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Study of the LT-LTB Line via Transfer Matrix Measurements

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Abstract

We have studied the optics of the LT-LTB transfer line by measuring transfer matrix elements between four dipole correctors and a number of beam position monitors along the line. This procedure allows us to check the model used to simulate the optics of the line versus experimental results and to identify and localise errors in the files as well as possible hardware faults.

1. Introduction

The LT-LTB beam line, which links the CERN hadron linacs (Linac II, III) to the PS Booster (PSB), has been studied by measuring the transfer matrices between four dipole correctors and a number of beam position monitors. The aim of this study was to verify the existing beam line files and to create a set of reference files, which will then allow reliable computation of optics parameters such as Twiss parameters and dispersion, and will hence allow re-matching of the line at the injection into the PS Booster. Before one can use a simulation code to compute the optics of the line, one has to make sure that the beam line files represent exactly the equipment in the real machine. This can be done via measurements of transfer matrix elements.

The transformation of beam parameters from any arbitrary point "0" in a beam line to another point "1" can be described in linear approximation by

$$\begin{pmatrix} x(1) \\ x'(1) \end{pmatrix} = \begin{pmatrix} C_x & S_x \\ C_x' & S_x' \end{pmatrix} \cdot \begin{pmatrix} x(0) \\ x'(0) \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} y(1) \\ y'(1) \end{pmatrix} = \begin{pmatrix} C_y & S_y \\ C_y' & S_y' \end{pmatrix} \cdot \begin{pmatrix} y(0) \\ y'(0) \end{pmatrix}$$

where x, x', y, y' are the beam positions and momenta at positions "0" and "1" and C_x, S_x, C_y, S_y are transfer matrix elements. If x(0) = 0 (beam centred at location of dipole) and x'(0) is known (deflection given by the dipole), the equation reads

$$x(1) = S_x\, x'(0)$$

and the matrix element S_x can be determined from a measurement of beam positions x(1) for known deflection angles x'(0). The same equations apply to the vertical plane. As this is a relative measurement of the beam position, the dispersion causes an offset but does not influence the results.

2. Experimental Results

Earlier experiments had shown discrepancies between simulated and measured matrix elements [1]. The study from 2001 was resumed to investigate the possibility of creating a valid model of the LT-LTB line. The transfer matrix elements S_x and S_y between four corrector dipoles (LT.DHZ20, LT.DVT20, LTB.DHZ10 and LTB.DVT10) and the downstream pick-ups in the LT and LTB lines were measured. The measurements were done by giving horizontal and vertical deflections to the beam using the four dipoles and measuring the displacements of the beam centre using the pick-ups along the line. Linear fits applied to the plots of beam position vs. deflection angle yielded the matrix elements S_x and S_y. The plots of the beam centre as a function of the deflection angle (Fig. 1) show a linear response on all the relevant pick-ups. The resulting values of the matrix element are given in Tab. 1.

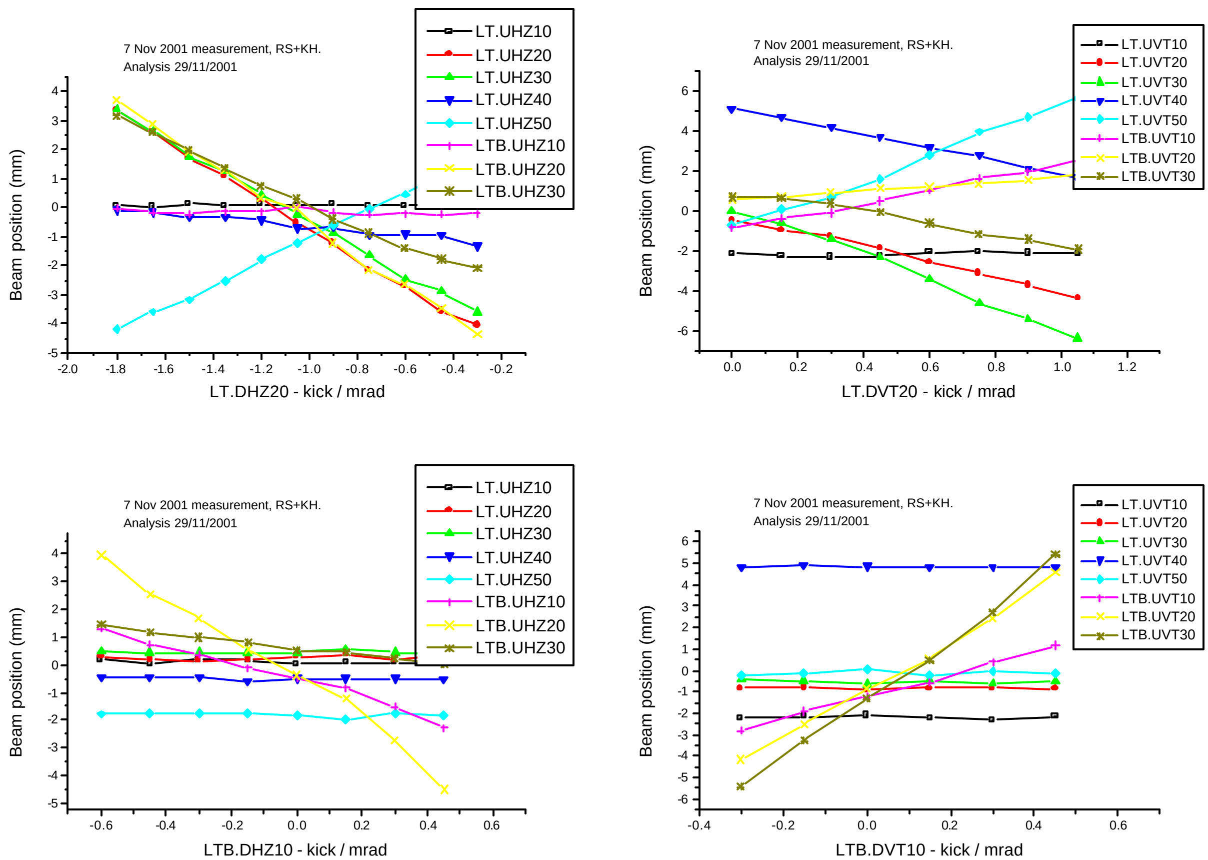

Figure 1: Plots of the displacement of the beam centre in each pick-up in the LT and LTB line as a function of the angle applied by one of the corrector dipoles.

	LT.U10	LT.U20	LT.U30	LT.U40	LT.U50	LTB.U10	LTB.U20	LTB.U30
LTB.DHZ10						-3.19976	-7.59509	-1.31619
error						0.16477	0.33263	0.05558
	LT.U10	LT.U20	LT.U30	LT.U40	LT.U50	LTB.U10	LTB.U20	LTB.U30
LTB.DVT10						5.22275	11.42978	14.10546
error						0.13608	0.37894	0.4555
	LT.U10	LT.U20	LT.U30	LT.U40	LT.U50	LTB.U10	LTB.U20	LTB.U30
LT.DHZ20		-5.02266	-4.6609	-0.76822	3.91237	-0.08834	-5.31539	-3.61016
error		0.06596	0.06367	0.05274	0.05066	0.05072	0.09155	0.0965
	LT.U10	LT.U20	LT.U30	LT.U40	LT.U50	LTB.U10	LTB.U20	LTB.U30
LT.DVT20		-3.7537	-6.2938	-3.32755	6.24593	3.25259	1.15277	-2.68557
error		0.12789	0.18706	0.06029	0.19224	0.09511	0.06728	0.17524

Table 1: Transfer matrix elements S_x and S_y between four different corrector dipoles and the pick-ups.

3. The LT-LTB model

Starting from a previous TRACE input file for the LT-LTB line, the latest CERN survey data was incorporated from the GEODE database, where differences in excess of 1m were found.
The following corrections to polarities and current-to-field conversion factors had to be made:

1. The lattice was converted to a FODO structure (the control system naming is not consistent in this respect).
2. The quadrupole LT.QFW70 current-to-field conversion hade to be adjusted from 15.0 to 13.9
3. The quadrupoles LTB.QFW30 to 60 were replaced by new magnets in the 1996-97 shutdown.
4. The polarity of the steering dipoles (and hence the measured data) from LT.DHZ20, LT.DVT20 and LTB.DHZ10 had to be inverted.
5. All measured values had to be scaled by a factor 1.22 (either due to a steerer miss-calibration or an error in the beam position calculation).
6. The results from pick-up LT.UVT40 are ignored as they are far from the model value.

All the quadrupole settings that were used during the final simulation can be found in Tab. 2 below. The settings of the bending magnets were not changed from the old model and can be found in Tab. 3.

Name	Distance to the centre of the element [m]	Effective length [m]	Current [A]	Field gradient [T/m]	Field strength (50mm gap) [T]	Field strength used in the model (FODO) [T]	Corre-sponding conversion factor [A*m/T]	
LT.QFN10	1.977	0.255	290.96	4.6184	0.2309	0.2309	63.00	
LT.QDN12	2.777	0.255	-230.65	-3.6611	-0.1831	-0.1831	63.00	
LT.QFN20	7.462	0.255	130.28	2.0679	0.1034	0.1034	63.00	
LT.QDN22	8.462	0.255	-92.67	-1.4710	-0.0735	-0.0735	63.00	
LT.QFN30	13.322	0.255	45.57	0.7233	0.0362	0.0362	63.00	
LT.QDN32	14.322	0.255	-73.41	-1.1652	-0.0583	-0.0583	63.00	
LT.QFN40	18.972	0.255	118.83	1.8862	0.0943	0.0943	63.00	
LT.QDN42	19.972	0.255	-98.12	-1.5575	-0.0779	-0.0779	63.00	
LT.QFN50	30.627	0.255	-53.19	-0.8443	-0.0422	0.0422	-63.00	
LT.QDN55	34.823	0.255	53.19	0.8443	0.0422	-0.0422	-63.00	
LT.QFN60	39.694	0.255	-33.85	-0.5373	-0.0269	0.0269	-63.00	
LT.QDN65	41.619	0.255	33.85	0.5373	0.0269	-0.0269	-63.00	
LT.QFW70	46.750	0.467	-7.5	-0.5000	-0.0250	0.0270	-13.89	**Tuned!**
LT.QDN75	50.136	0.255	42.64	0.6768	0.0338	-0.0338	-63.00	
LTB.QFN10	58.301	0.255	63.74	1.0117	0.0506	0.0506	63.00	
LTB.QDN20	59.294	0.255	-36.97	-0.5868	-0.0293	-0.0293	63.00	
LTB.QFW30	69.045	0.461	-11.5	-0.8244	-0.0412	0.0412	-13.95	**Canadian quad**
LTB.QDW40	70.045	0.461	11.1	0.7957	0.0398	-0.0398	-13.95	**Canadian quad**
LTB.QFW50	79.595	0.461	-10	-0.7168	-0.0358	0.0358	-13.95	**Canadian quad**
LTB.QDW60	80.895	0.461	10	0.7168	0.0358	-0.0358	-13.95	**Canadian quad**

Table 2: Quadrupole settings

Name	Distance to the centre of the element [m]	Effective length of central trajectory [m]	Field strength [T]	Entrance and exit angle [deg]	1/Radius of curvature [1/m]	Half of gap width [m]
LT.BHZ20	24.008	1.002	0.2886	8.0	0.2787	0.05
LT.BHZ30	53.995	1.006	-0.3952	-11.0	0.3817	0.05

Table 3: Bending magnet settings.

4. PATH Simulation

The simulations were performed in PATH with the model described above. The reference file can be found in the linac2 directory [2]. There is a corresponding file for TRACE in [3]. The transfer matrices from the beginning of the line were calculated with PATH. The transfer matrices from LT.D20 and LTB.D10 were then obtained by standard matrix operations. The elements S_x and S_y of the transfer matrices were plotted together with the measured values. The results are shown in Figs. 2 – 5. The squares connected by a line are the simulated values. The diamonds are the measured values and the triangles are the measured values scaled by the factor 1.22. The agreement between the simulated and the scaled measured values is very good. To test if this scaling factor is due to an error in the pick-ups or in the dipole correctors some further simulations were performed and compared to measurements done by using the SEM grids. This study was not conclusive.

5. SEM Grid Measurements

The scaling factor used to make the measured positions correspond to the data from the model could either be due to a systematic error in the pick-ups or the dipole correctors. To test this hypothesis, measurements were performed with the same four dipole correctors (LT.DHZ20, LT.DVT20, LTB.DHZ10 and LTB.DVT10) as before, but using the SEM grids LTB.MSF30 and 40 to measure the beam position. The measured results require scaling factors of 0.85±0.40 and 1.70±0.16 to fit the model for LTB.MSF30 and 40 respectively. In both cases the factor 1.22 found from pick-up measurements is far from the mean value in this case. A large systematic error seems to be present in this measurement and it cannot confirm the previous scaling error. The results of the data are given in Tab. 4 below.

	LTB.MSF30		**LTB.MSF40**	
	Measured	**Simulated**	**Measured**	**Simulated**
LT.DHZ20	-1.132	-0.365	4.40638	7.652
Error	0.11458		0.07512	
LT.DVT20	3.25255	-4.251	-1.57813	2.371
Error	0.06828		0.08212	
LTB.DHZ10	4.20327	3.627	2.96915	5.004
Error	0.11725		0.1164	
LTB.DVT10	5.82677	5.302	8.21095	15.535
Error	0.12668		0.21202	

Table 4: S_x and S_y measurements in the LT-LTB line with protons. The signs of the values measured from LT.DVT20 should be inverted to correspond to the simulated values.

6. Conclusion

The comparison of measured and computed transfer matrix elements in the LT and LTB beam lines has revealed several errors in the beam line files used so far for the computation of the optics parameters. Several element positions were found to be wrong in the files and have been corrected according to the CERN survey data. The quadrupole settings and polarities have been set to the values as in the control system, where one quadrupole (LT.QFW70) had to be calibrated to achieve agreement between computed and measured data. A remaining scaling factor of 1.22 could be due to a calibration error in the dipole deflection angle.

Having taken into account all these effects, there is excellent agreement between simulation and experimental results. We conclude that the beam line files that we have created contain the correct geometry and settings of the line and can be considered as reference files for any further simulations.

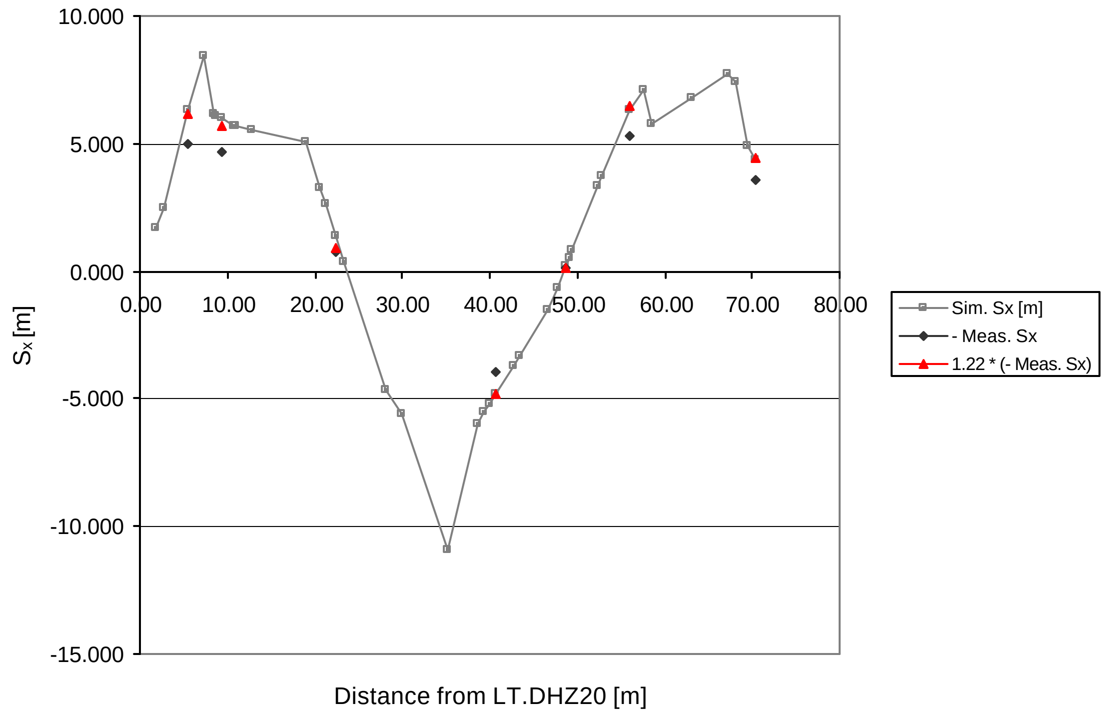

Fig 2: Simulated, measured and scaled measured values of S_x. All values are measured/simulated from LT.DHZ20.

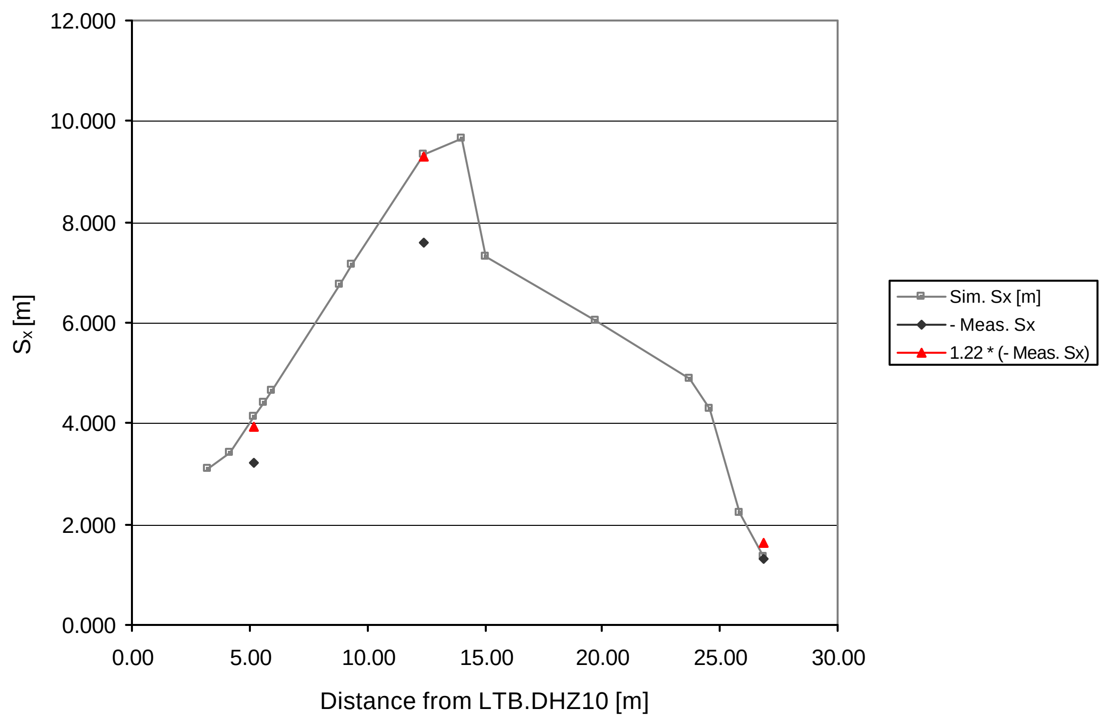

Fig 3: Simulated, measured and scaled measured values of S_x. All values are measured/simulated from LTB.DHZ10.

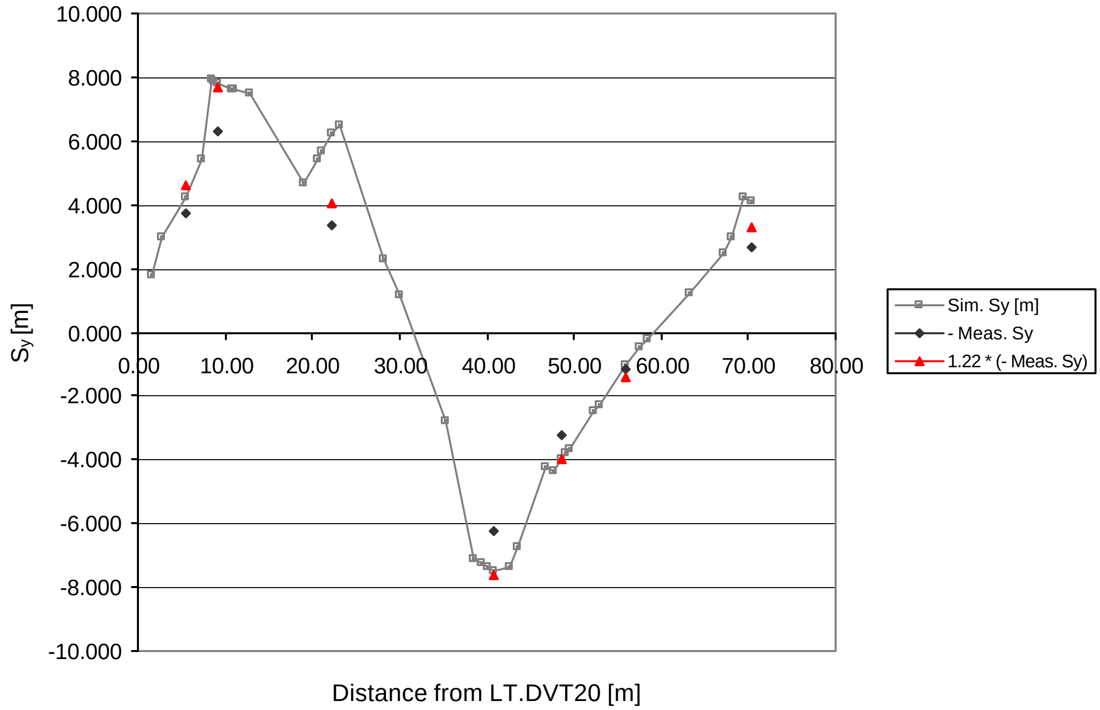

Fig 4: Simulated, measured and scaled measured values of S_y. All values are measured/simulated from LT.DVT20.

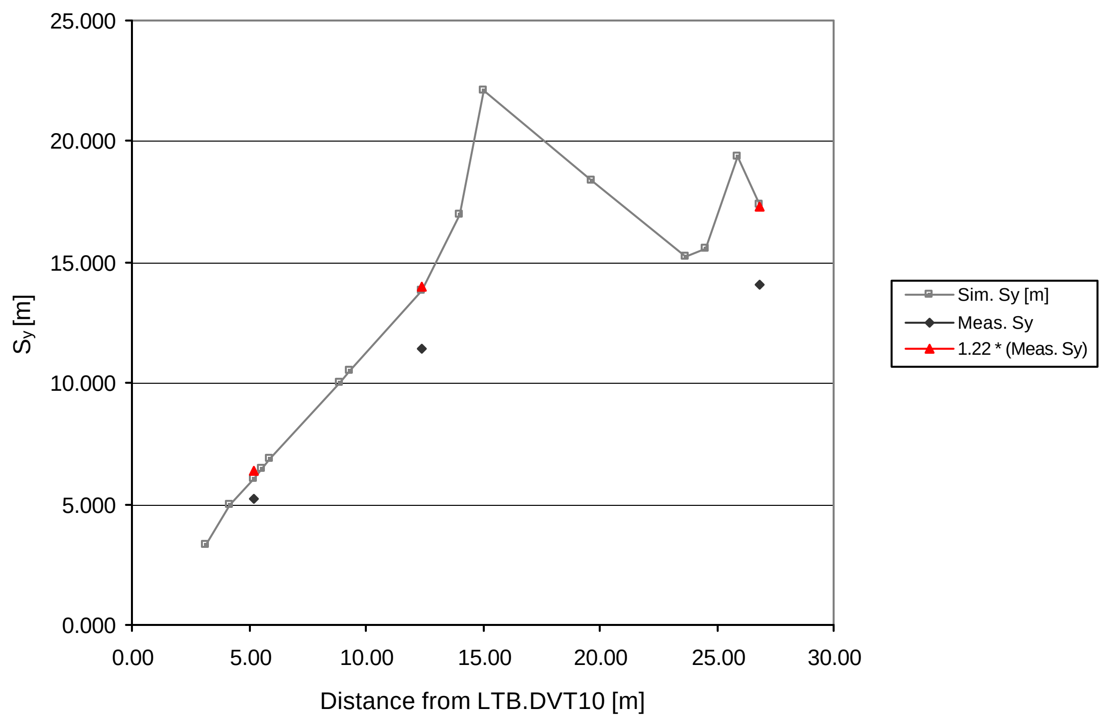

Fig 5: Simulated, measured and scaled measured values of S_y. All values are measured/simulated from LTB.DVT10.

References

[1] K. Hanke, A. Lombardi, R. Scrivens, "Measurements of the Optics Parameters in the LT-LTB and ITH Lines", CERN PS/PP Note 2000-005 (2000).

[2] \\Cernhome05\linac2\Simulation\lt-ltb\Path Manager project.

[3] \\Cernhome05\linac2\Simulation\lt-ltb\Trace lt-ltb line (0 mA).

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