Measurements with electroweak bosons at LHCb

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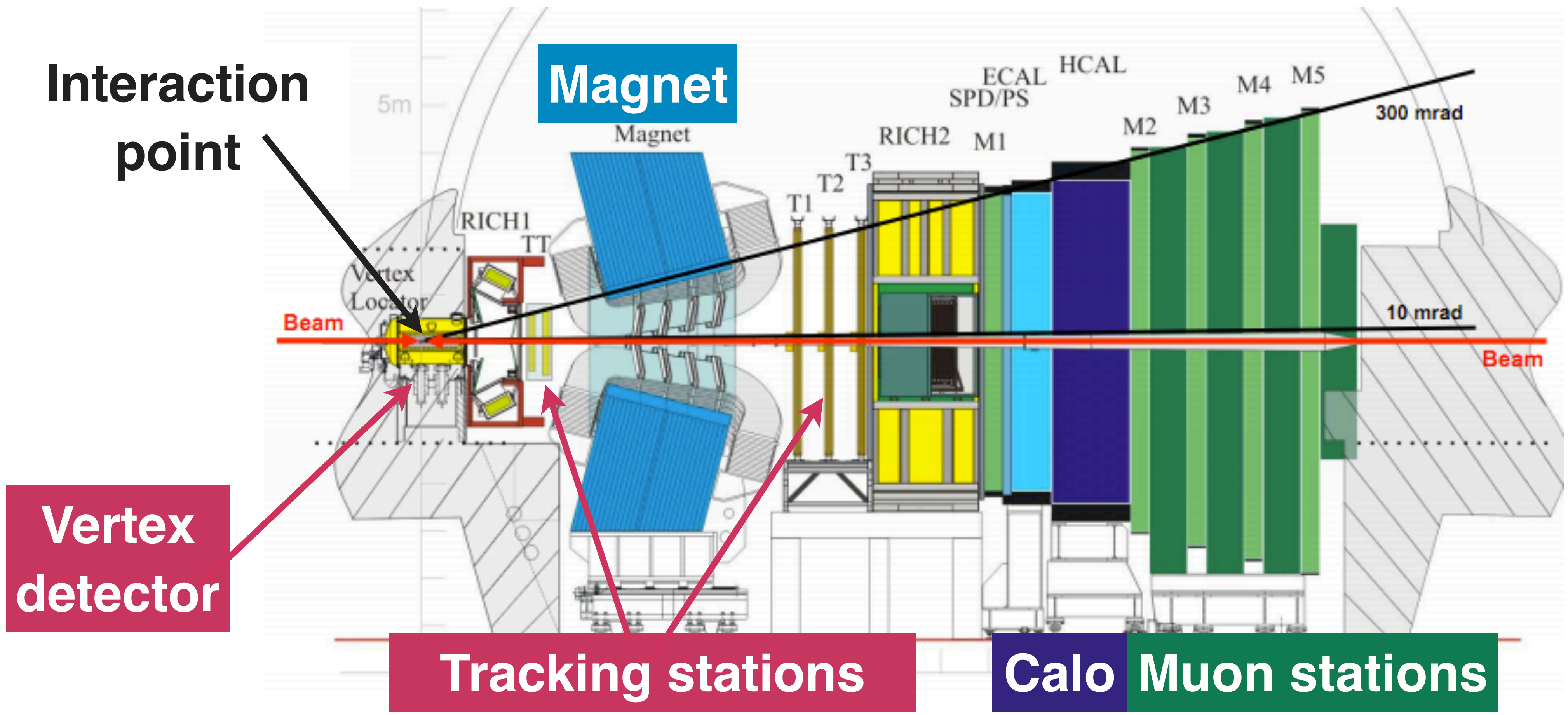
For the LHCb collaboration

LHCb detector

- Optimised for measurements of B and D mesons at the LHC
- Fully instrumented in the **forward region (2 < η < 5)**



>90% efficiency

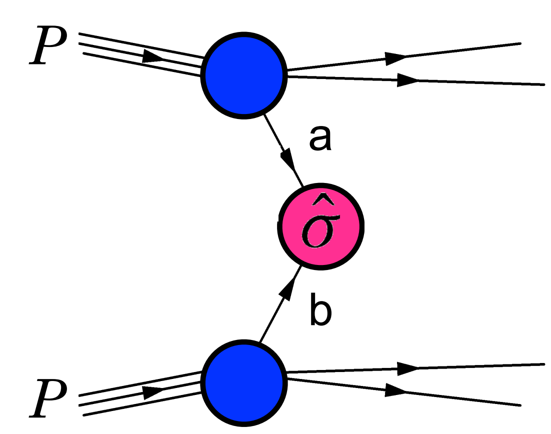
- 2010: 37 pb^{-1}
- 2011: 1 fb^{-1}
- 2012: 616 pb^{-1} so far ($\sqrt{s}$ = 8 TeV)

Only results based on 2010 and 2011 are shown here ($\sqrt{s}$ = 7 TeV)

Cross-sections

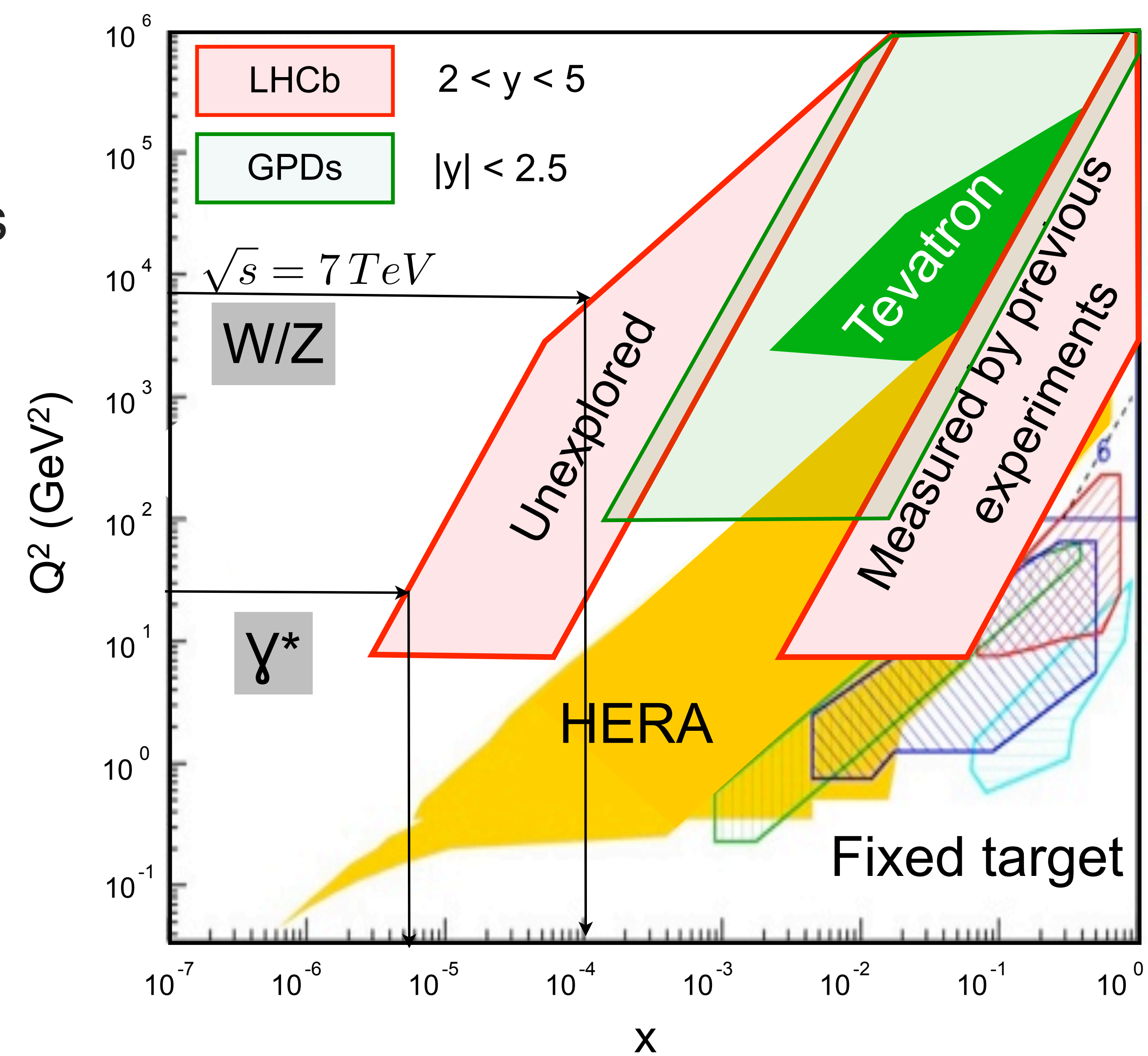
$$\sigma_{AB\to X} = \int dx_a dx_b f_{a/A}(x_a, Q^2) f_{b/B}(x_b, Q^2) \hat{\sigma}_{ab\to X}$$

PDFs (from data) **Partonic interaction** (pQCD)



LHC cross-section calculations factorised
- Partonic part from pQCD
- proton structure from previous measurements

LHCb probes unique low-x region
- test QCD
- constrain PDFs



Inclusive Z production

All events triggered using either single muon or single electron line ($p_T > 10$ GeV)

$Z \rightarrow \mu\mu$: LHCb-PAPER-2012-008
- 2010 data (37 pb^{-1})
- Both muons must have $p_T > 20$ GeV and $2 < \eta < 4.5$
- $60 < M_{\mu\mu} < 120$ GeV

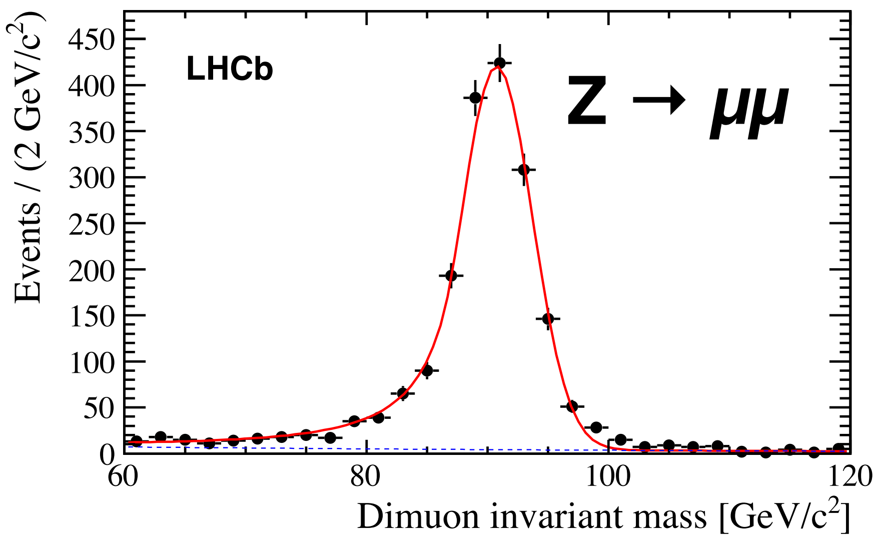
$Z \rightarrow ee$: LHCb-CONF-2012-011
- 2011 data (945 pb^{-1})
- Both electrons must have $p_T > 20$ GeV and $2 < \eta < 4.5$
- $M_{ee} > 40$ GeV
- Energy from momentum measurement only (no bremsstrahlung correction)

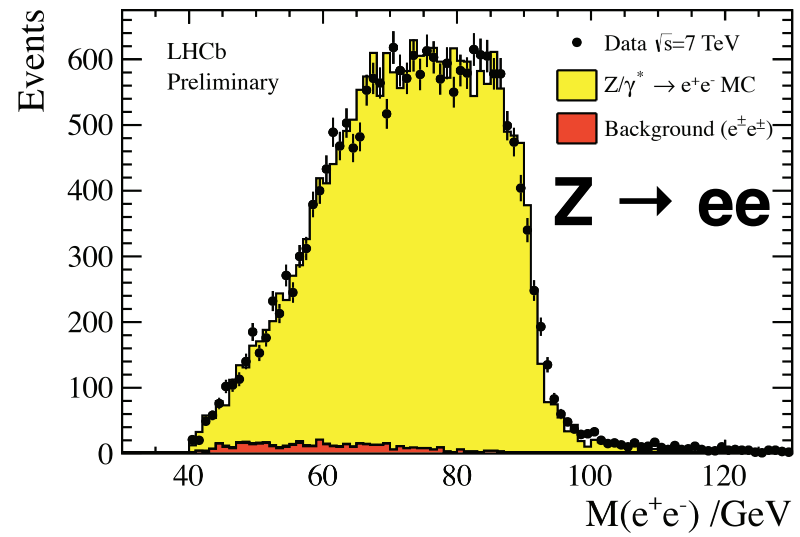
$Z \rightarrow \tau\tau$ ($\rightarrow \mu\mu$ or μe): LHCb-CONF-2011-041
- 2010 and 2011 data (247 pb^{-1})
- one muon with $p_T > 20$ GeV and another lepton with $p_T > 5$ GeV
- require isolated leptons with $\Delta\phi > 2.7$
- For dimuon final state require unbalanced muon pT to remove $Z \rightarrow \mu\mu$

Reconstruction efficiencies are determined from data using tag-and-probe methods

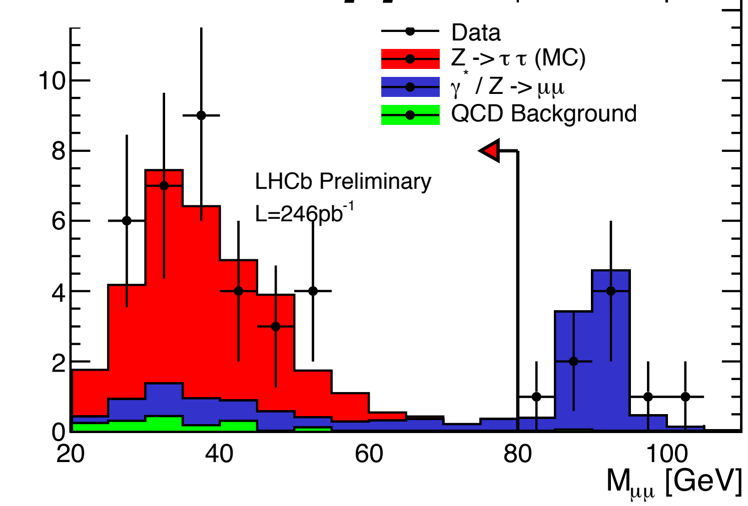
Inclusive Z production

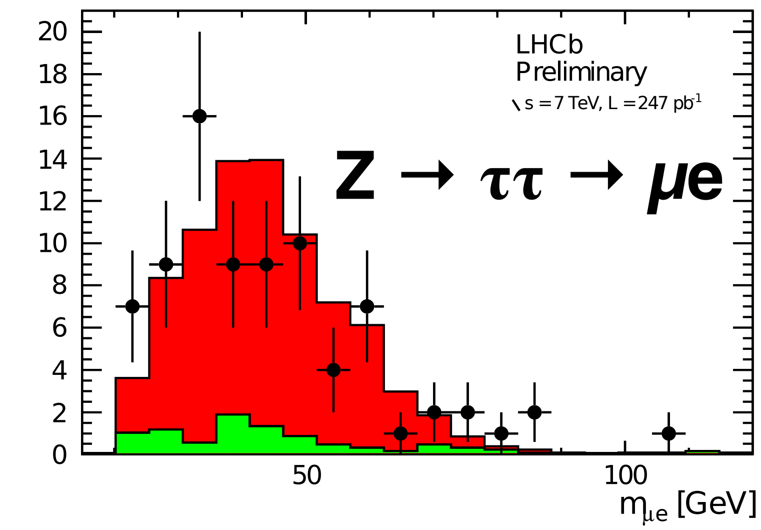
LHCb-PAPER-2012-008
LHCb-CONF-2012-011
LHCb-CONF-2011-041





Z → ττ → μμ





Z → μμ
Luminosity: $37\ pb^{-1}$
Candidates: 1966
Purity: 99.7%

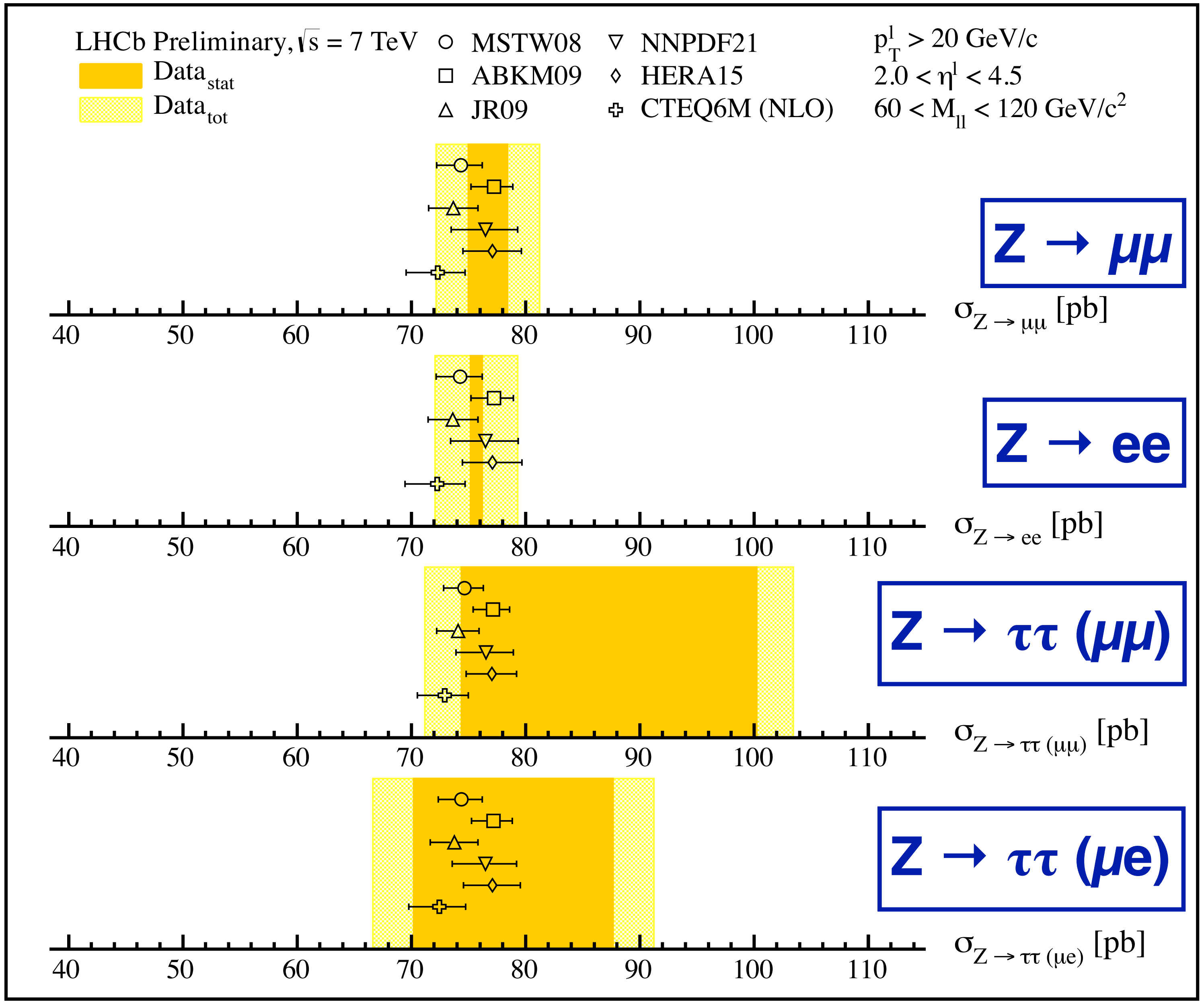
Z → ee
Luminosity: $945\ pb^{-1}$
Candidates: 21k
Purity: 97.8%

Z → ττ
Luminosity: $247\ pb^{-1}$
Candidates: 81 (μe) and 33 (μμ)
Purity: ~80%

Precision:	Z→ μμ	Z→ ee	Z→ ττ μe	Z→ ττ μμ
Statistical [%]	2.2	0.7	17	12
Luminosity[%]	3.5	3.5	5.1	
Systematic[%]	4.3	3.1	16	10
Luminosity[pb]	37.5	945	247	

Systematics will reduce with more statistics

Inclusive Z production



LHCb-PAPER-2012-008

LHCb-CONF-2012-011

LHCb-CONF-2011-041

LHCb-CONF-2011-041

NNLO (DYNNLO) PDF uncertainties at 68% CL

Z rapidity

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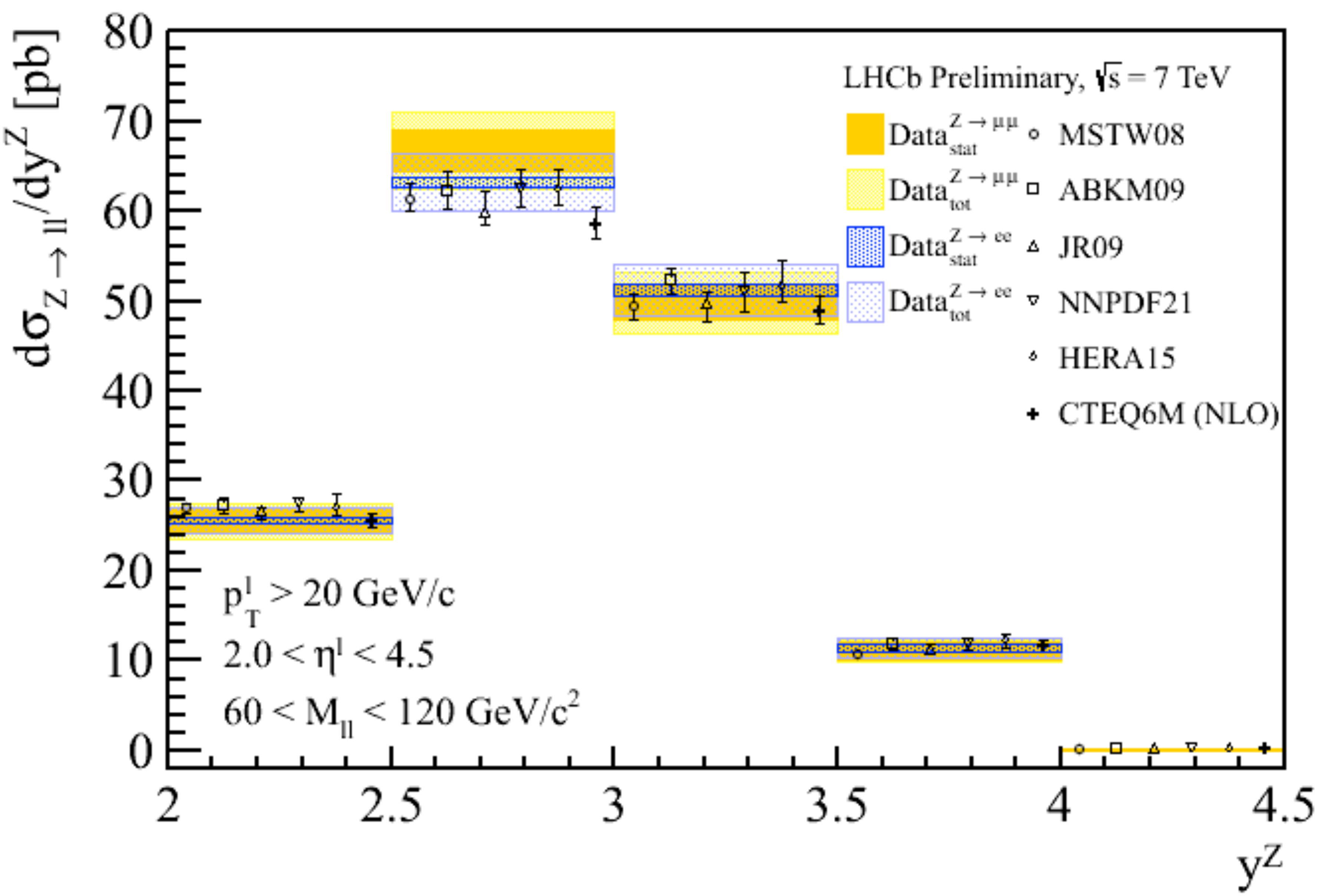
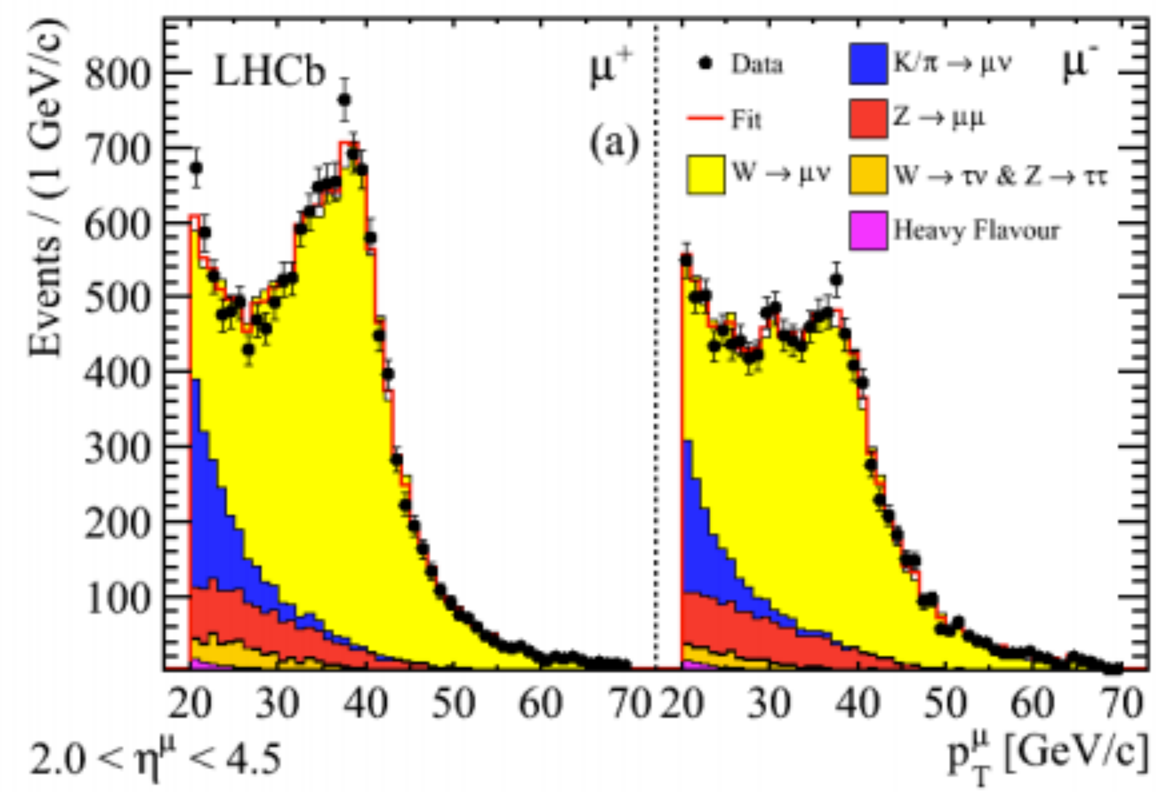
LHCb-CONF-2012-011



Inclusive W production

LHCb-PAPER-2012-008

W → *μν*:
- 2010 data (37 pb^{-1})
- Muon must:
  - pass single muon trigger line
  - have pT > 20 GeV and 2 < η < 4.5
  - be isolated
  - be compatible with the primary pp vertex
  - have E(calorimeter)/p < 0.04
- Sample purity from fit to muon pT spectrum
- Selection efficiency using Z → *μμ* sample
- Reconstruction efficiencies determined from data

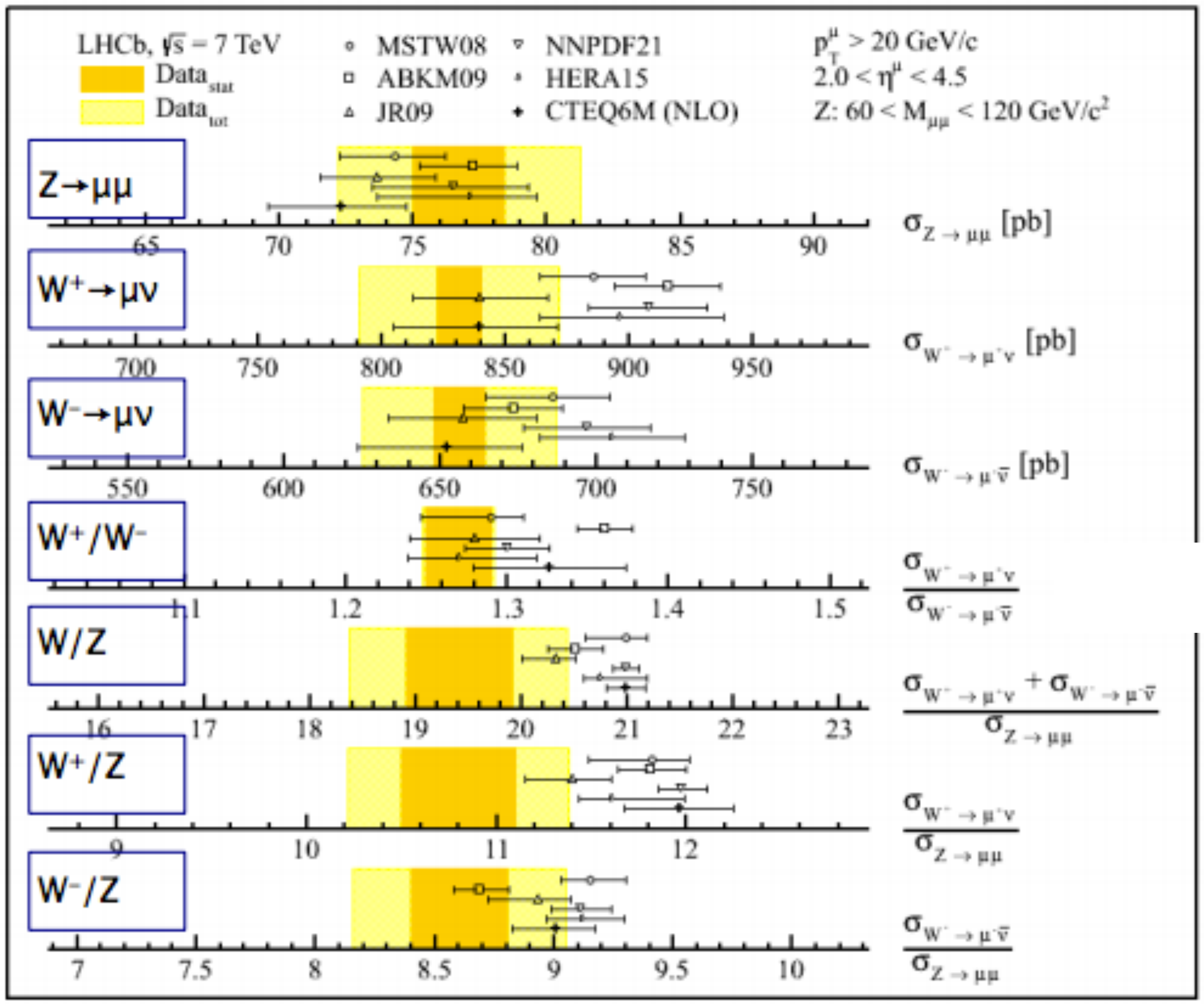


	Shape	Norm.
W →μν	Simulation	Fit
K/π decay in flight	Data	Fit
γ*/Z→μμ	Simulation	Fixed
W→τν , Z→ττ	Simulation	Fixed
Heavy Flavour	Data	Fixed

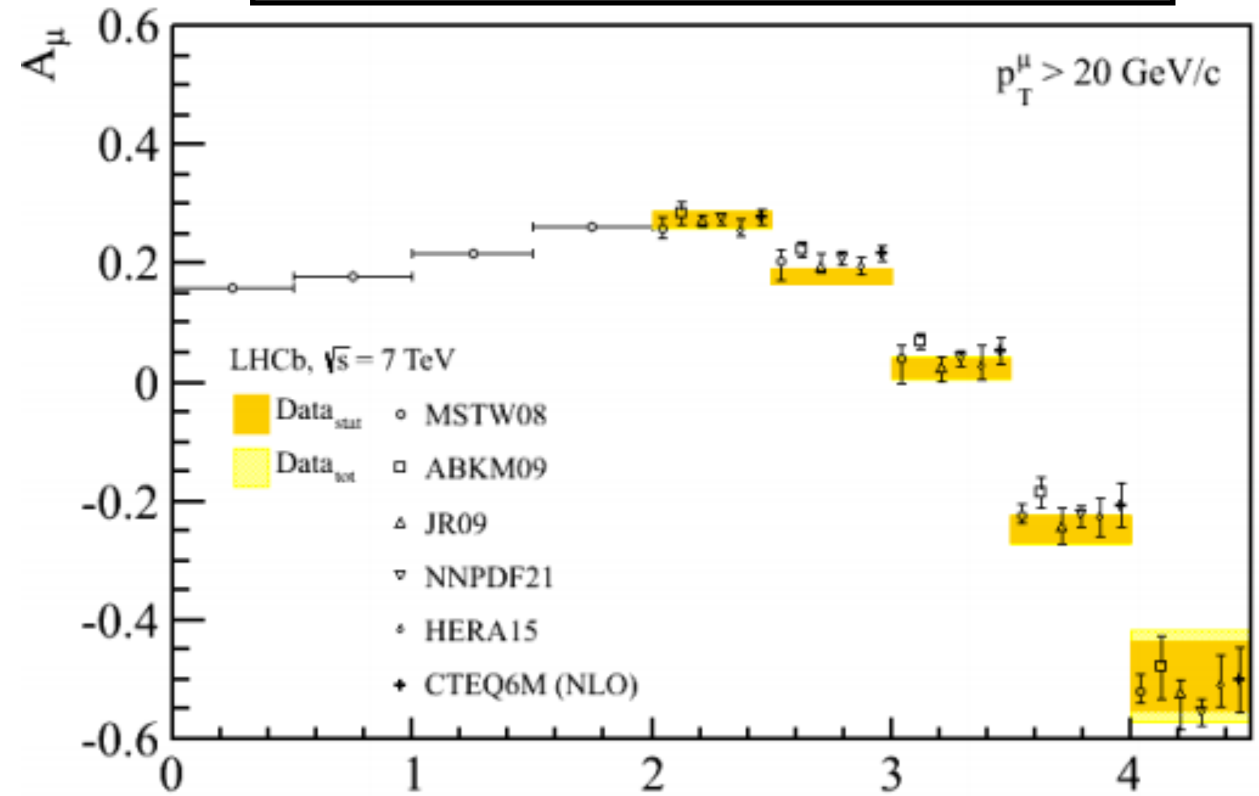
Normalisation
- Signal and decay in flight: fitted
- Others : fixed from data

Inclusive W results

LHCb-PAPER-2012-008



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



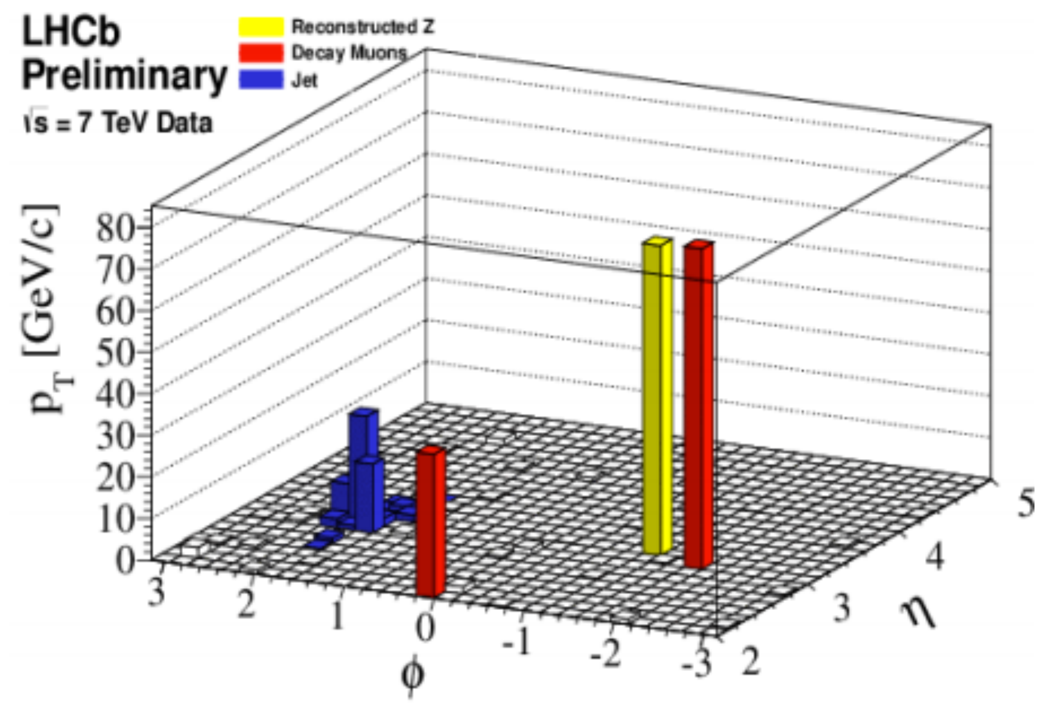
Lepton pseudorapidity

Z (→ $\mu\mu$) + jets

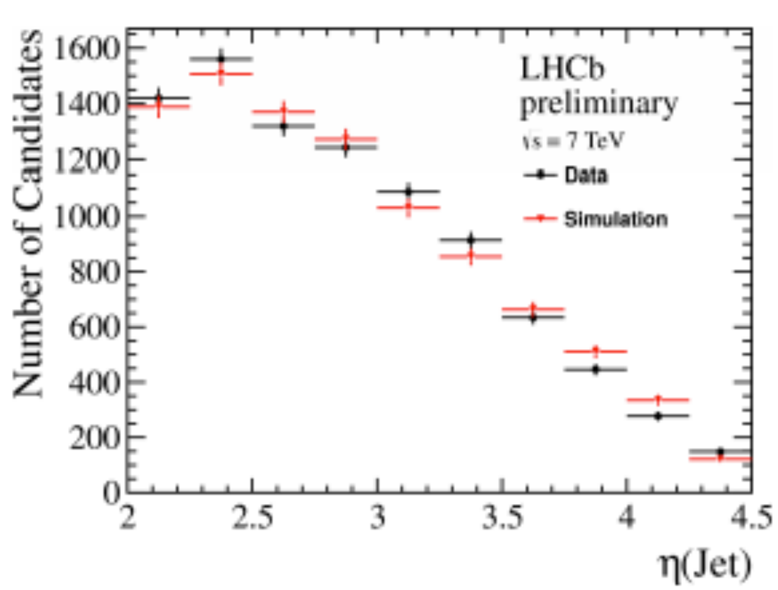
LHCb-CONF-2012-016

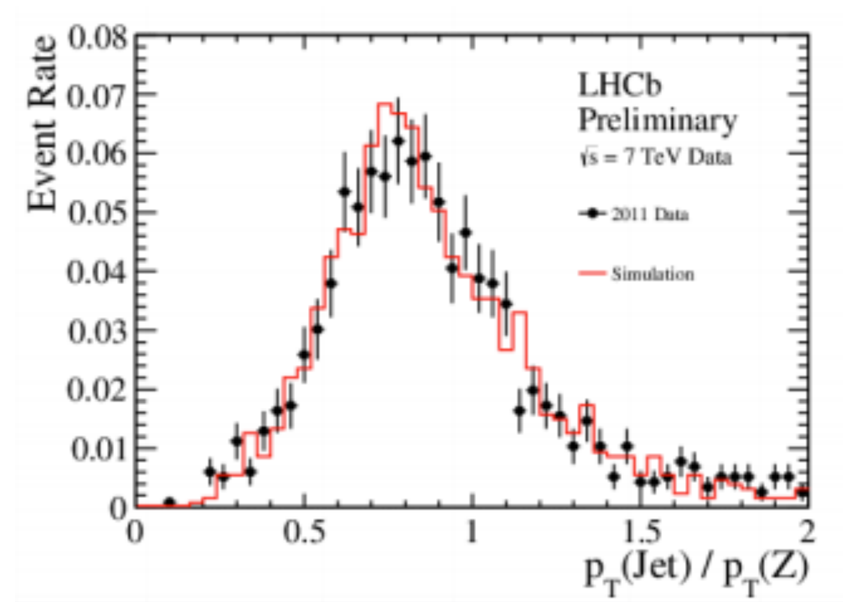
Data:
- 2011 data (1 fb^{-1})
- Same trigger and event selection as Z → $\mu\mu$

Jet selection:
- particle flow method using tracks, photons, neutral hadrons and V0s
- anti-kT algorithm (R=0.5)
- pT > 10 GeV and 2 < η < 4.5
- ΔR(jet,μ) > 0.4



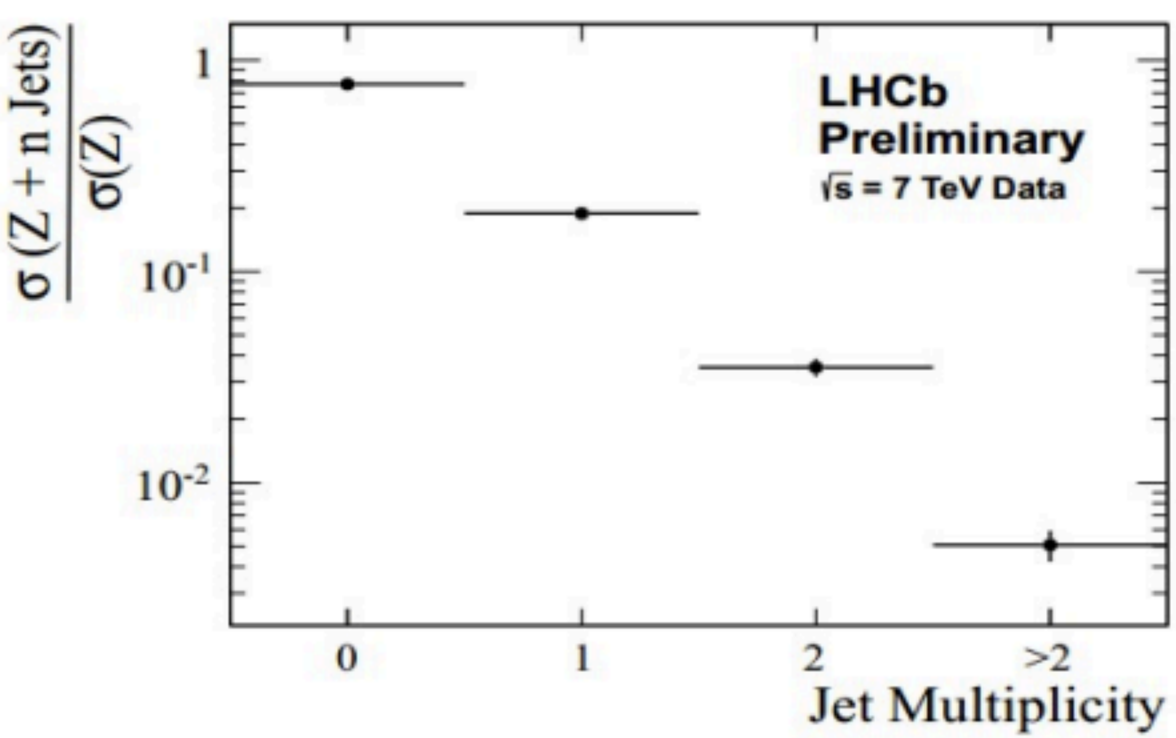
Jet energy correction from simulation:
- validated from data using Z + 1 jet events
- simulation and data agree well at detector level

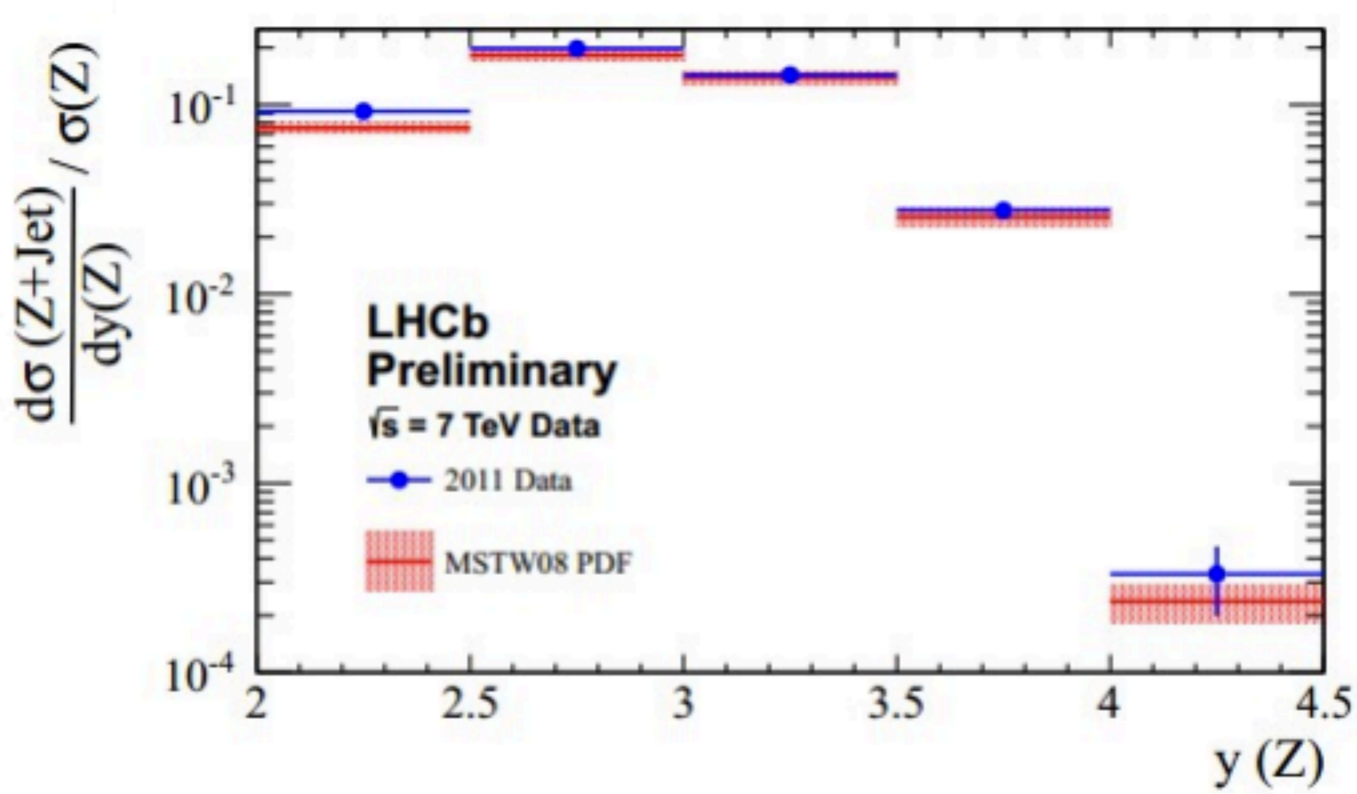




Z (→ $\mu\mu$) + jets results

LHCb-CONF-2012-016





Fraction of events with at least one jet:

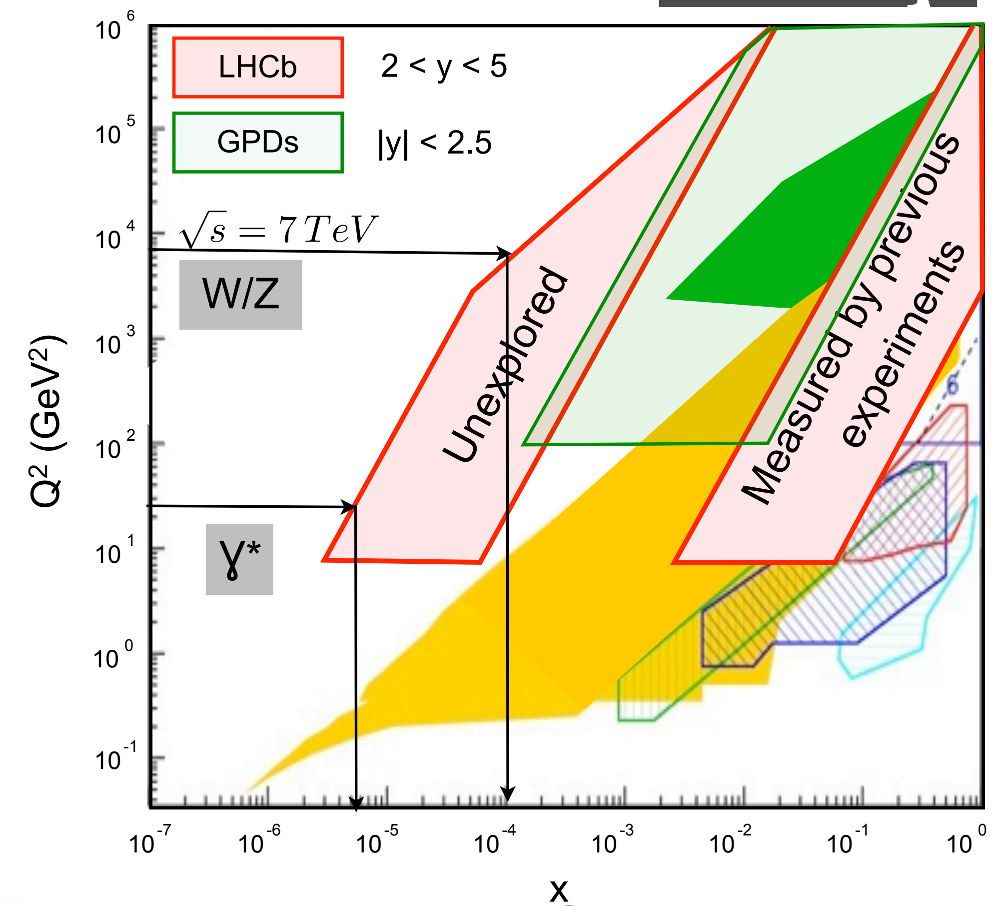
LHCb preliminary:
$0.229 \pm 0.006(\text{stat}) \pm 0.009(\text{syst}))$

NLO: FEWZ with MSTW0 (parton level)
$0.212\ ^{+0.006}_{-0.009}$ (PDF) ± 0.016 (scale)

(measurements at hadron level)

Low mass Drell-Yan production

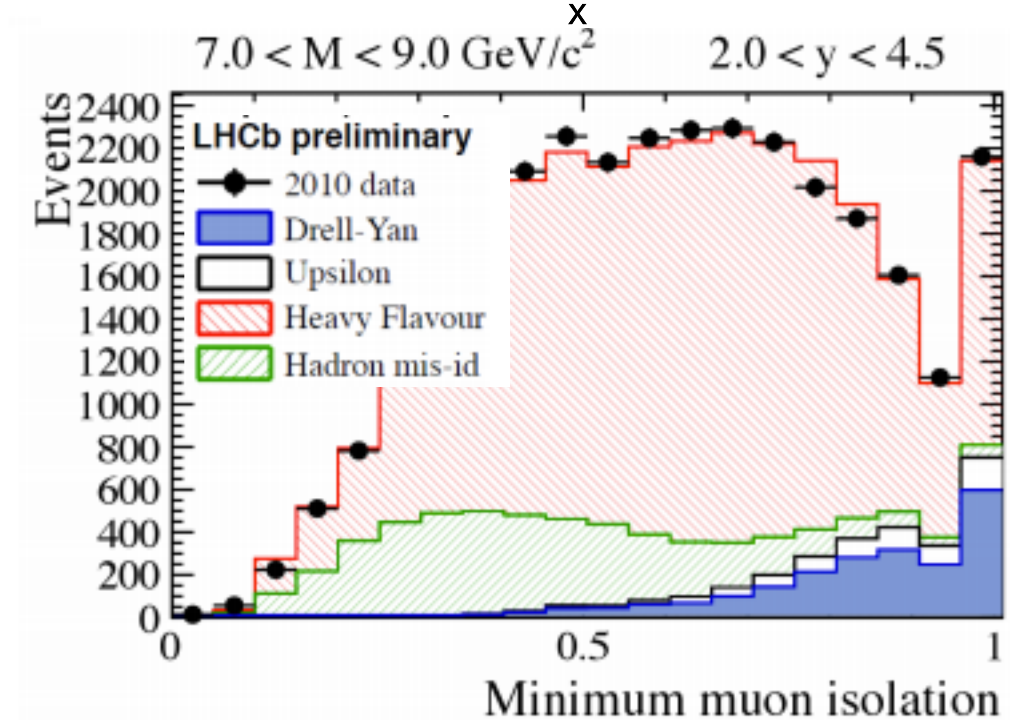
LHCb-CONF-2012-013



Low mass DY probes lower x values

Data and selection:
- 2010 data (37 pb-1)
- events pass dimuon trigger $M_{\mu\mu} > 2.5$ GeV
- muons must have p > 10 GeV, pT > 3 GeV and $2 < \eta < 4.5$
- measurements between $5 < M_{\mu\mu} < 120$ GeV

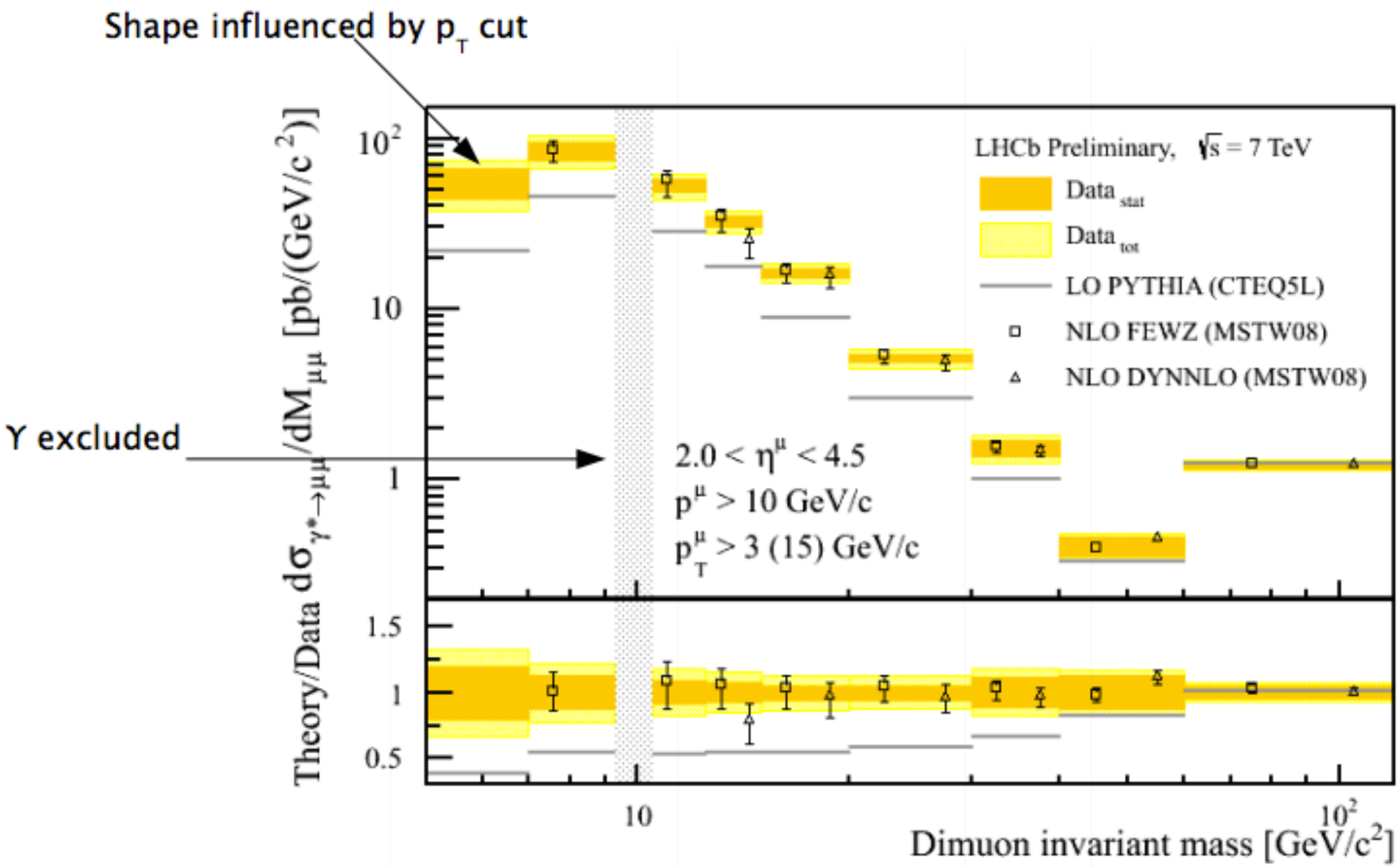
Purity:
- determined from fit to muon isolation
- dominant backgrounds from heavy flavour decays and hadron mis-id
- background templates from data, signal template from simulation



Experimental efficiencies from data

Low mass Drell-Yan results

LHCb-CONF-2012-013



Compared to NLO predictions (FEWZ and DYNNLO) and PYTHIA
FEWZ predictions above 7 GeV/c^2, DYNNLO above 12.5 GeV/c^2

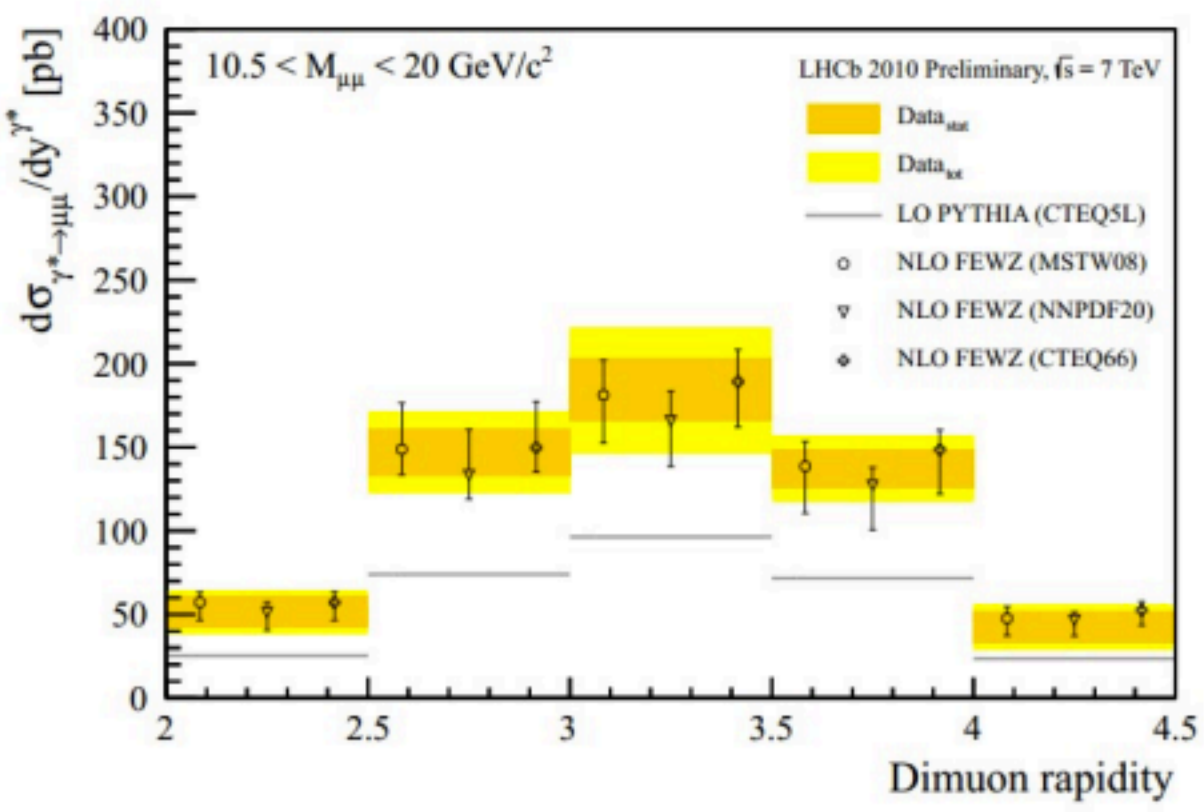
Conclusions

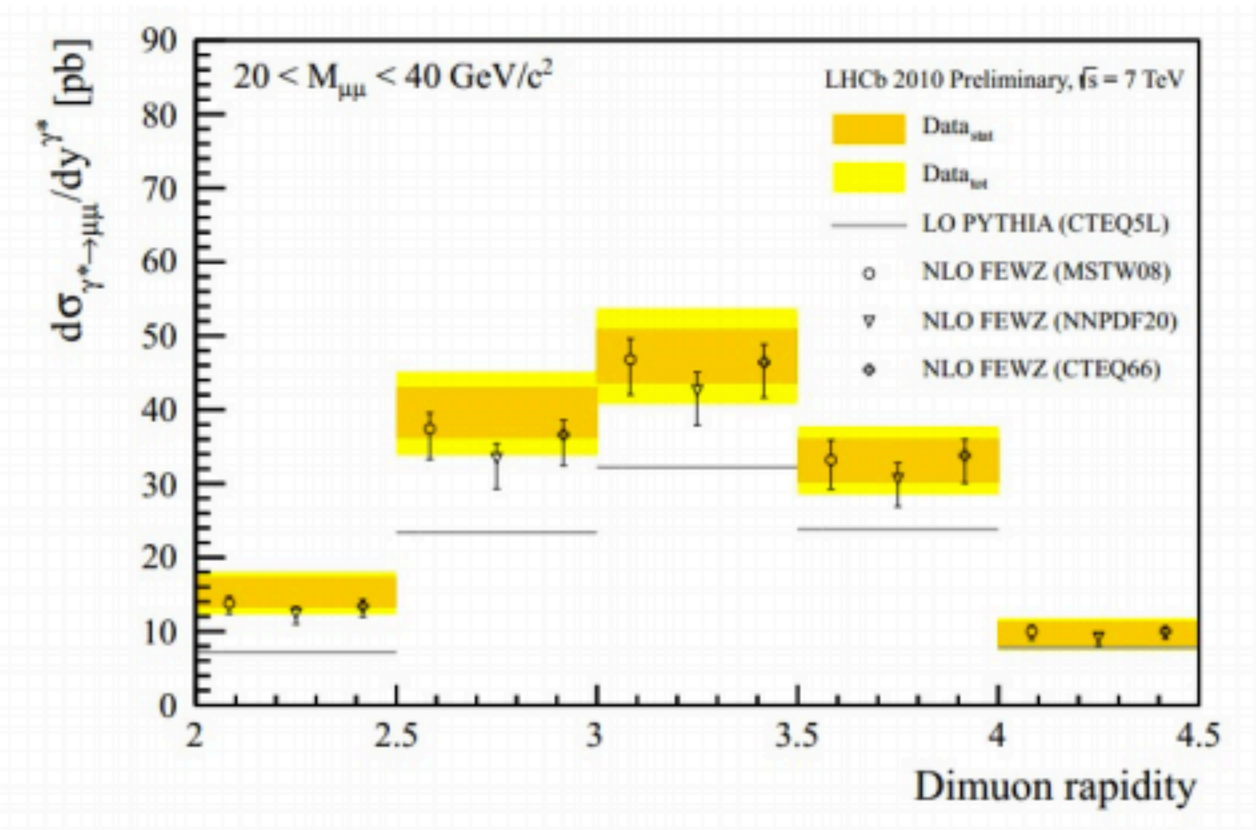
LHCb probes a unique kinematic region (down to $x \sim 5 \times 10^{-6}$)
- Measurements test QCD and constrain PDFs

Measurements in agreement with theoretical predictions
- in many cases the uncertainties are already comparable with the theory uncertainties

Measurements will be updated with full 2011 and 2012 datasets
- improved experimental precision
- higher energies will probe even lower x values

Low mass Drell-Yan results - backup





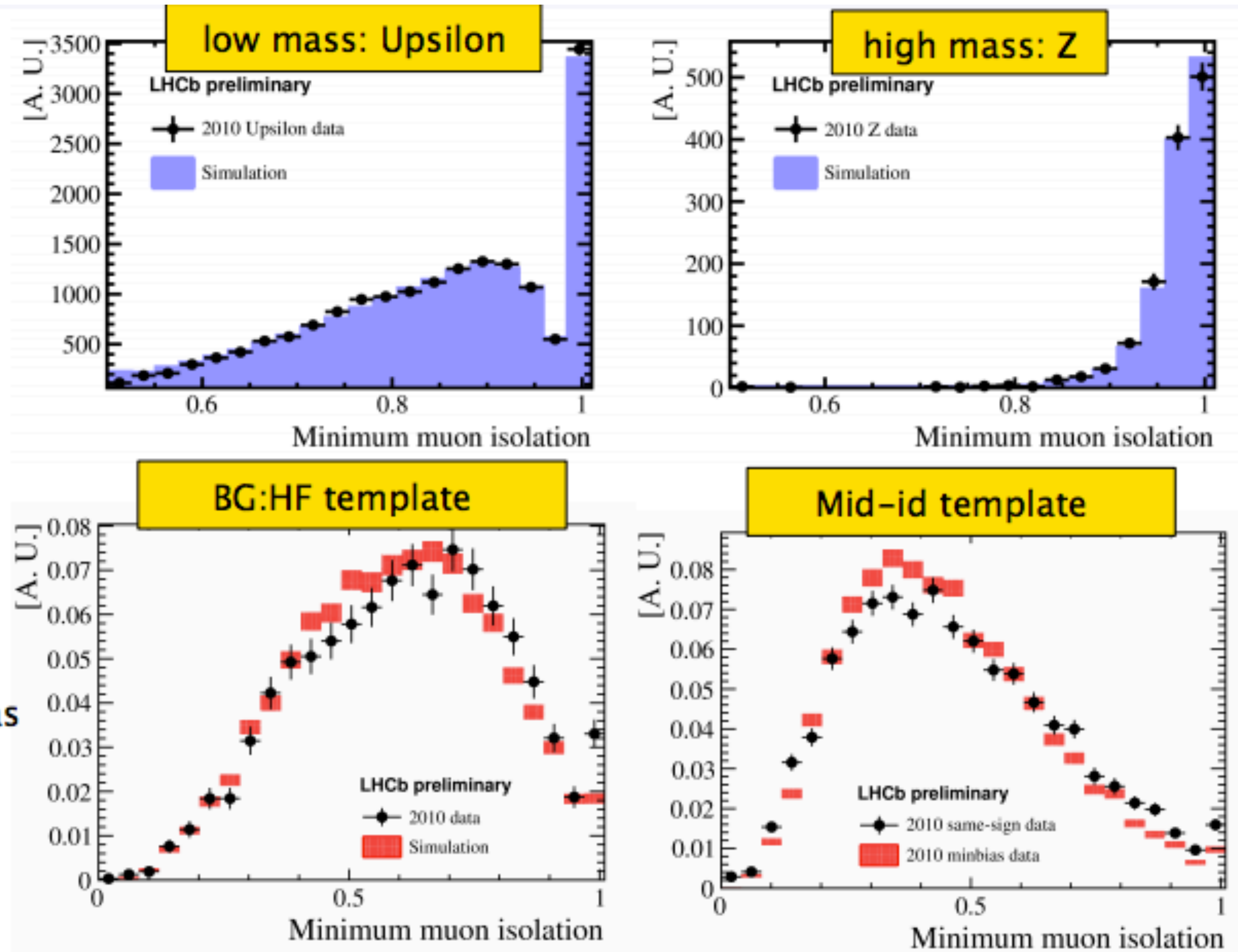
LHCb-CONF-2012-013

Low mass Drell-Yan templates - backup

Signal template:
Compare data and MC

Background templates:
1) Heavy Flavour
- data: IP cut
- simulation

2) Kaon–Pion mis–id
- data: minimum bias
- data: same sign



Systematic uncertainties due to templates:
Background: Difference in fitted signal fraction when using different background templates
Signal: distort signal template

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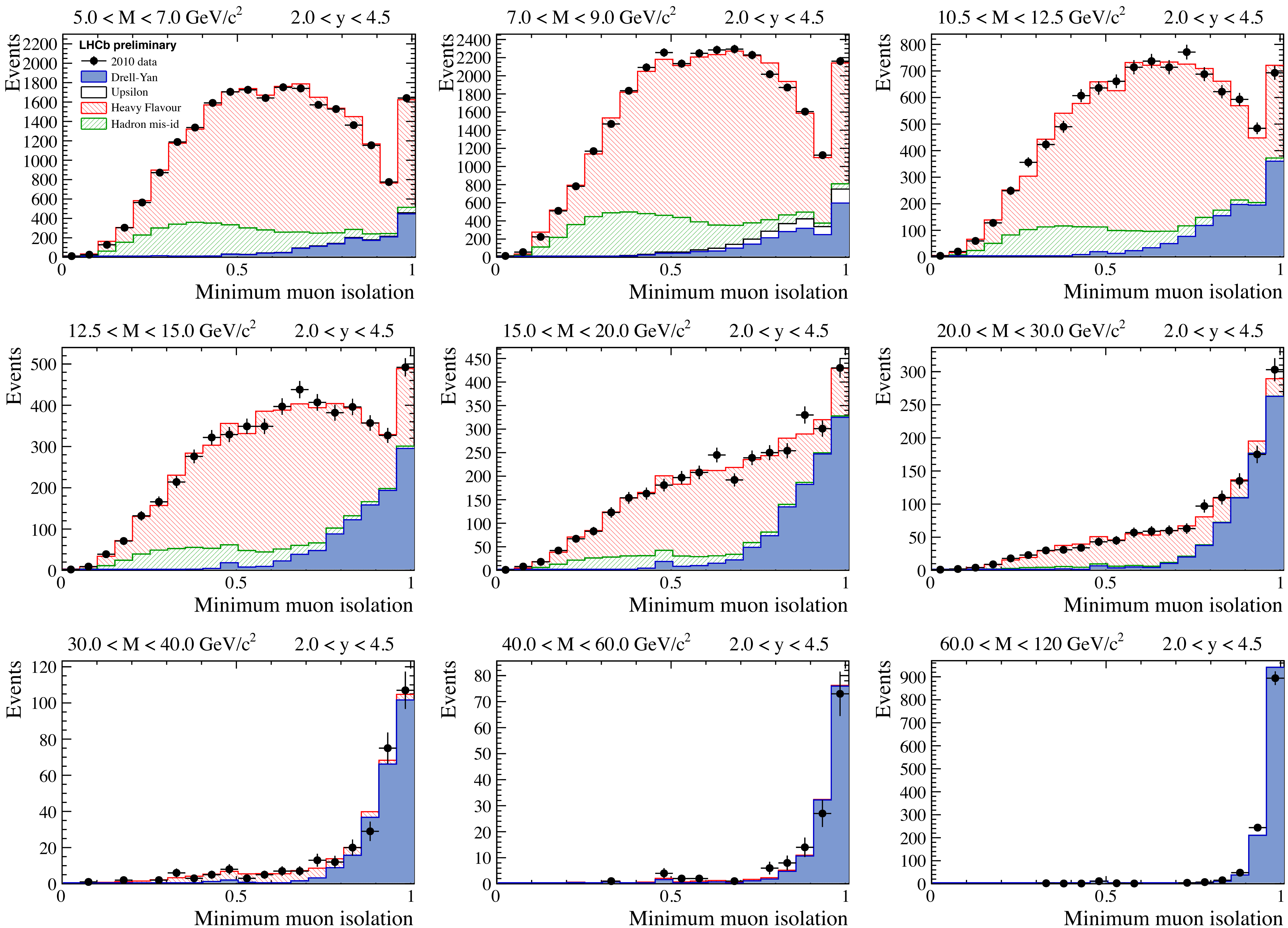
Low mass Drell-Yan production - backup



LHCb-CONF-2012-013

PDF sets - backup

Results compared to NNLO predictions (DYNNLO)with 6 recent PDF sets

- MSTW08. A. Martin, W. Stirling, R. Thorne and G. Watt
  arXiv:0901.0002
- ABKM09: S. Alekhin, J. Blumlein, S. Klein and S. Moch
  arXiv:0908.2766
- JR09: P. Jimenez-Delgado and E. Reya
  arXiv:0810.4274
- NNPDF D. Ball et al.
  arXiv:1002.4407
- HERA15 H1 and ZEUS collaboration
  arXiv: 0911.0884
- CTEQ6M P. M. Nadolsky et al. (NLO)
  arXiv:0802.0007

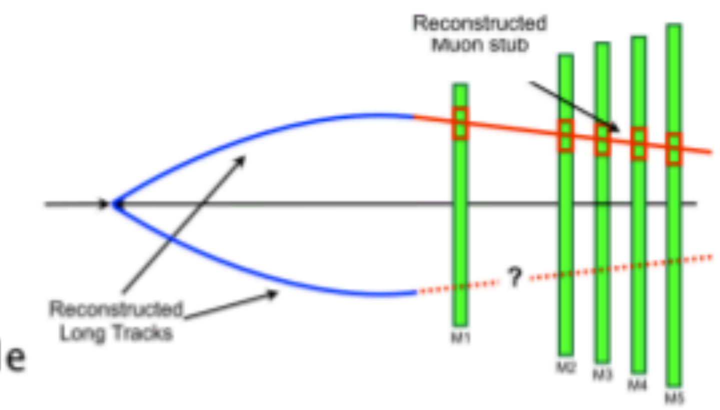
Reconstruction efficiencies - backup

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

ρ: purity
A: acceptance
L: luminosity
ϵ: efficiency
N: candidates
f_{FSR}: final state radiation

Efficiencies mostly from data
tracking, identification and trigger: tag and probe in Z sample

Muon identification



Tag:
well identified, triggered muon/electron

Probe:
Identification: fully reconstructed track
Tracking: muon-stub -TT hits
Trigger: identified muon/electron
Electron tracking from MC

Selection (Z→ττ) from MC
μμ: ϵ_{sel} = 0.172 ± 0.014
μe: ϵ_{sel} = 0.46 ± 0.03

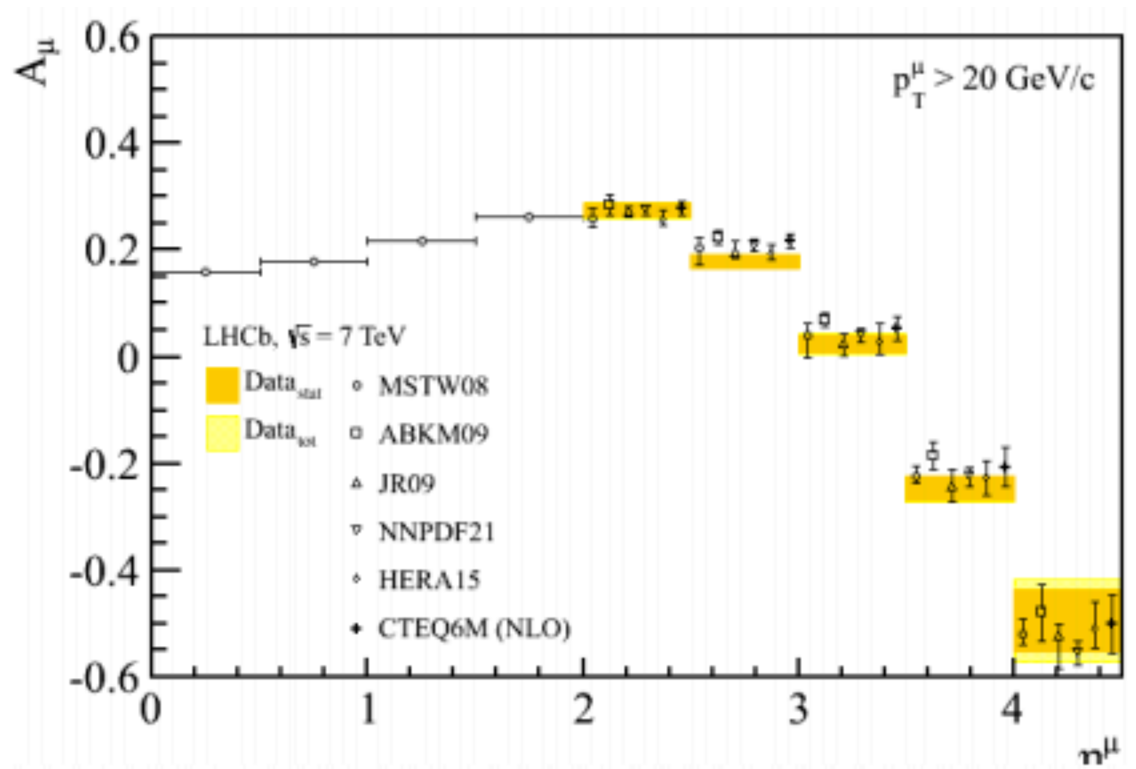
Acceptance:
Result within fiducial range of measurement

Z→ μμ:	>0.99
Z → ee:	0.4-0.6
Z→ττ:	0.25 (μe), 0.39 (μμ)

Typical efficiencies
Tracking: 90%
Muon identification: >99%
Electron identification: 95%
Muon Trigger: 88%
Electron Trigger: 85%

Corrected event-wise as function of η_μ
Checked for charge bias

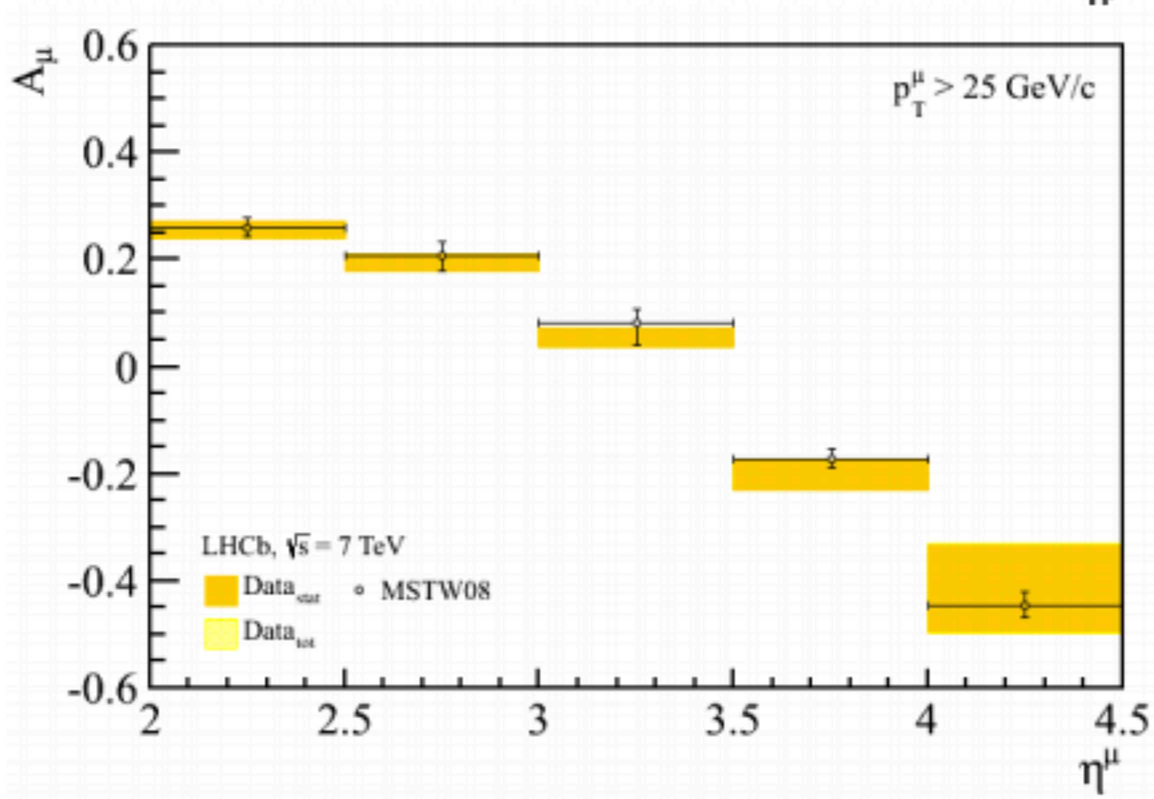
W lepton asymmetry - backup

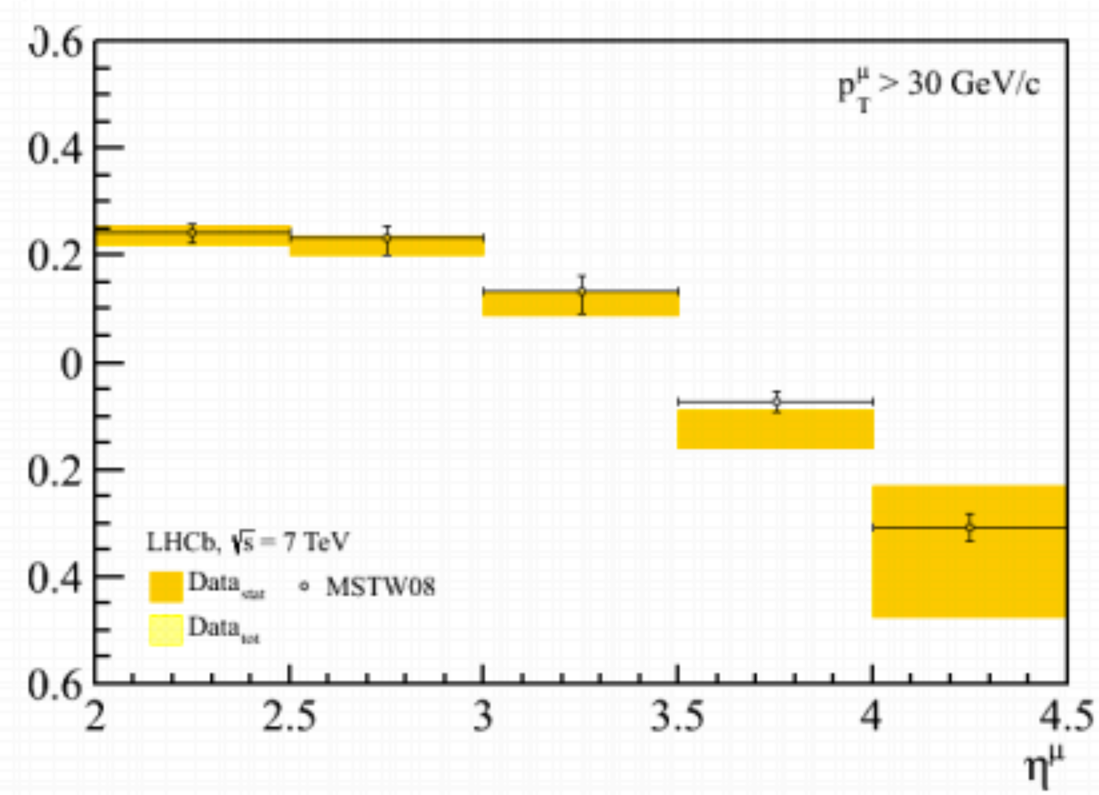


W lepton charge asymmetry for different p_T thresholds

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

LHCb-PAPER-2012-008

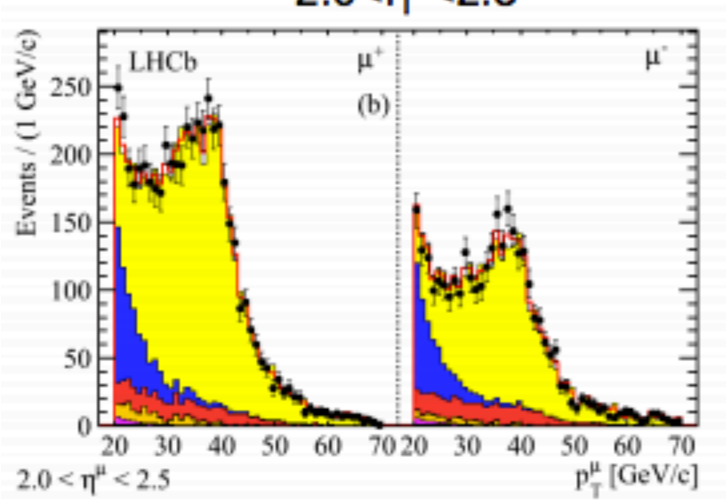




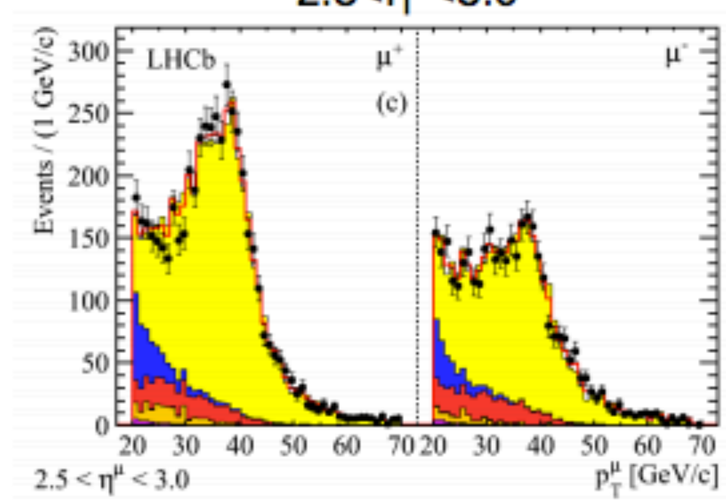
W purity fits - backup

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

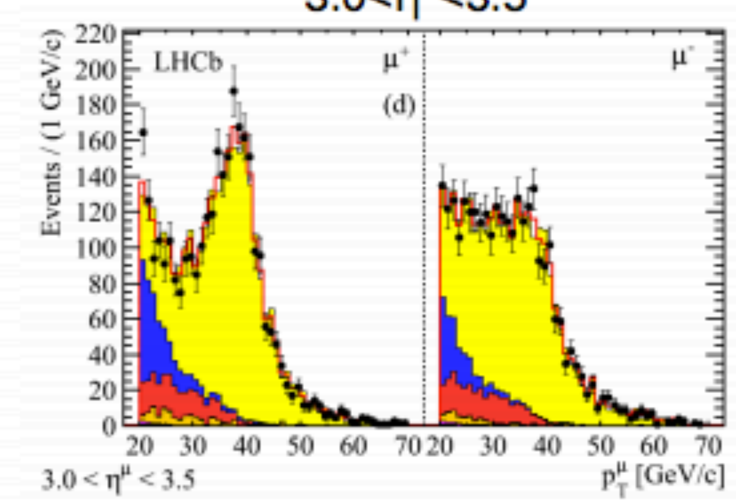
$2.0<\eta^{\mu}<2.5$



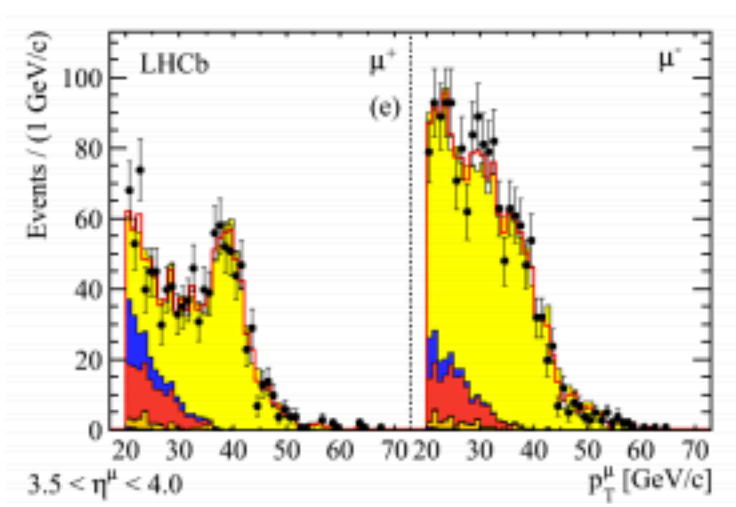
$2.5<\eta^{\mu}<3.0$



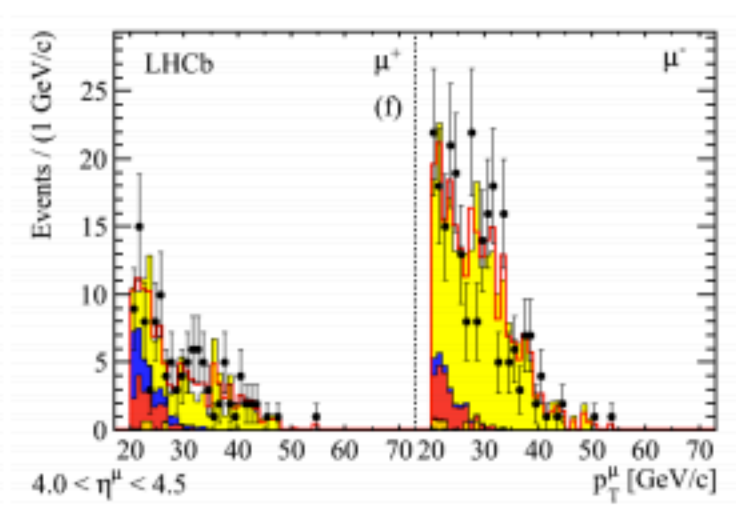
$3.0<\eta^{\mu}<3.5$



$3.5<\eta^{\mu}<4.0$



$4.0<\eta^{\mu}<4.5$

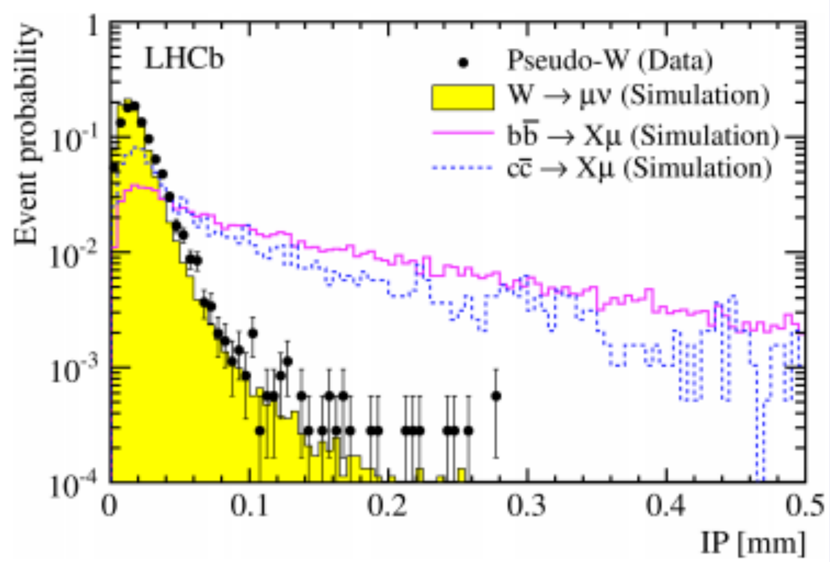


	Shape	Norm.
$W \to \mu\nu$	Simulation	Fit
K/π decay in flight	Data	Fit
$\gamma^*/Z \to \mu\mu$	Simulation	Fixed
$W \to \tau\nu$, $Z \to \tau\tau$	Simulation	Fixed
Heavy Flavour	Data	Fixed

LHCb-PAPER-2012-008

W background suppression - backup

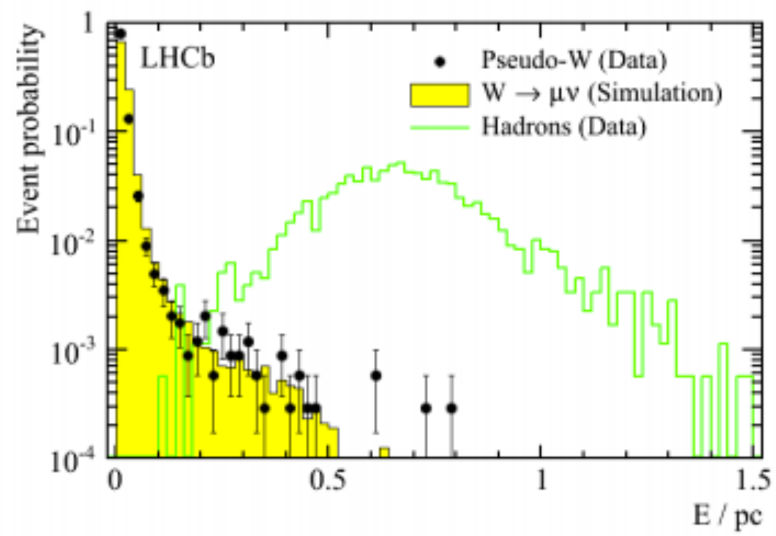
Muon impact parameter distribution



Signal: pseudo-W data

Background: semileptonic decays of hadrons containing b or c quarks from simulation

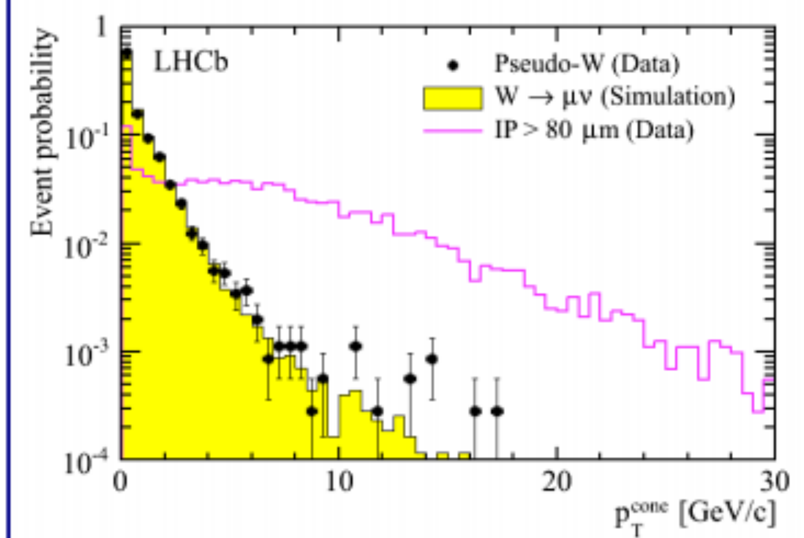
Energy in calorimeters



Signal: pseudo-W data

Background:
hadrons from randomly triggered events

Muon isolation: p_T in cone



Signal: pseudo-W data
Z events with one muon removed

Backgrounds:
- semileptonic decays of heavy flavour
- kaon, pion misidentification

From data: muons with impact parameter > 80 μm

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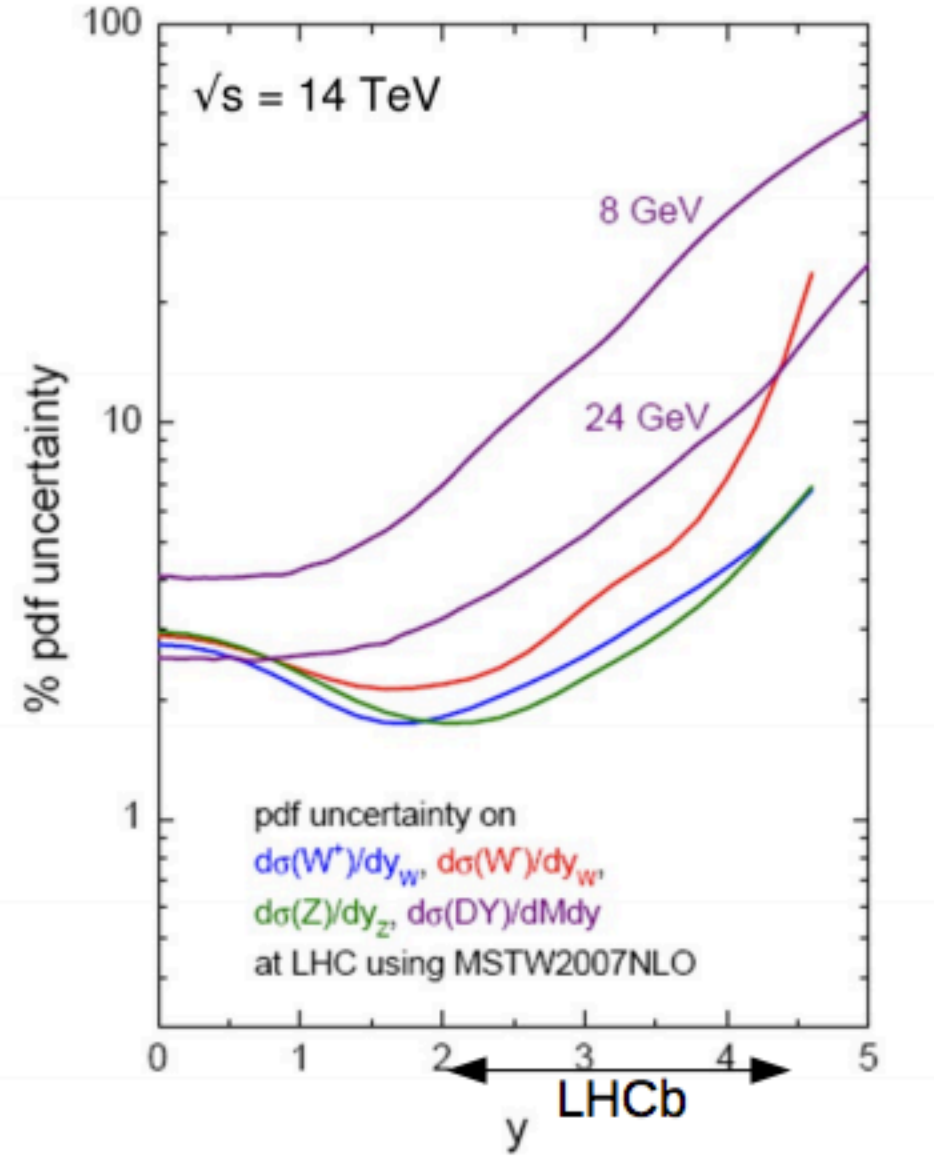
PDF uncertainties - backup

$$\underbrace{\sigma\left(x,Q^2\right)}_{hadronic\ x-sec.} = \sum_{a,b}\int_0^1 dx_1\,dx_2\underbrace{f_a\left(x_1Q^2\right)f_b\left(x_2Q^2\right)}_{PDFs\ 2-8\%}\ \underbrace{\hat{\sigma}\left(x_{1,}x_{2,}Q^2\right)}_{partonic\ x-sec.:\ NNLO\ 1\%}$$

Theoretical predictions

- Cross-sections known to NNLO to %-level
- PDF uncertainty dominates at large rapidities 3% at y <2, 6-8% at y~5
- Low mass Drell-Yan: uncertainties much larger



Plot from Thorne et al. (arXiv:0808.1847)

PDF uncertainties - backup

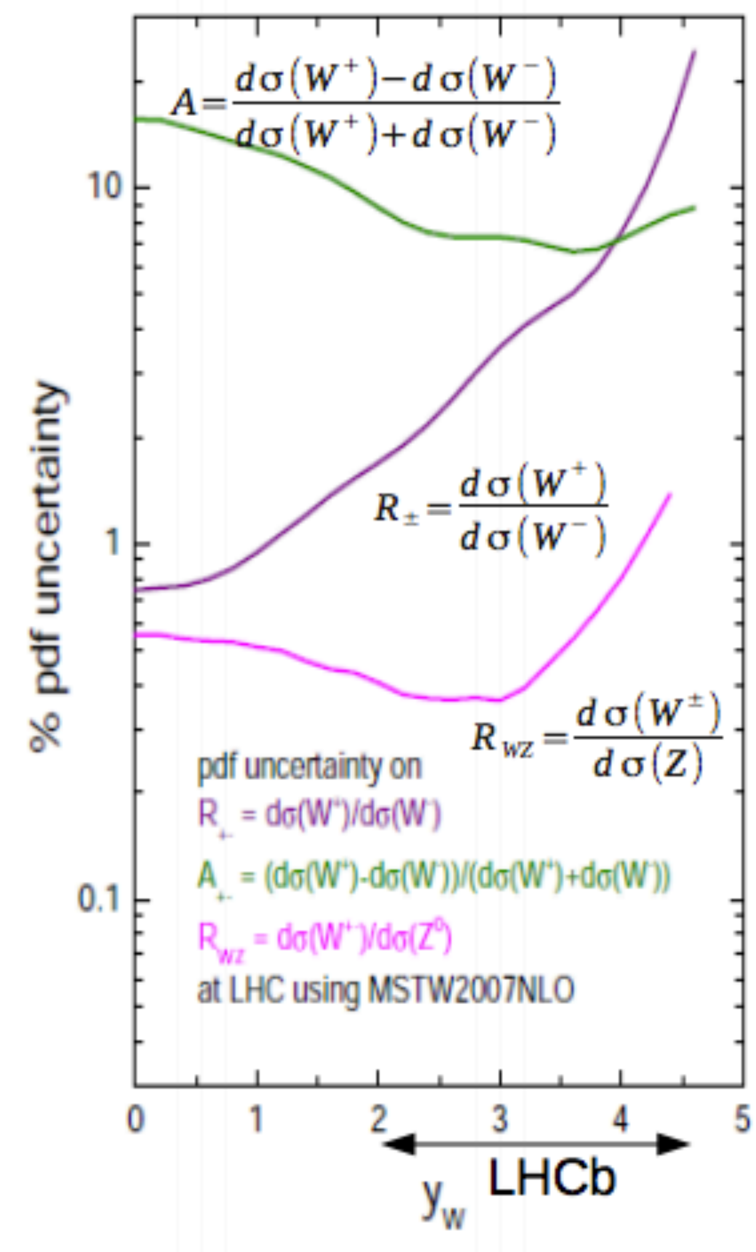
Cancel or highlight PDF uncertainties with ratios

- Many systematic uncertainties cancel
- Theoretical uncertainties partially cancel
- $A_W = (d\sigma(W^+) - d\sigma(W^-))/(d\sigma(W) + d\sigma(W^-))$

  tests valence quarks: difference btw. u_V and d_V
- $R_{+-} = d\sigma(W^+)/d\sigma(W^-)$

  tests valence quarks: u_V/d_V ratio
- $R_{WZ} = d\sigma(W^{+-})/d\sigma(Z)$

  almost insensitive to PDFs
  precise test of SM



Plot from Thorne et al. (arXiv:0808.1847)