Progress on a Novel 7BA Lattice for a 196-m Circumference Diffraction-Limited Soft X-Ray Storage Ring*

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Introduction

- ALS-U needs to increase brightness over ALS by ×100 at 1 keV
- At 2 GeV & 500 mA this calls for $\varepsilon_x = \varepsilon_y < 75$ pm rad (round beam, fully coupled) ➞ corresponding to $\varepsilon_0 \approx 90$ pm rad (bare lattice, flat beam) at zero current
- Continue previous work on 7BA lattice [IPAC'18, THPMF077] with distributed chromatic correction ➞ correct chromaticity at the source ➞ reduce chromatic beat ➞ large off-mom. DA ➞ large MA ➞ long Touschek lifetime despite low energy
- 7BA emittance further suppressed by heavy use of longitudinal gradient bends and reverse bending
- Linear optics have been tuned to achieve higher-order achromat (➞ suppress RDTs) & low beta functions in the IDs
- Nonlinear optics (10 sextupole families) has been optimized for large DA and good off-energy performance; MOGA has been used to confirm and refine solution
- The effect of IBS has been calculated for 500 mA taking into account gaps in the fill pattern and the effect of 3HCs

Lattice Design

- Preserving 196-m circumference, 12-fold periodicity, and roughly 5.3-m ID straight ➞ based alternate lattice on a 7BA (leaves space for one SF & SD in each unit cell)
- The 5° dipole of the 7BA would render larger emittance than desired ➞ employ longitudinal gradient bends (LGBs) to suppress dispersion where it creates emittance (i.e. locations of small bending radius ρ)

$$\varepsilon_0 \propto \gamma \frac{I_5}{I_2 - I_4} \propto \frac{I_5}{J_x U_0}$$

$$I_5 = \oint \frac{\mathcal{H}}{|\rho^3|} ds, \quad \mathcal{H} = \gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2$$

Suppress *H* (i.e. focus dispersion) where bending is strong

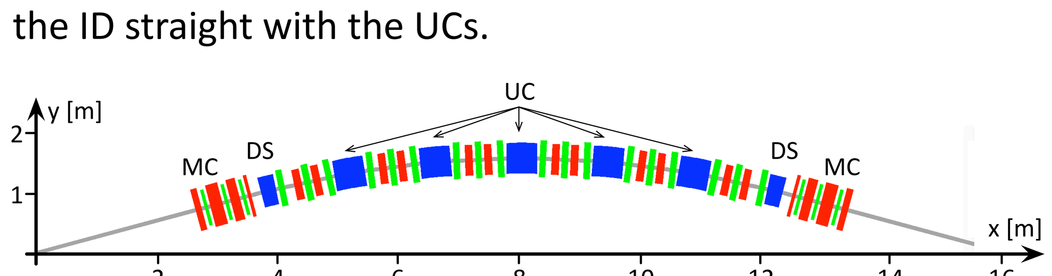
- In order to exploit the LGB, we also employ a reverse bend (RB) which allows focusing the dispersion independently of the beta function ➞ LGB is tuned for lowest emittance, while the RB (displaced QF) allows choosing a favorable cell tune & prevents the lattice from becoming quasi-isochronous

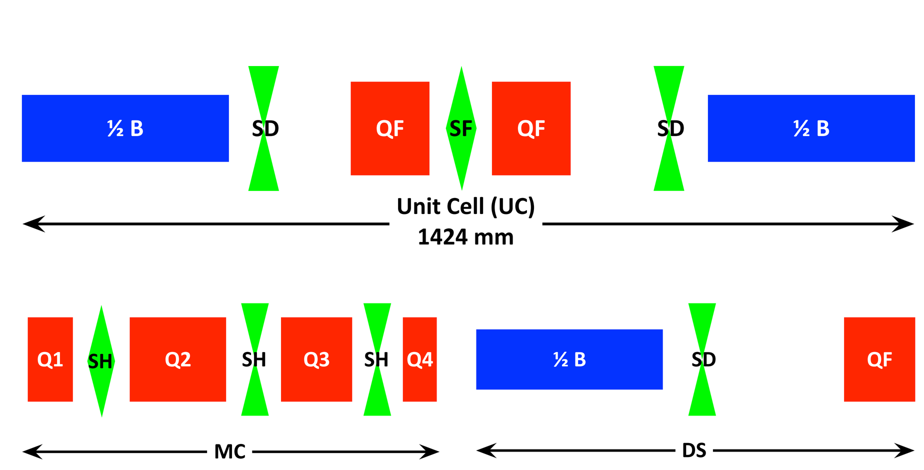
$$\alpha_c = \frac{1}{C}\left(\int_{LGB} \frac{\eta_x}{\rho} ds + \int_{RB} \frac{\eta_x}{\rho} ds\right) < 0$$

small / large / negative

RB contribution can dominate ➞ sizable (negative) momentum compaction

- We have designed a lattice with realistic magnets lengths and magnet spacing to limit cross-talk. Drift space for 120 BPMs and some vacuum equipment is provided.
- Each 7BA consists of 5 unit cells (UCs). On each side, a dispersion suppressor (DS) and matching cell (MC) connect the ID straight with the UCs.





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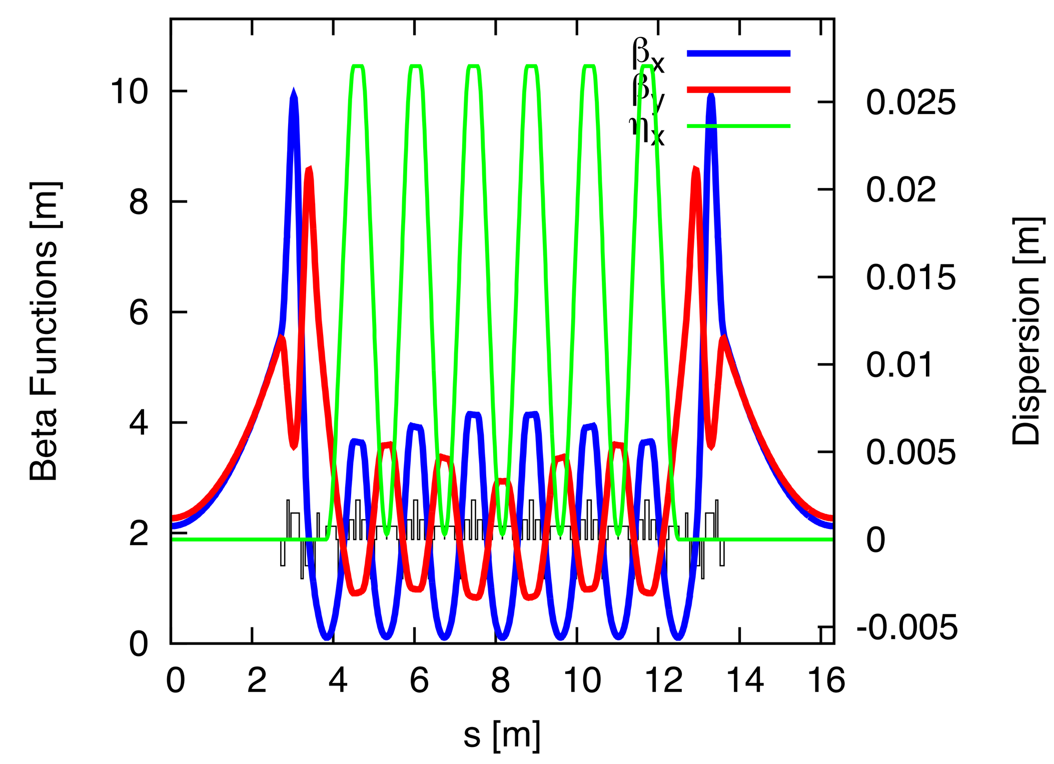
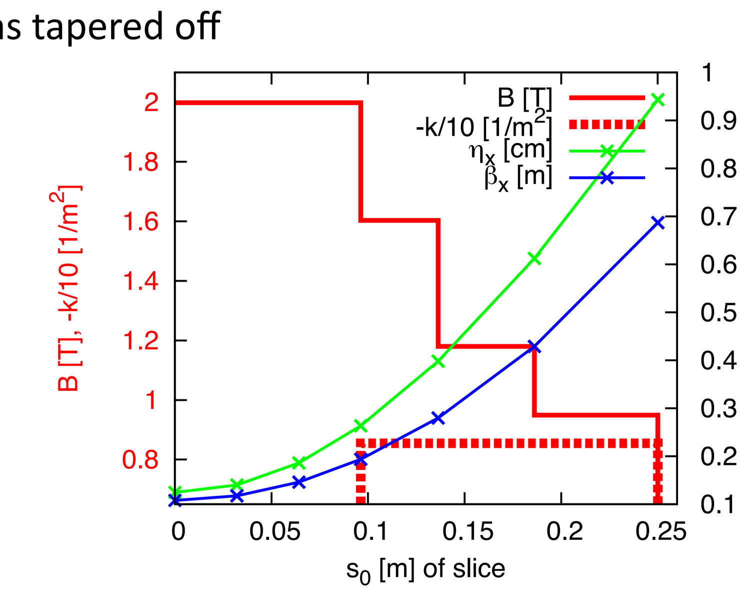


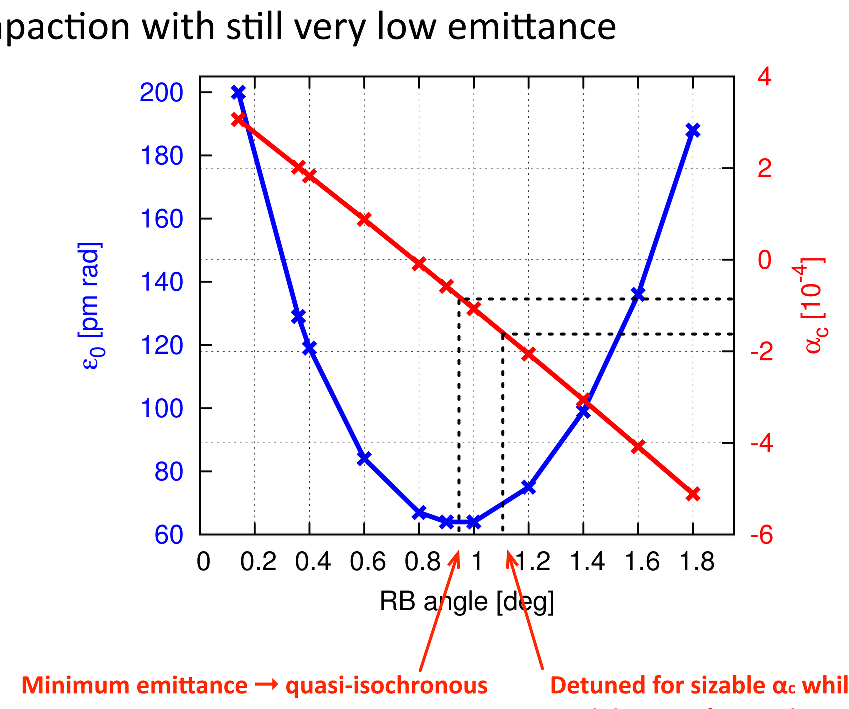
Energy	2.0 GeV
Circumference	195.942 m
$\varepsilon_0 \rightarrow \varepsilon_x = \varepsilon_y$ (round beam)	78 → 49 pm rad
$\varepsilon_x = \varepsilon_y$ (w/ IBS at 500 mA)	54 pm rad
ν_x, ν_y	40.38, 14.36
J_x	1.72
U_0 (bare lattice)	442.6 keV/turn
α_c (linear)	-1.0×10^{-4}
σ_δ (natural)	1.06×10^{-3}
$\xi_{x,y}$ (natural → corrected)	−106.4, −40.1 → −1.0
$\sigma_{x,y}$ in ID (w/ IBS at 500 mA)	11 μm

Linear Optics Tuning

- Initial 5° UC bend angle provided by LGB needs to be increased to compensate for RB
- Tune UC for ultra-low emittance and so that arc becomes higher-order achromat ➞ set UC tunes to (3/7,1/7)×2π
- Model LGB as discrete slices ➞ optimize profile for min. ε_0 while fulfilling above conditions & assuming:
  - peak bend field can be as high as 2 T
  - vertical focusing (implement as transverse gradient) can only be performed in outer LGB sections where bend field has tapered off



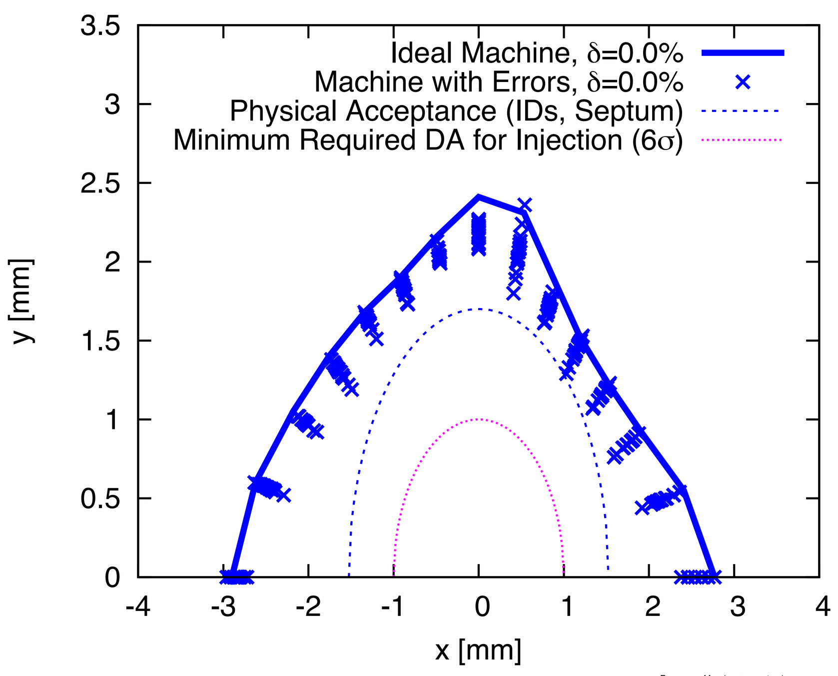
- Choosing RB angle for minimum emittance (64 pm rad achieved here for 0.95°) gives quasi-isochronous lattice
- However, because of ultra-low emittance can detune from minimum-emittance condition ➞ sizable momentum compaction with still very low emittance

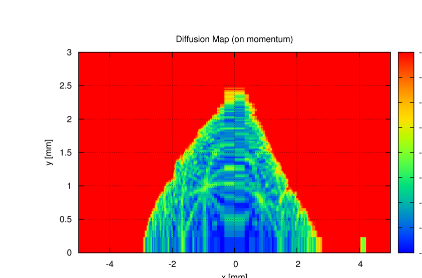


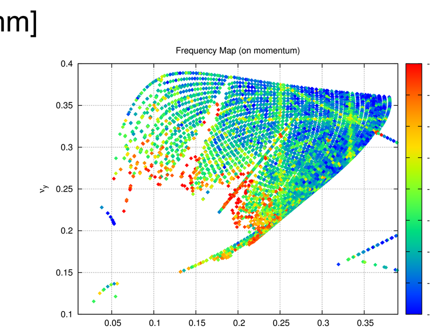
- For the UC we choose 1.16° which renders for the entire storage ring $\alpha_c = -1.0\times10^{-4}$ and ε_0 = 78 pm rad
- DS focusing tuned to cancel any dispersion into MC & straight
- MC tuned for $\beta_{x,y} \approx 2.2$ m at ID source points (good matching to photon beam from IDs) and storage ring tunes near linear coupling resonance (facilitating round beam operation)
- Max. required quadrupole gradient $b_2 < 16.1$ m^{-2} while sextupole gradient $b_3 < 1637$ m^{-3} ➞ 18 mm bore (limit pole-tip fields) ➞ allows for chamber leaving uniform ±7.5 mm aperture to beam throughout arc

Resulting Performance

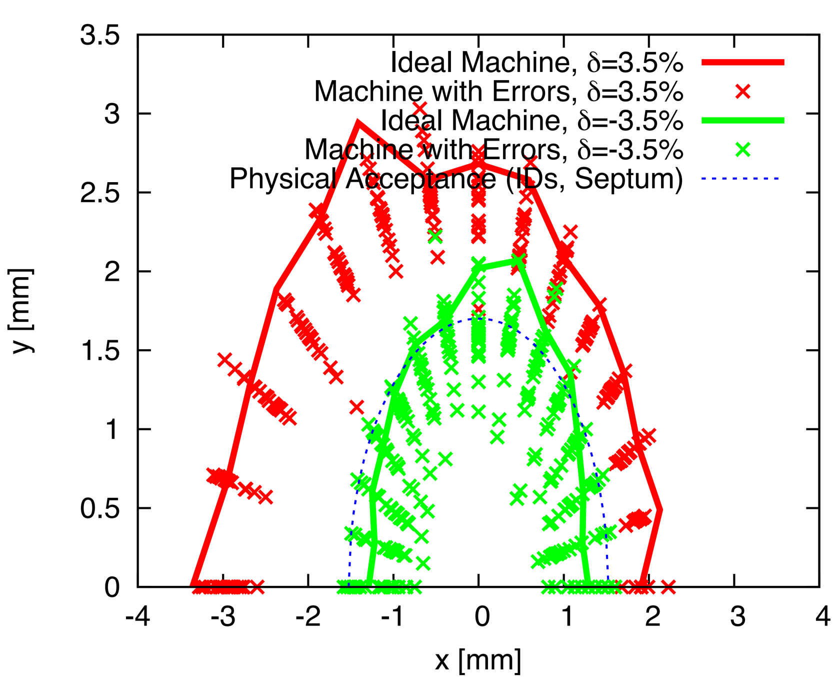
- DA including field & alignment errors shows ±2.5 mm at injection point ➞ ample reserves for on-axis inj. from AR

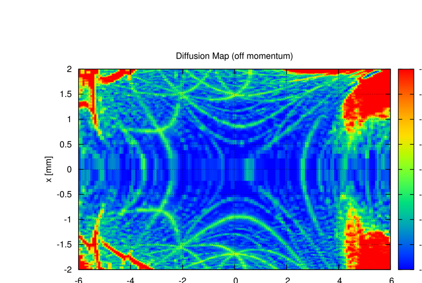


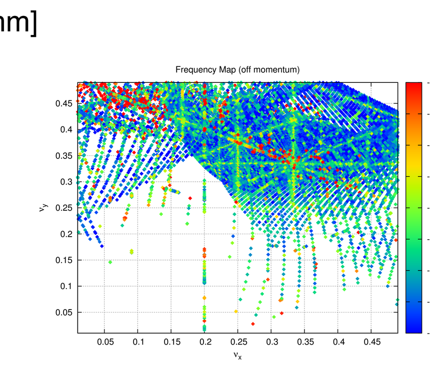


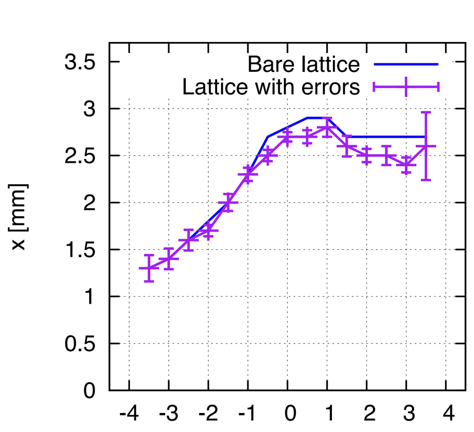


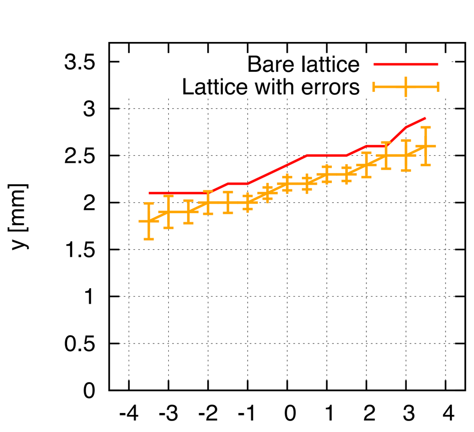
- Off-momentum DA including field & alignment errors shows sizable DA even at ±3.5% ➞ provides large LMA



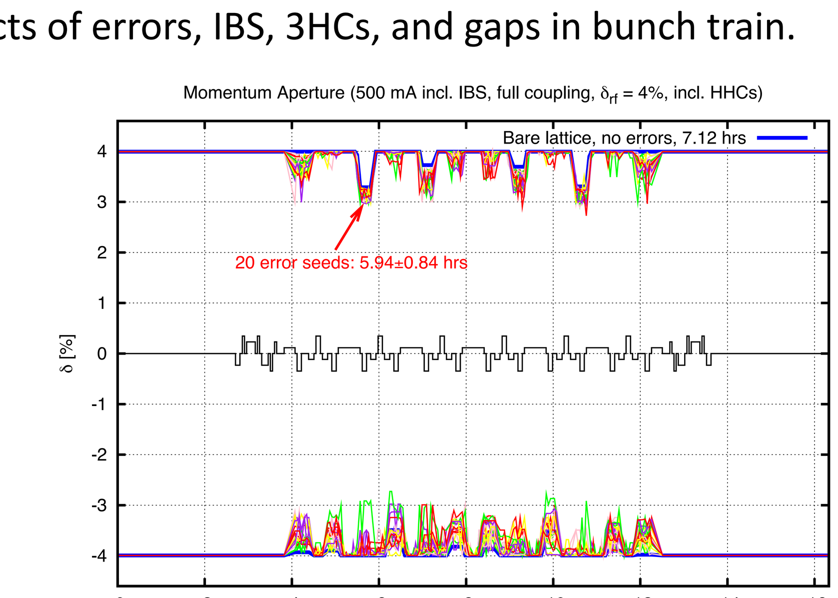








- Large off-momentum DA (including field & alignment errors) together with 4% RF acceptance provides for large LMA.
- Touschek lifetime of 6 hours calculated for 500 mA including effects of errors, IBS, 3HCs, and gaps in bunch train.



- Brightness has been calculated for a few ALS-U flagship IDs including the effect of IBS at 500 mA as well as broadening of the undulator peak from beam energy spread.
- Peak brightness at 1 keV is ≈3×10[21] ph/s/mm^2/mrad^2/0.1%BW while the coherent fraction is 24%, indicative of good matching of electron beam to photon beam.