SPS TRANSVERSE BEAM SCRAPING AND LHC INJECTION LOSSES

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Abstract

Machine protection sets strict requirements for the quality of the injected beam, in particular in the transverse plane. Losses at aperture restrictions and protection elements have to be kept at a minimum. Particles in the beam tails are lost at the tight transfer line collimators and can trigger the LHC beam abort system. These particles have to be removed by scrapers in the vertical and horizontal plane in the SPS. Scraping has become vital for high intensity LHC operation. This paper shows the dependence of injection quality on the SPS scraping and discusses an improved scraper setting up strategy for better reproducibil ity with the current scraper system.

INTRODUCTION

Injection efficiency into the LHC depends on the quality of the beam delivered from the injectors. At injection the LHC is protected by collimators in the transfer line and the injection regions. Showers from high beam losses at these collimators are picked up by the LHC beam loss monitor (BLM) system due to proximity and can trigger a protection beam dump [1].

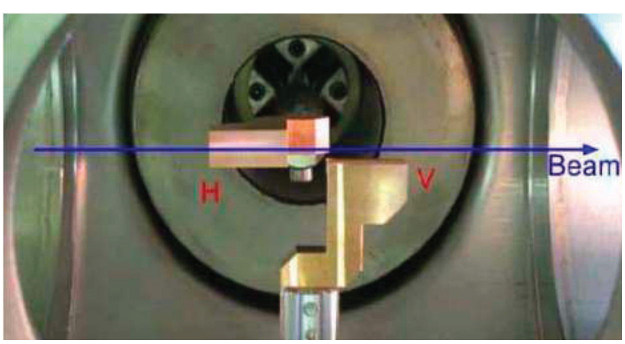

Figure 1: Picture of a copper scraper installed in the SPS. Courtesy of H. Burkhardt.

The LHC beams produced in the injectors have a larger tail population than truly Gaussian beams. These large amplitude tail particles do not contribute significantly to the luminosity [2], but impact on the transfer line collimators, see Fig. 2. Due to the tails, beam loss of ~ 25 % of the dump threshold is reached already for a 12 bunch injection. A full injected LHC batch in 2011 consisted of 144 bunches. The run conditions towards the end of the LHC proton run are summarized in Table 1. The LHC beams need scraping in the last pre-injector, the SPS, before extraction towards the LHC.

The beam distribution tails of all LHC beams (except the very low intensity pilot beams, bunch intensity of $5 \cdot 10^9$) are removed by means of scrapers in the horizontal and vertical plane. An example of a scraper is shown in Fig. 1. Scraping takes place towards the end of the SPS ramp. The effect of scraping on the losses at the transfer line collimators is illustrated in Fig. 3. For 50 ns LHC physics beams about 3 % of the total produced beam intensity are scraped off in the SPS.

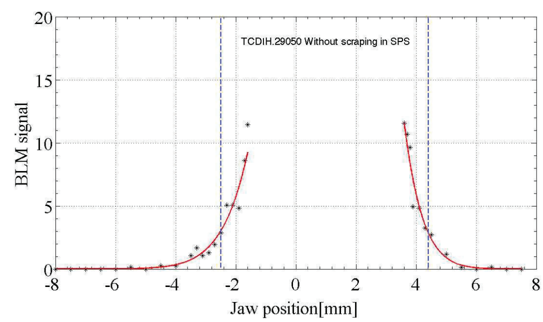

Figure 2: Tail scan at horizontal transfer line collimator (TCDIH.29050): The nominal collimator position is marked with blue lines. Without scraping the tails of the beam distribution impact the collimators.

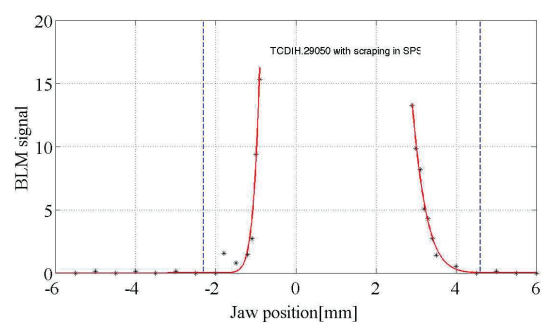

Figure 3: Tail scan at horizontal transfer line collimator (TCDIH.29050) after scraping: Scraping removes the particles in the tails. The number of particles impacting the collimator is much reduced. (Nominal collimator position in blue).

The transverse emittances with the 50 ns beams, see Table 1, are smaller than the 3.5 μm emittance of the nominal bunch spacing of 25 ns. We will show in this paper that even for nominal emittances injection losses are no issue as long as the scraping is well set up.

Table 1: 2011 LHC run conditions

Number of bunches - nominal injection	144
Number of bunches - intermediate injection	12
Maximum bunches circulating	1380
Injected emittance	$\sim 2\ \mu$m
Intensity per bunch (protons)	$1.5 \cdot 10^{11}$
Bunch spacing	50 ns

INJECTION QUALITY STUDIES

The dependency of injection losses on longitudinal and transverse beam quality was studied during a dedicated machine test [3]. The effects of several longitudinal parameters were investigated: satellite population, bunch length, radial steering in the SPS, momentum spread at SPS extraction and wrong settings in the SPS 800 MHz RF system. The effect on injection losses was small and the studies showed that the SPS Beam Quality Monitor (BQM) prevents extraction in case of degradation for most of the parameters.

Injection losses depend however heavily on any degradation in the transverse plane: transfer line trajectory changes [5] and scraping depth in the SPS. The dependence of injection quality on SPS scraper settings was studied in detail. The studies were performed with the 50 ns intermediate intensity, consisting of 12 bunches. Emittances from ~ 2.5 μm to nominal emittances of 3.5 μm were studied. Screens were inserted in the SPS injection line to obtain the larger emittances. The scraper position was varied while recording losses at the LHC injection septum MSI, one of the typical high loss locations right downstream of the transfer line collimators. The transfer line collimators were kept at their nominal settings. All studies were performed for LHC transfer line TI 2, the injection line of LHC beam 1.

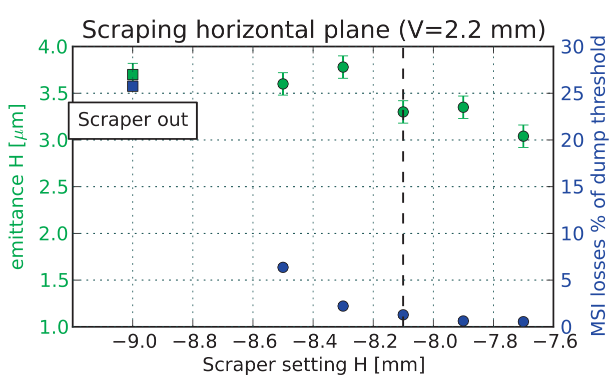

Figure 4: Measured emittance in the horizontal plane and losses at the MSI versus horizontal scraper position for initially nominal emittance beam (3.5 μm). The vertical scraper was kept constant at 2.2 mm. The losses could be reduced from 25.7% (no scraping) to 1.3% of dump threshold without reducing the emittance. Moving the scraper further into the beam does not significantly reduce the losses further.

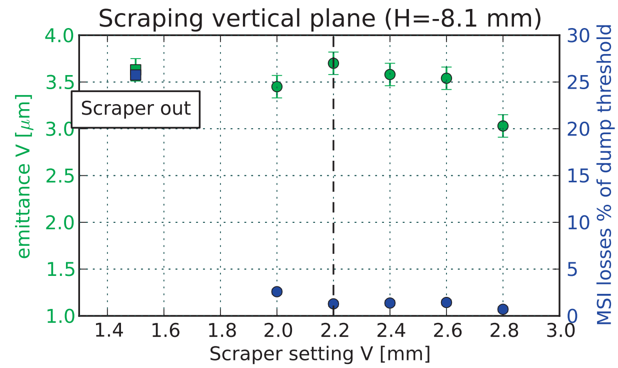

Figure 5: Measured emittance in the vertical plane and losses at the MSI versus vertical scraper position for initially nominal emittance beam (3.5 μm). The horizontal scraper was kept constant at -8.1 mm. Losses are reduced from 25.8% (no scraping) to 1.3% of dump thresholds with the scrapers at nominal setting. Moving the scraper further into the beam does not significantly reduce the losses further.

The results for the 3.5 μm beams for the vertical and horizontal plane are shown in Fig. 4 and 5. In both planes scraping reduced the losses from 25% to less than 1.5% of dump threshold at the MSI beam loss monitor. 1.5% is more than acceptable for 12 bunches and gives sufficient margin for the full injected batch of 144 bunches. To optimize LHC luminosity performance, the beam population in the beam core must not be reduced by scraping. At one point scraping deeper does not further reduce the losses at MSI, but reduces the emittance and thus starts cutting into the core. The optimum scraper setting just removes the particle distribution tails. For small and larger emittances the same scraper settings were valid during the test (indicated as dashed lines in Figs. 4 and 5).

The positive outcome of this study is that nominal 3.5 μm emittance beams can be injected into the LHC at a similar loss level as the low emittance 50 ns beams as long as the scraper settings are correct.

SCRAPER SCANS - REPRODUCIBILITY

Correct scraper settings can be found via scans as illustrated in Fig. 4. The LHC transfer lines have to be well corrected during this exercise. The distance of the scraper from the beam center can be found by scanning the scraper position and recording scraped intensity versus scraper setting. The beam sigma and beam center with respect to scraper offset can be obtained through Eq. 1, [4].

$$I(x) = I_0 e^{-\frac{(x-x_0)^2}{2\sigma^2}} \tag{1}$$

In case the SPS orbit is reproducible, the scrapers settings should not have to be changed during the LHC run. The reproducibility of the beam position at the scraper over a short period was checked during another test. The scans

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were performed keeping one scraper constant while moving the other stepwise into the beam. For each plane a scan of 5 points and another one of 3 measurement points were carried out with a time of ∼1.5 h in between. Five measurements were taken per point for statistics. Fitting the obtained curves using Eq. 4 gives beam position and beam size, see Fig. 6, 7, 8 and 9. Three scan points are enough to fit the beam parameters, provided a good fraction of the beam is scraped off (∼25%). The scans show that the beam position at the scraper is sufficiently stable and loss variations at the transfer line collimators are more likely to come from shot-by-shot variations of the trajectories [5]. The reproducibility of the SPS orbit will have to be further investigated in 2012. Scans will have to be repeated several times through the LHC run and the evolution of the scraper settings through the year will be investigated.

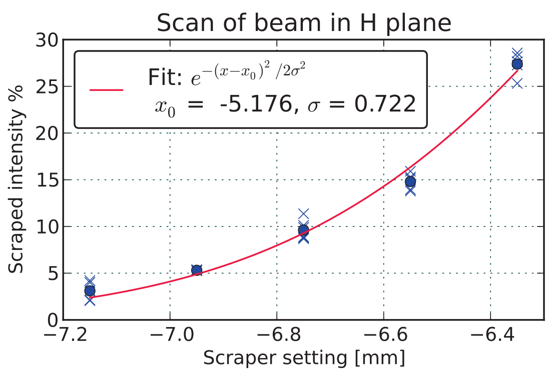

Figure 6: Horizontal scraper scan: The beam size and position are calculated by fitting Eq.1.

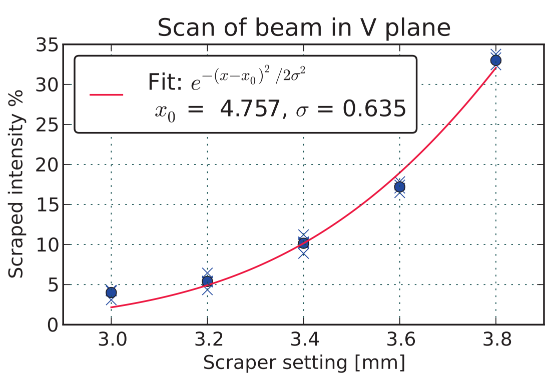

Figure 7: Vertical scraper scan: The beam size and position relative to the scraper are calculated using Eq. 1.

SUMMARY

Transverse beam scraping in the SPS is vital to keep losses at injection into the LHC under control. No scraping of full SPS batches of 144 bunches for 50 ns or 288 bunches for 25 ns will lead to beam abort at the moment of injection due to losses from large tails on the transfer line

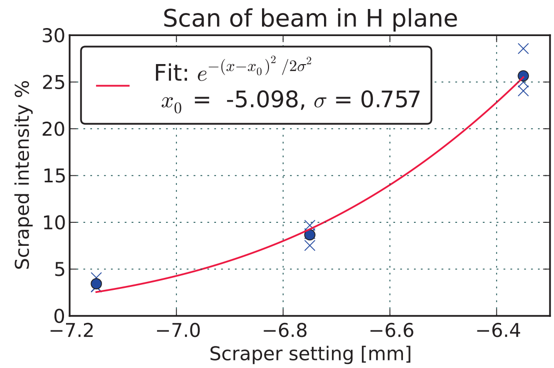

Figure 8: The horizontal scan was repeated after 1.5 hours using three measurement points. The obtained beam position is similar to the result in Fig. 6.

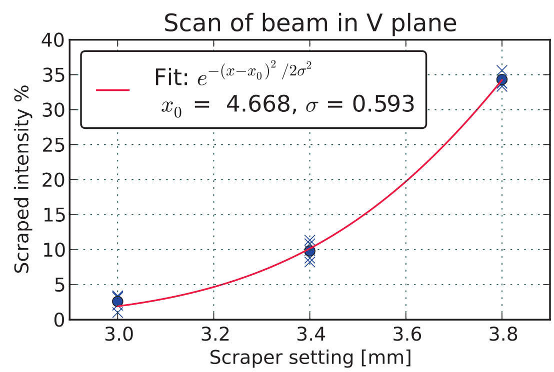

Figure 9: After about 1.5 hours the vertical scan was repeated using three measurement points. The beam position is similar to the result in Fig. 7.

collimators. Methods have been established to optimize the scraper settings. Correctly set up scrapers reduce the losses sufficiently at injection without cutting into the core of the beam distribution. Provided that the scrapers are at the correct positions, injection of nominal emittances of 3.5 μm beam leads to the same low loss levels as the 50 ns low emittance beams.

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