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Proton losses in the dispersion suppressors of IR1 and IR5 of LHC

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Summary

This work continues the study [1], [2] of the beam losses in the insertions IR1 and IR5 of LHC. The latest collision schemes [3] for the lattice version 6.1 are taken into account in the tracking of the off-momentum protons produced in the interaction points. The beam loss density in the dispersion suppressors is presented in detail and compared with our previous results [1].

The previous study [1] of the off-momentum proton losses downstream of the high luminosity interaction points IP1 and IP5 used the LHC optics version 6.0 without the collision scheme elements.The new collision scheme [3] for the optics versions 6.1 and 6.2 is the main reason to continue the study of the beam losses with the same methods as in [1].

The scheme provides the crossing angle of 0.3 mrad in the vertical plane in IP1 and the same in the horizontal plane in IP5. Six orbit correctors (three per a half of an IR) are introduced in [3] to achieve the goal. The addition of any dipole into the lattice changes the dispersion function by definition. The difference between the optics of IR1 and IR5 is illustrated in Figure 1 where the trajectories of the off-momentum protons are shown. Obviously some changes can be expected in the loss distributions along IR1 and IR5 with respect to those from [1].

A significant part of our study concerning mainly the losses in the straight sections has been reported already in [2] where two horizontal collimators are proposed to be installed in the straight sections upstream of D2 and Q5. The first one protects the chain of magnets D2-Q4 and the second one protects the magnets downstream. The results of the study concerning the dispersion suppressors are reported below.

The distribution of the loss density along the dispersion suppressors has the maximum ($1.3 \cdot 10^6$ p/s for IR1 and $4.0 \cdot 10^6$ p/s for IR5) inside the dipole B8B (see the solid histograms in Figures 2 and 3). These maxima are below the quench limit of $8 \cdot 10^6$ m^{-1}s^{-1} [4] but not too far from it.

A combination of the closed orbit distortions with the mechanical errors of the single

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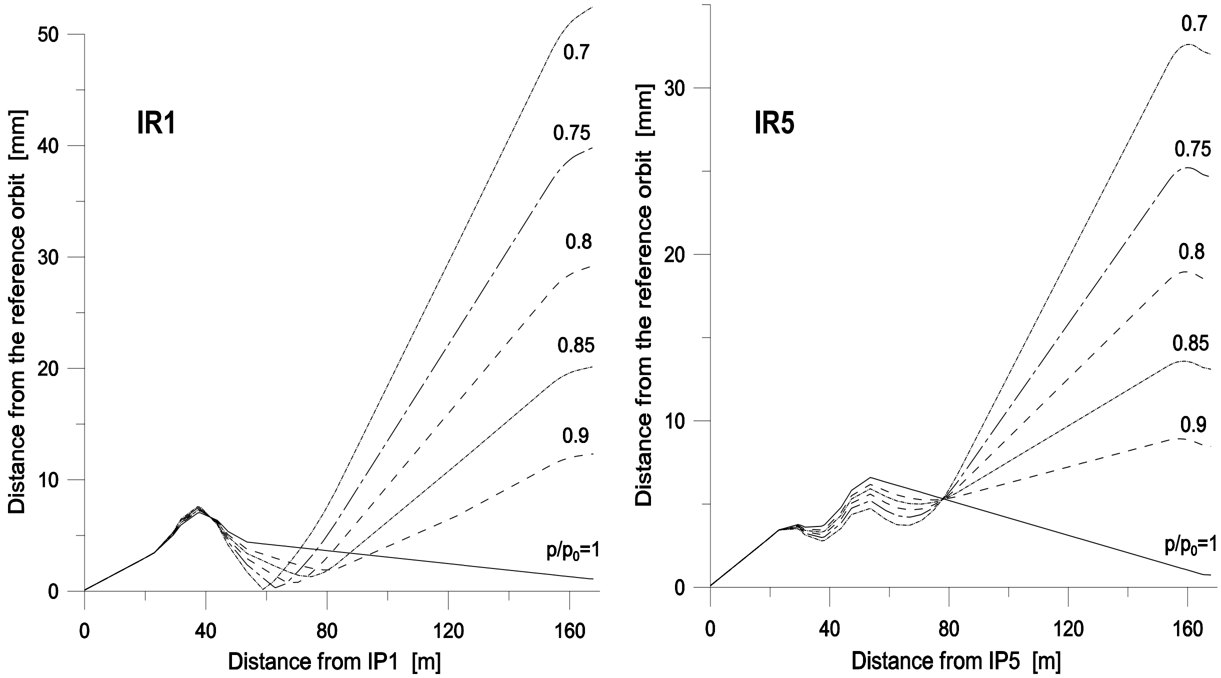

Figure 1: Trajectories of the off-momentum protons emitted from IP in the beam direction.

magnet aperture can result in an aperture reduction with the consequent rise of losses. Table 1 represents the results of our investigation of sensitivity of the peak loss density in B8B.R1 to the transversal displacements of this dipole.

Table 1: Relative maximum loss density in the dipole B8B of IR1 as a function of the horizontal and vertical displacements Δx and Δy of the dipole axis with respect to the beam axis.

Δx [mm]	0	2	4
Δy $[mm]$			
0	1.0	1.6	2.6
2	2.8	3.1	3.5
4	5.4	6.2	7.1

As can be seen from the table the loss rise can be significant even within the tolerable range [5] of the displacements. The loss density in the displaced B8B is shown in Figures 2 and 3 as the dashed histogram. The peak at the magnet entrance reaches the quench limit [4]. Even larger displacements of the next dipole B9A do not result in the loss density exceeding 65% of the quench limit.

The collimator at D2 cannot intercept the protons able to reach DS. Therefore the only place for the collimator protecting the magnets of DS is the warm section upstream of Q5. The dotted histograms in Figures 2 and 3 show that the collimator at ∼11m upstream of

Q5 with the horizontal position of the jaw $x_c = 15\sigma_x$ can reliably protect the dispersion suppressor magnets from quench. If the peak loss in the displaced B9A is found too high then the reduction of x_c to $\sim 12\sigma_x$ can solve the problem.

The estimation of radiation damage and induced radiation in the dispersion suppressors requires the loss rates corresponding to the effective luminosity averaged over 24 hours of LHC operation. This effective luminosity is half the nominal one and the corresponding average rate of inelastic interactions in the IP is $3.5 \cdot 10^8$ s^{-1} [6].

The loss distributions for the case without any collimators in the straight section are presented in Figure 4 for IR1 (vertical crossing) and in Figure 5 for IR5 (horizontal crossing). The main reason for the difference between the new results and the previous result [1] is that with the new collision scheme[3] the dispersion function at the end of the straight sectionis not matched to zero. Further work on the collision scheme will result in better matching of the dispersion function [7]. In that case the loss distribution in the dispersion suppressors will be closer to the result of [1] rather than to the results of the present work. Therefore the beam loss densities from [1] are not obsolete.

Figure 4 and Figure 5 represent the case when collimators are installed upstream of both D2 and Q5. The above comments explain the difference with respect to the previous results. It should be noted that the collimator upstream of D2 does not affect the losses in the dispersion suppressors and only the collimator at Q5 is responsible for loss reduction.

The detailed longitudinal distributions of the beam losses in the dispersion suppressors are presented in the form of tables in the Appendix.

Acknowledgements

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References

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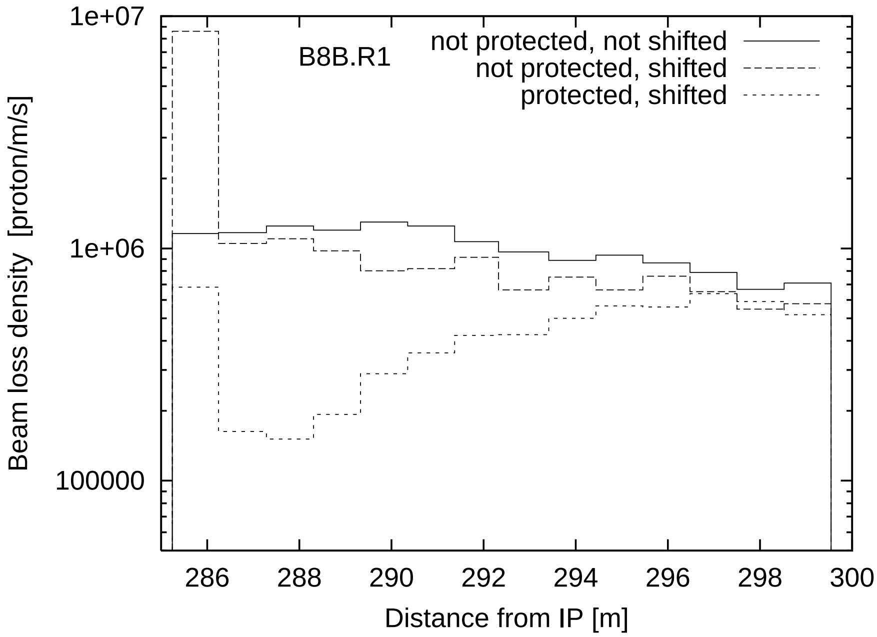

Figure 2: The beam loss density in the dipole B8B of IR1 at the nominal luminosity 10^{34} cm^{-2}s^{-1}. The solid histogram represents the case without any collimators in the straight section and with the perfect alignment of B8B. The dashed histogram shows the effect of the transversal displacement (Δx=4mm, Δy=4mm) of B8B. The dotted histogram is for the case when displaced B8B is protected by the collimator at Q5 with the horizontal jaw at $x_c = 15\sigma_x$.

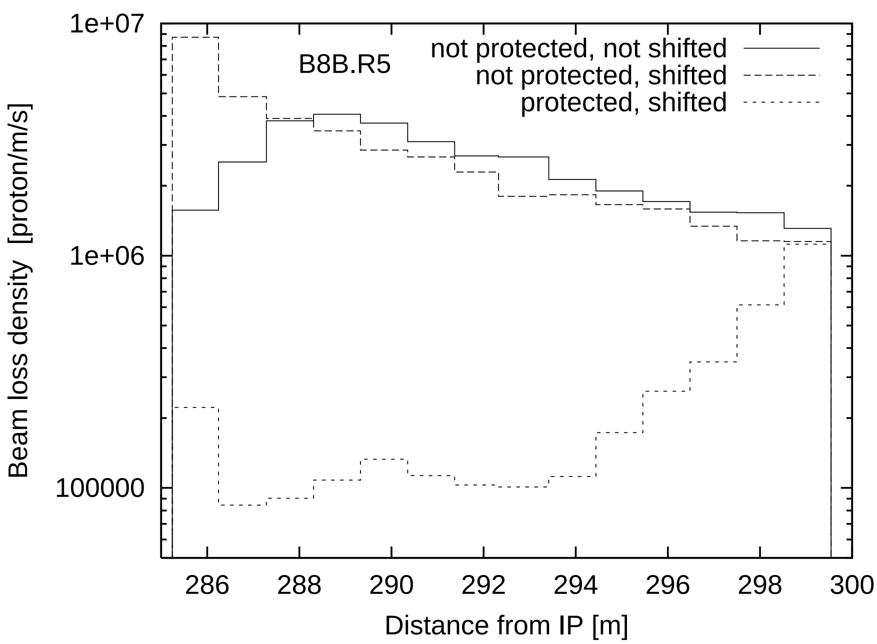

Figure 3: The same as Figure 2 for the dipole B8B of IR5.

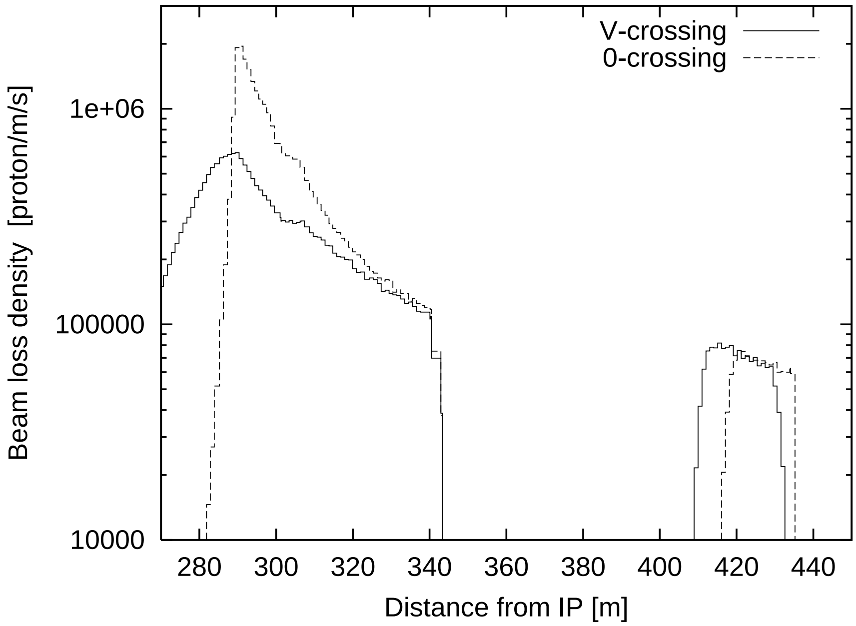

Figure 4: Beam loss density in the dispersion suppressor of IR1 (vertical crossing) at the average luminosity for the case without any collimator in the straight section. The data from [1] (zero crossing) are presented by the dashed histogram. The corresponding inelastic interaction rate in the IP is $3.5 \cdot 10^8$ s^{-1} [6].

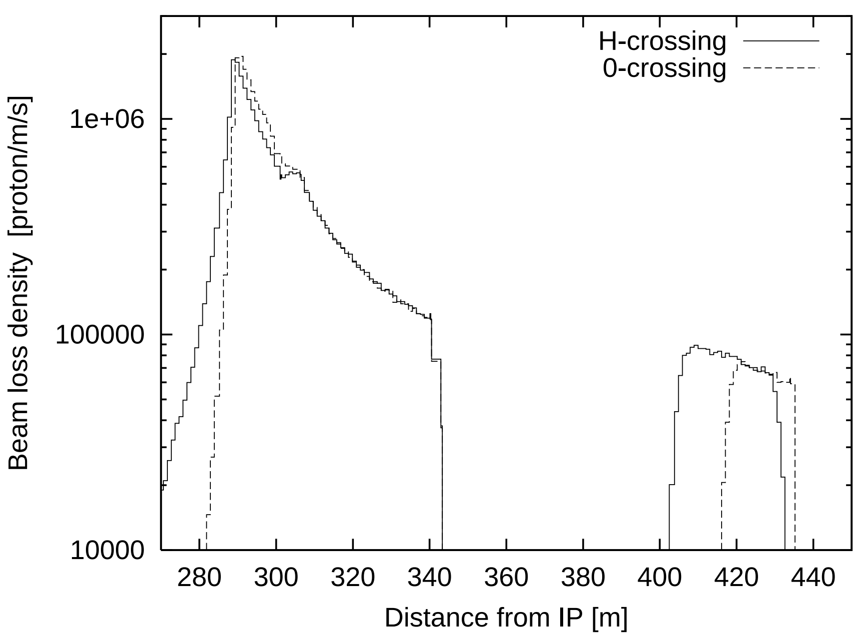

Figure 5: The same as Figure 4 for IR5 (horizontal crossing).

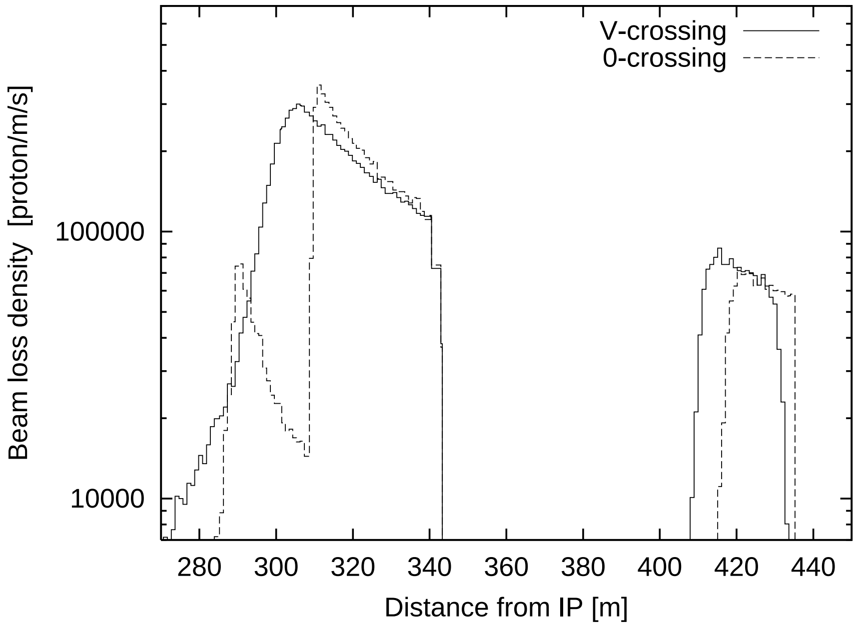

Figure 6: Beam loss density in the dispersion suppressor of IR1 (vertical crossing) at the average luminosity for the case with the collimators upstream of D2 and Q5. The data from [1] (zero crossing) are presented by the dashed histogram. The corresponding inelastic interaction rate in the IP is $3.5 \cdot 10^8$ s^{-1} [6].

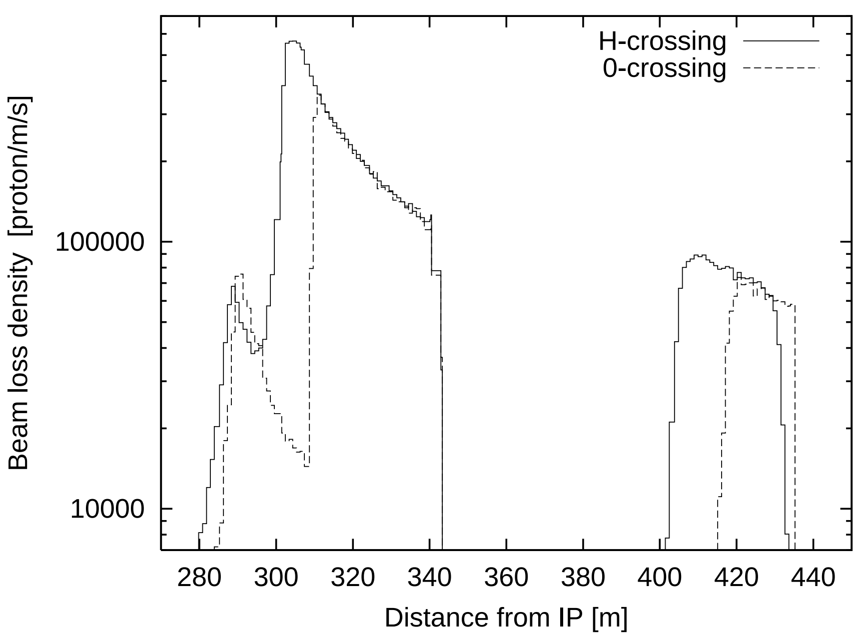

Figure 7: The same as Figure 6 for IR5 (horizontal crossing).

A Appendix

The Tables below contain the calculated proton loss density in the dispersion suppressors of IR1 and IR5. The values of the loss density are presented for one half of the peak luminosity to correspond to the rate of inelastic interactions in the IP averaged over 24 hours of operation. This average rate is defined in [6] as $3.5 \cdot 10^8$ s^{-1}.

The Table 2 represents the case of the IR layout without any collimator in the straight section. The total proton loss rate in the DS is equal to $2.3 \cdot 10^7$ p/s for IR1 and $3.4 \cdot 10^7$ p/s for IR5. The corresponding loss rate from [1] is $3.3 \cdot 10^7$ p/s without a distinction between IR1 and IR5.

A single jaw collimator upstream of the quadrupole Q5 reduces the losses in the DS significantly. The case with the collimator at Q5 is presented in Table 3. The total proton loss in the DS is equal to $1.1 \cdot 10^7$ p/s for IR1 and $1.3 \cdot 10^7$ p/s for IR5. The corresponding loss rate from [1] is $8.5 \cdot 10^6$ p/s.

Table 2: Beam loss density $\dot{n}$ in the elements of the dispersion suppressor for vertical (V) crossing in IP1 and horizontal (H) crossing in IP5 along with the data [1] for zero (0) crossing angle in IP1 or IP5. The case without collimators in the straigt section. The losses correspond to $3.5 \cdot 10^8$ inelastic interactions per second in the IP. s_{entr} is the distance between the IP and the element entrance. l_{elem} is the length of the element.

Lattice element			$\dot{n}$ [p/m/s]		
Name	s_{entr} [m]	l_{elem} [m]	'V'	'H'	'0'
drift	268.90	0.680	$1.3 \cdot 10^5$	$1.6 \cdot 10^4$	$5.0 \cdot 10^2$
B8A	269.58	1.021	$1.5 \cdot 10^5$	$1.9 \cdot 10^4$	$5.0 \cdot 10^2$
B8A	270.61	1.021	$1.7 \cdot 10^5$	$2.1 \cdot 10^4$	$5.0 \cdot 10^2$
B8A	271.63	1.021	$1.9 \cdot 10^5$	$2.6 \cdot 10^4$	$5.0 \cdot 10^2$
B8A	272.65	1.021	$2.2 \cdot 10^5$	$3.2 \cdot 10^4$	$5.0 \cdot 10^2$
B8A	273.67	1.021	$2.4 \cdot 10^5$	$3.9 \cdot 10^4$	$5.0 \cdot 10^2$
B8A	274.69	1.021	$2.7 \cdot 10^5$	$4.2 \cdot 10^4$	$6.3 \cdot 10^2$
B8A	275.71	1.021	$3.0 \cdot 10^5$	$5.0 \cdot 10^4$	$5.8 \cdot 10^2$
B8A	276.73	1.021	$3.1 \cdot 10^5$	$6.0 \cdot 10^4$	$1.1 \cdot 10^3$
B8A	277.76	1.021	$3.5 \cdot 10^5$	$7.1 \cdot 10^4$	$1.8 \cdot 10^3$
B8A	278.78	1.021	$3.9 \cdot 10^5$	$8.7 \cdot 10^4$	$3.1 \cdot 10^3$
B8A	279.80	1.021	$4.2 \cdot 10^5$	$1.1 \cdot 10^5$	$4.2 \cdot 10^3$
B8A	280.82	1.021	$4.5 \cdot 10^5$	$1.4 \cdot 10^5$	$8.0 \cdot 10^3$
B8A	281.84	1.021	$4.9 \cdot 10^5$	$1.8 \cdot 10^5$	$1.5 \cdot 10^4$
B8A	282.86	1.021	$5.3 \cdot 10^5$	$2.3 \cdot 10^5$	$2.7 \cdot 10^4$
drift	283.88	1.360	$5.6 \cdot 10^5$	$3.1 \cdot 10^5$	$5.2 \cdot 10^4$
B8B	285.24	1.021	$5.9 \cdot 10^5$	$4.6 \cdot 10^5$	$1.0 \cdot 10^5$
B8B	286.27	1.021	$6.0 \cdot 10^5$	$6.4 \cdot 10^5$	$1.9 \cdot 10^5$
B8B	287.29	1.021	$6.1 \cdot 10^5$	$1.0 \cdot 10^6$	$3.8 \cdot 10^5$
B8B	288.31	1.021	$6.2 \cdot 10^5$	$1.9 \cdot 10^6$	$9.1 \cdot 10^5$
B8B	289.33	1.021	$6.3 \cdot 10^5$	$1.8 \cdot 10^6$	$1.9 \cdot 10^6$
B8B	290.35	1.021	$5.9 \cdot 10^5$	$1.6 \cdot 10^6$	$2.0 \cdot 10^6$
B8B	291.37	1.021	$5.5 \cdot 10^5$	$1.4 \cdot 10^6$	$1.7 \cdot 10^6$
B8B	292.39	1.021	$5.1 \cdot 10^5$	$1.2 \cdot 10^6$	$1.5 \cdot 10^6$
B8B	293.42	1.021	$4.8 \cdot 10^5$	$1.1 \cdot 10^6$	$1.3 \cdot 10^6$
B8B	294.44	1.021	$4.4 \cdot 10^5$	$9.8 \cdot 10^5$	$1.2 \cdot 10^6$
B8B	295.46	1.021	$4.2 \cdot 10^5$	$8.7 \cdot 10^5$	$1.1 \cdot 10^6$
B8B	296.48	1.021	$4.0 \cdot 10^5$	$8.1 \cdot 10^5$	$1.0 \cdot 10^6$
B8B	297.50	1.021	$3.8 \cdot 10^5$	$7.3 \cdot 10^5$	$9.6 \cdot 10^5$
B8B	298.52	1.021	$3.5 \cdot 10^5$	$6.8 \cdot 10^5$	$8.3 \cdot 10^5$
drift	299.54	1.490	$3.3 \cdot 10^5$	$6.0 \cdot 10^5$	$6.9 \cdot 10^5$
PU	301.03	0.220	$3.1 \cdot 10^5$	$5.3 \cdot 10^5$	$6.9 \cdot 10^5$
drift	301.25	0.200	$3.0 \cdot 10^5$	$5.5 \cdot 10^5$	$6.9 \cdot 10^5$

Table 2 continued

Lattice element			$\dot{n}$ [p/m/s]		
Name	s_{entr} [m]	l_{elem} [m]	'V'	'H'	'0'
QD8	301.45	0.960	$3.0 \cdot 10^5$	$5.3 \cdot 10^5$	$6.2 \cdot 10^5$
QD8	302.41	0.960	$3.0 \cdot 10^5$	$5.5 \cdot 10^5$	$6.1 \cdot 10^5$
QD8	303.37	0.960	$3.0 \cdot 10^5$	$5.7 \cdot 10^5$	$6.1 \cdot 10^5$
QD8	304.33	0.960	$2.9 \cdot 10^5$	$5.6 \cdot 10^5$	$5.8 \cdot 10^5$
QD8	305.29	0.960	$3.0 \cdot 10^5$	$5.6 \cdot 10^5$	$5.8 \cdot 10^5$
drift	306.25	0.255	$3.0 \cdot 10^5$	$5.5 \cdot 10^5$	$5.3 \cdot 10^5$
CV	306.51	0.840	$3.0 \cdot 10^5$	$5.2 \cdot 10^5$	$5.3 \cdot 10^5$
drift	307.35	1.300	$2.8 \cdot 10^5$	$4.6 \cdot 10^5$	$4.7 \cdot 10^5$
B9A	308.65	1.021	$2.7 \cdot 10^5$	$4.2 \cdot 10^5$	$4.1 \cdot 10^5$
B9A	309.67	1.021	$2.6 \cdot 10^5$	$3.8 \cdot 10^5$	$3.9 \cdot 10^5$
B9A	310.69	1.021	$2.5 \cdot 10^5$	$3.5 \cdot 10^5$	$3.6 \cdot 10^5$
B9A	311.71	1.021	$2.5 \cdot 10^5$	$3.4 \cdot 10^5$	$3.4 \cdot 10^5$
B9A	312.73	1.021	$2.3 \cdot 10^5$	$3.1 \cdot 10^5$	$3.2 \cdot 10^5$
B9A	313.76	1.021	$2.3 \cdot 10^5$	$3.0 \cdot 10^5$	$2.9 \cdot 10^5$
B9A	314.78	1.021	$2.1 \cdot 10^5$	$2.8 \cdot 10^5$	$2.8 \cdot 10^5$
B9A	315.80	1.021	$2.1 \cdot 10^5$	$2.6 \cdot 10^5$	$2.7 \cdot 10^5$
B9A	316.82	1.021	$2.0 \cdot 10^5$	$2.5 \cdot 10^5$	$2.5 \cdot 10^5$
B9A	317.84	1.021	$2.0 \cdot 10^5$	$2.4 \cdot 10^5$	$2.4 \cdot 10^5$
B9A	318.86	1.021	$2.0 \cdot 10^5$	$2.4 \cdot 10^5$	$2.3 \cdot 10^5$
B9A	319.88	1.021	$1.8 \cdot 10^5$	$2.2 \cdot 10^5$	$2.2 \cdot 10^5$
B9A	320.90	1.021	$1.7 \cdot 10^5$	$2.0 \cdot 10^5$	$2.1 \cdot 10^5$
B9A	321.93	1.021	$1.8 \cdot 10^5$	$2.0 \cdot 10^5$	$2.0 \cdot 10^5$
drift	322.95	1.360	$1.6 \cdot 10^5$	$1.9 \cdot 10^5$	$1.9 \cdot 10^5$
B9B	324.31	1.021	$1.6 \cdot 10^5$	$1.8 \cdot 10^5$	$1.8 \cdot 10^5$
B9B	325.33	1.021	$1.6 \cdot 10^5$	$1.8 \cdot 10^5$	$1.7 \cdot 10^5$
B9B	326.35	1.021	$1.5 \cdot 10^5$	$1.7 \cdot 10^5$	$1.6 \cdot 10^5$
B9B	327.37	1.021	$1.4 \cdot 10^5$	$1.6 \cdot 10^5$	$1.6 \cdot 10^5$
B9B	328.39	1.021	$1.4 \cdot 10^5$	$1.6 \cdot 10^5$	$1.6 \cdot 10^5$
B9B	329.42	1.021	$1.4 \cdot 10^5$	$1.5 \cdot 10^5$	$1.6 \cdot 10^5$
B9B	330.44	1.021	$1.4 \cdot 10^5$	$1.5 \cdot 10^5$	$1.4 \cdot 10^5$
B9B	331.46	1.021	$1.4 \cdot 10^5$	$1.4 \cdot 10^5$	$1.5 \cdot 10^5$
B9B	332.48	1.021	$1.3 \cdot 10^5$	$1.4 \cdot 10^5$	$1.4 \cdot 10^5$
B9B	333.50	1.021	$1.2 \cdot 10^5$	$1.4 \cdot 10^5$	$1.4 \cdot 10^5$
B9B	334.52	1.021	$1.3 \cdot 10^5$	$1.4 \cdot 10^5$	$1.3 \cdot 10^5$
B9B	335.54	1.021	$1.2 \cdot 10^5$	$1.3 \cdot 10^5$	$1.3 \cdot 10^5$
B9B	336.57	1.021	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.2 \cdot 10^5$
B9B	337.59	1.021	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.2 \cdot 10^5$
drift	338.61	1.490	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.2 \cdot 10^5$
PU	340.10	0.220	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.2 \cdot 10^5$
drift	340.32	0.200	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.2 \cdot 10^5$
QF9A	340.52	2.400	$7.0 \cdot 10^4$	$7.7 \cdot 10^4$	$7.5 \cdot 10^4$
drift	342.92	0.400	$3.9 \cdot 10^4$	$3.7 \cdot 10^4$	$3.8 \cdot 10^4$

Table 2 continued

Lattice element			$\dot{n}$ [p/m/s]		
Name	s_{entr} [m]	l_{elem} [m]	'V'	'H'	'0'
B11A	400.43	1.021	$5.0 \cdot 10^2$	$2.8 \cdot 10^3$	$5.0 \cdot 10^2$
B11A	401.15	1.021	$5.0 \cdot 10^2$	$7.0 \cdot 10^3$	$5.0 \cdot 10^2$
drift	402.48	1.360	$5.0 \cdot 10^2$	$2.0 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	403.84	1.021	$5.0 \cdot 10^2$	$4.4 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	404.86	1.021	$5.4 \cdot 10^2$	$6.4 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	405.88	1.021	$1.3 \cdot 10^3$	$8.0 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	406.90	1.021	$3.5 \cdot 10^3$	$8.2 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	407.92	1.021	$9.1 \cdot 10^3$	$8.7 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	408.94	1.021	$2.2 \cdot 10^4$	$8.9 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	409.96	1.021	$4.2 \cdot 10^4$	$8.6 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	410.99	1.021	$6.2 \cdot 10^4$	$8.6 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	412.01	1.021	$7.5 \cdot 10^4$	$8.6 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	413.03	1.021	$7.8 \cdot 10^4$	$8.1 \cdot 10^4$	$9.2 \cdot 10^2$
B11B	414.05	1.021	$7.8 \cdot 10^4$	$8.2 \cdot 10^4$	$3.0 \cdot 10^3$
B11B	415.07	1.021	$8.2 \cdot 10^4$	$8.4 \cdot 10^4$	$9.0 \cdot 10^3$
B11B	416.09	1.021	$7.7 \cdot 10^4$	$7.8 \cdot 10^4$	$2.1 \cdot 10^4$
B11B	417.11	1.021	$7.8 \cdot 10^4$	$8.2 \cdot 10^4$	$3.9 \cdot 10^4$
drift	418.14	1.034	$8.0 \cdot 10^4$	$7.9 \cdot 10^4$	$5.9 \cdot 10^4$
drift	419.17	1.034	$7.1 \cdot 10^4$	$7.9 \cdot 10^4$	$6.8 \cdot 10^4$
drift	420.20	1.034	$7.6 \cdot 10^4$	$7.7 \cdot 10^4$	$7.2 \cdot 10^4$
drift	421.24	1.034	$7.0 \cdot 10^4$	$7.3 \cdot 10^4$	$7.5 \cdot 10^4$
drift	422.27	1.034	$7.1 \cdot 10^4$	$7.2 \cdot 10^4$	$7.2 \cdot 10^4$
drift	423.31	1.034	$6.7 \cdot 10^4$	$7.0 \cdot 10^4$	$7.0 \cdot 10^4$
drift	424.34	1.034	$7.0 \cdot 10^4$	$7.0 \cdot 10^4$	$6.8 \cdot 10^4$
drift	425.37	1.034	$6.4 \cdot 10^4$	$6.7 \cdot 10^4$	$6.8 \cdot 10^4$
drift	426.41	1.034	$6.6 \cdot 10^4$	$7.1 \cdot 10^4$	$6.8 \cdot 10^4$
drift	427.44	1.034	$6.3 \cdot 10^4$	$6.7 \cdot 10^4$	$6.6 \cdot 10^4$
drift	428.48	1.034	$6.4 \cdot 10^4$	$6.5 \cdot 10^4$	$6.5 \cdot 10^4$
drift	429.51	1.034	$5.2 \cdot 10^4$	$5.4 \cdot 10^4$	$6.7 \cdot 10^4$
drift	430.54	1.034	$3.9 \cdot 10^4$	$3.9 \cdot 10^4$	$6.0 \cdot 10^4$
drift	431.58	1.034	$2.2 \cdot 10^4$	$2.2 \cdot 10^4$	$6.1 \cdot 10^4$
drift	432.61	1.034	$9.2 \cdot 10^3$	$6.8 \cdot 10^3$	$6.0 \cdot 10^4$
PU	433.65	0.220	$2.8 \cdot 10^3$	$3.1 \cdot 10^3$	$6.0 \cdot 10^4$
drift	433.87	0.200	$3.1 \cdot 10^3$	$2.2 \cdot 10^3$	$6.3 \cdot 10^4$
QT	434.07	1.150	$1.6 \cdot 10^3$	$5.9 \cdot 10^2$	$5.9 \cdot 10^4$

Table 3: Beam loss density $\dot{n}$ in the elements of the dispersion suppressor for vertical (V) crossing in IP1 and horizontal (H) crossing in IP5 along with the data [1] for zero (0) crossing angle in IP1 or IP5. The case with the collimators upstream of D2 and Q5. The losses correspond to $3.5 \cdot 10^8$ inelastic interactions per second in the IP. s_{entr} is the distance between the IP and the element entrance. l_{elem} is the length of the element.

Lattice element			$\dot{n}$ [p/m/s]		
Name	s_{entr} [m]	l_{elem} [m]	'V'	'H'	'0'
drift	268.90	0.680	$7.3 \cdot 10^3$	$9.9 \cdot 10^2$	$5.0 \cdot 10^2$
B8A	269.58	1.021	$6.4 \cdot 10^3$	$1.5 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	270.61	1.021	$7.2 \cdot 10^3$	$2.8 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	271.63	1.021	$6.8 \cdot 10^3$	$2.7 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	272.65	1.021	$7.7 \cdot 10^3$	$2.3 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	273.67	1.021	$1.0 \cdot 10^4$	$2.8 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	274.69	1.021	$1.0 \cdot 10^4$	$3.0 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	275.71	1.021	$9.5 \cdot 10^3$	$4.8 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	276.73	1.021	$1.1 \cdot 10^4$	$4.6 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	277.76	1.021	$1.1 \cdot 10^4$	$5.6 \cdot 10^3$	$5.0 \cdot 10^2$
B8A	278.78	1.021	$1.3 \cdot 10^4$	$6.4 \cdot 10^3$	$1.8 \cdot 10^3$
B8A	279.80	1.021	$1.5 \cdot 10^4$	$8.1 \cdot 10^3$	$1.6 \cdot 10^3$
B8A	280.82	1.021	$1.4 \cdot 10^4$	$8.8 \cdot 10^3$	$2.8 \cdot 10^3$
B8A	281.84	1.021	$1.6 \cdot 10^4$	$1.2 \cdot 10^4$	$3.0 \cdot 10^3$
B8A	282.86	1.021	$1.9 \cdot 10^4$	$1.5 \cdot 10^4$	$5.9 \cdot 10^3$
drift	283.88	1.360	$2.0 \cdot 10^4$	$2.0 \cdot 10^4$	$7.2 \cdot 10^3$
B8B	285.24	1.021	$2.0 \cdot 10^4$	$2.9 \cdot 10^4$	$8.8 \cdot 10^3$
B8B	286.27	1.021	$2.2 \cdot 10^4$	$4.2 \cdot 10^4$	$1.8 \cdot 10^4$
B8B	287.29	1.021	$2.7 \cdot 10^4$	$5.8 \cdot 10^4$	$2.5 \cdot 10^4$
B8B	288.31	1.021	$2.6 \cdot 10^4$	$6.8 \cdot 10^4$	$4.6 \cdot 10^4$
B8B	289.33	1.021	$3.3 \cdot 10^4$	$5.9 \cdot 10^4$	$7.4 \cdot 10^4$
B8B	290.35	1.021	$4.2 \cdot 10^4$	$5.0 \cdot 10^4$	$7.6 \cdot 10^4$
B8B	291.37	1.021	$4.8 \cdot 10^4$	$4.7 \cdot 10^4$	$6.1 \cdot 10^4$
B8B	292.39	1.021	$5.5 \cdot 10^4$	$4.2 \cdot 10^4$	$5.6 \cdot 10^4$
B8B	293.42	1.021	$7.1 \cdot 10^4$	$3.8 \cdot 10^4$	$4.6 \cdot 10^4$
B8B	294.44	1.021	$8.2 \cdot 10^4$	$3.9 \cdot 10^4$	$4.2 \cdot 10^4$
B8B	295.46	1.021	$1.0 \cdot 10^5$	$4.0 \cdot 10^4$	$4.1 \cdot 10^4$
B8B	296.48	1.021	$1.3 \cdot 10^5$	$4.3 \cdot 10^4$	$3.1 \cdot 10^4$
B8B	297.50	1.021	$1.5 \cdot 10^5$	$5.8 \cdot 10^4$	$2.8 \cdot 10^4$
B8B	298.52	1.021	$1.8 \cdot 10^5$	$7.5 \cdot 10^4$	$2.4 \cdot 10^4$
drift	299.54	1.490	$2.1 \cdot 10^5$	$1.2 \cdot 10^5$	$2.3 \cdot 10^4$
PU	301.03	0.220	$2.4 \cdot 10^5$	$2.0 \cdot 10^5$	$2.3 \cdot 10^4$
drift	301.25	0.200	$2.4 \cdot 10^5$	$2.1 \cdot 10^5$	$2.3 \cdot 10^4$

Table 3 continued

Lattice element			$\dot{n}$ [p/m/s]		
Name	s_{entr} [m]	l_{elem} [m]	'V'	'H'	'0'
QD8	301.45	0.960	$2.5 \cdot 10^5$	$3.8 \cdot 10^5$	$1.9 \cdot 10^4$
QD8	302.41	0.960	$2.7 \cdot 10^5$	$5.5 \cdot 10^5$	$1.8 \cdot 10^4$
QD8	303.37	0.960	$2.8 \cdot 10^5$	$5.6 \cdot 10^5$	$1.8 \cdot 10^4$
QD8	304.33	0.960	$2.9 \cdot 10^5$	$5.6 \cdot 10^5$	$1.7 \cdot 10^4$
QD8	305.29	0.960	$3.0 \cdot 10^5$	$5.6 \cdot 10^5$	$1.6 \cdot 10^4$
drift	306.25	0.255	$3.0 \cdot 10^5$	$5.3 \cdot 10^5$	$1.6 \cdot 10^4$
CV	306.51	0.840	$3.0 \cdot 10^5$	$5.2 \cdot 10^5$	$1.6 \cdot 10^4$
drift	307.35	1.300	$2.8 \cdot 10^5$	$4.6 \cdot 10^5$	$1.4 \cdot 10^4$
B9A	308.65	1.021	$2.7 \cdot 10^5$	$4.2 \cdot 10^5$	$7.9 \cdot 10^4$
B9A	309.67	1.021	$2.6 \cdot 10^5$	$3.8 \cdot 10^5$	$2.9 \cdot 10^5$
B9A	310.69	1.021	$2.5 \cdot 10^5$	$3.6 \cdot 10^5$	$3.5 \cdot 10^5$
B9A	311.71	1.021	$2.5 \cdot 10^5$	$3.3 \cdot 10^5$	$3.3 \cdot 10^5$
B9A	312.73	1.021	$2.3 \cdot 10^5$	$3.1 \cdot 10^5$	$3.0 \cdot 10^5$
B9A	313.76	1.021	$2.3 \cdot 10^5$	$2.9 \cdot 10^5$	$2.9 \cdot 10^5$
B9A	314.78	1.021	$2.2 \cdot 10^5$	$2.8 \cdot 10^5$	$2.7 \cdot 10^5$
B9A	315.80	1.021	$2.1 \cdot 10^5$	$2.7 \cdot 10^5$	$2.6 \cdot 10^5$
B9A	316.82	1.021	$2.0 \cdot 10^5$	$2.5 \cdot 10^5$	$2.4 \cdot 10^5$
B9A	317.84	1.021	$2.0 \cdot 10^5$	$2.4 \cdot 10^5$	$2.4 \cdot 10^5$
B9A	318.86	1.021	$1.9 \cdot 10^5$	$2.3 \cdot 10^5$	$2.2 \cdot 10^5$
B9A	319.88	1.021	$1.8 \cdot 10^5$	$2.2 \cdot 10^5$	$2.1 \cdot 10^5$
B9A	320.90	1.021	$1.8 \cdot 10^5$	$2.1 \cdot 10^5$	$2.0 \cdot 10^5$
B9A	321.93	1.021	$1.7 \cdot 10^5$	$2.0 \cdot 10^5$	$2.0 \cdot 10^5$
drift	322.95	1.360	$1.7 \cdot 10^5$	$1.9 \cdot 10^5$	$1.9 \cdot 10^5$
B9B	324.31	1.021	$1.6 \cdot 10^5$	$1.8 \cdot 10^5$	$1.8 \cdot 10^5$
B9B	325.33	1.021	$1.5 \cdot 10^5$	$1.7 \cdot 10^5$	$1.8 \cdot 10^5$
B9B	326.35	1.021	$1.6 \cdot 10^5$	$1.7 \cdot 10^5$	$1.6 \cdot 10^5$
B9B	327.37	1.021	$1.5 \cdot 10^5$	$1.6 \cdot 10^5$	$1.6 \cdot 10^5$
B9B	328.39	1.021	$1.4 \cdot 10^5$	$1.6 \cdot 10^5$	$1.5 \cdot 10^5$
B9B	329.42	1.021	$1.4 \cdot 10^5$	$1.5 \cdot 10^5$	$1.5 \cdot 10^5$
B9B	330.44	1.021	$1.4 \cdot 10^5$	$1.5 \cdot 10^5$	$1.4 \cdot 10^5$
B9B	331.46	1.021	$1.3 \cdot 10^5$	$1.5 \cdot 10^5$	$1.4 \cdot 10^5$
B9B	332.48	1.021	$1.3 \cdot 10^5$	$1.4 \cdot 10^5$	$1.4 \cdot 10^5$
B9B	333.50	1.021	$1.3 \cdot 10^5$	$1.3 \cdot 10^5$	$1.4 \cdot 10^5$
B9B	334.52	1.021	$1.3 \cdot 10^5$	$1.4 \cdot 10^5$	$1.3 \cdot 10^5$
B9B	335.54	1.021	$1.2 \cdot 10^5$	$1.3 \cdot 10^5$	$1.3 \cdot 10^5$
B9B	336.57	1.021	$1.2 \cdot 10^5$	$1.2 \cdot 10^5$	$1.3 \cdot 10^5$
B9B	337.59	1.021	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.2 \cdot 10^5$
drift	338.61	1.490	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.1 \cdot 10^5$
PU	340.10	0.220	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.1 \cdot 10^5$
drift	340.32	0.200	$1.1 \cdot 10^5$	$1.3 \cdot 10^5$	$1.1 \cdot 10^5$
QF9A	340.52	2.400	$7.3 \cdot 10^4$	$7.8 \cdot 10^4$	$7.5 \cdot 10^4$
drift	342.92	0.400	$3.8 \cdot 10^4$	$3.3 \cdot 10^4$	$3.7 \cdot 10^4$

Table 3 continued

Lattice element			$\dot{n}$ [p/m/s]		
Name	s_{entr} [m]	l_{elem} [m]	‘V‘	‘H‘	‘0‘
B11A	400.43	1.021	$5.0 \cdot 10^2$	$2.8 \cdot 10^3$	$5.0 \cdot 10^2$
B11A	401.45	1.021	$5.0 \cdot 10^2$	$7.8 \cdot 10^3$	$5.0 \cdot 10^2$
drift	402.48	1.360	$5.0 \cdot 10^2$	$2.1 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	403.84	1.021	$5.0 \cdot 10^2$	$4.2 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	404.86	1.021	$5.0 \cdot 10^2$	$6.7 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	405.88	1.021	$1.1 \cdot 10^3$	$8.0 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	406.90	1.021	$3.2 \cdot 10^3$	$8.4 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	407.92	1.021	$1.0 \cdot 10^4$	$8.6 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	408.94	1.021	$2.1 \cdot 10^4$	$8.9 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	409.96	1.021	$4.1 \cdot 10^4$	$8.8 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	410.99	1.021	$6.1 \cdot 10^4$	$8.9 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	412.01	1.021	$7.2 \cdot 10^4$	$8.6 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	413.03	1.021	$7.5 \cdot 10^4$	$8.4 \cdot 10^4$	$5.0 \cdot 10^2$
B11B	414.05	1.021	$8.0 \cdot 10^4$	$8.1 \cdot 10^4$	$3.3 \cdot 10^3$
B11B	415.07	1.021	$8.7 \cdot 10^4$	$7.9 \cdot 10^4$	$1.1 \cdot 10^4$
B11B	416.09	1.021	$7.5 \cdot 10^4$	$7.9 \cdot 10^4$	$1.9 \cdot 10^4$
B11B	417.11	1.021	$7.5 \cdot 10^4$	$8.1 \cdot 10^4$	$4.2 \cdot 10^4$
drift	418.14	1.034	$7.9 \cdot 10^4$	$8.0 \cdot 10^4$	$5.5 \cdot 10^4$
drift	419.17	1.034	$7.3 \cdot 10^4$	$7.2 \cdot 10^4$	$6.2 \cdot 10^4$
drift	420.20	1.034	$7.1 \cdot 10^4$	$7.7 \cdot 10^4$	$7.3 \cdot 10^4$
drift	421.24	1.034	$7.1 \cdot 10^4$	$7.3 \cdot 10^4$	$6.9 \cdot 10^4$
drift	422.27	1.034	$7.1 \cdot 10^4$	$7.3 \cdot 10^4$	$6.9 \cdot 10^4$
drift	423.31	1.034	$7.0 \cdot 10^4$	$7.3 \cdot 10^4$	$7.0 \cdot 10^4$
drift	424.34	1.034	$6.8 \cdot 10^4$	$7.0 \cdot 10^4$	$6.3 \cdot 10^4$
drift	425.37	1.034	$6.3 \cdot 10^4$	$7.1 \cdot 10^4$	$6.7 \cdot 10^4$
drift	426.41	1.034	$6.9 \cdot 10^4$	$6.7 \cdot 10^4$	$6.7 \cdot 10^4$
drift	427.44	1.034	$6.2 \cdot 10^4$	$6.4 \cdot 10^4$	$6.1 \cdot 10^4$
drift	428.48	1.034	$5.7 \cdot 10^4$	$6.2 \cdot 10^4$	$6.3 \cdot 10^4$
drift	429.51	1.034	$5.3 \cdot 10^4$	$5.5 \cdot 10^4$	$6.0 \cdot 10^4$
drift	430.54	1.034	$3.6 \cdot 10^4$	$4.1 \cdot 10^4$	$6.0 \cdot 10^4$
drift	431.58	1.034	$2.3 \cdot 10^4$	$2.1 \cdot 10^4$	$6.0 \cdot 10^4$
drift	432.61	1.034	$8.0 \cdot 10^3$	$8.0 \cdot 10^3$	$5.7 \cdot 10^4$
PU	433.65	0.220	$3.9 \cdot 10^3$	$1.1 \cdot 10^3$	$5.8 \cdot 10^4$
drift	433.87	0.200	$1.8 \cdot 10^3$	$2.2 \cdot 10^3$	$5.8 \cdot 10^4$
QT	434.07	1.150	$8.0 \cdot 10^2$	$6.9 \cdot 10^2$	$5.8 \cdot 10^4$