Measurement of the Drell-Yan cross section at 7 TeV

Norbert Neumeister

Department of Physics
Purdue University

on behalf of the CMS Collaboration
Outline

• Introduction and Motivation
• The CMS detector
• Analysis Strategy and Procedure
  • Event Selection
  • Background Estimation
  • Detector Resolution
  • Acceptance and Efficiencies
  • Systematic Uncertainties
• Results
  – $d\sigma/dM$
  – $d^2\sigma/dMdY$
• Summary
Motivation

• **Drell-Yan process**
  - Is an important Standard Model benchmark channel
  - Theoretical cross section calculated up to NNLO
    • allowing tests of perturbative QCD
  - Differential cross section $d\sigma/dM$ depends on parton density functions (PDFs)
    • can be used to constrain PDFs
  - Drell-Yan is an important background for searches for physics beyond the Standard Model

• **Measure the differential cross section** $(1/\sigma_Z)d\sigma/dM$
  • normalize differential cross sections to the cross section at the $Z$ peak
  • performed in muon and electron channel

• **Measure the double differential cross section** $(1/\sigma_Z)d^2\sigma/dMdY$
  • measurement directly usable to constraint PDFs
  • performed in muon channel $|Y| < 2.4$
The CMS Detector

CMS can detect leptons ($\mu$ and e) up to 2.4, 2.5 in pseudorapidity and, effectively, in di-lepton rapidity ($\gamma$)
Drell-Yan Event

CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

Muon $p_T= 67.3, 50.6$ GeV/c
Inv. mass $= 93.2$ GeV/c$^2$
Analysis Overview

• Full 2011 CMS dataset, containing $4.5 \text{ fb}^{-1}$ of proton collision data is used

• Drell-Yan samples are produced with POWHEG MC generator
  • Rescaled to NNLO cross section from FEWZ

• Analysis procedure is the same for muon and electron channel
  – Event selection
  – Subtraction of Backgrounds
  – Momentum scale and resolution correction
  – Acceptance and Efficiency correction using MC
  – Efficiency correction using data-driven methods
  – Correction for Final State Radiation (FSR) effects based on MC
  – Systematic uncertainty estimation
  – Normalization to $Z$ peak cross section
  – Comparison with theoretical predictions
Cross Section Measurement

• To measure the cross section per bin, we use the following formula:

\[
\sigma_{i,j} = \frac{N^u_{i,j}}{A_{i,j} \cdot \varepsilon_{i,j} \cdot C_{i,j} \cdot L_{\text{int}}}
\]

\[
R_i = \frac{1}{\sigma_z} \frac{d\sigma}{dM}
\]

• Note: the acceptance correction is not applied for the 2D measurement

• Binning

  • 1D: 40 mass bins (15-1500 GeV)
  • 2D: 6 mass slices
    • 20, 30, 60, 120, 200, 15000 GeV
  • \(|\gamma| < 2.4\)
  • 24 rapidity bins up to 200 GeV
  • 12 rapidity bins in 200-1500 GeV

We take advantage of the CMS detector’s capabilities to measure very low mass DY.
Event Selection

• **Muon channel:**
  • Un-prescaled double muon trigger with no isolation requirement on the level of HLT is used (online muon $p_T > 13, 8$ GeV)
  • 2 muons with opposite charge, $p_T > 14, 9$ GeV, $|\eta| < 2.4$
  • Muon track quality cuts
  • Relative combined particle-flow isolation with electrons and photons excluded
  • Select the highest vertex probability muon pair
    • cut on di-muon vertex probability and 3D angle to reject cosmics and muons not coming from the same collision/process

• **Electron channel:**
  • Un-prescaled di-electron trigger ($E_T > 8, 13$ GeV)
  • 2 particle-flow electrons, $E_T > 20, 10$ GeV, $|\eta|< 2.5$
    • Exclude ECAL gap
  • Apply electron ID cuts
  • Conversion rejection using vertexing method
    • No missing inner hits allowed
  • Particle-flow isolation
Background Estimation (I)

- **Muon channel:**
  - Low-mass region: QCD multi-jets
  - Peak region: Drell-Yan → \(\tau^+\tau^-\), \(W \rightarrow l + \nu\), dibosons
  - High-mass region: top pair production, dibosons
  - QCD background determination using the data-driven ABCD method
  - All other backgrounds are estimated from MC

- **Electron channel:**
  - Data-driven technique to estimate backgrounds
  - e-\(\mu\) method: Drell-Yan → \(\tau^+\tau^-\), \(t\bar{t}\), WW, single top
  - Fake rate: QCD, W+jets

Mass spectrum in the detector acceptance for data and MC events. The signal is normalized to the NNLO cross section.
Background Estimation (II)

Norbert Neumeister, Purdue University
Detector Resolution (I)

• The mass spectrum is corrected for resolution effects by using the response matrix unfolding technique
• The “true” spectrum is obtained by constructing the response matrix $T$ where:
  $N_{i}^{obs} = \sum_{k} T_{ik} N_{k}^{true}$
  – $T_{ik}$ is the probability that an event belonging in mass bin $k$ is reconstructed in mass bin $i$
  – $T_{ik}$ is extracted from MC simulation
  – The momentum scale correction, taking into account the effects of detector misalignment, is applied

• By inverting $T$, the corrected spectrum can be obtained
  • We use the technique of matrix inversion to unfold the spectrum
    $N_{i}^{true} = \sum_{k} (T_{ik})^{-1} N_{k}^{obs}$
  • FSR correction is performed as a separate step
Detector Resolution (II)

- The unfolding procedure corrects the effects of the detector resolution on the mass spectrum.

- Muons:
  - Response matrix is nearly diagonal
  - Off-diagonal elements located adjacent: \(< 0.1\)

- Electrons:
  - Large effects below Z peak due to FSR photons in response matrix.
Detector Resolution (III)

• For the 2D measurement, the conventional unfolding method is used
  – Convert 2D rapidity-mass into a 1D mass yield distribution
  – Apply the usual 1D unfolding procedure

The resulting response matrix has a block-diagonal structure with each block corresponding to a given mass-rapidity bin. The entries off the main diagonal are due to migration effects.

132 × 132 unfolding matrix
Final State Radiation Correction

- FSR corrections are determined from simulation
  - The FSR modeling in the POWHEG signal sample is used to derive the corrections bin by bin
  - FSR effects are very well modeled in MC
- FSR-correction factors are derived bin-by-bin
- Correction is applied in order to compare the measurement to the theoretical calculations which don’t include FSR
Acceptance and Efficiency (I)

- Acceptance*efficiency is derived from MC according to:
  \[
  A \cdot \varepsilon = \frac{N_{\text{RECO}}^{\text{Acc}}}{N_{\text{GEN}}^{\text{Acc}}} = \frac{N_{\text{RECO}}\cdot N_{\text{GEN}}^{\text{Acc}}}{N_{\text{GEN}}}
  \]

- The acceptance accounts for the lepton \( p_T \) and \( \eta \) cuts, the efficiency reflects the full selection

- Efficiencies for leptons are measured using data driven techniques
  - MC efficiencies are corrected to match data

- FEWZ NNLO reweighting procedure is applied to correct for model dependence

- At low invariant masses, the two high-\( p_T \) leptons in the analysis, indirectly impose the existence of a hard gluon in the process (\( \Rightarrow \) NLO)

- The lepton kinematic distributions in this region are very sensitive to the exact description (especially for very low invariant mass)
  - Thus for proper description of the low invariant mass region NNLO is mandatory!
Acceptance and Efficiency (II)

• For the 2D measurement, only efficiency correction is applied
  • No acceptance correction is applied
  • 2D measurement is model independent

• Efficiency corrections
  • Data-driven efficiency scale factors are applied to correct for systematic deviations between data and MC
  • Single lepton efficiencies are estimated using the data-driven Tag-and-Probe technique
  • The efficiency correction tables are determined for each individual efficiency as
    • \( \rho = \rho(p_T, \eta) = \frac{\varepsilon_{\text{Data}}(p_T, \eta)}{\varepsilon_{\text{MC}}(p_T, \eta)} \)
    • The efficiency corrections are applied per lepton and are used to weight the MC events
Systematic Uncertainties

• Muon channel
  – Unfolding & momentum scale correction: 0.5% at low mass; 28% at high mass
  – Estimation of backgrounds: about 0.5% at low masses; up to 23% at high mass
  – Efficiency estimation: about 0.5% at low masses; up to 3.5% at high masses

• Electron channel
  – Energy scale correction: 1-6% (in low and high mass regions) to 10% (Z peak region)
  – Unfolding: 1-5% (in low and high mass regions) to 10% (Z peak region); highest mass bin: 34%
  – Estimation of backgrounds: about 0.5% (low mass) to 6% (high mass)
  – Efficiency estimation: ~1% (Z peak region) to 6% (in low and high mass regions); highest mass bin: 19%

• PDF uncertainties: 3% in low mass region to 1% in high mass region
• The modeling uncertainty on acceptance for the $d\sigma/dM$ measurement is largest at low mass: up to 10%
• The luminosity uncertainty cancels out due to the normalization to the Z peak cross section
Normalized cross-section is calculated as:

\[ R_{pre \ FSR}^i = \frac{N_u^i}{A_i \epsilon_i \rho_i} / \frac{N_{u, norm}}{A_{norm} \epsilon_{norm} \rho_{norm}} \]

- Where ‘norm’ refers to the measurement in the normalization region (Z peak: 60 < M < 120 GeV)
- 40 mass bins covering the range from 15 to 1500 GeV are used

The Drell-Yan cross section normalized to the Z peak is calculated for both muons and electrons in the full phase space
- will be available in the acceptance region as well
The data distribution is well described by NNLO. At low invariant masses it is difficult to control the “modeling” uncertainty, at high invariant masses statistics plays a major role.
d^2\sigma/dM dY Results (1)

- The 2D measurement is performed within the detector acceptance, to reduce the model dependence.
- The result of the double differential cross section measurement is presented as the following ratio per absolute rapidity bin \( i \) within the invariant mass slice \( j \):

\[
R_{\text{pre FSR}}^{i,j} = \frac{N_u^{i,j}}{\epsilon^{i,j} \rho^{i,j}} / \frac{N_u^{\text{norm}}}{\epsilon^{\text{norm}} \rho^{\text{norm}}}
\]

- \( j \) – rapidity index, \( i \) – mass index
- Where ‘norm’ refers to the measurement in the normalization region (Z peak: \( 60 < M < 120 \) GeV) within \(|Y| < 2.4\)
- Performed in 24 rapidity bins between 0 and 2.4 (12 Y-bins for the highest mass bin) and
- 6 mass ranges: (20-30), (30,45), (45,60), **(60,120)**, (120, 200), (200,1500) GeV
$d^2\sigma/dMdy$ Results (II)

- Currently we compare to FEWZ + MSTW2008@NNLO and POWHEG + CT10@NLO
- Moving away from the Z peak we gain discrimination power
- The full covariance matrix is to be included in the paper being finalized. Studies in the electron channel are also being finalized and are part of the paper in preparation.
  - At this point we can test the influence of our measurement on global PDF fits
d²σ/dMdY Results (III)

Within the detector acceptance

- Good agreement observed for most mass bins
- Low mass region is very sensitive to PDF uncertainties
- To properly take into account the PDF uncertainty, the comparisons with various NNLO PDF sets are being performed
  - including NNPDF2.1, JR09VFNS, ABKM and CT10W NNLO PDF sets
Summary

- The Drell-Yan differential cross-section normalized to the Z peak was measured in the muon and electron channel with 40 mass bins, covering the mass range 15–1500 GeV
  - The full 2011 dataset was used: 4.5 fb^{-1}
  - The results agree with NNLO theory calculations
  - The precision makes the measurement sensitive to the NNLO theoretical predictions

- The double-differential cross section was measured in the muon channel. The measurement was performed in 6 invariant mass bin covering the mass range of 20-1500 GeV and absolute rapidity range of |Y| < 2.4
  - The measurement is performed within the detector acceptance to reduce the model dependence of the result
  - The d^2σ/dMdY measurement results can be directly used to constrain PDFs