BEAM STABILITY AND TAIL POPULATION AT SPS SCRAPERS

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Abstract

Before injection into the LHC the beams are scraped in the SPS to remove the tails of the transverse particle distributions. Without scraping the tail population is large enough to create losses above the beam abort thresholds of the LHC beam loss monitor system when injecting. The scrapers are only effective if correctly set up. This paper shows the results of periodical scraper scans. The beam position and beam size at the scraper is changing with time. The scraper settings hence need to follow accordingly. The scans also give insight into the transverse tail population and could therefore provide useful beam quality diagnostics. The impact on new scraper designs and setting up strategy are discussed.

INTRODUCTION

The beams produced by the injectors for the LHC can have a large non-Gaussian tail population. These tails must be removed before injection to avoid high losses on the injection elements and later in the LHC cycle on the ring collimators. If these particles are not removed the losses can be high enough to trigger a beam abort in the LHC [1]. The tails are removed in the last LHC pre-injector, the SPS, by means of a horizontal and vertical scraper. Graphite plates are moved close to the beam towards the end of the SPS ramp and scatter the large amplitude particles. The particles are lost in the SPS during the remainder of the ramp.

The 2012 LHC 50 ns full SPS batch consists of 144 bunches with bunch intensities of typically 1.6×10^{11} protons. 3 - 5 % of the intensity is scraped off before each LHC injection. The intensity reduction is clearly visible towards the end of the ramp in the SPS, see Fig. 1.

Tests have shown that correct positioning of the scrapers with respect to the beam is essential to control injection losses. Correct positioning implies removing the tails without touching the core of the beam and hence conserving the emittance [2].

During the run of 2012 it was noticed that the scraped intensity can change significantly. This could be due to changes of the beam position at the scraper location, the emittance or the tail population. The strategy of the SPS operations crew was to change the scraper setting to keep the scraped intensity constant. Scraper scans were carried out over the summer 2012 to investigate the sources of the continuous change of scraping conditions. The results are summarized in this paper.

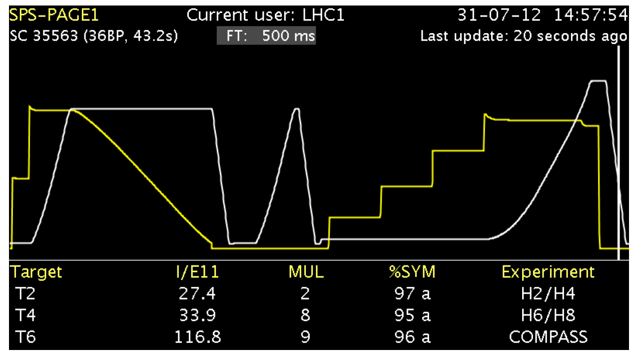

Figure 1: The SPS super cycle configuration during LHC filling. The traces of different magnetic cycles are shown in white. The last one is the LHC cycle. The yellow traces show the intensity of the beam. 4 injections of 36 bunches are required for a full SPS batch of LHC 50 ns beam. The LHC beams are scraped towards the end of the ramp (scraping at 409 GeV) before extraction to the LHC (extraction at 450 GeV).

SCRAPER SCANS

Because the scraper scans give a detailed description of the beam distribution they can be used as a tool to measure the tail distribution. The beam is scanned by moving the scraper step-wise closer to the beam core and recording the intensity removed by the scrapers. The beam size, σ, and beam position, x_0, with respect to the scrapers can be calculated by Eq. (1) [3].

$$I_1(x) = I_0 e^{-\frac{(x-x_0)^2}{2\sigma^2}} \quad (1)$$

Eq. (1) assumes Gaussian beams, but the scans done reveal that the beams can have large non-Gaussian tails. A double Gaussian function as in Eq. (2) fits the resulting distribution better. The corresponding fit parameters are beam position x_0, two beam sizes σ_1 and σ_2 for the different Gaussians and the fraction of the amplitudes in each distribution, denoted by c.

$$I_2(x) = I_0(1-c)e^{-\frac{(x-x_0)^2}{2\sigma_1^2}} + I_0 c e^{-\frac{(x-x_0)^2}{2\sigma_2^2}} \quad (2)$$

Tails can only be studied if the whole beam is scraped. Each plane has to be scanned separately. To minimize the losses only 36 bunches are used instead of a whole 144 bunch batch. Nevertheless, part of the beam loss monitor system close to the scrapers has to be temporarily masked not to trigger beam aborts in the SPS during the scans.

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An example of a scraper scan result is shown in Fig. 2. The Gaussian fit was done using only points where more than 50 % of the intensity was scraped. The Gaussian as well as a double Gaussian fit are shown in the plot. The difference of the integral of the two fit functions gives an estimate for the tail population.

With the current system, the scraper can assume only one scraping position per cycle. With about 15 steps per scan and 3 measurements per step a full scan takes about 30 minutes per plane and is therefore not done routinely.

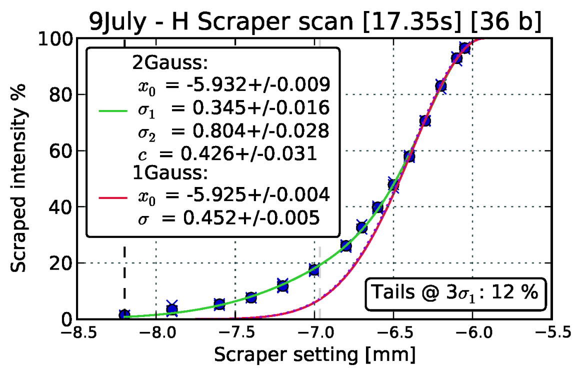

Figure 2: Scan of the beam in the horizontal plane at the end of the ramp (operational scraper setting) done 9. July 2012. The scan shows that the beam has a large tail population.

STABILITY OF BEAM PARAMETERS AT SCRAPERS

During the summer months of 2012 several scraper scans as described in the previous section were performed. All scans were done at the moment in the cycle where scraping occurs for LHC physics beams (409 GeV, cycle time = 17.35 s).

Beam Position Change at Scrapers

Figure 3 shows the results for the beam positions at the scrapers in the horizontal and vertical plane obtained from the fits of the scan profiles. The plots also show the setting of the operational scraper settings used during that period. The change of applied setting tracks the change of beam position well and indicates correct setting up of the scraping. Large changes to the beam position can occur. The reason for the SPS orbit changes has to be investigated further. The evolution of the scraper settings from beginning of July 2012 to beginning September 2012 is depicted in Fig. 4. The plot indicates that despite the fact that orbit jumps can occur, the beam position at the scraper remains the same within ± 1 mm. Some of the outliers are also due to periods with increased scraping (6 - 10 % instead of 3 %).

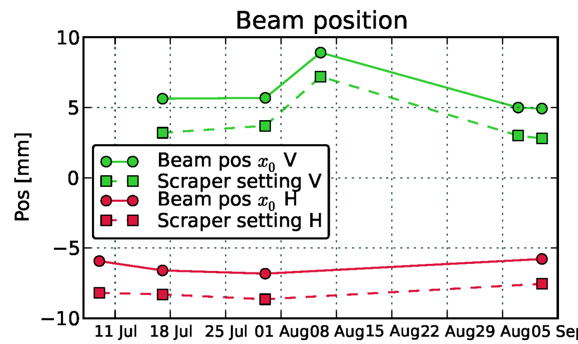

Figure 3: The beam position at the vertical scraper changed by up to $\sim$ 4 mm during the measurements and in the horizontal plane by up to $\sim$ 1 mm. The operational scraper settings follow the beam position changes well.

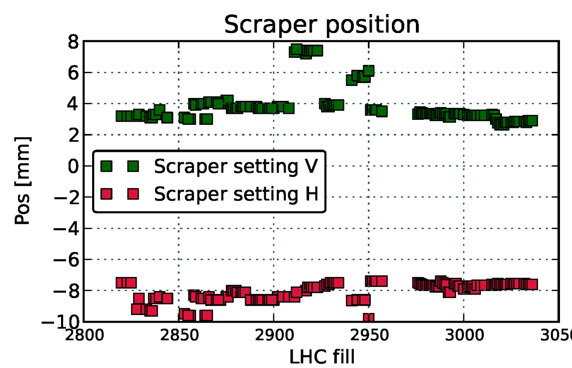

Figure 4: Logged scraper settings versus LHC fill number for the period of beginning of July to beginning of September: at a few occasions the applied scraper settings changed significantly. The overall stability is however within ± 1 mm, which is reasonable.

Beam Size and Tails

Figure 5 shows the horizontal emittances calculated from the beam sizes obtained by the scraper scans and compares them to the wire scan emittances. σ_1 of a double Gaussian seems to underestimate the beam size whereas σ of Gaussian core fit overestimates the beam size. The emittances did not change significantly over the period of interest as indicated by the wire scanners. The variation for the beam size from the double Gaussian fit is larger. Except for one measurement with a large error, the emittances from the Gaussian core fit follow the wire scanner results.

Also for the vertical plane the emittances based on the Gaussian core fits follow the emittance trends measured by the wire scanner, see Fig. 6. Again there is a discrepancy between the emittances from Gaussian or double Gaussian with the emittances from the wire scanner. Possible uncertainties from the position calibration of the scrapers and other sources still have to be investigated.

The evolution of the tail population for the different scans is shown in Fig. 7. Here the scraped intensity at 3 σ

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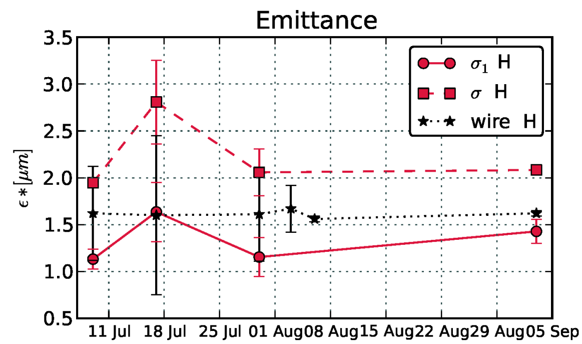

Figure 5: Normalized emittance calculated from σ_1 of double Gaussian fits and σ of the Gaussian core fit compared to the measurements from the wire scanners in the horizontal plane. The Gaussian core fit emittances follow the wire scan emittances reasonably well.

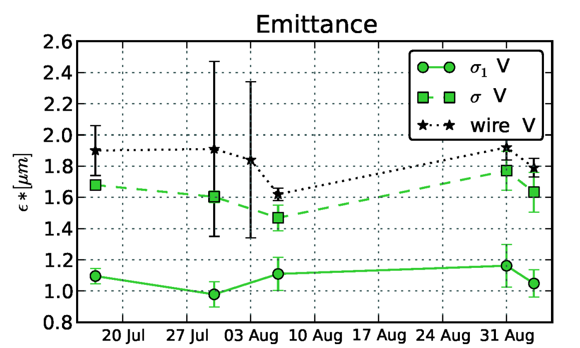

Figure 6: Normalized emittance calculated from σ_1 of double Gaussian fits and σ of the Gaussian core fit compared to the measurements from the wire scanners in the vertical plane. In the vertical plane the wire scan measurements are larger than both curves, but follow the single Gaussian fit closest.

is compared between the double Gaussian fit and the Gaussian fit of the core. The tail population of the LHC beams stays fairly constant within the measurement errors. The difference between the scraped intensity at 3 σ and the one expected from a purely Gaussian particle distribution is between 4 to 12 %.

EVOLUTION OF TAILS THROUGH SPS CYCLE

The LHC beams always have non-Gaussian tails at the SPS flat top. To investigate the origin of the tails, scans were done at various points through the SPS cycle: flat bottom (26 GeV, at 2.0 s and 9.0 s in the SPS cycle), during the ramp (at 13.0 s, 17.3 s and 17.35 s in the cycle) and at the flat top (450 GeV, at 18.2 s cycle).

In the vertical plane 3 series of scans were done, The results are shown in Fig. 8. This investigation revealed that even if tail free beams are injected into the SPS, tails are generated in the course of the SPS cycle, see Fig. 9 for the beam profiles at injection and during the ramp on 6. August 2012. In case the beams are already injected with tails, the tails are further enhanced. The growth occurs already during the injection plateau and continues in the ramp. The mechanism is not clear. Further studies are planned to investigate this phenomenon.

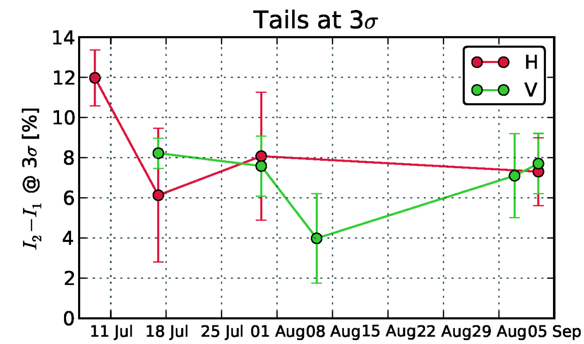

Figure 7: Difference between the scraped intensity at 3 σ and the one expected from a purely Gaussian particle distribution is between 4 % and 12 % for all the scraper scans.

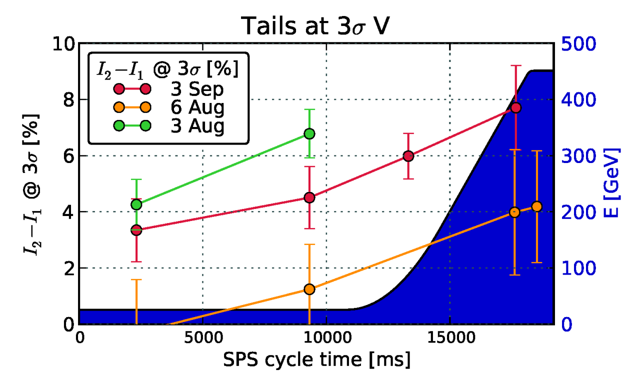

Figure 8: Three series of scans were done to monitor the evolution of tails through the SPS cycle. Tails are generated or increased through the LHC cycle. The origin is still unclear.

For the horizontal plane only one series of measurements could be done. The results are similar, see Fig. 10.

LHC INJECTOR UPGRADE: NEW SCRAPER DESIGN

The current scraper system has limitations. As already mentioned above only one scraper setting per cycle can be chosen. Thus a scraper scan has to be done over many cycles. This takes a long time and introduces additional errors due to shot-by-shot variations of beam parameters.

For the LHC Injector Upgrade (LIU) a new scraper design has been proposed. The new design is based on local

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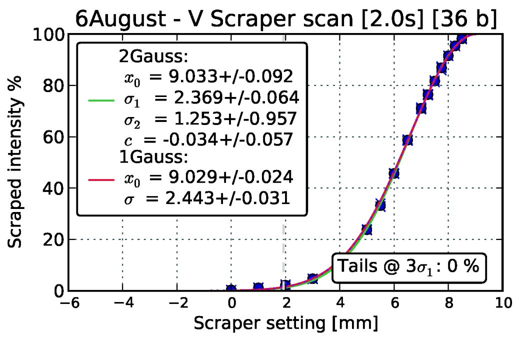
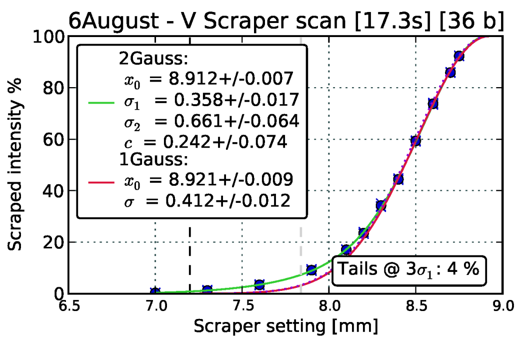


(a) cycle time = 2.0 s (flat bottom)



(b) cycle time = 17.3 s (ramp)

Figure 9: Two beams scans from 6. August 2012, show the appearance of tails later in the cycle. The first scan show the beam 2.0 s after injection without tails. 9(a). Later in the cycle tails are present 9(b).

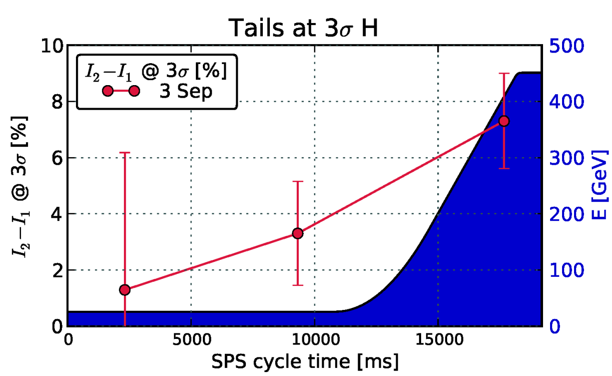


Figure 10: One series of scraper scans through the SPS cycle was done in the horizontal plane. The plot shows the tail population at 3 σ. The tail population is growing through the SPS cycle.

orbit bumps in both planes which move the beam towards a fixed mask rather than moving scrapers towards the beam. Power converters can be programmed in a more flexible way through the SPS cycle than the current scraper system. Scans during the injection plateau and the flat top will be able to be carried out within one cycle. Scraper scans can become routine operational measurements with the new scraper design.

The specifications foresee possible beam position changes of 9 mm in the horizontal plane and 7 mm in the vertical plane, which is largely sufficient for what has been observed so far.

CONCLUSION

The correct setting of the transverse scrapers in the SPS is essential for injection quality and transmission through the LHC cycle. The 50 ns LHC beams have significant non-Gaussian tails. The scrapers reduce these to acceptable values.

During the summer months of 2012 several scraper scans were carried out to track the change of beam parameters like the beam position at the scrapers and tail population. The beam position at the scraper can change by several mm for certain periods, but is otherwise constant within ± 1 mm. The scraper settings are tracking the beam position changes well. Currently the scraper settings are chosen such to give constant amount of scraped intensity at flat top. Full beam scans are necessary to fit the measurement results due to the significant tails. The scraper scans proved to be a useful technique to measure the tail population of the LHC beam in the SPS.

With the planned upgrade of the SPS scraper based system on a magnetic bump and fixed bump, scraper scans will become routine operation. This will guarantee correct scraping under all conditions and could provide a very sensitive diagnostics tool to measure tail population.

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