FCC-ee Collective Effects

(open points and where help is needed)

M. Migliorati

C. Antuono, E. Carideo, Y. Zhang, M. Zobov

Outline

- FCC-ee main parameters
- Overview of wakefields and impedances evaluated so far
- Longitudinal and transverse single beam instabilities
- Interplay between beam-beam and longitudinal beam coupling impedance
- Possible ABP support

FCC-ee main parameters

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	91.180			
Bending radius of arc dipole	[km]	9.935			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1400	135	26.7	5.00
Bunches / beam		8800	1320	280	42
Bunch population	[10^{11}]	2.76	1.94	1.81	2.26
Horizontal emittance ε_x	[nm]	0.71	2.17	0.64	1.49
Vertical emittance ε_y	[pm]	1.42	4.34	1.29	2.98
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.5		7.33	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	150 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		55.543 / 55.600		100.543 / 99.600	
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0.138	0.069 / 0.137	0.103 / 0.202	0.157 / 0.238
Bunch length (SR/BS) σ_z	[mm]	4.32 / 15.2	2.96 / 5.90	2.50 / 4.90	1.67 / 2.54
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.35 / 0	2.48 / 0	4.0 / 7.67
Synchrotron tune Q_s		0.0370	0.0237	0.0438	0.0890
Long. damping time	[turns]	1170	216	64.5	18.5
RF acceptance	[%]	1.6	4.3	2.3	3.7
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y [a]		0.0040 / 0.159	0.0135 / 0.110	0.0185 / 0.141	0.096 / 0.138
Luminosity / IP	[10^{34}/cm^{2}s]	181	17.4	7.8	1.25
Lifetime (q + BS)	[sec]	–		422	2770
Lifetime (lum)	[sec]	1136	1197	552	743

[a] incl. hourglass.

Lowest beam energy: highest beam current, highest number of bunches, highest bunch population, and (almost) lowest emittance

Important for collective effects

FCC-ee updated main parameters at lowest energy: comparison with CDR

In Layout 31.10
→ 4 IPs

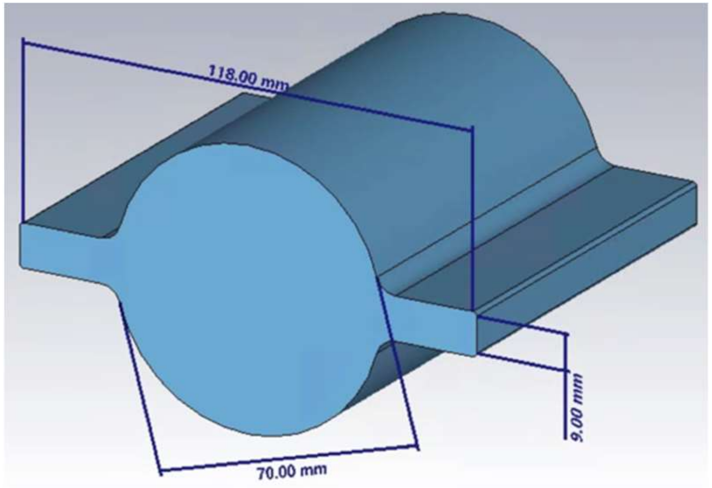
Parameter list	Layout 31.10	CDR
Circumference (km)	91.180	95.146
Beam energy (GeV)	45.6	45.6
Beam current (A)	1.28	1.4
Bunch population [10^{11}]	2.76	1.69
Bunch length [mm](SR/BS)	4.32/15.2	3.5/12.1
Energy spread(SR/BS) [10^{-3}]	0.39/1.38	0.38/1.54
Synchrotron tune	0.0370	0.0248
Bunches/beam	8800	16400
Mom compaction [10^{-6}]	28.5	15.3
Energy loss/turn (MeV)	39.1	35.7
RF Voltage (MV)	120	98

Outline

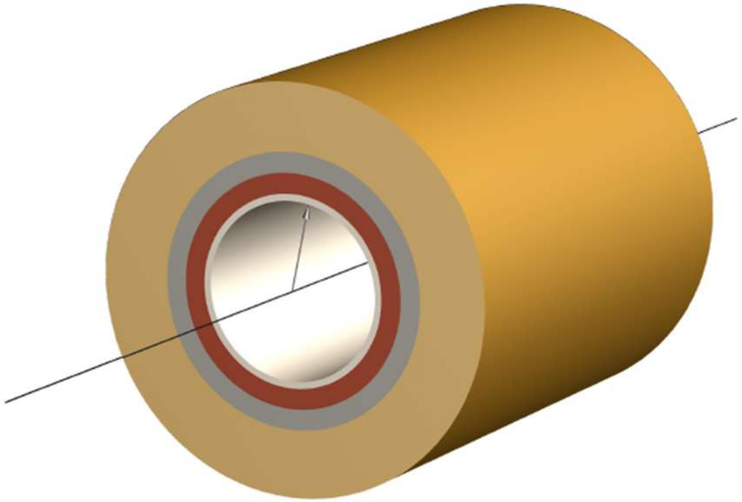
- FCC-ee main parameters
- Overview of wakefields and impedances evaluated so far
- Longitudinal and transverse single beam instabilities
- Interplay between beam-beam and longitudinal beam coupling impedance
- Possible ABP support

Resistive wall

Real beam pipe cross section

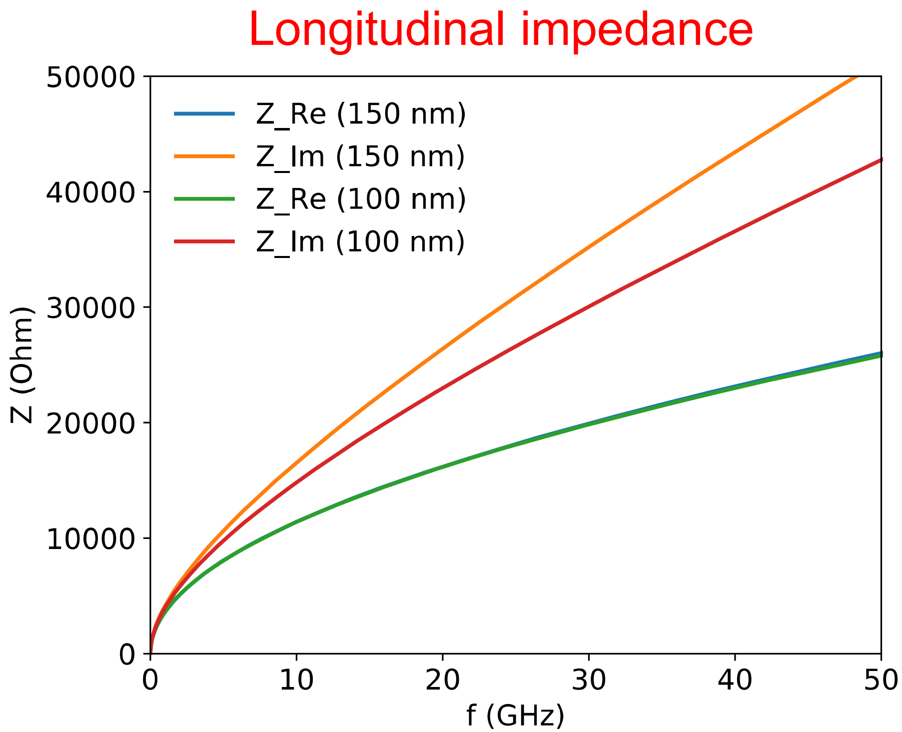


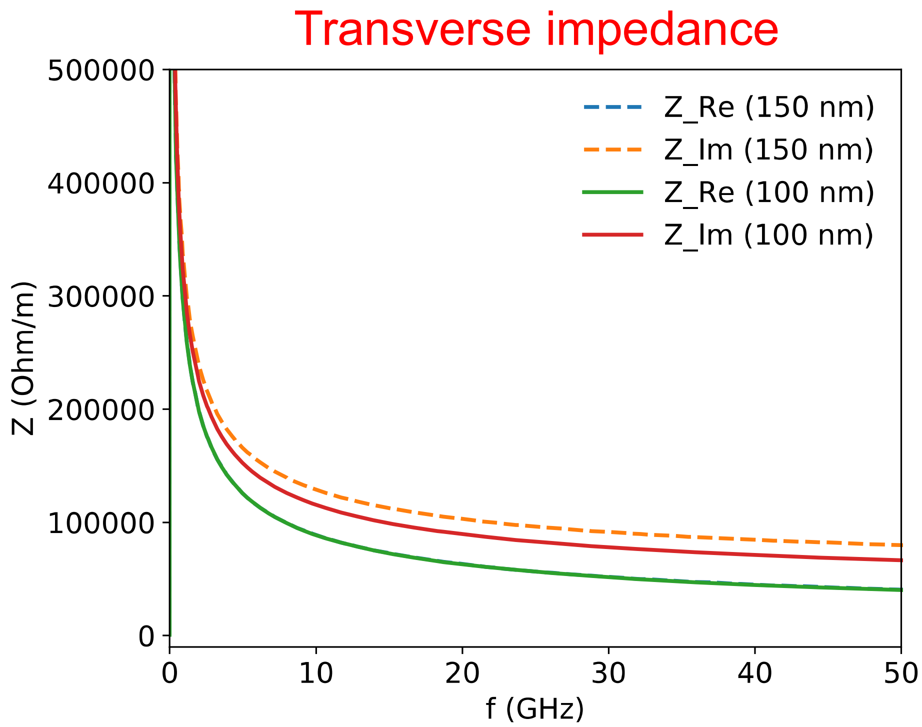
IW2D used model



IRON	$\Delta = \infty$	$\rho = 6.89 \cdot 10^{-7} \Omega m$
DIELECTRIC	$\Delta = 6\ mm$	$\rho = 10^{-15} \Omega m$
COPPER	$\Delta = 2\ mm$	$\rho = 1.66 \cdot 10^{-8} \Omega m$
NEG	$\Delta = 150\ nm$	$\rho = 10^{-6} \Omega m$

Resistive wall

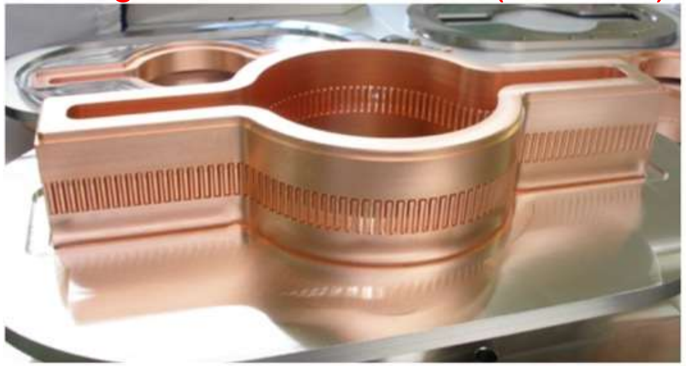


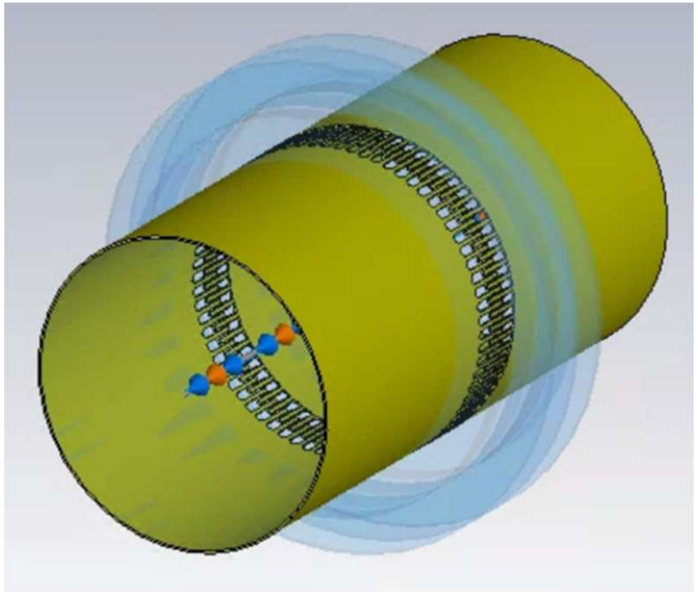


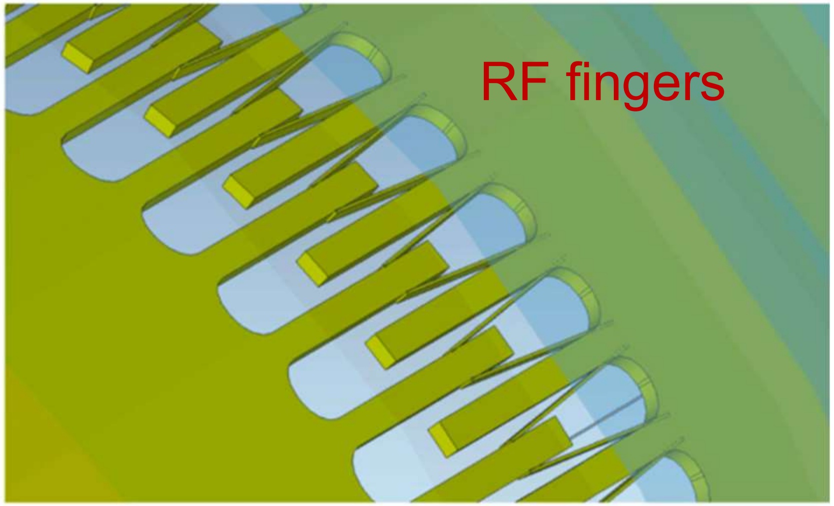
IW2D results: comparison between 100 nm and 150 nm coatings
(new reference value from vacuum group)

Bellows – initial model

Y. Suetsugu, Japan-Italy Collaboration Meeting "Crab Factories” 2008 (INFN-LNF)







A comment on the number of bellows:

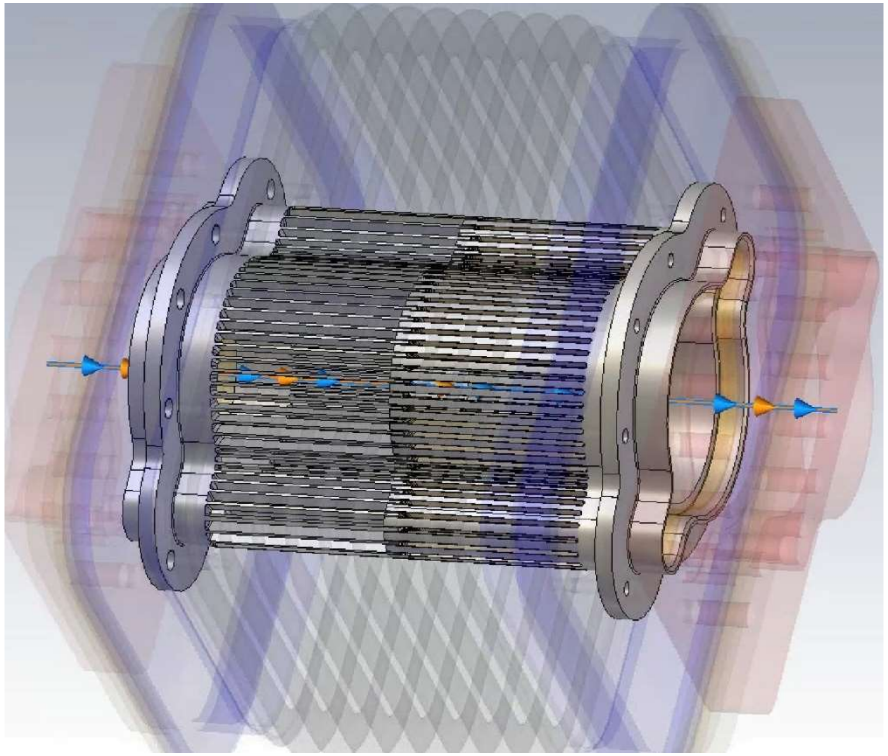
- 2900 dipole arcs 24 m long. We consider bellows every 8 m → 2900*3=8700
- 2900 quads/sextupoles arcs

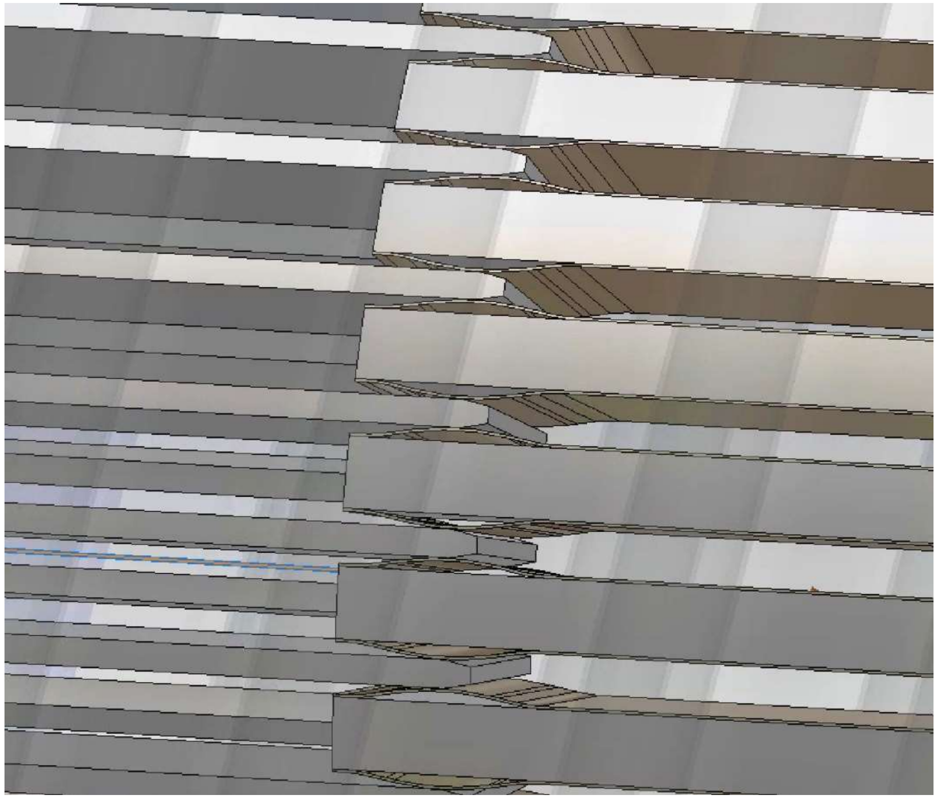
total of 11600 bellows plus:

- RF, injection system, collimators, …

As a pessimistic estimation we have considered 20000 bellows

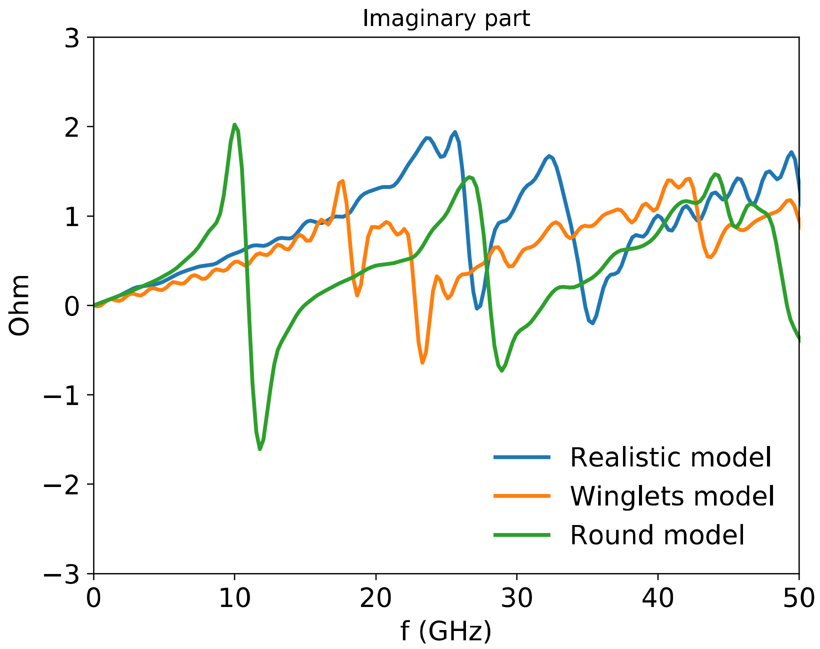
Bellows – realistic model

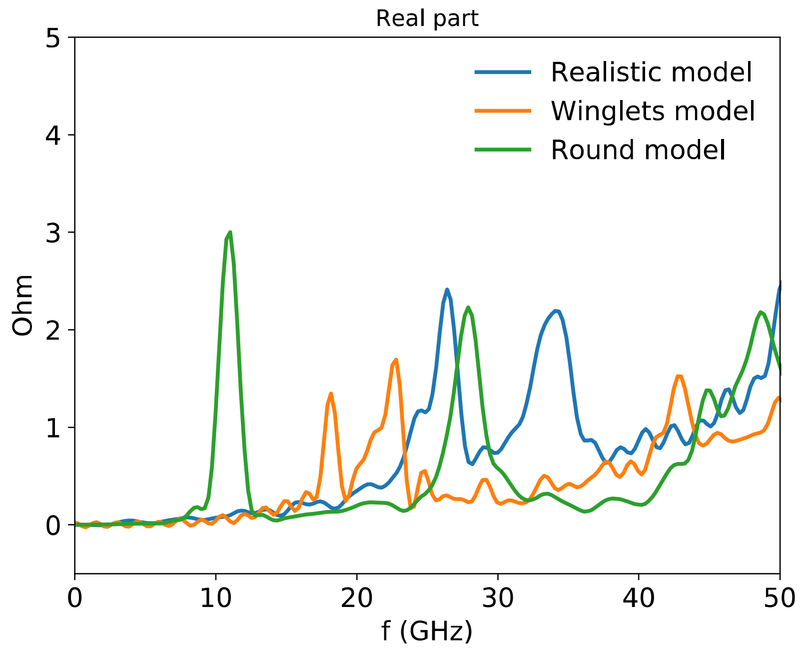




Bellows – realistic model

Longitudinal impedance

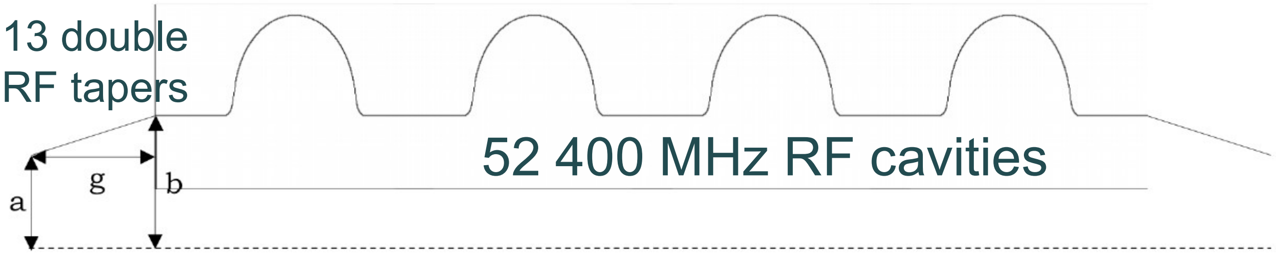


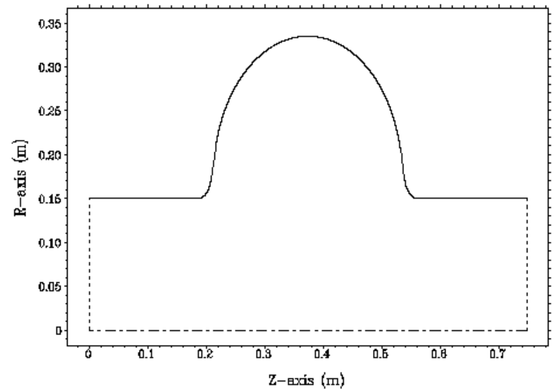


RF system

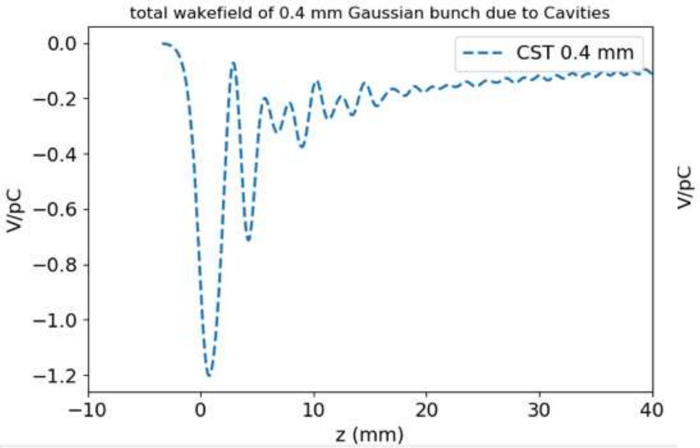
13 double
RF tapers

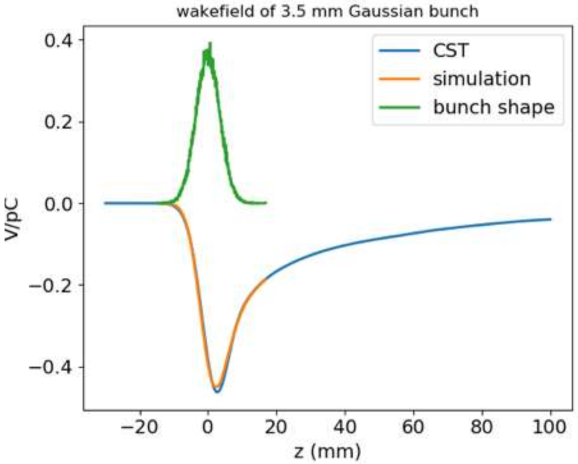
52 400 MHz RF cavities

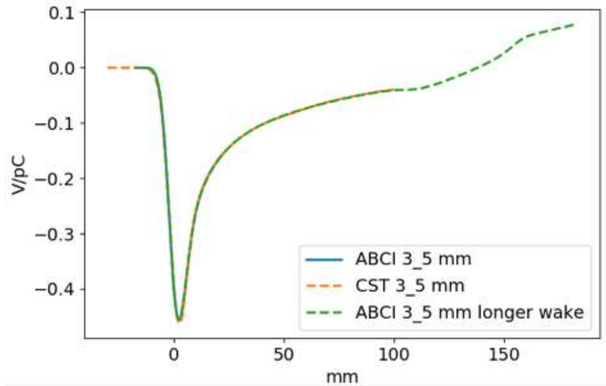




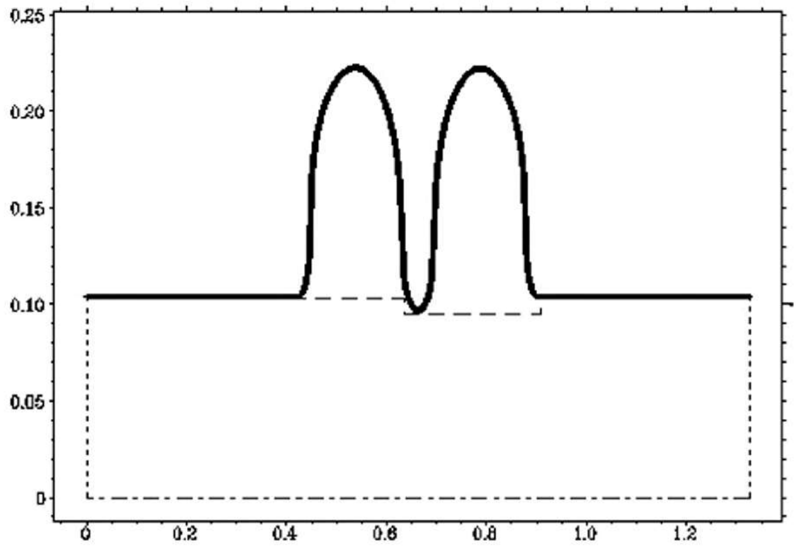
Tapers: transition from radius a = 50 mm outside the cryomodule to radius b = 150 mm inside the cryomodule (or vice-versa).
We assumed g = 0.5 m

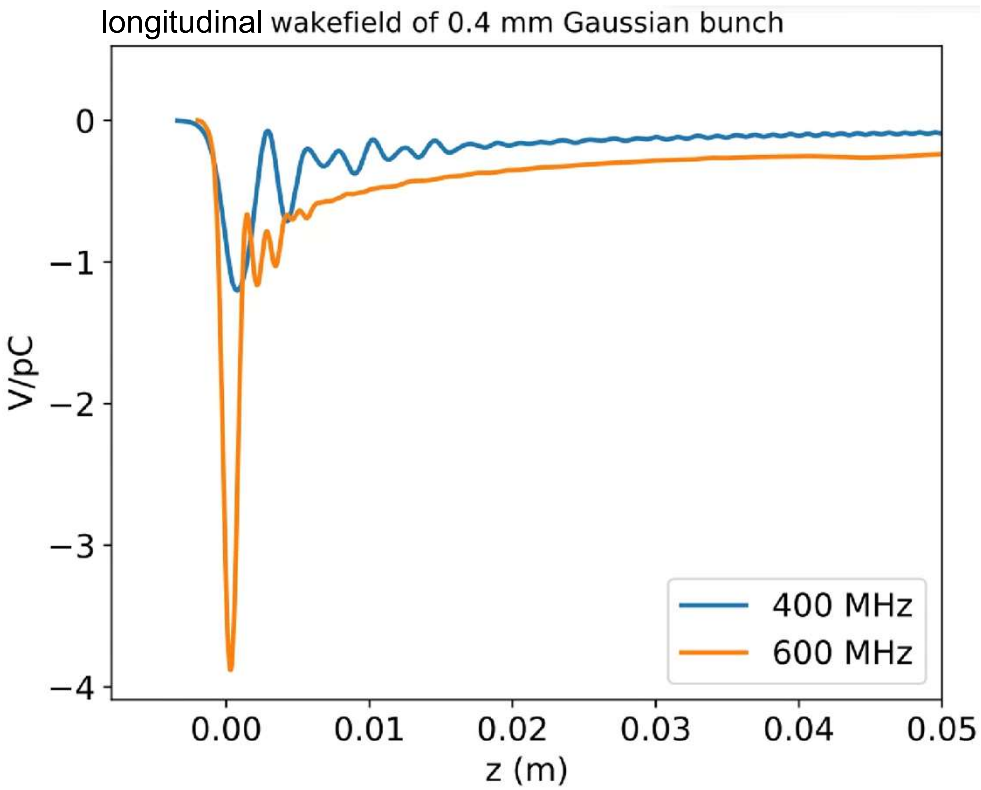




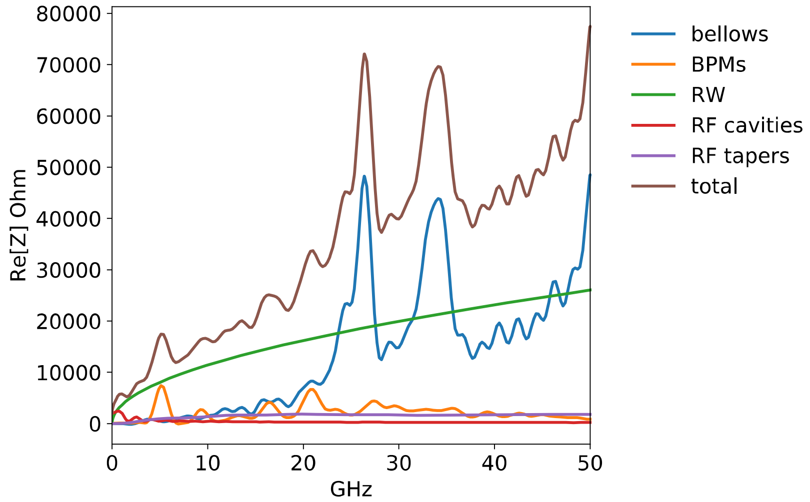


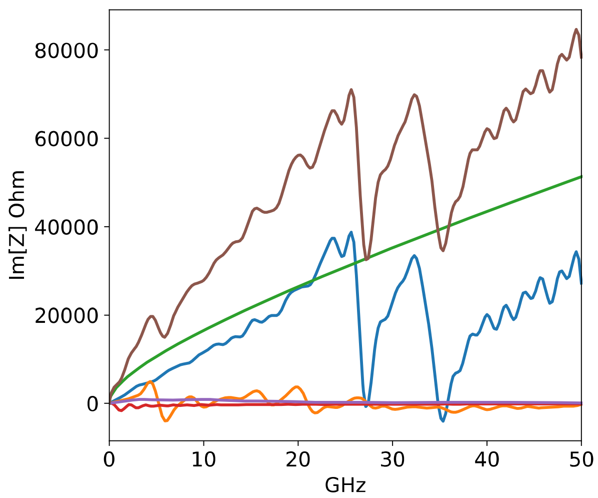
RF system – 600 MHz cavity option

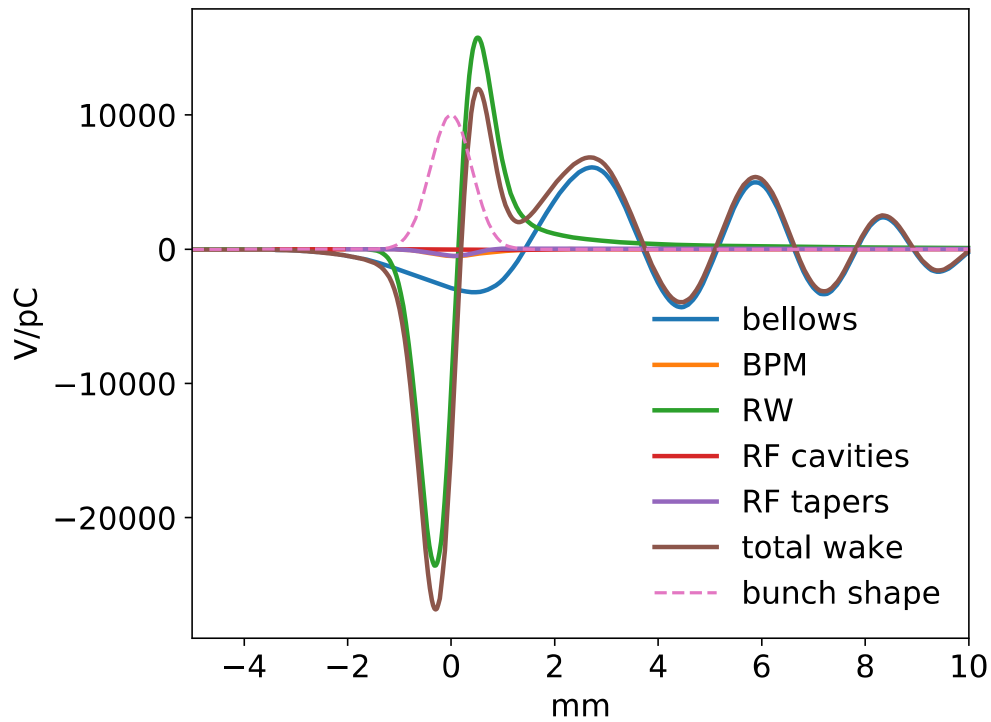




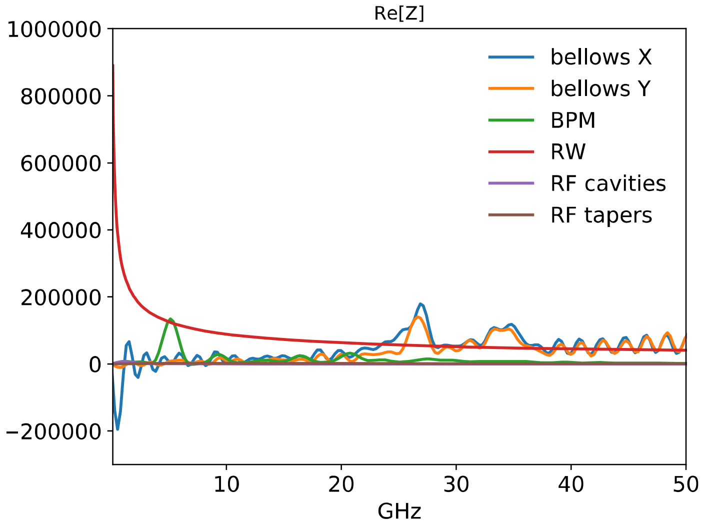
Total impedance and wake – longitudinal plane

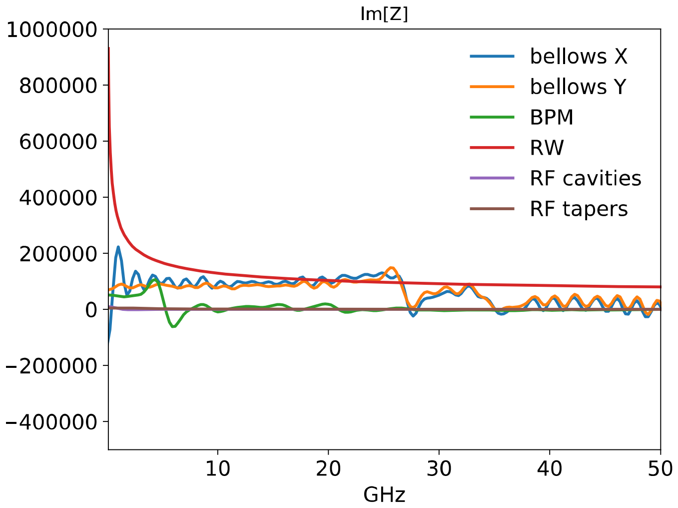


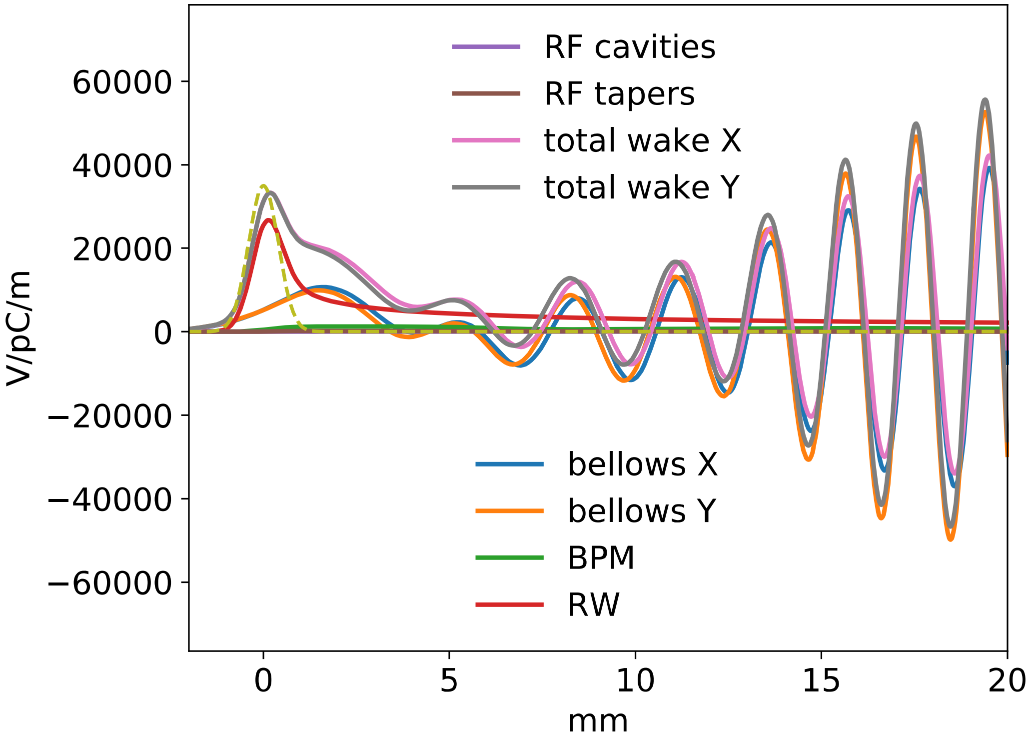




Total impedance and wake – transverse plane





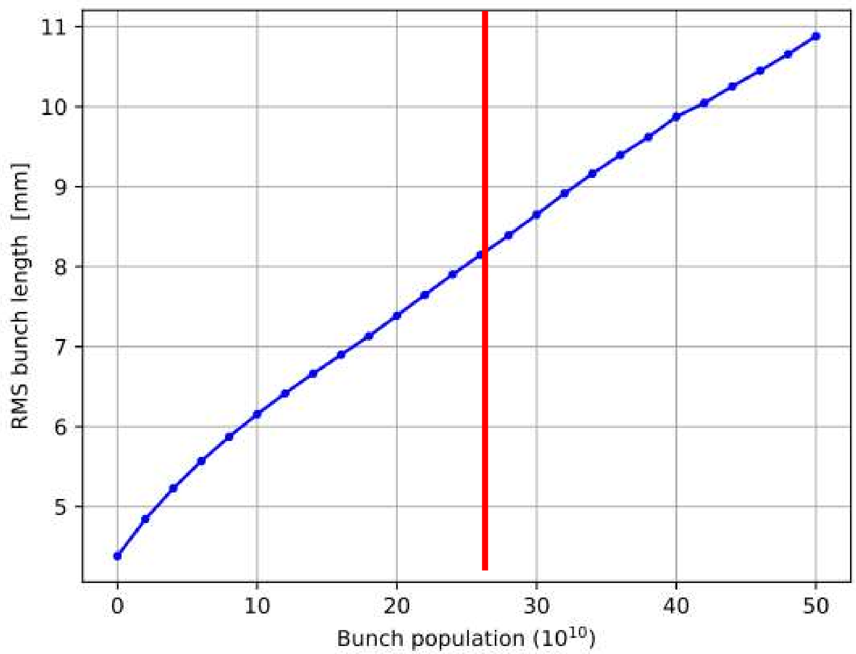


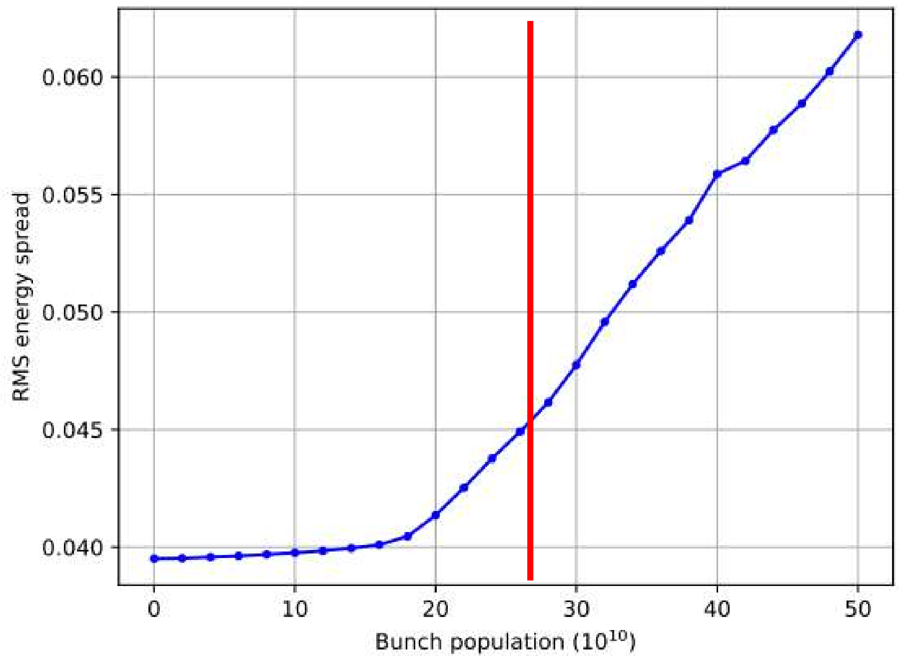
Outline

- FCC-ee main parameters
- Overview of wakefields and impedances evaluated so far
- Longitudinal and transverse single beam instabilities
- Interplay between beam-beam and longitudinal beam coupling impedance
- Possible ABP support

Effects on beam dynamics (PyHT simulations): longitudinal MI

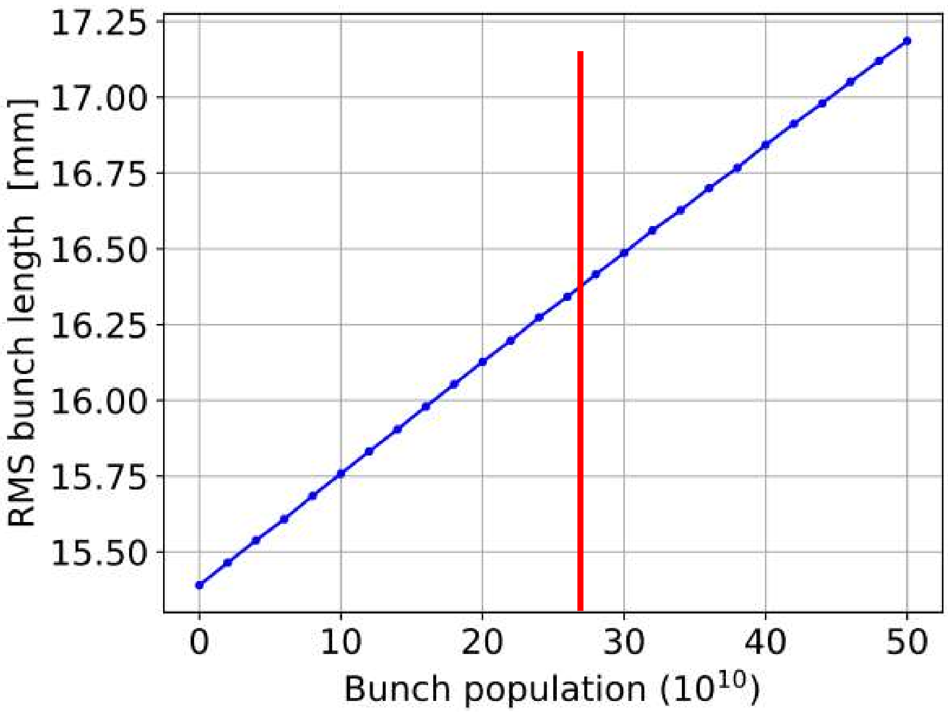
Only SR

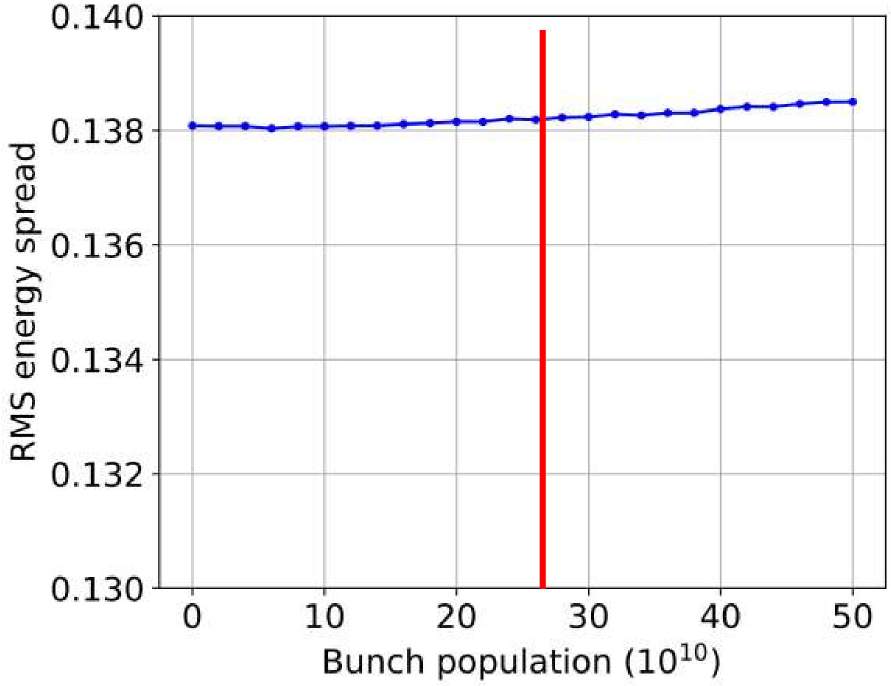




Effects on beam dynamics (PyHT simulations): longitudinal MI

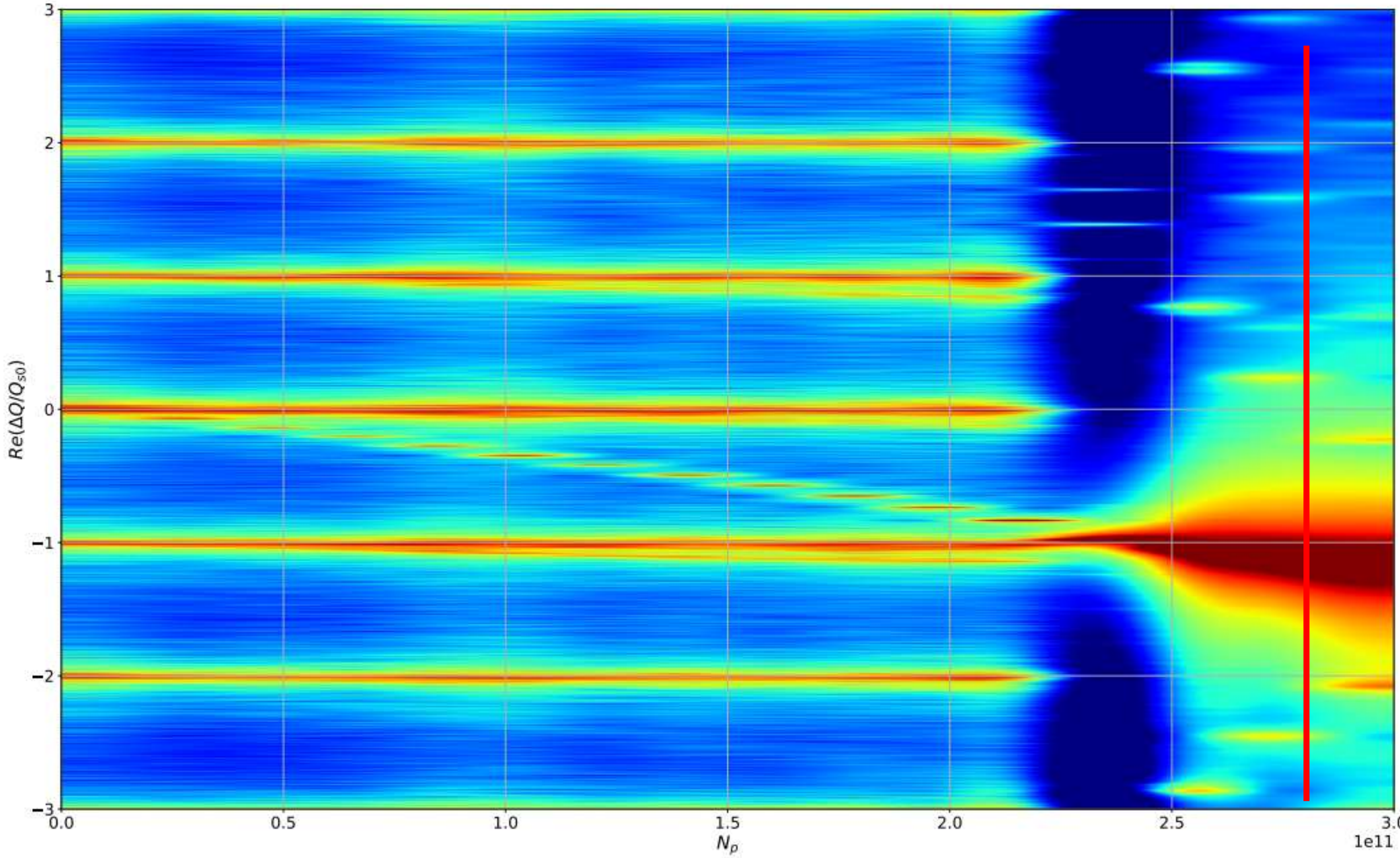
SR + beamstrahlung





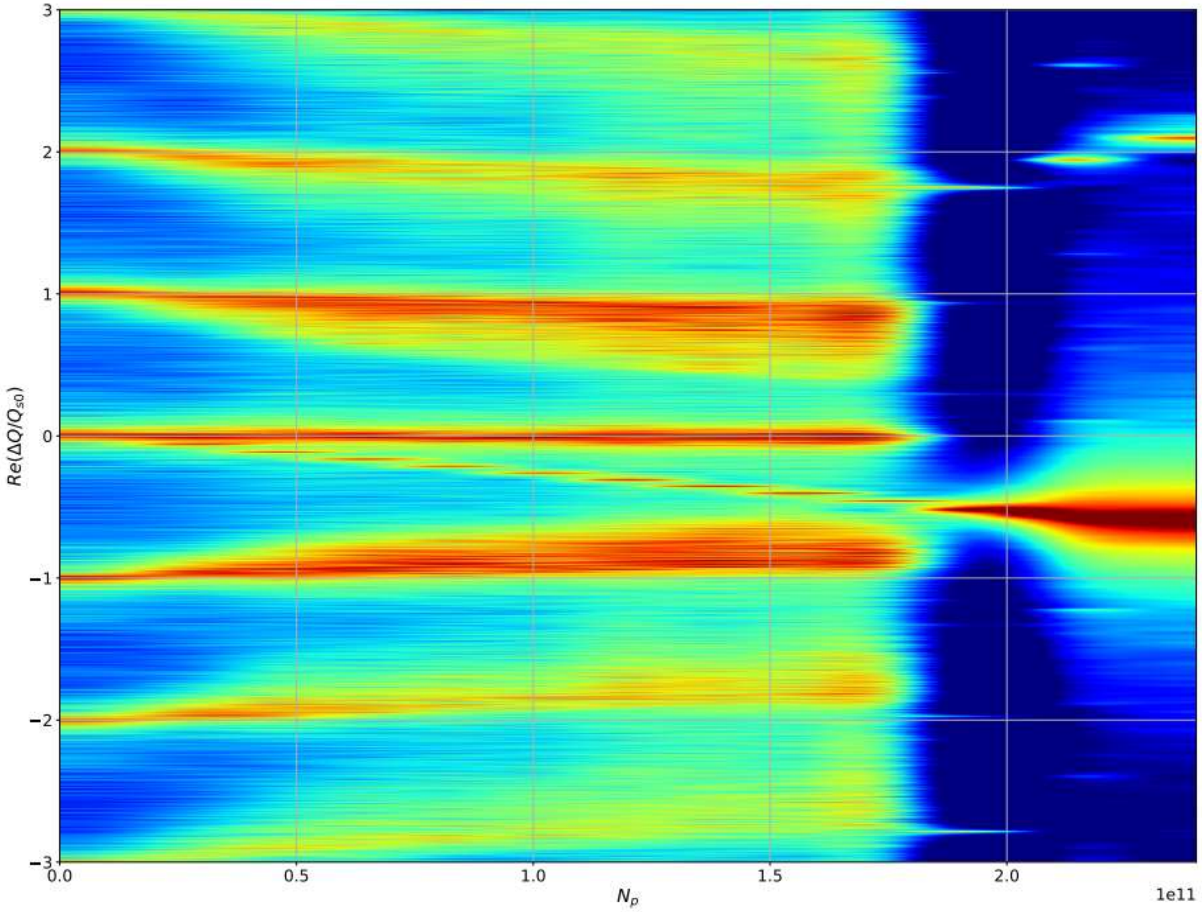
Effects on beam dynamics (PyHT simulations): transverse TMCI

Only SR – Only transverse wake



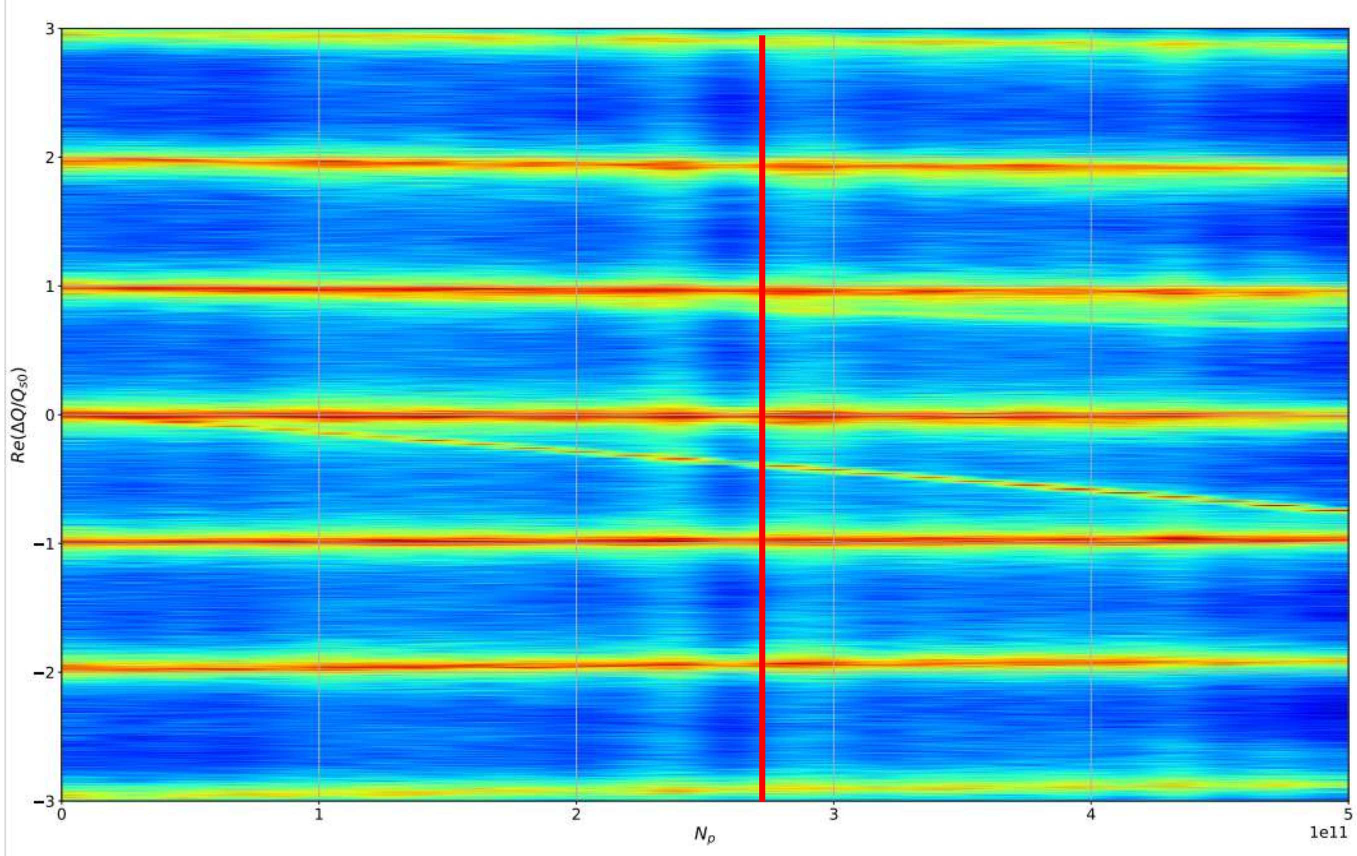
Effects on beam dynamics (PyHT simulations): transverse TMCI

Only SR – Longitudinal and transverse wake – x plane



Effects on beam dynamics (PyHT simulations): transverse TMCI

SR + beamstrahlung (longitudinal + transverse wake)

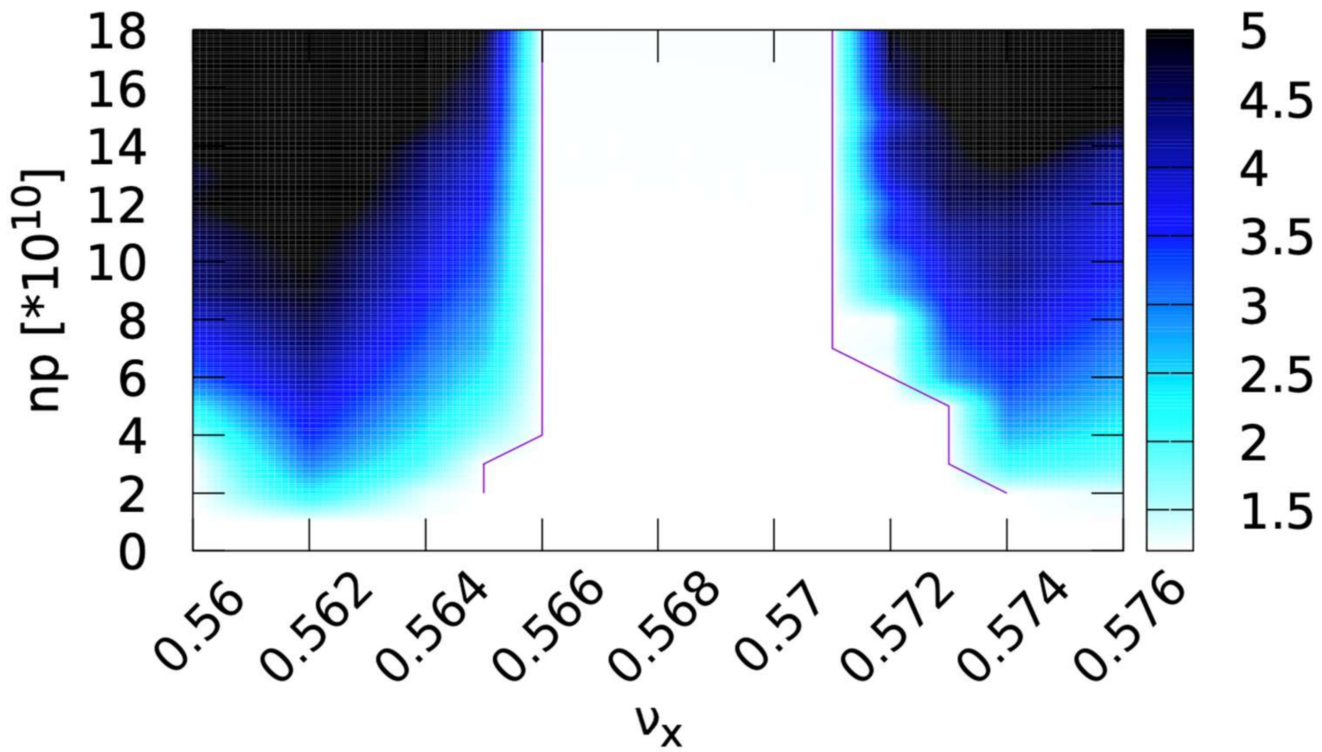


Outline

- FCC-ee main parameters
- Overview of wakefields and impedances evaluated so far
- Longitudinal and transverse single beam instabilities
- Interplay between beam-beam and longitudinal beam coupling impedance
- Possible ABP support

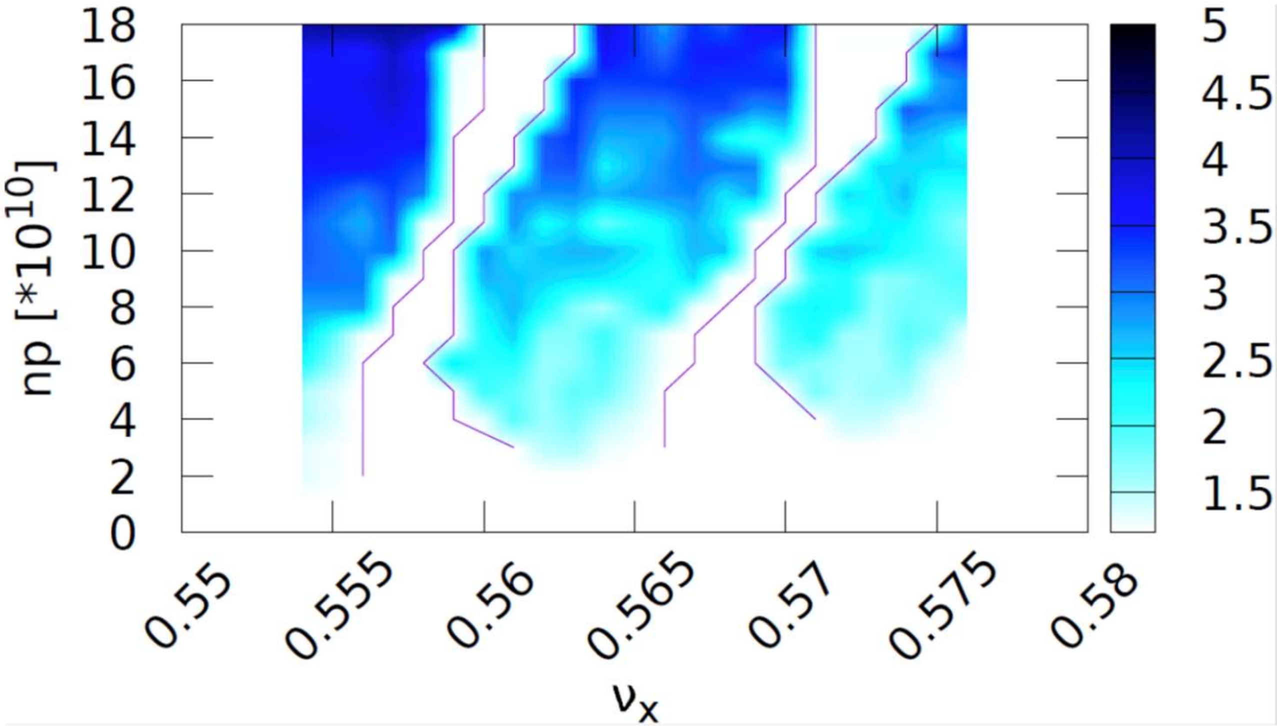
Interplay between beam-beam and longitudinal impedance

The X-Z instability is a novel coherent beam-beam instability appearing with a large crossing angle and resulting in a blow-up of the horizontal beam size



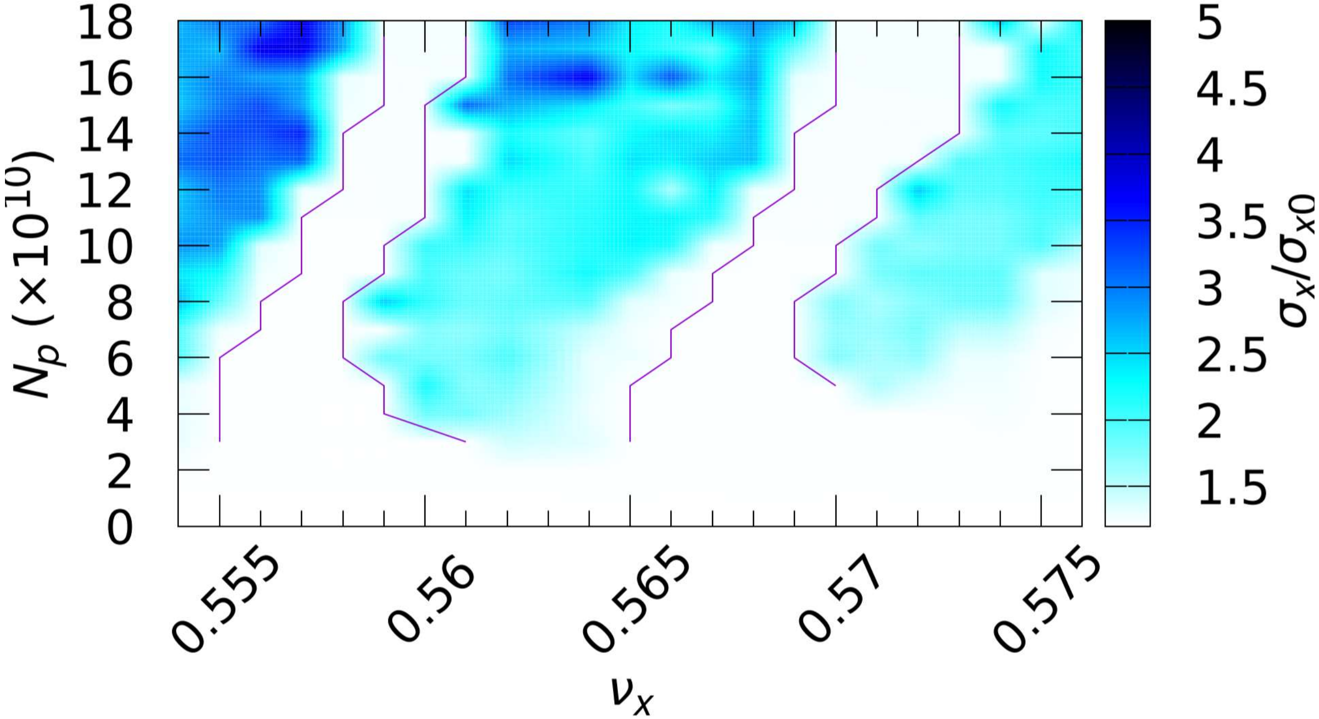
Without impedance – CDR parameters

Interplay between beam-beam and longitudinal impedance



With impedance – CDR parameters

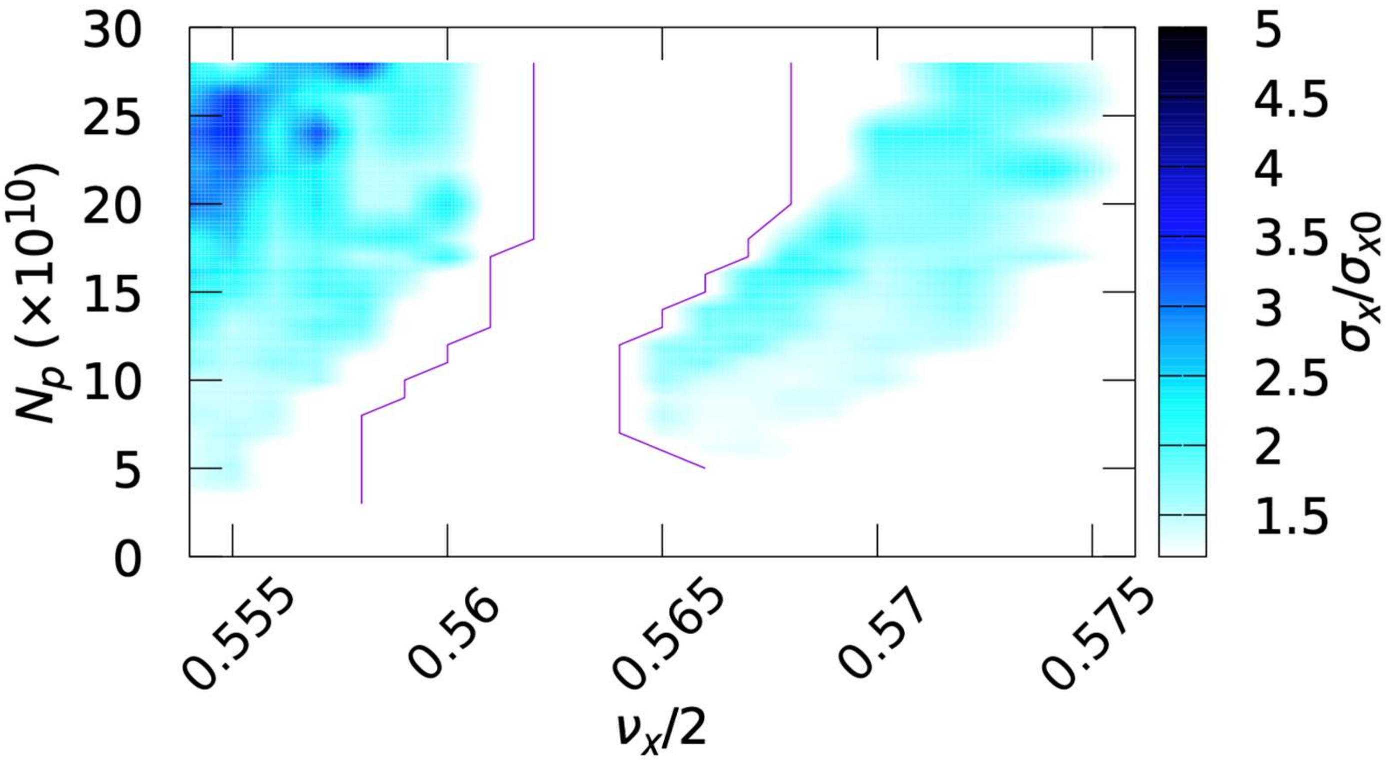
Interplay between beam-beam and longitudinal impedance



With impedance – CDR parameters – Qx'=5

Interplay between beam-beam and longitudinal impedance

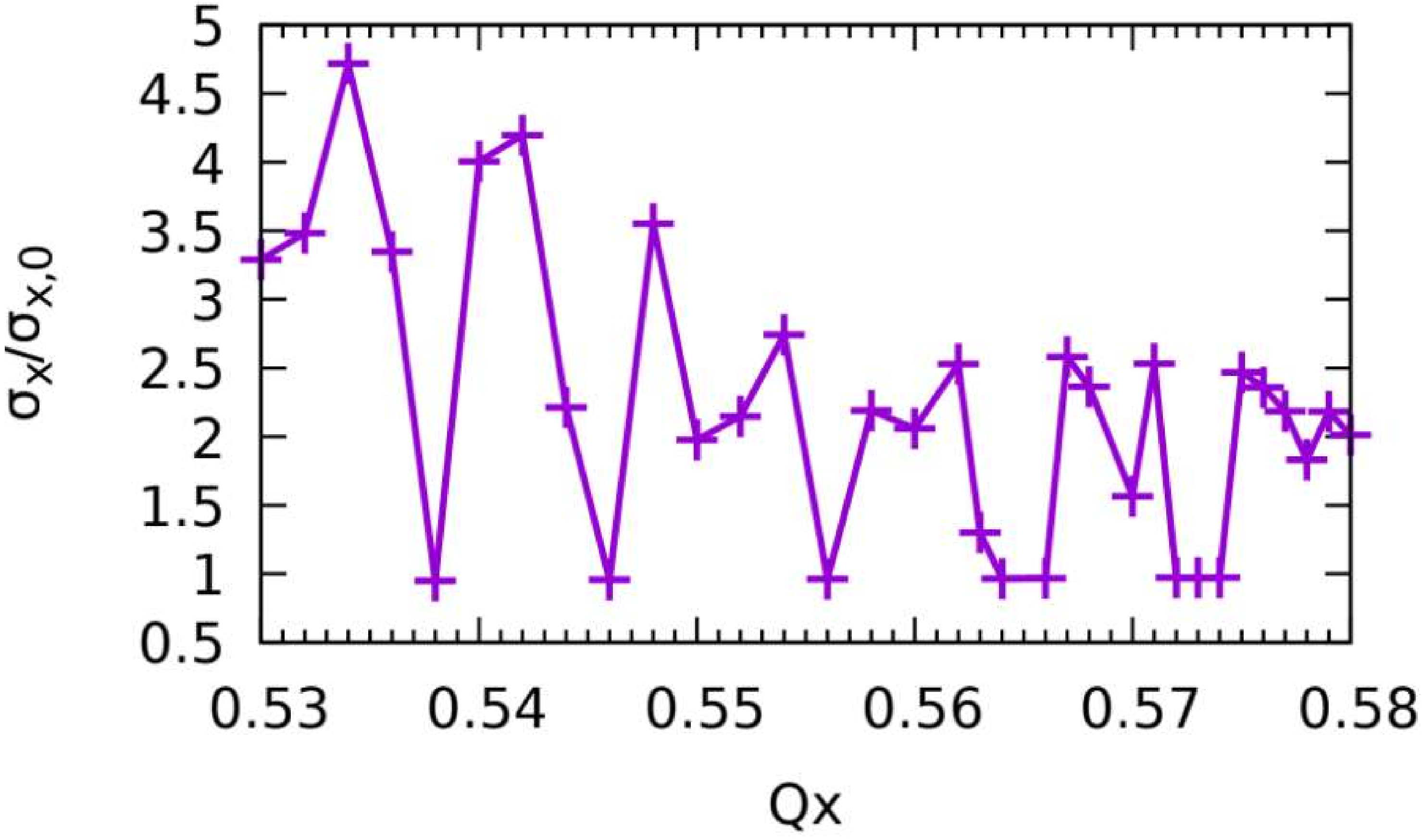
Mitigation methods for CDR parameters: higher harmonic cavity, higher momentum compaction factor



Higher momentum compaction factor

Interplay between beam-beam and longitudinal impedance

Preliminary study with new parameters: relative transverse size vs tune at nominal intensity with updated parameters and impedance



Outline

- FCC-ee main parameters
- Overview of wakefields and impedances evaluated so far
- Longitudinal and transverse single beam instabilities
- Interplay between beam-beam and longitudinal beam coupling impedance
- Possible ABP support

Work in progress

- Working on a repository for impedance/wakefields and input files for beam dynamics simulations
- Important missing sources:
  - Collimators
  - Kickers
  - Vacuum Flanges
  - SR absorbers (first estimation gave negligible contribution)
- A fellows should start to work for the impedance budget starting from January 2022

Open points and possible help: wake fields and impedance

- The evaluation of wake and impedance needs time and computing resources since the bunch length is quite small and the vacuum chamber quite large → we expect that in the following more and more elements will be defined by the different groups (vacuum, instrumentation, …) and, maybe, one single person could not be sufficient.

- For example, it would be nice to be able to count on the ABP expertise for the evaluation of the collimators' impedance.

Open points and possible help: PyHT

- So far, we have used a single localized kick for both longitudinal and transverse wake. Also the longitudinal and transverse maps are localized in a single point of the machine
- For the transverse plane, it is possible to split the machine into segments (it's necessary to change the script, not the code), but this has not been done so far
- For the longitudinal plane, as far as I understand, this is not possible and one should change the source
- It would be nice to count on the ABP experts for modifying scripts and, in case, PyHT source, to adapt the code to the different needs

Open points and possible help: PyHT

- It is interesting to split the machine into segments, each one having its own longitudinal wake, transverse wake weighted by the local beta function, RF system (which is not evenly distributed along the machine), eventually a higher harmonic cavity system, …
- This could also allow to study the effects of possible transverse localized impedances
- So far the transverse map has been considered linear. It would be interesting to import MADX lattice and use directly this one for the simulations of transverse dynamics

Open points and possible help: PyHT

- More ambitious and long-lasting plan:
- The collective effects in PyHT have been tested against several codes (e.g. SBSC and MuSiC for the longitudinal dynamics and DELPHI Vlasov solver for the transverse one)
- For FCC-ee it is of fundamental importance the interplay of collective effects and beam-beam
- So far only the longitudinal wake has been taken into account in the beam-beam effect thanks to the collaboration with Yuan Zhang from IHEP - China (that I hope can continue in the future!)

Open points and possible help: PyHT

- Is it possible to develop a routine for PyHT to include the beam-beam effect into the code?
- Does this require additional computing resources with respect to the ones that we are using now (HTCondor)?
- This would allow to study the interplay of longitudinal and transverse dynamics with beam-beam
- T. Pieloni is working on a project of code development for FCC …

Other topics

- Electron could, including the multi-bunch effects
- Ion instabilities
- Impedance evaluation, repository, and collective effects in the Booster and in the whole injection system
- Longitudinal and transverse feedback system for coupled bunch instabilities (in particular, very important for the transverse plane due to the resistive wall, also in the Booster)
- …