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CMS CR 2007/031

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# CMS Conference Report

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June 15, 2007

## Studies of high-mass Drell-Yan dimuon events in the CMS experiment

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### Abstract

The potential of the Compact Muon Solenoid (CMS) experiment to measure Drell-Yan muon pairs is discussed. Muon pairs can be measured in CMS with high precision up to very high invariant masses. The systematic errors are considered. The potential to carry out precise measurements of the forward-backward asymmetry is discussed.

Presented at Hadron Collider Physics Symposium,  
La Biodola, Isola d'Elba, Italy, 20-26 May 2007

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The Standard Model (SM) has been tested by the experiments at LEP, SLC and Tevatron with high accuracy. Extending these tests at the new energy scale available with LHC is one of the priority tasks for particle physics. The results presented here are based on note [1] (see also [2]), which extends the studies for the LHC SM workshop (see [3] and references therein), using large samples of simulated events and the CMS full detector simulation and reconstruction. In the Standard Model, the production of lepton pairs in hadron-hadron collisions, the Drell-Yan (DY) process, is described by  $s$ -channel exchange of photons or  $Z$  bosons. For measuring the mass dependence of Drell-Yan cross section one should know the detection efficiency, acceptance, resolution and total luminosity. Simulation of Drell-Yan events in proton-proton collisions at 14 TeV centre-of-mass energy is performed with PYTHIA 6.217 using the CTEQ5L parton distribution functions. To simulate the detector geometry, materials and particle propagation inside the detector, the GEANT4-based simulation of the CMS detector is used. The trigger simulation is based on the on-line reconstruction algorithms selecting single- and double-muon triggers. The total efficiency of triggering including reconstruction and trigger selection efficiency is 98 % at 1 TeV. The additional cuts on calorimeter and tracker isolation of muon tracks are not applied at High Level Trigger.

The off-line muon reconstruction algorithm is applied only to events which have passed trigger selection. At the off-line level two muons inside the CMS acceptance  $|\eta| \leq 2.4$  are required. The overall efficiency of the full reconstruction procedure taking into account trigger and off-line reconstruction inefficiency is between 97 % and 93 % for a mass range of 0.2 to 5 TeV/ $c^2$ , as shown in the upper plot of Figure 1. In the case of an ideal detector the mass resolution smearing for fully-reconstructed events is between 1.8 % and 6 % for the same mass range (see the lower plot of Figure 1). The effect of misalignment on the mass resolution varies from 1.1 % up to 2.3 depending on the level of misalignment at the  $Z$  and from 5 % up to 25 % for 3 TeV/ $c^2$  [4].

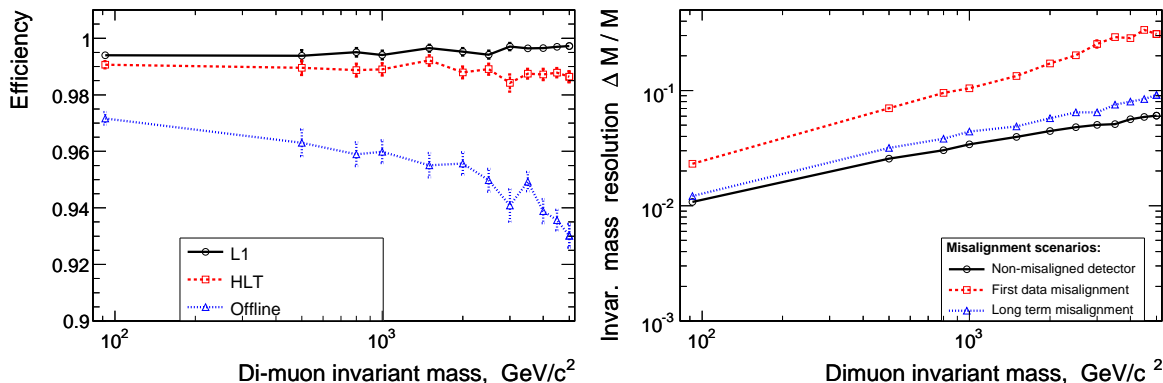


Figure 1: Left plot: dimuon reconstruction efficiency; Right plot: invariant mass resolution; both as a function of the invariant mass cut.

The backgrounds considered are vector boson pair production  $ZZ$ ,  $WZ$ ,  $WW$ ,  $t\bar{t}$  production etc. The simulation and pre-selection of background events is done with the same cuts as for the signal above. In the SM the expected leading-order cross section of these events is negligible in comparison with the Drell-Yan [1]. The  $\tau\bar{\tau}$  background (from  $\tau$  decaying to  $\mu$  and neutrinos) is 0.8 % at the  $Z$  pole and 0.7 % for masses above 1 TeV/ $c^2$ . The background from Drell-Yan production of  $q\bar{q}$  pairs (mostly semi-leptonic  $b$  or  $c$  decays) is 0.3 % at the  $Z$  pole without applying any isolation cuts and below 0.1 % for masses above 1 TeV/ $c^2$ . The other background sources are negligible. If the need arises they can be further suppressed by acoplanarity and isolation cuts in the tracker.

The statistical errors for 1, 10 and 100 fb<sup>-1</sup> runs and the systematic uncertainty due to detector effects and uncertainties in the theory are given in Table 1. One can see that the systematic uncertainty due to smearing of the reconstructed dimuon mass leads to modification of the cross section as a function of dimuon mass and does not exceed 2.9 % which is reached for a mass of 3 TeV/ $c^2$ . The misalignment does not affect the efficiency of dimuon reconstruction for any masses [1, 4]. Taking into account that the trigger efficiency changes from 98.5 % to 97 % for masses from 0.2 to 5 TeV/ $c^2$ , very conservatively we may assign half of this change, i.e., 0.75 %, as systematic uncertainty.

An important ingredient in the cross section measurement is the precise determination of the luminosity. A promising possibility is to go directly to the parton luminosity [5] by using the  $W^\pm$  ( $Z$ ) production of single (pair) leptons. New estimates show that in this way the systematic error on  $\sigma_{DY}^{high Q^2}$  relative to  $\sigma_Z$  can be reduced to  $\approx 5 - 12$  % [6].

Table 1: Relative errors of the Drell-Yan muon pairs cross section measurements in the fiducial volume.

$M_{\mu^+\mu^-}$ , $\text{TeV}/c^2$	Detector smearing	Statistical			Theor. Syst.
		$1 \text{ fb}^{-1}$	$10 \text{ fb}^{-1}$	$100 \text{ fb}^{-1}$	
$\geq 0.2$	$8 \cdot 10^{-4}$	0.025	0.008	0.0026	0.058
$\geq 0.5$	0.0014	0.11	0.035	0.011	0.037
$\geq 1.0$	0.0049	0.37	0.11	0.037	0.063
$\geq 2.0$	0.017		0.56	0.18	0.097
$\geq 3.0$	0.029			0.64	0.134

On the theory side we consider several sources of systematic uncertainties. The possible contributions from higher-order terms in the dimuon production cross section are taken into account by using a  $K$  factor of  $1.30 \pm 0.05$  as calculated with the program [7]. It is expected that the total value of additional NNLO contributions does not exceed 8%. The EW corrections change the cross section by 10-20% [3, 8]. The calculation [9] of the weak radiative corrections to the Drell-Yan processes due to additional heavy bosons contributions shows that these corrections are about 2.9% to 9.7% for mass region between  $0.2 \text{ TeV}/c^2$  and  $5 \text{ TeV}/c^2$ . The phenomenological origin of PDF gives an additional systematic error due to the PDF-dependence of the acceptance efficiency. The changes in the acceptance efficiency estimated by using the PDF sets CTEQ5L, CTEQ6L and MRST2001E are up to 0.5%. The ambiguity in the acceptance efficiency due to internal PDF uncertainties is larger, but less than 1.4% for any mass region. The experimental measurements of Drell-Yan cross section allow to fix these theoretical uncertainties.

The summary of the estimated systematic uncertainties as a function of the dilepton mass is given in Figure 2. Current uncertainties from theory are larger than the experimental uncertainties. The statistical errors will dominate for invariant masses larger than  $2 \text{ TeV}/c^2$  even for  $100 \text{ fb}^{-1}$ .

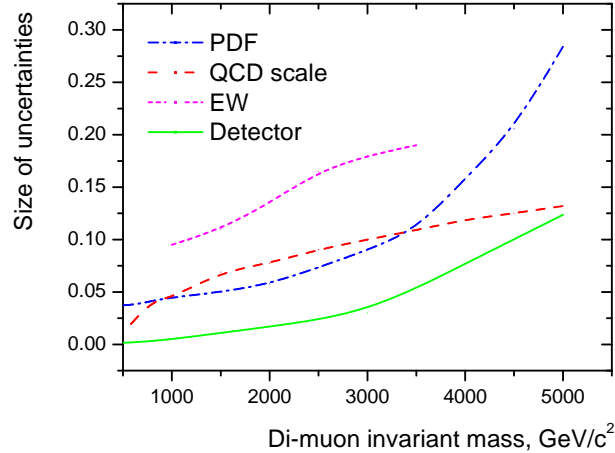


Figure 2: Size of the EW corrections and the cross section uncertainties from PDFs, hard process scale and detector understanding as a function of the dimuon invariant mass cut.

The parton cross section in the lepton-pair centre-of-mass system has the form:

$$\frac{1}{\sigma} \frac{d\sigma}{d(\cos \theta^*)} = \frac{3}{2(3+b)} (1 + b \cos^2 \theta^*) + A_{FB} \cos \theta^*$$

where  $\cos \theta^*$  is angle between the outgoing negative lepton and quark in the dilepton rest frame. To measure the forward-backward asymmetry  $A_{FB}$  we need the original quark and anti-quark directions of the initiating partons, but these are not known in the case of  $pp$  experiments, where the initial state is symmetric. In Ref. [10, 11] it is shown that it is possible to approximate the quark direction with the boost direction of the dimuon system with respect to the beam axis. This is due to the fact that the valence quarks have on average larger momentum than the sea anti-quarks, and therefore the dimuon boost direction approximates the quark direction. The most unambiguous tagging occurs for large dimuon rapidity.

Without correction for mistags and acceptance the apparent  $A_{FB}$  value will be twice smaller than the original

asymmetry ( $\approx 0.6$  for Drell-Yan events). However, using multi-dimensional fits [12] or reweighting techniques depending on the mistag and acceptance which are under development, we can measure the original asymmetry.

The accuracy of asymmetry measurements depends on:

- statistical uncertainty which grows with rising the mass cut value, since the number of events for a given integrated luminosity  $\int L dt = 100 \text{ fb}^{-1}$  decreases with mass.
- systematic uncertainty from the variation of the mistag probabilities for various PDF sets, typically below 10%.

We expect the systematic uncertainty to dominate the statistical one for integrated luminosity of  $\int L dt = 100 \text{ fb}^{-1}$  and dimuon masses around  $500 \text{ GeV}/c^2$ , while the statistical one to be more important for dimuon mass cuts above  $1000 \text{ GeV}/c^2$ .

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