University of Zurich[UZH]

Electroweak physics, QCD and jets in the forward region

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on behalf of the LHCb collaboration

Epiphany Conference, 7.-9. January 2013

Further (QCD) Topics

- Measurement of the forward energy flow
  in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ with the LHCb experiment

  (arXiv:1212.4755 [hep-ex])
- Measurement of charged particle multiplicities
  in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ in the forward region

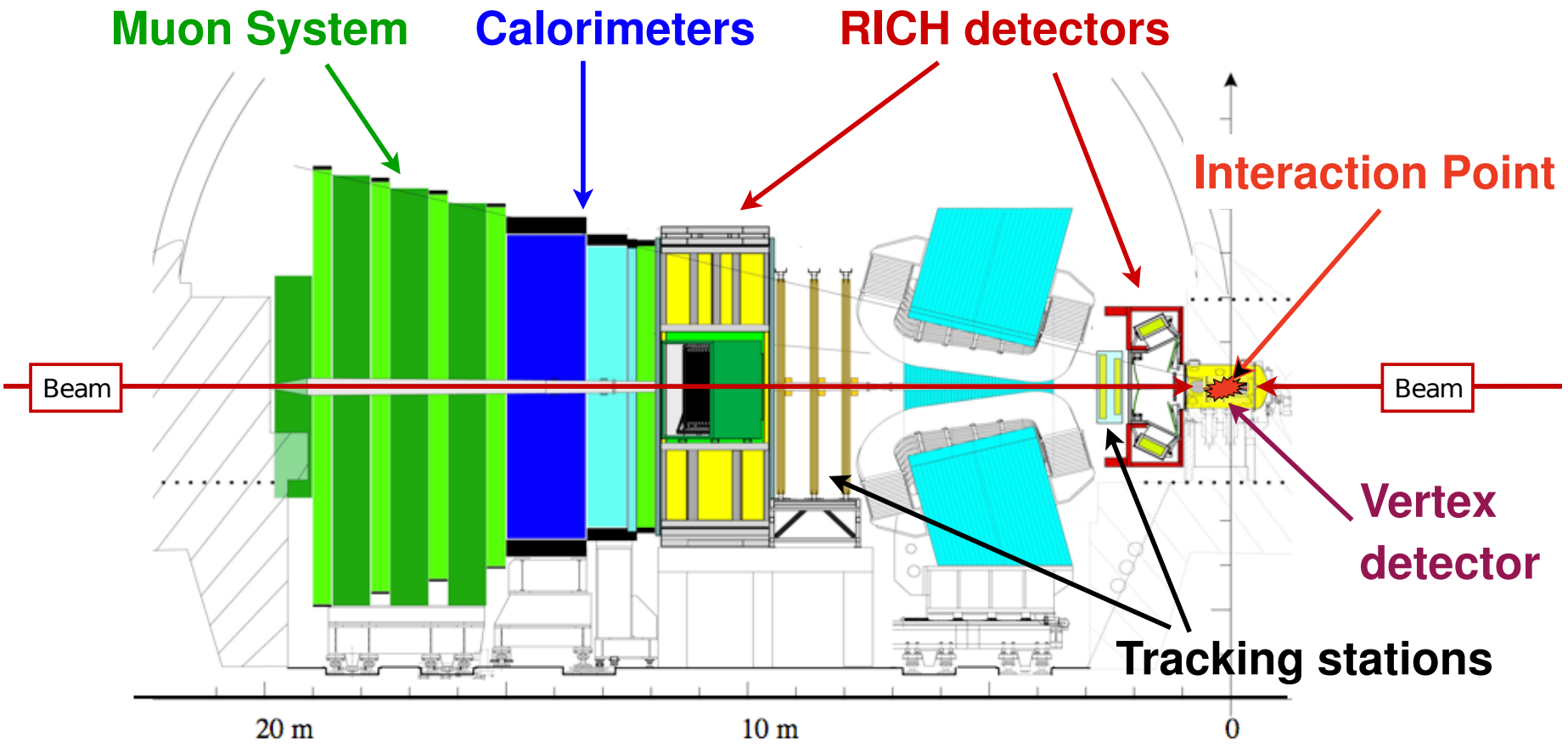
  (Eur. Phys. J. C 72 (2012) 1947)
- Measurement of the inclusive ϕ cross-section
  in pp collisions at $\sqrt{s} = 7\,\text{TeV}$

  (Phys. Lett. B 703 (2011) 267-273)
- Measurement of V^0 production ratios
  in pp collisions at $\sqrt{s} = 0.9$ and $7\,\text{TeV}$

  (J. High Energy Phys. 08 (2011) 034)
- Prompt K^0_S production
  in pp collisions at $\sqrt{s} = 0.9\,\text{TeV}$

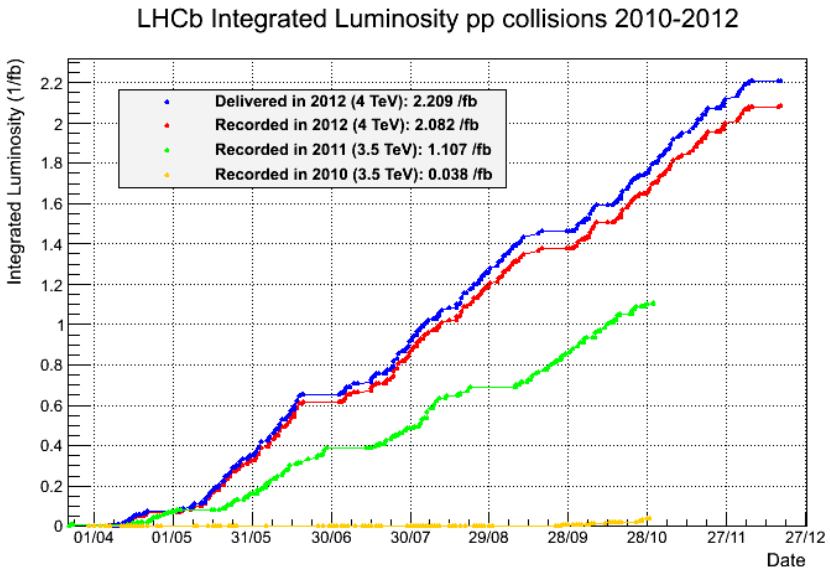
  (Phys. Lett. B 693 (2010) 69-80)

The LHCb Detector



- Forward spectrometer, fully instrumented in $2 < \eta < 5$
- Trigger threshold: $M_{\mu\mu} > 2.5\,\text{GeV}/c^2$

Data Taking



Data Recorded

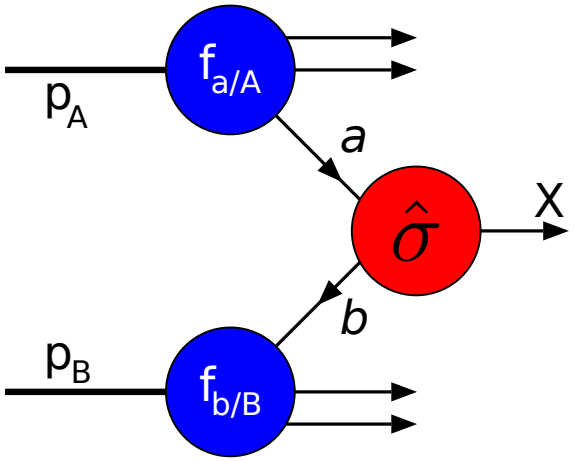
Year	$\mathcal{L}$	E_{CM}
2010	$37\,pb^{-1}$	7.0 TeV
2011	$1.1\,fb^{-1}$	7.0 TeV
2012	$2.1\,fb^{-1}$	8.0 TeV

Average number of interactions constant in all 3 years (1.5)

Cross-Section Measurements

scattering process at LHC

- parton parton scattering described by perturbative QCD
- needs parton distribution functions
- parton distribution functions determined from measurements



$$\sigma_{AB\to X} = \int dx_a dx_b \cdot f_{a/A} f_{b/B} \cdot \hat{\sigma}_{ab\to X}$$

parton distribution function

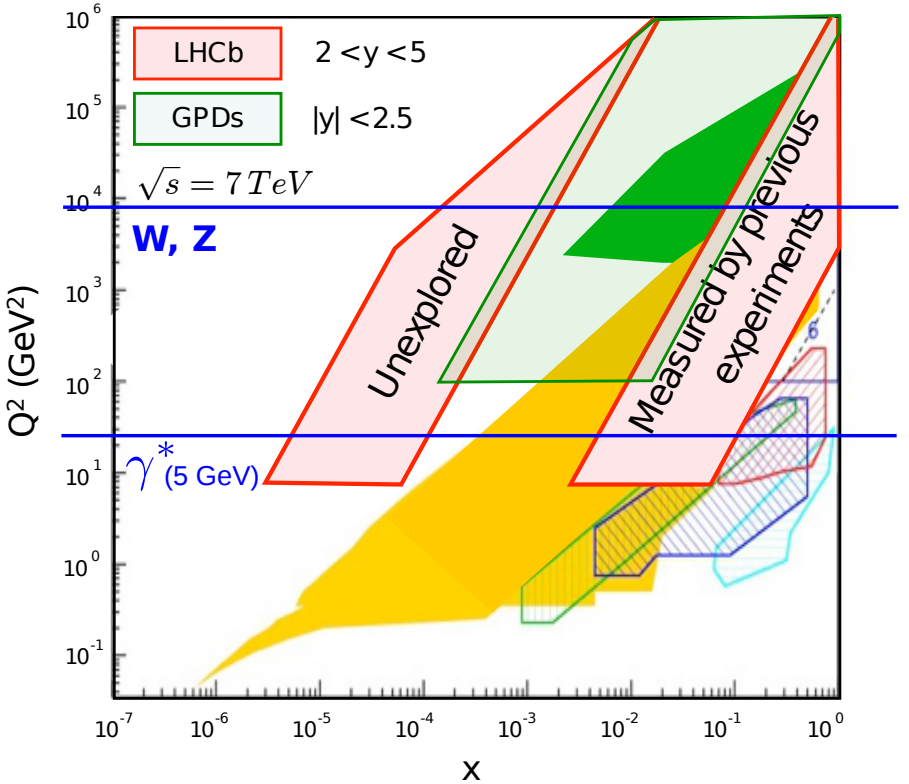
parton parton scattering

Electroweak Measurements at LHCb

$x_{a,b} = \frac{M}{\sqrt{s}} \cdot e^{\pm\eta}$ fraction of proton momentum carried by parton

$Q^2 = M^2$ 4-momentum transfered

- LHCb probes two distinct regions in x/Q^2 plane
- unique region at low x down to $x = 8 \cdot 10^{-6}$



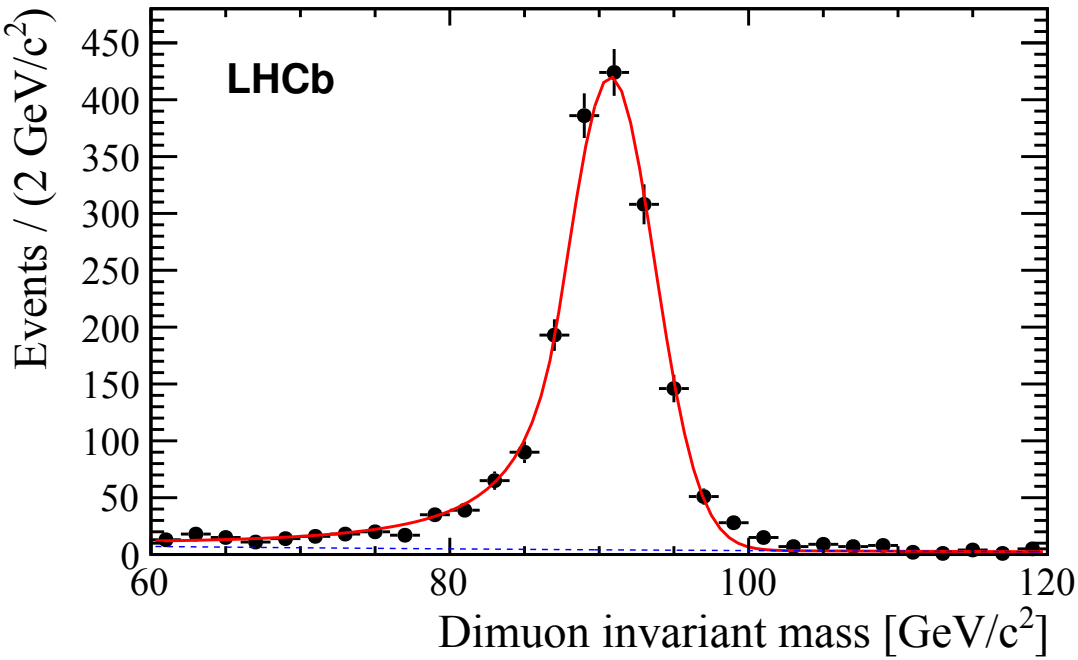
$pp \to Z \to \ell^+\ell^-$

$Z \to \mu^+\mu^-$

(JHEP 2012, 6 (2012), 58)

Data

- 2010 dataset
  $\mathcal{L} = 37\,\text{pb}^{-1}$
- $60 < M_{\ell\ell} < 120\,\text{GeV}/c^2$
- $2 < \eta_\ell < 4.5$
- $p_T > 20\,\text{GeV}/c$



Nr. of Candidates	1966
Purity	99.7 %

$Z \to e^+e^-$

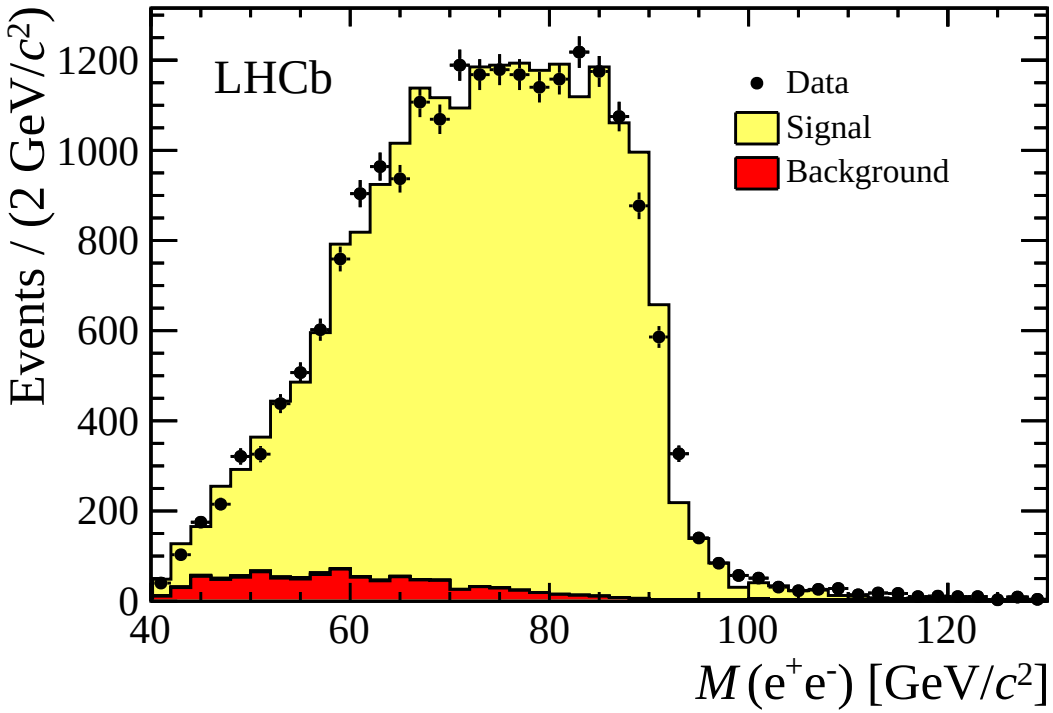
(arXiv:1212.4620 [hep-ex])

Data

- 2011 dataset
  $\mathcal{L} = 945\,\text{pb}^{-1}$

Challenges

- Energy measurement
  - saturation in calo
  - bremsstrahlung
- QCD background
  - use same-sign data



Nr. of Candidates	21 420
Purity	95.5 %

$Z \to \tau^+\tau^-$

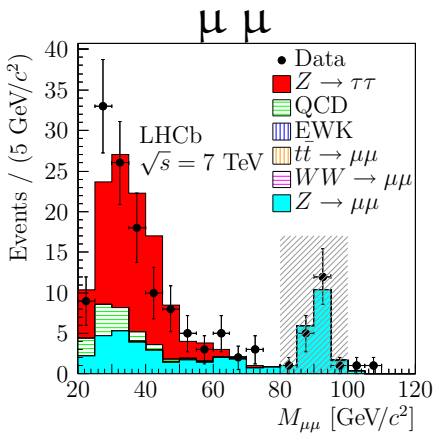
(arXiv:1210.6289 [hep-ex])

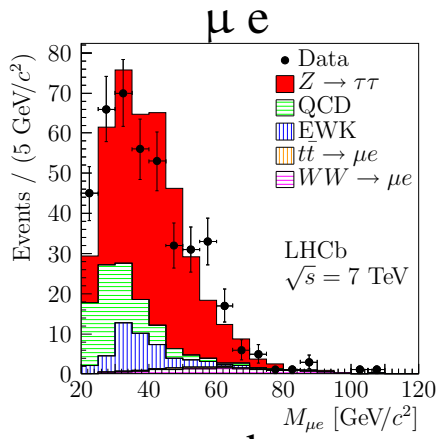
Data

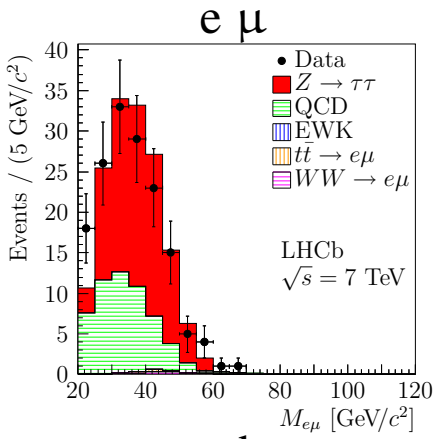
- 2011 dataset
  $\mathcal{L} = 1\,\text{fb}^{-1}$

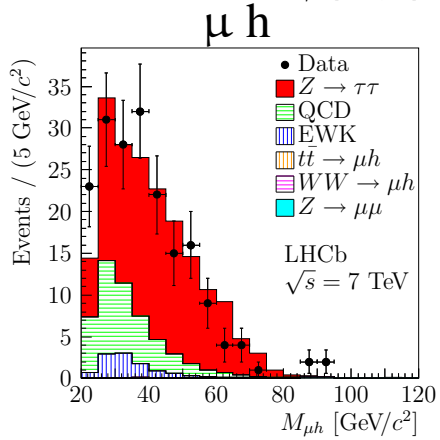
Challenges

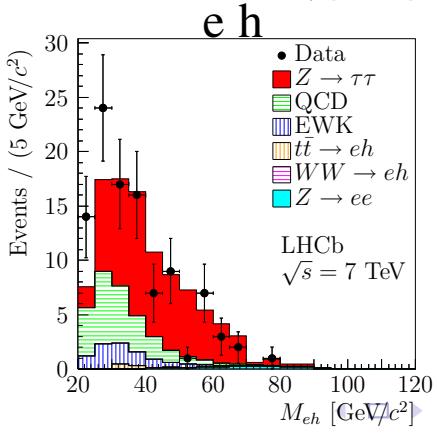
- partial reconstruction of different final states
- many backgrounds







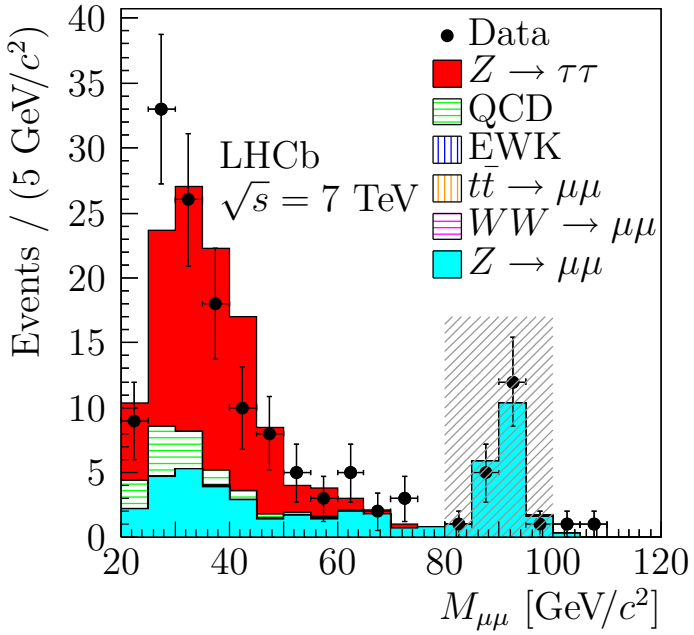




$Z \to \tau^+\tau^-$: Two Examples

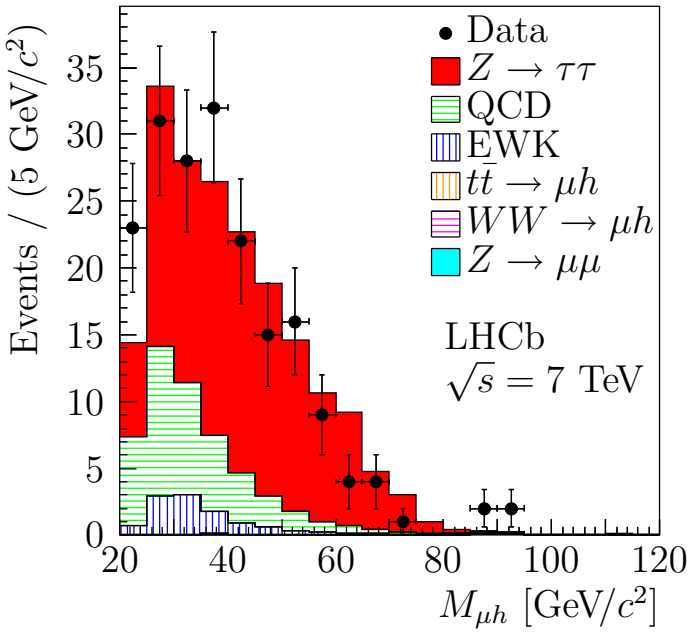
(arXiv:1210.6289 [hep-ex])

$Z \to \tau^+\tau^- \to \mu^+\mu^-$



Nr. of Candidates 124
Purity 75 %

$Z \to \tau^+\tau^- \to \mu h$



Nr. of Candidates 189
Purity 78 %

Total Nr. of Candidates 990

Common Considerations

- All events triggered by single muon or single electron trigger
- Most efficiencies determined from data (tag & probe)
- Magnitude of most uncertainties dominated by statistics (most important for $Z \to \mu^+\mu^-$)

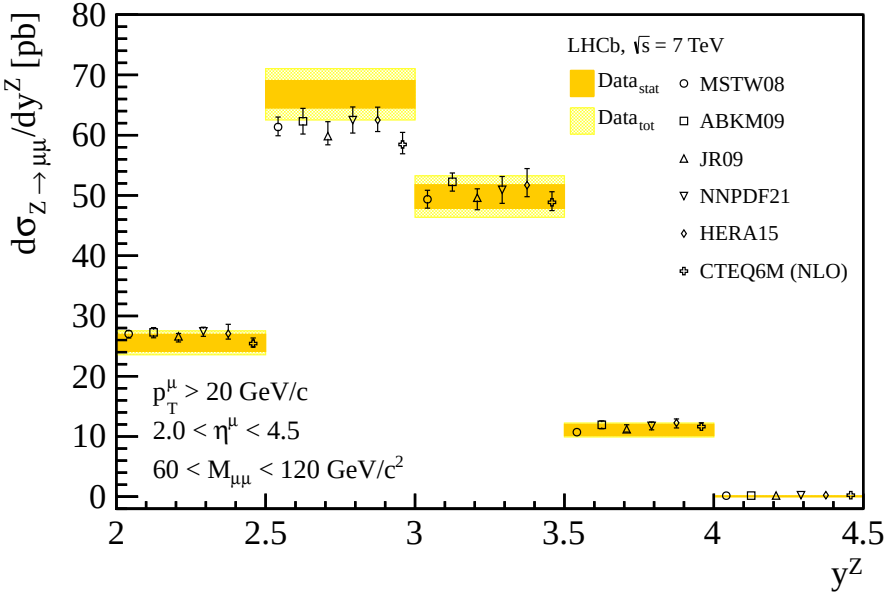
Uncertainties [%]

	$Z \to \mu^+\mu^-$	$Z \to e^+e^-$	$Z \to \tau^+\tau^-$ (combined)
Statistic	2.2	1.1	4.9
Systematic	4.3	2.6	3.9
Luminosity	3.5	3.5	3.5

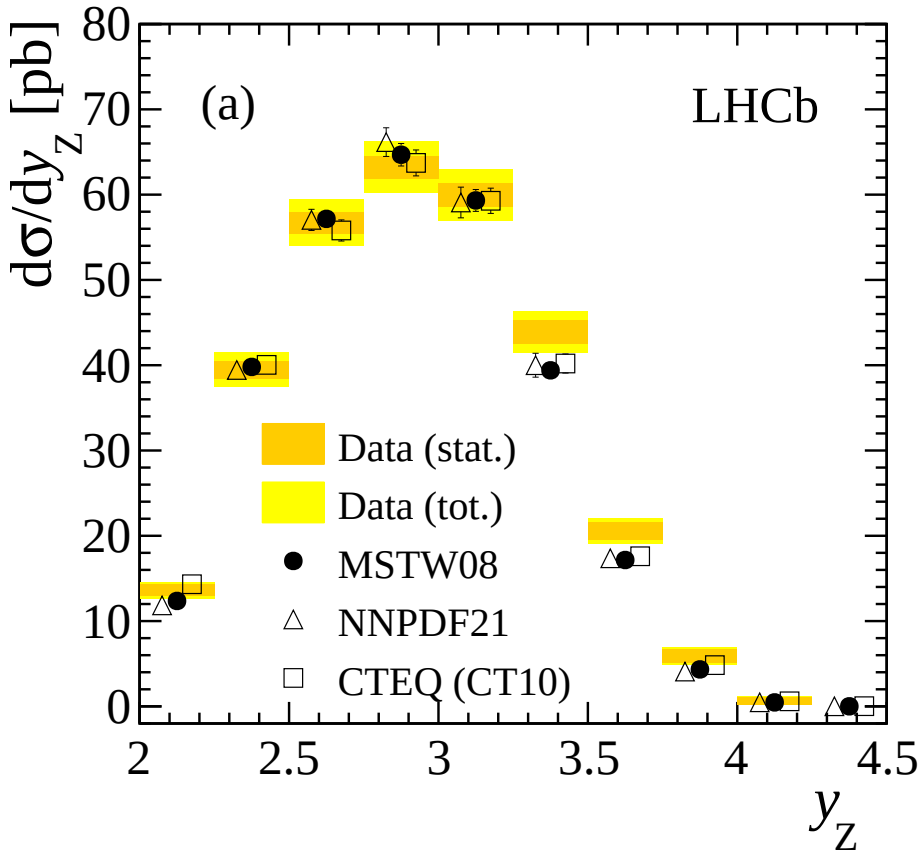
Differential Production Cross Sections

(JHEP 2012, 6 (2012), 58; arXiv:1212.4620 [hep-ex])

$pp \to Z \to \mu^+\mu^-$



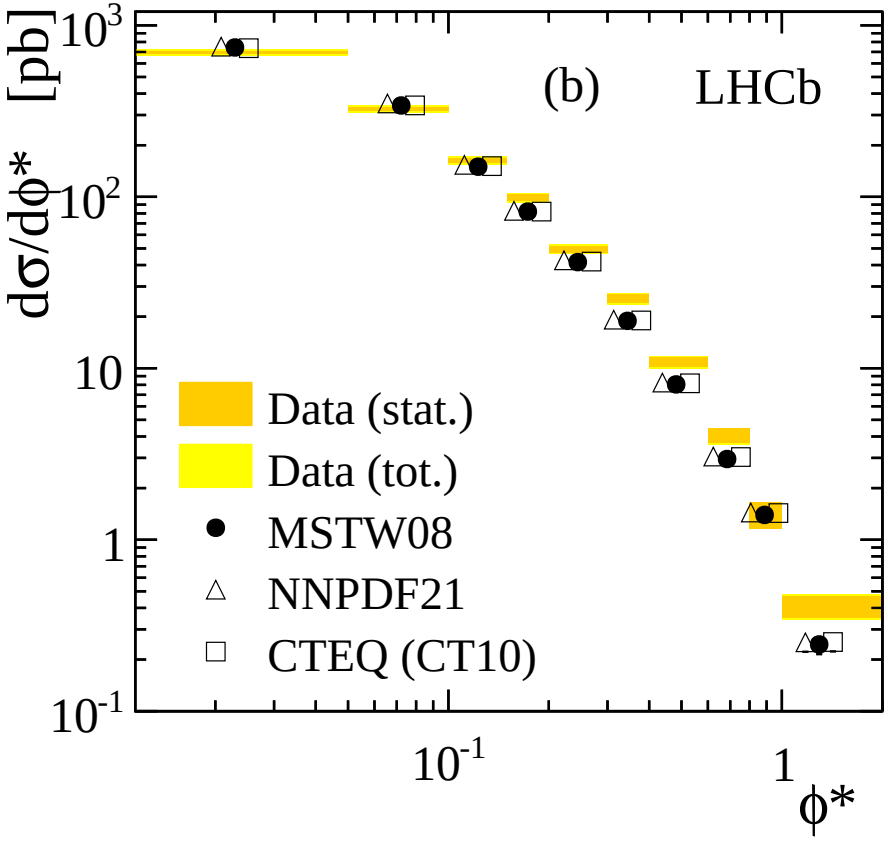
$pp \to Z \to e^+e^-$



Compared to NNLO predictions (DYNNLO)

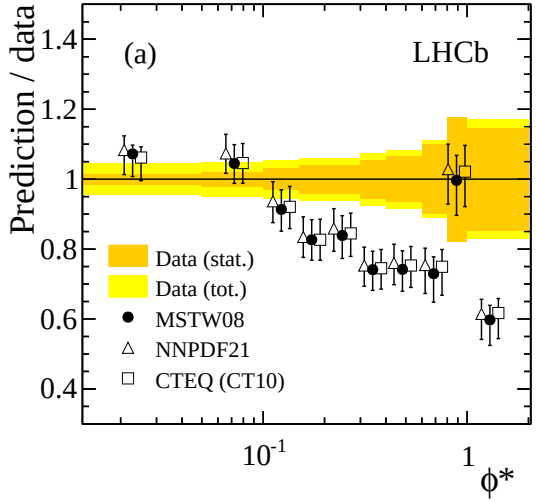
e^+e^- Angular Result

(arXiv:1212.4620 [hep-ex])

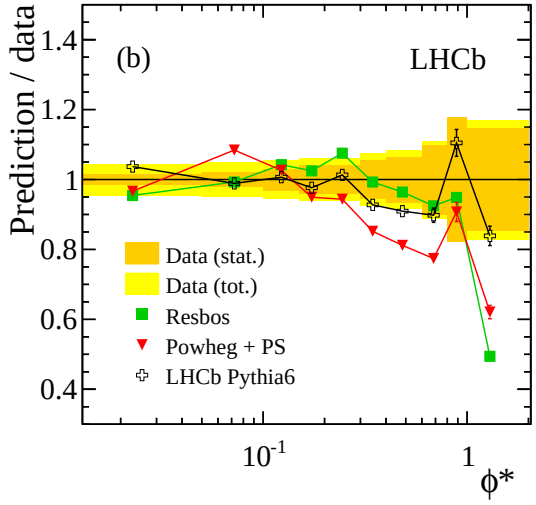


$$\phi^* \equiv \frac{\tan\left(\frac{\pi - |\Delta\phi|}{2}\right)}{\cosh\left(\frac{\Delta\eta}{2}\right)} \approx \frac{p_T}{Mc}$$

Fixed Order (no soft gluons)

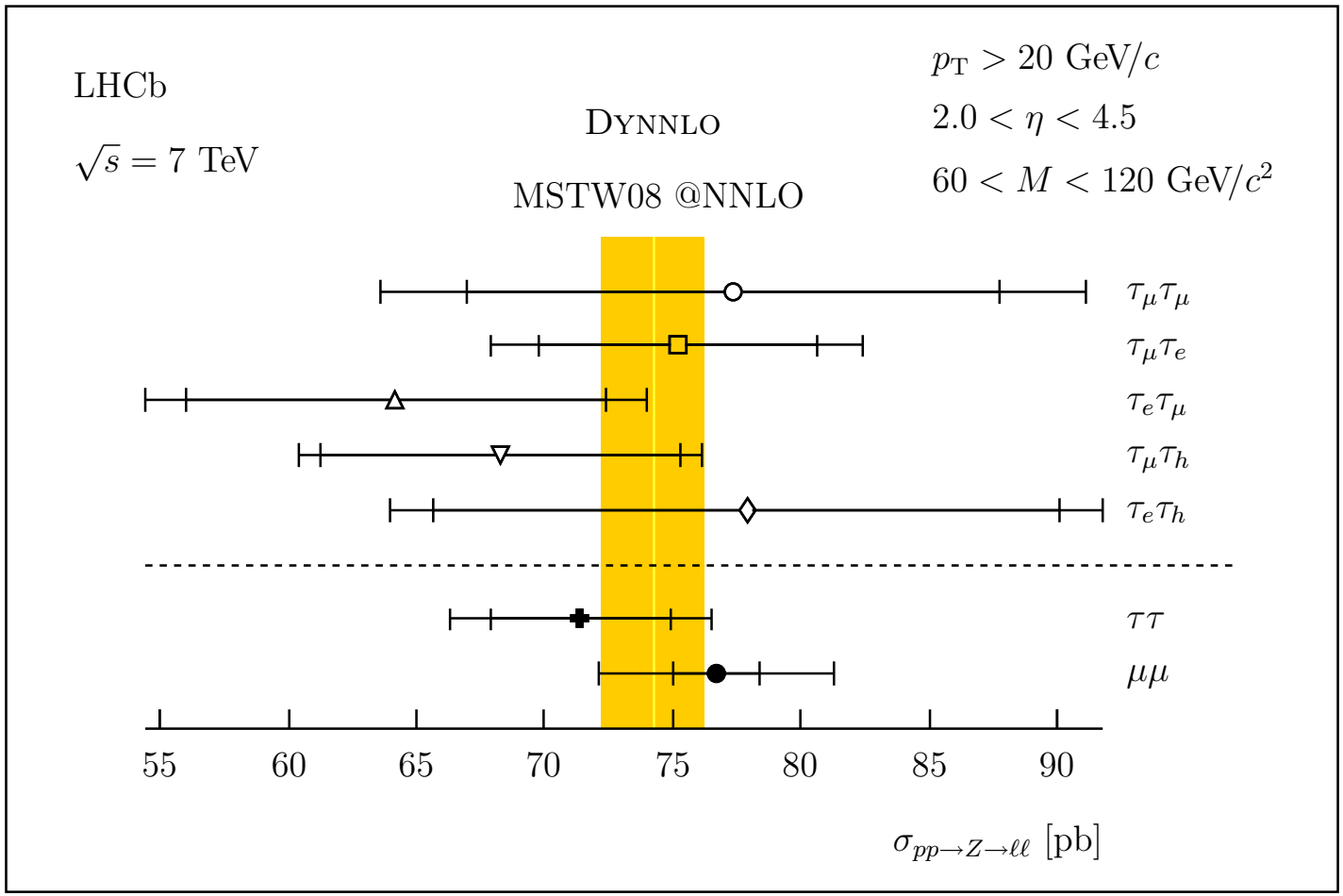


Resummation / Parton Shower



Results: $\tau^+\tau^-$

(arXiv:1210.6289 [hep-ex])



$pp \to Z \to \mu^+\mu^-$ + Jets

$Z \to \mu^+\mu^-$ + Jets

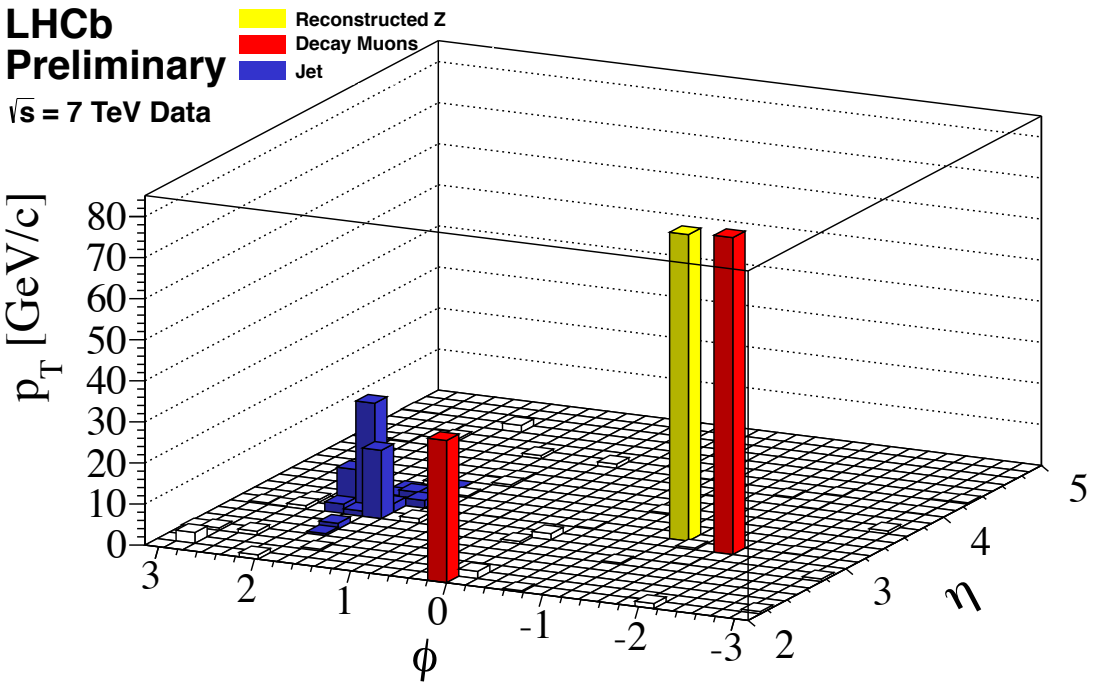
(LHCb-CONF-2012-016)

Data

- 2011 dataset $\mathcal{L} = 1\,\text{fb}^{-1}$
- $Z \to \mu^+\mu^-$ selection

Challenges

- jet reconstruction energy scale and resolution



(example of signal candidate)

The Jets

(LHCb-CONF-2012-016)

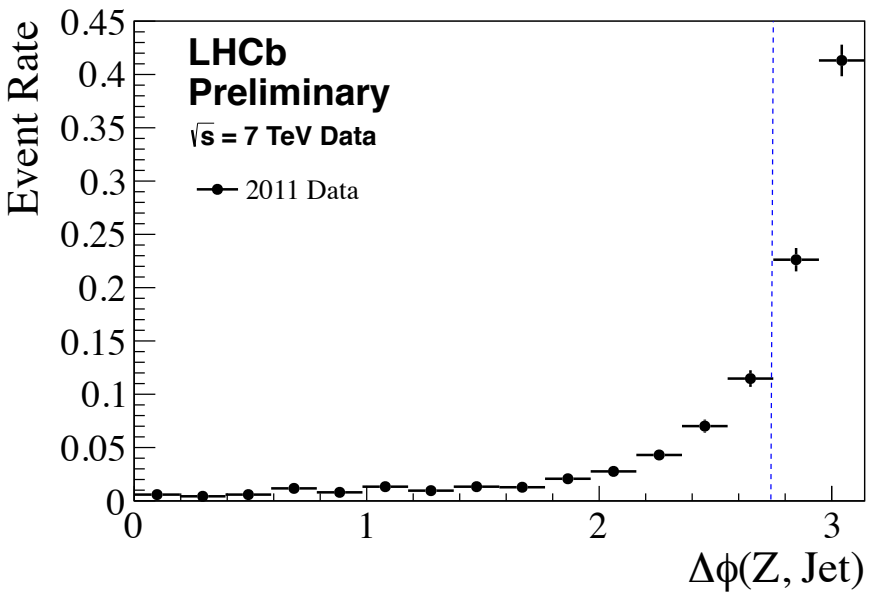
Definition

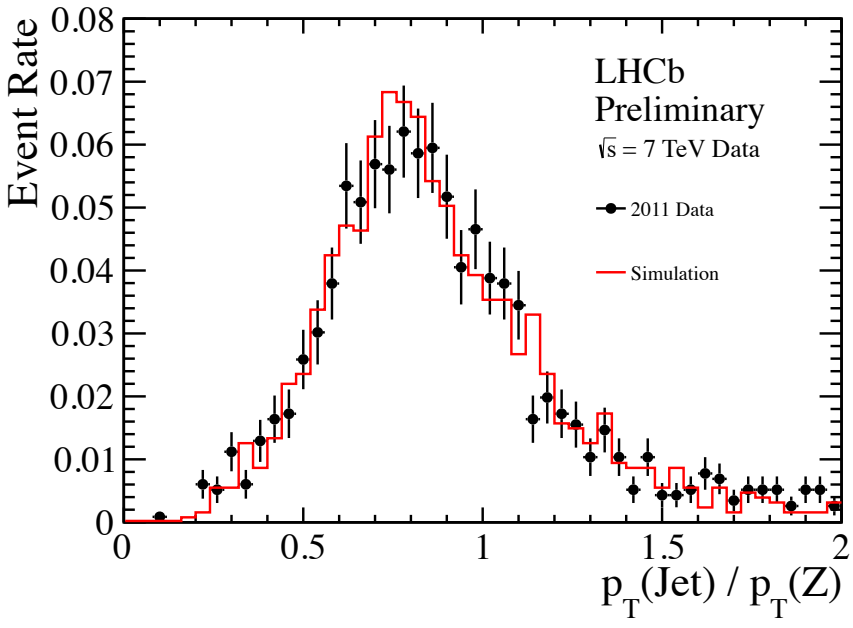
- anti-k_T clustering algorithm
- radius parameter $R = 0.5$

Selection

- $p_T(\text{jet}) > 10\,\text{GeV}/c$
- $2.0 < \eta_{\text{jet}} < 4.5$
- jet isolated from μ (R = 0.4)

Energy Calibration (dominant systematic uncertainty)

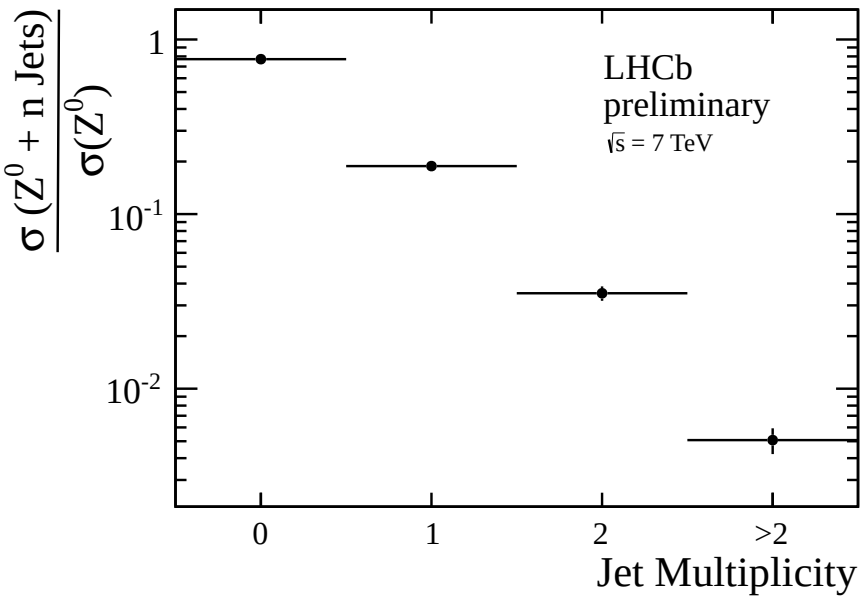


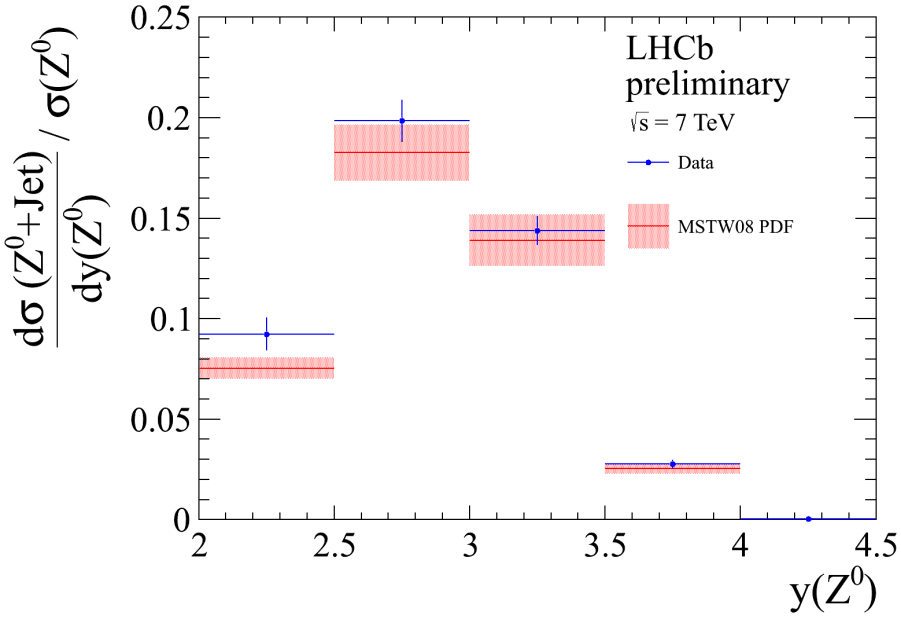


Normalized Z + Jet

(LHCb-CONF-2012-016)

- measurement at hadron level
- predictions at parton level (order α_s^2)





$$\frac{Z + Jet}{Z}$$

LHCb $0.229 \pm 0.006\,(\text{stat}) \pm 0.009\,(\text{syst})$

Theory $0.212^{+0.006}_{-0.009}\,(\text{PDF}) \pm 0.016\,(\text{scale})$

$pp \to W \to \mu\,\nu$

$W \to \mu\,\nu$

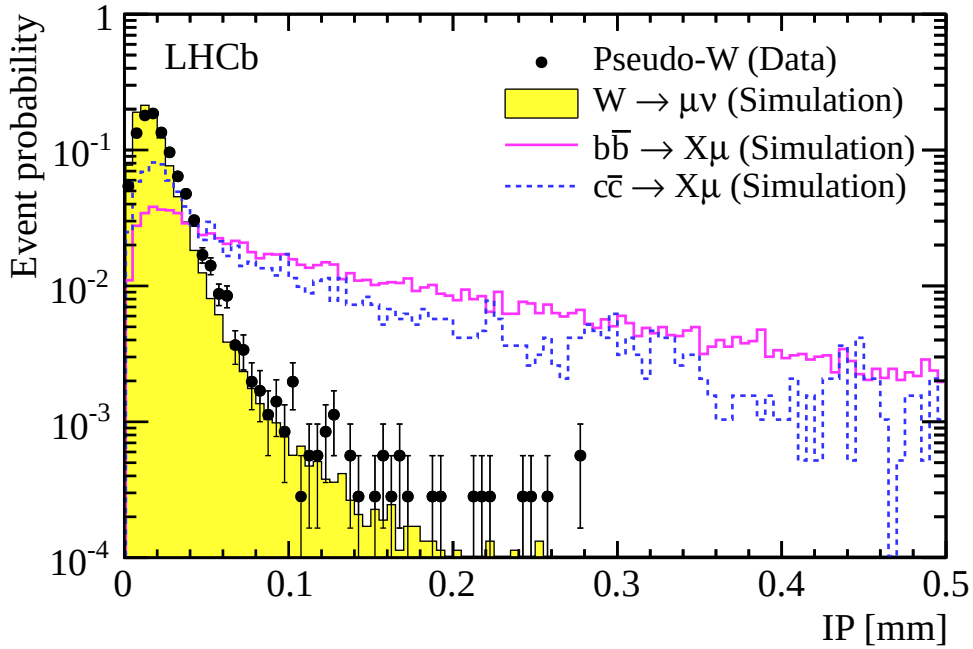
(JHEP 2012, 6 (2012), 58)

Data

- 2010 dataset
  $\mathcal{L} = 37\,\text{pb}^{-1}$
- $2 < \eta_\mu < 4.5$
- $p_T > 20\,\text{GeV}/c$

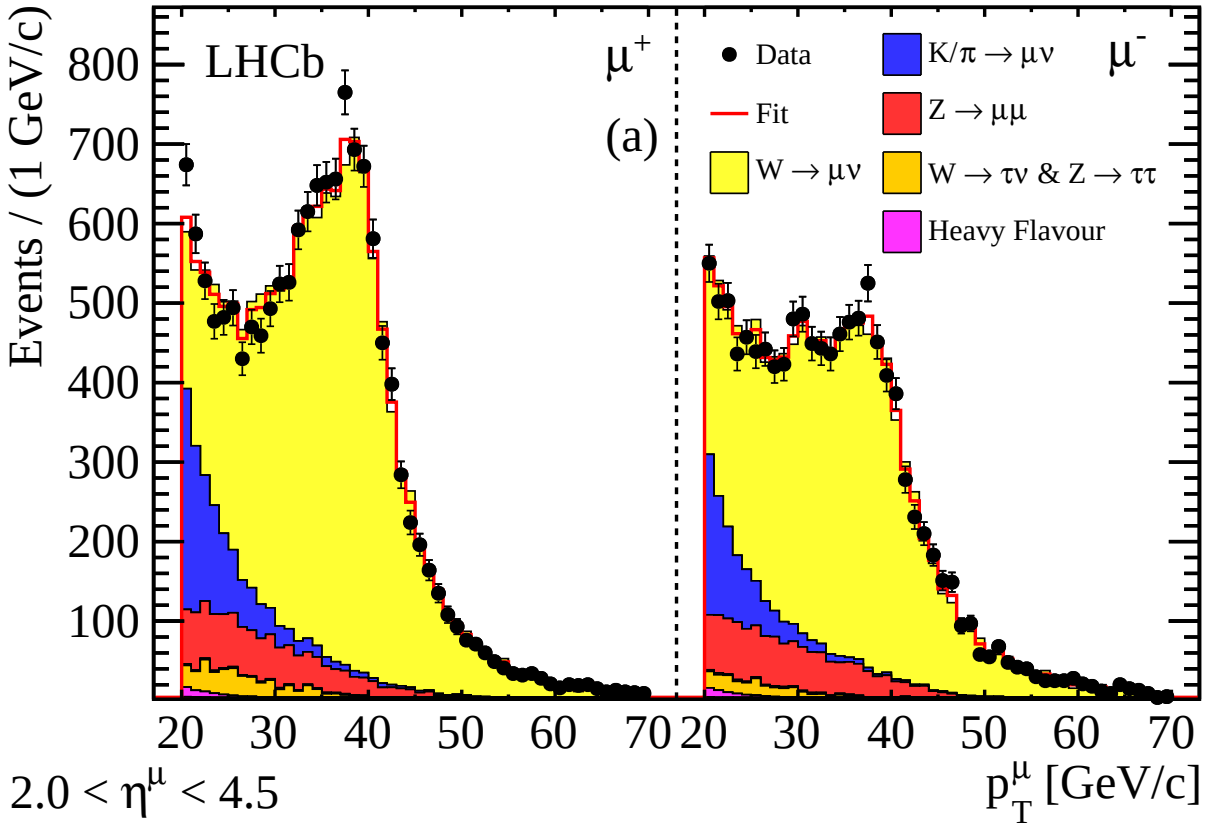
Challenges

- selection efficiencies
  - from data
  - using $Z \to \mu^+\mu^-$ events with one μ removed
- backgrounds



Purity from Template Fit

(JHEP 2012, 6 (2012), 58)



	Shape	Normalisation
$W \to \mu\,\nu$	simulation	fit
K/π decay in flight	data	fit
$\gamma^*/Z \to \mu^+\mu^-$	simulation	fixed
$W \to \tau\,\nu$, $Z \to \tau^+\tau^-$	simulation	fixed
Heavy Flavour	data	fixed

	Cand.	Purity [%]
W^+	14660	78.8
W^-	11618	78.4

Production Cross Section and Ratios

(JHEP 2012, 6 (2012), 58)

σ_Z

σ_{W+}

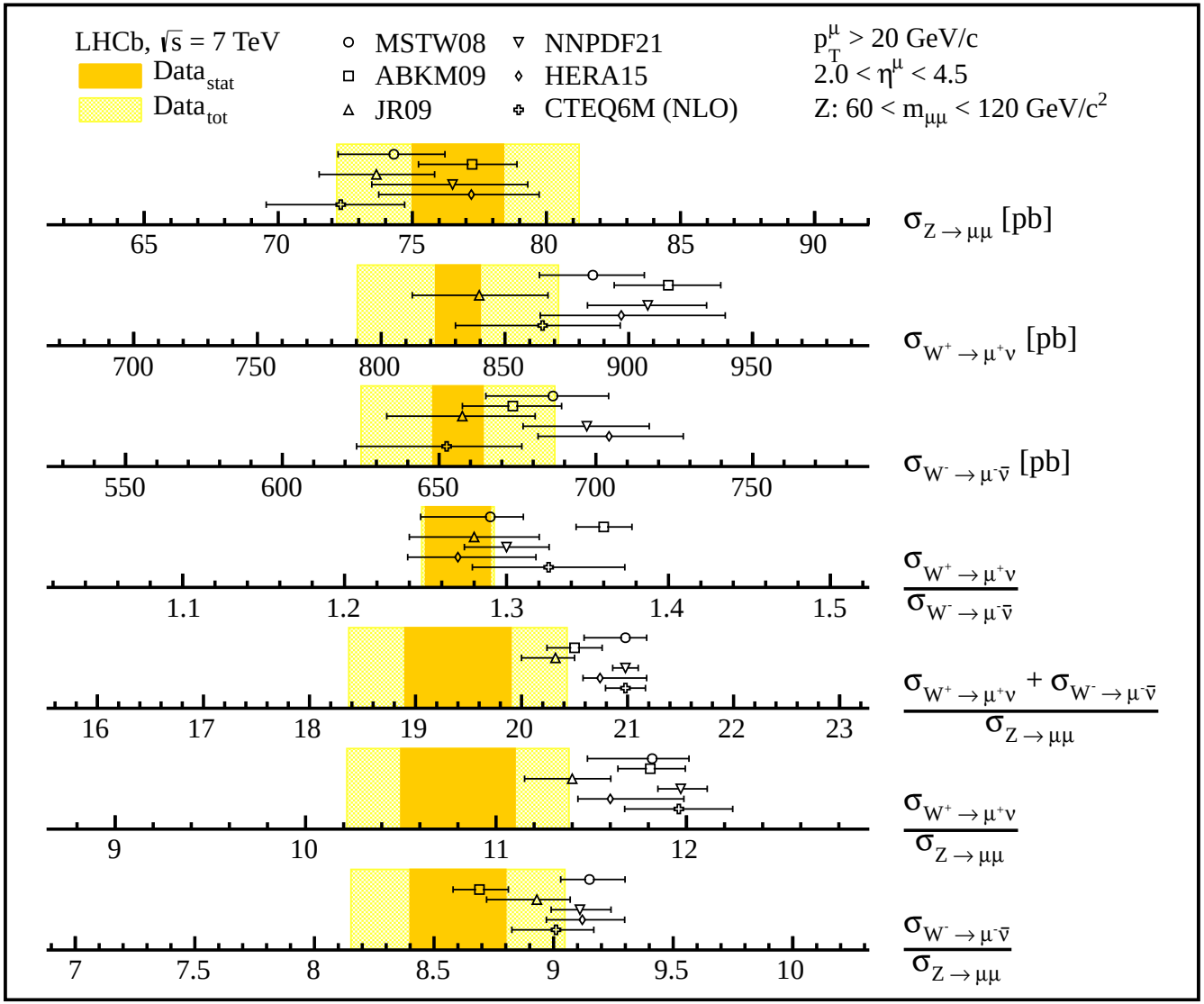
σ_{W-}

$\frac{\sigma_{W+}}{\sigma_{W-}}$

$\frac{\sigma_{W+}+\sigma_{W-}}{\sigma_Z}$

$\frac{\sigma_{W+}}{\sigma_Z}$

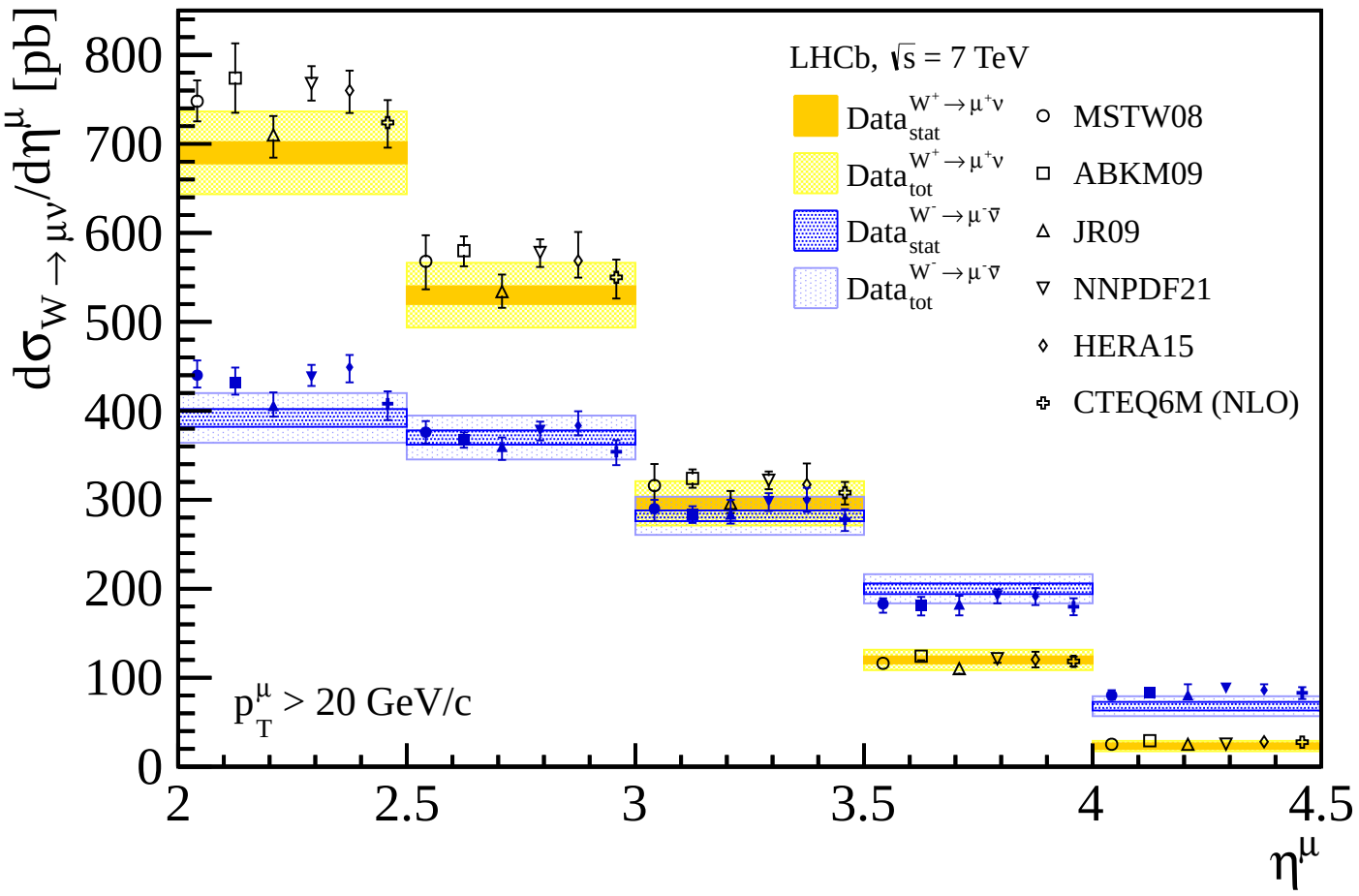
$\frac{\sigma_{W-}}{\sigma_Z}$



Compared to NNLO predictions (DYNNLO)

Differential W Cross Section

(JHEP 2012, 6 (2012), 58)

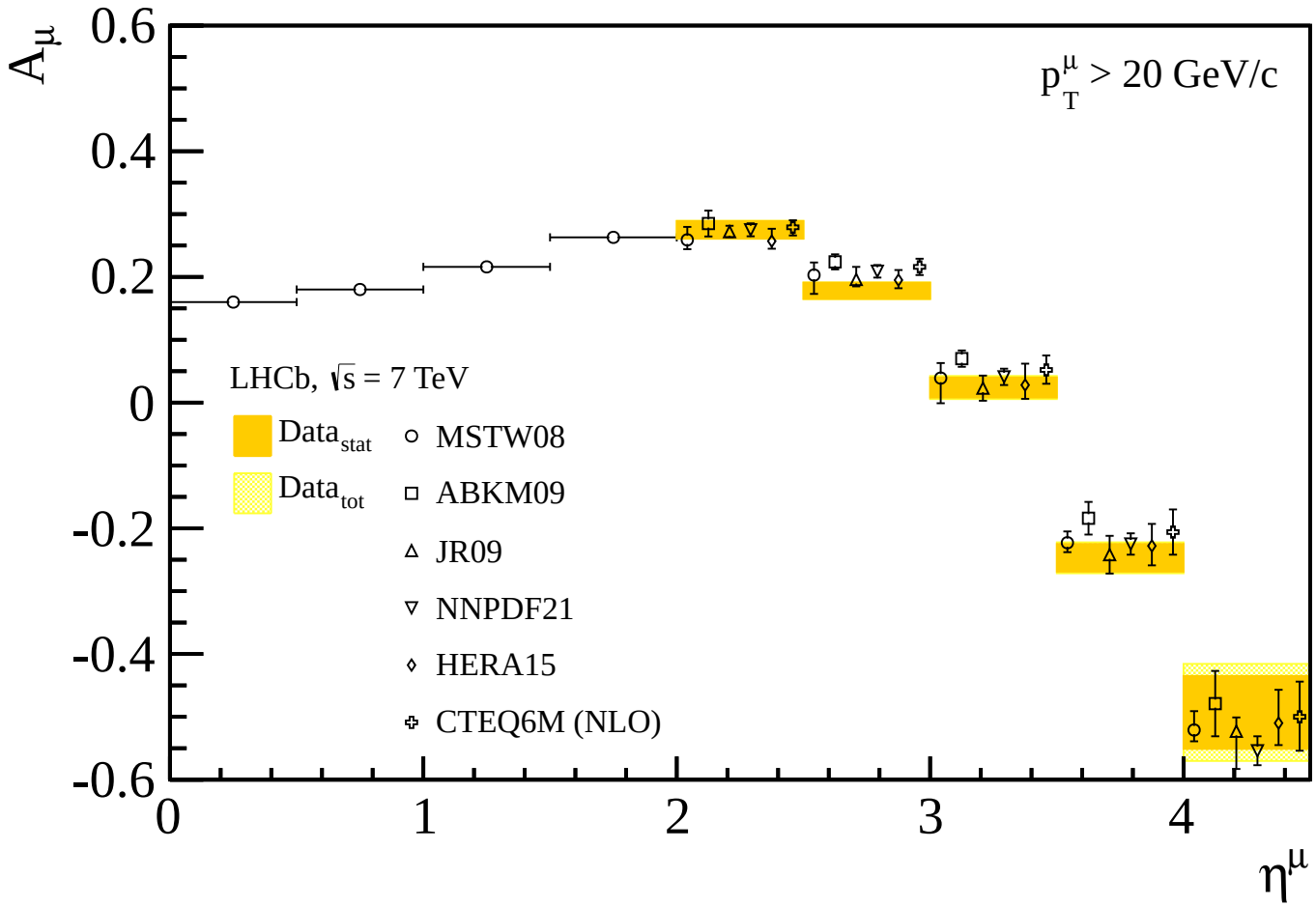


As expected W^- production higher than W^+ in forward region

Lepton Charge Asymmetry

(JHEP 2012, 6 (2012), 58)

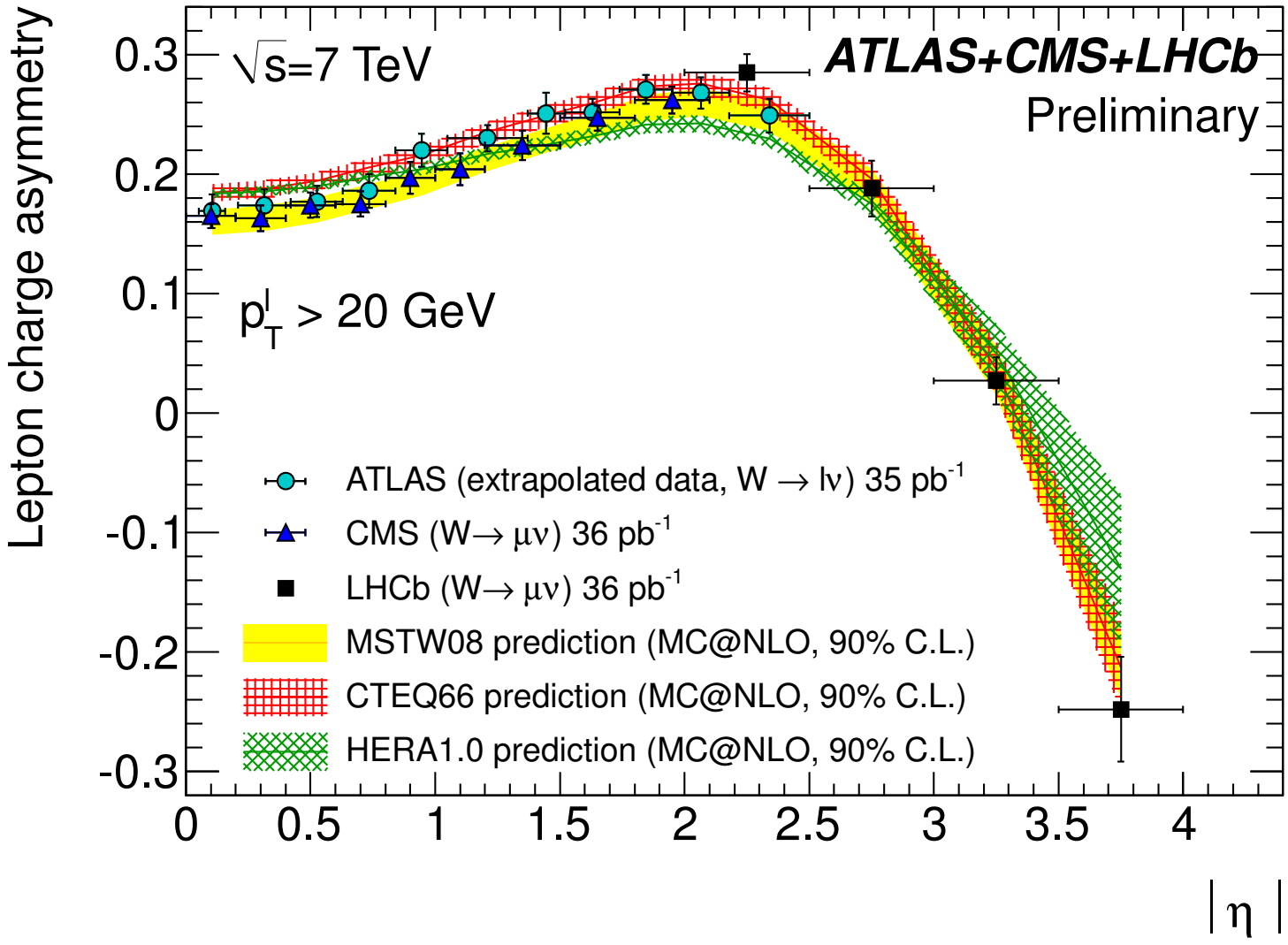
$$A_\mu = \frac{\sigma_{W^+\to\mu^+\nu} - \sigma_{W^-\to\mu^-\bar{\nu}}}{\sigma_{W^+\to\mu^+\nu} + \sigma_{W^-\to\mu^-\bar{\nu}}}$$



Precise measurement in good agreement with predictions

LHC Combination

(ATLAS-CONF-2011-129)



Low Mass Drell-Yan

$pp \to \gamma^*/Z \to \mu^+\mu^-$

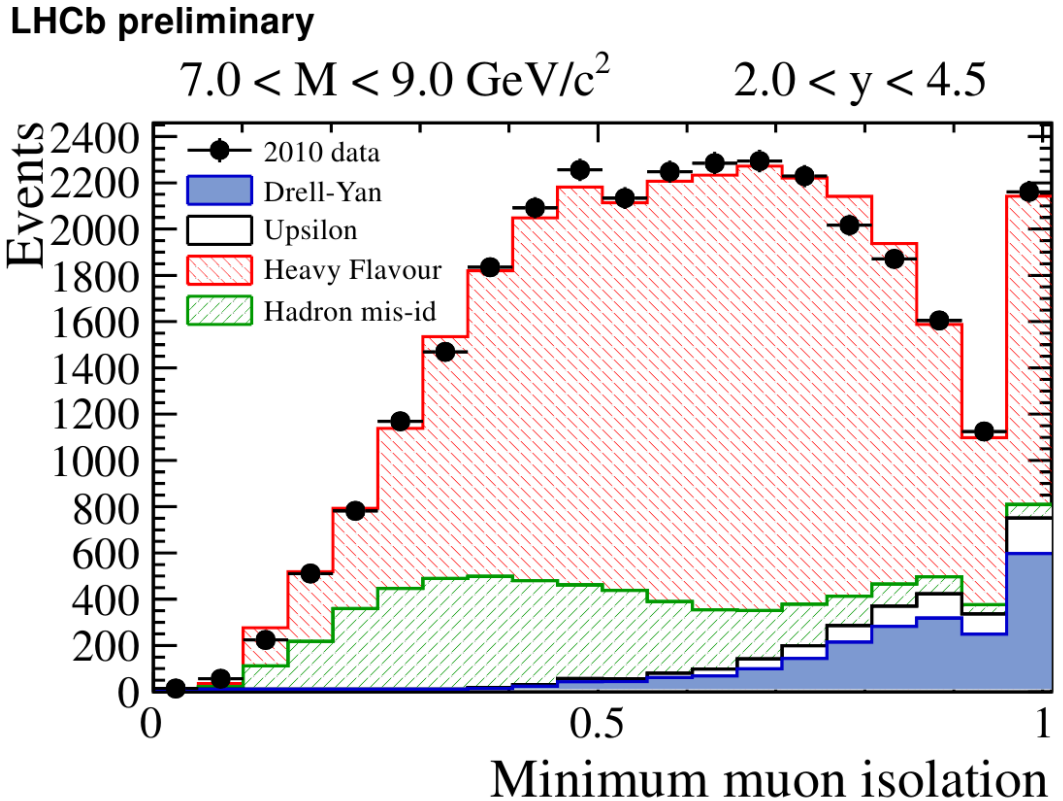
(LHCb-CONF-2012-013)

Data

- 2010 dataset
  $\mathcal{L} = 37\,\text{pb}^{-1}$
- $2 < \eta_\mu < 4.5$
- $p_T > 3\,\text{GeV}/c$

Challenges

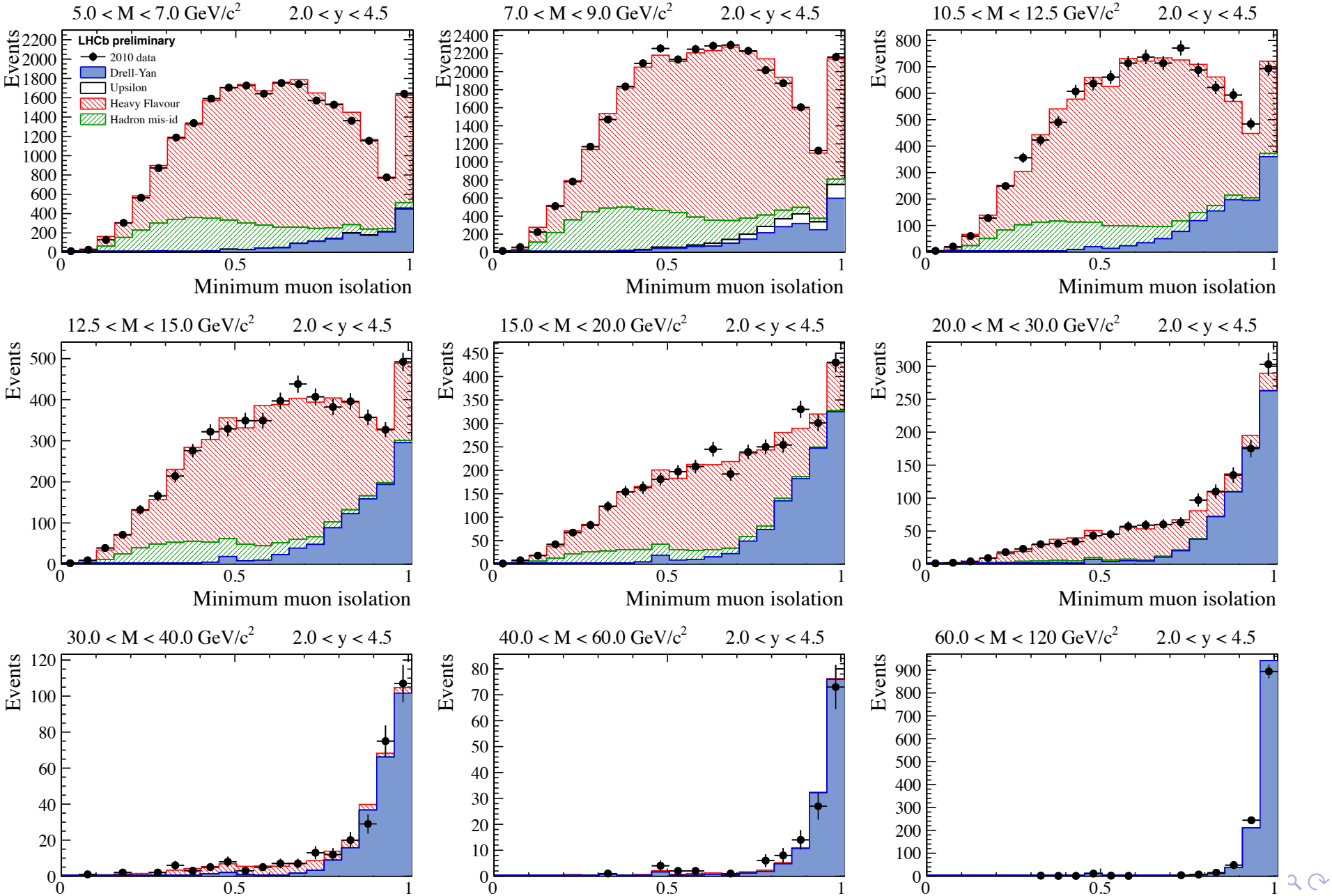
- $5 < M_{\mu\mu} < 120\,\text{GeV}/c^2$
- different backgrounds



$$\text{muon isolation} = \frac{P_T^{\mu - \text{in Jet}}}{P_T^{\text{full Jet}}}$$

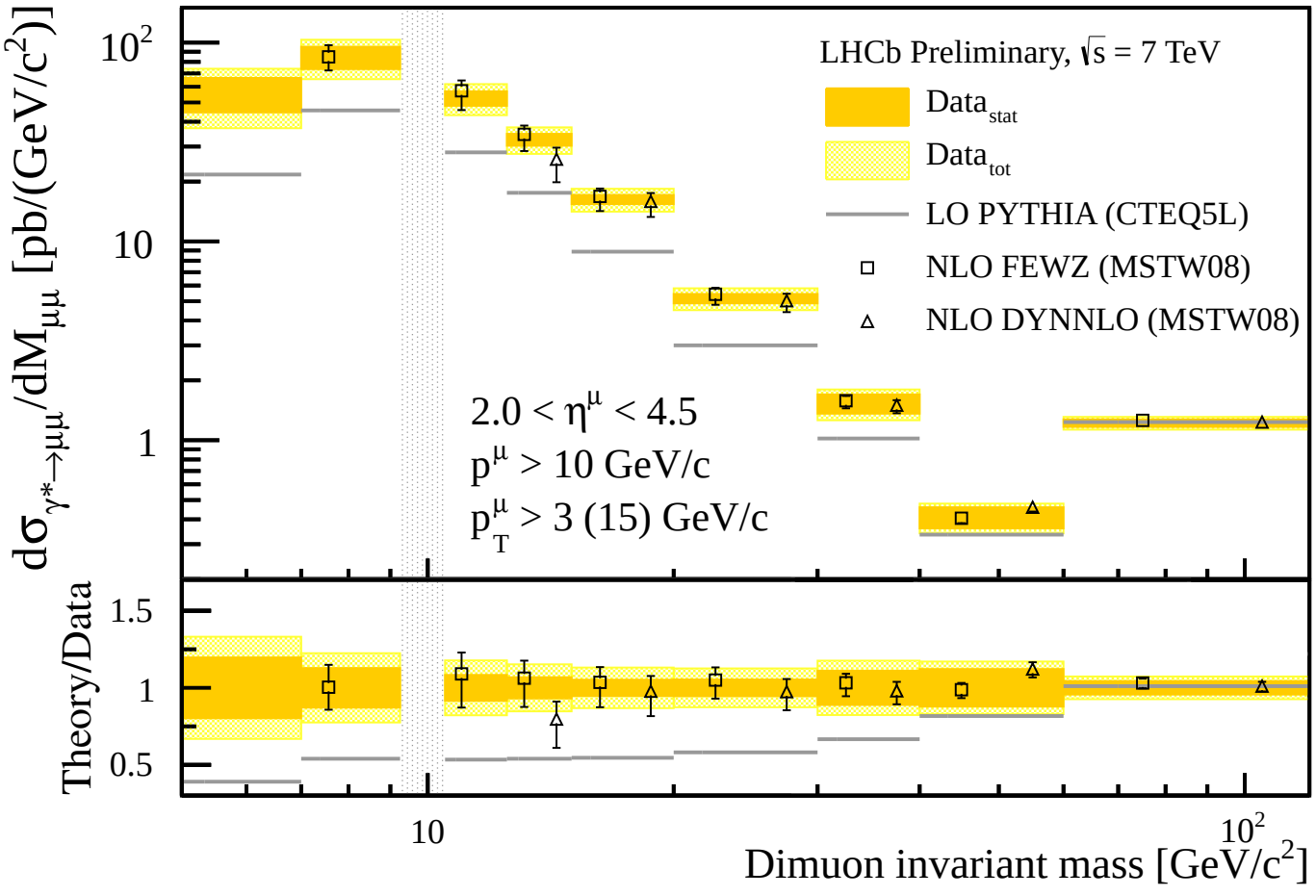
Mass Bins

(LHCb-CONF-2012-013)



Result

(LHCb-CONF-2012-013)



Also differential measurements in 5 dimuon rapidity-bins
(for $M_{\mu\mu}$ in 10.5 - 20 GeV/c^2 and 20 - 40 GeV/c^2)

Summary & Outlook

Summary

- LHCb: Unique kinematic range down to $x = 8 \cdot 10^{-6}$
- W/Z production at LHCb in agreement with NNLO predictions
- Ratio W^+/W^- cross section: 1.7 % uncertainty
- Measurement of low mass Drell-Yan production
- First measurements of Z + jet production

Outlook

- update remaining analyses with 2011 dataset($\mathcal{L}$ = 1.1 fb^{-1})
- analyze 2012 dataset ($\mathcal{L}$ = 2.1 fb^{-1} at 8 TeV)
- W and Z production in association with b and c jets

Thank you for your attention

Systematic Uncertainties: Z + Jets

(LHCb-CONF-2012-016)

n Jets	0	1	2	≥ 3
Bin-to-Bin Migration	0.2	1.0	2.9	9.7
GEC and Trigger	0.3	0.9	1.5	3.8
μ ID	0.2	0.6	0.9	1.4
μ Tracking	0.5	1.3	4.0	3.6
Jet E Correction	1.0	2.6	7.0	11.0
Jet E Resolution	0.1	0.6	1.7	3.6
Jet ID	0.3	0.8	1.6	2.9
Total	1.2	3.4	9.1	16

All numbers in %

Systematic Uncertainties: $W \to \mu\,\nu$

(JHEP 2012, 6 (2012), 58)

Source	$\Delta\sigma_{Z\to\mu^+\mu^-}$	$\Delta\sigma_{W^+\to\mu^+\nu}$	$\Delta\sigma_{W^-\to\mu^-\nu}$
Signal purity	0.1	1.2	0.9
Template shape	–	0.9	1.0
Efficiencies	4.3	2.2	2.0
Additional selection	–	1.8	1.7
FSR correction	0.02	0.01	0.02
Total	4.3	3.2	2.9
Luminosity	3.5	3.5	3.5

All numbers in %