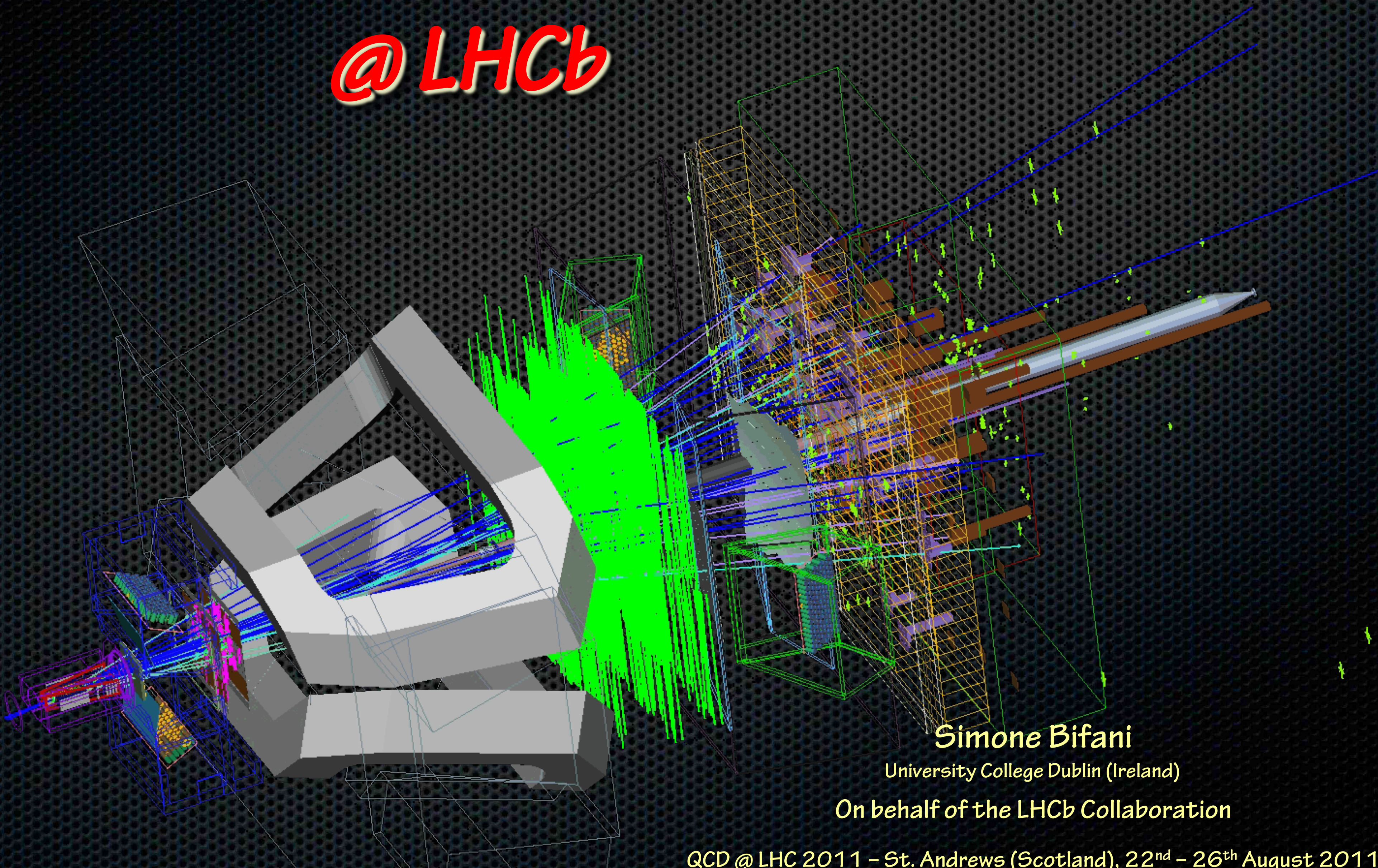
W & Z Production @ LHCb



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On behalf of the LHCb Collaboration

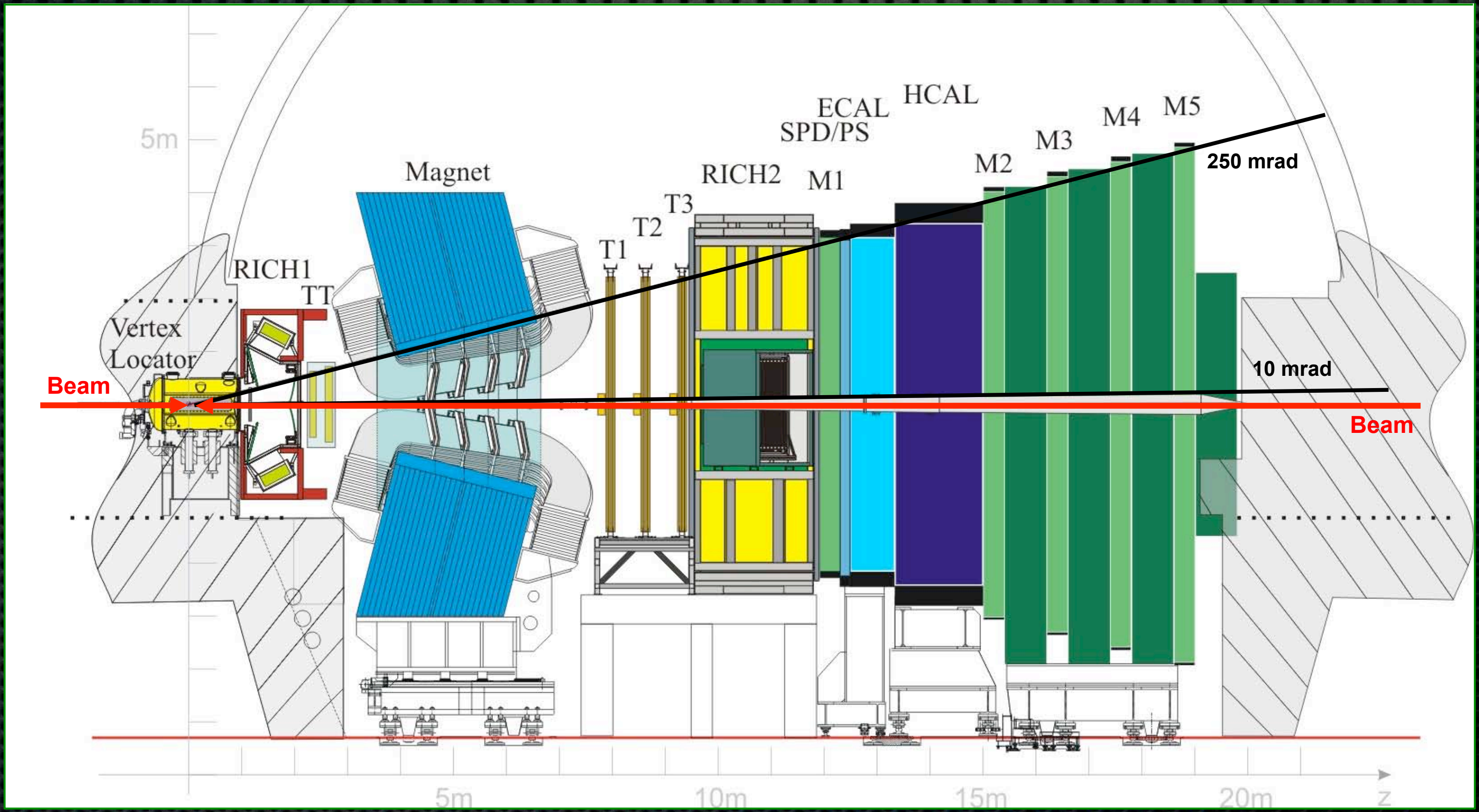
QCD @ LHC 2011 – St. Andrews (Scotland), 22nd – 26th August 2011

Outline

- LHCb Overview
- W & Z Production and PDF Sensitivity
- Preliminary Results
  - $Z \to \mu\mu$
  - $Z \to \tau\tau$
  - $W \to \mu\nu$
- Summary and Outlook

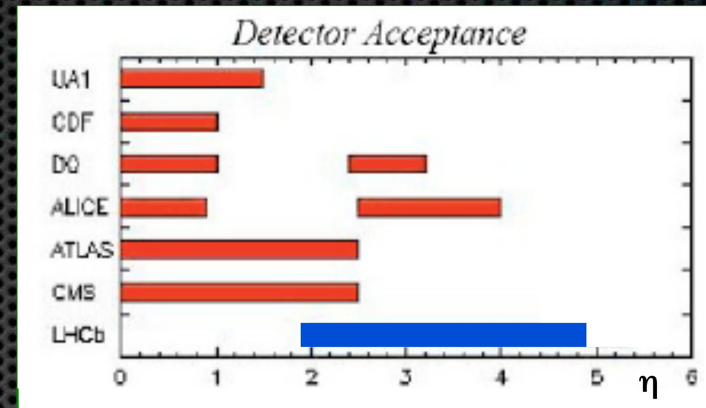
LHCb – A Forward Spectrometer

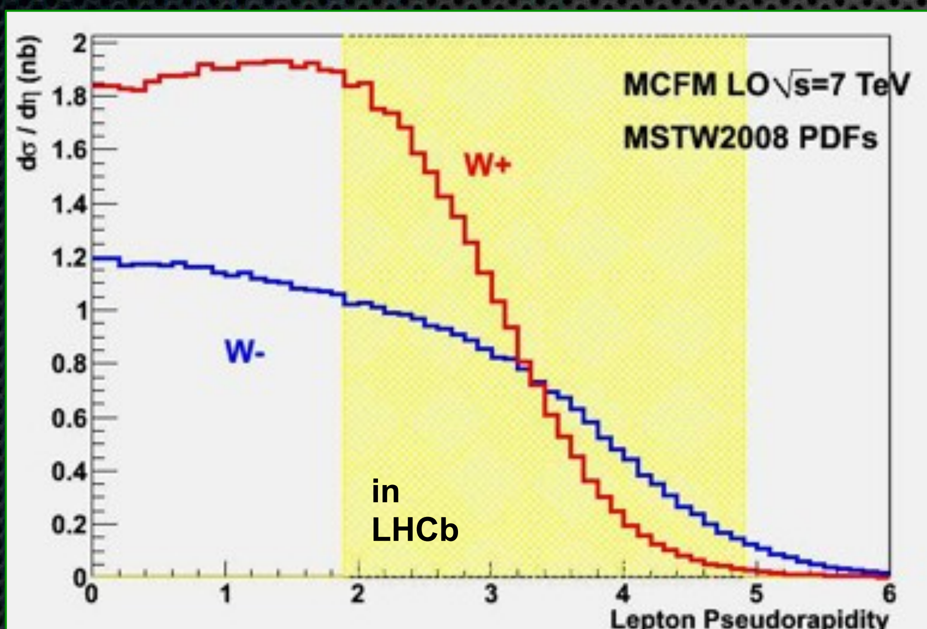
- Designed to look at CP violation in B decays @ LHC
- Fully instrumented within $1.9 < \eta < 4.9$
- Muon reconstruction capabilities: $P_t > 1\ GeV/c$, $m_{\mu\mu} > 2.5\ GeV/c^2$



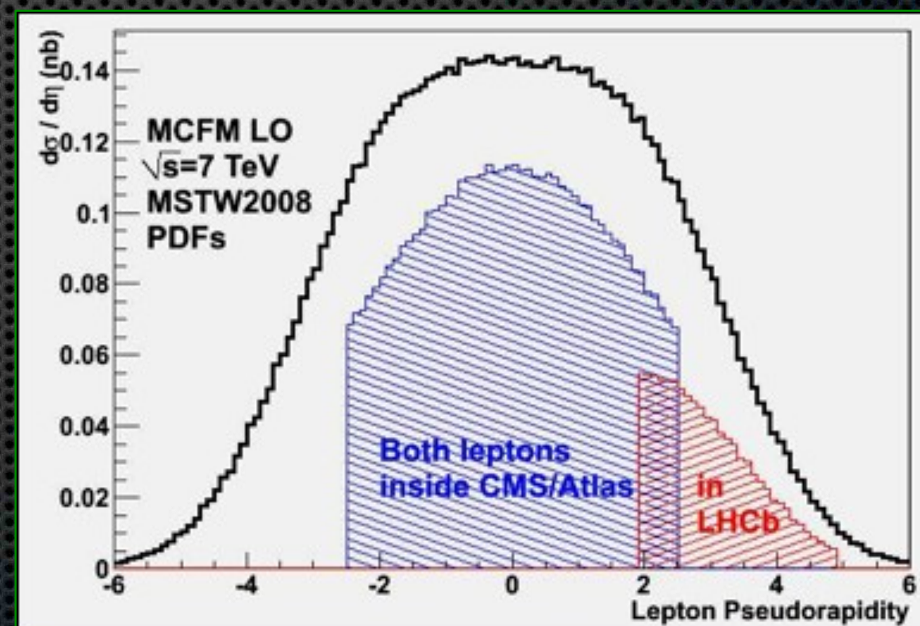
LHCb – A Forward Spectrometer

- Complementary η range to ATLAS & CMS
  - » Overlap for cross check
    $1.9 < \eta < 2.5$
  - » Unique to LHCb
    $2.5 < \eta < 4.9$





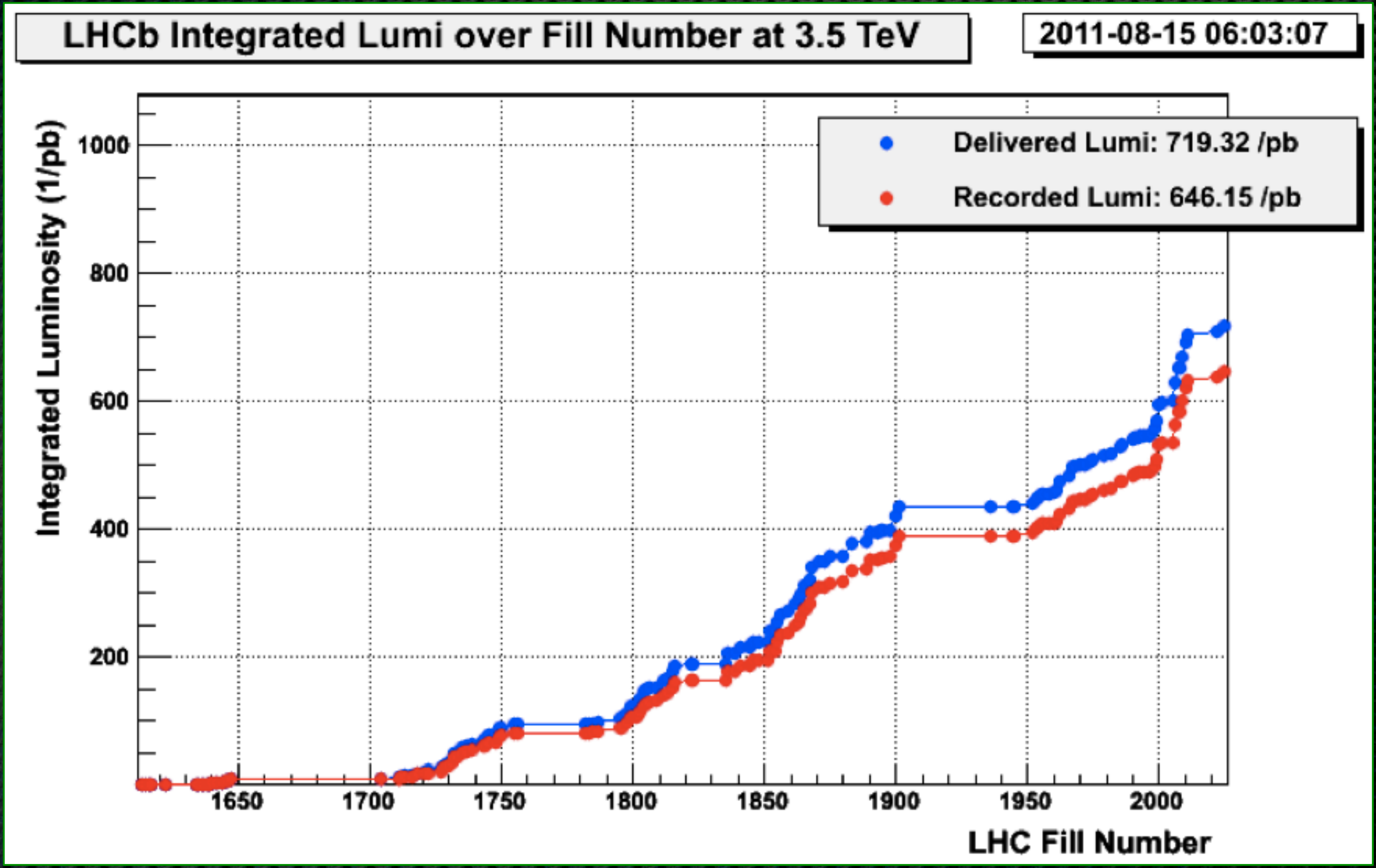
17%(16%) of $W^+(W^-)$ within LHCb



8% of Z within LHCb

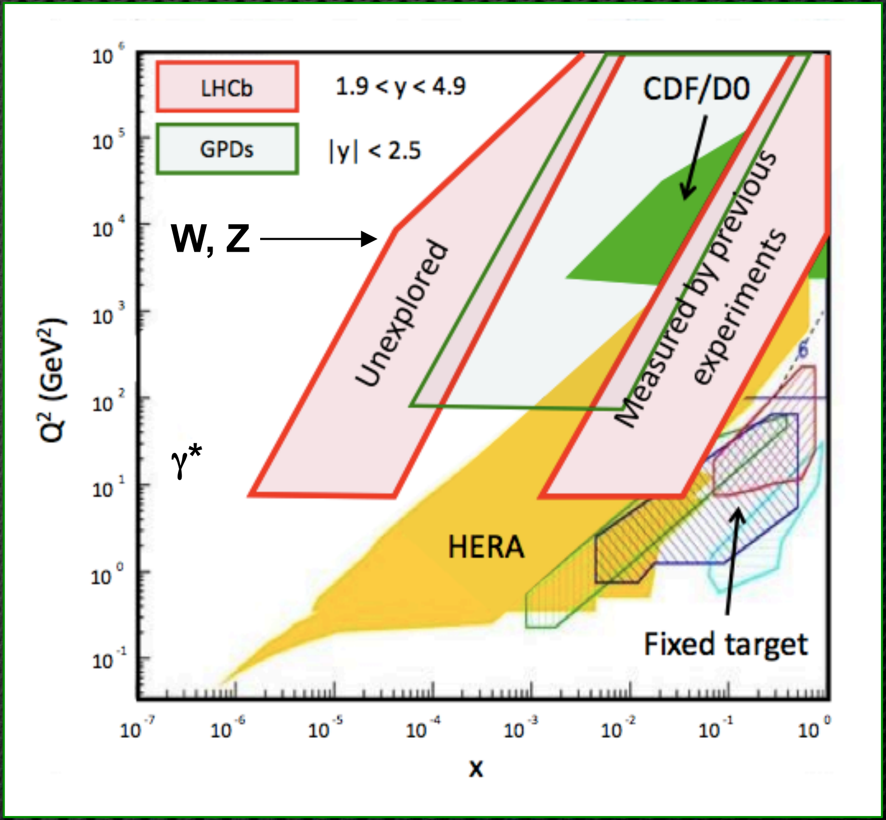
Datasets

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



W & Z Production and PDFs

- LHCb's forward acceptance provides very interesting possibilities for PDF studies
- Take large-x from one proton and a small-x from the other
  -> probe two distinct regions in (x, Q^2) space
- Can probe the low-x, high-Q^2 region inaccessible to other experiments (PDF predictions for this region are more sensitive to model changes than in central acceptance)
- Explore with W, Z (x of 10^{-4}, 10^{-1}) and low-mass Drell-Yan (x -> 10^{-6})

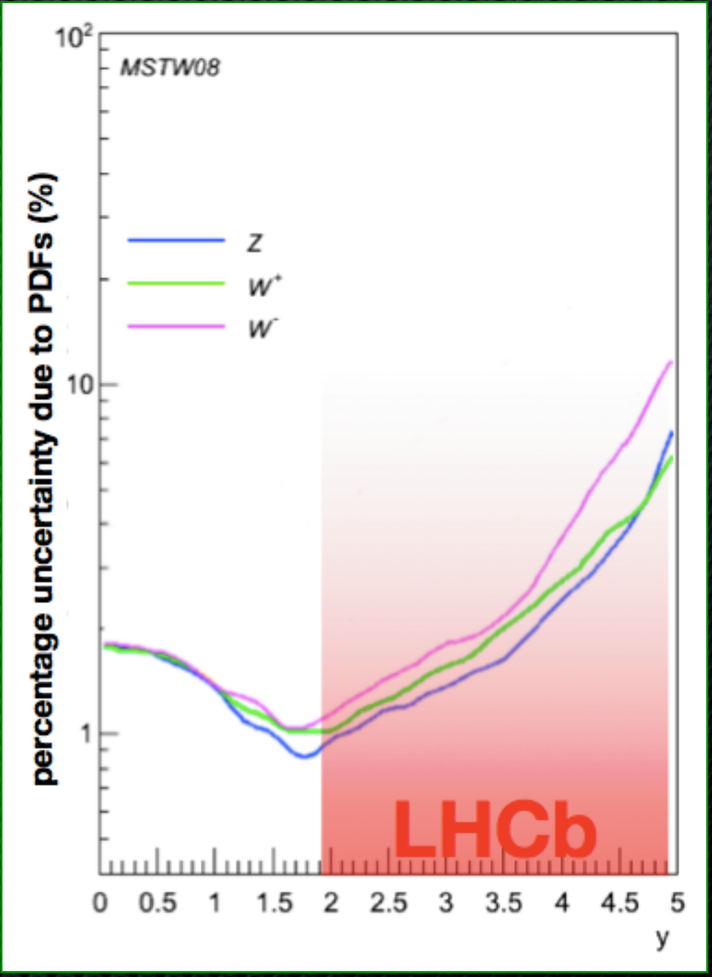


$$Q^2 = M^2 \;,\; x_{1,2} = \frac{M}{\sqrt{s}} \cdot e^{\pm y}$$

W & Z Production and PDFs

- Theoretical predictions
  - Partonic cross-sections known @ NNLO to 1%
  - PDF uncertainty dominates @ large rapidities (1% @ y<2, 6-8% @ y~5)

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



- Experimental measurements
  - Clean signature
  - Easily reconstructible final state
  - Low statistical and systematic errors

Cross-section measurements @ LHCb can constrain PDFs

W & Z Production and PDFs

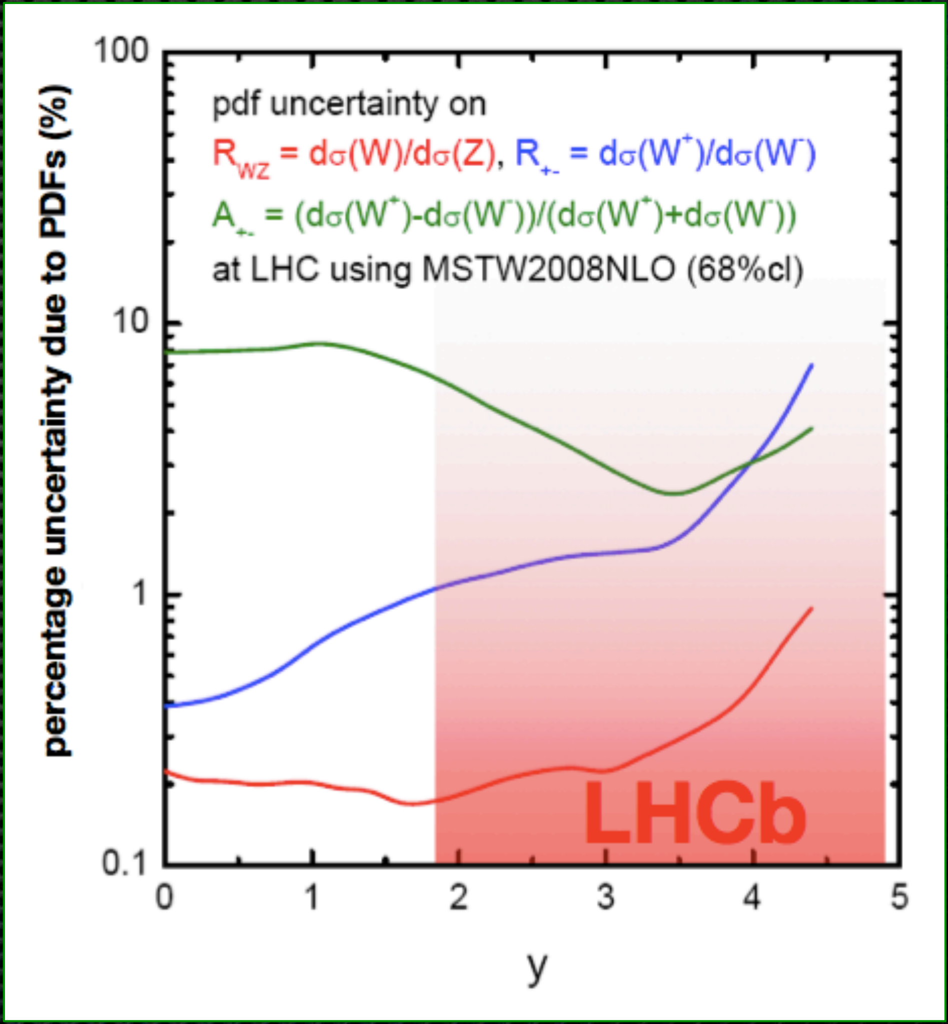
› Cancel or highlight PDF uncertainties with ratios

» $A_{+-} = (d\sigma_{W+} - d\sigma_{W-}) / (d\sigma_{W+} + d\sigma_{W-})$
tests u_V and d_V difference

» $R_{+-} = d\sigma_{W+} / d\sigma_{W-}$
tests d_V/u_V ratio

» $R_{WZ} = d\sigma_{W+-} / d\sigma_Z$
almost insensitive to PDFs
precise test of SM

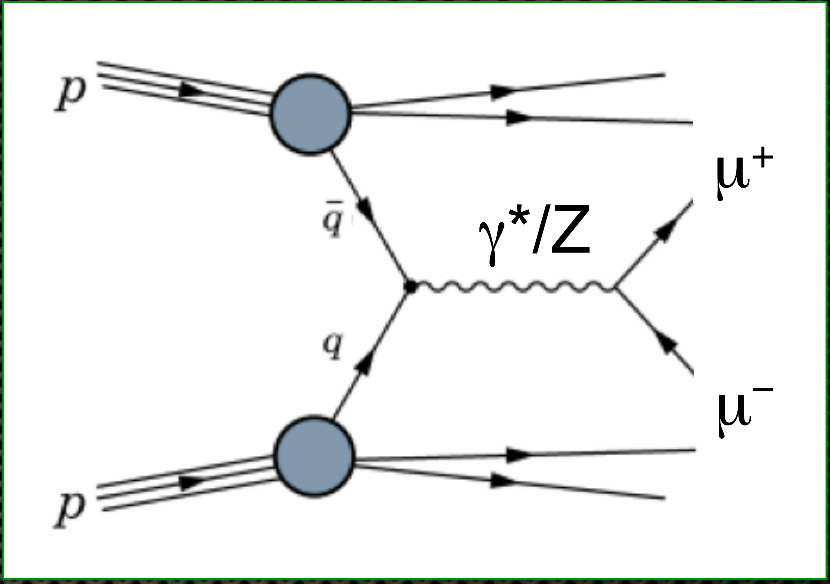
Many systematic errors cancel

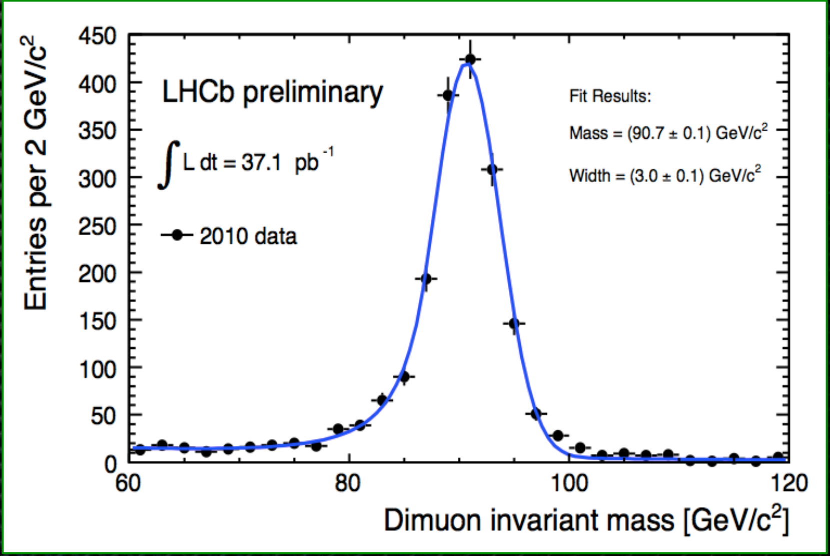


$Z \to \mu\mu$

LHCb Preliminary
LHCb-CONF-2011-039

- Single muon trigger: $P_t > 10$ GeV/c
- 2 reconstructed muons
  - $P_t > 20$ GeV/c
  - $2.0 < \eta < 4.5$
  - $60\ \mathrm{GeV}/c^2 < m_{\mu\mu} < 120\ \mathrm{GeV}/c^2$
- Backgrounds
  - $Z \to \tau\tau = 0.61 \pm 0.04$ (MC)
  - Heavy flavour = 4.3 ± 1.7 (Data)
  - π/K mis-ID = 0 ± 1 (Data)
- $N_{Candidates} = 1966$
- $N_{Background} = 4.9 \pm 2.0$



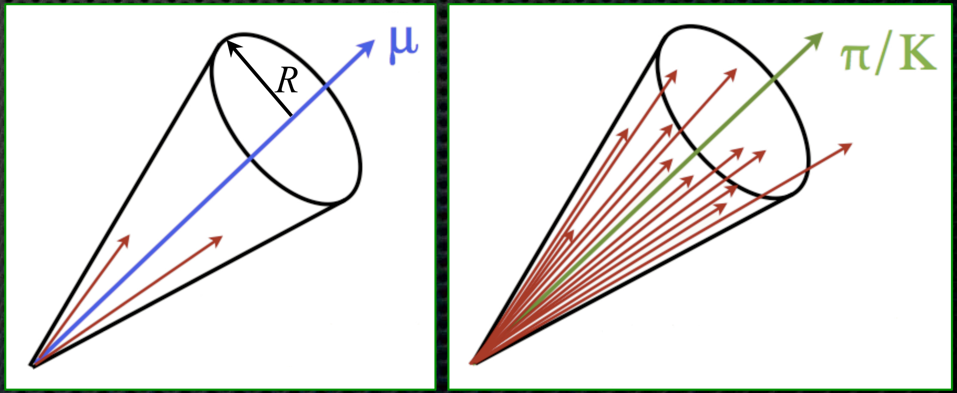


$Z \to \tau\tau$

- Both τs decay to μ
- One τ decays to μ, one to e

Single muon trigger: $P_t > 10$ GeV/c

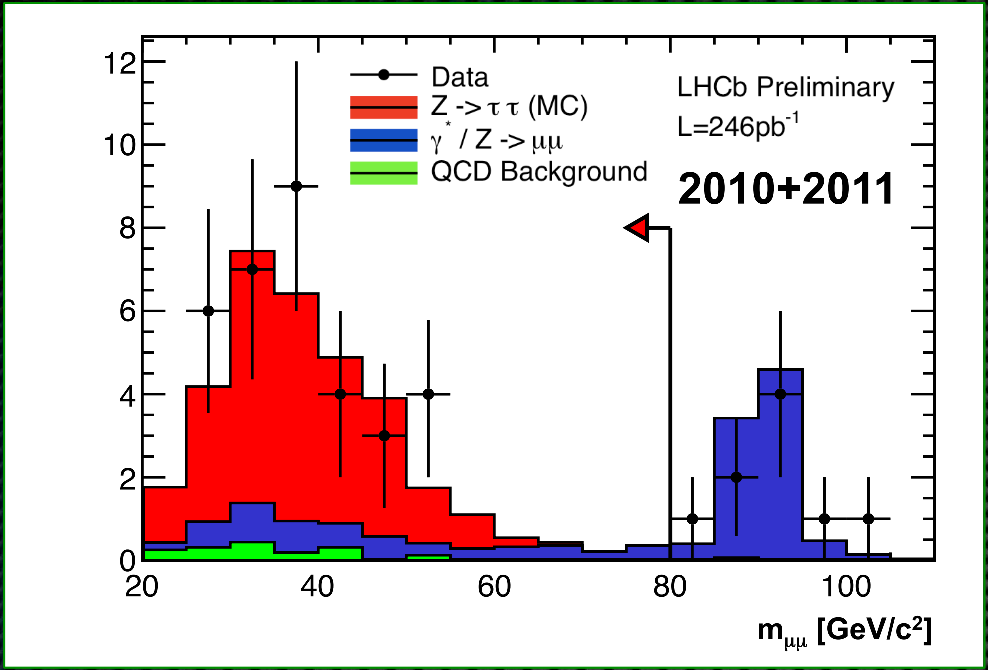
- **2 reconstructed isolated μs**
  - $P_{t,1} > 20$ GeV/c, $P_{t,2} > 5$ GeV/c
  - $2.0 < \eta < 4.5$
  - $\Delta\phi > 2.7$
  - Cone P_t asymmetry (R=0.5) > 0.8
  - Muon P_t asymmetry > 0.2
  - Impact parameter significance > 4
  - $m_{\mu\mu} < 80$ GeV/c^2
- **1 reconstructed & isolated μ & e**
  - $P_{t,\mu} > 20$ GeV/c, $P_{t,e} > 5$ GeV/c
  - $2.0 < \eta < 4.5$
  - $\Delta\phi > 2.7$
  - Cone P_t asymmetry (R=0.5) > 0.8

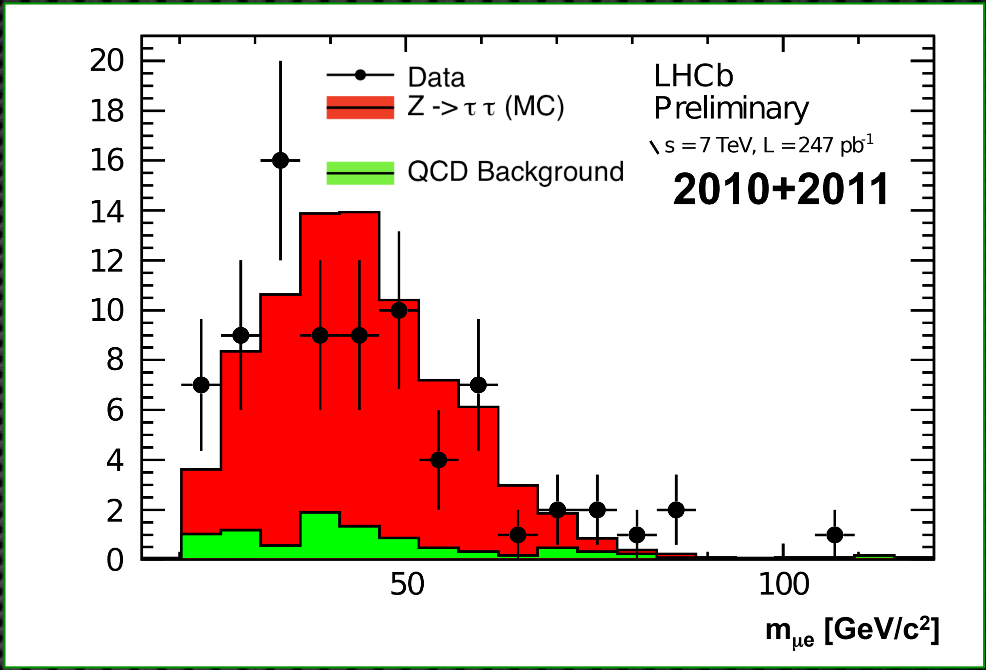


$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

Z -> ττ

LHCb Preliminary
LHCb-CONF-2011-041



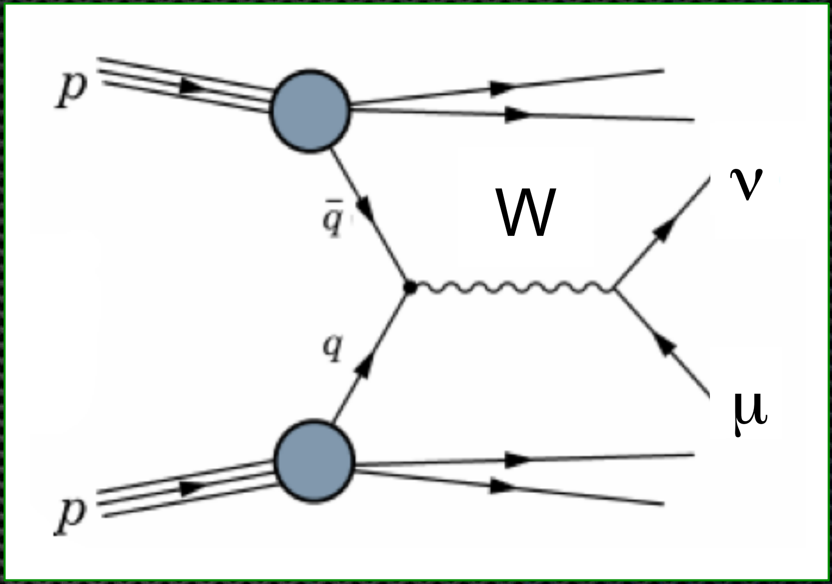


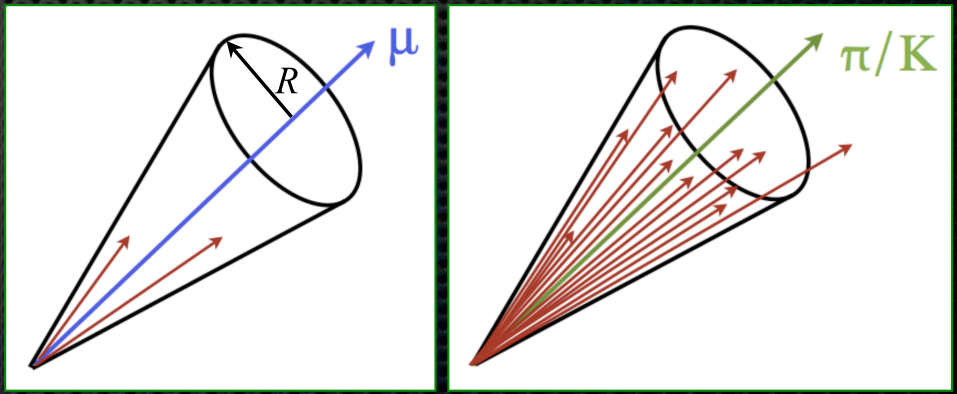
- **Backgrounds**
  - EW = 5.5 ± 1.8 (Data)
  - QCD = 1.6 ± 1.3 (Data)
- $N_{Candidates} = 33$

- **Backgrounds**
  - EW = 3.0 ± 1.2 (MC)
  - QCD = 9.5 ± 3.0 (Data)
- $N_{Candidates} = 81$

$W \to \mu\nu_\mu$

- 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
  - $\gamma^*/Z \to \mu\mu$ (MC)
  - $W \to \tau\nu$ and $Z \to \tau\tau$ (MC)
  - K/π punchtrough (Data)
  - K/π decay in flight (Data)
  - Heavy flavour (Data)





$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

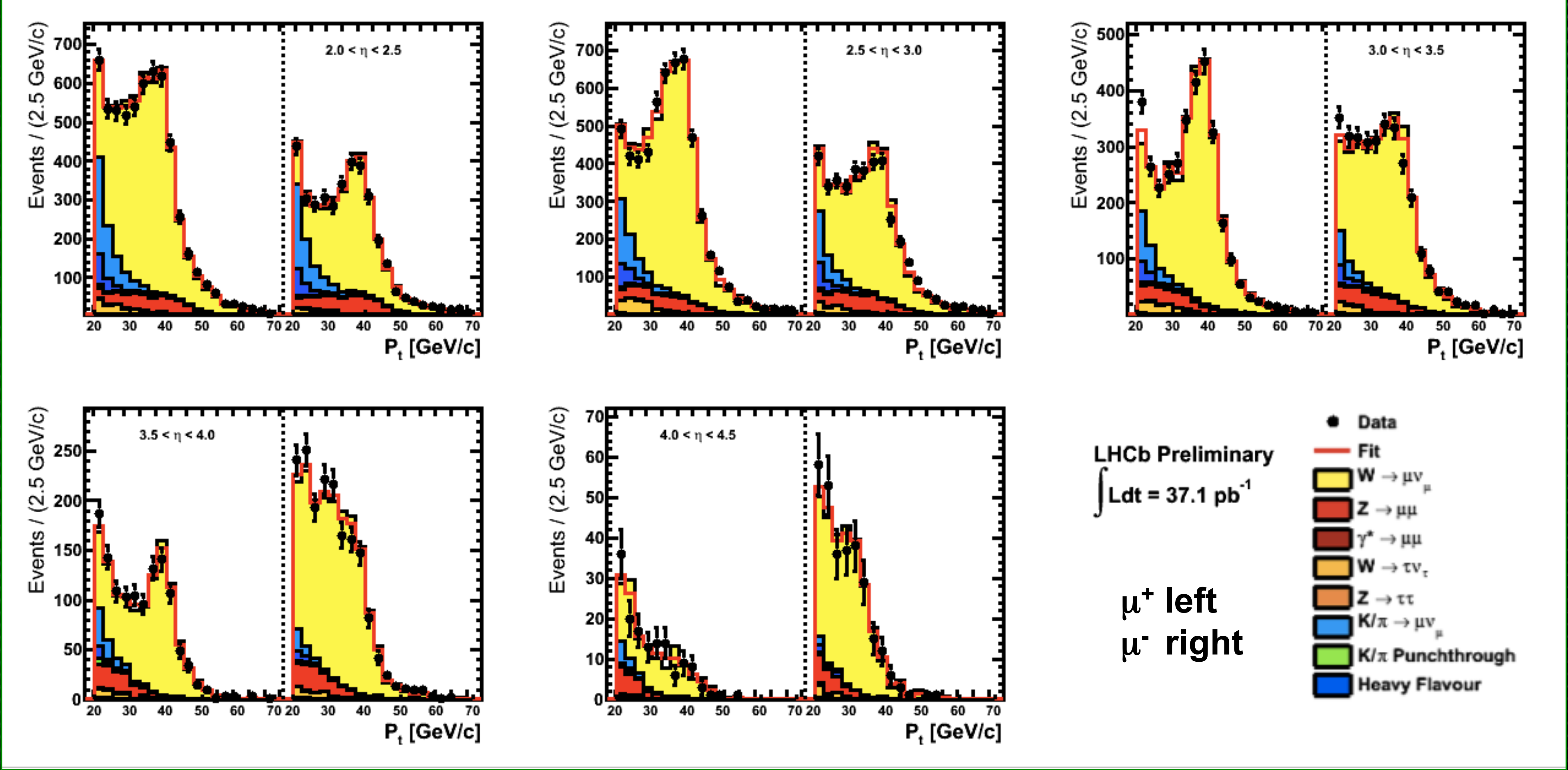
$W \to \mu\nu_\mu$

- Specific cuts implemented to reduce each background component
- $\gamma^*/Z \to \mu\mu$
  - No extra muons with $P_t > 5$ GeV/c
- $W \to \tau\nu$, $Z \to \tau\tau$ and Heavy flavour
  - Impact parameter < 40 μm
- K/π punchthrough
  - $E_{E+H} / P < 4\%$
- K/π decay in flight
  - Largest residual background besides $Z \to \mu\mu$ with one muon outside the acceptance
  - Modelled with tracks which have not caused the event to fire any trigger, weighted by their probability to decay measured from data

$W \to \mu\nu_\mu$

LHCb Preliminary
LHCb-CONF-2011-039

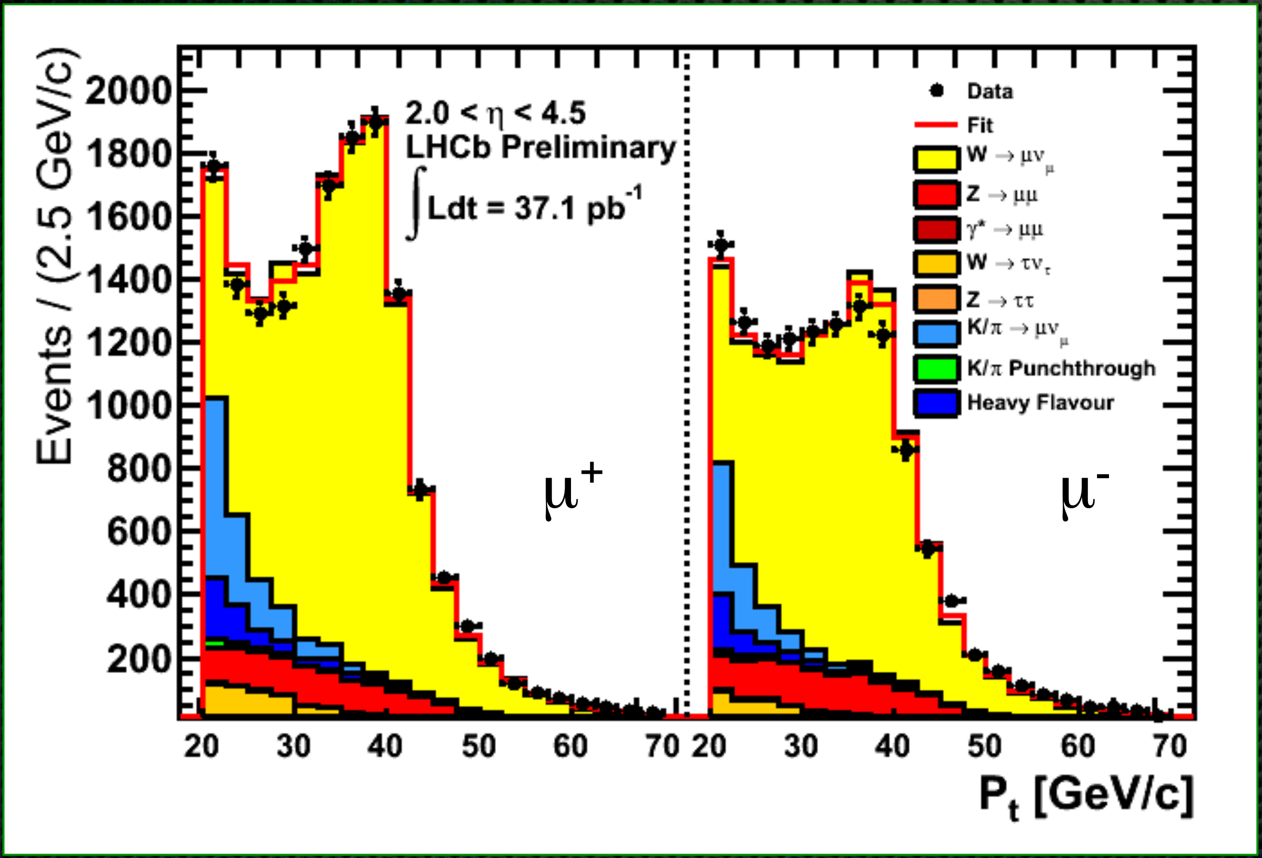
- Fit positive and negative muon P_t spectra in data to expected shapes for signal and backgrounds in 5 η bins



$W \to \mu\nu_\mu$

LHCb Preliminary
LHCb-CONF-2011-039

› Fit positive and negative muon P_t spectra in data to expected shapes for signal and backgrounds in 5 η bins



$N^{+}_{Candidates}$ = 15608

$N^{-}_{Candidates}$ = 12301

$Purity^{+}$ ~ 80%

$Purity^{-}$ ~ 78%

Efficiencies

- The cross-section for boson production can be expressed as

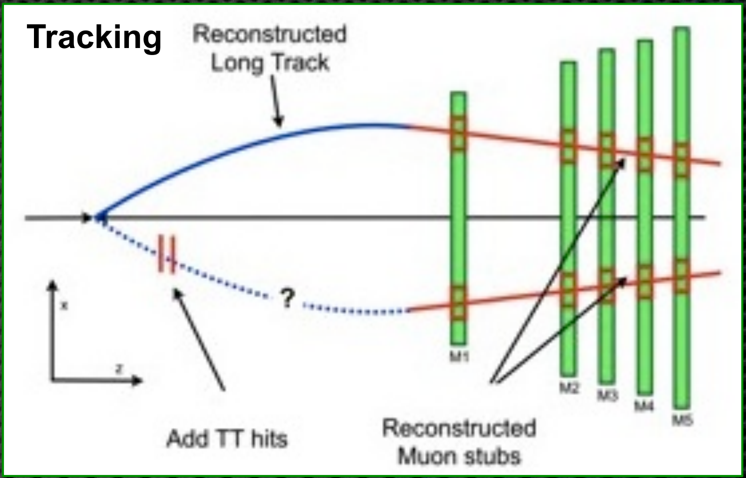
$$\sigma = \frac{N_{Candidates} - N_{Background}}{A \cdot \varepsilon_{Trigger} \cdot \varepsilon_{Tracking} \cdot \varepsilon_{ID} \cdot \varepsilon_{Selection} \cdot \int L}$$

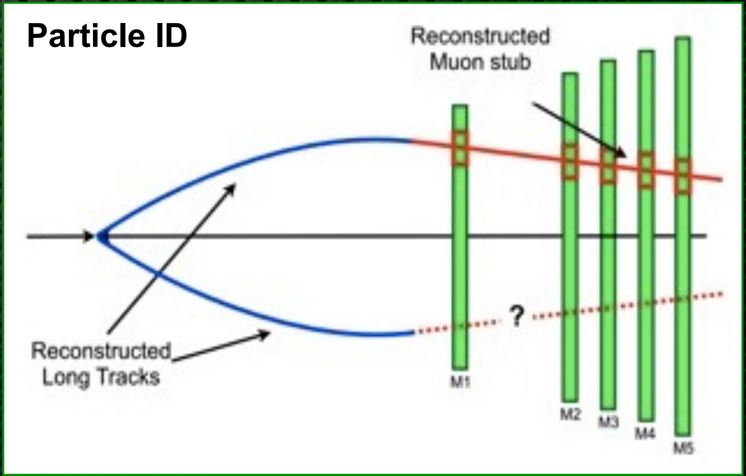
- Measurements performed in the forward region ($2.0<\eta<4.5$) for leptons with $P_t>20$ GeV/c -> A = 1 (except for Z->ττ, obtained from MC)
- Efficiencies determined from data and cross checked with simulation

- Selection efficiency
  - Z->μμ selection criteria define the measurement kinematic region
  - Z->ττ: determined from MC
  - W->μν: measured from Z->μμ data with 1 muon masked

Efficiencies

- Efficiencies determined with a Tag&Probe method in Z->ll 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 ϕ, P_t, and #PV
  - No evidence for charge bias
  - Correction vs η





Systematics

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

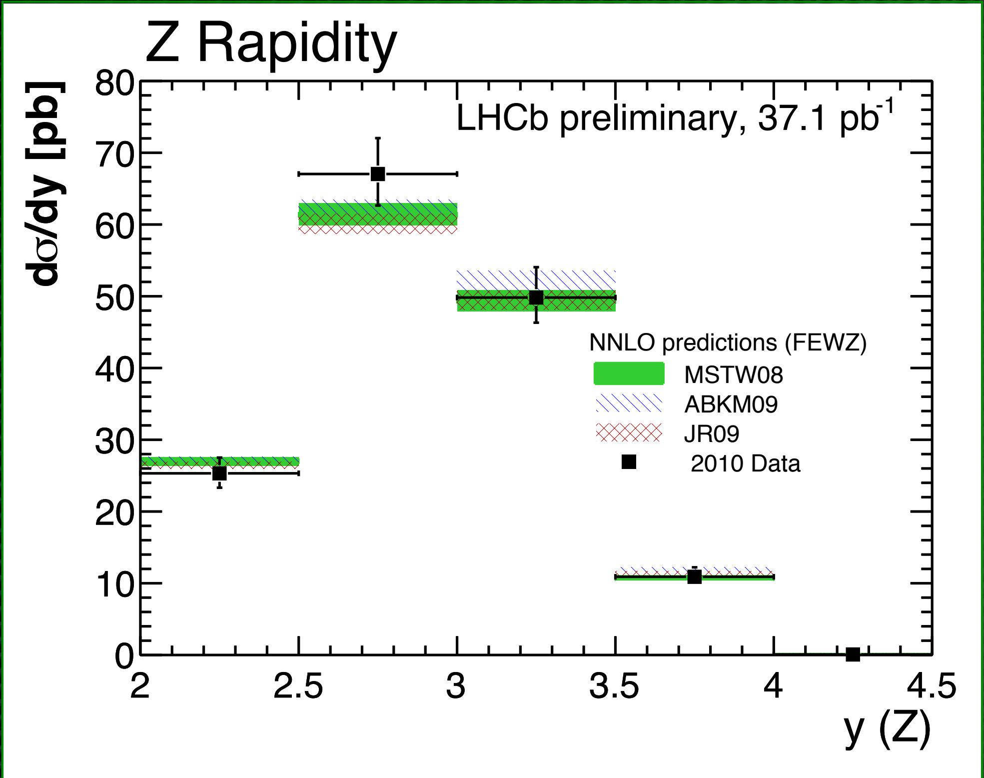
Source	$Z \to \mu\mu$	$Z \to \tau\tau(\mu\mu)$	$Z \to \tau\tau(\mu e)$	$W^+ \to \mu^+\nu_\mu$	$W^- \to \mu^-\bar{\nu}_\mu$
Background	0.4	7	5	1.6	1.6
Shape (Fit)	-	-	-	1.9	1.7
Efficiency	5.1	9	8	2.5	2.3
Acceptance	-	2	5	-	-
FSR	0.3	0.2	0.2	0.2	0.2
Systematic	5.1	11	10	3.5	3.2
Luminosity	3.5	5.1		3.5	
Statistical	2.1	17	12	0.9	1.1

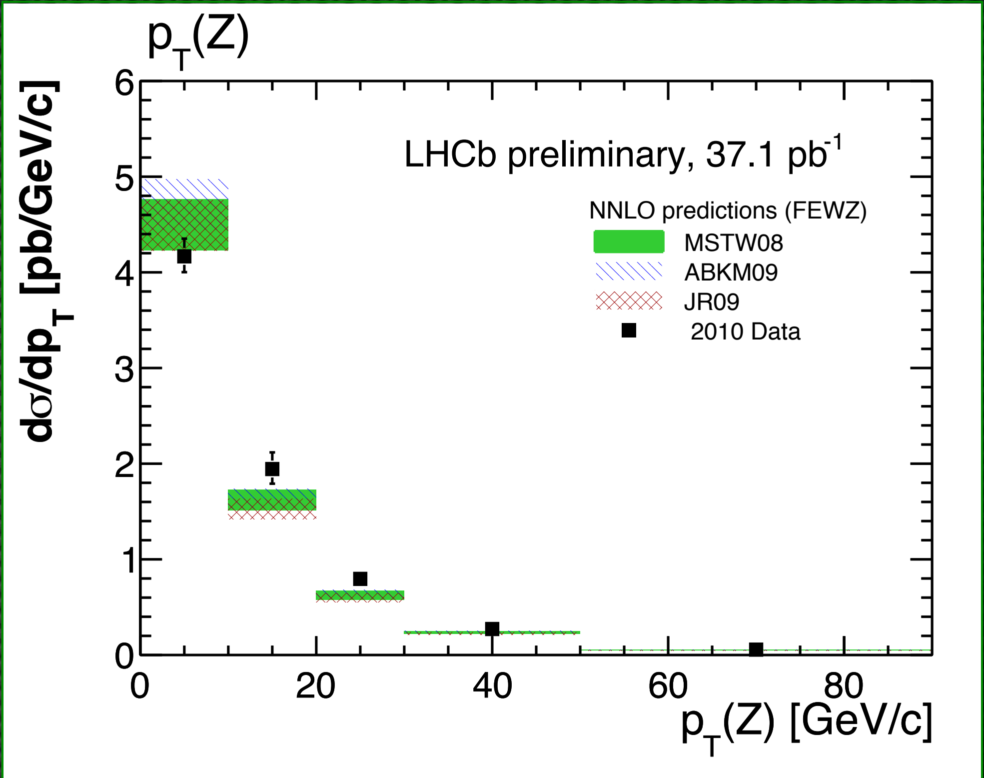
relative error

Z Cross-Section

LHCb Preliminary
LHCb-CONF-2011-039(041)

> **Kinematic range**: $2.0 < \eta_l < 4.5$, $P_{t,l} > 20$ GeV/c and $60 < m_{ll} < 120$ GeV/c^2





$\sigma_{Z\to\mu\mu} = 74.9 \pm 1.6_{stat} \pm 3.8_{syst} \pm 2.6_{lumi}$ [pb]

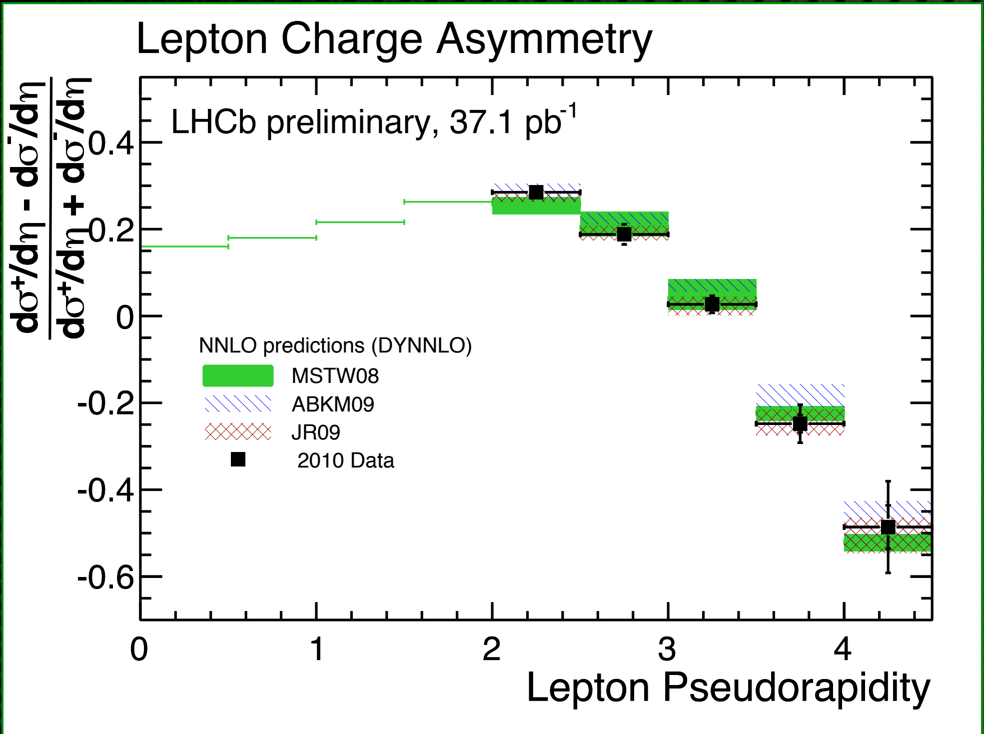
$\sigma_{Z\to\tau\tau} = 82 \pm 8_{stat} \pm 7_{syst} \pm 4_{lumi}$ [pb]

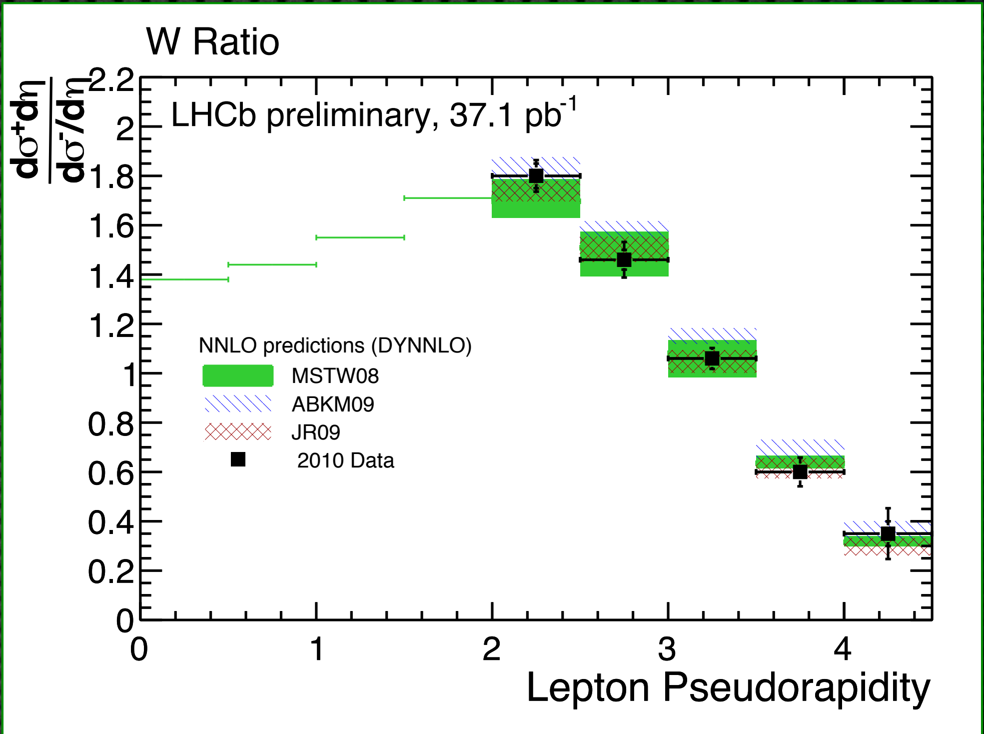
$\Gamma(Z\to\tau\tau) / \Gamma(Z\to\mu\mu) = 1.09 \pm 0.17$

W Cross-Section

LHCb Preliminary
LHCb-CONF-2011-039

> **Kinematic range**: $2.0 < \eta_l < 4.5$ and $P_{t,l} > 20$ GeV/c



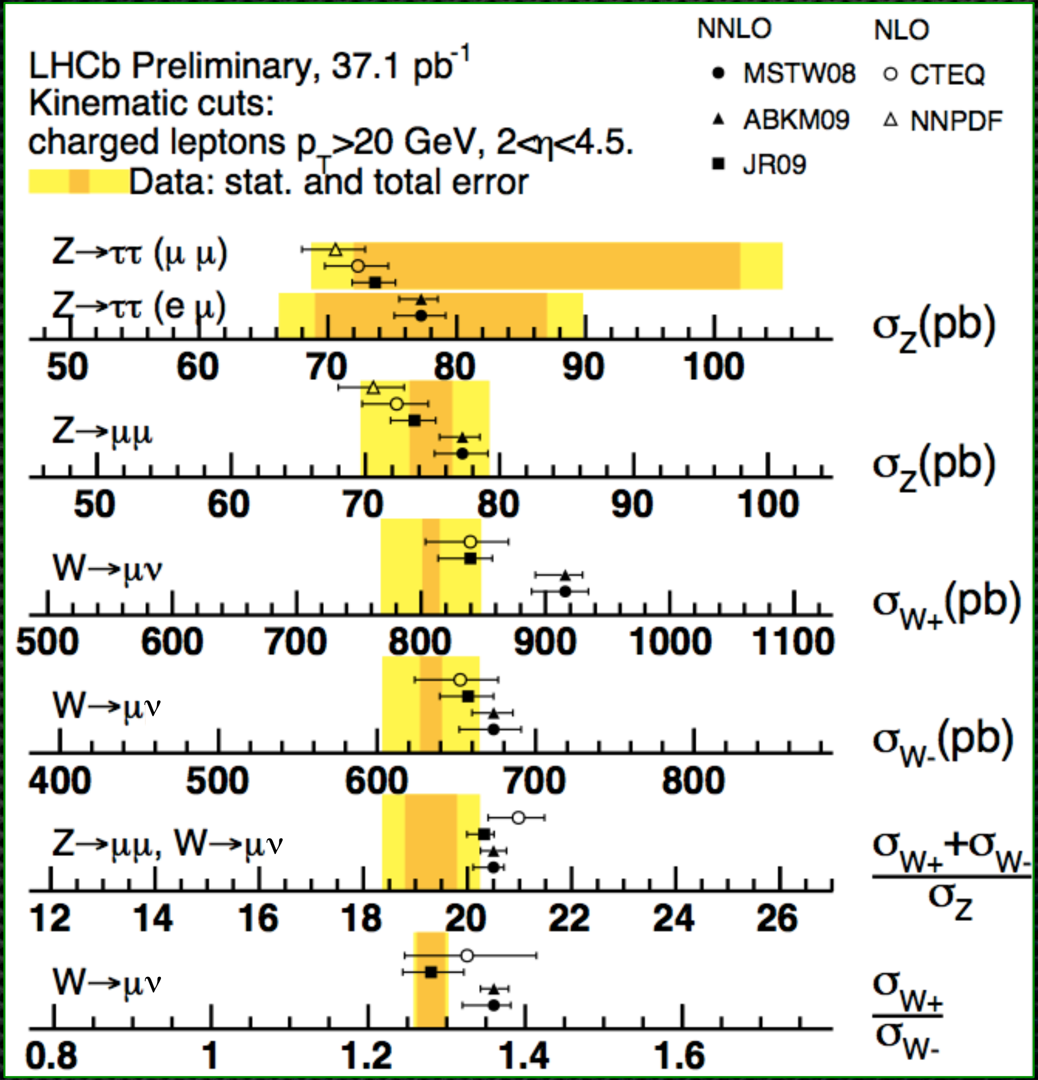


$$\sigma_+ = (808 \pm 7_{stat} \pm 28_{syst} \pm 28_{lumi})\ \text{pb}$$
$$\sigma_- = (634 \pm 7_{stat} \pm 21_{syst} \pm 22_{lumi})\ \text{pb}$$
$$\sigma_+ / \sigma_- = 1.28 \pm 0.02_{stat} \pm 0.01_{syst}$$

Comparisons

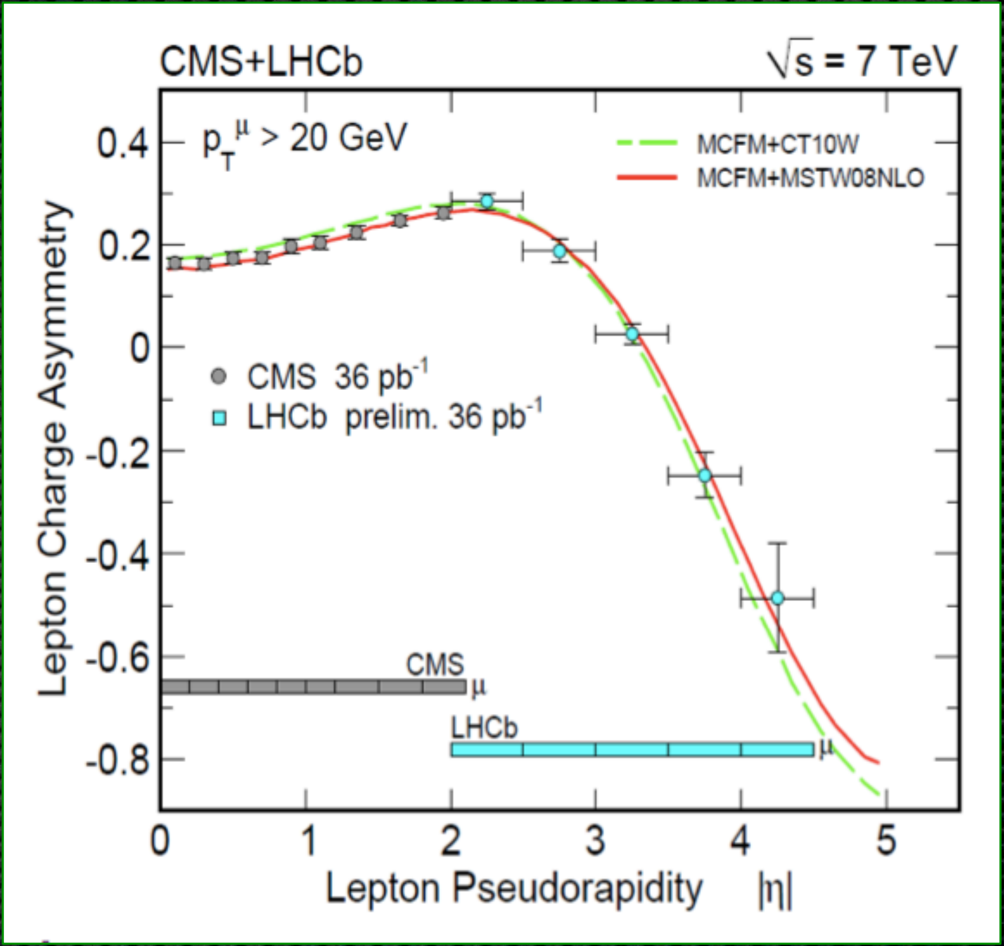
LHCb Preliminary
LHCb-CONF-2011-039(041)

> All W and Z observations are consistent with NNLO predictions



Improvements on PDFs

- Central and forward measurements of the W charge asymmetry will reduce the PDF uncertainty in both the large and small x regions



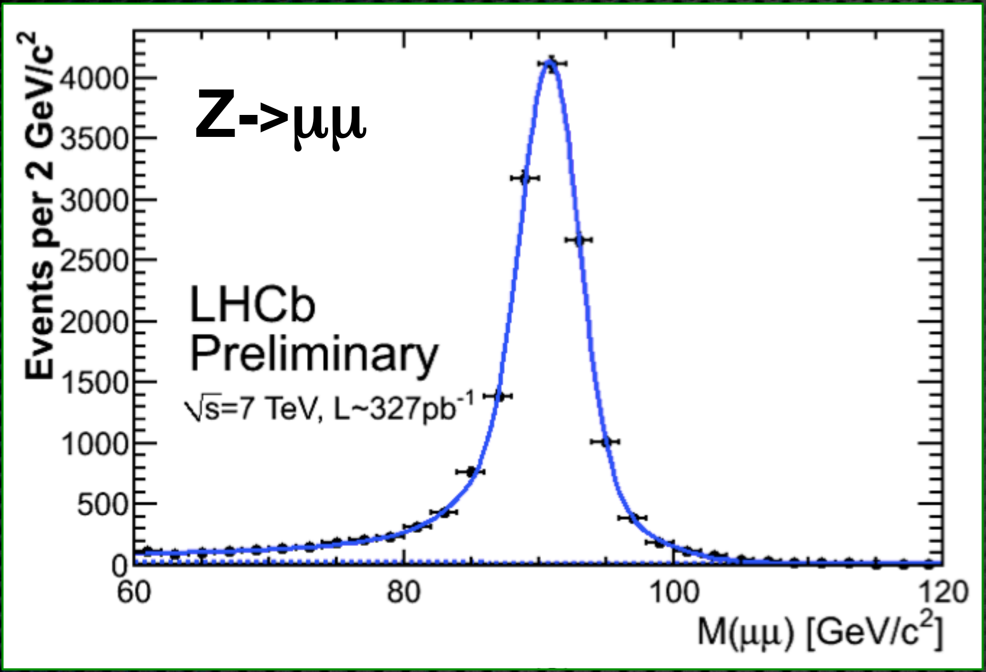
J. Alcaraz, EPS 2011

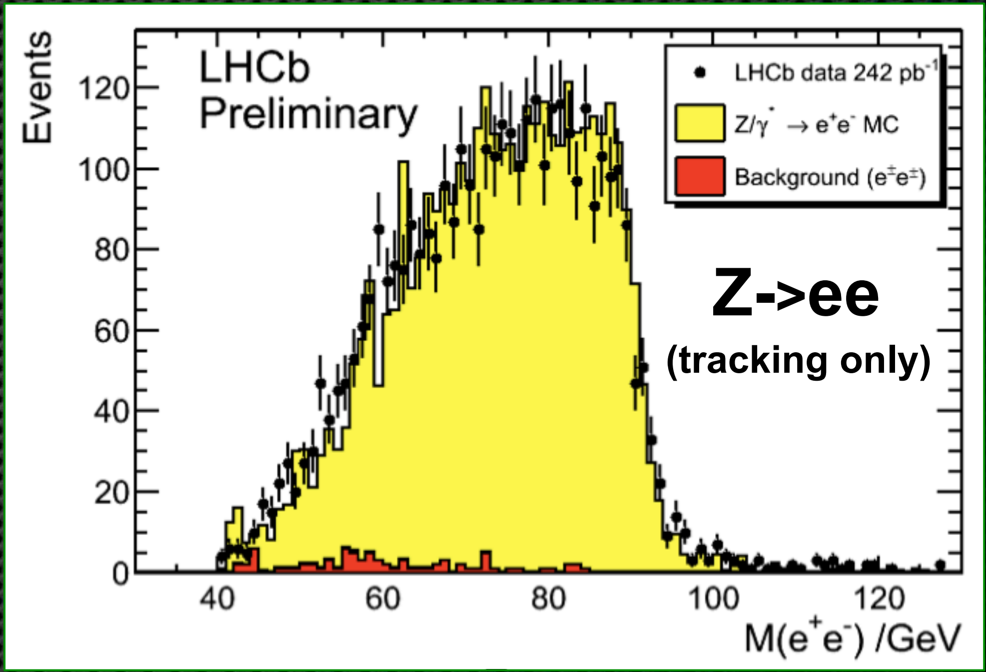
Summary and Outlook

- Cross-sections and ratios of W and Z measured @ 7TeV in the kinematic range $2.0 < \eta < 4.5$ and $P_t > 20$ GeV/c
- All observations consistent with the current NNLO predictions

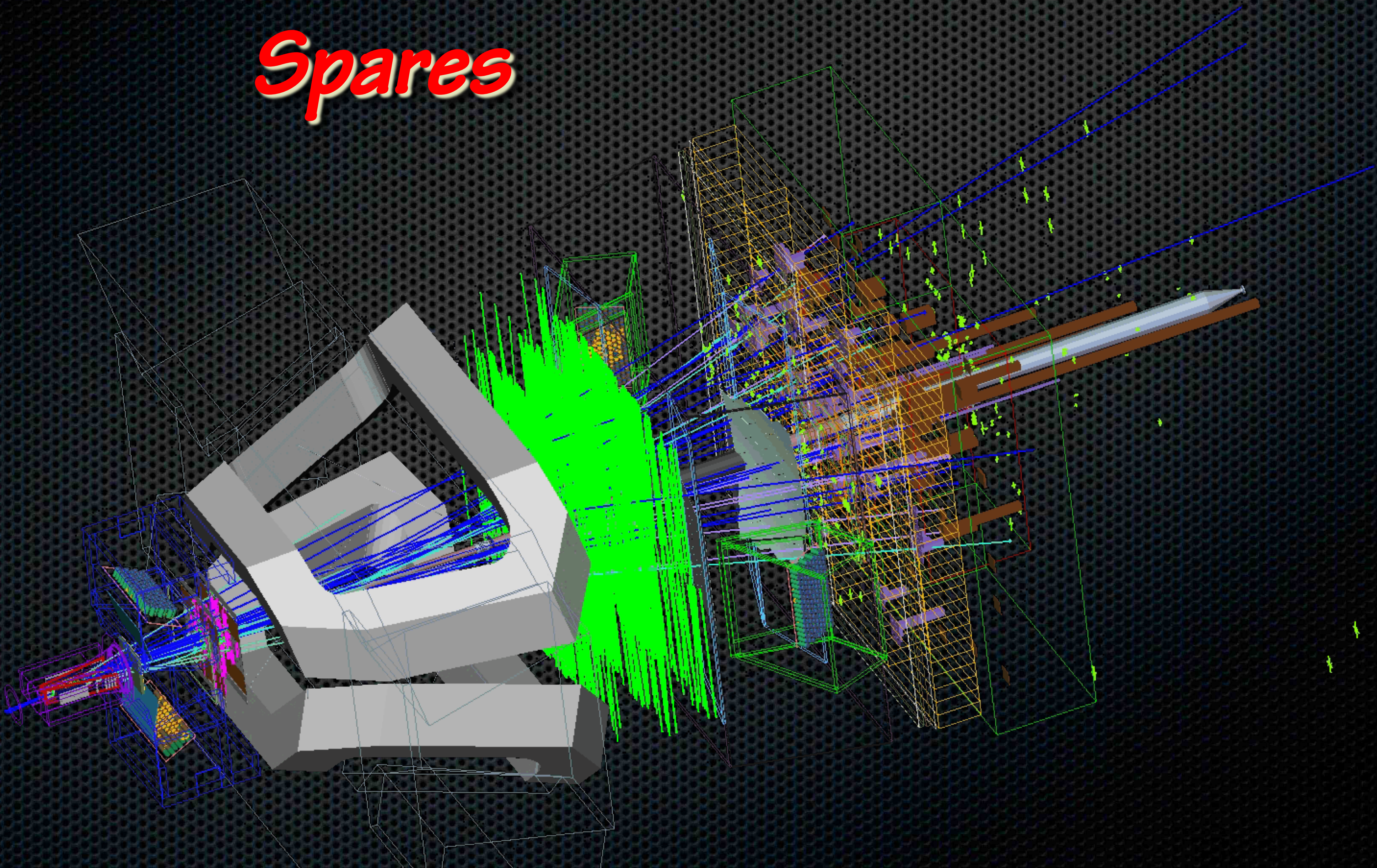
- Expect to collect ~1 fb^{-1} in 2011
  -> improved efficiency and background knowledge
- Probe PDFs in previously unexplored regions
- Distinguish different PDF models

Summary and Outlook





Spares

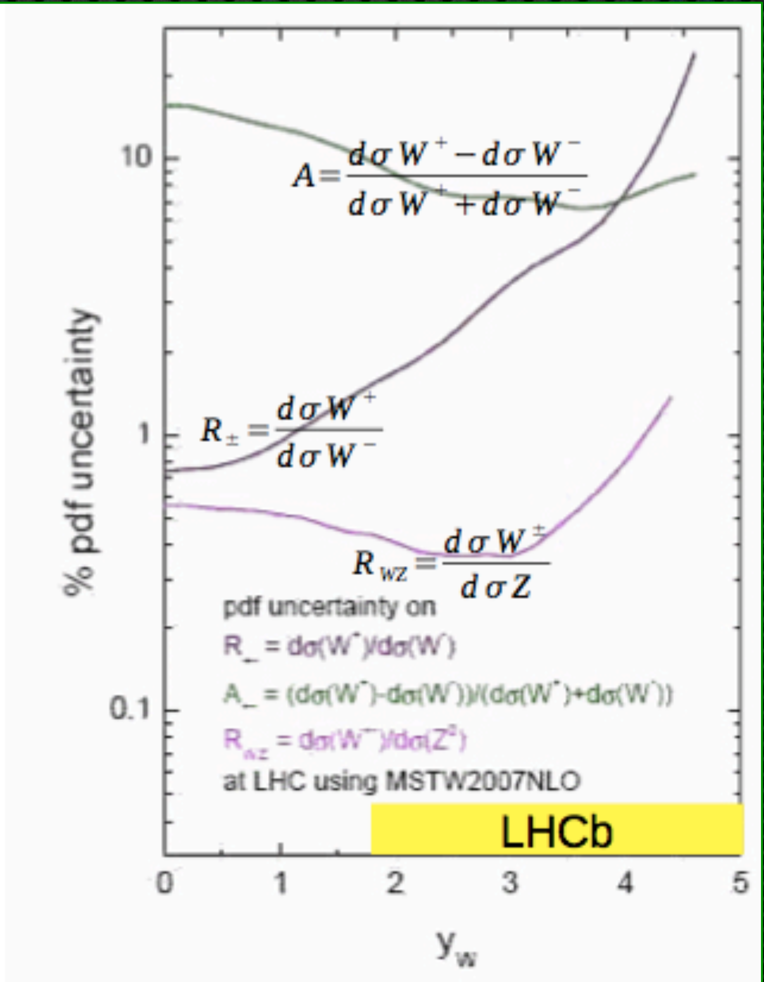


W&Z Production and PDFs

- R_{+-}=dσ(W⁺)/dσ(W⁻) tests valence quarks: d_V/u_V ratio

$$R(y)=\frac{d\sigma/dy(W^-)}{d\sigma/dy(W^+)}\approx\frac{d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2)}\approx\frac{d(x_1)}{u(x_1)}$$

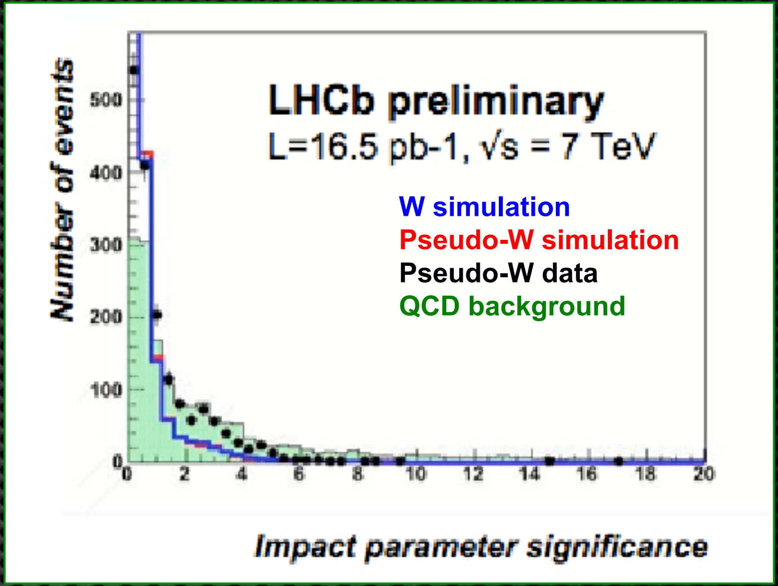
- A_W =(dσ(W⁺)–dσ(W⁻))/(dσ(W)+dσ(W⁻)) tests valence quarks: difference btw. u_V and d_V



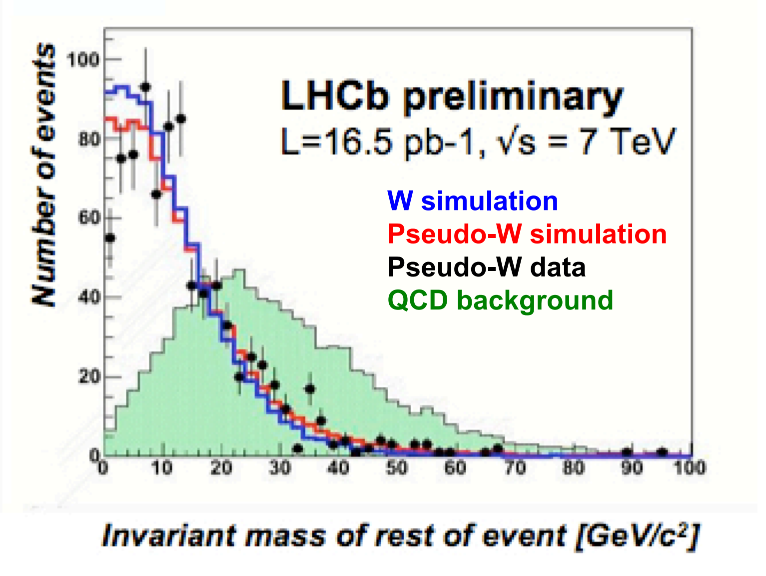
$$A(y)=\frac{d\sigma/dy(W^+)-d\sigma/dy(W^-)}{d\sigma/dy(W^+)+d\sigma/dy(W^-)}\approx\frac{u(x_1)\bar{d}(x_2)-d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2)+d(x_1)\bar{u}(x_2)}\approx\frac{u(x_1)-d(x_1)}{u(x_1)+d(x_1)}$$

W -> $\mu\nu_\mu$

- Backgrounds defined by anti cuts
  - K/π punchtrough: E_{E+H} / P > 10%
  - K/π decay in flight: Prob(K/π->μν, P)
  - Heavy flavor: Impact parameter > 80 μm



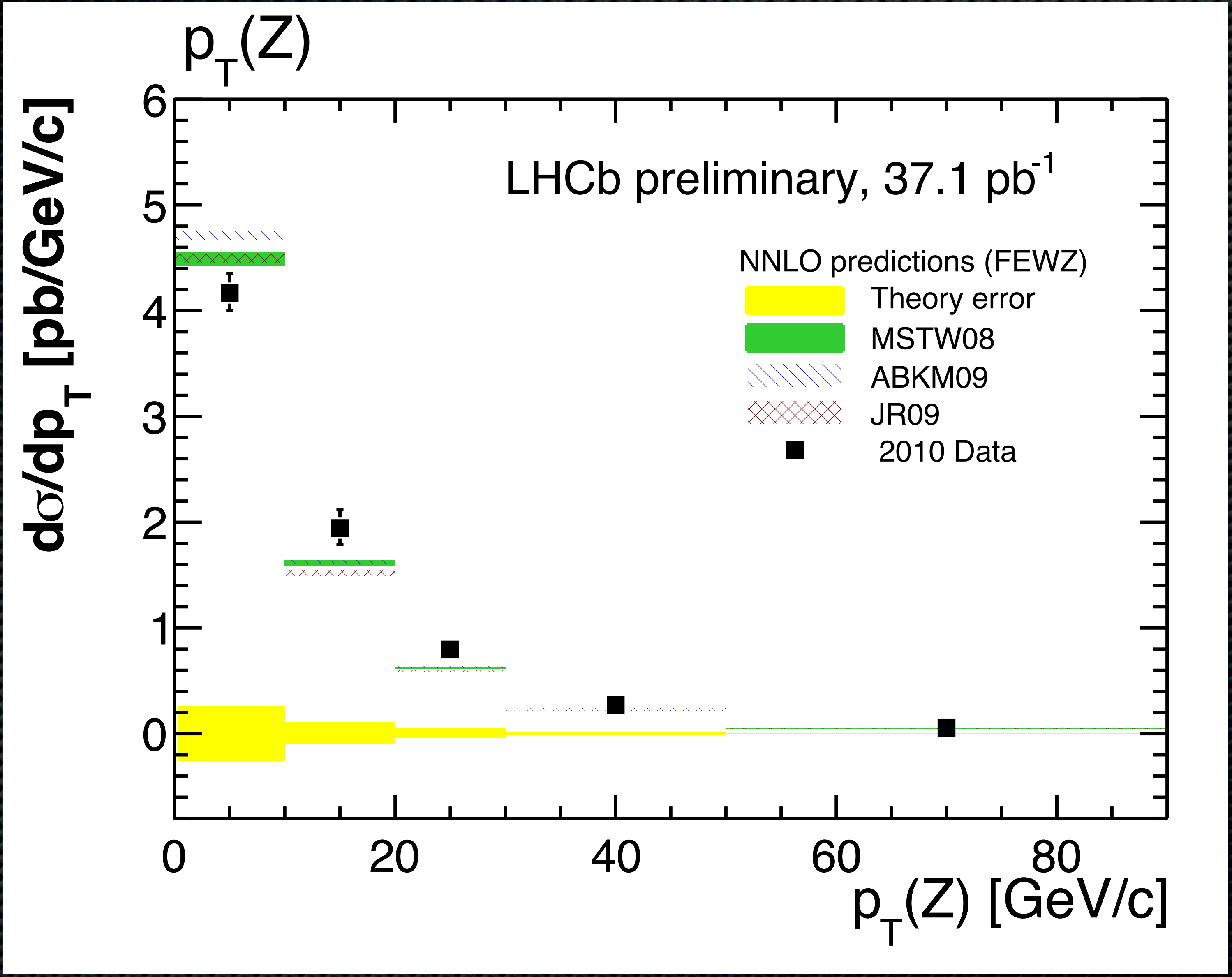
- Pseudo-W (Z events with 1 muon masked)
  - Pseudo-W and W simulated distributions look similar
  - Pseudo-W data described by simulation
  - Signal can be modeled with Pseudo-W data



Efficiencies

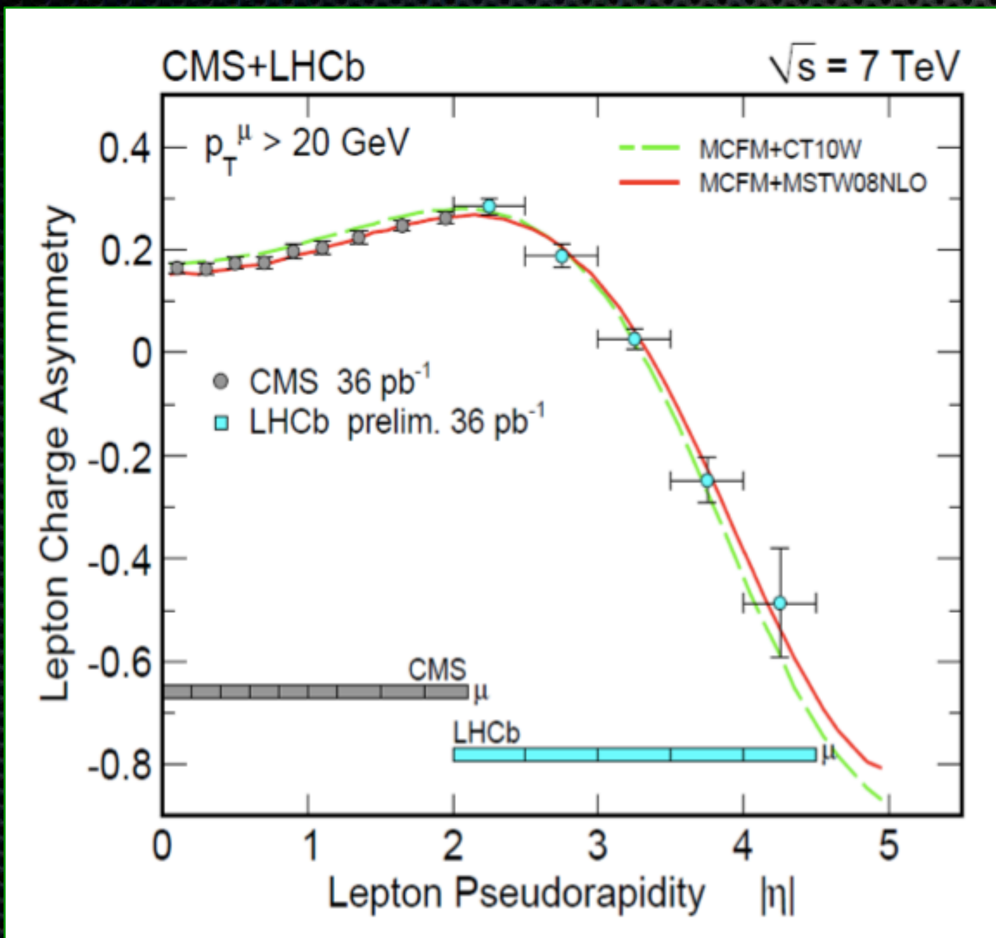
Source	Z->μμ	Z->ττ(μμ)	Z->ττ(μe)	W->μν_μ
Trigger	90	86	78	78
Tracking	82	84	84 80	79
ID	98	99.1	99.1 96.2	99
Selection	-	17.2	46	45-80
Acceptance	1	38.6	24.9	1

Z Cross-Section

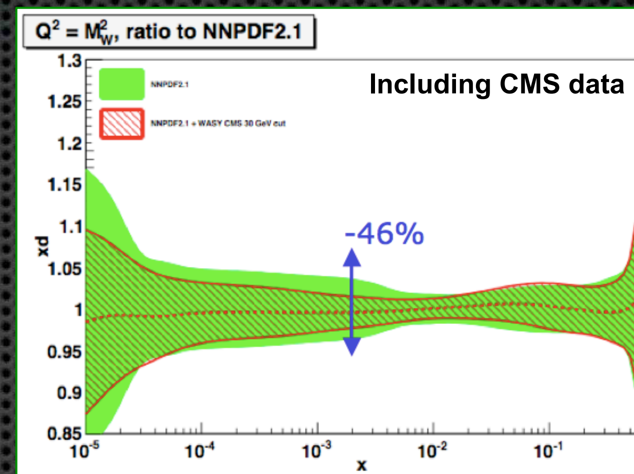


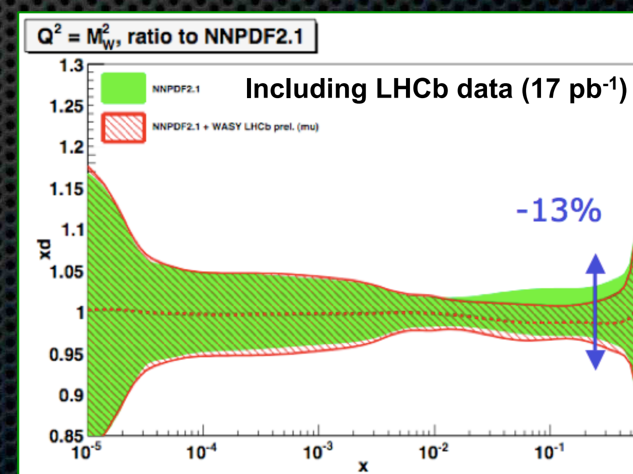
Improvements on PDFs

> LHCb measurement of the W charge asymmetry slightly reduce the uncertainty in the large-x region while small-x is unchanged



J.Alcaraz, EPS 2011





M.Ubiali, LHC EWK 2011

Improvements on PDFs

PDF correlation between asymmetry and u_v-d_v versus x