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MEBT 3:1 Selector Reproducibility

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Abstract: This note explores the tuning of the ISAC-MEBT 3-to-1 selector, which allows filtering of partially populated RFQ output bunches. The device is also referred to as the MEBT chopper and has historically required manual tuning by operators prior to DTL injection. The results of recent RF equipment upgrades upon the devices reproducibility are documented.

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1 Introduction

The ISAC dual-frequency chopper[1, 2] employs two pairs of parallel plates to transversely deflect unwanted satellite bunches from the ISAC-RFQ. Located between quadrupoles 3 and 4 in MEBT, it is positioned just downstream of the bunch rotator and upstream of the stripping foil carousel. At this location, a 2 mm chopper slit limits the beam's horizontal size. Figure 2 shows MEBT beam envelopes and the locations of RF components, based on original `T3D` simulations.

The chopper is not a resonant RF cavity. Instead, it is driven by a resonant coil circuit mounted above the unit, which applies an oscillating voltage to two of the four plates, while the opposing plates are held at a DC offset[1]. The system can operate at either 5.8 MHz or 11.8 MHz, **however, this report focuses exclusively on the more commonly used 11.8 MHz configuration.**

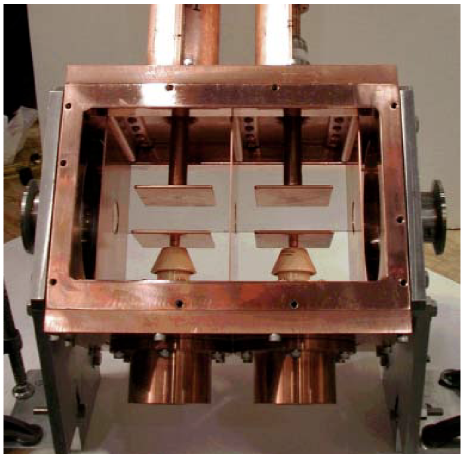


Figure 1: The dual-frequency ISAC chopper on a workbench, obtained from [3].

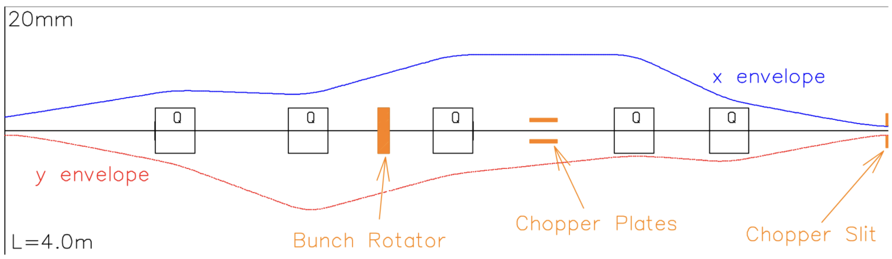


Figure 2: Design beam envelopes[2] in the first 4m of the MEBT section, spanning quadrupoles 1 to 5, terminating at the chopper slit and stripping foil.

2 Tuning

The chopper is manually tuned by adjusting RF amplitude and phase while monitoring MEBT:RPM5 near the chopper slit. Figure 3 shows centroids of three RFQ bunches for an unoptimized chopper configuration: The main bunch (solid line) carries up to 85% of the beam, and satellites (dotted lines) up to 15%. Figure 4 shows the RFQ time structure and chopper waveforms for 3-to-1 bunch selection.

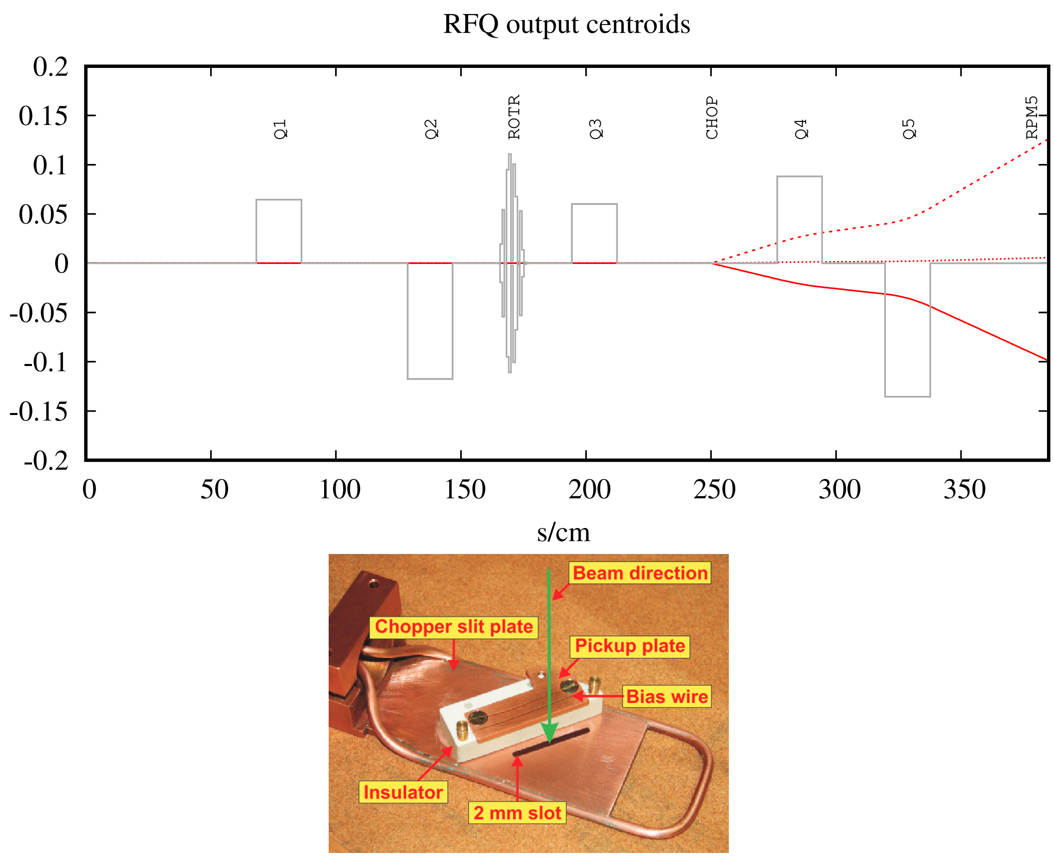


Figure 3: **Top:** `TRANSOPTR` computed centroids (in cm) through MEBT, assuming perfect input centeredness and deflection through the 11 MHz chopper, which is not optimized. **Bottom:** Image of the MEBT chopper slit, narrowest along the x-axis and widest along y, pictured on a workbench, obtained from [4].

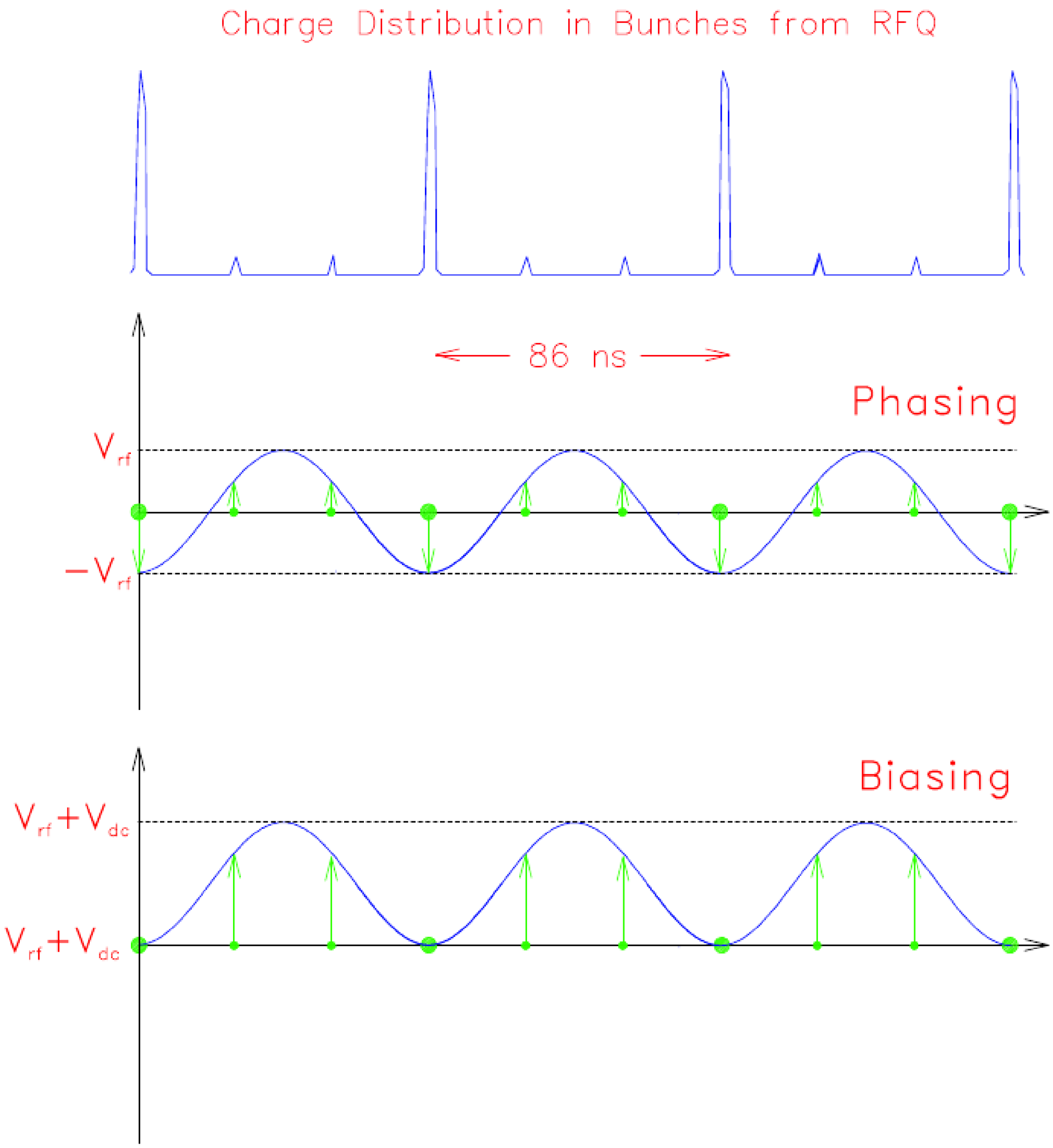


Figure 4: **Top:** Time-structure of ISAC-RFQ output accelerated beam, showing periodicity for groups of three bunches. Only the most populated "main" bunch is generally desired for DTL acceleration. **Middle:** Representation of the sinusoidal RF waveform's effect upon the bunches, with the chopper plates producing transverse defelection (green arrows) upon each bunch traversing the device. **Bottom:** Applying a DC offset to the chopper, in addition to the RF voltage, with proper timing, causes no net deflection for the main bunch, while removing both satellites.

2.1 Manual Tuning Illustration

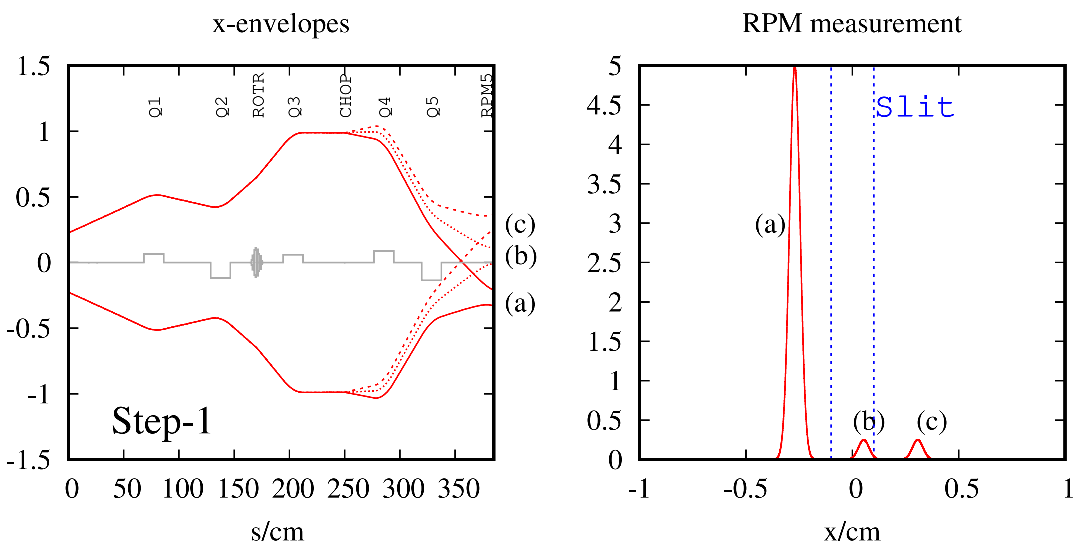


Figure 5: Chopper is powered on at non-optimal amplitude and phase and beam separation is observed at MEBT:RPM5 (**Left**), HV plate is off.

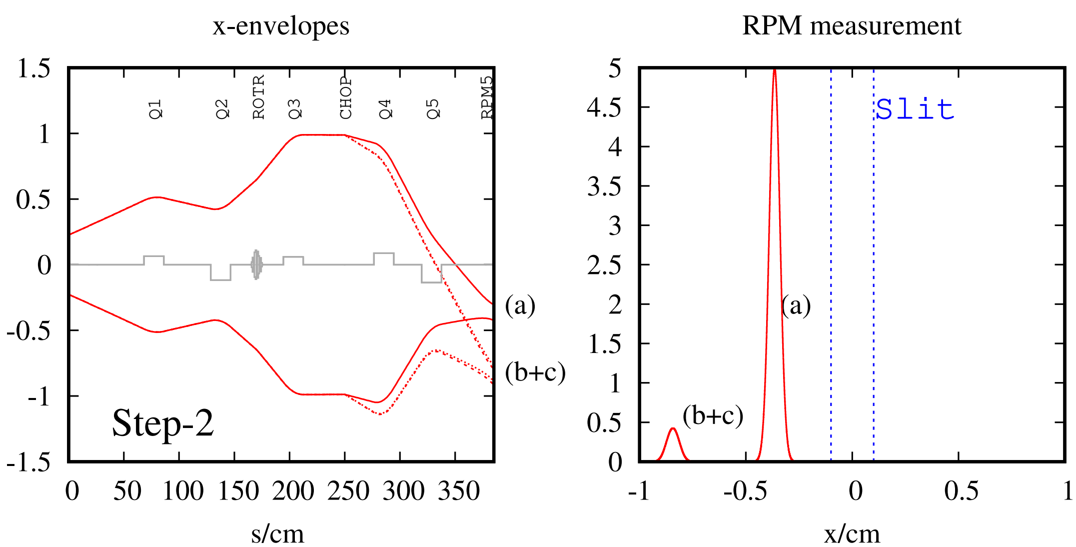


Figure 6: Chopper phase adjusted to overlap both satellites while observed at MEBT:RPM5 (**Left**), HV plate is off and beam is uncentered.

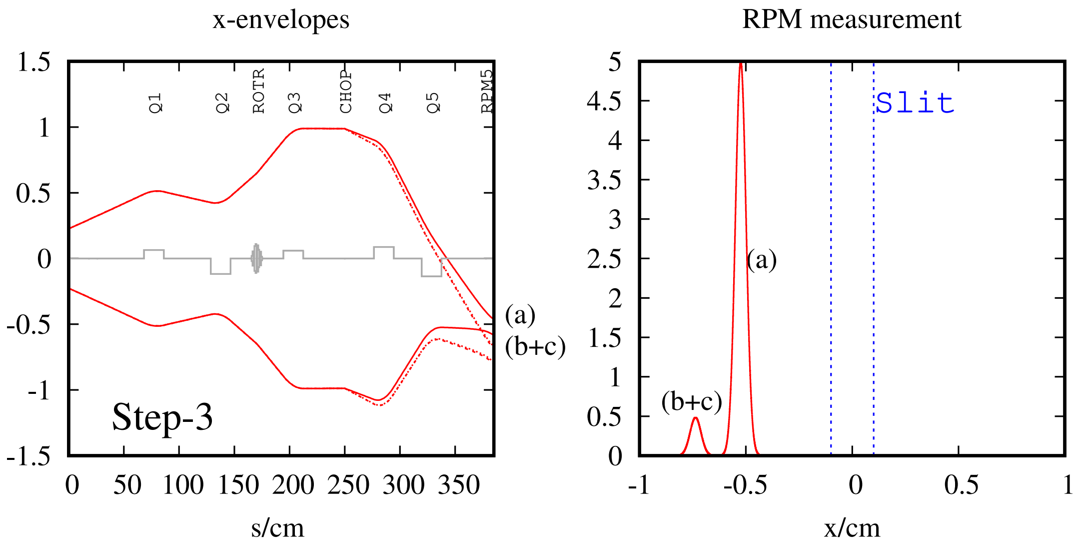


Figure 7: Chopper amplitude adjusted to minimize separation between mean peak and overlapped satellites at MEBT:RPM5 (**Left**), HV plate is off, beam remains uncentered.

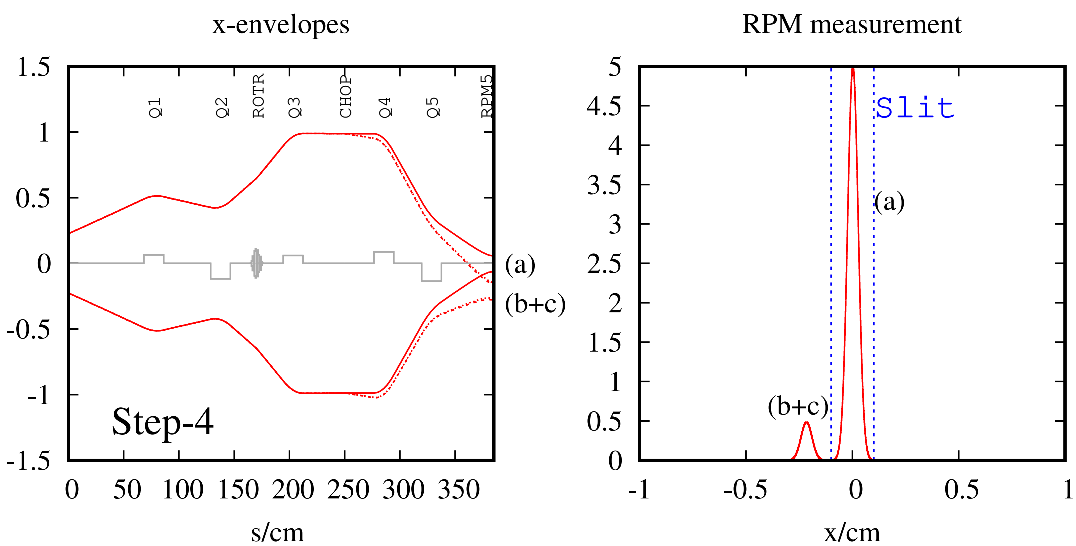


Figure 8: **Left:** Chopper HV plate is set to center beam through chopper slit while causing both satellites to impinge upon pickup wire.

3 Discussion

Section 2.1 describes the standard chopper tuning process. Initially (Fig. 5), the chopper displays misaligned peaks. The RF amplitude is increased to separate the peaks, and the 11 MHz phase is adjusted in 10–20° steps while scanning MEBT:RPM5 until the satellites overlap (Fig. 6), with the HV bias off.

Next, the RF amplitude is reduced so the satellites nearly align with the main peak (Fig. 7), still with no beam transmission due to the inactive HV bias. RF tuning concludes at this stage. The HV plate is then activated and adjusted to maximize beam current at MEBT:FC9, assuming the dipoles are set (Fig. 8). At this point, the satellites should align with the pickup plate (Fig. 3, bottom).

4 Manual Tuning Reproducibility

The MEBT chopper is manually retuned each time beam is delivered, with phase adjustment often needed to restore the main peak–satellite configuration. Figure 9 shows RF amplitude and HV bias for $^{23}Na^{+}$ beams, highlighting that multiple tuning solutions exist for the same beam parameters, indicating the method does not converge to a unique result.

Finding 1: Historical manual tuning of the 11 MHz MEBT chopper does not produce similar final values for the RF amplitude, HV offset or phase.

Figure 10 shows 11 MHz RF phase settings across various beam A/q values, revealing no clear trend. This is notable, as beam velocity—and thus time of flight—remains constant. Although bunch swapping due to prebuncher phasing is possible, the data shows no clustering around three expected phase values.

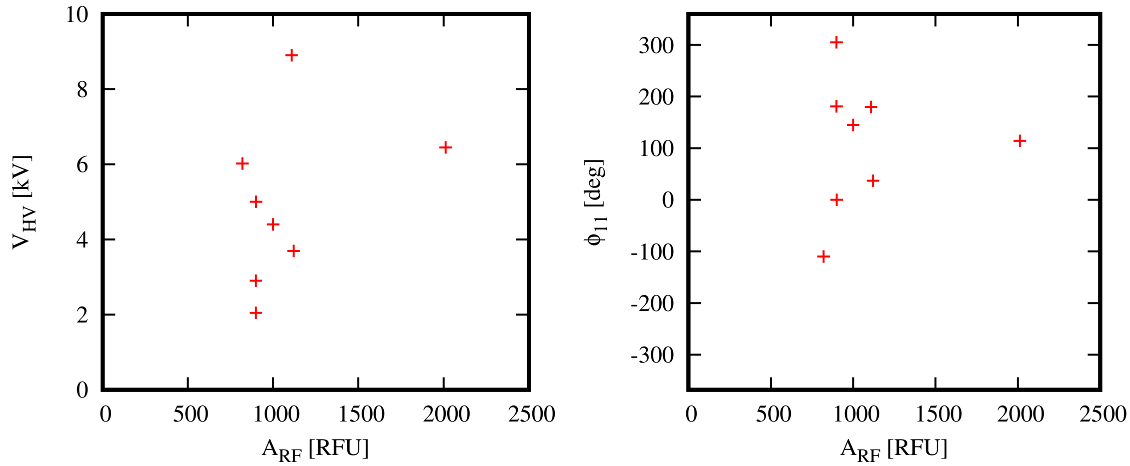


Figure 9: Past operational saved values for the 11 MHz chopper RF amplitude in control system RF units, shown against **Left:** HV plate bias and **Right:** RF phase for different instances of ^{23}Na^{+}.

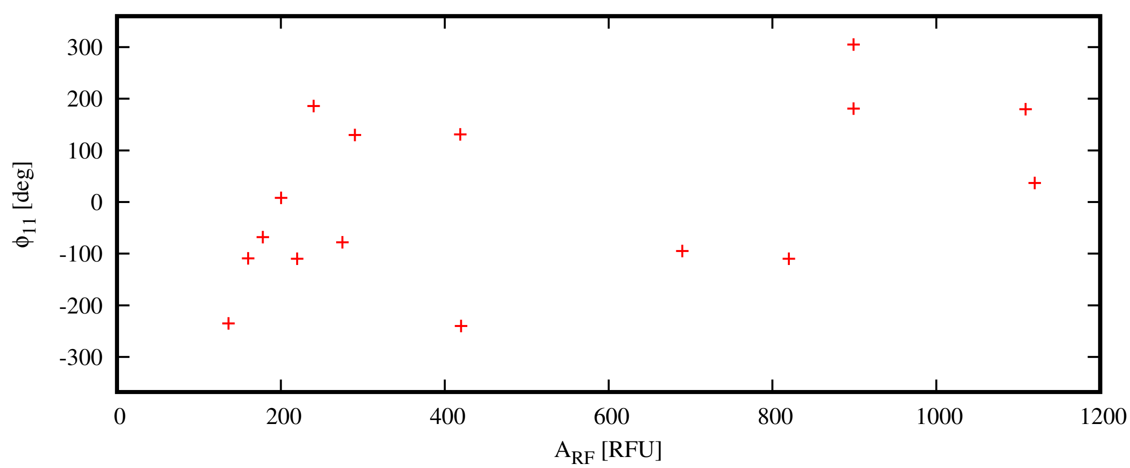
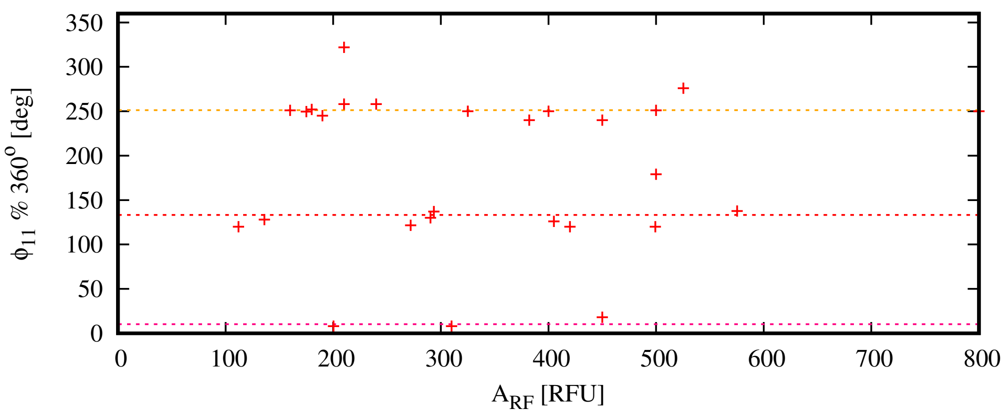


Figure 10: Past operational saved values for the 11 MHz chopper RF amplitude in control system RF units, shown against RF phase, for various beam compositions and charges.

Finding 2: Historically, final phase values for the 11 MHz chopper do not show any clear pattern, when inspecting tunes for different A/q's in the MEBT section.

The RF equipment controlling the chopper was upgraded during 2024. Figure 11 shows chopper settings for 2024 tunes. The top panel plots 11 MHz phase versus RF amplitude for various A/q beams, revealing clusters along dotted reference lines. In the bottom panel, 11 MHz phases are modulo divided by 120°, with an average remainder of 13.8°. This suggests phase variability, but clustering near three values—approximately 120° apart— consistent with three different extant RFQ bunches at 35 MHz. The main bunch may occupy any of these three buckets, depending on pre-buncher all-frequencies phase setting.



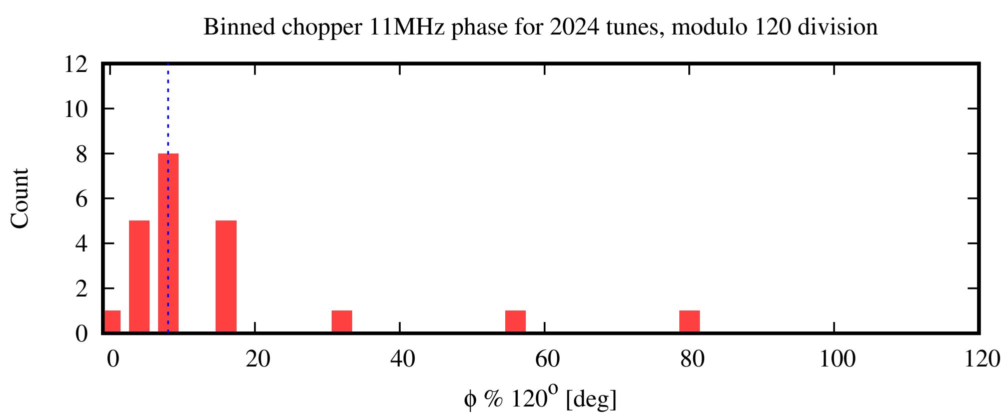


Figure 11: **Top:** 2024 operational saved values for the 11 MHz chopper RF amplitude in control system RF units, shown against **T-Left:** HV plate bias and **T-Right:** RF phase for all accelerated beams. **Bottom:** All chopper 11 MHz phases, after modulo division by 120°, showing a clustering near zero, but with an average remainder of 13.8° after the modulo 120 operation.

Finding 3: From 2024 onward, following RF equipment upgrades, manual operational tuning of the 11 MHz chopper results in phases which clusters around 13.8°, 133.8° and 253.8°.

Finding 4: From 2024 onward, despite clustering of phases, there remains variability in chopper tuning. An upgrade of chopper tuning methodology should be undertaken to improve reproducibility.

5 2024 MDEV Test

The chopper's new RF electronics were systemtically tested on 2024-11-28 during machine development at ISAC. Operational savetune 8826 was used, with an OLIS beam of ^{22}Ne^{4+} through RFQ. Both the prebuncher all frequencies and Chopper 11MHz phases were varied, looking at the profile on MEBT:RPM5. Figure 12 shows recorded solutions which produce optimum profiles (Fig. 8, right plot) as blue datapoints, while antisymmetric solutions (satellite peaks on opposite side of slit) are shown in red.

Finding 5: For any optimum prebuncher all-frequencies value (assuming correctly tuned harmonics), another identical solution can be found at MEBT:RPM5 by varying all-frequencies phase by ±125° and the chopper phase by ±120°.

The chopper phase can thus be expressed in terms of the prebuncher all-frequencies phase ϕ_{AF}, using the following relationship, where $\mathbb{Z}$ denotes the integers:

$$\phi_{\mathrm{Chop11}} = 0.96\phi_{\mathrm{AF}} - 82^\circ + n \cdot 360^\circ,\ n \in \mathbb{Z} \quad (1)$$

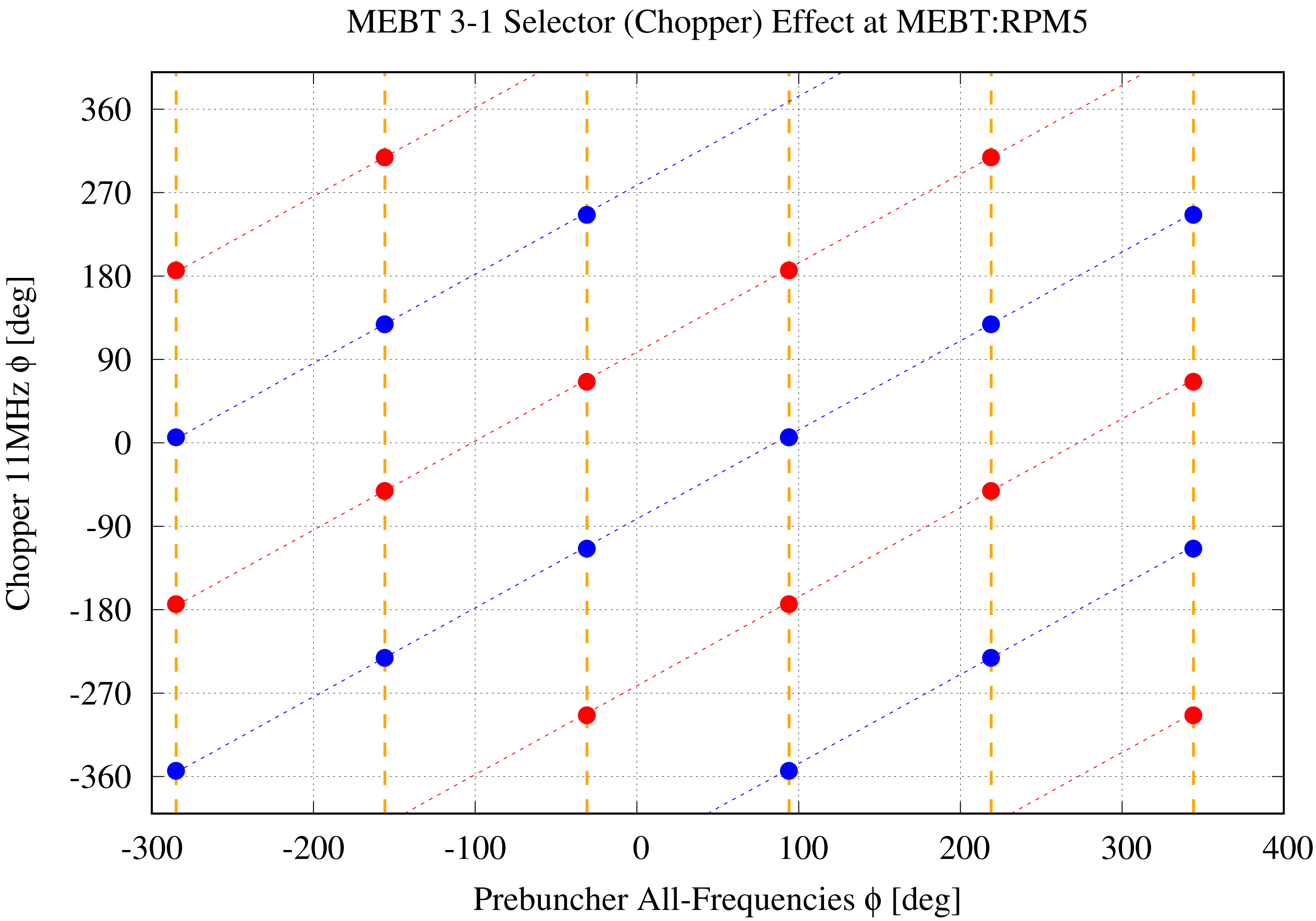


Figure 12: Recorded relationship between prebuncher all frequencies and 11 MHz chopper frequency. Blue dots represent optimum MEBT:RPM5 profile, with sufficient satellite peak separation and overlap to produce a signal on the wire pickup, while red dots show anti-symmetric profiles. Orange dotted lines denote optimum all-frequencies phase for RFQ transmission.

References

[1] R. Laxdal. A Chopper for MEBT. Technical Report TRI-DN-00-02, TRIUMF, January 2001.

[2] RE Laxdal, M Pasini, L Root, et al. Beam Dynamics Design Study and Beam Commissioning of the ISAC Two Frequency Chopper. *LINAC2002, Gyeongju, Korea*, page 407, 2002.

[3] AK Mitra, ZT Ang, R Hohbach, RE Laxdal, J Lu, and RL Poirier. Design, test and commissioning of a dual frequency chopper for the TRIUMF ISAC facility. In *Proc. LINAC'02, Gyeongju, ROK (2002).*, 2002.

[4] M Marchetto, J Aoki, K Langton, RE Laxdal, W Rawnsley, JE Richards, et al. The ISAC-II current monitor system. *LINAC10, Tsukuba*, 2010.