Beam Physics Note
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Investigation of ISAC Mass Separator Optics

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Abstract: This document details IMS optics checks that were performed during May 2022, using ^{28}Al^{+} at 30.0 keV. IMS emittance readings were used to analyze the IMS beam envelope, comparing TRANSOPTR simulations to RPM intensity profiles in the (x,y) dimensions. An on-line tune is established at IMS. Findings on-line are discussed.

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1 Summary

Using ITW with a FEBIAD target in May 2022, RIB operators were given instructions to perform emittance scans in the IMS section. These data have been used to run performance checkups of the IMS optics transport system. This report summarizes these measurements and presents a few interim conclusions about the state of the mass separator optics.

2 IMS:Q11 and Q12

The parameters from Table 1, obtained from an ops H/V emittance scan at IMS:EMIT11 was used to simulate quadrupoles IMS:Q11 and Q12, looking at IMS:RPM14. Note that each PV controls two quadrupoles each, with the beamline sequence Q11-Q12-Q12-Q11 installed. TRANSOPTR computed beam envelopes are shown in Figures 1 and 2.

E [keV]	q	ϵ_x [μm]	x_i [mm]	x'_i [mrad]	r_{12}	ϵ_y [μm]	y_i [mm]	y'_i [mrad]	r_{34}
30.00	1	15.26	2.87	5.92	-0.440	13.37	0.51	26.20	0.07

Table 1: TRANSOPTR starting beam parameters, obtained from RIB Ops emittance scan results on 2022-05-16, used to compute transverse beam envelopes in Figures 1 and 2.

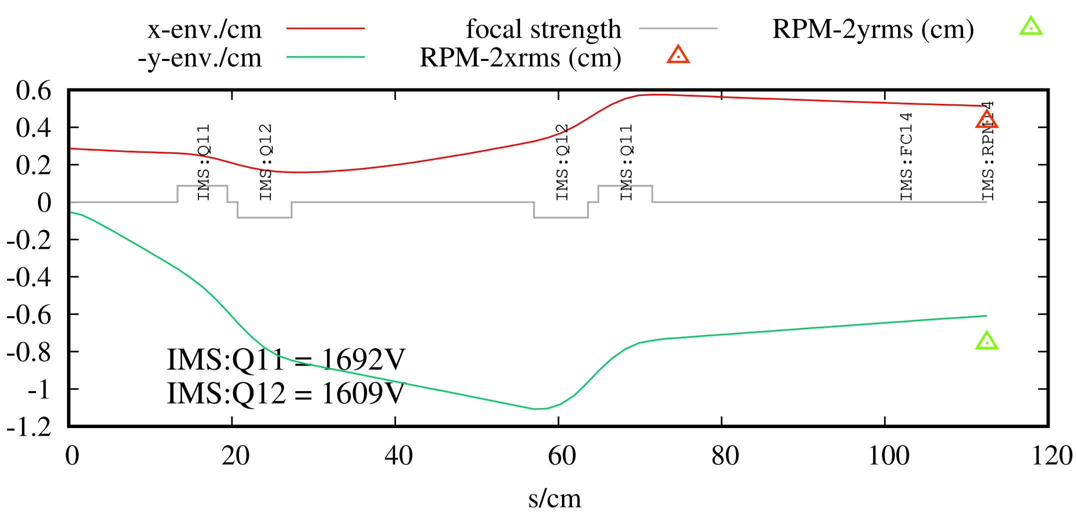

Figure 1: TRANSOPTR 2rms beam envelopes from location of IMS:YSLIT11B to IMS:RPM14.

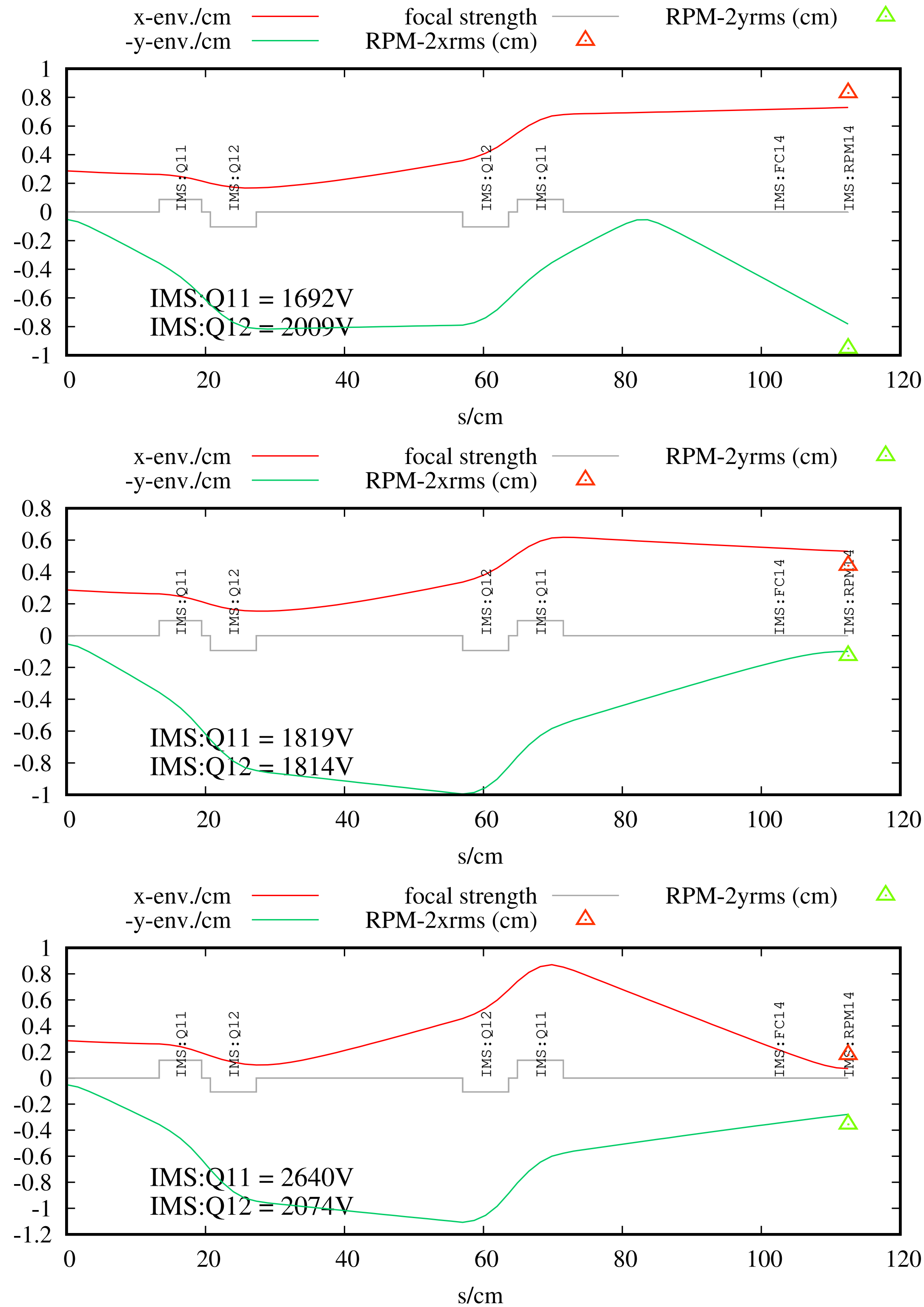

Figure 2: TRANSOPTR 2rms beam envelopes from location of IMS:YSLIT11B to IMS:RPM14.

3 IMS:Q11 to Q18

several different combinations of settings for IMS:Q15 to Q18 were set on-line and the corresponding IMS:RPM18 profiles for (x,y) recorded. These were in turn fit in TRANSOPTR, which was called in a loop to find the initial twiss parameters at the IMS emittance rig, subject to the fit constraints of the recorded intensity distribution sizes at IMS:RPM14 and RPM18. The beam parameters including fit starting (x,y) sizes and correlations are shown in Table 2.

E [keV]	q	ϵ_x [μm]	x_i [mm]	x'_i [mrad]	r_{12}	ϵ_y [μm]	y_i [mm]	y'_i [mrad]	r_{34}
30.00	1	11.06	2.91	6.67	0.82	14.29	0.47	31.40	-0.05

Table 2: Fit initial beam parameters at IMS:EMIT11 along with the `python` package `profiles`[1].

Finding 1: IMS quadrupole lenses Q11 to Q18 appear to operate nominally, producing intensity profiles at IMS:RPM14 and RPM18 consistent with expected beam envelopes.

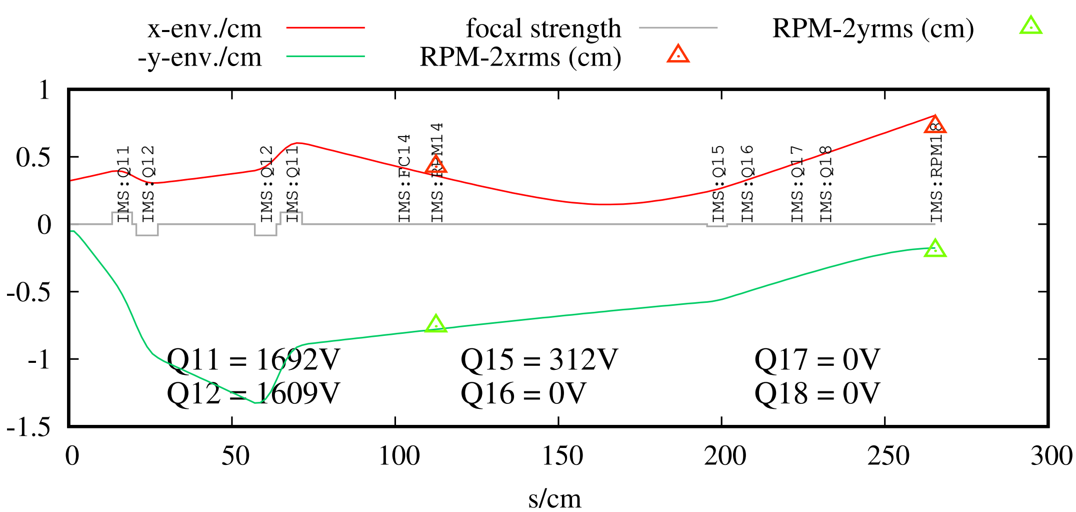

Figure 3: TRANSOPTR 2rms beam envelopes from location of IMS:YSLIT11B to IMS:RPM18.

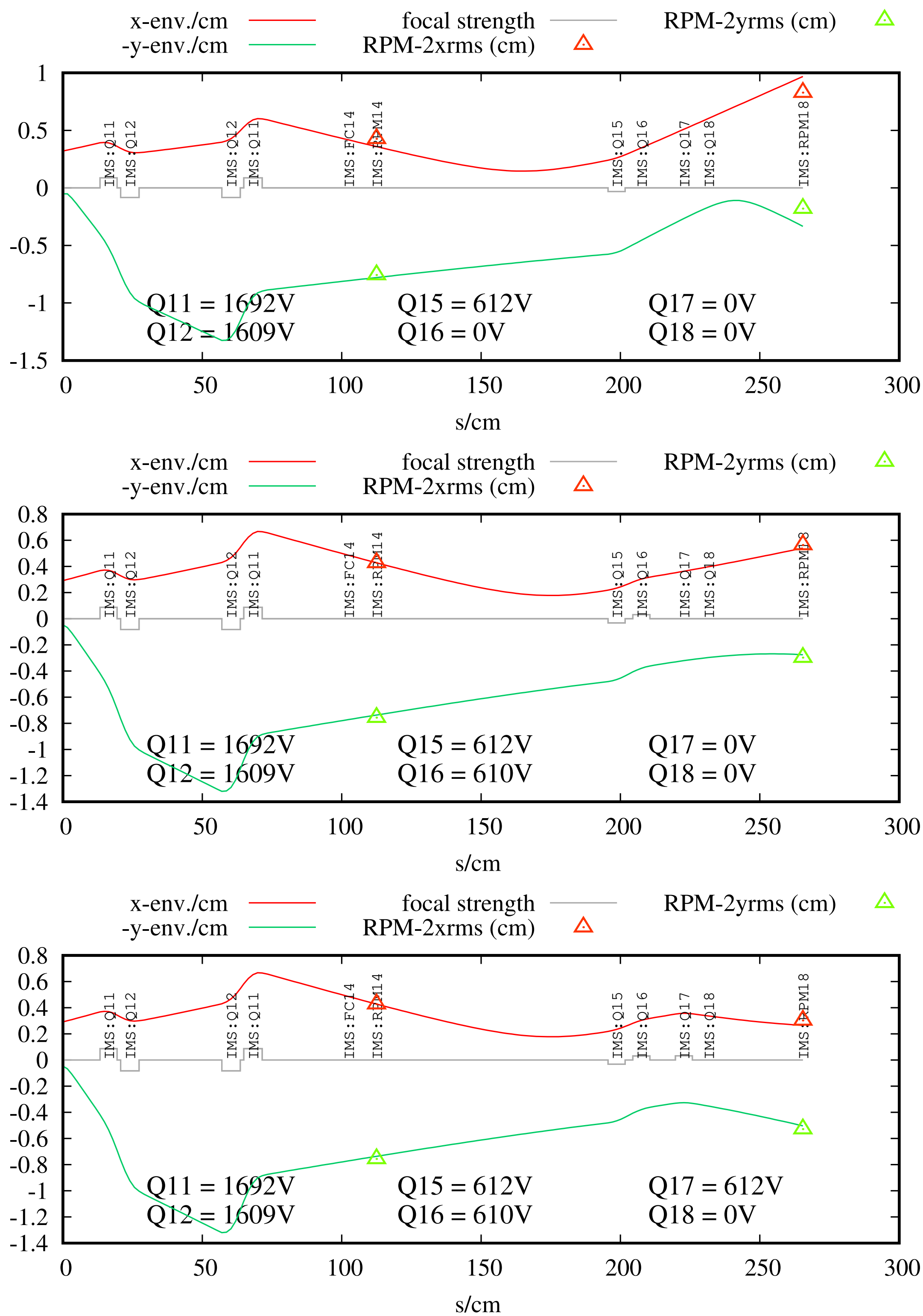

Figure 4: TRANSOPTR 2rms beam envelopes from location of IMS:YSLIT11B to IMS:RPM18.

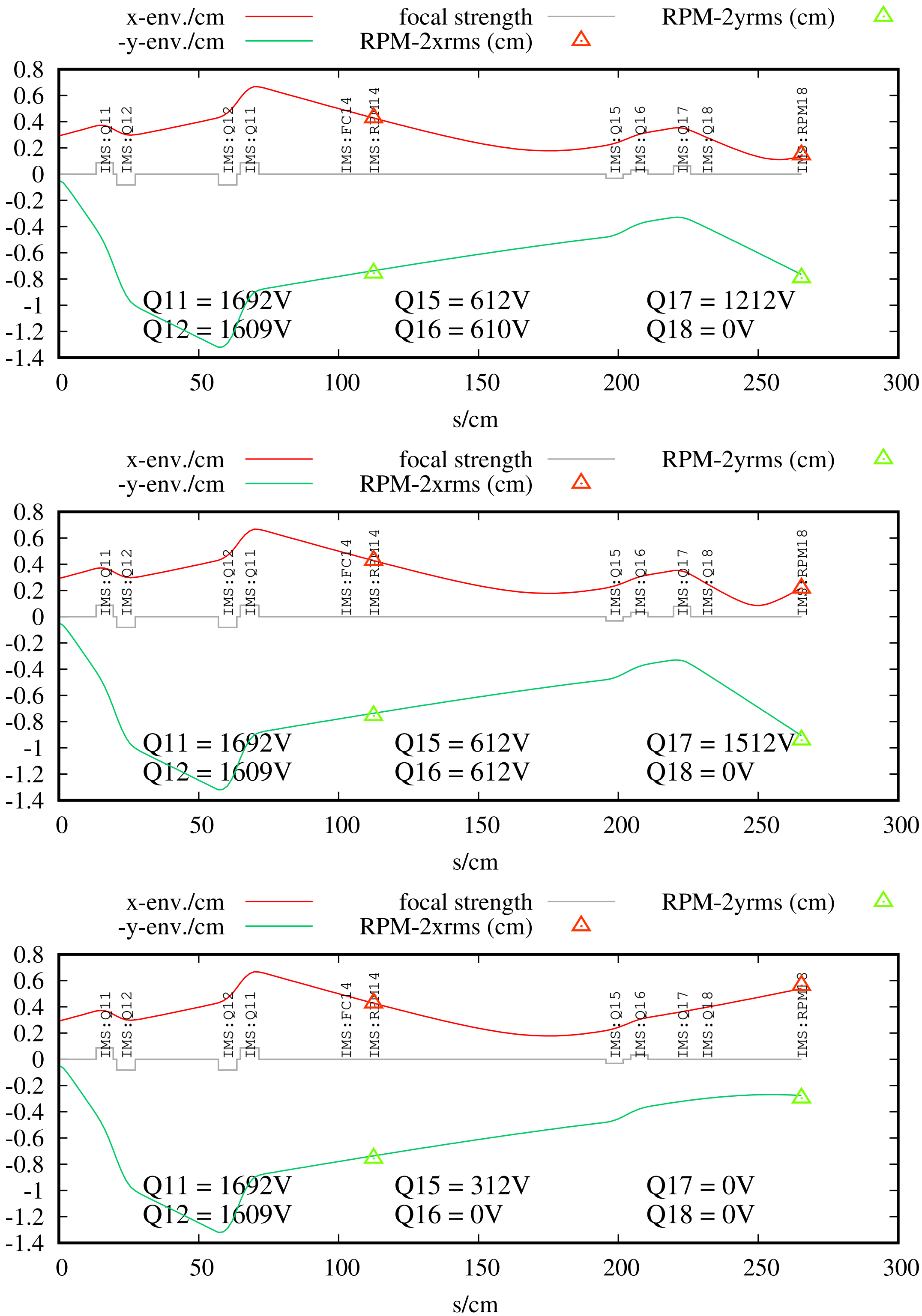

Figure 5: TRANSOPTR 2rms beam envelopes from location of IMS:YSLIT11B to IMS:RPM18.

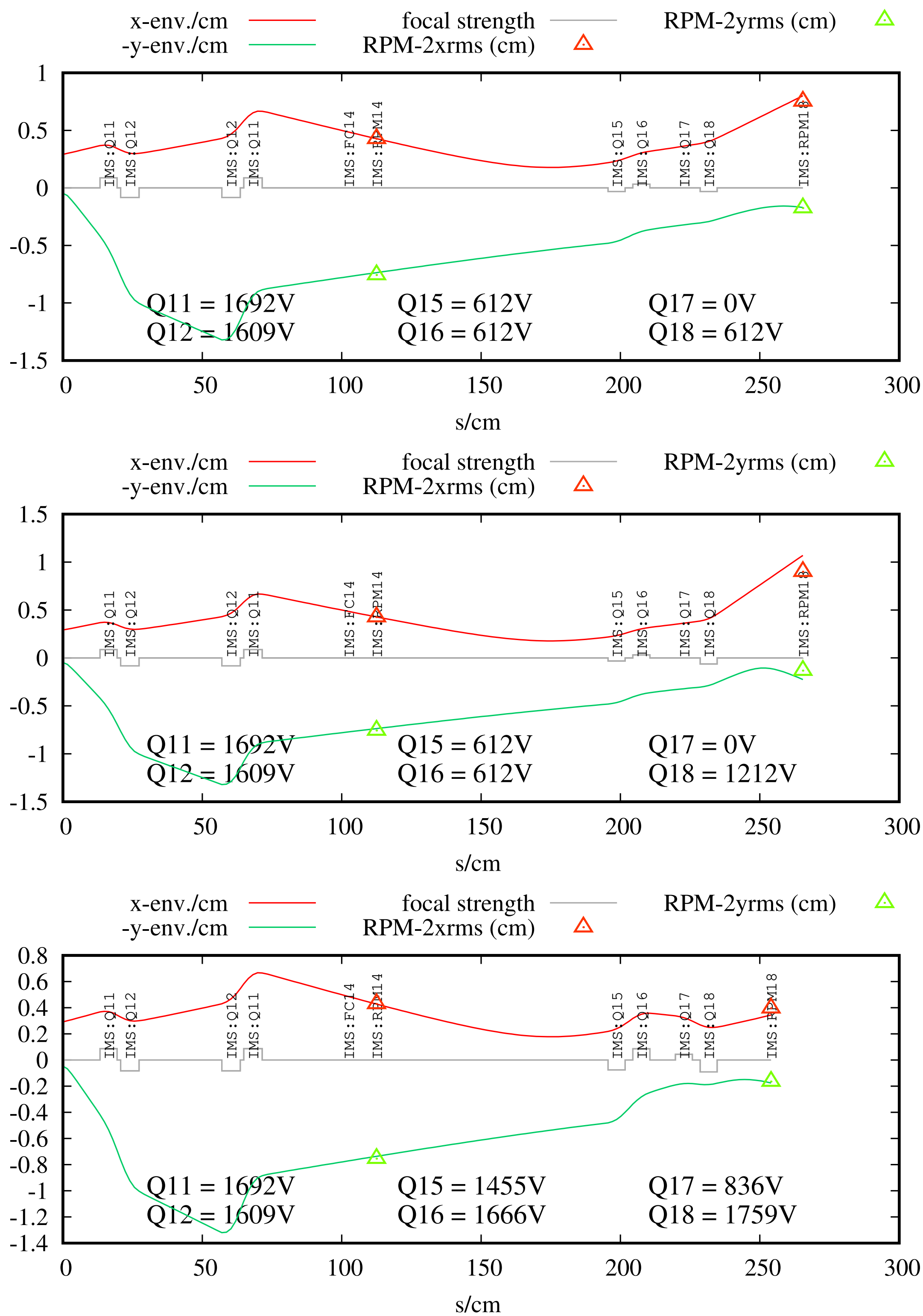

Figure 6: TRANSOPTR 2rms beam envelopes from location of IMS:YSLIT11B to IMS:RPM18.

4 Evidence for YSLIT11B/IMS:Q11,Q12 Misalignment

Finally, while tuning quadrupoles Q11 and Q12 in IMS, it was noticed that considerable x-steering was required to correct the vertical beam centroid position on IMS:RPM14. Recall that in the IMS section, the convention is reversed form the rest of the ISAC experimental hall, with x being vertical and y horizontal. There is a strong centroid response in x to changes in Q11 and Q12 settings, shown in Figure 7, where the package `profiles` was used to extract the RPM14 beam centroids in (x,y) at a variety of IMS:Q11 and Q12 settings. Notice that in the x-dimension (Fig. 7, bottom), beam is nearly off the vertical scale. In both plots the dotted black lines show the neutral/centered position, at 1.27 cm for x and 3.81 cm for y. The steering effect is considerable in the x-dimension, suggesting a vertical misalignment exists at the exit of the ISAC mass separator.

Quadrupoles Q11 and Q12 are the first lenses after the second separator slit IMS:YSLIT11B, and for reference Baartman's tune for 30 keV, charge state 1 calls for Q11/Q12 set to 1404/1469V, respectively. Consulting Figure 7, we see that for these settings we expect a considerable vertical misalignment, with beam centroid being displaced to roughly the 0.5 cm position on IMS:RPM14. This represents a centroid shift of 0.77 cm. Keeping in mind that the downstream slits IMS:X/YSLIT/22/24 are typically set to 0.8 cm for delivery, these data suggest we are dealing with beam centroid errors of the same magnitude of the slit widths, causing the need for corrective detuning. Also note that the effect produced by steerer IMS:XCB14 and its common plate IMS:CCB14 is much lesser than the dipole kick effect from quadrupoles IMS:Q11 and Q12. Thus, operators manually tuning those optics will find it easier to detune the quadrupoles to correct the centroid, which in turn will require additional corrective detuning of IMS:Q15 to Q18, attempting to manually restore the beamsize downstream and avoid transmission loss due to mismatches, particularly given the aperture constraints in the IMS line.

Finding 2: IMS:Q11 and Q12 cause appreciable dipole kicks to the beam centroids, particularly in the vertical (x)-dimension, observable at IMS:RPM14.

Finding 3: This is evidence of a vertical misalignment between IMS:MB2, the ISAC mass separator magnet, and downstream optics IMS:Q11 and Q12.

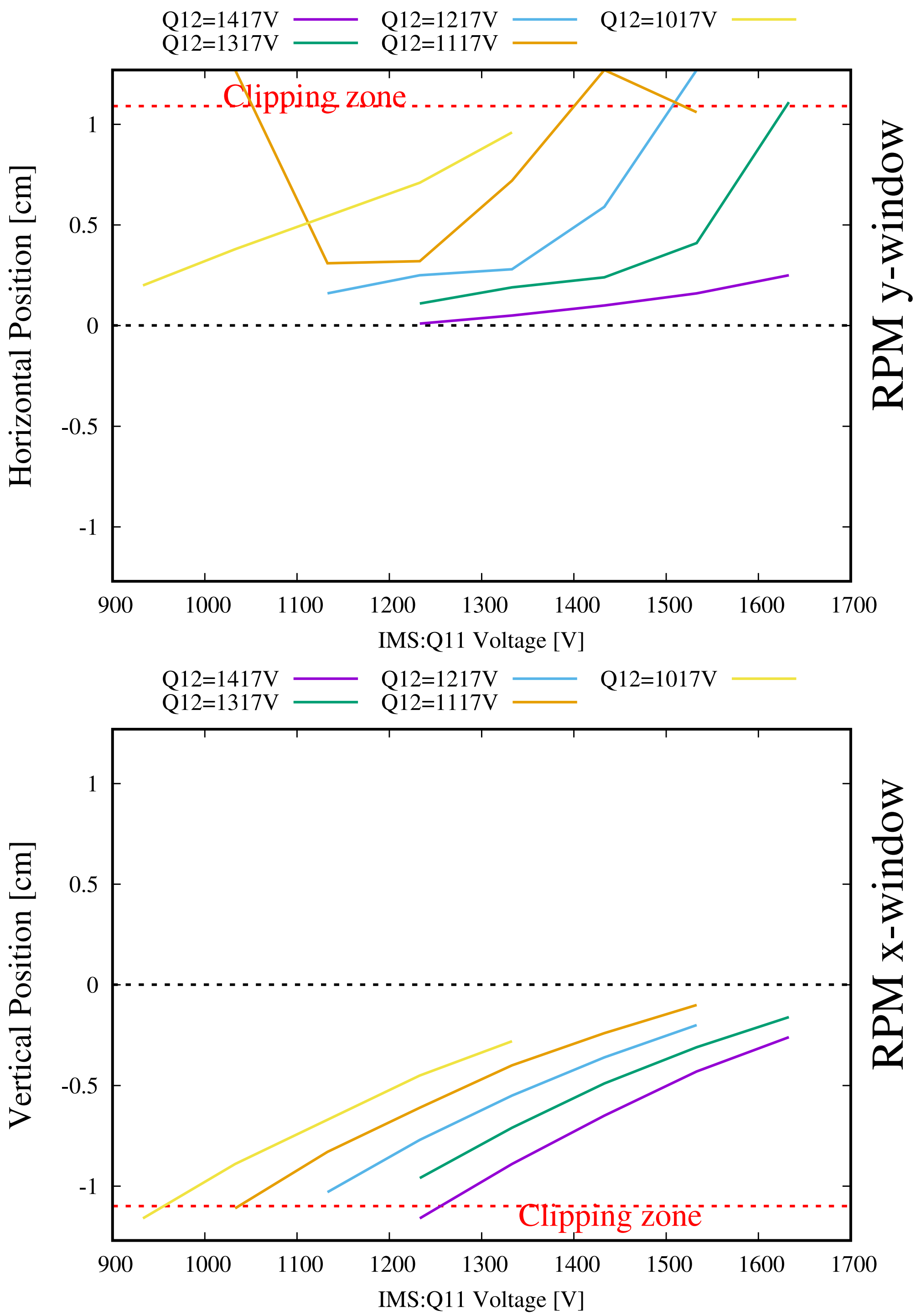

Figure 7: **Top:** computed horizontal (y) intensity trace centroid at IMS:RPM14, using the package `profiles`. **Bottom:** computed vertical (x) intensity trace centroids at the same RPM. Centroids in both dimensions have been recorded at a variety of IMS:Q11 and Q12 settings, showing the transverse kicks produced by both quadrupoles. Appendix A shows an RPM14 reading from that day, while Appendix B shows an unrelated RPM14 reading on the RPM/Compare utility, showing the relative dimensions.

5 Autofocusing of IMS Optics On-Line

RIB Ops emittance measurements were used to find the IMS:YSLIT11B σ-matrix elements for (x,y), shown in Table 3. An on-line tune optimization was performed using sequential optimization. The envelopes and on-line measured profiles are shown in Figure 8. After corrective steering, operators reported this tune produced a transmission of 91% from IMS:FC14 to IMS:FC34. The 9% transmission drop is not currently understood and should be investigated further.

E [keV]	q	ϵ_x [μm]	x_i [mm]	x'_i [mrad]	r_{12}	ϵ_y [μm]	y_i [mm]	y'_i [mrad]	r_{34}
30.00	1	11.32	2.51	5.10	0.463	11.37	0.43	26.20	-0.07

Table 3: `TRANSOPTR` starting beam parameters, obtained from RIB Ops emittance scan results on 2022-05-19, used to compute transverse beam envelopes in Figures 8.

Finding 4: The IMS optics from Q11 until IMS:FC34 produce beam intensity profiles consistent with the expected `TRANSOPTR` envelopes, on-line.

Finding 5: IMS slits 22 and 24 were found to produce drastic transmission loss when set to 8 mm, larger than the expected beamsize. The analog and digital readbacks of the slits did not agree.

Finding 6: There is a need for considerable steering throughout the IMS line. Though some of this may be explained by a vertical misalignment at MB2, the electrical behaviour of the line should be examined to ensure there are no unexpected floating voltages.

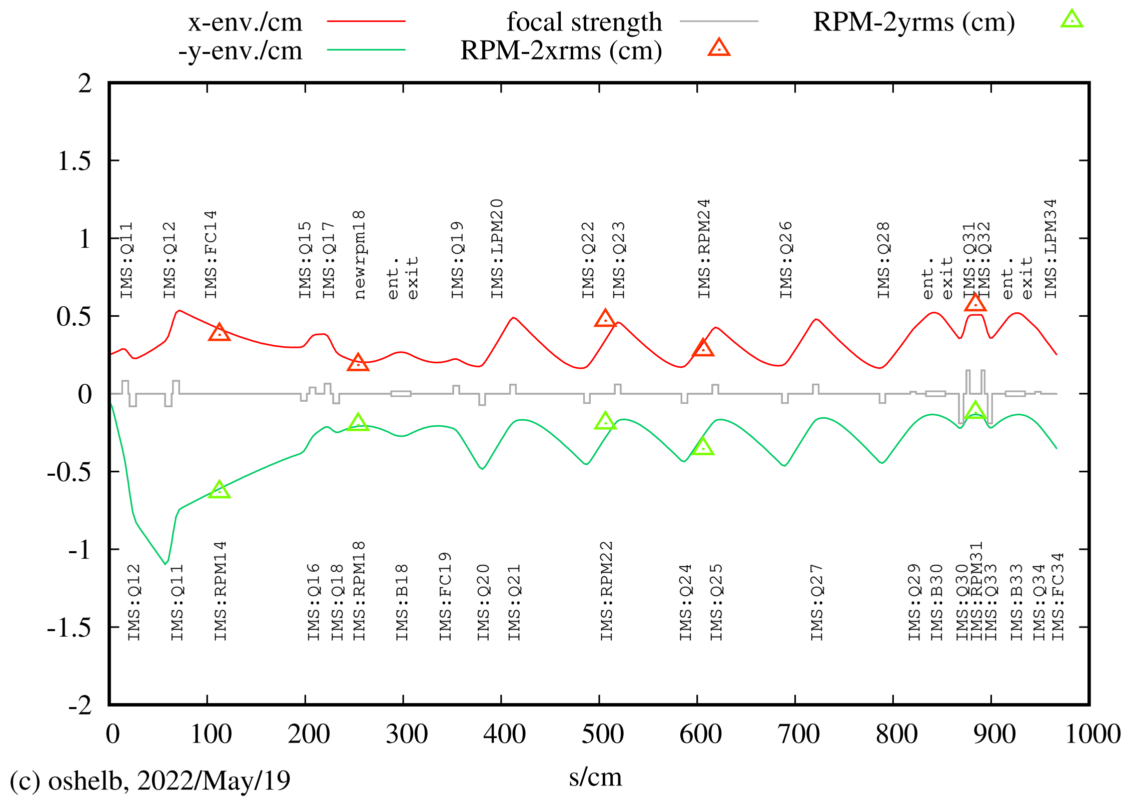

Figure 8: TRANSOPTR envelopes representing on-line tune `220519_1211-itw-ily-yield.snap`, which was computed using sequential optimization, from IMS:YSLIT11B up to IMS:FC34. On-line 2rms beamsizes, computed using the package `profiles`, are displayed for comparison.

6 Conclusion

This report has analyzed the behaviour of the mass separator optics from the exit slit YSLIT11B to IMS:RPM18 and found that the quadrupoles appear free of wiring errors. The envelopes produced by realtime TRANSOPTR simulations agree with measured beam profiles using IMS:RPM14 and RPM18. It is therefore concluded that Q11 to Q18 operate nominally. An on-line tune computation was found to produce high transmission and profile agreement up to IMS:FC34. Considerable steering required throughout the line may cause beam loss due to alignment issues. Though the need for steering could be due to beamline alignment, it cannot be ruled out that a floating voltage in the line produces an unexpected deflection to the beam.

Strong vertical (x) kicks caused by quadrupoles Q11 and Q12 observed at IMS:RPM14 were found not to be correctible using IMS:XCB14 and CCB14. Instead, it was necessary to detune IMS:Q11 and Q12 to correct the vertical centroid at RPM14, which in turn required further manual tuning of quadrupoles Q15 to Q18 to restore downstream transmission. This is evidence of a vertical misalignment issue in the IMS line between mass separator (IMS:MB2) and its downstream optics. The alignment state of the beamline should be investigated urgently. The electrical continuity and performance of the optics should also be investigated.

References

[1] Kristin Wu. Profile Monitor Classification using Random Forest Classifier . Technical Report TRI-BN-21-11, TRIUMF, 2021.

Findings (recalled)

Finding 1: IMS quadrupole lenses Q11 to Q18 appear to operate nominally, producing intensity profiles at IMS:RPM14 and RPM18 consistent with expected beam envelopes.

Finding 2: IMS:Q11 and Q12 cause appreciable dipole kicks to the beam centroids, particularly in the vertical (x)-dimension, observable at IMS:RPM14.

Finding 3: This is evidence of a vertical misalignment between IMS:MB2, the ISAC mass separator magnet, and downstream optics IMS:Q11 and Q12.

Finding 4: The IMS optics from Q11 until IMS:FC34 produce beam intensity profiles consistent with the expected TRANSOPTR envelopes, on-line.

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Appendix A - Example IMS:RPM14 Screengrab

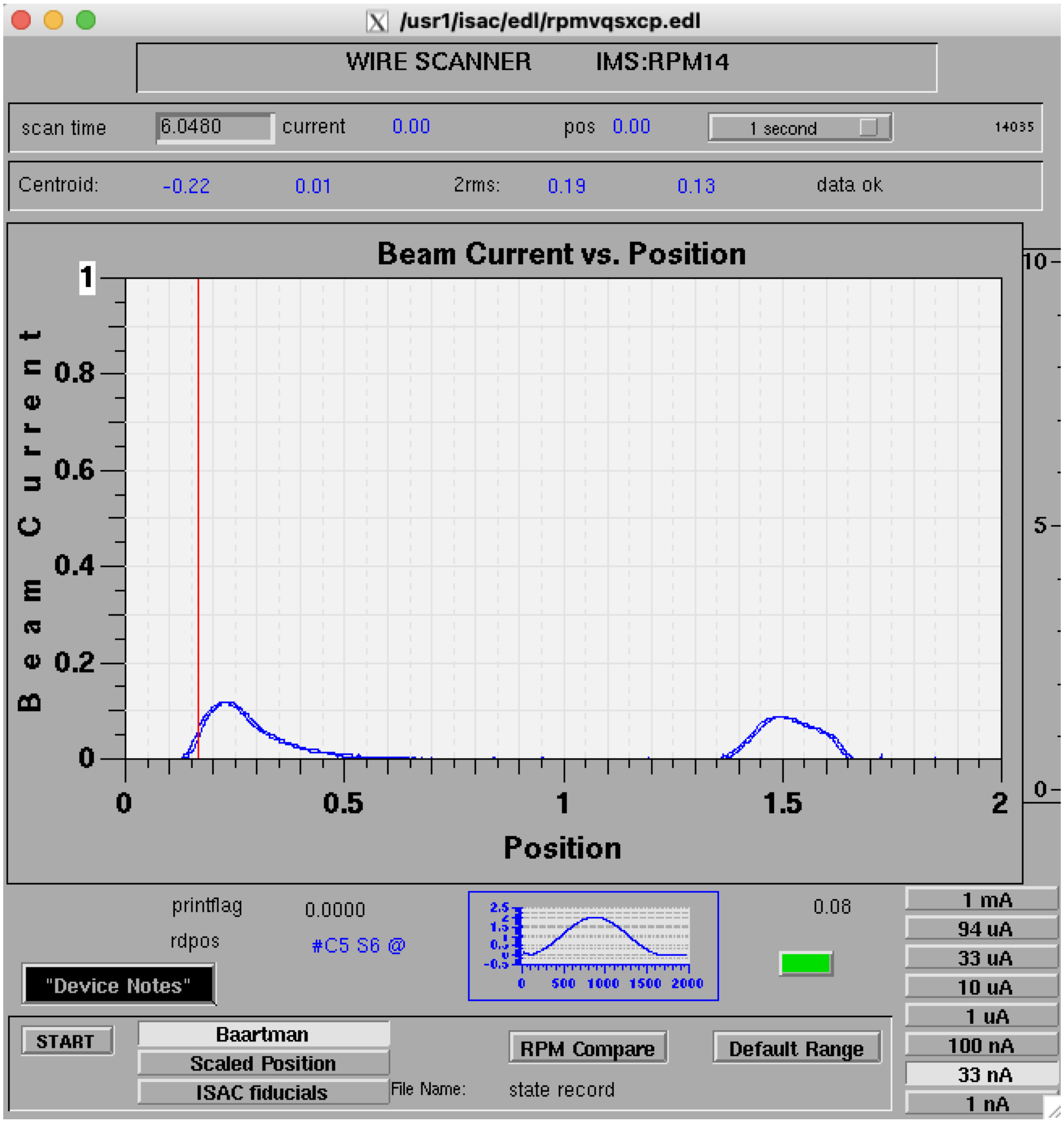

Figure 9: Screenshot of IMS:RPM14, showing vertically displaced beam profile in the x-dimension (left). As beam approaches the left edge of the RPM window, the distribution becomes clipped, invalidating the centroid and size computations. As the Q11 voltage is lowered, beam displaces vertically toward the left edge of the RPM window.

Appendix B - RPM/Compare Display for IMS:RPM14 (Unrelated tune)

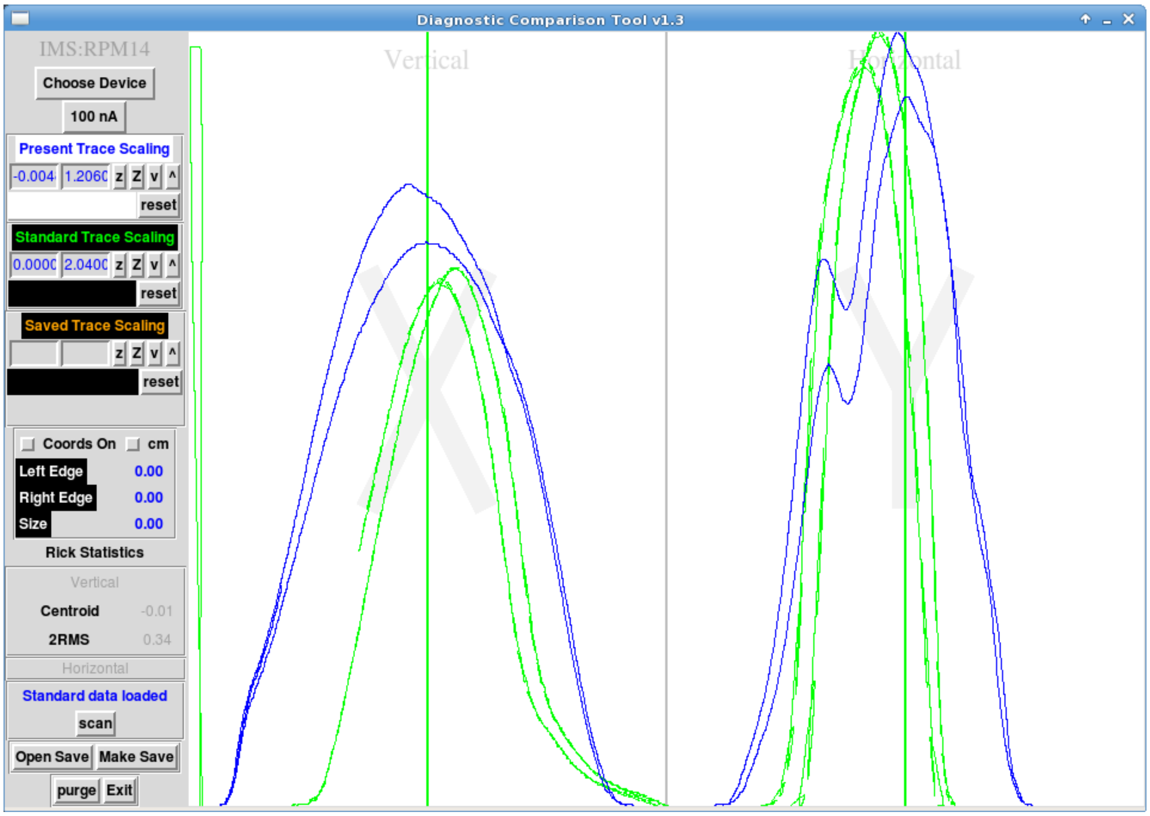

Figure 10: Screenshot of IMS:RPM14 for an unrelated beam during a different tuning session. The image shows the relative (x,y) orientations, with the vertical dimension is on the left.