BEAM LOSSES AT CERNS PS AND SPS MEASURED WITH DIAMOND PARTICLE DETECTORS

F. Burkart*, W. Bartmann, B. Dehning, E. Effinger, M. A. Fraser, B. Goddard,
V. Kain, O. Stein, CERN, Geneva, Switzerland
E. Griesmayer, CIVIDEC, Vienna, Austria

Abstract

Diamond particle detectors have been used in the LHC to measure fast particle losses with a nanosecond time resolution. In addition, these detectors were installed in the PS and the SPS. The detectors are mounted close to the extraction septum of the PS (transfer line to SPS) and the SPS (transfer lines TI2 and TI8 to LHC). Mainly, they monitor the losses occurring during the extraction process but the detectors are also able to measure turn-by-turn losses in the accelerators. In addition, detailed studies concerning losses due to ghost bunches were performed. This paper will describe the installed diamond detector setup, discuss the measurement results and possible loss mitigations.

INTRODUCTION

Experience with LHC machine protection (MP) during the last years of operation shows that the MP systems sufficiently protect the LHC against damage in case of failures leading to beam losses with a time constant exceeding 400 μs. For faster losses, but also for better understanding of slower losses, an improved understanding of the loss distribution within a bunch train is required. Diamond particle detectors with nanosecond time resolution and high dynamic range have been developed, successfully tested and characterized at the LHC [1] [2]. They were also installed in the SPS extraction region in LSS6 and at the extraction at the PS to monitor the losses during the extraction process.

MEASUREMENT SYSTEM

For these measurements polycrystalline diamond particle detectors (dBLMs) from CIVIDEC (Vienna, Austria) were used. They consist of a pCVD diamond material with a size of 10 x 10 mm and a thickness of 500 μm. The bias voltage was set to 500 V, which corresponds to an electric field strength of 1 V/μm across the diamond material. The signals were amplified with a +40dB amplifier with a bandwidth of 2.5 GHz. The system was connected to a 50 Ohm terminated measurement system with an oscilloscope.

Locations

In the PS the dBLM system is installed at the TPS15 a protection devices in the ring. In the SPS the dBLM is placed at the end of the septum protection (TPSG) in LSS6. Figure 2 and 1 show the installation in the SPS tunnel. The setup including dBLM and amplifier is mounted on a support, the dBLM is placed ~ 40 cm under the beam axis.

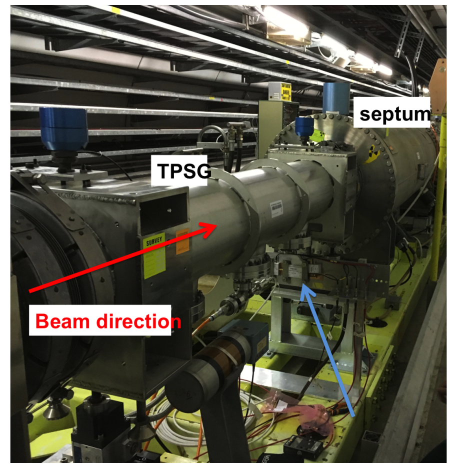

Figure 1: Picture of the installed dBLM system in LSS6 in the SPS, marked with the blue arrow. They are installed under the septum protection TPSG.

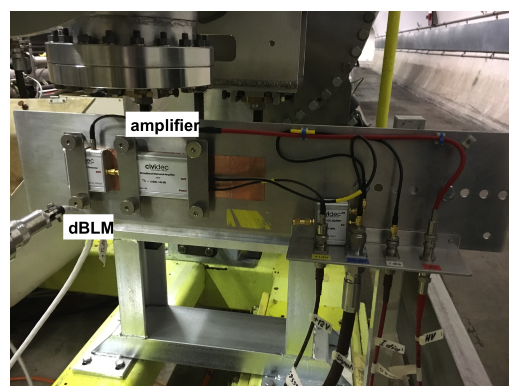

Figure 2: Picture of the installed dBLM system in LSS6 in the SPS. dBLM and amplifier are mounted on the support.

Loss Mechanism

Previous studies showed that losses can occur from particles which are captured in the SPS RF-buckets after the injection from the PS, the so-called recaptured beam or ghost bunches. This recaptured beam is located before and after the nominal bunches. With the start of the extraction kicker MKE6 rise time these particles get a small kick, not strong enough to reach the septum protection TPSG. These particles will stay in the SPS. Between ~ 20 and 80 % kick strength of the MKE6 the particles are lost on the TPSG, before they are moved to the next protection element, which is the horizontal TCDI in the transfer line to LHC. When the MKE6 reaches the maximum kick strength, the particles move through the transfer line and end up on the injection

* florian.burkart@cern.ch

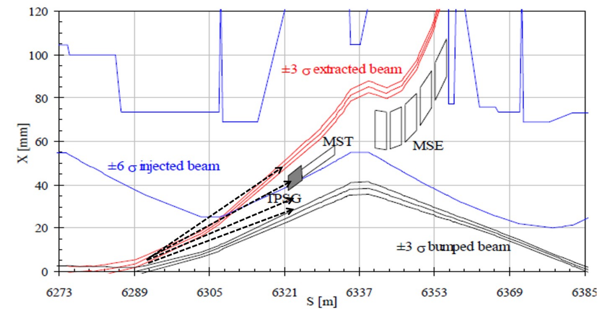

Figure 3: Schematic of the extraction process. In black the circulating SPS beam, in red the extracted beam trajectory, the black arrows indicate the ghost bunches swept over the TPSG during the MKE6 rise time.

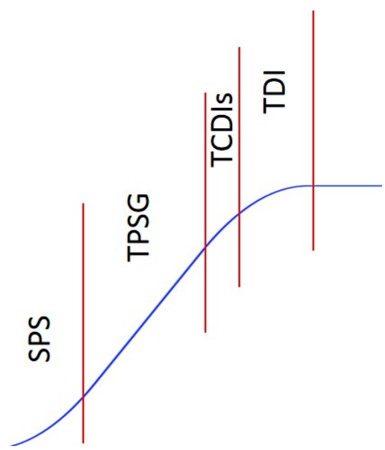

Figure 4: Schematic of the loss locations during the MKE6 rise time (6 μs). With small kick strength, the particles get lost in the SPS, with a certain kick strength, particles hit the septum protection (TPSG), with higher kick strength the losses move to the horizontal transfer line collimators (TCDIs).With the MKE6 at flat top and MKI off, the particles hit the TDI with full impact parameter.

protection absorber TDI in the LHC, assuming that the LHC injection kicker MKI has not yet started to rise the magnetic field. The process is schematically shown in Fig. 3, the black arrows indicate the swept ghost bunches from circulating beam orbit (black) to the extraction trajectory (red). The loss locations during the 6 μs long MKE6 rise time is schematically illustrated in Fig. 4.

The same loss procedure in reverse direction will occur during the fall time of the MKE6. The measured waveform of this kicker is shown in Fig. 5. The position of the first bunch of a bunch train is at 38.5 μs [3].

MEASURED LOSSES

During 2015 run, the dBLMs in LSS6 measured the losses for extraction of one single bunch, trains of 12, 36, 72 and 144 bunches. The loss signal for four different extractions of a bunch train of 12 bunches spaced by 25 ns is shown in Fig.

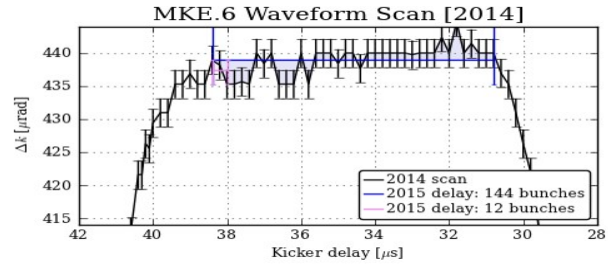

Figure 5: Measured waveform of MKE.6.

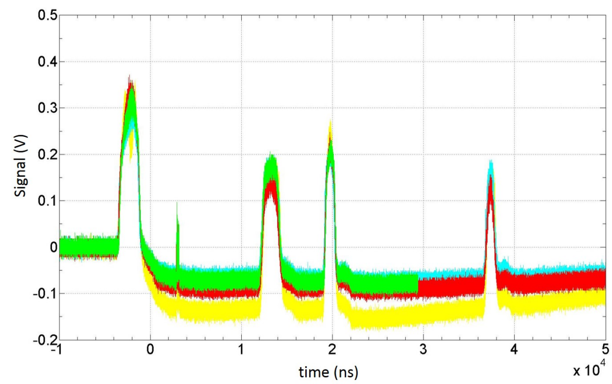

Figure 6: The loss signal for four different extractions of a bunch train of 12 bunches spaced with 25 ns. The first part between -3.8 and +1.5 μs is the loss pattern during MKE6 rise time, the 12 bunches are visible at 2.5 μs. The next loss part is induced by the MKE6 fall time. The following two losses signals at 20 and 37 μs are losses induced by particles getting a small kick from the MKE6 (beginning of rise time and end of fall time - indicated by the arrows) and making one additional turn in the SPS.

6. The first part between -3.8 and +1.5 μs is the loss pattern during MKE6 rise time, the 12 bunches are visibile at 2.5 μs. The next loss part is induced by the MKE6 fall time. The following two losses signals at 20 μs and 37 μs are losses induced by particles getting a small kick from the MKE6 (beginning of rise time and end of fall time) and making one additional turn in the SPS (length: 23 μs).

Figure 7 shows the loss pattern for three extractions of 144 bunches (2 x 72 bunches). The loss pattern is different compared to the 12 bunches extraction. Apparently no losses were induced during the MKE6 fall time, this means, that there are only losses induces by recaptured beam before the nominal bunch train.

First measurements during commissioning in 2016 were performed and the extraction of one nominal bunch to LHC was observed. The result is shown in Fig. 8. The loss pattern is similar to the extraction of 12 bunches, the extraction of the bunch is visible at 7000 ns. In the zoom into the first part of the loss pattern (see Fig. 9) ghost bunches are clearly visible. The ghost bunches appear already ~ 5.3 μs before and ~ 12 μs after the nominal bunch. These bunches are an issue for high losses at LHC injection. The origin of these ghost bunches is currently under study and will be further

ISBN 978-3-95450-147-2

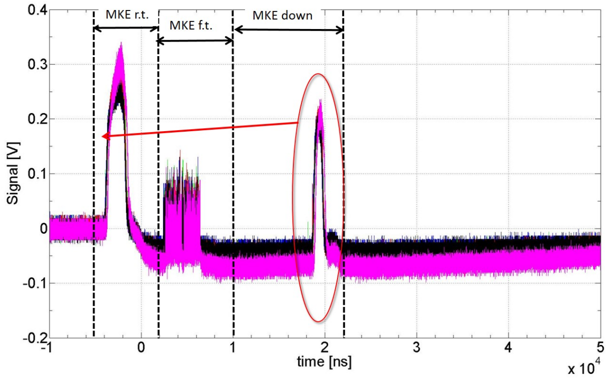

Figure 7: Loss pattern for three extractions of 144 bunches (2 x 72 bunches). The loss pattern is different compared to the 12 bunches extraction. Apparently no losses were induced during the MKE6 fall time, this means, that there are only losses induces by particles before the nominal bunch train.

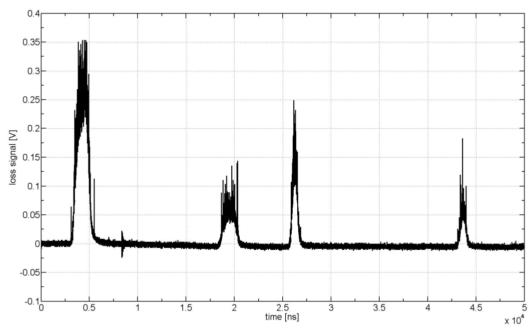

Figure 8: Extraction of one nominal bunch to LHC. The loss pattern is comparable to the extraction of 12 bunches.

studied during the commissioning and intensity ramp-up in 2016. In addition possible loss mitigation techniques like cleaning around the beam in the SPS with the SPS tune kicker will be tested [4].

With the dBLM system in the PS first measurements were performed, Fig. 10 shows a screenshot of the OASIS oscilloscope during the extraction of 72 bunches spaced by 25 ns to the SPS. The horizontal resolution is 200 ns per division,

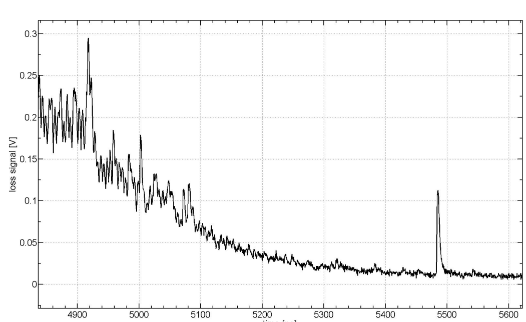

Figure 9: Zoom into the first part of the loss pattern of Fig. 8. Ghost bunches are clearly visible.

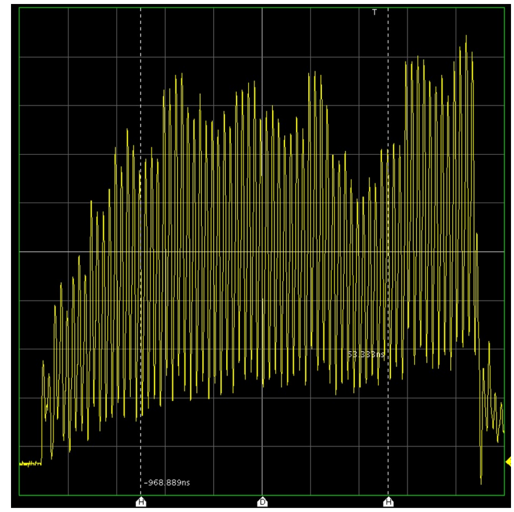

Figure 10: Measured loss pattern during the extraction of 72 bunches spaced by 25 ns to the SPS. The horizontal resolution is 200 ns per division, vertical resolution is 50 mV per division.

vertical resolution is 50 mV per division. The studies of the measured losses will be continued during the 2016 run.

CONCLUSION

For the first time losses at SPS extraction were measured with diamond based beam loss monitors, their nanosecond time resolution showed, that recaptured beam and ghost bunches are distributed before and after the nominal bunches. This recaptured beam is swept over the septum protection TPSG during the rise and fall time of the LSS6 extraction kicker. The study of the measured signals in the SPS and the set-up of the system in the PS will be continued during commissioning and intensity ramp-up in 2016. In addition possible loss mitigations, like cleaning in the SPS with the tune kicker, will be tested.

REFERENCES

[1] O. Stein, F. Burkart *et al.*, "Response of polycrystalline diamond particle detectors measured with a high intensity electron beam", in *Proc. of IPAC'15*, Richmond, USA, paper MOPTY058.

[2] F. Burkart *et al.* "Diamond particle detector properties during high fluence material damage tests and their future applications for machine protection in the LHC", in *Proc. of IPAC'14*, Shanghai, China, paper THPME172.

[3] L. Drosdal, "LHC injection beam quality during LHC run I", Ph.D. Thesis, Rep. CERN-THESIS-2015-254.

[4] F. Burkart *et al.*, "How to obtain clean injections", presented at LHC workshop, Evian, France, 2015.