



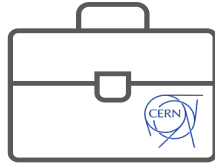
Probing Transverse Impedances in the High Frequency Range at the CERN-SPS

HB conference, 9-13 Oct. 2023, *Flash presentation*

Elena de la Fuente García, Ingrid Mases Sole, Hannes Bartosik, Giovanni Rumolo, Carlo Zannini



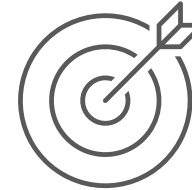
About me



2 years at CERN with
graduate program

Now started PhD at CERN
in Jul 23' 😊

In collab with UPM, Madrid,
Spain



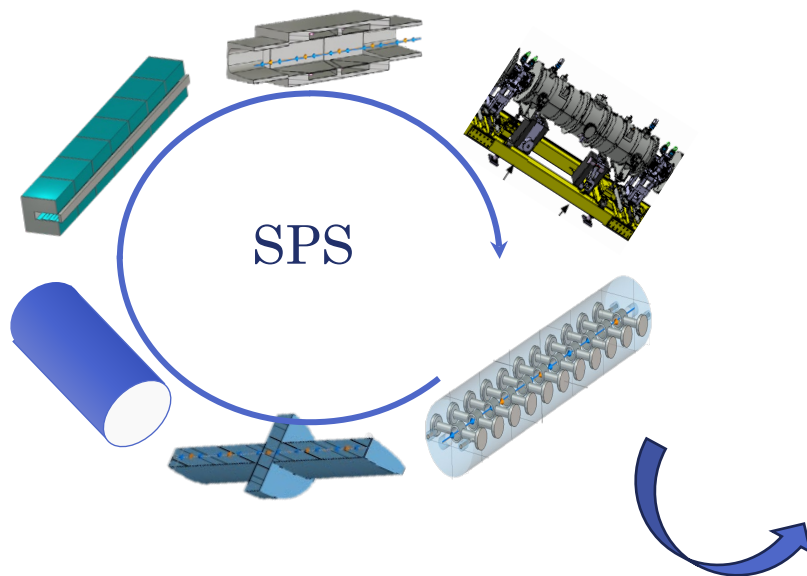
Working at CERN-
BE-ABP-CEI section

PhD topic: “3D Time
domain wake solver for
impedance calculations”



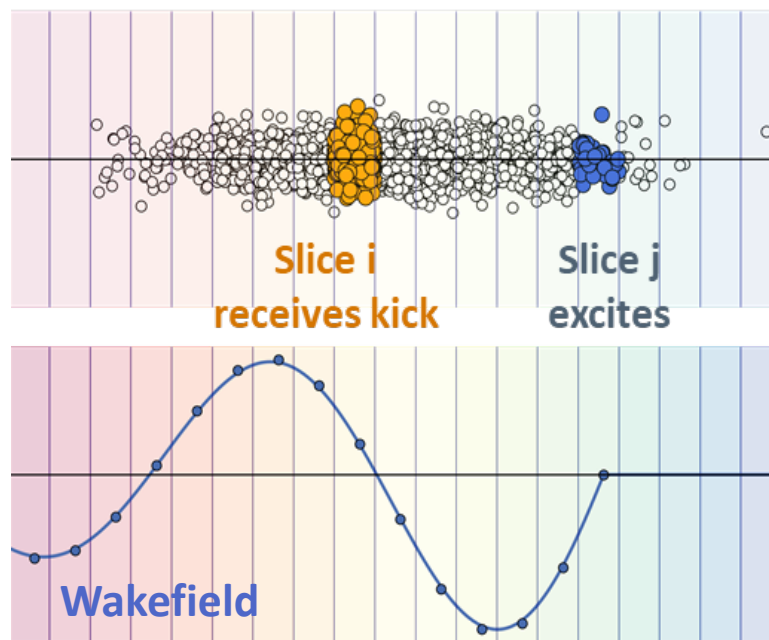
Motivation of the studies

We construct the **SPS impedance model** from simulations and/or bench measurements



Need to benchmark the model!

We use the impedance model in **PyHEADTAIL simulations** to predict beam behavior

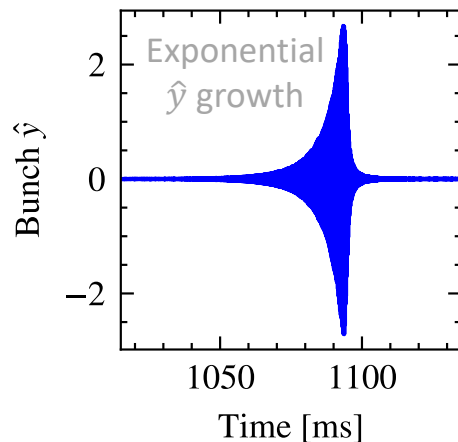
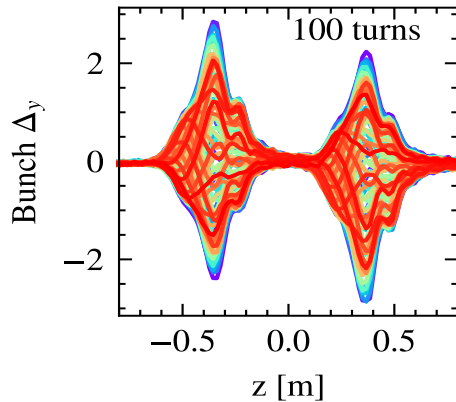


*Images from K. Li and G. Rumolo "Beam Instabilities III", CAS 2022, Sevrier, France [\[link\]](#)



Growth rate measurements

Head-Tail mode zero signature (mirrored)



Beam-based measurements benchmark:

Measure Head-Tail mode zero instability **growth rate** vs **chromaticity** to benchmark the **transverse impedance** model

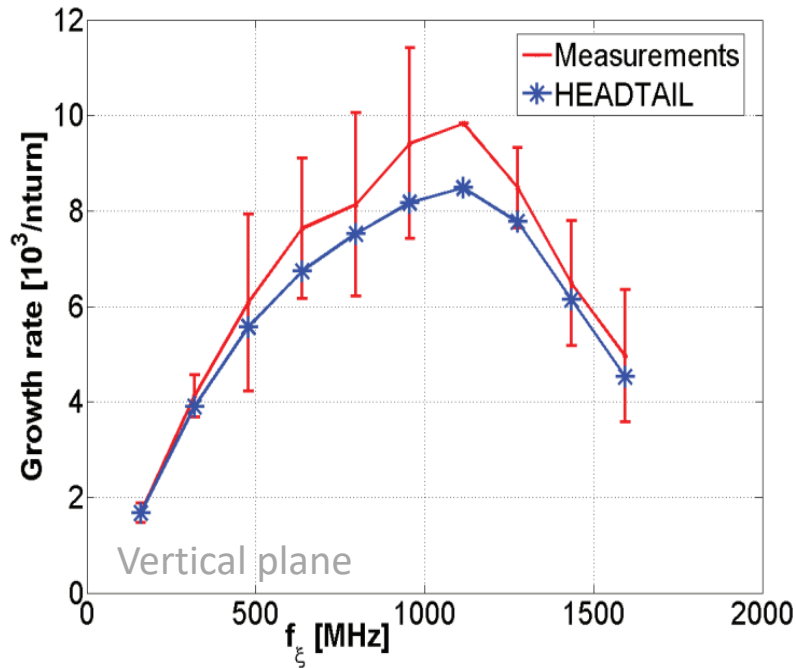
$$\tau^{-1}(\xi) = \Gamma\left(\frac{1}{2}\right) \frac{\text{Re}\left[Z_{\perp,dip}^{eff}(\xi)\right] N r_0 c^2}{8\pi^2 \gamma Q_{\perp} \sigma_z}$$



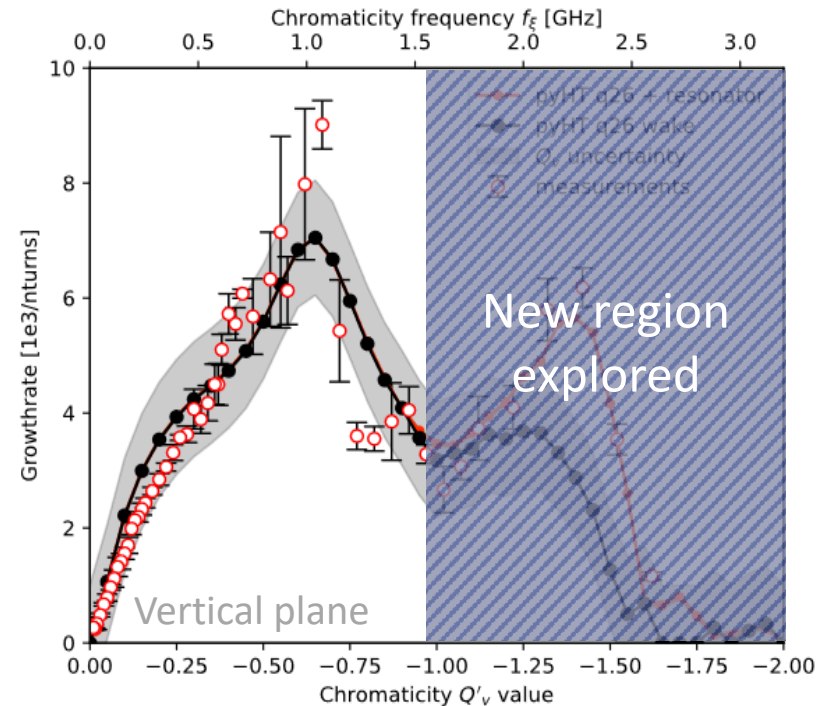
Previous findings

2013 measurements*

Pre-LS2



2022 measurements**



Uncertainty of the second peak:

- Lack of chromaticity Q' measurements
- Scarcity of points

*C. Zannini, MOPJE049, IPAC 15

**E. de la Fuente, WEPL155, IPAC 23



Chromaticity measurements

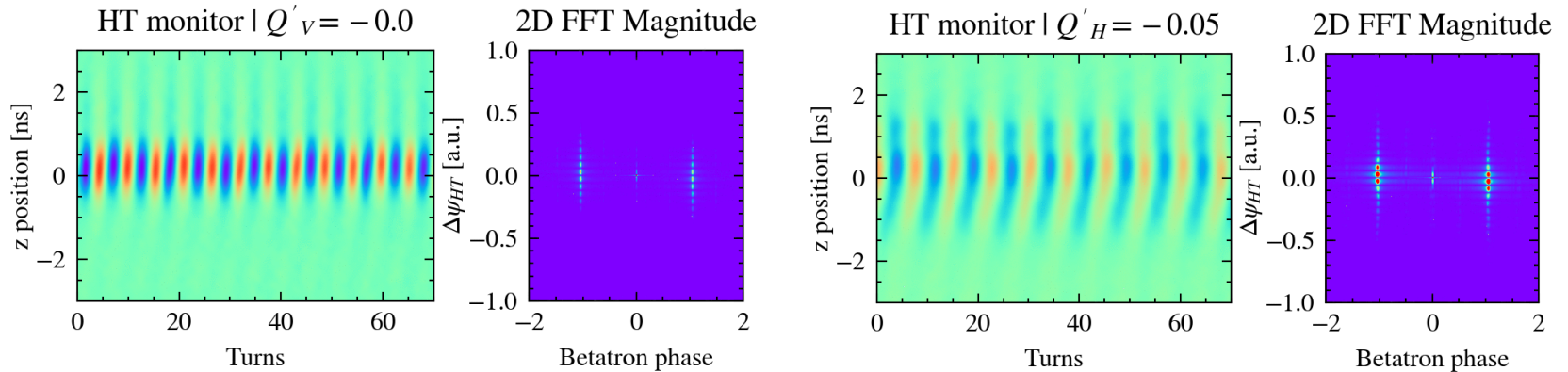
2023 measurements: Measuring Q' from Head-Tail phase shift data using 2D Fourier Transform



Chromaticity measurements

2023 measurements: Measuring Q' from Head-Tail phase shift data using 2D Fourier Transform

Measurements

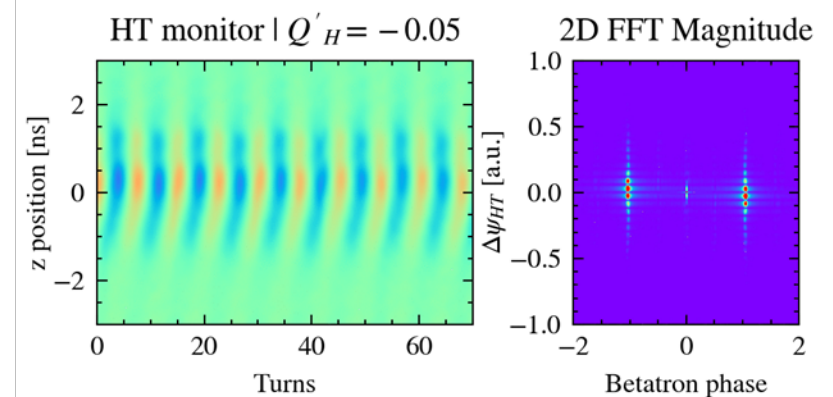
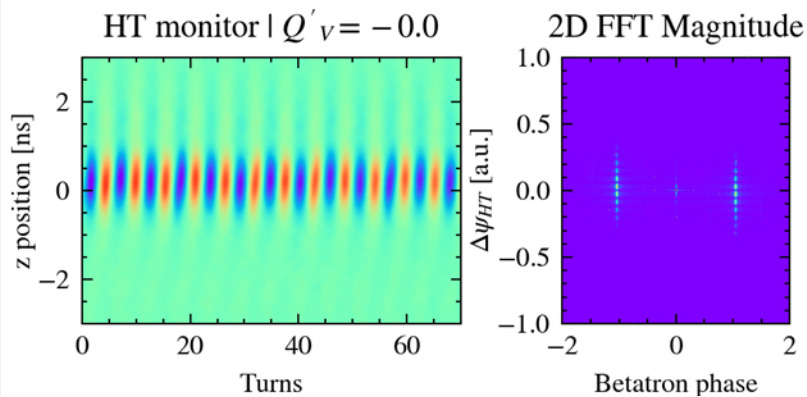




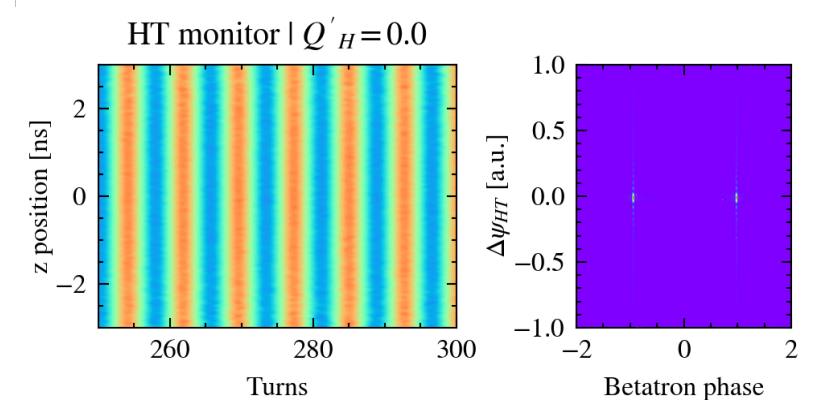
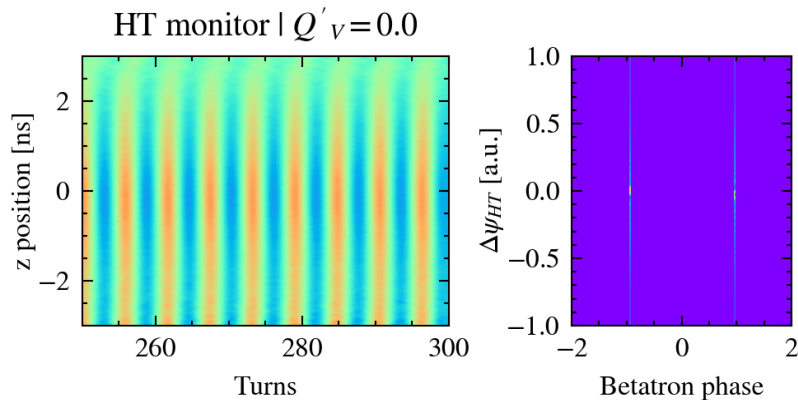
Chromaticity measurements

2023 measurements: Measuring Q' from Head-Tail phase shift data using 2D Fourier Transform

Measurements



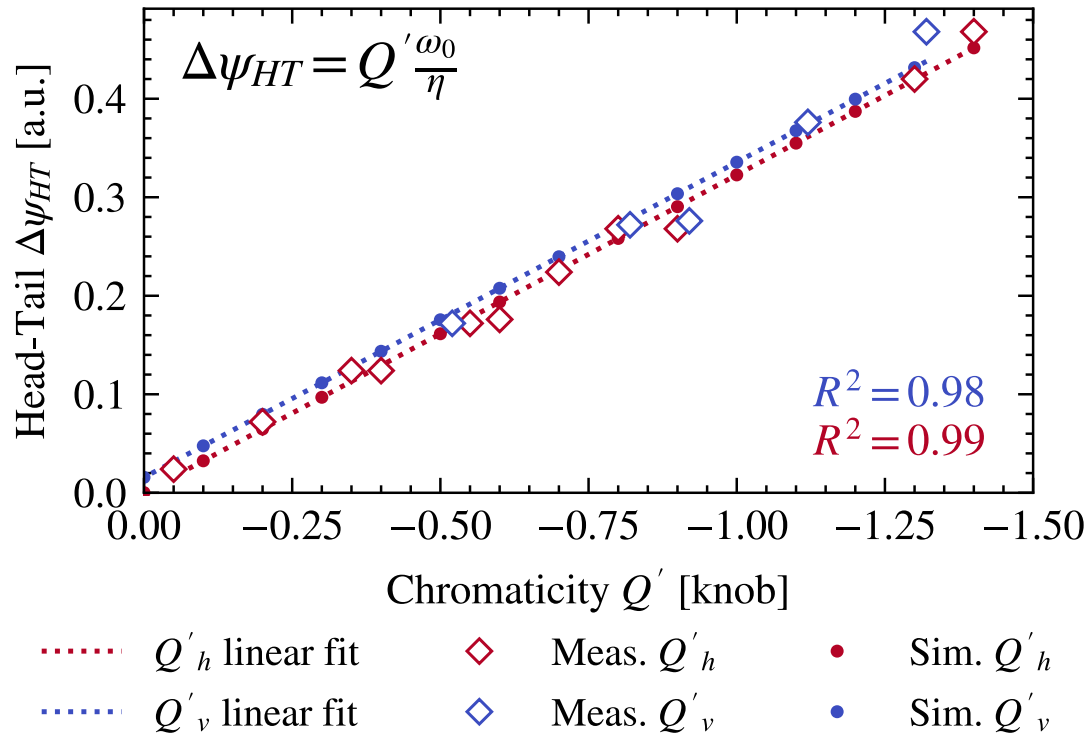
PyHEADTAIL





Chromaticity measurements

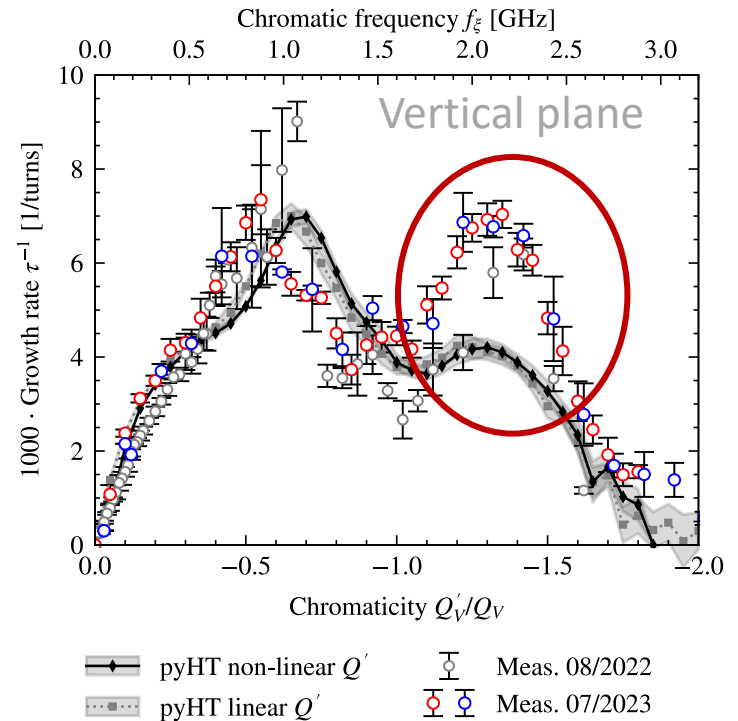
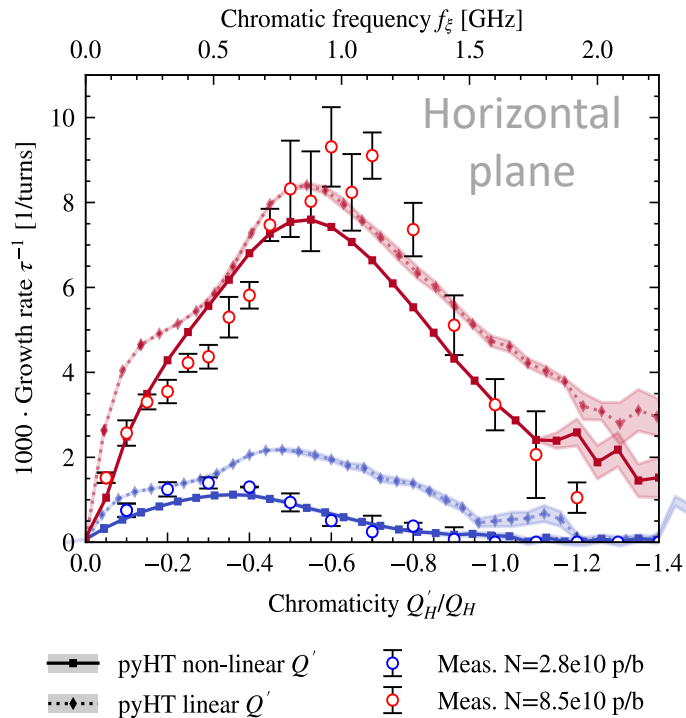
2023 measurements: Linearity of phase shift $\Delta\psi_{HT}$ with Q' probed





Key results

2023 measurements



Future work aims to clarify the origin of this impedance contribution

Thank you
& see you at the poster session 😊 !!!

Probing Transverse Impedances in the High Frequency Range at the CERN-SPS

E. de la Fuente¹, I. Mases², H. Bartosik, G. Rumolo, C. Zannini

¹ also at Polytechnic University of Madrid, Madrid, Spain ² also at Goethe University of Frankfurt, Frankfurt am Main, Germany

Overview

The SPS transverse impedance model which includes the major impedance contributions in the machine, can be benchmarked through measurements of the head-tail mode zero instability. Since the SPS works above transition energy, the head-tail mode zero is unstable for negative values of chromaticity. The measured instability growth rate is proportional to the real part of the transverse impedance. Studies performed after the LHC Injector Upgrade (LIU) showed a relevant impedance contribution around 2 GHz with high chromaticity values (CQ).

This paper presents a follow-up to probe the behavior of this beam coupling impedance contribution. Our studies include measurements of instability growth rates in both vertical and horizontal planes, spanning a broad spectrum of negative chromaticity values. To address the uncertainties in the high chromaticity frequency range, the SPS Head-Tail monitor data is used to calculate the fit-bunch chromaticity content through a 3d-dimensional frequency domain analysis.

GROWTH RATE MEASUREMENTS

Studying the instability growth rate for a wide range of negative chromaticities $\xi = Q^* < 0$ provides information on the frequency dependence of the SPS transverse impedance Z_{\perp} . The order slip factor σ of the high-gain transition CQ2 optics (1) together with the delayed term strategy inherent in (2) allow to explore the high frequency regime $f = (Q_{\text{ext}}/\sigma) \approx 1.2$ GHz.

During the 2022 studies (3) the 40 modulation method (MURC) to measure chromaticity provides unambiguous values for ξ - adding an uncertainty to the growth rate data in the high frequency regime.

As an alternative, chromaticity can be deduced from the instability width-bunch monitor using the head-tail phase shift technique (5)

$$\varphi(\xi) = A \cos[2\pi f_0 + 2\pi \nu_{\text{ext}} \text{Re}(Z_{\perp} Q_{\text{ext}}) - \xi]$$

Each bunch slice $\nu(\xi)$ suffers a betatron phase modulation that translates into a longitudinal ordering of the bunch:

- The ordering angle depends on the chromaticity value $\nu(\xi) = \nu_0 + \nu_1 \xi$ is clearly observed in SPS head-tail monitor measurement (Fig. 2a).
- Applying a 2D Fast Fourier Transform (FFT) to the data allows to measure the offset between the two head-tail monitors (Fig. 2b).
- Fig. 2c probes the quality of the above offset when varying the chromaticity value. For such measurements, the HYPAD3D simulation, measuring the uncertainty of ξ in the high frequency regime.

SEQUENCE

1. When a negative chromaticity trim is applied, the beam becomes unstable, allowing sharp intensity losses (Fig. 3a).
2. If the scan of negative chromaticity is performed in the vertical plane, the bunch vertical centroid position exhibits an exponential growth (Fig. 3b).
3. The growth rate ω of the bunch-bunch ω data is obtained applying the Moving Window Fourier Transform (Fig. 3c).

COMPARISON WITH SIMULATIONS

Simulations of the instability growth rates using the latest CQ2 SPS transverse impedance model's wake (4) have been matched to beam observations using the Pedagogical macroparticle tracking code (5), including an updated non-linear chromaticity model with coefficients Q^* measured since in 2023.

HORIZONTAL PLANE

Two sets of 50 scans with different chromaticities are compared to simulations (Fig. 3d).

For the set with lower chromaticity, the exponential growth rate was not visible, yielding $\omega^* = 0$ to $\xi = -0.4$.

Thus, a set of measurements was conducted at higher chromaticity to enhance the instability growth rate ω^* at high f .

VERTICAL PLANE

The new set of 50 scans together with 2022 data, are compared to simulations (Fig. 3e).

The comparison showed 0.1 GHz to have some noise and points to a possible impedance contribution that is not present in the current impedance model.

This missing impedance could be modeled by a broad-band resonator with $\nu_{\text{ext}} = 1.2$ GHz (Fig. 4) in 2D-GM.

Conclusions

As part of the LIU-LIU initiative, a further benchmarking of the current transverse SPS impedance model, not conducted through reference impedance measurements of the mode-zero head-tail instability in both transverse planes, extending to high chromaticity frequencies with the CQ2 optics.

- To address the uncertainty of negative chromaticity values, we employed a 2D Fourier analysis to measure the head-tail phase shift, proportional to the machine chromaticity.
- Comparing our measurements with HYPAD3D simulations, incorporating the latest CQ2 transverse wake and non-linear chromaticity model, we found good agreement in the horizontal plane. However, in the vertical plane, measurements confirmed a discrepancy around 2.0 GHz, consistent with previous findings.

Further work will involve dedicated studies aimed at refining the existing impedance model in the high-frequency regime.

References

(1) M. Giovannozzi, et al., Proc. 2017 IPAC, pp. 2205-2208, 2017.
(2) E. de la Fuente, et al., Proc. 2017 IPAC, pp. 2209-2212, 2017.
(3) E. de la Fuente, et al., Proc. 2022 IPAC, pp. 2205-2208, 2022.
(4) E. de la Fuente, et al., Proc. 2022 IPAC, pp. 2209-2212, 2022.
(5) E. de la Fuente, et al., Proc. 2022 IPAC, pp. 2205-2208, 2022.

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