Larger Momentum Compaction at Z

as another possible option

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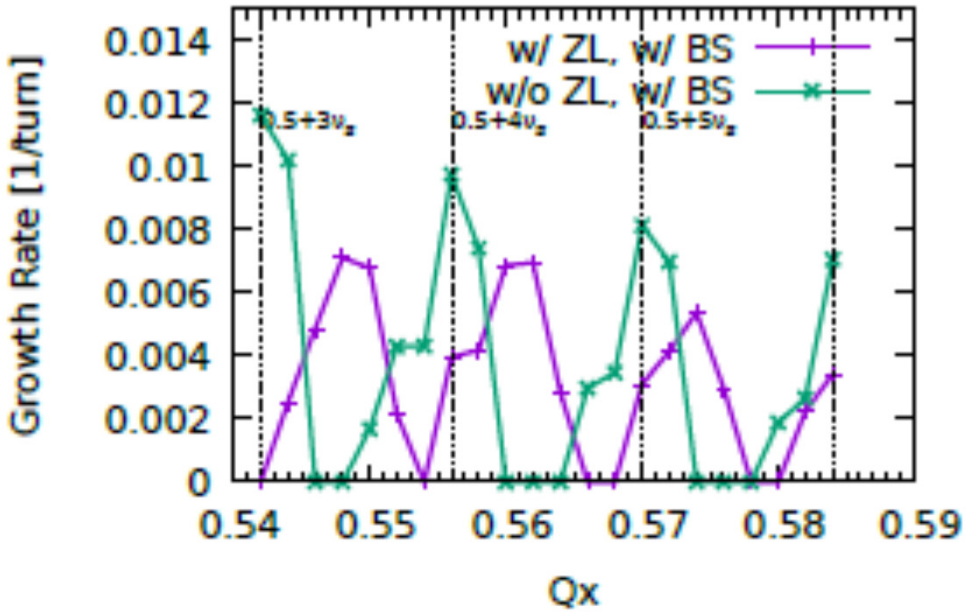
133th FCC-ee Optics Design Meeting

CERN, 5 Mar 2021

Introduction & Motivation

M. Zobov et al., “Combined effect of beam-beam interaction and longitudinal beam coupling impedance”, 131st FCC-ee Optics Design Meeting, 22 Jan 2021.

Impedance => Synchrotron tune shift and spread => Reduction of sizes of the stable tune areas.



Simulations by Y. Zhang for CEPC at Z energy

To solve such problems, we were helped by an increase in the momentum compaction factor. Maybe we should try to increase it even more?

Specifically, we will consider switching from 60°/60° to 45°/45° arc cell lattice and the possible implications for beam-beam interaction and luminosity.

The Model and Simple Estimates

The lattice for 45°/45° arc cell does not exist [yet]. The momentum compaction and emittances were obtained by scaling (rough estimates). Currently, the model is simple: linear lattice without impedance + beam-beam.

For flat beams:

$$L = \frac{\gamma}{2er_e}\cdot\frac{I_{tot}\xi_y}{\beta_y^*}\cdot R_{hg} \qquad \xi_y = \frac{r_e}{2\pi\gamma}\cdot\frac{N_p}{\sigma_x\sqrt{(1+\phi^2)}}\sqrt{\frac{\beta_y^*}{\varepsilon_y}} \xrightarrow{\phi\gg 1} \frac{r_e}{\pi\gamma\theta}\cdot\frac{N_p}{\sigma_z}\cdot\sqrt{\frac{\beta_y^*}{\varepsilon_y}}$$

Maximum critical energy of emitted BS photons: $u_c \propto \frac{\gamma^2 N_p}{\sigma_x\sigma_z}$

With larger emittance, R_{hg} slightly decreases and BS weakens. If we want to leave the luminosity unchanged, BS will be also pretty much the same.

$$\xi_x = \frac{r_e}{2\pi\gamma}\cdot\frac{N_p\beta_x^*}{\sigma_x^2(1+\phi^2)} \xrightarrow{\phi\gg 1} \frac{2r_e}{\pi\gamma\theta^2}\cdot\frac{N_p\beta_x^*}{\sigma_z^2}$$

When $\sigma_z >> \sigma_{z0}$ (BS dominated regime), then $\sigma_z \propto \sqrt{N_p}$

ξ_x does not depend on the bunch population!

Table of Parameters

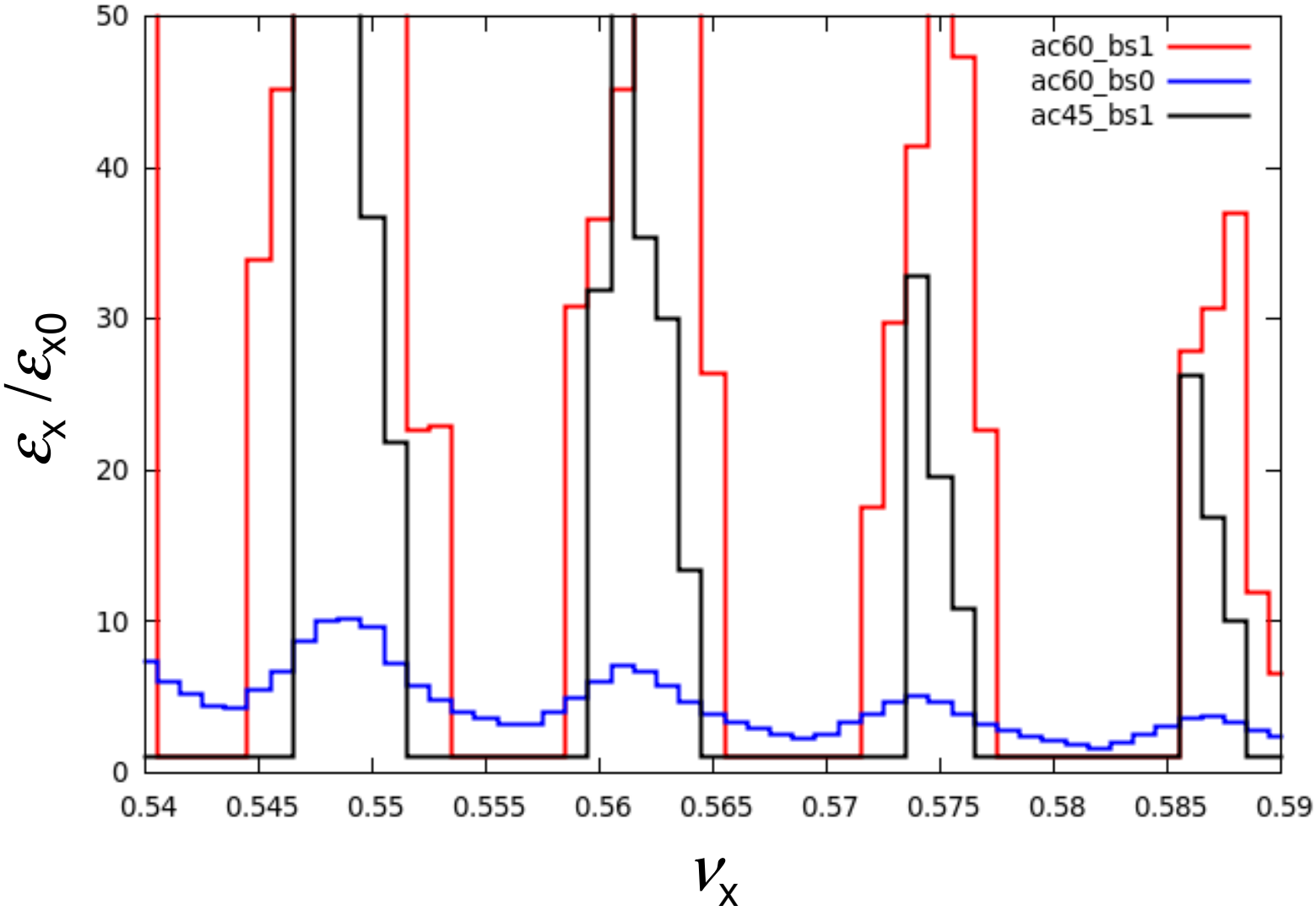
Arc Cell	**60° / 60°**		**45° / 45°**		
α_p [10^{-5}]	1.48		2.5 -?		
ε_x [nm]	0.27		0.6 -?		
ε_y [pm]	1.0		1.5		
RF voltage [MV]	100		100		66
ν_z / superperiod	0.0125		0.0163		0.0125
RF acceptance [%]	1.9		1.46		0.91
σ_{z0} [mm]	3.5		4.5		5.8
Beamstrahlung	OFF	ON	ON		
N_p [10^{11}]	0.5	1.7	1.7	2.8	3.6
N_b	56580	16640	16640	10100	7860
σ_z [mm]	3.5	12.	11.5	15.2	19.8
σ_δ [10^{-4}]	3.8	13.	9.7	12.7	12.7
ϕ	8.2	28.5	18.2	24	31.3
ξ_x	0.013	0.004	0.004	0.004	0.003
L/IP [10^{36} $cm^{-2}c^{-1}$]	2.3	2.3	1.9	2.3	2.3

Some observations from the Table

1) In the 1st column, $\xi_x > \nu_z$ => coherent beam-beam instability cannot be avoided. In order to decrease ξ_x, N_p should be decreased => luminosity drops. BS helps ?!
2) On the other hand, Piwinski angle in the 1st column is not so large => coherent beam-beam instability will be weaker (see the next slide).
3) RF acceptance in the last column is too small, but the same $\nu_z = 0.0125$ can be obtained with U_{RF} = 100 MV and 3rd harmonic RF cavities. In this case the RF acceptance will be sufficient.
4) Compare columns 2 and 3. With the same bunch population and σ_{z0} larger for 3rd, σ_z is slightly smaller for 3rd. This is due to the fact that in the latter case BS is weaker. Luminosity in this case is smaller due to larger ε_z and hour-glass. Note that ξ_x are [almost] equal for these two cases, since σ_z are also almost equal.
5) To achieve the design luminosity, N_p should be increased (column 4). Note that ξ_x does not change!
6) Compare columns 4 and 5: the same luminosity and the same energy spread (that is, the same BS). Compare with column 2: almost the same σ_δ.
7) For the coherent beam-beam instability, the ratio ξ_x / ν_z is important. In columns 2, 3 and 4 ξ_x is the same, but ν_z is higher for 3 and 4. In column 5, ν_z is the same as in column 2, but ξ_x is smaller. Generally, ξ_x / ν_z is better (smaller) for 45°/45°.

Coherent Beam-Beam Instability

(impedance not accounted yet)



Related Questions and Next Steps

- Population of the pilot bunches (for polarization) is limited by Touschek lifetime. With larger α_p, all three beam sizes increase => larger N_p => better signal.
- We need to discuss once again the limitation for the synchrotron tune. But in general, the situation becomes better with larger α_p.
- We need to discuss the new parameters with injection complex experts. Are there any objections?
- Is it possible to design a flexible lattice so that we can efficiently switch from 60°/60° to 45°/45° arc cell without changing hardware?
- Longitudinal impedance will be inserted into `Lifetrac` soon. After that it will be necessary to repeat the simulations.
- Any comments/suggestions from experts on collective instabilities? Are we heading in the right direction?