

ATLAS

Cutaway view of the ATLAS detector for CERN's LHC proton-proton collider. The outer toroidal magnet will extend over 26 metres, with an outer diameter of almost 20 metres. The total weight of the detector is 7,000 tonnes.

In Greek mythology, Atlas was a Titan who had to hold up the heavens with his hands as a punishment for having taken part in a revolt against the Olympians. For LHC, the ATLAS detector will also have an onerous physics burden to bear, but this is seen as a golden opportunity rather than a punishment.

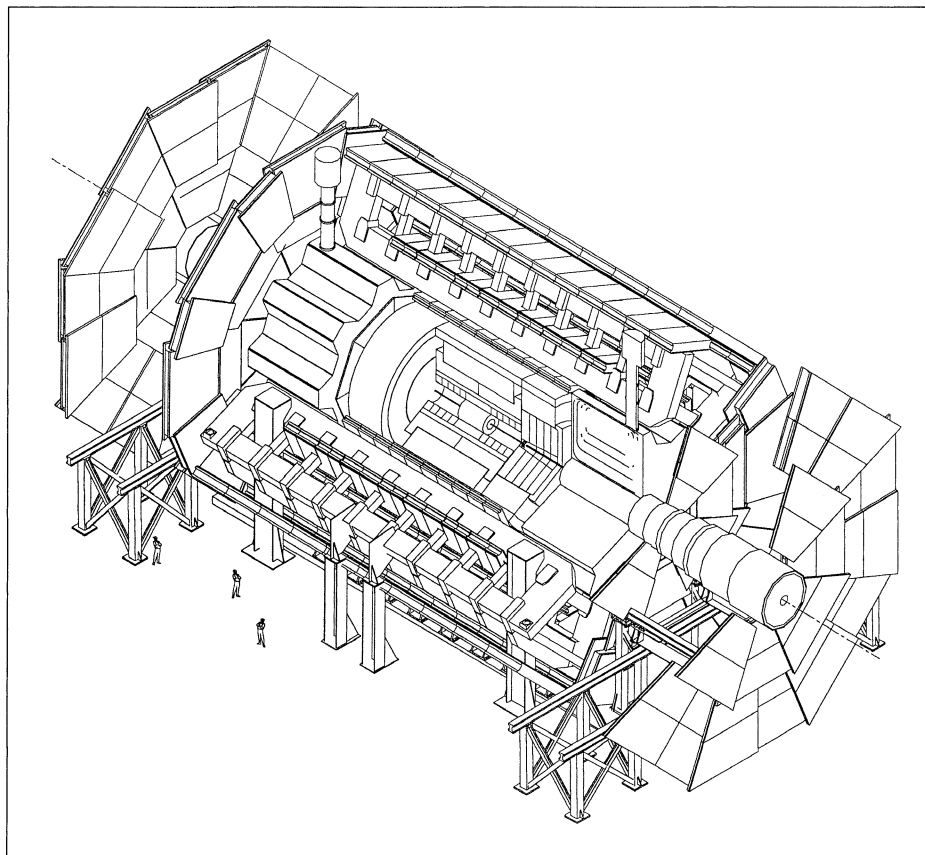
The major physics goal of CERN's LHC proton-proton collider is the quest for the long-awaited 'higgs' mechanism which drives the spontaneous symmetry breaking of the electroweak Standard Model picture. The large ATLAS collaboration proposes a large general-purpose detector to exploit the full discovery potential of LHC's proton collisions.

LHC will provide proton-proton collision luminosities at the awe-inspiring level of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, with initial running in at 10^{33} . The ATLAS philosophy is to handle as many signatures as possible at all luminosity levels, with the initial running providing more complex possibilities.

The ATLAS concept was first presented as a Letter of Intent to the LHC Committee in November 1992. Following initial presentations at the Evian meeting ('Towards the LHC Experimental Programme') in March of that year, two ideas for general-purpose detectors, the ASCOT and EAGLE schemes, merged, with Friedrich Dydak (MPI Munich) and Peter Jenni (CERN) as ATLAS co-spokesmen.

Since the initial Letter of Intent presentation, the ATLAS design has been optimized and developed, guided by physics performance studies and the LHC-oriented detector R&D programme (April/May, page 3).

The overall detector concept is characterized by an inner superconducting solenoid (for inner tracking) and large superconducting air-core



toroids outside the calorimetry. This solution avoids constraining the calorimetry while providing a high resolution, large acceptance and robust detector.

The outer magnet will extend over a length of 26 metres, with an outer diameter of almost 20 metres. The total weight of the detector is 7,000 tonnes. Fitted with its end-cap toroids, the outer magnet alone will weigh 1,400 tonnes. Estimated total cost of the detector is 450 million Swiss francs.

To achieve its basic aims, the ATLAS design has gone for: very good electromagnetic calorimetry for electron and photon identification and measurements, complemented by complete (hermetic) jet and missing energy calorimetry;

efficient tracking at high luminosity for lepton momentum measurements, for heavy quark tagging, and for good electron and photon identification, as well as heavy flavour vertexing and reconstruction capability; precision muon momentum measurements up to the highest luminosities and very low transverse momentum triggering at lower luminosities.

Other overall design aims have been large angular coverage together with triggering and particle momentum capabilities at low transverse momenta.

The inner detector is contained in a cylinder 6.8 metres long (with a solenoid of length 5.3 metres) and diameter 2.3 metres, providing a magnetic field of 2 Tesla. Design of the coil is being developed by the Japanese KEK Laboratory. Reflect-

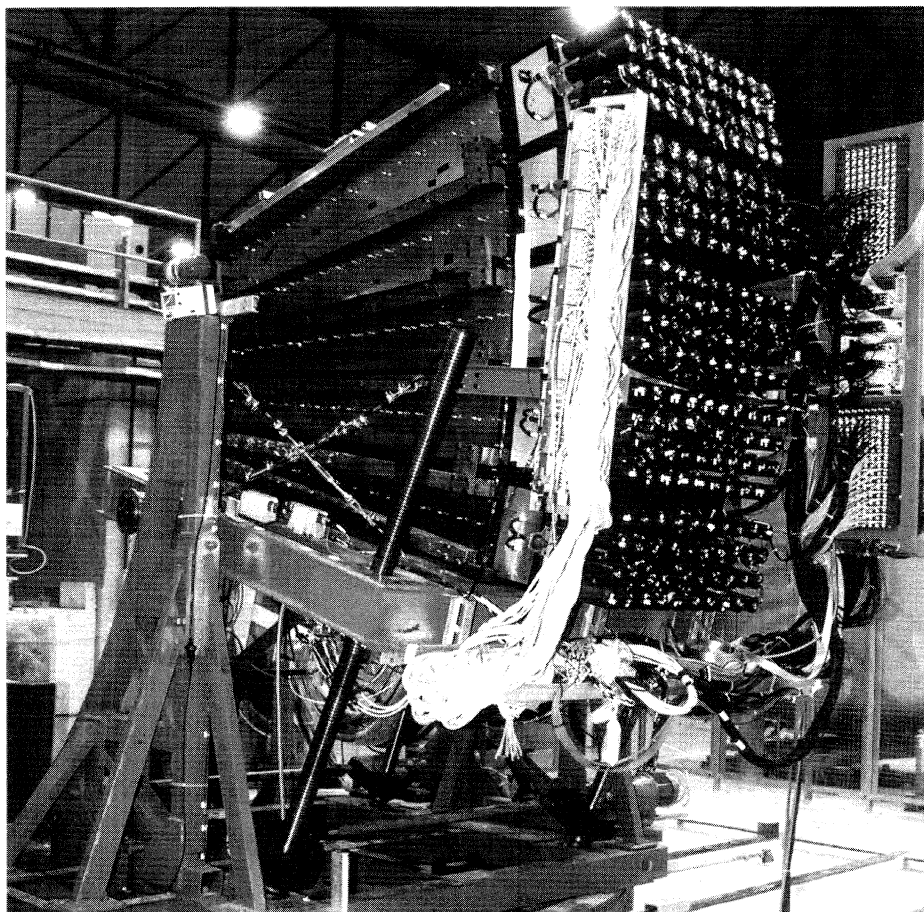
ATLAS hadronic calorimetry under test. The design uses a novel tile scintillator with plastic scintillator plates embedded in iron absorber.

ing LHC's bold physics aims and the pace of detector R&D, this inner detector is packed with innovative tracking technology (compared with existing major detectors) including high-resolution pixel and strip detectors inside and straw-tubes with transition radiation capability further away from the beam pipe. Finest granularity will be provided by semiconductor pixel detectors immediately around the beam pipe, providing about a hundred million pixels. With this technology moving rapidly, the final solution will benefit from ongoing R&D work.

Surrounding the tracking region will be highly granular electromagnetic sampling calorimetry, probably based on liquid argon (however studies on an alternative liquid krypton scheme are still in progress), contained in an 'accordion' absorber structure in a cylinder 7 metres long and 4.5 metres across, plus two endcaps. The inner solenoid coil is integrated into the vacuum vessel of the calorimeter cryogenics, reducing the amount of material that emerging particles have to cross.

Liquid argon is used for both electromagnetic and hadronic calorimetry in the endcaps of the calorimeter, the former arranged in a 'Spanish fan' geometry to cover all azimuthal angles without cracks, the latter in a wheel-like structure using copper absorber. Integrated into the endcaps is the forward calorimetry based on an array of rods and tubes embedded in a tungsten absorber some 5 metres from the interaction point.

The bulk of the hadronic calorimetry is provided by three large barrels of a novel tile scintillator with plastic scintillator plates embedded in iron absorber and read out by wavelength-shifting fibres. The tiles, laid perpendicular to the beam direction, are staggered in depth to simplify



construction and fibre routing.

Total weight of the calorimetry system is 4,000 tonnes (the entire UA1 detector which ran at CERN's proton-antiproton collider for a decade and was considered a big detector in its time weighed 2,000 tonnes).

The air-core toroid magnet, with its long barrel and inserted endcaps, generates a substantial field over a large volume but with a light and open structure minimizing troublesome multiple scattering. The toroid route was chosen because this geometry features the magnetic field perpendicular to the particle, and avoids large volumes of iron flux return (see page 12). The French Saclay Laboratory is responsible for the barrel and the UK Rutherford

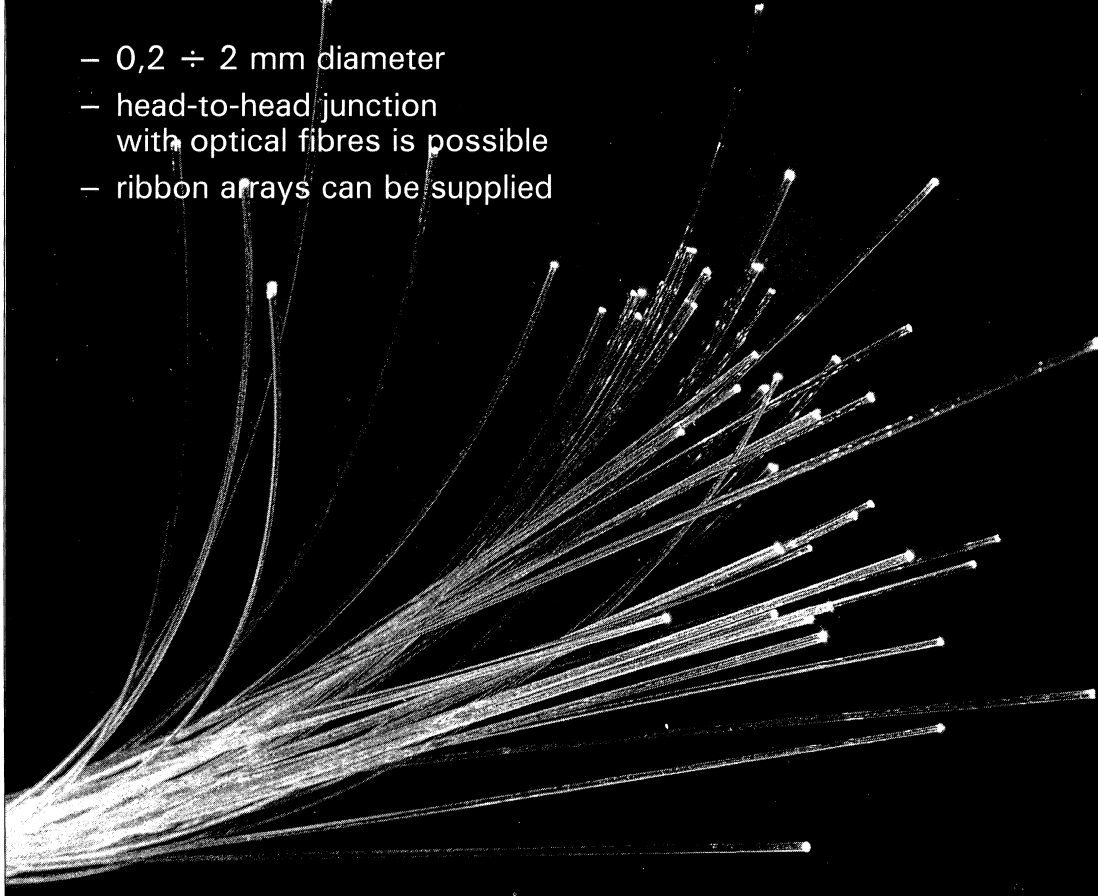
Appleton Laboratory for the endcaps.

Interleaved with the main air toroid magnet will be the muon chambers, the last outposts of ATLAS. These chambers, arranged in projective towers in the barrel region, are diametrically 22 metres apart, with the central muon barrel extending 26 metres and forward muon chambers 42 metres apart along the beam direction. Cathode strip chambers will be used in the highest rate environment close to the beam direction, supplemented further out by 'monitored' drift tubes - pressurized thin-wall tubes arranged in several layers.

Overall, ATLAS involves so far some 1500 scientists and engineers representing 140 institutions in 31 countries (including 17 CERN Member States). The participation of Non-

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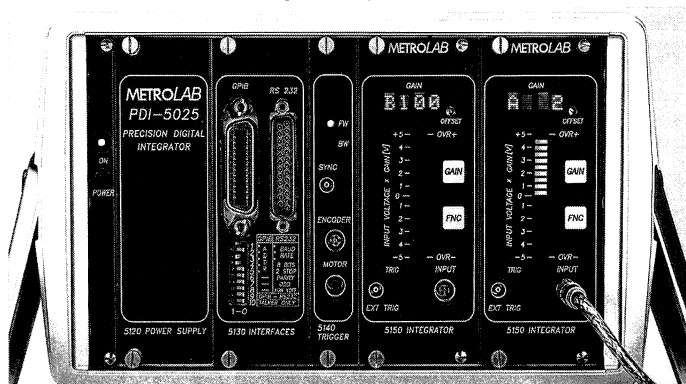
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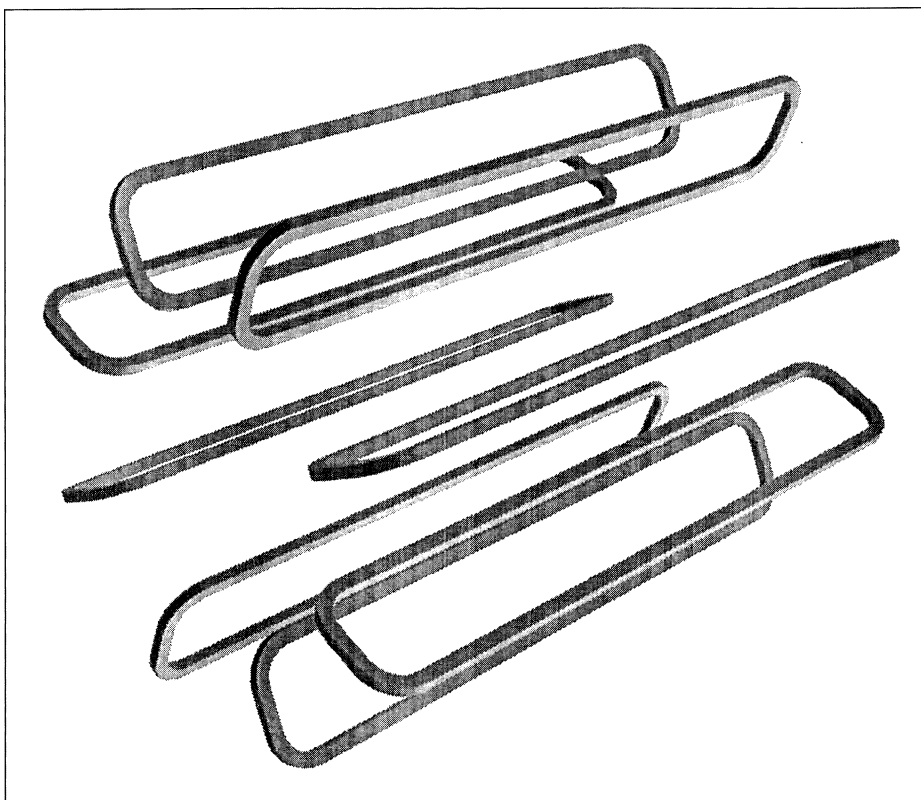
ATLAS uses a toroidal electromagnet. Usually used in tokamaks for fusion research, toroids are rarely encountered in particle physics.

Member State groups is still subject to the satisfactory establishment of bilateral agreements between CERN and the appropriate funding agencies.

However their potential involvement in ATLAS is already woven deeply into the fabric of the collaboration. For example semiconductor strips for the inner detector could involve teams from institutes in Australia, Canada, the Czech Republic, Finland, Germany, Japan, Norway, Poland, Russia, Sweden, Switzerland, the UK and the US, while the scintillator tiles could involve Armenia, Brazil, the Czech Republic, France, Italy, Portugal, Romania, Russia, Spain, Sweden, CERN and the US.

In addition to the 7,000 tonnes of ATLAS hardware, software and data acquisition requires a major effort. To handle ATLAS data, the first level trigger, which identify unambiguously which event crossing is responsible for the event, operates at the full bunch crossing rate of 40 MHz (one bunch every 25 nanoseconds). It takes about 2 microseconds for the first level trigger information to take shape and be distributed. During Level 1 trigger processing time, all data is held in pipelines prior to output at 100 kHz for subsequent processing at Level 2. During this 10 milliseconds, the Level 2 processors look at subsets of detector data before passing it on for final processing (at about 1 kHz) at Level 3, where complete event reconstruction becomes possible. Trigger processors at all three levels will be programmable.

The master plan is to have ATLAS ready for data taking at the end of 2003, when the planet's largest particle physics detector will be ready to begin the job for which it was so carefully designed and planned.



Solenoids and toroids

A solenoid (from the Greek meaning 'pipe-shaped') is the usual way of making an electromagnet from a cylindrical coil of wire. Solenoids have a long tradition in physics, from pioneer experiments on electromagnetic induction by Oersted, Biot, Savart and Faraday in the early 19th century to contemporary particle physics experiments at colliding beam machines.

Large toroidal magnets were first required to confine an isotropic plasma in tokamak machines for experiments on thermonuclear fusion. As well as looking very different, toroidal magnets have distinctive properties.

- A solenoid gives constant resolution in the transverse momentum of particles which emanate from the

centre and traverse the coil. However 'forward' particles moving along the solenoid axis encounter progressively less bending as they near the end of the coil and the resolution deteriorates rapidly. In contrast, the toroid gives transverse momentum resolution which improves as the particle moves forward.

- The solenoid permits using the (usually very precise) transverse beam position given by the tracking system to reconstruct the particle trajectory. The toroid can also make use of the longitudinal position.

- The solenoid needs an external flux return but the toroid is self-contained.

Overall, there is no decisive argument in favour of either the solenoid or the toroid - it is the integration into the detector design which is the deciding factor.