Journal logo

Status of CMS and First Collider Results

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Abstract

Since November 2009 the new Large Hadron Collider (LHC) at CERN has resumed operation delivering the first p-p collisions at 7 TeV on the 30th of March 2010. The CMS detector is registering data with a prospect to integrate 1 pb^{-1} of luminosity in a few months. The detector systems show excellent performances and many physics objects are already commissioned. First results on detector performance and physics, including also the 0.9 and 2.36 TeV pilot runs, are presented.

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1. Introduction

The first LHC [1] collider run started in November 2009. After nearly twenty years of design, construction and commissioning, collision data have been recorded, by CMS [2], first at centre-of-mass energies of 0.9 and 2.36 TeV and more recently at 7 TeV.

The outstanding performances of the subdetectors and agreement with MC simulation are impressive for a collider detector at startup. Physics results, from an initial and small data sample, were ready for publication just a few weeks after recording.

With collision data it is now possible to improve on the study of the detector and reconstruction performance for physics objects: muons, electrons, jets, b-tags, τ, missing transverse energy (MET), etc. Beam intensity, bunch spacing and instantaneous luminosity will be gradually increased. The run is expected to deliver about 1 fb^{-1} integrated luminosity at $\sqrt{s}$ =7 TeV before the end of 2011 and we hope to integrate about 1 pb^{-1} of luminosity in a few months of data taking. In this paper subdetectors performance and initial physics results are presented together with the illustration of early new physics potential and a roadmap toward discoveries [3].

2. The CMS Detector

CMS [2] is one of the two general purpose particle detector experiments located at the LHC at CERN.

At design luminosity of $10^{34}cm^{-2}s^{-1}$, the 7 TeV proton beams will cross inside CMS every 25 ns providing an average of 20 collisions per crossing, and thousands tracks in the detector. To sustain such a rate the detector has extremely high granularity.

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The overall size of the detector is set by the muon tracking system that in turn makes use of the steel return yoke of the magnet. The central feature of the CMS apparatus is therefore the superconducting solenoid of 6 m internal diameter delivering a uniform magnetic field of 3.8 T. Immersed in the magnetic field are the inner tracker, the crystal electromagnetic calorimeter (ECAL) and the brass-scintillator hadron calorimeter (HCAL). The tracker consists of three layers of silicon pixel detectors (66M channels) followed by 10 layers of silicon microstrips (10M channels) measuring charged particles within the pseudorapidity range $|\eta|<2.5$. It provides an impact parameter resolution of about 100 μm and a 15μm vertex position accuracy. The tracker was aligned initially using cosmic ray data in advance of the LHC commissioning. The precision achieved for the positions of the detector modules with respect to particle trajectories is 3-4 μm in the barrel for the coordinate in the bending plane.

ECAL, made of about 76,000 lead-tungstate scintillating crystals, has an energy resolution of about 0.5% for high energy electromagnetic showers, with a low mass Higgs decay to two photons as a benchmark channel.

Muons are measured in different gas-ionization detectors (Drift Tubes, Cathode Strip Chambers and Resistive Plate Chambers). The momentum resolution, combined with tracker, is 1% at low p_T and 5% at 1 TeV.

The overall CMS detector is segmented in wheels and disks. It was completely assembled on surface and lowered in the collision hall cavern slice by slice.

3. Commissioning

Starting in August 2008, CMS ran in global mode as a single detector a few days per week and a full week per month logging millions of cosmic triggers.

On September 2008, LHC injected beam in the accelerator and in the following few days the experiment accumulated "beam splash" and "beam halo" events from circulating beams.

These different data sets have enabled CMS to align the detector components, both spatially and temporally and to establish the relative alignment of the tracking and muon systems. In addition, the calorimeter calibration from test beam results has been integrated and crosschecked, thus providing an initial energy calibration of about 5%. The CMS magnet has been field mapped. The trigger and data acquisition systems have been run at full speed. The data analysis system has been exercised at full design bandwidth for Tier0, Tier1 and Tier2 sites. Monte Carlo simulation of the CMS detector at a detailed geometric level has been tuned using test beam and other production data to provide a realistic model of the CMS detector prior to first collisions.

3.1. Cosmic Run at Four Tesla (CRAFT)

After the LHC incident in September 2008 CMS went back to cosmic operation. The aim of CRAFT was to run CMS for four weeks during 2008 fall with all subsystems participating, collecting data continuously to gain further operational experience.

We collected more than 370 million cosmic events. A lot of information has been extracted and the results of these studies are described in 23 performance papers submitted for publication before the start of collisions in 2009 [8].

We have published a measurement of the ratio of positive to negative charged atmospheric muons, as a function of the muons momentum [4].

3.2. Pilot runs at 0.9 GeV and 2.36 TeV

The first LHC collider run started in October 2009 with a short beam commissioning phase.

On November 23rd 2009 the CMS experiment recorded the first LHC proton-proton collisions.

In the following weeks CMS collected approximately 350 thousand collision events at a centre-of-mass energy of 0.9 TeV and 20 thousand events at 2.36 TeV with the magnet switched on at the nominal value of 3.8 T. These data correspond to an integrated luminosity of about 10 μb^{-1}, with about 85% data taking efficiency.

3.3. Collisions at 7 TeV

CMS is collecting luminosity at $\sqrt{s}$=7 TeV since March 30th 2010 (see Fig. 1). The expected luminosity to be delivered before the short winter shut down is 100 pb^{-1} and 1 fb^{-1} by the end of 2011.

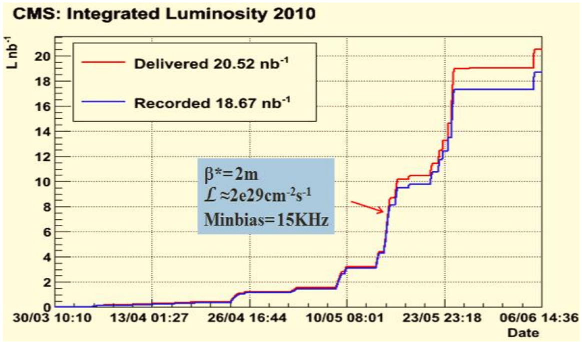

Fig. 1. CMS integrated luminosity up to beginning of June.

4. Detector Performance

The first physics resonance observed in collision data has been the π^0 in the $\gamma\gamma$ invariant mass distribution. A peak was already visible on the online monitor 5 minutes after the start of collisions at 7 TeV. Updated versions of the π^0 di-photon invariant mass, with more data (5% of available statistics) and simulated events, are shown in Fig. 2.

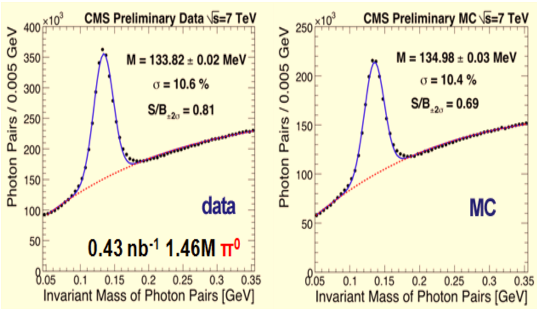

Fig. 2. Invariant mass of photon pairs for data and simulation.

The peak position and signal to background ratio for data and simulation are in good agreement. The mass reconstructed from data and Monte Carlo agrees within 2%, in agreement with calibration of the electromagnetic calorimeter at start up. After applying a simulation based correction for single photon energies (shower containment, threshold effects and energy loss in the material in front), the mass values obtained are at 2% from PDG values. Similar results are obtained for the eta resonance ($\eta\rightarrow\gamma\gamma$). This data is useful to intercalibrate the calorimeter crystals: the target is a relative calibration of 0.5% at 10 pb^{-1}.

In Fig. 3a the mass peak is shown for π^0events in which one of the photons converted in the tracker and is reconstructed as an e^+e^- pair.

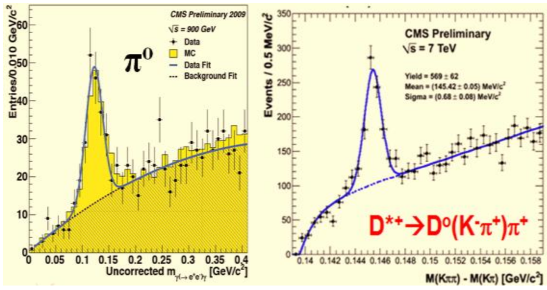

Fig. 3. Invariant mass distributions for (a): π^0 decay events with one of the photons converted in a e^+e^- pair; (b): M($K\pi\pi$)-M($K\pi$) for $D^{*+}\rightarrow D^0(K^-\pi^+)\pi^+$ decays.

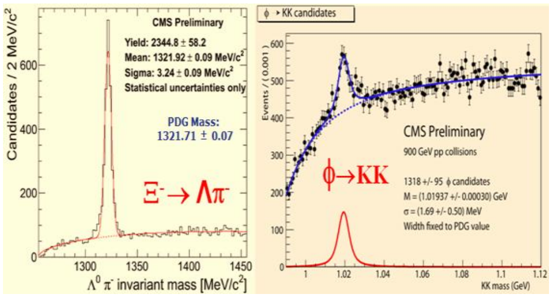

Fig. 4. Invariant mass distributions for (a): $\Xi^-\rightarrow\Lambda^0\pi^-$decays; (b): $\phi(1020)\rightarrow K^+K^-$ decays.

Beam spot and primary vertices are reconstructed by the tracker system with high efficiency and resolution. The performance of the tracker is demonstrated by studying long lived particles decaying to charged hadrons off the primary vertex After the magnet was switched on, $K^0_S\rightarrow\pi^+\pi^-$ and $\Lambda^0\rightarrow p\pi^-$ invariant mass peaks were reconstructed with a mass scale correct to <0.1% and good agreement in resolution for data and simulation, confirming that the magnetic field and the material budget are modeled accurately. These particles are long lived and create a secondary vertex detached from the collision primary vertex.

We used identified long lived resonances, like K^0_S candidates, combined with a charged track from the primary vertex to look for other resonances such as $K^*(891)\rightarrow K^0_S\,\pi^-$. The mass reconstructed is 888 ± 3 MeV, consistent with the PDG value.

Ξ^- resonance was reconstructed through its decay to $\Lambda^0\pi^-$ (Fig. 4a) and the search for $\Phi(1020)\rightarrow K^+K^-$

(Fig. 4b) exploited the possibility to identify kaons at low p_T by measuring dE/dx in the silicon layers. All resonances masses observed are in agreement with the values listed in the PDG, (see also Fig. 3b).

CMS is using the particle flow method to combine information from different detectors. The method shows an improved performance for photons, charged and neutral hadrons, jets, MET, for energy resolution and particle identification.

In CMS jets can be reconstructed with three methods: using calorimeters only, using calorimeters with track corrections, using the particle flow. These methods are being studied and compared to simulation and are showing nice agreement. The distributions of the number of jet constituents in di-jet events match the simulation expectations.

A three jets event is shown in Fig. 5.

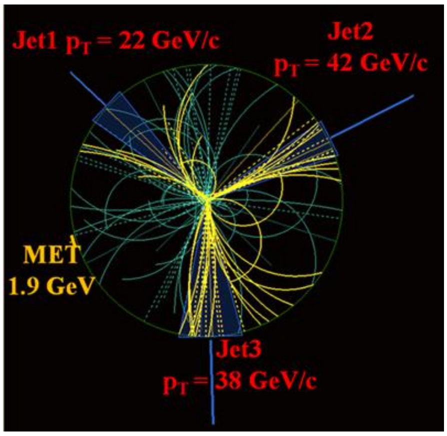

Fig. 5. A display of a three jets event.

The tracker is also used to tag bottom jets. All basic b-tagging variables are well described by simulation. A two b-jets candidate event is shown in Fig.6.

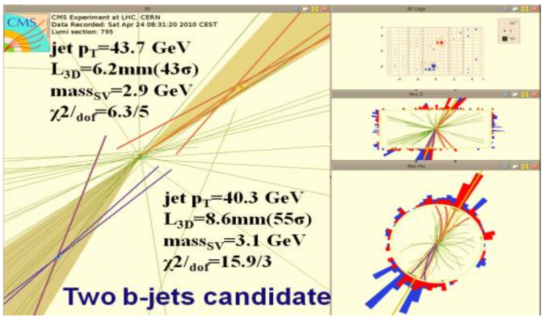

Fig. 6. A two b-jets candidate event.

Anomalous noise in ECAL and HCAL was causing high MET values. A very efficient cleaning procedure has been introduced to reduce those tails.

5. First Physics Results and Physic Program

Measurements of particle yields and kinematical distributions are an essential first step in exploring particle collisions at a new energy regime.

The study of charged hadrons spectra is important since it provides measurement of basic quantities to tune the soft particle production (not calculable from first principles) models and the background of more exclusive channels. We have started focusing on a series of measurements mainly regarding QCD physics at low momentum transfer.

The good understanding of the detector performance allowed a fast publication of the first CMS physics measurement from collision data: the inclusive charged-hadrons transverse momentum and pseudorapidity distributions in p-p minimum bias events [5, 6]. The results at 900 GeV are in agreement with previous measurements, confirming the expectation of near equal hadron production in p-pbar and p-p collisions. We repeated the charged particle yields analysis at the new energy frontiers available at LHC: 2.36 TeV [5] and at 7 TeV [6].

The Bose-Einstein correlation is a constructive interference phenomenon which enhances the probability to emit pairs of identical bosons with a low relative momentum. We published a first measurement for charged hadrons at $\sqrt{s}$=0.9 and 2.36 TeV [7].

Everything other than the hard scattering process in a collision is referred as the underlying event (soft interactions among beam partons and hadronization of non-interacting beam partons).

Soft hadronic interactions, minimum bias events, are the most common events. The measurement of their properties is top priority in order to study reconstruction efficiency and understand background contribution to physics studies. Our paper on underlying events is in process to be submitted for publication.

All these measurements constitute a valuable input to improve the Monte Carlo description of CMS data, for precision Standard Model (SM) measurements and searches for new physics.

We are improving our understanding of physics objects, we are studying the jet energy scale from W → jet jet events and started an extensive use of b-tagging. We will understand and measure the background to SUSY and Higgs searches and start looking for possible extraordinary signatures, i.e. Z', W' resonances. With larger integrated luminosity we will extend limits, explore large part of SUSY and start searches for new resonances at about a few TeV. With luminosity in the 1000 pb^{-1} range we will enter the Higgs discovery era.

Leptons and photons play a crucial role at LHC in several fields. They are essential in Higgs decay channels, they can be signature of the decay of new heavy bosons, they play a role in SUSY and are, of course, central in the reconstruction of electroweak and QCD processes. CMS, featuring a finely grained, high resolution e.m. calorimeter and excellent muon tracking performances, is well equipped for the task of measuring these particles with high resolution.

No new physics discover will be possible before the rediscover of SM that can be used as the ultimate detector commissioning tool. In the roadmap towards discoveries with leptons as a function of increasing luminosity, we should first measure heavy quarks resonances as J/Ψ, and Y that are available with just a few pb^{-1} of integrated luminosity.

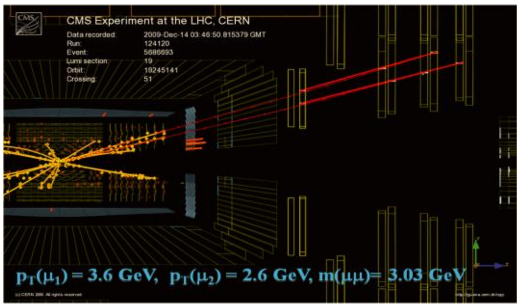

Fig. 7. Event display of a $J/\Psi \rightarrow \mu^+\mu^-$ candidate event.

Heavy quarks are copiously produced at LHC offering new opportunities to improve our understanding of flavor physics. Quarkonia studies play an important role in early data analysis and can be used to study trigger and reconstruction efficiency and detector calibration. The production cross section for J/Ψ, and Y are expected to be the first physics results.

Already in the CMS initial dataset, muon and electron pair events have been identified (see Fig. 7, 8) and J/Ψ and Y heavy resonances have been observed.

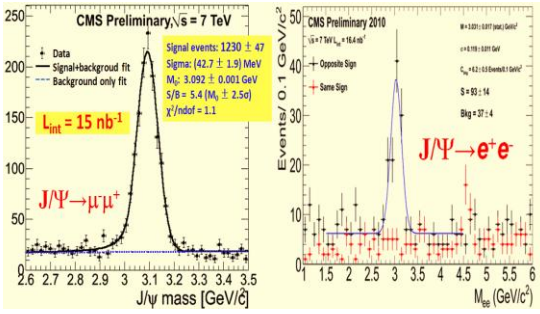

Fig. 8. First distributions for (a): $J/\Psi \rightarrow \mu^+\mu^-$ and (b) $J/\Psi \rightarrow e^+e^-$, using a preliminary and loose selection criteria.

The understanding of SM processes is crucial in the early searches for new physics therefore a considerable effort is invested to measure them precisely. Starting at low integrated luminosity such as 10-20 pb^{-1} and up to several 100 pb^{-1} we will measure SM, recording many di-leptons, di-jets, W, Z and top quark events.

We should establish important SM reference signals like the Z peak (order of 10 pb^{-1}) and W cross-section measurements.

First Z and W candidate events have been observed. For the channel $W^{\pm} \rightarrow \mu^{\pm}\nu$ we have 57 candidate events with M_T > 50 GeV in 16 nb^{-1} of data at 7 TeV while for the channel $W^{\pm} \rightarrow e^{\pm}\nu$ we have 40 candidates with M_T > 50 GeV in 12.6 nb^{-1} of data, (see Fig. 9 top row). For the channel $Z^0 \rightarrow \mu^+\mu^-$ and $Z^0 \rightarrow e^+e^-$ we have 5 candidate events each in 16 nb^{-1} of data at 7 TeV, (Fig. 9 bottom row).

These SM measurements, at the beginning of the data taking, can be used for a detailed understanding of instrumental effects, detector performance, optimization of reconstruction algorithms, to tune Monte Carlo detector simulation, to understand the underlying events and the MET resolution.

The production of Z boson is foreseen to be used to estimate lepton reconstruction efficiencies and trigger efficiency using a tag and probe method. This is done by selecting events with a lepton satisfying very stringent cuts (tag lepton) and then looking for a second lepton in the event which is consistent with originating from Z decay and passing the set of cuts for which one wants to determine the efficiency (probe lepton). W and Z production have several advantages: the cross section is large, of the order of nb, they have charged leptons in the final state which can be triggered on and their decay properties have been measured at previous accelerators to high precision. In Z events the background can be estimated from off resonance regions in the di-lepton invariant mass spectrum (side bands). Since theoretical calculations of the cross section are very precise (1%) one can turn this measurement into a luminosity measurement.

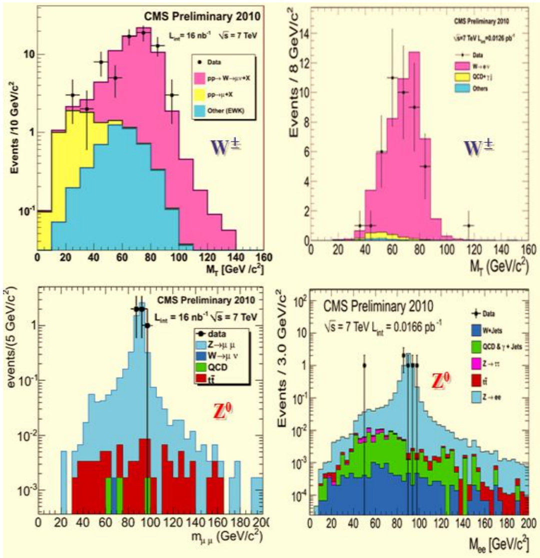

Fig. 9. Top row: searching for $W^{\pm}$ decays into leptons. Transverse mass distributions for (a) $\mu^{\pm}\nu$ and (b) $e^{\pm}\nu$ events. Bottom row: searching for Z^0 decays into two charged leptons. Invariant mass distributions for (c) $\mu^+\mu^-$ and (d) e^+e^- candidates.

We should start looking for Drell-Yan spectrum beyond $M_{lepton\ lepton} > 700$ GeV^2.

One of the most promising signals for new physics in the first data are high mass lepton pairs. If these particles have SM like couplings to leptons and quarks then one expects sizable production cross section and BR to e^+e^- and $\mu^+\mu^-$ resulting in very clean signatures above a low and well defined Drell-Yan continuum background.

Extending the knowledge beyond the Z boson reach relies on Monte Carlo extrapolation. Good understanding of the Drell-Yan spectrum from data will be a key check-point on the roadmap to discoveries.

The t-tbar production cross section at NLO is about a factor 100 higher at LHC compared to Tevatron. LHC will be therefore a top quark factory and should allow to study the properties of top in great details: not only mass and cross section but also BR, coupling and rare decays. Final states of top pair events are determined by the fact that the decays are almost exclusively into W and a b-quark and by the branching fraction of the W boson. The b-tagging performance can be studied in these events.

If SUSY exists at the electroweak scale should be discovered at LHC but first we will have to overcome MET challenges.

A key question in particle physics is the origin of electroweak symmetry breaking.

The most elegant explanation within the SM is a Higgs field with at least one scalar particle: the Higgs Boson. At high luminosity, of the order of a few fb^{-1}, we will start to hunt for the Higgs but the potential of discovering at relatively early days of LHC operation strongly depends on its mass. As the luminosity starts reaching a few hundred pb^{-1} we will reach 150-160 GeV sensitivity, comparable to the Tevatron result.

6. Conclusions

This year saw the final achievement of almost 20 years of development and building of CMS. All subdetectors are operational and close to their design performance specifications.

The first physics analyses are only preparations for the physics goals for which CMS has been designed, but CMS has shown that can deliver high quality data, and is more than ready for discoveries, and looking forward to the next step in energy from LHC in 2013 and in luminosity.

References

[1] L. Evans and P. Bryant editors, JINST 3 (2008) S08001.

[2] R. Adolphi *et al.* [CMS Collaboration], JINST 3 (2008) S08004.

[3] [CMS Collaboration], Nucl. Part. Phys. 34 (2007) 995.

[4] V. Khachatryan *et al.* [CMS Collaboration], Phys. Lett. B 692 (2010) 83.

[5] V. Khachatryan *et al.* [CMS Collaboration], JHEP 1002 (2010) 041.

[6] V. Khachatryan *et al.* [CMS Collaboration], Phys. Rev. Lett. 105 (2010) 022002.

[7] V. Khachatryan *et al.* [CMS Collaboration], Phys. Rev. Lett. 105 (2010) 032001.

[8] S. Chatrchyan *et al.* [CMS Collaboration], JINST 5 (2010) .