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Related Subjects

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W, Z and top production measurements at LHCb

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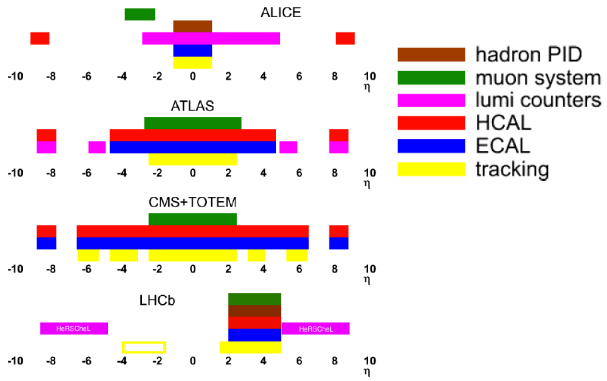
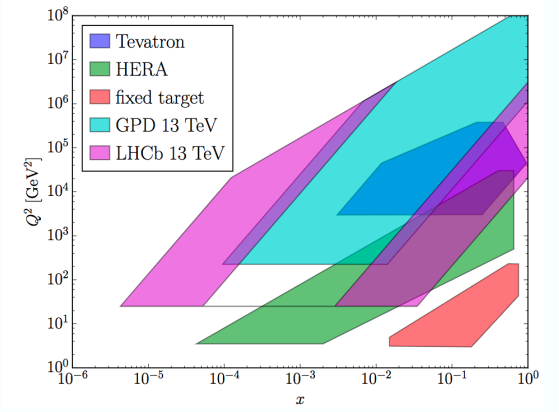
Electroweak scale physics at LHCb

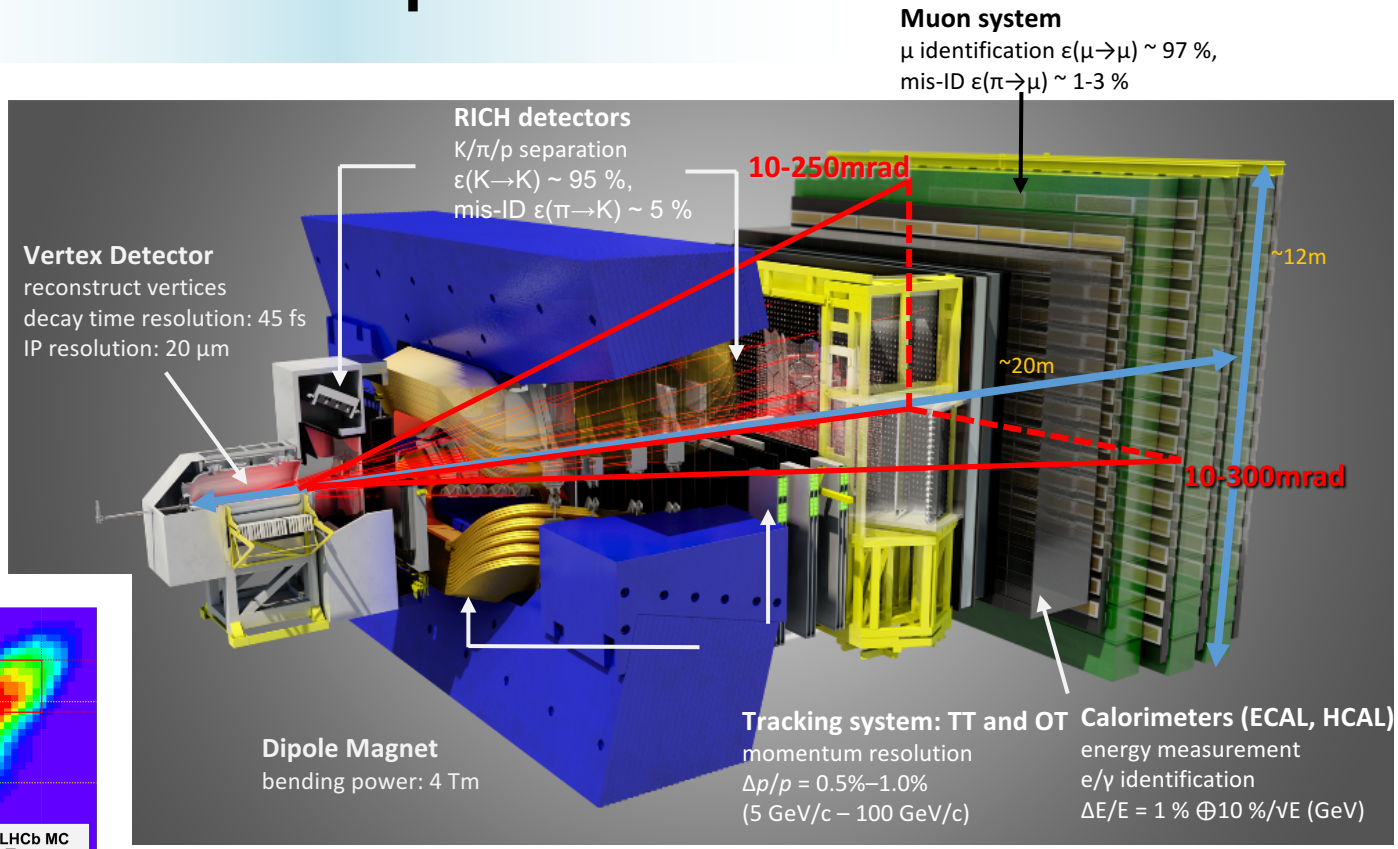
- LHCb is specialised in heavy flavour precision physics, beauty and charm:
  - Optimised for low pile-up collisions
  - Instruments fully the forward region: 2<η<5
    - Precise vertexing: reconstruction of secondary vertices to tag heavy flavour jets
- Extensive program and precision measurements in electroweak sector by ATLAS and CMS, however LHCb can play an important role:
  - Unique kinematic region, covering asymmetric parton collisions: large or small *x*



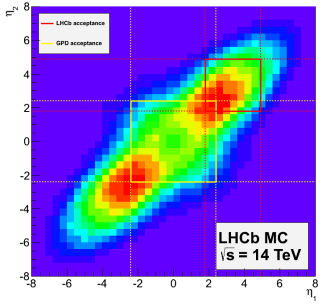


The LHCb experiment

[IJMPA 30 (2015) 1530022]
[JINST 3 (2008) S08005]

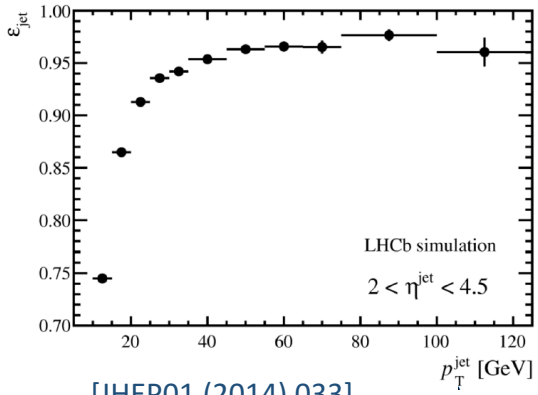


$b\bar{b}$ acceptance

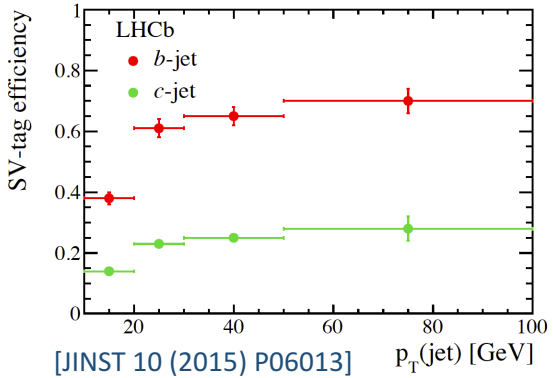


Jet reconstruction at LHCb

- Based on particle flow including neutral recovery, anti-*k*T clustering algorithm with $R = 0.5$
- Energy resolution of 10-15% and efficiency >95% above $p_T = 20$ GeV
- Calibrated on data, using $Z \rightarrow \mu\mu$ + jets
- Already used in a growing number of analysis, beyond the initial physics program of LHCb : measurements of associated production of W and Z with jets, heavy long-lived particles decaying to jets, J/ψ production in jets, …
- Heavy flavour (*b* and *c*) tagging of jets:
  - Reconstruct secondary vertices from displaced tracks
  - Kinematic and quality requirements on vertices and tracks,
  - Jet is tagged if the secondary vertex is within $|\Delta R|<0.5$ of the jet axis
  - Further separation between light and heavy flavour and between charm and beauty provided by Boosted Decision Trees



[JHEP01 (2014) 033]

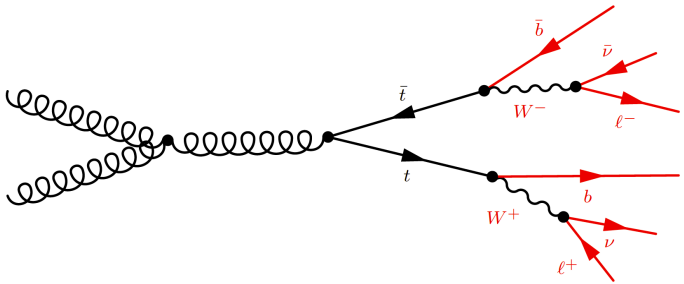


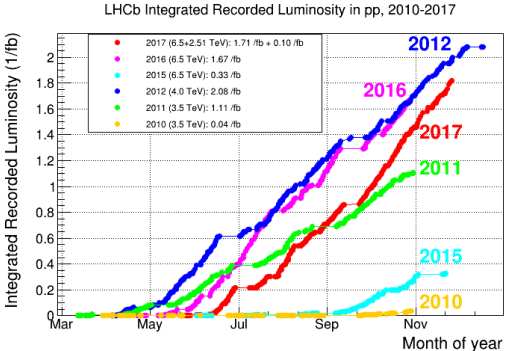
[JINST 10 (2015) P06013]

[arXiv:1803.05188]

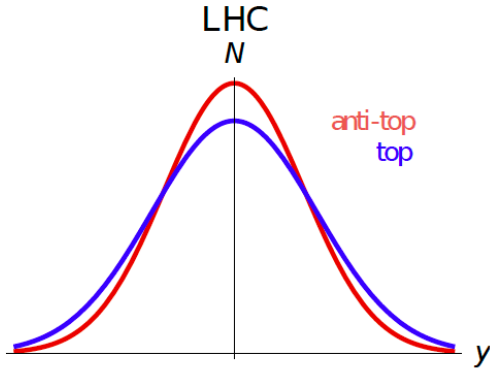
$t\bar{t}$ production measurement

- Top production measurements in LHCb acceptance provide strong constraints on PDF, in particular large-*x* gluon PDF
- $t\bar{t}$ charge asymmetry in *pp* collisions is enhanced in the forward region
- First measurements of top production in the forward region were obtained with 7 and 8 TeV *pp* collisions in the μb [PRL 115 (2015) 112001], $\mu b\bar{b}$ and $eb\bar{b}$ [PLB767 (2017) 110] final states.
- New measurement with 2 fb^{-1} of 13 TeV *pp* collisions (2015+2016) with μeb final state.





$t\bar{t}$ production enhanced by factor 10 in the LHCb acceptance compared to 8 TeV

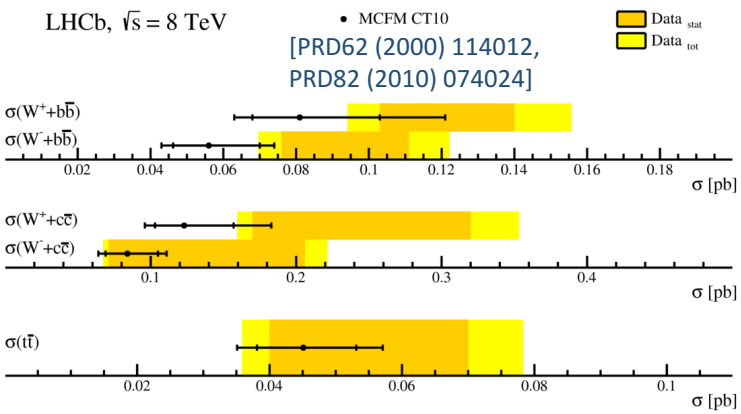


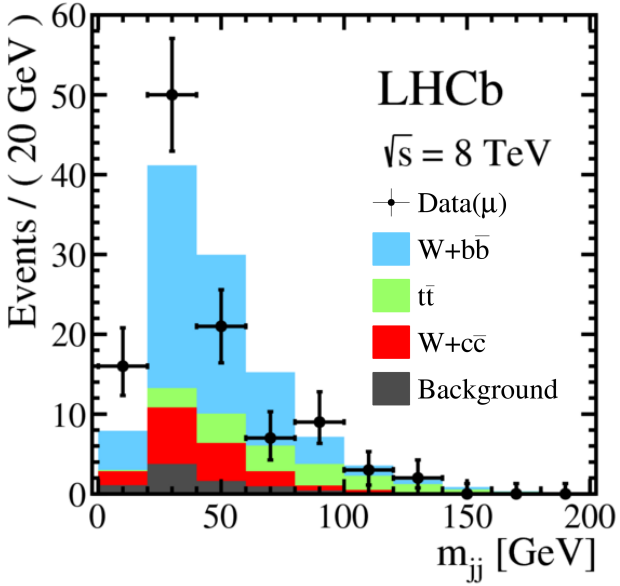
Cross-section in $t\bar{t}$ events

[PLB767 (2017) 110]

$t\bar{t}$ production with $eb\bar{b}$ and $\mu b\bar{b}$

- Using 2 fb^{-1} of 8 TeV data, measuring simultaneously $t\bar{t}$, W+$b\bar{b}$ and W+$c\bar{c}$ cross-sections:
  - $2.2 < \eta_{jet} < 4.2$, p_{Tjet}>12.5 GeV
  - $p_T(e,\mu)$>20 GeV, $2<\eta_\mu<4.5$ and $2<\eta_e<4.25$
- Simultaneous fit to di-jet mass, MVA classifier and BDT (*c* or *b*) output
- Cross-sections (and predictions) in fiducial region



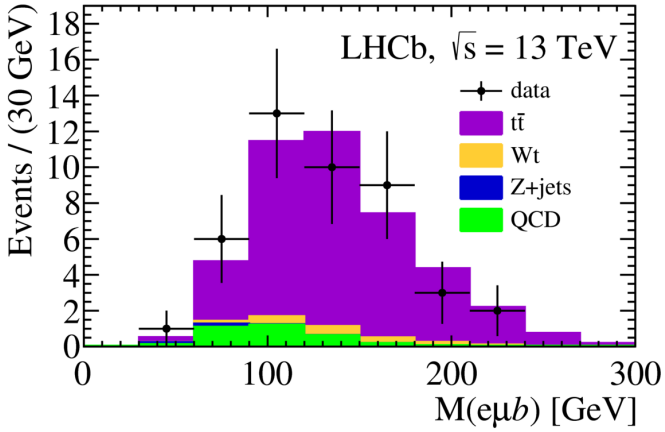


Di-jet mass

[arXiv:1803.05188]

$t\bar{t}$ production with μeb channel

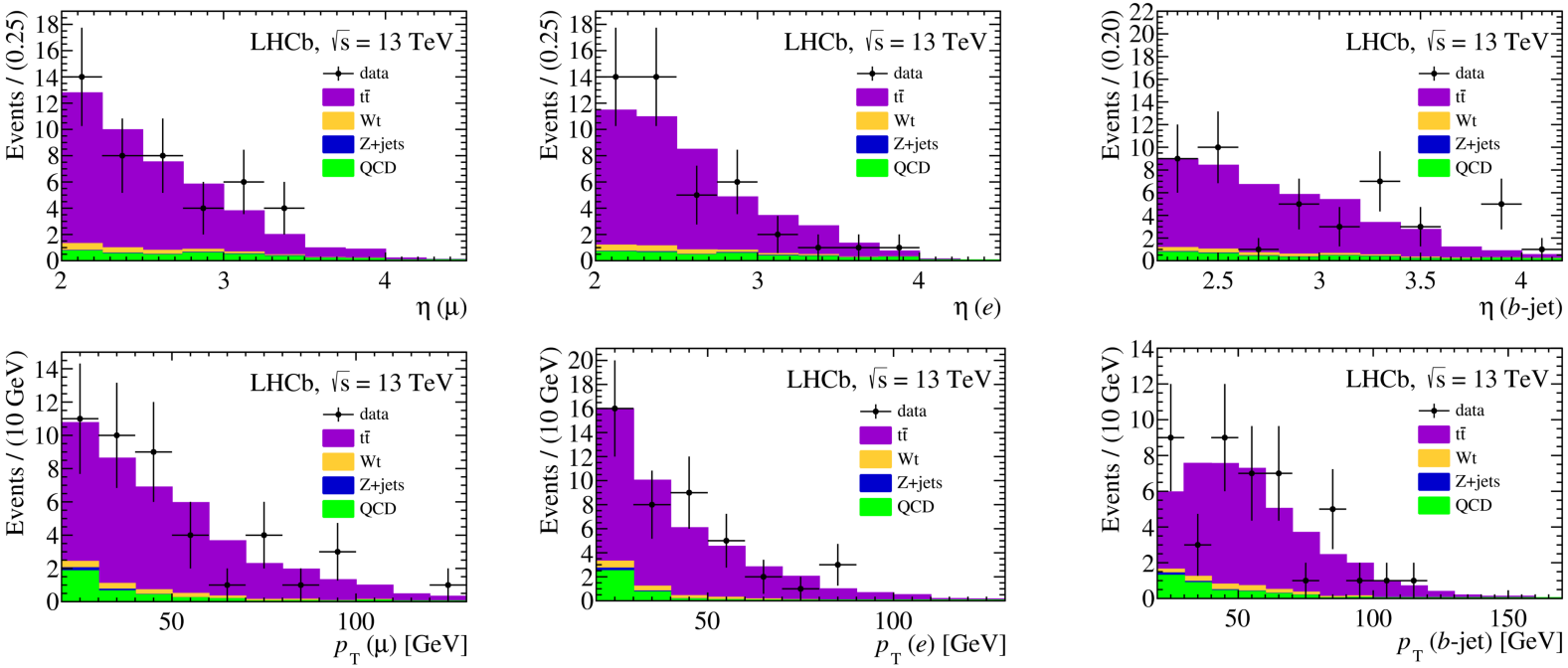
- Two leptons in the final state gives high purity
  - At the cost of efficiency due to limited acceptance: partial reconstruction
  - Requirement of second lepton suppresses background from QCD and W+$b\bar{b}$
  - Leptons with two different flavours suppress background from Z+$b\bar{b}$
  - Analysis not possible with Run 1 data because of too low statistics
- Selections:
  - Prompt, isolated μ and e with p_T>20 GeV and $2.0 < \eta < 4.5$
  - *b* jet tagged with secondary vertex in $2.2 < \eta < 4.2$
  - ΔR(lepton,jet) > 0.5, $\Delta R(\mu,e) > 0.1$
  - 44 candidates selected with 87% purity
- Contributions to background:
  - Z+jets, with shape taken from simulation and normalized to $Z \to \mu\mu$ + *b*-jet from data
  - W+*t* determined from simulation based on POWHEG
  - QCD determined from data



[arXiv:1803.05188]

$t\bar{t}$ events: kinematic variables

- Shape of various kinematic variables of the different contributions agree well with expectations from simulation



[arXiv:1803.05188]

$t\bar{t}$ production: results

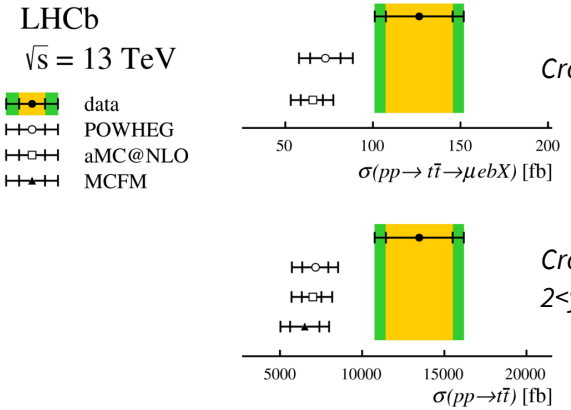
- Cross-section in fiducial region defined by analysis kinematic requirements:

$$\sigma_{t\bar{t}} = 126 \pm 19\,(\text{stat}) \pm 16\,(\text{syst}) \pm 5\,(\text{lumi})\ \text{fb}$$

- Compatible with Standard Model prediction with 15% statistical uncertainty
- Systematic uncertainty determined by jet tagging efficiency, background related uncertainty dominated by QCD background
  - They both will improve with more statistics since their determination is data driven

Source	Efficiency
trigger	0.811 ± 0.016
muon reconstruction	0.930 ± 0.010
electron reconstruction	0.916 ± 0.026
muon identification	0.978 ± 0.008
electron identification	0.918 ± 0.012
jet reconstruction	0.975 ± 0.016
event selection	0.564 ± 0.023
jet tagging	0.556 ± 0.056
total	0.190 ± 0.022

Systematic uncertainties



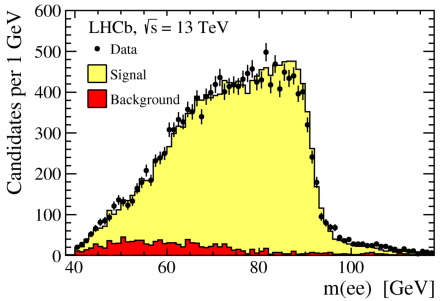
Cross-section in fiducial region

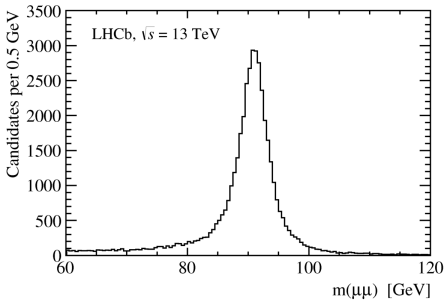
Cross-section extrapolated to $2<y^{top}<5$ and $p_T^{top}>10$ GeV

[JHEP 09 (2016) 136]

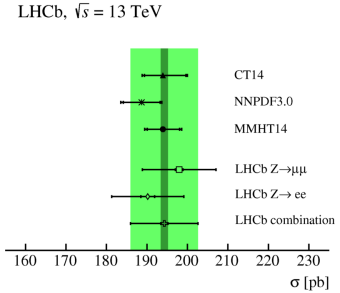
Z boson production at 13 TeV

- Using two final states, *ee* and μμ, and 300 pb^{-1} of *pp* collisions at 13 TeV
- Fiducial region defined by $2<\eta(e,\mu)<4.5$, $p_T(\underline{e},\mu)>20$ GeV and $60<M(ee,\mu\mu)<120$ GeV





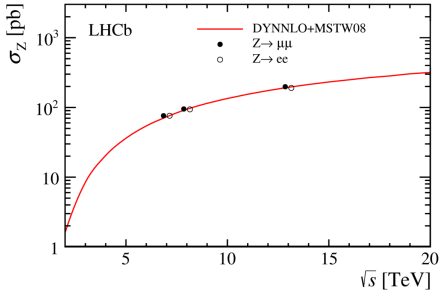
- Precise results in good agreement between the two channels and with predictions



$$\sigma_Z^{\mu\mu} = 198.0 \pm 0.9 \pm 4.7 \pm 7.7\,\text{pb},$$
$$\sigma_Z^{ee} = 190.2 \pm 1.7 \pm 4.7 \pm 7.4\,\text{pb}.$$

$$\sigma_Z^{\ell\ell} = 194.3 \pm 0.9 \pm 3.3 \pm 7.6\,\text{pb}$$

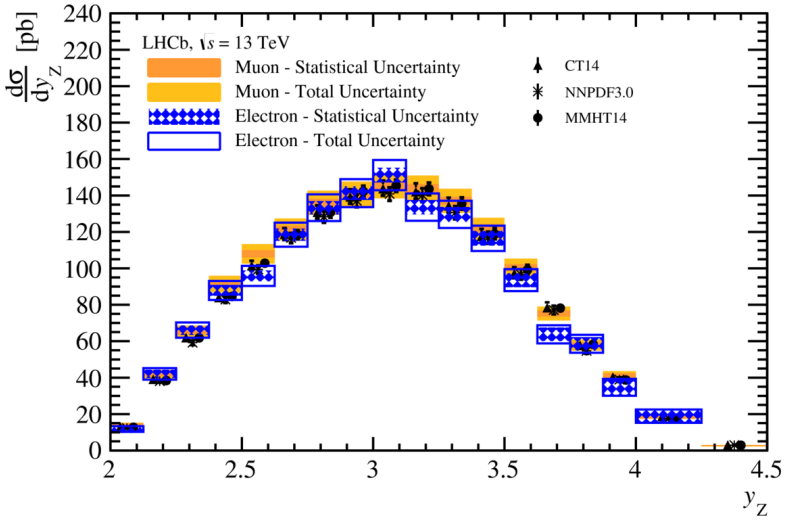
Stat./Syst./Lumi.

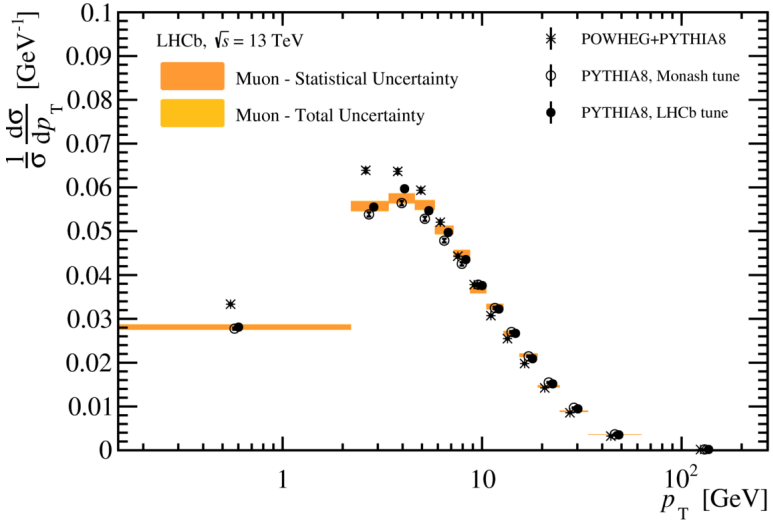


[JHEP 09 (2016) 136]

Z boson production at 13 TeV

- Also measured differentially as a function of y and p_T.

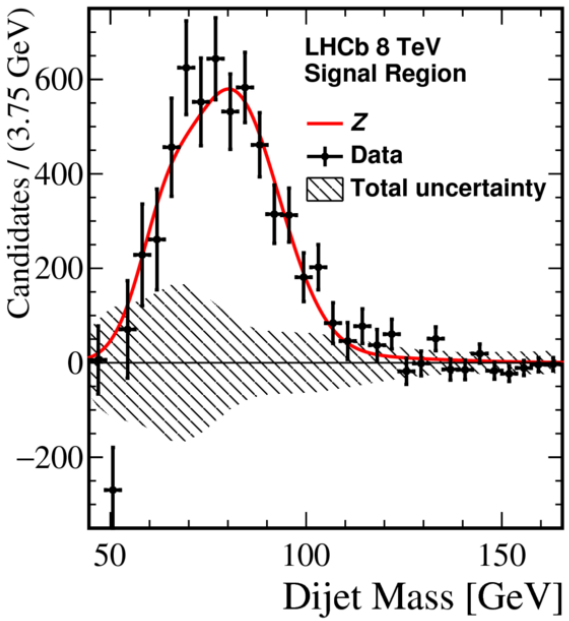




[Phys. Lett. B776 (2017) 430]

Observation of $Z \to b\bar{b}$ in forward region

- First observation in the forward region: important validation of jets and *b*-tagging
- Using 2 fb^{-1} of *pp* collisions at 8 TeV Run 1 data
- *b* jets with p_T>20 GeV and 2.2<η<4.2
- Third jet required to suppress QCD background
- Multivariate analysis with 4 kinematic variables of the 3-jet system
- Measured cross-section in agreement with aMC@NLO prediction



Conclusions

- Interesting measurements in electroweak sector obtained by the LHCb experiment
- Top cross-section measurements benefit from increase of center-of-mass energy and will become more and more precise with increasing statistics: 6 fb^{-1} of data will be available at end of Run 2
- Measurements of Z/W production can also be obtained in different systems like *p*Pb collisions, where they can put strong constraints on nuclear PDF determinations