DIAGNOSTICS NEEDS FOR BEAM-BEAM STUDIES AND OPTIMIZATION

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Abstract

During the past years of LHC operation we analyzed the situation of beam instrumentation and the need to optimize it for the beam-beam studies. The most important beam instrumentation devices will be highlighted and modifications or optimization will be suggested. A complete wish list will be presented to make sure we will be ready after LS1 (long shut-down 1) to study the beam-beam effect in a more complete way.

INTRODUCTION

The LHC Beam-Beam studies during last 3 years have been very fruitful thank the machine availability and the preparation of the beam studies at the injectors level. The help of some expert in the SPS and the CPS complex to obtain very intense bunch with low emittance were the important precondition to study the beam-beam phenomena in the LHC. A full set of measure has taken place in the LHC like:

1.0 Beam –beam losses for decreasing crossing angle.
2.0 Losses on Landau damping and measure the chromaticity.

During these studies we have heavily used the beam instrumentation devices and we could see that some important instrumentation was missing or not yet operational for beam-beam granularity measurements.

MOTIVATION

Beam instrumentation is extremely important for beam - beam studies, dedicated study of instabilities caused by beam-beam & data analysis to understand the phenomena. An ambitious aim would be to have a bunch-by-bunch measurement of tune, chromaticity, intensity and transverse emittance. A control of the beam stability is essential, to determine the turn-by-turn bunch position to measure the rise time and the frequency of the instability. This would allow us to measure and determine which mode is unstable, which instability type is present, as well as single/coupled bunch, single/coupled beam. An increased control of the stability would also help to understand the generation of the instability by impedance, electron cloud, beam-beam or a combination.

Another important achievement throughout a better stability control would be to determine which mode is present. The ADT future development might allow us to measure the two beams synchronized in time (at turn level). The new head tail monitor could give access to intra bunch motion and a reliable, continuous chromaticity measurement. Finally, an interesting study could be combined beam-beam/impedance modes.(Fig 1)

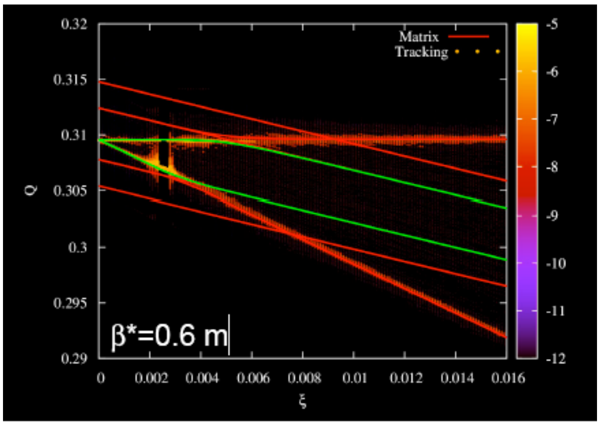

Fig 1: Combine beam-beam/impedance modes.

Another important reason for bunch-by-bunch measurement is to be able to characterize bunch parameters from beam-beam perspective and correlate to luminosity lifetime degradation. If we compare this to simulation and try to understand the process, we could reduce the trial and error method and improve optimisation of the luminosity lifetime. Working point optimization gave 15-20% reduced emittance growth over first 15min HEP stores in Tevatron RUN II away from 5^{th} and 12^{th} order resonance. Parameter space to scan is large, tune, chromaticity, octupoles and damper setting are the most important candidates. (Fig 2)

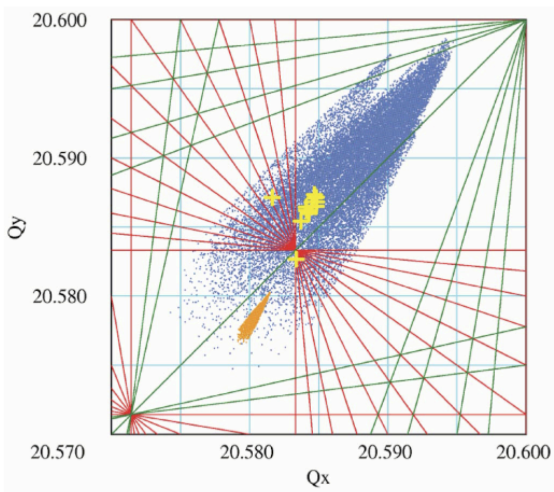

Fig 2: Tevatron tune footprint

During regular operation beam-beam parameters have a slow evolution therefore measurements from a few seconds to 1 minute would be suitable.

In the squeeze or colliding beam processes instabilities can develop very fast. We need a triggered measurement from a few seconds to one minute to catch these instabilities. A snapshot of the machine parameters and bunch by bunch measurement covering the full collision beam process (60 sec) would be the adequate tool to observe and understand the nature of the instabilities.

If instabilities due to beam-beam provoke a beam dump the only observable signal will be available from the post mortem system. A possible improvement will be to extend the buffer to 1 sec.

We need:

High resolution, as the instabilities are fast (200 turns)

Large data buffer, we need to acquire all bunches for a maximum of turns.

Triggering system, to be able to acquire 1, 2 sec before instabilities are detected (by BBQ, BLM, other system?) , to make sure the instabilities are always caught when they occur.

OBSERVATION OF ISTABILITIES

In 2012, the optimization of the machine performance by reaching small emittances , small β*,tight collimator settings (leading to large impedance), and more intensity per bunch; lead to instabilities which started to limit LHC efficiency. If we can measure tune and chromaticity for specific bunches we will be able to understand and possibly cure these instabilities.

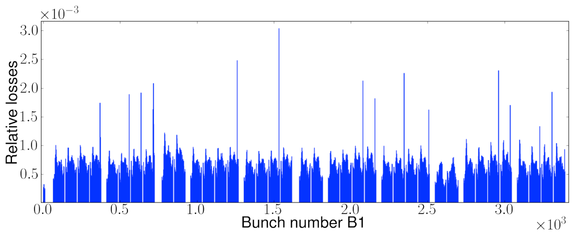

Fig 3: Bunch-by-bunch relative losses during the end of squeeze instability

Instabilities in 2012 were essentially observed by BLM, BBQ, MIM (Multiband-Instability-Monitor) and transverse damper signals.

The new head tail monitors will enables to look inside the bunch and understand the type of instability by analyzing the transverse motion. Its operational development is paramount as it is the only device that can observe the mode of instability. (Fig 4)

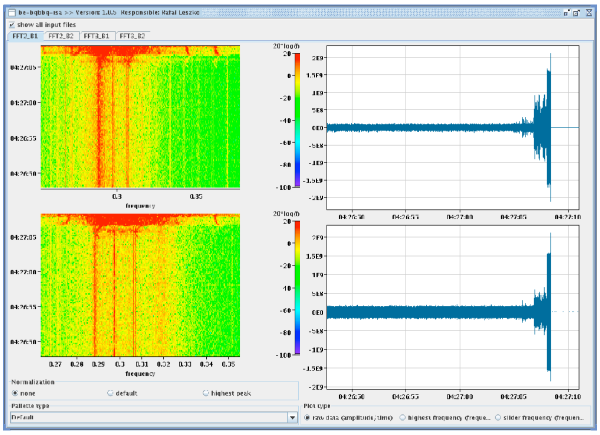

Fig 4: Multiband-Instability-Monitor MIM (Intrabunch instability)

The tune measurement is vital for beam-beam studies. The BBQ system facilitated a reliable commissioning and operation of the LHC. Single bunch tune could be measured by both BBQ & Schottky systems. During protons run 2012 Schottky signal was only sufficient on B1H for single & multi bunch measurements at injection & stable beams. Unfortunately large coherent signals saturate and destroy the pre-amplifiers in the other systems. The Schottky system is one of the systems capable of measuring bunch-by-bunch tune and chromaticity in a non-invasive independent way. We strongly hope to have tune and chromaticity reliable measurements available after LS1. Schottky system have been used successfully in other machine (SPS, Fermilab, RHIC)

Transverse damper (ADT) buffer can measure 72 turns, and we need to increase it. If we could measure more then 72 turns we could start to determine the frequency, mode pattern, and the rise time of the instability.

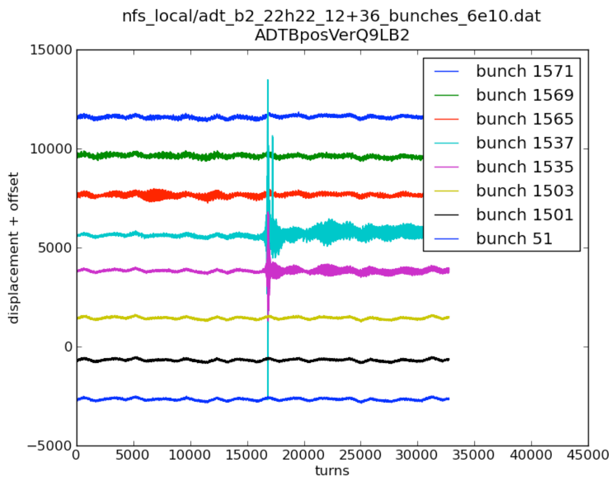

Fig 5: Instability at injection during Ecloud

Chromaticity measurement and control is extremely important in a proton-proton collider, the LHC nominal chromaticity should be +2 and we need chromaticity knowledge better than 1 unit to control and analyze this important machine parameter. The past LHC run with high-energy instabilities it reinforced this need. The BBQ is the only instrument capable to measure it so far, the Schottky development should be encouraged to get reliable continuous bunch-by-bunch tune and chromaticity measurements at any time to understand the instabilities issues and Pacman bunches effect.

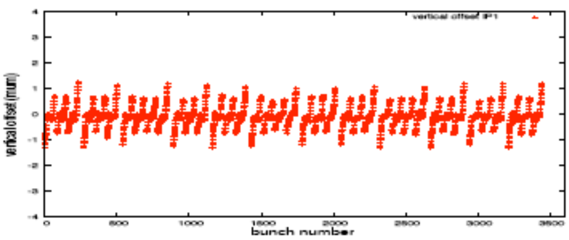

Fig 6: Pacman bunches during long-range interaction

The Beam Transfer Function could be useful at LHC to understand the tune spread; RHIC does a BTF measurement in stable beam every 15 minutes. We could study beam-beam coherent modes normally Landau damped and not visible on BBQ measurement. We have enough simulation knowledge to start exploiting this technique.

The LHC PLL could provide similar data after dedicated commissioning.

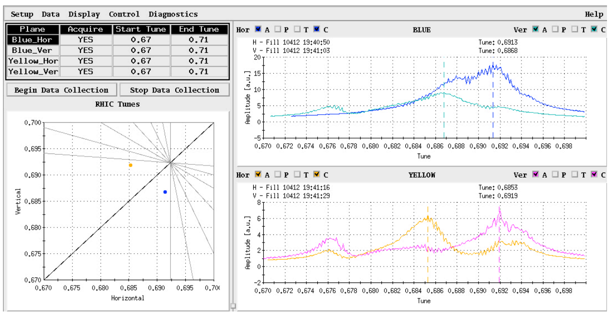

Fig 7: RHIC BTF measurements during stable beams

Reliable continuously emittance measurement, bunch by bunch is paramount to be able to study the beam-beam phenomena in the LHC.

In 2012 the BSRT (synchrotron light) was the only instrument capable allowing continuous non-invasive bunch-by-bunch measurement. Calibration was done with wire scanners. In the future we should improve the knowledge of the machine optics to reduce the uncertainty of this measurement. Fast scan (1380 bunches 7 mins) available since May 2012 were very helpful for day-to-day operation and machine studies. A new server with fast automatic scans was available since October 2012.

CONCLUSION

The beam-beam team would like to thank excellent collaboration with the Operation & Beam instrumentation group. It allowed achieving important results on the LHC beam-beam studies. To further investigate the origin of instabilities limiting the LHC performance, we would have to upgrade our instrumentation toward a bunch-by-bunch observation.

These new tools will allow to better control the LHC machine parameters, to mitigate the instabilities and optimize its operation by maximizing the integrated luminosity.

LHC after LS1 will be a “new” machine. After this important upgrade we will be ready to face a new scenario. The luminosity levelling with offset beam has been part of the routine operation since 2011. It allows maximizing the integrated luminosity while keeping the peak luminosity and pile-up at the optimum value for the detectors performances.

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