Tune survey with lattice and beamstrahlung + dynamic β

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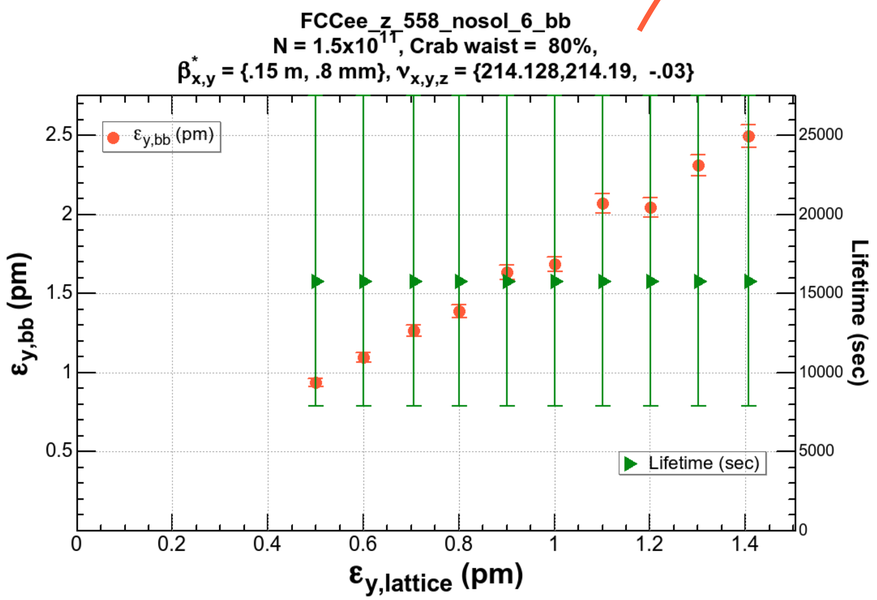
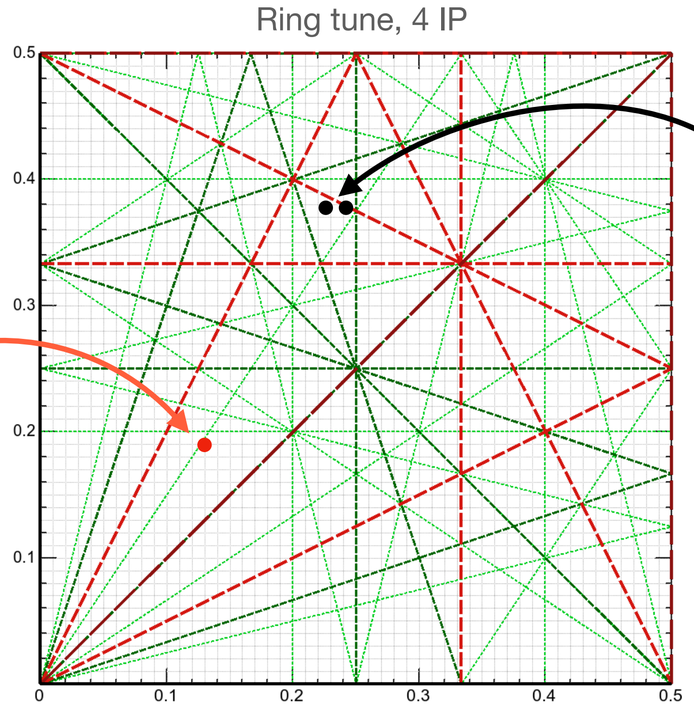
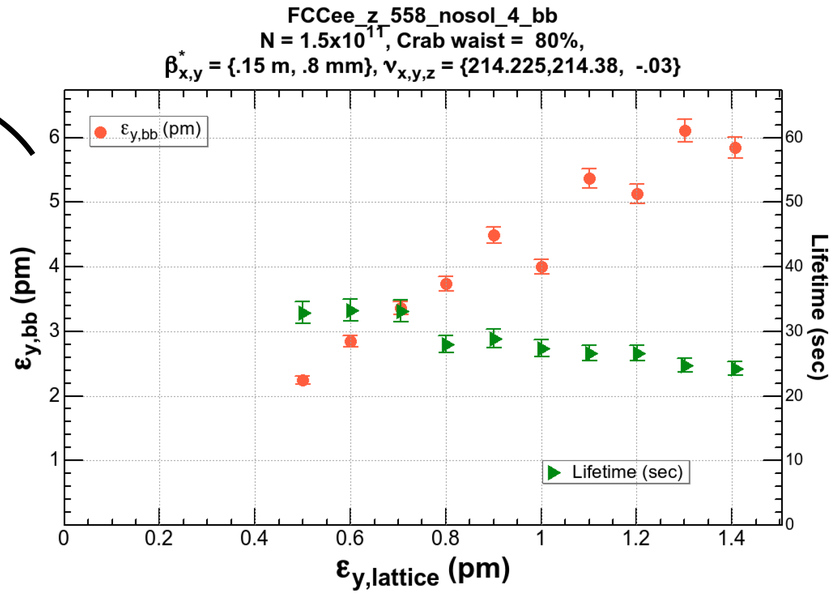
A new tune

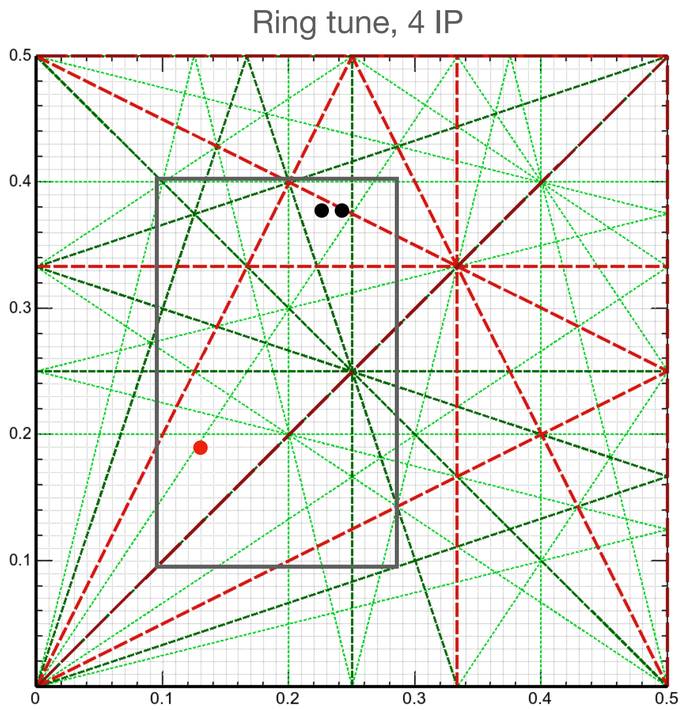


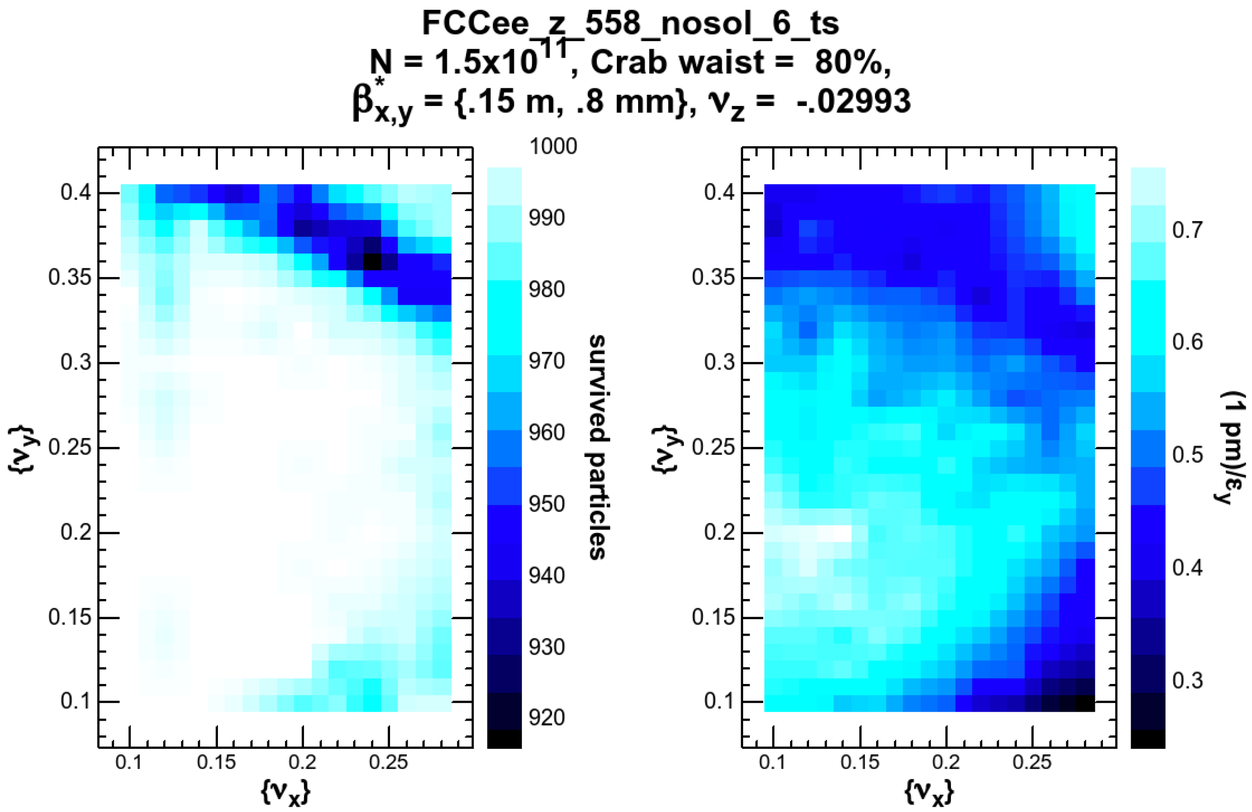




- The lifetimes with lattice and beamstrahlung at previous lattice tunes (black) were very short (25 - 30 s) with 1 RF config.
  - Emittance blowup ~x5 has been observed, too.
- Then D. Shatilov has found that 2 RF looks OK.
- Inspired by Dmitry's, I tried the same fractional tune as the 2 IP case (red).
- Then, the lifetime has drastically improved (x500!).
  - The beam blowup due to beam beam has been also improved.

Tune survey





- Then a tune survey has been tried.
  - Indeed the previous tunes are right on a synchrobeta resonance:

$$\nu_x + 2\nu_y - \nu_z = N\,.$$

- The space around the new tune looks broad enough.
  - The gradation in the right plot $(1/\varepsilon_y)$ may be due to that the sextuple is only optimized at the new tune.
- Other conditions such as coherent beam-beam instability will matter.

Dynamic β?

- The new tunes/IP ($\{\nu_y\} \sim 0.55$) is much closer to half integer than before.
- Then the dynamic-β effect becomes more significant.

$$\mathrm{M}_0 = \begin{pmatrix} \cos\mu & \beta^* \sin\mu \\ -\frac{\sin\mu}{\beta^*} & \cos\mu \end{pmatrix}, \qquad \mathrm{B} = \begin{pmatrix} 1 & 0 \\ -\frac{2\pi\xi}{\beta^*} & 1 \end{pmatrix},$$

$$\mathrm{M} = \mathrm{B}\mathrm{M}_0\mathrm{B} = \begin{pmatrix} \cos\mu - 2\pi\xi\sin\mu & \beta^*\sin\mu \\ \frac{-\sin\mu + 4\pi\xi(-\cos\mu + \pi\xi\sin\mu)}{\beta^*} & \cos\mu - 2\pi\xi\sin\mu \end{pmatrix}$$

$$= \begin{pmatrix} \cos\mu' & \beta^{*\prime}\sin\mu' \\ -\frac{\sin\mu'}{\beta^{*\prime}} & \cos\mu' \end{pmatrix},$$

which gives

$$\cos\mu' = \cos\mu - 2\pi\xi\sin\mu\,,$$

$$\beta^{*\prime} = \frac{\sin\mu}{\sin\mu'}\beta^* = \frac{\sin\mu}{\sqrt{1-(\cos\mu - 2\pi\xi\sin\mu)^2}}\beta^*\,.$$

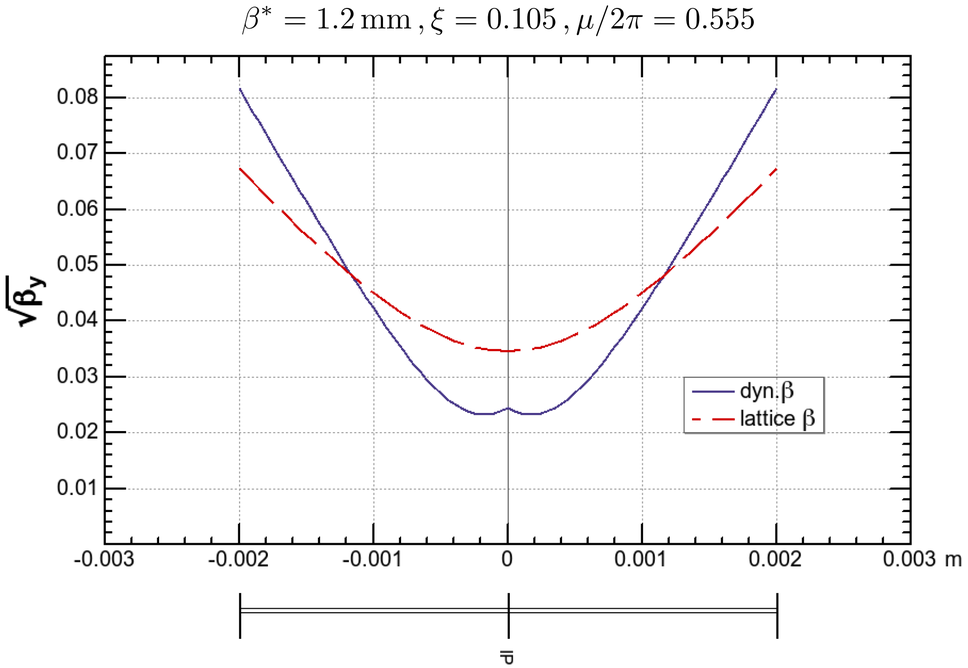
- If we plug in numbers at the new tune:

$$\mu/2\pi = 0.555\,,\ \xi = \xi_y = 0.105\,,$$

which gives

$$\beta^{*\prime} = 0.486\,\beta^*\,.$$

- The simulations and parameter tables should include the dynamic-β.
  - Dmitry's Quasi-strong-strong automatically includes it.



- The β-function around the IP is no longer a simple parabola after the dynamic-β.
- The beam has a waist right before the IP, then focused by the other beam. There is an anti-hourglass effect at the beam crossing.
- The emittance is also changed by the beam-beam focusing.
- The parameter table somewhat consistent with the dynamic-β is in progress….

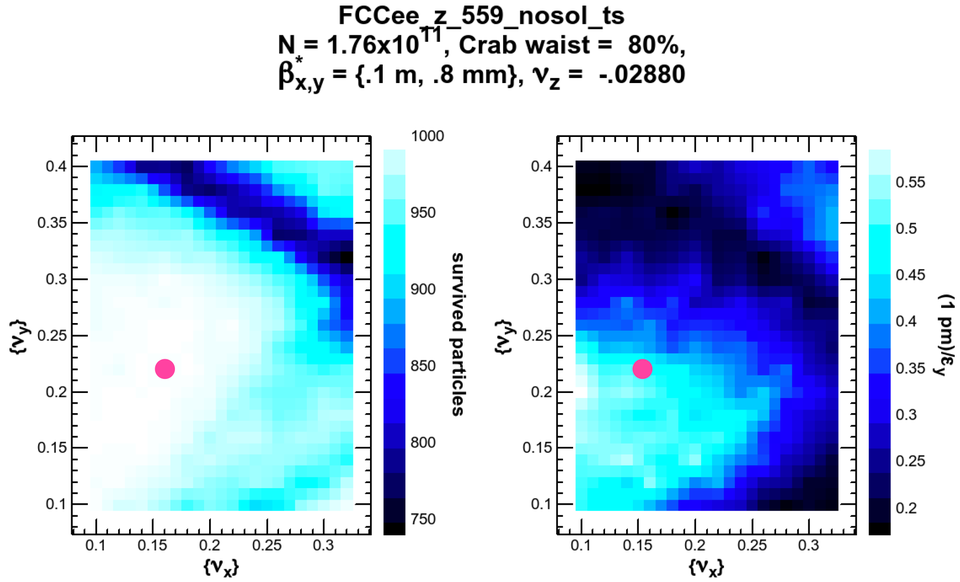
Very tentative parameters (no dynamic β yet)

Table 1: FCC-ee collider parameters for Z as of Apr. 6, 2023. No dynamic-β effect is included.

Beam energy	[GeV]	45.6		
Version		Apr. 4	Apr. 6	Feb. 07
Layout		PA31-3.0		
# of IPs		4		
Circumference	[km]	90.658816		
Bending radius of arc dipole	[km]	9.936		
Energy loss / turn	[GeV]	0.0394		
SR power / beam	[MW]	50		
Beam current	[mA]	1270		
Colliding bunches / beam		16000	13600	9200
Colliding bunch population	[10^{11}]	1.50	1.76	2.60
Horizontal emittance at collision ε_x	[nm]	0.71		
Vertical emittance at collision ε_y	[pm]	1.4		
Arc cell		Long 90/90		
Momentum compaction α_p	[10^{-6}]	28.6		
Arc sextupole families		75		
$\beta^*_{x/y}$	[mm]	150 / 0.8	100 / 0.8	100 / 0.8
Transverse tunes $Q_{x/y}$		214.129 / 214.200	214.158 / 214.220	214.260 / 214.380
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0/086	0.039 / 0.099	0.039 / 0.143
Bunch length (SR/BS) σ_z	[mm]	5.40 / 11.8	5.61 / 14.2	4.37 / 15.9
RF voltage 400/800 MHz	[GV]	0.084 / 0	0.079 / 0	0.120 / 0
Harmonic number for 400 MHz		121200		
RF freuqeuncy (400 MHz)	MHz	400.786684		
Synchrotron tune Q_s		0.0299	0.0288	0.0370
Long. damping time	[turns]	1158		
RF acceptance	[%]	1.1	1.05	1.6
Energy acceptance (DA)	[%]	±1.0		
Beam crossing angle at IP	[mrad]	±15		
Crab waist ratio	[%]	80	80	97
Beam-beam ξ_x/ξ_y [a]		0.0036 / 0.110	0.002 / 0.106	0.0023 / 0.139
Luminosity / IP	[10^{34}/cm^{2}s]	140	141	186
Lifetime (q + BS + lattice)	[sec]	15000	1600	20
Lifetime (lum) [b]	[sec]	1340	1330	1010

[a] incl. hourglass.

[b] only the energy acceptance is taken into account for the cross section



Summary

- The beam lifetime at Z with beamstrahlung and 1 RF/ring configuration can be significantly improved.
- As the new vertical ring tuns becomes much closer to an integer, so the dynamic-β effect becomes stronger.
  - β_y^* is typically reduced by 50% by the beam-beam focusing.
- A consistent parameter set is under development, taking beamstrahlung, lifetime, dynamic-β, dynamic emittance, etc., into account….but in Dmitry's next talk…