LHC Project Note 388

October 31, 2006

(Marcel.Gyr@cern.ch)

Strategy for allocating the MSD magnets and vacuum chambers

B. Goddard, M. Gyr / AB-BT, B. Jeanneret / AB-ABP and S. Ramberger / AT-MEL

Keywords: Septum Magnets, MSD, Extraction, LBDS

Abstract

An analogous strategy as applied for the MSI septum magnets [1] allows an optimisation of the installation of the MSD septa regarding magnet and chamber allocation. Even if the gain in aperture is small, of the order of half a millimetre, it is not negligible and — being essentially for free — should nevertheless be implemented.

1. Introduction

The alignment of the different MSD magnets is summarized in [2]. For normal operation (all 15 MKD kickers synchronised with the beam hole, closed orbit within specified tolerances) the aperture for the circulating beam is n_1>7.5 and therefore rather comfortable [3]. It only becomes critical for off-normal operating conditions of either the dump system itself (unsynchronised dump, only 14 MKD magnets firing) or of the LHC machine. The bottleneck for the aperture is at the exit of the MSDC for both the circulating and extracted beam.

2. Overall alignment constraints

- The MSD magnets are aligned in the horizontal plane to optimise the aperture for the circulating and extracted beams as described in [3]. The exact septa positions (Figure 1) are listed in [2], Table 3.
- Each MSD magnet is aligned in the vertical plane to follow the circulating beam trajectory.
- The vacuum chambers for the extracted beam are aligned to follow the vertical beam trajectory, Figure 2.
- The horizontal deflection of the extracted beam varies around its nominal trajectory by an amount corresponding to ± 5% amplitude modulation of the kicker waveform.
- It must be noted that the horizontal aperture is already limited to $n_1 = 6.5$ by the upstream TCDS diluter that protects the MSD in case of failure of the MKD- or closed-orbit system (cf. Fig. 3 in [3]).

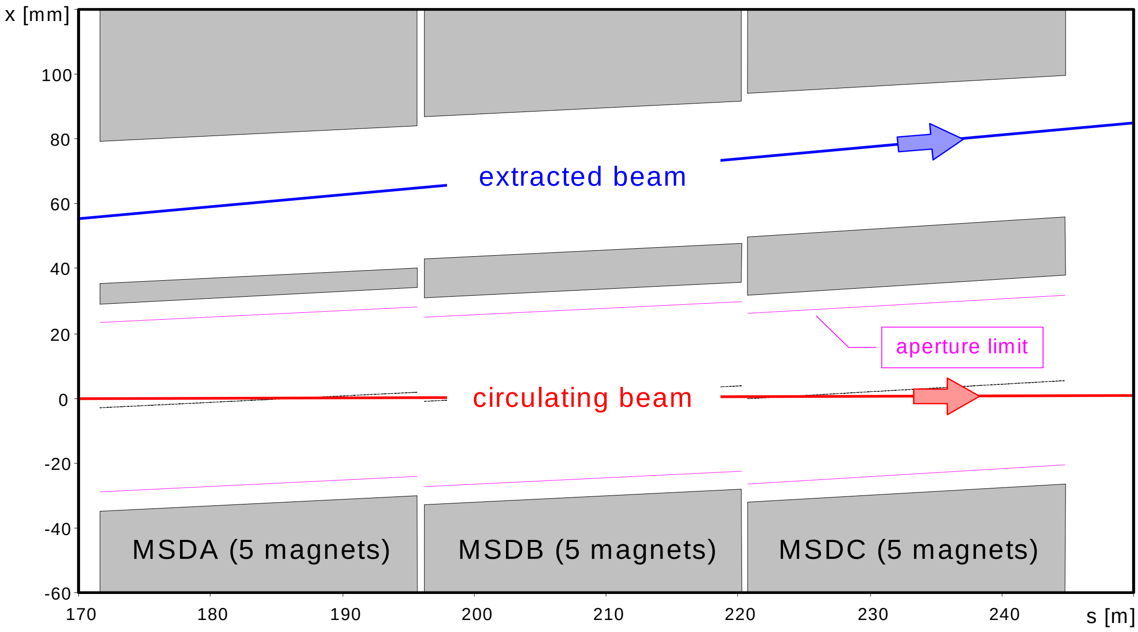

Figure 1. Horizontal alignment of MSD septa

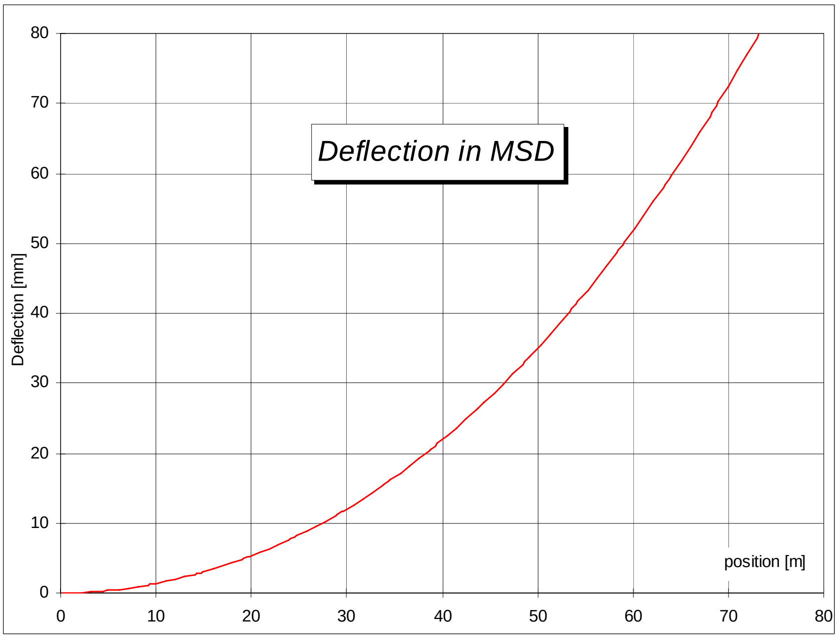

Figure 2. Vertical deflection of extracted beam in the MSD field gap

3. Aperture at limiting locations

3.1 Circulating beam

For the circulating beam aperture, the calculated n_1 values at the entrance and exit of the MSDA, the MSDB and the MSDC are given in Table 1 (with entrance and exit always defined here in the sense of the extracted beam). These values refer to LHC optics 6.5, assuming a momentum offset at injection $dp/p = 1.5{\cdot}10^{-3}$, a peak radial closed orbit offset $CO_{rad} = 4$ mm [4], a relative parasitic dispersion $k_D = 0.273$, a beta beating $k_\beta = \sqrt{1.21}$, a peak linear dispersion in the arc $D_{QF} = 2.1$ m [5] and $\beta_{QFx} = 180$ m [6].

Table 1: n_1 values for the circulating beam at the different locations and apertures

	MSDA		MSDB		MSDC	
	entrance	exit	entrance	exit	entrance	exit
Beam 1 (TD68)	9.85	10.50	10.96	9.24	11.02	7.85
Beam 2 (TD62)	9.65	10.31	10.72	9.04	10.79	**7.63**

Figure 3 shows the geometry of the primary beam with its halo at the most unfavourable orbit position for the limiting values of n_1=7.85 (beam 1) and n_1=7.63 (beam 2).

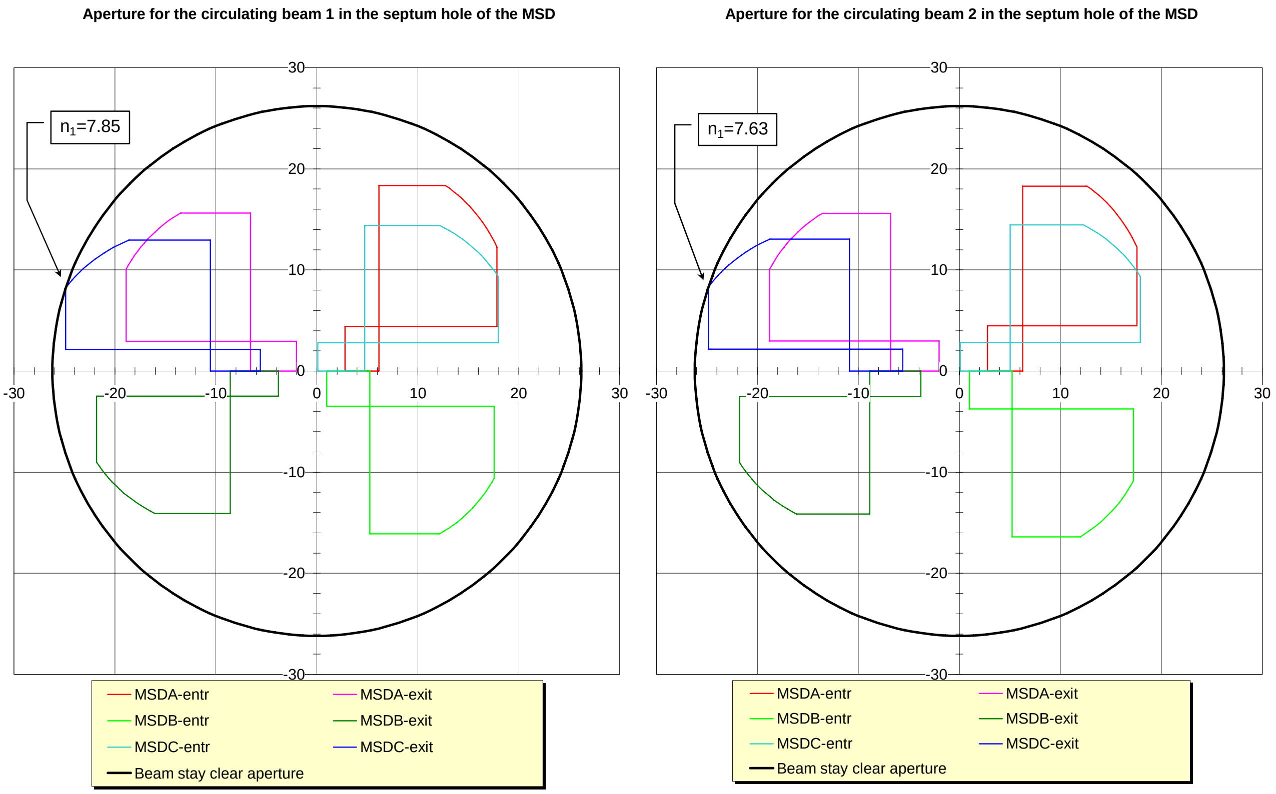

Figure 3. n_1 for the apertures at the entrance and exit (in beam direction) of the MSDA, MSDB and MSDC for beam 1 and beam 2 in IR6.

3.2 Extracted beam

The horizontal aperture is the most critical at the exit of the MSDC (cf. Fig. 3. in [3]) where it is limited to ~ 6.2 σ in the case of normal operation (all 15 MKD kickers synchronised with the beam hole, closed orbit controlled with feedback system to stay within ± 2 mm).

4. Circulating beam chamber geometry

Most of the µ-metal vacuum chambers being already equipped with their heating elements, it is almost impossible to precisely measure their dimensions and rectitude. Therefore, since no further measurements were available, the chambers measured for (and attributed to) the injection septa MSI are considered to be a statistically representative sample of all the other chambers [1]:

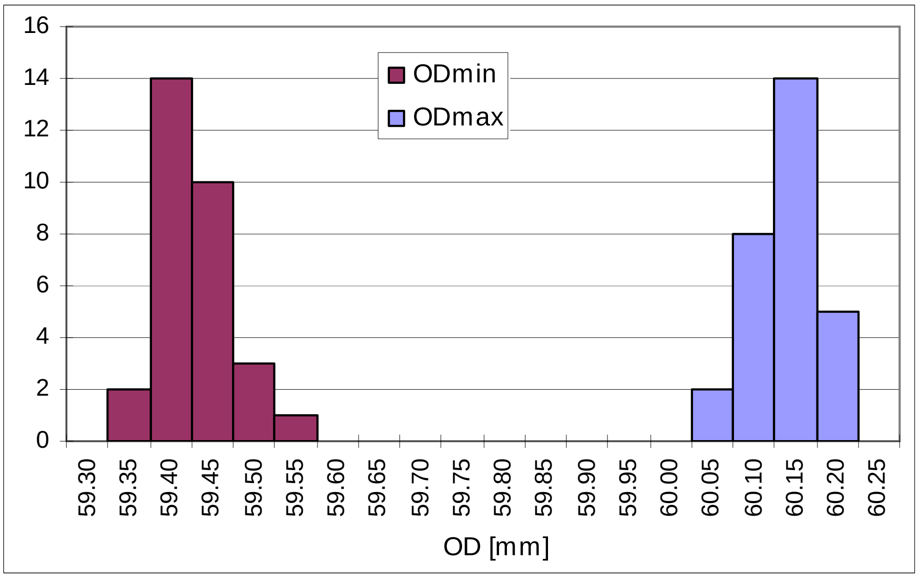

Figure 4. Distribution of chamber minimum and maximum outer diameter (OD)

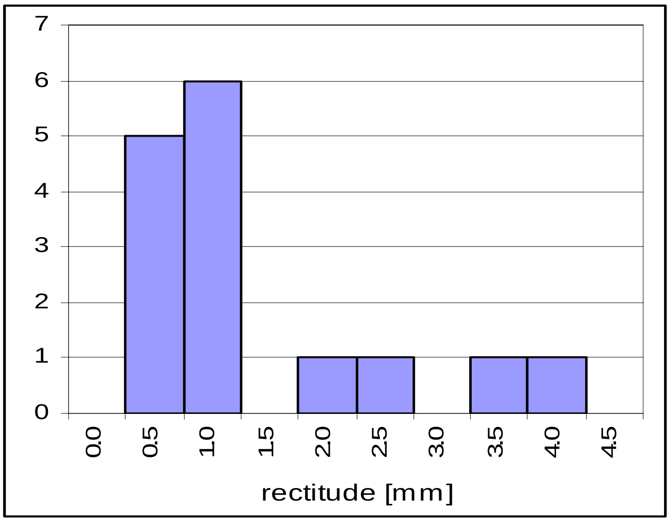

Figure 5. Distribution of measured chamber rectitude before insertion into septum hole

5. Magnet geometry

The magnets are measured horizontally and vertically, and the sagitta S_c determined as the full width of the envelope of measured positions with respect to the average centre line. Since the hole for the circulating beam is in the centre of the magnet, Figure 6, the twist α_t of the magnet yoke has no influence and the sagitta for the circulating beam apertures $S_b = S_c$.

For the extracted beam however, the vertical offset Δ_b changes from 0 to 8 mm in the MSDA, from 8 to 33 mm in the MSDB and from 33 to 80 mm in the MSDC. The maximum sagitta for the extracted beam must therefore be corrected by $\alpha_t \times \Delta_b$:

$$S_e = S_c + \alpha_t \times \Delta_b$$

For ease of calculation the maximum corresponding offset is assumed in all magnets, for estimating the sagitta for the extracted beam.

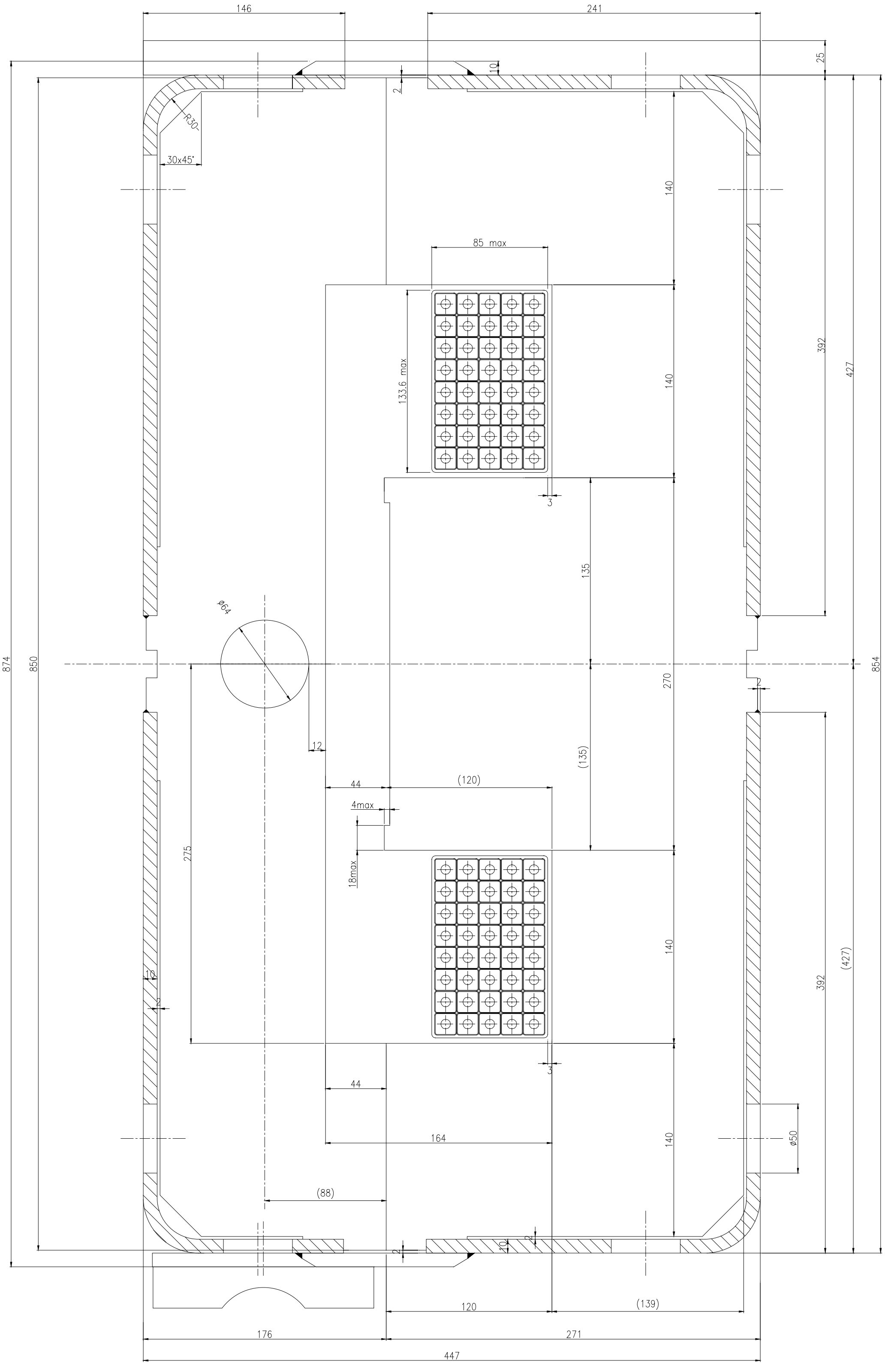

Figure 6. MSDC cross-section.

The measured sagitta (Figure 7), twist- and tilt angles for the different MSD modules together with the horizontal sagitta S_e calculated for the extracted beam apertures are given in Table 2. The influence of the twist (increase of S_e) on the horizontal aperture is shown in Figure 8. For the MSDCs this effect is in the same order of magnitude than the measured sagitta and therefore not negligible.

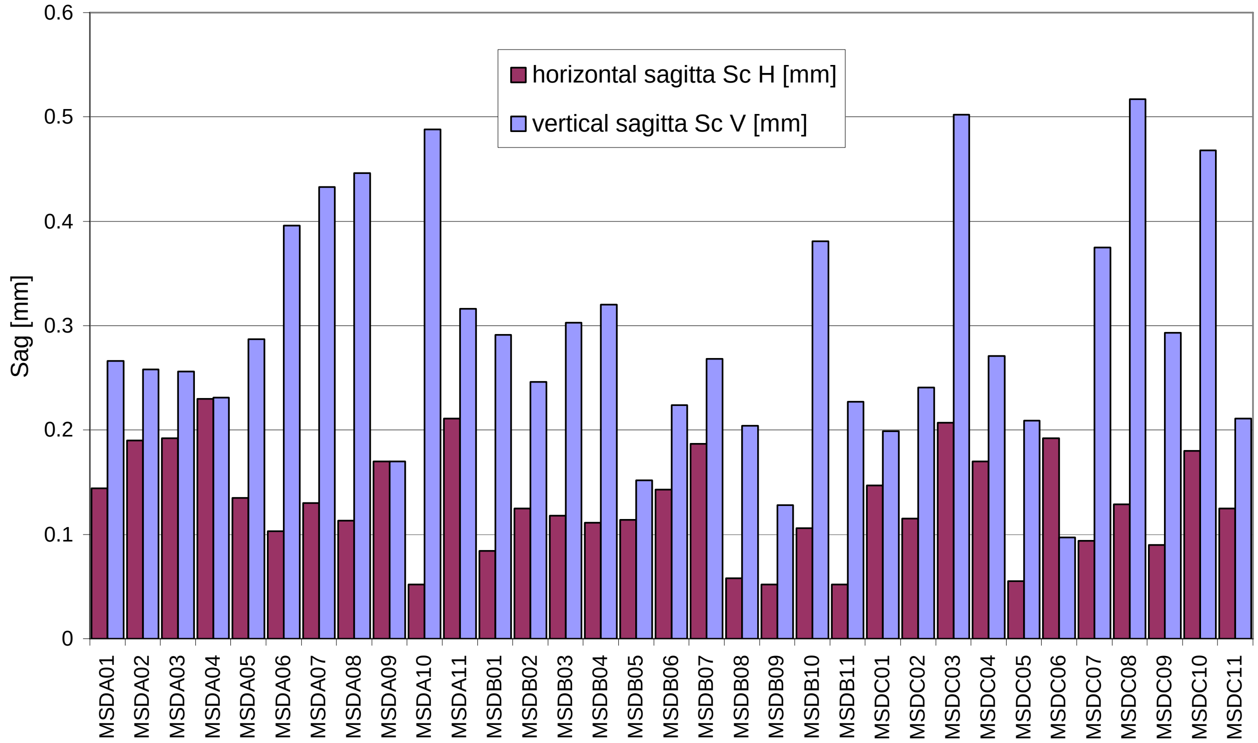

Figure 7. Measured horizontal & vertical sagitta

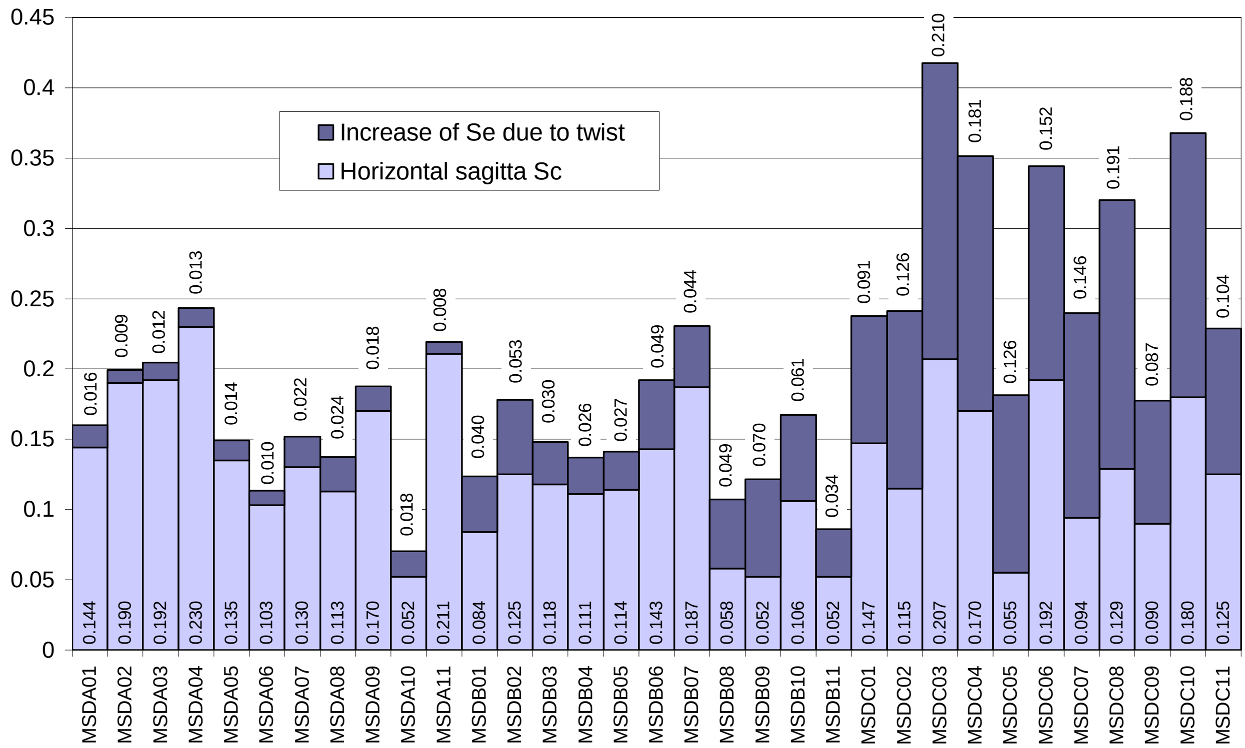

Figure 8. Measured S_{cH}, and calculated increase of S_e due to twist.

Table 2: Measured hor. & ver. sagitta, twist- and tilt-angle with calculated maximum horizontal sagitta for the extracted beam

Magnet name	sag horiz. S_{cH} [mm]	sag vert. S_{cV} [mm]	twist [mrad]	tilt [mrad]	sag horiz. S_{eH} [mm]
MSDA01	0.144	0.266	1.984	-0.867	0.160
MSDA02	0.190	0.258	1.140	-0.032	0.199
MSDA03	0.192	0.256	1.562	-0.164	0.204
MSDA04	0.230	0.231	1.647	0.068	0.243
MSDA05	0.135	0.287	1.773	-0.184	0.149
MSDA06	0.103	0.396	1.309	-0.320	0.113
MSDA07	0.130	0.433	2.744	-1.215	0.152
MSDA08	0.113	0.446	3.040	0.236	0.137
MSDA09	0.170	0.170	2.195	-0.088	0.188
MSDA10	0.052	0.488	2.280	0.220	0.070
MSDA11	0.211	0.316	1.013	0.284	0.219
MSDB01	0.084	0.291	1.198	0.188	0.124
MSDB02	0.125	0.246	1.612	0.098	0.178
MSDB03	0.118	0.303	0.909	0.250	0.148
MSDB04	0.111	0.320	0.785	-0.110	0.137
MSDB05	0.114	0.152	0.827	-0.278	0.141
MSDB06	0.143	0.224	1.488	-0.012	0.192
MSDB07	0.187	0.268	1.322	0.098	0.231
MSDB08	0.058	0.204	1.488	-0.630	0.107
MSDB09	0.052	0.128	2.108	-0.051	0.122
MSDB10	0.106	0.381	1.860	0.008	0.167
MSDB11	0.052	0.227	1.033	-0.196	0.086
MSDC01	0.147	0.199	1.133	-0.364	0.238
MSDC02	0.115	0.241	1.578	-0.812	0.241
MSDC03	0.207	0.502	2.631	-0.023	0.417
MSDC04	0.170	0.271	2.266	-0.755	0.351
MSDC05	0.055	0.209	1.578	-0.291	0.181
MSDC06	0.192	0.097	1.902	0.414	0.344
MSDC07	0.094	0.375	1.821	-0.467	0.240
MSDC08	0.129	0.517	2.388	-0.858	0.320
MSDC09	0.090	0.293	1.093	0.180	0.177
MSDC10	0.180	0.468	2.347	-1.291	0.368
MSDC11	0.125	0.211	1.295	-0.073	0.229

6. Magnet and chamber allocation

Almost all µ-metal vacuum chambers whose outer diameter and rectitude have been measured are already allocated to the MSI magnets [1]. Since no further measurements exist for the remaining chambers, and provided that they all are within the specified tolerances [7] & [8] , they are allocated arbitrarily to the different MSD magnets. This is justifiable since due to very little play (< 0.3 mm) between the chambers and the surrounding yoke, their final rectitude and cylindricity will mainly be imposed by the magnet geometry.

Considering that the aperture in the MSD is mainly restricted by the upstream TCDS rather than by the vacuum chamber itself, the only location to be optimised for aperture is at the exit of the MSDC.

Taking into account the maximum horizontal and vertical sagitta shown in Table 2, the maximum aperture n_{1max} was calculated for all MSDC-units assuming they were assigned to the slots MSDC.E4R6.B1 and MSDC.E4L6.B2 respectively. The values are plotted in Figure 9 which clearly shows that the n_{1max} is roughly 0.2 smaller for beam 2 than for beam 1:

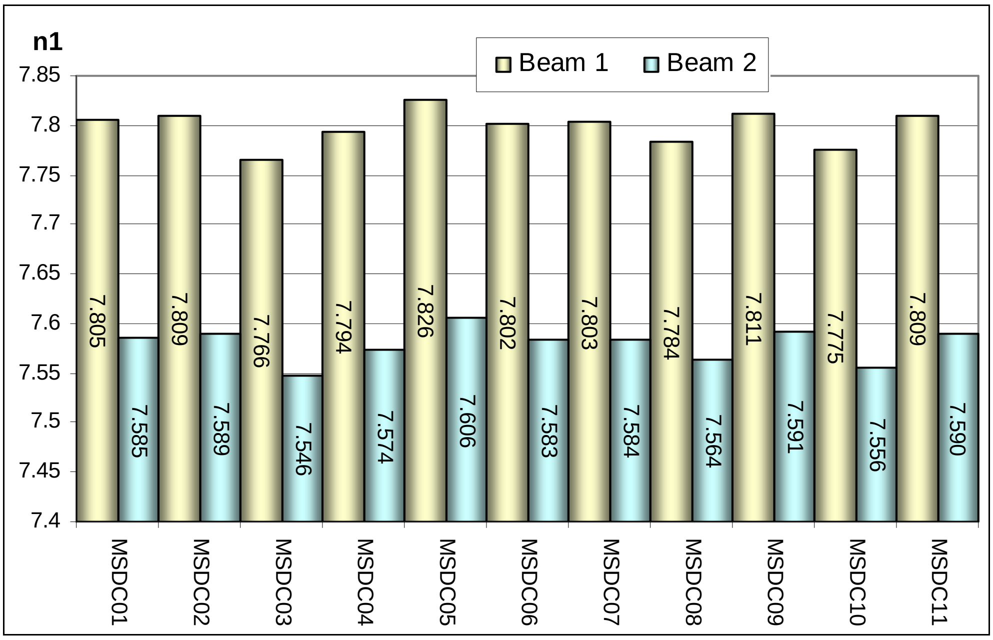

Figure 9 : Maximum aperture n_{1max} for the different units if located at the MSDC exit

To allocate the magnets using the above data, the following method has been applied. The resulting allocations are given in Table 3.

- The two MSDC with highest n_{1max} (MSDC05 and MSDC09) are allocated to slots E4L6.B2 and E4R6.B1 respectively.
- The MSDC with third highest n_{1max} is foreseen as spare unit.
- The remaining MSDC are allocated in decreasing order of n_{1max} to the slots further beam upstream as shown in Table 3.
- The MSDA and MSDB are allocated in chronological order, since being in the shadow of the TCDS, their location is not critical.
- The circulating beam chambers are installed with the orientation of the "ovalisation" such that the horizontal aperture is maximised.

Table 3: Allocation of MSD magnets

MSDA		**MSDB**		**MSDC**	
MTF Name	Functional position Name	MTF Name	Functional position Name	MTF Name	Functional position Name
MSDA01	MSDA.E4L6.B1	MSDB01	MSDB.C4L6.B1	MSDA02	MSDA.A4R6.B2
MSDC05	MSDC.E4L6.B2	MSDB02	MSDB.C4L6.B2	MSDC03	MSDC.A4R6.B1
MSDA03	MSDA.D4L6.B1	MSDB03	MSDB.B4L6.B1	MSDA04	MSDA.B4R6.B2
MSDC02	MSDC.D4L6.B2	MSDB04	MSDB.B4L6.B2	MSDC08	MSDC.B4R6.B1
MSDA05	MSDA.C4L6.B1	MSDB05	MSDB.A4L6.B1	MSDA06	MSDA.C4R6.B2
MSDC07	MSDC.C4L6.B2	MSDB06	MSDB.A4L6.B2	MSDC06	MSDC.C4R6.B1
MSDA07	MSDA.B4L6.B1	MSDB07	MSDB.A4R6.B1	MSDA08	MSDA.D4R6.B2
MSDC04	MSDC.B4L6.B2	MSDB08	MSDB.A4R6.B2	MSDC01	MSDC.D4R6.B1
MSDA09	MSDA.A4L6.B1	MSDB09	MSDB.B4R6.B1	MSDA10	MSDA.E4R6.B2
MSDC10	MSDC.A4L6.B2	MSDB10	MSDB.B4R6.B2	MSDC09	MSDC.E4R6.B1
MSDA11	spare	MSDB11	spare	MSDC11	spare

7. Vacuum chambers for extracted beam

The chambers for the extracted beam should be measured, with particular attention paid to the horizontal aperture.

8. Spare policy

The spare magnet for the MSDC is chosen to be the 3rd best one such as to eventually replace one damaged unit at the MSDC exit.

9. Summary

The simple measures described in this document allow approximately ½ mm to be gained on the aperture available for the circulating beam at the exit of the MSD septa.

10. References

[1] B. Goddard, B. Jeanneret & S. Ramberger, "Strategy for allocating MSI magnets and chambers", LHC Project Note 387, 2006

[2] M. Gyr, "Alignment of injection (MSI) and extraction septa (MSD)", LHC-MS-ES-0001 rev 1.1, EDMS 488061, 2006.

[3] B. Goddard & M. Gyr, "The Aperture and Layout of the LHC Extraction Septa and TCDS Diluter with an enlarged MSDC Vacuum chamber", LHC Project Note 320, 2003

[4] LHC Design Report, Vol. 1, chapter 4, section 4.3

[5] B. Jeanneret & R. Ostojic, "Geometrical acceptance in LHC Version 5.0", LHC Project Note 111, 1997

[6] B. Jeanneret & T. Risselada, "Geometrical aperture in LHC at injection", LHC Project Note 66, 1996

[7] M. Gyr, B. Henrist, J.M. Jimenez, J-M. Lacroix, S. Sgobba: "Aperture and Field Constraints for the Vacuum System in the LHC Injection Septa", IEEE Proceedings of the 2005 Particle Accelerator Conference (PAC05), Knoxville, 16 - 20 May 2005, pp. 2732-2734, (LHC Project Report 815).

[8] J.M. Jimenez & B. Henrist, "Vacuum Chambers for the Circulating Beams in the LHC Injection and Extraction Septa", Functional Spec. LHC-VCRS-ES-0001 v.1.0, EDMS Doc. 405734.