LHCb

Status of the EW Analyses

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On behalf of the LHCb Collaboration
LHC EW WG, 28th – 30th November 2011
Outline

Analyses
- $Z \rightarrow \mu\mu$
- $Z \rightarrow \tau\tau$
- $W \rightarrow \mu\nu$

Preliminary Results
- Inclusive and Differential Cross-Sections
- Cross-Section Ratios
- W Charge Asymmetry

Summary and Outlook
Datasets

> \( \int L_{2010} = (37.1 \pm 1.3) \text{ pb}^{-1} \) (Z-\( \rightarrow \mu\mu \), Z-\( \rightarrow \tau\tau \) and W-\( \rightarrow \mu\nu \) analyses)
> \( \int L_{2011} \sim 210 \text{ pb}^{-1} \) (Z-\( \rightarrow \tau\tau \) analysis)

LHCb Integrated Luminosity at 3.5 TeV in 2011

\( \sim 1.1 \text{ fb}^{-1} \) on tape
Single muon trigger: $p_T > 10$ GeV/c

2 reconstructed muons
- $p_T > 20$ GeV/c
- $2.0 < \eta < 4.5$
- $60 < m_{\mu\mu} < 120$ GeV/c$^2$

Backgrounds
- $Z \rightarrow \tau\tau = 0.61 \pm 0.04$ (MC)
- Heavy flavour = 4.3 $\pm$ 1.7 (Data)
- $\pi/K$ mis-ID = 0 $\pm$ 1 (Data)

$N_{\text{Candidates}} = 1966$
$N_{\text{Background}} = 4.9 \pm 2.0$
Both τs decay to μ

One τ decays to μ, one to e

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

2 reconstructed isolated μs

$\Rightarrow p_{T,1} > 20 \text{ GeV}/c$, $p_{T,2} > 5 \text{ GeV}/c$

$2.0 < \eta < 4.5$

$\Delta \phi > 2.7$

Cone $p_T$ asymmetry ($R=0.5$) > 0.8

$\Rightarrow$ Muon $p_T$ asymmetry > 0.2

$\Rightarrow$ Impact parameter significance > 4

$m_{\mu\mu} < 80 \text{ GeV}/c^2$

1 reconstructed & isolated μ & e

$\Rightarrow p_{T,\mu} > 20 \text{ GeV}/c$, $p_{T,e} > 5 \text{ GeV}/c$

$2.0 < \eta < 4.5$

$\Delta \phi > 2.7$

Cone $p_T$ asymmetry ($R=0.5$) > 0.8

\[ R = \sqrt{\Delta \eta^2 + \Delta \phi^2} \]
> Backgrounds

» EW = 5.5 ± 1.8 (Data)

» QCD = 1.6 ± 1.3 (Data)

> N_{Candidates} = 33

> Backgrounds

» EW = 3.0 ± 1.2 (MC)

» QCD = 9.5 ± 3.0 (Data)

> N_{Candidates} = 81
W → µνµ

> Single muon trigger: $p_T > 10$ GeV/c
> 1 reconstructed & isolated muon
  » $p_T > 20$ GeV/c
  » $2.0 < \eta < 4.5$
  » Cone $p_T (R=0.5) < 2$ 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)
  » $K/\pi$ punchthrough (Data)
  » $K/\pi$ decay in flight (Data)
\( W \rightarrow \mu \nu \nu \mu \)

- Specific cuts implemented to reduce each background component
  - \( Z/\gamma^* \rightarrow \mu \mu \)
    - No extra muons with \( p_T > 5 \text{ GeV/c} \)
  - \( W \rightarrow \tau \nu, Z \rightarrow \tau \tau \) and Heavy flavour
    - Impact parameter < 40 \( \mu \text{m} \)
  - \( K/\pi \) punchthrough
    - \( E / p < 4\% \)
  - \( K/\pi \) decay in flight
    - Largest residual background besides \( Z \rightarrow \mu \mu \) 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 5 $\eta$ bins.
Fit positive and negative muon $p_T$ spectra in data to expected shapes for signal and backgrounds in 5 $\eta$ bins.

- $W\rightarrow\mu\nu\mu$

- $N^+\text{ Candidates} = 15608$
- $N^-\text{ Candidates} = 12301$
- $Purity^+ \sim 80\%$
- $Purity^- \sim 78\%$

$W$ and $Z$ muon $p_T$ spectrum @ NLO (POWHEG)
The cross-section for boson production can be expressed as

\[
\sigma = \frac{N_{\text{Candidates}} - N_{\text{Background}}}{A \cdot \varepsilon_{\text{Trigger}} \cdot \varepsilon_{\text{Tracking}} \cdot \varepsilon_{\text{ID}} \cdot \varepsilon_{\text{Selection}} \cdot \int L}
\]

Measurements performed in the forward region (2.0<\eta<4.5) for leptons with \( p_T > 20 \text{ GeV/c} \) \( A = 1 \) (except for Z\( \rightarrow \tau\tau \), obtained from MC)

Efficiencies determined from data (except for Z\( \rightarrow \tau\tau \)) and cross checked with simulation

Selection efficiency

- Z\( \rightarrow \mu\mu \) selection criteria define the measurement kinematic region
- Z\( \rightarrow \tau\tau \): determined from MC
- W\( \rightarrow \mu\nu \): measured from Z\( \rightarrow \mu\mu \) data with 1 muon masked
Efficiencies

Efficiencies determined with a Tag&Probe method in Z-\(\rightarrow\)\(\mu\mu\) samples

**Trigger**
- Tag: triggered muon
- Probe: offline identified muon

**Tracking** (electron from MC)
- Tag: identified muon track
- Probe: trajectory from muon stub and minimal tracking information

**Particle ID**
- Tag: identified lepton
- Probe: reconstructed track

Efficiencies flat in \(\phi\), \(p_T\), and \#PV
- No evidence for charge bias
- Correction vs \(\eta\)

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Systematics

- Background error large for $W$ because of uncertainty on shapes
- Efficiency uncertainties dominated by limited statistics

<table>
<thead>
<tr>
<th>Source</th>
<th>$Z\rightarrow\mu\mu$</th>
<th>$Z\rightarrow\tau\tau(\mu\mu)$</th>
<th>$Z\rightarrow\tau\tau(\mu\epsilon)$</th>
<th>$W^+\rightarrow\mu^+\nu_\mu$</th>
<th>$W^-\rightarrow\mu^-\bar{\nu}_\mu$</th>
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<tr>
<td>Background</td>
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<td>5</td>
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<td>1.6</td>
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<td>Shape (Fit)</td>
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<td>-</td>
<td>-</td>
<td>1.9</td>
<td>1.7</td>
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<tr>
<td>Efficiency</td>
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<td>8</td>
<td>2.5</td>
<td>2.3</td>
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<td>Acceptance</td>
<td>-</td>
<td>2</td>
<td>5</td>
<td>-</td>
<td>-</td>
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<tr>
<td>FSR</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

| Systematic | 5.1                   | 11                                | 10                                | 3.5                           | 3.2                               |
| Luminosity | 3.5                   | 5.1                               | 3.5                               | 3.5                           | 3.5                               |
| Statistical| 2.1                   | 17                                | 12                                | 0.9                           | 1.1                               |

(relative error)
Kinematic range: \(2.0 < \eta_l < 4.5, p_{T,l} > 20 \text{ GeV}/c \) and \(60 < m_{ll} < 120 \text{ GeV}/c^2\)

\[
\sigma_{Z \rightarrow \mu\mu} = (74.9 \pm 1.6_{\text{stat}} \pm 3.8_{\text{syst}} \pm 2.6_{\text{lumi}}) \text{ pb}
\]

\[
\sigma_{Z \rightarrow \tau\tau} = (82 \pm 8_{\text{stat}} \pm 7_{\text{syst}} \pm 4_{\text{lumi}}) \text{ pb}
\]

\[
\frac{\Gamma(Z \rightarrow \tau\tau)}{\Gamma(Z \rightarrow \mu\mu)} = 1.09 \pm 0.17
\]
**W Cross-Section**

*Kinematic range: 2.0 < \( \eta_\mu \) < 4.5 and \( p_T,\mu > 20 \) GeV/c*

\[
\sigma_{W^+} = (808 \pm 7_{\text{stat}} \pm 28_{\text{syst}} \pm 28_{\text{lumi}}) \text{ pb} \\
\sigma_{W^-} = (634 \pm 7_{\text{stat}} \pm 21_{\text{syst}} \pm 22_{\text{lumi}}) \text{ pb} \\
\frac{\sigma_{W^+}}{\sigma_{W^-}} = 1.28 \pm 0.02_{\text{stat}} \pm 0.01_{\text{syst}}
\]
All W and Z observations are consistent with NNLO predictions.
Cross-sections and ratios of $W$ and $Z$ measured at 7 TeV in the kinematic range $2.0 < \eta < 4.5$ and $p_T > 20$ GeV/c.

All observations are consistent with the current NNLO predictions.

2010 final results & paper are currently under discussion.

- $W$ and $Z$ muon $p_T$ spectrum at NNLO (see talk by T. Shears).
- Reduced $W$ background systematic.
- Moved from HORACE to PHOTOS for FSR correction.
- Differential $W^+$ and $W^-$ cross-section.

LHCb collected $\sim 1.1$ fb$^{-1}$ in 2011.

- Improved efficiency and background knowledge (see talk by R. McNulty)
Spares
LHCb – A Forward Spectrometer

- Designed to look at CP violation in B decays @ LHC
- Fully instrumented within $1.9 < \eta < 4.9$
- Muon reconstruction capabilities: $p_T > 1 \text{ GeV/c}, m_{\mu\mu} > 2.5 \text{ GeV/c}^2$
LHCb – A Forward Spectrometer

> Complementary \( \eta \) range to ATLAS & CMS
  
  » Overlap for cross check
  1.9 < \( \eta \) < 2.5
  
  » Unique to LHCb
  2.5 < \( \eta \) < 4.9

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17\%(16\%) of \( W^+(W^-) \) within LHCb

8% of Z within LHCb
LHCb’s forward acceptance provides very interesting possibilities for PDF studies.
> Backgrounds defined by anti cuts

- K/π punchthrough: \( E_{E+H} / P > 10\% \)
- K/π decay in flight: \( \text{Prob}(K/\pi \rightarrow \mu \nu, P) \)
- Heavy flavor: Impact parameter \( \geq 80 \ \mu \text{m} \)

> Pseudo-W (Z events with 1 muon masked)

- Pseudo-W and W simulated distributions look similar
- Pseudo-W data described by simulation
- Signal can be modeled with Pseudo-W data
## Efficiencies

<table>
<thead>
<tr>
<th>Source</th>
<th>Z→μμ</th>
<th>Z→ττ(μμ)</th>
<th>Z→ττ(μe)</th>
<th>W→μνμ</th>
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<tbody>
<tr>
<td>Trigger</td>
<td>90%</td>
<td>86%</td>
<td>78%</td>
<td>78%</td>
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<tr>
<td>Tracking</td>
<td>82%</td>
<td>84%</td>
<td>84% 80%</td>
<td>79%</td>
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<tr>
<td>ID</td>
<td>98%</td>
<td>99.1%</td>
<td>99.1% 96.2%</td>
<td>99%</td>
</tr>
<tr>
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<td>46%</td>
<td>45%-80%</td>
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<tr>
<td>Acceptance</td>
<td>1</td>
<td>38.6%</td>
<td>24.9%</td>
<td>1</td>
</tr>
</tbody>
</table>
Central and forward measurements of the $W$ charge asymmetry will reduce the PDF uncertainty in both the large and small $x$ regions.
PDF correlation between asymmetry and $u_\nu - d_\nu$ versus $x$

$W^\pm \to \Gamma_\nu$ at the LHC ($\sqrt{s} = 7$ TeV) with $p_T > 20$ GeV