Beam Physics Note
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OLIS Theories

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Abstract: This note records the observation that there currently exists multiple definitions of 'theory' tunes at the ISAC Offline Ion Source.

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Preface

Previous investigation of OLIS has aimed to understand operational OLIS tuning, following the observation of anomalous tunes[1, 2] as explained by the TRANSOPTR model of the source[3]. Inspection of the mechanical layout of the optics identified deviations from the original design, including modification of spherical bender skimmer electrodes to act as collimators[4], longitudinal misplacement of quadrupoles[5] and collimators[1]. In the case of misplaced quadrupoles (Q2 and Q5), this changed the effective length of the devices. Incorrect skimmer electrode geometry was additionally identified on the 9° deflector[4]. This device is significantly detuned from its theoretical values as a regular operational course. Additionally, numerous sets of design drawings have been found, evidencing the evolution of the design over the years.

This report documents the observation in 2023 that there are three sets of OLIS tunes, referred to as theoretical by TRIUMF staff. These tunes, as will be shown, differ from each other, and two are of uncertain origin. This report acknowledges this state of affairs as not ideal, and issues recommendations for future improvements.

1 Theory vs. Theory

During a development shift on 2023-03-07, using a $^{7}Li^{+}$, 14.28 kV beam, I noticed the OLIS tune which was in use deviates from the Baartman tune shown in Fig. 1. After inquiring with the source physicsit, I was informed that the source optics had been procedurally loaded, using an EPICS button shown in Fig. 2, whose existence and function were unknown to the beam physics group.

Recommendation 1: There should be a single process and means through which tunes are loaded into the apparatus at ISAC.

Recommendation 2: At the eve of the ARIEL era, tuning of low energy beamlines and separators should be consistent between CANREB and ISAC.

Recommendation 3: Any future apparatus including beam transport and acceleration sections which is part of the ISAC beamline network, should be modelled and analyzed in a manner consistent with the remainder of the system.

Name	Value	
IOS:BIAS	14.280	kV
IOS:EE	1.072	kV
IOS:B1A	1.993	kV
IOS:XCB1AW	1.527	kV
IOS:XCB1AE	1.527	kV
IOS:Q1	.417	kV
IOS:Q2	.801	kV
IOS:Q3	1.030	kV
IOS:MB	1517	Gauss
IOS:Q4	1.157	kV
IOS:Q5	.811	kV
IOS:Q6	.000	kV
IOS:Q7	.294	kV
IOS:Q8	.505	kV

Figure 1: Baartman computed OLIS SIS design tune for ^{7}Li^{+} at 14.28kV bias.

On top of the EPICS generated tune and Baartman's values, there additionally exists tunes contained on tuneX, a tune scaling application frequently used by operations. The tune it produces is shown in Figure 4

Finding 1: There now exists several tune scaling methods at ISAC, including legacy spreadsheets, perl code, tuneX and the Beam Dynamics webpage.

All three tunes were simulated in TRANSOPTR, using an uncoupled starting beam matrix distribution corresponding to (x, x', r_{12})=(y, y', r_{34})=(0.07 cm,14 mrad,0.0). These are found to disagree with Baartman's design tune, shown in Figs. 5 and 6. Note however the resemblance between IOS:Q4 and IOS:Q5 in both Figs. 4 and 3, implying their origin may be common. In any case, the beam physics group is unaware of the provenance of these numbers and does not scantion their use.

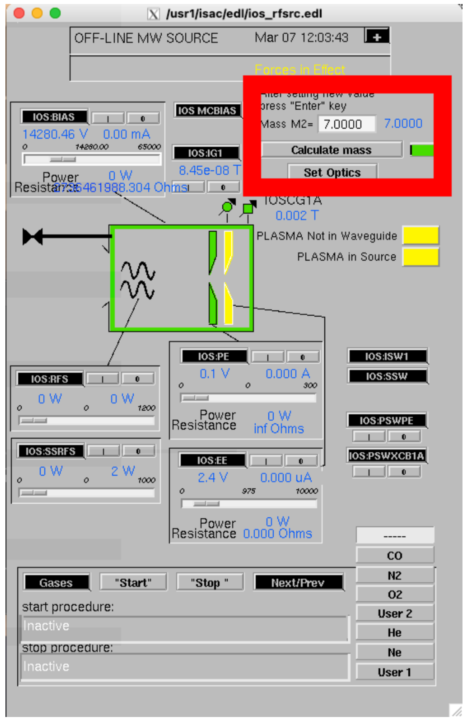

Figure 2: A 'set optics' button is used by Beam Delivery group members to set the OLIS optics. The numbers loaded by this button are referred to as 'theory', though no documentation for their provenance is known.

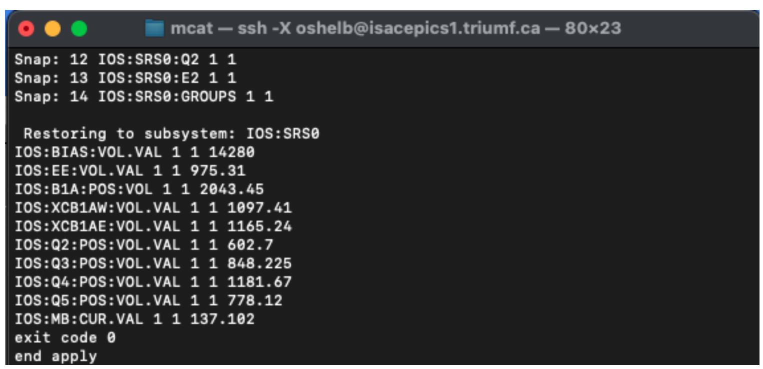

Figure 3: Upon activation, a printout is given on `isacepics1` of the optics setpoints that are returned.

Finding 2: The process by which the Beam Physics group maintains awareness and oversight of tunes at ISAC is not clearly defined.

PV	Calculated Setpoint	Units
IOS:B1A:POS:VOL	2024.5	V
IOS:YCB1A:VOL	427.9	V
IOS:XCB1AW:VOL	1076.41	V
IOS:XCB1AE:VOL	1149.62	V
IOS:Q1:POS:VOL	0.0	V
IOS:Q2:POS:VOL	603.5	V
IOS:Q3:POS:VOL	909.2	V
IOS:YCB3:VOL	260.4	V
IOS:MB:FLD:SETP	1540.95	G
IOS:YCB4:VOL	278.7	V
IOS:CCB4:VOL	300.0	V
IOS:Q4:POS:VOL	1181.7	V
IOS:Q5:POS:VOL	778.6	V
IOS:Q6:POS:VOL	0.0	V
IOS:YCB6:VOL	284.8	V
IOS:XCB7:VOL	360.9	V
IOS:Q7:POS:VOL	30.4	V
IOS:Q8:POS:VOL	347.4	V

Figure 4: `tuneX` values for ^{7}Li^{+} at 14.28kV extraction.

Finding 3: OLIS expert procedures, such as dipole mass calibration, do not include beam physicists.

Recommendation 4: Members of the Beam Physics group should structurally be required to participate in expert calibrations, such as at OLIS. This would ensure oversight of the tune status.

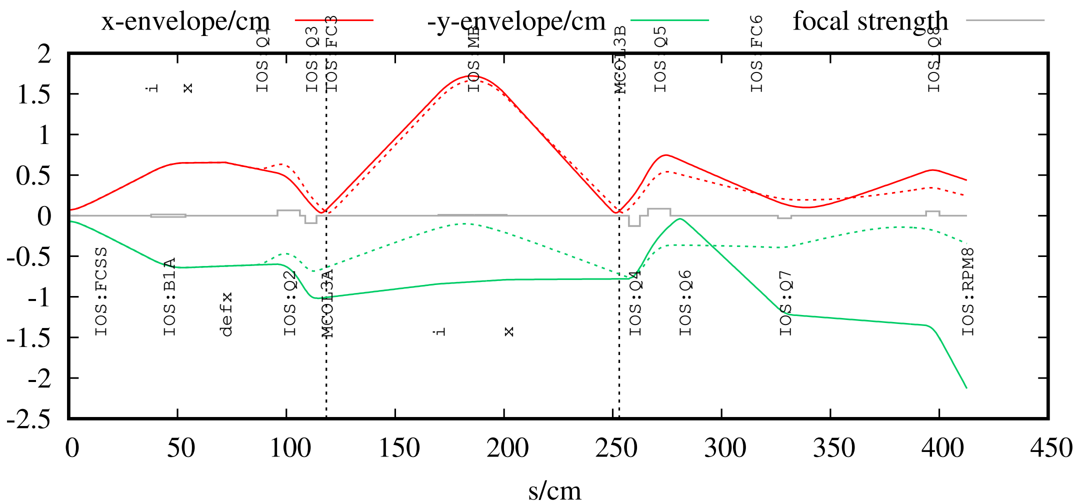

Figure 5: Comparison between Baartman tune (dotted lines) and unknown 'Set Optics' tune (solid). Location of collimators shown as vertical dotted lines.

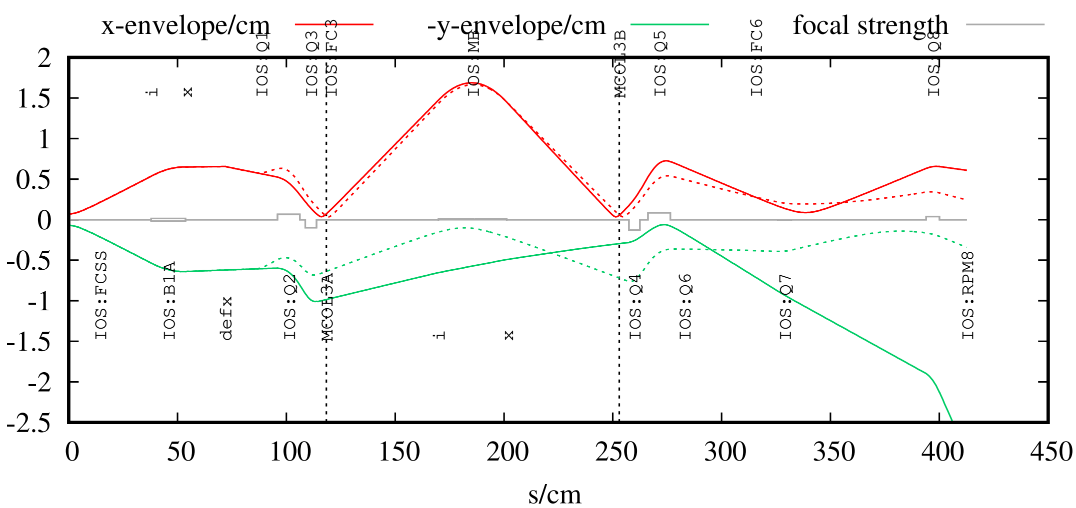

Figure 6: Comparison between Baartman tune (dotted lines) and `tuneX` tune (solid). Location of collimators shown as vertical dotted lines.

Both 'Set Optics' and `tuneX` tunes cause mismatches into either the low energy experiment beamlines or towards the ISAC-RFQ. Mismatched output OLIS beam will exist in each case that the source is tuned in this manner. To illustrate this, the phase space ellipses at IOS:RPM8 for Baartman, 'Set Optics' and `tuneX` are shown in Fig. 7.

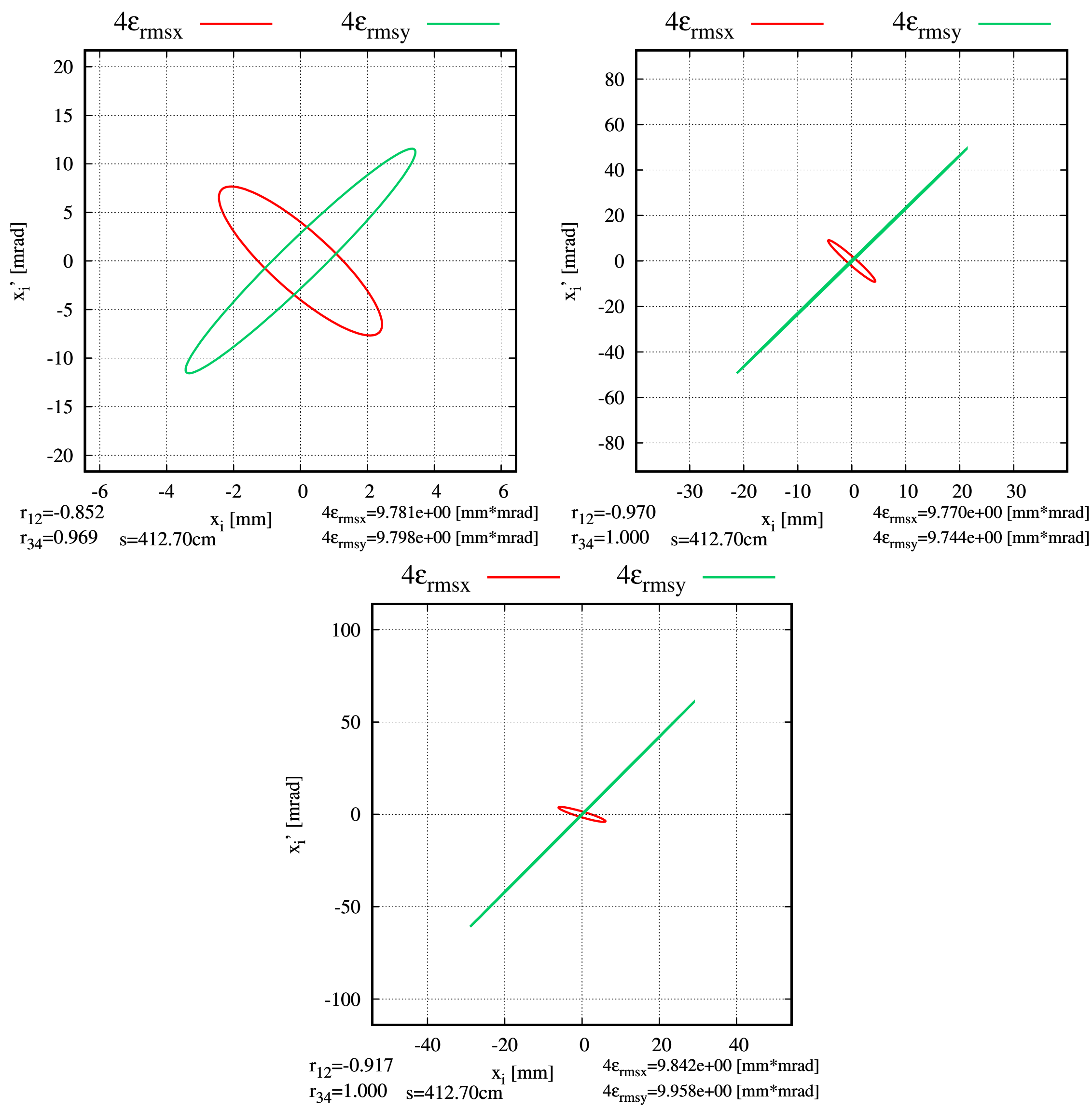

Figure 7: Phase space ellipses at IOS:RPM8 caused by Baartman's tune (left) and the 'Set Optics' tune (right) and `tuneX` (bottom). The low energy tunes are designed to match Baartman's distributions (top left) into the downstream transport lines.

2 Discussion

Fundamentally, this state of affairs arose because of the historic lack of a singular means of handling theoretical tunes. The term *theory* itself has become something of a familiar jargon, moreso referring to the computerized provenance of the values, as opposed to the means by which they came into being. In particular, operational jargon referes to theoretical tunes those saved on `tuneX`, even if in this report it has been shown to significantly deviate from a theoretical tune arising from an optics model.

Finding 4: The term theoretical tune has come to acquire degenerate, overlapping meanings at ISAC.

Additionally, the progressive proliferation of tunes evidences a lack of centralized means. This is also historical: different sections at ISAC have been managed by different generations of staff, each with differing relationship to beam dynamic theory. This ranges from fully manual tuning procedures for some sections, to model-based tuning for others. In the present, this has caused the emergence of an uneven set of procedural approaches for tuning, for example contrasting the low energy experiment tuning with accelerator tuning methodologies. This is because a unified tool was lacking.

Recommendation 5: An institutional shift towards model-coupled tuning, using the `MCAT` technique[6], should be undertaken.

Additionally noting that tune scaling is an inherently un-intuitive process, by which sometimes large groups of numbers are manipulated by applying scaling coefficients, there have been numerous instances of errors or omissions. This is because the beam, other than for profile monitors, remains hidden, unseen and frequently unthought of. Finally, it is noted that different groups of individuals have had control and ownership of the source theoretical tunes presented in this report. In cases where communication is lacking or nonexistant between parties, or divergences of opinion may arise, no clear process exists to decide which tune is 'official'.

Recommendation 6: Tune scaling should progressively be discontinued at ISAC and CANREB, as it leads to confusion, divergent theoretical tunes, and in some cases conflicts.

Finding 5: A centralized, consistent MCAT implementation, in which a digital twin of the system is used to compute tunes in real-time, would both improve efficiency, reduce risk of miscommunication and deconflict machine tuning at TRIUMF.

Recommendation 7: A sustained and periodic campaign of OLIS beam optics development should be undertaken, including source physicists, beam physicists and operators, ensuring good mutual communication, awareness and transition to model coupled tuning.

3 Conclusion

There continues to be confusion around the operational tuning of OLIS. This state of affairs may arise due to the existence of competing channels of authority and theoretical stewardship on the offline ion source. The structural and institutional issues around OLIS tuning should now be scrutinized more seriously, as the normalization of deviance at the offline source risks causing an unsafe condition for beam delivery and operation. Additionally, continually tuning OLIS for transmission prevents the necessity of further investigating and improving the source optics, as the anomalous operational tunes, designed to maximize transmission (at the cost of matching), lead to the assessment that no further OLIS development is required.

References

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

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[3] Olivier Shelbaya. OLIS to RFQ Beam Transport and Acceleration in TRANSOPTR. Technical Report TRI-BN-20-13, TRIUMF, 2020.

[4] Olivier Shelbaya. OLIS Maintenance Summary by Oli S. Technical Report TRI-BN-20-04, TRIUMF, 2020.

[5] Olivier Shelbaya. Report On OLIS Quadrupoles 5 and 7 . Technical Report TRI-BN-22-12, TRIUMF, 2022.

[6] O. Shelbaya. *Model Coupled Accelerator Tuning*. PhD thesis, University of Victoria, Department of Physics and Astronomy, 2023.