Presentation on the Status of the Compact Muon Solenoid Detector at the LHC

Presentation by Prof. H. Neal (Yale University)
On behalf of the CMS Collaboration at Beauty 2003
October 15th, 2003
CMS Detector Status at BEAUTY 2003

p-p collider

$\mathcal{L} = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

$\sqrt{s}$ up to 14 TeV

$10^9$ events/s
CMS experimental area overview
- Cavern has a height of 26.5m and length of 53m

CMS Detector Status at BEAUTY 2003

- RR53 & RR57 Cavern Handed over May 2003
- UXC5 – Second Phase Invert 75%, Walls 50%
- USC5 - Crown 40%
- Bypass UL54 60%
- Bypass UL56 40%
- UJ53-95%
- UJ57- 80%

A. Hervé – August 25th, 2003
The main access shaft

The detector pit

CMS Detector Status at BEAUTY 2003 – H. Neal
- 13 m long
- free inner diameter of 5.9 m
- measurement up to a pseudo rapidity of 2.4.
- The magnetic flux is returned via a 1.5 m thick saturated iron yoke
- Total iron mass = 7000 tons
- Total weight including coil is 12000 tons
Inner radius = 3.18 meters
Length = 12.4 m
Stored energy = 2.7 Giga Jules
Compressive force at mid plane = 148 Mega Newtons
• Yoke and metallic structures completed one year ago
18.5 (out of 21) full lengths of conductor have been successfully produced at Techmeta.

The 2.5 remaining lengths will be completed for mid-October 2003.

About 43% of the construction has been completed.

Test of the Magnet in Surface Hall first half of 2005

A. Hervé
Z component of Magnetic field in kGauss
Tracker + Calorimetry + Coil

CMS Detector Status at BEAUTY 2003 – H. Neal
CMS Detector Status at BEAUTY 2003 – H. Neal

The layout of the CMS inner tracker

2→3 pixels + 10→14 strip hits
Pixel system currently in R&D phase

<table>
<thead>
<tr>
<th>Test Name</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
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</thead>
<tbody>
<tr>
<td><strong>Pixel</strong></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Readout chip</td>
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<tr>
<td>Chip design</td>
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<tr>
<td>DMLI</td>
<td></td>
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<tr>
<td>Production run full size DMLI chip</td>
<td></td>
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</tr>
<tr>
<td>Translation into 0.25mm</td>
<td></td>
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<tr>
<td>First full size readout chip submission (0.25)</td>
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<tr>
<td>Backup full size readout chip submission (0)</td>
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<tr>
<td>Final submission for 0.25 chip production</td>
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<tr>
<td>Sensor</td>
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<td>First production full size oxygenated barrel</td>
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<td>Iteration oxygenated barrel sensor</td>
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<td>Final submission for barrel sensor production</td>
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<tr>
<td>HDI</td>
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<tr>
<td>Production of barrel HDI prototype for DMLI</td>
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<td>Production of barrel HDI prototype for 0.25</td>
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<tr>
<td>Module</td>
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<tr>
<td>1st barrel module DMLI</td>
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<tr>
<td>Test DMLI barrel module</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>1st barrel module 0.25mm</td>
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</tr>
<tr>
<td>Test 0.25mm barrel module</td>
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<tr>
<td>Barrel module production setup</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Start production barrel modules</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Production barrel modules for layers 1 &amp; 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Assembly and installation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Radius [mm]</th>
<th>Faces (*)</th>
<th>full/half Modules</th>
<th>Chips</th>
<th>Pixels [m^2]</th>
<th>Area [m^2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>low luminos.</td>
<td>41–45</td>
<td>18</td>
<td>128/32</td>
<td>2304</td>
<td>6.35 x 10^6</td>
</tr>
<tr>
<td>Layer 2</td>
<td>low &amp; high luminos.</td>
<td>70–74</td>
<td>30</td>
<td>224/32</td>
<td>3840</td>
<td>10.6 x 10^6</td>
</tr>
<tr>
<td>Layer 3</td>
<td>high lumi</td>
<td>107–112</td>
<td>46</td>
<td>352/32</td>
<td>5888</td>
<td>16.2 x 10^6</td>
</tr>
</tbody>
</table>
PIXEL System
conversion of the readout chips to 0.25 μm
First prototype modules

Silicon Strip Tracker
All final contracts for module parts are active
Start of module production and validation
First Front End Driver prototype
Large progress on procurement of mechanical structures

Status from Gigi Rolandi – 9/2003

TIB reception at CERN & tests – Feb→Apr 2005
TOB completed - April 2005
Reception and tests of TEC – Oct 2005
- Composed of 80000 lead tungstate (PbWO4) crystals readout by avalanche photodiodes that collect the scintillating light
- Barrel uses 22x22x230mm crystals with thickness 25.8 X°
- supported by 0.4mm thick alveolar structures made from carbon-fiber (in the endcaps) and glass fiber (in the barrel)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Barrel</th>
<th>Endcaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudorapidity coverage</td>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>ECAL envelope: $r_{\text{inner}}, r_{\text{outer}}$ [mm]</td>
<td>$1238, 1750$</td>
<td>$316, 1711$</td>
</tr>
<tr>
<td>ECAL envelope: $z_{\text{inner}}, z_{\text{outer}}$ [mm]</td>
<td>$0, \pm 3045$</td>
<td>$\pm 3170, \pm 3900$</td>
</tr>
<tr>
<td>Granularity: $\Delta \eta \times \Delta \phi$</td>
<td>$0.0175 \times 0.0175$ typical: $21.8 \times 21.8 \times 230$ $25.8$</td>
<td>$0.0175 \times 0.0175$ to $0.05 \times 0.05$ $24.7 \times 24.7 \times 220$ $24.7$</td>
</tr>
<tr>
<td>Crystal dimension [mm$^3$]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth in $X_0$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of crystals</td>
<td>61 200</td>
<td>21 528</td>
</tr>
<tr>
<td>Total crystal volume [m$^3$]</td>
<td>8.14</td>
<td>3.04</td>
</tr>
<tr>
<td>Total crystal weight [t]</td>
<td>67.4</td>
<td>25.2</td>
</tr>
<tr>
<td>Modularity</td>
<td>36 supermodules</td>
<td>4 Dees</td>
</tr>
<tr>
<td>1 supermodule/Dee</td>
<td>1700 crystals (20 in $\phi$, 85 in $\eta$)</td>
<td>5382 crystals</td>
</tr>
<tr>
<td>1 supercrystal unit</td>
<td>–</td>
<td>36 crystals</td>
</tr>
</tbody>
</table>
Lead Tungstate crystal SIC-78 from China
A full super-module has recently been assembled and is currently being tested using beams from the SPS.
• New architecture front ends proto-typed and working
  – Currently being used in the test beam
    • Includes all new boards
    • Optical control and readout of data and trigger

• New technology chosen for ASICs. All hardware components prototyped
  VFE ASICS in 0.25µm developed
  – Chips tested and working
  – Small size system running

• Low voltage system and DCS system design progressing well

• 32 Barrel modules assembled
  Almost all Super-Module mechanics procured, 3SMs assembled

• Full system tests in progress
Crystals: 32% delivered
APD production/screening should be finished by April 04
Capsules: 38% early Sept 03
Alveolas: 50% delivered end Q2-03, completion by end 03
Tablets: 73% end Q2-03
Present daily rate: 50 x 2 (centres) = 100 crystals/day = 4 Modules/month
EB Crystal production

- Planning
- Delivered jj-Sep-aa
- Critical path

<table>
<thead>
<tr>
<th>Date</th>
<th># crystals</th>
</tr>
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<tbody>
<tr>
<td>Q1 2001</td>
<td>6000</td>
</tr>
<tr>
<td>Q2 2001</td>
<td>7500</td>
</tr>
<tr>
<td>Q3 2001</td>
<td>8000</td>
</tr>
<tr>
<td>Q4 2001</td>
<td>8500</td>
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<tr>
<td>Q1 2002</td>
<td>8500</td>
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<tr>
<td>Q2 2002</td>
<td>8700</td>
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<tr>
<td>Q3 2002</td>
<td>8900</td>
</tr>
<tr>
<td>Q4 2002</td>
<td>11700</td>
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<td>Q1 2003</td>
<td>14700</td>
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<td>Q2 2003</td>
<td>17700</td>
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<td>Q3 2003</td>
<td>20300</td>
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<td>Q4 2003</td>
<td>23300</td>
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<tr>
<td>Q1 2004</td>
<td>26300</td>
</tr>
<tr>
<td>Q2 2004</td>
<td>30800</td>
</tr>
<tr>
<td>Q3 2004</td>
<td>36200</td>
</tr>
<tr>
<td>Q4 2004</td>
<td>41600</td>
</tr>
<tr>
<td>Q1 2005</td>
<td>47300</td>
</tr>
<tr>
<td>Q2 2005</td>
<td>53000</td>
</tr>
<tr>
<td>Q3 2005</td>
<td>58700</td>
</tr>
<tr>
<td>Q4 2005</td>
<td>64150</td>
</tr>
</tbody>
</table>

32%
New methods of cutting ingots are speeding up crystal production.
- EB Trial insertion of 1 SuperModule
  - Trial February 2005
- EB+
  - Installation in surface hall: 27/06/05 to 19/08/05
- EB-
  - Installation in pit: 1/12/05 to 6/01/06 & Cabling 15/02/06 to 31/03/06
New Preshower mechanical design

- Windows (Al honeycomb + paraffin) + inner drum + support cone remain as complete discs – need to install BEFORE the beam pipe
- Lead planes stuffed with electronics divided into two “D”s – can be installed AFTER the beam pipe

- Endorsed by CMS in March 2003
- Gives a degree of freedom to the Preshower installation schedule
The CMS Hadron Calorimeter

HCAL barrel
HCAL Outer
HCAL Forward
HCAL Endcap
• Hadron Calorimeter (HCAL) Barrel (HB) covers 0 < |\eta| < 1.3 and r = 1.81→2.95 m
  79 cm deep, which at =0 is 5.15 \lambda in thickness
  2 half barrels of 18 calorimeter "wedges" Each is 4.3 meters long in z and weighs 25.7 metric tonnes.

• HCAL endcaps (HE) cover the pseudorapidity range 1.3 < |\eta| < 3.0
  - 10 absorption lengths (19 active layers)
  - brass absorber sampling thickness is 8 cm
  - front and back plates are made of stainless steel to increase strength
  - absorber plates are bolted together to form a single monolithic structure, with gaps for scintillator insertion.

• In the region |\eta|<3.0 the first muon absorber layer is instrumented with scintillator tiles to form an Outer Hadronic Calorimeter (HO).

• The region 3.0<|\eta|<5.0 is instrumented with a quartz fiber calorimeter (HF) for hermiticity
Both HCAL endcaps have now been installed on the endcap yokes
Muon Barrel
- Resistive Plate Chambers (RPC) for timing
- Drift Tubes (DT) for position

Muon EndCaps:
- RPCs
- Cathode Strip Chambers (CSC)

- 4 layers of Muon chambers covering up to $|\eta|=2.4$, providing 3 track segments along a muon track
- Muon ID with at least $16 \lambda$ down to $|\eta|=2.4$
- Standalone transverse momentum resolution $8-1 \, \delta \frac{pt}{pt}$ (at 10 GeV), $20-40\% \, \delta \frac{pt}{pt}$ (at 1 TeV)
- Global momentum resolution $1.0 \rightarrow 1.5 \% \, \delta \frac{pt}{pt}$
- Unambiguous BX identification
d- Single and di-muon first level trigger with variable $pt$ thresholds down to $|\eta|=2.1$
- Correct charge assignment up to $p=7$ TeV
- Ability to withstand the highest radiation and interaction background foreseen at the LHC

- From P. Giacomelli
468 CSCs

- 144 Large CSCs (3.4x1.5 m$^2$):
- 216 Small CSCs (1.8x1.1 m$^2$):
- 108 20° CSCs (1.9x1.5 m$^2$):
- Frontend Electronics:
- 170K Cathode channels
  140K Anode channels
- Trigger&DAQ
  (on-chamber part)
- Alignment&Services
• **Highlights:**
  
  - 91% (439 of 482) chambers assembled
    - Fermilab assembly site finished in April 2003
    - IHEP assembly site will be finished in a month
  
  - 46% (223 of 482) chambers assembled with electronics and tested
    - PNPI and IHEP FAST sites are operational since March-April 2003
  
  - 26% (125 of 482) chambers are at CERN, 105 ready for installation
  
  - 20% (90 of 468) chambers are installed

  *From Guenakh Mitselmakher*
• June 16: installation at SX5 begins with 7 months of delay (SX5 was not ready)
• Installation rate 6 CSC/day (planned 4 CSC/day)

90 chambers installed
## Assembled chambers

<table>
<thead>
<tr>
<th>chamber type</th>
<th>number of assembled chambers</th>
<th>assembling site</th>
</tr>
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<tbody>
<tr>
<td>RB1</td>
<td>11</td>
<td>HT</td>
</tr>
<tr>
<td>RB1</td>
<td>13</td>
<td>Bari</td>
</tr>
<tr>
<td>RB2</td>
<td>40</td>
<td>GT</td>
</tr>
<tr>
<td>RB3</td>
<td>50</td>
<td>Bari</td>
</tr>
</tbody>
</table>

**total=114**

## Tested chambers

<table>
<thead>
<tr>
<th>Tested chambers</th>
<th>number of chambers</th>
<th>test site</th>
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</thead>
<tbody>
<tr>
<td>RB1</td>
<td>3</td>
<td>Bari</td>
</tr>
<tr>
<td>RB2</td>
<td>26</td>
<td>Bari</td>
</tr>
<tr>
<td>RB3</td>
<td>45</td>
<td>Bari</td>
</tr>
</tbody>
</table>

**total = 74**

From G. Iaselli
CMS Level-1 Trigger

CMS Detector Status at BEAUTY 2003 – H. Neal

From W. Smith
Status 2003: Good progress on all fronts

- Prototypes manufactured & final validation tests completing
- Integration tests underway: Detector - Trigger - DAQ
- Tests with structured “LHC-like” beam (very valuable!)
- Software being developed for testing & operation

Plans for 2004:

- Further tests: integration, surface (SX5), structured beam
- Production on all systems (some started in 2003)

From W. Smith
Pilot Run
First Beam in April 2007
Collisions in June 2007

Shutdown
Physics Run start in August/September 2007
@ $1 \rightarrow 2 \times 10^{33}$
Run until 5-10 fb$^{-1}$

CMS Initial Detector for Physics Run

Staged items:
- Muons: ME4, RE4, REs at small radius (RE1/1, RE2/1, RE3/1)
- New: restore ME4/1.
- Tracker: 3rd forward pixel disks
- 50% DAQ

Descoped items:
- HCAL (reduced no. of longitudinal samplings), ME1/1a (3 channels in one, no muon trigger beyond $|\eta| = 2.1$)

From M. Della Negra

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from A.Ball – 22 Sept 2003

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CMS Detector Status at BEAUTY 2003 – H. Neal
• Much progress has been made and CMS will be ready for the April 1st, 2007 LHC test run
• The schedule is very tight in many cases but recent developments should keep us on schedule
• See presentations on the CMS Online Event Selection by Marcin Konecki and on B-physics at CMS by Nanci Marinelli