Beam Physics Note
TRI-BN-25-10
May 30, 2025

OLIS BOIS Tuning

Omar Hassan, Christopher Charles, Olivier Shelbaya
TRIUMF

Abstract: Bayesian Optimization for Ion Steering (BOIS) was used at OLIS, to find optimum solutions that maximize transmission up to the OLIS source cup, IOS:FC6. Debugging allowed for issues with BOIS to be addressed. Lack of available beam imaging diagnostics renders the quality of the optimized beams uncertain, which is discussed.

4004 Wesbrook Mall, Vancouver, B.C. Canada V6T 2A3 · Tel: 604 222-1047 · www.triumf.ca

1 Introduction

Recent investigations have found that ISAC's low energy sections suffer from steerer lensing [1, 2], which arise due to circular skimmer apertures together with identically biased opposing steering plates [3]. These exhibit quadrupole effects that have been found to be proportional to the sum of the parallel plate voltages [4]. Due to this steerer lensing problem, it is not advisable to run steerers and commons at high voltages relative to the beam bias V_B. A rule of thumb that has been in use is to bias commons at $V_B/120$[5].

OLIS beam testing during winter shutdown 2025 required a tune of the microwave source, in which operators found that very high initial steerer values were required (IOS:XCB1 and IOS:YCB1). The goal behind these tests was to try to minimize the steerer usage while maintaining a high transmission tune. BOIS has been tested extensively in the low-energy section of ISAC [6], and methods to mitigate steerer lensing have been developed [7]. The most successful method was scaling down the commons according to the beam energy while bounding the steerer values to allow for a maximum of roughly 2mrad steering.

2 Results

2.1 Initial Tests

An initial test was done using the typical procedure: optimizing steerers with UCB at $\beta = 3$ on the downstream Faraday cup (IOS:FC6). UCB is the Upper Confidence Bound acquisition function with a hyperparameter β determining the exploration vs exploitation trade off, it is defined as UCB($\mathbf{x}$) $= \mu(\mathbf{x}) + \sqrt{\beta}\sigma(\mathbf{x})$ [8]. BOIS found higher transmission than the operators, shown in figure 1. However, found solutions used larger voltage differences: 3 steerers were now maxed out (IOS:XCB1, IOS:YCB1, IOS:YCB4), 1 was held at 848 V (IOS:YCB6), and one was not used at all (IOS:YCB3). See figure 2 for the explored input space.

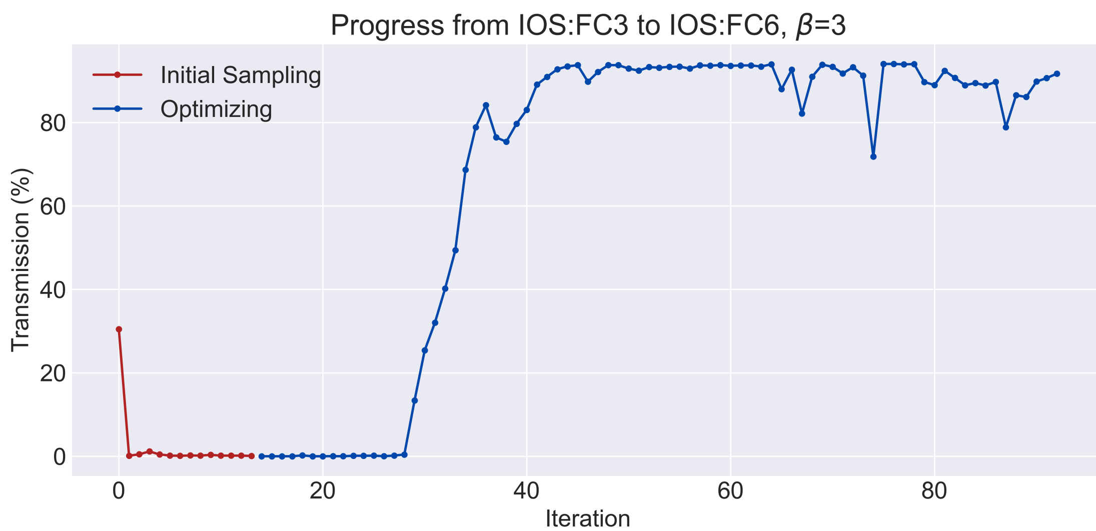

Figure 1: Initial BOIS run starting from IOS:XCB1 to IOS:FC6.

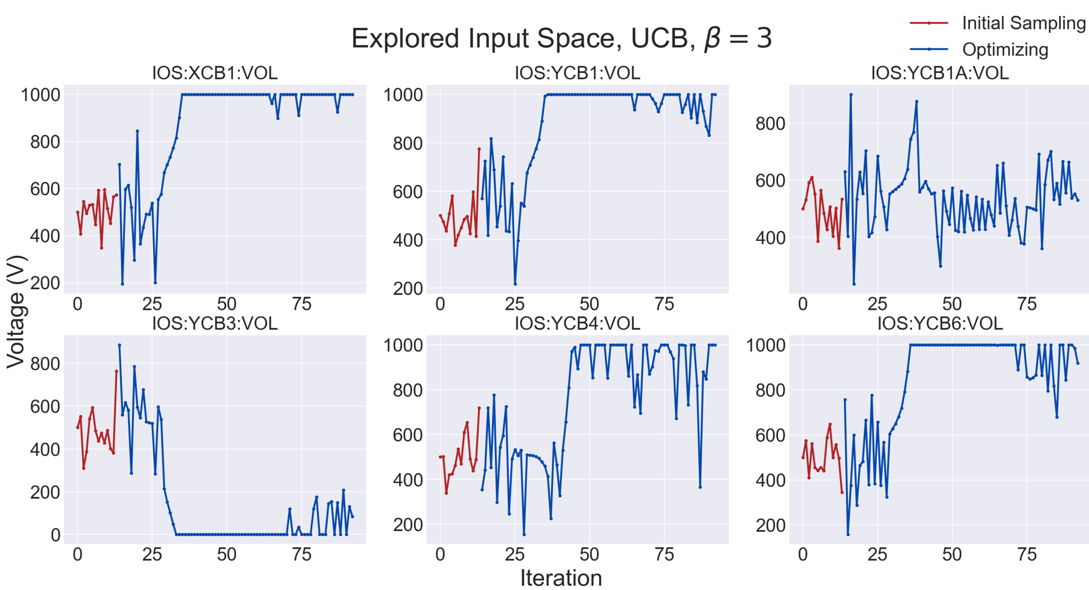

Figure 2: Explored input space with UCB at $\beta = 3$.

Following this, another test was carried out where the inputs were bounded:

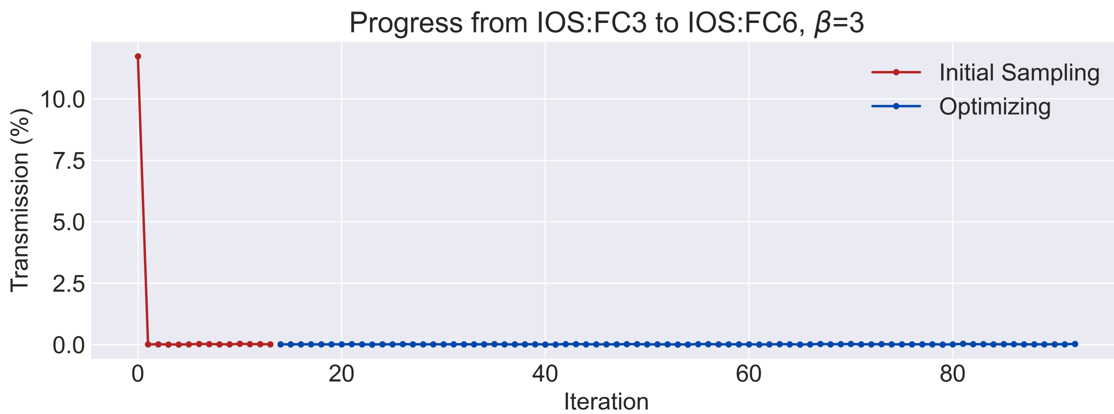

Figure 3: Bounded BOIS run starting from IOS:XCB1 to IOS:FC6.

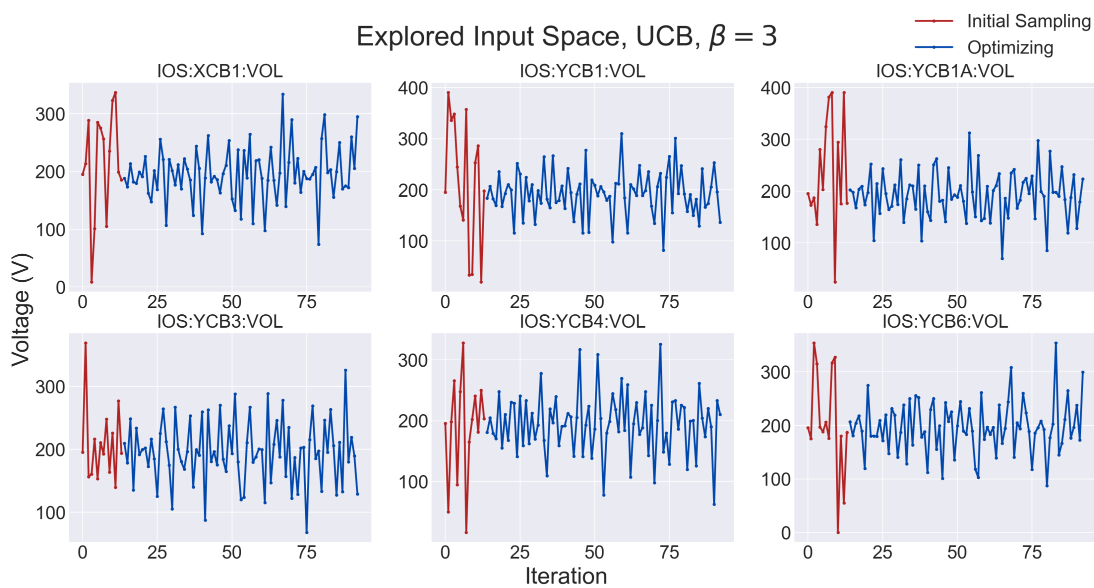

Figure 4: Explored input space with UCB at $\beta = 3$ for the bounded case.

Figure 3 shows that the bounded case fails to produce any measurable transmission through OLIS. There is little to no difference between the sampling and optimization stages (compare figure 2 and 4). Following this, a test using both quadrupoles and steerers was carried out, shown in figures 5 and 6.

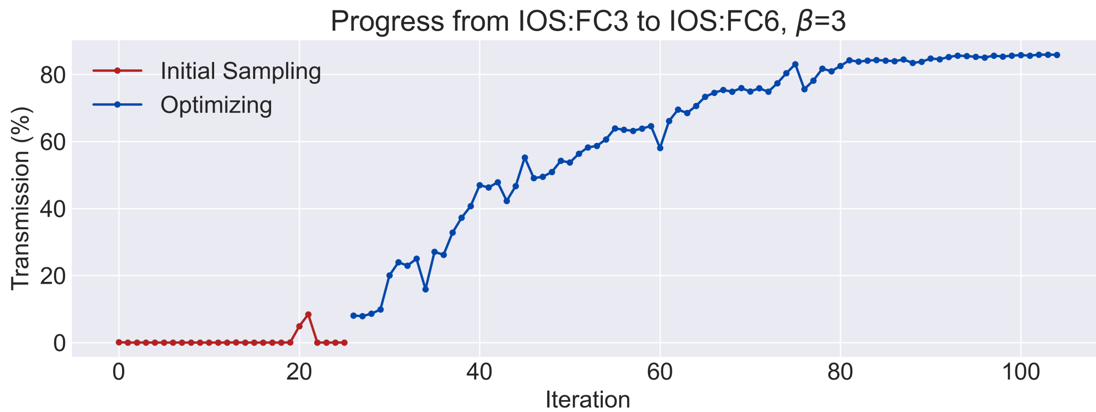

Figure 5: Steerers + Quadrupoles BOIS run starting from IOS:FC3 to IOS:FC6.

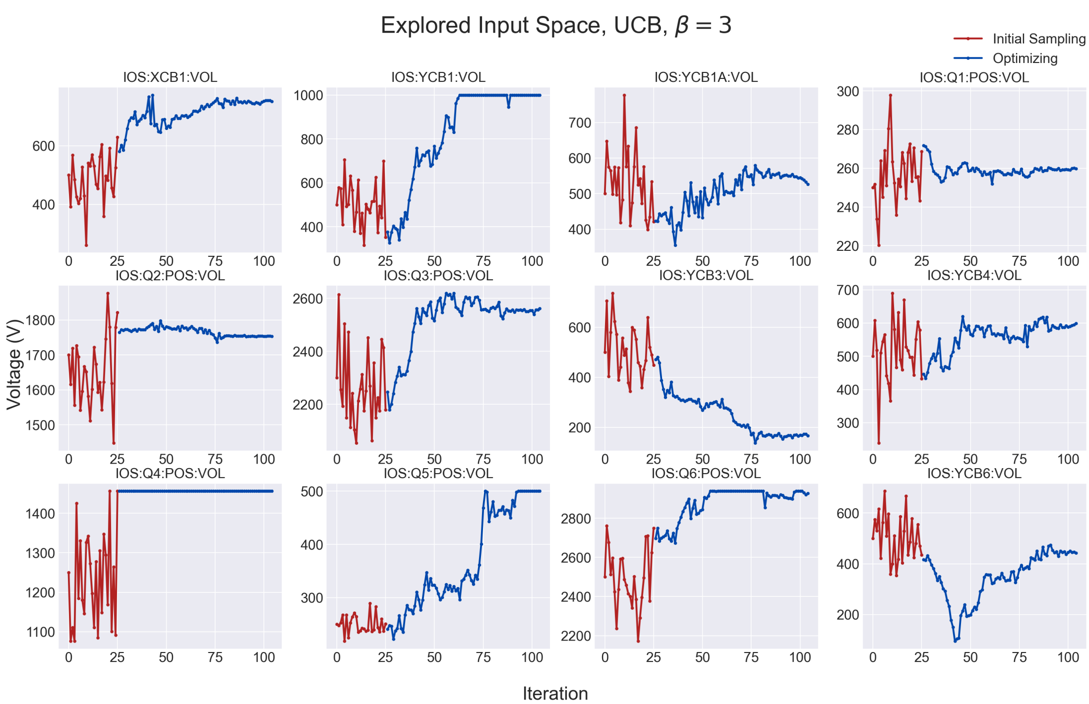

Figure 6: Explored input space with UCB at $\beta = 3$.

Utilizing quads showed no noticeable improvement in the transmission, however several steerers are no longer maxed out and IOS:YCB3 is no longer set to 0. While this does somewhat address our problem, it comes at the cost of new problems which would be experienced downstream, particularly when matching to the RFQ injection. It also suggests that the OLIS quadrupoles are being used for steering corrections. The considerable steering necessary in OLIS hints at a system alignment issue [9, 10].

2.2 Debugging Bayesopt

There were a few issues with bayesopt that were either discovered or fixed during these tests:

- The objective value is determined as the average over 20 measurements on the Faraday cup. The wait time between each measurement is 0.01s, which is far quicker than the response time for the server (0.2s). This causes the issue seen in figure 3 where the first point is sampled before the server updates the Faraday cup with the new settings. This issue has been fixed, and better averaging for current measurements will be addressed later in the future.
- During these tests, the implementation of acquisition functions and their optimization function in `BoTorch` [11] was investigated. By re-initializing all the model properties (kernel, priors, etc.) and feeding in the collected data, one can obtain the model state of any previous run at any given point. Earlier tests showed significant over-exploration while using the expected improvement (EI) acquisition function [12, 13], the model state was obtained for these tests and it was discovered that switching from `BoTorch` version `0.11.3` to `0.13` fixed the over-exploration by expected improvement.

Most of the tests carried out in this note are affected by the first issue we discussed, where the model receives incorrect input-output pairs. This ends up misleading the model and slows down training.

2.3 Secondary Tests

The slit positions had been moved following the tests listed in Section 2.1, so a secondary set of tests was carried out with the new slit positions. Firstly, with just steerers in figures 7 and 8:

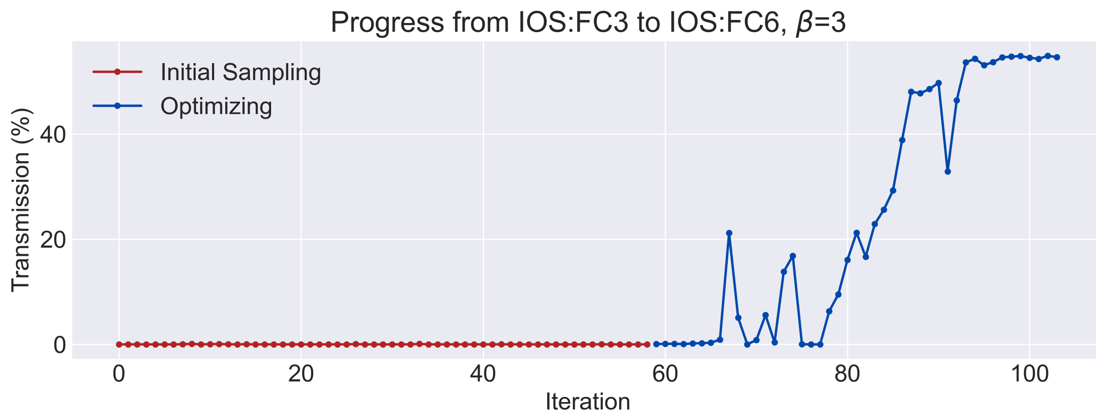

Figure 7: BOIS run starting from IOS:XCB1 to IOS:FC6.

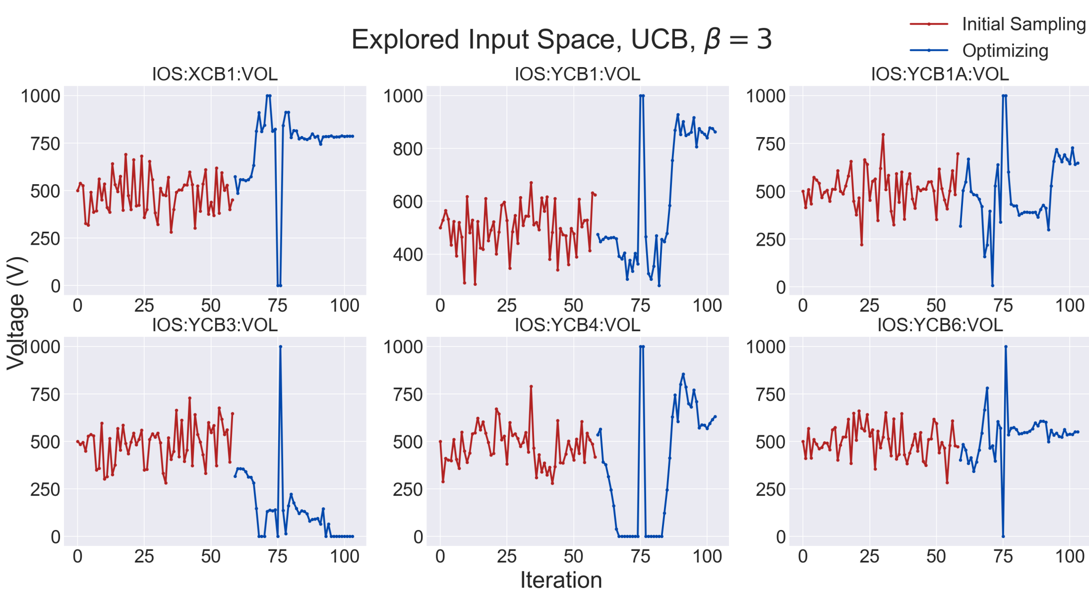

Figure 8: Explored input space with UCB at $\beta = 3$.

Followed by a test with the quadrupoles included as well, in figures 9 and 10:

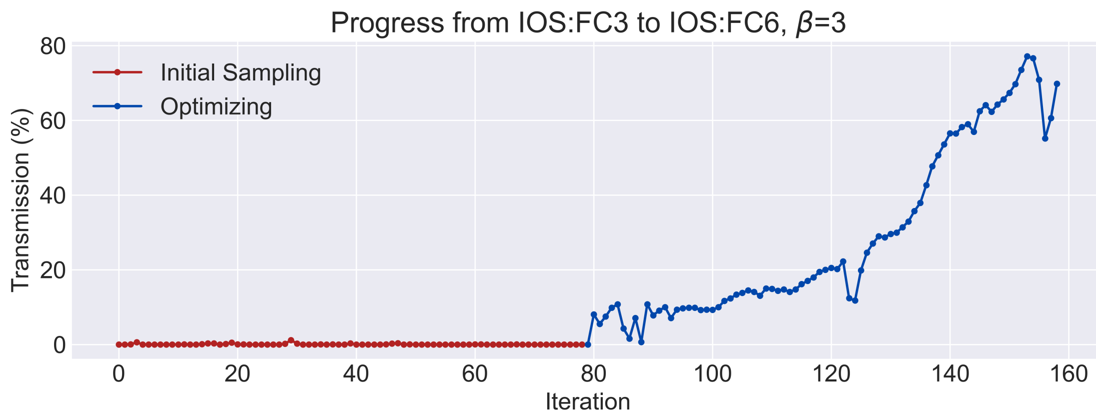

Figure 9: BOIS run starting from IOS:XCB1 to IOS:FC6.

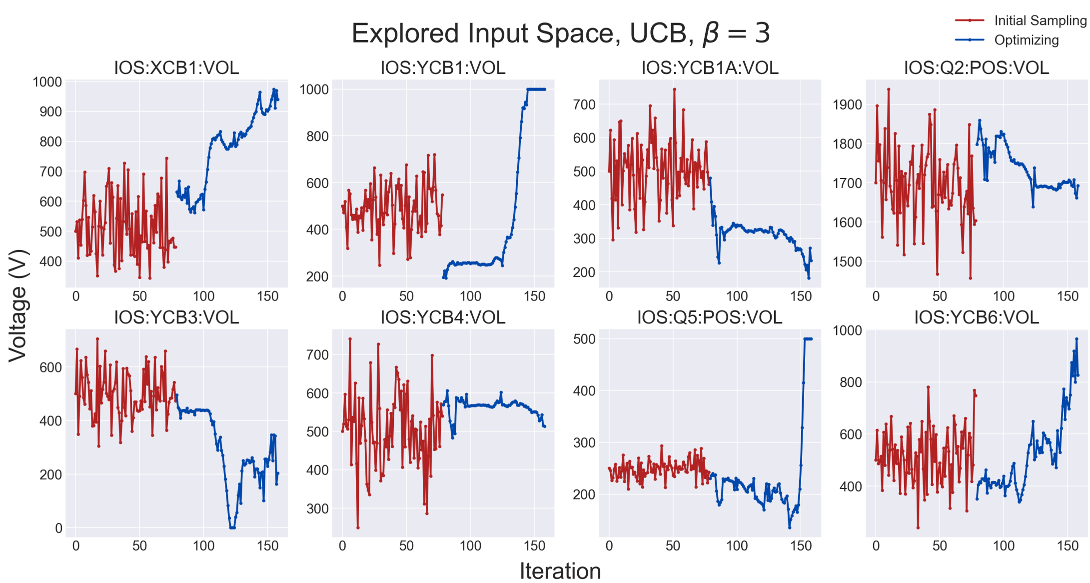

Figure 10: Explored input space with UCB at $\beta = 3$.

The second run with quadrupoles and steerers achieved a transmission of roughly 80%, while using only steerers yielded a transmission just below 50%. No characterization of the beam distribution was possible during these tests due to the absence of beam imaging diagnostics prior to IOS:FC6. As previously noted, these transmissions are for the IOS:FC3 to IOS:FC6 segment of the system proper and past operational experience suggests aggressive tuning of the OLIS quadrupoles causes transport mismatches downstream.

3 Conclusion

Several investigations of the OLIS beam tune up to IOS:FC6 using BOIS were carried out. BOIS was unable to find solutions with lower steerer voltages when only using steerers. Using quadrupoles led to less significant steerer voltage ranges, however it should be stressed that BOIS is complementary to MCAT, and should ideally only provide beam orbit corrections. These tests led to the discovery of an issue with the sampling rate by BOIS in the low energy section. After further probing of EI's excessive exploration across multiple sections, a fix was found by updating the BoTorch version.

Regarding OLIS, dearth of imaging diagnostics upstream of IOS:FC6 renders precision matching of extracted OLIS beams extremely difficult and frequently causes situations where maximized transmission up to IOS:FC6 do not transport downstream. Use of the transmission metric as the sole indicator of beam quality at OLIS causes persistent matching issues into the low energy transport system at ISAC. Diagnostic improvements at the source as outlined in [14, 5] would greatly improve MCAT and BOIS ability to reliably extract OLIS beams and match them into the ISAC system.

References

[1] O. Shelbaya, J. Adegun. A Record of OLIS Steerer Lensing. Technical Report TRI-BN-24-05, TRIUMF, 05 2024.

[2] O. Shelbaya. Mitigation of Steerer Lensing Effects for Radioactive Beam Transport. Technical Report TRI-BN-24-25, TRIUMF, 09 2024.

[3] I.V. Bylinskii, R.A. Baartman, K. Jayamanna, T. Planche, and Y.-N. Rao. Recent Improvements in Beam Delivery with the TRIUMF's 500 MeV Cyclotron. In *Proc. of International Conference on Cyclotrons and Their Applications (Cyclotrons'16), Zurich, Switzerland, September 11-16, 2016*, number 21 in International Conference on Cyclotrons and Their Applications, pages 133–136, Geneva, Switzerland, Jan. 2017. JACoW. doi:10.18429/JACoW-Cyclotrons2016-TUA04.

[4] R. Baartman, T. Planche. Electrostatic Steerer Lensing Effect. Technical Report TRI-BN-24-30, TRIUMF, 30 2024.

[5] Olivier Shelbaya. Mitigation of steerer lensing effects for radioactive beam transport. Technical Report TRI-BN-24-25, TRIUMF, 2024.

[6] E. Ghelfi, A. Katrusiak, R. Baartman, W. Fedorko, O. Kester, G. Kogler Anele, O. Shelbaya, and D. Tanyer. Bayesian optimization for ion beam centroid correction. *Review of Scientific Instruments*, 96(2):023304, 02 2025.

[7] A. Katrusiak, E. Ghelfi, O. Hassan. Common Plate Voltage Reduction Methods Using BOIS. Technical Report TRI-BN-24-30, TRIUMF, 30 2024.

[8] Niranjan Srinivas, Andreas Krause, Sham Kakade, and Matthias Seeger. Gaussian process optimization in the bandit setting: No regret and experimental design. pages 1015–1022, 07 2010.

[9] Olivier Shelbaya. Anomalous Operational OLIS Tunes. Technical Report TRI-BN-19-20, TRIUMF, 2019.

[10] R. Baartman. OLIS optics and how to fix. Technical Report TRI-BN-24-28, TRIUMF, 10 2024.

[11] Maximilian Balandat, Brian Karrer, Daniel R. Jiang, Samuel Daulton, Benjamin Letham, Andrew Gordon Wilson, and Eytan Bakshy. Botorch: A framework for efficient monte-carlo bayesian optimization, 2020.

[12] O. Hassan. BOIS Tuning Strategy: MEBT Corner to HEBT2. Technical Report TRI-BN-25-03, TRIUMF, 03 2025.

[13] J. Mockus, Vytautas Tiesis, and Antanas Zilinskas. *The application of Bayesian methods for seeking the extremum*, volume 2, pages 117–129. North-Holland, 09 2014.

[14] O. Shelbaya. Profile Monitor Additions to ISAC-OLIS. Technical Report TRI-BN-24-15, TRIUMF, 07 2024.