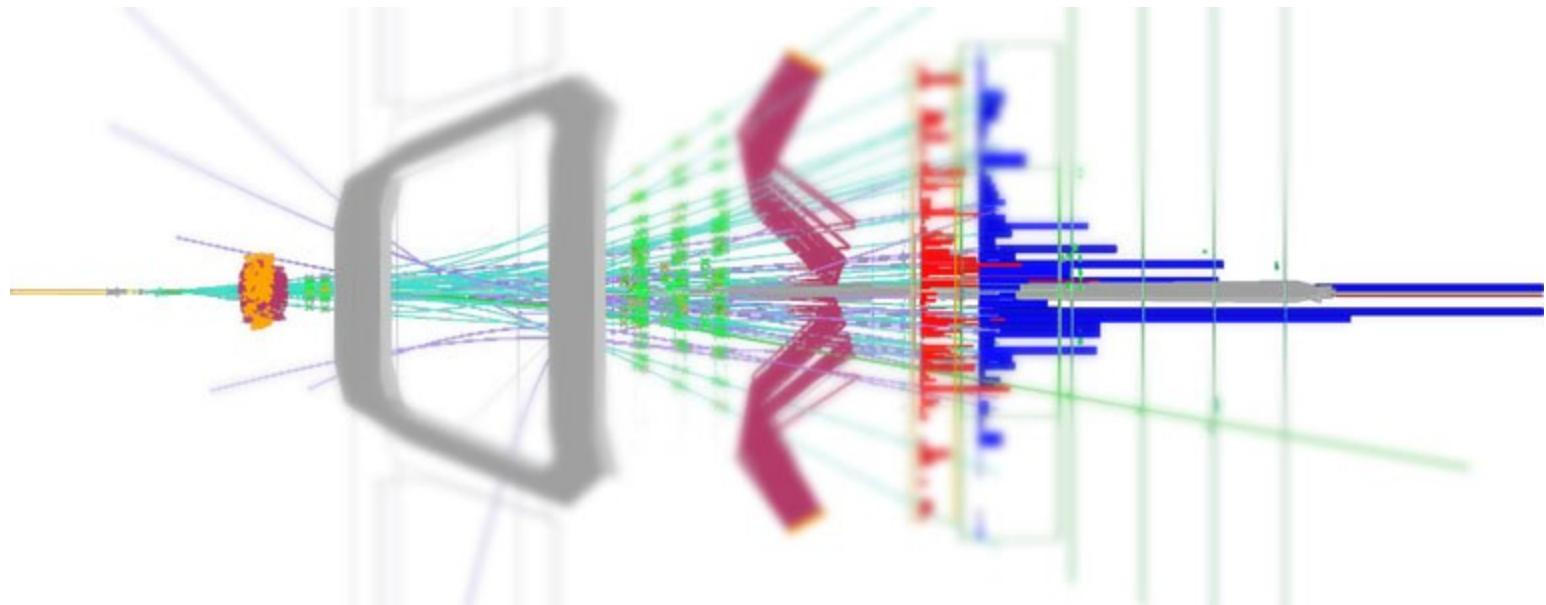


# Electroweak results at LHCb

Katharina Müller  
on behalf of LHCb



## Introduction

$Z \rightarrow \mu\mu, Z \rightarrow ee, (Z \rightarrow \tau\tau)$

$W \rightarrow \mu\nu$

Low mass Drell-Yan  $\gamma^*/Z \rightarrow \mu\mu$

Conclusion



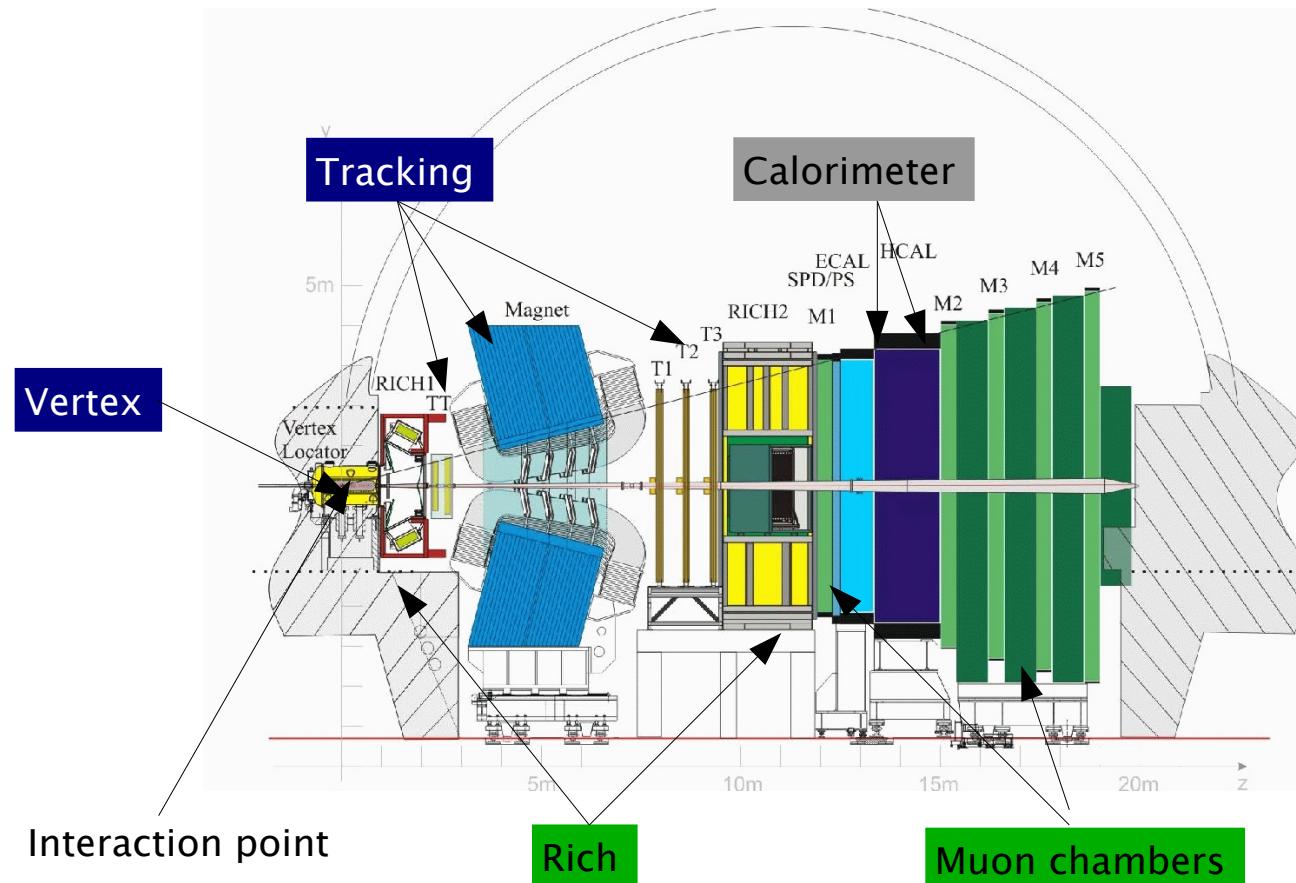
University of  
Zurich<sup>UZH</sup>  
Physics Institute



# Introduction

## LHCb detector

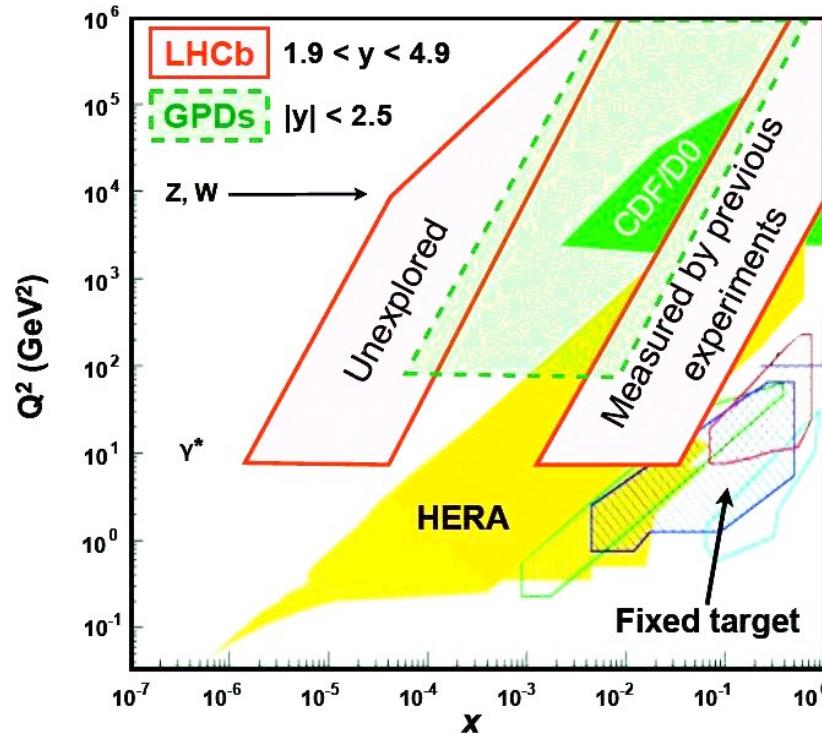
- Forward spectrometer designed to search for new physics in B and D decays
- Fully instrumented in the forward region ( $2 < \eta < 5$ )



- Excellent vertex resolution and tracking
- Particle identification
- Trigger on muons  $M(\mu\mu) > 2.5 \text{ GeV}/c^2$

More LHCb talks:

- Michelle Nicol  
Rare B decays
- Luigi Li Gioi  
CP violation in  $B \rightarrow hh$
- Christopher Thomas  
Charm results
- Conor Fitzpatrick  
 $\phi_s$  measurement
- Sneha Sirirshkumar Malde  
Gamma from  $B \rightarrow DK$
- Marcin Kucharczyk  
Jet measurements in LHCb  
And their relevance for pdfs



- LHCb probes two distinct regions in  $x-Q^2$
- Unique region at low  $x$  down to  $x = 10^{-6}$
- SM predictions known at NNLO order
- Input for PDF fits in previously unexplored region
- Medium  $Q^2$  (10'000 GeV $^2$ ): Z and W measurements
- Low  $Q^2$  (25 GeV $^2$ ): Drell-Yan ( $\gamma^*$ )

## Data

- 2010  $L = 37 \text{ pb}^{-1}$
- Trigger: single  $\mu$ ,  $p_T > 10 \text{ GeV}/c$

## Muon

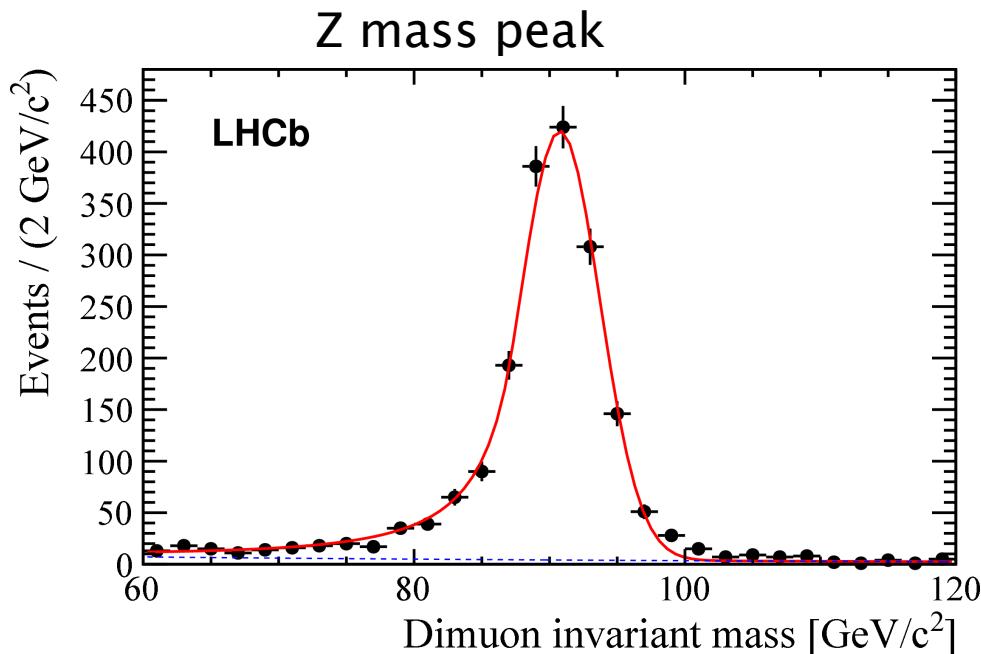
- two identified muons
- $p_T > 20 \text{ GeV}/c$
- $2.0 < \eta_\mu < 4.5$

## Z selection

- $60 < M(\mu\mu) < 120 \text{ GeV}/c^2$

## Background

- $Z \rightarrow \tau\tau$  (MC)
- W-pair (MC)
- Top-pair (MC)
- Heavy flavour (Data)
- K/ $\pi$  misid. (Data)



Candidates: 1966

Background:  $4.8 \pm 1.0$

Purity: 99.7%

## Data

- 2011  $L = 1 \text{ fb}^{-1}$
- Trigger: single electron,  $p_T > 15 \text{ GeV}/c$

## Electrons

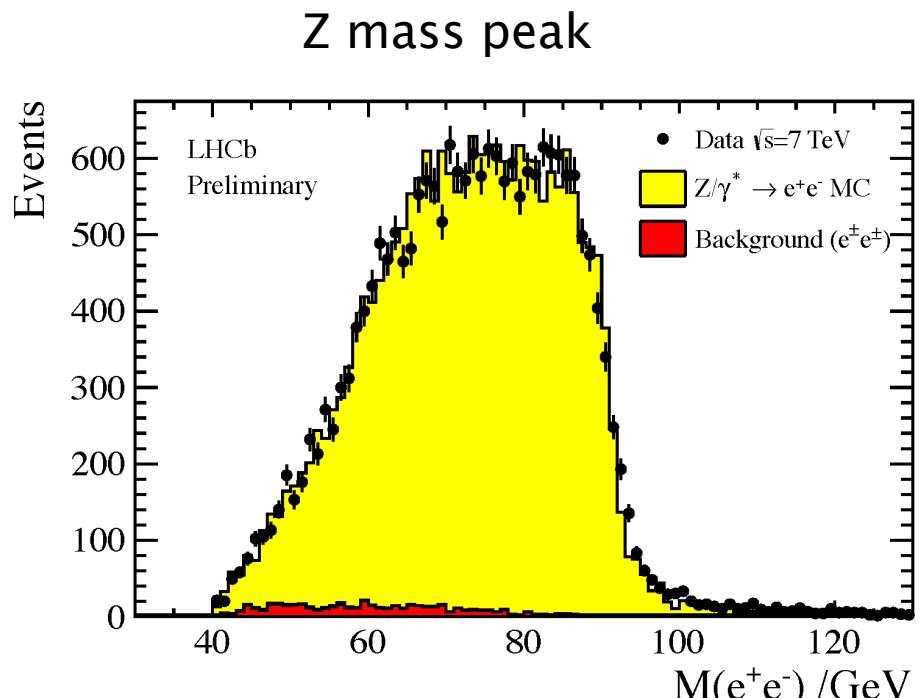
- two electrons
- $p_T > 20 \text{ GeV}/c$
- $2.0 < \eta_\mu < 4.5$

## Z selection

- $M(ee) > 40 \text{ GeV}/c^2$

## Background

- $Z \rightarrow \tau\tau$  (MC)
- Top-pair (MC)
- QCD (Data)



Candidates: 21535

Background: 473

Purity: 97.8%

# Selection

$W \rightarrow \mu\nu$

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Data: 2010  $L = 37 \text{ pb}^{-1}$   
Single  $\mu$ ,  $p_T > 10 \text{ GeV}/c$

Muon: one muon  
 $20 < p_T < 70 \text{ GeV}/c$ ,  $2.0 < \eta_\mu < 4.5$

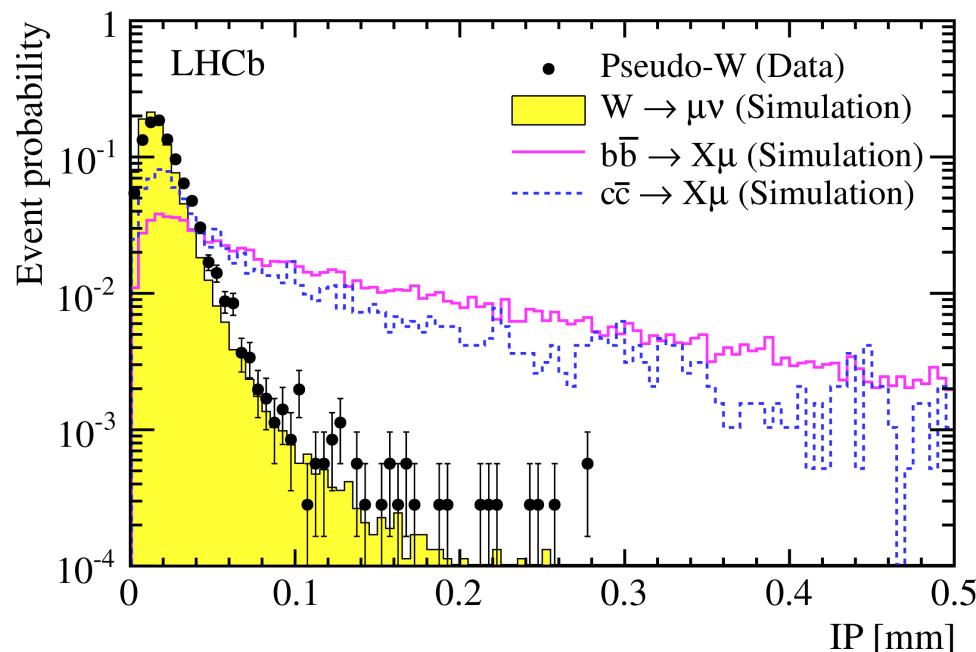
Isolation  $E_T^{\text{cone}} < 2 \text{ GeV}$  (Cone R<0.5 around  $\mu$ )  
 $p_T^{\text{cone}} < 2 \text{ GeV}/c$

Cuts against background:

- from semi-leptonic decays of heavy flavour  
Impact parameter <  $40 \mu\text{m}$
- $Z/\gamma$ : No other muon with  $p_T > 2 \text{ GeV}/c$
- $K/\pi$  punch through  
 $E(\text{Calorimeter})/\text{pc} < 0.04$

Candidates:  $N_{W+} = 14660$   
 $N_{W-} = 11618$

Purity obtained by fit to  $p_T^\mu$  spectrum in data  
to expected shapes for signal and background

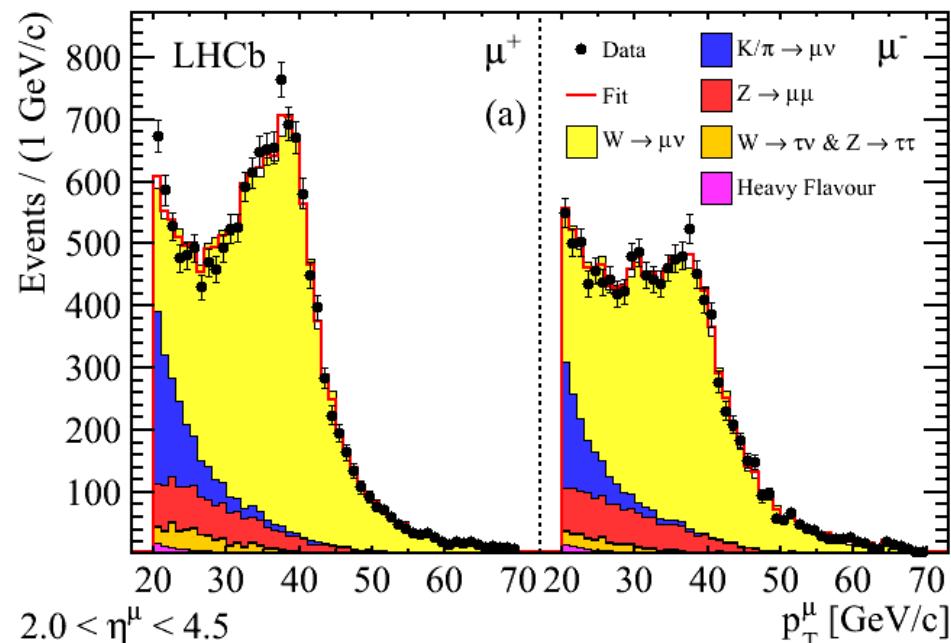


Purity: fit to positively and negatively charged muon  $p_T$  distribution in 5  $\eta$  bins  
 (15 free parameters: 10 signal, 5 background)

| Shape   | Source          |
|---|-----------------|
| $W \rightarrow \mu\nu$                          | Simulation      |
| K/ $\pi$ decay in flight                        | Data            |
| $\gamma^*/Z \rightarrow \mu\mu$                 | Simulation/Data |
| $W \rightarrow \tau\nu, Z \rightarrow \tau\tau$ | Simulation/Data |
| Heavy Flavour                                   | Data            |

#### Normalisation

- Signal and decay in flight: fitted
- Others : data driven methods



|               | W+               | W-               |
|---------------|------------------|------------------|
| Signal Purity | $44.1 \pm 1.2\%$ | $34.4 \pm 1.1\%$ |
|               | 78.8%            | 78.4%            |

# Cross-sections

# Efficiencies

$$\sigma = \frac{\rho N}{A L \epsilon} f_{FSR}$$

Efficiencies from data

tracking, identification and trigger: tag and probe in Z sample

Tag:

well identified, triggered muon/electron

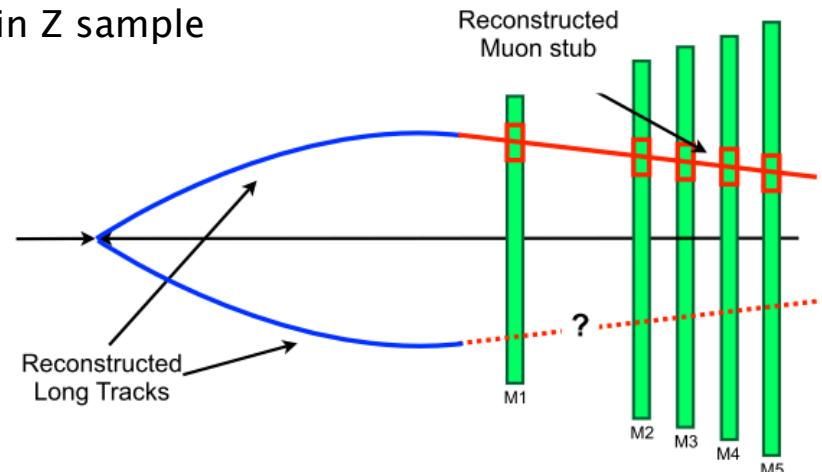
Probe:

Trigger: identified muon/electron

Identification: fully reconstructed track

Tracking: muon-stub -TT hits

Electron tracking from MC



W selection ( $E/p$ ), IP,  $P_T^{\max}$ ,  $E_T^{\text{cone}}$  from pseudo-W events

Pseudo-W events

Z events with one muon removed

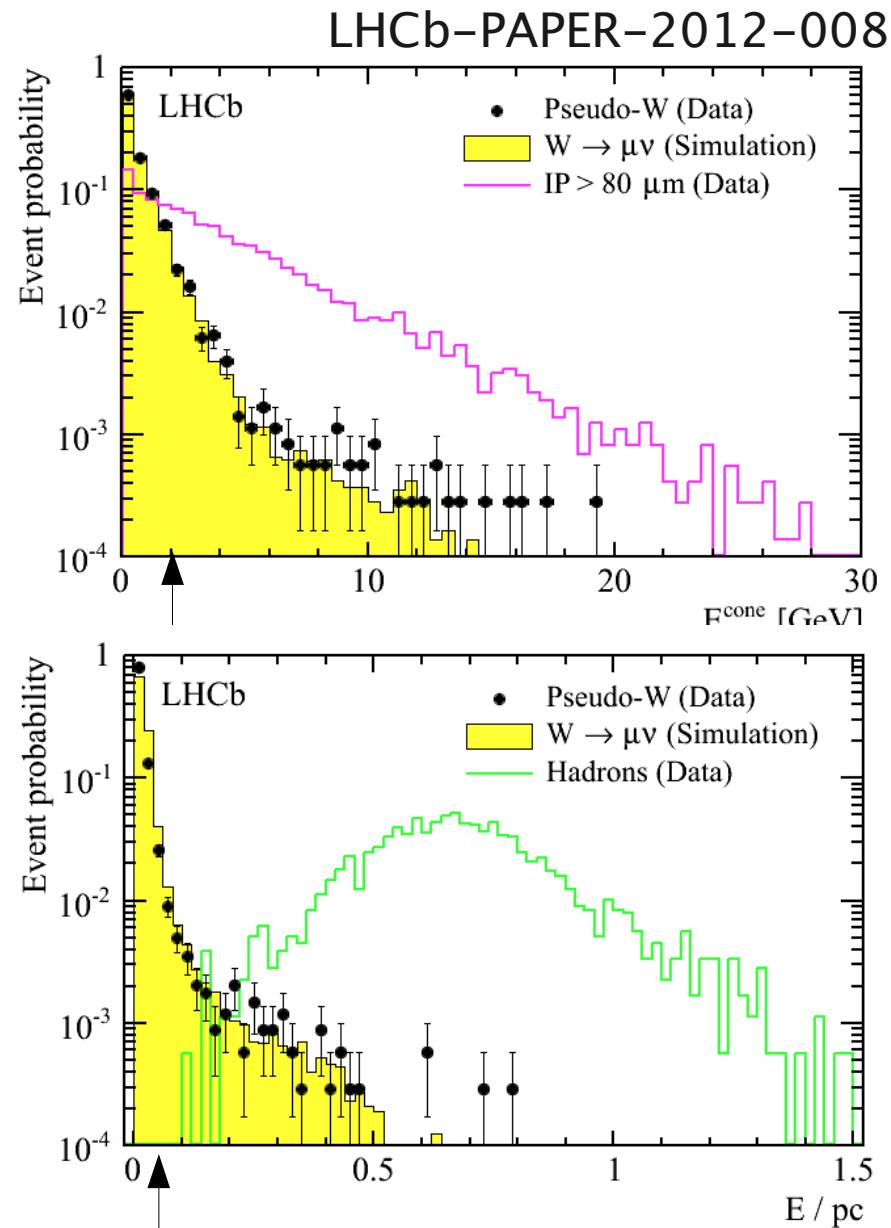
# Cross-Sections

# Additional Selection efficiency

W selection ( $E/p$ ), IP,  $P_T^{\max}$ ,  $E_T^{\text{cone}}$   
 from pseudo-W events:  $\epsilon_{\text{sel}} = 0.3\text{--}0.7$   
 Z events with one muon removed

Z  $\rightarrow \mu\mu$ , Z  $\rightarrow ee$ : no additional selection

Z  $\rightarrow \tau\tau$   
 Selection efficiency determined from MC  
 $\mu\mu$ :  $\epsilon_{\text{sel}} = 0.172 \pm 0.014$   
 $\mu e$ :  $\epsilon_{\text{sel}} = 0.46 \pm 0.03$



# Cross section

# Precision

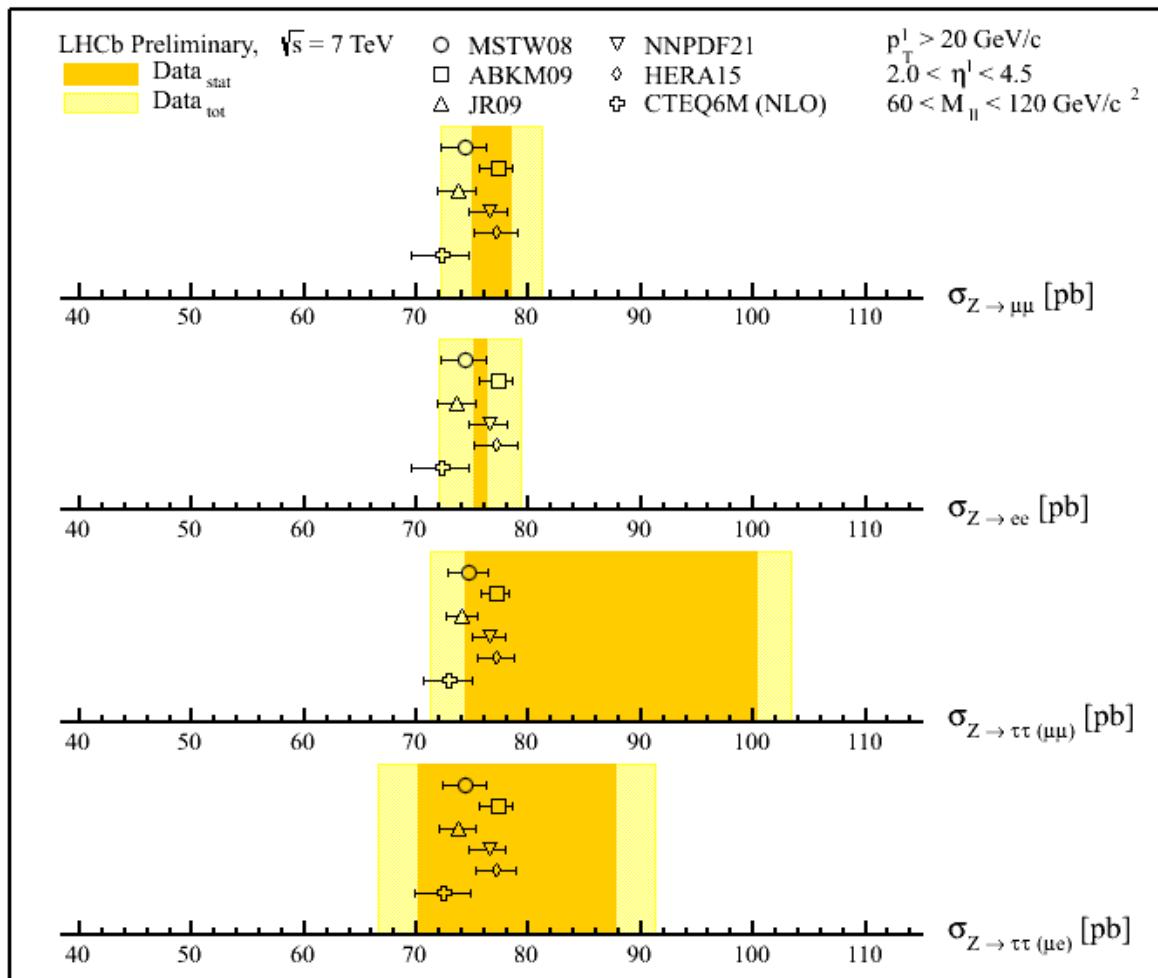
|                | $Z \rightarrow \mu\mu$ | $Z \rightarrow ee$ | $Z \rightarrow \tau\tau$<br>$\mu e/\mu\mu$ | $W \rightarrow \mu\nu$<br>$W^+/W^-$ |
|----------------|------------------------|--------------------|--|-------------------------------------|
| Statistical    | 2.2%                   | 0.7%               | 17/12%                                     | 1.1/1.2%                            |
| Luminosity     | 3.5%                   | 3.5%               | 5.1%                                       | 3.5%                                |
| Systematic     | 4.3%                   | 3.1%               | 10/16%                                     | 3.2/2.9                             |
| Luminosity[pb] | 37.5                   | 945                | 247  | 37.5                                |

Systematic uncertainties will reduce with more statistics

Dominant systematic uncertainties:

- Efficiencies
- Purity for W analysis
- $Z \rightarrow \tau\tau$ : limited by statistics
- $Z \rightarrow \mu\mu$  : limited by efficiency uncertainty (statistical)
- $Z \rightarrow ee$  ,  $W \rightarrow \mu\nu$ : luminosity uncertainty

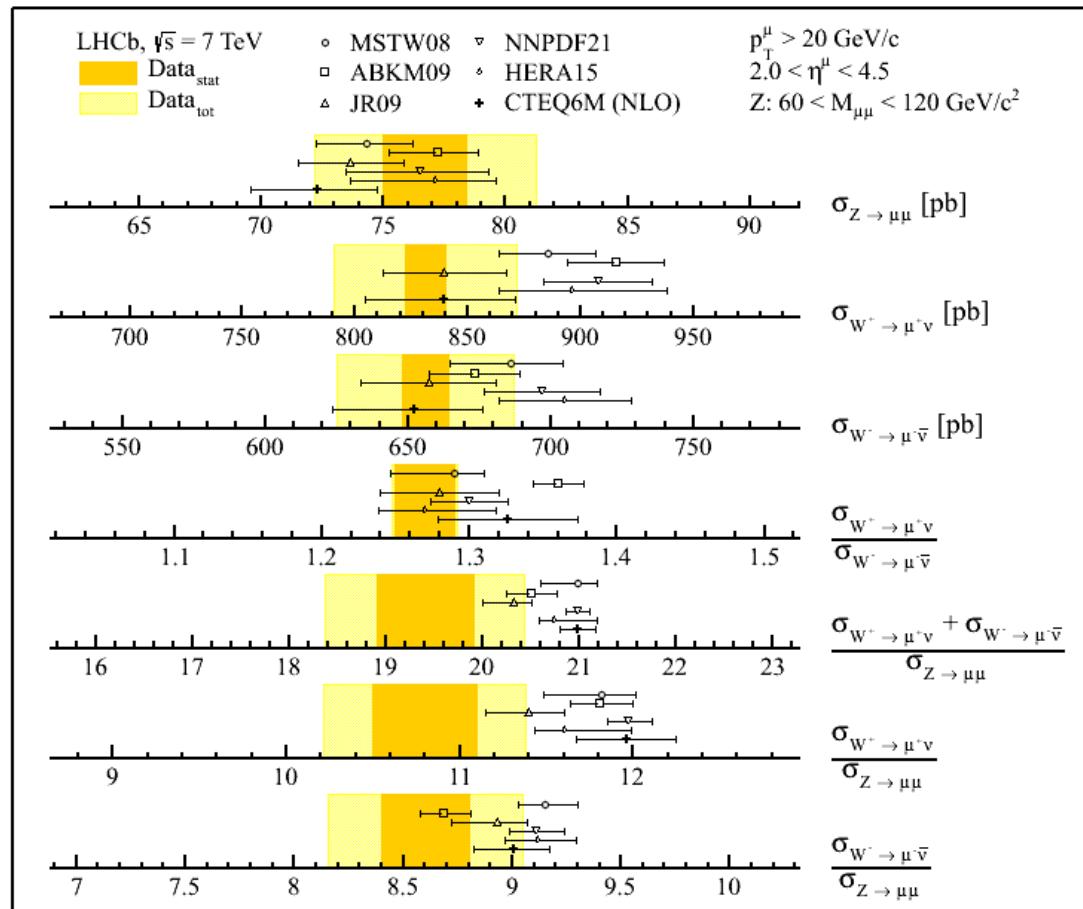
Theoretical predictions at NNLO (DYNNLO) PDF uncertainties at 68% CL  
All Z measurements in agreement with NNLO predictions



# Results

## W and Z production and ratios ( $\mu\mu$ )

Measurements of W and Z production and W/Z ratios in general agreement with NNLO predictions

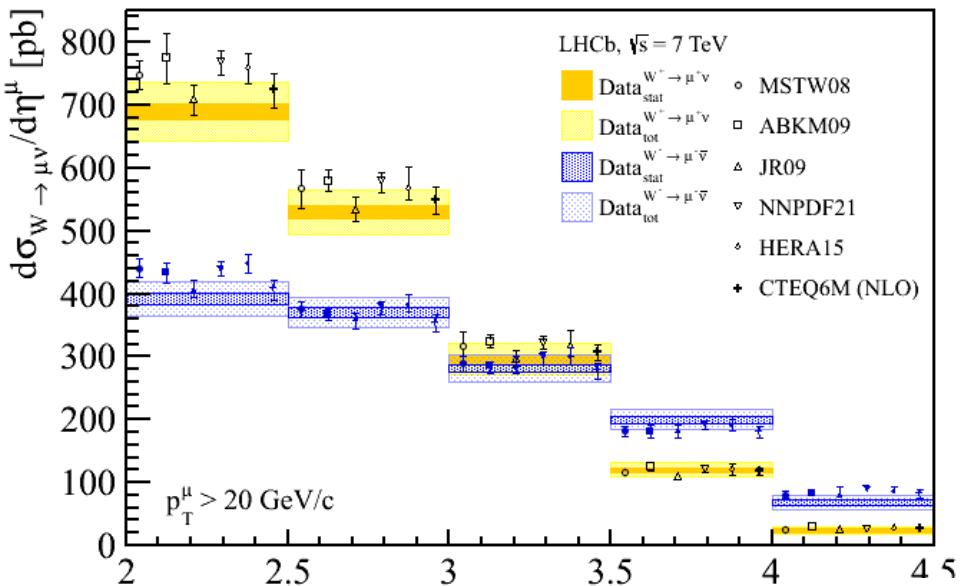


LHCb-PAPER-2012-008

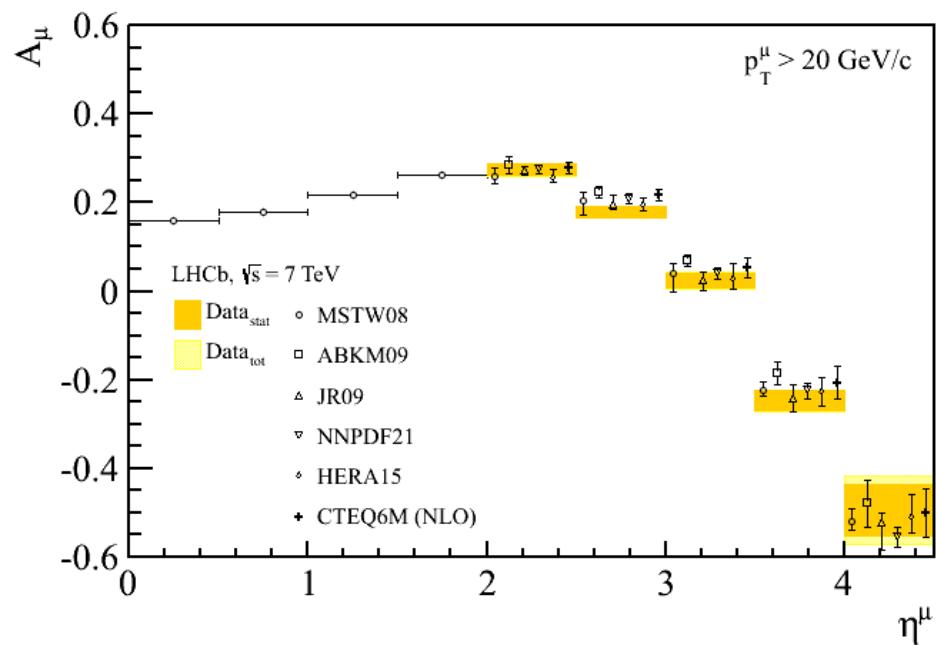
# Results

## Differential W cross section and asymmetry

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$$A_\mu = \frac{\sigma(W^+ \rightarrow \mu^+ \nu_\mu) - \sigma(W^- \rightarrow \mu^- \bar{\nu}_\mu)}{\sigma(W^+ \rightarrow \mu^+ \nu_\mu) + \sigma(W^- \rightarrow \mu^- \bar{\nu}_\mu)}$$



# Selection

## Low mass Drell-Yan $\gamma^* \rightarrow \mu\mu$

LHCb-CONF-2012-013

### Data

- 2010  $L = 37.1 \text{ pb}^{-1}$
- Trigger: Dimuon,  $p_T > 2.5 \text{ GeV}/c$

### Muon

- two identified muons
- $p_T > 3 \text{ GeV}/c$ ,  $p > 10 \text{ GeV}/c$
- $2.0 < \eta_\mu < 4.5$

### Mass selection

- $5 < M(\mu\mu) < 120 \text{ GeV}/c^2$

### Background

- Heavy flavour (Data)
- $K/\pi$  misid. (Data)
- Radiative tail of Upsilon ( $M < 10 \text{ GeV}/c^2$ )

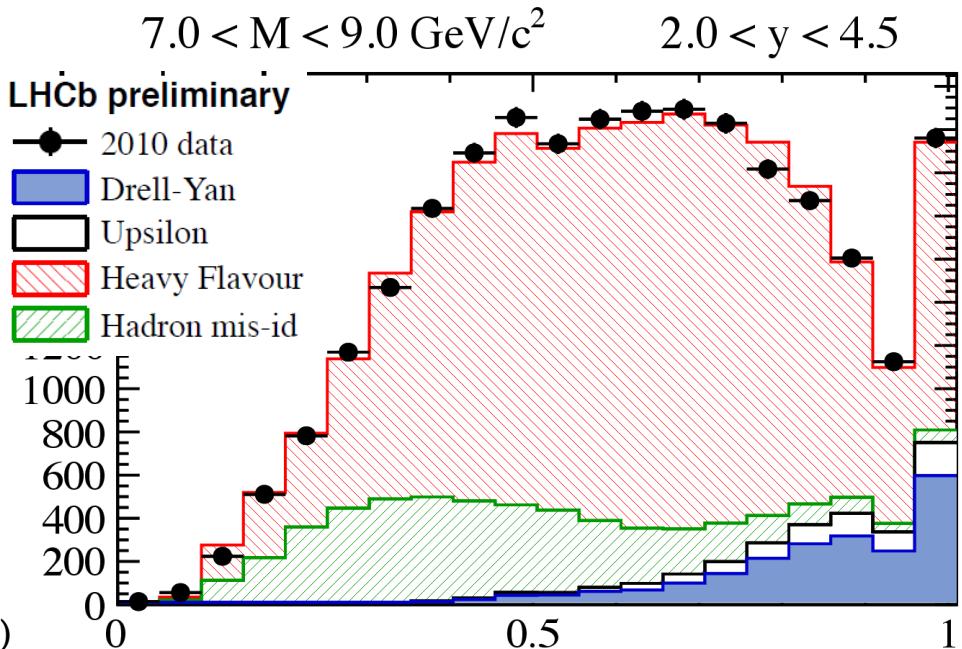
### Muon isolation: $p_T(\mu)/p_T(\mu-\text{Jet})$

### Signal extraction

- Template fit to minimum muon isolation
- Fit for 9 mass bins
- Fit for 5  $\eta$  bins (two mass ranges)

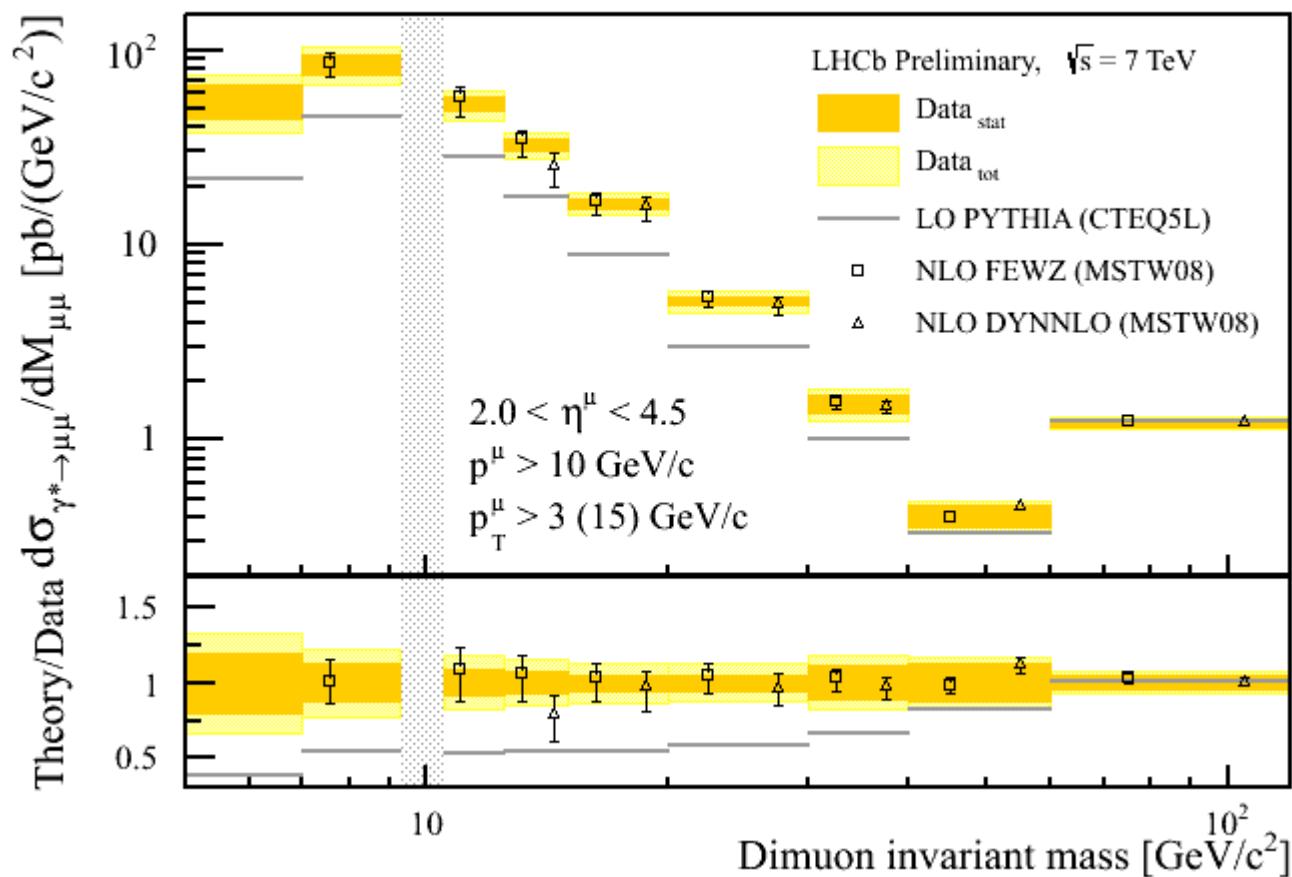
### Systematic uncertainties

- At low masses: shapes used for template fit 24%
- Efficiencies



### Minimum muon isolation

| Mass [ $\text{GeV}/c^2$ ] | Purity [%] |
|---------------------------|------------|
| 5-7.5                     | 6.8        |
| 7.5-9                     | 9.0        |
| 10.5-12.5                 | 14.9       |
| 12.5-15                   | 20.4       |
| 15-20                     | 32.1       |
| 20-30                     | 54.9       |
| 30-40                     | 70.5       |
| 40-60                     | 91.4       |
| 60-120                    | 100        |



Compared to NLO predictions (FEWZ and DYNNLO) and PYTHIA

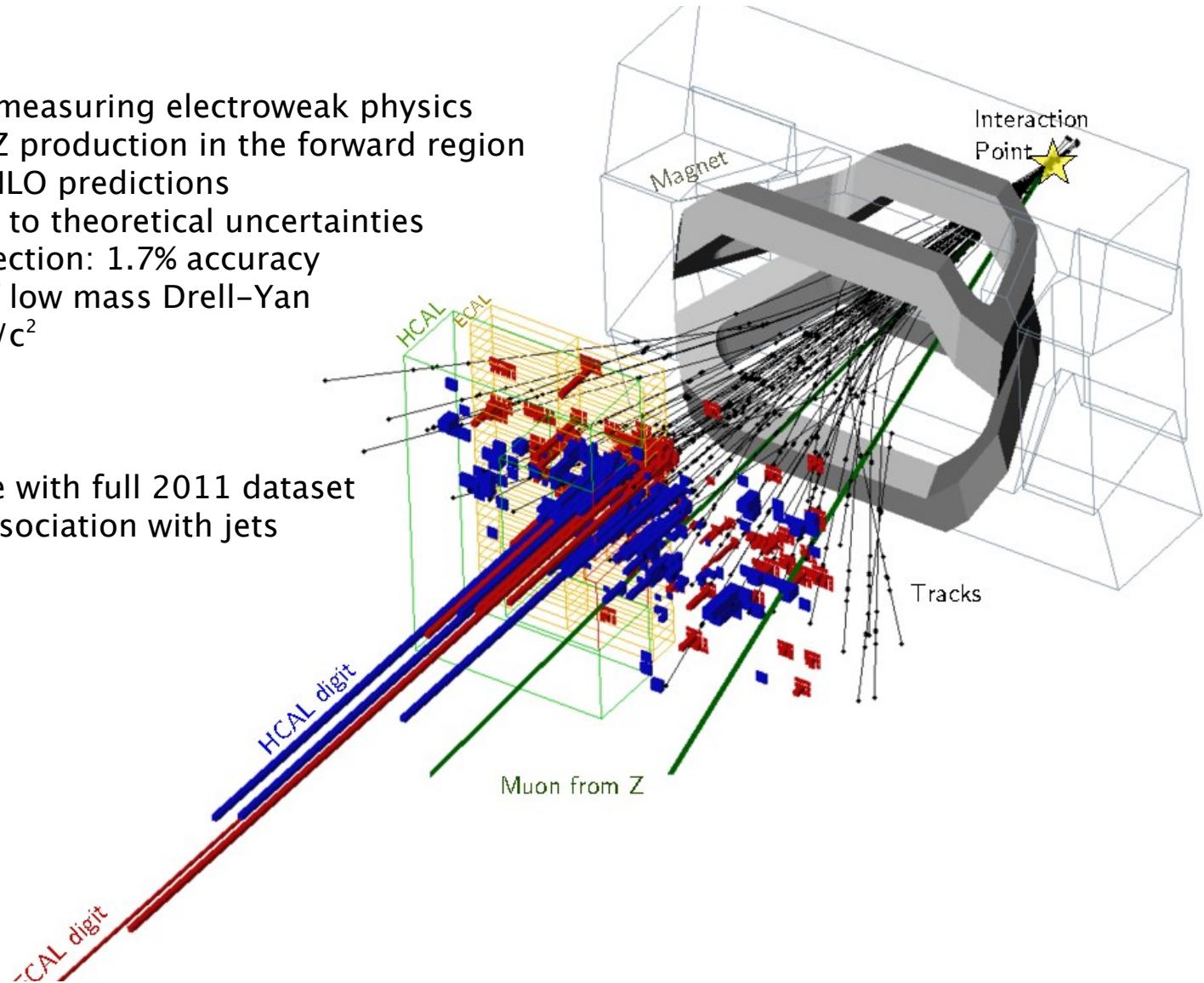
# Summary & Outlook

## Summary

- LHCb is successfully measuring electroweak physics
- Measurements of W/Z production in the forward region
- In agreement with NNLO predictions
- Precision comparable to theoretical uncertainties
- Ratio  $W^+/W^-$  cross section: 1.7% accuracy
- First measurement of low mass Drell-Yan production,  $M>5\text{GeV}/c^2$

## Outlook

- Precision will improve with full 2011 dataset
- W, Z production in association with jets



# Backup

## Data

- 2010 + 2011 Data (1/4),  $L = 250 \text{ pb}^{-1}$
- Two final states considered
- ( $\mu\mu$ ) and ( $\mu e$ )
- Single Muon Trigger,  $p_T > 10 \text{ GeV}/c$

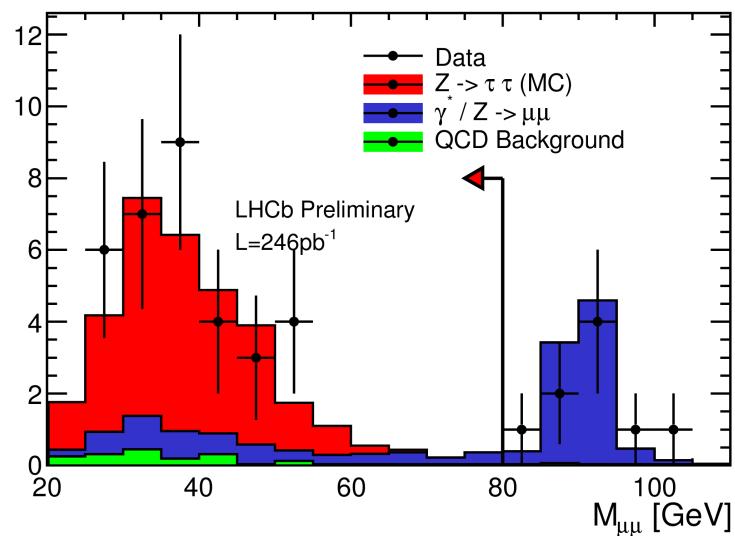
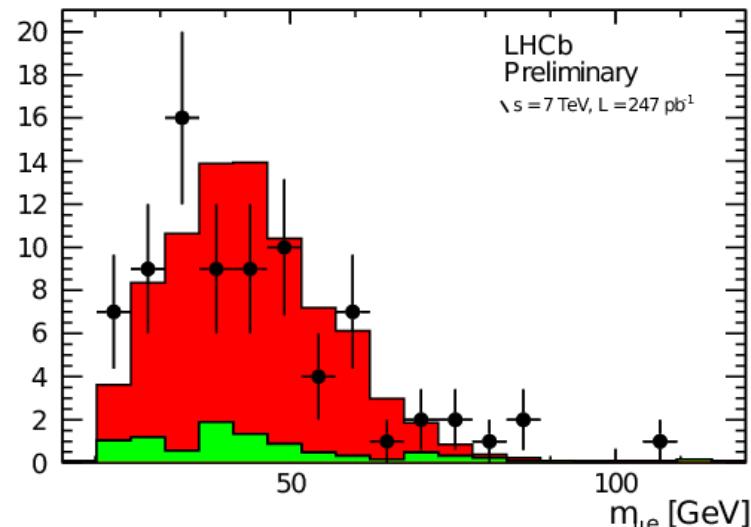
## Background

- $Z \rightarrow \mu\mu$  ( $\mu\mu$  only):  
 $p_T$  not balanced  
Cut on impact parameter
- Other electroweak processes  
(WW, WZ, ZZ)  
Leptons back-to-back
- QCD: leptons isolated

QCD background from data

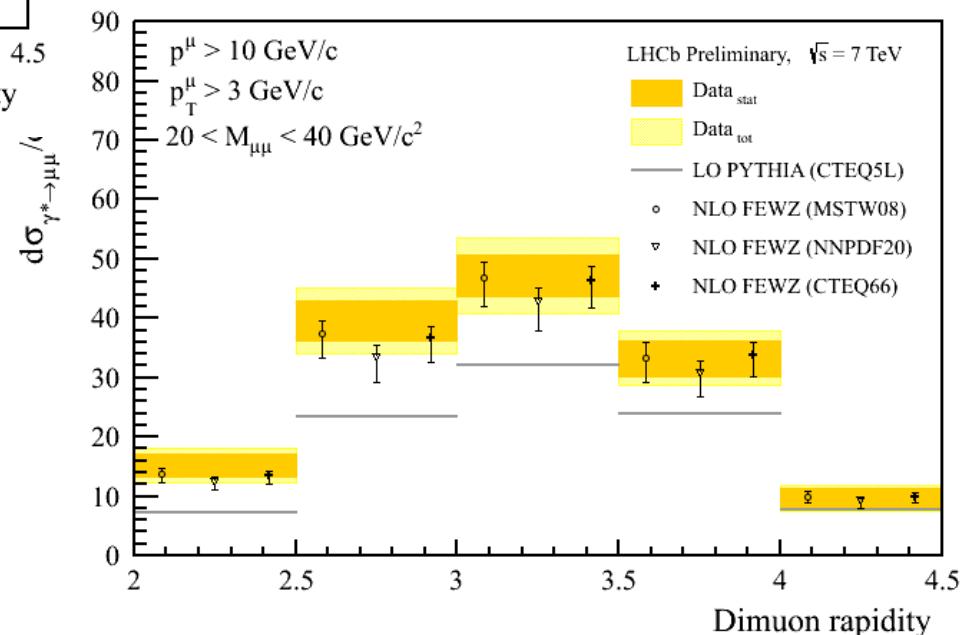
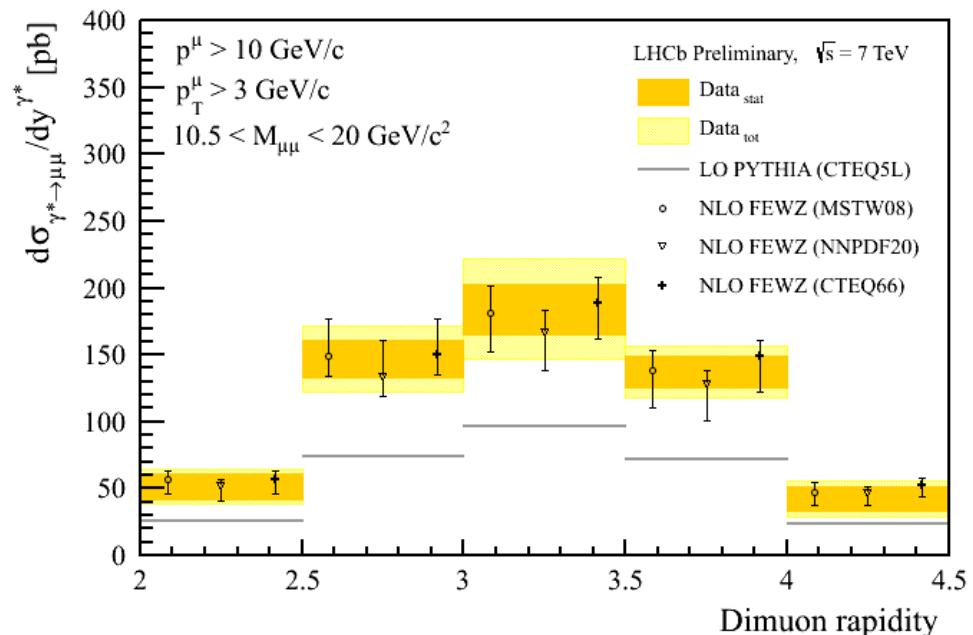
 $Z \rightarrow \mu\mu$  from MC normalised to data

|             | $\mu e$        | $\mu\mu$      |
|-------------|----------------|---------------|
| Candidates: | 81             | 33            |
| Background: | $12.4 \pm 2.7$ | $7.1 \pm 2.0$ |
| Purity:     | 85%            | 78%           |



# Results

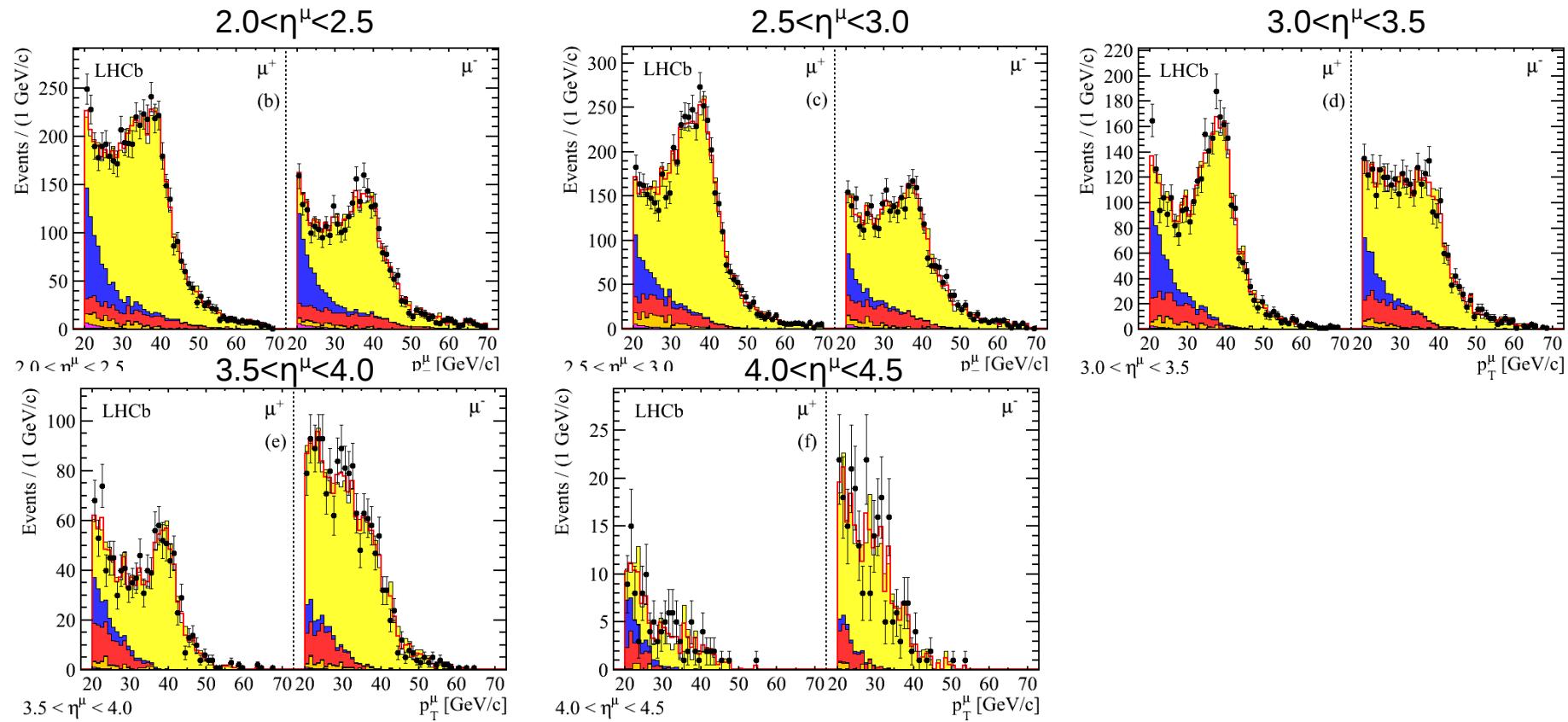
## Low mass Drell-Yan $\gamma^* \rightarrow \mu\mu$ LHCb-CONF-2012-013



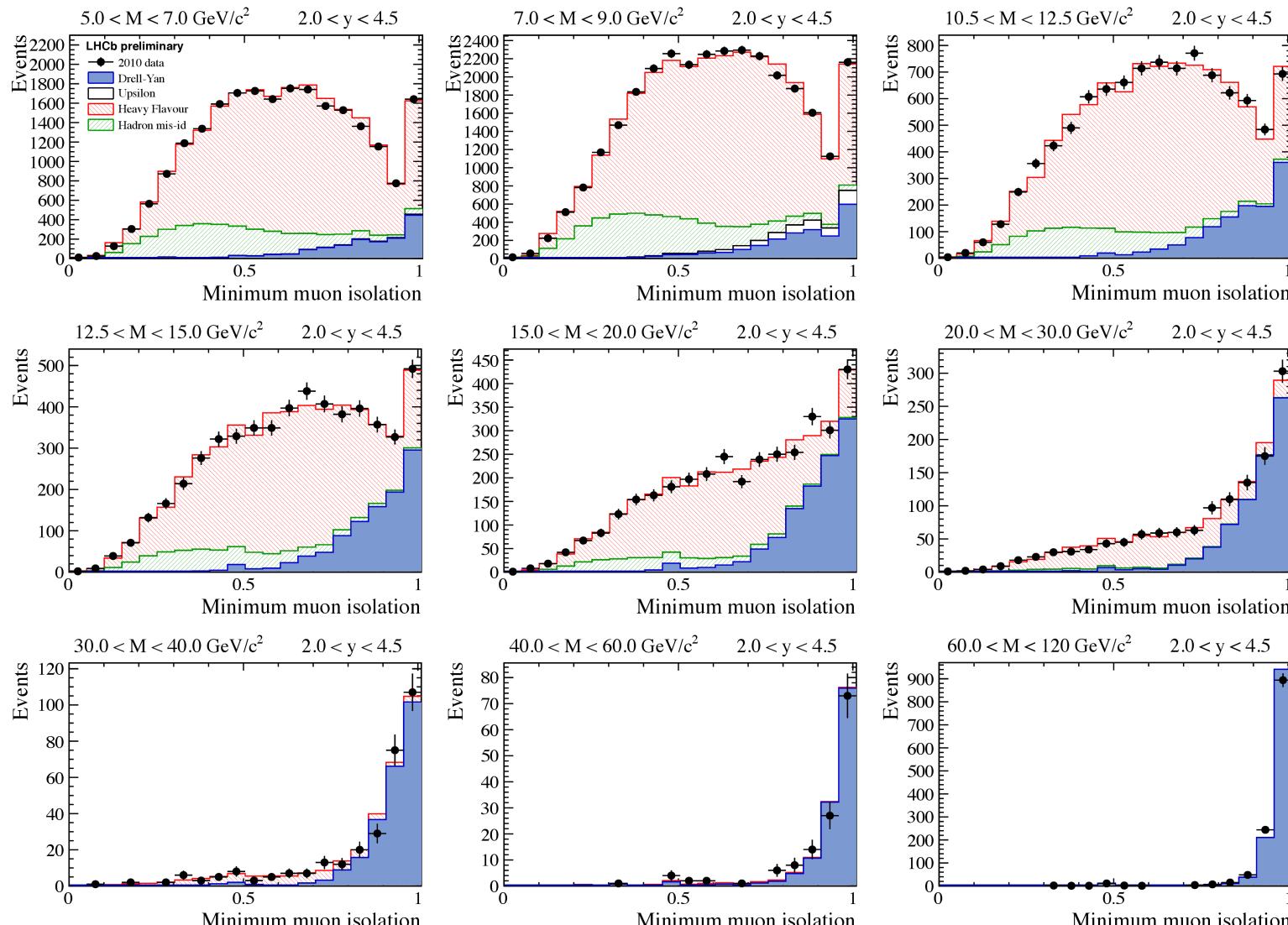
Compared to NLO predictions (FEWZ)  
and PYTHIA

# Purity

## W analysis: fit signal fraction in eta bins



LHCb-PAPER-2012-008



# Systematic uncertainties

| Source                                  | $\Delta\sigma_{Z \rightarrow \mu\mu}$ (%) | $\Delta\sigma_{W^+ \rightarrow \mu^+\nu}$ (%) | $\Delta\sigma_{W^- \rightarrow \mu^-\bar{\nu}}$ (%) |
|---|---|---|---|
| Signal purity                           | $\pm 0.1$                                 | $\pm 1.2$                                     | $\pm 0.9$   |
| Template shape (fit)                    | –   | $\pm 0.9$                                     | $\pm 1.0$   |
| Efficiency (trigger, tracking, muon id) | $\pm 4.3$                                 | $\pm 2.2$                                     | $\pm 2.0$   |
| Additional selection                    | –   | $\pm 1.8$                                     | $\pm 1.7$   |
| FSR correction                          | $\pm 0.02$                                | $\pm 0.01$                                    | $\pm 0.02$  |
| Total                                   | $\pm 4.3$                                 | $\pm 3.2$                                     | $\pm 2.9$   |
| Luminosity                              | $\pm 3.5$                                 | $\pm 3.5$                                     | $\pm 3.5$   |