Identification of impedance sources responsible of longitudinal beam instabilities in the CERN PS

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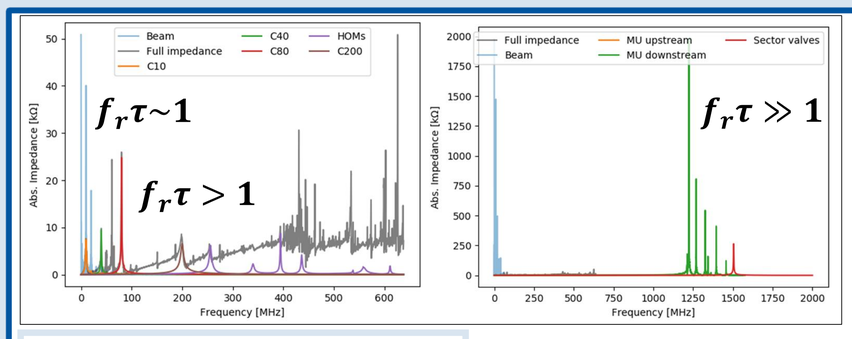
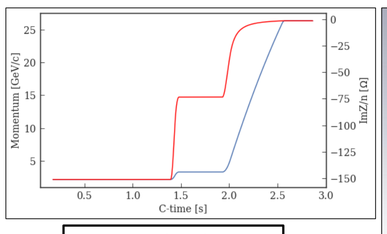
Abstract

Longitudinal instabilities in the CERN PS are an important limitation in the framework of the LHC Injector Upgrade (LIU) project to reach the expected beam intensity and longitudinal emittance at PS extraction. The observed instabilities include dipolar and quadrupolar coupled-bunch instabilities, as well as uncontrolled longitudinal emittance blow-up with protons. A microwave instability develops quickly at transition crossing with ion beams. To identify the potential sources of these instabilities, two strategies were adopted. Firstly, measurements were performed for different impedance configurations, i.e. by partially detuning the main rf cavities. Secondly, a thorough survey of the devices in the machine and rf studies allowed to refine the PS impedance model, in order to find potentially missing sources. Measurements were compared with particle simulations using the updated impedance model of the PS. Although the source of dipolar coupled-bunch instabilities was already identified in the past, this study led to the identification of the impedance sources driving the other types of longitudinal instabilities.

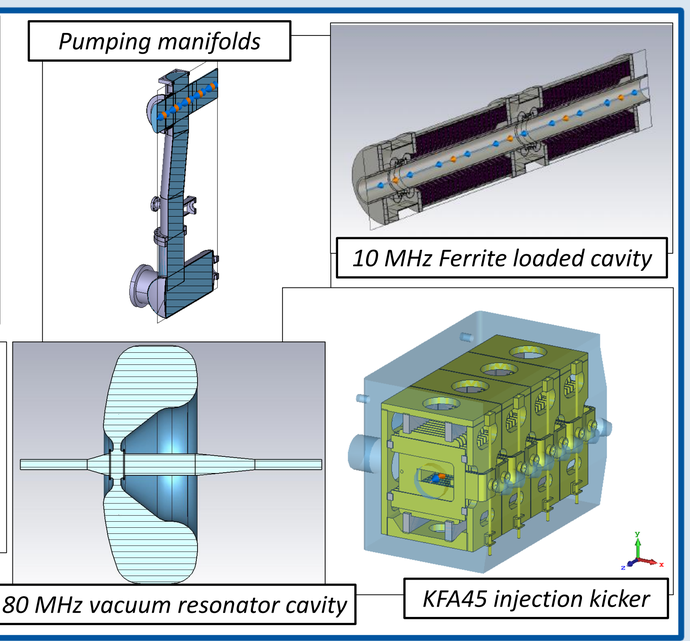
PS beam-coupling impedance model [1-5]



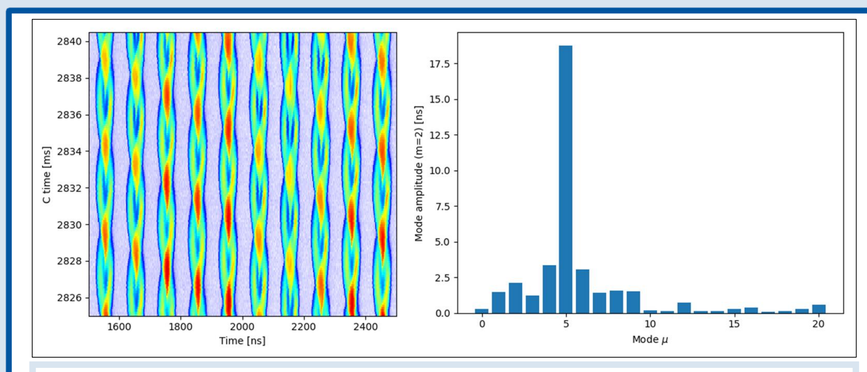
- Thorough (ongoing) survey and modelling of devices contributing to the PS beam-coupling impedance
- Diverse contributions: broadband, narrow band, high and low frequency
- ➢ **Various types of instabilities**



Longitudinal space charge (p+)

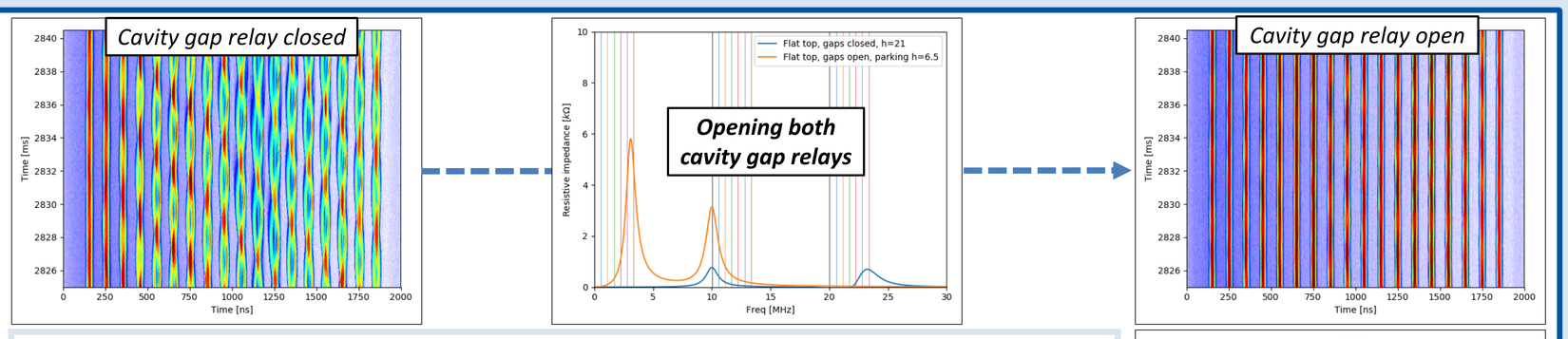


Quadrupolar coupled-bunch instability ($f_r\tau \sim 1$)

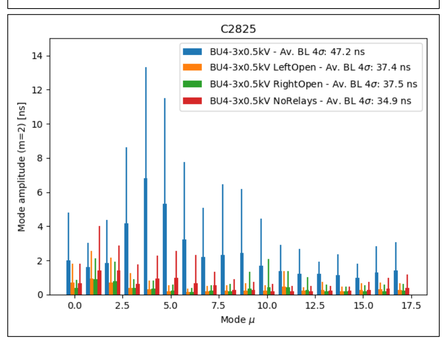


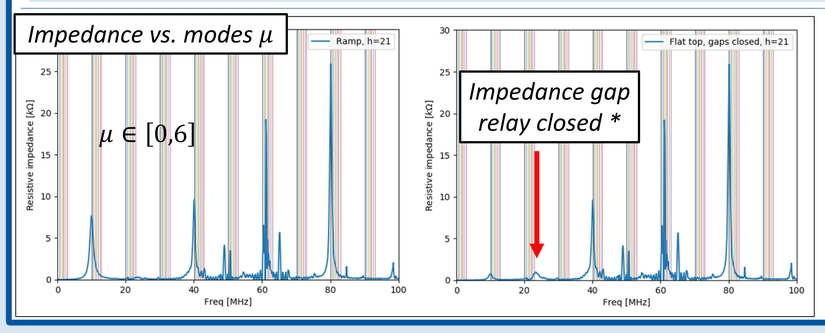
- The PS suffers from coupled bunch instabilities, the dipolar oscillations are damped by a dedicated feedback [6]. The quadrupolar oscillations can be analyzed to find the responsible impedance source.

$$A_\mu \sin(m\omega_s t + \phi_\mu) = \frac{1}{N_b}\sum_{p=0}^{N_b-1} A_b \sin\left(m\omega_s t + \phi_b - \frac{2\pi\,\mu\,p}{N_b}\right)$$



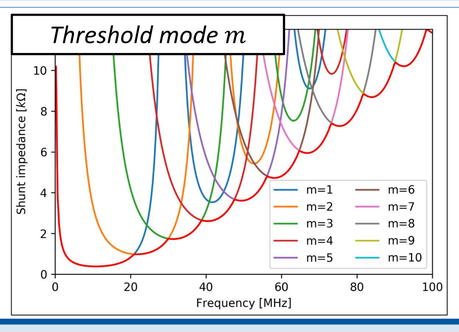
- Changing the 10 MHz cavity impedance to evaluate its influence on coupled-bunch instability
- The gap relay of the cavities are closed to minimize beam loading when cavities are not in use. These can be left open (right gap, left gap, or both) and cavities tuned at low frequency, far from the quadrupolar instability region (NB: dipolar instability still damped by the coupled bunch feedback)
- ➢ **The impedance of the 10 MHz cavities with closed gap relay at ~23 MHz is a clear candidate as drive of the quadrupolar coupled-bunch instability**





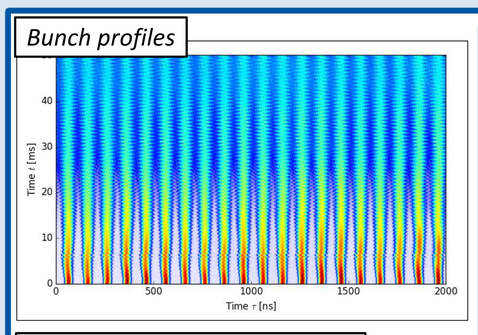
- Finding the characteristics of the impedance from the coupled bunch mode (coupled bunch instability with narrow-band resonator)
- We look for location in frequency favorable to drive $m = 2$ (right) and $\mu = 5$ (left) using Eqs. (1) and (2) [7]

(1) $f_{p,\mu} = (p\,N_b + \mu)\,f_{\text{rev}} + m\,f_s$
($m = 1$ -> dipole, $m = 2$ -> quadrupole)

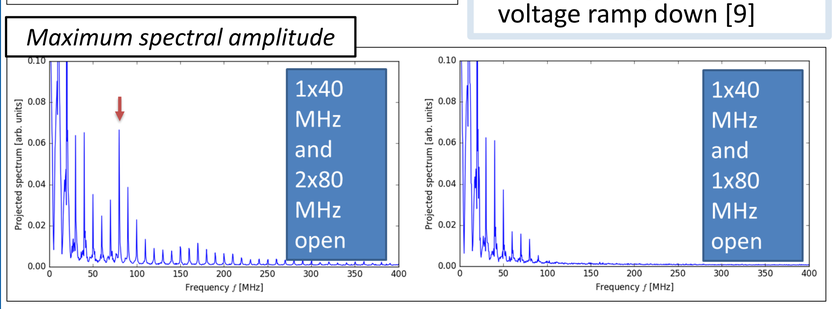


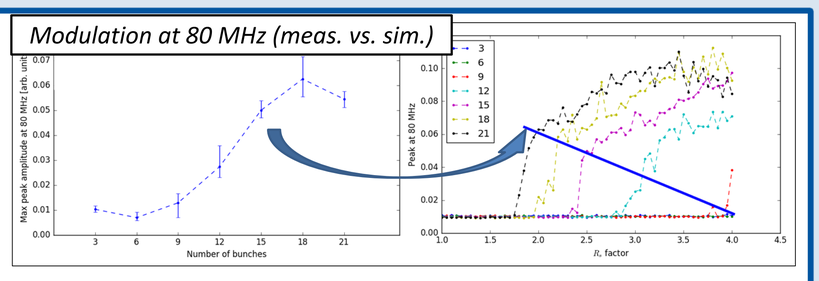
(2)
$$R_{sh} < \frac{|\eta|E}{eI_0\beta^2}\left(\frac{\Delta E}{E}\right)^2 \frac{\Delta\omega_s}{\omega_s}\frac{F}{f_0\tau}G(f_r\tau)$$
$$G(x) = x\min\{J_m^{-2}(\pi x)\} \quad F \sim 0.3$$

Modulation of beam profile with rf off ($f_r\tau > 1$)



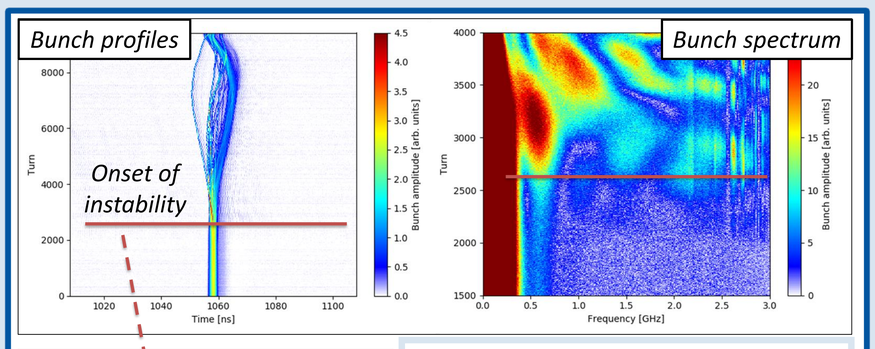
- RF voltage of 10 MHz cavities isoadiabatically decreased to 1 kV in $h = 21$ (then switched off)
- The beam is modulated by high frequency impedance sources $f_r\tau \gg 1$. Requires slow debunching provided by small $\Delta p/p$ with RF voltage ramp down [9]

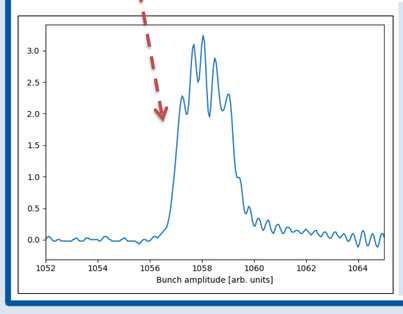




- Peak amplitude of the spectrum at 80 MHz in measurements (left) and simulations using BLonD with only the 80 MHz cavities impedance [8] (right)
- For a large number of bunches, the most relevant parameter is the shunt impedance (and not R/Q)
- ➢ **The original 80 MHz impedance model in simulations missed a factor of 2-3 depending on the number of bunches. Investigations are ongoing to find the source of discrepancy (influence of direct feedback, etc.)**

Ions transition cross. ($f_r\tau \gg 1$)





- The beam is modulated by high frequency impedance sources $f_r\tau \gg 1$, slow debunching at transition with slippage $\eta_0 \approx 0$, perturbation spectrum is $S_1 \sim n\,S_0(n - n_r)$ [9-10]
- ➢ **Already some suspect impedance sources at high frequency**

Conclusions

The development of the PS impedance model is done by combining efforts of modelling the devices in the machine but also by performing beam measurements of the impedance. The impedance sources responsible of longitudinal instabilities are mostly identified or have clear suspects:

- ➢ **The 10 MHz cavities with closed gap relay at ~23 MHz are responsible of the quadrupolar coupled-bunch instability**
- ➢ **The 80 MHz cavities are responsible of uncontrolled blow-up during splitting**
- ➢ **High frequency impedance sources (e.g. pumping manifolds, sector valves) are suspected to drive microwave instability at transition crossing for ions**

Progress in particle simulations is also ongoing and will require an accurate modelling of feedbacks to reproduce all measured instabilities.

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