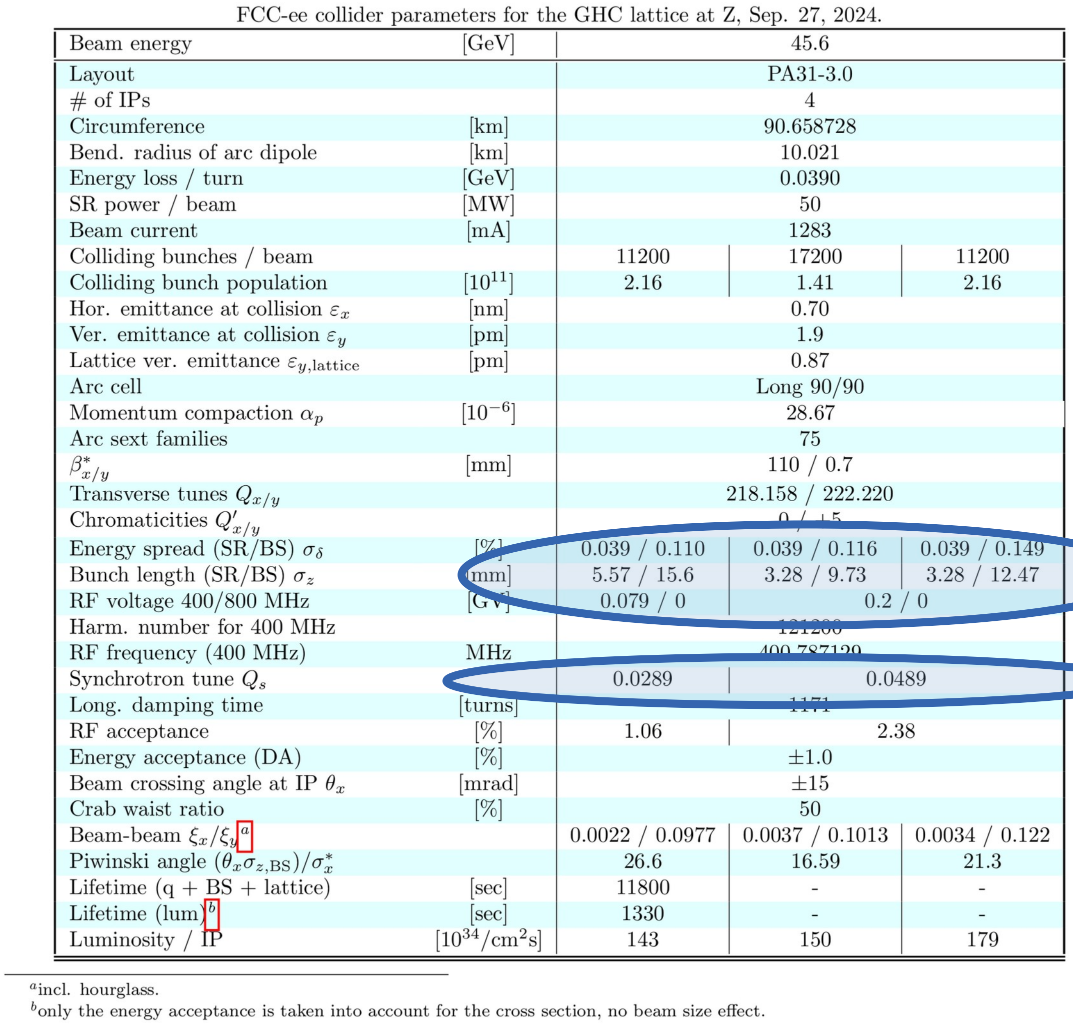
Tentative new scenario with 2 cells cavities at the Z

X. Buffat, I. Karpov, L. Mether, M. Migliorati, K. Oide, R. Soos, F. Zimmerman, M. Zobov

- Parameter tables with 200MV
- Electron cloud with shorter bunch spacing
- Single beam stability
- Beam-beam simulations
- Conclusion

Parameter table

K. Oide



FCC-ee collider parameters for the GHC lattice at Z, Sep. 27, 2024.

Beam energy	[GeV]	45.6		
Layout		PA31-3.0		
# of IPs		4		
Circumference	[km]	90.658728		
Bend. radius of arc dipole	[km]	10.021		
Energy loss / turn	[GeV]	0.0390		
SR power / beam	[MW]	50		
Beam current	[mA]	1283		
Colliding bunches / beam		11200	17200	11200
Colliding bunch population	[10^{11}]	2.16	1.41	2.16
Hor. emittance at collision ε_x	[nm]	0.70		
Ver. emittance at collision ε_y	[pm]	1.9		
Lattice ver. emittance $\varepsilon_{y,\mathrm{lattice}}$	[pm]	0.87		
Arc cell		Long 90/90		
Momentum compaction α_p	[10^{-6}]	28.67		
Arc sext families		75		
$\beta^*_{x/y}$	[mm]	110 / 0.7		
Transverse tunes $Q_{x/y}$		218.158 / 222.220		
Chromaticities $Q'_{x/y}$		0 / +5		
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0.110	0.039 / 0.116	0.039 / 0.149
Bunch length (SR/BS) σ_z	[mm]	5.57 / 15.6	3.28 / 9.73	3.28 / 12.47
RF voltage 400/800 MHz	[GV]	0.079 / 0	0.2 / 0	
Harm. number for 400 MHz		121200		
RF frequency (400 MHz)	MHz	400.787129		
Synchrotron tune Q_s		0.0289	0.0489	
Long. damping time	[turns]	1171		
RF acceptance	[%]	1.06	2.38	
Energy acceptance (DA)	[%]	±1.0		
Beam crossing angle at IP θ_x	[mrad]	±15		
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Beam-beam ξ_x/ξ_y[a]		0.0022 / 0.0977	0.0037 / 0.1013	0.0034 / 0.122
Piwinski angle $(\theta_x \sigma_{z,\mathrm{BS}})/\sigma^*_x$		26.6	16.59	21.3
Lifetime (q + BS + lattice)	[sec]	11800	-	-
Lifetime (lum)[b]	[sec]	1330	-	-
Luminosity / IP	[10^{34}/cm^{2}s]	143	150	179

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[a] incl. hourglass.

[b] only the energy acceptance is taken into account for the cross section, no beam size effect.

- The proposal is to increase the total voltage in order to limit transient beam loading

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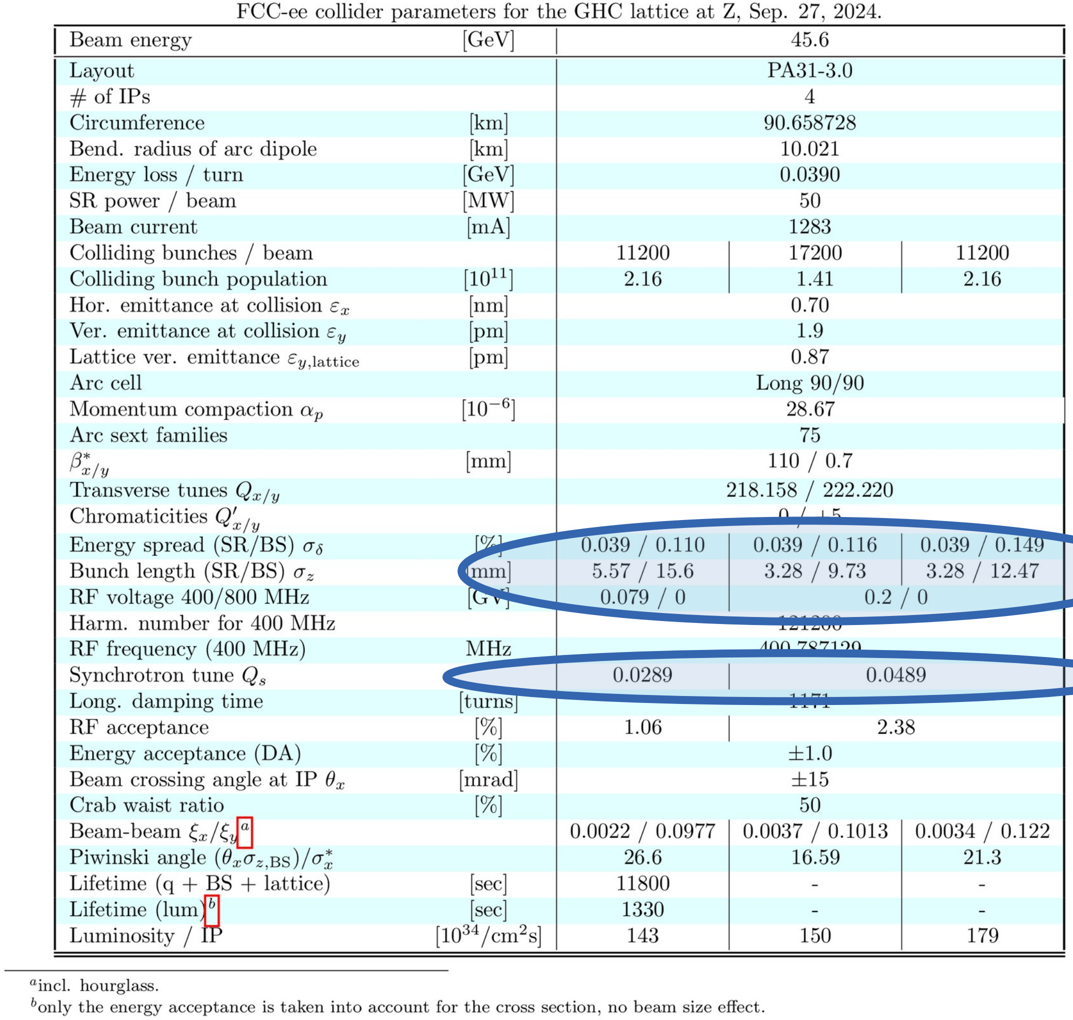

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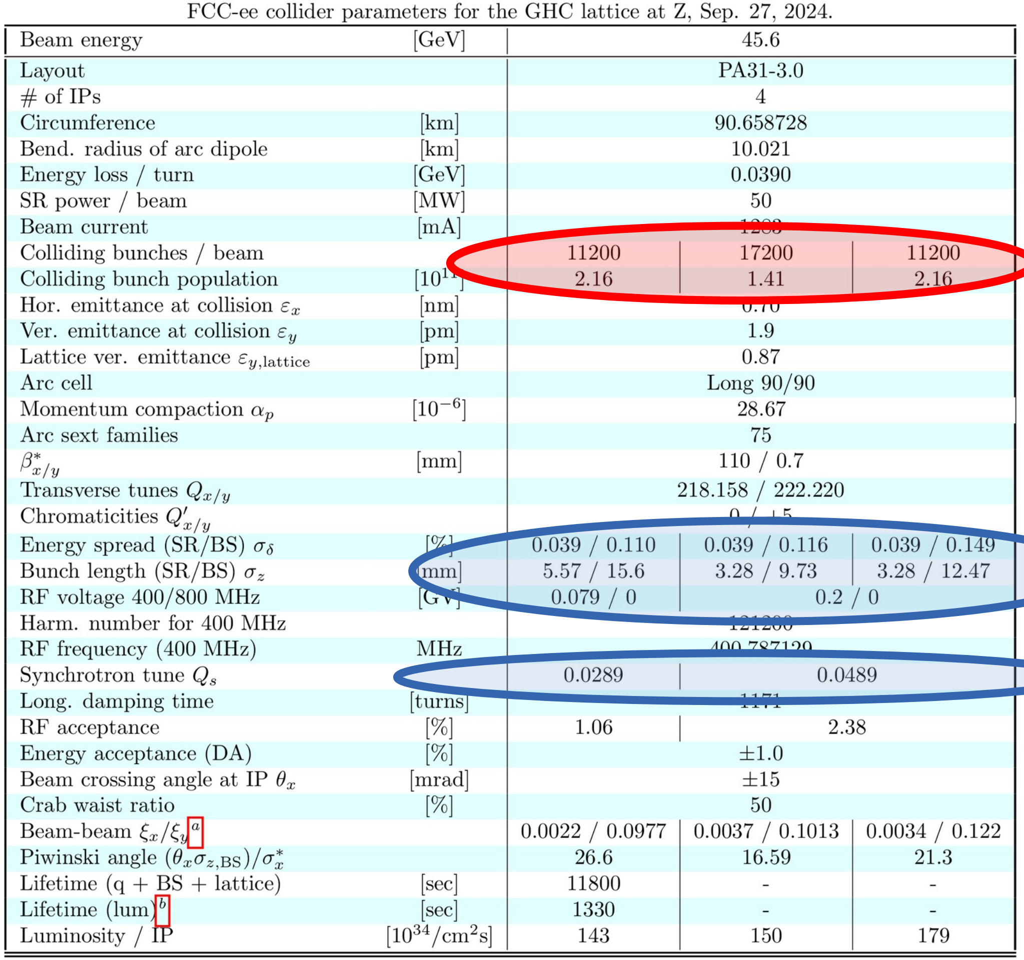

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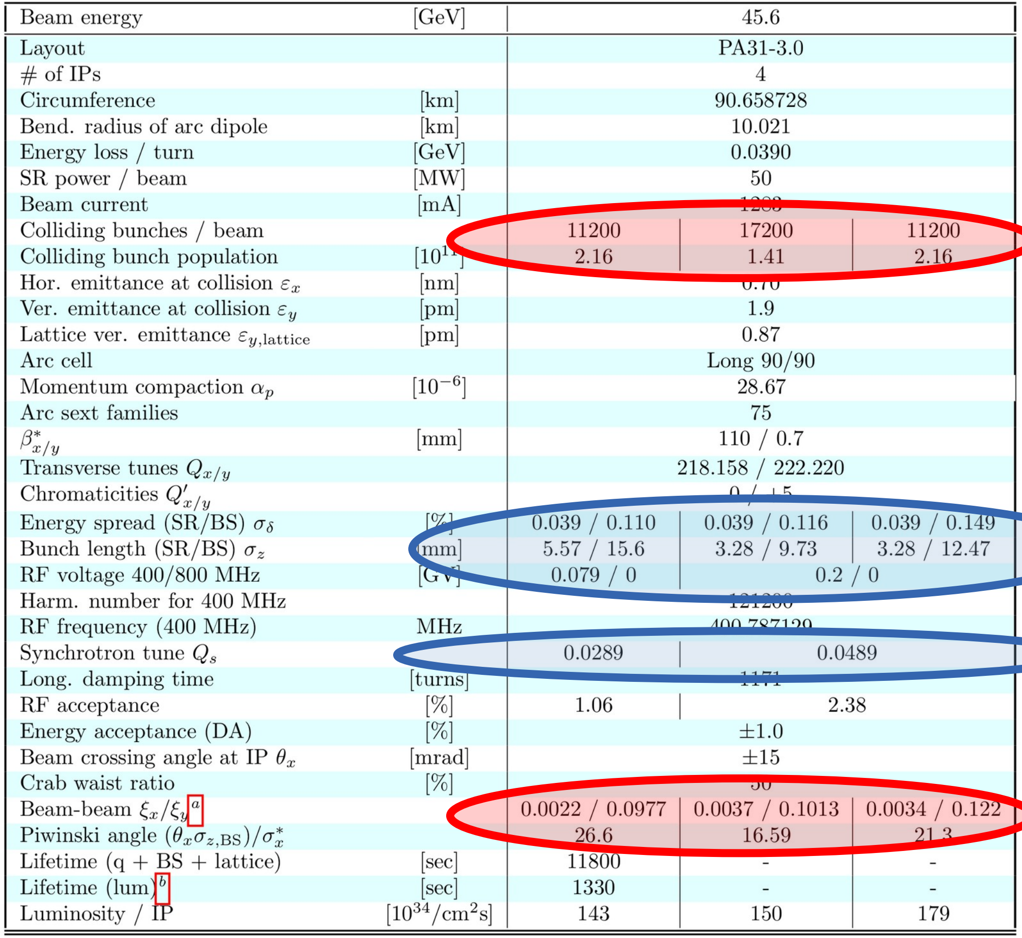

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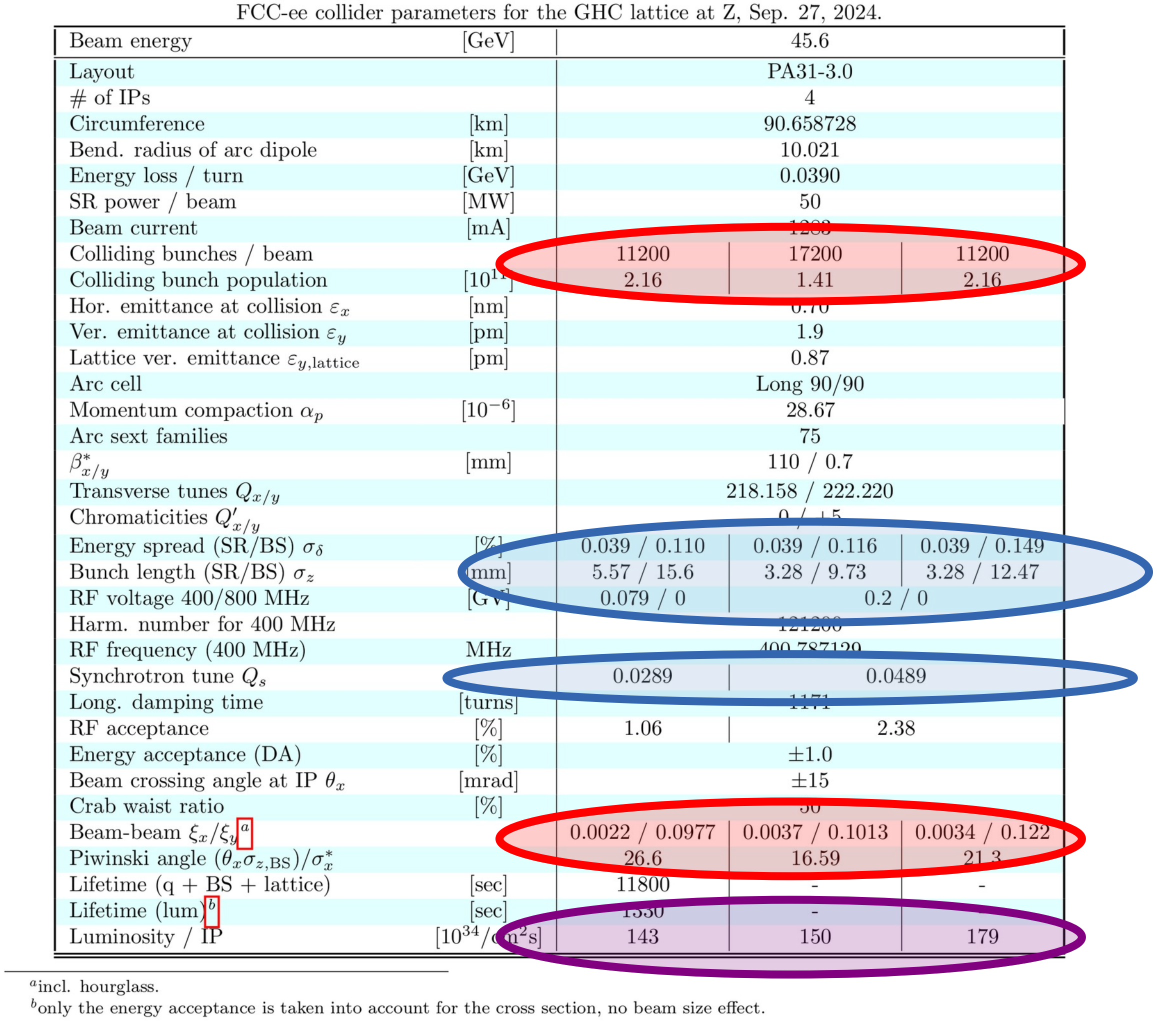

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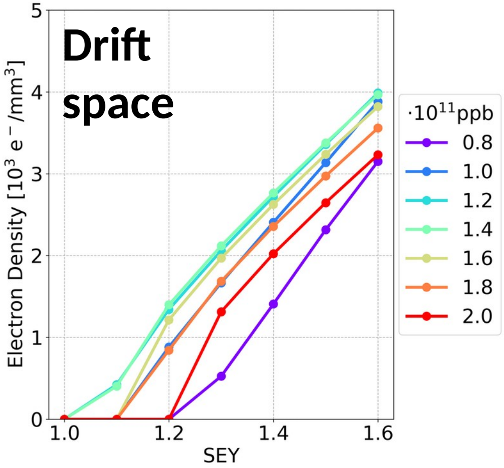
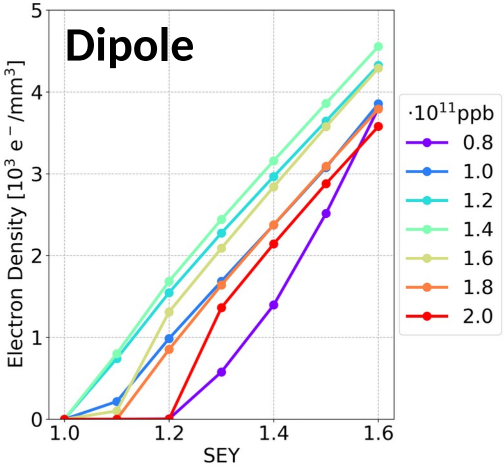
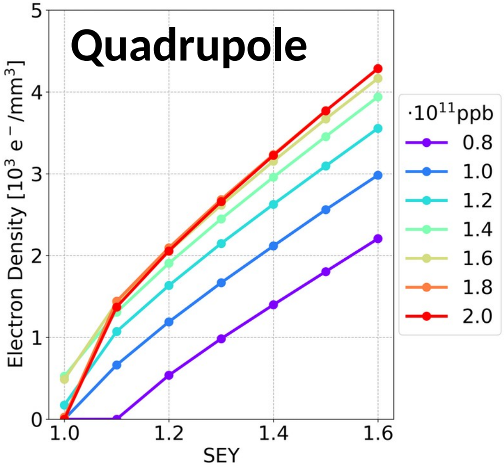
Simulation Results: Bunch Intensity

L. Sabato

- bunch spacing 15 ns, longer bunch length:







- In the drift space and dipole, the electron density has a similar behaviour with respect to the bunch intensity
  - the dependence on the bunch is not monotonic: the worst case is the **$1.4 \cdot 10^{11}$ ppb**
- In the quadrupole,
  - the bunch intensity has a non-negligible effect on the electron density
  - less bunch intensity less electron density

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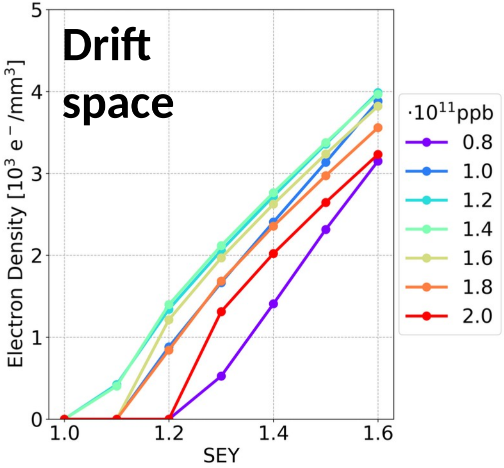
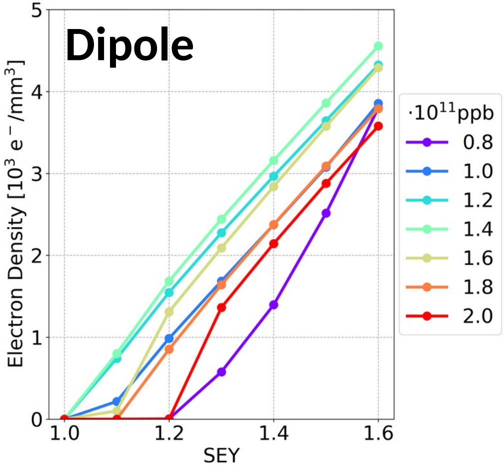
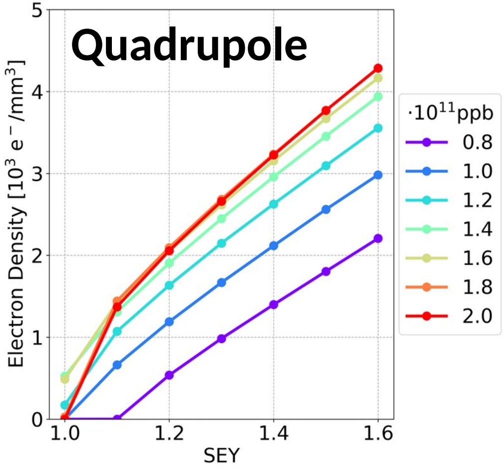
Not exactly the right scenario considered, but bunch length is not the main driver







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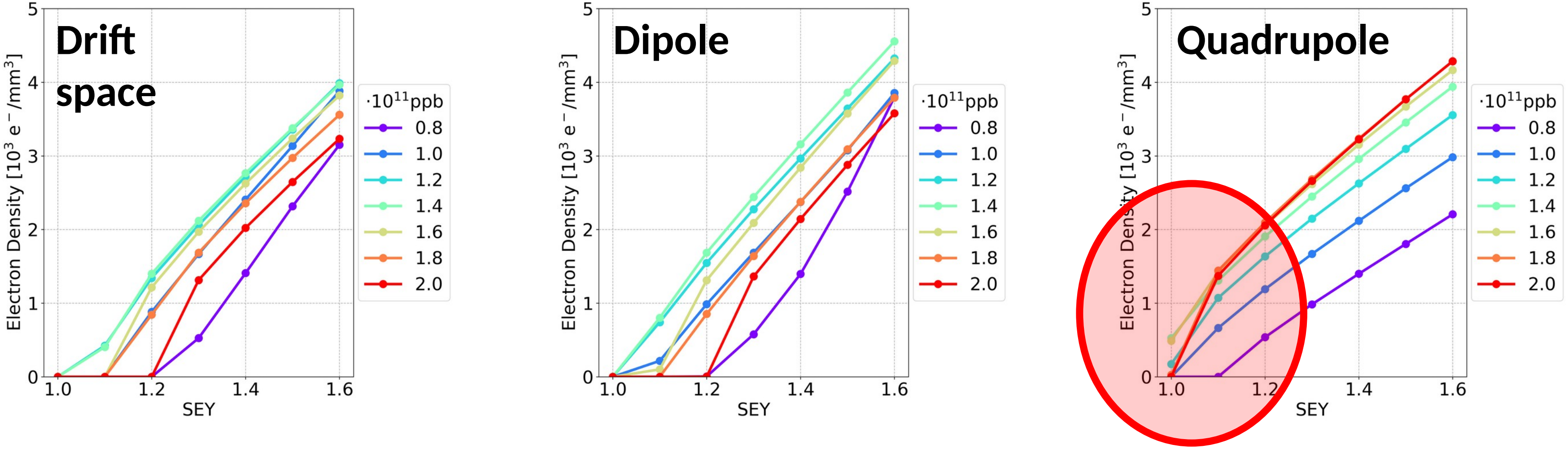

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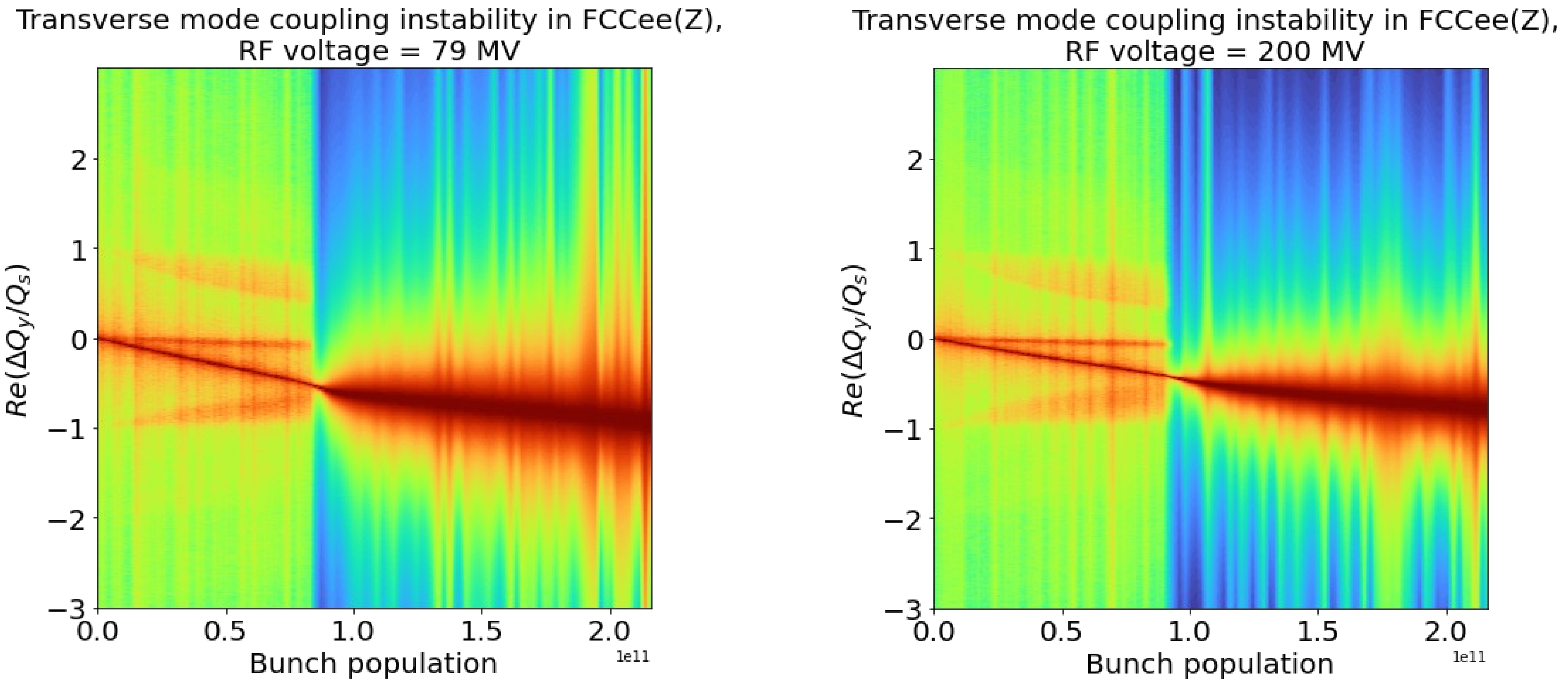
Multipacting (and beam instabilities) are expected already with an SEY of 1.0

TMCI without beam-beam, damper or chroma

R. Soos

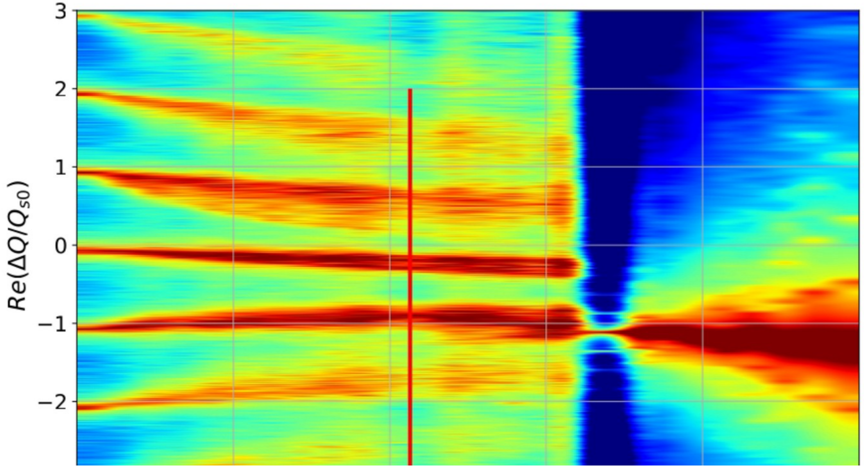


- The tune shift driven by the impedance is larger due to the shorter bunch, but since Qs is larger, the TMCI occurs at the same intensity

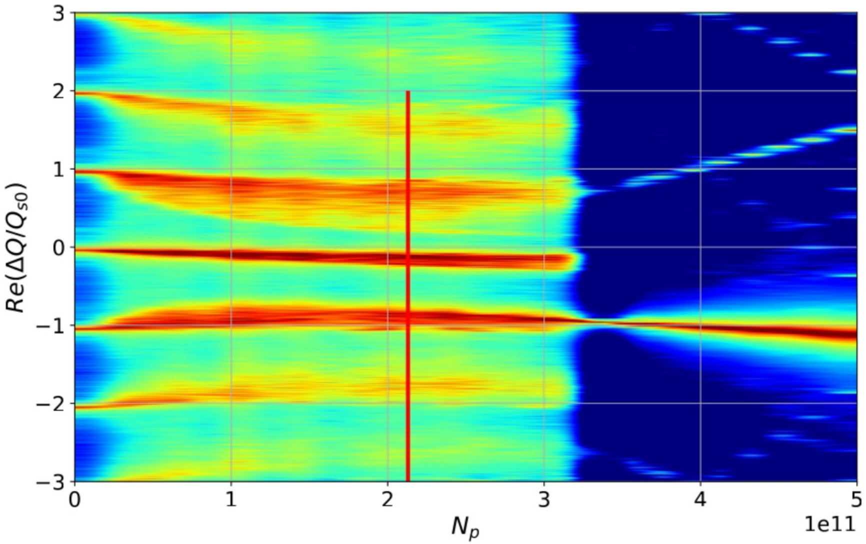
TMCI

With an (ideal) bunch-by-bunch feedback system on (damping of 4 turns), chroma = 5, and the current impedance model, no noticeable differences are found in the vertical plane between the two regimes. If the lower single bunch population (1.41×10^{11}) is chosen with the higher voltage, the TMCI threshold margin is, of course, larger.

baseline parameters



higher voltage parameters



TMCI

In the same conditions, in the horizontal plane, no TMCI is observed in the higher voltage regime.

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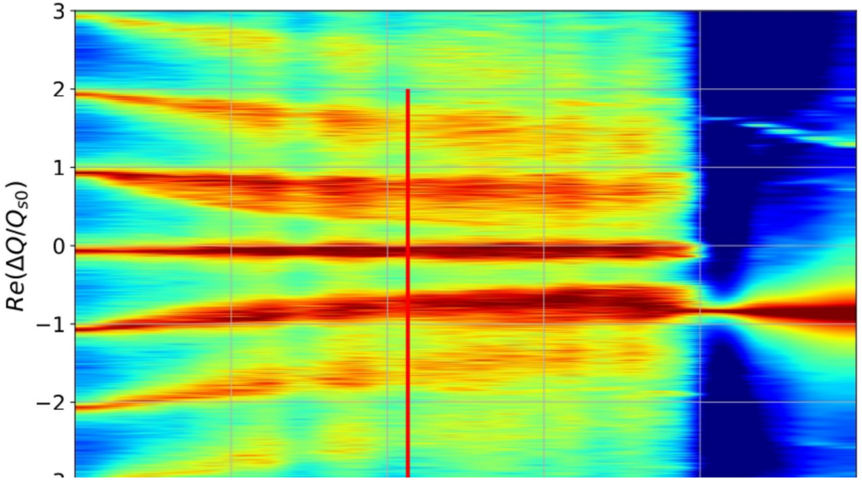

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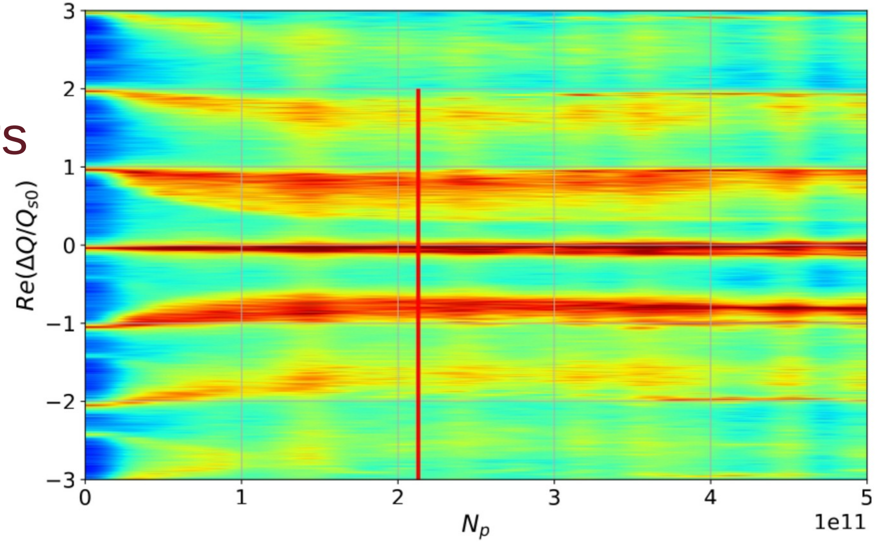
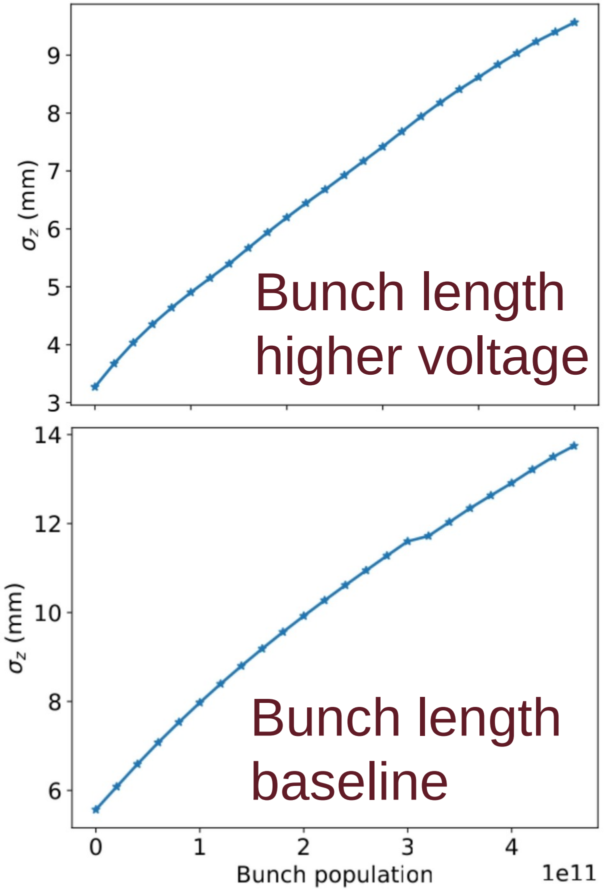


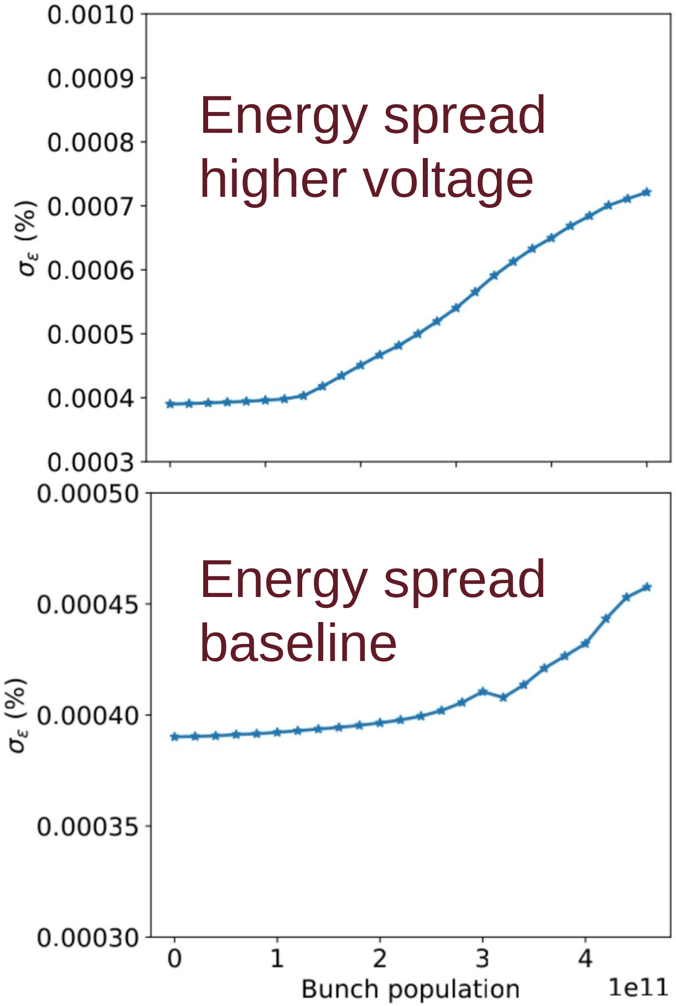
Bunch length and energy



Bunch length higher voltage

Bunch length baseline

If, with higher voltage, the higher single bunch population option is chosen (2.16x10^{11}), there could be a bit of microwave instability due to the shorter zero current bunch length.

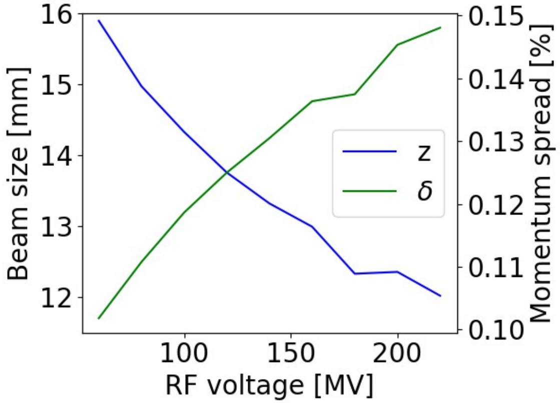


Energy spread higher voltage

Energy spread baseline

Beam-beam simulations (proposal 2)

- Quasi-strong-strong simulation with beam-beam (no impedance) are agreement with Oide’s parameter table



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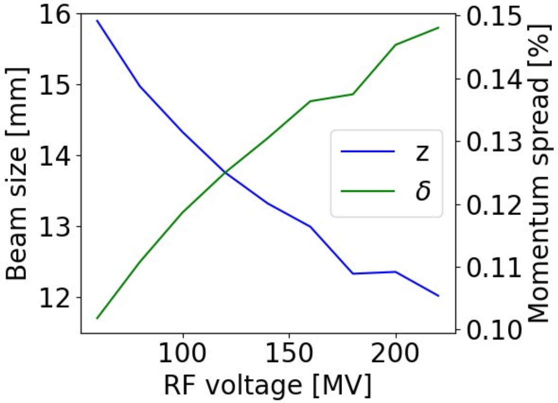

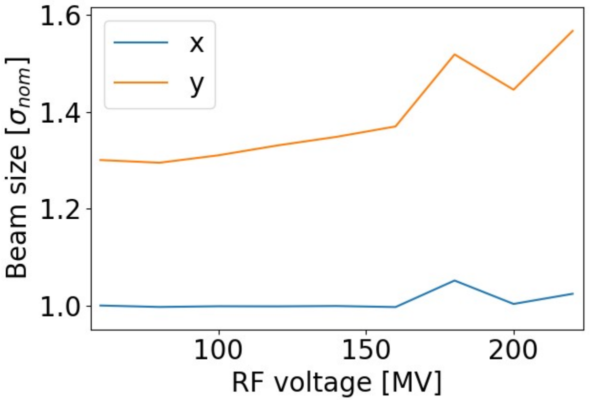

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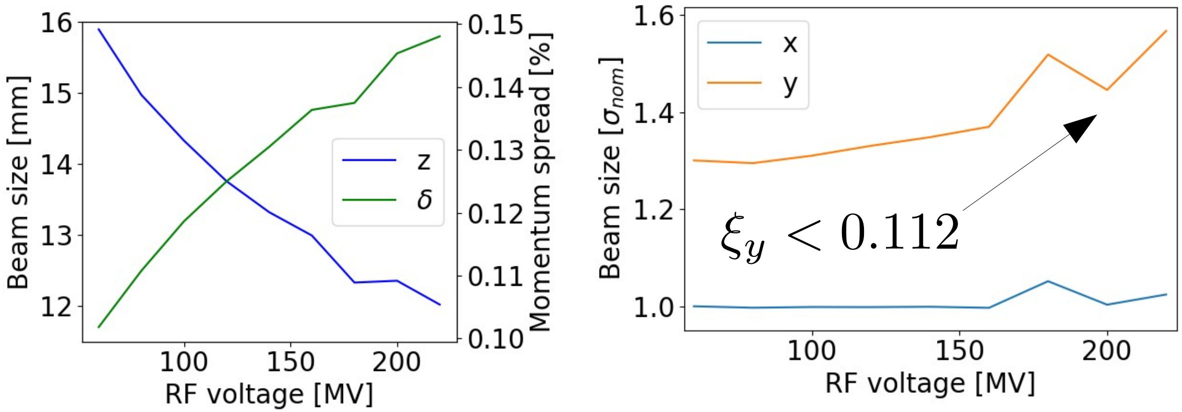

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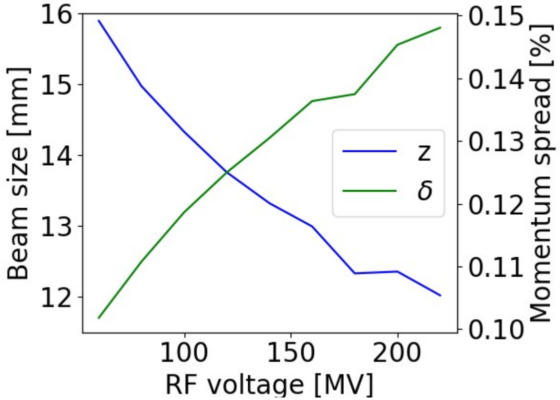
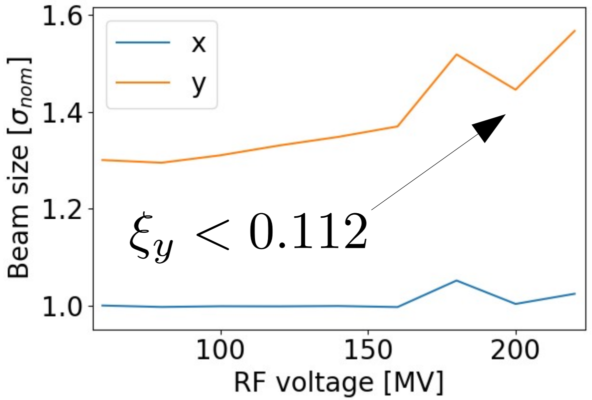
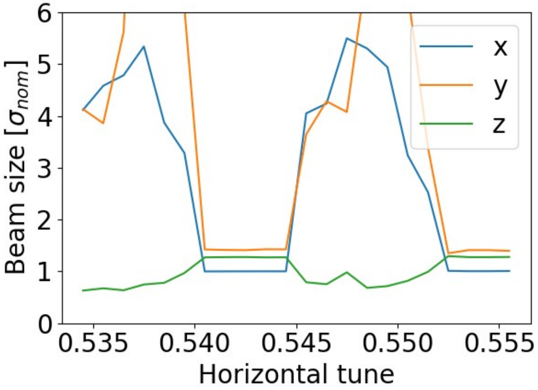
- Strong-strong simulations show a horizontal tune space of ~3E-3 (i.e. 1.2E-2 for the total machine → similar to other options)
  - Compatible with the synchrotron tune spread with RP (From I. Karpov at last meeting: 2.5e-3)







$$L \propto \frac{N\xi_y}{\beta_y}, \quad \xi_y \propto \frac{N\sqrt{\beta_y/\varepsilon_y}}{\sigma_z\theta}, \quad \xi_x \propto \frac{N}{(\sigma_z\theta)^2}$$

X-Z instability: $N_{th} \propto \frac{\nu_s}{\xi_x} \propto \frac{\alpha_c\sigma_p\sigma_z}{\beta_x}$

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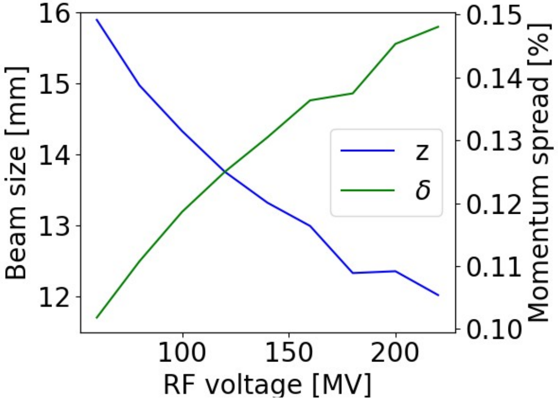
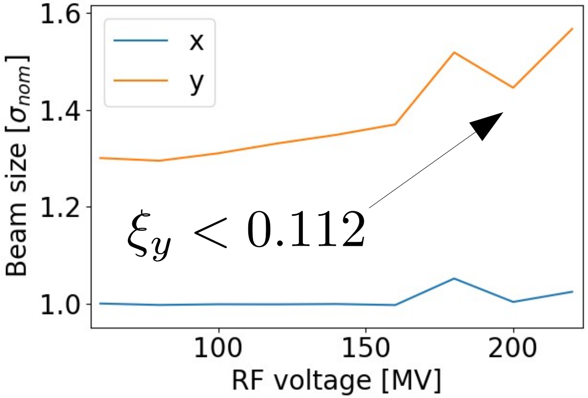
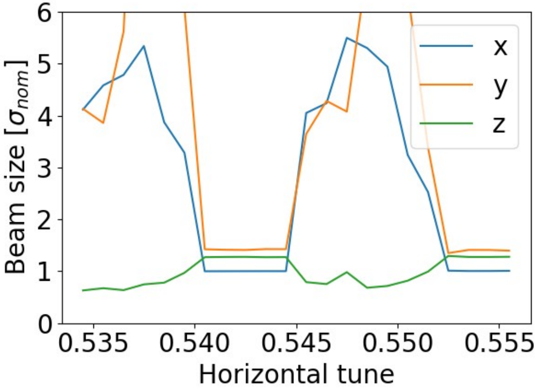
    → Need to consider additional synchrotron tune spread and potentially additional odd synchrobetatron resonance with longitudinal impedance







$$L \propto \frac{N\xi_y}{\beta_y}, \quad \xi_y \propto \frac{N\sqrt{\beta_y / \varepsilon_y}}{\sigma_z \theta}, \quad \xi_x \propto \frac{N}{(\sigma_z \theta)^2}$$

X-Z instability: $N_{th} \propto \frac{\nu_s}{\xi_x} \propto \frac{\alpha_c \sigma_p \sigma_z}{\beta_x}$

Beam-beam simulations (proposal 2)

- Quasi-strong-strong simulation with beam-beam (no impedance) are agreement with Oide’s parameter table

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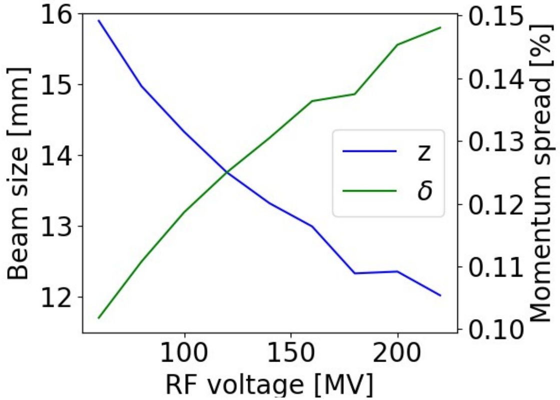
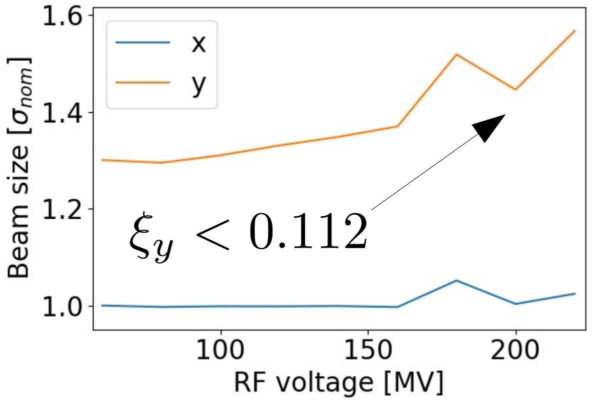
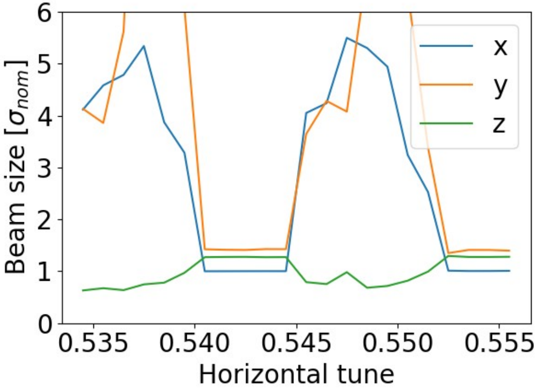
    → Need to consider additional synchrotron tune spread and potentially additional odd synchrobetatron resonance with longitudinal impedance

    → In case of issues, one would need to consider larger β_x to increase the available tune space





$\xi_y < 0.112$



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Weak-strong tune survey

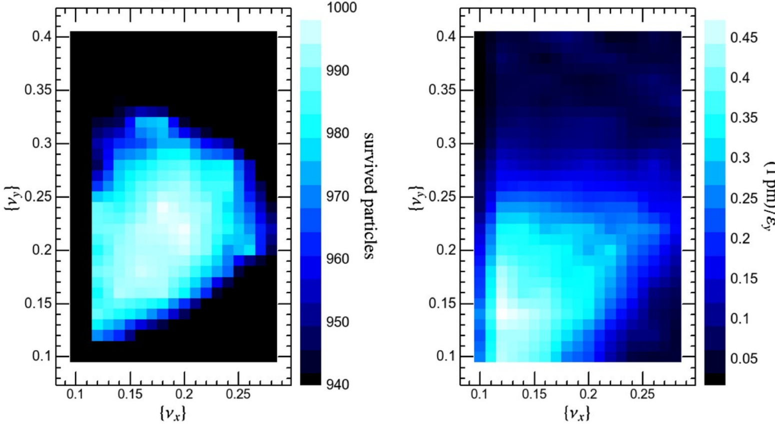
K. Oide

- The area of good tunes is reduced due to the larger beam-beam parameter

Proposal 2: `FCCee_z_605_nosol_2_200MV_1_bb_ts.sad`

$N = 2.16 \times 10^{11}$, Crab waist = 50%, turns = 4000, particles = 1000,

$\beta^*_{x,y} = \{.11\,\mathrm{m},\ .7\,\mathrm{mm}\}$, $\nu_z = -.0489$, $\varepsilon_{y,\mathrm{lattice}} = .8715\,\mathrm{pm}$



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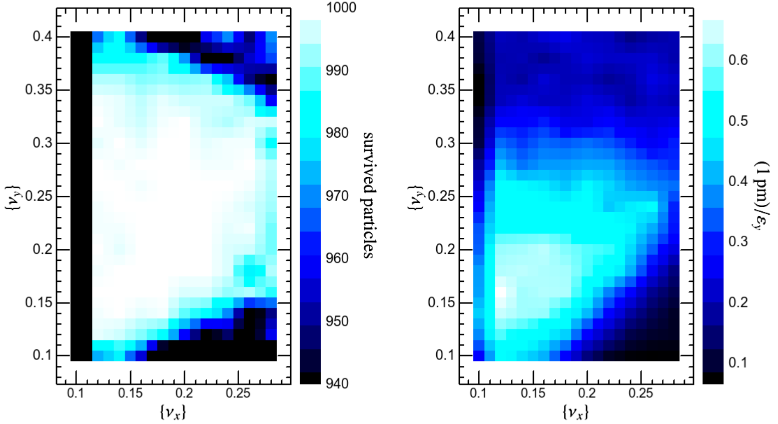

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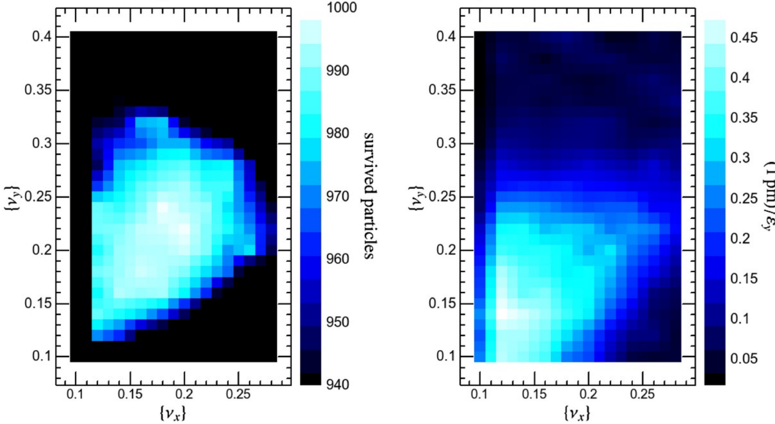
  → Consider larger vertical emittance, i.e. ‘coarser’ optics tuning (+25% brings both the luminosity and the vertical beam-beam tune shift to the level of the present ‘80MV’ scenario) ? (See K. Oide)



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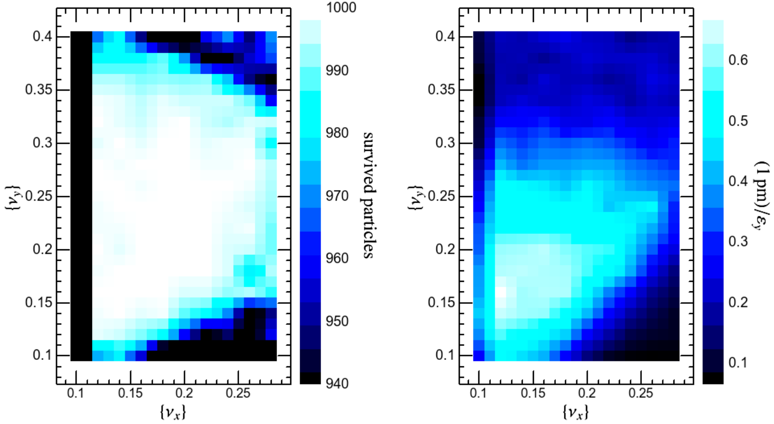

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  – Beamstrahlung does not depend strongly on the vertical emittance:

$$\frac{1}{\rho_{\min}} \propto \frac{N_p}{\gamma\sigma_x\sigma_z} \propto \frac{\xi_y}{\sqrt{\beta_x^*\beta_y^*}}\sqrt{\frac{\varepsilon_y}{\varepsilon_x}}$$

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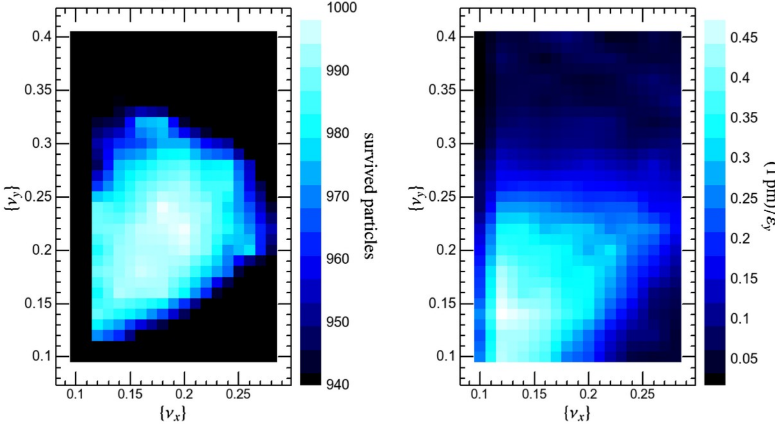

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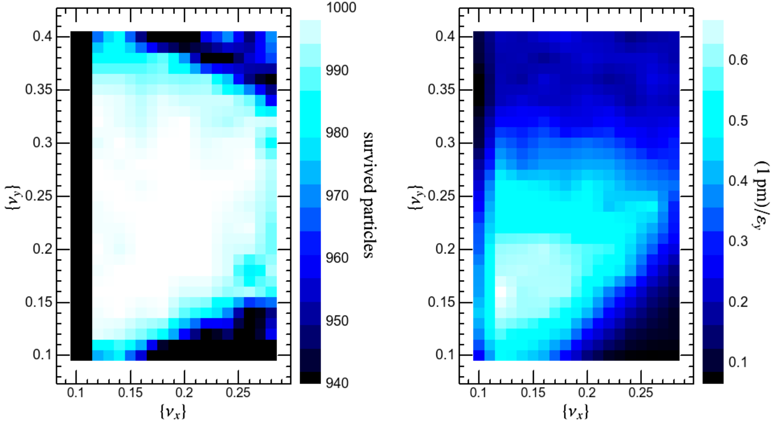

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  - The reduction of bunch length linked to the increased voltage is partially compensated by higher beamstrahlung (→ larger energy spread), further lengthening is expected due to the longitudinal impedance → Combine effect of longitudinal impedance and beam-beam should be further studied (Main concern: horizontal tune space between sidebands → X-Z instability)

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