Measurements of inclusive vector boson production from ATLAS

Mikhail Karnevskiy

Uni. Mainz.
on behalf of the ATLAS collaboration.

5.08.2014
The mass spectrum is sensitive to the parton distribution functions (PDFs) for a wide kinematic range.

\[ Q^2 = M_{W/Z}^2 \quad \text{and} \quad x_{1,2} = e^{\pm y \frac{M_{W/Z}}{\sqrt{s}}} \]

- Production of \( W, Z \) bosons is theoretically well understood and provide clear experimental signature in the leptonic decay.
- The differential cross-section \( \frac{d\sigma}{dm_{ll}} \) is described by perturbative QCD (pQCD) calculations at next-to-next-to-leading order (NNLO).
- Studies of invariant mass shape at higher masses is interesting for searching of new resonances.
- Combined measurements are compared with NNLO theory predictions with different PDFs.
**Low Mass DY at 7 TeV**

- $m_{ll}$ shape was measured down to 25 GeV in $e$ channel and 12 GeV in $\mu$ channels.
- Dominant uncertainty is due to imperfect knowledge of background (vary from 3.9% to 1.6% from lowest to highest mass bin in electron channel)
- Combined data are in agreement with measurements performed with 2010 and 2011 data sets and with NNLO theory predictions.
Fitting of the PDFs was performed using deep inelastic scattering data from HERA and the new measurements presented here.

The QCD analysis performed at NNLO is in a good fit with a total $\chi^2$ value of 16.3 for 14 measurements.
High Mass DY at 7 TeV

- The measurement is performed in electron channel and covers the mass region 166-1500 GeV
- Dominant systematic uncertainties is due to electron identification for the lower mass bins and background subtraction in the higher mass bins
- Statistical uncertainties is larger than systematic for $m_{ee} > 400$ GeV
High Mass DY at 7 TeV

The measurement was compared to the predictions of the PYTHIA, MC@NLO and SHERPA MC generators.

The deviations between predictions based on different PDFs are within the total uncertainty band assigned to the MSTW2008 prediction. The predictions show a good compatibility with data points.

\[ \sigma_{d} \text{[pb/GeV]} \]

Data
Sys. uncertainty
Total uncertainty

ATLAS

\[ m_{ee} \text{[GeV]} \]

\[ > 25 \text{ GeV}, \eta < 2.5 \]

\[ L dt = 4.9 \text{ fb}^{-1} \]

\[ \sqrt{s} = 7 \text{ TeV} \]

1.8 % luminosity uncertainty not included

\[ \text{MC/Data} \]

\[ 0.6 \quad 0.8 \quad 1 \quad 1.2 \quad 1.4 \]

\[ \text{Theor./Data} \]

\[ 0.6 \quad 0.8 \quad 1 \quad 1.2 \quad 1.4 \]

\[ \text{MSTW2008 w/68\% CL (PDF + } \alpha_s \text{) + scale + PI unc.} \]

\[ \text{MSTW2008 w/o PI corrections + scale unc.} \]

\[ \text{HERAPDF1.5 CT10 ABM11 NNPDF2.3} \]
Measurement forward-backward asymmetry $A_{FB}$

- The leptons produced in the annihilation process are asymmetric with respect to the quark direction in the rest frame of the di-lepton system.

- The forward-backward asymmetry $A_{FB}$ was measured using angles in the Collins–Soper frame in electron (both central-central and central-forward) and muon channels.

- Electron central-forward ($|\eta_{e1}| < 2.5, |\eta_{e2}| > 2.5$) measurement is most sensitive to forward-backward asymmetry.
Measurements of weak mixing angle.

- Measurements of the leptonic effective weak mixing angle, $\sin^2 \theta_{W}^{\text{eff}}$, have been made using the raw $A_{FB}$ spectra.
- The dominant uncertainty is due to the limited knowledge of the proton parton density function.
- Presented measurement is in agreement with SM and most precise measurements.
The transverse momentum characterises the initial state radiation of the Drell-Yan process.

Measurements of the $p_T$ cross section tests therefore perturbative QCD calculations (higher-order corrections, resummation technique).

These measurements are used to tune parton shower algorithm.

Probe of $p_T^Z$ spectrum can be studied by the reconstructed $p_T^ll$ and alternatively by the

$$\phi^* = \tan((\pi - \Delta \phi)/2) \sin(\theta^*)$$

where

$$\cos(\theta^*) = \tanh((\eta^- - \eta^+)/2)$$

is a complementary to $p_T^Z$ measurement but have smaller uncertainties.

---

arXiv:1406.3660, Phys. Lett. B 720 (2013) 32-51
$Z_{p_T}$ at 7 TeV

- The ResBos-GNW prediction agrees with the data within 5–7%, NLO+NNLL calculation matches the data within 10–12%. The prediction uncertainties are almost sufficient to cover the difference with the data.

- Born-level combined result was compared to theoretical predictions from Fewz, Dynnlo, ResBos (all with CT10 PDFs) and NLO+NNLL (with CTEQ6m PDFs) calculation.

$Z_{p_T}$ was measured under the peak mass region 66-116 GeV and compared with different theory predictions.
\( \phi^* \) at 7 TeV

- Measurement performed with 0.5-0.8% precision and compared with different MC predictions
- None of the tested predictions is able to reproduce the detailed shape of the measured cross section

\[ \phi^* \] at 7 TeV

- Measurement performed with 0.5-0.8% precision and compared with different MC predictions
- None of the tested predictions is able to reproduce the detailed shape of the measured cross section

\[ \phi^* \] at 7 TeV

- Measurement performed with 0.5-0.8% precision and compared with different MC predictions
- None of the tested predictions is able to reproduce the detailed shape of the measured cross section

\[ \phi^* \] at 7 TeV

- Measurement performed with 0.5-0.8% precision and compared with different MC predictions
- None of the tested predictions is able to reproduce the detailed shape of the measured cross section
MC tuning using $Z_{p_T}$ and $\phi^*$ data.

- Comparison of the Pythia8 generator with the 4C and AZ tunes to the muon-channel $Z_{p_T}$ data and electron-channel $\phi^*$ data are presented.

- The tuned predictions agree with the measurement to better than 2% in the range used for the tuning, below $Z_{p_T} = 50$ GeV.

- At higher transverse momentum, discrepancies of around 15% for Pythia8 remain, indicating the limited accuracy of the NLO signal matrix element and suggesting the need for contributions from higher parton multiplicity.

```
arXiv:1406.3660
```
4-lepton at the Z resonance. 7 and 8 TeV

- Z resonance provides a test of the SM and a cross-check of the detector response to the 4 final state.
- Inclusive 4l production cross-section were measured at 4e 4μ and 2e2μ final states for each 7 TeV and 8 TeV datasets.
- Branching ratio: $\frac{\Gamma_{Z \rightarrow 4l}}{\Gamma_{Z}} = (3.20 \pm 0.25{\text{(stat)}} \pm 0.13{\text{(syst)}}) \times 10^{-6}$, where $80 < m_{4l} < 100$ GeV and $m_{ll} > 4$ GeV
- Higgs peak appears at higher masses and not studies in this measurement

**Graphs:**
- ATLAS: $\sqrt{s} = 7$ TeV, 4.5 fb$^{-1}$
- ATLAS: $\sqrt{s} = 8$ TeV, 20.3 fb$^{-1}$

**References:**
- Phys. Rev. Lett. 112, 231806 (2014), arXiv:1406.3827
Summary

- Several properties of $Z/\gamma^*$ production at ATLAS were measured at higher accuracy using high statistics data (millions of $Z$ events).
- Inclusive and differential $Z \rightarrow ll$ cross-section measurements are sensitive to PDFs and provide new constraints for future PDF-sets.
- Cross-section measurements in bins of boson transverse momentum provide precision tests of QCD dynamics from soft re-summation effects to hard multiple jet emission.
- Analysis of the 2011 data is almost finalized.
- Several 8 TeV analyses are in progress.
**A_{FB} definition**

The forward-backward $A_{FB} = \frac{\sigma_{\cos \theta_{CS} > 0} - \sigma_{\cos \theta_{CS} < 0}}{\sigma_{\cos \theta_{CS} > 0} + \sigma_{\cos \theta_{CS} < 0}}$ using angles in the Collins–Soper frame: 

\[
\cos \theta_{CS} = \frac{p_{i}^{2}}{|p_{i}^{2}|} \frac{2(p_{1}^{+} p_{2}^{+} - p_{1}^{+} p_{2}^{+})}{m_{\perp} \sqrt{m_{\perp}^{2} + p_{T,\perp}^{2}}}, \quad p_{i}^{\pm} = \frac{E_{i} \pm p_{z, i}}{\sqrt{2}}
\]