Beam Physics Note
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Replacing The TUDA-I Quadrupoles

Olivier Shelbaya

TRIUMF

Abstract: The TRANSOPTR model of the ISAC-HEBT3 line is used to re-compute the TUDA-I experiment injection tune, hypothetically using L2-type quadrupoles. This is intended to confirm that, should the existing optics be replaced by such devices, the ability to establish the TUDA experiment focus will not be hindered.

4004 Wesbrook Mall, Vancouver, B.C. Canada V6T 2A3 Tel: 604 222-1047 www.triumf.ca

1 Background

In the note [1], the TRANSOPTR (optr) model for the HEBT beamlines in the acc/ database was presented, built from Design Office drawings of the high energy sections. That work featured a benchmark simulation of the optr code for each beamline segment with that of original Trace3D simulations, originating from M. Marchetto. During recent discussions, I was approached regarding the possibility that the TUDA-I quadrupoles be replaced. The devices, which differ from other quadrupoles in use at ISAC-HE, are potentially needed elsewhere. L2-type quadrupoles, available at ISAC, are considered here for as replacement for the TUDA experiment quadrupoles.

In this short note, I present the results of TRANSOPTR simulations of the original TUDA injection tune, however replicated using these hypothetical replacements. For simplicity, I have placed them at the same centerpoint location as the current optics. This was done in the acc/ database and the optr files generated via xml2optr[1], which ensures that the drift distances remain preserved. Using optr's internal optimizer with identical beam parameters as for [1], the same beamspot at experiment is reproduced with the L2 quads, showing that they can reproduce the same tune. I have also demonstrated that the same round beamspot can be achieved using only three, instead of four quadrupoles, should it be desirable to use fewer optics.

L2-Type Quadrupole:

$$L_{\text{eff}} = 30.0\,\text{cm}$$
$$a_0 = 2.6\,\text{cm}.$$

Here, L_{eff} is the quadrupole field effective length and a_0 denotes the quadrupole aperture radius. An example L2-type quadrupole B-I relationship is shown at the end of the document, in Fig. 5, though this will be power supply dependent.

2 TRANSOPTR Beam Distributions

The input beam distribution is taken inside the HEBT3 line from original Trace3D simulations of the TUDA tune. These same simulations were those provided to ISAC Operations and that were used for on-line tuning of the experiment. In Figure 1, the input (x,y) phase space 2rms containment ellipses are shown along with beam parameters. The output distributions obtained at the approximate location of the TUDA chamber, taken as roughly 100cm downstream of the final quadrupole, are shown in Figure 3. Note that it is trivial to move the location of the round focus using optr's optimizer, so the distance does not have to be exact, but simply reflective of the setup.

[1] Credit: Paul Jung, TRIUMF/UVic

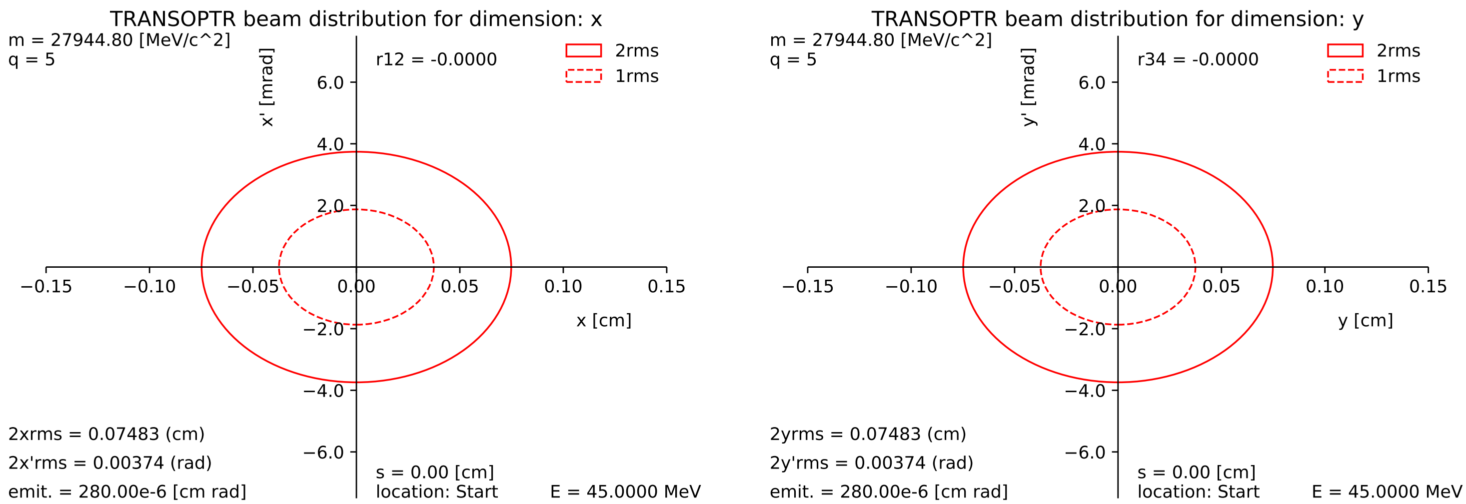

Figure 1: `TRANSOPTR` input beam distribution used for computation, showing x (horizontal), left and y (vertical) to the right.

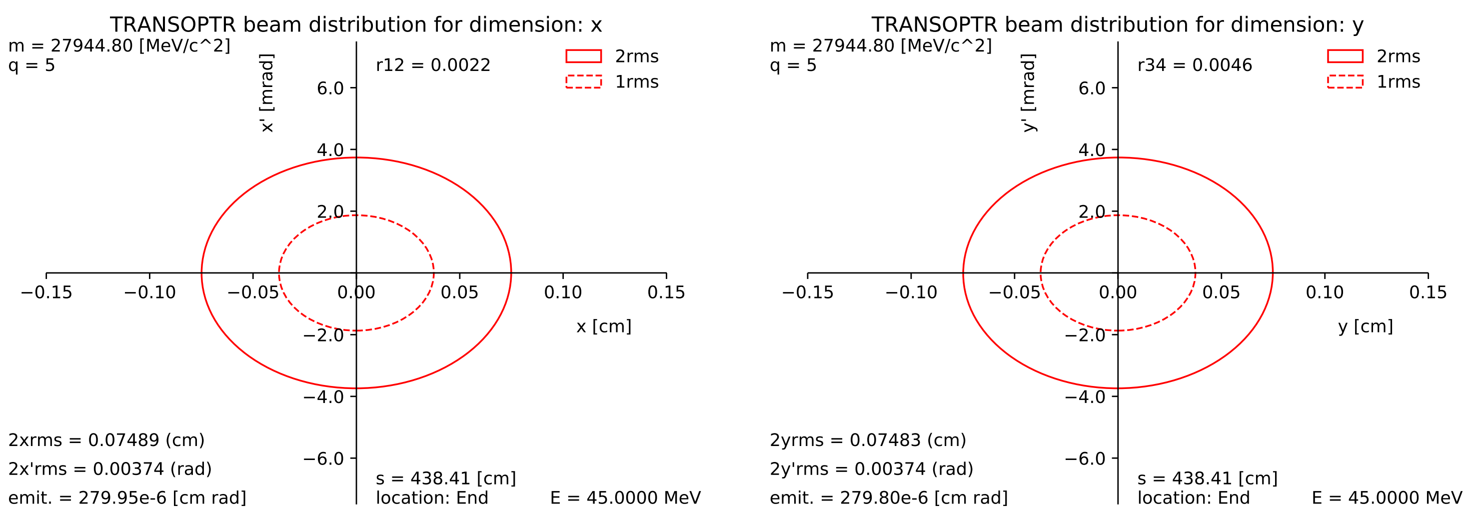

Figure 2: `TRANSOPTR` output beam distributions obtained at approximate location of TUDA chamber, showing x (horizontal), left and y (vertical) to the right.

Quadrupole	B [T]
HEBT3:Q5	0.0844
HEBT3:Q6	0.1616
HEBT3:Q7	0.1769
HEBT3:Q8	0.0864

Table 1: TRANSOPTR computed L2-type quadrupole pole tip fields for tune shown in Fig. 3.

3 Beam Envelopes for L2-Type Quadrupoles

3.1 Using Four L2-Quads:

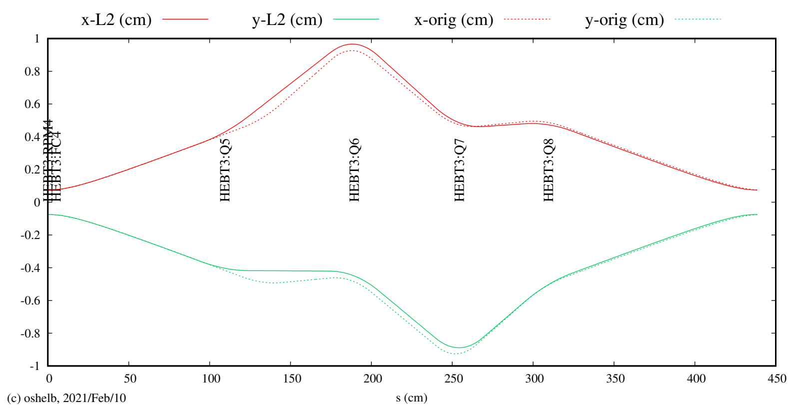

Figure 3: TRANSOPTR 2rms beam envelopes using four L2-type devices to replace the TUDA quadrupoles. The original Trace3D envelope is superimposed in dotted lines. All L2 quadrupoles here are placed at the same centerpoint as the existing TUDA optics. TRANSOPTR computed pole tip fields are shown in Table 2. 2rms envelopes show an A/q=6, E/A=1.5 MeV/u beam.

Quadrupole	B [T]
HEBT3:Q5	0.1205
HEBT3:Q6	0.1701
HEBT3:Q7	0.1305

Table 2: TRANSOPTR computed L2-type quadrupole pole tip fields for tune shown in Fig. 4.

3.2 Using Three L2-Quads:

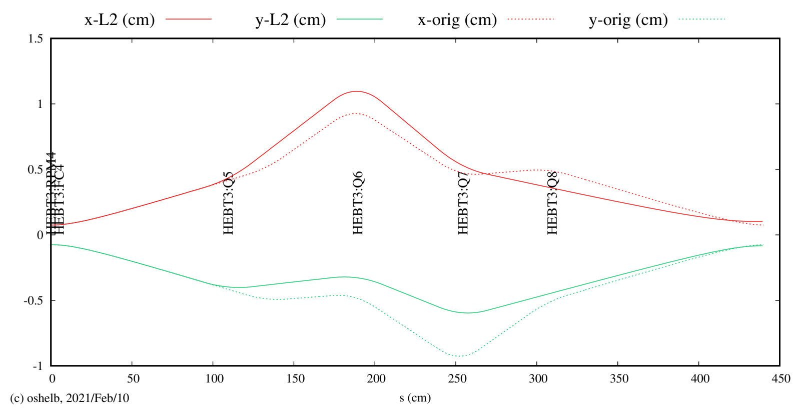

Figure 4: TRANSOPTR 2rms beam envelopes using three L2-type devices to replace the TUDA quadrupoles. The original Trace3D envelope is superimposed in dotted lines. All L2 quadrupoles here are placed at the same centerpoint as the existing TUDA optics, but Q8 has been removed. TRANSOPTR computed pole tip fields are shown in Table 2. 2rms envelopes show an A/q=6, E/A=1.5 MeV/u beam.

4 Discussion

From these simulations it is clear that replacing the present TUDA optics with L2 type quadrupoles should not change the ability to achieve a round beam waist matching the original design tune. Computed pole tip fields are well below 1 T making the B-I relationship of any chosen power supply-quadrupole pair important. As an exmaple, the B-I relationship for L2 type quadrupoles in the ISAC-II experimental hall (SEBT1) possess an assumed B-I relationship as shown in Figure 5. It is noted that the effects of hysteresis should be taken into consideration. Ongoing optics investigative work at ISAC-HE suggest hysteresis induced magnetic field errors on the order of roughly 10-20 mT, depending upon the quadrupole and power supply pair. Consequently, should quadrupole replacement at TUDA proceed, it is recommended to perform magnetic field surveys on those quadrupoles, using the same power supplies that will be used for operation. Quantification of the field error in such a way will allow for more precise tune computations.

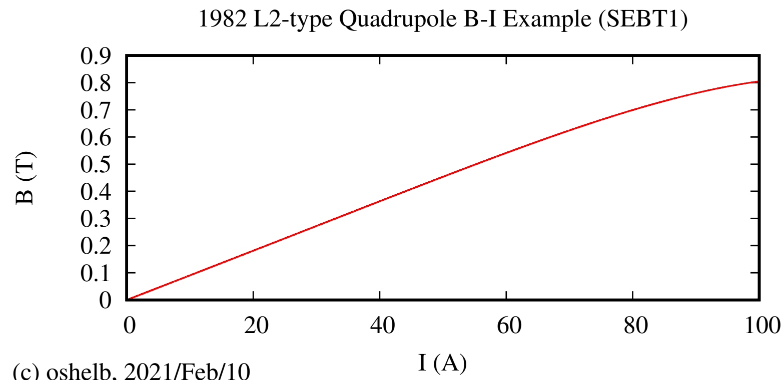

Figure 5: Measured B-I relationship presently in use in the TRANSOPTR model similar L2-type quadrupoles in ISAC-II. Note the saturatory behavior begins near 0.8 T. Computed tunes, using either two doublets (Fig. 3) or one triplet (Fig. 4) required pole tip fields of up to ∼0.17T, well below this point.

5 Summary

Replacing the TUDA-I quadrupoles with L2 types as discussed in this document is found to reproduce the original Trace3D tune which is documented in [1]. This study was carried out for an A/q=6 beam of E/A = 1.53 MeV/u, the limiting case of the ISAC-DTL. Transverse envelopes remain sufficiently well bounded as to remain within the linear response region of the quadrupole fields, per TRANSOPTR's optimizer. Required pole-tip fields are found to be below ∼0.2 T.

An optional triplet option is presented, should quadrupoles be short in supply, which also produces an equivalent round focus at the location of the TUDA-I chamber. However, the triplet requires a round focus upstream of the first quadrupole and produces a focus-to-focus condition. Practically, the four quadrupole arrangement will allow operators more flexibility to define a round (x, y) focus should the distribution at the entrance of the first quadrupole (HEBT3:Q4) not correspond to the design assumption. This is viewed as the more prudent option, should the quadrupoles be available.

References

[1] Olivier Shelbaya. TRANSOPTR Implementation of the HEBT Beamlines. Technical Report TRI-BN-19-06, TRIUMF, 2019.