SPS test: what can we learn? Impedance/power loss aspects: stability/power loss as a function of tuning/operational mode of the cavity

N. Biancacci and B. Salvant

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Outline

- **Introduction**
- **Impedance model of the SPS**
- **Y-Chamber impedance optimization**
- **Crab cavities impedance and observables in the SPS**
  - Longitudinal plane
  - Transverse plane
  - Power loss
- **Conclusions**

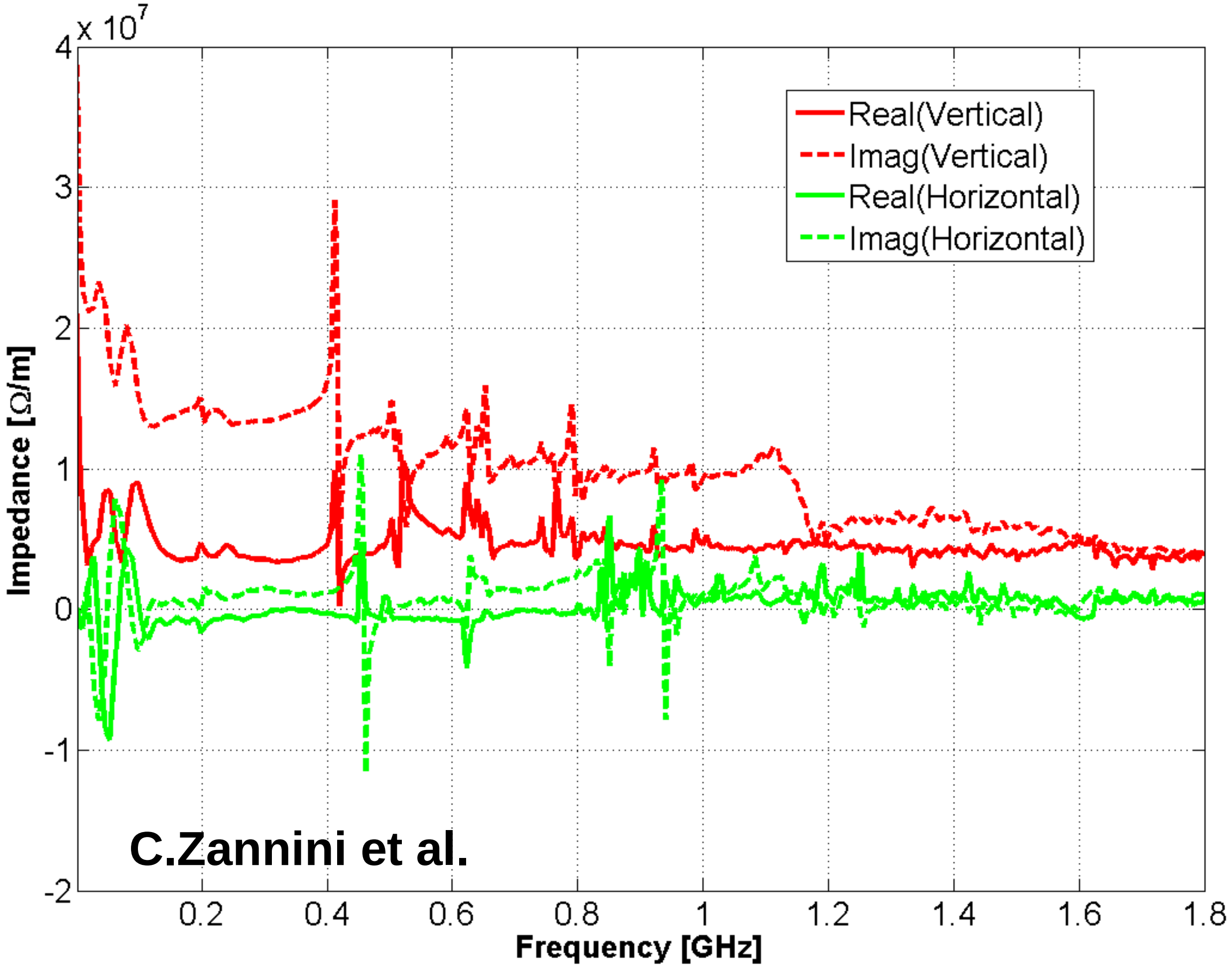
Introduction

- The SPS machine is one of the best machine in terms of knowledge of the impedance and comparison with measurement, at least for the single bunch case.

- This is a result of years of strong team efforts in order to carefully to localize and quantify the different impedance sources of the machines in both longitudinal and transverse plane.

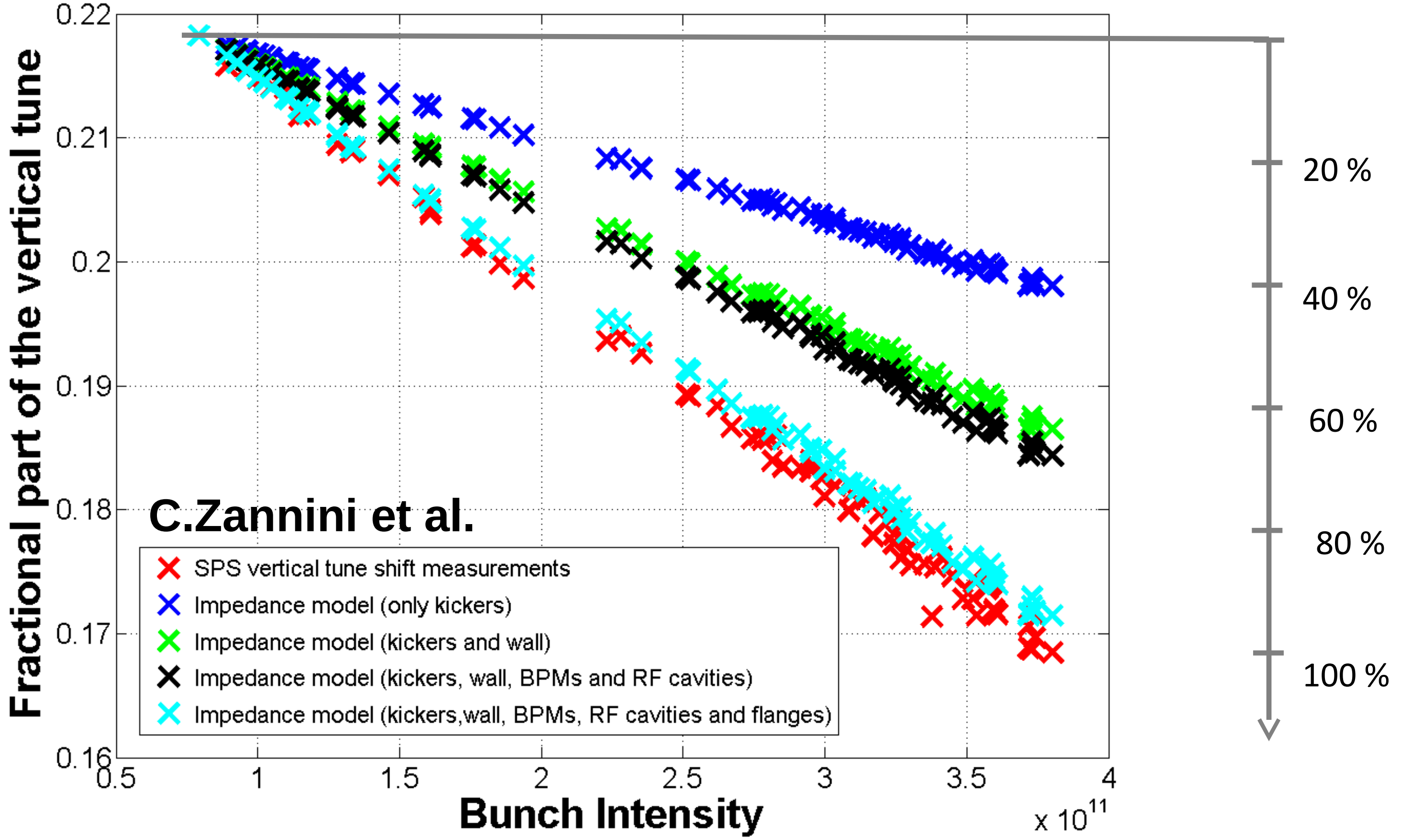
- The installation of a new device, and a characterization in terms of impedance-related effects, is therefore easier in a context where we have deep knowledge of the boundary conditions.

The SPS impedance model



The SPS impedance model – Tune shift

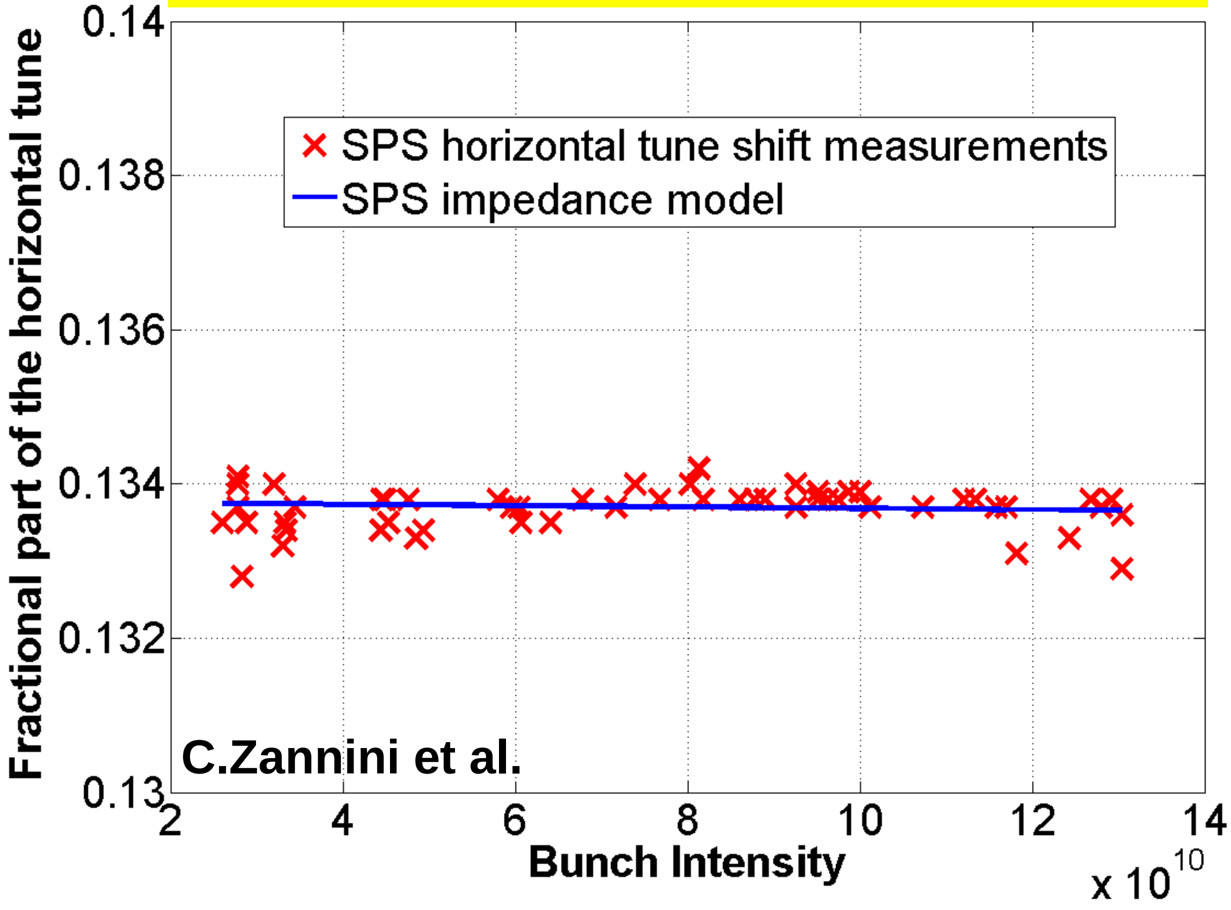
Vertical coherent tune shift: Measurements performed in September 2012



The SPS impedance model explains more than 90% of the measured vertical coherent tune shift

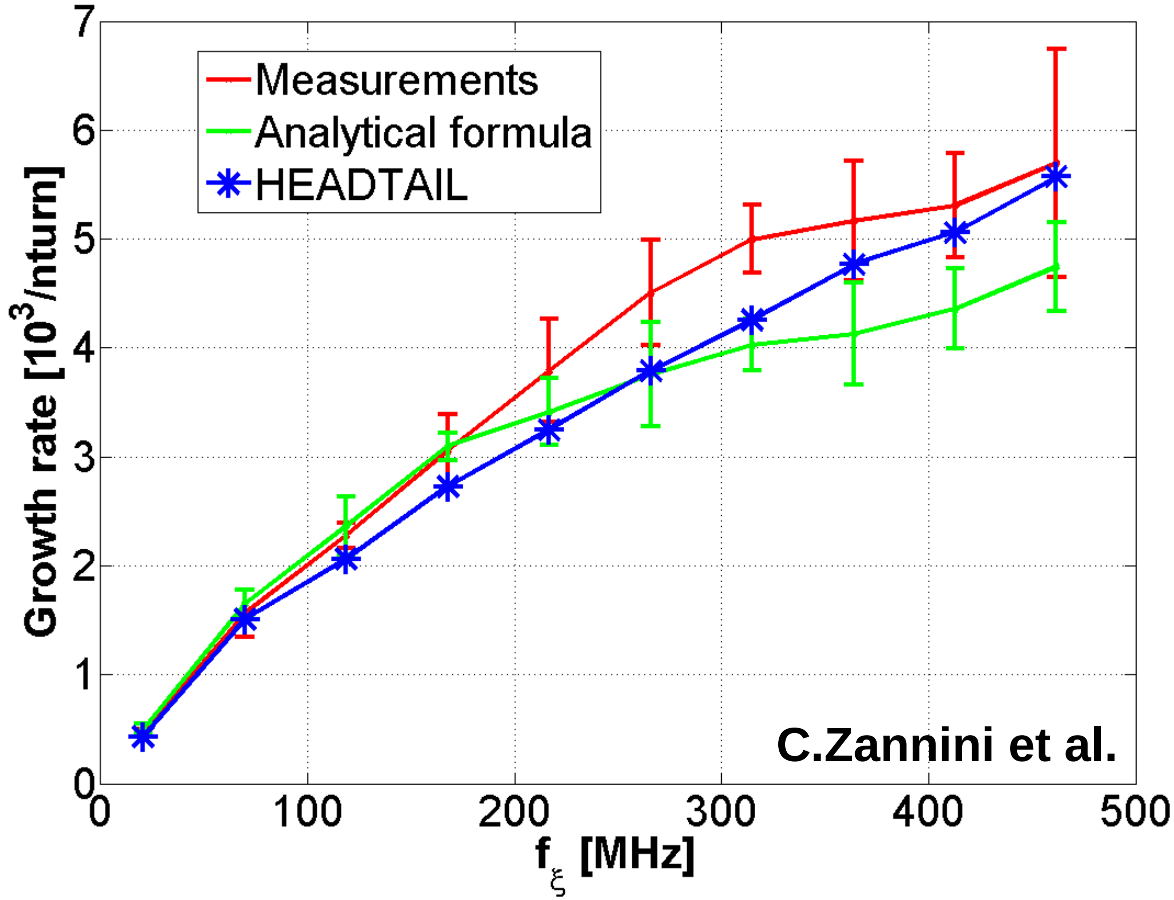
The SPS impedance model – Tune shift

Horizontal coherent tune shift: Measurements performed in February 2013



The SPS impedance model predicts a very small horizontal tune shift (almost flat) in agreement with the measurements

The SPS impedance model – Growth rates



Strong indication that the SPS transverse impedance model is close to reality up to 500 MHz

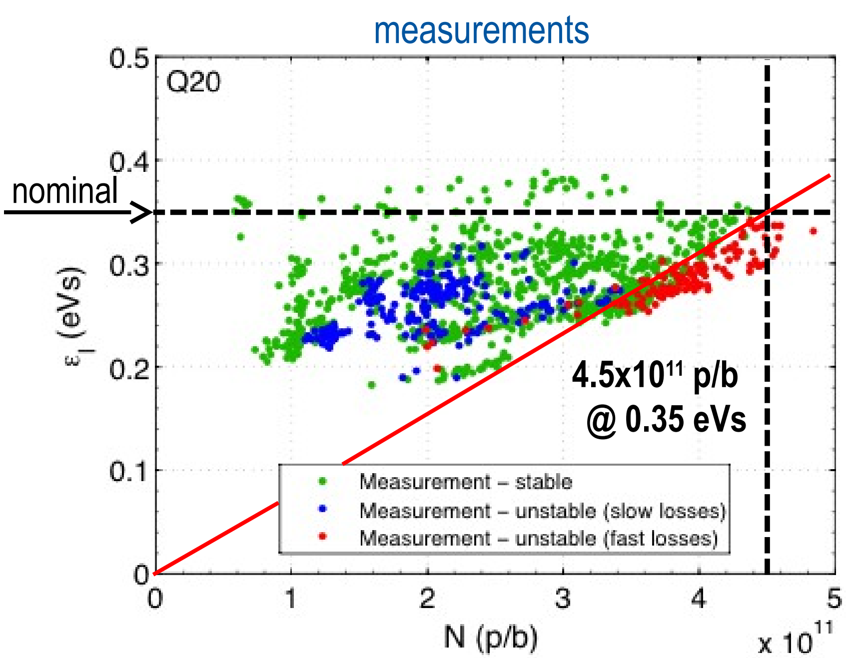
The SPS impedance model – TMCI threshold

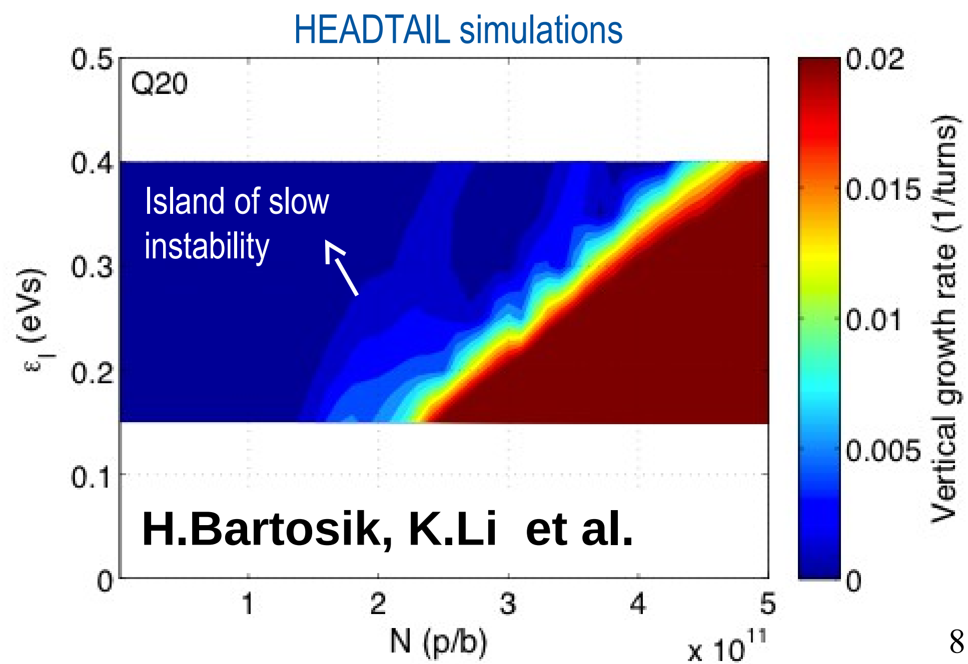
Two regimes of instability in measurements

- Fast instability threshold with linear dependence on ε_l
- Slow instability for intermediate intensity and low ε_l

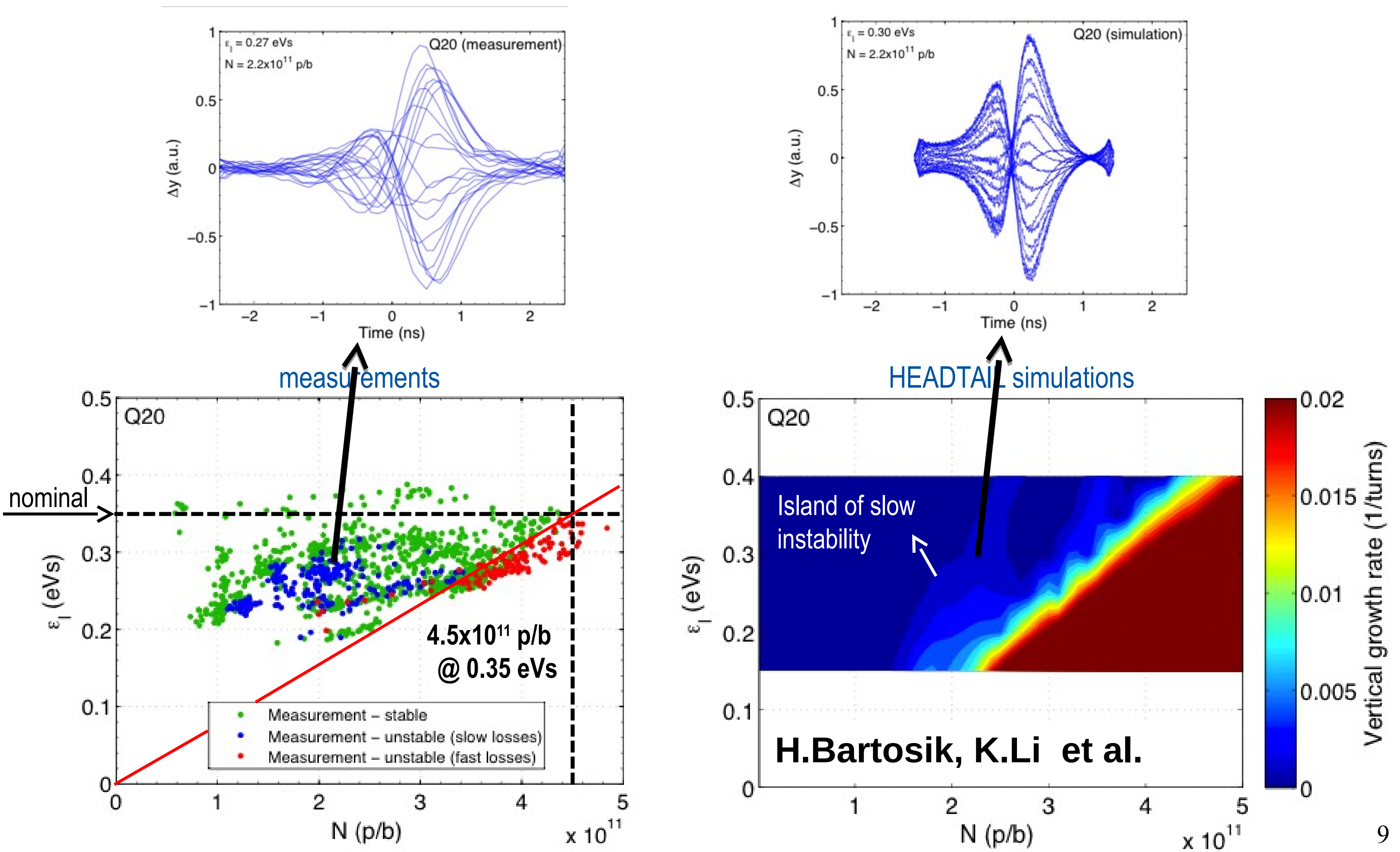
Very well reproduced with HEADTAIL simulations

- SPS impedance model includes kickers, wall, BPMs and RF cavities
- Direct space charge not included

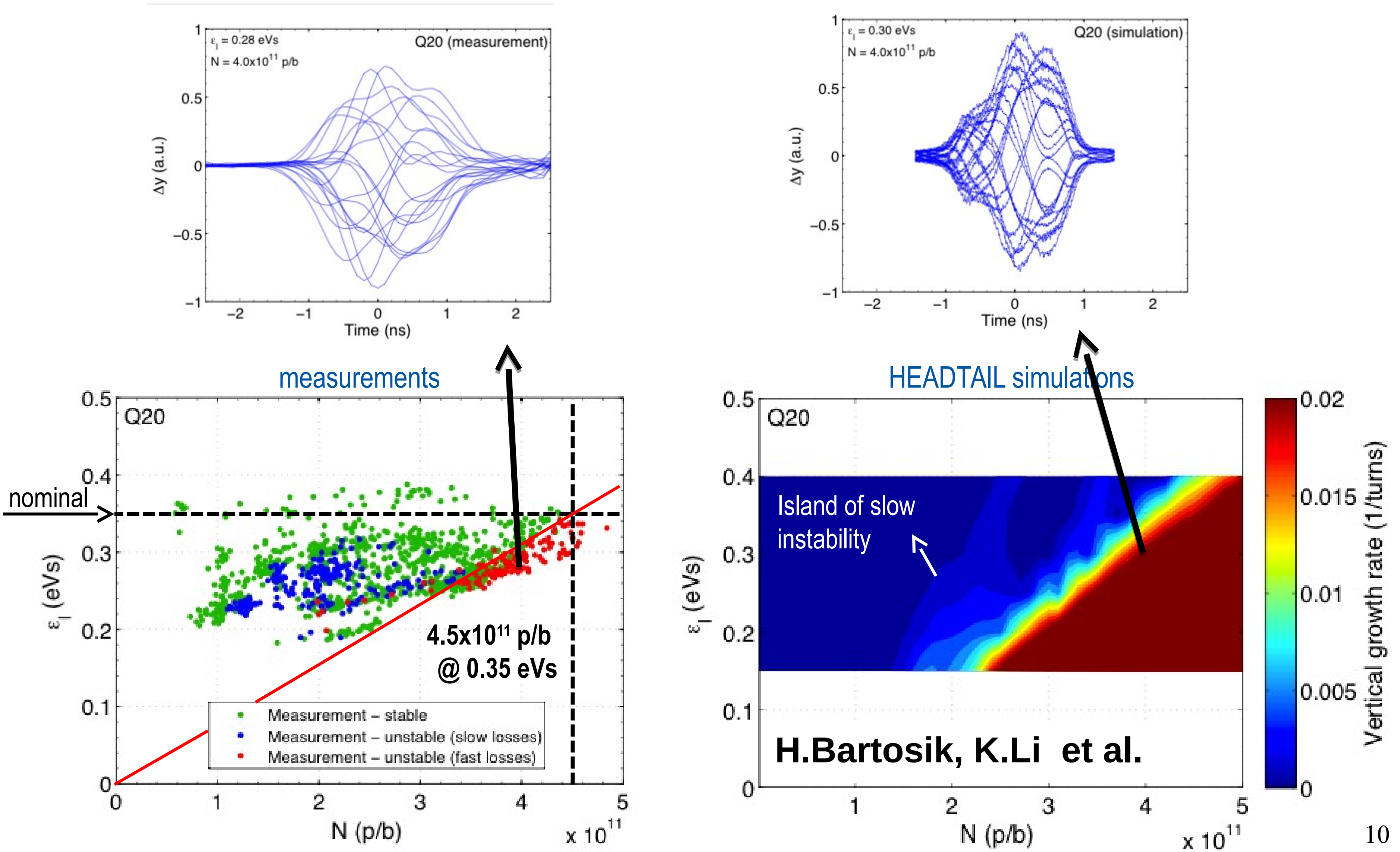




The SPS impedance model – TMCI threshold



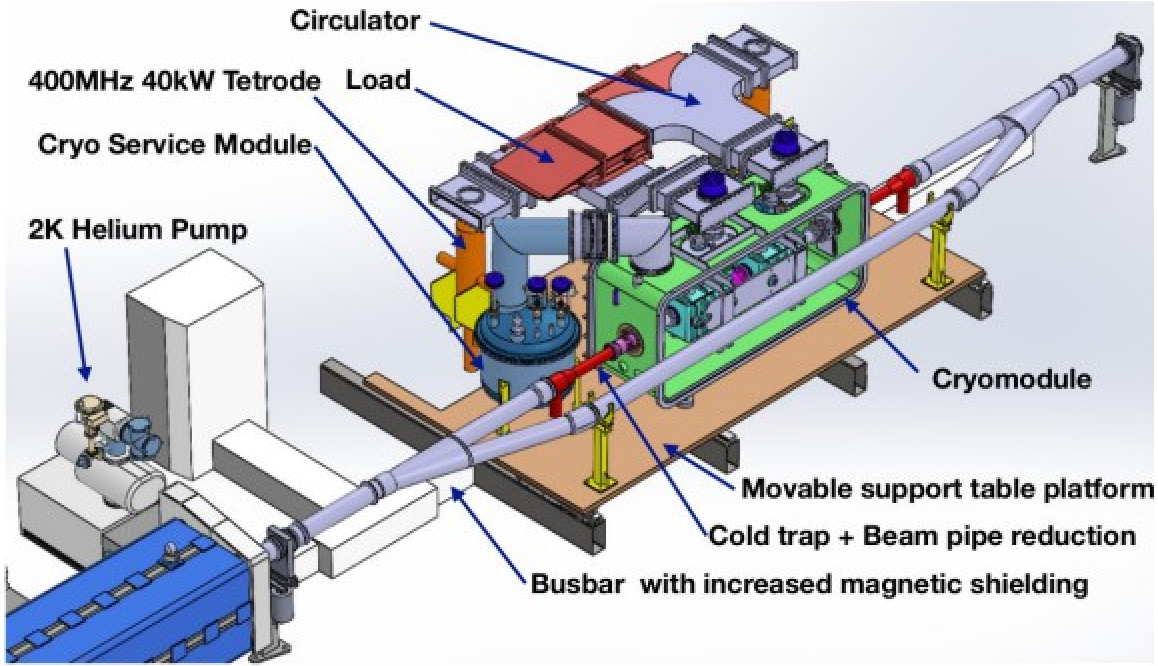
The SPS impedance model – TMCI threshold



Crab Cavities installation in the SPS

Crab Cavities installation ⟶ What can we already expect from an impedance point of view?

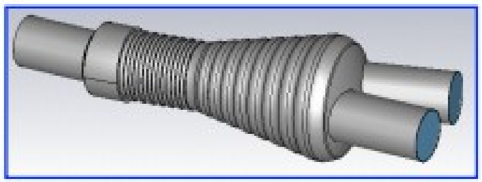
- Any effect from the Y-chamber introduced to send the beam to the CC?
- Any effect from the CC themselves?

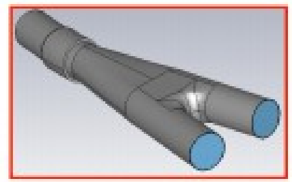


Courtesy R. Calaga and CCTC

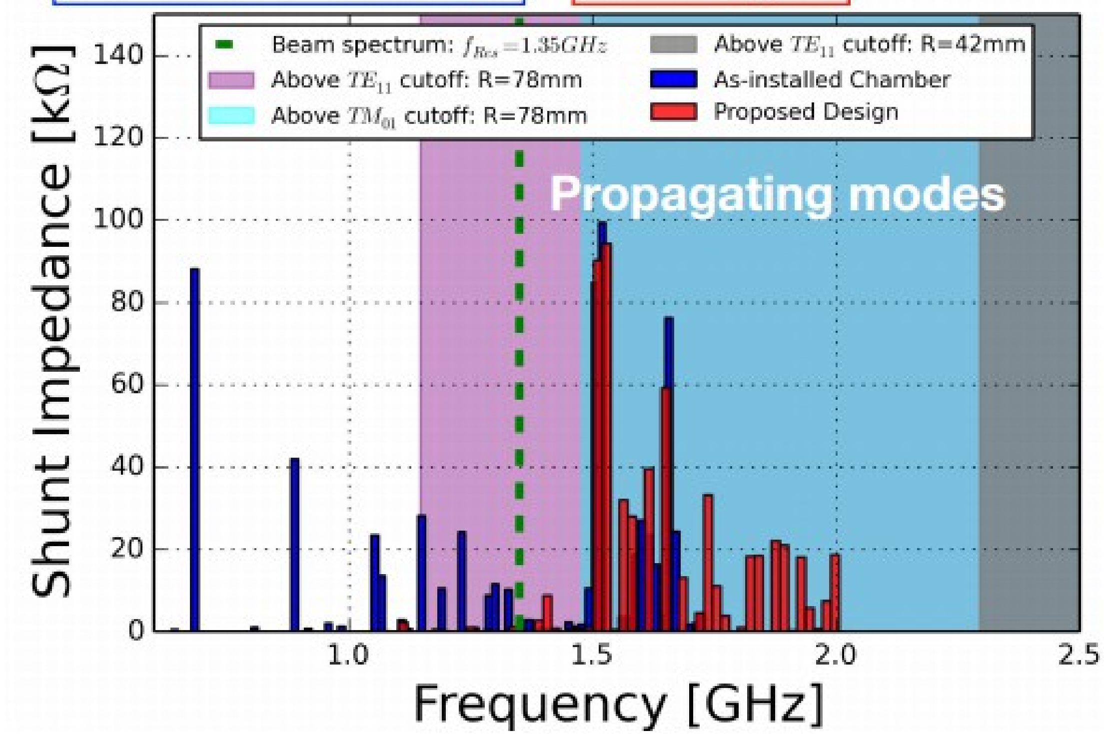
Y chamber design optimization

- New design proposed
- Smaller transverse aperture → Pushes HOMs above cut-off
- More suitable from impedance point of view: the new chamber is expected to be better than the old one.





Simulations:
Phoevos Kardasopoulos et al.

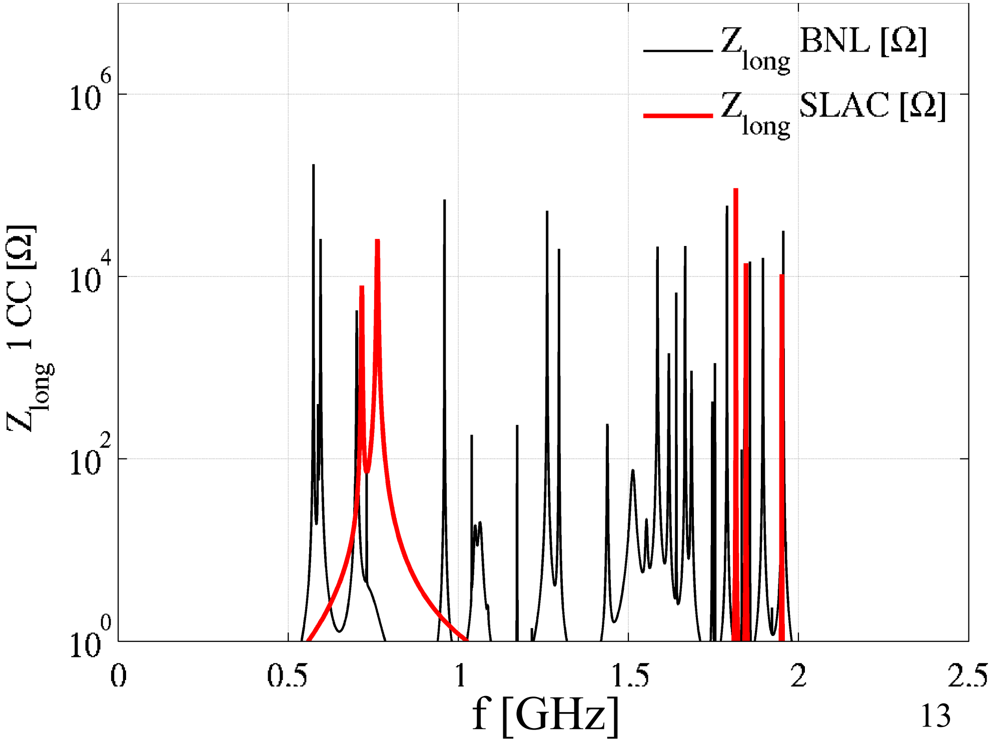


BNL (DQW) and ODU/SLAC (RFD)

- Main longitudinal modes (in circuit convention):

f (GHz)	Q	R (Ohm) per cavity
0.573	4636.811	1.70E+05
0.594	1.27E+03	2.58E+04
0.959	7.20E+03	7.01E+04
1.260	4.06E+03	5.27E+04
1.295	6.54E+03	2.01E+04
1.585	2.73E+03	2.12E+04
1.666	6.07E+03	2.16E+04
1.789	1.51E+04	5.98E+04
1.856	8.82E+04	1.46E+04
1.895	5.89E+03	1.60E+04
1.954	7.89E+03	3.17E+04

f (GHz)	Q	R (Ohm/m) per cavity
0.76	275	2.579E+04
1.815	47988	9.330E+04
1.845	27998	1.398E+04



→ SLAC cavity looks more optimized from longitudinal modes point of view

BNL (DQW) and ODU/SLAC (RFD)

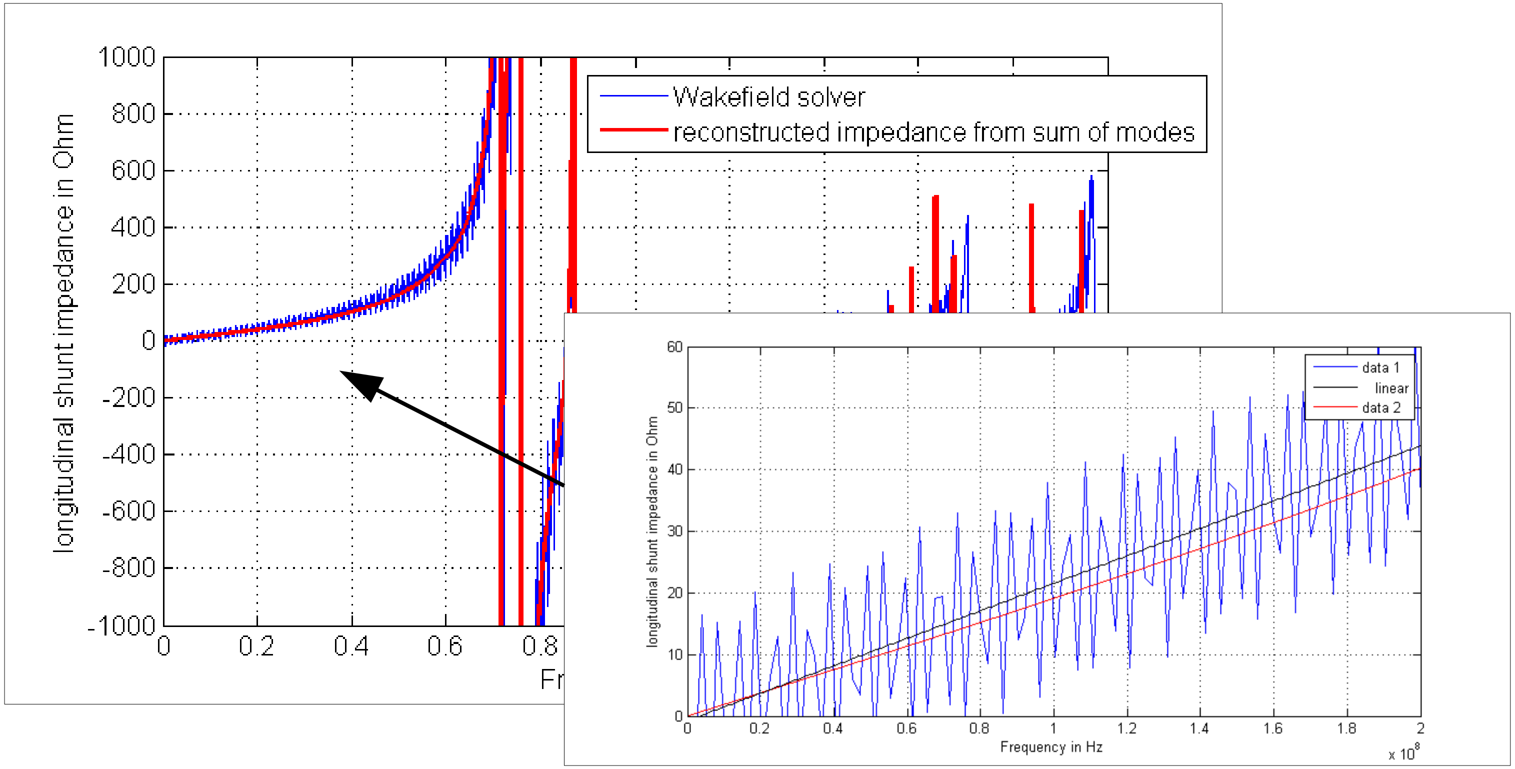
- Main transverse modes (> 100 kOhm/m in circuit convention):

f (GHz)	Q	R (Ohm/m) per half cavity	plane	Deltaf in kHz
0.400	6.66E+09	5.98E+12	V	-
0.685	1880	4.67E+05	H	365
0.927	8600	1.38E+06	H	108
1.30	6540	3.73E+05	V	200
1.50	10800	2.67E+05	H	140
1.66	24200	3.14E+05	H	69
1.75	5800	2.57E+05	H	301
1.75	4160000	1.81E+08	H	0.4
1.84	9990	3.34E+05	V	185
1.86	26400	4.17E+05	H	70
1.86	88200	1.56E+06	V	21
1.92	102000	1.85E+06	H	18
1.96	54400	1.15E+05	H	36

f (GHz)	Q	R (Ohm/m) per half cavity	plane	Deltaf in kHz
0.4			V	
0.634	672	1.64E+05	H	940
1.27	1790	1.63E+05	V	707
1.48	78200	2.29E+06	H	19
1.48	1710	1.95E+05	V	870
1.72	109000	6.18E+05	H	16
1.77	93700	3.10E+06	H	19
1.88	432000	4.89E+05	H	4
1.96	413000	4.01E+06	V	5
1.96	1150000	1.77E+07	H	2
1.99	4260000	1.33E+08	H	0.5
2.00	586000	1.11E+07	H	3

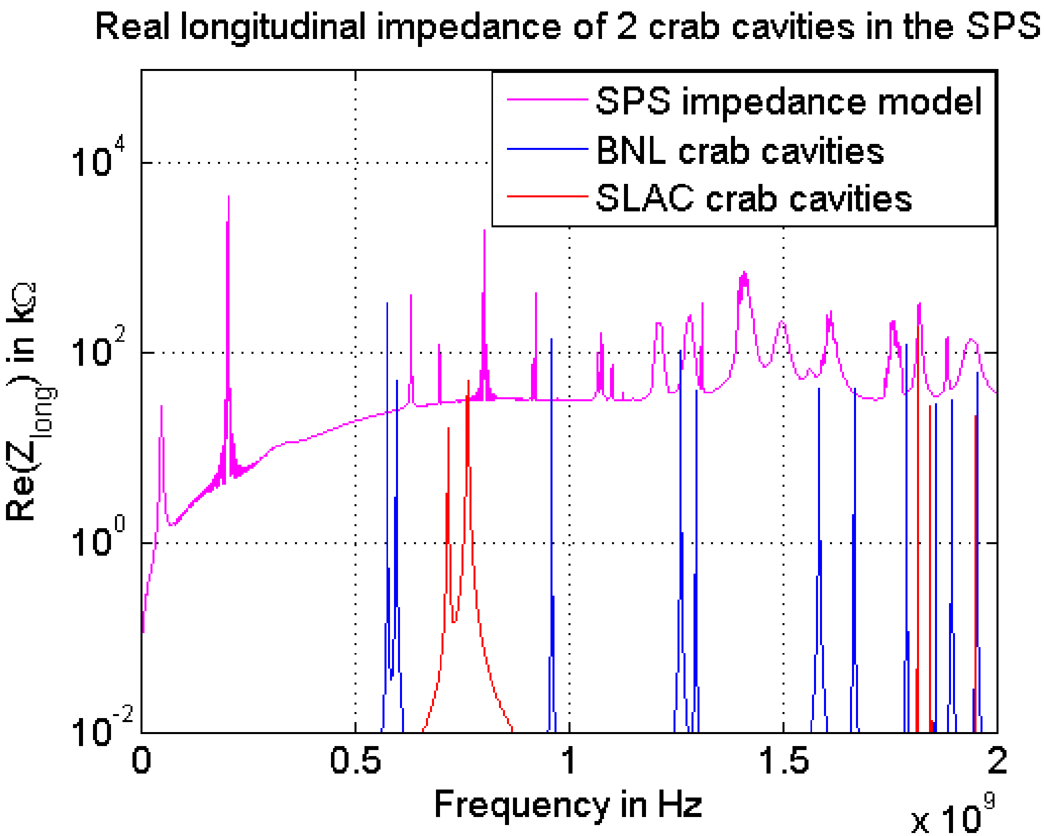
→ Largest amplitude modes (>100MOhm/m) have a very thin width (~400 Hz) and are less likely to be hit by a revolution frequency (44 kHz for SPS)

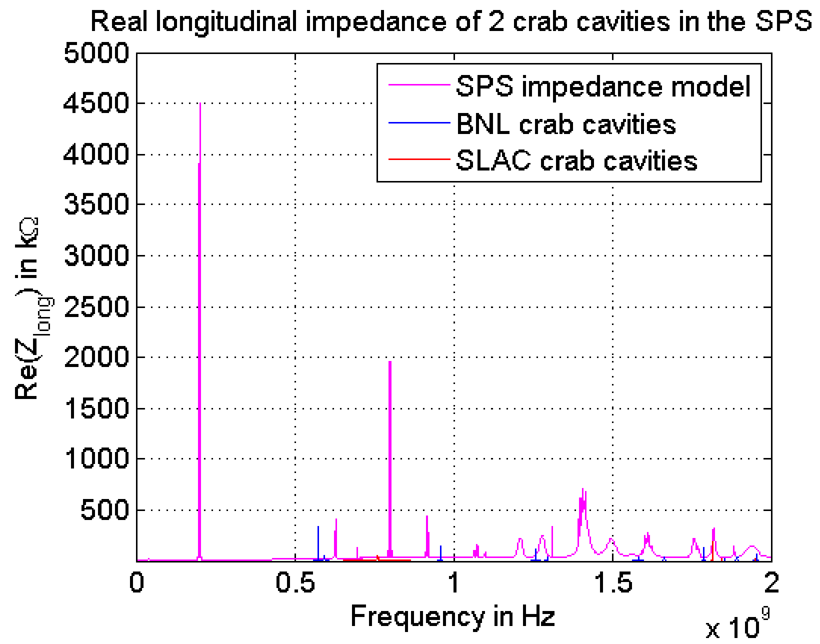
Imaginary longitudinal impedance in SPS



- **Z/n ~ 10 mOhm** per crab cavity (for SPS), to be compared with **3.5 Ohm for full SPS.**
- Negligible impact on SPS effective impedance (and single bunch stability).

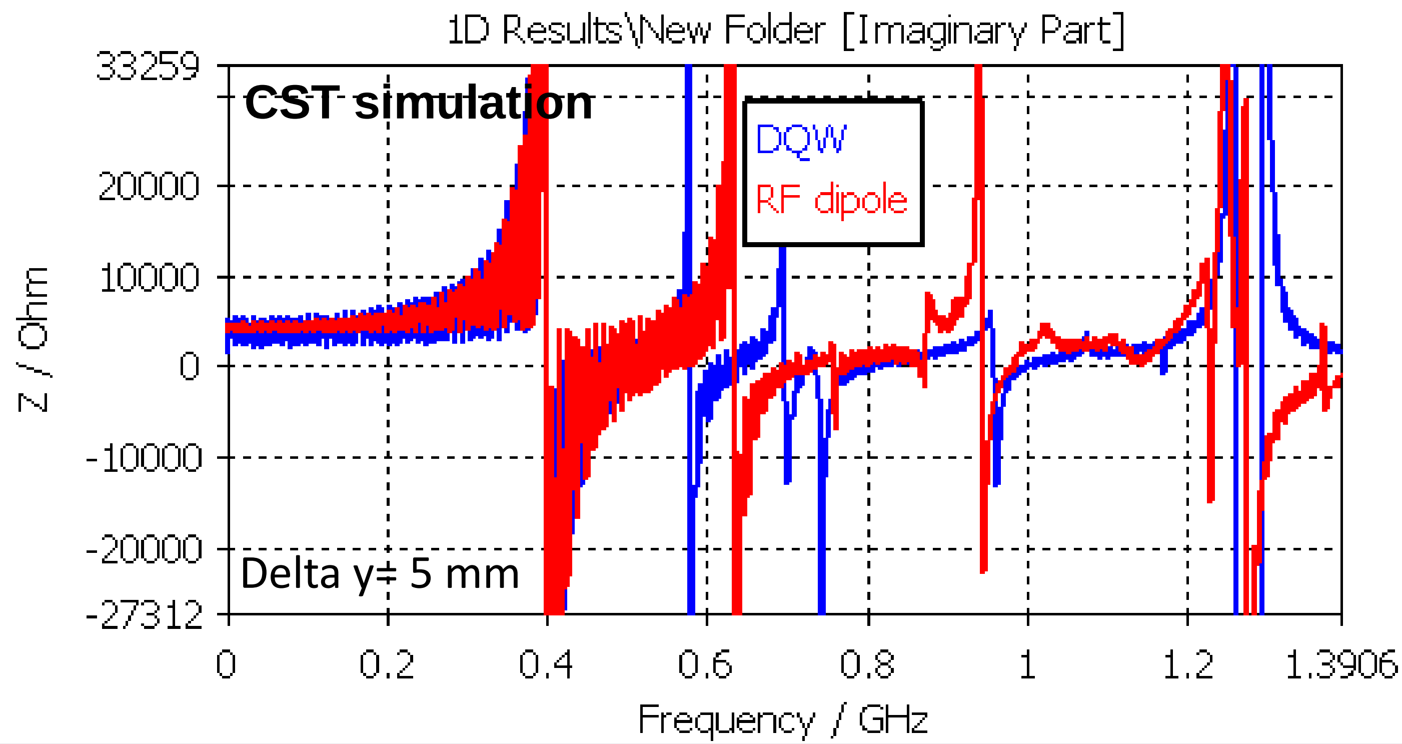
Real longitudinal impedance in SPS





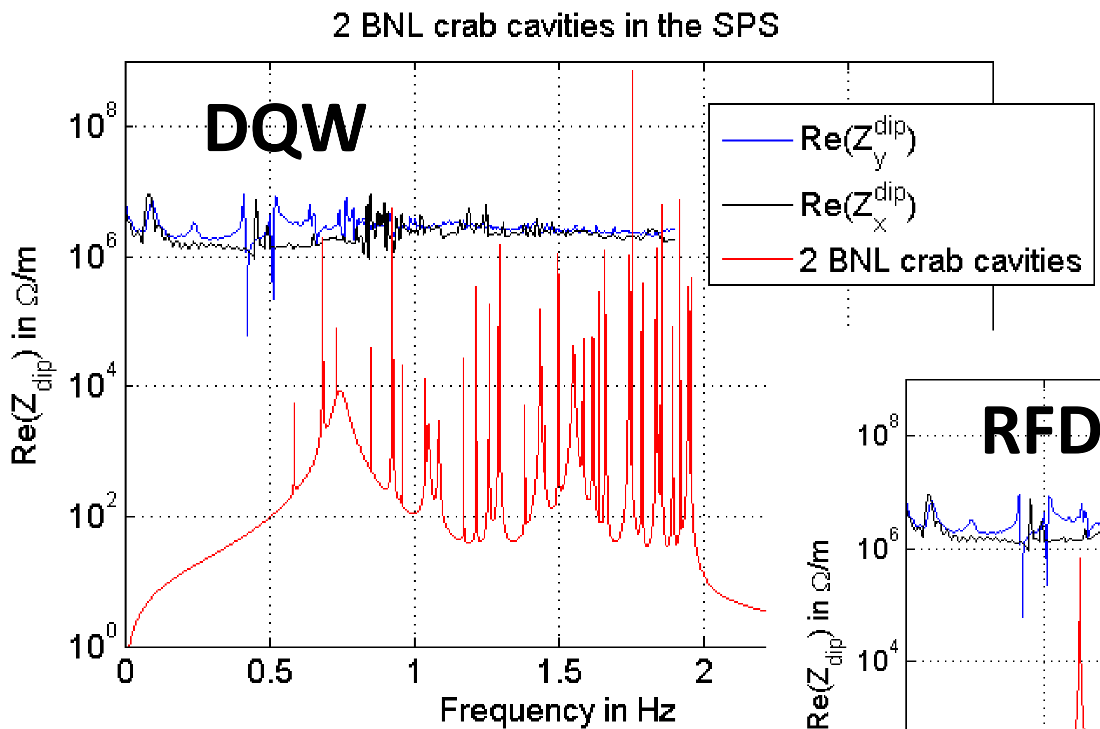
- Latest impedance model development taken into account (J.Varela et al.)
- The first 3 modes of the BNL cavities are coming out of the SPS background, while the SLAC cavity modes remain below the background.
- Can the first BNL mode at 580 MHz lead to more instabilities in SPS or be observed with a debunching bunch?

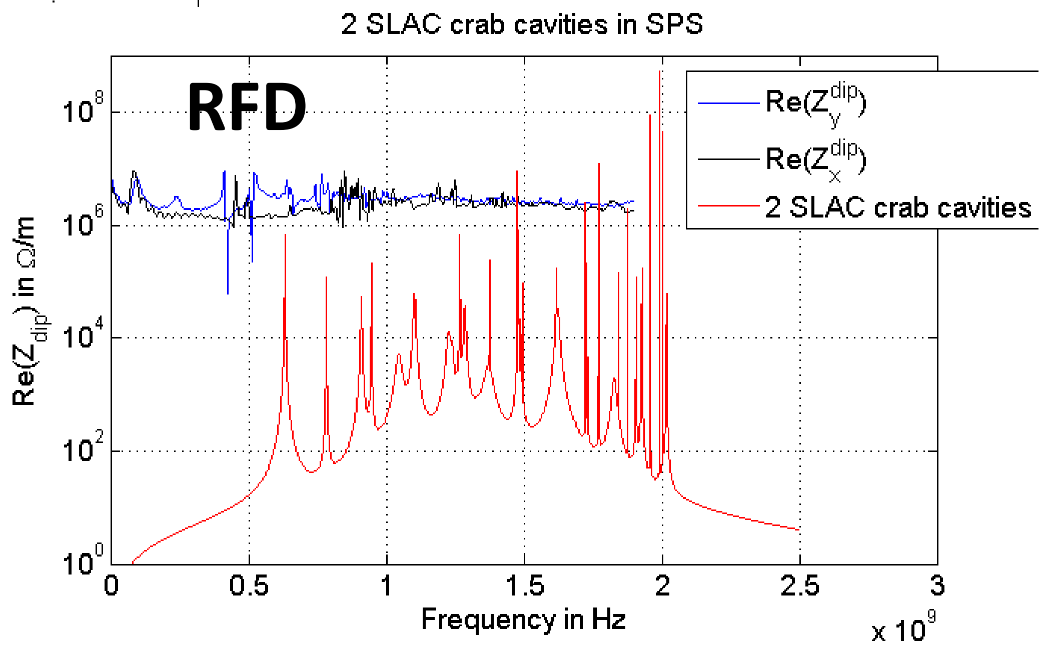
Imaginary transverse impedance in SPS



- **Z^{eff} ~4 kOhm/m** for 1 cavity, **8 kOhm/m** for 2 cavities, to be compared with **20 MOhm/m for the full SPS** in the vertical plane (most critical).
- Negligible impact of crabs on vertical SPS transverse effective impedance (and single bunch stability)
- Maybe could be seen in the H plane, but would require ~1e-5 resolution in tune → seems difficult!

Real transverse impedance in SPS

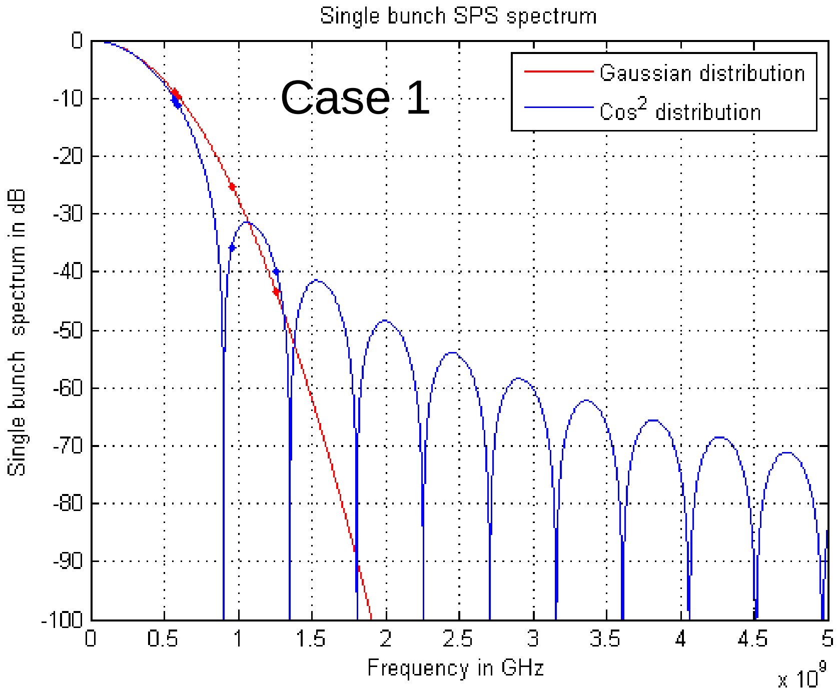


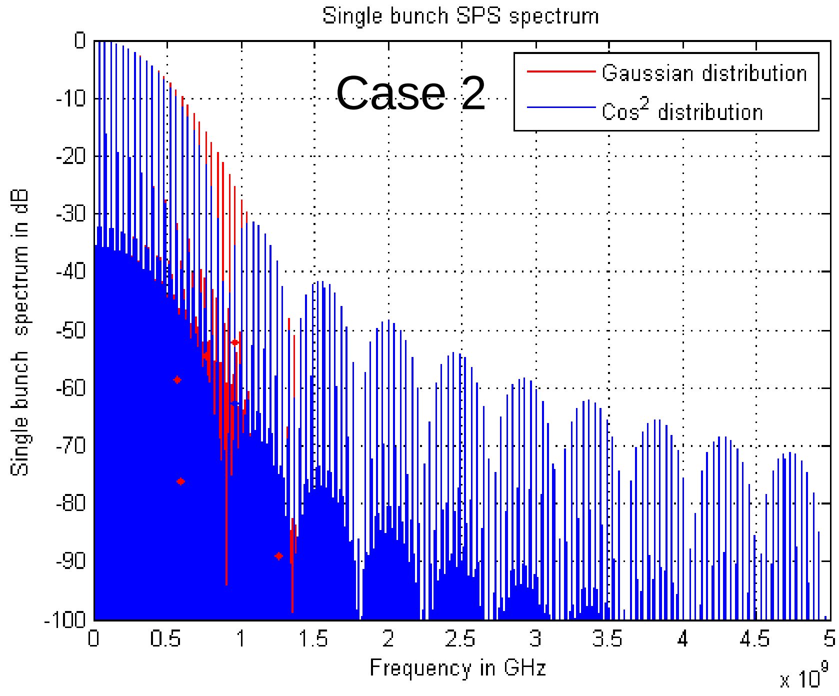


- Not much should be detected by the SPS beam from the crabs transverse modes (assuming the deflecting mode is always feed-backed on).
- Mode at 1.7 GHz in the DQW could be seen? Studies on coupled bunch instability on going..

Power loss

- Case 1: the lines falls on the beam spectrum lines.
- Case 2: if lines are do not fall on top of the beam spectrum lines.

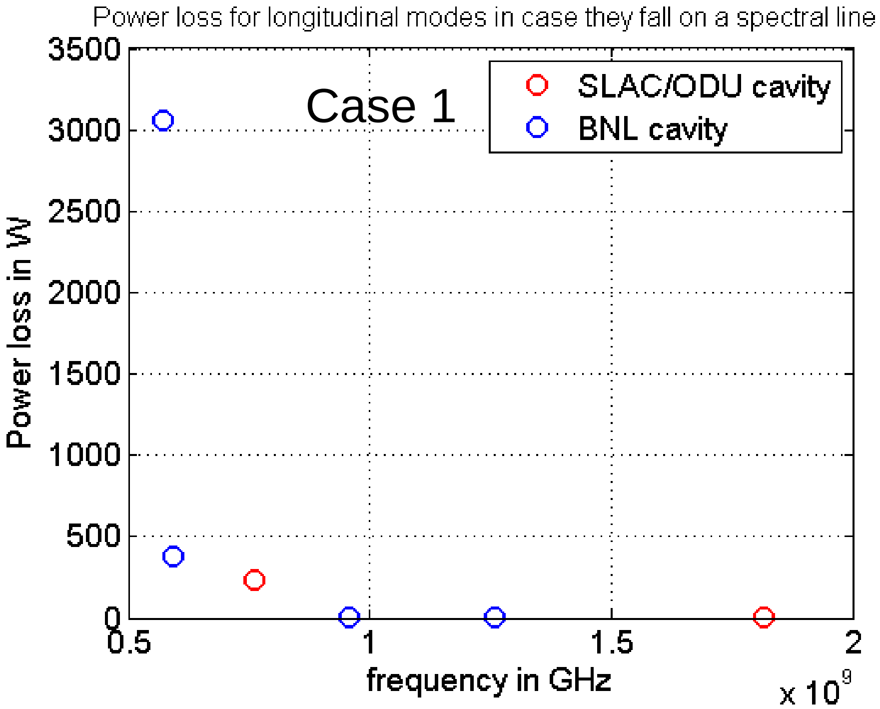


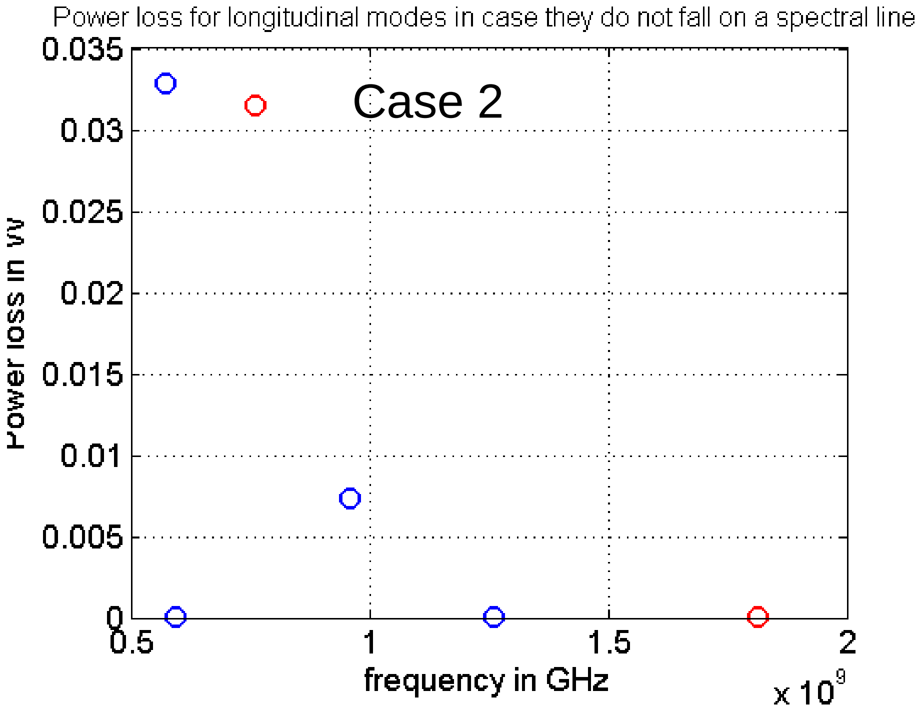


M=4x72 bunches
Nb=1.3.10^11 p+/b

Power loss

- Case1: kW range if CC lines falls on the beam spectrum.
- Case2: Negligible if lines are not overlapping.





M=4x72 bunches
Nb=1.3.10^11 p+/b

Conclusions and outook

SPS impedance model:

- Reviewed the SPS impedance model, and the good agreement with respect to measurements of tune shifts with intensity, rise times, TMCI threshold.

Crab Cavity impedance related aspects:

- Longitudinal impedance: the effect of 2 crab cavities in the longitudinal plane is negligible: 10mOhm vs 3.5 Ohm of the full SPS. Few modes ~500MHz would be visible in the longitudinal impedance budget → possibility for observation.
- Transverse vertical impedance: the effect is also here negligible: 8kOhm/m vs 20MOhm/m of the full SPS. Maybe mode at 1.7 GHz of DQW could be seen.
- Power loss: kW range if the cavity mode would overlap with the beam; negligible otherwise.

SPS vs LHC:

The observation of impedance related effects in the SPS appears much less evident than in the LHC due to:

- much smaller beta function: beta_y in Q20 is 67 while in the LHC is 3600, i.e. 60 times less.
- much higher "background impedance": the CC impedance is anyway masked by the high transverse impedance of the SPS in vertical plane.
- A tune shift on the order of 10^-5 could be observed in the horizontal plane where the SPS total impedance is almost zero.
- Number of cavities: the effects is smaller of a factor 8 wrt LHC.

Thanks!