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Sign Flip in IMS Emittance Correlations

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Abstract: This report documents the finding that the beam correlation coefficients extracted via software from the IMS emittance rig at TRIUMF-ISAC's rare isotope separator have an incorrect sign.

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The IMS Emittance Rig

The ISAC mass separator's emittance rig[1, 2], conceptually shown in Figure 1, is used to measure the emittance of beams at the location of the mass separator magnet exit slit.

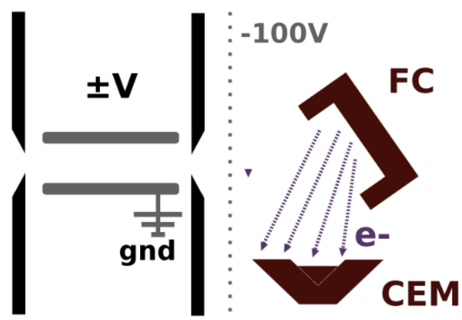

Figure 1: Schematic representation of the emittance rig's function. Beam propagates from left to right and is selected by two sets of slits with a transverse electric field applied between parallel plates. Image taken from [3].

Emittance Scans

Routine emittance measurements were taken by RIB Operations using target **ITE-TM2 Ta#68 HP-SIS**, during preparation for 20keV RIB delivery to yield and TRINAT experiments. The scans are shown in Figure 2 and 3.

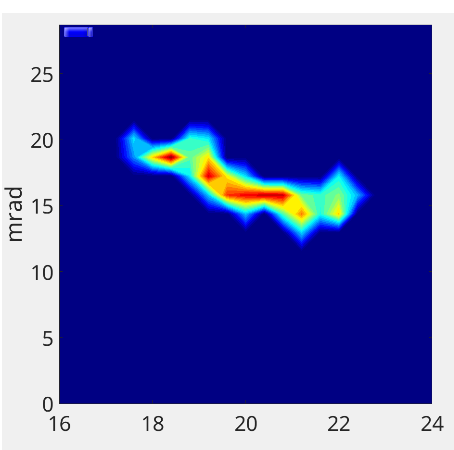

Figure 2: **241004_0818IMSEMIT11.txt**
x-dimension

Start	End	Steps	Range	Steps	Offset
16	24	21	45	21	27

2xrms[mm]	2x'rms[mrad]	r_{12}	emit-x[μm]
2.59	3.58	-0.77	5.92

$^{39}K^{+}$, E=8.16 keV, **60uA p+**.

Tune: Snapshot. CCB: 167V

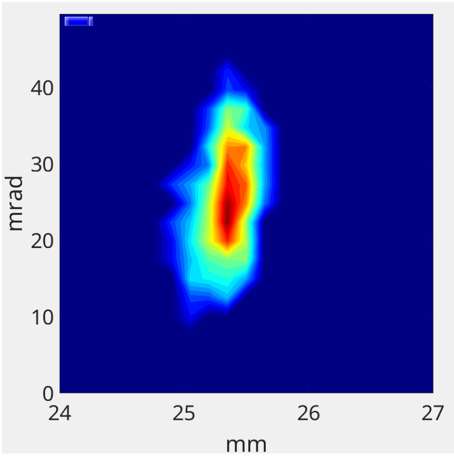

Figure 3: **241004_0803IMSEMIT11.txt**
y-dimension

Start	End	Steps	Range	Steps	Offset
24	27	21	77	21	122

2yrms[mm]	2y'rms[mrad]	r_{34}	emit-y[μm]
0.351	14.0	0.267	4.64

^{39}K$^+$, E=20.0 keV, **60uA p+**.

Tune: Snapshot. CCB: 167V

These were used in a parallel modelling test to match quadrupoles IMS:Q11 to Q18 for transport. Figure 4 shows the observed results. Note the significant size discrepancy at IMS:RPM18, located at distance coordinate ~2.5m on the plot. The original sign assumption for r_{12} (Figure 2) predicts a sharp waist at RPM18, while a comparatively larger beamsize is observed, consistent with a sign flip for r_{12}.

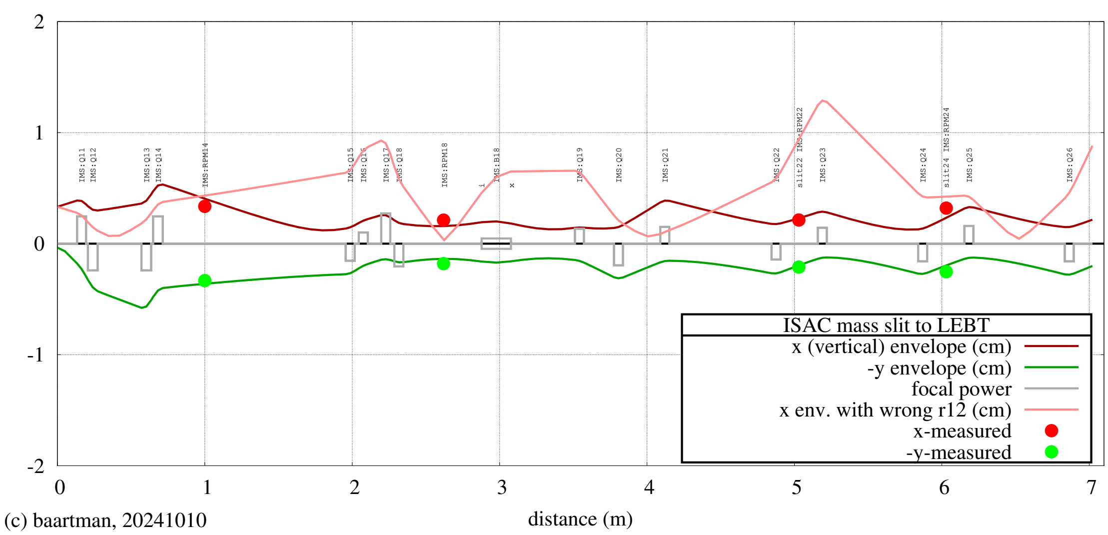

Figure 4: TRANSOPTR 2rms beam envelopes showing a sign flip for r_{12}. x-envelopes corresponding to the (incorrect) sign are shown in pink, while the correct (flipped polarity) case are in dark red. Measured 2rms beamsizes with RPMs shown as points on the plot.

On The Sign for r_{34}

Since the beam is at a waist in the y-dimension at the mass separator image slit, it is less straightforward to verify the sign for r_{34} since it is zero with the design tune in effect.

To check the sign of r_{34}, IMS:Q10 which is upstream of the mass separator magnet can be varied and its effect at the exit slit should be to change r_{34} appreciably. `TRANSOPTR` simulations shown in Figure 5 show the effect: Lowering Q10 from its design value makes r_{34} negative and increasing it with respect to the design value makes r_{34} positive.

Emittances were run for this test by RIB Operations, by setting the tune to design through the separator and running a first emittance scan for reference, shown in Figure 6.

IMS:Q10 was then lowered by 200V. The horizontal emittance for this case is presented in Figure 7, **showing that the correlation coefficient increased with respect to the initial tune.** Increasing IMS:Q10 by 200V with respect to its original value produces the emittance scan shown in Figure 8, **causing the correlation coefficient to decrease with respect to the initial tune.**

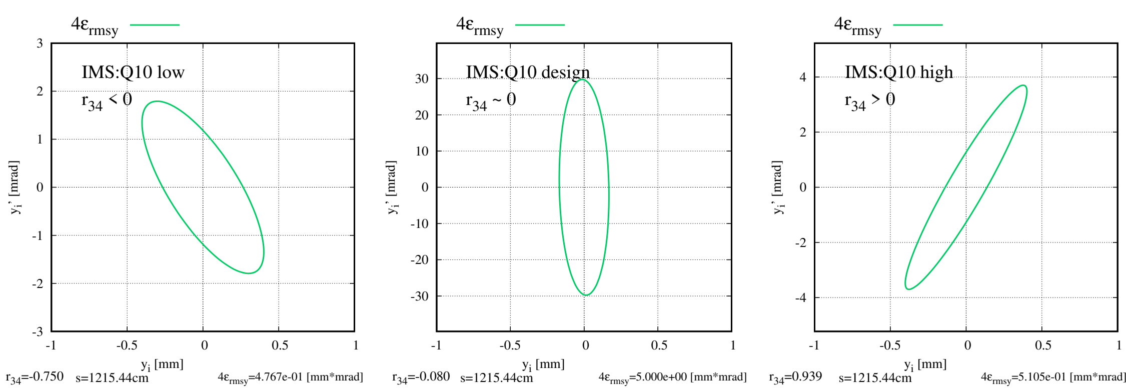

Figure 5: Simulated horizontal (y) beam distributions at IMS emittance rig. We expect r_{34} more negative with IMS:Q10 lowered from the design tune, r_{34} near zero at the design tune and r_{34} positive above the design value. Changes in emittance due to aperture collisions with the separator's object and image slits.

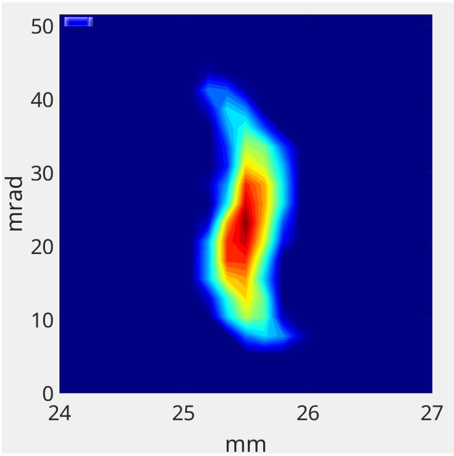

Figure 6: **241106_0227IMSEMIT11.txt**
y-dimension. **Q10: Design**

Start	End	Steps	Range	Steps	Offset
24	27	21	77	21	122

2yrms[mm]	2y'rms[mrad]	r_{34}	emit-y[μm]
0.509	22.0	-0.392	10.3

$^{39}K^+$, E=25.0 keV, **80uA p+**.

Tune: Snapshot. CCB: 208V

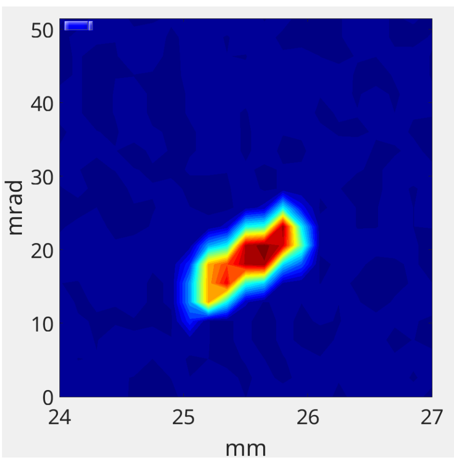

Figure 7: **241106_0339IMSEMIT11.txt**
y-dimension. **Q10: -200V**

Start	End	Steps	Range	Steps	Offset
24	27	21	77	21	122

2yrms[mm]	2y'rms[mrad]	r_{34}	emit-y[μm]
0.516	7.77	**+0.568**	3.3

$^{39}K^+$, E=25.0 keV, **80uA p+**.

Tune: Same as Fig.6, IMS:Q10 -200V CCB: 208V

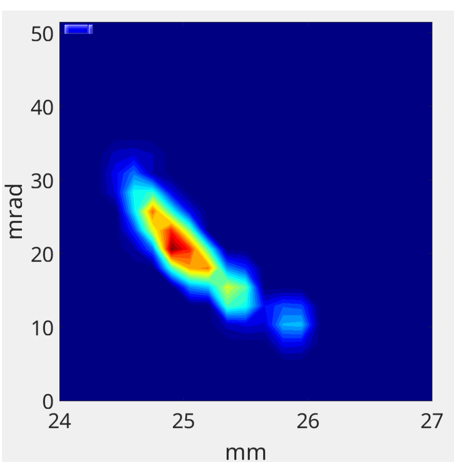

Figure 8: **241106_0332IMSEMIT11.txt**
y-dimension. **Q10: +200V**

Start	End	Steps	Range	Steps	Offset
24	27	21	77	21	122

2yrms[mm]	2y'rms[mrad]	r_{34}	emit-y[μm]
0.73	11.5	**-0.884**	3.93

$^{39}K^+$, E=25.0 keV, **80uA p+**.

Tune: Same as Fig.6, IMS:Q10 +200V CCB: 208V

Conclusion

Analysis of beams exiting the mass separator magnet in the IMS section reveals that **both the correlation coefficients for the horizontal and vertical phase space dimensions, as extracted from the MATLAB emittance processing program, have the incorrect sign.**

This means that, transversely converging beams have been interpreted as being diverging, and vice versa. It also means that using the fit emittances to drive parallel modelling simulations, for example with MCAT, or with previous incarnations of parallel modelling programs, will not produce a match in the mass separator transport beamlines, unless r_{12}=r_{34}=0, exactly.

For the purposes of this work, it was not possible to determine when this issue arose, however it has likely existed since at least 2018. It possibly dates back to the start of the ISAC project. Following this investigation, the sign for both r_{12} and r_{34} as returned by the MATLAB emittance program have been reversed, meaning **any processed emittance data from before the date of this report has incorrect signs for transverse correlation coefficients.**

References

[1] Pierre Bricault, Richard Baartman, Marik Dombsky, Andrew Hurst, Clive Mark, Guy Stanford, and Paul Schmor. Triumf-isac target station and mass separator commissioning. *Nuclear Physics A*, 701(1):49–53, 2002. 5th International Conference on Radioactive Nuclear Beams.

[2] Aurelia Laxdal, F Ames, R Baartman, W Rawnsley, A Sen, and V Verzilov. Allison scanner emittance diagnostic development at triumf. *THIOC02, LINAC2014, Geneva, Switzerland*, 2014.

[3] Olivier Shelbaya. Isotope Separation On-Line at ISAC. Technical Report TRI-BN-18-03, TRIUMF, 2018.