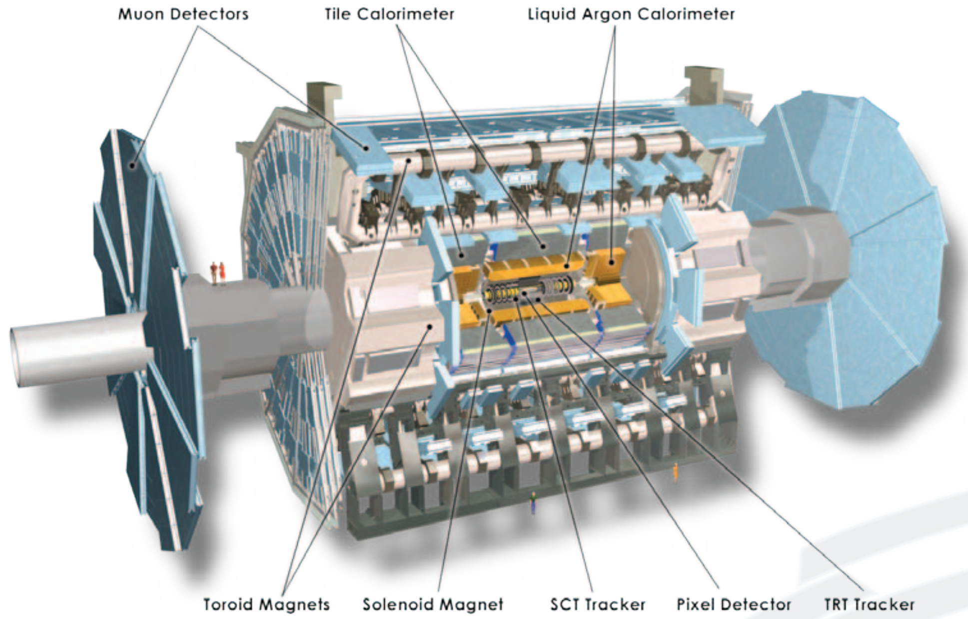
The ATLAS Detector

- Diameter 25 m -- Length : 46 m
- Barrel toroid length 26 m
- Overall weight 7 000 tonnes
- ~ 100 million electronic channels
- ~ 3 000 km of cables



Calorimeters

Measure the energies carried by the particles

Liquid Argon (LAr) Calorimeter

- Barrel 6.4 m long, 53 cm thick, 110 000 channels.
- Works with Liquid Argon at -183° C
- LAr endcap consists of the forward calorimeter, electromagnetic (EM) and hadronic endcaps.
- EM endcaps each have thickness 0.632 m and radius 2.077 m.
- Hadronic endcaps consist of two wheels of thickness 0.8 m and 1.0 m with radius 2.09 m.
- Forward calorimeter has three modules of radius 0.455 m and thickness 0.450 m each.

Tile Calorimeter (TileCal)

- Barrel made of 64 wedges, each 5.6 m long and 20 tonnes.
- Each Endcap has 64 wedges, each 2.6 m long.
- 500 000 plastic scintillator tiles.

Muon System

Identifies and measures the momenta of muons

Thin Gap Chambers

For triggering and 2nd coordinate measurement (non-bending direction) at ends of detector.

- 440 000 channels

Resistive Plate Chambers

For triggering and 2nd coordinate measurement in central region.

- 380 000 channels
- Electric Field 5 000 V/mm

Monitored Drift Tubes

Measure curves of tracks.

- 1171 chambers with total 354 240 tubes (3 cm diameter, 0.85-6.5 m long).
- Tube resolution 80 µm

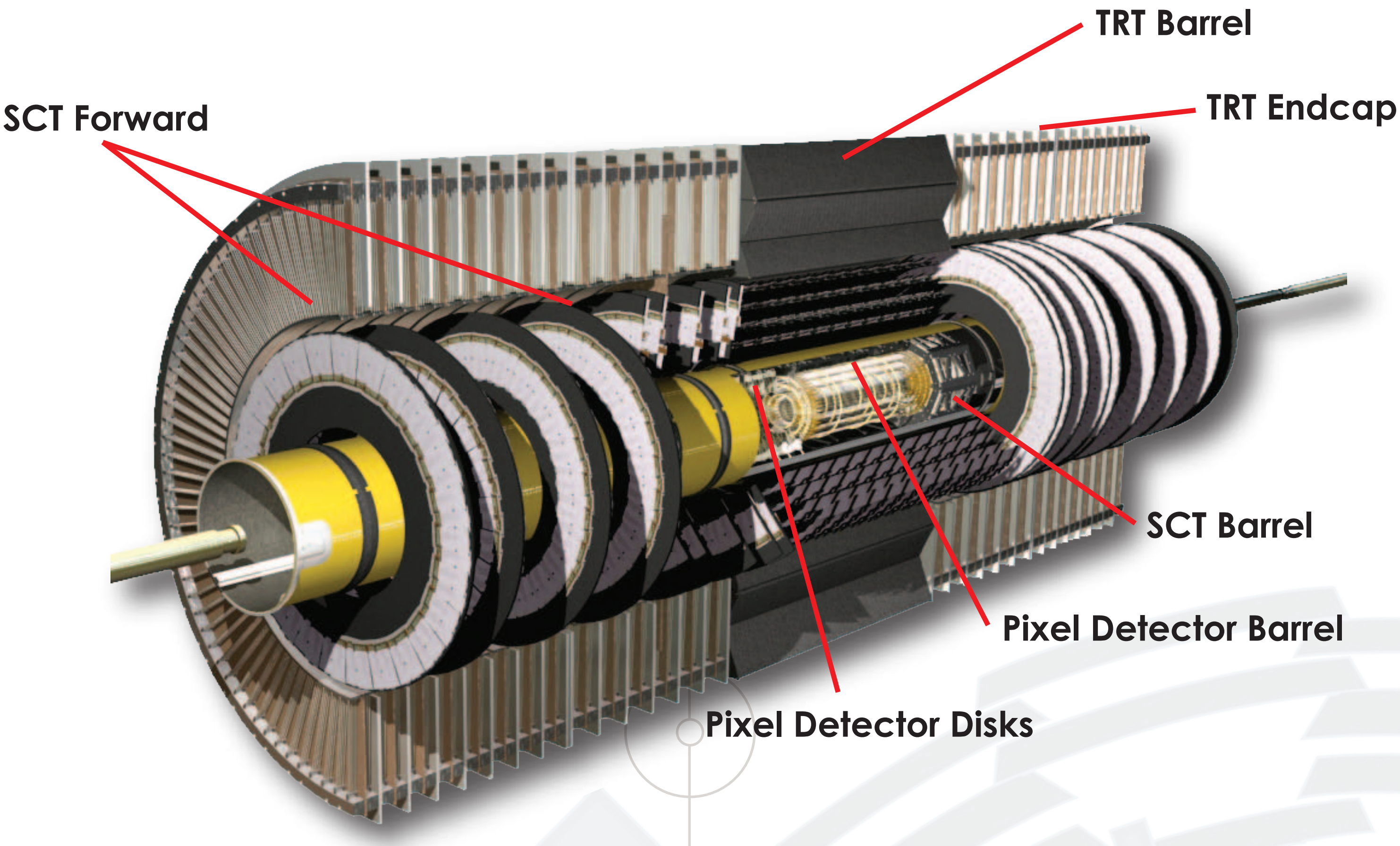
Cathode Strip Chambers

Measure precision coordinates at ends of detector.

- 70 000 channels
- Resolution 60 µm

The Inner Detector (ID)

Measures the momentum of each charged particle



Pixel Detector

- 80 million pixels (80 million channels). Area 1.7 m^2. 15 kW power consumption.
- Barrel has 1744 modules (10cm^2) with 46 080 readout channels per module
- Pixel size 50 × 400 μm^2 . Resolution 14 × 115 μm^2.
- Three Pixel disks (in each endcap) have 6.6 million channels.
- 3 barrel layers: 1456 modules (i.e. 67M)
- 3 disks in each end-cap: 288 modules (i.e. 13M)

Semiconductor Tracker (SCT)

- A silicon microstrip tracker consisting of 4088 two-sided modules and over 6 million implanted readout strips (6 million channels).
- 60 m^2 of silicon distributed over 4 cylindrical barrel layers and 18 planar endcap discs.
- Readout strips every 80 µm on the silicon, allowing the positions of charged particles to be recorded to an accuracy of 17 µm per layer (in the direction transverse to the strips).

Transition Radiation Tracker (TRT)

- 350 000 read-out channels
- Volume 12 m^3
- Basic detector element: straw tube with 4mm diameter, in the center a 0.03mm diameter gold-plated tungsten wire
- 50 000 straws in Barrel, each straw 144 cm long. The ends of a straw are read out separately
- 250 000 straws in both endcaps, each straw 39 cm long
- Precision measurement of 0.17 mm (particle track to wire)
- Provides additional information on the particle type that flew through the detector, i.e. if it is an electron or pion

Surface Hall (SX1)

84 m long, 24 m wide, 18 m high
Two cranes, can each carry 140 tonnes.
Heaviest pieces to lower down:
- Tile Calorimeter base part (260 tonnes)
- Liquid Argon Barrel (180 tonnes)
- 2 Liquid Argon Endcaps (270 tonnes each)
- 2 End Cap Toroid Magnets (240 tonnes each)
- Two vertical access shafts: One 13 m and one 18 m wide

Cavern (UX15)

Start of civil engineering: 1997
Excavation of 300 000 tonnes of rock, 50 000 tonnes of concrete used.
LEP accelerator continued operation during excavation work!
Construction sequence:
- Construct surface buildings and install cranes.
- Dig vertical shafts and build concrete walls.
- Excavate top 10 metres of cavern.
- Build vaulted ceiling (2 m thick, 10 000 tonnes, suspended by 38 steel cables, fixed in a gallery in the rock 17 metres above).
- Excavate complete cavern.
- Concrete floor (5 m thick steel-enforced slab).
- Build side walls (2 m thick).
- Release steel cables.

Dimension:
- 53 m long
- 35 m high (10-storey building)
- 30 m wide
- floor 92 m below ground

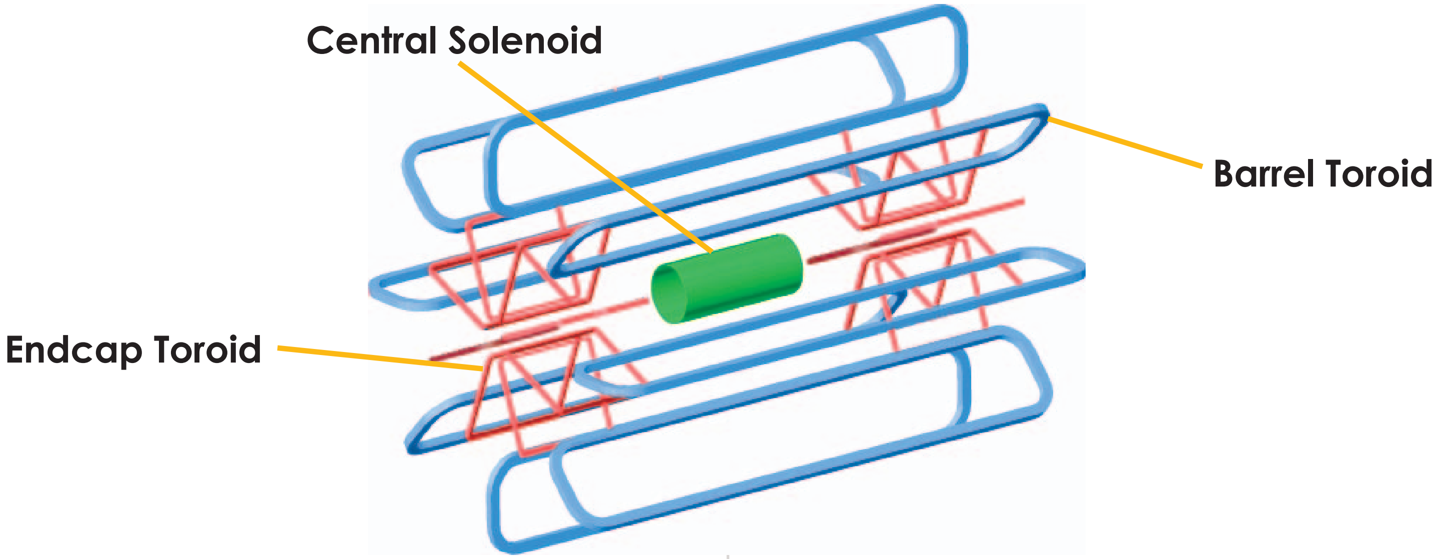
Start infrastructure installation: June 2003
Start detector installation (magnet feet): November 2003
Cranes: 2, each can carry 65 tonnes (heavier objects move on rails and air pads).
Floor moves presently slightly upwards (~ 0.5 mm per year until it reaches stabilization).

Detector

Support structure: 1 000 tonnes
Total weight: 7 000 tonnes (weight of metallic structure of Eiffel Tower is 7 300 tonnes).
Diameter: 22 m
Length: 43 m
Size is comparable to half the size of the Notre Dame cathedral in Paris.

ATLAS Magnet System

Bends charged particles for momentum measurement



Central Solenoid Magnet

- 5.3 long, 2.4 m diameter, 4.5 cm thick
- 5 tonne weight
- 2 tesla (T) magnetic field with a stored energy of 38 megajoules (MJ)
- 9 km of superconducting wire
- Nominal current: 7.73 kiloampere (kA)

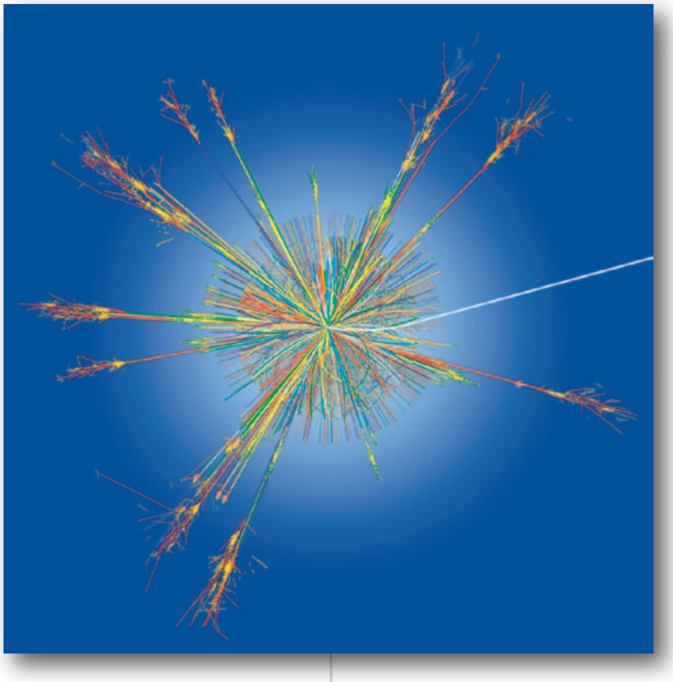
Barrel Toroid parameters

• 25.3 m	length
• 20.1 m	outer diameter
• 8	separate coils
• 1.08 GJ	stored energy
• 370 tonnes	cold mass
• 830 tonnes	weight
• 4 T	magnetic field on superconductor
• 56 km	Al/NbTi/Cu conductor
• 20.5 kA	nominal current
• 4.7 K	working point temperature
• 100 km	superconducting wire

Parameters for each End-cap Toroid

• 5.0 m	axial length
• 10.7 m	outer diameter
• 8 coils	8 coils in a common cryostat each
• 0.25 GJ	stored energy in each
• 160 tonnes	cold mass each
• 240 tonnes	weight each
• 4 T	magnetic field on superconductor
• 13 km	Al/NbTi/Cu conductor each
• 20.5 kA	nominal current
• 4.7 K	working point temperature

For comparison an ordinary MRI magnet in a hospital has a magnetic field of 1.5 tesla (T). The toroids are rare and very impressive to see, and the large magnetic field volume is quite unique.



Event Rates

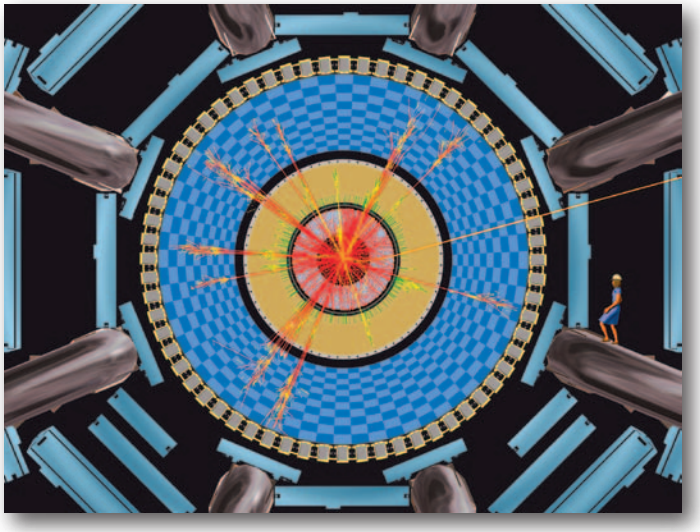
- At a beam luminosity of 10^{34} cm^{-2} s^{-1}, there will be about 20 collisions per bunch crossing.
- 40 million bunch crossings per second.
- Yields about 1 billion collisions per second.
- Level 1 trigger filters that down to about 75 000 events per second.
- Level 2 trigger reduces it to about 2 000 events per second.
- The Event Filter then selects for permanent storage about 200 “interesting” events per second.

Frequency of producing a Higgs boson that has decayed to two Z bosons each of which has decayed to an electron-positron pair is extremely rare: once in 10^{13} = 10 000 000 000 000 interactions or one every 3 hours (a similar rate occurs when the Z boson decay to $\mu^+ \mu^-$ pairs).

Possible physics processes

Expected event rates at production in ATLAS at Energy = 14 TeV and Luminosity = 10^{33} cm^{-2} s^{-1}

Process	Events/s	Events for $10fb^{-1}$	Total statistics collected at previous machines by ‘07
Inelastic proton-proton reactions	10^8	10^{15}	
$W \rightarrow e\nu$	20	10^8	10^4 LEP / 10^7 Tevatron
$Z \rightarrow ee$	2	10^7	10^7 LEP
$t\bar{t}$	1	10^7	10^4 Tevatron
$b\bar{b}$	10^6	10^{13}	10^9 Belle/BaBar
Higgs m = 120 GeV	0.04	10^5	---
Gluinos and Squarks m = 1 TeV	0.001	10^4	---
Black holes m > 3 TeV (M_D=3 TeV, n=4)	0.0001	10^3	---



Supersymmetric Particles

A particle (called a neutralino) predicted by supersymmetry is a good candidate for the dark matter that makes up 85% of the matter in the universe (and 23% of matter plus energy). Since the neutralino mass can be measured to about 10%, the discovery of supersymmetry and the measurement of the neutralino mass at LHC can solve the mystery of dark matter.

The neutralino is observed indirectly in the decay of other supersymmetric particles such as squarks and gluinos, the supersymmetric partners of quarks and gluons.

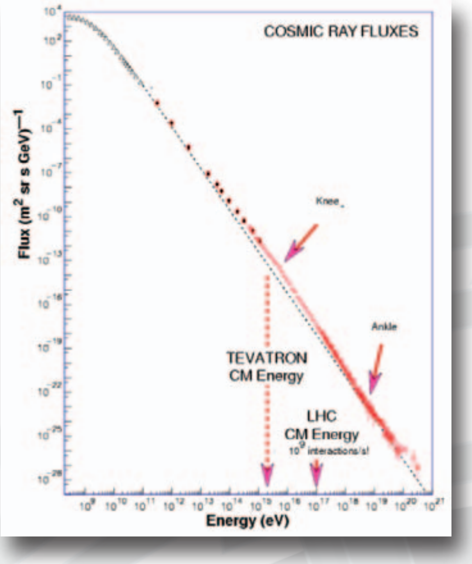
ATLAS Discovery reach for squarks or gluinos versus time at energy = 14 TeV (with jets + E_T^{miss} signature)

Time at Luminosity	mass reach
1 month at 10^{33} cm^{-2} s^{-1}	~ 1.3 TeV
1 year at 10^{33} cm^{-2} s^{-1}	~ 1.8 TeV
1 year at 10^{34} cm^{-2} s^{-1}	~ 2.5 TeV
ultimate (300 fb^{-1})	~ 2.5-3 TeV

But : it will take a lot time to understand the detectors and the backgrounds …

Comparing LHC with Cosmic Rays

Energy of 14 TeV in Collider corresponds to Energy of about 100 000 TeV for a fixed target proton beam. The LHC will be the first machine able to explore the high-E part of the cosmic ray spectrum.



Heavy ion Collisions

- Pb-Pb collision (lead nuclei)
- 5.5 TeV/coll. nucl.
- Luminosity 10^{27} cm^{-2} s^{-1}

Heavy Ion Collision physics goal:

Study of phase transition at high density from hadronic matter to plasma of deconfined quarks and gluons (complementing the ALICE Experiment also at LHC). Transition plasma → hadronic matter happened in universe ~ 10^{-5} s after Big Bang.

Trigger and Data Acquisition (TDAQ)

The trigger system selects 100 interesting events per second out of 1000 million total.
The data acquisition system channels the data from the detectors to storage.

Bunches of protons cross 40 million times a second.
Each bunch contains 10^{11} protons.
Number of proton-proton collisions in the detector: 1 billion per second.
When any of the protons collide, the process is called an "event".
A given bunch crossing sometimes has particles from more than one proton-proton collision.

If all data would be recorded, this would fill 100 000 CDs per second. This would create a stack of CDs 150 m (450 ft) high every second, which could reach to the moon and back twice each year.
This data rate is also equivalent to making 50 billion telephone calls at the same time.

TDAQ has a 3 level Trigger system (reduction in three steps).
Total event reduction factor by the trigger system: 200 000.

- 1st level trigger: Hardware, level 1 is done using special-purpose processors.[1]
- 2nd level trigger: Software, large computing farms with ~ 500 dual pc processors.
- 3rd level trigger: Software, large computing farms with ~ 1700 dual pc processors.

The rates and reduction factors at 14 TeV are summarized as:

	Incoming event rate per second	Outgoing event rate per second	Reduction factor
Level 1	40 000 000	100 000	400
Level 2	100 000	3 000	30
Level 3	3 000	200	15

TDAQ records 320 Mbytes per second, which would fill more than 27 CDs per minute.

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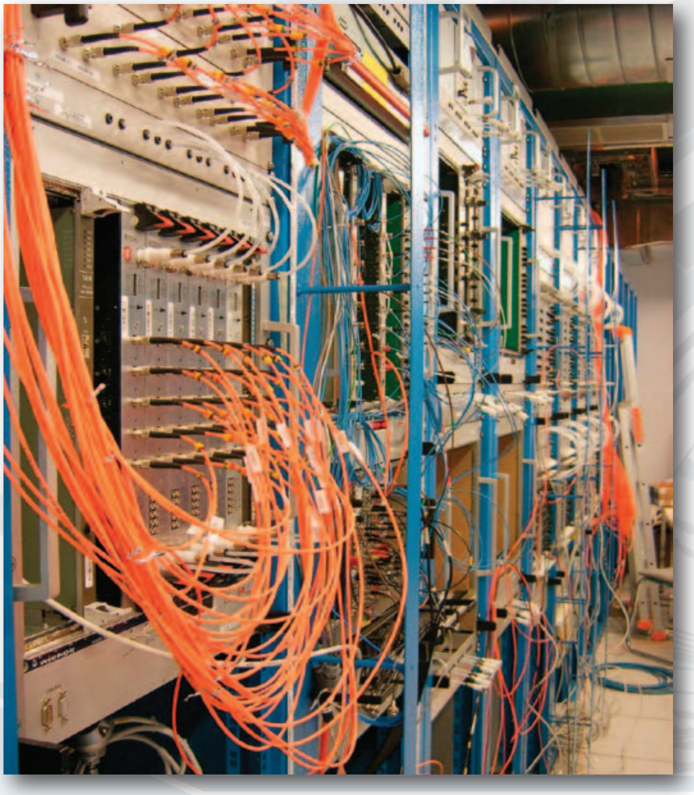
[1] massive parallel architecture pipeline processors (ASIC, FPGA)



Computing

Analysing 1000 Million events recorded per year

Data recording:

- The raw data are recorded after 3rd level Trigger (see previous page).
- The raw data are analysed in terms of particles produced in the collision (tracks, shower in the calorimeters etc.) and this "reconstructed" data is recorded.
- From this the physics data is extracted with specialized software and recorded.

Recorded	per event	per year
raw data	1.6 Mbytes	3 200 Tbytes
reconstructed data	1 Mbytes	2 000 Tbytes
physics data	0.1 Mbytes	200 Tbytes

(A terabyte is a million megabytes)

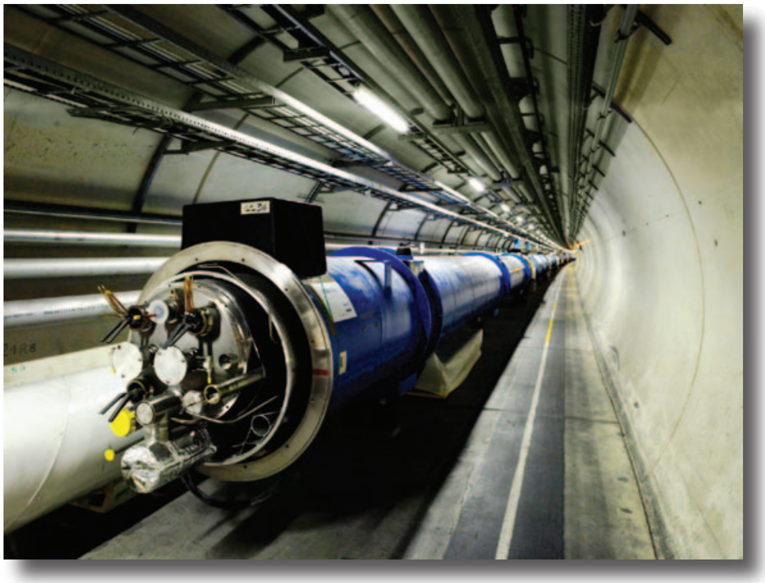
The 3200 terabytes of data that will be seen by ATLAS each year are the equivalent of the content in:

- 160 million trees made into books.
- 7 km (4 miles) of CD-ROMs stacked on top of each other.
- 600 years of listening to songs.
- 160 US Library of Congress (3 billion books).

Offline Computing:

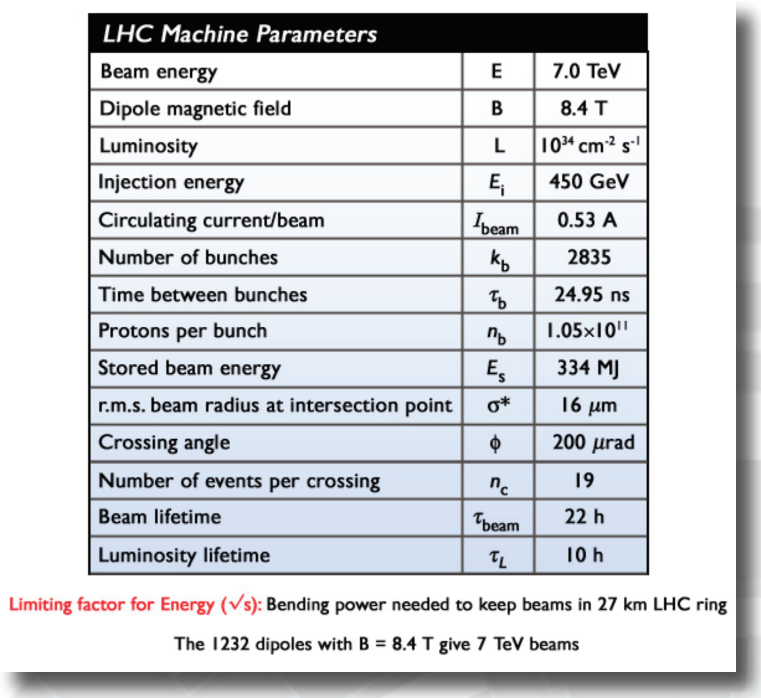
- Number of PCs for event reconstruction at CERN: ~3 000
- **ATLAS offline, including simulation, worldwide in 2008: ~36 000 PCs**
- CPU time planned for reconstruction of a full event: 15 s
- **Estimated lines of code (C++): ~ 5 million**
- More than 200 software developers worldwide are involved
- To interpret the data correctly interesting physics relations as well as background are simulated as events in the detector. Due to the fine granularity of the ATLAS detector, the **simulation** has to deal with as many as **30 000 000** objects.

Data is exported from CERN at a rate of 1 GB/s (8 Gbps) to 10 main computing centres in 3 continents, where data are stored, processed and further distributed to ~50 collaborating institutes for analysis. All members of the ATLAS Collaboration have equal access possibilities to all ATLAS data, independently of their geographical location, thanks to the Worldwide LHC Computing Grid.



Large Hadron Collider

- The Large Hadron Collider is a 27 km long collider ring housed in a tunnel about 100 m underground near Geneva.
- Total energy $\sqrt{s} = 14$ TeV (7 times higher than Tevatron at Fermilab) allowing searches for new massive particles up to m ~ 5 TeV.
- Luminosity $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$ (More than 100 times higher than Tevatron at Fermilab). Allows searches for rare processes.
- Revolution Frequency: 11.2 kHz (11 200 times a second)
- Power Consumption: ~ 120 MW
- Each proton beam at full intensity will consist of 2 808 bunches.
- Each bunch will contain 1.15×10^{11} protons at the start of nominal fill.
- Bunches are a few cm long but their transverse dimensions are squeezed to 16 microns at the collision points.
- Total superconducting cable required is around 7 600 km. The cable is made up of strands which are made up of filaments. Total length of filaments is 5 times to the sun and back.
- Ultrahigh vacuum 10^{-10} torr (~ 3 million molecules/cm^3) to avoid collisions with gas molecules. This is equivalent to the pressure at an altitude of 1 000 km. Atmospheric pressure is 760 torr.
- LHC superconducting magnets will sit in a 1.9 K bath of superfluid helium at atmospheric pressure.



LHC Machine Parameters		
Beam energy	E	7.0 TeV
Dipole magnetic field	B	8.4 T
Luminosity	L	$10^{34}\ cm^{-2}\ s^{-1}$
Injection energy	E_i	450 GeV
Circulating current/beam	I_{beam}	0.53 A
Number of bunches	k_b	2835
Time between bunches	τ_b	24.95 ns
Protons per bunch	n_b	1.05×10^{11}
Stored beam energy	E_s	334 MJ
r.m.s. beam radius at intersection point	σ^*	16 μm
Crossing angle	ϕ	200 μrad
Number of events per crossing	n_c	19
Beam lifetime	τ_{beam}	22 h
Luminosity lifetime	τ_L	10 h

Limiting factor for Energy ($\sqrt{s}$): Bending power needed to keep beams in 27 km LHC ring

The 1232 dipoles with B = 8.4 T give 7 TeV beams

LHC Magnets

Full LHC magnet cell (~ 120 m long) : 6 dipoles + 4 quadrupoles; nominal current (12 kA).

Not only dipole magnets...

Dipoles	1 232
Quadrupoles	400
Sextupoles	2 464
Octupoles/decapoles	1 568
Orbit correctors	642
Others	376
Total	~ 6 700

Large Hadron Collider

The LHC ring will store a beam energy of 360 megajoules.

$2\,808$ bunches × $1.15\ 10^{11}$ protons @ 7 TeV each =

$2\,808 \times 1.15 \times 10^{11} \times 7 \times 10^{12} \times 1.602 \times 10^{-19}$ joules = 362 MJ per beam

This can be compared to:

Kinetic energy
- 1 small cruise ship of 10 000 tonnes moving at 30 km/hour
- 450 automobiles of 2 tonnes moving at 100 km/hour

Chemical energy
- 80 kg of TNT
- 16 kg of chocolate (counting the calories)

Thermal energy
- melt 500 kg of copper
- raise 1 cubic meter of water 85° C: "a tonne of tea"

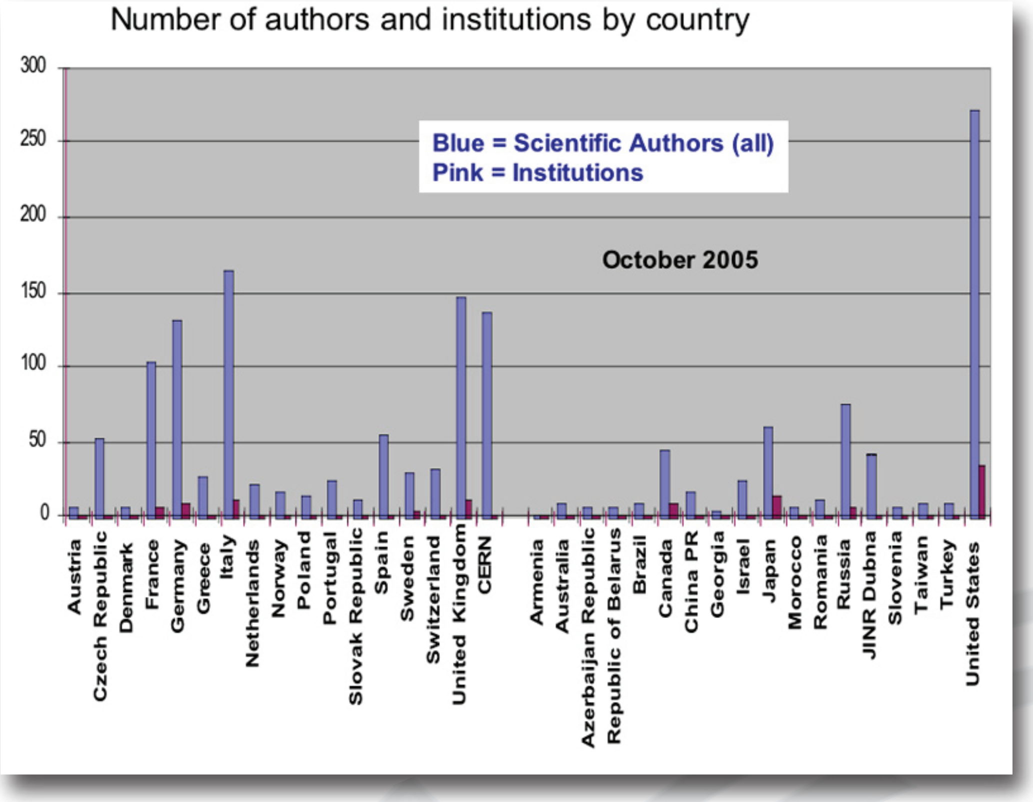
Milk chocolate is 520 calories per 100 g , which gives 350 MJ = 16 kg of chocolate.

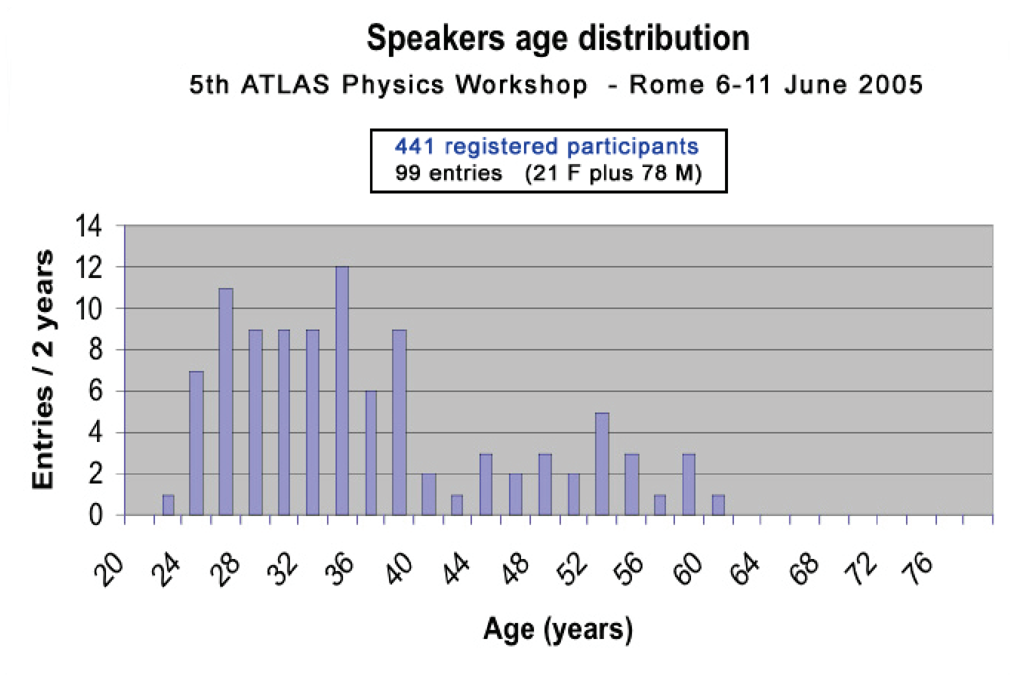
The energy in chocolate is released a bit more slowly than in TNT!

ATLAS Collaboration (as of July 2011)

38 countries
174 institutions
3000 scientific authors

ATLAS Collaboration





How ATLAS Collaborates

Building a detector involves more than just following a sheet of instructions. It is a collaboration of 1850 individuals who have to work together as a team while being thousands of miles apart. We posed questions to a few of these men and women to see what happens behind the scenes to make an undertaking like this work.

Questions:

What is the balance between individual creativity and the process of being part of a large collaboration?

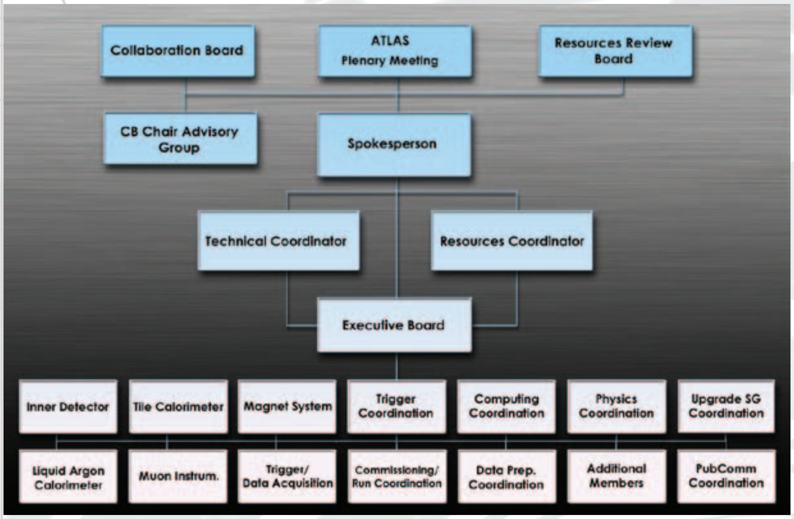
The successful design and construction of a large and complex state-of-the-art detector requires the creative participation of many many people. It is not the collaboration that is creative, but the sum of its individual members. There are numerous subsystems and sub-subsystems so that people mostly work in small groups, and creatively contribute. The fact that all the systems must fit and work together, and be affordable, necessarily imposes some limits on the creative directions that people can take.

How do important decisions get made? How do individuals not in the leadership get their voices heard?

Many of the important decisions involve just one or two of the subsystems. The pros and cons are initially discussed in the subsystem plenary meetings. The term "plenary" here implies that all collaborators working within the specified group (for example the subsystem) can participate in the meeting and make their voices heard. Recommendations are then discussed in the ATLAS Executive Board, and presented in ATLAS plenary meetings which play a primary role in forming a large consensus about issues for which decisions are required. The leadership can only 'lead' the collaboration to decisions which are understandable to all, or at least to a large majority. Practical constraints may influence decisions, like costs, schedule, the availability of teams to take responsibilities for the execution... Procedurally there is a clear sequence of steps to formally make decisions, with a hierarchical structure from sub-system to systems, and ultimately with the vote in the Collaboration Board being the final step for very major decisions.

How is the leadership structured?

The leadership and administration of ATLAS is well defined as shown in the organization chart below. At the level of systems and subsystems similar forms of organization exist.



How is the leadership selected?

ATLAS elects its leadership. Candidates for a particular leadership position (such as Project Leader for a particular system) are proposed by the groups working on that system. Candidates for Spokesperson, and Collaboration Board (CB) Chair are proposed by the membership of the whole collaboration. The leadership

How ATLAS Collaborates

is then elected, and their proposed "management teams" have to be endorsed. The "electing bodies" are the institutions relevant to the particular position, namely the whole collaboration for the CB Chair or Spokesperson, or the institutions participating in a given detector system in the case of a project leader for that system.

How is such a large and far-flung collaboration managed?

Each detector subsystem has its own management team. At the same time, the ATLAS Executive Board and Spokesperson maintain general oversight of the Project. The Technical Coordination team is responsible for making sure that all the separate subsystems can fit together. In parallel, there are national representatives whose functions are to oversee the distributions of resources from each participating country to all the collaborating groups from that country, and make sure that those resources are well-used. The Collaboration Board sets out the policy issues, and is not involved with the execution, which is the domain of the management. However frequent contacts between for example the Spokesperson and the Collaboration Board Chair ensure that policy issues are properly handled, and that fair solutions are found for difficult problems. Finally one should not underestimate the importance of direct contacts between individuals and teams with the collaboration management.

How do 3 000 people communicate among themselves? In such communication, how do you bridge the large distances and time differences?

Electronics communication plays a major role (e-mail, WWW, telephone, video conferencing). However regular direct human contacts are crucial elements in the communication. Meetings therefore play an important role in the life of ATLAS.

How does one apportion the tasks?

One tries to match the interests and resources of the participating teams to the tasks. This can succeed only if everyone is also willing to share the less interesting but necessary tasks. This in turn works because the physicists are motivated by the prospect of the exciting results to be obtained, and know that these depend on having a complete working detector system.

How does one apportion the costs?

There is no absolute mechanism or formula for that. One attempts to negotiate a fair sharing of the costs. Large teams from countries with wealthy economies are expected to carry a larger share of the costs than small teams from countries with still developing economies. Consideration of the possible contributions of teams/countries is a central part of the process of forming the collaboration.

Where does the money come from?

The large project funds come mostly from the science funding agencies of the various countries participating in ATLAS. There are also contributions from CERN, and some resources from individual university funds.

How do people join?

Teams interested in ATLAS may contact the spokesperson, and their interest is then brought to the attention of the Collaboration Board (CB). After clarifications on their resources, their potential share of the work, their relationships with other teams already working in ATLAS etc., the CB votes on the admission of the candidate group.

How ATLAS Collaborates

How do you assure that all the detector pieces fit together?

The Technical Coordinator, supported by the Technical Coordination Team, works with all the subsystem groups to ensure that the separate pieces will fit together without interference, and that the full detector can be assembled in its Interaction Region.

How was the site chosen? (Why Geneva?)

CERN is the world's largest particle physics centre. Founded in 1954, the laboratory was one of Europe's first joint ventures, and has become a shining example of international collaboration. The CERN site on the edge of Geneva crosses the border between France and Switzerland. CERN was a logical location for the Large Hadron Collider because of the extensive experience and infrastructure, and the opportunity to use an existing tunnel which housed the LEP. At any other location, tunneling costs would have been a significant fraction of the costs of constructing a new particle collider.

Why have an international collaboration?

International collaboration is the only way to achieve sufficient intellectual and financial resources to realize so large and challenging a project as the LHC and its detectors, and to exploit effectively its scientific output.

How will data be analyzed among 3000 people?

The ATLAS data will provide experimental input for a large number of separate research topics. ATLAS scientists will pursue these research areas mostly in small groups working at their home institutions. All collaborators will be invited to analyze the data by being part of analysis teams.

In some respects data analysis by individual ATLAS physicists can be compared to data analysis by astronomers using the Hubble Space Telescope (though ATLAS looks at the micro-cosmos). Both groups of scientists will choose the research areas and data that interest them most.

How will papers be agreed upon?

Generally the data analysis work will be done in small groups pursuing different research directions. At the point where new results are sufficient to warrant writing a paper, the group involved will likely produce a draft. Both the analysis and its description in the draft will then be subject to comments by all ATLAS collaborators, to careful review, and eventually to discussion within a plenary meeting. Hopefully this process will lead to a consensus, and the agreed-upon paper can be submitted for publication.

How does any one collaborator get credit for his/her contributions?

Internal publications within the Collaboration, usually with one or a few authors, will document the individual contributions. These can be made known to the whole scientific community. Also, leading contributions are often recognized by asking the person in question to present results at conferences. Often major results are obtained in a collective way, because people need to share the tasks.

What is the impact of the global spread of the collaboration? How does one contribute from 9000 kilometers (6000 miles) away (from US, Japan, Russia)?

The global spread implies that factors such as transport of components need to be taken into account during the construction, and that communication logistics play a major role. It also implies that scientists from outside Europe have to travel long distances to participate in the discussions and meetings, in the detector assembly and testing, and eventually in the operation of the experiment. They may have to spend extended periods away from their homes and home institutions. However all scientists are after the same goal in ATLAS, namely doing the frontline physics of the LHC, and they are willing to endure the above inconveniences to achieve that goal.

ATLAS Collaboration

Approximately 250 of the 3000 members of ATLAS in Building 40 at CERN (many ATLAS offices are in Bldg. 40).

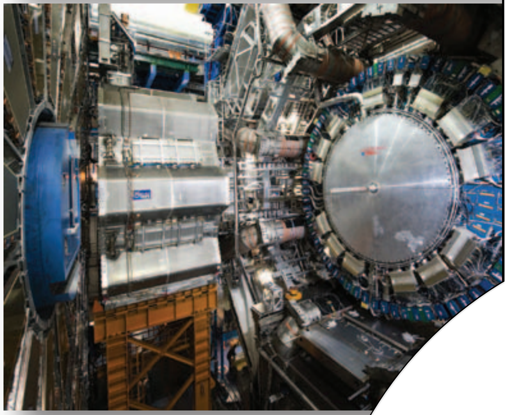
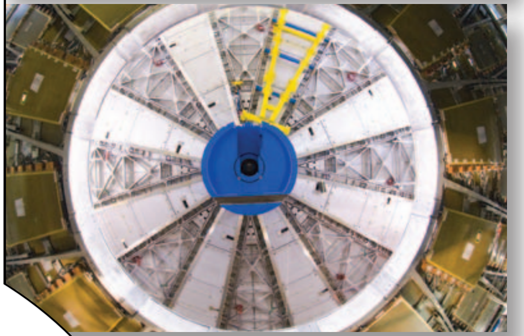
ATLAS Images

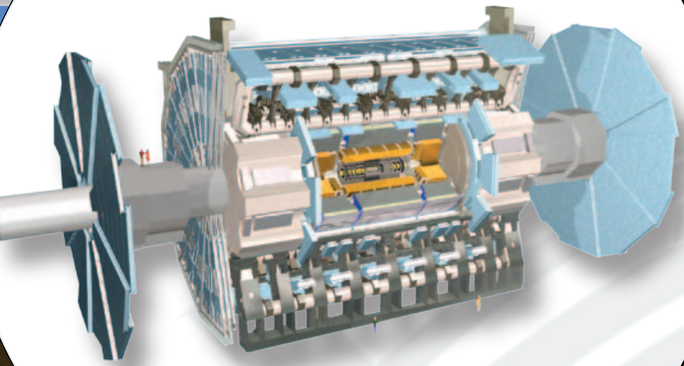
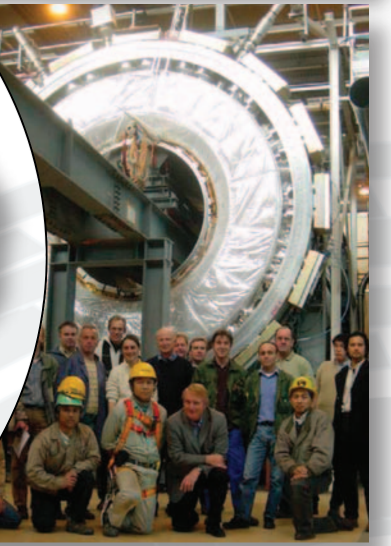
These images are samples of a larger collection of images that are available at the ATLAS website.

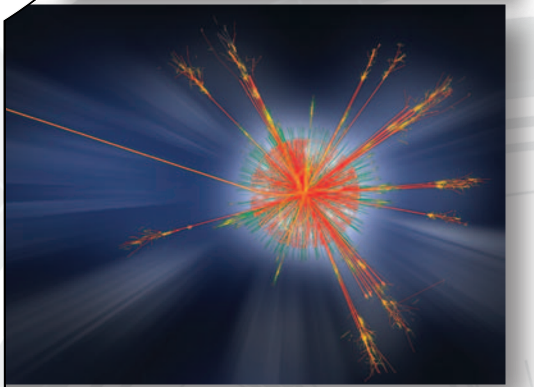
The entire photo collection can be found at:

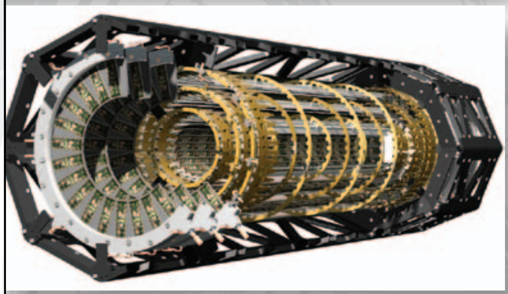
atlas.ch/photos/



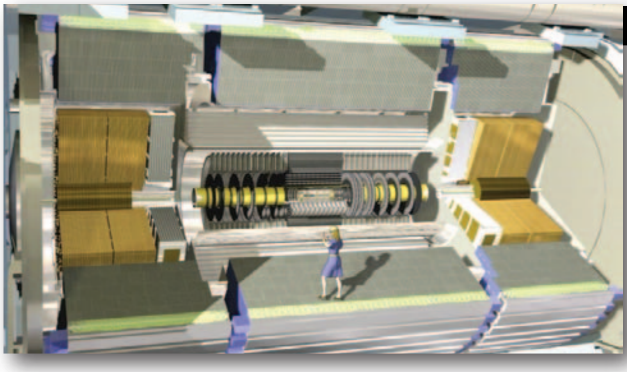




ATLAS Video

These images are samples of a larger collection of video clips that are available at the ATLAS website.

atlas.ch/multimedia/



Episode 2 - The Particles Strike Back

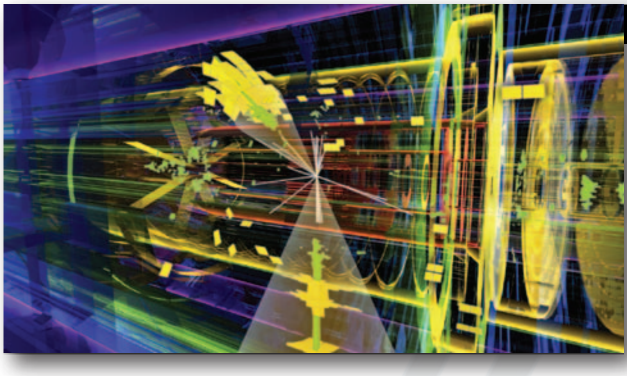
The second episode in a three part series that uncovers the mysteries of the ATLAS experiment.

Duration = 14 minutes

What We Do Is Not In Textbooks

A short film featuring several of the different physicists who work on ATLAS today.

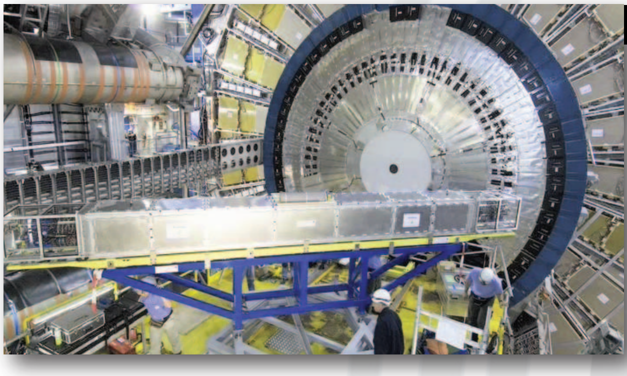
Duration = 9 minutes



Di-jet Collision Event

An event with two jets produced. Animation was created from data from an actual ATLAS collision event in 2010.

Duration = 1 minute



ATLAS Built in Three Minutes

A short video compiled from webcam footage and still photographs over the length of the ATLAS detector's construction. (2009)

Duration = 3 minutes