Noise studies with Crab Cavities in the SPS for the HL-LHC project

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy

by

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Day Month Year

Abstract

Acknowledgments

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E	Energy
CC	Crab Cavity
f_{CC}	*CC* frequency

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Chapter 1

Introduction

This is the introduction of my PhD thesis.

Testing for footers and headers Testing citation [1]. wefefklje

Test list of symbols with E .

Chapter 2

Basics of accelerator beam dynamics

Chapter 3

Theory of Crab Cavity noise induced emittance growth

Chapter 4

First experimental campaign in the SPS

In 2018, two prototype Crab Cavities (CCs) were installed in the SPS to be tested for the first time with proton beams. One of the operational issues that needed to be addressed concerned the expected emittance growth due to noise in their RF control system. A theoretical model that describes this emittance growth had already been developed and validated by tracking simulations [1]. Based on those studies a dedicated experiment was performed to benchmark the models with experimental data and to confirm the analytical predictions. In particular, the idea was to inject various noise levels in the CC RF system and record the emittance evolution. In this chapter, the experimental procedure, the measurement methods and results are presented and discussed.

The chapter is stractured as follows: Section 4.1 describes the operational setup for the SPS CC tests and discusses the main diagnostic deployed for the derivation of the CC voltage.

blah blah ... describe sections and subsections after they are completed.

4.1 Crab Cavities in the SPS

For the SPS tests two prototype CCs of the Double Quorter Wave (DQW) type were fabricated by CERN and were assembled into the same cryomodule [2]. The cryomodule was installed in the SPS-LSS6 zone and was placed on a mobile transfer table [3]. The table moved with high precision and without breaking the vaccum the cryomodule in the beam line for the CC tests and out of it for the usual SPS operation. For the emittance growth measurements only one of these CCs was used and its main optics and desgin parameters are listed in Table 4.1.

Operational considerations

Energy ramp
SPS recieves the beam at 26 GeV. It was observed that if the ramp to higher energies was performed with the CC on, the beam was lost while crossing one of the vertical betatron sidebands due to resonant excitation. Therefore, it was established the

Table 4.1: CC parameters for the SPS emittance growth tests

Parameters	**Values**
crabbing plane	vertical
s-location	6313.32 m
f_{CC}	400 MHz
$\beta_{x,\mathrm{CC}}$	30.31 m
$\beta_{y,\mathrm{CC}}$	73.82 m

energy ramp has to be performed with the CC off and its voltage must be set up only after the energy of interest has been achieved. It should be noted here that this will be the operational scenario also for the HL-LHC.

Crab Cavity - main RF synchronisation
Another issue of concern was the fact that the CC operate at the fixed frequency of 400 MHz while the SPS main RF system operates at 200 MHz. In order to make sure that the beam will experience the same effect from the CC each turn the SPS main RF has to be re-phased such as it becomes synchronous with the crabbing signal. For studies at the injection energy of 26 GeV this synchronisation took place shortly after the injection. For the emittance growth measurements which were performed at 270 GeV the synchronisation took place at the end of the ramp shortly after the cavity was switched on.

4.1.1 Crab Cavity voltage callibration

The Head-Tail (HT) monitor was the main diagnostic device used for the measurement of the CC voltage in the experiment. In the first part of this section some basic information on the instrument and its usage will be discussed. Subsequently the method used for the voltage callibration from its reading will be explained.

The Heat-Tail monitor
A standard beam position monitor (BPM) measures the bunch centroid position in the transverse planes at every passage of the beam. The HT monitor is a high bandwidth version of a standard BPM and can measure the transverse offset within the bunch. Its reading consists of the sum Σ and the difference Δ of the electrode signals of a straight stripline coupler [4]. The Σ signal is the longitudinal line density while the Δ signal corresponds to the intra-bunch offset.

Figures 4.1 - 4.3 show some example signals obtained from the HT monitor. In particular, Fig. 4.1 illustrates the signal acquired over a single turn of the bunch around SPS. It should be noted here, that the signal after ~ 9 ns is just the reflected pulse of the bunch signal from the opposite end of the stripline. Figure 4.2 illustrates the signals acquired over several turns while Fig. 4.3 shows the 2D representation. Color?? wait for Hannes question. In the 2D representation the blue color corresponds to the reflected signal. In the specific example a clear periodic oscillation of the vertical Δ signal is observed. This is a result of the main RF system not being synchronous with the CC frequency.

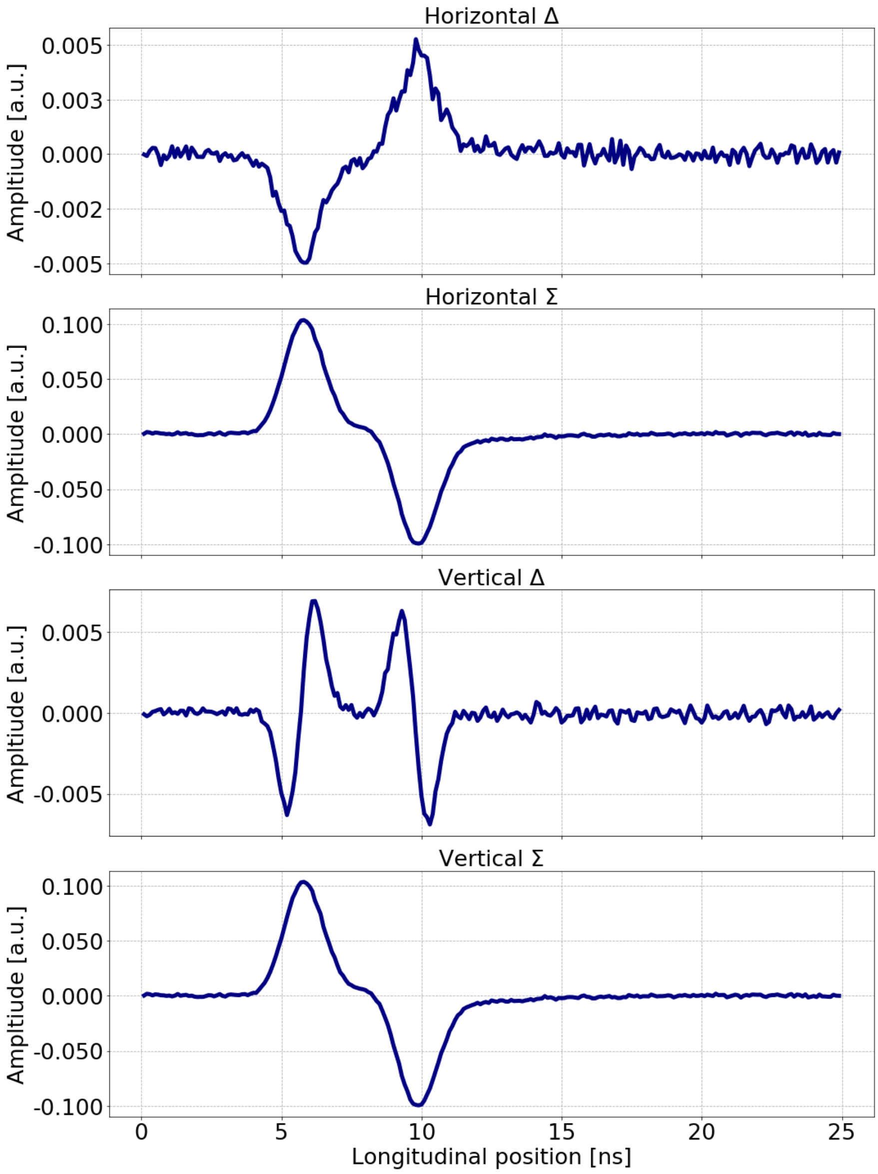

Figure 4.1: Example Δ and Σ signals obtained from the HT monitor for a window of 25 ns, acquired in a single SPS revolution.

What is needed –> unsynchronised

The effect of the CC on the beam was measured

Voltage measurement with HT monitor. blah balah. why was it chosen over the other instruments.

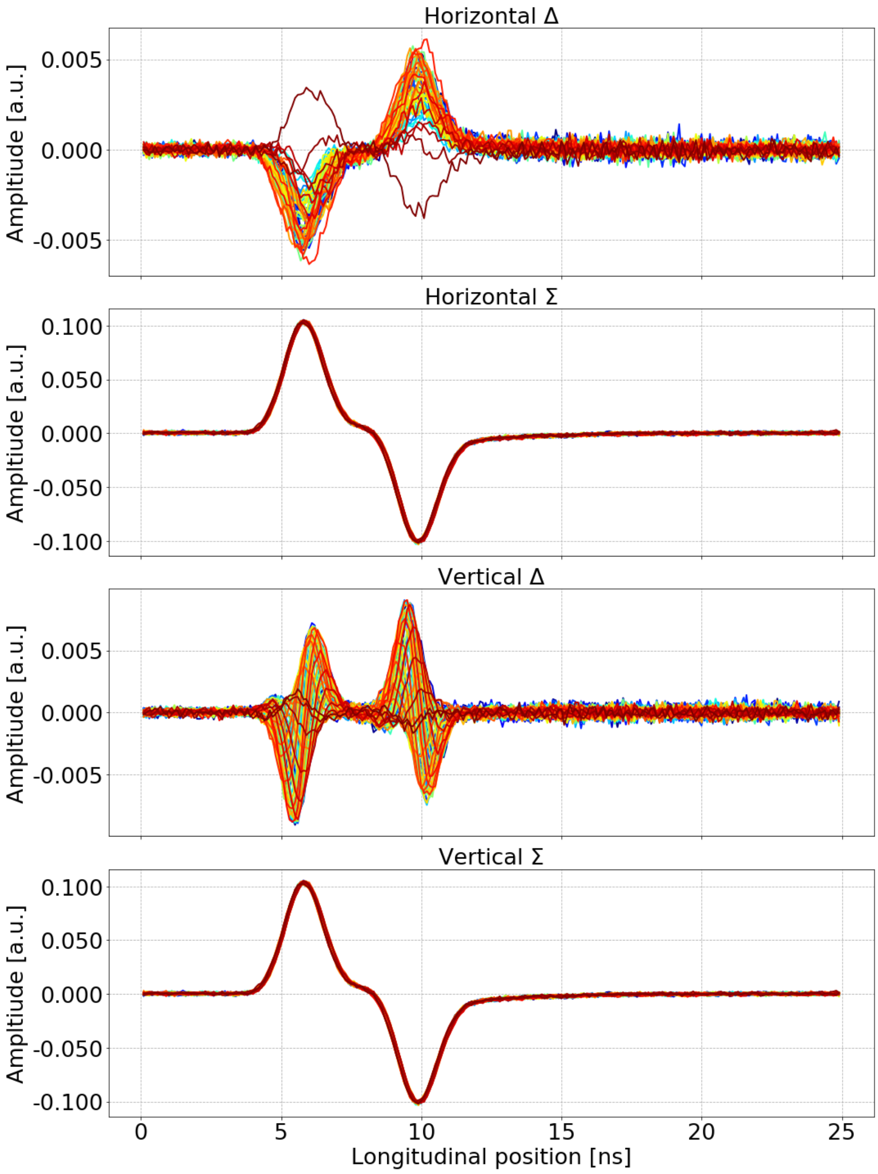

Figure 4.2: Example Δ and Σ signals obtained from the HT monitor for a window of 25 ns, acquired over several SPS revolutions. The color code indicates the different turns around the machine.

4.2 Experimental procedure

4.2.1 Machine and beam configuration

4.2.2 Measurement methods

What do we measure and how? emittance (show plot ws) bunch length ABWLM –> we take the measurement directly from the resposnible tema –> show also from the instrument that we saw the unstable bunches.

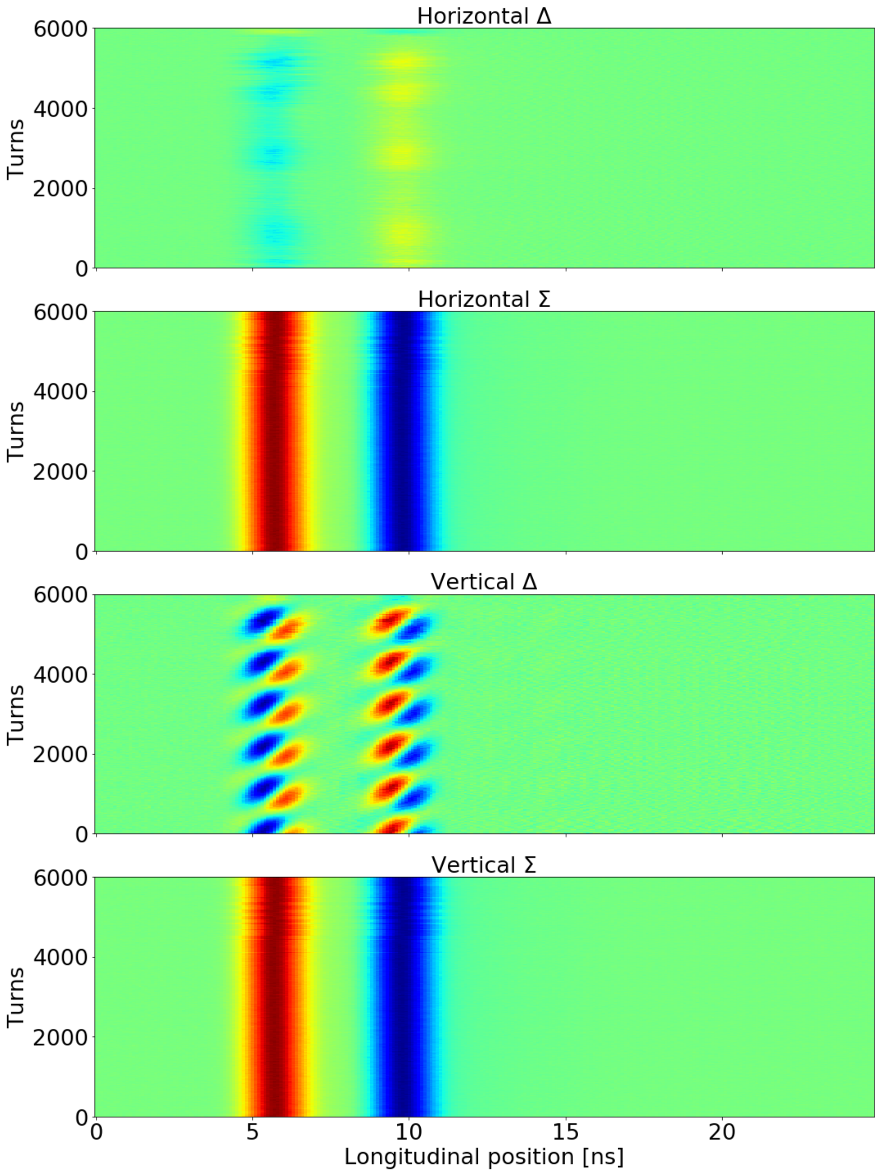

Figure 4.3: 2D representation of example Δ and Σ signals obtained from the HT monitor for a window of 25 ns, acquired over several SPS revolutions.

4.3 Experimental resutls

4.3.1 Overview

- bunches 2, 3 and 4 unstable

4.3.2 Comparison with the theory

This chapter is adapted from the the studies published in Ref. [5]

4.4 Experimental Setup

Several experimental studies have been performed (2010-2017) to identify the optimal conditions for the emittance growth studies with CCs in the SPS [6, 7]. Based on these preparatory studies, the measurements in the SPS were performed with four low intensity ($\sim 3 \cdot 10^{10}$ ppb) bunches at 270 GeV. To minimise the emittance growth from other sources [7] the first order chromaticity, Q', of the machine was corrected to small positive values (~ 1-2) in both the horizontal and the vertical planes. During the measurements the Landau octupoles were switched off. It should be note, though, that a residual non-linearity was present in the machine mainly due to multipole components in the dipole magnets [8, 9]. Only one CC was used, providing a vertical kick to the beam. The transverse feedback system was switched off. Even though the emittance growth is a single bunch effect four bunches were used to reduce the statistical uncertainty of the measurements. The distance between the bunhces was 524 ns. An overview of the relevant SPS parameters during the experiment is given in Table

4.4.1 Injected RF noise

In order to characterize the CC noise induced emittance growth, controlled noise was injected into their LLRF system and the evolution of the bunch was recorded for about 20-40 minutes. The injected noise was a mixture of amplitude and phase noise up to 10 KHz, overlapping and primarily exciting the fisrt betatron sideband at ~ 8 kHz. The phase noise was always dominant.

Chapter 5

Investigation of the discrepancy

Chapter 6

Simple model of describing the decoherence suppression from impedance

Chapter 7

Application and impact for HL-LHC

Chapter 8

Conclusion

Appendix A

Appendix Title

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