Experiments - experience and future

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Abstract

The talk discusses the input from the experiments that is relevant to define next year's program. It covers the target for integrated luminosity for 2017 and the requests for special runs (high β^*, VdM scans, low energy runs, high or low pile-up running). The impact of LHC parameters and conditions on the experiments is also discussed, including the effect of pileup, bunch length, background etc.. In addition the need and different possibilities for luminosity levelling in ATLAS/CMS will be discussed, as well as feedback on the observed luminosity difference between ATLAS/CMS in 2016 running.

2016 RUNNING

2016 was an extremely successful year for the LHC complex and the experiments, with all parts of the scheduled programme exceeding expectations. Figure **??** shows the delivered luminosity to the experiments as a function of time during the 2016 pp run. About 40 fb^{-1} of pp data at 13 TeV was delivered to ATLAS and CMS (with 25 fb^{-1} the goal), with nearly 2 fb^{-1} delivered to LHCb and more than 10 pb^{-1} to ALICE, allowing a large number of searches for new physics, and physics measurements to be carried out. Four days of special running at a β^* of 2.5 km delivered 350 μb^{-1} to TOTEM and ATLAS (ALFA) for total cross-section measurements. The year ended with a very successful four weeks of running with proton-lead collisions at both 5 TeV and 8 TeV nucleon-nucleon centre-of-mass energy, allowing to satisfy the different physics requests from the experiments.

The high luminosity pp running benefited from an excellent availability with $\approx$50 % of the available physics time spent in stable beams, and a peak luminosity of $\approx 1.5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (50 % above the design luminosity). The high peak luminosity and the limited number of bunches (limited to 2220 by the SPS beam dump vacuum) meant the peak pileup in ATLAS/CMS was nearly a factor of two higher than the design. This stressed the experiments, but they were able to cope with these harsh pileup conditions. A significant issue in 2016 was the apparent imbalance in luminosity delivered to ATLAS/CMS, with ATLAS receiving $\approx$10 % less luminosity than CMS.

During the high luminosity running the CT-PPS roman pots were inserted during routine operation to 15 σ from the beam without problems (the ATLAS(AFP) pots were inserted, on one side of the IP, during the intensity ramp-up for fills with up to 600 bunches). During the year a bunch length levelling procedure was implemented to keep the average bunch length above 0.9 ns as requested by LHCb to reduce the pileup density during operation with their dipole

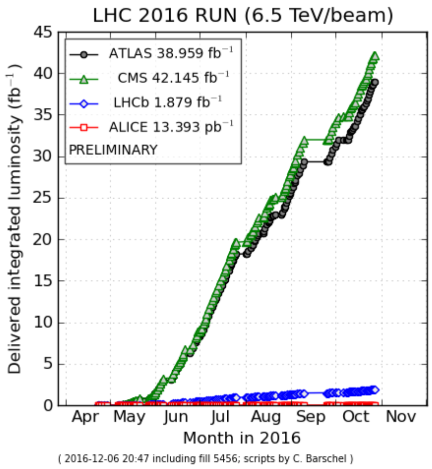

Figure 1: Luminosity delivered to the LHC experiments as a function of time during the 2016 pp run. The luminosity values are using a non-final offlibe calibration.

in positive polarity. Beam related backgrounds were generally very low in 2016, and about a factor of three lower than in 2015. There was a short period where high losses at injection caused problems for the ALICE detector, but this was solved when an additional 40 MHz RF cavity was used in the PS.

During 2016 there were a number of very useful test fills carried out for the experiments, for example testing levelling the luminosity in ATLAS/CMS using beam separation, a fill where the crossing angle was reduced to zero to study the IP1/5 luminosity imbalance and a high pileup fill to allow the experiments to test running at higher pileup.

2017 RUNNING

The experiments view 2017 as a luminosity production year. Due to the extended year end technical stop (EYETS) there is no ion run scheduled, giving a similar number of pp physics days in 2017 as in 2016 with the current schedule.

Nominal running

In order to maximize the integrated luminosity in 2017 both ATLAS/CMS would like to continue with the low emittance BCMS beam. Both experiments believe they will be able to deal with the high pileup that this will lead to. Improvements to the experiment systems over the shut down should allow them to cope with peak pileup values up to 60 and luminosities up to 2×10^{34} cm^{-2}s^{-1}. If one or both experiments prefer to reduce the pileup at the beginning of the fills, we believe this can be achieved using luminosity levelling by beam separation, which was demonstrated in 2016 tests. The luminosity may anyway need to be levelled to lower values due to the limits on the triplet cooling in IP1/5.

In general the experiments do not have strong opinions on the choice of the β^* and the type of optics (ATS or standard) for 2017 running, as long as changes do not significantly increase the setup time. Although there is a preference for non-ATS optics from CT-PPS (as discussed later).

For 2017 high luminosity running both the CT-PPS and AFP roman pots request to be inserted to 15 σ from the beam.

CMS request that the beam-line is re-aligned in IP5 during the EYETS such that the collision point is 2 mm lower. This would give more uniform illumination of the pixel detector which is important for the detector lifetime.

Special run requests

For the rest of Run-2 (so including both 2017/2018) the experiments have requested the following special running periods:

- Running at intermediate β^* ($\approx$90 m) - requested by TOTEM for glue-ball and low mass SUSY searches. The LHCC suggest this is done in 2018 and could be 1-2 weeks of running and setup time.

- *pp* running at 5 TeV centre-of-mass energy (as reference for the ion data with nucleon collision energy of 5 TeV). This is requested by ATLAS/CMS and ALICE, although the length of the request is driven by ALICE as they take the data at low rate. During discussions at the LHCC it was suggested that a good time for this could be at the end of 2017 running, where this data taking could act as a cool down period. It is foreseen that it would take about ten days to acquire the requested data set.

- There is interest from TOTEM/ATLAS(ALFA) for a total cross-section measurement (with very high β^* data) at low energy (900 GeV or 2 TeV) which could be scheduled in Run-2 if there is sufficient time (otherwise this could be done in Run-3).

We believe that the relevant accelerator experts should work on the optimal machine configurations in order to satisfy the above requests in the most efficient manner. The exact scheduling of these will depend on the re-start after the EYETS and the LHC performance in 2017, but a baseline planning could see the 5 TeV *pp* reference run taking place at the end of 2017 running.

In addition to the above it is also foreseen to have van der Meer scans taken in 2017 with the same configuration as in 2016.

Forward physics during high luminosity running

Both the CT-PPS and AFP roman pot systems request to be inserted during nominal high luminosity running in 2017. This allows studies of central exclusive production of rare Standard Model processes, as well as searches for new physics. In 2016 the physics acceptance of CT-PPS was found to be poor with the 40 cm β^* optics and a special orbit bump (the so-called *TOTEM bump*) was introduced in order to improve this, in addition the pots were allowed to be inserted to 15 σ from the beam after TS1 which also improves the acceptance. In preparation for 2017 running both CT-PPS and AFP have tested possible optics configurations (with standard and ATS optics) to assess the acceptance for each option. For AFP the pots are inserted in the separation plane, which gives reasonable acceptance for the different optics sets. However for CT-PPS the pots are in the crossing plane, and this limits the acceptance as the dispersion from the crossing angle partially cancels that from the D1 magnets. CT-PPS therefore prefer to have a smaller crossing angle to reduce this effect. The CT-PPS acceptance is considerably better for the non-ATS optics (as shown in Figure **??**). CT-PPS request an orbit bump in order to improve the dispersion and their acceptance. The feasibility of an orbit bump depends on how much corrector strength is available which in turn depends on how the re-alignment of the CMS beam-line is carried out. If this can partially be done with a mechanical re-alignment around the IP, this would free up corrector strength for a possible orbit bump.

ATLAS/CMS luminosity imbalance

The measured delivered luminosities by ATLAS/CMS show that $\approx$10 % less luminosity was delivered to ATLAS than CMS. This difference is significantly larger than the luminosity measurement uncertainty. Studies suggest that this is mainly coming from the fact that the horizontal emittance is generally larger than the vertical emittance, which coupled with the vertical(horizontal) crossing plane in IP1(5) would give different geometric factors, and therefore different luminosities at the two IPs. A model taking into account the measured emittances in the two planes, predicts a luminosity imbalance between the two IPs consistent with what is observed for much of the year, however for the last $\approx$15 fills in 2016 the emittance measurements suggest the beams are round, whereas the luminosity imbalance is still observed in these fills [**?**][**?**]. In order to study this further a test was carried out where the crossing angle in IP1/5 was reduced in steps to zero, and the luminosity and beam size was measured. This test suggests that the luminosity imbalance is driven by the crossing angle (the luminosity difference was reduced from 11 % at nominal crossing angle to 4 % with zero crossing angle). A full analysis of this test can be seen in Ref. [**?**].

If it is confirmed that the luminosity imbalance is coming from emittance differences in the two planes, this can be corrected for by normalizing the value of the crossing angle by the emittance in the relevant plane, which has the advantage of correctly compensating beam-beam effects in the two IPs. However it remains an open question how to reliably determine the emittances to set the crossing angles.

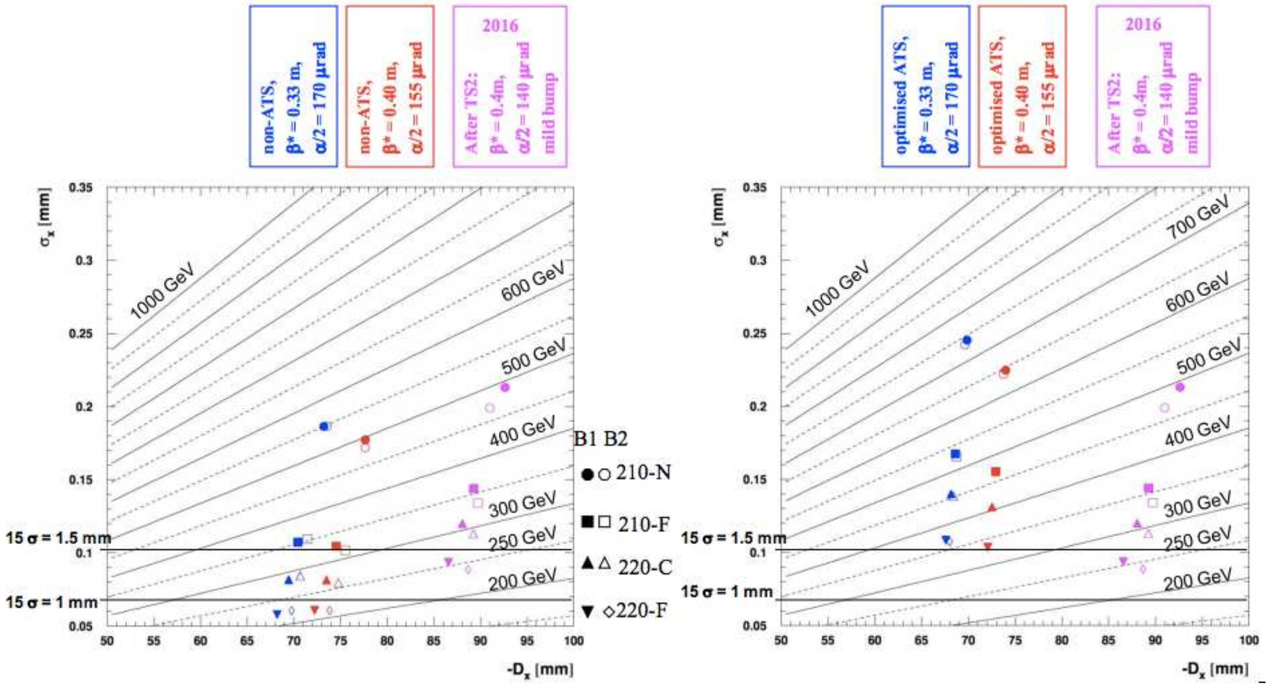

Figure 2: The minimum mass for which there is non-zero acceptance, in terms of beam size at the pot (σ_x) and dispersion (D_x), of the different CT-PPS roman pots for non-ATS optics (left) and ATS optics (right) for β^* of 33 cm (blue) or 40 cm (red). The 2016 acceptance is shown in magenta. For good physics performance the pots 210-F, 220-C and 220-F need to be in the acceptance. Plots courtesy of M. Deile.

A simple scheme should be adopted where the crossing angle is not changed often, to minimize any re-validation overhead, but can be modified at technical stops to allow corrections based on the recent running experience.

In parallel a Z-boson counting analysis is ongoing in ATLAS/CMS to give an additional comparison of the delivered luminosity which is independent of the nominal luminosity measurements from the experiments. Preliminary results confirm the luminosity imbalance at the level of that observed with the nominal luminosity measurements.

SUMMARY

2016 was a great year for the LHC experiments with the machine performance exceeding all expectations. The experiments coped well with the challenging pileup conditions. For 2017 the experiments prefer to run with BCMS beams to maximize the luminosity, and expect to be able to cope with the increased pileup. However it is expected that luminosity levelling in IP1/5 (either or both) will be operational in 2017 if needed. There is a request from CT-PPS to improve their physics acceptance with an orbit bump, but this depends on the IP5 re-alignment strategy. In terms of special running conditions in Run-2, the experiments have requested an intermediate β^* run (likely to be scheduled in 2018) and a 5 TeV pp reference run (likely to be scheduled at the end of 2017).

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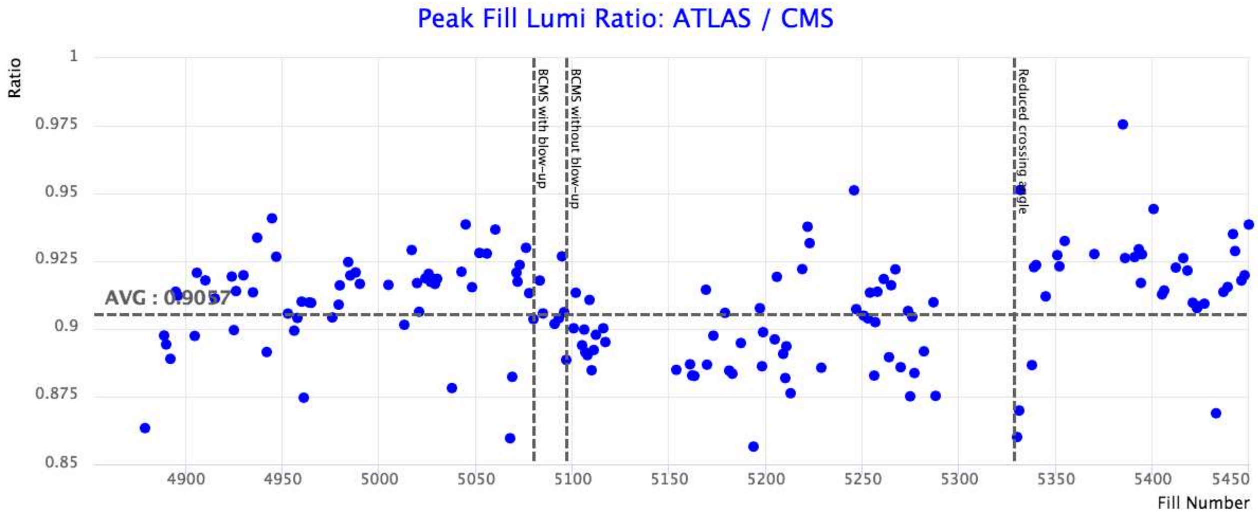

Figure 3: The ratio of the peak luminosity in IP1 to the peak luminosity in IP5 as a function of fill number, for all the stable beam fills in the 2016 *pp* data taking period. The luminosity values from the experiments are using non-final offline calibrations.