# LHC 2011 OPERATION - AS VIEWED FROM THE EXPERIMENTS

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*Abstract*

The 2011 LHC run is reviewed from the experiments' perspective. The LHC achievements directly related to physics production are summarized. This includes high luminosity $p$-$p$ and Pb-Pb running, special activities (such as intermediate energy $p$-$p$ physics, 90 m optics, luminosity calibrations) and other experiments (for example satellite-main bunch collisions in IP2, 25 ns stable beams tests, etc.).

## INTRODUCTION

First, a brief review of the 2011 LHC run is presented, with emphasis on physics operation. Second, the 2011 special physics runs are reviewed. Lessons from the 2011 run, as seen by the experiments, are discussed in the third section, where some comments and suggestions for 2012 operation are also made.

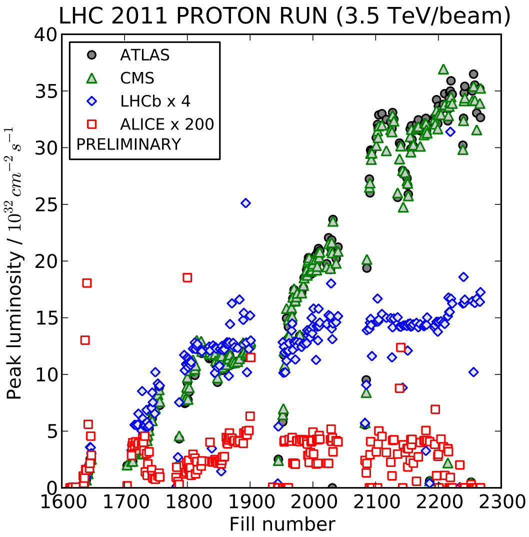
## SUMMARY OF 2011 RUN

LHC operation started on February 21 and stopped on December 7. There were five techical stops (TS), starting on March 28, May 9, July 4, September 29, November 7. Just before each TS (except TS1) there was a machine development (MD) session. The LHC physics run can be divided in several phases:

- Phase 1: Intensity ramped up to $\sim$ 200 bunches at 3.5 TeV/beam with 75 ns spacing and with optics $\beta^* = 1.5/3/10$ m in IP1&5 / IP8 / IP2, followed by an intermediate energy run (1.38 TeV/beam) just before the first technical stop (TS1).
- Phase 2: Switched to 50 ns spacing and ramped up the intensity to $\sim$ 800 bunches by TS2.
- Phase 3: Continued ramping up the intensity, reaching 1380 bunches by TS3.
- Phase 4: Integrated luminosity with 1380 bunches until TS4, while pushing down the transverse emittance from $\sim$ 2.5 to $\sim$ 2 $\mu$m (deployment of 50 ns 'double-batch' injection).
- Phase 5: Reduced $\beta^* = 1$ m in IP1&5 and integrated luminosity with 1380 bunches till TS5.
- Phase 6: Ion run (Pb-Pb) from TS5 to end of operation, with reduced $\beta^* = 1$ m in IP2.

Tables 3 to 8 (at the end of this contribution) list all the physics fills for these six phases. The state of the LHCb dipole spectrometer and of the ALICE dipole and solenoid spectrometers are indicated in the tables. The polarity ('+' or '$-$') refers to the power converter polarity ('0' means 'off').

In order to facilitate operation with bunch trains, all IPs were set up with an external (full) crossing angle from the beginning: 240 $\mu$rad vertical (horizontal) in IP1 (IP5), 500 $\mu$rad horizontal in IP8, giving a net angle of 1040 $\mu$rad (40 $\mu$rad) for the + (-) LHCb polarity, and $\pm$160 $\mu$rad vertical in IP2, giving a net angle of $\pm$440 $\mu$rad.



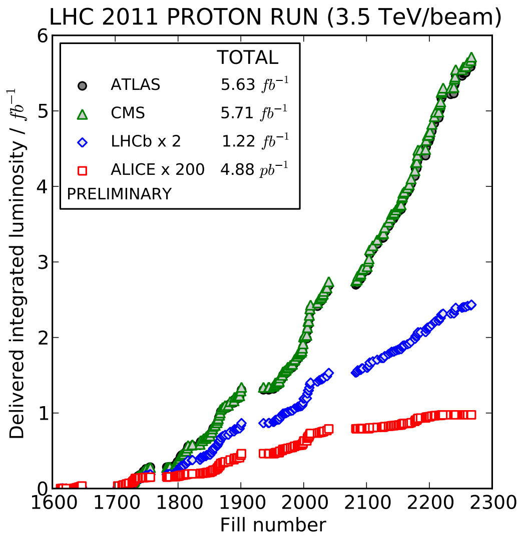




Figure 1: Overview of the 2011 proton run. The top (bottom) graph shows the evolution of the peak (integrated) luminosity in the four interaction points.

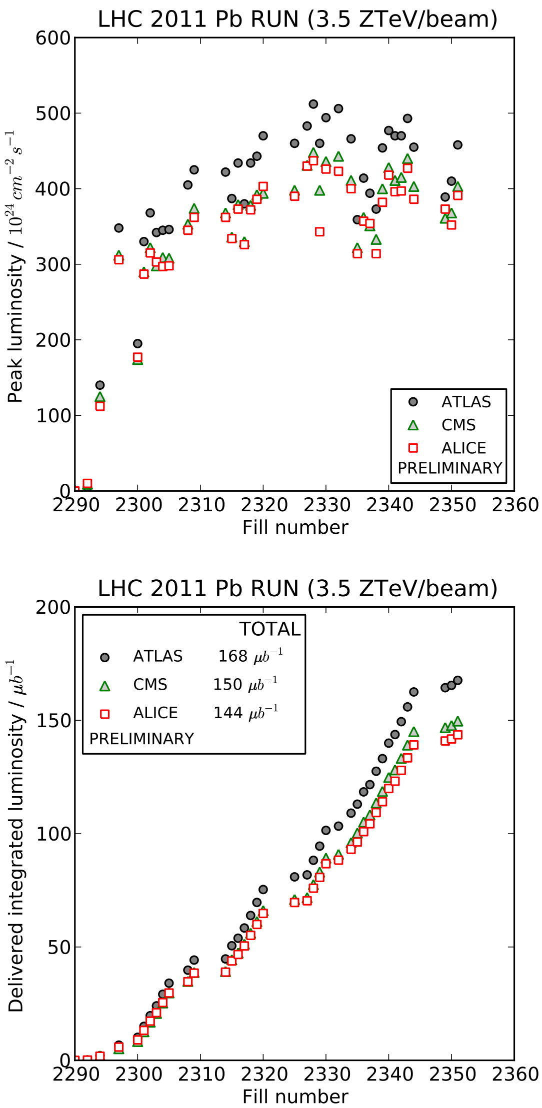



Figure 2: Overview of the 2011 Pb run. The top (bottom) graph shows the evolution of the peak (integrated) luminosity in the three interaction points.

Summaries of the peak and integrated luminosity as a function of fill number are displayed in figures 1 ($p$-$p$) and 2 (Pb-Pb). Other yearly summary plots are available at the LHC Programme Coordinations web site [1]. The peak proton luminosity achieved in IP1&5 was $\sim 3.6 \cdot 10^{33}$ cm$^{-2}$s$^{-1}$, while the luminosity was leveled at IP2 and IP8 to the target value chosen by the ALICE ($0.5...2 \cdot 10^{30}$ cm$^{-2}$s$^{-1}$) and LHCb experiments ($2...3.5 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$). Luminosity leveling was made by transverse separation in the non-crossing plane. The total delivered luminosity was approximately 5.7 fb$^{-1}$ in IP1&5, 1.2 fb$^{-1}$ in IP8 and 4.9 pb$^{-1}$ in IP2.

As in 2010, the LHC ion run benefited from the operational and commissioning experience of the proton run. Ion operation started in MD4 and stopped on December 7. The beam rigidity remained untouched ($E = 3.5$ $Z$TeV). Only the IP2 squeeze was changed, going down from 10 m to 1 m. The crossing angle in IP2 was chosen such as to give the smallest possible net angle, in this case 60 $\mu$rad, limited by the understanding of the aperture in IR2. The TCTVB collimators in IR2 were opened enough to not create any shadow on the ALICE ZDC during physics. The LHCb dipole was switched off during the ion run. The average bunch intensity varied between 0.6 and $1.2 \cdot 10^{10}$ charges ($7.3...14.6 \cdot 10^{7}$ Pb ions) at the start of STABLE BEAMS (for more details on LHC and injector performance with Pb beams see reference [2]). The number of bunches was rapidly increased to 358 with the newly implemented 200 ns bunch spacing. The peak and integrated luminosity were increased by a factor 16 relative to 2010. The peak luminosity reached about $4.5 \cdot 10^{26}$ cm$^{-2}$s$^{-1}$, while the total delivered luminosity was about 160 $\mu$b$^{-1}$ per IP.

As summarized in table 1, in total, the LHC operated 1565 hours in STABLE BEAMS (1361 hours with $p$ and 204 hours with Pb), out of about 205 days of actual physics operation (181 days of $p$ and 24 days of Pb), i.e. not including the main setup and scrubbing time. The ratio of STABLE BEAMS time to scheduled physics time amounts to about 31.8% on average (31.3% for $p$ and 35.4% for Pb). The 1361 hours of $p$ physics include 35 hours spent at 1.38 TeV/beam. Figure 3 shows the time spent in STABLE BEAMS throughout 2011. Note that these numbers include all special physics runs and their setup time (some of which did not request STABLE BEAMS, e.g. some roman pot physics).

| Physics type | time in STABLE BEAMS | scheduled physics time | ratio |
|---|---|---|---|
| Any | 1565 h | 4920 h | 31.8% |
| $p$ | 1361 h | 4344 h | 31.3% |
| Pb | 204 h | 576 h | 35.4% |

Table 1: Summary of STABLE BEAMS and overall physics times (includes all special physics).

These formidable achievements of LHC 2011 operation have brought ATLAS and CMS on the verge of discovering or excluding the Standard Model Higgs boson [3, 4]. Meanwhile, LHCb continued pushing down the limits on the FCNC decay channel $B_s \to \mu\mu$ [5]. LHCb also observed an intriguing CP violating asymmetry in the charm sector [6], not accounted for by state-of-the-art SM calculations. The 2012 run's highest priority goal should be to make these results unambiguous.

## SPECIAL PHYSICS

Three main 'special physics' activities (i.e. activities that were not directly related to luminosity integration at

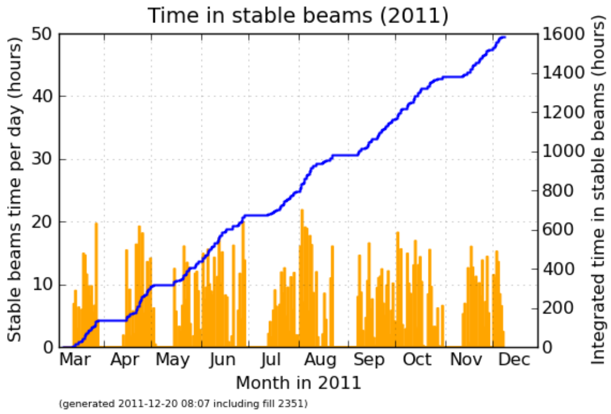



Figure 3: Time spent in stable beams throughout 2011. Left scale is for the daily result (yellow bar chart), the right scale is for the integrated result (blue curve).

3.5 TeV/beam) were planned and successfully carried out. They are summarized here.

**Van der Meer (VDM) scans:**

Luminosity calibration experiments were performed in different conditions:

- March 2011: $p$-$p$ at 1.38 TeV/beam, $\beta^*$ = 11/10/11/10 m (IP 1/2/5/8). All four experiments performed VDM scans at this intermediate beam energy during normal physics production fills.
- May 2011: $p$-$p$ at 3.5 TeV/beam, 1.5/10/1.5/3 m. Due to detector modifications, the 2010 ATLAS calibration could not be ported to 2011 with full accuracy. In order to recover the full precision, ATLAS requested an early re-calibration. A dedicated fill for VDM scans was inserted and all four experiments used it.
- June 2011: $p$-$p$ at 3.5 TeV/beam, 1.5/10/1.5/3 m. Scans were done during a normal physics production fill by CMS only, as a verification of their May 2011 results.
- October 2011: $p$-$p$ at 3.5 TeV/beam, 90/10/90/10 m. Here, ALICE and LHCb took advantage of the injection optics (large $\beta^*$) to perform high precision luminosity calibration experiments in a dedicated fill. ATLAS scans were also planned, but unfortunately left out in the end due to a premature beam dump.
- December 2011: Pb-Pb 3.5 $Z$TeV/beam, 1/1/1/3 m. A re-calibration of the ion luminosity was performed in ALICE, ATLAS and CMS, all during normal physics production fills.

Length scale calibrations were performed during the same fills or during standard physics production fills. The results of these experiments and their consequences have been addressed in details at the 2012 LHC LUMI DAYS workshop [7]. Substantial improvements on the bunch current normalization uncertainty were achieved which opened the door to cross section measurements at the level of about 2%. We refer the reader to the proceedings of the LUMI DAYS workshop for further information.

In total, approximately 30 h of *dedicated* machine-available time (19 h of STABLE BEAMS time) was invested in these luminosity calibration experiments, including TCT setup/validation time and LHC turn-around time.

**Intermediate energy run:**

The request to plan an early $p$-$p$ run at the equivalent heavy-ion energy per nucleon (thus 1.38 TeV/beam) was expressed by ALICE and recommended by the LHCC [8]. The LHCC stressed the importance of scheduling a run *"as early as convenient in order to ensure a speedy analysis and publication of the heavy-ion results"*. ALICE and the LHCC stressed that without such a reference run, the ion results would be hampered by large systematic errors from the energy interpolation. The run was inserted just before TS1. The external angle was set to zero at all IPs and adequate filling schemes were devised with 525 ns spacing and with about 80 high-intensity bunches of $\sim 10^{11}p$ each. The luminosity per bunch was in the order of $5{\cdot}10^{28}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at the start of fill. After a few initial difficulties with setting up the machine, successful and stable operation was achieved (increasing the transverse emittance was a key change), in time to deliver a total of 34.3h of STABLE BEAMS time just before the start of TS1. This fully satisfied the ALICE request. The total machine-available time invested was about 3.5 days ($\sim$ 90 h).

**Roman pots and 90 m optics:**

The Roman Pot (RP) detectors are designed principally for special physics runs at low luminosity. For this scope, special LHC optics were developed and needed to be commissioned in order to achieve $\beta^* \approx 90$ m at IP1 and IP5 (while keeping 10 m at IP2 and IP8). The RPs were also commissioned and tested in stages prior to their use in the dedicated 90 m fills. In 2011, 24 TOTEM RPs (4 V and 2 H on each side of the IP, at 220 m and 147 m) and 8 ALFA/ATLAS V-RPs were available for use (H stands for horizontal motion, V for vertical motion).

Interlock tests of TOTEM/ALFA pots without beam were required and were carried out on 14 Apr [9] at the cost of about 2 h of machine-available time. Mid-May 2011, RP beam-based alignment exercises with squeezed optics were performed with one $8 \cdot 10^{10}p$ bunch and nine probes of $1 \cdot 10^{10}p$. After some initial hiccups, eight ALFA RPs (45 min/pot) and twelve TOTEM H-RPs (30 min/pot) were aligned, working on the two rings simultaneously (fill 1788) [10]. A short period of ($\sim$ 3 h) data-taking with the TOTEM V-RPs at $\sim 5\sigma_{\rm nom}$, H-RPs at $\sim 7\sigma_{\rm nom}$ and the ALFA RPs at $\sim 14\sigma_{\rm nom}$ was allowed (in ADJUST mode). Subsequently, these RPs were brought to 'nominal' settings for squeezed physics optics (V at $\sim 14\sigma_{\rm nom}$ and H at $\sim 17\sigma_{\rm nom}$) and the positions were validated with loss maps. This enabled routine operation of the pots at these 'nominal' positions during ulterior squeezed physics fills.

In total, approximately 27 h of machine-available time was used, including the various operational hiccups (3 unwanted dumps caused by 'forgotten' interlocks). Without the hiccups, this would have amounted to about 16 h. The amount of time spent with the RPs moved in during squeezed physics was 6 hours (3 h during the alignment fill and 3 h on 13 Oct).

Note that the validity of these squeezed optics RP settings needed to be extended during the regular loss maps throughout the year (simply by including the RPs in the loss maps).

The 90 m optics were first tested in 'dry' runs. Then, a first study with beam was performed in MD1 (one 8 h shift) [11]. The test was successful and demonstrated the feasibility of these optics. First global optics measurements were made with the AC dipole. Later studies had to be taken from physics time.

A second study was performed on Jun 28, just before MD2 with two low-intensity bunches per beam [12]. The main points in this study were the introduction of parallel separation bumps to allow for collisions and the introduction of optics corrections based on the first study. The test was partly successful. The optics corrections established in the first study were applied and tested locally by measuring $\beta^*$ with K-modulation. Unfortunately, the AC dipole was not working, which precluded new global optics measurements. Collisions were established and measured. The 220 m TOTEM RPs and the 8 ALFA RPs were moved in to about $10\sigma_{\rm nom}$ and the experiments collected each 100 to 150 thousand triggers (the raw inelastic rate was about $\sim$ 50 Hz, the elastic $\sim$ 10 Hz). Data were taken for only about one hour, but their excellent quality allowed already the first measurement of the total $p$-$p$ cross-section at LHC using the Optical Theorem [13]. The cost of this study was about 10 h of machine-available time.

A third study was carried out on Tue 23 Aug. Time was lost at injection due to the mixing of high and low intensity bunches in the ring (bad readings of the BPMs near threshold). This was known and documented by BE-BI since MD2, but escaped our attention. The low-intensity bunches must be well below the threshold (which is around $2 \cdot 10^{10}$ $p$). In the end, three $7 \cdot 10^{10}$ $p$ bunches per beam were used, the first two with $\sim 3$ $\mu$m emittance, the third with reduced emittance (screen removed at SPS). One ramp was dumped by the inadequate reboot of a front-end card. A second ramp worked, but the defocusing caused a dump (at around 30 m) due to an non-smooth incorporation of settings from the last test, which could have been avoided by an emulation. The third ramp made it all the way to 90 m and collisions. In one hour the TCTs were aligned in IP1, IP5 and IP8. Then, in three hours all 220 m TOTEM V-RPs were aligned. Unfortunately the beams were prematurely dumped by a warm compensator trip. The ALFA RPs could not be aligned due to an issue with a PXI. This whole study costed about 20 h of machine-available time.

A fourth study took place between 7:00 on Sep 30 to 7:30 on Oct 1 (gracefully stopped by a VIP visit). A first ramp was dumped after defocusing due to a faulty TCT at IP5. A second ramp was lost due to an LVDT interlock limit on an ALFA RP. Priority was then given to the optics measurements. A first ramp with three low-intensity bunches was lost due to a magnet trip, a second one due to a UPS trip in UJ56.

Finally, a fifth study was performed from 9:30 on Oct 18 to 22:30 Oct 20. After a laborious start at injection plateau, a first ramp was achieved (2227) with two high-intensity and twelve low-intensity bunches. Beam-based alignment was completed: all ALFA and all 220 m TOTEM RPs were aligned. Data-taking was attempted, but given the poor beam conditions it was decided to perform loss maps and refill. A second ramp for beta-beat and K-modulation measurements was made (2228). A third ramp (2229) was lost due to an LBDS self-trigger. In a fourth attempt (2230) the beams were lost due to a power converter trip in Point 4, when reaching $4\sigma_{\rm nom}$ with the primary collimators. The fifth attempt (2231) was dumped by an SIS limit in the defocusing (a forgotten adaptation of SIS limits for the orbit correctors). The sixth and last attempt (2232) was successful. Two medium-intensity ($6 \cdot 10^{10}p$) and twelve low-intensity ($8{\cdot}10^{9}p$) bunches were used. Several hours of data taking (in ADJUST) were used, with the RPs and collimators in different positions. Multistage cleaning was tried (TCS-V & TCLA-V in Point 7 and on ring 1) and seemed to give a reduction of the background seen by TOTEM. The reduction was possibly due (also ?) to the fact that one secondary collimator was inadvertently moved closer to the beam (thus scraping the beam) and then retracted. In the end, the following positions were reached (approximate values): V TCPs to $4.6\sigma_{\rm nom}$, V TCSs to $5.2\sigma_{\rm nom}$, TOTEM V-RPs to $4.8\sigma_{\rm nom}$ ALFA RPs to $6\sigma_{\rm nom}$. For this last study, about 63 h of machine-available time were used.

In total, the machine-available time invested in RP activities and 90 m physics was of the order of 140 h.

Assuming a machine availability of about 60%, 140 h correspond to about 5.5 % of the total machine-available time in the 2011 $p$ run. The other activities, namely the $E = 1.38$ TeV run and the VDM scans, used respectively 90 h and 30 h, i.e. 3.5% and 1.2%. The sum of the three activities amounted to about 10%.

In addition to these, one should add that two shifts (about 16 h) of machine-available time were invested in two high pile-up tests (requested by ATLAS and CMS), one shift as an MD (fill 2201) and one shift taken from physics time (fill 2252), and one shift of machine-available time was invested in a 25 ns test (fill 2186) as requested by all four large experiments.

An overview of the yearly break down of the 2011 LHC run is shown in table 2.

## 2011 LESSONS

**Modus operandi, schedule:**

In 2011, MD's were introduced as 5-day blocks, planned just before each TS (except before TS1, when the interme-

| ACTIVITY | SCHEDULED CALENDAR DAYS | | | | |
|---|---|---|---|---|---|
| | As presented in ref. [14] and LHC schedule v1.0 | LHC schedule v3.2 | Actually scheduled | | Notes |
| TS days | $\sim 24$ | 23 | 23 | | |
| TS recovery | $\sim 6$ | 5 | 5 | | |
| MD days | $\sim 20$ | 20 | 22 | | |
| Set up / commission protons | 20 - 30 | 21 | 24 | | (a) |
| Scrubbing run | $\sim 10$ | 10 | 7 | | |
| $p$ intensity ramp up (to $\sim$ 900 bunches) | 30 - 40 | | 30 | | |
| 75 ns, to 200b | | | | 10 | |
| 50 ns, to 912b | | | | 20 | |
| Post-TS intensity recoveries (ramp-up) | | | 11 | | (b) |
| 'High luminosity physics' | 144 - 124 | | 121 | | |
| $p$ intensity ramp up (50 ns, to 1380 bunches) | | | | 35 | |
| 1380b physics | | | | 86 | |
| Other physics | $\sim 10$ | | 19 | | |
| RP + 90 m | | | | 9.7 | (c) |
| E=1.38 TeV | | | | 6.3 | (c) |
| VDM | | | | 2 | (c) |
| High Pile-Up & 25 ns | | | | 1 | (c) |
| All proton physics | 184 - 174 | 183 | 181 | | |
| Total proton run | 264 | 262 | 262 | | (d) |
| Set up ions | | 4 | 4 | | |
| Ion physics | | 24 | 24 | | |
| Total ion run | 34 | 28 | 28 | | (d) |
| Total days | 295 | 290 | 290 | | |

Table 2: Break down of 2011 run (21 Feb - 7 Dec). Number of days are approximate and include the machine non-availability, which is inhomogeneously spread over the different activities.
(a) Includes 2 days set up time of $\beta^* = 1$ m (after TS4) and 1 day for ALICE polarity reversal.
(b) A ramp-up of intensity (nr. of bunches) to reach a previously achieved intensity.
(c) Machine-available time converted to calendar days with an assumed machine availability of 60%.
(d) All Technical Stops (TS) and machine developments (MD) were arbitrarily counted in the proton run.

diate energy run took place). Two extra 'floating' days of MD were introduced in $p$ operation and an 8 h quench test for ion collimation was added in the last week of operation. Overall, this new modus operandi worked well.

Scheduling of special physics could be improved by reducing the number of blocks of such activities (perhaps two blocks of a few days per year ?). This could reduce the impact on operational efficiency.

The reduction of the number of TS (to five), without much reduction of the total number of TS days (23), worked well. The draft 2012 schedule foresees to explore this even further with four TS (total of 20 days). The impact of TS's in 2011 is discussed in reference [15].

**Overal LHC efficiency in physics:**

Phase 4 was entirely focused on luminosity production and is therefore representative of a long period of time without interference from special activities. If we define $H$ (the 'Hübner factor') as

$$H = \frac{\int L(t)\, dt}{T_{\mathrm{physics}}\, L_{\mathrm{peak}}} \tag{1}$$

and apply it to phase 4 ($\phi 4$) with the average peak luminosity at IP1&5 $\langle L_{\mathrm{peak},\phi 4} \rangle \approx 1.8 \cdot 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ one finds the factor (for IP&5)

$$H_{\phi 4} \approx \frac{1.4\ \mathrm{fb}^{-1}}{45\ \mathrm{days} \cdot 1.8 \cdot 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}} = 0.2\,. \tag{2}$$

Out of the 45 days (1080 hours), there were 307 hours of STABLE BEAMS ($\sim 28\%$ of the actual time). The rest, i.e the ratio $0.2/0.28 \approx 0.7$, is to be attributed to luminosity decay (and to the low luminosity fills of the post-TS intensity ramp-up).

A more detailed analysis of LHC operation and performance can be found in reference [16].

**Increasing stored beam energy:**

The increase of beam intensity (stored energy) in the LHC machine to 1380 bunches (about 100 MJ) was carried out in 3.5 months, following a strict procedure (at least 3 fills with at least 20 h of STABLE BEAMS per step, and in steps of 144 bunches). After that, a fast ramp-up procedure was used when recovering from a TS: about 4 steps of each one fill with incremental stored energy. For 2012, it is important to realize that the achievements of the previous year (2011) will stress even more the need for a fast initial ramp-up. Given that the changes will be less significant (compared to the changes between 2010 and 2011), a faster ramp-up after recommissioning seems possible, for example using the model of the 2011 post-TS ramp-up. If no new difficulties are encountered, full beam intensity (1380 bunches) could be available after a few days of physics operation. Clearly, vigilance (i.e. monitoring) must remain the motto for machine protection in 2012.

If dynamic vacuum issues are expected (due to interventions during the winter stop), it seems adequate to schedule a scrubbing run before starting high luminosity physics operation.

**Luminosity production filling schemes:**

The LHC currently hosts many experiments with diverse requirements on beam conditions. Filling the LHC in such a way that all experiments are adequately served is a challenge. For 2011, 50 ns operation was the workhorse. A scheme was devised for maximum number bunches fulfilling the following requests or requirements (in decreasing priority):

1. Last injectable bucket = 31181. This injection protection requirement comes from the Abort Gap Keeper (AGK) system.

2. Keep a space of at least 370 buckets (925 ns) between the last already filled bucket and the bucket assigned to the first bunch of the to-be-injected batch (injection protection requirement).

3. Always start with a pilot, then with a 12b train, then continue with 'physics' batches (injection protection requirement).

4. Maximize the number of colliding pairs at IP1&5 (but see 6 below) and at IP8 (which is longitudinally displaced!).

5. Accommodate enough collisions to satisfy the ALICE luminosity request, while minimizing the impact on IP1&5 and IP8.

6. Include at least one non-colliding bunch (per beam) with a 'sufficiently long' collision-free period before the arrival of this non-colliding bunch (ATLAS and CMS request). The length of the quiet space depends on the crossing angle and the possible presence of ghost bunches. A space of 150 ns was found adequate and well matched to the maximization of the number of colliding pairs at IP8.

A first 1380b scheme[1] was devised that included main bunch collisions ('main-main') in IP2, which required transversely separating the beams at IP2 to keep the pile-up and luminosity at acceptable levels. Later in the year, after proving that 'satellite-main' collisions provided a viable solution, a second scheme[2] was devised which avoided main-main collisions at IP2 (see below). For this scheme, a gap of 250 ns between PS trains is used in the SPS (instead of 225 ns). This, combined with the requirement of the AGK, precludes keeping the pilot bunch (it must be 'over-injected'). In order to keep it, the AGK limit should be raised to at least 31191 (which might be possible).

Many other schemes were produced for the intensity ramp-up, for special physics run, for the ion run, etc. These can all be found in the LHC Injection Scheme Display (a java/web application from BE-OP) or at the http://cern.ch/lpc web site (under 'Filling schemes').

**Injection:**

Injection of batches with more than 1.5 MJ (144 bunches of $1.5 \cdot 10^{11} p$ at 450 GeV) became routine in the summer of 2011, which was an important achievement. Nevertheless, much of the turn-around time is still spent at injection (typically 2 hours) [17]. Dedicated LHC filling was generally not used. On average, the used SPS supercycle allowed one to inject every 40-45 seconds, while the design goal is to achieve one injection every 21 s and an LHC filling time of about 15 minutes [18]. This loss of machine-available time integrates over *all* fill attempts (not only to the fraction of fills which makes it into STABLE BEAMS).

The use of a permanent intermediate intensity batch ($\sim 10^{12} p$ or less) is still mandatory which affects the maximum possible number of collisions (1380 vs 1404). The Abort Gap Keeper (AGK) window length was set to prevent any injection of the first bunch of a batch beyond RF bucket 31181. If this could be pushed back by 10 buckets, it would allow keeping the pilot bunch in the scheme with satellite-main collisions in IP2.

**Spectrometers, polarity reversals:**

In the 2011 proton run the LHCb dipole polarity was reversed 11 times. One reversal was made on request of the LHC as the '-' polarity had been hypothesized to be the source of an LHC performance degradation (around end of July). The suspicion was on the long-range collisions of the 12-bunch batches in IR8 with a small net crossing angle. This turned out not to be related to any LHC issue. The LHCb reversal had little impact on LHC operation, owing to the fact that LHCb has a single spectrometer magnet and used a fixed external angle. This latter feature turned out to be inconvenient from the physics point of view (two drastically different net angles). For 2012, operation with a vertical external crossing angle has been proposed [19] and should be explored, as it would bring benefits to LHCb

[1] 50ns_1380b+1small_1318_39_1296_144bpi13inj.

[2] 50ns_1380b_1331_0_1320_144bpi12inj.

physics (identical net angle amplitude for the two polarities, with the center-of-mass boost being just mirrored in the vertical plane).

The ALICE dipole and solenoid polarities were reversed once in the $p$ run. The ALICE reversals involve two magnets and a changing external angle (when present) which required more effort (compared to IP8). The solenoid introduces a trajectory change in the horizontal plane which is not compensated by dedicated magnets (contrary to the dipole spectrometer fields). The crossing angle bump includes injection protection devices (TDI), which need to be re-aligned and checked when reversing the external angle. The single change in IP2 was done around September 4-7 and costed approximately 18 h of machine-available time (plus some hours to understand an issue with the TCLI). In detail, the time was invested in

- 4h at injection to check/correct the orbits before and after the reversal,
- 7h at injection for IR2 TDI/TCLI alignment and validation,
- 1h at injection for IR2 TCTs alignment/validation,
- 5h to bring the beams to flat top, check the orbits, align the IR2 TCTs at flat top and after the optics squeeze.
- 1h to do betatron loss maps in collisions and one off-momentum loss map, followed by a ramp-down.

For the Pb run, a trick was developed to switch the external angle on the fly after squeezing (see fill 2319). This avoided the need to re-align the injection protection devices. Therefore, the ALICE polarity could be reversed at a smaller beam time cost. First considerations indicate that this trick cannot be applied to $p$ operation at 50 ns. A second, closer look might be useful.

In addition, ALICE, ATLAS, CMS and LHCb requested 'field off' collisions (see tables 3 to 8). In field 2204, a test with a reduced ALICE solenoid field was attempted ($\sim$ 40% of nominal field), which resulted in enhanced background rates probably due to insufficiently scrubbed areas (scrubbing was suppressed by the continuous presence of the B field).

**Luminosity scans and leveling:**

In early 2011, a new mode of operation, called 'luminosity leveling' was developed and deployed. Automatic luminosity leveling by transverse separation in the non-crossing plane was tested at the end of fill 1711 and again during fill 1712 (in IP8). Later the same method was deployed for IP2.

For IP8, the leveling separation was typically in the range of 0 to 2 $\sigma_{\rm beam}$ ($\sigma_{\rm beam}$ is the average beam transverse size at the IP). For IP2, in the range of 2 to 4 $\sigma_{\rm beam}$ (0 to 2 $\sigma_{\rm beam}$) when colliding main bunches on main (satellite) bunches.

Operation with separation-based luminosity leveling proved to be very effective and was crucial to reach (and even exceed) the 1 $\mathrm{fb}^{-1}$ integrated luminosity in IP8. No issue with this method of luminosity leveling has been observed throughout 2011.

Note that, in 2012, inclined crossing might be used in IP8, which will require an upgrade of the leveling application (now limited to the H or V plane).

The Luminosity Scan application was again extensively used for luminosity optimization for physics, for VDM scans, for IP steering, for length scale calibrations, etc. Some of these use cases required extensive manual actions. A proposal for an upgrade (more flexible) application for such IP trim sequences has been written down [20].

**Offline data from the experiments:**

Offline data on luminosity and luminous region imaging were stored as compressed text files in a dedicated storage space on AFS [21]. For 2012, it is recommended to upgrade this facility to a more professional and more easily maintainable infrastructure. A functional specification has been written [22].

**Satellite-main collisions in IP2 (ALICE):**

In order to satisfy the low pile-up requirements of ALICE and, at the same time, reduce the number of main bunch collisions taken away from IP1, 5 and 8, it was proposed to use main-satellite collisions at IP2. Normal 50 ns fills exhibited a small (yet visible) satellite distribution with a 5 ns spacing (every second LHC RF bucket). In a first step, the spontaneous satellites at 25 ns from the main bunches were made to collide with a main bunch at IP2. In this filling scheme, no main-main collision occurred at IP2 and the transverse separation could be switched off. First tests of this idea were carried out in fill 1787 and in the summer (August, fills 1844 to 1961), however in sub-optimal conditions. The achieved luminosity was just about too small to satisfy the ALICE request. The luminosity could have been increased by squeezing in IP2, though at a considerable cost in setup time. Instead of that, an RF trick[3] in the PS was developed to enhance the 25 ns satellites without further degrading the global distribution of satellites in other buckets. In this way, the relevant satellite population could be adjusted manually to a few percent of the main bunch population. This trick was successfully applied to fill the LHC in fills 2261, 2266 and 2267. The ALICE luminosity could be tuned at will up to $\sim 8 \cdot 10^{30} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, without any risk of suddenly blasting the ALICE detector with head-on main-main collisions.

Figures 4 and 5 show the population of the 25 ns satellites relative to the main bunches for fills 2219 and 2222 (both with spontaneous satellites), measured with the LHC Longitudinal Density Monitors. The measurements were taken 10 minutes after reaching the flat top energy. The figures 6, 7 and 8 show the same for the fills 2261, 2266 and 2267 (which had enhanced satellites). The comparison clearly shows the success of the satellite enhancement. Figure 9 shows the full longitudinal distribution within

[3]Many thanks to Steve Hancock for the impressive work on this subject, and to Thomas Weiler for the associated SPS adjustments and checks.

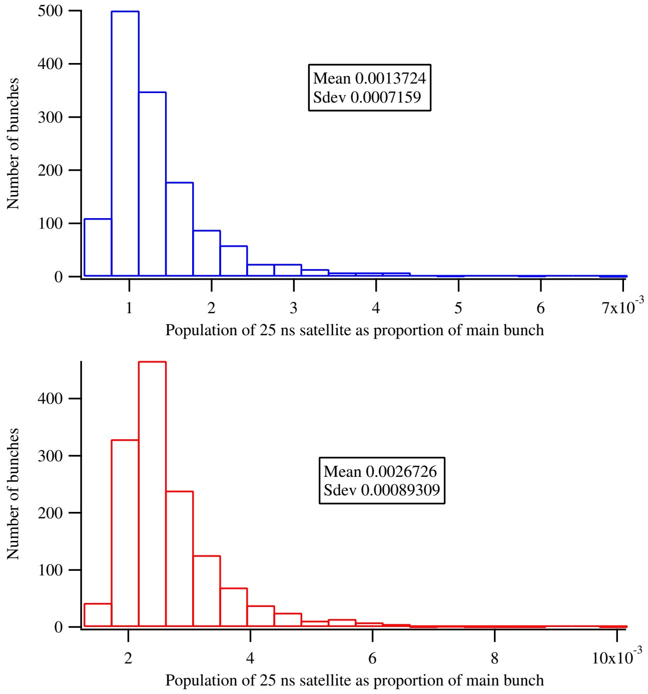



Figure 4: Population of the 25 ns satellites relative to the 50 ns nominally filled bucket populations for fill 2219 (spontaneous satellites). Top: beam1, bottom: beam2. Courtesy of Adam Jeff.

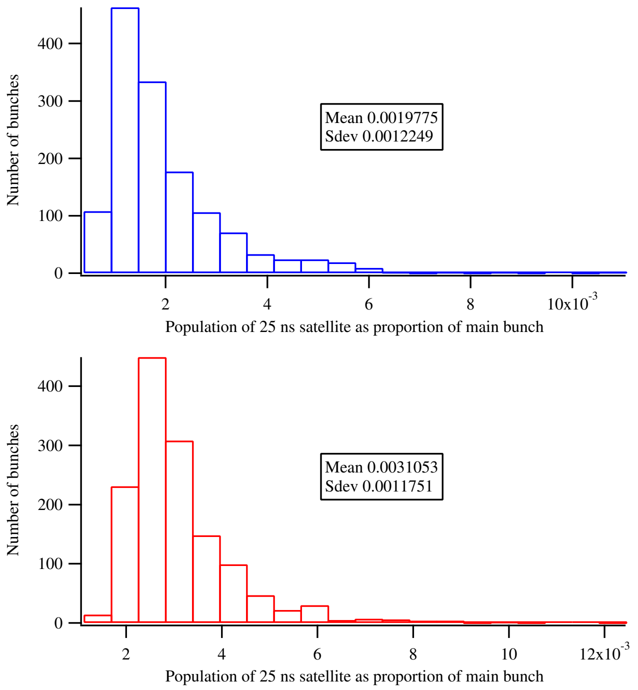



Figure 5: Population of the 25 ns satellites relative to the 50 ns nominally filled bucket populations for fill 2222 (spontaneous satellites). Top: beam1, bottom: beam2. Courtesy of Adam Jeff.

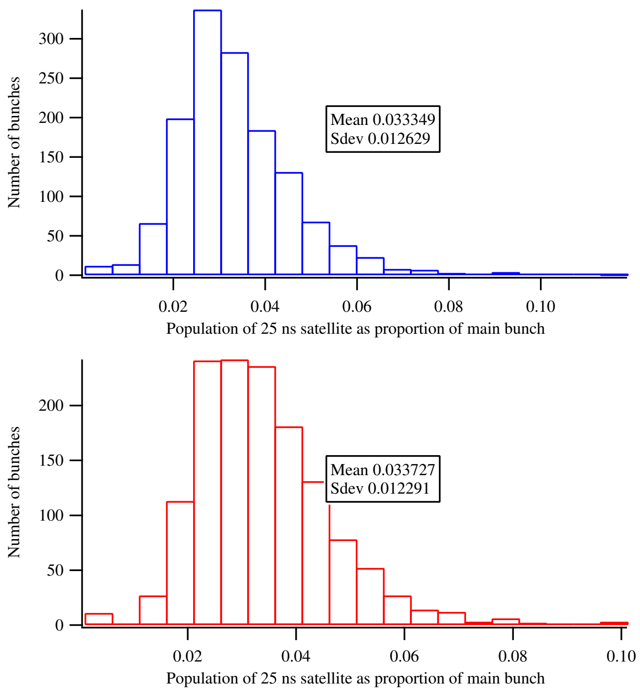



Figure 6: Population of the 25 ns satellites relative to the 50 ns nominally filled bucket populations for fill 2261 (enhanced satellites). Top: beam1, bottom: beam2. Courtesy of Adam Jeff.

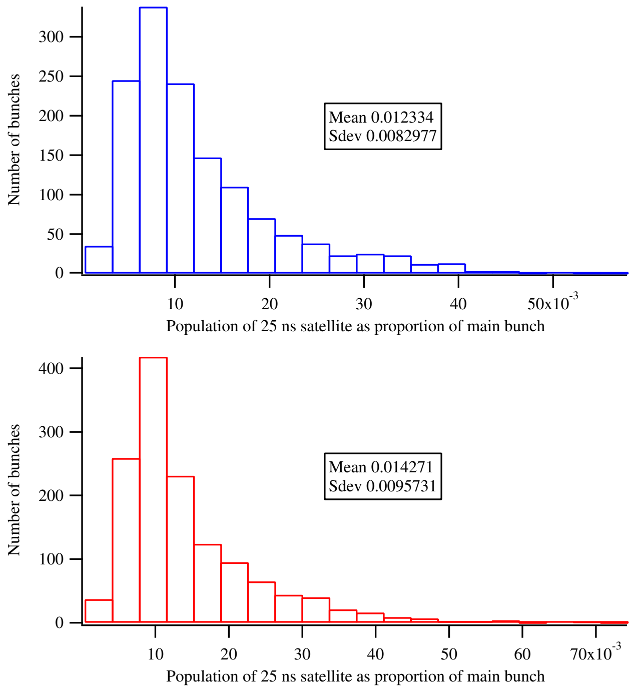



Figure 7: Population of the 25 ns satellites relative to the 50 ns nominally filled bucket populations for fill 2266 (enhanced satellites). Top: beam1, bottom: beam2. Courtesy of Adam Jeff.

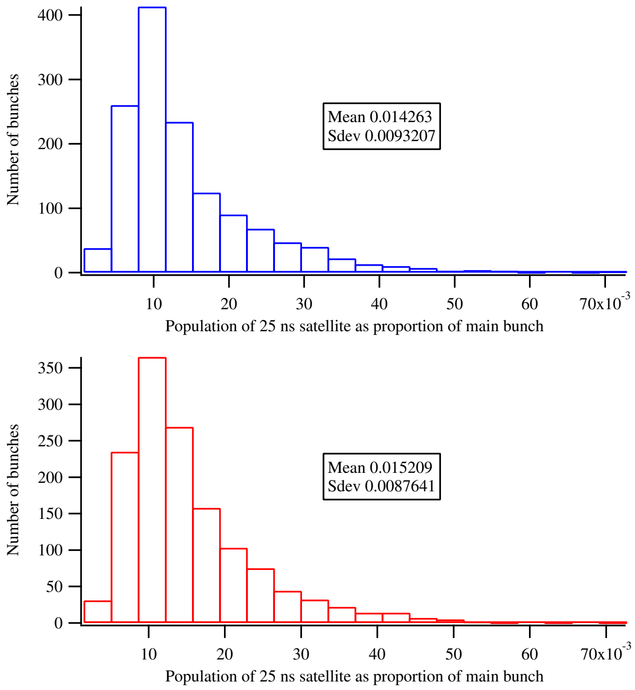



Figure 8: Population of the 25 ns satellites relative to the 50 ns nominally filled bucket populations for fill 2267 (enhanced satellites). Top: beam1, bottom: beam2. Courtesy of Adam Jeff.

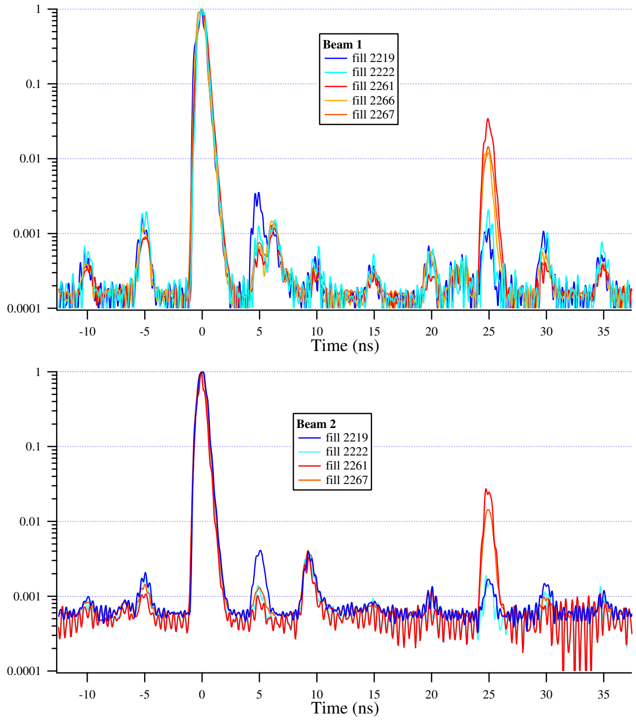



Figure 9: Longitudinal charge distribution within $[-12.5, +37.5]$ ns of a nominally filled slot, averaged over all filled slots, for fills 2219 and 2222 (spontaneous satellites) and fills 2261, 2266 and 2267 (enhanced satellites). Top: beam1, bottom: beam2 (2266 missing). Courtesy of Adam Jeff.

$[-12.5, \ +37.5]$ ns of a nominally filled slot, averaged over all filled slots.

In general, this test was a success. The conditions for ALICE were improved (less pile-up, no risk of excessive luminosity, reduced separation), and the number of collisions at IP1&5 and IP8 was increased by 1% and 2% respectively. This type of operation also requires 250 ns gaps between PS trains in the SPS, instead of the tighter (and more demanding) 225 ns gaps for the standard filling scheme used previously. A more detailed analysis by ALICE can be found in reference [23].

For 2012 operation, ALICE prefers to choose the correct $\beta^*$ squeeze such as to *not* need the enhancement of the 25 ns satellites. The trick of satellite-main collisions could perhaps also be used to satisfy an ATLAS/CMS request of low pile-up data (depending on the amount of data needed).

Finally, the production of controlled (enhanced) 25 ns satellites in the PS was demonstrated and could potentially become useful if, for example, the high luminosity LHC upgrade branches off on the 50 ns spacing. In this case, beam-beam effects could complicate LHC operation with IP1, IP5 and IP8. Given the upgrade luminosity requirements of LHCb ($2 \cdot 10^{33}\text{cm}^{-2}\text{s}^{-1}$), one could perhaps escape the beam-beam issues by producing satellite-main collisions in IP8.

**Vacuum and background issues:**

Several vacuum and background issues were observed throughout 2011. All vacuum pressure rises were due to dynamic effects (beam related). Large pressure increases were observed in the vicinity of the D1 magnets and TDIs (IR2 and IR8), and at 18 m right of IP5. Data taking in ALICE and CMS was occasionally hampered by beam-gas background from such pressure rises. See reference [24] for more details on the vacuum pressure observations.

**25 ns test:**

On 7 October fill 2186, with 25 ns spacing, was brought to physics conditions (STABLE BEAMS). A filling scheme with 60 bunches (12+24+24) was used. The bunch intensities were around $1.1 \cdot 10^{11}$, with $\sim 3$ $\mu$m emittance. The experiments are still evaluating the data, but no major issue was observed online.

**High pile-up tests:**

On ATLAS and CMS request, two high pile-up fills were scheduled. In fill 2201, a scheme with a single main bunch colliding in IP1 and IP5 was prepared. A pile-up of about 31 was reached, if one assumes an inelastic cross section of 73.5 mb (bunch pair luminosity of about $4.7 \cdot 10^{30}$ cm$^{-2}$s$^{-1}$ at the start of fill). A second high pile-up test was performed in fill 2252 (following the 25 ns scrubbing MD and taking advantage of the 1 m squeeze) with 10 main bunches per beam (Single_11b+1small_10_1_1_HighPileUp). This time, a pile-up of almost 35 was obtained (the luminosities per bunch varied between 4.4 and $5.3 \cdot 10^{30}$ cm$^{-2}$s$^{-1}$

at the start of fill). The experiments concluded from this test that physics data can be acquired at such high pile-up, though some slight degradation of various physics quantities becomes visible and should be studied further (such as the combinatoric background affecting photon identification efficiency, or a degradation of vertex reconstruction due to pile-up) [25].

## CONCLUSION

Cooperation between machine and experiments was again very constructive. The LHC produced $pp$ physics collisions at $\sqrt{s} = 7$ TeV with a peak luminosity reaching about $3.6 \cdot 10^{33}$ cm$^{-2}$s$^{-1}$ and delivering more integrated luminosity than expected ($\sim 5.7$ fb$^{-1}$ in IP1&5, $1.2$ fb$^{-1}$ in IP8).

Thanks to this excellent LHC performance, ATLAS and CMS came close to discover or exclude the SM Higgs boson, while increasing further the pressure on supersymmetric models. LHCb was able to set unprecedented limits on the branching ratio of $B_s \to \mu\mu$ and to observe an intriguing CP violating asymmetry in charm decay.

An intermediate energy $pp$ run was successfully carried out to complement the heavy ion physics data. Furthermore, an impressive 16-fold increase in peak and integrated luminosity with Pb beams was realized ($4.5 \cdot 10^{26}$ cm$^{-2}$s$^{-1}$ and about 160 $\mu$b$^{-1}$ per IP). ALICE, ATLAS and CMS produced a wealth of new heavy ion physics results that will sharpen the understanding of the quark-gluon plasma.

A first TOTEM measurement of the total $pp$ cross section was realized and more diffractive physics results obtained with Roman Pots (TOTEM and ALFA/ATLAS).

Luminosity calibration measurements with van der Meer scans and beam-gas imaging were further improved, to the point that cross sections could be measured with about 2% accuracy.

A detailed list of facts, observations and suggestions for possible improvements was presented.

## ACKNOWLEDGEMENTS

I would like to express my gratitude to all the people in the CERN machine departments, LHC experiments and CERN management for their support and collaboration, and for making my six years of LHC Programme Coordination a delight. I wish at least as much pleasure to the new LHC Programme Coordinator, Benedetto Gorini, and his deputy, Emilio Meschi.

Special thanks to

- Colin Barschel for his help in organizing the data exchange with the experiments and for his excellent work on the DCCT calibration studies,

- Delphine Jacquet, Giulia Papotti and Werner Herr for not complaining about the more than 65 physics filling schemes,

- the LHC and Injector Complex Operators, Engineers in Charge, Machine Coordinators, rMPP members and the many LPC contact persons for their kind patience with me (I would name you all explicitly, were I not afraid of forgetting one name),

- the BCNWG members (in particular Jean-Jacques Gras) and all luminosity calibration addicts for the interesting discussions,

- Helmut Burkhardt for looking after many aspects of the high $\beta^*$ optics, VDM scans and background-related issues.

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| Fill nr. | Stable beams start | stop | E (TeV) | Filling scheme | Magnets IP8 | IP2 | $\beta^*$ (m) |
|---|---|---|---|---|---|---|---|
| 1613 | Sun 13.03 18:05 | Mon 14.03 01:09 | 3.5 | Single_3b_2_2_2_wp | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1615 | Mon 14.03 05:13 | Mon 14.03 07:21 | 3.5 | Single_3b_2_2_2_wp | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1616 | Mon 14.03 10:40 | Mon 14.03 15:57 | 3.5 | Single_3b_2_2_2_wp | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1617 | Tue 15.03 01:59 | Tue 15.03 04:54 | 3.5 | Single_3b_2_2_2_wp | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1622 | Wed 16.03 02:09 | Wed 16.03 08:30 | 3.5 | Single_3b_2_2_2_wp | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1634* | Fri 18.03 15:05 | Fri 18.03 21:05 | 3.5 | 75ns_32b+4small_34_26_28_8bpi8inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1635* | Fri 18.03 23:30 | Fri 18.03 23:35 | 3.5 | 75ns_32b+4small_34_26_28_8bpi8inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1636* | Sat 19.03 04:37 | Sat 19.03 10:37 | 3.5 | 75ns_32b+4small_34_26_28_8bpi8inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1637* | Sat 19.03 13:18 | Sat 19.03 20:00 | 3.5 | 75ns_64b+4small_66_52_56_8bpi12inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1638* | Sat 19.03 22:44 | Sun 20.03 05:50 | 3.5 | 75ns_64b+4small_66_52_56_8bpi12inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1639* | Sun 20.03 11:41 | Sun 20.03 18:01 | 3.5 | 75ns_64b+4small_66_52_56_8bpi12inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1640* | Sun 20.03 21:31 | Mon 21.03 06:05 | 3.5 | 75ns_136b+4small_138_102_105_24bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1642† | Mon 21.03 15:13 | Mon 21.03 21:46 | 3.5 | 75ns_136b+4small_138_102_105_24bpi11inj | 0 | 0/0 | 1.5 / 10 / 1.5 / 3 |
| 1644† | Tue 22.03 12:11 | Tue 22.03 18:08 | 3.5 | 75ns_136b+4small_138_102_105_24bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1645 | Tue 22.03 21:15 | Wed 23.03 06:12 | 3.5 | 75ns_200b_194_178_188_24bpi9inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1646 | Wed 23.03 09:18 | Wed 23.03 09:32 | 3.5 | 75ns_200b_194_178_188_24bpi9inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1647 | Wed 23.03 22:18 | Thu 24.03 10:19 | 3.5 | 75ns_200b_194_178_188_24bpi9inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1650 | Fri 25.03 06:11 | Fri 25.03 08:59 | 1.38 | 525ns_80b+4small_68_64_32_8bpi14inj | + | -/- | 11 / 10 / 11 / 10 |
| 1651 | Fri 25.03 19:02 | Fri 25.03 21:36 | 1.38 | 525ns_80b+4small_68_64_32_8bpi14inj | + | -/- | 11 / 10 / 11 / 10 |
| 1653‡ | Sat 26.03 18:20 | Sun 27.03 16:55 | 1.38 | 525ns_72b+4small_64_48_16_8bpi9inj | - | -/- | 11 / 10 / 11 / 10 |
| 1658‡ | Sun 27.03 21:16 | Mon 28.03 05:32 | 1.38 | 525ns_72b+4small_64_48_16_8bpi9inj | + | -/- | 11 / 10 / 11 / 10 |

Table 3: All fills with STABLE BEAMS during phase 1 of the 2011 LHC proton run. Magnets: IP8 = LHCb dipole, IP2 = ALICE dipole & solenoid.
*ATLAS solenoid and toroids off.
†ATLAS toroids off.
‡VdM scans and length scale calibrations.

| Fill nr. | Stable beams start | stop | E (TeV) | Filling scheme | Magnets IP8 | IP2 | $\beta^*$ (m) |
|---|---|---|---|---|---|---|---|
| 1704 | Wed 13.04 14:57 | Wed 13.04 16:38 | 3.5 | 50ns_1164b_36x2bpi_18inj_scrub* | 0 | 0/0 | 1.5 / 10 / 1.5 / 3 |
| 1711† | Fri 15.04 01:58 | Fri 15.04 12:12 | 3.5 | 50ns_228b+1small_214_12_180_36bpi8inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1712 | Fri 15.04 15:49 | Fri 15.04 19:18 | 3.5 | 50ns_228b+1small_214_12_180_36bpi8inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1713 | Sat 16.04 00:19 | Sat 16.04 05:16 | 3.5 | 50ns_228b+1small_214_12_180_36bpi8inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1716 | Sat 16.04 17:38 | Sat 16.04 19:09 | 3.5 | 50ns_336b+1small_322_12_288_36bpi11inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1718 | Sun 17.04 03:19 | Sun 17.04 12:29 | 3.5 | 50ns_336b+1small_322_12_288_36bpi11inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1721 | Mon 18.04 22:46 | Tue 19.04 00:21 | 3.5 | 50ns_336b+1small_322_12_288_36bpi11inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1722 | Tue 19.04 05:28 | Tue 19.04 11:12 | 3.5 | 50ns_336b+1small_322_12_288_36bpi11inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1727 | Wed 20.04 23:56 | Thu 21.04 07:42 | 3.5 | 50ns_336b+1small_322_14_288_72bpi7inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1728 | Thu 21.04 11:14 | Thu 21.04 20:09 | 3.5 | 50ns_480b+1small_424_12_468_36bpi15inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1729 | Thu 21.04 23:52 | Fri 22.04 06:54 | 3.5 | 50ns_480b+1small_424_12_468_36bpi15inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1730 | Fri 22.04 11:36 | Fri 22.04 16:09 | 3.5 | 50ns_336b+1small_322_14_288_72bpi7inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1731 | Fri 22.04 19:09 | Sat 23.04 07:41 | 3.5 | 50ns_480b+1small_424_12_468_36bpi15inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1732 | Sat 23.04 12:25 | Sun 24.04 06:23 | 3.5 | 50ns_480b+1small_424_12_468_36bpi15inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1733 | Sun 24.04 16:27 | Sun 24.04 16:37 | 3.5 | 50ns_480b+1small_424_14_468_72bpi11inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1735 | Sun 24.04 20:59 | Mon 25.04 13:34 | 3.5 | 50ns_480b+1small_424_14_468_72bpi11inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1736 | Mon 25.04 16:20 | Mon 25.04 20:40 | 3.5 | 50ns_480b+1small_424_14_468_72bpi11inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1737 | Mon 25.04 23:42 | Tue 26.04 04:51 | 3.5 | 50ns_480b+1small_424_14_468_72bpi11inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1739 | Tue 26.04 23:28 | Wed 27.04 07:08 | 3.5 | 50ns_480b+1small_424_14_468_72bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1743 | Wed 27.04 23:17 | Thu 28.04 09:20 | 3.5 | 50ns_624b+1small_598_16_576_72bpi11inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1744 | Thu 28.04 16:15 | Thu 28.04 16:58 | 3.5 | 50ns_624b+1small_598_16_576_72bpi11inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1745 | Thu 28.04 21:41 | Fri 29.04 11:05 | 3.5 | 50ns_624b+1small_598_16_576_72bpi11inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1748 | Sat 30.04 06:35 | Sat 30.04 08:20 | 3.5 | 50ns_624b+1small_598_16_576_72bpi11inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1749 | Sat 30.04 13:38 | Sun 01.05 05:27 | 3.5 | 50ns_624b+1small_598_16_576_72bpi11inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1753 | Sun 01.05 19:01 | Sun 01.05 20:30 | 3.5 | 50ns_768b+1small_700_16_756_72bpi15inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1755 | Mon 02.05 06:13 | Mon 02.05 12:11 | 3.5 | 50ns_768b+1small_700_16_756_72bpi15inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1756 | Tue 03.05 13:45 | Tue 03.05 14:03 | 3.5 | 50ns_768b+1small_700_16_756_72bpi15inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |

Table 4: All fills with STABLE BEAMS during phase 2 of the 2011 LHC proton run. Magnets: IP8 = LHCb dipole, IP2 = ALICE dipole & solenoid.
*Only first 10 injections (228b+1small), special fill to check scrubbing effect with no collisions in IP2 and IP8, ATLAS & CMS magnets all off.
†CMS solenoid at 2 T for part of the fill, then ramped to 3.8 T.

| Fill | Stable beams | | E | Filling | Magnets | | $\beta^*$ |
|---|---|---|---|---|---|---|---|
| nr. | start | stop | (TeV) | scheme | IP8 | IP2 | (m) |
| 1782 | Sun 15.05 07:23 | Sun 15.05 08:40 | 3.5 | Single_2b_1_1_1_wp | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1783* | Sun 15.05 12:32 | Sun 15.05 23:20 | 3.5 | Single_38b+1small_14_16_22_4bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1785* | Mon 16.05 11:26 | Mon 16.05 14:56 | 3.5 | 50ns_228b+1small_214_12_180_36bpi8inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1787 | Wed 18.05 03:24 | Wed 18.05 05:22 | 3.5 | 50ns_480b+1small_424_3_468_72bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1795 | Thu 19.05 23:34 | Fri 20.05 07:43 | 3.5 | 50ns_768b+1small_700_16_756_72bpi15inj_b | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1796 | Fri 20.05 15:52 | Fri 20.05 16:47 | 3.5 | 50ns_768b+1small_700_18_756_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1798 | Sat 21.05 03:17 | Sat 21.05 11:55 | 3.5 | 50ns_768b+1small_700_18_756_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1799 | Sat 21.05 20:33 | Sun 22.05 07:10 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1800 | Sun 22.05 14:11 | Sun 22.05 15:43 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1801 | Sun 22.05 20:40 | Sun 22.05 21:27 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1802 | Mon 23.05 02:13 | Mon 23.05 05:24 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1803 | Mon 23.05 09:34 | Mon 23.05 19:47 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1804 | Tue 24.05 02:13 | Tue 24.05 12:19 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1805 | Tue 24.05 23:26 | Wed 25.05 02:43 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1806 | Wed 25.05 08:21 | Wed 25.05 11:20 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1809 | Fri 27.05 22:40 | Sat 28.05 00:25 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1812 | Sat 28.05 08:17 | Sat 28.05 18:59 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1813 | Sun 29.05 03:15 | Sun 29.05 04:45 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1815 | Sun 29.05 10:53 | Sun 29.05 21:20 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1816 | Mon 30.05 02:14 | Mon 30.05 11:11 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1822 | Tue 31.05 04:55 | Tue 31.05 06:22 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1823 | Tue 31.05 09:10 | Tue 31.05 10:38 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1835 | Wed 01.06 19:31 | Wed 01.06 20:38 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1836 | Thu 02.06 02:03 | Thu 02.06 16:58 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1839 | Thu 02.06 21:46 | Thu 02.06 21:50 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1841 | Fri 03.06 05:55 | Fri 03.06 13:30 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1844 | Fri 03.06 20:55 | Fri 03.06 21:18 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1845 | Sat 04.06 02:17 | Sat 04.06 07:56 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1846 | Sat 04.06 13:24 | Sat 04.06 16:19 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1848 | Sat 04.06 23:29 | Sun 05.06 00:15 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1851 | Sun 05.06 06:31 | Sun 05.06 06:56 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1852 | Sun 05.06 09:25 | Mon 06.06 00:32 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1854 | Mon 06.06 07:30 | Mon 06.06 07:39 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1855† | Mon 06.06 15:55 | Tue 07.06 07:26 | 3.5 | 50ns_1104b+1small_1042_35_1008_108bpi_ob | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1856 | Tue 07.06 22:34 | Wed 08.06 09:21 | 3.5 | 50ns_1104b+1small_1042_35_1008_108bpi_ob | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1859 | Thu 09.06 01:10 | Thu 09.06 05:05 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1862 | Thu 09.06 13:39 | Fri 10.06 00:52 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1863 | Sat 11.06 03:41 | Sat 11.06 13:16 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1864 | Sun 12.06 00:29 | Sun 12.06 07:17 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1865 | Sun 12.06 13:56 | Mon 13.06 03:22 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1866 | Mon 13.06 10:36 | Mon 13.06 10:56 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1867 | Mon 13.06 13:25 | Mon 13.06 21:52 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1868 | Tue 14.06 07:30 | Tue 14.06 22:38 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1871 | Thu 16.06 07:22 | Thu 16.06 14:50 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1873 | Fri 17.06 01:13 | Fri 17.06 02:07 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1875* | Fri 17.06 06:14 | Fri 17.06 14:04 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1880 | Sat 18.06 06:59 | Sat 18.06 07:48 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1883 | Tue 21.06 00:15 | Tue 21.06 18:12 | 3.5 | 50ns_1092b+1small_1042_35_1008_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1889 | Fri 24.06 11:04 | Fri 24.06 13:46 | 3.5 | 50ns_1236b+1small_1180_37_1152_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1890 | Fri 24.06 22:53 | Sat 25.06 13:00 | 3.5 | 50ns_1236b+1small_1180_37_1152_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1893 | Sun 26.06 01:01 | Sun 26.06 01:40 | 3.5 | 50ns_1236b+1small_1180_37_1152_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1894 | Sun 26.06 04:23 | Sun 26.06 06:33 | 3.5 | 50ns_1236b+1small_1180_37_1152_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1895 | Sun 26.06 09:38 | Sun 26.06 09:55 | 3.5 | 50ns_1236b+1small_1180_37_1152_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1898 | Sun 26.06 14:57 | Sun 26.06 16:50 | 3.5 | 50ns_1236b+1small_1180_37_1152_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1900 | Mon 27.06 02:27 | Mon 27.06 22:22 | 3.5 | 50ns_1236b+1small_1180_37_1152_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1901 | Tue 28.06 02:16 | Tue 28.06 16:07 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |

Table 5: All fills with STABLE BEAMS during phase 3 of the 2011 LHC proton run. Magnets: IP8 = LHCb dipole, IP2 = ALICE dipole & solenoid.
*VdM scans and/or length scale calibrations.
†No STABLE BEAMS from 22:28 to 23:41 (RF klystron test).

| Fill | Stable beams | | E | Filling | Magnets | | $\beta^*$ |
|---|---|---|---|---|---|---|---|
| nr. | start | stop | (TeV) | scheme | IP8 | IP2 | (m) |
| 1936 | Wed 13.07 09:29 | Wed 13.07 11:39 | 3.5 | Single_2b_1_1_1_wp | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1944 | Thu 14.07 16:45 | Thu 14.07 19:21 | 3.5 | 50ns_48b+1small_10_0_36_36bpi3inj* | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1945 | Fri 15.07 00:32 | Fri 15.07 03:34 | 3.5 | 50ns_264b_249_0_240_36bpi8inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1952 | Sat 16.07 19:15 | Sun 17.07 01:07 | 3.5 | 50ns_840b_807_0_816_108bpi12inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1953 | Sun 17.07 04:36 | Sun 17.07 10:17 | 3.5 | 50ns_840b_807_0_816_108bpi12inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1954 | Sun 17.07 19:34 | Sun 17.07 23:00 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1955 | Mon 18.07 03:42 | Mon 18.07 09:50 | 3.5 | 50ns_1092b+1small_1042_35_1008_108bpi | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1956 | Mon 18.07 15:23 | Mon 18.07 15:41 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1958 | Mon 18.07 22:19 | Mon 18.07 22:41 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1960 | Wed 20.07 04:42 | Wed 20.07 05:52 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1961 | Wed 20.07 12:51 | Wed 20.07 14:59 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1962 | Wed 20.07 22:30 | Thu 21.07 13:57 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1966 | Fri 22.07 14:28 | Fri 22.07 23:03 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1967 | Sat 23.07 02:01 | Sat 23.07 13:27 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1968 | Sat 23.07 18:25 | Sat 23.07 19:11 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1970 | Sun 24.07 01:36 | Sun 24.07 03:13 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1971 | Sun 24.07 05:41 | Sun 24.07 06:50 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1972 | Sun 24.07 11:32 | Sun 24.07 12:20 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1974 | Mon 25.07 00:15 | Mon 25.07 05:31 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1975 | Mon 25.07 08:01 | Mon 25.07 10:27 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1979 | Mon 25.07 22:25 | Tue 26.07 04:28 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 1982 | Wed 27.07 03:34 | Wed 27.07 06:04 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1985 | Wed 27.07 17:18 | Thu 28.07 04:41 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1986 | Thu 28.07 09:56 | Thu 28.07 12:25 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1990 | Fri 29.07 01:13 | Fri 29.07 08:57 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1991 | Fri 29.07 17:48 | Fri 29.07 22:43 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1992 | Sat 30.07 11:50 | Sat 30.07 12:46 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1993 | Sat 30.07 22:57 | Sat 30.07 23:54 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1994 | Sun 31.07 03:51 | Sun 31.07 04:37 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1996 | Sun 31.07 10:15 | Sun 31.07 11:24 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1997 | Tue 02.08 01:39 | Tue 02.08 04:26 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1998 | Tue 02.08 08:00 | Tue 02.08 14:54 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 1999 | Tue 02.08 19:15 | Wed 03.08 06:37 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2000 | Wed 03.08 08:43 | Thu 04.08 06:19 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2001 | Thu 04.08 08:44 | Thu 04.08 11:33 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2005 | Fri 05.08 02:40 | Fri 05.08 03:12 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2006 | Fri 05.08 07:24 | Sat 06.08 09:23 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2007 | Sat 06.08 14:29 | Sun 07.08 07:42 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2008 | Sun 07.08 19:11 | Sun 07.08 19:40 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2009 | Mon 08.08 02:48 | Mon 08.08 18:07 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2010 | Mon 08.08 23:33 | Tue 09.08 18:19 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2011 | Wed 10.08 05:49 | Wed 10.08 14:30 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2022 | Fri 12.08 05:40 | Fri 12.08 10:40 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2025 | Fri 12.08 19:05 | Fri 12.08 03:37 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2028 | Tue 16.08 23:53 | Wed 12.08 02:58 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2029 | Wed 17.08 05:40 | Wed 12.08 09:48 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | -/- | 1.5 / 10 / 1.5 / 3 |
| 2030 | Wed 17.08 13:58 | Wed 17.08 15:37 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 2031 | Wed 17.08 22:11 | Wed 17.08 23:03 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 2032 | Thu 18.08 01:10 | Thu 18.08 06:22 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 2037† | Sun 21.08 06:41 | Sun 21.08 14:41 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |
| 2040 | Mon 22.08 00:26 | Mon 22.08 18:03 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | -/- | 1.5 / 10 / 1.5 / 3 |

Table 6: All fills with STABLE BEAMS during phase 4 of the 2011 LHC proton run. Magnets: IP8 = LHCb dipole, IP2 = ALICE dipole & solenoid.

*Misnamed 50ns_48b_9_0_36_36bpi2i_wp.

†About 1.5 h spent for a tight collimation test after STABLE BEAMS.

| Fill nr. | Stable beams start | stop | E (TeV) | Filling scheme | Magnets IP8 | IP2 | $\beta^*$ (m) |
|---|---|---|---|---|---|---|---|
| 2083$^{*}$ | Wed 07.09 14:36 | Wed 07.09 20:37 | 3.5 | 50ns_264b+1small_250_25_216_36bpi9inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2085$^{\dagger}$ | Wed 07.09 23:58 | Thu 08.09 06:04 | 3.5 | 50ns_480b+1small_424_14_468_72bpi11inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2086$^{\ddagger}$ | Thu 08.09 08:56 | Thu 08.09 19:12 | 3.5 | 50ns_912b+1small_874_20_864_108bpi11inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2090 | Fri 09.09 05:39 | Fri 09.09 06:51 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2091 | Fri 09.09 12:05 | Fri 09.09 14:26 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2092 | Fri 09.09 20:53 | Sat 10.09 03:12 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2093 | Sat 10.09 10:46 | Sat 10.09 11:27 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2094 | Sat 10.09 17:08 | Sat 10.09 17:43 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2101 | Mon 12.09 13:15 | Mon 12.09 16:39 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2103 | Tue 13.09 00:56 | Tue 13.09 09:07 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2104 | Tue 13.09 17:42 | Tue 13.09 21:04 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2105 | Wed 14.09 02:39 | Wed 14.09 19:13 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2110 | Thu 15.09 19:57 | Fri 16.09 02:15 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2117 | Fri 16.09 18:38 | Sat 17.09 03:28 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2124 | Mon 19.09 01:44 | Mon 19.09 11:04 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2126 | Mon 19.09 22:22 | Mon 19.09 22:41 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2127 | Tue 20.09 03:40 | Tue 20.09 04:18 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2129 | Tue 20.09 10:04 | Tue 20.09 20:23 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2135 | Wed 21.09 10:35 | Wed 21.09 21:53 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2138 | Thu 22.09 04:30 | Thu 22.09 11:00 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2140 | Thu 22.09 15:00 | Thu 22.09 20:53 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2143 | Fri 23.09 03:22 | Fri 23.09 03:29 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2144 | Fri 23.09 07:30 | Fri 23.09 09:42 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2147 | Fri 23.09 17:48 | Fri 23.09 22:14 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2150 | Sat 24.09 14:32 | Sat 24.09 19:19 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2151 | Sun 25.09 00:07 | Sun 25.09 00:23 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2152 | Sun 25.09 02:37 | Sun 25.09 04:53 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2155 | Sun 25.09 15:10 | Sun 25.09 15:46 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2156 | Sun 25.09 19:04 | Mon 26.09 07:28 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2157 | Mon 26.09 12:48 | Mon 26.09 14:35 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2158 | Mon 26.09 17:43 | Mon 26.09 22:32 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2160 | Tue 27.09 05:09 | Tue 27.09 07:02 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2165 | Wed 28.09 04:35 | Wed 28.09 10:23 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2168 | Thu 29.09 02:56 | Thu 29.09 07:01 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2171 | Thu 29.09 20:01 | Fri 30.09 06:05 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2177 | Sat 01.10 22:00 | Sun 02.10 13:01 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2178 | Sun 02.10 18:43 | Mon 03.10 09:25 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2180 | Mon 03.10 20:34 | Mon 03.10 20:48 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2181 | Mon 03.10 23:57 | Tue 04.10 12:13 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2182 | Tue 04.10 20:37 | Wed 05.10 05:31 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2186 | Fri 07.10 05:23 | Fri 07.10 08:15 | 3.5 | 25ns_60b+1small_58_36_36_24bpi4inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2194 | Sat 08.10 04:33 | Sat 08.10 05:10 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2195 | Sat 08.10 11:42 | Sun 09.10 04:57 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2197 | Sun 09.10 11:11 | Sun 09.10 18:02 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2199 | Mon 10.10 01:45 | Mon 10.10 02:15 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2200 | Mon 10.10 05:27 | Mon 10.10 09:51 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2201$^{\spadesuit}$ | Mon 10.10 15:27 | Mon 10.10 19:19 | 3.5 | Single_2_1_1_1_wp_(but no 2nd main bunch) | + | +/+ | 1 / 10 / 1 / 3 |
| 2204$^{\bullet}$ | Wed 12.10 04:21 | Wed 12.10 17:22 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2208 | Thu 13.10 02:54 | Thu 13.10 16:44 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2210 | Thu 13.10 22:53 | Fri 14.10 05:00 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2215 | Sat 15.10 03:04 | Sat 15.10 04:33 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2216 | Sat 15.10 09:28 | Sat 15.10 20:44 | 3.5 | 50ns_1380b+1small_1318_39_1296_144bpi13inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2217 | Sun 16.10 01:47 | Sun 16.10 02:54 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2218 | Sun 16.10 05:30 | Sun 16.10 08:09 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2219 | Sun 16.10 15:13 | Mon 17.10 06:59 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2220 | Mon 17.10 14:11 | Mon 17.10 15:45 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2222 | Mon 17.10 22:11 | Tue 18.10 02:12 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | + | +/+ | 1 / 10 / 1 / 3 |
| 2234$^{\diamond}$ | Fri 21.10 06:26 | Fri 21.10 14:29 | 3.5 | Single_36b_4_16_16_4bpi9inj | + | +/+ | 90 / 10 / 90 / 10 |
| 2239 | Sat 22.10 06:45 | Sat 22.10 07:45 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2240 | Sat 22.10 11:14 | Sun 23.10 01:45 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2241 | Sun 23.10 06:31 | Sun 23.10 08:54 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2242 | Sun 23.10 18:48 | Mon 24.10 05:09 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2252$^{\spadesuit}$ | Tue 25.10 16:22 | Tue 25.10 19:38 | 3.5 | Single_11b+1small_10_1_1_HighPileUp | - | +/+ | 1 / 10 / 1 / 3 |
| 2254 | Wed 26.10 06:22 | Wed 26.10 09:30 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2256 | Wed 26.10 22:54 | Wed 26.10 23:03 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2258 | Thu 27.10 03:52 | Thu 27.10 04:33 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2261$^{\heartsuit}$ | Fri 28.10 20:51 | Fri 28.10 02:02 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2266$^{\heartsuit}$ | Sun 30.10 07:28 | Sun 30.10 09:49 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |
| 2267$^{\heartsuit}$ | Sun 30.10 12:59 | Sun 30.10 17:10 | 3.5 | 50ns_1380b_1331_0_1320_144bpi12inj | - | +/+ | 1 / 10 / 1 / 3 |

Table 7: All fills with STABLE BEAMS during phase 5 of the 2011 LHC proton run. Magnets: IP8 = LHCb dipole, IP2 = ALICE dipole & solenoid.

$^{*}$ATLAS toroids off for muon alignment.

$^{\dagger}$ATLAS toroids trip off at the end of the fill.

$^{\ddagger}$ATLAS toroids ramping up during the fill.

$^{\bullet}$Tested 40% reduction of ALICE solenoid.

$^{\diamond}$VdM scans and length scale calibrations.

$^{\spadesuit}$High pile-up test.

$^{\heartsuit}$Enhanced satellites test.

| Fill nr. | Stable beams start | stop | E (TeV) | Filling scheme | Magnets IP8 | IP2 | $\beta^*$ (m) |
|---|---|---|---|---|---|---|---|
| 2290 | Sat 12.11 06:41 | Sat 12.11 11:48 | 3.5 | Single_2b_1_1_1 | 0 | -/- | 1 / 1 / 1 / 3 |
| 2292 | Sun 13.11 14:40 | Sun 13.11 21:38 | 3.5 | Single_9b_8_8_0_1bpi9inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2294 | Tue 15.11 01:30 | Tue 15.11 08:24 | 3.5 | 200ns_170b_168_144_0_24bpi9inj_IONS* | 0 | -/- | 1 / 1 / 1 / 3 |
| 2297 | Tue 15.11 18:22 | Wed 16.11 00:05 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2300 | Thu 17.11 00:20 | Thu 17.11 08:59 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2301 | Thu 17.11 12:57 | Thu 17.11 20:00 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2302 | Fri 18.11 00:34 | Fri 18.11 06:08 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2303 | Fri 18.11 09:34 | Fri 18.11 14:48 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2304 | Fri 18.11 22:42 | Sat 19.11 05:15 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2305 | Sat 19.11 08:11 | Sat 19.11 14:24 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2308 | Sun 20.11 02:49 | Sun 20.11 09:25 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2309 | Sun 20.11 12:54 | Sun 20.11 17:29 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2314 | Mon 21.11 23:30 | Mon 21.11 23:50 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2315 | Tue 22.11 04:33 | Tue 22.11 11:49 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2316 | Tue 22.11 19:35 | Tue 22.11 22:24 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2317 | Wed 23.11 13:15 | Wed 23.11 18:13 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2318 | Wed 23.11 21:53 | Thu 24.11 03:30 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2319† | Wed 23.11 09:02 | Thu 24.11 18:06 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2320 | Thu 24.11 22:44 | Fri 25.11 04:08 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2325 | Sat 26.11 08:04 | Sat 26.11 13:46 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2327 | Sat 26.11 19:59 | Sat 26.11 20:31 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2328 | Sun 27.11 00:02 | Sun 27.11 06:12 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2329 | Sun 27.11 12:29 | Sun 27.11 18:48 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2330 | Sun 27.11 22:04 | Mon 28.11 05:13 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | -/- | 1 / 1 / 1 / 3 |
| 2332 | Mon 28.11 19:11 | Mon 28.11 20:22 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2334 | Thu 01.12 04:59 | Thu 01.12 10:44 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2335‡ | Thu 01.12 15:26 | Thu 01.12 21:11 | 3.5 | 200ns_352b_344_324_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2336 | Fri 02.12 04:20 | Fri 02.12 10:33 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2337‡ | Fri 02.12 13:18 | Fri 02.12 17:29 | 3.5 | 200ns_352b_344_324_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2338 | Sat 03.12 00:29 | Sat 03.12 08:09 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2339 | Sat 03.12 14:06 | Sat 03.12 20:01 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2340 | Sat 03.12 22:54 | Sun 04.12 05:52 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2341‡ | Sun 02.12 11:48 | Sun 02.12 14:55 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2342 | Sun 02.12 18:25 | Sun 02.12 23:59 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2343 | Mon 05.12 03:15 | Mon 05.12 09:34 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2344• | Mon 05.12 22:53 | Tue 06.12 05:57 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2349 | Tue 06.12 21:02 | Tue 06.12 22:37 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2350 | Wed 07.12 02:57 | Wed 07.12 03:42 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |
| 2351 | Wed 07.12 08:41 | Wed 07.12 10:17 | 3.5 | 200ns_358b_356_336_0_24bpi15inj_IONS | 0 | +/+ | 1 / 1 / 1 / 3 |

Table 8: All fills with STABLE BEAMS during the 2011 LHC ion run. Magnets: IP8 = LHCb dipole, IP2 = ALICE dipole & solenoid.

*Filling scheme wrongly named 200ns_170b_168_168_0_24bpi9inj_IONS

†Part of fill (15:02-17:43) in ADJUST to test ALICE external angle reversal on the fly.

‡VdM scans and/or length scale calibrations.

•ATLAS toroids partly off (till 01:00) as recovering from a glitch.