Towards a measurement of the inclusive $W \to \mu \nu$ and $Z \to \mu^+ \mu^-$ cross sections in pp collisions at $\sqrt{s} = 10$ TeV

The CMS Collaboration

Abstract

We discuss and develop methods for the measurement of the cross sections $pp \to W + X \to \mu \nu + X$ and $pp \to Z + X \to \mu^+ \mu^- + X$ with the CMS detector at the LHC, at a center-of-mass energy of 10 TeV. We assume an integrated luminosity of 10 pb$^{-1}$. For the $Z$ measurement, both the event yield and the average trigger, isolation, and reconstruction efficiencies can be extracted simultaneously from fits of the invariant mass spectrum. For the $W$ measurement, we update results shown in the 2007/002 Physics Analysis Summary note.
1 Selection of W and Z samples

We reconstruct $Z \rightarrow \mu^+\mu^-$ decays from pairs of reconstructed muons with opposite charge. Each muon track must have hits in both the tracker system and the muon chambers, and satisfy a requirement on the transverse momentum: $p_T > 20\text{ GeV}/c$. At least one of the muons must be compatible with a High Level Trigger muon track that triggered the event. A simple and robust single non-isolated muon trigger is applied. In order to select isolated muons, we require the $p_T$ sum of all tracks in a $\Delta R(=\sqrt{\Delta\eta^2 + (\Delta\phi)^2})$ cone of 0.3 around the muon direction to be less than $3\text{ GeV}/c$. The invariant mass of the $\mu^+\mu^-$ pair must be greater than $20\text{ GeV}/c^2$. Figure 1 shows the invariant mass distribution of dimuon candidates from Drell-Yan and background processes after the selection requirements. The distributions are normalized to an integrated luminosity of $10\text{ pb}^{-1}$.

![Invariant mass distribution of dimuon candidates](image)

Figure 1: Invariant mass of the selected $Z \rightarrow \mu^+\mu^-$ candidates in CMS for signal and background processes, and assuming an integrated luminosity of $10\text{ pb}^{-1}$. The predicted shapes are obtained from the leading order generator program PYTHIA, interfaced with a detailed simulation of the CMS detector.

Candidates for $W \rightarrow \mu\nu$ events must have a reconstructed muon with $p_T > 25\text{ GeV}$ and $|\eta| < 2$ and be isolated. The isolation criteria for $W \rightarrow \mu\nu$ requires the $p_T$ sum of all tracks in a $\Delta R$ cone of 0.3 around the muon direction, normalized to the muon $p_T$, to be less than 0.09.

Figure 2 shows the reconstructed transverse mass, $M_T$, of the $W$ system after $W \rightarrow \mu\nu$ selection cuts. The $W$ system is built in the plane transverse to the beam by combining the measured muon and the missing transverse energy in the event. The latter is interpreted as a measurement of the transverse momentum of the undetected neutrino. The figure shows that the QCD background is largely suppressed with the cut $M_T > 50\text{ GeV}$.

To estimate the amount of QCD background left after selection, several data-driven methods were devised for that purpose. Determination of reconstruction, isolation, and trigger efficiencies relies on tag-and-probe methods with high purity $Z \rightarrow \mu^+\mu^-$ samples. More details about these methods can be found in ref. [1].
2 $Z \rightarrow \mu^+ \mu^-$ cross section measurement

Reconstruction, isolation and trigger efficiencies can be measured from data using tag-and-probe methods as shown in a previous note [1]. However, for an early measurement, when the available statistics of tag-probe pairs may not be sufficient to perform a detailed study as a function of transverse momentum $p_T$ and pseudorapidity $\eta$, an alternative method can be applied.

We consider additional independent samples of $Z \rightarrow \mu^+ \mu^-$ candidates, which are selected with looser requirements on the muons. The yields for these samples can be related to the average reconstruction, isolation, and trigger efficiencies. We assume negligible correlations among the efficiency terms of the two muons. The residual correlations due to kinematic correlations between the two muons have been estimated to be at the per mill level. However, non-negligible correlations can still originate from global effects such as the level of pile-up, the level of noise in the detectors, or the quality of vertex reconstruction. The $Z \rightarrow \mu^+ \mu^-$ samples considered in the analysis are the following:

1. $Z^{2\text{HLLT}}_{\mu\mu}$ sample. Defined by the standard $Z$ selection described above; both muons are found to satisfy the trigger requirements.

2. $Z^{1\text{HLLT}}_{\mu\mu}$ sample. Defined by the standard $Z$ selection described above but with only one muon satisfying the trigger requirements.

3. $Z_{\mu\mu}$ sample. Defined by only requiring that one of the muon tracks has hits in the muon chambers. The other muon track must have hits in both the tracker and muon systems and must satisfy the trigger requirements.
4. $Z_{\mu\mu}$ sample. Defined by only requiring that one of the muon tracks has hits in the tracker system. The other muon track must have hits in both the tracker and muon systems and must satisfy the trigger requirements.

5. $Z_{\mu\mu}^{\text{notiso}}$ sample. Defined by requiring that at least one of the muons does not satisfy the isolation requirement. At least one of the muons must satisfy the trigger requirements.

The signal yield and the relevant efficiencies are determined by a simultaneous chi-square fit to the invariant mass distributions of the $Z \rightarrow \mu^+\mu^-$ samples in the mass region $[60 - 120]$ GeV/c$^2$. We use a signal shape description taken from the invariant mass distribution of the $Z \rightarrow \mu^+\mu^-$ candidates surviving the standard selection, since the background is negligible. We use phenomenological descriptions of the background shapes in the $Z_{\mu\mu}$, $Z_{\mu\mu}^{\text{notiso}}$, and $Z_{\mu\mu}^{\text{notiso}}$ samples, which are taken from sidebands.

The analysis strategy has been tested on samples of fake data built from detailed simulations of the CMS detector response to signal and background processes. All the simulations assume a perfect knowledge of detector conditions. The statistics of the samples corresponds to different luminosities scenarios: 5, 10, 45, and 133 pb$^{-1}$. Figure 3 illustrates the stability of the cross section determination for different luminosity scenarios.

![Figure 3](image)

Figure 3: Fitted $Z \rightarrow \mu^+\mu^-$ cross section in fake data samples with a statistics corresponding to different luminosity scenarios. The simulations assume a perfect knowledge of detector conditions. The results are normalized to the cross section determination in the 133 pb$^{-1}$ sample. Only the statistical errors are shown.

References

[1] The CMS Collaboration, Towards a measurement of the inclusive $W \rightarrow \mu\nu$ and $Z \rightarrow \mu^+\mu^-$ cross sections in pp collisions at $\sqrt{s} = 14$ TeV, CMS PAS 2007/002.