Commissioning and performance of the CMS calorimeter systems with proton-proton collisions at the LHC

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On behalf of CMS collaboration

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- Overview
- Start-up conditions
- Detector performance
- Physics object performance
- Conclusions
CMS Detector

SILICON TRACKER
Pixels (100 x 150 μm²)
~1 m²  66M channels
Microstrips (50-100μm)
~210 m²  9.6M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
76k scintillating PbWO₄ crystals

PRESHOWER
Silicon strips
~16 m²  137k channels

SUPERCONDUCTING SOLENOID
Niobium-titanium coil
carrying ~18000 A

STEEL RETURN YOKE
~13000 tonnes

HCAL
|\eta| < 5

ECAL
|\eta| < 3.0

Tracker
|\eta| < 2.5

Muons
|\eta| < 2.4

Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

MUON CHAMBERS
Barrel: Drift Tubes & Resistive Plate Chambers
Endcaps: Cathode Strip Chambers & Resistive Plate Chambers

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The CMS calorimeters

- **Electromagnetic calorimeter, ECAL:** Homogeneous PbWO$_4$ crystal calorimeter
  - Barrel (EB): PbWO$_4$
    - $26\Delta\eta\Delta\phi = 0.0174 \times 0.0174$
  - Endcap (EE): PbWO$_4$
    - $25\Delta\eta\Delta\phi = 0.021 \times 0.021 \sim 0.050 \times 0.050$
  - Preshower in endcap (ES): 3X$_0$ lead with 2 planes of 61mm x 1.9mm Si strips
  - Target resolution: 0.5% at high energy
  - > 99% working channels (EB: 99.3, EE: 98.94, ES: 99.8)
  - Stable conditions: temp. RMS 0.003°C (EE: 0.015°C), Laser response stability < 0.02%.

- **Hadronic calorimeter, HCAL:**
  - Barrel (HB): Brass + Scintillators
    - $\Delta\eta\Delta\phi = 0.087 \times 0.087$
  - Barrel tail catcher (HO): Scintillators
  - Endcap (HE): Brass + Scintillators
    - $\Delta\eta\Delta\phi = 0.087 \times 0.087 \ldots 0.35 \times 0.087$
  - Forward (HF): Steel + quartz fibre (Čerenkov)
    - $\Delta\eta\Delta\phi = 0.349 \times (0.175 \text{ or } 0.35)$
  - > 99.75% working channels (100% in HB/HE/HF)
ECAL start-up conditions

- **Synchronization**
  - All channels synchronized.
  - Providing a time measurement precision better than 1ns.

- **Calibration**
  - Start-up calibration uses results from a 10-year campaign of test-beam and cosmics rays precalibration, in-situ “splash” events and $\pi^0$ calibration.
  - Precision of start-up calibration:
    - EB: 0.5% – 2.2% (1.2% in central region with first 120 nb$^{-1}$)
    - EE: 5%
    - ES: 2.2% (better than design goal)
  - Target with 10 pb$^{-1}$: 0.5% in EB; 1%~2% in EE

- **Alignment**
  - ES vs EE:
    - misalignment < 0.5mm (+/- 0.2mm)
  - Tracker vs ES/EE:
    - $\Delta y = 7$~8mm for + and – side
    - $\Delta x \sim 5$mm for + side
  - Possible small displacement in EB. Will be measured with the increased integrated luminosity

More details in posters #824 (Y. Yang), #507 (Z.-K. Liu), #477 (Y.-M. Tzeng)
HCAL start-up conditions

- All channels synchronized
  - Providing a time measurement precision in HB and HE better than 2ns.

- Precalibration
  - Absolute scale set in test beam
  - Intercalibration made in-situ with Co$^{60}$ source
  - Cosmic rays and “splash” events (beam dumped on a collimator 150 m from IP)

- Data-driven calibrations
  - Target: 5% on absolute scale, 0.5% (2%) on relative scale for barrel (endcap)
  - Requires ~10 pb$^{-1}$. With available data, set limit on systematic uncertainties.
  - Single particle response: $E_{\text{calo}}/p_{\text{track}}$
    - barrel: agreement with Monte Carlo within 3%
    - endcap: response ≤ 8% higher than Monte Carlo. It will be adjusted with more data when performing the actual calibration.
  - Jet energy scale: from dijet balance
    - Uncertainties currently used in analyses, $10\% + 2\% |\eta|$ is confirmed within the statistics errors (71 nb$^{-1}$, but with trigger prescale)

More details in P. De Barbaro’s poster #854
Detector response comprehension, ECAL

- Data and Monte Carlo in very good agreement without any Monte Carlo tuning

![Graph showing data and Monte Carlo agreement](image)

- $\eta$ distribution of channel with max. energy

- Ratio of energy deposited in 3x3 crystal matrix to cluster energy.

See R. Salerno's talk on electron and photon reconstruction.
Distribution of $M_{ee}$ of selected $Z \rightarrow e^+e^-$ candidates

See J. Mans' talk and M. Cepeda's talk
Detector response comprehension, HCAL

- Single particle response measurement as function of the track momentum. Selecting isolated charged particles with low deposit in ECAL (< 500MeV).
Jet measurement resolution

- Position resolution estimated by comparing tracker and calorimeter based measurements.

- $P_T$ resolution estimated with dijet asymmetry method:

  - Particle Flow technique strongly improves resolution in low $P_T$ range.

  - Already better than design resolution ($100%/\sqrt{E\oplus5%}$).

See J. Weng’s talk
High mass dijet event

CMS Experiment at LHC, CERN
Run 133450   Event 16358963
Lumi section: 285
Sat Apr 17 2010, 12:25:05 CEST
Missing E_T for Dijet events measured with two methods. $p_T > 25$GeV/c

Monte Carlo describes the data well over 3 orders of magnitude without tuning.

Missing E_T Gaussian core resolution:
- < 10 GeV on whole $\Sigma E_T$ range up to 350GeV.
- Factor 2 improvement from Particle Flow technique.

See particle flow algorithm F. Beaudette's talk this afternoon
Conclusions

- Excellent detector performance since the very beginning of data taking.
- Commissioning is essentially finished. It has fully exploited the (limited!) amount of available data.
- Calibration will advance very fast with the LHC luminosity ramp-up.
- First physics analyses with excellent results.

![Missing $E_T$ distribution in $W \rightarrow e\nu$ candidate events](image)
Backup
Anomalous signal

ECAL barrel
- **origin**: heavily ionizing particles deposit energy in the Avalanche Photodiode
- **characteristic**: large signal on an isolated channel. Signal shape \( \sim 1 \) in \( 10^3 \) minimum bias events.
- **filtering**: topological cut + timing

HCAL barrel - endcap
- **origin**: ion feedback, noise & discharges in HPDs
- **characteristic**: Random, \( \sim 10\text{-}20 \text{ Hz} \) (E>20 GeV).
- **filtering**: topology + timing

HCAL forward
- **origin**: Čerenkov light by particles going through PMT glass
- **characteristic**: Appear mostly in one channel in time with collisions
- **filtering**: based on energy sharing between long and short fibers + timing

**EB discriminating variables plot for the highest energy hit** (\( E_T > 3 \text{ GeV} \))