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Enhanced MEBT Optics

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Abstract: This report presents a new prospective lattice for the medium energy section of the ISAC accelerator, producing doubly achromatic injected beam in the ISAC-DTL, while replicating the main performance requirements for the original layout. The new design allows for the addition of DTL injection beam imaging diagnostics.

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1 Introduction

The ISAC Medium Energy Beam Transport (MEBT) section transports beams accelerated from the ISAC rf quadrupole linac (RFQ) and inject them into the separated function DTL. The section is designed to accept beams at up to A/q = 30, and inject into DTL at up to A/q = 6. Beam energy remains unchanged through the section, though there are two rf cavities [1] which transform longitudinally diverging output RFQ beam and produce a time-focus at the mid-point of the first DTL accelerating tank, at the end of the MEBT section.

Investigations and modelling of MEBT reveals the section causes a persistent injection mismatch into the ISAC-DTL [2, 3], manifest through high sensitivity to exact magnetic quadrupole field gradients. Additionally, the MEBT corner by design is singly achromatic, meaning at a location downstream the dispersion is zero, but not its derivative; dispersion is nonzero elsewhere. This condition remains true everywhere downstream. These correlations between (x, x') and (z, z') in the beam distribution, result in a coupling between rf phasing in and upstream of MEBT and the horizontal beam size. Owing to the constrictive apertures of the ISAC-DTL[4], this ultimately translates into diurnal-like transmission variations across the ISAC-I linac[5]. This report presents a prospective novel optics for ISAC-MEBT, which addresses these key issues.

2 Constraints of the MEBT Section

The original design tune for ISAC-MEBT is shown in Figure 1, for an A/q = 6 beam at E/A = 0.153 $\mathrm{MeV/u}$. The tune produces six principal desirable transformations to the beam:

1. Capture of the strongly divergent output RFQ accelerated beam,
2. Transport through ISAC Bunch-Rotator cavity and time-focus at the stripping foil,
3. Establish a first round waist at the MEBT stripping foil and conceptually perform a 45° reference frame rotation,
4. Establish of a second horizontal waist at the symmetric midpoint of the MEBT corner, where the charge selection slit `XSLIT7` is located,
5. Establish a second round waist at the midpoint of the ISAC Rebuncher rf cavity and time-focus into DTL Tank-1,
6. Establish a third round waist at the midpoint of DTL Tank-1.

A new MEBT optics must at the very least replicate the above criteria to maintain the functionality of the ISAC-I accelerator.

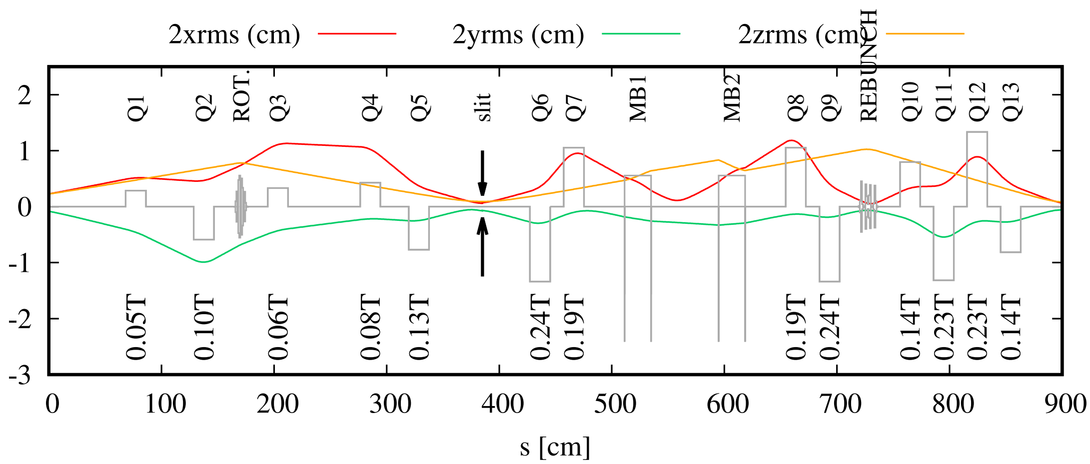

Figure 1: TRANSOPTR envelopes for the original design ISAC-MEBT.

3 Optical Enhancements

Inspection of the original MEBT design tune (Fig. 1) reveals the following undesirable effects:

1. The design tune causes the need for relatively low gradient requirements,
2. This causes beam envelopes in the MEBT corner to be sensitive to small field errors[2, 3].
3. The MEBT corner introduces transverse-longitudinal couplings which persist downstream into DTL, HEBT and beyond.
4. These factors introduce a mismatch at DTL injection.

The new design should strive to mitigate such conditions in the beam.

4 Beam Dynamics Parameters

2xrms [mm]	2x’rms [mrad]	r_{12}	2yrms [mm]	2y’rms [mrad]	r_{34}	2zrms [cm]	2z’rms [mrad]	r_{56}
2.27	4.0	0.917	0.84	5.0	0.703	2.26	3.4	

Table 1: RFQ extracted beam parameters used for this report.

5 MEBT Waists

Thus, the new MEBT corner and DTL injection optics are designed to:

1. Replicate the MEBT foil spot at three distinct locations: Corner symmetry point, Rebuncher, DTL Tank-1.
2. Produce double-achromaticity out of the corner, eliminating transverse-longitudinal coupling in the beam.
3. Minimize tune sensitivity upon small quadrupole tip-field errors.
4. Fit in the existing footprint of the original ISAC-MEBT.

It is shown in Figure 2. Diagnostic boxes and RF cavities are shown in Figure 3. Like the original MEBT design, quadrupoles up to the foil are tilted by 45° in (x,y). The first five quadrupoles up to the stripping foil in diagnostic box 5 remain unchanged. Downstream of the transverse reference frame rotation, the new optics begins.

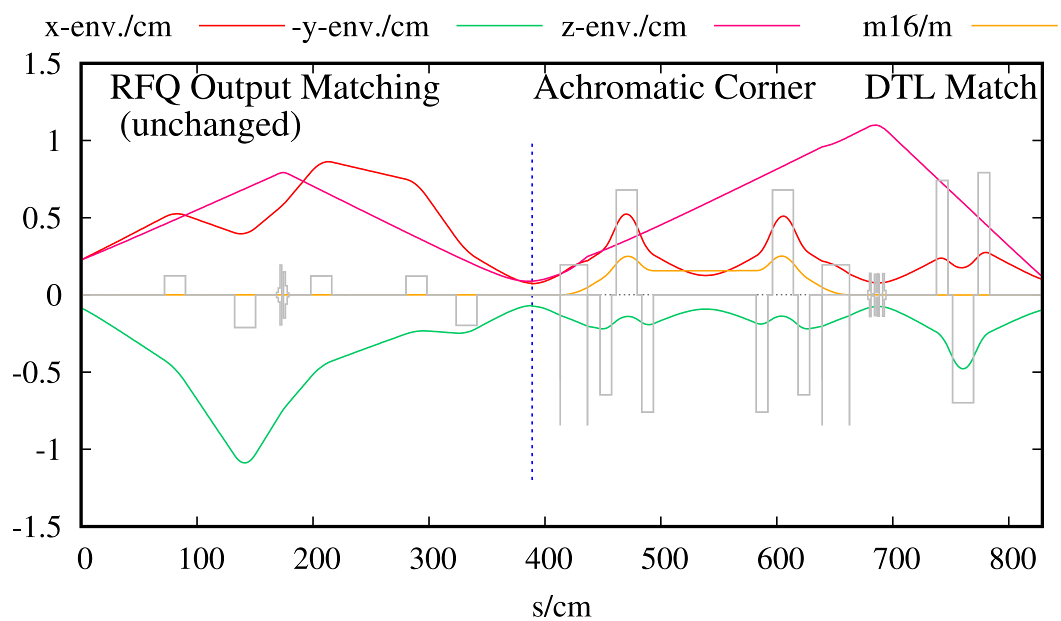

Figure 2: A prospective new ISAC-MEBT section optics, accomplishing all listed transformations to the beam distribution for RFQ to DTL beam injection. An A/q = 6 beam is shown, at E/A = 153 keV/u. Quadrupole effective lengths and rf cavity field map lengths are shown at the top of the plot. Reference frame (x,y) by 45° rotation shown at location of vertical dotted blue line.

Device	s-coordinate [cm]	Length [cm]	y-coord. [cm]	x-coord [cm]
MEBT:Q1	80.96	18.00	0.0	80.96
MEBT:XY1	104.14	10.0	0.0	104.14
MEBT:Q2	141.45	18.00	0.0	141.45
ROTR	174.64	12.30	0.0	174.64
MEBT:Q3	207.17	18.00	0.0	207.17
MEBT:XY3	227.63	10.0	0.0	227.63
MEBT:Q4	289.24	18.00	0.0	289.24
MEBT:Q5	332.42	18.00	0.0	332.42
MEBT:XY5	355.60	10.0	0.0	355.60
	45° rotation		0.0	386.25
MEBT:MB1	422.36	23.56	-1.62	424.61
MEBT:Q7	450.00	10.00	-14.14	445.55
MEBT:Q8	468.00	18.00	-23.14	458.28
MEBT:Q9	486.00	10.00	-32.14	471.01
MEBT:Q10	584.69	10.00	-81.48	540.79
MEBT:Q11	602.69	18.00	-90.48	553.52
MEBT:Q12	620.69	10.00	-99.48	566.25
MEBT:MB2	648.33	23.56	-114.29	583.96
Rebuncher	684.44	19.92	-139.62	586.25
MEBT:XY6	715.00	10.0	-161.23	586.25
MEBT:Q13	740.00	10.00	-178.91	586.25
MEBT:Q14	758.00	18.00	-191.63	586.25
MEBT:Q15	776.00	10.0	-204.36	586.25

Table 2: New MEBT section device locations. Original Q1 to Q5 layout at the top, highlighted in gray. For quadrupoles (MEBT:Q), device length corresponds to the effective length of the quadrupole, while for the bending dipoles, it is the length of the reference trajectory from effective field boundaries at the entrance and exit. For the corrective steerers (MEBT:XY), the length corresponds to the physical size of the device.

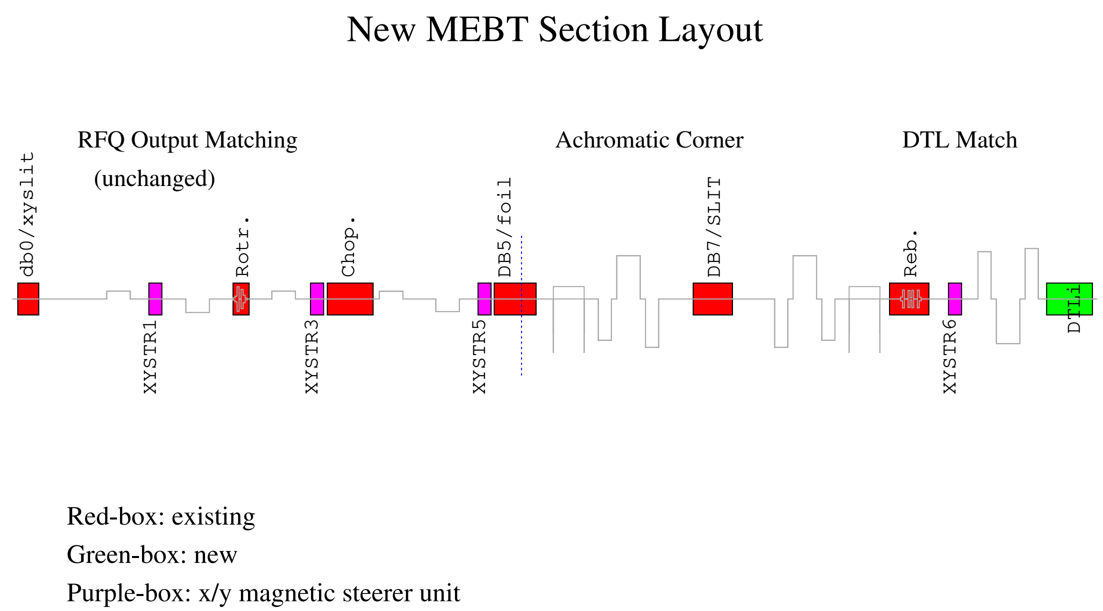

Figure 3: New conceptual locations for existing (red) and new (green) boxes and devices in ISAC-MEBT. A new and DTL-input (`DTLi`) diagnostic box can be added. Transverse 45° frame rotation denoted by dotted vertical blue line.

6 Discussion

The MEBT corner is still defined by the existing magnets `MB1` and `MB2`, however they have been pushed apart toward the RFQ and DTL, respectively, shown in Figure 4. The additional inter-dipole drift space that is created by such a transformation creates the necessary space for both quadrupole triplets that now define the corner. These enable a round waist at the corner's symmetry point while establishing double achromaticity downstream (see Fig. 2, M_{16}). The triplets are each identical to each other; their relative spacing keep the envelopes through MEBT rounder, minimizing eccentricity in the transverse distributions of the beam.

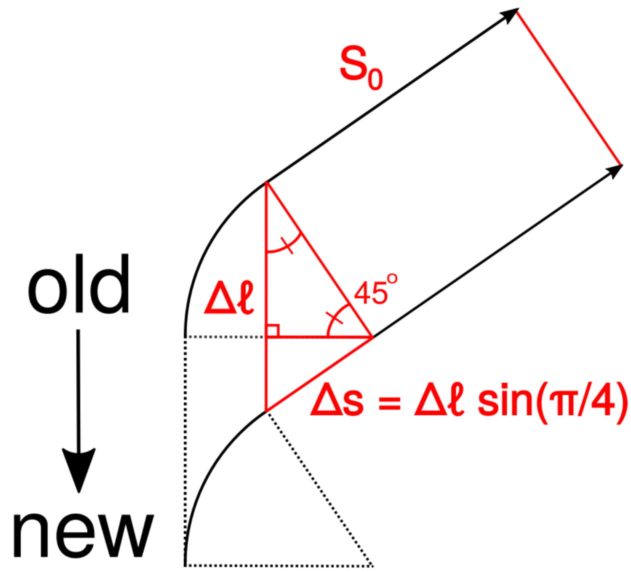

Figure 4: Pushing the MEBT dipoles toward the RFQ and DTL creates an additional drift space in the 45° leg of the MEBT corner.

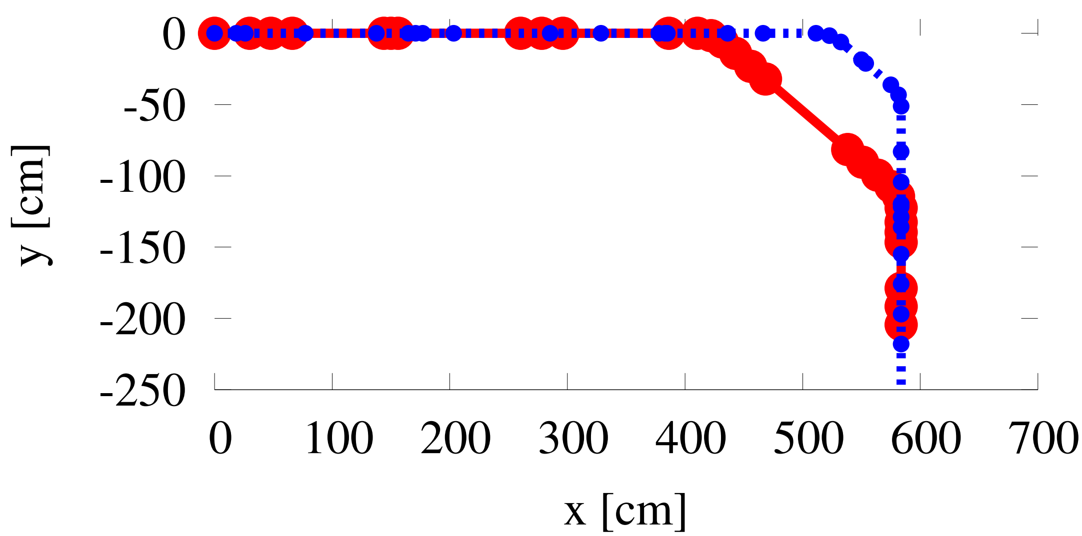

Figure 5: Layout comparison of the original (blue) and new (red) MEBT section and optics. The RFQ vacuum box ends at (0,0).

7 Quadrupole Strengths

The limiting case is an A/q = 30 beam, from RFQ to stripping foil, shown in Figure 6, including pole-tip fields, and constitutes the upper bound requirement for quadrupole strength.

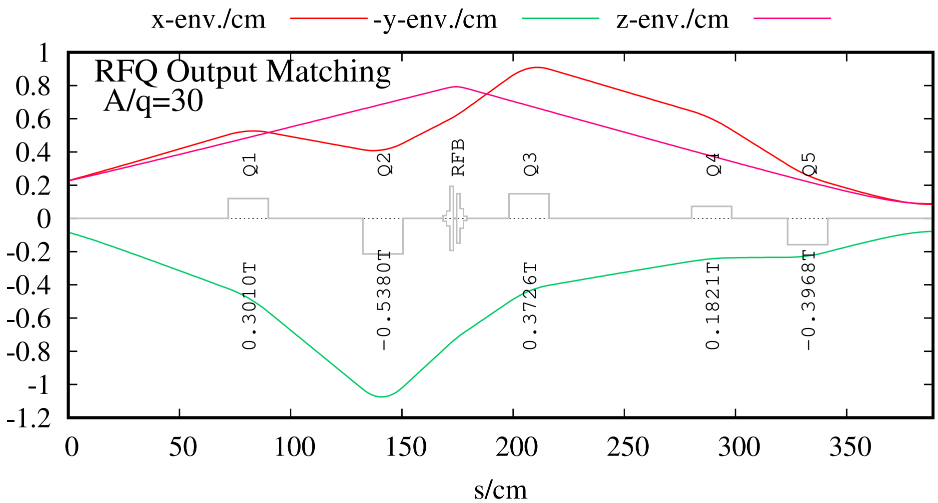

Figure 6: An A/q = 30 beam from the RFQ to the stripping foil, at the second round waist. Required tip-fields, for the posted effective lengths, specify the maximum strength of the first 6 quadrupoles.

Device Name	Effective Length [cm]	Tip Field [T]	Strength [m^{-2}]	Polarity
MEBT:Q1	18.0	0.301	6.9	+
MEBT:Q2	18.0	0.531	12.2	-
MEBT:Q3	18.0	0.373	8.5	+
MEBT:Q4	18.0	0.182	4.2	+
MEBT:Q5	18.0	0.397	9.0	-
MEBT:Q7	10.0	0.413	37.0	-
MEBT:Q8	18.0	0.347	39.5	+
MEBT:Q9	10.0	0.511	45.8	-
MEBT:Q10	10.0	0.511	45.8	-
MEBT:Q11	18.0	0.347	39.5	+
MEBT:Q12	10.0	0.413	37.0	-
MEBT:Q13	10.0	0.498	44.7	+
MEBT:Q14	18.0	0.348	39.6	-
MEBT:Q15	10.0	0.472	42.3	+

Table 3: `TRANSOPTR` computed strengths for the tune shown in Figure 2, assuming an A/q=30 up to foil, then stripped to A/q=6. Beam E/A=153 keV/u. Positive (+) polarity is horizontally defocusing.

8 Comparative Field Error Sensitivity

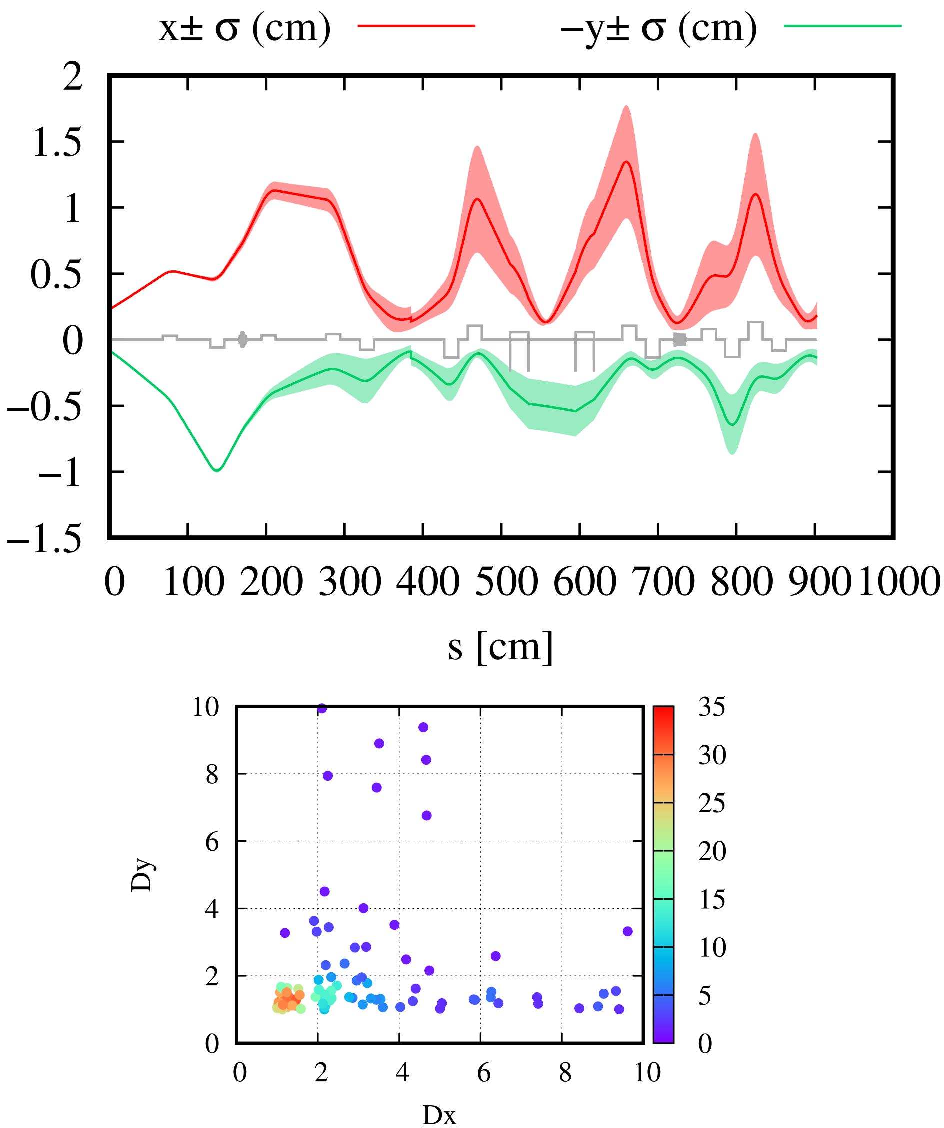

Figure 7: The original MEBT Section **Top:** A monte-carlo simulation in `TRANSOPTR`, using $\pm$5mT tip field errors on the MEBT quadrupoles, shows the expected mean and variance in rms envelopes through the section. **Bottom:** the resulting DTL injection mismatch parameters[7] are shown.

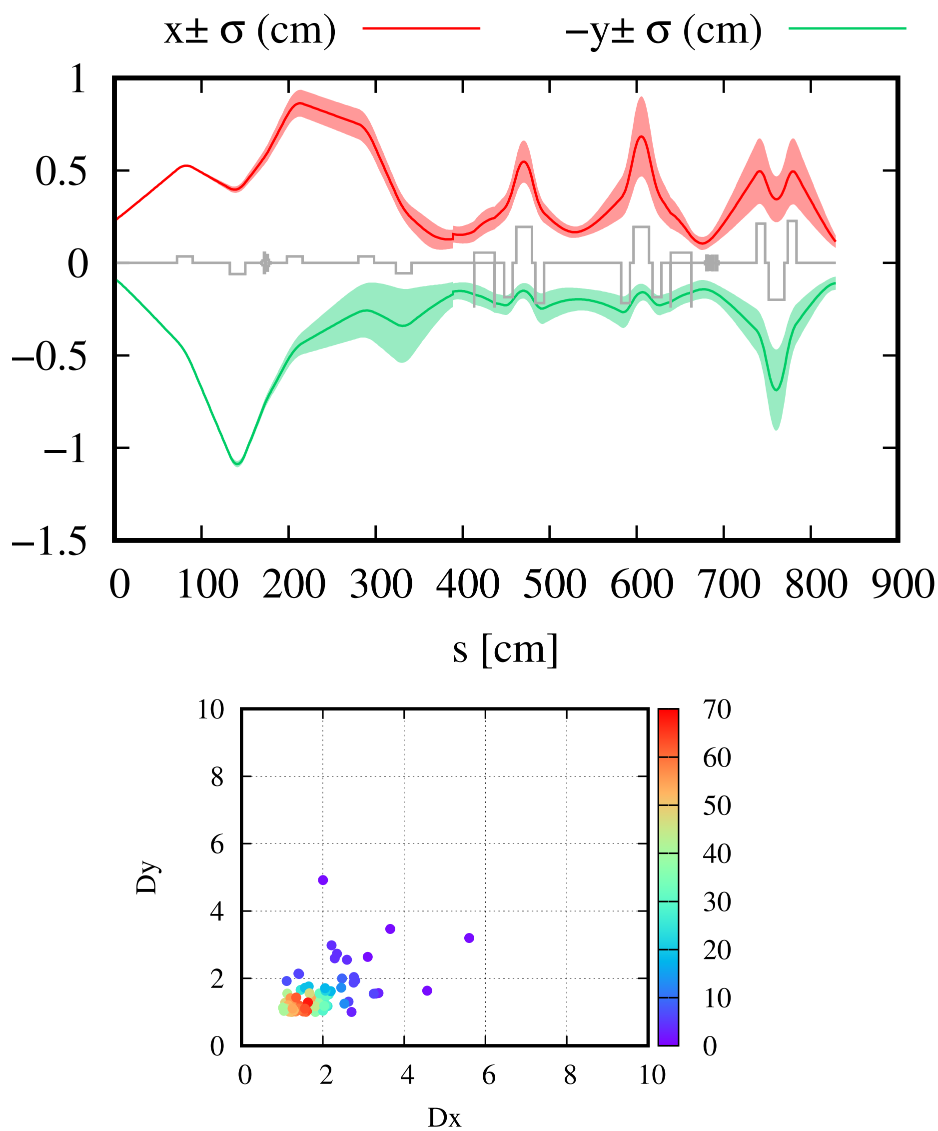

Figure 8: New MEBT optics: **Top:** A monte-carlo simulation in `TRANSOPTR`, using $\pm$ 5mT tip field errors on the MEBT quadrupoles, shows the expected mean and variance in rms envelopes through the section. **Bottom:** the resulting DTL injection mismatch parameters[7] are shown.

9 Conclusion

This report has outlined a conceptual upgrade to the ISAC-MEBT section optics, using a combination of existing 18 cm effective length quadrupoles (5 devices required), together with 10 new, shorter ($L_{\rm eff}$=10.0 cm) devices. The new optics is composed of three triplets, which establish waists at the requisite locations along the medium energy section. By pushing the two MEBT 45° dipole bender magnets further apart, available space in the inter-dipole leg of the MEBT corner is increased, allowing for doubly achromatic bend optics. The new design also enables the eventual installation of new diagnostics for DTL input beam distribution imaging.

References

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