REQUIREMENTS FROM THE EXPERIMENTS

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Abstract

In this contribution, the LHC experiments desiderata in the current LHC context are presented, with a clear emphasis on 2010. For setting the scene, a brief reminder is given of the impact on the physics program of the beam energy and integrated luminosity. Possible physics run scenari are discussed and a few specific requests for special physics running conditions outlined.

INTRODUCTION

One year ago, at the 2009 LHC Workshop in Chamonix the question was addressed of the minimum amount of data needed in a first run, as a function of energy, to compete with state-of-the-art high energy physics experiments. Ref. [1] exposes the results of various projections (simulations) from the LHC experiments. Based on the information available at that time, it was decided to plan an LHC run that would start at the end of 2009, with beam commissioning, and gradually move toward a long physics run in 2010 at the center-of-mass energy $\sqrt{s} = 10$ TeV, collecting at least 200 pb^{-1} of good data per experiment. Shortly after Chamonix 2009, a measurement campaign, laboratory studies and simulations were launched to better understand the copper splice stabilizers of LHC magnet interconnects. The most recent results [2] indicate that safe 5 TeV/beam operation would require warming up all sectors for warm resistance measurements of dipole and quadrupole interconnections and the repair of splices with excessive resistance. A few scenari have been considered, among which the two following ones: (*a*) a staged scenario, spread over several years, interleaving a few months of physics operation at $\sqrt{s} = 7$ TeV with a few months of shutdown for splice repair of a few sectors per shutdown, and (*b*) a long run at $\sqrt{s} = 7$ TeV (2010-2011) followed by a long shutdown (2012) to fully consolidate the LHC for 14 TeV operation. For the LHC experiments, the second scenario is clearly preferred. The question now arises: how much data would the experiments need at the single energy of $\sqrt{s} = 7$ TeV in order to be competitive ?

The rest of this paper is organised as follows. Firstly, the main principles are reminded that govern physics reach versus energy and luminosity, and an answer to the above question is formulated. Following this, the main wishes of the experiments are presented and a few important numbers are outlined that should be considered when planning the 2010-2011 run. Then, the needs for machine stops are briefly reviewed. Finally, some concluding remarks and a summary are presented.

PHYSICS VERSUS ENERGY AND LUMINOSITY

Contrary to a lepton-antilepton collider where all the energy of the interaction can be transferred to a single object, the LHC collides two complex objects (protons) composed of partons (quarks, gluons and their anti-particles). The production cross section of a massive object depends on the nature of the partons involved in the production process and their couplings to this massive object. Each parton type has its own parton distribution function which describes the probability to find the given parton with the given longitudinal momentum fraction at a given energy scale (four-momentum transfer).

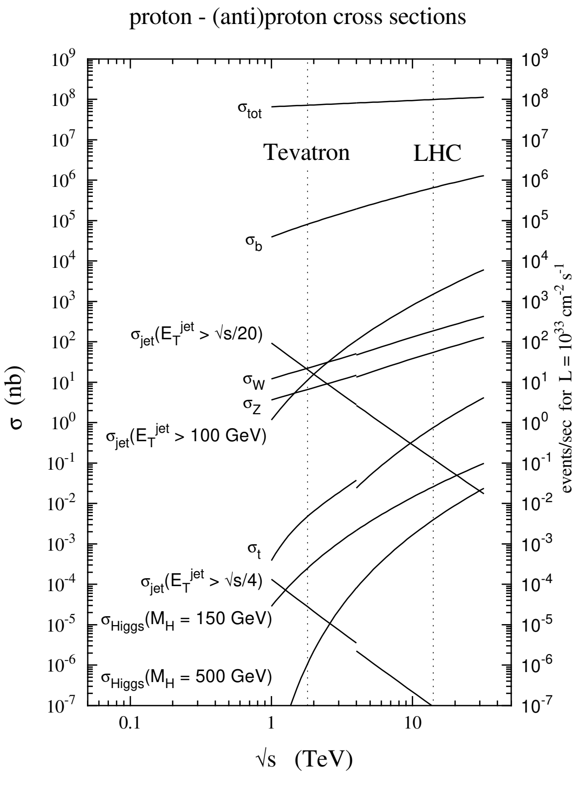

Figure 1: Cross section of various hard scattering processes in pp and $p\bar{p}$ interactions as a function of center-of-mass energy $\sqrt{s}$. For details see Ref. [3] where the figure was taken from (courtesy of M. Mangano).

The production cross section of some massive systems is depicted in Fig. 1 (taken from Chapter 1 in Ref. [3]). The figure shows the production cross section as a function of center-of-mass energy $\sqrt{s}$ in pp and $p\bar{p}$ collisions for different processes. The heavier the system, the steeper the dependence of its production cross section on $\sqrt{s}$. For example, in the energy range accessible to the LHC, the production of top-antitop quark pairs ($2m_t \approx 350$ GeV) goes down approximately by a factor 6 from $\sqrt{s} = 14$ TeV to $\sqrt{s} = 7$ TeV, while it decreases by less than a factor 4 for a hypothetical Higgs bosons of mass $m_H = 150$ GeV. For $b\bar{b}$ production ($2m_b \approx 10$ GeV), the reduction is only a factor 2. Therefore, the integrated luminosity needed for ATLAS and CMS to set limits on hypothetical particles comparable to those that the Tevatron experiments will reach by the end of 2011 depends strongly on the mass of the considered object and on the energy at which the ATLAS and CMS will acquire these data. For specific examples, see Ref. [1]. Also important, but more complicated to summarize, is the physics background to the process of interest. Generally, the signal-to-background ratio increases with increasing $\sqrt{s}$.

Looking back in Ref. [1] at the figures given by the experiments, one concludes that at $\sqrt{s} = 7$ TeV an integrated luminosity of ~ 1 fb^{-1} per IP by the end of 2011 would allow the LHC experiments to become competitive, and possibly take leadership, on direct searches of most (hypothetical) heavy particles, on $t\bar{t}$ studies and on B_s physics.

Various scenari of energy increase and integrated luminosity have been recently discussed. The consensus among the experiments is that a long run at $\sqrt{s} = 7$ TeV, followed by a long shutdown to prepare the LHC for 14 TeV operation, is clearly preferred over a more fragmented plan with one or two hundred pb^{-1} delivered at $\sqrt{s} = 7$ TeV, followed by a shutdown, and another one or two hundred pb^{-1} at $\sqrt{s} < 10$ TeV, etc. However, for the "preferred" scenario to be effective, the experiments wish to collect each about 1 fb^{-1} by the end of 2011.

WISHES FROM THE EXPERIMENTS

We list (or remind) the main wishes and boundary conditions from the experiments.

Energy

The highest priority is to obtain as quickly as possible collisions at the target energy (currently, 3.5 TeV/beam) and integrate luminosity at this energy.

Some collisions at 450 GeV/beam would be welcome, rather early on (two weeks after start-up ?), provided the overhead time to deliver such collisions remains modest (one or two days). These collisions would be useful for further commissioning (or re-commissioning) of the detectors. A few hundred thousand interactions would be enough. The rate should be at least 20 Hz per IP to avoid unnecessary overhead for luminosity optimisation. Such a rate is exceeded with 2x2 bunches each with $3 \cdot 10^{10}$ p (or 4x4 bunches each with $2 \cdot 10^{10}$ p).

The ALICE Collaboration expressed interest in collecting as well a few 10^7 events in both a short "Tevatron-energy" run (i.e. pp at 1 TeV/beam) and at the NN-equivalent in PbPb at 3.5TeV/beam (i.e pp at 1.5 TeV/beam). Planning such runs (if possible at all) will strongly depend on the overhead effort required to set up the machine at a different flat top energy.

Finally, worth to be reminded that the LHCb VELO (Vertex Locator) cannot be fully closed if the beam energy is below ~ 2 TeV/beam (assuming no squeeze and no correction for the internal angle due to the dipole).

Luminosity, squeeze, pile-up

In order to make a realistic scenario for the 2010-2011 run, one needs to consider the target of 1fb^{-1} integrated luminosity per IP by the end of 2011 and assume some value for the run efficiency. In 2009, a "machine availability" of about 60% was achieved [4]. An inter-physics time of 3 to 5 hours seems feasible, see Ref. [5]. Assuming a beam life time of 10 hours (which, given the observations made in 2009, seems conservative, but not unrealistic) one obtains a "turn-around reduction factor" between 30 and 40%. A simple calculation yields the following target figure for the LHC machine:

To deliver 1fb^{-1}by end of 2011 a peak luminosity is needed of around $\mathbf{2 \cdot 10^{32}\ cm^{-2}s^{-1}}$ for a run of about **10 months**.

This sets a clear target (and a tough challenge!) for the machine performance at the end of 2010.

The strategy to reach the optics and beam parameters required for producing such a luminosity is now being discussed. A good balance between luminosity increase, machine protection and operational experience needs to be found. In addition, the 2010 plan will include a Heavy Ion period of about 1 month.

For ATLAS and CMS, the highest possible luminosity should be aimed at. Expected pile-up values for 2010-2011 ($\mu < 3$) are no problem at all. Here, we use $\mu = 80\ \text{mb} \cdot N^2/(4\pi\sigma^2)$, with N the bunch population and σ the transverse beam size.

Best conditions for LHCb are obtained with a few 10^{32} cm^{-2}s^{-1} at minimum pile-up[1].

During pp running, ALICE will collect data at a luminosity of 10^{29} cm^{-2}s^{-1} (for minimum bias physics), and at a maximum luminosity of approximately $5 \cdot 10^{30}$ cm^{-2}s^{-1} (for rare processes). Therefore the 2010 pp run is of particular importance for the physics programme of ALICE,

[1] Pile-up becomes a worry when the average number of visible interactions per bunch crossing exceeds ~ 1, although the performance degradation is expected to be gradual and only experience with real data will tell what pile-up is actually acceptable.

as these luminosities can be more easily and naturally provided than in later years. Optimal conditions for ALICE are a large number of colliding pairs with small pile-up ($\mu < 0.05$) and a small transverse size of the luminous region ($\sigma_{x,y}$ less than $\sim 50\ \mu$m), such that the beam axis can be used as a vertex constraint for the measurement of heavy flavor production.

Bunch filling schemes

One of the challenges will be to provide maximum luminosity to ATLAS and CMS while simultaneously satisfying the specific requirements of ALICE (IP2) and LHCb (IP8). As mentioned previously, the optimal pp luminosity for ALICE is about $10^{29}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and the maximum is about $5 \cdot 10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. The highest possible peak luminosity is required for LHCb, like for ATLAS and CMS, until it reaches approximately $5 \cdot 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. At this point, minimum pile-up is preferable for LHCb, while keeping such a luminosity level. New filling schemes have been proposed to optimize the collision patterns for these luminosity requirements [6, 7].

For the proton filling schemes, two important differences arise with the reduction of the target energy from 5 to 3.5 TeV/beam. Firstly, the expected maximum beam intensity limit from cleaning inefficiency is increased from $2 \cdot 10^{13}$ to $6.5 \cdot 10^{13}$ (for "intermediate" collimator settings), see Ref. [8]. Secondly, the luminosity reach without (external) crossing angle, i.e. with maximum 156x156 collision pattern, falls from $\sim 1.2 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (at 5 TeV/beam) to $\sim 6 \cdot 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (at 3.5 TeV/beam), mostly due to the expected reach in beam cross section area $\sigma_x \sigma_y \propto \epsilon\beta^*$ which scales like γ^{-2} at fixed normalised transverse emittance.

For 5 TeV/beam, the 156x156 scheme represented an interesting intermediate target (on the way to bunch trains), possibly allowing luminosities *in excess* of $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ while already approaching the expected intensity limit. This is no longer valid for 3.5 TeV/beam. Therefore, for the 2010 run it is proposed to skip from the 43x43 equidistant scheme straight to a truncated 50 ns scheme with crossing angle, which has the potential to bring luminosities beyond $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. This would also immediately double the number of collisions at IP8 (the currently proposed 43x43 and 156x156 equidistant bunch schemes deliver less than half the number of colliding pairs to IP8 as compared to IP1 and IP5).

Optimal conditions for ALICE are a large number of colliding pairs with small pile-up and a small transverse size of the luminous region. The bunches should be spaced by at least 100 ns. It has been proposed to inject dedicated bunches for IP2. Best conditions for ALICE require filling the LHC with bunches (or bunch trains) characterized by a different spacing and different population as the main bunches (which collide in the other IPs). An injector MD was requested (to be planned for early 2010?) to prepare for such an option. However, utilization of this option will be subject to an assessment of the consequences for LHC operation. Furthermore, the possibility to use the same bunch charge as the main bunches, with squeezed beams in IP2 and transversely offset beams, should also be explored.

NB: IP2 and IP8 will generally see non-colliding pairs. This is not a priori true for IP1 and IP5 (for the baseline filling schemes). ATLAS, CMS, LHCf and TOTEM would like to keep the option (for 2010/2011) to have 1 or 2 non-colliding bunches for background monitoring.

The experiments are also interested in taking some data with 25 ns bunch crossing, at the end of the 50 ns run period, in order to prepare the road for nominal conditions. In view of the long shutdown after the 2010-2011 runs, such a brief exploration will be important.

Spectrometer magnets

The ATLAS and CMS solenoids will be operated at nominal field, independent of the beam energy, and using a fixed polarity. (The ATLAS toroids have no effect on the beams). For the time being, and until further notice, these magnets are solely operated from the respective experiment Control Rooms. The magnets should (a-priori) always stay on during machine operation, unless otherwise required by the machine. It is reminded that the CMS and ATLAS magnets are large superconducting devices with ramp time of the order of 2 to 4 hours [9, 10].

To reduce systematics uncertainties, the ALICE and LHCb Collaborations wish to collect physics data with the two spectrometer polarities. For LHCb, one of the dipole polarities, $\oplus$, is problematic with 3.5 TeV/beam *and* non-zero external crossing angle [11]. On the contrary, with zero external angle (i.e. bunch spacing larger than 500 ns), both polarities are equally achievable at any beam energy. Therefore, it is proposed to utilize the early physics periods to collect physics data with both polarities. Furthermore, cycling the LHCb magnet should be reduced to the minimum needed, e.g. by keeping the magnet always on (no ramping) or by ramping down (if absolutely needed) to an intermediate value of the current, rather than to zero. During LHC operation, the ALICE dipole and solenoid and the LHCb dipole are operated from the CCC.

For the forthcoming run, the desiderata from LHCb and ALICE are as follows.
LHCb:

- start with $\ominus$ polarity, keep always at full field (i.e. no cycling/ramping),
- while still $\alpha_{\mathrm{ext}} = 0$, reverse polarity between fills (a couple of times),
- rather early on: a short run with zero field at 3.5 TeV/beam,
- when arriving at $\alpha_{\mathrm{ext}} \neq 0$, start with $\ominus$ polarity,
- later in 2010, possible request to introduce the $\oplus$ polarity with $\alpha_{\mathrm{ext}} \neq 0$, which would require an MD (this request will depend on data analysis results).

ALICE:

- use always the same relative polarity for dipole and solenoid (both $\ominus$, both $\oplus$ or both off),
- start with $\ominus$ polarities, keep always at full field (i.e. no cycling/ramping),
- reverse polarities about once per month (or less frequent),
- rather early on: a short run with both magnets off at any energy, but such that about 10k muons can be recorded in the muon system (the rate is about 1 muon per 300 minimum bias events at 450 GeV; hence, the sample can be taken in about 8 hours as soon as a minimum bias rate of more than 50 Hz can be delivered).

Special requests

At the start of beam operation, "splash events" (produced by stopping the beam at injection on the tertiary collimators or on the TI2/8 TED blocks, or by sending the beam through the beam screens) are generally considered as a useful step for setting up and debugging the detector (time and space alignment, muon rates, etc.). Typically, 10-30 (100-300) probe bunch splashes on each TCT (on each TED) are sufficient.

At some point, ALICE would like to perform a "stress test" of its detector (in particular the TPC) with a higher than currently foreseen 1-turn pile-up, for example with a special fill during the 43x43 phase with a luminosity of a few $10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$.

TOTEM

The T2 detectors are installed on both sides. One side was commissioned with beam in 2009. One arm of the T1 telescope is ready for installation while the second is waiting for commissioning in the SPS test beam line H8 in spring. Both telescopes should be installed in the same shutdown which would require a stop of the order of two months. All twelve RP220 detectors are in the machine. A first test of the RP220 motion with circulating beam was carried out in the LHC in 2009 [12]. More such tests will be required in 2010, in particular at 3.5 TeV/beam. The RP147 detectors are being prepared.

TOTEM will operate under all running conditions. However, for an important part of the TOTEM physics programme, for instance the luminosity-independent measurement of the total cross-section, special beam optics with high β^* are mandatory. As soon as technically feasible, TOTEM will request a dedicated run with the $\beta^* = 90$ m optics (possibly reached by gradual defocussing from $\beta^* =$ 2 m to higher values). This would allow TOTEM to carry out a first measurement of the total pp cross section with the Optical Theorem.

LHCf

The proposal for the 2010 run is to allow LHCf to carry out a complete set of measurements at $\sqrt{s} = 7$ TeV and, when the dose taken by the detector approaches 1 kGy (corresponding to about $2\ \mathrm{pb}^{-1}$ with the detector in the physics position), to replace the LHCf detectors with the ATLAS ZDC electromagnetic modules. This could be arranged at the first subsequent technical stop (~ 5 hours to remove LHCf on both sides and ~ 9 hours to both remove LHCf and install the ATLAS electromagnetic modules).

To obtain a complete data set, LHCf will collect events in three different vertical positions, without and with[2] crossing angle. The needed integrated luminosity per configuration is about $6\ \mathrm{nb}^{-1}$. Optimal running conditions for LHCf are obtained with a bunch spacing of at least 2 μs (like in the 43x43 scheme) and a luminosity of about $10^{29}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, while pile-up should stay small: $\mu < 0.5$ at 3.5 TeV/beam (hence, a luminosity per bunch pair of $< 7 \cdot 10^{28}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$). These conditions can be achieved early on, for example in a 4x4 scheme with 2 colliding pairs of $3.5 \cdot 10^{10}\ p$ per bunch at $\beta^* = 2$ m, or $8 \cdot 10^{10}\ p$ per bunch at $\beta^* = 11$ m. The data taking time is of the order of 16 hours per LHCf detector position.

Worth to remind that the LHCf collaboration intends to re-install detectors in IR1 at a later time in order to take data at other center-of-mass energies.

SPECIFIC REQUIREMENTS FOR STOPS

The experiments have no specific technical stop requirements, in the sense that they can work in line with the needs of the LHC machine and injector (a 3-day stop about every month). For instance, the replacement of the LHCf detectors by the ATLAS ZDC electromagnetic modules can fit during one of the foreseen 3-day stops. The installation of Roman Pots in the 147 m location can be started during any technical stop in summer 2010 and completed in the Christmas stop at the end of 2010.

Installation of the two TOTEM T1 telescopes requires a stop of the order of two months.

For ALICE, a shutdown longer than at least three months would open up the possibility of opening the L3 magnet to install additional TRD and EMCAL modules.

For longer shutdowns, it is worth to note that, for ATLAS, opening the detector is not possible (not efficient) if the shutdown lasts for less than 4 months (the detector stays on standby). If the shutdown lasts for more than 4 months, the detector can be opened and many more interventions can be planned.

CONCLUDING REMARKS AND SUMMARY

The LHC experiments are ready to restart in 2010. They support the scenario of a long (18 months) run period with a short technical stop at the end of 2010, with the hope of obtaining approximately $1\ \mathrm{fb}^{-1}$ at $\sqrt{s} = 7$ TeV. A heavy

[2] The crossing angle must be such that the momentum resultant of the two beams points downward.

ion run with ‘early’ beams at the end of 2010 would allow to carry out first heavy ion physics.

ACKNOWLEDGMENTS

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