PROCEEDINGS OF SCIENCE

Measurements of Drell-Yan Differential Cross Sections at the LHC and W Charge Asymmetry in pp Collisions at 7 TeV with the CMS Detector

Dimitri Bourilkov[*†]
University of Florida, Gainesville, Fl, USA
E-mail: bourilkov@phys.ufl.edu

Measurements of inclusive W, Z and Drell Yan production cross sections and the W lepton charge asymmetry in pp collisions at 7 TeV center-of-mass energy are presented, based on data recorded by the CMS detector at the LHC in 2010. The measurements are performed in the electron and muon channels. The charge asymmetry measurements cover the central region up to 2.4 in lepton pseudorapidity. These results can be used to constrain the parton densities for valence quarks and sea anti-quarks.

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[*] Speaker.
[†] On behalf of the CMS collaboration.

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The interactions of quarks and anti-quarks, proceeding through γ^*/Z or $W^{\pm}$ to final states containing pairs of leptons, are widely studied at hadron colliders. In the neutral case a quark-antiquark pair of the same flavor annihilates, producing a pair of leptons of opposite charge, or a neutrino pair. In the charged case an up and down type quark and anti-quark interact, producing a charged lepton and a neutrino. The CMS collaboration has used the data collected at the LHC in 2010 at 7 TeV center-of-mass energy to measure the production of $W^{\pm}$ and γ^*/Z, decaying to final states with electrons or muons [1 – 3].

The high event rates for W/Z production at the LHC, combined with the clean signals for leptonic decays to electrons or muons $l\nu_l$ and l^+l^-, make it a heavy gauge boson factory, well suited for precision tests of the Standard Model at highest momentum transfers, and for constraining the Parton Density Functions (PDFs) of the incoming protons. The W/Z are standard candles, crucial for understanding and calibrating the detector response: trigger, identification, resolution, efficiencies; at the same time they are important backgrounds in many early searches like for W', $Z,'$ etc. These processes are extensively studied in perturbative QCD, calculations at NNLO are available.

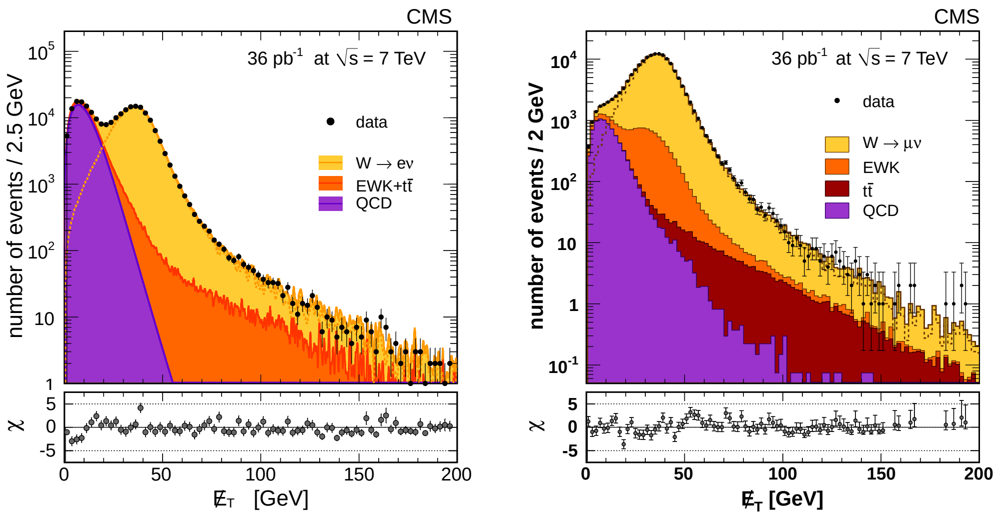

Figure 1: $\not\!\!E_T$ distributions for W: electron (left) and muon (right) channels.

Uniform analysis procedures are applied for all channels. The events are selected on-line using unprescaled single lepton triggers. The acceptance and efficiency are calculated using Monte Carlo (MC) simulations, and scale factors based on data-driven methods (tag-and-probe technique), are applied on top to account for differences between simulations and data. The low background Z peak samples are used for this end, as well as for resolution estimates, and for fixing the momentum/energy scales. The dominant backgrounds are estimated using various data-driven methods.

Electrons are selected by requiring a high transverse energy deposit in the electromagnetic calorimeter (ECAL), matched to a track: $E_T > 25$ GeV, pseudorapidity $|\eta| < 2.5$. The transition barrel-endcap region is excluded (for $|\eta|$ 1.44-1.57). To reject QCD background, the track, ECAL and hadron calorimeter (HCAL) energies observed in a cone $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2} < 0.3$ around the candidate must be limited (isolation). Here φ is the azimuthal angle. Additional cuts are applied to reject photon conversions. To select $W^{\pm}$ events, the missing transverse energy distributions $\not\!\!E_T$,

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determined from a particle flow algorithm based on track and energy deposits sorted into charged and neutral types, are used.

For muons, the transverse momentum is required to be above 20 GeV in $|\eta| < 2.4$ for the Z selection, and above 25 GeV in $|\eta| < 2.1$ for W candidates. Track quality is assured by requiring and least 10 tracker and 1 pixel hits, and $\chi^2 < 10$ per degree of freedom from the track fit. To reject QCD background, we require isolation, similar to electrons for the W case, and based on tracks only for the Z selection. To reject cosmic muons we require the distance from the beam spot to be < 0.2 cm in the transverse plane. The $\not{E}_T$ and invariant mass distributions for the selected W or Z events are shown in Figures 1 and 2.

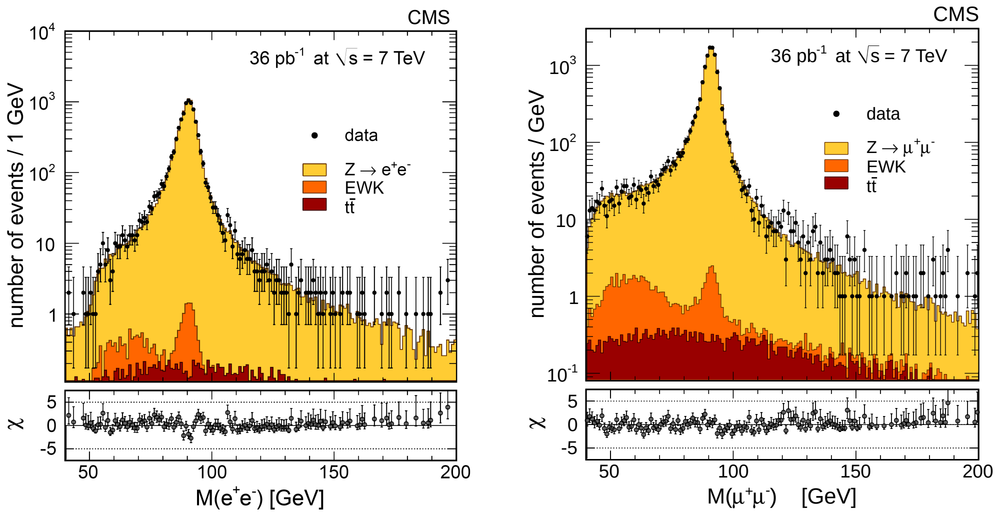

Figure 2: Invariant mass distributions for Z selection: electrons (left) and muons (right).

The acceptance and efficiency are determined separately for W^+ and W^-. The W signature is a high P_T lepton and missing energy due to the neutrino. The background contributions for the electron (muon) channel are: 7.6 (4.6) % from Drell-Yan (including $\tau\tau$), 3.0 (3.0) % from $W \to \tau\nu$ decays, 0.1 (0.1) % from WW, WZ and ZZ events, 0.4 (0.4) % from $t\bar{t}$, less than 0.01 % from cosmic muons. The signal yield is extracted from a maximum likelihood fit to the $\not{E}_T$ distributions. The signal shape is obtained from MC simulations, and from $Z \to l^+l^-$ data to tune for the hadron recoil. The QCD background is determined from data with the lepton identification criteria reversed. It comes directly from the fit in the electron channel, and is estimated to be 5.1 % for the muon channel. The correlation between $\not{E}_T$ and the isolation cuts is included in the systematics.

The Z event signature is two isolated high p_T leptons with invariant mass between 60 and 120 GeV. The background sources are similar, but the level is very low: 0.43 ± 0.14 and 0.44 ± 0.02 % for the electron or muon channels. The signal is extracted by cut and count for the electron, by simultaneous fit to the mass and efficiency for the muon channel.

The W and Z cross sections are shown in Table 1 and in Figure 3. The results, including the W^+/W^- and W/Z ratios, agree well with the NNLO FEWZ+MSTW08NNLO prediction. The measurements are already reaching a level of precision where we start to be limited by the theory systematic uncertainty.

	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Acceptance	0.4933±0.0003	0.4543±0.0003	0.3876±0.0005	0.3978±0.0005
Efficiency	73.5±0.9 %	84.8±0.8 %	60.9±1.1 %	from fit
W^+ events	81568±297	84091±291		
W^- events	54760±246	56666±240		
Z events			8442±93	13728±121
	Systematic errors			
Experimental	1.6 %	1.1 %	1.8 %	0.7 %
Theoretical	0.9 %	1.1 %	1.6 %	1.9 %
Total	1.8 %	1.6 %	2.4 %	2.0 %
Luminosity	4 %			
	Cross sections [nb]			
Stat. & syst. errors	10.48±0.03±0.17	10.18±0.03±0.16	0.992±0.011±0.024	0.968±0.008±0.020

Table 1: Summary of W and Z data and results.

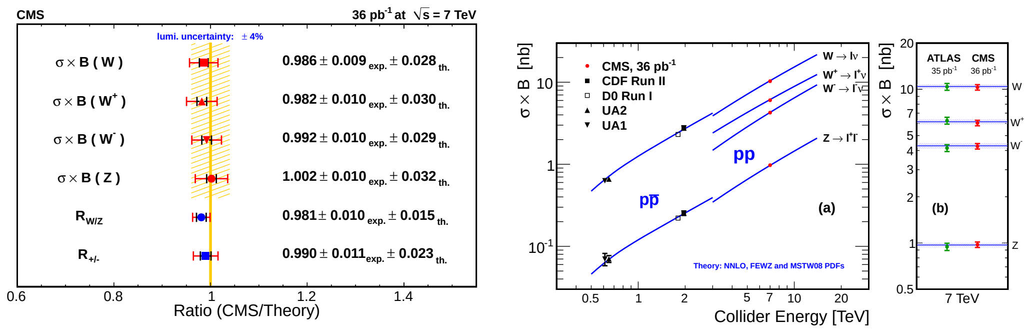

Figure 3: Results for the inclusive W and Z cross sections.

The difference in u/d valence quark distributions in the proton results in rate difference between W^+ and W^- bosons in pp collisions. An asymmetry measurement $(W^+ - W^-)/(W^+ + W^-)$ for the cross sections as function of boson rapidity can be used to constrain the proton PDFs. The lepton pseudorapidities tend to “follow” the W rapidities, as shown in Figure 4. We measure the W yield in pseudorapidity bins. The analysis procedure is the same as for the W cross section measurement. For signal extraction, the muon channel uses a fit to a modified isolation variable, not $\not\!\!E_T$. The fit is performed in six pseudorapidity bins:

- for electrons: [0.0, 0.4], [0.4, 0.8], [0.8, 1.2], [1.2, 1.4], [1.6, 2.0], [2.0, 2.4]
- for muons: [0.0, 0.4], [0.4, 0.8], [0.8, 1.2], [1.2, 1.5], [1.5, 1.8], [1.8, 2.1].

The W charge asymmetries for electrons and muons agree with each other, as evident from Figure 4. The precision is < 1.1 % (statistical), < 1.5 % (total) for all bins. These measurements are used already as inputs to new PDF global fits.

The Drell-Yan (DY) mass spectrum contains information about QCD, the Parton Density Functions (PDFs), and the electroweak couplings. The “observed” DY mass spectrum adds detector

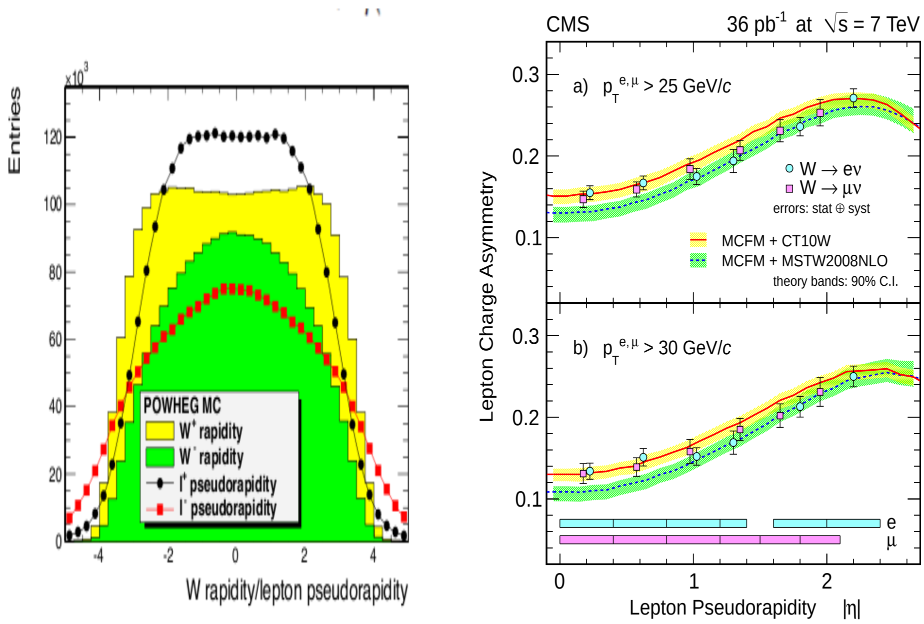

Figure 4: W asymmetry expectations (left), measurements (right).

effects. The analysis follows the Z cross section measurements with modifications for low mass. We use asymmetric kinematic cuts on the electrons and muons in order to collect more data in the low mass region:

- Electrons: $E_T^1 > 20$ GeV, $E_T^2 > 10$ GeV
- Muons: $p_T^1 > 16$ GeV $|\eta| < 2.1$, $p_T^2 > 7$ GeV $|\eta| < 2.4$.

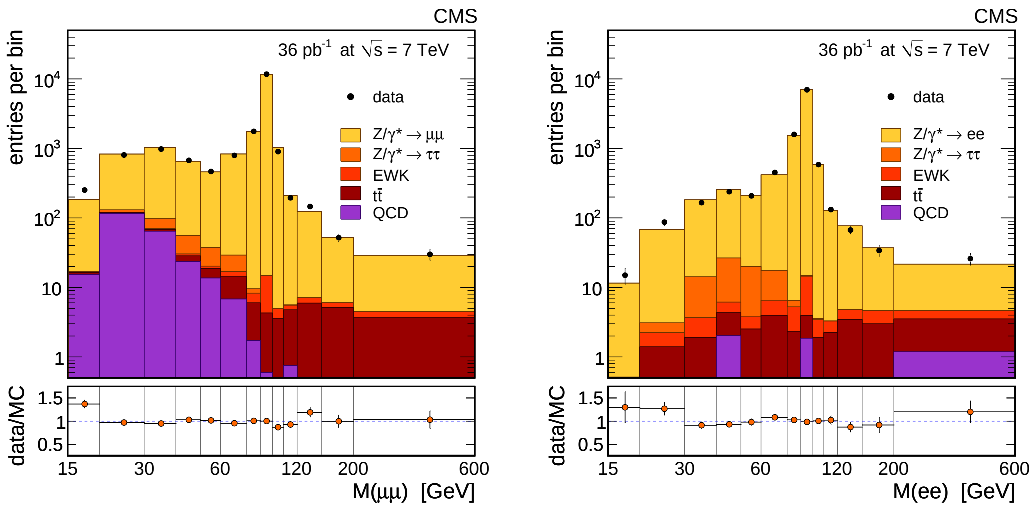

Figure 5: The observed di-muon (left) and di-electron (right) invariant mass spectra. The points represent the data, while the various contributions from simulated events are shown as stacked histograms.

The selected event distributions are shown in Figure 5. We use matrix unfolding in two steps for the differential cross section measurements to correct for event migration between neighboring bins. First we correct for detector resolution effects, and then for final state radiation (FSR), which modifies the observed di-lepton invariant mass. The FSR effects are corrected using the POWHEG+PYTHIA simulation. After unfolding the result is parton cross sections folded with PDFs. The combined Drell-Yan mass spectrum is shown in Figure 6.

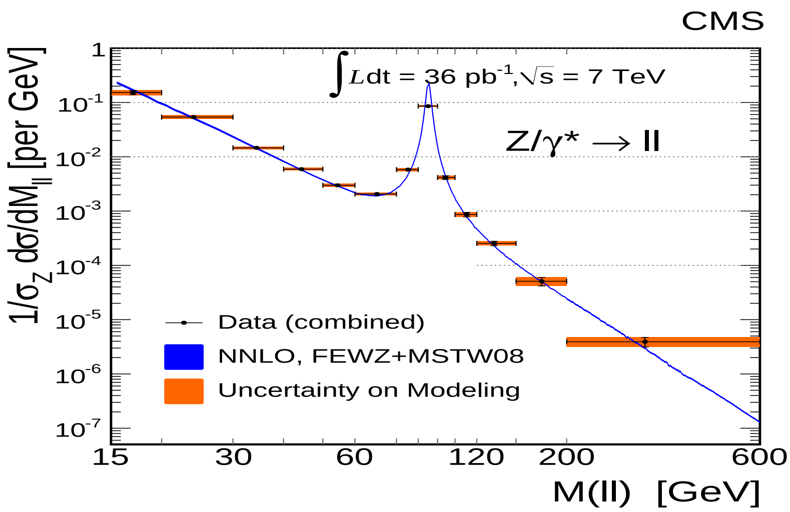

Figure 6: Normalized Drell–Yan mass spectrum, $(1/\sigma_Z)d\sigma/dM$, as measured (with statistical and systematic uncertainties summed in quadrature) and as predicted by NNLO calculations, for the full phase space. The band indicates the theory uncertainty resulting from the model-dependent kinematical distributions inside each bin.

The CMS collaboration has launched a broad program of electroweak measurements with the data from the first LHC run in 2010 at 7 TeV. The standard W and Z candles provide excellent tools to understand and improve the detector performance. The W/Z and Drell-Yan results with electrons and muons in the final state provide precise measurements of W and Z inclusive cross sections and ratios. We observe good agreement between electron and muon channels, and with NNLO QCD predictions. We have performed precise measurements of W lepton charge asymmetries and detailed studies of the invariant mass differential cross sections in Drell-Yan production. In summary, all results show excellent agreement with the Standard Model predictions.

References

[1] S. Chatrchyan *et al.* [CMS Collaboration], "*Measurement of the Inclusive W and Z Production Cross Sections in pp Collisions at sqrt(s) = 7 TeV,*" to appear in JHEP, [arXiv:1107.4789 [hep-ex]].

[2] S. Chatrchyan *et al.* [CMS Collaboration], "*Measurement of the lepton charge asymmetry in inclusive W production in pp collisions at* $\sqrt{s} = 7$ *TeV,*" JHEP **1104** (2011) 050. [arXiv:1103.3470 [hep-ex]].

[3] S. Chatrchyan *et al.* [CMS Collaboration], "*Measurement of the Drell-Yan Cross Section in pp Collisions at sqrt(s) = 7 TeV,*" JHEP **JHEP10** (2011) 007. [arXiv:1108.0566 [hep-ex]].