



SAPIENZA
UNIVERSITÀ DI ROMA

DIPARTIMENTO DI SCIENZE DI BASE
E APPLICATE PER L'INGEGNERIA



Collective effects with ttbar configuration

M. Migliorati, E. Carideo, D. Quartullo, M. Zobov

Acknowledgements:

E. Belli, R. Calaga, I. Karpov, K. Oide, S. G. Zadeh, F. Zimmermann



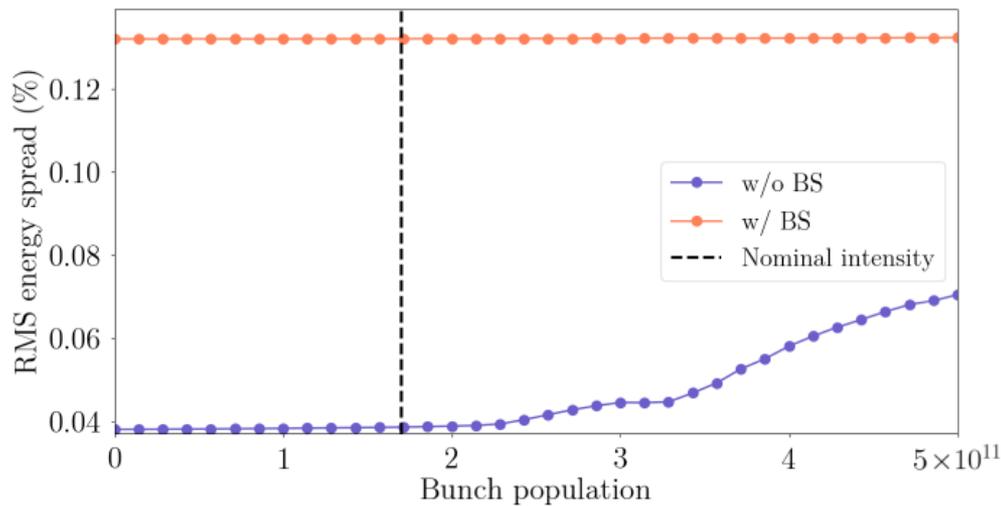
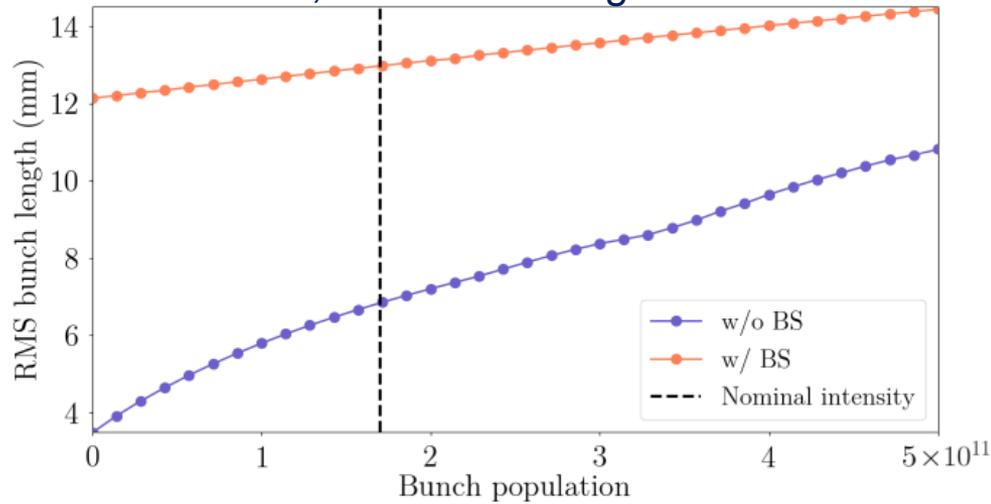
This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

Parameter list (from CDR)

Parameter list	Z	t	
Beam energy (GeV)	45.6	182.5	
Beam current (mA)	1390	5.4	
Bunch population [10^{11}]	1.7	2.3	
Mom compaction [10^{-6}]	14.8	7.3	
Bunch length [mm](SR/BS)	3.5/12.1	2.0/2.5	
Energy spread(SR/BS) [10^{-3}]	0.38/1.32	1.5/1.92	
Synchrotron tune	0.025	0.087	
Bunches/beam	16640	48	
Energy loss/turn (GeV)	0.036	9.2	
Longitudinal damping time(SR/BS) [s]	0.415	0.0067	
RF frequency (MHz)	400	400	800
RF voltage (GV)	0.1	4	6.9
# cells/cavity	1	4	5
# cavities/beam	52	272	372

Z-pole microwave and TMCI instabilities

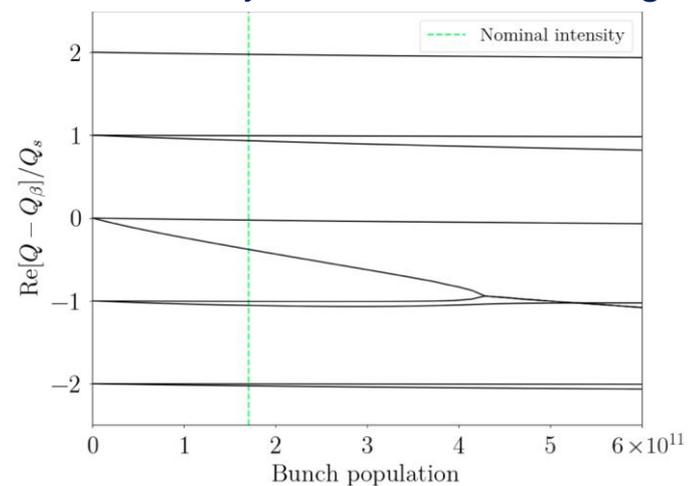
Total wake, 100 nm coating



E. Belli PhD thesis

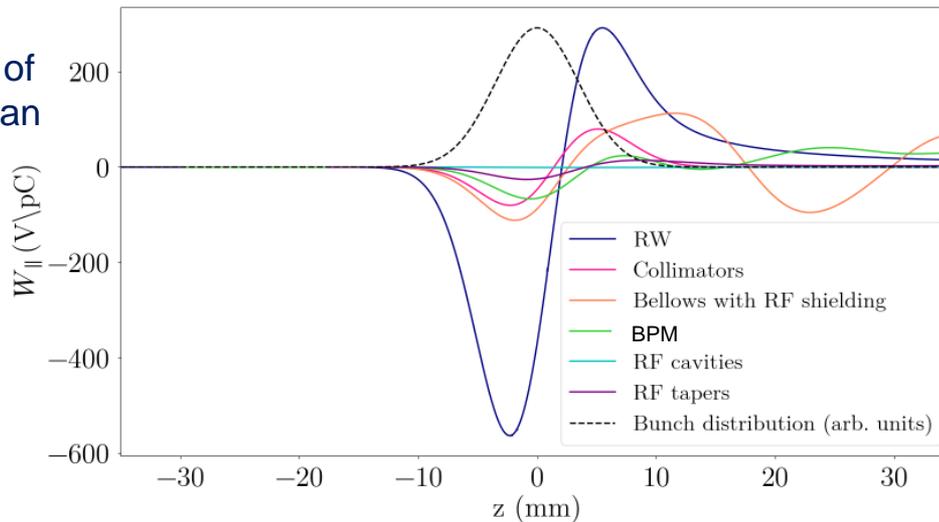
Component	Number	k_{loss} [V/pC]	P_{loss} [MW]
Resistive wall	97.75km	210	7.95
Collimators	20	18.7	0.7
RF cavities	56	18.5	0.7
RF double tapers	14	26.6	1.0
BPMs	4000	40.1	1.5
Bellows	8000	49.0	1.8
Total		362.9	13.7

TMCI, only RW, 100 nm coating



Z-pole longitudinal microwave instability

Wake potential of
3.5 mm Gaussian
bunch



E. Belli PhD thesis

- The thresholds at Z pole without BS are 2.5×10^{11} ppb for microwave instability and 4.2×10^{11} ppb for TMCI, but with BS they are much higher.
- For ttbar the total impedance becomes larger due to the RF system: what are the new instability thresholds?
- Moreover, the bunch length at ttbar will not be much affected by BS.

Some scaling considerations: microwave instability

$$I_{th} = \frac{\sqrt{2\pi}\alpha_c (E/e)(\sigma_{\varepsilon 0}/E)^2 \sigma_{z0}}{R|Z/n|}$$

$$\frac{I_{th}^{tt}}{I_{th}^Z} = \frac{(7.3/14.8) \times (182.5/45.6) \times (0.15/0.038)^2 \times (1.97/3.5)}{|Z/n|} = \frac{17.3}{|Z/n|}$$

Some scaling considerations: TMCI

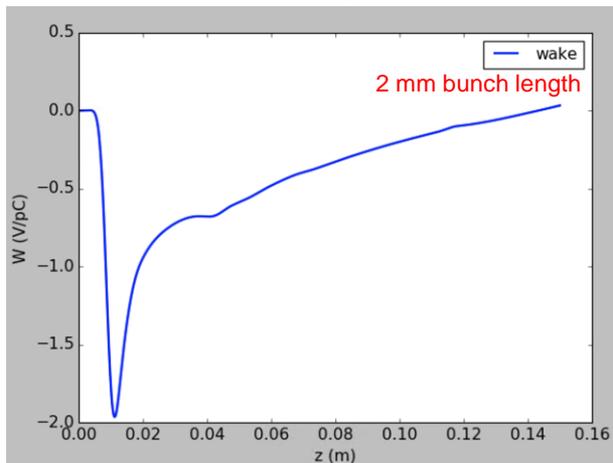
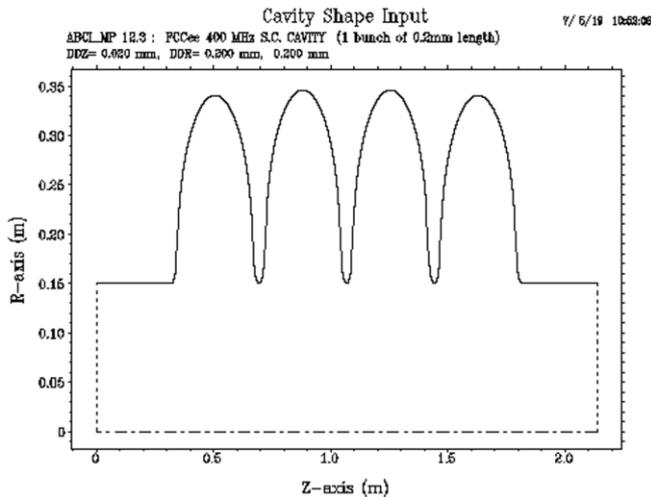
$$I_{th} = \frac{4(E/e)v_s}{R \Sigma \{ [\text{Im } Z_T] \beta_y \}} \frac{4\sqrt{\pi}}{3} \sigma_z$$

$$\frac{I_{th}^{tt}}{I_{th}^Z} = \frac{(182.5/45.6) \times (0.0872/0.025) \times (1.97/3.5)}{\text{Im } Z_T \times (269/389)} \approx \frac{11.36}{\text{Im } Z_T}$$

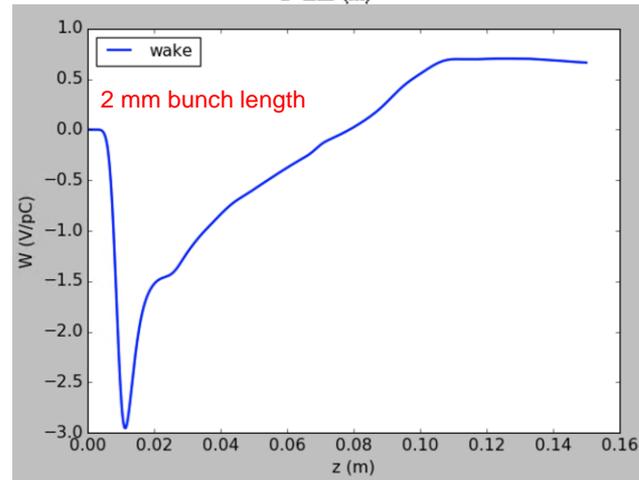
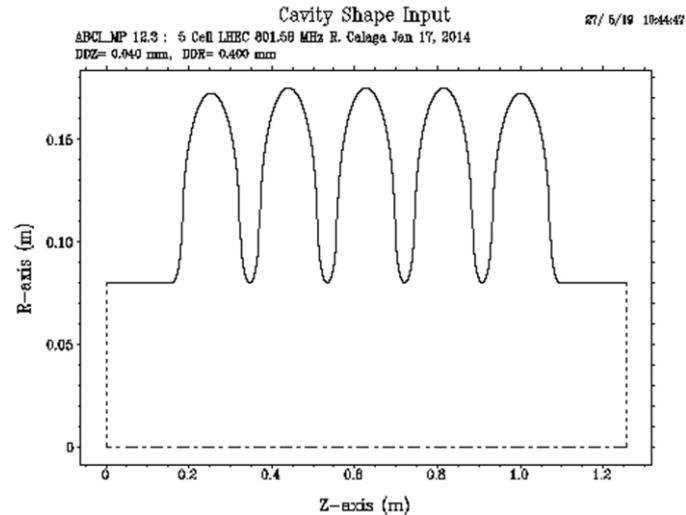
Average beta inversely proportional to machine tune

RF system for ttbar

ABCI 400 MHz system



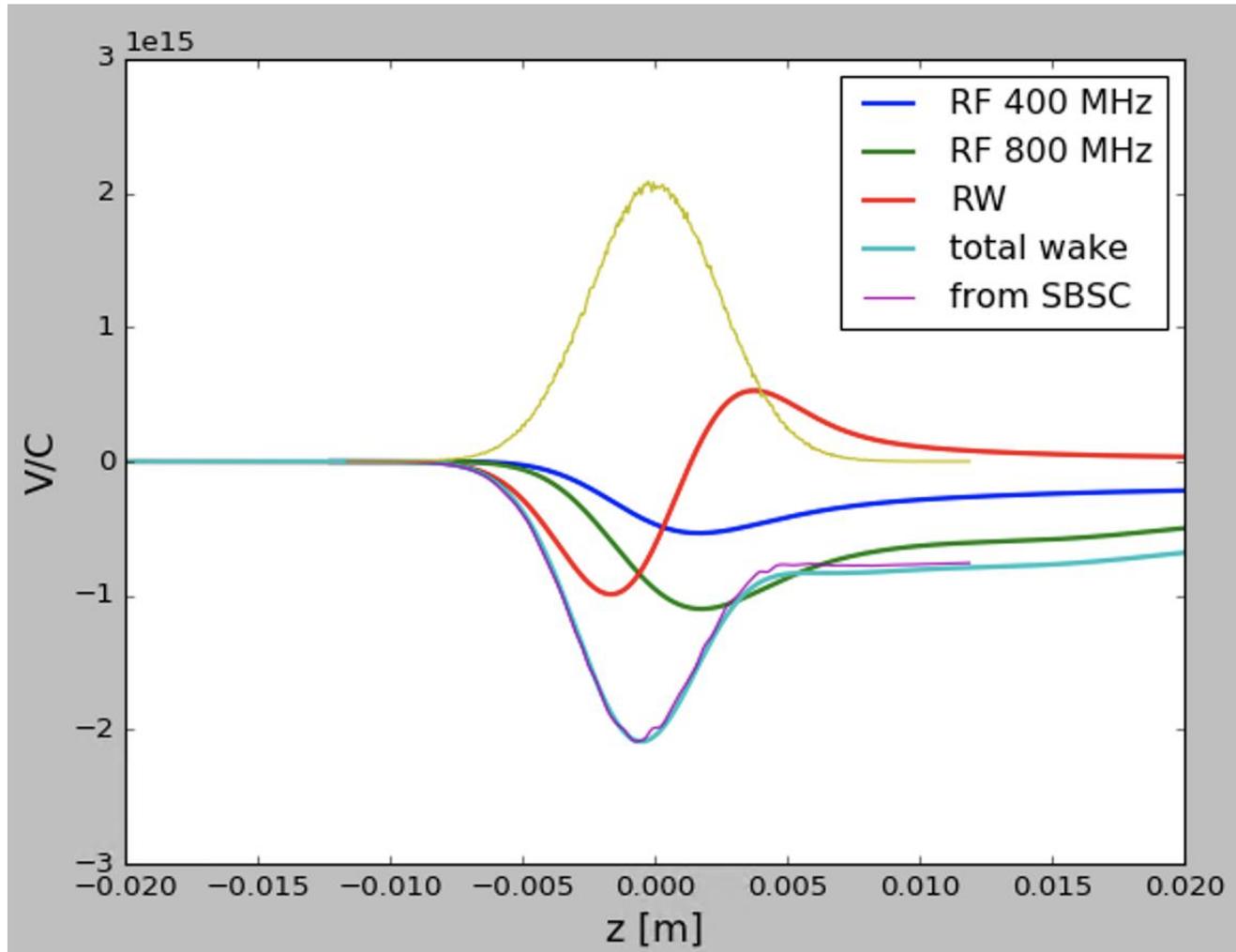
ABCI 800 MHz system



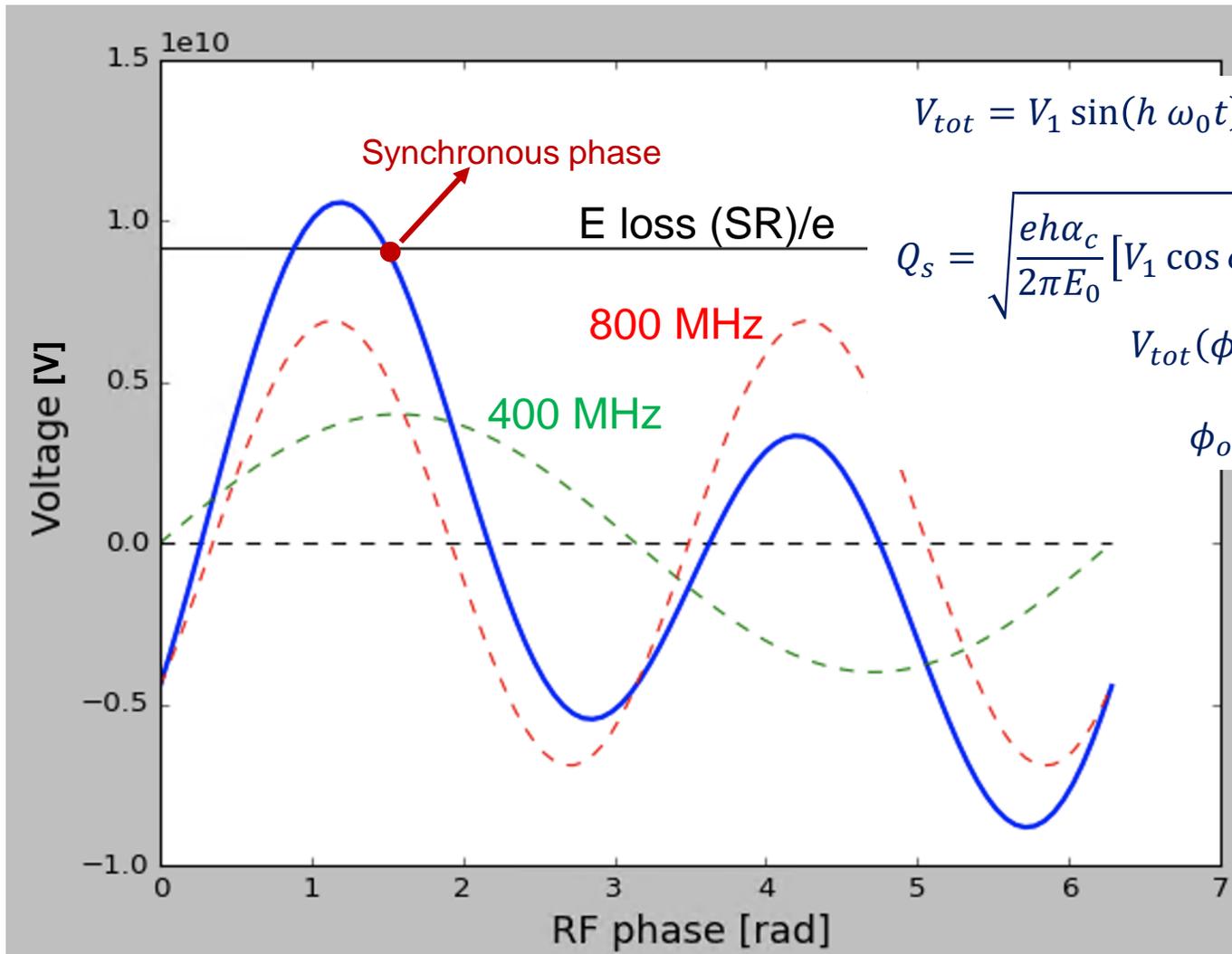
The wake potentials are similar to that of a cavity with attached tubes at high frequencies described by an impedance of the kind:

$$Z(\omega) = \frac{1 - j\text{sign}(\omega)}{\sqrt{\omega}} Z_c$$

Total wake potential of 2.4 mm bunch



Double harmonic system and synchronous phase



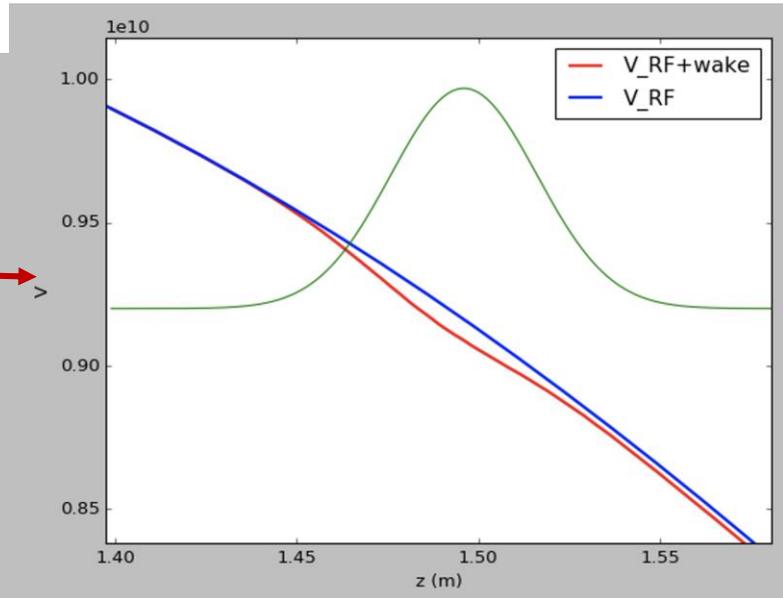
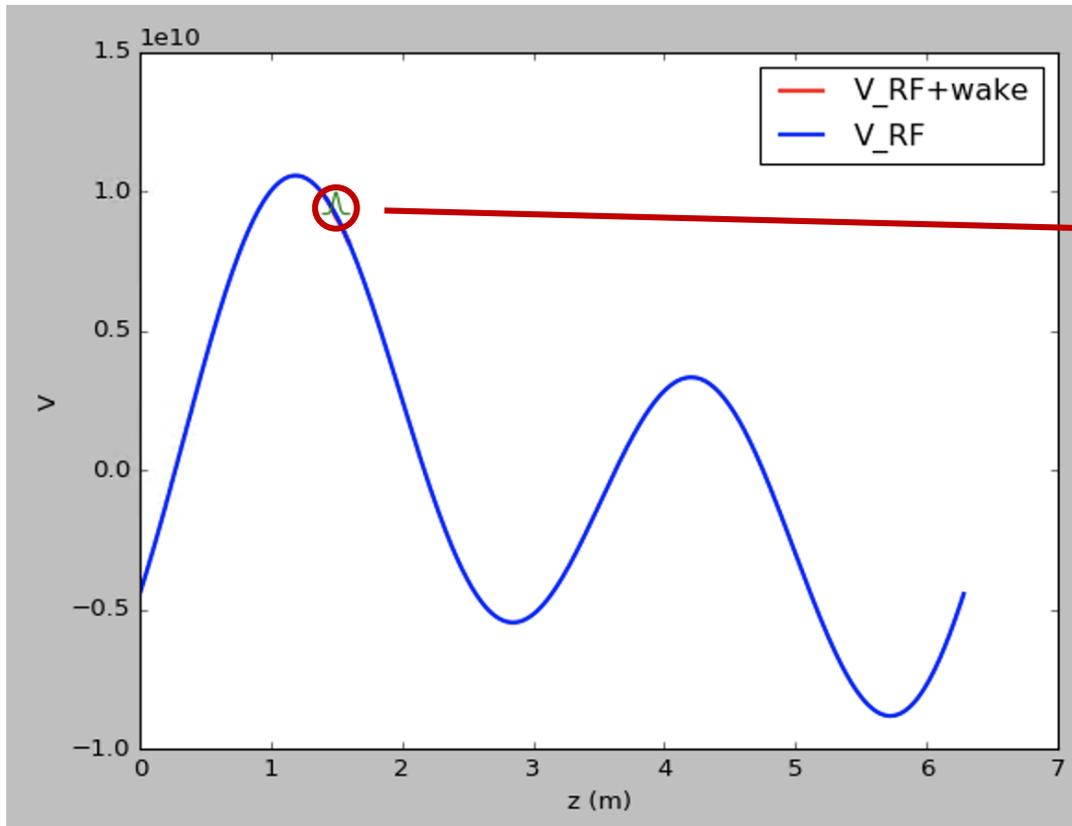
$$V_{tot} = V_1 \sin(h \omega_0 t) + V_2 \sin(2h\omega_0 t - \phi_{off})$$

$$Q_s = \sqrt{\frac{eh\alpha_c}{2\pi E_0} [V_1 \cos \phi_s + 2V_2 \cos(2\phi_s - \phi_{off})]}$$

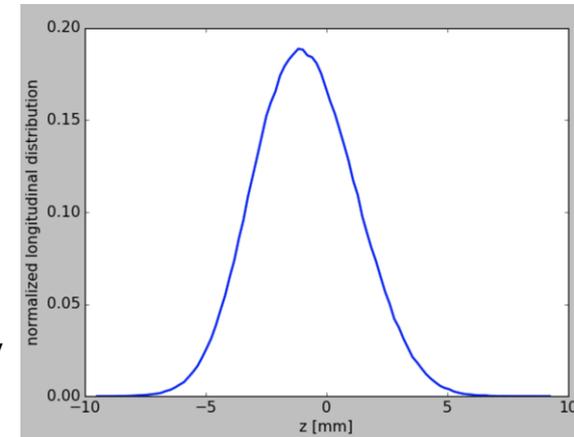
$$V_{tot}(\phi_s) = E_{loss}/e$$

$$\phi_{off} \approx 40^\circ$$

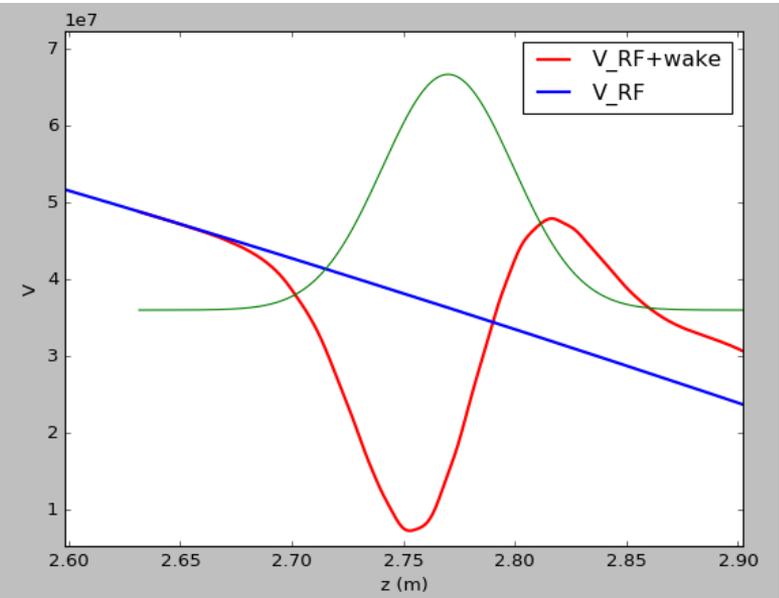
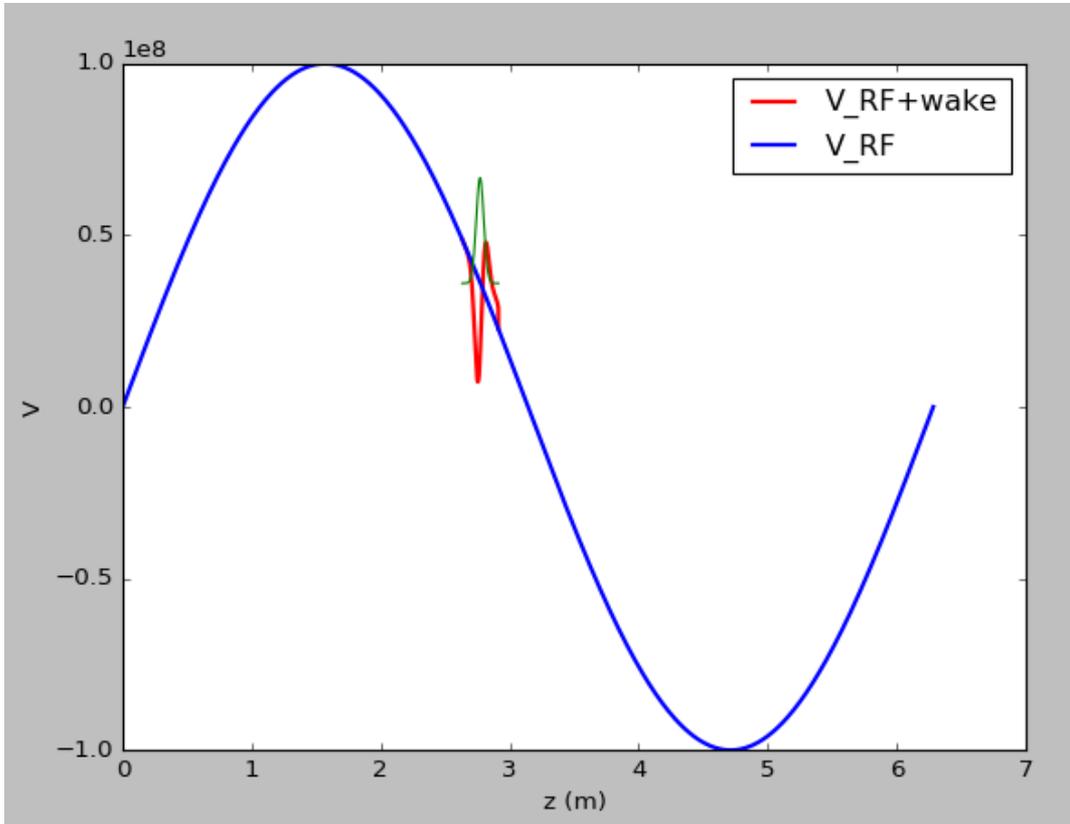
Induced voltage at tbar for 2.3×10^{11} ppb



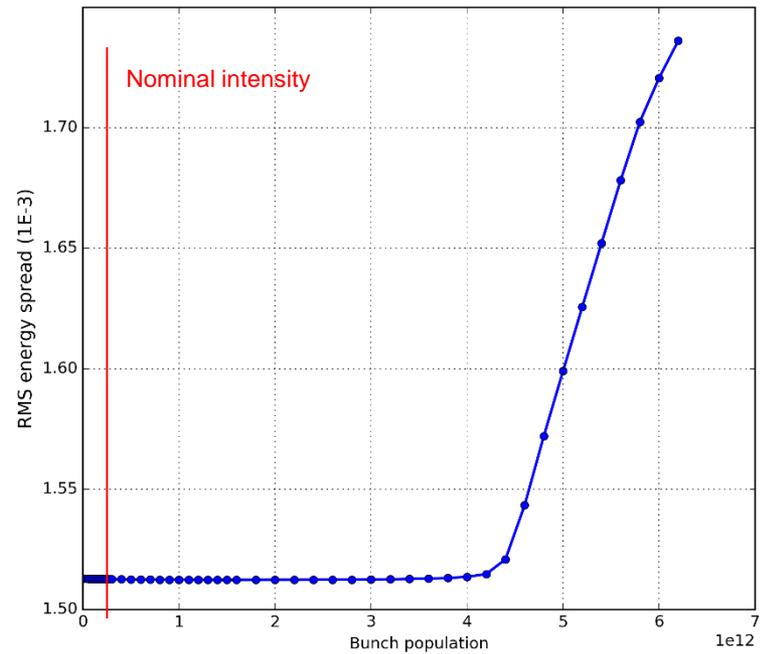
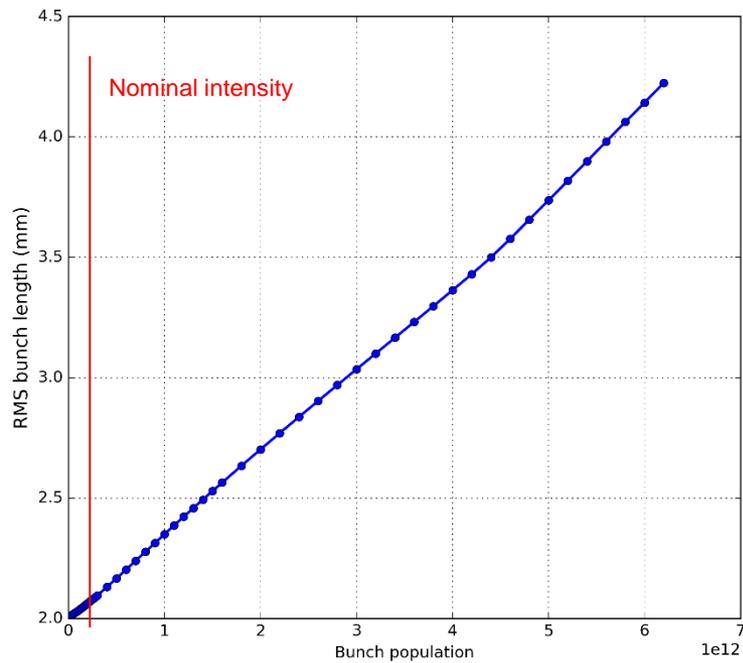
There is no evident deformation from Gaussian shape, just a small displacement due to energy losses



Induced voltage at Z-pole for 2.3×10^{11} ppb

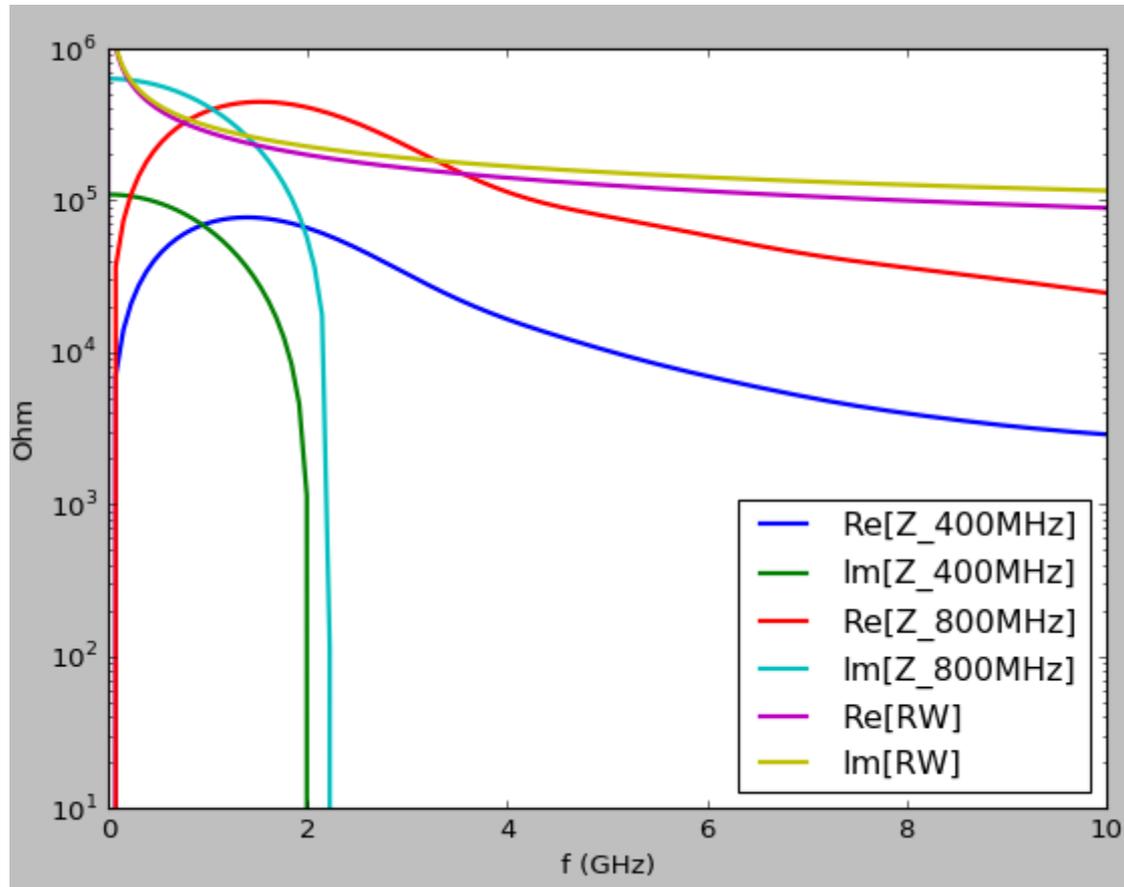


Longitudinal beam dynamics simulations at ttbar



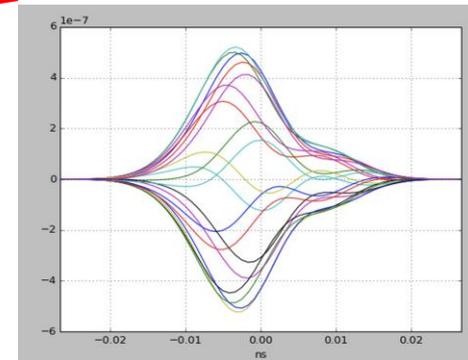
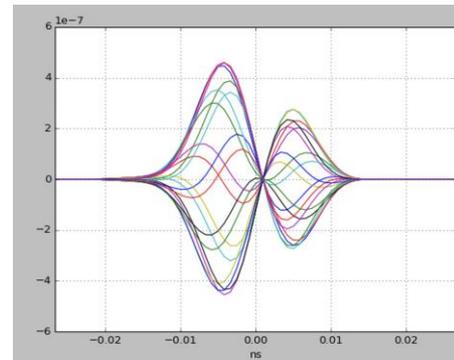
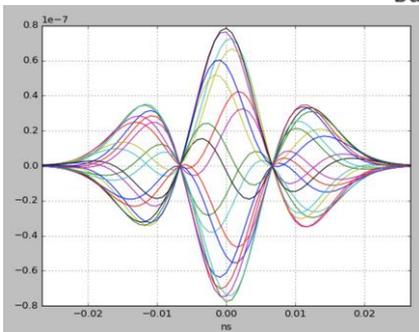
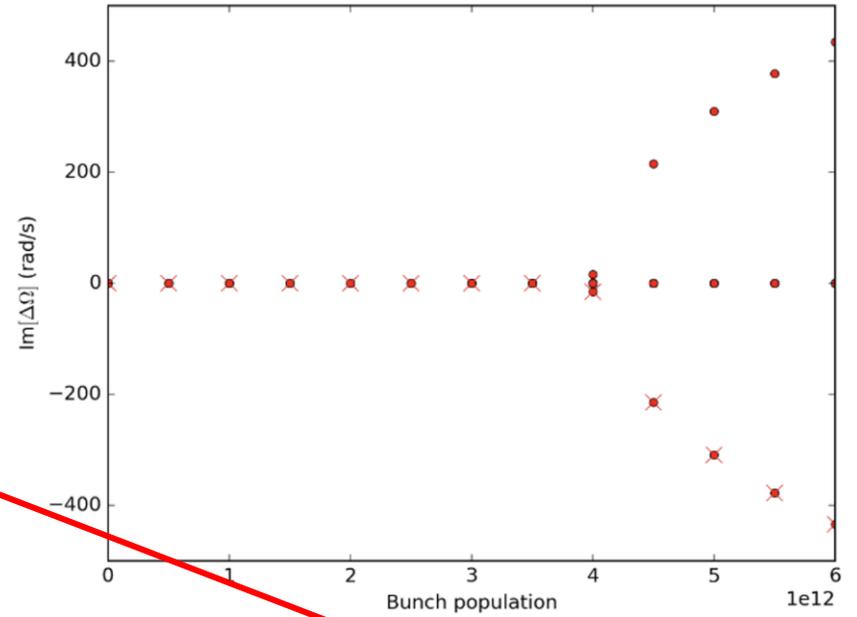
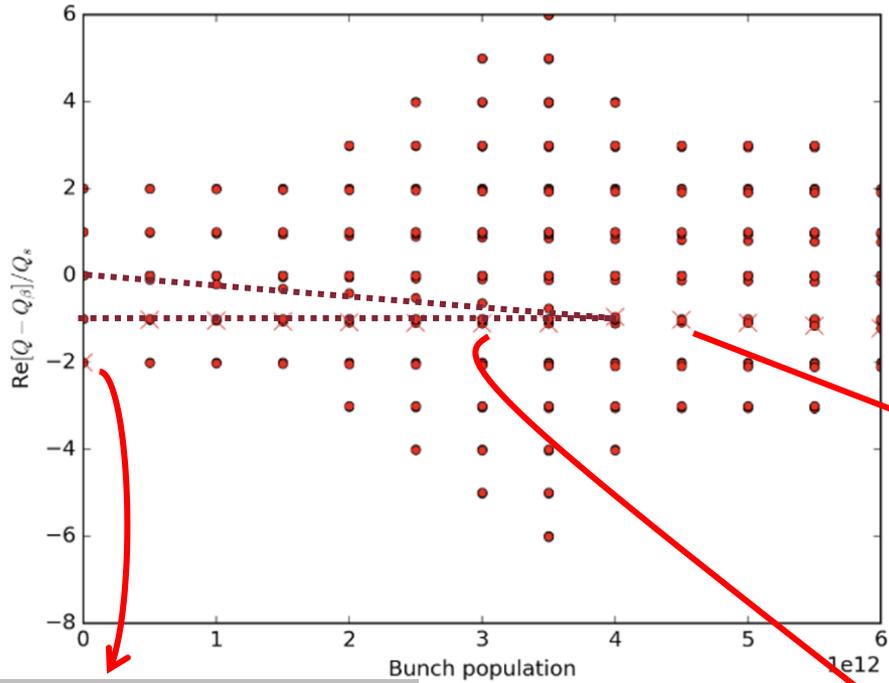
Preliminary results

Transverse impedance



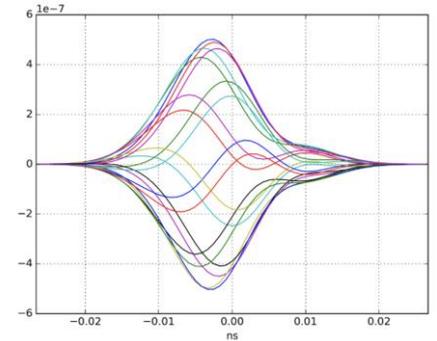
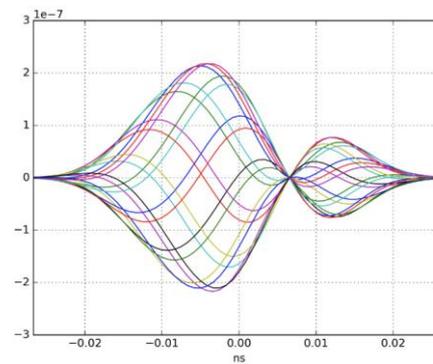
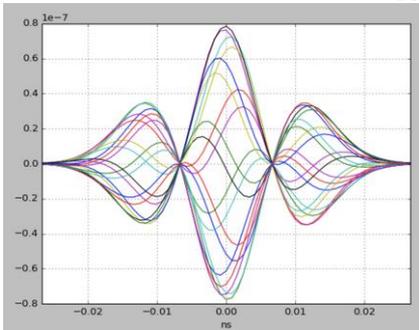
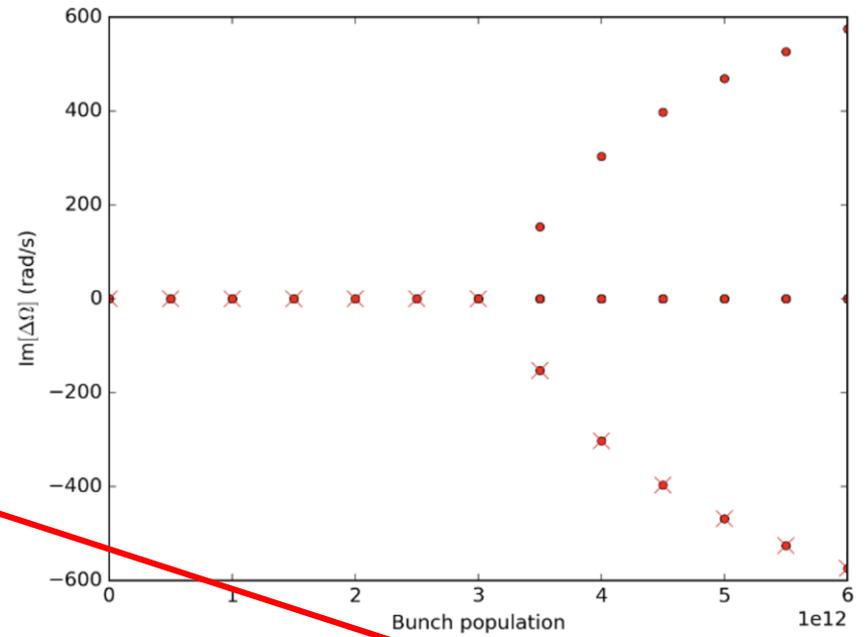
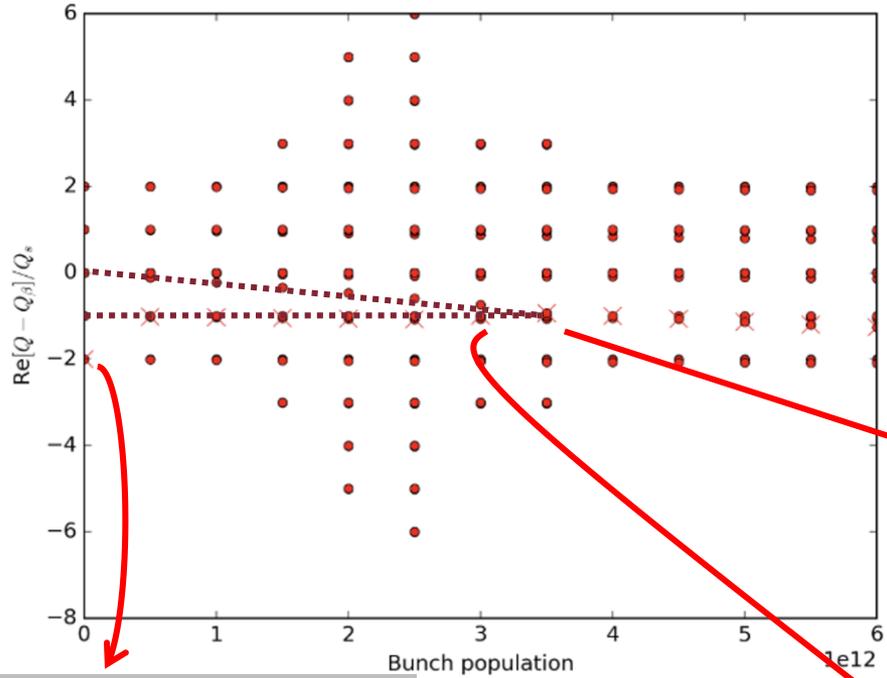
TMCI threshold

DELPHI code, only RW



TMCI threshold

DELPHI code, RW + RF system



Conclusions

- Despite the large number of cavities the TMCI and the microwave instability do not seem to be dangerous for the FCC-ee at the ttbar energy.
- This becomes evident from:
 - The intuitive picture of the RF voltage perturbation by the wake potential
 - The scaling of Boussard criterion
 - The numerical simulations
 - A much stronger radiation damping

**Thank you very much
for your attention**