LHC Experiments

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Large Hadron Collider (LHC) is under construction at the CERN Laboratory in Switzerland. Four experiments (ATLAS, CMS, LHCb, ALICE) will try to study the new physics by LHC from 2006. Its goal to explore the fundamental nature of matter and the basic forces. The PDF file of the transparency is located on http://www-atlas.kek.jp/sub/documents/lepsymp-stanaka.pdf.

1 Introduction

The Large Hadron Collider (LHC) is a proton-proton collider with 14 TeV center of mass energy and design luminosity of $10^{34} cm^{-2} s^{-1}$. Beam crossings are 25 ns apart and at design luminosity there are 23 interactions per crossing [1]. The LHC will consist of two "colliding" synchrotrons installed in the 27 km LEP tunnel. They will be filled with protons delivered from the SPS and its pre-accelerators at 0.45 TeV. Two super conducting magnetic channels will accelerate the protons to 7-on-7 TeV, after which the beams will counter-rotate for several hours, colliding at the experiments, until they become so degraded that the machine will have to emptied and refilled. The magnetic channels will be housed in the same yoke and cryostat, a unique configuration that not only saves space but also gives a 25 % cost saving over separate rings. High energy LHC beams need high magnetic bending fields, because the machine radius was not a parameter which could have been increased to provide gentle curves. To bend 7 TeV protons around the ring, the LHC dipoles must be able to produce fields of 8.36 Tesla, over five times those used a few years ago at the SPS proton-antiproton collider, and almost 100,000 times the earth's magnetic field. Superconductivity makes this possible. This is the ability of certain materials, usually at very low temperatures, to conduct electric current without resistance and power losses, and therefore produce high magnetic fields. For comparable power consumption, the LHC can delivery 25 times the energy and 10,000 times the luminosity of the SPS collider.

LHC beam will provide to four experiments groups (ATLAS, CMS, LHCB, ALICE). ATLAS and CMS experiments are aimed to omni purpose high energy physics, in particular searching Higgs particles and SUSY particles. LHCB experiment is to the B-physics and ALICE is to the high energy nuclear physics by using heavy nucleon interactions (Pb-Pb). LHC consists many type of the super conducting magnets which are produced not only by CERN but also by many another institutes (Japan group is also joining. see figure 1)

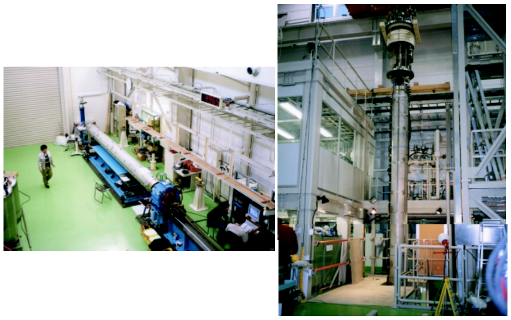


Figure 1: The Quadrupole magnet which is produced by Japan LHC group. Operating Gradient field = 215T/m and length = 6.3m.

Table 1: LHC design parameters.

Parameters	
Energy at Collision	7 TeV
Luminosity	$10^{34} cm^{-2} s^{-1}$
Luminosity lifetime	10 hours
Dipole field at 7 TeV	8.33 T
Bunch separation	24.95 ns

2 ATLAS Detector

ATLAS is a general-purpose experiment for recording proton-proton collisions at LHC. The ATLAS collaboration consists of 149 participating institutions with more than 1850 physicists and engineers (including 15 Japan institutes). The detector design has been optimized to cover the largest possible range of LHC physics: searches for Higgs bosons and alternative schemes for the spontaneous symmetry-breaking mechanism; searches for supersymmetric particles, new gauge bosons, leptoquarks, and quark and lepton compositeness indicating extensions to the Standard Model and new physics beyond it; studies of the origin of CP violation via high-precision measurements of CP-violating B-decays; high-precision measurements of the third quark family such as the top-quark mass and decay properties, rare decays of B-hadrons, spectroscopy of rare B-hadrons, and B^0s-mixing. The ATLAS detector, (shown in the Figure: 2,3), includes an inner tracking detector inside a 2 T solenoid providing an axial field, electromagnetic and hadronic calorimeters outside the solenoid and in the forward regions, and barrel and end-cap air-core-toroid muon spectrometers. The precision measurements for photons, electrons, muons and hadrons, and identification of photons, electrons, muons and b-quark jets are performed over $\eta <$ 2.5. The complete hadronic energy measurement extends over $\eta < 4.7$. The inner tracking detector consists of straw drift tubes (TRT) interleaved with transition radiators for robust pattern recognition and electron identification, and several layers of semiconductor strip (SCT) and pixel detectors providing high-precision space points. The e.m. calorimeter is a lead-Liquid Argon sampling calorimeter with an integrated preshower detector and a presampler layer immediately behind the cryostat wall for energy recovery. The end-cap hadronic calorimeters also use Liquid Argon technology, with copper absorber plates. The end-cap cryostats house the e.m., hadronic

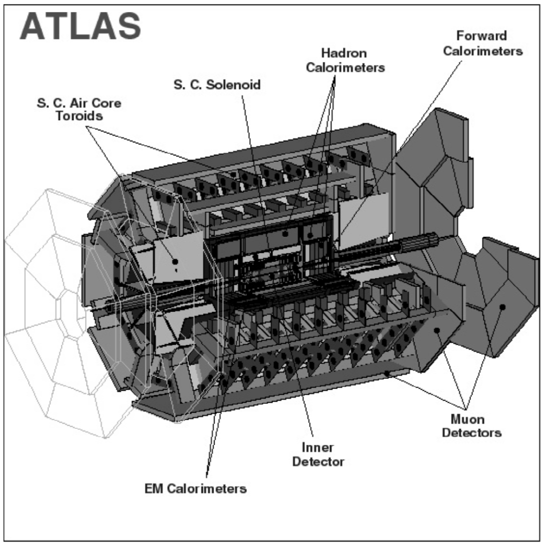


Figure 2: The ATLAS Detector.

and forward calorimeters (tungsten-Liquid Argon sampling). The barrel hadronic calorimeter is an iron-scintillating tile sampling calorimeter with longitudinal tile geometry. Air-core toroids are used for the muon spectrometer. Eight superconducting coils with warm voussoirs are used in the barrel region complemented with superconducting end-cap toroids in the forward regions. The toroids will be instrumented with Monitored Drift Tubes (MDT) (Cathode Strip Chambers (CSC) at large rapidity where there are high radiation levels). The muon trigger and second coordinate measurement for muon tracks are provided by Resistive Plate Chambers (RPC) in the barrel and Thin Gap Chambers (TGC) in the end-caps. The ATLAS trigger scheme is a three-level trigger and data-acquisition system. The first-level trigger signatures are: high-PT muons, electrons, photons, jets and large missing transverse energy. For low-luminosity operation of LHC, a low-PT muon signature will be used in addition. At levels two and three, more complex signatures will be used to select the events to be retained for analysis.

The ATLAS experiment has been on the construction phase for many of its detector components, with a strict schedule to meet the first collisions at LHC from the year 2006. Japan ATLAS group contributes many detector components, which are listed in:

- SCT production,
- Solenoid magnet production,
- TGC production, (see figure 4)
- TGC trigger electronics,
- ATLAS Software production (including detector simulation),
- DAQ system,

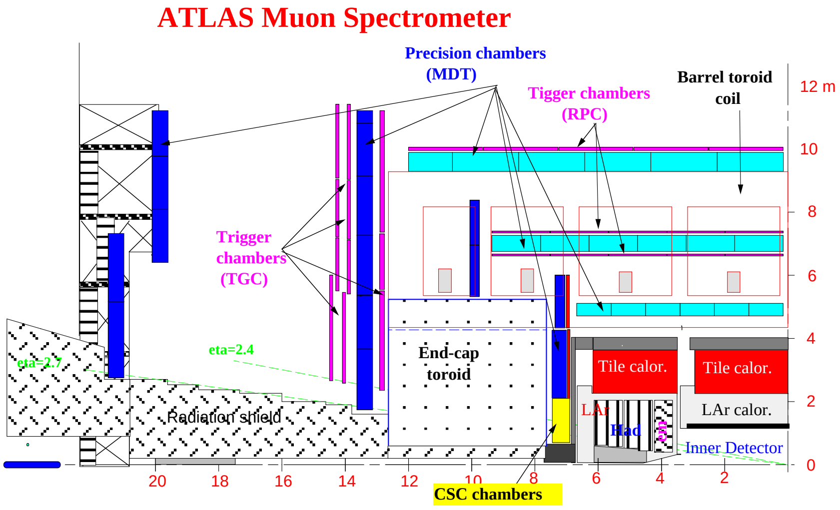


Figure 3: A cross section of ATLAS detector.

- TDC chip production for MDT

3 Construction Schedule

The LHC project schedule requires the initial detector to be installed by the end of Dec 2005.

The availability of the experimental cavern for starting the installation of the infrastructure is currently projected for March 2003, ATLAS is optimizing its installation plans within these two boundaries.

- The installation schedule is separated into 8 phases, and after phase 7 the initial (staged) detector configuration will be ready for the first physics run in 2006 (The installation schedule is summarized in Figure 5).

- The staged components can be installed in a technical shut-down of a few months in 2007 (phase 8 of the installation sequence).

The initial detector configuration for the first physics run consists of the following elements.

Magnet system

A meaningful detector needs the full magnet system, no reasonable staging is possible. Furthermore the construction of the barrel toroid is critical for the schedule, as it will condition the installation for all the other detector components.

Inner Detector

The initial ID configuration will include: All SCT (mechanics and on-detector electronics), All barrel TRT (mechanics and on-detector electronics), A 2-point Pixel system (including the B-layer), TRT end-cap wheels types A and B (mechanics and on-detector electronics), About 80% of the RODs(Read-Out-Driver), which needed for the initially installed detectors.

The following components will be deferred (staging/upgrades): Part of the Pixel system (3rd point), Part of the RODs, Potentially some TRT electronics, TRT end-cap wheels type C,

Figure 4: A scene of TGC production.

Calorimetry

Full basic calorimeter coverage is required for the initial LHC physics (and also as shielding for the muon system).

- LAr Calorimeter Readout electronics staging/upgrades would directly impact the resolutions and background rejections also at low luminosity. The least destructive staging/upgrade possibilities that have been identified are: Reduced ROD system, Reduced redundancy in HV power supplies.
- Tile Calorimeter The following component will be deferred (staging/upgrades): Cryostat-Gap scintillators.

Muon instrumentation

The following components will be deferred (staging/upgrades) for the low luminosity phase: some end-cap MDT chambers, electronics and supports, Half of the CSC chamber layers (mechanics and electronics). The following component can appear as partially staged item: Part of the end-wall MDT chambers.

High Level Trigger and DAQ

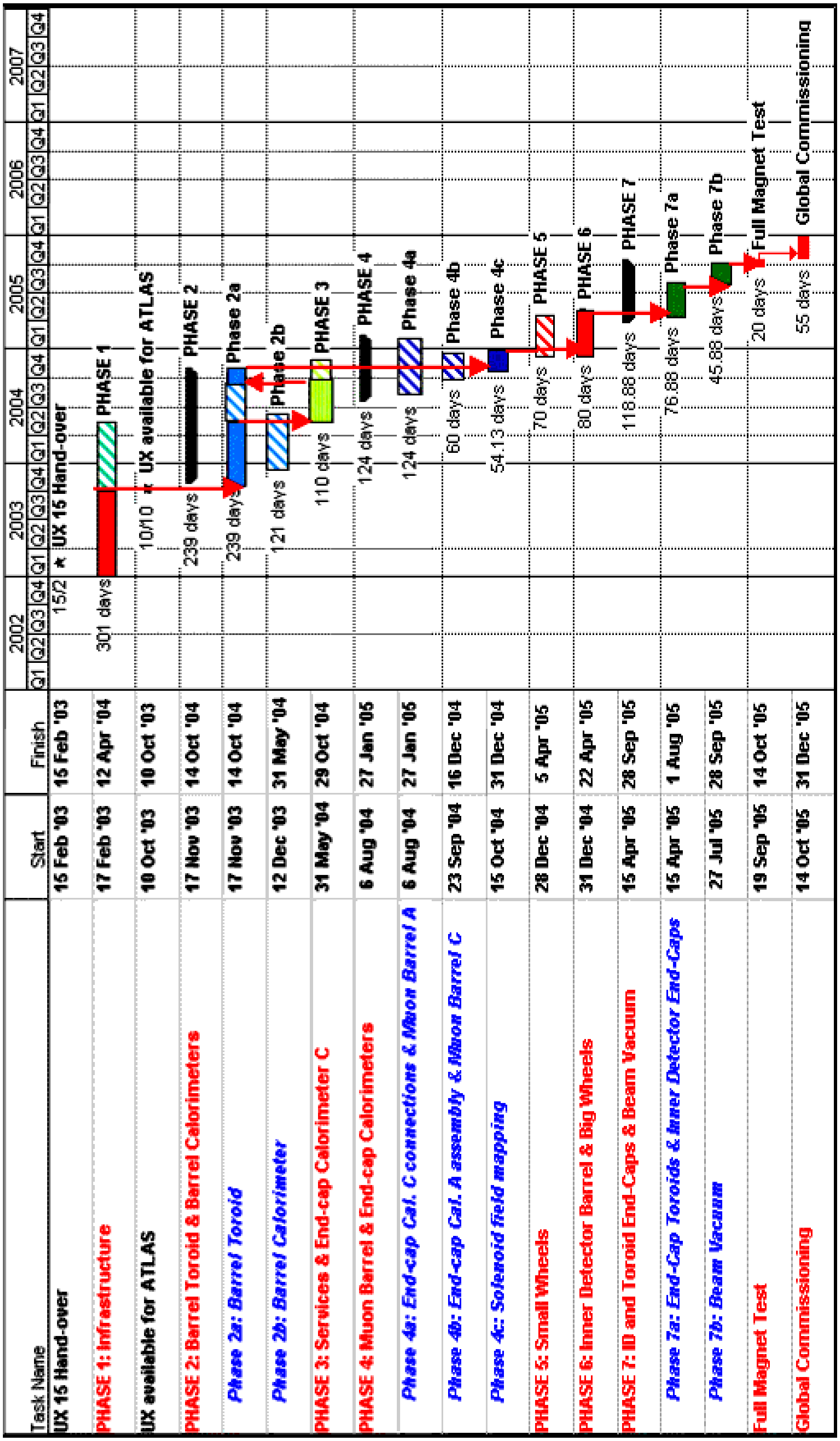
The system needs to be designed to cost in a way that it can be easily upgraded Reduced processors from ATLAS Common Projects.

Shielding

A limited part of the high-luminosity shielding can be deferred by about one year to ease funding profiles and open late in-kind CP contributions.

4 The physics implication of the initial detector

The physics implication of the initial detector configuration has been studied for the test case of the low mass Higgs discovery potential during the first physics run (10 fb^{-1}). The figure 6



Task Name	Start	Finish
UX 15 Hand-over	15 Feb '03	15 Feb '03
PHASE 1: Infrastructure	17 Feb '03	12 Apr '04
UX available for ATLAS	10 Oct '03	10 Oct '03
PHASE 2: Barrel Toroid & Barrel Calorimeters	17 Nov '03	14 Oct '04
Phase 2a: Barrel Toroid	17 Nov '03	14 Oct '04
Phase 2b: Barrel Calorimeter	12 Dec '03	31 May '04
PHASE 3: Services & End-cap Calorimeter C	31 May '04	29 Oct '04
PHASE 4: Muon Barrel & End-cap Calorimeters	6 Aug '04	27 Jan '05
Phase 4a: End-cap Cal. C connections & Muon Barrel A	6 Aug '04	27 Jan '05
Phase 4b: End-cap Cal. A assembly & Muon Barrel C	23 Sep '04	16 Dec '04
Phase 4c: Solenoid field mapping	15 Oct '04	31 Dec '04
PHASE 5: Small Wheels	28 Dec '04	5 Apr '05
PHASE 6: Inner Detector Barrel & Big Wheels	31 Dec '04	22 Apr '05
PHASE 7: ID and Toroid End-Caps & Beam Vacuum	15 Apr '05	28 Sep '05
Phase 7a: End-Cap Toroids & Inner Detector End-Caps	15 Apr '05	1 Aug '05
Phase 7b: Beam Vacuum	27 Jul '05	28 Sep '05
Full Magnet Test	19 Sep '05	14 Oct '05
Global Commissioning	14 Oct '05	31 Dec '05

Figure 5: ATLAS detector installation schedule.

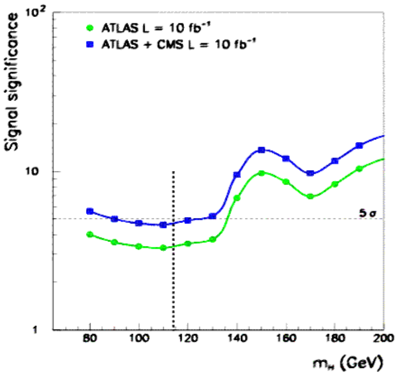


Figure 6: Higgs signal significance plot as a function of Higgs mass.

Table 2: Expected number of signal and background events, and significance, for m_{Higgs} = 115 GeV in ATLAS alone.

	h → γγ	ttH → tt bb	Both Channels
S(Signal)	150	15	
B(Background)	3900	45	
S/B	0.04	0.3	
$S\sqrt{B}$	2.4	2.2	3.2

shows the SM Higgs signal significance for the complete (TDR [2]) ATLAS detector (also see Table: 2) and for combining ATLAS and CMS.

The main impact of the initial detector configuration is that the discovery potential for the Higgs signal in several final states will be degraded by about 10% (meaning that 20% more integrated luminosity is required to compensate). These effects are summarized in Table: 3. Possible penalties on the pattern recognition performance from the less robust tracking systems are not included in these results.

Additional staging of the ATLAS detector, which would in many cases (such as calorimetry, TRT, end-cap magnets) imply a full block of detector sub-system missing, would lead to heavy cuts into the physics, not compatible with the goals of the first physics run of LHC. There are two indicative examples:

- One end-cap LAr calorimeter missing would reduce the Higgs signal significance by 30% in the electron and gamma channels and loose completely SUSY as shown in the figure 7.

- No muon instrumentation in one end-cap would affect the Higgs signal significance at a similar level.

Table 3: Possible penalties on the pattern recognition performance from the less robust tracking systems.

Staged items	Main impact expected on	Loss in Significance
One pixel layer	ttH → ttbb	∼ 8%
Outermost TRT wheel + MDT	H →	∼7%
Cryostat Gap scintillators	H → 4e	∼8%
MDT	A/H → 2 μ	∼10% from m ∼ 300 GeV

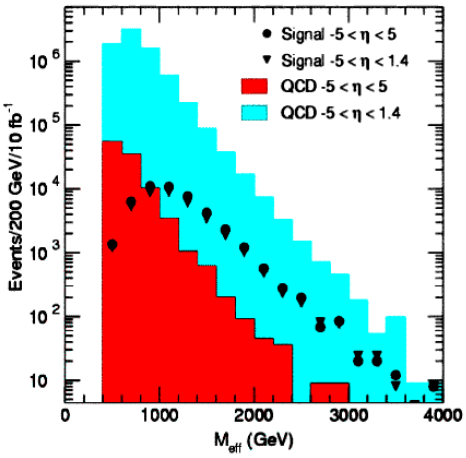


Figure 7: Effective mass distributions for SUSY particle and QCD backgrounds.

5 Conclusions

Large Hadron Collider (LHC) is under construction at the CERN Laboratory in Switzerland. Four experiments (ATLAS, CMS, LHCb, ALICE) will try to study the new physics by LHC from 2006. Many Japan instinutes are joining with ATLAS experiment (including also ICEPP). The ATLAS detector construction is in general progressing well along the planning for an initial detector operational for the first physics run commencing in summer 2006. The first large components of the Common Projects have been delivered to CERN and are ready for integration work. The same is the case for several of the detector (sub-) systems, in particular large pre-assembly and module integrations will start in 2002 for the calorimetry. Large-scale system tests are being made, or are in the final preparation phase for 2002, for all of the (sub-) systems, along with continued calibration efforts in test beams. The next year will see a steep increase in integration and pre-operation activities at CERN. In parallel a broad spectrum of coherent software, computing and physics preparations are in full swing, the Data Challenges will act as an important focal point for these activities. The production progress and the many activities are accessible on the Web at http://aenews.cern.ch or http://atlasinfo.cern.ch/Atlas/Welcome.html.

References

1. Design study of the Large Hadron Collider (LHC), CERN Yellow Report CERN-AC-DI-FA-90-06 (1990).
2. ATLAS Technical Design Reports, http://atlasinfo.cern.ch/ATLAS/internal/tdr.html.