CMS detector performance

Snoek, H

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Hella Snoek*
University of Zurich, Physik-Institut, Winterthurerstr. 190, 8057 Zurich, Switzerland (On behalf of the CMS collaboration)
E-mail: `hella.snoek@cern.ch`

The performance of the CMS detector is presented with special attention for B-physics. The reconstruction of charged particles heavily depends on the tracker detector and is the key element to the reconstruction of primary and secondary vertices that are used for the identification of the b-hadron decays. The distribution of the track impact parameters are compared with the prediction of Monte Carlo simulation. The performance of vertex reconstruction and *b*-quark identification algorithms as directly derived from data are shown. Special attention is given to the reconstruction and identification of muons as they are crucial in the reconstruction of the golden *B* decay modes and the searches beyond the standard model. The muon detection and reconstruction efficiency determined with the proton-proton collisions are described. The performance of the trigger, necessary to identify the events of interest, is discussed.

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*Speaker.

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1. The CMS experiment

The CMS experiment is one of the four large experiments at the CERN Large Hadron Collider (LHC). The CMS experiment uses a right-handed coordinate system with the origin located at the nominal interaction point (IP). The x axis is pointing to the center of the LHC ring, the y axis is perpendicular to the LHC plane and points upwards. The z axis points in the direction along the direction of beam 1. The transverse direction is transverse to the beam-axis while the longitudinal direction is along the beam-axis. CMS is a multipurpose experiment described in detail in [1]. In these proceedings we discuss in more detail the elements that are important for the online selection, reconstruction and identification of b-hadrons. The LHC has delivered proton-proton collisions since the fall of 2009 at increasing center-of-mass energies. From March to December 2010 LHC has delivered ~ 47 pb^{-1}, at a center of mass energy of $\sqrt{s} = 7$ TeV, of which ~ 43 pb^{-1} have been recorded by the CMS experiment. The delivered and recorded luminosity in 2010 is presented in Fig. 1. The operational fraction of all the CMS sub-detector systems is in this run well above 98%.

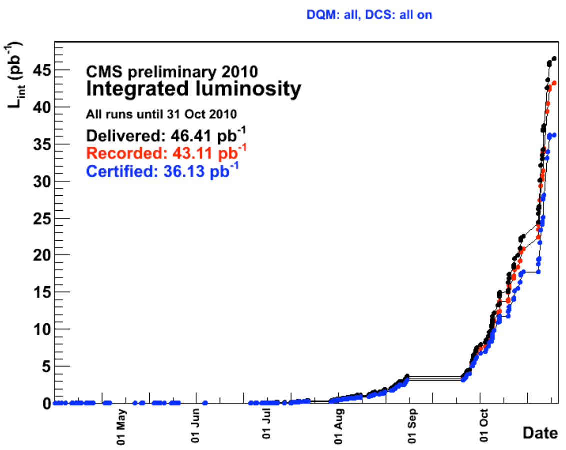

Figure 1: Integrated delivered and recorded luminosity versus time for the 2010 run.

2. Tracking and vertexing performance

The CMS tracker is composed of silicon pixel and strip detectors. The silicon-pixel detector has 3 barrel and 2 endcap layers (on each side) and 66M readout channels in ~ 2 m^2 of active material. The most inner (outer) layer is at 4.3 (10.2) cm from the nominal interaction point. The silicon-strip detector has 10-12 layers in both the barrel and the endcap region and spans a radial region between 20 and 116 cm. There are 9.3M readout channels in an active surface of almost 200 m^2. All modules are aligned up to ~ 10 μm accuracy [2].

Tracks are built using a multiple-iteration algorithm that utilizes the hits recorded by the silicon tracker [3] and are used to reconstruct primary vertices (PVs). Splitting methods have been used to measure the PV resolution and reconstruction efficiency [4]. The left plot in Fig. 2 shows the reconstruction efficiency as a function of the number of tracks associated to the PV. The reconstruction efficiency is almost 100% for PVs with more than two associated charged tracks. The resolution of the reconstructed PV, as a function of the number of tracks, is shown in the middle and

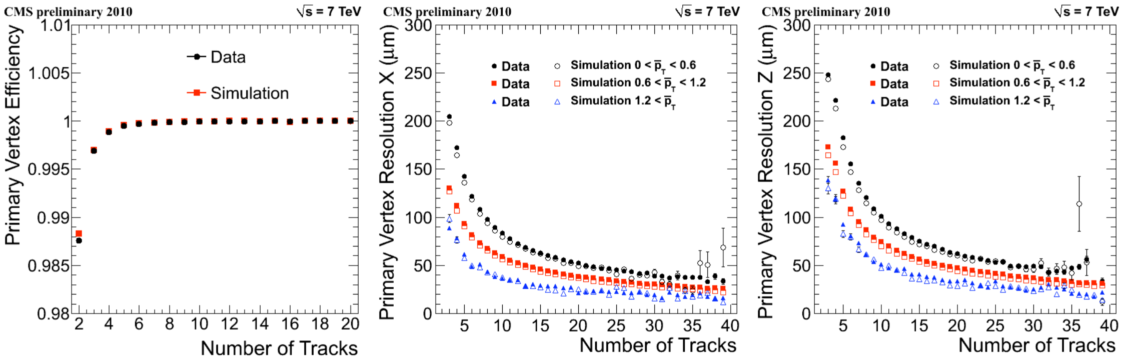

Figure 2: Left: The primary vertex reconstruction efficiency as a function of the number of associated tracks. Middle and right: The primary vertex resolution in x and z as a function of the number of associated tracks for different average transverse momentum $\overline{p_T}$. The Pythia8 Tune1 [5] is used in the simulation.

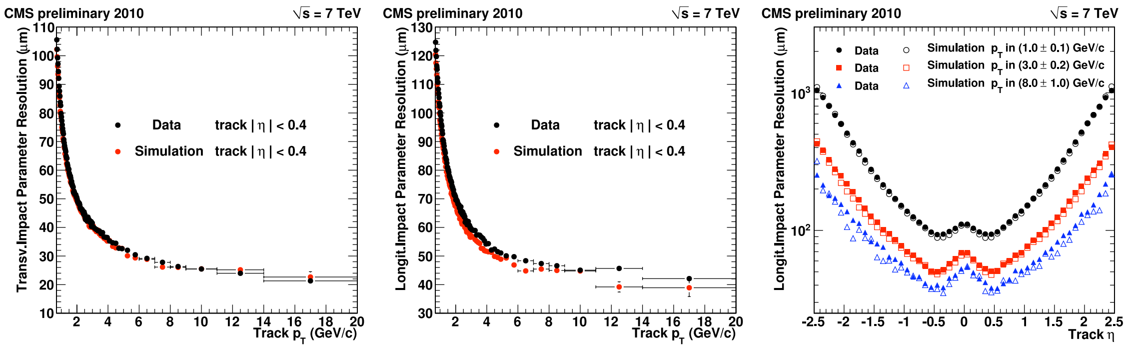

Figure 3: Left and middle: The measured resolution of the track transverse and longitudinal impact parameter as a function of track p_T. Right: The measured longitudinal impact parameter as a function of track-η.

right plot in Fig. 2. For a PV with more than 10 tracks of average $p_T > 1.2$ GeV/c, the reconstructed resolution is close to 20 μm.

The impact parameter (IP) of a track with respect to the primary vertex is an important ingredient for the identification of b-hadrons. The impact parameter resolution is measured by removing tracks that belong to the PV and re-reconstructing both the removed track and the PV [4]. The resulting measured resolution is shown in Fig. 3. The measured resolution in data agrees very well with the simulation. The transverse (longitudinal) resolution is ~ 30 (~ 60) μm for a track with $p_T \sim 6$ GeV/c. The longitudinal IP resolution shows a strong dependence in η. For larger η the resolution deteriorates because of the increasing passive material. At about $|\eta| = 0.5$ the longitudinal IP resolution is optimal because of charge sharing in the pixel detector, given by inclined tracks, resulting in a better hit resolution.

The efficiencies for hadron-track reconstruction are found to be consistent between data and simulation and have an uncertainty of about 4% [6]. The relative momentum resolution is measured using the J/ψ-mass line-shape [7] and is presented in Fig. 4.

Particle identification is possible up to a momentum of roughly 1 GeV/c using the energy loss in the silicon-strip tracker. The left plot in Fig. 5 shows the observed energy loss as a function of the

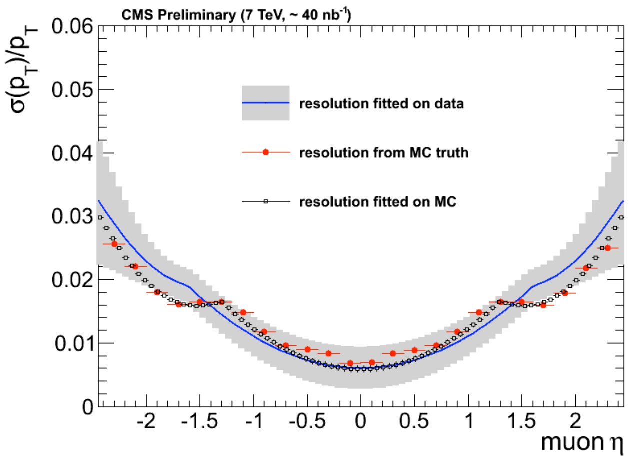

Figure 4: Measured resolution on the track transverse momentum. The grey band shows the error on the fitted function to the observed data.

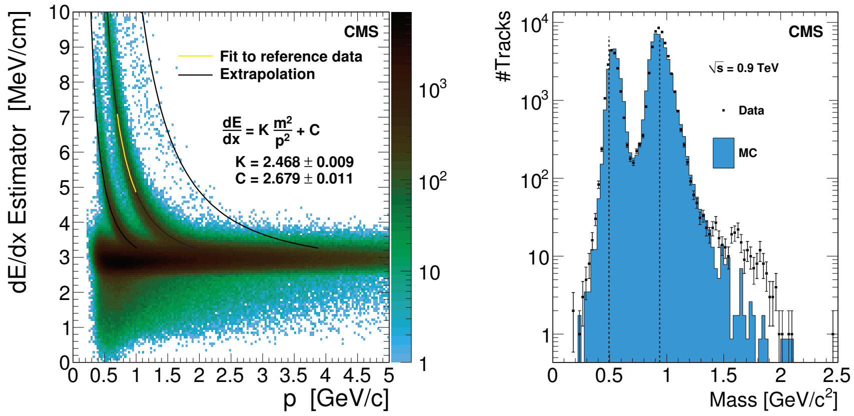

Figure 5: Left: The measured dE/dx distribution versus the momentum of the track. Right: The reconstructed mass distribution using the momentum and dE/dx information of the tracks with $p < 0.2$ GeV/c [8].

track momentum, projected are the fitted lines of the kaon, proton and deuteron mass hypothesis. The right plot in Fig. 5 shows the incidence of the fitted mass hypothesis for data and simulations. Data and simulation have excellent agreement with the exception of the deuterons which are not produced in the simulation.

3. Reconstruction of muons

The CMS muon detector consists of three sub-detectors. The Drift Tube (DT) is a 4-layer barrel shaped gaseous detector of about 13 meters length. It consists of about 250 individual chambers and is integrated with the magnet return yoke. The Cathode Strip Chambers (CSC) has 468 chambers of gaseous detectors and covers the endcap region, again integrated with the magnet return yoke. Resistive Plate Chambers (RPCs) are integrated in both the DT and CSC detector volumes and provide excellent time resolution (~ 2 ns). The muon system is completely redundant.

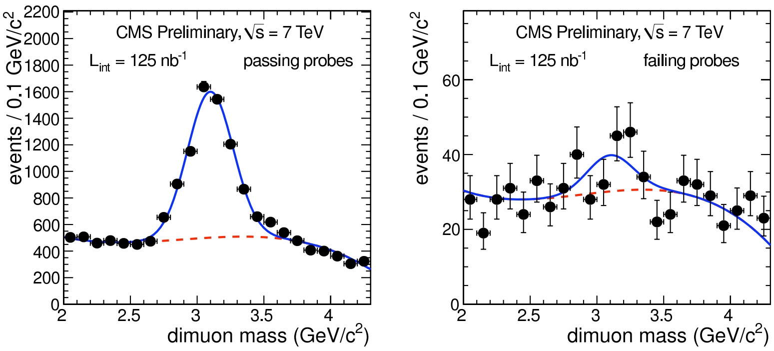

Figure 6: Distributions of dimuon invariant mass for tag muons paired with passing (left) and failing (right) probes. The momentum of the muons is measured only with the muon detectors.

Region	Data Eff. (%)	Sim Eff. (%)	Data/Sim
$0.0 \leq \|\eta\| < 1.1$	$100.0^{+0.0}_{-0.3}$	$100.0^{+0.0}_{-0.1}$	$1.000^{+0.001}_{-0.003}$
$1.1 \leq \|\eta\| < 1.6$	$99.2^{+0.8}_{-1.0}$	$99.8^{+0.1}_{-0.1}$	$0.994^{+0.009}_{-0.010}$
$1.6 \leq \|\eta\| < 2.1$	$97.6^{+0.9}_{-1.0}$	$99.3^{+0.1}_{-0.1}$	$0.983^{+0.009}_{-0.010}$
$2.1 \leq \|\eta\| < 2.4$	$98.5^{+1.5}_{-1.6}$	$97.6^{+0.2}_{-0.2}$	$1.010^{+0.015}_{-0.016}$
Combined	$98.8^{+0.5}_{-0.5}$	$99.2^{+0.1}_{-0.1}$	$0.996^{+0.005}_{-0.005}$

Table 1: Measured tracking efficiency values from tag-and-probe on data and simulation for different pseudorapidity ranges [6].

The reconstruction of muons in the detector is based on the information from both the silicon tracker and the muon detectors. Seeding of muon tracks is done in two directions [9]. So called "Tracker Muons" are tracks reconstructed in the silicon tracker that are matched with reconstructed segments in the muon detector. In the other direction, "Global Muons" are tracks reconstructed in the muon detector which are connected to build tracks in the silicon tracker. The measurement of the momentum of the reconstructed muon can be performed in both the silicon tracker as in the muon detector.

The muon identification efficiency is measured with a tag-and-probe method using the J/ψ resonance [6]. Figure 6 shows the dimuon mass of the tracks that pass (left) and fail (right) the test. The identification efficiency is calculated for different pseudorapidity ranges and summarized in Tab. 1. The identification efficiency is close to 100% and within the expectations of the simulation.

The misidentification of the "Global Muons" due to hadronic punch-through in the muon systems is determined by studying $K^0_s \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$ and $\phi \rightarrow K^+K^-$ decays [9]. The resulting misidentification probabilities are presented in Fig. 7. They are less than 2‰ and within the expectations.

4. The muon trigger

The CMS trigger is structured in two levels. Level 1 (L1) is a programmable hardware trigger which uses mainly the information from the muon systems and the calorimeters. The decision time has a maximum latency of 3.2 μs, and reduces the event rate to 100 kHz. The second level is the

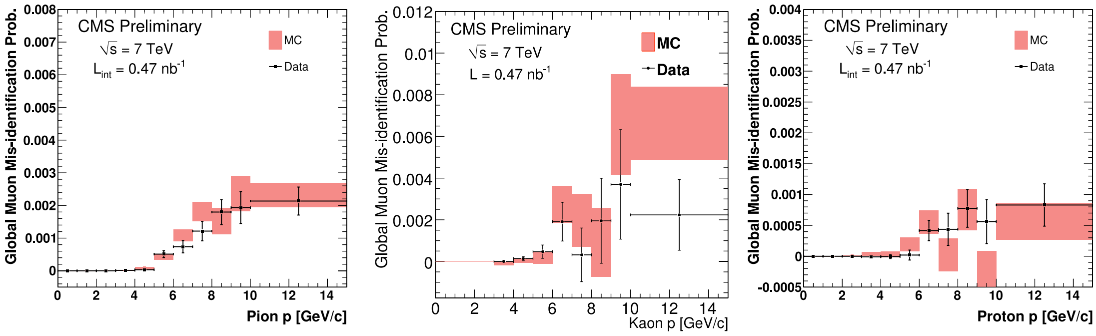

Figure 7: The fraction of pions (left), kaons (middle) and protons (right) that are mis-identified as global muons as a function of momentum. The uncertainties that are indicated by error bars (data) and the grey boxes (simulation) are statistical only.

High Level Trigger (HLT) which uses a large computing farm and reconstructs physics objects. The computing time per event averages to about 70 ms. It reduces the event rate to between 100 and 300 Hz.

The L1 muon trigger is based on building track segments in the three muon systems (DT, CSC and RPC). Timing information is used to match the track segments to the correct bunch crossing. The HLT muon trigger refits the L1 segment objects using the full granularity of the detector. At this stage a more precise momentum cut on the reconstructed muon is possible. After this, in the regions which are of interest and compatible with the PV, hits are reconstructed from pixel seeds in the tracker volume and full tracks are build.

During the 2010 run, CMS has used different muon trigger selections based on both single and double muon criteria. The muon trigger selections are easily adaptable to the different luminosity phases of the LHC start-up. A single muon trigger selection with a very low transverse momentum cut of about 3 GeV/c, was used at the start of the 2010 run. This allowed a measurement of inclusive beauty production in the very low momentum range [10].

The CMS experiment has recorded, in the 2010 run, more than 2M of $J/\psi \to \mu\mu$ and more than 10k of $Z \to \mu\mu$ candidates.

5. *b*-Quark identification methods

At the LHC the b-hadrons are primarily produced in jets. Their relative long lifetimes, of on average around 1.5 ps, together with the Lorentz boost result in displaced decay vertices that characterizes them. CMS has developed different strategies to identify *b*-quarks. Inclusive *b* production searches have been performed using jet algorithms using secondary vertex identification methods [11]. Angular correlation studies of *b*-jets have used techniques that reconstruct the secondary vertex with a high angular separation power [12]. Exclusive reconstruction methods reconstruct the four-momentum of *B*-mesons [13, 14].

6. Summary

The CMS detector is in an excellent shape to perform B-physics. The detector performance

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in tracking and vertexing, as well as muon identification and reconstruction efficiencies have been determined with data-driven methods. All measured performance quantities are well within the expectations from the simulation. The PV reconstruction efficiency is close to 100% for PVs with more than two associated charged tracks with a resolution close to 20 μm for PVs with more than 10 charged tracks and average $p_T > 1.2$ GeV/c. The resolution of the impact parameter is about 30 μm (60 μm) in the transverse (longitudinal) direction for a track with p_T 6 GeV/c. The muon identification efficiency is close to 100% with a misidentification probability of less than 2‰ for "Global Muons". The open muon trigger in 2010 allowed for b-hadron and J/ψ cross section measurements that extended in the low momentum range. Several powerful experimental techniques exist, and are being exploited, that are adopted to inclusive b-quark identification and exclusive b-hadron decays.

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