Detectors at the Large Hadron Collider

a review and a status report

the countdown has started

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Outline

• Detector Design Considerations
• Technical Implementations
• Status & Commissioning Results
The ‘general purpose’ LHC detectors are radically different from their predecessors at the SppS collider, LEP, SLC, HERA, Tevatron, etc.

They are designed for a luminosity of \(10^{34} \text{ cm}^{-2}\text{s}^{-1}\) for pp collisions at an energy of 14 TeV.

Detectors need to be fast, radiation hard (also the electronics) and big.

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**Large Hadron Collider**

Luminosity \(L\): collision rate normalized to cross section \(10^{34} \text{ cm}^{-2}\text{s}^{-1}\)

\[
L = \frac{N^2 k_b f \gamma}{4\pi e_0 \beta^* F}
\]

\(k_b f = 40\) MHz: bunch crossing frequency, i.e. 25 ns between bunches.
The Large Hadron Collider - experiments

Two ‘general purpose’ 4π detectors are in preparation
pp collisions at high L; some capabilities for PbPb
ATLAS and CMS

One dedicated PbPb detector with some capabilities
for pp
ALICE

One dedicated detector for studying B mesons
(CP violation; rare decays), prolifically produced
in the forward (backward) hemisphere
LHCb

Furthermore:
precision (1%) measurement of total cross section
(and more)
TOTEM ($\sigma_{\text{tot}} \sim 100 \text{ mb}$)

study of forward production of $\pi^0$ s
LHCf (LHC energy equivalent to $10^{17}$ eV beam on
fixed target – cf cosmic rays)

search for magnetic monopoles
Moedal
**Experimental Challenge**

**High Interaction Rate:** $N = L_\sigma = 10^{34} \times 100 \times 10^{-27} = 10^9 \text{ Hz}$

Data for only ~100 out of the 40 million crossings can be recorded per sec
Level-1 trigger decision will take ~2-3 $\mu$s
- electronics need to store data locally (pipelining)

**Large Particle Multiplicity**

- ~ <20> superposed events in each crossing
- ~ 1000 tracks stream into the detector every 25 ns
- need highly granular detectors with good time resolution for low occupancy
  - large number of channels

**High Radiation Levels**

- radiation hard (tolerant) detectors and electronics

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**Physics Requirements**

At the LHC the SM Higgs provides a good benchmark to test the performance of a detector

<table>
<thead>
<tr>
<th>Natural Width</th>
<th>0.01</th>
<th>1</th>
<th>10</th>
<th>100</th>
<th>GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGGS MASS GeV</td>
<td>50</td>
<td>100</td>
<td>200</td>
<td>300</td>
<td>400</td>
</tr>
</tbody>
</table>

- Lep 190 LEP200(>), $M_H > 114.4$ GeV
- $H \rightarrow \gamma\gamma$ (WH → γγ l l H → γγ l l)
- $H \rightarrow \ell^+\ell^-$ → 4 l
- $H \rightarrow ZZ \rightarrow 4l$
- $H \rightarrow ZZ \rightarrow 2\ell^+\ell^- \ell^+\ell^-$ or $2\ell^+\ell^- \ell^+\ell^-$
**Physics Requirements**

Very good muon identification and momentum measurement

trigger efficiently and measure sign of a few TeV muons

momentum resolution 10% at 1 TeV

High energy resolution electromagnetic calorimetry

$\sim 0.5\%$ @ $E_T \sim 50$ GeV

Powerful inner tracking systems

factor 10 better momentum resolution than at LEP

Hermetic calorimetry

good missing $E_T$ resolution

(Affordable detector)

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Charged particle moving in magnetic field $B$

Sagitta $s$

$s = R - R \cos\frac{\theta}{2} \approx R \theta^2 / 8$

$p = 0.3 BR$

$L = R \theta$

$s = \frac{0.3 BL^2}{8p}$

Units: Tesla, meter, GeV
Detector Design Considerations

Charged particle moving in magnetic field B

Resolution on \( s \) determines resolution on \( p \)

\[
\frac{dp}{p} = \left(\frac{p}{F}\right)ds
\]

\[
F = \frac{0.3BL^2}{8}
\]

\( ds \) depends on resolution tracking devices (technology!)
10 \( \mu \) (Si) – 100 \( \mu \) (Drift)

\( F \) is also determined by state of the art technology:
large magnets with high fields (superconducting)
1 – 4 Tesla

Large \( L \) better than high \( B \), but the volume of the detector grows as \( L^3 \)
1 – few Meters

Detector Design Considerations

Multiple Scattering

Multiple Coulomb scattering adds an apparent deflection angle, i.e. apparent sagitta

\[
\theta_{\text{mit}} = \frac{13.6[\text{MeV}]}{\beta pc} Z \sqrt{\frac{L}{X_0}}
\]

\[
\left(\frac{dp}{p}\right)_{\text{mit}} \approx 0.05 \frac{1}{B \sqrt{LX_0}}
\]

Use light material in trackers
Calorimetry

Energy and position measurement of
- photons, electrons, positrons – electromagnetic calorimetry
e.m. showers thru Bremsstrahlung, pair creation, etc.
Energy \( E \sim N \) charged ‘ionizing’ (or generating scintillation, Cerenkov) light.

\[
\frac{\Delta E}{E} = k / \sqrt{E} + \ldots
\]

\( k \) smaller for more samplings (cf. homogeneous calorimeters)

Calorimeter depth determined by radiation length. Approximately:

\[
X_0 = \frac{716.4A}{Z(Z+1) \ln(287/\sqrt{Z})} \quad [g \ cm^{-2}]
\]

Granularity determined by Molière radius (lateral shower size)

\[
\rho_M = 21.2 X_0 / \varepsilon_c
\]

• hadrons
Energy resolution scales as for e.m. calorimetry but with \( k \) typically larger
Calorimeter depth determined by interaction length
Courser granularity than e.m.

• jets

<table>
<thead>
<tr>
<th>Material</th>
<th>( X_0 ) [cm]</th>
<th>( \lambda_{int} ) [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>1.76</td>
<td>16.8</td>
</tr>
<tr>
<td>Pb</td>
<td>0.56</td>
<td>17.0</td>
</tr>
<tr>
<td>PbWO\textsubscript{4}</td>
<td>0.89</td>
<td>18.0</td>
</tr>
</tbody>
</table>
Electromagnetic Calorimetry at LHC

In several scenarios moderate mass narrow states decaying into photons or electrons are expected:

- SM: intermediate mass $H \rightarrow \gamma \gamma$, $H \rightarrow ZZ^{*} \rightarrow 4e$
- MSSM: $h \rightarrow \gamma \gamma$, $H \rightarrow \gamma \gamma$, $H \rightarrow ZZ^{*} \rightarrow 4e$

In all cases the observed width (cf. signal over background) will be determined by the instrumental mass resolution. Need:
- good e.m. energy resolution
- good photon angular resolution
- good two-shower separation capability

\[ M^2 = 2E_1E_2(1 - \cos \theta) \]
\[ dM / M \propto d \cos \theta / \cos \theta \]
\[ dM / M \propto dE / E \]
\[ \tan(\theta_{\text{min}} / 2) = M / 2(E_1 + E_2) \]

Hadronic Calorimetry at LHC

- **Jet energy resolution**
  - Limited by jet algorithm, fragmentation, magnetic field and energy pileup at high luminosity
  - Can use the width of jet-jet mass distribution as a figure of merit
    - Low $p_T$ jets: $W, Z \rightarrow $ Jet-Jet, e.g. in top decays
    - High $p_T$ jets: $W', Z' \rightarrow $ Jet-Jet
  - Fine lateral granularity ($\lesssim 0.1$) high $p_T$ $W$'s, $Z$'s

- **Missing transverse energy resolution**
  - Gluino and squark production
    - Forward coverage up to $|\eta| = 5$
    - Hermeticity - minimize cracks and dead areas
    - Absence of tails in the energy distribution is more important than a low value for the stochastic term
  - Good forward coverage is also required to tag processes initiated vector boson fusion
'Granularity', size of read-out 'cells'

Convenient variable: 'one particle phase space is uniform in rapidity'

Inelastic particle production shows a 'rapidity plateau' (from ~-3 to +3 at LHC)

Rapidity has a geometrical interpretation → detector 'granularity' corresponding to fixed rapidity intervals (and similarly for \( \phi \), azimuthal angle, intervals) (cf. calorimeter cell size)

\[
d^4P \delta(E^2 - P^2 - m^2) = d \vec{P} / E = p_\parallel dP / d\phi d\eta d\eta
\]

\[
d\eta = p_\parallel / E
\]

For \( E >> m \) :

\[
y = \frac{1}{2} \ln \frac{E + p_\parallel}{E - p_\parallel}
\]

Muon spectrometers
1 TeV muon to be measured with 10% resolution

ATLAS
- Standalone \( \mu \) momentum measurement; safe for high multiplicities;
- Air-core toroid
- Property: \( p_{\parallel} \) flat with \( \eta \)

CMS
- Measurement of momentum in tracker and B return flux;
- Solenoid with Fe flux return
- Property: muon tracks point back to vertex
**Tracking at LHC**

**Factors that determine performance**

- Track finding efficiency – occupancy
- Momentum resolution
- Secondary vertex reconstruction

![Fluence over 10 years graph](image)

- $\lesssim 4 \times 10^7 \text{ h/cm}^2/\text{s}$
  - pixels ($\approx 10^4 \mu\text{m}^2$)
  - occupancy $\approx 10^{-4}$
- $\lesssim 4 \times 10^8 \text{ h/cm}^2/\text{s}$
  - Si strip det. ($\approx 10 \text{ mm}^2$)
  - occupancy $\approx 1\%$
- $\lesssim 4 \times 10^5 \text{ h/cm}^2/\text{s}$
  - Si or Gas detectors. ($\approx 1 \text{ cm}^2$)
  - occupancy $\approx 1\%$

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**Detector Implementations**

Very recently published in *Journal of Instrumentation (JINST)*:

- **The CERN Large Hadron Collider: Accelerator and Experiments**
  - *LHC Machine*
    - Lyndon Evans and Philip Bryant (editors)
    - 2008 JINST 3 S08001
  - **The ALICE experiment at the CERN LHC**
    - The ALICE Collaboration, K Aamodt *et al*
    - 2008 JINST 3 S08002
  - **The ATLAS Experiment at the CERN Large Hadron Collider**
    - The ATLAS Collaboration, G Aad *et al*
    - 2008 JINST 3 S08003
  - **The CMS experiment at the CERN LHC**
    - The CMS Collaboration, S Chatrchyan *et al*
    - 2008 JINST 3 S08004
  - **The LHCb Detector at the LHC**
    - The LHCb Collaboration, A Augusto Alves Jr *et al*
    - 2008 JINST 3 S08005
  - **The LHCf detector at the CERN Large Hadron Collider**
    - The LHCf Collaboration, O Adriani *et al*
    - 2008 JINST 3 S08006
  - **The TOTEM Experiment at the CERN Large Hadron Collider**
    - The TOTEM Collaboration, G Anelli *et al*
    - 2008 JINST 3 S08007
The ATLAS Detector

- Muon Detectors
- Electromagnetic Calorimeters
- Solenoid
- Forward Calorimeters
- End Cap Toroid

- Barrel Toroid
- Inner Detector
- Hadronic Calorimeters
- Shielding

The CMS Detector

- SUPERCONDUCTING COIL
- ECAL: Scintillating PbWO4 crystals
- HCAL: Plastic scintillator/brass sandwich
- IRON YOKE
- TRACKER: Silicon Microstrips
- Pixels

- Total weight: 12,500 t
- Overall diameter: 15 m
- Overall length: 21.6 m
- Magnetic field: 4 Tesla

- MUON BARREL
- Drift Tube Chambers
- Resistive Plate Chambers
- Cathode Strip Chambers
- Resistive Plate Chambers
- MUON ENDCAPS
Detector Implementations

Tracking (|\eta|<2.5, B=2T):
-- Si pixels and strips
-- Transition Radiation Detector (e/\pi separation)

Calorimetry (|\eta|<5):
-- EM: Pb-LAr
-- HAD: Fe-scintillator (central), Cu/W-LAr (fwd)

Muon Spectrometer (|\eta|<2.7):
air-core toroids with muon chambers (standalone capabilities)

Tracking (|\eta|<2.5, B=4T): Si pixels and strips

Calorimetry (|\eta|<5):
-- EM: PbWO4 crystals
-- HAD: brass-scintillator (central+ end-cap), Fe-Quartz (fwd)

Muon Spectrometer (|\eta|<2.5): return yoke of solenoid instrumented with muon chambers

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MAGNETS

ATLAS

20 kA s.c.; GJ’s stored energy
unique objects!

CMS

0.6 T

4 T
From talks at ICHEP2008 by

Martine Bosman (ATLAS)

and

Austin Ball (CMS)

I have made a selection, impossible to be even nearly complete in finite amount of time; even after selection I may have to skip some of the material ‘on the fly’

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**Inner Detector**

Tracking $|\eta|<2.5$, $B=2T$

- Silicon pixels (Pixel): $0.8 \times 10^8$ channels
- Silicon strips (SCT): $6 \times 10^8$ channels
- Transition Radiation Tracker (TRT): straw tubes (Xe), $4 \times 10^5$ channels
- $e/\pi$ separation

$\sigma/p_T \sim 5 \times 10^{-4} p_T \oplus 0.01$
**Electromagnetic Calorimeter**

- **Barrel, Endcap**: Pb-LAr
- ~10%/$\sqrt{E}$ energy resolution $e/\gamma$
- 180,000 channels: longitudinal segmentation

**Hadron Calorimeter**

- **Barrel**: Iron-Tile EC/Fwd, Cu/W-LAr (~20,000 channels)
- $\sigma/E \sim 50%/E \otimes 0.03$ pion (10 $\lambda$)
- Trigger for $e/\gamma$, jets, Missing $E_T$

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**Muon System**

**Stand-alone momentum resolution**

- $\Delta p/t < 10\%$ up to 1 TeV

- 2-6 Tm $|\eta| < 1.3$
- 4-8 Tm $1.6 < |\eta| < 2.7$

- ~1200 MDT precision chambers for track reconstruction (+ CSC)

- ~600 RPC and ~3600 TGC trigger chambers
short history of the construction & installation

**JUNE 2003**

Cavern
92m underground
55m long
32m wide
35m high

**Today**
ATLAS is built

**February 2004**

**October 2004**

**July 2005**
A historical moment

Closure of the LHC beam pipe ring on 16th June (the last piece was the one shown here in ATLAS)
Hardware Readiness

- All hardware is essentially ready and installed – very few dead channels – some refurbishment was necessary
- Beam pipe baked out
- Magnet system tested (central solenoid – 8 barrel toroids – 2 x 8 end-cap toroids)

Trigger / DAQ

- Level-1 Trigger
- Calorimeter
- Muon System

- Region of Interest Builder
e/γ, μ, jet, ...

- High-Level Trigger
  - 850 nodes farms
  - High bandwidth
  - Data Network

- Front End Electronics
- Readout Drivers

- Detector
- Readout System
  - Custom built buffers in PC farm

- PC Farms
- Event Building
  - More PC farms on Data Network

- Custom Hardware
- Detector
- PC Farms

- 300 MByte/s
to Computer Center
.. Pbytes stored / year

- DAQ software
  - Control, configuration, monitoring on Control Network
Full Online system being exercised since ~2 years
H/w now being completed - Ready for data-taking

Towards data-taking: Cosmic Muons

Muon impact points extrapolated to surface as measured by Muon Trigger chambers (RPC)
(Calorimeter trigger also available)

Rate ~100 m below ground:
~ O(15 Hz) crossing Inner Detector
Commissioning with Cosmics

\[ r_i = r_i + t_{\text{offset}} \]

RMS \(~160 \mu m\)

Measure t0 and (r,t) relation
Alignment of chambers
To reach 40 \( \mu m \) will need large samples
of tracks B field ON and OFF

Conclusion

- ATLAS is built and installed
- Cavern in restricted access mode since 24th July
- Intense on-going commissioning activities
- Will continue with single beam
  
  **Ready for collisions !**
- Proceed with detector calibration
- Study SM processes

and start searching for new physics
CMS Assembly Sequence

**SURFACE**: independent of underground Civil Engineering

- construct magnet barrel yoke & pre-cable
- prepare solenoid vac tanks
- construct endcap yoke & pre-cable
- assemble hadron calorimeters
- install muon chambers (barrel+ec) in yoke
- assemble coil & insert in vac tank
- insert HCAL inside coil
- Test magnet + parts of all subsystems
- separate elements and lower sequentially

**UNDERGROUND**: 2006-2008

- re-install HCAL
- install ECAL barrel & cable central wheel
- install Tracker & cable
- install beampipe & bake-out
- install ECAL endcaps
- close & finish commissioning

**Surface & Underground 2001-2**

- modular: ease of surface pre-assembly
  - lowering as 15 large modules
  - rapid access for maintenance
Surface & Underground 2003-4

Surface & Underground 2004-5
First Closure of CMS (2006)

In preparation for surface testing and field mapping of the 4T solenoid magnet

- Air-pads, grease pads & locking jacks proven to work
- 3 days to open or close endcap

Full rehearsal of:
- ECAL, HCAL & Tracker installation.
- Closure of barrel and endcaps

Magnet Test & “Cosmic Challenge” 2006

1’st CMS system test

Surface testing and field-mapping of magnet

Parasitic system test, with elements of all subsystems plus central trigger & DAQ at nominal field

(Investment in surface infrastructure, DAQ, rack & control rooms)
**“Cosmic Challenge” 2006**

Cosmic muon data normalised to Monte Carlo simulation

Reasonable agreement between data and simulation.

Tested nearly all aspects of final CMS from detector through DAQ, controls & DQM to the software framework and gave the first “physics” result

**Azimuthal distribution.**

**p_T distribution measured by DT’s**

Cosmic in TK, ECAL, HCAL, Mu

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**Heavy Lowering Nov 2006-Jan 2008**

15 objects in total: 350-2000 t each

#1

#9

#15

Connected to pre-installed cable chains

Surveyed & aligned: few x 0.1mm

Connected to pre-installed cable chains
Underground installation: barrel calorimeters

Two ½ barrels (removed for heavy lowering, following surface test). (weight restrictions on central section)

Two ½ barrels, each installed as 18 pre-tested supermodules (~1800 crystals each)

Central wheel (YB0) services May-Dec 07

Estimated ~50,000 man-hours of work on critical path!!

Completion triggered Tracker installation, then beampipe installation
Tracker Installation & Connection

Pre-cabling of services to patch panels inside the solenoid vacuum tank simultaneous with Si-strip Tracker surface pre-commissioning. Speeded up the final connections, completed in 4 months.

Muon System: Barrel Drift Tubes

Underground re-commissioning

Angular distributions

250 chambers in 5 wheels of 12 sectors each ~172200 channels (0.2% inoperative)

DAQ & trigger fully integrated providing reliable “trigger service” for ECAL/HCAL/Tracker

Total rate stable at ~200Hz

Residual distributions in the 4 layers of a sector

Single hit resolution ≤ 250µm as anticipated
Electromagnetic Calorimeter, ECAL

**Surface:** 36/36 barrel supermodules calibrated using cosmics ~1.5% crystal intercalibration
9/36 also beam calibrated.

**Underground:** All 36 barrel supermodules readout
84/61200 (0.14%) masked channels
Commissioning with cosmics
(typically 250MeV mip deposit)

Track-cluster association

μ trigger : 288GeV cluster!

Response to high energy e-
α/E=0.42±0.01%

Occupancy map: 3 x 3 matrix around >70 MeV seed

Tracker: underground recommissioning

Delayed 2-3 months due to failures & subsequent repairs of cooling plant

Noise and S/N performance from surface confirmed as typical
~95% of ~29k optical readout channels worked first try
DAQ fully integrated

Using ~90k cosmic tracks

TIB Z+

Inner Barrel
- Track alignment
- Surveys
- ”Engineering geometry”
System Integration: global cosmic runs

Pre-requisites:
- infrastructure, detectors,
- \( \mu \)-trigger, DAQ integration,
- r/o synchronization,
- \( \mu \)-calibration,
- track reconstruction

Benchmark of detector readiness

Programme for remainder of 2008: I

Prior to beam: the last few moves ….
- Complete cabling & tests of recently installed detectors (pixel, EE)
- Close magnet yoke
- Continue local & global detector commissioning with cosmics (in parallel)
- Re-confirm magnet operation up to 4T
- Configure forward detectors & shielding for beam

Magnet

Cryogenics:
- Cooldown complete.
- Stable at operating temperature

Mechanical Tests: all OK.

Electrical System:
- All connections made and tested
- Power converter tested.

Control and safety systems:
- Tested & working
Programme for remainder of 2008: II

From first beam up to 10pb$^{-1}$. p-p collisions at (900GeV) & 10 TeV :

Commission beam radiation monitoring system including abort
Tune operating procedures for beam operation
Establish (lack of) effect of solenoid field on beams
Synchronize detectors using beam timing
Commission beam trigger, start “physics commissioning”:

Align and calibrate with beam-halo events, min-bias events, etc
Measure jet and lepton rates; observe W, Z, top
First look for possible extraordinary signatures…

Conclusion

- Construction of the CMS experiment is almost completed.
- Commissioning work already carried out gives confidence that CMS detectors will operate with the expected performance.
- Integrated operation of subdetectors and central systems using cosmic triggers is routine with near-final complexity and functionality.
- Challenges conducted around the clock @ 100% of 2008 load show that Computing, Software & Analysis tools are ready for early data.
- Preparations for the rapid extraction of physics are being made.

- Later this month, CMS will be closed with magnetic field on, taking cosmic data, in (eager!) anticipation of beam.
Collisions: a physics Roadmap

- **Higgs discovery sensitivity** ($M_H=130\sim500$ GeV)
  
  - Explore SUSY to $m \sim$ TeV
  - Precision SM measurements

- **Sensitivity to 1-1.5 TeV resonances → lepton pairs**
  
  - Understand SUSY and Higgs background from SM
  - More accurate alignment & EM/Jet/ETmiss calibration

- **Search for very striking new physics signature**
  
  - Use SM processes as “standard candles”
  - Initial detector & trigger synchronisation, commissioning, calibration & alignment, material

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- **10 fb-1**
  
  - Test beam, cosmic runs, pre-alignment & calibration,

  - extensive simulations ...

- **100 fb-1**

- **14 TeV**
  
  2009

- **10 TeV**
  
  2008
Hardware Readiness Liquid Argon Calorimeters

**Installation in the cavern**
Barrel in October 2004, End-caps by 2006

**Electronics equipment completed**
Back-End May 2007
Front-End April 2008
(some refurbishment was needed)

**Since May 2008**
full calorimeter up, integrated in DAQ, slow control in steady running mode
~190,000 channels read-out
~0.02% dead (isolated) channels
+ ~1.5% (½ barrel module - power supply control lost) will be repaired during shutdown
Commissioning on-going
**Hardware Readiness: Tile Calorimeter**

**Installation in the cavern**
- Ext. Barrel C: December 2004
- Barrel: October 2005

```
full calorimeter up and running, integrated in DAQ
~10000 PMTs → 5000 cells
~0.2% dead (isolated) cells
~0.2% 1ext.barrel – power supply problem
will be repaired during shutdown
```

**Electronics equipment completed** May 2008
(some refurbishment was needed)

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**Hardware Readiness: Inner detector**

- TRT/SCT installed Aug 2006
- Pixel installed June 2007
- ID volume sealed complex End-Plate with 1000 feed-throughs
- needed to achieve closing ATLAS by end of June

```
TRT operational and in test mode
SCT sign-off tests (with cooling)
Only few weeks of running
Barrel: May 07, Apr 08
Endcap A: Jan08
Endcap C: Feb 08
6 days Pixel sign-off test
end April 2008
interrupted by cooling plant incident
```

April/May 2008
Hardware Readiness: Inner Detector

- **Solenoid field**: mapping done with precision $\sim 10^{-4}$
- **Pixel** ~0.6% dead/problematic channels except EndCap wheel A: ~4.2% (+ 8.3% if cooling loop inoperable)
- **SCT** barrel ~0.35%, end-caps ~0.26% dead/problematic channels except EndCap wheel C: ~1.6% (1.3% due to cooling loop failure)
- **TRT**: dead channels 1.2-2.0%, delivery of some readout elements being completed run with Xenon or not – to be decided

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Cooling plant repair completed on 23rd July → on time for beam pipe bake-out (done successfully 29-31 July)

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- Pixel resumes commissioning: ~4 weeks standalone commissioning before joining common ATLAS running
- SCT will join for limited periods and depending on the overall tune-in progress
- TRT commissioning proceeds steadily

Hardware Readiness: Muon system

- **All chambers installed** (few chambers staged 09)
- All wheels in final position.
- Most alignment rays are operational
- Good results: $\sim 200 \mu m$

- **Magnetic field** measurement
  - < 5% of probes lost
  - expect $\Delta B/B = 1.5\%$ at day-1

- **Very few bad channels**
- Few chambers with problems (gas leak, overpressure accident,...)
- Some loss of redundancy but no acceptance hole

- Finishing up connections in barrel RPC and final alignment of a few chambers
- TGC: now running with n-Pentane
Toroids & Solenoid Magnet System

- **Central Solenoid** up to full field at 7.73 kA nominal in Aug 06
- **Barrel Toroid** up to full field at 20.5 kA nominal in Nov 06

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Combined test June 08 OK

- **EndCap-C Toroid** up to full field at 20.5 kA nominal in June 08
- **EndCap-A Toroid**

Leak in electrical pipe isolators - 23rd May

Toroid warmed-up/reppaired/cooled - 20th July

EndCap-A tested up to 21kA – 23rd July

Combined test of 3 magnets at 15kA - 31rst July

Beampipe insertion & bake-out

Endcap disks closed along beampipe for bakeout

bakeout complete 25 Jun

- end 20 May
+ end 1 Jun

4m long Be central section braised to stainless steel cones connecting to endcap cones
Pixel Tracker installation

3 cylindrical layers at 4, 7, 11 cm mounted on 2 half-shells
At each end, 2 disks of overlapping blades Mounted on two half-shells

66 mega pixels!!

ECAL Endcap Installation

Preshower support drum moved along beampipe
Tracker: surface commissioning

20% section tested over 5 months (5M)

Signal/Noise $> 25/1$ in “Peak” Readout Mode

Performance check at $-15^\circ C$

Noise Performance $< 3/1000$ noisy strips

Layer efficiency 99.8%

Layer efficiency 100%

Layer efficiency 1%