



Impedance model & TMCI threshold

Emanuela Carideo

Acknowledgements: M. Migliorati, F. Zimmermann, D. Quartullo, M. Zobov, D. De Arcangelis



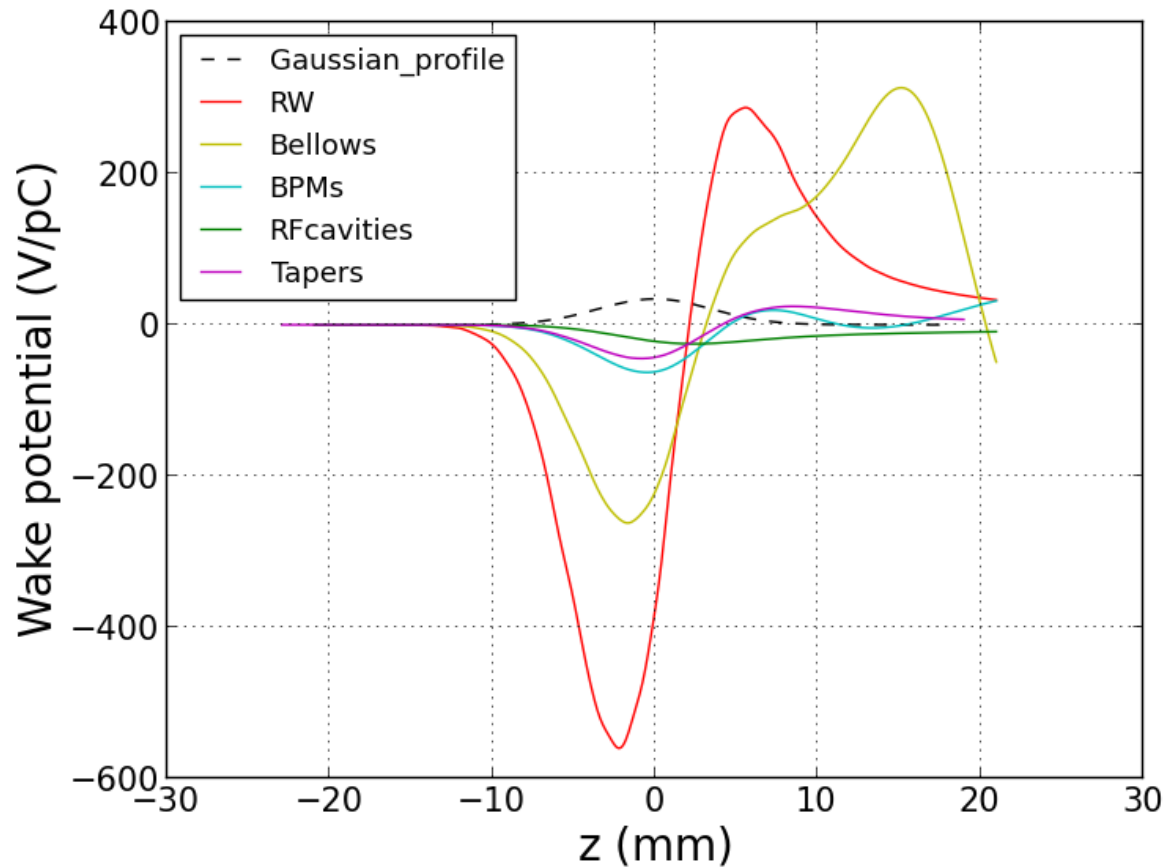
FCC WP 2 Workshop
Optics Correction and Beam Measurement



Outline

- Wakefields and impedances evaluated so far: The method used to calculate the wakepotential
- Repository
- Longitudinal single beam instabilities: MI analysis
- Transverse single beam instabilities : TMCI mode analysis
- Collaboration with the Super KEKB : Collimators

Impedance Sources: CST and IW2D simulations



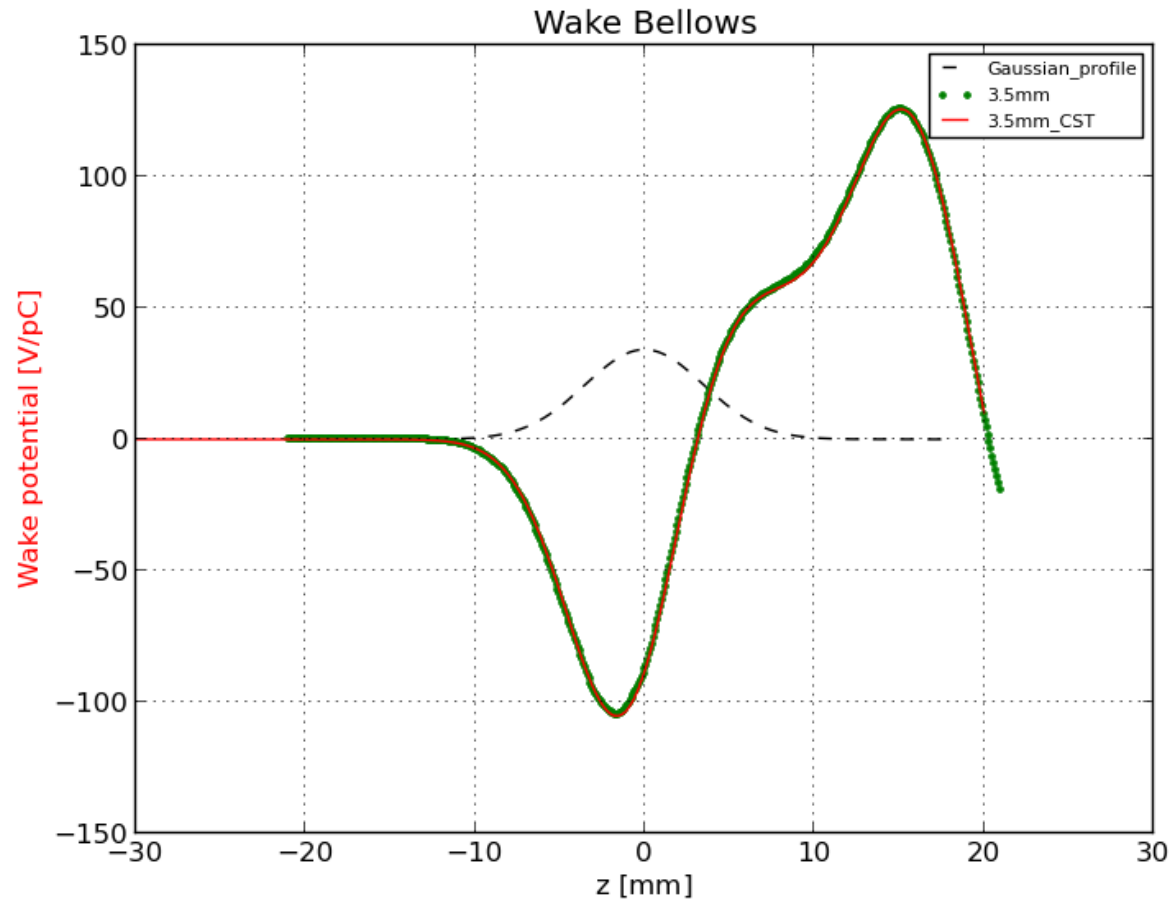
Longitudinal wake potentials for a Gaussian bunch with nominal bunch length $\sigma_z = 3.5$ mm due to the main FCC-ee components, evaluated so far.

How did we do these simulations?

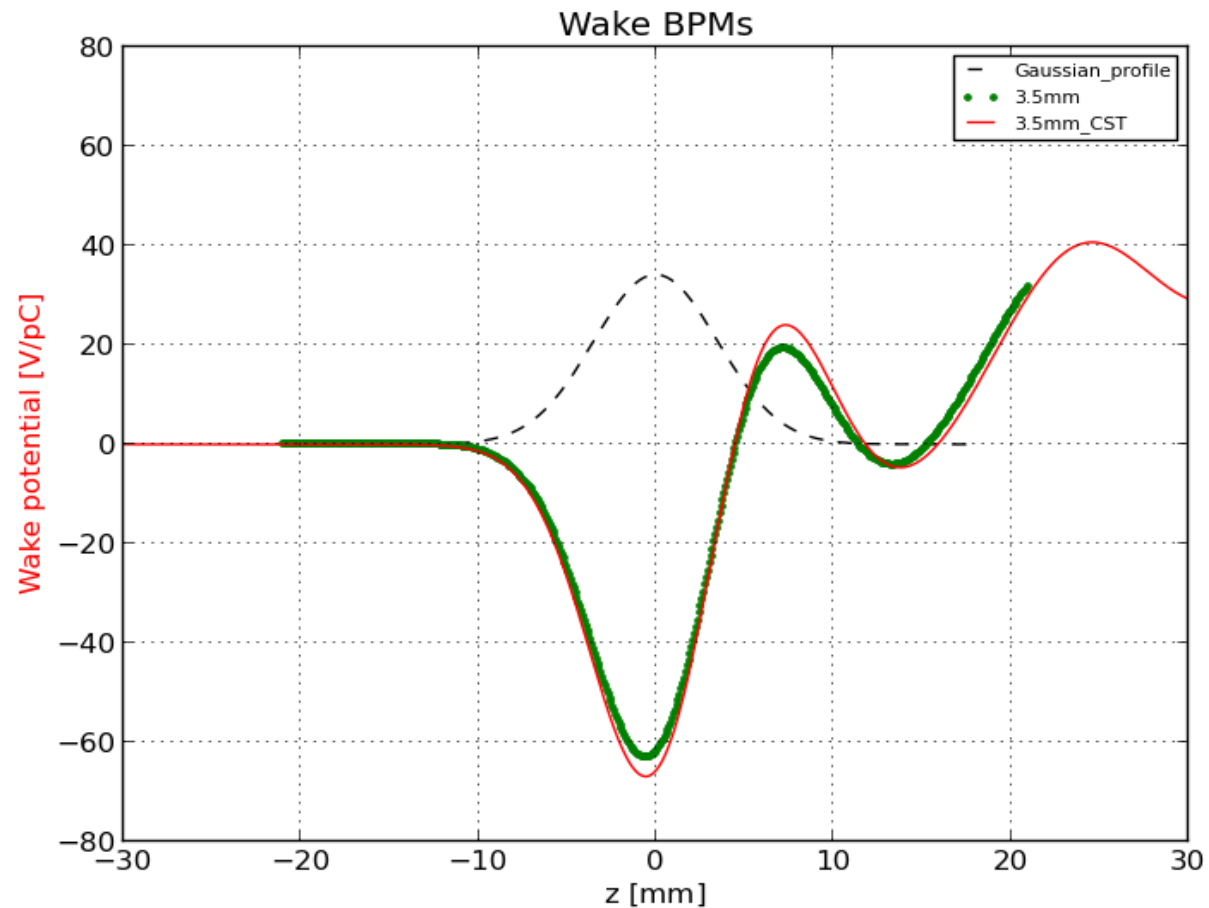
Method to calculate the Wake Potential by software simulation

Comparison of the wake potential of 3.5 mm bunch length between PyHT and CST: Bellows

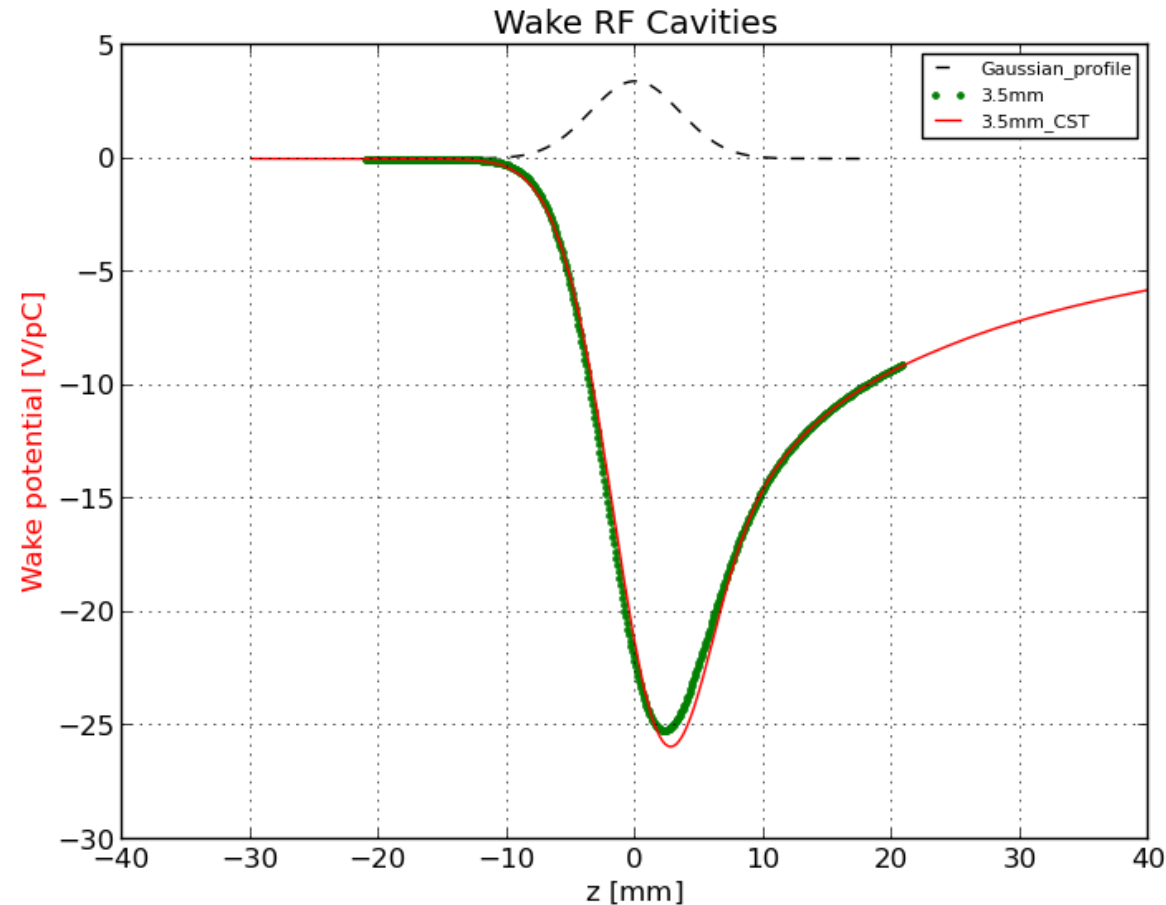
Wake potential for a Bellow of a 3.5 mm Gaussian bunch obtained directly by CST (red curve) and with the convolution by using the wake potential of 0.4 mm Gaussian bunch (green dots).



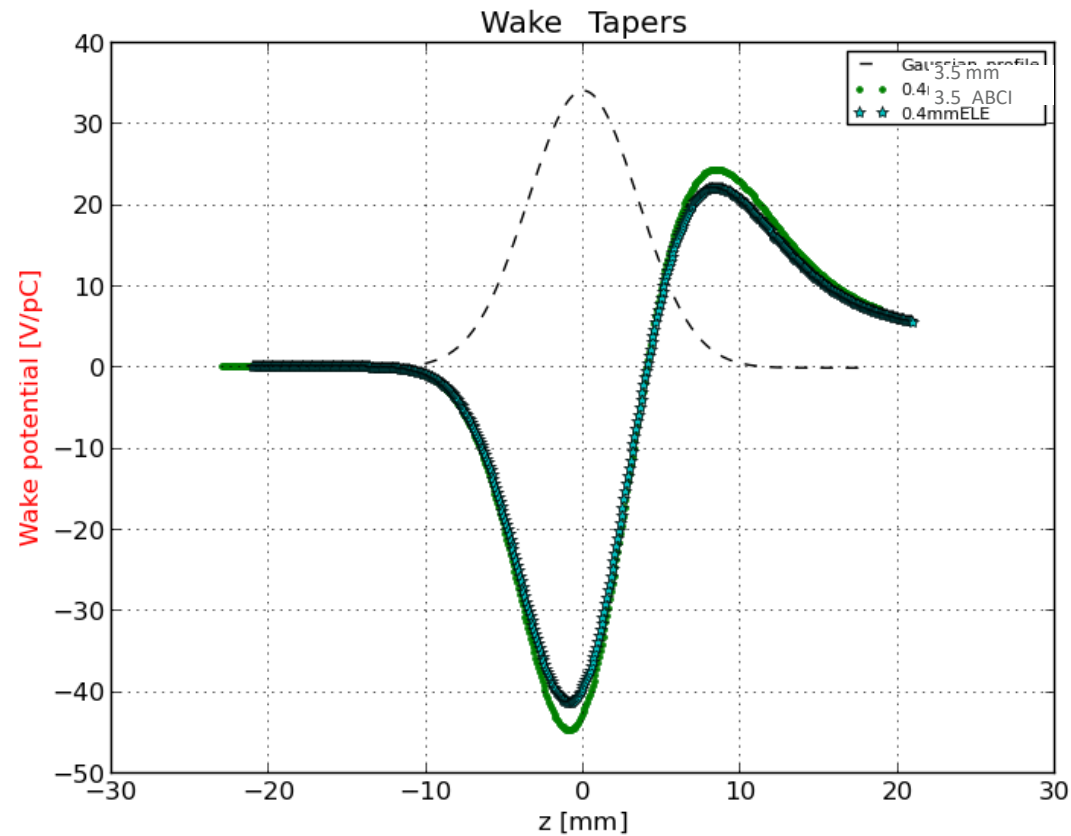
Comparison of the wake potential of 3.5 mm bunch length between PyHT and CST: BPMs



Comparison of the wake potential of 3.5 mm bunch length between PyHT and CST: RF Cavities

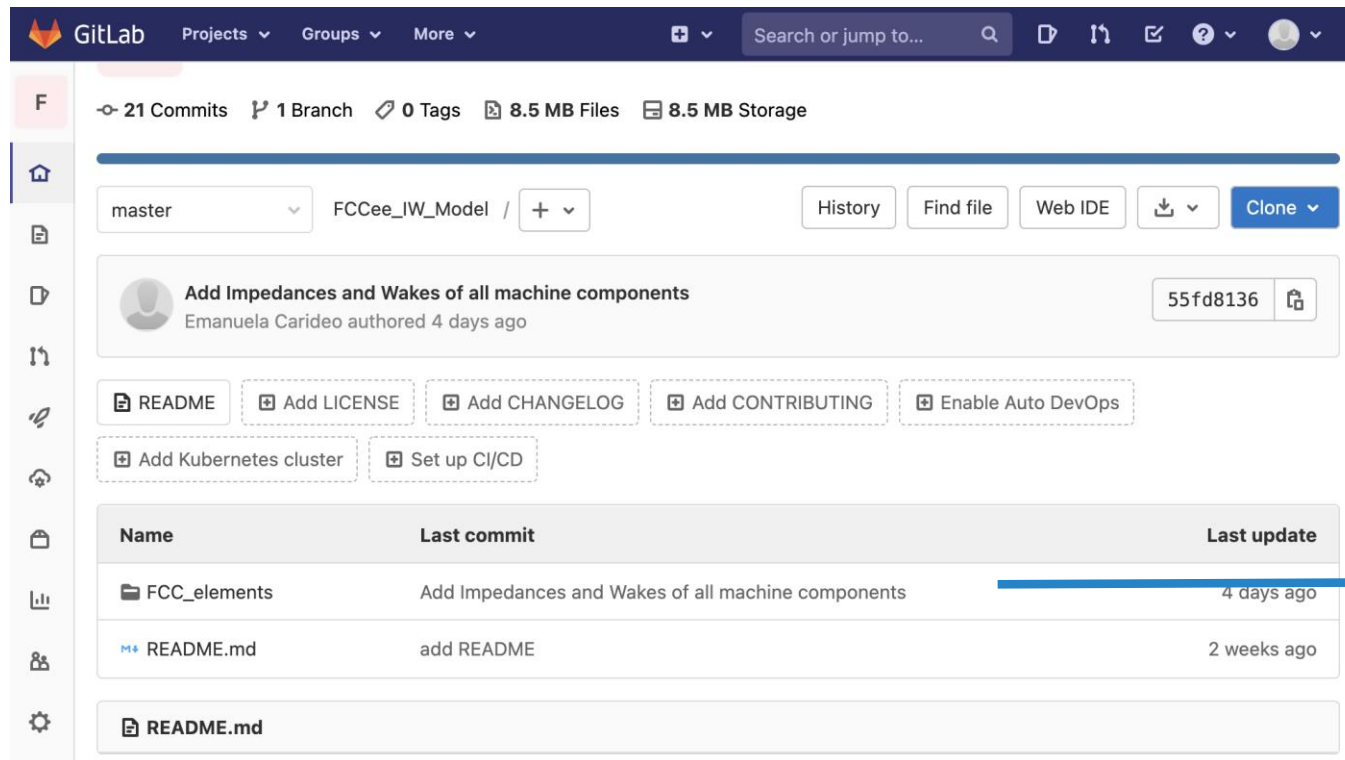


Comparison of the wake potential of 3.5 mm bunch length between PyHT and CST: RF double tapers



Wake and impedance repository for FCC-ee: https://gitlab.cern.ch/ecarideo/FCCee_IW_Model

A repository, or Git project, encompasses the entire collection of files and folders associated with a project. Working in repositories keeps development projects organized and organized and protected.



The Repository also provides more opportunities for project transparency and collaboration, working together to build the best possible final product.

How is it developed?

In this folder there are some of FCC-ee components and for each machine components the calculated impedance and wake

FCCee_IW_Model/FCC_elements/

Name	Last commit	Last update
..		
📁 BPMs_from_CST	Add Impedances and	
📁 Bellows_from_CST	Add Impedances and	
📁 RF_Cavity_from_CST	Add Impedances and	
📁 RW_from_IW2D	Add Impedances and	
📁 Tapers_ABCI	Add Impedances and Wakes of all machine components	33 seconds ago
🔗 Total_FCCee_Impedance.py	Add Impedances and Wake	
📄 Z_tot_Im.pdf	Add Impedances and Wake	
📄 Z_tot_Re.pdf	Add Impedances and Wake	

The same procedure for every folders

The total FCCee Impedance comes from all machine components

FCCee_IW_Model/FCC_elements/BPM_from_CST/

GitLab Emanuel Carideo > FCCee_IW_Model > Details

master FCCee_IW_Model / FCC_elements History Find file Web IDE Clone

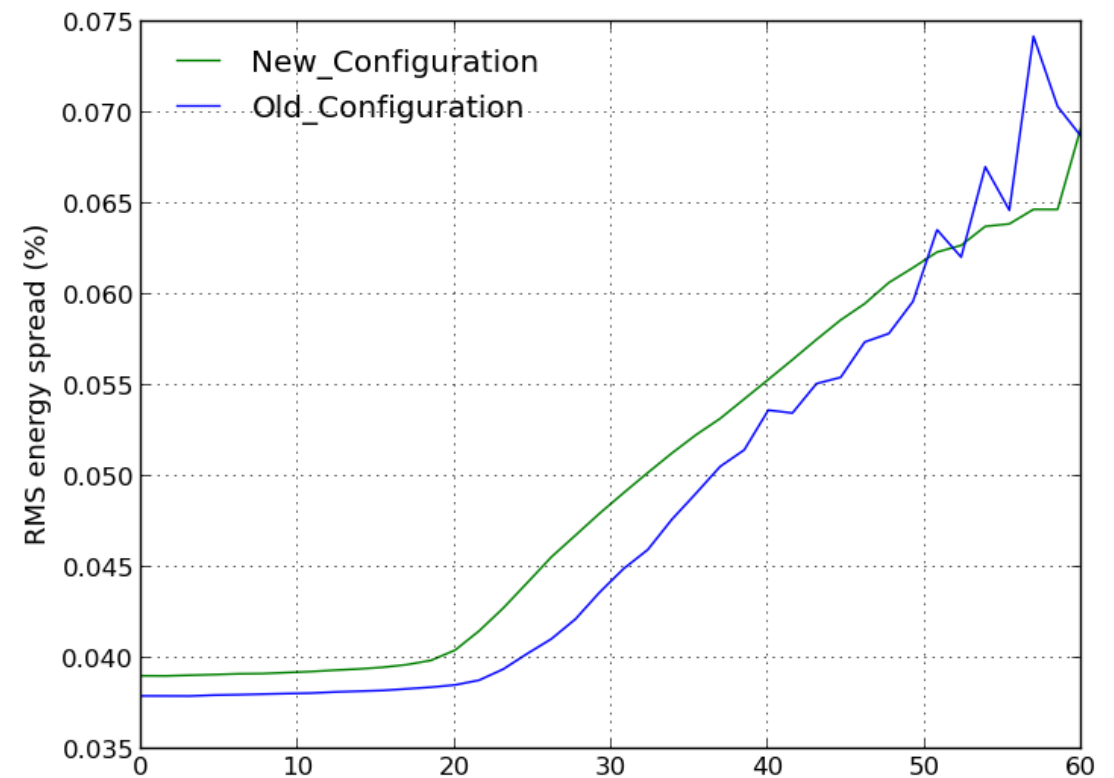
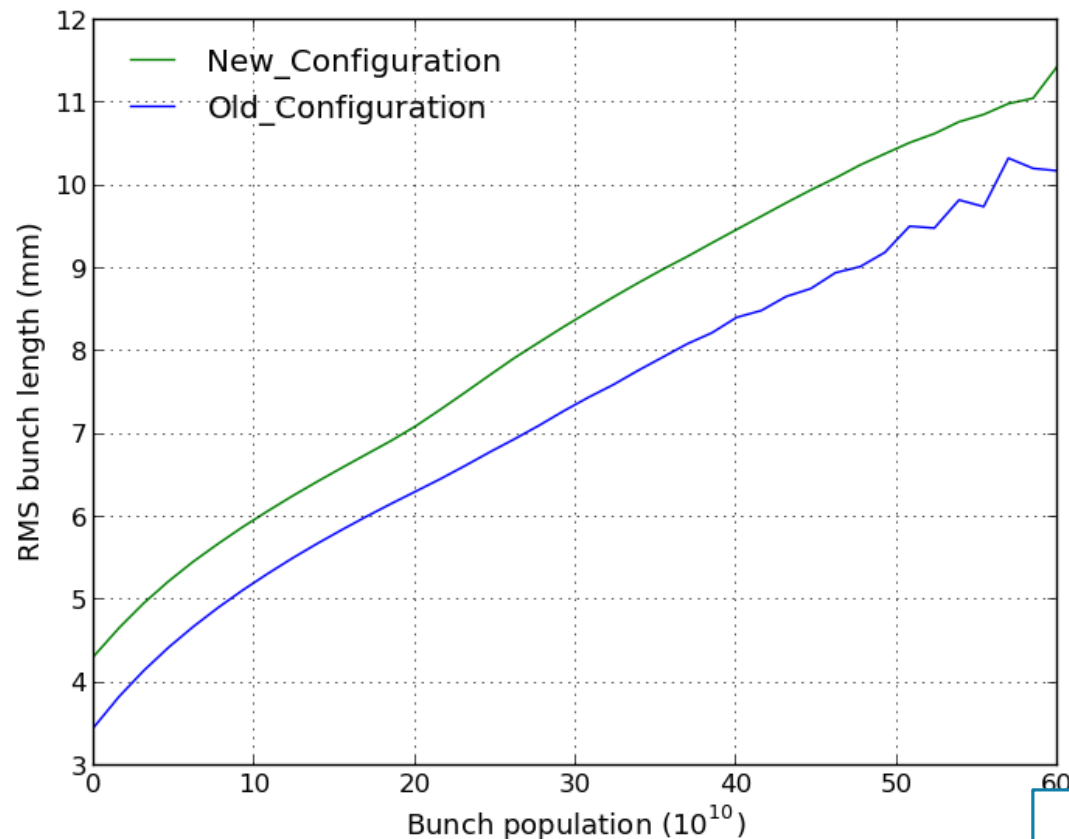
/ BPMs_from_CST / +

Add Impedances and Wakes of all machine components
Emanuela Carideo authored 4 days ago 55fd8136

Name	Last commit	Last update
..		
Impedance	Real and Imaginary Longitudinal Impedance	4 days ago
Wake	Wake potential	4 days ago
BPM_four_buttons.cst	Model used for CST simulation	1 week ago
loss_factors.txt	Calculation of the loss factor	1 week ago

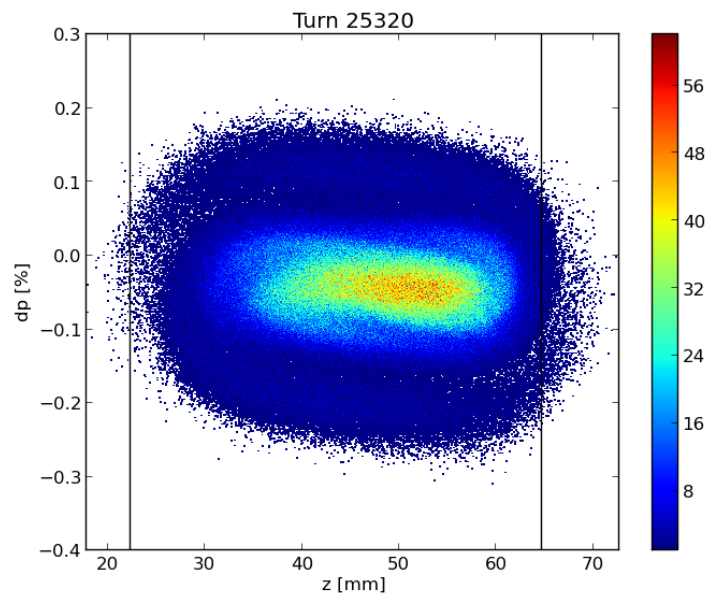
New Wakes with new machine parameters :

Longitudinal RW with 150nm of coating plus the Bellows without neglected the perturbation introduced by the lateral winglets used to place synchrotron radiation absorbers (Chiara Antuono)

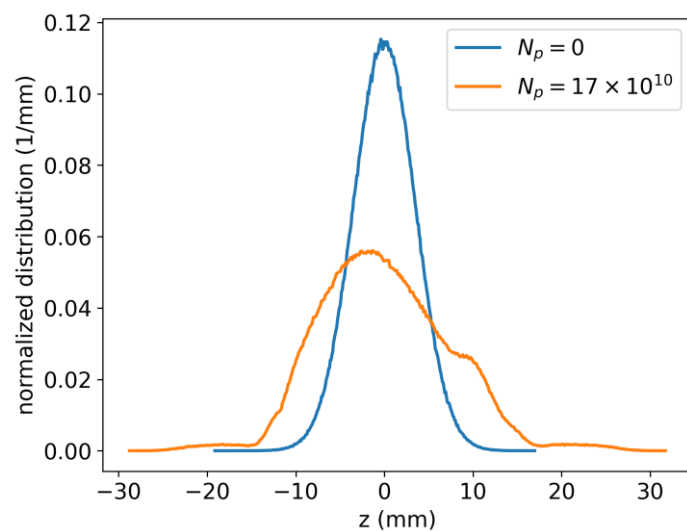


<https://indico.cern.ch/event/995850/contributions/4401571/attachments/2275135/3864813/FCCweek.pdf>

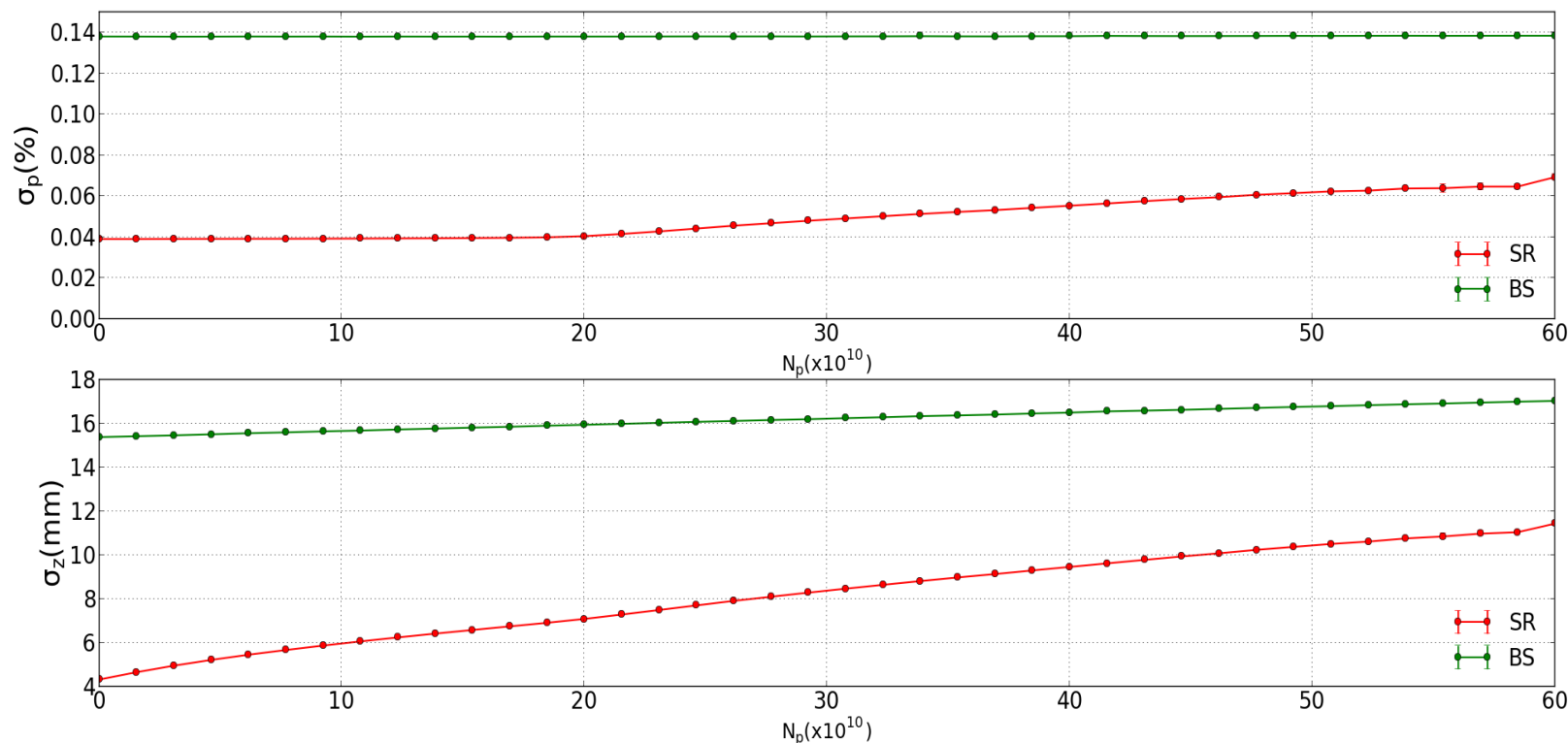
LONGITUDINAL DYNAMICS



Longitudinal
phase
space



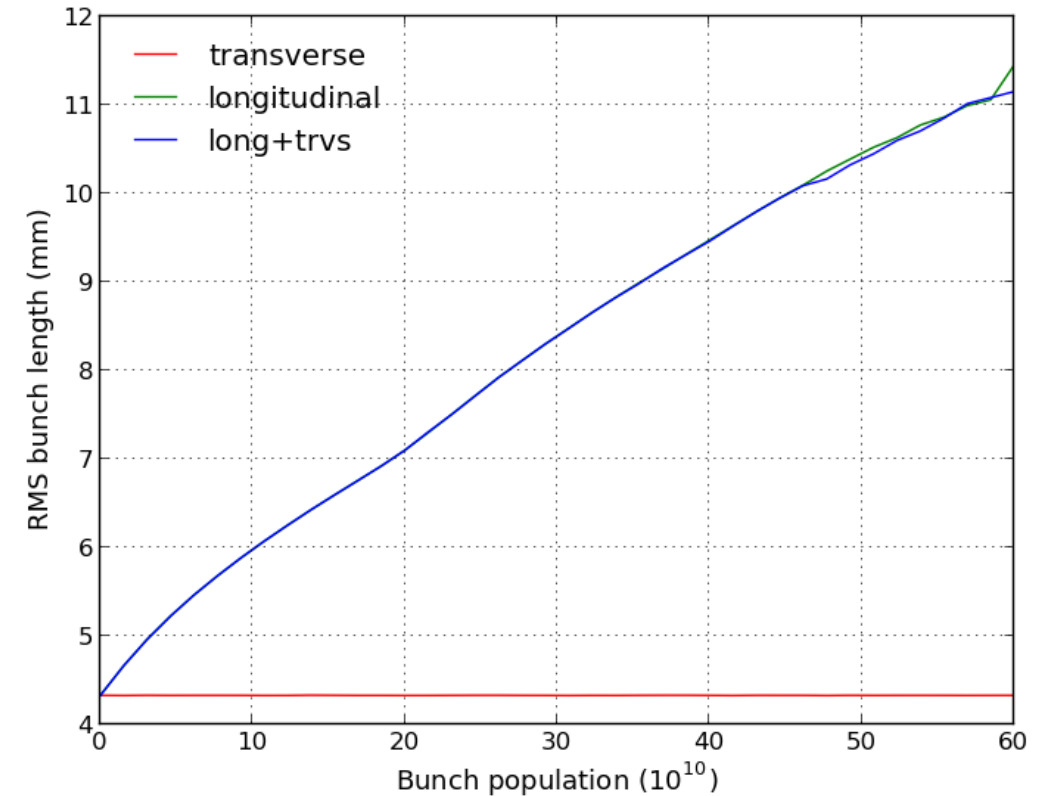
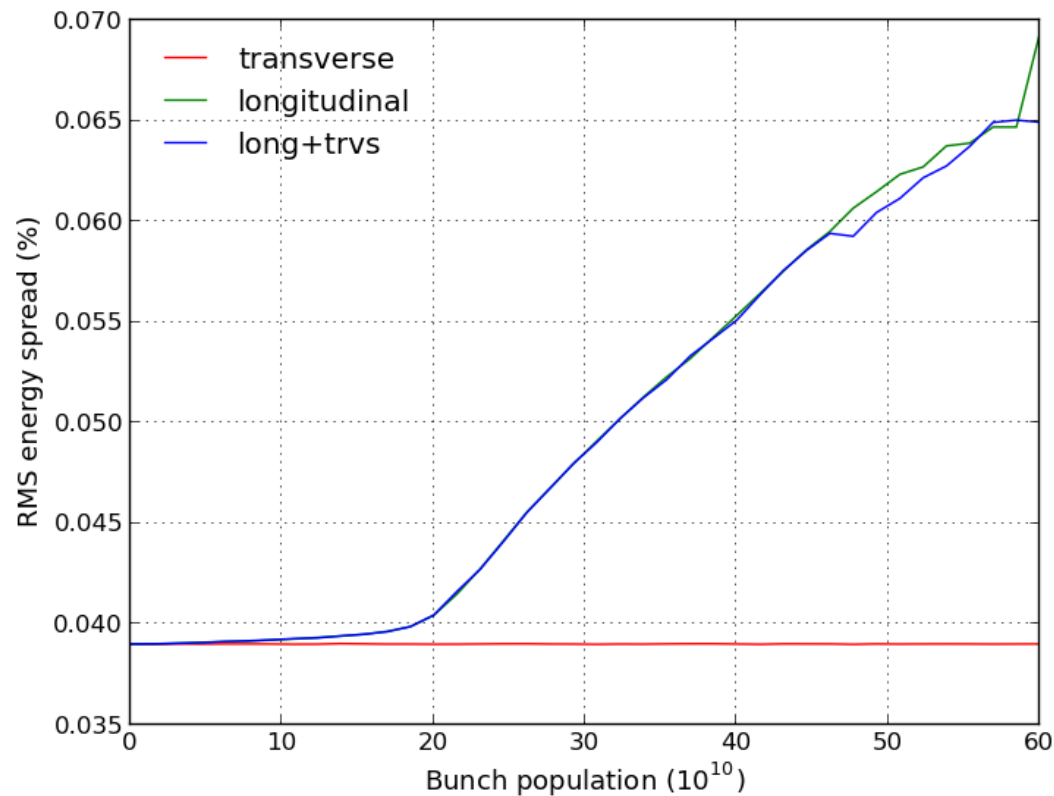
Bunch shape distortion at nominal intensity from the original Gaussian one.



Bunch length (bottom) and RMS energy spread (top) as a function of bunch population in the case with (BS) and without (SR) beamstrahlung, which is considered here independent of the longitudinal impedance.

Bunch length and energy spread for considered cases

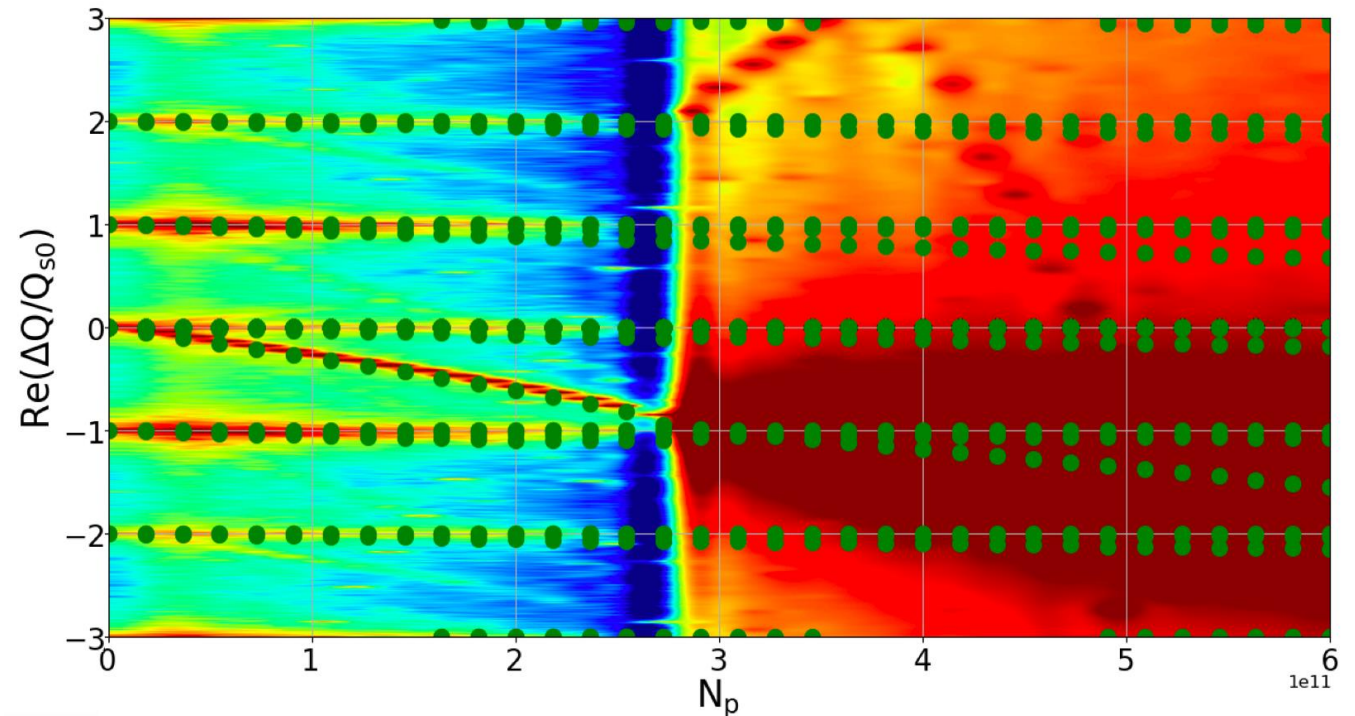
- The transverse impedance almost does not affect the longitudinal dynamics



Transverse Dynamics: Checked the method

In addition to simulations with the tracking code, the TMCI threshold has been also evaluated with the analytic Vlasov solver DELPHI. For PyHEADTAIL, we have used the RW wakefield of a short bunch with a length of 0.4 mm as Green function. DELPHI uses the impedance in frequency domain given directly by IW2D.

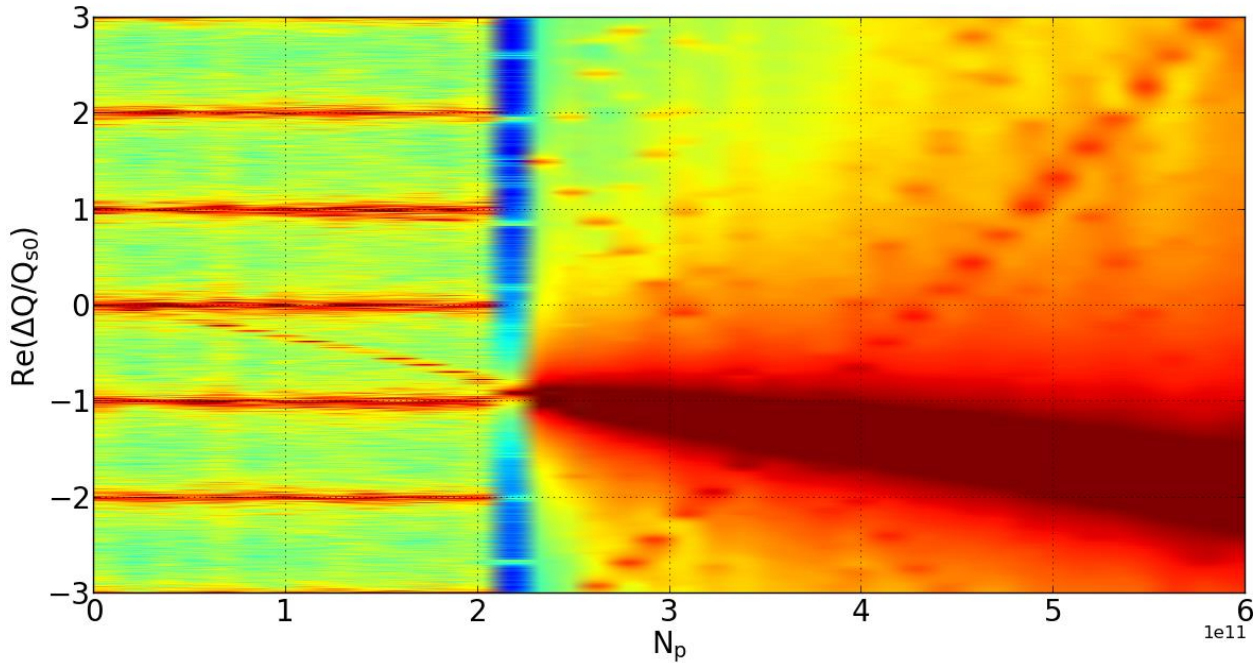
The green dots represent the DELPHI results, which well fit with the PyHEADTAIL simulations for which the colours are proportional to the amplitude of the frequency spectrum of the various moments of the distribution. Red corresponds to the largest amplitude, blue to the lack of signal.



There is an excellent agreement between the two methods up to the instability threshold

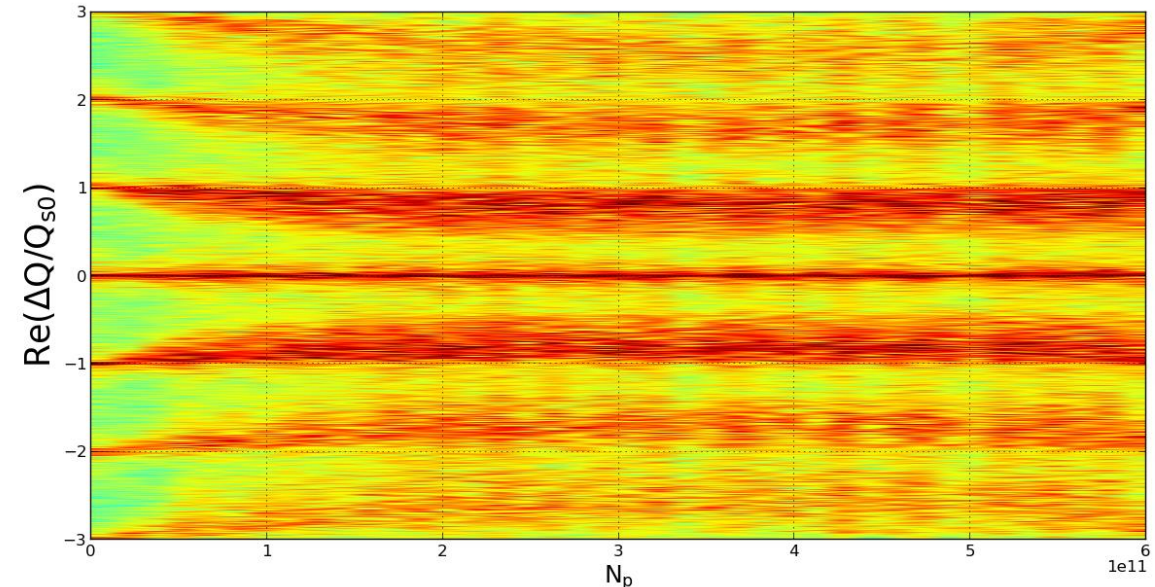
Transverse Dynamics

The TMCI, **Transverse Mode Coupling Instability**, occurs when the frequencies of two neighboring coherent oscillation modes merge together. Above the transverse instability threshold the bunch is lost and this makes the TMCI very dangerous for the beam.



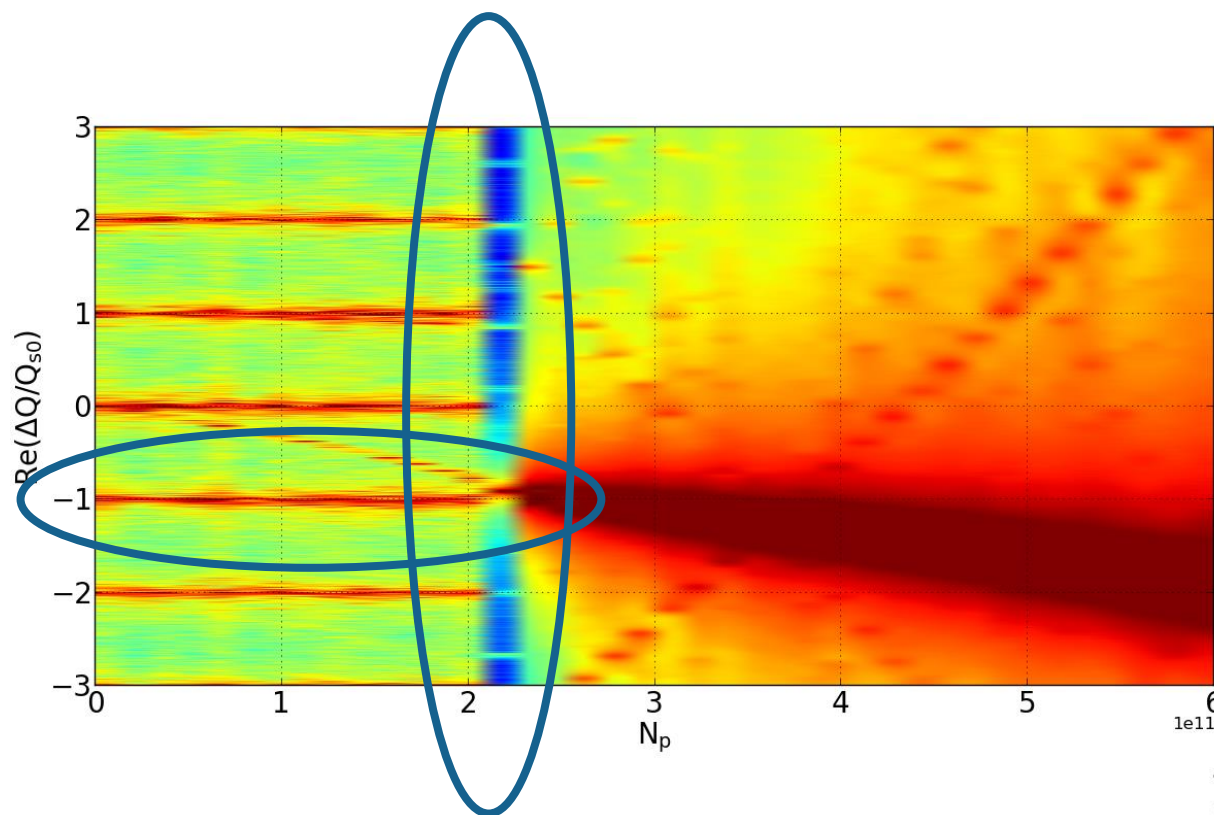
On the top, real part of the frequency shift of the first coherent oscillation modes as a function of the bunch population without beamstrahlung, by considering only the RW impedance produced by a NEG film with 150 nm thickness given by IW2D.

On the right, real part of the coherent tune shift as a function of intensity considering the longitudinal resistive wall wakefield, by using PyHEADTAIL.



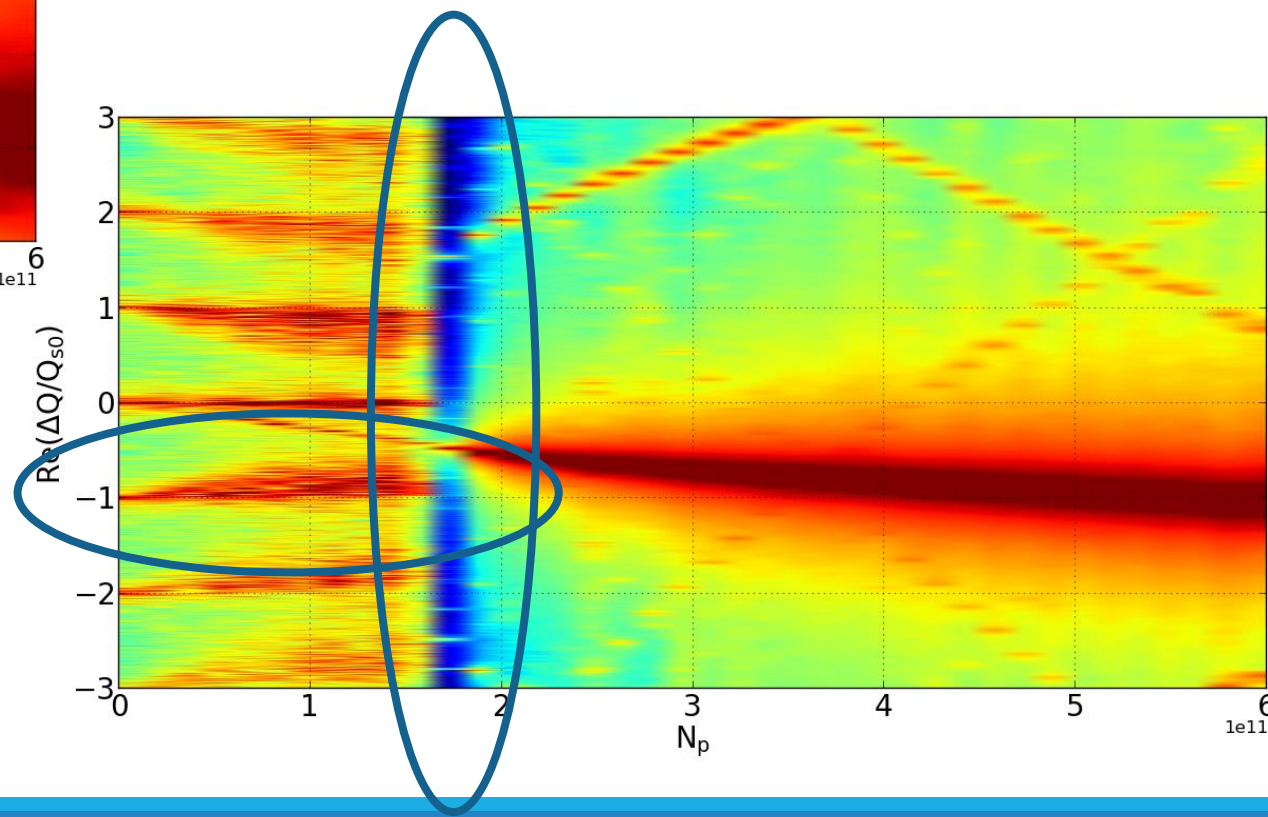
TMCI

SR: Bunch length of 4.35 mm

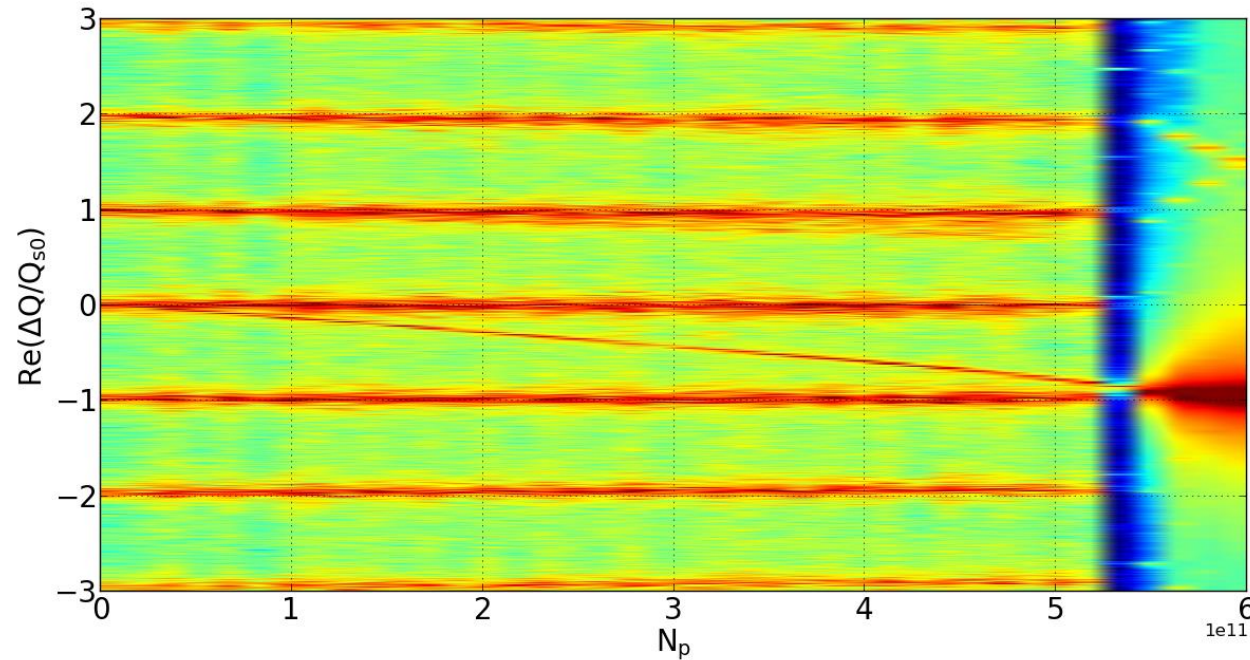


Without longitudinal
resistive wall wakefield

Considering the longitudinal
resistive wall wakefield

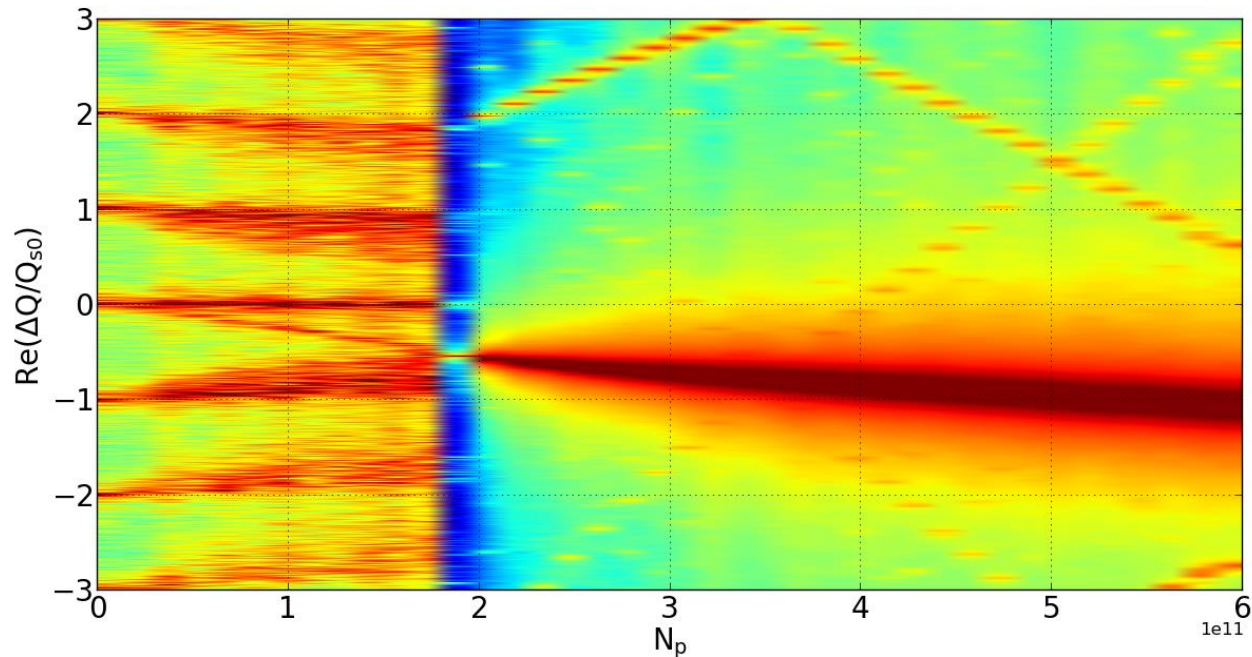


TMCI: longitudinal and transverse wake with a bunch length of 15.2 mm (BS)



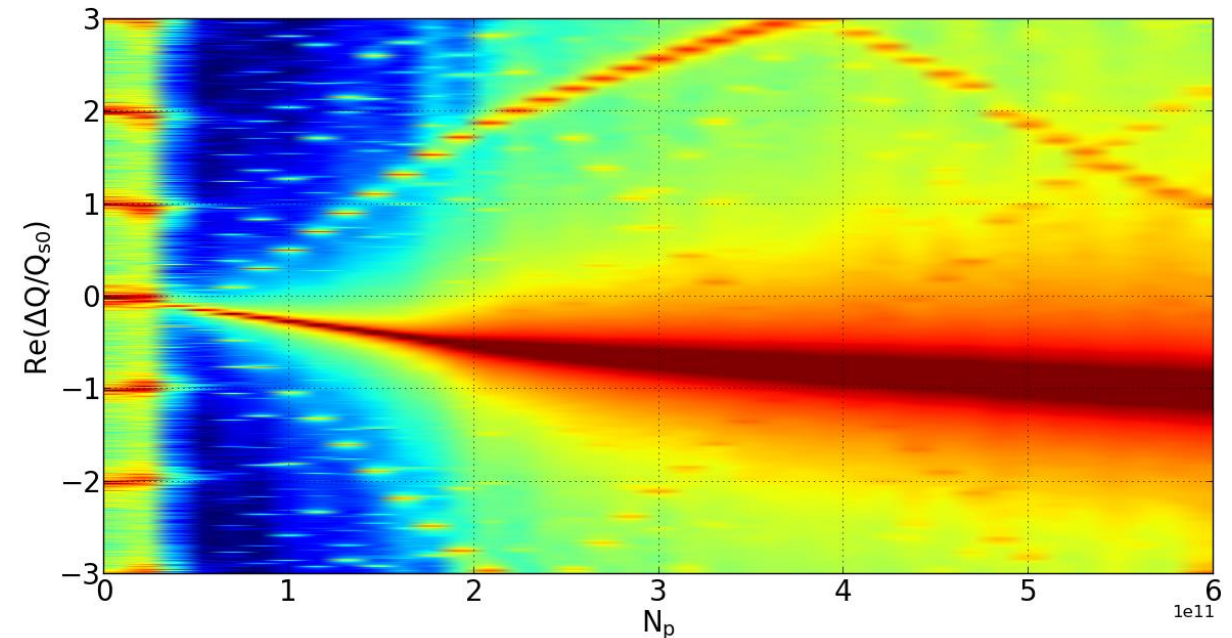
In the back-up slides (#37) you can find the other plots (transverse and longitudinal separately)

Variable Chromaticity

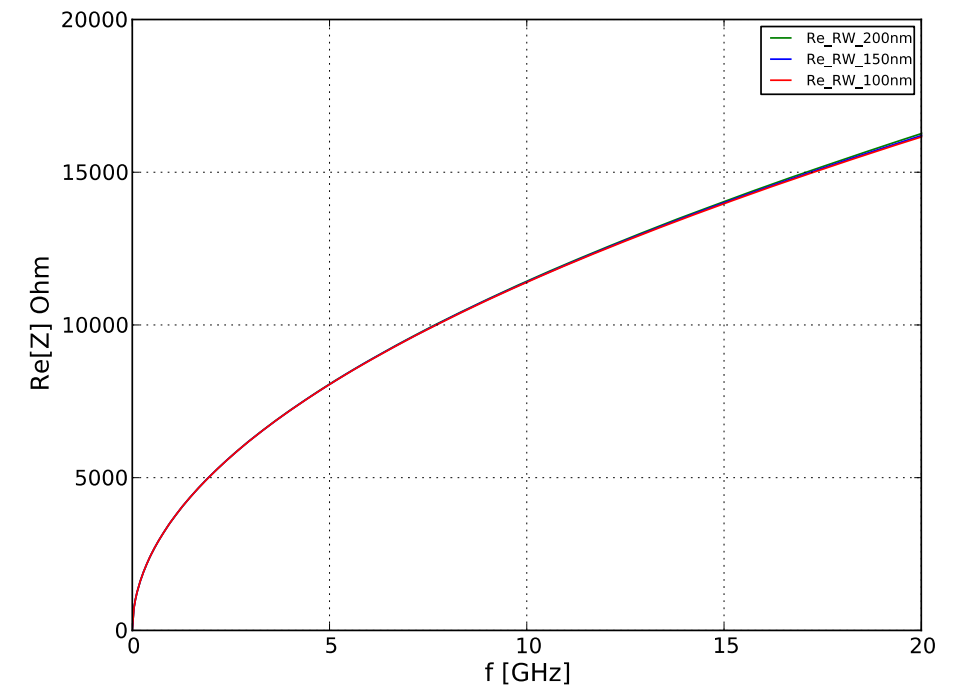
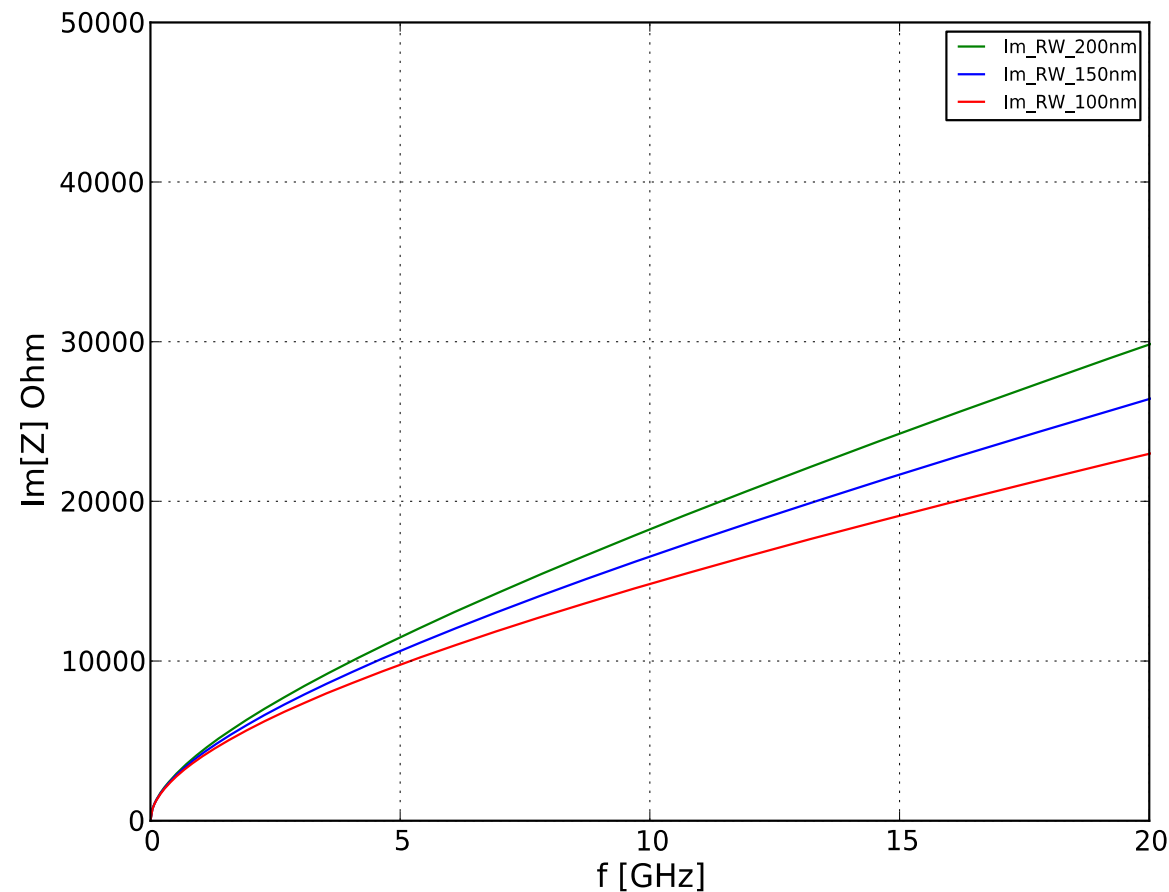


On the right, real part of the frequency shift of the first coherent oscillation modes as a function of the bunch population without beamstrahlung, so considering a bunch length of 4.32mm and a value of Chromaticity of -5

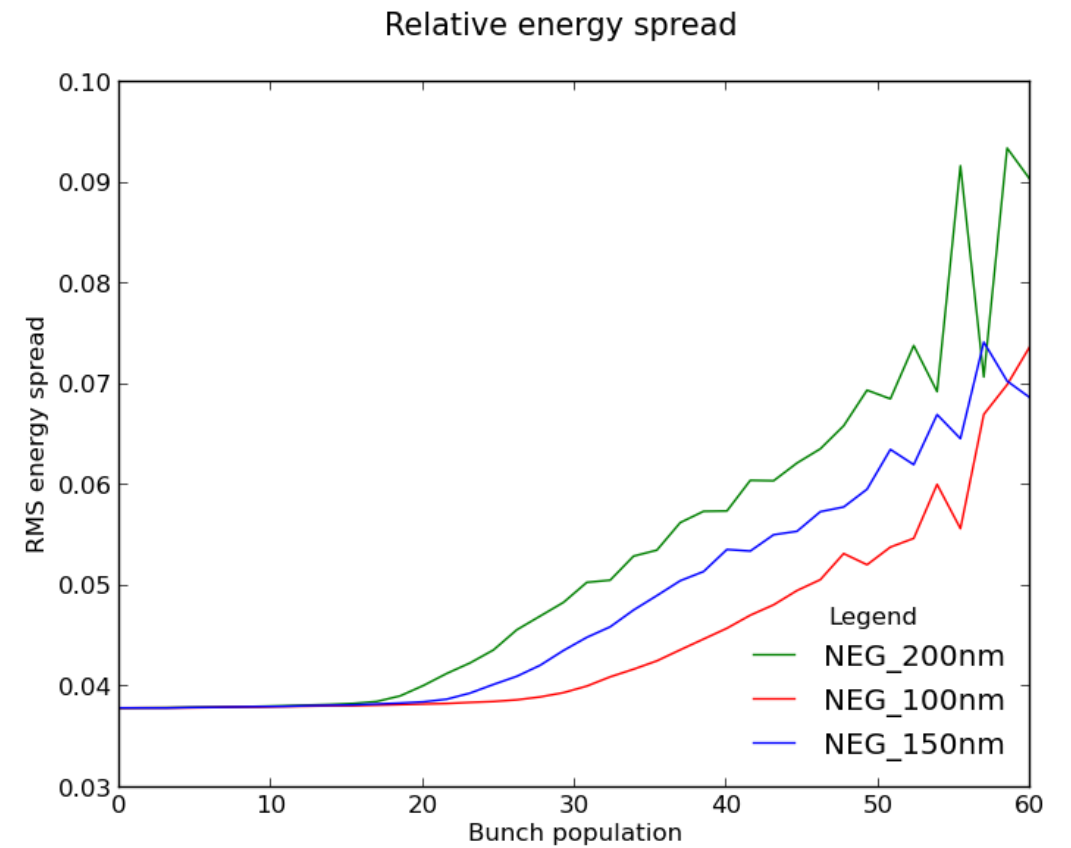
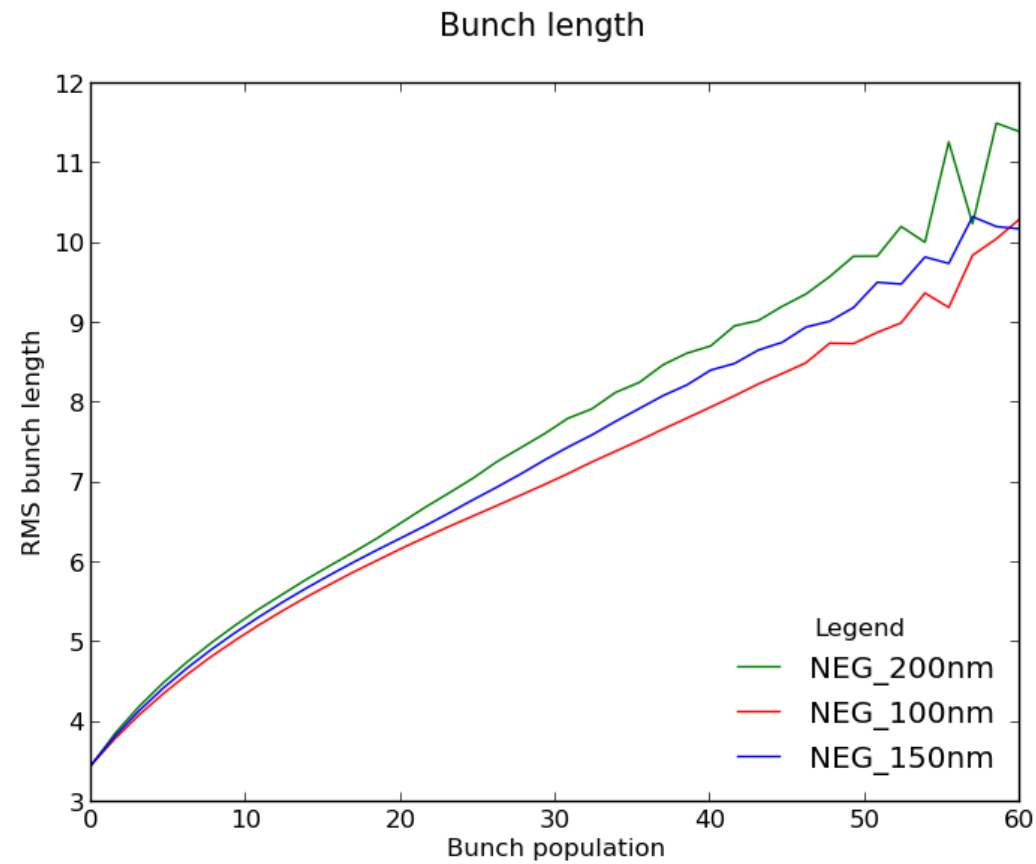
On the left, real part of the frequency shift of the first coherent oscillation modes as a function of the bunch population without beamstrahlung, so considering a bunch length of 4.32mm and a value of Chromaticity of +5



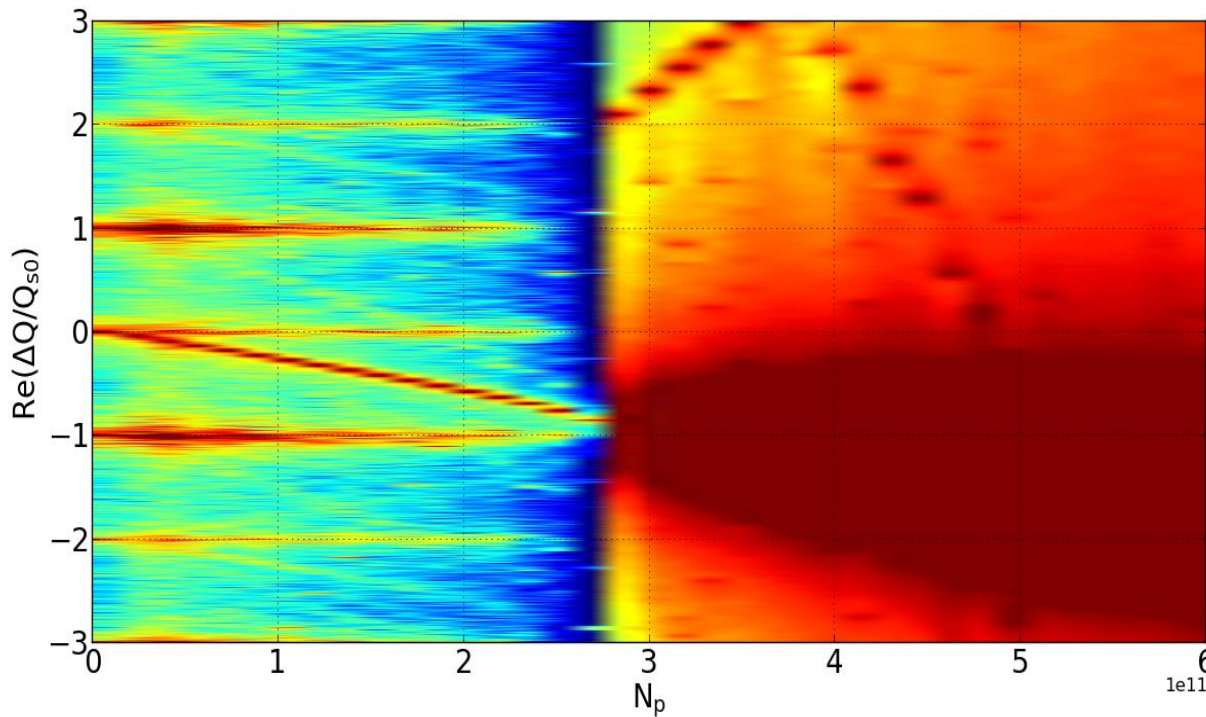
New evaluation of the impedances using different NEG coating : 100 nm 150 nm and 200 nm



LONGITUDINAL DYNAMICS

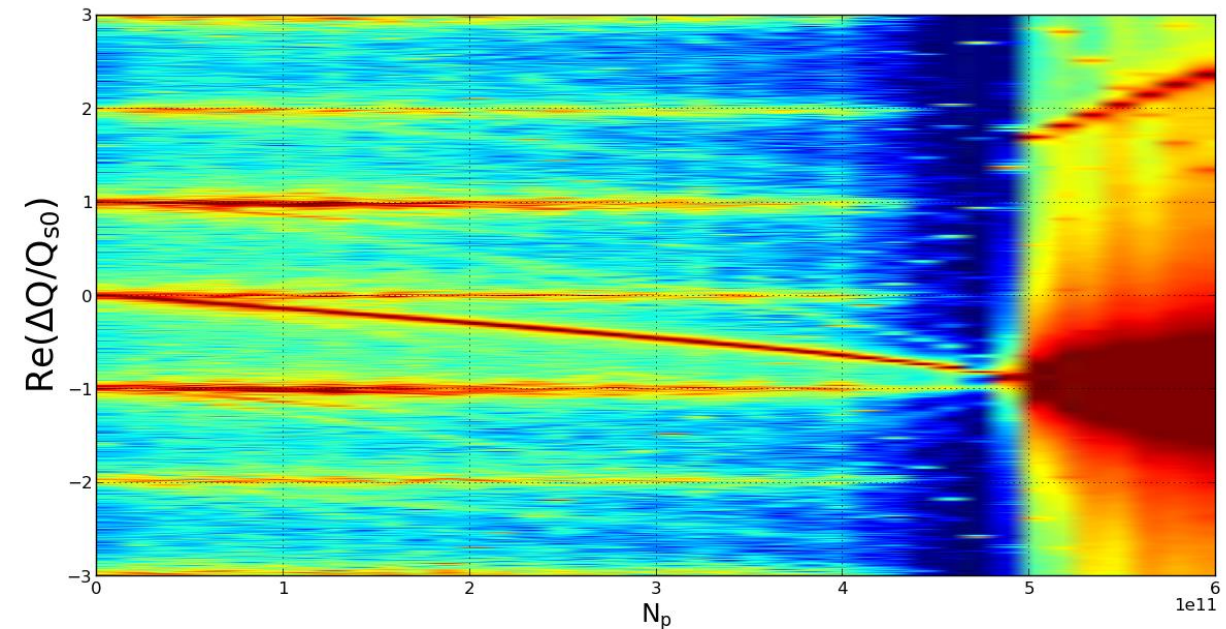


TMCI analyzes using wake with different NEG's : **100nm, 150 nm and 200 nm**

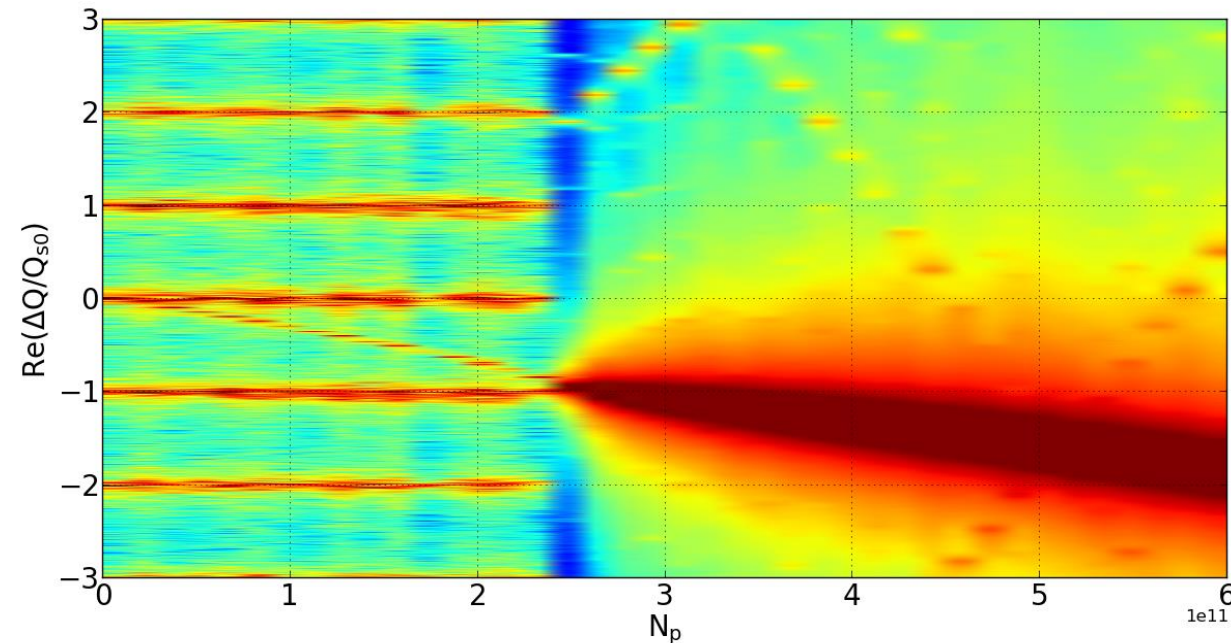


On the left the plot of the TMCI considering a wake with 100nm of NEG and a beam length of 3.5mm

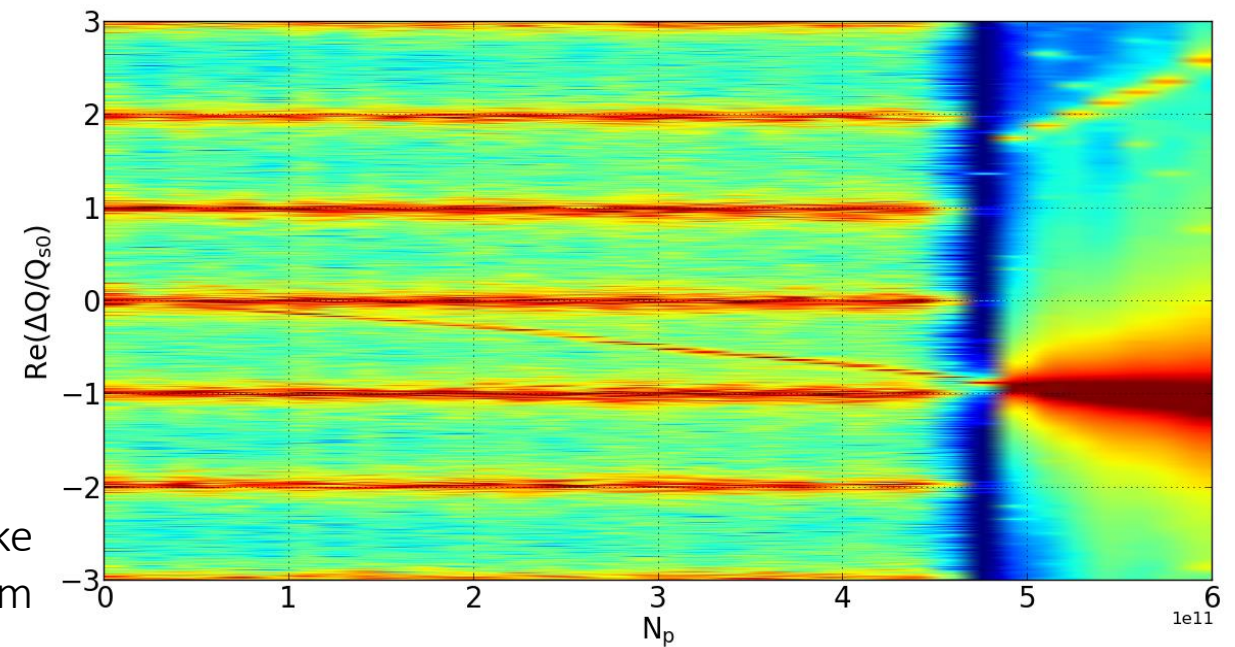
On the right the plot of the TMCI considering a wake with 100nm of NEG and a beam length of 12.1mm



TMCI analyzes using wake with different NEG's : 100nm, **150 nm** and 200 nm

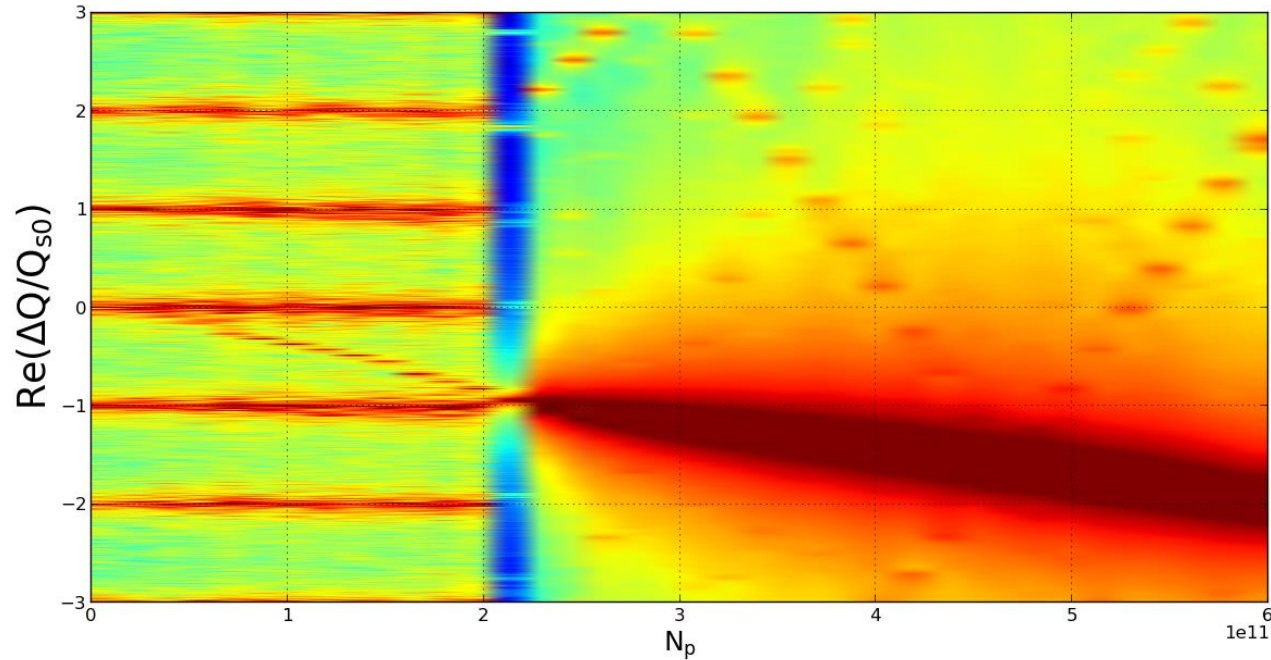


On the left the plot of the TMCI considering a wake with 150nm of NEG and a beam length of 3.5mm

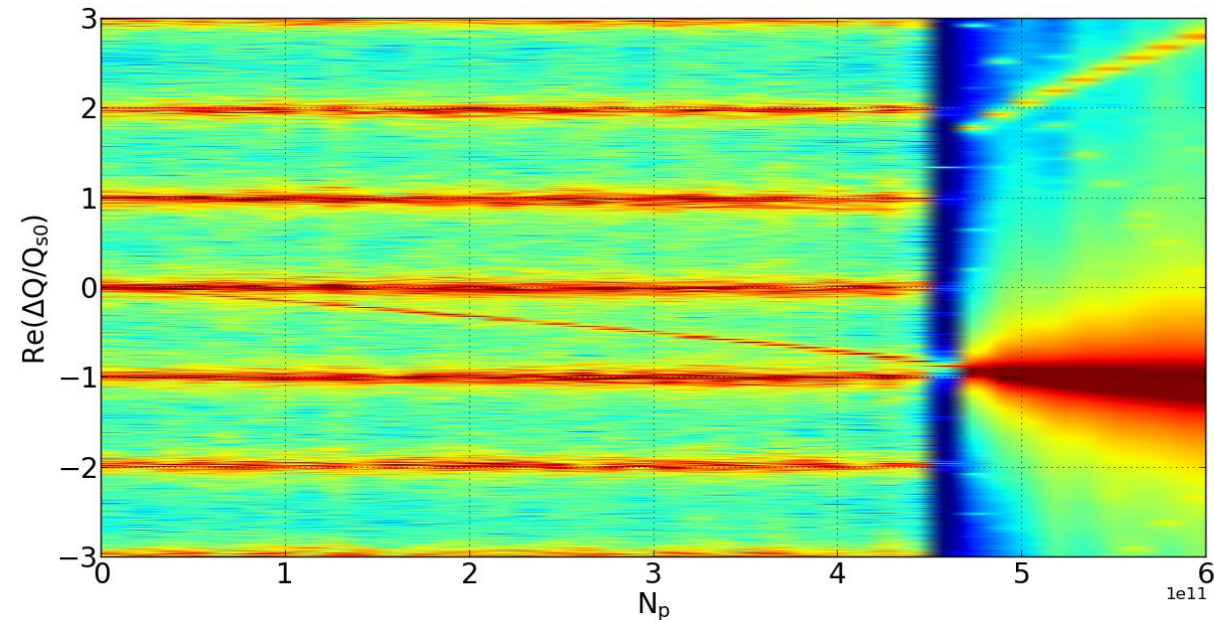


On the right the plot of the TMCI considering a wake with 150nm of NEG and a beam length of 12.1mm

TMCI analyzes using wake with different NEG's : 100nm, 150 nm and 200 nm

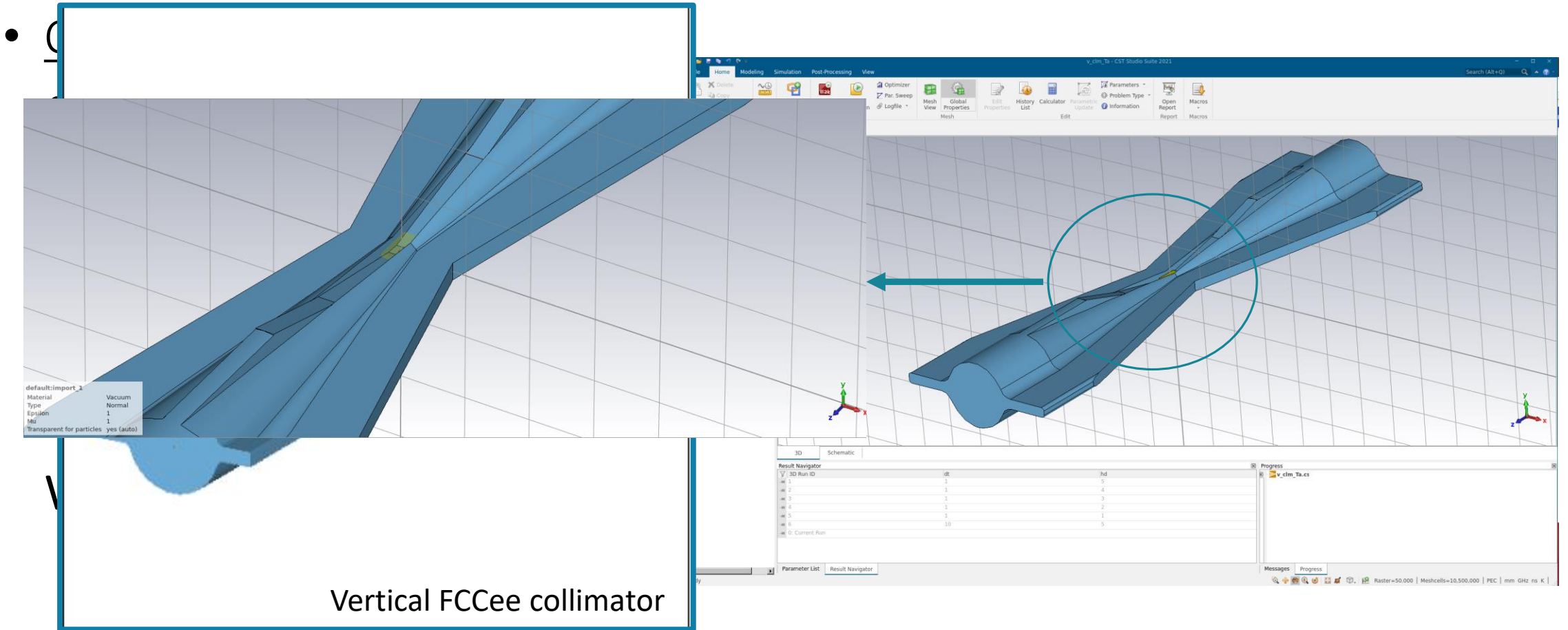


On the left the plot of the TMCI considering a wake with 200nm of NEG and a beam length of 3.5mm



On the right the plot of the TMCI considering a wake with 200nm of NEG and a beam length of 12.1mm

Work in progress



Preliminary work

- Used a round taper model to calculate the transverse impedance
- The approximate formula that I have used for the round taper is extrapolated from Stupakov1 's paper :

$$Z_{\perp}^{round} = -\frac{iZ_0}{2\pi} \int dz \left(\frac{g'}{g} \right)^2$$

$Z_0=377 \text{ # Ohm}$

a, b_1, b_2 are gaps

$\alpha_1= 11.74*0.0174533$ is the angle of the taper in radiant

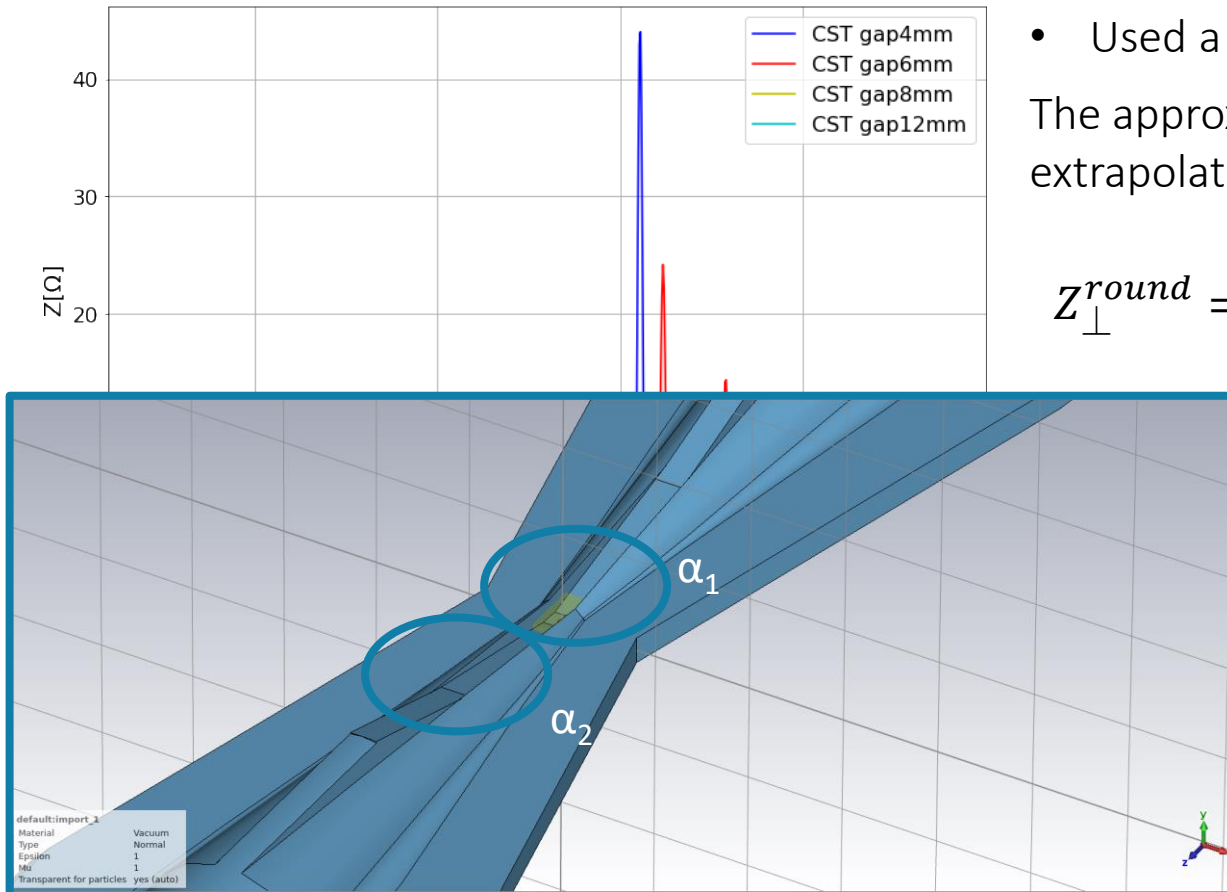
$\alpha_2= 4.38*0.0174533$ is the angle of the taper in radiant



$$Z_{\perp 1}^{round} = \frac{Z_0 * \tan(\alpha_1)}{2\pi} \left(\left(\frac{1}{a} \right) - \left(\frac{1}{b_1} \right) \right)$$

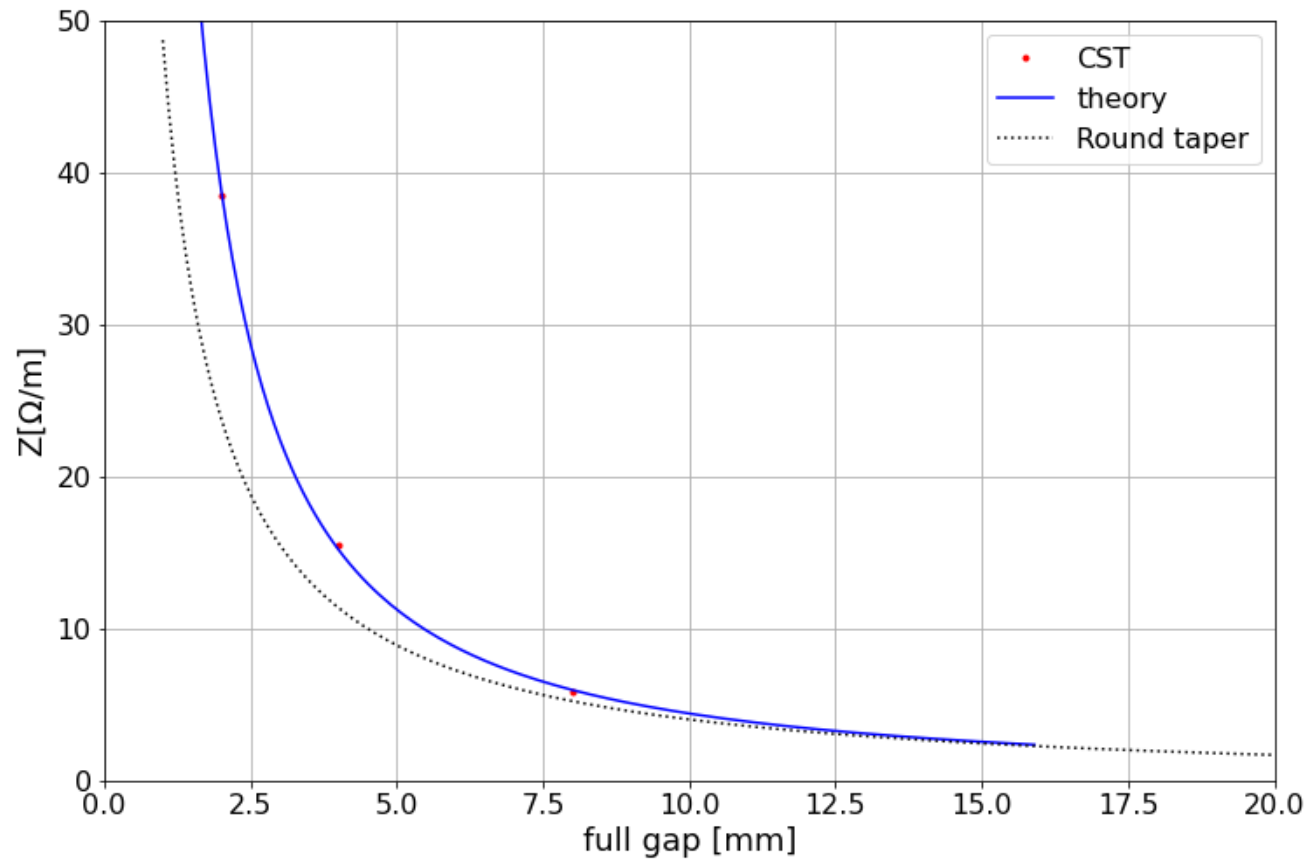
$$Z_{\perp 2}^{round} = \frac{Z_0 * \tan(\alpha_2)}{2\pi} \left(\left(\frac{1}{b_1} \right) - \left(\frac{1}{b_2} \right) \right)$$

$$Z_{\perp}^{round} = Z_{\perp 1}^{round} + Z_{\perp 2}^{round}$$



1: "Low frequency impedance of tapered transitions with arbitrary cross sections" G. Stupakov, Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

First result



We had the simulation data for some gaps.
Hence, we extrapolate the transverse impedance at different gaps by using a nonlinear fits in Python:

$$Z = A * g^{-\alpha}$$

Where:

Z - transverse impedance

g - gap

A and α - constants to be found during the fit.

Future Plan

- Continue the work for the evaluation, reduction and optimization of the impedances of the main machine elements (e. g. flanges, collimators), and also implementing the FCC-ee repository.
- In addition to the bellows, update of some impedance sources (e. g., BPMs, RF tapers) with more realistic models.
- Future investigations about the reduction of the TMCI threshold due to the longitudinal wake are required, as well as possible mitigation solutions.
- Continue the work with the CST simulations and continue the “segments project” (splitting the accelerator ring in to segments) to study the effect of different distributed wake along the machine.

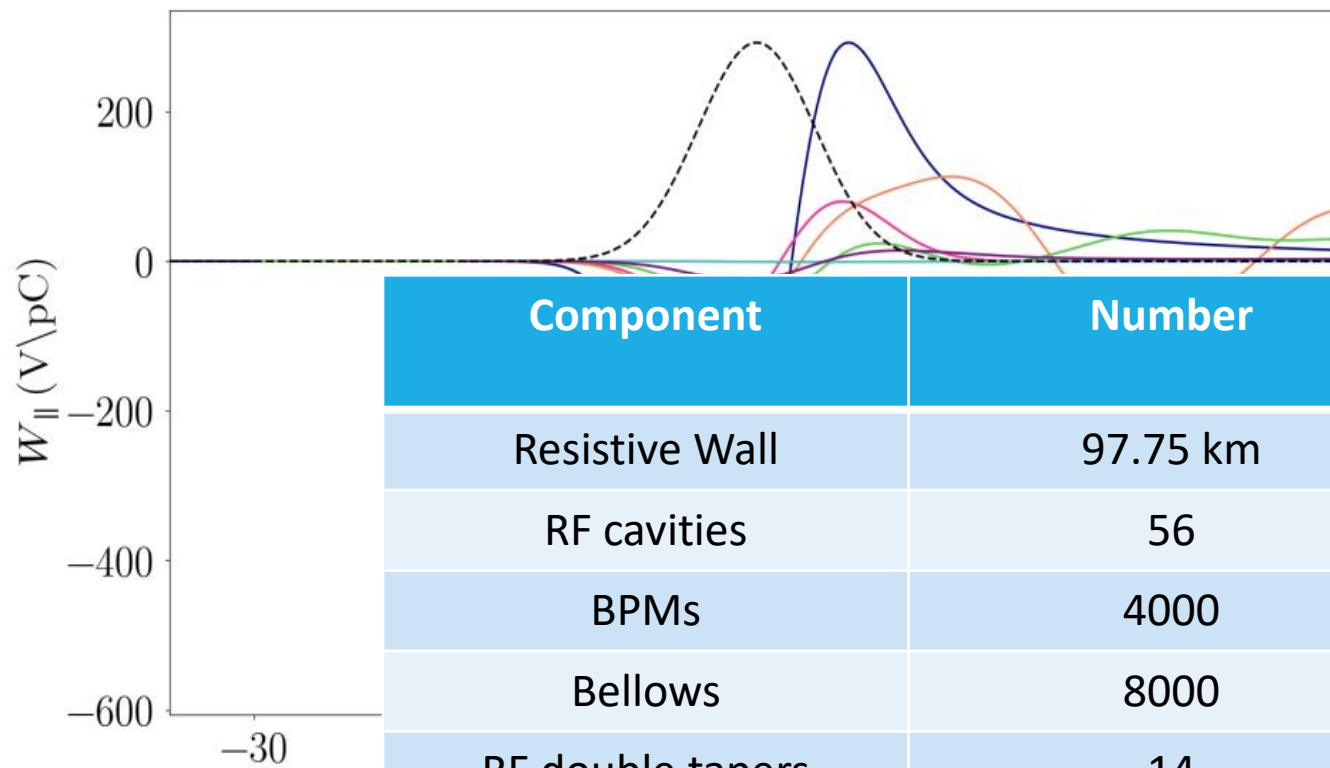


Thanks for your attention!

Any questions or suggestions?
Time for further discussion this afternoon in 6/R-012

Back-up Slides

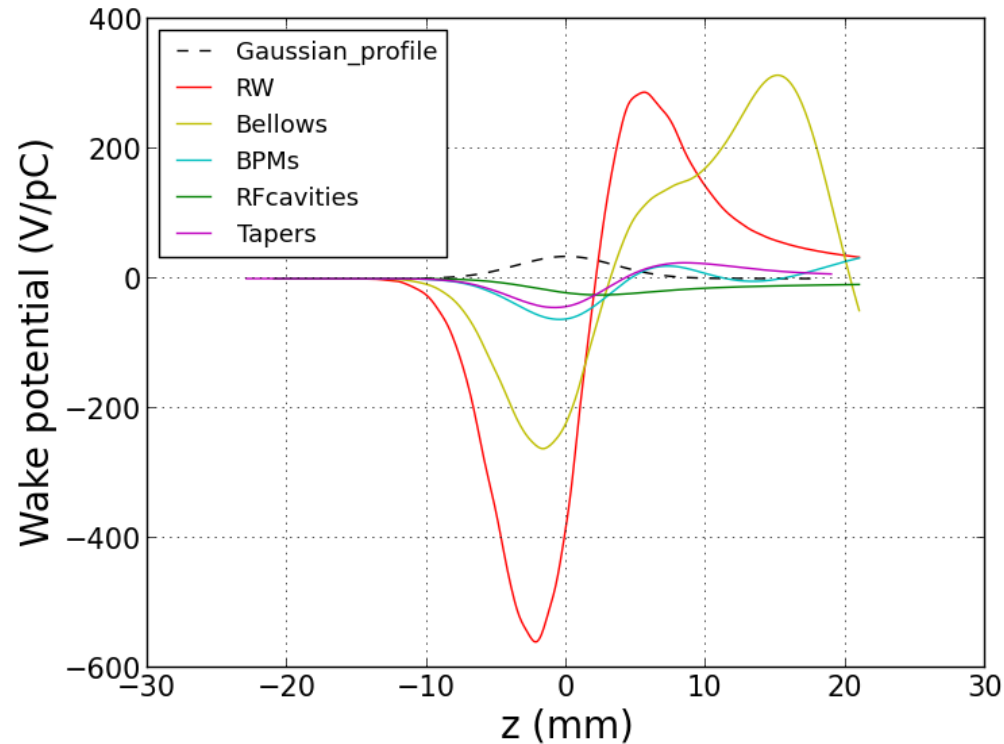
Updated FCC-ee impedance model



Longitudinal wake potentials of some machine elements evaluated so far for a Gaussian bunch with a nominal bunch length of 3.5 mm, considering 8000 bellows.

Component	Number	$K_{\text{loss}}(3.5\text{mm})[\text{V/pC}]$	$K_{\text{loss}}(12.1\text{mm})[\text{V/pC}]$
Resistive Wall	97.75 km	210	33.1
RF cavities	56	18.5	9.44
BPMs	4000	40.1	4.81
Bellows	8000	49	4.7e-5
RF double tapers	14	26.6	2.5116

Impedance Sources: CST and IW2D simulations

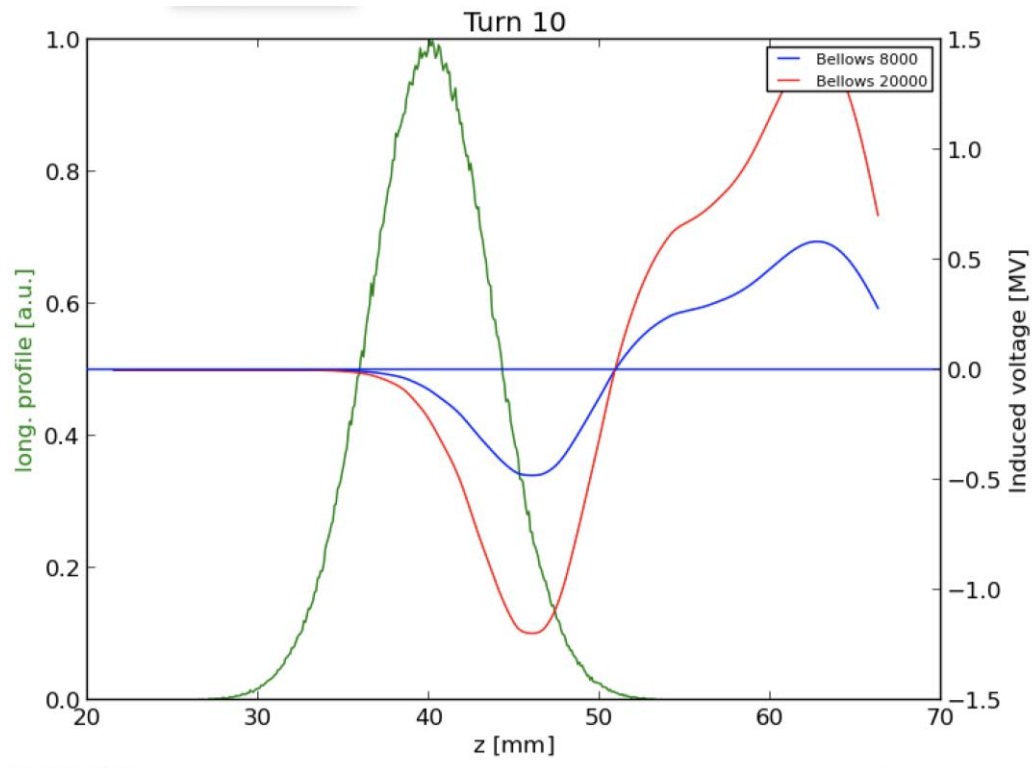


Longitudinal wake potentials for a Gaussian bunch with nominal bunch length $\sigma_z = 3.5\text{mm}$ due to the main FCC-ee components, evaluated so far.

Loss factor and Power loss contribution of FCC-ee devices at nominal intensity and bunch length of 12.1 mm, in the lowest energy case of 45.6 GeV

Component	Number	$K_{\text{loss}}(12.1\text{mm})[\text{V/pC}]$	$P_{\text{loss}}[\text{MW}]$
Resistive Wall	97.75 km	33.1	1.21
RF cavities	52	8.76	0.334
BPMs	4000	4.81	0.180
Bellows	20000	23.95	0.880
RF double tapers	13	2.33	0.088

Updated FCC-ee impedance model: 20000 Bellows



We initially considered a number of
8000 Bellows

↓ BUT

85% of arcs (~ 79 km)

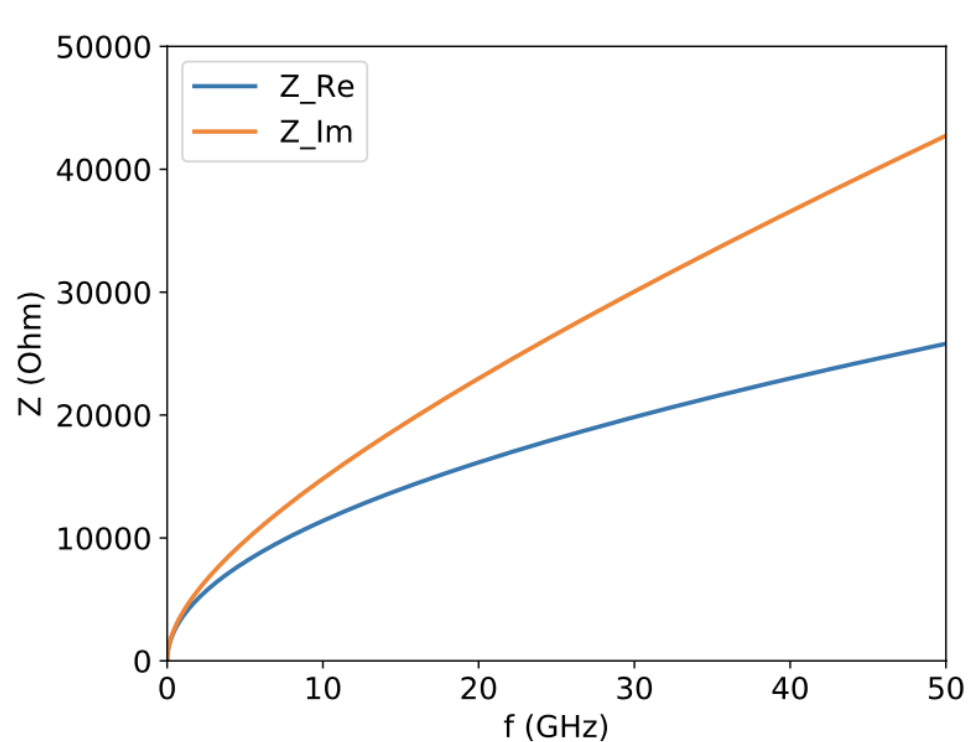
↓

Every arc is 8m long
X2 because we have another
bellow before any quadrupole

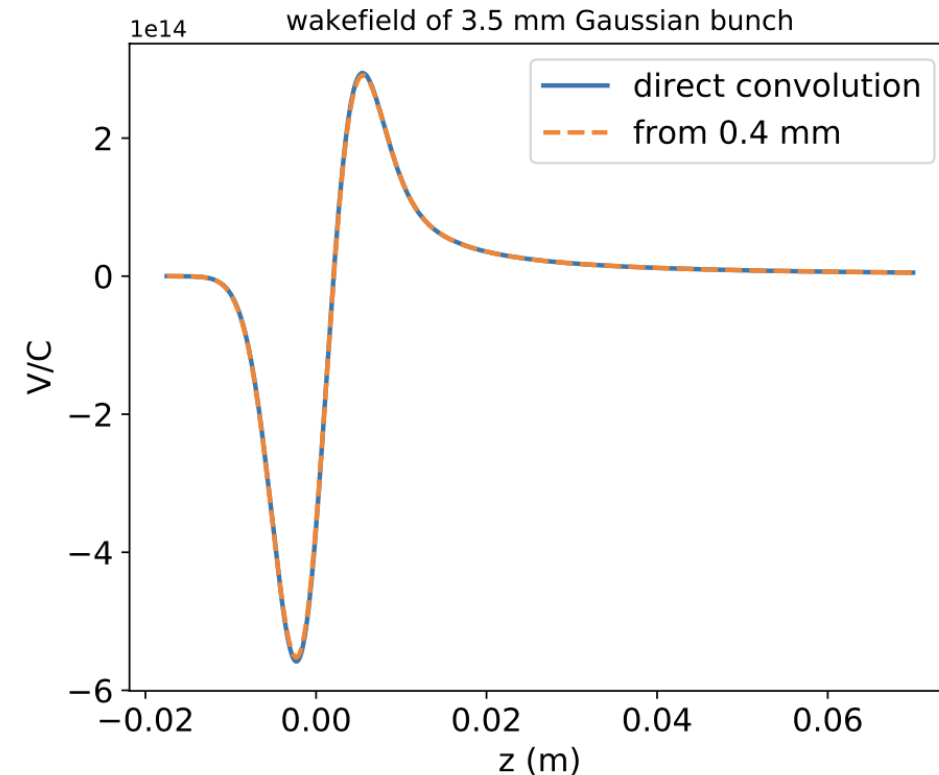
↓

12000-13000 but to be sure we are performing our
calculations considering up to 20000 bellows

Method to calculate the Wake Potential by software simulation: Resistive Wall

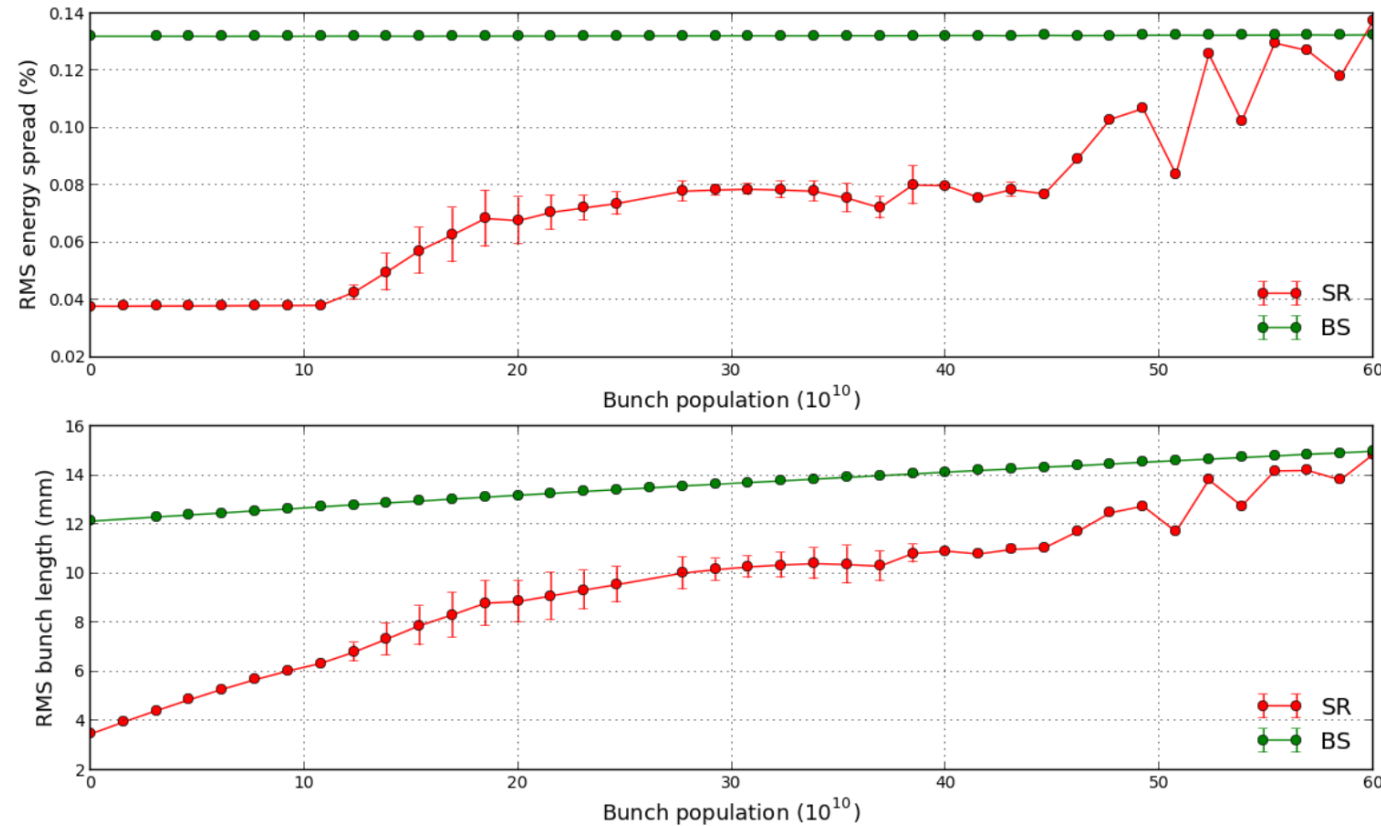


Real and imaginary part of the resistive wall impedance calculated by using the code **IW2D**



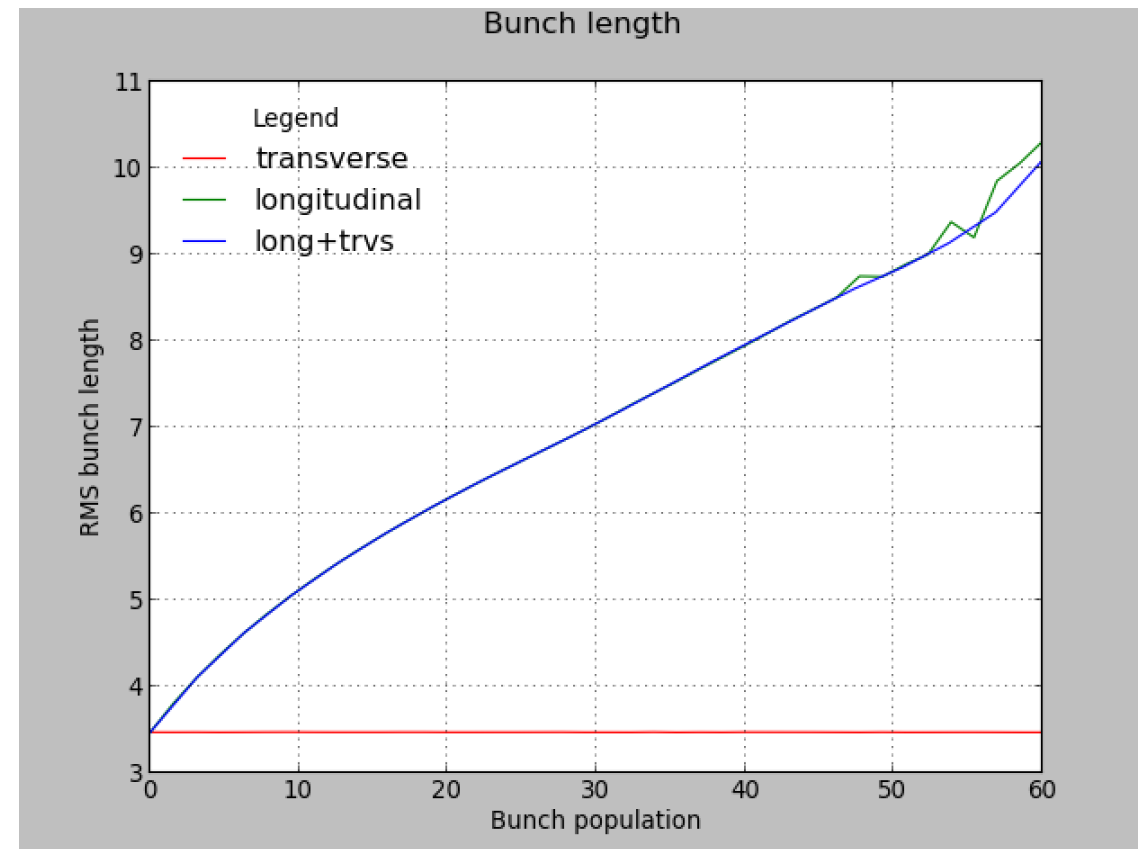
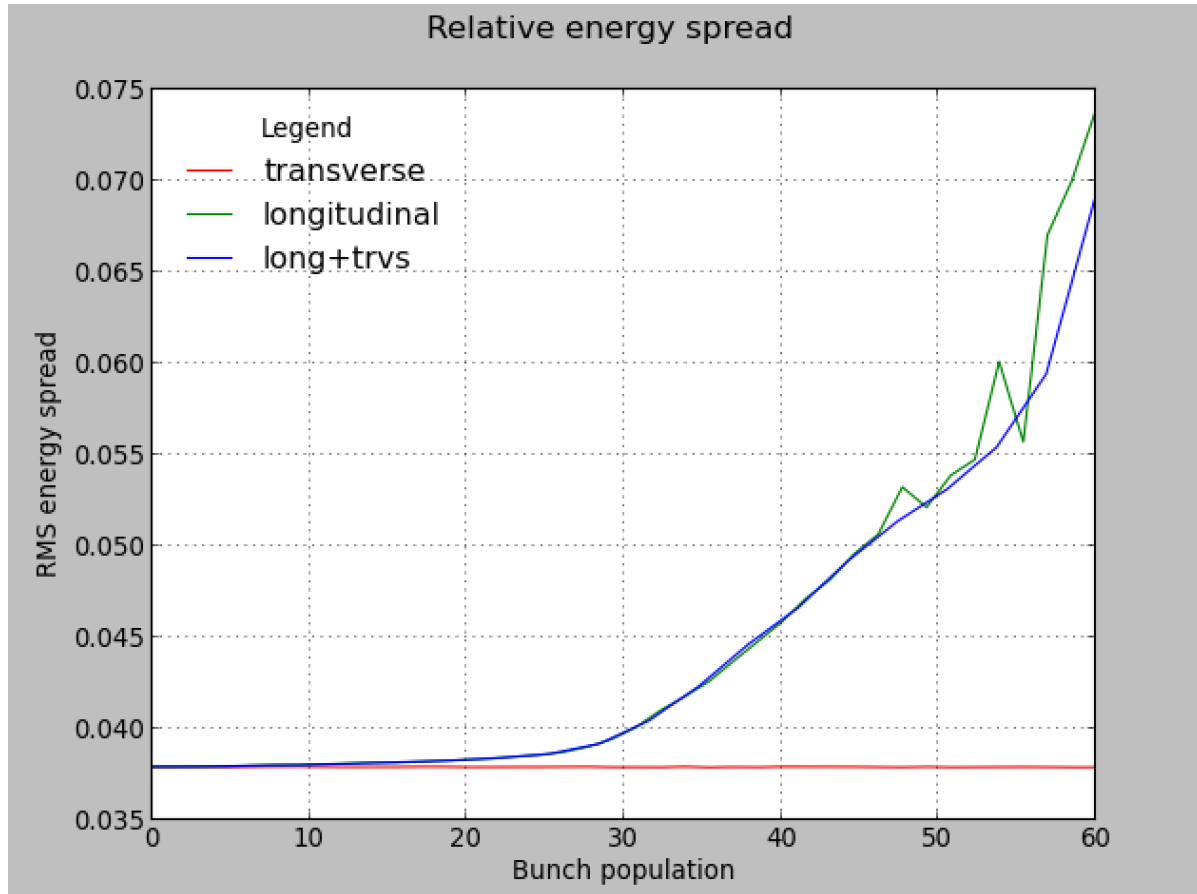
Wake potential of a 0.4 mm Gaussian bunch convoluted with the nominal bunch length and compared with the wake potential obtained directly from the convolution of the wakefield with the 3.5 mm Gaussian bunch.

LONGITUDINAL DYNAMICS: OLD MACHINE PARAMETERS



Bunch length (bottom) and RMS energy spread (top) as a function of bunch population in the case with (BS) and without (SR) beamstrahlung, which is considered here independent of the longitudinal impedance.

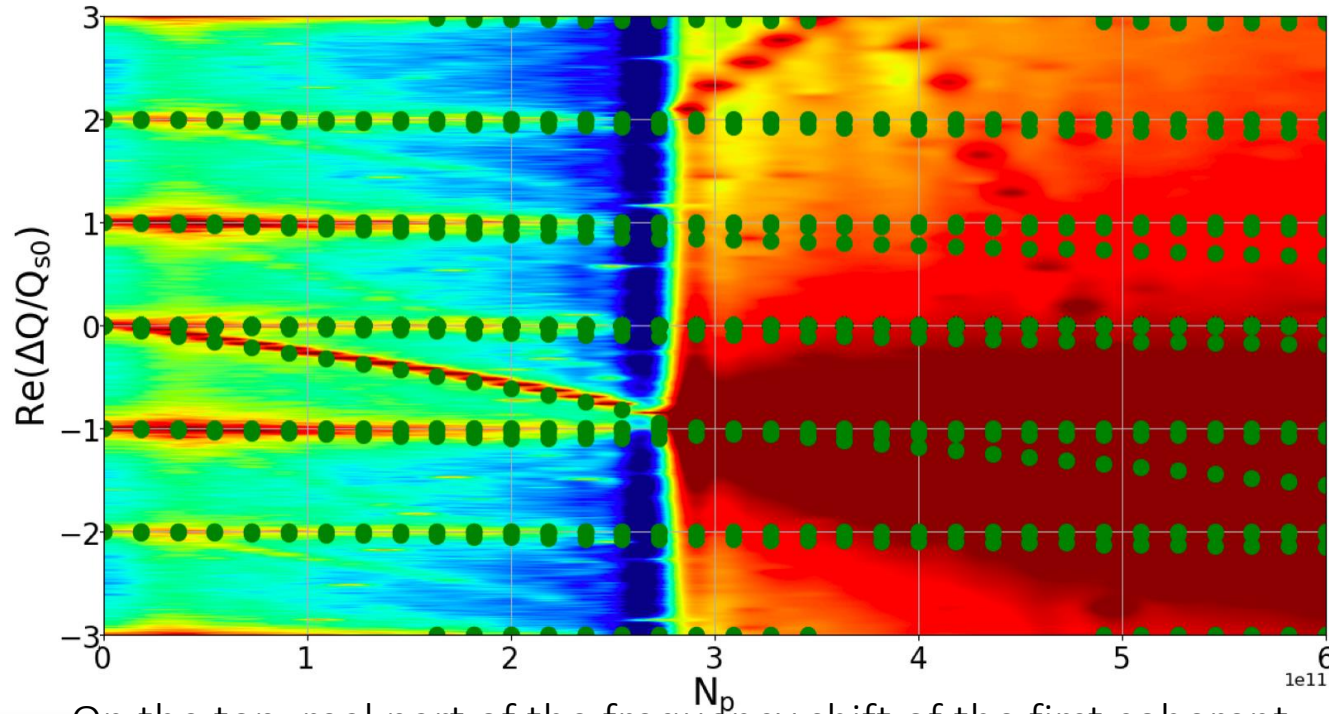
Bunch length and energy spread (old machine parameters)



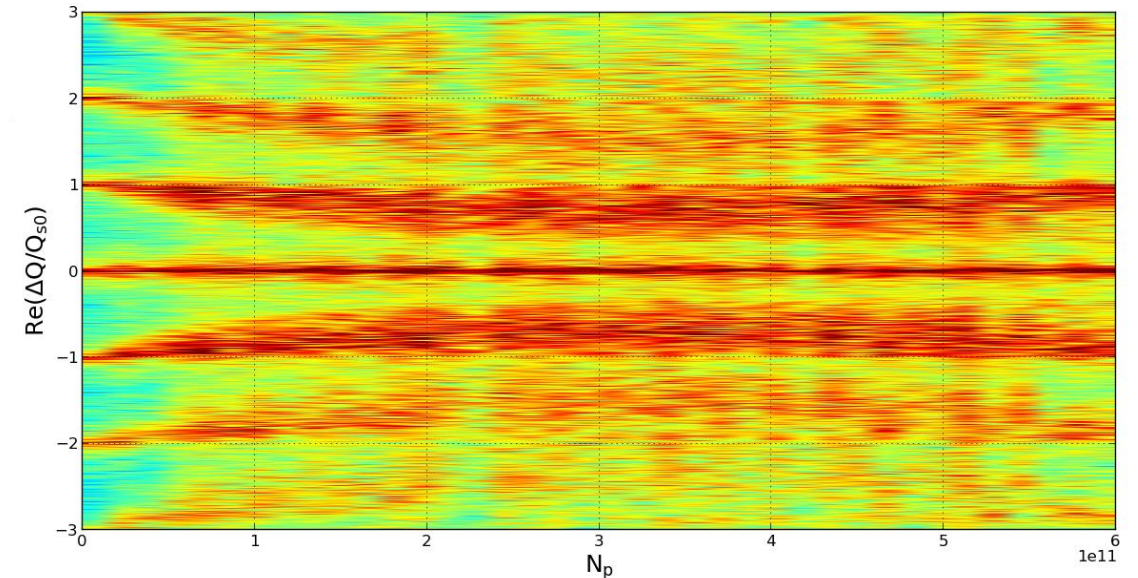
Transverse Dynamics

The TMCI occurs when the frequencies of two neighbouring coherent oscillation modes merge together. Above the transverse instability threshold the bunch is lost and this makes the TMCI very dangerous for the beam.

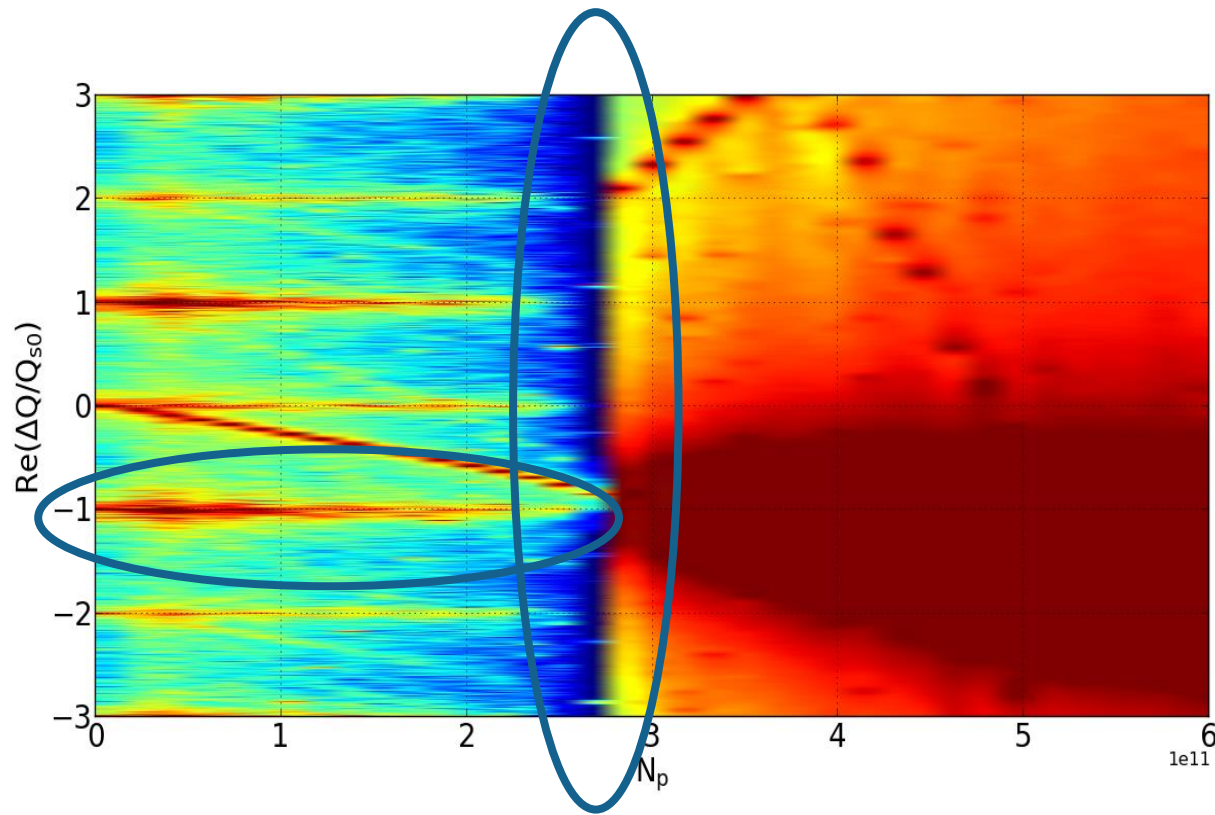
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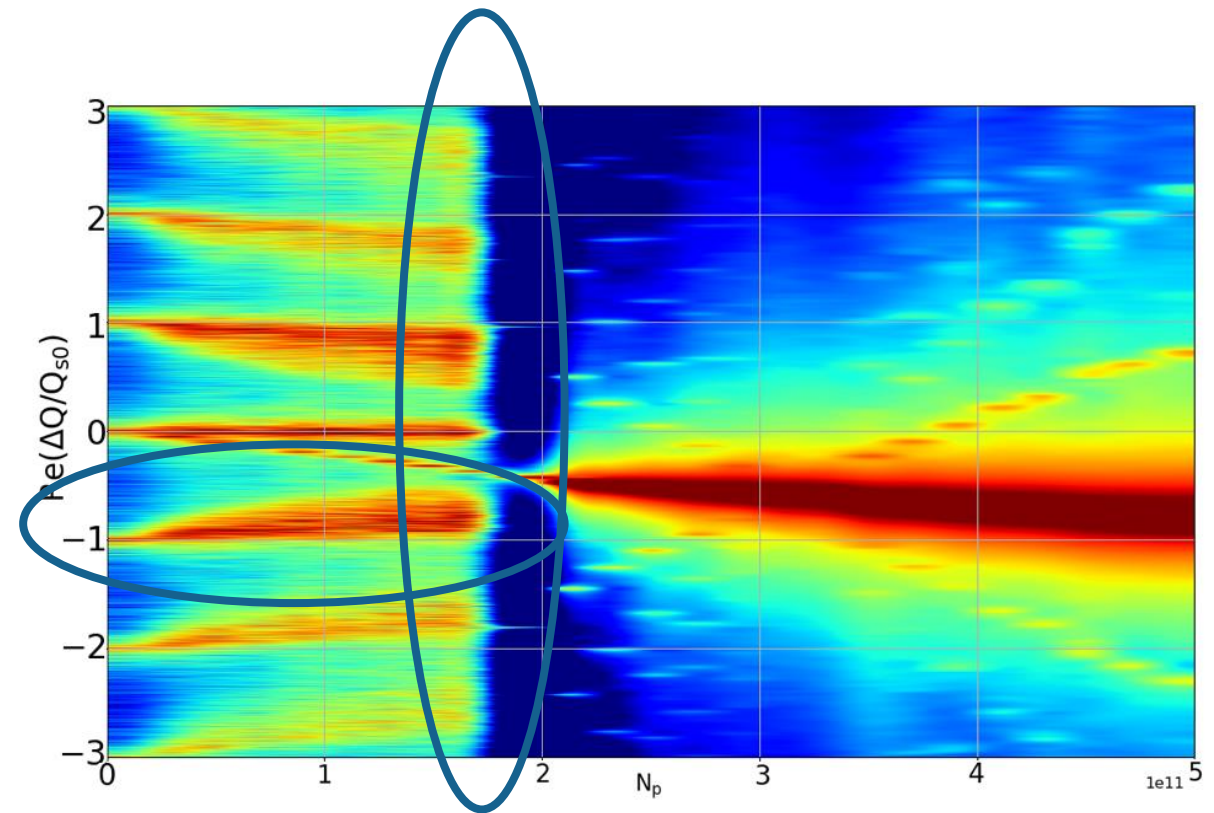
On the right, real part of the coherent tune shift as a function of intensity considering the longitudinal resistive wall wakefield, by using PyHEADTAIL.



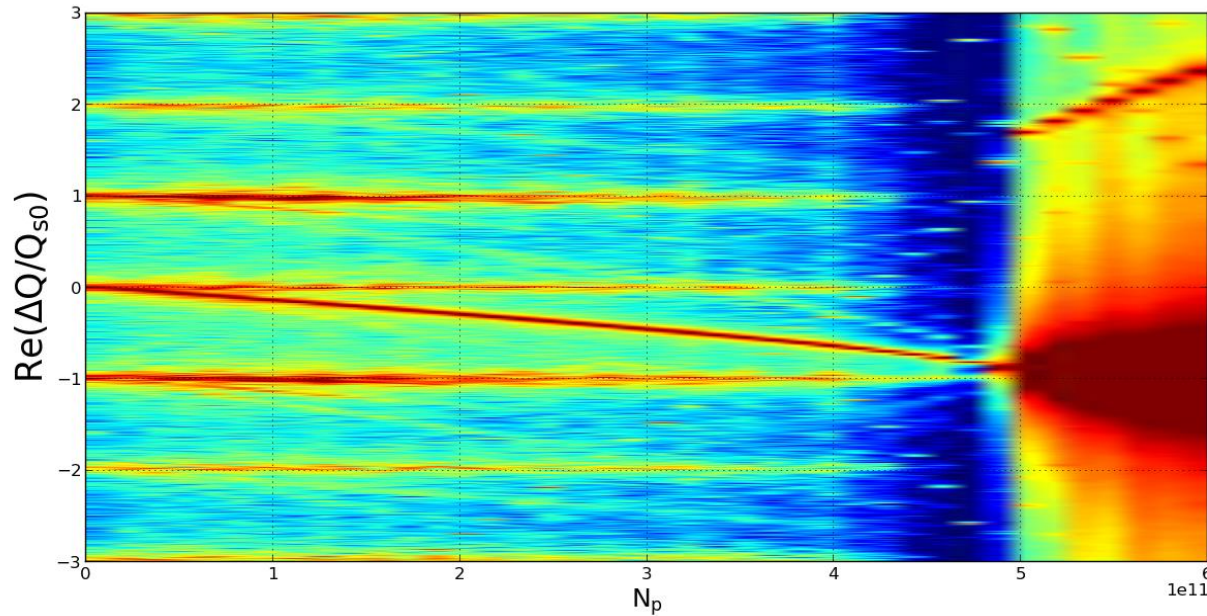
Without longitudinal
resistive wall wakefield

TMCI

Considering the longitudinal
resistive wall wakefield



Transverse RW for a beam length of 12.1mm: TMCI analysis

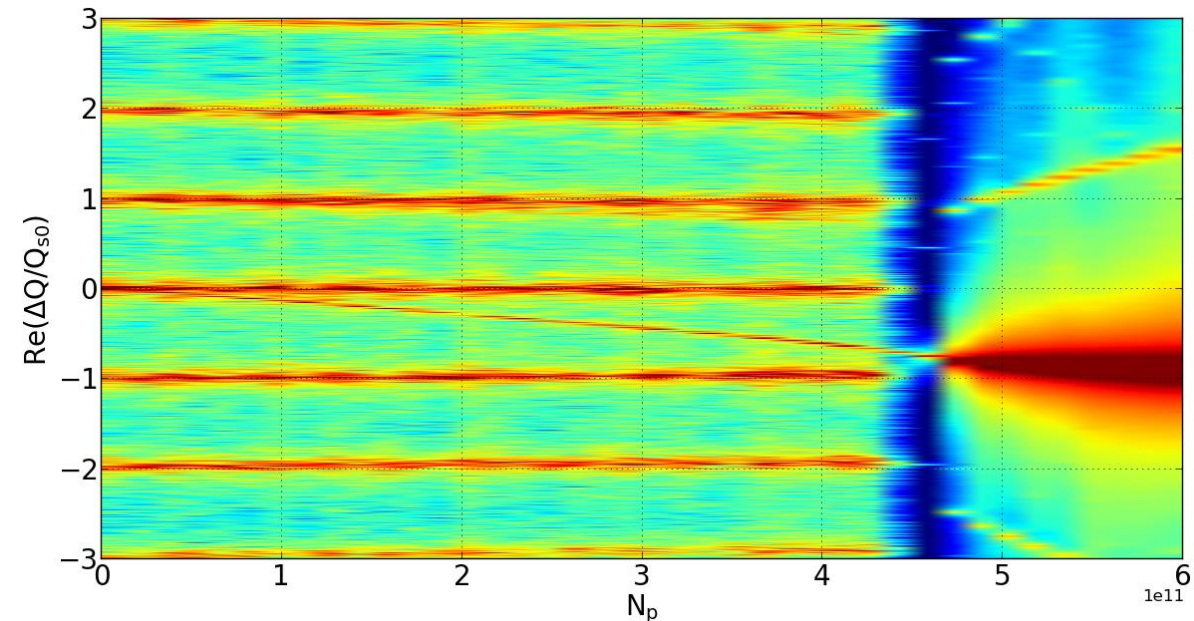


Without longitudinal
resistive wall wakefield

Longitudinal RW

Transverse RW: PyHT vs Delphi

Considering the longitudinal
resistive wall wakefield



TMCI: longitudinal wake (on the right) and transverse wake (on the left) with a bunch length of 15.2 mm

