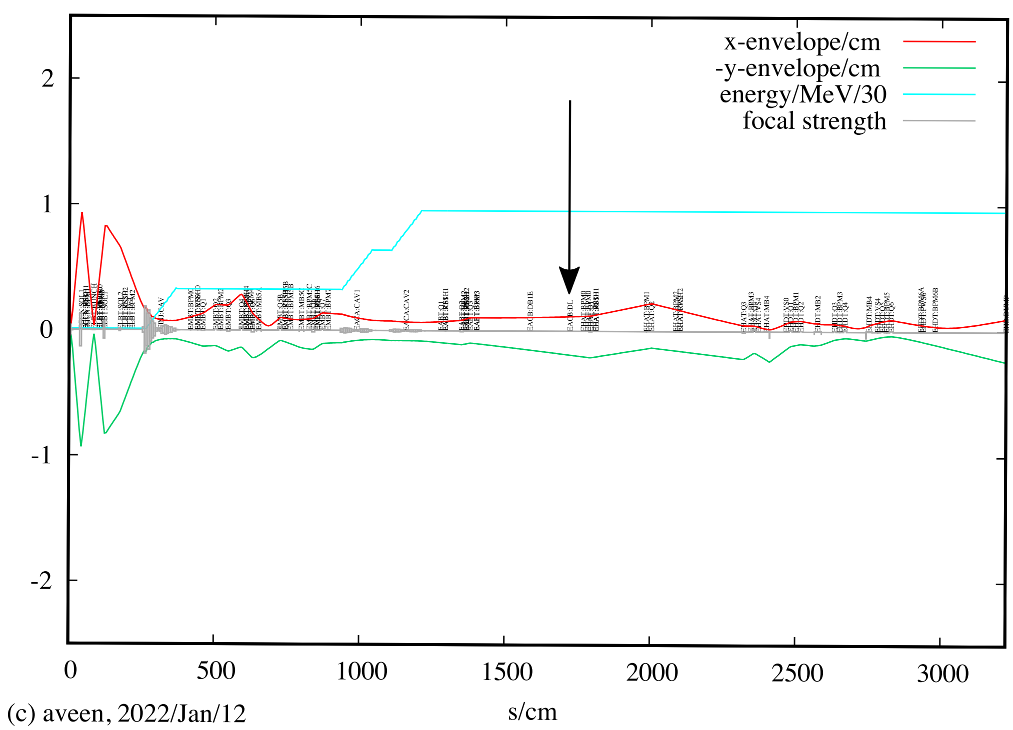

Figure 1: Optimized 2 RMS full e-Linac envelope with no scattering. Bounds of the y-axis are set at the aperture of the beampipe (≈ 1 inch radius).

It is then essential to know how much scattering will be added to the beam for a given target thickness. An additional study on the effect of target foils on beam spread was performed by Kate Pachal in [1], and from this study we obtain the RMS scattering values for various foil thicknesses, presented in table 1:

Foil thickness	1 μm	5 μm	10 μm
Beam RMS	7.7 mrad	18 mrad	26 mrad

Table 1: Beam RMS for various target foil thicknesses.

Using these values, I implemented the built-in ADDSCATTER2 routine in TRANSOPTR to visualize the effect on the 2RMS envelope of the beam. Figure 2 shows the resulting beam envelopes after adding the 7.7 mrad RMS scattering from the 1 μm foil. It can be seen that the beam envelope expands dramatically after the DarkLight target, which would result in it hitting the sides of the beampipe. This would incur incredible amounts of beam losses downstream of the target, which would exceed the 1 W/m machine protection requirement [2]. Therefore, the 1 μm target foil is not a viable option for this experiment.

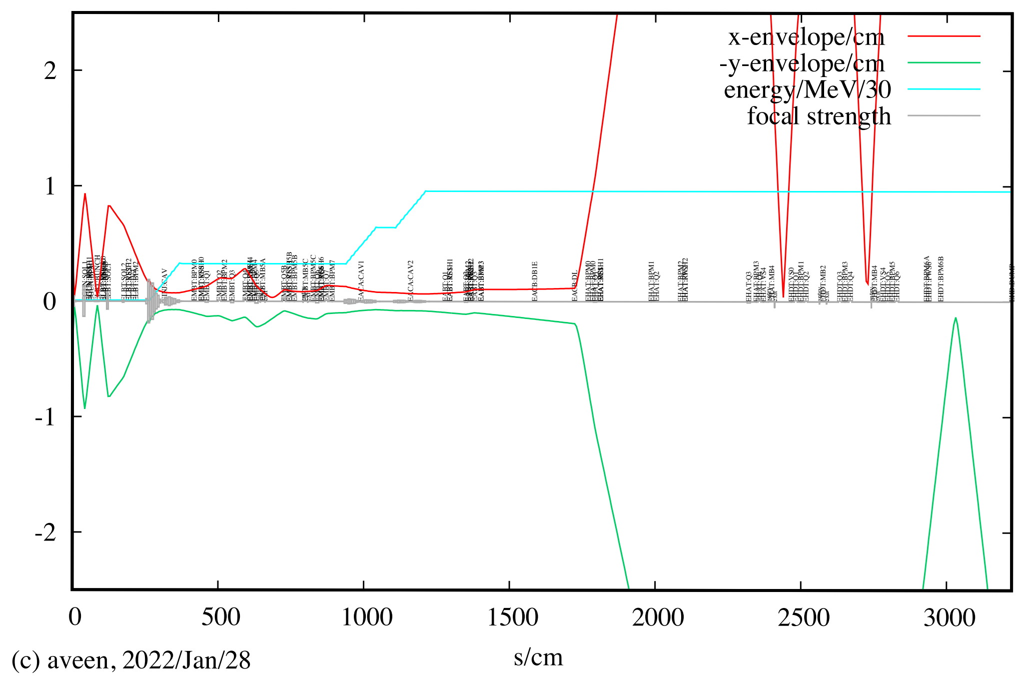

Figure 2: Optimized 2 RMS full e-Linac envelope with added 7.7 RMS scattering from 1 μm target foil. Bounds of the y-axis are set at the aperture of the beampipe (≈ 1 inch radius).

3 Calculation of maximum target thickness

The results from the previous section indicate that the currently proposed target would incur a degree of scattering that cannot be tolerated by the e-Linac beamline. An initial suggestion by Douglas Hasell of the DarkLight collaboration is to further focus the beam onto the target, which would help minimize the overall scattering. This is implemented by optimizing the three quadrupoles upstream of the target to this effect. However, this alone will not be sufficient to reduce the scattering to manageable levels. Therefore, it is necessary to calculate the maximum tolerable scattering - and thereby maximum target thickness - using this configuration.

The maximum allowance for beam losses in the e-Linac is 1 W/m of beamline; this limitation is key to determining the maximum tolerable scattering. I modeled a 10 kW beam assuming a Gaussian distribution, and integrated it for the value of sigma where 1/10 000 W would be lost. This calculation is shown in equation 1, and returns a value of 3.7 sigma.

$$\int_{3.7\sigma}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-\mathrm{x}^2}{2\,\sigma^2}\right] = 10^{-4} \tag{1}$$

Plotting this 3.7 sigma envelope allows me to determine how much scattering we can add before reaching the limit on beam losses. Figure 3 shows this 3.7 sigma envelope from the exit of the EACA cryomodule to the beam dump with no added scatter.

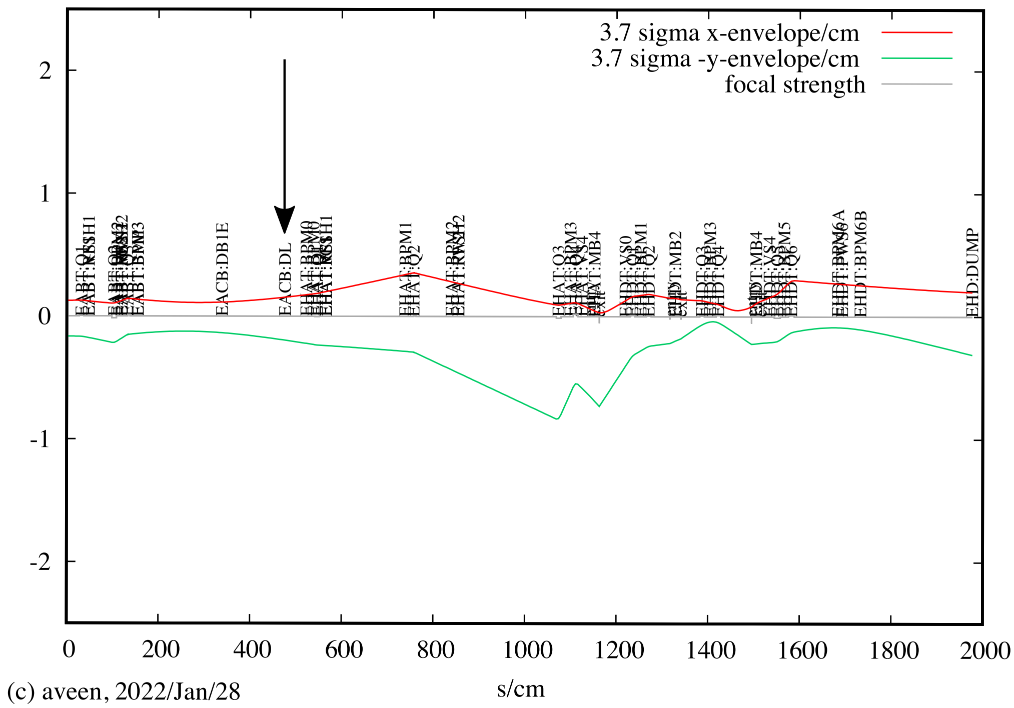

Figure 3: Newly optimized $3.7\,\sigma$ envelope from the exit of EACA to the beam dump with no scattering. Bounds of the y-axis are set at the aperture of the beampipe ($\approx$1 inch radius).

I once again make use of the ADDSCATTER2 routine to test how much scattering can be added before this envelope hits the aperture of the beampipe. Figure 4 shows the final envelope that I was able to obtain, which corresponds to an added scattering of 0.65 RMS. Adding more scattering than this causes the y-envelope to exceed the y-axis limits of the plot, which signifies a loss greater than 1 W/m. Therefore, the maximum scattering that can be incurred from the DarkLight target foil is 0.65 RMS. This value can be used to find the corresponding foil thickness using the square root relation for multiple scattering [3]:

$$\theta_{\mathrm{RMS}} = \frac{13.6\,\mathrm{MeV/c}}{\beta p}\, z \sqrt{\frac{x}{X_0}} \quad \Longrightarrow \quad \theta_{\mathrm{RMS}} \propto \sqrt{x} \tag{2}$$

Comparing this with the known RMS/thickness ratios from table 1, I find a corresponding foil thickness of $\approx$ 7 nm. Therefore, 7 nm is the maximum foil thickness tolerable for the DarkLight target such that we do not exceed the beam loss allowance.

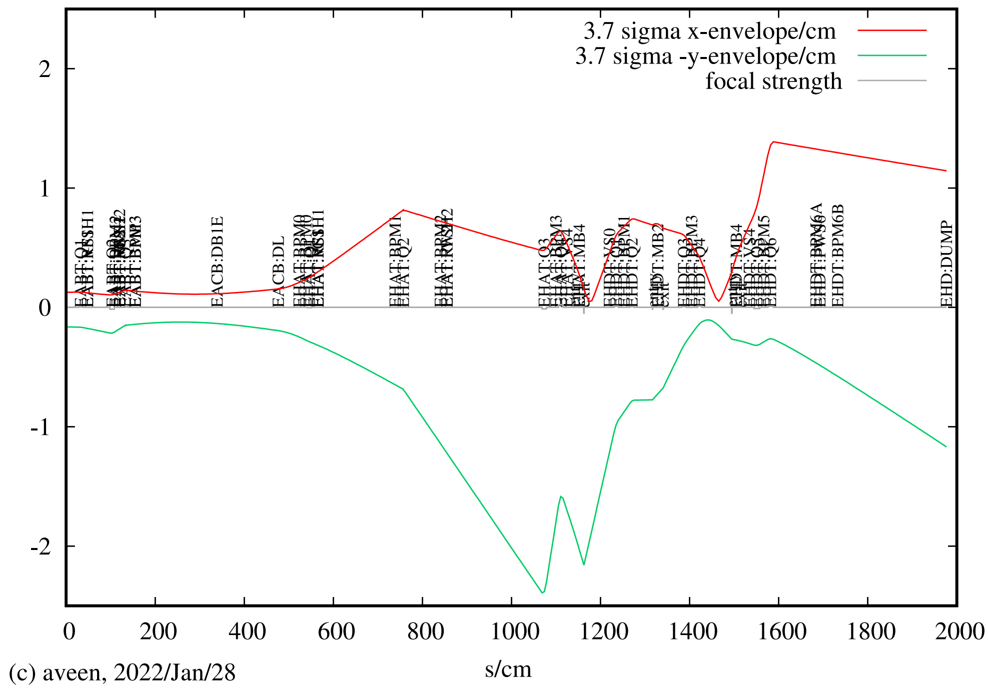

Figure 4: Newly optimized $3.7\,\sigma$ envelope from the exit of EACA to the beam dump with added 0.65 RMS scattering. Bounds of the y-axis are set at the aperture of the beampipe (≈ 1 inch radius).

References

[1] K. Pachal, A look at beam spread and radiation from foils, Tech. rep., TRIUMF (2021).

[2] S. Koscielniak, ARIEL e-linac machine protection system rationale, Tech. Rep. Document-119398, TRIUMF, https://documents.triumf.ca/docushare/dsweb/Get/Document-119398 (2013).

[3] T. D. Collaboration, Technical Design Report (Working Document) For DarkLight at ARIEL, Tech. rep. (2021).