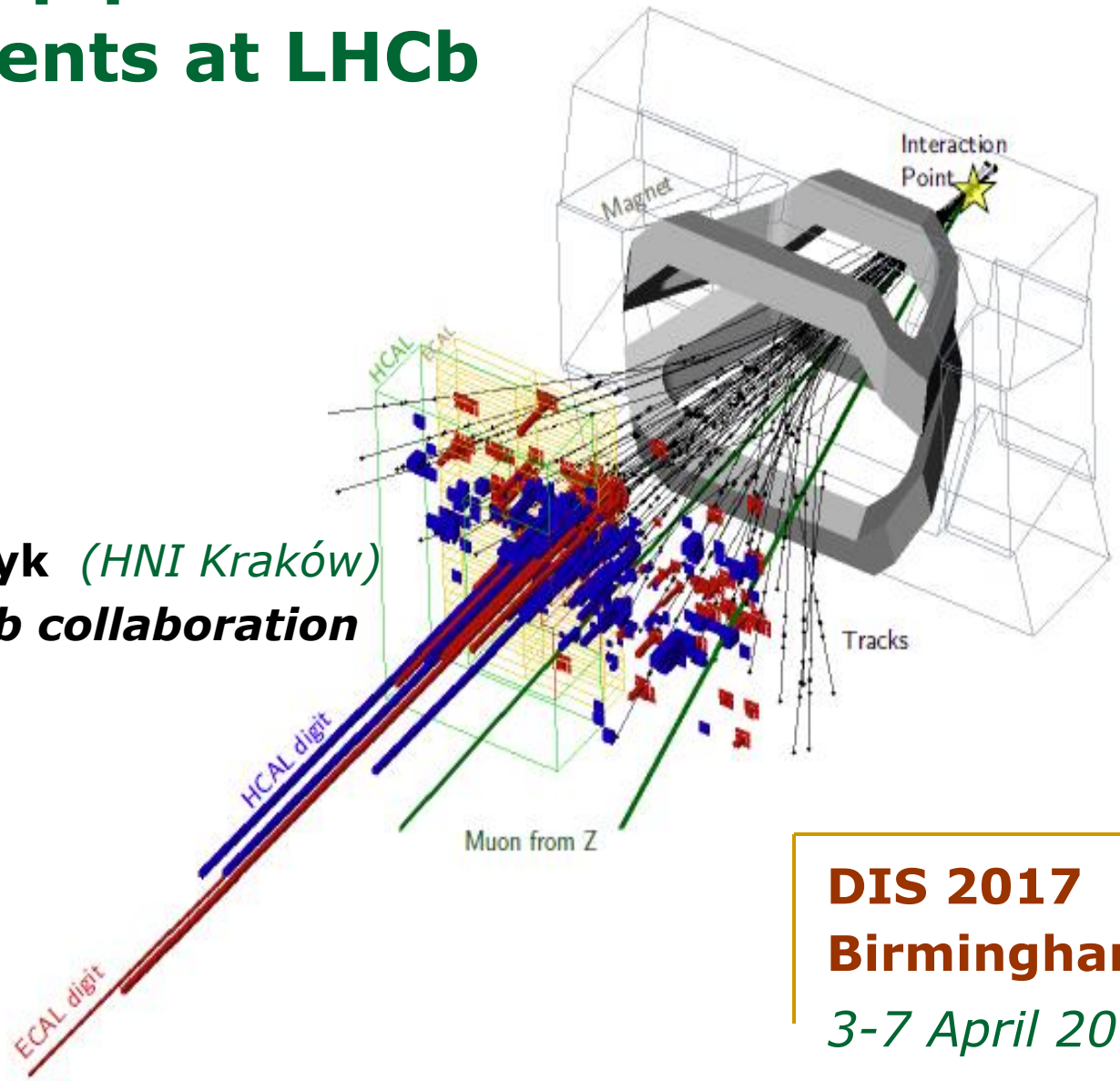
W, Z and top production measurements at LHCb

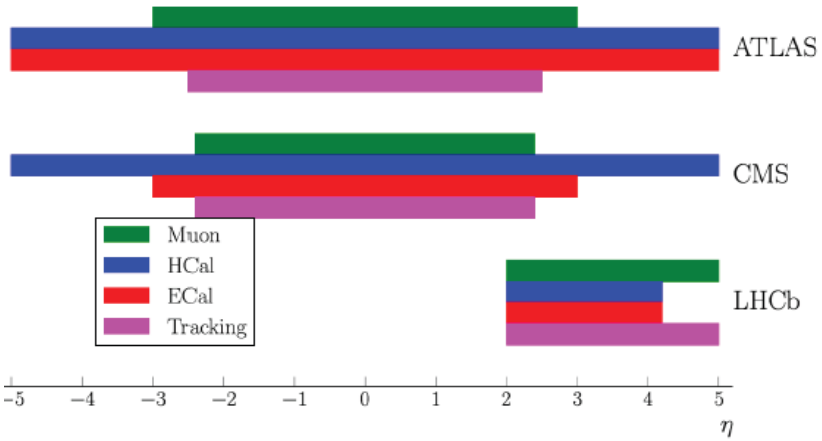
Marcin Kucharczyk *(HNI Kraków)*
on behalf of LHCb collaboration

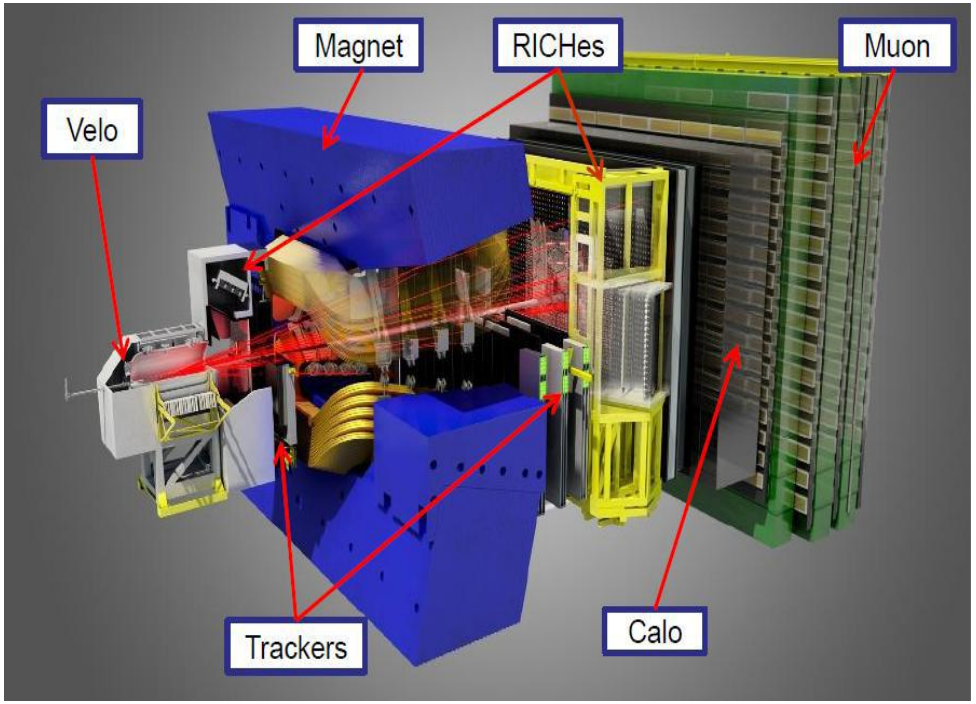


DIS 2017
Birmingham
3-7 April 2017

LHCb detector

- single arm spectrometer fully instrumented in forward region
- designed to study CP violation in *B*, now considered as **General Forward Detector**
- momentum resolution:
  0.4% at 5 GeV to 0.6% at 100 GeV
- excellent tracking and vertexing
  σ(IP) = 13-20 μm for high-p_T tracks
- good PID separation up to 100 GeV
- efficient trigger with *μ's*
- small pile-up
- coverage unique for LHCb:
  2.0 < η < 5.0





[Int. J. Mod. Phys. A30 (2015) 1530022]

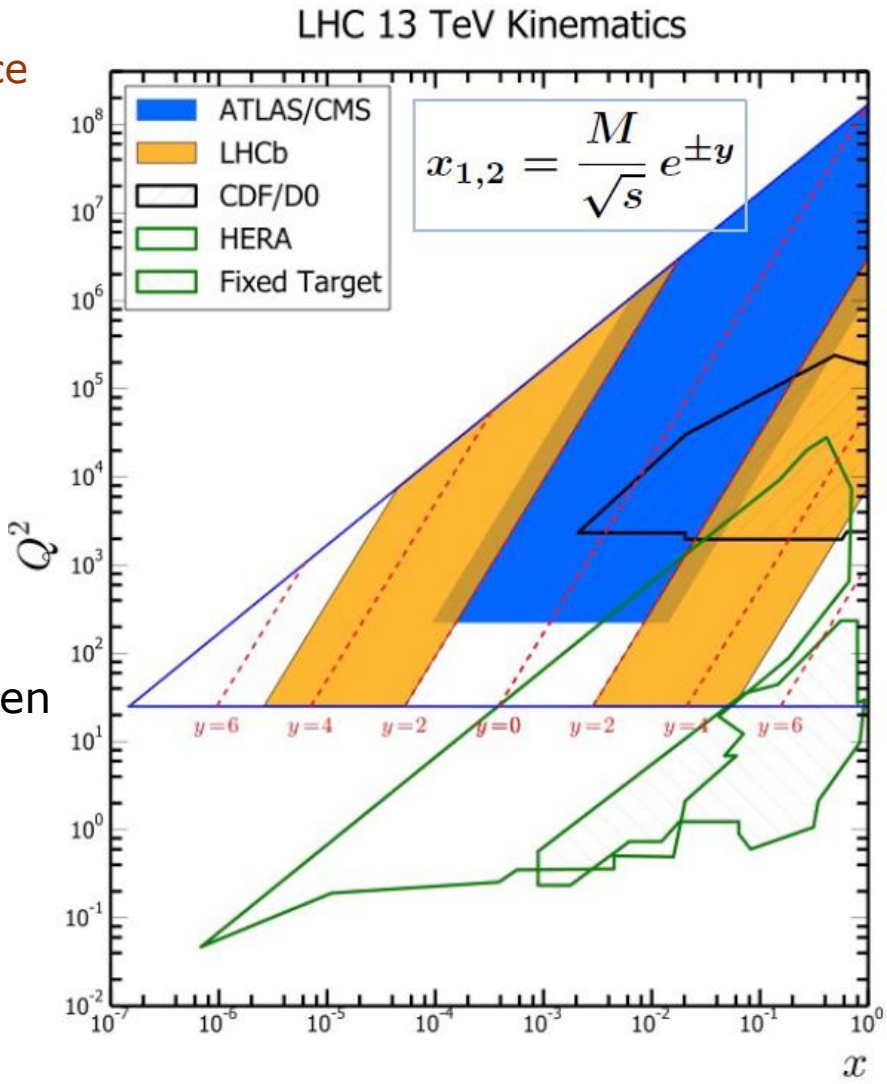
Datasets:

2011: 1.0 ± 1.7% fb^{-1} @ √s = 7 TeV
2012: 2.0 ± 1.2% fb^{-1} @ √s = 8 TeV
2015: 0.3 ± 3.9% fb^{-1} @ √s = 13 TeV

Motivation

- LHCb provides complementary phase space coverage compared to ATLAS and CMS
- EW and jets measurements provide important tests of SM
- access to PDFs in high and low *x*-Bjorken regions
- low *x*-region unexplored by previous experiments
- LHCb produces W/Z by collisions between low-*x* and high-*x* partons

Top measurements also possible



Luminosity measured with high precision using Van der Meer scan and beam gas imaging

Inclusive Z production at 7 and 8 TeV (I)

Based on $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$

μμ 7 TeV: [JHEP 08 (2015) 039]
μμ 8 TeV: [JHEP 01 (2016) 155]
ee 7 TeV: [JHEP 08 (2013) 106]
ee 8 TeV: [JHEP 05 (2015) 109]

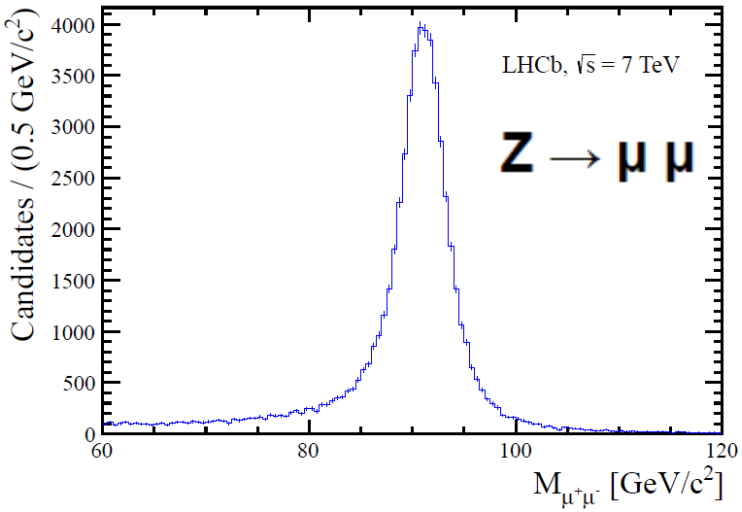
Fiducial acceptance

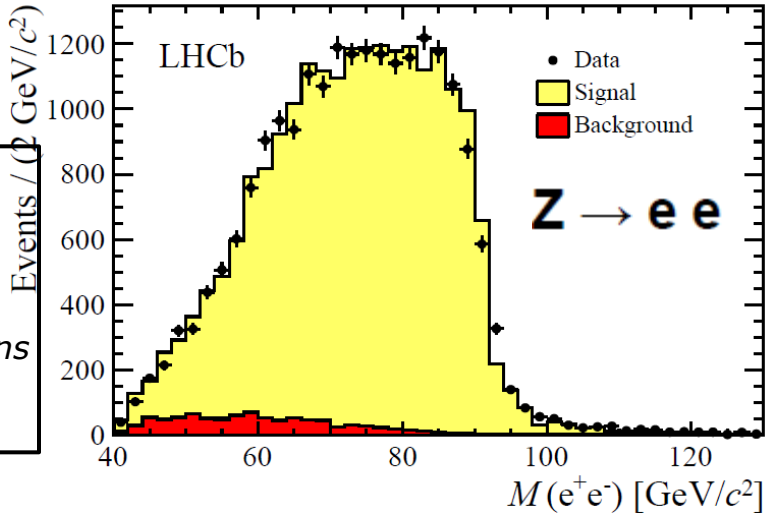
→ *leptons with* $p_T > 20$ *GeV/c*

→ $2 < \eta_l < 4.5$

→ $60 < m_{\mu\mu} < 120$ *GeV*, $m_{ee} > 40$ *GeV*

- purity above 99% for $\mu^+\mu^-$
- purity above 92% for e^+e^-
- efficiencies from data *(tag & probe)*





Z→ ee

- dominant background from electron mis-id
- peak smeared by bremsstrahlung

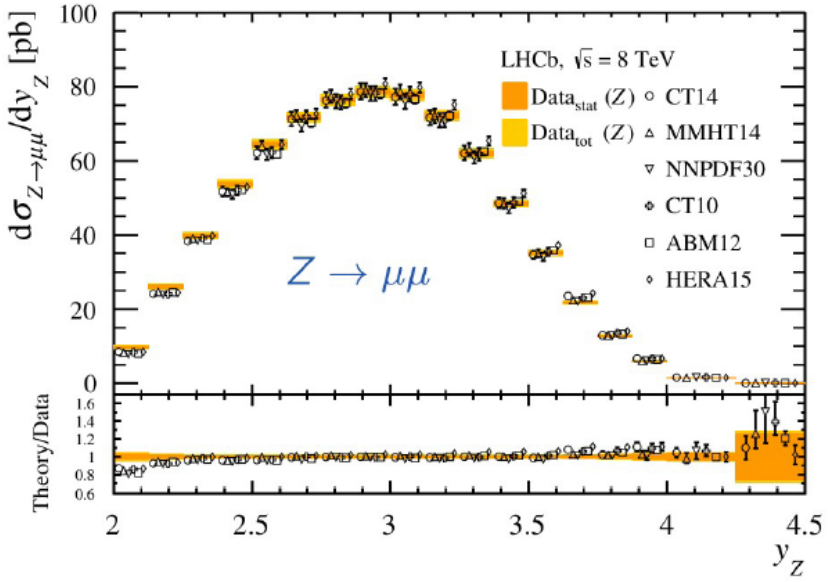
→ *bremsstrahlung photons often overlap with Z electrons*

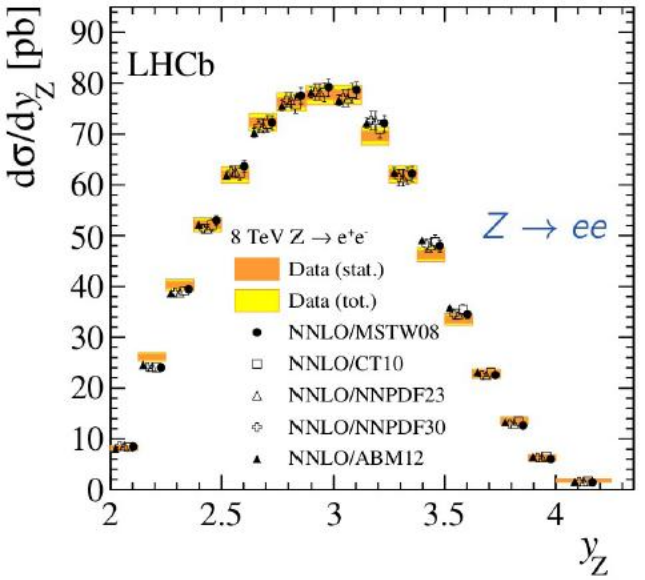
→ *bremsstrahlung recovery limited by ECAL saturation*

Inclusive Z production at 7 and 8 TeV (II)

[JHEP 01 (2016) 155]
[JHEP 05 (2015) 109]

Differential cross section in bins of rapidity





- experimental precision of 2-4%
- uncertainty dominated by lumi. determination and beam energy uncertainy
- good agreement with NNLO predictions using different PDFs

Z production at 13 TeV (I)

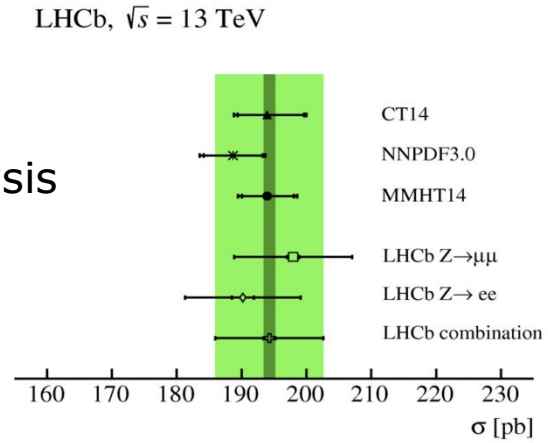
NEW!

[JHEP 09 (2016) 136]

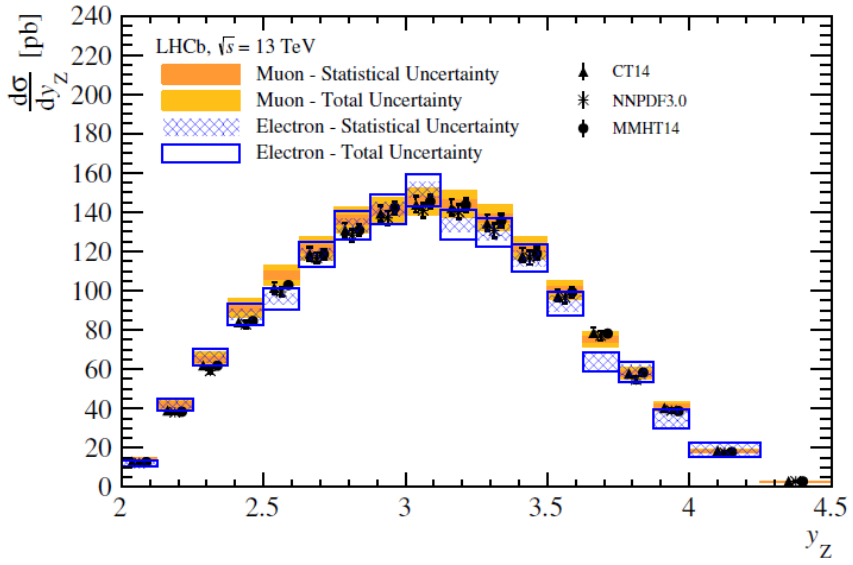
Inclusive $Z \to ll$ cross section at 13 TeV

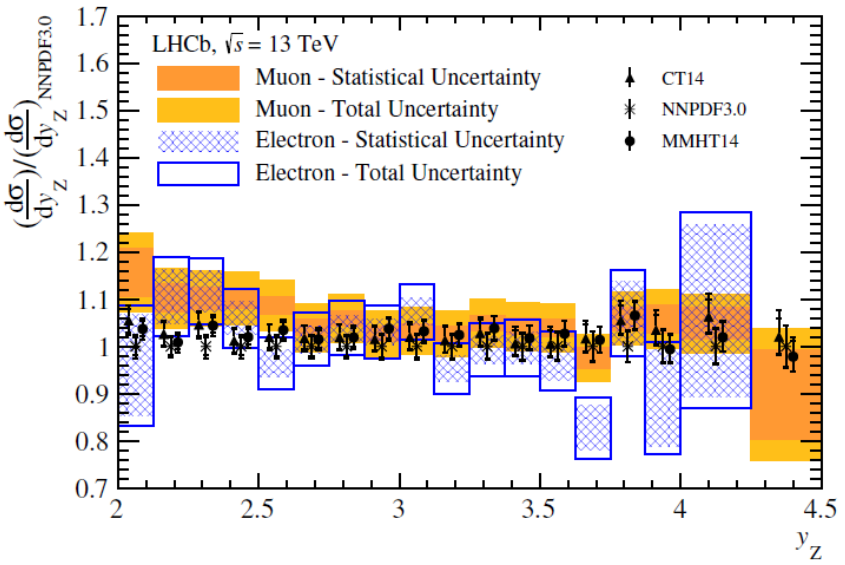
- may probe PDFs at lower x value than Run I
- smaller dataset ~0.3 fb^{-1}
- same strategy and fiducial region as in Run I analysis
- agreement with theory predictions
  (no PDF set favoured)
- good agreement between **$Z \to ee$** and **$Z \to \mu\mu$**

limited by luminosity uncertainty (3.9%)



Ratios to central values of NNPDF3.0 predictions





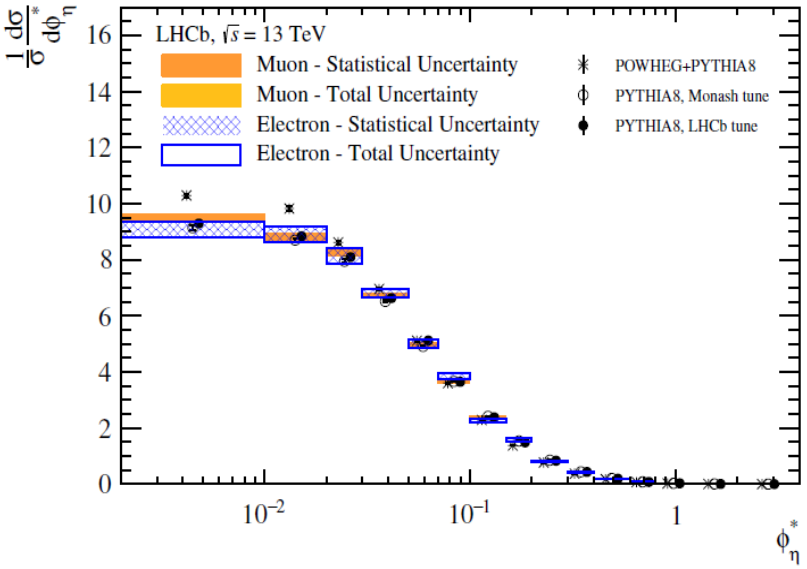
Z production at 13 TeV (II)

NEW!

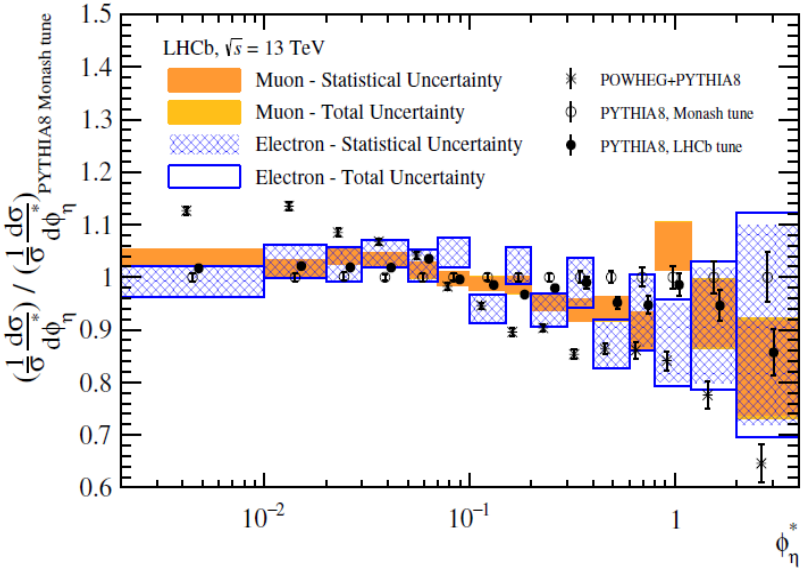
[JHEP 09 (2016) 136]

$$\phi^* \equiv \tan\left(\frac{\phi_{\rm acop}}{2}\right) \Big/ \cosh\left(\frac{\Delta\eta}{2}\right) \approx \frac{p_{\rm T}}{Mc}$$

$\phi_{acop} = \pi - \Delta\phi_{\ell\ell}$



Ratios to central values of Monash 2013 tune of Pythia 8



- no significant deviation between data and theory observed
  → *PYTHIA gets the shape better than POWHEG*
- clear statistical limitation → awaiting more data in 2016 and beyond

Inclusive W→μν production at 7 and 8 TeV

[JHEP 08 (2015) 039], [JHEP 01 (2016) 155]

Fiducial acceptance

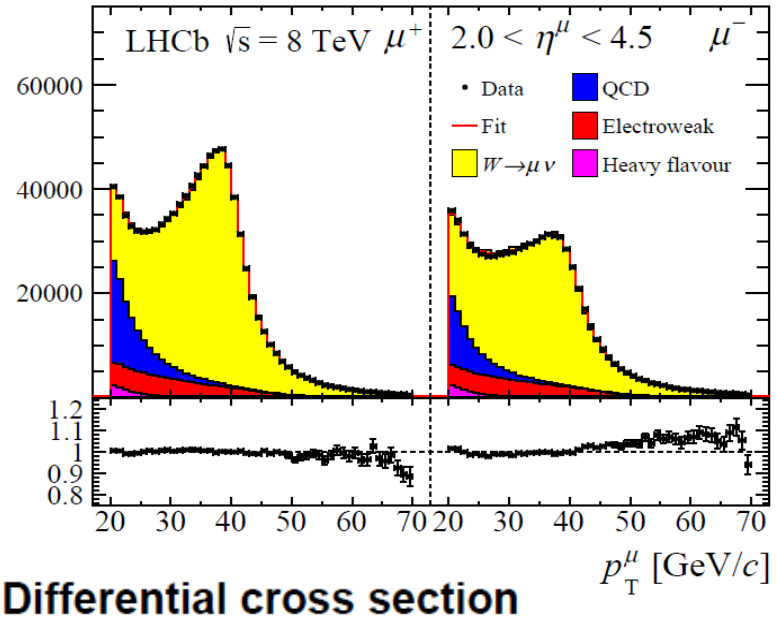
→ *one muon with p_T > 20 GeV*

→ *$2 < \eta_\mu < 4.5$*

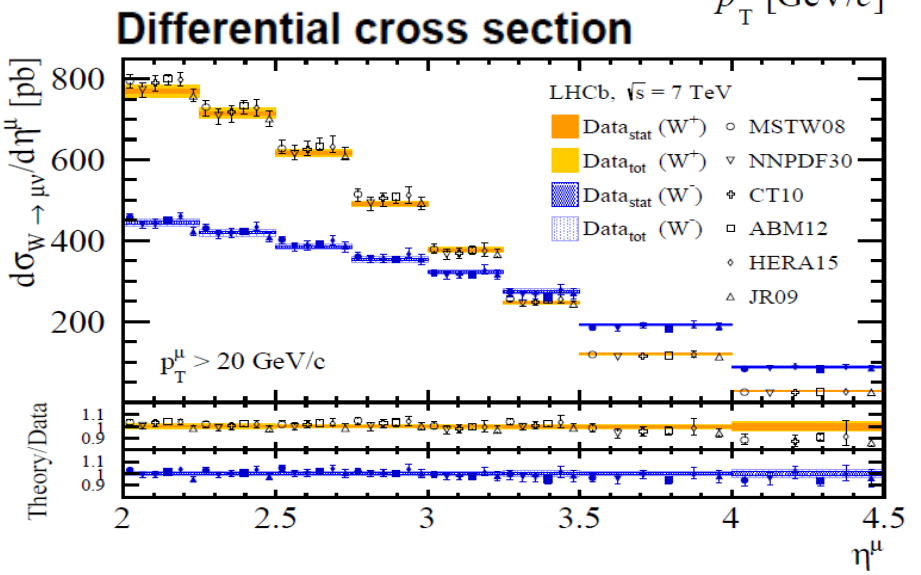
Additional selection

→ *muon isolated, prompt*

→ *small E_{CALO} / p*



- **LHCb is not 4π**
  - → *no E-miss, no transverse mass*
  - → *signature: single high p_T lepton*
- purity measured in bins of η
  (fits to muon p_T)
- typically: purity ~77%
- uncertainty dominated by luminosity and beam energy determination
- NNLO predictions for different PDFs compatible with data



Inclusive W→eν production at 8 TeV

NEW!

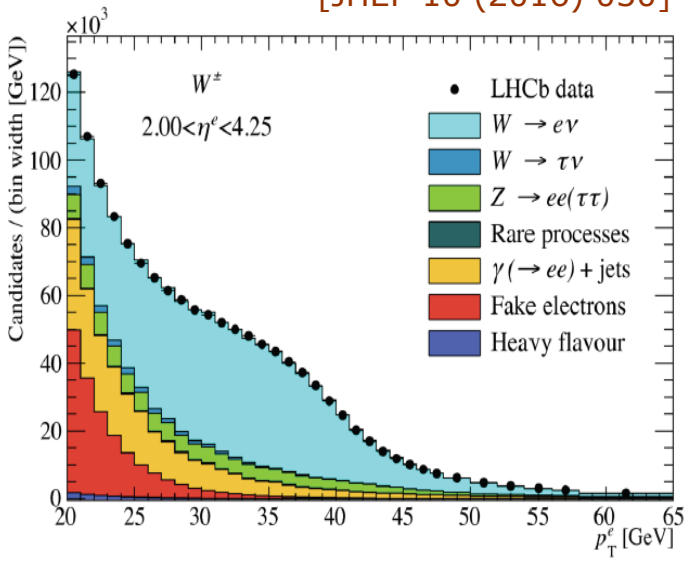
[JHEP 10 (2016) 030]

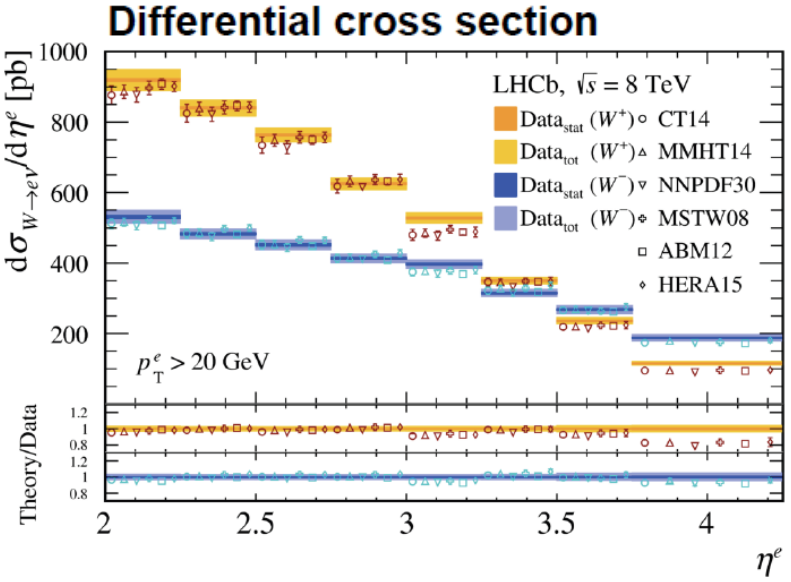
First measurement of $W \to e\nu$ at LHCb with 2 fb^{-1}

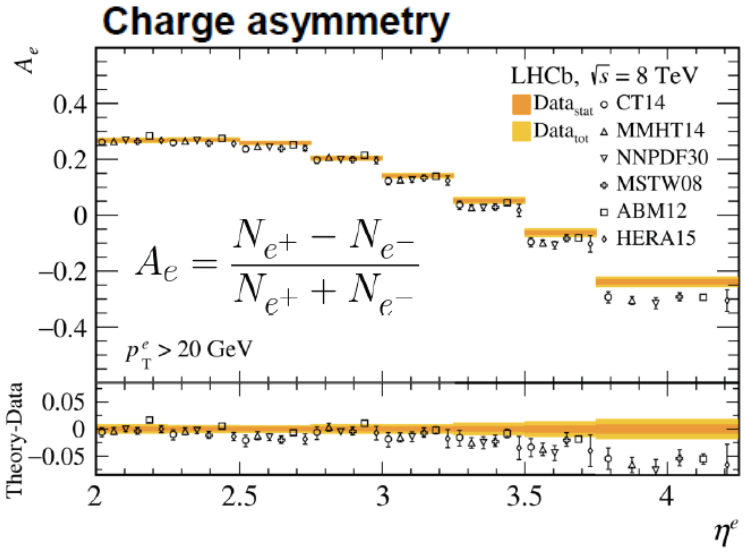
Fiducial acceptance

→ *single electron with* $p_T > 20$ *GeV,* $2 < \eta_e < 4.25$

- purity ~60%
- additional $\gamma \to ee$ background
- softer p_T spectrum compared to W→μν
- efficiencies data driven







Good agreement between measured cross-section and theoretical predictions with different PDFs

W / Z ratios

Ratios of W and Z production *($W^+/W^-/Z$, 7/8 TeV, double ratios)*

[JHEP 12 (2014) 079]
[JHEP 01 (2016) 155]

→ tests of SM

→ constraints on PDFs

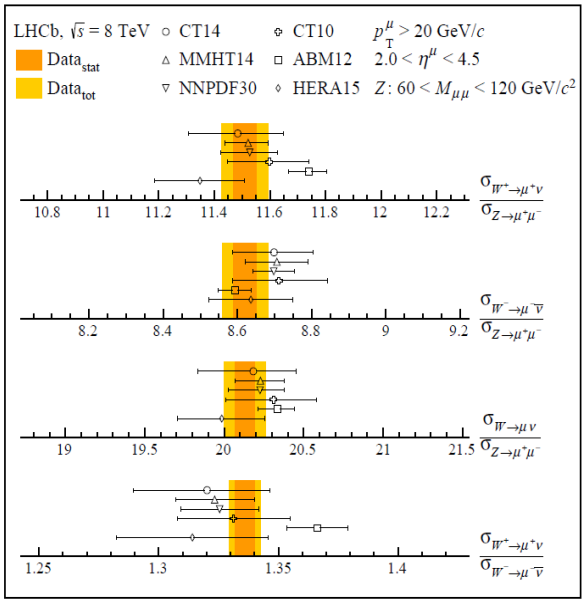
Many correlated uncertainties cancel!

→ luminosity and detection efficiency

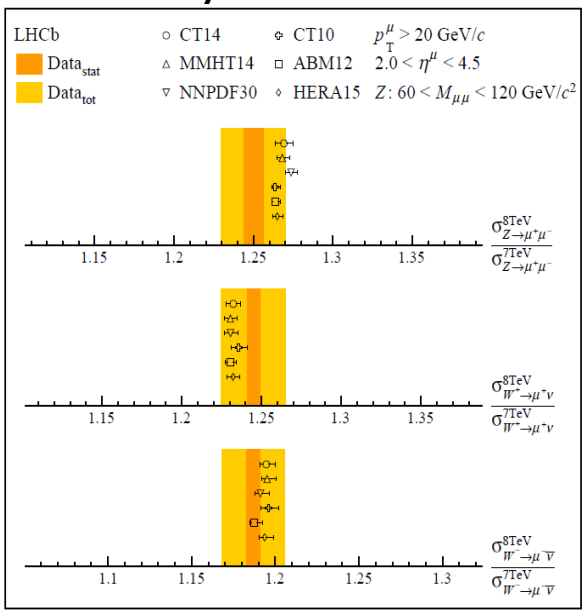
→ PDFs uncertainty

→ renormalisation and factorization scale uncertainties

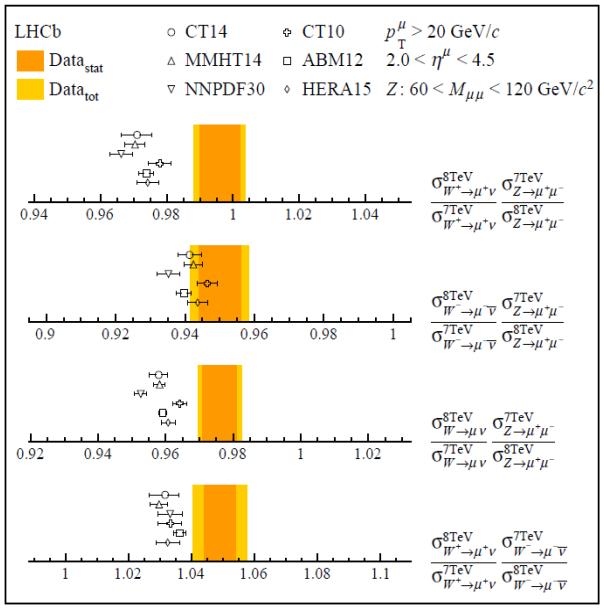
$W^+/W^-/Z$



7/8 TeV



double ratios



statistically limited → < 1% systematic error

W + jets and Z + jets at 8 TeV

[JHEP 05 (2016) 131]

Z and W fiducial acc. and selection same as before

Jet fiducial acceptance *(anti-k_T, R = 0.5)*

→ *$2.2 < \eta < 4.2$, $p_T > 20$ GeV*

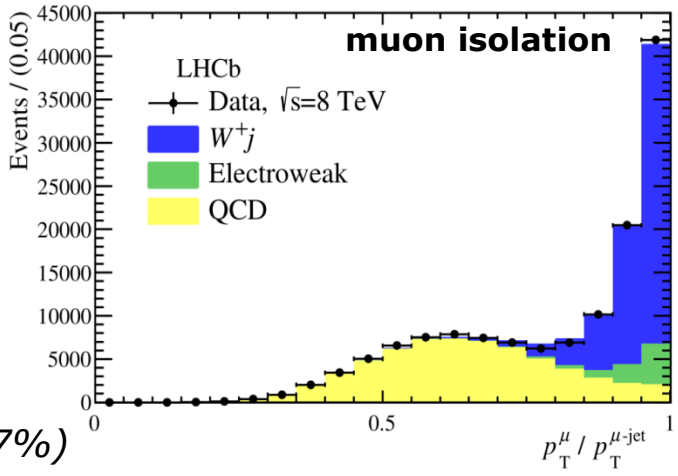
→ *W + jet: $p_T(\mu+jet) > 20$ GeV*

→ *only highest p_T jets*

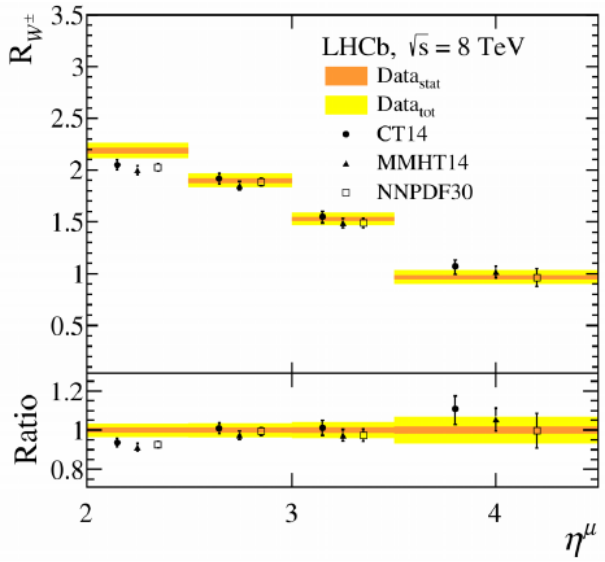
- uncertainties:

→ *9% (W^++jet), 11% (W^-+jet), 5% (Z+jet)*

→ *dominated by jet energy scale (~10%) and purity (~7%)*



comparison of $\sigma(W^+)/\sigma(W^-)$

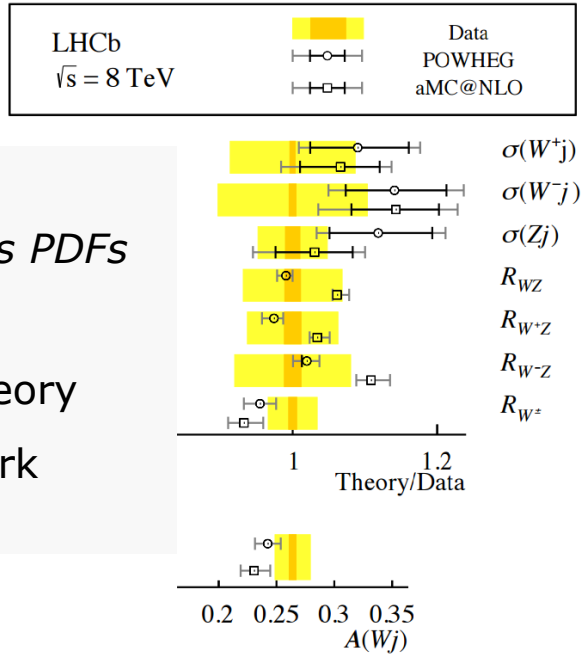


- theoretical predictions

→ *FEWZ fixed order + various PDFs*

→ *POWHEG and aMC@NLO*

- good agreement data vs theory
- additional sensitivity to quark and gluon PDFs

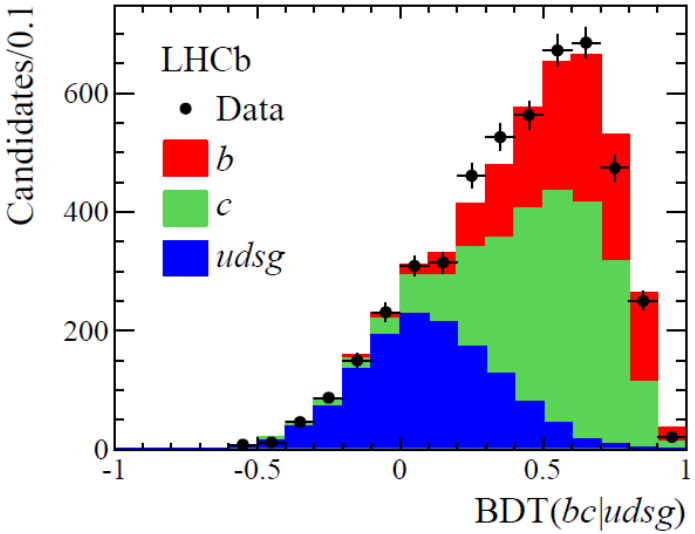


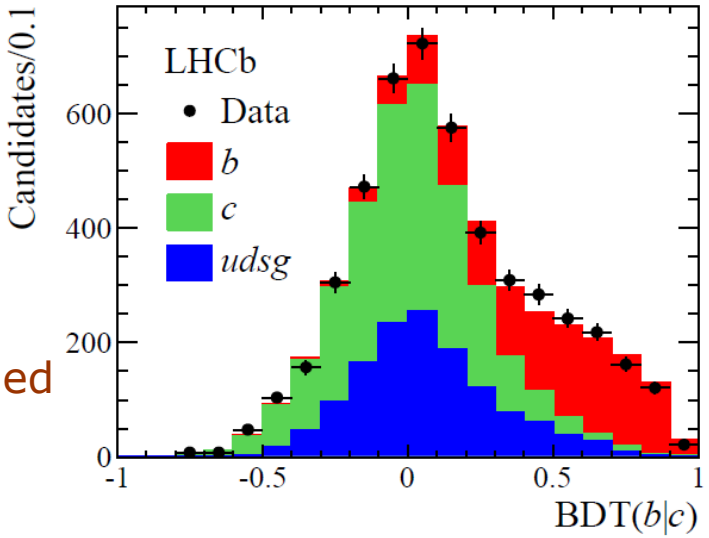
W + heavy flavour jets at 7 and 8 TeV (I)

[JINST10 (2015) P06013]

Jet flavour composition of the W + jet sample

- *b* and *c* hadrons tagged by reconstructing SV in a jet cone
- 2 BDTs trained for light / heavy and *b* / *c* separation
- input: *nr of vertices, nr of tracks, SV mass*
- jet content extracted from fits to 2D BDT distributions
- *b(c)* efficiency ~60% (20%) for 0.3% *udsg* contamination
- uncertainty dominated by statistical errors
- b and c tagging uncertainties (~10%) determined from data





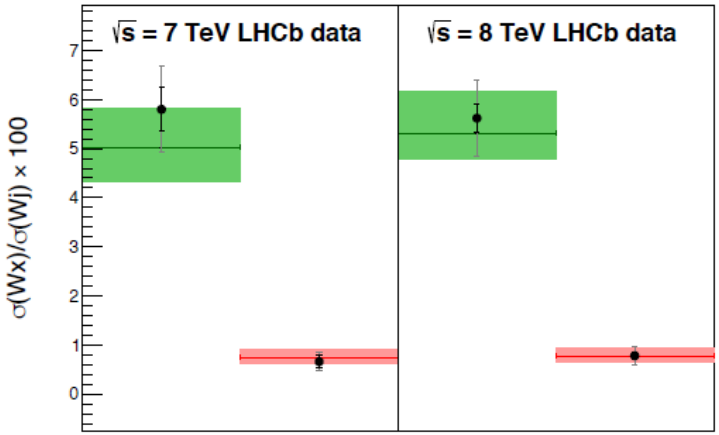
W + heavy flavour jets at 7 and 8 TeV (II)

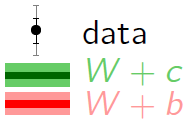
[PRD 92 (2015) 052001]

W ratios *(W+b(c) / W+light)* and charge asymmetries

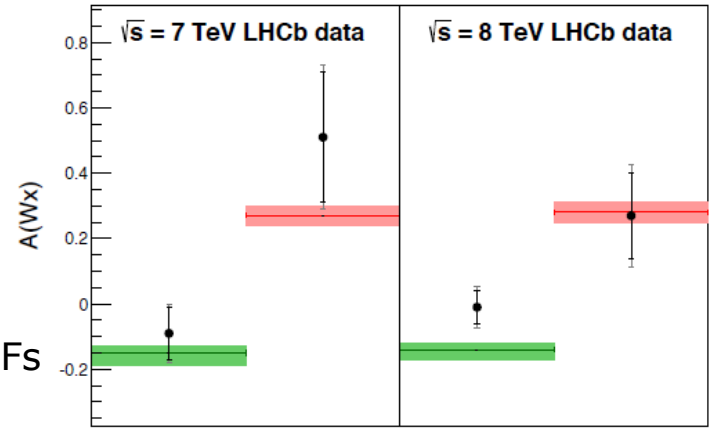
Motivation:

- W+c/W+jet constrains *s* quark PDF
- W+b/W+jet constrains *b* PDF and *bb(bar)* gluon splitting, top production, BSM,…





predictions:
MCFM (NLO)
with CT10 PDFs



Measurements are compatible with theory

→ measured W + c asymmetries ~2σ smaller than SM expectations

→ possibly additional tuning needed for s-quark PDF?

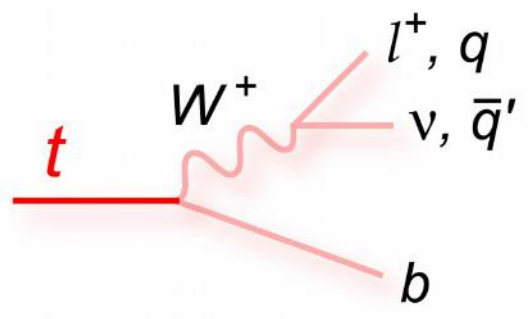
Top production at 7 and 8 TeV (I)

[Phys. Rev. Lett. 115 (2015) 112001]

First observation of top in forward region

Motivation

- at large rapidities expected increase of *tt* production via *qq / qg* wrt *gg* fusion
  - → *large charge asymmetry*
  - → *sensitive to BSM physics*
- probe gluon PDFs at high *x* and high Q^2



Data: 1 fb-1 at 7 TeV and 2 fb-1 at 8 TeV

Fiducial acceptance

→ *muon* $p_T > 25$ *GeV*

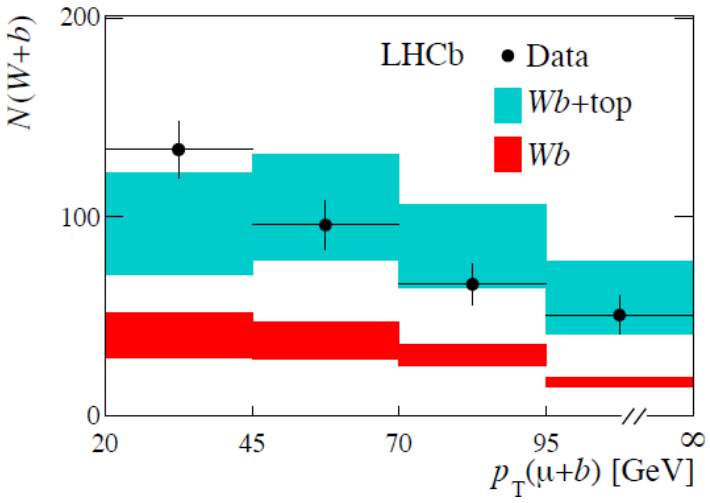
→ $50\ GeV < p_T^{b\text{-}jet} < 100\ GeV$

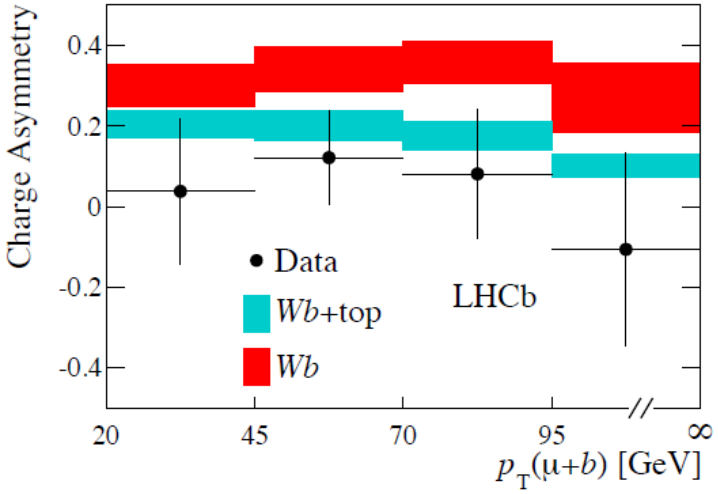
- *t->Wb* from fit to yields
- charge asymmetry in $p_T(\mu+b)$ bins *(see next slide)*

Top production at 7 and 8 TeV (II)

Observation consistent with SM prediction

[Phys. Rev. Lett. 115 (2015) 112001]



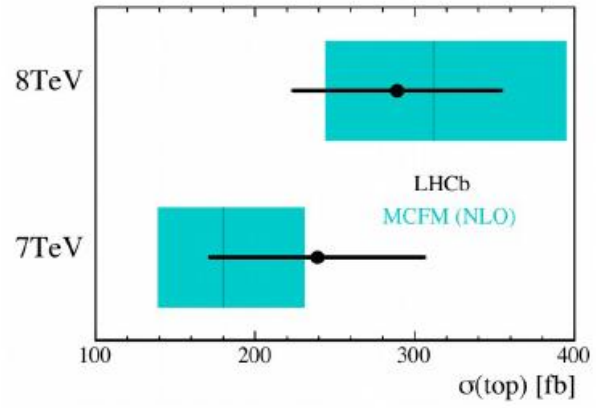


Results for inclusive *(tt(bar) + t + t(bar))* production x-section in fiducial acceptance

$$\sigma(\text{top})[7\,\text{TeV}] = 239 \pm 53\,(\text{stat}) \pm 38\,(\text{syst})\,\text{fb}$$
$$\sigma(\text{top})[8\,\text{TeV}] = 289 \pm 43\,(\text{stat}) \pm 46\,(\text{syst})\,\text{fb}$$

SM prediction

$180^{+51}_{-41}(312^{+83}_{-68})$ fb at 7(8) TeV



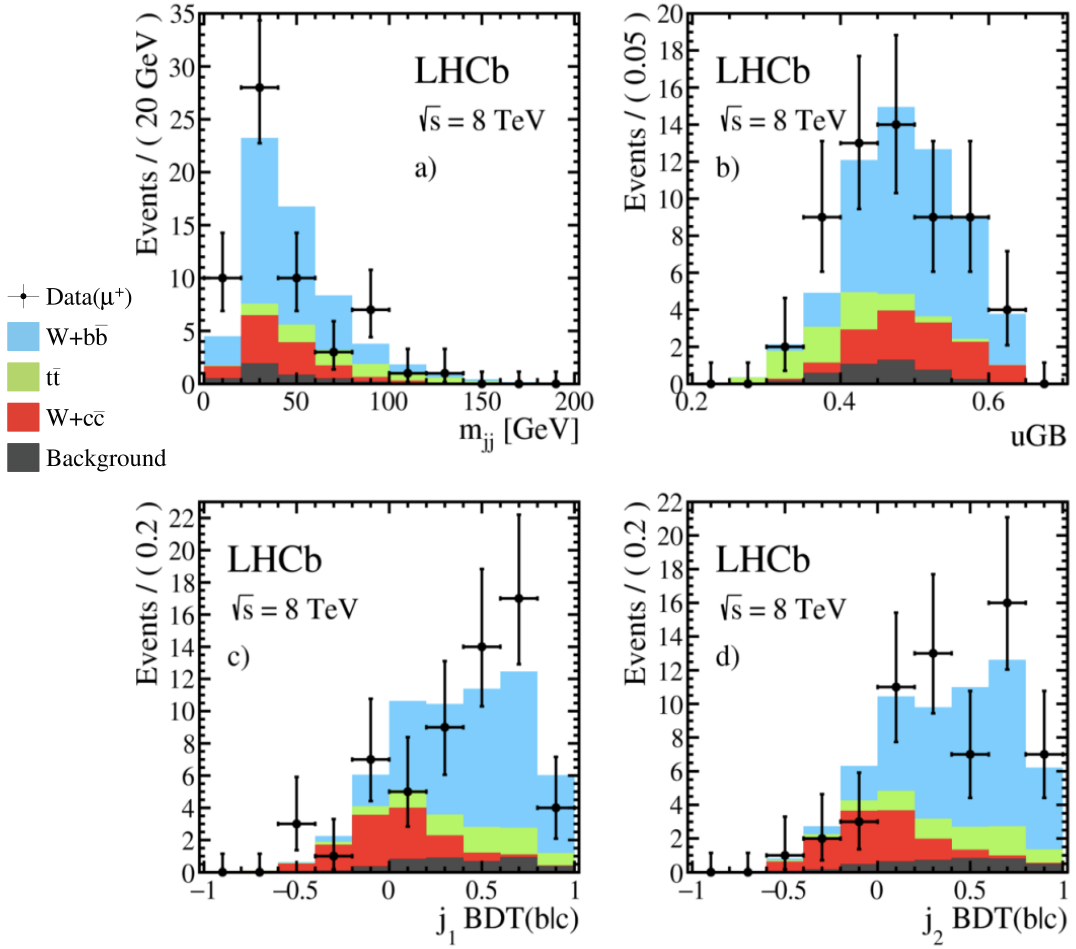
$Wb\bar{b}$, $Wc\bar{c}$ and $t\bar{t}$ cross-section at 8 TeV NEW!

[Phys. Lett. B767 (2017) 110]

Analysis extended to one isolated lepton *(muon or electron)* and two heavy-flavour tagged jets using 2 fb^{-1}

- leptons:
  - → *isolated*
  - → p_T >20 GeV
  - → 2 < η < 4.5 (4.25) for μ (e)
- jets:
  - → p_T > 12.5 GeV
  - → 2.2 < η < 4.2
- ΔR*(lepton-jet)* > 0.5

Fit projection on μ⁺



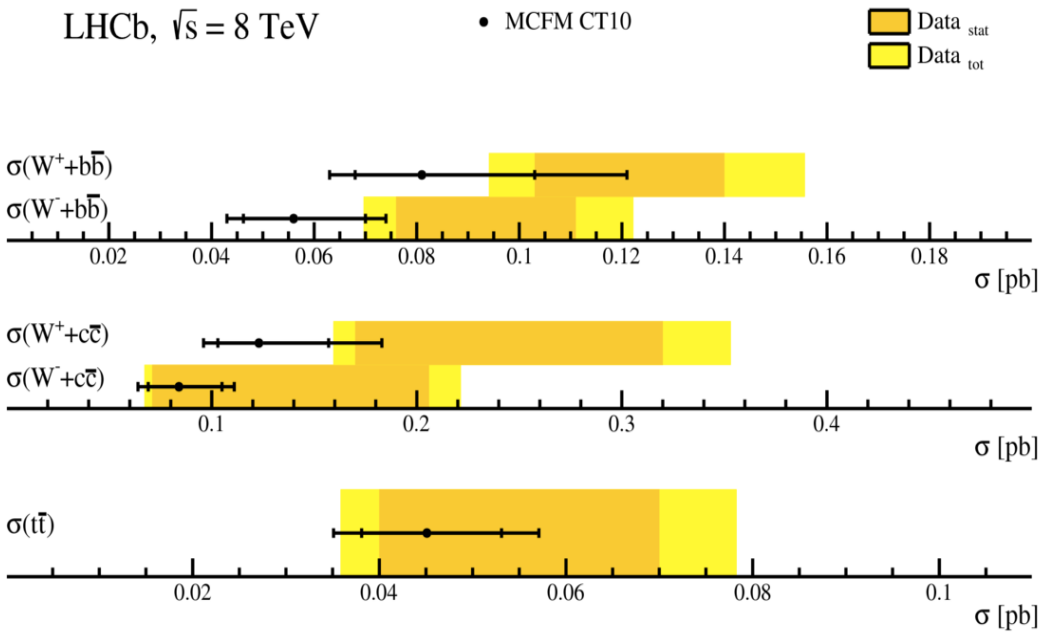
- simultaneous 4D fit to μ^+, μ^-, e^+, e^-
  - → *$Wb\bar{b}$, $Wc\bar{c}$ and $t\bar{t}$ floated*
- MVA (uGB) to separate $Wb\bar{b}$ from $t\bar{t}$
  - → *topology*
  - → *kinematic variables*
  - → *sub-combination masses*

Novel measurement of W + cc prōduction

$Wb\bar{b}$, $Wc\bar{c}$ and $t\bar{t}$ cross-section at 8 TeV NEW!

[Phys. Lett. B767 (2017) 110]

- MCFM NLO prediction with PDF set CT10
- Showering and hadronization using Pythia 8



Sample	Significance
$t\bar{t}$	4.9σ
$W^+ + b\bar{b}$	7.1σ
$W^- + b\bar{b}$	5.6σ
$W^+ + c\bar{c}$	4.7σ
$W^- + c\bar{c}$	2.5σ

Good Agreement with NLO predictions

Conclusions

- LHCb's acceptance complementary to ATLAS and CMS
  - ability to probe high and low Björken-x values
- Many precise W and Z boson measurements at 7, 8 and 13 TeV
  - inclusive and in association with jet(s)
  - cross-section ratios important for SM tests
  - first Run-II measurement of Z production at LHCb
- First observation of top in the forward region
  - also tt(bar) x-section for Run I data
  - ~10 x higher cross-section expected within LHCb acceptance at 13 TeV
- Much more results expected for Run II and beyond
  - collect at least 2 fb^{-1} per year
  - higher cross sections and acceptance for W and Z physics

Backup

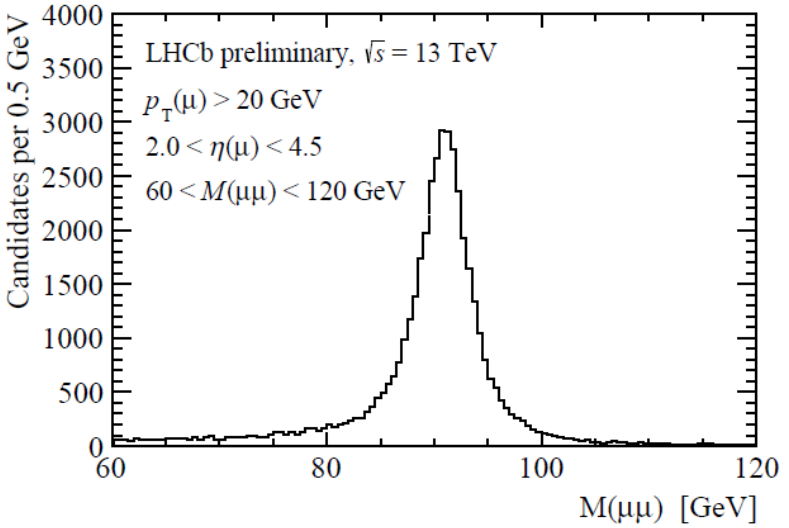
Z production at 13 TeV

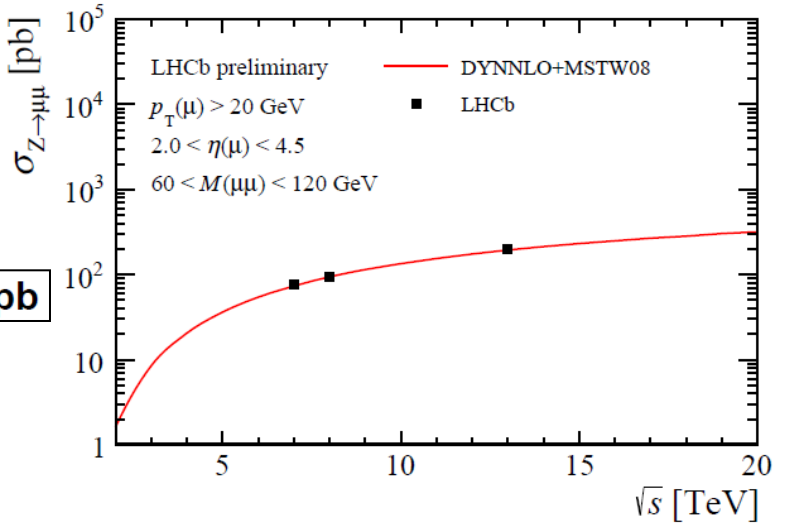
[LHCb-CONF-2016-002]

Inclusive $Z \to \mu^+\mu^-$ cross section at 13 TeV

- dataset used ~0.3 fb^{-1}
- same procedure and fiducial region as in Run I analysis
- may probe PDFs at lower x value than Run I

limited by luminosity determination





$\sigma(pp \to Z + X) = 198.4 \pm 1.0\ (stat.) \pm 4.7\ (syst.) \pm 7.7\ (lum.)$ pb