Effect of RF Frequency Change on Luminosity Performance

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FUTURE CIRCULAR COLLIDER

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Introduction

Changing the RF frequency affects the synchrotron tune (hence the bunch length) and RF acceptance (bucket height). In turn, this can affect the choice of other parameters of the collider and the luminosity performance.

Next, we will consider the RF option of 650 MHz and compare it with the baseline (from the CDR) for all FCC-ee energies.

Most of the questions come up at low energy, so we'll start at high energy where things are simple.

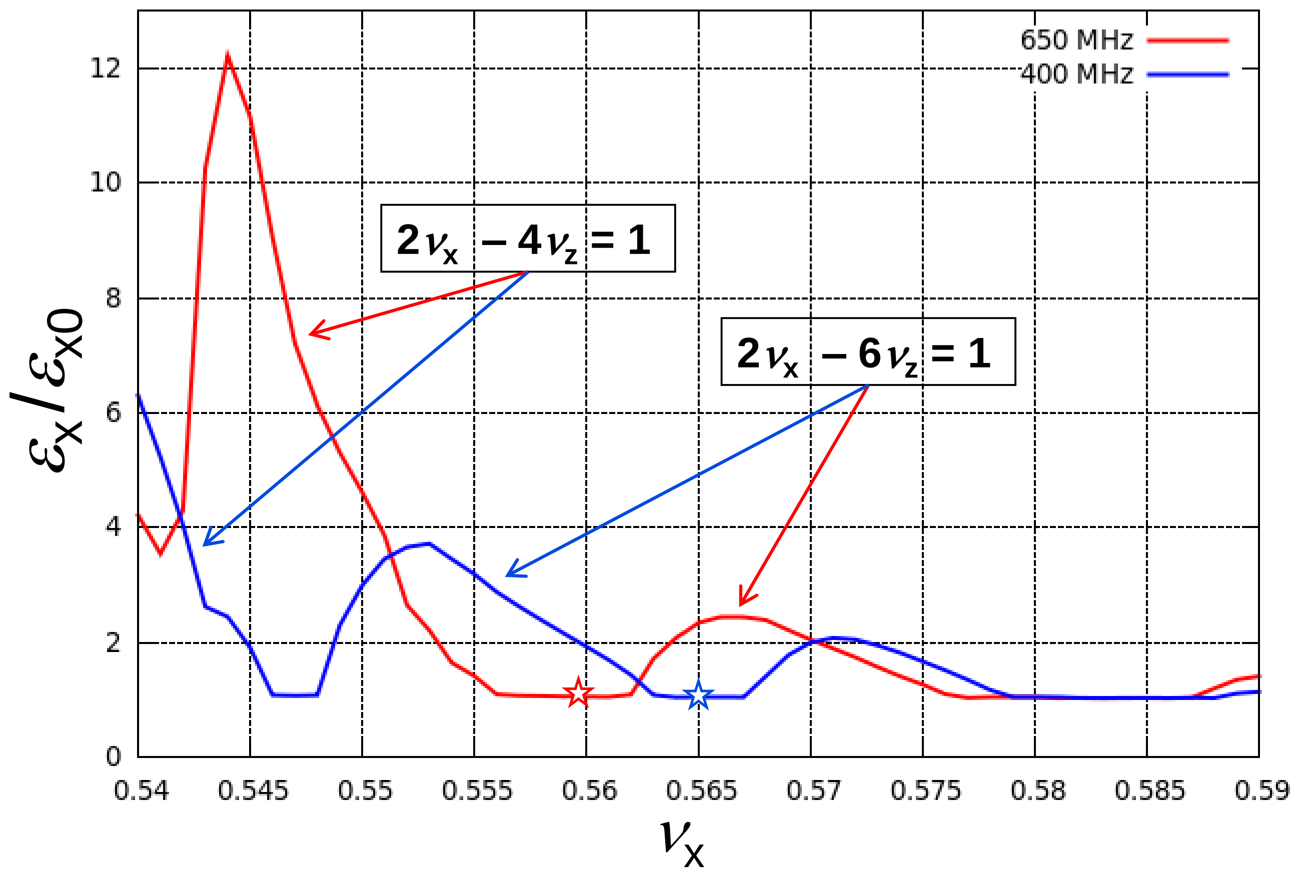
ttbar (182.5 GeV)

RF frequency [MHz]	400 + 800	650
Energy loss per turn [GV]	9.2	
RF voltage [GV]	4 + 6.9	10.75
RF acceptance [%]	3.36	3.55
Momentum accept. [%]	+2.4 / -2.8	
Synchrotron tune [ν_z]	0.087	0.087

All other parameters are the same.

No problems with switching to 650 MHz are expected.

ZH (120 GeV)

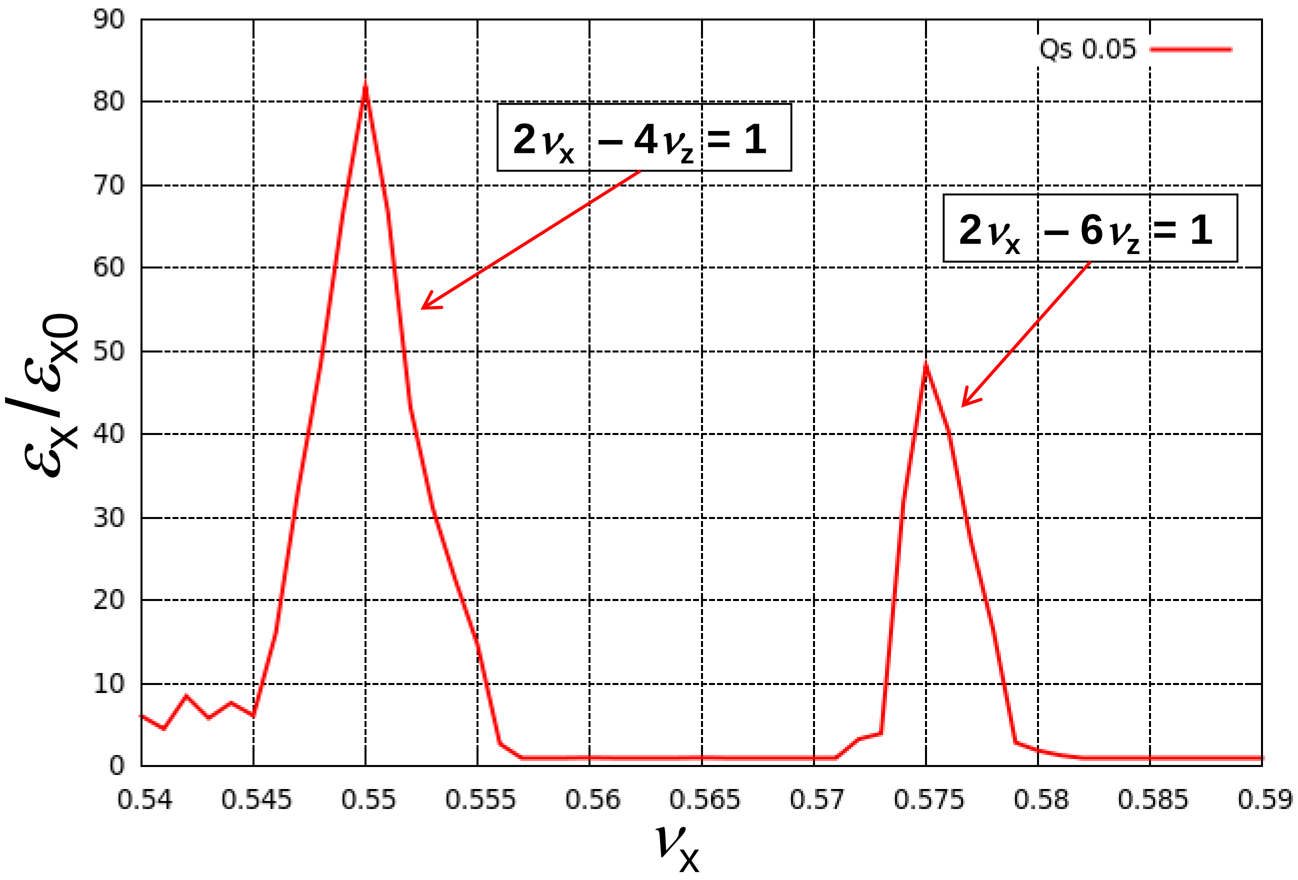


RF frequency [MHz]	400	650
Energy loss per turn [GV]	1.72	
RF voltage [GV]	2.0	2.0
RF acceptance [%]	2.3	1.84
Momentum accept. [%]	±1.7	
Synchrotron tune [ν_z]	0.036	0.046
Bunch length (bs) [mm]	5.3	4.1
Bunch population [10^{11}]	1.8	1.4
Number of bunches [N_b]	328	422
Piwinski angle	5.8	4.5

Coherent beam-beam instability (TMCI). High-order modes can be excited only at large Piwinski angles.

Some parameters will need to be changed, but in general there should be no problems.

WW (80 GeV)



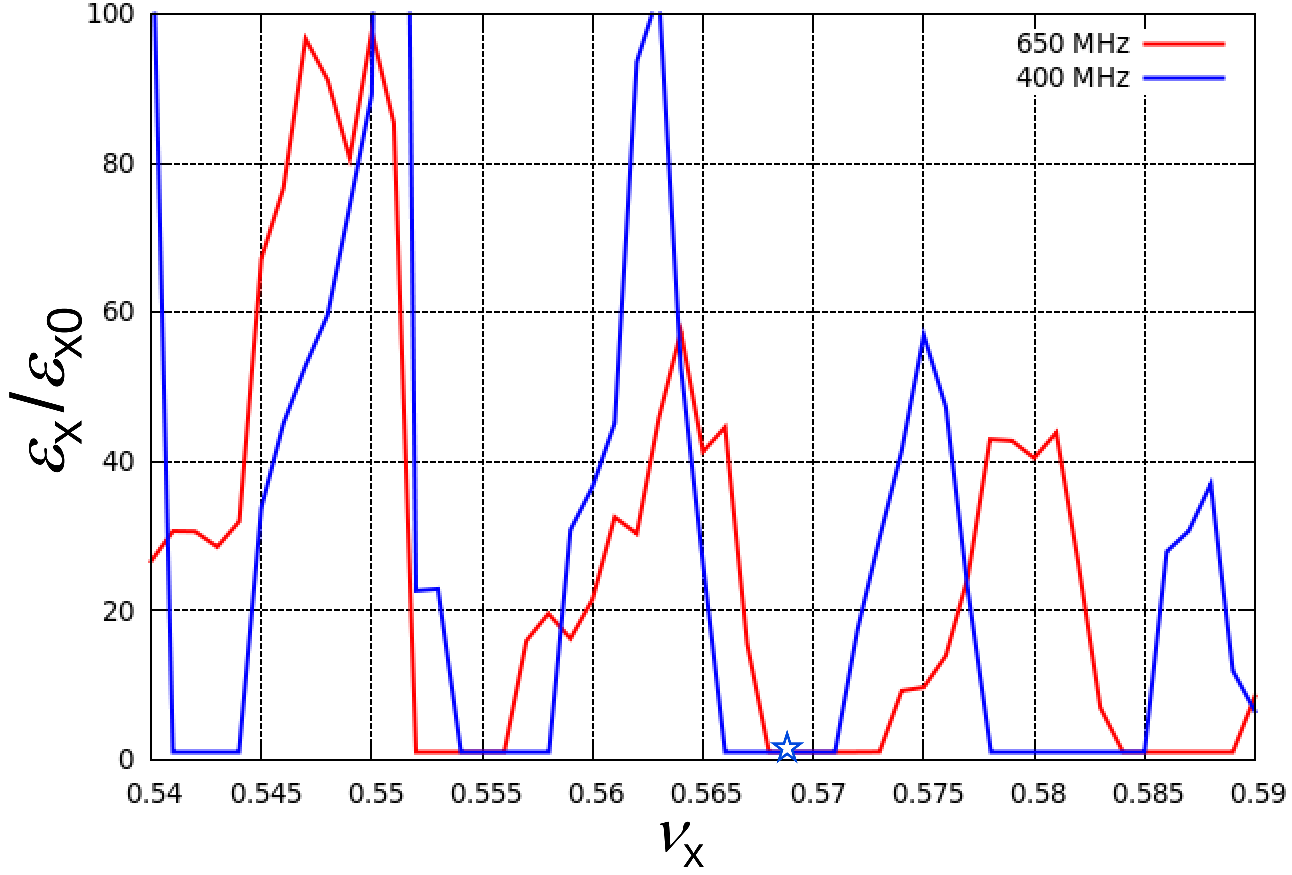
RF frequency [MHz]	400	650
Energy loss per turn [MV]	340	
RF voltage [MV]	750	530
RF acceptance [%]	3.5	1.66
Momentum accept. [%]	±1.3	
Synchrotron tune [ν_z]	0.05	0.05

All other parameters are the same.

Important: $\nu_z \geq 0.05$ is required for the energy calibration (detection of depolarization).

If we leave the same RF voltage 750 MV with a frequency of 650 MHz, then ν_z will increase to 0.06. This is significantly better for depolarization, and we can allow such an increase in ν_z.

Z (45.6 GeV), 60°/60° Arc Lattice



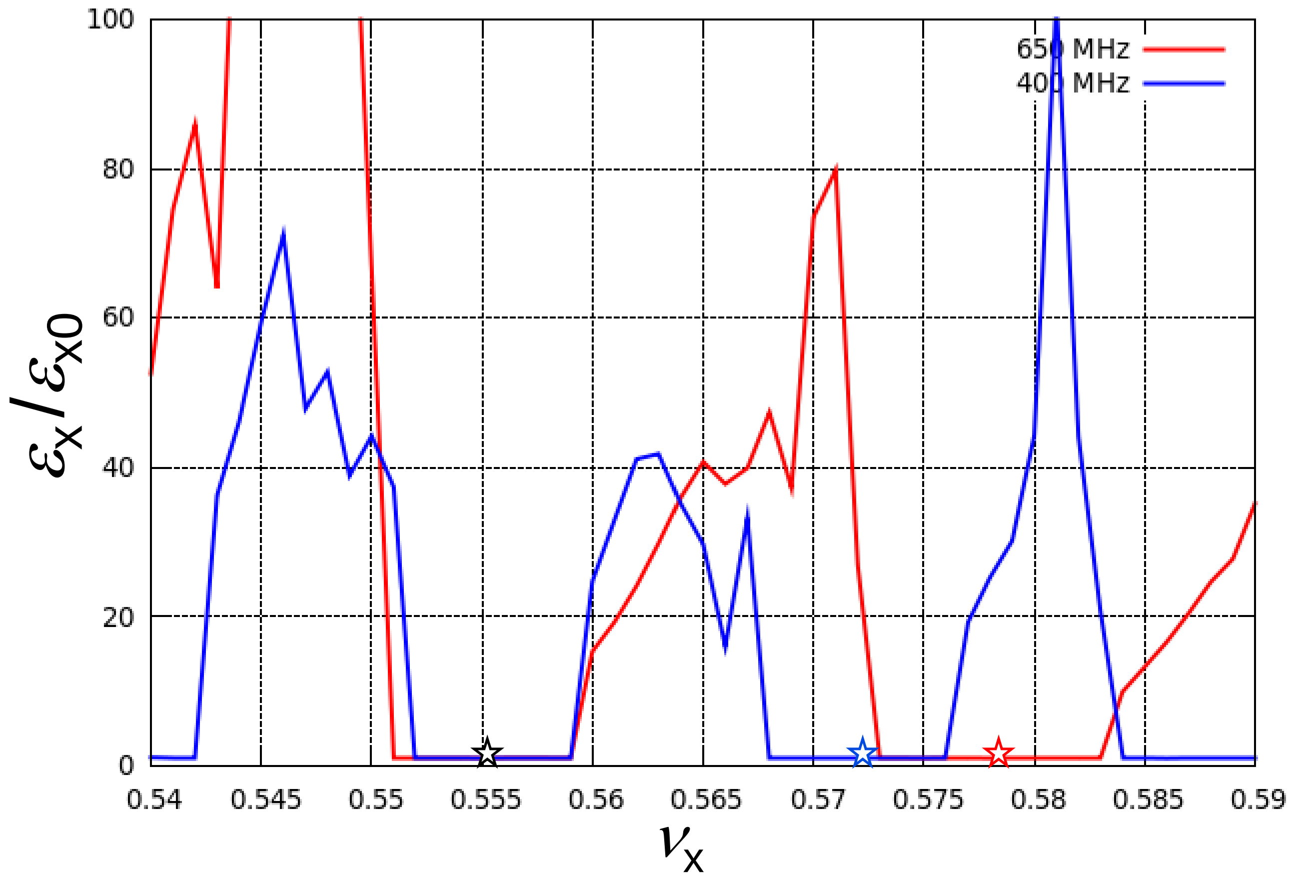
RF frequency [MHz]	400	650
RF voltage [MV]	100	100
RF acceptance [%]	1.9	1.5
Momentum accept. [%]	±1.3	
Synchrotron tune [ν_z]	0.025	0.032
Bunch length (bs) [mm]	12.1	9.4
Bunch population [10^{11}]	1.7	1.33
Number of bunches [N_b]	16640	21270

Important: $\nu_z \geq 0.025$ is required for the energy calibration (detection of depolarization).

An increase in ν_z leads to a shift of good ν_x areas to the right, which is undesirable. But in our case, perhaps, the damage will be minimal.

However, taking into account the impedance, the situation becomes much worse (simulated by Y. Zhang). The most effective way to improve it is to increase the momentum compaction factor (next slides).

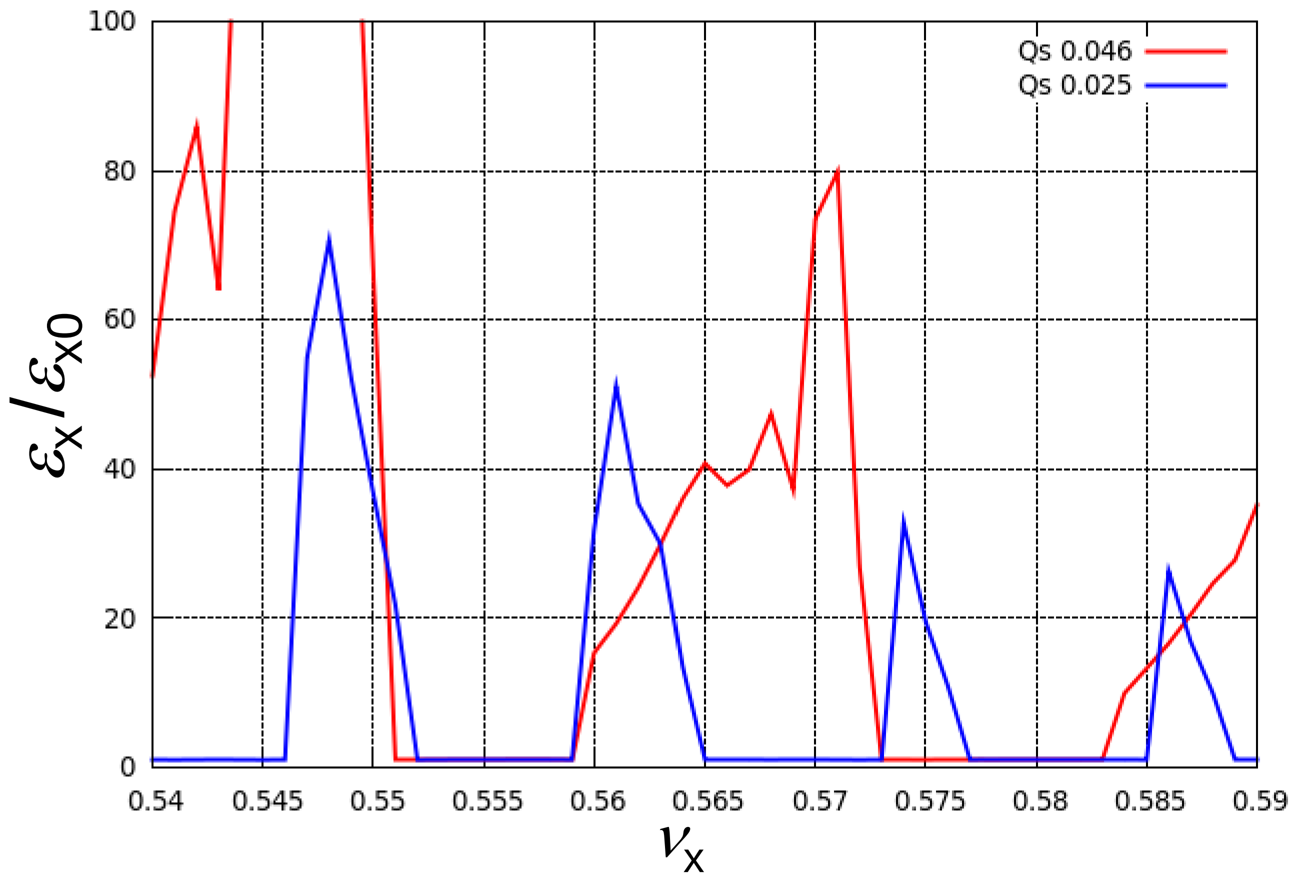
Z (45.6 GeV), 45°/45° Arc Lattice



RF frequency [MHz]	400	650
RF voltage [MV]	100	120
RF acceptance [%]	1.46	1.35
Momentum accept. [%]	$\pm$1.3	
Synchrotron tune [ν_z]	0.032	0.046
Bunch length (bs) [mm]	15.2	10.9
Bunch population [10^{11}]	2.8	2.0
Number of bunches [N_b]	10100	14140

Perhaps, ν_x = 0.555 will be good for both variants. But there is another important parameter: the number of bunches. Reducing N_b helps to mitigate problems associated with electron clouds, ion instabilities, etc. From this point of view, 400 MHz is better. But there is one more option: 3rd harmonic RF (next slide).

Z (45.6 GeV), 45°/45° Arc Lattice with 3rd Harmonic RF



RF frequency [MHz]	650	650 + 1950
RF voltage [MV]	120	120 + 27
RF acceptance [%]	1.35	1.32
Momentum accept. [%]	$\pm$1.3	
Synchrotron tune [ν_z]	0.046	0.025
Bunch length (bs) [mm]	10.9	19.8
Bunch population [10^{11}]	2.0	3.6
Number of bunches [N_b]	14140	7860

Important: $\nu_z \geq 0.025$ is required for the energy calibration (detection of depolarization).

A compromise is possible, e.g. 22 MV for 3rd harmonic, then $\nu_z = 0.03$ – this is better for depolarization.

Installation of cavities of the 3rd harmonic with a moderate voltage and without power transfer to the beam will make it possible to control the synchrotron tune. This will be very useful.

Summary

- At energies above Z, problems with the transition to the RF frequency of 650 MHz are not expected.
- At Z energy, with the transition to 650 MHz, the synchrotron tune will increase. This will have a slight negative impact, but the overall situation remains operational.
- If a decision is made to switch to 45°/45° arc lattice, an increase in the RF voltage from 100 to 120 MV will be required for 650 MHz.
- Installation of cavities of the 3rd harmonic with a moderate voltage will make it possible to control the synchrotron tune and will be very useful (this is only needed at Z with 45°/45°).