# Latest results on single electroweak boson production from LHCb experiment

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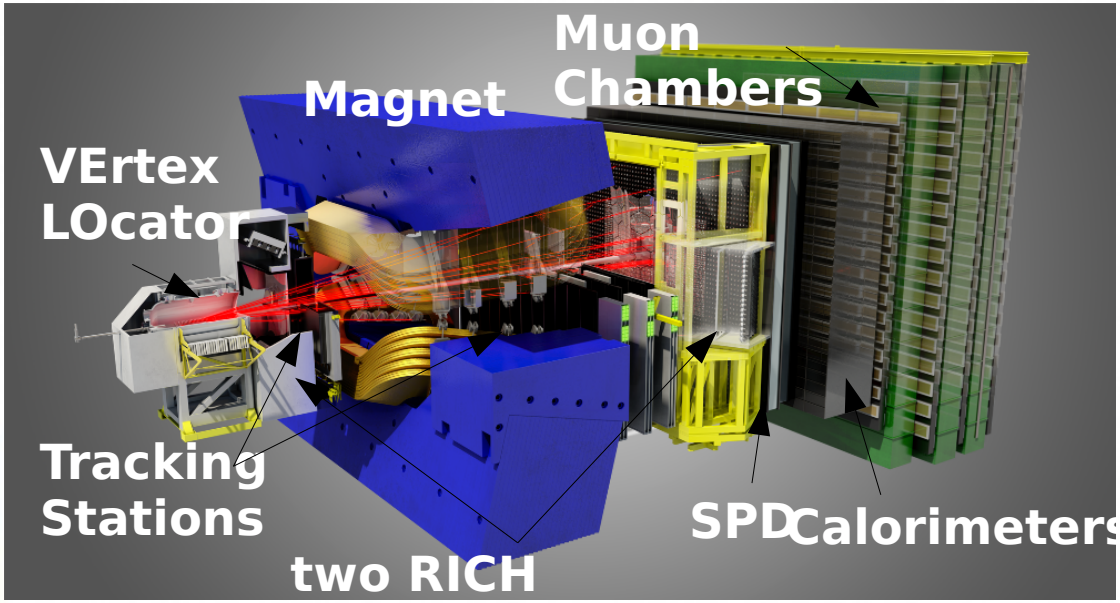
**On behalf of the LHCb collaboration**

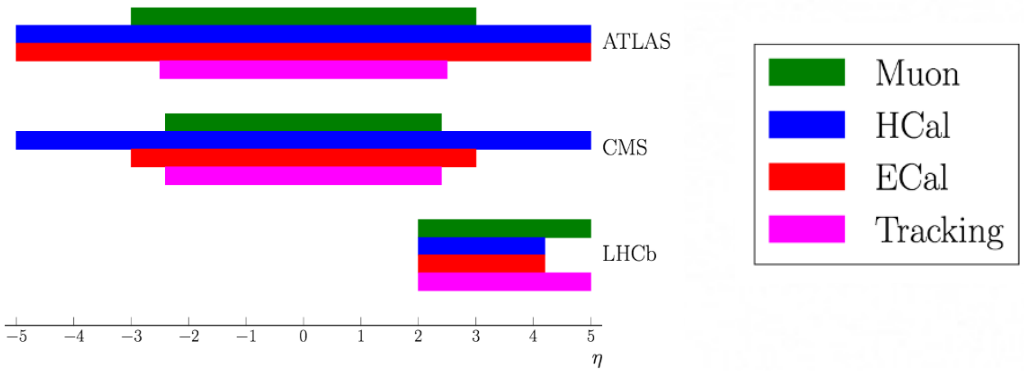
**LHCP, 08-06-2018, Bologna, Italy**

# LHCb: a general purpose forward detector

**JINST 3 (2008) S08005**




- Forward region: **unique acceptance** within the LHC experiments ($2 < \eta < 5$).
- **Momentum resolution**: 0.4% at 5 GeV and 0.6% at 100 GeV.
- **Muon ID efficiency**: 97% with 1-3% $\mu \rightarrow \pi$ mis-identification.
- **Electron reconstruction:** bremsstrahlung recovery and well-measured direction.
- **Excellent vertex reconstruction:** tagging of b and c jets.




**LHCb demonstrated its capability in EW and jet physics** → **General purpose forward detector**

# LHCb electroweak program

**LHCb has a wide electroweak program. Recent measurements presented today:**

- $Z \to \mu\mu$ and $Z \to ee$ @ 13 TeV
- $W \to e\,\nu$ @ 8 TeV
- W/Z + jets @ 8 TeV
- $Z \to b\bar{b}$ @ 8 TeV
- $Z \to \tau\tau$ @ 8 TeV **NEW**

# Motivations

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

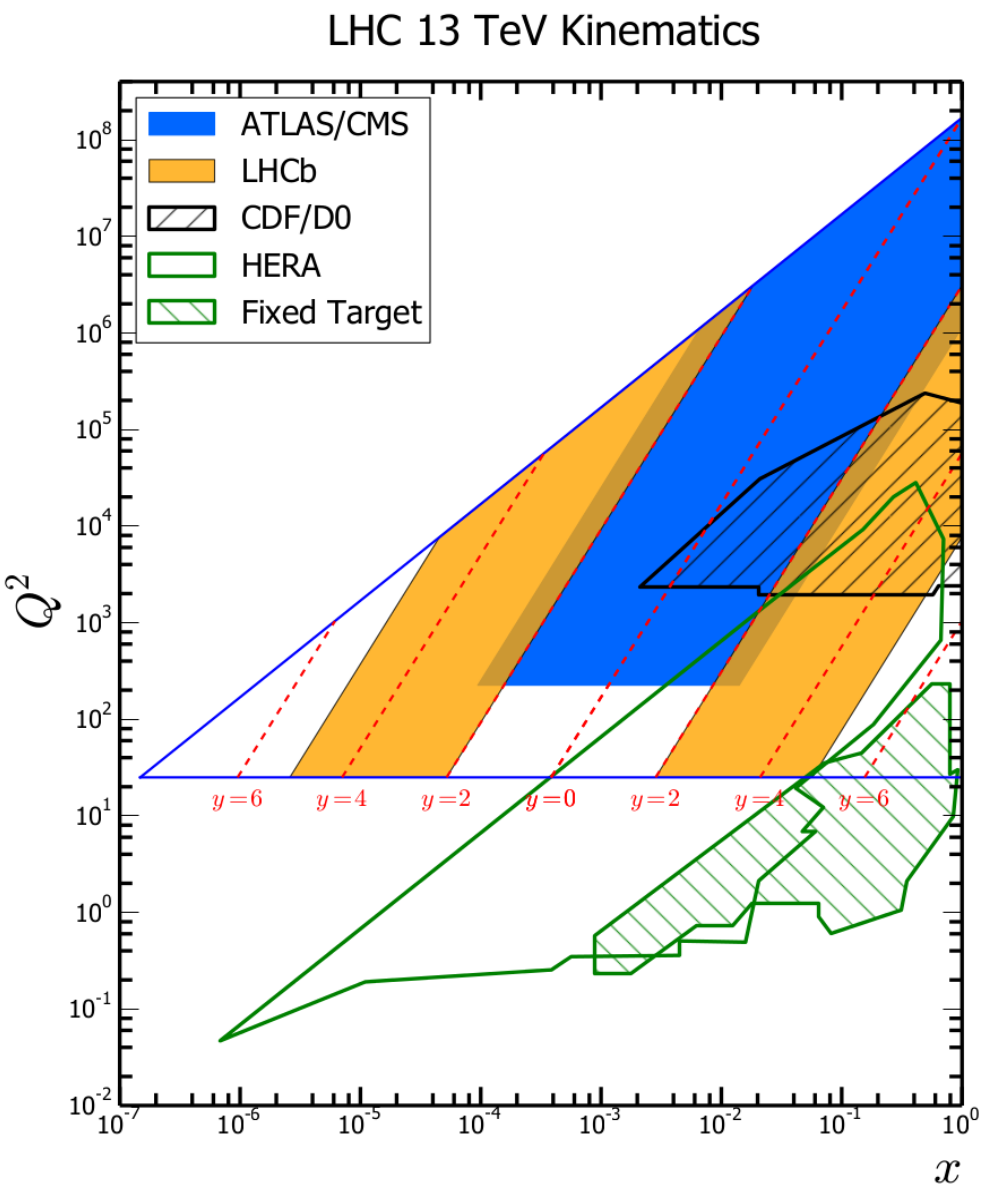
- Cross-sections measurements of **W and Z production in the forward acceptance** are important tests of the Standard Model.

- 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.**

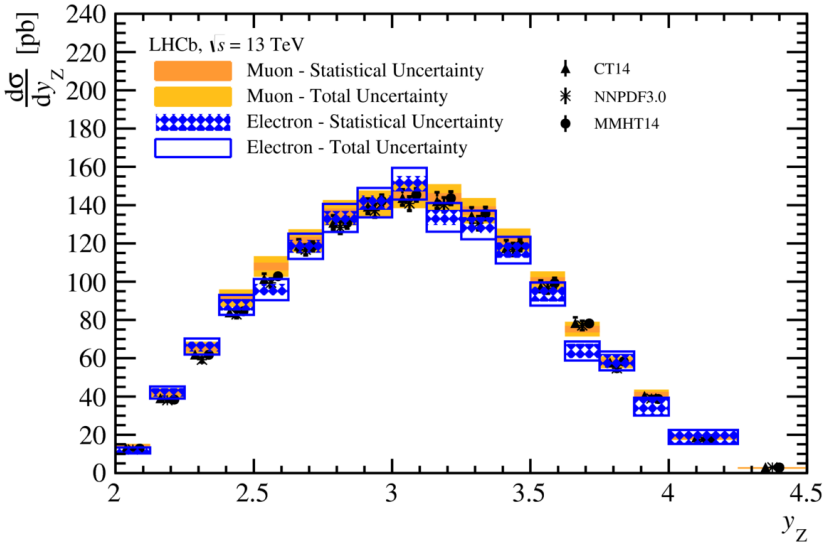
- We can aim to precisely measure fundamental parameters of the SM: **the electroweak mixing angle, the W mass** etc.

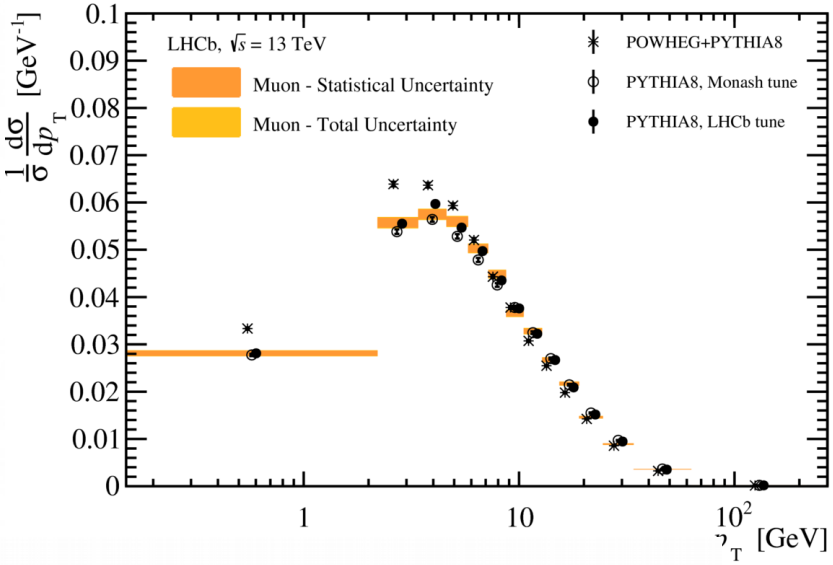


# Z production at 13 TeV

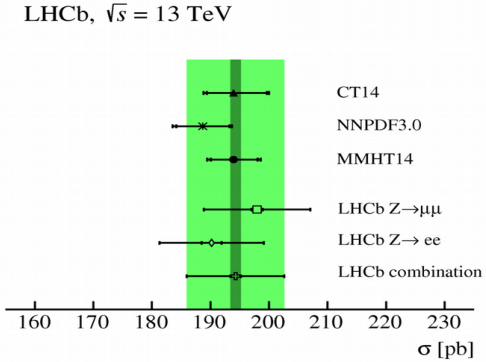
**JHEP 09 (2016) 136**

- Lepton final states Z → μμ and Z → 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 → μμ and 92.2% for Z → ee.



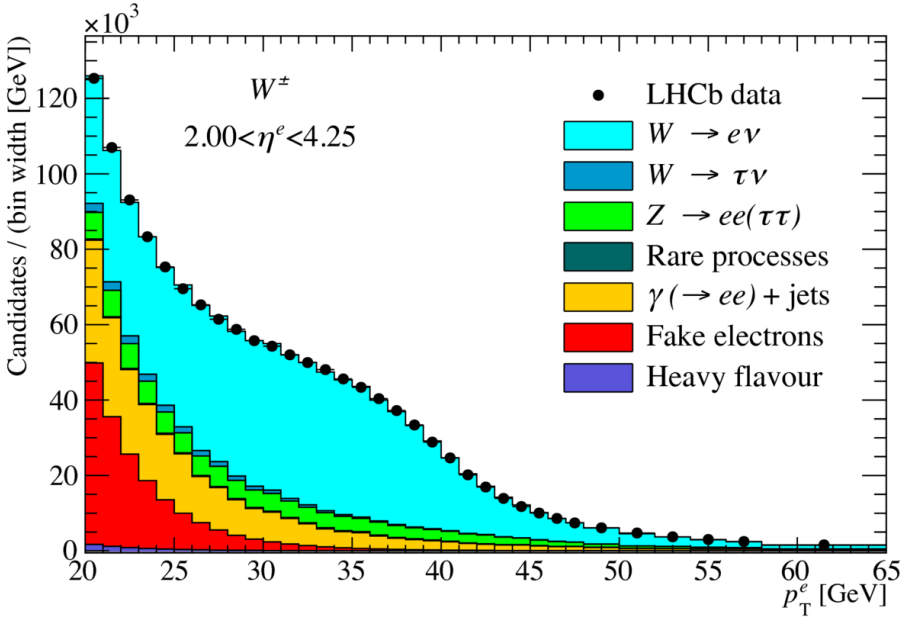

- Differential cross-sections compatible with predictions.
- Uncertainty dominated by the luminosity measurement (3.9%) → not final calibration.
- Z → μμ and Z → ee measured cross-sections are compatible within the uncertainities.

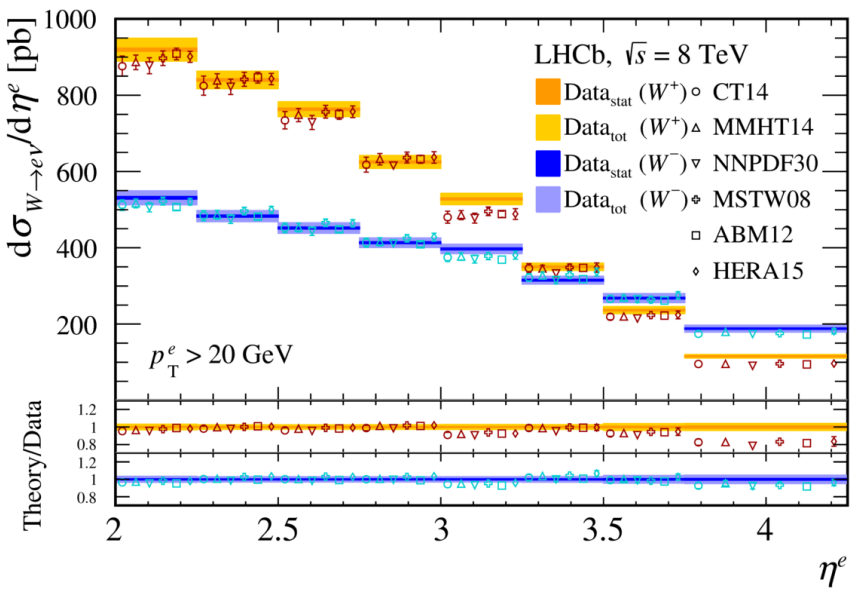


# W → eν production at 8 TeV

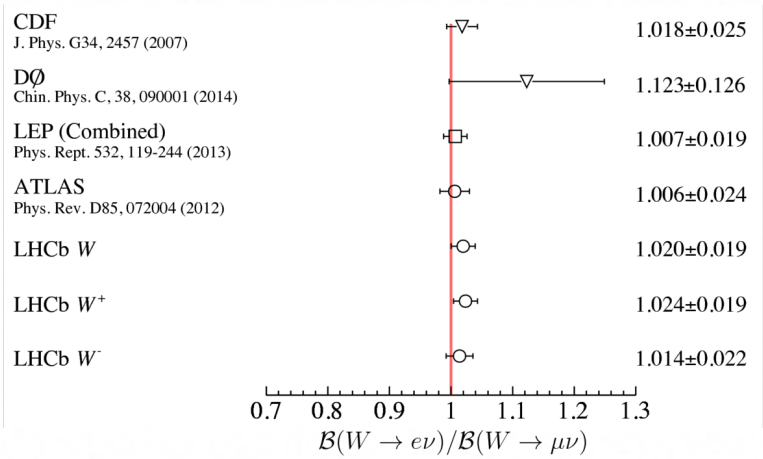
**JHEP 10 (2016) 030**

- 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 η is compatible with the prediction.




B(W → eν )/B(W → μν)




W → μν @ 8 TeV: **JHEP 01 (2016) 155**

# W/Z + jet production at 8 TeV

## JHEP 05 (2016) 1-23

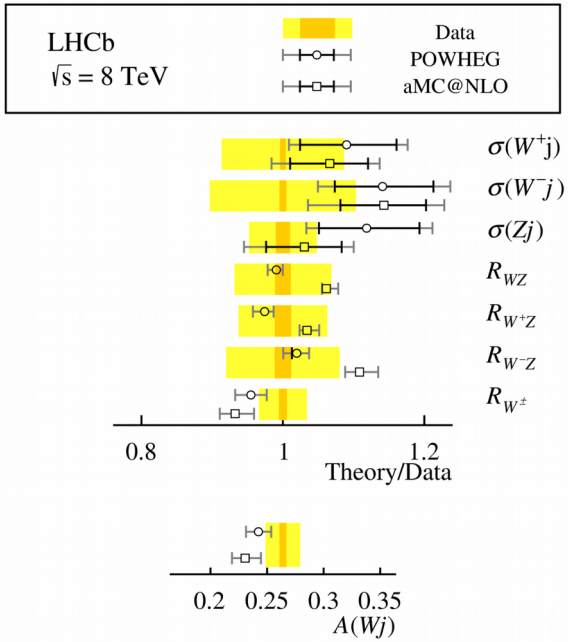
- **Important measurement to validate the jet reconstruction at LHCb and to probe PDFs in the forward region.**

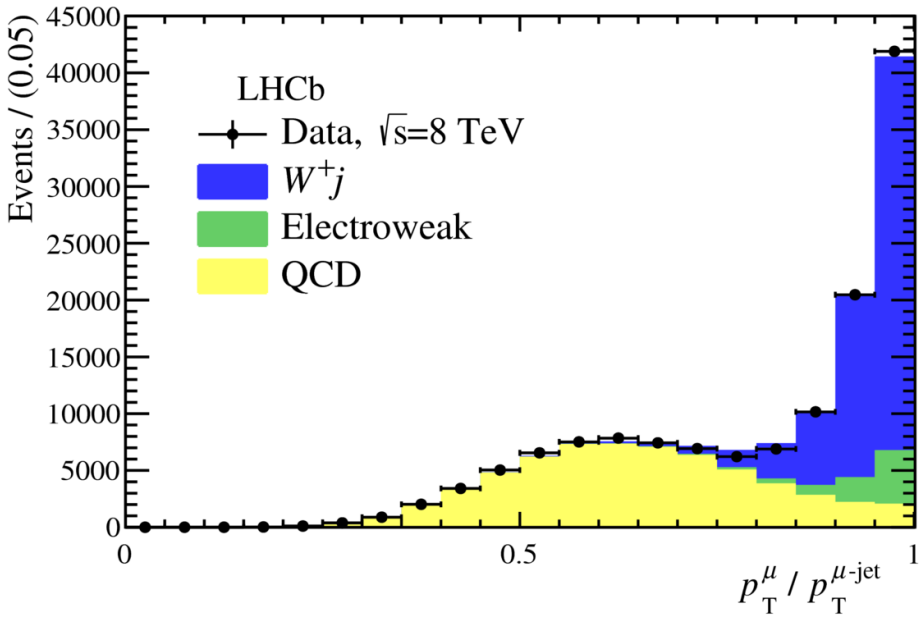
- LHCb standard jets: anti-kt with R=0.5

- W → μν and Z → μμ decay channels.

- $p_T$(jet) > 20 GeV, 2.2 < η(jet) < 4.2, ΔR(jet,μ)>0.5

- Fit to the muon isolation $p_T(\mu)/p_T(\mu\text{-jet})$ to extract $W^+$+jet, $W^-$+jet purity.




- Purity of Z+jet: 97.8%

- Systematic uncertainty on the cross-section measurement are dominated by the purity determination and by the jet energy scale/resolution.

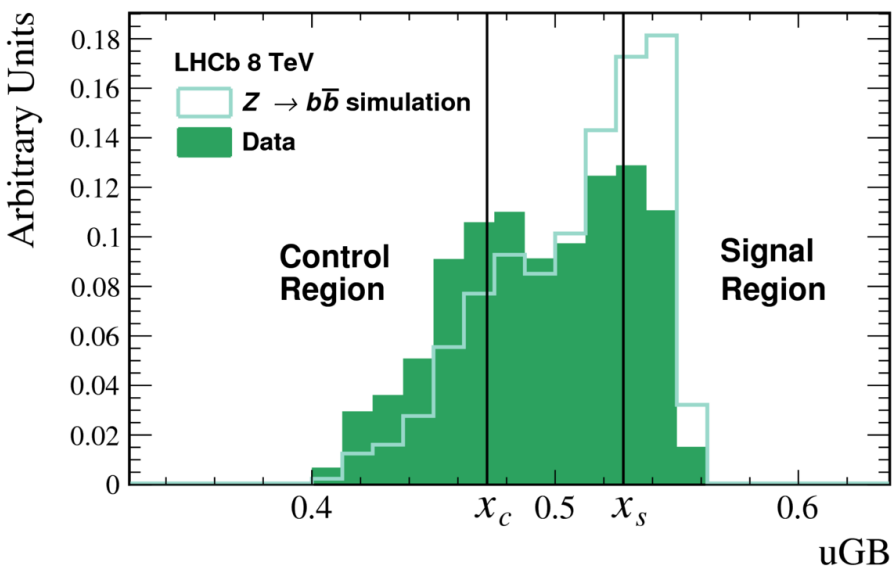
- W/Z ratios and $W^+/W^-$ asymmetry are also determined.

- Measurements are in good agreement with POWHEG and aMC@NLO predictions.

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

**Phys. Lett. B776 (2017) 430-439**

- 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: $p_T(jet_{1,2}) > 20$ GeV, $2.2 < \eta(jet_{1,2}) < 4.2$, $45 < m_{jj} < 165$ GeV

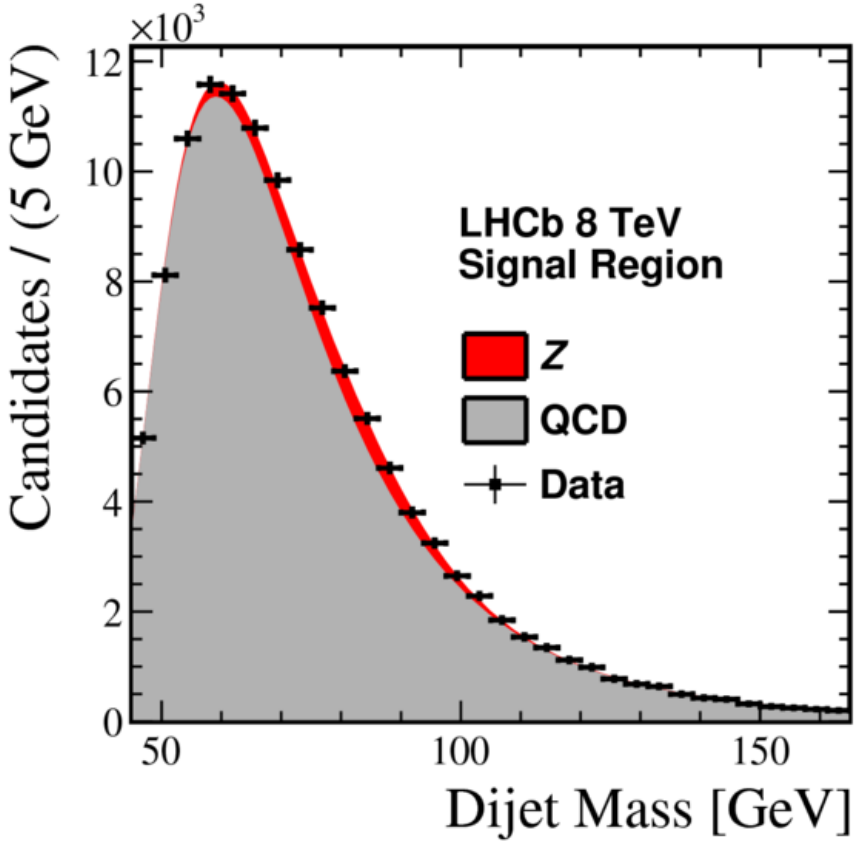


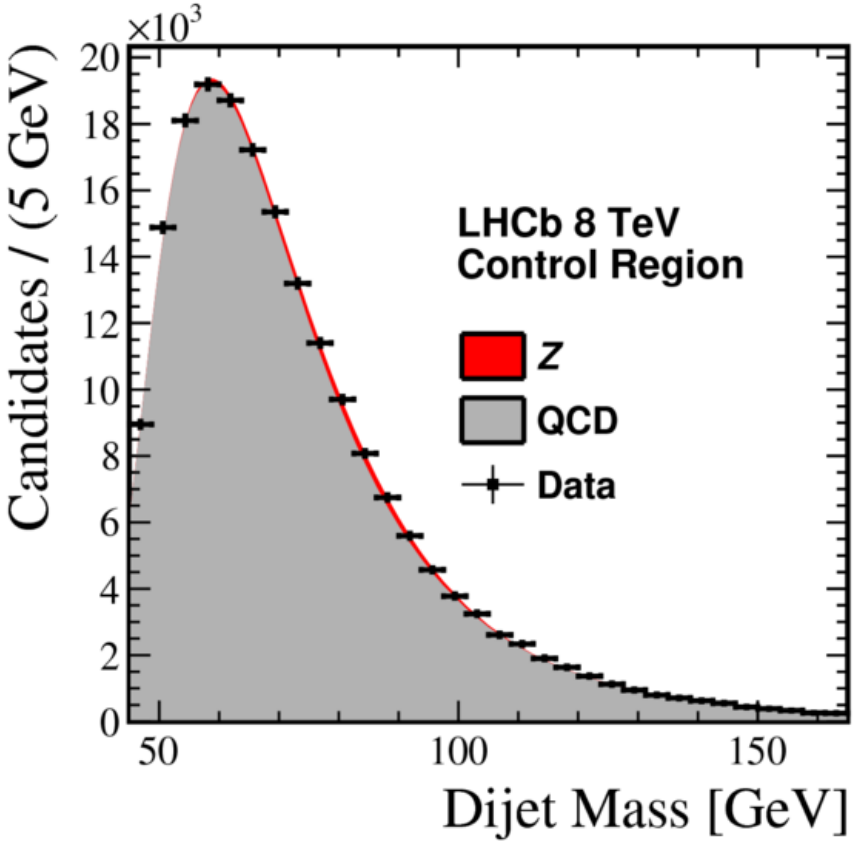

- An additional **balancing jet** ($jet_3$) that makes $p_T(Z+jet_3)$ minimum is selected to separate $Z \to b\bar{b}$ from QCD.
- A BDT is trained to separate $Z \to b\bar{b}$ from QCD, input observables are related to the 3-jets kinematic.
- Simultaneous fit to $m_{jj}$ in signal (enhanced $Z \to b\bar{b}$ yield) and control (low $Z \to b\bar{b}$ yield) regions, to measure the Z yield.

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

**Phys. Lett. B776 (2017) 430-439**

- $Z \to b\bar{b}$ model is taken from simulation, but a Jet Energy Scale factor ($E_{data}/E_{MC}$) is measured in the fit.
- QCD model: Pearson IV distribution.



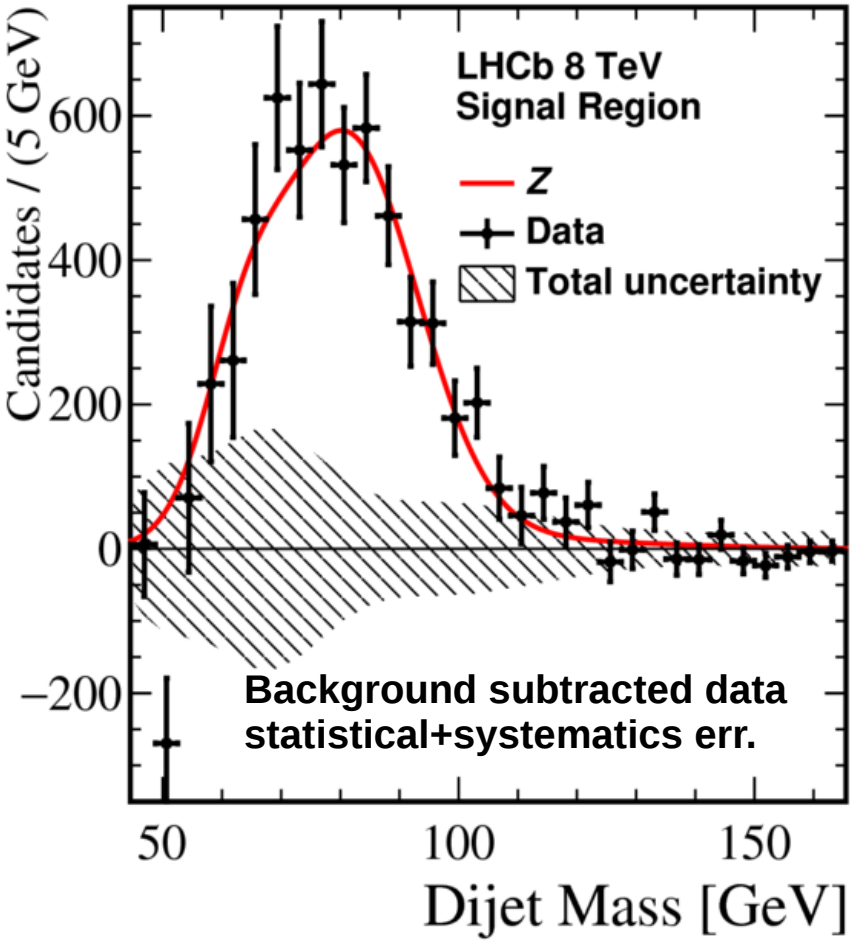



# $Z \to b\bar{b}$ production at 8 TeV

**Phys. Lett. B776 (2017) 430-439**

- $Z \to b\bar{b}$ peak mean is ~ 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)




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

- The $Z \to bb$ cross-section measurement is compatible with the aMC@NLO prediction.

**Measured:**

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

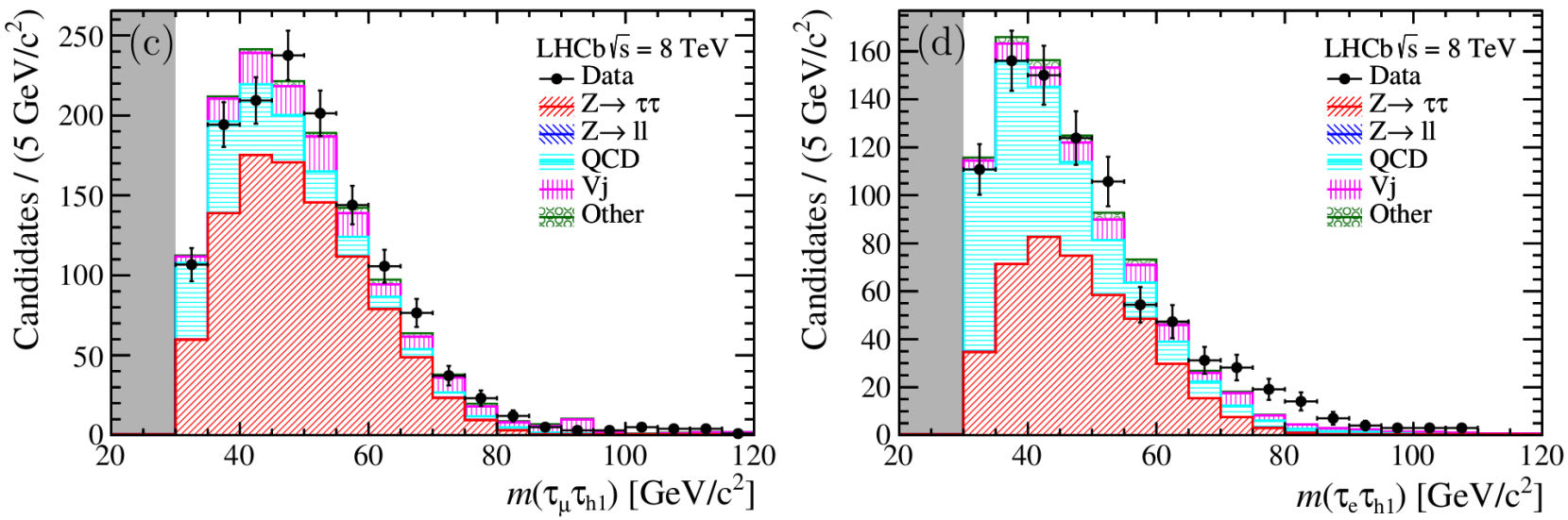
**Prediction:**

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

# $Z \to \tau\tau$ production at 8 TeV

**LHCb-PAPER-2018-016 NEW**

- Measurement of Z decay in di-tau final state.
- Probe of high enery tau reconstruction at LHCb.
- The comparison with $Z \to \mu\mu$ and $Z \to ee$ is a test of lepton flavour universality.
- Tau is reconstructed in leptonic (muon or electron) or hadronic (one or three hadrons) final state. Seven streams: $\tau_e\tau_e$, $\tau_\mu\tau_\mu$, $\tau_\mu\tau_{h1}$, $\tau_e\tau_{h1}$, $\tau_\mu\tau_{h3}$, $\tau_e\tau_{h3}$, $\tau_\mu\tau_e$.



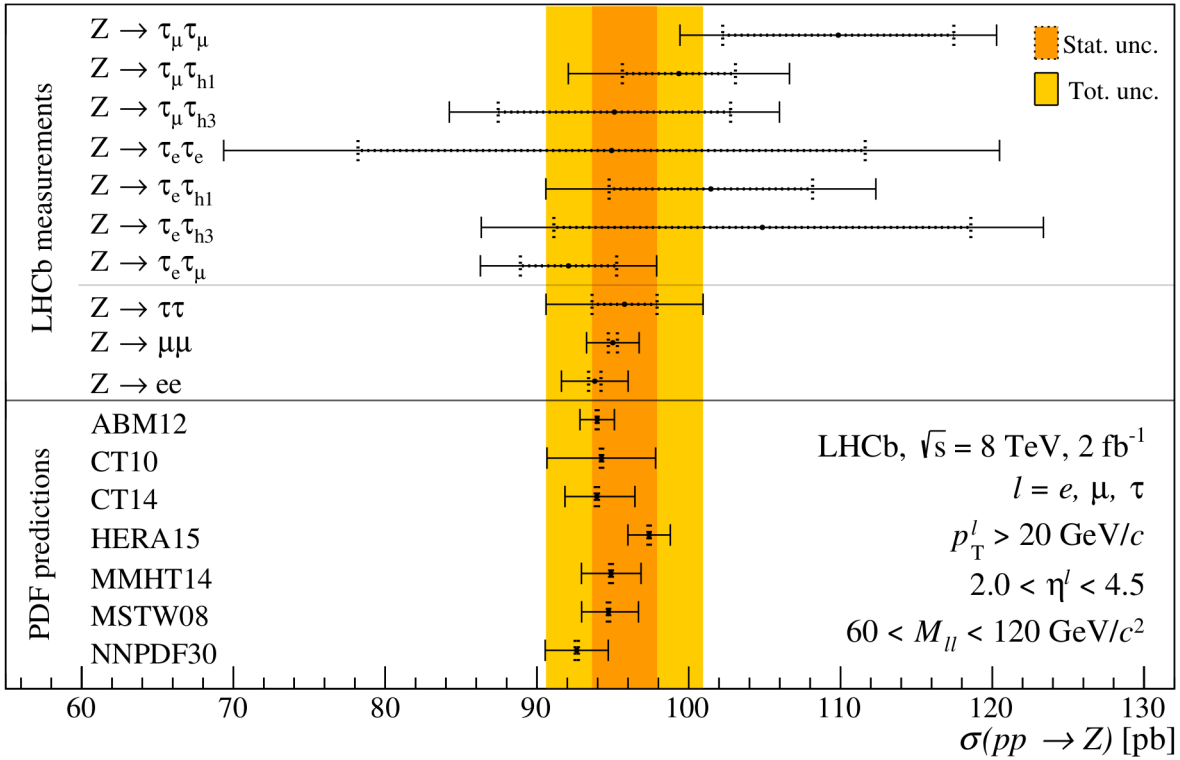

- Main backgrounds obtained with data-driven techniques.
- Signal yield = data minus expected background.

# Z → ττ production at 8 TeV

**LHCb-PAPER-2018-016 NEW**

- Cross sections are measured in the fiducial region with 2.0 < η(τ) < 4.5, pT(τ)> 20 GeV and 60 < m(ττ) < 120 GeV.

- The measurements are compatible with NNLO predictions and different PDFs sets.




**Lepton flavour universality test**

$$\frac{\sigma^{8\,\mathrm{TeV}}_{pp\to Z\to\tau^+\tau^-}}{\sigma^{8\,\mathrm{TeV}}_{pp\to Z\to\mu^+\mu^-}} = 1.008 \pm 0.055 \quad , \quad \frac{\sigma^{8\,\mathrm{TeV}}_{pp\to Z\to\tau^+\tau^-}}{\sigma^{8\,\mathrm{TeV}}_{pp\to Z\to e^+e^-}} = 1.021 \pm 0.057\,,$$

# Conclusions

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

- We performed measurements of **W/Z 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 can be used to test Lepton Flavour Universality.**

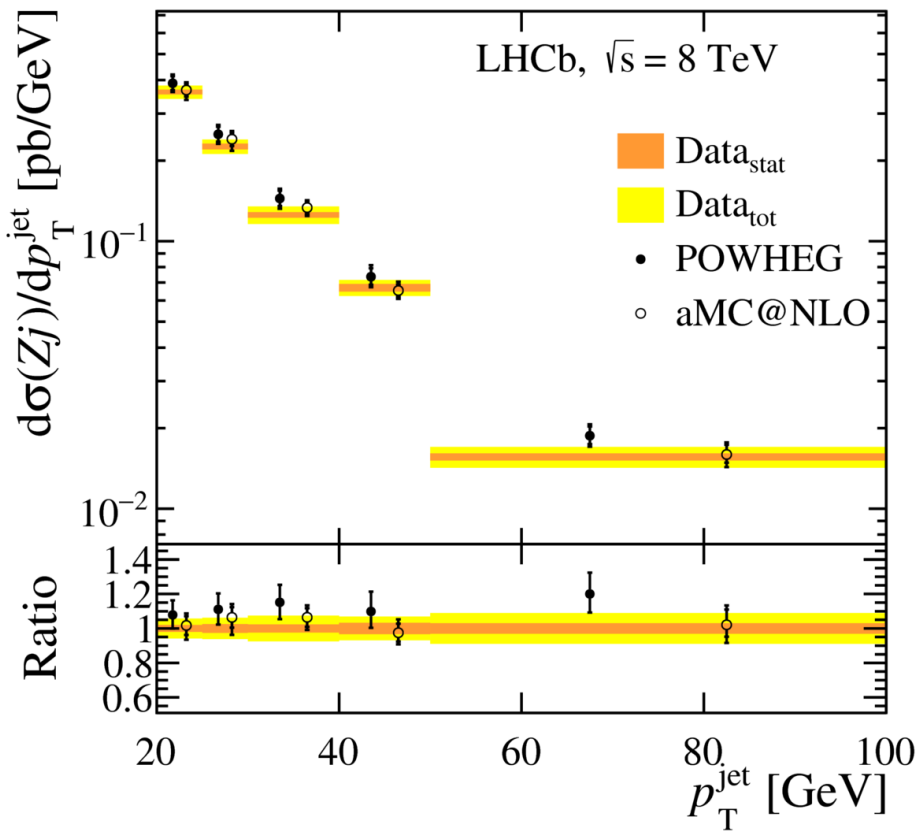
- A lot of work is in progress for new exciting measurements!

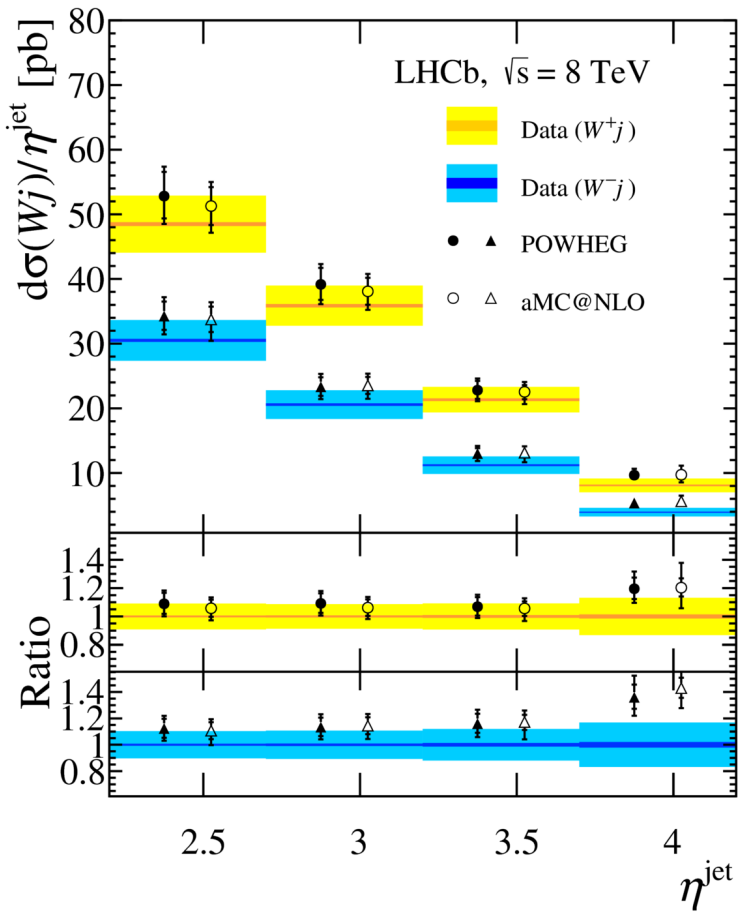
Thanks for your attention!

# W/Z + jet production at 8 TeV

**JHEP 05 (2016) 1-23**

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



# Jets heavy flavour identification

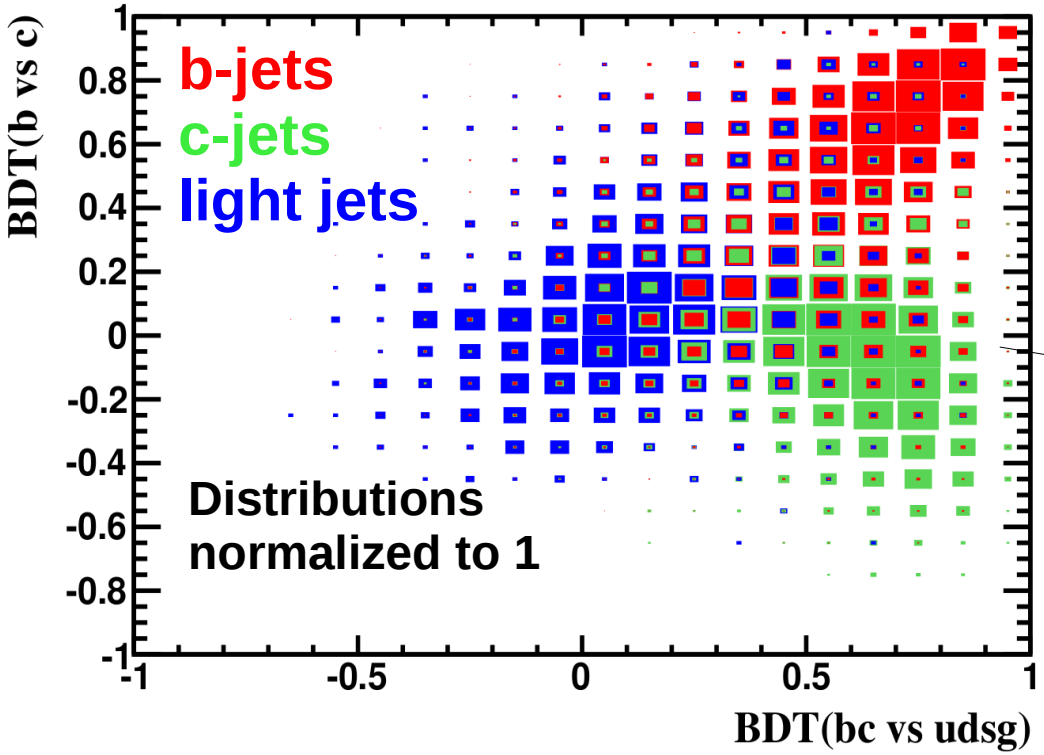
**JINST 10 (2015) P06013**

• Jets are heavy flavour tagged if one Secondary Vertex compatible with a b or c hadron decay is found with ΔR < 0.5 from the jet axis.

**BDT(bc|udsg)**
To separate **heavy flavour** jets from **light** jets

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

**BDT(b|c)**
To separate **b-jets** from **c-jets**




**A good discrimination power is achieved!**

Dedicated talk in QCD session last tuesday

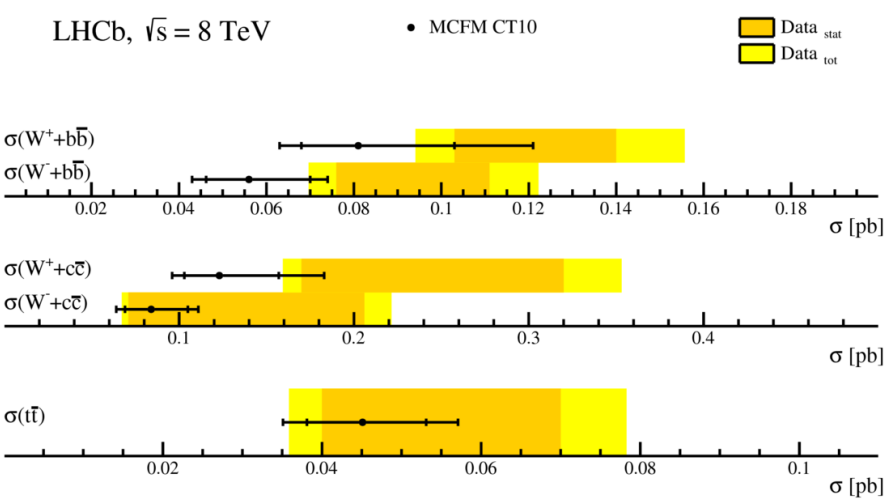
# $W+b\bar{b}/W+c\bar{c}$ production at 8 TeV

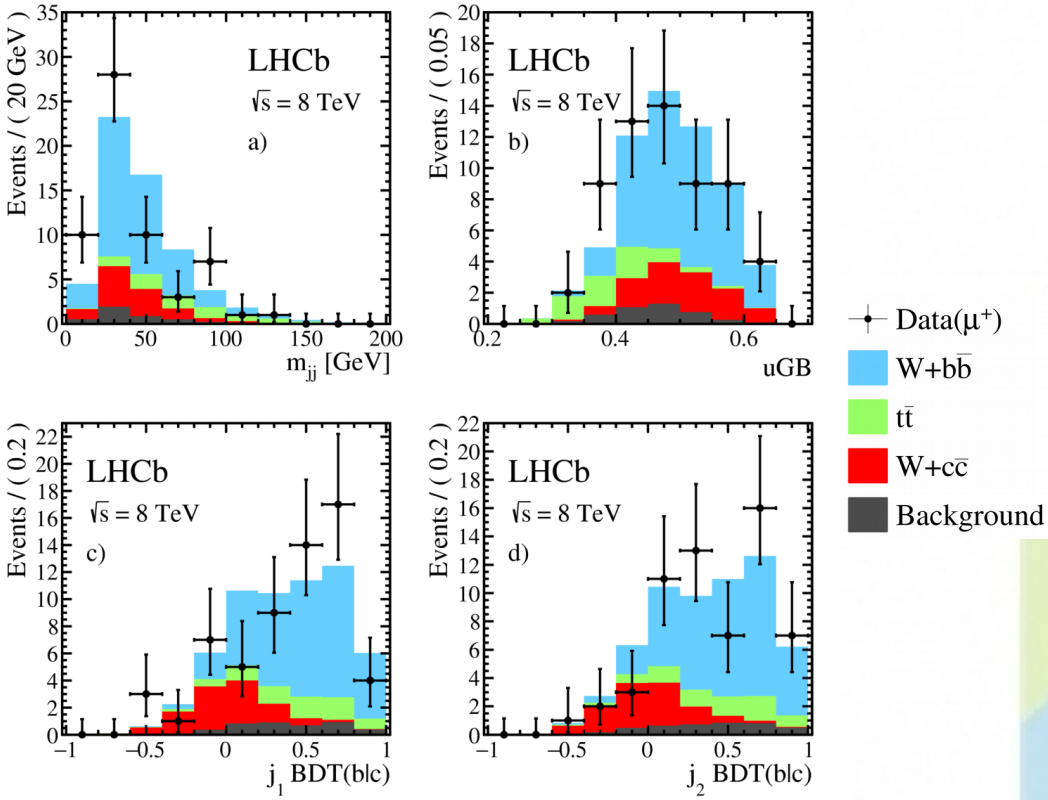
**Phys. Lett. B767 (2017) 110**

- W( → μ/e ν) plus two heavy flavour tagged jets.

- $p_T(jet_{1,2}) > 20$ GeV, $2.2 < \eta(jet_{1,2}) < 4.2$, $\Delta R(jet_{1,2},\mu/e)>0.5$, $\Delta R(jet_1,jet_2) > 0.5$

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




- Fit to $m_{jj}$, BDT(b|c) for both jets and uGB($W+b\bar{b}|t\bar{t}$) to measure the cross-sections.

- **$t\bar{t}$ production in the forward region is also measured!**

- Measurements are compatible with NLO predictions.

# Backup slides