Signals and Backgrounds for the LHC
OR "Is your theory falsifiable?"

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Topics that I may cover

- Overview of LHC Scope and Schedule
- Generic Properties of New Physics: Observables and Triggers
- Calculating and Measuring backgrounds: What to believe
- Some specific examples
- Extra-Dimensions
  Little Higgs
  SUSY
  yours
- LHC is no just a discovery machine,so I will discuss detailed measurements.

Disclaimer

Many of the examples that I will provide are from ATLAS.

The physics capabilities of ATLAS and CMS are similar.

Apologies to CMS for the imbalance in the plots shown.

I am not discussing, b-physics, heavy ion physics and much of the SM physics that the LHC will probe

Your Homework

I have not yet prepared a 4^{th} lecture.

I will use this to answer questions and discuss "new physics" cases suggested by you.
I will try to answer "Is this model measurable at LHC?"

- I need from you: A model for discussion
  It could be a preprint or just a "crazy idea". The more precise it is, the more specific I will be.
  Send it to me via e-mail, no later than midnight tomorrow. I may not care if it is ruled out?

If Chris has not discussed the "no Higgs" scenario, I can do this also

The Motivation

- The last 20 years has seen a remarkable synthesis. The "Standard Model" has triumphed in explaining a host of data.
- This very success enables more fundamental questions to be posed and better defines them.
- The photon and the W/Z bosons are related by a symmetry. but their masses are very different. Why? What about quark/lepton masses?
- There are a host of theoretical ideas (Supersymmetry, extra-dimensions, composite quarks ...) one might even be right
- No progress is possible the without Experimental discoveries from LHC

- The case is even stronger now than when the LHC was first suggested 20 years ago.

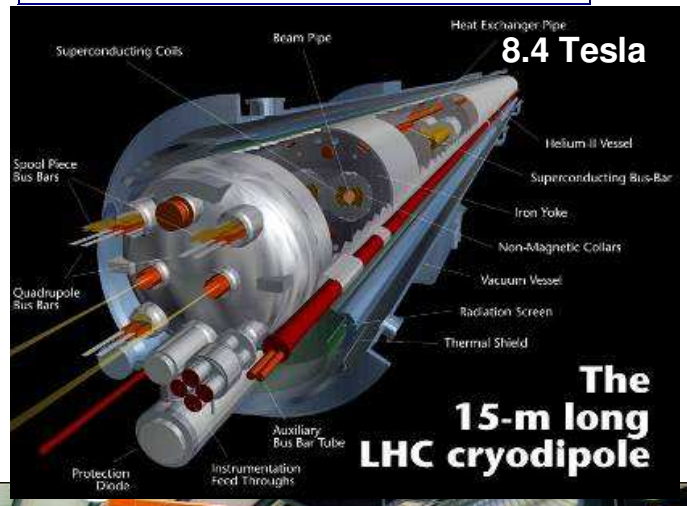
- LHC's task is to find the particle(s) responsible for mass generation. Could be Higgs, many Higgs's, SUSY, Extra dimensions

- Power of LHC is its enormous mass reach relative to current facilities.

- LHC results will define and support the ILC case.

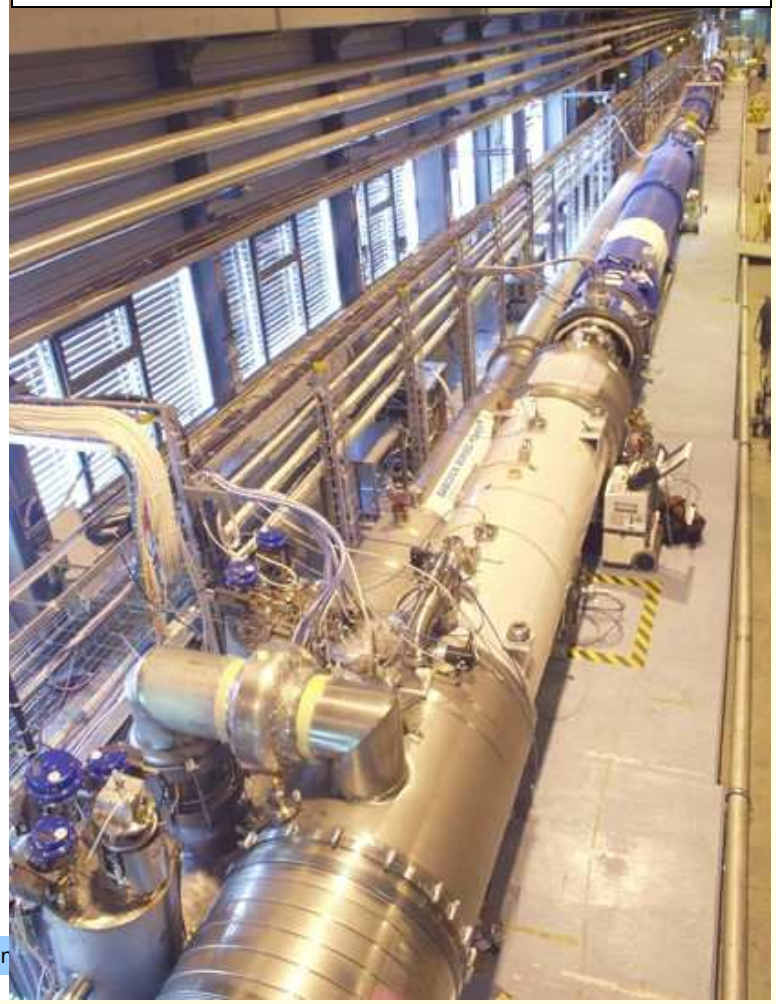
LHC Status

The LHC machine



More than half of the 1232 dipoles are produced

First full LHC cell (~ 120 m long) :
6 dipoles + 4 quadrupoles;
successful tests at nominal current (12 kA)



LHC construction and installation

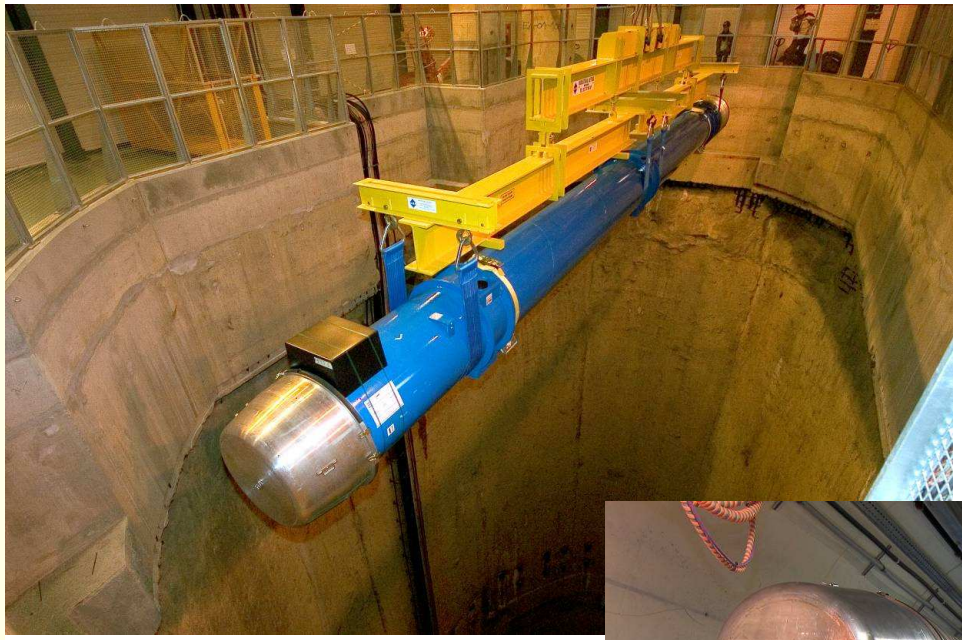
Dipoles ready for installation

Cryogenics (QRL) in the tunnel

Dipole installation in the tunnel

The magnet production proceeds very well and is on schedule, also the quality of the magnets is very good

On the critical path for the first collisions, which are planned for Summer 2007, is the installation of the LHC in the tunnel, in particular due to delays in the cryogenic services lines (QRL) which initially had problems, and for which a recovery plan was implemented successfully



Lowering of the first dipole into the tunnel (March 2005)

Installation of dipoles in the LHC ring has started

6-6-2005, P. Jenni

Lyn Evans' conclusions from the his presentation at the last RRB on the LHC status (end April 2005)

- **QRL installation is now proceeding smoothly.**
- **The main remaining problem is the fast ramp up of production of service modules to feed the installation sites at the speed required.**
- **Machine installation has started.**
- **Hardware commissioning finished by end June 2007. Ready for beam.**

LHC operation

- Single Beam operation – Spring/Summer 2007
- Collisions – Fall 2007
- Operation in "low luminosity mode" for 3 years 2×10^{33} cm^{-2} sec^{-1}
- 1 month per year of heavy ion running.
- Full luminosity in ~ 2010 10^{34} cm^{-2} sec^{-1}, multiple interactions per crossing cause some degradation in performance $e.g.$ b-tagging.
- Serious planning for a further factor of 10 in luminosity is underway: Physics studies are being carried out

LHC program evolves

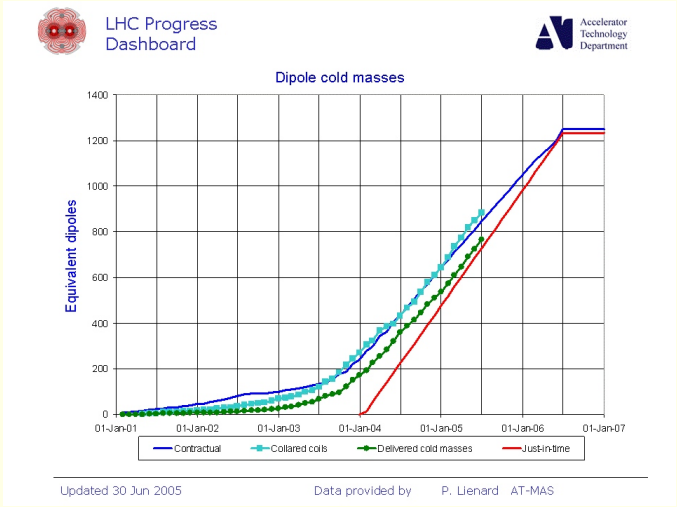
- Even very low luminosity will open a new window.
  - $10pb^{-1}$ (1 day at 1/100 of design luminosity) produces 8000 top quarks and 100 QCD jets beyond the kinematic limit of the Tevatron
  - If Supersymmetry is correct, it could be found with in few weeks.

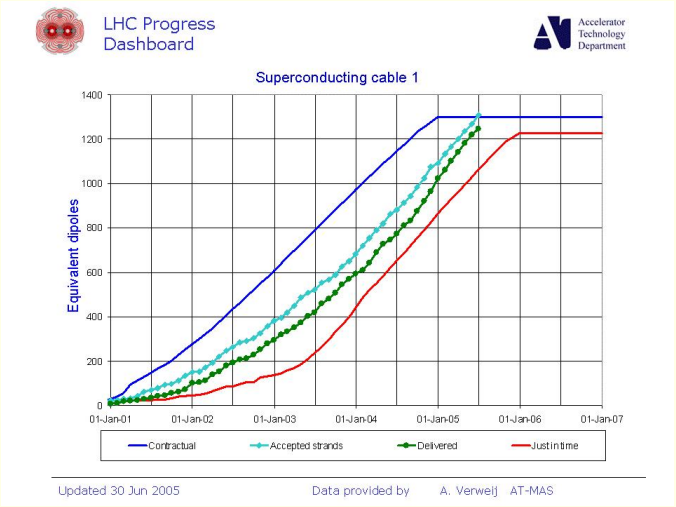
- The LHC experiments are better thought of as a facility
  It will make many measurements in areas currently covered by BaBar, Tevatron, RHIC: Its power lies in its scope and versatility

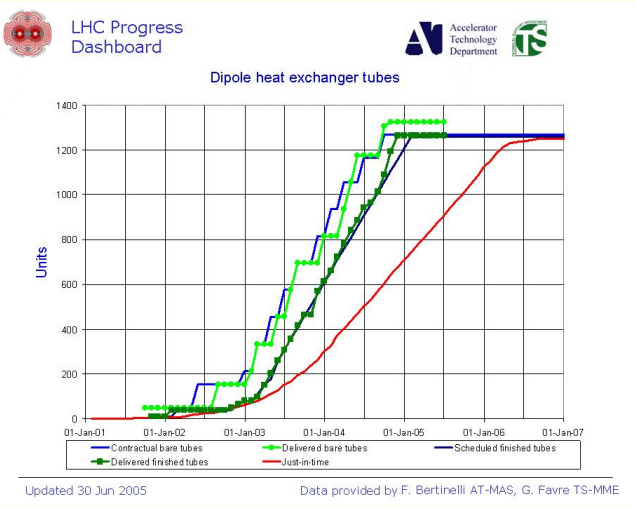
- Rich 10+ year program but some physics could benefit further increases in Luminosity
  This requires modest upgrades to the accelerator and the detectors which need to be funded shortly

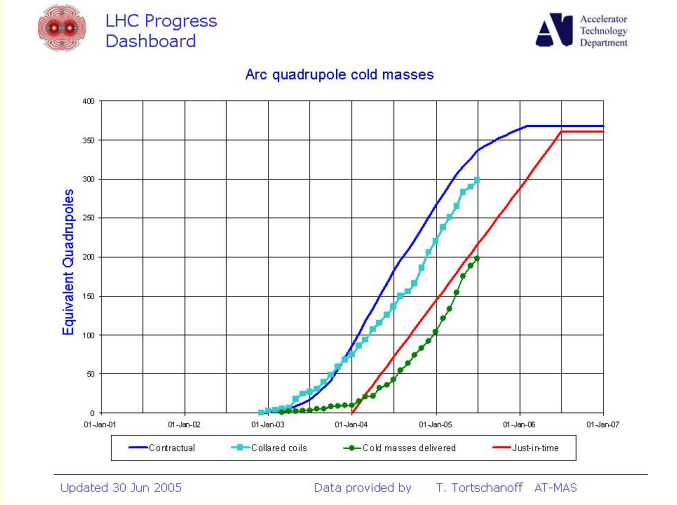
You can view the status via monthly on-line updates

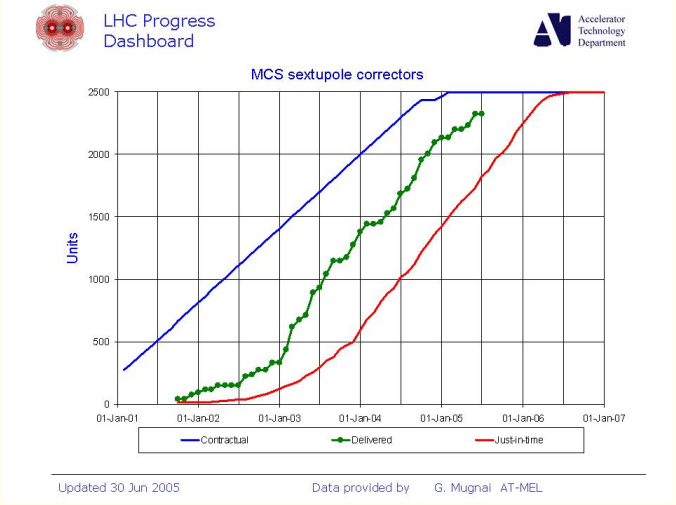
http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/DashBoard/index.asp

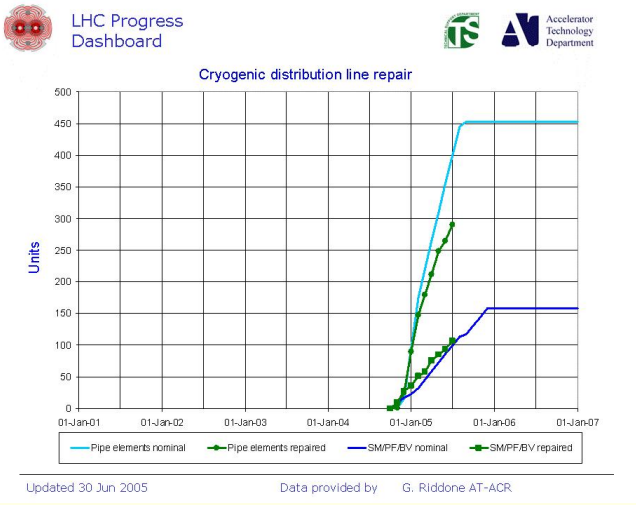




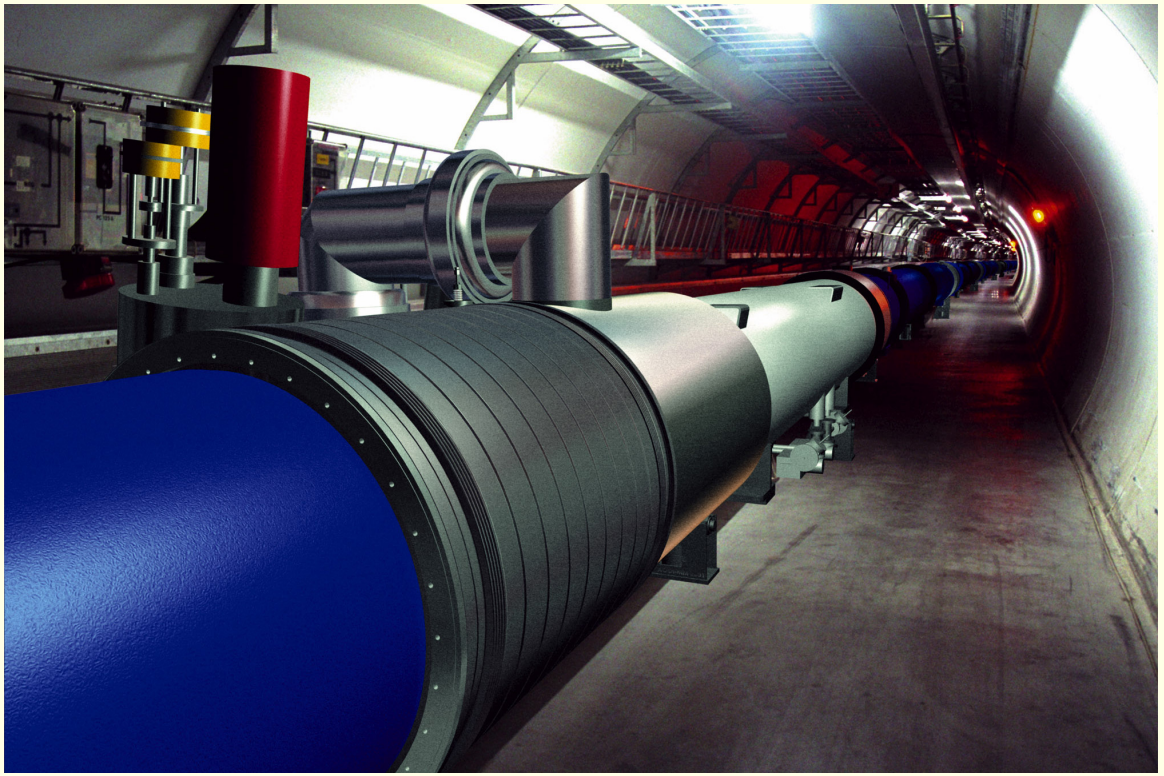








What the tunnel will look like

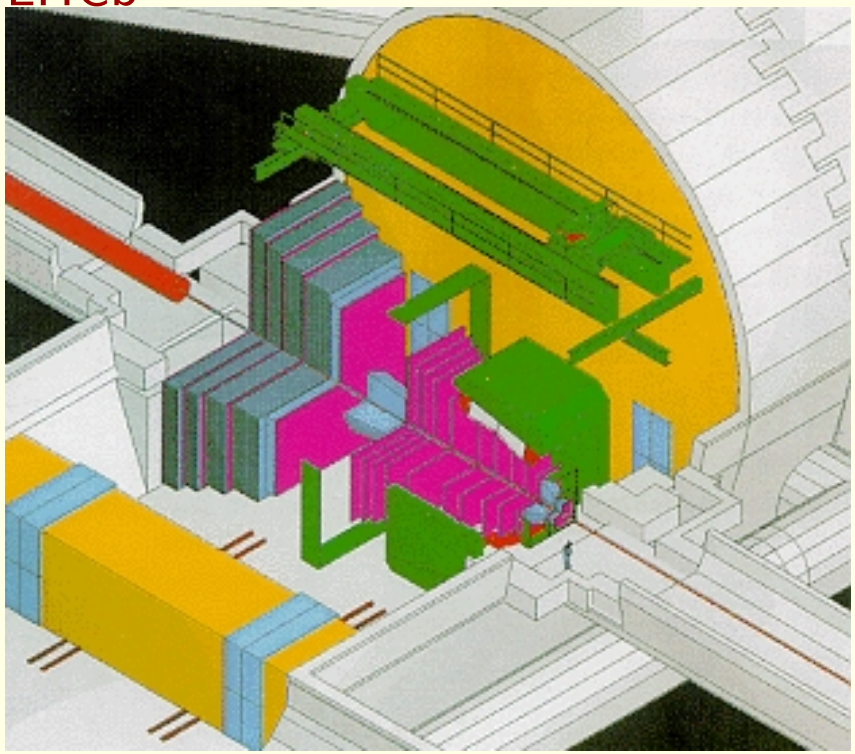


The Experiments

There are four experiments situated around the LHC ring

Two are special purpose

LHCb



A detector designed for B Physics

ALICE

Designed for Heavy Ion physics

The big Detectors: ATLAS and CMS

ATLAS and CMS are aimed at "new physics"

Independent of what is produced, if unstable, it must decay to standard model particles:

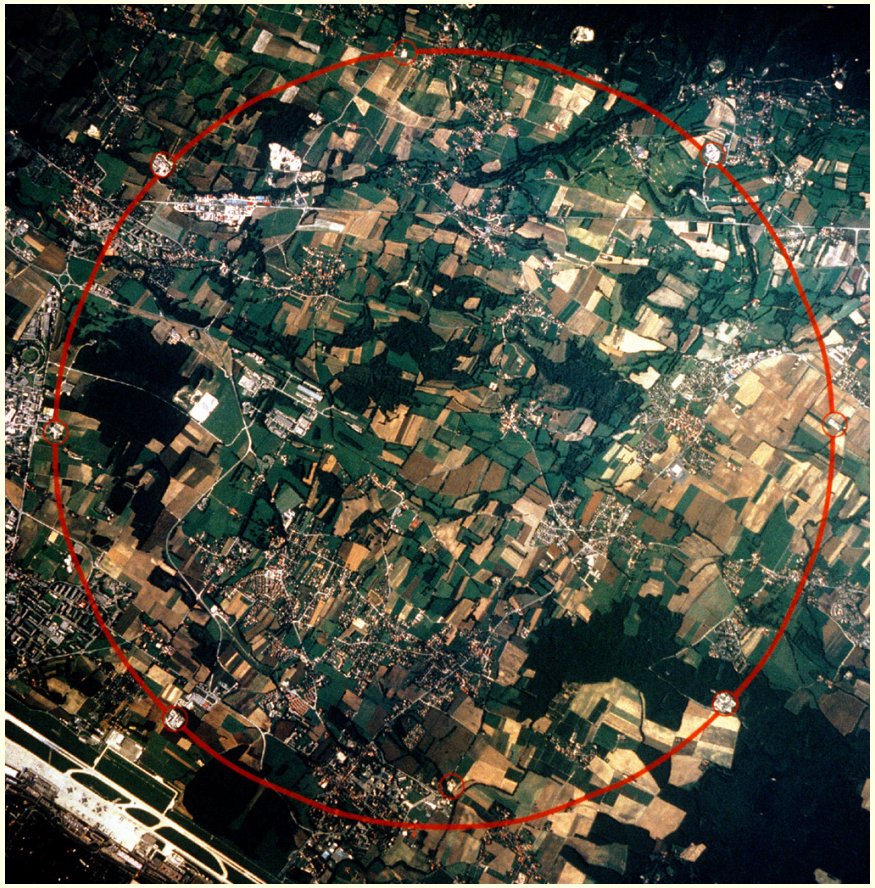
- Electrons, muons and tau leptons.
- Quarks and gluons: manifested as narrow "jets" of particles
  b-quarks can be found by looking in the jets for long-lived B-hadrons
- Neutrinos: do not interact in detector, but give unbalanced events ("missing energy")
- Photons, W and Z bosons: Latter detected via decays

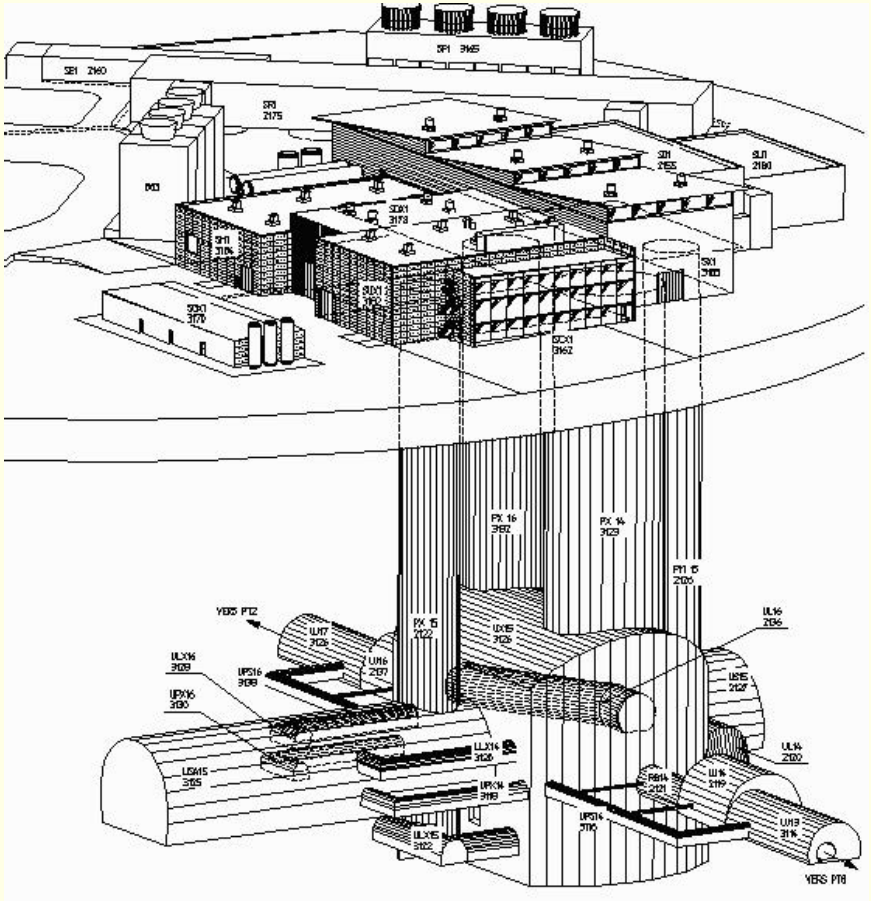
ATLAS and CMS provide full coverage for physics objects, $i.e.$ leptons and jets, missing energy: Physics performance of similar, technology choices are quite different

Approx 4000 physicists on these experiments: 20% from US. 60 US Universities/labs

Atlas–Buildings and location

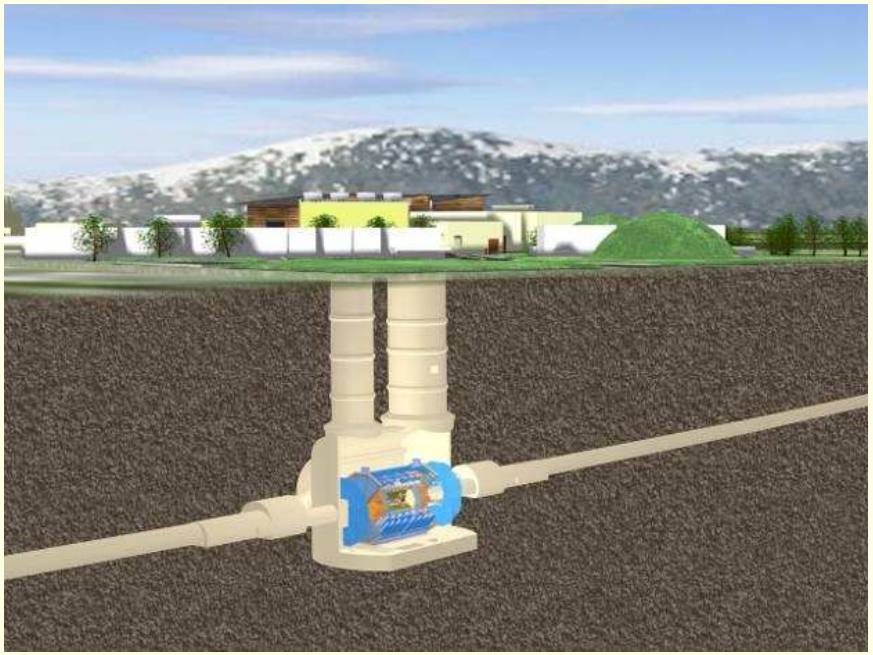
Surface building – across street from CERN main gate





Above

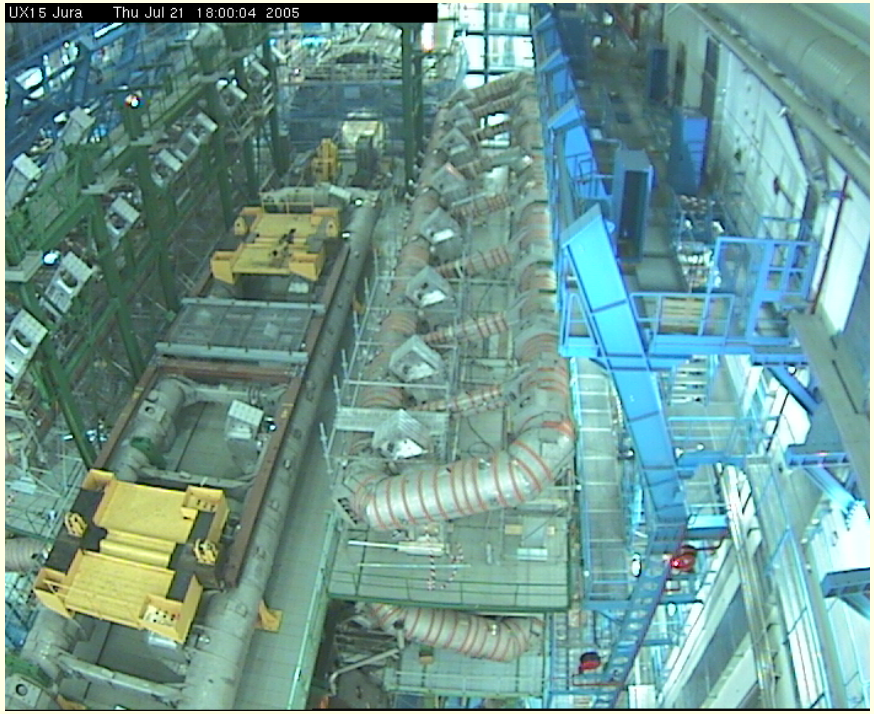
Below

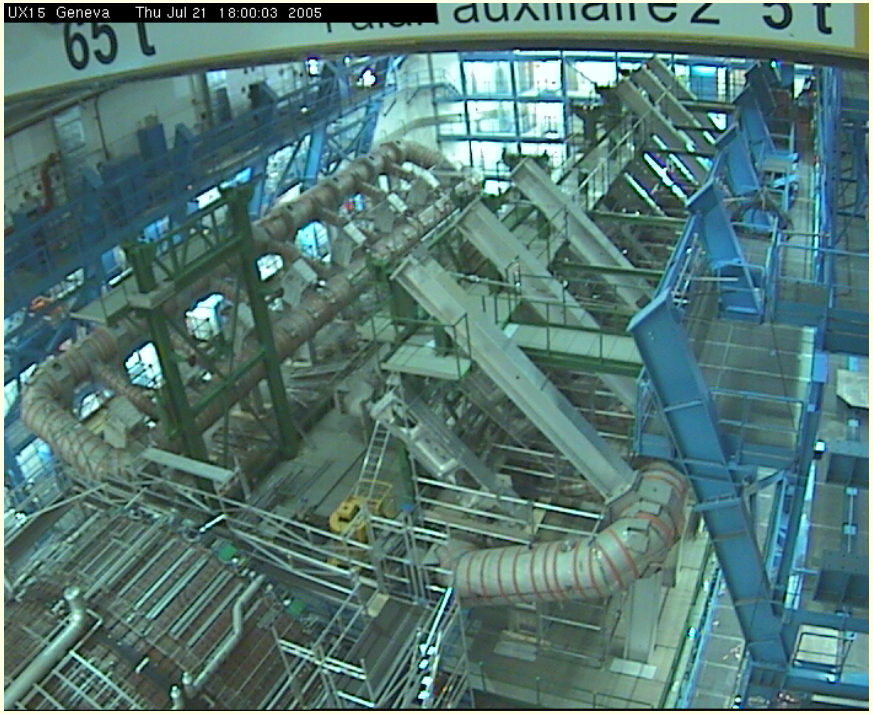


Last weeks photos

LHC Beam is at A and C

In the center is the support structure for the detector





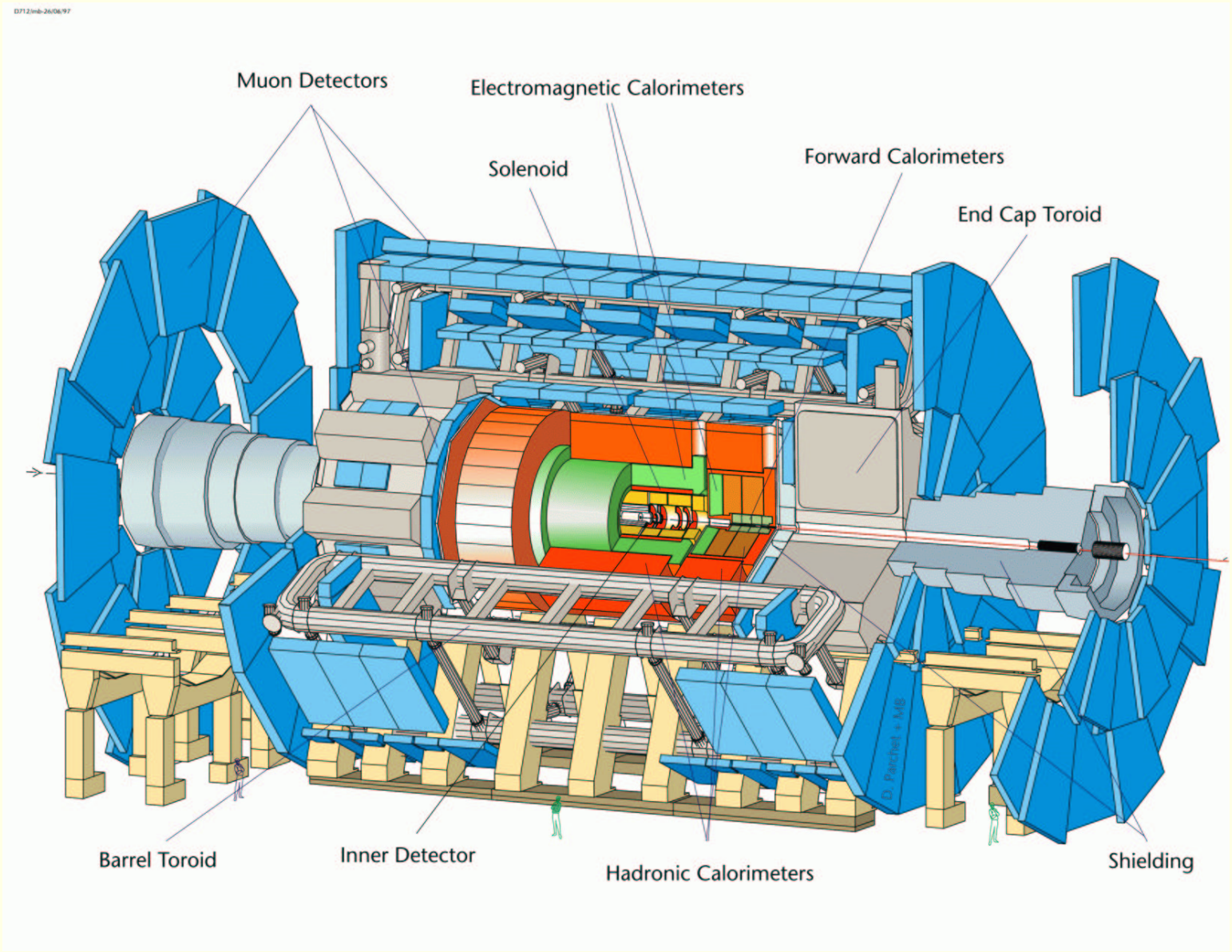
Overview of ATLAS

ATLAS and CMS are aimed at "new physics"

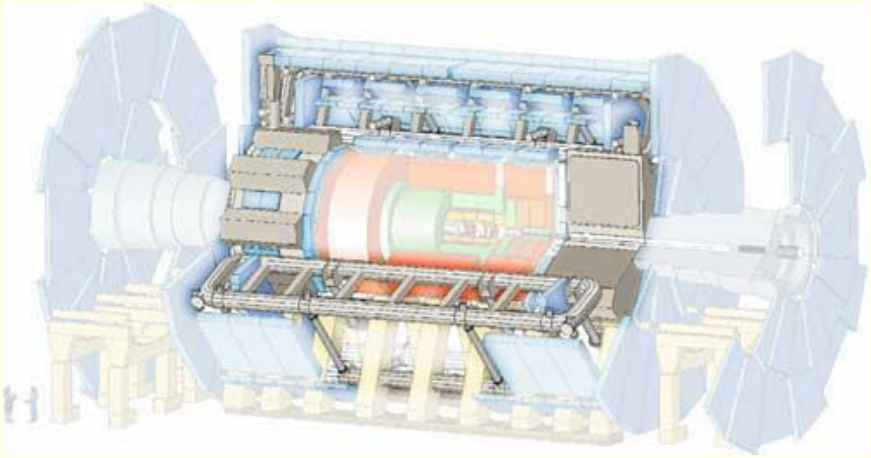
"Full acceptance" for physics objects, $i.e.$ leptons and jets, missing E_T

Many detector choices driven by specific physics goals ($e.g.$ LiAr Calorimeter) Equal response for e and μ

Physics performance is expected to be similar to CMS, technology choices are quite different


Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

Magnet system

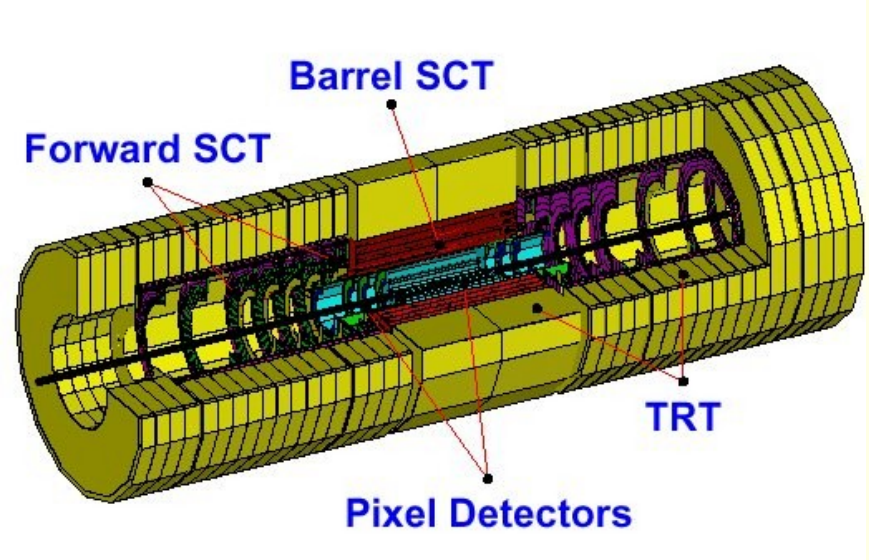


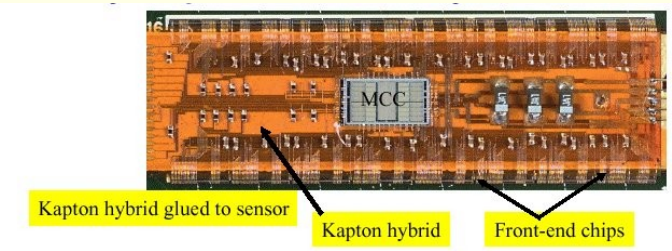
Solenoid – Central tracking

Muon endcap

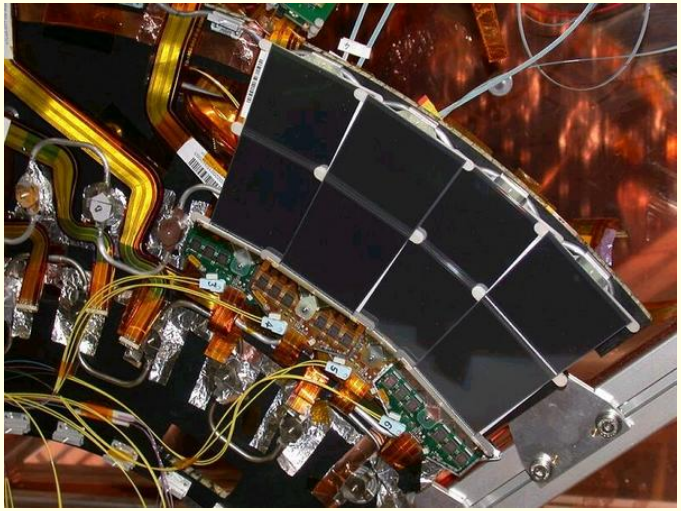
Central toroid under assembly

Inner Detector





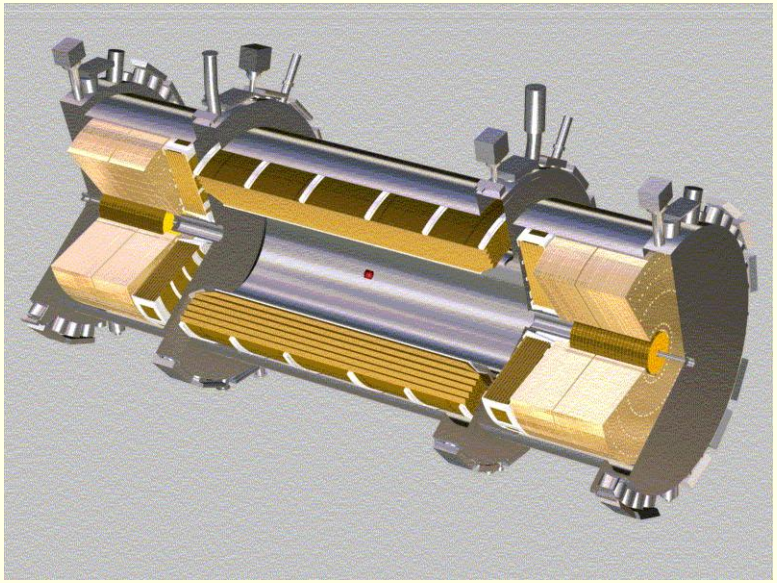
Pixel Hybrid

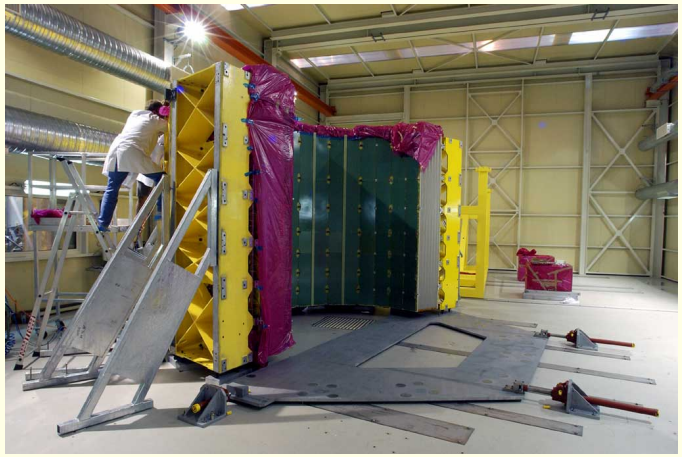


Forward Si Strip Module

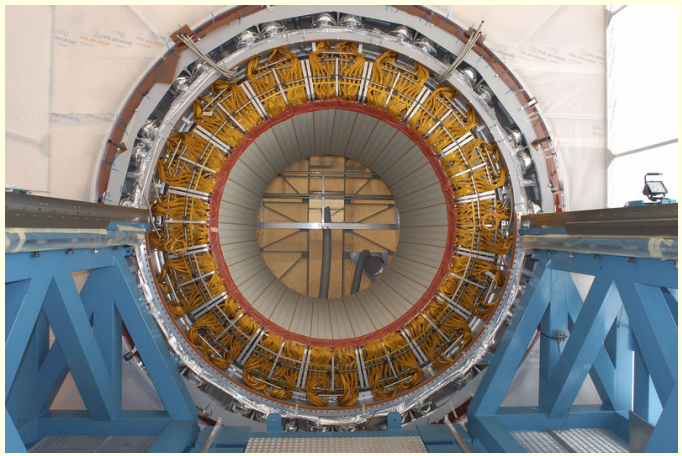
Forward TRT wheel

LiAr (EM) Calorimeter

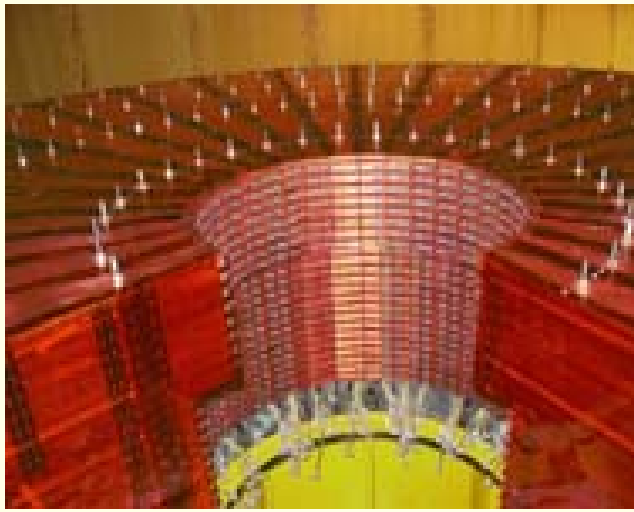




Barrel EM

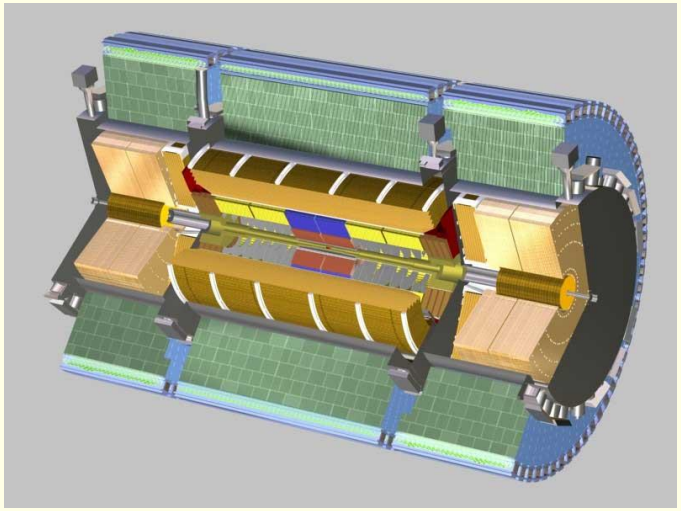


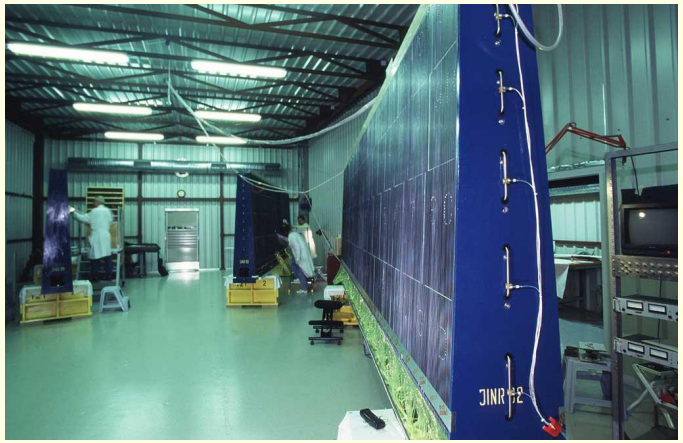
Barrel Cryostat



hadronic end cap

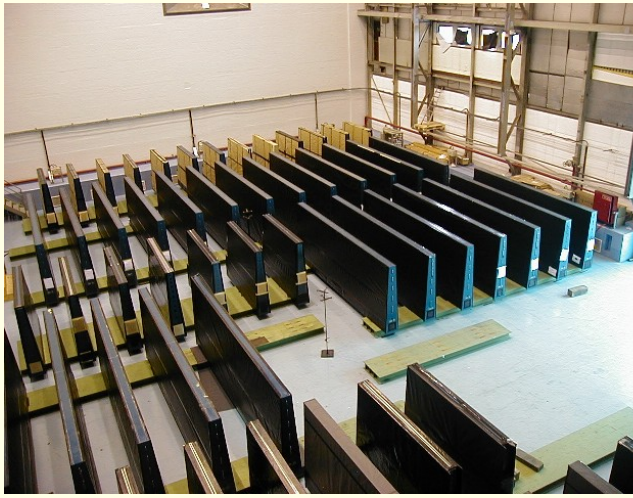
Tile (Hadronic) Calorimeter





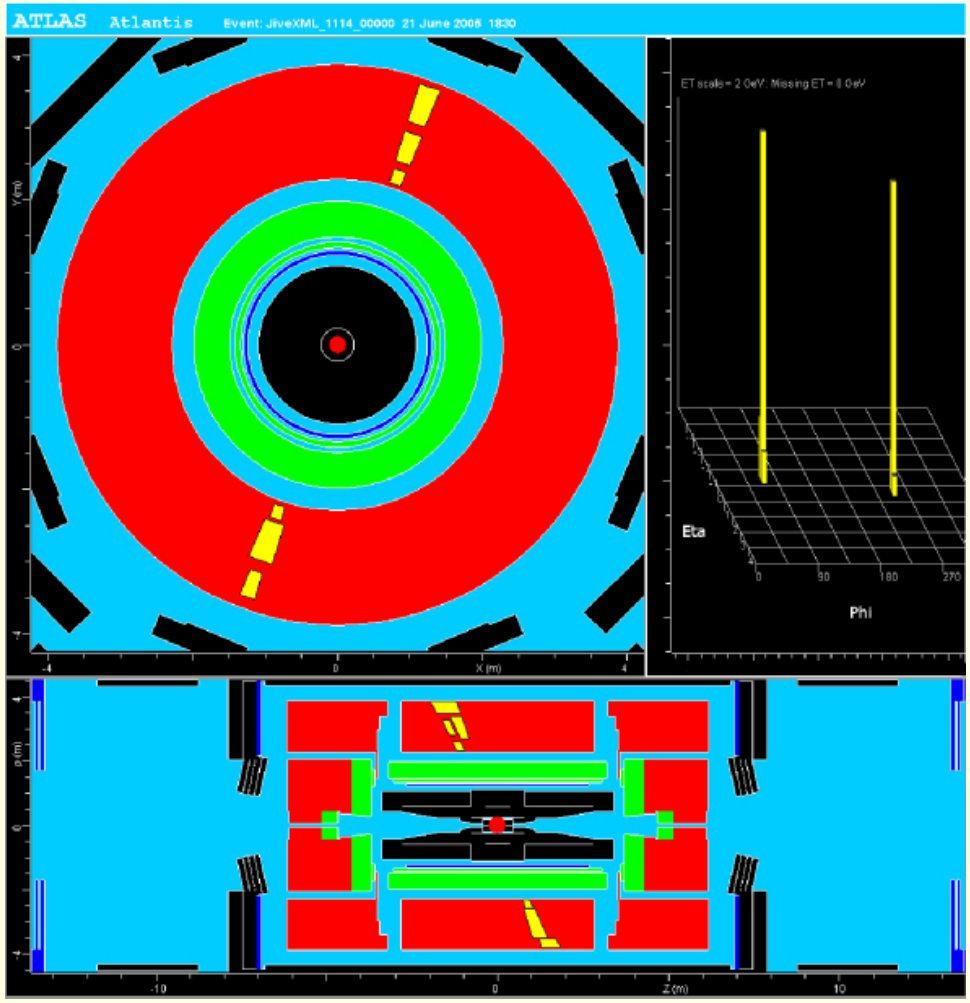
Single element

Barrel



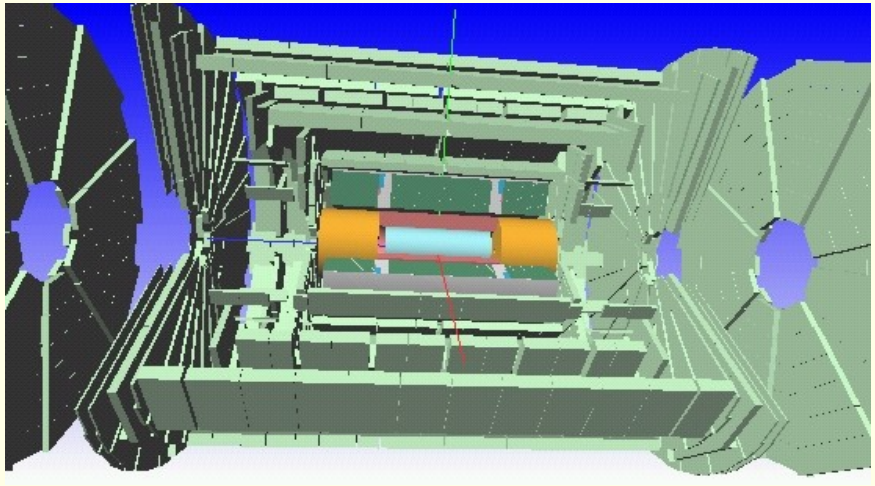
Sections in storage

This system is taking data!!



This is a real cosmic ray event: not a simulation

Muons



Characteristic New signatures at LHC

Not all present in all models

$\not{E}_T$

High Multiplicity of large p_t jets

Many isolated leptons

Copious b production

Large Higgs production

Isolated Photons

Quasi-stable charged particles

Characteristic New signatures at LHC

Not all present in all models

$\not\!\!E_T$

High Multiplicity of large p_t jets

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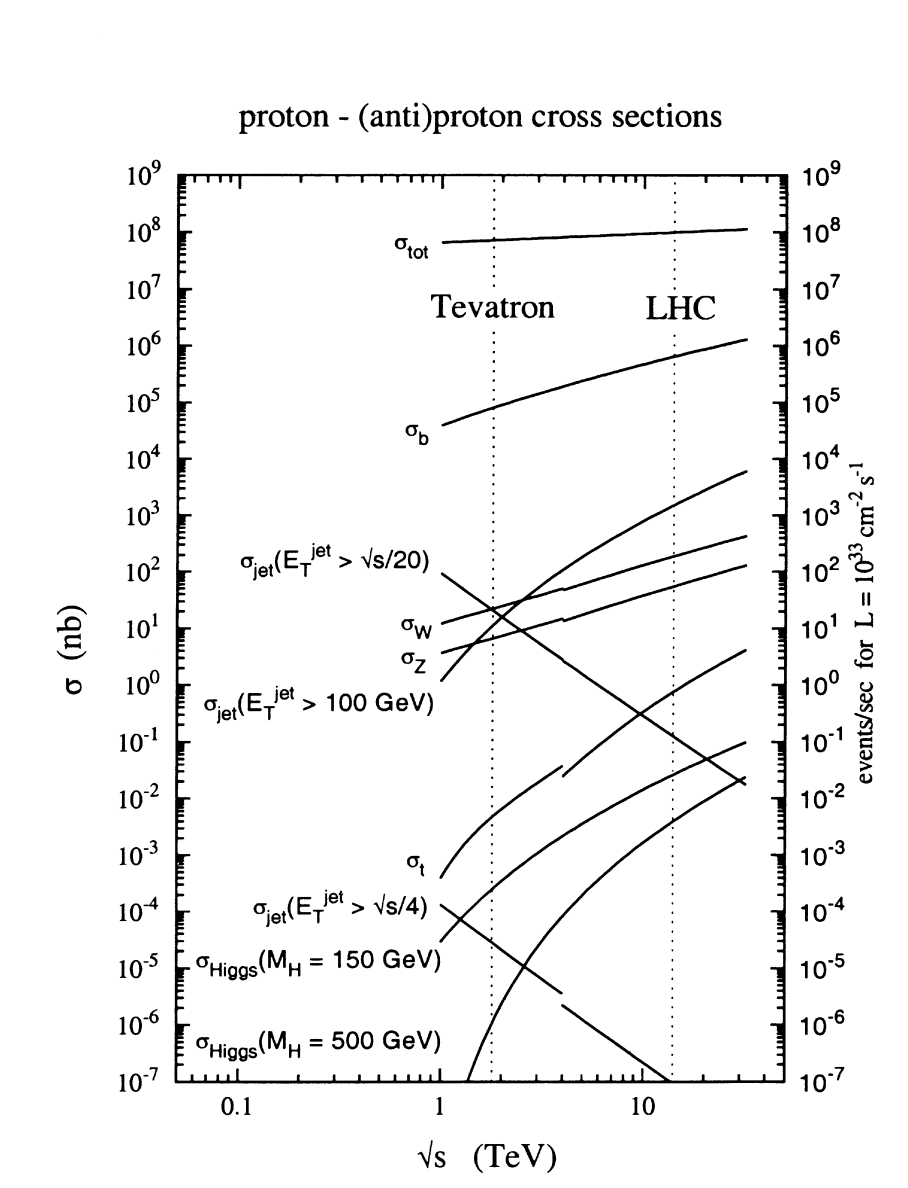
N.B.Production of heavy objects implies subset these signals

Important for triggering considerations

Start with what you know

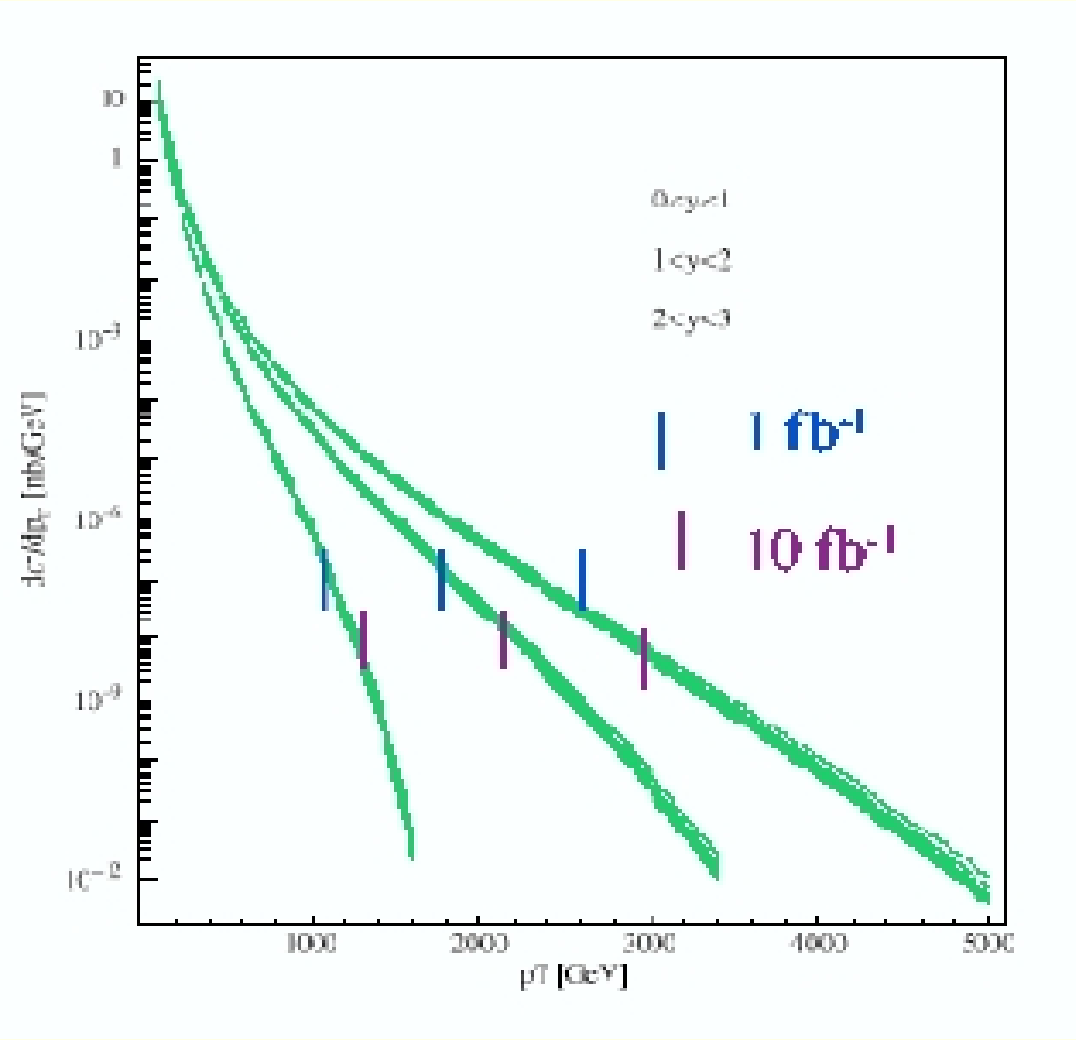
Before trying to sell a Higgs boson or SUSY, better look at Standard Model

Standard model rates



Sources of jets

This starts immediately and never ends
Don't expect any new physics at the bottom end
Biggest exptl. uncertainty comes from Jet energy scale (later)
500 GeV jets with $100nb^{-1}$
50 GeV Jets with $100\mu b^{-1}$
Initially tune up Monte Carlo
Eventually measure α_s More on measuring jets if you want



This is the second most likely source of "wrong new physics"

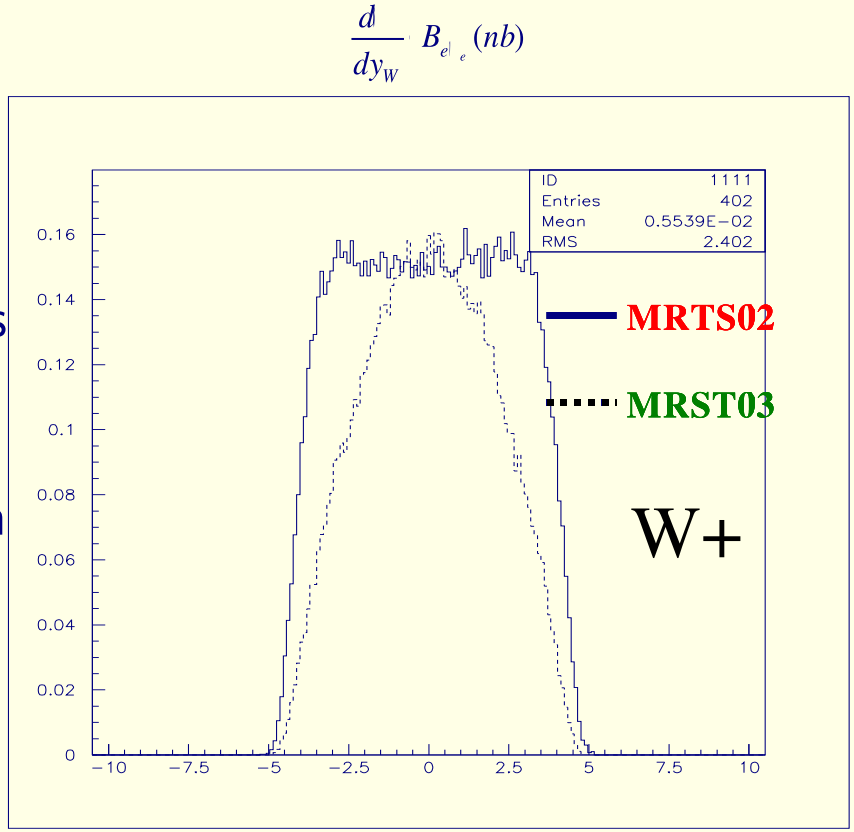
Sources of electrons: Irreducible

$W \to e\nu$

Physics measurements of cross-sections and structure functions

Note big uncertainty in forward region

A long term goal will be precision measurement of W mass:



Need this to determine structure functions

Sources of electrons: Reducible

- Most "new physics" gives isolated electrons
  Typically defined by E_T in cone $\Delta R = \sqrt{(\Delta\eta)^+(\Delta\phi)^2}$
- Isolated ones come from W or Z
- Non Isolated come from b and c: rate depends on definition. these are important for Higgs
- Fakes come from jets. Discuss

Sources of muons

- Isolated are the same is e
- Non Isolated come from b and c: rate depends on definition. these are important for Higgs
- Non Isolated come from K and π: Not the same as e
- Fakes come from jets. Not same as e Discuss

Sources of taus

- leptonic tau decays are of limited use.
- $\tau \rightarrow \pi\nu$, $\tau \rightarrow \rho\nu$ etc
- Isolated are the same is e
- Non Isolated are useless Ask
- Fakes come from jets. Discuss
- Only lepton where polarization might be measurable

Sources of Missing ET

- Irreducible comes from neutrinos
- Muons escaping beyond end of muon system
- Cracks in detector
- Non contained jets
- Mis measured jets

Detecting b-jets

Later

Techniques also apply to measuring lifetimes of new particles

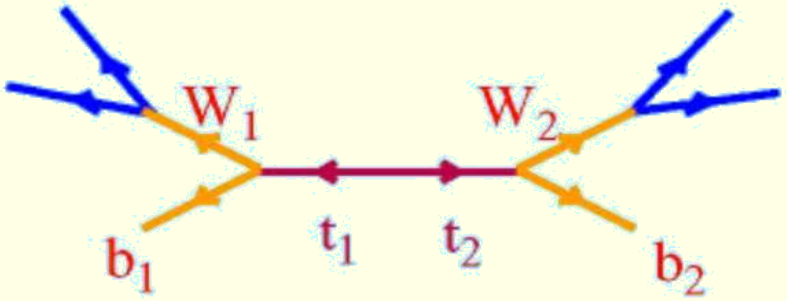
Detecting taus

Later

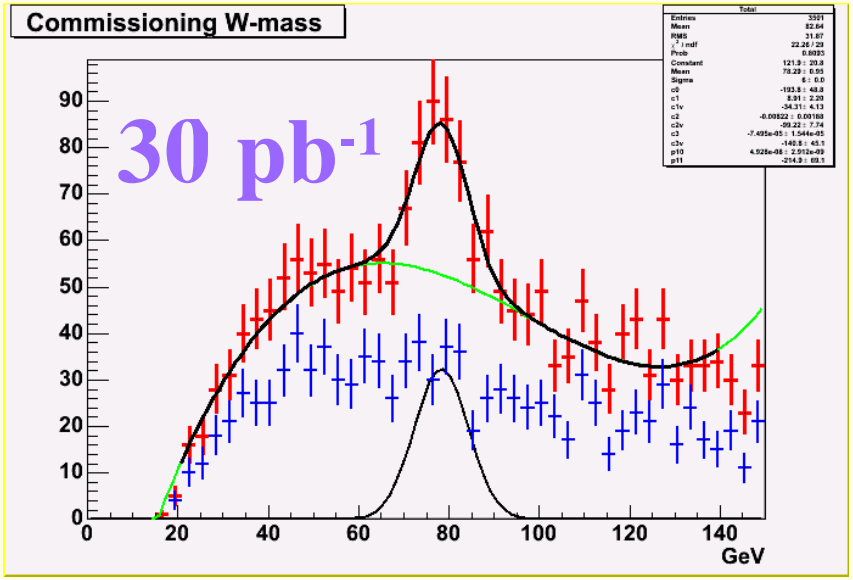
Standard Model: Top

- $10pb^{-1}$ (1 day at 1/100 of design luminosity) gives 8000 $t\bar{t}$
- S/B better than Tevatron
- Ultimate Gaol is precise measurement of top mass
- Initially, Calibrate the detector, measure cross-section

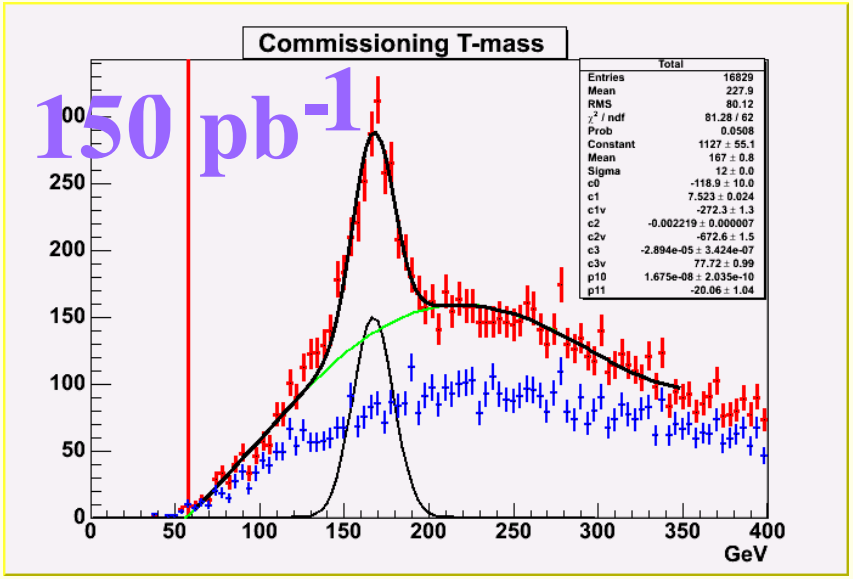
Use the semileptonic decay
Clean and plenty of rate
No b-tagging is needed It needs working tracking or EM calorimeter and jet finding



Use these to calibrate jets from W



assume b-jet scale is same (approx)
reconstruct top peak
measure cross section



Now have sample of events with two b's for measuring the b-tagging.

Many more

- B production rates
- Drell-Yan
- ψ and Υ
- WW, ZZ, $W\gamma$ at low p_T where SM should be OK

30 days with luminosity 10^{31} does most of this program:
Don't believe any claims of new physics until the above has been done!!