Pushing the MAX IV 3 GeV Storage Ring Brightness and Coherence Towards the Limit of its Magnetic Lattice

Simon C. Leemann†, MAX IV Laboratory, Lund University, SE-22100 Lund, SWEDEN
Ward A. Wurtz, Canadian Light Source, Saskatoon, SK, S7N 2V3, CANADA

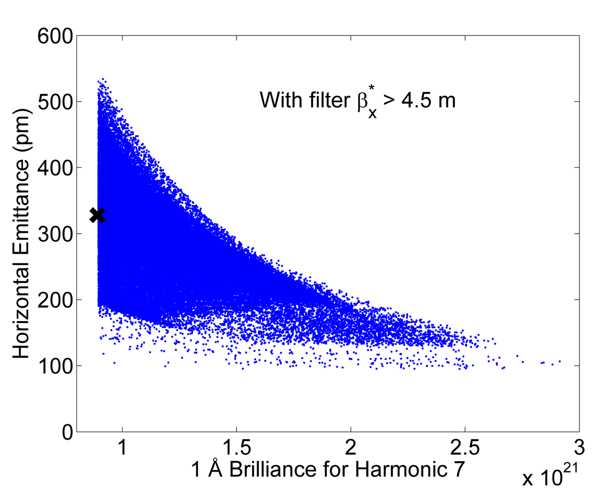
MAX IV LABORATORY — LUND UNIVERSITY — Canadian Light Source / Centre canadien de rayonnement synchrotron

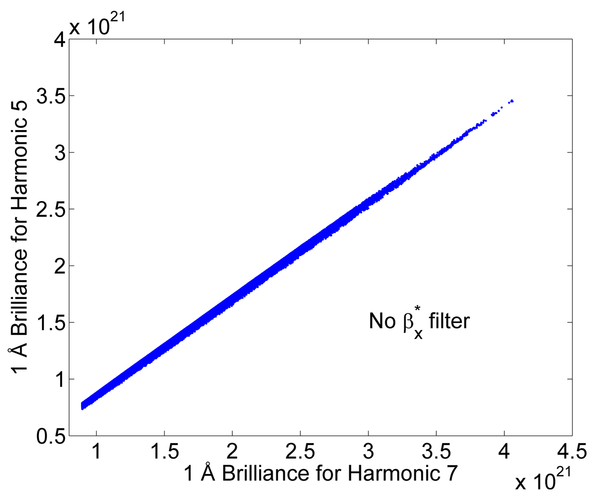
In a Nutshell

- MAX IV 3 GeV storage ring is *the first MBA-based light source to go into operation*; with IDs it is expected to reach ~190 pm rad at 500 mA in top-off.
- Accelerator development program for the next decade foresees an increase of brightness and coherence substantially beyond baseline performance.
- So far, designs for such improvements have been pursued by optimizing the coupling and beta function matching to IDs as well as by an emittance reduction from harder focusing optics in the arcs.
- Now, we further increase the focusing in the arcs and allow some dispersion to leak into the straights in order to arrive at a minimum lattice emittance still compatible with *off-axis injection.*
- This optics assumes power supplies can be exchanged and boundary constraints defined only by electrical/thermal limits of the iron magnets and their coils.
- Using *GLASS* we have targeted an optics for maximum brightness for *a typical MAX IV undulator at 1 Å* while requiring $\beta_x^* > 4.5$ m to remain compatible with off-axis injection and peak $\beta_y < 50$ m in order to keep natural chromaticities in check.
- A solution has emerged with 211 pm rad bare lattice emittance (-36%) which will ultimately *increase the brightness at 1 Å about 3-fold compared to the baseline design*.

Brightness & Emittance

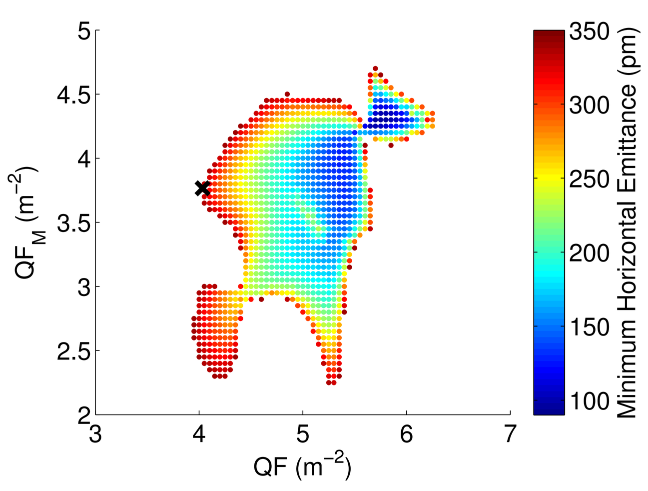
- GLASS solutions confirm that minimizing bare lattice emittance is necessary but not sufficient for maximizing brightness (black cross indicates baseline design optics).
- Optimize for 1 Å brightness from a typical MAX IV undulator with 18.5 mm period, 3.8 m length, and $0.4 < K < 1.92$.
- GLASS solutions confirm that optimizing for 1 Å brightness at 7th harmonic is equivalent to optimizing at 5th harmonic.

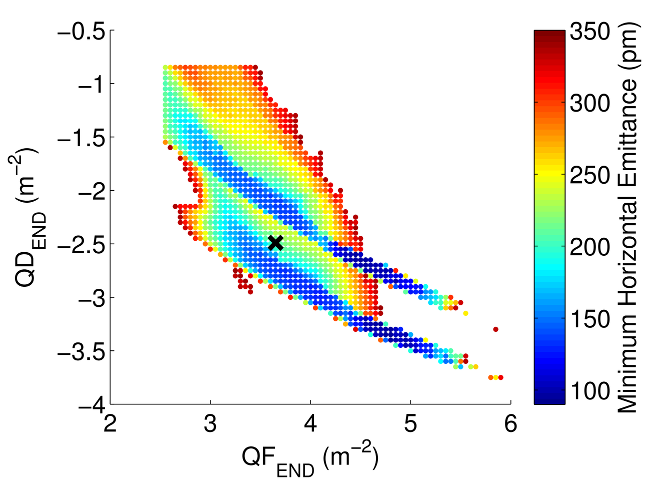




GLASS Solution Space

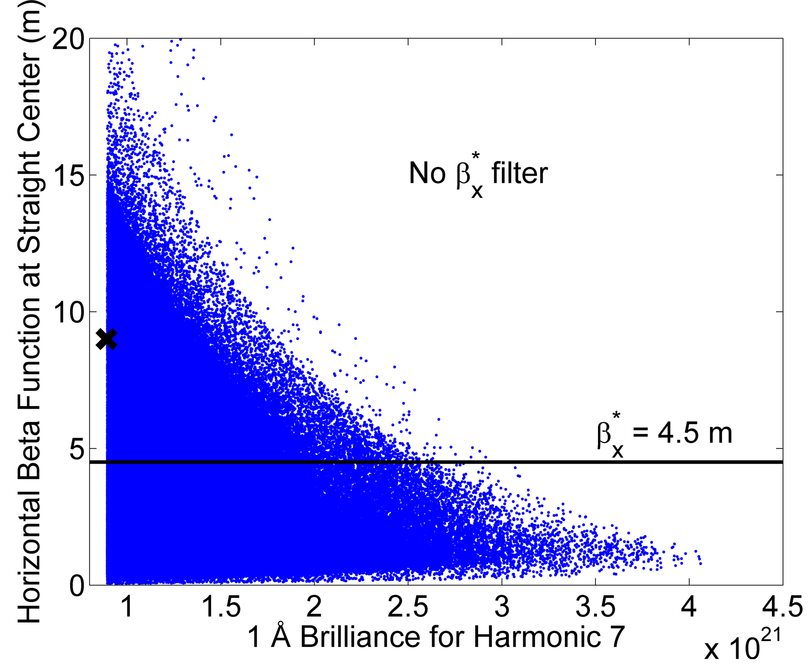
- GLASS solutions for the 4 families of dedicated quadrupoles showing resulting emittance with cuts for $\varepsilon_x < 340$ pm rad and $\beta_x^* > 4.5$ m (black cross indicates baseline design optics).

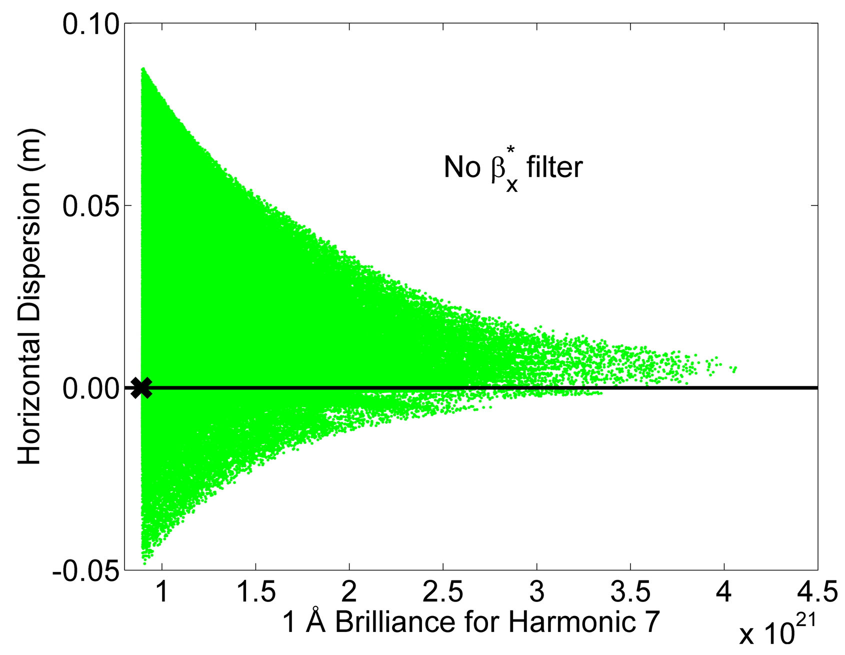




Survey: Straight Section β & η vs. Brightness

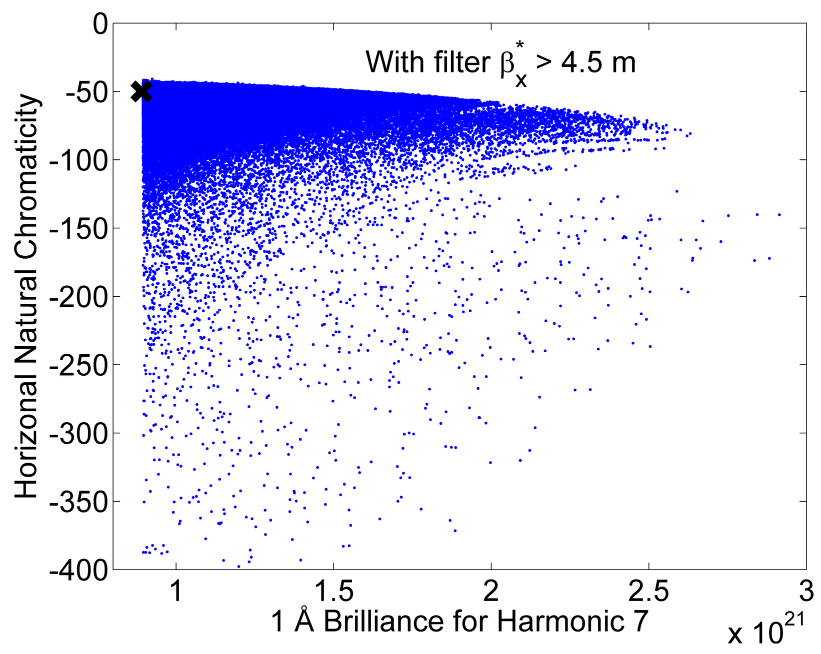
- Maximum brightness (→ ~100 pm rad) would require switching to on-axis injection ($\beta_x^* < 4.5$ m).
- Leaking a bit of dispersion into straights ($\eta_x^* \approx 10$ mm → 3% of σ_x^*) maximizes overall brightness.

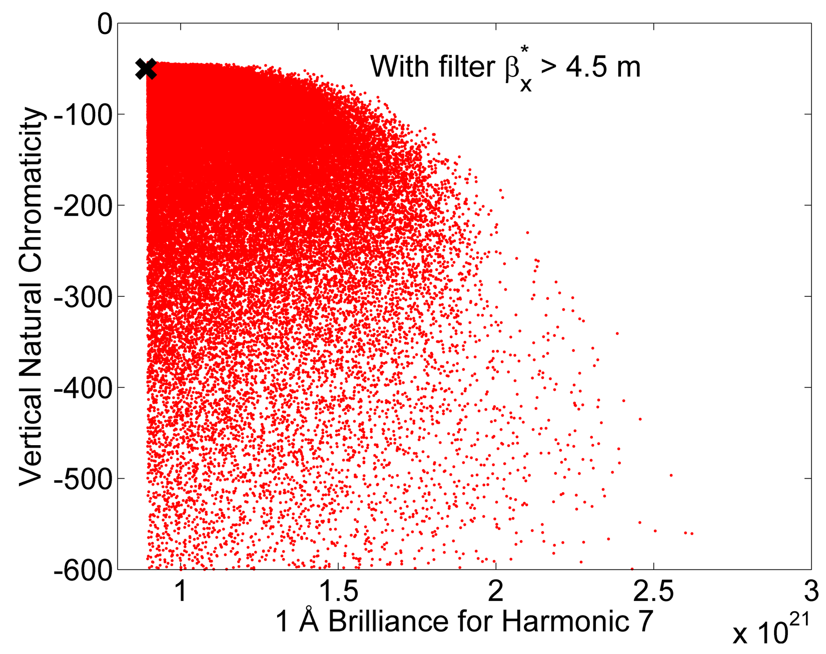




Survey: Natural Chromaticity vs. Brightness

- Most high-brightness GLASS solutions call for large peak β_y → excessive natural chromaticity.
- Solutions exist, however, with moderate natural chromaticity that still double the brightness.

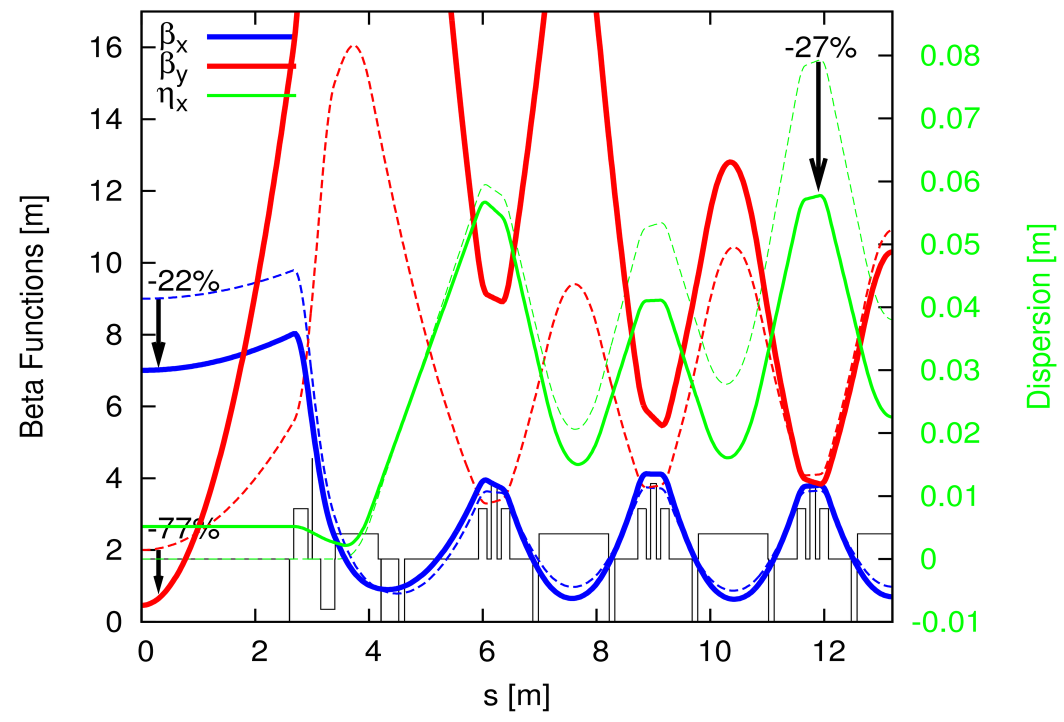




Resulting Upgrade Optics & Lattice

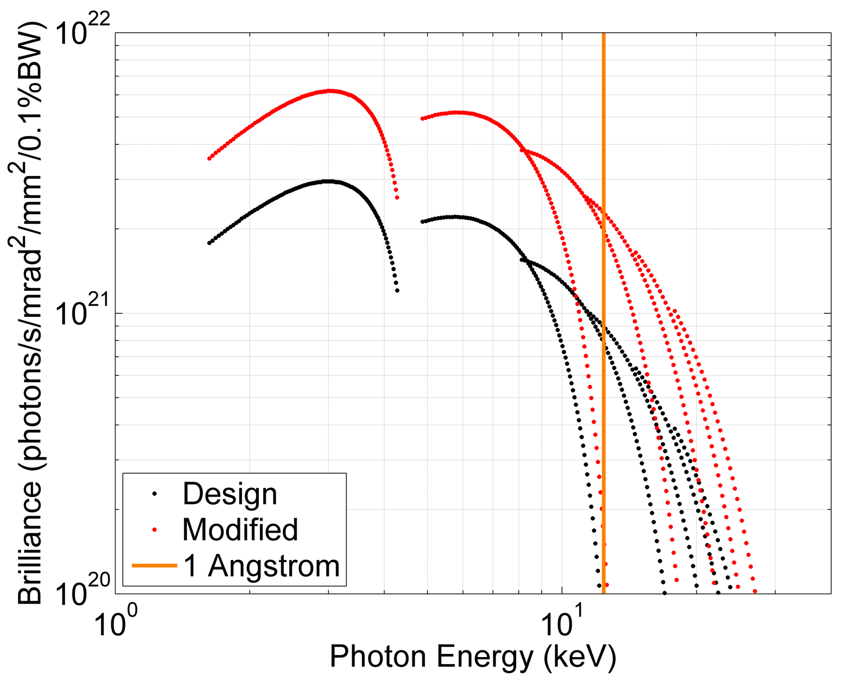
- All gradients within thermal limits of coils & magnet iron; octupoles offer ample headroom.
- New power supplies will definitely be required; recabling will not be necessary.
- Nonlinear optics supply sufficient MA, but DA presently still somewhat limited when incl. errors.

	Required Norm. Gradient		
Family	Design	Upgrade	Rel. Change
DIP	$-0.865\,\mathrm{m}^{-2}$	$-0.882\,\mathrm{m}^{-2}$	+2.0%
DIPm	$-0.871\,\mathrm{m}^{-2}$	$-0.888\,\mathrm{m}^{-2}$	+2.0%
QF	$4.033\,\mathrm{m}^{-2}$	$4.634\,\mathrm{m}^{-2}$	+14.9%
QFm	$3.766\,\mathrm{m}^{-2}$	$3.935\,\mathrm{m}^{-2}$	+4.5%
QFend	$3.651\,\mathrm{m}^{-2}$	$3.798\,\mathrm{m}^{-2}$	+4.0%
QDend	$-2.491\,\mathrm{m}^{-2}$	$-2.709\,\mathrm{m}^{-2}$	+8.8%
SFi	$208.7\,\mathrm{m}^{-3}$	$333.0\,\mathrm{m}^{-3}$	+59.6%
SFo	$174.0\,\mathrm{m}^{-3}$	$171.0\,\mathrm{m}^{-3}$	−1.7%
SFm	$170.0\,\mathrm{m}^{-3}$	$177.0\,\mathrm{m}^{-3}$	+4.1%
SD	$-117.0\,\mathrm{m}^{-3}$	$-163.8\,\mathrm{m}^{-3}$	+40.0%
SDend	$-170.0\,\mathrm{m}^{-3}$	$-194.0\,\mathrm{m}^{-3}$	+14.1%
OXX	$-1681\,\mathrm{m}^{-4}$	$8900\,\mathrm{m}^{-4}$	+429.4%
OXY	$3263\,\mathrm{m}^{-4}$	$-6367\,\mathrm{m}^{-4}$	+95.1%
OYY	$-1428\,\mathrm{m}^{-4}$	$1933\,\mathrm{m}^{-4}$	+35.4%



Expected Performance of Upgrade Optics

- Limit peak $\beta_y < 50$ m, chose $\beta_x^* = 7$ to retain off-axis injection & leak $\eta_x^* = 5$ mm to max. brightness.
- Overall, results in 80% brightness increase for the bare lattice at 1 Å.
- With IDs expect a **3-fold increase of brightness compared to the baseline design at 1 Å.**



	Design	Upgrade
ε_0 (bare lattice)	328 pm rad	221 pm rad
ε_0 (fully ID-loaded)	190 pm rad	130 pm rad
ν_x, ν_y	42.20, 16.28	47.20, 15.28
ξ_x, ξ_y (natural)	−50.0, −50.2	−56.5, −127.8
J_x	1.85	1.57
σ_δ (natural)	7.69×10^{-4}	7.01×10^{-4}
α_c (linear)	3.06×10^{-4}	2.05×10^{-4}

MAX IV Facility → http://www.maxiv.lu.se/

WEPAB002, IPAC'17, Copenhagen, DENMARK, May 14–19, 2017

†) New address: Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA, SCLeemann@lbl.gov