EW production at LHCb

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PANIC 2017
Outline

Electroweak boson production at LHCb

- $W/Z$ boson cross-section @ 8+13 TeV
- $W/Z + \text{jets} @ 8 \text{ TeV}$
- $W + b\bar{b}$ and $W + c\bar{c} @ 8 \text{ TeV}$
- $Z \rightarrow b\bar{b} @ 8 \text{ TeV}$
LHCb detector

LHCb is a forward spectrometer initially designed for $b$ physics

Unique acceptance: $2 < \eta < 5$

Momentum resolution:
- 0.4% at 5 GeV, 0.6% at 100 GeV

Excellent track and vertex reconstruction

Good PID separation

Flexible trigger
- trigger low momentum objects
LHCb detector provides access to Parton distribution functions (PDFs)
- High Bjorken-x region
- Low Bjorken-x region: unexplored by other experiments
**W → μν at 8 TeV**

**W → μν channel:**
- 2.0 < η < 4.5
- \( p_T > 20 \text{GeV} \)
- Isolated muon

\[
\sigma_{W^+ → μ^+ν} = 1093.6 \pm 2.1 \pm 7.2 \pm 10.9 \pm 12.7 \text{ pb},
\]
\[
\sigma_{W^- → μ^−\bar{ν}} = 818.4 \pm 1.9 \pm 5.0 \pm 7.0 \pm 9.5 \text{ pb},
\]

Stat. Syst. Beam energy luminosity

**Fiducial region:** (2.0 < η < 4.5, \( p_T > 20 \text{ GeV} \))
$W \rightarrow \mu\nu$ at 8 TeV

Agreement between measured results and NNLO calculations with different PDF sets

Uncertainties: dominated by luminosity and beam energy uncertainty
$W/Z$ cross section ratios

Ratios ($W^+/W^-$, $W/Z$, 8/7 TeV) provides even more stringent tests on SM predictions.
Z production at 13 TeV

Lepton final states $Z \rightarrow \mu\mu$ and $Z \rightarrow ee$

Event Selections:
- $p_T > 20$ GeV
- $2.0 < \eta < 4.5$
- $60 < M_{\mu\mu} < 120$ GeV, $M_{ee} > 40$ GeV
- High purity:
  - $99.2\%$ for muon channel
  - $92.2\%$ for electron channel

$$\sigma_Z = 194.3 \pm 0.9 \text{ (stat.)} \pm 3.3 \text{ (syst.)} \pm 7.6 \text{ (lumi.)} \text{ pb}$$

$(2.0 < \eta < 4.5, p_T > 20 \text{ GeV}, 60 < M_Z < 120 \text{ GeV})$
**Z production at 13 TeV**

Good agreement between electron and muon channel

Differential cross-section agree with predictions

- Rapidity distribution agrees well with NNLO QCD calculation
- $p_T, \phi^*$ distributions agree better with PYTHIA8 than POWHEG predictions at low $p_T$

Largest systematic uncertainty from the luminosity measurement (3.9%)
**W/Z + jet production at 8 TeV**

Important measurement to validate jet reconstruction at LHCb

LHCb standard jets: anti-kt with $R = 0.5$

$W$ events in muon channels

Fiducial volume for jets:
- $p_T(jet) > 20$ GeV
- $2.2 < \eta(jet) < 4.2$
- $\Delta R(jet, \mu) > 0.5$

Fit muon isolation $p_T^\mu / p_T^{\mu-jet}$ to extract signal
- $Z$ purity: $\sim98\%$
- $W$ purity: $46\%$ ($37\%$)

Good agreement with POWHEG and aMC@NLO predictions
$W/Z + \text{jet}$ production at 8 TeV

Differential cross-section measurements are in agreement with POWHEG and aMC@NLO predictions

Main uncertainties: jet energy scale $\sim 10\%$, $W$ purity $\sim 7\%$

$A = \frac{\sigma_{W^+ j} - \sigma_{W^- j}}{\sigma_{W^+ j} + \sigma_{W^- j}}$

$Z + \text{jet}$

$W + \text{jet}$

$W + \text{jet}$ charge asymmetry $\eta^\mu$

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Jets heavy flavour identification

**b,c tagging with secondary vertex in jet cone**

Two BDTs to separate:

1. $\text{BDT}(bc | \text{udsg})$: heavy flavour jets from light jets
2. $\text{BDT}(b | c)$: b-jets from c-jets

A good discrimination power is achieved!
$W + b\bar{b}/W + c\bar{c}$ production at 8 TeV

$W (\rightarrow \mu/e/\nu) +$ two heavy flavour tagged jets

- $p_T(\text{jet1,2}) > 20$ GeV, $2.2 < \eta(\text{jet1,2}) < 4.2$
- $\Delta R(\text{jet1,2,}\mu/e) > 0.5, \Delta R(\text{jet1,jet2}) > 0.5$

A BDT is trained to separate $W + b\bar{b}$ from $t\bar{t}$

The uniform Gradient boost technique is applied to achieve low correction with di-jet invariant mass

Discrimination: $M_{jj}$, BDT(b|c), MVA($W + b\bar{b}/t\bar{t}$)

4-dimensional fit, simultaneous for $e^+, e^-, \mu^+, \mu^-$
$W + b\bar{b}/W + c\bar{c}$ production at 8 TeV

Results in agreement with NLO predictions

(MCFM with CT10, interleaved with PYTHIA8)
$Z \rightarrow b\bar{b}$ production at 8 TeV

$Z \rightarrow b\bar{b}$: two heavy flavour tagged jets

Selections:
- $p_T(jet1, 2) > 20$ GeV, $2 < \eta(jet1, 2) < 4.2$
- $45 < M_{jj} < 165$ GeV

An additional balancing jet:
- $p_T(Z + jet3)$ minimum to separate $Z \rightarrow b\bar{b}$ from QCD

UGB BDT is trained to separate $Z \rightarrow b\bar{b}$ from QCD

Input variables: 3-jets kinematic

Simultaneous fit to $M_{jj}$ in signal, control region, to get signal yield.
Z → b\bar{b} production at 8 TeV

Z → b\bar{b} model is taken from simulation, but a jet Energy Scale factor (E_{Data}/E_{MC}) is measured in the fit
  ◦ Validate the MC JES uncertainty (2%)

QCD model: Pearson IV distribution.

Uncertainty: heavy flavour tagging efficiency (~17%)  

Measured result is compatible with aMC@NLO prediction

Measured:
\[ \sigma(pp → Z)B(Z → b\bar{b}) = 332 \pm 46\text{(stat.)} \pm 59\text{(syst.)} \text{ pb} \]

Prediction:
\[ \sigma(pp → Z)B(Z → b\bar{b}) = 272^{+9}_{-12}\text{(scale)} \pm 5\text{(PDFs)} \text{ pb} \]
Conclusions

➢ LHCb detector has unique acceptance, EW production results are complementary to that of ATLAS and CMS
  • Sensitive to high and low Bjorken-x (down to $10^{-5}$) region

➢ Production cross section measurements in the forward region
  • Precision tests on the SM predictions

➢ Validate reconstruction techniques: electrons, jets, $b$-jets etc

➢ Many works are in progress for new exciting measurements
Backup
$W \rightarrow e\nu$ at 8 TeV

First measurement of $W$ with electron final state at LHCb

$W \rightarrow e\nu$ channel:
- $2.0 < \eta < 4.5$
- $p_T > 20$ GeV
- Electron quality cuts
- Purity: ~60%

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

$(2.0 < \eta < 4.5, p_T > 20 \text{ GeV})$
$W \rightarrow ev$ at 8 TeV

Agreement between measured results and NNLO calculations with different PDF sets

Precision test of lepton universality:

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

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Impact of LHCb results on NNPDF3.1

LHCb W/Z production measurements has been used in NNPDF3.1