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Libera Hadron: demonstration at SPS (CERN)

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Introduction

Libera Hadron has been demonstrated at CERN. The demonstration took place on September 14th and September 15th 2011 at SPS ring.

The Libera Hadron system implements the following basic functionalities:

- Single Pass – High Resolution, Single Bunch Transversal Beam Position measurement of individual bunches

- Single Bunch Precise Charge measurements

- Turn by Turn – High Resolution, Turn averaged Beam Position and Charge measurements

- Slow Acquisition - Beam Position Slow streaming for monitoring purposes

In addition, it can offer the following advanced functionalities:

- Single Pass - High Resolution, Individual Bunch Arrival Time measurement

- Fast Acquisition – Very High Resolution Beam Position measurement streaming at 10 kHz rate on dedicated output for Fast Feedback purposes
- Bunch Map and Bunch Fill Pattern measurements

The Libera Hadron system is implemented on a uTCA based 19" 2U platform chassis. The chassis can populate up to 4 BPM modules in order to acquire simultaneously the position from 8 BPM planes. The instrument consists of a high performance stabilized RF front-end and state-of-the-art analog to digital converters. The digital signal processing is implemented on Virtex_5 FPGA and a computing module that can access to large data buffers (up to 8 Gbits per BPM) through a PCIe bus. The data acquired by the BPM modules can be transferred through dedicated low latency LVDS links to FPGA based real time DSP modules for further processing and SFP streaming for feedback purposes.

Fig 1.: Libera Hadron: A Hadron Beam Processing System in 19" 2U rack-mount chassis implementing a high performance RF front-end, FPGA real-time processing, computing module and auxiliary slots for further processing, SFP data streaming and the implementation of event receiving functionality.

Measurements at SPS (CERN)

Libera Hadron was installed on two different types of the SPS BPM pickups: shoe-box pick-ups and button pick-ups. Two electrodes corresponding to one vertical plane were connected to the channels A and C of the instrument.
The geometrical factors used for the position measurement are $ky=46$ mm and $ky=21.15$ mm respectively for shoe-box and button pick-ups.

The measurements were performed on the SPS ring, on the LHC injection beam. Five different LHC injection beam patterns were measured:

- *single batch of 12 bunches with 50 ns spacing*
- *single batch of 36 bunches with 50 ns spacing*
- *double batch of 36 bunches with 50 ns spacing*
- *triple batch of 36 bunches with 50 ns spacing*
- *quadruple batch of 36 bunches with 50 ns spacing*

The first measurements were performed at less charge per turn than the last measurements. Figure 2 shows the acquired raw BPM signals in the case of shoe-box pickups during 400 us time scale, representing 17 SPS turns.

Single batch of 12 bunches with 50 ns spacing
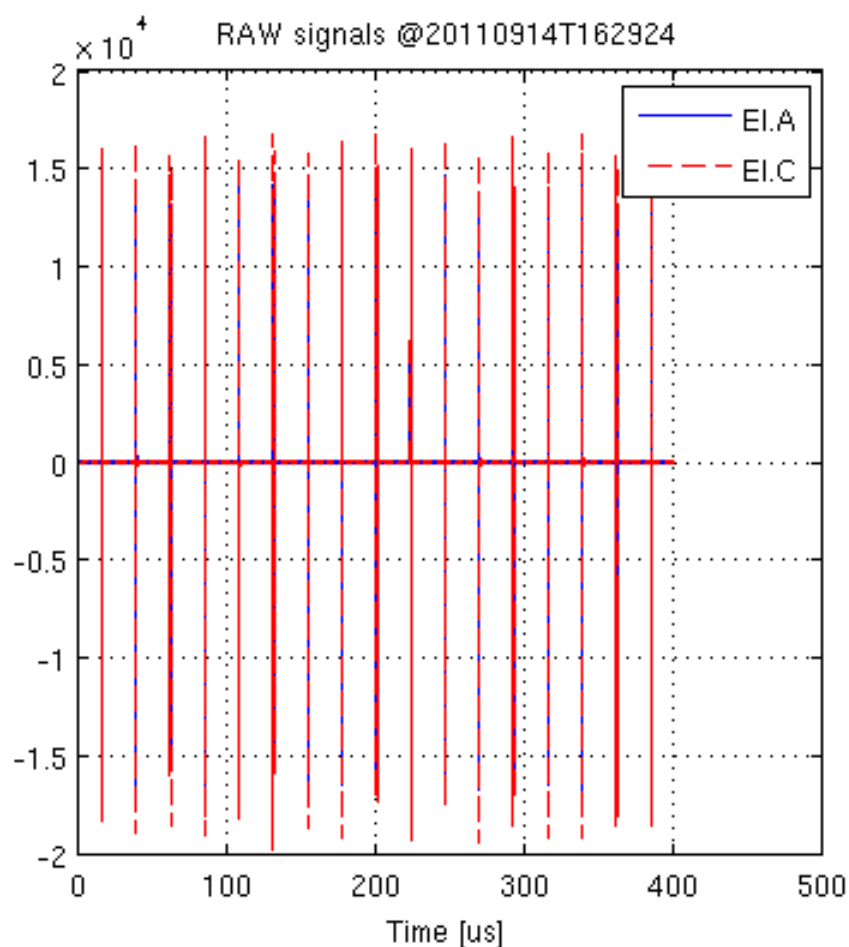
Fig 2.: Acquired raw shoe-box BPM signal, the picture presents a 400 us acquisition of 17 SPS turns.

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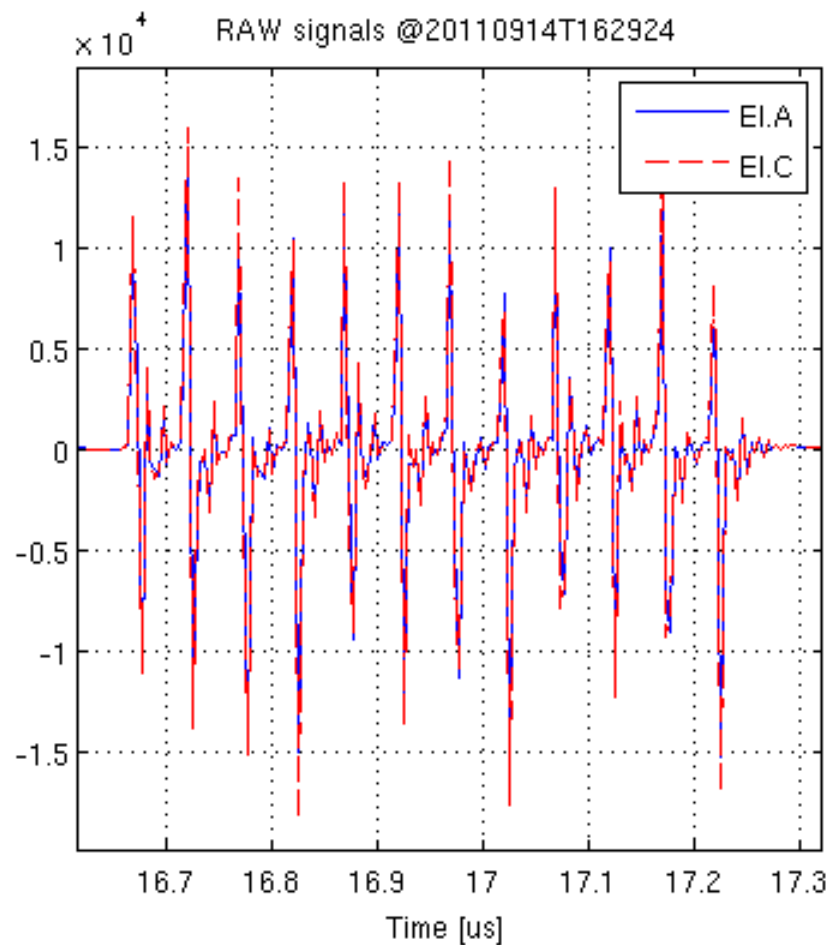
Fig 3: Acquired RAW shoe-box BPM signal showing the zoom-in of the pick-up response to the 12 filled buckets stored into SPS with 50 ns spacing.

The Libera Hadron system digitally processes the acquired data in order to provide the acquired signals at different rates and present different information content. The available signals are:

- *Raw data: (refer to figure 3)*

- *Single Pass: the Libera Hadron system automatically detects the bunches in the acquired signals, isolates them, extracts each bunch charge information, the position information in the transversal plane and the beam arrival time information. Figure 4 represents the measured Single Bunch (Single Pass) signal.*

- *Turn by Turn acquisition: Another acquisition supported by the Libera Hadron system is the turn based averaged data known as "Turn by Turn" measurements. The averaging can involve predefined stored buckets. Figure 6 shows a Turn by Turn measurement at SPS.*
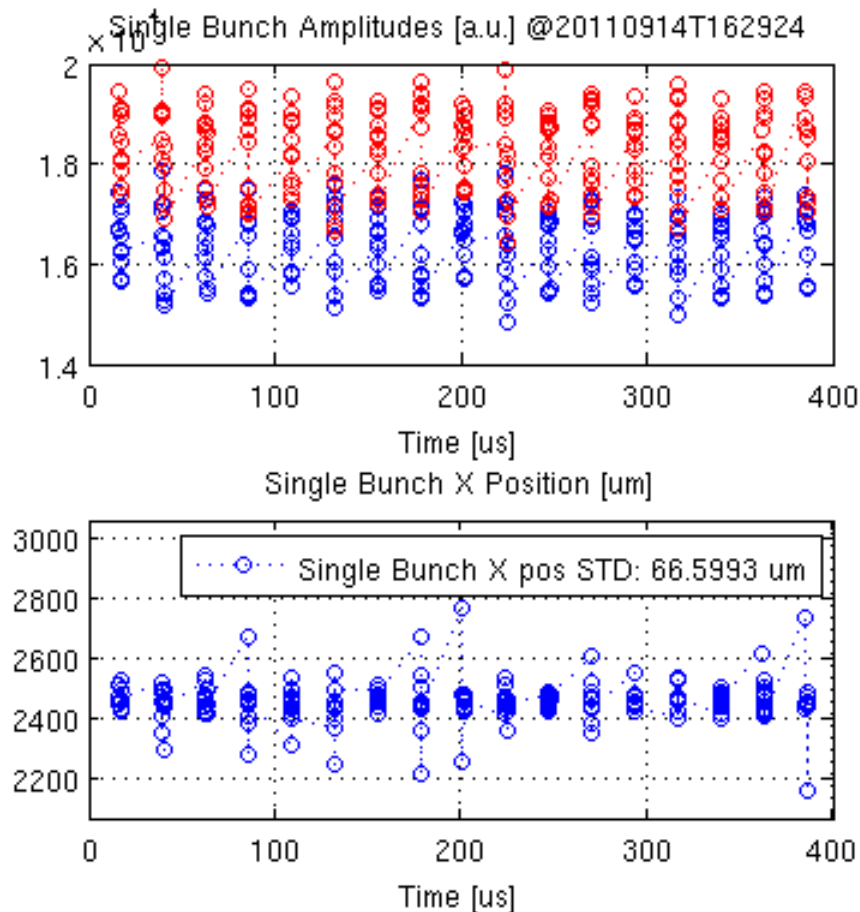
Fig 4.: Acquired SPS Single Bunch (Single Pass) signal in the time frame of 400 us (corresponding to approx. 17 SPS turns). The upper plot represents the amplitude samples for individual bunches. The lower plot represents the position measurements for individual bunches. The Single Bunch position standard deviation (calculated in a 400 us time-frame) is 67 um.
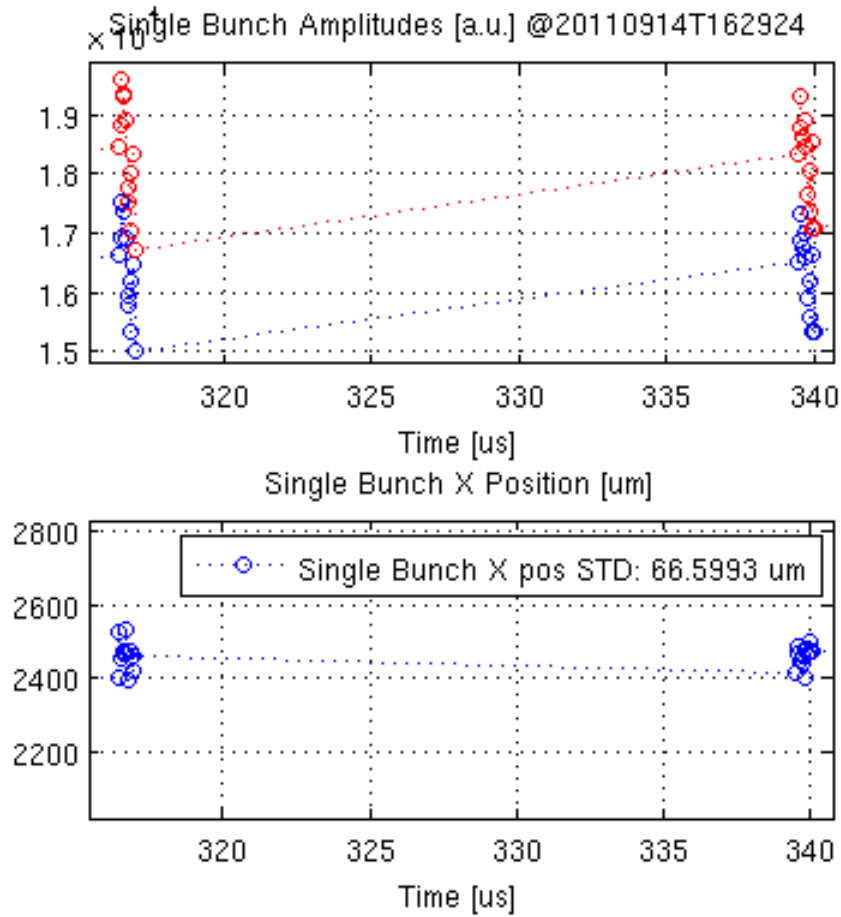
**Fig 5.: Zoom in of the acquired Single Bunch (Single Pass) signal over a turn. The amplitude plot shows the charge distribution among bunches. The relative position measurements are available from the second plot.**
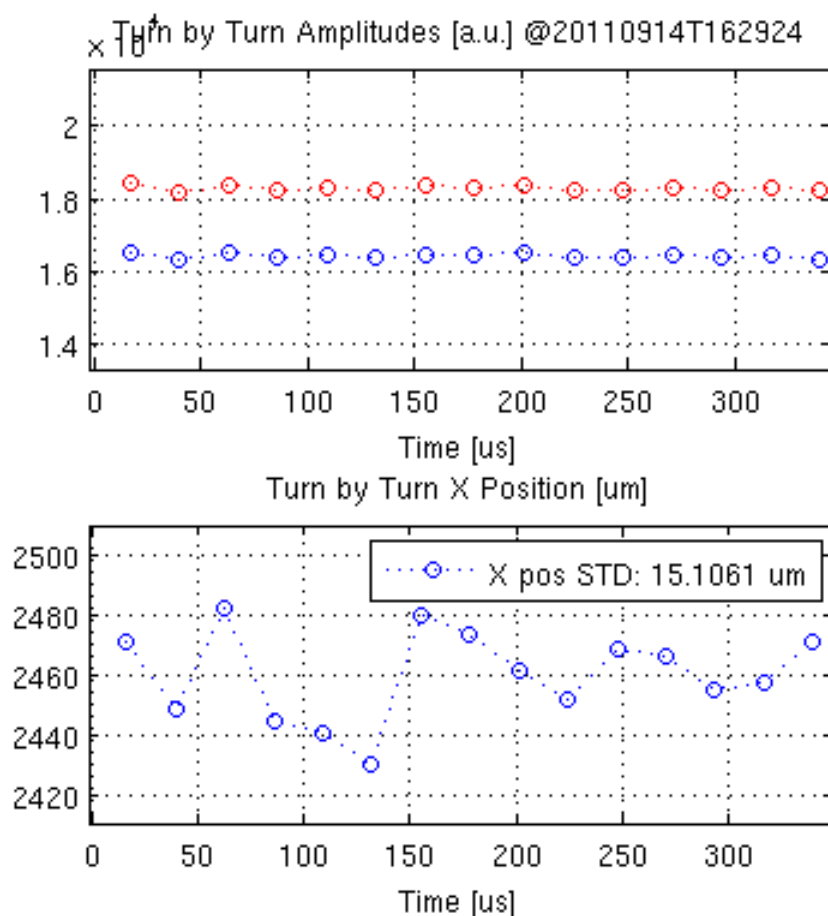
Fig 6.: Libera Hadron Turn by Turn position measurement at CERN SPS. The first diagram shows the average amplitudes and the second diagram the average position. Each sample corresponds to a RHIC turn, over a frame of 400 us. The position measurement standard deviation is 15.1 um. An average position offset of approx. of 2.46 mm is measured.

Similar measurements were performed also with button pickups in the vertical plane. Figure 7 shows the raw BPM signals representing 12 bunches acquired with button pick-ups.
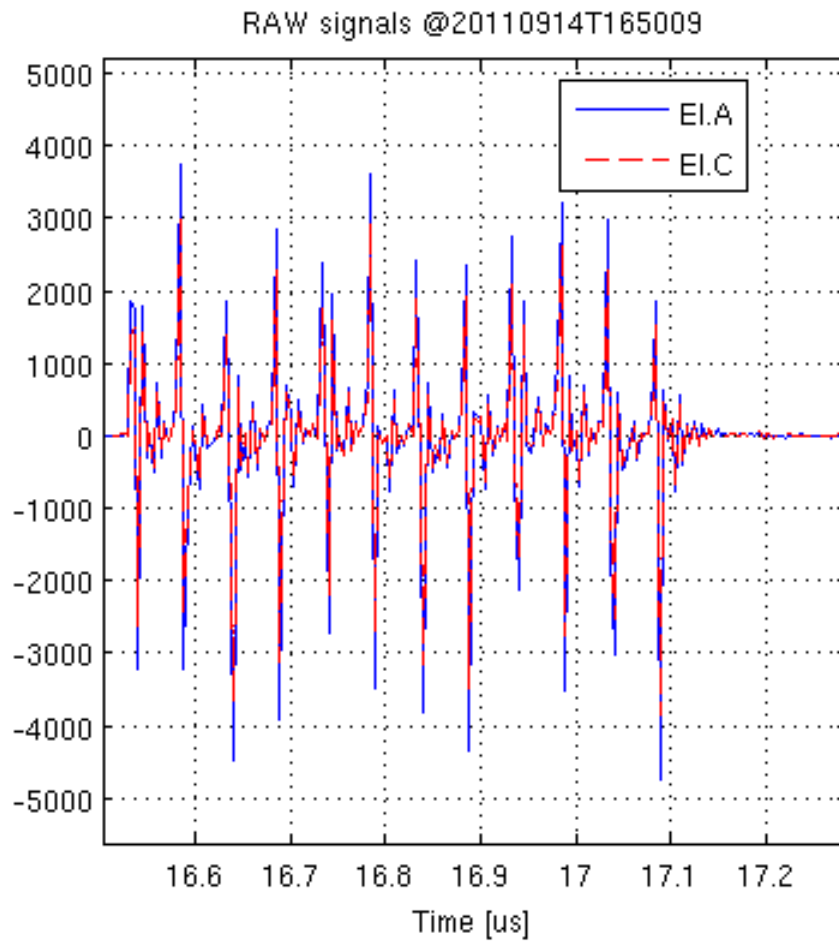
Fig 7.: Libera Hadron raw data acquisition: 12 SPS bunches acquired through button pickups in the vertical plane.
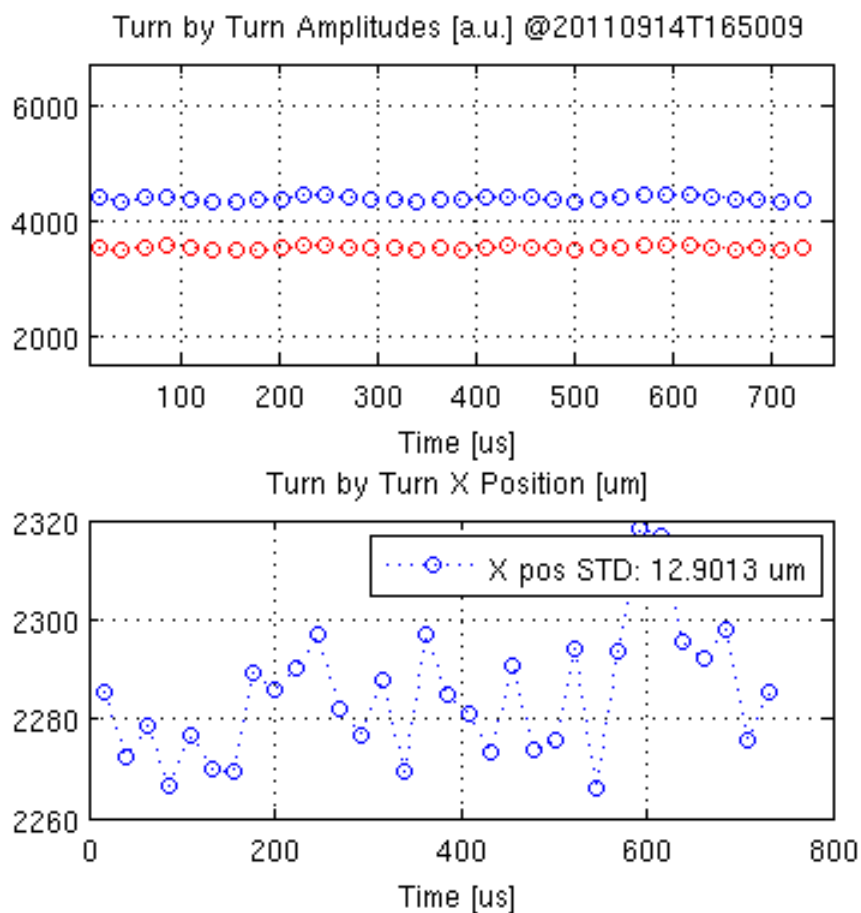
Fig 8.: Libera Hadron Turn by Turn position measurement with SPS button BPMs in the vertical plane. The position standard deviation, calculated over approx. 800 us, is 12.9 um. An average position offset of approx. of 2.28 mm is measured.

Single batch of 36 bunches with 50 ns spacing

The following figures show other Libera Hadron button BPM acquisition over 1 ms time frame of 36 bunches stored in the SPS ring.
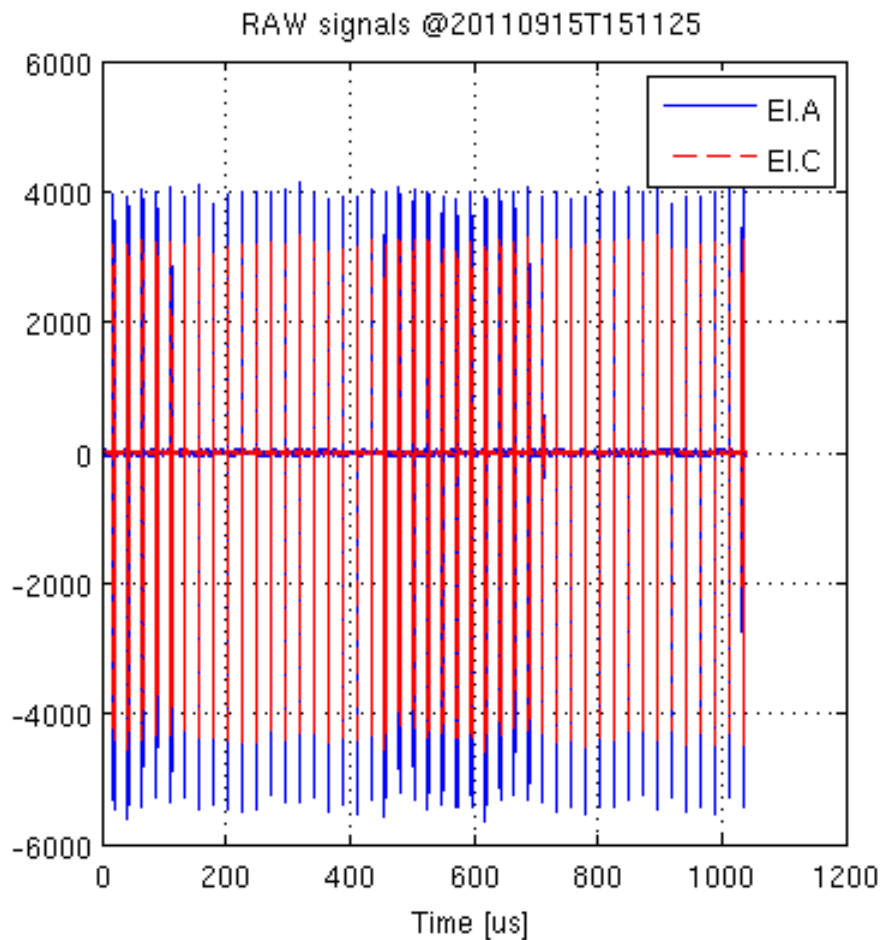

Fig 8.: Libera Hadron raw button BPM signal acquisition over a time frame of 1 ms, corresponding to the case of 36 bunches stored in SPS.

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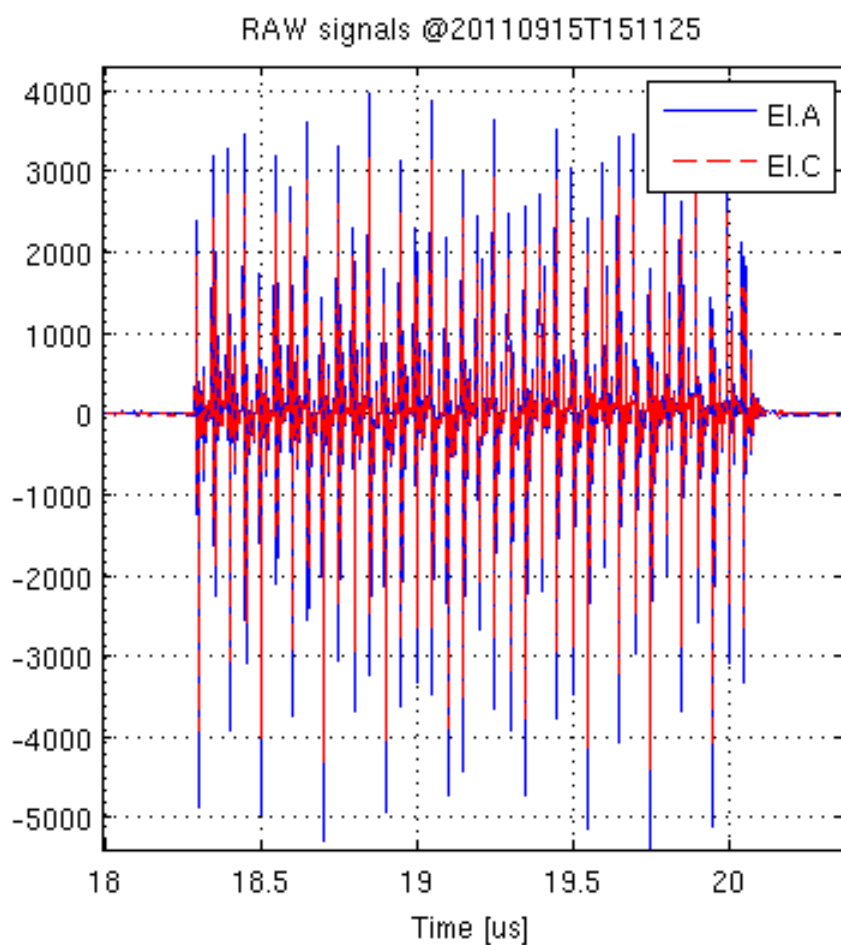
Fig 9.: Libera Hadron raw button BPM signal acquisition, one turn detail showing 36 bunches stored in SPS.
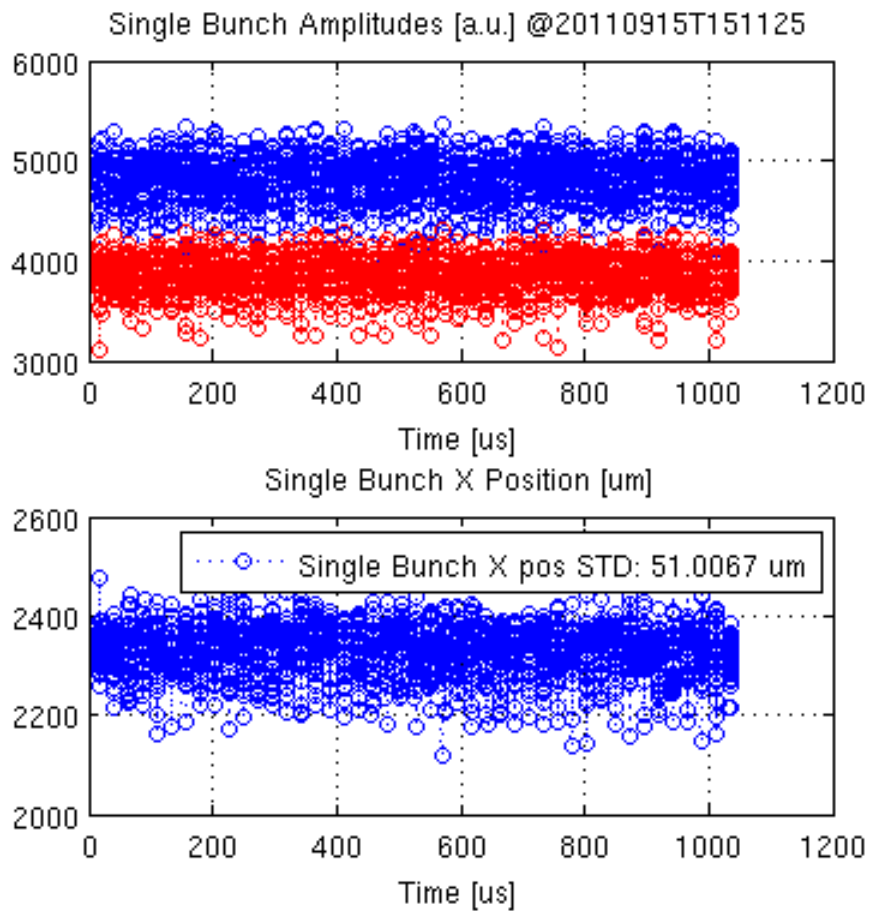
Fig 10.: Libera Hadron Single – Bunch position measurement for 36 bunches circulating in SPS. The bunches are identified, isolated and measured during the time-frame of 1 ms. The measurement standard deviation of individual bunch measurement is 51 um.
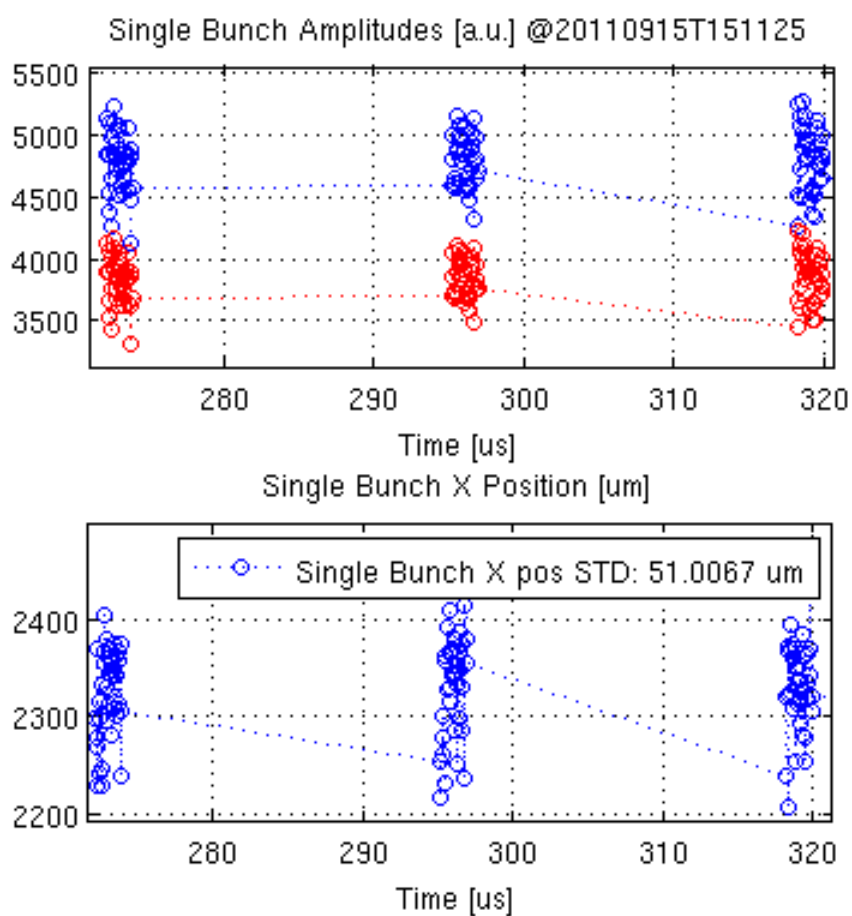
**Fig 11.: Libera Hadron Single – Bunch measurements: detail of three turns filled with a batch of 36 bunches.**
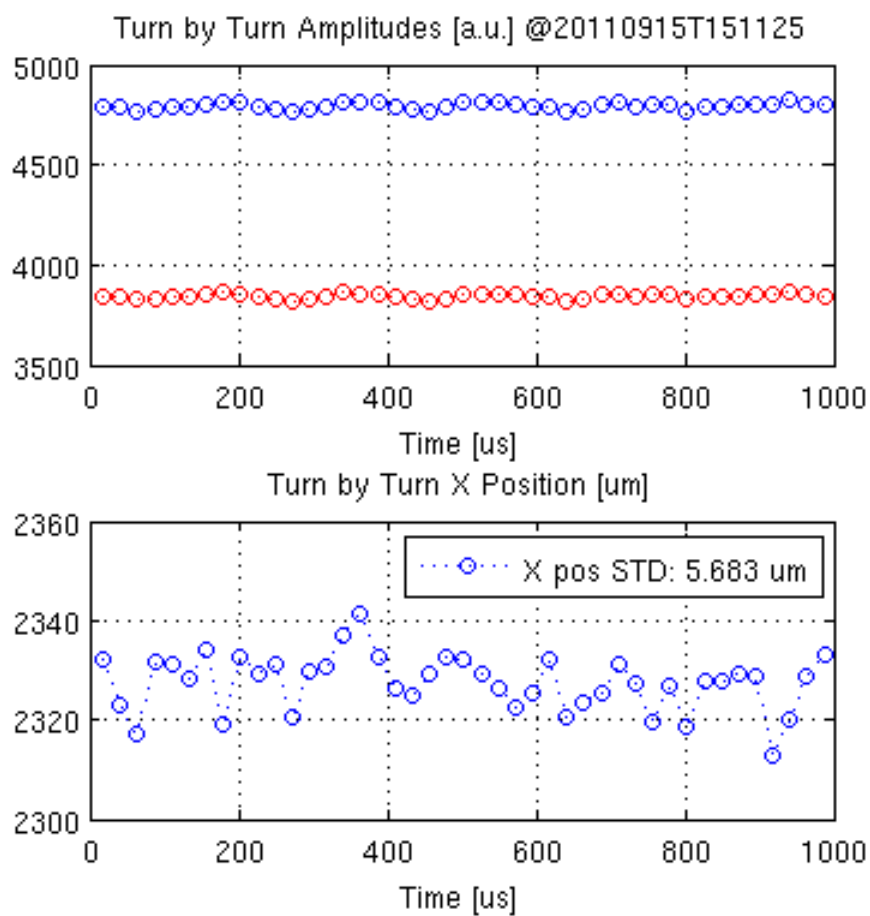
Fig 12.: Libera Hadron, Turn by Turn measurement: The standard deviation over 1 ms is 5.7 um. The average position offset in the vertical plane is 2330 um.

Double batch of 36 bunches with 50 ns spacing

The following figures refer to acquisitions performed during injection into LHC. Four different beam structures were stored into the SPS ring: single batches of 36 bunches with 50 ns spacing, 2,3 and 4 batches of 36 bunches with 50 ns spacing.

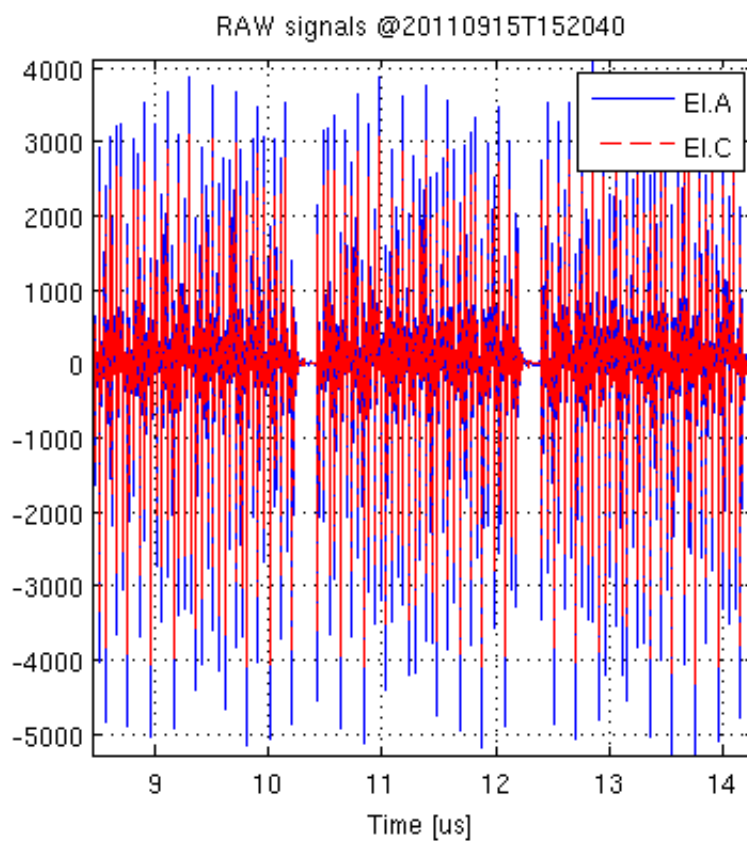*Figure 13 shows the 2 batches of 36 bunches with 50 ns spacing.*
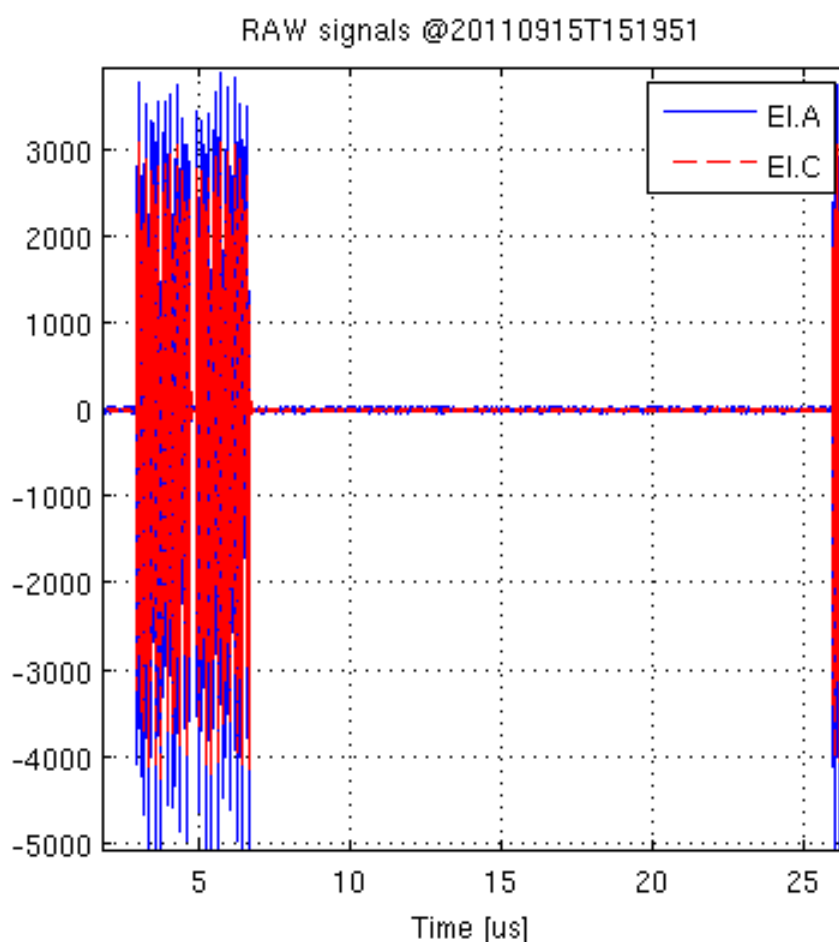
Fig 13.: Libera Hadron, raw acquisition: Two batches of 36 bunches stored into SPS before being injected into LHC.
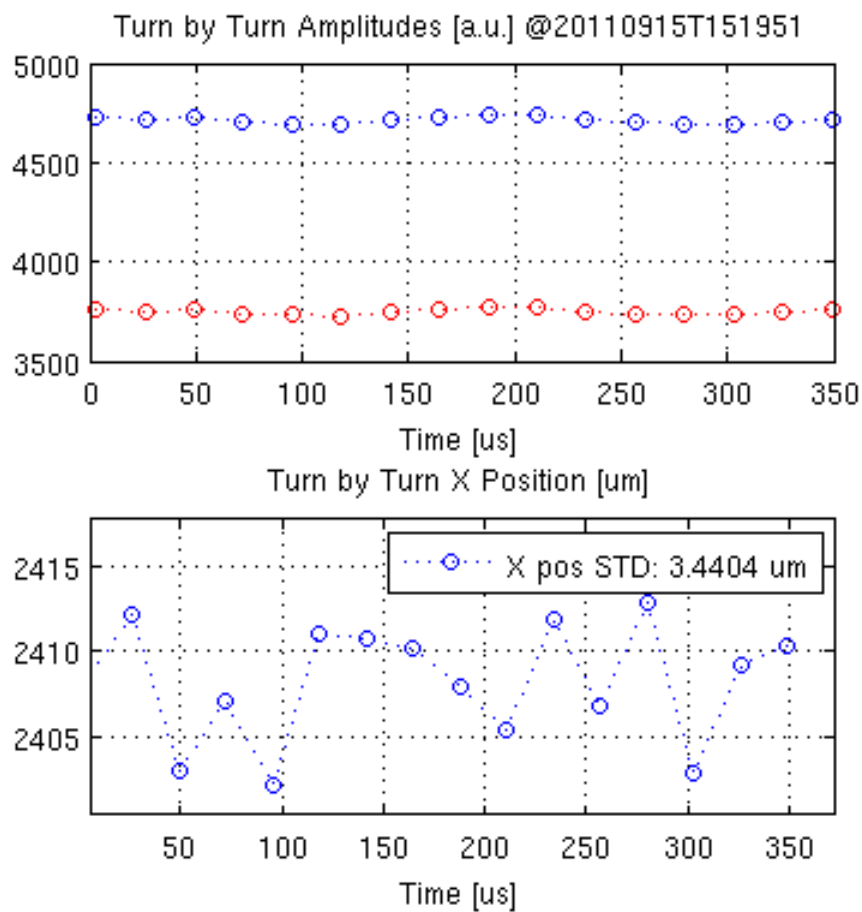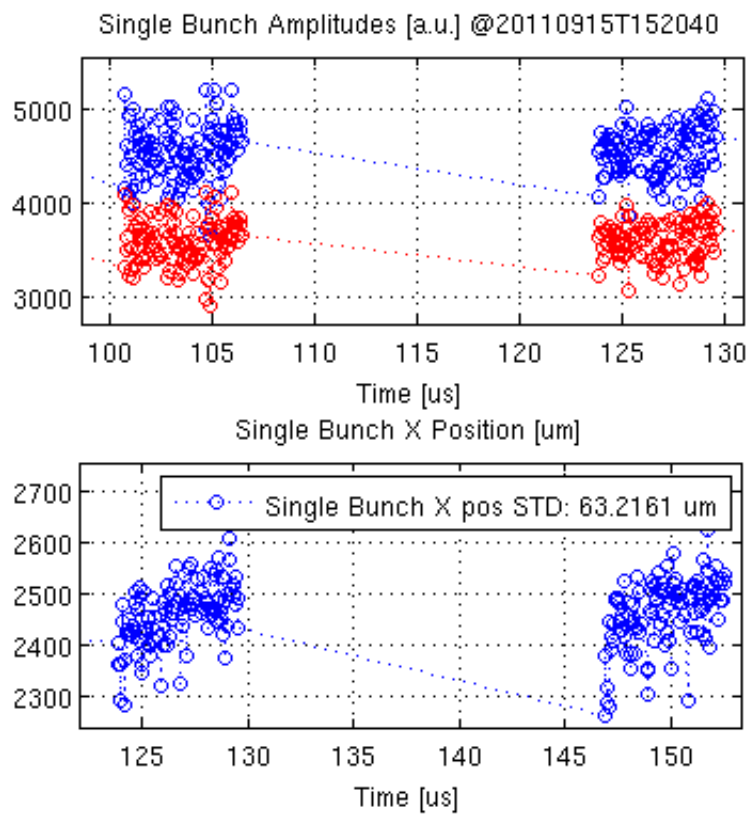
Fig 14.: Libera Hadron, Turn by Turn acquisition: Corresponding to a beam signal produced by two batches of 36 bunches stored into SPS before being injected into LHC. The standard deviation calculated over 400 us is 3.44 um. The average beam position in the vertical plane is 2408 um.
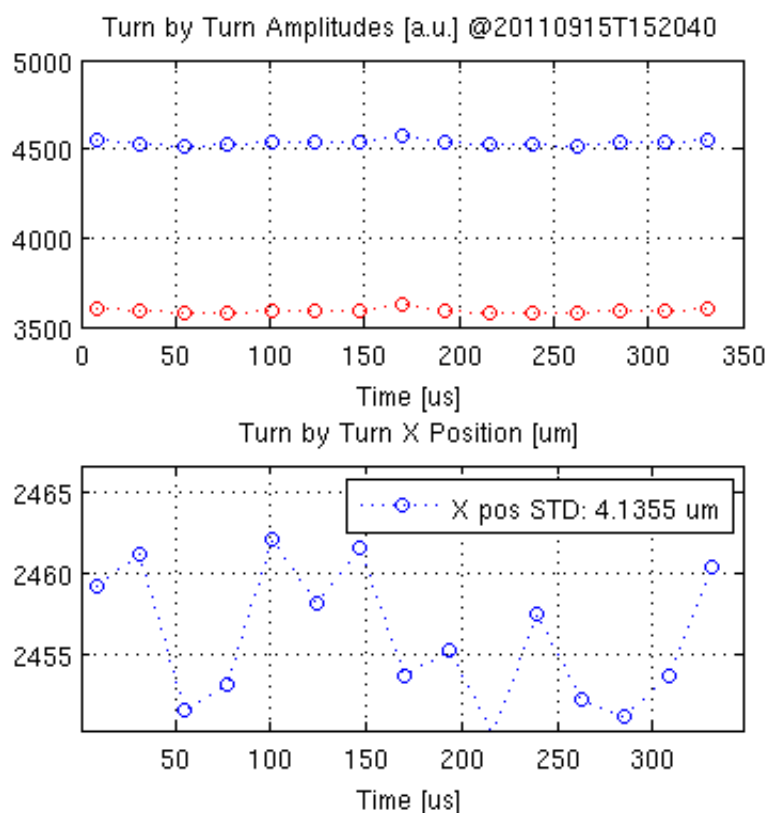
Triple batch of 36 bunches with 50 ns spacing

Fig 15.: Libera Hadron, Raw acquisition: Detail of three batches of 36 bunches stored into SPS before being injected into LHC.
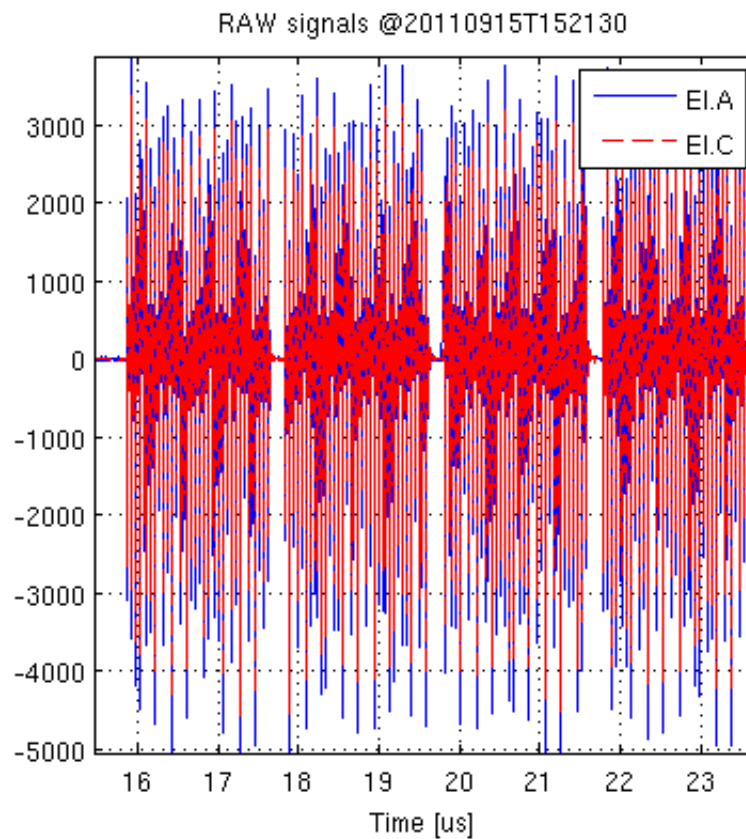
Fig 16.: Libera Hadron, Single Bunch position measurement: Three batches of 36 bunches stored into SPS before being injected into LHC. The position plot describes, for the 108 bunches stored, a position pattern that has high correlation with the next turn position data. It seems that the main contribution to the position standard deviation is produced by beam movements.
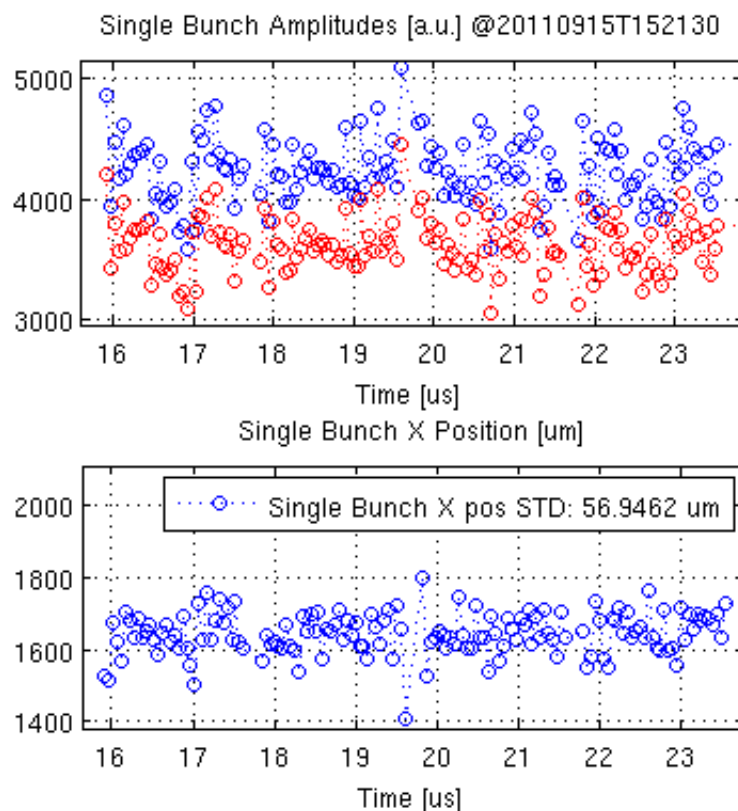
Fig 17.: Libera Hadron, Turn by Turn position measurement: produced by three batches of 36 bunches stored into SPS before being injected into LHC. The measured turn by turn position standard deviation is 4.14 um.
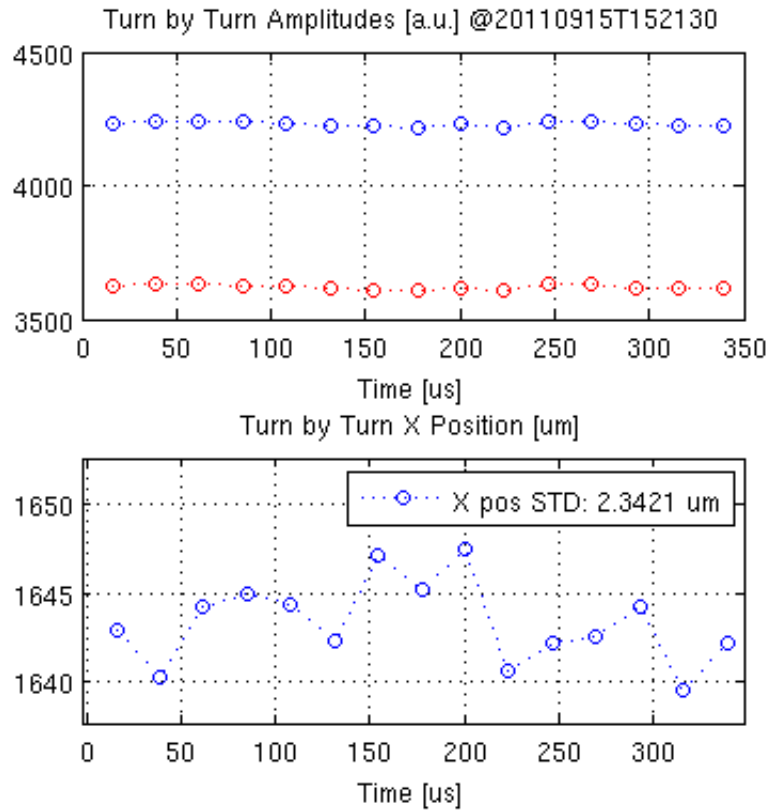
Quadruple batch of 36 bunches with 50 ns spacing

Fig 18.: Libera Hadron, raw acquisition with button BPMs: Four batches of 36 bunches stored into SPS before being injected into LHC.

Fig 19.: Libera Hadron, Single Bunch measurement with button BPMs: Detailed veiw of four batches of 36 bunches stored into SPS before being injected into LHC. The Single Bunch standard deviation calculated over 400 us is 57 um.

Fig 20.: Libera Hadron, Turn by Turn measurement with button BPMs: Four batches of 36 bunches stored into SPS before being injected into LHC. The Turn by Turn standard deviation calculated over 400 us is 2.34 um while the average beam position is 1643 um. It can be observed that during the operation with 4 batches of 36 bunches each the position in the vertical plane changed for about 800 um.

Acknowledgements: