EW production at LHCb

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ON BEHALF OF LHCb COLLABORATION

PANIC 2017

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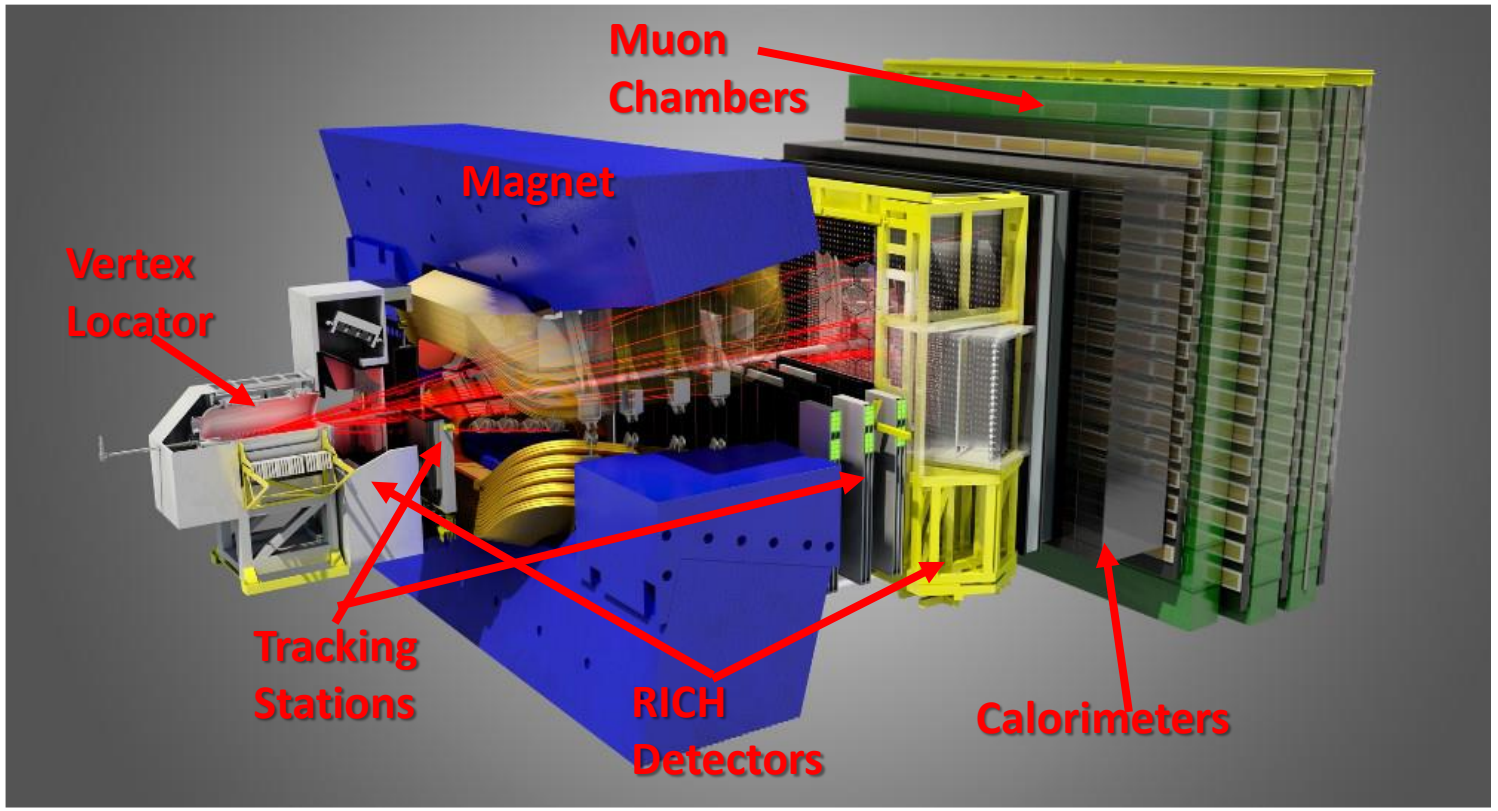
Outline

- **Electroweak boson production at LHCb**
  - W/Z boson cross-section @ 8+13 TeV
  - W/Z + jets @ 8 TeV
  - $W + b\bar{b}$ and $W + c\bar{c}$ @ 8 TeV
  - $Z \rightarrow b\bar{b}$ @ 8 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

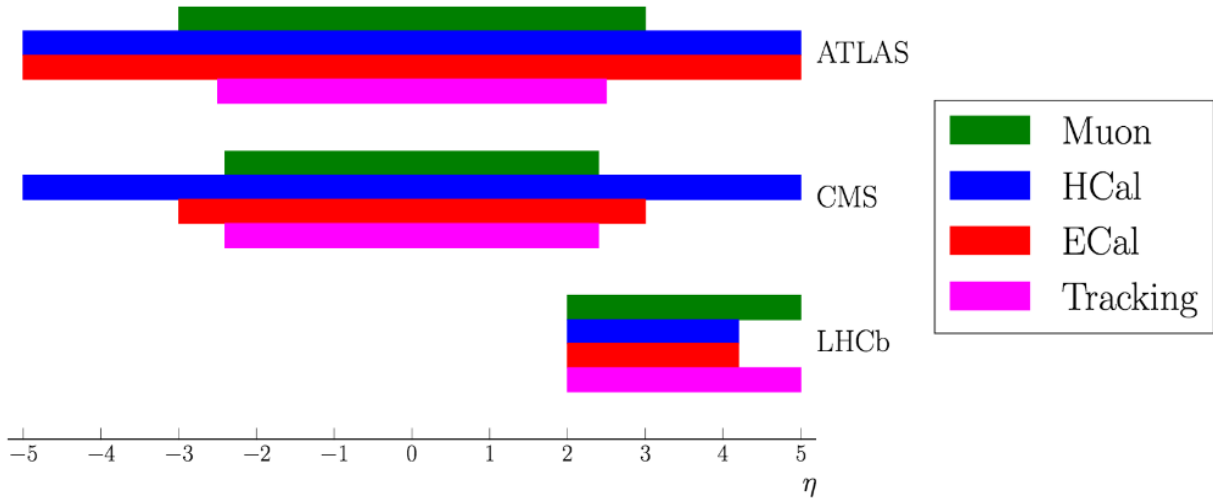
- trigger low momentum objects

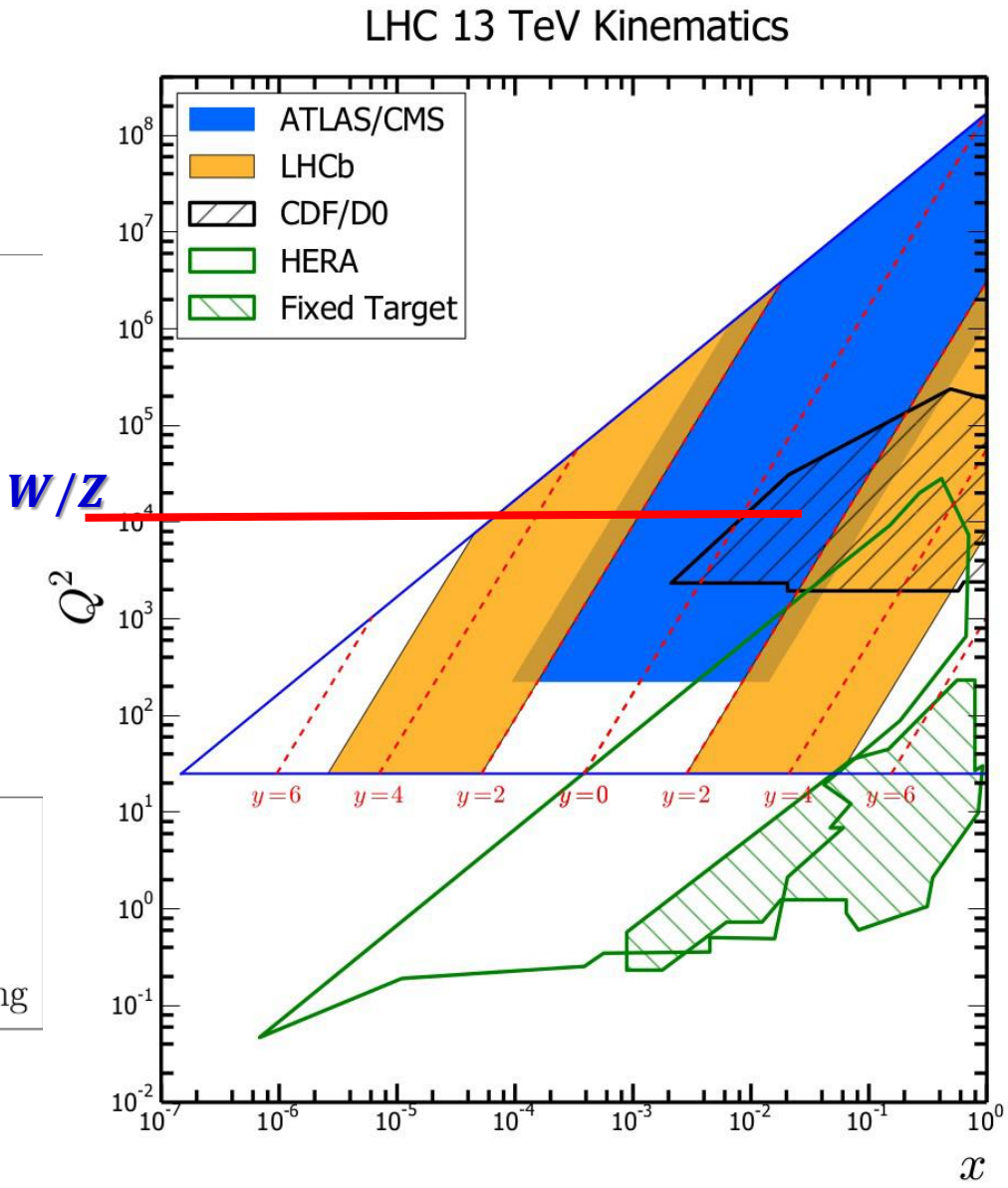
JINST 3 (2008) S08005

Probe PDFs

LHCb detector provides access to Parton distribution functions (PDFs)

- **High Bjorken-x region**
- **Low Bjorken-x region: unexplored by other experiments**

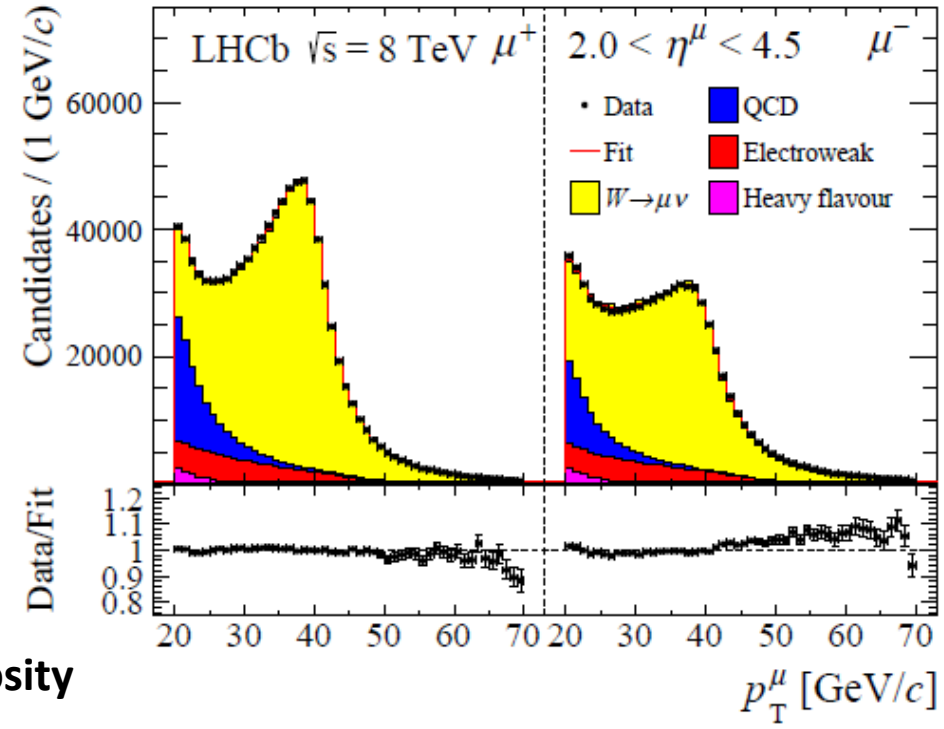




$W \to \mu\nu$ at 8 TeV

$W \to \mu\nu$ channel:

- $2.0 < \eta < 4.5$
- $p_T > 20$GeV
- Isolated muon



$$\sigma_{W^+ \to \mu^+ \nu} = 1093.6 \pm 2.1 \pm 7.2 \pm 10.9 \pm 12.7\,\text{pb}\,,$$
$$\sigma_{W^- \to \mu^- \bar{\nu}} = 818.4 \pm 1.9 \pm 5.0 \pm 7.0 \pm 9.5\,\text{pb}\,,$$

Stat. Syst. Beam energy luminosity

Fiducial region: $(2.0 < \eta < 4.5, p_T > 20\ \text{GeV})$

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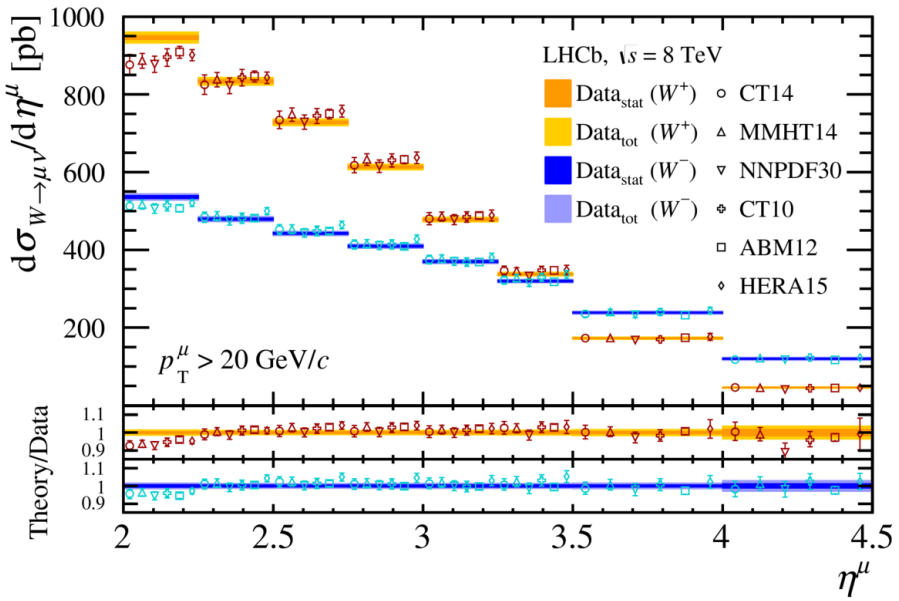
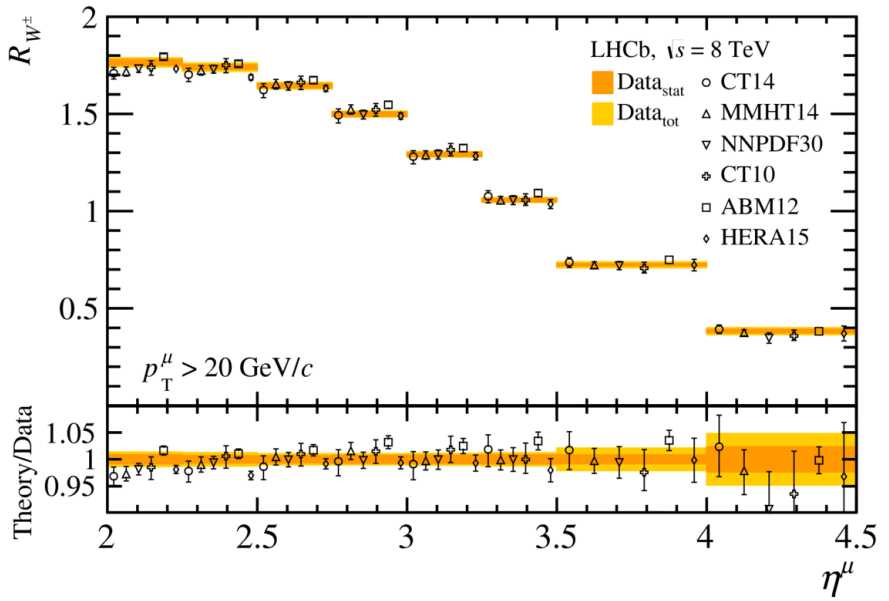
$W \to \mu\nu$ at 8 TeV





Agreement between measured results and NNLO calculations with different PDF sets

Uncertainties: dominated by luminosity and beam energy uncertainty

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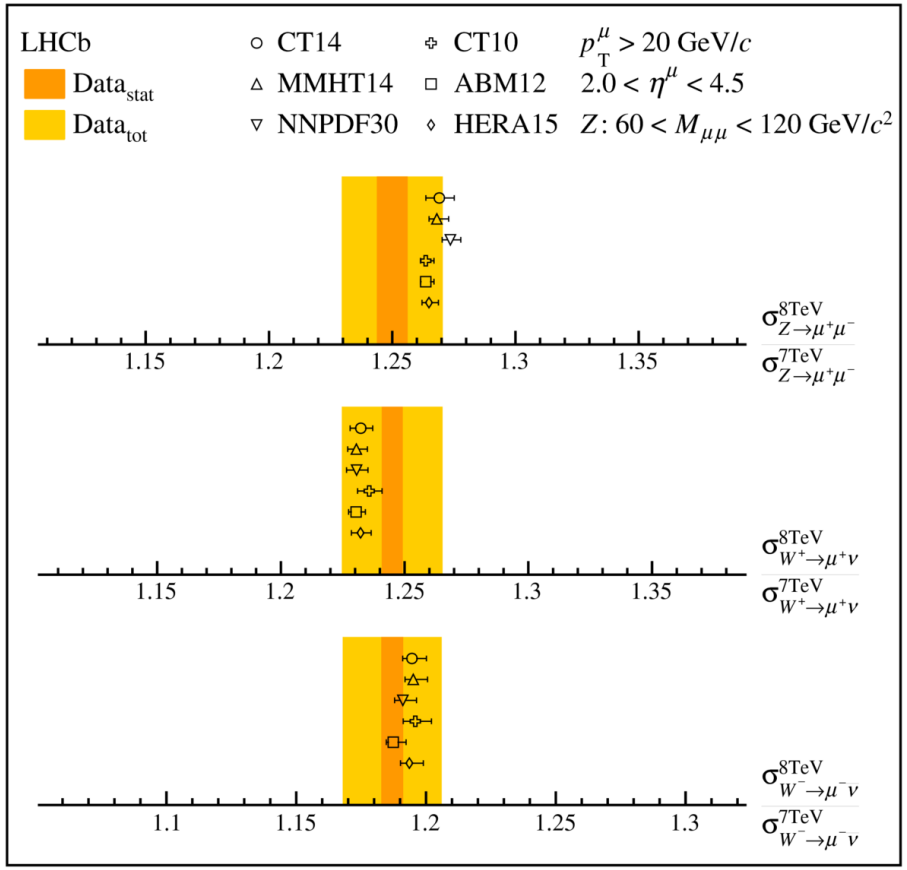
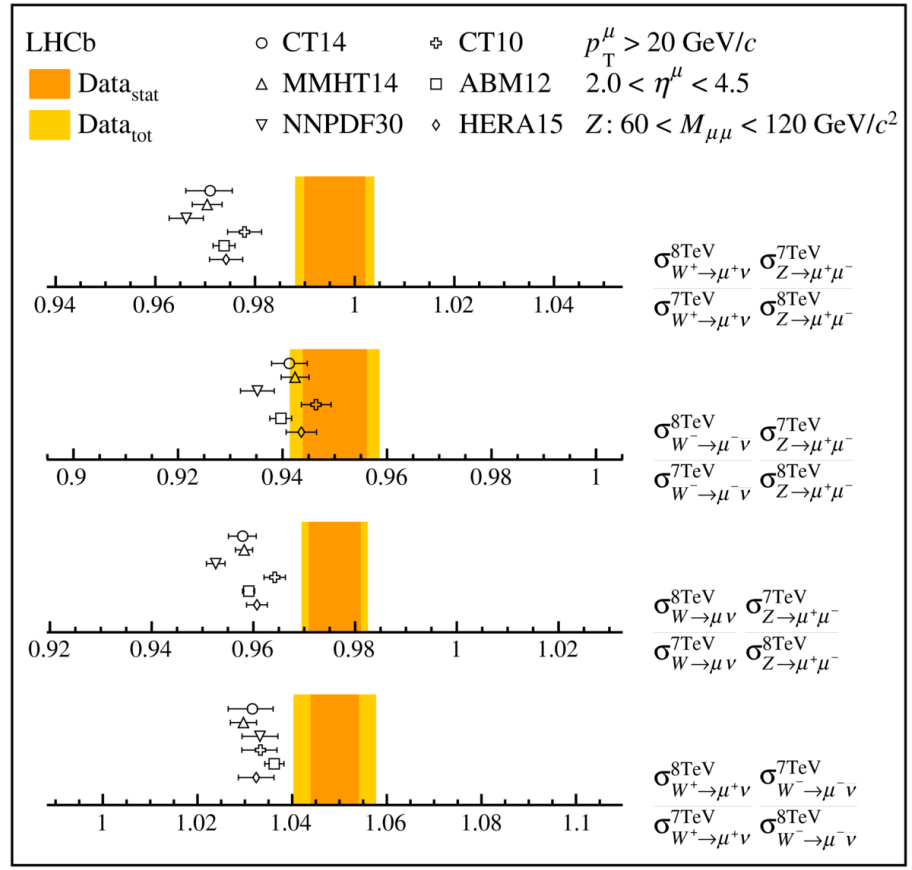
W/Z cross section ratios

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





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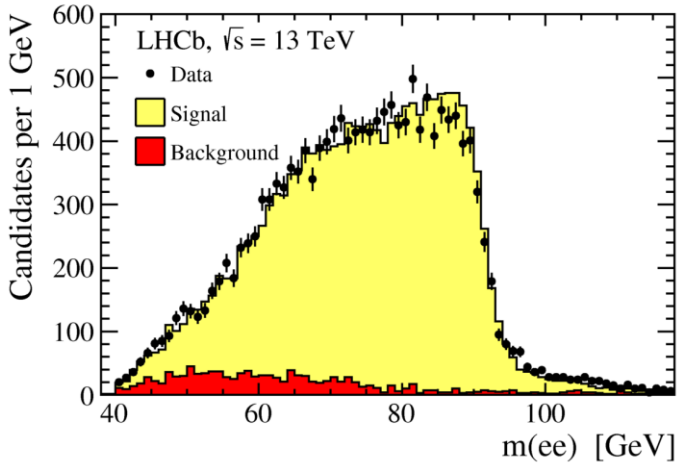
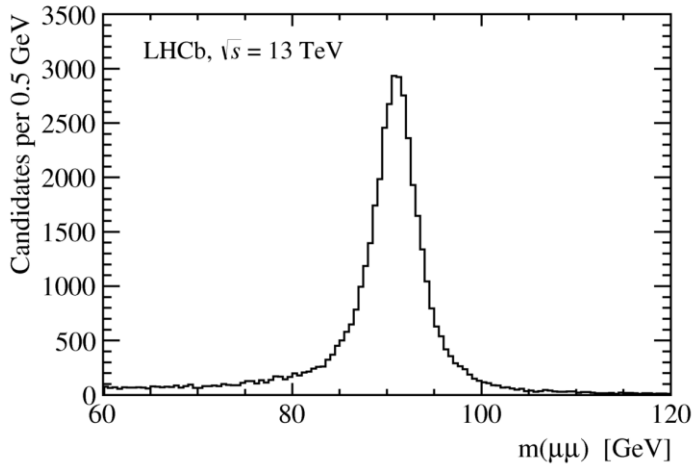
Z production at 13 TeV

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

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





$$\sigma_Z = 194.3 \pm 0.9\,(\text{stat.}) \pm 3.3\,(\text{syst.}) \pm 7.6\,(\text{lumi.})\ \text{pb}$$
$$(2.0 < \eta < 4.5, p_T > 20\ \text{GeV}, 60 < M_Z < 120\ \text{GeV})$$

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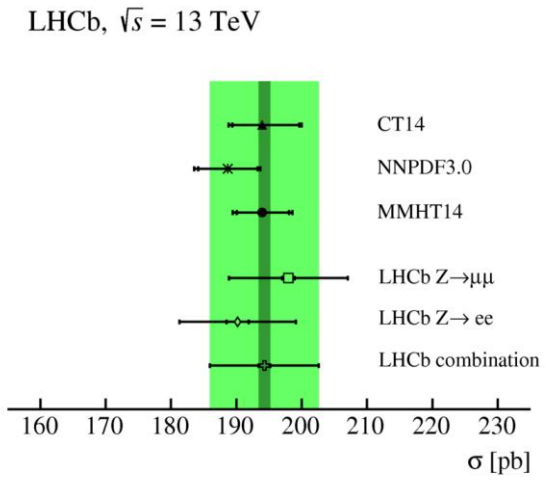
Z production at 13 TeV

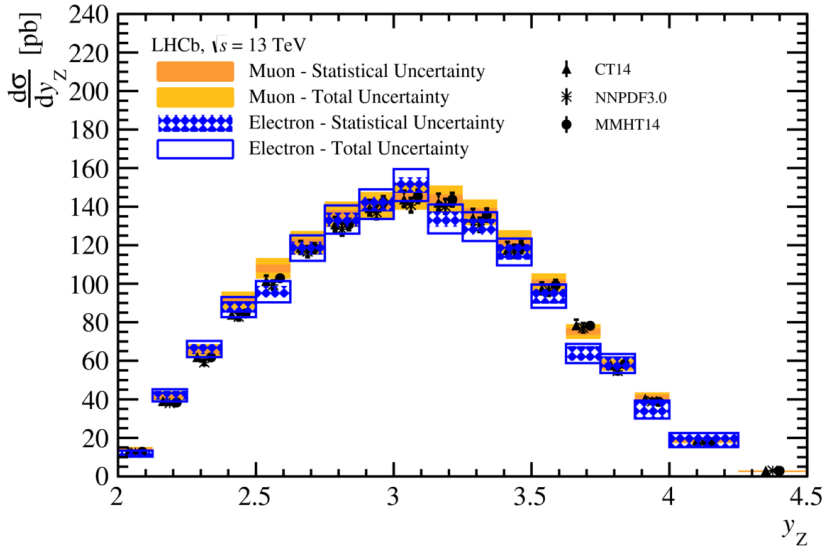
Good agreement between electron and muon channel

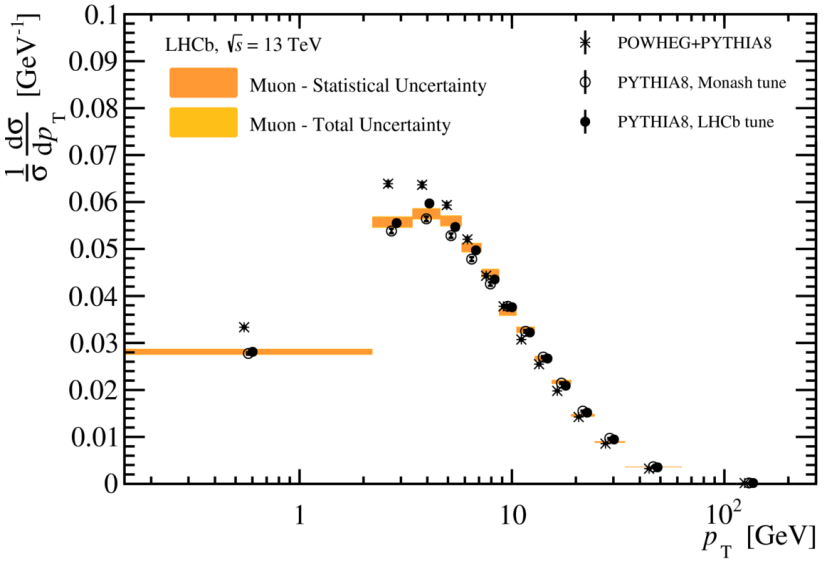
Differential cross-section agree with predictions

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

Largest systematic uncertainty from the luminosity measurement (3.9%)







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W/Z +jet production at 8 TeV

Important measurement to validate jet reconstruction at LHCb

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

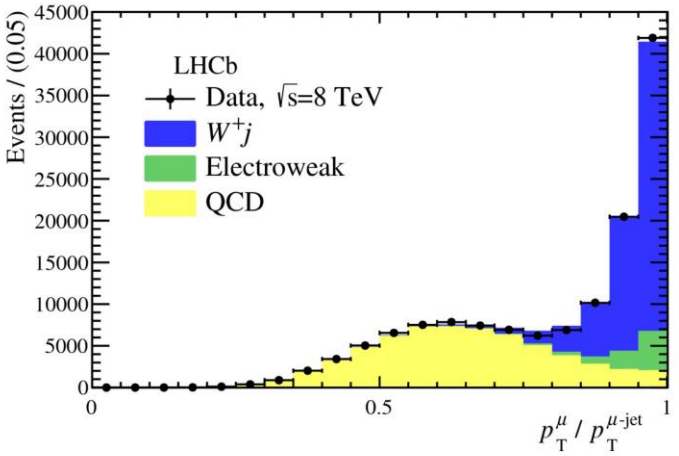
W events in muon channels

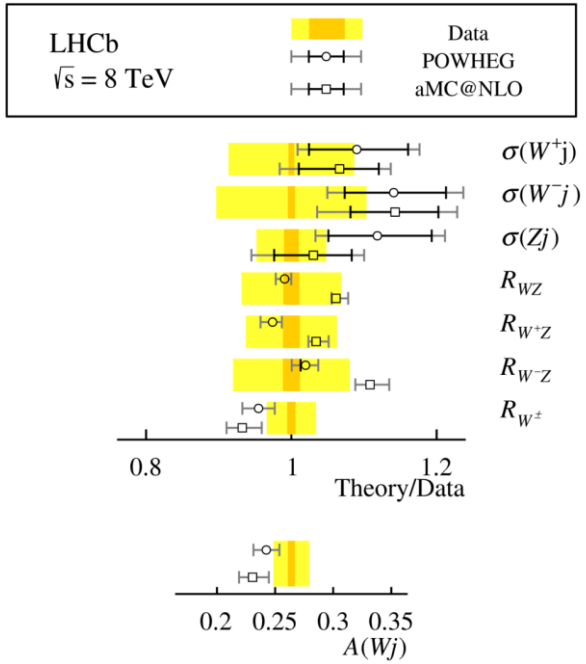
Fiducial volume for jets:

- $p_T(\text{jet}) > 20$ GeV
- $2.2 < \eta(jet) < 4.2$
- $\Delta R(jet, \mu) > 0.5$

Fit muon isolation $p_T^{\mu}/p_T^{\mu-\text{jet}}$ to extract signal

- Z purity: ~98%
- W purity: 46% (37%)





Good agreement with POWHEG and aMC@NLO predictions

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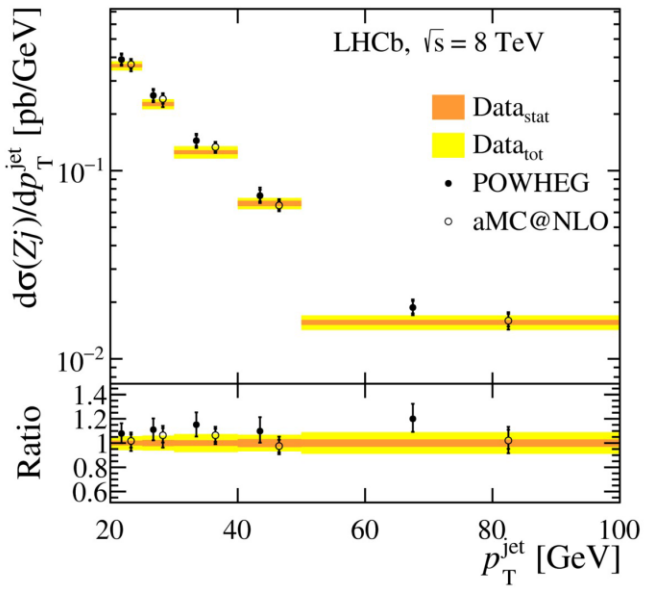
W/Z +jet production at 8 TeV

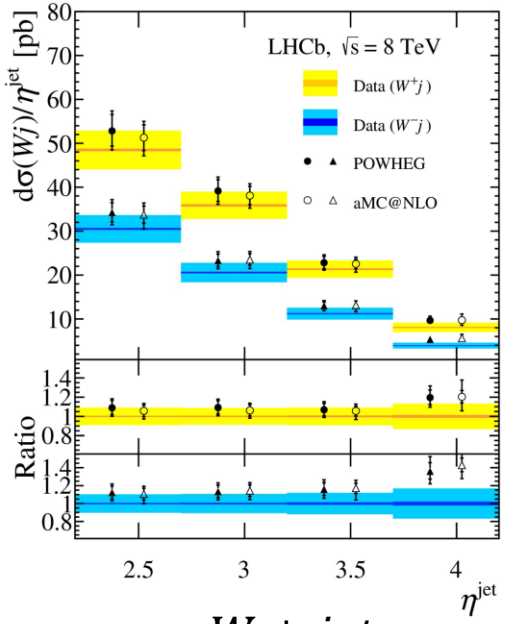
Differential cross-section measurements are in agreement with POWHEG and aMC@NLO predictions

Main uncertainties: jet energy scale ~ 10%, W purity ~ 7 %

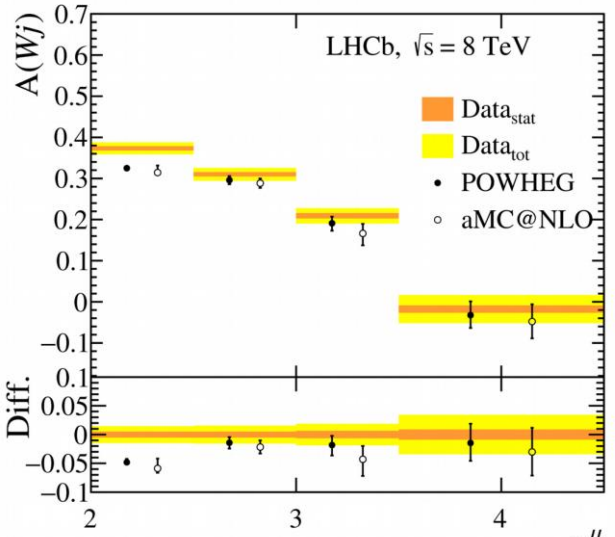
$$A = \frac{\sigma_{W^+ j} - \sigma_{W^- j}}{\sigma_{W^+ j} + \sigma_{W^- j}}$$



$Z + jet$



$W + jet$



$W + jet$ charge asymmetry

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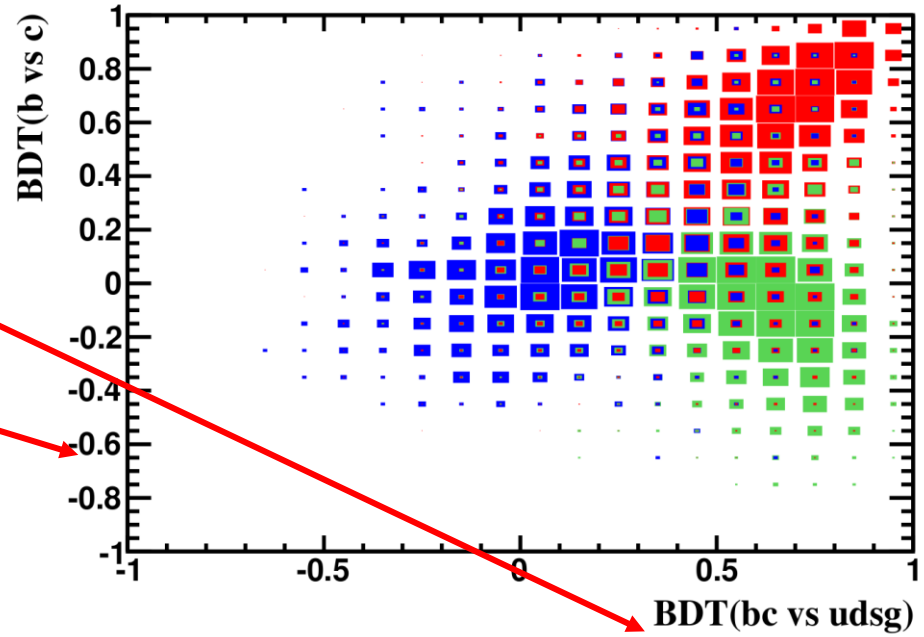
Jets heavy flavour identification

b,c tagging with secondary vertex in jet cone

Two BDTs to separate:

- **(1) BDT(bc|udsg): heavy flavour jets from light jets**
- **(2) BDT(b|c): b-jets from c-jets**



A good discrimination power is achieved!

J. Instrum. 10 (2015) P06013

$W + b\bar{b}/W + c\bar{c}$ production at 8 TeV

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

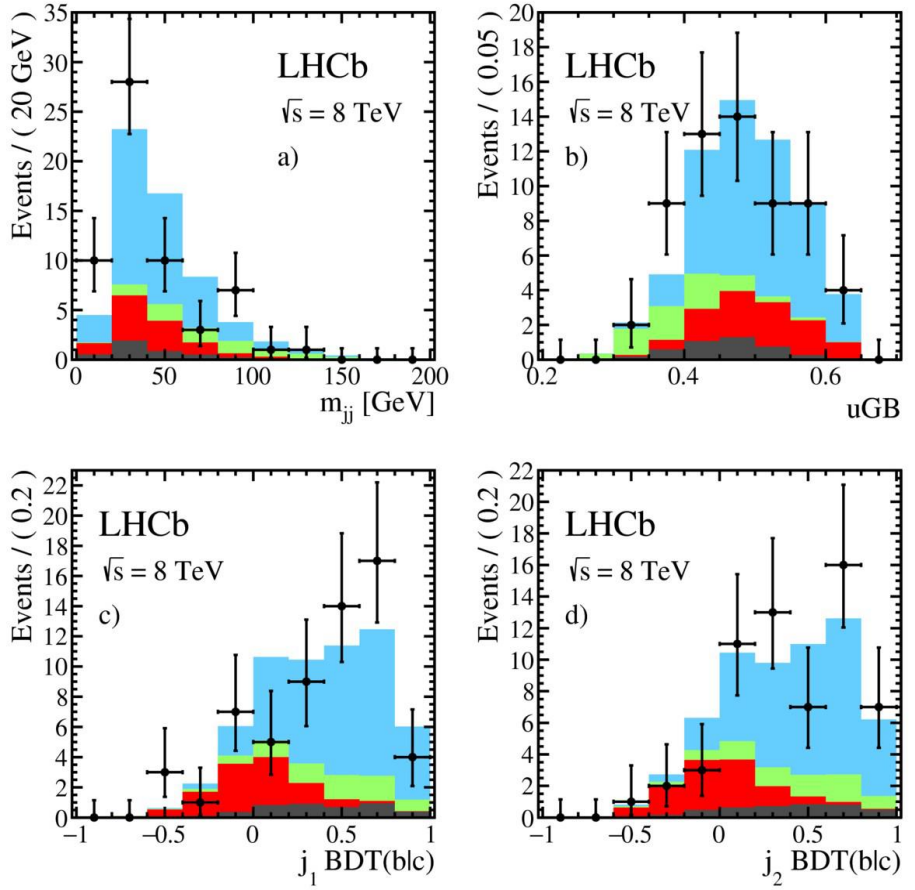
- $p_T(\text{jet1, 2}) > 20\ \text{GeV}, 2.2 < \eta(\text{jet1, 2}) < 4.2$
- $\Delta R(\text{jet1, 2}, \mu/e) > 0.5, \Delta R(\text{jet1}, jet2) > 0.5$

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^-, μ^+, μ^-

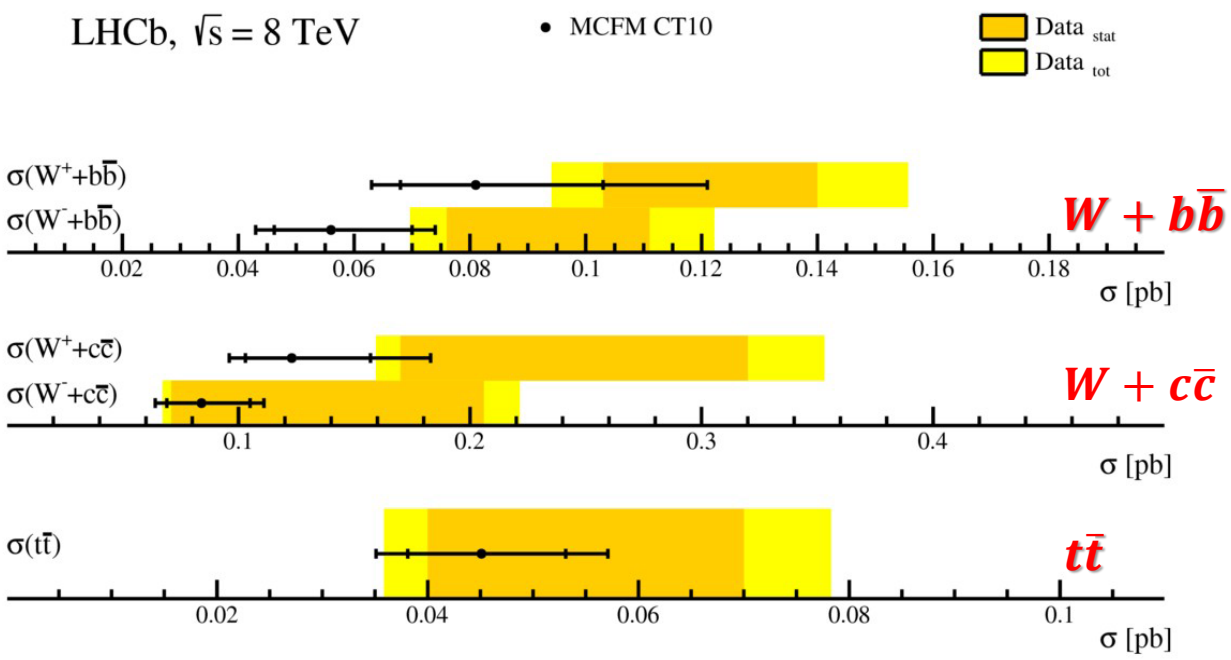


Phys. Lett. B767 (2017) 110

$W + b\bar{b}/W + c\bar{c}$ production at 8 TeV

Results in agreement with NLO predictions

(MCFM with CT10, interleaved with PYTHIA8)



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$Z \to b\bar{b}$ production at 8 TeV

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

Selections:

- $p_T(\text{jet1, 2}) > 20\ \text{GeV}, 2.2 < \eta(\text{jet1, 2}) < 4.2$
- $45 < M_{jj} < 165\ GeV$

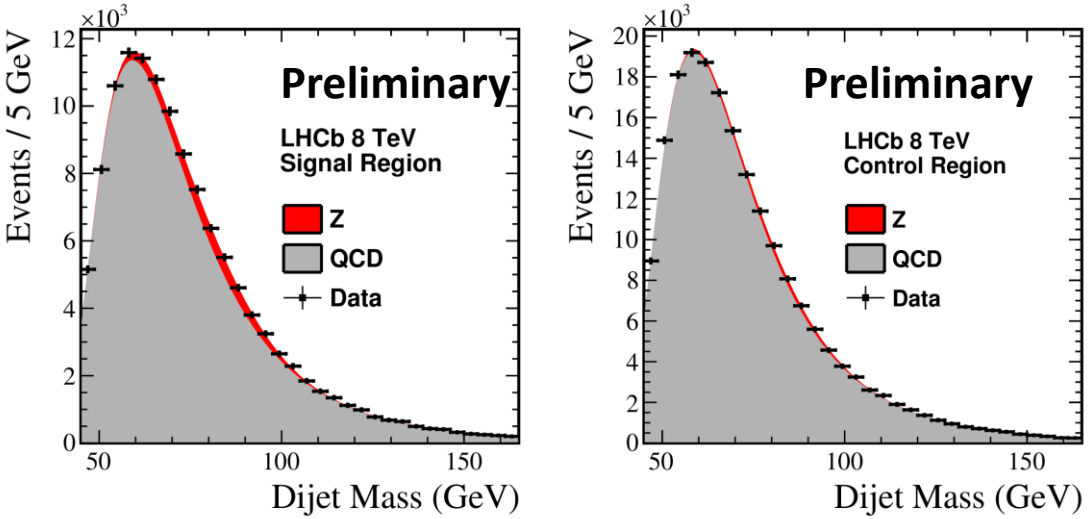
An additional balancing jet :

- $p_T(Z + \text{jet3})$ minimum to separate $Z \to b\bar{b}$ from QCD

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

Input variables: 3-jets kinematic

Simultaneous fit to M_{jj} in signal, control region, to get signal yield.



LHCb-PAPER-2017-024

$Z \to b\bar{b}$ production at 8 TeV

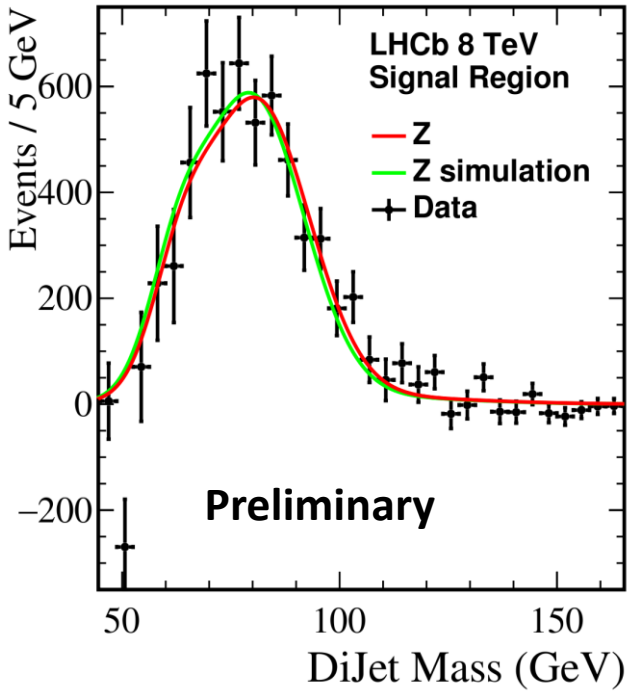
$Z \to b\bar{b}$ model is taken from simulation, but a jet Energy Scale factor ($E_{\mathrm{Data}}/E_{\mathrm{MC}}$) is measured in the fit

- 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:

$$\sigma(pp \to Z)\mathcal{B}(Z \to b\bar{b}) = 332 \pm 46(\mathrm{stat.}) \pm 59(\mathrm{syst.})\ \mathrm{pb}$$

Prediction:

$$\sigma(pp \to Z)\mathcal{B}(Z \to b\bar{b}) = 272^{+9}_{-12}(\mathrm{scale}) \pm 5(\mathrm{PDFs})\ \mathrm{pb}$$

LHCb-PAPER-2017-024

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**

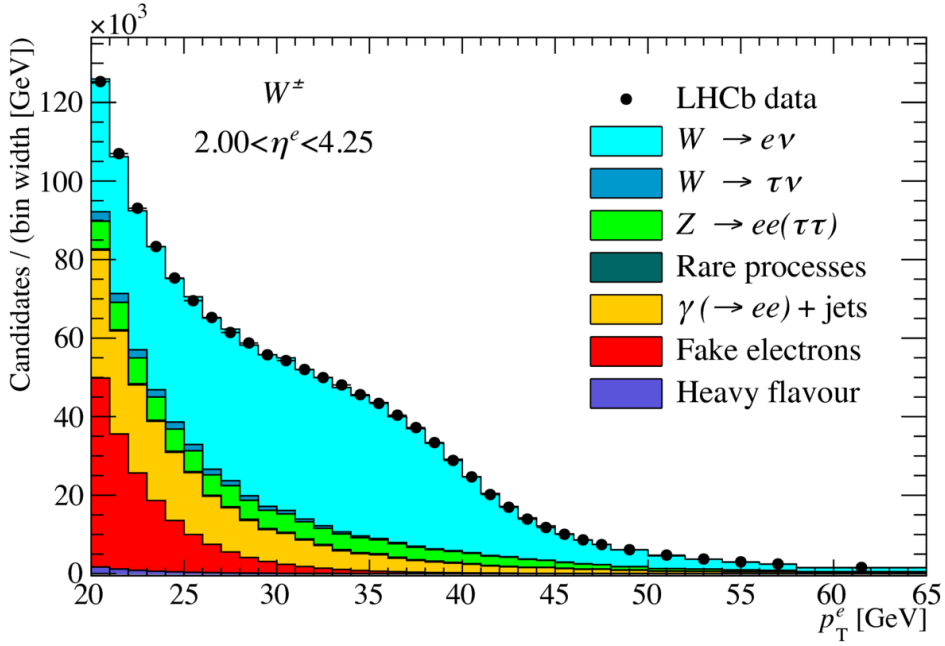
Backup

$W \to e\nu$ at 8 TeV

First measurement of W with electron final state at LHCb

$W \to e\nu$ channel:

- $2.0 < \eta < 4.5$
- $p_T > 20$ GeV
- Electron quality cuts
- Purity: ~60%



$$\sigma(W^{\pm} \to e^{\pm}\nu) = 1933.3 \pm 2.9(\text{stat.}) \pm 38.2(\text{syst.}) \pm 22.4(\text{lumi.})\ \text{pb}$$
$$(2.0 < \eta < 4.5, p_T > 20\ \text{GeV})$$

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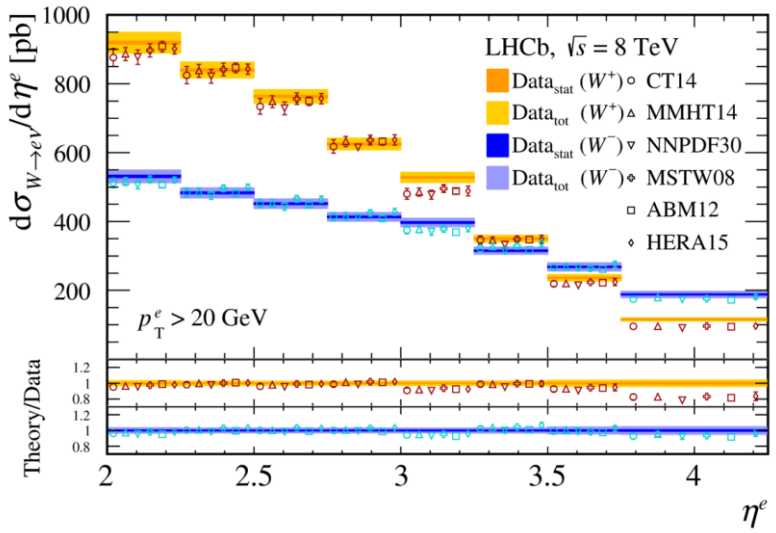
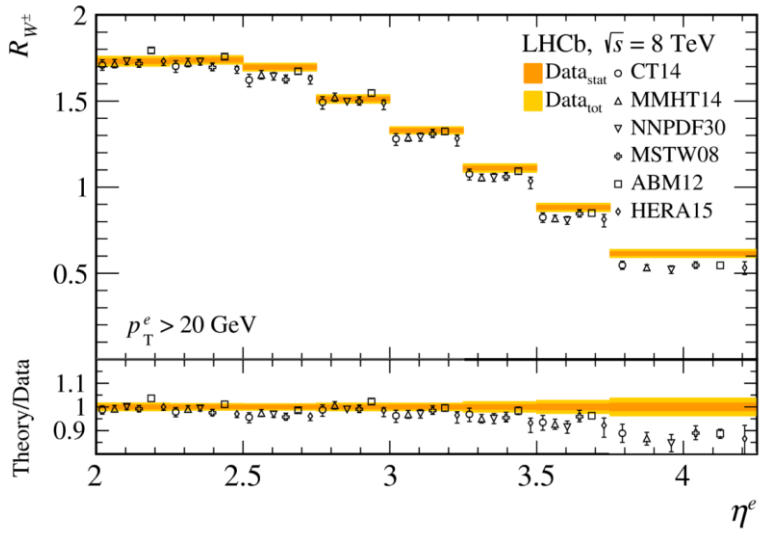
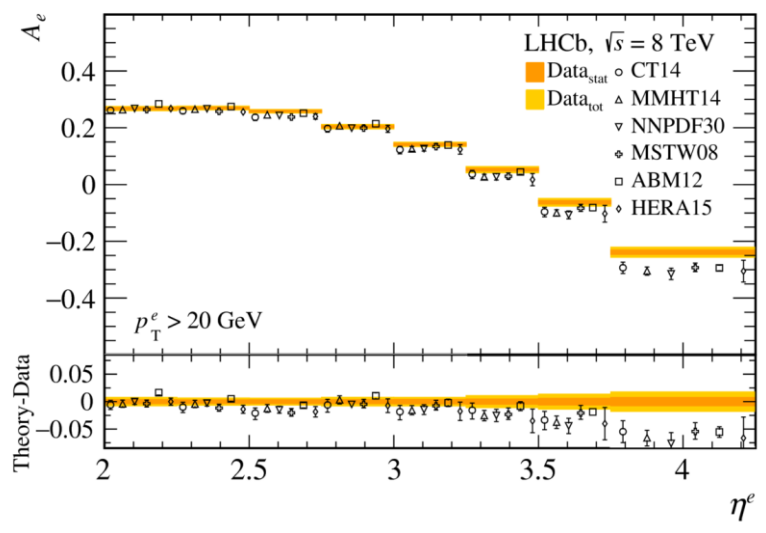
$W \to e\nu$ at 8 TeV







Agreement between measured results and NNLO calculations with different PDF sets

Precision test of lepton universality: $\frac{B(W\to e\nu)}{B(W\to \mu\nu)} = 1.020 \pm 0.002 \pm 0.019$

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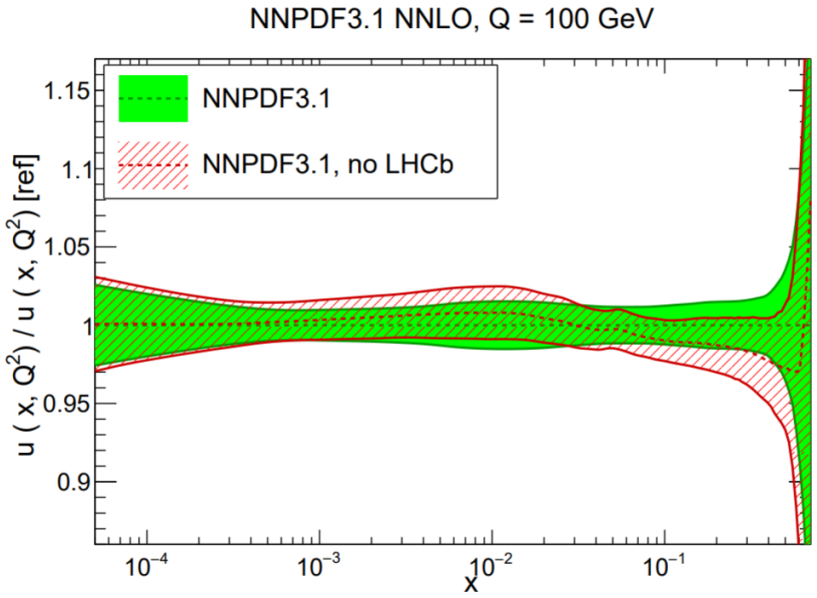
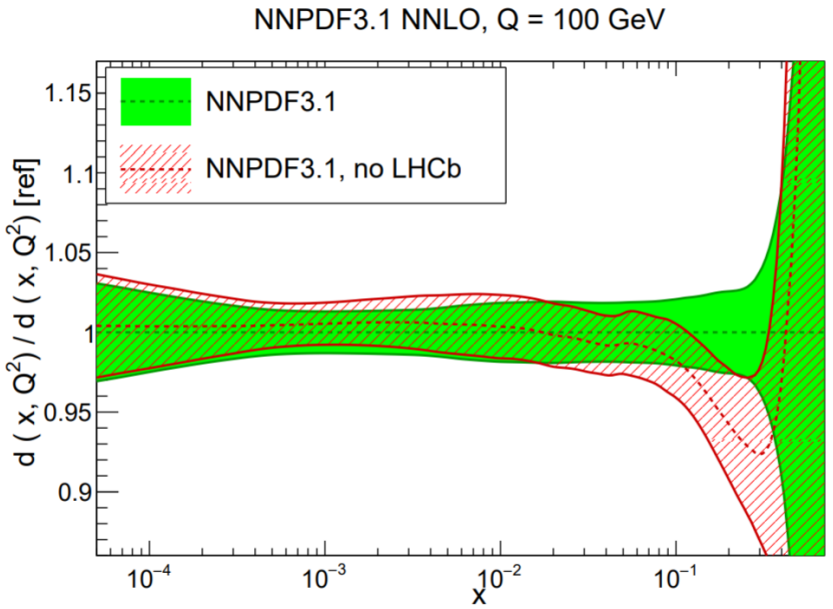
Impact of LHCb results on NNPDF3.1

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





arXiv:1705.04468