LHC Injectors Upgrade

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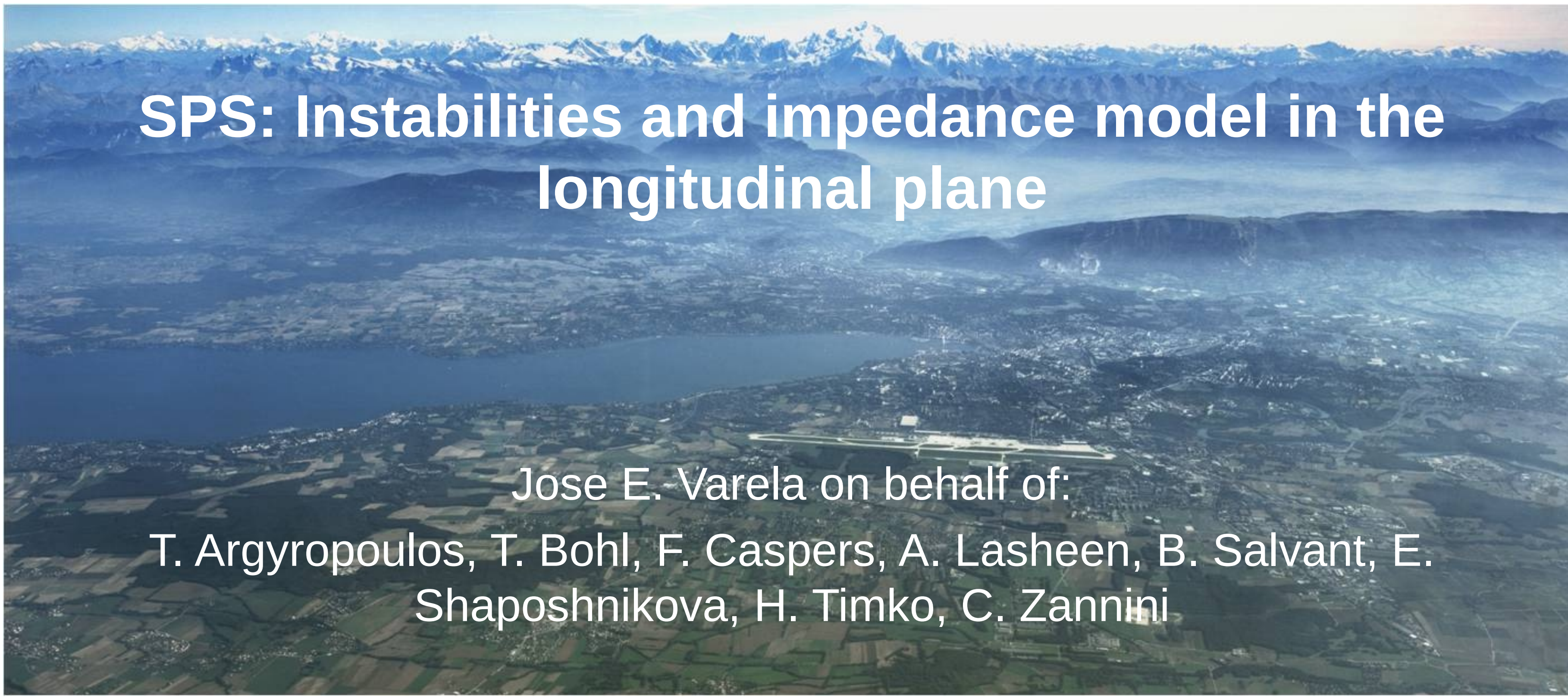


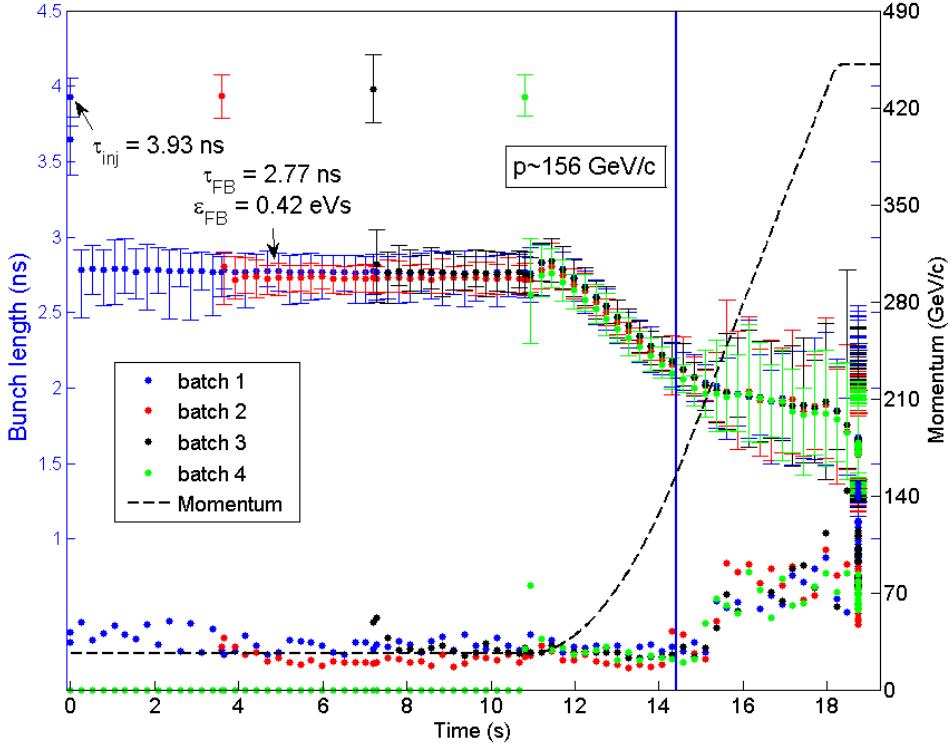
SPS: Instabilities and impedance model in the longitudinal plane

Jose E. Varela on behalf of:

T. Argyropoulos, T. Bohl, F. Caspers, A. Lasheen, B. Salvant, E. Shaposhnikova, H. Timko, C. Zannini

Multi-bunch instabilities (I)

Average bunch length along cycle
(4 batches, 50 ns spacing, 1 RF, Q26)



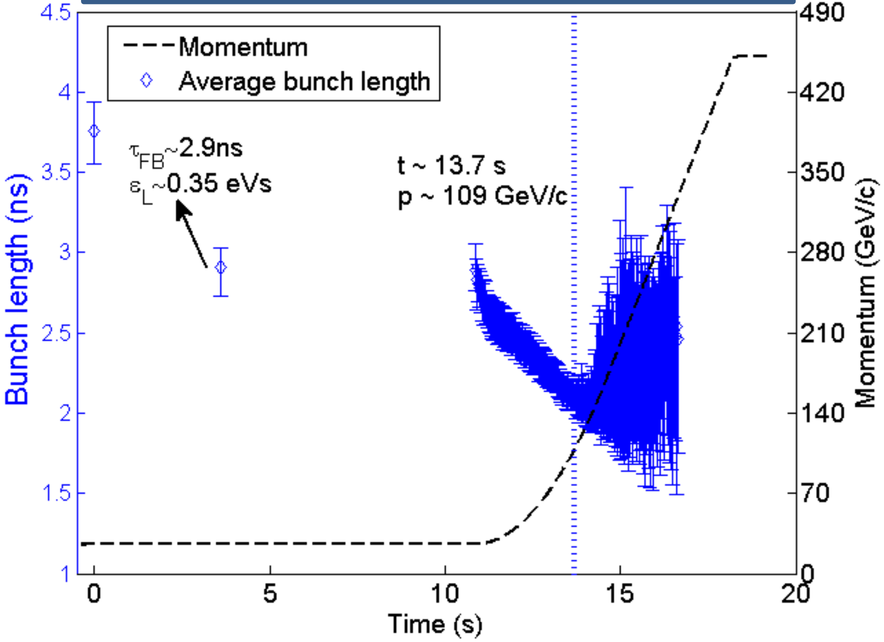
- **Instability threshold** N_{th}~ 1/energy
- Multi-bunch **instability threshold** during the ramp for bunches spaced at $t_b = 25$ & 50 ns is **much lower than for a single bunch**
- Similar N_{th} for 1, 2, 3 or 4 batches
  - **No interactions between batches** spaced by $T_B = 225$ ns
- Wake decay time (Q-factor)

$$t_b < t_{wake} < T_B$$

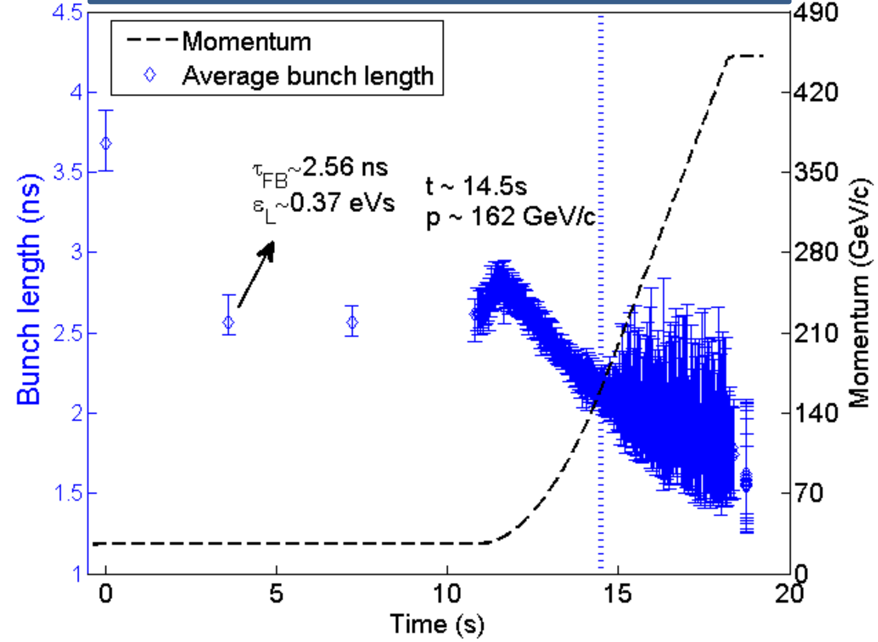
$$\mathbf{50\ ns} < \frac{2Q}{\omega_r} < \mathbf{225\ ns}$$

Multi-bunch instabilities (II)

25 ns – Energy threshold



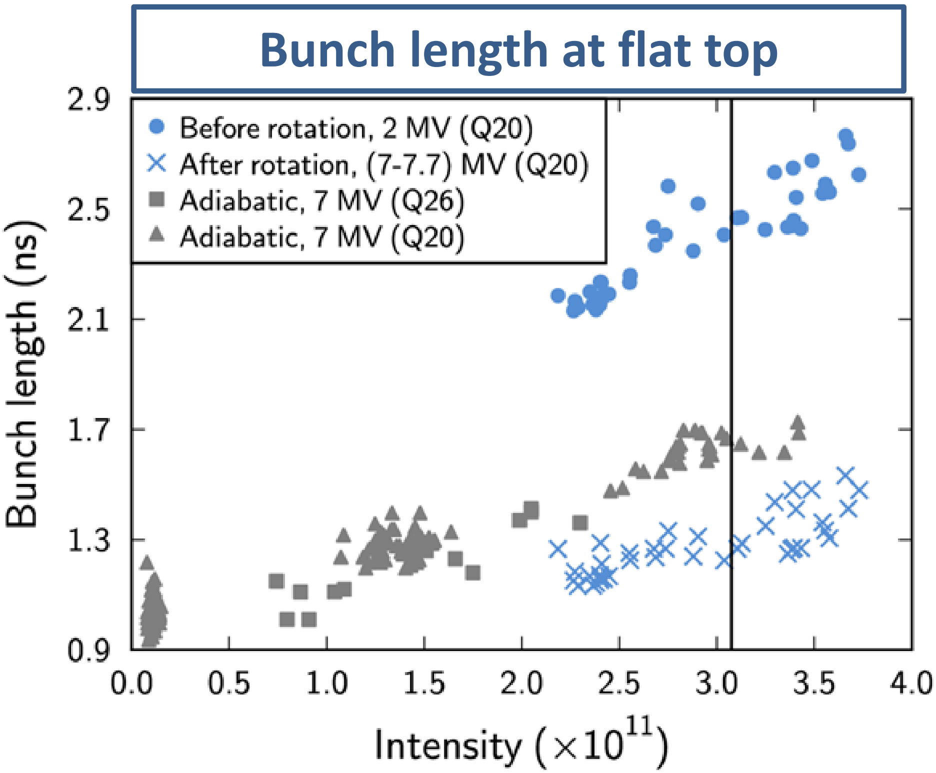
50 ns – Energy threshold



- **Energy threshold** approximately **scales with total current** as $^{1}/_{E_{th}} \sim {}^{N_b}/_{T_b}$

- **Emittance at flat top scales with bunch intensity** → (**+ single bunch effect ?**)
  - 50 ns : $\epsilon_l = 0.46$ eVs with $N_b = 1.6 \cdot 10^{11}$, $N_b/T_b \approx 0.51$ A
  - 25 ns : $\epsilon_l = 0.47$ eVs with $N_b = 1.35 \cdot 10^{11}$, $N_b/T_b \approx 0.86$ A

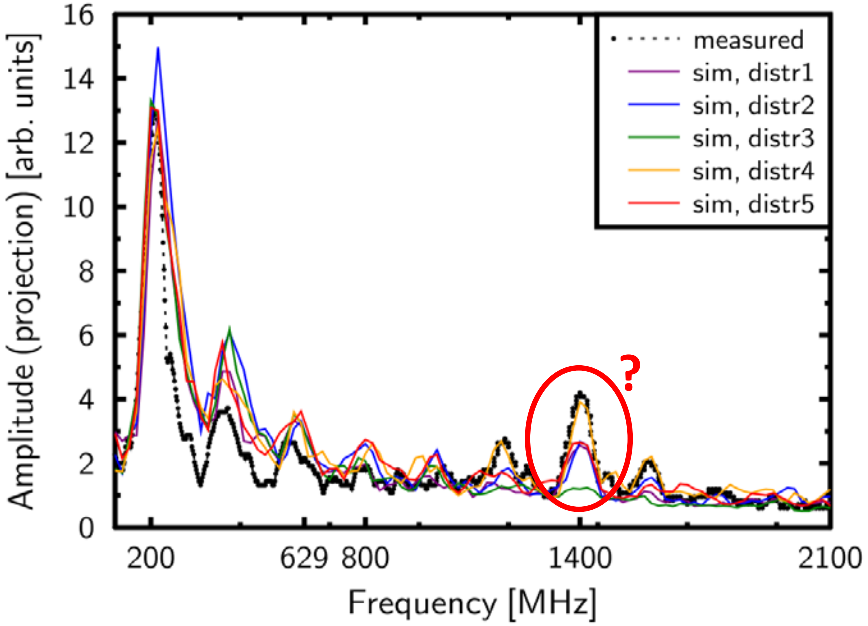
Single bunch instability



- Bunch lengthening with intensity
- To explain this bunch lengthening by potential well distortion one needs Im(Z)/n = 12 - 15Ω
- Microwave instability due to some high frequency impedances?

High frequency impedance

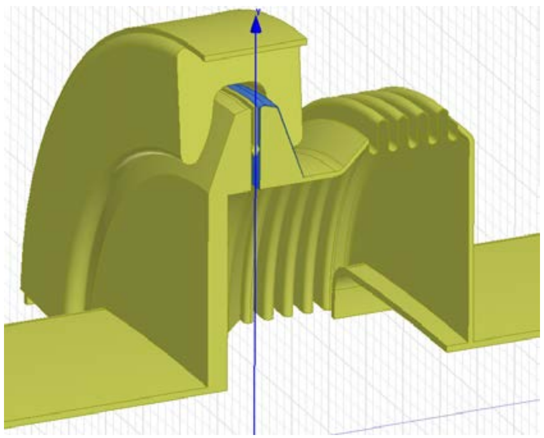
Measured and simulated unstable spectrum of 25 ns long bunches with $N = 1 \cdot 10^{11}$ (RF off)



- **Amplitude peaks correspond to SPS resonant impedances** (on the top of 200 MHz harmonics)
- Strong peak at **1.4 GHz** for $N_b > 8 \cdot 10^{10}$ (observed also in 2001)
- Reproduced in simulations with SPS impedance model impedances with high R/Q and Q in wide range

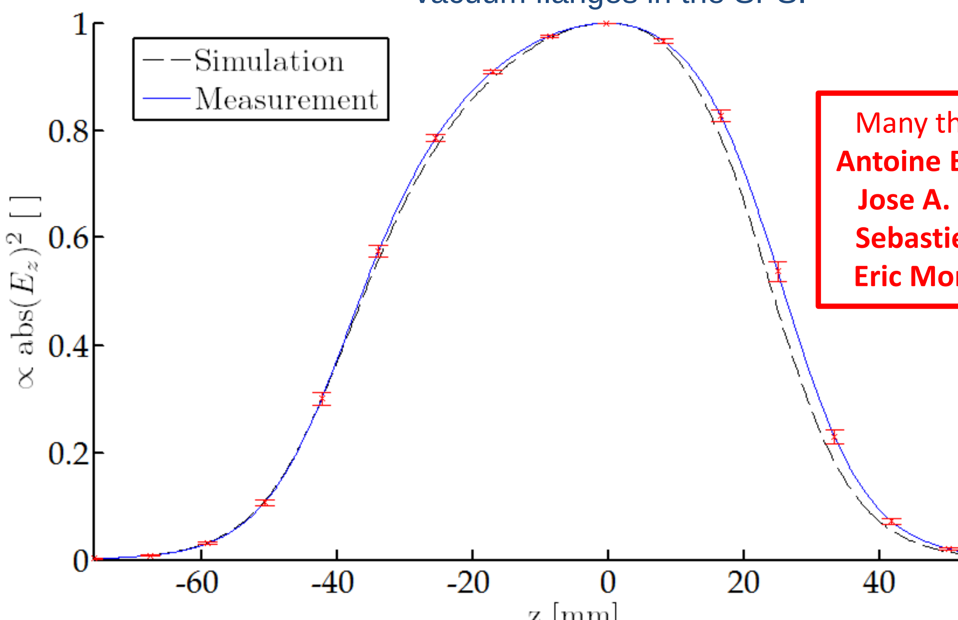
Vacuum flanges simulations and measurements

The vacuum flanges have been identified as sources of the **1.4GHz** impedance peak



		Damping Resistor	fres [GHz]	Q		R/Q [Ω]
MBA – QF	Sim.	No	1.415	1800		82
Non enamelled	Meas.	No	1.401	1100	≈ 5.5	85 ± 2.5%
	Meas.	Short	1.395	200		81 ± 2.5%
MBA – MBA	Sim.	No	1.410	285		75
Enamelled	Meas.	No	1.415	270	≈ 3.5	79 ± 5%
	Meas.	Short	1.415	75		65 ± 5%

A layout survey was carried out to count and classify vacuum flanges in the SPS.



Many thanks to:
Antoine Boucherie
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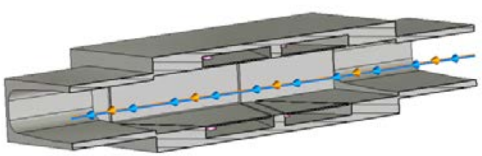
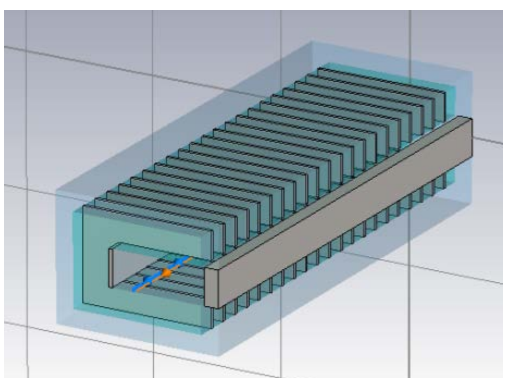
Eric Montesinos

The longitudinal impedance model (I)

Travelling Wave Cavities

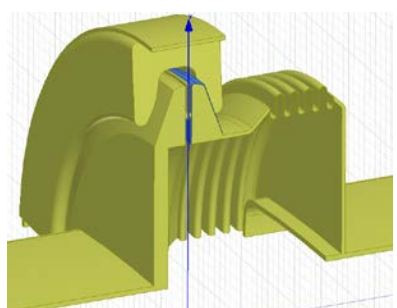


BPM - B. Salvant



Kickers - C. Zannini

+



Main known longitudinal impedance sources in the SPS*

Element	Number	f [MHz]	Z [kΩ]	Q	*2Q/ωr [ns]*	R/Q [kΩ]	Im(Z)/n [Ω]
Serigraphy	18	44	26	11	80	2.4	
200 TWC – 54 cell	2	200	**2860**	230	366	**12.6**	2.72
200 TWC – 43 cell	2	200	**1752**	180	286	**14.6**	2.18
200 TWC - HOM	4	630	388	500	252	0.8	0.11
800 TWC	2	800	**1936**	300	120	6.5	0.35
Kickers	18	810	20.5	1	0.4	**20.5**	
Vac. Flanges	**129**	1200	1130	250	65	4.5	-
Vac. Flanges	**123**	1400	**1875**	200	**45**	**9.3**	0.97
Kickers	18	1500	12	1	0.2	**12**	
Vac. Flanges	59	1600	630	395	79	1.6	-
BPM - H	106	1600	597.5	686	136	0.9	0.16
Kickers	18	3000	14.5	1	0.1	**14.5**	

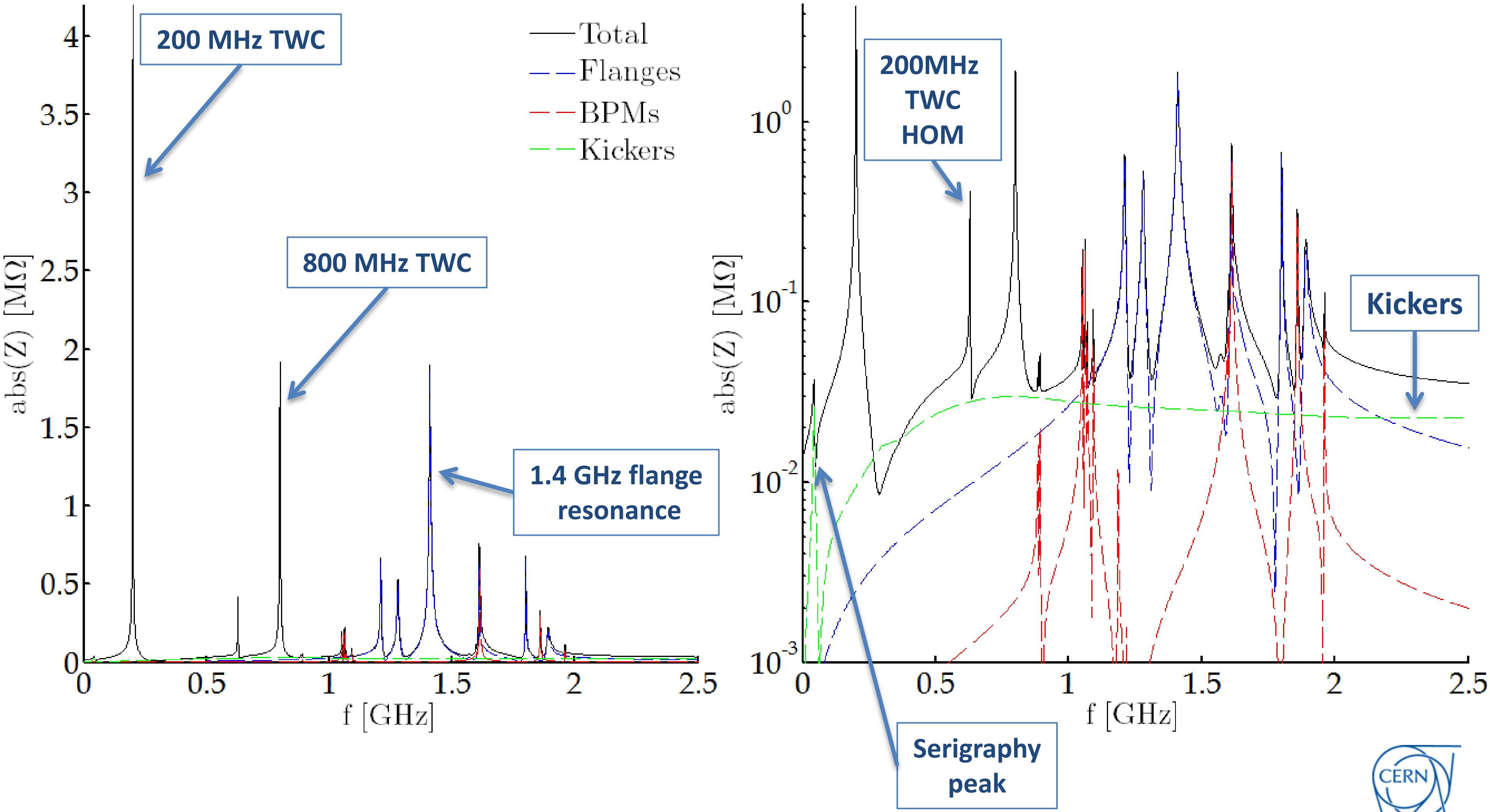
* Approximated by resonant impedances

$$\mathbf{50\ ns} < \frac{2Q}{\omega_r} < \mathbf{225\ ns}$$

More details on the current longitudinal impedance model can be found in [LIU-SPS BD WG, 27/03/2014 meeting]

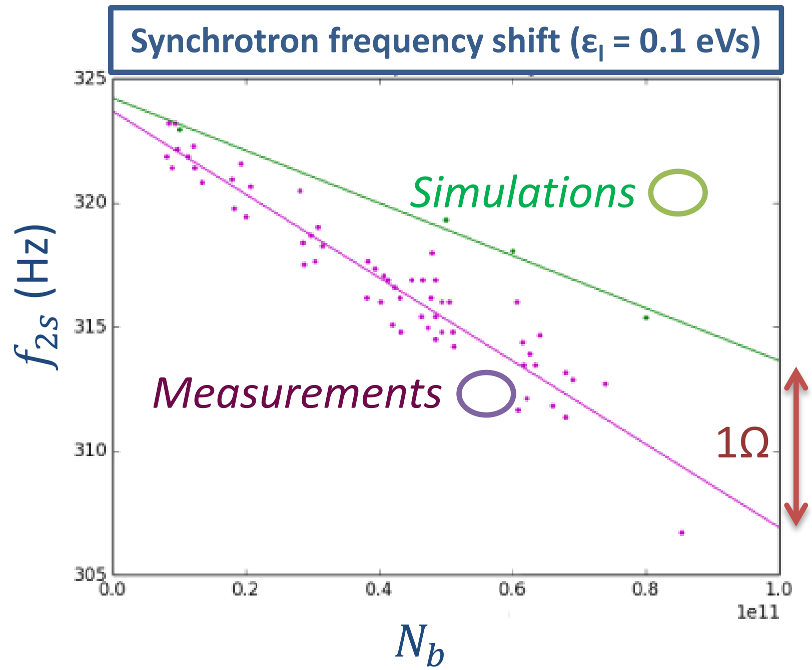
The longitudinal impedance model (II)

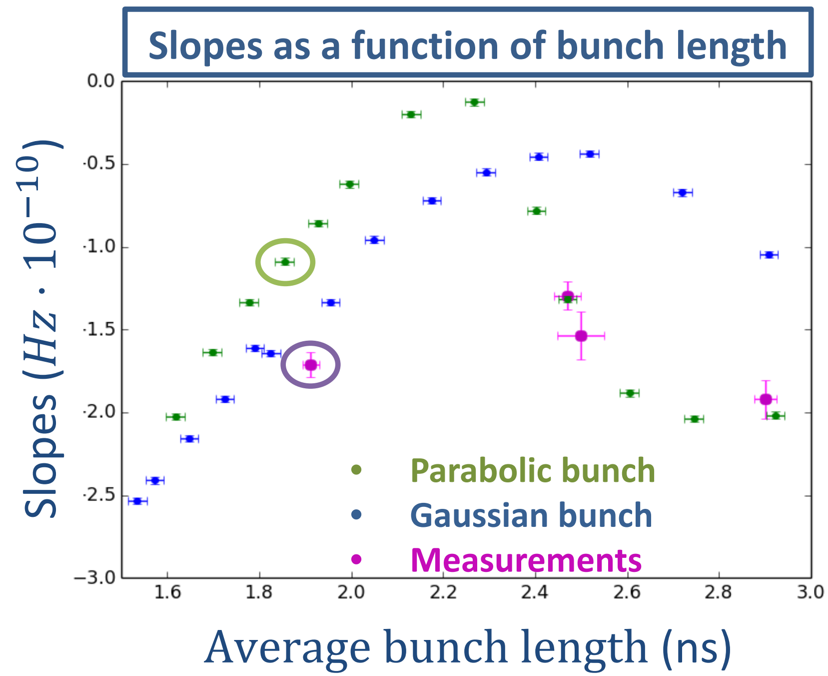
Current longitudinal impedance model in linear and logarithmic scale



Estimation of the inductive impedance (measurements and simulations)

- Quadrupole synchrotron frequency f_{2s} was measured from bunch length oscillations after injection of a single bunch into mismatched voltage.
  - Reduction of impedance observed with serigraphed MKEs (slope was reduced from $-4Hz \cdot 10^{-10}$ for 2.2 ns)

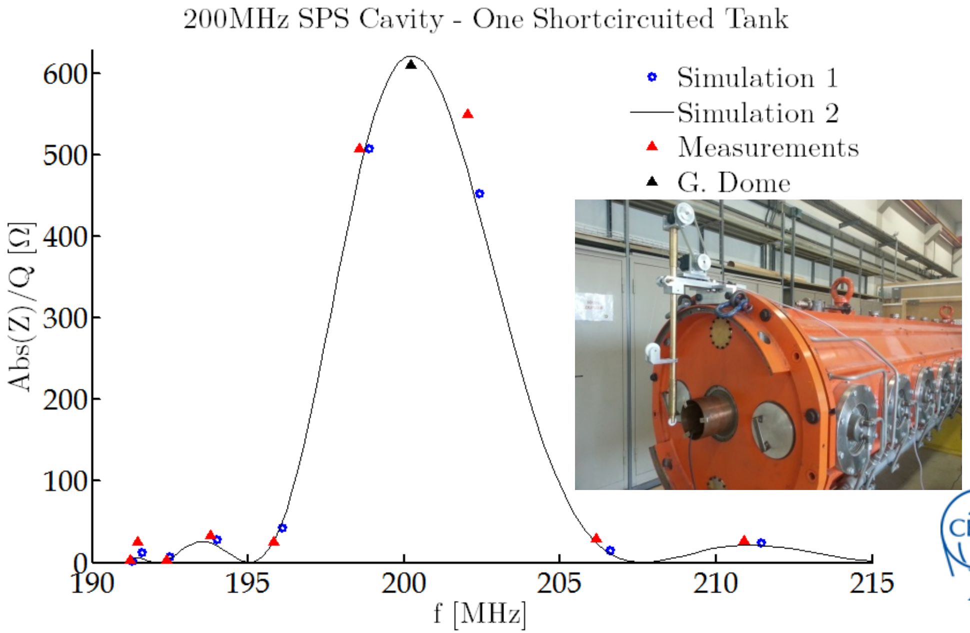




- **Estimation of effective Im(Z)/n** by comparison with simulations (based on SPS model)
- There is a strong dependence on bunch length => at 2.2 ns?
- **Still missing some impedance** (-1.5Ω for space charge)
  - Measurements at higher energies.

Conclusions

- **Instabilities are limiting the SPS performance**
  - Impedance reduction would help to reach *HL-LHC goals*
  - More simulations and beam measurements to confirm the guilty impedance sources
- From beam measurements, **current impedance model is not complete**
  - Travelling wave cavities – Measurements of the fundamental and higher order modes.
  - Other elements:
    - vacuum valves
    - unshielded pumping ports
    - …



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THANK YOU FOR YOUR ATTENTION!

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First thoughts on 1.4 GHz impedance reduction

Damping the resonances **does not help for single bunch instabilities** since R/Q remains approximately constant.

Any R/Q reduction strategy will imply opening **450** vacuum flanges…