Single-Bunch Instabilities

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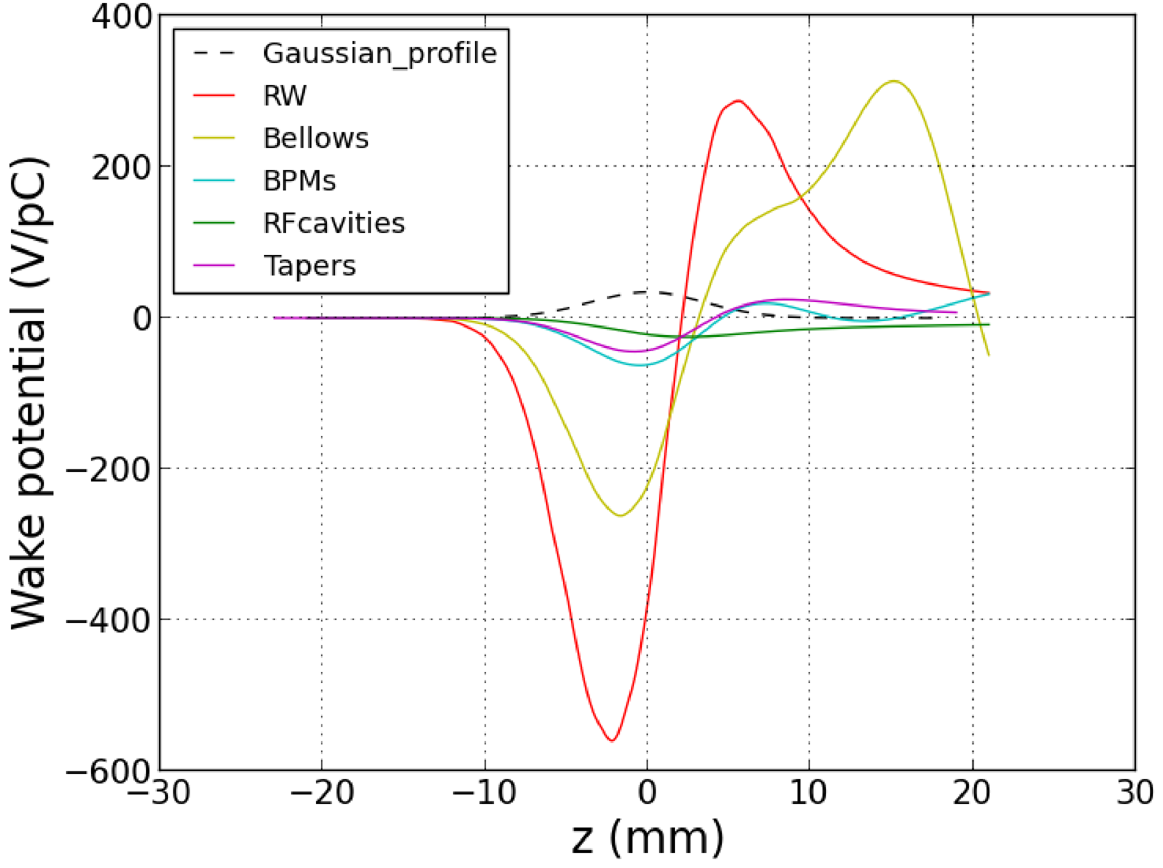
Outline

- 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
- ITSR instability
- One possible strategy for calculating the impedance of collimators

Impedance Sources: CST and IW2D simulations



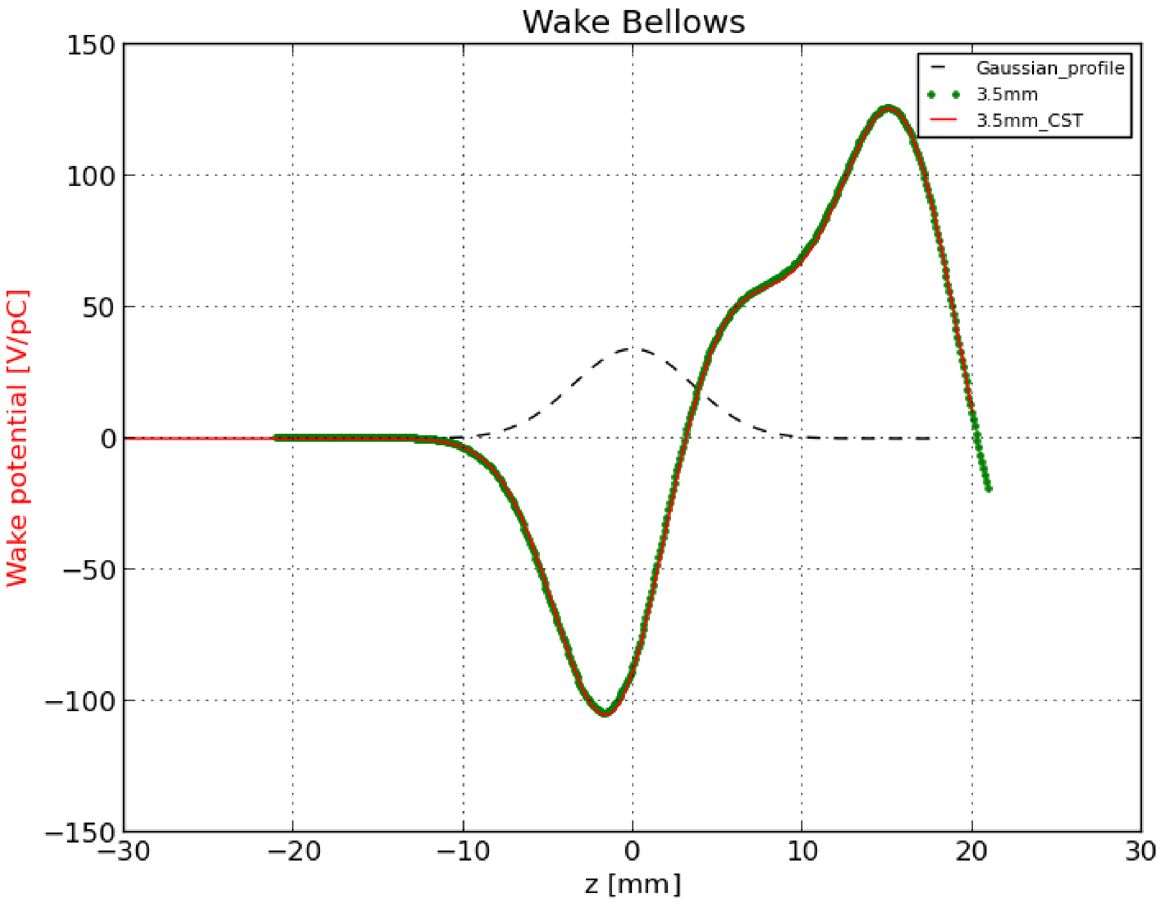
Longitudinal wake potentials for a Gaussian bunch with nominal bunch length due to the main FCC-ee components, evaluated so far.

How did we do these simulations?

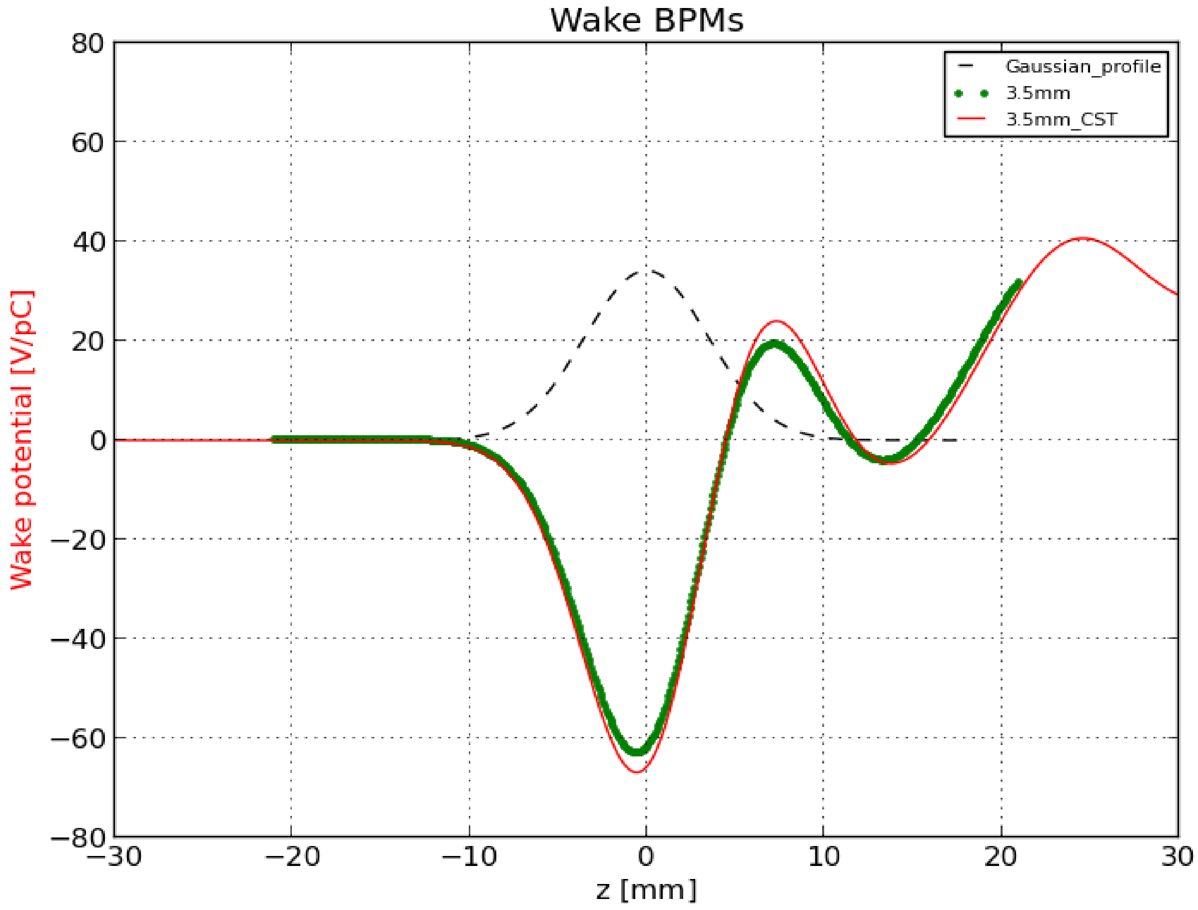
Method to calculate the Wake Potential by software simulation

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

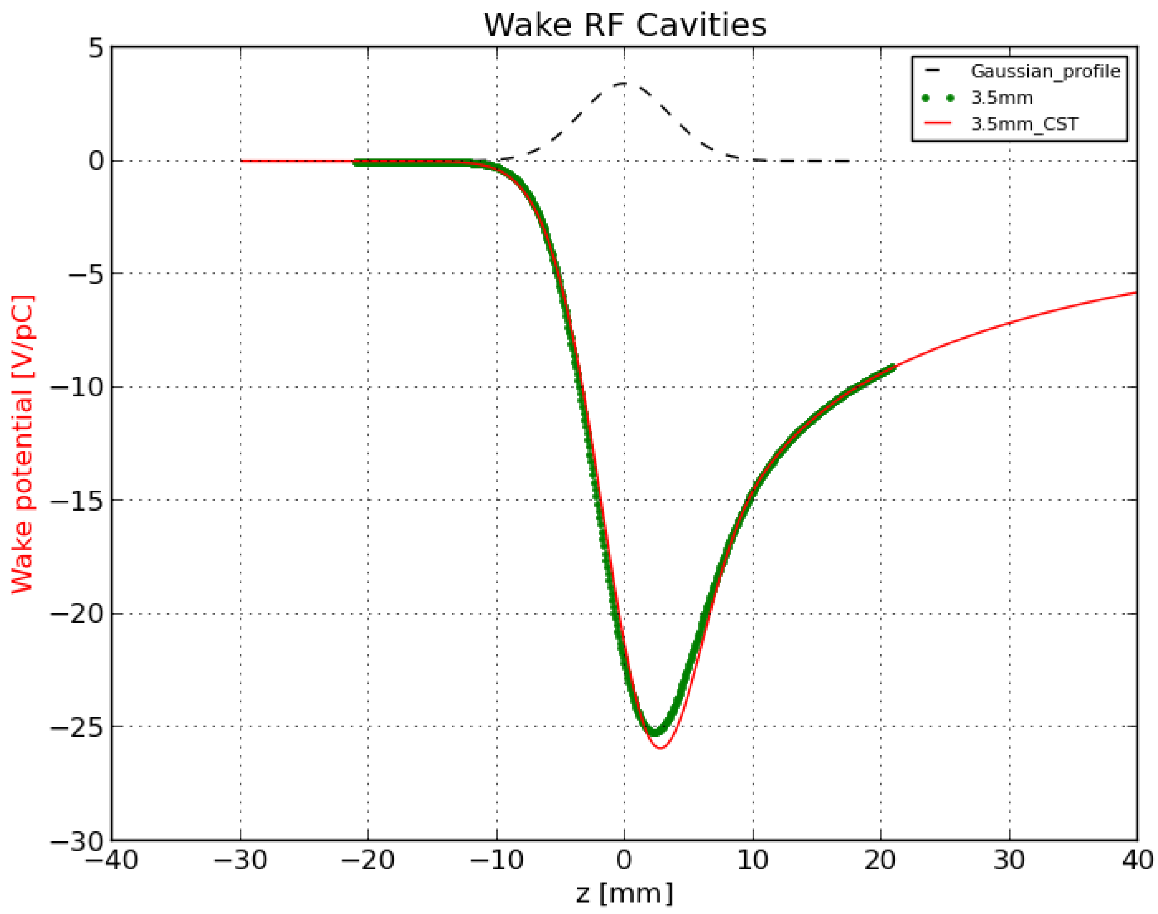
Wake potential for a Bellow of a 3.5 mm Gaussian bunch obtained directly by CST (red curve) and with the convolution by using the wake potential of 0.4 mm Gaussian bunch (green dots).



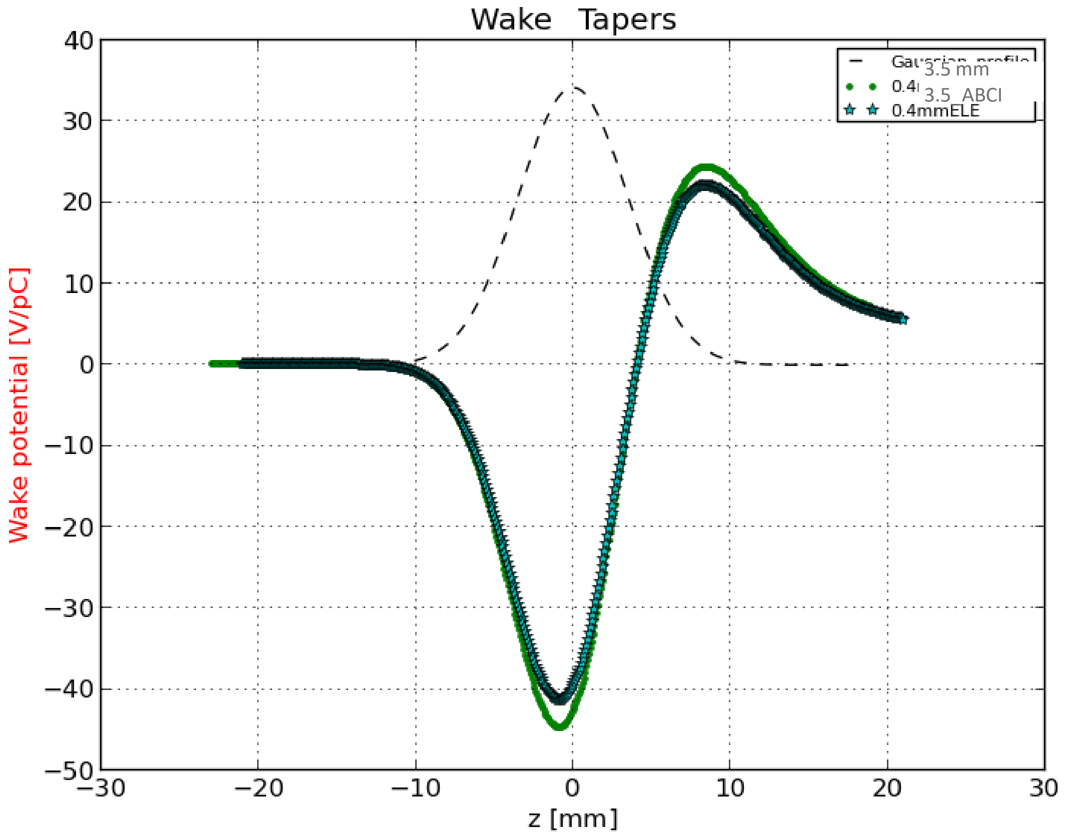
Comparison of the wake potential of 3.5 mm bunch length between PyHT and CST: BPMs



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

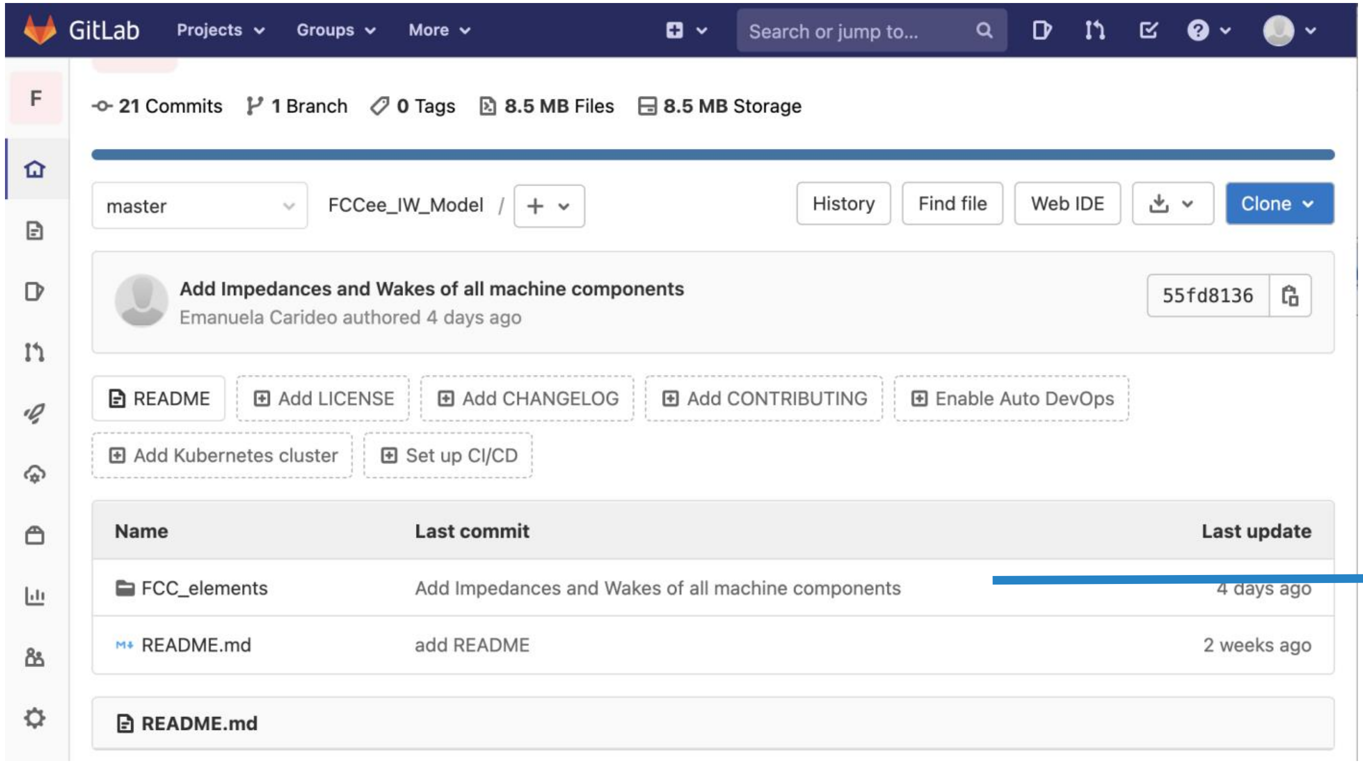


Comparison of the wake potential of 3.5 mm bunch length between PyHT and CST: RF double tapers



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

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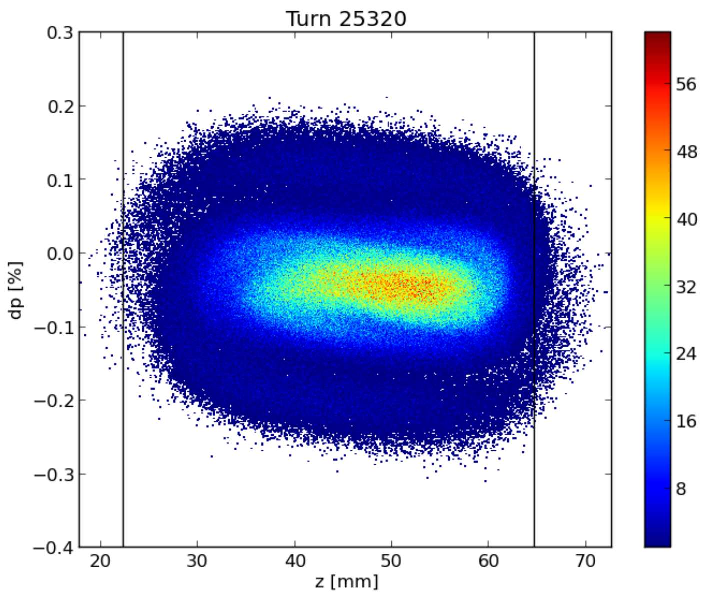
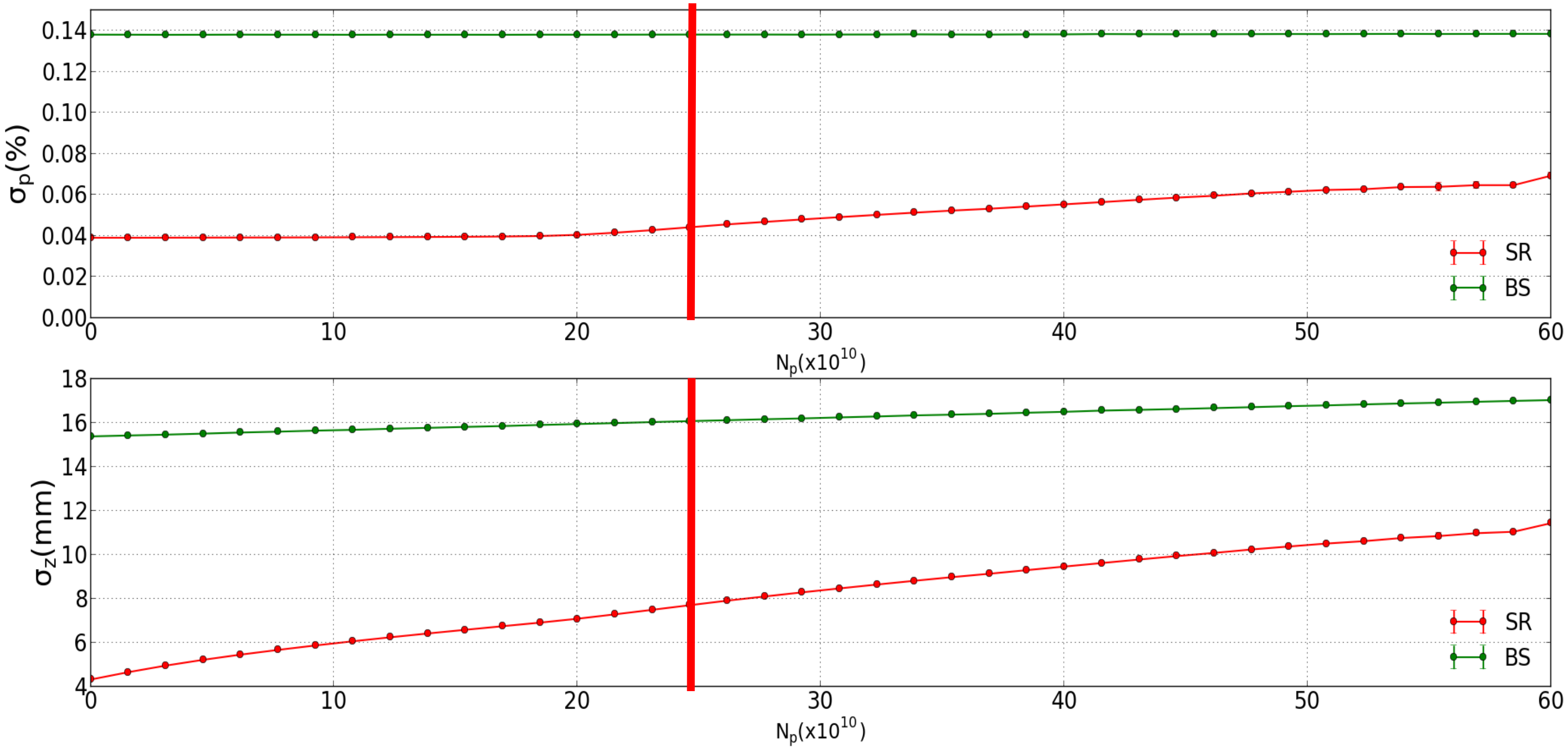
LONGITUDINAL DYNAMICS



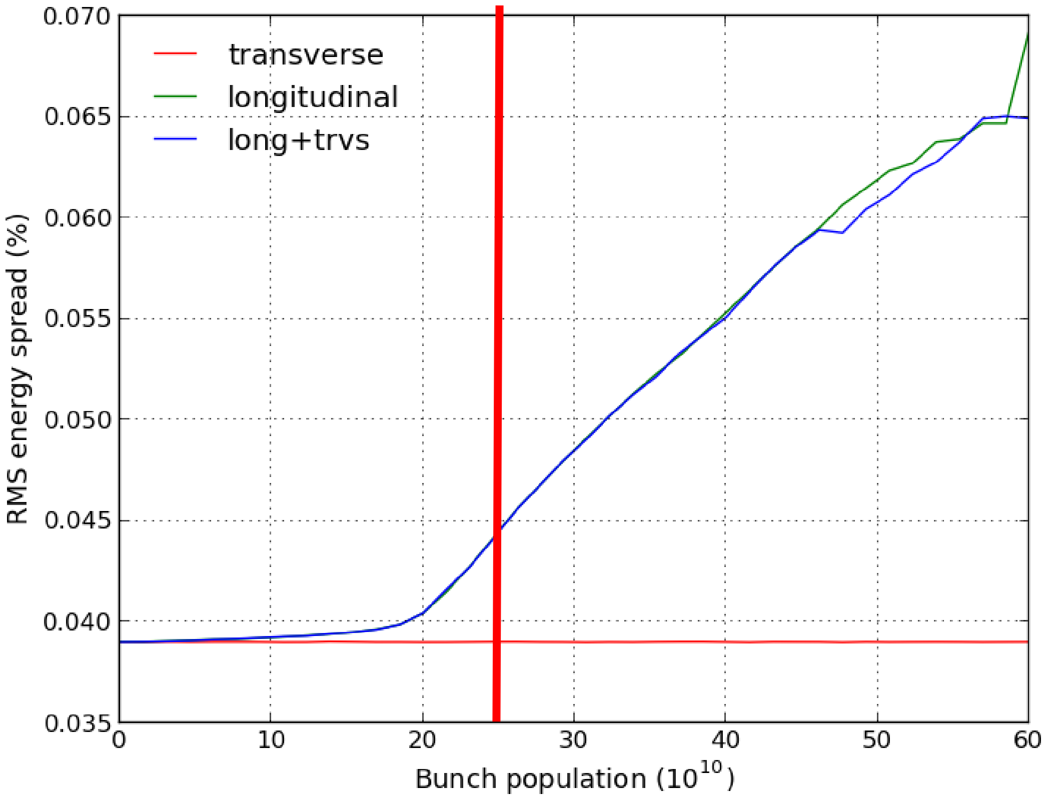
Longitudinal phase space

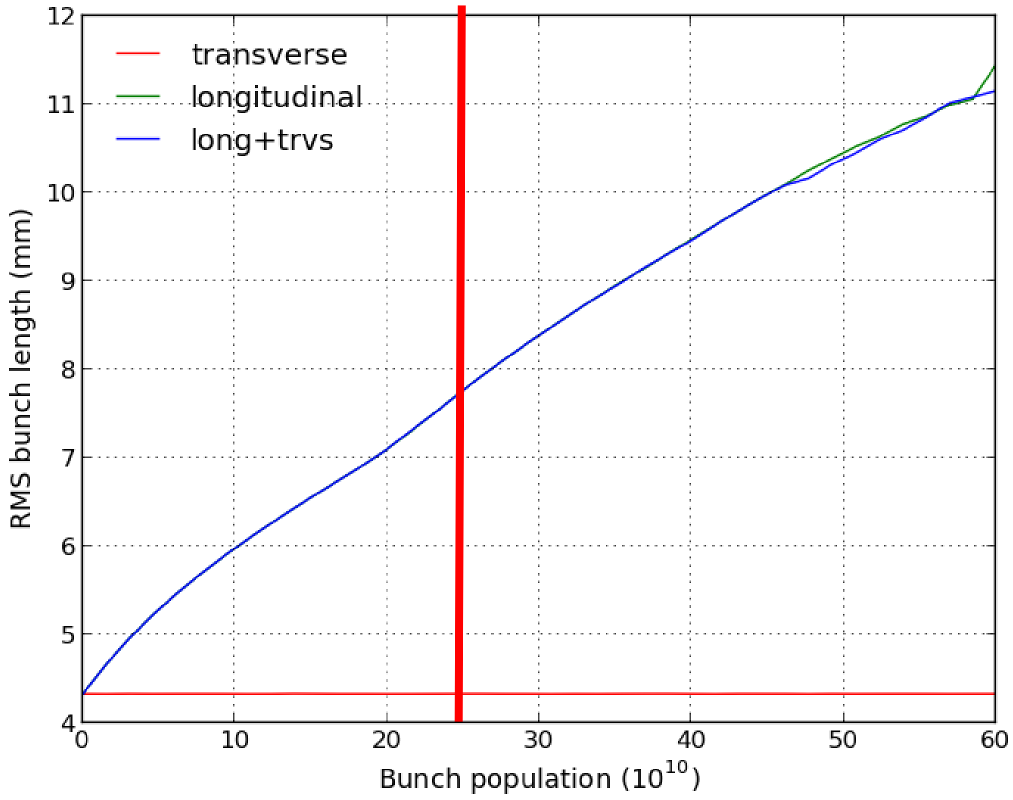


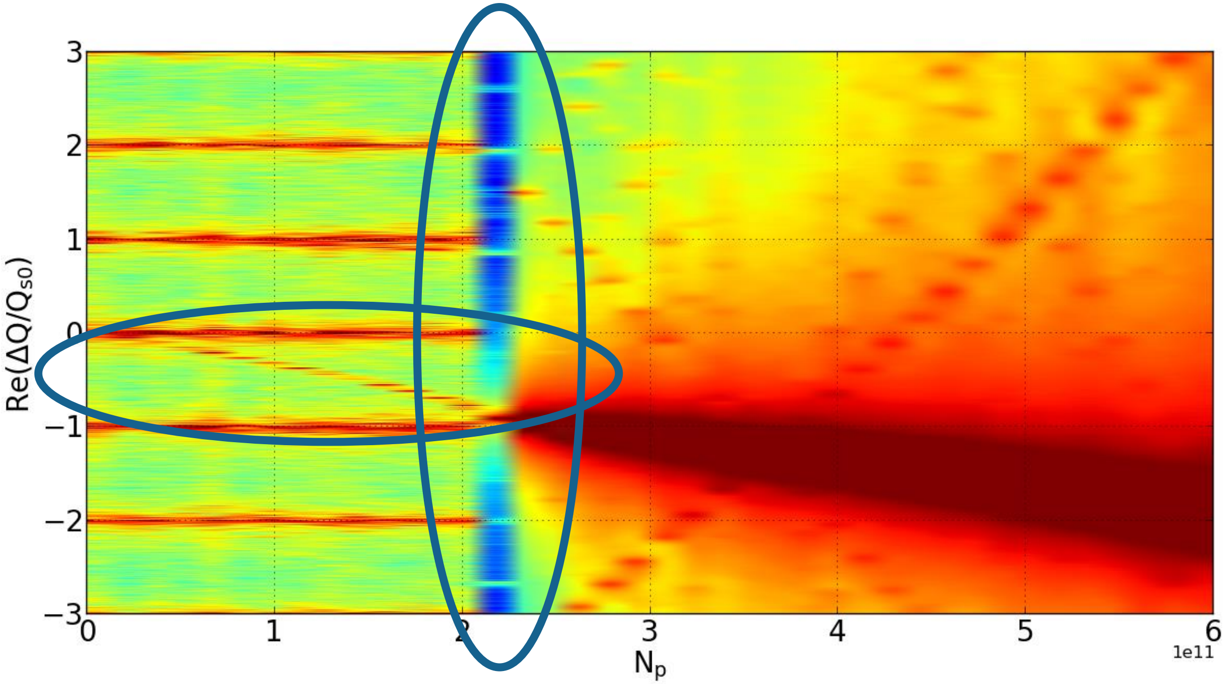
Bunch length (bottom) and RMS energy spread (top) as a function of bunch population in the case with (BS) and without (SR) beamstrahlung, which is considered here independent of the longitudinal impedance.

Bunch length and energy spread for considered cases

- The transverse impedance almost does not affect the longitudinal dynamics







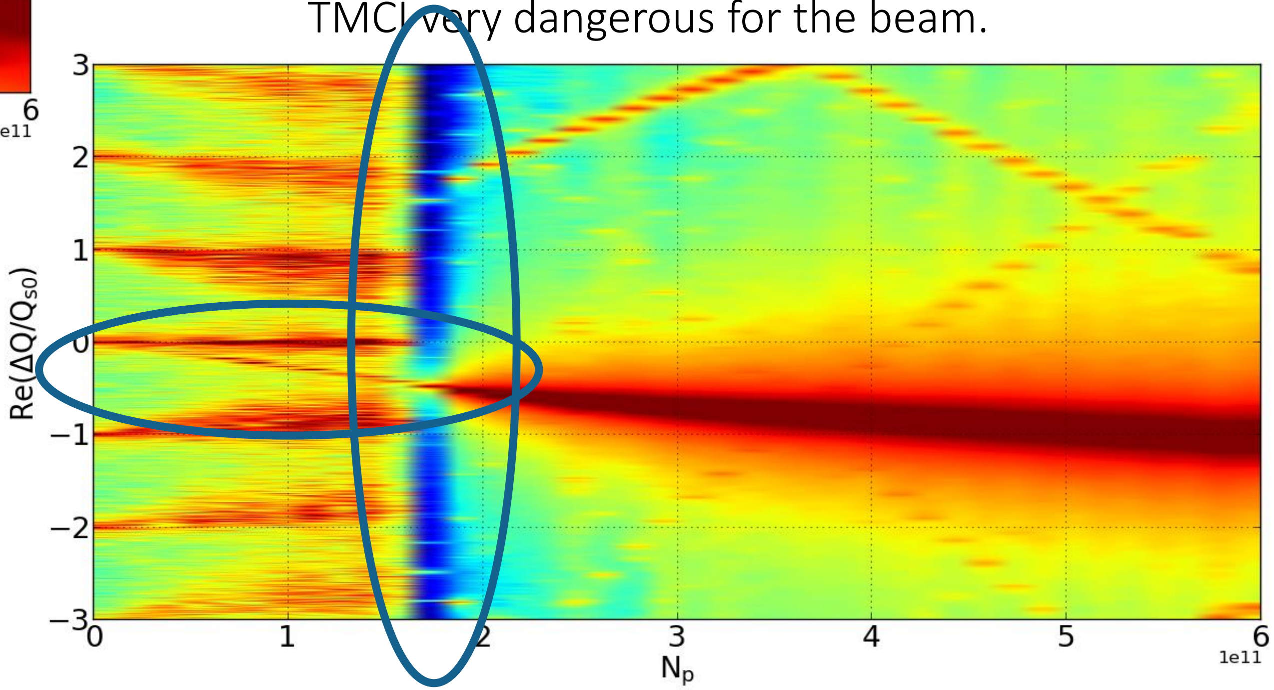
Transverse Dynamics

SR: Bunch length of 4.37 mm

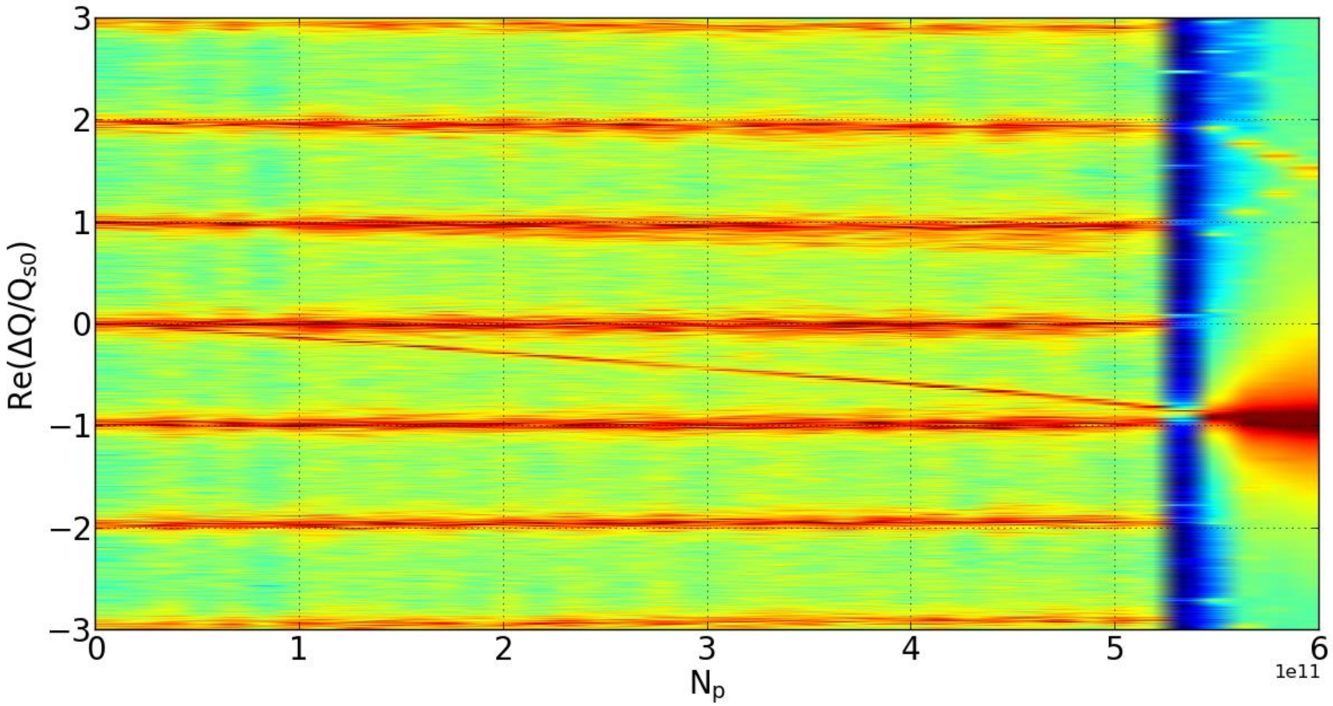
The TMCI, **Transverse Mode Coupling Instability,** occurs when the frequencies of two neighboring coherent oscillation modes merge together. Above the transverse instability threshold the bunch is lost and this makes the TMCI very dangerous for the beam.

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.

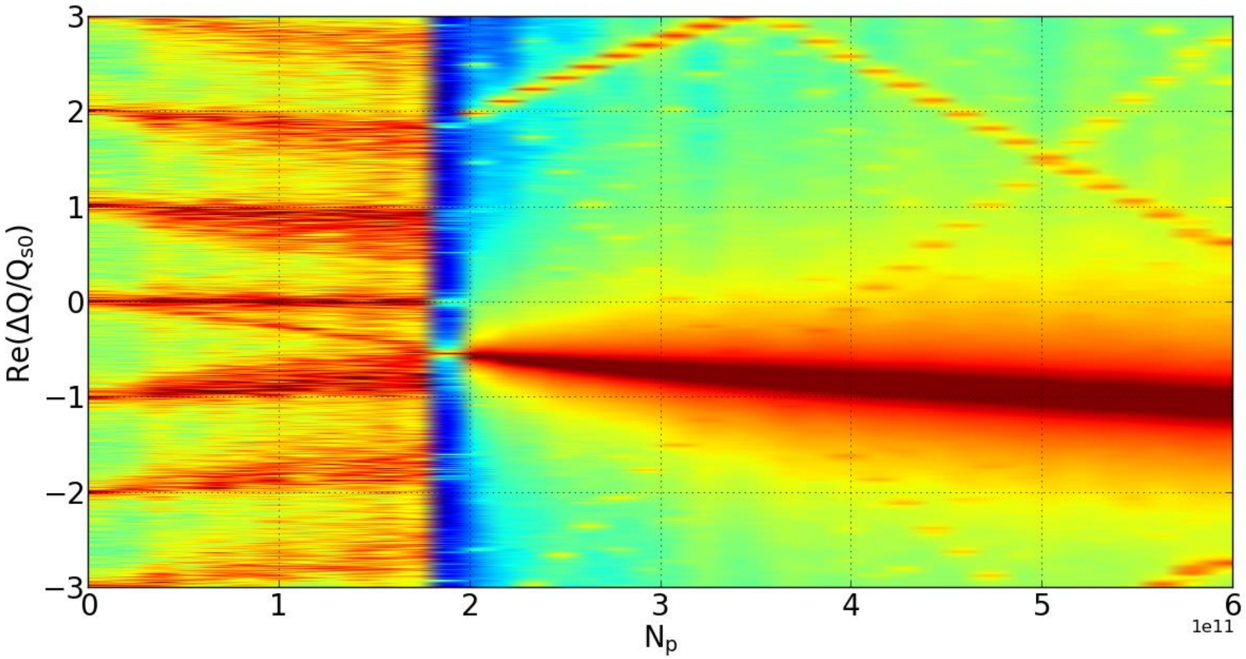
On the right, real part of the coherent tune shift as a function of intensity considering both longitudinal and transverse wakefield, by using PyHEADTAIL.



TMCI: longitudinal and transverse wake with a bunch length of 14.5 mm (BS)

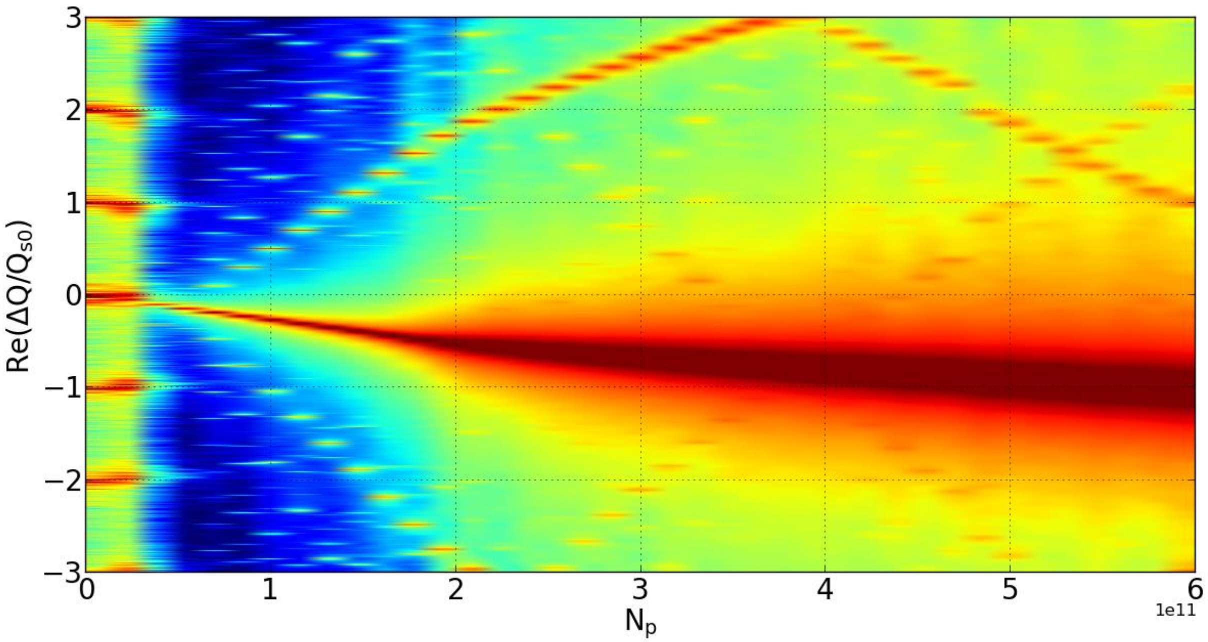


Variable Chromaticity

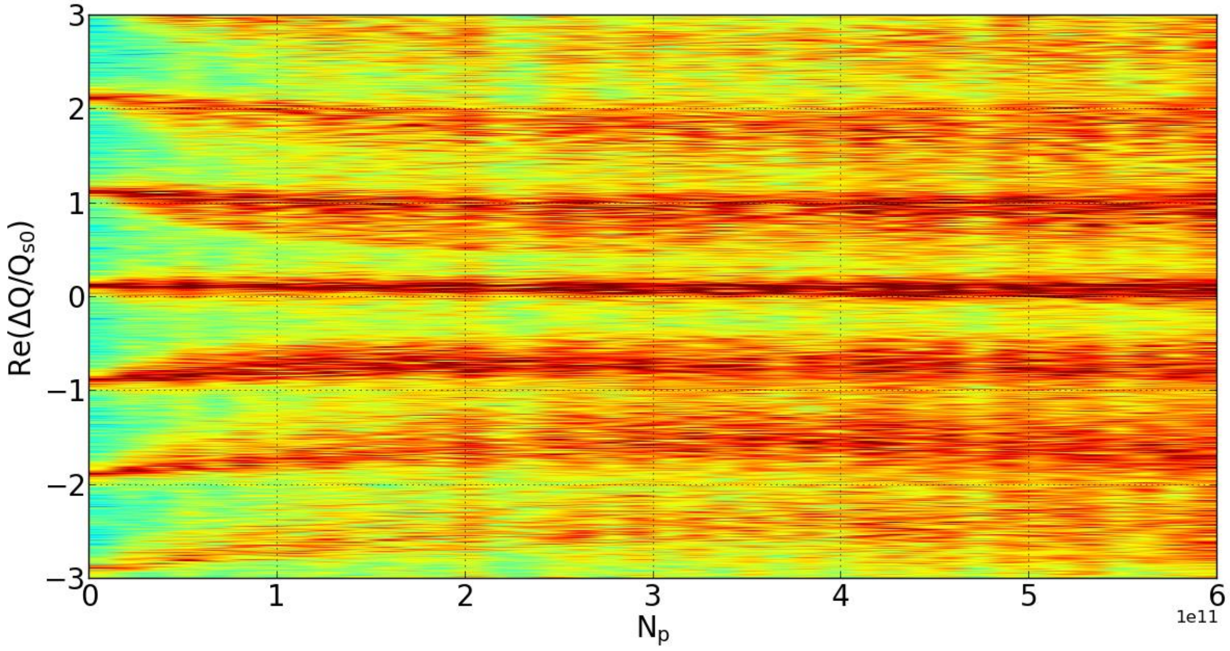


On the left, real part of the frequency shift of the first coherent oscillation modes as a function of the bunch population without beamstrahlung, so considering a bunch length of 4.37mm and a value of Chromaticity of +5

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 4.37mm and a value of Chromaticity of -5



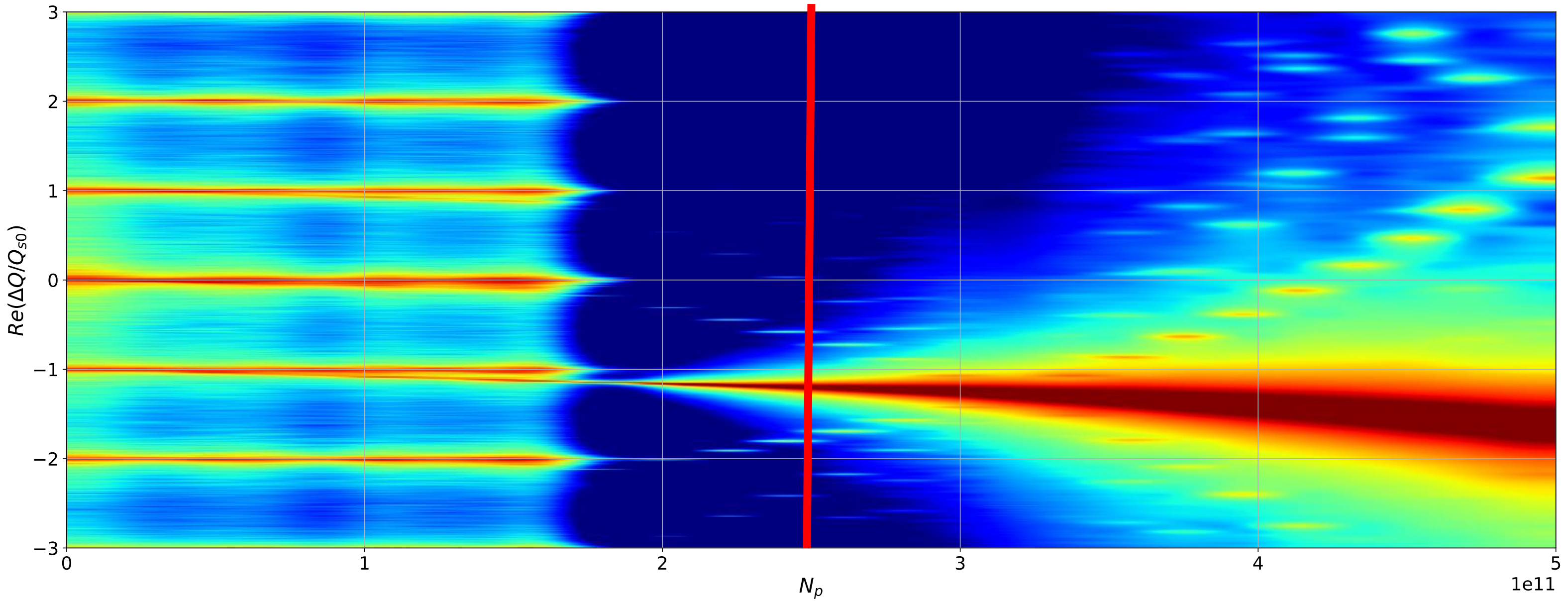
Strong dependence of the TMCI from the Chromaticity

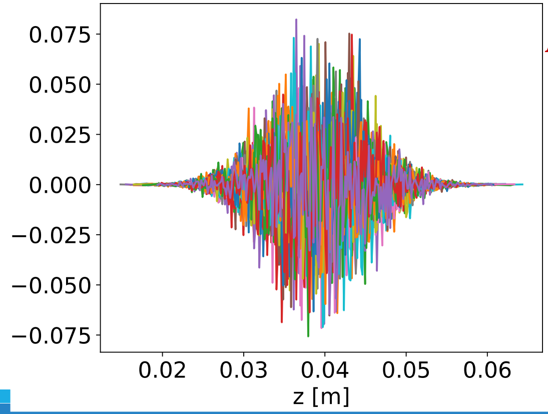


Real part of the frequency shift of the first coherent oscillation modes as a function of the bunch population considering a bunch length of 4.37mm and a value of Chromaticity of +50 (Absurd of course!)

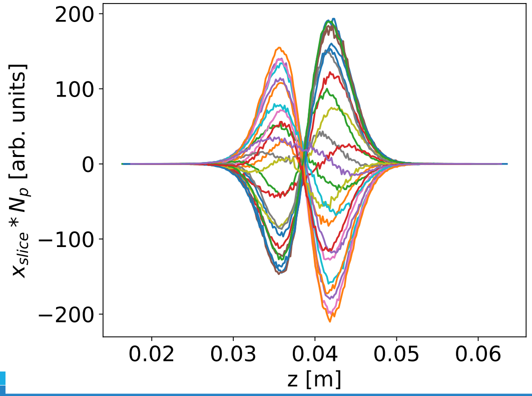
ITSR instability: Imaginary Tune Split and Repulsion

Only Transverse wakefield, resistive feedback, 10 turns damping time





$N_p = 16 \times 10^{10}$



$N_p = 18 \times 10^{10}$

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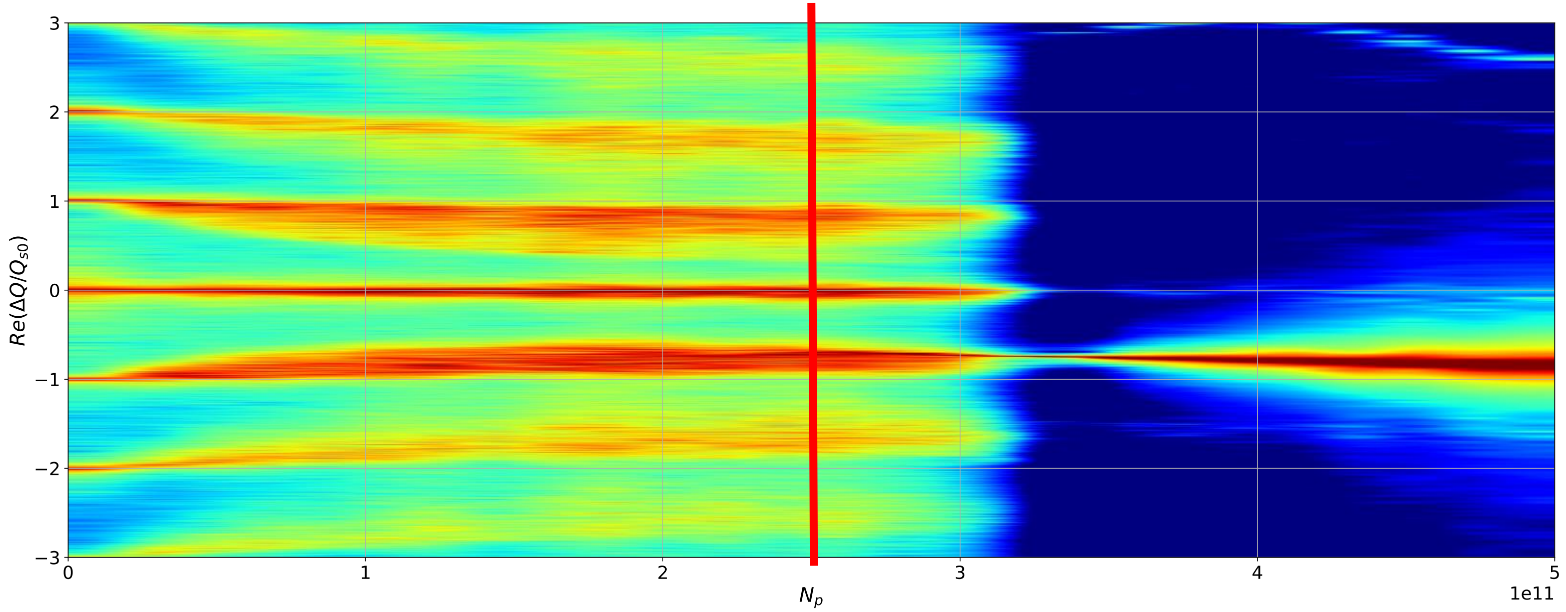
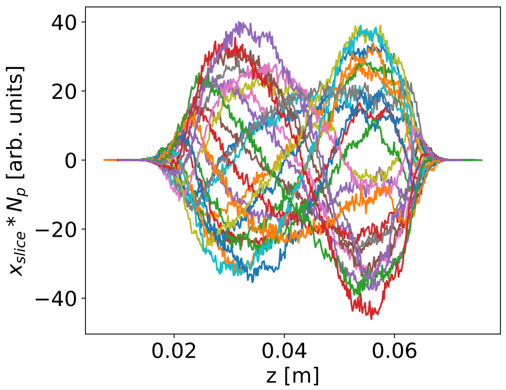
ITSR instability: Imaginary Tune Split and Repulsion

Long. + Transverse wakefield, resistive feedback, 10 turns damping time



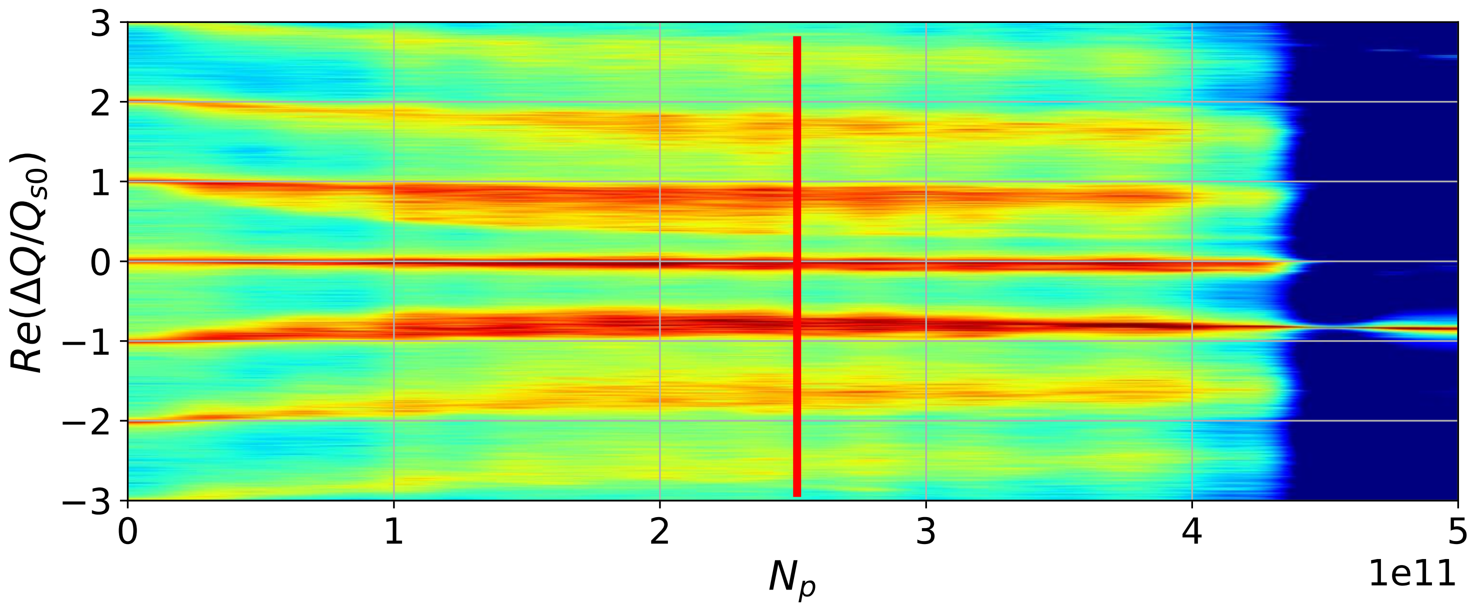


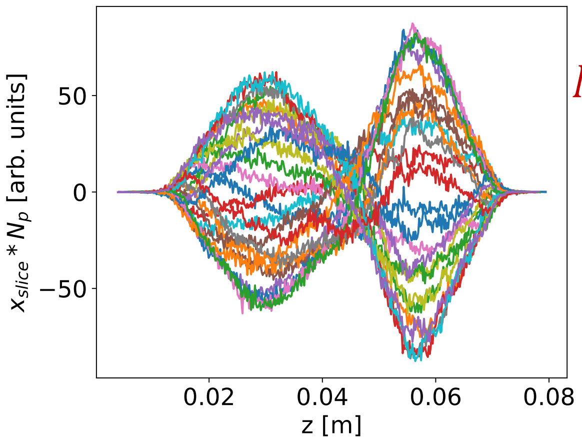
$N_p = 34 \times 10^{10}$

The spread in the synchrotron tune due to the longitudinal wakefield helps to mitigate the ITSR instability

ITSR instability: Imaginary Tune Split and Repulsion

Long. + Transverse wakefield, resistive feedback, 4 turns damping time

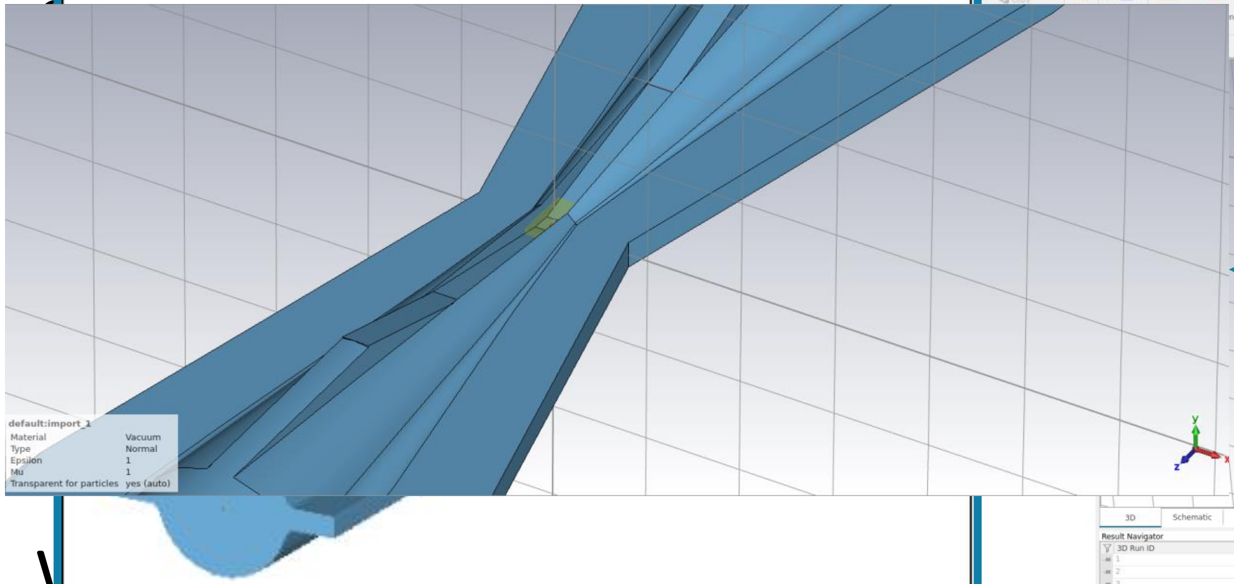


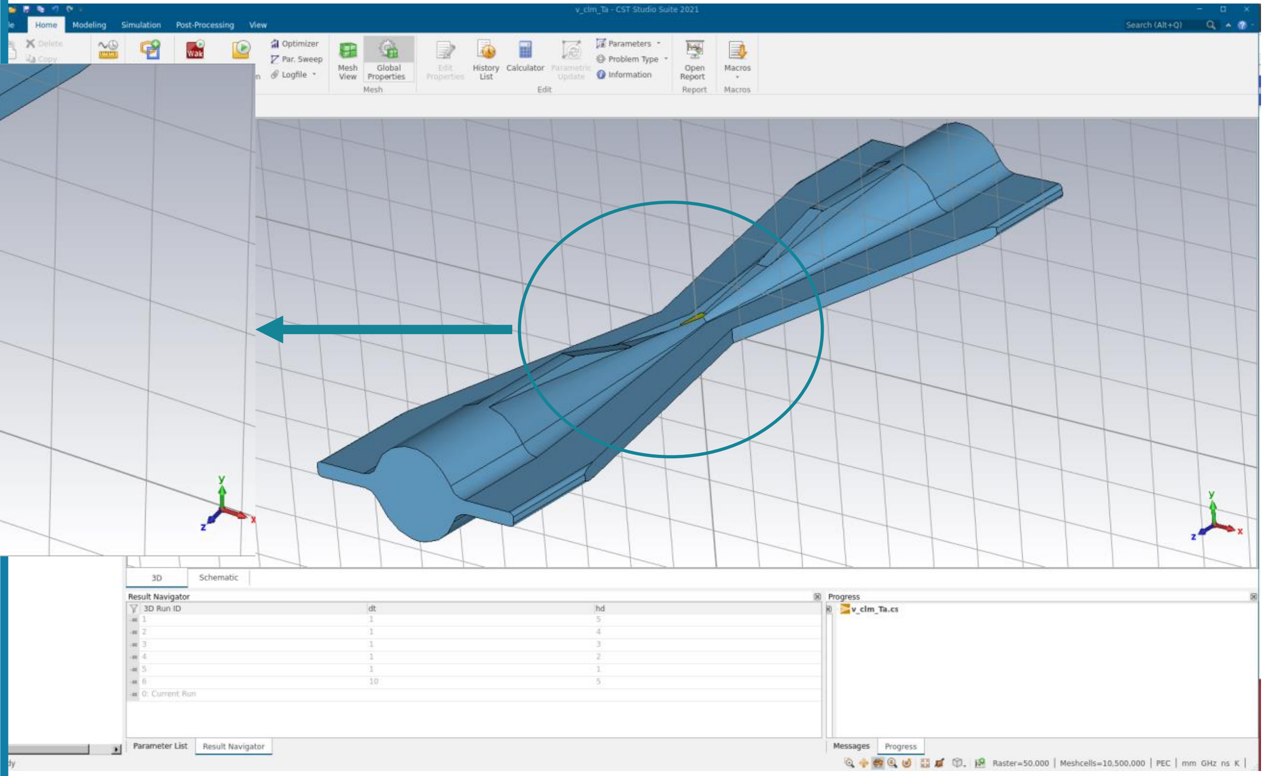


$N_p = 46 \times 10^{10}$

Beamstrahlung reduces the effect of the longitudinal wakefield which, on its turn, has a beneficial effect on the TMCI with a resistive transverse damper. What happens if both effects are present?

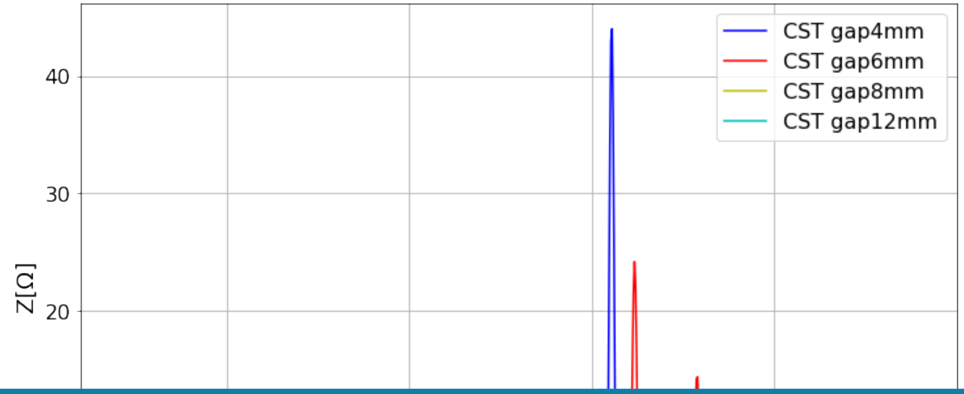
Work in progress

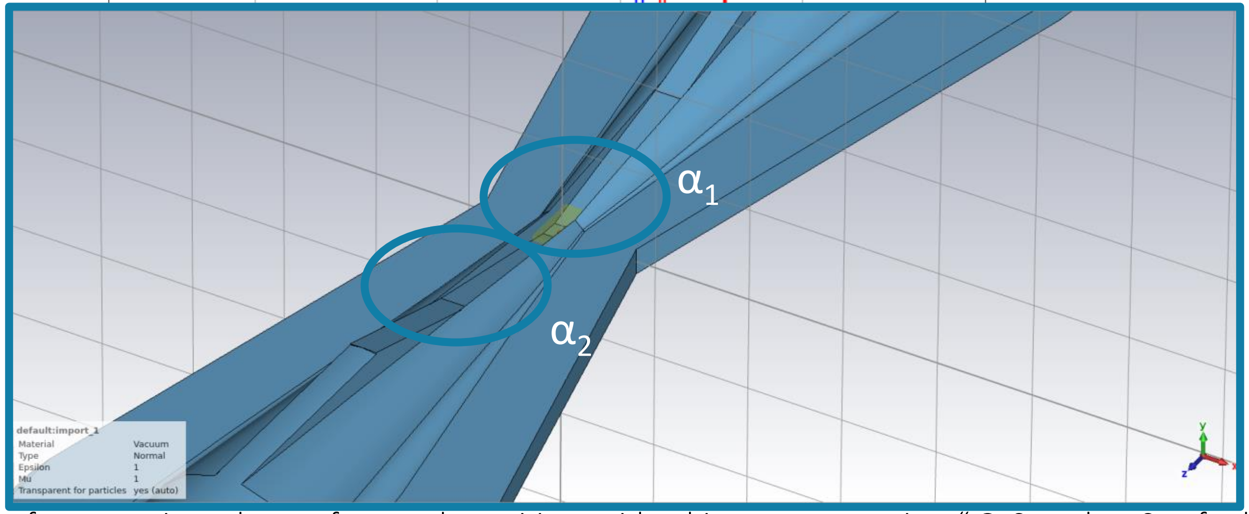




Vertical FCCee collimator

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 # Ohm
a, b_1, b_2 are gaps
α_1= 11.74*0.0174533 is the angle of the taper in radiant
α_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

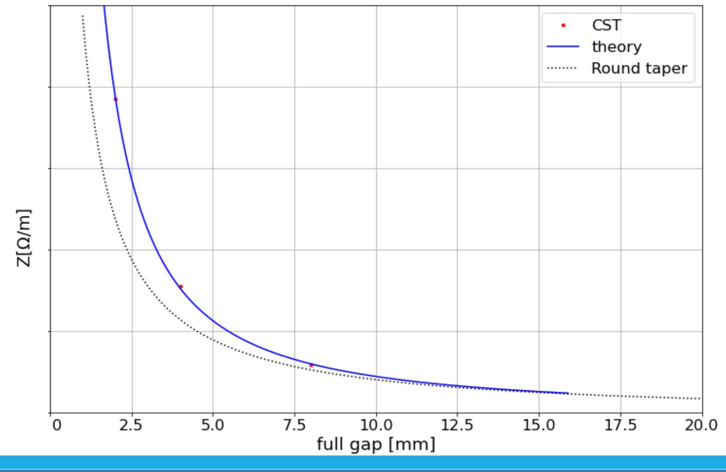
How could we do?

- We have the simulation data for some gaps.
- 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 alpha - constants to be found during the fit.

- We have the impedance from the theory



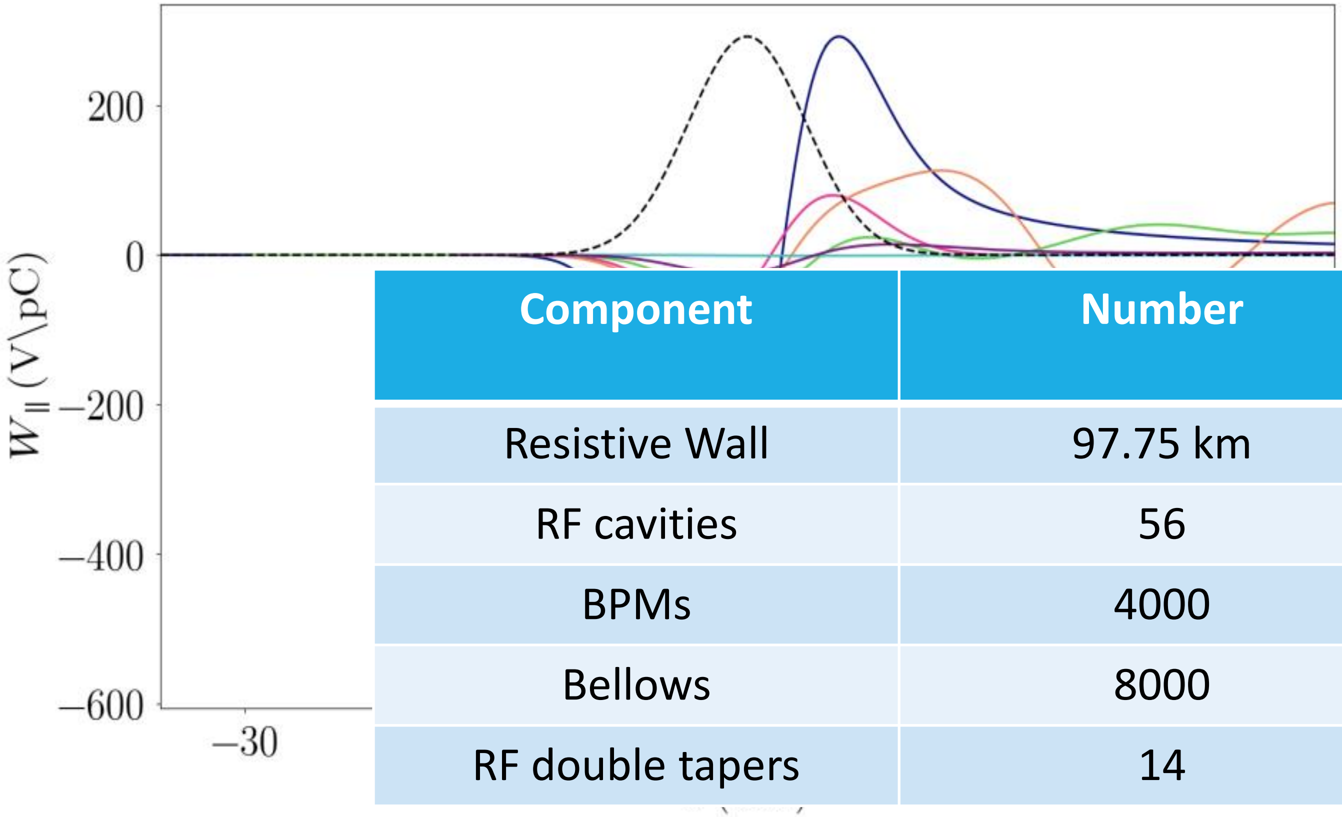
Future Plan

- 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 additionally 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.
- For the ITSR instabilities: In additionally to the resistive feedback we want to study what happen adding a reactive feedback
- Implement 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!

Back-up Slides

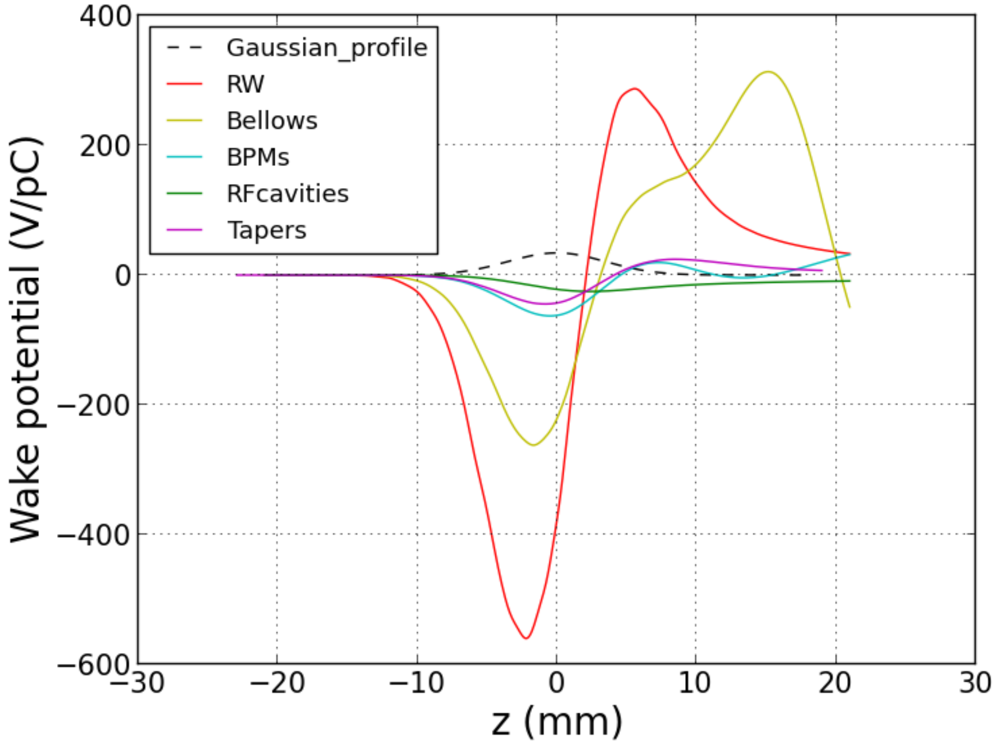
Updated FCC-ee impedance model



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_{loss}(3.5mm)[V/pC]	K_{loss}(12.1mm)[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

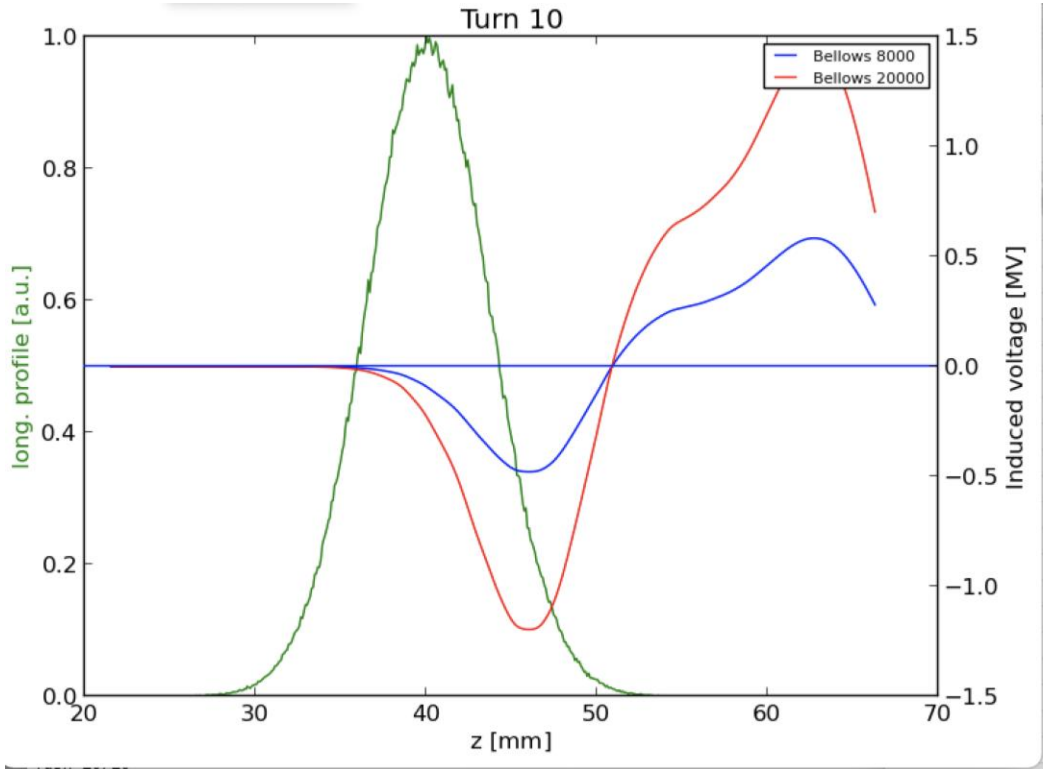


Longitudinal wake potentials for a Gaussian bunch with nominal bunch length σ_z = 3.5mm due to the main FCC-ee components, evaluated so far.

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_{loss}(12.1mm)[V/pC]	$P_{loss}\,[MW]$
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

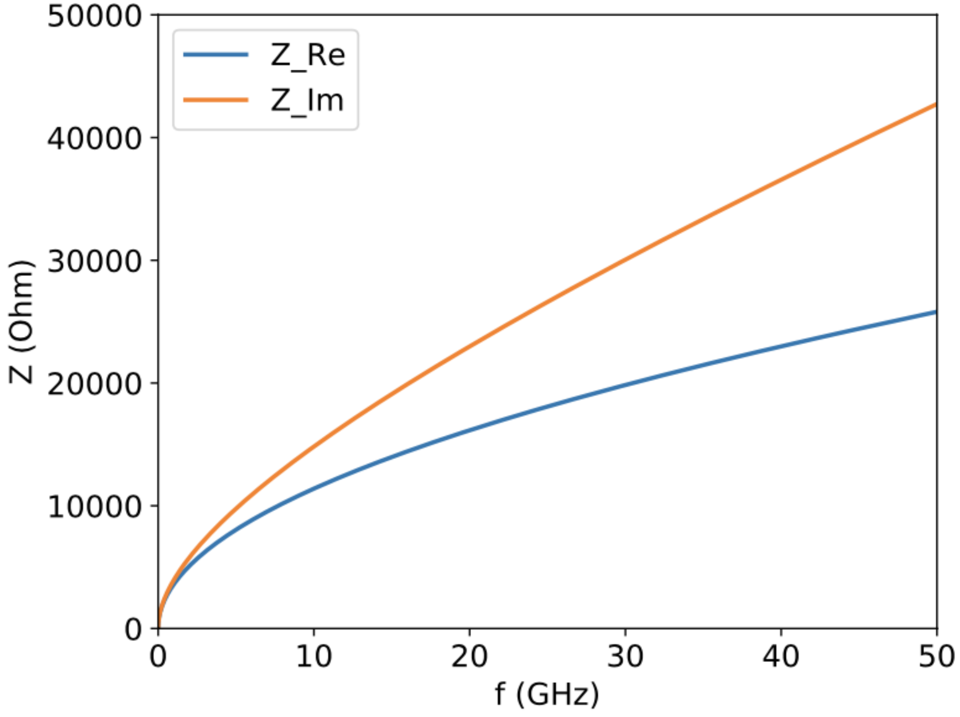
BUT

85% of arcs (~ 79 km)

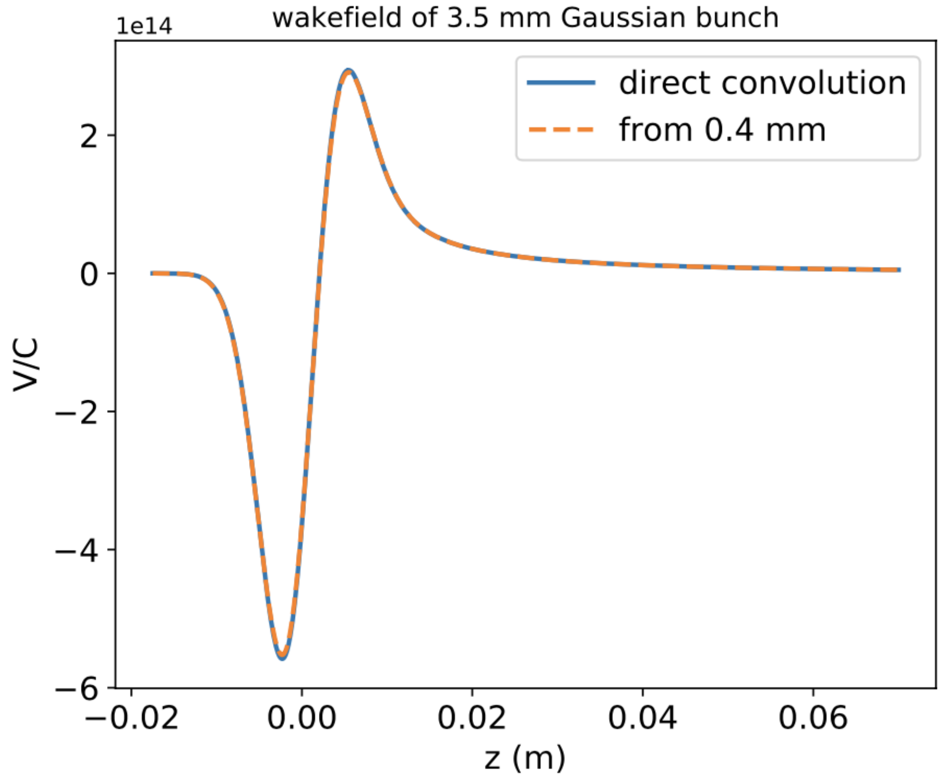
Every arc is 8m long
X2 because we have another bellow before any quadrupole

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



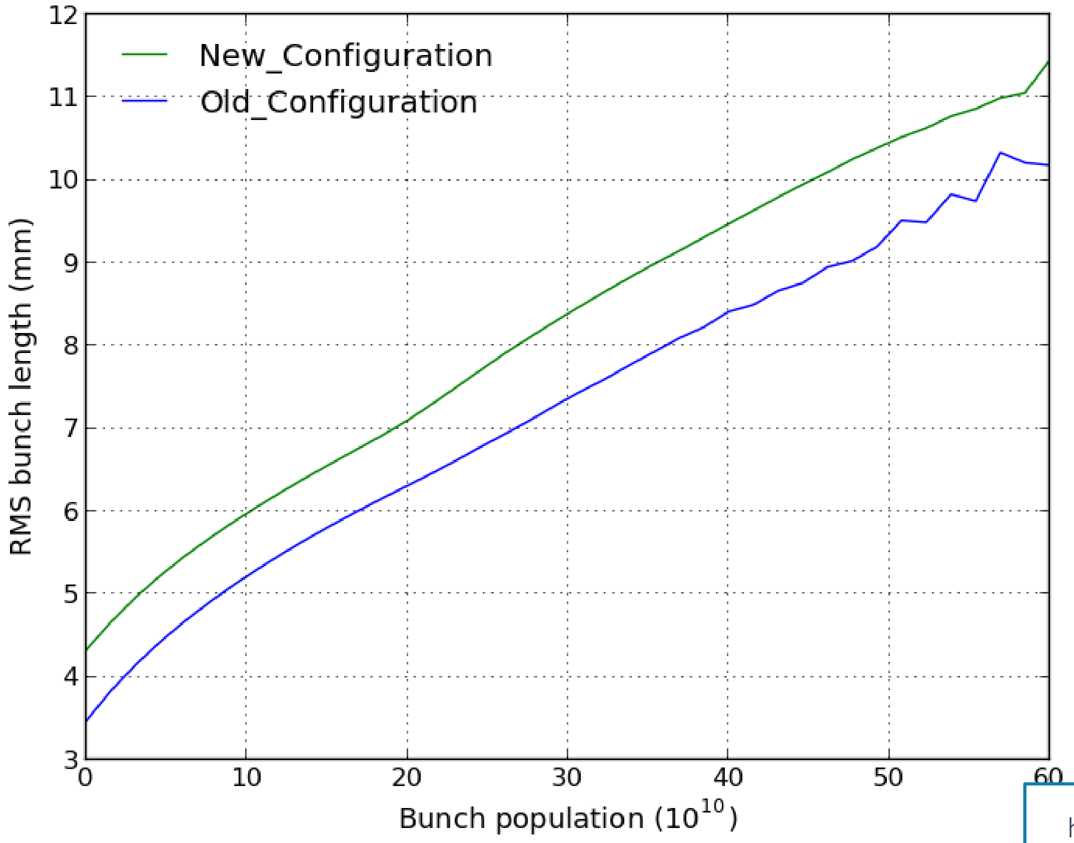
Real and imaginary part of the resistive wall impedance calculated by using the code ***IW2D***

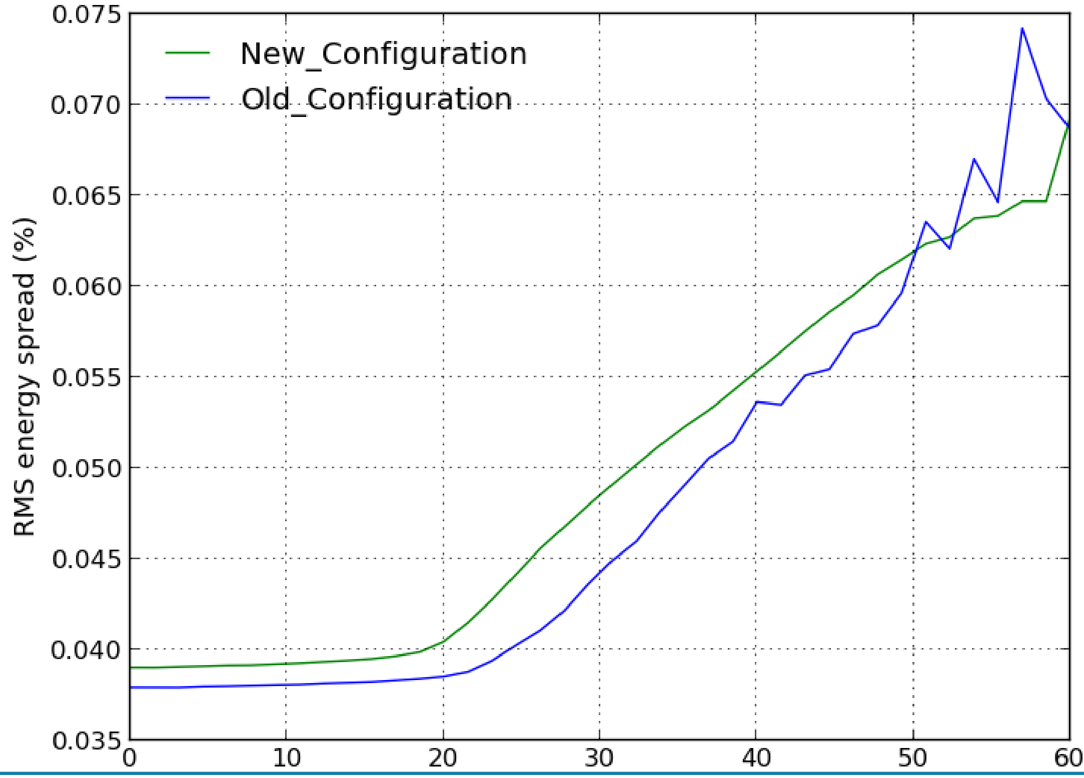


Wake potential of a 0.4 mm Gaussian bunch convoluted with the nominal bunch length and compared with the wake potential obtained directly from the convolution of the wakefield with the 3.5 mm Gaussian bunch.

New Wakes with new machine parameters :

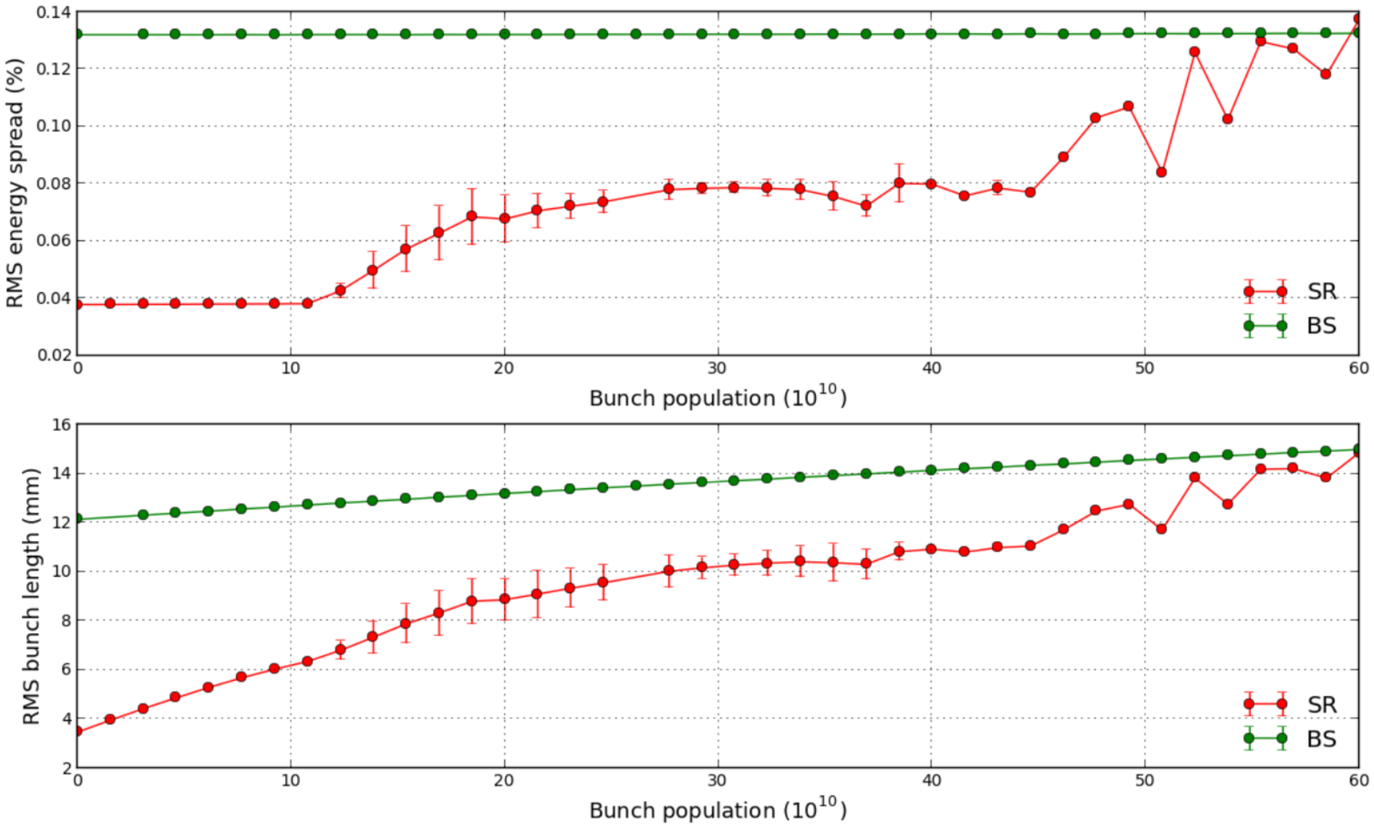
Longitudinal RW with 150nm of coating plus the Bellows without neglected the perturbation introduced by the lateral winglets used to place synchrotron radiation absorbers





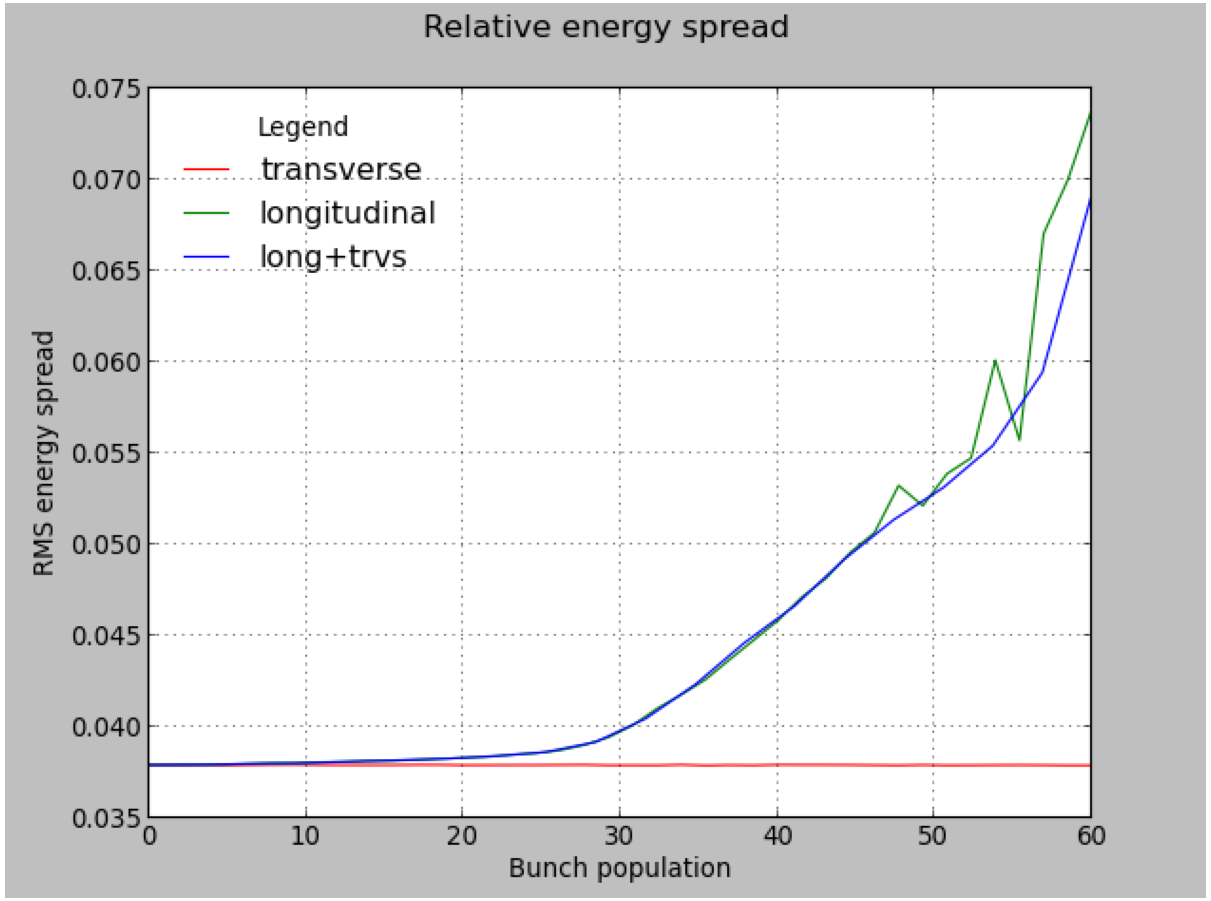
https://indico.cern.ch/event/995850/contributions/4401571/attachments/2275135/3864813/FCCweek.pdf

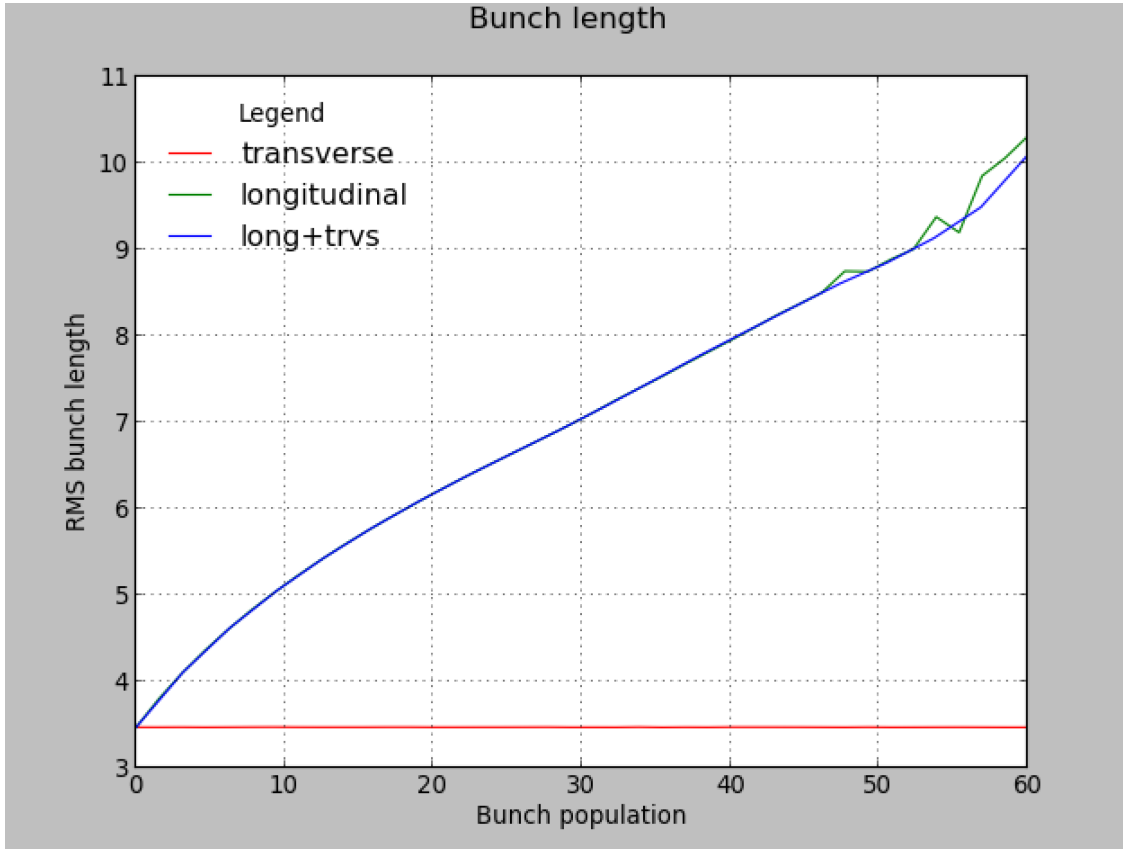
LONGITUDINAL DYNAMICS: OLD MACHINE PARAMETERS



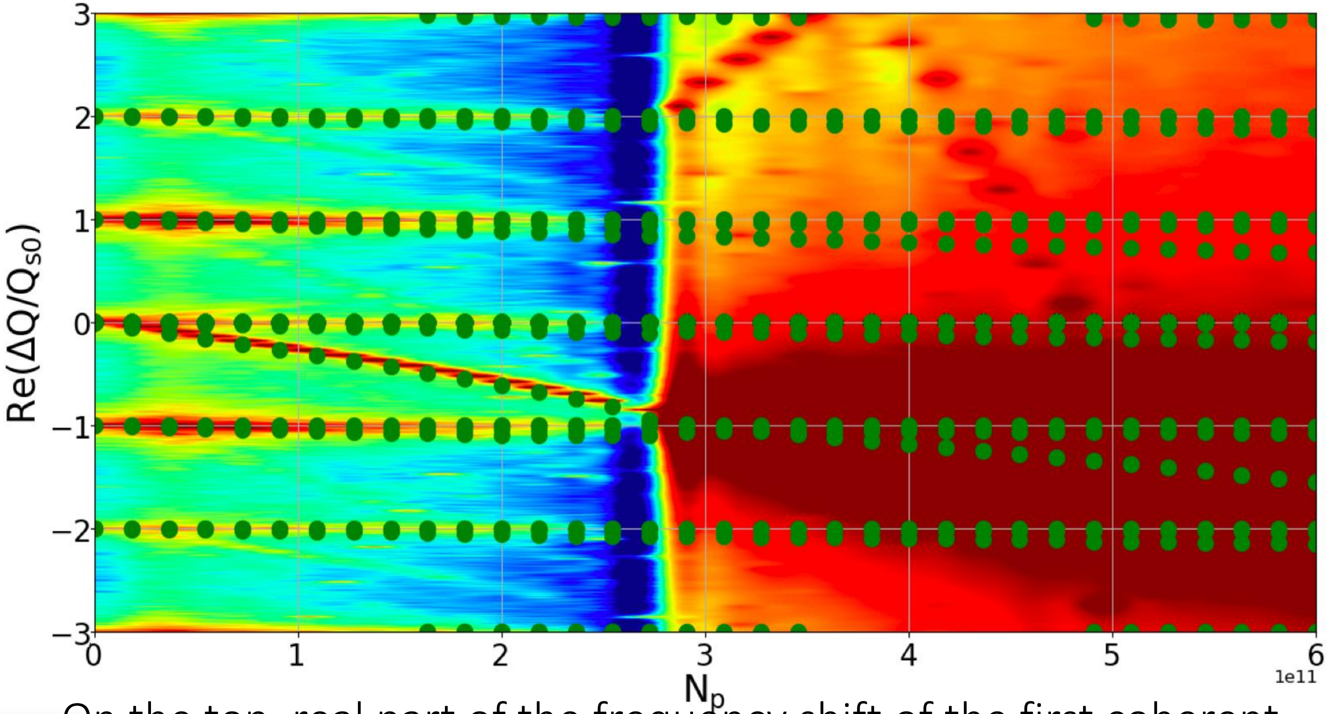
Bunch length (bottom) and RMS energy spread (top) as a function of bunch population in the case with (BS) and without (SR) beamstrahlung, which is considered here independent of the longitudinal impedance.

Bunch length and energy spread (old machine parameters)





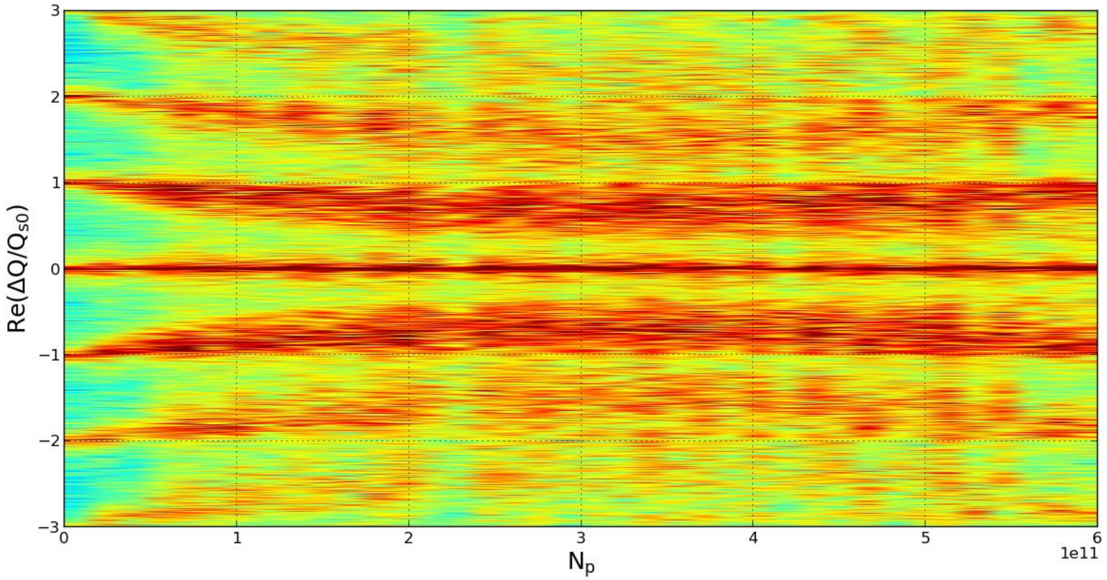
Transverse Dynamics



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.

In addition to simulations with the tracking code, the TMCI threshold has been also evaluated with the analytic Vlasov solver DELPHI

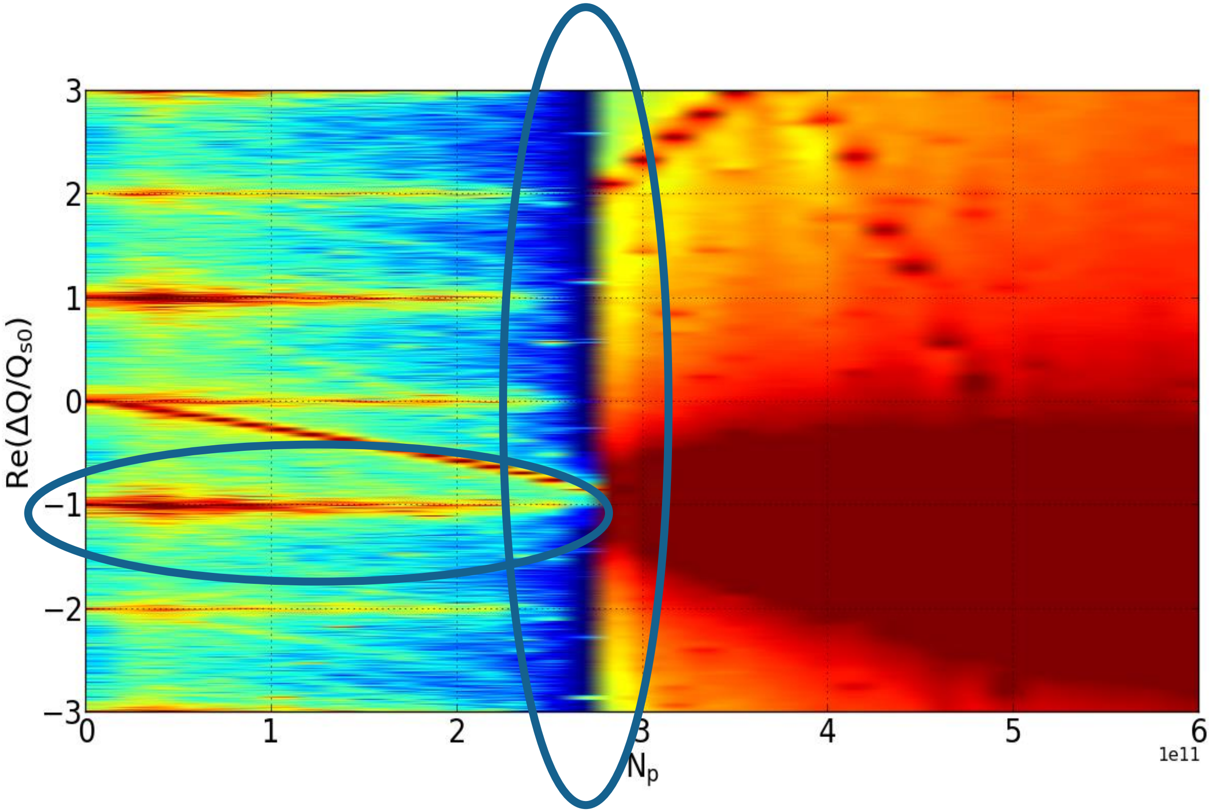
On the top, real part of the frequency shift of the first coherent oscillation modes as a function of the bunch population without beamstrahlung, by considering only the RW impedance produced by a NEG film with 150 nm thickness given by IW2D.



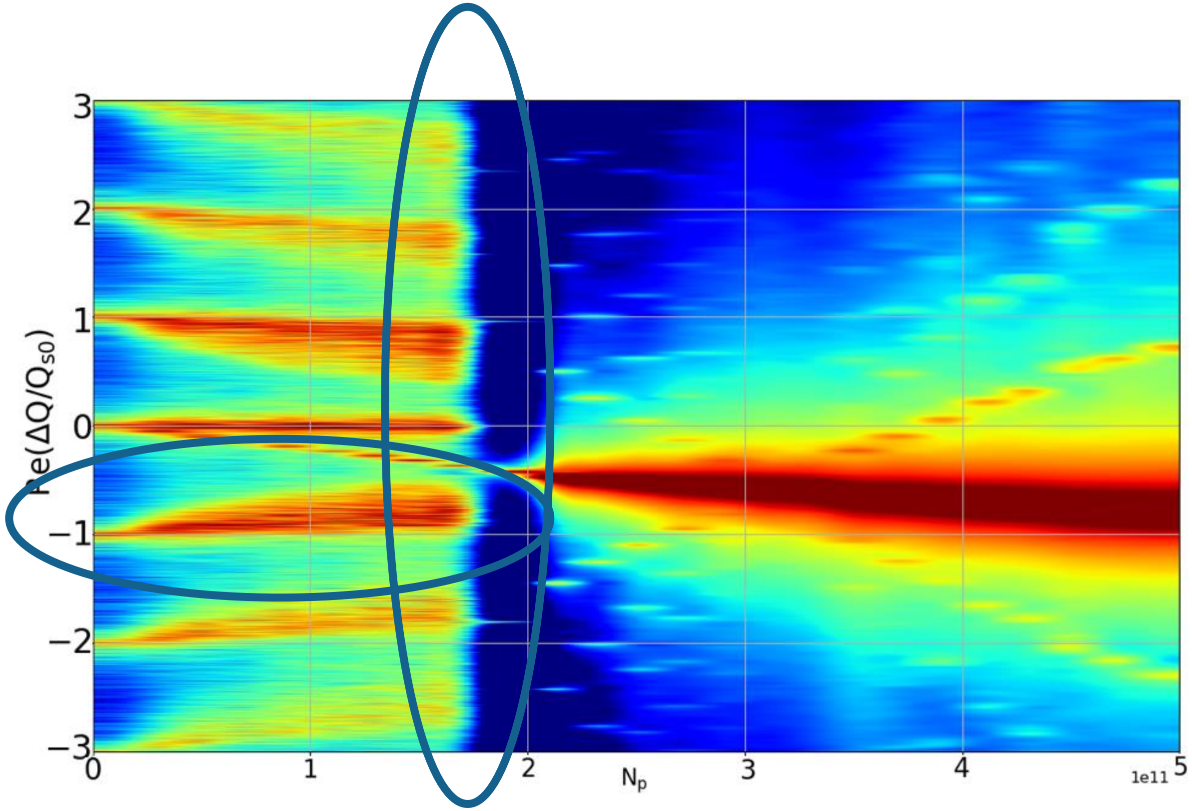
On the right, real part of the coherent tune shift as a function of intensity considering the longitudinal resistive wall wakefield, by using PyHEADTAIL.

TMCI

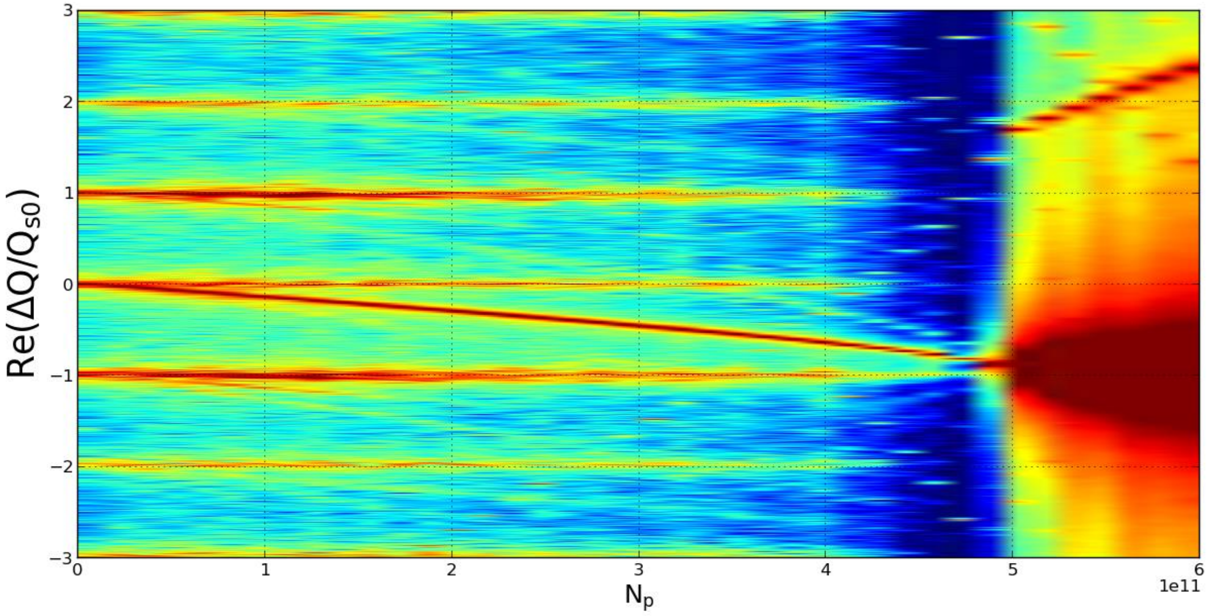
Without longitudinal resistive wall wakefield



Considering the longitudinal resistive wall wakefield



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

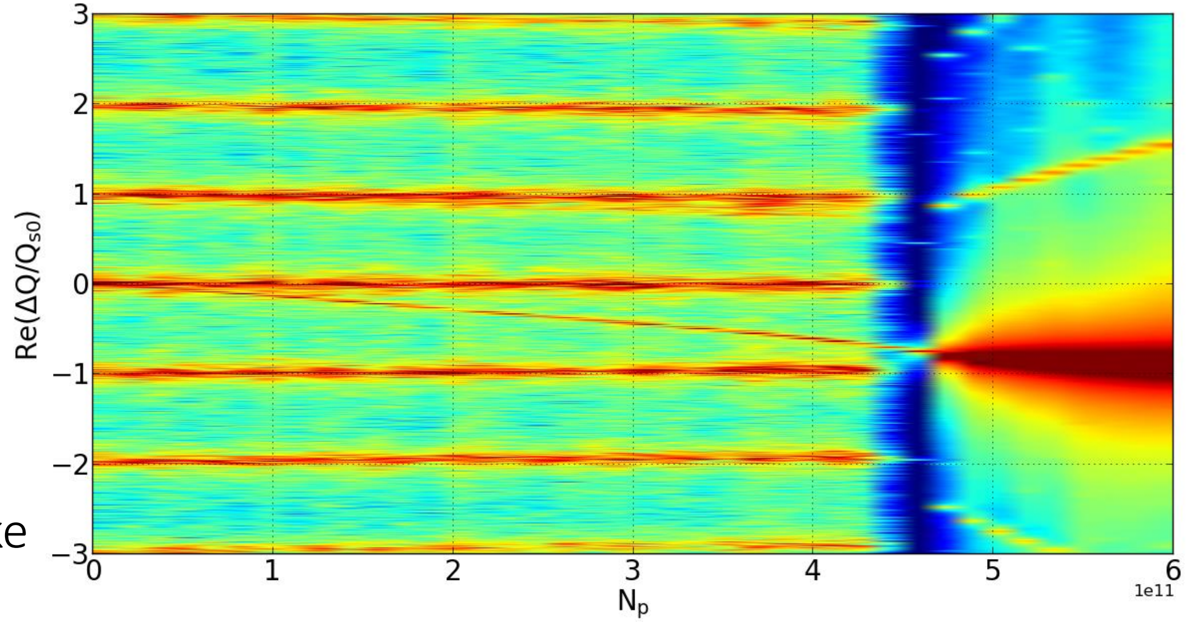


Without longitudinal wakefield

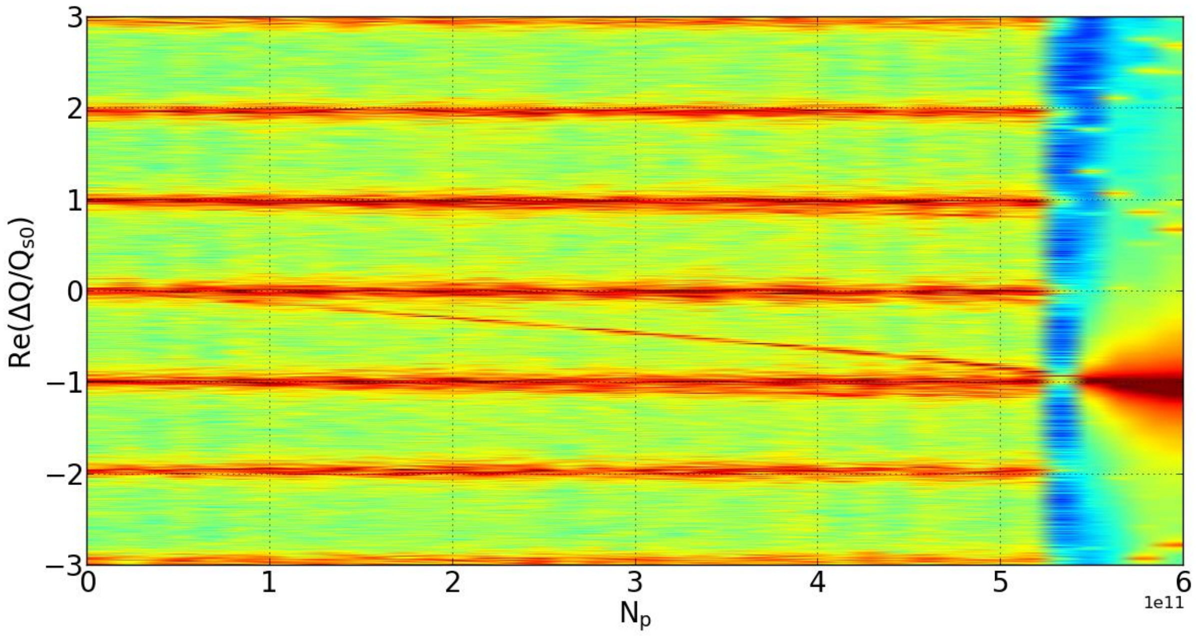
Transverse wake: PyHT vs Delphi

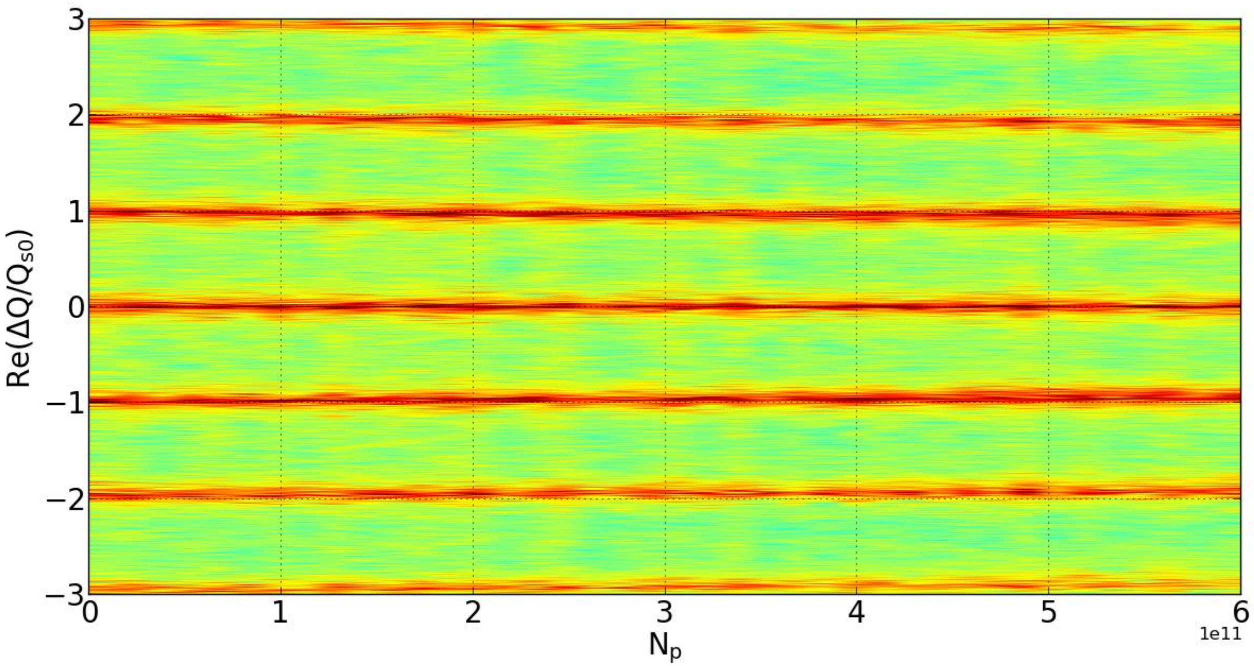
Considering the longitudinal wakefield

Longitudinal wake

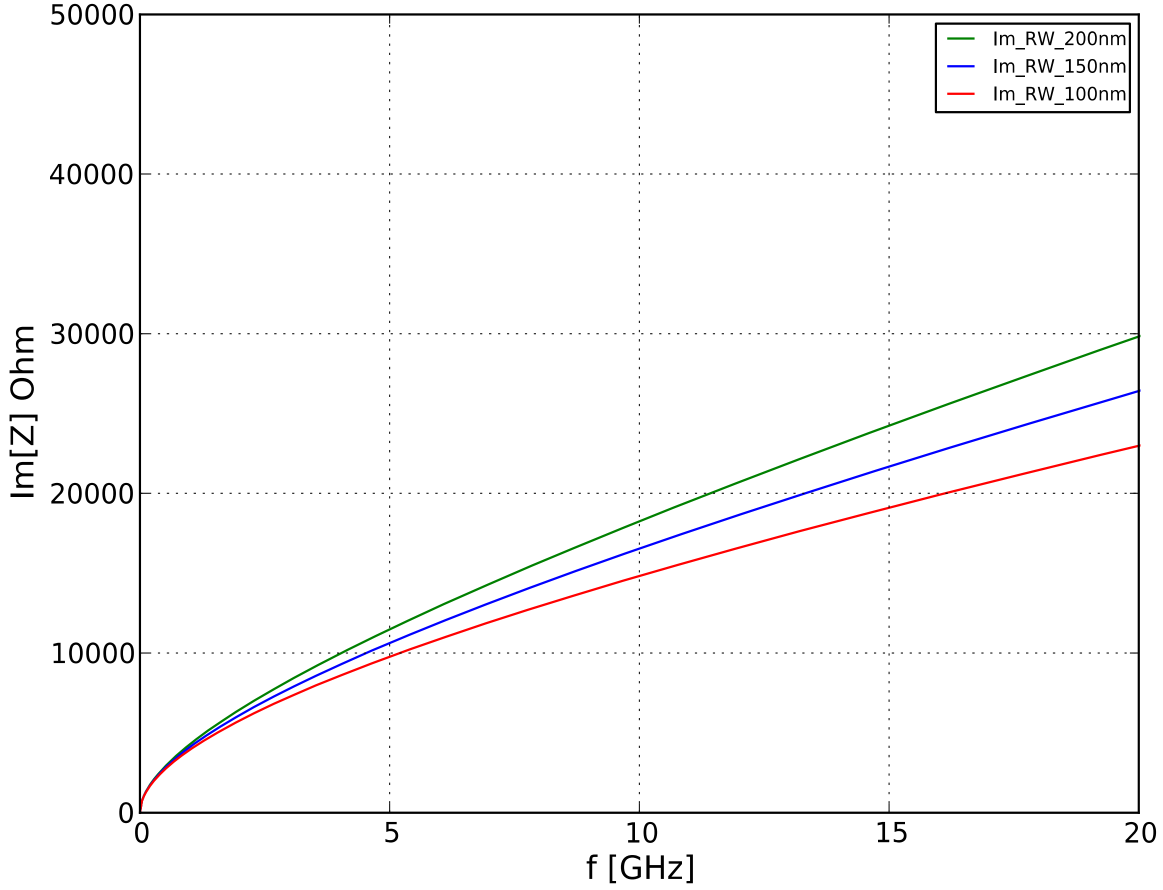


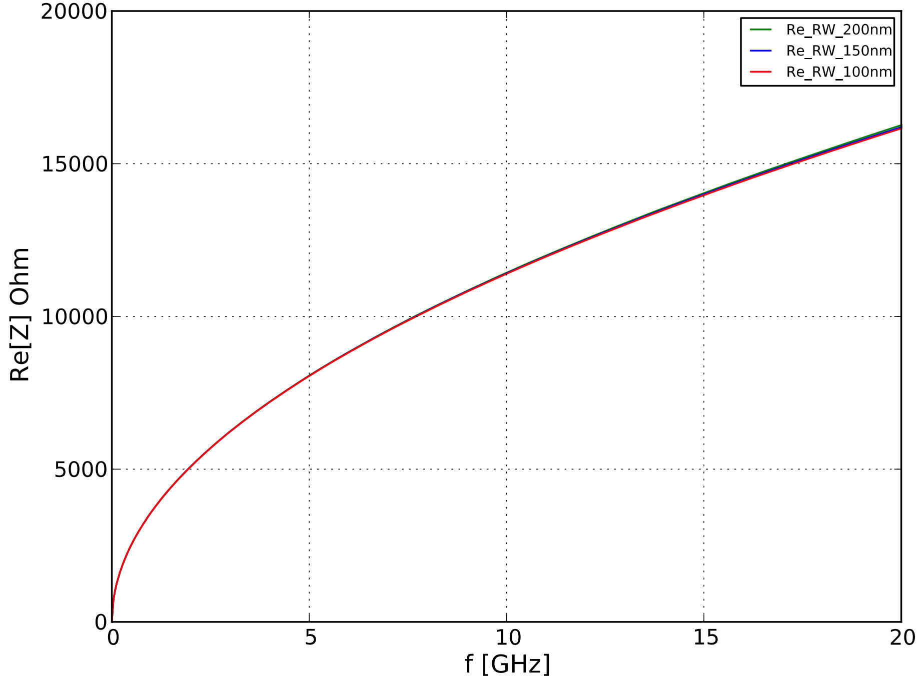
TMCI: longitudinal wake (on the right) and transverse wake (on the left) with a bunch length of 14.5 mm





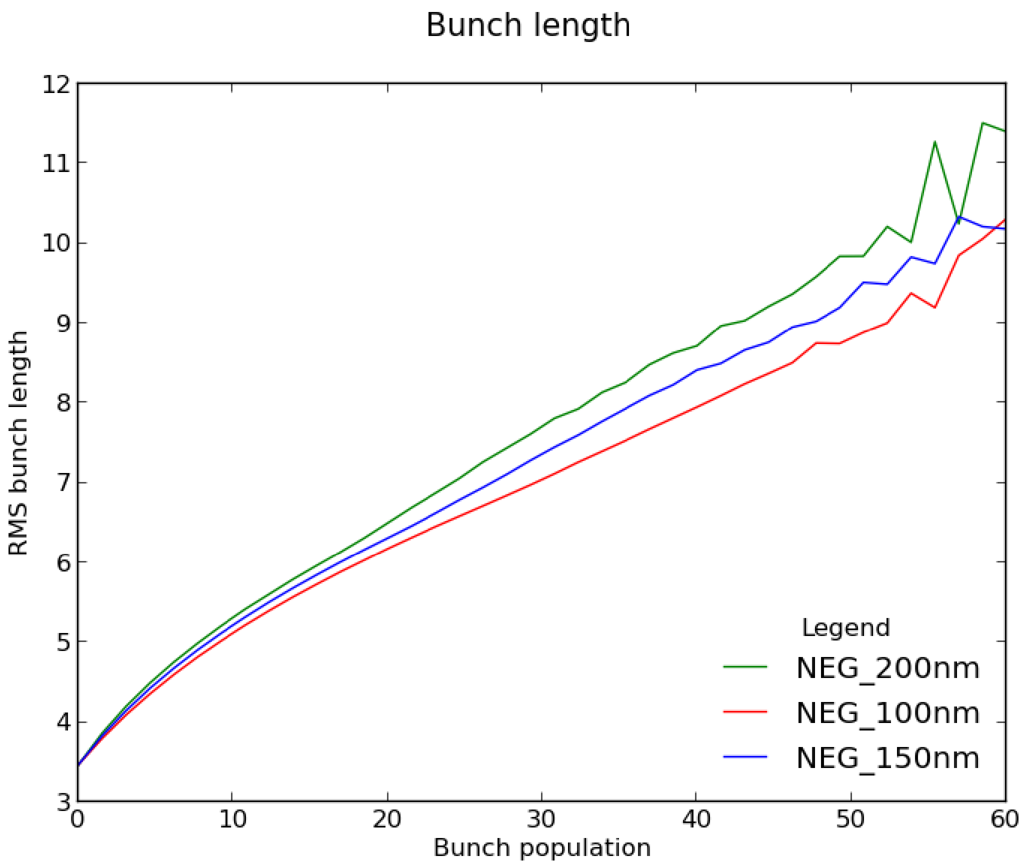
New evaluation of the impedances using different NEG coating : 100 nm 150 nm and 200 nm

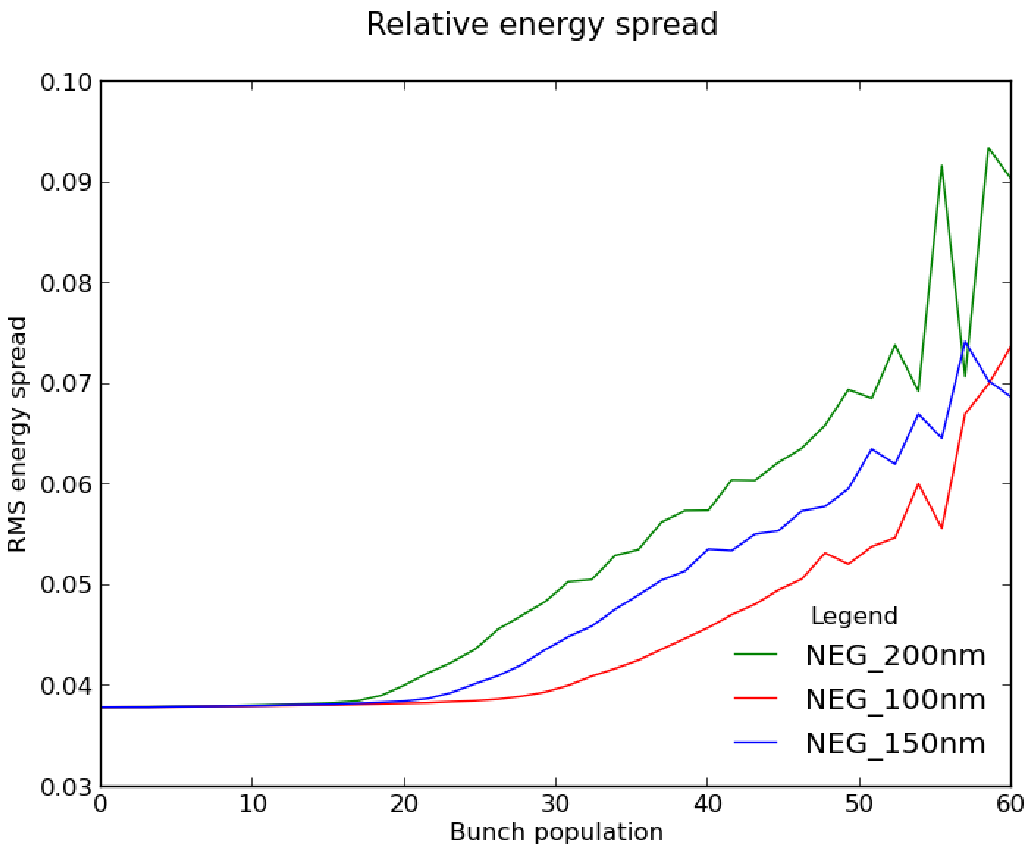




FUTURE CIRCULAR COLLIDER

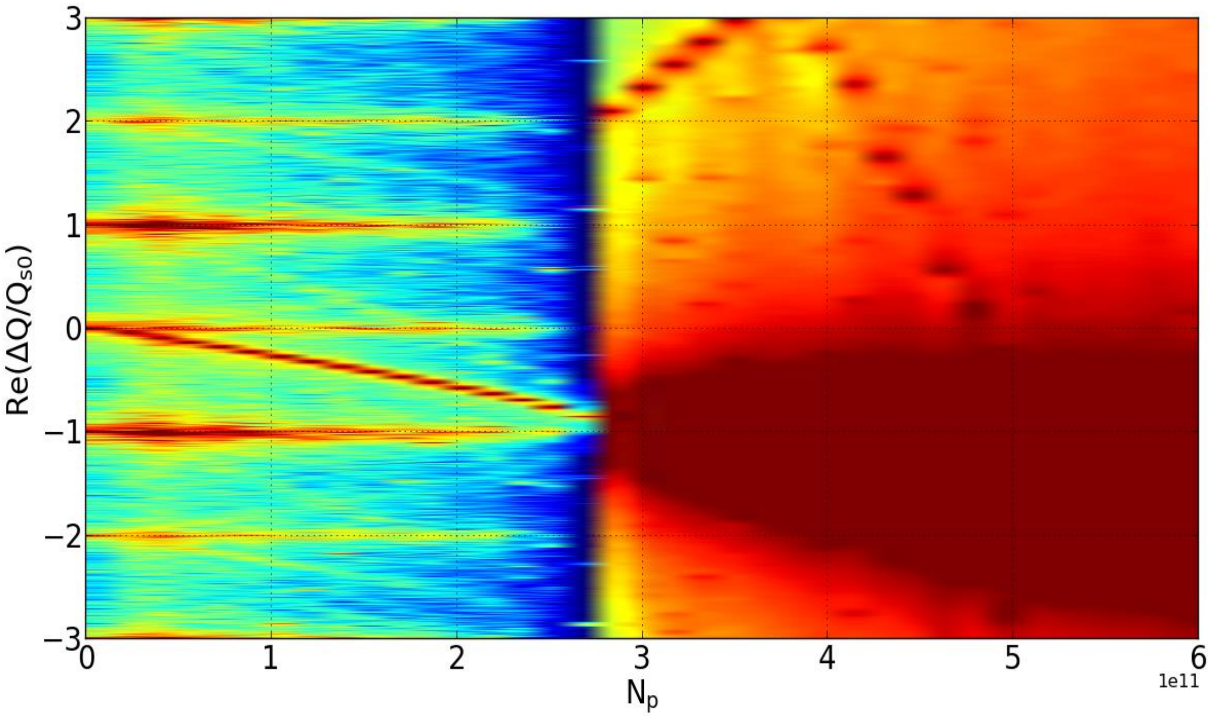
LONGITUDINAL DYNAMICS





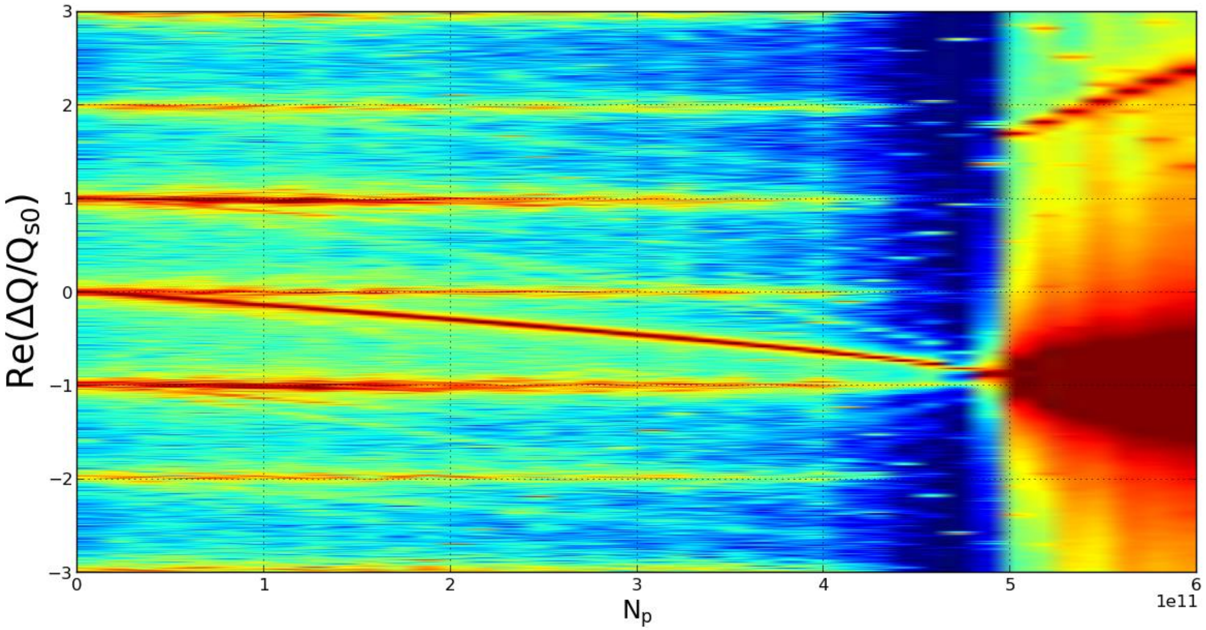
FUTURE CIRCULAR COLLIDER

TMCI analyzes using wake with different NEGs : **100nm,** 150 nm and 200 nm

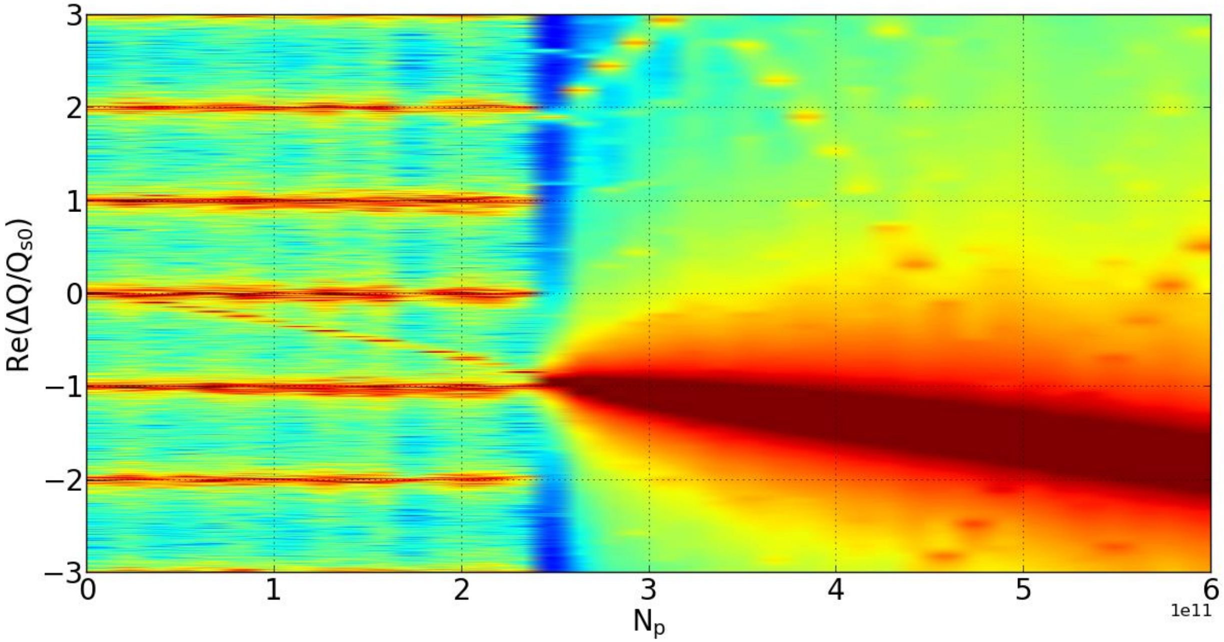


On the letf the plot of the TMCI considering a wake with 100nm of NEG and a beam length of 3.5mm

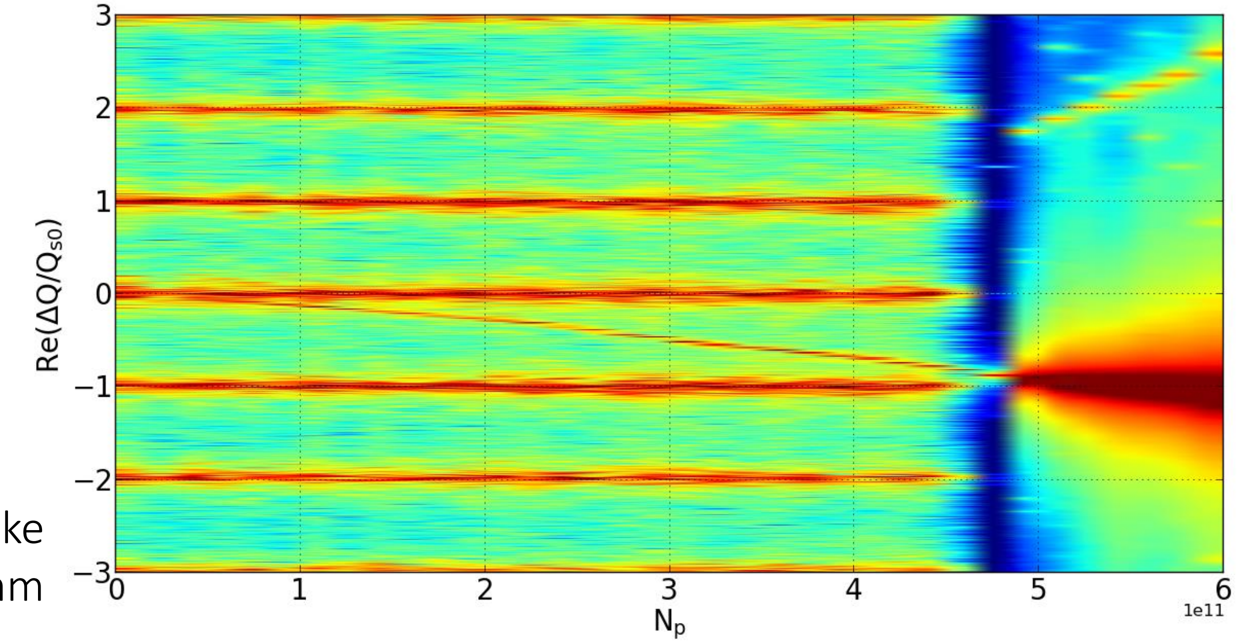
On the right the plot of the TMCI considering a wake with 100nm of NEG and a beam length of 12.1mm



TMCI analyzes using wake with different NEGs : 100nm, **150 nm** and 200 nm

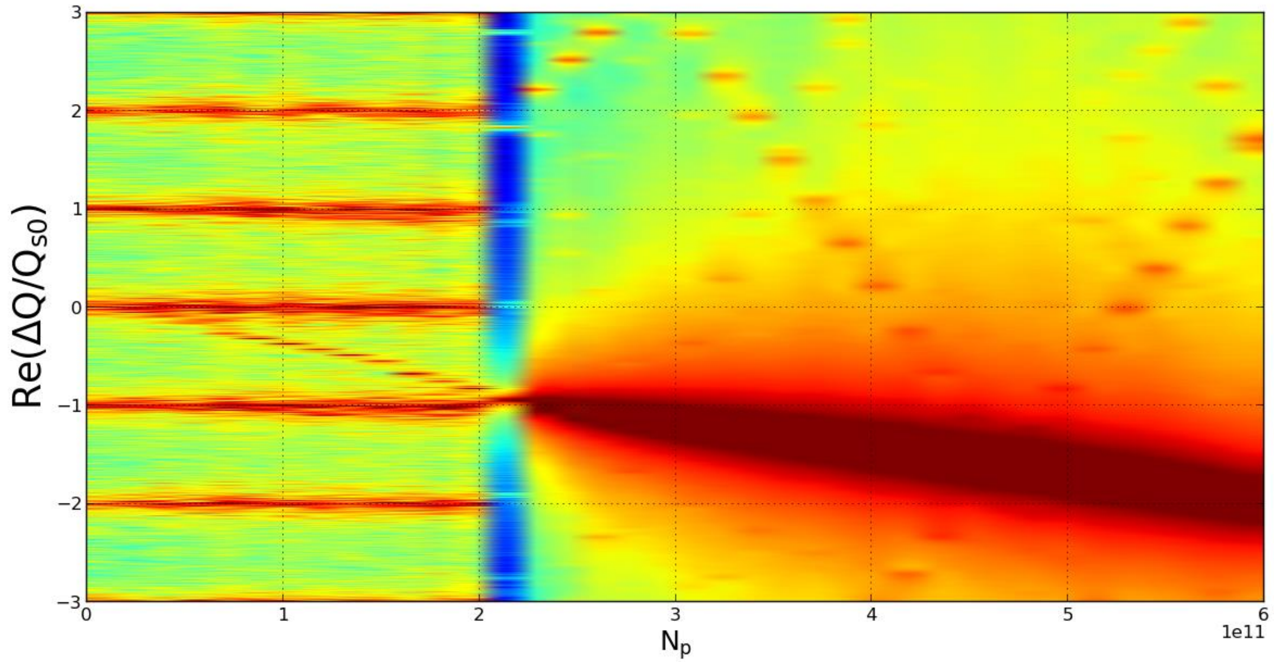


On the letf the plot of the TMCI considering a wake with 150nm of NEG and a beam length of 3.5mm

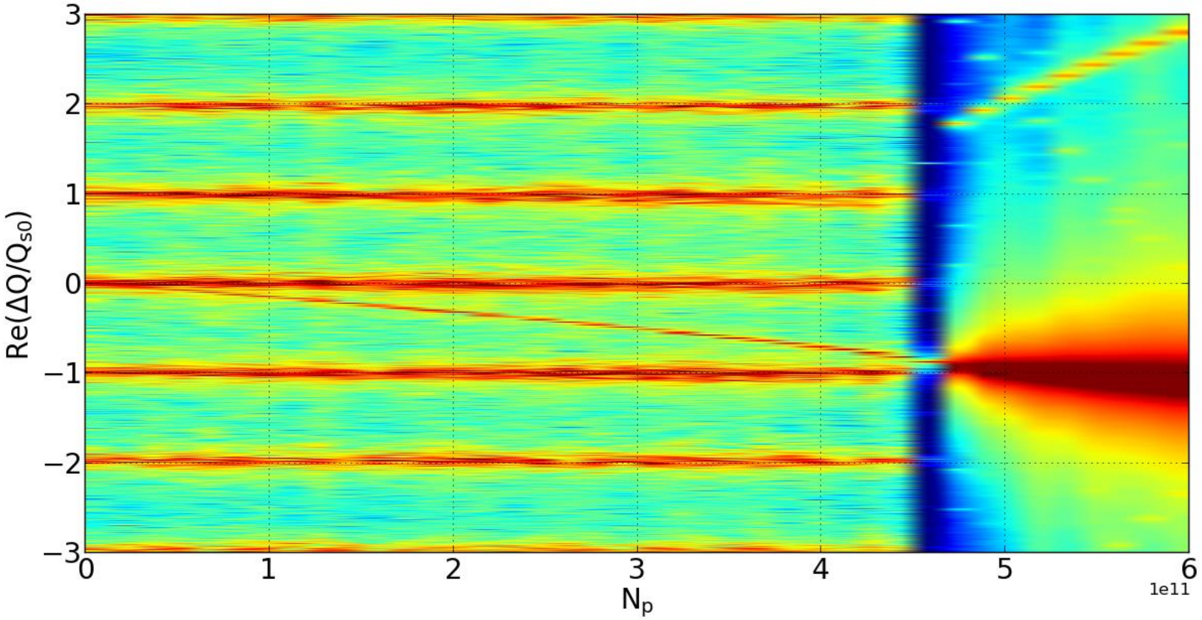


On the right the plot of the TMCI considering a wake with 150nm of NEG and a beam length of 12.1mm

TMCI analyzes using wake with different NEGs : 100nm,150 nm and **200 nm**



On the letf 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