Detectors at the
Large Hadron Collider

a review and a status report

the countdown has started

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CERN
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.
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 $10^{34}$ cm$^{-2}$s$^{-1}$ for pp collisions at an energy of 14 TeV.

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

**Large Hadron Collider**

Luminosity L:
collision rate normalized to cross section $10^{34}$ cm$^{-2}$s$^{-1}$

$L = \frac{N^2 k_b f \gamma}{4\pi \epsilon_n \beta^*} F$

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

Two ‘general purpose’ $4\pi$ detectors are in preparation for 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 $\sigma_{b\bar{b}} \approx 500 \mu b$  $gg \rightarrow b\bar{b}$
The Large Hadron Collider - experiments

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
Detector Design Considerations

**Experimental Challenge**

**High Interaction Rate: N=Lσ = 10^{34} \times 100 \times 10^{-27} = 10^9 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
Physics Requirements

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

- **Natural Width**
  - 0.01
  - 1
  - 10
  - 100 GeV

- **Higgs Mass**
  - 50
  - 100
  - 200
  - 300
  - 400
  - 500
  - 1000

- **Lep 190 LEP200(>, M_H>114.4 GeV**

- **H → γγ (WH → γγl) (t̅t H → γγ l)**
- **H → ZZ → 4l**
- **H → ZZ → 2ν 1 2μ or 2τ**

**Physics Requirements**

At the LHC the SM Higgs provides a good benchmark to test the performance of a detector.
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
\[ \sim 0.5\% \, @ \, E_T \sim 50 \, \text{GeV} \]

Powerful inner tracking systems
factor 10 better momentum resolution than at LEP

Hermetic calorimetry
good missing \( E_T \) resolution

(Affordable detector)
Detector Design Considerations

**Charged particle moving in magnetic field B**

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

\[ p = 0.3BR \]

\[ L = R \theta \]

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

Units: Tesla, meter, GeV
Charged particle moving in magnetic field $B$

Resolution on $s$ determines resolution on $p$

$$\frac{dp}{p} = (\frac{p}{F}) ds$$

$$F = 0.3BL^2 / 8$$

$ds$ 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
Multiple Scattering

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

\[
\theta_{\text{mlt}} = \frac{13.6[\text{MeV}]}{\beta p c} Z \sqrt{\frac{L}{X_0}}
\]

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

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.

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

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

Calorimeter depth determined by radiation length. Approximately:

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

Granularity determined by Molière radius (lateral shower size)

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

- **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**

Some examples of materials:

<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$_4$</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:

\[ \text{SM : intermediate mass } H \rightarrow \gamma \gamma, H \rightarrow ZZ^* \rightarrow 4e \]
\[ \text{MSSM: } h \rightarrow \gamma \gamma, H \rightarrow \gamma \gamma, H \rightarrow ZZ^* \rightarrow 4e \]

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

\[ M^2 = 2E_1E_2(1 - \cos \theta) \]
\[ \frac{dM}{M} \propto \frac{d \cos \theta}{\cos \theta} \]
\[ \frac{dM}{M} \propto \frac{dE}{E} \]

\[ \tan(\frac{\theta_{\text{min}}}{2}) = \frac{M}{2(E_1 + E_2)} \]
In several scenarios moderate mass narrow states decaying into photons or electrons are expected:

- **SM**: intermediate mass H → Z Z* → 4e
- **MSSM**: h → Z Z* → 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
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### 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: $W, Z →$ Jet-Jet, e.g. in top decays
    - High $p_t$ jets: $W', Z' →$ Jet-Jet
  - Fine lateral granularity ($≤ 0.1$) 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
Detector Design Considerations

‘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 φ, azimuthal angle, intervals) (cf. calorimeter cell size)

\[ \frac{d^4P}{E^2 - P^2 - m^2} = \frac{d\vec{P}}{E} = P_T dP_T d\phi dy \]
\[ dy = \frac{dP_\parallel}{E} \]

For \( E \gg m \):
\[ y \approx \eta = -\ln \frac{1}{2} \tan \theta \]

\[ y = \frac{1}{2} \ln \frac{E + p_\parallel}{E - p_\parallel} \]
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 azimuthal angle, intervals) (cf. calorimeter cell size)

For $E >> m$:
'
Granularity', size of read-out 'cells'

CMS
Measurement of momentum in tracker and B return flux;
Solenoid with Fe flux return
Property: $\sigma_p$ flat with $\eta$

ATLAS
Standalone $\mu$ momentum measurement; safe for high multiplicities;
Air-core toroid
Property: $\sigma_p$ flat with $\eta$

Muon spectrometers
1 TeV muon to be measured with 10% resolution
Tracking at LHC
Factors that determine performance
Track finding efficiency – occupancy
Momentum resolution
Secondary vertex reconstruction

Fluence over 10 years

\[ \leq 4 \times 10^7 \text{ h}^2/\text{cm}^2/\text{s} \]

\[ \text{pixels} \approx 10^4 \mu\text{m}^2 \]

occupancy \approx 10^{-4}

\[ \leq 4 \times 10^6 \text{ h}^2/\text{cm}^2/\text{s} \]

Si \( \mu \)-strip det.

\( \approx 10 \text{ mm}^2 \)

occupancy \approx 1%

\[ \leq 4 \times 10^5 \text{ h}^2/\text{cm}^2/\text{s} \]

Si or Gas detectors.

\( \approx 1 \text{ cm}^2 \)

occupancy \approx 1%
## Detector Implementations

Very recently published in Journal of Instrumentation (JINST):

The CERN Large Hadron Collider: Accelerator and Experiments

<table>
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<tr>
<th>Detector Implementation</th>
<th>Collaborations</th>
<th>Journal Reference</th>
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</thead>
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<tr>
<td>LHC Machine</td>
<td>Lyndon Evans and Philip Bryant (editors)</td>
<td>2008 JINST 3 S08001</td>
</tr>
<tr>
<td>The ALICE experiment at the CERN LHC</td>
<td>The ALICE Collaboration, K Aamodt et al</td>
<td>2008 JINST 3 S08002</td>
</tr>
<tr>
<td>The ATLAS Experiment at the CERN Large Hadron Collider</td>
<td>The ATLAS Collaboration, G Aad et al</td>
<td>2008 JINST 3 S08003</td>
</tr>
<tr>
<td>The CMS experiment at the CERN LHC</td>
<td>The CMS Collaboration, S Chatrchyan et al</td>
<td>2008 JINST 3 S08004</td>
</tr>
<tr>
<td>The LHCb Detector at the LHC</td>
<td>The LHCb Collaboration, A Augusto Alves Jr et al</td>
<td>2008 JINST 3 S08005</td>
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<tr>
<td>The LHCf detector at the CERN Large Hadron Collider</td>
<td>The LHCf Collaboration, O Adriani et al</td>
<td>2008 JINST 3 S08006</td>
</tr>
<tr>
<td>The TOTEM Experiment at the CERN Large Hadron Collider</td>
<td>The TOTEM Collaboration, G Anelli et al</td>
<td>2008 JINST 3 S08007</td>
</tr>
</tbody>
</table>
The ATLAS Detector

A Toroidal LHC ApparatuS

Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid

Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

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

**CALORIMETERS**
- **ECAL**
  - Scintillating PbWO4 crystals
- **HCAL**
  - Plastic scintillator/brass sandwich

**SUPERCONDUCTING COIL**

**TRIGGER**
- Silicon Microstrips
- Pixels

**MUON BARREL**
- Drift Tube Chambers
- Resistive Plate Chambers
- Cathode Strip Chambers

**IRON YOKE**

**TOTAL WEIGHT**: 12,500 t
**OVERALL DIAMETER**: 15 m
**OVERALL LENGTH**: 21.6 m
**MAGNETIC FIELD**: 4 Tesla

**HCAL**
- Plastic scintillator/brass sandwich
## 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 ($|\eta| < 2.5$, $B = 4T$):
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- EM: PbWO$_4$ crystals
- HAD: brass-scintillator (central+ end-cap), Fe-Quartz (fwd)

### Muon Spectrometer ($|\eta| < 2.5$):
- Return yoke of solenoid instrumented with muon chambers
**Tracking (|<2.5, B=2T):**
- Si pixels and strips
- Transition Radiation Detector (e/π separation)

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

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**Magnets**

**ATLAS**
- 20 kA s.c.; GJ’s stored energy
- Unique objects!
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’
Silicon pixels (Pixel): $0.8 \times 10^8$ channels
Silicon strips (SCT): $6 \times 10^6$ channels
Transition Radiation Tracker (TRT):
  straw tubes (Xe), $4 \times 10^5$ channels
e/$\pi$ separation

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

**Electromagnetic Calorimeter**
barrel, endcap: Pb-LAr
~10%/\sqrt{E} energy resolution e/\gamma
180000 channels: longitudinal segmentation

**Hadron Calorimeter**
barrel Iron-Tile EC/Fwd, Cu/W-LAr (~20000 channels)
\sigma/E \sim 50%/\sqrt{E} \oplus 0.03 \text{ pion (10 } \lambda)\)

Trigger for e/\gamma, jets, Missing E_T
Muon System

Stand-alone momentum resolution $\Delta p_t/p_t < 10\%$ up to 1 TeV

$2-6\text{ Tm }|\eta|<1.3 \quad 4-8\text{ Tm }1.6<|\eta|<2.7$

$\sim1200\text{ MDT}$ precision chambers for track reconstruction (+ CSC)

$\sim600\text{ RPC}$ and $\sim3600\text{ TGC}$ trigger chambers
short history of the construction & installation

JUNE 2003

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

Today
ATLAS is built
Today ATLAS is built. It is a cavern 92m underground, 55m long, 32m wide, and 35m high.

- **February 2004**
- **July 2005**
- **October 2004**
A historical moment
Closure of the LHC beam pipe ring on 16th June (the last piece was the one shown here in ATLAS)
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
Hardware Readiness

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Front End Electronics
- Readout Drivers
- Readout System
  - Custom built buffers in PC farm
  - Event Building
    - More PC farms on Data Network

DAQ software
- Control, configuration, monitoring on Control Network

**Trigger / DAQ**

**Custom Hardware**

- Level-1 Trigger
  - Calorimeter
  - Muon System

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

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

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

**Detector**

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

- **Front End Electronics**
  - **Readout Drivers**
  - **Readout System**
    - Custom built buffers in PC farm

- **PC Farms**
  - **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

\[ r_i = r(t_i + t_{\text{offset}}) \]

**RMS \sim 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
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- ATLAS is built and installed
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  Ready for collisions!

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- 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:

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

modular: ease of surface pre-assembly
lowering as 15 large modules
rapid access for maintenance

2000-2007

2006-2008
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* close & finish commissioning

modular: ease of surface pre-assembly
: rapid access for maintenance

2000-2007
2006-2008
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

Full rehearsal of:

- ECAL, HCAL & Tracker installation.

- Closure of barrel and endcaps

Air-pads, grease pads & locking jacks proven to work

3 days to open or close endcap
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 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.
Heavy Lowering Nov 2006-Jan 2008

15 objects in total: 350-2000 t each

#1
Connected to pre-installed cable chains

HF- (Nov’06)

#9
Surveyed & aligned: few x 0.1mm
few x 0.1 m rad

YB0 (Feb ’07)

#15
Connected to pre-installed cable chains

YE-1 (Jan 08)
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

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

Angular distributions

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

Residual distributions
in the 4 layers of a sector

Single hit resolution \( \leq 250\mu m \) as anticipated

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

Total rate stable at \(~200Hz\)
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-: $\sigma/E = 0.42\pm0.01\%$

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

Entries 2414802
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

Run 50905 Event 1576, y vs x

Using ~90k cosmic tracks

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

July global run

Cosmic Trigger
≥ 2 layers in top and bottom sectors of muon wheel

Pre-requisites:
infrastructure, detectors, µ-trigger, DAQ integration, r/o synchronization, µ-calibration, track reconstruction …

Benchmark of detector readiness

Global track fit
**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.
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ALICE Detector
LHCb Spectrometer

OT
Magnet
RICH1
VELO
RICH2
Muon System
Calo. System
Averaged Throughput from 00 Hrs on 21/05/08 to 00 Hrs on 25/05/08
V0-wise Data Transfer From CERN-CIC To All Sites

This slide is only a ‘place holder’ to underline that the LHC Computing Grid is a reality now.

15 $10^{15}$ Bytes per year

Tier0 – Tier1 – Tier2
>100,000 processors
Collisions: a physics Roadmap

Test beam, cosmic runs, pre-alignment & calibration, extensive simulations ...

10 pb-1

100 pb-1

1 fb-1

14 TeV
2009

10 TeV
2008

time

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

Sensitivity to 1-1.5 TeV resonances $\rightarrow$ 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
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% (# barrel module - power supply control lost) will be repaired during shutdown
Commissioning on-going
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
Installation in the cavern
Ext. Barrel C  December 2004
Barrel             October 2005
Ext. Barrel A     May 2006

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)
Hardware Readiness: Inner detector

TRT/SCT installed Aug 2006

Pixel installed June 2007

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

ID volume sealed complex End-Plate with 1000 feed-throughs
needed to achieve closing ATLAS by end of June
Hardware Readiness: Inner Detector

- **Solenoid field**: mapping done with precision $\sim10^{-4}$
- **Pixel**: $\sim0.6\%$ dead/problematic channels
  except EndCap wheel A: $\sim4.2\%$ (+ 8.3\% if cooling loop inoperable)
- **SCT**: barrel $\sim0.35\%$, end-caps $\sim0.26\%$ dead/problematic channels
  except EndCap wheel C: $\sim1.6\%$ (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:
  $\sim4$ 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: \(~200 \, \mu m\)

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

Very few bad channels
Few chambers with problem
  (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/repaiired/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

Barrel

25 Jul 08

Forward

31 Jul 08

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

24 Jul 08

Preshower support drum moved along beampipe

31 Jul 08
Tracker: surface commissioning

20% section tested over 5 months (5M)

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

Noise Performance < 3/1000 noisy strips

Layer efficiency 99.8%

Performance check at -15°C
Tracker: surface commissioning

TOB
TIB

1%
100%

"Noise Performance < 3/1000 noisy strips"

20% section tested over 5 months (5M cosmics).

Performance check at -15°C

Signal/Noise > 25/1 in "Peak" Readout Mode

Layer efficiency 99.8% -15°C