EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PS-Note-2000-003 PP

Measurement of the Optics Parameters in the LTB and ITH Lines

K. Hanke, A. Lombardi, R. Scrivens

Abstract

In the past there has been a lack of understanding of the beam optics of the ITH and LTB beam lines at CERN. The ITH beam line links the CERN heavy ion linac (Linac III) to the PS Booster (PSB), while the LTB line links the CERN proton linac (Linac II) to the booster. For both lines, the experimental data could not be reproduced in simulations. A series of systematic measurements of the optics parameters in the line was therefore done during the 1999 lead ion run as well as during the 2000 proton run. The goal is to fully understand the beam optics of both lines and hence to have a consistent and verified model. This can then be used for optimizing the optics, matching and minimization of the dispersion.

Geneva, Switzerland

July 5, 2000

1 ITH Line

1.1 Transfer Matrix Measurement

The transport of beam coordinates and momenta between two arbitrary points in a beam line can for the case of linear optics (no space charge, no linear coupling) be described by a matrix formalism:

$$\begin{pmatrix} x(1) \\ x'(1) \\ dp/p \end{pmatrix} = \begin{pmatrix} C & S & D \\ C' & S' & D' \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x(0) \\ x'(0) \\ dp/p \end{pmatrix}. \tag{1}$$

Here, x and x' (y and y') are the beam positions and momenta at the corresponding positions in the line, δ is the momentum spread and D and D' are the horizontal (vertical) dispersion and dispersion derivative. If we assume that the dispersion is zero we can solve the system for the case that $x(0) = 0$ and $x'(0)$ is known:

$$x(1) = Sx'(0). \tag{2}$$

The matrix element S can experimentally be determined: an initial angle $x'(0)$ is given to the beam using a dipole corrector and the displacement of the beam at position '1' is measured by means of a beam position monitor (BPM). In the plot of position versus kick angle, the slope of a linear fit is the required matrix element S. If the measured matrix element agrees with the one given by a simulation of the beam line, the optics is well understood. If both values do not agree, this indicates either an error in the model or a hardware error. The method of transfer matrix measurement can hence be used to identify and localize such problems [1].

In two experimental sessions during the 1999 lead ion run[1)] the transfer matrix elements were determined using the D10, D21 and D30 dipoles to induce horizontal and vertical kicks and the SEM15, SEM30 and SEM40 secondary electron monitors (SEM) to measure the displacement of the beam. For all combinations, a number of kick angles was applied. The resulting plots of beam position versus kick angle are shown in Figs. 1 - 10. The measured matrix elements are summarized and compared with the theoretical values in Tab. 1.

	measured		model	
	horizontal	vertical	horizontal	vertical
D21-SEM15	3.12	2.71	3.05	2.29
D21-SEM30	(0.06)	4.88	3.3	12.0
D10-SEM30	4.98	5.93	3.9	5.1
D10-SEM40	3.95	17.47	8.0	21.0
D30-SEM40	6.19	5.09	11.95	7.78

Table 1: Measured and theoretical transfer matrix elements.

As can be seen from Fig. 3, the measured value is not useful. The value is put in brackets in the above table. As far as the other values are concerned, there is reasonable agreement between model and measurement for D21-SEM15 and D10-SEM30. For the other matrix elements, there is a considerable discrepancy.

1) MD sessions of 22/09/99 and 23/11/99, K.Hanke and A.Lombardi.

2 LTB Line

2.1 Transfer Matrix Measurement

The same technique as for the ITH line was applied to the LTB line. The measurements were in this case taken with 50 MeV protons[2)], and the available dipole correctors were D10, D20 and D30 (in both planes). The shift of the beam position was again recorded using the SEM monitors SEM30 and SEM40. The plots of beam position versus kick angle are shown in Figs. 11 - 18 and experimental and theoretical values of S are summarized in Tab. 2.

	measured		model	
	horizontal	vertical	horizontal	vertical
D10-SEM30	4.66	4.67	3.65	5.30
D10-SEM40	2.47	10.64	8.60	10.31
D20-SEM40	3.30	12.56	12.07	8.26
D30-SEM40	5.01	5.60	12.64	6.61

Table 2: Measured and theoretical transfer matrix elements.

Reasonable agreement is found for D10-SEM30, D10-SEM40 (vertical) and D30-SEM40 (vertical). Bad to very bad agreement is found for D10-SEM40 (horizontal), D20-SEM40 and D30-SEM40 (horizontal).

2.2 Dispersion Measurement

In addition to the transfer matrix elements, the horizontal dispersion was measured at all available monitors. The dispersion is generally measured by changing the beam momentum and measuring the displacement of the beam using beam position monitors. Again, a linear fit yields the quantity $D_{x(y)} = \frac{\Delta x(y)}{dp/p}$.

In the LTB line, the beam energy was changed using the debuncher. Five settings of the debuncher were applied and the corresponding beam energy determined using a spectrometer. Table 3 gives the debuncher phase for the different settings as well as the corresponding beam energy and dp/p.

phase [deg]	E [MeV]	p [MeV/c]	dp/p [10^{-4}]
115	50.248	311.1562	8.9
135	50.210	311.0355	5.1
155	50.171	310.9115	1.1
175	50.129	310.778	-3.1
195	50.109	310.7144	-5.2

Table 3: Debuncher phase and corresponding dp/p used during dispersion measurement.

The horizontal dispersion was measured using the SEM30 and SEM40 monitors as well as a number of pick-ups. The plots of Δx versus dp/p are shown in Figs. 19 - 26 and measured and theoretical values are summarized in Tab. 4. The dispersion measurement suffers from significant error, both in the energy measurement as well as in the beam position measurement. As can be seen from Figs. 21 and 22, some of the values are not useful at all. The corresponding

[2)] MD session on 30/05/00, K.Hanke and R.Scrivens.

	measured D_x [m]	model
SEM30	-4.082	-
SEM40	-0.877	-
LT.U10	(-0.054)	-
LT.U30	(0.131)	-
LT.U40	-1.596	0.652
LT.U50	-0.433	0.328
LTB.U10	3.773	-1.6
LTB.U20	7.376	-3.3

Table 4: Measured and theoretical horizontal dispersion in the LTB line.

values are put in brackets in Tab. 4. The dispersion measurement is therefore not yet conclusive and future measurements with more statistics are needed to decrease the measurement error.

The vertical dispersion is zero along the line since there is no vertical bending.

2.3 Twiss Parameter Measurement

Finally, the Twiss parameters were measured for the nominal optics in the LBE measurement line. The results are given in Tab. 5.

	horizontal	vertical
β [m]	2.5	6.6
α	0.9	-0.8
γ	0.7	0.2
ε [mm mrad]	4.8	11.4

Table 5: Horizontal and vertical Twiss parameters measured in the LBE measurement line for nominal optics.

3 Conclusion

The transfer matrix measurements indicate that the optics is not fully understood for certain regions in both beam lines considered. The reason for this can be either an inconsistency of the model with the real beam line geometry (wrong element position, wrong element setting) or a hardware problem (quadrupole intercoil short, wrong polarity etc). For the LTB line, the quadrupole setting has already been checked and was found consistent with the nominal one (Fig. 27). The calibration constants of the dipole correctors need to be checked.
The dispersion measurement is with the present precision not yet conclusive. It has to be repeated with sufficient statistics to decrease the systematic error. The knowledge of the dispersion is also required to solve equation (1) more accurately. Neglecting the dispersion imposes an incertainty on the measured transfer matrix elements, which might explain certain discrepancies found in the horizontal plane.

References

[1] G. Arduini, M. Giovannozzi, K. Hanke, J.-Y. Hémery, *Study of the TT2/TT10 Transfer Line Optics via Transfer Matrix Measurement*, CERN PS Note (CA) 98-020 and CERN SL-MD Note 98-056 (1998).

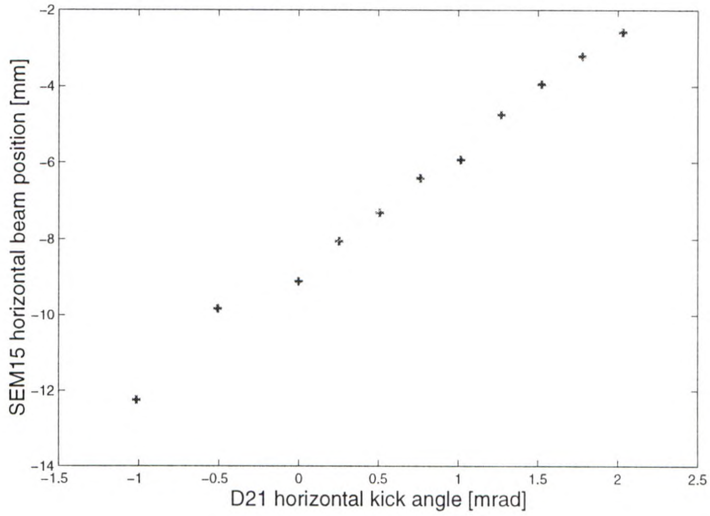

Figure 1: Horizontal displacement of the beam measured at SEM15 versus DHZ21 deflection angle. A linear fit yields a slope of 3.12 mm/mrad.

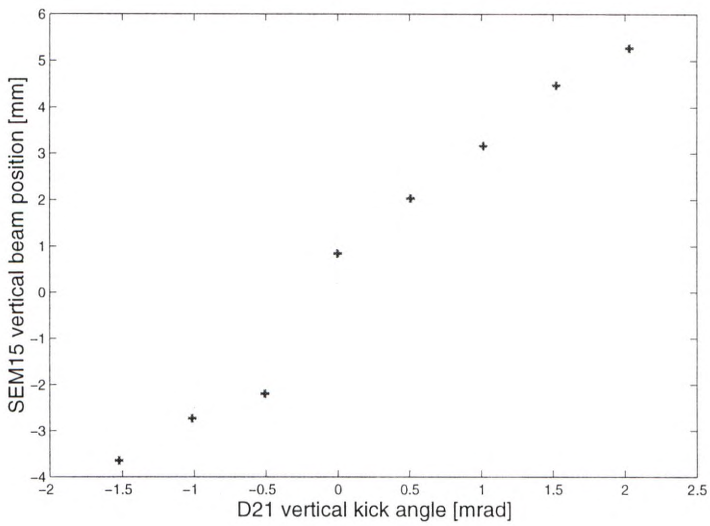

Figure 2: Vertical displacement of the beam measured at SEM15 versus DVT21 deflection angle. A linear fit yields a slope of 2.71 mm/mrad.

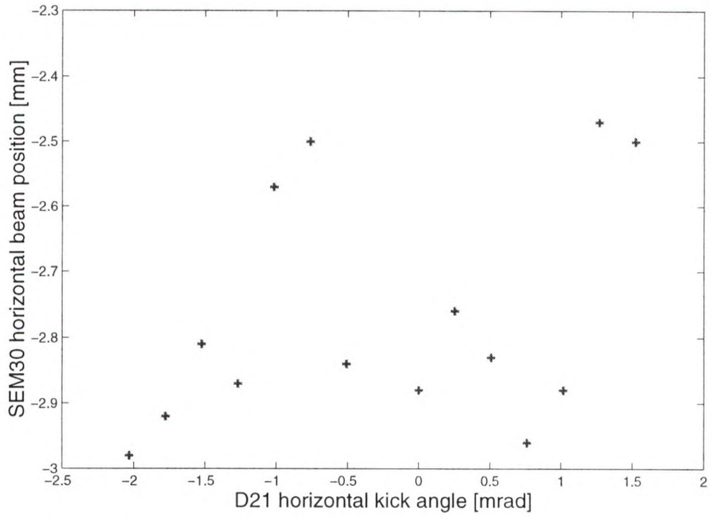

Figure 3: Horizontal displacement of the beam measured at SEM30 versus DHZ21 deflection angle. A linear fit yields a slope of 0.06 mm/mrad. The data are not useful.

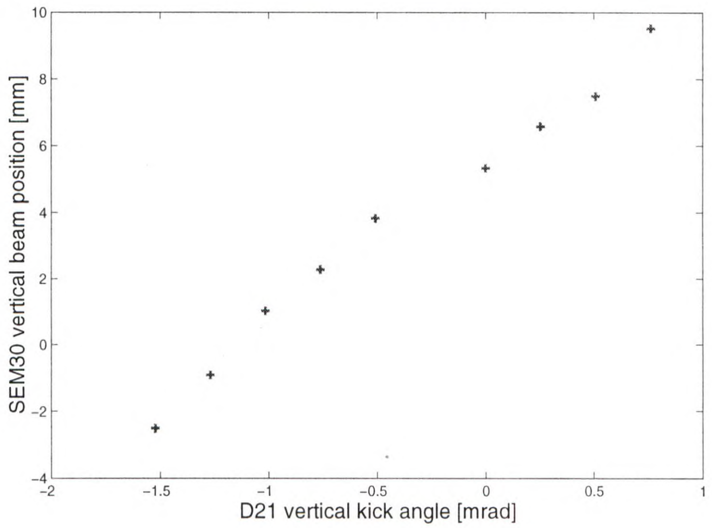

Figure 4: Vertical displacement of the beam measured at SEM30 versus DVT21 deflection angle. A linear fit yields a slope of 4.88 mm/mrad.

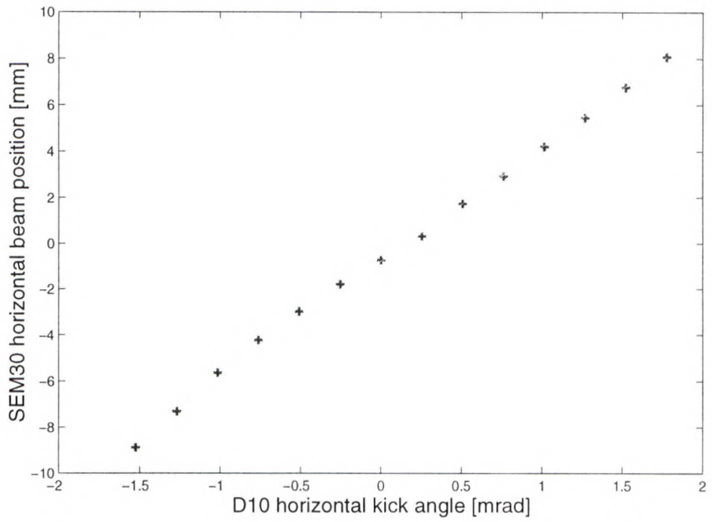

Figure 5: Horizontal displacement of the beam measured at SEM30 versus DHZ10 deflection angle. A linear fit yields a slope of 4.98 mm/mrad.

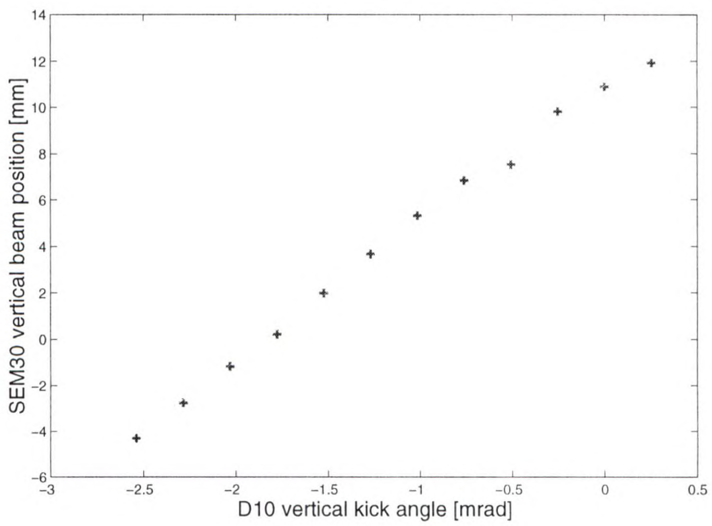

Figure 6: Vertical displacement of the beam measured at SEM30 versus DVT10 deflection angle. A linear fit yields a slope of 5.93 mm/mrad.

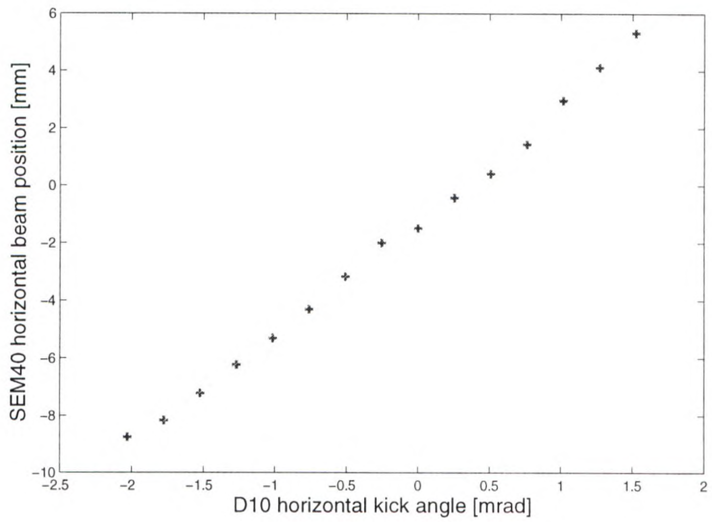

Figure 7: Horizontal deflection of the beam measured at SEM40 versus DHZ10 deflection angle. A linear fit yields a slope of 3.95 mm/mrad

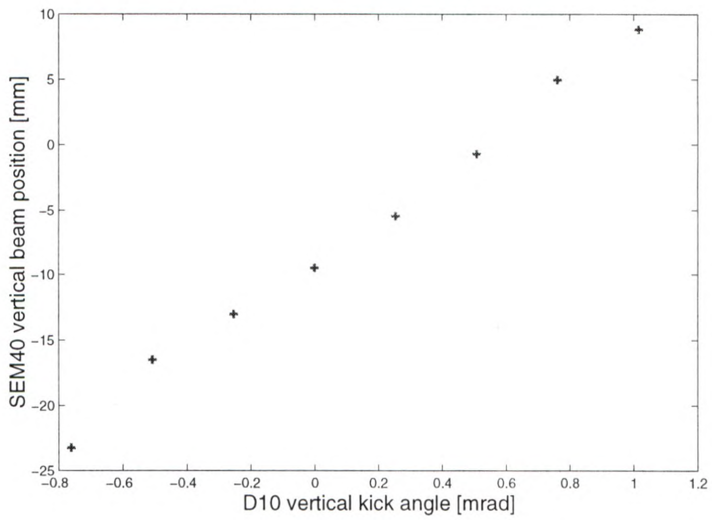

Figure 8: Vertical deflection of the beam measured at SEM40 versus DVT10 deflection angle. A linear fit yields a slope of 17.47 mm/mrad.

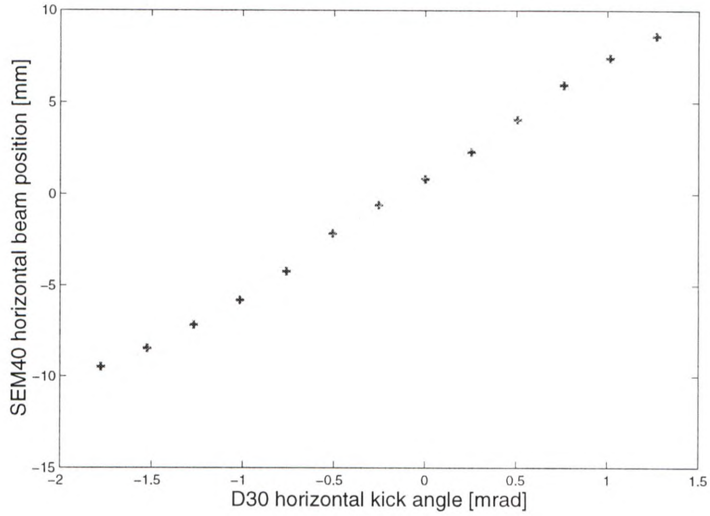

Figure 9: Horizontal displacement of the beam measured at SEM40 versus DHZ30 deflection angle. A linear fit yields a slope of 6.19 mm/mrad.

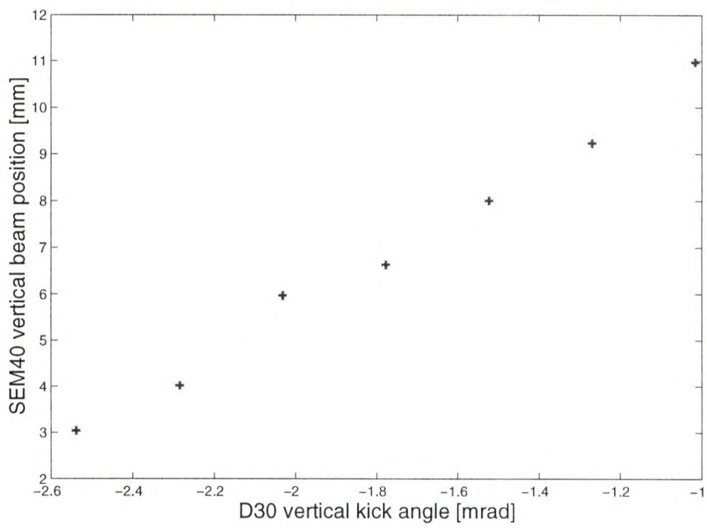

Figure 10: Vertical displacement of the beam measured at SEM40 versus DVT30 deflection angle. A linear fit yields a slope of 5.10 mm/mrad.

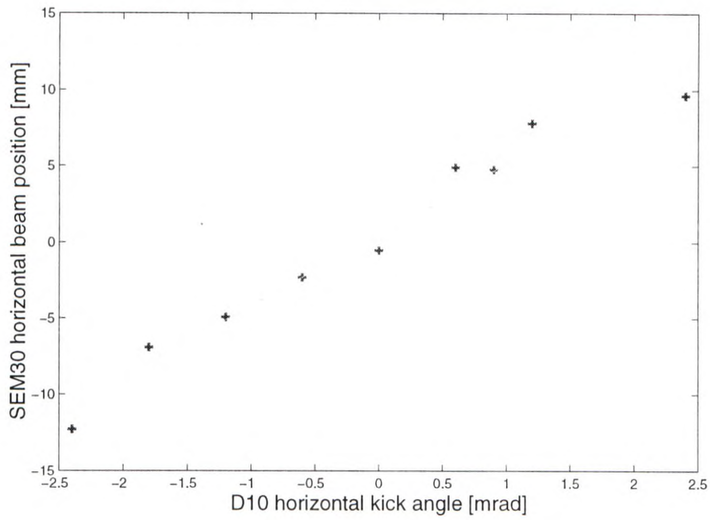

Figure 11: Horizontal displacement of the beam measured at SEM30 versus D10 horizontal deflection angle. A linear fit yields a slope of 4.66 mm/mrad.

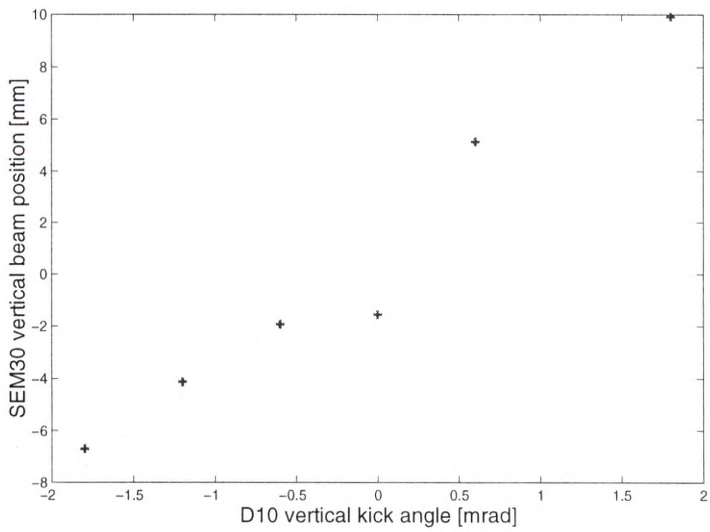

Figure 12: Vertical displacement of the beam measured at SEM30 versus D10 vertical deflection angle. A linear fit yields a slope of 4.67 mm/mrad.

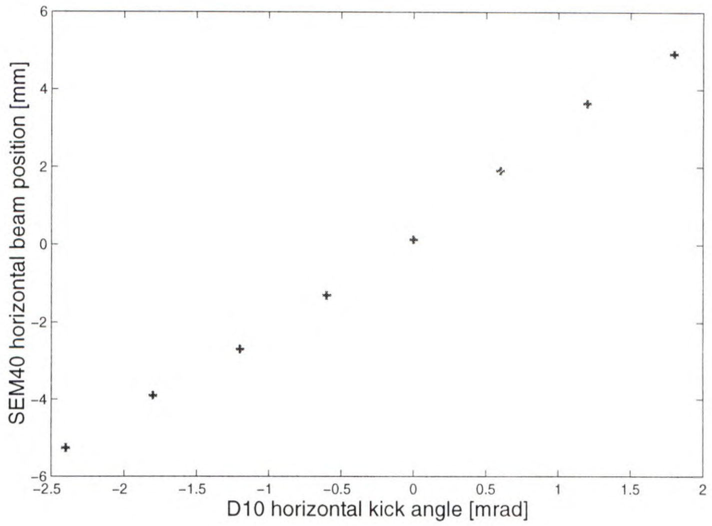

Figure 13: Horizontal displacement of the beam measured at SEM40 versus D10 horizontal deflection angle. A linear fit yields a slope of 2.47 mm/mrad.

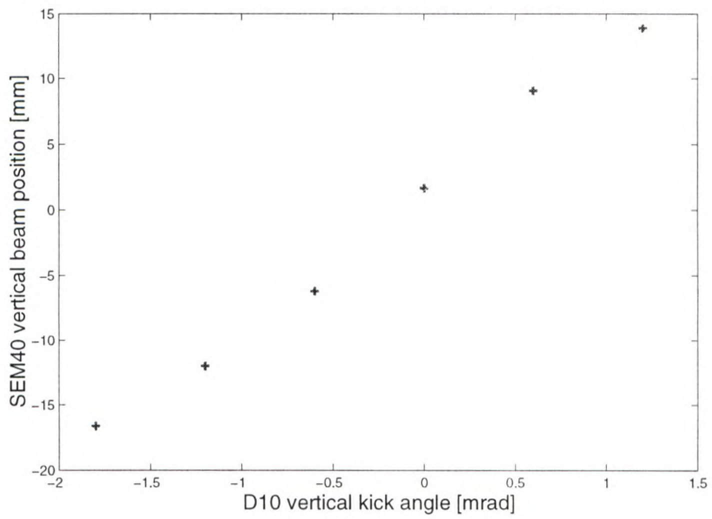

Figure 14: Vertical displacement of the beam measured at SEM40 versus D10 vertical deflection angle. A linear fit yields a slope of 10.64 mm/mrad.

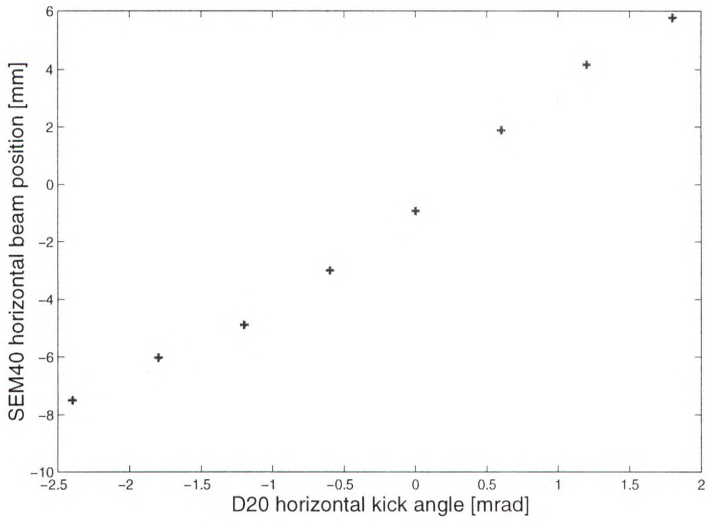

Figure 15: Horizontal displacement of the beam measured at SEM40 versus D20 horizontal deflection angle. A linear fit yields a slope of 3.30 mm/mrad.

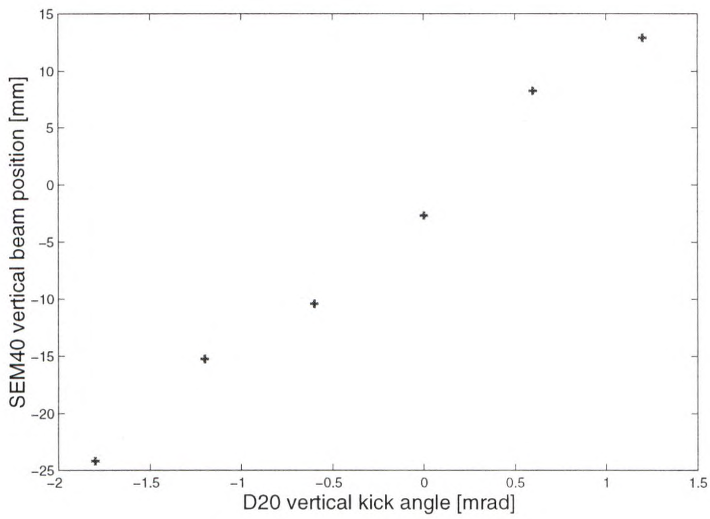

Figure 16: Vertical displacement of the beam measured at SEM40 versus D10 vertical deflection angle. A linear fit yields a slope of 12.56 mm/mrad.

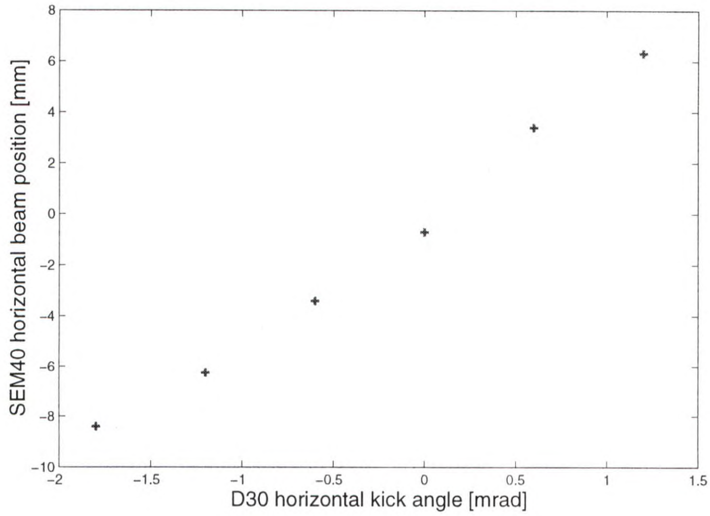

Figure 17: Horizontal deflection of the beam measured at SEM40 versus D30 horizontal deflection angle. A linear fit yields a slope of 5.01 mm/mrad

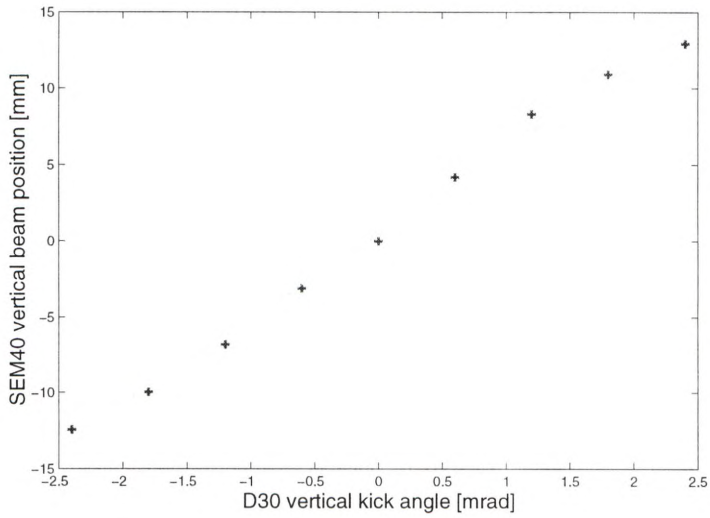

Figure 18: Vertical deflection of the beam measured at SEM40 versus D10 vertical deflection angle. A linear fit yields a slope of 5.60 mm/mrad.

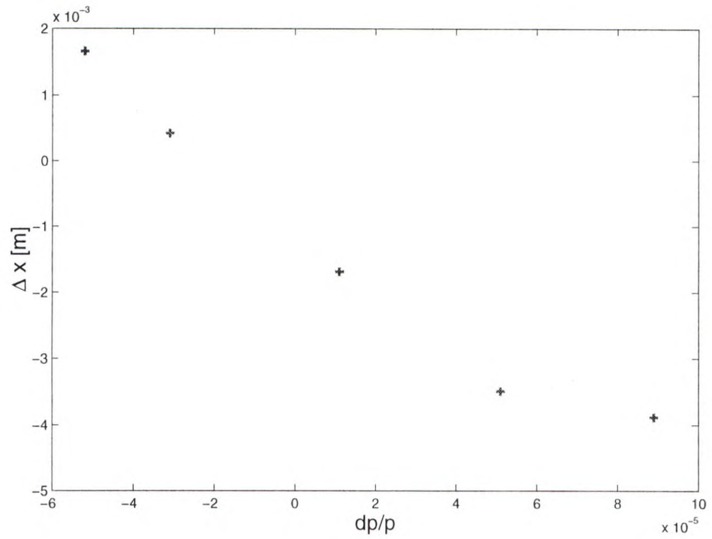

Figure 19: Horizontal displacement of the beam measured at SEM30 versus momentum change. A linear fit yields a dispersion of -4.082 m.

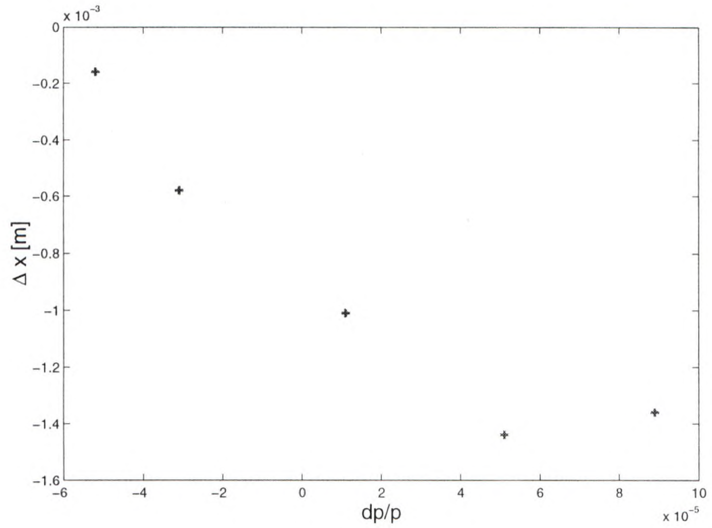

Figure 20: Horizontal displacement of the beam measured at SEM40 versus momentum change. A linear fit yields a dispersion of -0.877 m.

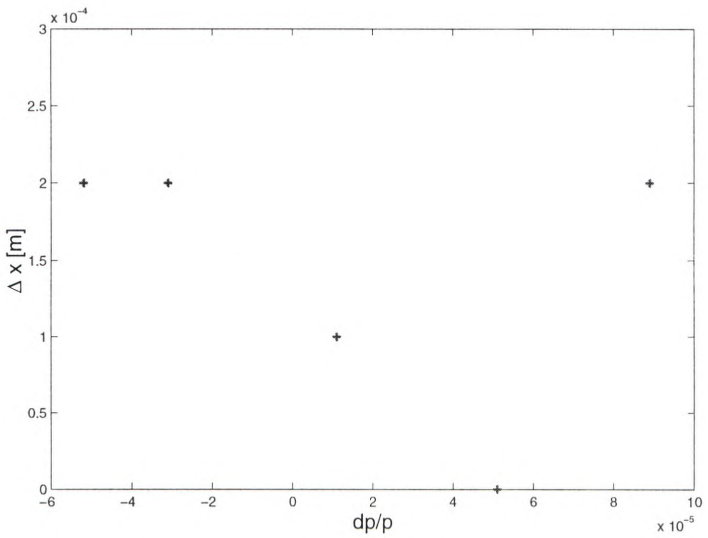

Figure 21: Horizontal displacement of the beam measured at LT.U10 versus momentum change. A linear fit yields a dispersion of -0.054 m. The data are not useful.

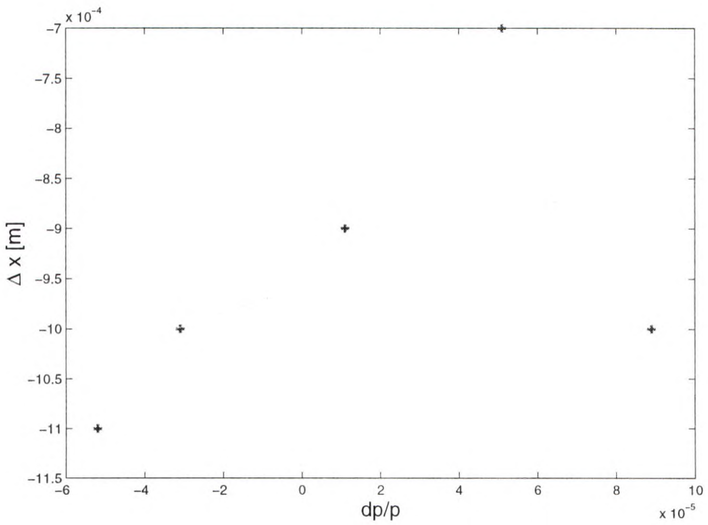

Figure 22: Horizontal displacement of the beam measured at LT.U30 versus momentum change. A linear fit yields a dispersion of 0.131 m. The data are not useful.

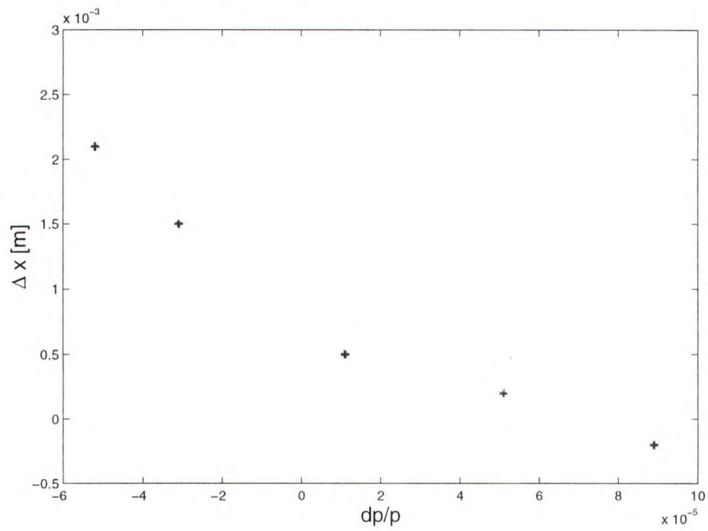

Figure 23: Horizontal displacement of the beam measured at LT.U40 versus momentum change. A linear fit yields a dispersion of -1.596 m.

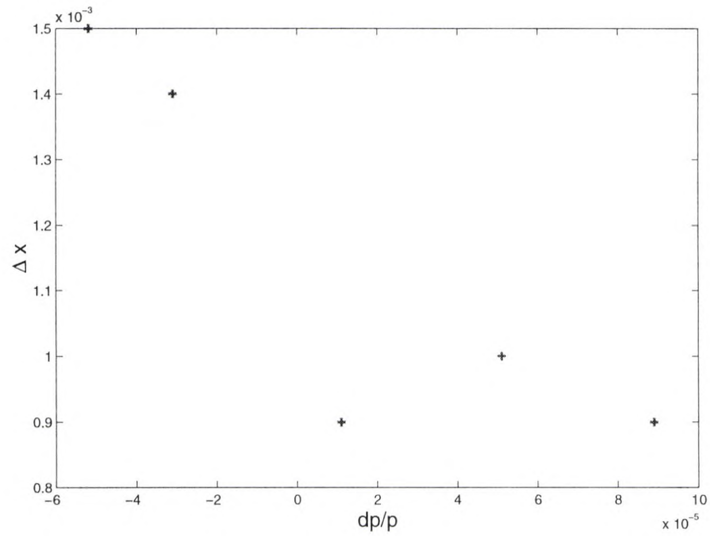

Figure 24: Horizontal displacement of the beam measured at LT.U50 versus momentum change. A linear fit yields a dispersion of -0.433 m.

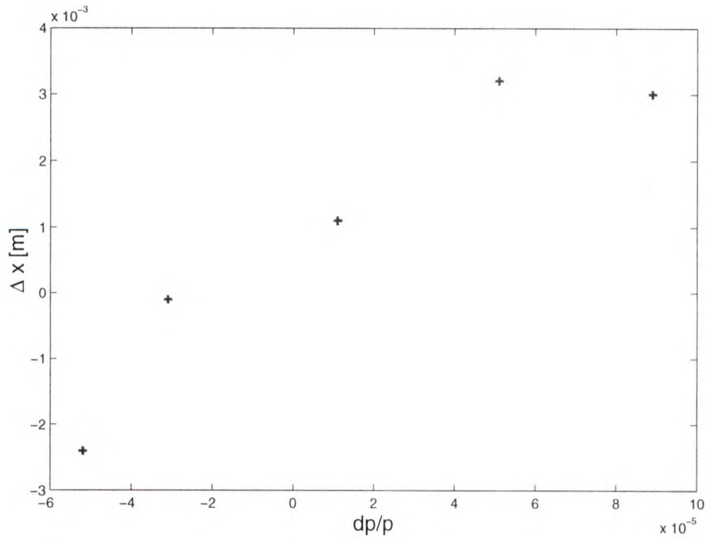

Figure 25: Horizontal displacement of the beam measured at LTB.U10 versus momentum change. A linear fit yields a dispersion of 3.773 m.

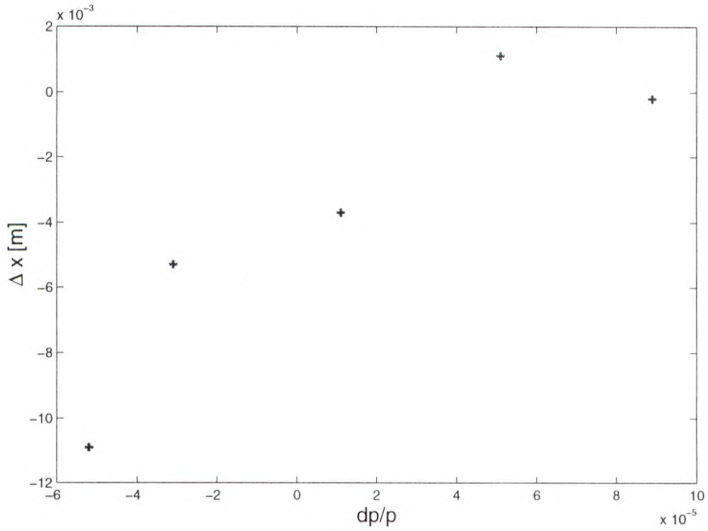

Figure 26: Horizontal displacement of the beam measured at LTB.U20 versus momentum change. A linear fit yields a dispersion of 7.376 m.

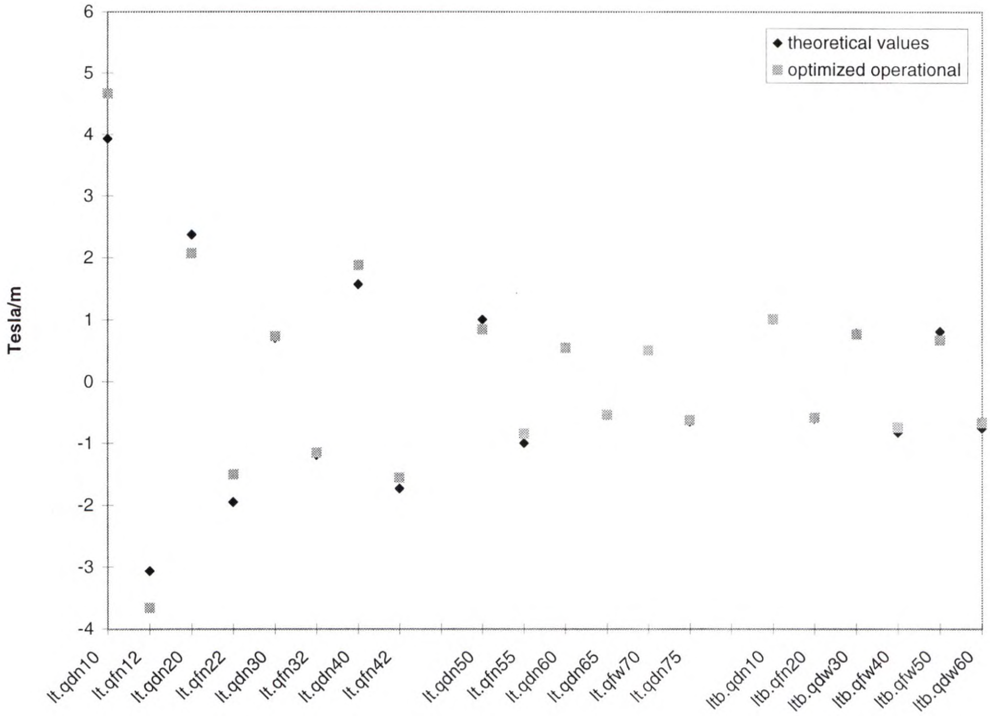

Figure 27: Nominal and measured quadrupole setting for the LTB line.