COLLIMATION DOWN TO 2 SIGMA IN SPECIAL PHYSICS RUNS IN THE LHC

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Abstract

We report on observations with collimation very close to the beam. Primary collimators were moved in small steps down to $2\,\sigma$ from the beam axis to allow for measurements of very forward proton scattering in special high-beta runs in the LHC. We studied the reduction in intensity as a function of collimator position which provides information about the halo shape. After scraping at $2\,\sigma$, collimators were retracted to $2.5\,\sigma$. This allowed for measurements of very forward proton-proton scattering with roman pot detectors at $3\,\sigma$ from the beam axis at acceptable background levels for about an hour. Good background conditions were restored by another scraping with primary collimators at $2\,\sigma$. Beam lifetimes and halo repopulation times were found to be sufficiently long to allow for several periods with acceptable background levels between scraping integrating to several hours of data taking in a single LHC fill.

INTRODUCTION

The Large Hadron Collider LHC is equipped with a multi-stage cleaning system. The primary collimators in the warm cleaning insertion IR7 are the closest to the beam [1]. In the standard LHC high-luminosity operation in 2012, they were closed to $4.3\,\sigma$. The more general performance and experience of the LHC collimation system in 2012 is described in other contributions to this conference [2, 3]. Here we concentrate on special runs in the LHC, in which roman pot detectors are moved very close to the beam in the LHC interaction regions IR1 and IR5 to record very low angle proton-proton scattering in the roman pot detectors of the ATLAS-ALFA and TOTEM experiments [4, 5].

At the interaction points (no slope in β and vanishing dispersion), the beam sizes $\sigma_{x,y}$ and beam divergence $\sigma'_{x,y}$ depend only on the emittances $\epsilon_{x,y}$ and $\beta^*_{x,y}$

$$\sigma_u = \sqrt{\beta^*_u \epsilon_u}$$
$$\sigma'_u = \sqrt{\frac{\epsilon_u}{\beta^*_u}}, \qquad (1)$$

where u stands for either x or y, which represent the horizontal and vertical planes respectively. Reducing the β function decreases the beam size and increases the angular beam divergence. Numerical values for the beam sizes and beam divergence are listed in Table 1. In standard 2012 operation, the beams are squeezed to a low $\beta^* = 0.6$ m at the interaction points, to maximize the luminosity as required for rare processes like Higgs particle production.

Table 1: Nominal Beam Size and Divergence at 4 TeV (Normalized emittance of $\epsilon_N = 3.5\,\mu$m in both x, y)

$\beta^*_{x,y}$ (m)	$\sigma_{x,y}$ (μm)	$\sigma'_{x,y}$ (μrad)
0.6	22.2	37.0
1000	906	0.91

The requirements for the special runs discussed here are very different from what is needed for high-luminosity. The aim here is a precise measurement of the proton-proton cross section.The cross-section is large, roughly 0.1 barn at LHC energies, which leads to the pile-up of several collisions per bunch crossing in the LHC at high-luminosity. A precise proton-proton cross-section measurement can be done at much lower luminosity. What is important instead in these special runs, is to be able to measure the proton-proton scattering down to very small angles of the order of few μrad. It is achieved by

1. minization of the angular beam-divergence, and
2. detection of proton scattering very close to the beam axis.

The beam divergence is minimised by maximising β^*. We reached a value of $\beta^* = 1000$ m. It reduces the beam divergence at the interaction points by a factor of 40 compared to standard operation to value of about $1\,\mu$rad. The development and features of this special high-β optics are described in another contribution to this conference [6]. The change of optics is done locally in the interaction regions IR1 and IR5. The optics in the rest of the ring and in particular in the warm collimation insertions IR3 and IR7 remains the same as used in standard operation.

We will now describe in this contribution our special efforts on very tight collimation, which enabled the roman pot detectors to record proton scattering close to the beam axis.

OBSERVATIONS

For the high-β runs, the total beam intensity was limited to 3×10^{11} protons per beam, which is nearly 3 orders of magnitude less than the 2.2×10^{14} used in regular operation. We used only 3 intense bunches per beam. Initial sin-

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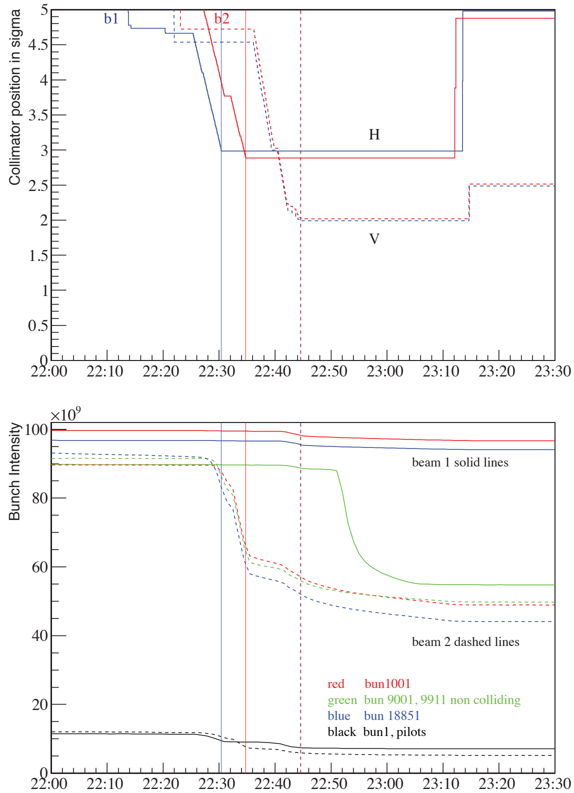

Figure 1: Collimators jaw positions and bunch intensities, 22:00 to 23:30, 1st scraping.

gle bunch intensities were close to 10^{11} protons, or just below the LHC design bunch intensity [7], which is sufficient to still cause significant damage by direct beam-impact and requires protection by the primary collimators at all times.

The main observations described here are from the unique high-$\beta^* = 1000$ m physics fill 3216 in the LHC. Beams were collided in IP1 and IP5 at 1000 m at 22:00 on the 24 October and dumped at the end in the morning of the following day at 8:34. Figure 1 shows the primary collimator settings as well as the bunch intensities for the first 1.5 hours after collision.

All collimator settings in this contribution refer to the nominal normalized emittance of 3.5μm. Actual emittances were monitored with wire scanners. At injection, the normalized emittances were found to be all within 1.3 to 1.6 μm. The emittances increased during the de-squeeze to high-β, likely caused by imperfect tune correction (tune signals not sufficiently clean, tune feedback off). The emittance blow up was more significant for beam 2, see Table 2.

After minor re-optimisation to centre the collisions, we started at 22:07 to close the primary collimators in small steps. The losses in intensity by scraping were most significant for beam 2 in the horizontal plane, which qualitatively agrees with the wire scan measurements of Table 2. For purely Gaussian beams, we would expect a 1% reduction in intensity by cutting at $3\,\sigma$ [8]. Closing the primary horizontal collimators to $3\,\sigma$ resulted here in a reduction of the beam 2 intensity by 33%, indicating the presence of non-Gaussian tails or further emittance increase.

Table 2: Normalized Emittances (measured at 21:50 just before beams were collided)

Beam	$\epsilon_{V,\mathrm{N}}$ (μm)	$\epsilon_{H,\mathrm{N}}$ (μm)
1	1.83	1.30
2	3.31	2.24

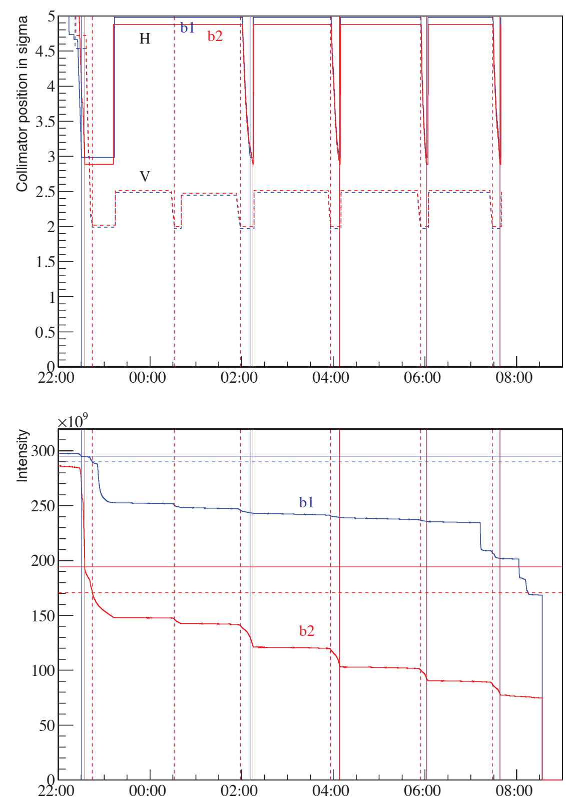

Figure 2: Collimators jaw positions and beam intensities, 22:00 to 09:00.

Figure 2 shows the various scrapings made in both planes of B1 and B2 as a function of time. The last four B1 and B2 horizontal scrapings, for which there is the largest scraping range (5 - 3 σ), were analyzed further. Around 1.6% and 15% is lost respectively for B1 and B2 with each scraping. The lost beam intensity as a function of the collimator jaw half gap is shown in Fig. 3. A purple line denotes the Gaussian distribution in both cases for comparison. The over-populated tails in the measured data are apparent from the comparison.

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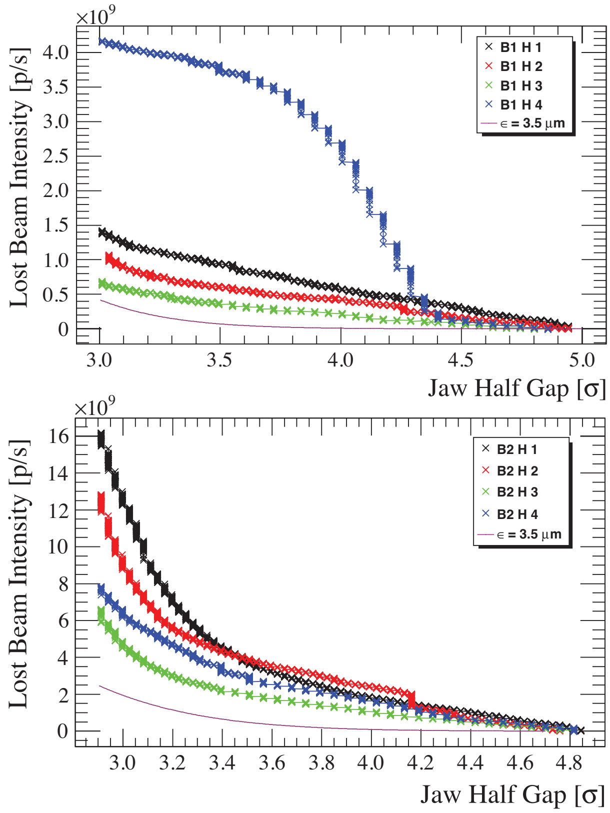

Figure 3: Beam intensity loss as a function of collimator jaw half gap. H 1 to H 4 refers to the successive scrapings.

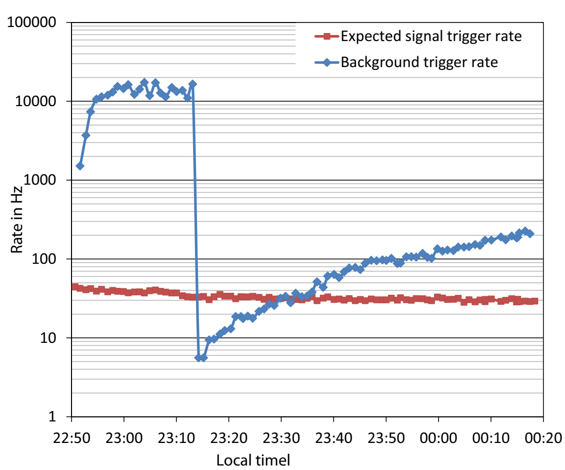

Figure 4: Background trigger rate and signal rate observed in the ATLAS-ALFA Roman Pots.

CLEANING AND DATA TAKING

The next step was to move in the roman pot detectors. At 22:55, or 10 min after setting the primary collimators to their tights setting (3σ in H, 2σ in V), the vertical ATLAS-ALFA roman pot detectors were set to 3 σ and started to record signals and observed back-to-back elastic scattering events characteristic of elastic proton-proton scattering together with left-right uncorrelated backgrounds. The backgrounds reduced very significantly (more than 3 orders of magnitude), when the primary vertical collimators were retracted at 23:13 from 2 to 2.5 σ and the horizontal from 3 to 5 σ. Figure 2 shows the primary collimator settings and the bunch intensities from the moment that beams were collided up to the end of the physics run. After the retraction of the vertical collimators, backgrounds were observed to slowly increase with time as shown in Fig. 4. Within about 1 hour, the backgrounds had increased to an unacceptable level. Backgrounds improved at 00:40, after a halo cleaning with vertical collimators at 2.0 σ and retraction to 2.5 σ. For the next cleaning step just after 2:00, we decided to move both horizontal and vertical primary collimators to 3.0 and 2.0 σ respectively, resulting in very low background levels after retraction (back to 5 σ in H, 2.5 σ in V). This cleaning was repeated another 3 times. Between the cleaning, it was possible to take data with acceptable background levels over periods between 1 and 2 hours.

SUMMARY AND CONCLUSION

We operated the LHC in a special high-β physics run over many hours with very tight collimator settings. In the vertical plan, we moved the vertical collimators down to 2 σ for cleaning for few minutes, and retracted them to 2.5 σ for data talking. This made it possible to record proton-proton scattering with roman pots moved down to 3 σ, at acceptable background levels and for the first time at LHC energies to measure proton-proton scattering down to the Coulomb interference region.

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