OVERVIEW OF LHC BEAM LOSS MEASUREMENTS

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Abstract

The LHC beam loss monitoring system provides measurements with an update rate of 1 Hz and high time resolution data by event triggering. This information is used for the initiation of beam aborts, fixed displays and off line analysis. The analysis of fast and localized loss events resulted in the determination of their rate, duration, peak amplitudes and scaling with intensity, number of bunches and beam energy. The calibration of the secondary shower beam loss signal with respect to the needed beam energy deposition to quench the magnet coil is addressed at $450GeV$ and $3.5TeV$. The adjustment of collimators is checked my measuring the loss pattern and its variation in the collimation regions of the LHC. Loss pattern changes during a fill allow the observation of non typical fill parameters.

INTRODUCTION

The main function of the LHC beam loss system is the protection of superconducting magnets against quench or damage by the measurements of the lost proton initiated secondary particle showers. 3600 ionisation chambers detect the losses at almost every element around the ring distinguishing between the counter rotating beams. The beam loss measurement data streams are recorded at $1Hz$ and high time resolution data ($40\mu s$, $2ns$,) triggered by events. The $1Hz$ data stream includes 12 different integration windows for every channel with a minimum duration of $40\mu s$ up to $83s$. For integration windows with a duration of less than $1s$ the maximum value is selected from the values calculated for a particular integration time during the previous second. This procedure allows determination of losses with a minimum duration of 40 μs even if data is only logged with a frequency of $1Hz$.

ANALYSIS OF FAST LOSSES

In summer 2010 first events occurred with the characteristics of being very localised (see Fig. 1) and short (see Fig. 2). The beam loss is generated by a beam coming from the left side between the second and third cluster of monitors. The monitors are located at the quadrupole magnets and the bending magnets located in between are not observed. Signals are seen in monitors for both beams due to particle crosstalk. A typical fast loss has a FWHM time scale of about $1ms$. For more detailed analysis the losses

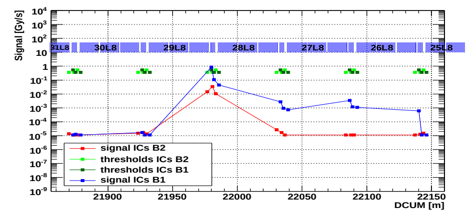

Figure 1: Longitudinal loss profile for a fast event with several measurement locations at every quadrupole magnet (blue: monitors for beam from left, red: from right side, green: abort thresholds).

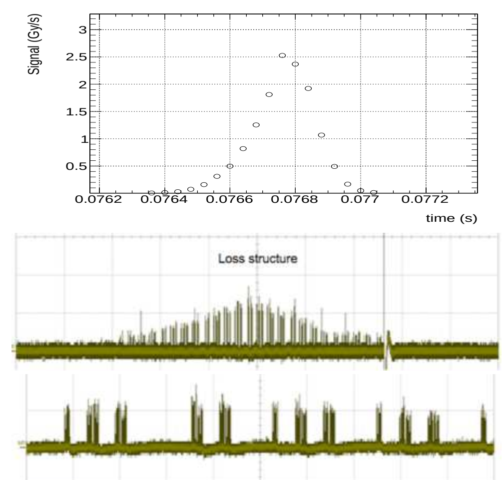

Figure 2: Typical time evolution of a fast loss event (top: signal integration over 40 μs), middle and bottom $2ns$ with different time scales).

are also observed with nano second time resolution diamond based detectors (see Fig. 2). The fast loss shape is observed over many turns (Fig. 2, middle) and the sub-turn snapshot (Fig. 2 bottom) shows that the bunch structure is maintained. To analyse the phenomenon sub abort threshold events have been used to determine event rate, loss duration and peak amplitude signal. The loss duration has been determined by fitting the signal recorded in different integration windows (see Fig. 3). The crossing of the two straight line parametrisations gives an estimate of the loss duration. The evolution of the thresholds as a function of the integration window is shown as well as the evolution

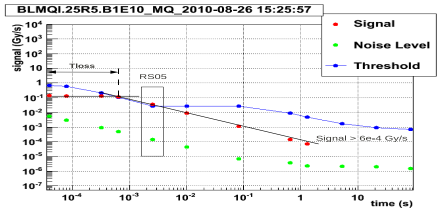

Figure 3: Beam loss signal versus duration of signal integration window. The recording threshold is set to signal larger than $610^{-4}\ Gy/s$.

of the signal noise. The separation between both allows a detection of fast loss events down to 0.01 of the threshold levels. The duration of the losses decreases with the intensity during the LHC operation periods in 2010 and 2011 (see Fig. 4). The small dots represent the duration for every single loss whereas the larger circles show an average. The fits predict a loss duration of $130\mu s$ at the nominal LHC intensity. The average maximum loss signal amplitude shows no intensity dependence and is $5 \cdot 10^{-2} Gy/s$. The loss rate is estimated to be about 8 events per hour with the LHC filled with 1380 bunches. The rate as function of the bunch numbers shows an increase, but further investigations are needed before drawing conclusions. To estimate

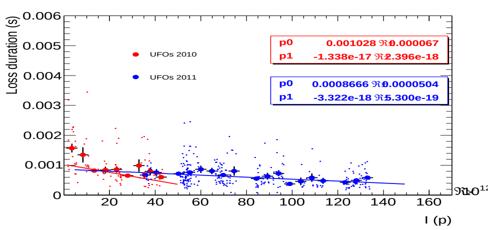

Figure 4: Loss duration versus beam intensity.

the dependence of the observed loss signal on beam energy, comparable fast loss events have been generated with the beam wire scanner (see Fig. 5). The dependence differs slightly for the three monitors observing one beam at the quadrupole magnet. The extrapolated loss signal amplitude increases by a factor 2 to 3.5 at $7TeV$ relative to $3.5TeV$.

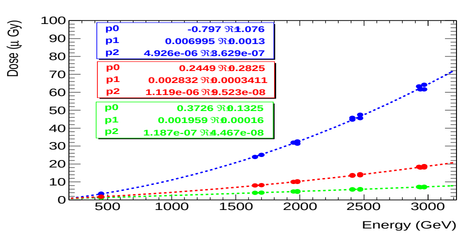

Figure 5: Energy dependence of secondary particle showers created by wire scans for the three monitors at quadrupole magnets.

THRESHOLD AND QUENCH LEVEL

The accurate setting of the beam abort threshold with respect to the quench levels of the superconducting magnet coils has been treated in depth with simulations to be able to maximise the operation time. New measurements recorded during a quench test show not only the loss signals but also the voltage drop development in the radiation exposed coil (see Fig. 6). The losses are again generated

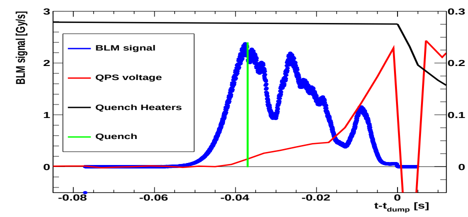

Figure 6: Beam loss signal (blue trace) and superconducting voltage drop (red trace) as function of time. The interruption of the voltage signal is due to a signal disturbance during the firing of the magnet quench heaters (black trace).

with a beam wire scanner. The beam loss signal shape as a function of time is probably due to wire vibrations. The

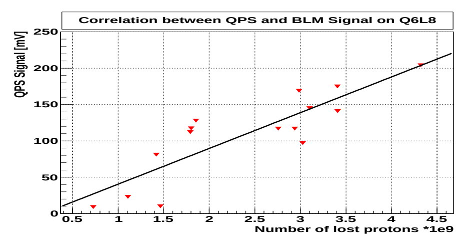

Figure 7: Maximum of voltage drop on a superconducting magnet coil due to the energy deposition of secondary particle showers initiated by protons impacting on a collimator.

development of the maximum superconducting coil voltage drop for different beam intensities shows a linear behaviour (see Fig. 7). For this experiment the injected beam was directed towards a collimator with the secondary shower particles depositing their energy in the magnet coil. A similar experiment but unintentionally initiated by a failure in the injection system caused massive beam losses and several magnet coil quenches at the same time (see Fig. 8). The events allow the conclusion that the quench level of the bending magnets lies between 1 and $2 \cdot 10^9$ impacting protons, that the quench of the quadrupole magnet Q6 is above 7 and below $40 \cdot 10^9$, and that Q8 has a quench level above $10 \cdot 10^9$.

LOSS PATTERN AND ITS EVOLUTION

The loss patterns in the collimation regions reflect the relative position settings of their jaws. The actual settings are usually verified by the transverse blow-up of the beam through resonance crossing (see Fig. 9). Several of these

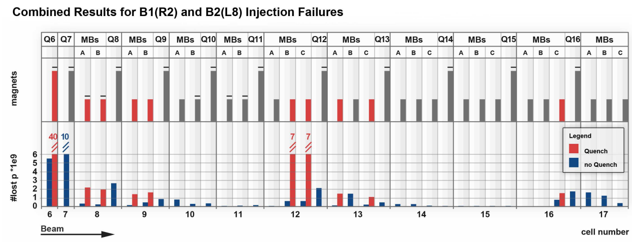

Figure 8: Magnet type and proton beam intensity impacting on magnet beam screen as function of magnet number. The beam energy has been $450GeV$. Red bars in the top row indicate that the magnet coil quenched and the small top bar indicates that the magnet is equipped with beam loss monitors. In the lower row the shaded area is indicating that the bar is extending to the value written in top.

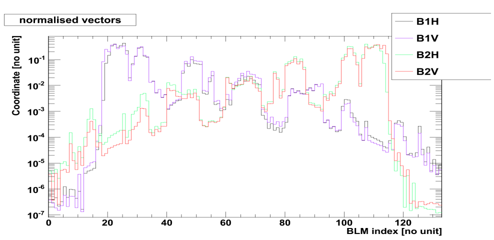

Figure 9: Reference loss patterns as function of the beam loss monitor index in the collimation region of LHC point 7. The patterns are normalised and differences between horizontal and vertical losses only occur at the primary collimators (highest losses).

patterns are averaged to construct a reference pattern for the horizontal and vertical planes of both beams. The relative standard deviation is below 5% for all monitors. These measurements show that the beam only once has been used for reference loss map generation (horizontal or vertical excitation). In case a beam is used twice the differences to the reference maps are visible. These reference patterns

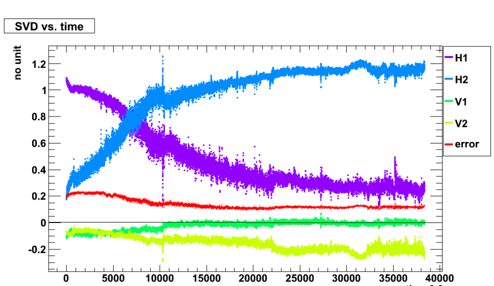

Figure 10: Evolution of the loss patterns during a fill (21^{th} May 2011, fill 1785).

can also been used to follow the evolution during fills (see Fig. 10). It is observed that the beams lose more particles horizontally than vertically. It is also seen that beam 1 horizontal dominates initial losses but that after about 2 hours beam 2 horizontal takes over the dominant role. The col-

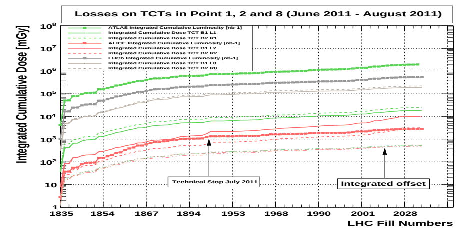

Figure 11: Integrated cumulative dose at different final focus magnet collimators as function of fill number. For comparison the integrated luminosity is plotted (arbitrary units) as well as dose offset for the 6 monitors.

limators protecting the final focus magnets of the four experiments are stopping the the tertiary beam halo. Losses at these TCTs scale with the luminosity of the main experiments (see Fig. 11). Shown are the scaled luminosities (arbitrary units) and the losses for the TCT for beam 1 (left) and beam 2 (right side of the experiment). The integrated beam loss offset signal is shown to indicate the magnitude of the correction applied to the TCT signals. Losses at the low luminosity experiment ALICE are the only ones which show larger differences between right and left collimators. The losses normalized to the intensity are a measure of the optimal setting of the accelerator parameters (see Fig. 12). A few weeks ago the LHC vacuum was degraded due to

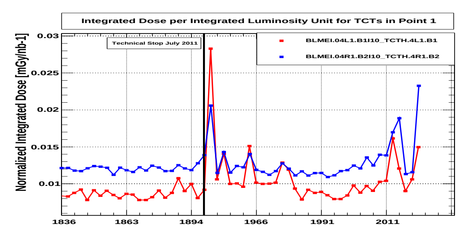

Figure 12: Normalized integrated cumulative dose at different final focus magnet collimators as function of fill number.

conditioning work in the triplet beam screens, which is clearly visible a few fills after fill number 1894 as an increase in the normalized loss and then it steadily decreases down to the level observed before the vacuum conditioning event.

CONCLUSIONS

Beam loss measurements have allowed the characterisation and prediction of how fast LHC loss events will change with increasing beam intensity and energy. The loss signal to quench level calibration has been further studied to include the magnet coil voltage drop measurements to allow for more model checks. Beam loss measurements are continually used to check collimator adjustment variations and other accelerator fill to fill variations.