CERN-RRB-2012-075
15 October 2012

ATLAS Progress Report for the October 2012 RRB

1. Introduction

The period since the last RRB meeting in April has been characterised by the long-awaited ground-breaking discovery of a new particle with features compatible to those expected for the Standard Model (SM) Higgs boson.

The 2012 LHC run has been proceeding well since first 8 TeV collisions were delivered on 1st May. ATLAS recorded sufficient luminosity (approximately the same amount as in all of 2011) in advance of the International Conference on High Energy Physics (ICHEP, 4-11 July 2012, Melbourne) which, coupled with improvements in search techniques, enabled the discovery of a Higgs-like boson to be made already at the beginning of July. Since that time, the 2012 dataset has almost tripled and the proton-proton running in 2012 has been extended until the end of the year, with a projected integrated luminosity of about 25 fb^{-1}.

ATLAS, from the detector through the computing chain to final analysis, has been performing extremely well, despite new challenges from the increase in beam energy and event pileup (compared both to 2011 and to LHC design specifications). Efficient recording and rapid processing of high quality data, which resulted in about 90% of the delivered luminosity to be used in the successful Higgs search, is evidence of excellent performance; some data used in the results reported at the 4th July CERN seminar and at ICHEP were taken only a few days earlier.

The large 7 TeV centre-of-mass dataset recorded in 2011 (about 5 fb^{-1}) has been used to produce a wide range of physics results, especially concerning searches for new physics beyond the Standard Model. It continues to be used for precise measurements of various Standard Model processes. Meanwhile, first results with the larger and growing 8 TeV dataset have been released for both measurements and searches. This dataset will enable a rich physics programme that will be conducted throughout the 2013-2014 long shutdown, including initial studies of the properties of the Higgs-like boson, as well as other studies ranging from detailed precision measurements to searches for new physics.

A large number of new results were presented at ICHEP and other summer conferences, documented either in public conference notes or journal articles. As of 15 October, 198 journal articles based on collision data had been submitted or published, including more than fifty since the April 2012 RRB meeting. In addition, ATLAS has now released more than four hundred conference notes. This productivity demonstrates that the Collaboration is able to deliver a large wealth of physics results very quickly, thanks also to the smooth and effective operation of the computing grid infrastructure based on the WLCG backbone.

These accomplishments require very substantial operational effort. Operation Tasks (OTs), defined as all activities essential to the operation of ATLAS, from central shifts and on-call tasks at Point-1 to computing and data preparation tasks, require ~650 FTE, plus shifts. Responsibility for OTs is shared among the Institutions in proportion to their number of authors. Effort on ATLAS-specific WLCG operation, at the level of approximately 180 FTE, is in addition.

ATLAS has a well-established programme for the 2013-2014 long shutdown (LS1), including installation of a new inner-detector cooling plant, replacement of the liquid-argon and tile calorimeter low voltage power supplies, completed installation of staged muon chambers, improvement of the magnets cryogenic system and additional consolidation work. Furthermore, the so-called “Insertable B-layer” (IBL) will be installed in the Pixel detector with a new beam pipe and possibly with new pixel services. (LS1 activities will be reported more fully in the next report to the RRB in April 2013). Substantial progress continued on R&D activities and planning of detector improvements in preparation for LHC luminosity upgrades. The Collaboration Board (CB) recently approved the New Small Wheel project for the muon spectrometer, planned on the timescale of the second long LHC shutdown in 2018 (LS2), to proceed to development of a Technical Design Report. A Letter of intent (LoI) for the second phase of upgrades planned in 2022-2023 (LS3) is being prepared for presentation early next year.

The ATLAS Collaboration consists today of 176 institutions from 38 countries with approximately 3000 active scientists, of which 1800 with Ph.D. (hence considered for M&O cost-sharing) and about 1200 students. At its June 2012 meeting, the ATLAS CB admitted University of Adelaide, Australia as a new member institution. At the same meeting, the CB also elected David Charlton of University of Birmingham, UK, as the next ATLAS spokesperson, for a two-year term starting 1 March 2013.

ATLAS is extremely grateful to the Funding Agencies for their continuous support over nearly two decades. This support has enabled the Collaboration such a successful start in the exploitation of the immense physics potential of the LHC.

2. Detector Operations

The 2012 proton-proton run is proceeding well, with the LHC having already delivered 15 fb^{-1} to ATLAS by the beginning of October, of which ATLAS has recorded 14 fb^{-1} during stable beam operations (Fig. 1).

Following the maintenance and consolidation activities of the 2011-2012 winter technical stop, the ATLAS detector was well prepared for data taking this year. A constant, aggressive programme of small repairs and remedies has maintained the detector in excellent condition. For instance, the fraction of non-operational detector channels is low in all subdetectors, ranging from a few permil to less than five percent.

The overall ATLAS data-taking efficiency during stable LHC beam conditions is 93.7% in 2012 to date, quite similar to 2011. Efficient operation has required continual maintenance of general infrastructure, such as electricity, cryogenics, cooling and ventilation, of individual detector elements, and of control, trigger and data acquisition systems. Prompt and effective intervention of the shift crew and on-call experts was also crucial for the efficient recording of high-quality data. An extensive programme to provide expert systems to assist shifters and tools to automate recovery from faults has been, and continues to be, conducted.

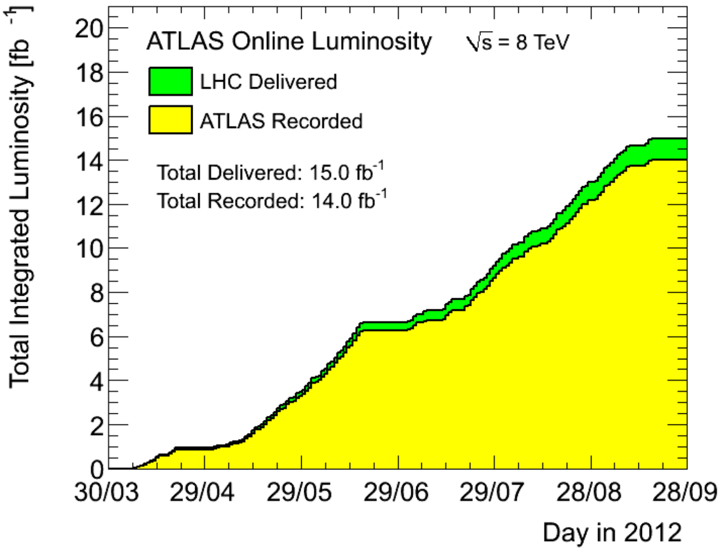

Figure 1: Integrated luminosity vs. time for the 2012 proton-proton running to date.

The quality of data recorded in 2012 is excellent (Table I). Data quality requirements depend on the specific analysis, but more than 93.7% of the 2012 recorded data is good for use in essentially all analyses.

ATLAS p-p run: April-Sept. 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.3	99.5	97.0	99.6	99.9	99.8	99.9	99.9	99.7	99.2
All good for physics: 93.7%										
Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and September 17th (in %) – corresponding to 14.0 fb⁻¹ of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.										

Table I: Luminosity-weighted relative fraction of good quality data delivery by subdetector.

As expected, the pile-up conditions in 2012 are very challenging, with a mean number of interactions per crossing as high as 35-40 at the start of fills (to be compared to the LHC design value of about 23).

The following subsections briefly address recent operational aspects for the various subdetectors.

2a. Magnet System

The ATLAS superconducting magnet system comprises the central solenoid, the barrel toroid, two endcap toroids, and their common services.

Overall, the ATLAS magnet system has been performing very well. Since the last RRB meeting in April, the Solenoid and Toroid have experienced no fast dumps. The Solenoid has experienced four unscheduled slow dumps, and the Toroid six. In all cases, the magnet system reacted as expected. Causes of the slow dumps were various, including external perturbations on the electrical network and power converter faults. In three cases, a negligible amount of data was lost for physics (see Table I).

2b. Inner Detector

The inner detector (ID) combines three concentric sub-systems, the Pixel detector, the silicon strip detectors (SCT), and the transition radiation straw tracker (TRT), listed from inside to outside.

Failures of the off-detector optical transmitter plug-ins (TXs) used in both the Pixel and SCT detectors continue to demand attention. A two-pronged approach was adopted to address this issue. TXs with new VCSELs that are resistant against the ingress of moisture were installed during the technical stop last winter. Although the failure rate has been low in 2012, it is larger than expected from bench and industry tests, and is of some concern. Meanwhile, the new vendor making optical sub-assemblies has failed to produce usable units. Work has now started with another vendor. Although no data has been lost to date, the failures are not completely understood; consequently, there is residual concern about longevity of similar units used in the Pixel on-detector electronics (the on-detector optical transmitters used by the SCT are of a different type).

The decision on whether to install newly constructed Pixel services during the IBL installation will be made around the end of 2012. The risks of bringing the Pixel detector to the surface in 2013-14, as necessary for installation of new services, are being balanced against the risks of installing the IBL *in situ* in the ATLAS cavern and the risk of eventual on-detector TX failures. Both installation scenarios are being prepared, as well as their risk analyses.

Over the last year the TRT gas system has developed some leaks, seven in total, resulting in a loss of xenon gas. The total loss of Xe is about 150 litres per day. All leaks are in the exhaust side of the circuit. The working hypothesis is corrosion in small pipes that is accelerated by ozone produced in the gas avalanche in the straw. The leak rate has been minimised by reducing gas flow. This mode will be used until the end of the current LHC run. Some leaks can be fixed in LS1. The physics performance of the TRT has not been affected.

The ID evaporative cooling system has continued to operate very smoothly, with only minor interventions. The thermosiphon-based replacement evaporative cooling system will be ready for tests in early 2013.

2c. Calorimeters

The calorimeter system includes a liquid argon (LAr) electromagnetic calorimeter, a barrel and two extended barrel Tile hadronic calorimeters, liquid argon endcap hadronic calorimeters (HEC), and liquid argon forward calorimeters (FCal).

The frequency of high voltage trips in the LAr calorimeters, which was an issue in the past, remains low (1 per 10 hours), and its effect on data quality has been minimised through automatic reactions. Sporadic noise occurs in the LAr presampler. This effect has been mitigated by reducing the applied high voltage; meanwhile studies are investigating the noise source in search of a long-term remedy.

While the original low voltage power supplies (LVPS) on the Tile calorimeter have continued to trip frequently (>9000 trips in 2012 to date), the forty (out of 256) redesigned LVPS installed during the technical stop at the end of 2011 have been operating well, with only one trip in 2012. The remaining complement of new supplies, which also have better noise performance, will be installed in the upcoming long shutdown, as will the remaining 46 (out of 58) redesigned LAr LVPS.

2d. Muon Detectors

The muon spectrometer is instrumented with precision chambers for momentum measurement (Monitored Drift Tube chambers, MDTs, and for a small higher-radiation forward area Cathode Strip Chambers, CSCs) and with fast chambers for triggering (Resistive Plate Chambers, RPCs, in the barrel, and Thin Gap Chambers, TGCs, in the endcaps).

Recent data recorded with no magnetic field have enabled improvements in the alignment of the muon spectrometer, particularly significant in the endcap region.

Two CSC layers in the same sector (out of four in the sector) failed in July, bringing the total number of dead layers to five out of 128. Detection of muons is unaffected except at the highest values of rapidity where muons are not measured by the inner detector. Repair or replacement during LS1 is being investigated.

The CSC readout system is presently operating at its hardware limit in the beginning minutes of high luminosity LHC fills, when the conditions of level 1 trigger rate are near design value (~75 kHz) and event pileup is well beyond design. Recent optimisations have minimised the impact on ATLAS data taking, and the overall data loss due to operational problems in the CSC system is negligible. The readout system will be replaced during LS1 in order to allow for increased level 1 trigger rates in 2015.

2e. Forward Detectors

The ATLAS forward detectors consist of a Luminosity Cerenkov Integrating Detector (LUCID) placed around the beam pipe inside the forward shielding at ± 17 m from the Interaction Point (IP), a Zero Degree Calorimeter (ZDC) placed in the TAN absorber structure where the beams enter separate beam pipes at ±140 m from the IP, and an Absolute Luminosity for ATLAS (ALFA) system based on fiber detectors located in Roman Pots at ±240 m from the IP.

In 2012, LUCID has continued running as a luminosity detector. Although operation without gas radiator, utilizing Cherenkov radiation in the quartz windows to count particles, has allowed minimisation of saturation effects due to pileup, the latter remains a concern.

ALFA has experienced elevated temperatures from RF losses; consequently, external cooling and protective measures have been implemented. A successful special run with β^*=90m provided ALFA with data for analysis of elastic and diffractive processes. Beam optics have been commissioned for a special run with β^*=1km later this year, which if successful will enable measurements in the Coulomb scattering regime and total cross section determination independent of luminosity measurement via traditional Van der Meer scans. Analysis of 2011 β^*=90m data is being finalised for precision measurement of the total cross section.

The ZDC was removed for high-luminosity proton-proton running in order to protect against radiation damage. It will be reinstalled for the proton-lead run in early 2013, except for the electromagnetic section of one arm, which will be replaced by the LHCf detector for this run.

2f. Trigger and DAQ System

The major sub-systems of the Trigger and Data Acquisition System (TDAQ) are the Level-1 Trigger (with the sub-systems calorimeter, muon, and central trigger processor, CTP), the High Level Trigger (HLT – comprising the Level-2 trigger and the Event Filter), the Data Acquisition (DAQ), and the Detector Control System (DCS).

The trigger selections (“menu”) defined for 2012 have demonstrated the flexibility required by the evolving high-luminosity conditions in 2012. Optimization of the selections has allowed ATLAS to run with similar thresholds as in 2011 for the main physics objects (*e.g.* leptons and photons) in spite of the higher energy and luminosity. Improvements made to HLT algorithms in order to better manage high event pileup have proven successful. Refinements have been made in the menu during the course of the year in order to improve selection of physics channels of particular interest, such as certain Higgs decay modes. The strategy of giving full bandwidth to high priority triggers at the start of each LHC fill and, as their rate decreases, allocating some bandwidth to lower priority triggers was practiced. Typical trigger rates at high luminosity are 70 kHz at Level 1, 6 kHz at Level 2, and 400 Hz at the output of the Event Filter. An additional “delayed stream” of up to 200 Hz of triggers of slightly lower priority is being recorded for reconstruction during LS1, when Tier 0 resources are no longer required for prompt reconstruction.

The HLT/DAQ system has responded capably to the demands of high luminosity and high pileup and to the strategy to run at higher trigger output rate than originally specified. The system currently operates near the data bandwidth and CPU limits of the current hardware installation. The number of SFO’s (HLT/DAQ output nodes) has been expanded to handle larger event sizes and higher trigger rates. The capacity of HLT processing will require expansion for higher energy, higher luminosity conditions in 2015.

3. Computing and Software

The entire ATLAS and WLCG computing and software chain has continued to perform in an outstanding fashion in 2012. The computing model and the operations team have demonstrated the flexibility and capacity to accommodate higher trigger rates and higher event pileup than anticipated, intense simulation of Monte Carlo samples, and demands of the worldwide analysis effort. Intense efforts to optimise both the technical and physics performance of the software, particularly with respect to high event pileup, also are proving successful.

The large integrated luminosity being collected in 2012, also in light of the extension of proton-proton running, is producing a dataset of considerable size. Data analysis, reprocessing, and simulation activities associated with this dataset will continue in full swing through the upcoming long shutdown, and will require the full computing resources requested for 2013 and 2014.

The core computing infrastructure and services tasks, defined as M&O Category A, continue to play a crucial role for the smooth operation of the software and computing chain. They enable ATLAS to exploit the large investments of computing resources made worldwide by the WLCG collaboration partners.

4. Physics

The first priority for the physics analysis of 2012 data was to investigate the hints of an excess at 126 GeV seen in the Standard Model Higgs search with the full 2011 dataset. Building on the improvements to physics object reconstruction for high pile-up conditions made at the end of 2011 and beginning of 2012, the Higgs search analyses were reoptimised and validated with 2011 7 TeV data before analyzing the new 8 TeV dataset. Results from the γγ and 4-lepton channels with the first 5.8 fb^{-1} collected until mid-June were shown at the CERN 4th July seminar and shortly after at the ICHEP conference in Melbourne. When combined with the reoptimised analyses of the 2011 data in these two channels, and existing analyses in other channels, clear evidence for the production of a new boson with a mass of ~126 GeV was seen, at the level of 5.0σ. Subsequent analysis of the same dataset in the *WW→eνμν* channel also supported this hypothesis, and ATLAS submitted a paper reporting the observation of a new neutral boson with a mass of 126.0±0.6 GeV at a significance of 5.9σ to Physics Letters B on 31st July (Fig. 2). Further analysis of

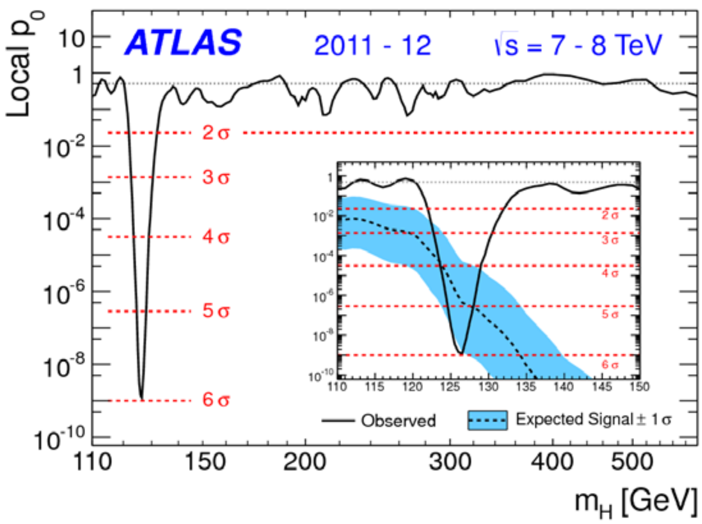

Figure 2: The local probability p_0 for the observed data to be due to background only as a function of m_H. The dashed curve (inset) shows the expected p_0 under the hypothesis of SM Higgs production at each mass.

this dataset has allowed initial investigation of the properties of this new particle, testing its consistency with the Standard Model Higgs boson hypothesis. These studies are being extended as ATLAS continues to accumulate data at 8 TeV.

Searches for new physics have continued with both the full 2011 and 2012 datasets. Inclusive searches for supersymmetry with the early 2012 data have further constrained the allowed SUSY parameter space, with mass limits in mSUGRA/CMSSM models with equal squark and gluino masses being pushed beyond 1.5 TeV. SUSY models with a relatively light 3rd generation (top and bottom squarks) are of particularly theoretical interest (*e.g.* to explain the light observed Higgs-like boson), and give rise to a rich phenomenology depending the whether the top squark is lighter or heavier than the top quark. A set of dedicated searches with the full 7 TeV dataset has severely constrained the allowable parameter space for such models (Fig. 3). A large number of searches for non-SUSY beyond-Standard Model physics with the full 2011 dataset have been completed, including limits on the production of dark matter candidates in mono-jet and mono-photon topologies, and searches for top-anti-top resonances at high invariant mass, which require boosted jet substructure techniques to resolve the individual top decay products within a single "fat" jet. Several searches looking for exotic stable or semi-stable particles stopping or decaying a long way from the LHC beam interaction point have also been performed, exploiting the complementary capabilities of the different ATLAS subdetectors in novel ways.

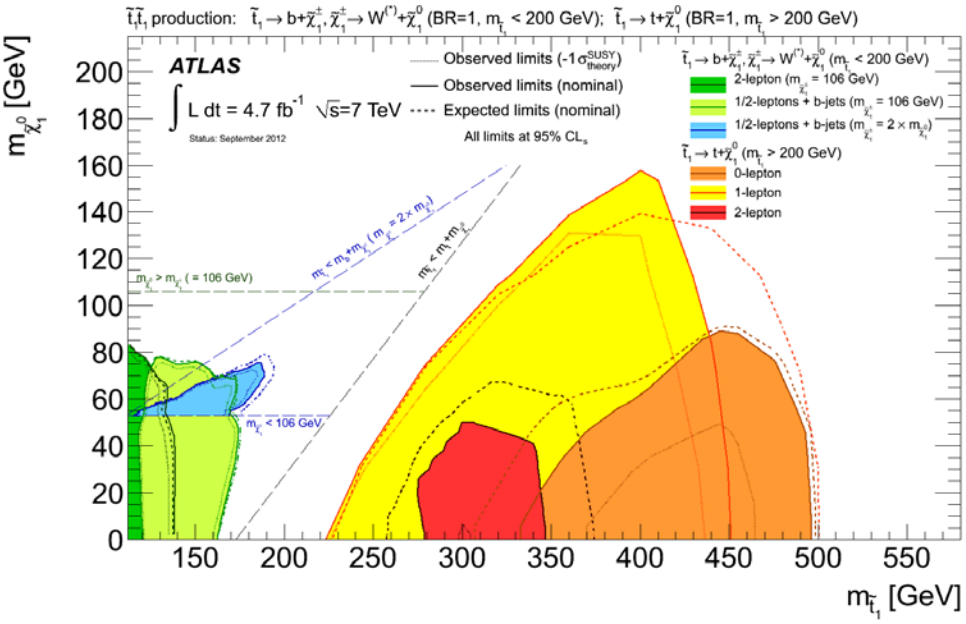

Figure 3: Summary of the five dedicated searches for top squark pair production based on 4.7 fb^{-1} of 7 TeV data. Exclusion limits at 95% CL are shown in the (top-squark, neutralino) mass plane.

These and other searches for new physics with the 2011 and 2012 data are built on a foundation of detailed Standard Model measurements, which have been refined using the 7 TeV data sample. The large sample of top quarks has allowed precise measurements of the top and W polarisation in top-pair events, and observation of spin correlations. Precise measurements of top production cross-sections have been complemented with measurements involving tau leptons, and evidence has been seen for the associated production of a single top quark and a W boson. Detailed studies of inclusive minimum bias and multijet events, and heavy flavour production, have provided further input for tuning event generators to describe physics at LHC energies. A large-statistics study of $B_s \rightarrow J/\Psi\ \Phi$ decays has allowed a sensitive test of the SM description of CP-violation.

The large sample of Pb-Pb collisions collected in late 2011, together with advances in techniques for event-by-event subtraction of the underlying event activity, have allowed new analyses exploiting reconstructed electrons and photons to be developed. A particular highlight is the measurement of photon-jet and Z-jet correlations; unlike jets, photons and Z-bosons emerge unaffected from the hot, dense medium produced in the Pb-Pb collisions, and can therefore be used as a reference to study the medium's effect on hadronic objects.

This productive physics output should continue through 2013 and well into 2014. In particular, the anticipated full 2012 data sample of about 25 fb^{-1} should allow the coupling of the 126 GeV Higgs-like particle to fermions to be investigated directly through the bb and ττ decay modes, together with first determinations of its spin and parity and improved measurements of couplings to vector bosons.

5. Status of FDL Activities and Planning for LHC Luminosity Upgrades

The activities foreseen during the long LHC shutdown of 2013-2014 (LS1) include also a number of items from the 2002 Completion Plan for the Full Design Luminosity (FDL) detector. Improvements and consolidation in infrastructure are planned, particularly to shielding, electrical, cooling, gas, and cryogenic systems. Improvements to the hermeticity of the muon system are also planned. Improvements will be made to the readout systems of several detectors in order to operate with a 100 kHz level 1 trigger rate in 2015 and after. The Insertable Pixel B-layer (IBL) project is progressing well in preparation for installation during LS1. All sensors and ASICs have already been delivered, and the first assembled "stave" of sensors is presently being tested. Along with IBL installation, which includes a beryllium beam pipe, aluminium beam pipes in the forward regions will be installed. As already mentioned, an option to replace the pixel services also exists. A status report on FDL detector activities is provided in CERN-RRB-2012-078.

ATLAS plans two phases of detector upgrades aligned with CERN plans to increase the luminosity of the LHC beyond design value: Phase I after the second long shutdown (LS2) in 2018 and Phase II (the HL-LHC era) after LS3 assumed in 2022. As previously reported, ATLAS plans to proceed via Letters of Intent (LoI) for each upgrade phase, followed by project-specific Technical Design Reports (TDR) and Construction MoU Addenda. The Phase-I LoI was endorsed by the LHCC at its March 2012 meeting.

Detector improvements for Phase I target the integration of ~300 fb^{-1} by the start of the next decade, exploiting peak instantaneous luminosities of 2×10^{34} $cm^{-2}s^{-1}$ and above. Improvements focus primarily on enhancing trigger capabilities in order to maintain good physics selectivity despite much higher data and background rates. Two upgrade projects have now successfully completed initial design reviews and gained Collaboration Board approval to prepare Technical Design Reports: a hardware track finder (FTK) at the input to the Level-2 trigger (CB approved 24 June 2011) and New Small Wheels (NSW) for the muon spectrometer (CB approved 5 October 2012). The NSW will be based upon two detector technologies, thin gap chambers with small gaps (sTGC) functioning primarily in a triggering role and micromegas detectors functioning primarily in a precision measurement role, supported by common electronics and infrastructure services. Following successful laboratory tests, a prototype of a vertical slice of FTK has been installed in ATLAS, where it will run parasitically through the end of 2012 data taking. Other specific upgrade projects, level-1 LAr and Tilecal trigger electronics and Trigger and Data Acquisition, continue to progress towards initial design reviews in the first half of 2013 and Technical Design Reports in the second half of 2013. New detectors for ATLAS Forward Physics (AFP) target CB approval and Technical Design Report in 2014.

Detector improvements in preparation for the HL-LHC era target integrating 250-300 fb^{-1} per year, exploiting peak luminosity of approximately $5x10^{34}$ $cm^{-2}s^{-1}$, with high radiation and event pile-up levels. Studies of requirements in this environment for the inner detector, endcap hadronic calorimeter electronics, forward calorimeters, and detector readout, trigger and data acquisition are well advanced. A programme of urgent R&D on long lead-time improvements is being conducted. For instance, R&D for a new all-silicon inner detector, with suitable granularity and radiation hardness for the HL-LHC environment is a major focus. Some of these upgrades, *e.g.* replacement of the inner detector, are needed to operate ATLAS in the next decade also without the Phase-II LHC luminosity upgrades.

Examples of the physics potential of ATLAS at the HL-LHC have been reported to the European Strategy Preparatory Group, for instance illustrating the capability to measure the couplings of a Standard Model Higgs Boson to between 5% and 25%, depending upon coupling. Rare Higgs decay modes and self-coupling measurements would also become accessible with the projected integrated luminosity of about 3000 fb^{-1} by the end of the next decade. The Phase-II Letter of Intent, describing the detector upgrades for the HL-LHC phase, is well advanced and should be presented to the LHCC in early 2013.