The SLHC prospects at ATLAS and CMS

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Abstract. The LHC will start pp collisions at 14 TeV in 2008. The luminosity will ramp up to the design goal of $10^{34}$ cm$^{-2}$s$^{-1}$ over the next few years. After several years data taking at design luminosity, an upgrade of the LHC is being considered, in several stages, which would increase the luminosity by a factor of ten. The increased statistics would extend significantly the physics potential of the LHC. The ATLAS and CMS detectors must be upgraded to cope with the very high pile-up rates and radiation levels to take advantage of the SLHC. This talk summarises the physics goals, SLHC machine plans, and the needs of ATLAS and CMS to adapt to the unprecedented pile-up and radiation levels.

1. Introduction
The ATLAS and CMS experiments are preparing for first pp collisions at 14 TeV in 2008, and the luminosity will ramp up to the design goal of $10^{34}$ cm$^{-2}$s$^{-1}$ over the next few years. This will continue until around 2015-2016 when the lifetime of parts of the machine and experiments are expected to be reached due to radiation damage. On this timescale, a proposal to extend the physics potential of the LHC with a major luminosity upgrade (SLHC) has been endorsed by the CERN council strategy group [1]. The goal is a factor ten increase in luminosity. While completion and exploitation of the LHC remains highest priority, the long lead times involved in such an upgrade require that this work starts well in advance.

2. Physics motivation
The increased physics potential of a luminosity upgrade can be divided into three areas\textsuperscript{1}.

(i) Extending the mass reach, due to the increased statistics of high-$x$ parton interactions. Heavy multi-TeV particles appear in many extensions of the Standard Model (SM), for example; extra gauge-bosons, resonances in extra-dimension models, heavy SUSY particles. For the case of the heavy gauge-boson $Z'$ an increased mass reach of $\sim$1TeV is gained.

(ii) Improved precision of measurements, especially in looking for deviations from the SM. For example, measurement of anomalous triple gauge-boson couplings (TGCs) provides a powerful test of the non-Abelian structure of the SM. A tenfold increase in statistics will provide typically a factor of $\sim$2 improvement in precision. In addition, should physics beyond the SM be discovered at the LHC, then there will be strong motivation to measure as precisely as possible the parameters of the new physics.

\textsuperscript{1} Examples taken from [2].
(iii) Increased sensitivity to rare processes. For example, the decay of top quarks induced by flavour changing neutral currents (FCNCs) is suppressed in the SM (forbidden at the tree level). However a large class of theories beyond the SM predict much higher branching ratios for these decays, but which would be still at the limit of LHC sensitivity.

3. Machine upgrade
Upgrading the LHC to increase the luminosity by a factor of ten will be challenging and the implications are still being investigated [3]. A two phase scenario is being explored. The first stage would aim to push to the ultimate luminosity of \(2.3 \times 10^{34}\ \text{cm}^{-2}\text{s}^{-1}\). This would be facilitated with the replacement of the inner triplet focusing magnets. This would have minimal impact on the experiments and could be implemented well in advance of the full upgrade. The second phase would aim to reach \(10^{35}\ \text{cm}^{-2}\text{s}^{-1}\). Two scenarios are being considered.

(i) Improved beam focusing (ie reducing the \(\beta^*\)), based on early separation of the proton beams. This would require positioning dipole magnets closer to the interaction point, deep inside the experiments. In this scenario a bunch spacing of either 25 ns or 50 ns is possible. However, it is not clear if the integration of machine elements within the experiments is feasible and studies are currently underway to assess the implications.

(ii) Increasing the beam currents, which has the advantage of not requiring beam magnets inside the experiments. The disadvantage is that this would be more demanding on the machine, with consequences for beam dynamics, machine-protection, radiation protection and beam injection. In this scenario only 50 ns bunch spacing is possible.

It has been established that reducing the LHC bunch spacing to below 25 ns is not possible due to beam heating effects. A consequence of this is that the number of pp interactions in a bunch crossing becomes very high, 300 – 400 compared with \(~25\) at the LHC. The 25 ns scenario results in greater peak luminosity, but because of its shorter lifetime, the average luminosity is similar to the 50 ns case. Ideas of “luminosity levelling” are being explored which would dynamically vary the luminosity to produce a more constant luminosity [3]. For physics measurements what is important is not the peak luminosity but the time integrated luminosity.

4. Experiment upgrades
The most significant upgrade for both ATLAS and CMS will be the replacement of the inner tracker systems, which will be showing signs of serious radiation damage by ~2016. In addition to issues of radiation hardness, the new trackers will have also to be redesigned to handle the increased occupancy rates. This will mean using more detector channels to maintain good pattern recognition performance, but without exceeding the limited power and material budgets. Simulations are underway to investigate the performance of different tracker layouts [4].

The bulk of the tracker will be silicon planar technology. Silicon \(n\text{-in-}p\) is favoured compared with \(p\text{-in-}n\) because it can operate partially depleted, avoiding the need for very high bias-voltages. For the inner layers (excluding the innermost b-layer) silicon pixel detectors \((n\text{-in-}p)\) are favoured. For the innermost b-layer the levels of radiation background are so high that new technology is required. The current favourites are 3D silicon and Diamond, but other options are being considered such as micromegas and thin Si planar (for an overview see [5]).

Beyond the inner tracker upgrade concerns become detector specific. In general, all aspects of an experiment need to be considered: detectors, electronics, powering, cooling, engineering, readout, data-acquisition, trigger, computing and physics. Most of the ATLAS and CMS calorimetry should be robust against the increased radiation backgrounds, although R&D is required in some areas. The ATLAS forward calorimeter may need upgrading due to possible beam heating of the LAr. If its functionality is compromised then drastic solutions such as a new warm forward calorimeter in front of the existing one may have to be considered. For CMS
there are concerns that the hadronic calorimeter scintillator may suffer radiation damage in the forward regions.

For the ALAS muon system, the level of required upgrade is not clear because there are large uncertainties in the predictions of the radiation backgrounds at the LHC. A safety factor of five was included in the design. If the predictions are accurate it is estimated that only parts of forward chambers would need to be replaced with chambers of higher rate capability. However, if the background predictions are underestimated by a factor of five then most of the chambers would have to be replaced. Therefore, experience with running at the LHC is required. For CMS, the muon system is expected to be quite robust, although some of the electronics may require changing due to radiation damage. It is also likely that CMS will have to upgrade its Level 1 trigger because there will not be enough rejection power using the existing muon and calorimeter triggers to handle the higher luminosity conditions at the SLHC. A possible but challenging solution being investigated is to add tracking information at Level 1 [6].

5. Conclusions
The implications of a major luminosity upgrade sometime around 2016 are being studied by the LHC machine and experiments. A factor of ten increase in luminosity will extend significantly the physics potential, although the detailed case will be known better with LHC data. The main priority is the completion and exploitation of the LHC.

The machine upgrade is likely to happen in several stages. Two scenarios are being considered for reaching the luminosity goal of $10^{35} \text{cm}^{-2} \text{s}^{-1}$; one is based on early separation of the beams and improved focusing while the other is based on increasing beam currents. The original proposal of 12.5 ns is no longer being considered due to beam heating effects, leaving the options of 25 ns and 50 ns which will vastly increase pile-up compared with the LHC.

Because of radiation damage and increasing particle occupancies, both ATLAS and CMS will require new inner trackers. Simulations and layout studies are currently underway. The impact on detectors, electronics, engineering, readout, powering, cooling, data-acquisition, trigger, computing and physics are being considered. The ATLAS forward calorimeter may need upgrading, as well as parts of the muon system. CMS will need to revise its Level 1 trigger strategy. A better understanding of the upgrade requirements for ATLAS and CMS will be gained from running at the LHC.

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[1] See strategy statement in: http://council-strategygroup.web.cern.ch/council-strategygroup/
[2] Gianotti et al., 2005, Eur. Phys. J. C 39 293
[3] Talk by J-P. Koutchouk, June 2007, http://hep.ph.liv.ac.uk/~burdin/slhc20070627/
[4] See for example: http://www-pnp.physics.ox.ac.uk/~tseng/slhc/
[5] Talk by C. Da Via, June 2007, http://hep.ph.liv.ac.uk/~burdin/slhc20070627/
[6] C. Foudas et al., 2005, arXiv:physics/0510227