Beam Loss Signal Calibration for the LHC Diamond Detectors during Run 2

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Abstract

Chemical Vapour Deposition (CVD) diamond detectors can be used as fast beam loss monitors in particle accelerators. In the Large Hadron Collider (LHC) at CERN, they are installed in the betatron collimation region, a high-radiation environment. In addition to their high-radiation tolerance, their main advantage is a time resolution of 1 ns which makes possible not only turn-by-turn, but also bunch-by-bunch loss measurements. An analysis of the LHC diamond beam loss monitor signals recorded during the last months of Run 2 (September 2018-November 2018) is presented with the aim of obtaining a signal-to-beam-loss calibration.

Introduction

The LHC Beam Loss Monitoring (BLM) system:

- Is a **machine protection system** against beam losses
- Can also be used as a **diagnostics tool** -> Precise number of **lost beam particles** and **identification of loss mechanisms**

Only **Ionization Chamber** (IC) BLM detectors considered in the past for this analysis

Equivalent calibration of the **Diamond BLM** (dBLM) detectors -> Under test in certain LHC locations in the last months of Run 2, provide bunch-by-bunch loss measurements

LHC dBLM detectors layout

LHC Run 2 -> **6 dBLM detectors** (3 per beam) installed in the betatron collimation region:

- Collimators which clean the beam from transverse halo particles
- dBLM detector **downstream primary vertical collimator** -> Highly sensitive mainly to beam particles lost in that collimator
- dBLM detector **downstream empty slot**
- dBLM detector **downstream additional collimators**

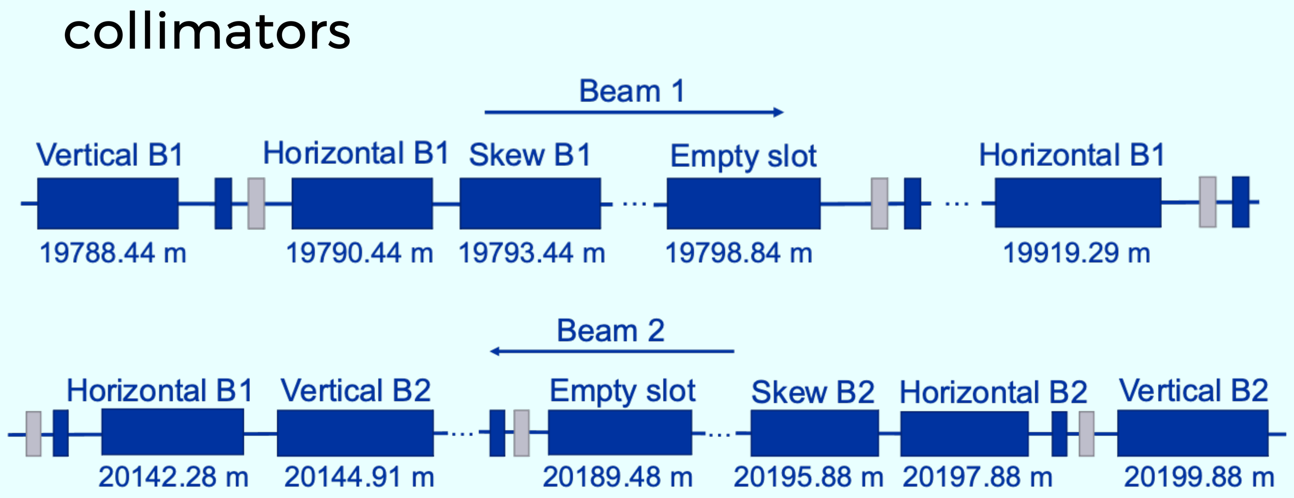

Figure 4. dBLM layout in the LHC betatron collimation region for **a.** Beam 1 and **b.** Beam 2. dBLM detectors indicated as grey vertical rectangles.

Calibration validation

Algorithms applied to dBLM and IC BLM signals:

- LHC **Squeeze beam modes** in regular periods
- After Technical Stop September 2018
- 27 Squeeze beam modes
- Around 11 min each

IC BLM algorithm shows a better agreement with measurements with the BCT detector -> **dBLM method can follow the same trend**

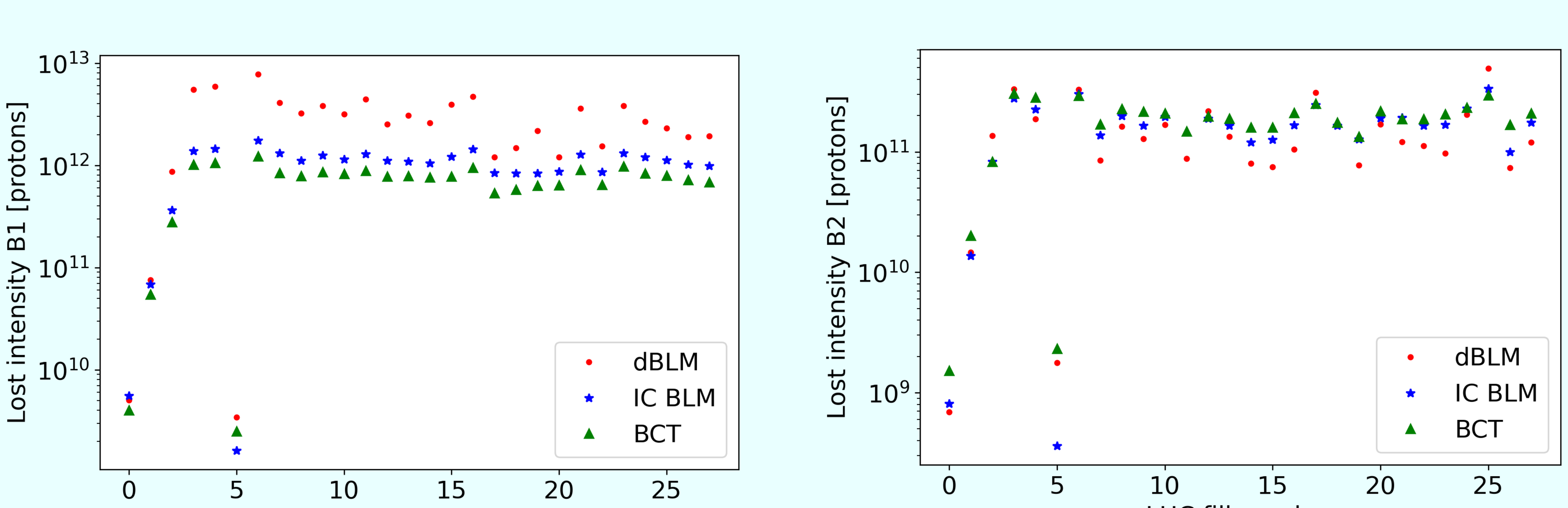

Figure 6. Total **a.** Beam 1 and **b.** Beam 2 lost intensity during LHC Squeeze beam modes as calculated with the dBLM algorithm (red dots), the IC BLM algorithm (blue stars) and measured with the BCT detector (green triangles).

LHC BLM detectors

The IC BLMs and the dBLMs are the two most relevant beam loss detector types in the LHC BLM system for this analysis:

IC BLMs

- Most common detector type in the LHC BLM system
- Stainless steel cylindrical tube filled with nitrogen gas
- Contains aluminium plates alternatively used as high voltage and signal electrodes
- Analog signal induced from the ionization of the gas when the lost particles traverse the chamber
- Signal digitized with a CFC card

dBLMs

- Squared pCVD diamond detector
- Time resolution in the order of the ns
- Signal digitized and pre-processed in the digital back-end
- Various measurement modes
- Integral mode used in this analysis, **bunch-by-bunch** integration of the measured losses for every second and subtraction of a baseline reconstruction within bunches

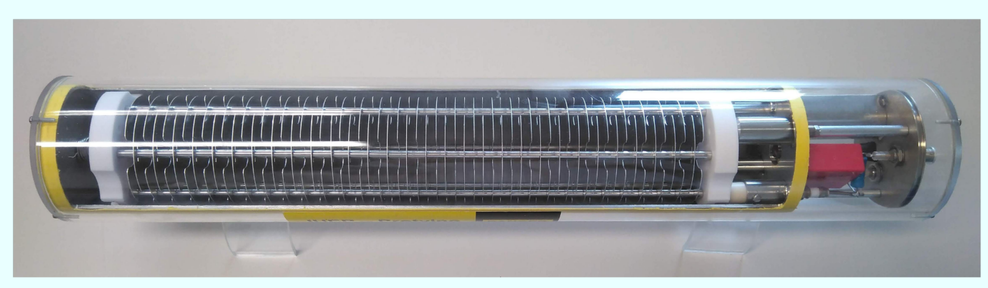

Figure 1. Internal part of an IC BLM detector (electrodes).

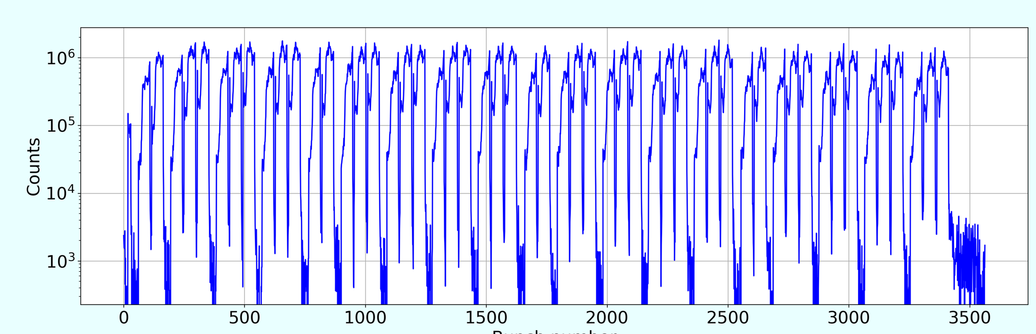

Figure 2. dBLM bunch-by-bunch integrated loss signal.

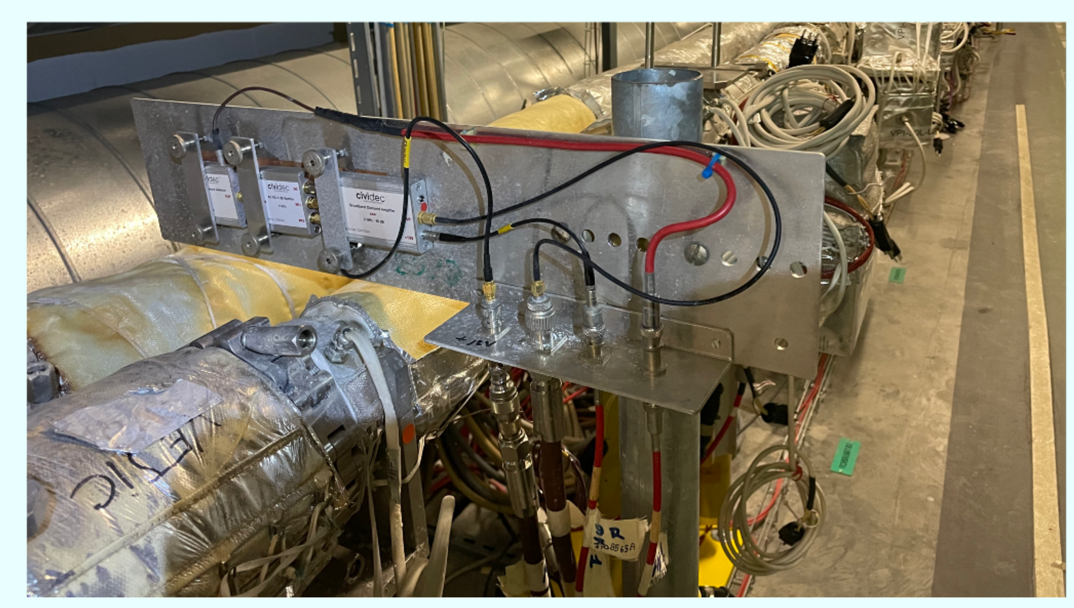

Figure 3. dBLM detector and analog front-end electronics located above the LHC beam pipes.

LHC dBLM detectors calibration

For protons lost in horizontal collimators:

$$S_{iH} = \alpha_{iH} \times \Delta I_H$$

α_{iH} -> **Response factor** for horizontal losses

Set of BLMs and protons lost in different loss scenarios:

$$\vec{S} = \boldsymbol{M} \times \overrightarrow{\Delta I}$$

$\boldsymbol{M}$ -> **Response matrix** including response factors for various loss scenarios

In nominal LHC fills:

$$\overrightarrow{\Delta I} = \boldsymbol{M}^{-1} \times \vec{S}$$

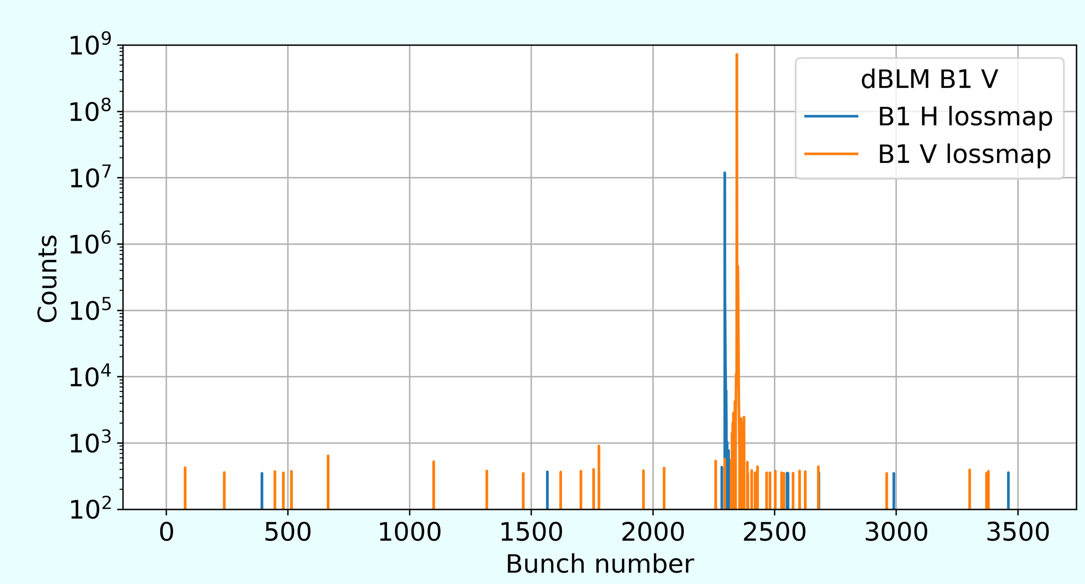

Figure 5. Integrated signal of the beam 1 dBLM detector downstream the primary vertical collimator for B1 horizontal and vertical lossmaps.

Response factors calculated from **lossmaps** -> Beam losses generated on purpose with low-intensity beam -> Bunches excited independently with white noise in selected plane

Horizontal and vertical lossmaps during LHC Squeeze beam mode -> No collisions

Conclusion

The signals from the BLM detectors can also be used as a powerful diagnostics tool to improve the performance of the accelerator by providing a precise number of the lost beam intensity and identifying the beam loss mechanisms. In the past, this was only done with the signals from the IC BLM detectors. However, a set of dBLM detectors were installed and under test in the LHC betatron collimation region during the last months of Run 2. A global calibration for the dBLM detectors was carried out. Even if the IC BLMs still show a higher accuracy for this kind of analysis, they can also be calibrated so that the loss measurement is provided in total number of protons lost.