HALO SCRAPINGS WITH COLLIMATORS IN THE LHC

F. Burkart*, R. W. Assmann, R. Bruce, M. Cauchi, D. Deboy,
S. Redaelli, A. Rossi, G. Valentino, D. Wollmann†, CERN, Geneva, Switzerland
L. Lari, IFIC (CSIC-UV),Valencia, Spain and CERN, Geneva, Switzerland

Abstract

Understanding the population and the shape of the beam halo is important to predict possible intensity limitations due to collimation at 7 TeV. Therefore the population of the beam halo has been measured in horizontal, vertical and skew plane, using the primary collimators of the LHC collimation system. In addition these measurements were used to calibrate the beam loss monitor signals to a particle loss rate at the primary collimators. Within this paper the halo scraping method, the measured halo distribution and the calibration factors are presented and discussed.

INTRODUCTION

To avoid quenches of the superconducting magnets due to uncontrolled proton losses the LHC has a powerful collimation system [1,2]. The cleaning of the beam halo is the main purpose of this system, where the so-called primary collimators define the smallest aperture in the LHC [3,4]. During physics operation at 3.5 TeV the lowest beam lifetimes and therefore the highest losses at primary collimators appear when the two LHC beams are brought into collision [3]. As this could become an intensity limit for the LHC at 7 TeV it is important to measure the population and shape of the beam halo.

These measurements were performed with the primary collimators. Therefore one jaw of the collimator was moved through the beam. For the so-called slow scrapings the jaw was moved with a step size of 40 μm every 4 seconds into the 450 GeV-beam with an intensity of one nominal bunch ($\sim$1.1e11 p) until the beam was fully scraped away. From the beam intensity profile during the scraping it is possible to calculate the particle population at each position of the collimator [4,5,6]. In addition fast full beam scrapings were conducted. There the collimator was moved with the constant speed of 2 mm/s through the beam.

During the beam distribution MD in July 2011 a set of beam scrapings was performed. The intensity of the two beams during the beam distribution MD is shown in Figure 1. The slow scrapings in the different planes (horizontal, vertical and skew) and the fast scrapings in the vertical plane are marked in the plot. To get the instantaneous losses on a collimator it was necessary to calibrate the beam intensity signals from the fast beam current transformers (FBCT) to the signals from the beam loss monitor S^i_{blm} on the corresponding collimator. An overview of the calibration factors f^i_{calib} for the different slow scrapings during the MD in July is shown in Table 1.

* florian.burkart@cern.ch
† daniel.wollmann@cern.ch

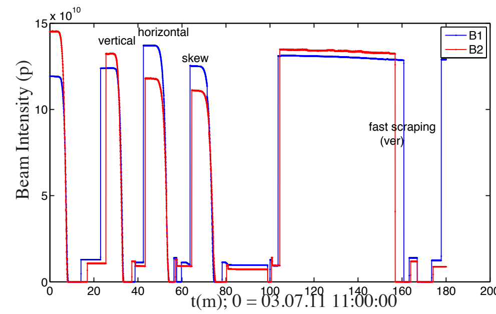

Figure 1: Intensity during the beam distribution MD, July 2011. It can be seen that B1 and B2 were scraped away in parallel with a delay of 2 seconds between the movement of the respective primary collimators. The fast and slow full beam scrapings are labelled in the plot accordingly.

Table 1: Overview of the calibration factors f^i_{calib} for the different slow scrapings.

Scraping	f^i_{calib} [p/Gy] B1	f^i_{calib} [p/Gy] B2
slow vertical (TCP.D)	1.20×10^{12}	1.13×10^{12}
slow horizontal (TCP.C)	1.25×10^{12}	1.26×10^{12}
slow skew (TCP.B)	1.94×10^{12}	1.75×10^{12}

BEAM SCRAPING WITH COLLIMATORS

The instantaneous particle loss rate at collimator i can be calculated as

$$R_i(t) = f^i_{calib} S^i_{blm}(t). \quad (1)$$

With one step every 4 seconds and the publishing frequency of the BLM signals of 1 Hz the lost intensity at each collimator jaw position u is given as

$$I_L(u) = \sum_{j=1}^{4} (R_i(t_{u,j}) \cdot 1s) . \quad (2)$$

where $t_{u,j}$ is the time when the collimator jaw is on position u.

The remaining intensity in the beam at each collimator jaw position u can then be written as

$$I(u) = \sum_{u}^{u_{end}} I_L(u) = \sum_{u}^{u_{end}} \sum_{j=1}^{4} (R_i(t_{u,j}) \cdot 1s) , \quad (3)$$

with $I(u_{end}) = 0$.

The total intensity is given by

$$I_{total} = \sum_{u_{start}}^{u_{end}} I_L(u), \quad (4)$$

with the starting position of the collimator jaw u_{start}.

The normalized, integrated, lost intensity at the collimator jaw position u can be calculated as

$$I_{tot,lost}(u) = \sum_{u_{start}}^{u} I_L(u)/I_{total}. \quad (5)$$

RESULTS OF THE SLOW SCRAPINGS

After the determination of the calibration factors and the calculation of the loss rates (equation (2)) (shown in Figure 2) and the remaining intensity after each step (equation (3)), the measurement data were fitted with a double gaussian function

$$I_{fit}(u) = I_1 \left(1 - e^{\frac{-(u-\mu)^2}{2\sigma_1^2}}\right) + I_2 \left(1 - e^{\frac{-(u-\mu)^2}{2\sigma_2^2}}\right) \quad (6)$$

with the fit coefficients μ, σ_1, σ_2, I_1 and I_2 [5]. The measurement data and the fit curves with the two terms of equation 6 are shown in Figure 3. Table 2 lists the fit coefficients for the slow scrapings in the different planes and beams. Furthermore the beam offset μ and the difference to the collimation set-up in March 2011 is shown. In B2 the agreement is better than 210μm whereas in B1 the agreement is only better then 350μm. This is mainly caused by slow orbit drifts of the beams since the setup.

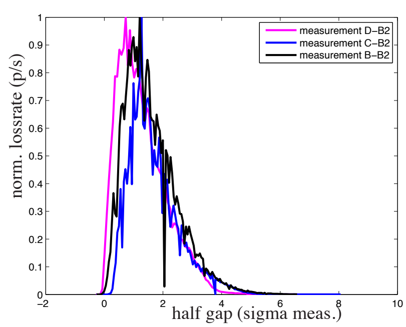

Figure 2: Normalized instantaneous loss rates during the scraping experiments on B2 versus the collimator half gap in units of measured beam size, σ_{meas}. The scrapings were performed in the vertical (purple), horizontal (blue) and skew plane (black) with the respective primary collimators in IR7: D-ver, C-hor and B-skew.

In Figure 4 the normalized integrated lost beam intensity of B2 can be seen. From this, the population of the beam halo above a certain beam sigma can be derived directly. Table 3 summarizes the measured fraction of beam intensity in the tails of the beams at 450 GeV. The results show that the horizontal tails are more populated than the vertical tails.

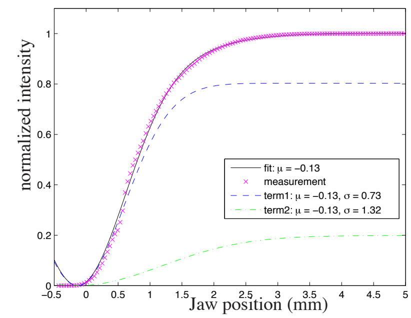

Figure 3: Measured normalized beam intensity $I(u)/I_{total}$ versus collimator jaw position (purple) with a double Gaussian fit (black) and the two terms of the fit function given in equation 6 (green, blue). The fit coefficients are shown in the legend. Horizontal scraping in B1 with TCP.C6L7.B1.

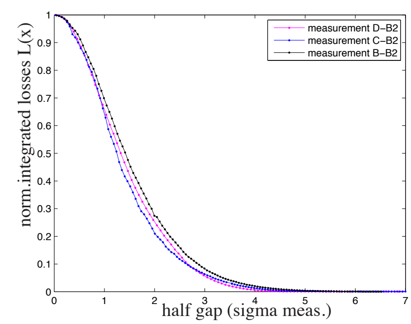

Figure 4: Normalized integrated lost beam intensity versus jaw postion in units of measured beam sigma, during vertical (purple), horizontal (blue) and skew (black) scrapings on B2.

RESULTS OF THE FAST SCRAPINGS

During the fast scraping the vertical primary collimators were continuously moved into the beam with a speed of 2 mm/s until the beams were completely scraped away. The beam intensity was logged with a frequency of 50 Hz. The measured normalized beam population versus jaw position in units of measured beam sigma during the fast and slow scraping in the vertical planes of B1 are depicted in Figure 5. The measured data were fitted with the function given in equation 6. The comparison between the measured beam population of the fast and slow scraping shows that the width of the beam distributions measured during the fast scrapings is 70% of the width measured during the slow scrapings. This can possibly be explained from the previously observed temporal tails during the slow beam scrapings with collimators. These temporal tails presents a slow decay of the BLM-signal after a step of the collimator jaw. The analysis shows that the lost intensity after each second is only 70% of the lost intensity after each step of the collimator jaw, which is summed up over 4 seconds [7]. During a fast scraping these temporal tails are

Table 2: Fit coefficients for the slow scrapings in the different planes and beams. The last two columns show the beam offsets μ as measured in the corresponding primary collimators during the collimation setup in March 2011 and the differences to the fitted values.

Scraping plane	I_1	I_2	σ_1 [mm]	σ_2 [mm]	μ [mm]	μ [mm] Coll setup	$\Delta\ \mu$ [mm]
B1 ver	0.396	0.604	0.403	0.74	0.404	0.47	-0.066
B1 hor	0.806	0.195	0.729	1.322	-0.135	-0.31	0.175
B1 skew	0.540	0.460	0.620	1.09	-0.290	-0.64	0.350
B2 ver	0.998	-	0.71	-	0.65	0.65	0.0
B2 hor	0.610	0.390	0.62	1.12	0.050	-0.160	0.210
B2 skew	0.353	0.648	1.29	0.83	-0.619	-0.635	0.016

Table 3: Measured fraction of beam intensity in the tails of the beam outside selected multiples of the measured beam size, σ_{meas}, at 450 GeV.

u [σ_{meas}]	$I_{tot,lost}(u)/I_{total}$ vertical	$I_{tot,lost}(u)/I_{total}$ horizontal	$I_{tot,lost}(u)/I_{total}$ skew
	B1	B1	B1
4	9.4e-3	3.8e-2	4.5e-2
5	2.2e-3	7.8e-3	1.3e-2
5.7	8.4e-4	1.6e-3	3.8e-3
6.7	1.8e-4	1.8e-4	4.4e-3
8	2.0e-6	3.3e-5	8.0e-6
8.5	6.2e-8	1.4e-5	9.6e-7
9	-	1.0e-6	-
	B2	B2	B2
4	1.3e-2	1.5e-2	2.77e-2
5	8.9e-4	2.3e-3	5.8e-3
5.7	2.8e-4	1.3e-3	1.65e-3
6.7	3.0e-5	6.6e-4	7.0e-5
8	4.0e-6	1.6e-5	5.0e-6
8.5	5.3e-7	8.0e-6	8.7e-7
9	-	8.5e-7	-

not taken into account, which causes the smaller width of the measured beam distribution. The physical processes, which cause these temporal tails, are currently under investigation.

SUMMARY

For the first time a complete set of slow full beam scrapings in horizontal, vertical and skew plane was performed with the LHC primary collimators. The calibration factors f^i_{calib} were achieved from correlating the BLM signals to the beam intensity signals. The measurement data were fitted with a double Gaussian function. The fit curves showed a good agreement to the measurements. The measured populations in the tails are summarized in figure 4 and table 3. The results showed that the horizontal tails are more populated than the vertical tails. The comparison between slow and fast vertical scrapings showed that the width of the measured beam population for the fast scraping is about 70% of the width one measured with the slow scraping. Most probably this is caused by the slow decay of beam loss after a stepwise movement of a jaw (temporal tails).

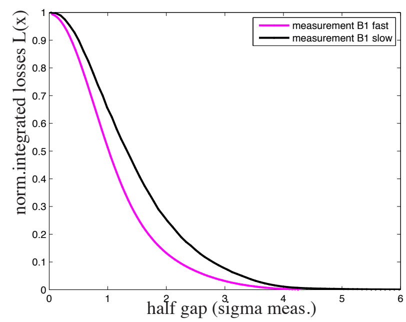

Figure 5: Comparison of normalized integrated lost beam intensity, $I_{tot,lost}(u)/I_{total}$, versus jaw position in units of measured beam sigma, σ_{meas}, during slow (black) and fast (purple) vertical scraping on B1. Note: It was assumed $\sigma_{meas} = 0$ for the collimator jaw position $u_i = \mu_{i,0}$, with the fitted beam offset $\mu_{i,0}$ for scraping i.

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