**Beam Physics Note**
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# Mitigation of Steerer Lensing Effects for Radioactive Beam Transport

Olivier Shelbaya
TRIUMF

**Abstract:** Steerer lensing effects previously documented elsewhere at TRIUMF are found to be a likely cause of tuning difficulties with TRIUMF's ISAC Mass Separator (IMS) beamline, used for transport of radionuclide beams. A corrective tuning procedure is presented.

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

# 1 Introduction

In a previous report, transverse focal effects from corrective electrostatic steerers are documented at ISAC's offline ion source[1] using a horizontal emittance meter. In turn, this issue had been previously encountered at TRIUMF's I1, the 520 MeV cyclotron's electrostatic injection beamline for $H^-$ ions.

Figure 1 shows an operational tune at ISAC for a 40 keV beam. Though lensing effects should be weaker at this higher bias, the underlying tuning issues they case nevertheless cause another issue: de-tuning quadrupoles for compensation. As tunes are scaled from

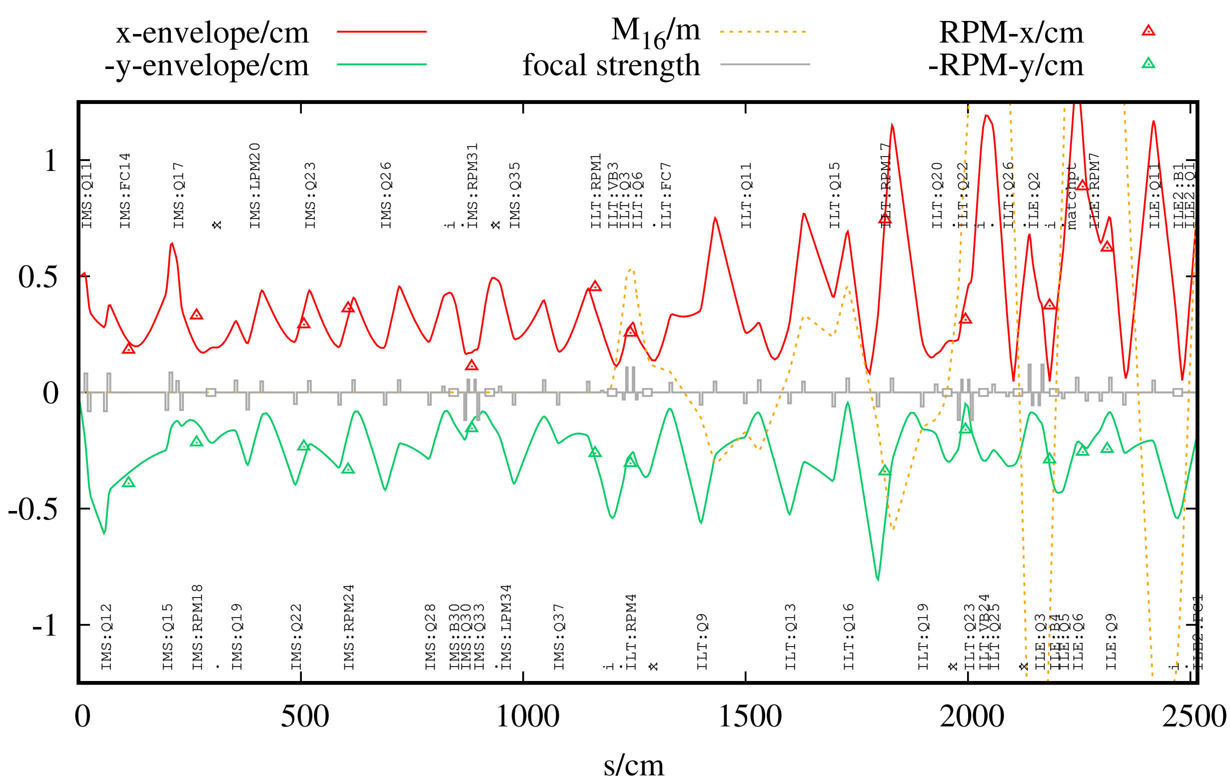


Figure 1: TRANSOPTR 2rms envelopes for an operational 40keV tune starting at the exit/image slit of the ISAC mass separator (MB2) dipole and running to near the start of the polarizer beamline at ILE2:FC1. Note the breaking of periodic transport beyond approx. s=1300 cm, the start of the vertical beamline. Note good agreement up to vertical section, consistent with [2].

reference values, this leads to a broader practice of delivering beams with mismatched optics due to the requirement of tune scalability. As the lensing effect from the steerers is beam bias dependent[3], it would be manifest in different ways depending on the configuration of ISAC-IMS. It also means the mismatch is coupled to steerer use.

The emergence of a nonzero transfer matrix element $M_{16}$ after the vertical section's entrance bends causes chromatic couplings in the beam, which leads to the emergence of a halo, rendering it more difficult to tune through apertures. This, together with lensing mismatches causes a constant requirement to tune matching sections, on top of the reality that different RIB targets produce different emittances and cause a further need for re-tuning.

## 2 Mitigation Strategy

The above findings are applied toward the elaboration of a tuning procedure that is designed to reduce these undesirable lensing effects which ultimately produce mismatches in the tune and associated losses. Rectifying this issue also obviates the need to manually alter quadrupole settings along the system.

In discussions, it has been pointed out that operating the common plates on the ISAC electrostatic steerers at 500V for all beams, regardless of energy, is unnecessary: The voltage difference between both plates is typically up to about 100V or less in IMS. This means that both plates are biased 400V higher than required to achieve the requisite steering correction.

# 3 $\beta$-NMR Tune Test

In September 2024, the $\beta$-NMR experiment collaborated with the Beam Physics Dept. to test a lowered-common voltage tune from the mass separator to the polarizer beamline. Figure 2 shows envelopes of the tune compared to 2rms beamsizes computed from the profile monitors.

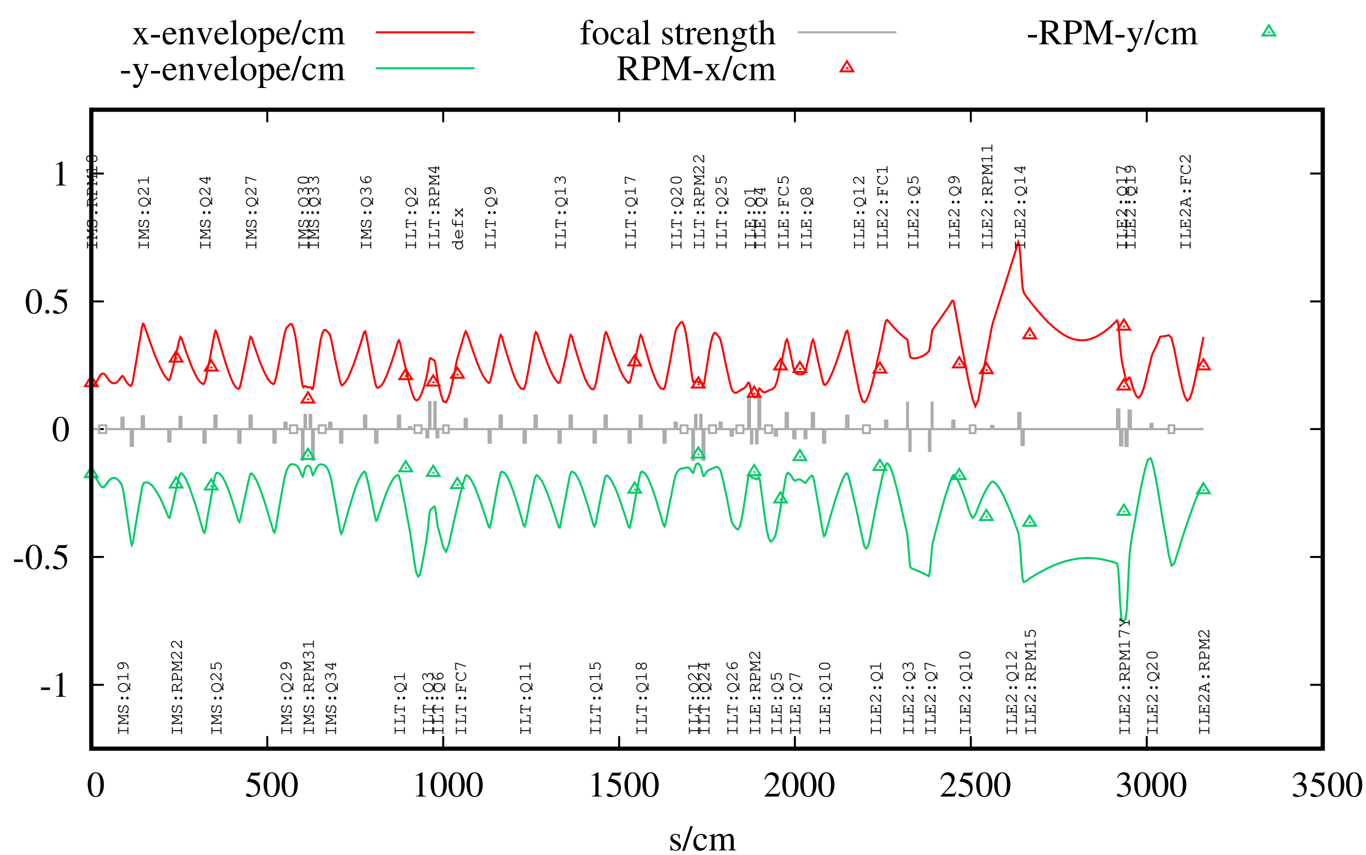


Figure 2: `TRANSOPTR` computes 2rms beam envelopes (solid lines) from profile monitor IMS:RPM18 to end of the ISAC polarizer beamline[4]. Rotary profile monitor (RPM) extracted 2rms beamsizes are shown as triangles. Simulation represents $^{7}Li^{+}$ beam at 25 keV from ITE to $\beta$-NMR experiment.

For this tune, all steerers were set to $V_B$/120, where $V_B$ is the beam bias. This produced 208V on both plates initially. The operators then tuned the steerers to maximize transmission from faraday cup to faraday cup.

Importantly, during this test there was no need to detune quadrupoles in the ILT vertical section. The procedure is outlined in the next section.

# 4 Procedure

1. Start by setting all steering plates to V = $V_B$/120. See Figure 3 for the interface that was used for the tune in Figure 2.
2. Perform an emittance scan with the IMS emittance rig, ensuring that the fit correlation coefficients $r_{12}$ and $r_{34}$ are zero.
3. Beam must be matched from the mass separator exit to profile monitor IMS:RPM18, producing equal (x,y) profile sizes, visible in Figure 2 for s=0 cm. Use quadrupoles IMS:Q11 to Q18 to achieve this. Do not alter any downstream quadrupoles, ensuring that they are set to values computed by MCAT.
4. Use all steerers available between mass separator exit and beam destination to maximize transmission on Faraday cups. Use spherical benders as needed.
5. Check profile monitors between all pairs spherical benders, ensuring that beam is transversely centered.
6. Document tune with snapshot utility[1].

[1] https://beta.hla.triumf.ca/snapshot/landing

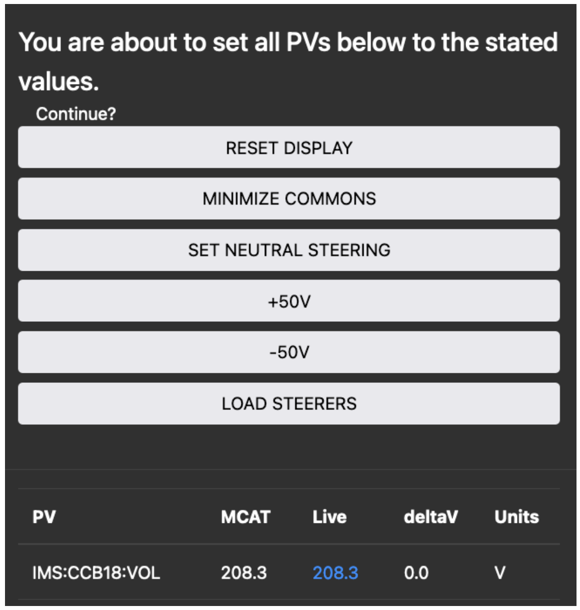


Figure 3: MCAT's new steering modification popup interface, showing newly implemented features. Realtime voltages are shown at the bottom.

## 4.1 MCAT's Steerer Popup

The new interface for electrostatic steering is shown in Figure 3. A brief overview of the available buttons is listed below:

**RESET DISPLAY:** Resets the list of all steering PV's corresponding to the displayed MCAT beampath.

**MINIMIZE COMMONS:** Finds the largest possible voltage that can be subtracted from all plates and commons for the selected beampath (this is not used in the above procedure, but is an experimental feature that enables further lowering the voltage).

**SET NEUTRAL STEERING:** Sets all plates and commons to $V_B$/120.

**+50V and -50V:** Adds or subtracts 50V from all plates and commons. Use this if plates are set to max/min voltages and more steering is required.

**LOAD STEERERS:** Loads whichever set of values have been selected to the control system. **No values are loaded by default for all of the above, until the user selects LOAD STEERERS.**

## 5 Conclusion

This note has documented a new steering methodology for TRIUMF-ISAC's electrostatic RIB transport beamlines, which was shown to produce excellent agreement between TRANSOPTR simulations performed and 2rms beam sizes. This can now be used for regular beam delivery.

In future, this can be applied from the target frontend, up to the 135$^\circ$ separator. This opens the door to on-line methods such as sequential optimization[5] in which the tune is computed in real-time from first principles, enabling the imposition of user-defined constraints using software such as MCAT[6].

Finally, the tune from Figure 2, when transported to the $\beta$-NMR experiment, required re-tuning of steering in ILE2A3 and also re-tuning of the Einzel lenses, suggesting that previously used values were not tailored to a matched beam in the polarizer. The match condition reported in this document was not previously observed at ISAC for such experiments, likely due to persistent steerer lensing.

## References

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

[2] Olivier Shelbaya. Investigation of ISAC Mass Separator Optics . Technical Report TRI-BN-22-15, TRIUMF, 2022.

[3] Rick Baartman and Thomas Planche. Relectrostatic steerer lensing effect. Technical Report TRI-BN-24-22, TRIUMF, 2024.

[4] Olivier Shelbaya, Emma Ghelfi, Giordano Kogler Anele, and Rick Baartman. IMS to Polarizer Beam Transport. Technical Report TRI-BN-23-30, TRIUMF, 2023.

[5] Olivier Shelbaya. Sequential Tune Optimization with TRANSOPTR. Technical Report TRI-BN-20-14, TRIUMF, 2020.

[6] Olivier Shelbaya. Model Coupled Accelerator Tuning (PhD thesis). Technical Report TRI-BN-23-04, TRIUMF, UVic Dept. of Physics & Astronomy, 2023.