EW boson production at LHCb

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Outline

Electroweak boson production at LHCb:

- $Z$ @ 13 TeV
- $W/Z + \text{jets} @ 8 \text{ TeV}$
- $W+b\bar{b}$ and $W+c\bar{c}$ @ 8 TeV
- **NEW** $Z \rightarrow b\bar{b}$ @ 8 TeV
LHCb is a forward spectrometer initially designed for B physics.

- It covers a unique acceptance within the LHC experiments ($2 < \eta < 5$).

- Momentum resolution: 0.4% at 5 GeV and 0.6% at 100 GeV.

- Impact parameter resolution of 13-20 $\mu$m at high $p_T$.

- Muon ID efficiency: 97% with 1-3% $\mu \rightarrow \pi$ mis-identification.

LHCb demonstrated its capability in EW physics. General purpose forward detector
Introduction

- LHCb offers a **complementary phase space region with respect to ATLAS and CMS** for Electroweak and jets measurements.

- Cross-sections measurements of **W and Z production in the forward acceptance** are important tests of the Standard Model.

- These measurements provide access to **Parton Distribution Functions** in two different regions:
  - at high Bjorken-x values;
  - at low x values, **unexplored by other experiments**.

- They can be used to validate reconstruction techniques.

- I am going to present measurements at **8 TeV** and **13 TeV** in the pp centre-of-mass energy.
Z production at 13 TeV

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

- $p_T(\mu/e) > 20$ GeV, $2.0 < \eta(\mu/e) < 4.5$, $60 < m(\mu\mu/ee) < 120$ GeV

- High purity samples: 99.2% for $Z \rightarrow \mu\mu$ and 92.2% for $Z \rightarrow ee$.

- Differential cross-sections compatible with predictions.

- Uncertainty dominated by the luminosity measurement (3.9%) → not final calibration.

- $Z \rightarrow \mu\mu$ and $Z \rightarrow ee$ measured cross-sections are compatible within the uncertainties.
W/Z + jet production at 8 TeV
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- Important measurement to validate the jet reconstruction at LHCb.
- LHCb standard jets: anti-kt with $R=0.5$
- $W \to \mu\nu$ and $Z \to \mu\mu$ decay channels.
- $p_T(\text{jet}) > 20 \text{ GeV}, 2.2 < \eta(\text{jet}) < 4.2, \Delta R(\text{jet},\mu) > 0.5$
- Fit to the muon isolation $p_T(\mu)/p_T(\mu-\text{jet})$ to extract $W^+\text{+jet, } W^-\text{+jet}$ purity.

- Purity of $Z+\text{jet}$: 97.8%
- Systematic uncertainty on the cross-section measurement are dominated by the purity determination and by the jet energy scale/resolution.
- $W/Z$ ratios and $W^+/W^-$ asymmetry are also determined.
- Measurements are in good agreement with POWHEG and aMC@NLO predictions.

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- Differential cross-sections measurements are in agreement with POWHEG and aMC@NLO predictions
Jets are heavy flavour tagged if one Secondary Vertex compatible with a b or c hadron decay is found with $\Delta R < 0.5$ from the jet axis.

- Two **Boosted Decision Trees** are used to identify b and c jets.

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


- \( W(\rightarrow \mu/e\nu) \) plus two heavy flavour tagged jets.

- \( p_T(\text{jet}_{1,2}) > 20 \text{ GeV}, 2.2 < \eta(\text{jet}_{1,2}) < 4.2, \Delta R(\text{jet}_{1,2}, \mu/e) > 0.5, \Delta R(\text{jet}_1, \text{jet}_2) > 0.5 \)

- A BDT is trained to separate \( W+b\bar{b} \) from \( \tt \): the uniform Gradient Boost technique is applied to achieve low correlation with the dijet invariant mass \( (m_{jj}) \). [JINST 10 (2015) T03002]

- Fit to \( m_{jj}, BDT(b|c) \) for both jets and \( u\text{GB}(W+b\bar{b}|\tt) \) to measure the cross-sections.

- \( \tt \) production in the forward region is also measured! ([Stephen Farry's talk in Top session](#))

- Measurements are compatible with NLO predictions.
Z → b\bar{b} production at 8 TeV

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- Challenging measurement at hadron colliders because of the overwhelming QCD background.
- Previous measurements by CDF, ATLAS and CMS. Now first measurement in the forward region!
- Two heavy flavour tagged jets are selected.
- Fiducial region: \( p_T(j_{1,2}) > 20 \text{ GeV}, 2.2 < \eta(j_{1,2}) < 4.2, 45 < m_{jj} < 165 \text{ GeV} \)

- An additional balancing jet (jet_3) that makes \( p_T(Z+\text{jet}_3) \) minimum is selected to separate \( Z → b\bar{b} \) from QCD.
- UGB BDT is trained to separate \( Z → b\bar{b} \) from QCD, input observables are related to the 3-jets kinematic.
- Simultaneous fit to \( m_{jj} \) in signal (enhanced \( Z → b\bar{b} \) yield) and control (low \( Z → b\bar{b} \) yield) regions, to measure the \( Z \) yield.
\[ Z \rightarrow b\bar{b} \] production at 8 TeV

- \[ Z \rightarrow b\bar{b} \] model is taken from simulation, but a Jet Energy Scale factor \( (E_{\text{data}}/E_{\text{MC}}) \) is measured in the fit.

- QCD model: Pearson IV distribution.
\( Z \rightarrow b\bar{b} \) production at 8 TeV

**NEW LHCb-PAPER-2017-024**

- \( Z \rightarrow b\bar{b} \) peak mean is \( \sim 80 \) GeV, jet energy is not corrected for radiation outside of the jet cone and missing energy.

- It is also reduced by the features of the jet reconstruction (asymmetric jet energy resolution)

\[
\text{Residual} = \text{data} - \text{bkg}
\]

\[5462 \pm 763 \text{ Z events}\]

- The systematic uncertainty on the cross-section measurement is dominated by the heavy flavour tagging efficiency (\( \sim 17\% \))

- The \( Z \rightarrow bb \) cross-section measurement is compatible with the \texttt{aMC@NLO} prediction.

Measured:

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

Prediction:

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

- In the last years LHCb has made great progresses in **Electroweak physics**.

- We performed measurements of **$W/Z (+\text{jets})$ production in the forward region of $pp$ collisions**, unexplored by other experiments.

- They provide unique tests of the Standard Model and constraints to the PDFs.

- They are fundamental to validate reconstruction techniques (i.e. electrons, jets, b-jets etc.)

- **First measurement of the $Z \rightarrow b\bar{b}$ production in the forward region.**

- A lot of work is in progress for new exciting measurements!
Thanks for your attention!
Backup slides
W → ev production at 8 TeV
JHEP 10 (2016) 030

- Important measurement to validate the high $p_T$ electron reconstruction and identification at LHCb.
- $p_T(e) > 20$ GeV, $2.0 < \eta(e) < 4.25$
- Fit to the electron $p_T$ distribution to extract the W yield.
- Differential cross section as a function of the electron $\eta$ is compatible with the prediction.

$W \rightarrow e \nu$ @ 8 TeV: JHEP 01 (2016) 155