Beam Physics Note
TRI-BN-24-30
April 22, 2024

Common Plate Voltage Reduction Methods Using BOIS

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Abstract: An investigation into the success of different possible methods of achieving a high transmission tune – at ISAC-OLIS – while reducing the overall field present in electrostatic steerers.

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1 Background

In the report TRI-BN-24-05[1], the design of the ISAC electrostatic steerers is shown to produce a quadrupole field dependant on the field present in the steerer. This effect has been characterized as:

$$\text{quadrupole effect} \propto \text{steering plate voltage} + \text{common plate voltage}, \tag{1}$$

by Rick Baartman and Thomas Planche[2]. This effect has been known since 2015 in the cyclotron injection line [3, 4]. Here the solution was identified as either changing the skimmer aperture slot to match the rectangular profile of the electrodes, or to use a steering field generated by plates with opposite polarity.

This effect is greatest at two points along the optical axis for each steerer. The quadrupole field appears halfway between the skimmer plate and the beginning of the electrode, so ions experience this lensing twice as they go through each steerer, once on entrance and once on exit.

This report presents a brief analysis different tuning methods to reduce this effect, specifically in the low energy at ISAC, from OLIS to the RFQ shown in Figure 1. The four methods are compared using Faraday cup current at ILT:FC49 and the beam profile at ILT:RPM49.

While we only focus on the section of beamline from OLIS to the RFQ here, this effect is happening in every electrostatic steerer at ISAC with the same build geometry and electrode power supply configuration. However, this effect is more apparent in this section due to the high steering required after the ion source. High steering is required due to the additional field generated by the MCIS.

2 Methods of reducing common voltage

The `BOIS`[5, 6], tool was adapted in several ways, all trying to find tunes that keep the common plate at the minimum possible voltage. For context, `BOIS` is a Bayesian Optimisation algorithm which finds the steerer settings to maximise transmission at a FC. `BOIS` has a method called `scaleBOIS`, which deters the model from configuring the system to have large amounts of steering. Additionally, the `boundBOIS` method restricts the limits of steering to 2mrad at each steerer.

1. **Final common reduction**, operate `BOIS` as with commons at nominal voltages (300V in IOS and 500V in ILT) and compute the common reduction described above at the end of the optimization.
2. **Continuous common reductions**; operate `BOIS` in terms of voltage differences rather than steering plate voltage. At every step, calculate the lowest common plate voltage setting to accommodate that, and set commons and steering plates accordingly.
3. **Scaled common reduction**; add the common plates as parameters and bias the objective function `BOIS` works with by multiplying it by a value which scales linearly with the common voltages, favouring solutions where the commons are lowered, similar to `scaleBOIS`
4. **Initial common reduction**; this works in tandem with `boundBOIS`[5, 6] specifically, which limits the steering ranges to 2 mrad. Given the limited steering ranges (e.g. for a 30 keV

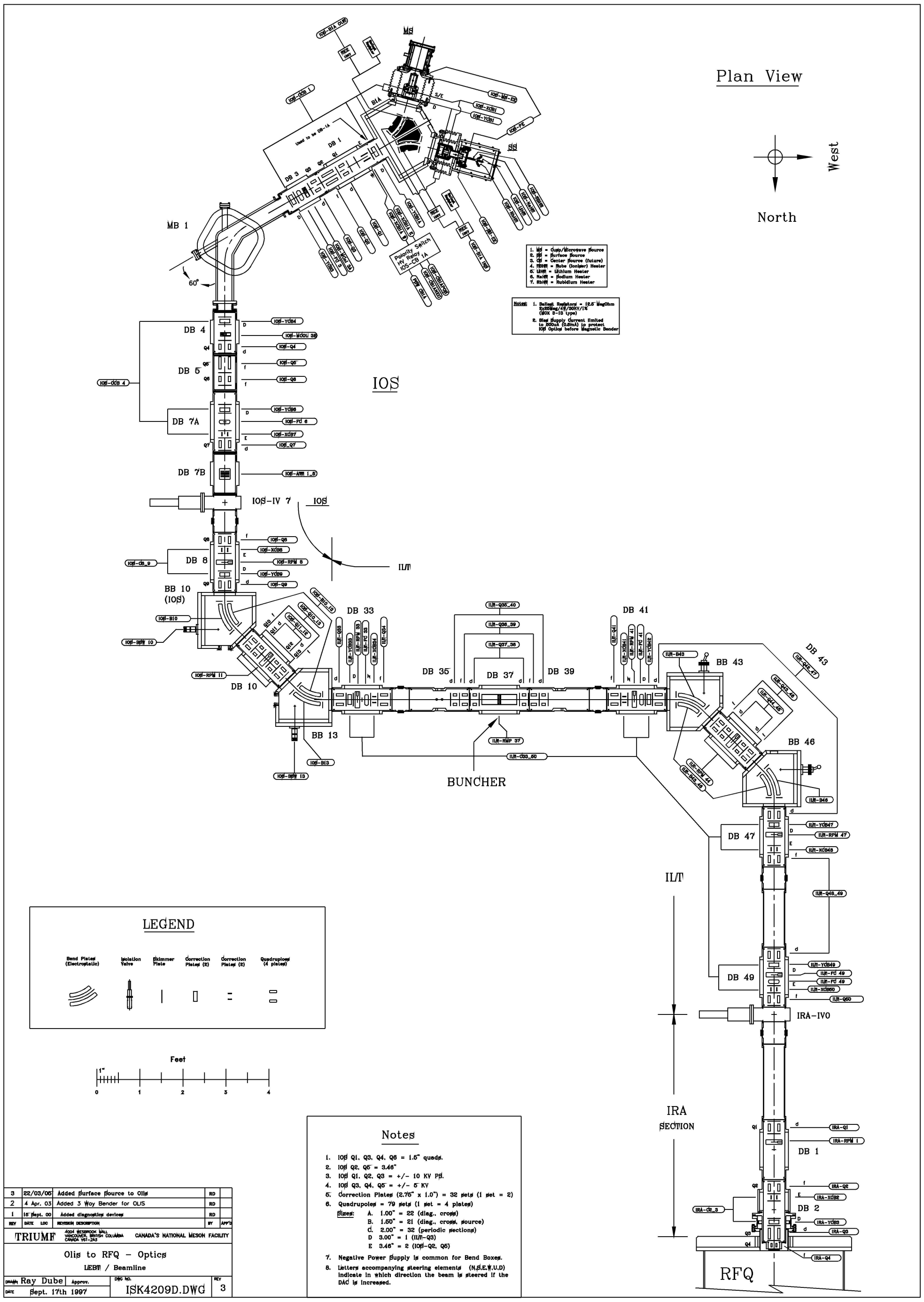

Figure 1: Beamline diagram from OLIS to the RFQ.

beam, this would be 120 V), we set the common plates to the middle of the range, plus some δx (e.g. for a 30 keV beam, 60 V) and let `scaleBOIS` work in that range.

3 Results

Tests were done during two different machine development shifts. The first results are with a $^{14}N^{+}$ MWS beam using methods 1–3, the second results are from a $^{7}Li^{+}$ SIS beam using method 4. Success was judged on the ability for `TRANSOPTR` to fit the RPM data. Indeed, we assume that since the `TRANSOPTR` model does not account for steerer lensing, if data from the real system matches the `TRANSOPTR` model well then steerer lensing effects must be minimized.

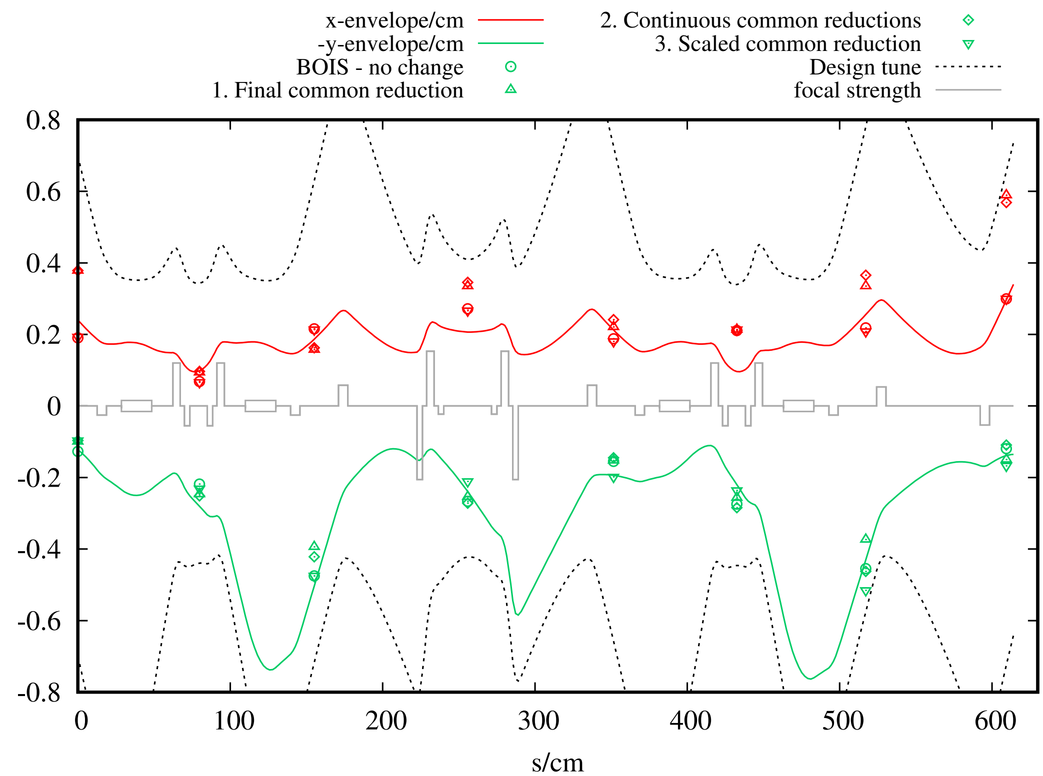

Figure 2: $^{14}N^{+}$ beam at RFQ injection energy (2.04 keV/u) from IOS:RPM8 to ILT:RPM49. Various RPM data are plotted including a standard `BOIS` tune, and common plate reduction methods 1–3. Solid red and green lines are specifically fit to the "`BOIS`: reduction" data (method 1). Fits for all data sets were performed with very similar envelopes found, so excluded for readability. MCAT calculated design tune shown in dotted line. No data matches the model fit very well.

Results from testing methods where the voltage on the common plates are either lowered during,

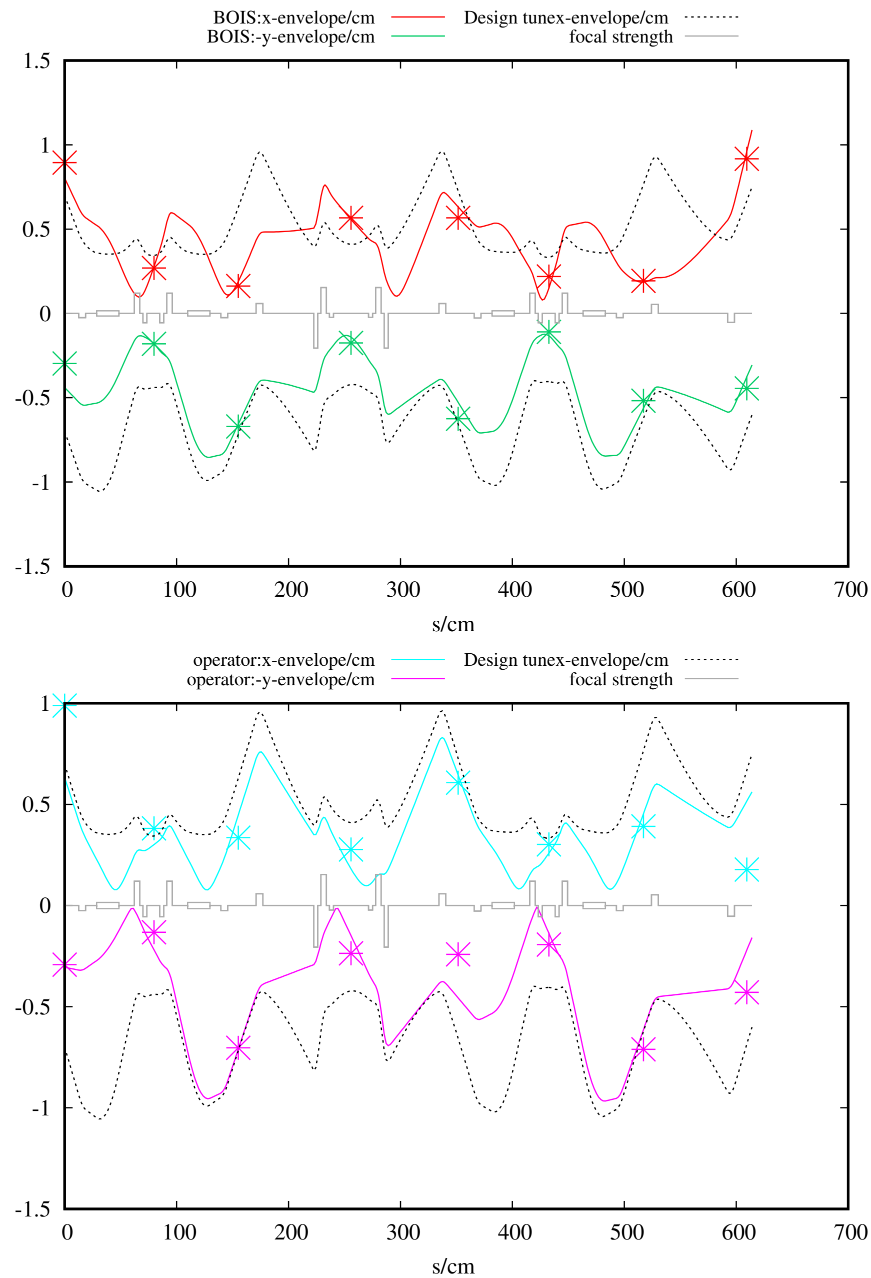

Figure 3: $^{7}Li^{+}$ beam at RFQ injection energy from IOS:RPM8 to ILT:RPM49. (TOP) `TRANSOPTR` fit to RPM data after tuning with commons at 62V per method 4 and (BOTTOM) fit to Operator tune with commons at 300V before running `BOIS`. MCAT calculated design tune shown in dotted line.

or after the optimization, are shown in figure 2. While the y-envelopes could be considered close, the x-envelopes are not well fit by the model. This is a good sanity check, since the x steering is much more severe in this region due to the combination of source fields and correction after mass separation, more steering should exaggerate this deviation. These data are likewise not close to the MCAT envelope for this section, which can be explained by the beam's mismatch to the initial conditions. Extracting initial conditions using MCAT in this section proves difficult when the model does not account for extra lensing in each steerer.

Adjusting the method to lower all commons before tuning allowed the data to be fit much closer by the envelope model, as seen in figure 3. Here the common voltage is set to only allow $\pm 2mrad$ of deflection, the order of the divergence, and scales with energy. This is calculated by linearly extrapolating that $30keV$ beam needs $120V$ to steer $2mrad$:

$$\text{Common voltage } = E * \frac{4V}{keV}, \tag{2}$$

where E is the beam energy in keV. Tuning the beam in this regime was much easier for `BOIS` as well, as even at the far bounds there was non-zero transmission.

Comparing the envelopes in figure 3 to the MCAT envelopes, while they are certainly closer than figure 2, the initial match is still not made. However, noticeably this `BOIS` tune produces the desired image of IOS:RPM8 at ILT:RPM49, whereas the operator tune does not, in figure 4.

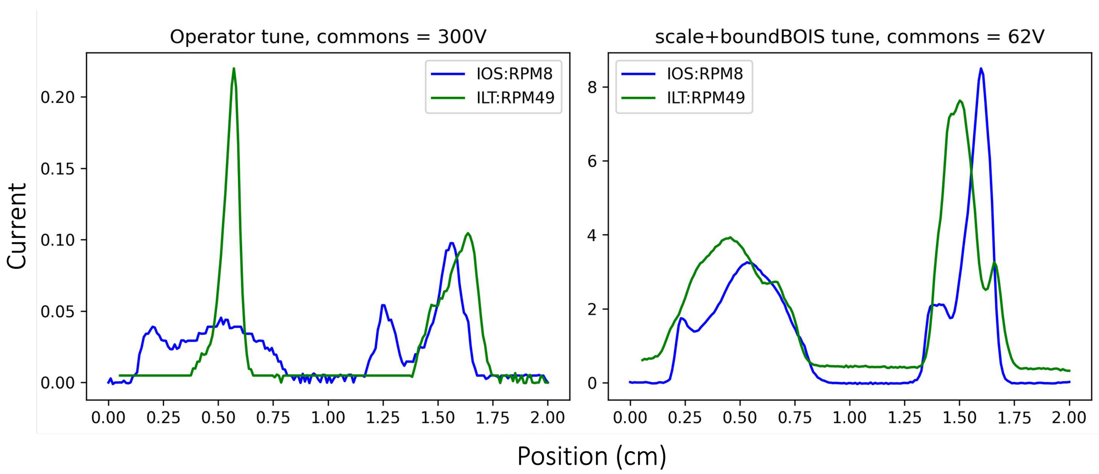

Figure 4: Beam Profiles of the image point from IOS:RPM8 to ILT:RPM49 comparing when common voltage is set to 300V or 62V. Reducing common steering voltage to 62V makes a closer image.

4 Discussion and Conclusion

Specifically IOS:XCB7 was excluded from this study due to its necessity in correcting beam out of the OLIS mass selection magnet. It has proven difficult to include IOS:XCB7 in our procedure since it consistently needs high steering, and repeatedly settles in the same setting, thus not needing tuning. Instead it should be looked at for a separate study if the relation between IOS:MB, IOS:MCOL3, and IOS:XCB7 can be adjusted with `BOIS` in isolation.

The method of reducing the common voltage based on the beam energy has shown to produce beams with closer agreement to `TRANSOPTR` models from IOS:RPM8 to ILT:RPM49. This method is not tied to using `BOIS` to tune, and can be used by anyone tuning electrostatic steerers in ISAC to get closer model agreement. This method can be applied to improve initial conditions in MCAT-OLIS to account for the mismatch as shown in figures 2 and 3.

References

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

[2] Rick Baartman and Thomas Planche. Electrostatic Steerer Lensing Effect. Technical Report TRI-BN-24-22, TRIUMF, 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] J.A. Maloney, R. Baartman, T. Planche, and S. Saminathan. Electrostatic potential map modelling with cosy infinity. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 376:171–174, 2016. Proceedings of the XVIIth International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS2015), Grand Rapids, MI, U.S.A., 11-15 May 2015.

[5] E. Ghelfi, A. Katrusiak, O. Kester, O. Shelbaya, R. Baartman, and W. Fedorko. Bayesian optimization for beam centroid correction at isac. In *Proc. IPAC'24*, number 15 in IPAC'24 - 15th International Particle Accelerator Conference, pages 1786–1789. JACoW Publishing, Geneva, Switzerland, 05 2024.

[6] E. Ghelfi, A. Katrusiak, R. Baartman, W. Fedorko, O. Kester, G. Kogler Anele, O. Shelabaya, and D. Tanyer. Bayesian optimization for ion beam centroid correction. in review at RSI.