DESIRES AND CONSTRAINTS OF EXPERIMENTS DURING EARLY LHC OPERATION

D. Macina, CERN, Geneva, Switzerland

Abstract

This paper is a compilation of the desires and constraints of the experiments during the early LHC operation. Issues like special beams for commissioning, bunch spacing, instantaneous luminosity, special proton runs, low energy runs, $^{208}Pb^{82+}$ runs and shutdown requests are discussed.

GENERAL CONSIDERATIONS

This paragraph deals with general considerations for the early LHC operation. It should be noticed that the two high luminosity experiments have in general no particular constraints and that their main goal is to attain the nominal conditions foreseen during the early operation as soon as possible trying to minimize the number of overlapping events whenever feasible. On the other hand, in order to attain the best conditions for the low luminosity experiments during the early runs, a little bit more effort may be required from the operation point of view including providing good background conditions. Nevertheless the experiments will make use of any kind of beam provided by the machine for the detector commissioning and for recording the first pp collisions. It should be clearly underlined that in this paper the different experimental requirements are presented regardless of any physics priorities.

ATLAS & CMS

Important physics discoveries can be made even at modest integrated luminosities [1]. The Standard Model Higgs boson, for example, can be discovered in the mass regions 140-155 GeV and 190-450 GeV using the 'gold-plated' mode (H->ZZ* -> 4 leptons), for ATLAS and CMS combined, by delivering an integrated luminosity of 4 fb^{-1}. In addition some SUSY particles, given their large cross-sections, can be found quickly with integrated luminosities of more than 1 fb^{-1}. Finally, it should be underlined that the potential for b-physics can be exploited right from start-up. Therefore it is clear that the ideal goal should be to go as fast as possible to stable operation with 25 ns bunch spacing, nominal energy and $L \geq 10^{33}$ cm^{-2} s^{-1}. ATLAS and CMS underline that the understanding of the performance of the detectors is easier when there are few or no overlapping events. In fact in this case the track density is low, making the track and energy reconstruction much easier. In addition the quality of calibration, alignment and synchronization can be checked more easily. Furthermore overlapping events degrade electron, photon, tau and b-jet identification and the effectiveness of isolation cuts in separating signal from background processes. Hence ATLAS and CMS would like to operate in conditions with no more than ~ 2 pileup events during the initial physics runs until the performance of the detectors is properly understood.

LHCb

The LHC will be by far the most copious source of B mesons, due to both the high $b\bar{b}$ cross section and the high luminosity. The LHCb experiment plans to operate with a nominal average luminosity of 2 x 10^{32} cm^{-2} s^{-1}. Running at this luminosity has a lot of advantages. The events will be dominated by single pp interactions that are easy to analyse, the detector occupancy will remain low and the radiation damage will be reduced. Therefore the LHCb experiment has been optimized for an average luminosity of 2 x 10^{32} cm^{-2} s^{-1} and 25 ns bunch spacing. In this case the bunch crossing rates with only one, and with more than one pp interaction, are 9.3 MHz and 3.0 MHz, respectively. In addition this luminosity will allow the experiment to collect data for many years under constant conditions since it can be obtained from the beginning of the LHC operation and can be kept at its nominal value while the luminosities at the other interaction points are being progressively increased to their design values. This is feasible since the low-beta insertion at IR8 is tunable in the range 1 m < β^* < 50 m. Therefore LHCb wishes to exploit this possibility from first collisions.

ALICE

Proton-proton collisions are an integral part of the heavy-ion physics programme because of their intrinsic interest and because they are needed to obtain reference data. Moreover, pp runs will provide low multiplicity, thus simpler, data to commission and calibrate the components of the ALICE detector. Hence, they are needed during the whole period of ALICE operation, both initially as well as in later years prior to every heavy ion run. The pp runs will be in parallel with the other experiments but at reduced luminosities in IP2 to keep the pile-up in the TPC and Silicon Drift Detectors at an acceptable level. The luminosity during the pp runs has to be limited to ~ 5 x 10^{30} cm^{-2} s^{-1}, corresponding to an interaction rate of ~ 200 kHz. At this rate, ALICE records on average 50 overlapping events, i.e. 97 % of the data volume corresponds to unusable partial events. The optimal detector operation and physics performance with the TPC, i.e. no pile-up, is at ~ 10^{29} cm^{-2} s^{-1}. ALICE will therefore request pp operation in IP2 with both the maximum acceptable rate (5 x 10^{30} cm^{-2} s^{-1}) in order to maximise integrated luminosity for rare processes as well as lower luminosity (10^{29} cm^{-2} s^{-1}) to collect statistics for large cross section observables and global event properties at optimum DAQ bandwidth and detector performance. For the muon spectrometer the highest acceptable luminosity of about 5 x 10^{31} cm^{-2} s^{-1} is set by the RPC illumination limit. It should be noticed that for L ≥ 10^{32} cm^{-2} s^{-1} the detectors will be exposed to too much radiation leading to possible damage. Depending on the beam intensity the luminosity reduction can be obtained either with displaced beams or with larger β* values which, however, are limited by the available aperture in the inner triplet and by the necessity of separating the beams in order to limit the long range beam-beam interaction in the common drift space. During the LHC commissioning phase, beam intensities and luminosities are lower than their nominal ones and therefore the reduction in luminosity may be reached by simply increasing the β* values. If feasible, this is highly desirable since the more stable running conditions are expected together with a better defined vertex.

Experimental Magnets

The ATLAS magnet system consists of a superconducting 2 T solenoid and air-core toroids while CMS uses one superconducting 4 T solenoid. All these magnets will be kept on during filling since they have a long ramping time. However, if required for LHC commissioning, they could be left off during some initial runs.

The ALICE experiment uses two magnets: a 0.5 T solenoid (constructed for the L3 experiment at LEP) and a large warm dipole magnet with resistive coils and a high field integral of 3 Tm horizontal field perpendicular to the beam axis. This dipole is used for the muon spectrometer. Both the solenoid and the dipole polarities will be changed between 1 and 4 times per year (the solenoid and the dipole are changed at the same time). A few runs with magnets off may also be required for alignment purposes. These three different magnet operating conditions should be commissioned during the pilot run. For completeness, it should be mentioned that, during a later phase of LHC operation, runs with intermediate magnet strength may be required to increase the detector acceptance for some physics events.

The LHCb spectrometer dipole is a warm magnet with a high field integral of 4 Tm oriented vertically. The polarity of the field will be changed every run to reduce systematic errors in the CP-violation measurements that could result from a left-right asymmetry of the detector. However, if required for the LHC commissioning, the dipole polarity may remain unchanged over a number of fills during the pilot run. The dipole magnet is expected to remain at its nominal field and polarity during each entire LHC physics run. A few runs with magnets off may also be required for alignment purposes. The three different magnet operating conditions should be commissioned during the pilot run.

EARLY PROTON OPERATION

Single beam runs

All experiments will make use of single beam runs to carry out studies of synchronization, vacuum quality, beam-gas interactions and their rejection, muon halo triggers and catalogue detector problems. However in general there are no specific requests to run with single beams for longer than needed by the machine. It should be noticed that ALICE and LHCb are much more interested in Beam 1 (their detectors are effectively single-arm spectrometers) and that TOTEM is very interested in single beam runs to perform background studies at the Roman Pot locations.

Pilot physics runs: 43 or 156 bunch operation

During this phase of the LHC commissioning, the experiments will continue studies of synchronization, will continue to catalogue detector problems and start recording the first pp collisions. However, with this filling scheme, in order to provide collisions in LHCb it will be necessary to displace some bunches in one beam by 75 ns. These displaced bunches will cause events offset by 11.25 m in the other experiments. This proposal is fine with all experiments with the exception of TOTEM who needs to check the impact of the event offset on the Roman Pots when in the data taking position. It should be noticed that, during this phase of the LHC operation, LHCb will get very low luminosity and that this could be partially compensated by tuning β* to the minimum value. In addition, given the low intensity bunches foreseen during the pilot run a L ~ 10^{29} cm^{-2} s^{-1} could be achieved at ALICE without beam displacement by tuning β* to ~ 200 m.

Operation with 75 ns bunch spacing

The 75 ns operation is useful for synchronization purposes, background studies and for initial luminosity runs for pp physics. However ~ 2 weeks may be enough for this purpose. Hence the 75 ns operation need not last longer than a few weeks provided a reasonable operation can be achieved at 25 ns without a long set up. This means that the bunch intensity can be increased until ATLAS and CMS get 2 pileup events and then move to 25 ns bunch spacing operation. However, if 25 ns operation gives problems 75 ns operation could be continued, provided the experiments have understood the detector operation with a large number of overlapping events. It should be underlined that for a given instantaneous luminosity, 25 ns operation is always preferable with respect to 75 ns operation.

It should be noticed that the 75 ns operation is particularly limiting for the LHCb experiment. In fact, as already mentioned before, contrary to the high luminosity experiments, LHCb has been optimized for one event per bunch crossing and therefore, with 75 ns operation, LHCb suffers a significant loss in the B rate.

Finally, a L < 5 x 10^{30} cm^{-2} s^{-1} could be achieved at ALICE without beam displacement tuning β* > 100 m according to the bunch intensity. It is therefore highly desirable to study the maximum β* value at IP2 compatible with the available aperture in the inner triplet and the necessity to limit the long range beam-beam interactions in the common drift space.

SPECIAL PROTON RUNS

The physics programme of the TOTEM experiment includes the measurement of the total cross-section as well as extensive studies of diffractive process in the very forward region. The total cross section will be measured using the luminosity independent method which is based on a simultaneous measurement of elastic scattering at low momentum transfer and inelastic interactions. The studies mentioned above require different beam parameters and running conditions. The resulting different running scenarios are outlined in [2]. The study of the total cross-section and measurement of low four-momentum transfer squared ($-t \sim 10^{-3}$ GeV^2) elastic scattering can only be performed with special optics at high β* which allows the detection of particles emitted at very small angles. In fact with high β* optics the beam divergence at the IP becomes very small while the beam size is relatively large. The detection of the particles emitted at very small angles will require moving the Roman Pots as close as possible to the beam. The reduction and the control of the beam halo is therefore of crucial importance as well as the reduction of beam-gas interactions. In addition the minimum distance of approach is proportional to the size of the beam at the position of the Roman Pots themselves. Operation with a transverse emittance reduced by ~ a factor 3 with respect to the nominal one will then have the two desirable consequences of reducing both the beam size and the beam angular spread. However it should be underlined that the total cross-section measurement by the luminosity independent method can be successful at nominal emittance. A standard special TOTEM period would consist of ~ 3 short 1-day runs at β*=1540 m and ~ 2 short runs at β*=18 m. It is clear that with a single one-day run TOTEM gets enough statistics to complete the measurements. However, understanding the systematic errors will require more than one run. The TOTEM requirements on beam conditions, which are only partially mentioned in this paper, are quite demanding. The impact on the machine operation can be found in [3].

HEAVY ION RUNS

In addition to ALICE, both ATLAS and CMS request heavy ion collisions. In general there are no special requirements for the heavy ion runs since the detectors are supposed to be commissioned during the proton runs. Moreover no access to the detectors is planned when switching from proton to heavy ion operation. However both ATLAS and CMS are planning to install ZDCs in the TAN. Depending on the radiation hardness of these detectors and on their operation, ZDCs may be required to be removed during the proton high luminosity runs.

ALICE requests the nominal period foreseen for the heavy ion operation (~ 4 weeks) after the first long shutdown according to the so-called "early ion scheme" . However it should be noticed that a pilot run before the first long shutdown, even if of a short duration and low luminosity, could already provide a wealth of information on global event properties and large cross section observables.

LOW ENERGY RUNS

This paragraph deals with the possibility of running the LHC at a centre-of-mass energy ,$\sqrt{s}$, much lower than the nominal one.

Low energy runs are currently neither in the ATLAS nor in the CMS baseline physics programme. However this request may come at a later phase of the LHC operation.

The ALICE physics programme foresees a dedicated pp run at $\sqrt{s}$ = 5.5 TeV corresponding to the nucleon-nucleon centre-of-mass for nominal $^{208}Pb^{82+}$ for a direct comparison of the $^{208}Pb^{82+}$ and proton data. Additional $^{208}Pb^{82+}$ runs at lower energy would also allow the measurement of an energy excitation function and to connect to the RHIC results. However both requests are foreseen for a later phase of the LHC operation.

Lowering the centre-of-mass would allow TOTEM to probe smaller values of the four-momentum transfer squared. Centre-of-mass energies below 8 TeV will probe the region where the interference between the nuclear interaction and the Coulomb interaction takes place and thus give access to the ρ parameter. TOTEM wishes to explore this possibility during the first phase of the LHC operation. In addition, but at a later phase, it would be interesting to run at the TEVATRON center-of-mass energy for a cross check of the total cross-section measurement.

SHUTDOWN REQUESTS

Apart from CMS, none of the experiments is actually planning a shutdown after the pilot run. On the contrary CMS, based on its understanding of the likely conditions and duration of a pilot run ($L < 5 \times 10^{32}$ cm^{-2} s^{-1}), requests a shutdown to install:

- The pixel tracker detector (not installed by choice); 3 weeks are needed for the entire operation including essential operations to be performed on the beam pipe
- The ECAL endcaps which are not available for the pilot run before summer 07; 3 months are needed for this operation

It should be noticed that, according to CMS, a pilot run includes also some operation at 75 ns and hopefully at 25 ns. In addition it is important to underline that, even without the ECAL endcaps, physics is still possible with the CMS detector even though acceptance is reduced. Moreover it is worth noticing that, after the beam pipe installation and bakeout, CMS intends to stay in the "ready to close" position until ~ 2 weeks (to be agreed) before first beam through IP5.

Finally the requests of the experiments regarding the annual shutdown can be found in the following:

- ALICE: 4 months if access to the Inner Tracker System is required, 3 months otherwise
- ATLAS: 3 months
- CMS: is anticipating 3-4 months annual shutdown but it is able to do useful major maintenance in a shutdown longer than one week
- LHCb: 2 months
- TOTEM: a few days for the Roman Pots and in the shadow of CMS for the central detectors

NEW PROPOSALS

Two new proposals, which, if approved, could influence the LHC operation during its first phase, have been recently encouraged by the LHCC:

"ATLAS Forward Detectors for Luminosity Measurements and Monitoring" [4]

The primary goal of this proposal is the determination of the absolute luminosity L by Coulomb normalization. This method is based on the measurement of elastic scattering down to small four momentum transfer squared (- t ~ 10^{-4} GeV^2). This requires Roman Pots at IR1, β*= 2625 m and a transverse emittance reduced by ~ a factor 3 with respect to the nominal one. The requirements on beam conditions are very similar to the TOTEM ones and therefore it is possible to run in parallel with TOTEM. The impact on the machine operation can be found in [3]. It is important to notice that, if small emittances cannot be obtained during the initial phase of the LHC operation, it is very difficult to reach the Coulomb region of the elastic scattering and so to measure the absolute luminosity at IP1. However, even in this case, the measurement of the extrapolated forward elastic rate is still interesting either to measure the total cross-section calculating L from machine parameters or to measure L using the total cross-section from TOTEM. The ATLAS Roman Pots may not be operational during the first physics runs.

"Measurement of Photons and Neutral Pions in the Very Forward Region of LHC" [5]

The purpose of this experiment is to measure the energy distribution of particles emitted in the very forward region to help understand cosmic ray phenomena. This can be done measuring neutral particles emitted in the very forward region by placing a small movable calorimeter between the beam pipes at the recombination chamber at IR1 or IR8. The preferred beam parameters are listed in the following:

- L ~ 10^{29}-10^{30} cm^{-2} s^{-1}
- No more than 10 bunches (to avoid pileup in the 10 μs readout time)
- Injection optics looks fine

In order to reduce the absorbed radiation dose, the calorimeter may be removed during the high luminosity runs. The ideal LHCf running schedule is to take data during three shorts runs integrated over the first years of the LHC operation. LHCf is also interested in N-N and p-N runs since N is the most abundant nucleus in the atmosphere.

CONCLUSIONS

All five experiments will be ready for commissioning and first physics which is expected in summer 2007. Exciting physics looks within reach at the luminosities envisaged during the first phase of the LHC operation (L ~ 10^{33} cm^{-2} s^{-1}). Therefore ATLAS and CMS hope to attain the nominal conditions foreseen during the early operation as soon as possible minimizing the number of overlapping events whenever feasible. It is possible to provide nominal conditions to LHCb even at the very early stage of the LHC commissioning by lowering β* to ~ 2m at IP8 as foreseen for ATLAS and CMS at IP1 and IP5. The ALICE request of getting the necessary luminosity reduction during the proton operation without displaced beams needs further studies. Nevertheless ALICE is very interested in exploring this possibility. In addition ALICE requires ~ 4 weeks heavy ion run (early scheme) after the first long shutdown. Finally, a number of very interesting studies, which do not require high luminosity, can be performed with special proton runs. It should be noticed that none of the experiments, with the exception of TOTEM, requires runs at lower energy during the first phase of the LHC operation.

In conclusion, it is obvious that the LHC Physics Programme is very rich and, therefore, more and more appealing. However, the variety of requests is not compatible with the commissioning of the machine and so careful prioritization needs to be done during the early phase of the LHC operation.

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