Updates to the MAX IV 1.5 GeV Storage Ring Lattice

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Abstract

As a result of ongoing detailed magnet design work [1], the lattice for the MAX IV 1.5 GeV storage ring has been modified. The lattice files have been updated: a new 20120904 branch [2] will replace the previous 20120313 branch. The updated lattice includes minor changes to the field profiles (in an otherwise unmodified slice model) and slightly lengthened SCi magnets. Because of the minor modifications to the linear optics, the nonlinear optics have been re-optimized. The resulting parameters and performance of the lattice are however very close to those of the previous branch. This note summarizes the changes in the new lattice branch and attempts to investigate performance and error-tolerance of the new linear and nonlinear optics. In this sense it can be considered an update of the DDR chapter on beam dynamics in the 1.5 GeV storage ring [3]. The note concludes with a list of current lattice files and their purpose.

1 Summary of Changes in the New Lattice

The following is a summary of changes applied to the 20120313 branch resulting in the new 20120904 branch.

- The magnetic length of SCi has increased from 55 mm to 70 mm. The extra space was taken from drifts on both sides of SCi in equal amounts, so that the location of the magnetic center of SCi remains unchanged.
- The longitudinal field profiles in the quadrupoles and sextupoles has been modified according to the 3rd iteration magnet design [1].

[1]This document is available for download at `http://www.maxlab.lu.se/node/999`

2 Updated Linear Optics

The magnet slice model for the 1.5 GeV storage ring was retained from the previous lattice branch. The actual bending angles and gradients were however updated according to the 3rd iteration magnet design [1]. In order to restore the design optics and working points, several scalings were applied:

- The dipole field and gradients in DIP were scaled simulating a change of current to the dipole in order to achieve the design bending angle of 15°: $f_{\text{deg}} = 0.9989769$.
- The straight section optics and working point were restored by scaling the gradients in the dipoles and quadrupoles: $f_{\text{DIP}} = 0.99998220$, $f_{\text{SQFi}} = 0.99649723$, $f_{\text{SQFo}} = 0.99445026$. In the real machine the former corresponds to an excitation of the pole-face strips (PFS's) while the latter can be accomplished by changing the currents to the quadrupoles.

The design optics were restored very well with these adjustments. Note a minor increase in horizontal beta function: $\beta_x = 5.684\,\text{m} \rightarrow 5.692\,\text{m}$. An overview of the optics and lattice properties are given in Fig. 1 and Table 1.

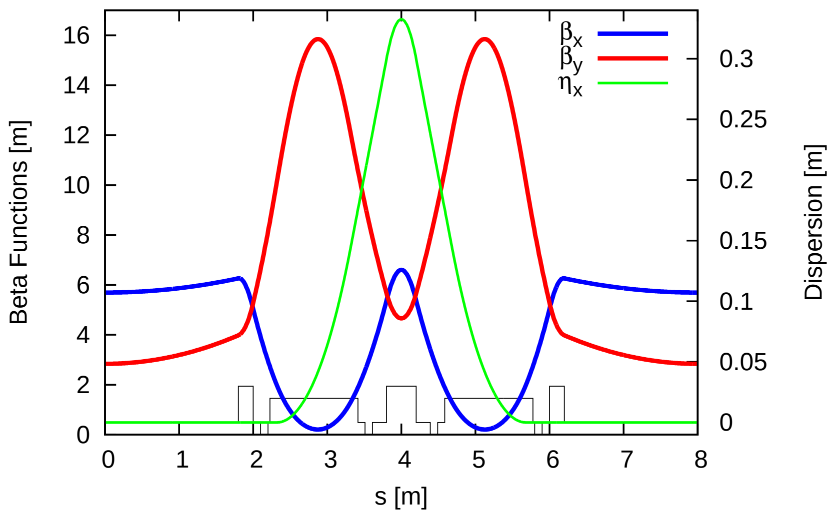

Figure 1: The updated optics in one of the 12 DBA's of the MAX IV 1.5 GeV storage ring. The magnetic structure is indicated at the bottom.

Table 1: The most important properties of the updated lattice for the MAX IV 1.5 GeV storage ring.

Periodicity	12
Circumference	96 m
Horizontal tune ν_x	11.22
Vertical tune ν_y	3.15
Natural horizontal chromaticity ξ_x	-22.981
Natural vertical chromaticity ξ_y	-17.141
Momentum compaction (linear) α_c	3.055×10^{-3}
Horizontal damping partition J_x	1.4635
Bare lattice emittance ε_0	5.980 nm rad
Bare lattice energy loss per turn	114.1 keV
Bare lattice natural energy spread σ_δ	0.745×10^{-3}
Bare lattice horizontal damping time τ_x	5.751 ms
Bare lattice vertical damping time τ_y	8.416 ms
Bare lattice longitudinal damping time τ_E	5.478 ms

3 Updated Nonlinear Optics

With the updated linear and nonlinear optics the natural chromaticity has slightly shifted: $\xi_x = -22.964 \rightarrow -22.981$ and $\xi_y = -17.145 \rightarrow -17.141$. In order to correct this linear chromaticity to +2.0 in both planes the sextupole component of SQFi is adjusted by scaling with $f_{\mathrm{SQFi},2} = 0.997573$ and setting $(b_3)_{\mathrm{SDi}} = -74.057985\,\mathrm{m}^{-3}$. In addition, the nonlinear dynamics are improved by the following harmonic sextupole settings: the sextupole component of SQFo is left unscaled, i.e. $f_{\mathrm{SQFo},2} = 1.00$ and SDo is set to $(b_3)_{\mathrm{SDo}} = -101.92\,\mathrm{m}^{-3}$. This constitutes the 531 nonlinear optics. The tune footprint and dynamic aperture (DA) for the m5-20120904-531 lattice are displayed in Figs. 2 and 3. The large apparent vertical DA available for low horizontal amplitudes is an artifact: an island structure was not recognized by the adaptive step control causing the island to be considered to be part of the continuous DA. This is confirmed by the diffusion map shown in Fig. 5. The available off-momentum DA for ±4% is required to achieve the target lattice momentum acceptance (MA).

Diffusion and frequency maps have been generated for the new m5-20120904-531 optics. Figs. 5 and 6 show tune diffusion for on and off-momentum particles. The

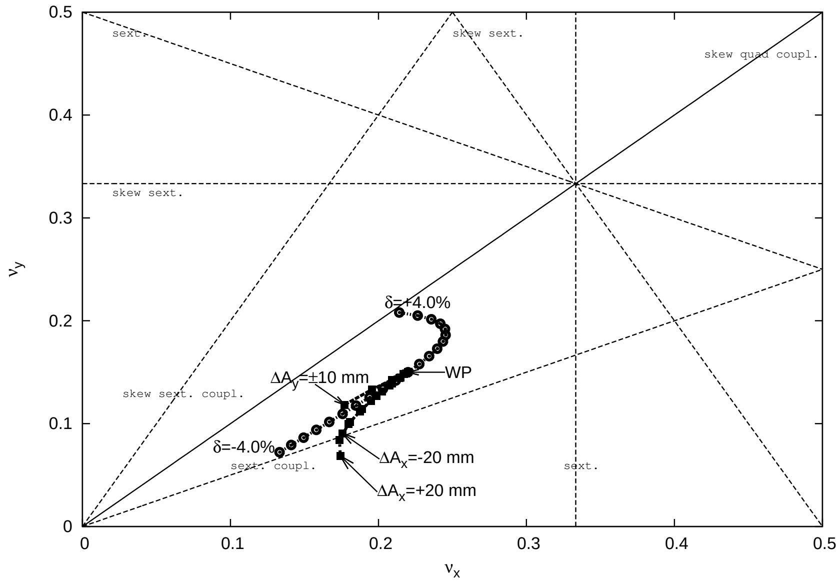

Figure 2: The tune footprint of the new m5-20120904-531 optics of the MAX IV 1.5 GeV storage ring.

on-momentum diffusion map (DM) was limited so as to exclude the island above the continuous DA. The on-momentum frequency map analysis (FMA) reveals that the area required for injection and lifetime show very low diffusion. The increased diffusion observed in the semicircular strip around $(-22/+18, 0) \times (0, 10.4)$ is caused by $6\nu_x = 67$. This resonance can be clearly seen in the FM.

The off-momentum DM reveals increased diffusion around $\delta = -4.75\%$ caused by crossing the sextupole coupling resonance $\nu_x - 2\nu_y = 5$. The resonance $6\nu_x = 67$ leads to increased diffusion around $\delta = -2.75\%$, whereas $6\nu_y = 19$ leads to increased diffusion around $\delta = +1\%$. The coupling resonance $\nu_x - \nu_y = 8$ is crossed around $\delta = 4\%$, but in the DM presented here this does not show up as an area of increased diffusion. Finally, elevated levels of diffusion are caused by $\nu_x + 4\nu_y = 24$ which is encountered beyond $\delta = 5.75\%$.

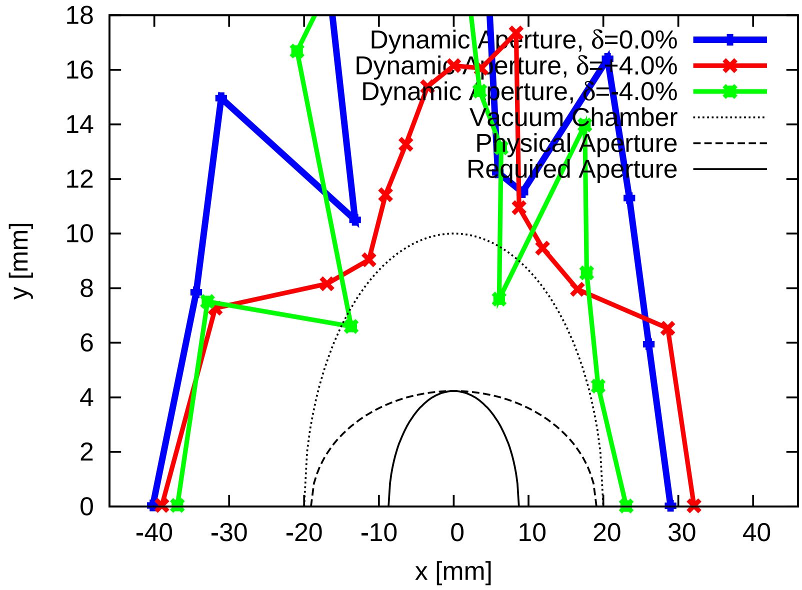

Figure 3: Dynamic aperture calculated with Tracy-3 in 6D for the new m5-20120904-531 optics of the MAX IV 1.5 GeV storage ring.

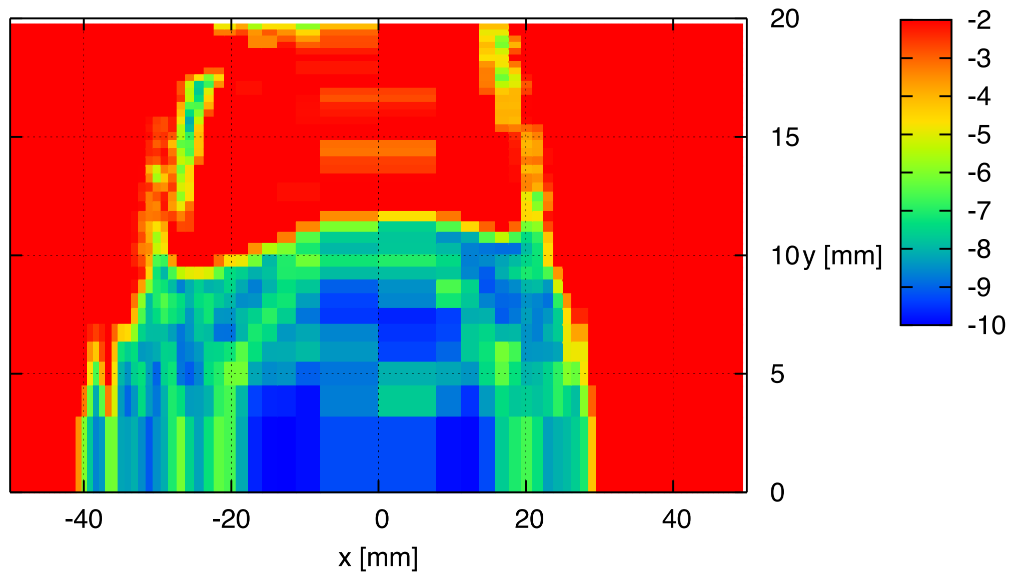

Figure 4: Diffusion map for on-momentum particles calculated in Tracy-3 for the new m5-20120904-531 optics of the MAX IV 1.5 GeV storage ring. The data confirms the island above the continuous DA.

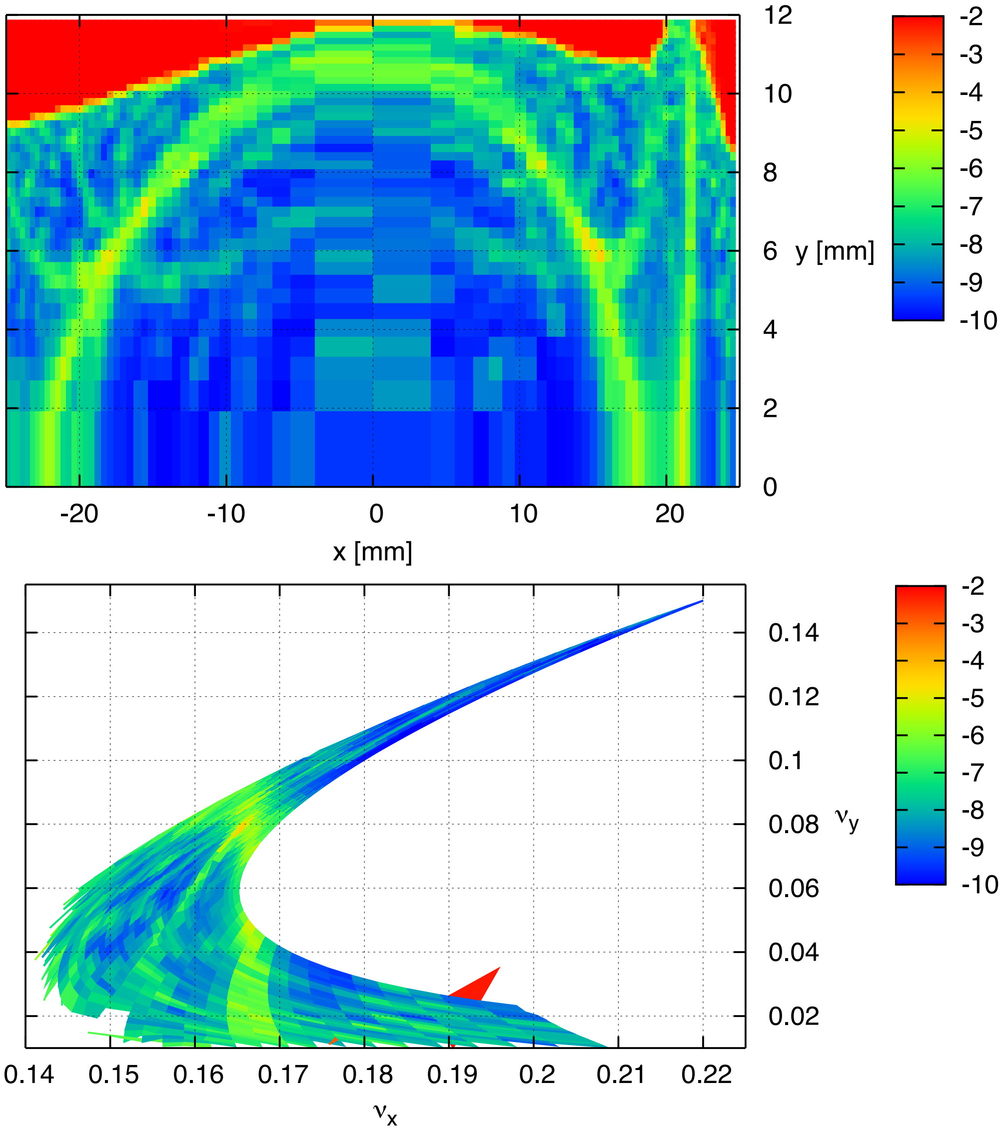

Figure 5: Frequency map analysis with Tracy-3 for the new m5-20120904-531 optics of the MAX IV 1.5 GeV storage ring. Top: Diffusion map for on-momentum particles. Bottom: Frequency map corresponding to data points plotted in top plot.

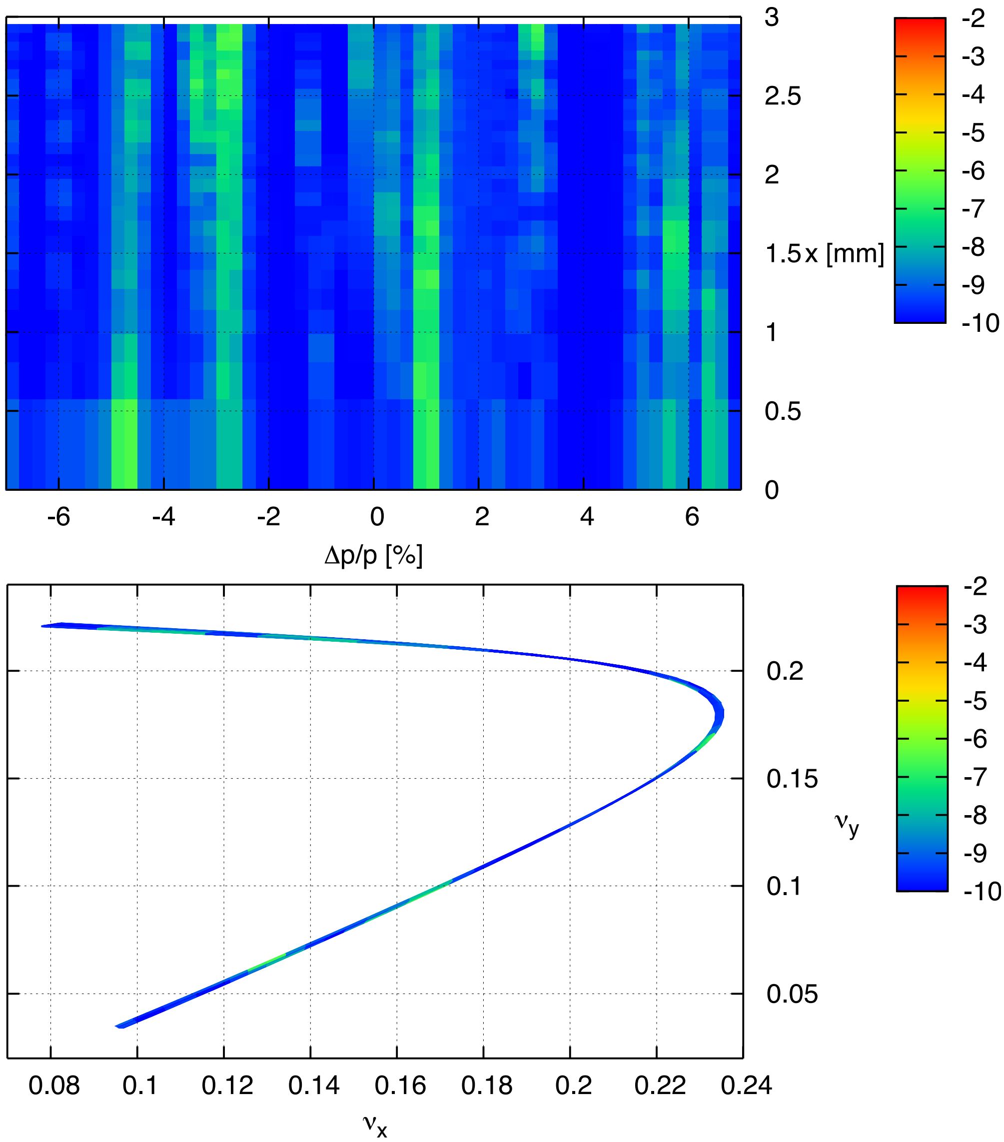

Figure 6: Frequency map analysis with Tracy-3 for the new m5-20120904-531 optics of the MAX IV 1.5 GeV storage ring. Top: Diffusion map for on-momentum particles. Bottom: Frequency map corresponding to data points plotted in top plot (upper lobe corresponds to positive momentum offsets).

In the MAX IV 1.5 GeV storage ring the chromaticity correction and nonlinear optics are achieved by the built-in sextupole components in the SQFi/o magnets as well as the dedicated SDi/o. An alternative nonlinear optics setting attempts to correct the linear chromaticity to +1.0 in both planes. This is achieved by powering the correction sextupoles SCi and changing the current setting on the SDi. In addition, the correction sextupole SCo are varied as well to improve the nonlinear dynamics (a change of SDo is not required). The resulting optics is referred to as m5-20120904-533.

Table 2: List of sextupole gradient changes by magnet family required to correct the linear chromaticity to $+1.0$ in both planes.

Magnet family	Sextupole gradient change	Rel. difference
SDi	$b_3 = -74.057985\,\mathrm{m}^{-3} \longrightarrow -68.321490\,\mathrm{m}^{-3}$	-7.8%
SDo	$b_3 = -101.920\,\mathrm{m}^{-3} \longrightarrow -101.920\,\mathrm{m}^{-3}$	0.0%
SCi	$b_3 = 0.000\,\mathrm{m}^{-3} \longrightarrow -6.716391\,\mathrm{m}^{-3}$	n/a
SCo	$b_3 = 0.000\,\mathrm{m}^{-3} \longrightarrow -3.200\,\mathrm{m}^{-3}$	n/a

The tune footprint and dynamic aperture (DA) for the m5-20120904-533 lattice are displayed in Figs. 7 and 8. The island structure above the continuous DA is again missed by the DA routine but clearly revealed in the diffusion map (cf. Fig. 9). Compared to the 531 nonlinear optics, the 533 nonlinear optics show a much more compressed tune footprint both for large amplitudes and momentum offsets. Since the chromatic tune shifts are wrapped up more tightly in the 533 nonlinear optics, the distance to the linear coupling resonance for large positive momentum deviations is increased. This is reflected by the DA: while the on-momentum DA is comparable, the DA at $\delta = \pm 4.0\%$ for 533 is increased so it almost matches the on-momentum DA.

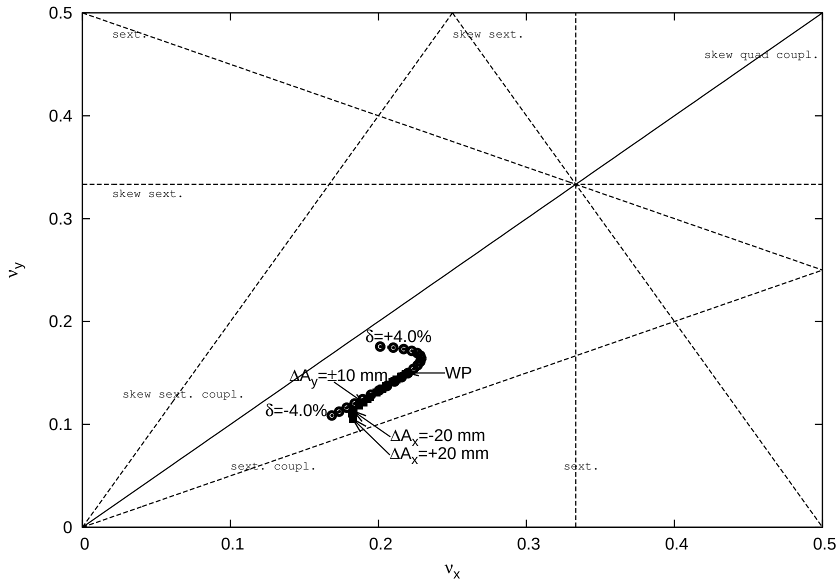

Figure 7: The tune footprint of the new m5-20120904-533 optics of the MAX IV 1.5 GeV storage ring.

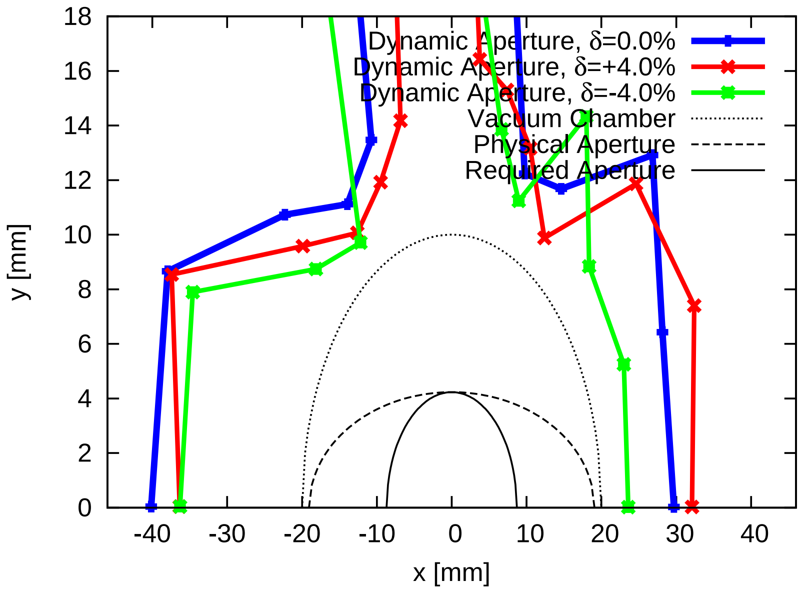

Figure 8: Dynamic aperture calculated with Tracy-3 in 6D for the new m5-20120904-533 optics of the MAX IV 1.5 GeV storage ring.

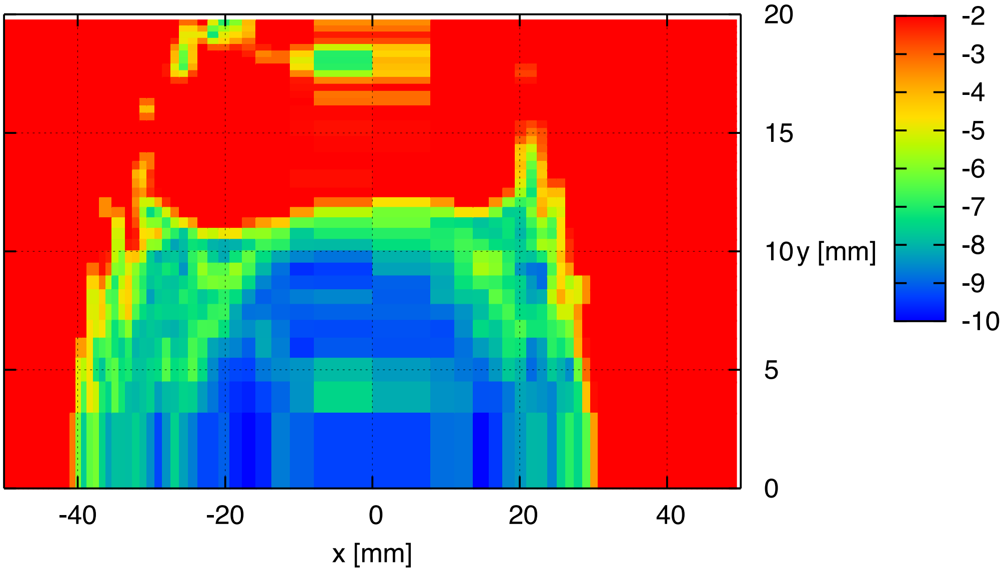

Figure 9: Diffusion map for on-momentum particles calculated in Tracy-3 for the new m5-20120904-533 optics of the MAX IV 1.5 GeV storage ring. The data confirms the island above the continuous DA.

Frequency map analysis has also been performed for the new m5-20120904-533 optics. Figs. 10 and 11 show tune diffusion for on and off-momentum particles. The on-momentum diffusion map (DM) was again limited so as to exclude the island above the continuous DA. The on-momentum FMA reveals again that the area required for injection and lifetime show very low diffusion. The increased diffusion observed in the semicircular strip around $(+22/-28, 0) \times (0, 11)$ is caused by $\nu_x - 2\nu_y = 5$. The area of elevated diffusion just beyond this strip is caused by $6\nu_x = 67$ which can be clearly recognized in the FM. Slightly elevated diffusion occurs in the vicinity of $(0, 4)$. This is caused by crossing $4\nu_x + \nu_y = 48$.

The off-momentum DM reveals increased diffusion around $\delta = -5.25\%$ caused by crossing $6\nu_x = 67$. Slightly elevated diffusion occurs in the vicinity of $\delta = -0.75\%$. This is caused by crossing $4\nu_x + \nu_y = 48$ and/or $2\nu_x + 4\nu_y = 35$. Increased levels of diffusion encountered around $\delta = 2.5\%$ are the result of crossing $6\nu_y = 19$. The coupling resonance $\nu_x - \nu_y = 8$ is crossed just slightly above $\delta = 4.5\%$, but this is not resolved by the DM presented here. The crossing of $6\nu_x = 67$ then causes elevated diffusion around $\delta = 5\%$ as does crossing $2\nu_x + 4\nu_y = 35$ around $\delta = 6\%$.

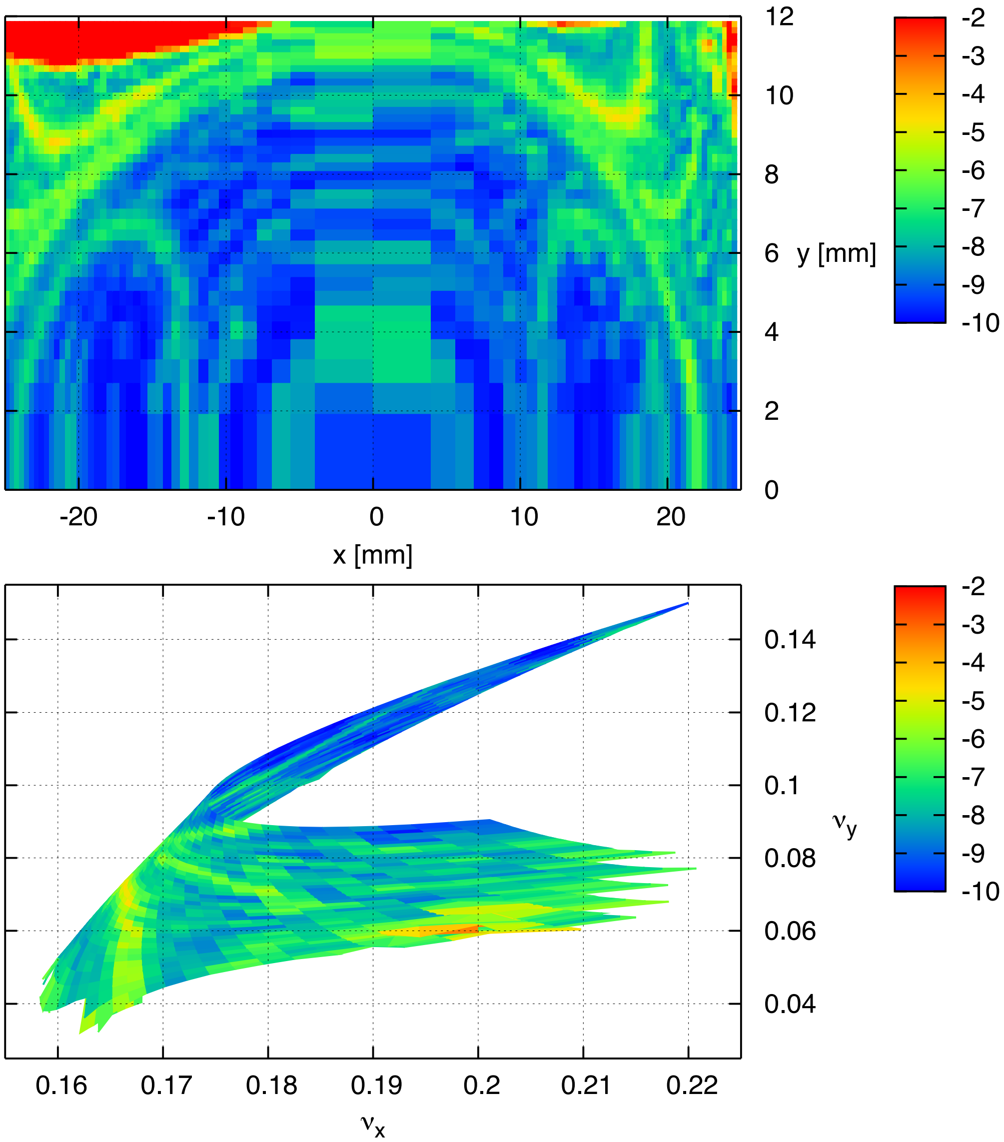

Figure 10: Frequency map analysis with Tracy-3 for the new m5-20120904-533 optics of the MAX IV 1.5 GeV storage ring. Top: Diffusion map for on-momentum particles. Bottom: Frequency map corresponding to data points plotted in top plot.

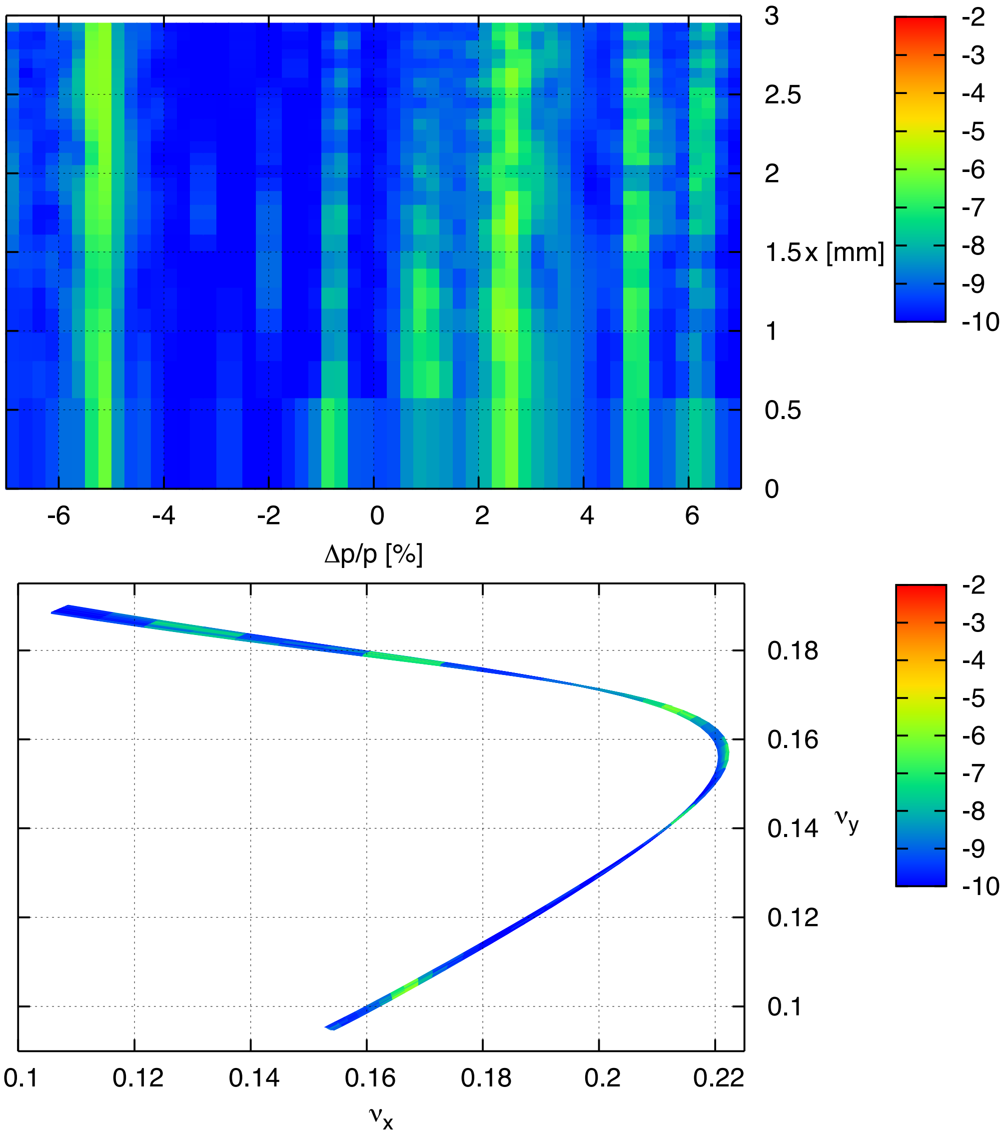

Figure 11: Frequency map analysis with Tracy-3 for the new m5-20120904-533 optics of the MAX IV 1.5 GeV storage ring. Top: Diffusion map for on-momentum particles. Bottom: Frequency map corresponding to data points plotted in top plot (upper lobe corresponds to positive momentum offsets).

4 Expected Performance of the New Lattice

Work in progress...

5 Current Lattice Files

Table 3 lists all current lattice files [2] and what type of elements are included. The lattice files are human-readable and in Tracy-3 format. All lattice files contain BPM's and correctors (SOFB). Girder markers are also included.

Table 3: List of all current lattice files.

File name	Lattice contains
m5-20120904-531-bare.lat	Bare lattice, injection elements included, chromaticity corrected to +2.0 in iron
m5-20120904-533-bare.lat	Bare lattice, injection elements included, chromaticity corrected to +1.0 with SCi/o

References

[1] M. Johansson, draft of an updated DDR Chapter 3.5, unpublished, updated July 27, 2012.

[2] The updated lattice files can be found at `http://www.maxlab.lu.se/node/999`

[3] The MAX IV Detailed Design Report, available at `http://www.maxlab.lu.se/node/1136`