SPS SCRAPING AND LHC TRANSVERSE TAILS

L. Drøsdal, K. Cornelis, B.Goddard, V. Kain, M. Meddahi, O. Mete
B. Salvachua, G. Valentino, E. Veyrunes, CERN, Geneva, Switzerland

Abstract

All high-intensity LHC beams have to be scraped before extraction from the SPS to remove the non-Gaussian transverse tails of the particle distributions. The tail particles would otherwise cause unacceptably high losses during injection or other phases of the LHC cycle. Studies have been carried out to quantify the scraping using injection losses and emittance measurements from wire scanners as diagnostics. Beams scraped in the SPS were scraped again in the LHC with collimators to investigate possible tail repopulation. The results of these studies will be presented in this paper.

INTRODUCTION

Before injection into the LHC the high intensity beams are scraped to remove transverse tails. The scraping is done in the last injector, the SPS, at the end of the ramp. Around 3 % of the intensity is removed for normal operations. These particles are high amplitude particles that do not contribute significantly to the luminosity, but if they are not removed they cause beam loss at the collimators in the injection region or later in the LHC cycle [1].

During a machine development study in October 2012 the effect of scraping in the SPS on the injected beam was investigated. The beams were first scanned at the scraper in the SPS to know the beam profile and then injected into the LHC. Only data at the SPS scraper in the horizontal plane could be obtained. Scans in the vertical plane were erroneous due to controls problems. The measured beam profiles were fitted by a double Gaussian function, see Eq. 1, which describes the LHC particle distributions with their non-Gaussian tails well. A single Gaussian fit of the beam core is included in the analysis for comparison. To be able to compare different scans the measurements are given in units of nominal beam size assuming a normalized emittance of ε^* =3.5 μm.

$$I(x) = I_1 \cdot e^{-\frac{(x-x_0)^2}{2\sigma_1^2}} + I_2 \cdot e^{-\frac{(x-x_0)^2}{2\sigma_2^2}} \qquad (1)$$

LHC SCRAPED BEAM PROFILES

The evolution of the transverse profiles in the LHC, after they had been scraped in the SPS, was studied by scanning the tails again in the LHC using a similar technique as in the SPS. The LHC primary collimators were operated as scrapers for this study [2]. For comparison, beam without scraping in the SPS as well as beam with scraping was scanned. Only low intensity beam consisting of three bunches could be used for these studies. The beam was first scanned in the SPS as a reference, see Fig. 1.

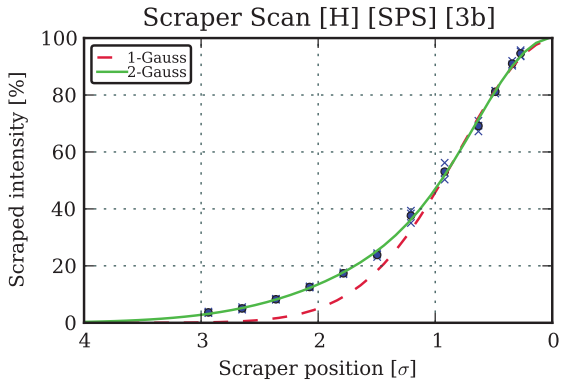

Figure 1: A beam scan done by the scraper in the SPS as a reference for scans in the LHC after injection. The measurements are fitted by a single and a double Gaussian. Because of the large tails the double Gaussian function gives the best approximation.

In the LHC the horizontal collimators TCP.C6L7.B1 and TCP.C6R7.B2 were used. For the two cases, profile scan with and without scraping in the SPS, both beams were injected into the LHC at the same time. Beam 1 was scanned first and beam 2 about 30 min after injection. This allowed to also to conclude on the possible re-generation of the tails on the injection plateau. See Table 1 for a list of parameters for the four scans done. The emittances were measured after injection by the LHC wire scanners.

Table 1: Parameters for LHC Beam Scans

	Time after injection	Scan duration	SPS scraped intensity	Emittance $\epsilon_H[\mu m]$	$\epsilon_V[\mu m]$
B1	13 min	13 min	17.8 %	1.25	1.06
B2	32 min	18 min	16.6 %	1.52	1.31
B1	8 min	17 min	0 %	1.39	1.21
B2	27 min	16 min	0 %	1.55	1.40

The beam scans done in the LHC are shown in Fig. 2 for beam 1 and in Fig. 3 for beam 2. The LHC scans confirm the large transverse tails in case the beams are not scraped before injection. When the beams are scraped this measurements show that scraping in the SPS successfully removes the tails and that the tails are not repopulated through the injection process or any other mechanism during the injection plateau. The 30 minutes waiting time before the beam 2 scan could be started corresponds roughly to the time the LHC filling takes.

In Table 2 the fit results for the double Gaussian (Eq. 1)

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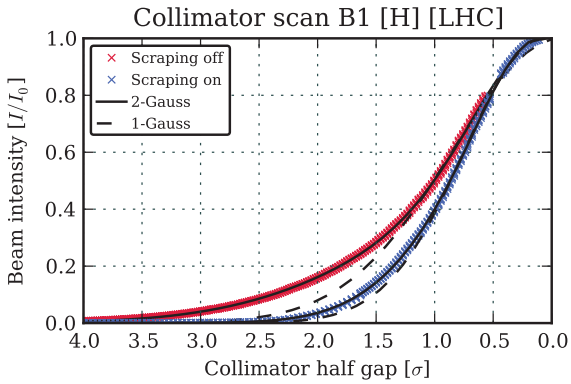

Figure 2: Collimator scans in the LHC after injection of beam with and without tail scraping in the SPS are shown. Both a double and a single Gaussian function have been fitted to the data. For the scraped beam the tails are much smaller and the profile is very close to a Gaussian.

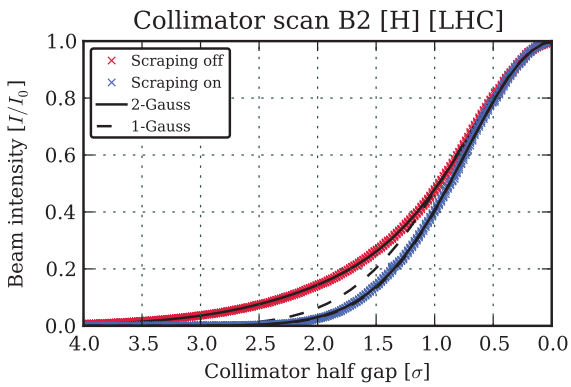

Figure 3: Collimator scans for beam 2 with and without scraping are shown. Both a single Gaussian and a double Gaussian have been plotted. For the beam which has been scraped the two lines are identical.

are given in units of nominal σ. For the beam which is not scraped the parameters are very close to those of the SPS scan. The emittances calculated from the single Gaussian of the scraped beam give 1.6 μm for beam 1 and 2.0 μm for beam 2 which are both higher than the emittances measured by the wire scanners (Table 1), however there could be errors in the wire scanner measurements.

Table 2: Comparison of fit results, and the LHC with (*) and without scraping in the SPS.

	$\sigma_1[\sigma]$	$\sigma_2[\sigma]$	I_1	I_2
SPS	0.60±0.26	1.27±0.31	0.54±0.29	0.46±0.29
LHC B1*	0.44±0.07	0.78±0.05	0.29±0.08	0.71±0.08
LHC B1	0.59±0.05	1.33±0.05	0.53±0.04	0.47±0.04
LHC B2*	0.77±0.03	8.27±106	1.00±0.02	0.00±0.02
LHC B2	0.65±0.04	1.36±0.05	0.58±0.05	0.42±0.05

SPS SCRAPING AND LHC INJECTION LOSSES

The last part of the machine development study was dedicated to investigate scraping depth versus losses on the collimators in the transfer lines between the SPS and the LHC. The transfer line collimators are located close to the LHC injection point and the losses on the collimators are picked up by the LHC beam loss monitoring system [3].

The setting of the transfer line collimators was 5 σ. Before starting the measurements in the LHC another beam scan was done in the SPS to determine the profile and intensity in the tails, see Fig. 4. Large transverse tails were apparent. An intermediate intensity beam of 6 bunches was used for this study. The test then consisted of recording the losses in the injection region and emittance in the SPS as a function of the scraper settings.

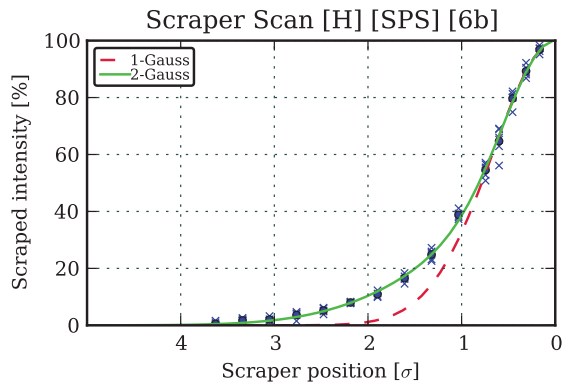

Figure 4: Beam scan was done in the SPS using a beam of 6 nominal bunches for injection loss measurements. The double Gaussian fit indicates that there are large tails.

Without scraping the losses scaled to a 144 bunch injection reach 50 % of dump threshold for beam 1 and 30 % for beam 2. Injection with tighter collimator settings (e.g. 4.5 σ as in the beginning of the LHC run 1) or of a full 25 ns batch of 288 bunches would trigger a beam dump without scraping in the SPS.

As can be seen from Fig. 5 and 6 low enough losses are reached with a scraper setting of about 3 σ from the beam center, where σ is calculated assuming nominal emittance. At this level the emittance of the beam is not affected, only tails are scraped. This corresponds to scraping around 2-3 % of the beam intensity, as can be seen from Fig. 4. This is similar to the operational values used during LHC fills, see Fig. 7. For beam 2 one of the BLMs still show some losses as this point, to be investigated further together with losses coming from trajectory offsets. At this scraping level a 2 σ margin is left for offsets in the transfer line trajectories. For the original 4.5 σ setting of the LHC transfer line collimators scraping of about 5 % of the intensity would have been required for similar loss levels.

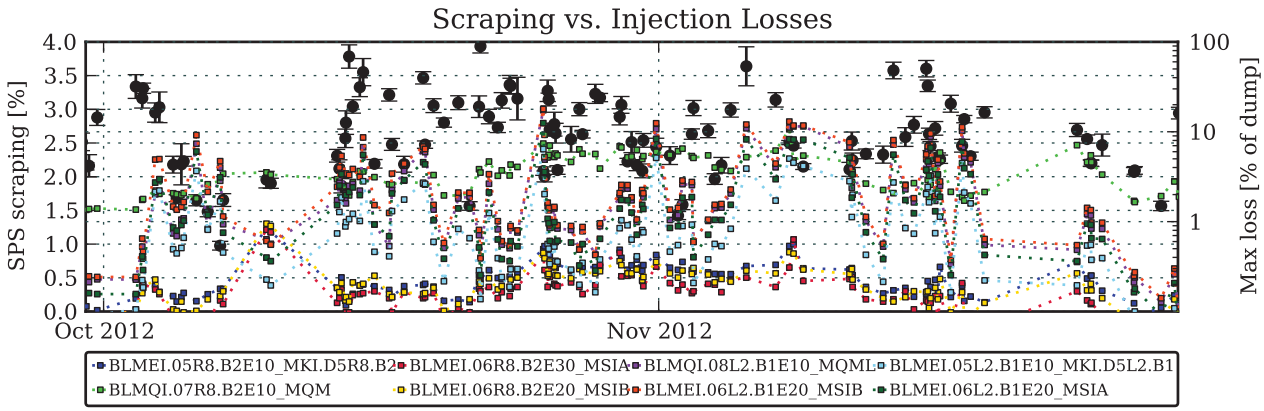

Figure 7: The amount scraped for LHC fills is given in black. Normally 2-4 % of the beam is scraped to remove tails. The beam losses are given for a number of BLMs in the injection region.

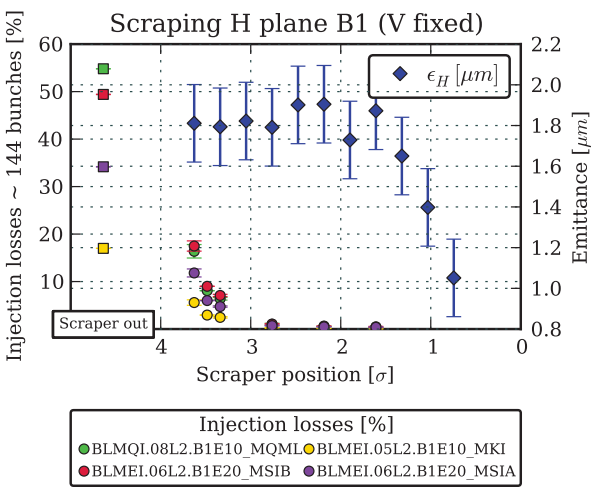

Figure 5: Beam losses at injection for varying scraper depths are shown for beam 1. The losses are scaled to 144 bunches and taken with respect to the LHC dump thresholds. If the beam is not scraped the losses are above 50 % of dump thresholds. Scraping reduce the losses to an acceptable level already at 3 σ while the emittance is not reduced until around 2 σ.

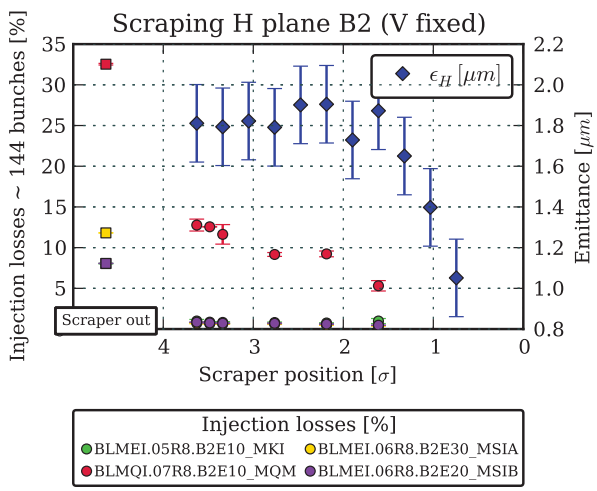

Figure 6: Beam losses at injection for B2 also show that the losses are reduced to an acceptable level by scraping the beam in the SPS. The monitor BLMQI.07R8.B2E10_MQM still show some losses.

SUMMARY

The effect of transverse tail scraping in the SPS on injection losses and tail population in the LHC has been studied. The tests were done using a low intensity beam of 3-6 bunches. At the end of the LHC injector chain the transverse distribution of the beams has substantial non-Gaussian tails. To achieve acceptable losses at injection into the LHC around 3 % of the intensity need to be scraped in the SPS. This corresponds to a scraper setting at around 3 nominal σ from the beam center.

By scraping the whole beam and recording at the same the scraped intensity as function of scraper position one can reconstruct the original transverse profile. This technique was used in the SPS with the scrapers and also in the LHC with the primary ring collimators. This revealed that neither the injection process nor other effects during the injection plateau repopulate the tails once the beams have been scraped in the SPS. Measurements of beam losses later in the LHC cycle shows that the tails are repopulated during the ramp even if the tails are small at injection [4].

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