W & Z production at ATLAS

Feedback to the theory of strong interactions

M. Boonekamp, for the ATLAS Collaboration
**W and Z production as a probe of strong interactions**

- Event reconstruction, kinematics

\[ p_T^1, \eta^1 \]
\[ p_T^1 + u = E_T^{\text{miss}} \Rightarrow p_T^v \]
\[ M_T = \left[ 2 p_T^1 p_T^v (1 - \cos \Delta \phi) \right]^{1/2} \]

\[ p_T^1, \eta^1 ; p_T^2, \eta^2 \]
\[ M = \left[ 2 p_T^1 p_T^2 (\cosh \Delta \eta - \cos \Delta \phi) \right]^{1/2} \]
W and Z production as a probe of strong interactions

- Probing the proton

From detector-level to parton-level kinematics:

- $\frac{1}{2} \ln \frac{(E^2 + p_T^2)}{(E^2 - p_T^2)} = y^2 = \frac{1}{2} \ln x_1/x_2$
  - $q_i(x)$? $\bar{q}_i(x)$?

- $p_T^1 + p_T^2 \rightarrow p_T^z = p_T$ imbalance of incoming partons (LO) + hard radiation (HO)
  - what generates the transverse momentum distribution?
Discussed below:

- Measurements (2010, ~35 pb$^{-1}$)

- Interpretation
  - Monte Carlo tuning: ATL-PHYS-PUB-2011-015
  - PDF determination: arXiv:1203.4051
Cross sections (W)

- Event selections:
  - \( W \rightarrow e\nu \):
    - \( p_{T,e} > 20 \) GeV, \( |\eta_e| < 2.47 \), excluding \( 1.37 < |\eta_e| < 1.52 \),
    - \( p_{T,\nu} > 25 \) GeV, \( m_T > 40 \) GeV
  - \( W \rightarrow \mu\nu \):
    - \( p_{T,\mu} > 20 \) GeV, \( |\eta_\mu| < 2.4 \), \( p_{T,\nu} > 25 \) GeV, \( m_T > 40 \) GeV

- ~135k events selected per channel; W+ and W- measured separately
- Backgrounds subtracted using Monte Carlo or data-driven methods
Cross sections (Z)

- Event selections:

  \( Z \rightarrow ee : \)
  \[
  p_{T,e} > 20 \text{ GeV}, \text{ both } |\eta_e| < 2.47, \\
  \text{excluding } 1.37 < |\eta_e| < 1.52, \\
  66 < m_{ee} < 116 \text{ GeV};
  \]

  \( Z \rightarrow \mu\mu : \)
  \[
  p_{T,\mu} > 20 \text{ GeV}, \text{ both } |\eta_\mu| < 2.4, \\
  66 < m_{\mu\mu} < 116 \text{ GeV}.
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- \(~10k \text{ events selected per channel}\)

- “forward Z selection” in the electron channel: \(2.5 < \eta_2 < 4.9\)
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- Event selections:
  
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- “forward Z selection” in the electron channel: \( 2.5 < \eta_z < 4.9 \)

![Graphs showing energy distributions for Z production](graphs.png)
Cross sections

- Efficiency and acceptance corrections

  - Primary result: fiducial cross sections and distributions: efficiency/resolution corrected data, as close as possible to the experimental measurement. They feed the strong interaction studies downstream:

  \[
  \sigma_{\text{fid}} = \frac{N - B}{C_{W/Z} \cdot L_{\text{int}}}
  \]

  \[
  \eta_\ell = [0.00, 0.21, 0.42, 0.63, 0.84, 1.05, 1.37, 1.52, \\
  1.74, 1.95, 2.18, 2.47 (e) \text{ or } 2.40 (\mu)]
  \]

  \[
  y_{\nu\nu} = [0.0, 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8, 3.6]
  \]

  - Also extrapolated cross section (to full phase space), for comparison with existing theoretical calculations:

  \[
  \sigma_{\text{tot}} = \sigma_{W/Z} \times BR(W/Z \rightarrow \ell\nu/\ell\ell) = \frac{\sigma_{\text{fid}}}{A_{W/Z}}
  \]
Experimental results

- Longitudinal distributions
  - Z rapidity
  - Decay lepton pseudorapidity for W+ and W-

These processes are sensitive to different parton flavour configurations, which their combined interpretation allows to disentangle
Experimental results

- **Fiducial → total (extrapolated) cross sections**

  data are still less precise than single predictions, but more than differences among predictions: some model discrimination already

   fiducial cross sections provide better model discrimination than total cross sections
Experimental results

- Transverse momentum distributions

Z bosons

W bosons
Experimental Results

- Data seem to give a consistent picture
  - NLO predictions undershoot data at high $p_T^{W, Z}$, NNLO or higher-order ME predictions restore agreement: higher-order corrections to this distribution are important
  - Data allow to refine parton shower / resummation models (ATLAS W and Z channels compare consistently to ResBos, recently confirmed by CDF)

![Graph showing data and theory comparison](http://www-cdf.fnal.gov/physics/ewk/2011/zpt21/)
Applications: Monte Carlo tuning

- Data are exploited to refine the “tuning” of non-perturbative parameters entering our Monte Carlo programs
  - Refines the description of transverse distributions in W and Z events
  - Implications for cross section measurements (acceptance), and precision electroweak ($M_W$, where the Jacobians peaks need accurate description in order to be interpreted properly)
A long-lasting mystery in the proton structure is the strange density poorly constrained at Hera, where $F_2$ is mostly sensitive to the total $(u+c)$ and $(d+s)$ components. Particularly relevant at the LHC, where $W$ & $Z$ are produced in pp, and at low $x$, enhancing second generation contributions to the production rate.

ATLAS data (specifically, $W$ asym and $W/Z$ ratio) provide new insights on $s$:
A long-lasting mystery in the proton structure is the strange density

- Poorly constrained at Hera, where $F_2$ is mostly sensitive to the total $(u+c)$ and $(d+s)$ components
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ATLAS data provide new insights on $s$. Define $r_s = \frac{1}{2} (s + \bar{s})/d$:

At $Q = 1.9$ GeV:

At $Q = M_Z$:

$$r_s = 1.00 \pm 0.07_{\text{exp}} \pm 0.03_{\text{mod}}^{+0.04}_{-0.06_{\text{par}}} \pm 0.02_{\alpha_S} \pm 0.03_{\text{th}}$$

Atlas result based on Hera+W,Z data only, ~not affected by non-perturbative uncertainties (fragmentation, nuclear corrections)
Summary and perspectives

- 2010 data analyzed and digested: $\sqrt{s} = 7$ TeV; $\mathcal{L} = 35$ pb$^{-1}$
  - Percent level measurements, already constraining our uncertainties
  - Improved description of parton shower / resummation
  - New constraints on the strange density

- 2011 data measurements being finalized: $\sqrt{s} = 7$ TeV; $\mathcal{L} = 5$ fb$^{-1}$
  - Target precisions of few/mil, tightening the 2010 constraints
  - Major challenge to detector performance, in particular selection efficiencies

- 2012: $\sqrt{s} = 8$ TeV; $\mathcal{L} = 6$ fb$^{-1}$ and counting
  - Increase in energy provides new handles

"LHC Run1" will likely end with 20-30 fb$^{-1}$ of data collected by ATLAS

Unseen samples: $10^8$ selected W events, $10^7$ Z events

Providing knowledge of our detector, of QCD, and – ultimately – EW symmetry breaking