# Interplay of Touschek Scattering, Intrabeam Scattering, and RF Cavities in Ultralow-Emittance Storage Rings

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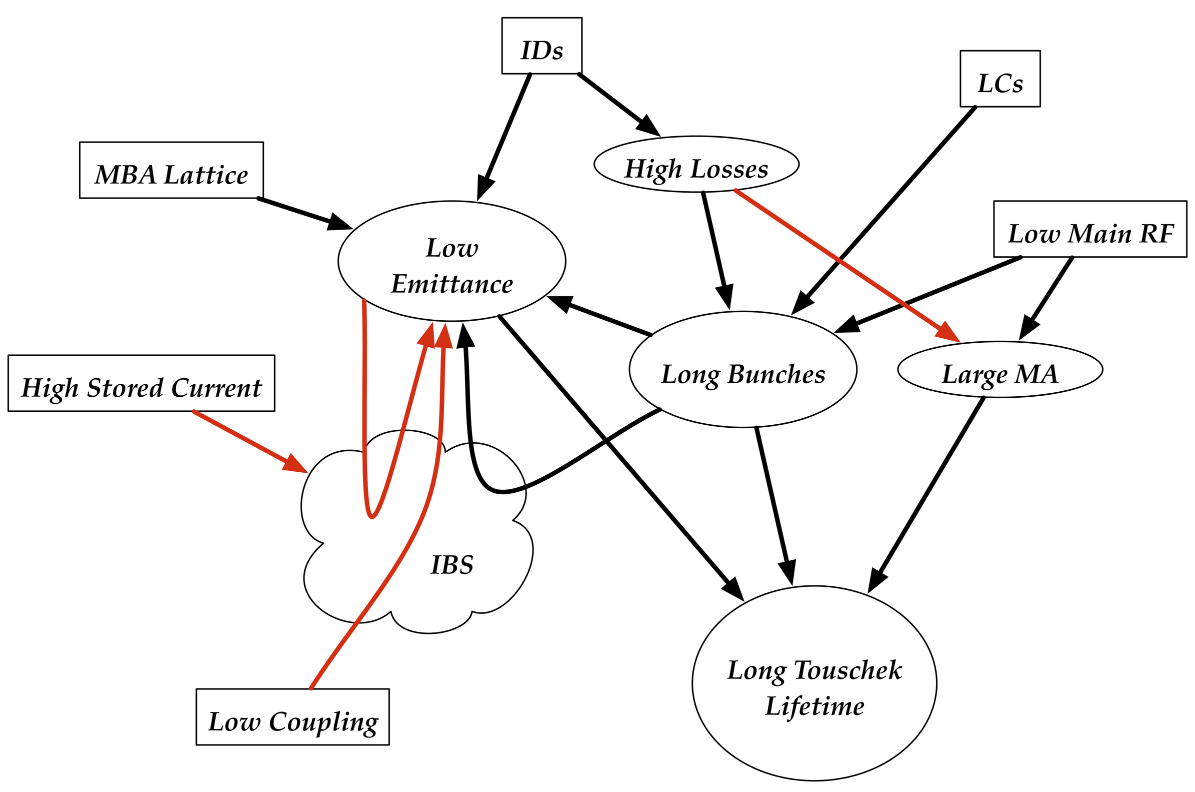
## In a Nutshell

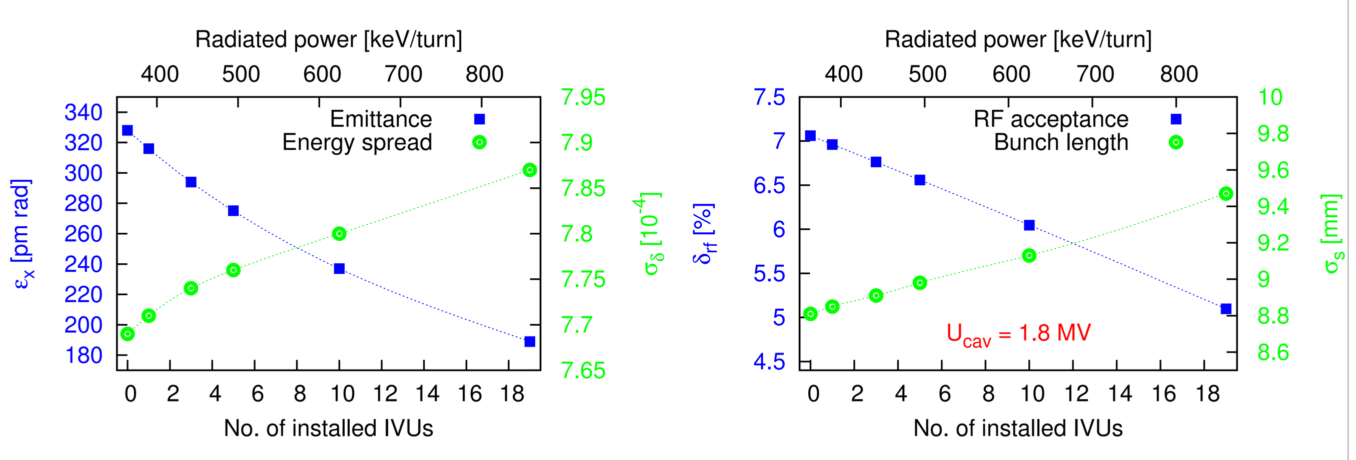
- MAX IV 3 GeV storage ring will become the first ultralow-emittance ring based on a multibend achromat lattice.
- Such storage rings have comparably low radiated losses in the dipoles compared to the IDs. Therefore, parameters such as emittance, energy spread, and radiated power are no longer lattice constants, but depend on ID types and ID gap settings.
- Combination of ultralow emittance and high bunch charge leads to strong IBS and therefore, 6D emittance becomes dependent on stored current.
- The result is an intricate interplay between transverse emittance (ID types and ID gaps, emittance coupling), longitudinal emittance (main cavity tuning, bunch lengthening from harmonic cavities), and choice of bunch charge.
- Updated equilibrium emittance needs to be calculated in a self-consistent fashion taking into account ID types, momentary gap settings, and RF cavity settings (including bunch lengthening from harmonic cavities); Touschek lifetime varies along with 6D emittance and needs to be calculated accordingly.

## Ultralow-Emittance Rings

- MBA lattices achieve very low emittance by using many weak dipoles.
- Radiated losses from dipoles are low compared to losses from DWs and/or IDs.
- As a consequence, emittance, energy spread, RF acceptance and natural bunch length depend on the the type of installed IDs and vary during user shifts depending on gap settings.

PRST-AB **17**, 050705 (2014)



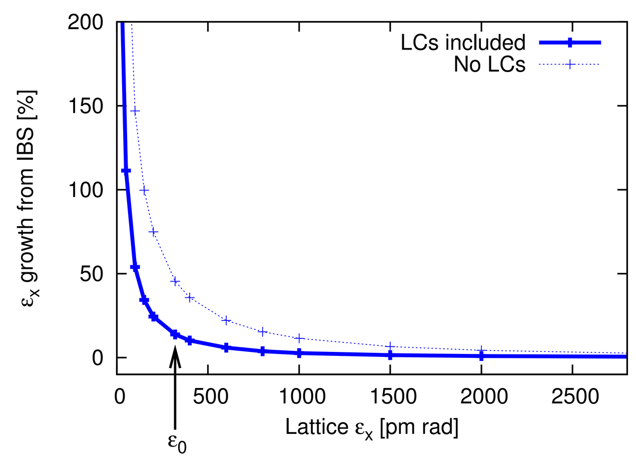




*Beam parameters of the MAX IV 3 GeV storage ring as a function of the number of installed IVUs. At fully closed gap each IVU adds 26 keV/turn to the synchrotron radiation losses. Left: zero-current emittance and natural energy spread. Right: RF acceptance and zero-current bunch length assuming 1.8 MV overall cavity voltage.*

## Emittance & Intrabeam Scattering

PRST-AB **17**, 050705 (2014)

- Combination of high bunch charge and ultralow emittance leads to very strong IBS at medium and low energies.
- Strong IBS blows up beam's 6D emittance.
- IBS also depends on bunch length and energy spread; both can vary during user operation as a consequence of gap motion.
- Resulting emittance at any time needs to be calculated in a self-consistent fashion taking into account bunch charge, ID gap settings, RF cavity settings, coupling, etc.
- Tracy-3 has been used to calculate 6D emittance as a function of IDs and RF cavity settings taking into account bunch lengthening from harmonic LCs.
- Results confirm large effect of DWs and IDs on emittance at 500 mA stored current (5 nC per bunch).
- Results also show that harmonic LCs can be used to mitigate strong emittance blow-up from IBS at 500 mA stored current.




*Horizontal emittance growth from IBS at 500 mA as a function of lattice emittance assuming the latter can be adjusted freely while keeping the energy spread constant. The overall MA has been set to 4.5% and the vertical emittance is always adjusted to 8 pm rad.*

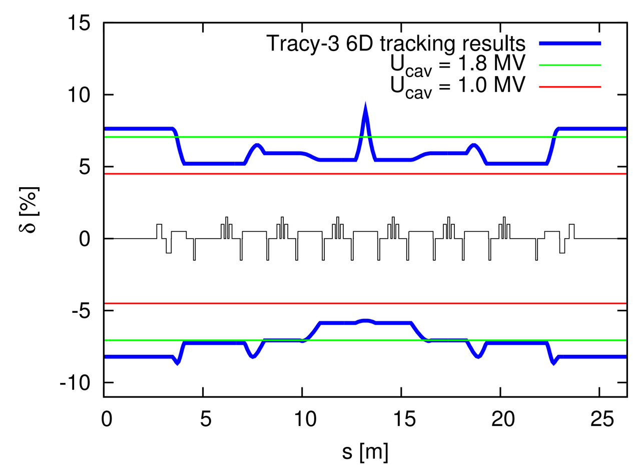
*Emittance results in [pm rad] at 500 mA.*

| | Zero-current | | IBS | IBS & LCs |
|---|---|---|---|---|
| | $\varepsilon_y$ | $\varepsilon_x$ | $\varepsilon_x$ | $\varepsilon_x$ |
| Bare | 8 | 320 | 466 | 364 |
| | 2 | 326 | 552 | 404 |
| DWs | 8 | 226 | 354 | 264 |
| | 2 | 232 | 436 | 302 |
| Loaded | 8 | 179 | 292 | 213 |
| | 2 | 185 | 365 | 247 |

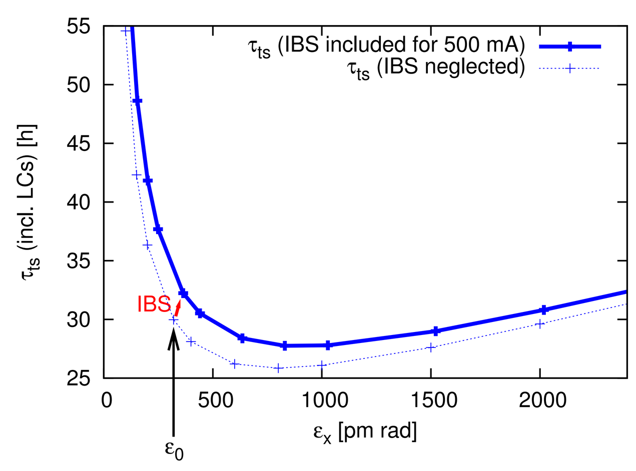
## Momentum Acceptance & Lifetime

PRST-AB **12**, 120701 (2009)

- Touschek lifetime relies strongly on 6D emittance; if the latter varies during user shifts, Touschek lifetime will change accordingly.
- In ultralow-emittance storage rings transverse momenta are small; if overall MA is large, Touschek lifetime will be high and will actually improve when the emittance is further reduced.
- DWs and IDs reduce the transverse emittance and can therefore increase Touschek lifetime.
- Harmonic LCs stretch bunches, therefore diluting charge density in the bunch and hence increase Touschek lifetime.
- Tracy-3 results confirm Touschek lifetime is increased as DWs and/or IDs are added.
- Tracy-3 results also confirm LCs can be used to achieve excellent Touschek lifetime despite ultralow emittance and small coupling.



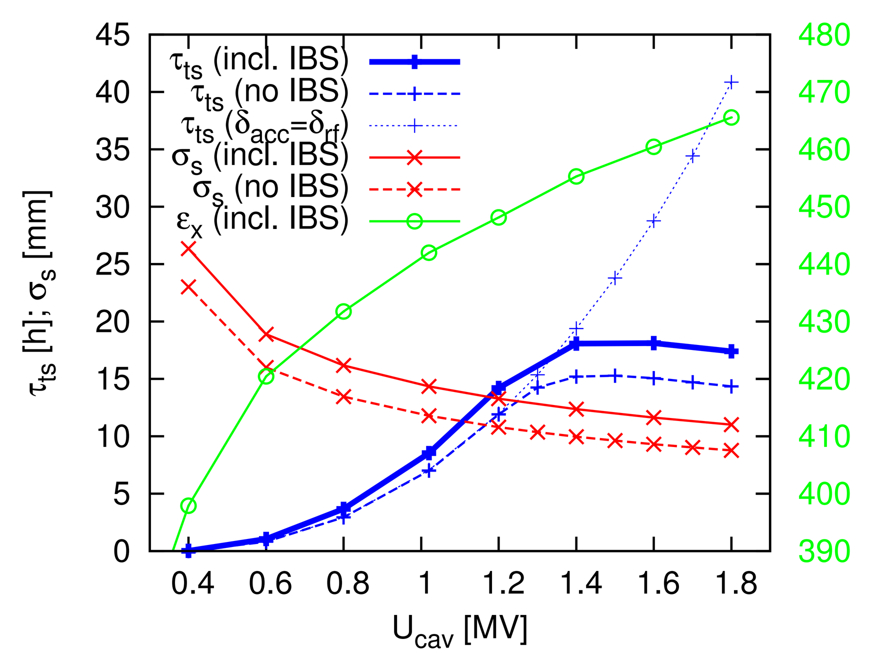

*Lattice MA for one achromat of the MAX IV 3 GeV storage ring from 6D tracking with Tracy-3 using actual vacuum chamber apertures.*



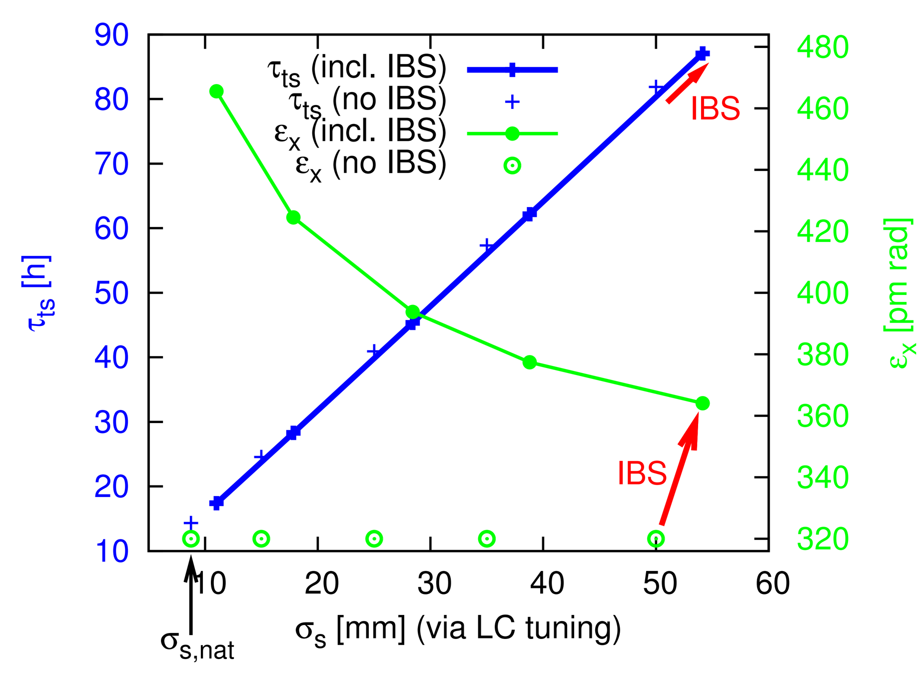

*Touschek lifetime from 6D tracking with Tracy-3 as a function of equilibrium emittance assuming the lattice emittance could be adjusted freely while keeping the energy spread constant. The overall MA has been set to 4.5% while the vertical emittance is adjusted to 8 pm rad.*

*Tracy-3 results for Touschek lifetime in hours.*

| | $\varepsilon_y$ [pm rad] | 500 mA no LCs | 500 mA incl. LCs | Incl. err. & narr. gaps |
|---|---|---|---|---|
| Bare | 8 | 17.4 | 87.1 | 64.3 |
| | 2 | 9.6 | 45.9 | 40.7 |
| DWs | 8 | 20.5 | 114.3 | 66.2 |
| | 2 | 10.4 | 56.1 | 48.7 |
| Loaded | 8 | 11.7 | 65.0 | 37.7 |
| | 2 | 5.8 | 31.4 | 27.3 |




*Touschek lifetime, bunch length, and horizontal emittance in the MAX IV 3 GeV storage ring bare lattice as functions of the RF cavity voltage. Stored current set to 500 mA, vertical emittance adjusted to 8 pm rad.*




*Touschek lifetime and horizontal emittance as functions of bunch length. Stored current set to 500 mA, vertical emittance adjusted to 8 pm rad. The calculated Touschek lifetime is based on resulting overall MA from tracking and actual vacuum apertures.*

**MAX IV Project → http://www.maxlab.lu.se/maxiv**

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