EW boson production at LHCb

Lorenzo Sestini
Università di Padova and INFN
On behalf of the LHCb collaboration

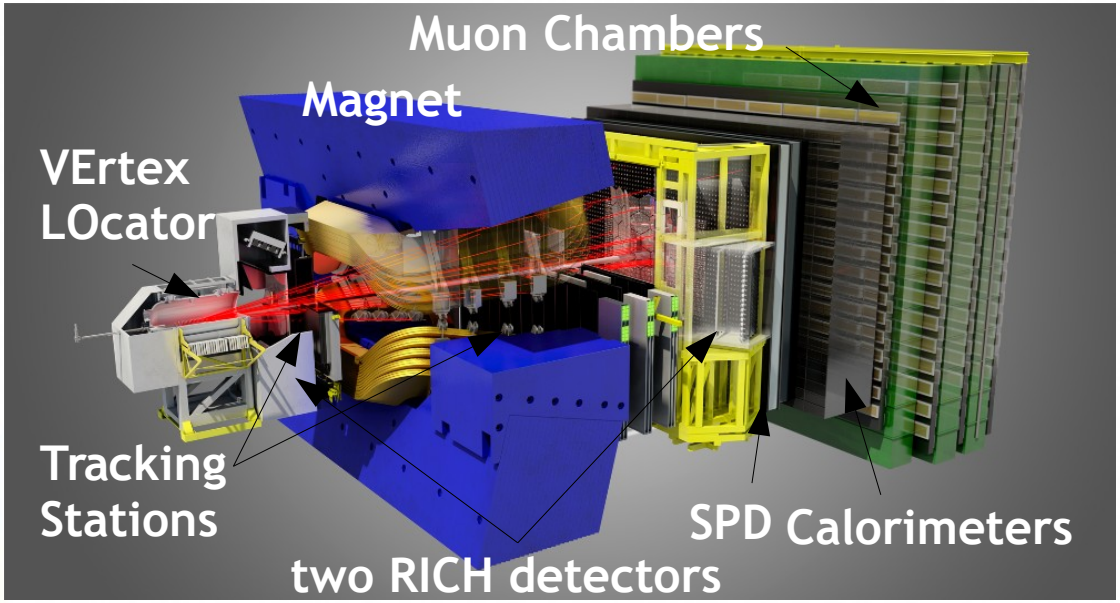
EPS-HEP conference, 2017-07-06, Lido di Venezia

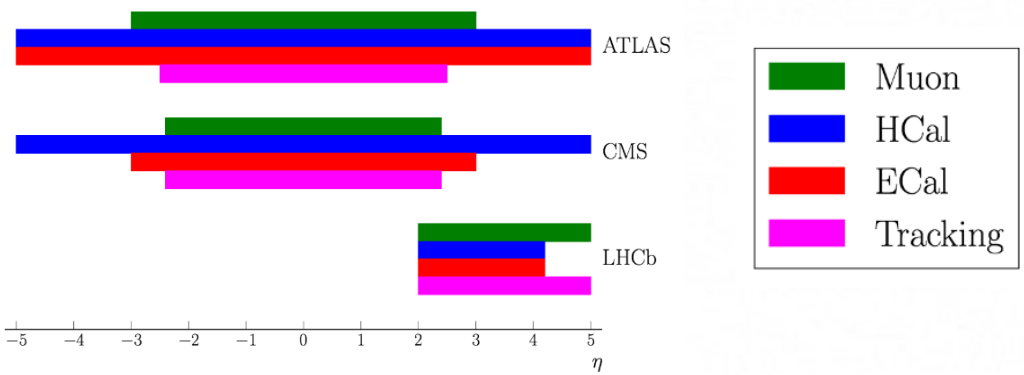
Outline

Electroweak boson production at LHCb:

- Z @ 13 TeV
- W/Z + jets @ 8 TeV
- $W+b\bar{b}$ and $W+c\bar{c}$ @ 8 TeV
- **NEW** $Z \rightarrow b\bar{b}$ @ 8 TeV

LHCb detector
JINST 3 (2008) S08005





- **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 μm 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

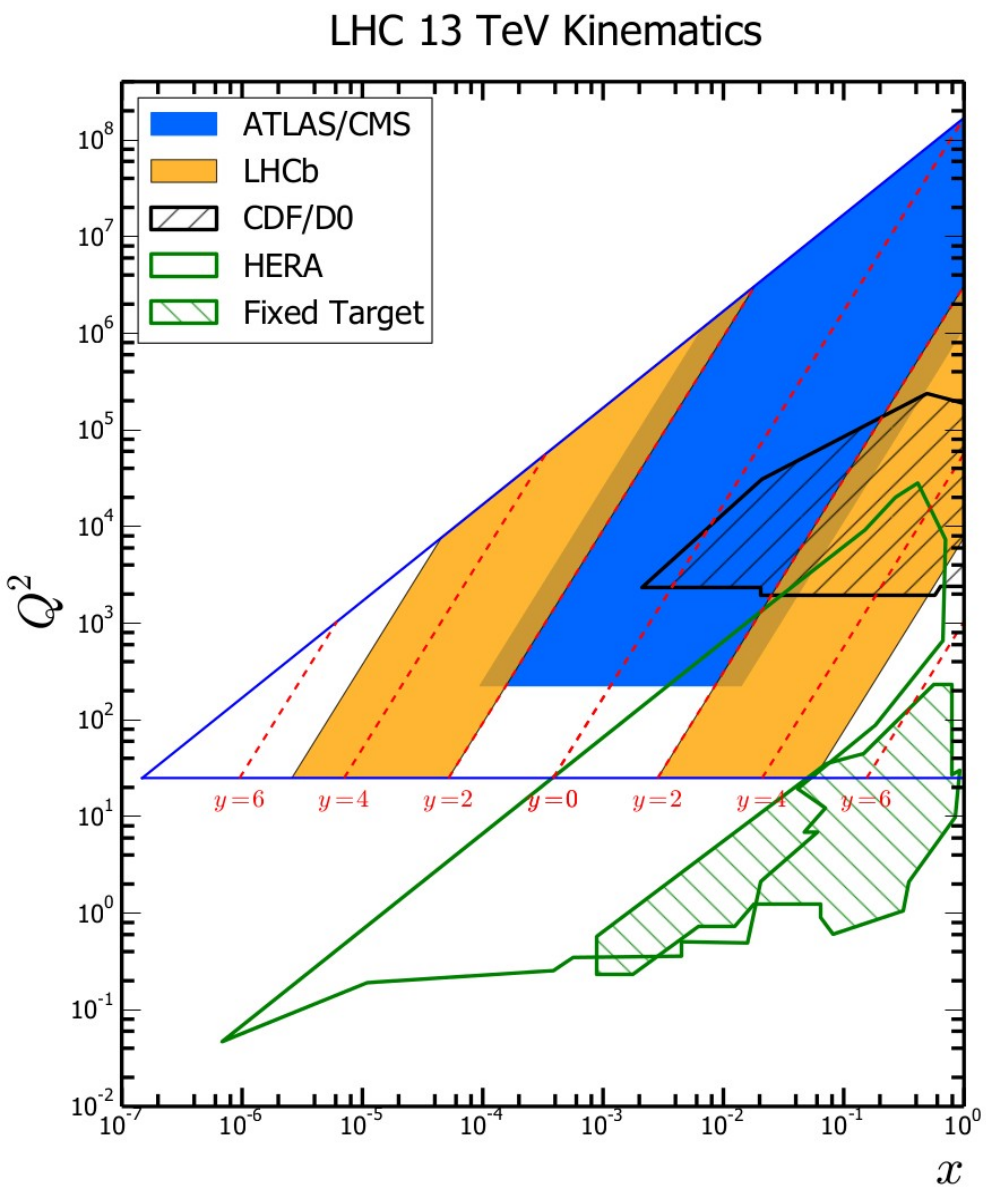
- LHCb offers a **complementary phase space region with respect to ATLAS and CMS** for Electroweak and jets measurements.

- 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.

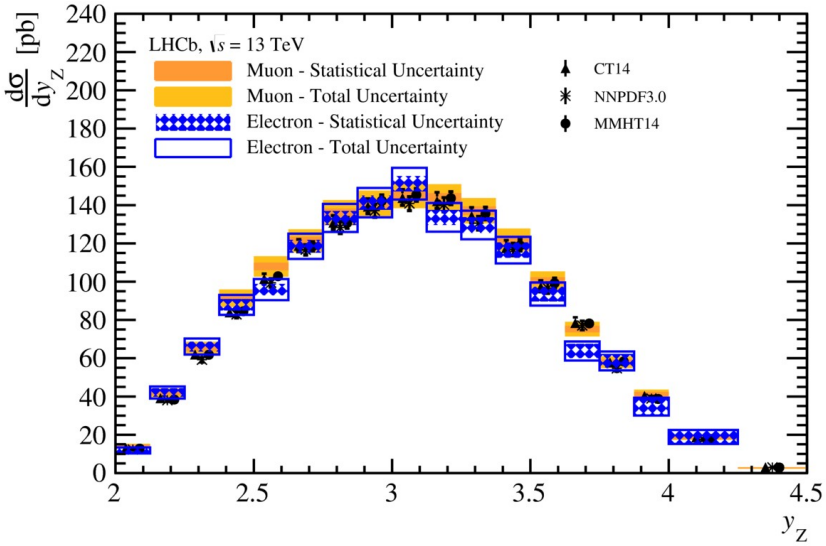
- I am going to present measurements at **8 TeV** and **13 TeV** in the pp centre-of-mass energy.

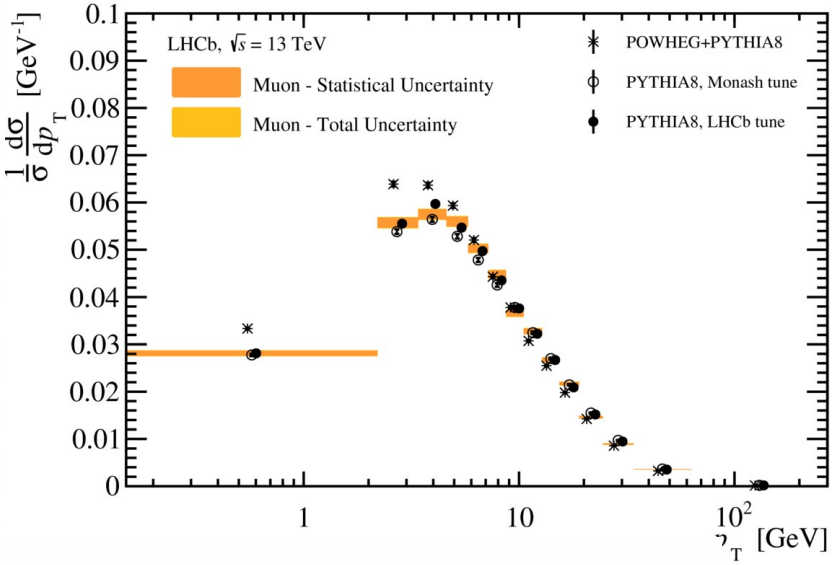


Z production at 13 TeV

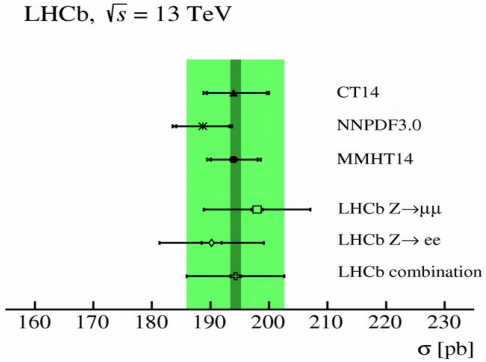
JHEP 09 (2016) 136

- 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.





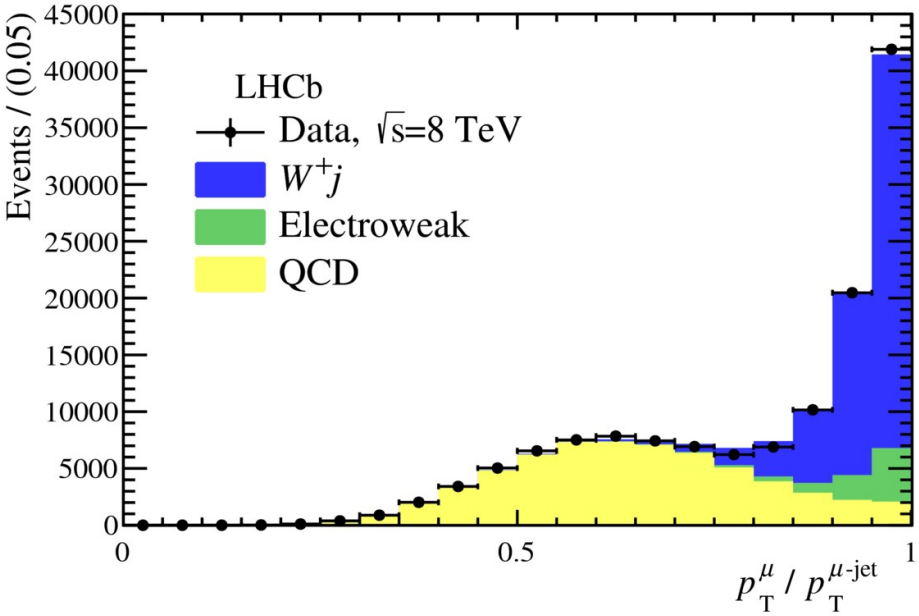
- Differential cross-sections compatible with predictions.
- Uncertainty dominated by the luminosity measurement (3.9%) → not final calibration.
- Z → μμ and Z → ee measured cross-sections are compatible within the uncertainities.

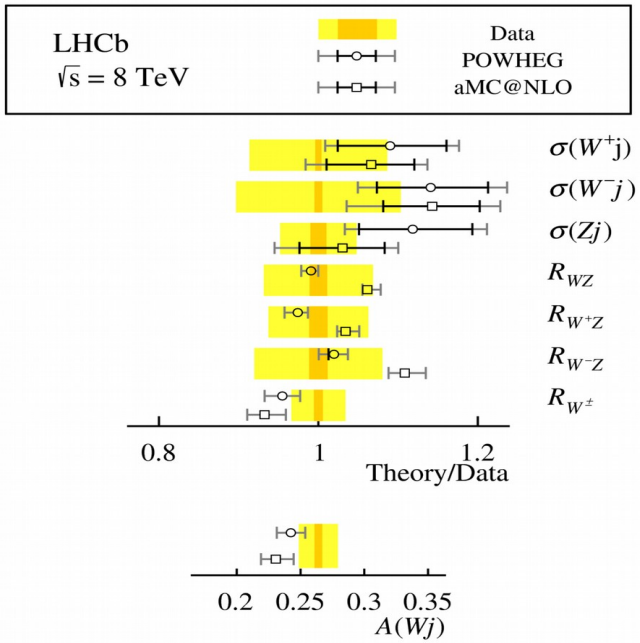


W/Z + jet production at 8 TeV

JHEP 05 (2016) 1-23

- Important measurement to validate the jet reconstruction at LHCb.
- 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.



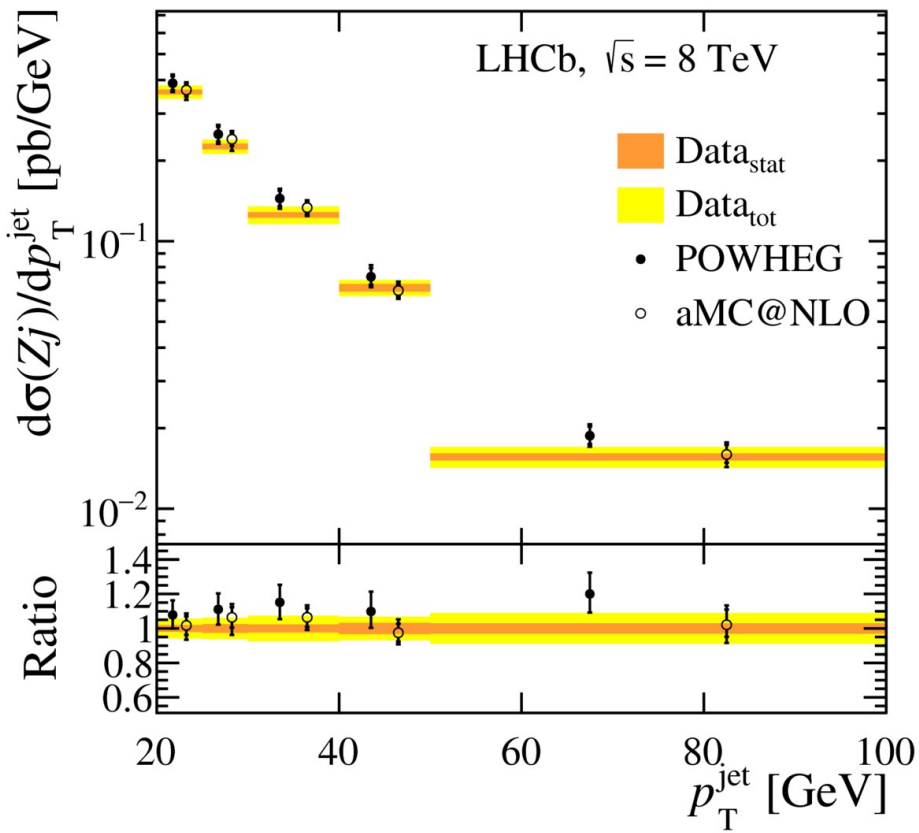


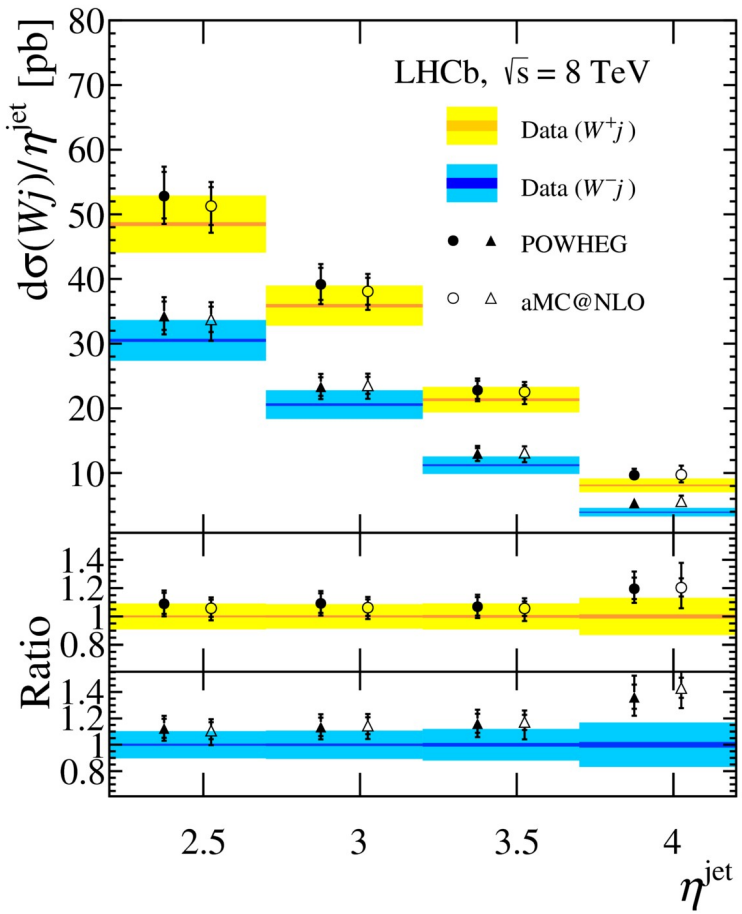
- Purity of Z+jet: 97.8%
- Systematic uncertainty on the cross-section measurement are dominated by the purity determination and by the jet energy scale/resolution.
- W/Z ratios and W^+/W^- asymmetry are also determined.
- Measurements are in good agreement with POWHEG and aMC@NLO predictions.

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

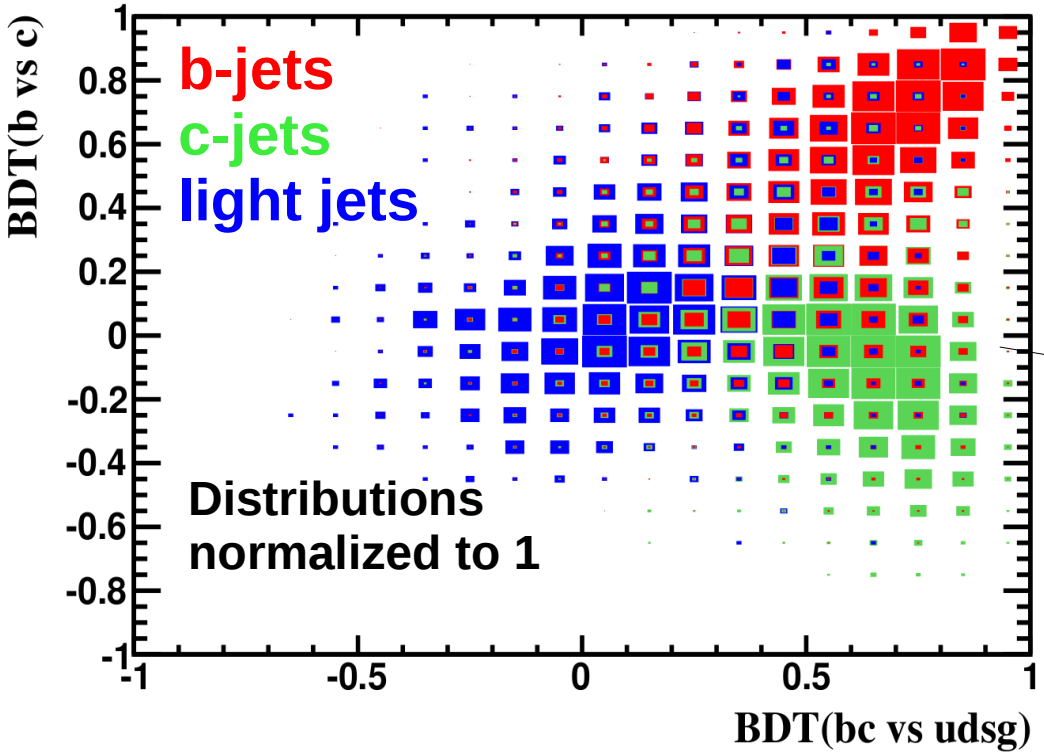
JINST 10 (2015) P06013

- 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!

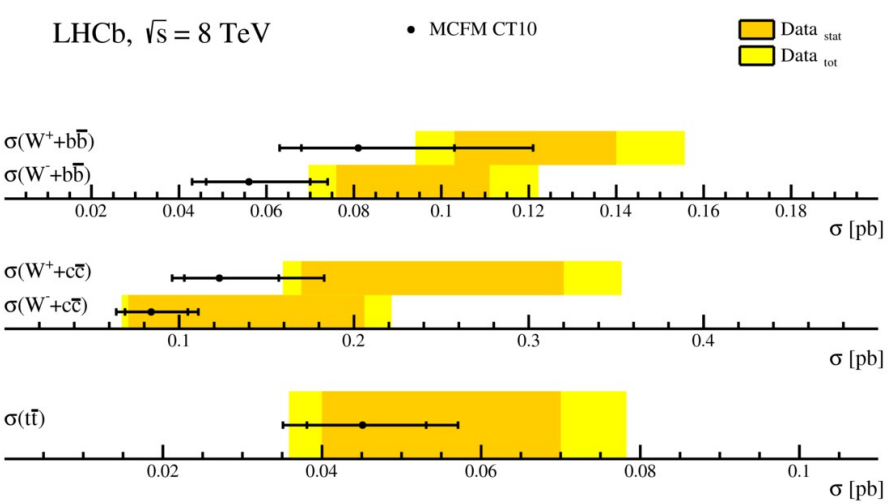
$W+b\bar{b}/W+c\bar{c}$ production at 8 TeV

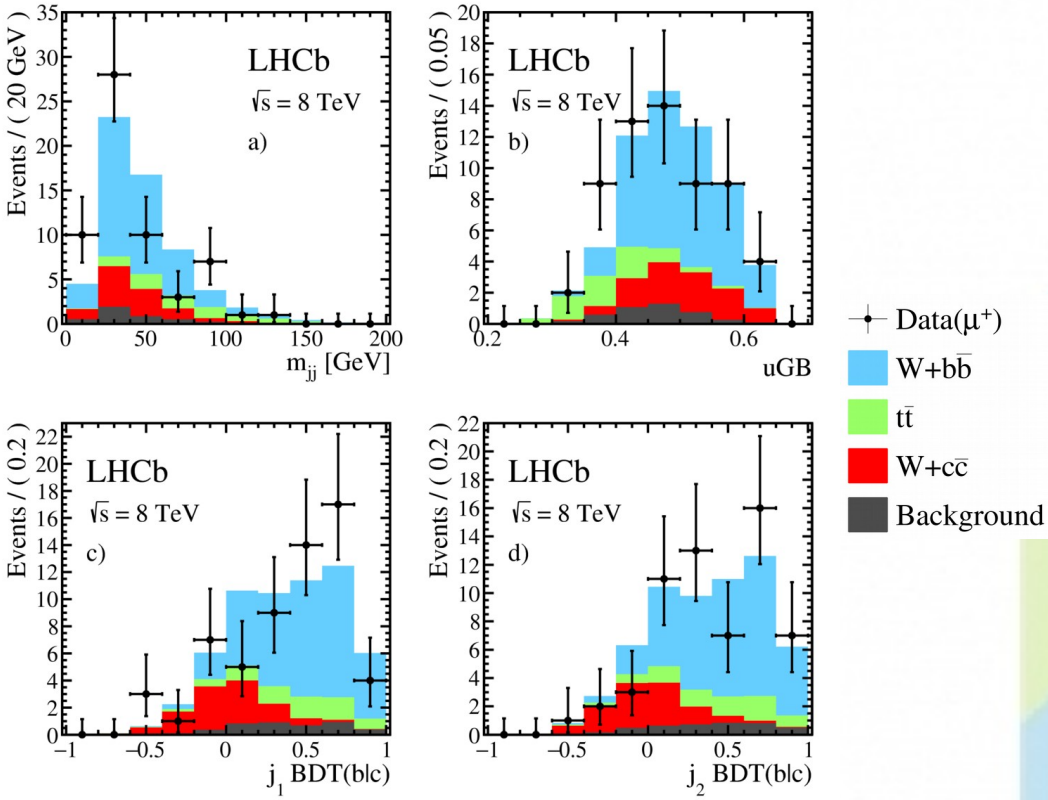
Phys. Lett. B767 (2017) 110

- 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.

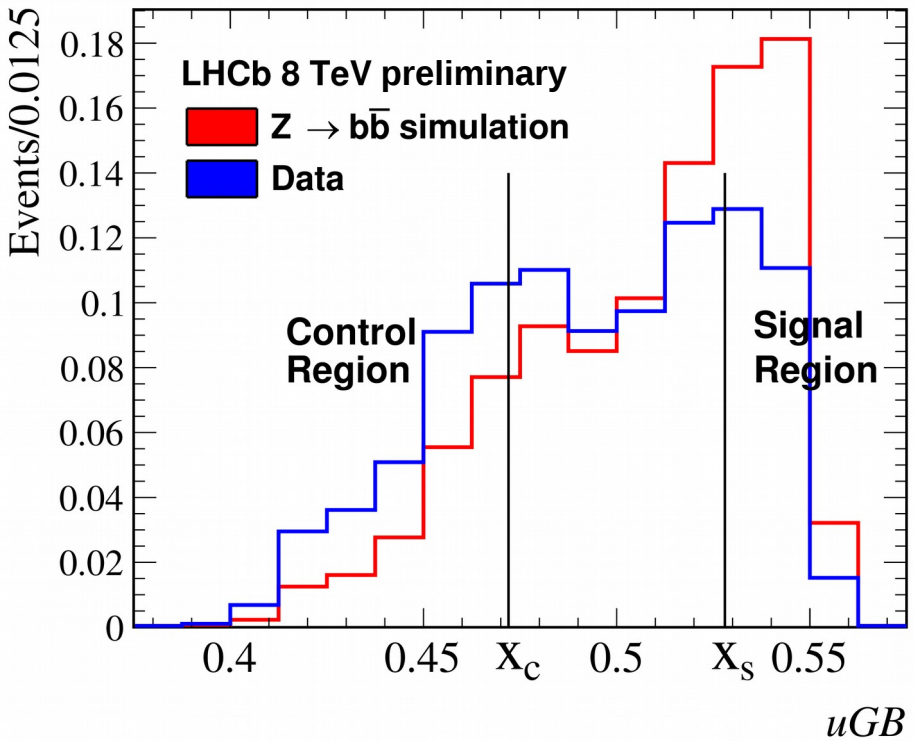
- **$t\bar{t}$ production in the forward region is also measured!** (**Stephen Farry's talk in Top session**)

- Measurements are compatible with NLO predictions.

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

NEW LHCb-PAPER-2017-024

- 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

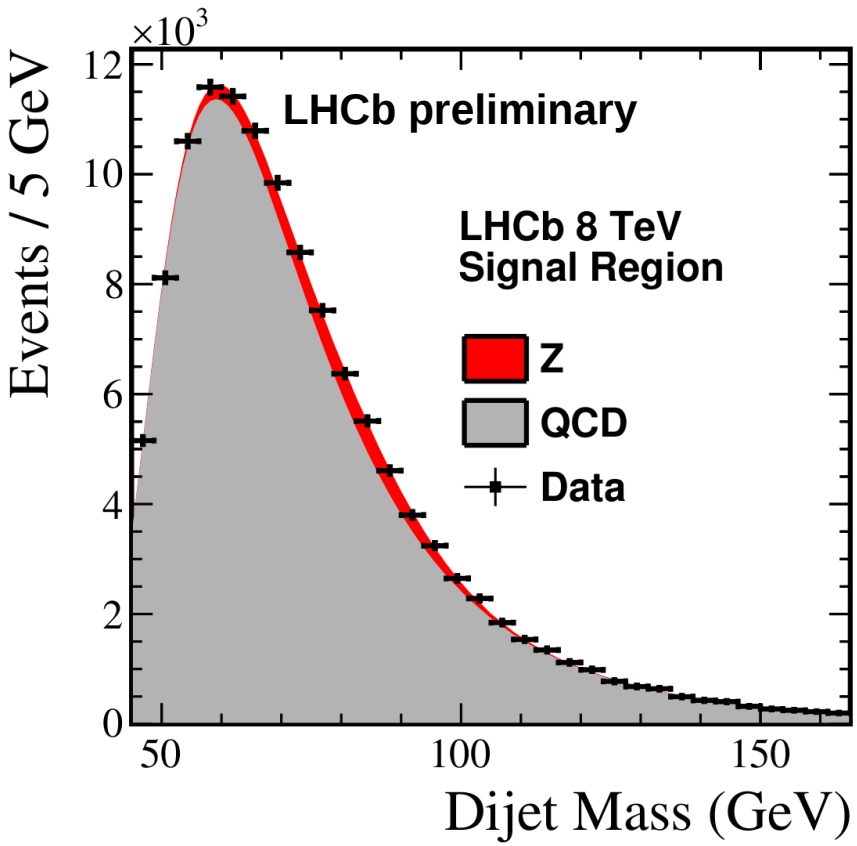


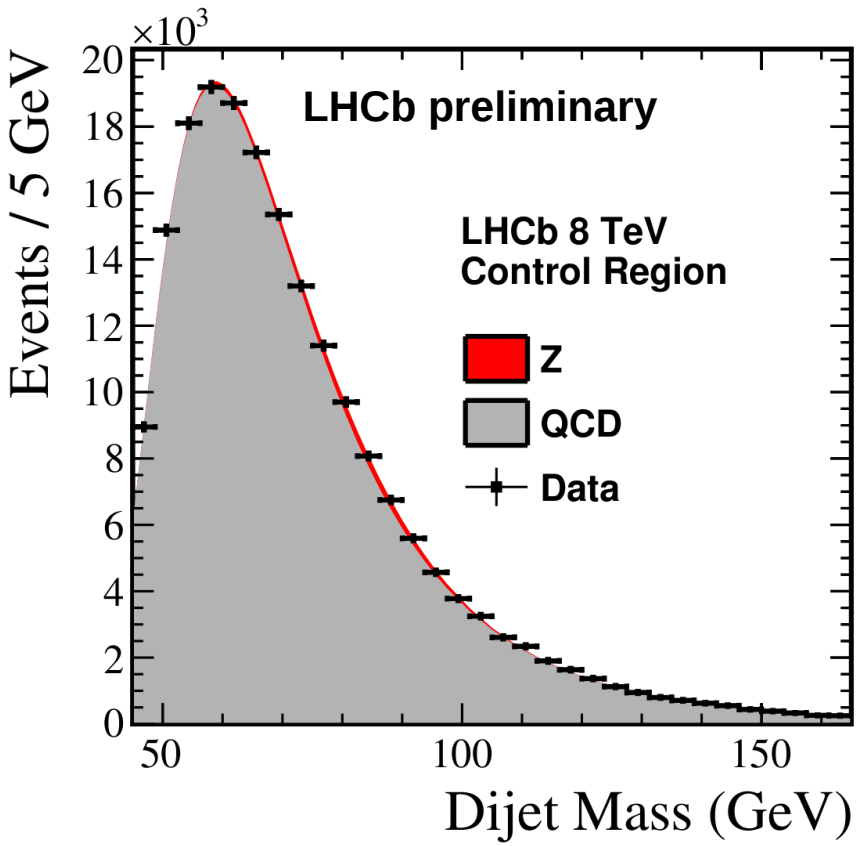
- An additional **balancing jet** (jet_3) that makes $p_T(Z+jet_3)$ minimum is selected to separate $Z \to b\bar{b}$ from QCD.
- UGB BDT is trained to separate $Z \to b\bar{b}$ from QCD, input observables are related to the 3-jets kinematic.
- Simultaneous fit to m_{jj} in signal (enhanced $Z \to b\bar{b}$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

NEW LHCb-PAPER-2017-024

- $Z \to b\bar{b}$ 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.



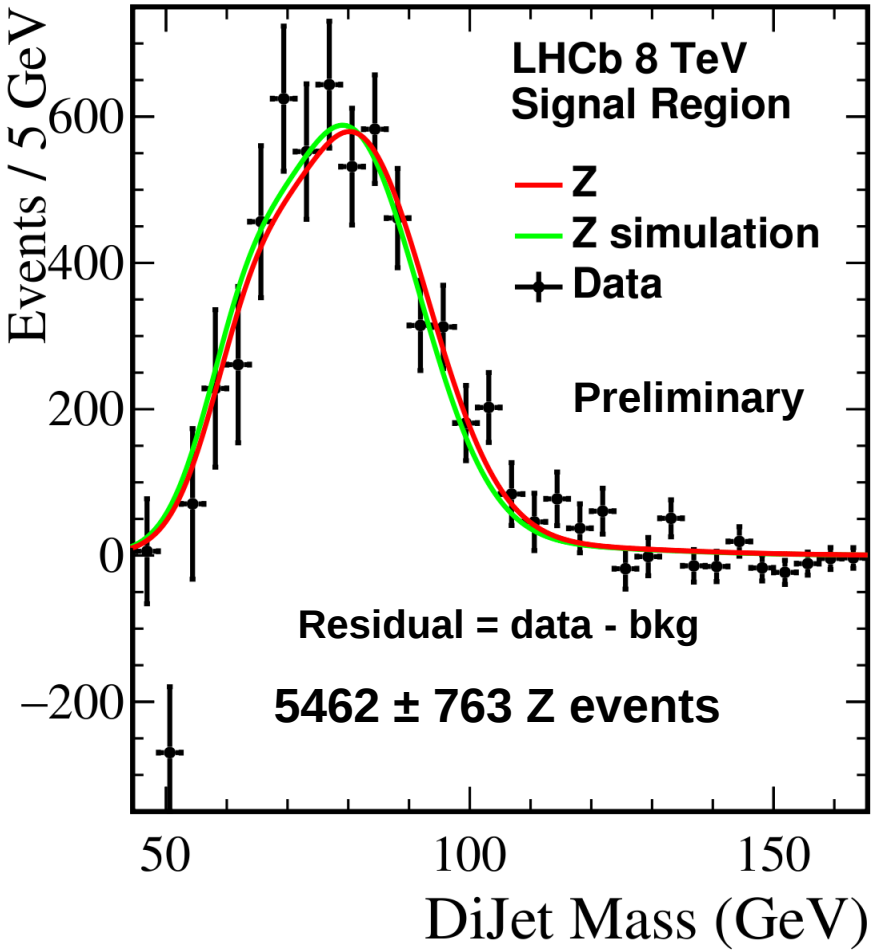


$Z \to b\bar{b}$ production at 8 TeV

NEW LHCb-PAPER-2017-024

- $Z \to b\bar{b}$ 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:

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

Conclusions

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

- We performed measurements of **W/Z (+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!

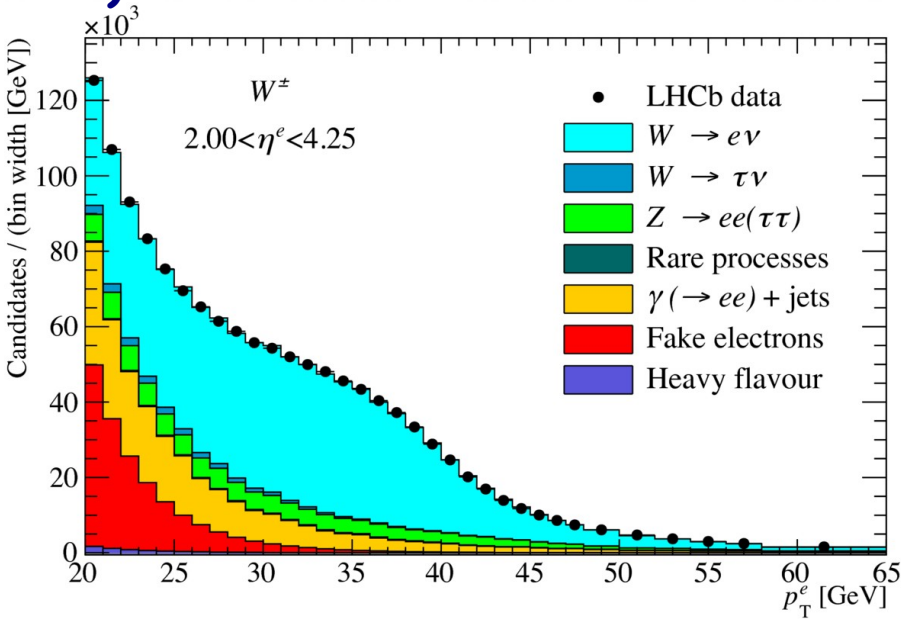
Thanks for your attention!

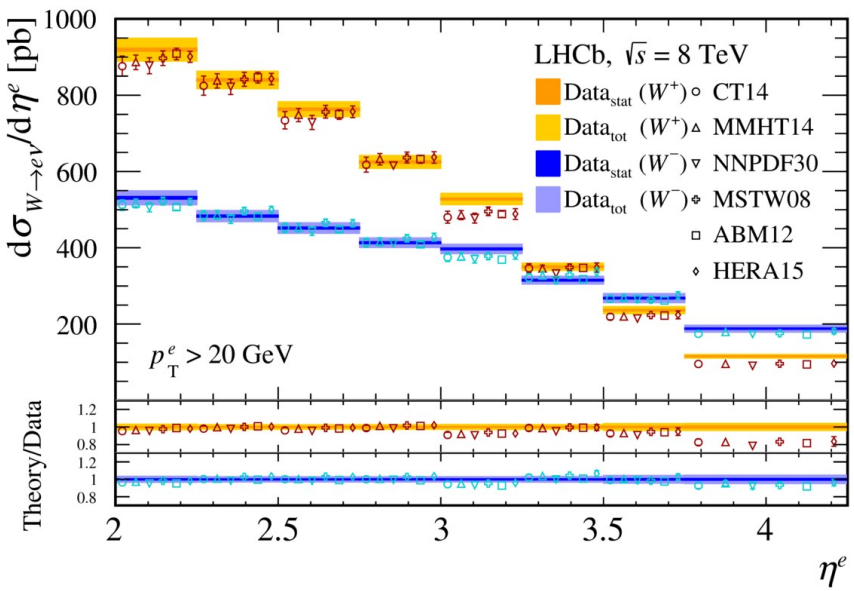
Backup slides

W → eν production at 8 TeV

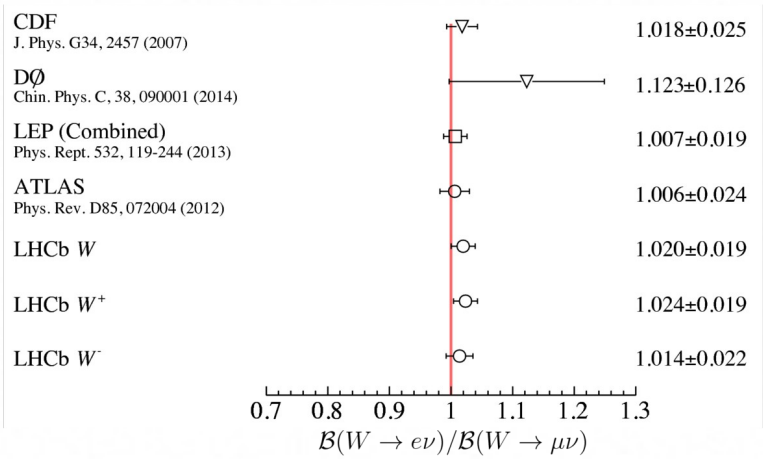
JHEP 10 (2016) 030

- 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**