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Measurements with electroweak gauge bosons at LHCb

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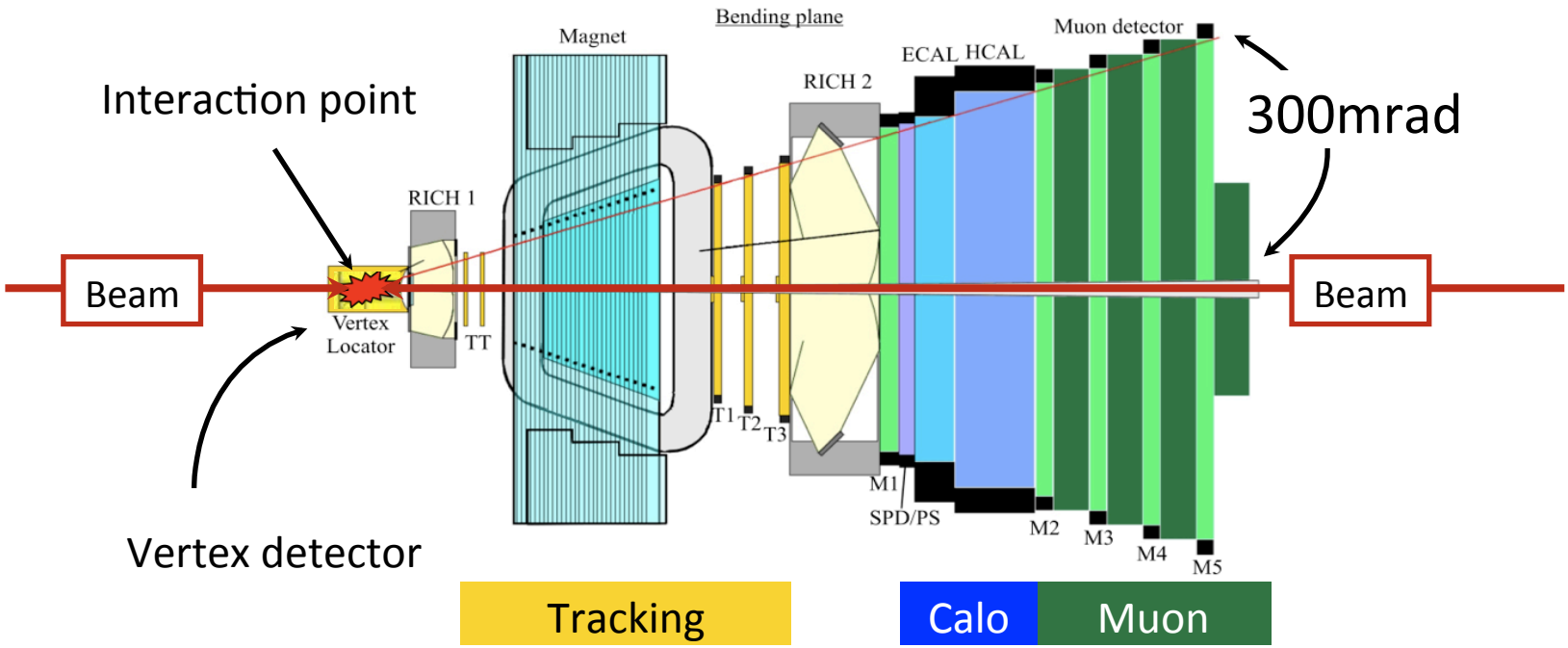


LHCb: a general purpose detector instrumented within $2 \leq \eta \leq 5$

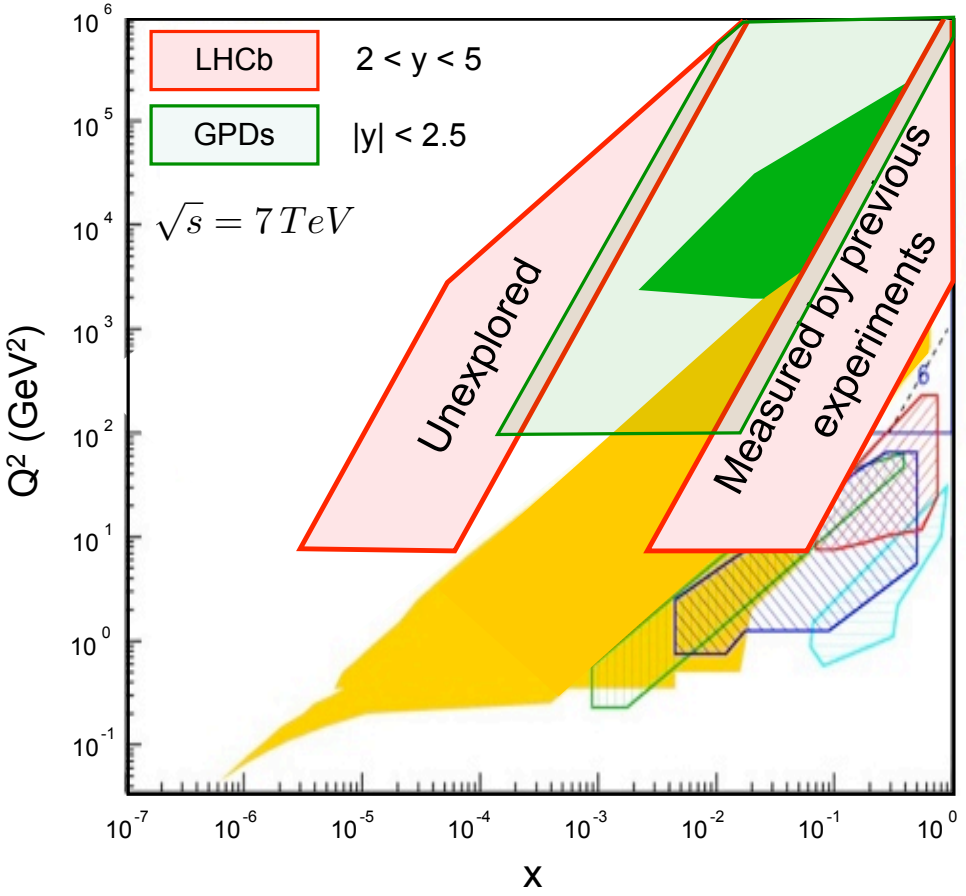
Recorded luminosity:

- (2010): 0.038 fb^{-1} $\sqrt{s}$ = 7 TeV
- (2011): 1.107 fb^{-1} $\sqrt{s}$ = 7 TeV
- (2012): 2.082 fb^{-1} $\sqrt{s}$ = 8 TeV

W&Z production predicted at NNLO.
Precision limited by PDF uncertainty.

LHCb measurements probe two x-Q^2 regions
Low x, high Q^2 previously unexplored

Overlap region allows direct ATLAS/CMS comparison.



References

In this talk:

$Z \rightarrow \mu\mu$	LHCb-CONF-2013-007
$Z \rightarrow ee$	JHEP02 (2013) 106
$Z \rightarrow \tau\tau$	JHEP01 (2013) 111
$W \rightarrow \mu\nu$	JHEP06 (2012) 058

Not covered here:

Low mass DY $\rightarrow \mu\mu$	LHCb-CONF-2012-013
Z + jet production	LHCb-CONF-2012-016

$$\sigma = \frac{\rho N . f_{fsr}}{\varepsilon A L}$$

Inclusive cross-sections:

Z; $p_T^l > 20$ GeV, $2 < \eta^l < 4.5$, $60 < M_{ll} < 120$ GeV

W; $p_T^\mu > 20$ GeV, $2 < \eta^\mu < 4.5$

Differential cross-sections:

Z: $\mathbf{y^Z}$, ϕ^*, p_T^Z

W: $\boldsymbol{\eta^\mu}$

$$\phi^* = \frac{\tan\left(\left(\pi - \left|\Delta\phi\right|\right)/2\right)}{\cosh\left(\Delta\eta/2\right)}$$

$Z \rightarrow \mu\mu$

LHCb-CONF-2013-007

Dataset: 1 fb^{-1}

Trigger:

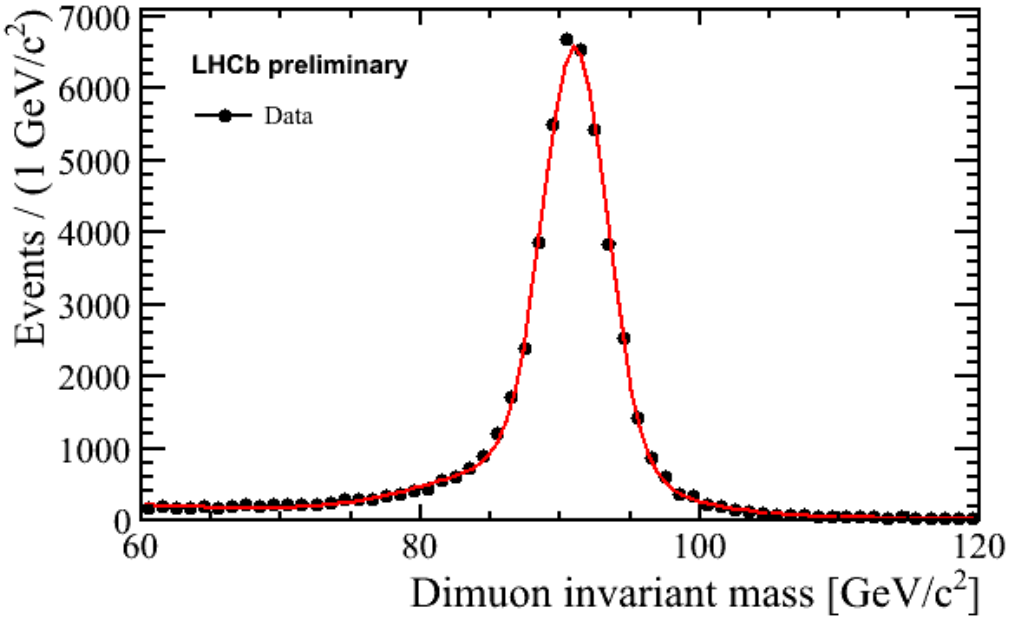
$p_T^{\mu} > 10$ GeV

Selection:

2 μ: $p_T^{\mu} > 20$ GeV

$2 < \eta^{\mu} < 4.5$

$60 < M_{\mu\mu} < 120$ GeV



Heavy flavour	**data**
Hadron mis-id	data
$Z \rightarrow \tau\tau$	simulation
WW	simulation
$t\bar{t}$	simulation

N ~ 52600
Purity: 99.7%

$Z \rightarrow ee$

JHEP02 (2013) 106

Dataset: 945 pb^{-1}

Trigger:

$p_T^e > 10, 15$ GeV

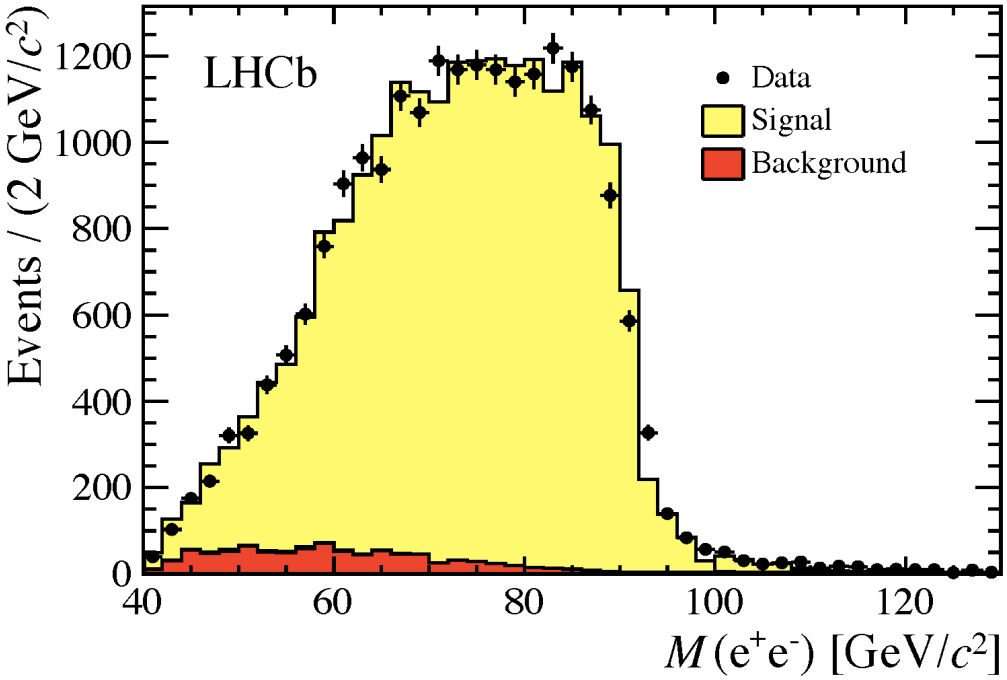
Selection:

2e: $p_T^e > 20$ GeV

$2 < \eta^e < 4.5$

$M_{ee} > 40$ GeV

Heavy flavour	data
Hadron mis-id	**data**
$Z \rightarrow \tau\tau$	simulation
$t\bar{t}$	simulation



N ~ 21400
Purity: 95%

$Z \rightarrow \tau\tau$

JHEP01 (2013) 111

Dataset: 1 fb^{-1}

Trigger:

$p_T^{\mu} > 10$ GeV, $p_T^{e} > 10,15$ GeV

Selection:

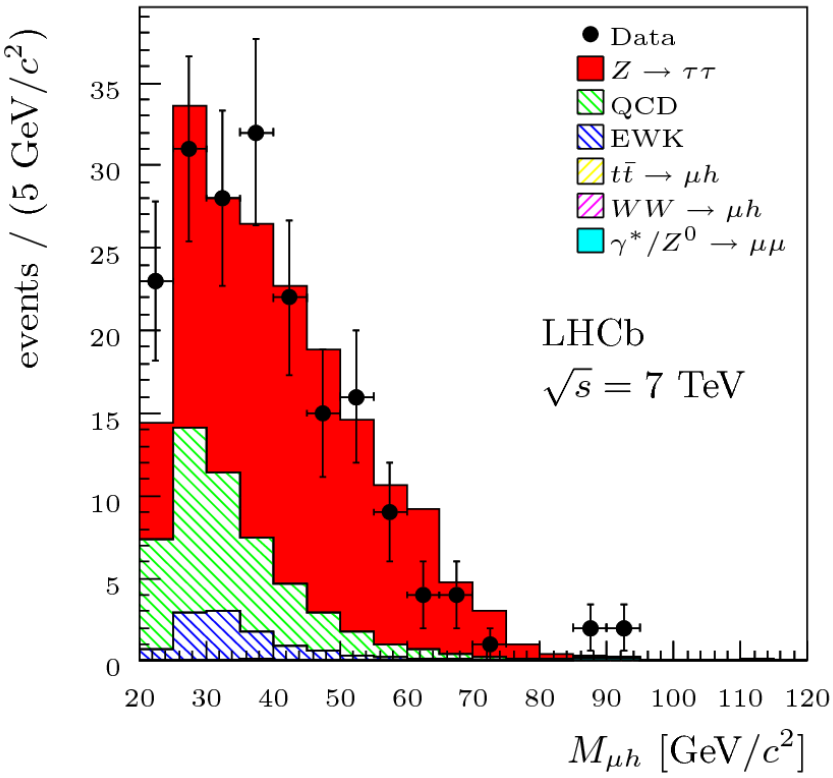
$\tau_\mu\tau_\mu$, $\tau_\mu\tau_e$, $\tau_e\tau_\mu$, $\tau_e\tau_h$, $\tau_\mu\tau_h$

$p_T > 20$ GeV, $p_T > 5$ GeV

$2 < \eta^{e\mu} < 4.5$, $2.25 < \eta^{h} < 3.75$

$60 < M_{\tau\tau} < 120$

Isolated; p_T imbalance; back-back; lifetime.



QCD (heavy flavour + mis-id)	**data**
EWK (W/Z+Hadron mis-id)	data
$Z \rightarrow ll$	simulation
WW	simulation
tt	simulation

N ~ 990
purity 60- 70%

$W \rightarrow \mu\nu$

Dataset: 36 pb^{-1}

Trigger:

$p_T^{\mu} > 10$ GeV

Selection:

$20 < p_T^{\mu} < 70$ GeV

$2 < \eta^{\mu} < 4.5$

$E/p < 0.04$

Isolated; no lifetime;

no other μ

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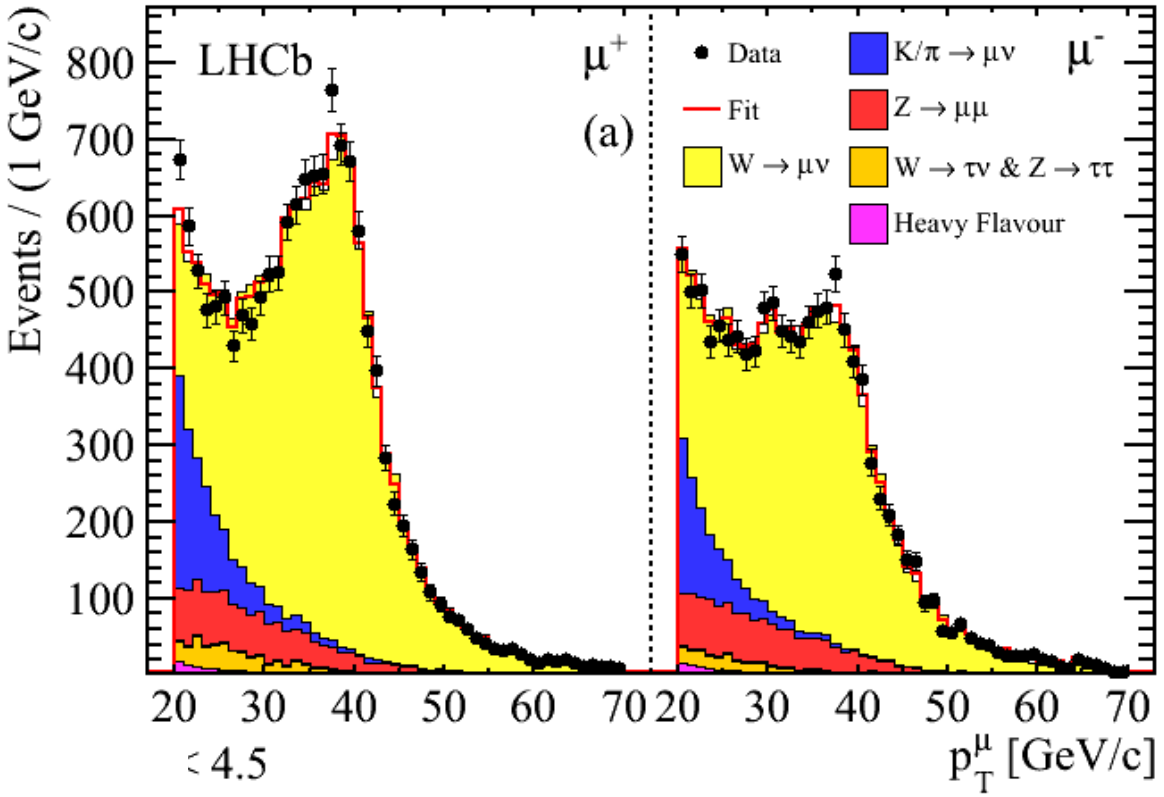


Heavy flavour	data
Hadron mis-id	**data**
$W \rightarrow \tau\nu$, $Z \rightarrow \tau\tau$	Simulation (data)
$Z \rightarrow \mu\mu$	**Simulation (data)**

N ~ 26 000.
Purity ~ 78%

$$\sigma = \frac{\rho N \cdot f_{fsr}}{\varepsilon A L}$$

A, f_{fsr}: simulation

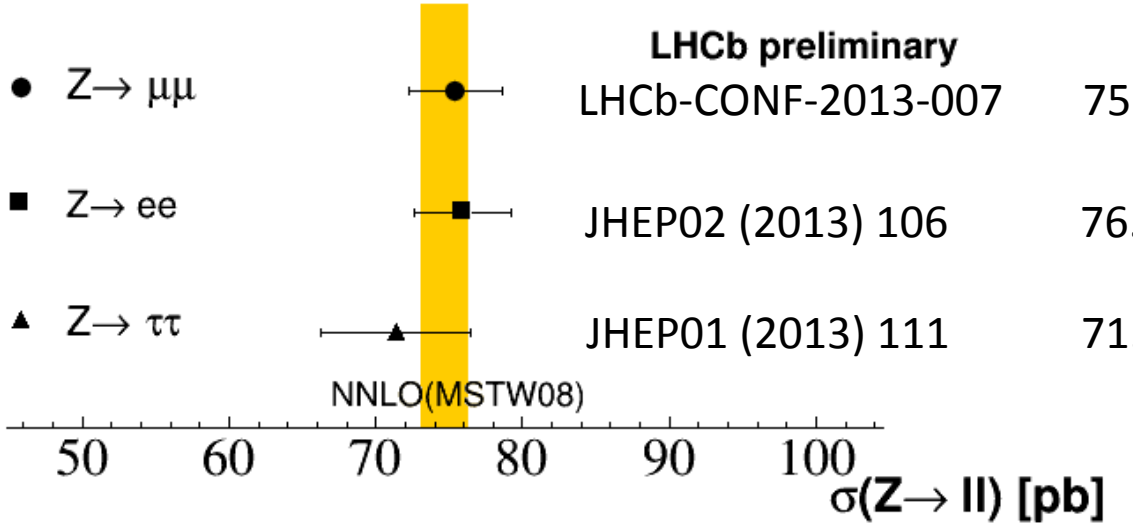
ε: tag and probe (data)

- Trigger
- Track
- Identification

selection;

- W ($Z \rightarrow \tau\tau$) data (MC+data)

σ(Z)



Z→ μμ	LHCb-CONF-2013-007	75.4 ± 0.3 ± 1.9 ± 2.6 pb
Z→ ee	JHEP02 (2013) 106	76.0 ± 0.8 ± 2.0 ± 2.6 pb
Z→ ττ	JHEP01 (2013) 111	71.4 ± 3.5 ± 2.8 ± 2.5 pb

Results agree with NNLO and for all final states

Measurements limited by statistics (ττ), or luminosity (ee, μμ)

Main systematics:

- reconstruction (μμ),
- tracking efficiency (ee)
- backgrounds, efficiency (ττ, channel dependent),

σ(W)

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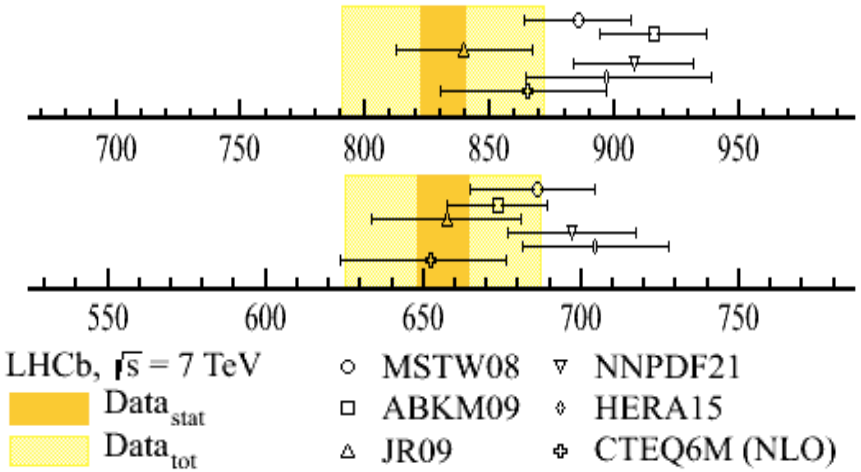


σ(W+) [pb] 831 ± 9 ± 27 ± 29 pb

σ(W-) [pb] 656 ± 8 ± 19 ± 23 pb

Results agree with NNLO

Measurements limited by luminosity

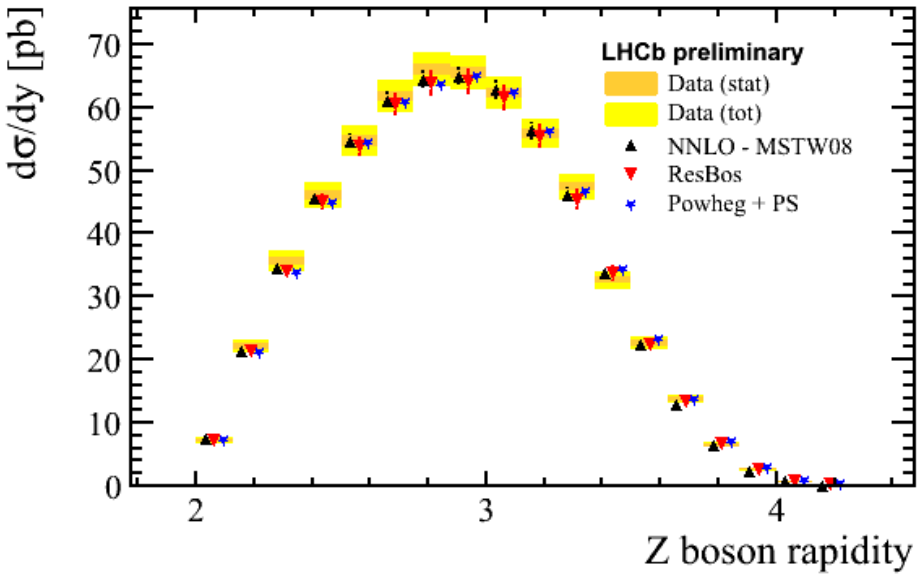
Main systematic errors:

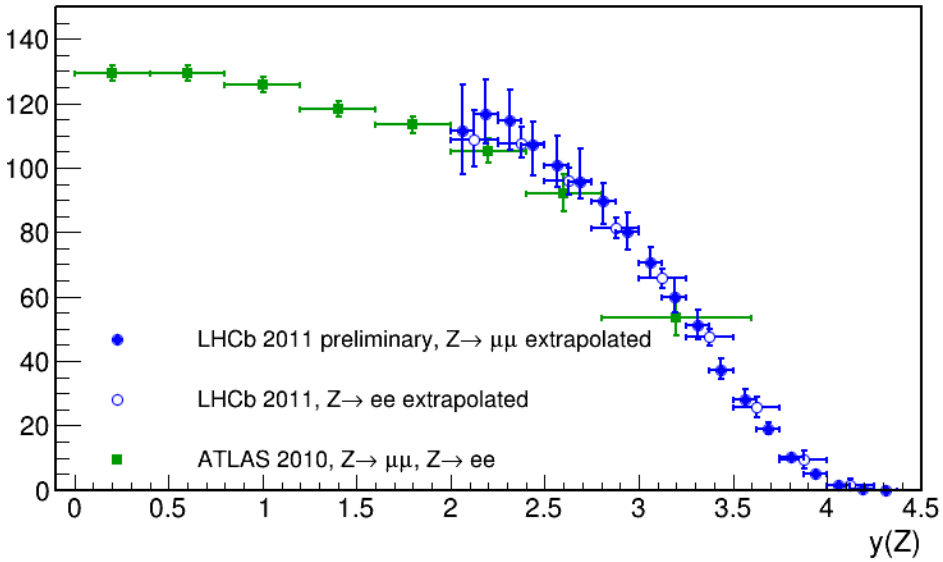
background templates,

efficiencies (statistical in nature)

$d\sigma(Z)/dy^Z$

LHCb-CONF-2013-007





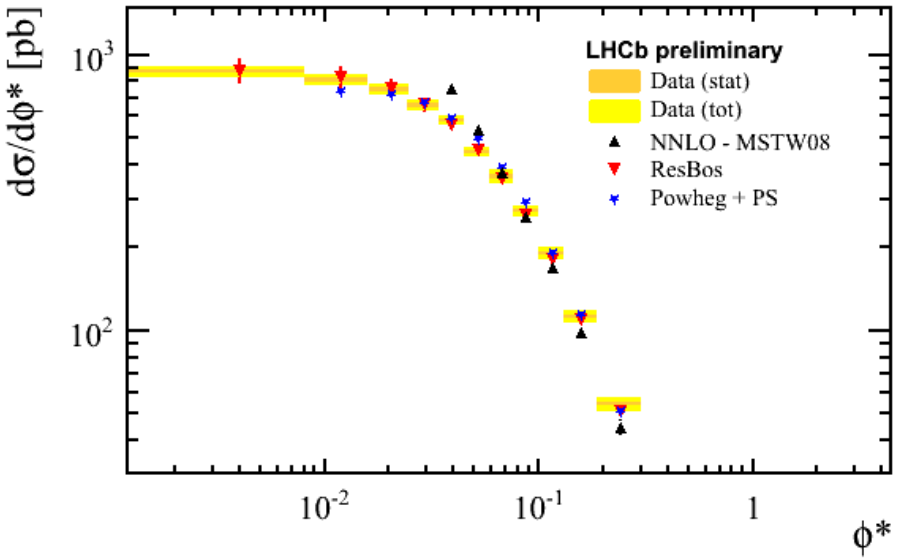
Good agreement with NNLO as a function of y^Z

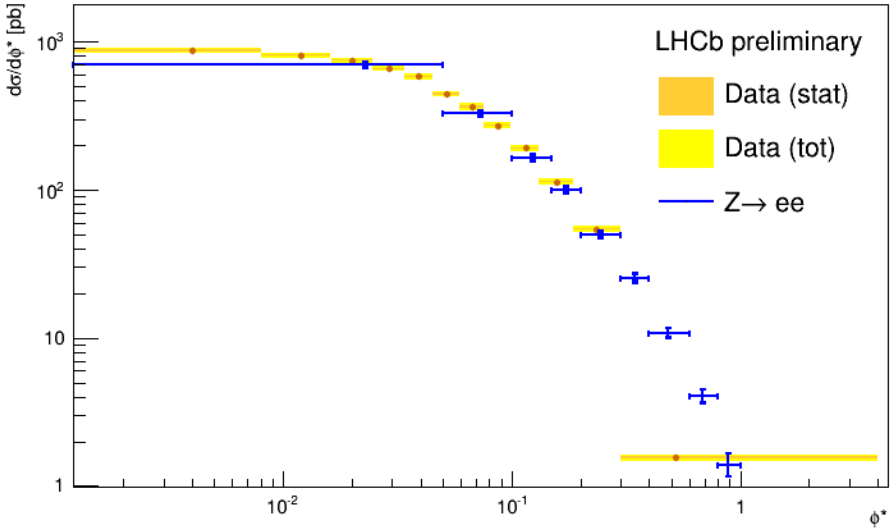
Good agreement between muon and electron final states

Good agreement with ATLAS when extrapolated to ATLAS fiducial

dσ(Z)/dϕ*

LHCb-CONF-2013-007





NNLO agrees well at high ϕ*, diverges at low ϕ* (low p_T^Z)

Better agreement when compared to POWHEG, RESBOS

Good agreement between muon and electron final states

$d\sigma(W)/d\eta^{\mu}$

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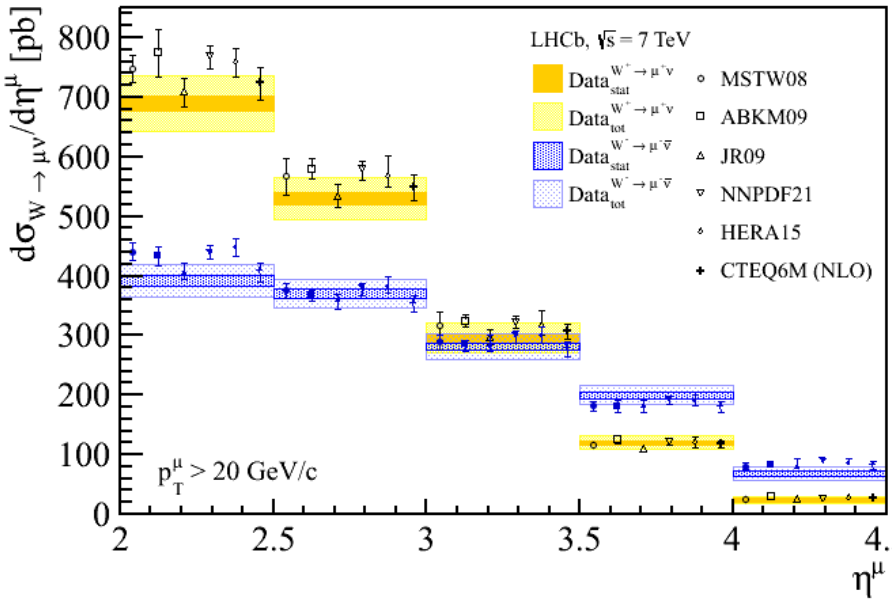
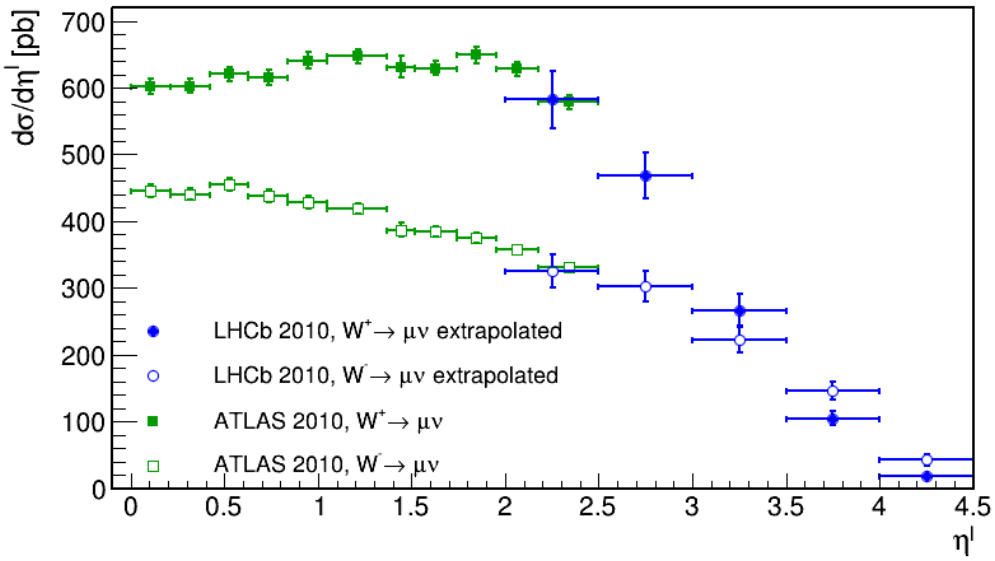


LHCb-CONF-2013-005



Good agreement with NNLO as a function of η^{μ}

Good agreement with ATLAS when extrapolated to ATLAS fiducial

Charge asymmetry wrt η^{μ}

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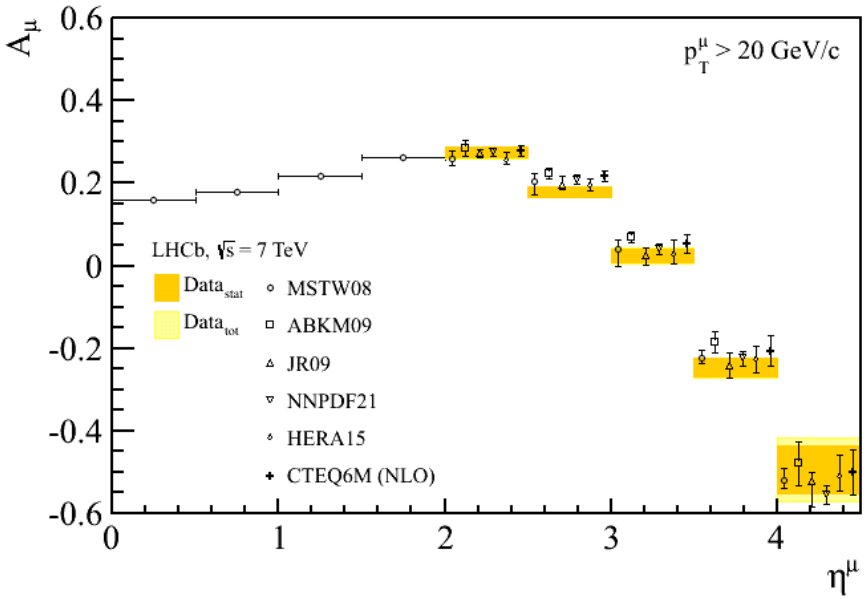

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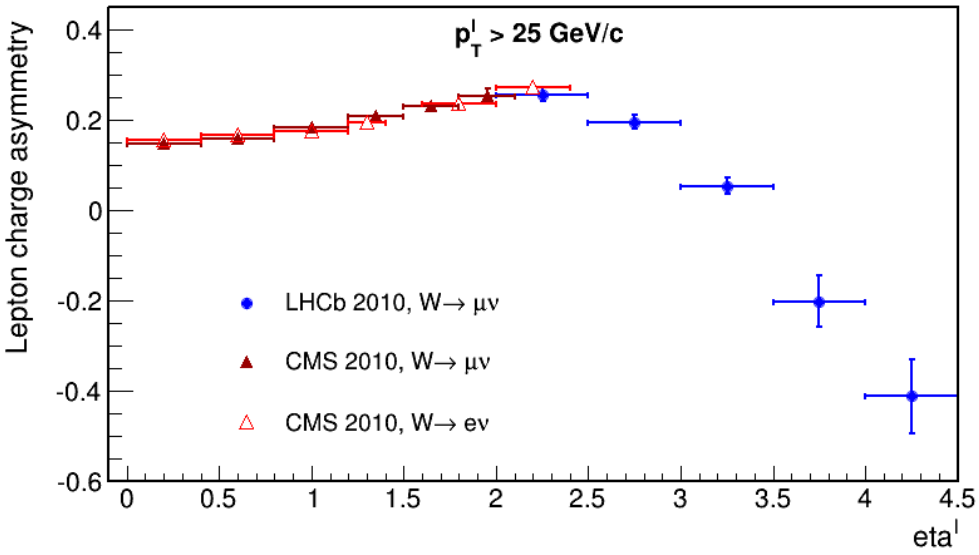


Good agreement with NNLO as a function of η^{μ}

Charge asymmetry probes u_v - d_v

Good agreement with CMS when CMS p_T^{μ} cuts applied

LHCb can measure Z and W production in the forward region

Z:

Inclusive Z cross-sections for different lepton decays are consistent
NNLO describes differential production wrt y^Z
Powheg, RESBOS describe production wrt ϕ^*
Measurements wrt y^Z agree with ATLAS when extrapolated.

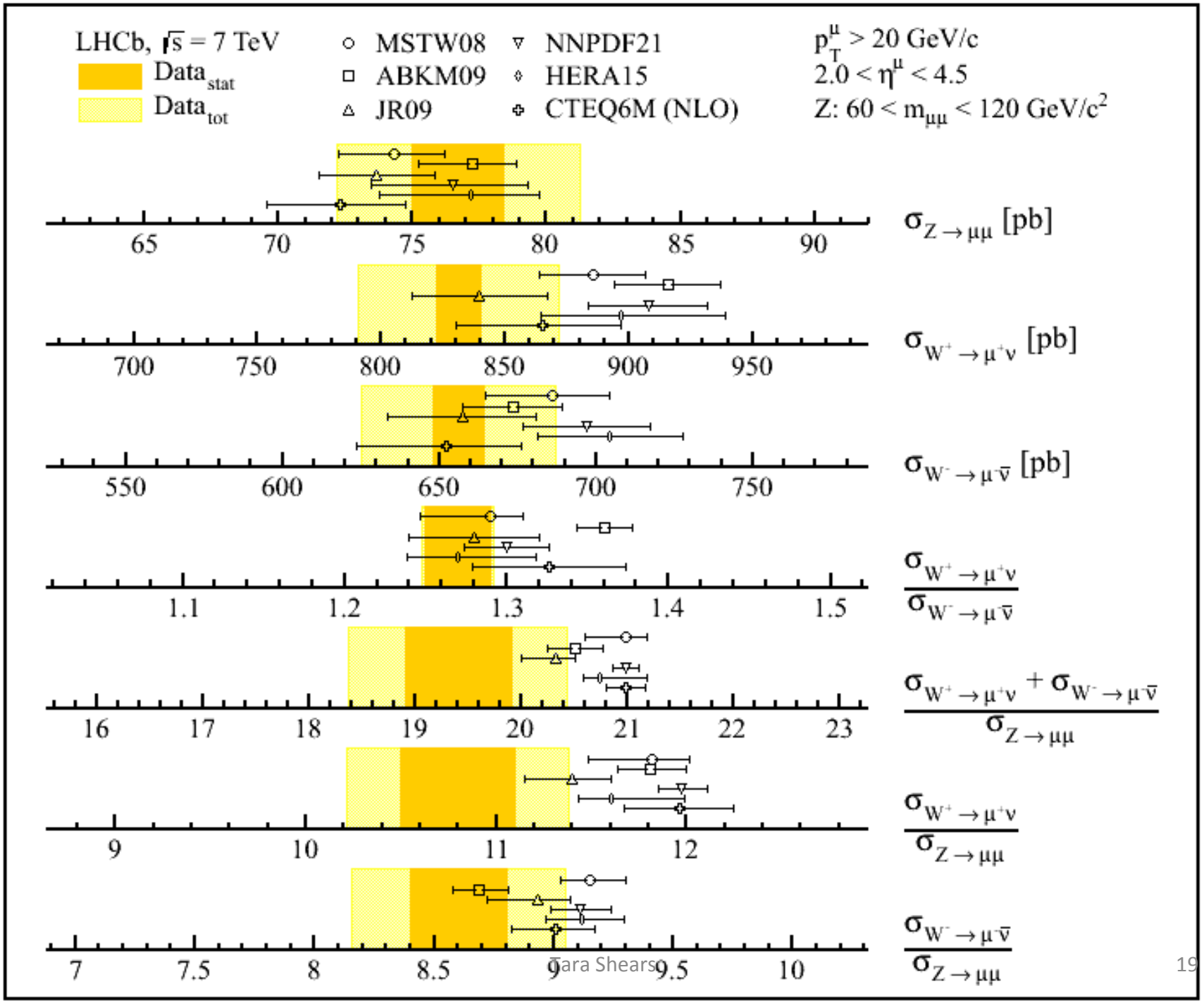
W:

NNLO describes inclusive and differential production (wrt η^μ) well.
W+, W- measurements agree with CMS, and ATLAS when extrapolated.

References:

- MSTW08: A. Martin, W. Stirling, R. Thorne and G. Watt arXiv:0901.0002
- ABKM09: S. Alekhin, J. Blmlein, 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.


LHCb, $\sqrt{s}$ = 7 TeV
Data$_{stat}$
Data$_{tot}$
MSTW08
ABKM09
JR09
NNPDF21
HERA15
CTEQ6M (NLO)
$p_T^\mu > 20$ GeV/c
$2.0 < \eta^\mu < 4.5$
Z: $60 < m_{\mu\mu} < 120$ GeV/c^2
65 70 75 80 85 90
$\sigma_{Z \to \mu\mu}$ [pb]
700 750 800 850 900 950
$\sigma_{W^+ \to \mu^+\nu}$ [pb]
550 600 650 700 750
$\sigma_{W^- \to \mu^-\bar{\nu}}$ [pb]
1.1 1.2 1.3 1.4 1.5
$\frac{\sigma_{W^+ \to \mu^+\nu}}{\sigma_{W^- \to \mu^-\bar{\nu}}}$
16 17 18 19 20 21 22 23
$\frac{\sigma_{W^+ \to \mu^+\nu} + \sigma_{W^- \to \mu^-\bar{\nu}}}{\sigma_{Z \to \mu\mu}}$
9 10 11 12
$\frac{\sigma_{W^+ \to \mu^+\nu}}{\sigma_{Z \to \mu\mu}}$
7 7.5 8 8.5 9 9.5 10
$\frac{\sigma_{W^- \to \mu^-\bar{\nu}}}{\sigma_{Z \to \mu\mu}}$

Z → μμ systematic errors:

Source	Uncertainty (%)	Between bins
Tracking efficiency	±1.1	mostly correlated
GEC efficiency	±1.1	correlated
Muon-id efficiency	±0.5	mostly correlated
Muon trigger efficiency	±0.5	mostly correlated
Magnet polarity	±1.6	uncorrelated
Bin-to-bin migrations	±0.7	uncorrelated
FSR correction	±0.2	uncorrelated
Signal purity	±0.03	correlated
Total	±2.5	
Luminosity	±3.5	correlated

Z → ee cross-section inputs:

	Data sample I	Data sample II
$\int \mathcal{L} dt\ [\mathrm{pb}^{-1}]$	581 ± 20	364 ± 13
ϵ_{GEC}	0.947 ± 0.004	
ϵ_{trig}	0.715 ± 0.021	0.899 ± 0.003
$\epsilon_{\mathrm{track}}$	0.913 ± 0.015	
ϵ_{kin}	0.500 ± 0.007	
ϵ_{PID}	0.844 ± 0.011	
f_{FSR}	1.049 ± 0.005	
f_{MZ}	0.967 ± 0.001	

Z → ττ systematic errors:

Stream		$\Delta\sigma_{pp\to Z\to\tau\tau}$ [%]				
		$\tau_\mu\tau_\mu$	$\tau_\mu\tau_e$	$\tau_e\tau_\mu$	$\tau_\mu\tau_h$	$\tau_e\tau_h$
$\mathcal{A}$		1.48	1.61	1.32	1.10	1.11
$\mathcal{B}$		0.46	0.32	0.32	0.32	0.33
N_{bkg}	N_{QCD}	4.33	0.80	3.08	0.40	0.92
	N_{EWK}	4.22	1.54	1.52	0.40	0.72
	$N_{t\bar{t}}$	0.02	0.08	0.12	0.00	0.58
	N_{WW}	0.02	0.14	0.13	0.09	0.08
	N_Z	8.00	–	–	0.22	0.23
Total N_{bkg}		10.03	1.75	3.44	0.61	1.32
ε_{rec}	ε_{GEC}	0.10	0.10	0.10	0.10	0.10
	ε_{trg}	0.88	0.71	2.29	0.72	4.30
	$\varepsilon_{\text{trk}}^{(1)}$	0.71	0.74	3.67	0.79	3.67
	$\varepsilon_{\text{trk}}^{(2)}$	0.34	3.67	0.61	1.76	1.68
	$\varepsilon_{\text{id}}^{(1)}$	0.38	0.28	1.72	0.29	1.73
	$\varepsilon_{\text{id}}^{(2)}$	0.78	0.18	0.56	0.03	0.09
Total ε_{rec}		1.47	4.21	4.73	2.08	6.15
ε_{sel}	ε_{kin}	–	1.04	2.89	–	1.91
	$\varepsilon_{I_{p_T}}$	1.79	1.91	3.19	1.65	2.75
	$\varepsilon_{\lvert\Delta\Phi\rvert}$	1.08	1.03	1.86	0.60	0.97
	ε_{IPS}	2.70	–	–	1.92	2.85
	$\varepsilon_{A_{p_T}}$	2.03	–	–	–	–
Total ε_{sel}		3.97	2.41	4.69	2.60	4.50
Total systematic		11.13	5.41	7.56	3.88	7.88

W $\rightarrow \mu\nu$ systematic errors:

Source	$\Delta\sigma_{W^+\rightarrow\mu^+\nu}$ (%)	$\Delta\sigma_{W^-\rightarrow\mu^-\bar{\nu}}$ (%)
Signal purity	± 1.2	± 0.9
Template shape (fit)	± 0.9	± 1.0
Efficiency (trigger, tracking, muon id)	± 2.2	± 2.0
Additional selection	± 1.8	± 1.7
FSR correction	± 0.01	± 0.02
Total	± 3.2	± 2.9
Luminosity	± 3.5	± 3.5