Vector Boson studies in LHCb
(including A_{FB} from CMS/ATLAS)

Murilo Rangel
on behalf of the LHCb Collaboration

LHCI 13-18 June Lund, Sweden 2016

Outline

→ Recent Results at LHCb

p-p collisions 13 TeV

+ Studies of Z(μμ) boson production at 13 TeV

p-p collisions 7/8 TeV

+ Differential cross-section measurements
+ Ratios of cross-sections
+ Forward-backward asymmetry (CMS and ATLAS included)

Recent LHCb results not covered in this talk:

+ V plus jets – arXiv:1605.00951
+ W plus b-jet – Phys.Rev.D92 (2015) 052001
+ Z plus b-jet – JHEP 01 (2015) 064
+ Z→ee - JHEP 05 (2015) 109
+ Observation of Z production in proton-lead - JHEP 09 (2014) 030

See Katharina Mueller's talk for impact of PDF (13/06 – 17:40)
See Giovanni Passaleva's talk for QCD Results from LHCb (14/06 – 11:00)
See Laure Marie Massacrier's talk for Heavy Ion LHCb results (14/06 – 15:45)

LHCb Detector

JMPA30(2015)1530022

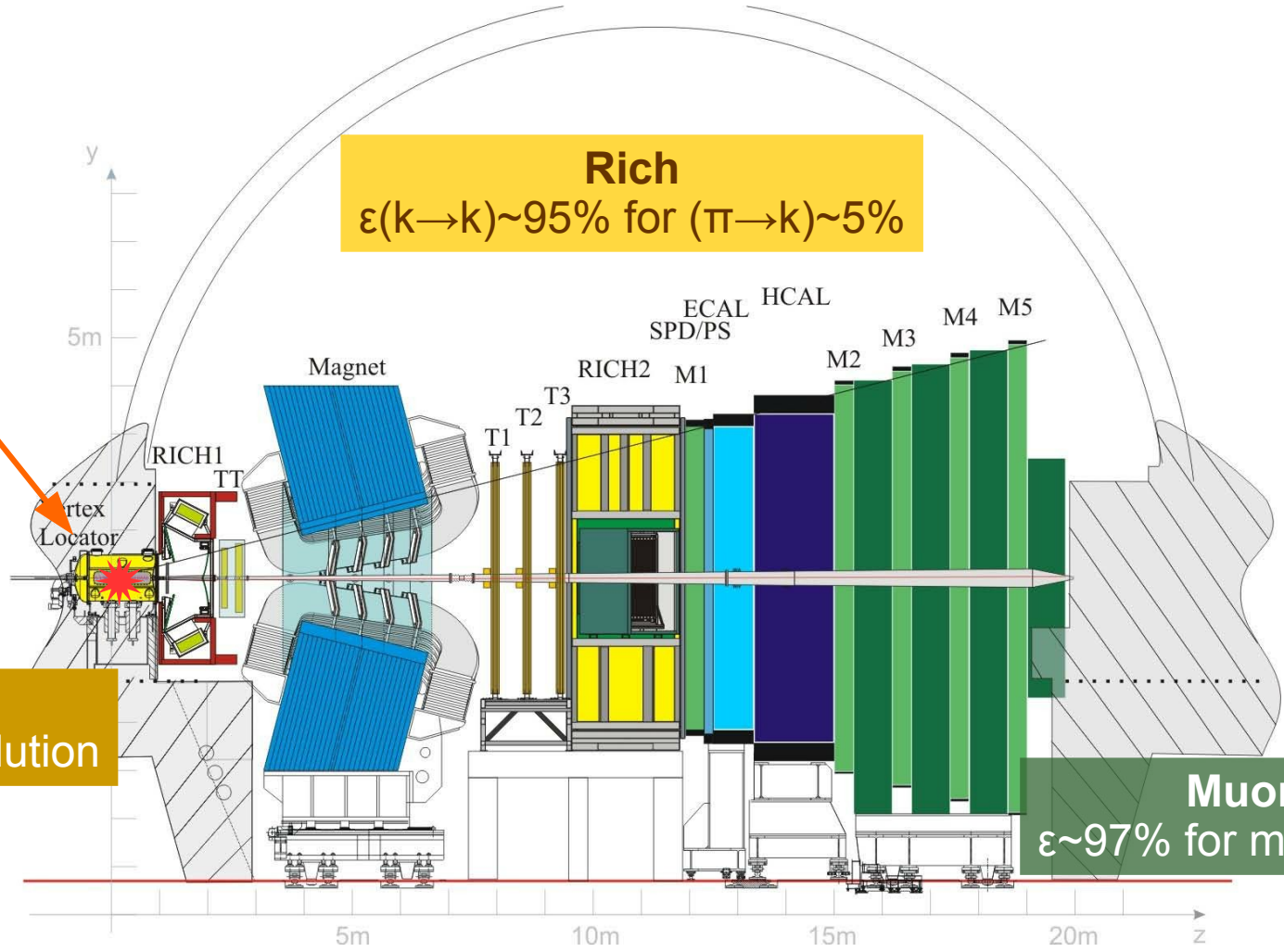
LHCb is a single arm spectrometer fully instrumented in the forward region (2.0<η<5.0)
Designed for heavy flavour physics ↔ Explored for general purpose physics

Rich
ε(k→k)~95% for (π→k)~5%

Collision

Luminosity Unc.
~1-2%

VELO
~20μm IP resolution

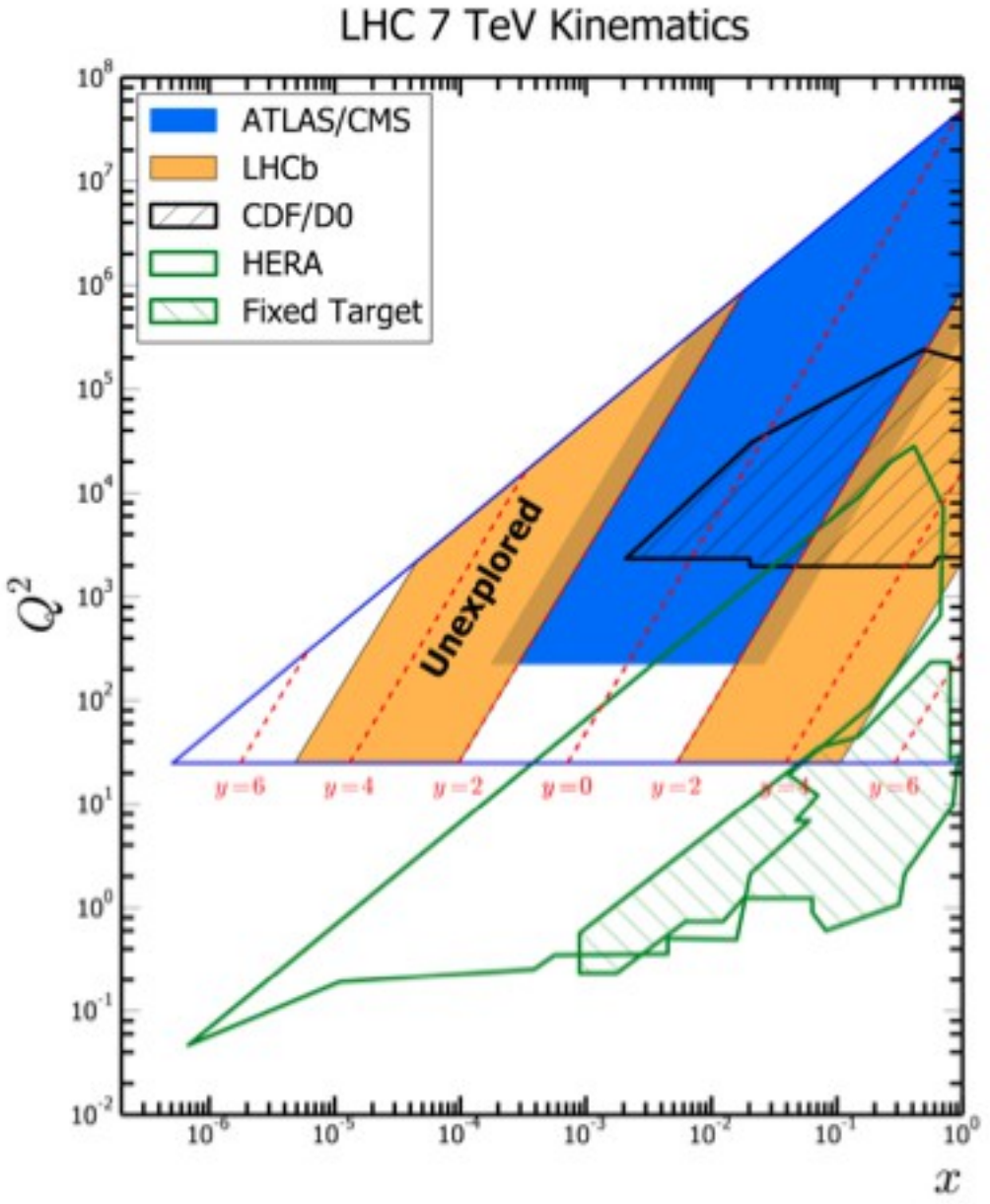


Muon
ε~97% for misID~2%

Tracking
0.4%-0.6% momentum resolution (0.2-100 GeV)

LHCb Measurements

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



LHCb measurements:

1) are sensitive to previously unexplored regions of low x and high Q^2 phase space.

2) can be used to constrain PDFs.

3) probe the standard model when PDF errors are not relevant (ratios)

13 TeV
$Z \rightarrow \mu\mu$ cross-section

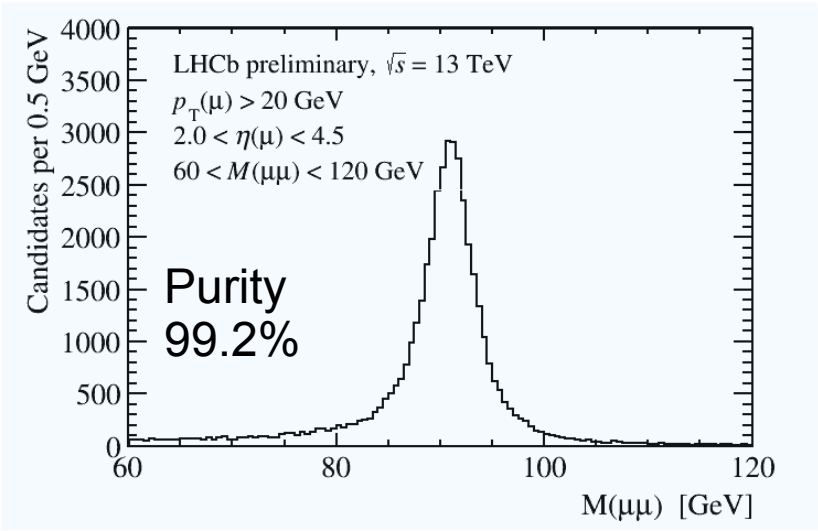
Z→μμ at 13 TeV

Data: 300/pb at 13 TeV

Fiducial acceptance:

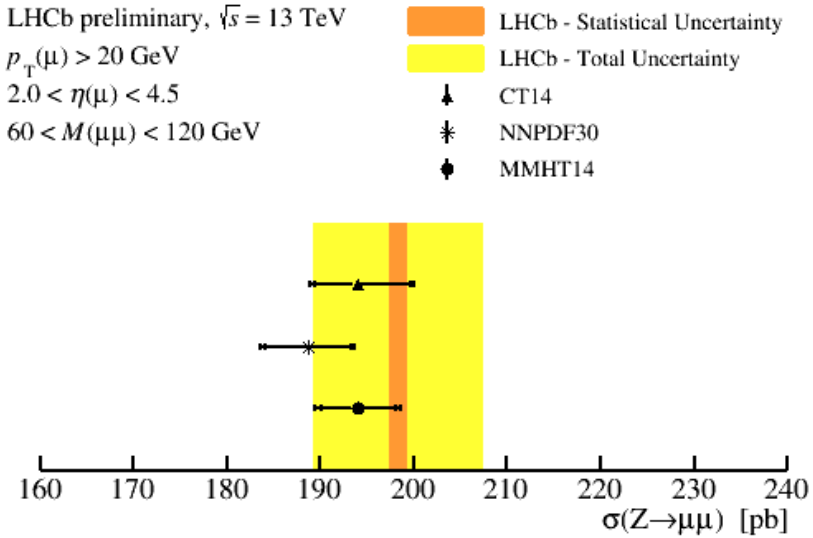
$2.0 < \eta(\mu) < 4.5$, $p_T(\mu) > 20$ GeV

$60 < M(\mu\mu) < 120$ GeV



Uncertainties

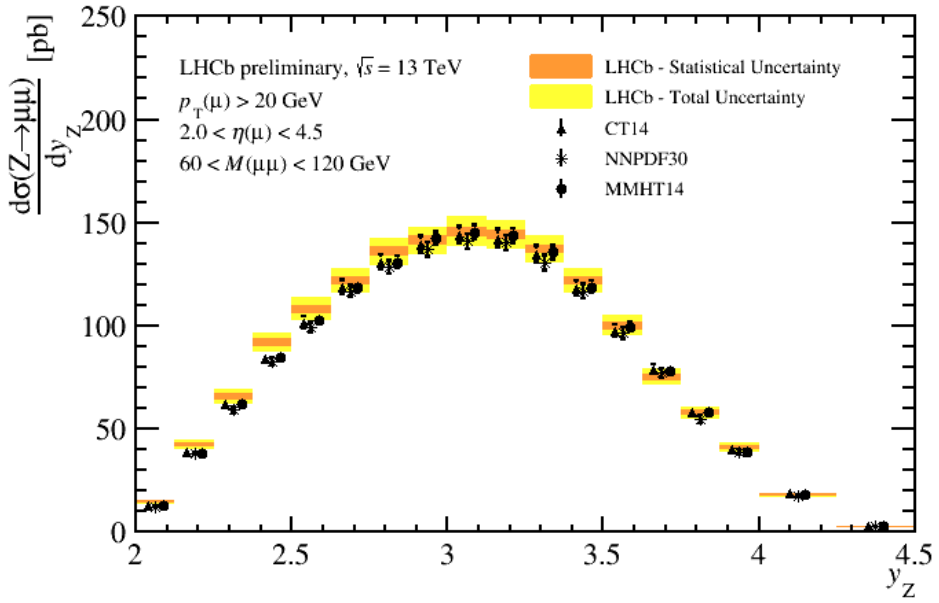
Source	$\Delta\sigma_{Z\to\mu\mu}$ [%]
Statistical	0.5
Reconstruction efficiencies	2.4
Purity	0.2
FSR	0.1
Total systematic (excl. lumi.)	2.4
Luminosity	3.9
Total uncertainty	4.6

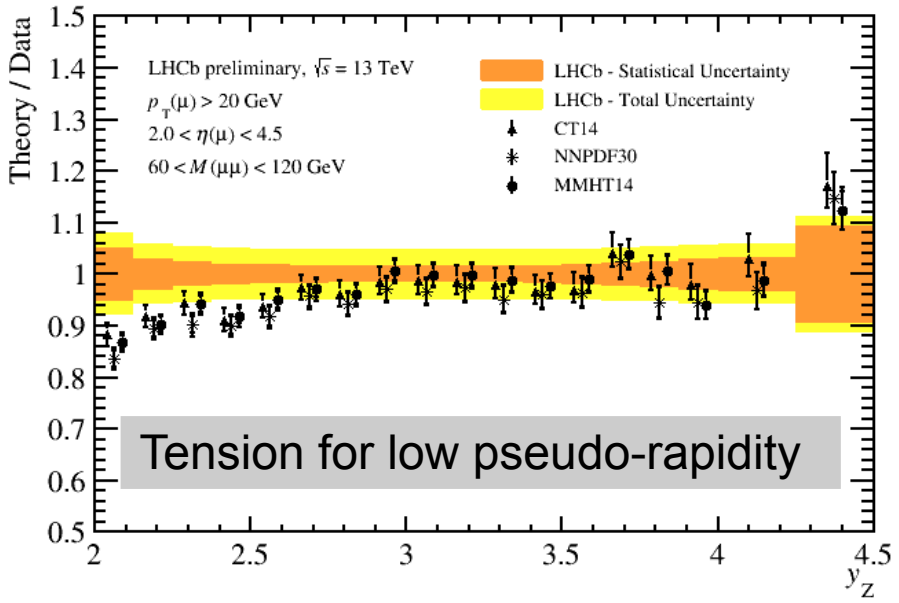


Total cross-section is in agreement with FEWZ at NNLO predictions

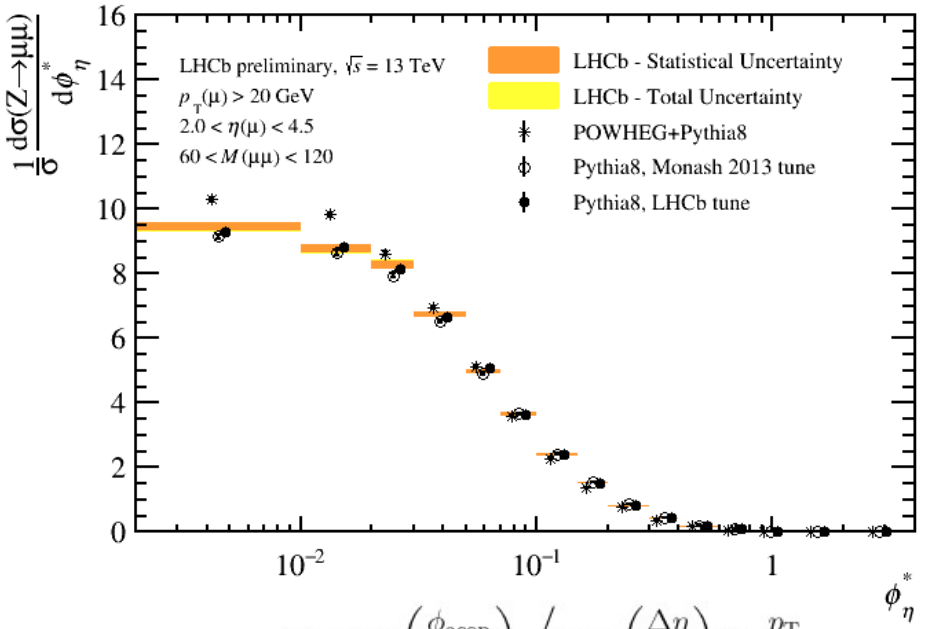
Z→μμ at 13 TeV

LHCb-CONF-2016-002

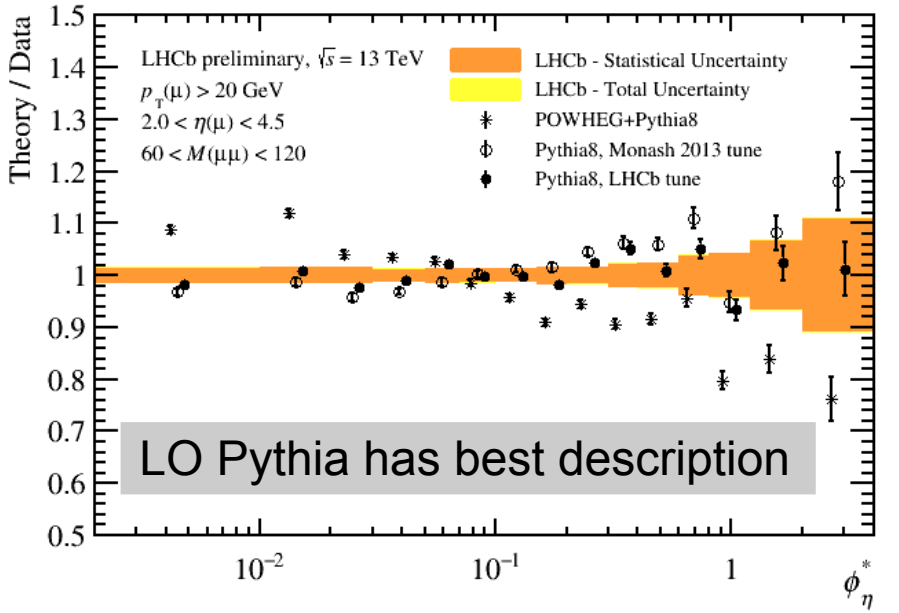




Tension for low pseudo-rapidity



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



LO Pythia has best description

7/8 TeV
W/Z cross-sections

Z→μμ and W→μν production at 7/8 TeV

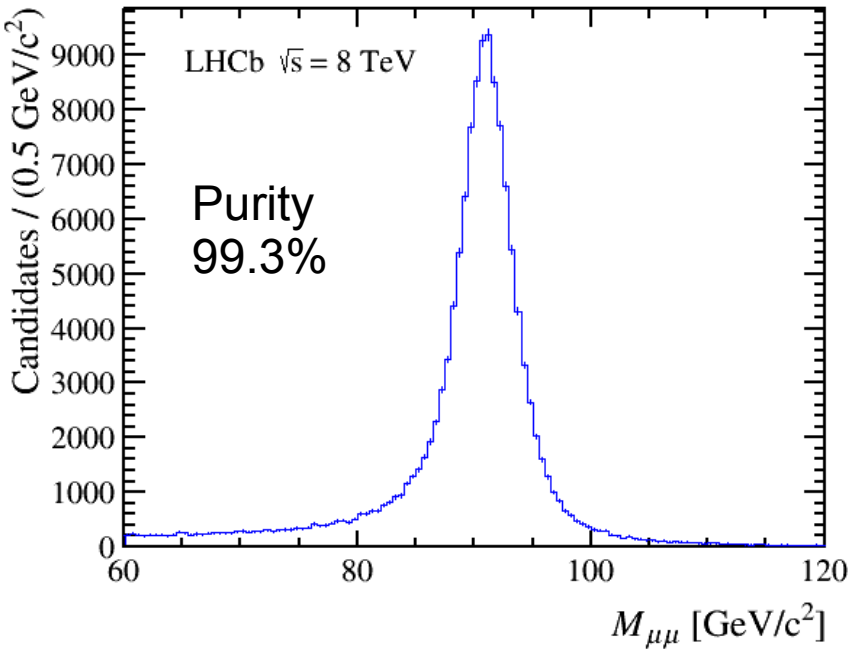
JHEP01(2016)155

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

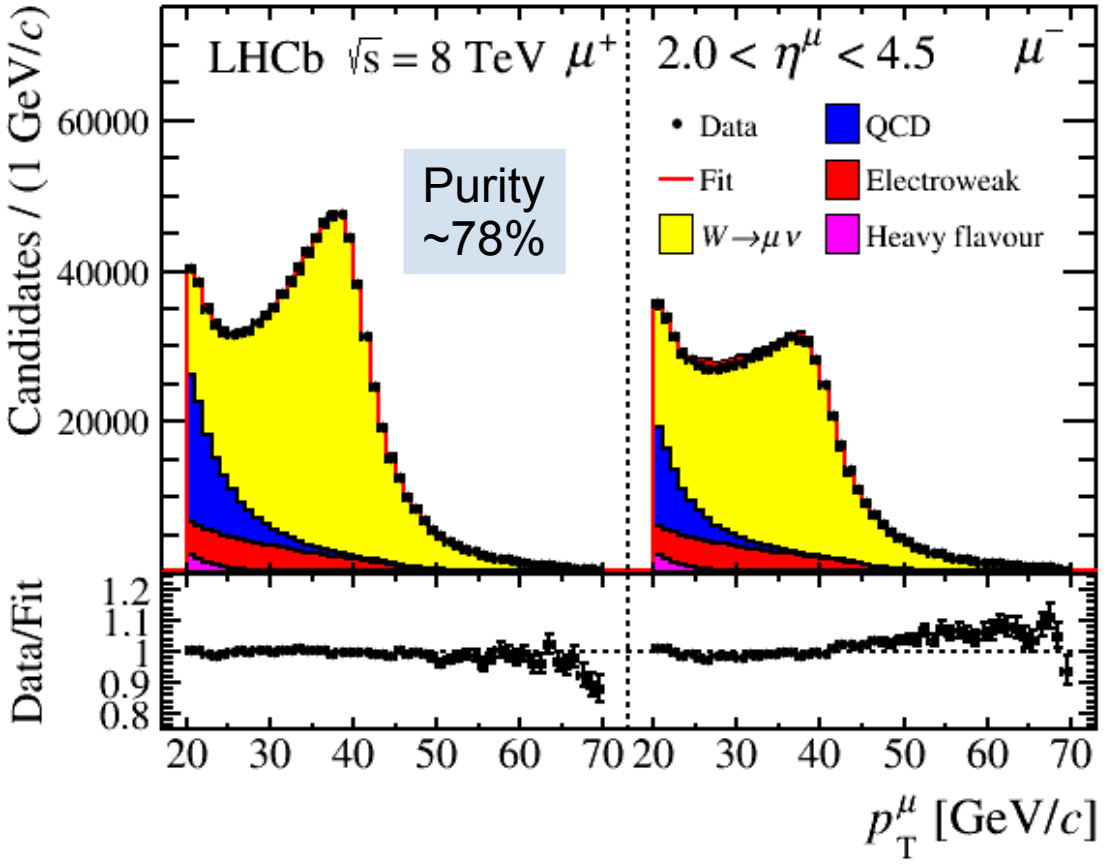
Fiducial acceptance:

$2.0 < \eta(\mu) < 4.5$, $p_T(\mu) > 20$ GeV

$60 < M(\mu\mu) < 120$ GeV for Z

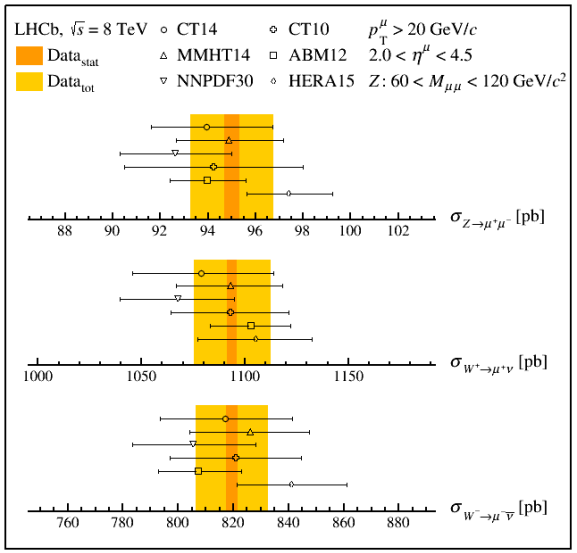


Fit to $p_T(\mu)$ to extract signal yields

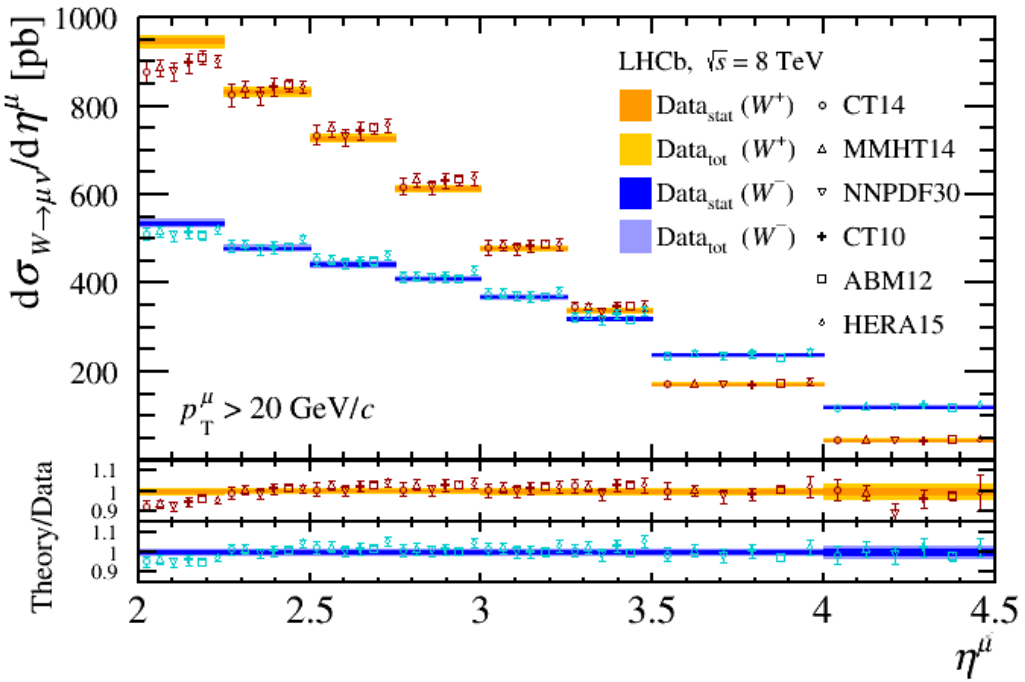


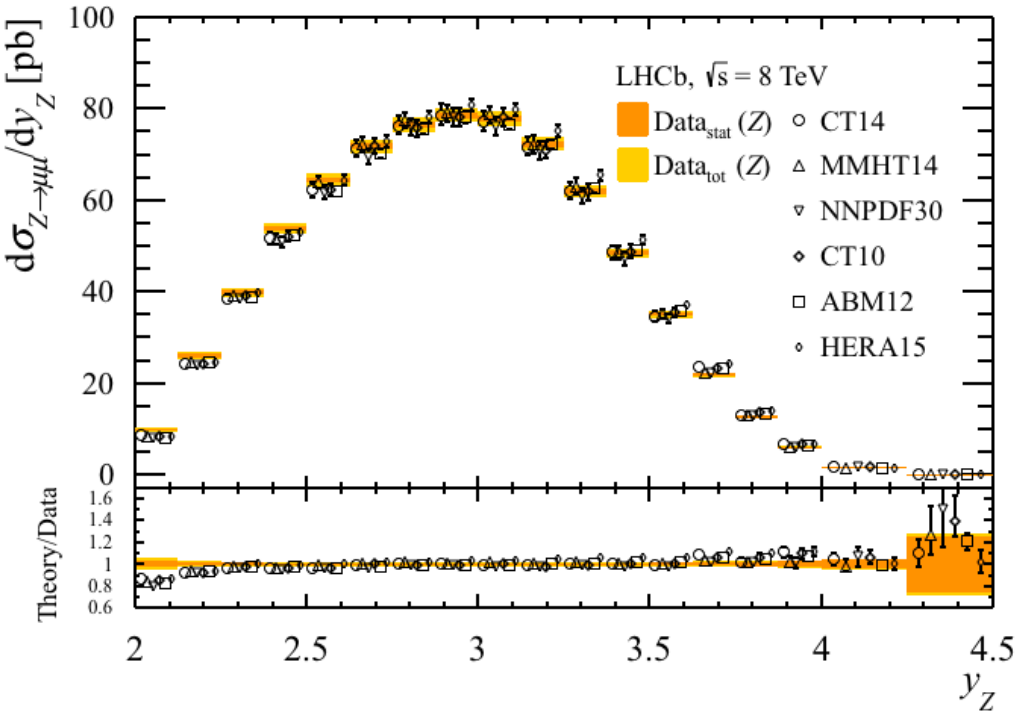
Z→μμ and W→μν production at 7/8 TeV

JHEP01(2016)155



Comparison with FEWZ at NNLO fixed order





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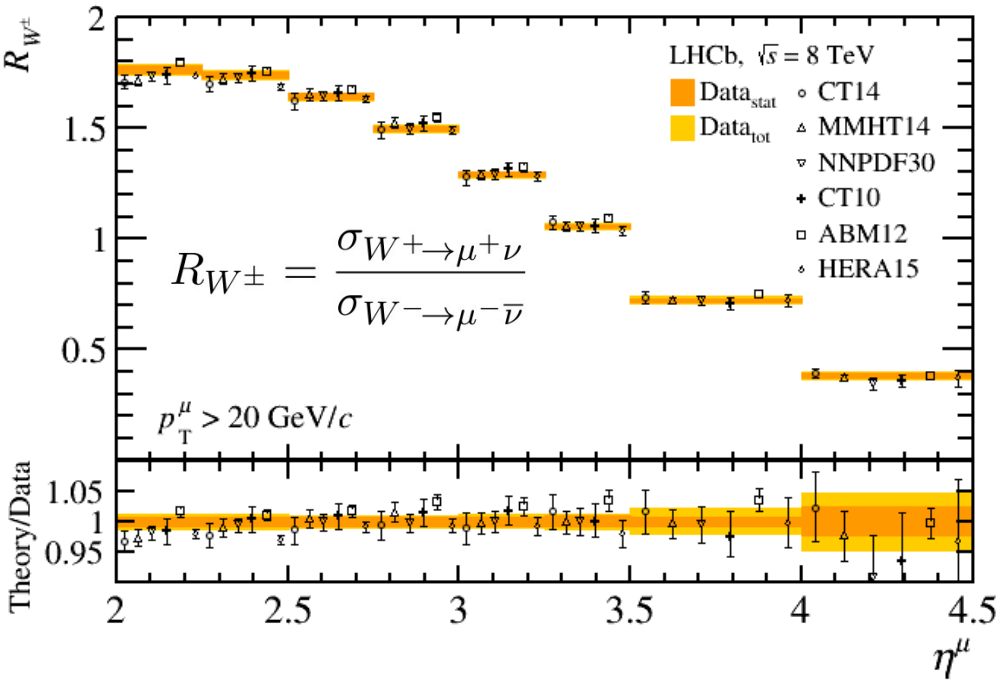
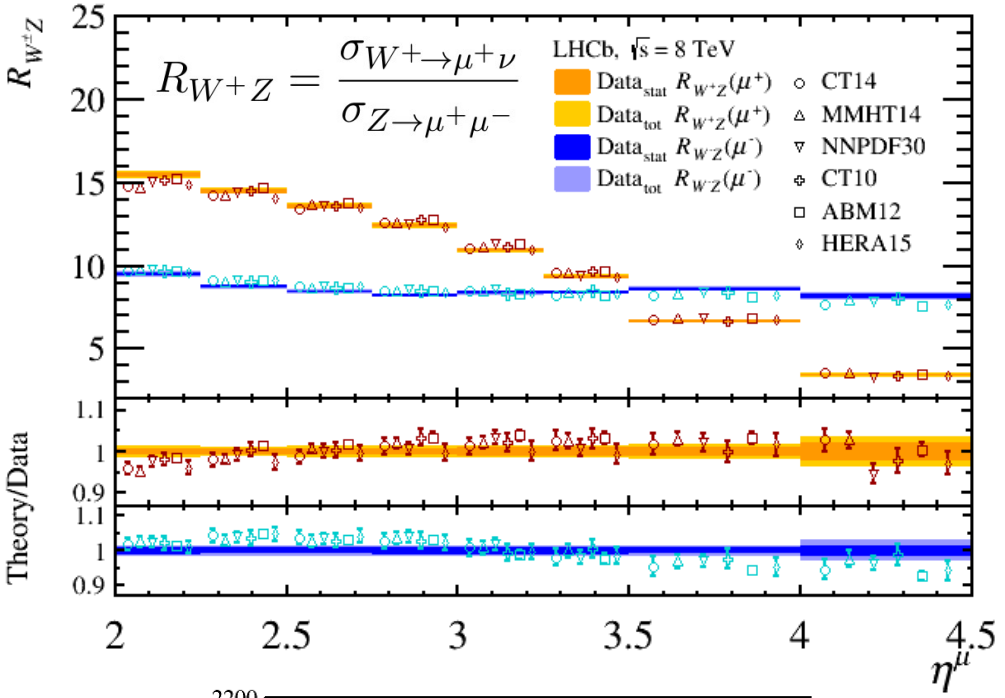
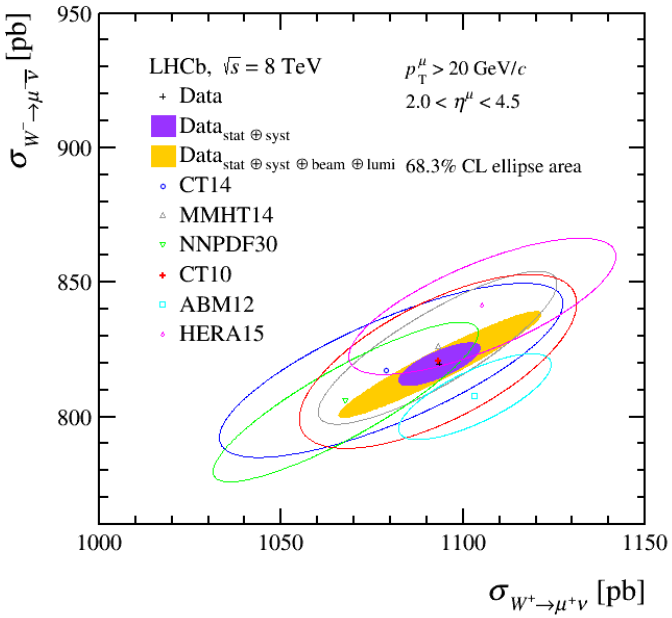
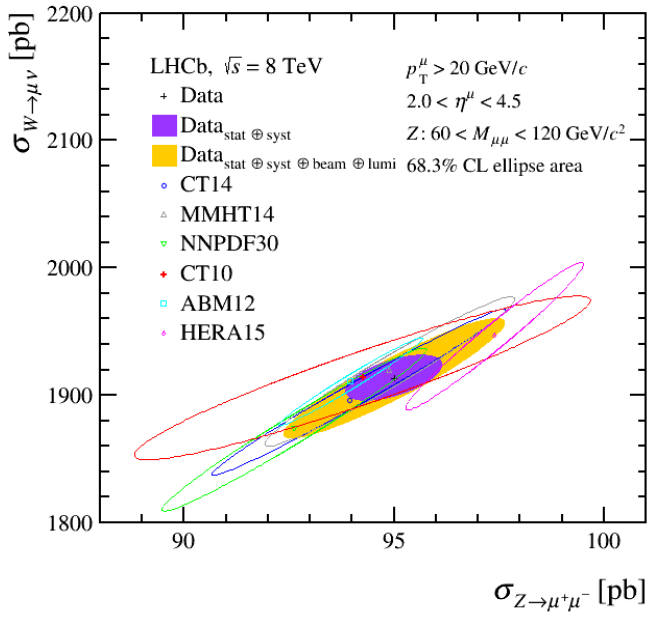
Ratios of cross-sections provide more precise measurements





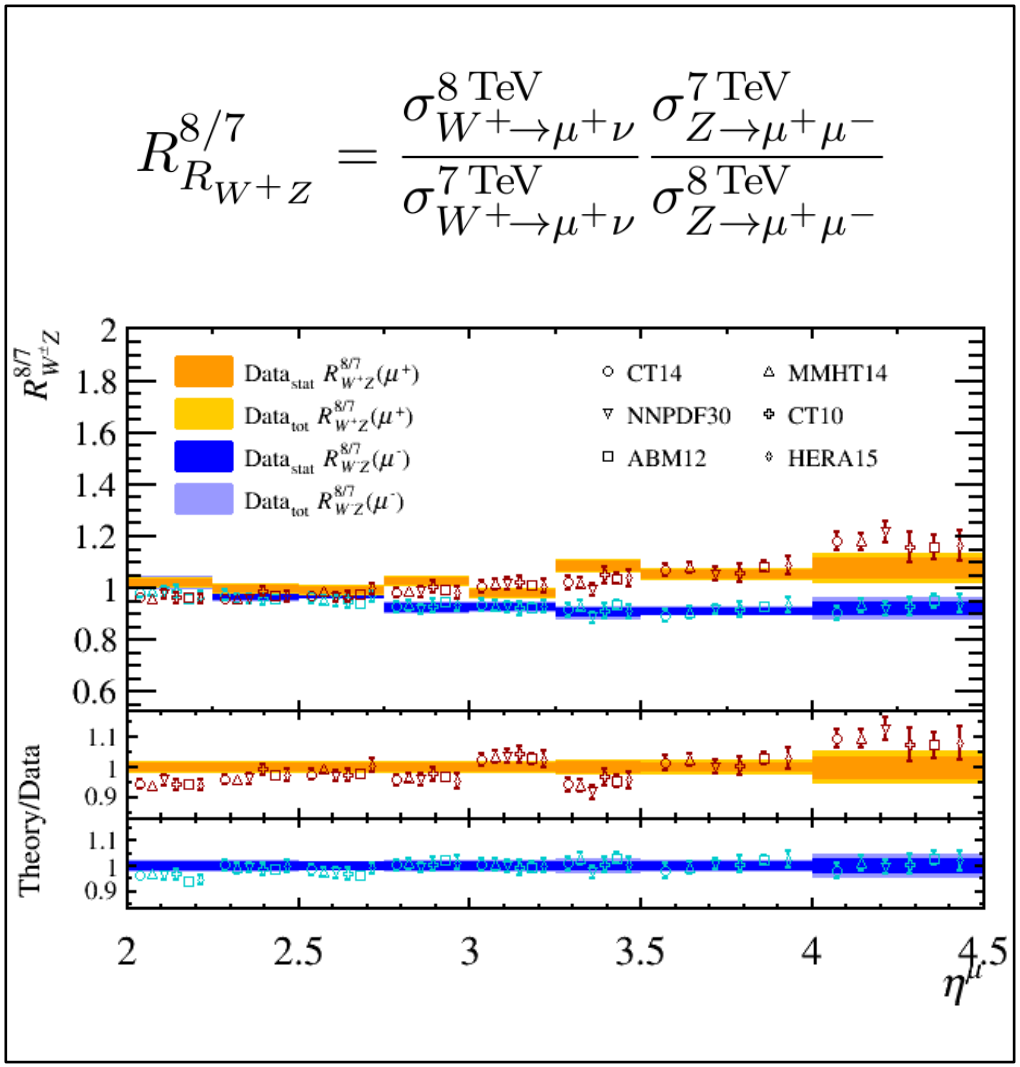


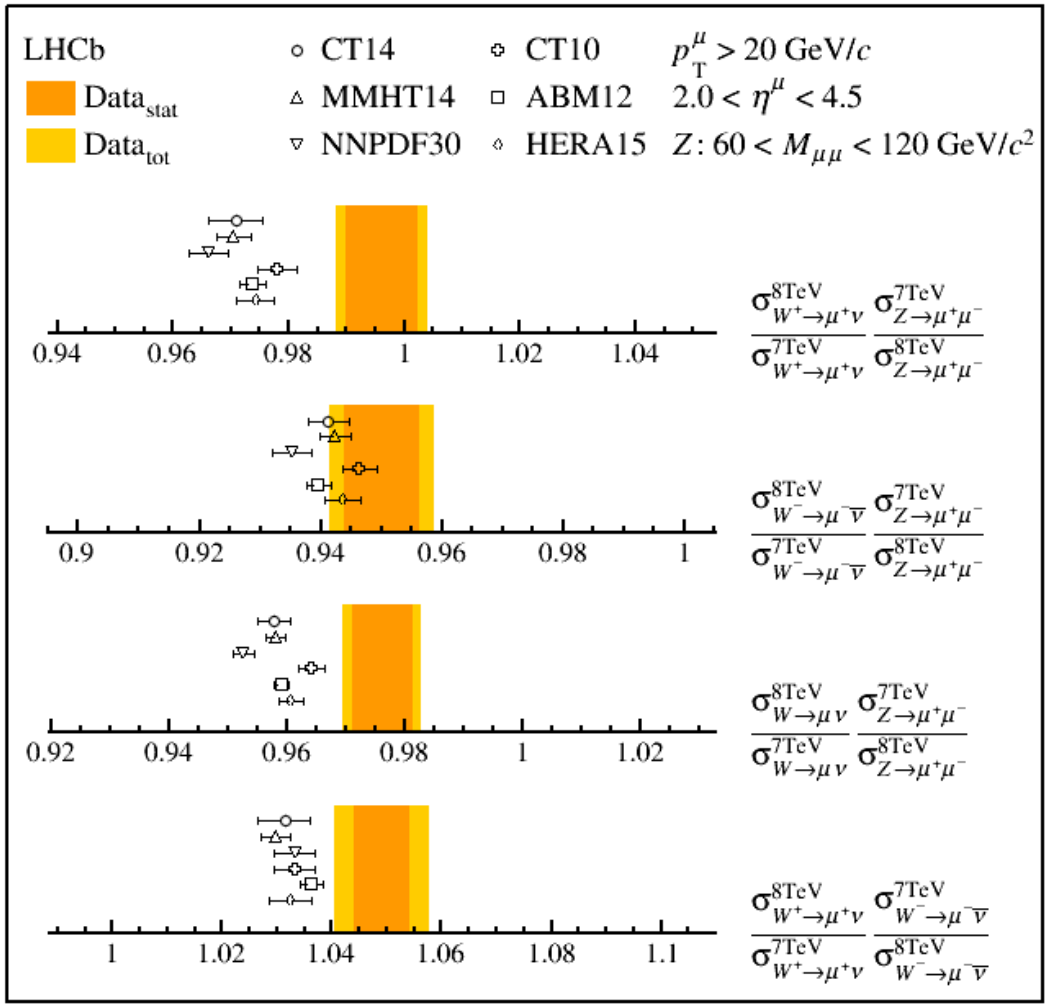


JHEP01(2016)155

Double ratios of cross-sections provide even more precise measurements

$$R^{8/7}_{R_{W+Z}} = \frac{\sigma^{8\,\mathrm{TeV}}_{W^+\to\mu^+\nu}}{\sigma^{7\,\mathrm{TeV}}_{W^+\to\mu^+\nu}} \frac{\sigma^{7\,\mathrm{TeV}}_{Z\to\mu^+\mu^-}}{\sigma^{8\,\mathrm{TeV}}_{Z\to\mu^+\mu^-}}$$

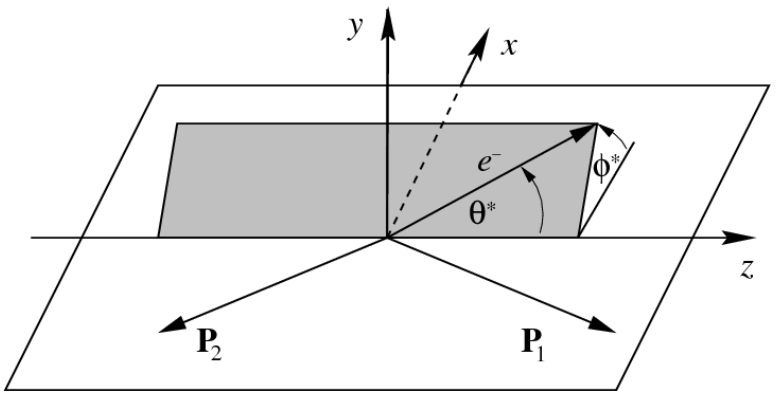




The predictions deviate from the measurements

Forward-Backward asymmetry - AFB ($\sin^2\theta^{eff}_W$)

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} = A(1+\cos^2\theta^*) + B\cos\theta^*$$



θ^* is the polar angle of negatively charge lepton in the Collins-Soper frame.
Forward (backward) is defined by $\cos\theta^*>0$ ($\cos\theta^*<0$)

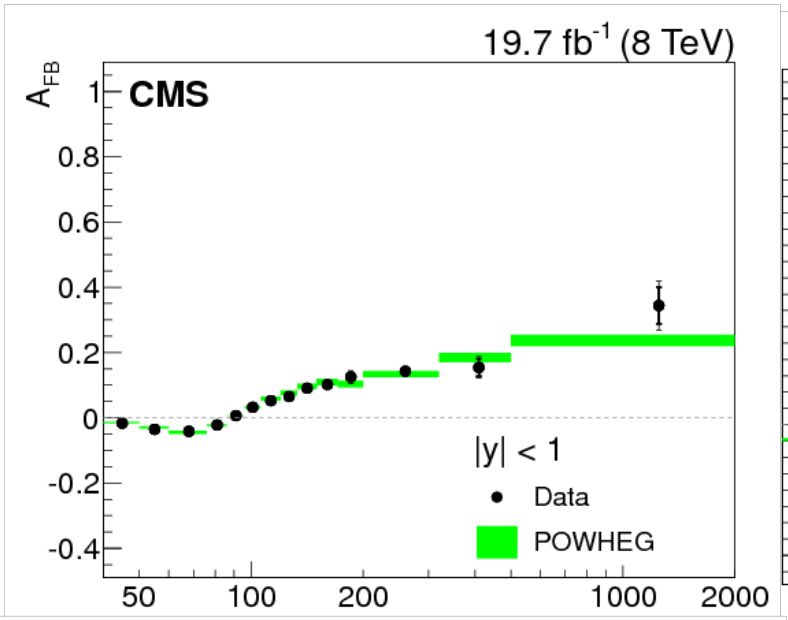
$$A_{\mathrm{FB}} \equiv \frac{N_{\mathrm{F}} - N_{\mathrm{B}}}{N_{\mathrm{F}} + N_{\mathrm{B}}}$$

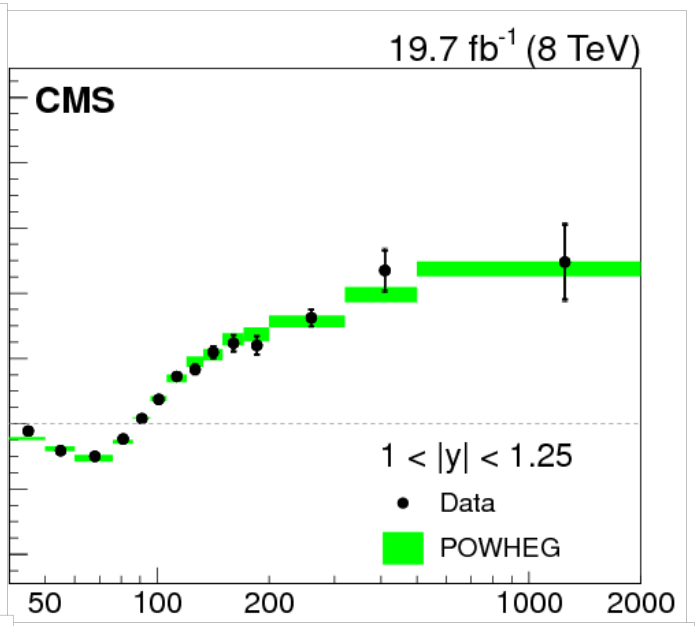
AFB at CMS

arXiv:1601.04768

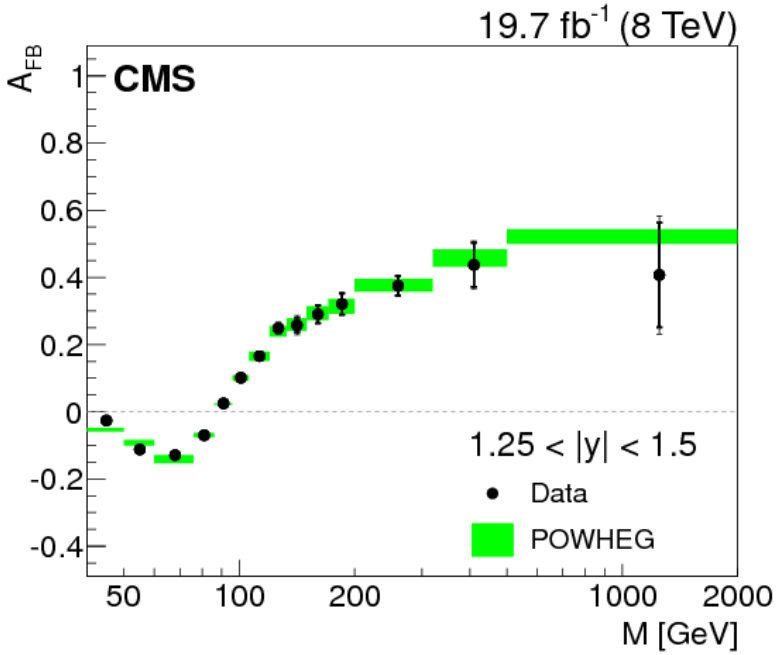
Data: 19.7/fb at 8 TeV

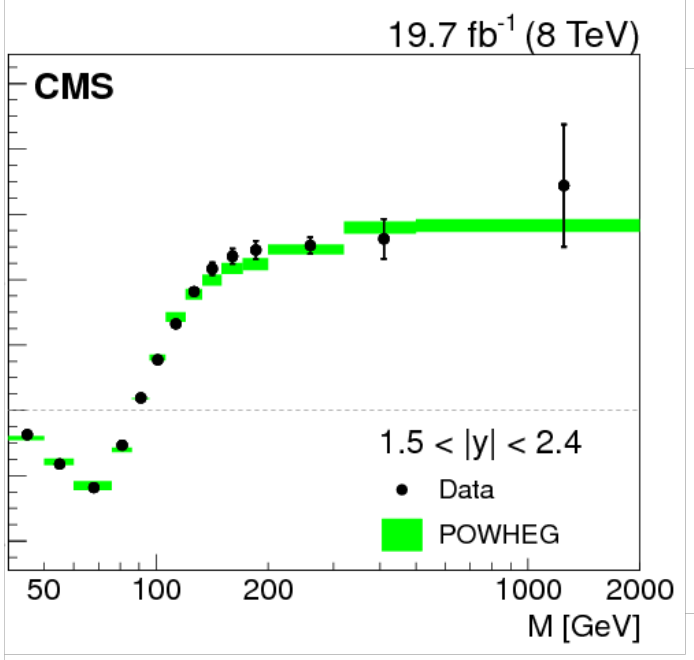
Using both Z→ee and Z→μμ final states

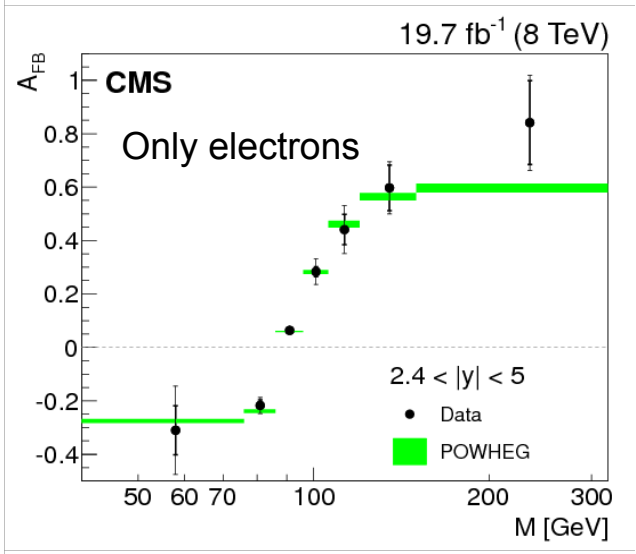




Predictions calculated with POWHEG NLO are in agreement with measurements



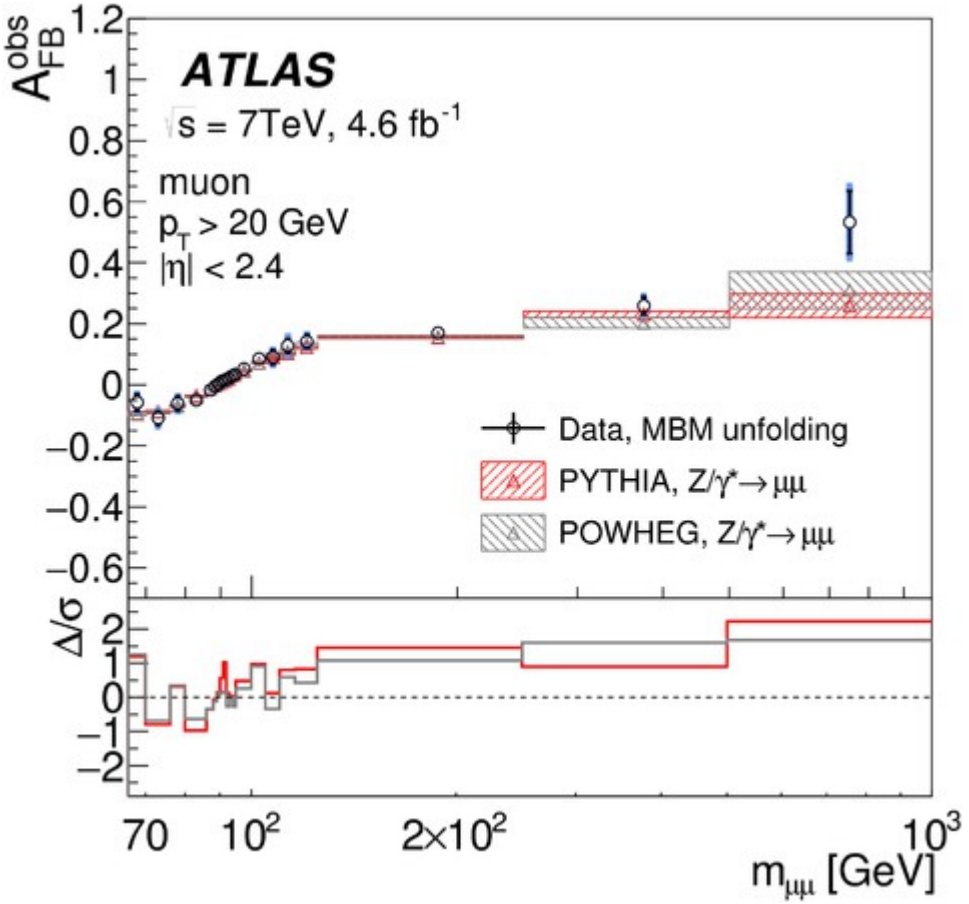


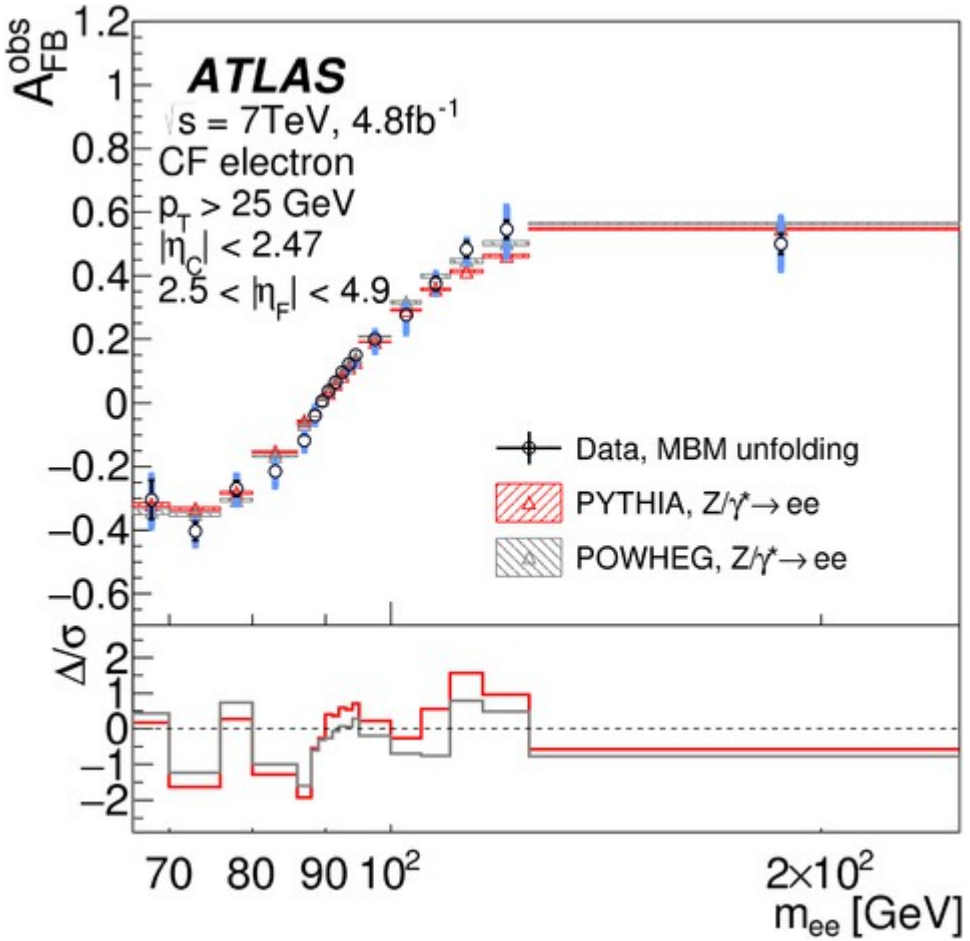


JHEP09(2015)049

Data: 4.8/fb at 7 TeV

Using both Z→ee and Z→μμ final states



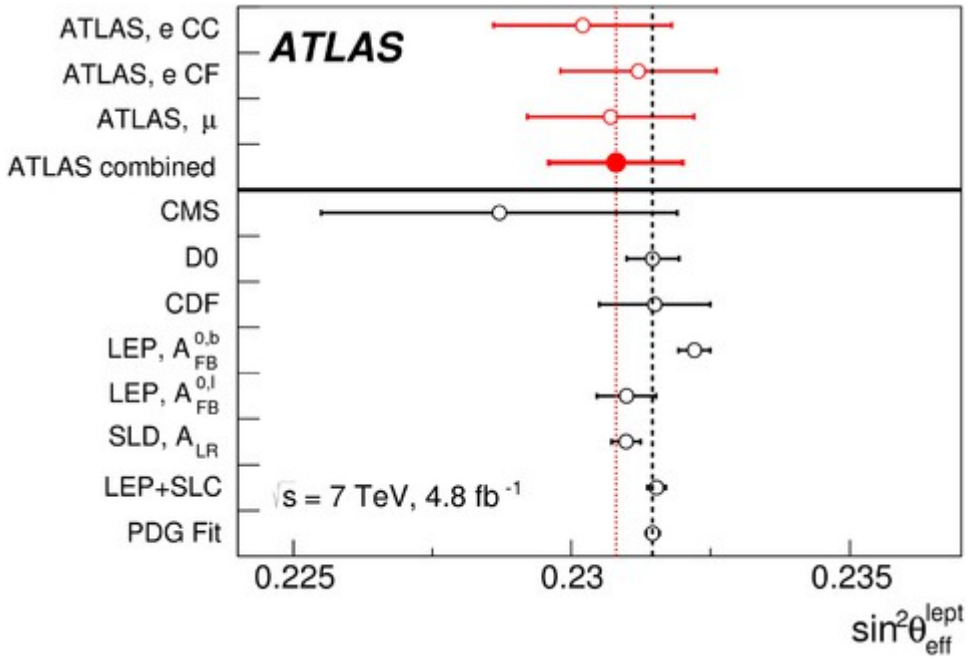


Predictions of PTYHIA LO and POWHEG NLO are in agreement with measurements

JHEP09(2015)049

Using χ^2 fit using different templates (from PYTHIA),
the effective weak mixing angle is measured

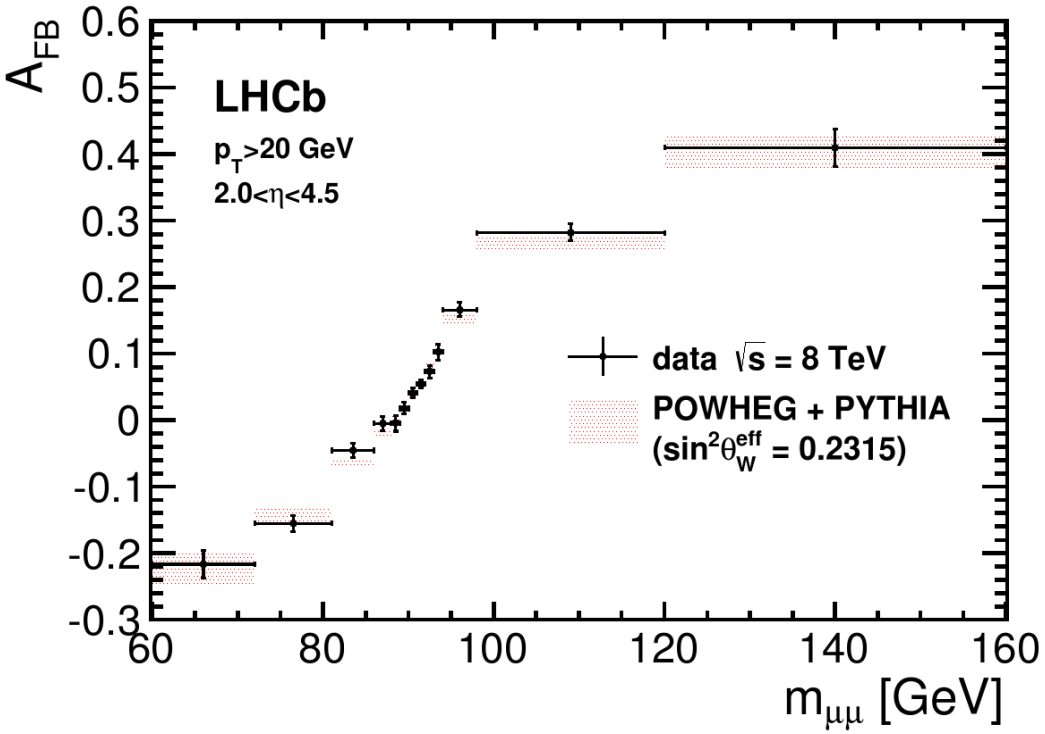
Uncertainty source	CC electrons $[10^{-4}]$	CF electrons $[10^{-4}]$	Muons $[10^{-4}]$	Combined $[10^{-4}]$
PDF	10	10	9	9
MC statistics	5	2	5	2
Electron energy scale	4	6	—	3
Electron energy resolution	4	5	—	2
Muon energy scale	—	—	5	2
Higher-order corrections	3	1	3	2
Other sources	1	1	2	2

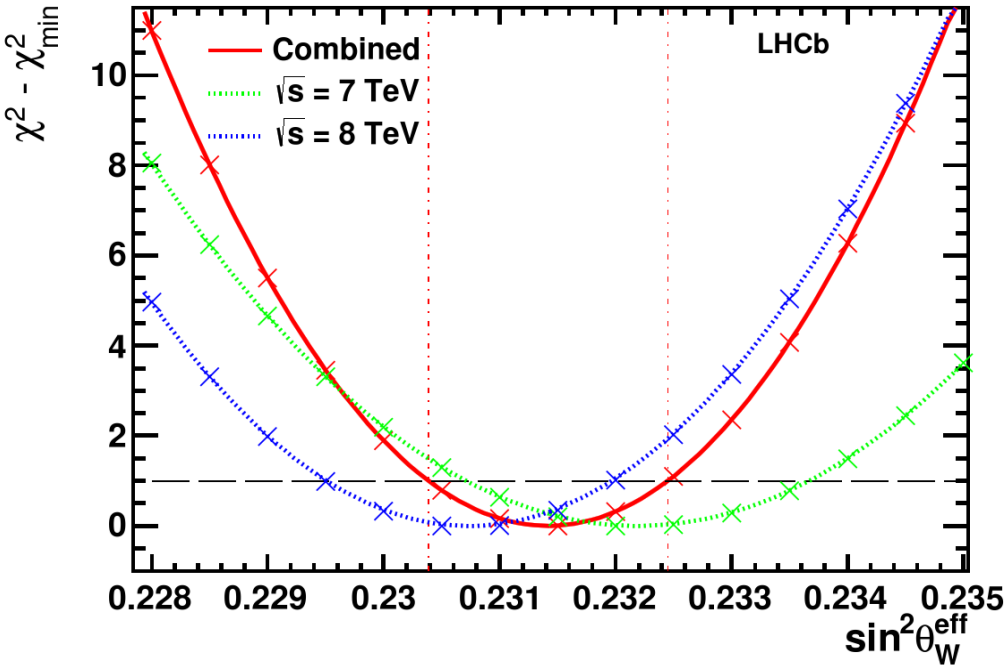


JHEP11(2015)190

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

Using only Z→μμ final state in the forward region

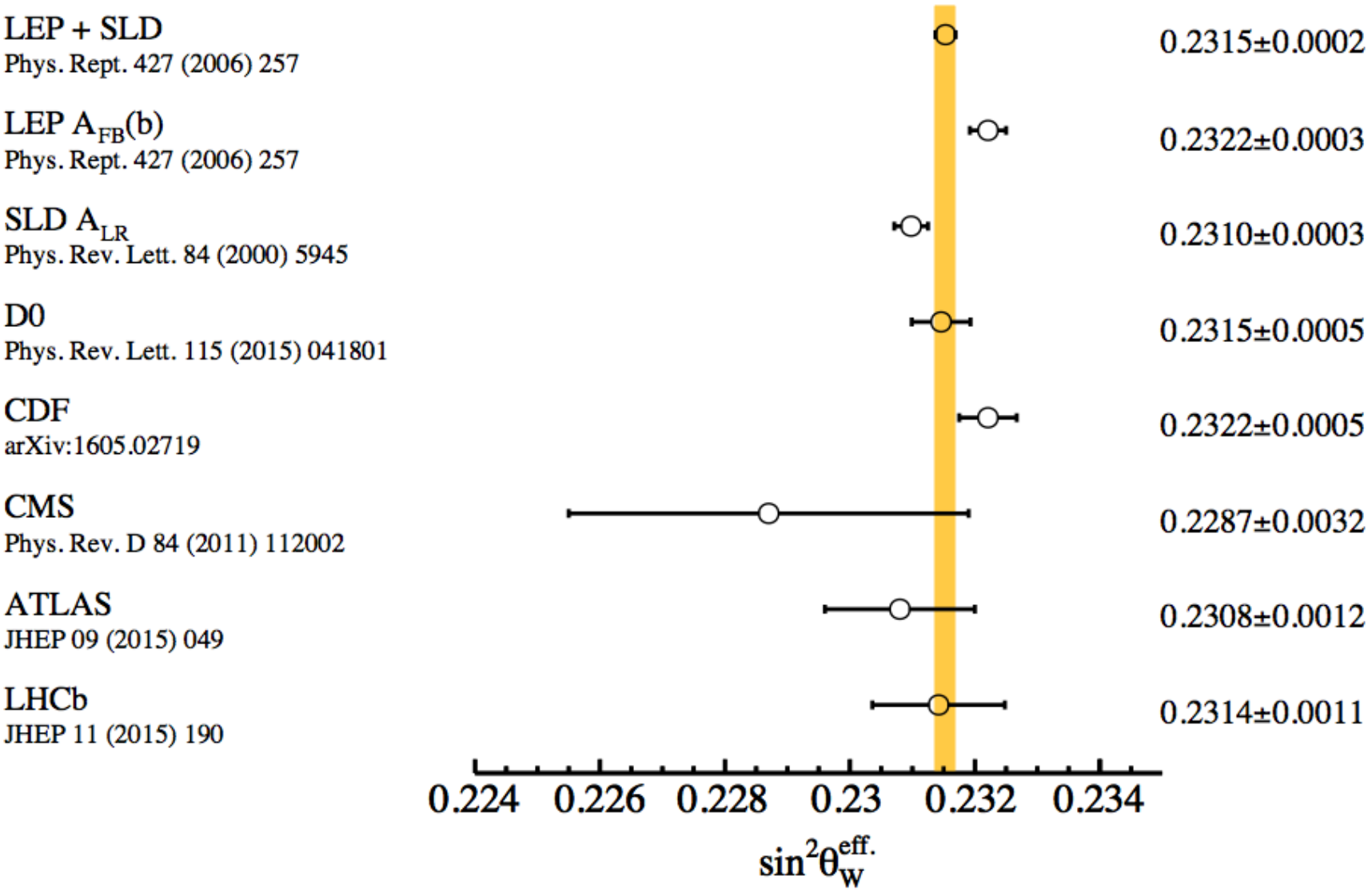




POWHEG-BOX at NLO is used to generate the fit templates

AFB - Summary

JHEP11(2015)190



LHCb has the most precise measurement at LHC

Summary

→ LHCb probes a unique coverage in η and low p_T reach at LHC

→ First measurements at 13 TeV presented

→ Comprehensive set of precise measurements available for 7/8 TeV

→ Most of measurement are in good agreement with theoretical predictions and can be used to constrain PDFs or tunes

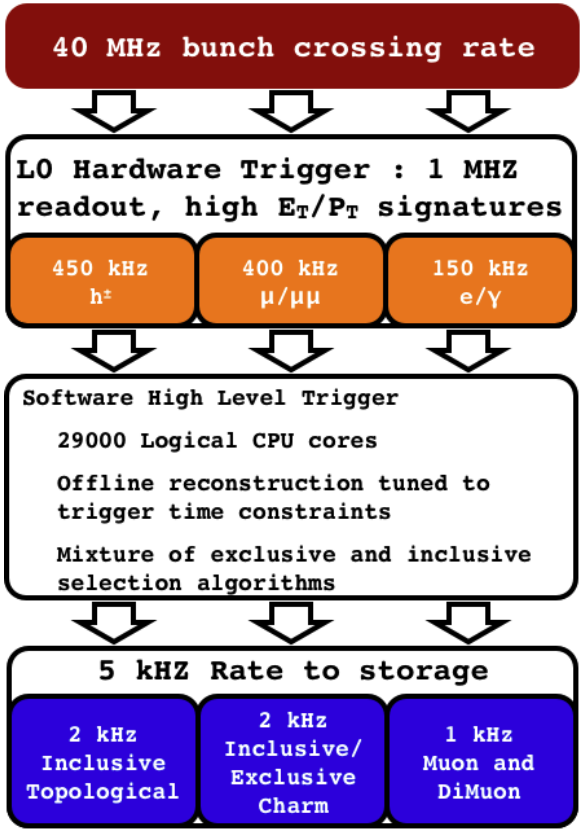
→ Many other results not covered in this talk are available here LHCb Results

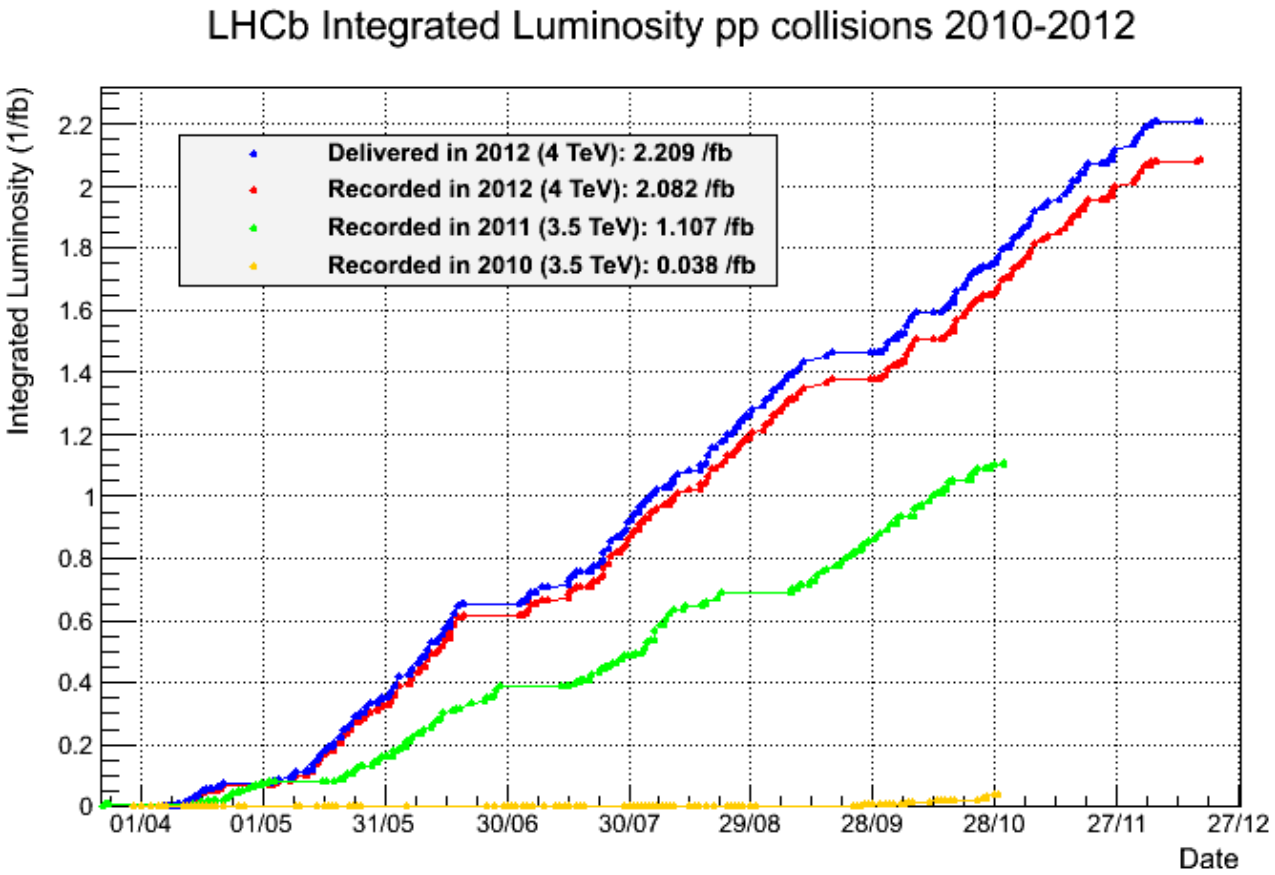
→ More exciting 13 TeV results to come!

THANK YOU!

Back up

LHCb Data





>90% data taking efficiency

>99% DQ efficiency

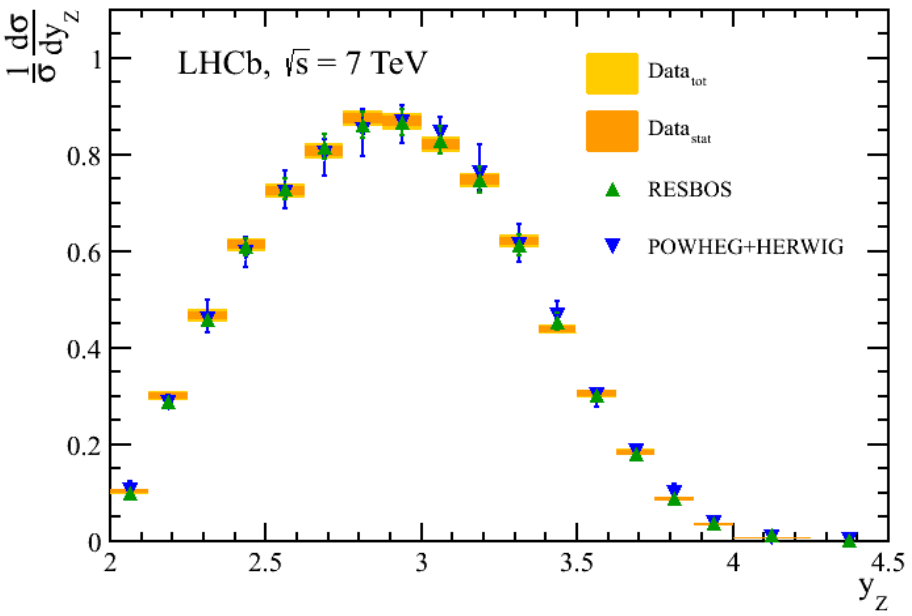
2010 → 37/pb at $\sqrt{s}$ = 7 TeV

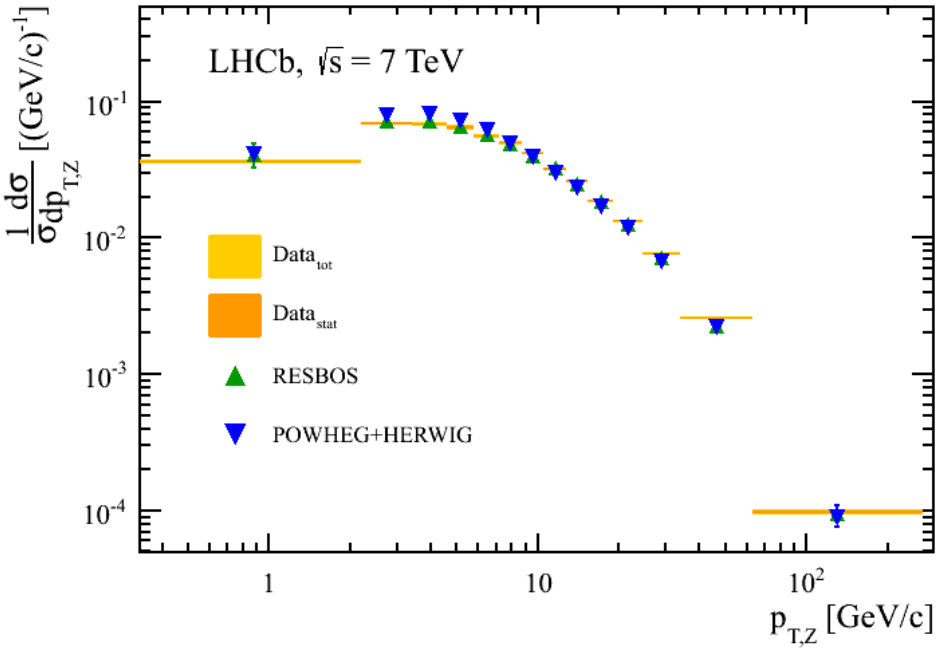
2011 → 1.0/fb at at $\sqrt{s}$ = 7 TeV

2012 → 2/fb at at $\sqrt{s}$ = 8 TeV

Z→μμ production

JHEP08(2015)039



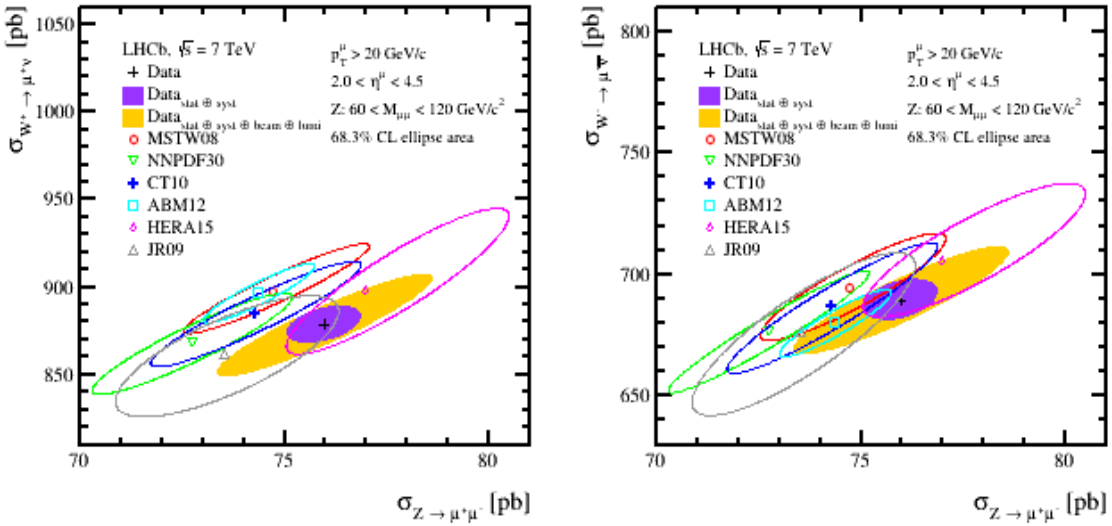


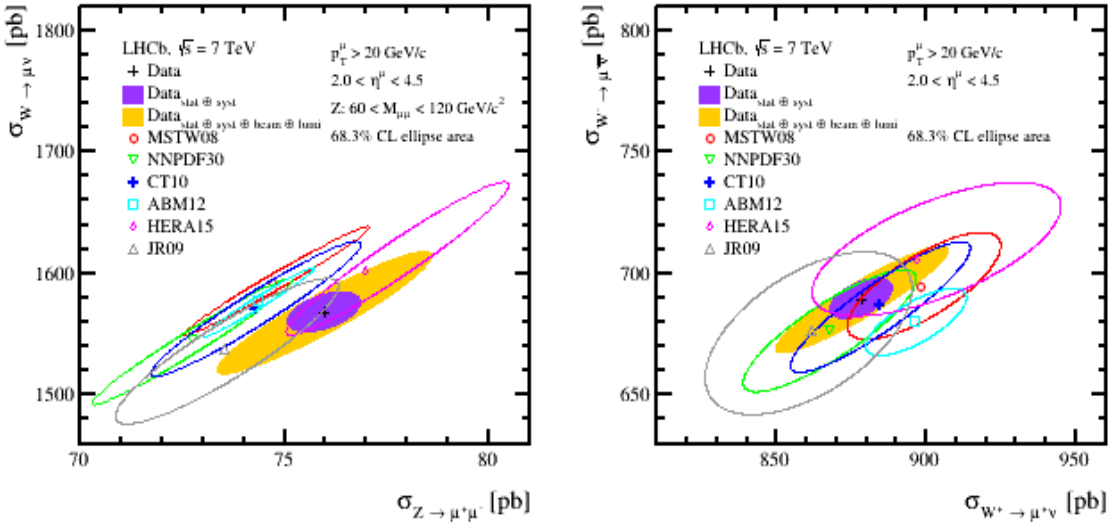
Source	Uncertainty (%)
Statistical	0.39
Trigger efficiency	0.07
Identification efficiency	0.23
Tracking efficiency	0.53
FSR	0.11
Purity	0.22
GEC efficiency	0.26
Systematic	0.68
Beam energy	1.25
Luminosity	1.72
Total	2.27

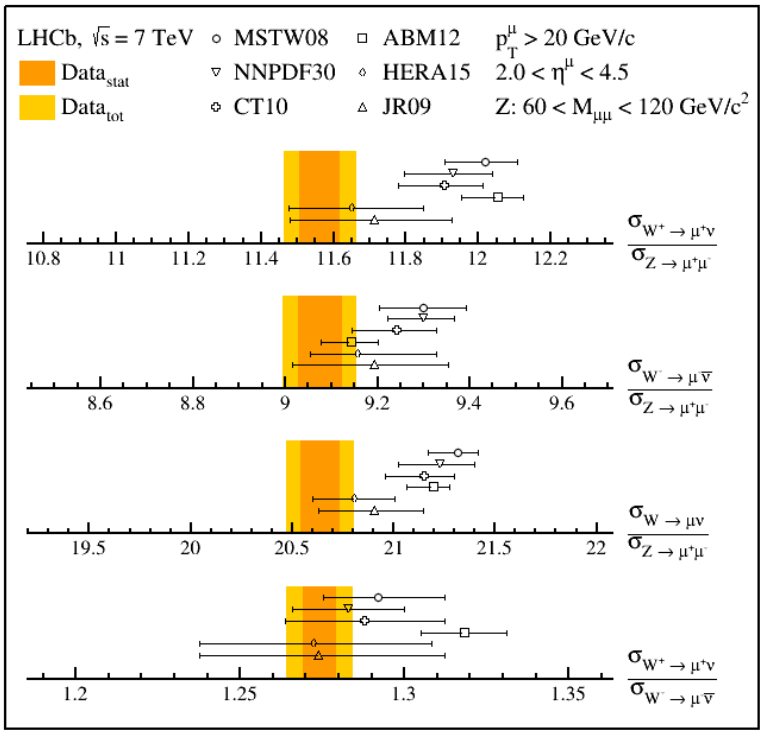
JHEP08(2015)039

Data: 1/fb at 7 TeV

Analysis: Ratios cancel many scale uncertainties (mainly theoretical)







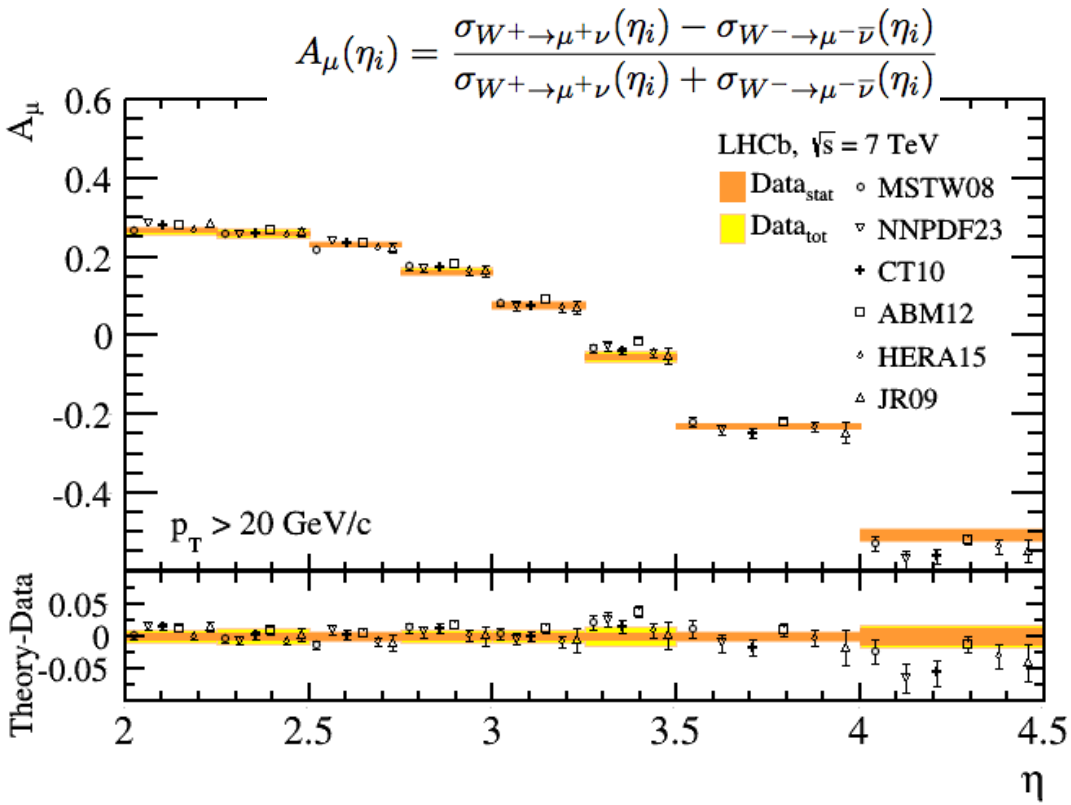
Tension between PDF sets

JHEP08(2015)039

Data: 1/fb at 7 TeV

Fiducial acceptance: $2.0<\eta(\mu)<4.5$, $p_T(\mu)> 20$ GeV

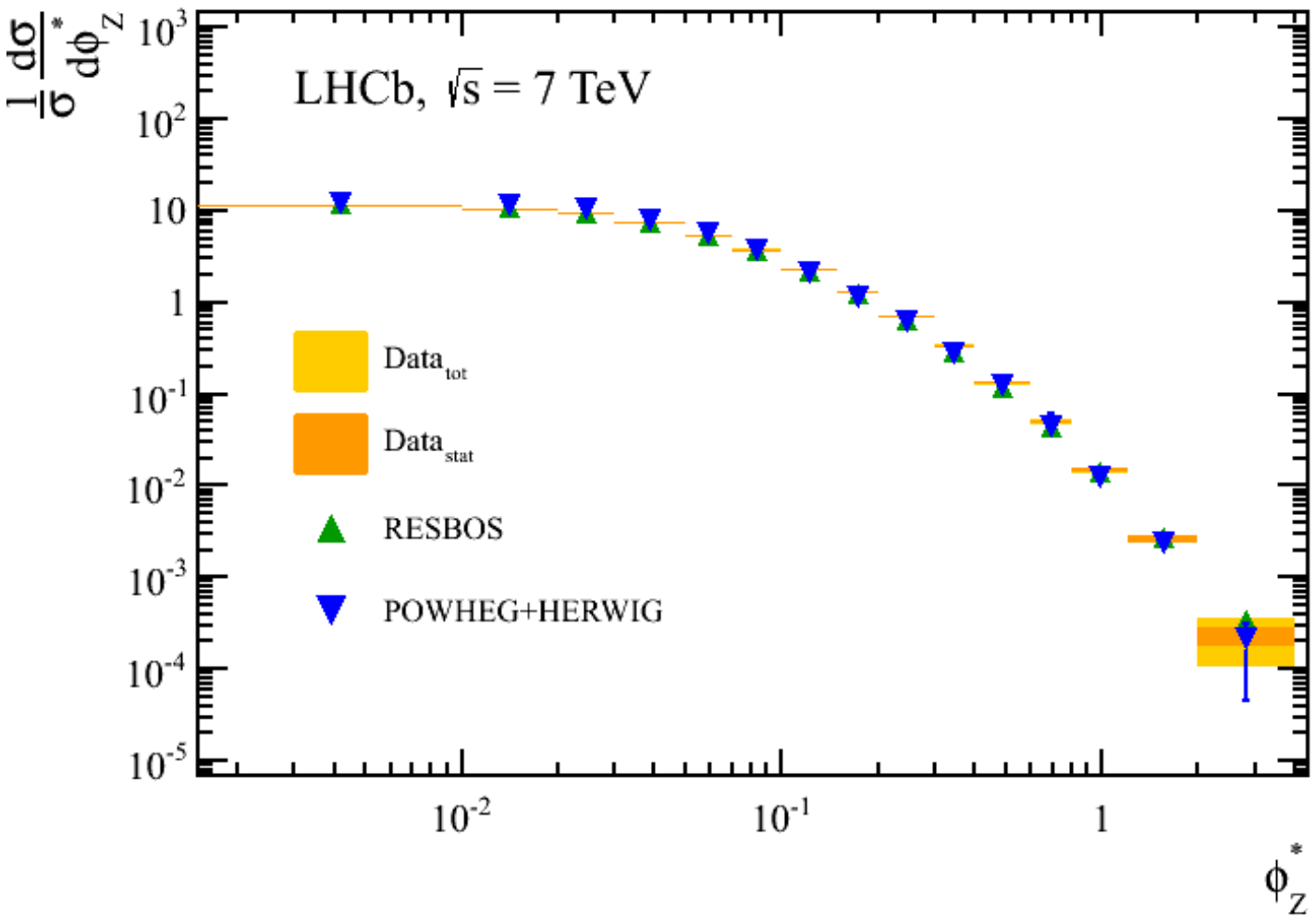
$60<M(\mu\mu)/\text{GeV}<120$ for Z



Good agreement with NNLO
Sensitive to PDF variation

Lepton charge asymmetry - PDF
Good agreement with NNLO predictions

JHEP08(2015)039



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

Z→ee production

JHEP05(2015)109

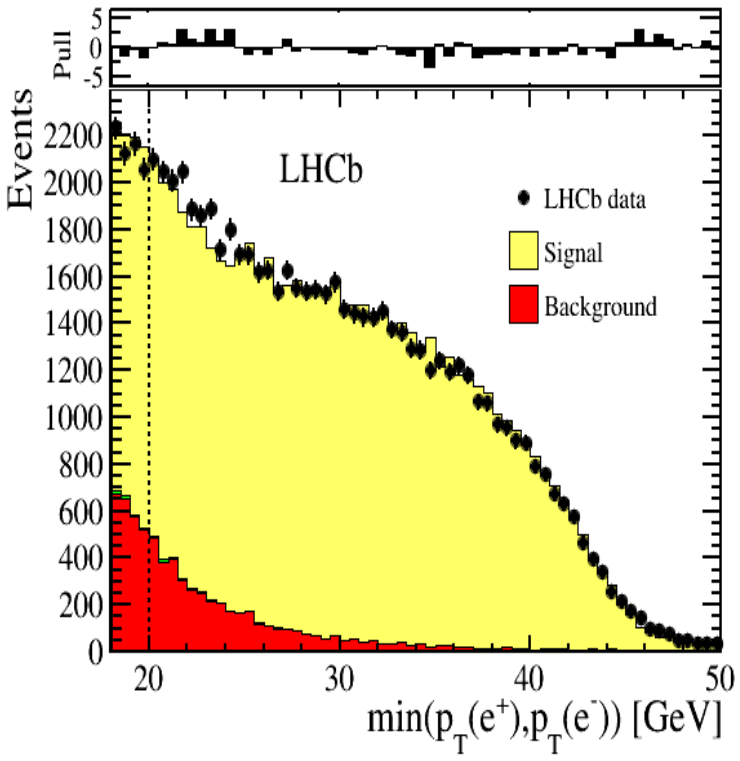
Data: 2/fb at 8 TeV

Fiducial acceptance: $2.0<\eta(e)<4.5$, $p_T(e)> 20$ GeV, $60<M(ee)/GeV<120$

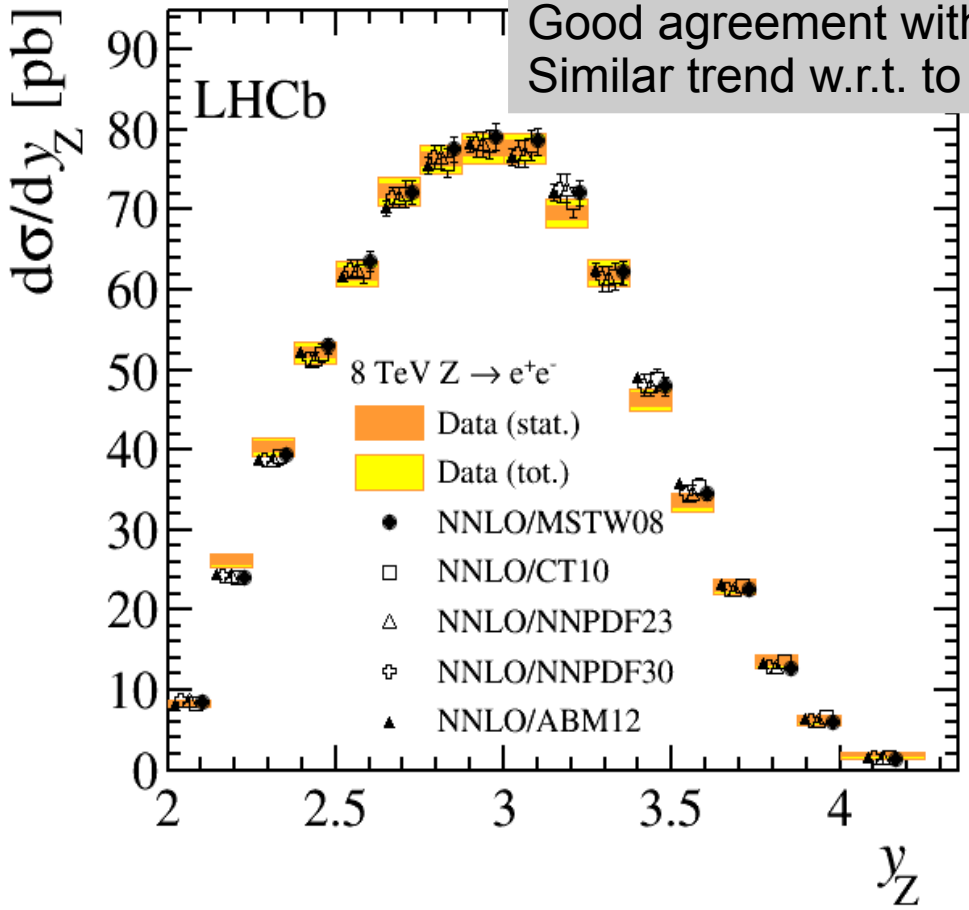
Analysis:

Calorimeter information used to identify the electron

~90% purity – main background is electron mis-identification



Good agreement with NNLO
Similar trend w.r.t. to PDF variation



Z→ee production

JHEP05 (2015) 109

Data: 2/fb at 8 TeV

Fiducial acceptance: $2.0<\eta(e)<4.5$, $p_T(e)> 20$ GeV, $60<M(ee)/GeV<120$

Analysis:

Calorimeter information used to identify the electron

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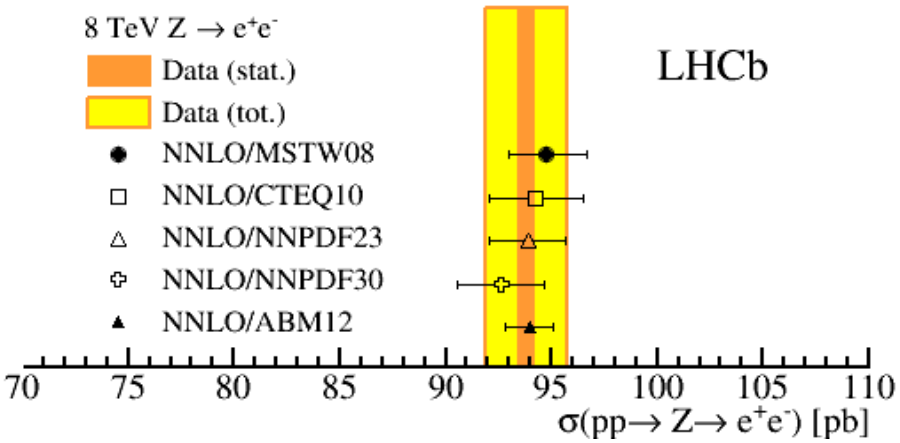

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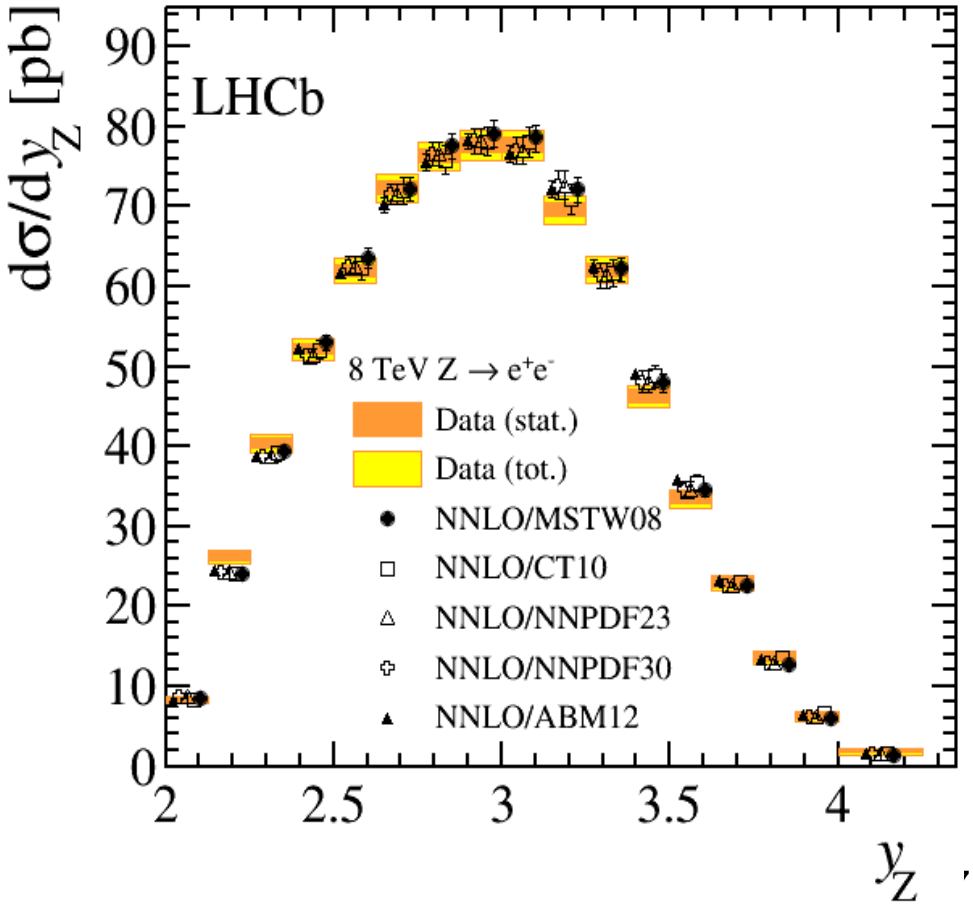


W→μν production

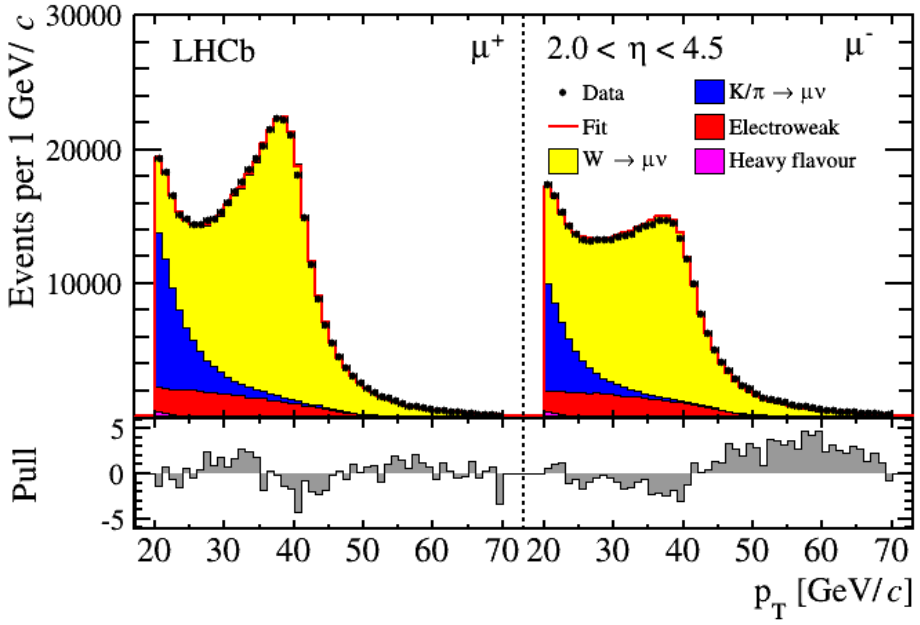
JHEP12(2014)079

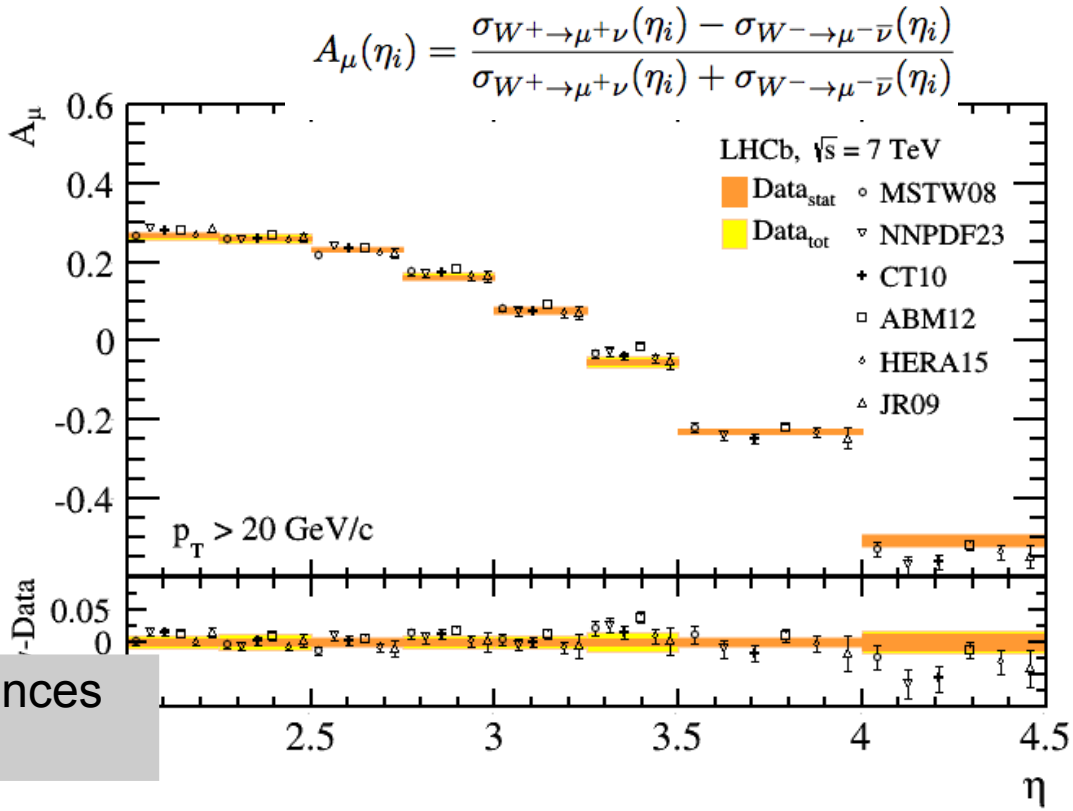
Data: 1/fb at 7 TeV

Fiducial acceptance: $2.0<\eta(\mu)<4.5$, $p_T(\mu)> 20$ GeV

Analysis:

+ Signal extracted with template fit of $p_T(\mu)$
+ ~77% purity
+ Cross-section and charge lepton asymmetry vs η(μ)





Lepton charge asymmetry probes PDF differences
Good agreement with NNLO predictions

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Ratios of cross-sections provide more precise measurements

Source	Uncertainty [%]			
	$R_{W^\pm}$	R_{W^+Z}	R_{W^-Z}	R_{WZ}
Statistical	0.30	0.33	0.36	0.31
Purity	0.25	0.35	0.30	0.30
Tracking	0.05	0.22	0.24	0.23
Identification	0.01	0.11	0.11	0.11
Trigger	0.04	0.10	0.09	0.09
GEC	0.13	0.22	0.23	0.21
Selection	0.10	0.24	0.24	0.23
Acceptance and FSR	0.21	0.21	0.19	0.17
Systematic	0.37	0.59	0.56	0.54
Beam energy	0.14	0.15	0.29	0.21
Total	0.50	0.69	0.73	0.66