Measurement of the $p_T$ and $y$ Differential Cross Sections for Z bosons at $\sqrt{s} = 7$ TeV

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On behalf of the CMS Collaboration
Outline

- Theoretical Motivation
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- Overview of analysis
- The CMS Detector
- Triggers and Event Selection
- Background Estimation
- Acceptance and Efficiency
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Theoretical Motivation

- Imperfect knowledge of parton density functions shape the rapidity distribution
  - Left, simulation of Z boson $y$ from different pdf tunes.
- Initial state gluon radiation greatly effects the high $p_T$ spectrum
- The low $p_T$ spectrum is dominated by effects attributed to the underlying event.

CT10: arXiv: 1007.2241
Previous Studies

- Multiple studies of Z boson differential cross sections were performed at the Tevatron

- We aim to extend the effective $\eta_1$ reach of the rapidity analysis, as well as the range in $p_T$ reviewed.
Analysis Overview

We perform an analysis which measures the shape normalized to the total cross section:

- The Z is defined as lepton pairs in the range of $60 < M_{ll} < 120$
- The Analysis is performed on the first 36 pb$^{-1}$ of LHC, pp data

The above formula completely encodes the analysis procedure:

1. Perform a bin by bin correction for estimated background ($B_k$)
2. Unfold the spectrum for the effects of detector resolution and final state radiation ($\Sigma_k R_{ik}$)
3. Correct the unfolded spectrum for detector inefficiency and acceptance ($\Delta_i \cdot (A \times \epsilon)_i$)
4. Normalize to the total cross section
The Compact Muon Solenoid
The Compact Muon Solenoid

- For the Detection of electrons, CMS features a lead-tungstate electromagnetic calorimeter combined with the inner silicon tracker for electrons with $|\eta| < 3.0$, and is capable of energy resolution to $\sim 1\%$
- The forward hadronic calorimeter supplements the electron endcap in the high $\eta$ region, allowing the measurement to extend to $3.0 < |\eta| < 5.0$
  - By using short and long quartz fibers, the forward HCAL is able to identify electrons
- Both channels use the barrel and endcap hadronic calorimeter for isolation
For the identification of muons, CMS features a gas ionization chambers embedded in iron.

The inner tracker is used for the determination of $p_T$, accurate to 1-3%.

The 3.8 T magnetic field is provided by the superconducting solenoid (for which the detector is named...
Triggers and Event Selection

- CMS employs a 2 tier trigger scheme, with data reduction as illustrated above.
- Muons: 15 GeV trigger threshold, and a 20 GeV offline cut.
- Electrons: electron and photon triggers were use with a threshold of 17 GeV, again a 20 GeV offline cut.
Further Event Selection

- The $d\sigma/dp_T$ measurement requires leptons to have $|\eta| < 2.1$

- For the $d\sigma/dy$ analysis, muons are restricted to have $|\eta| < 2.1$

- For the electron rapidity analysis we require 1 electron to be in the ECAL barrel or endcap ($|\eta| < 3.0$), with the second allowed to be in either the ECAL or HF ($3.1 < |\eta| < 4.6$).

- In both instances we require the leptons be isolated.

- Further details are listed in the supporting slides.
Dielectron Mass

![Graph of dielectron mass spectrum with data, signal (MC), and background (Fit) for different Ecal and HF configurations.](attachment:image)

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# Dimuon Mass

![CMS preliminary graph](image)

36 pb\(^{-1}\) at \(\sqrt{s} = 7\) TeV

<table>
<thead>
<tr>
<th></th>
<th>Events / GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\times 10^3)</td>
</tr>
<tr>
<td>Muons</td>
<td></td>
</tr>
<tr>
<td>Barrel-Barrel</td>
<td>(\sim 3,900)</td>
</tr>
<tr>
<td>Barrel-Endcap</td>
<td>(\sim 5,900)</td>
</tr>
<tr>
<td>Endcap-Endcap</td>
<td>(\sim 2,500)</td>
</tr>
<tr>
<td>Electrons</td>
<td></td>
</tr>
<tr>
<td>ECAL-ECAL</td>
<td>(\sim 10,000)</td>
</tr>
<tr>
<td>ECAL-HF</td>
<td>(\sim 2,000)</td>
</tr>
</tbody>
</table>
Background Estimation

- As good agreement is found, all backgrounds levels are taken from Monte Carlo
- Background are checked from data driven techniques
  - $t\bar{t}$ control region of the electron-muon $p_T$ spectrum is inspected (shown)
  - Background contribution from QCD is estimated using several techniques
Acceptance & Efficiency

- For the $d\sigma/dp_T$ analysis, leptons with $|\eta| < 2.1$ are used, as well as limiting phase space of lepton $p_T > 20$ GeV

- For $d\sigma/dy$, corrections are made such that all phase space of $\eta$ and $p_T$ are considered

- Efficiency is measured via tag and probe for both triggers and offline selection.
  - Muon: trigger $\sim 99\%$, selection $\sim 90\%$
  - Electron: trigger $\sim 97\%$, selection $\sim 80\%$
Unfolding Detector Resolution

- We unfold the data using the unregularized matrix inversion technique.
- For detector resolution, matrices are trained on data tuned resolution functions.
- For FSR, we rely on pythia simulation.
- We include efficiency & acceptance s.t. all non-BG corrections are performed in a single step.
- We report uncertainties and a corresponding covariance matrix.

Increasing $p_T$ from low to high
Sources of Systematic Error

- For electrons:
  - The inclusion of HF makes systematics from QCD significant
  - Imperfect knowledge of HF electromagnetic energy scales

- For rapidity, acceptance corrections in regions where coverage is lacking causes uncertainties

- Uncertainty induced by dependencies to PDF shapes effect estimation of efficiency, acceptance, and unfolding

- Uncertainty arising from the sample size is largest effect

- For muons:
  - The largest systematic uncertainties come from variation of the detector resolution
Results - Rapidity

- The rapidity is a direct probe of the PDFs
- A bin size of $\Delta y = 0.1$ are used
- As the distribution is symmetric about 0, $|y|$ is measured
- The results are consistent with the CT10 pdf, and should provide feedback for improved tuning, particularly in the high $y$ region.
Results - Transverse Momentum

- We compare POWHEG @ NLO using the Z2 UE tune to combined e + mu data, finding disagreement in both the high (shown) and low \( p_T \) regions.

- Additionally, the FEWZ NLO calculator is compared to data, showing improved agreement at the highest \( p_T \).
Results - Transverse Momentum (2)

- The low end of the transverse momentum spectrum is dominated by non-perturbative effects, generally attributed to the underlying event.

- Several models are checked, with ProQ20 having the best agreement (p = 66%).
Conclusions

- We report a measurement of both the $y$ and $p_T$ distributions for the first 36 pb$^{-1}$ of LHC pp data at $\sqrt{s} = 7$ TeV
- The CT10 PDF is compared to data, showing good agreement extending to high regions of $y$
- The predictions of the POWHEG and FEWZ NLO calculator are compared to the perturbative regime of data, with good agreement to FEWZ
- Several Tuntes of the UE are tested in the non-perturbative region, showing the best agreement for the ProQ20 tune
- The Analysis Summary can be found by searching for CMS-PAS-EWK-10-010 located on the CERN document server
- Additional comparisons to FEWZ at NNLO and variations on the PDF are to be included in the paper from this study, coming soon
- An ATLAS study of the $Z p_T$ Spectrum has been released as well, and can be found for comparison on arXiv:1107.2381v1
Supporting Slides
Triggers and Event Selection

- We select the mass window of $60 \text{ GeV} < M_{\ell\ell} < 120 \text{ GeV}$

- **Muons**
  - Muons are required to have 11 or more tracker hits, at least one of which is in the inner pixel tracker.
  - Reconstructed using both an inside out and outside in extrapolation.
  - The $\chi^2$/NDF < 10 for the fit of the track to the tracker/muon system hits.
  - Muons required to have opposite charge.
  - Transverse impact parameter w.r.t. the beam spot is less than 0.2.

- **Electrons**
  - Electrons reconstructed in the electromagnetic calorimeters must have associated with it a track which extrapolates to the deposit.
  - Combinations considered are either 2 in the ecal+track region, or 1 in the ecal+ track region and 1 in the HF region.