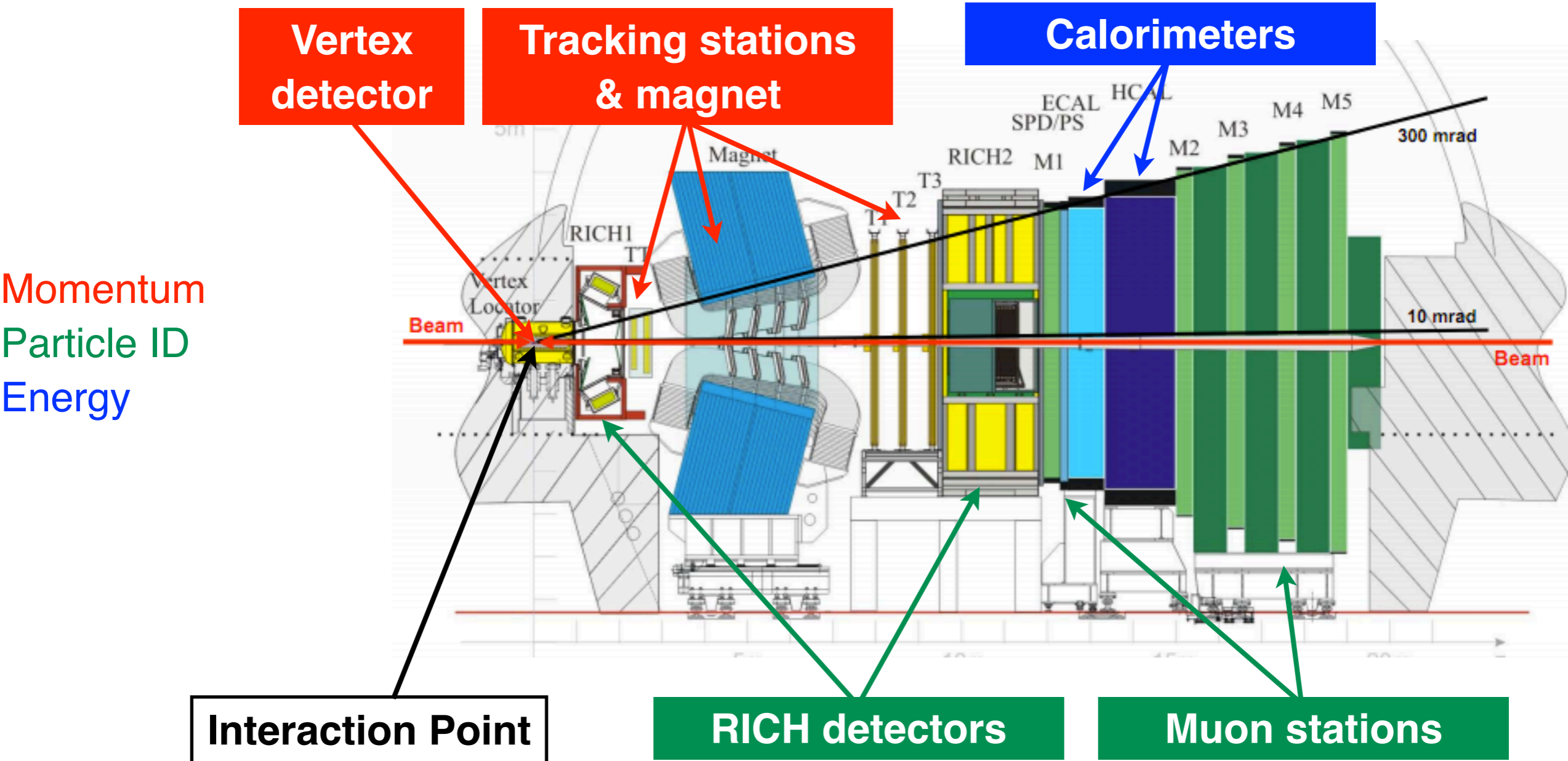# W and Z production in the forward region at LHCb

Jonathan Anderson,   University of Zurich

For the LHCb collaboration
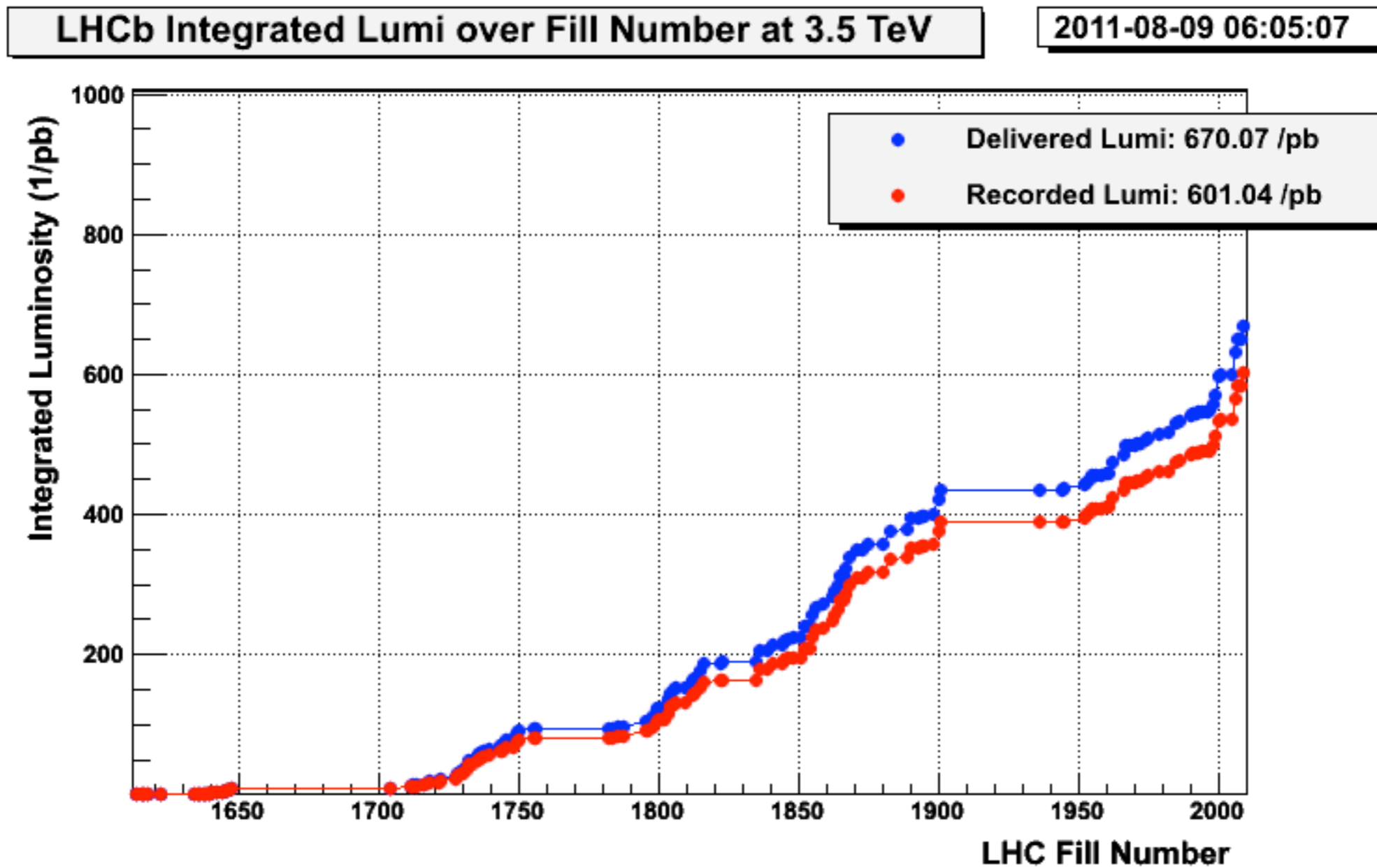
LHCb: A **forward** spectrometer

- Designed to search for new physics in B and D decays at LHC

- bb pairs mainly produced in same forward or backward cone

- Fully instrumented in the forward region ($1.9 < \eta < 4.9$)

Momentum
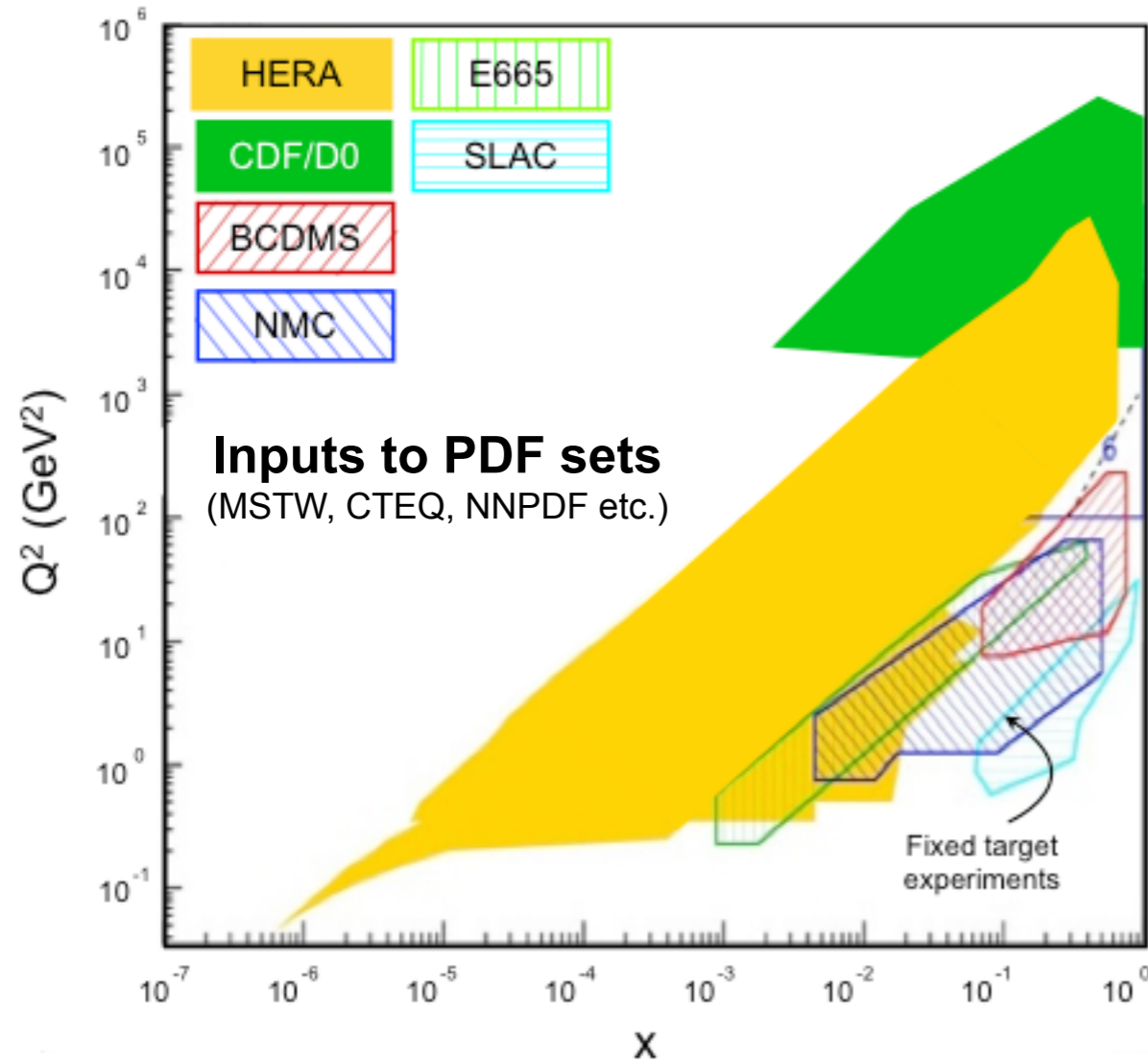Particle ID
Energy

Vertex detector

Tracking stations & magnet

Calorimeters

Interaction Point

RICH detectors

Muon stations

Datasets

2010: 37.7 pb^{-1}

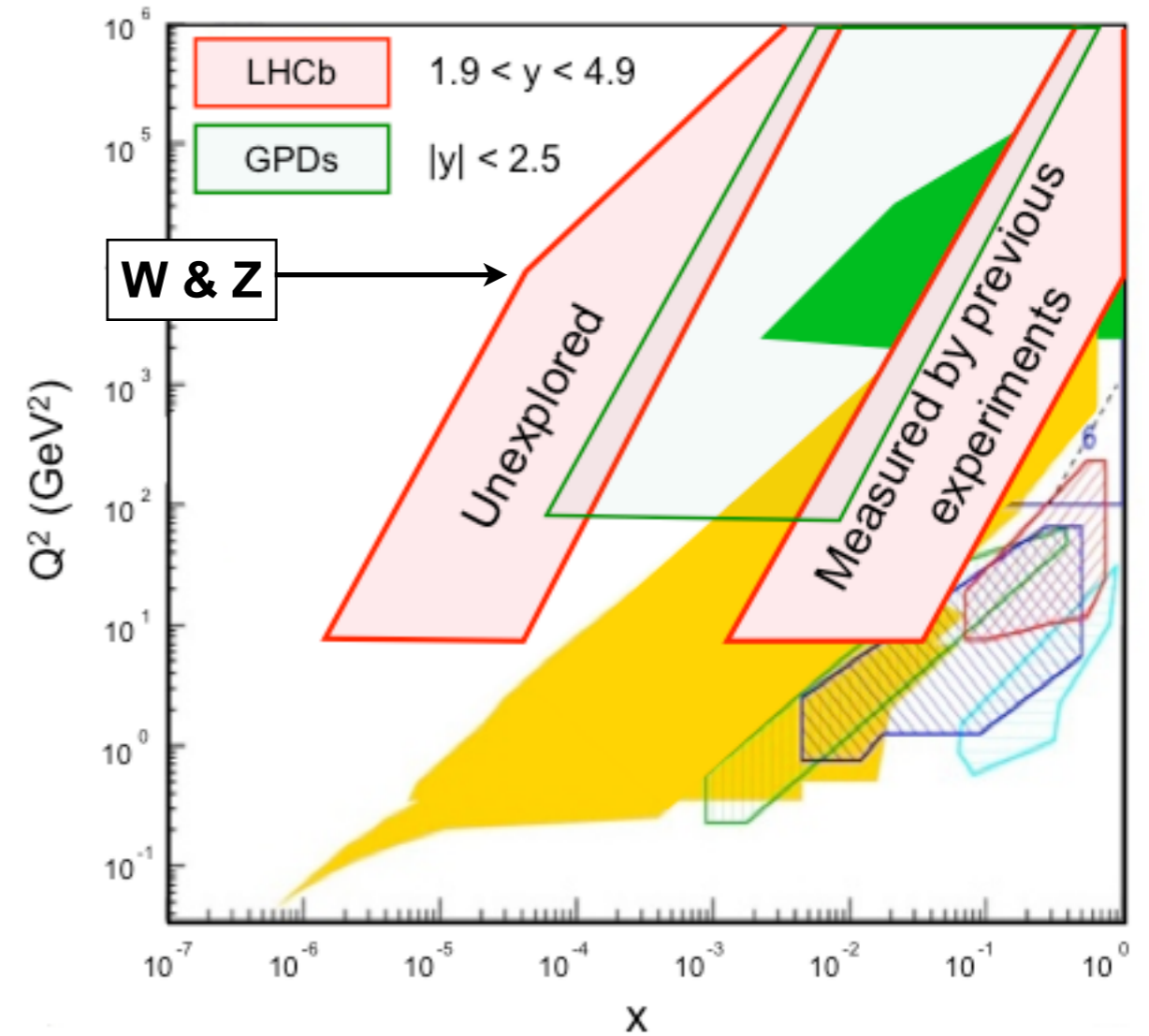**2011:** 601 pb^{-1} (210 pb^{-1} analysed here)

Kinematic reach at LHCb

Current inputs to proton PDFs
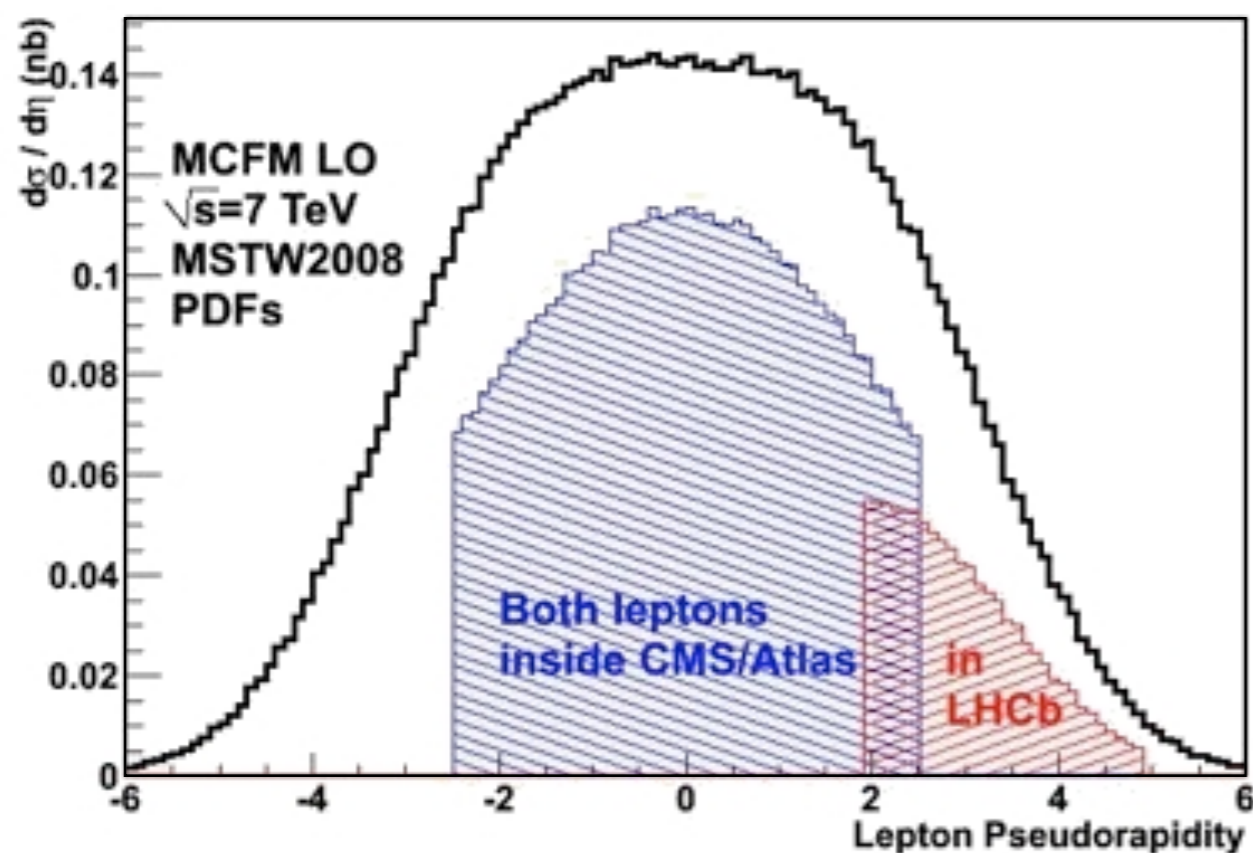
Low-x region currently only probed
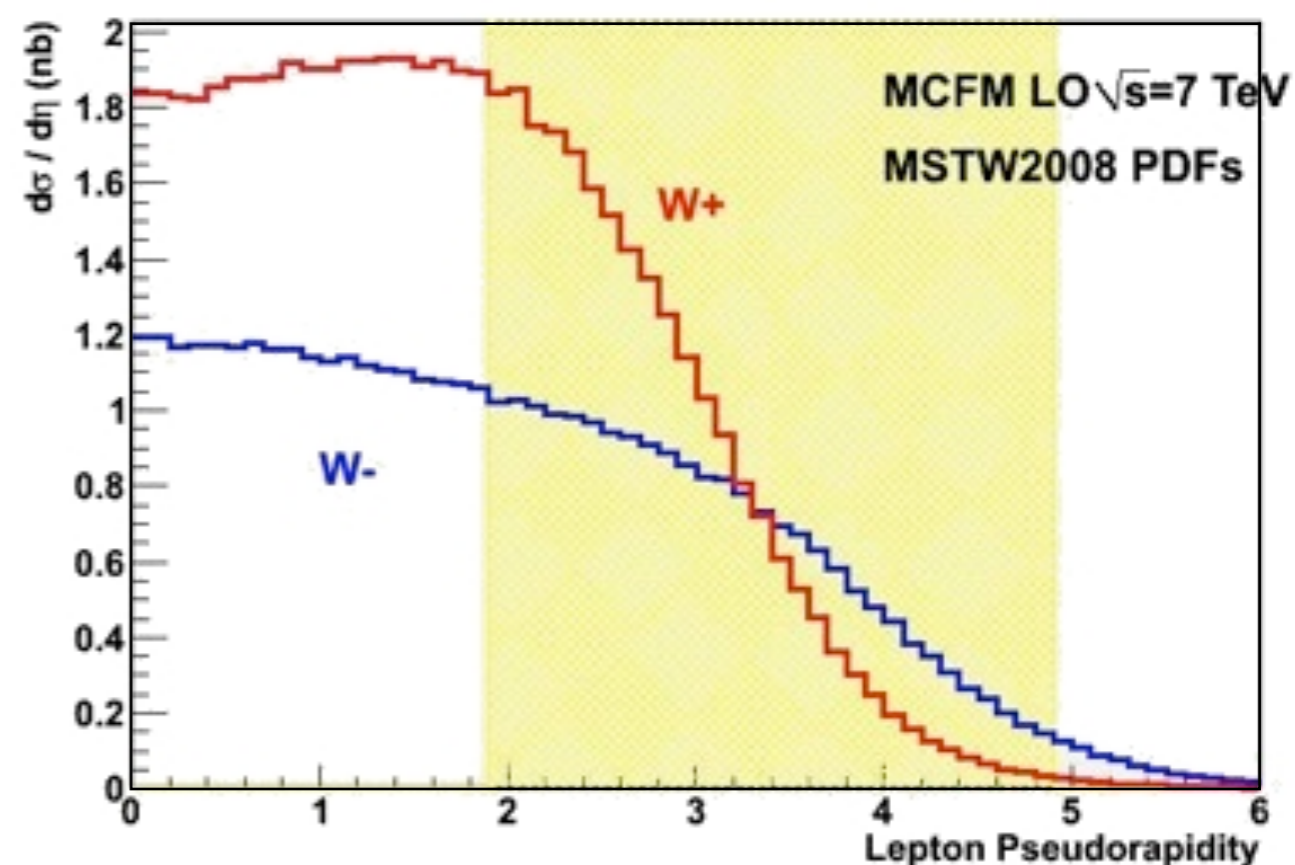by HERA

(x, Q^2) explored by LHCb

LHCb will probe 2 distinct regions
Low-x region previously unexplored
W & Z: $x_1 = 10^{-1}$ and $x_2 = 10^{-4}$

W and Z production at LHCb

- Complimentary range to ATLAS/CMS

- Overlap region for cross-check

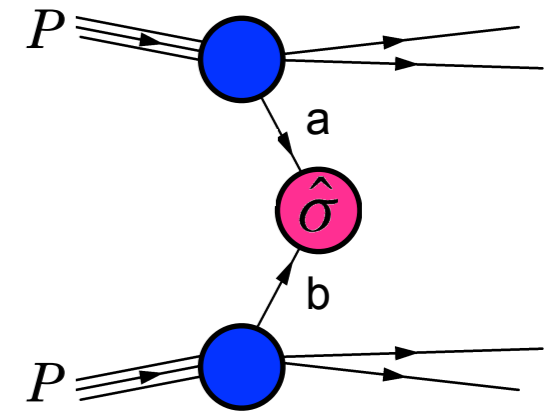- Crossover point of W asymmetry inside acceptance

8% of Z within LHCb acceptance

~ 16% of W within LHCb acceptance.

W and Z production at LHCb

$$\sigma_{AB \to X} = \int dx_a dx_b f_{a/A}(x_a, Q^2) f_{b/B}(x_b, Q^2) \hat{\sigma}_{ab \to X}$$
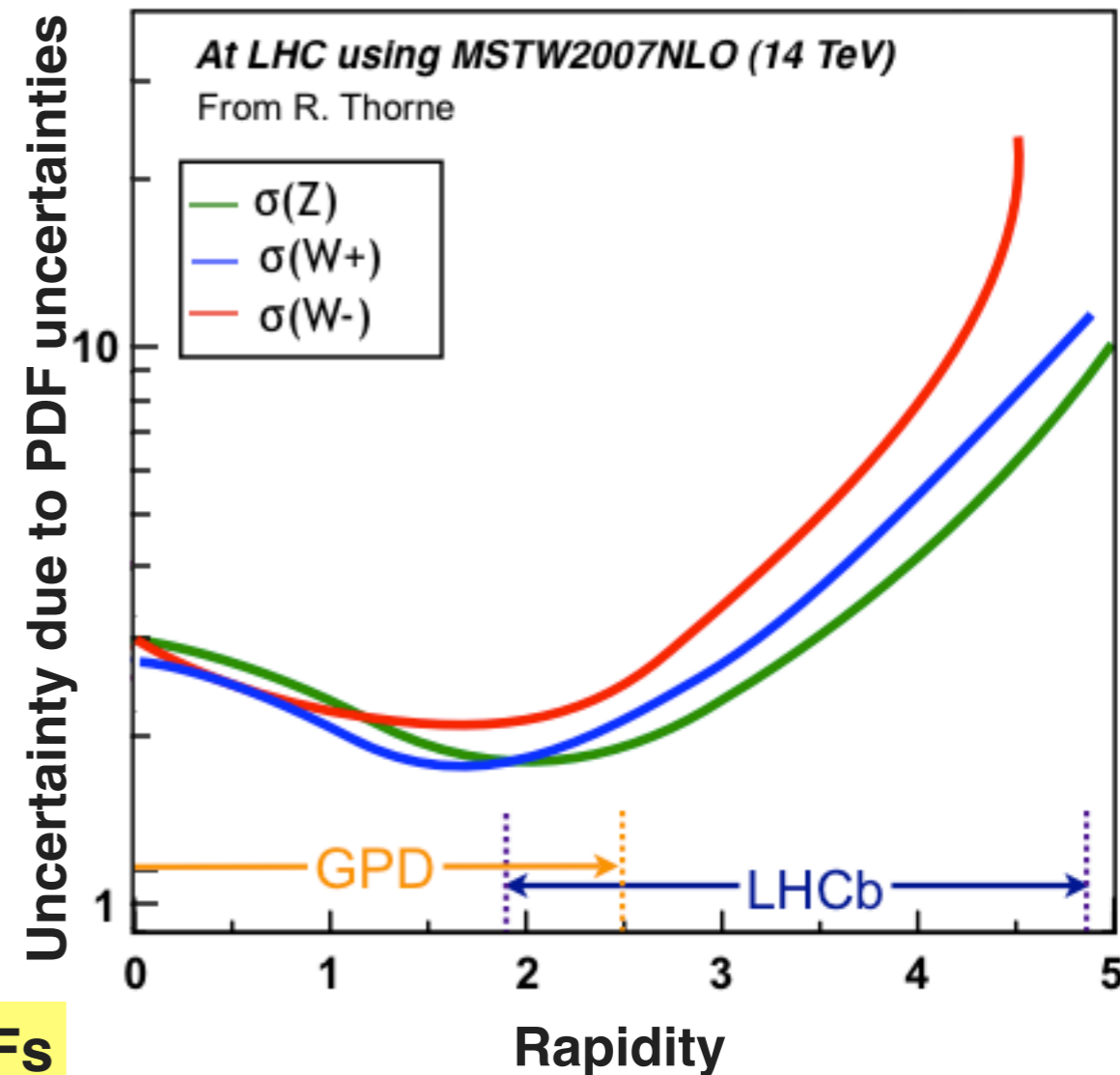
PDFs (from data)   **Partonic interaction** (pQCD)

Theoretical predictions
- Factorised calculation (partonic cs & proton pdfs)
- Partonic cross-sections known to 1% (NNLO)
- PDF uncertainties dominate at large rapidities (6-8% at y=5)

Experimental measurements
- Clean signature
- Easily reconstructed final states
- Low systematic uncertainties

**W and Z measurements at LHCb will constrain PDFs**

At LHC using MSTW2007NLO (14 TeV)
From R. Thorne
— σ(Z)
— σ(W+)
— σ(W-)

Uncertainty due to PDF uncertainties

GPD   LHCb

Rapidity

W and Z ratios at LHCb

Many experimental uncertainties cancel
- Luminosity etc.

Cancel or highlight PDF uncertainties with ratios

- $R_{+-} = d\sigma(W^+)/d\sigma(W^-)$
  Tests d_v/u_v ratio

- $A_{+-} = (d\sigma(W^+)-d\sigma(W^-))/(d\sigma(W^+)+d\sigma(W^-))$
  Tests difference between d_v and u_v

- $R_{WZ} = d\sigma(W)/d\sigma(Z)$
  Almost insensitive to PDFs
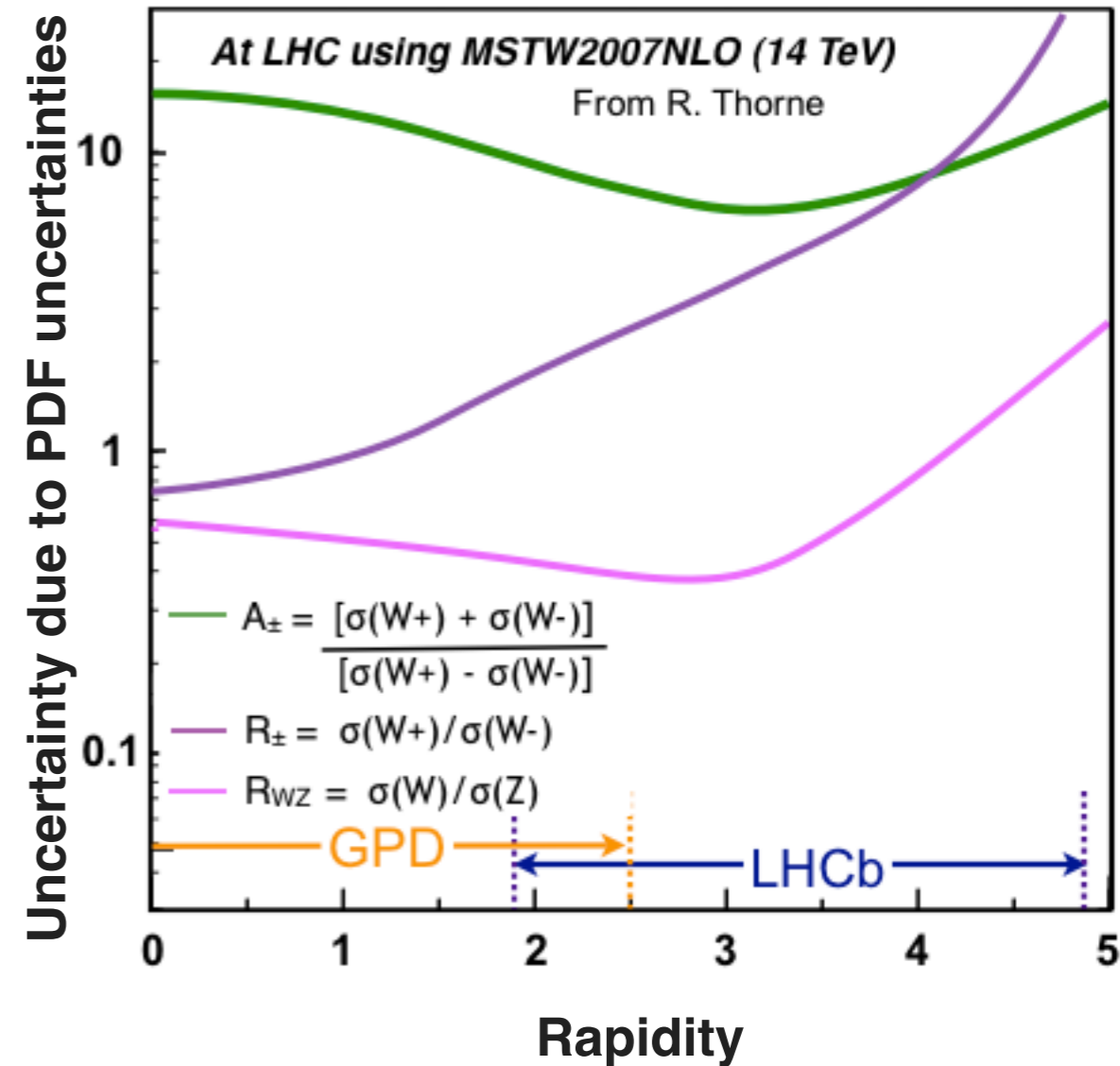
Z → μμ and W → μ ν   (37.1 pb⁻¹)

Z → μμ selection

Trigger: single muon with pT > 10 GeV/c

Offline: 2 reconstructed muons with
  - Good track quality
  - pT > 20 GeV/c
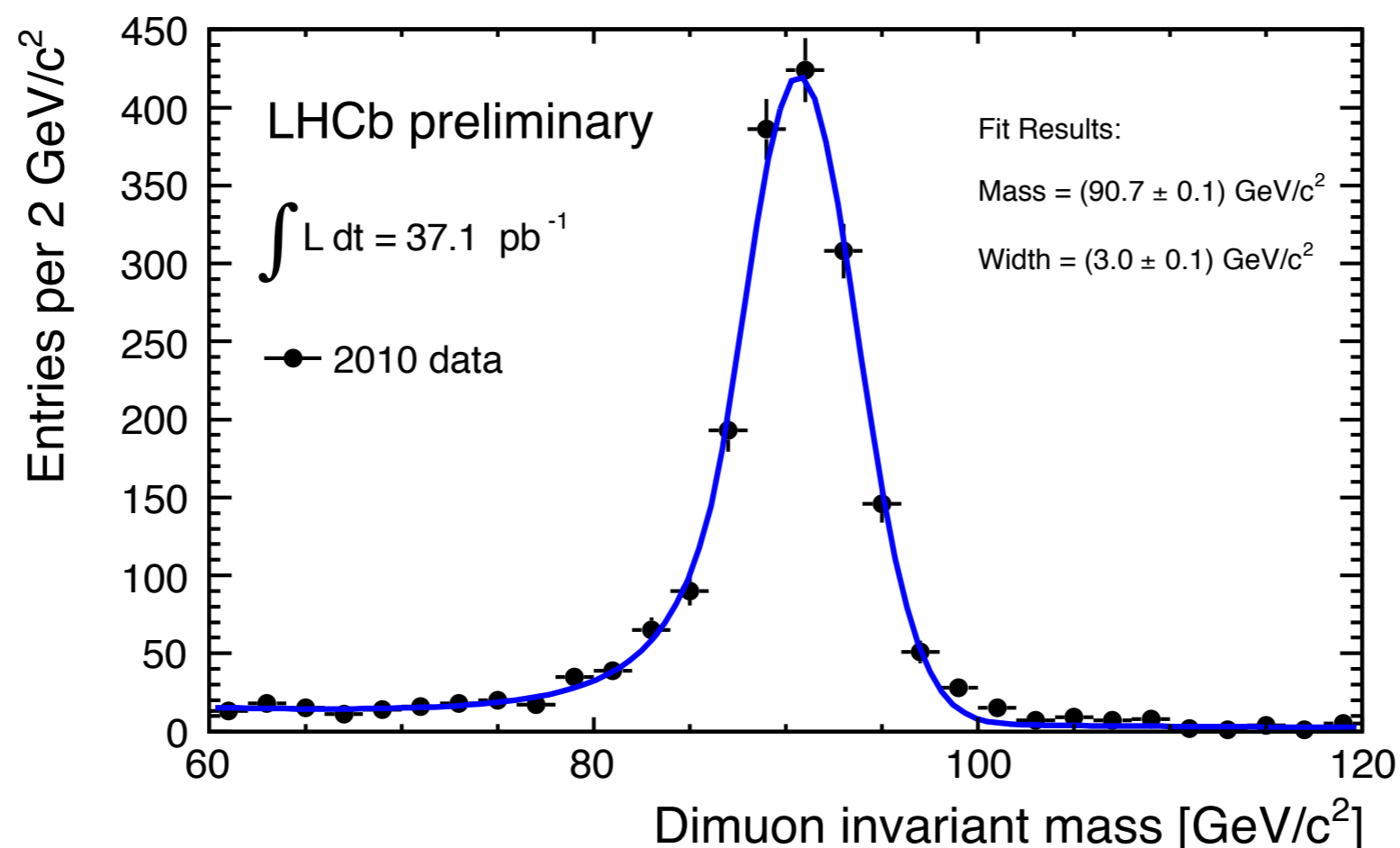 - 2 < η < 4.5
  - 60 GeV/c^2 < M$_{\mu\mu}$ < 120 GeV/c^2

Backgrounds:
  - Heavy flavour: 4.3 ± 3.0 (data)
  - Hadron mis-id: 0 ± 1 (data)
  - Tauonic Z decays: 0.6 ± 0.2 (MC)

Preliminary Results with 37.1 pb^{-1}:

N$_{candidates}$ = 1966
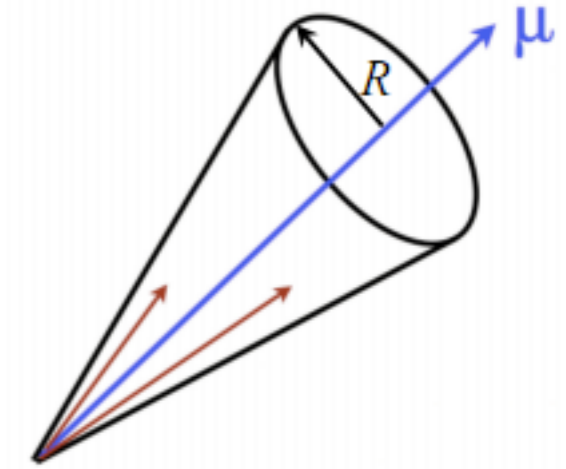
N$_{background}$ = 4.9 ± 4.2

W → μ ν selection

Trigger: single muon with pT > 10 GeV/c

Offline: 1 reconstructed muon with
- - Good track quality
- - pT > 20 GeV/c
- - 2 < η < 4.5
- - Impact parameter w.r.t. primary vertex < 40 μm
- - E/p < 0.04
- - Sum pT + E in cone around muon < 2 GeV/c (R=0.5)
- - No other muon with pT > 5 GeV/c

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

Backgrounds:
- - Heavy flavour (data)
- - Hadron mis-id (data)
- - Muonic Z decays (MC & data)
- - Tauonic W & Z decays (MC & data)

Preliminary Results with 37.1 pb^{-1}:

$N_{candidates}(+) = 15608$

$N_{candidates}(-) = 12301$

Purity ~ 80%

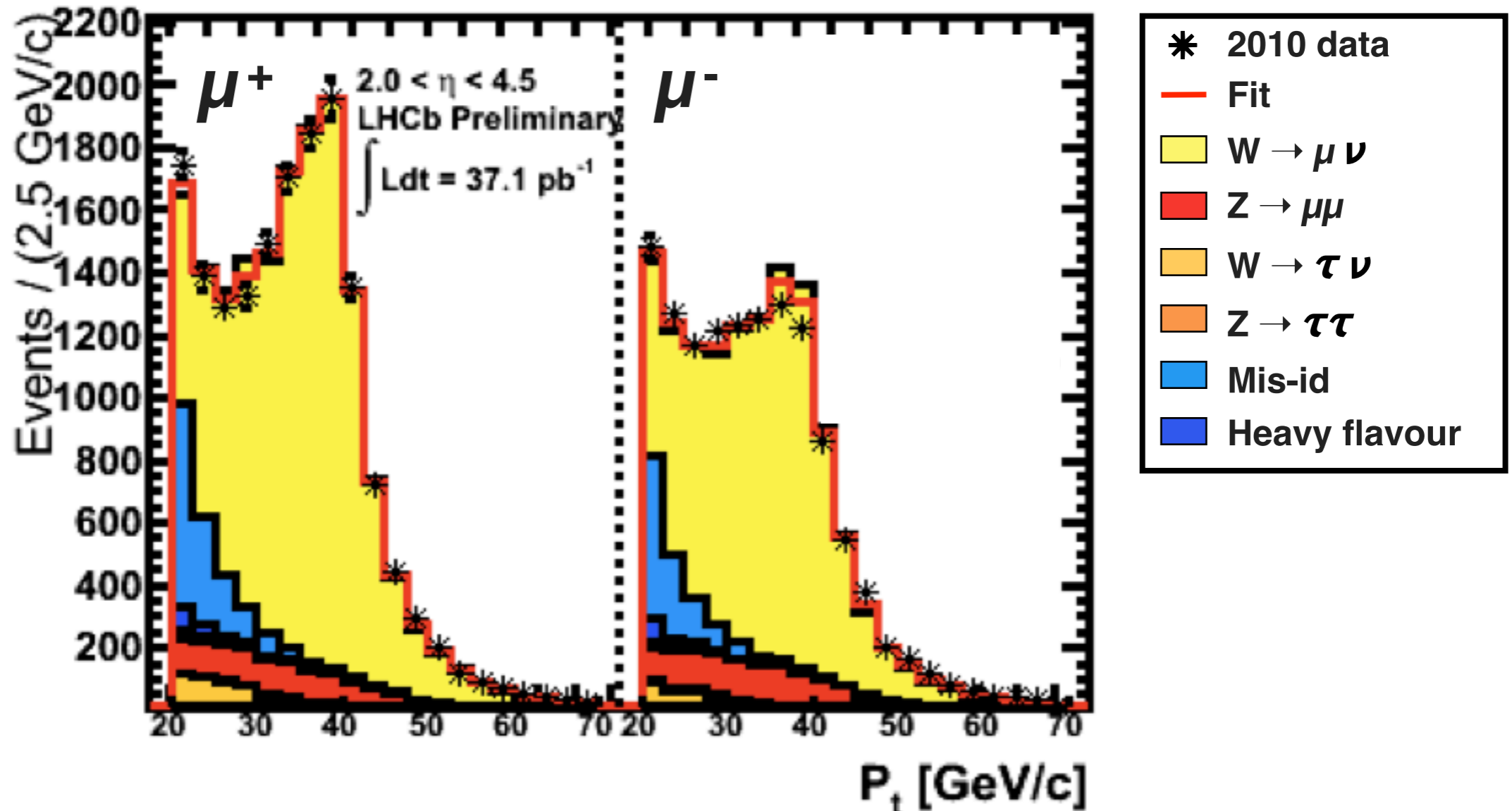**Purities determined by fit to muon pT spectra**

W → μ ν purity determination

Determination purities

- Fit muon pT spectrum in data to expected shapes for signal and backgrounds (fit is performed in eta bins to obtain differential results - see next slide)
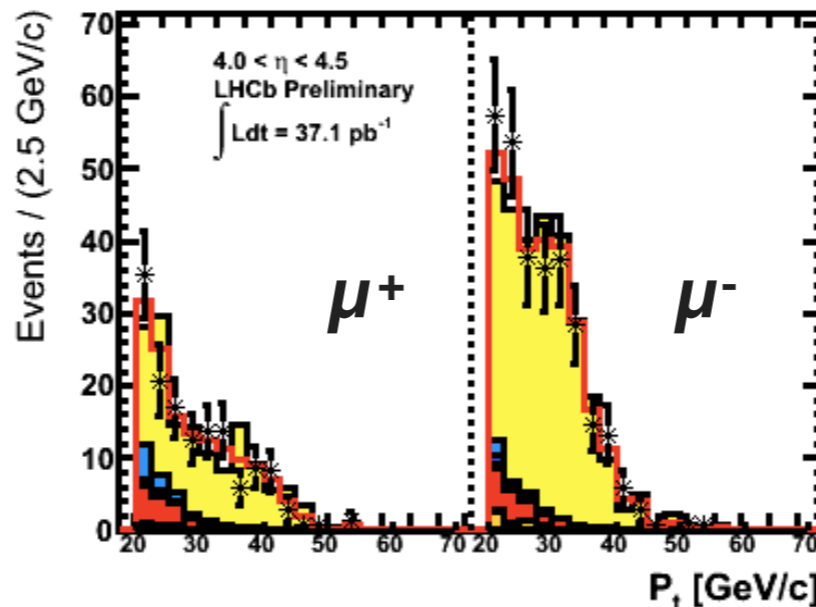
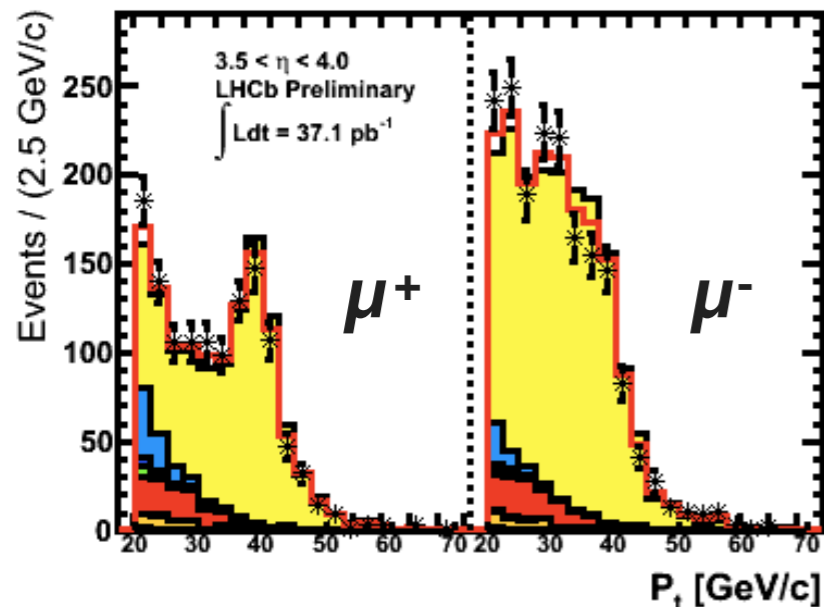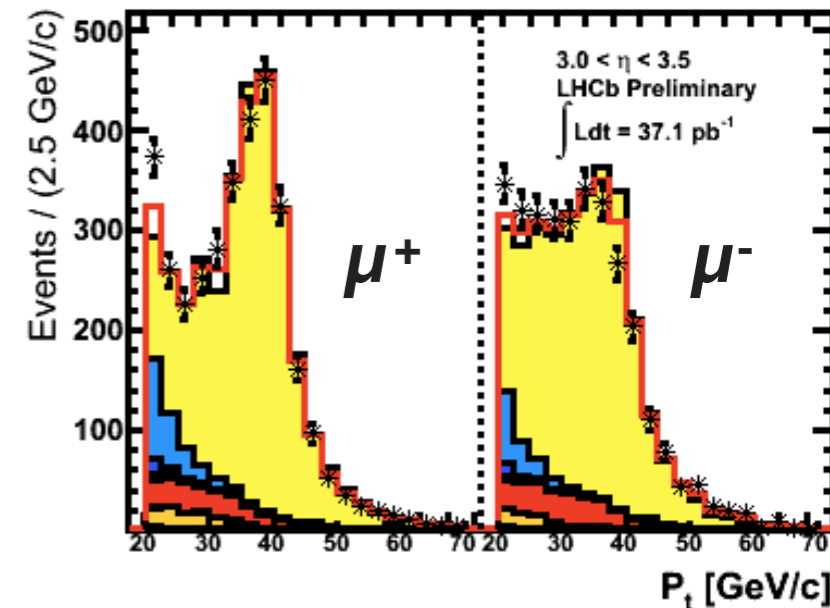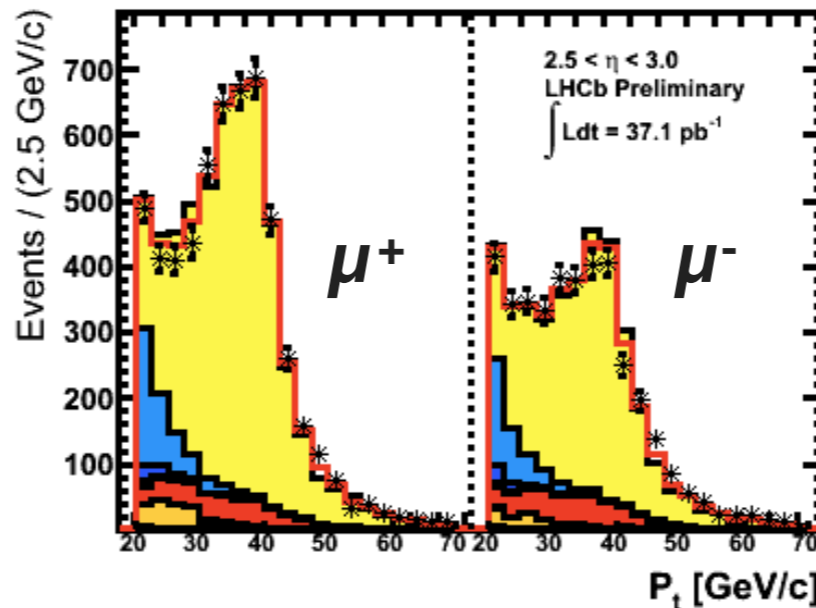# W → μ ν purity versus lepton rapidity
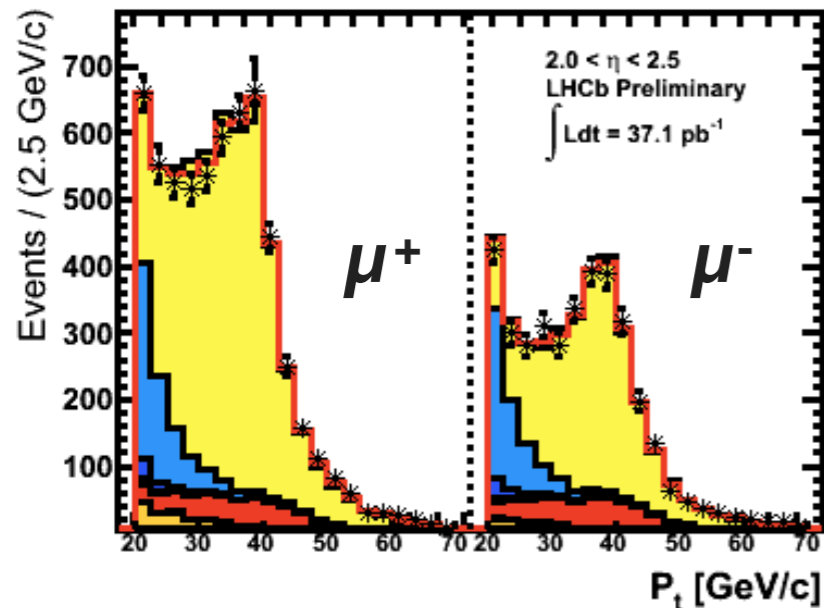
Efficiency determination for W & Z measurements

The cross-section can be expressed as:

$$\sigma = \frac{N_{candidates} - N_{bg}}{\varepsilon \cdot \int L}$$

Where ε is the total efficiency and can be expressed as:

$$\varepsilon = A \cdot \varepsilon_{trigger} \cdot \varepsilon_{tracking} \cdot \varepsilon_{\mu-ID} \cdot \varepsilon_{selection}$$

Since we measure inside a limited fiducial volume (pT > 20 GeV/c and 2 < η < 4.5), A = 1 by definition.

The trigger, tracking and muon ID **efficiencies are determined from data** and cross-checked against Monte-Carlo (see the following slides)

Trigger efficiency

$$\varepsilon = A \cdot \varepsilon_{trigger} \cdot \varepsilon_{tracking} \cdot \varepsilon_{\mu-ID} \cdot \varepsilon_{selection}$$

Single muon trigger efficiency

- Determine from data using an offline selected
  Z sample and tag and probe method
    Tag: muon passing single muon line
    Probe: Offline identified muon

- Efficiency given by how often the probe
  muon passes the single muon line

Flat versus muon ϕ, muon pT and number
of primary vertices

No evidence of charge bias

Correction performed bin-wise in muon η
Overall efficiency = 78.1 ± 0.5 %

Tracking efficiency

$$\varepsilon = A \cdot \varepsilon_{trigger} \cdot \varepsilon_{tracking} \cdot \varepsilon_{\mu-ID} \cdot \varepsilon_{selection}$$

Single muon tracking efficiency

- Determine from data using an offline selected
  Z sample and tag and probe method
  Tag: long track muon passing trigger
  Probe: Muon stub with TT hits added

- Efficiency given by how often the probe
  is identified as a muon

Flat versus muon φ, muon pT and number
of primary vertices

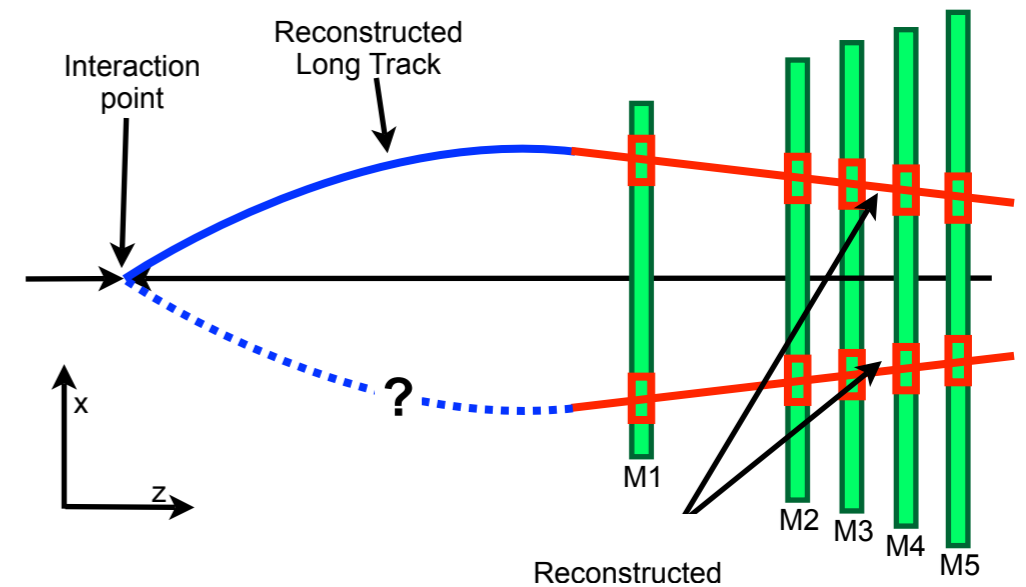No evidence of charge bias

Correction performed bin-wise in muon η
Overall efficiency = 90 ± 3 %

Muon ID efficiency

$$\varepsilon = A \cdot \varepsilon_{trigger} \cdot \varepsilon_{tracking} \cdot \varepsilon_{\mu-ID} \cdot \varepsilon_{selection}$$

Single muon identification efficiency

- Determine from data using an offline selected
  Z sample and tag and probe method
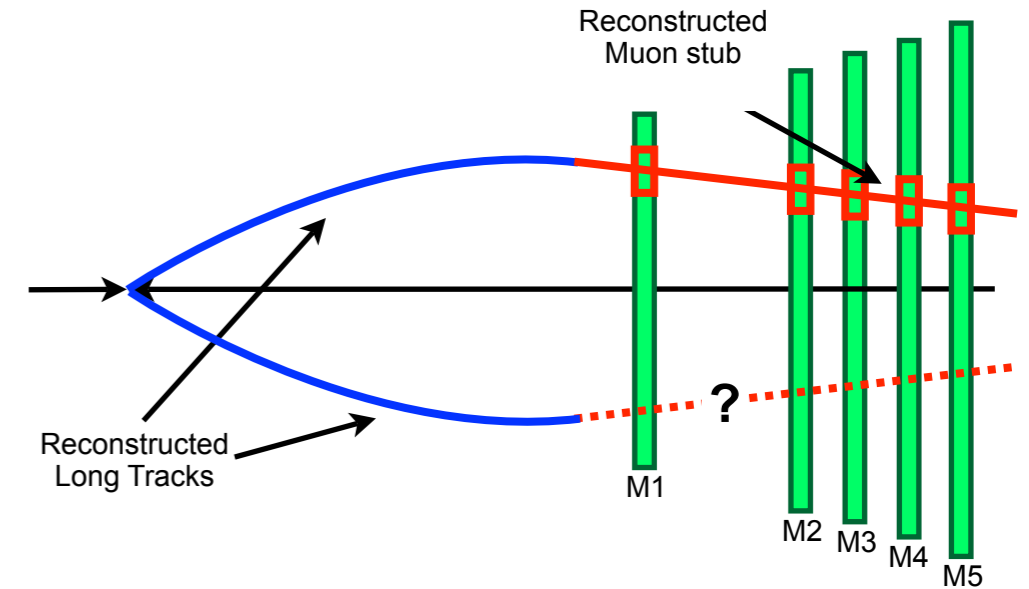 **Tag:** long track muon passing trigger
  Probe: Long track

- Efficiency given by how often the probe
  is identified as a muon

Flat versus muon φ, muon pT and number
of primary vertices

No evidence of charge bias

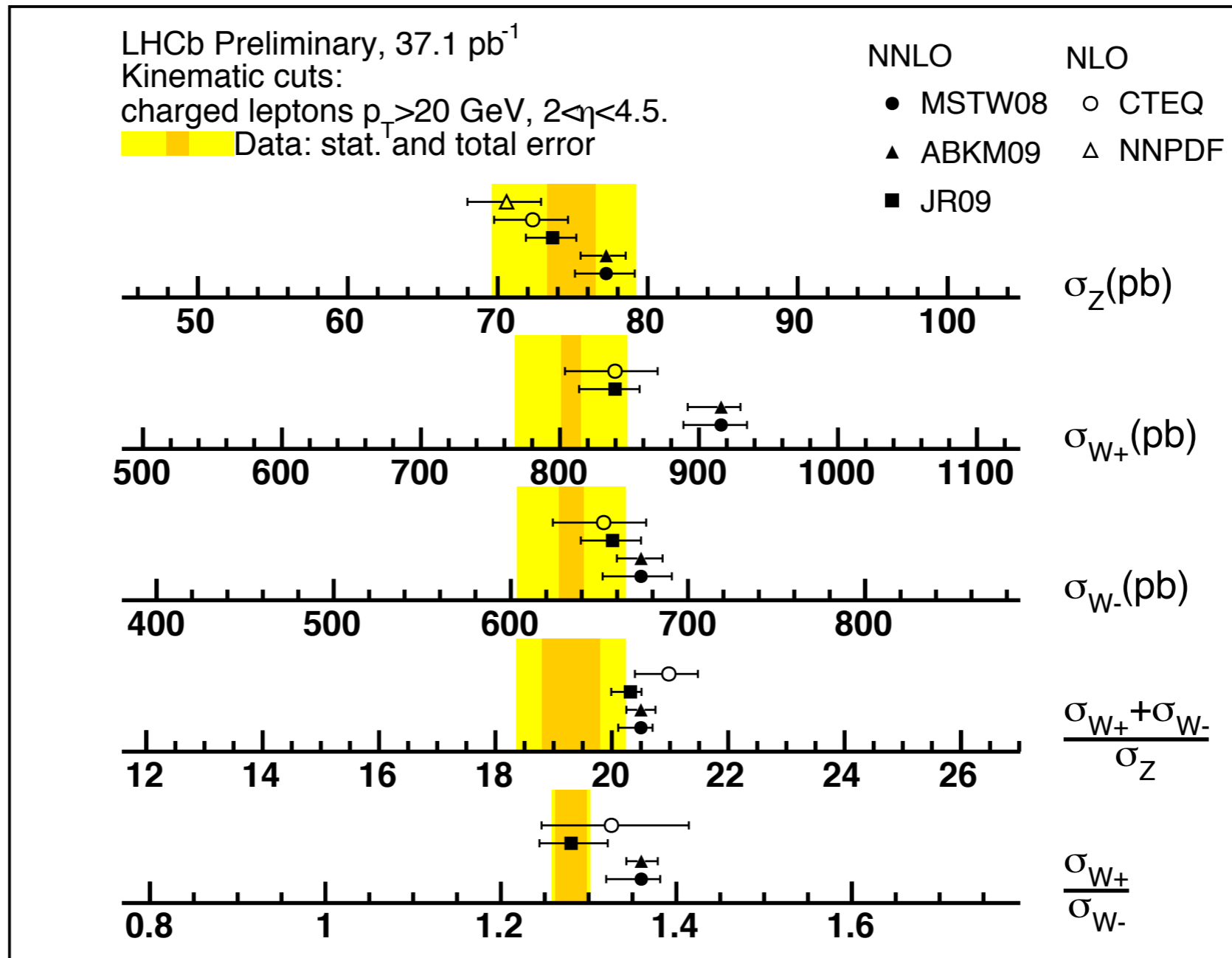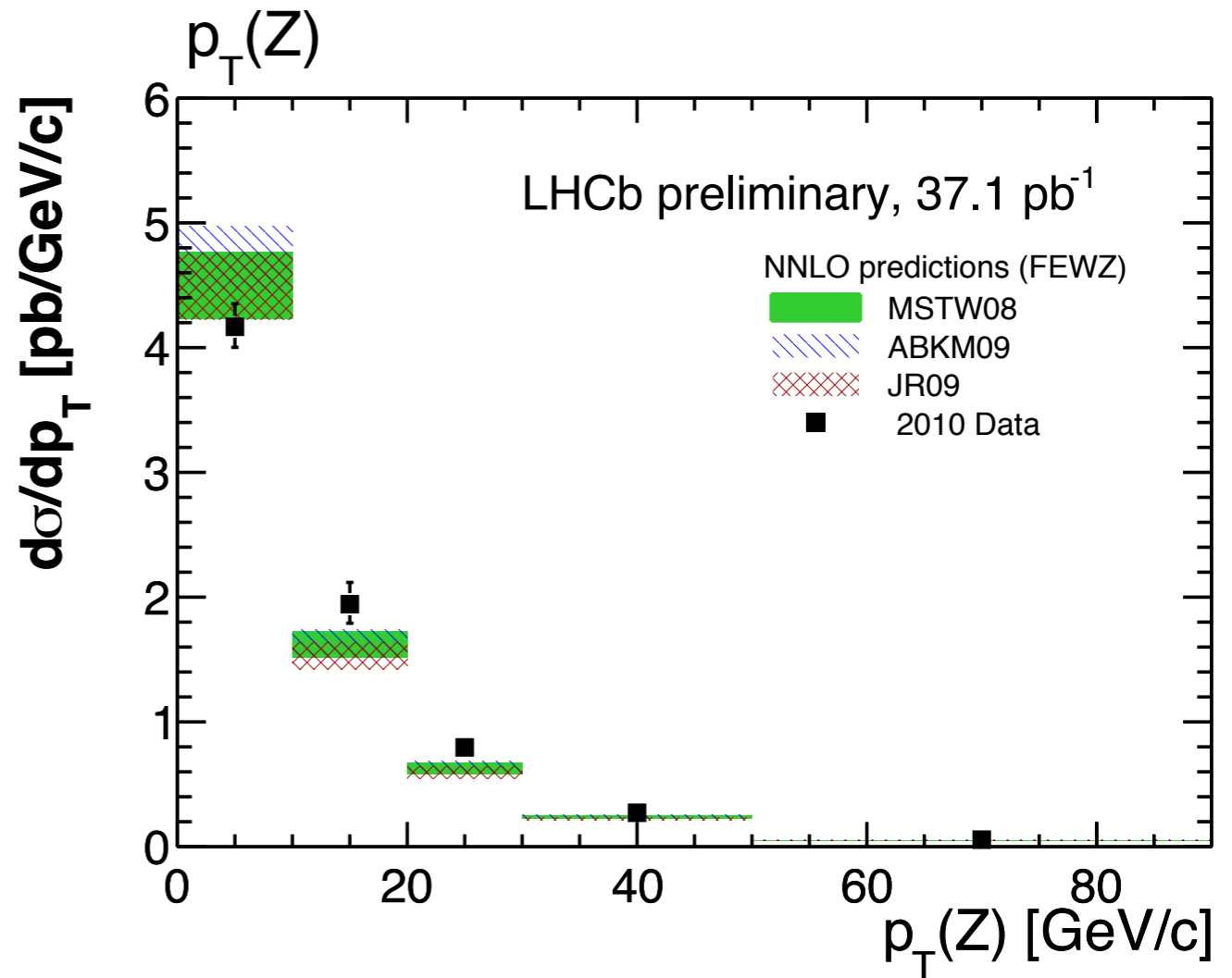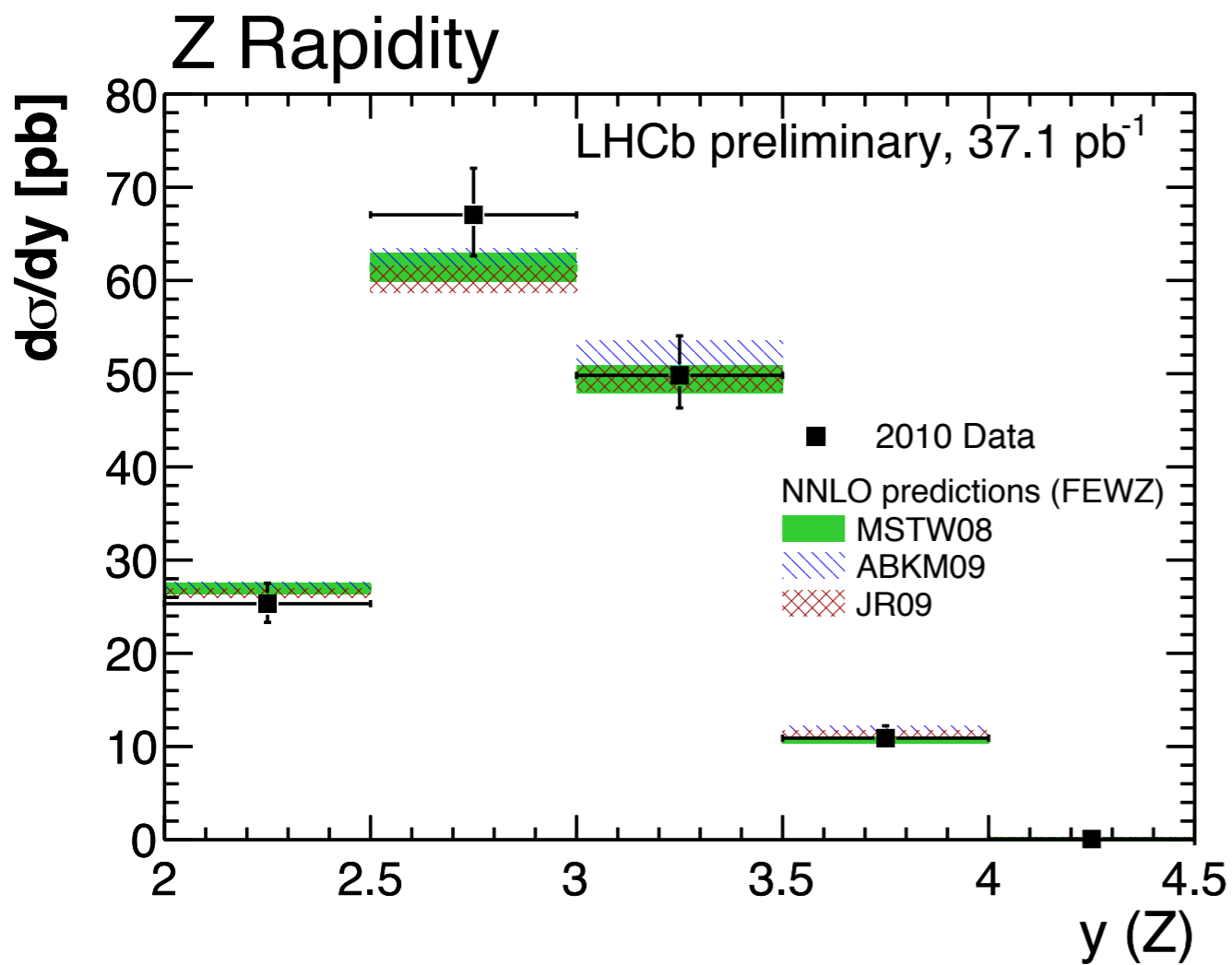Correction performed bin-wise in muon η
Overall efficiency = 98.9 ± 0.7 %

Reconstructed
Muon stub

Reconstructed
Long Tracks

M1
M2
M3
M4
M5

?

Systematic uncertainties

	$\Delta\sigma(W+)$ [%]	$\Delta\sigma(W-)$ [%]	$\Delta\sigma(Z)$ [%]
Background	1.6	1.6	0.4
Shape (fit)	1.9	1.7	n/a
Efficiency	2.0	1.8	5.1
FSR correction	0.2	0.2	0.3
Systematic	3.5	3.2	5.1
Luminosity	3.5	3.5	3.5
Statistical	0.9	1.1	2.1

Results

Z differential distributions

Z Rapidity

LHCb preliminary, 37.1 pb^{-1}

2010 Data

NNLO predictions (FEWZ)
- MSTW08
- ABKM09
- JR09

p$_T$(Z)

LHCb preliminary, 37.1 pb^{-1}

NNLO predictions (FEWZ)
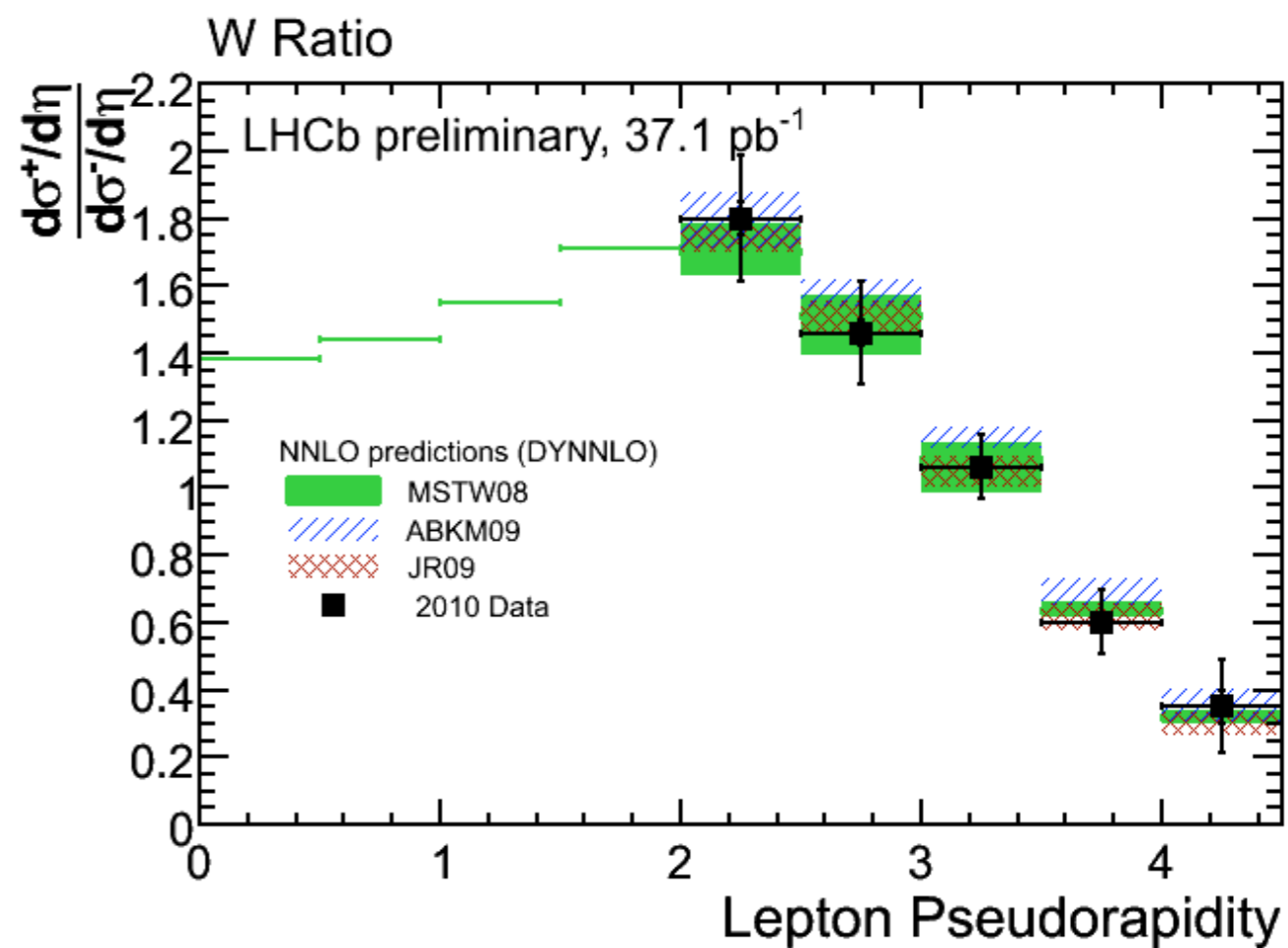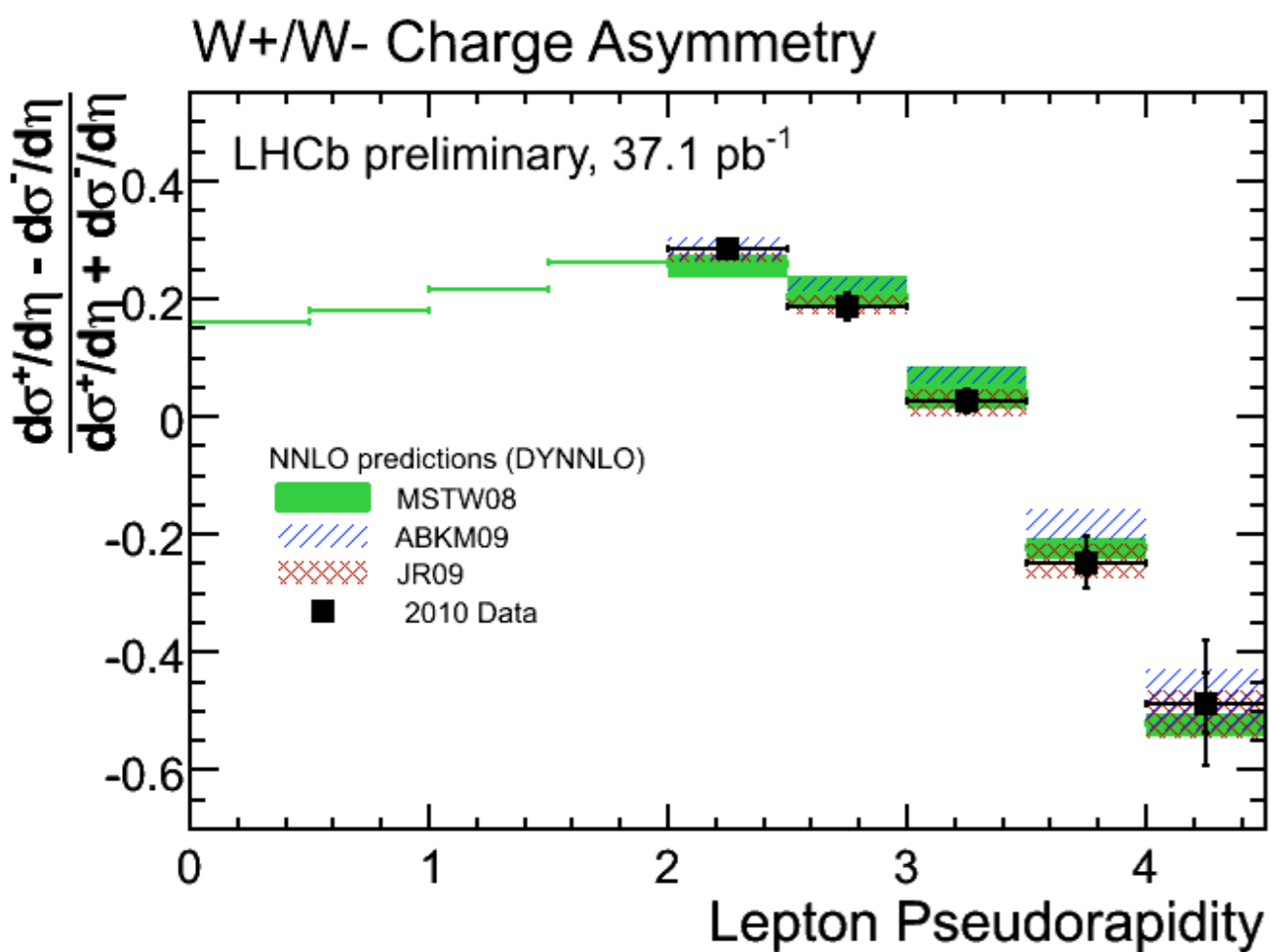- MSTW08
- ABKM09
- JR09

2010 Data

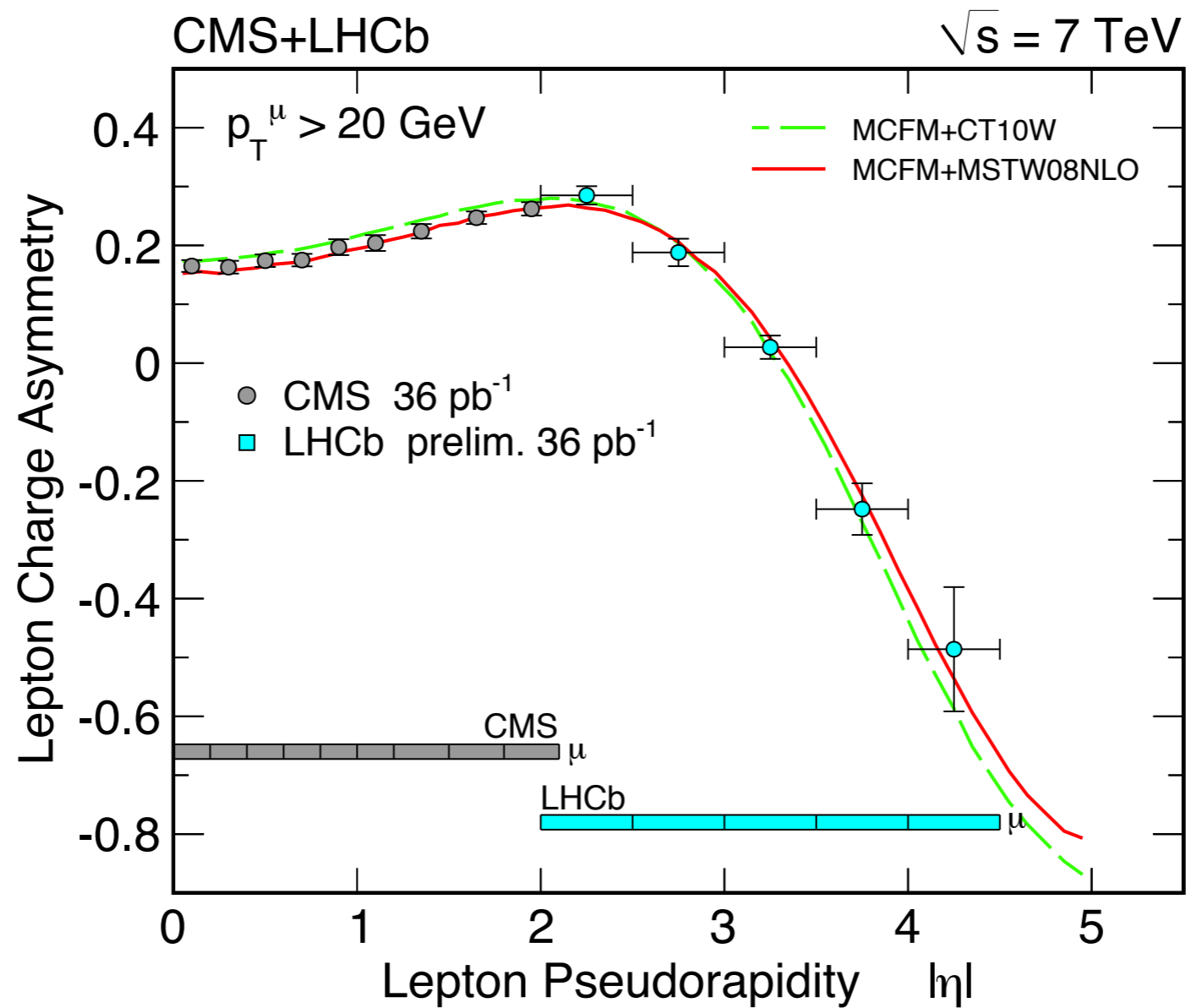FEWZ - arXiv:1011.3540v1 (hep-ph)   MSTW08 - [arXiv:0901.0002 (hep-ph)]
ABKM09 - [arXiv:0908.2766 (hep-ph)]
JR09 - [arXiv:0810.4274 (hep-ph)]

W lepton asymmetry and ratio

W lepton asymmetry - LHCb and CMS

$$Z \rightarrow \tau\tau \rightarrow \mu\mu \text{ or } \mu e \quad (247 \text{ pb}^{-1})$$

Z → ττ → μe selection

Trigger: single muon with pT > 10 GeV/c

Muon
- pT > 20 GeV/c
- 2 < η < 4.5
- E/p < 0.2

Electron
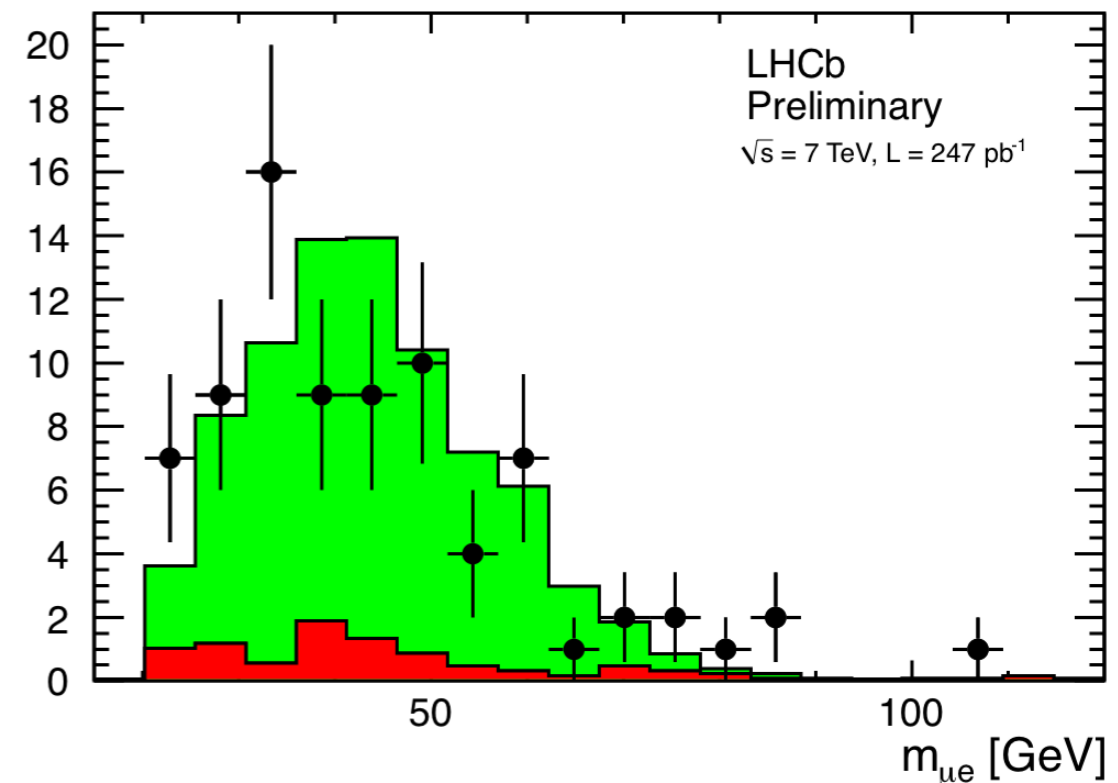- pT > 5 GeV/c
- 2 < η < 4.5
- $E_{ecal}/p > 0.1$, $E_{hcal}/p < 0.05$, $E_{PRS} > 0.05$ GeV/c

Additional requirements
- Lepton acoplanarity > 2.7 radians
- Track isolation

$$I = \min\left(\frac{p_{\mu,e} - \sum p_{track}}{p_{\mu,e} + \sum p_{track}} \right) > 0.8$$

81 candidates
Backgrounds:
QCD: 9.5 ± 3
EWK: 3 ± 1.2

LHCb
Preliminary
√s = 7 TeV, L = 247 pb⁻¹

Z → ττ → μμ selection

Trigger: single muon with pT > 10 GeV/c

Offline:
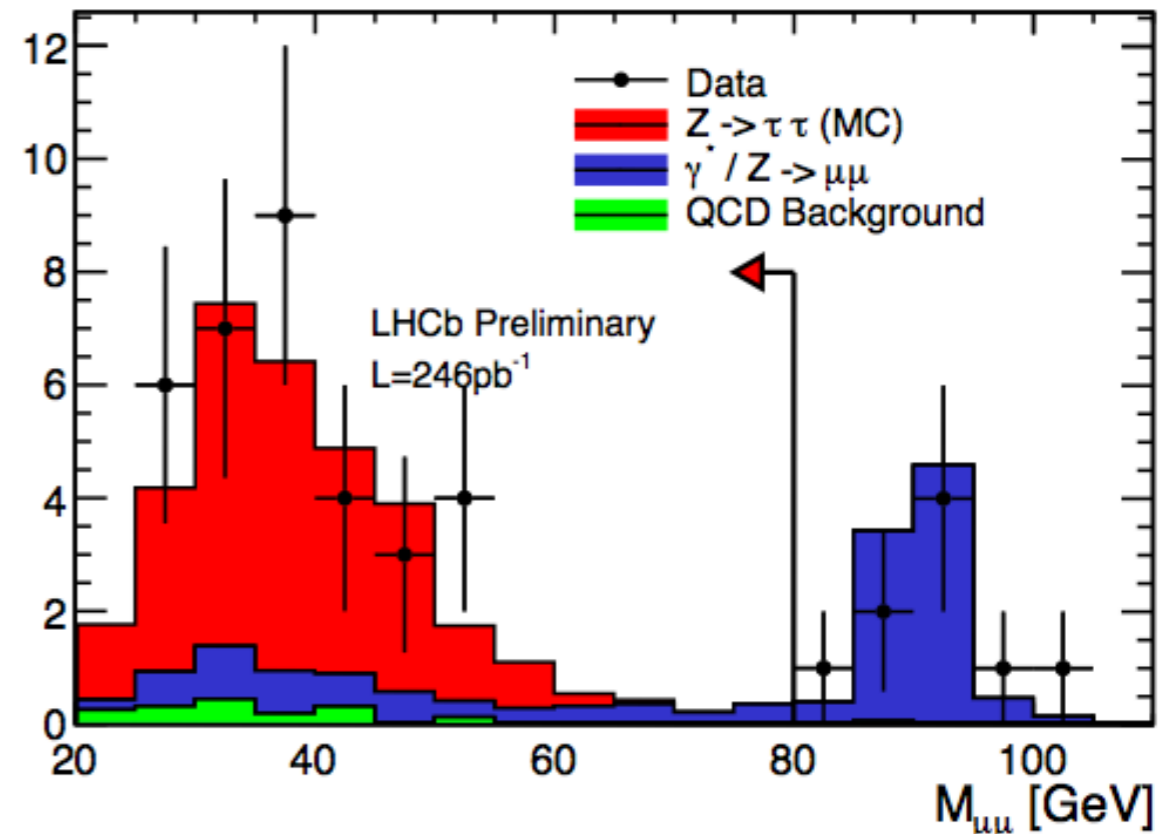- pT(1) > 20 GeV/c and pT(2) > 5 GeV/c
- 2 < η < 4.5
- E/p < 0.2

Additional requirements
- Lepton acoplanarity > 2.7 radians
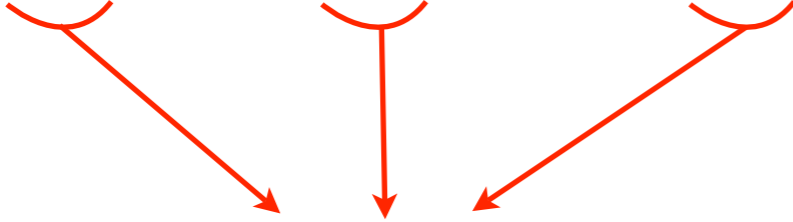- IP significance > 4
- Track isolation > 0.8
- Lepton pT balance

$$A_{PT} = \left(\frac{P_T^{\mu 1} - P_T^{\mu 2}}{P_T^{\mu 1} + P_T^{\mu 2}} \right) > 0.2$$

33 candidates
Backgrounds:
QCD: 1.6 ± 1.3
EWK: 5.5 ± 1.8

Uncertainties

$$\varepsilon = A\ \varepsilon_{\mu}^{track}\ \varepsilon_{e}^{track}\ \varepsilon^{muon}\ \varepsilon^{electron}\ \varepsilon^{trig}\ \varepsilon^{selection}$$

Same as Z → μμ and W → μ ν analyses

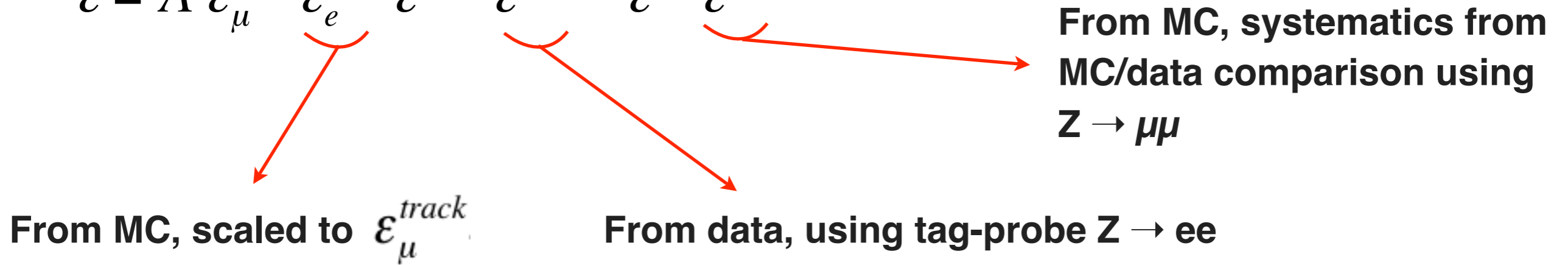|	Δσ(eμ) [%]	Δσ(μμ) [%]
Background	± 5	± 7
Efficiency	± 8	± 9
Acceptance	± 5	± 2
Sys. error	± 10	± 11
Luminosity	± 3.5	± 3.5
Stat. error	± 12	± 17

Uncertainties

$$\varepsilon = A \; \varepsilon_\mu^{track} \varepsilon_e^{track} \varepsilon^{muon} \varepsilon^{electron} \varepsilon^{trig} \varepsilon^{selection}$$
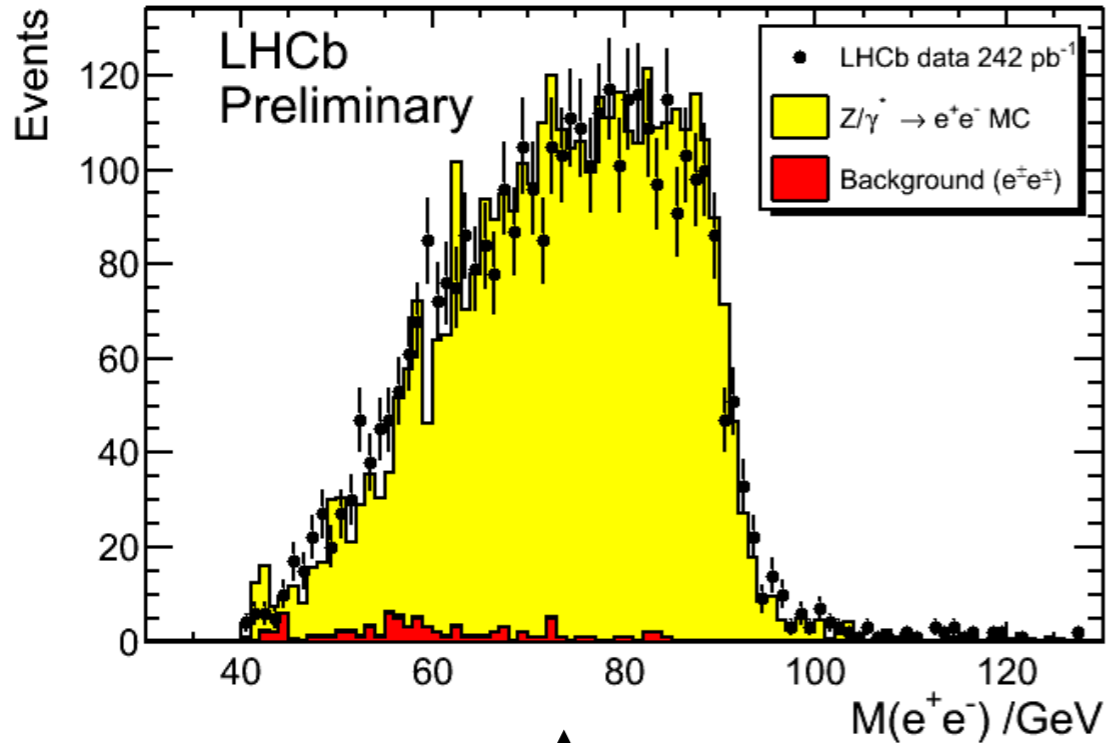
From MC, systematics from MC/data comparison using $Z \to \mu\mu$

From MC, scaled to ε_μ^{track}

From data, using tag-probe $Z \to ee$

	$\Delta\sigma(e\mu)$ [%]	$\Delta\sigma(\mu\mu)$ [%]
Background	± 5	± 7
Efficiency	± 8	± 9
Acceptance	± 5	± 2
Sys. error	± 10	± 11
Luminosity	± 3.5	± 3.5
Stat. error	± 12	± 17

Results

Outlook

Z → ee

Z → μμ
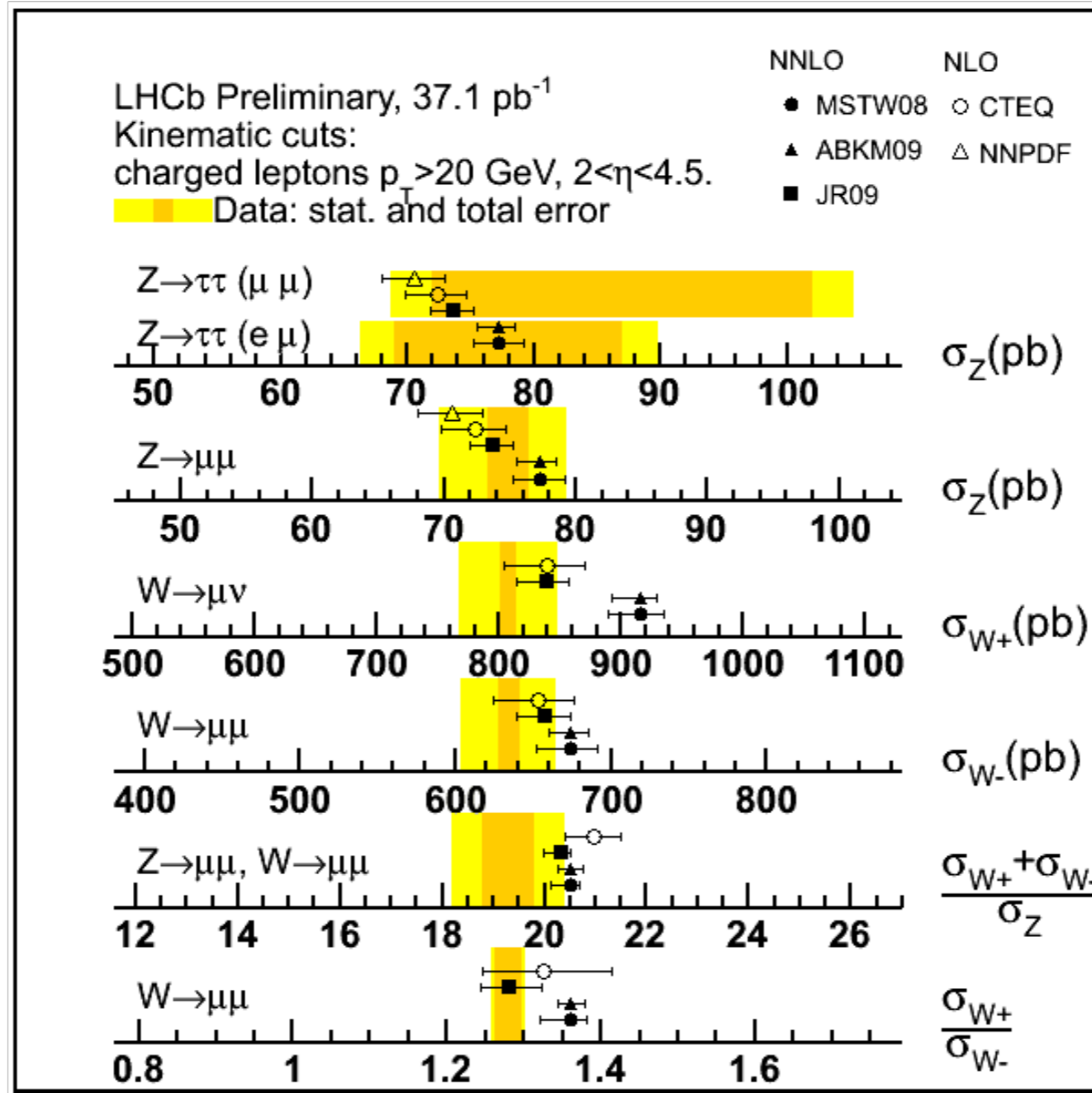
Only track properties used
(bremsstralung recovery restricted
by calo readout saturation)
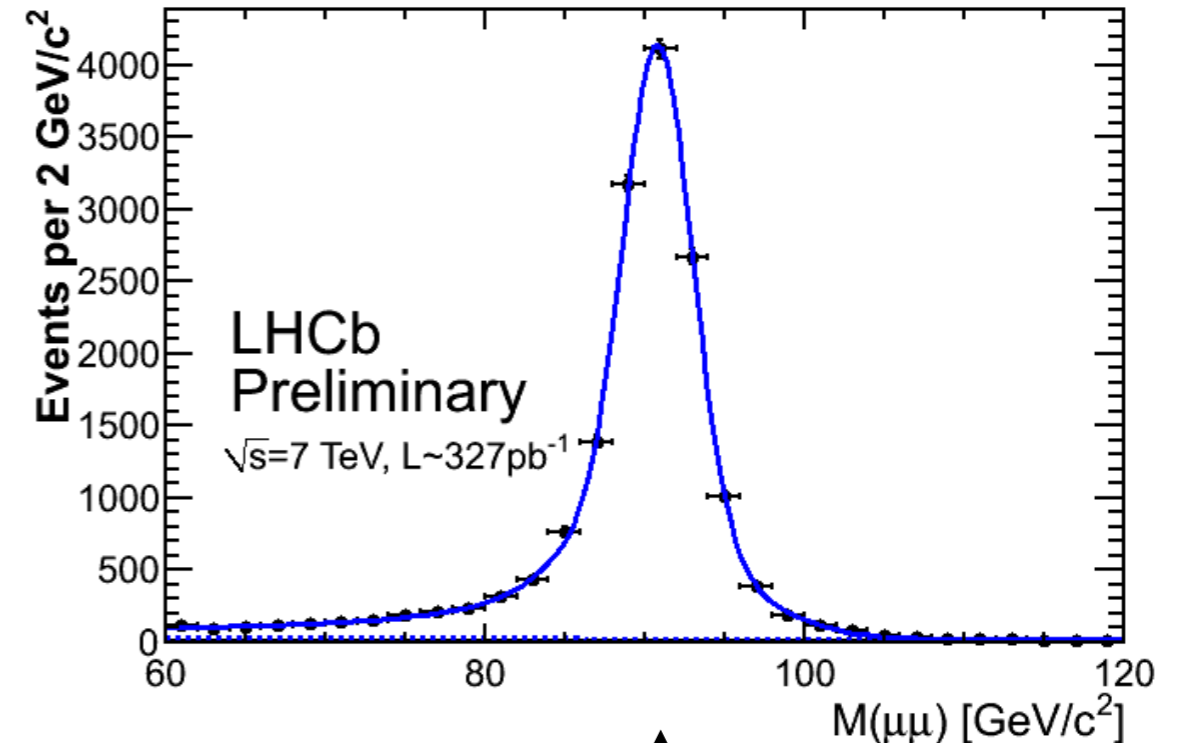
Large statistics recorded in 2011
(expect corresponding reduction in
stat. and syst. uncertainties)

Conclusions

W and Z measurements at LHCb complimentary to ATLAS/CMS

- Probe PDFs in previously unexplored region

Z → μμ and W → μ ν

- Cross-sections and ratios measured with 2010 data (37.1 pb^{-1})
- Consistent with NNLO predictions
- Data driven method, precision will improve with 2011 data

Z → ττ

- Cross-section measured in μμ and μe channels with 247 pb^{-1}
- Consistent with NNLO predictions