INSTRUMENTATION: WHAT TO EXPECT NEXT YEAR

J. Barros, E. Bravin, E. Effinger, M. Gasior, R. Jones, J. Kral, M. Lasch, T. Lefevre, T. Levens*,
D.M. Louro Alves, J. Olexa, A. Sounas, G. Trad, T. Tydecks, M. Wendt, C. Zamantzas
CERN, Geneva, Switzerland

Abstract

This paper presents the expectations for the LHC Beam Instrumentation systems going into the 2018 run. Planned upgrades during the YETS will be presented and opportunities for future development, in order to better exploit the available instrumentation, will be discussed.

INTRODUCTION

Although there have not been any major changes in the 2017 run for the large Beam Instrumentation systems (BPMs, BLMs, etc) in the LHC, a number of other instruments and systems have seen significant research and development. This paper will focus on these instruments and present some of the advancements that have been made during 2017, the upgrades planned during the YETS and provide an outlook to the performance foreseen for the 2018 run. The first section will cover the changes to already operational instruments, while the second section will cover new instruments and developments.

OPERATIONAL INSTRUMENTS

DOROS

Diode ORbit and OScillation (DOROS) is a high-resolution beam position measurement system originally developed for the automatic alignment of the LHC collimators with embedded Beam Position Monitors (BPMs). At of the time of writing, 13 DOROS front-ends have been installed to process the signals from 21 collimators. At the beginning of 2017, it was discovered that the system gave quite large errors for wide collimator gaps. The problem has been solved during 2017 by the introduction of a new algorithm for the proper handling of the variable aperture of the collimator. Previously a complex 18 coefficient polynomial was used per BPM, resulting in significant errors of greater than 10% in some cases. The new algorithm uses a global bi-linear correction that is common for all BPMs and provides a reliable position with less than 5% error for ±3 mm offsets. A measurement comparing the old and new algorithms for a varying jaw gap is shown in Fig. 1.

Since the second technical stop in 2017, the beam position measured by DOROS at 10 collimators has been used to generate a software interlock. As any unavailability of an interlocked DOROS front-end would result in an unintended beam dump and potentially require an access to repair, a lot of work has been done to make the system hardware and software reliable. This effort has paid off, with no problems encountered with these systems during the year. For the 2018 run, it is planned to enhance the availability by implementing a full redundancy of all interlocked DOROS boxes with two independent front-ends processing each set of BPM signals. With this configuration a faulty front-end would not block operation and could be replaced during the next convenient access.

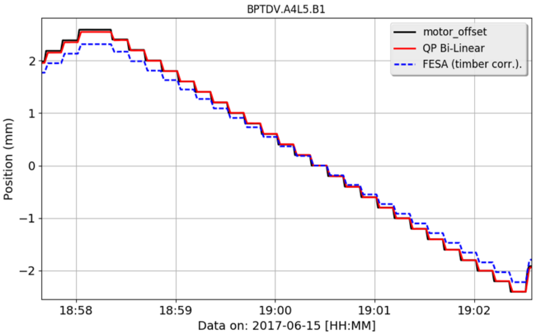

Figure 1: Comparison between the measured jaw position (black) and DOROS readings for both the old method (blue) and improved method (red) of data processing.

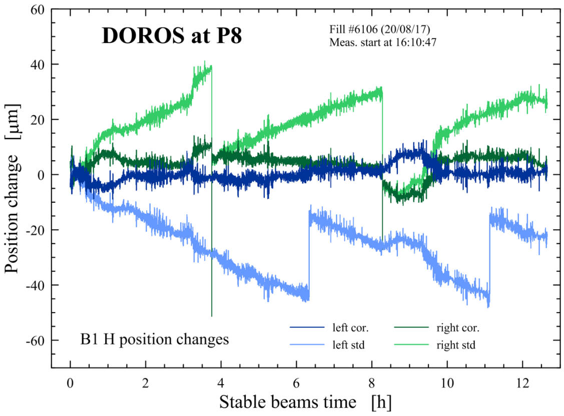

Figure 2: DOROS data over 12 hours of stable beams with and without linearity correction.

In addition to the installations on collimators, DOROS is installed in parallel to the standard LHC BPM system on the Q1 triplet BPMs and in a few other locations around the LHC. Since fill #6371, real-time linearity correction for these systems has been made operational in FESA. This correction reduces systematic position errors caused by beam-intensity changes when operating at large position offsets. Figure 2 shows a comparison of the measurements with and without correction over 12 hours of stable beams. Note that these systematic errors are not a concern for the collimator BPMs that generally operate with centered beams.

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* tom.levens@cern.ch

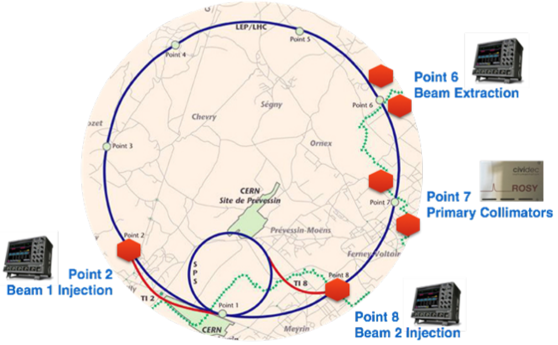


Figure 3: Current Diamond BLM installations in the LHC.

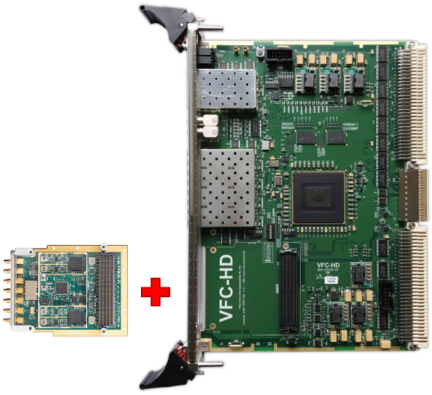


Figure 4: Future acquisition system consisting of the BI standard VFC-HD carrier board and a commercial 1 GSPS 14-bit FMC ADC.

The DOROS diode detector time constant is the only setting in the system which needs to be changed during operation. The optimal value depends on the number of bunches present in the machine and the filling pattern, but is not dependent on the bunch intensity. During 2017, the time constant could only be changed by an expert. Unfortunately this sometimes meant that the wrong value was used and resulted in sub-optimal measurement quality. To avoid this sort of issue in the future, an automatic procedure for selecting the correct time constant has been developed and will be implemented in FESA for 2018.

Diamond BLMs

Fast Diamond Beam Loss Monitors (BLMs), that are capable of measuring bunch-by-bunch beam losses, are currently installed at a number of locations in the LHC as shown in Fig. 3. They are installed at Point 2 and 8 for observation of injection losses, at point 6 for extraction losses and at the TCPs and crystal collimators at Point 7. A total of ten detectors, including a temporary installation at 16L2, are currently acquired using either a commercial oscilloscope or a “ROSY” digitiser provided by Cividec. While intended to be temporary, a number of software tools have already been build around these acquisition systems and they will remain in place for 2018 to avoid disruption during the last part of the run.

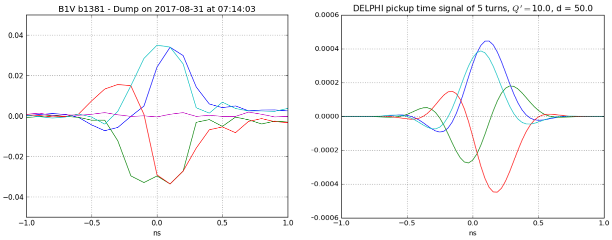


Figure 5: First 16L2 instability event captured with the Head-Tail Monitor (left) compared to DELPHI simulation (right).

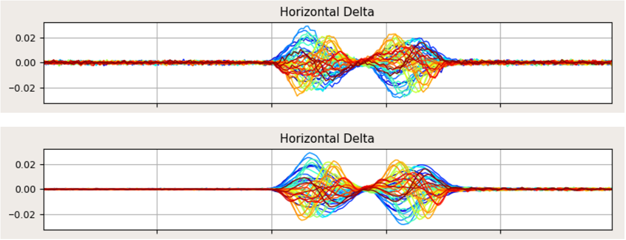
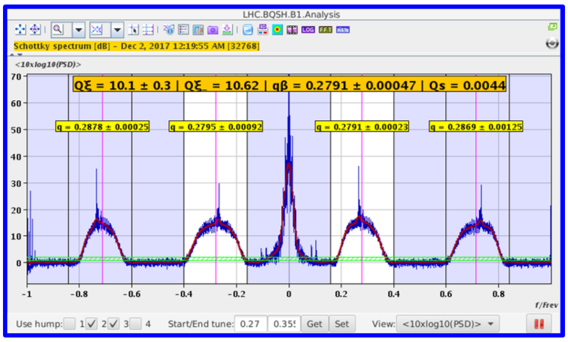


Figure 6: Comparison between existing oscilloscopes used for the LHC Head-Tail monitor (top) and new model (bottom) showing increase in resolution.

A new acquisition based on the new BI standard VFC-HD carrier board and a commercial 1 GSPS 14-bit FMC ADC card, shown in Fig. 4 is being developed in synergy with the Fast BCT systems and will become the operational acquisition system after LS2. The new system is currently installed in parallel on four detectors at Point 2, 7 and 8 and the remaining installations will be equipped as the electronics become available during 2018. The analogue signals are split before the input to the acquisition to allow for bench-marking the new acquisition system against the current one and uninterrupted development and deployment. The firmware and FESA server are already available and the main functionality has been implemented. More features for data reduction and synchronization will become available during 2018. The new acquisition system will allow histograms and waveform acquisition of both channels in parallel with separate settings and finer controls.

Head-Tail Monitor

During 2017 the LHC Head-Tail Monitor has continued to be used regularly during operation and MD sessions. In order to provide diagnostics for the fast instabilities that occur just before a dump due to a 16L2 event, it has become necessary to trigger the Head-Tail synchronously with the beam dump in order to capture the final turns before the dump. Unfortunately, the standard Post Mortem timing event, distributed by the General Machine Timing (GMT) can have a latency of milliseconds after the beam is actually dumped. Since the Head-Tail monitors have only a 1 ms acquisition buffer, this event arrives too late to acquire the turns before the dump. During 2017, a low-latency beam dump trigger



Schottky spectrum [dB] - Dec 2, 2017 12:19:55 AM [32768]

Qξ = 10.1 ± 0.3 | Qξ_ = 10.62 | qβ = 0.2791 ± 0.00047 | Qs = 0.0044

q = 0.2878 ± 0.00025

q = 0.2795 ± 0.00092

q = 0.2791 ± 0.00023

q = 0.2869 ± 0.00125

Use hump: ☐ 1 ☑ 2 ☑ 3 ☐ 4

Start/End tune: 0.27 0.355

View: <10xlog10(PSD)>

Figure 7: OP GUI for the LHC Schottky Monitor providing tune and chromaticity.

has been commissioned using a direct connection to the "beam-info" signal provided by the Beam Interlock System (BIS). This new trigger has allowed systematic capture of the last 10 turns before every dump and provide input to help validate the 16L2 simulation models. Figure 5 shows the first 16L2 instability event captured with the Head-Tail Monitor compared to a DELPHI simulation of the event.

For 2018 a major upgrade of the Head-Tail Monitors will be performed. New digitisers will be installed to increase the number of turns (from 11 to 450) and increase the resolution of the acquisition (from 8-bit to 10-bit). The new model has been tested in the SPS in 2017 and shows a marked improvement in the signal to noise ratio with a 9 dB lower noise floor, shown in Fig. 6. However the increased acquisition size (from 40 MB to 3.2 GB) presents new challenges for data transport, storage and processing. In order to avoid saturation of the Technical Network during the transfer of these large files, a dedicated 10-GbE Ethernet link between LHC point 4 and the CCR will be installed during YETS.

At the end of 2017, a calibration of the Head-Tail Monitor for Beam 2 was performed as a parasitic MD. The beam was displaced in the Head-Tail pick-ups up to 5 mm in both planes with steps of 1 mm. From this, the scaling of the Head-Tail data into millimeters can be performed. It is proposed that this calibration should be repeated for both beams with the upgraded system during recommissioning.

Schottky Monitor

While previously only usable with expert support, work on the LHC Schottky Monitor in 2017 focused on the online data processing and analysis required to make the instrument operational. The calculation of the tune and chromaticity from the Schottky spectrum is is now performed online, the results are logged and available in an OP GUI, shown in Fig. 7. The gate, used to select which bunch is analysed, is automatically configured based on the fsilling scheme. In order to validate the systems, a dedicated MD was performed to compare the calculated chromaticity to the setpoint and the value obtained with radial modulation. The discrepancy was measured to be less than 2 units, as shown in Fig. 8.

At injection the monitor performs quite well, and it is now available to OP for continuous non-invasive chromaticity

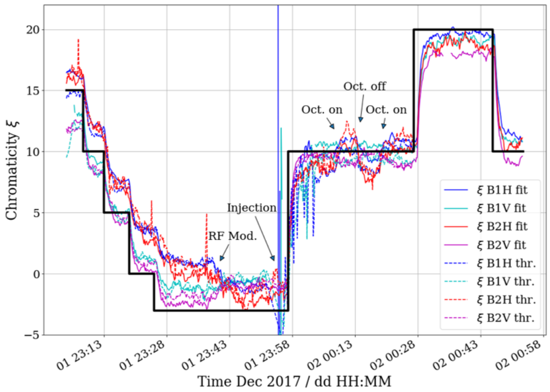


Figure 8: MD2408 results showing the chromaticity calculated from the Schottky spectrum compared to the programmed value.

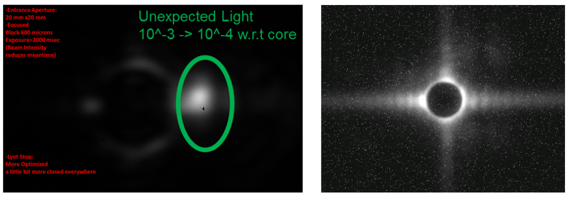


Figure 9: Comparison of the coronagraph at 6.5 TeV in 2016 (left), where the image is dominated by parasitic light, and in 2017 (right)

measurements. However, measurements the ramp and at flat top remain challenging and work will continue to improve the measurements under these scenarios. It is suggested to integrate the Schottky Monitor data into the "Accelerator Cockpit" application along with the results from radial modulation to allow the operators to make a direct comparison between the measurement methods during normal operation.

INSTRUMENTATION DEVELOPMENTS

Coronagraph & BSRS

In 2016 the synchrotron light coronagraph, designed for beam-halo measurements, was installed on Beam 2 and its working principal was demonstrated at 450 GeV. However, interpretation of the light was difficult at 6.5 TeV as the halo was dominated by a parasitic light source, as seen in Fig.9. In 2017 the coronagraph was dismounted during the EYETS and the layout slightly altered to better control the synchrotron radiation entrance. Observation cameras were installed in the system along with a gated intensified camera to enable bunch by bunch measurements. Shaving of the dipole edge radiation was introduced to reduce the the parasitic light. Since these alterations, measurements are now possible at 6.5 TeV. MD studies in 2017 at 6.5 TeV demonstrated halo control with sensitivity to halo variation of 2×10^{10} (horizontal) and 2×10^{9} (vertical) measured, as shown Fig.10. The contrast reach of the system was also shown to be $4 - 6 \times 10^{-4}$.

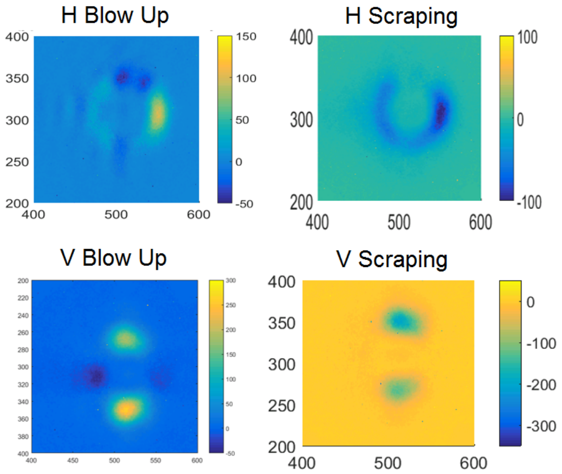


Figure 10: Halo control results from the coronagraph.

Another development for the synchroton light systems, the BSRS (slit-scanner) is a new instrument with the potential to overcome the profile distortion observed due to intensifier aging in the BSRT. Similar to the operation of a wirescanner, a scanning slit is passed through the beam image formed at the synchrontron light focus building up a beam profile over a number of turns. With this configuration, eventual aging of the PMT reduces the total sensitivity of the system but no longer distorts the profile. Profile acquisitions of the full machine would be available in a few hundreds of milliseconds. This R&D instrument will be installed in parallel to the Beam 1 interferometer line during YETS for tests during 2018.

Electromagnetic beam-size measurements

One area currently being investigated is the use of electromagnetic monitors to provide a measurement of the beam-size. These developments are designed to complement the operational emittance measurement devices, i.e. the BSRT and wirescanners, which both suffer limitations which make their use impossible under certain beam conditions. The wirescanners cannot be used with high intensity at top energy as the wire would be destroyed through interaction with the beam. The BSRT cannot provide accurate during the ramp due to distortions of the profile caused by the shift in its light source from the low-energy undulator to the edge radiation of the separation dipole that is used at top energy. Two instruments that were studied for electromagnetic beam size measurements during 2017 were quadrupolar pickups (QPU) and the Schottky Monitor. For both instruments, data was taken in dedicated MD sessions throughout the year.

The QPU principal takes advantage of the fact that the beam size ($\sigma_x^2 - \sigma_y^2$) is embedded in the voltage signal from a BPM:

$$V = i_b(c_0 + c_1 x + c_2(x^2 - y^2 + \sigma_x^2 - \sigma_y^2) + \ldots)$$

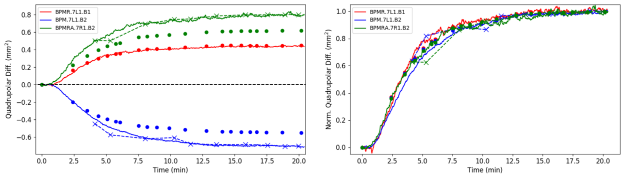


Figure 11: Results from MD2733, the differential measurement on the left and the measurements normalised to flat top on the right.

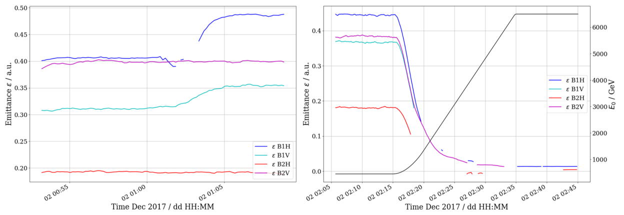


Figure 12: Schottky monitor results from MD2408, during artificial blow up (left) and during the ramp (right).

Absolute measurements of the beam size are possible by performing scans of the BPM aperture, for example using the embedded BPMs on the collimator jaws. With constant aperture BPMs it is not possible to determine the absolute beam-size, but only make a differential measurement compared to some baseline. In MD2733, differential beam size measurements were taken at 1 Hz during the ramp with the DOROS systems on Q7 left and right of Point 1. The results are shown in Fig. 11 showing good agreement between the change in beam size measured with the QPU and the emittances measured with the wirescanners.

During the Schottky MD (MD2408), the horizontal emittance of Beam 1 was blown up from 1 um to 3.5 um using the Transverse Damper (ADT). A clear change in the Schottky spectrum is visible during the blow up, as shown in the left plot of Fig. 12, although the measured ratio is somewhat smaller than expected. During the same MD, the change of beam-size during the ramp was also measured and is shown in the right plot of Fig. 12. The final ratio measured between injection and flat-top (0.04 for B2V) is close to the expectation of 450/6500 = 0.07. However, the beam size reduction also leads to a decrease in the signal level from the Schottky monitor, making the measurements at flat-top challenging.

While both measurements show significant promise at being able to provide beam size measurements during the ramp, it is clear that more study is needed and additional machine development time will be requested in 2018.

CONCLUSION

While it is not possible to cover every development currently ongoing in the BI group, a number of instruments in the LHC have seen considerable development during 2017 and will undergo further upgrades during the year-end technical stop. This paper aimed to highlight some of the developments in the operational systems and a few new developments which will be further studied during 2018.

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