ATLAS – At the Energy Frontier

Dave Charlton
17 November 2004

The physics: *why* we are doing it

How we are doing it: the Large Hadron Collider

ATLAS – being built near you!

Putting it all together

The Standard Model

An obligatory slide in a particle physics talk...

Matter particles

e^-	μ^-	τ^-
υ_e	υ_μ	υ_τ
d	s	b
u	c	t

plus antiparticles

Masses and mixings

Gauge bosons

γ

W Z

g

Higgs sector

?H?

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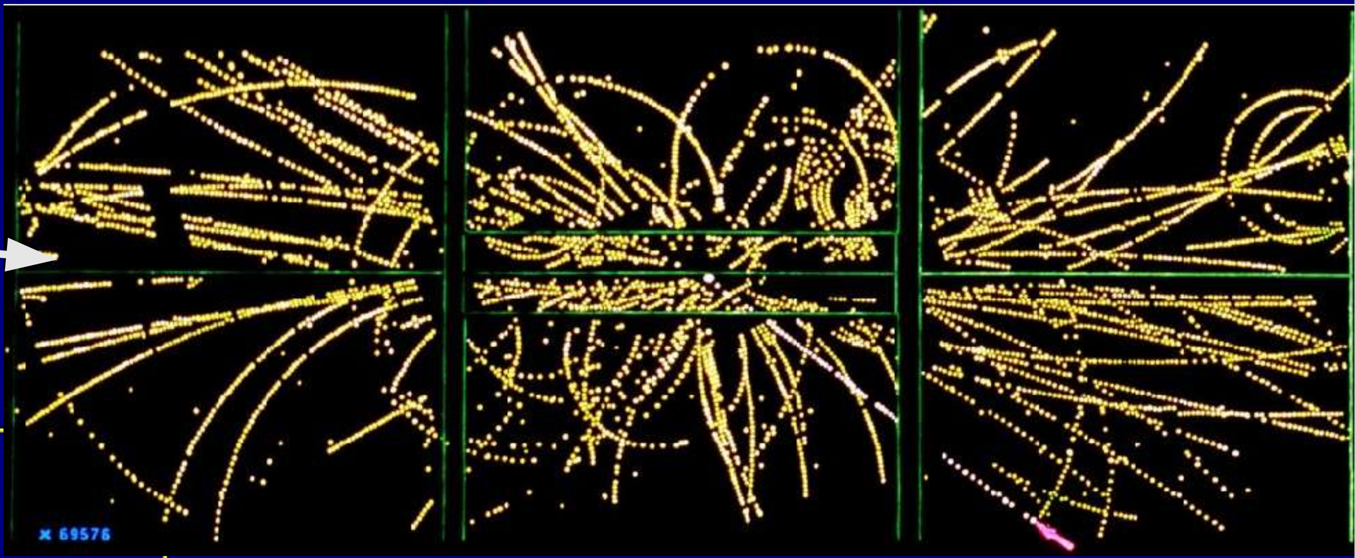
Higgs sector

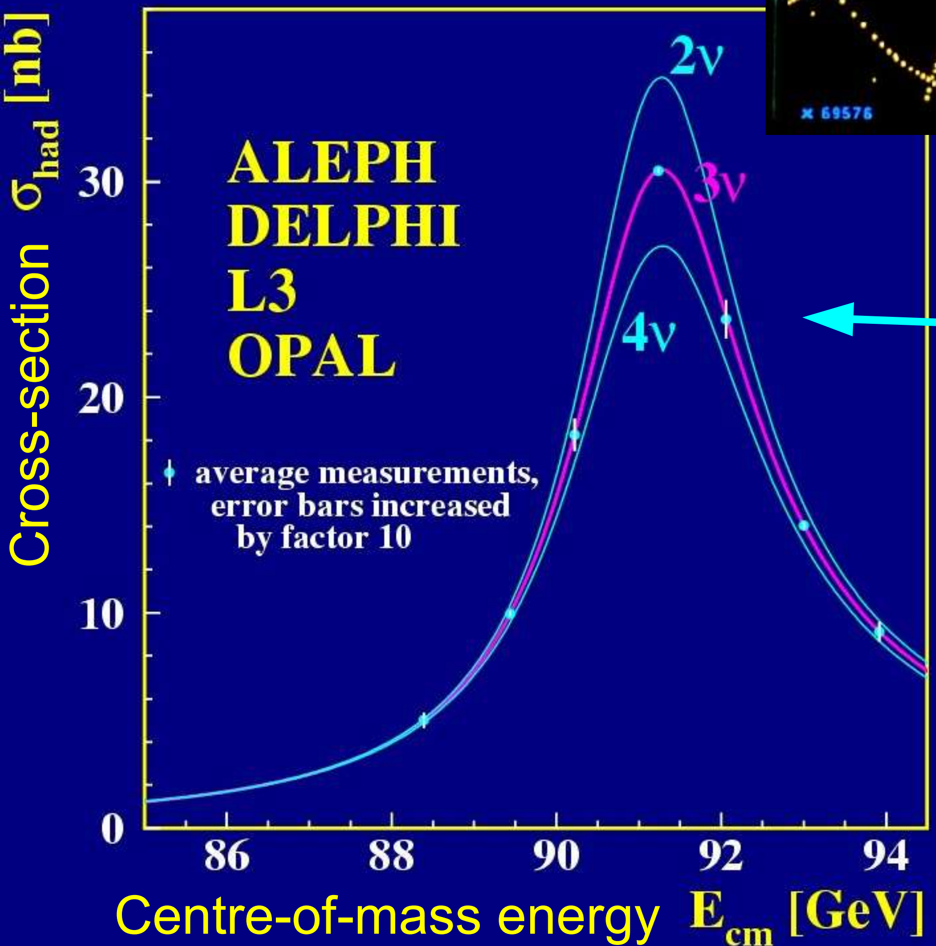
?H?

and what else is there?

Electroweak Gauge Bosons

W,Z discovery in 1982-3 by UA1 experiment at CERN





Properties of Z and W studied in depth at LEP in 1989-2000

Millions of Z's

Tens of thousands of W's

Electroweak precision physics

e.g. $N(\nu) = 2.9841 \pm 0.0083$

Electroweak Symmetry-Breaking
"EWSB"

The W and Z are massive, and the γ is not

Following LEP, we know electroweak unification happens, and that it describes LEP physics at the level of quantum corrections (per mille level)

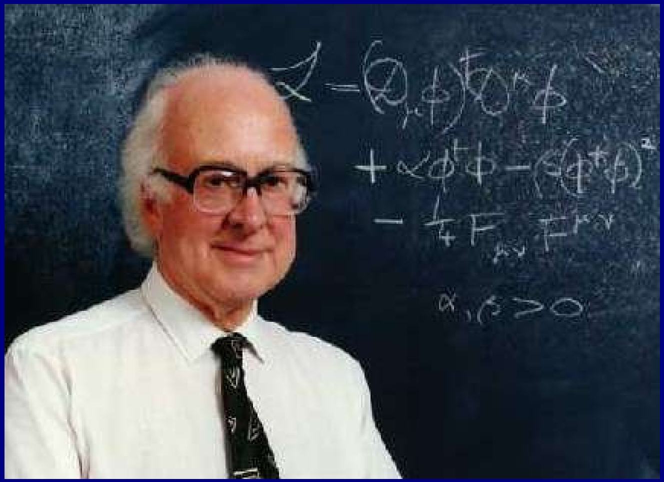
What we do *not* know is *how* the mass of the gauge bosons and fermions arises – cannot just add mass terms to the electroweak lagrangian, as it breaks gauge invariance

We believe gauge invariance must be maintained as it ensures renormalisability (perturbative calculability)

This is the N°1 problem in particle physics today

EWSB – the Higgs Mechanism

Higgs proposed a mechanism to add masses without breaking gauge invariance, by postulating an all-pervasive scalar field in the vacuum



In the model, the physical vacuum breaks the EW symmetry

Scalar field → W/Z masses
Also new physical scalar boson(s) – Higgs bosons

There are a wide variety of ways this may be implemented, with different numbers of physical Higgs bosons

EWSB – Standard Model Higgs

In the simplest (Standard Model) form of the Higgs mechanism, ***exactly one*** physical Higgs boson should be observable

Is this right?

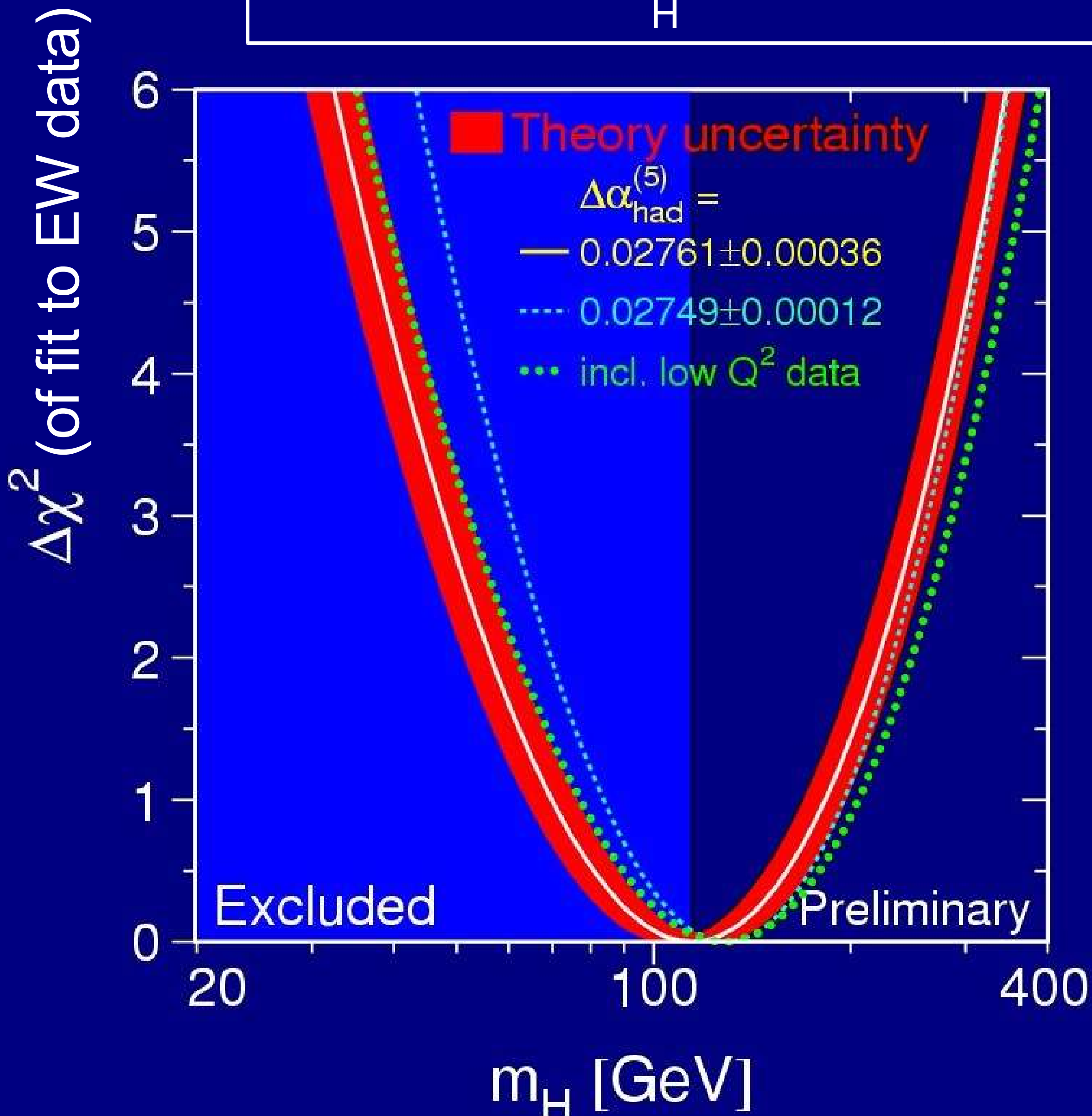
- *no direct* evidence – we have not seen the H
- *indirect* support from precise electroweak data (→)
- simplest known model consistent with data

Ockham

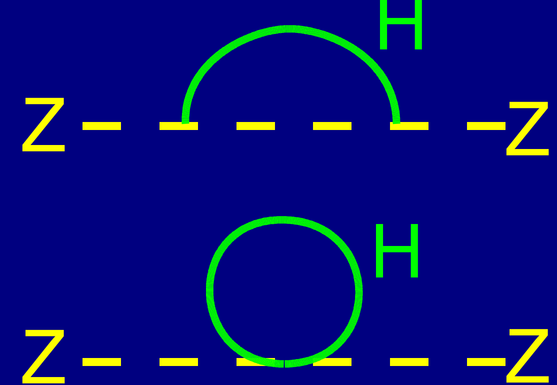
EWSB Probes – to date

Direct searches for SM Higgs all negative

LEP: $M_H > 114$ GeV (at 95% CL)



Also sensitive to H via quantum corrections at Z



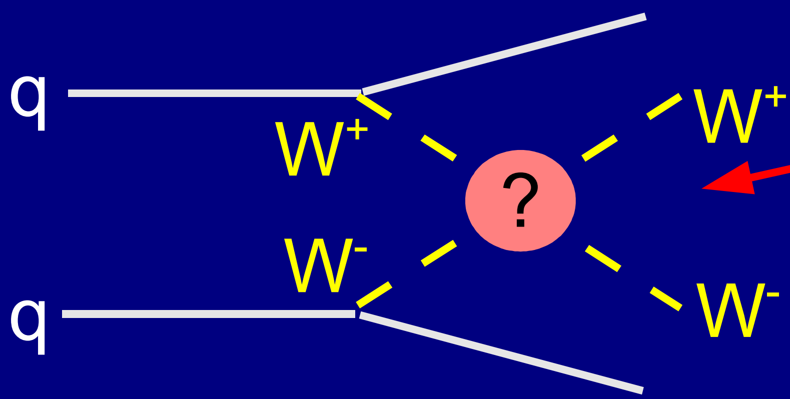
If the H behaves as in SM:

$M_H <$ ~300 GeV

The TeV Scale

We expect Higgs(es) to show up with masses no more than hundreds of GeV – dictates TeV scale collisions

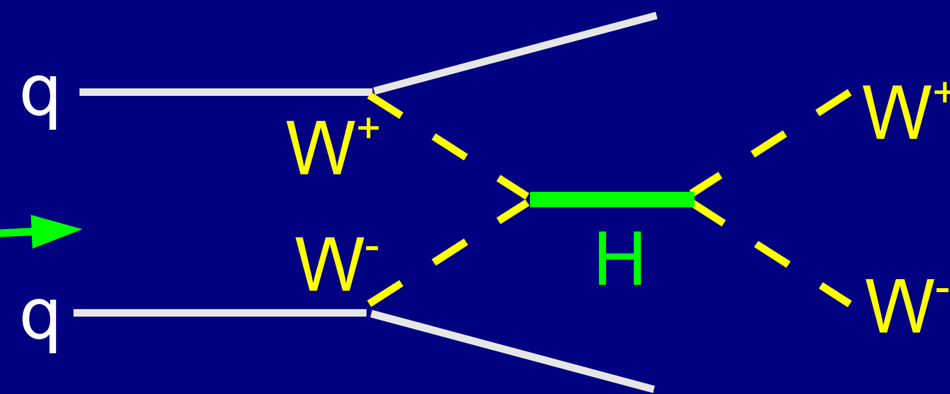
More generally, if no explicit EWSB mechanism, problems at TeV scale



For energy > 1 TeV, probability for WW scattering rises above 1

Must probe into this region

Standard Model solution

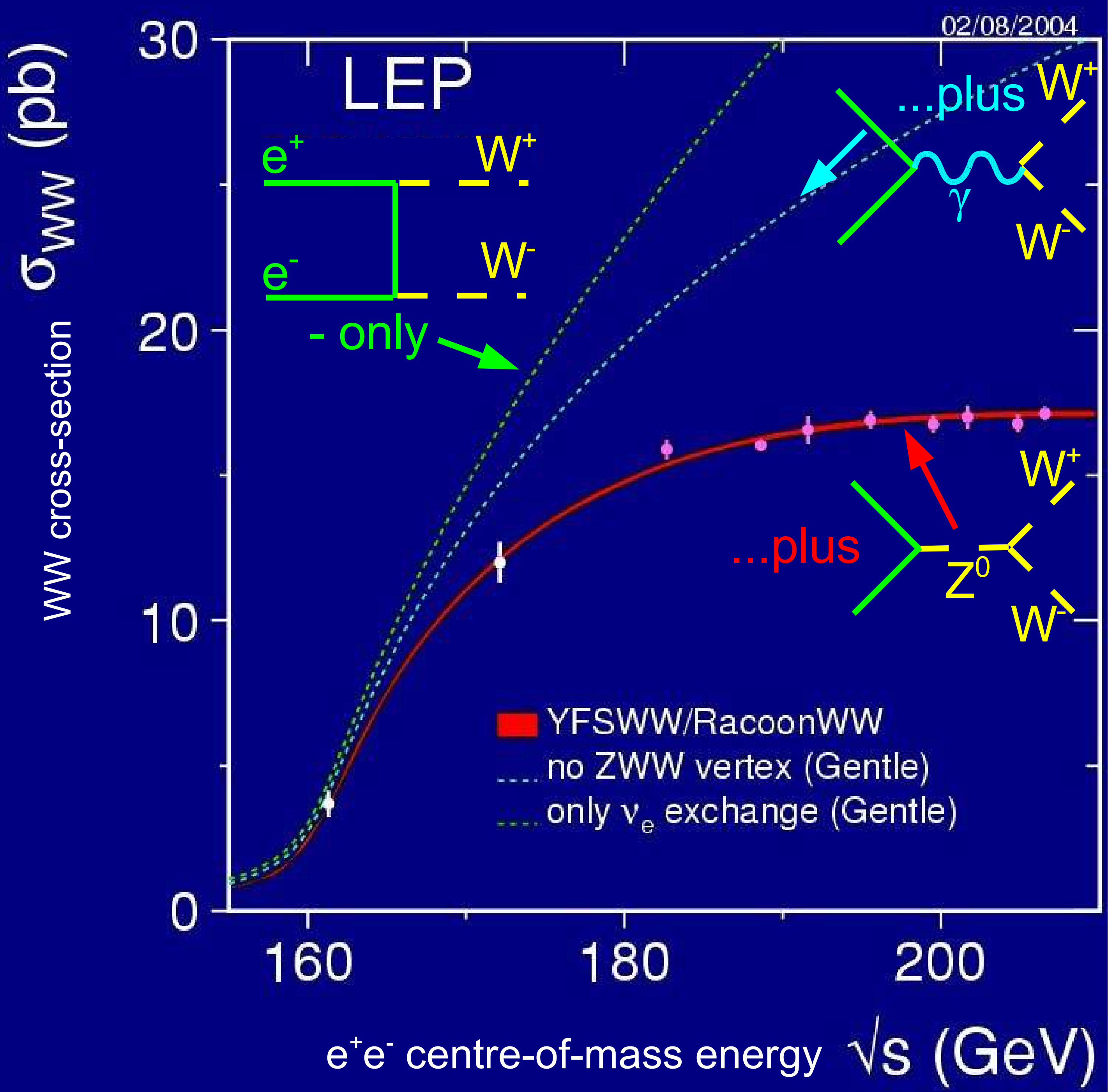


Vector Boson Self-Interactions

Important to test 3-way and 4-way gauge boson vertices

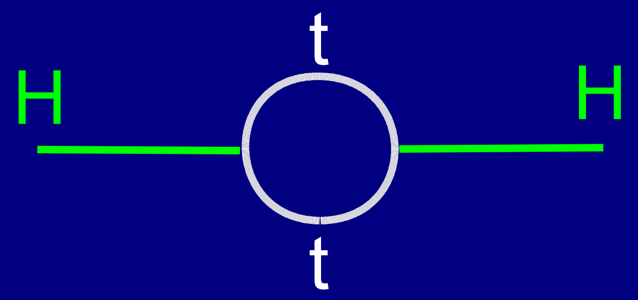
Example from LEP: WW production

Data agree only with prediction with SM vector boson self-couplings (negative interference)



Another Problem

Even if the SM H is the right answer, we expect large quantum corrections to its mass



Corrections are of the order of the energy scale at which the next new physics enters – must "fine-tune" to suppress

If next scale is the Planck scale (10^{19} GeV) fine-tuning must be remarkably precise

Known as the ***hierarchy problem***

Strong motivation for physics beyond the Standard Model at the TeV scale

Possibilities: supersymmetry, large extra dimensions, …

The Plan of Attack

We can obtain TeV scale collisions either:

- by colliding leptons with TeV-scale energies
- by colliding hadrons with multi-TeV energies
  (colliding quarks/gluons carry only a fraction of the hadron energy)

Protons technically “simplest” → LHC (p on p)

Leptons → proposed International Linear Collider (e^- on e^+)

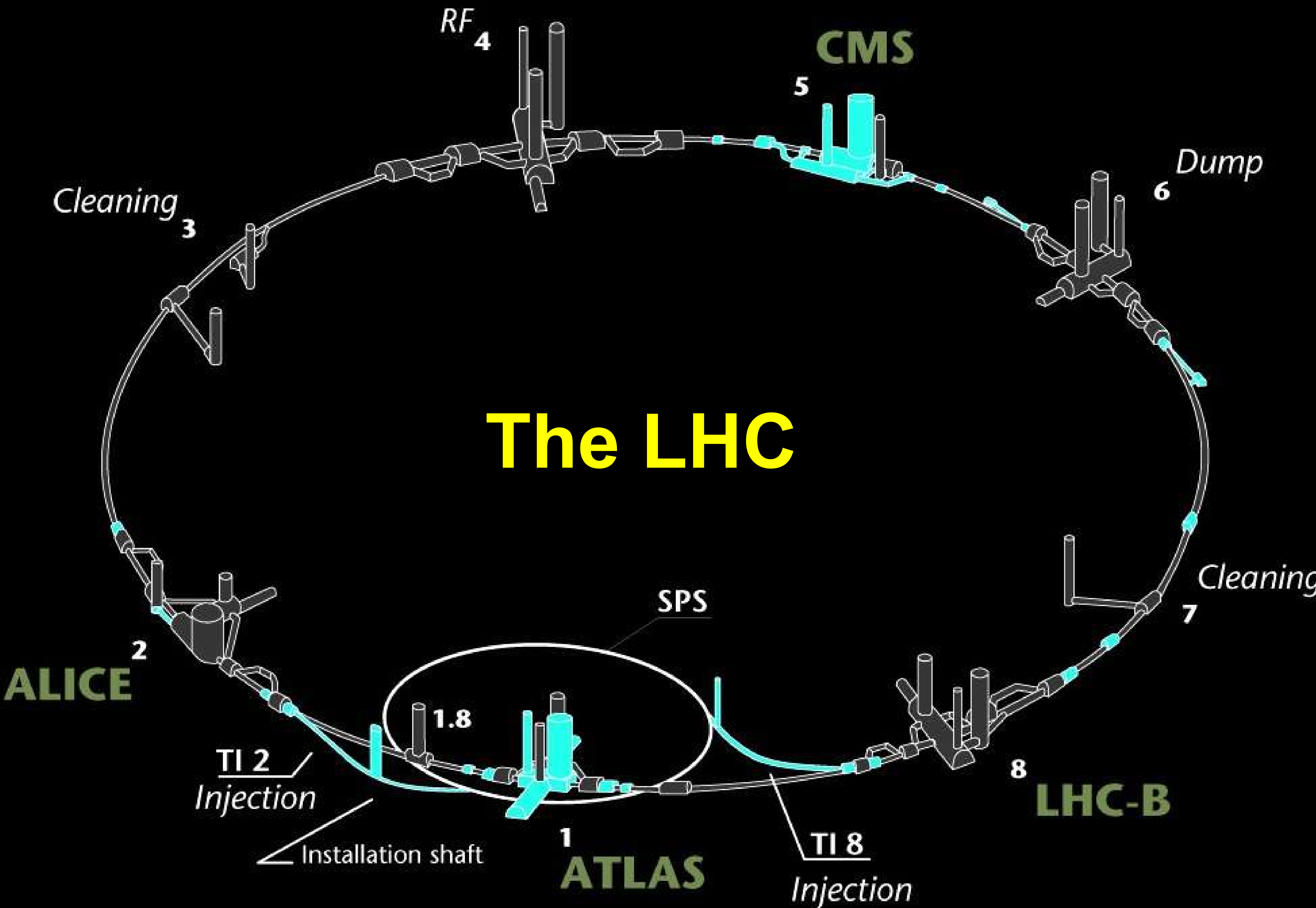
Cost **is** an issue – each facility is now a world-wide collaboration

The LHC is the world's next particle physics facility

E_{cm}=14 TeV – 7 times the energy of the Tevatron


LHC tunnel
(50-100m underground)
The LHC
ATLAS site
CERN main site

The LHC


RF 4
CMS
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Dump
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Cleaning 3
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SPS
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ALICE
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TI 2
Injection
Installation shaft
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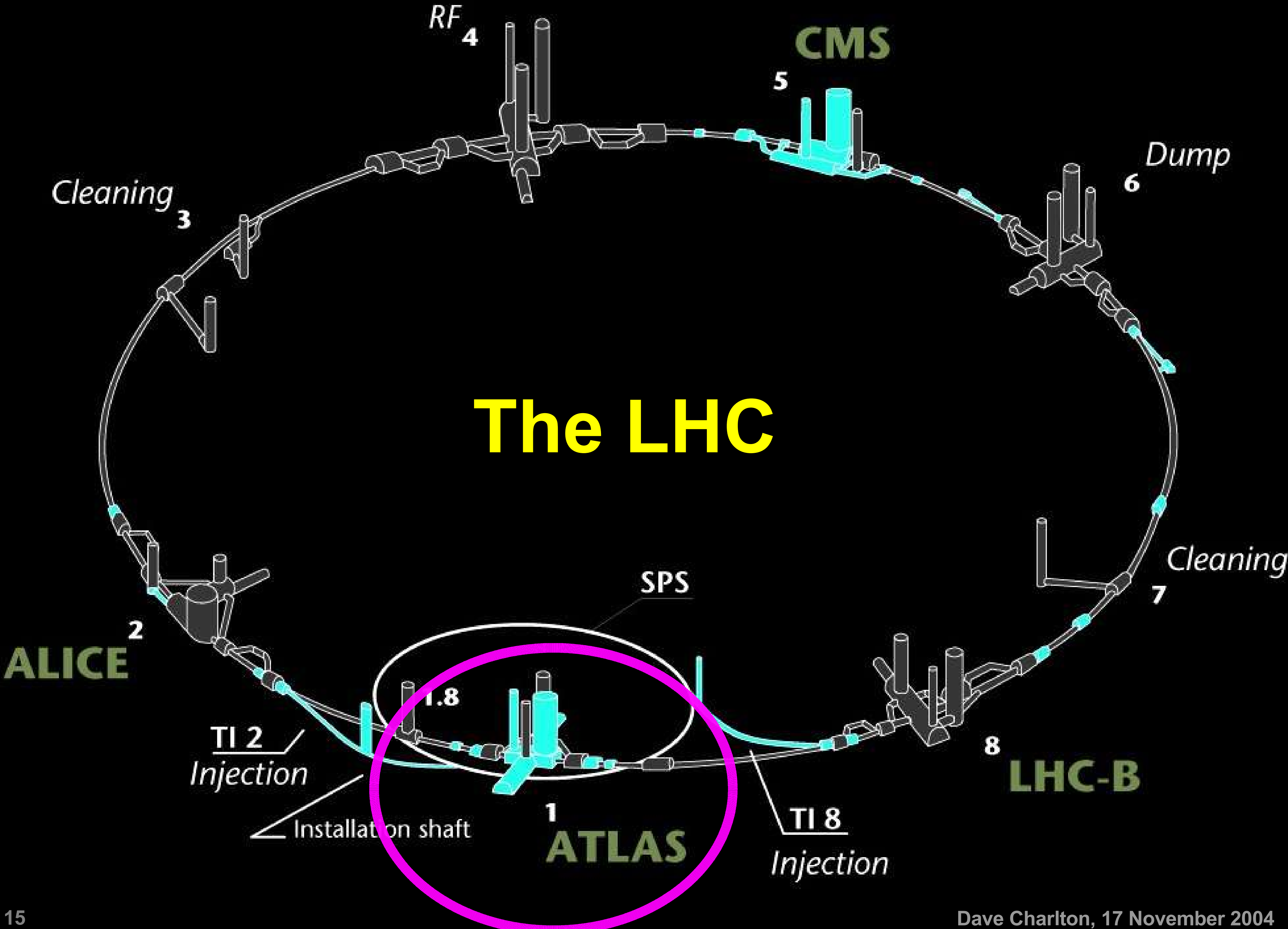
ATLAS
TI 8
Injection
8
LHC-B

The LHC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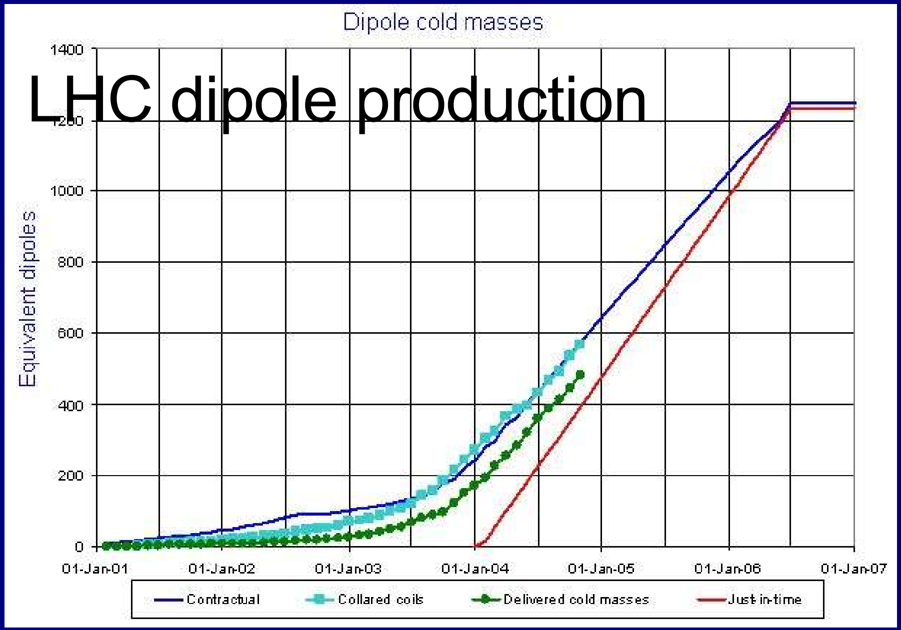
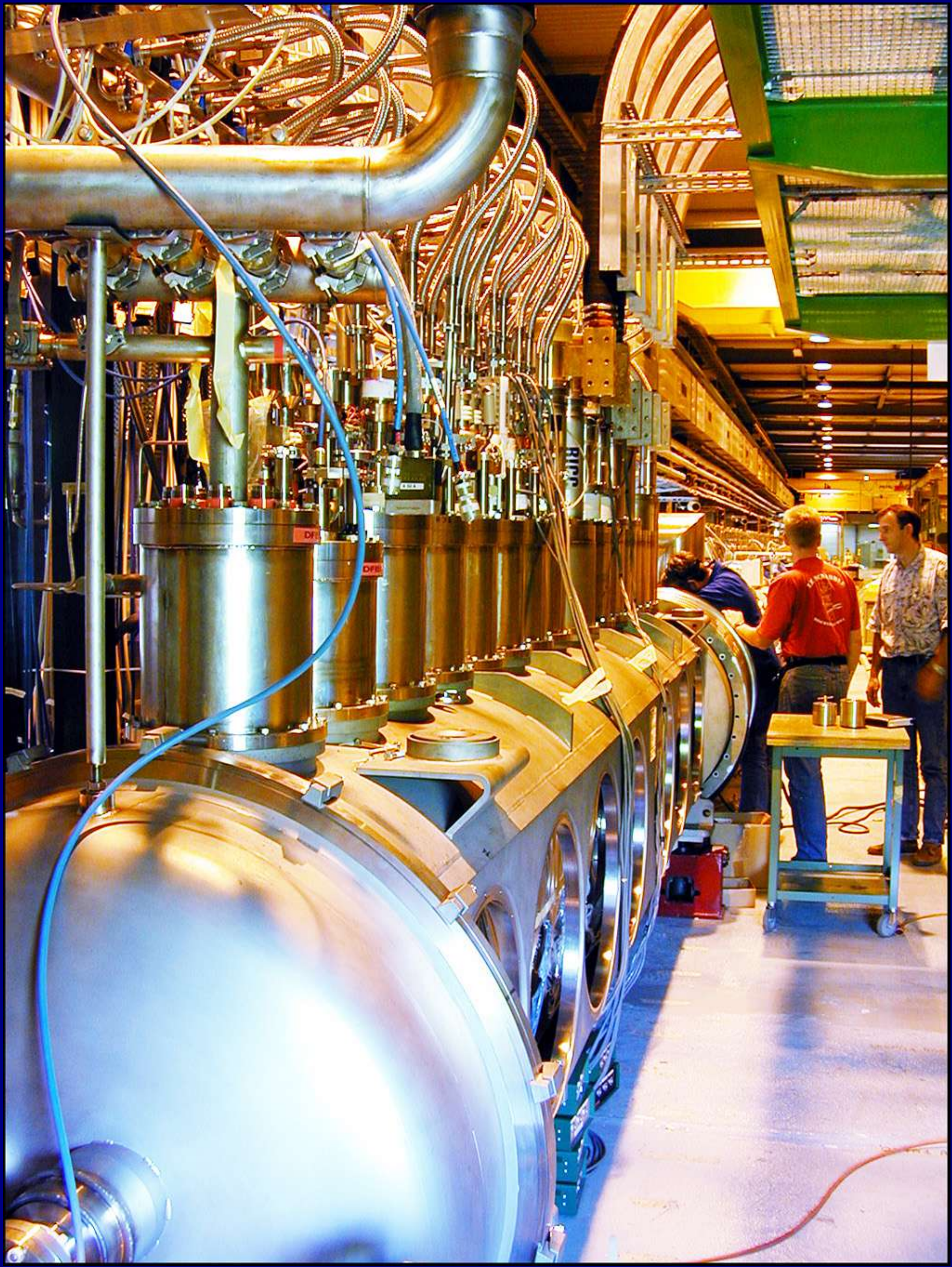
The LHC Machine

Energy and luminosity both as high as possible

Superconducting magnets – 27 km at LHe temperatures





On track for first collisions in 2007

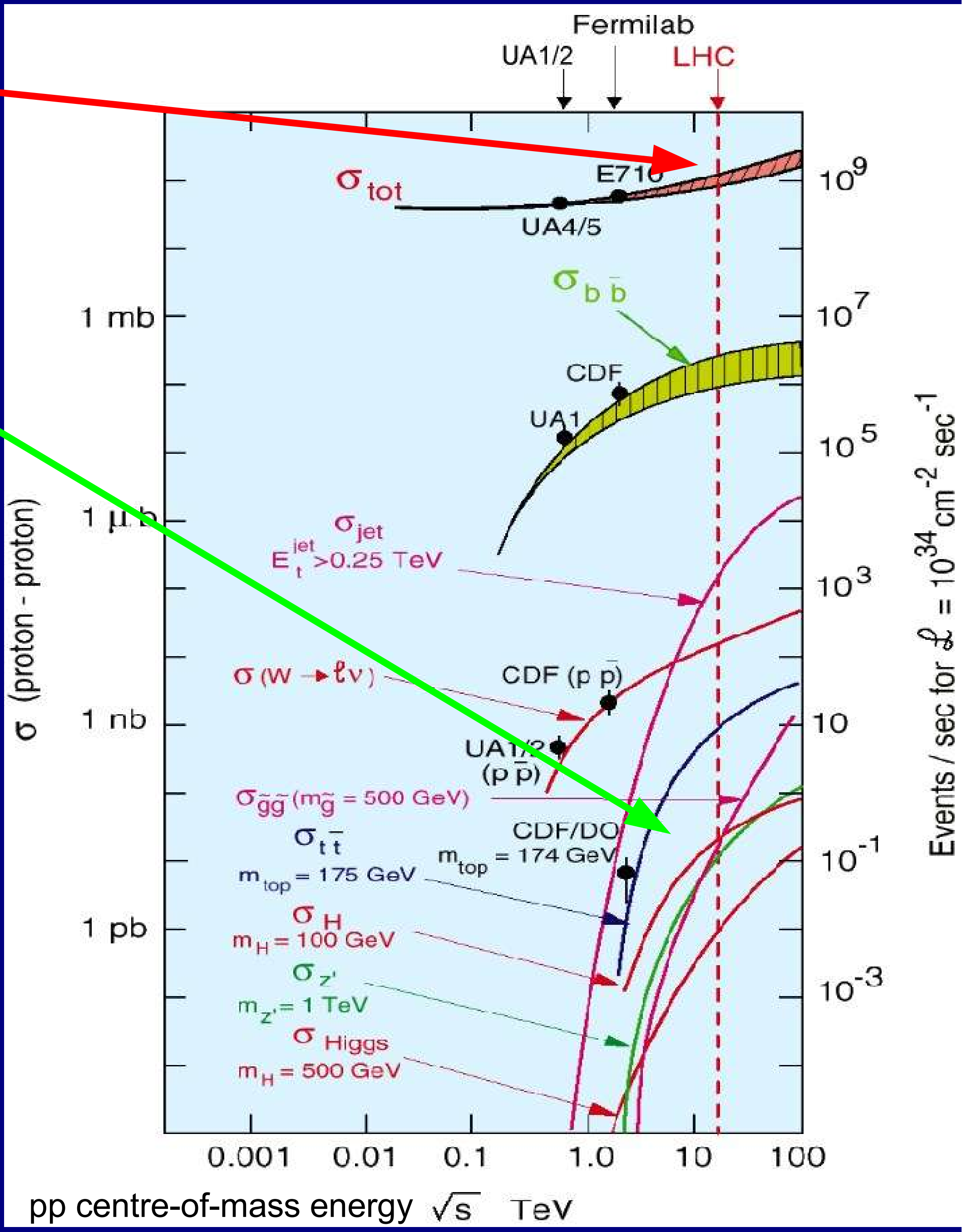
Experimental Challenges

Total cross-section high (100 mb)

Interesting cross-sections very low (pb)

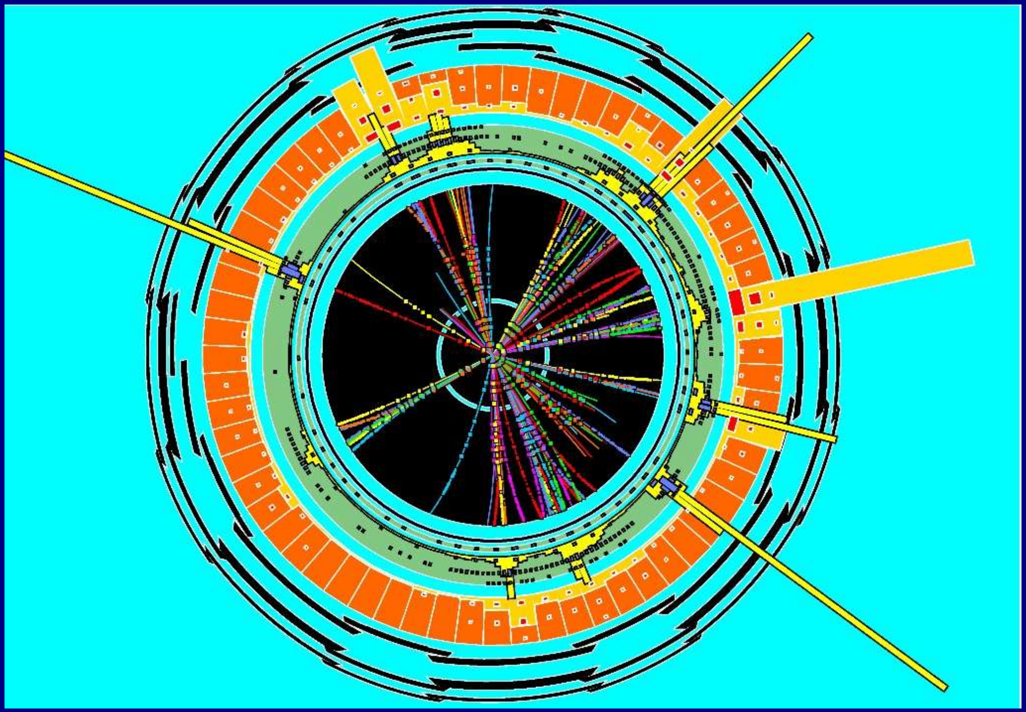
Consequences

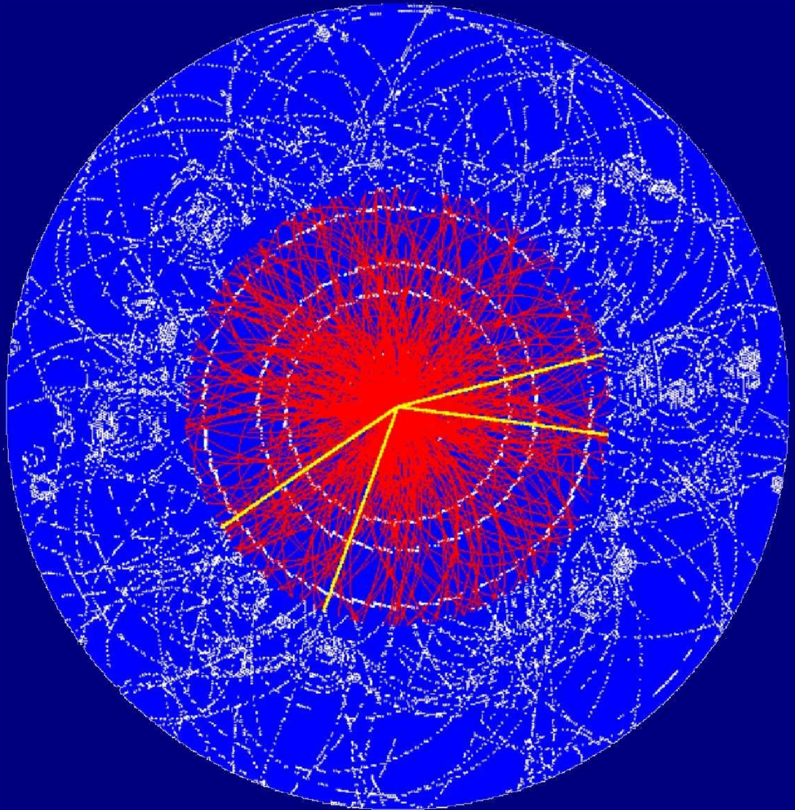
- **Triggering**: must reduce rate to ~200 Hz online
- Radiation: special **detector** solutions (Si)
- **Computing**: huge data rates and volumes



Key Event Signatures at the LHC

- Products of heavy particle decays: *high energy* jets, photons, leptons
- Charged leptons: e, μ, τ
- Neutrinos $\nu \rightarrow$ missing momentum

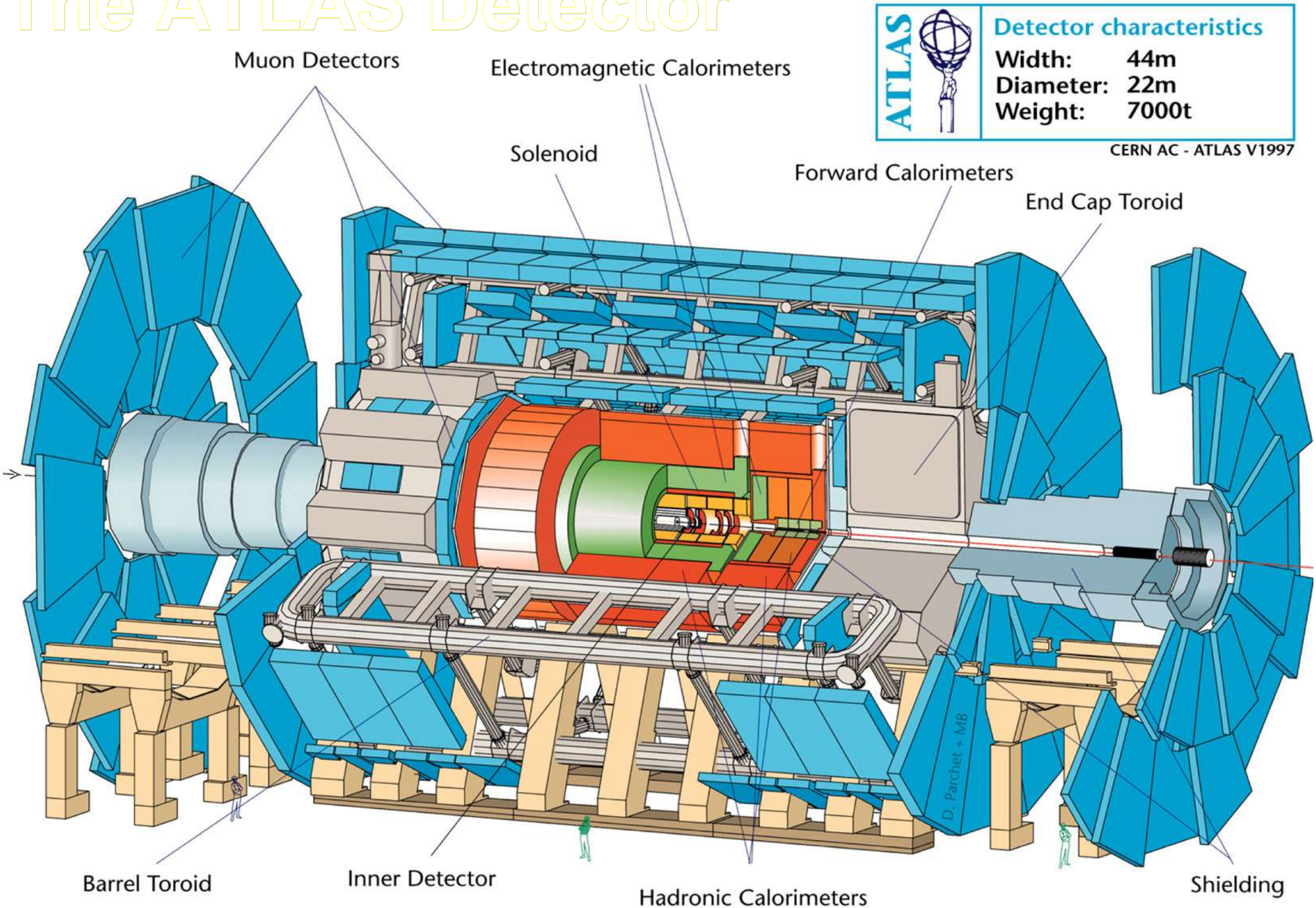




- New weakly interacting particles $\rightarrow$ missing momentum

High granularity and precise tracking are essential

The ATLAS Detector



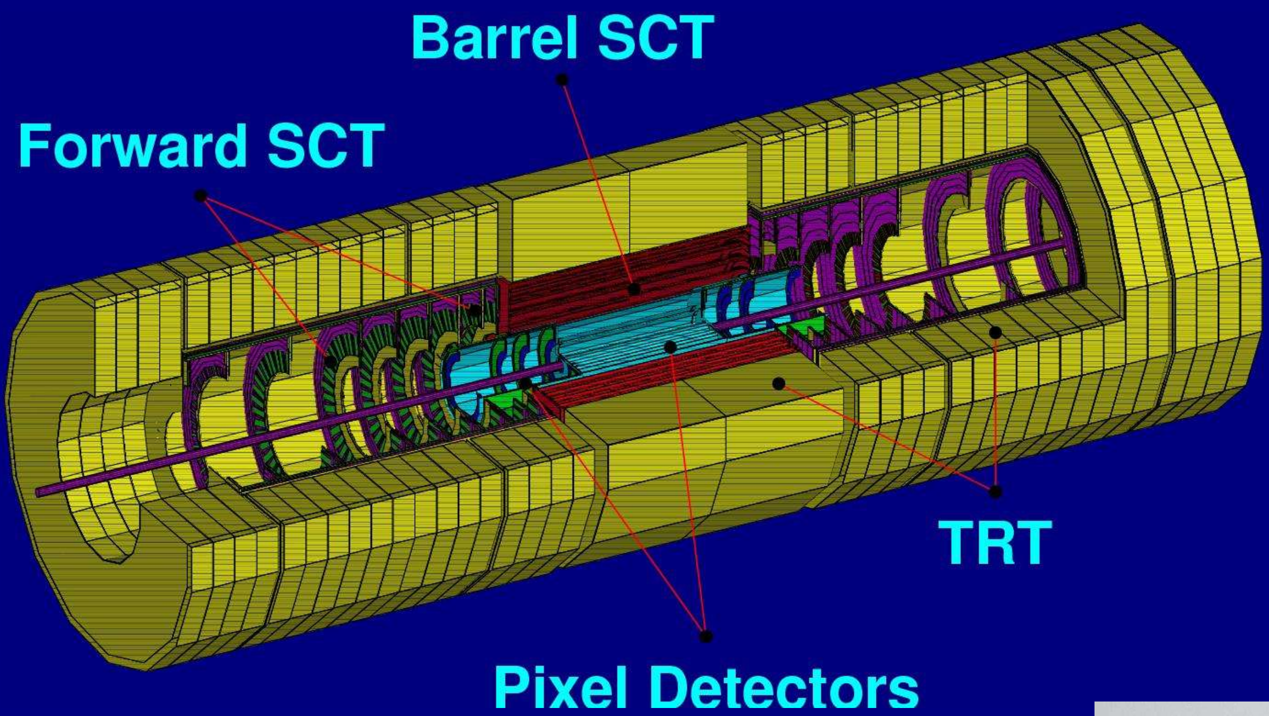
Distributed Construction...

ATLAS is being constructed all around the world – a truly global enterprise

Here in Birmingham:

- **Tracking**: Readout circuitry and data acquisition
- **Triggering**: Hardware and software for calorimeter trigger, builds on major contributions to the design
- Offline **software and Grid**-enabled computing

The Semi-Conductor Tracker SCT



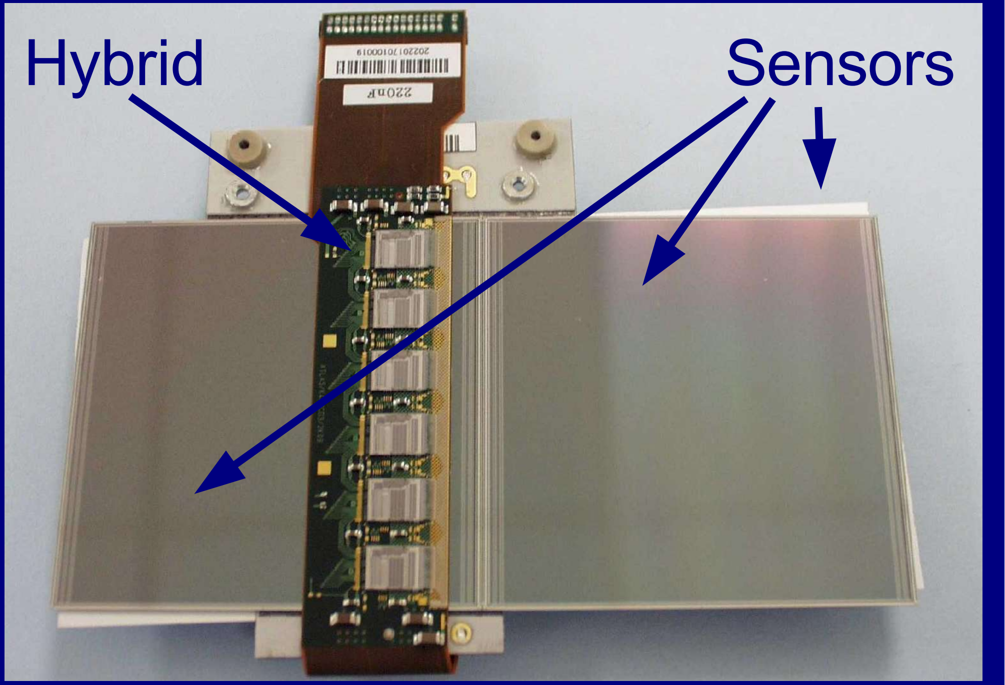
High precision tracking

Dual purpose:

- measure momenta very well – esp. high momentum particles
- reconstruct decay vertices (b, c, τ)

SCT composed of 4088 modules

Silicon strip sensors, 80µm pitch → 23µm spatial precision

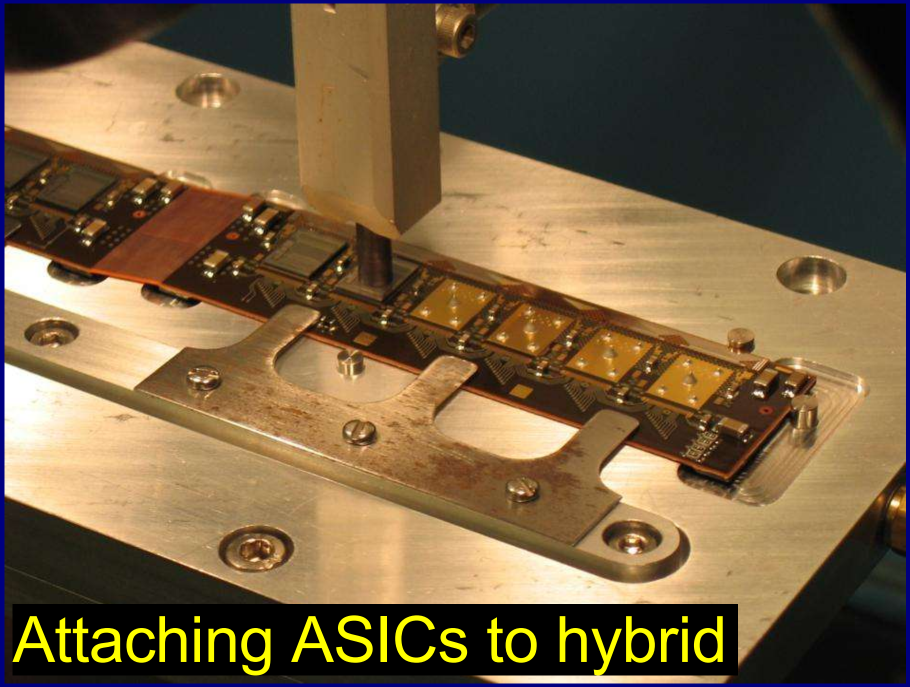


Hybrid Assembly

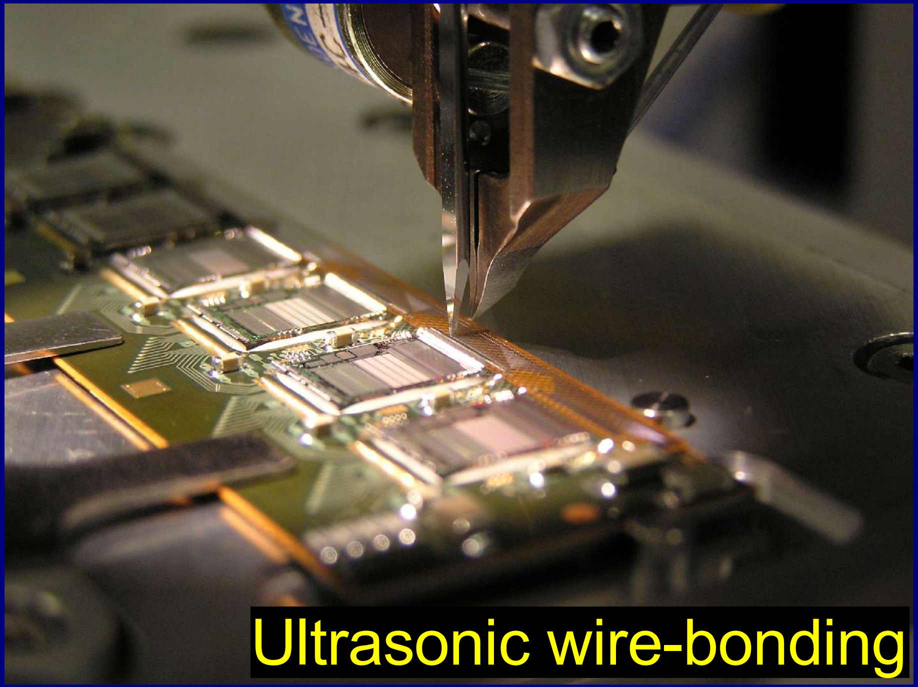
DGC, Bruce Gallop, Ivan Hollins, Pedja Jovanovic, Simon Pyatt, Xen Serghi, John Wilson

In Birmingham, we assembled and tested 730 hybrids

15-step production/test procedure, takes ~2 weeks per hybrid, up to 30 in pipeline



Attaching ASICs to hybrid

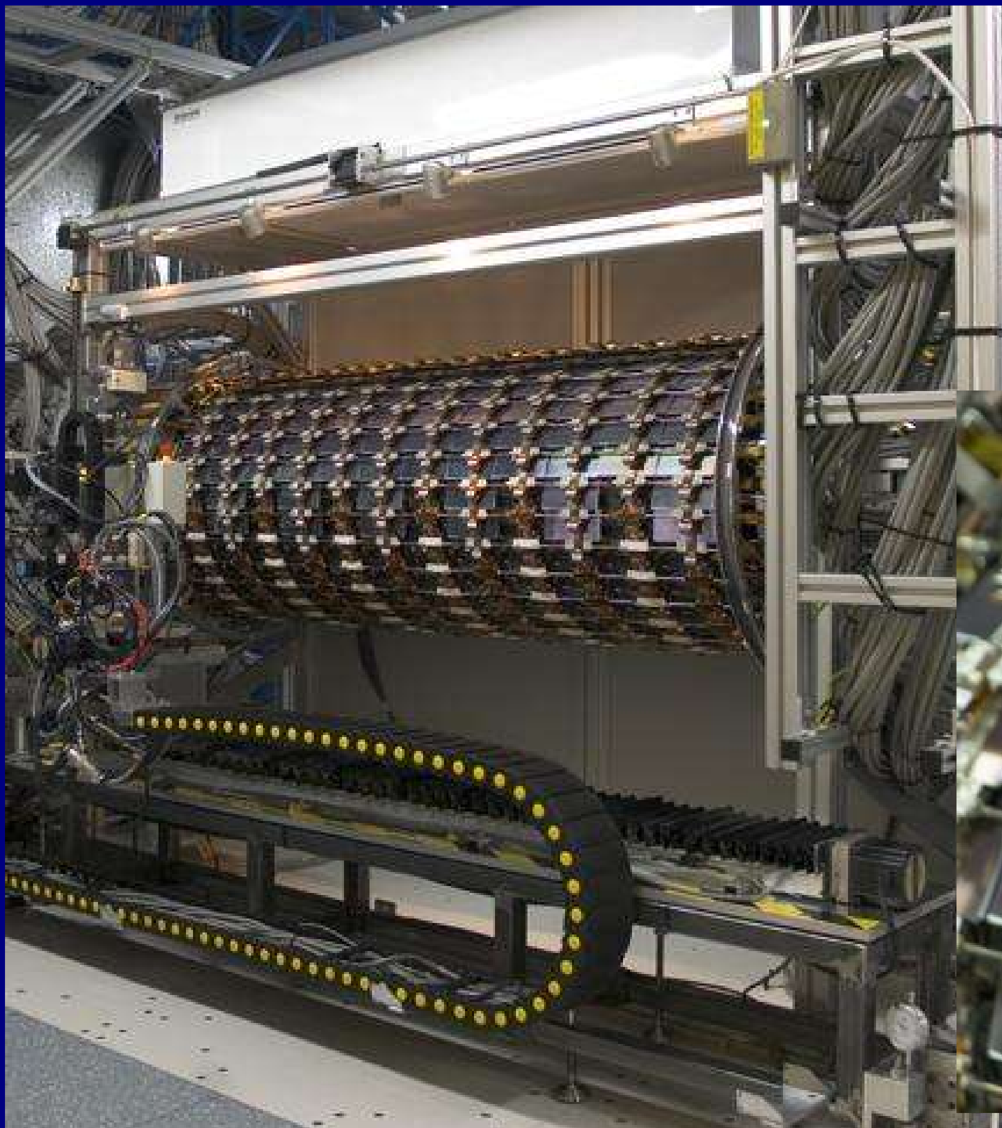


Ultrasonic wire-bonding

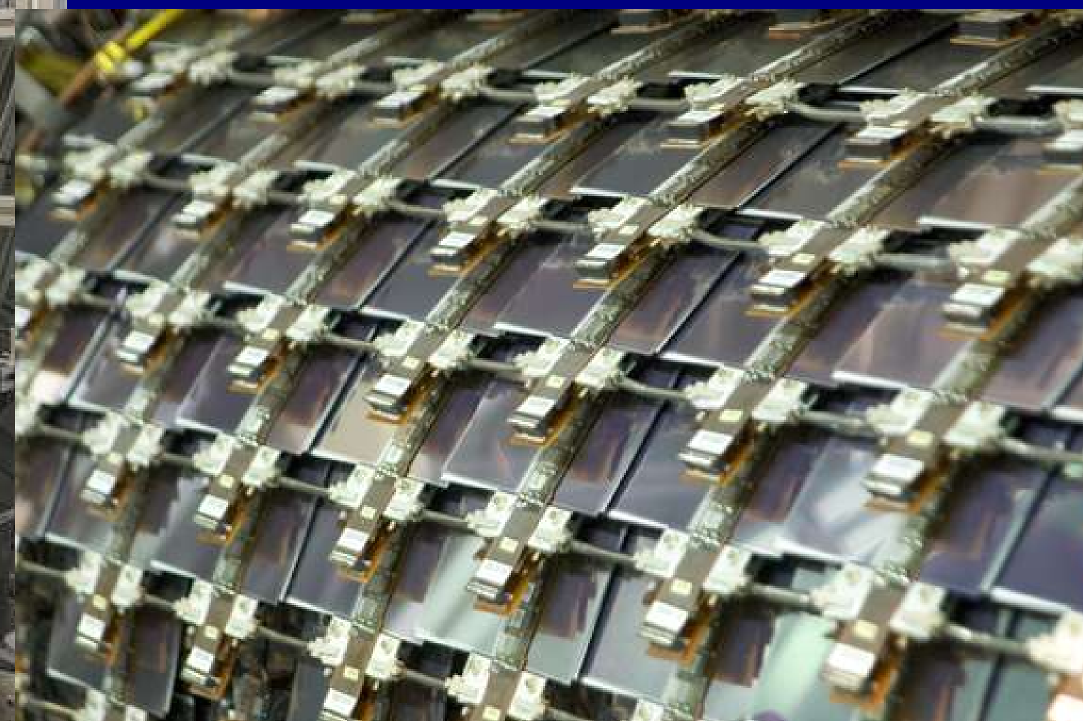
8760 ASICs, 1642500 wire bonds, over 27 months

Now completed – hybrids are now on modules

Module assembly to barrels



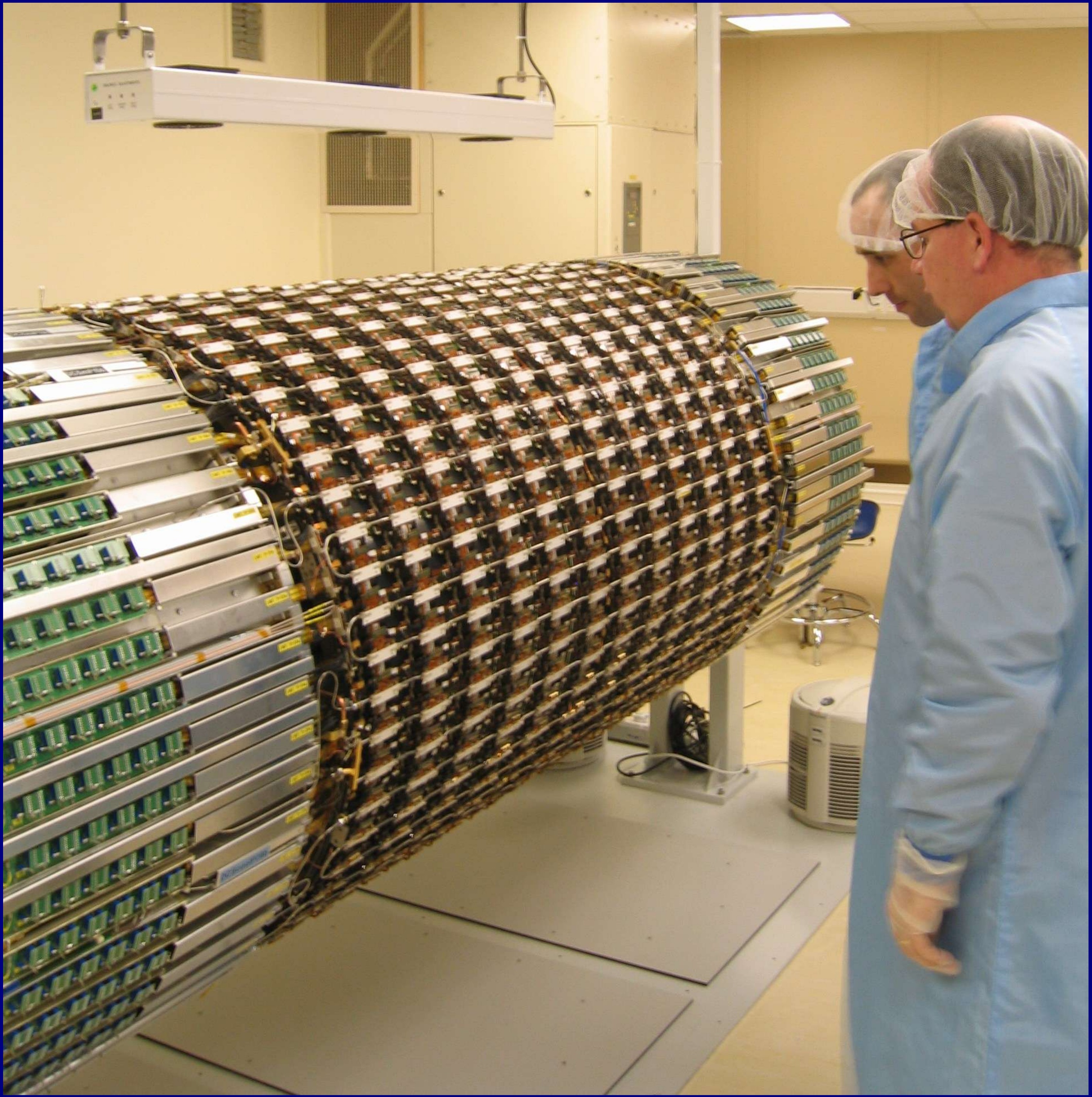
Modules are mounted on one of four concentric barrels by special-purpose robot (at Oxford)



Installation in ATLAS foreseen in early 2006

Outer-most SCT barrel at RAL on Friday - before any modules mounted

(2nd of 4)



The Trigger System

Task:
select < 200 of 10^9 evts/sec

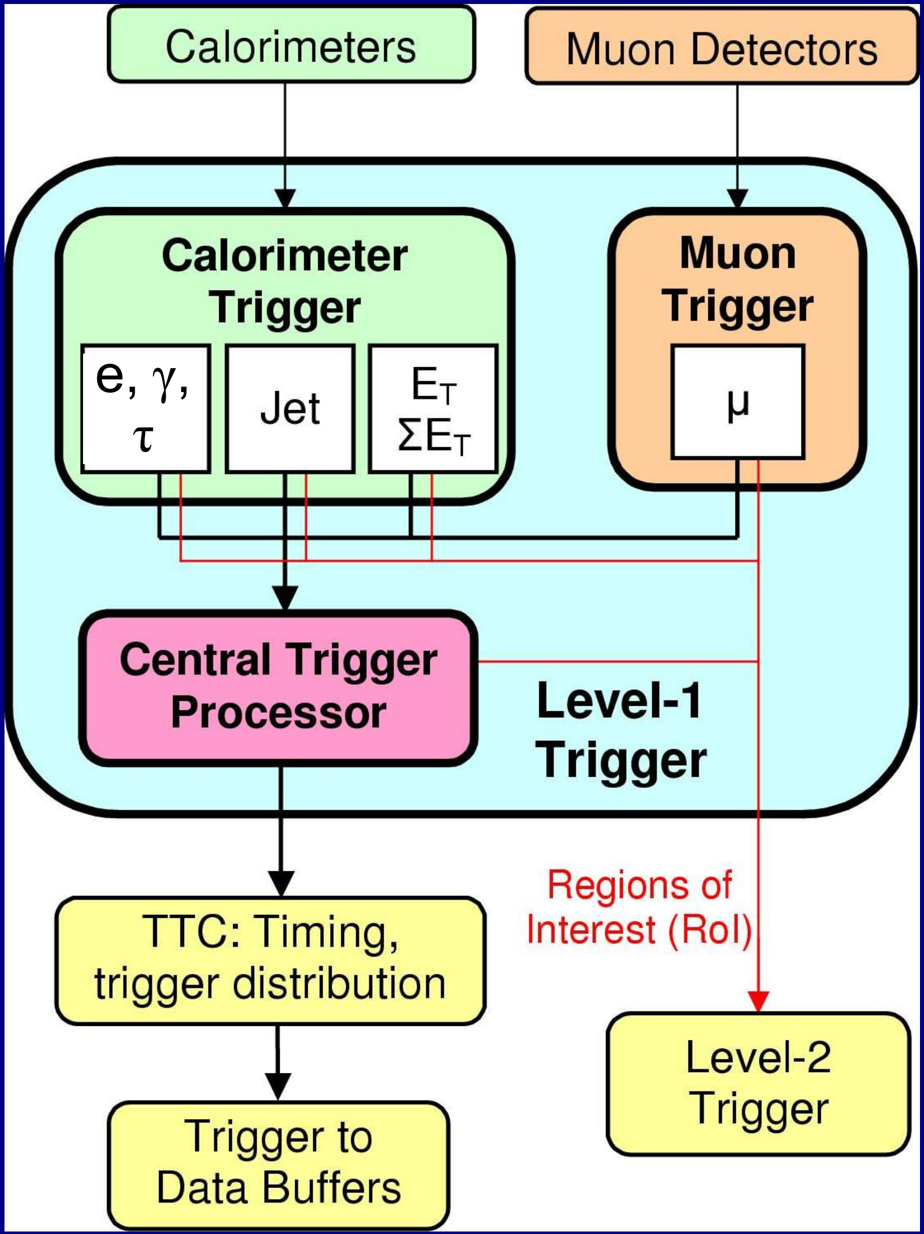
Requires a *multi-level* system

First level (L1) trigger:

- Beam crosses every 25ns
- Rejection factor ~ 10^4
- Yes/no in < 2μs

Energy and *muon* information

In B'ham we work on the energy trigger "L1calo"



Richard Booth, Steve Hillier, Gilles Mahout, Tamsin Moye, Richard Staley, Jürgen Thomas, Dimitrios Typaldos, Pete Watkins, Alan Watson

Calorimeter Trigger – the CPM

Cluster processor module (CPM) – finds energy clusters from e, γ and τ

Birmingham responsibility

Complex pipelined design uses multiple FPGAs
Time-critical: latency 250ns

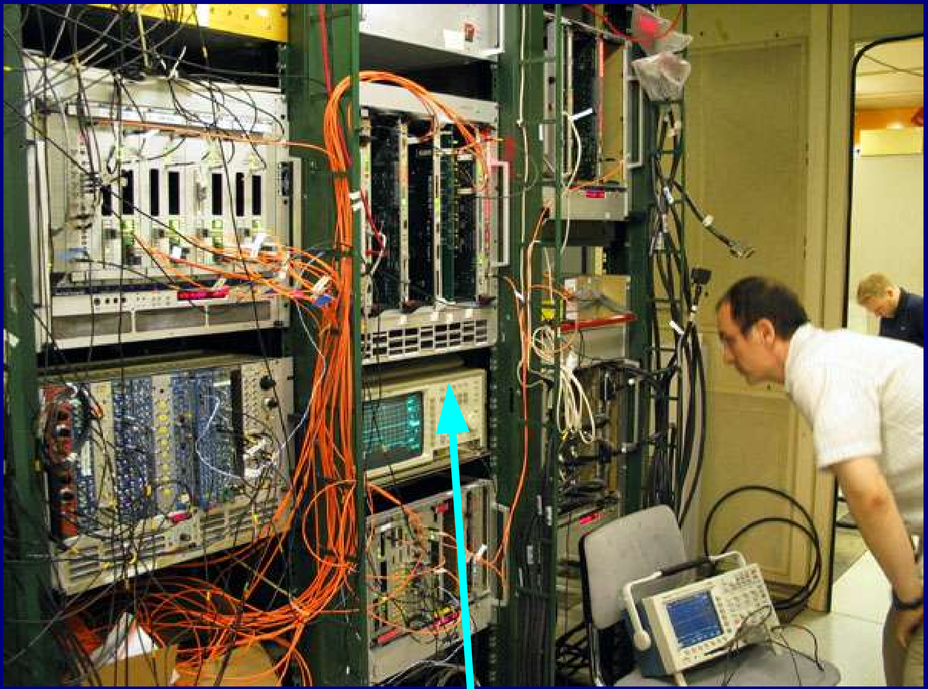
Module designed, debugged and tested locally

Bulk production in 2005: 56 CPMs in ATLAS

Trigger Testing and Integration

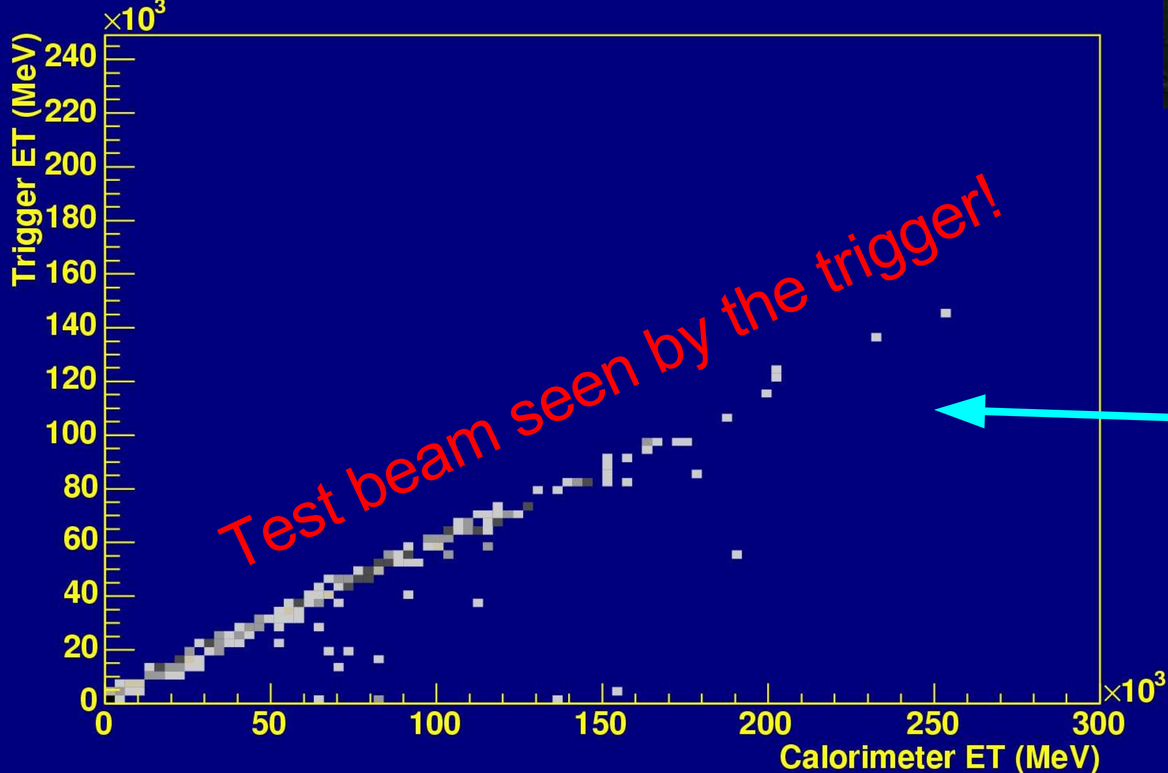
Major activity also to test trigger operation – individual boards to full system in ATLAS

Full programme running through to 2007 and beyond



October 2004

“Combined test beam” at CERN – full chain: detectors, trigger & data-taking – it worked!



The Computing Challenge

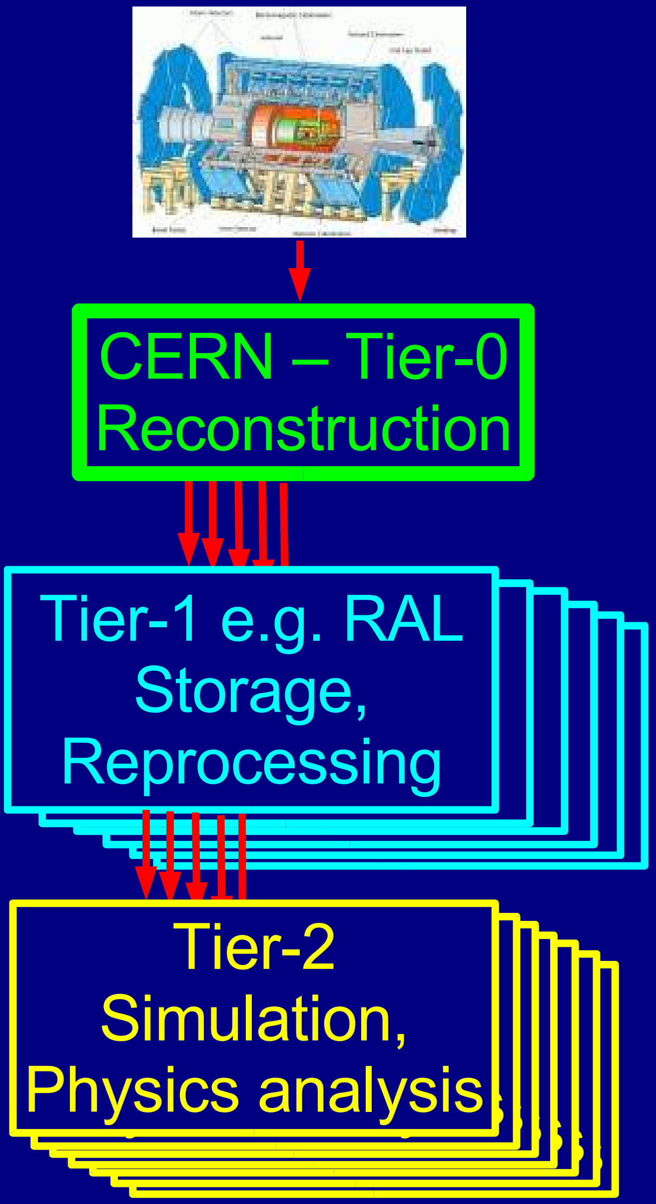
Data written from the detector at ~ 300 MB/s = ~ 3 PB per year, plus simulated data

Data processing, simulation, data analysis requires ~ 60000 2GHz-equivalent PCs

Dictates distributed CPU and disk resources – **the Grid**

Local work on Grid tests ("data challenges") and enabling ATLAS applications for the Grid

Pete Faulkner, Lawrie Lowe, Alvin Tan,
Jürgen Thomas, Pete Watkins, Ethan Woehrling



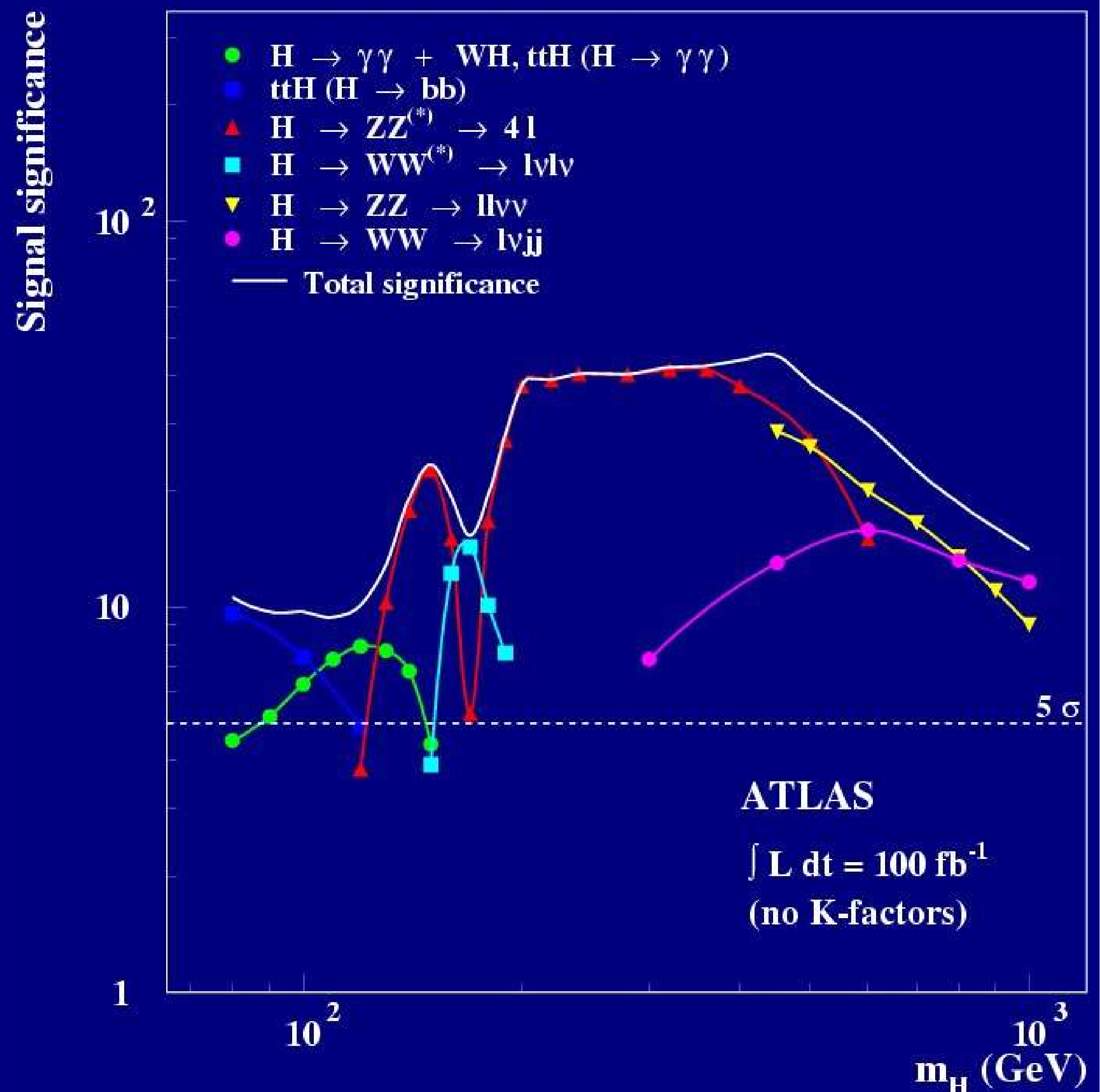
Physics reach

Higgs search simulated for various M_H

Standard Model predicts Higgs production/decay precisely for given M_H

Signature varies with $M_H \rightarrow$ broad search strategy

If EWSB is via SM H, ATLAS will find it



An LHC Physics Menu

A sample of the LHC physics programme for the first 3 years

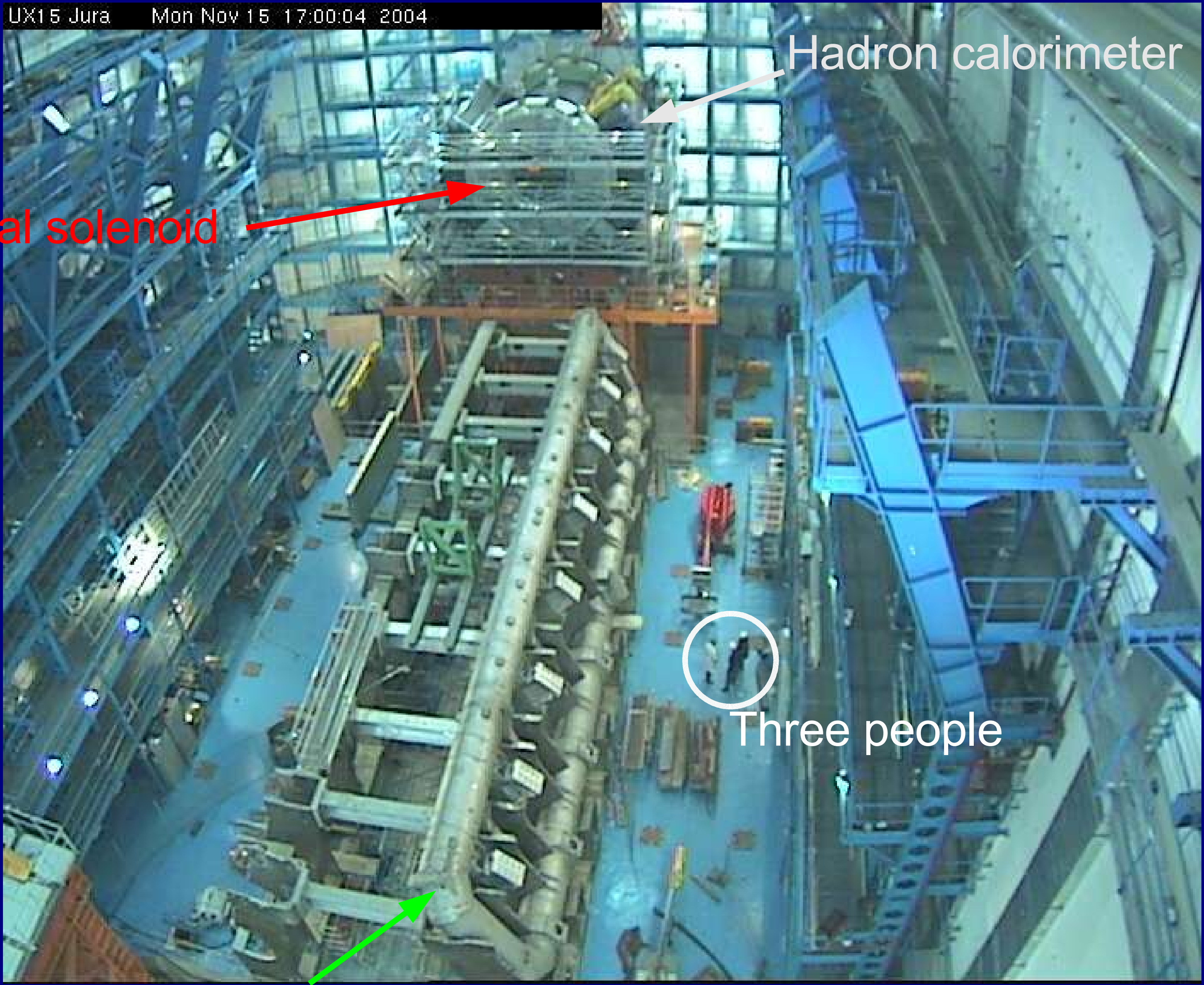
- detector commissioning
- trigger commissioning
- heavy flavour production
- CP violation in B system
- Rare B decays
- B_s oscillations
- B_c physics
- parton density functions
- jet physics: α_s
- diffractive physics
- heavy ion physics
- W and Z production
- Drell-Yan production
- W mass measurement
- Z forward-backward asymmetry
- precision top mass
- top quark decays and couplings
- triple gauge couplings
- quartic gauge couplings
- WW scattering

- Higgs searches
- SUSY searches
  - Supergravity models
  - GMSB models
  - R-parity violating models
- extra dimensions searches
- W', Z' searches
- technicolour searches
- excited fermion searches
- new sequential fermion searches
- compositeness searches
- monopole searches

Most exciting: measuring properties of new physics discoveries – hard to predict! Some examples...

- Higgs mass and width
- Higgs spin-parity
- Higgs self-coupling (hard!)
- SUSY spectrum and parameters

Putting it all together



http://cern.ch/atlaseye-webpub/web-sites/pages/UX15_webcams.htm