



Stephen Farry
on behalf of the LHCb Collaboration

University of Liverpool



Electroweak Physics at LHCb

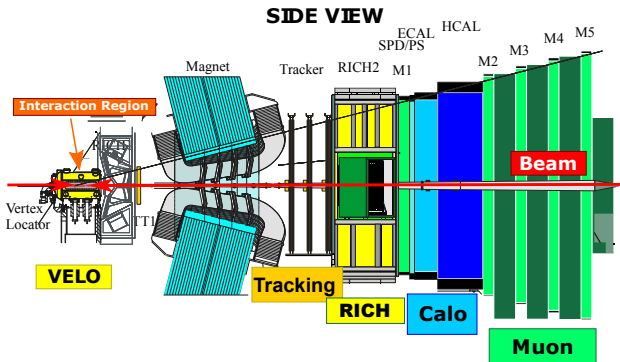
ICHEP 2014 – Valencia – July 4, 2014

Outline

- ① Introduction
- ② Inclusive W Production^{NEW}
- ③ Z + jet Production
- ④ Z + D Production
- ⑤ Z in pA collisions^{NEW}
- ⑥ Conclusion

LHCb

- Forward arm spectrometer at the LHC
- Designed to study \mathcal{CP} Violation in B Decays
- Fully instrumented between $2.0 \leq \eta \leq 5.0$
- ATLAS/CMS coverage - $|\eta| < 2.5$
- Unique Region $2.5 \leq \eta \leq 5.0$

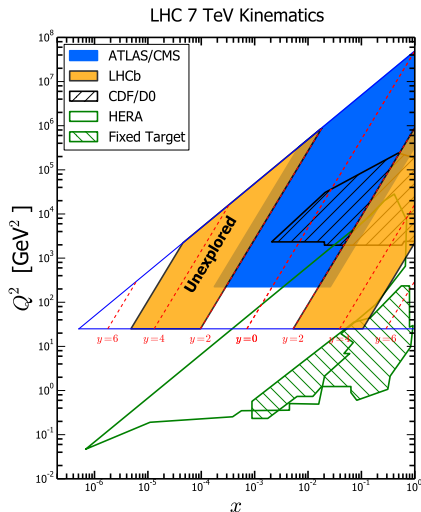


2010 - 37.1 pb^{-1} - 7 TeV 2012 - 2.0 fb^{-1} - 8 TeV

2011 - 1.0 fb^{-1} - 7 TeV 2013 - 1.6 nb^{-1} - 5 TeV - pA

Parton Density Functions

- LHCb's forward acceptance provides interesting possibilities to study the Parton Density Functions (PDFs)
- Two distinct large and small- x regions covered
- Small x -region unexplored by previous experiments
- Measurements of W , Z and Drell-Yan production at LHCb can constrain the PDFs in this region
 - W and Z
(x of $\sim 10^{-4}$ and $10^{-1} - 10^0$)
 - Low-mass Drell-Yan
(x down to 10^{-6} at $M_{\mu\mu} \sim 5$ GeV)

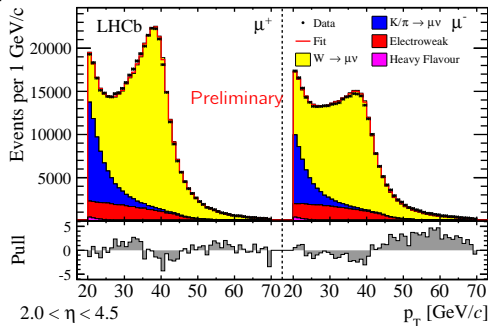


$$W \rightarrow \mu\nu^{\text{NEW}}$$

- Updated measurement with 996 pb⁻¹ of 2011 data
- Single high- p_T muon final state
 - $p_T^\mu > 20$ GeV
 - $2.0 < \eta^\mu < 4.5$
 - Prompt
 - Isolated
- Purity determined by fit to muon p_T spectrum

Shape	Source
$W \rightarrow \mu\nu$	Simulation
K/π Decay In Flight	Data
$\gamma/Z^* \rightarrow \mu\mu$	Simulation
$W \rightarrow \tau\nu, Z \rightarrow \tau\tau$	Simulation
Heavy Flavour	Data

- **Signal** and **Decay In Flight** templates float free in fit
- Other shapes normalised using data-driven methods
- Fit performed in eight η^μ bins



$W \rightarrow \mu\nu$ – Systematic Uncertainties

LHCb-PAPER-2014-033 (Preliminary)

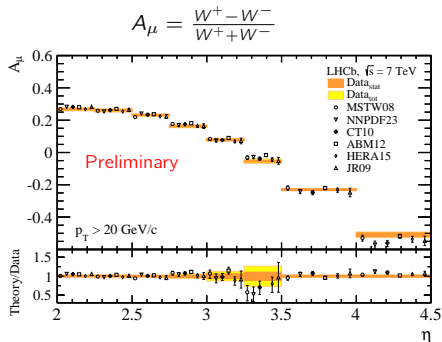
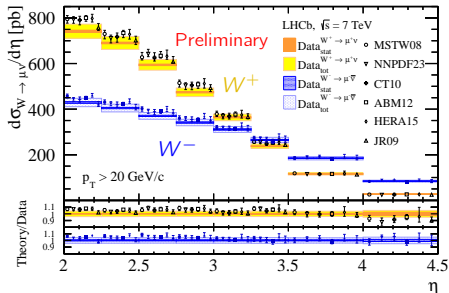
- Measurement updated from 2010 result [[JHEP 1206 \(2012\) 058](#)]

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%	3.5%

- Reduction in systematic uncertainties
- Detector effects better understood
- Larger statistics available for data-driven efficiency determinations
- Expect similar improvements soon for updated $Z \rightarrow \mu\mu$ measurement

$W \rightarrow \mu\nu$ - Differential Distributions

LHCb-PAPER-2014-033 (Preliminary)

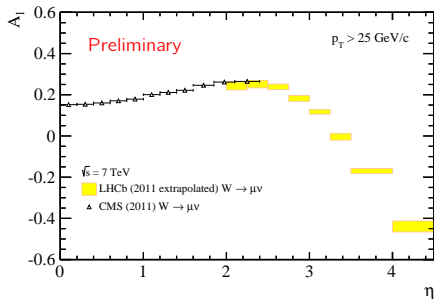
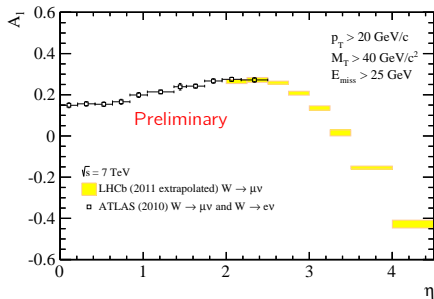


- Compared to NNLO predictions calculated using FEWZ
- Data corrected for FSR using Pythia interfaced with PHOTOS
- Good agreement with predictions for variety of PDF sets

$W \rightarrow \mu\nu$ - ATLAS/CMS Comparison

LHCb-PAPER-2014-033 (Preliminary)

- LHCb result extrapolated to ATLAS and CMS fiducial regions using simulation
 - ATLAS - $M_T > 40$ GeV, $E_T^{\text{miss}} > 25$ GeV
 - CMS - $p_T > 25$ GeV



- Good agreement in overlap regions

Z+jet

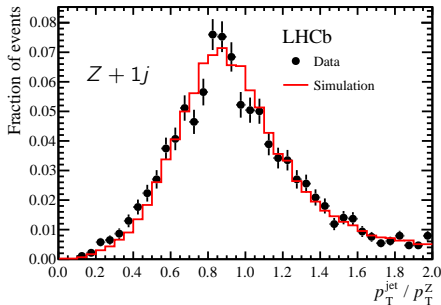
- Associated production of Z boson and jets important test of PDFs and perturbative QCD
- Important benchmark for other jet studies

Jet Reconstruction at LHCb

- Particle flow
 - Charged tracks
 - Calorimeter clusters
- Anti- k_T algorithm - $R = 0.5$

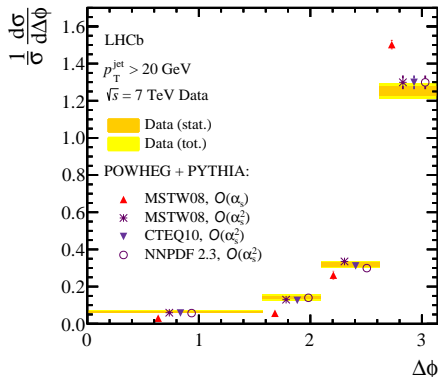
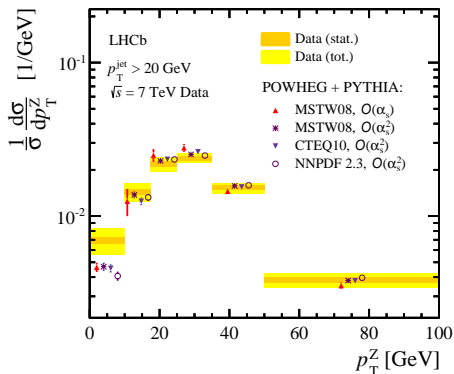
Z + jet selection

- $p_T^\mu > 20$ GeV, $2 < \eta^\mu < 4.5$
- $60 < M_{\mu\mu} < 120$ GeV
- $p_T^j > 10(20)$ GeV
- $\Delta R(\mu^\pm, jet) > 0.4$



- Simulation accurately describes detector response
- Jet energy correction determined from simulation
 - $\sim 0.9 - 1.1$
- Unfolded to hadron-level using D'Agostini Method

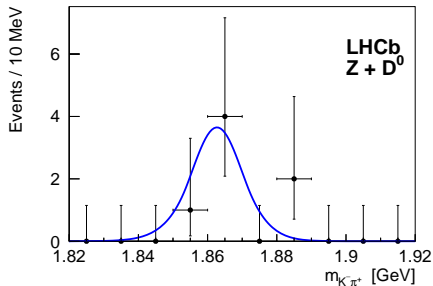
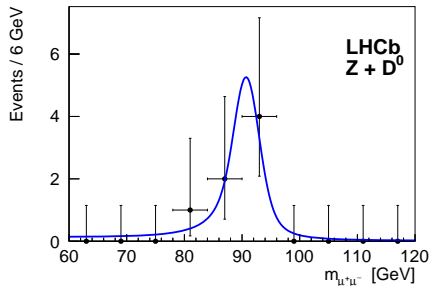
Z+Jet – Results



- Data compared to theory predictions using POWHEG + Pythia (Parton Shower)
- In general NLO predictions describe the data well
 - LO predictions fail to describe $|\Delta\phi|$ distribution
- Better agreement seen in p_T^Z and $|\Delta\phi|$ for higher p_T^j threshold

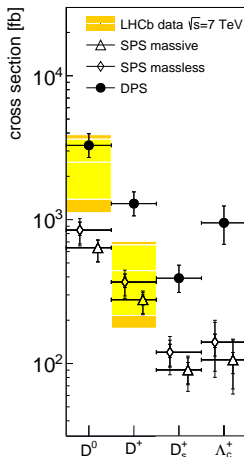
Z + D

- Associated production of a Z boson and a D-meson
 - Test charm PDF, production mechanism and DPS
- D-mesons reconstructed in channels
 - $D^0 \rightarrow K^- \pi^+$
 - $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$



- Fiducial Region:
 - $2.0 < \eta^\mu < 4.5$, $p_T^\mu > 20$ GeV, $60 < M_{\mu\mu} < 120$ GeV
 - $2.0 < y^D < 4.0$, $2 < p_T^D < 12$ GeV
- 11 Candidates observed - 7 D^0 and 4 D^\pm
- Purity $\sim 95\%$

Z + D – Results

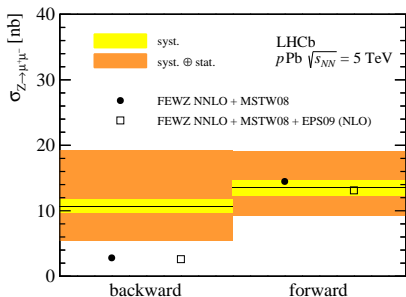
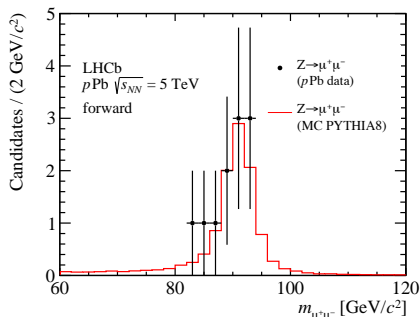


- Contributions from single- and double-parton scattering events
- Single parton scattering determined from MCFM at parton-level and corrected to hadron level
- Double parton scattering determined assuming factorisation of Z and D cross-sections
- $\sigma_{Z \rightarrow \mu\mu, D^0} \times \mathcal{B}_{Z \rightarrow \mu\mu} = 2.50 \pm 1.12 \pm 0.22$ pb
- $\sigma_{Z \rightarrow \mu\mu, D^\pm} \times \mathcal{B}_{Z \rightarrow \mu\mu} = 0.44 \pm 0.23 \pm 0.03$ pb

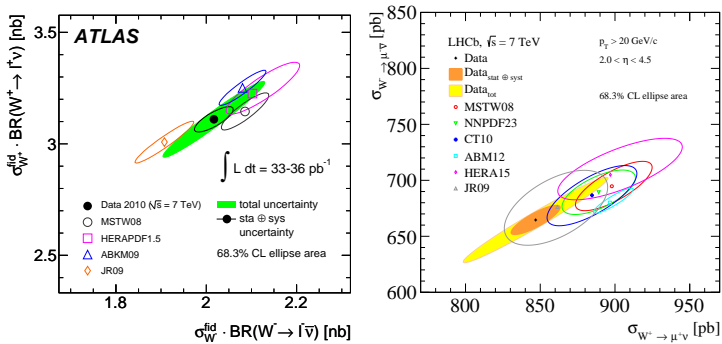
Z in pA collisions

LHCb-PAPER-2014-022

- 1.6 nb⁻¹ of pA data collected by LHCb in 2013 at $\sqrt{s_{NN}} = 5$ TeV
- Z production important input for nucleon PDF
- $Z \rightarrow \mu\mu$ selection as in inclusive Z and $Z + j$ analysis
- 15 candidates selected (11 forward + 4 backward)
- Purity > 99%
- Dominated by statistical uncertainty



Summary

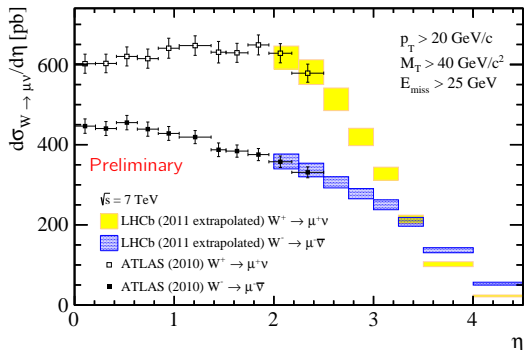


- LHCb has a unique rapidity coverage
 - Can provide important inputs to PDFs in the forward region
- Updated measurement of inclusive $W \rightarrow \mu\nu$ production at 7 TeV presented
 - Systematic uncertainties reduced by almost a factor of 3
- Improved measurement of $Z \rightarrow \mu\mu$ at 7 TeV to follow shortly
- Measurements also presented of $Z + jet$, $Z + D$ and Z in pA
 - Many other measurements in progress
- Measurements at 8 TeV underway

BACKUP

BACKUP

$W \rightarrow \mu\nu$ – ATLAS Comparison



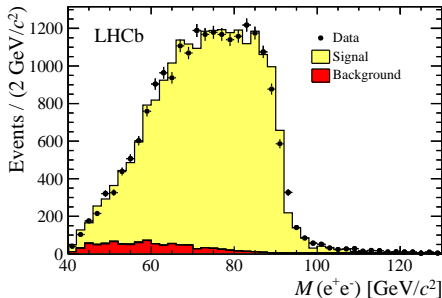
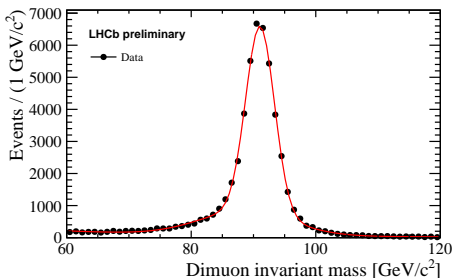
$$Z \rightarrow \mu\mu, \quad Z \rightarrow ee$$

LHCb-CONF-2013-007, LHCb-PAPER-2012-036

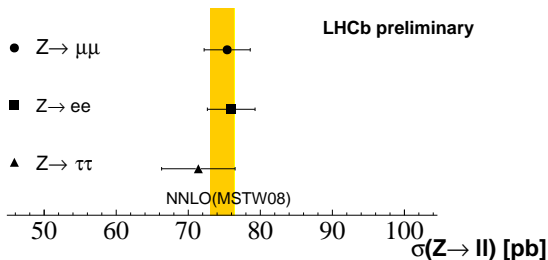
Selection:

- Two identified muons/electrons
- $p_T^\ell > 20$ GeV
- $2 < \eta^\ell < 4.5$
- $60 < M_{\mu\mu} < 120$ GeV, $M_{ee} > 40$ GeV

- $Z \rightarrow ee$ mass peak smeared by Bremsstrahlung
- $N = 52626$, Purity $> 99\%$ ($\mu\mu$)
- $N = 21420$, Purity $\sim 95\%$ (ee)

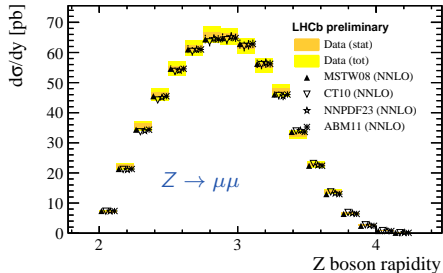


Z Results

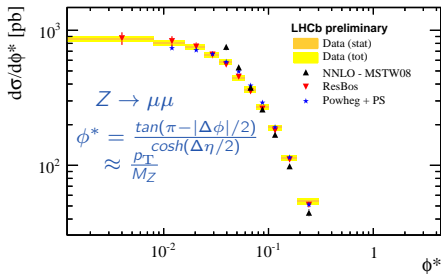
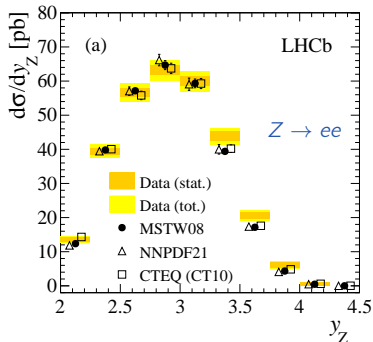


- Measurements agree with NNLO predictions
- Limited by statistics ($\tau\tau$) or luminosity (ee , $\mu\mu$)
- Main systematics: reconstruction efficiency ($\mu\mu$), tracking efficiency (ee), backgrounds and efficiency ($\tau\tau$)

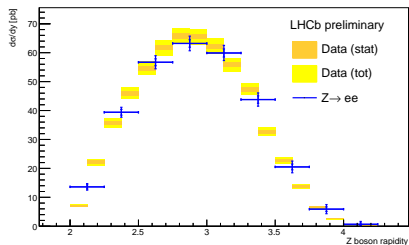
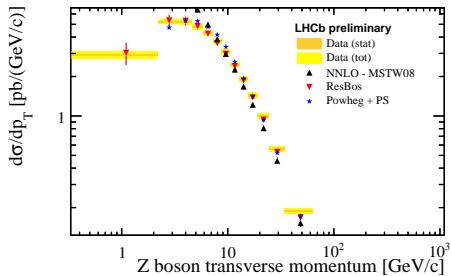
Z Results



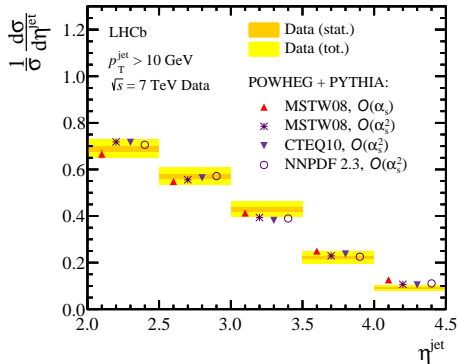
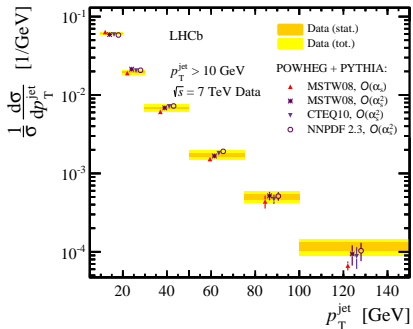
- Good agreement with NNLO predictions
- Good agreement between electron and muon channels
- Resbos and Powheg+PS describe ϕ^* distribution well



$$Z \rightarrow \mu\mu$$



Z + jet



$Z + \text{jet}$ 