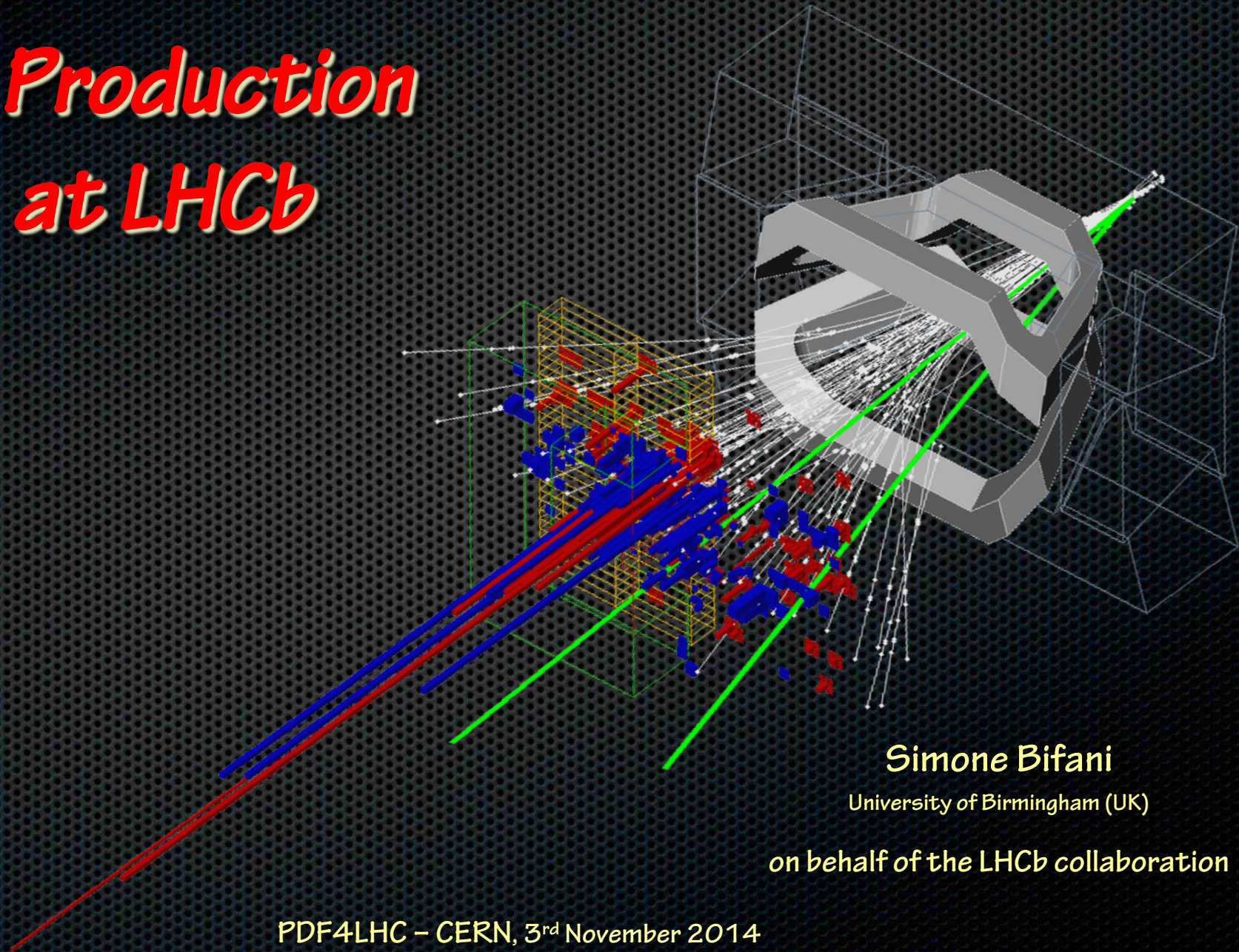




# *W Production at LHCb*



**Simone Bifani**

University of Birmingham (UK)

on behalf of the LHCb collaboration





# Outline



- > Analysis
- > Results
- > Impact on PDFs
- > Summary and Outlook

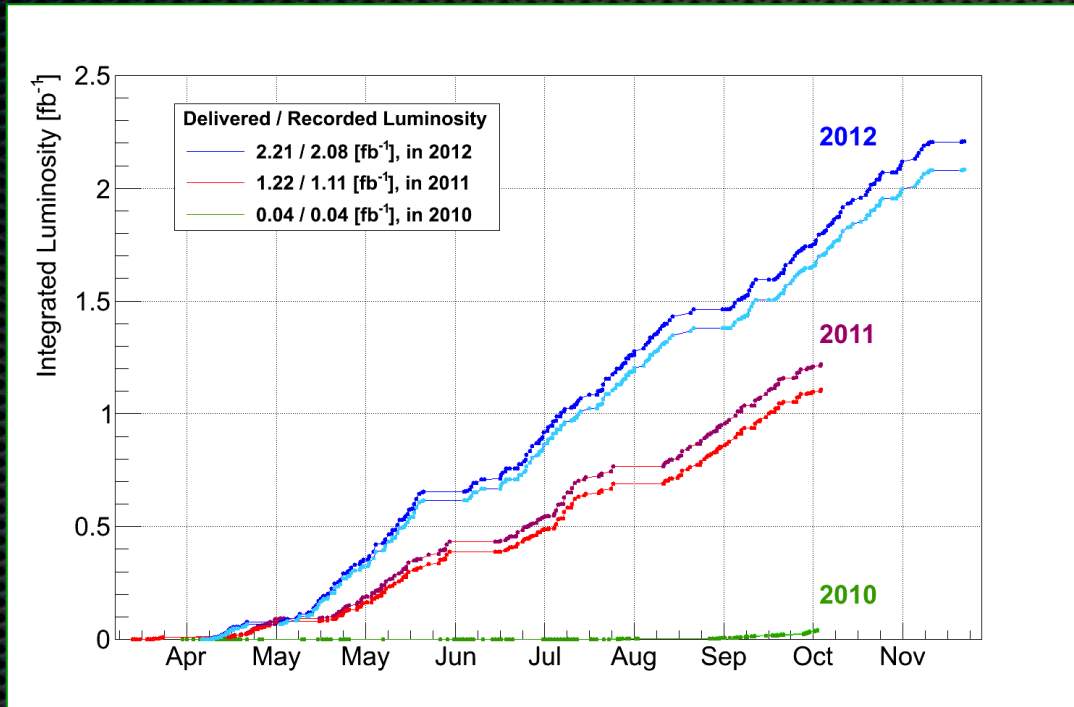




# Datasets



- › Analyses based on 2011 pp data samples at 7 TeV
- › 2012 pp data at 8 TeV are currently being analysed



»  $\int L_{2011} \sim 1 \text{ fb}^{-1}$   
»  $\int L_{2012} \sim 2 \text{ fb}^{-1}$

- › Due to luminosity levelling, same running conditions throughout fills
- › EW trigger thresholds unchanged during years





# Selection

arXiv:1408.4354

> **Single muon trigger:**  $p_T > 10 \text{ GeV}/c$

> **1 reconstructed & isolated muon**

»  $p_T > 20 \text{ GeV}/c$

»  $2.0 < \eta < 4.5$

» Cone  $p_T (R=0.5) < 2 \text{ GeV}/c$   
(charged & neutral information)

> **Backgrounds**

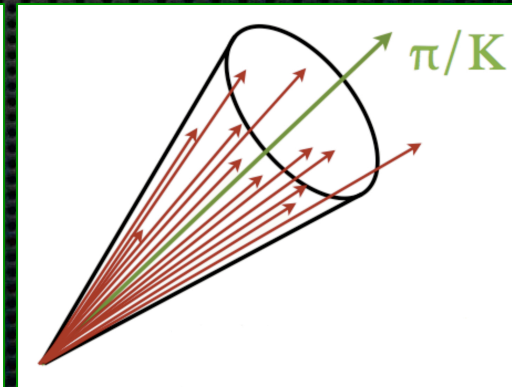
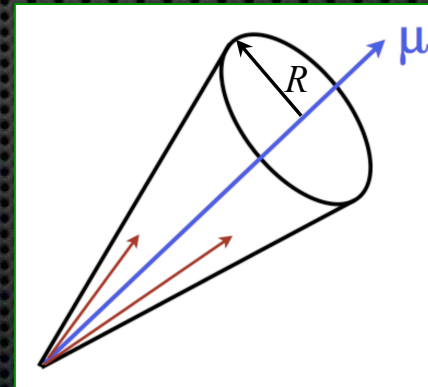
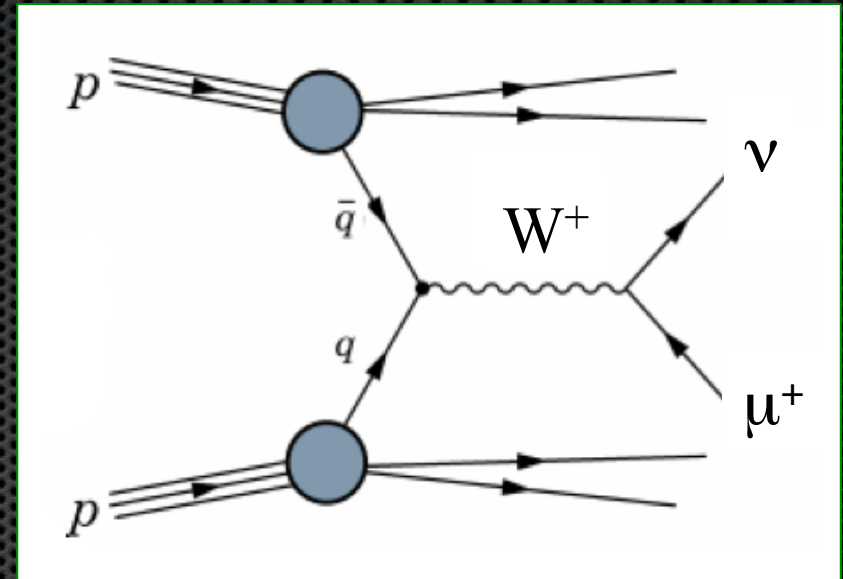
»  $Z/\gamma^* \rightarrow \mu\mu$  (MC)

»  $W \rightarrow \tau\nu$  and  $Z \rightarrow \tau\tau$  (MC)

» Heavy flavour (Data)

»  $K/\pi$  decay in flight (Data)

»  $K/\pi$  punchthrough (Data)



$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$





# Selection

arXiv:1408.4354

› Specific cuts implemented to reduce each background component

›  $Z/\gamma^* \rightarrow \mu\mu$

›› Veto on extra muons with  $p_T > 2 \text{ GeV}/c$

›  $W \rightarrow \tau\nu$ ,  $Z \rightarrow \tau\tau$  and Heavy flavour

›› Impact parameter  $< 40 \mu\text{m}$

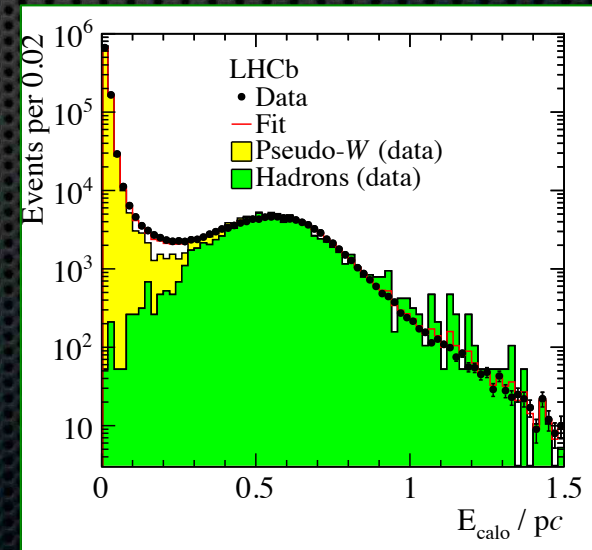
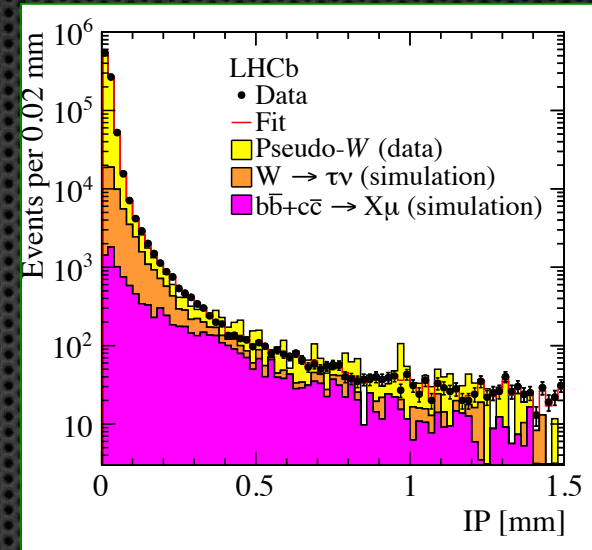
›  $K/\pi$  punchthrough

››  $E / p_c < 4\%$

› Largest residual backgrounds

›› Decays in flight of  $K/\pi$

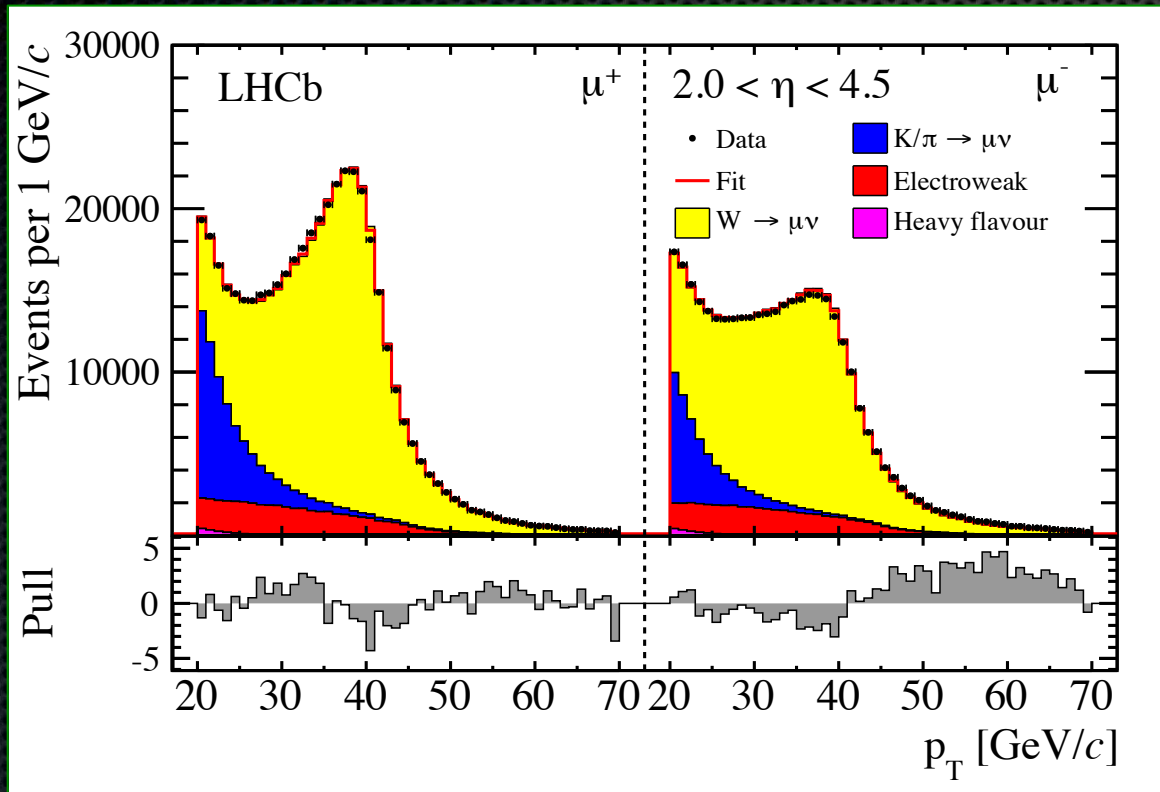
››  $Z \rightarrow \mu\mu$  events with one muon outside the acceptance







- Fit positive and negative muon  $p_T$  spectra in data to expected shapes for signal and backgrounds in  $\delta \eta$  bins



Signal and decay in flight templates free to vary  
Remaining backgrounds fixed

$N_{\text{Candidates}} = 448k^+, 355k^-$   
Purity  $\sim 77\%$

- W and Z muon  $p_T$  spectra at NNLO (ResBos)





# Systematics

arXiv:1408.4354

› Update to 2010 result [JHEP 1206 (2012) 058]

Source	2010	2011
Statistical	1.1%	0.3%
Systematic		
Purity	1.1%	0.3%
Template Shape	1.0%	0.3%
Reconstruction Efficiency	2.1%	1.2%
Selection Efficiency	1.8%	0.3%
Total	3.1%	1.3%
Luminosity	3.5%	1.7%

› *Detector effects better understood*

› *Larger statistics available for data-driven inputs*

› *Precision of luminosity significantly increased*

*“The most precise luminosity measurement achieved so far at a bunched-beam hadron collider” [LHCb-PAPER-2014-047]*

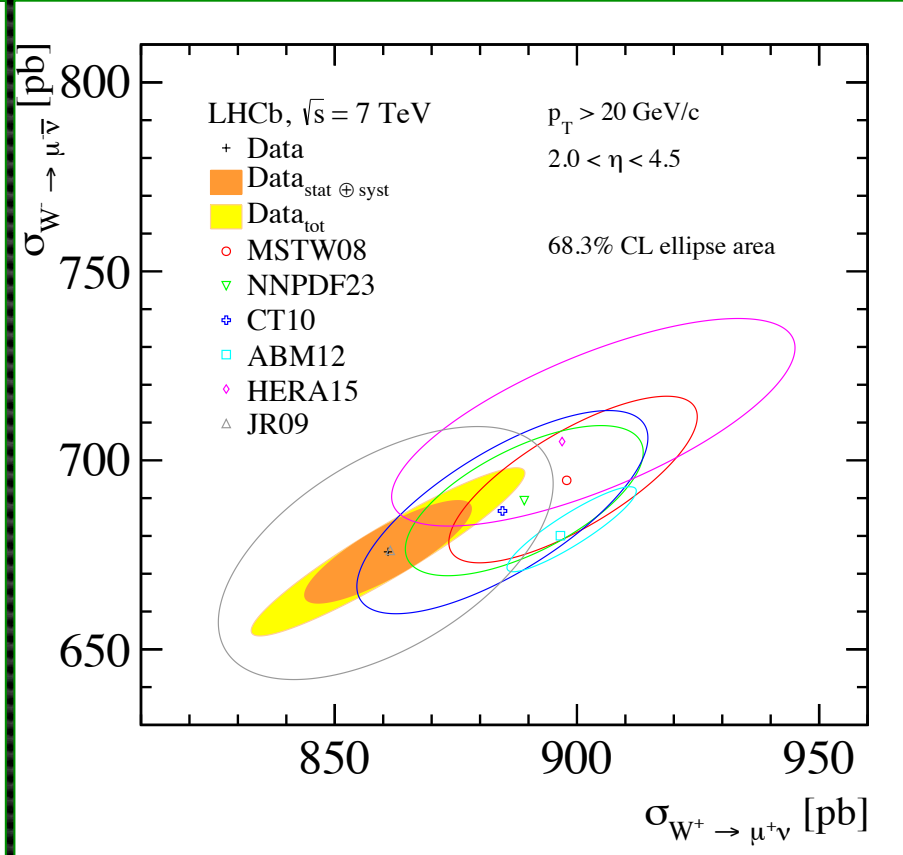
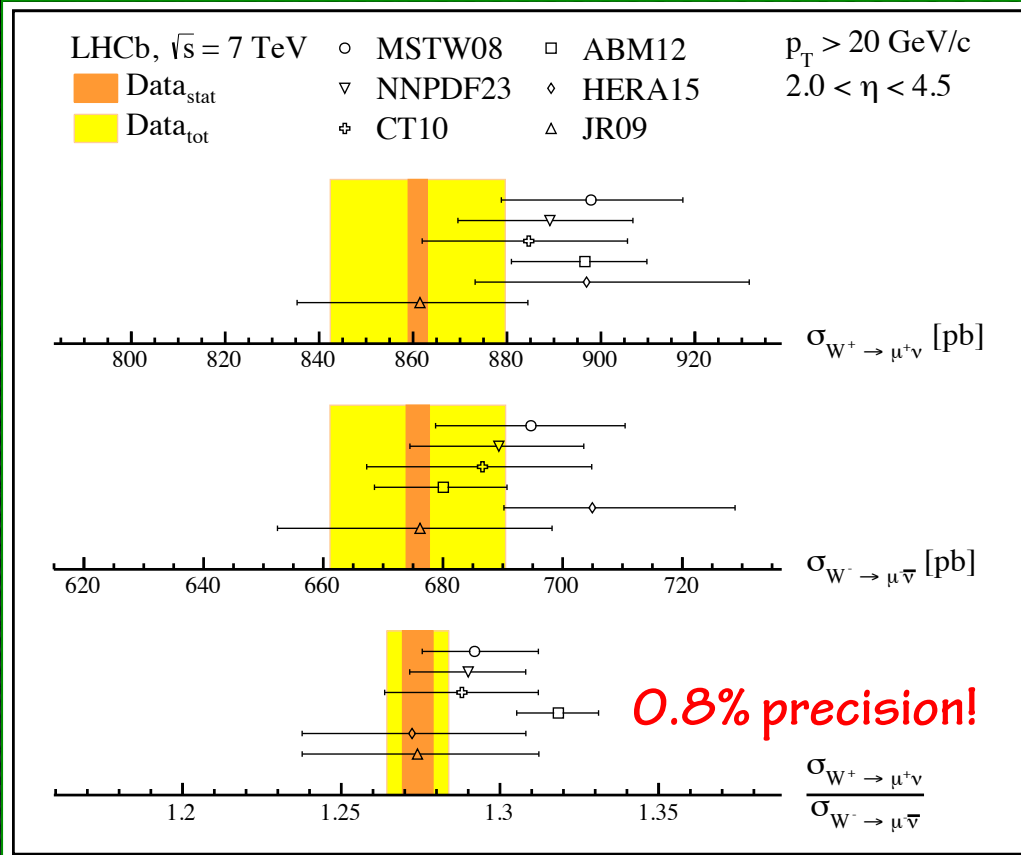




# Results

arXiv:1408.4354

> **Fiducial volume:**  $p_{T,\mu} > 20 \text{ GeV}/c$ ,  $2.0 < \eta_{\mu} < 4.5$



> Results in general agreement with NNLO predictions

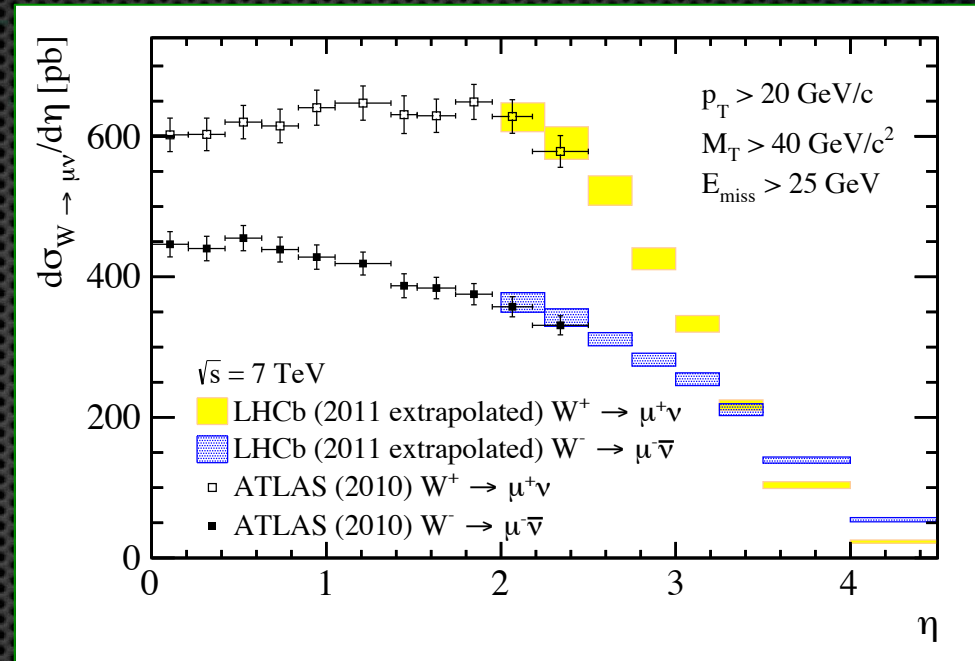
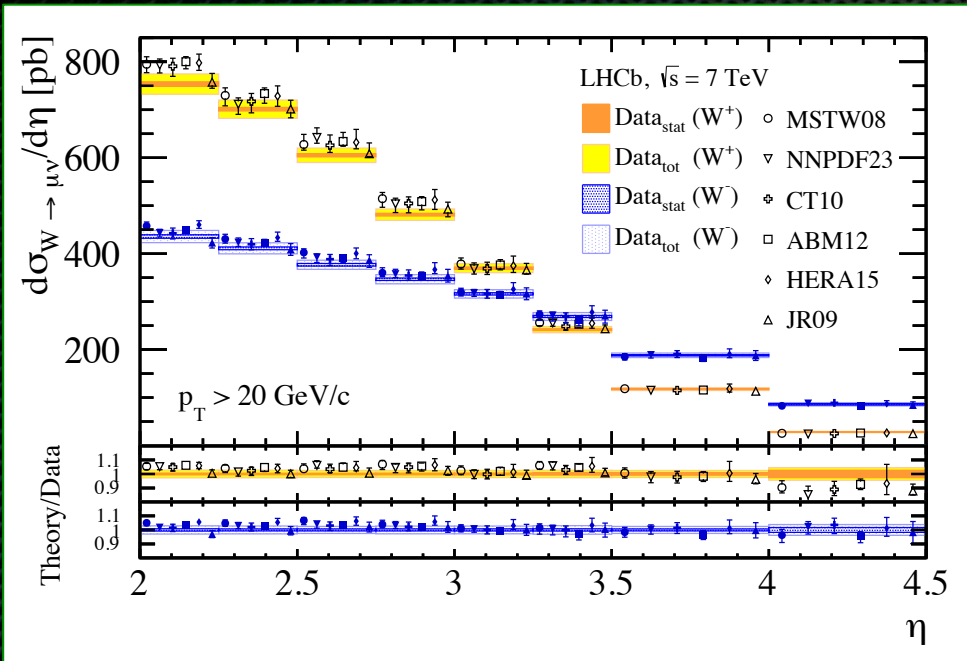
> Main systematics: template fit, reconstruction efficiencies





# Results

arXiv:1408.4354



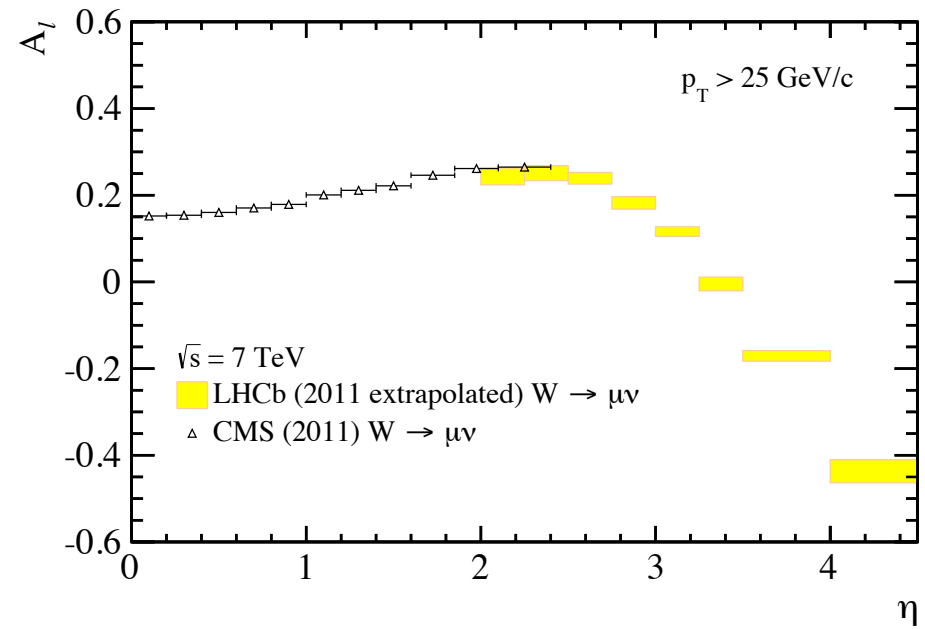
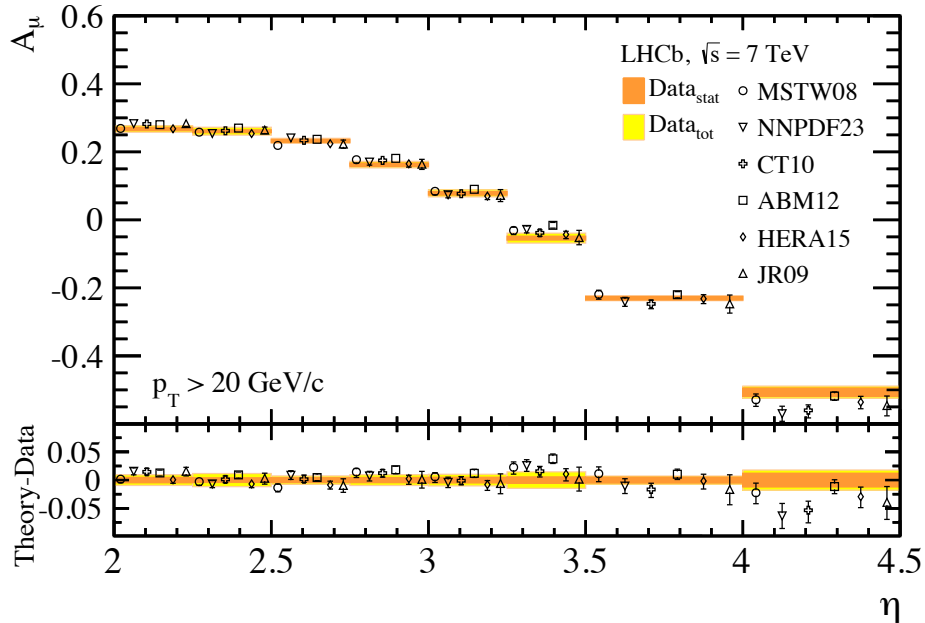
> Good agreement with NNLO

> Good agreement with ATLAS (after extrapolating to ATLAS cuts)





## Lepton charge asymmetry



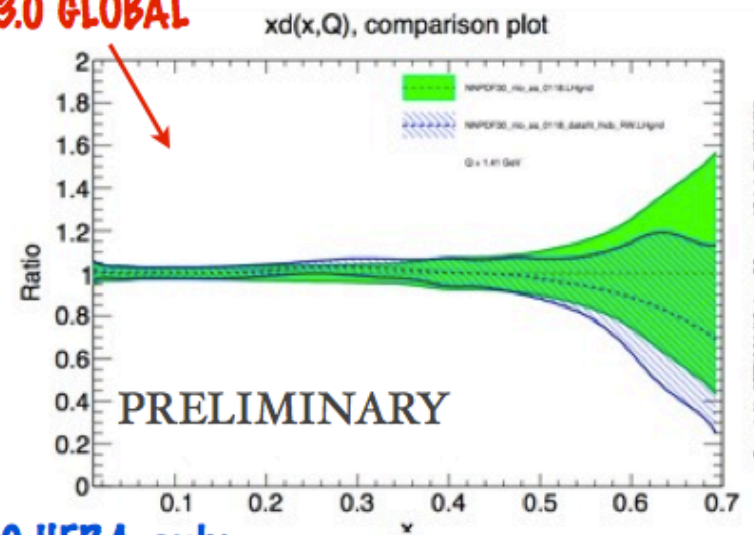
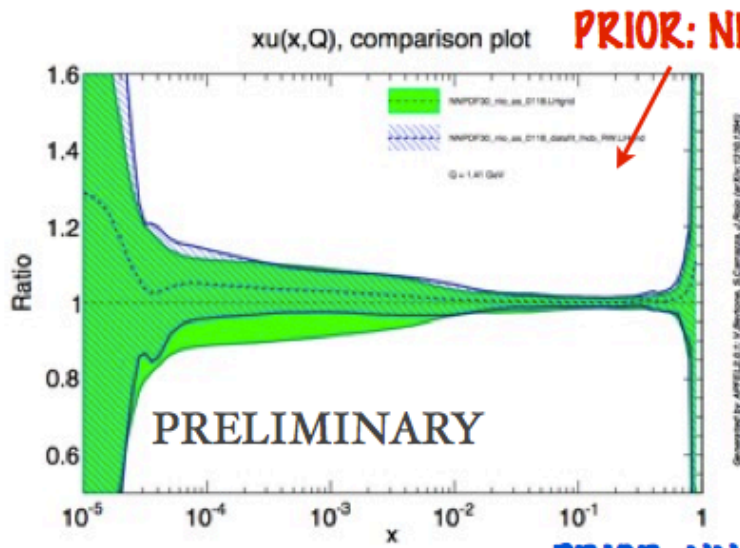
> Good agreement with NNLO

> Good agreement with CMS (after extrapolating to CMS cuts)

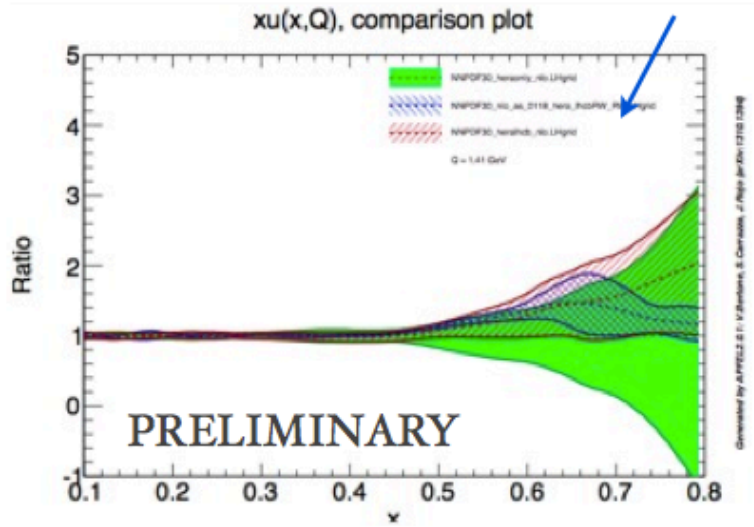




# Impact on PDFs



**PRIOR: NNPDF3.0 HERA-only**



- \* Reweighting using NNPDF3.0 prior  
**Nucl.Phys. B855 (2012) 608**
- \* Large impact of precise  $W$  measurements on global fit: visible reduction of u/d uncertainty
- \* Even larger impact on HERA only fit  
**RED:** HERA prior + LHCb (old)  
**BLUE:** HERA prior + LHCb (new)

10/18

> **M.Ubiali @ LHCb Impication Workshop**





# Summary and Outlook

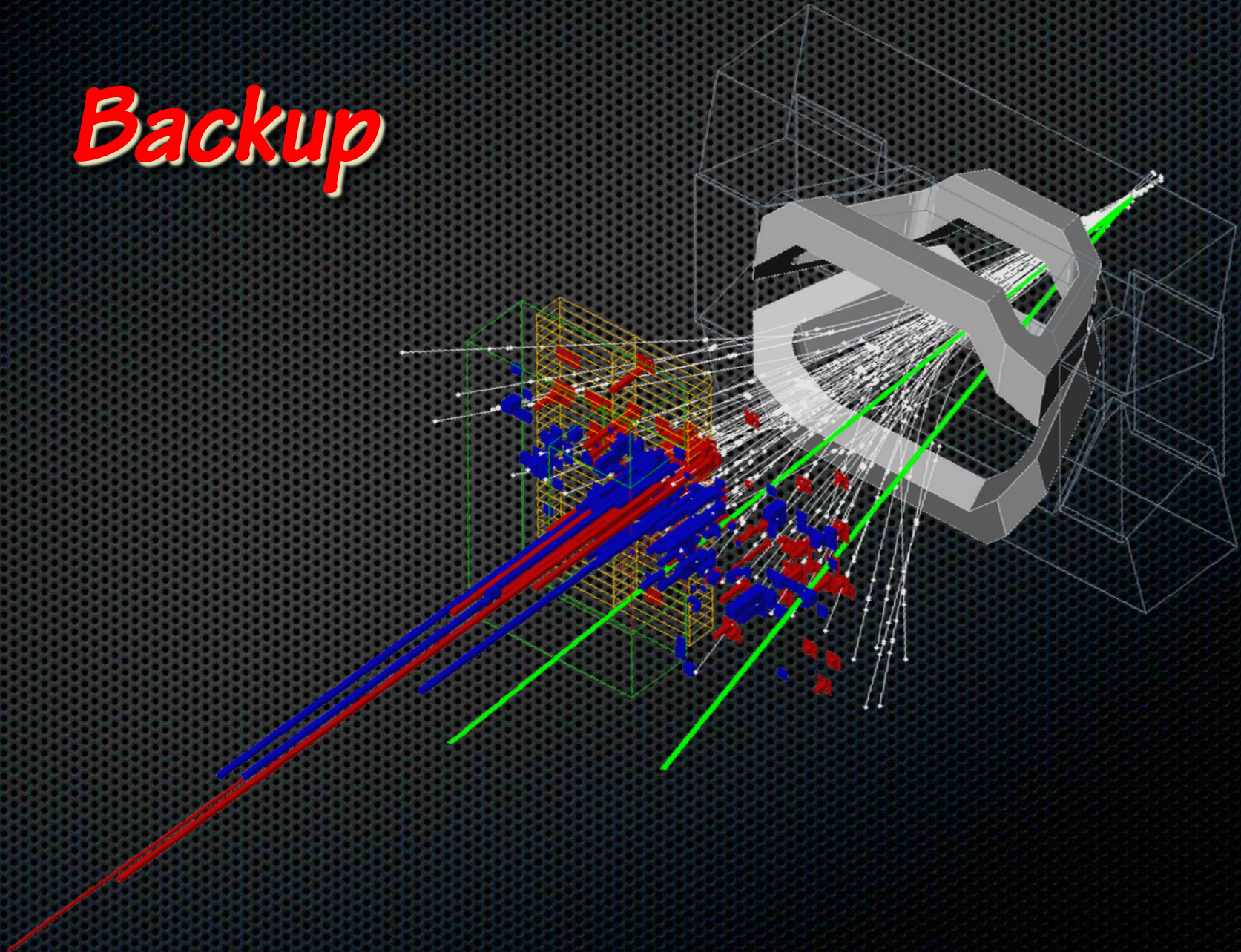


- › LHCb probes a unique region in  $\eta$  and low  $p_T$  reach at LHC
- ›  $W$  production cross-sections measured in the forward region at 7 TeV with  $1 \text{ fb}^{-1}$  of data
- › Results consistent with theoretical predictions calculated at NNLO using recent parameterisation of the PDFs
  
- › New results expected soon
  - » 2011  $Z$  in review
  - » 2011  $Z+b$  coming shortly
  - » 2012  $W$  and  $Z$  well underway
  - » 2011+2012  $W+b,c$  in review





# Backup



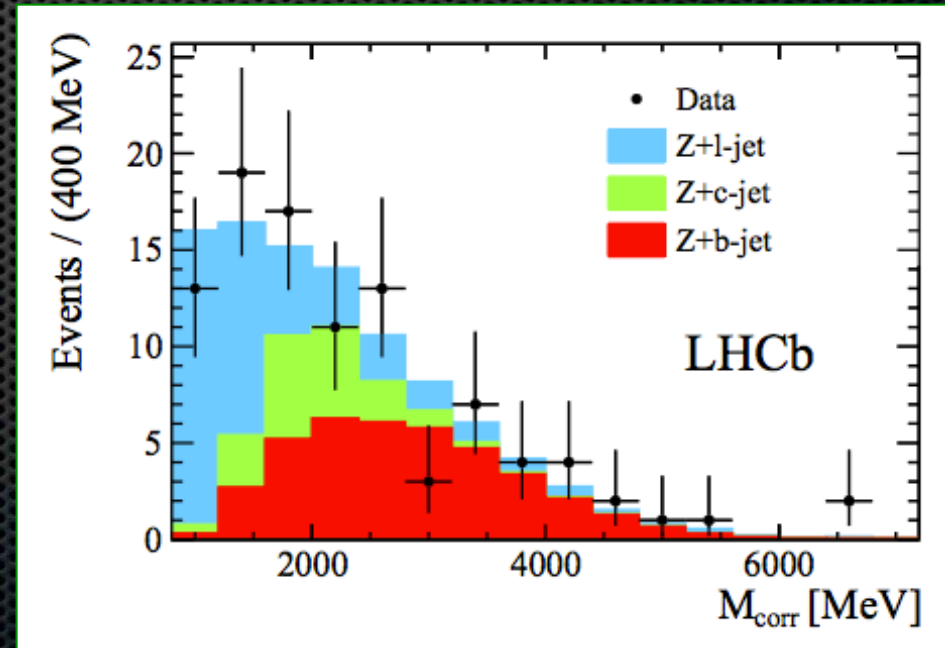




- > Z+jet analysis (JHEP 01 (2014) 033) extended to perform measurement of Z+b production at LHCb
- > Jet b-tagged by searching for secondary vertices within reconstructed jet
- > B-tagging efficiency of ~50-55% at high  $p_T$
- > Purity determined by performing template fit to  $M_{corr}$  of the vertex

$$M_{corr} = \sqrt{M^2 + p^2 \sin^2 \theta} + p \sin \theta$$

- > Represents mass of secondary vertex corrected for missing particles
- > Templates taken from simulation

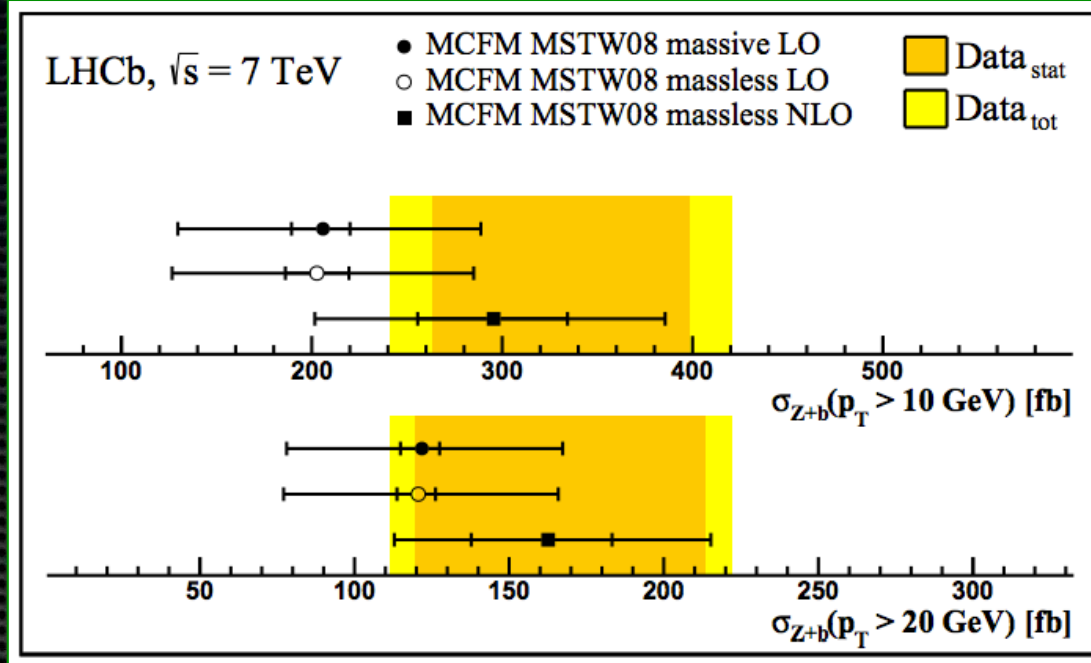






# Z+b

LHCb-PAPER-2014-055

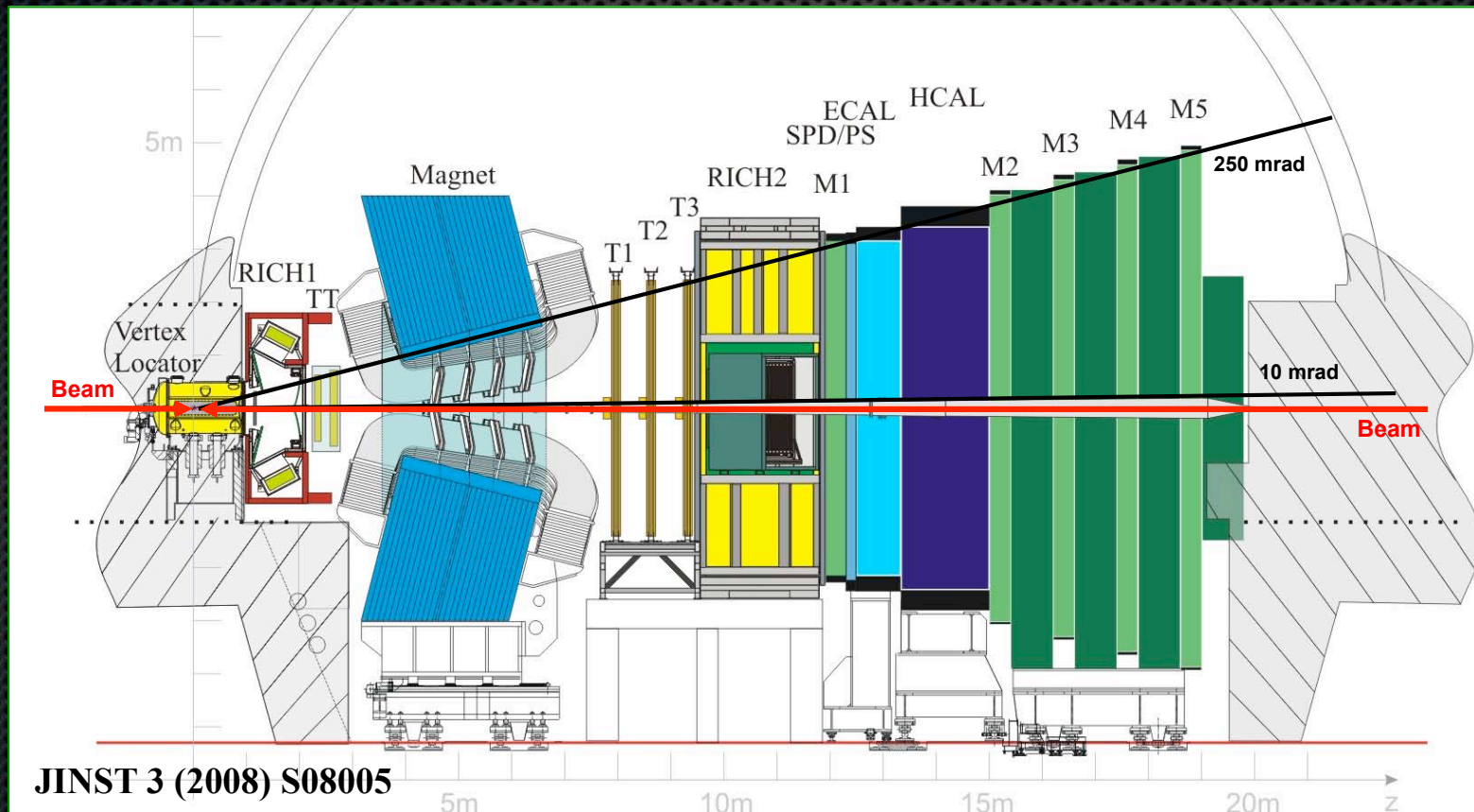


- › Measurement uncertainty dominated by *b*-tagging and purity determination (~15%)
- › Measurement compared to theory predictions calculated using MCFM using both massless (LO, NLO) and massive (LO) *b*-quarks and corrected for fragmentation and hadronization using PYTHIA 8
- › Good agreement with predictions



# LHCb - A Forward Spectrometer

- › Designed to look at CP violation in B decays @ LHC
- › Fully instrumented within  $2.0 < \eta < 5.0$ 
  - › 2.0-2.5: *overlap* with ATLAS & CMS
  - › 2.5-5.0: *complementary* range







# LHCb - A Forward Spectrometer



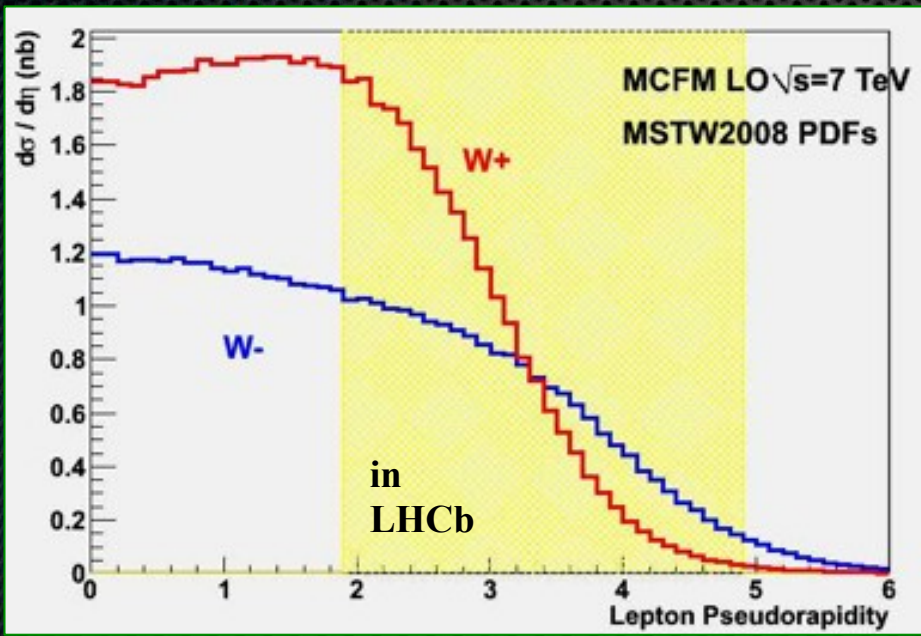
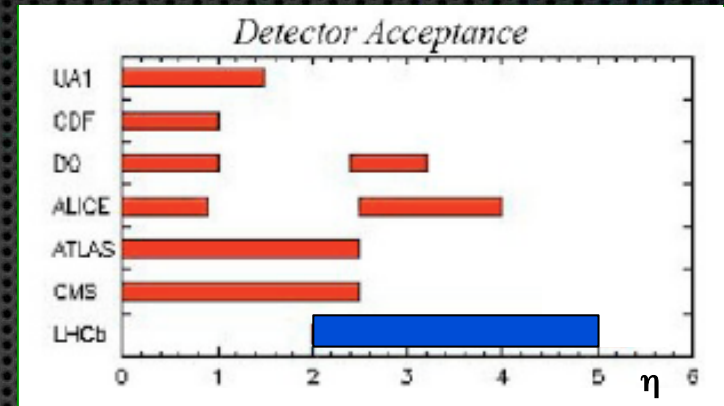
Complementary  $\eta$  range to ATLAS & CMS

Overlap for cross check

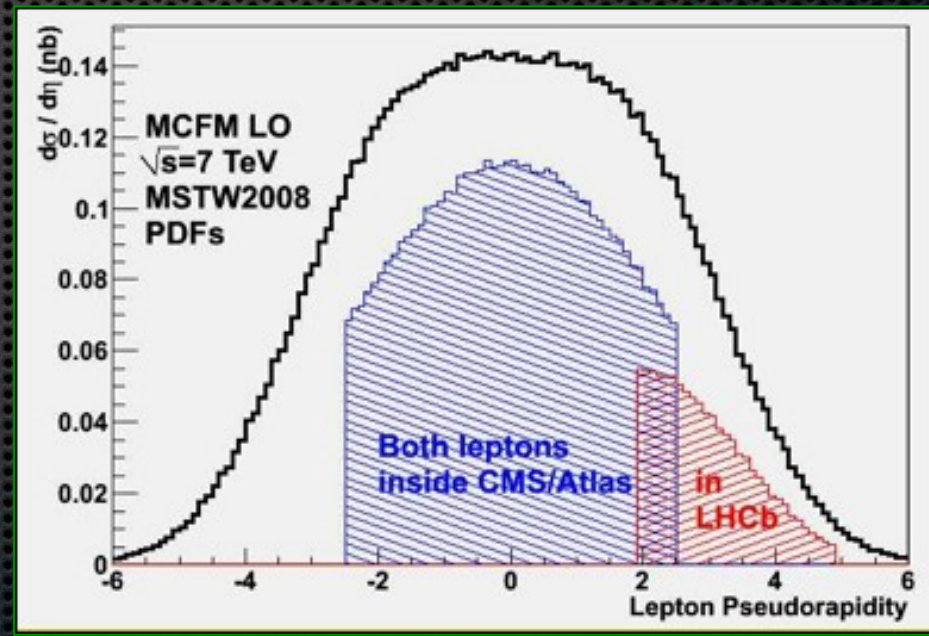
$$2.0 < \eta < 2.5$$

Unique to LHCb

$$2.5 < \eta < 5.0$$



17% (16%) of W<sup>+</sup> (W<sup>-</sup>) within LHCb



8% of Z within LHCb

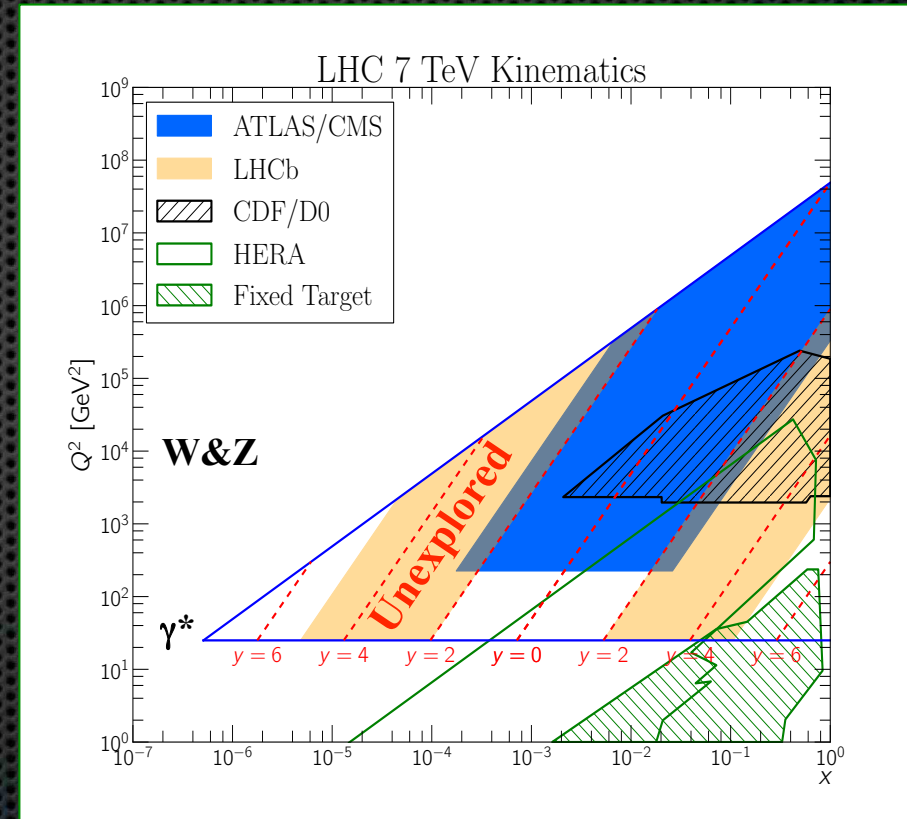




# W Production and PDFs



- › LHCb's forward acceptance provides very interesting possibilities to study the proton Parton Density Functions
- › Take large-x from one proton and a small-x from the other  
→ probe two distinct regions in the  $(x, Q^2)$  space
- › Can probe the low-x, high- $Q^2$  region inaccessible to other experiments
  - › W and Z  
(x of  $10^{-4}$  and  $10^{-1}$ )
  - › Low-mass Drell-Yan  
(x down to  $10^{-6}$ )



$$x_{1,2} = \frac{M}{\sqrt{s}} \cdot e^{\pm y} \quad Q^2 = M^2$$





# W Production and PDFs



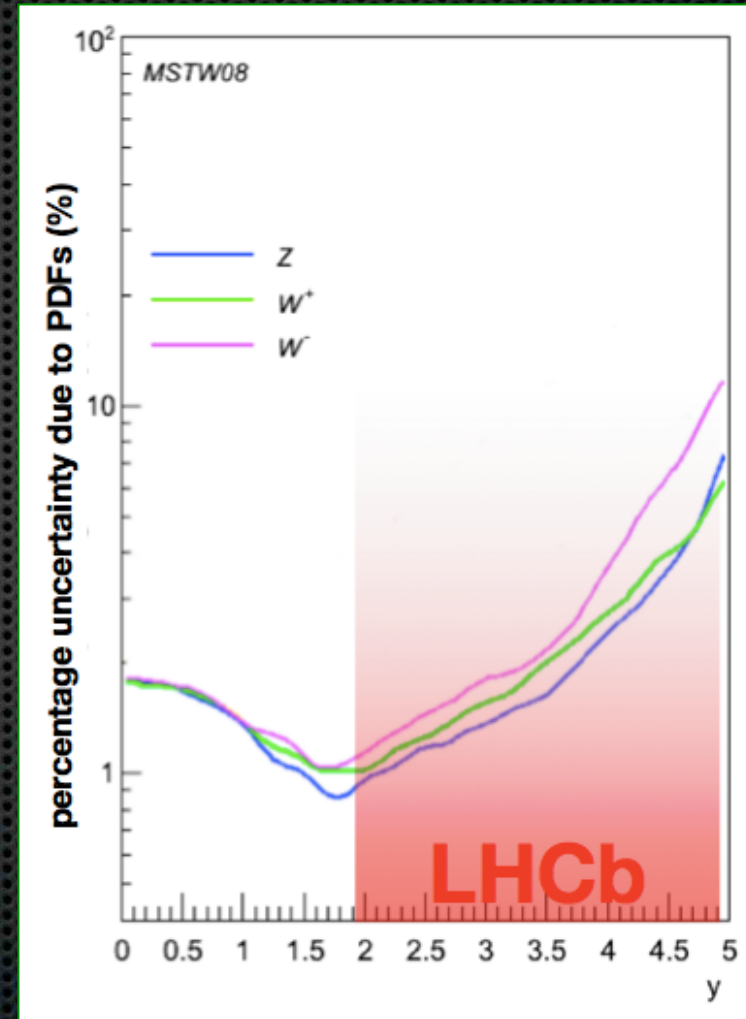
## > Theoretical predictions

- » Partonic cross-sections known at NNLO to few %
- » PDF uncertainty dominates at large rapidities (1% for  $y < 2$ , 6-8% at  $y \sim 5$ )

$$\underbrace{\sigma(x, Q^2)}_{\text{hadronic } x\text{-sec.}} = \sum_{a,b} \int_0^1 dx_1 dx_2 \underbrace{f_a(x_1 Q^2) f_b(x_2 Q^2)}_{\text{PDFs } 2-8\%} \underbrace{\hat{\sigma}(x_1, x_2, Q^2)}_{\text{partonic } x\text{-sec.: NNLO } 1\%}$$

## > Experimental measurements

- » Muon modes provide clean signature and easily reconstructible final states
- » Electron and tau modes provide complementary measurements and test lepton universality



**Cross-section measurements @ LHCb can constrain PDFs**





# W Production and PDFs



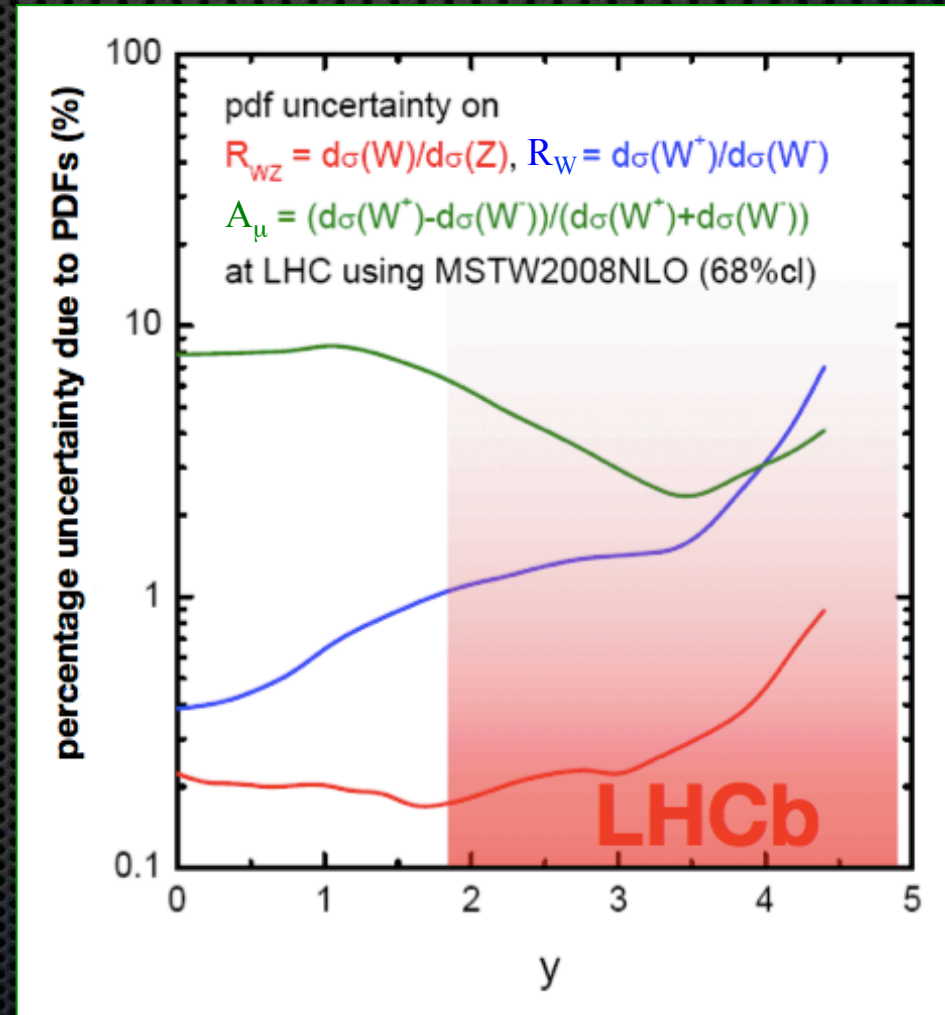
› Cancel or highlight PDF uncertainties with ratios

›  $A_\mu = (d\sigma_{W^+} - d\sigma_{W^-}) / (d\sigma_{W^+} + d\sigma_{W^-})$   
tests  $u_V$  and  $d_V$  difference

›  $R_W = d\sigma_{W^+} / d\sigma_{W^-}$   
tests  $d_V/u_V$  ratio

›  $R_{WZ} = d\sigma_W / d\sigma_Z$   
almost insensitive to PDFs  
precise test of SM

**Many systematic errors cancel**







# Cross-Section



- > The **cross-section** for boson production can be expressed as

$$\sigma \cdot BR = \frac{1}{\int \mathcal{L}} \cdot \frac{N_{Candidates} \cdot \rho}{A \cdot \epsilon_{Trigger} \cdot \epsilon_{Tracking} \cdot \epsilon_{ParticleID} \cdot \epsilon_{Selection}} \cdot f_{FSR}$$

- > Measurements performed in the forward region ( $2.0 < \eta < 4.5$ ) for leptons with  $p_T > 20 \text{ GeV}/c$ : **Acceptance** = 1 for  $Z \rightarrow \mu\mu$  and  $W \rightarrow \mu\nu$ , but obtained from MC for  $Z \rightarrow ee$  and  $Z \rightarrow \tau\tau$
- > **Efficiencies** determined mostly from data and cross checked with simulation
- > **FSR** correction evaluated using HERWIG++ and PHOTOS+PYTHIA





# Reconstruction Efficiencies



## > Trigger

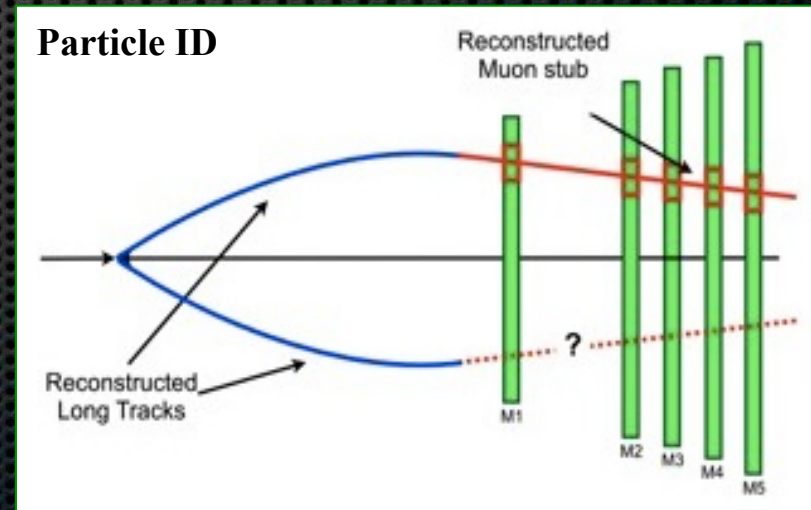
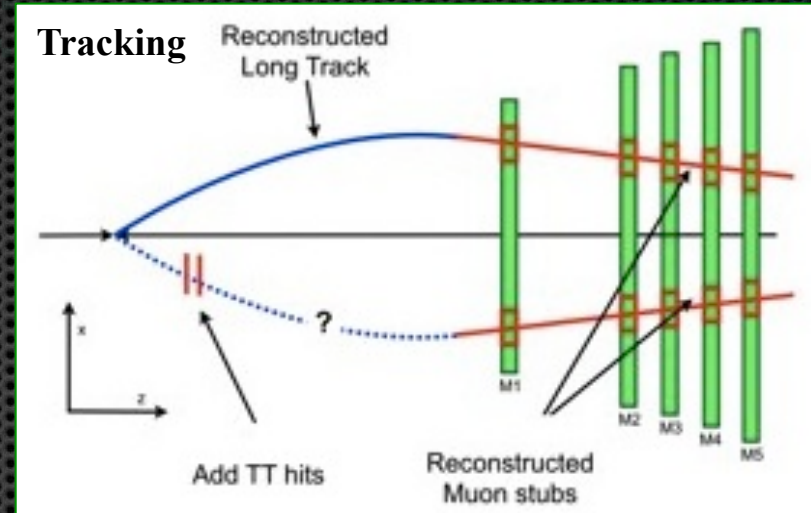
- » Tag: triggered muon
- » Probe: offline identified muon

## > Tracking

- » Tag: identified muon track
- » Probe: trajectory from muon stub and minimal tracking information

## > Particle ID

- » Tag: identified muon
- » Probe: reconstructed track







# Systematics

Table 1: Summary of the systematic uncertainties on the inclusive cross-sections and their ratio.

Source	$\Delta\sigma_{W^+\rightarrow\mu+\nu}$ [%]	$\Delta\sigma_{W^-\rightarrow\mu-\bar{\nu}}$ [%]	$\Delta R_W$ [%]
Template shape	0.28	0.39	0.59
Template normalisation	0.10	0.10	0.06
Reconstruction efficiency	1.21	1.20	0.12
Selection efficiency	0.33	0.32	0.18
Acceptance and FSR	0.18	0.12	0.21
Luminosity	1.71	1.71	—





# References



- MSTW08: A. Martin, W. Stirling, R. Thorne and G. Watt arXiv:0901.0002
- ABKM09: S. Alekhin, J. Blumlein, S. Klein and S. Moch arXiv:0908.2766
- JR09: P. Jimenez-Delgado and E. Reya arXiv:0810.4274
- NNPDF: R. D. Ball et al. arXiv:1002.4407
- HERA15: H1 and Zeus collaboration arXiv:0911.0884
- CTEQ6m: P.M. Nadolsky et al. (NLO) arXiv:0802.0007
  
- DYNNLO: S. Catani, L. Cieri, G. Ferrera, D. de Florian and M. Grazzini arXiv:0903.2120
- FEWZ: R. Gavin, Y. Li, F. Petriello and S. Quackenbush arXiv:1011.3540
- POWHEG: P. Nason arXiv:hep-ph/0409146; S. Frixione, P. Nason and C. Oleari arXiv:0709.2092; S. Alioli, P. Nason, C. Oleari and E. Re arXiv:1002.2581
- RESBOS: G. A. Ladinsky and C.-P. Yuan arXiv:hep-ph/9311341; C. Balazs and C.-P. Yuan arXiv:hep-ph/9704258; F. Landry, R. Brock, P. M. Nadolsky and C.-P. Yuan arXiv:hep-ph/0212159.