

# ATLAS experiment

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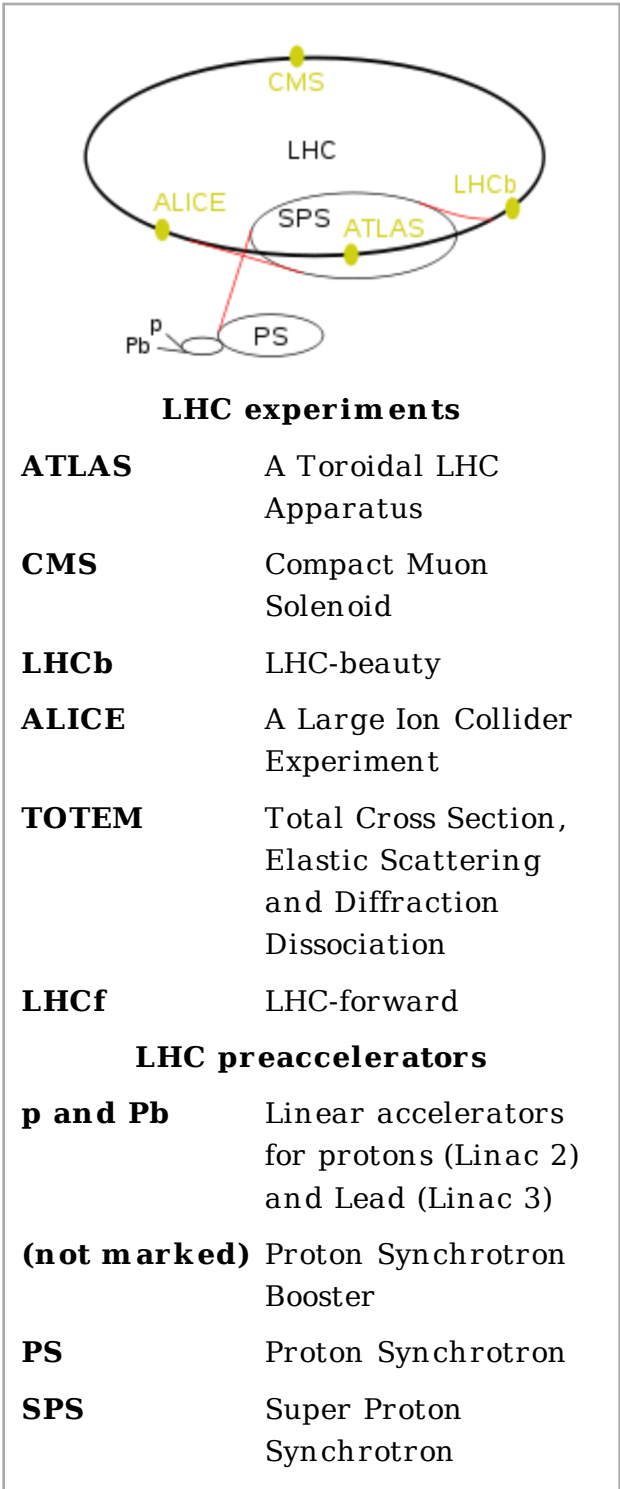


**ATLAS (A Toroidal LHC ApparatuS)** is one of the six particle detector experiments (ALICE, ATLAS, CMS, TOTEM, LHCb, and LHCf) constructed at the Large Hadron Collider (LHC), a new particle accelerator at the European Organization for Nuclear Research (CERN) in Switzerland.

ATLAS is 44 metres long and 25 metres in diameter, weighing about 7,000 tonnes. The project is led by Fabiola Gianotti and involves roughly 2,000 scientists and engineers at 165 institutions in 35 countries.<sup>[1]</sup> The construction was originally scheduled to be completed in June 2007, but was ready and detected its first beam events on 10 September 2008.<sup>[2]</sup> The experiment is designed to observe phenomena that involve highly massive particles which were not observable using earlier lower-energy accelerators and might shed light on new theories of particle physics beyond the Standard Model.

The *ATLAS collaboration*, the group of physicists building the detector, was formed in 1992 when the proposed EAGLE (**Ex**periment for **A**ccurate **G**amma, **L**epton and **E**nergy **M**easurements) and ASCOT (**A**pparatus with **S**uper **C**onducting **T**oroids) collaborations merged their efforts into building a single, general-purpose particle detector for the Large Hadron Collider.<sup>[3]</sup> The design was a combination of those two previous designs, as well as the detector research and development that had been done for the Superconducting Supercollider. The ATLAS experiment was proposed in its current form in 1994, and officially funded by

Large Hadron Collider (LHC)



the CERN member countries beginning in 1995. Additional countries, universities, and laboratories joined in subsequent years, and further institutions and physicists continue to join the collaboration even today. The work of construction began at individual institutions, with detector components shipped to CERN and assembled in the ATLAS experimental pit beginning in 2003.

ATLAS is designed as a general-purpose detector. When the proton beams produced by the Large Hadron Collider interact in the center of the detector, a variety of different particles with a broad range of energies may be produced. Rather than focusing on a particular physical process, ATLAS is designed to measure the broadest possible range of signals. This is intended to ensure that, whatever form any new physical processes or particles might take, ATLAS will be able to detect them and measure their properties. Experiments at earlier colliders, such as the Tevatron and Large Electron-Positron Collider, were designed based on a similar philosophy. However, the unique challenges of the Large Hadron Collider—its unprecedented energy and extremely high rate of collisions—require ATLAS to be larger and more complex than any detector ever built.

## Contents

- 1 Background
- 2 Physics Program
- 3 Components
  - 3.1 Inner detector
  - 3.2 Calorimeters
  - 3.3 Muon spectrometer
  - 3.4 Magnet system
  - 3.5 Forward detectors
- 4 Data systems and analysis
- 5 Hall of Fame
- 6 Notes
- 7 References
- 8 External links

## Background

The first cyclotron, an early type of particle accelerator, was built by Ernest O. Lawrence in 1931, with a radius of just a few centimetres and a particle energy of 1 megaelectronvolt (MeV). Since then, accelerators have grown enormously in the quest to produce new particles of greater and greater mass. As accelerators have grown, so too has the list of known particles that they might be used to investigate. The most comprehensive model of particle interactions available today is known as the Standard Model of Particle Physics. With the important exception of the Higgs boson, all of the particles predicted by the model have been observed. While the standard model predicts that quarks, electrons, and neutrinos should exist, it does not explain why the masses of the particles are so very different. Due to this violation of "naturalness" most particle physicists believe it is possible that the Standard Model will break down at energies beyond the current energy frontier of about one teraelectronvolt (TeV) (set at the Tevatron). If such beyond-the-Standard-Model physics is observed it is hoped that a new model, which is identical to the Standard Model at energies thus far probed, can be developed to describe particle physics at higher energies. Most of the currently proposed theories predict new higher-mass particles, some of which are hoped to be light enough to be observed by ATLAS. At 27 kilometres in circumference, the Large Hadron Collider (LHC) will collide two beams of protons together, each proton carrying about 7 TeV of energy — enough energy to produce particles with masses up to roughly ten times more massive than any particles currently known — assuming of course that such particles exist. With an energy seven million times that of the first accelerator the LHC represents a "new generation" of particle accelerators.

Particles that are produced in accelerators must also be observed, and this is the task of particle detectors. While interesting phenomena may occur when protons collide it is not enough to just produce them. Particle detectors must be built to detect particles, their masses, momentum, energies, charges, and nuclear spins. In order to identify all particles produced at the interaction point where the particle beams collide, particle detectors are usually designed with a similarity to an onion. The layers are made up of detectors of different types, each of which is adept at observing specific types of particles. The different features that particles leave in each layer of the detector allow for effective particle identification and accurate measurements of energy and momentum. (The role of each layer in the detector is discussed below.) As the energy of the particles produced by the accelerator increases, the detectors attached to it must grow to



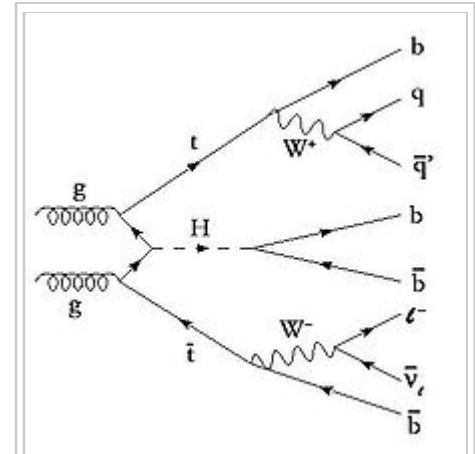
ATLAS experiment detector under construction in October 2004 in its experimental pit; the current status of construction can be seen here ([http://atlas-eye-webpub.web.cern.ch/atlas-eye-webpub/web-sites/pages/UX15\\_webcams.htm](http://atlas-eye-webpub.web.cern.ch/atlas-eye-webpub/web-sites/pages/UX15_webcams.htm)). Note the people in the background, for comparison.

effectively measure and stop higher-energy particles. ATLAS is the largest detector ever built at a particle collider as of 2008.<sup>[1]</sup>

## Physics Program

ATLAS is intended to investigate many different types of physics that might become detectable in the energetic collisions of the LHC. Some of these are confirmations or improved measurements of the Standard Model, while many others are searches for new physical theories.

One of the most important goals of ATLAS is to investigate a missing piece of the Standard Model, the Higgs boson.<sup>[4]</sup> The Higgs mechanism, which includes the Higgs boson, is invoked to give masses to elementary particles, giving rise to the differences between the weak force and electromagnetism by giving the W and Z bosons masses while leaving the photon massless. If the Higgs boson is not discovered by ATLAS, it is expected that another mechanism of electroweak symmetry breaking that explains the same phenomena, such as technicolour, will be discovered. The Standard Model is simply not mathematically consistent at the energies of the LHC without such a mechanism. The Higgs boson would be detected by the particles it decays into; the easiest to observe are two photons, two bottom quarks, or four leptons. Sometimes these decays can only be definitively identified as originating with the Higgs boson when they are associated with additional particles; for an example of this, see the diagram at right.



A schematic, called a Feynman diagram, of two virtual gluons from colliding LHC protons interacting to produce a hypothetical Higgs boson, a top quark, and an antitop quark. These in turn decay into a specific combination of quarks and leptons that is very unlikely to be duplicated by other processes. Collecting sufficient evidence of signals like this one may eventually allow ATLAS collaboration members to discover the Higgs boson.

The asymmetry between the behavior of matter and antimatter, known as CP violation, will also be investigated.<sup>[4]</sup> Current CP-violation experiments, such as BaBar and Belle, have not yet detected sufficient CP violation in the Standard Model to explain the lack of detectable antimatter in the universe. It is possible that new models of physics will introduce additional CP violation, shedding light on this problem; these models might either be detected directly by the production of new particles, or indirectly by measurements made of the properties of B-mesons. (LHCb, an LHC experiment dedicated to B-mesons, is likely to be better suited to the latter.)<sup>[5]</sup>

The top quark, discovered at Fermilab in 1995, has thus far had its properties measured only approximately. With much greater energy and greater collision rates, LHC will produce a tremendous number of top quarks, allowing ATLAS to make much more precise measurements of its mass and interactions with other particles.<sup>[6]</sup> These measurements will provide indirect information on the details of the Standard Model, perhaps revealing inconsistencies that point to new physics. Similar precision measurements will be made of other known particles; for example, ATLAS may eventually measure the mass of the W boson twice as accurately as has previously been achieved.

Perhaps the most exciting lines of investigation are those searching directly for new models of physics. One theory that is the subject of much current research is broken supersymmetry. The theory is popular because it could potentially solve a number of problems in theoretical physics and is present in almost all models of string theory. Models of supersymmetry involve new, highly massive particles; in many cases these decay into high-energy quarks and stable heavy particles that are very unlikely to interact with ordinary matter. The stable particles would escape the detector, leaving as a signal one or more high-energy quark jets and a large amount of "missing" momentum. Other hypothetical massive particles, like those in Kaluza-Klein theory, might leave a similar signature, but its discovery would certainly indicate that there was some kind of physics beyond the Standard Model.

One remote possibility (if the universe contains large extra dimensions) is that microscopic black holes might be produced by the LHC.<sup>[7]</sup> These would decay immediately by means of Hawking radiation, producing all particles in the Standard Model in equal numbers and leaving an unequivocal signature in the ATLAS detector.<sup>[8]</sup> In fact, if this occurs, the primary studies of Higgs bosons and top quarks would be conducted on those produced by the black holes.

## Components

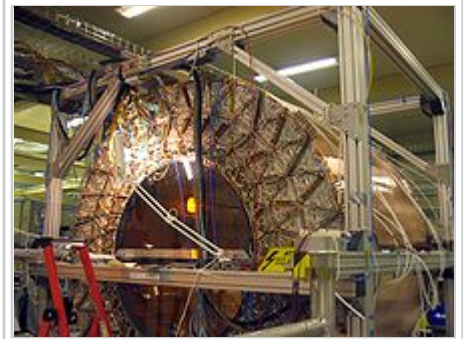
The ATLAS detector consists of a series of ever-larger concentric cylinders around the interaction point where the proton beams from the LHC collide. It can be divided into four major parts: the Inner Detector, the calorimeters, the muon spectrometer and the magnet systems.<sup>[9]</sup> Each of these is in turn made of multiple layers. The detectors are complementary: the Inner Detector tracks particles precisely, the calorimeters measure the energy of easily stopped particles, and the muon system makes additional measurements of highly penetrating muons. The two magnet systems bend charged particles in the Inner Detector and the muon spectrometer, allowing their momenta to be measured.

The only established stable particles that cannot be detected directly are neutrinos; their presence is inferred by noticing a momentum imbalance among detected particles. For this to work, the detector must be "hermetic", and detect

all non-neutrinos produced, with no blind spots. Maintaining detector performance in the high radiation areas immediately surrounding the proton beams is a significant engineering challenge.

## Inner detector

The Inner Detector begins a few centimetres from the proton beam axis, extends to a radius of 1.2 metres, and is seven metres in length along the beam pipe. Its basic function is to track charged particles by detecting their interaction with material at discrete points, revealing detailed information about the type of particle and its momentum.<sup>[10]</sup> The magnetic field surrounding the entire inner detector causes charged particles to curve; the direction of the curve reveals a particle's charge and the degree of curvature reveals its momentum. The starting points of the tracks yield useful information for identifying particles; for example, if a group of tracks seem to originate from a point other than the original proton-proton collision, this may be a sign that the particles came from the decay of a bottom quark (see B-tagging). The Inner Detector has three parts, which are explained below.



The **ATLAS TRT** central section, the outermost part of the Inner Detector, as of September 2005, assembled on the surface and taking data from cosmic rays.

The Pixel Detector, the innermost part of the detector, contains three layers and three disks on each end-cap, with a total of 1744 *modules*, each measuring two centimetres by six centimetres. The detecting material is 250  $\mu\text{m}$  thick silicon. Each module contains 16 readout chips and other electronic components. The smallest unit that can be read out is a pixel (each 50 by 400 micrometres); there are roughly 47,000 pixels per module. The minute pixel size is designed for extremely precise tracking very close to the interaction point. In total, the Pixel Detector will have over 80 million readout channels, which is about 50% of the total readout channels; such a large count created a design and engineering challenge. Another challenge was the radiation the Pixel Detector will be exposed to because of its proximity to the interaction point, requiring that all components be radiation hardened in order to continue operating after significant exposures.

The Semi-Conductor Tracker (SCT) is the middle component of the inner detector. It is similar in concept and function to the Pixel Detector but with long, narrow strips rather than small pixels, making coverage of a larger area practical. Each strip measures 80 micrometres by 12.6 centimetres. The SCT is the most critical part of the inner detector for basic tracking in the plane perpendicular to the beam, since it measures particles over a much larger area

than the Pixel Detector, with more sampled points and roughly equal (albeit one dimensional) accuracy. It is composed of four double layers of silicon strips, and has 6.2 million readout channels and a total area of 61 square meters.

The Transition radiation tracker (TRT), the outermost component of the inner detector, is a combination of a straw tracker and a transition radiation detector. The detecting elements are drift tubes (straws), each four millimetres in diameter and up to 144 centimetres long. The uncertainty of track position measurements (position resolution) is about 200 micrometres, not as precise as those for the other two detectors, a necessary sacrifice for reducing the cost of covering a larger volume and having transition radiation detection capability. Each straw is filled with gas that becomes ionized when a charged particle passes through. The straws are held at about -1500V, driving the negative ions to a fine wire down the centre of each straw, producing a current pulse (signal) in the wire. The wires with signals create a pattern of 'hit' straws that allow the path of the particle to be determined. Between the straws, materials with widely varying indices of refraction cause ultra-relativistic charged particles to produce transition radiation and leave much stronger signals in some straws. Xenon gas is used to increase the number of straws with strong signals. Since the amount of transition radiation is greatest for highly relativistic particles (those with a speed very near the speed of light), and particles of a particular energy have a higher speed the lighter they are, particle paths with many very strong signals can be identified as the lightest charged particles, electrons. The TRT has about 351,000 straws in total.

## Calorimeters



The calorimeters are situated outside the solenoidal magnet that surrounds the inner detector. Their purpose is to measure the energy from particles by absorbing it. There are two basic calorimeter systems: an inner electromagnetic calorimeter and an outer hadronic calorimeter.<sup>[11]</sup> Both are *sampling calorimeters*; that is, they absorb energy in high-density metal and periodically sample the shape of the resulting particle shower, inferring the energy of the original particle from this measurement.

The electromagnetic (EM) calorimeter absorbs energy from particles that interact electromagnetically, which include charged particles and photons. It has high precision, both in the amount of energy absorbed and in the precise location of the energy deposited. The angle between the particle's trajectory and the detector's beam axis (or more precisely the pseudorapidity) and its angle within the perpendicular plane are both measured to within roughly 0.025 radians. The energy-absorbing materials are lead and stainless steel, with liquid argon as the sampling material, and a cryostat is required around the EM calorimeter to keep it sufficiently cool.

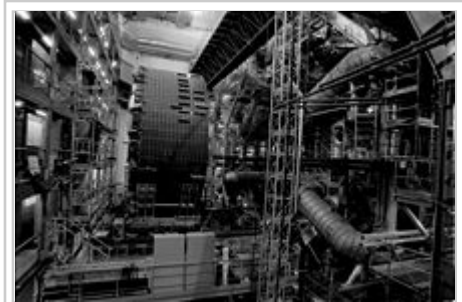
The hadron calorimeter absorbs energy from particles that pass through the EM calorimeter, but do interact via the strong force; these particles are primarily hadrons. It is less precise, both in energy magnitude and in the localization (within about 0.1 radians only).<sup>[5]</sup> The energy-absorbing material is steel, with scintillating tiles that sample the energy deposited. Many of the features of the calorimeter are chosen for their cost-effectiveness; the instrument is large and comprises a huge amount of construction material: the main part of the calorimeter—the tile calorimeter—is eight metres in diameter and covers 12 metres along the beam axis. The far-forward sections of the hadronic calorimeter are contained within the EM calorimeter's cryostat, and use liquid argon as it does.

## Muon spectrometer

The muon spectrometer is an extremely large tracking system, extending from a radius of 4.25 m around the calorimeters out to the full radius of the detector



September 2005: the main barrel section of the ATLAS hadronic calorimeter, waiting to be moved inside the toroid magnets.



One of the sections of the extensions of the hadronic calorimeter, waiting to be inserted in late February 2006

(11 m).<sup>[9]</sup> Its tremendous size is required to accurately measure the momentum of muons, which penetrate other elements of the detector; the effort is vital because one or more muons are a key element of a number of interesting physical processes, and because the total energy of particles in an event could not be measured accurately if they were ignored. It functions similarly to the inner detector, with muons curving so that their momentum can be measured, albeit with a different magnetic field configuration, lower spatial precision, and a much larger volume. It also serves the function of simply identifying muons—very few particles of other types are expected to pass through the calorimeters and subsequently leave signals in the muon spectrometer. It has roughly one million readout channels, and its layers of detectors have a total area of 12,000 square meters.

## **Magnet system**

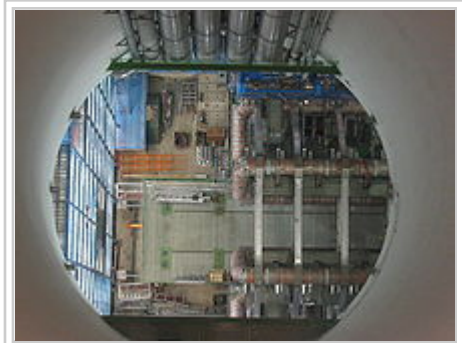
The ATLAS detector uses two large superconducting magnet systems to bend charged particles so that their momenta can be measured. This bending is due to the Lorentz force, which is proportional to velocity. Since all particles produced in the LHC's proton collisions will be traveling at very close to the speed of light, the force on particles of different momenta is equal. (In the theory of relativity, momentum is *not* proportional to velocity at such speeds.) Thus high-momentum particles will curve very little, while low-momentum particles will curve significantly; the amount of curvature can be quantified and the particle momentum can be determined from this value.

The inner solenoid produces a two tesla magnetic field surrounding the Inner Detector.<sup>[12]</sup> This high magnetic field allows even very energetic particles to curve enough for their momentum to be determined, and its nearly uniform direction and strength allow measurements to be made very precisely. Particles with momenta below roughly 400 MeV will be curved so strongly that they will loop repeatedly in the field and most likely not be measured; however, this energy is very small compared to the several TeV of energy released in each proton collision.

The outer toroidal magnetic field is produced by eight very large air-core superconducting barrel loops and two end-caps, all situated outside the calorimeters and within the muon system.<sup>[12]</sup> This magnetic field is 26 metres long and 20 metres in diameter, and it stores 1.6 gigajoules of energy. Its magnetic field is not uniform, because a solenoid magnet of sufficient size would be prohibitively expensive to build. Fortunately, measurements need to be much less precise to measure momentum accurately in the large volume of the muon system.

## Forward detectors

The ATLAS detector will be complemented with a set of detectors in the very



The ends of four of eight ATLAS toroid magnets, seen from the surface, about 90 metres above, in September 2005.



Part of the ATLAS, as it looked February 2007.

forward region. These detectors will be located in the LHC tunnel far away from the interaction point. The basic idea is to measure elastic scattering at very small angles in order to get a handle on the absolute luminosity at the interaction point of ATLAS.

## Data systems and analysis

The detector generates unmanageably large amounts of raw data, about 25 megabytes per event (raw; zero suppression reduces this to 1.6 MB) times 40 million beam crossings per second in the center of the detector, for a total of 1 petabyte/second of raw data.<sup>[13]</sup> The trigger system uses simple information to identify, in real time, the most interesting events to retain for detailed analysis. There are three trigger levels, the first based in electronics on the detector and the other two primarily run on a large computer cluster near the detector. After the first-level trigger, about 100,000 events per second have been selected. After the third-level trigger, a few hundred events remain to be stored for further analysis. This amount of data will require over 100 megabytes of disk space per second — at least a petabyte each year.<sup>[14]</sup>

Offline event reconstruction will be performed on all permanently stored events, turning the pattern of signals from the detector into physics objects, such as jets, photons, and leptons. Grid computing will be extensively used for event reconstruction, allowing the parallel use of university and laboratory computer networks throughout the world for the CPU-intensive task of reducing large quantities of raw data into a form suitable for physics analysis. The software for these tasks has been under development for many years, and will continue to be refined once the experiment is running.

Individuals and groups within the collaboration will write their own code to perform further analysis of these objects, searching in the pattern of detected particles for particular physical models or hypothetical particles. These studies are already being developed and tested on detailed simulations of particles and their interactions with the detector. Such simulations give physicists a good sense of which new particles can be detected and how long it will take to confirm them with sufficient statistical certainty.

## Hall of Fame

The Transition radiation tracker was built by groups from CERN, Denmark, Poland, Russia, Sweden, Turkey, and the US. The central, or barrel, section was built in the US by groups at Duke University, Hampton University, and Indiana University. The electronics for the entire TRT was built by the University of Pennsylvania and Yale University.

## Notes

- <sup>a b</sup> CERN (2006-11-20). "World's largest superconducting magnet switches on" (<http://press.web.cern.ch/Press/PressReleases/Releases2006/PR17.06E.html>) . Press release. <http://press.web.cern.ch/Press/PressReleases/Releases2006/PR17.06E.html>. Retrieved 2007-03-03.
- <sup>a</sup> CERN. "First beam and first events in ATLAS" (<http://www.atlas.ch/news/2008/first-beam-and-event.html>) . <http://www.atlas.ch/news/2008/first-beam-and-event.html>. Retrieved 2008-09-13.
- <sup>a</sup> "ATLAS Collaboration records" (<http://library.cern.ch/archives/isad/isaatlas.html>) . CERN Archive. <http://library.cern.ch/archives/isad/isaatlas.html>. Retrieved 2007-02-25.
- <sup>a b</sup> "Introduction and Overview" (<http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node4.html#SECTION00400000000000000000>) . *ATLAS Technical Proposal*. CERN. 1994. <http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node4.html#SECTION00400000000000000000>.
- <sup>a b</sup> \*N. V. Krasnikov, V. A. Matveev (September 1997). "Physics at LHC" (<http://arxiv.org/abs/hep-ph/9703204>) . *Physics of Particles and Nuclei* **28** (5): 441–470. doi:10.1134/1.953049 (<http://dx.doi.org/10.1134/1.953049>) . <http://arxiv.org/abs/hep-ph/9703204>.
- <sup>a</sup> "Top-Quark Physics" (<http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node416.html#SECTION0024100000000000000000>) . *ATLAS Technical Proposal*. CERN. 1994. <http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node416.html#SECTION0024100000000000000000>.
- <sup>a</sup> C.M. Harris, M.J. Palmer, M.A. Parker, P. Richardson, A. Sabetfakhri and B.R. Webber (2005). "Exploring higher dimensional black holes at the Large Hadron Collider". *Journal of High Energy Physics* **5**: 053. doi:10.1088/1126-6708/2005/05/053 (<http://dx.doi.org/10.1088/1126-6708/2005/05/053>) .
- <sup>a</sup> J. Tanaka, T. Yamamura, S. Asai, J. Kanzaki (2005). "Study of Black Holes with the ATLAS detector at the LHC" (<http://www.springerlink.com/content/x067g845688470r4/>) . *The European Physical Journal C* **41** (s2): 19–33. doi:10.1140/epjcd/s2005-02-008-x (<http://dx.doi.org/10.1140/epjcd/s2005-02-008-x>) . <http://www.springerlink.com/content/x067g845688470r4/>.
- <sup>a b</sup> "Overall detector concept" (<http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node6.html#SECTION00420000000000000000>) . *ATLAS Technical Proposal*. CERN. 1994. <http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node6.html#SECTION00420000000000000000>.
- <sup>a</sup> "Inner detector" (<http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node10.html#SECTION00433000000000000000>) . *ATLAS Technical Proposal*. CERN. 1994. <http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node10.html#SECTION00433000000000000000>.

- /node10.html#SECTION00433000000000000000.
11. ^ "Calorimetry" (<http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node9.html#SECTION00432000000000000000>) . *ATLAS Technical Proposal*. CERN. 1994. <http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node9.html#SECTION00432000000000000000>.
  12. ^ <sup>a</sup> <sup>b</sup> "Magnet system" (<http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node8.html#SECTION00431000000000000000>) . *ATLAS Technical Proposal*. CERN. 1994. <http://atlas.web.cern.ch/Atlas/TP/NEW/HTML/tp9new/node8.html#SECTION00431000000000000000>.
  13. ^ Marjorie Shapiro. (June 18, 2007). *Supersymmetry, Extra Dimensions and the Origin of Mass: Exploring the Nature of the Universe Using PetaScale Data Analysis* (<http://www.youtube.com/watch?v=-cdbnwaW34g>) . Event occurs at 35:00. <http://www.youtube.com/watch?v=-cdbnwaW34g>. Retrieved 2007-12-08. See also 32:30 for information on the various trigger levels.
  14. ^ "The sensitive giant" (<http://www.eurekalert.org/features/doe/2004-03/dnal-tsg032604.php>) . *United States Department of Energy Research News*. March 2004. <http://www.eurekalert.org/features/doe/2004-03/dnal-tsg032604.php>.

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## External links

- Official ATLAS Public Webpage (<http://atlas.ch>) at CERN (*The "award winning ATLAS movie" is a very good general introduction!*)
- Official ATLAS Collaboration Webpage (<http://atlas.web.cern.ch/Atlas/internal/Welcome.html>) at CERN (*Lots of technical and logistical information*)
- ATLAS Cavern Webcams ([http://atlaseye-webpub.web.cern.ch/atlaseye-webpub/web-sites/pages/UX15\\_webcams.htm](http://atlaseye-webpub.web.cern.ch/atlaseye-webpub/web-sites/pages/UX15_webcams.htm))
- Time lapse video of the assembly ([http://www.youtube.com/watch?v=kVrUR\\_S0ykk](http://www.youtube.com/watch?v=kVrUR_S0ykk))
- ATLAS section from US/LHC Website ([http://www.uslhq.us/What\\_is\\_the\\_LHC](http://www.uslhq.us/What_is_the_LHC))

/Experiments/ATLAS)

- PhysicsWorld article on LHC and experiments (<http://physicsweb.org/articles/world/13/5/9/1>)
- New York Times article on LHC and experiments (<http://www.nytimes.com/2000/11/21/science/21HIGG.html?ex=1130040000&en=5282f51cf019f1b7&ei=5070&ex=1082001600&en=39ccf65ca6047eb2&ei=5070>)
- United States Department of Energy article on ATLAS (<http://www.eurekalert.org/features/doe/2004-03/dnal-tsg032604.php>)
- The Large Hadron Collider ATLAS Experiment Virtual Reality (VR) photography panoramas (<http://www.petermccready.com/portfolio/05091901.html>)
- Large Hadron Collider Project Director Dr Lyn Evans CBE on the engineering behind the ATLAS experiment, *Ingenia* magazine, June 2008 (<http://www.ingenia.org.uk/ingenia/articles.aspx?Index=489>)
- Atlas Experiment News and social networking (<http://www.AtlasExperiment.net>)
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- Press release from October 2008 by EB Industries regarding the ATLAS project (<http://ebindustries.com/ATLAS%20article.pdf>)

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