Single boson production and differential cross sections measurements in LHCb

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Outline

- Introduction
- W and Z production cross-section results at LHCb
- Impact of LHCb results on NNPDF3.1
- $Z \rightarrow \mu\mu$ forward-backward asymmetry
- Summary and outlook
LHCb sensitivity to parton density functions

- Electroweak measurements provide important tests of SM
- LHCb provides complementary phase space coverage compared to ATLAS and CMS
- LHCb forward acceptance gives access to previously unexplored kinematic regions of PDFs
LHCb detector

- General purpose forward detector, optimized for flavour physics
- Acceptance: $2<\eta<5$
- Momentum resolution:
  - 0.4% at 5 GeV, 0.6% at 100 GeV
- Excellent track and vertex reconstruction
- Good PID separation
$W \rightarrow \mu \nu$ at 8 TeV

- Selection criteria
  - Muon channel
    - Trigger
    - $2.0 < \eta < 4.5$
    - $P_T > 20$ GeV
    - Isolated muon

\[
\sigma(W^\pm \rightarrow \mu^\pm \nu) = 1897.2 \pm 2.3\text{ (stat.)} \pm 13.2\text{ (syst.)} \pm 22.0\text{ (lumi.) pb}
\]

($2.0 < \eta < 4.5, P_T > 20$ GeV)
W → μν at 8 TeV

- compared to NNLO predictions with different PDF sets
- reasonable agreement between measured results and NNLO calculation with different PDF sets
- experimental precision: dominated by luminosity and beam energy uncertainty
First measurement of $W$ with the electron final state at LHCb

☐ Selection criteria

- Electron channel
  - $2.0 < \eta < 4.5$
  - $P_T > 20$ GeV
  - Electron quality cuts

- Purity achieved $\sim 60\%$

$\sigma(W^\pm \rightarrow e^\pm \nu) = 1933.3 \pm 2.9\text{ (stat.)} \pm 38.2\text{ (syst.)} \pm 22.4\text{ (lumi.)pb}$

(2.0 < $\eta$ < 4.5, $P_T > 20$GeV)
$W \rightarrow e\nu$ at 8 TeV

Precise test of lepton universality:

$$\frac{B(W \rightarrow e\nu)}{B(W \rightarrow \mu\nu)} = 1.020 \pm 0.002 \pm 0.019$$

CDF

DØ

LEP (Combined)
Phys. Rept. 532, 119-244 (2013)

ATLAS

LHCb W

LHCb W$^+$

LHCb W$^-$
Forward $Z$ production at $\sqrt{s} = 8$TeV

- **Selection criteria**
  - $Z \rightarrow e^+e^- (Z \rightarrow \mu^+\mu^-)$
  - $2.0 < \eta < 4.5$
  - $P_T > 20$GeV
  - $60$GeV$< M < 120$GeV (40GeV$< M$)
  - High energy deposition

\[ \sigma(Z \rightarrow e^+e^-) = 93.81 \pm 0.41 \text{(stat.)} \pm 1.48 \text{(syst.)} \pm 1.14 \text{(lumi.)} \text{pb} \]
\[ \sigma(Z \rightarrow \mu^+\mu^-) = 95.0 \pm 0.3 \text{(stat.)} \pm 0.7 \text{(syst.)} \pm 1.1 \text{(lumi.)} \text{pb} \]

($2.0 < \eta < 4.5$, $P_T > 20$GeV, $60$GeV$< M(Z) < 120$GeV)
Forward $Z \rightarrow \mu\mu$ production at $\sqrt{s} = 13$TeV

- **Selection criteria**
  - Muon channel
    - $2.0 < \eta < 4.5$
    - $P_T > 20$GeV
  - $60$GeV$<M(ll)<120$GeV

High purity sample (99%)

$\sigma(Z) = 194.3 \pm 0.9$ (stat.) $\pm 3.3$ (syst.) $\pm 7.6$ (lumi.) pb

$(2.0 < \eta < 4.5, P_T > 20$GeV, $60$GeV$<M(Z)<120$GeV)
Forward $Z$ differential cross-section at $\sqrt{s} = 13$ TeV

Rapidity distribution agrees well with NNLO QCD calculated

$p_T$, $\phi^*$ differential distributions agree well with NLO + LL predictions
W/Z cross-sections ratios at different centre-of-mass energies

ratios extracted from 7 and 8 TeV datasets

ratios \((W^+ / W^- / Z, 7/8 \text{ TeV})\) provide even more stringent SM tests
Impact of LHCb on NNPDF3.1

- LHCb results so far on EW gauge bosons have already been used to constrain different proton PDFs

- Uncertainty on $d$ PDF reduced by a factor of 2 at $x \sim 0.2$

- Models where non-perturbative charm can carry much more than 1% of the total proton’s momentum are strongly disfavored by the LHCb data

Plots courtesy of Juan Rojo
arXiv:1705.04468
Z → μμ forward-backward asymmetry

- Interference of vector and axial-vector couplings of Z and γ* to fermions leads to asymmetry

\[ A_{FB} = \frac{N(\cos \theta > 0) - N(\cos \theta < 0)}{N(\cos \theta > 0) + N(\cos \theta < 0)} \]

- \( A_{FB} \) is sensitive to the weak mixing angle

- LHCb advantages:
  - Forward direction minimizes forward-backward dilution
  - PDF uncertainties smaller
$Z \rightarrow \mu\mu$ forward-backward asymmetry

Combination results:

$$\sin^2 \theta_W^{\text{eff}} = 0.23142 \pm 0.00073(\text{stat}) \pm 0.00052(\text{exp}) \pm 0.00056(\text{theo})$$

- most precise measurement at LHC
  - statistically dominated
  - theory error dominated by PDFs
  - dominant exp. syst. uncertainty: momentum scale
  - expected to improve with more data
Summary and outlook

- LHCb’s acceptance complementary to ATLAS and CMS
  - sensitive to high and low Bjorken-\(x\) (down to \(10^{-5}\))

- W/Z measurements at 7 and 8 TeV
  - cross-section ratios are agreement with SM
  - ratios of the same quantities have been measured at different \(\sqrt{s}\)

- Forward-backward asymmetry for Z has been measured for 7 and 8 TeV data. The measured value consistent with global fit.

- Expectations for run-II
  - will take \(\sim 5 \text{ fb}^{-1}\) in Run II (3 fb\(^{-1}\) in Run I)
  - expected to get better result for single W and Z boson measurement
Back Up
LHCb performance

- Trigger efficiencies: 90% for dimuon channels
- Muon ID efficiency: 97% with 1-3% $\pi \rightarrow \mu$ mis-id probability
- Electron ID efficiency: 90% with 4% $h \rightarrow e$ mis-id probability
\[ \phi^* = \frac{\tan\left(\phi_{acop}/2\right)}{\cosh(\Delta\eta/2)} \approx \frac{p_T}{M} \]

- \( \Delta\eta \): the difference in pseudorapidity between the leptons
- \( \phi_{acop} = \pi - |\Delta\phi| \): the acoplanarity angle depends on the difference between the azimuthal directions of the lepton momenta
W and Z cross-sections ratios at 8TeV

- Many uncertainties can cancel or are reduced by ratio

- Luminosity, detection efficiency, PDFs, scale uncertainties
Beam Energy uncertainty

- The systematic uncertainty on cross-section measurements due to knowledge of the beam energy is process dependent.
- The DYNNLO generator is used to study the variation of the $W$ and $Z$ cross-sections as a function of the COM energy and assess a systematic uncertainty.

![Graphs showing cross-sections and ratios as a function of the COM energy.](image)

*Figure 20: (Left) cross-section for (dash-dotted) $W^+$, (dashed) $W^-$ and (solid) $Z$ production as a function of the COM energy. (Right) ratios of cross-sections for (solid) $R_{W^\pm}$, (dash-dotted) $R_{W^+Z}$ and (dashed) $R_{W^-Z}$ as a function of the COM energy. Calculations are performed at NNLO with the DYNNLO generator and the MSTW08 PDF set. The grey bands represent the uncertainty on the beam energy measurement at 7 and 8 TeV.*