Measurement of the Neutral Current DY process with the ATLAS detector

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The Neutral-Current Drell-Yan process

Measurements in low and high mass regions are complementary to the Z mass peak cross-section.

Below and above the Z mass peak the Drell-Yan cross section is dominated by a virtual photon exchange.

"Measurement of the low-mass Drell-Yan differential cross section at $\sqrt{s} = 7$ TeV using the ATLAS detector" arXiv:1404.1212 *new

Low mass Drell-Yan measurement. Motivation

- Since the measurement is photon exchange dominated it has different sensitivity to up-type, down-type quarks and anti-quarks compared to measurements near the Z resonance:

  \[ \sigma_{\gamma^*} \sim 0.44(u\bar{u} + c\bar{c}) + 0.11(d\bar{d} + s\bar{s} + b\bar{b}) \]
  \[ \sigma_Z \sim 0.29(u\bar{u} + c\bar{c}) + 0.37(d\bar{d} + s\bar{s} + b\bar{b}) \]

- Complementary to DIS kinematic region.

- Test of the Standard Model predictions at NLO, NNLO, and NLO matched to LL parton shower calculations.
Two analyses are performed in the Low Mass region:

**Nominal measurement**
1.6 fb$^{-1}$ of 2011 data at $\sqrt{s} = 7$ TeV
electron and muon channels

Fiducial region:
$$26 < M_{\ell\ell} < 66 \text{ GeV}$$
$$p_T^{\ell,\text{leading}} > 15 \text{ GeV}, \ p_T^{\ell,\text{sub-leading}} > 12 \text{ GeV}$$
$$|\eta^\ell| < 2.4$$

**Extended measurement**
35 pb$^{-1}$ of 2010 data at $\sqrt{s} = 7$ TeV
muon channel

Fiducial region:
$$12 < M_{\mu\mu} < 66 \text{ GeV}$$
$$p_T^{\mu,\text{leading}} > 9 \text{ GeV}, \ p_T^{\mu,\text{sub-leading}} > 6 \text{ GeV}$$
$$|\eta^\mu| < 2.4$$
Inclusive multijet production is the largest source of background:
- between 5% and 15% from the data from highest to lowest mass bins.
- estimated from the data using isolation distribution.

The dominant source of the systematic uncertainty is coming from the background estimation and electron reconstruction efficiency.

The total uncertainty of the measurement is 3.2% - 6% from highest to lowest mass bins.
The main backgrounds arise from $Z/\gamma^* \rightarrow \tau\tau$ and multijet production. Form highest to lowest mass bins:

- $Z/\gamma^* \rightarrow \tau\tau$ 6% - 1% of the data,
- multijet 1% - 5% of the data.

- estimated using both MC and data-driven template fit.

- The dominant source of the systematic uncertainty is coming from the isolation efficiency.

- The nominal muon measurement has total precision 1.9 - 3.6% from highest to the lowest mass bins.
The extended muon measurement benefits from the low-threshold trigger used in 2010 and allows to extend invariant mass region up to 12 GeV.

The largest background source is from multijet production: 6% to 23% from the data from highest to lowest $M_{\ell\ell}$.

The dominant systematic uncertainty is coming from the isolation efficiency.

The total precision of the measurement is 7% - 13% from highest to lowest bins.
1. The differential cross section $d\sigma/dM_{\ell\ell}$ calculation in each channel:
   a) background events are subtracted from the data,
   b) the data is **unfolded** for - detector acceptance,
      - selection efficiency
      - and resolution effects.

2. **Combination** of the electron and muon data for the nominal measurement using the $\chi^2$ minimisation method. The total uncertainty is reduced to 1.6-3%.

3. Extrapolation of nominal combined data and extended data to the full phase space using NNLO FEWZ calculations.
The measurements are compared to theoretical predictions from FEWZ at NLO and NNLO and from POWHEG at NLO + LL resummed parton shower.

Corrections are applied to account for higher order electroweak radiative effects and photon induced processes $\gamma\gamma \rightarrow \ell\ell$.

The FEWZ NLO predictions provide a poor description of the data at low $M_{\ell\ell}$. 
QCD analysis of the data is performed to investigate the disagreement with pure NLO calculations.

The Low mass Drell-Yan are included to NLO and NNLO fits of HERA DIS data: the $\chi^2$ function is evaluated after fitting the PDFs to the data.

The parametrisation:
- quark distributions
  \[ xq_i(x) = A_i x^{B_i} (1 - x)^{C_i} P_i(x) \]
- gluon distribution
  \[ xg(x) = A_g x^{B_g} (1 - x)^{C_g} P_g(x) - A_g' x^{B_g'} (1 - x)^{C_g'} \]

APPLGRID and MCFM theoretical predictions at NLO.

Higher order electroweak corrections including photon induced corrections and NNLO k-factors are applied to the theory.
Low mass Drell-Yan. QCD analysis

- NLO fit is not able to describe the data
- Good description from the NNLO calculation

<table>
<thead>
<tr>
<th></th>
<th>NLO Fit</th>
<th>NNLO Fit</th>
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<tbody>
<tr>
<td>Nominal $\chi^2/n_{dof}$</td>
<td>40.7/8</td>
<td>8.5/8</td>
</tr>
<tr>
<td>Extended $\chi^2/n_{dof}$</td>
<td>117.1/6</td>
<td>7.8/6</td>
</tr>
</tbody>
</table>

At low masses the phase space is constrained by $p_T^\ell$: $M_{\ell\ell} \sim 2p_T^\ell$
High Mass Drell-Yan measurement

Electron channel

4.9 fb\(^{-1}\) of 2011 data at \(\sqrt{s} = 7\) TeV

Fiducial region:

\[116 < M_{ee} < 1500\ \text{GeV}\]

\[p_T^{\pm e} > 25\ \text{GeV}\]

\[|\eta^e| < 2.5\]

- The measurement allows for precision test of perturbative QCD.
- Access to poorly known distribution of antiquarks at large \(x\).

The dominant background contributions (6-16% depending on $M_{ee}$) are from dijet and $W + jets$ production.

The total systematic uncertainty of the measurement is 4.2% for lower mass region to 9.8% for the highest mass region.

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>116–130 GeV [%]</th>
<th>1000–1500 GeV [%]</th>
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</thead>
<tbody>
<tr>
<td>Total background estimate (Stat.)</td>
<td>0.1</td>
<td>7.6</td>
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<tr>
<td>Total background estimate (Syst.)</td>
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<td>Electron energy scale &amp; resolution</td>
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<td>Electron identification</td>
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<td>Electron reconstruction</td>
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<td>Bin-by-bin correction</td>
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<td>Trigger efficiency</td>
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<td>MC statistics ($C_{DY}$ stat.)</td>
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<td>MC modelling</td>
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<tr>
<td>Theoretical uncertainty</td>
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</tbody>
</table>
The measurement is compared to FEWZ calculations at NNLO QCD with NLO electroweak corrections using the $G_\mu$ electroweak parameter scheme.

The lower ratio plot shows the influence of the photon-induced corrections on the MSTW2008 prediction. The effect has the same size as the choice of different PDFs.

The Standard Model predictions are consistent with the data.
The ATLAS Neutral-Current Drell-Yan measurements cover the invariant dilepton mass range between 12 and 1500 GeV.

The measurements agree well with the NNLO QCD and NLO+LLPS QCD calculations corrected for higher-order electroweak effects including a photon induced term.

The data sensitive to photon induced corrections could contribute to photon PDF constraints.

The measurements in different mass regions are sensitive to different quark distributions within the proton and can be used for PDF fits.