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E APPLICATE PER L' INGEGNERIA

FUTURE
CIRCULAR
COLLIDER
Innovation Study

Single-beam collective effects: overview and impedance update

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FCCIS WP2 – accelerator session

Overview and impedance update	M. Migliorati (Sapienza)
Single-bunch instabilities	E. Carideo (Sapienza & CERN)
Resistive wall impedance	A. Rajabi (DESY)
Combined effect beam-beam & impedance	Y. Zhang (IHEP)
Recent Advances on the FCC-ee Electron Cloud Build-up Studies	F. Yaman (IIT)

Outline

- FCC-ee main parameters
- Review of wakefields and impedance model
- Transverse coupled bunch instabilities and feedback system
- Interplay between longitudinal wakefield, transverse wakefield, feedback system and beam-beam

FCC-ee main parameters

Layout	PA31-1.0			
	Z	WW	ZH	$t\hat{t}$
Circumference (km)	91.174117 km			
Beam energy (GeV)	45.6	80	120	182.5
Bunch population (10^{11})	2.53	2.91	2.04	2.64
Bunches per beam	9600	880	248	36
RF frequency (MHz)	400			400/800
RF Voltage (GV)	0.12	1.0	2.08	4.0/7.25
Energy loss per turn (GeV)	0.0391	.37	1.869	10.0
Longitudinal damping time (turns)	1167	217	64.5	18.5
Momentum compaction factor 10^{-6}	28.5		7.33	
Horizontal tune/IP	55.563		100.565	
Vertical tune/IP	55.600		98.595	
Synchrotron tune	0.0370	0.0801	0.0328	0.0826
Horizontal emittance (nm)	0.71	2.17	0.64	1.49
Verical emittance (pm)	1.42	4.34	1.29	2.98
IP number	4			
Nominal bunch length (mm) (SR/BS)*	4.37/14.5	3.55/8.01	3.34/6.0	2.02/2.95
Nominal energy spread (%) (SR/BS)*	0.039/0.130	0.069/0.154	0.103/0.185	0.157/0.229
Piwinski angle (SR/BS)*	6.35/21.1	2.56/5.78	3.62/6.50	0.79/1.15
ξ_x/ξ_y	0.004/0.152	0.011/0.125	0.014/0.131	0.096/0.151
Horizontal β^* (m)	0.15	0.2	0.3	1.0
Vertical β^* (mm)	0.8	1.0	1.0	1.6
Luminosity/IP ($10^{34}/\text{cm}^2\text{s}$)	181	17.4	7.8	1.25

*SR: syncrotron radiation, BS: beamstrahlung

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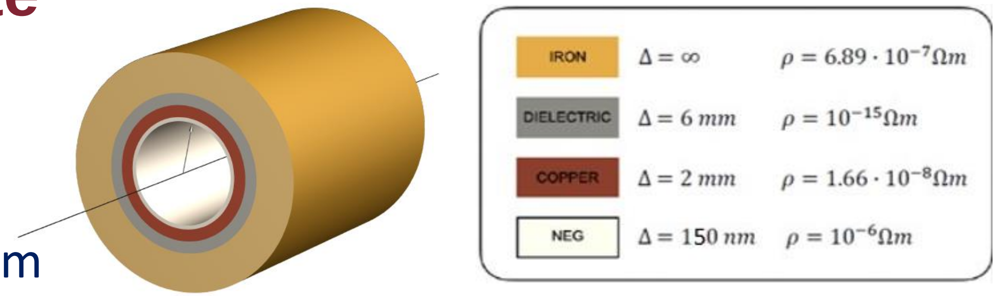
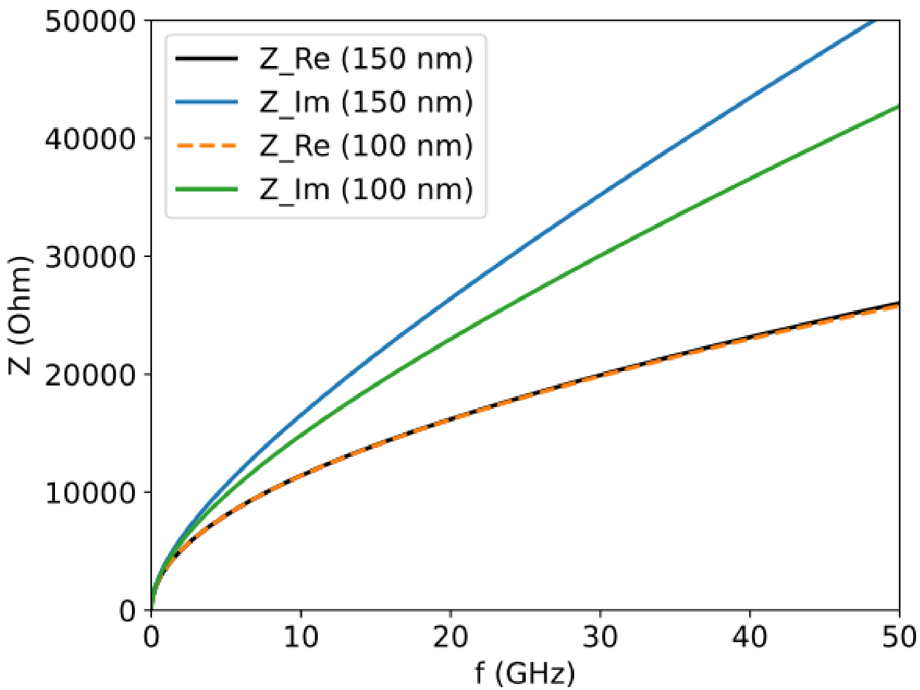
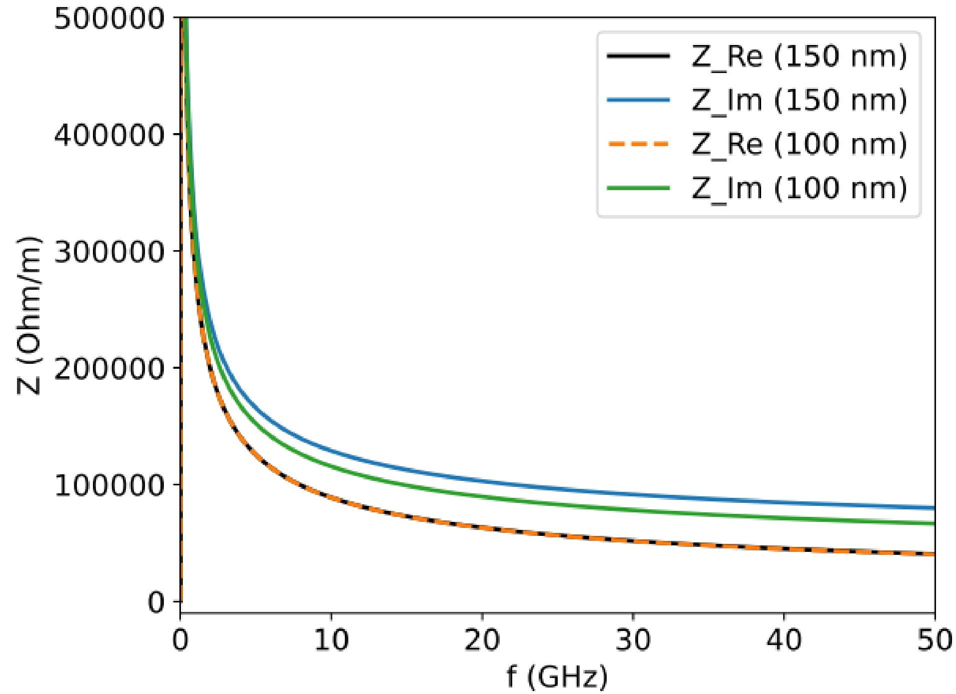
Resistive wall - update

In order to guarantee a uniform coating all along the beam pipe, coating thickness was increased from 100 nm to 150 nm (R. Kersevan).



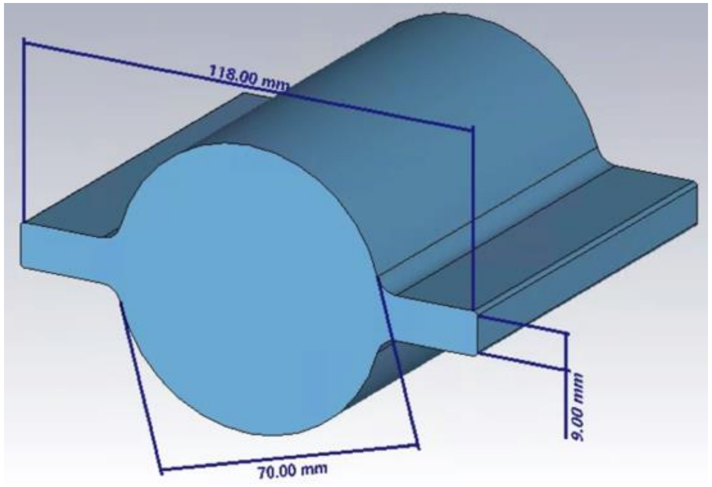
IW2D results for a circular pipe





Resistive wall – winglets contribution

1) We have first evaluated the impedance with the real vacuum chamber geometry but with a single layer and a ‘relatively’ low conductivity (still in the good conductor regime) with CST.

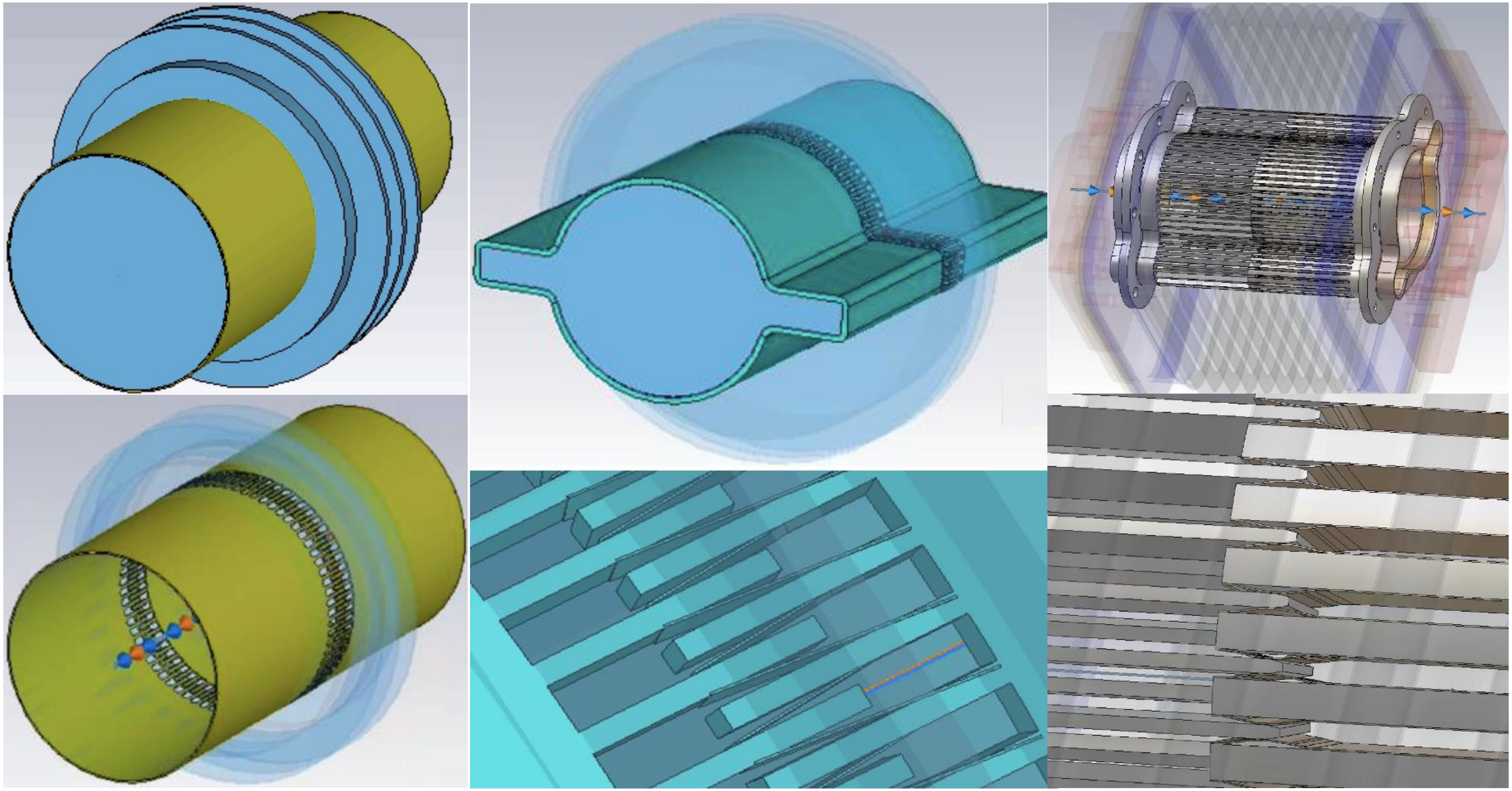


2) We have divided this impedance by its surface impedance and multiplied it by that of a double layer one.

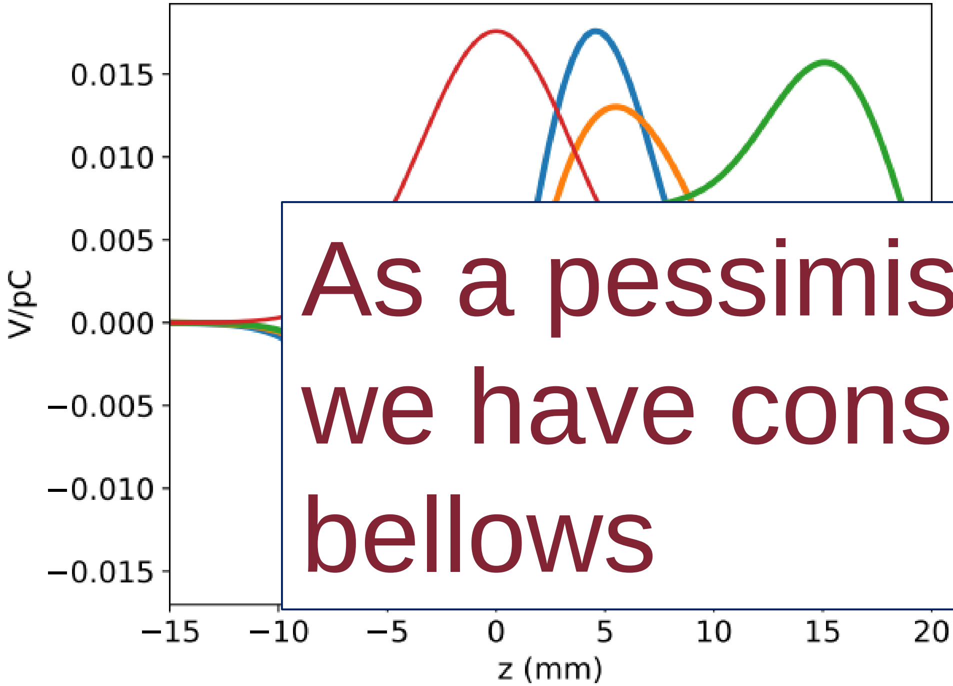
3) We have compared this final impedance with that of a circular pipe and two layers.

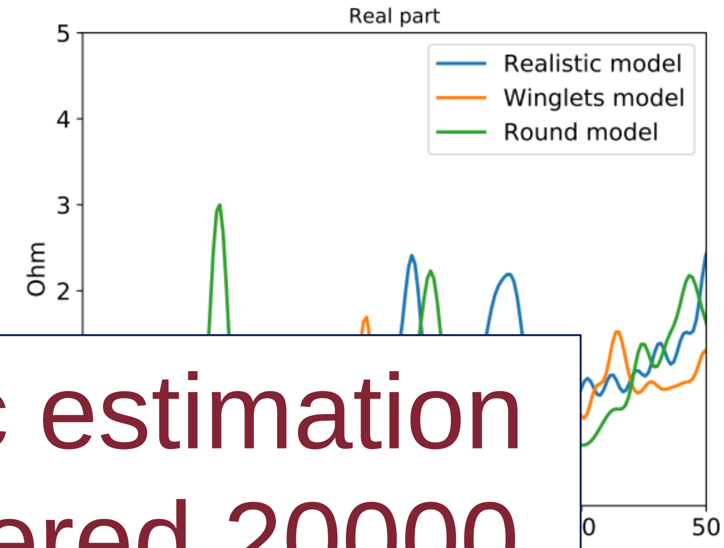
4) The difference is about a factor 1.1 that we have used to multiply the results of IW2D for both the longitudinal and transverse planes.

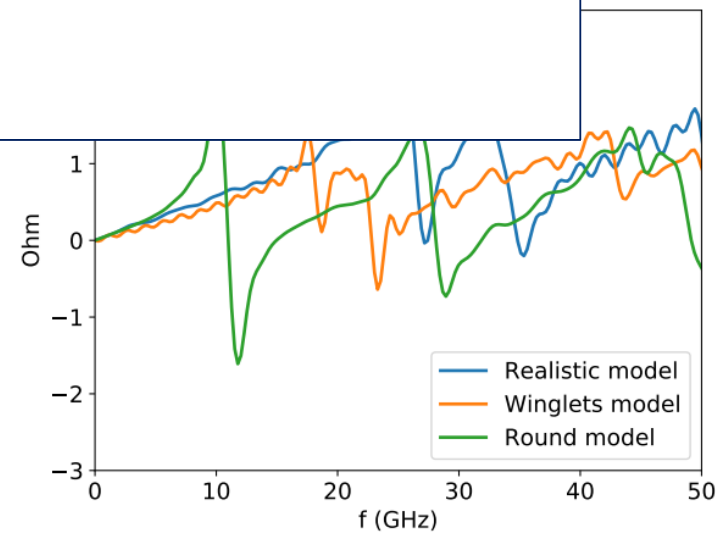
Bellows



Bellows - update







As a pessimistic estimation we have considered 20000 bellows

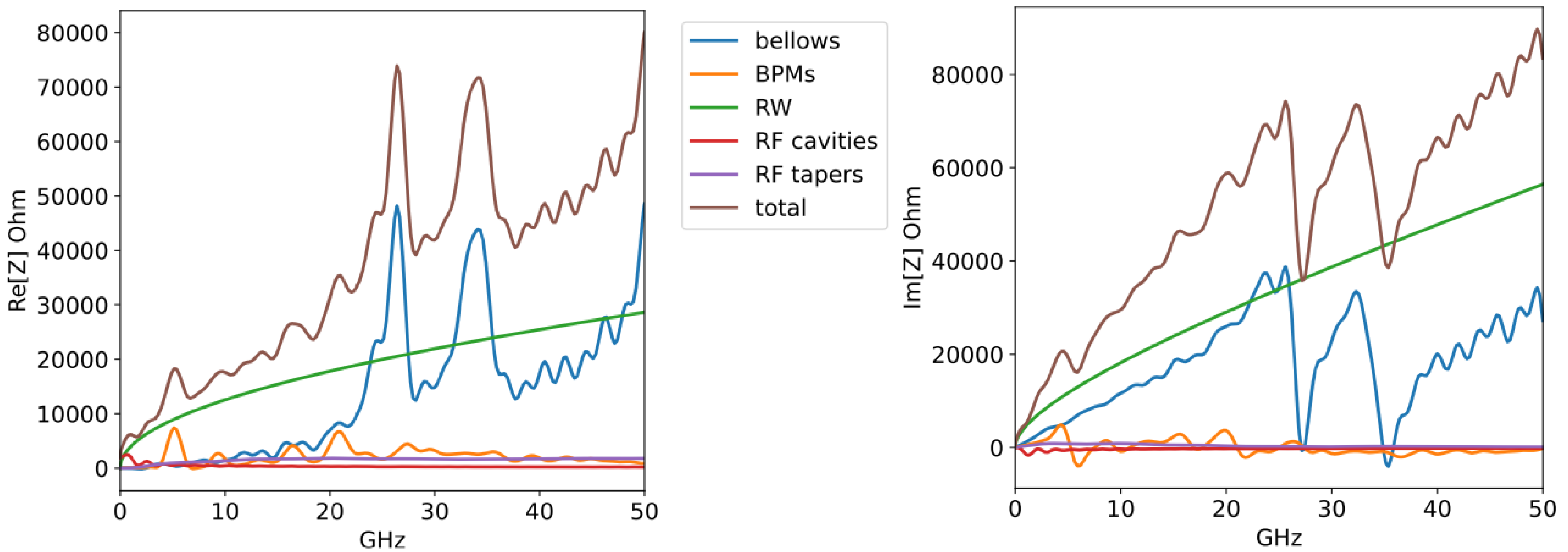
A comment on the number of bellows:

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

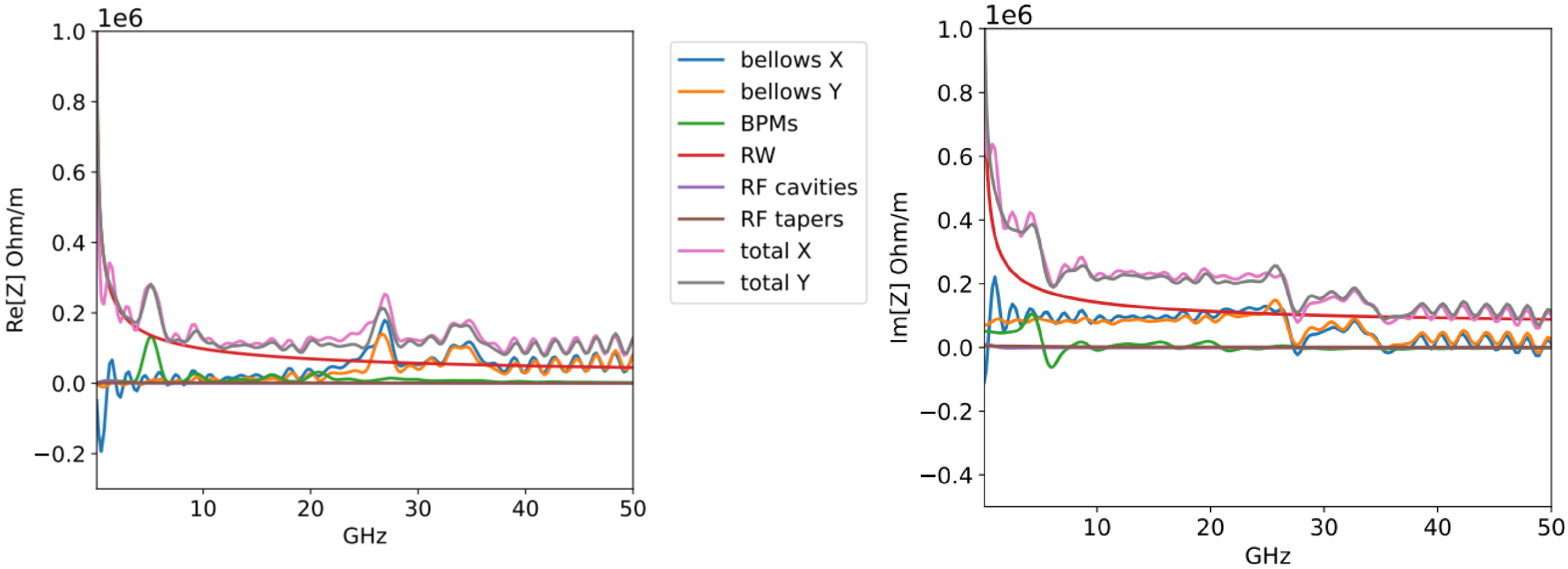
total of 11600 bellows plus:

- RF, injection system, collimators, …

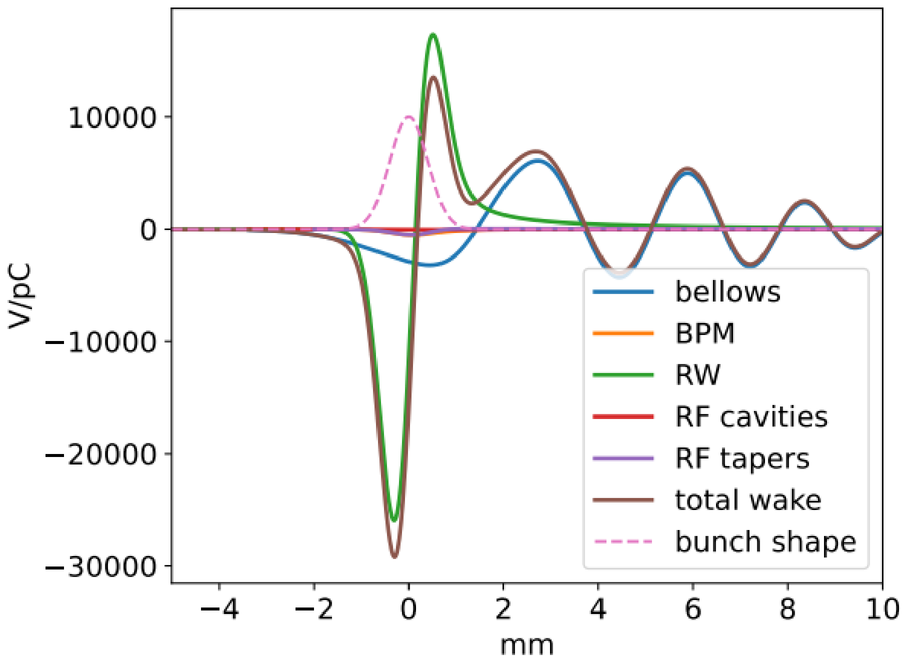
Total impedance: longitudinal

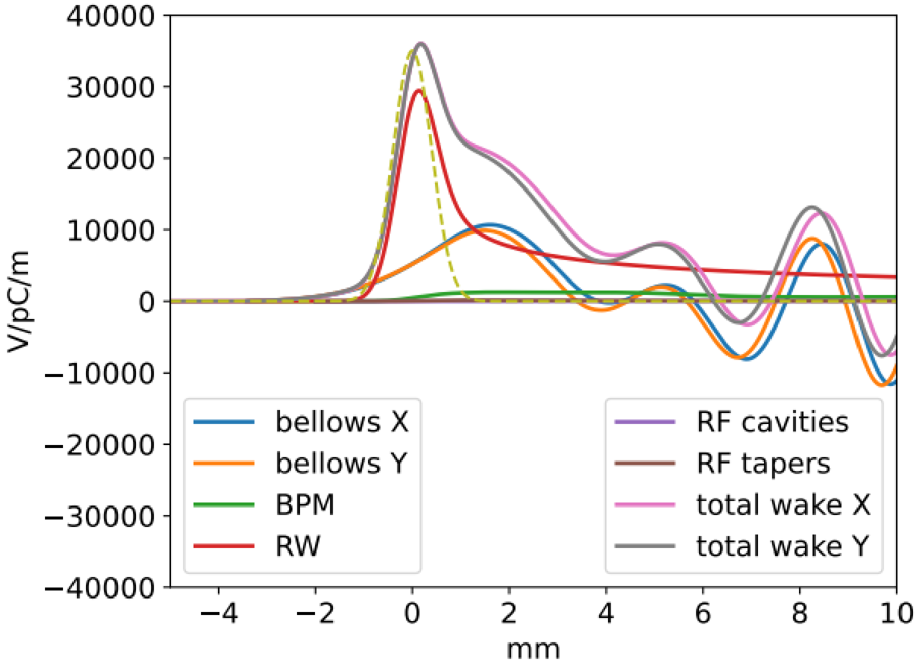


Total impedance: transverse dipolar

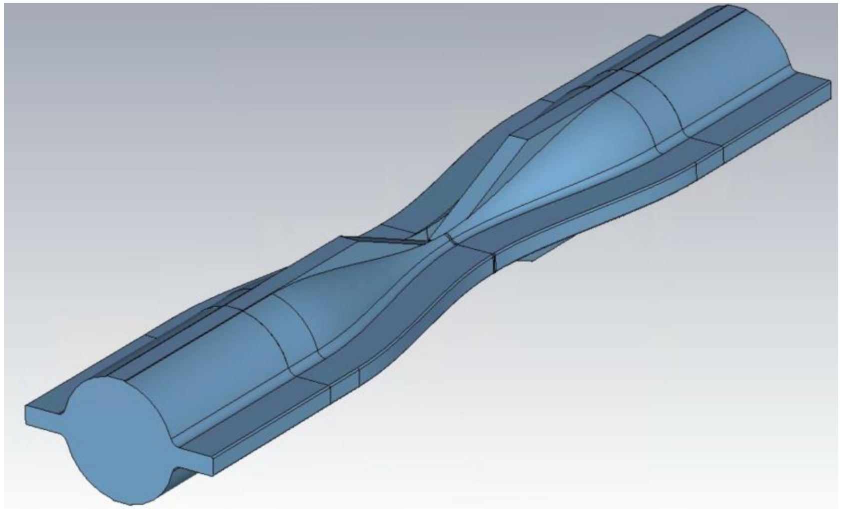


Wake potential of 0.4 mm Gaussian bunch

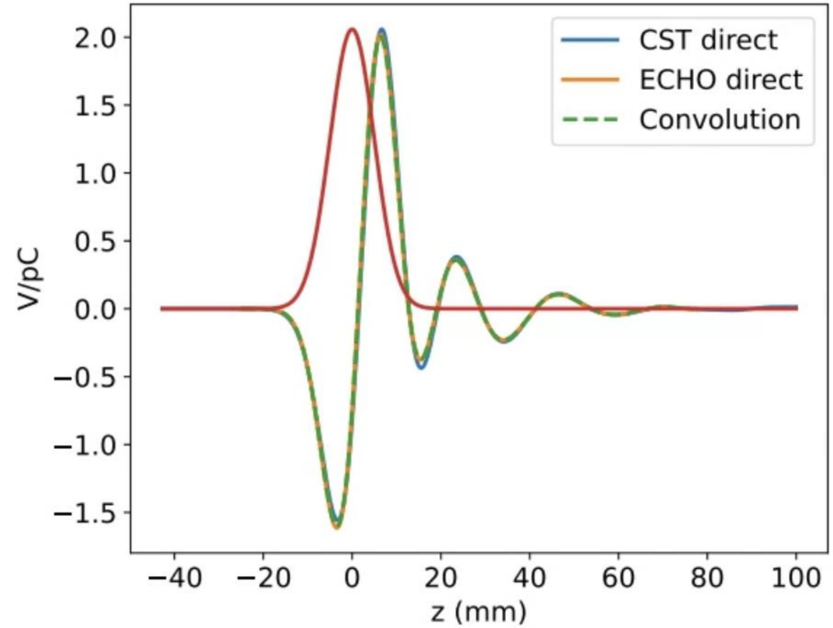




Preliminary work on collimation system



geometric longitudinal wakefield of a 5 mm Gaussian bunch



Summary of the collimator settings for the Z mode. The table doesn't include the SR collimators around the IPs, nor the collimators for a separate off-momentum collimation insertion. The collimator settings and parameters are very preliminary.

#ID	name	S_from_IPA[m]	angle[rad]	betax[m]	betay[m]	halfgap[m]	Material	Length[m]	nsig
1	TCP.H.B1	42515.0	0.0000000000E+00	2.3409490076E+03	5.2815752133E+01	1.5900392552E-02	C	6.00000E-01	2.00000E+01
2	TCP.V.B1	42520.0	1.5707963268E+00	2.2052869730E+03	5.3330774325E+01	1.0223908927E-03	C	6.00000E-01	1.40000E+02
3	TCS.V1.B1	42544.43	1.5707963268E+00	1.6009831201E+03	6.9460296781E+01	1.2834797764E-03	C	1.00000E+00	1.54000E+02
4	TCS.H1.B1	42661.16	0.0000000000E+00	5.5183272400E+01	4.5851766751E+02	2.6243639250E-03	C	1.00000E+00	2.15000E+01
5	TCS.H2.B1	42781.26	0.0000000000E+00	4.9268611828E+02	1.3375254057E+02	7.8416146547E-03	C	1.00000E+00	2.15000E+01
6	TCS.V2.B1	43103.49	1.5707963268E+00	3.7084032928E+02	1.4986857019E+03	5.9617806710E-03	C	1.00000E+00	1.54000E+02

Some comments on the impedance budget and collective effects

- FCC-ee is still an ongoing project, and, as we evaluate and add new devices, the total machine impedance increases more and more
- We are still missing several important devices, such as the collimation system, vacuum flanges, …
- On the other hand, the impedance evaluated so far already demonstrates how this machine can become critical due to collective effects (see Emanuela's and Yuan's talks)
- The instabilities shown in the following talks will change based on the new impedance contributions that will gradually be added, but they suggest that we need to look for diversified mitigation solutions.

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TBCI and feedback system

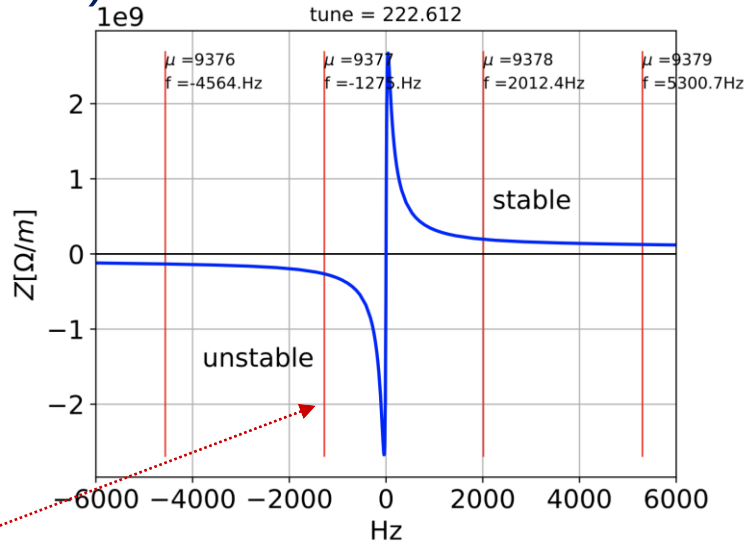
Transverse Coupled Bunch Instability (TCBI)

$$\frac{1}{\tau_{\mu,\perp}} = -\frac{ecI}{4\pi E Q_\beta} \sum_q \mathrm{Re}\left[Z_\perp(\omega_q)\right] G_\perp\left(\frac{\sigma_z}{c}\omega'_q\right)$$

where $$\mathrm{Re}\left[Z_\perp(\omega)\right] = \mathrm{sgn}(\omega)\frac{C}{2\pi b^3}\sqrt{\frac{2Z_0 c}{\sigma_c|\omega|}}$$

$$\omega_q = (qM + \mu + Q_\beta)\omega_0$$

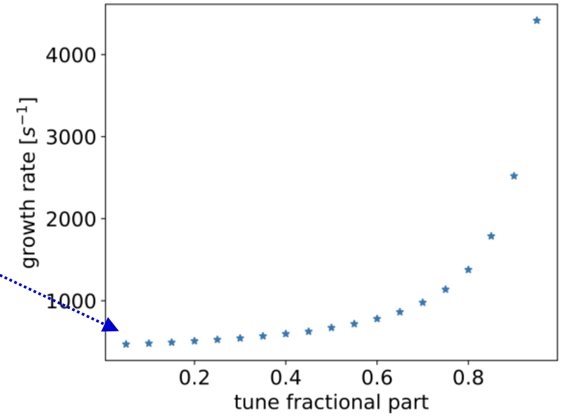
$$\omega'_q = \omega_q + \xi\frac{\omega_\beta}{\eta}$$



The most dangerous mode is that closest to the origin (with negative frequency)

Growth time of about 6 revolution turns

A robust feedback is required for the instability suppression!



TBCI and feedback system

- In SuperKEKB the transverse feedback was one important source of the '-1' mode instability which limited the machine to reach the nominal intensity. Its damping time is around 100 turns, that is about 1000 1/s.

- What is the effect of feedback in FCC-ee that needs about the same damping time, but this corresponds to only few turns?

- Is the TMCI perturbed by the feedback? And what about the longitudinal effect of the wake?

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Imaginary tune split and repulsion single-bunch instability mechanism in the presence of a resistive transverse damper and its mitigation

E. Métral

Introduction

[…] However, a resistive transverse damper also destabilizes the single-bunch motion below the transverse mode coupling instability intensity threshold (for zero chromaticity), introducing a new kind of instability, which has been called ITSR instability (for imaginary tune split and repulsion). […]

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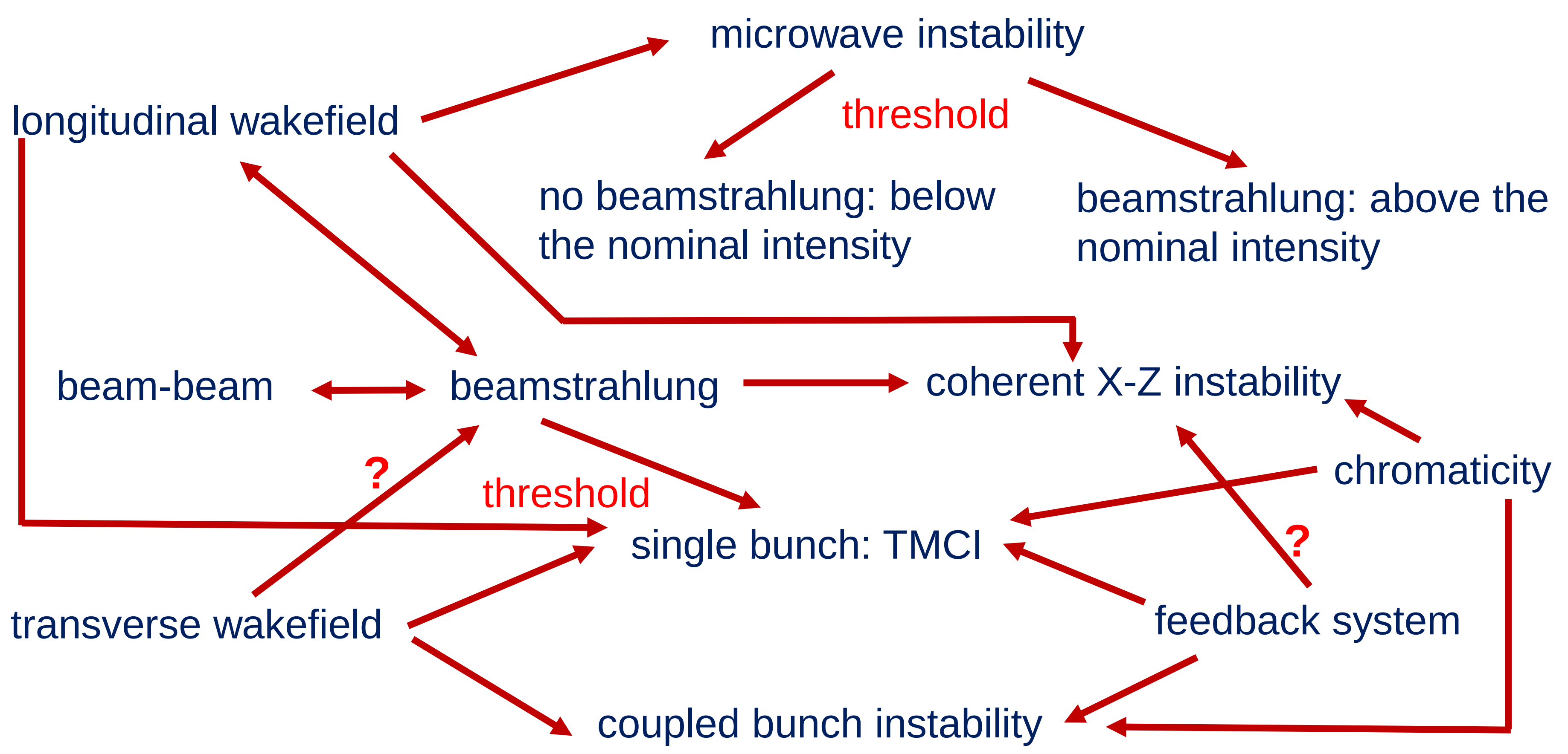
Interplay between different collective effects for FCC-ee (mainly single bunch) that we have analysed so far



Challenges and future plan

- Continue the evaluation of impedance and wakefield of other machine devices (collimation system, …)
- Evaluate the detuning (quadrupolar) impedance and its effect
- Continue to improve and update the impedance repository
- Continue to investigate the interplay between beamstrahlung, longitudinal and transverse coupling impedance (see Y. Zhang talk)
- Continue to investigate possible mitigation techniques (feedback system, chromaticity, …)
- 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), …
- Study the effects of possible transverse localized impedances (in particular for the collimation system)
- Use a more realistic transverse lattice
- Other effects: electron could, (also multi-bunch), ion instabilities …

Challenges and future plan

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Thank you for your attention