INJECTION LOSSES AND PROTECTION

W. Bartmann, R. Appleby, P. Baudrenghien, C. Bracco, B. Dehning, A. Di Mauro, L. Drosdal, J. Emery, B. Goddard, E.B. Holzer, W. Höfle, V. Kain, M. Meddahi, S. Redaelli, E. Shaposhnikova, J. Uythoven, D. Valuch, J. Wenninger, C. Zamantzas, M. Zerlauth, CERN, Geneva, Switzerland
E. Gianfelice-Wendt, Fermilab, Batavia, US

Abstract

Injection losses are compared for 2010 and 2011 operation. Mitigation techniques which were put in place in 2010 to reduce losses at injection are described. Issues in 2011 operation, their potential improvements and the performance reach for 2012 are shown.

INTRODUCTION

In 2010 a maximum of 48 bunches per injection were injected into LHC, Table 1. Scaling the 2010 loss levels for higher numbers of bunches per injection, an operational limit of 100 bunches per injection was expected. In 2011, 144 bunch injections with $1.5 \cdot 10^{10}$ particles per bunch and 2 μm emittance were used in daily LHC operation and 288 bunch injection with $1.05 \cdot 10^{10}$ ppb and 2.5-2.7 μm emittance were tested in machine development studies with 30% losses of dump threshold, Fig. 1. The different techniques which allowed for reduction of injection losses in 2011 will be shown in the following section.

Table 1: Measured losses in % of dump theshold for B1/B2 up to 48 bunches per train, expected loss levels for 96 and 144 bunches are shown in *italic*.

Loss type	**8b**	**16b**	**24b**	**48b**	***96b***	***144b***
TCDI shower	1/2	3/5	4/6	23/24	*< 50?*	*< 75?*
Uncapt. beam	4/2	12/3	12/5	20/8	*< 40?*	*< 60?*

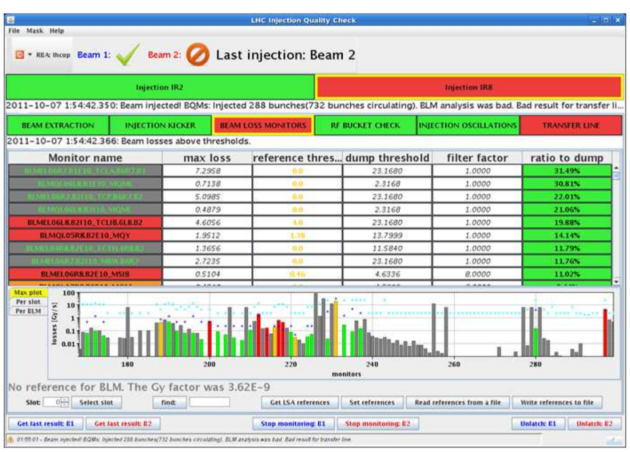

Figure 1: Losses in the LHC injection region for the first B2 288 bunch injection.

MITIGATION TECHNIQUES

Below mitigations techniques are divided into three categories according the injection loss origin.

- Overinjection and MKI failure
  - Interlocking, procedure
- Loss showers from the TCDI collimators
  - Local shielding between TCDIs and LHC
  - Beam scraping in the SPS
  - Opening TCDIs
  - Button BPM in TCDIs
  - BLM sunglasses (temporal inhibit of BLM channels)
- Losses due to uncaptured beam in the LHC
  - Local shielding downstream of TDI
  - Minimisation of capture losses
  - Injection and abort gap cleaning
  - Carefully monitoring beam quality in injectors (transverse beam size and shape, bunch length, satellites)
  - BLM sunglasses

Protection against MKI failure is treated in [2], beam scraping in the SPS in [3] and SPS extraction septum (MSE) stability in [4] and will not be covered here. Also not shown here are local TCDI shielding and beam quality monitoring in the injectors due to only minor changes between 2010 and 2011.

TCDI opening

On September 26^{th}, 2011, the TCDI half gap was opened from 4.5 to 5.0 σ nominal beam size, see details in [1]. This was motivated by regular dumps while injecting B1 into LHC due to loss showers from TCDI collimators into the LHC injection region. The loss showers were caused by shot-to-shot trajectory variations of up to 1 mm originating from the SPS extraction septum in LSS6. Since the TCDIs were validated for half gap openings up to 5.0 σ, and expecting a factor 4 loss reduction, the margin of opening by 0.5 σ was considered to significantly reduce the number of unnecessary dumps at injection and therefore

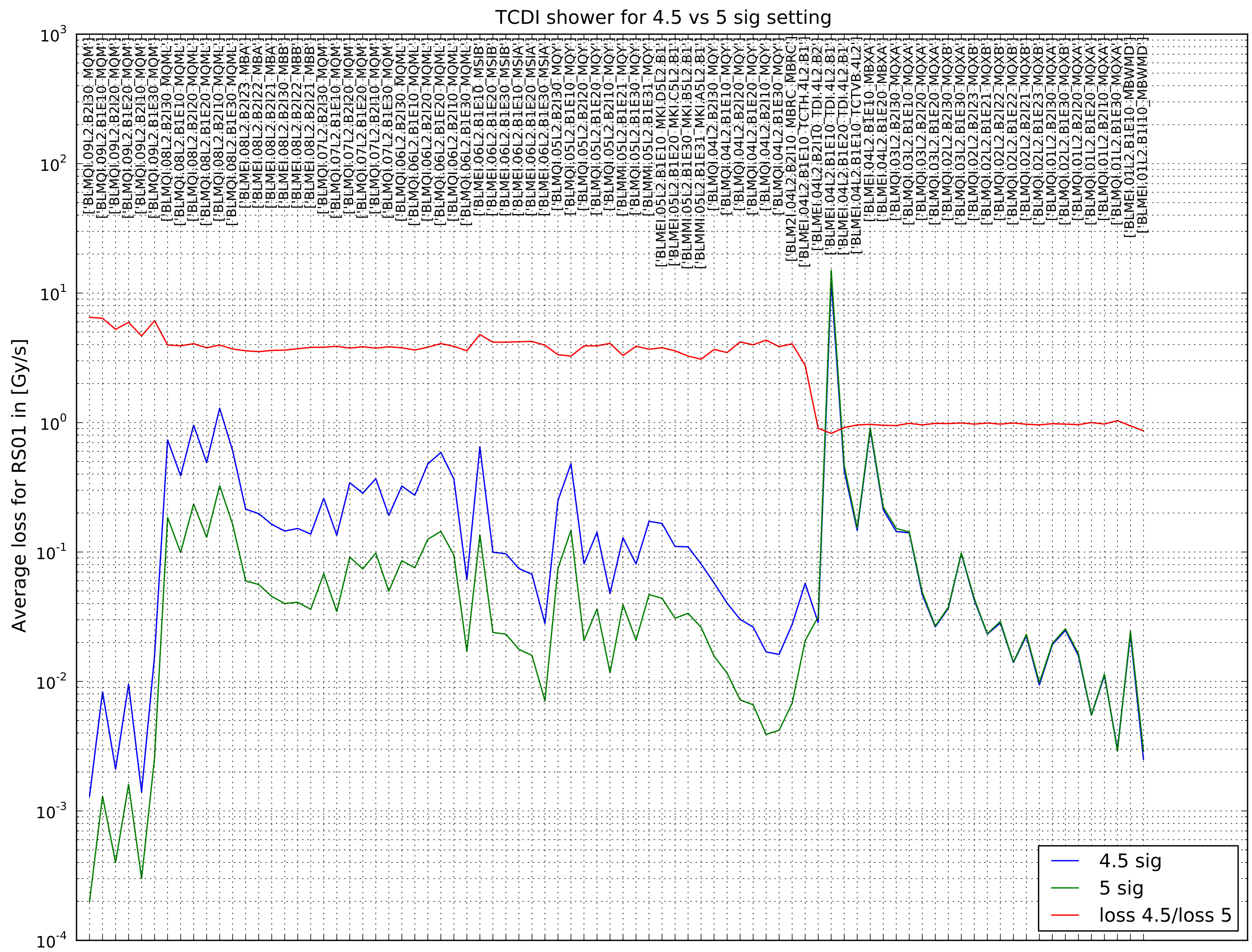

Figure 2: Loss shower from transfer line collimators (TCDI) for the cells 1 to 9 upstream of ALICE with the beam direction from left to right. The blue curve indicates the loss level with a TCDI opening of 4.5σ and the green curve shows the reduced loss level after opening the TCDIs further to 5σ.

deployed for TI 2. Figure 2 shows the average losses for $40\mu s$ on ring monitors for the cells 1 to 9 upstream of ALICE before and after opening the gap. The loss levels differ up to the loss peak of the injection collimator TDI and stay the same downstream the TDI in the triplet region. This expected loss behaviour shows that loss showers from the TCDIs dominate between Q8L2 and the TDI while monitors in the triplet region detect loss showers from the TDI caused by unbunched beam in the LHC injection kicker gap deflected on the lower collimator jaw. The measured loss reduction is about a factor 4. Figure 3 shows as comparison the loss levels for B2 where the loss level after September 26^{th}, 2011, is the same or higher than before. This measurement gives confidence that the improvement for B1 losses was not due to better beam quality from the injectors.

Moving/adding TCDIs

A longterm solution of the TCDI loss showers would be to install additional collimators further upstream which could be kept at the nominal gap while further opening the existing ones in the common tunnel region. Positions for new collimators keeping the phase advance constraint in between have been found and FLUKA simulations started [5]. The impact of an optics with integer tune 20 in the SPS has to be studied.

Local TDI shielding

Local shielding of the TDI was simulated and the results showed only small improvement in terms of reducing the loss shower downstream the TDI. However, ALICE pursues this possibility for background reduction.

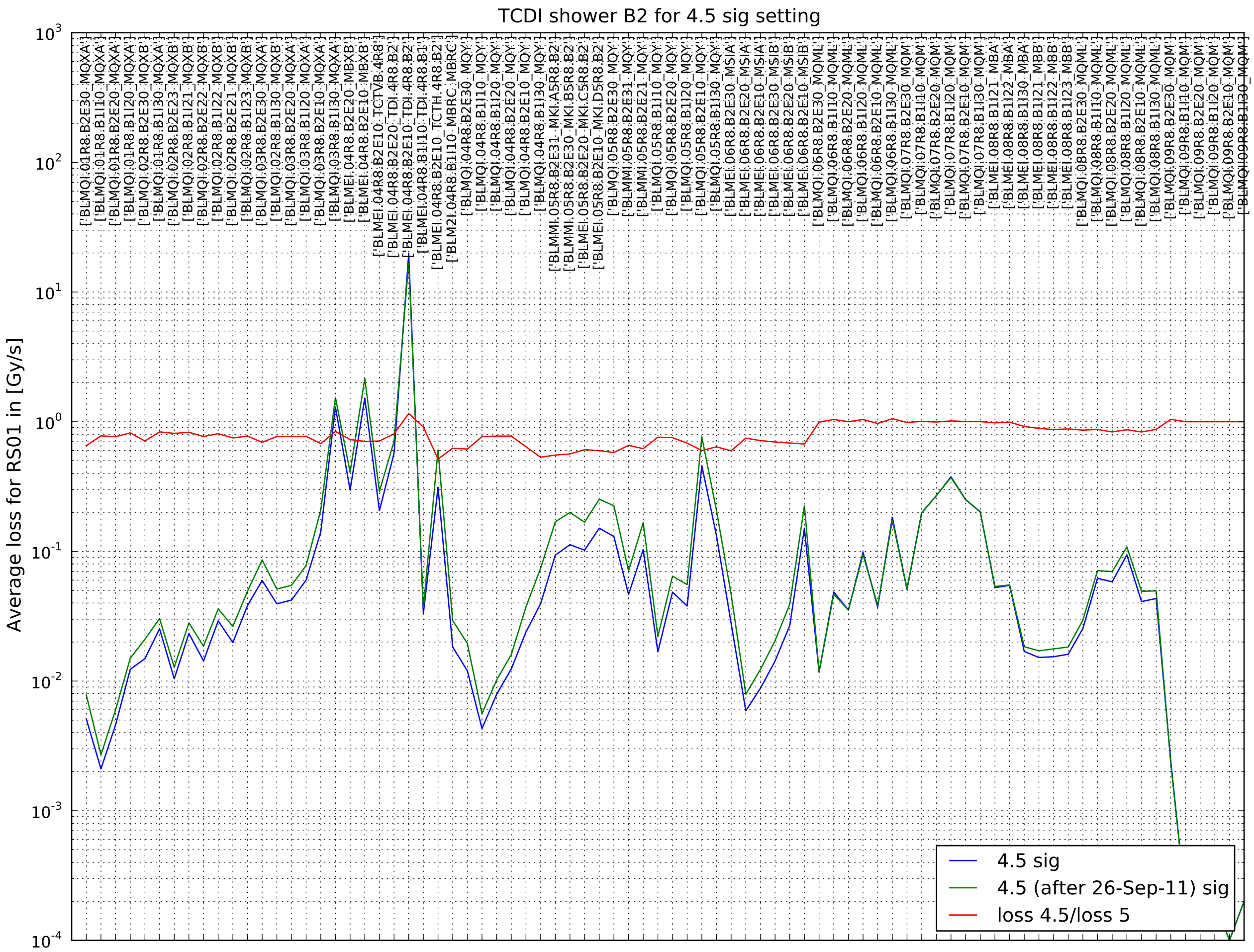

Figure 3: Loss shower from transfer line collimators (TCDI) for the cells 1 to 9 upstream of LHCb with the beam direction from right to left. The TCDIs in TI 8 were kept at 4.5σ. The blue and green curve corresponds to the same time span as shown in Fig. 2.

Capture

At the beginning of 2011 the RF voltage at injection was increased from 3.5 MV (matched case) to 6 MV to reduce the number of uncaptured particles [6]. The resulting loss levels in the triplet region can be seen in Figures 2 and 3. The capture voltage of 6 MV was kept throughout the year, a further increase could be envisaged up to 8 MV. However, an increase of the bucket height will not significantly improve the capture of particles in the longitudinal bunch tails and consequently is not believed to further reduce injection losses in the region downstream the TDI.

Abort gap and injection cleaning

Abort gap cleaning was already functional in 2010 but became more automatised. Injection cleaning was introduced and becoming operational in 2011. The main difference between the two systems is the control of critical settings. In case of injection cleaning the area to be cleaned has to be calculated depending the intended position for injected bunches and can therefore be less controlled by MCS. Development on abort gap cleaning in 2011 was mainly done for cleaning during physics. Here a reduction of luminosity due to abort gap cleaning was seen and therefore the cleaning will be switched on only in case of an increased level of abort gap population. Preparation of a fixed display for abort gap population and an application to improve the handling of abort gap and injection cleaning is foreseen for 2012.

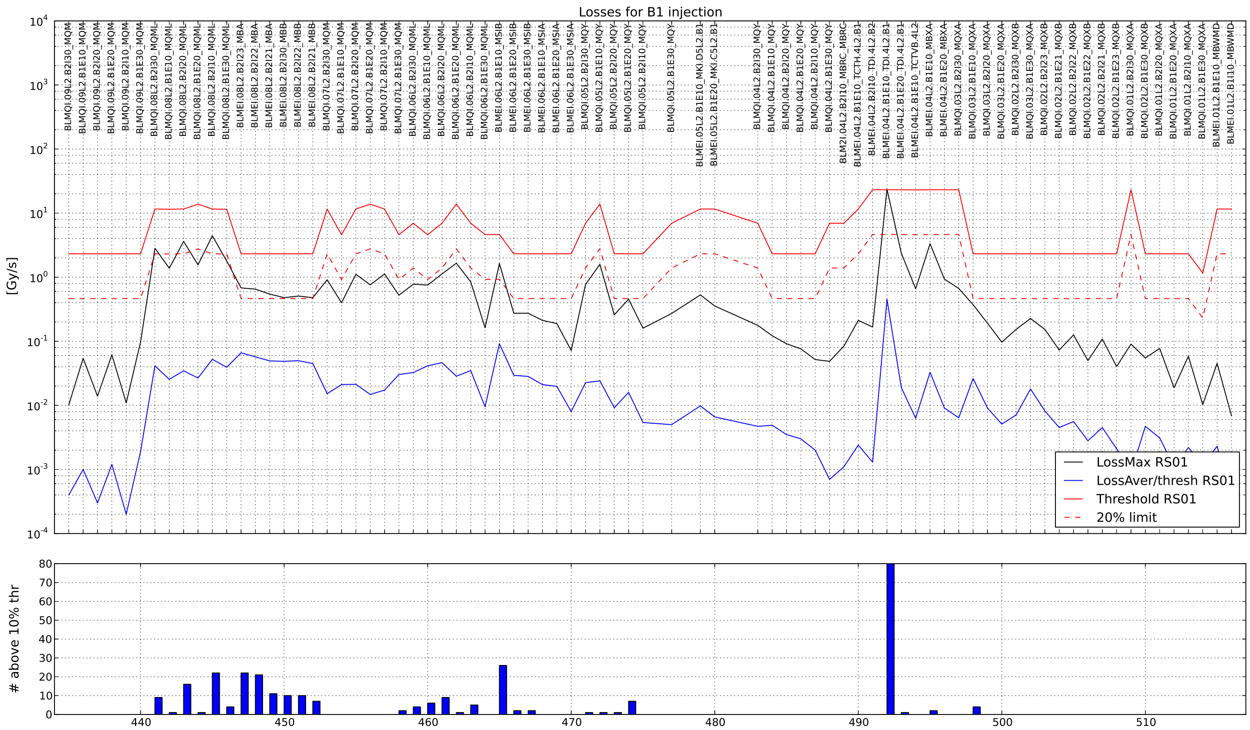

Figure 4: Maximum (black) and average (blue) losses for RS01 in the B1 injection region. Monitors with maximum losses above 20 % of the BLM threshold (red dashed) are considered for being replaced by shorter chambers. The lower plot shows the number of times these monitors are above 10 % of the dump threshold to avoid being sensitive to single bad injections.

BLM sunglasses

Loss showers from the TCDIs in the common tunnel region impinging the LHC beam loss monitors from the outside cause unnecessary beam dumps and consequently slow down injection. Also uncaptured beam hitting the TDI jaws leads to loss showers from the outside onto triplet beam loss monitors. Several options were proposed to avoid these beam dumps [7]. Their implication on the hardware and safety of the BLM system are discussed in [8]. The first option is to replace certain ionization chambers by shorter ones (LIC) and relax the dump thresholds at 450 GeV. There is no change to the hardware of the system required but the dump thresholds of certain monitors will be constantly higher at 450 GeV. As a second option it was discussed to blind out the input from certain monitors to the beam interlock system (BIS) while injection. Here an external signal is needed to define the injection time and severe changes to the software interlock system or beam loss system are required. As an advantage the dump thresholds are increased just at injection. Severe changes to the logic of a well working system outweigh the disadvantage of constantly increasing the dump thresholds at 450 GeV which lead to the suggestion of replacing several chambers by LICs. These shorter chambers have a factor 60 reduced signal compared to the existing ones and allow therefore for increasing the dump thresholds without running into the saturation limit.

As a first step a list of monitors will be replaced over the technical stop and the recommissioning will start deploying the same thresholds as were used in 2011. A maximum increase for these thresholds will be defined and only in case LHC operation is limited by unnecessary dumps at injection, this increase of dump thresholds will be applied. For the selection of monitors to be replaced an operational margin of factor 5 between actual losses and dump threshold was taken. In Figures 4 and 5 the threshold is shown in red with the factor 5 margin as red dashed line. The maximum and average losses for the 40 μs time scale are shown in black and blue, respectively. The lower part of the figure indicates the number of times a monitor signal was above 10% of the dump threshold. Monitors are suggested for replacement where the maximum loss (black) is higher than the factor 5 margin (red, dashed) and also a significant amount of triggers with respect to the count at the TDI is seen. This applies for 11 monitors in the B1 and 7 monitors in the B2 injection region, Table 2.

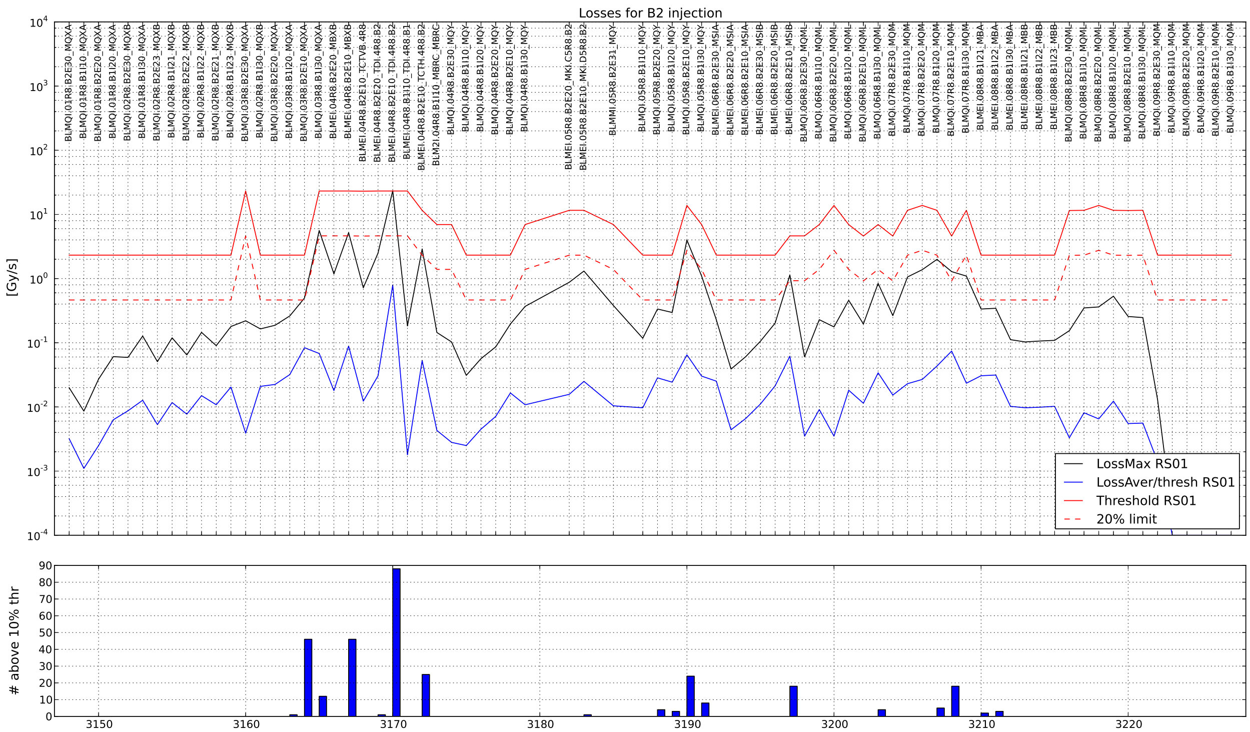

Figure 5: Maximum (black) and average (blue) losses for RS01 in the B2 injection region. Monitors with maximum losses above 20 $\%$ of the BLM threshold (red dashed) are considered for being replaced by shorter chambers. The lower plot shows the number of times these monitors are above 10 $\%$ of the dump threshold to avoid being sensitive to single bad injections.

Table 2: B1 and B2 monitors suggested for replacement by LICs.

B1 injection	**B2 injection**
BLMQI.08L2.B2I30_MQML	BLMQI.03R8.B1I30_MQXA
BLMQI.08L2.B2I20_MQML	BLMEI.04R8.B2E10_MBXB
BLMQI.08L2.B2I10_MQML	BLMEI.04R8.B2E10_TDI4R8.B2
BLMEI.08L2.B2I23_MBA	BLMEI.04R8.B2E10_TCTH.4R8.B2
BLMEI.08L2.B2I22_MBA	BLMQI.05R8.B2E10_MQY
BLMEI.08L2.B2I21_MBA	BLMEI.06R8.B2E10_MSIB
BLMEI.08L2.B2I30_MBB	BLMQI.07R8.B2E10_MQM
BLMEI.08L2.B2I22_MBB	
BLMEI.08L2.B2I21_MBB	
BLMEI.06L2.B1E10_MSIB	
BLMEI.04L2.B1E10_TDI.4L2.B1	

Expected future gain

The mitigation techniques are summarised in Table 3 with their expected future loss reduction potential.

OPERATIONAL ISSUES

The main operational issues regarding injection losses is the steering of the transfer lines which is covered in [4]. A further operational issue came up after the ALICE polarity flip on September, 4^{th} 2011. Loss levels on TCTH.B2 were increased by a factor 3. These losses are sensitive to a movement of the lower TCLIA.B1 jaw. The area was scanned with circulating beam for aperture bottlenecks without finding any obstacles. The TCTH losses increase from 12 to 36 bunch injections but stay rather constant for injections of 72, 108 and 144 bunches which is currently not understood. Eventually the gap was opened to the measured beam size and shifted by 400 μm towards the lower jaw which reduced the losses by 50 $\%$ and allowed to inject up to 144 bunches with loss levels below 50 $\%$ of the dump threshold [9].

PERFORMANCE REACH 2012

Injecting 288 bunches with $1.05 \cdot 10^{10}$ ppb and 2.5-2.7 μm emittance with 30% of the dump threshold is promising for a full SPS batch injection also with higher bunch intensities. The limit is rather the time spent at injection, when having difficulties already for 36, 72 or 144 bunch injections in case of trajectory instability. In order to reduce this time it is suggested to improve the trajectory stability hardware wise, make steering straight-forward by more so-

Table 3: Injection loss mitigation techniques with their potential future gain.

Mitigation	**Potential future gain**
TCDI shower	
Local shielding between TCDIs and LHC	Presently less gain than expected from simulations; difficult to increase shielding, in particular for TI 8
Beam scraping in SPS	No gain with present emittances, for future bigger emittances probably worse;
Opening TCDIs	No gain for TI 2 (already at 5 sig), but possible gain for TI 8 (at 4.5 sig), Machine Protection!
Moving/adding TCDIs	Potentially significant gain, under study
Button BPM in TCDIs	Potentially significant gain
Improve stability of MSE	Ripple improvement and phase stabilisation in place since end of Sept-11, effect to be checked
BLM sunglasses	With LICs at certain positions and removed filters factor 5 margin possible, Machine Protection!
Uncaptured beam	
Local shielding after TDI	No gain for inj losses, but ALICE interested to reduce background
Minimisation of capture losses	No gain: capture of longitudinal tails hardly affected by further voltage increase
Injection and abort gap cleaning	No gain: trade off with luminosity
Carefully monitoring beam quality in injectors	No gain in losses but better detection of bad beam quality early in the chain; Longitudinally already well covered by BQM, transv. can be improved
BLM sunglasses	With LICs at certain positions and removed filters factor 5 margin possible, Machine Protection!

phisticated information in IQC (trajectory at collimators, envelopes for monitors and correctors, intensity dependent and thus easy colour code), improve transverse diagnostics of the SPS-LHC transfer and not to change supercycles in injectors while LHC filling.

CONCLUSION

Since 2010 many mitigations were put in place which allowed injecting up to 288 bunches in 2011. Ongoing improvements are MSE power converter stabilization, BLM sunglasses, IQC sophistication and transverse diagnostics in the transfer lines. Moving or adding TCDIs is being investigated. In 2011 a lot of work was dedicated to reduce the injection losses - in 2012 the focus will be on reducing the time spent at injection.

REFERENCES

[1] W. Bartmann, "'Engineering Change Request, Opening of TCDI Collimators in TI 2"', LHC-MPP-ECR-0001, 22 September 2011, CERN, Geneva, Switzerland.

[2] C. Bracco, "'Injection and Dump Systems"', these proceedings.

[3] K. Cornelis, "'Beam preparation in injectiors adn beam characteristics through the injector complex"', these proceedings.

[4] L. Drosdal, "'Transfer lines - stability and optimization"', these proceedings.

[5] E. Gianfelice, "'TI 8 collimation system"', LIU-SPS, BEAM Loss, Protection , Transfer Lines Working Group Meeting, 5 October 2011, CERN, Geneva, Switzerland.

[6] P. Baudrenghien et al., "'LHC RF Status, March 29, 2011"', LBOC Meeting, CERN, Geneva, Switzerland, March 2011.

[7] C. Zamantzas, "'LHC BLM system: possible modification schemes to KEEP or to FORCE true the beam permit signal at injection"', LHC Machine Protection Panel, 30 September 2011, CERN, Geneva, Switzerland.

[8] J. Emery, "'BLM electronics failure mode cases for the selected proposal on LHCBLM sunglasses "', LHC Machine Protection Panel, 21 October 2011, CERN, Geneva, Switzerland.

[9] W. Bartmann et al., "'Injection status"', LBOC Meeting, 20 September 2011, CERN, Geneva, Switzerland.