1. INTRODUCTION

The Large Hadron Collider (LHC) at CERN will collide two proton beams with a center-of-mass energy of 14 TeV (7 times the energy of the Tevatrons proton-antiproton collisions) at a design luminosity of $10^{34}$ cm$^{-2}$s$^{-1}$ ($\approx$ 100 times that of the Tevatron). The machine is expected to lead to the discovery of the Higgs boson, the last missing block of the standard model of particle and interactions (SM) and of new particles predicted by theories going beyond the standard model that should be produced at these energies.

The first particle beams are expected to be injected in September 2008. Currently all the LHC magnets have been installed and every sector has reached the operating temperature of 1.8 K. The initial collision energy will be around 10 TeV to facilitate the startup. The full commissioning to 14 TeV is expected to take place after the winter shutdown. During the 10 TeV commissioning there will be few colliding counter-rotating pairs of proton bunches. The bunch crossing time will be 75 ns and the number of proton bunches will be gradually increased from 43 to 156. The luminosity is expected to be between $10^{29}$ cm$^{-2}$s$^{-1}$ and $2 \times 10^{31}$ cm$^{-2}$s$^{-1}$. The luminosity ramp up is expected to take several years. It will start by establishing operation with a 25 ns bunch crossing time at 14 TeV. Then the number of bunches will increase from 946 to 2808 yielding a luminosity between up to $1.2 \times 10^{32}$ cm$^{-2}$s$^{-1}$. The luminosity will continue to increase and the machine is expected to reach the design luminosity of $1 \times 10^{34}$ cm$^{-2}$s$^{-1}$ in 2012.

The physics reach of the LHC will be ultimately defined by the integrated luminosity delivered to the experiments. Exploiting the full potential of physics at the LHC, which includes upgrading its luminosity, is the highest priority of the European Strategy for Particle Physics, which was adopted unanimously by the CERN Council in July 2006 [1]. The high scientific priority of this goal was also highly supported by the US Particle Physics Prioritizing Panel (P5) in their may 2008 report [2].

The planned upgrade of the machine aims first, in the so called Phase 1, at providing reliable operation at $2 \times 10^{34}$ cm$^{-2}$s$^{-1}$. A decision to implement further machine upgrades to achieve $1 \times 10^{35}$ cm$^{-2}$s$^{-1}$ will be taken around 2011 once the physics from the LHC data becomes available to guide this choice. This second phase of the upgrade, often called phase 2 or SLHC, is especially challenging both for the machine and the experiments.

Here we discuss the machine plans to increase the LHC luminosity, the physics reach of an upgraded LHC, and the upgrade needed for the ATLAS and CMS experiments not only to cope with the more radiation hard environment but also to maintain or possibly improve their physics capabilities. I will describe the current plans developed by ATLAS and CMS both for Phase 1 and Phase II of the LHC upgrade.
2. MACHINE UPGRADE

The LHC luminosity upgrade plan has been under discussion since 2001. Studies on how to improve the integrated luminosity have found bottlenecks and weaknesses in the proton-injection and accelerator chain. Significant luminosity gains can be obtained by upgrading the injector chain which includes elements built in the 50s. Currently protons are accelerated successively by passing through the Linac 2, the Booster, the PS and the SPS before being injected into the LHC.

The plans for the luminosity upgrade foresee first a phase 1 that will reach a peak luminosity of \(3 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}\). The accelerator changes in the LHC injector proposed for phase include the replacement of Linac 2 with the Linac 4. Currently proton bunches at 50 MeV are injected from Linac 2 into the Booster in a process that dilutes the beam brightness. The Linac 4 will allow acceleration of 160 MeV H\(^-\) particles followed by injection in the Booster using a charge-exchange technique that removes excess electrons. This method will improve beam brightness and increase the luminosity in the LHC. Plans for the new Linac 4 are well advanced and CERN expects the construction of the machine to begin soon. The machine will be ready for commissioning by 2012. This will result in a doubling of peak LHC luminosity. The Phase 1 luminosity upgrade scenario will also include a new interaction region to reduce \(\beta^*\) from 0.5 to 0.25 m. This could also increase the peak luminosity by a factor 2. New focusing triplets based on Nb-Ti superconducting technology are expected to be implemented before the 2013 physics run to achieve this goal. The LHC collimation system and the separation elements near the interaction regions will also be improved to complete phase 1 of the luminosity upgrade.

Phase 2 of the upgrade will require further changes in the LHC injector chain. The Booster and the PS suffer from intensity limitations and have severe reliability problems because of their aging. Current planning foresee extending the energy of Linac 4 to several giga-electron-volts with a new machine called the Low Power Superconducting Proton Linac (LPSPL). This will be followed by a new 50 GeV synchrotron called PS2 which will increase the SPS injection energy and double the proton flux. The PS2 and the LPSPL are entering the R&D and design-optimization stage. A decision for their construction will be taken by 2011. The building of these new injectors could place in parallel with operation of the LHC and they could provide a luminosity between 8 and \(10 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}\) after a one year shutdown in 2017.

The current expectations for the peak and integrated luminosity that will be reached by an upgraded LHC are shown in Table 1.

In phase 1 of the upgrade the machine will continue operations at 25 ns bunch crossing which is the LHC baseline. Several different scenarios for the machine upgrade parameters have been considered to achieve \(1 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}\) in Phase 2. The original baseline foresaw operating at the ultimate bunch intensity of \(1.7 \times 10^{11}\), with 12.5 ns bunch spacing, a crossing angle about 50% larger than nominal, and correspondingly bunches of half the nominal length. The bunches were supposed to be shortened through a combination of higher harmonic rf and reduced longitudinal emittance. This scenario was attractive since it could achieve a luminosity of \(1 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}\) but it was abandoned since the expected heat reaches the maximum cooling capacity of 2.4 W/m per beam.

At the end of 2006 the Physics Opportunities and Future Proton Accelerators (POFPA) Committee recommended a 50 ns and 25 ns as the SLHC baseline and as the backup bunch crossing. The backup scenario with 25 ns bunch spacing is denoted as the early-separation(ES) scenario. The beam is squeezed down to a \(\beta^*\) of 10 cm in CMS and ATLAS. The ES scenario adds early-separation dipoles inside the detectors starting at \(\approx 3\) m from the IP and uses crab cavities. This scenario implies installation of new hardware inside the ATLAS and CMS detectors, as well as the first ever hadron beam crab cavities. The latter gains a factor 2 to 5 in luminosity. While this parameter configuration is less demanding for the injector system modification and it entails in average 300 pile-up event, it also requires the placement of dipole magnets adjacent to the inner detectors, which impose severe constraints for the detector upgrade. In the 50 ns scenario, which is often denoted as the large Piwinski angle (LPA) scenario longer, longitudinally flat, and more intense bunches are collided with a large Piwinski angle. The beta function at the interaction is reduced by a more moderate factor to a \(\beta^*\) of 25 cm. This scenario does not require accelerator elements inside the detector. Challenges are the operation with large Piwinski angle, which is still unproven for
Table I: Peak and integrated luminosity expected between 2009 and 2025 with and without the phase 2 upgrade.

| Year | With Phase 2 | | Without Phase 2 | |
|------|--------------|------|------------------|------|
|      | Peak L \(10^{34}\text{cm}^{-2}\text{s}^{-1}\) | Integrated L fb\(^{-1}\) | Peak L \(10^{34}\text{cm}^{-2}\text{s}^{-1}\) | Integrated L fb\(^{-1}\) |
| 2009 | 0.1          | 6    | 0.1              | 6    |
| 2010 | 0.2          | 18   | 0.2              | 18   |
| 2011 | 0.5          | 48   | 0.5              | 48   |
| 2012 | 1            | 108  | 1                | 108  |
| 2013 | 1.5          | 198  | 1.5              | 198  |
| 2014 | 2            | 318  | 2                | 318  |
| 2015 | 2.5          | 468  | 2.5              | 468  |
| 2016 | 3            | 648  | 3                | 648  |
| 2017 | 3            | 648  | 3                | 648  |
| 2018 | 5            | 948  | 3                | 828  |
| 2019 | 8            | 1428 | 3                | 1008 |
| 2020 | 10           | 2028 | 3                | 1188 |
| 2021 | 10           | 2628 | 3                | 1368 |
| 2022 | 10           | 3228 | 3                | 1548 |
| 2023 | 10           | 3828 | 3                | 1728 |
| 2024 | 10           | 4428 | 3                | 1908 |
| 2025 | 10           | 5028 | 3                | 2088 |

hadron beams, the high bunch charge, and the larger beam current. The LPA scenario is expected to yield a peak instantaneous luminosity of 1400 pp interactions per beam crossing (pile-up). The baseline scenario might require the installation of 8 m long slim quadrupole magnets near the interaction region, probably between the forward muon wheels.

The total integrated luminosity that will be achieved by the end of phase I will be about 648 fb\(^{-1}\) by the end of 2016. By 2025 the LHC will deliver about 5028 (2088) fb\(^{-1}\) with (without) the Phase 2 upgrade. The phase 1 luminosity upgrade will already require changes in the detector elements that will deteriorate because of radiation damage and/or will be affected by the higher occupancies that complicate pattern recognition or lead to increased dead time. Triggers will also degrade as the increased occupancy reduces the effectiveness of isolation and correlation algorithms. The large pile-up and radiation effect of phase 2 present a major experimental challenge especially for the detectors elements close to the IP at and in the forward region. The current ATLAS and CMS plans are discussed.

### 3. PHYSICS POTENTIAL

Current experimental observations predict exciting discoveries at the "terascale" which will be explored by the LHC. The physics opportunities at the LHC have been studied over a period of many years. We expect to finally understand the mechanism by which electroweak symmetry is broken (EWSB) and the Z and W gauge bosons acquire their masses. In the Standard Model, this is achieved by the Higgs mechanism and its manifestation is a scalar particle, the Higgs Boson, whose mass is expected to be between 0.115 TeV/c\(^2\) (LEP limit) and 1 TeV/c\(^2\). The search for the Higgs Boson is one of highest priority investigations at the LHC and we expect a discovery within a few years of LHC operations.

The discovery of the SM Higgs will be only begin the Terascale exploration. Quadratic divergences in the Higgs mass from radiative corrections lead to the expectation that new physics should appear near the Terascale. One popular set of BSM physics is Supersymmetry (SUSY) which solve this problem by introducing for every SM boson a
new SUSY fermion partner and vice versa. These new symmetry introduces an elegant cancelation of the divergency. If SUSY is realized in nature we expect exciting discovery of SUSY particles possibly even before the observation of the several Higgs particles that are associated with it. The LHC is sensitive also to other Physics Beyond the Standard Model (BSM) such as Large Extra Dimensions, new strong dynamics such as Technicolor, new gauge bosons, or lepto-quarks.

It is evident that more statistics will be required to study in depth both Higgs physics, rare standard model phenomena, and the BSM. For example if some hints of SUSY are found, there is a whole set of particles to discover. Only some of these new particles would be accessible at the LHC. Similarly if one or more Higgs candidates are discovered, it will be crucial to confirm their quantum numbers and couplings. These measurements are necessary to establish if they are truly elementary objects or are composite particles as expected in Technicolor.

The luminosity upgrade will provide the statistic necessary for these measurements and will expand the LHC physics potential. Here we described the SLHC impact on Higgs and SUSY. More complete information can be found at [5]. Nonetheless the higher luminosity will allow one to push the sensitivity of many searches to new mass scales especially $Z'$s. One or more new neutral gauge bosons are highly motivated in beyond the Standard model scenarios including Higgless theories and large extra dimensions models. A factor of 10 increase in luminosity extends the $Z'$s reach by 1-1.5 TeV/$c^2$.

3.1. Higgs Physics

The discovery of a SM Higgs over the full allowed mass range or of at least one SUSY Higgs boson, will be accomplished at the LHC. Nonetheless the luminosity upgrade will enhance the LHC potential by enabling the discovery of rare decay modes which extend the information knowledge on the Higgs couplings to fermions and bosons.

The decay $H \rightarrow Z\gamma$ of a SM Higgs in the mass region 100-160 GeV and has a branching ratio of the order of $10^{-3}$. Moreover only decays of the $Z$ into electron or muon pairs lead to final states which can be observed above the background at the LHC. The production cross-section times branching ratio for $H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$ is only $\sim 2.5$ fb yielding an expected significance for $600 \text{ fb}^{-1}$ (300 fb$^{-1}$ per experiment) of $\ll 3.5$. The factor of 2 increase in luminosity expected by the end of phase 1 will provide the first measurement while the factor of ten in luminosity would allow the observation of a signal at the 11$\sigma$ level. The mode $H \rightarrow \mu\mu$ is also expected to become accessible at the SLHC and it could be measured with a precision of 20%.

The Higgs couplings to fermions and bosons can determined by measuring the Higgs production rate in a given channel since $g^2_f \propto \Gamma_f$, where $\Gamma_f$ is the Higgs partial width for that channel. This requires that the Higgs production cross-section and total width are known from theory. The ratios of Higgs couplings, which can be evaluated by measuring the ratios of rates between two different final states, provides theory independent measurements since the total Higgs cross-section and width cancel in the ratio. We expect that at the SLHC ratios of Higgs couplings to fermions and bosons should be measured with precisions of 10% or better in most cases. In some cases, this represents an improvement by up to a factor of two on the ultimate precision expected at the standard LHC. Fig. [show the SLHC reach. For examples the ratio between the $H \rightarrow ZZ \rightarrow 4\mu$ and the $H \rightarrow WW \rightarrow \ell\mu\ell\nu$ which provides a direct measurement of the ratio $\Gamma_Z/\Gamma_W$, are shown for Higgs masses larger than 150 GeV. These measurements will provide useful constraints of the underlying theory.

The SLHC will also open the possibility of measuring the Higgs self-coupling which probes the non abelian nature of the Higgs sector. The LHC can not probe this fundamental parameter because of lack of statistic. At the SLHC we can measure the production of a pair of Higgs bosons, which is sensitive to the $H \rightarrow HH$ vertex. We expect to reach a sensitivity again of the order of 20-30%. A promising channel is the $H \rightarrow HH \rightarrow WWWW \rightarrow \ell\nu\ell\nu jj jj$ decay, with final states characterized by jets and same-sign leptons.
Figure 1: Expected sensitivity on the ratios of several Higgs partial widths for final states involving bosons (left) and bosons
and fermions (right), as a function of the Higgs mass. The closed symbols correspond to an integrated luminosity of 600 fb$^{-1}$
(LHC: ATLAS+CMS), the open symbols to an integrated luminosity of 6000 fb$^{-1}$ (SLHC: ATLAS+CMS).

3.2. SUSY

ATLAS and CMS are expected to discovery evidence for SUSY if it exists at the TeV scale. If the LHC delivers
a luminosity of 300 fb$^{-1}$ we expect to probe squarks and gluinos masses up to 2.5 TeV/c$^2$ as shown in Fig. 2. The
various contours are derived within the framework of minimal Supergravity models (mSUGRA), and are shown as a
function of the universal scalar mass $m_0$ and of the universal gaugino mass $m_{1/2}$. They were obtained by selecting
events with multi-high-pT jets and large missing transverse energy, which is most striking SUSY signature if R-parity
is conserved. The SLHC can enhance the discovery reach of about 0.5 TeV/c$^2$ up to 3 TeV/c$^2$, as can be seen from
Fig. 2.

Even if SUSY will be discovered at LHC, the reconstruction of SUSY particles as well as the measurement of
model parameters may be quite difficult at the LHC, depending on the scenario in which SUSY will manifest itself.
The precise measurement of SUSY particles requires in most cases the selection of exclusive decay modes, containing
e.g. leptons or b-jets, and excellent vertexing and tracking performance must be maintained. Some of these exclusive
channels are expected to be rate-limited at the LHC and would therefore benefit from a luminosity upgrade. Squark
and gluino reconstruction, becomes very difficult for large $\tan \beta$, the ratio of the vacuum expectation value of the
Higgs doublets $\tan \beta$. In this regime and a large region of the parameter space will not be available at the LHC.

The LHC luminosity upgrade also increases the reach for the SUSY Higgs sector. The LHC should be able to
discover two or more of the five SUSY Higgs bosons over most of the parameter space. However in the region at
large $m_A$ which is often defined as the decoupling limit, only the lightest state $h$ (which has very similar features
to the SM Higgs boson) can be observed, unless the heavier Higgs bosons have detectable decay modes into SUSY
particles. Neither the LHC or a future sub-TeV linear collider, could probe heavy SUSY higgs states. The SLHC,
on the contrary, could significantly extend the region over which at least one heavy Higgs boson can be discovered
covering the full region with $m_A < 500$ GeV/c$^2$.

4. ATLAS AND CMS LHC DETECTORS

The ATLAS detector employs silicon pixels and strips and a straw-tube based transition radiation detector
inside a superconducting solenoid with a 2 T field. Outside of this, a Pb-LAr electromagnetic calorimeter is enclosed
by iron scintillator (barrel) and Cu/W-LAr (forward) hadronic calorimetry. The ATLAS muon system is composed
Figure 2: CMS 5σ discovery reach in the mSUGRA \((m_0, m_{1/2})\) plane for the inclusive multi-jet plus transverse missing energy final states. The various curves show the discovery reach for integrated luminosities of 100 fb\(^{-1}\) and 200 fb\(^{-1}\) (LHC), for 1000 fb\(^{-1}\) and 2000 fb\(^{-1}\) (SLHC), and for 100 fb\(^{-1}\) and 28 TeV center-of-mass energy (VLHC). Isomass contours for squarks and gluinos are also shown by the dash-dotted curves. Integrated luminosity of 6000 fb\(^{-1}\) (SLHC: ATLAS+CMS).

of muon drift tubes, thin gap chambers and resistive plate chambers embedded in a large array of 8 air-core toroid magnets.

The CMS detector \[8\] uses silicon pixels and microstrips, PbWO\(_4\) crystal electromagnetic and brass-plastic scintillator hadronic calorimetry all inside a large 4T superconducting solenoid. The muon system is composed of drift tubes, cathode strip chambers and resistive plate chambers inserted between iron layers of the flux return. Both ATLAS and CMS Level-1 (L1) trigger systems reduce the input crossing rate of 40 MHz to less than 100 kHz with custom processing of calorimeter and muon detector information. Further processing that eventually involves all detector data is used by their Data Acquisition (DAQ) systems to select an output rate of \(\approx 100\) Hz of data archived.

5. DETECTOR UPGRADES

5.1. CMS

The CMS plan for the phase 2 upgrade is presented in \[9\]. CMS foresees to replace several detector elements to maintain the physics capability for phase 1 of the upgrade. The current pixel detector with three barrel layers
(BPix) and three end-cap disks (FPix) will be replaced. The possibility to introduce a fourth pixel layer which could be located at about 16 cm from the interaction region is also under evaluation. The insertion of this layer could significantly improve tracking if there was indication that the first silicon strip layer of the Tracker Inner Barrel (TIB) was degrading more rapidly than expected.

The performance of the current pixel sensors \[^{10}\] surpasses the design goals of \(6 \times 10^{14}\) neutron-equivalent-particles/cm\(^2\) set in the CMS technical Design Report \[^{8}\]. Nonetheless it significantly degrades after \(1.2 \times 10^{15}\) neutron-equivalent-particles/cm\(^2\) which would be accumulated by about 2014 with the expected ramp up of the machine. The Phase 1 scenario in table \[^{11}\] indicate that a total dose of \(3.2 \times 10^{15}\) /cm\(^2\) 1MeV neutron equivalent would be accumulated at the inner pixel barrel layer by 2017 without any upgrade. This will lead to a charge collection as low as 20 % towards the end of Phase 1 and to a large fraction of lost tracks, as shown. The second pixel layer will also be significantly impacted by the total fluence received by the end of phase I. The replacement of the pixel detector will allow the adoption of more radiation hard sensors for the inner pixel layers. The most promising option is to use n-on-p pixels. Recent results demonstrate that this technology can operate up to \(3 \times 10^{15}\) /cm\(^2\) 1MeV neutron equivalent \[^{11}\].

The current pixel readout chip (ROC), known as the PSI46\[^{?}\], was originally designed for placement at a radius of about 7 cm from the interaction region at design luminosity. The chip was subsequently improved upon, but nevertheless there will be a loss of data at a rate of about 4% from the readout chip at \(10^{34}\) cm\(^{-2}\)s\(^{-1}\) in the innermost layer at 4 cm as measured in test beam runs. At the nominal L1T accept rate of 100 KHz, the data loss of 4% at \(10^{34}\) cm\(^{-2}\)s\(^{-1}\) will increase to 8% and could reach 16% in Phase 1. The data loss is dominated by the buffer size. R&D has already started for a new version of the PSI46v2 readout chip with improved buffering. For a luminosity less than \(2.5 \times 10^{34}\) cm\(^{-2}\)s\(^{-1}\) the buffer size should be double to recover efficiency. Doubling the buffers in the 250 nm process will increase the size of the chip periphery by 0.8 mm which is acceptable. The 130 nm deep submicron processes is also under evaluation.

The luminosity increase expected in Phase II will require the replacement of the full CMS tracking system. The new tracker will be installed during a one year shutdown before the start of Phase 2. CMS is developing a strawman layout which provides excellent tracking and vertexing while also allowing tracking information for L1 triggers. The present CMS tracker produces a large amount of information for each Level 1 Trigger, at up to 100 KHz. For the Strip Tracker, the analogue information for each of the approximately 9 Million strips is read out for every triggered event. For the pixel detector, zero suppression is used to read out only the information for clusters above threshold. In the high level trigger (HLT), only clusters within given regions of interest are considered, at least in the early stages of the selection. It is implausible to access all this information for the purposes of a Level 1 Trigger at the SLHC and zero suppression will be required throughout the upgraded Tracker. Additional data reduction of at least one to two orders of magnitude is required prior to transmission for the L1 trigger decision. CMS is considering measuring track vectors with pairs of silicon sensors separated by a few centimeters to identify tracks with \(p_\text{T}\) above 10-20 GeV. Detailed studies are underway, to validate the performance of this layout and optimize its design \[^{13}\].

Another approach to reduce the Level 1 trigger relies on associative memories chips and radiation hard optical fiber technologies. One of the proposed systems is an evolution of the Silicon Vertex Tracker (SVT) built for the CDF experiment, at the Tevatron Collider, where tracks are reconstructed in real time. In order to cope with the large data volume to be processed, CMS plans to use the information coming from the radial region from 25 to 50 cm where radiation levels allow the operation of current hybrid pixel technologies and optical fibers. The large radius would also provide the lever arm required for a momentum measurement in the \(r - \phi\) plane. Studies are taking place to evaluate if such an approach can achieve the needed data reduction citetrig2.

The upgrade of the hadronic calorimeter (HCAL) foresee replacing the current hybrid photo-detectors (HPDs) with Silicon Photo-multiplier (SiPM) which have lower noise and higher gain. SiPMS have been shown to work at magnetic fields between 0T and 4T with higher quantum efficiency than HPDs and have a very large gain of \(10^6\). The small size and low cost of the SiPm will allow depth segmentation which is not possible with the current hybrid photo-detectors (HPD) due to space constraints. Introducing longitudinal segmentation will allow to correct for the loss of light in the inner layers of the Hadron Endcap calorimeter (HE) due to radiation damage. The large
gain will also permit accurate timing measurements of the deposited energies. This could be especially important since the increased out-of-time pileup at higher luminosity will degrade the jet and missing transverse energy (MET) resolution. These effects will introduce significant systematic uncertainties for the jet energy scale, and threaten the use of lepton isolation in both the hardware and software triggers.

New trigger boards will needed to accommodate the changes in the front end electronics due to the increased fiber data bandwidth and number of channels. We are closely evaluating the performance of the µTCA which incorporates the latest trends in high speed interconnect and switching, and takes advantage of industry standards. In µTCA, crates the controllers are accessed over ethernet, and the backplane consists of a large number of high speed (1-5 Gbps) serial links. High-speed cross-point switches could allow point-to-point communications and therefore yield the flexibility needed to combine information from various detectors. These correlations, which are not permitted in the current trigger architecture, could be essential for implementing more sophisticated trigger algorithms to cope with the higher luminosities.

CMS is also planning changes to the ECAL trigger system. Closer coupling of the ECAL and HCAL off detector electronics will yield a more consistent treatment of calorimeter energies associated with physics objects in the trigger/DAQ. ECAL trigger primitives could be sent to HCAL to assure all corresponding HCAL towers are read out for analysis of EM objects. Specifically, once the longitudinal segmentation in HCAL is increased, it will be advantageous to ensure that the first layers of HCAL are always read out to contain leakage for high energy EM objects and for use in isolation. Similarly, trigger primitives or regions of interest in HCAL should initiate a full readout of corresponding ECAL towers to ensure that cells associated with jets and taus are available at high level trigger and off-line. Such functionality will be relevant to maintaining consistent quality of physics objects with increases in default readout thresholds.

Further upgrades to the calorimeters might be needed for Phase 2. The increase in pile-up events and the harsher environment in the forward region requires a carefully study of the radiation resistance of the CMS endcap crystals. The scintillators of the CMS hadronic endcap calorimeter will likely be replaced.

The CMS muon system includes drift tube (DT) in the barrel region, cathode strip chamber (CSC) in the endcap and resistive plate chambers (RPC) in both the barrel and endcap. The barrel region ($0 < \eta < 1.2$) is composed by 5 wheels, each divided in 12 sectors with 4 iron gaps. The muon stations consist of one DT chamber and two RPC chambers joint together and are placed in the gaps of the iron return yoke plates. The two endcap are made of 3 iron disks and 4 layers divided in 2 or 3 stations (ME1/1, ME1/2, ME1/3, ME2/1, ME2/2, ME3/1, ME3/2, ME4/1 and ME4/2) of CSCs and RPCs (see Figure 3). Excellent trigger performances on single and multi-muons events and an unambiguous identification of the bunch crossing is obtained by combining the RPC which are fast and dedicated trigger detectors with detectors having precise spatial resolution like the DT and CSC. DT and CSC first process the local information of every chamber generating local triggers then muons from different chambers are collected by the Track Finder which combines them to form a muon track with an assigned transverse momentum value. The highest $p_T$ muon candidates from each system are selected and sent to the Global Muon Trigger which applies transverse momentum thresholds.

The CSC and the RPC are expected to survive the increased radiation levels from the phase 1 LHC luminosity upgrades. However, the muon triggering and readout require specific upgrades in order to maintain excellent triggering characteristics, high efficiency, and excellent position and time resolution despite the increased background levels. CMS proposes to recover triggering capability by adding the ME4/2 chambers. This addition will be necessary for Phase 1 to obtain an efficient L1 trigger threshold in the rapidity range 1.2 to 1.8 as shown in Fig. 8. At high luminosity, the rate of low-momentum muons becomes too high to run the CSC Track Finder in a two out of three station triggering configuration, and another CSC chamber station is needed to allow a three out of four station triggering configuration. CMS is also planning to upgrade the ME1/1 which is critical for muon momentum resolution, but suffers high particle rates which are at the limit of the data acquisition system to handle. For Phase 1, CMS will replace the current cathode front-end boards with digital boards that flash-digitize every channel rather than using a custom analog storage pipeline. The smaller size of the new boards should allow placing seven of these boards on each ME1/1 chamber, and thereby recover muon trigger capability at higher luminosity in the rapidity
range 2.1 to 2.4. In order to read out the new board will require some revision of the trigger electronics.

CMS is also planning to replace the muon port cards with high speed optical links and FPGAs, since they are currently the major CSC trigger data bottleneck, allowing only three muon stubs to be transmitted per crossing per 60-degree trigger sector. This will cause severe problems at the Phase 1 luminosity. CSC chambers are also equipped with trigger electronics to find muon track segments. A Local Charged Track (LCT) is formed when at least 4 out of the 6 layers give signals, either the strips (CLCT) or the wires (ALCT), which line up in a pattern consistent with a particle going through. The ALCT cards are currently the largest source of deadtime to the entire CMS experiment caused by periodic resets that recover from neutron-induced single-event upsets. These boards will also be replaced before Phase 1 of the luminosity upgrade.

The Muon systems should not be greatly affected by the Phase 2 luminosity increase. However, due to the modification to the LHC beam line, the forward shielding will probably need to be increased, thereby reducing the spectrometer acceptance from about $|\eta| < 2.5$ to about $|\eta| < 2.0$.

The CMS trigger system will need modifications to operate with adequate performance at the LHC Phase 1 upgrade luminosity of $2-4 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$. For Phase 1, the new information in the L1 trigger will come from use of more fine-grained information from the calorimeter and forward muon triggers and improved algorithms exploiting this new information. Further trigger upgrades will be needed for Phase 2. The Level-1 Trigger output should not exceed the 100 KHz limit in order to avoid rebuilding the front end electronics where possible. CMS expects that to deal with the SLHC luminosity of $10^{35} \text{ cm}^{-2}\text{s}^{-1}$ tracking information will be needed at L1.

An important feature of CMS that facilitates the incremental upgrades foreseen for Phase 1 is the relative accessibility of the parts of the detector that need to be modified. The End Cap Muon detector disks can be separated for maintenance and the surface on which the ME4/2 chambers mount is readily accessible. This will allow CMS to use several shutdowns for their installation. The Readout Boxes of the HCAL are similarly accessible once the CMS detector is opened. The Pixel Detector can be removed in two days (after time has been allowed for the radiation level to decrease and CMS has been opened) and a new one installed, cabled, and checked out in a few weeks. The underground control room that houses much of the Level 1 Trigger and DAQ can be accessed even while the beams are colliding.
5.2. ATLAS

The ATLAS collaboration is also focusing on the detector upgrades for the SLHC. ATLAS is planning modifications to their beamline. Currently central part of the ATLAS beamline is made of beryllium (Be), while the remaining part is stainless steel which can get activated and can yield large backgrounds, especially to the muon system. The beam pipe will be changed to Al for phase 1 and the Be for SLHC. This will lead to a large background reduction in critical areas of the muon system.

The most significant upgrade for ATLAS will be the full replacement of the tracker systems, which will be showing signs of serious radiation damage by 2016. Many changes are needed, including the replacement of the whole Inner Detector since the current TRT will not cope with the high hit rate. The Pixels and parts of the semiconductor tracker (SCT) will also have to be substituted since they will have suffered significant radiation damage. Moreover the SCT strip occupancy in certain regions would be very high at the peak luminosity of the LHC, degrading tracking performance.

The target survival for operation in the intense radiation field of the SLHC is assumed to be $6000 \text{ fb}^{-1}$. To cope with the severe increase in integrated radiation dose and the much higher track density ($\frac{dN_{ch}}{d\eta} \approx 1500$ from up to 200 events/crossing), the data links, data acquisition, triggering, off-detector electronics and computing will all need to be reworked across much of the experiment.

The Atlas collaboration has developed a strawman tracker design which is a first step towards establishing a baseline design. The process is driven by the need to achieve the necessary radiation hardness and the granularity to handle the increased occupancy rates. The ATLAS inner detector (ID) will need to be replaced since the upgraded luminosity will lead to doses greatly exceeding its design radiation hardness ($730 \text{ fb}^{-1}$ integrated luminosity). More detector channels are needed 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 [15]. The expected requirement of 1% maximum occupancy for adequate pattern recognition puts constraints on the technology that can be used at a certain radius. The results showed that adequate pattern recognition could be achieved with three pixel and four short strip (3 cm long, 80 $\mu$m pitch) layers. The TRT will also be replaced by two layers of long strip (9 cm length, 80 $\mu$m pitch) sensors giving approximately the same position resolution as the TRT. This layout, shown in Figure 4 with 9 silicon tracking layers from 5 to 95 cm radius [15] guarantees that the performance at SLHC should be similar to that of the current ATLAS tracker. The increase in sensor radiation damage and the required increase in electronic channel density also lead to major challenges in terms of power supply and cooling.

A major international effort is already underway to develop the technologies required for the tracker replacement. Radiation exposure concerns dominate the pixel region. For the innermost $b$-layer the levels of radiation background are so high that a new technology is required. ATLAS has a vibrant R&D program examining the use of diamond, which is a very radiation hard material, to build the inner layers for the SLHC. The ATLAS R&D program has already achieved major milestones including building and successfully operating in a beam test a full-sized ATLAS pixel diamond detector. A signal-to-noise ratio of 24 at a field of 2V/mm was obtained with a diamond sensor irradiated up to $1.8 \times 10^{16}$ p/cm$^2$, which corresponds to the 5-year integrated radiation dose at the SLHC [16]. Another potential technology for the inner layers is the 3D geometry which has shown excellent radiation hardness. In a 3D silicon detector, arrays of $n$ and $p$ electrodes are implanted in a silicon substrate. The advantages of this technology over the standard planar technology are: shorter collection distances, faster collection times, better signal efficiency and lower depletion voltages. Tests with 3D sensors bump-bonded to an ATLAS pixel readout chip have been performed in the CERN H8 pion beam. Preliminary results indicates that 3D sensors might lead to a better signal efficiency than diamond. The production of 3D sensors is currently using in-house processing but ATLAS is working with vendors to industrialize the process [17].

The sensor requirements at the intermediate radius are the focus of much of the ATLAS simulation effort. The bulk of the tracker will be silicon planar technology. Silicon $n$-in-$p$ is favored compared with $p$-in-$n$ because it can operate partially depleted, avoiding the need for very high bias voltages. The ATLAS collaboration is also developing the concept of a stave, an integrated multi-module object which is the basis for this new design. A stave is a self-contained object which includes a number of individual modules sharing a common mechanical, thermal, and electrical service
Figure 4: View of a basic all-silicon layout for a super-LHC tracker. Outer two layers contain long (10–12 cm) strips. Intermediate three layers contain short (3 cm) strips. Innermost layers are pixels.

structure [? ]. The stave consists of a core fabricated as a sandwich of high modulus carbon fiber laminates around a spacing material such as foam or honeycomb. This sandwich construction leads to high stiffness against gravitational sag. Within the spacing material are a U-shaped cooling loop which should offer the excellent cooling performance needed for operation a high radiation environment. Both mechanical and thermal simulations and electrical tests of stave structures show promising results. A full scale ATLAS stave design will be fabricated and tested in the near future. The results of these studies will guide the design an all-silicon tracker for the SLHC. The replacement of the full tracker system will take place during the one shut down before phase 2 of the upgrade. ATLAS is also discussing a plan to replace the $b$-layer, before the phase 1 upgrade.

Most of the ATLAS calorimetry should be robust against the increased radiation backgrounds, although R&D is required in some areas. ATLAS is evaluating a novel SiGe Bi-CMOS technology for the upgrade of the LaR readout. A baseline that allows operating at the rate and radiation hardness expected at the SLHC requires the digitization of all signals as soon as possible. Therefore the collaboration foresees using very fast ADC on the front end board (FEB) to avoid using an analog pipeline on the detector. To achieve this goal, the power lost in the digitization must be considerably reduced, possibly at the level of 0.4 W/ADC. Then the pipeline could be ‘off detector’ if fast optical link could be used.

The ATLAS forward calorimeter may also 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. 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. Experience with running at the LHC is necessary before identify the best solutions.

The Monitored Drift Tube (MDT) chambers and Cathod Strip Chambers (CSC) in the small angle region are the main tools for the muon identification and measurement in the ATLAS muon spectrometer. The main background for the muon chambers are low energy photons and neutrons which dominate the counting rate in most areas of the spectrometer, where an overall maximum counting rate of 500 Hz/cm$^2$ is expected. The upgrade to SLHC will involve fluxes ten times higher and therefore tests were carried out to understand the performance of the chambers after intense neutron dose. The irradiation of the MDTs was carried out at the Tapiro nuclear reactor facility, at ENEA Casaccia laboratories, on a MDT test chamber [10]. The main goals of the studies was to understand the
MDT performance under ATLAS-like neutron rates, and to test chamber robustness after an integrated neutron flux corresponding to \( \approx 40 \) years of real data taking. Cosmic ray data were acquired and analyzed to look for possible loss in gas gain or tracking efficiency. No significant variation from the standard MDT behavior was observed, neither at high background neutron rates, nor after massive irradiation.

ATLAS Level-1 muon trigger is provided by Resistive Plate Chambers (RPC) in the barrel and Thin Gap Chambers (TGC) in the end-cap. Ageing studies have been conducted and the preliminary results show that the RPC operate at SLHC if the background corresponds to simulation and the expected background can be reduced by a factor 2 by proper shielding. ATLAS expects that the first 1-2 year of operation are necessary to draw realistic conclusions on the behavior of the RPCs at the SLHC. Because of these uncertainties ATLAS is evaluating and upgrade of the muon forward region. An option under consideration is to upgrade forward trigger chambers (TGC) and possibly replace some forward MDT-CSC by smaller diameter tubes. Micromega chambers are a possible solution for precise measurement and trigger at the same time, due to their rate capability (tens of kHz/cm\(^2\)), time resolution (few ns) and space resolution (better than 100 \( \mu \)m). An R&D effort on Micromega chambers has been started by the ATLAS collaboration.

6. CONCLUSIONS

The LHC is expected to open the window to the Terascale physics. Nonetheless a deeper understanding of electroweak symmetry breaking and physics beyond the standard model is likely to require large amount of data. A luminosity upgrade of the LHC leads to the full exploitation of the LHC physics potential. The SLHC will extend the discovery mass reach by 20 to 30% and improve the sensitivity for precision measurements, for a modest capital investment compared to the LHC cost. Operation at the very high luminosity of the SLHC poses significant challenges to the ATLAS and CMS experiments. R&D is started both for the phase 1 and phase 2 luminosity upgrades.

6.1. Acknowledgments

The author wish to thank the organizers for the excellent conference and many members of the CMS and ATLAS collaborations for the input provided in preparing this talk.

This work is supported by Department of Energy contract DE-FG02-91ER40681A29 and by NSF funding for the maintenance and operation of CMS.

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