W and Z Studies at CMS

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On behalf of the CMS Collaboration

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Outline

• Present latest public results from CMS with 7 and 8 TeV data
  – Inclusive W and Z boson cross sections at 8 TeV
• Muon charge asymmetry at 7 TeV
• Drell-Yan differential cross section at 7 TeV
• Measurement of Z production as a function of pT and Y at 8 TeV
  – CMS-PAS-13-013 ➔ New result!
    – http://cds.cern.ch/record/1700115?ln=en
• All other public results are available at
  – https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP
W and Z Production at LHC

- Physics motivation: precision physics and tests of the Standard Model
  - $W$ and $Z$ productions are theoretically well understood
  - Constrain PDFs
- $W$ and $Z$ events are used to understand and calibrate our detector response
  - High rates at the LHC
  - Clean signal with leptonic decays
  - Trigger, identification, resolution, efficiencies
- They are important background in searches for new particles

\[ p p \rightarrow W^\pm, Z, \gamma^* l^\pm, l^\mp, \nu_l \text{ (−)} \]

Measurement range: $|y| < 2.5$

\[ 10^{-3} < x < 1 \text{ (target)} \]

\[ Q^2 (\text{GeV}^2) \]

\[ x, y = (M/14 \text{ TeV}) \exp(\pm y) \]

\[ Q = M \]

\[ M = 10 \text{ TeV} \]

\[ M = 1 \text{ TeV} \]

\[ M = 100 \text{ GeV} \]

\[ M = 10 \text{ GeV} \]

HERA $10^{-3} < x < 1$ (target)
Cross Section and Charge Asymmetry

Cross Section

\[ \sigma = \frac{N_{\text{observed}} - N_{\text{background}}}{\text{Acceptance} \cdot \text{Efficiency} \cdot \text{Correction} \cdot \text{Luminosity}} \]

Determine from simulation

Scale factor between data and MC simulation

2011(7TeV): ~5/fb
2012(8TeV): ~20/fb
~2.6% uncertainty

Charge Asymmetry

\[ A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \rightarrow l^+\nu) - \frac{d\sigma}{d\eta}(W^- \rightarrow l^-\nu)}{\frac{d\sigma}{d\eta}(W^+ \rightarrow l^+\nu) + \frac{d\sigma}{d\eta}(W^- \rightarrow l^-\nu)} \]
Inclusive W & Z Cross Section at 8 TeV

- Use 18.2/pb of 2012 data collected with low pile-up
  - ~5 interactions per bunch crossing
  - CMS requested special LHC conditions during luminosity ramp up
  - Single lepton trigger with lower $p_T$ threshold

- $Z \rightarrow e e, \mu \mu$
  - 2 isolated high $p_T$ leptons ($p_T > 25$ GeV)
    - $|\eta(\mu)| < 2.1, |\eta(e)| < 2.5$ due to acceptance of the trigger
  - Mass range: $60 < M(ll) < 120$ GeV
  - Minimal background contamination: ($Z \rightarrow \tau \tau$, diboson, ttbar, QCD)
Inclusive W & Z Cross Section at 8 TeV

- $W \rightarrow lv$
  - One isolated high $p_T$ lepton and missing transverse energy due to $\nu$
  - Background contributions
    - EWK: $W \rightarrow \tau \nu$, Drell-Yan, diboson
    - $tt\bar{t}$, QCD
  - Signal/background extraction
    - Signal shape: MC + recoil tuning from $Z \rightarrow ll$ data
    - QCD: from data with lepton id criteria reversed
    - Extract signal using the maximum likelihood fit to MET distributions
Inclusive W & Z Cross Section at 8 TeV

- Total inclusive cross sections times branching fractions for \( W^+ \), \( W^- \), \( W \) and \( Z \) and their ratios
  - Compare with theoretical expectation (NNLO FEWZ + MSTW08 PDF)
  - Yellow band: luminosity uncertainty (2.6%)

- Results are consistent between electron and muon channels
- Good agreement with theoretical prediction
Muon Charge Asymmetry at 7 TeV

- Up/down valence quark distribution in pp collisions results in rate difference between positive and negative W bosons
- An asymmetry measurement as a function of boson rapidity can be used to constrain PDFs
- Measure the asymmetry in 11 bins of $|\eta(\mu)|$ up to 2.4
- Similar event selection and signal/background extraction as inclusive W cross section measurement
Muon Charge Asymmetry at 7 TeV

- Dominant systematic uncertainty
  - Efficiency correction
  - QCD background
  - Muon momentum scale correction
- Measure muon charge asymmetry with two different $p_T$ cuts: 25 and 35 GeV
- Compare with NLO FEWZ predictions with 5 PDFs
  - Good agreement with CT10, NNPDF and HERA
  - Observe deviation with MSTW2008
    - Improve significantly by flexible parameterization in MSTW2008CPdeut
Muon Charge Asymmetry at 7 TeV

- Look into the impact of including this result in HERA PDF fit
  - 13 parameter fixed-s fit to the HERA I DIS data and CMS muon charge asymmetry result
  - Significant impact on the d-valence quark
Drell-Yan Diff. Cross Section at 7 TeV

- **Drell-Yan process**
  - Is an important Standard Model benchmark channel

- **We measure**
  - Differential cross section \((1/\sigma_Z)\frac{d\sigma}{dM}\) in dimuon and dielectron channel with 40 mass bins
    - \(15 < M(ee, \mu\mu) < 1500\) GeV
  - Double differential cross section \((1/\sigma_Z)\frac{d^2\sigma}{dMdY}\) in dimuon channel with 132 mass-rapidity bins
    - \(20 < M(\mu\mu) < 1500\) GeV, \(|Y(\mu\mu)| < 2.4\)
  - Normalized to Z peak
    - \(60 < M(\mu\mu) < 120\) GeV
  - Use full 7 TeV data (~5/fb)
Drell-Yan Diff. Cross Section at 7 TeV

- Result of \( (1/\sigma_Z) d\sigma/dM \)
  - Pre-FSR full acceptance normalized cross section in dimuon and dielectron
  - Provide results for post-FSR (no FSR correction) and fiducial region
- Dominant systematic uncertainties
  - Efficiency correction
  - Detector resolution
  - Backgrounds in high mass
- Very good agreement with NNLO theoretical prediction

The blue error band for the theory calculation includes the statistical error from the FEWZ calculation and 68% confidence limit (CL) PDF uncertainty combined in quadrature.
Drell-Yan Diff. Cross Section at 7 TeV

- Results of $(1/\sigma_Z)d^2\sigma/dMdY$
  - Fiducial region cross section with FSR correction
  - Provide full covariance matrices for PDF fits
- Comparison with various NNLO PDFs
Z $p_T$ and Y Cross Section at 8 TeV

- Z boson production at large $p_T$ is dominated by $qg$ process
  - Constrain gluon PDFs
- Use muon channel: $Z \rightarrow \mu \mu$
  - Use full 8 TeV dataset (~20/fb): improve a precision significantly (in particular $p_T > 100$ GeV) compared to previous $Z p_T$ CMS results
  - Determine cross section in fiducial region
  - Normalized to inclusive $Z$ cross section (in the fiducial region)
  - Use 10 bins of $p_T (Z)$ and 5 bins of $Y(Z)$
- Following corrections are applied
  - Efficiency: factorization of tracking, trigger, id, and isolation of muon
    - Parameterized by $p_T (\mu) \cdot |\eta(\mu)|$ and $p_T (Z) \cdot \cos \theta^* \cdot |\phi^*|$ to take into account the event kinematics
  - Muon momentum scale and resolution to correct misalignment
  - MC is weighted in $p_T (Z)$ and $Y(Z)$ shape in data to determine the response matrix for unfolding
  - Background subtraction using data-driven technique
Z $p_T$ and Y Cross Section at 8 TeV

- Absolute fiducial cross section
- Comparison to Madgraph+Pythia6 and RESBOS
  - Shape in $p_T(Z)$ is not well predicted by theory

| $0 \leq |Y(Z)| < 0.4$ | $0.8 \leq |Y(Z)| < 1.2$ | $1.6 \leq |Y(Z)| < 2$ |
|---------------------|---------------------|---------------------|
| Data | MadGraph $k_{\text{NNLO}}$ | Data |
| | | Data |
| Data | RESBOS | Data |
| | | Data |
| MC/Data | MC/Data | MC/Data |
| 0 | 100 | 200 | 300 |
| $P_T(Z)$ [GeV] | $P_T(Z)$ [GeV] | $P_T(Z)$ [GeV] |
Z $p_T$ and Y Cross Section at 8 TeV

- Normalized fiducial cross section
- Comparison to Madgraph+Pythia6 and RESBOS
  - Shape in $p_T (Z)$ is not well predicted by theory

![Graphs showing data and MC comparisons for different Y(Z) limits]
Summary

• Impressive amount of EWK results using $W$ and $Z$ boson production from CMS
  – Precise test of the Standard Model at TeV scale
  – Agreement with theory across orders of magnitude
  – Provide powerful constraints on electroweak parameters and PDFs
  – Measurements are challenging NLO and NNLO predictions
• You can find all details in the following link:
  – https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP#Vector_Boson_Production
  – Many more public results are available at the above link
• Many other results with 7 and 8 TeV datasets are in pipeline
  – More results with improved precision expected soon, stay tuned!