RF DEFLECTOR STUDIES:

BEAM-DEFLECTING CAVITIES INTERACTION AND VERTICAL INSTABILITY INDUCED IN CTF3 COMBINER RING

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OUTLINE

1) DEFLECTING FIELD EXCITED BY THE BEAM IN RF DEFLECTORS

2) ANALYSIS OF THE VERTICAL INSTABILITY IN THE CTF3 CR DUE TO THE RF DEFLECTORS:

a) Phenomenology

b) Vertical modes and wakefield model

c) Tracking code results

3) CURES:

a) Mitigate the instability changing the CR parameters

b) New RF deflectors design [wkg Linear collider test facilities, Damping of RF deflectors vertical instability in CTF3]

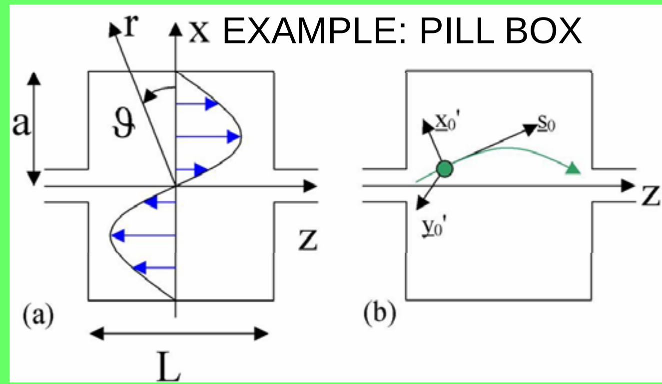
DEFLECTING FIELD EXCITED BY THE BEAM IN RF DEFLECTORS (1/2)

Unwanted deflecting field can be ***excited by the beam if the pass off-axis*** into the deflectors both in the horizontal than in the vertical plane.

This is due to the fact that the ***deflecting field has longitudinal electric field*** off-axis.

$$\underline{E}_D = \begin{cases} E_{Dz} = E_0 J_1(p_{11} x/a) \\ E_{Dx} = E_{Dy} = 0 \end{cases}$$

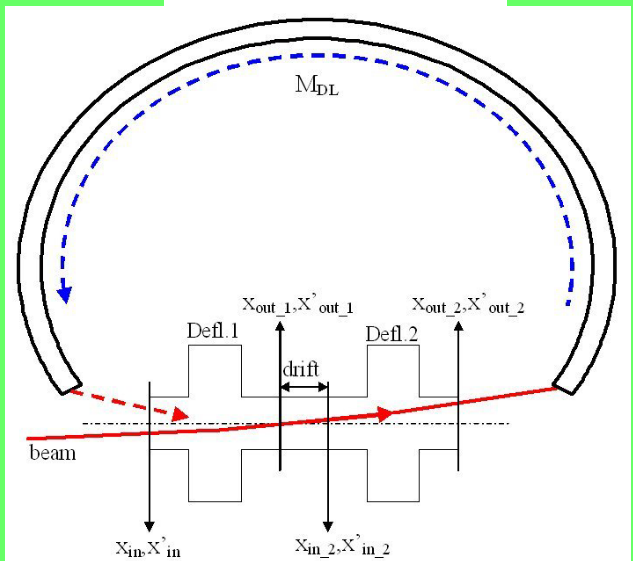
$$\underline{B}_D = \begin{cases} B_{Dz} = B_{Dx} = 0 \\ B_{Dy} = -jAE_0 J_1^{'}(p_{11} x/a) \end{cases}$$



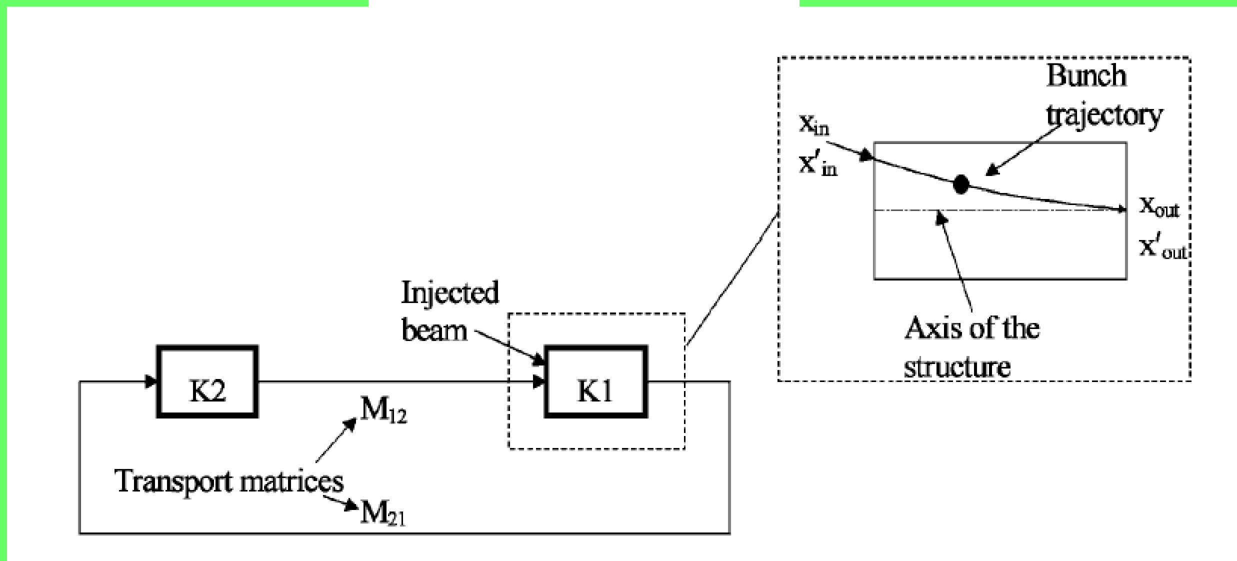
This happens, in the ***horizontal*** plane, even in the case of perfect injection and both in the DL than in the CR RF deflectors.

In the ***vertical plane there is beam loading only in case of a non-perfect steering*** of the orbit inside the structure.

DELAY LOOP



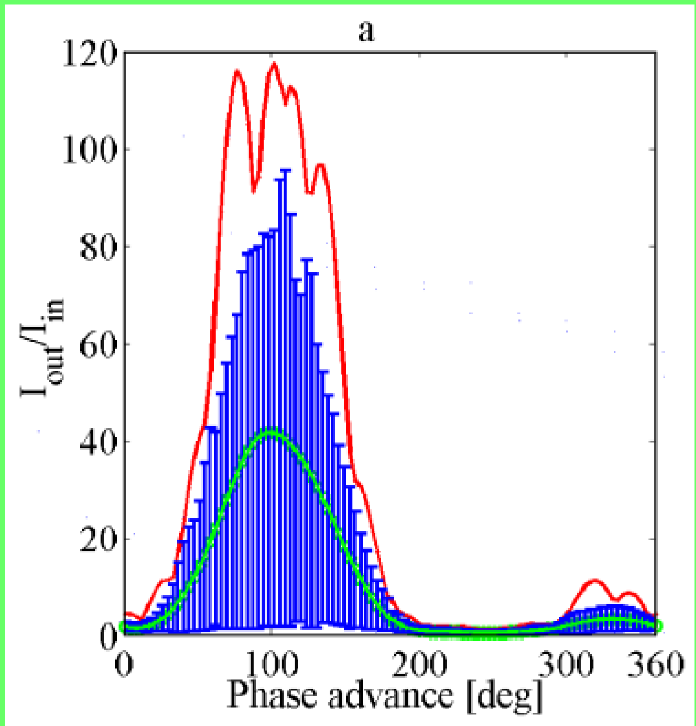
COMBINER RING



DEFLECTING FIELD EXCITED BY THE BEAM IN RF DEFLECTORS (2/2)

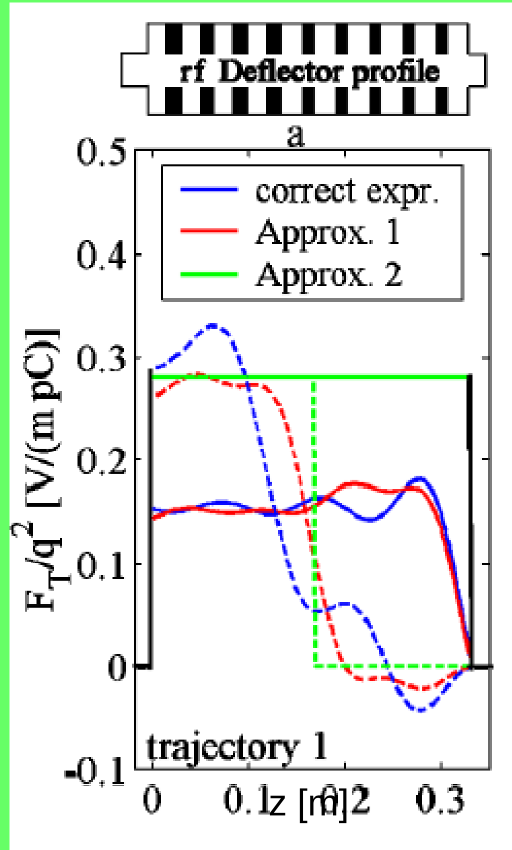
The beam loading effects in the ***horizontal plane have been extensively*** studied because of the ***off-axis passage of the beam even in case of perfect injection,*** and because the ***cavity is tuned exactly at the bunch repetition frequency***.

Example: transverse force probed by a trailing particle and generated by an off-axis passage of the leading one in the CR TW deflector



The result of the analysis is that the beam loading effect in the ***CR can be controllable*** with a proper choice of the machine parameters even in case of injection errors (In the figure there is an example of amplification of an initial error as a function of the ring phase advance).

This is due to the fact that, even if there is a build-up mechanism, the ***horizontal mode in the TW structures is strongly coupled to the external load.***



Also in the DL loop the cavities are strongly coupled to the external load and the are no beam loading effect.

D. Alesini and A. Gallo, ***Effect of beam loading in the RF deflectors of the CLIC test facility CTF3 combiner ring***, PRST AB 7, 2004

D. Alesini and F. Marcellini, ***CTF3 Delay loop RF deflectors design and beam loading effect analysis***, submitted to PRST

VERTICAL INSTABILITY IN THE CR: PHENOMENOLOGY

In the November 2007 run a vertical beam instability has been found in the Combiner Ring during operation.

The ***profile of the vertical oscillation*** as a function of the bunch positions is the ***same shot by shot***

The ***Δ-frequency*** of the oscillation (FFT) with respect to the fundamental one (2.99855 GHz) is ~***48 MHz***.

The instability is ***stronger*** if we increase the ***train length*** for a given bunch current

The instability is ***stronger*** if we increase the ***bunch charges***

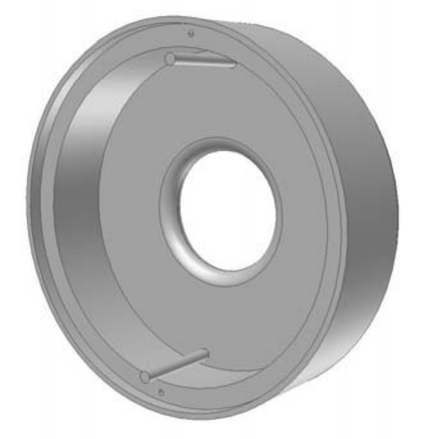
Dependence on the ***temperature of the deflectors***: a temperature variation of ***8°C did not change the scenario***

The instability occurs both in the case of a ***single train*** doing different turns than in the case of ***recombination***

Dependence on the vertical tune: no systematic study (probably near the integer stronger?)

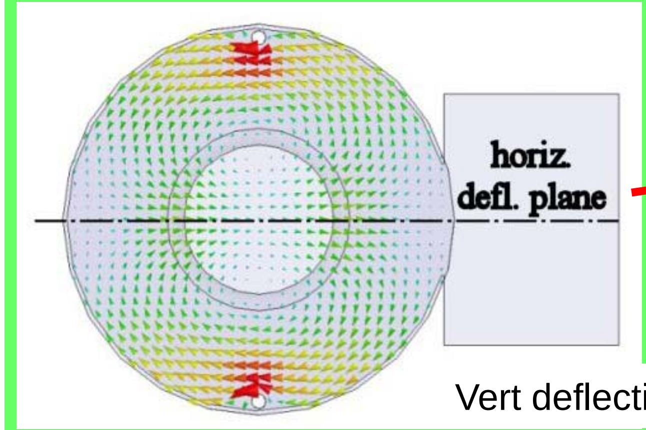
Dependence on the ***vertical orbit*** inside the deflectors: no systematic study but probably a **better steering inside the deflectors gives weaker instability**

VERTICAL MODES IN THE RF DEFL.(1/2)

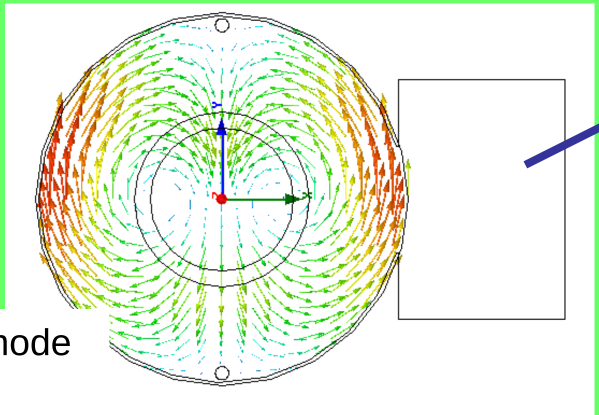


Metallic rods have been inserted to split in frequency the deflecting mode with vertical polarity.

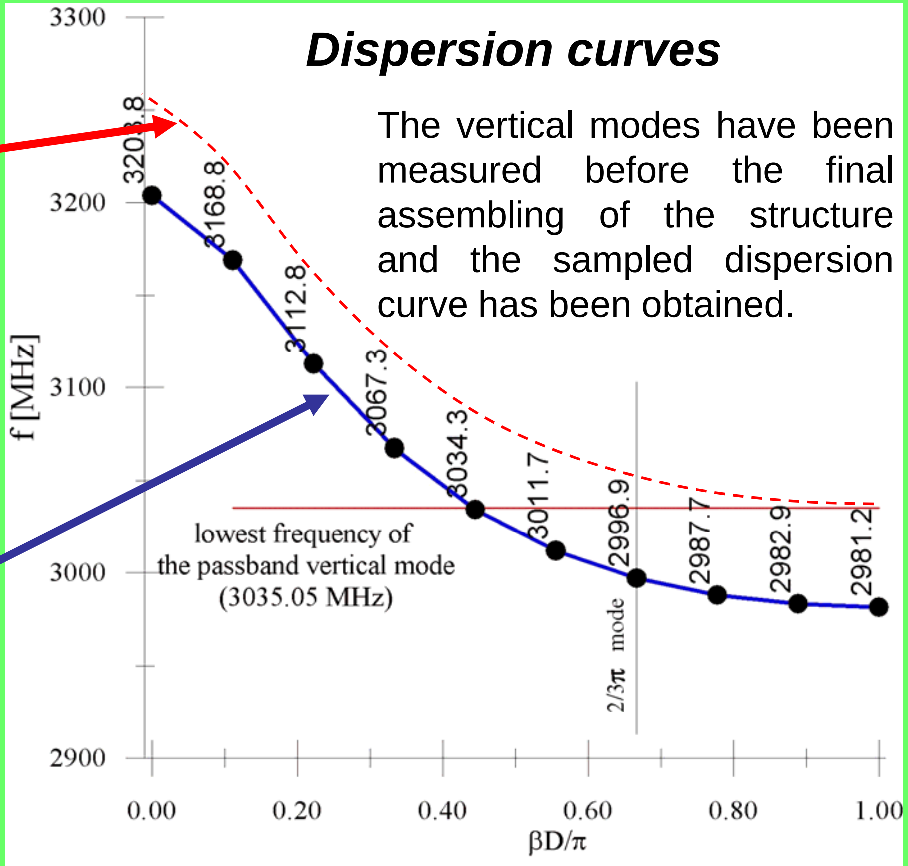
The dimensions and position of the rods have been choose in order to avoid the excitation of the vertical modes from the beam power spectrum line at 2.99855GHz and RF generator.



Vert deflecting mode



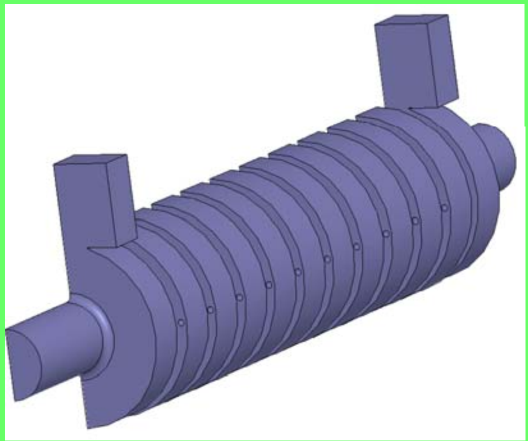
Hor. deflecting mode
(working mode)

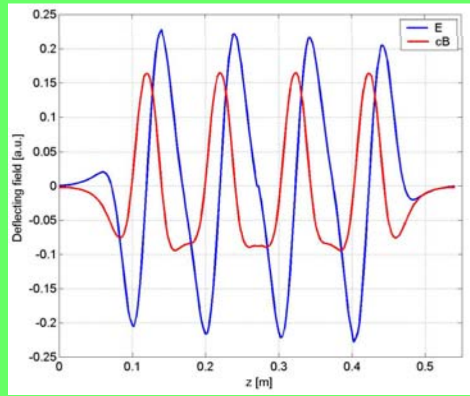


The vertical modes have been measured before the final assembling of the structure and the sampled dispersion curve has been obtained.

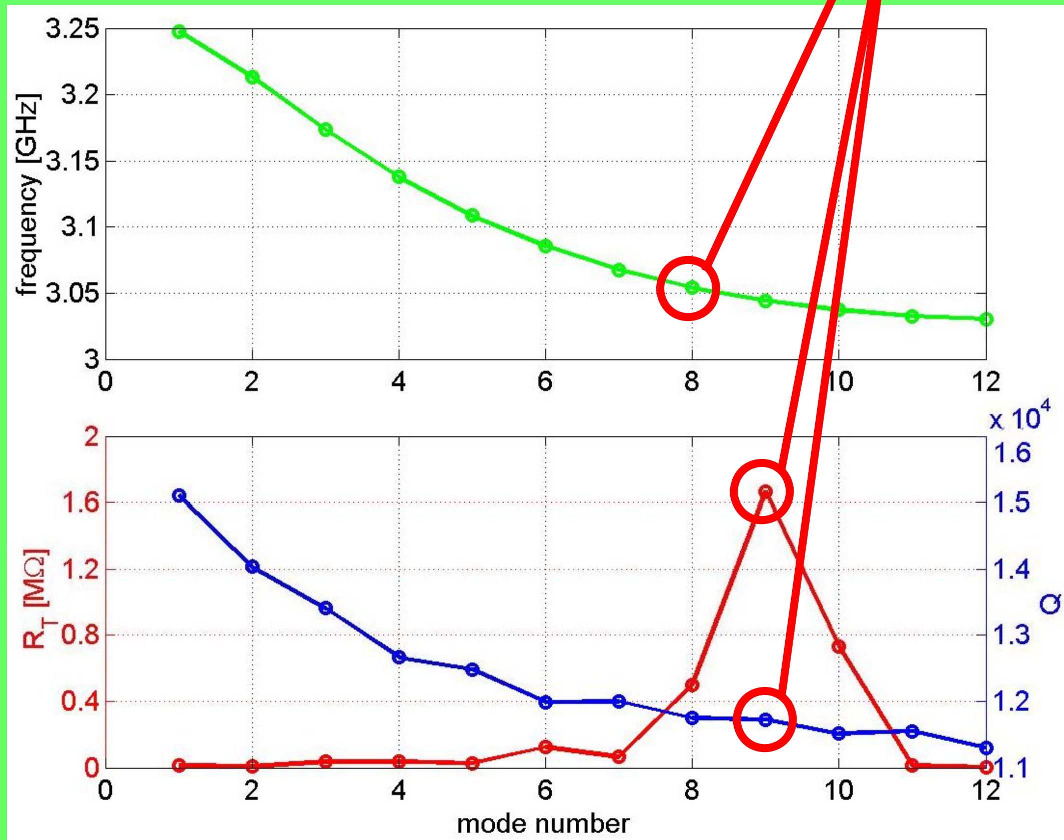
VERTICAL MODES IN THE RF DEFL.(2/2)

The resonant frequencies, quality factors and transverse shunt impedances of the vertical modes have been calculated by HFSS. ***There is one mode with the highest shunt impedance*** corresponding to the 2π/3 multi-cell mode.

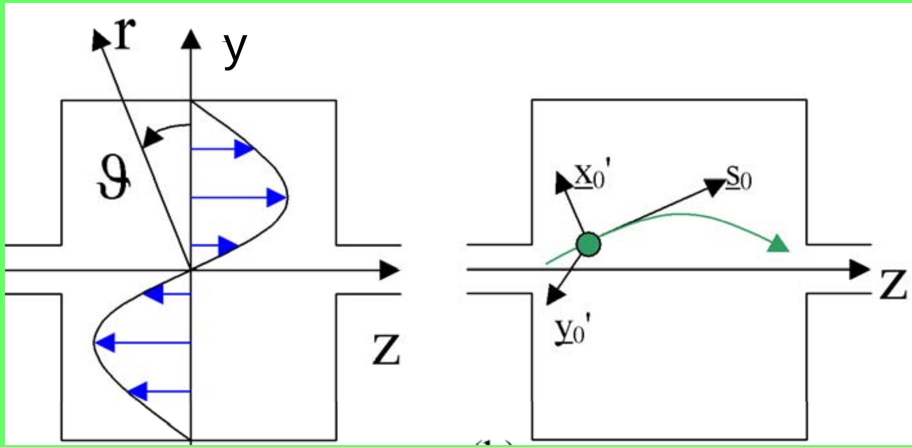


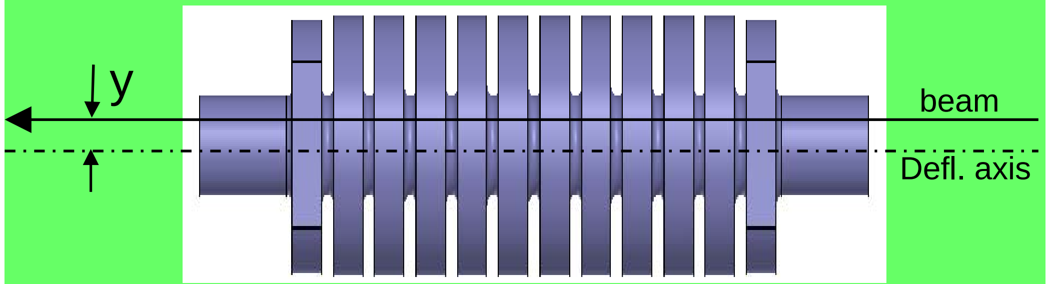


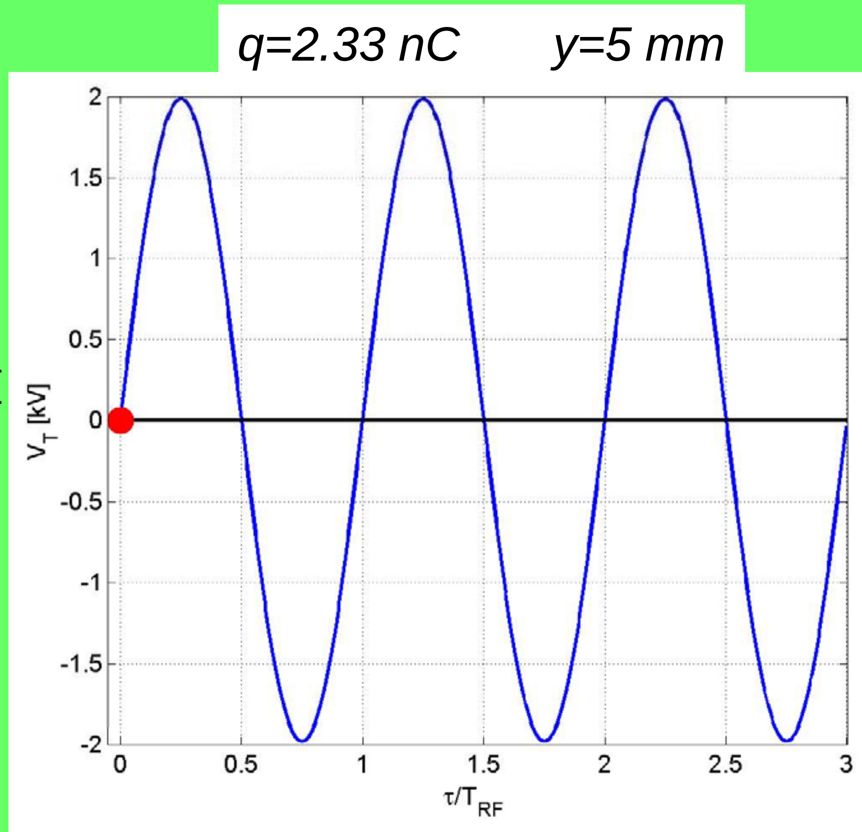
Q	11500
f_{RF}	~ 3.0443 GHz
R_T	~1.6 MΩ



WAKEFIELD INDUCED BY THE VERTICAL MODES (1/3)







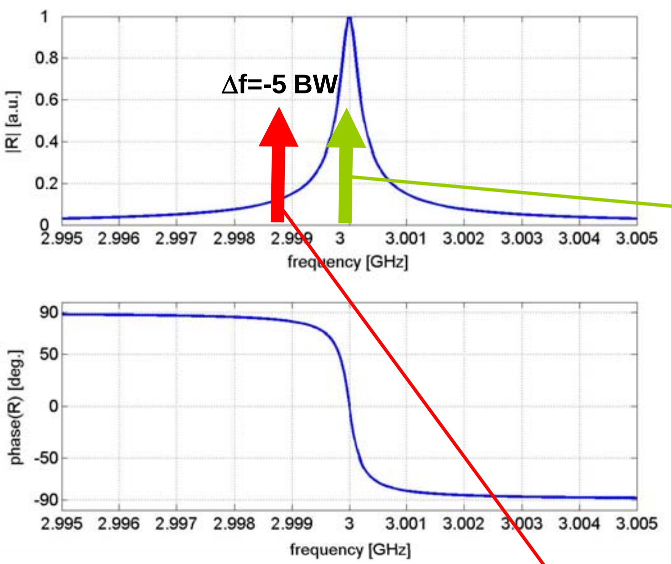
$$V_T(\tau) \cong q \frac{\omega_{RF}^2}{c}\frac{R_T}{Q}\, y\, e^{-\frac{\omega_{RF}}{2Q}\tau}\sin(\omega_{RF}\tau)$$

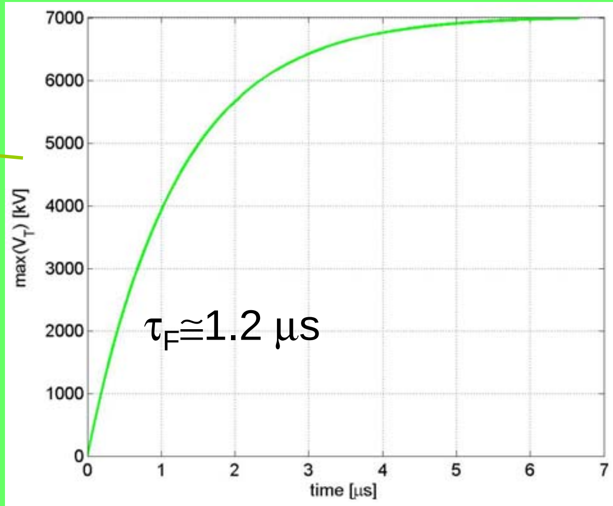
$$R_T = \frac{\left|\int_0^{L_c}(E_y + cB_x)\, e^{j\omega_{RF}z/c}\, dz\right|^2}{2P_{diss}}$$

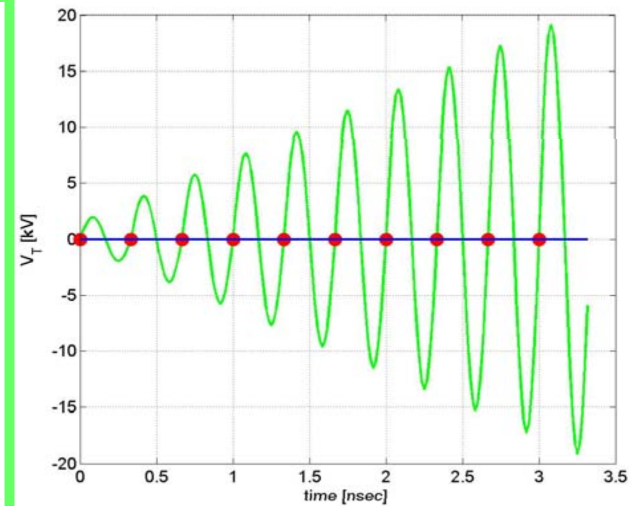
90 deg. out of phase wake

WAKEFIELD INDUCED BY THE VERTICAL MODES (2/3)

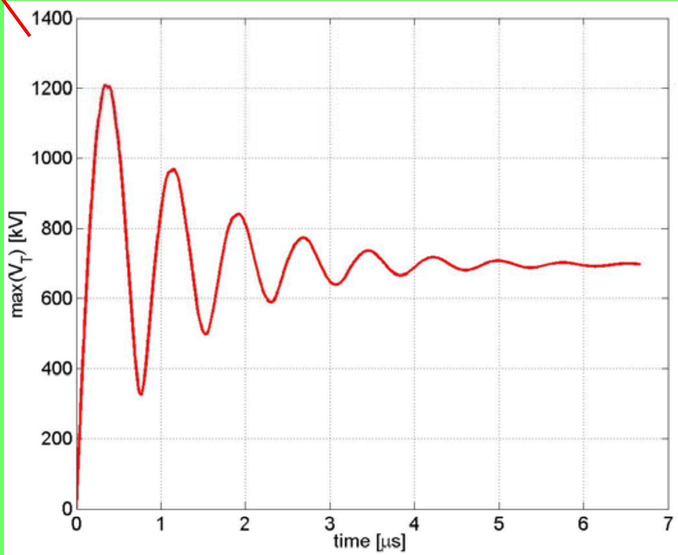
Multi-bunch excitation: q=2.33 nC; y=5 mm

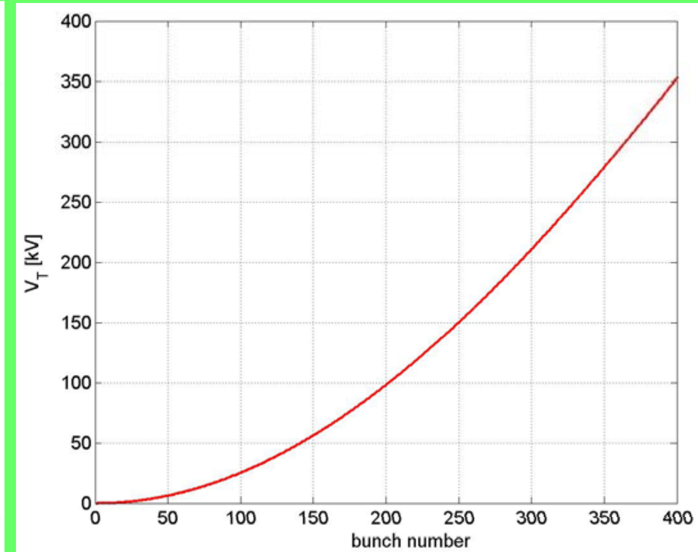






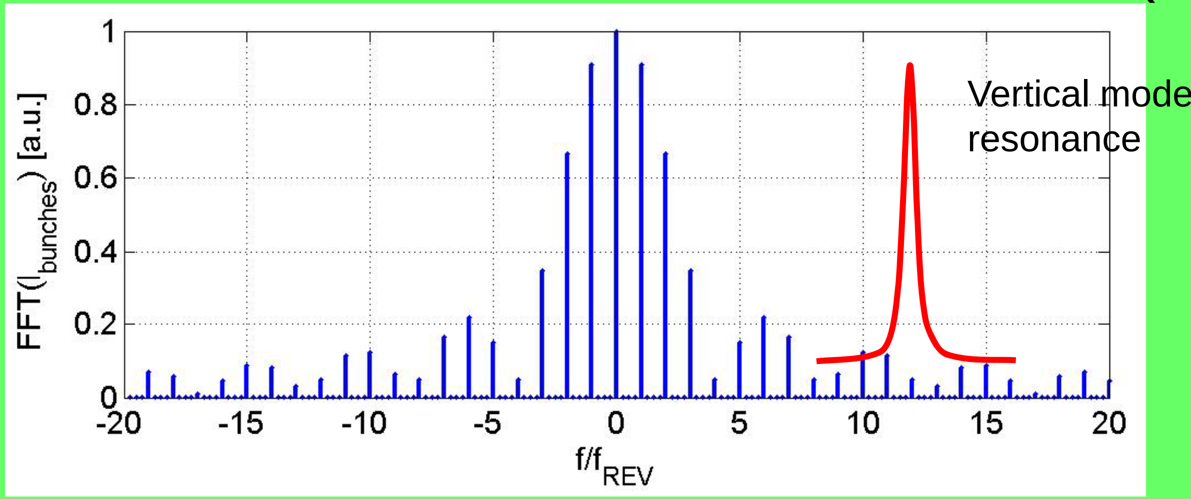
In case of multi-bunch excitation off-resonance the ***equivalent filling time can be much shorter then the filling time on resonance*** and the wake can became a cosine wake





WAKEFIELD INDUCED BY THE VERTICAL MODES (3/3)

Spectrum of a 200 bunches in the combiner ring in 4 turns (f_{REV}≅3.56 MHz)



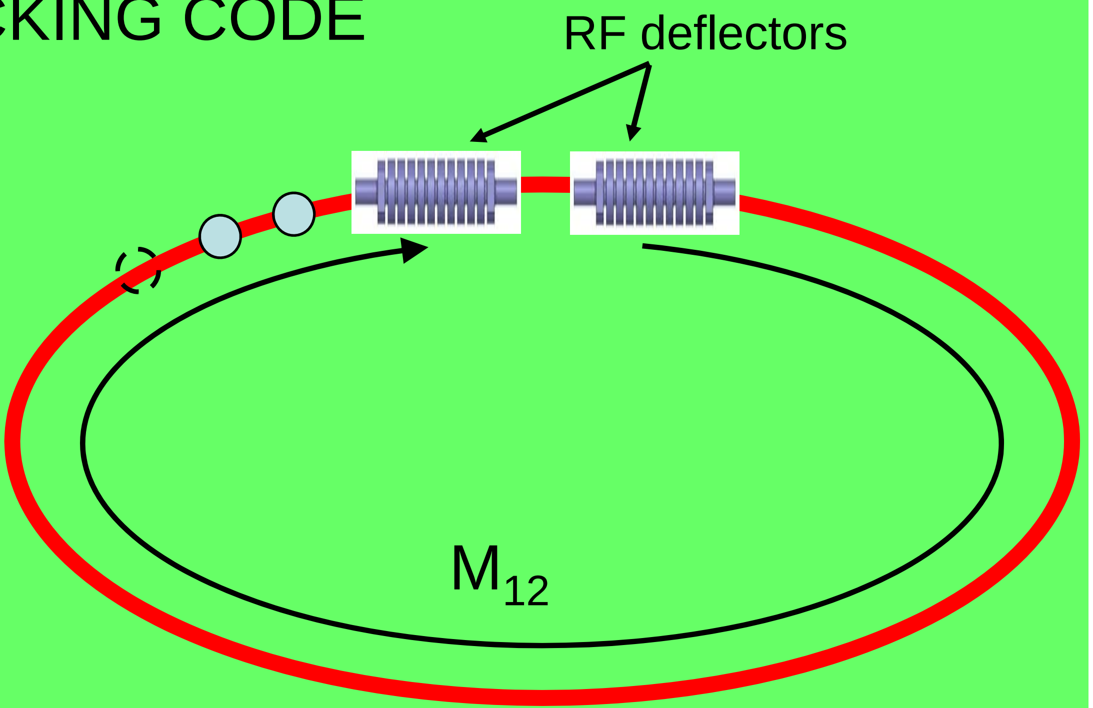
TRACKING CODE

A dedicated tracking code has been written to study the multi-bunch multi- turn effects.

All the ***results*** in term of the oscillation amplitude are ***proportional*** to:

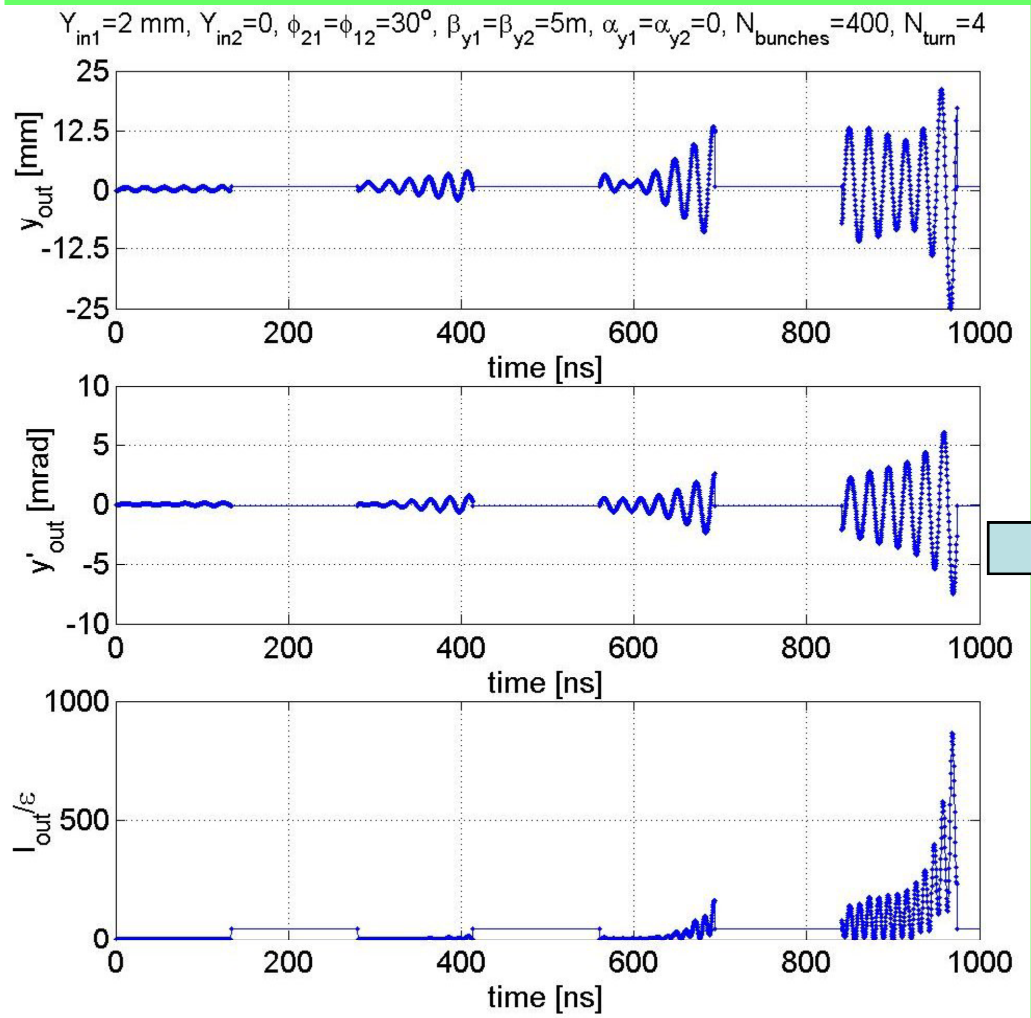
-the ***beam off axis*** ⇒ **y=2 mm** orbit in the deflector has been considered.

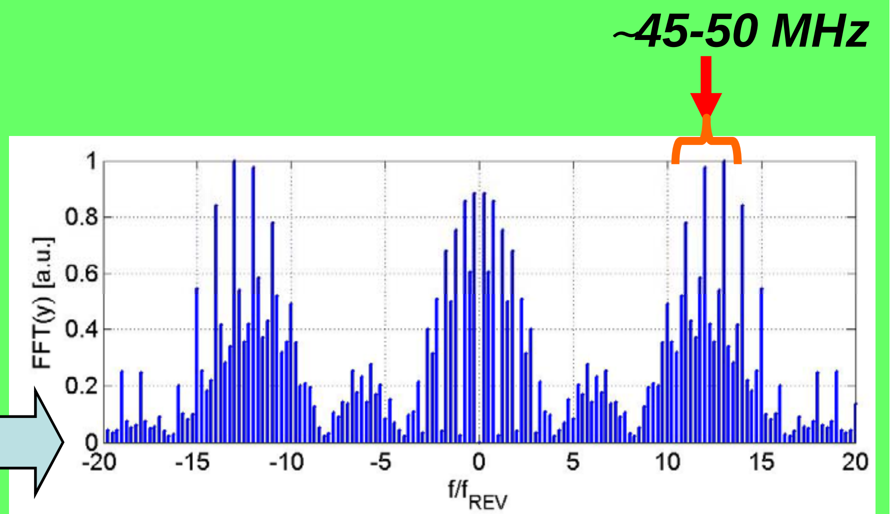
-the ***bunch charge*** ⇒ **q=2.33 nC** bunch charge has been considered



TRACKING CODE RESULTS

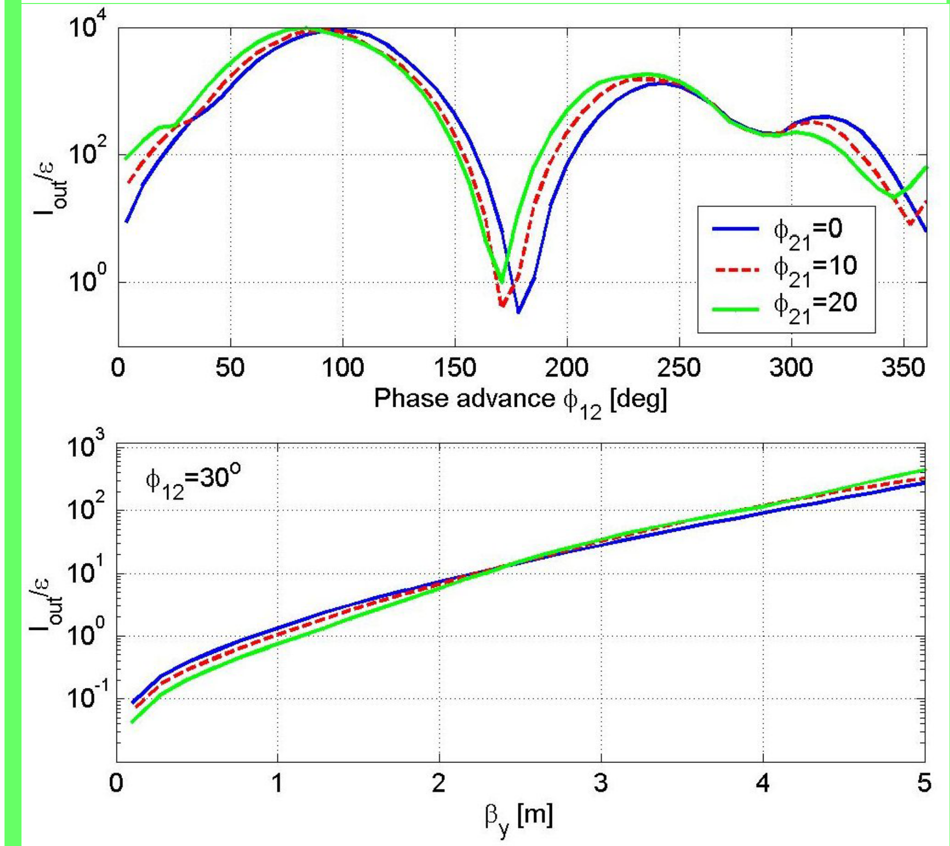
-The tracking allows studying the ***distribution of the Courant-Snyder invariants (I_{out})*** for all bunches and its dependence on the resonant mode properties and ring optical functions.



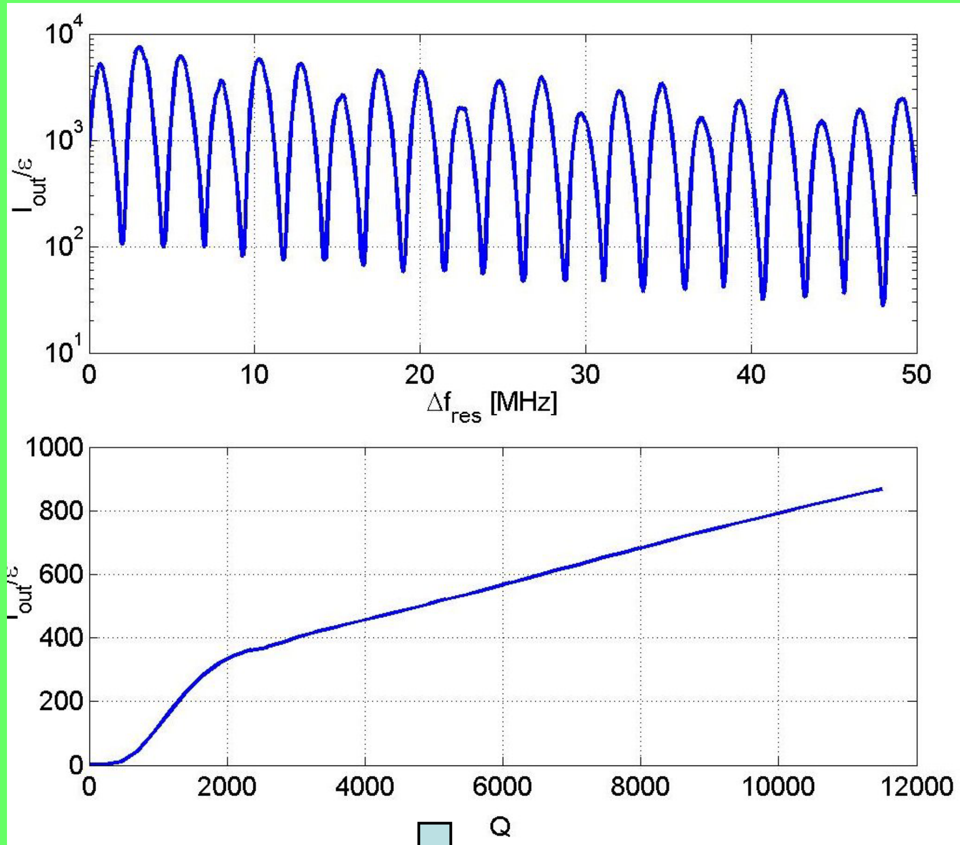


TRACKING CODE RESULTS: key parameters to reduce the instability

Optical phase advance between deflectors (ϕ_{12}) and β_y at the deflectors



Res. frequency and vertical mode quality factor dependence



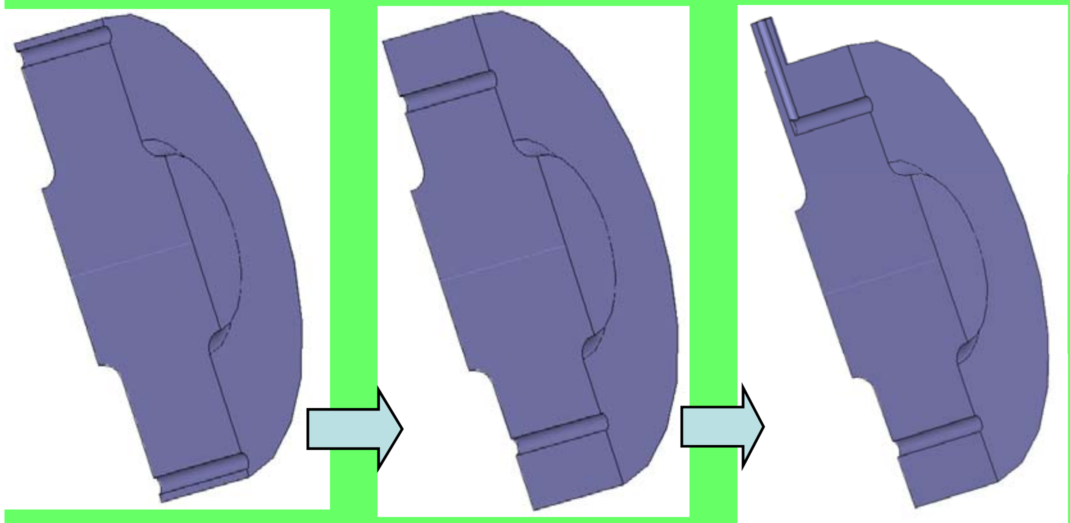
They suggested ***to strongly shift the resonant frequencies*** of the vertical modes and ***to strongly reduce their quality factors***.

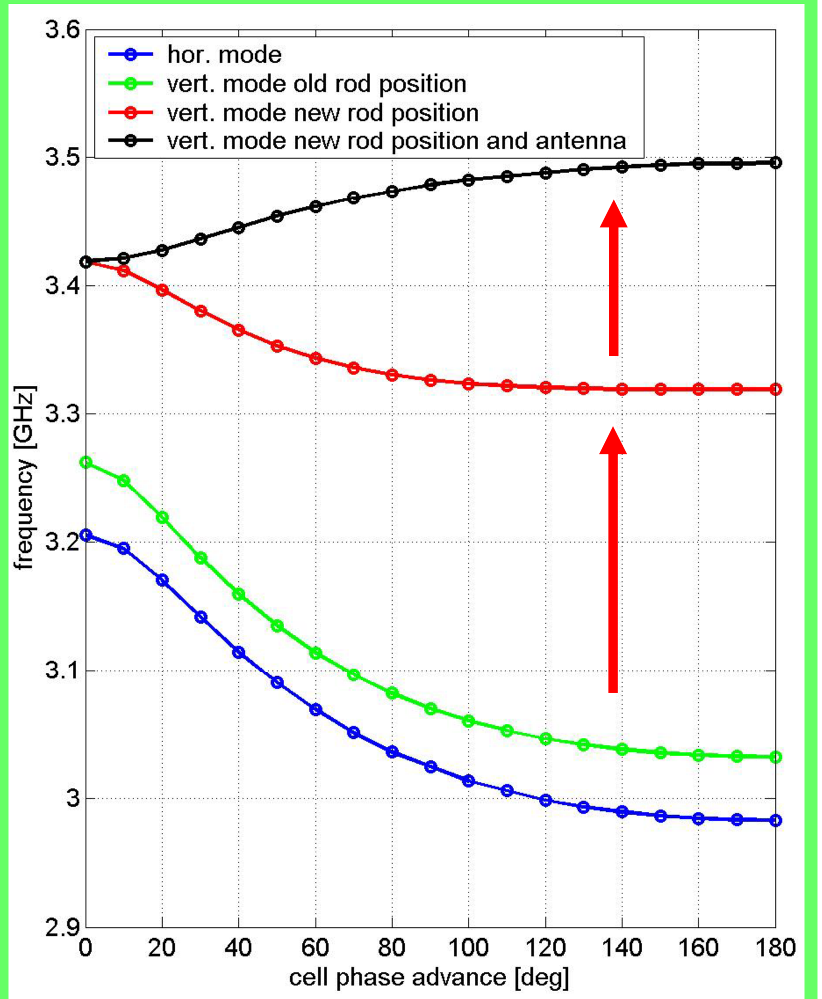
NEW RF DEFLECTOR DESIGN

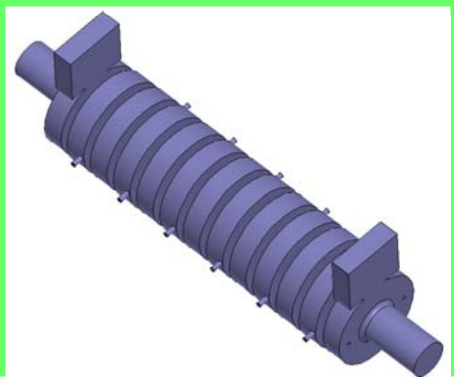
To ***increase the frequency shift*** of the vertical modes polarity we changed the ***position of the rods towards the axis of the structure***. In this way the vertical modes are shifted more than 300 MHz away from the horizonthal ones.

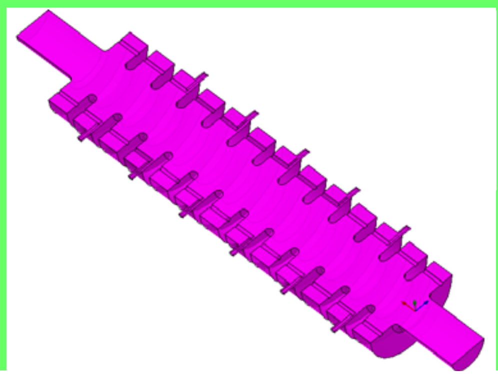
To damp the vertical modes excited by the beam the ***rods in the cell have been modified in order to be damping antennas***.

The result is a strong damping of the vertical modes and a further shift of the frequencies of the vertical modes.





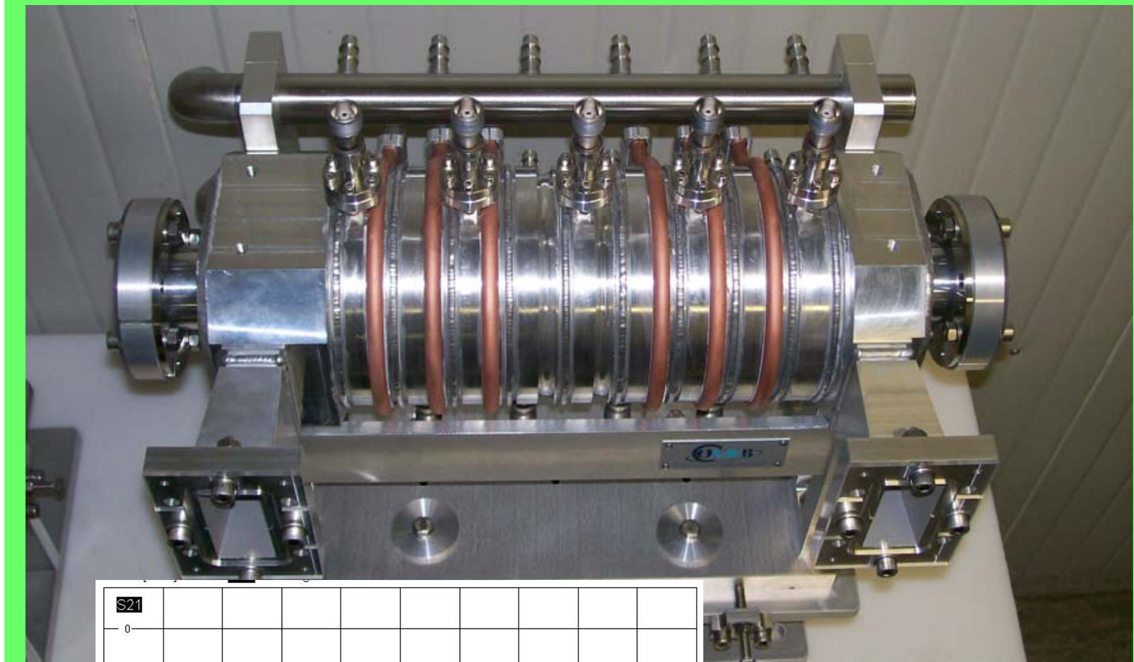


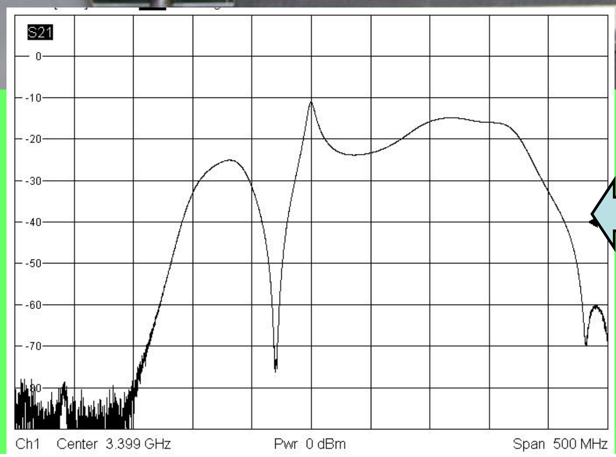


NEW RF DEFLECTOR REALIZATION

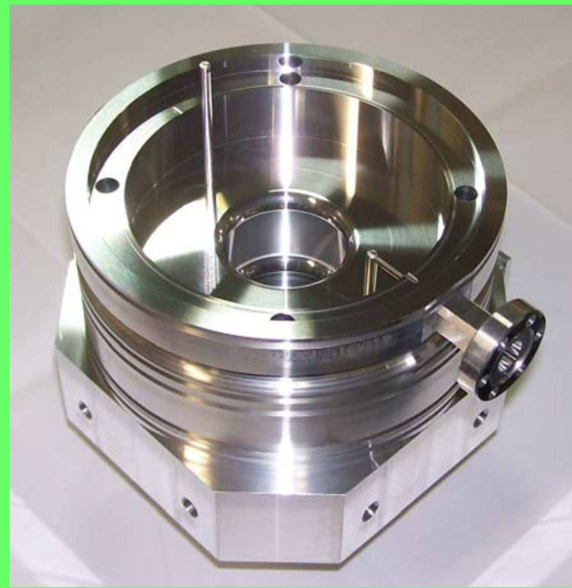
To reduce the cost and the delivery time of the device we decided to built the new RFDs in ***aluminium***. The cells have been machined, clamped together with tie rod to guarantee the RF contacts and welded.

Conditioning of cavities needed less than 1 hour. More than 10 MW have been fed in each cavity (nominal working power 7 MW) and no multi-pacting effect have been observed (except in one cavity at 200 kW for 5-6 minutes…)



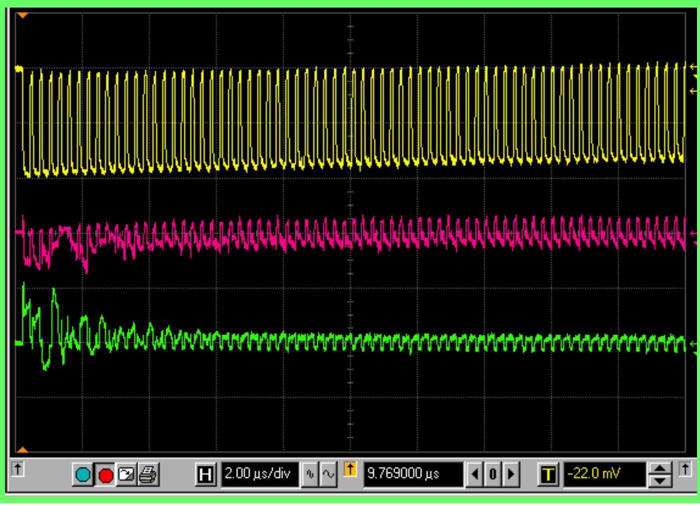


Strongly Damped vertical modes



NEW RF DEFLECTOR: TEST WITH BEAM

No vertical oscillation observed !



Thousand turns without observing beam losses!

SUMMARY

1) ***Beam loading in RF deflectors*** is crucial and has to be taken into account in the CR and DL design of CLIC.

2) The mechanism of the observed ***strong vertical instability*** in the CTF3 CR has been ***understood and modeled showing that the vertical beam loading is still crucial***. By simulation ***key parameters*** to reduce the instability strength have been found.

3) From simulation a ***half integer vertical tune*** could help in the control of the instability.

4) The ***new RF deflectors*** have been designed according to the beam dynamics results. They suggested ***to strongly shift the resonant frequencies*** of the vertical modes and ***to strongly reduce their quality factors***.

5) The deflectors have been built in ***aluminum*** to reduce the costs and delivery time. A dedicated fabrication/assembling technique has been developed to guarantee the RF contact and ultra high vacuum operation. ***RF test have been successfully done*** without observing multi-pacting phenomena.

6) Injection and recombination in the CR showed that the ***instability has been suppressed***.

CONTRIBUTIONS TO THE DEFLECTOR DESIGN, CONSTRUCTION AND REALIZATION:

Fabio Marcellini, Andrea Ghigo and Gianni Fontana

Thanks to: C. Biscari, G. Geschonke, R. Corsini, G. Mcmonagle and I. Syratchev