Readiness of the CMS Detector for First Data

Emilio Meschi
CERN PH-CMD
For the CMS Collaboration

XLIV Rencontres de Moriond
7-14 March 2009
Detector

EM calorimeter: ECAL
- PbWO4 crystal calorimeter
- High resolution
- High granularity > 80k crystals
- Barrel (EB) & Endcap (EE)

Superconducting Solenoid
- Very large, 6m x 13m
- 4T, 1.6 GJ stored energy

Hadronic calorimeter: HCAL
- Brass & scintillator
- Barrel (HB), Endcap (HE), Outer (HO)

Tracker
- 66M Si pixels & 10M Si strips

Compact, modular design
- 12,500 t, 15 m diameter, 21.6 long

Muon System
- Barrel: Drift Tubes (DT)
- Endcap: Cathode Strip Chambers (CSC)
- Barrel & Endcap interleaved with Resistive Plate Chambers (RPC)

Trigger/DAQ
- Hardware Level-1 (100 kHz)
- Tb/s Event Builder @ L-1 rate
- Software High Level Trigger (HLT) -> 300 Hz
From the CMS Album

dance of the endcaps

Barrel pixel insertion

YE-lowering
MTCC: the Beginnings

First system test
Scaled-down infrastructure
Slice of nearly all final components and DAQ

Parasitic to B-field measurements at 5 field values -> field maps for physics
March-August 2008: Waiting for Beam

- Operate CMS as a single detector
  - Integration of new sub-detectors
  - Increase complexity maximize stability
  - Coordinate with installation schedule

- Infrastructure
  - DAQ, trigger commissioning
  - DQM, DCS, DSS
  - Control Room
- **Subdetector** and **trigger** considered separately - 19 items, each equally weighted - box size represents approx. fraction included (25%, 50%, 75%, 100%)

- With exception of some parts of RPC, all CMS detector and trigger system ready for LHC
CRUZET3: Global Tracks

- **Di-muon Trigger:**
  - Drift-Tube coinc. in top+bottom, each 2 station segments

- Muon signals traced through
  - muon system
  - Tracker TOB+TIB
  - ECAL
  - HCAL

- Global track fit

- Data used for alignment
CRUZET4: Endcap ECAL

End of Aug08 – Endcap ECAL part of Global Runs

DT

Barrel ECAL

Endcap ECAL

HCAL
Aug08: all parts of Tracker integrated

First cosmic tracks with Pixels
Testing the muon High-Level Trigger

- Routinely running High-Level-Trigger menu (plus dedicated cosmic muon trigger path)
- Global fit with “L3” tracker track, seeded from “L2” muon track, seeded from “L1” trigger candidate:

Run 58733, event 1741135
Cosmic Shower Events:

- 0.02% rate of events with >100 segments in ~10M cosmic events at 0T
- Event-by-event spread in phi compatible with multiple scattering → all events compatible with a muon

\[ \frac{1}{2} \Delta \varphi \approx \tan \frac{1}{2} \Delta \varphi = \frac{r_{CMS}}{h} \]

Run 50908
- event 1057286
- 541 segments
Calling the Shots: First LHC Beam

- September 7-12 2008
  - Beam1 on collimators (upstream of CMS)
- 10 September (D-day)
  - Beam 1, then Beam 2 circulating (hundreds of turns)
- 11 September: RF capture (millions of orbits)
  - Beam halo through CMS
  - Beam-gas events
- About 40 hrs beam at or through CMS
  - All systems active except Tracker and Solenoid

CMS Trigger and DAQ fully functional: millions of beam events recorded
On 10th September
Beam Splash Event Display

- **Longitudinal views**
  - HCAL energy
  - ECAL energy

- **Transverse views**
  - DT muon chamber hits

Run 62003, Event 1534

Beach XLIV Recontres de Moriond (EW) - 14
> 99% of ECAL channels fired and ~200 TeV energy deposited in EB+EE

Beam (clockwise) came from plus side.

Endcap calibrations were not yet applied (lowest gain near the beam pipe).
Beam Splash Correlations

Correlation between Energies in barrel HCAL and ECAL

- ~150 TeV deposited in ECAL & ~1000 TeV deposited in HCAL per splash event

\[ p_0 = 6.518 \pm 0.002 \]
Time difference between predicted pulse arrival time and mean pulse arrival time for splash events, before and after using delays tuned from beam splash events.

- Note that HCAL Barrel region was already tuned with prior data.
- HCAL now timed in at nanosecond scale
Beam Halo: Muons outside of beam-pipe, arising from decays of pions created when off-axis protons scrape collimators or other beamline elements.

CSC Hit Distribution from Beam Halo Events

LHC Tunnel Profile
Halo Muons

Endcap muon chambers

Barrel muon drift tubes

Reconstructed Tracks

Endcap muon chambers
Halo and Cosmic Muon Angles

- Beam halo muons parallel to beam tangent (small angle)
- Cosmic Ray muons pass through the CSCs at a more oblique angle
- Beam-on distribution consists of two pieces, one resembling cosmic rays and the other matching the beam halo simulation.

beam ON data = combination of
  - beam halo
  - cosmic rays

orange: beam ON data
black: beam OFF data
blue: beam halo simulation
Beam Halo Rates in Muon Endcaps

First RF capture of beam

- CSC halo trigger rate in the minus endcap as a function of time.
- First successful capture lasted for 10 min and ended with beam abort
- Rate jumps preceding this are visible, due to earlier capture attempts.
HCAL Endcap: Beam Capture

- HCAL Endcap energy before and after RF capture of the beam.
  - Before, high rate of energy deposition near beamline.
  - After, beam is cleaner, depositing less energy in HE.
Evidence for Beam Gas Collisions

- Average energy as a function of eta in HF for circulating beam 2
- Events triggered by HF
- Peak in energy towards positive pseudo-rapidity is a signature of beam-gas interactions near or within the detector; the remnants of beam-gas interactions will have small $p_T$ and larger $p_L$ from the initiating proton.
Four weeks continuous running: target @ 70% eff.

- 19 days with B=3.8 T
- gain operational experience w 24/7 operation and identify areas of concern, understand efficiency

370M cosmic events, 290M with B=3.8T, and Tk on

- 87% events with muon track
- 3 % also have strip tk hits
- 0.03% have pixel hits

Data Operations

- 600 TB transferred
- Prompt reconstruction within 6 hrs
From the CMS Album

- Nice muon through tracker
- Opposite charge...
- Cosmic through barrel and endcap
From the CMS Album

Muon through pixels...

...with pixel hits
Strip and Pixel Tracker: Status

- **Strip Tracker**
  - TOB: 98.2% (0.6% recoverable)
  - TIB/TID: 96.9 % (1% recoverable)
  - TEC+: 99.2%
  - TEC-: 97.8 % (1.7% recoverable)

- **Pixels**
  - Barrel pixels: 99.1%
  - Forward pixels: 94.0%
    - Dominated by some readout chips without bias voltage and others without low voltage
    - Repair ongoing
Cosmic Tracking using Tracker

- Three tracking algorithm used for track reconstruction, with different acceptance for cosmics:
  - Combinatorial Track Finder (CTF standard algorithm for collisions)
  - Road Search
  - Cosmic Track Finder

- Momentum distribution for high quality tracks (partial statistics)
  - 8 hits
  - 1 hit in TIB L1/L2
  - 1 hit in TOB L5/L6
  - ~70K tracks expected out of full CRAFT statistics with $P_T > 100$ GeV
Tracker Barrel Alignment

- Mean of residual distributions (cm)
  - Sensitive to module displacements
- Only modules with >30 hits considered
  - TIB 96%, TID 98%, TOB 98%, TEC 94%
- HIP algorithm: TIB RMS = 26 $\mu$m, TOB RMS = 28 $\mu$m
Pixel Barrel Alignment

- Barrel aligned at module level (200-300 hits, 89%)
- Endcap aligned at half-disk level (8)

RMS=47 μm
Event selection:
Muon track matching in DT and Tracker
20 GeV/c < $P_\mu$ < 1000 GeV/c
CRAFT: 200 K events
MC: 15 K events
HB energy: signal from HB towers corrected for muon path length in HB
ECAL Occupancy and Timing

\[ E_{\text{seed}} > 100 \text{ MeV} \]
Stopping power

![Graph showing stopping power](image)
Since beginning of September 2008
- All installed CMS sub-detectors in global readout routinely
- All triggers operational, DAQ commissioned, high L1 rates tested
- Stability of running with all CMS components proven
- LHC clock and orbit signals tested
- Synchronization to few ns or better

Have continued global data-taking with cosmics
- CRAFT: Cosmic Run at “Four” Tesla, > 300M cosmic ray events

Detector opening started on Nov 17th
- Interventions/repairs for problematic channels (order of ~1%)
- CMS cooling system maintenance
- Installation of Preshower detector

Plan: continue global data-taking operations with cosmics this spring to prepare for beam this fall.
Point 5: Shutdown Activities
Shutdown Activities: Status

- Tracker Cooling Plant refurbishment
  - Plan reviewed: green light to proceed.
- Repair 6% of Fpix with lost LV
- HCAL: replaced faulty HPDs
- Muon DT/RB: ~ 10/250 chambers needed repair
  - (few per mille of channels) YB0, YB+1 completed.
- CSCs - repaired ~10/468 known faulty chambers
- Endcap RPCs: some chambers showed increasing leakage current – progress being made.
- ECAL LV lost on 200 channels – now repaired.
- Field Map
- Forward Region: TOTEM, ZDC, CASTOR

“We are within a few days of the schedule defined mid-November”
ECAL Preshower

All 4 Dees assembled and tested warm and cold.
Approach, connection and moving of ES-Dees completed successfully
Completing LV, HV, control and readout
Transport and lowering started
About 3 weeks required for each endcap for underground assembly, installation and check-out
Prospects for 2009-2010 Run

With first collision data:
- Understand reconstruction performance of physics objects: muons, electrons, photons, jets ... b-tagging, taus, missing transverse energy

With few pb-1:
- Hadron spectra, low-mass resonances, underlying event
Prospects for 2009-2010 Run

- 10 pb-1
  - Standard candles: $W$, $Z$, top x-sections at 10 TeV
  - Jet energy corrections
  - Searches using high-Et jets

- 100 pb-1
  - Precision measurements of SM
  - $W'$, $Z'$
  - JES from top
  - Heavy stable charged particles
  - SUSY searches
  - ...

- 2-300 pb-1
  - at 10 TeV $\Rightarrow$ start competing with Tevatron for Higgs masses around 160 GeV
Conclusions

- CMS is commissioned and has collected first data with LHC
  - It’s just been ~20 years
- After the unfortunate LHC incident, we are using the time for remaining issues and “final touches”
- See you next year with the “First Physics with the CMS Detector”
Backup slides
First Circulating Beam Through CMS

Beam1 arrives at +z monitor ~15ns before -z monitor (TOF)
Beam Detectors

- BCM1 L/F diamonds
  - $Z = \pm 1.9\,\text{m}$, $r = 4.3\,\text{cm}$

- BSC1: scintillators
  - $Z = \pm 10.9\,\text{m}$, $r = 4.3\,\text{cm}$

- BCM2 diamonds & BSC2 scintillators
  - $Z = \pm 14.4\,\text{m}$, $r = 29\,\text{cm}$

- BPTX beam pickup
  - $Z = \pm 175\,\text{m}$

BCM1 L/F and BCM2 PROTECTION of CMS
“Beam Splash” Events

- Single beam shots of $2 \times 10^9$ protons onto closed collimators ~150m upstream of CMS
  - Hundreds of thousands of muons pass through CMS per event
  - Enormous amount of energy deposited in calorimeters
- Allowed synchronization of triggers (previously with cosmic muons)
  - Muon end caps, BPTX beam pick up, etc
- Internal synchronization of sub-detectors
Status of the Machine

http://lhc.web.cern.ch/lhc/
Drift Tube Muon System at CRAFT

- Residuals
  - Reasonable agreement between data and MC after cosmic muon arrival time fit
  - Sigma ~ 200 – 260 μm
  - B field degrades MB1 in wheels +/-2
  - Sector 4, wheel -2 →

Clean up statistics boxes
Lower values correspond to Superlayers with some group of disconnected (temporary) channels.

Average of single DT cell efficiency per SuperLayer

Entries = 654
Mean = 98.54
RMS = 0.888
Measured Endcap Deformation at 3.8T

3 Straight Line Monitor (SLM) Laser Lines per Muon Endcap Station
10 optical CCD sensors per SLM
- Innermost stations on outer wheels have largest radial field
- Maximum difference in drift velocity is 3%
Energy spectrum

energyHigh_AllClusters, run 200

Cluster Energy (GeV)

Entries: 8411987
Mean: 0.5021
RMS: 2.029
Underflow: 0
Overflow: 328
Pixel Signal

Barrel Pixel cluster charge corrected for the track angle
Tracker Signal/Noise

On track Strip clusters S/N ratio in peak mode of the read-out chip, corrected for the track angle:

- TOB thick sensors: S/N = 32
- TIB/TID thin sensors: S/N = 27/25
- TEC (mixed thickness): S/N = 30

Track hit finding efficiency of TIB and TOB layers, excluding modules not in operation.
Tracker Alignment

χ²/ndof

- Unaligned
  - Mean = 5.46
- CRUZET
  - Mean = 3.39
- CRAFTHIP
  - Mean = 2.49
- CRAFTMP
  - Mean = 2.82
Pixel Occupancy Maps

Pixel hits in cosmics, $B=3.8$ T

Pixel barrel hits in cosmics, $B=3.8$ T