CMS Upgrades for SLHC

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Abstract

I will discuss the impact of the LHC luminosity upgrade on CMS detector. While most of the CMS can possibly cope with the increased luminosity, the Tracker must undergo a major redesign in technology both in terms of detector substrates as well as in the data transfer links. I will show the impact on CMS of reduced bunch length and machine elements close to the interaction point.

INTRODUCTION

The CMS detector at the LHC is a general purpose Collider detector. The momentum of charged particles is measured using a silicon tracker detector in a 4T magnetic field and their energies using electromagnetic (ECAL) and hadronic (HCAL) calorimeters. A muon system surrounds the detector. The design of the different subdetectors of CMS has been carefully studied in order to match the LHC running conditions, both in terms of the collision frequency as well regarding the harsh radiation environment, The R&D studies for the several detector components have been carried out in the time scale of a decade before starting the final construction and assembly.

The foreseen LHC upgrade (also known as SLHC), which is meant to provide an order of magnitude increase in the delivered luminosity, implies a general revision of the CMS detector to cope with the increased radiation levels and the (possible) increased frequency of the collisions.

The CMS Collaboration has carried out three workshops on the subject in the past two years[1]. The main point which has emerged from the discussions is that most of the CMS systems will survive and continue to operate without changes to inaccessible electronic systems, even if that will have constraints on the future machine operation. The major exceptions is represented by the Tracker which is expected to be entirely replaced for SLHC, due to the increased radiation, and the Trigger that has to rebuild the Level-1 processors. In addition there is a strong belief that the Tracker information must be taken into account already at the Level-1 trigger decision.

The paper is organised as follow. In Section I will briefely explain the implications of the increased radiation levels for the different CMS subdetectors. In Section I will address the impact of possible machine operations choices on CMS functioning at SLHC.

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RADIATION ENVIRONMENT

The harsh radiation environment of SLHC is shown in Table 1 which illustrates the expected dose and fluencies for the current CMS Tracking detectors at an integrated luminosity of 2500 fb^{-1}.

The current pixel detector can sustain about 3 $\times 10^{15}$ cm^{-2} fluencies. In addition, the increased track multiplicity per bunch crossing would increase by an order of magnitude, resulting in an unacceptable hit occupancy in the current detectors, compromising the tracking capability of CMS at SLHC. Also the cumulative damage (such as TID and NIEL) would increase by a factor of five.

It is therefore needed to replace the current Tracker of CMS with a more radiation tolerant and higher granularity system. The R& D of new sensor material technology is the goal of the RD50 Collaboration [2].

Table 1: Fluxes and doses at SLHC for 2500 fb^{-1} integrated luminosity at different radii, corresponding to the current positions of the pixel and silicon strip tracker detectors. Figures from M. Huhtinen talk at CMS SLHC workshop February 2004.

Pixel	4 cm	fast hadrons Dose	1.6 $\times 10^{16}$ cm^{-2} 4.2 MGy
Pixel	11 cm	fast hadrons Dose	2.3 $\times 10^{15}$ cm^{-2} 0.94 MGy
Strip	22 cm	fast hadrons Dose	8 $\times 10^{14}$ cm^{-2} 350 kGy
Strips	75 cm	fast hadrons Dose	1.5 $\times 10^{14}$ cm^{-2} 35 kGy
Strips	115 cm	fast hadrons Dose	1 $\times 10^{14}$ cm^{-2} 9.3 kGy

The description of a possible new Tracker layout goes beyond the scope of this report and is not given here. However is worth mentioning that CMS considers that the new Tracker will play an important role at the lowest Trigger level, participating actively to select, already at Level 1, interesting events from the QCD background. The new CMS Tracker will therefore be build according the above requirements.

The large radiation environment will also affect the run of the Electromagnetic Calorimeter (ECAL) in two respects. The first is due to the activation of the supercrystal electronics which are located in the end caps. The dose rate at pseudorapidity $\eta = 1.48$ (outer ECAL radius) is 0.2

mSv/h, while the one at $\eta = 3$ (inner ECAL radius) is 5 mSv/h. The high activation levels will therefore restrict the access time for human intervention on the electronics in case of needs. The second aspect of the large radiation increase at SLHC compared to LHC is the formation of color centres in the crystals, which will reduce the collected light yield. The dose in the ECAL end caps will vary from 0.1 to 1 MGy for 2500 fb^{-1} integrated luminosity. It is therefore under study whether the reduced light yield would need the ECAL end caps replacement with a different technology.

Also the very forward Hadron Calorimeter which extends up to $\eta = 5$ will need to have revised.

The Muon system of CMS will also suffer from the hostile cavern background, especially for the outermost muon chambers, where a better shielding is needed in order to operate at SLHC.

Finally, part of the Trigger Electronics located on the subdetectors the radiation damage, and eventually be replaced.

IMPACT OF THE MACHINE LAYOUT ON CMS RUNNING

Apart from the above mentioned subdetector upgrades or shielding, the impact of the SLHC on the CMS running is mainly visible in the Electronics, the Trigger and the Data Acquisition Systems.

The increased occupancy will degrade the performance of the algorithms, as well as increasing the event size to be read out. The First Level Trigger rates output should not exceed the 100KHz limit in order to avoid rebuilding the front end electronics where possible. It is believed that in order to match the above mentioned requirements CMS should develop a Trackeer Level 1 Trigger, and possibly export some of the Higher Level Trigger algorithms to Level 1.

The DAQ system will be a multi-Terabit/s network congestion free and scalable.

I will discuss now the impact of different machine layouts on CMS running.

Beam Pipe and forward shieldings

The current Beryllium beam pipe at the interaction point, whose diameter is 58 mm is not foreseen to be replaced. However the forward beam pipe diameter could increase up to 400 mm after the Hadron Forward Calorimeter and its shadow, since the TOTEM and CASTOR calorimeters will not be present.

In view of a better shielding in the very forward region, where the TAS is located, it will be needed to reinforce the rotating system which is near the limits of mechanical strengths. A new concept or supplementary system is needed.

Bunch spacing

A SLHC bunch spacing not multiple of 12.5 ns would have severe consequences for CMS Electronics. In fact at 12.5 ns many of the ECAL, HCAL and Muon front end electronics would remain; however for a 10 or 15 ns spacing CMS will need to rebuild most of this electronics. A cost review must be put in place to have the correct figure, but it is envisaged that the cost could easily exceed several hundreds Million Euros.

It is therefore highly beneficial for CMS to define at this stage the bunch spacing with one or two possible scenarios, which would offer a solid starting point for R&D and cost/benefits estimate.

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Any elements of the machine inside CMS will have conseqences in the forward detectors and need to be studied and evaluated once having in hand a proposal from the machine group. CMS would be able to accomodate some elements, but would clearly depend on the layout proposed.A possible location at around 20 meters from the interaction point might fit well with CMS. A re-design of the forward shielding will be needed and due to a probable increased sensitivity to beam accidents a super Beam Control Monitor will be needed. Of course it would be extremely beneficial the experience gained in running the LHC.

Maintenance

The increased activation will seriously affect the maintenance of the detector. In particular, as shown above, any worker working at the Tracker end-flange should not integrate more than 10 hours, while working at the ECAL end caps he/she will receive in one hour the one year allowed dose of 5mSv.

In addition, all those subdetectors which will not be replaced for SLHC must be very reliable by then, and is not excluded that some systems will reveal themselves be less radiation tolerant than expected and therefore need either maintenance or replacement. All interventions needed to access the detector will result in a integrated luminosity loss.

Finally, not all changes can be made in a single shutdown. Installing the new shielding might be in conflict with some new detector installation. It is envisaged that one or more extended shutdowns will be needed.

Additional delay will result from the commissioning of the new detectors. At the same time, the machine itself will probably need some understanding and would therefore not result in a total loss of time.

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REFERENCES

[1] Feb 2004 http://agenda.cern.ch/fullAgenda.php?ida=a036368 on the General startup; July 2004 http://agenda.cern.ch/fullAgenda.php?ida=a041379 mostly addressing the Tracker, Trigger and Electronics; July 2005 http://agenda.cern.ch/fullAgenda.php?ida=a053123 focusing on Trigger and Tracker upgrades

[2] RD50 Collaboration, rd50.web.cern.ch/rd50/