TRIUMF		Document-56631

TRI-DN-12-11: Electron High Energy Dump Transport (EHDT) Optics Design

Document Type:	**Specification**		
Release:	**7**	**Release Date:**	**2014/02/07**
Author(s):	**Y.-N. Rao**		

	Name:	Signature:	Date:
Author:	Y.-N. Rao	APPROVED	Feb. 04, 2014
Reviewed By:	R. Baartman	APPROVED	" " "
Reviewed By:	S. Koscielniak	APPROVED	2014/Feb/04
Reviewed By:	E. Guetre	APPROVED	5-Feb-2014
Approved By:	L. Merminga	APPROVED	7-Feb-2014

Note: Before using a copy (electronic or printed) of this document you must ensure that your copy is identical to the released document, which is stored on TRIUMF's document server.

History of Changes

Release Number	Date	Description of Changes	Author(s)
1	June 21, 2012	Revised in response to 2012 June 08's Review comments	Y. -N. Rao
2	Oct. 17, 2012	Revised in response to 2012 Sept. – Oct.'s Beam Modes Task Force discussion results	Y. -N. Rao
3	Feb. 08, 2013	Revised the table on page 11 for the quad EHDT:Q6, in response to E. Guetre's request	Y.-N. Rao
4	Apr. 03, 2013	Revised the tables on page 10 and 13 by (1) adding up one decimal place to each element's coordinates; (2) adding up the cross-over point coordinates of dipoles; (3) adjusting/correcting diagnostic element's coordinates. Also, revised the context with 4 raster magnets.	Y.-N. Rao
5	Apr. 26,2013	Revised the tables on page 10 and 13 for element coordinates such that (1) the cross-over point in the dipole EHAT:MB4 for the 30 degrees left bend is 1.86 mm apart from the one of 26 degrees right bend, instead of the previous 0.93 mm apart; (2) the coordinates of elements in the EHAT are now exactly the same as Chao's.	Y.-N. Rao
6	Dec.13,2013	Revised the tables in Sections 8 and 9 for element coordinates in terms of T. Emmen's latest Autocad drawing. Revised the context accordingly.	Y.-N.Rao
7	Feb.04,2014	In response to E. Guetre's request, updated the table in Section 8 to reflect the changes made for the coordinates of EHAT:DB4 and EHDT:ACCT4.	Y.-N.Rao

1 Abstract

The Electron High energy Dump Transport (EHDT) is defined in this document in terms of the optics design, geometrical layout and element coordinates, and element specifications.

2 Objective

The EHDT shall deliver electrons from the electron accelerator transport (EHAT) to a 100 kW tuning dump. This note describes the design of EHDT magnetic optics, covering major element coordinates and performance specifications.

3 Definitions

- **Coordinate system:** The Cartesian coordinate system defined herein is such that the origin is in the centre of cyclotron, $+x$ points to East, $+y$ points to North, and $+z$ points upward.
- **Beam profile monitor:** The beam profile monitor herein is meant either a view screen (VS) or a fast wire scanner (FWS), measuring both x and y beam distributions. Because the wire scanner is better at discerning tails and halos than the view screen, we shall put wire scanners at locations where the momentum resolution is high enough to monitor the halos.
- **Knob:** By knob is meant settable optical parameter. Implementation may be either through one-to-one correspondence between set point and a single independent power supply, or multiple supplies under software control as a single set point.
- **Intrinsic beam size:** is defined as $\sqrt{\beta\epsilon}$, where β is the betatron amplitude function and ϵ is the beam emittance. On average $\beta \sim 3.0$ m. The nominal emittance is ϵ=6 μm (r.m.s., normalized). The calculated beam envelopes described in this design note were performed with 6 μm.

4 Requirements and Constraints

4.1 Top Level Requirements [1]

- EHDT shall be capable to transport electron beam with energy between 25 and 75 MeV and power up to 100 kW.

- The layout shall be consistent with the site geometrical envelope.

4.2 General Requirements

- simple and robust.
- low loss.
- easy to tune.
- easy to maintain.
- within CFI budget and schedule.

4.3 Specific Requirements

- Shall be capable to transport electrons with loss less than 10^{-5}/meter [2].
- Shall provide 40 mm×40 mm full width square/round spot on the dump. This is increased from the previously proposed 20 mm×20 mm full width [3]. The instantaneous beam size shall be ≥1 mm (r.m.s.) and flexible up to 3 mm (r.m.s.) [5] at dump.
- Target group must provide information such as the peak and average density permitted, beam distribution and halo permitted, etc.
- Shall keep beam centroid displacement from the axis below 2.0 mm throughout the EHDT quadrupoles, so the quadrupole intrinsic-aberration-caused emittance growth is less than 0.5%.

4.4 General Constraints

- The layout shall fit within the ARIEL and e-hall building civil construction footprint.
- Shall stay within CFI budget and schedule: where possible, the number of magnet types shall be minimized.

4.5 Specific Constraints

- EHDT shall be at 266.5′ level in the e-hall [4].
- The last magnetic element of EHDT shall stay ≥ 2.0 m from the dump, upstream from the shielding wall.

- EHDT shall match the EHAT optical parameters at location ($x = -36.8470$ m, $y = +10.9300$ m, $z = -0.6096$ m) as defined in the global Cartesian system.

- The incoming beam condition shall be: ϵ=6 μm (r.m.s., normalized), $\delta p/p = 0.75 \times 10^{-3}$ (r.m.s.) at 75 MeV while the extreme value [6] of $\delta p/p$ is -3.3×10^{-3} at 75 MeV.

- At dump, the instantaneous electron beam size shall be ≥1 mm (r.m.s.) and flexible up to 3 mm (r.m.s.) [5].

4.6 Working Assumptions

- The instantaneous electron beam size shall be ≥1 mm (r.m.s.) at dump, and flexible up to 3 mm (r.m.s.). This can be achieved by simply tuning the last quadrupole doublet.

- The allowed insertion length shall be 15.0 cm for the short quadrupoles and 17.5 cm for the long ones [7].

- The dipole's allowed insertion length (rectangular shape) shall be 32.23 cm [8].

- The dipole EHDT:MB2 shall be of exactly the same design [9] as those in the EHBT, that is, rectangular shape, maximum B-field strength ≥0.67 Tesla, and maximum bend angle=34°. While the other 2 dipoles, EHAT:MB4 and EHDT:MB4, shall be of slightly different design: maximum B-field strength ≃0.74 Tesla, and maximum bend angle=30°.

- According to Thomas Planche's result [10] of tracking calculation using OPERA modelled field map, the cross-over points in the EHAT:MB4 for the 30° left bend and the 26° right bend are 1.86 mm apart, instead of 0.93 mm apart as resulted from the hard edge model. Based on this, the coordinates are therefore modified for each and every elements tabulated under sections 8 and 9 [11].

- The standard insertion length of BPM's shall be 12 cm, except where space considerations dictate the use of buttons of length 5.7 cm.

- The maximum allowed insertion length of XY-correctors shall be 7.0 cm (to mitigate interference of the slowly falling dipole field with neighbor quadrupoles).

- The raster magnet shall reach an integrated field strength up to 1.2 kG-cm.

- The overall emittance growth shall be smaller than 1% due to intrinsic aberrations of quadrupoles and dipoles, accordingly the beam emittance at output shall be ≤6.06 μm (r.m.s., normalized).

5 Implementation and Overall Layout

The EHDT layout was projected to be a $3 \times 30°$ bend to make 90° left bend. The 1st and the 3rd dipoles are mirror-symmetrical about the 2nd one. This is shown in Fig. 1.

6 $3 \times 30°$ Bend

Fig. 2 shows the calculated beam envelope and dispersion. The inner 2 knobs (Q1=Q4 and Q2=Q3) make the whole bend section achromatic and control the dispersion value in between. The doublet preceding the 1st dipole serves to control the beam size over the section, while the doublet following the 3rd dipole matches the beam onto the dump, depending on the instantaneous beam size required at the dump.

At location of FWS2, the momentum resolution in x plane reaches ∼1130. This is believed high enough for diagnosis of momentum tail.

We shall need polarity reversal for the quadrupole Q5 for degaussing purpose as it has to be running at very low strength (∼70 G) for the 3 mm spot case. Also, it's best to have polarity switchable for Q1 and Q4, Q2 and Q3 for degaussing purpose. A field error of ±25 G in the integrated strength due to the hysteresis effect will jeopardize the achromaticity.

6.1 BPM Placements

We shall put BPM1 and BPM3 symmetrically, in the mid-way between Q1 and Q2, between Q3 and Q4 respectively. BPM5 shall be put between Q5 and Q6. BPM6a and BPM6b in pair shall be used to capture the beam position with sufficient precision so that we can predict the rastered beam size at dump with 1 mm accuracy. Given that the resolution of BPM is better than $\pm 100\mu$m, and BPM6a is located at 189.19 cm upstream of optics end, then BPM6b must be at least 37.8 cm apart from BPM6a.

6.2 Correctors

We shall need one corrector at each dipole to correct for the roll angle. EHAT:XCB4 shall be an in-dipole horizontal corrector, having the same strength as the regular ones (500 Gauss-cm). XYCB0 is following EHAT:MB4. XYCB2 is between MB2 and Q3, while XYCB4 is between Q4 and MB4. With such configuration of the correctors, plus the BPM placements aforementioned, we can correct orbit errors to ≤1.8 mm throughout entire EHDT [15]. This meets the goal of 2.0 mm.

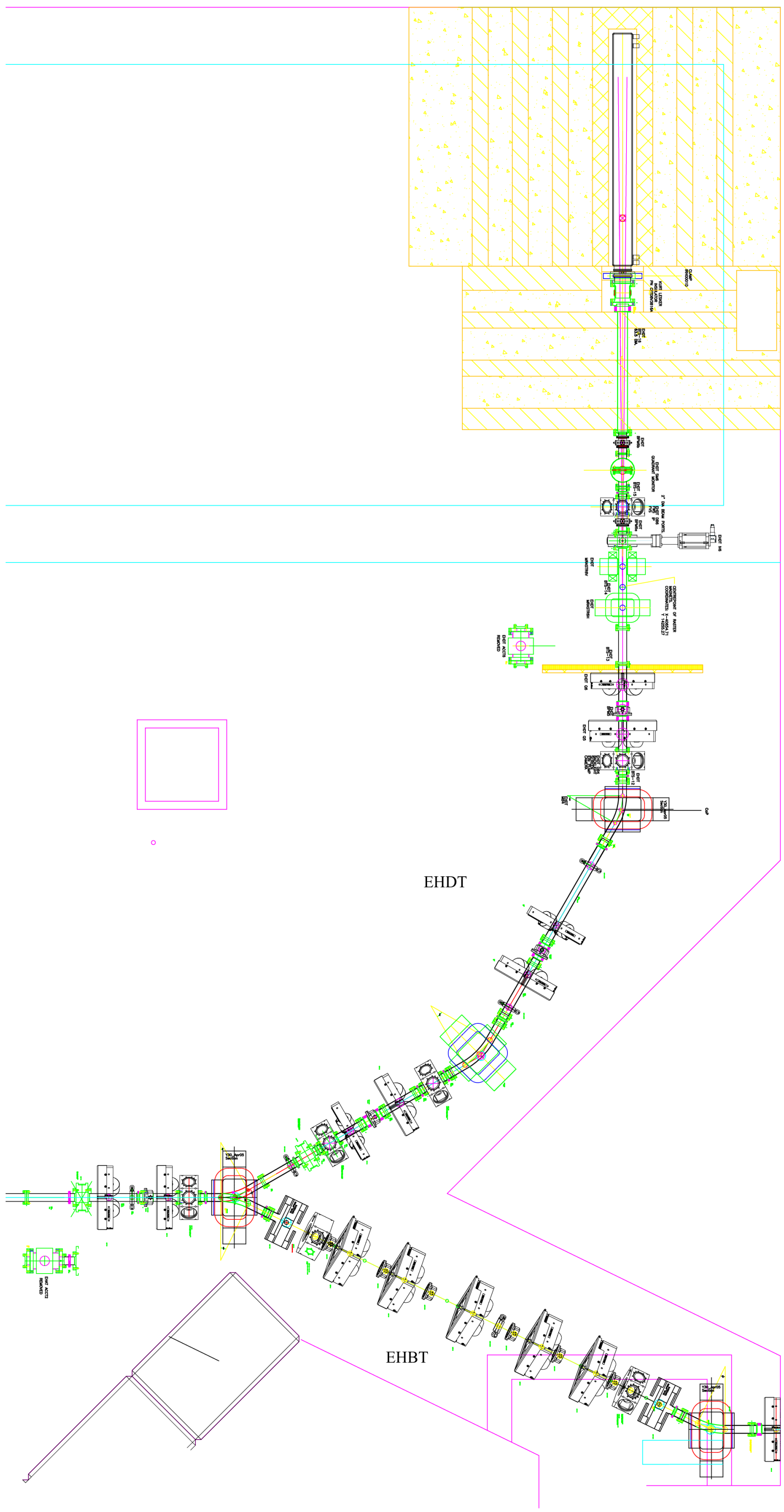

Figure 1: EHDT layout.

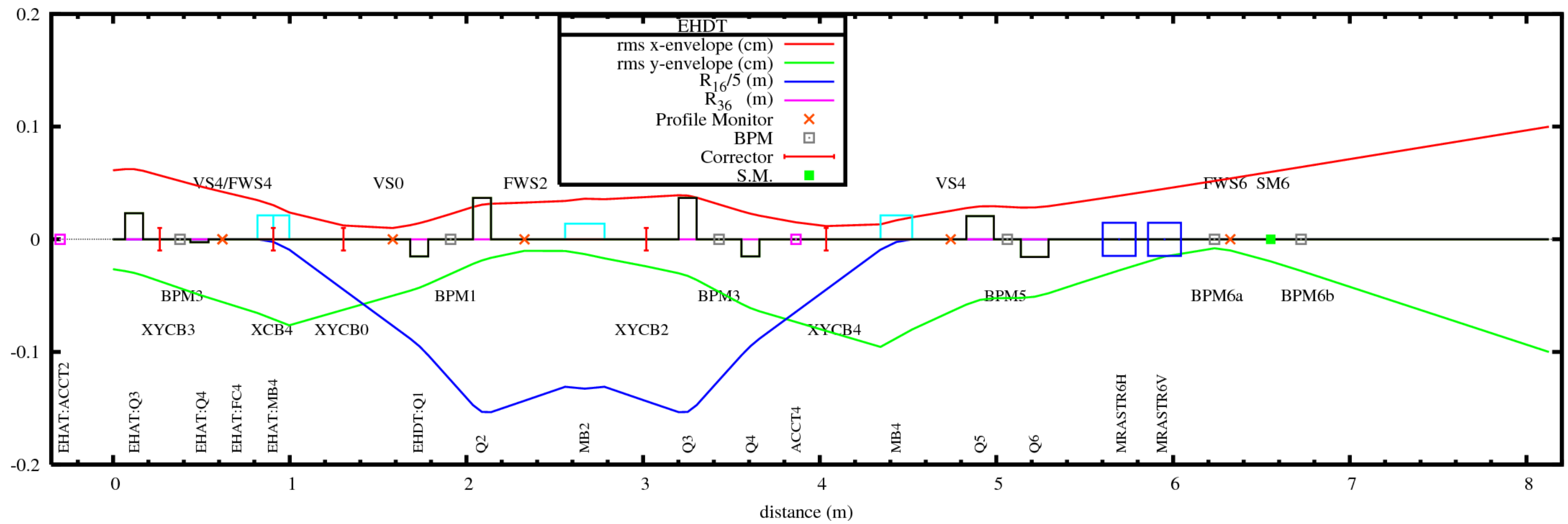

Figure 2: Beam envelope and dispersion at 75 MeV over the EHDT. The instantaneous beam size is 1 mm (r.m.s.) at the dump. The incoming Twiss parameters are $\alpha_x = -2.28$, $\beta_x = 9.24\,\mathrm{m}$; $\alpha_y = -1.57$, $\beta_y = 1.74\,\mathrm{m}$. The momentum resolution is $\sim$1100 at location of 2.32 m.

6.3 Profile Monitors

We shall use EHAT:VS4/FWS4, placed between EHAT:Q4 and EHAT:MB4, to find out the incoming Twiss parameters by using the quadrupole scan technique.

FWS2 shall be put where the momentum resolution is high. EHDT:VS4 shall be placed symmetrically with EHAT:VS4. FWS6 shall be put in the non-dispersive long drift and as close as possible to the dump. (View camera would be quickly damaged in radiation environment.) With these monitors, we shall be able to investigate beam properties in details.

In addition, we shall need, for example, a quandrant monitor QM6 placed as close as possible to the dump to measure the beam halo and/or transverse density distribution.

6.4 Faraday Cup

EHAT:FC4 shall serve as a beam stop.

The EHDT dump can be and shall be instrumented as a Faraday cup to measure the beam current, the accuracy may not be good enough, though So, it may not be used as the basis of a beam transmission measurement. For measuring the beam transmission at low duty cycle, we can use AC current transformer (ACCT) because pulsed beam mode shall be the major operation mode of the beam line before sending any continuous high power beam to the dump. Previously we proposed to have two current transformers, placed at either end of the EHDT, namely, EHAT:ACCT2 and EHDT:ACCT6. But because at the present time there is no budget for the ACCTs, it's agreed [16] that the ACCT is moved right after EHDT:Q4, just in order to leave space for a close-in shielding put after Q6 (but this shielding shall be required to be demountable).

7 Rastering onto Dump

We assume that we shall use fast raster magnets with integrated strength up to 1.2 kG-cm [14]. Such a magnet can generate a deflection of 4.76 mrad for 75 MeV. To produce a spot of 40 mm×40 mm full width on the dump, we shall need 2 raster magnets and R-matrix elements R_{12},R_{34} to be $\geq$2.1 m from the raster magnets to the optics end. In order to retain such a lever arm for the instantaneous beam size changeable between 1 and 3 mm (r.m.s.), we decide to place the raster magnets downstream instead of upstream from the last quadrupole doublet Q5 and Q6. Therefore, we can simplify the tuning by changing the doublet's excitation to vary the instantaneous beam size without affecting the rastering lever arm.

8 Magnetic Element List

The table that follows lists, in sequence, the coordinates of magnetic elements, including dipoles and quadrupoles.

edge or yFCE is either the entrance or exit of a dipole (hard edge model).

MBx means a dipole. For each dipole, I give the entrance, mid-point and exit along the reference trajectory; I also give the cross-over point (CoP) and bend angle. The cross-over point is the point where the axis of the incoming beam and the axis of outgoing beam intersect. All the dipoles are rectangular shape.

Dipoles EHAT:MB4 and EHDT:MB4 shall be powered in series with a single power supply while the other one EHDT:MB2 shall run with a separate power supply. This is because MB2 is a symmetrical bender (i.e. the edge angles are identical at entrance and exit) while the other two are not; thus MB2 will have a bend radius and current excitation which are different than the other two dipoles.

Qx means a quadrupole. For each quadrupole, I give the mid-point.

The 3rd column specifies the polarity of quadrupole.

The 4th column is the reference trajectory length in meter. The x, y and z coordinates are such that +x points to East, +y points to North, +z points upward. The origin is cyclotron centre.

The latitude on drawing is +/- 1 cm for the quadrupoles (Note: for any movement of any quad EHDT:Q1,Q2,Q3 and Q4, the symmetry MUST BE retained). The installation tolerances are 0.15 mm transverse and 1.0 mm longitudinal.

Location	Name	Pol.	s[m]	x[m]	y[m]	z[m]	Bend Angle[degr]
	Q3	F	0.11908	-36.84700	11.05000	-0.60960	
EHAT	Q4	D	0.48908	-36.84700	11.42000	-0.60960	
	edge		0.81715	-36.84700	11.74807	-0.60960	
	MB4		0.90716	-36.85872	11.83706	-0.60960	30
	CoP			-36.84700	11.84019	-0.60960	
	edge		0.99717	-36.89306	11.91998	-0.60960	
EHDT	Q1	D	1.73331	-37.26114	12.55750	-0.60960	
	Q2	F	2.08831	-37.43864	12.86494	-0.60960	
	edge		2.55922	-37.67409	13.27275	-0.60960	
	MB2		2.67039	-37.74157	13.36070	-0.60960	30

```
        CoP                  -37.73098  13.37130  -0.60960
        edge        2.78157 -37.82952  13.42819  -0.60960
        Q3    F     3.25247 -38.23734  13.66364  -0.60960
        Q4    D     3.60747 -38.54478  13.84114  -0.60960
        edge        4.34361 -39.18230  14.20921  -0.60960
        MB4         4.43363 -39.26522  14.24356  -0.60960     30
        CoP                  -39.26208  14.25527  -0.60960
        edge        4.52364 -39.35421  14.25527  -0.60960
        Q5    F     4.90751 -39.73808  14.25527  -0.60960
        Q6    D     5.21651 -40.04708  14.25527  -0.60960
================================================================================
```

The table that follows lists the strengths of quadrupoles at 75 MeV, and the information on how they shall be powered. The detailed specifications on the power supplies, such as polarity (switchable or unipolar), maximum current value, stability, and tuning resolution etc. are given in an all-in-one master spreadsheet put on the DocuShare [17] for the ARIEL magnets.

```
Note: The 2nd column specifies which quads are powered as singlets(1)
or in pair(2) with a single power supply.
       =============================================
        Name/Location    Quad's      Int. Strength
                        Quantity        (Tesla)
         EHDT:Q1,Q4         2            0.1200
         EHDT:Q2,Q3         2            0.3663
         EHDT:Q5            1            0.7698
         EHDT:Q6            1            0.7620
       =============================================
```

9 Diagnostic Element and Corrector List

The table below lists, in sequence, the coordinates of correctors and diagnostic elements, including BPM's, view screens, wire scanners, AC current transformers, raster magnets, and a special monitor.

```
For each element listed below, I give the mid-point coordinate. The 3rd
column is the reference trajectory length in meter.

The latitudes on drawing are respectively +/- 5 cm for BPM's and profile
monitors (any movement must be symmetrical wherever the optical symmetry
dictates), and +/- 10 cm for the correctors and ACCTs. The installation
```

tolerances are 0.15 mm transverse and 1.0 mm longitudinal.

Location	Name	s[m]	x[m]	y[m]	z[m]	Phase
EHAT	ACCT2		-36.84700	10.75000	-0.60960	1
	XCB3	0.26408	-36.84700	11.19500	-0.60960	1
	YCB3	0.26408	-36.84700	11.19500	-0.60960	1
	BPM3	0.37908	-36.84700	11.31000	-0.60960	1
	VS4	0.62608	-36.84700	11.55700	-0.60960	1
	FWS4	0.62608	-36.84700	11.55700	-0.60960	1
	FC4	0.67608	-36.84700	11.60700	-0.60960	1
	XCB4	0.90716	-36.85872	11.83706	-0.60960	1
EHDT	XCB0	1.30424	-37.04660	12.18591	-0.60960	1
	YCB0	1.30424	-37.04660	12.18591	-0.60960	1
	VS0	1.58307	-37.18602	12.42739	-0.60960	1
	BPM1	1.91081	-37.34989	12.71122	-0.60960	1
	FWS2	2.32891	-37.55894	13.07330	-0.60960	1
	XCB2	3.01790	-38.03419	13.54635	-0.60960	1
	YCB2	3.01790	-38.03419	13.54635	-0.60960	1
	BPM3	3.42997	-38.39106	13.75239	-0.60960	1
	ACCT4	3.86522	-38.76800	13.97001	-0.60960	1
	XCB4	4.03654	-38.91636	14.05567	-0.60960	1
	YCB4	4.03654	-38.91636	14.05567	-0.60960	1
	VS4	4.74151	-39.57208	14.25527	-0.60960	1
	BPM5	5.06201	-39.89258	14.25527	-0.60960	1
	MRASTR6H	5.69471	-40.52528	14.25527	-0.60960	1
	MRASTR6V	5.95171	-40.78228	14.25527	-0.60960	1
	BPM6a	6.23451	-41.06508	14.25527	-0.60960	1
	FWS6	6.32401	-41.15458	14.25527	-0.60960	1
	SM6	6.55261	-41.38318	14.25527	-0.60960	1
	BPM6b	6.72411	-41.55468	14.25527	-0.60960	1
	dump	8.12641	-42.95698	14.25527	-0.60960	1

10 Summary

In summary, the optics design of EHDT accommodates all the known operational modes. There is enough flexibility in the optics and it is easy to tune. The magnet design parameters are credible, and the number of magnet types have been rationalized and minimized. Provisions have been considered to incorporate steering, diagnostics elements and vacuum components.

References

[1] R. Dawson, *100 kW Beam Dump Requirements*, Jun 09, 2011.
http://elinac.triumf.ca/e-linac/wbs-areas/beamlines/dump/Tuning Beam Dump

[2] Shane Koscielniak, *E-linac requirements list*, Feb. 14, 2011.
http://elinac.triumf.ca/e-linac/requirements-list

[3] Shane Koscielniak, *Beam size requirements*, Apr.14, 2010.
http://elinac.triumf.ca/e-linac/wbs-areas/beamlines/raster-scanning/beam-size-requirements

[4] Shane Koscielniak, *2010 February 03: e-hall and tunnel N-S elevation*, Mar.02, 2010.
http://elinac.triumf.ca/e-linac/layouts/2010/0034x_A_1 e-Linac - tunnel integration Model -6.pdf

[5] Shane Koscielniak, *EHDT Beamline Design Note Review*, June 08, 2012.

[6] F. Jones, Private communication, April 24, 2012.

[7] R. Baartman, *Quad Tech Spec*, TRIUMF Beam Physics Note, TRI-BN-11-03, Jan., 2012.

[8] T. Planche, *EHBT magnet size*, Private communication, June 12, 2012.

[9] T. Planche, *E-linac strong dipoles: EABT:MB0, EHDT:MB2, EHBT:MB25/29/33/37 & EHBTE:MB6 - Design Note,* TRI-DN-12-22, Document-67321.

[10] T. Planche, *Y-30 cross-over points,* E-mail communication, April 23, 2013.

[11] E. Guetre, *Minutes from yesterday's e-Linac Beamlines Detailed Design meeting*, 2013 April 24.
http://elinac.triumf.ca/e-linac/wbs-areas/beamlines/meetings/meeting-23-apr-2013/Beamlines_Design_23Apr2013.docx/view

[12] Rick Baartman, *E-linac: Transporting beam to target*, Feb. 1, 2008.

[13] Rick Baartman, *Qauds for ARIEL electrons*, TRIUMF Beam Physics Note, TRI-BN-11-02, July, 2011.

[14] C. Yan et al, *BEAM RASTER SYSTEM AT CEBAF*, CEBAF-PR-93-005.

[15] Y.-C. Chao, *EHDT BPM-Corrector Configuration & Performance*, June 2012.
http://elinac.triumf.ca/e-linac/wbs-areas/beamlines/ehdt/EHDT_Performance.pdf/view

[16] Shane Koscielniak, *private communication*, Jan. 16, 2014.

[17] D. Louie, *Magnets PS Spec*, Nov. 29, 2013.
https://documents.triumf.ca/docushare/dsweb/Get/Document-104322/Magnets_PS_Spec_filled_out_v2 (3)Dlouie Ver26 (checked by EG 7-Oct-2013).xls