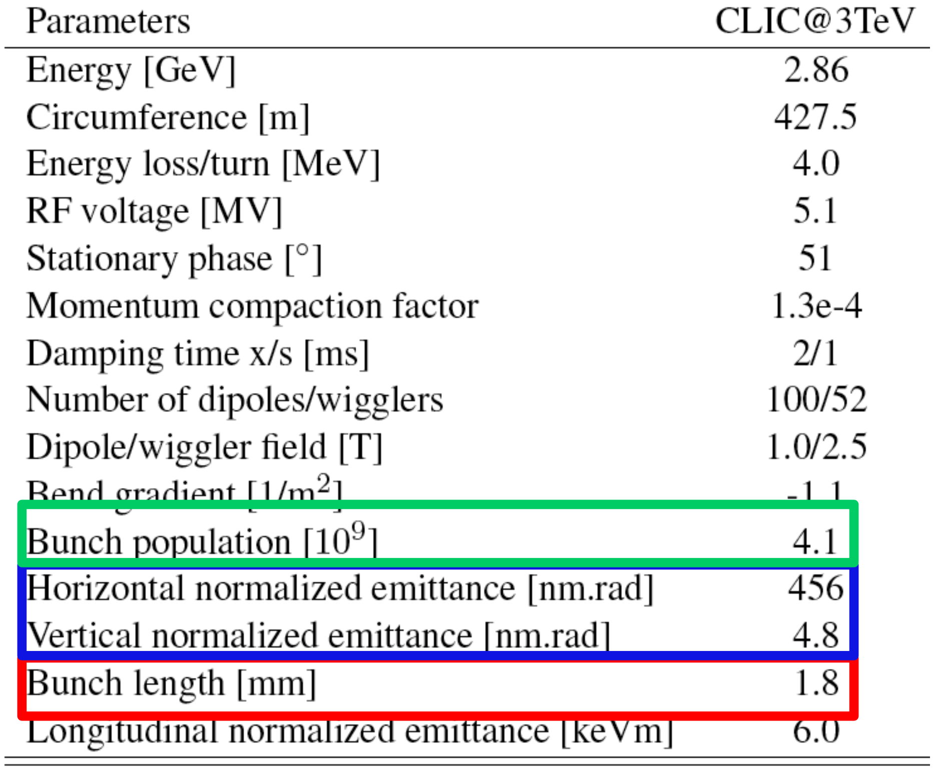
Impedance budget and effect of chamber coating on CLIC DR beam stability

Eirini Koukovini-Platia
EPFL, CERN

C. Zannini, K. Li, G. De Michele, N. Mounet, G. Rumolo, B. Salvant

Introduction (I)
Damping Rings

CLIC DR parameters



Parameters	CLIC@3TeV
Energy [GeV]	2.86
Circumference [m]	427.5
Energy loss/turn [MeV]	4.0
RF voltage [MV]	5.1
Stationary phase [°]	51
Momentum compaction factor	1.3e-4
Damping time x/s [ms]	2/1
Number of dipoles/wigglers	100/52
Dipole/wiggler field [T]	1.0/2.5
Bend gradient [1/m^2]	-1.1
Bunch population [10^9]	4.1
Horizontal normalized emittance [nm.rad]	456
Vertical normalized emittance [nm.rad]	4.8
Bunch length [mm]	1.8
Longitudinal normalized emittance [keVm]	6.0

- Small emittance, short bunch length and high current
- Rise to collective effects which can degrade the beam quality
- Their study and control will be crucial

Introduction (II)
Collective effects

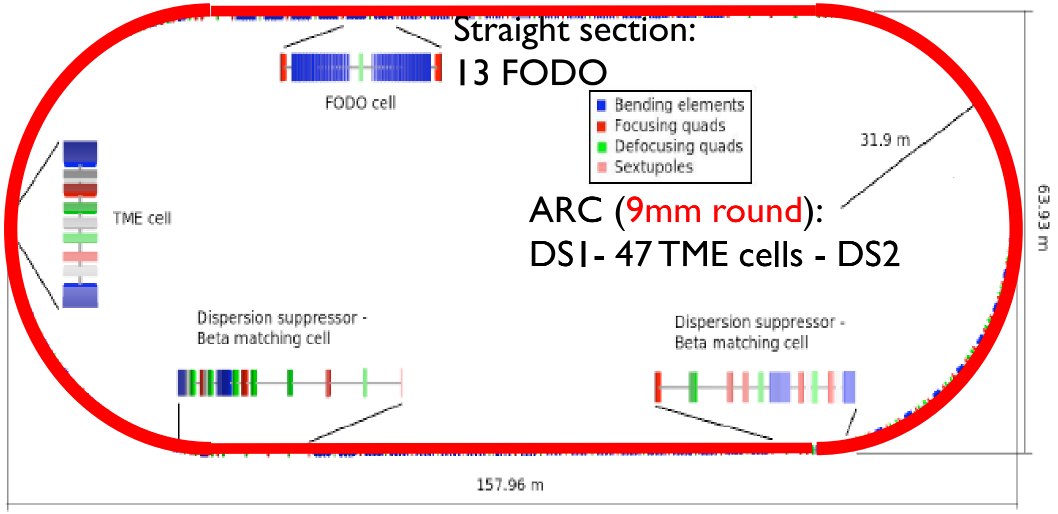
- Focus on instabilities driven by impedance
- Define the conditions to ensure safe operation under nominal conditions
- Define an impedance budget
- To suppress some of the collective effects, coating will be used
  - Positron Damping Ring (PDR): electron-cloud effects → amorphous carbon (aC)
  - Electron Damping Ring (EDR): fast ion instabilities → need for ultra-low vacuum pressure → Non-Evaporable Getter (NEG)
- Since the DR are under design, only some possible scenarios have been simulated so far

First results (I)
Single bunch simulations without space charge to define the instability thresholds

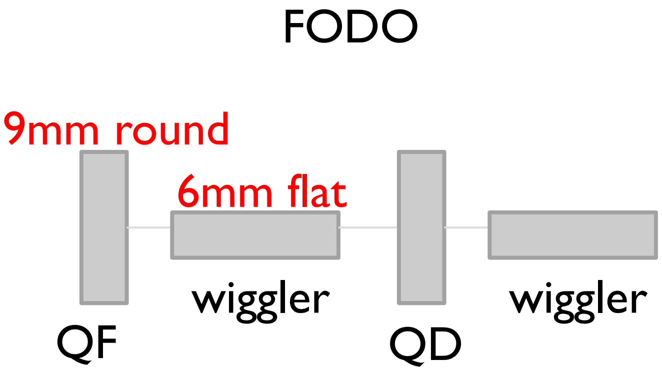
- HEADTAIL code
  - Simulates single/multi bunch collective phenomena associated with impedances (or electron cloud)
  - Computes the evolution of the bunch by bunch centroid as a function of time over an adjustable number of turns

- Goal
  - Estimate the available impedance budget for the various elements to be installed after known impedance sources such us the broad-band resonator, the resistive wall and the kickers are considered

First results (II)
Estimating the impedance budget with a 4-kick approximation



- A uniform **coating of NEG, 2μm** thickness, was assumed around the ring made from **stainless steel**
- The contributions from the resistive wall of the beam chamber were singled out for both the arc dipoles and the wigglers



1st kick →broadband resonator (S_{kick}=1m)

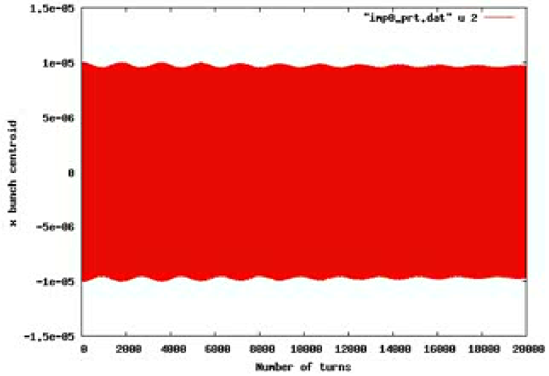
2nd kick → arc (L=270.2m, 9mm, round,<bx>=2.976m, <by>=8.829m, S_{kick}=150m)

3rd kick →wigglers (L=104m, 6mm, flat, <bx>=4.200m, <by>=9.839m, S_{kick}=41.3m)

4th kick → rest of the FODO (L=53.3m, 9mm, round,<bx>=5.665m, <by>=8.582m, S_{kick}=39.2m)

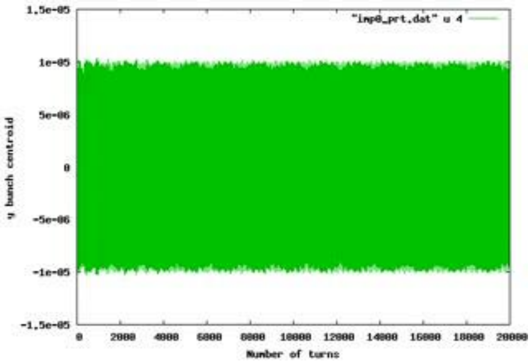
First results (III)
Estimating the machine impedance budget with a 4-kick approximation – single bunch simulations

x bunch centroid position



Number of turns

y bunch centroid

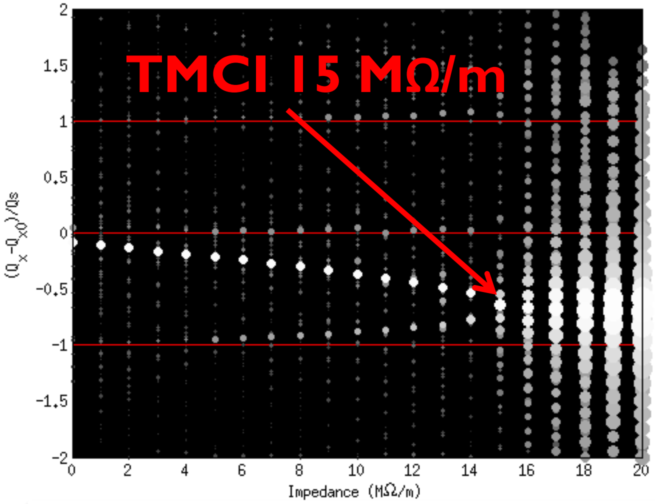


Number of turns

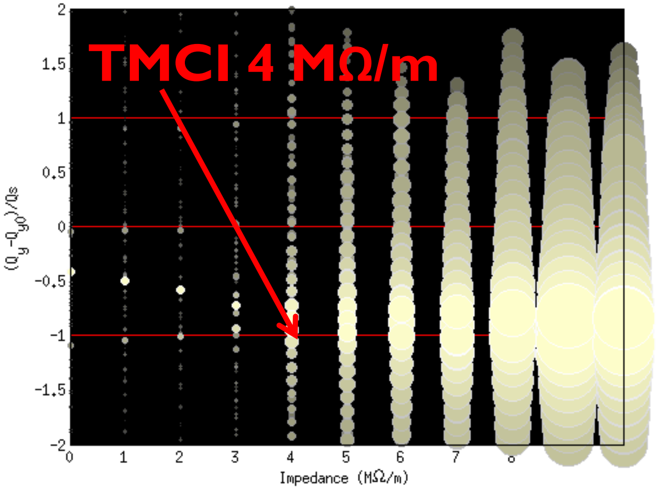
HEADTAIL output:
Position of the centroid over the number of turns

FFT/
Sussix

Mode spectrum of the horizontal and vertical coherent motion as a function of impedance



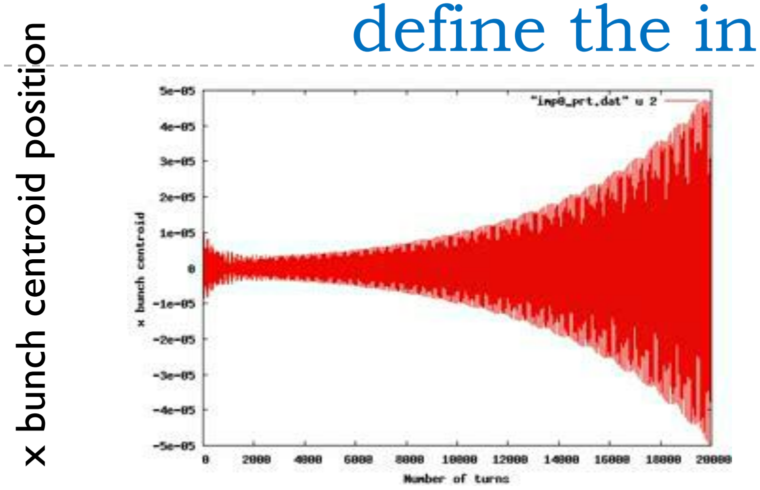
TMCI 15 MΩ/m

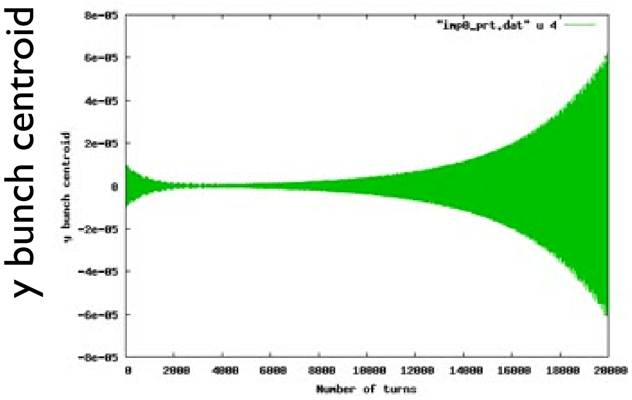


TMCI 4 MΩ/m

For zero chromaticity, the (remaining) impedance budget is estimated at 4 MΩ/m (7 MΩ/m for the BB only)

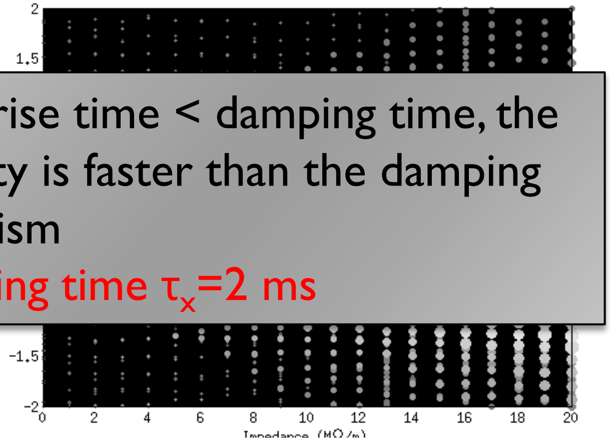
First results (III)
Single bunch simulations without space charge to define the instability thresholds



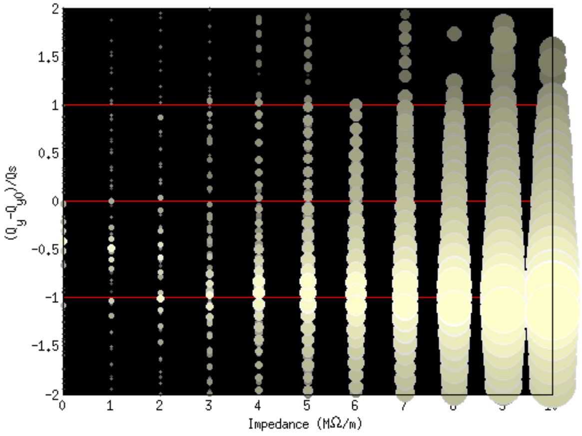


ξx	0.055
ξ_y	0.057

- ➢Another type of instability occurs, called the head-tail instability
- ➢Compare the rise time of instability with the damping time to define the threshold



- If the rise time < damping time, the instability is faster than the damping mechanism
- Damping time τ_x=2 ms



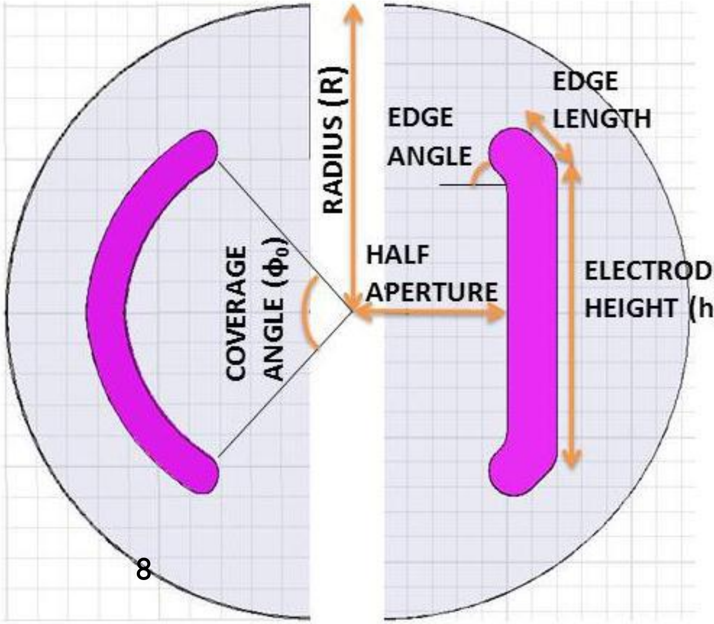
- No mode coupling observed
- Higher TMCI thresholds
- Mode 0 is damped
- Higher order modes get excited (m = -1)

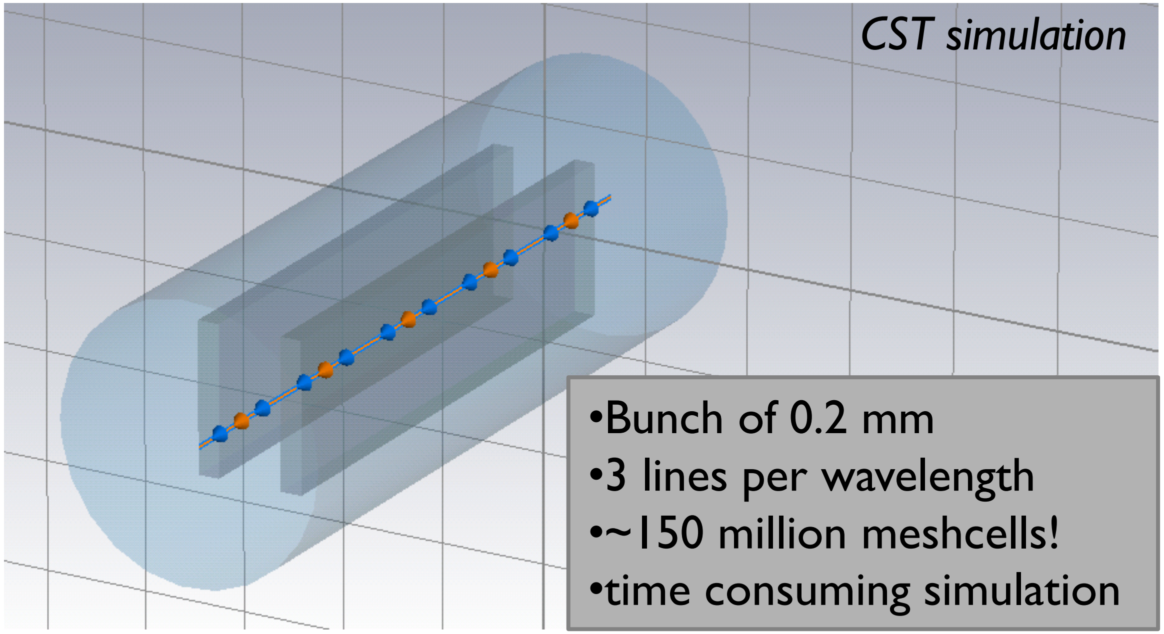
For positive chromaticity, the impedance budget is estimated now at 1 MΩ/m (4 MΩ/m for the BB only)

6-kick study- adding stripline kickers

- 2 kickers in the DR (injection&extraction)
- Calculate the wake function and add this wake as a kick in our impedance model
- Idea: Use the shortest bunch length possible in the CST simulation (Software package for electromagnetic field simulations) so that the wake function (input for HEADTAIL) could be approximated with the wake potential (output of CST)
- 0.2 mm bunch length

R=25mm, Aperture=12mm/20mm, h=20mm, Thickness=4mm

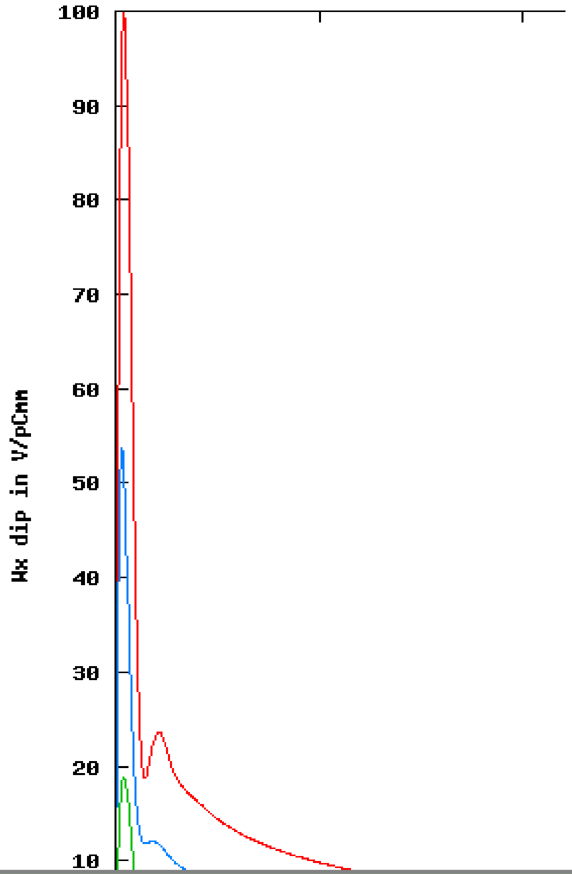


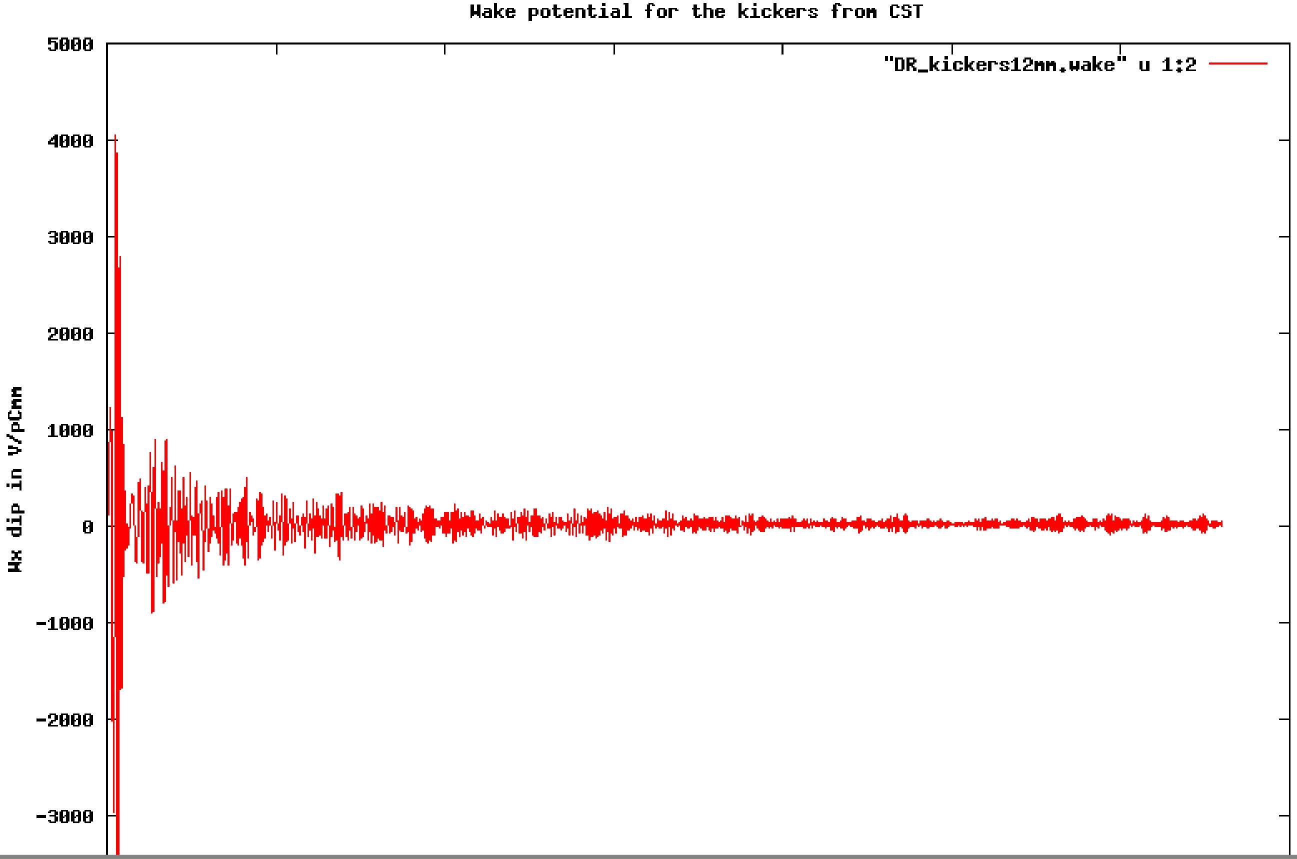


CST simulation

- Bunch of 0.2 mm
- 3 lines per wavelength
- ~150 million meshcells!
- time consuming simulation

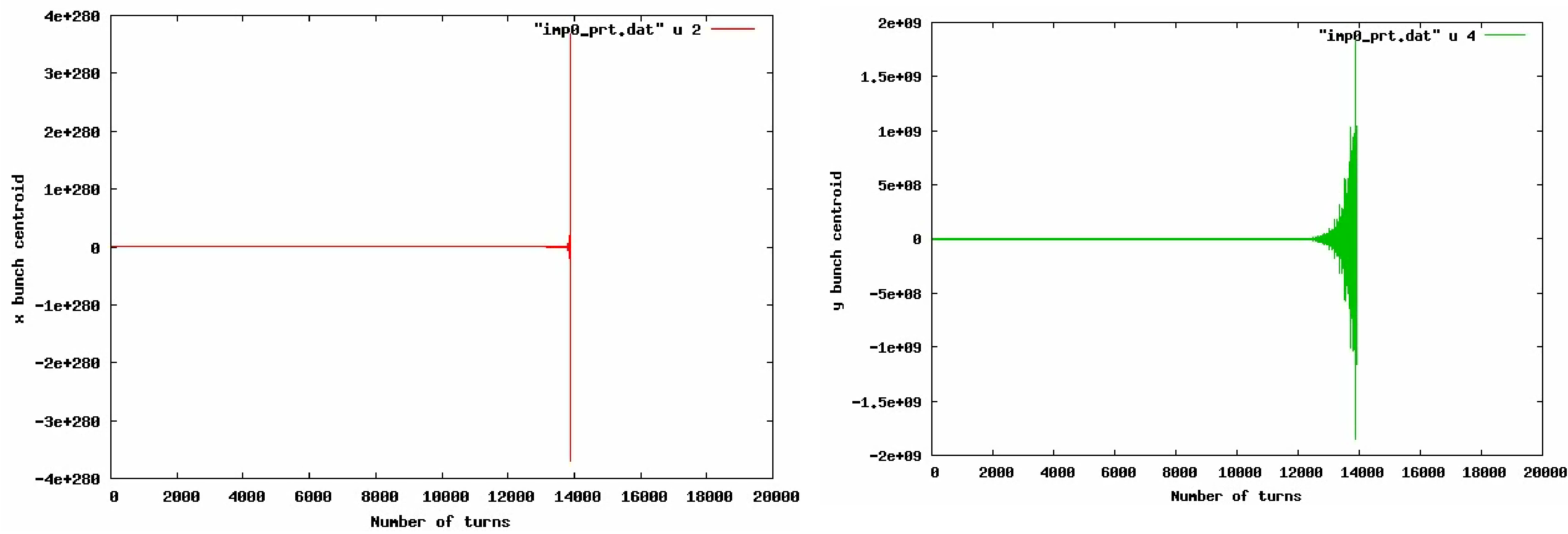
- 4 kicks as before (BB, arc, rest of the wiggler cell, wigglers)
- 2 kicks more added from the kickers



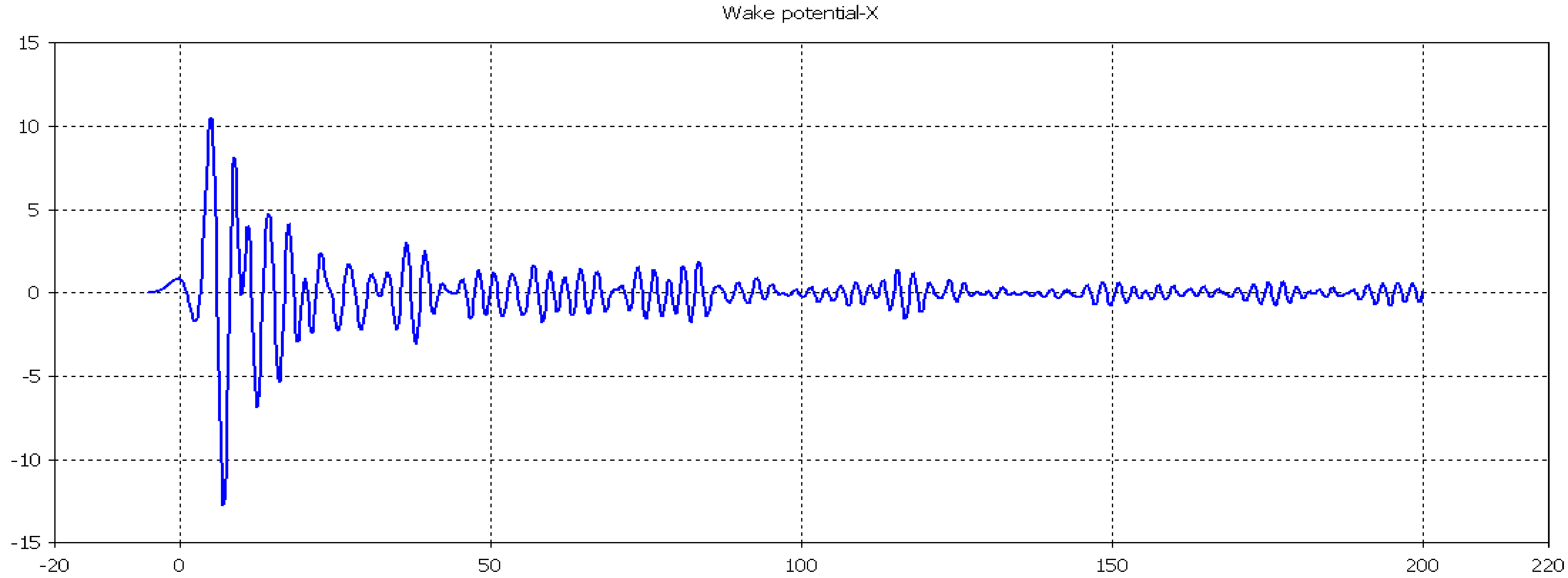


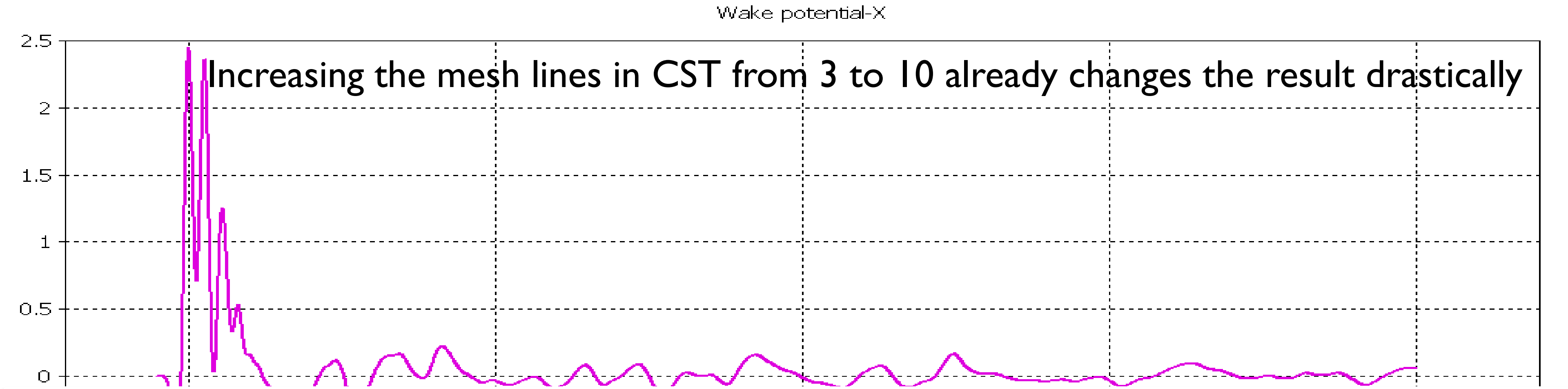
•Unphysically high values of the wake potential at disctances very close to the source charge (around 60 times stronger than the rest of the wakes used)
•Trustworthy results from CST?

6 kicks- HEADTAIL results



Unstable from the beginning. Problem with the wake calculation from CST?

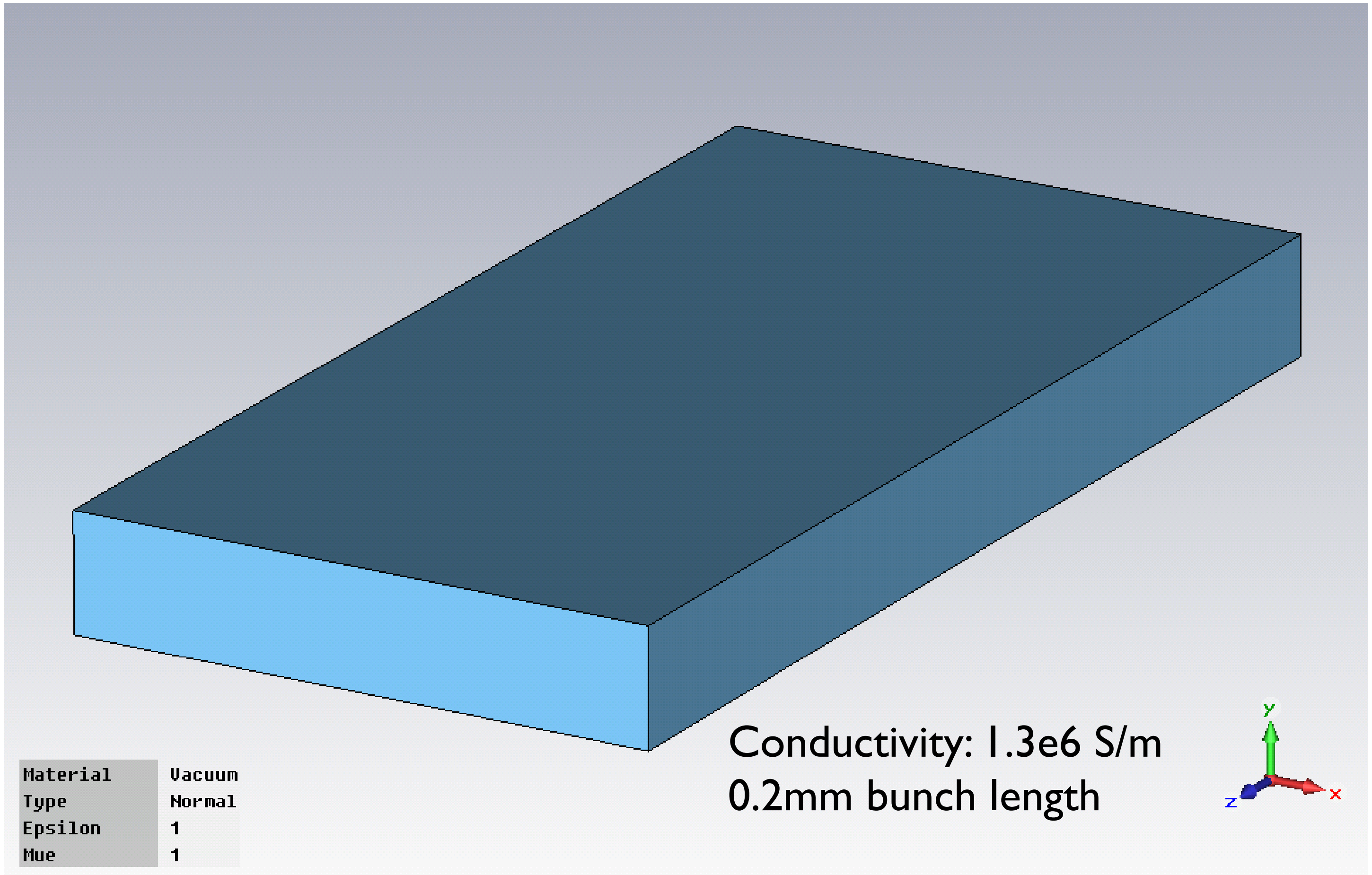




Increasing the mesh lines in CST from 3 to 10 already changes the result drastically

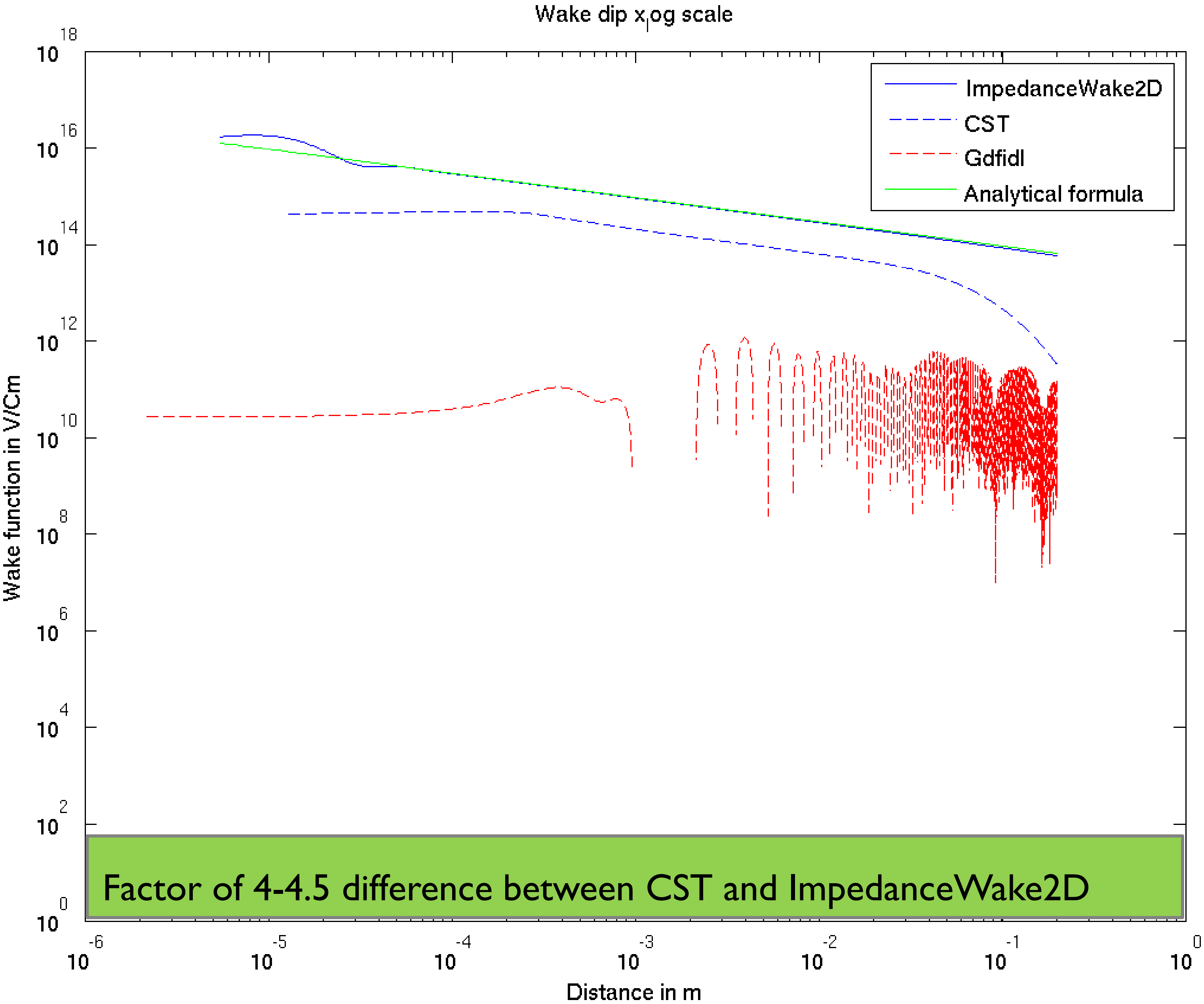
- Such a low mesh can't be trusted in CST, need at least 10 lines per wavelength → unable to use the short bunch length of 0.2 mm needed for this simulation
- CST in this frequency range cannot be just used as the wake function

Simple structure for resistive wall Compare CST, Gdfidl, ImpedanceWake2D and analytical formula



Material	Vacuum
Type	Normal
Epsilon	1
Mue	1

Conductivity: 1.3e6 S/m
0.2mm bunch length



Factor of 4-4.5 difference between CST and ImpedanceWake2D

Stripline kickers study- next steps

- Solve the difference between CST and the ImpedanceWake2D code results
- Try using local mesh properties, further optimization of the simulated structure
- Idea: for ultra short bunches, use CST Wakefield Solver with a longer bunch to find the impedance of the structure. The wake function could be then estimated with the inverse Fourier Transform.
- Try ABCI (Azimuthal Beam Cavity Interaction)
  - Calculations of wake fields, wake potentials, loss factors, and impedance

Material EM properties characterization

⇒Measurement of material EM properties in the high frequency range of NEG and a-C at high frequencies (CLIC@ 500 GHz)

⇒Establishing and testing a method to measure the properties of NEG

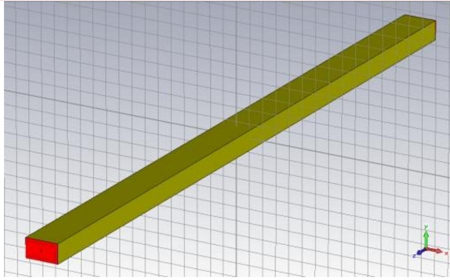
⇒Combine experimental results with CST simulations to characterize the electrical conductivity of *NEG*

⇒Powerful tool for this kind of measurements

Experimental method

50 cm Cu wg
9-12 GHz

CST MWS simulation

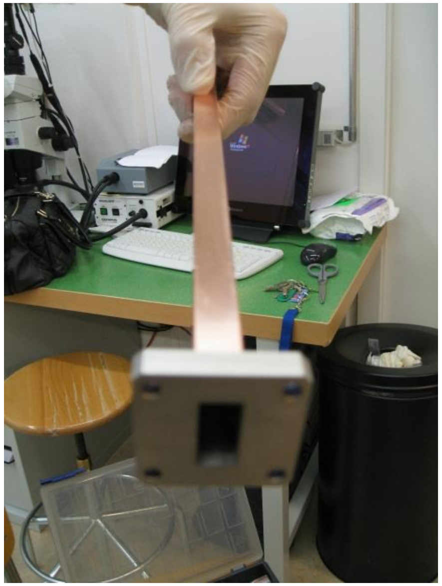


$S21(\sigma)$ Intersection $(f, S21)$

Material properties σ, ε, μ → Calculation of the wake fields → Study of instabilities with HEADTAIL

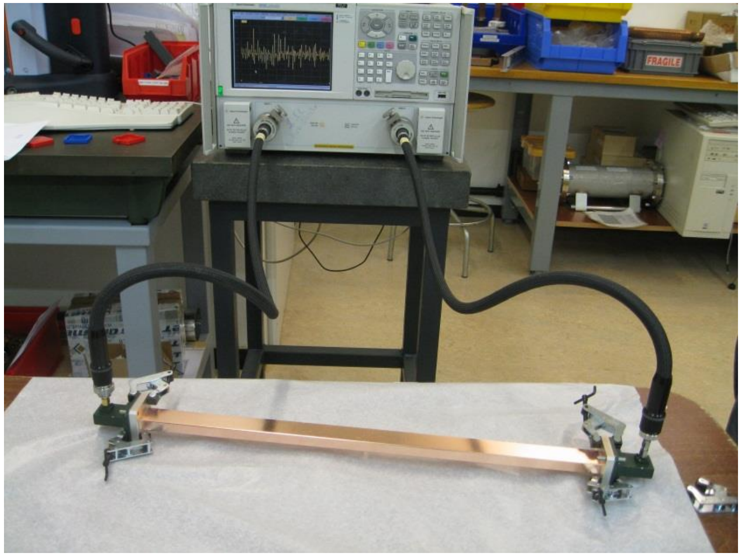
Experimental Method (I)

- Waveguide Method
  - First tested at low frequencies, from **9-12 GHz**
  - Use of a standard X-band waveguide, 50 cm length
  - Network analyzer
  - Measurement of the transmission coefficient S_{21}



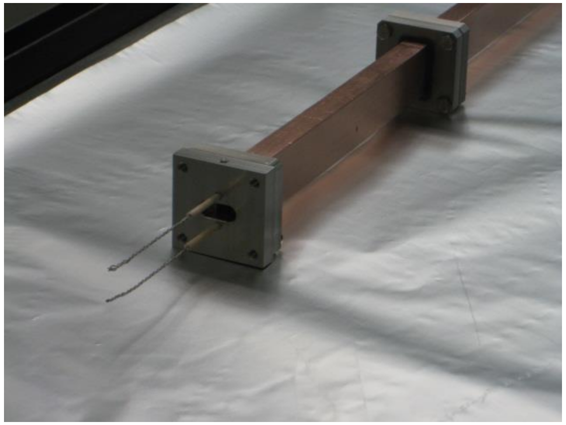
X band Cu waveguide of 50 cm length

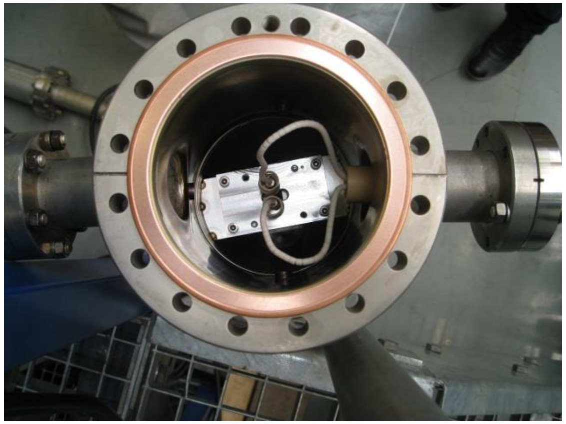
Experimental setup



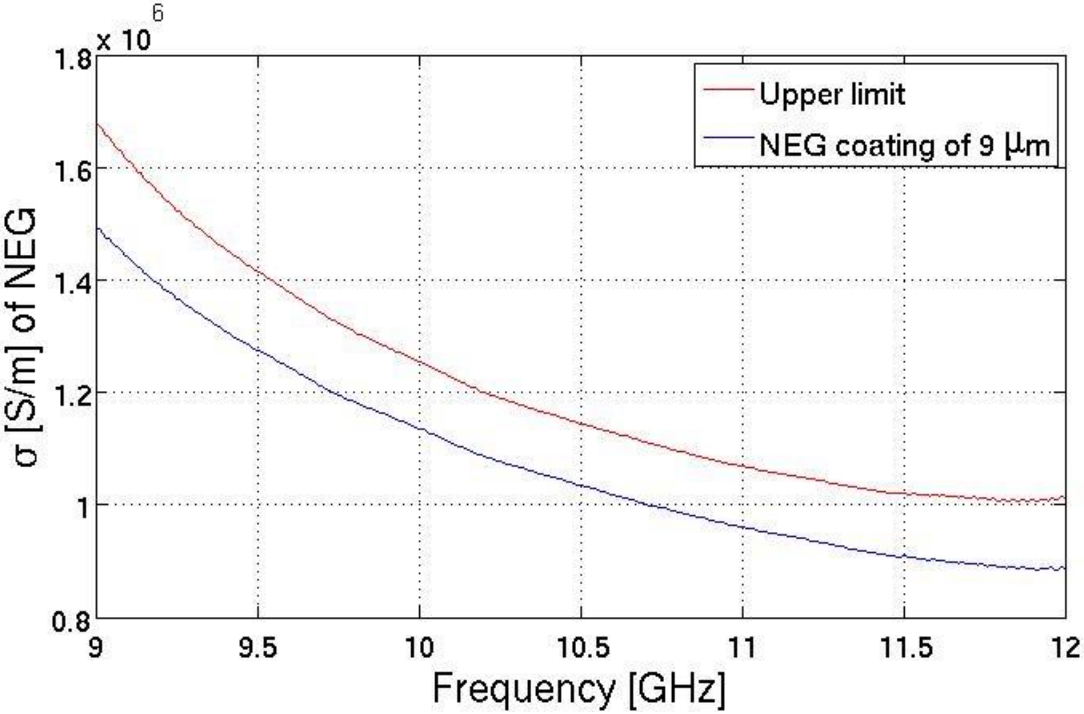
Experimental Method (II)

- NEG coated Cu waveguide
  - Same Cu waveguide used before is now coated with NEG
- Coating procedure
  - Elemental wires intertwisted together produce a thin Ti-Zr-V film by magnetron sputtering
  - Coating was targeted to be as thick as possible (9 μm from first x-rays results)





3D EM Simulations and measurements (II) Conductivity of NEG



- Upper limit for the conductivity of NEG in this frequency range
- Preliminary results

•Is this frequency dependent behavior physical? (repeat measurements with a spare Cu waveguide to check reproducibility)
•Waiting for the NEG coating of a spare Cu waveguide

Results on the impedance budget (4 kicks)
Effect of NEG conductivity & coating

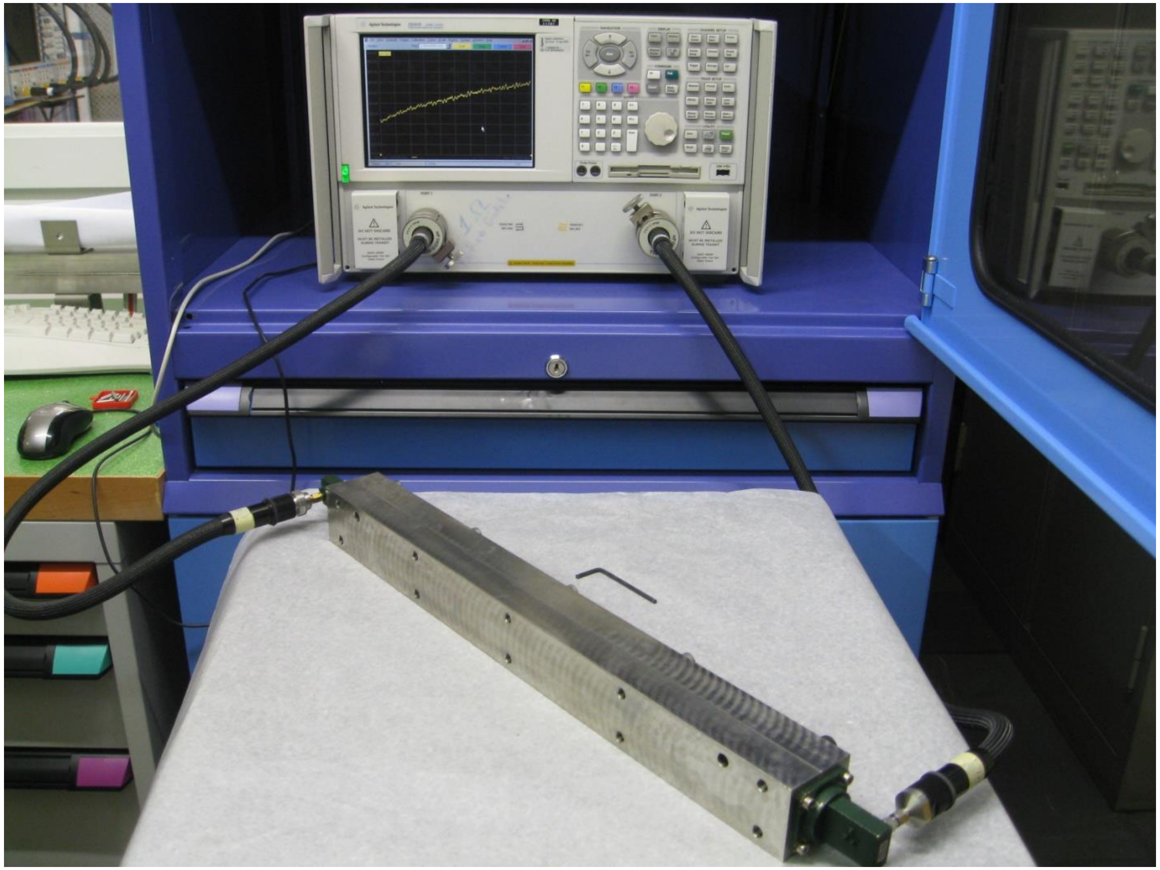
Pipe material/ coating	**Chromaticity**	**Impedance budget (MΩ/m)**
ss/ NEG 2μm ($\sigma_{NEG} = 10^6$ S/m)	0	4
	$\xi x = 0.055/\xi y = 0.057$	1
ss/ NEG 2μm ($\sigma_{NEG} = 1.6\ 10^6$ S/m)	0	5
	$\xi x = 0.055/\xi y = 0.057$	1
ss/ Cu 10 μm / NEG 2 μm ($\sigma_{NEG} = 1.6\ 10^6$ S/m)	0	5
	$\xi x = 0.055/\xi y = 0.057$	2

The characterization of NEG properties is important in the high frequency regime

Different coating has an effect, mainly important for positive chromaticity

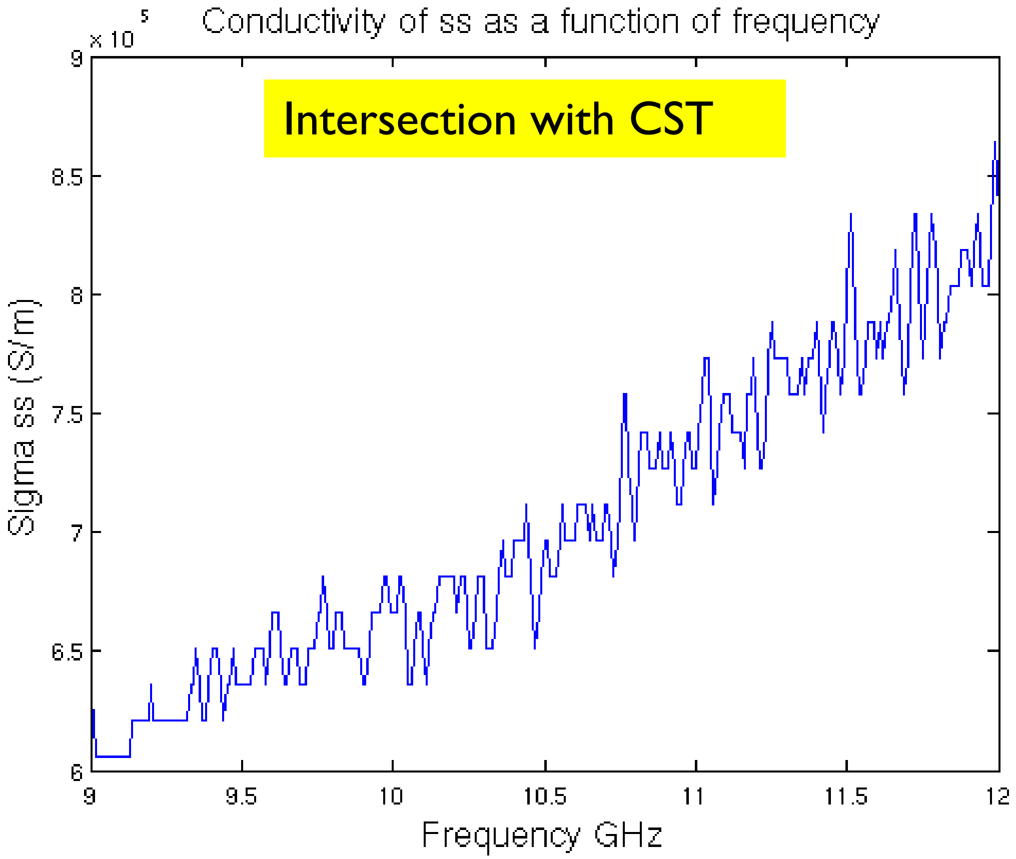
Measurements with the stainless steel waveguide

X band stainless steel (ss) waveguide of 50 cm length



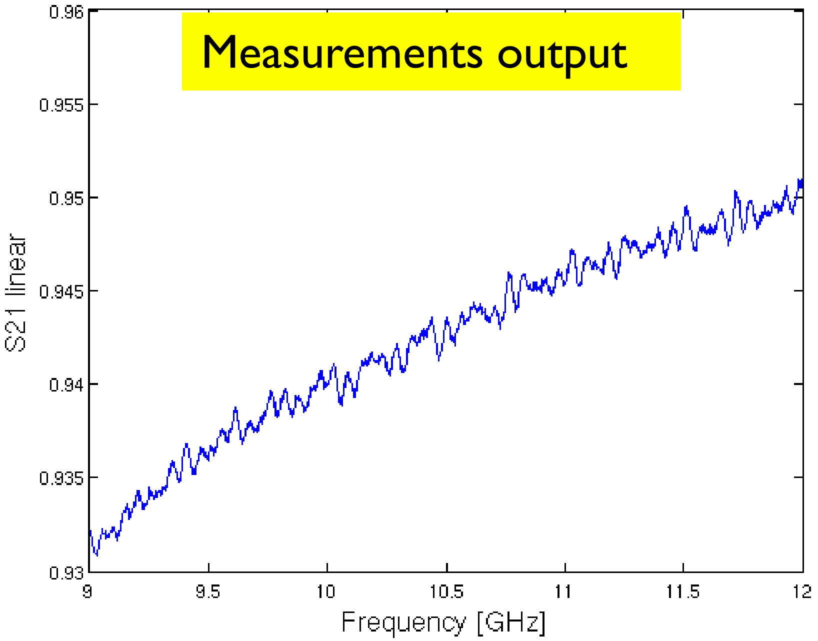
➢Define the accuracy of the experimental method

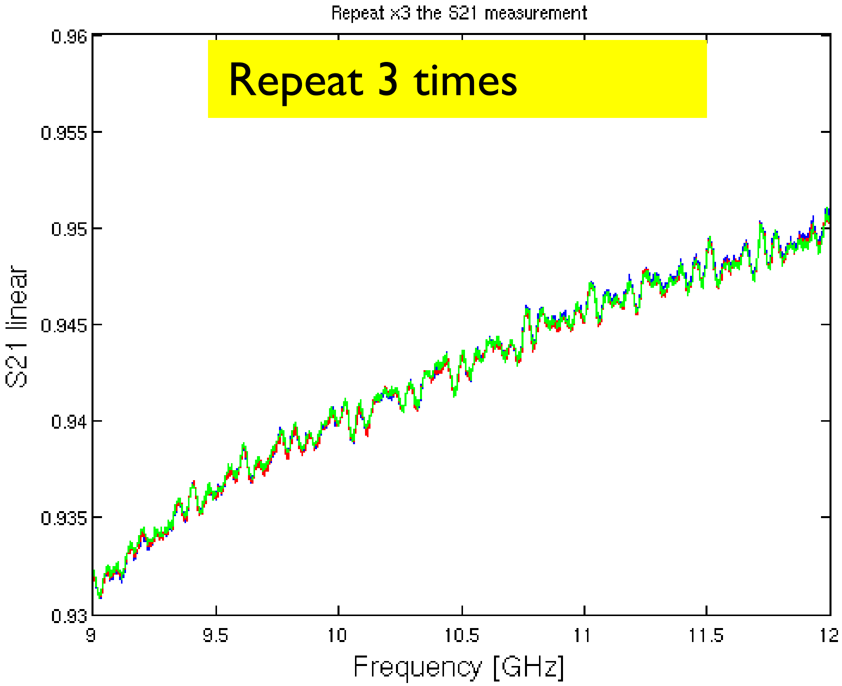
Results with the stainless steel waveguide Measurements and CST



- Average σ=0.75 10^6 S/m while expected DC value is 1.3 10^6 S/m
- Problem in the measurement or the model?

Further checks for errors during the measurements or the waveguide itself



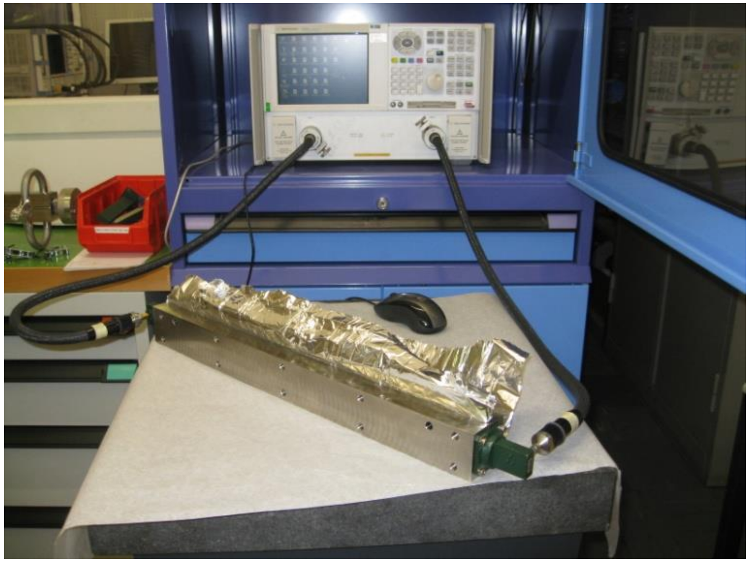


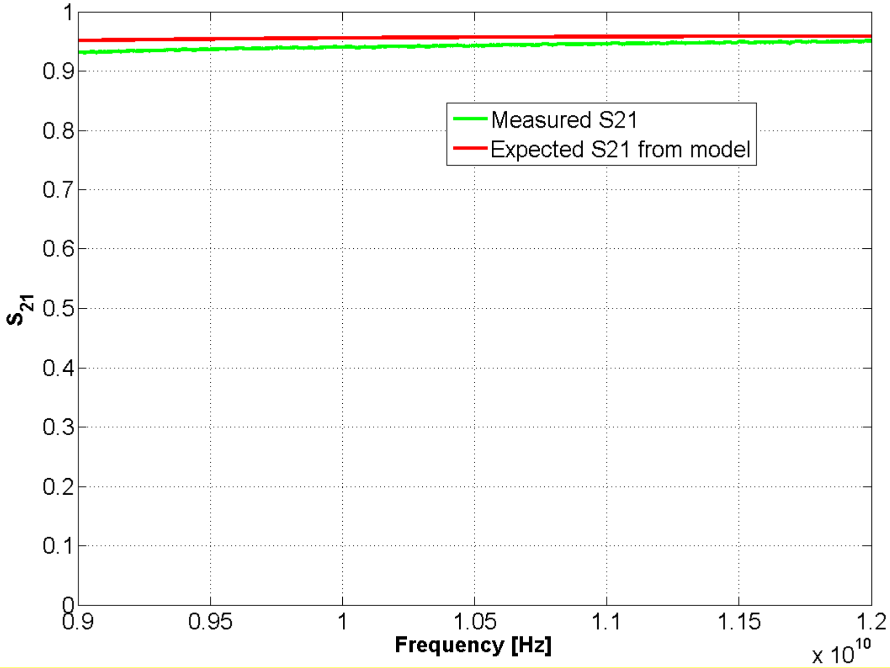
Results are in very good agreement, repeated the procedure 3 times

- Check if there is any resistance transversely in the waveguide with an ohmmeter

Problem of the waveguide?

- Add aluminum foil along the connection to ensure good contact and any extra losses (the material is not welded there but two different pieces hold together with screws) → Results are in very good agreement





- Seems the experimental results can be trusted
- Need to work on the model (try another code? Analytical calculation of the S21?)

Other tasks ongoing…

1. Data analysis from the SLS (Swiss Light Source) shifts of single bunch over intensity and cross check with HEADTAIL code predictions (tuneshift with intensity, instability thresholds etc)
2. Longitudinal radiation damping being implemented. Tests to be done in the near future.
3. Implementation of space charge in HEADTAIL. Modifying the code to give multiple kicks for space charge along the lattice of the ring. Tests to be done.
    1. Study the effect of space charge with impedance in the TMCI threshold
    2. Study the tolerable space charge tune spread in combination with the newly implemented radiation damping modules

Future tasks

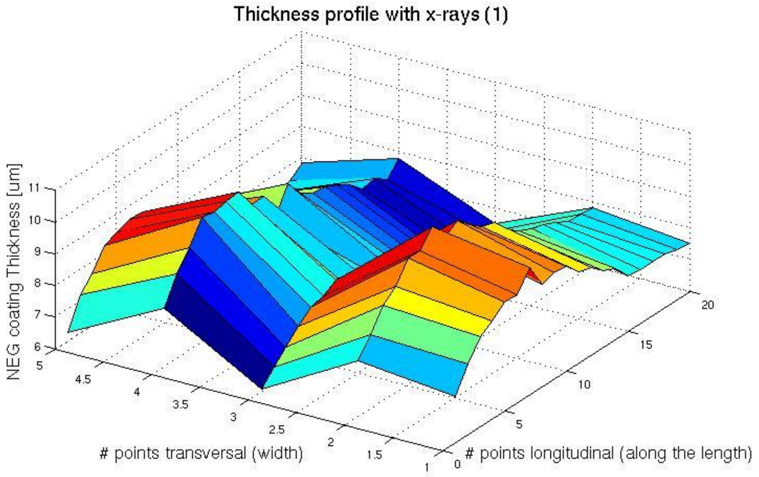
- Finalize the study for the stripline kickers → new calculation of the impedance budget
- Add the RF cavities to complete further the impedance budget study
- Implementation of the transverse radiation damping
- Space charge influence on the coherent modes→ indications from the theoretical study of A.Burov
- Waveguide measurements for NEG coating on copper with the new network analyzer up to 750 GHz recently obtained at EPFL. Opens the way for the future and challenging measurements of material properties at this unexplored regime
- Impedance measurements in the ALBA synchrotron
- Effect of the resistive wall with coating by studying the effect of its long range part (multi-bunch effects)
- Study the thresholds to preserve also the stability in the longitudinal plane

Thank you for your attention!

Back up slides

Cu waveguide coating measurements

- Challenges
  - Manufacture of the small waveguide
  - Coating technique
  - Profile measurements
- Simulation
  - Non-uniform coating

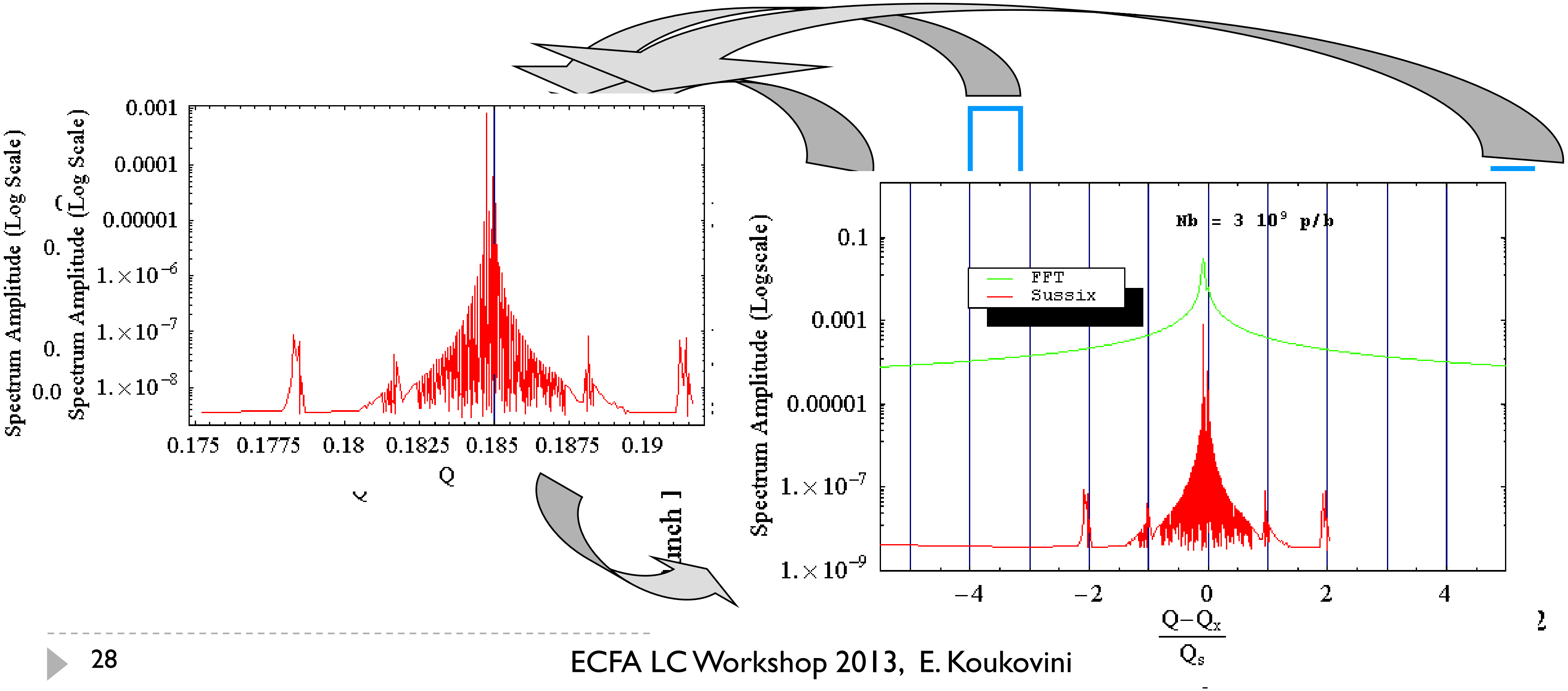


Thickness profile with x-rays (1)

Backup slides

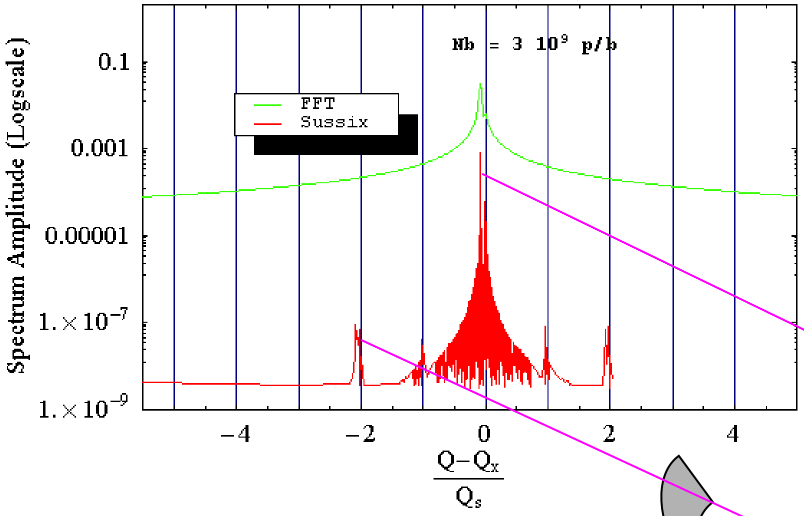
Methods : *What to do with HEADTAIL outputs ?*

1. Extract the position of the centroid of the bunch (vertical or horizontal) turn after turn → simulated BPM signal
2. Apply a classical FFT to this simulated BPM signal (*x*)
3. Apply SUSSIX* to this same simulated BPM signal (actually $x - j\,\beta_x x'$)
4. Translate the tune spectrum by $Q_{x0}=0$ and normalize it to Q_s

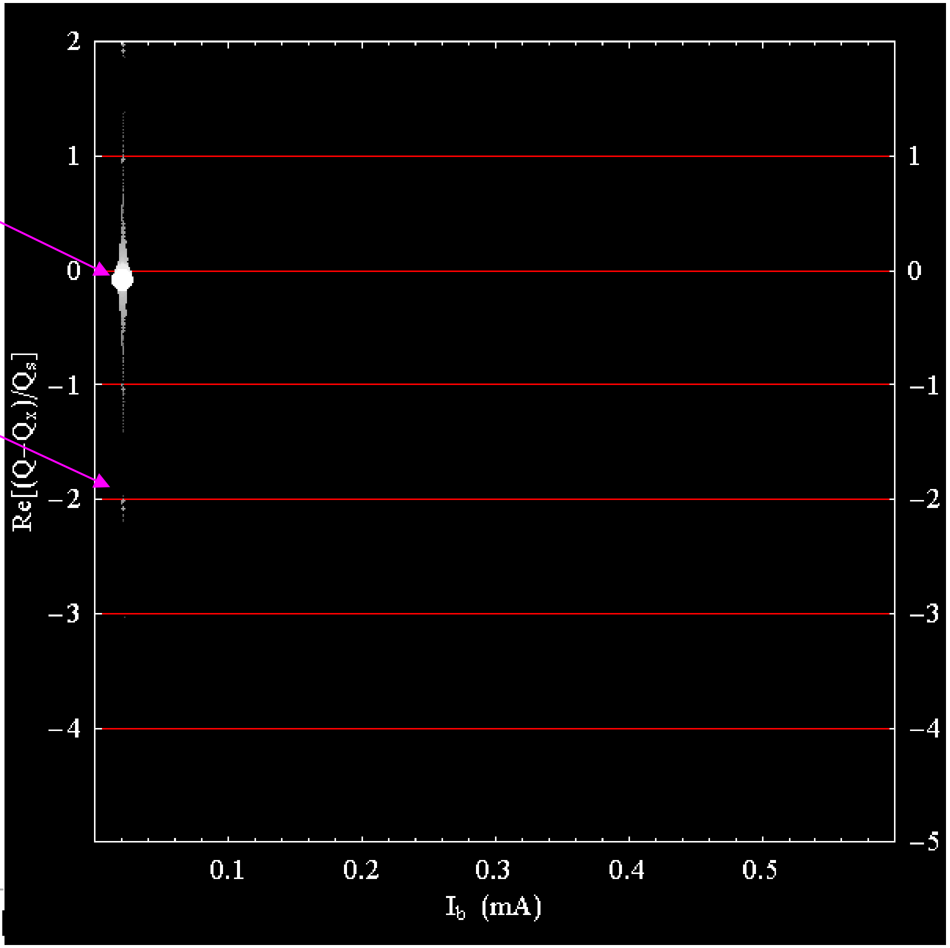


Another visualization of the tune spectrum

for Nb = 3 10^9 p/b (I_b = 0.02 mA)



Displaying the Sussix spectrum on one line per bunch intensity



The dots are brighter and bigger if the amplitude is larger