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Upgrade of the Tracking and Trigger System ATLAS and CMS

Fabrizio Parodi[*†]
Genoa University and INFN
E-mail: Fabrizio.Parodi@ge.infn.it

While the Large Hadron Collider (LHC) has started to record collisions in late 2009, plans are already advancing for an upgrade. The super-LHC (sLHC) project aims at ten times the LHC luminosity. Coping with the high instantaneous and integrated luminosity will require many changes to the ATLAS and CMS detectors. This paper summarizes the plans to upgrade the inner trackers and the trigger system.

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[*]Speaker.
[†]On behalf of the ATLAS and CMS collaborations.

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1. Introduction

The Large Hadron Collider (LHC), yielding proton-proton collisions, has just started up with collisions at 900 GeV in the autumn 2009. During 2010 and 2011 each of the two experiment is planning to accumulate about 1-2 fb^{-1} of collision data at 7 TeV. After this data taking period a long shutdown is foreseen to bring the center of mass energy to 14 TeV.

ATLAS and CMS [1, 2] are general-purpose detectors covering a wide variety of physics at LHC. In the first years running of LHC these two experiments will have the opportunity to discover the Higgs boson and part of the supersymmetric spectrum but to establish TeV scale physics after first discoveries, it will be necessary to make precision measurements of the discovered new phenomena, and also to extend and continue searches for new phenomena that have low rate or higher mass scale.

The planned upgrade of the LHC to fulfill this program (called super-LHC, sLHC) aims to achieve a luminosity of 10^{35} $cm^{-2}s^{-1}$, ten-times higher than the original design. This project is planned in two phases.

In the first phase (Phase-1) the target luminosity is $3 \cdot 10^{34}$ $cm^{-2}s^{-1}$. During a winter shutdown is foreseen to upgrade the Linac2 injector to Linac4 and also to upgrade the interaction region (IR) by installing new larger-aperture focusing-quadrupoles which will allow to reduce the beam size. Few hundreds fb^{-1} of luminosity will be collected by the end of the Phase-1.

Then, the LHC upgrade will enter in the second phase (Phase-2). A long shutdown of about 16 months will be devoted to this upgrade. Installation of new injectors and upgrades of IR are anticipated. The goal of the experiments in the Phase-2 is to collect data of about few thousands fb^{-1} of luminosity.

The ten-fold increase in luminosity will however give many challenges to the experiments. The number of minimum bias events per bunch-crossing will reach about 400 events overlaid on each other. The high occupancy in the tracking detectors may degrade the performance. And the detectors and front-end (FE) electronics will sustain a significantly increased radiation dose. Both ATLAS and CMS are planning to re-design the inner tracker and adapt the trigger and DAQ systems to handle the higher event rate.

2. Detectors upgrade: phase I

The ATLAS and CMS detectors have been designed for the original LHC peak luminosity of $10^{34}cm^{-2}s^{-1}$, and studies have been undertaken in order to understand whether all subsystems would perform optimally with the three-fold luminosity increase expected for Phase-1.

In particular, the performance of the innermost layer of the tracking system, part of the Pixel system, is expected to start degrading beyond $10^{34}cm^{-2}s^{-1}$, and 700 pb^{-1} of peak and integrated luminosity, respectively. Both parameters will be exceeded in the Phase-1 of LHC, and programs to substitute (part of) the pixel detector are underway.

2.1 ATLAS pixel detector upgrade for phase I

ATLAS is planning to install a new innermost pixel layer, the Insertable B- Layer (IBL). The inner radius of the new detector will be at about 3.2 cm from the beam axis. The new detector project includes new chip design to increase the live area of the footprint, improved sensor radiation hardness, development of new local support structure with carbon-carbon foams to reduce material budget.

Studies on the impact of the insertion of the new layer on b-tagging performance showed that degradation due to the choice of keeping in place the old B-Layer in place is minimal.

2.2 CMS pixel detector upgrade for phase I

CMS will substitute the full pixel detector on phase I, the new detector will be composed of four barrel layers (at 3.9, 6.8, 10.9, 16.0 cm radius) and three disks per side.

A number of technological improvements are under evaluation. These include a new lightweight mechanical support structure; evaporative CO_2 cooling (allowing material reduction); upgrade of the front-end chip; shift part of material away from central region using long pigtails for barrel modules. Novel powering and readout schemes are required because the upgraded detector will contain twice the number of readout chips.

3. Detectors upgrade: phase II

The challenges of operating a detector in a hadron collider at a luminosity of about $10^{35} cm^{-2} s^{-1}$ require a complete re-design of the Inner Trackers to cope with higher track density and radiation dose.

Trigger systems will also need to be updated since the leptonic signatures of the first level trigger (L1) are expected to give high rate, irrespective of the applied p_T threshold (rate of about 20kHz for L1 muon is expected for Phase-2). The use of extra information at L1 (from Inner Trackers) or improved selectivity of the existing L1 muon or L1 calorimeter triggers are needed to keep the L1 trigger rate below the design limit of 100 kHz.

For both experiment the tracker upgrade projects will be presented while the trigger update will be focusing on L1 track trigger for CMS and on the upgrade of L1 muon and L1 calorimeter triggers for ATLAS, even though upgrade projects for all L1 triggers are on-going for both experiments.

3.1 CMS tracker upgrade and L1 track trigger

CMS plans for the upgrade includes an hardware track trigger at L1, hence the design and development of the new Inner Tracker is closely linked to the strategy chosen for this trigger.

The readout of the full tracker within the future trigger latency of 6.4 μs is not possible. To reduce the data volume it has therefore been proposed to identify high-p_T tracks (greater than few GeV) and use only these tracks for the trigger decision.

In the following two different proposals for the identification of high-momentum tracks are presented. A decision on the track trigger concept has not yet been taken.

3.1.1 The Stacked Layers Approach

The idea behind this proposal is to compare hit patterns in closely spaced ("stacked") detection layers, as tracks with large p_T are less bent by the magnetic field than low-p_T tracks, and therefore produce different hit patterns [3]. Pixel detectors are required in this approach, with a pitch of

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the order of 100 μm in the bending plane. The distance between the two sensitive layers in one stack is of the order of 1 mm. The resulting 2-hit track pieces ("stubs") are forwarded to the L1 trigger. Several stacks could be combined to reconstruct "tracklets". The concept is compatible with thin sensors, preferred for their low mass, and provides information in the z-direction as well, as required for primary vertex identification.

3.1.2 The Cluster Width Approach

In the second proposal the discrimination between low and high-momentum tracks is based on the cluster width in a single sensor layer [4], which varies between low and high-p_T tracks due to the bending in the magnetic field. The hit information within a ϕ-slice of the detector is then brought out via high-bandwidth optical links and reconstructed off-detector in powerful FPGAs by comparison with templates. The reconstructed high-p_T tracks are then used in the L1 trigger.

This method works with classical strip modules with a pitch of the order of 100 μm but it is only efficient above a certain sensor thickness d and radial distance r from the beam pipe. In the cluster width approach the provision of precise z information is not foreseen, thus the vertex identification is less exclusive.

3.1.3 Inner Tracker Layout

The two different proposals for L1 track trigger can translate in various choices for the layout (see Fig. 1):

- **Hybrid Layout**: characterized by the combination of a minimalistic trigger configuration, consisting of two stacked layers at 25 and 35 cm radius with a layer separation within a stack of about 2 mm, and a classical 4-layer outer strip tracker;

- **Long Barrel Double-Stack Layout**: in contrast to the Hybrid layout the Long Barrel Double-Stack layout avoids end caps: it consists of three full layers of double-stacks, plus two short layers to improve the acceptance at high η; one such layer corresponds to two stacked layers or four sensor layers; in total there are therefore 12 sensor planes at $\eta = 0$ in this layout; all layers contribute to the trigger decision.

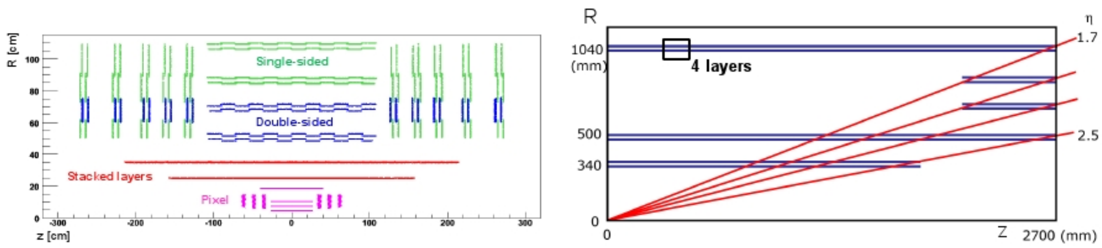

Figure 1: CMS Inner Tracker layout for phase II. Left: *rz*-view of one half of the "Hybrid" tracker layout. Right: *rz*-view of one quarter of the "Long Barrel Double-Stack" tracker layout. The pixel detector is shown only in the left figure.

3.2 ATLAS tracker upgrade and L1 trigger update

In ATLAS the tracker upgrade design has not so far been driven, as in CMS, by the trigger requirements. However, the collaboration is investigating both the hardware solution which will have an impact on the tracker layout and Regions of Interest (RoIs) based solution seeded by a calorimeter or muon trigger at a much higher rate than the present L1 trigger. The RoI solution will have an impact on the trigger architecture of the experiment.

In the following the Inner Tracker upgrade and L1 muon and L1 calorimeter update will be discussed.

3.2.1 ATLAS Inner Tracker for phase II

ATLAS has been built with an inner tracking system formed by three layers of Silicon pixel detector, four double layers of silicon strip detectors, and a Transition Radiation Detector with thin tubes providing tracking and particle identification with $\sim$ 36 hits per track.

An upgrade option being considered is an all-silicon inner tracker. In order to maintain good pattern recognition performance, the granularity is being optimized to keep the hit occupancy less than 1%. At the same time, efforts are underway to minimize the amount of materials by investigating technologies for powering, construction techniques etc. Simulation studies are in progress to define the layout. Fig. 2 shows the "strawman" layout which has been set as a starting point for evaluating the performance of different layout options. In the central region it has four pixel layers, three layers with short strips and two layers of long strips.

3.2.2 Pixels

In the strawman layout, the inner-most layer (called B-layer) is at r=5 cm and the outer three layers extend to r=28 cm. The pixel size in the inner two layers is 50 $\mu m \times 200$ μm and twice as long in the outer two. New technologies are under investigation for the B-layer which will be put under the most severe radiation condition. Several R&D studies are underway: three-dimensional silicon sensors, thin silicon combined with three-dimensional interconnects, gas over slim silicon pixels (GOSSIP), and diamond semiconductors.

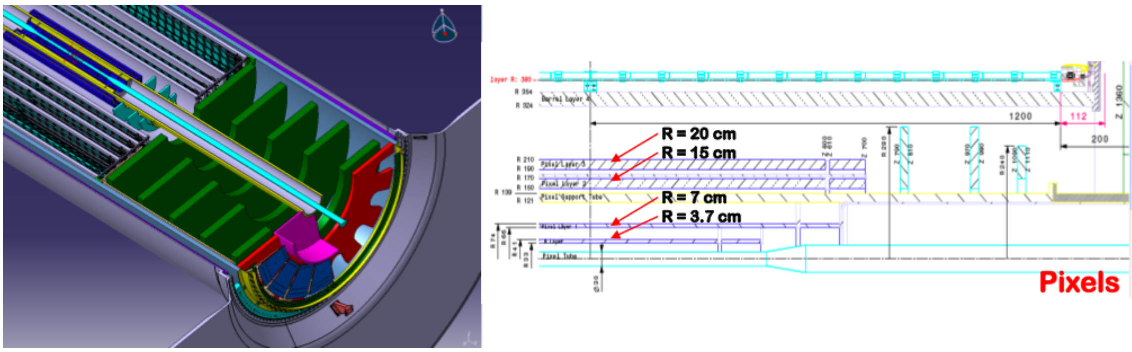

Figure 2: ATLAS Inner Tracker layout for phase II. Left: 3D-view of one half of the tracker layout. Right: rz-view of one quarter of the tracker layout.

3.2.3 Strips

An option being studied is to switch from the current p-in-n sensor technology to the n-in-p sensor technology. The n-in-p sensors are expected to be more radiation hard and also do not require full depletion which may not be achieved at high dose. Also, mechanics and assembly schema are under study. A complete ID system will be constructed to allow a rapid installation.

3.2.4 L1 muon and calorimeter triggers upgrade

Plans for upgrading L1 muon system include the possibility of having, in the barrel region, an extra layer of trigger chambers. In the end-cap region the so called "Small Wheels" (MDT and TGC) will have to be replaced because of the high accumulated dose before the beginning of Phase-2: studies are on-going to understand how new detectors can improve the momentum resolution.

The L1 calorimeter update project is planning to perform digitization on detector and have the full readout at 40 MHz. The access to full granularity will allow to improve the selectivity using: finer calorimeter resolution for feature identification, more sophisticated HLT techniques already at L1, better π^0 and photon conversion rejection using strips of $\Delta\eta = 0.003$ in the first LAr calorimeter sampling.

4. Summary

For sLHC phase-1 upgrade both ATLAS and CMS aim for the exchange (part of) of their pixel detector with a very similar, but larger and improved detector (less material, faster readout). The whole tracker will have to be replaced, in both experiments, for phase-2 together with an important update of the trigger system. The current status of several selected R&D projects has been presented. Several options exist and must be explored further until convergence can be reached, on the basis of the main physics performance requirements.

References

[1] ATLAS Coll., JINST **3** (2008) S08003.

[2] CMS Coll., JINST **3** (2008) S08004.

[3] J. Jones et al., A Pixel Detector for Level-1 Triggering at SLHC, CERN 2005-011 (2005).

[4] G. Barbagli, F. Palla and G. Parrini, Track Momentum Discrimination Using Cluster Width in Silicon Strip Sensors for SLHC, CERN-2007-007 (2007).

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