CMS detector status

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Large Hadron Collider
27 km circumference

TIPP 2011 Chicago
Outline

- Description of the CMS detector
- 2010, 2011 data taking
- Performance
- Conclusions
The CMS Detector

General purpose, hermetic experiment. Compact fully solenoidal design. All central tracking and calorimetry inside a superconducting solenoid (B=3.8T) -> Large BL²

ECAL

HCAL

IRON YOKE

Muon System Endcap (CSC+RPC)

TRACKER

15 m

21.6 m

12500 tons

Muon System Barrel (DT+RPC)
The CMS Detector

Pixel detector for precise reconstruction of secondary vertexes, Strip Tracker with excellent tracking efficiency and resolution $\Delta p/p < 1\% @ 100\text{GeV}$

- Tracks (100x150 $\mu m^2$) ~ 1 m$^2$
  66M channels
- Silicon Microstrips ~210 m$^2$
  9.6M channels
SST
15148 modules
24244 Silicon sensors
75000 readout chip
9.6 M readout channels
~25 M bondings
206 m² Silicon active area
29 modules types, 16 sensor designs
12 hybrids types
~150 km fibers/cables
1944 powers supply modules
356 control modules
37 K optical links
24 m³ volume

• Forward Pixel Detector (FPix) has two disks on each side at 34.5 cm and 46.5 cm
• FPix has 672 modules

• Barrel Pixel Detector (BPix) has 3 layers of radii 4.3 cm, 7.2 cm and 11.0 cm
• BPix has 768 modules

• Total of 1440 modules
1.1 m² Si sensors

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The CMS Detector

3.8T Solenoid

ECAL with high granularity, extremely good resolution, low noise, good uniformity/intercalibration

76k scintillating PbWO$_4$ crystals

Energy resolution: (~ 0.5% @ ET ~ 50 GeV)

$\left( \frac{\sigma}{E} \right)^2 = \left( \frac{2.8\%}{\sqrt{E}} \right)^2 + \left( \frac{0.12}{E} \right)^2 + (0.3\%)^2$
CMS Electromagnetic calorimeter

Homogenous PbWO$_4$ Crystal Calorimeter + Pb-Si Pre-shower

**BARREL (EB)** $|\eta|<1.48$
- 61200 crystal
- (2.2 x 2.2 x 23 cm$^3$) - 26$X_0$
- 36 Super Modules
- Avalanche Photo Diodes

**ENDCAP (EE)** $1.48 < |\eta| < 3.0$
- 4 Dee’s
- 14648 crystals
- (3 x 3 x 22 cm$^3$) - 25$X_0$
- Vacuum Photo Triodes

**PRESHOWER (ES)** $1.6 < |\eta| < 2.6$
- 4 Planes
- Total of 137216 Si strips
- Pb/Si - 3$X_0$

Crystals are projective and positioned slightly off-pointing for hermeticity.
The CMS Detector

HCAL compact, hermetic, good segmentation and coverage ($|\eta|<5.2$)
Jet angular resolution $\sim 20$ (30) mrad
in $\phi$ ($\theta$) at $ET \geq 100$ GeV

Jet transverse energy resolution
barrel ECAL+HCAL only

$$\left( \frac{\sigma}{E_T} \right)^2 = \left( \frac{1.25}{\sqrt{E_T}} \right)^2 + \left( \frac{5.6}{E_T} \right)^2 + (3.3\%)^2$$
The CMS Detector

Iron yoke instrumented to host the muon spectrometer => Measurement of muon momentum thanks to the saturation of the iron

15 m

3.8T Solenoid

ECAL

HCAL

IRON YOKE

Muon System

Endcap

(CSC+RPC)

12500 tons

Tracker

21.6 m

Muon System Barrel (DT+RPC)
The CMS Detector

Robust, efficient and redundant muon triggering system (RPC+DT, CSC)
Efficient muon identification and reconstruction
$\Delta p/p < 1\%$ @ 100GeV, $< 10\%$ @ 1 TeV

Muon System
Barrel (DT+RPC)

12500 tons
The CMS Detector

- Able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….

- Momentum / charge of tracks and secondary vertices (e.g. from b-quark decays) are measured in central tracker (Silicon layers).
- Energy and positions of electrons and photons measured in high resolution electromagnetic calorimeters. (~ 0.5% @ ET ~ 50 GeV)
- Energy and position of hadrons and jets measured mainly in hadronic calorimeters
- Muons identified and momentum measured in external muon spectrometer (+central tracker) dp/p<1% @ 100GeV and <10%@1 TeV
- Neutrinos “detected and measured” through measurement of missing transverse energy (ETmiss) in calorimeters (hermeticity; good Missing ET resolution)
The CMS Detector

started operations from summer 2008: a set of cosmic runs provided calibration constants (alignment..)
Trigger system

- Hardware L1: Based on muon detectors and calorimeters
  - Timing precision ≤1ns;
  - L1 45-70kHz

- Software HLT. Flexible
  - Fast (~50ms) full event reconstruction using also tracker information.
  - Data logging 200-600Hz.

- High efficiency and sharp turn-on curves

see P. Klabbers yesterday’s talk
Data taking 2010

- **pp**- collisions: 7 TeV from March 2010
  - LHC Delivered 47 pb\(^{-1}\), CMS recorded 43 pb\(^{-1}\).
  - Great flexibility of trigger system.
  - Overall data taking efficiency 92%, ~85% with all subdetectors in perfect conditions.

- **Heavy Ions**: 8\(^{th}\) November
  - Delivered ~ 8.4 µb\(^{-1}\), efficiency ~ 93%
Data taking 2011

- pp- collisions: 7 TeV from 14 March 2011
  - LHC Delivered 830 pb\(^{-1}\), CMS recorded 763 pb\(^{-1}\);
  - Overall data taking efficiency 91%

Several days with year 2010 lumi
Detector performance

Start as: “Don‘t expect everything to work at first. . . ”

– BUT… even such a complex apparatus do seem to be working as expected from simulations!
Tracker Basic Performance

- Fraction of active detector:
  - Pixel: 97.3% Strips: 97.8%
  - high hit efficiency: >99.9%
- Reconstructed hit signals match with expectation and MC
  - Strip S/N: ~19 (thin sensors), ~23 (thick sensors)
- Estimated intrinsic hit resolutions match with MC
  - tracks in overlap: cosmics and collisions

See also J. Agram talk

- Offline Calibrations:
  - Lorentz Angle
  - Dead/Noisy channels
    - Efficiency
    - Analog Signal equalization

Hit resolution from overlaps

Pixel Barrel
- rphi resolution: 12.7±/-2.3 μm
- z resolution: 28.2±/-1.9 μm

Excellent agreement with MC

Strip hit efficiency

Missing hits on tracks:
All Modules
Bad Modules removed

Typical rphi resolutions are better!! (track angle)
Tracker Power system

- Power System: it provides 1.25 and 2.5 Volts to the Fe electronics and up to 600 V to the Si modules. There are ~1200 electronics CAEN modules to power up the system: 356 control groups, 1944 power groups, 3888 HV channels.

The Tracker can do the HV OFF to HV ON transition in ~75”. The total power is 36-49 KW.

The system is stable and the overall exchange rate is at 1% level/year.
Tracker cooling system

Operational temperature @detector: 4 °C
Expected T decrease next year with intervention on bulk head sealing

Sniffing system inside TK volume:
Gas chromatograph installed (summer ‘10)

Few incidents occurred: HEX
Some leaks in one plant (SS2)
5/180 lines are closed but
the modules are operational

Leak rate (from Apr ‘11: 0.5 kg/day
~0.1% C₆F₁₄ measured inside TK

Interventions started to stabilize
the operation: VFD, P reduction,…
Tracking and muon performance

- Muon momentum resolution extracted from resonances, ‘almost’ as simulation (corrections $\sim 10^{-4}$)
  - Excellent resolution for Primary Vertex reconstruction and transverse impact parameter
  - B-tagging operational already at $15\text{nb}^{-1}$
Tracking and muon performance

- Thanks to high flexibility of trigger system!
- Excellent tracking resolution and alignment shows in resolution of $M_{\mu\mu}$

see also N. Beni’s talk later
Data Quality monitoring

- Detector performance are monitored using the DQM system
  - online to give prompt feedback during data taking
  - offline to analyse the full statistics and certify data

- The full tracker reconstruction chain is monitored through histograms on
  - Status of Feds, Occupancy, Clusters, Track parameters

- Module level histograms are further processed to
  - Create summary histograms
  - Perform Quality Test
  - Produce global DQM flags
Tracker Alignment

- 15148+1440 sensors: 6 degrees of freedom each, $O(10 \mu m)$ accuracy
- Distributions of Mean Residual (DMR): median of the residual distributions in each sensor ($N_{hit} > 200$) less affected by track, hit and multiple scattering uncertainties

- Minimization hit/track residuals $\chi^2$
  - track parameters and sensor positions
- Two approaches:
  - Millipede (II): Global minimization, custom track model
  - “Hits and Impact Points” (HIP): local minimization of sensor position, iterative, detailed track model
  - Applied sequentially from large substructures to sensor level
- DMRs spreads Barrel: $< 6 \mu m$ Endcaps: $<10 \mu m$
- Good complementarity between cosmics and minimum bias collision events
Particle Identification

• Energy loss in Si strip sensors used for particle ID

• Fundamental for searches of exotica particles

• Mass of candidate evaluated starting from the relation between the particle momentum and \(dE/dx\) estimator

Deuterons: not simulated
ECAL, photon and electron performance

Status: EB: 99.08%, EE: 98.56%, ES: 96.08%

- ECAL provides very good energy resolution down to low energies
- Performance in agreement with expectations
- At high ET the scale in the barrel region is now set by the $\pi^0$ calibration (correct to 1%); 3% shift in the endcap region

- Good knowledge of material budget (conversions, NI)
ECAL, photon and electron performance

- Di-electron mass spectrum
Conclusions

- CMS detector is operated since 2008: several millions of cosmics data have been collected until the LHC startup at the end of 2009.
- Since 2010 CMS has collected $\sim 900 \text{ pb}^{-1}$ of integrated luminosity in pp collisions at 7 TeV.
- No major problems occurred during the two years LHC pp operation.
- Detector performance are excellent, as expected from the simulations.

- Given the good LHC luminosity performance, stay tuned for new physics results soon !!!!.

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Back-up slides
The CMS design: goals

- **Good muon identification and momentum resolution:**
  - Redundant measurements and redundant trigger systems
  - $\Delta M_{\mu\mu} / M_{\mu\mu} \approx 1\%$ at 100 GeV
  - Unambiguous determination of the charge for $p_T^\mu < 1$ TeV

- **Precise and efficient inner tracking, including vertex capabilities:**
  - Efficient triggering and offline tagging of taus and b-jets
  - Pixel detectors close to the interaction region

- **Good electromagnetic identification and photon/electron energy resolution:**
  - $\Delta M_{ee} / M_{ee}, \Delta M_{\gamma\gamma} / M_{\gamma\gamma} \approx 1\%$ at 100 GeV
  - Large coverage and good granularity, $\pi^0$ rejection

- **Good jet and missing transverse energy resolution:**
  - Hermetic coverage, fine lateral segmentation
CMS inner tracking system

A huge, ultra-precise silicon tracker system:

- For $p_T \leq 100$ GeV, $\Delta p_T / p_T \approx 0.5$-2% ($|\eta| < 1.6$)
  - Muon resolution dominated by inner tracking resolution for $p_T \leq 100$ GeV
- $\Delta d_{xy} \approx 10$ μm resolution at very high $p_T$
- $\Delta z \approx 20$-40 μm resolution at very high $p_T$ ($|\eta| < 2$)
CMS: a special muon system

- The CMS muon system (barrel and also endcap) is optimized for:
  - Robust, efficient and redundant muon triggering system (chambers+RPCs)
  - Efficient muon identification and reconstruction ($|\eta|<2.4$, redundant coverage)
  - Precise measurement ($< 10\%$) for TeV momenta (good alignment + level arm)
CMS Electromagnetic Calorimeter

- A crystal calorimeter (PbWO$_4$): extremely good resolution (stochastic term $\approx 2.8\%$ at 1 GeV), low noise (noise term $\approx 120$ MeV), good uniformity/intercalibration (uniformity $\approx 0.3\%$ from test-beam studies):

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.8\%}{\sqrt{E}}\right)^2 + \left(\frac{0.12}{E}\right)^2 + (0.3\%)^2$$

(E in GeV)
CMS Hadronic Calorimetry

- Scintillator-brass/steel tile calorimeter: compact, hermetic, good segmentation and coverage (|η| < 5.2)
- Jet angular resolution ~ 20 (30) mrad in φ (θ) at E_T ≥ 100 GeV
- Jet transverse energy resolution (using ECAL+HCAL only, barrel):

\[
\left( \frac{\sigma}{E_T} \right)^2 = \left( \frac{1.25}{\sqrt{E_T}} \right)^2 + \left( \frac{5.6}{E_T} \right)^2 + (3.3\%)^2
\]