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

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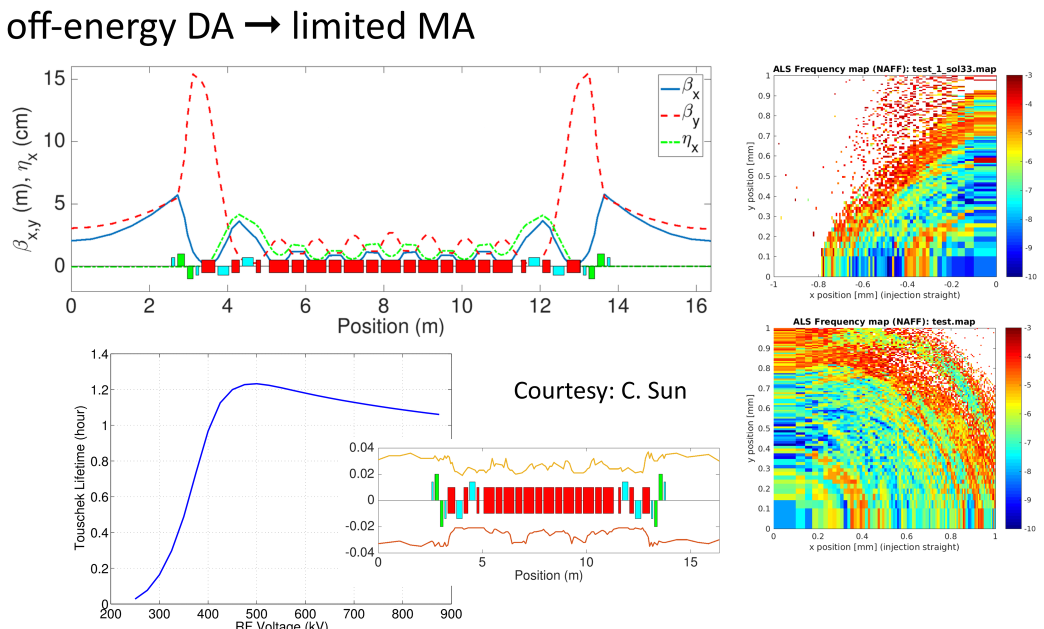
Introduction

- 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) ➞ corresponds to $\varepsilon_0 \approx 90$ pm rad (bare lattice, flat beam) at zero current
- Baseline lattice is 9BA with 2 dispersion bumps for localized chromatic corrections ➞ chromatic beta beating ➞ limited off-energy DA ➞ limited MA



- Despite heavy optimization of 9BA baseline lattice ➞ ≈1 hour Touschek lifetime incl. effects of HHCs ➞ stability? (top-off injection frequency, top-off deadband), radiation safety?
- ***New approach:*** distributed chromatic correction ➞ correct chromaticity at the source ➞ reduce chromatic beat ➞ large off-momentum DA ➞ large MA ➞ longer Touschek lifetime

Lattice Design

- Preserving 196-m circumference, 12-fold periodicity, and roughly 5.3-m ID straight ➞ base 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 the 3.33° dipole of the 9BA ➞ employ longitudinal gradient bends (LGBs) to suppress dispersion where it creates emittance (i.e. in 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

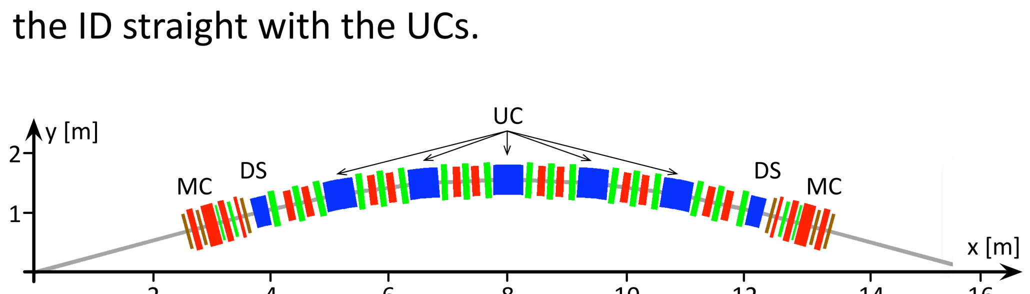
- In order to exploit the LGB, we also employ a reverse bend (RB) which allows focusing the dispersion independently of the beta function ➞ LGB is tuned for lowest emittance, while the RB (displaced QF) allows choosing a favorable cell tune & prevents the lattice from becoming quasi-isochronous

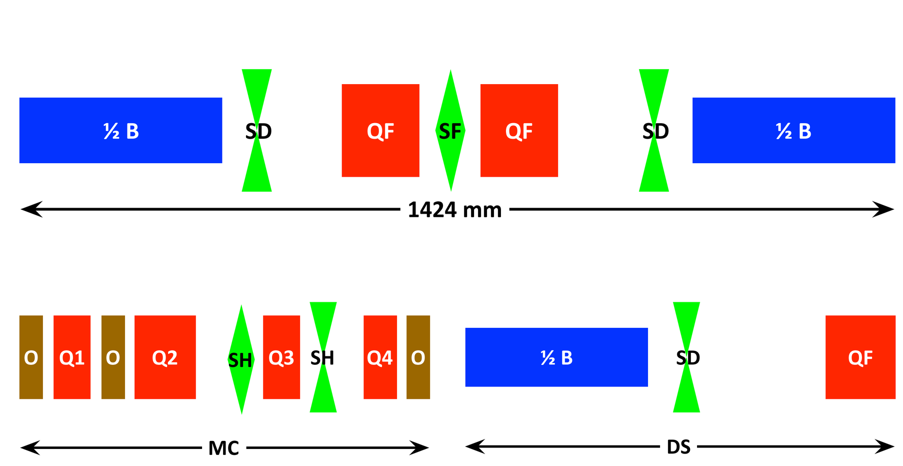
$$\alpha_c = \frac{1}{C}\left(\int_{LGB} \frac{\eta_x}{\rho} ds + \int_{RB} \frac{\eta_x}{\rho} ds\right) < 0$$

(small; large; negative)

RB contribution can dominate ➞ sizable (negative) momentum compaction

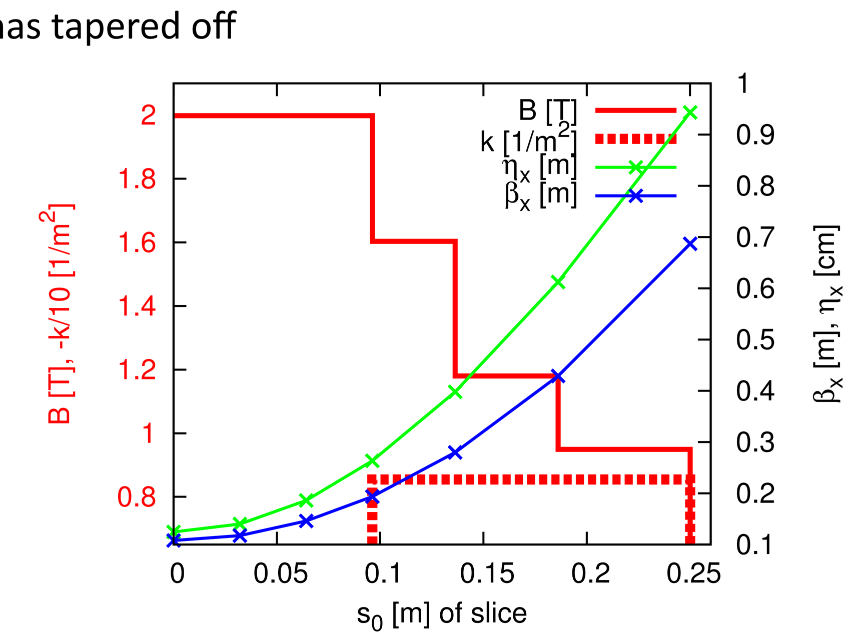
- We have designed a lattice with realistic magnets lengths and magnet spacing to limit cross-talk. Drift space for 120 BPMs and some vacuum equipment is provided.
- Each 7BA consists of 5 unit cells (UCs). On each side, a dispersion suppressor (DS) and matching cell (MC) connect the ID straight with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



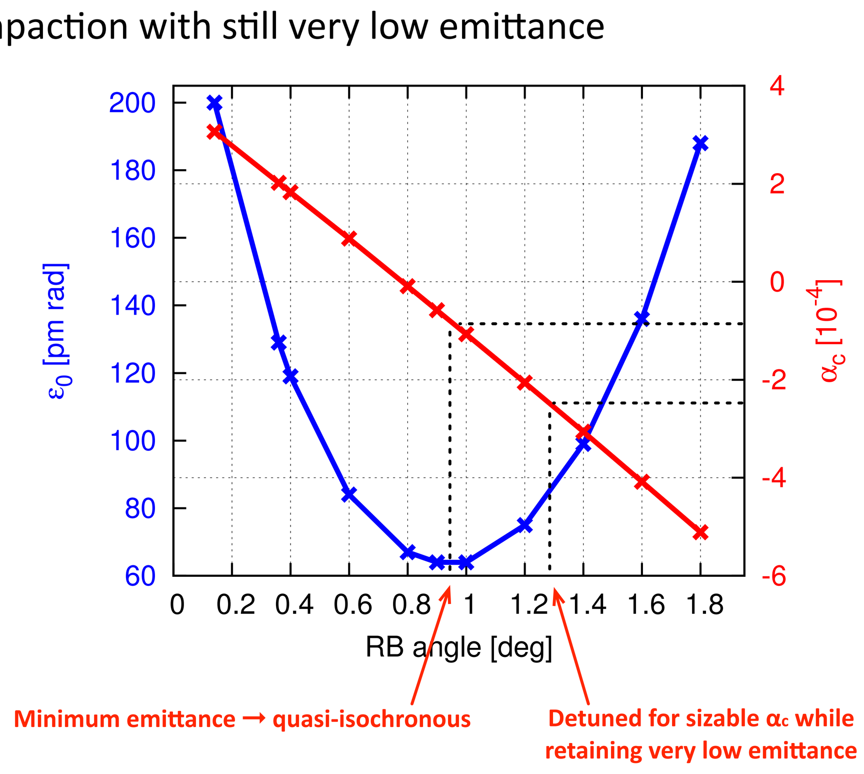


Linear Optics Tuning

- 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 1.27° which renders for the entire storage ring $\alpha_c = -1.25{\times}10^{-4}$ and $\varepsilon_0 = 89$ pm rad
- DS focusing tuned to cancel any dispersion into MC & straight
- MC tuned for $\beta_{x,y} \approx 2.5$ m at ID source points and storage ring tunes near linear coupling resonance (facilitating round beam operation)
- Max. required quadrupole gradient: <18 m^{-2} ➞ 18 mm bore

Nonlinear Optics Tuning

- 9 sextupole families (SF/SD/SH) tuned for:
  - set linear chromaticities to –1
  - cancel residual 1st-order resonance driving terms (RDTs)
  - choose suitable 2nd/3rd-order chromaticities to obtain favorable chromatic tune footprint
  - minimize 2nd-order RDTs & overall required sextupole strength
- 3 octupole families tuned to:
  - adjust 1st-order amplitude-dependent tune shifts ➞ tune footprint is minimized and kept clear of potentially dangerous resonances
- Target values achieved through weighted SVD provided by OPA, 6D tracking incl. errors provided by Tracy-3 ➞ iterate
- Max. required sext/oct gradients: <1750 m^{-3}, <19,000 m^{-4}

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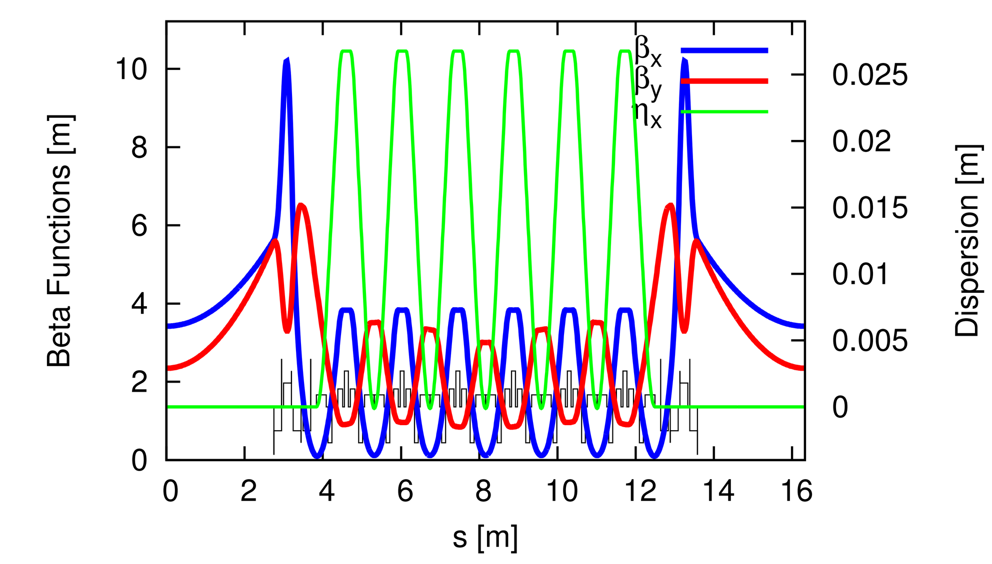
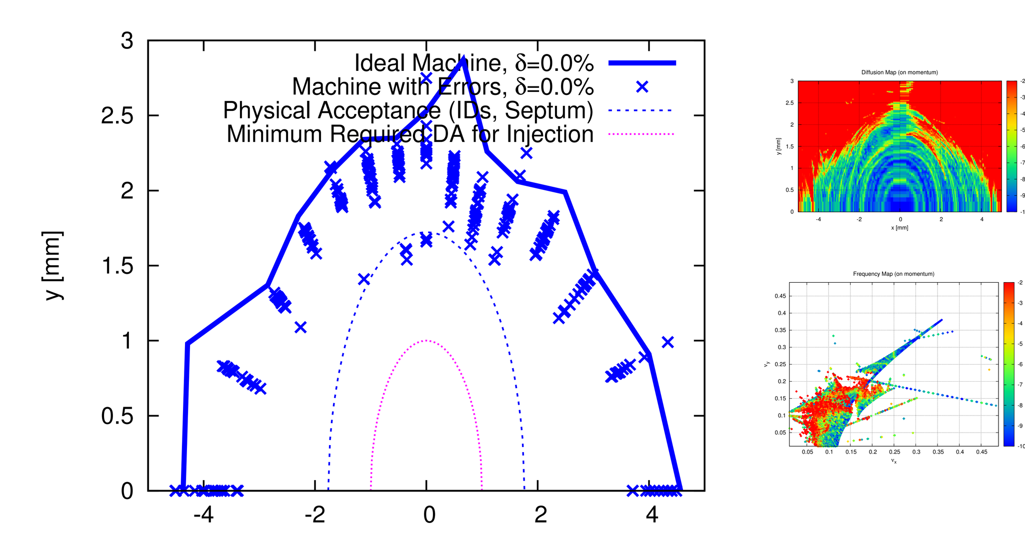
Resulting Performance

- 7BA can match 9BA baseline lattice's aggressive brightness

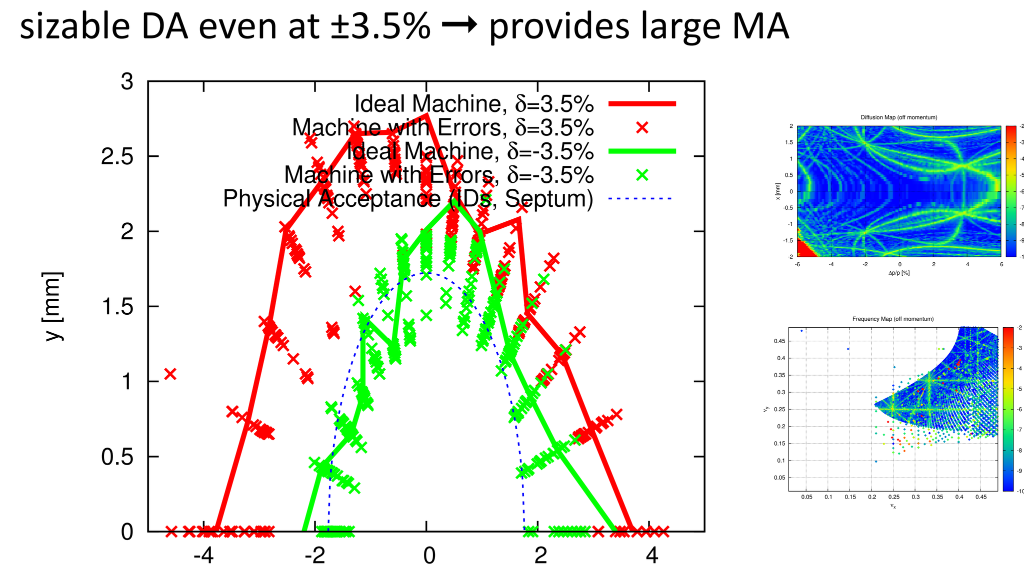
ε_0 (bare lattice)	89 pm rad
$\varepsilon_x = \varepsilon_y$ (round beam)	57 pm rad
ν_x, ν_y	39.36, 14.38
J_x	1.739
U_0 (bare lattice)	457.7 keV/turn
α_c (linear)	-1.25×10^{-4}
σ_δ (natural)	1.066×10^{-3}
$\xi_{x,y}$ (natural → corrected)	$-106.0, -35.9 \to -1.0$



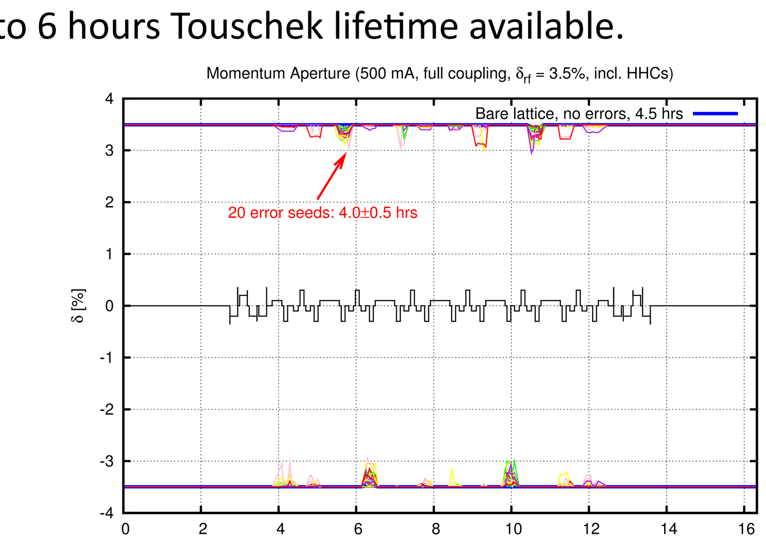
- DA incl. field & alignment errors well in excess of ±1 mm (approximately required for 100% efficiency on-axis injection)



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



- Large MA (incl. field & alignment errors) provides 4 hours Touschek lifetime at 500 mA (round beam, incl. HHCs)
- Note, LMA limited in most locations by 3.5% RF acceptance. Since ALS RF system can provide ≈4% incl. ID losses ➞ expect up to 6 hours Touschek lifetime available.



Conclusions & Outlook

- 7BA lattice matches aggressive brightness of the 9BA baseline lattice, while providing more than twice the DA & Touschek lifetime
- Next steps: iterations with magnet & vacuum engineering (refine lattice for technical feasibility), collective effects studies (stability at negative α_c), and further optimizations to increase overall brightness (lower ID $\beta_{x,y}$, lower ε_0, MOGA)

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