Update on transverse stability studies for the 200MHz cavity HOMs

D.Amorim

Thanks to N.Biancacci, K.Li, E.Métral, B.Salvant

LIU-SPS beam dynamic WG meeting

06/04/2017

Outline

- Introduction
- Impedance model used and stability simulations parameters
- Simulations results and remarks
- Conclusion and next steps

Outline

- Introduction
- Impedance model used and stability simulations parameters
- Simulations results and remarks
- Conclusion and next steps

Introduction

- Need to reduce the 620MHz longitudinal HOM
- Doing so might modify the 940MHz transverse HOM
- We want to assess the transverse stability margin supposing this mode grows when optimizing the 620MHz HOM

- Method: transverse stability simulations with DELPHI, crosschecked with Sacherer formula

- Follow up of the presentation on the 2/03/2017 meeting

Outline

- Introduction
- Impedance model used and stability simulations parameters
- Simulations results and remarks
- Conclusion and next steps

Impedance model used

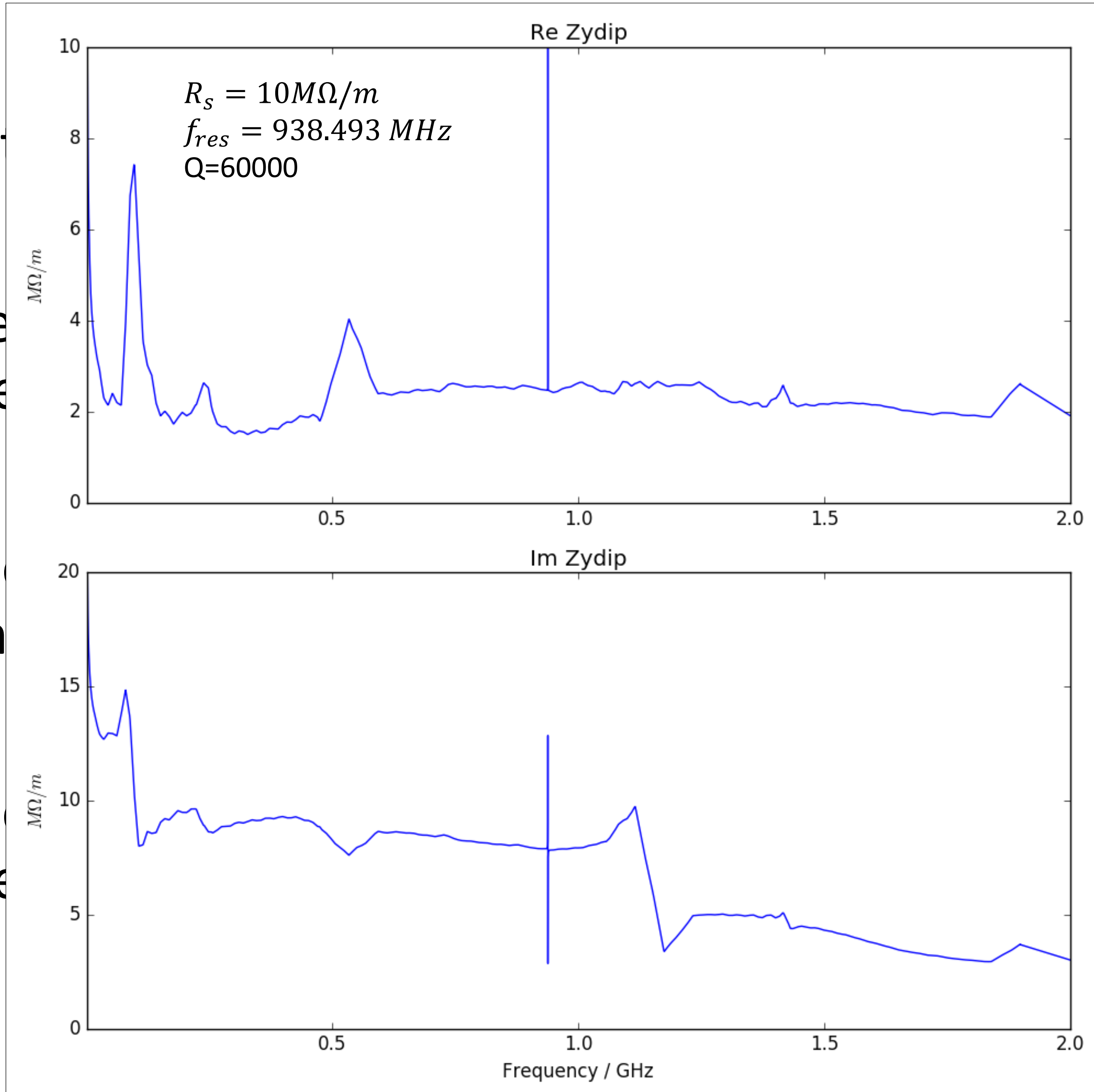
- Existing SPS impedance model, the 200MHz cavities are replaced by a single HOM
- Resonator parameters
  - $f_{res} = 938.493\ MHz$
  - Resonance frequency chosen to fall on top of a coupled bunch mode line (worst case scenario)
  - Quality factor: 1000/10000/60000
  - Scan in shunt impedance: $10 \leq R_s \leq 10^8\ M\Omega/m$

Impedance model used

- Existing SPS impedance model stops at 1.9GHz
- Extended the base model up to 10 GHz to properly cover the higher azimuthal modes
- Checked that the resonator impedance is properly sampled, especially for higher quality factors
- Checked that the addition of the resonator to the base model doesn't create discontinuities
- Ongoing work to include the transverse HOMs in the SPS impedance model
  - Simulations of the modes
  - Machine measurements (M.Beck)

Impedance model used

- Exis
- Exte ... erly cove
- Che ... rly sam
- Che ... he base



Stability simulations parameters

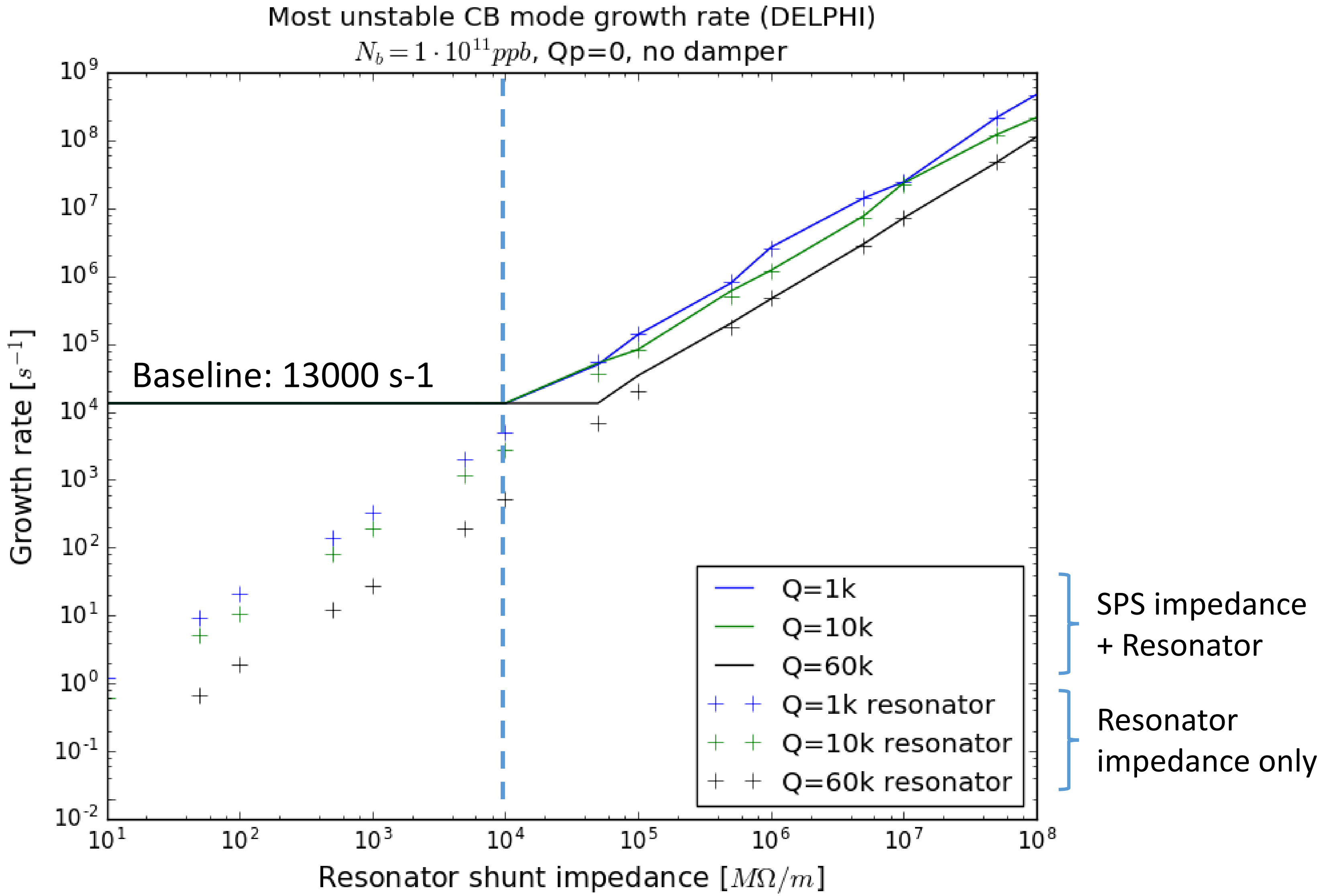
- Growth rates obtained with DELPHI
  - Vertical plane
  - 4620 bunches (5ns spacing)
  - Single bunch intensity $10^{11} ppb$
    - For fixed target experiment, single bunch intensity is $\sim 10^{10} ppb$ but the results scale linearly with intensity
  - **Zero chromaticity, no damper (conservative parameters)**

- Crosscheck with Sacherer formula:
  - Approximate calculation of rise time and frequency shift:
    - $\boldsymbol{\Delta\omega_m} = j \frac{1}{|m|+1} \cdot \frac{e^2 \beta N_b}{4\pi m_0 \gamma Q_{y0} c \tau_b} \left(Z_{eff}\right)_m$
    - With the effective impedance $\left(Z_{eff}\right)_m = \frac{\sum_p Z(\omega_p) h_m(\omega_p)}{\sum_p h(\omega_p)}$
    - h_m is the power spectrum
  - The growth rate GR (in s^{-1}) is proportional to the real part of the transverse impedance

Outline

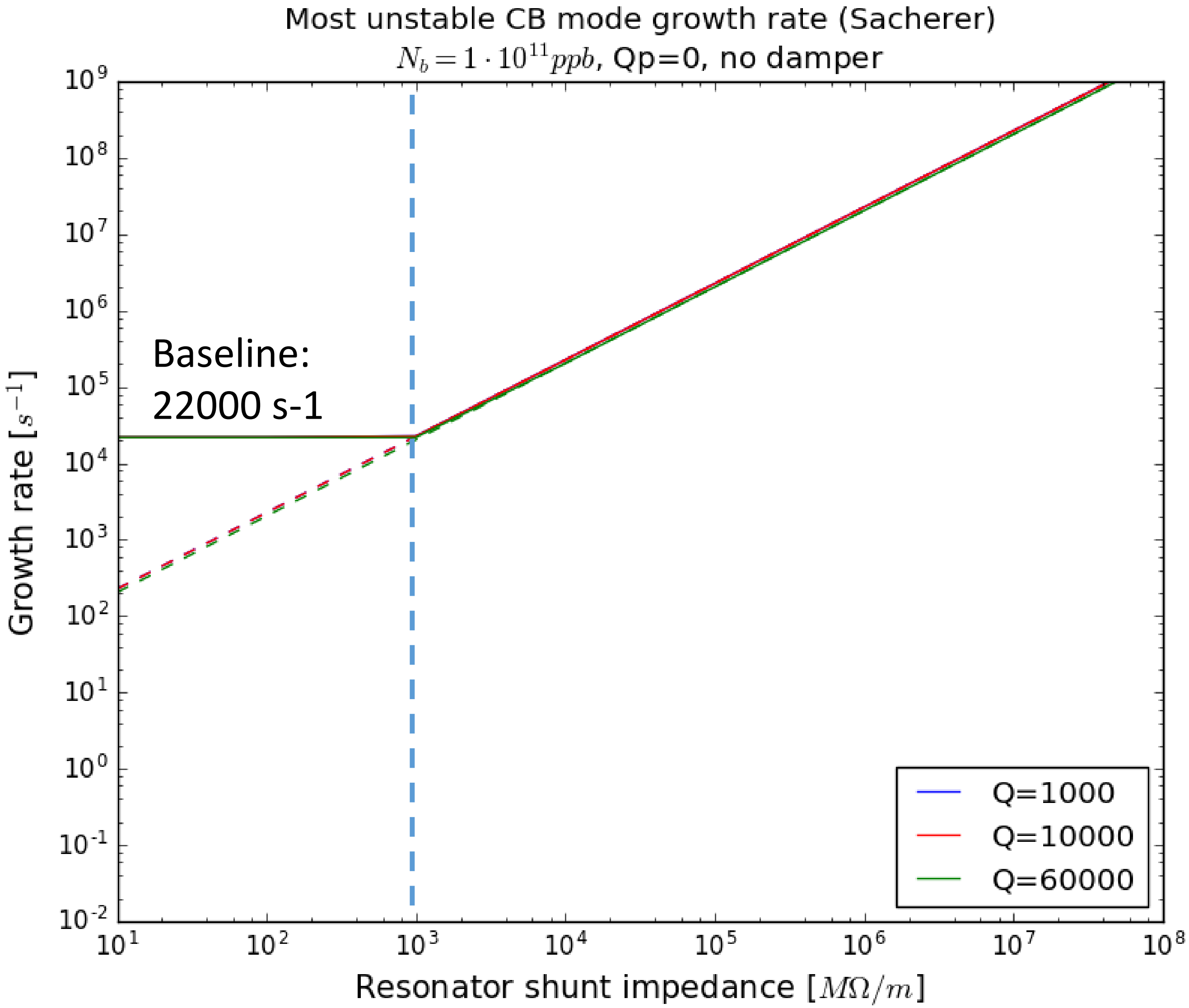
- Introduction
- Impedance model used and stability simulations parameters
- Simulations results and remarks
- Conclusion and next steps

DELPHI stability simulations results



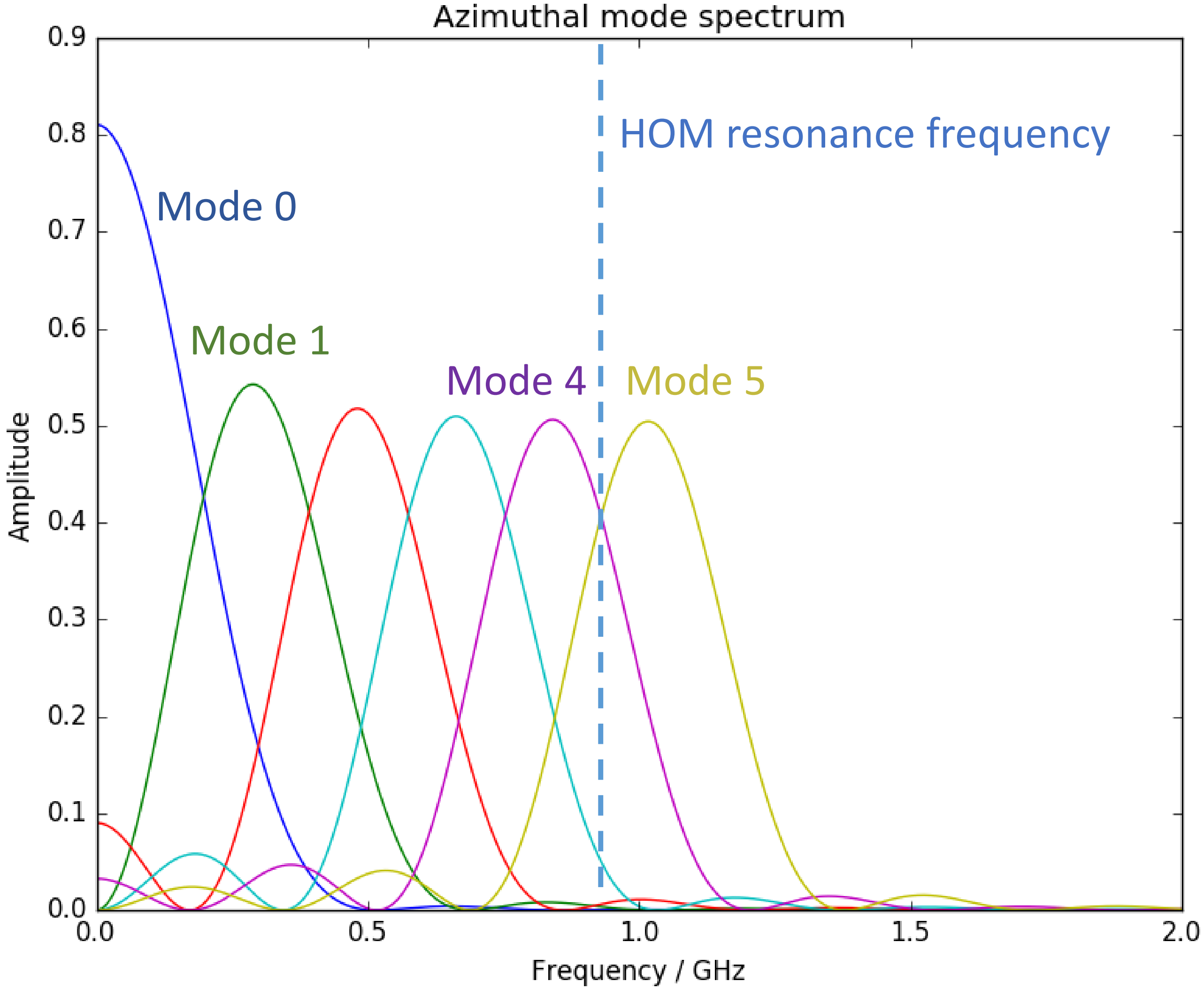
- For f_{res} on top of a coupled bunch mode line, the effect of the resonator starts to be seen at $10\ \mathrm{G}\Omega/m \leq R_s$

Sacherer formula results



- With Sacherer formula for the same impedance model, the effect of the resonator is seen at $1\ \mathrm{G\Omega}/m \leq R_s$

Sacherer formula results



- Sinusoidal modes are used for Sacherer formula
- The HOM will mostly drive azimuthal modes number 4 and 5

Results of simulations

- The HOM falls on top of the n_x=1451 coupled bunch mode. Both DELPHI and Sacherer formula find this mode as the most unstable

- DELPHI simulations show a higher shunt impedance threshold for Q=60000 (factor 5 compared to the lower quality factor cases)
  - This could come from the fact that the HOM is not exactly on top of a CB mode line or that at lower quality factor, multiple CB lines are overlapped by the HOM

- For all quality factors studied, Sacherer formula gives a lower shunt impedance threshold compared to DELPHI
  - Sacherer formula might overestimate the growth rates caused by azimuthal modes higher than 0 as showed by N. Biancacci (*DELPHI studies on HOM driven growth rates and CB spectrum for crab cavities*)

- Once scaled with intensity (single bunch intensity of $10^{10} ppb$), the growth rate values for the baseline impedance are:
  - 1300 s^{-1} (33 turns) for DELPHI results
  - 2200 s^{-1} (19 turns) for Sacherer formula results

- This factor 2 on the baseline growth rates could also be explained by the overestimation of the higher azimuthal modes by Sacherer formula

Outline

- Introduction
- Impedance model used and stability simulations parameters
- Simulations results and remarks
- Conclusion and next steps

Conclusion

- New studies performed for a more critical case: HOM resonance frequency falling on top of a coupled bunch mode line
- For $f_{res} = 938.493\ MHz$, Q=1000/10000/60000 no impact on the baseline until $1\ \mathrm{G\Omega}/m \leq R_s$ (Sacherer formula) or $10\ \mathrm{G\Omega}/m \leq R_s$

Next steps

- Add the transverse damper and chromaticity to reproduce existing observations
- Perform the simulations for the Q26 optics (used for fixed targets)
- Study the sensitivity to the HOM resonance frequency
  - Have the HOM falling either on top or between two coupled bunch mode lines
- Add to the model the other transverse HOMs identified: one at 460MHz with $Q \approx 70000$ (P. Kramer). Estimated shunt impedance needed to reduce the number of variables
- Better understand the differences between DELPHI results and Sacherer formula, as the last method can give a quick results
  - Study Sacherer with Gaussian modes

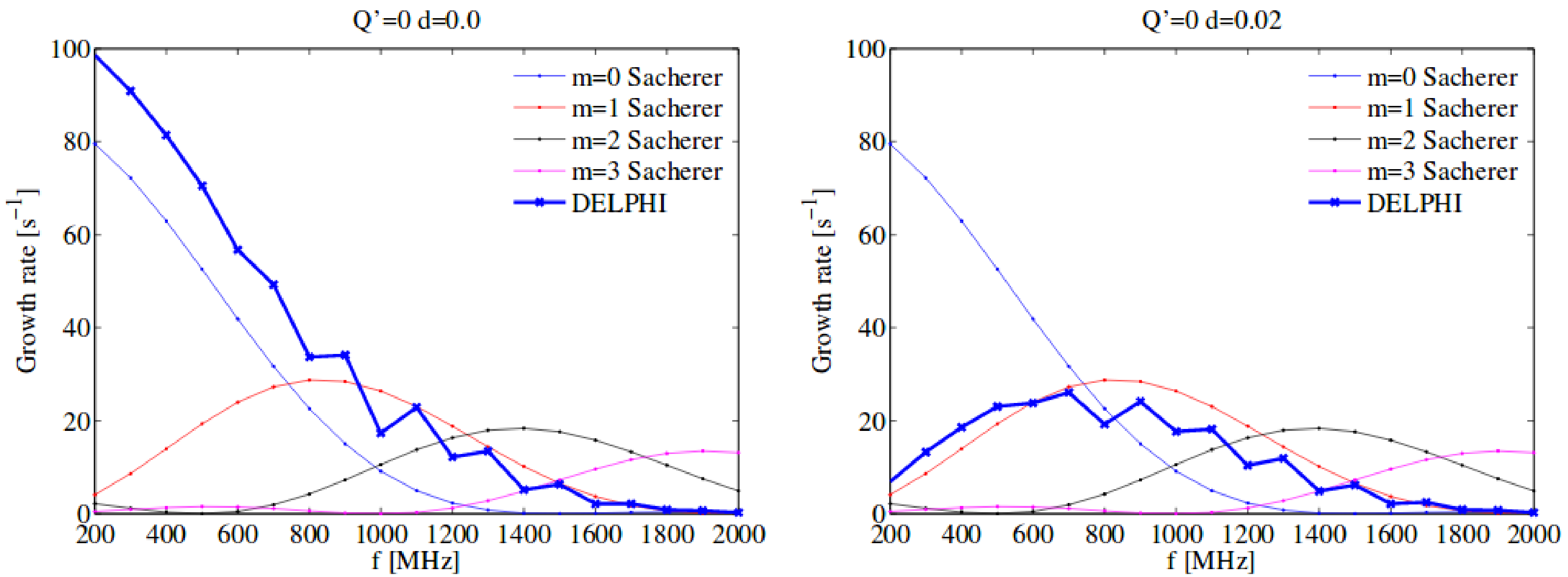
References

- 1) E. Shaposhnikova, *Resonant impedances in the SPS,* SL-Note 96-49 RF
- 2) N. Biancacci, *Impact of transverse HOM on beam stability in the HL-LHC,* 10/12/2014
- 3) N. Biancacci, *DELPHI studies on HOM driven growth rates and CB spectrum for crab cavities,* 25/03/2015
- 4) R.J. Lauckner and T.P.R Linnecar, *The transverse coupled bunch mode instability at 940MHz in the SPS*, 03/09/1980
- 5) K.Y.Ng, *Coupling Impedances and Beam Instabilities in Accelerator Rings,* 2015
- 6) C.Zannini, *Electromagnetic Simulation of CERN accelerator Components and Experimental Applications*, 2013

DELPHI modes

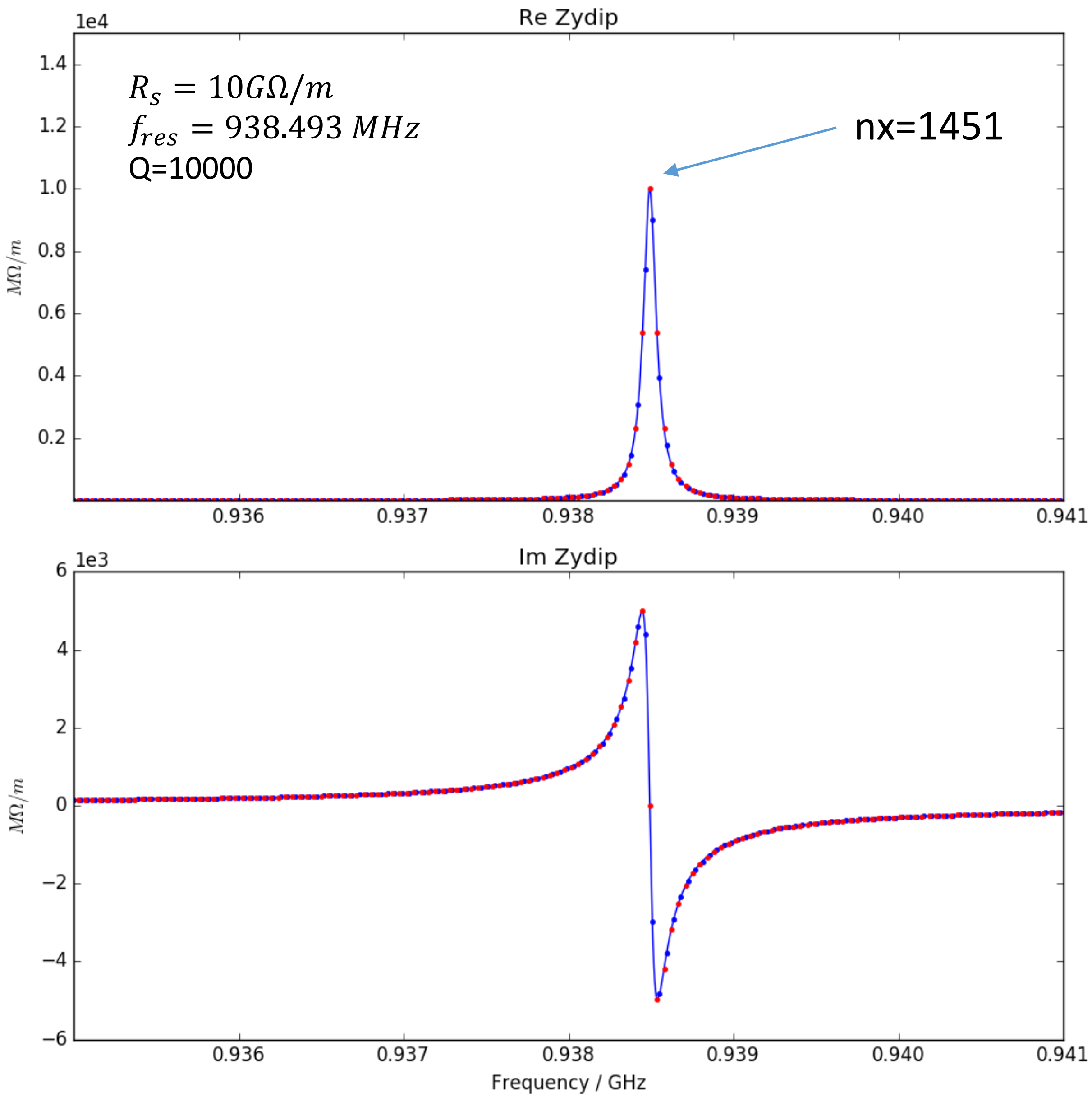
N.Biancacci

- Study of the instability growth rate driven by a transverse HOM with $R_s = 1.6\, M\Omega/m$ per crab cavity, $Q = 1000$ and variable frequency. This means a total Rs of $\simeq 1.3 G\Omega/m$ for 16 cavities at $\beta_y = 3600$ m.
- Comparison with Sacherer sinusoidal modes with and without damper and $Q' = 0$.



→ The damper can damp the mode 0 but not the mode 1.
→ It could be confirmed with HEADTAIL simulations.

CB mode lines and impedance



CB mode lines and impedance