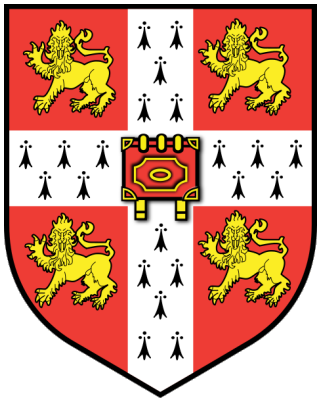


Physics with Electroweak Gauge Bosons at LHCb

PLHC 2012, Vancouver, Canada

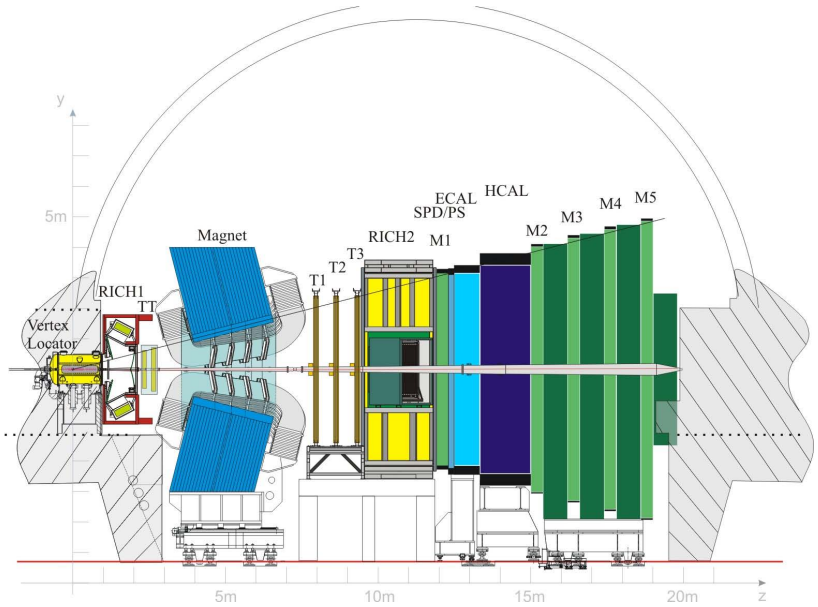
William Barter
On behalf of the LHCb collaboration

University of Cambridge

5^{th} June 2012

LHCb Detector

- Single arm spectrometer, fully instrumented in forward region ($2.0 < \eta < 5.0$). Designed to search for new physics in B and D decays.
- Overlap with GPDs in $2.0 < \eta < 2.5$, unique coverage in $2.5 < \eta < 5.0$.



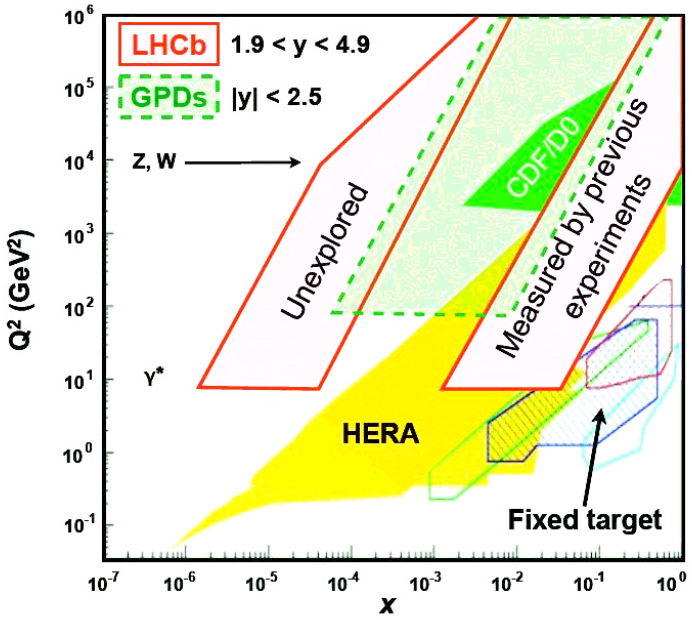
- Excellent vertex resolution (VELO),
- Tracking detectors, ECAL, HCAL, Muon chambers,
- Also 2 Cherenkov detectors for particle identification,
- Trigger on single lepton ($p_T > 10$ GeV) and dimuon ($M(\mu\mu) > 2.5$GeV).

LHCb can provide complementary measurements of Electroweak Physics to the GPDs.

Physics Motivation

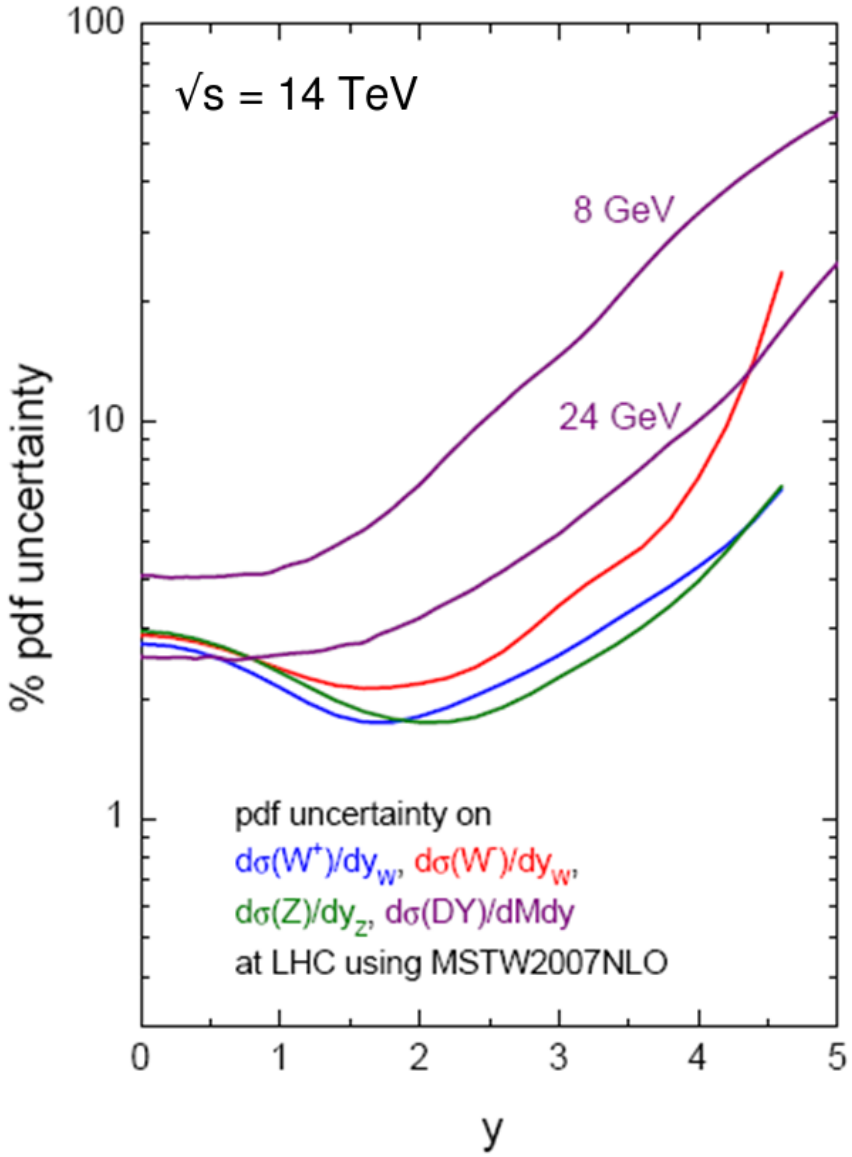
The forward region probed by LHCb means that:

- events visible at LHCb will be from one parton at high Bjorken-x, and the other parton at low x,



- PDFs at high x are well constrained by previous measurements,
- the low x parton is not well constrained: LHCb uniquely probes PDFs in the region down to $x \sim 10^{-6}$.
- reasonably high Q^2 probed by W, Z measurements; low Q^2 probed by low mass Drell-Yan measurements (left hand plot for $\sqrt{s} = 14$ TeV)

Physics Motivation



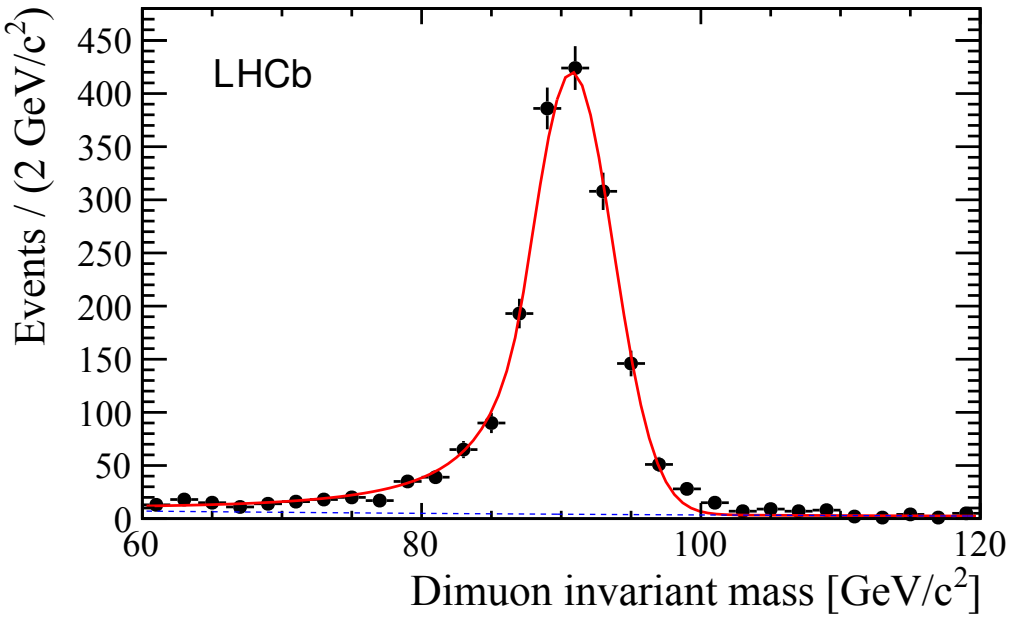
- Large PDF uncertainties on cross-sections as we probe previously unexplored region - measurements at LHCb can be used to provide PDF constraints.
- PDF uncertainties also cancel in particular ratios, allowing precise tests of the standard model.
- SM predictions known at NNLO order, allowing accurate predictions to compare our results against.

Plot from Thorne *et al.* (arXiv:0808.1847)

$Z \to \mu\mu$

LHCb-PAPER-2012-008 (arXiv:1204.1620, accepted by JHEP)

- 2010: $\int \mathcal{L} dt = 37$ pb^{-1}
- $\sqrt{s} = 7$ TeV
- single muon trigger ($p_T > 10$ GeV),
- Acceptance:
  - $p_T(\mu) > 20$ GeV,
  - $2.0 < \eta(\mu) < 4.5$,
  - $60 < M(\mu\mu) < 120$ GeV.



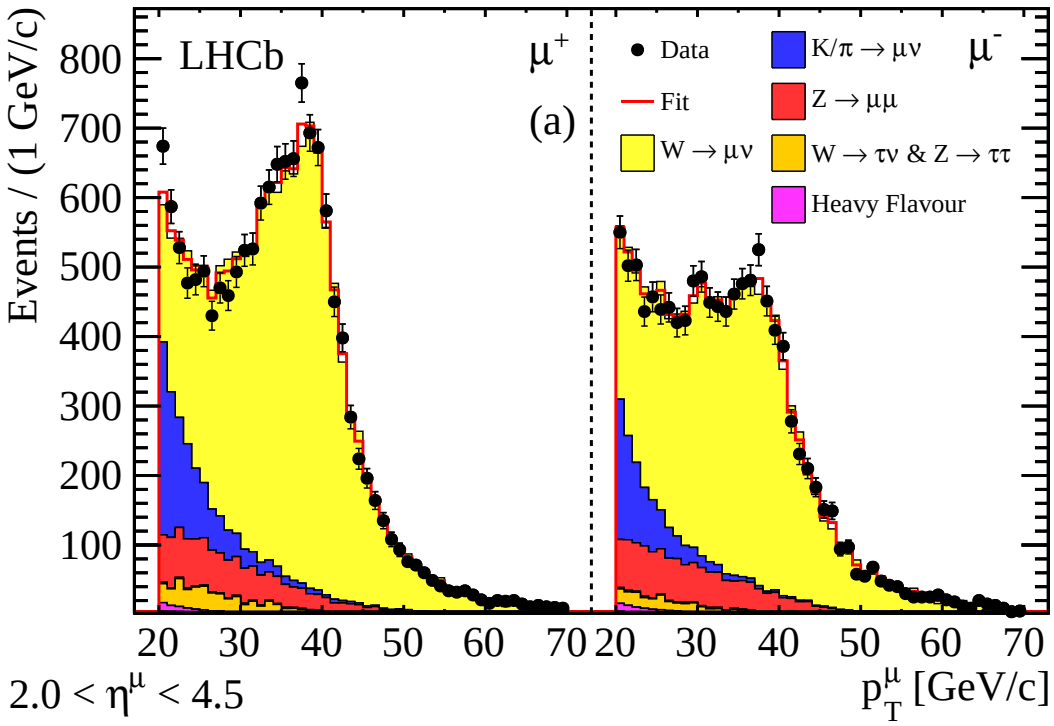
- Candidate Events: 1966
- Background: 4.9 ± 2.0 (taken from MC: $Z \to \tau\tau$, W-pair, Top-pair, taken from Data: Heavy flavour, K/π mis-ID)

- Dominant systematic from efficiency determination.

$W \to \mu\nu$

LHCb-PAPER-2012-008

- Acceptance:
  - $p_T(\mu) > 20$ GeV,
  - $2.0 < \eta(\mu) < 4.5$,
- Require the muon to be isolated and associated with the primary vertex.
- Small deposit associated with particle in ECAL and HCAL.
- No other muon in the event with $p_T > 2$ GeV.



- W^+ Candidate Events: 14660 W^- Candidate Events: 11618

- Background taken from MC: $Z \to \tau\tau$, W-pair, Top-pair,
  taken from Data: Heavy flavour, K/π mis-ID.

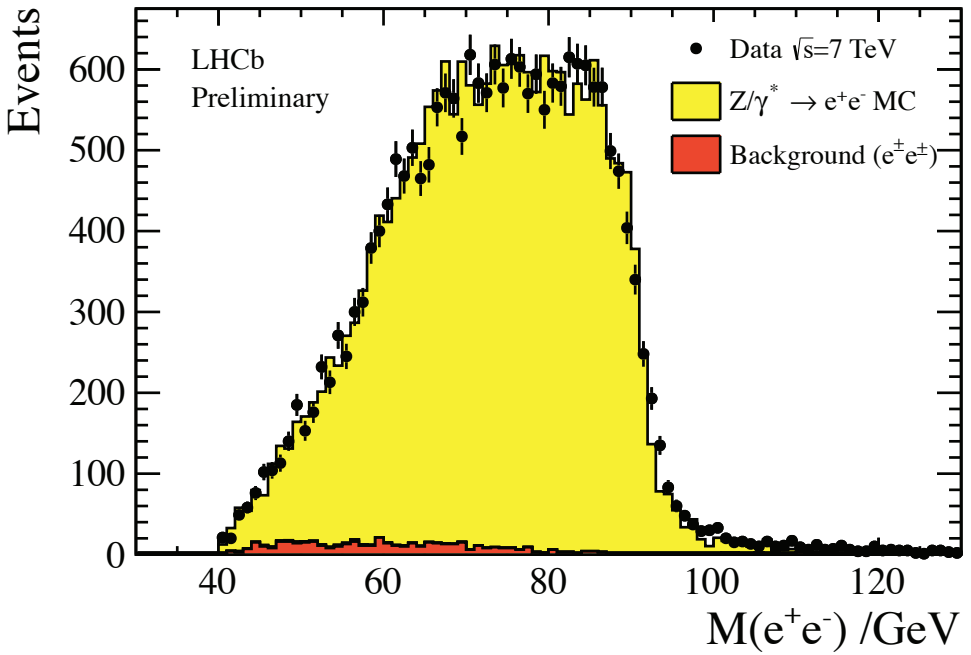
$Z \rightarrow ee$

LHCb-CONF-2012-011

- 2011: $\int \mathcal{L} dt = 945$ pb^{-1}
- $\sqrt{s} = 7$ TeV

- single electron trigger ($p_T > 10$ GeV),
- calorimeter based identification cuts to select electrons

- Acceptance:
  - $p_T(e) > 20$ GeV,
  - $2.0 < \eta(e) < 4.5$,
  - $60 < M(ee) < 120$ GeV

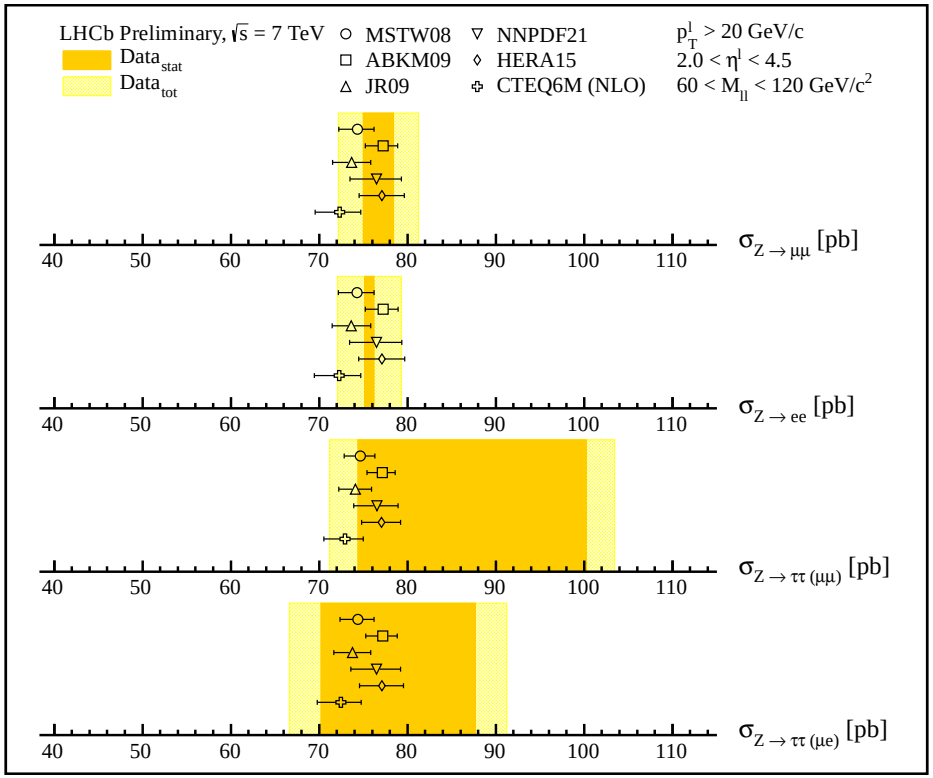


- Mass peak distorted by bremsstrahlung. Correcting this is the dominant systematic uncertainty.

- Candidate Events: 21535
- Background: 473 (taken from MC: $Z \rightarrow \tau\tau$, Top-pair, taken from Data: K/π mis-ID)

Cross-section measurements

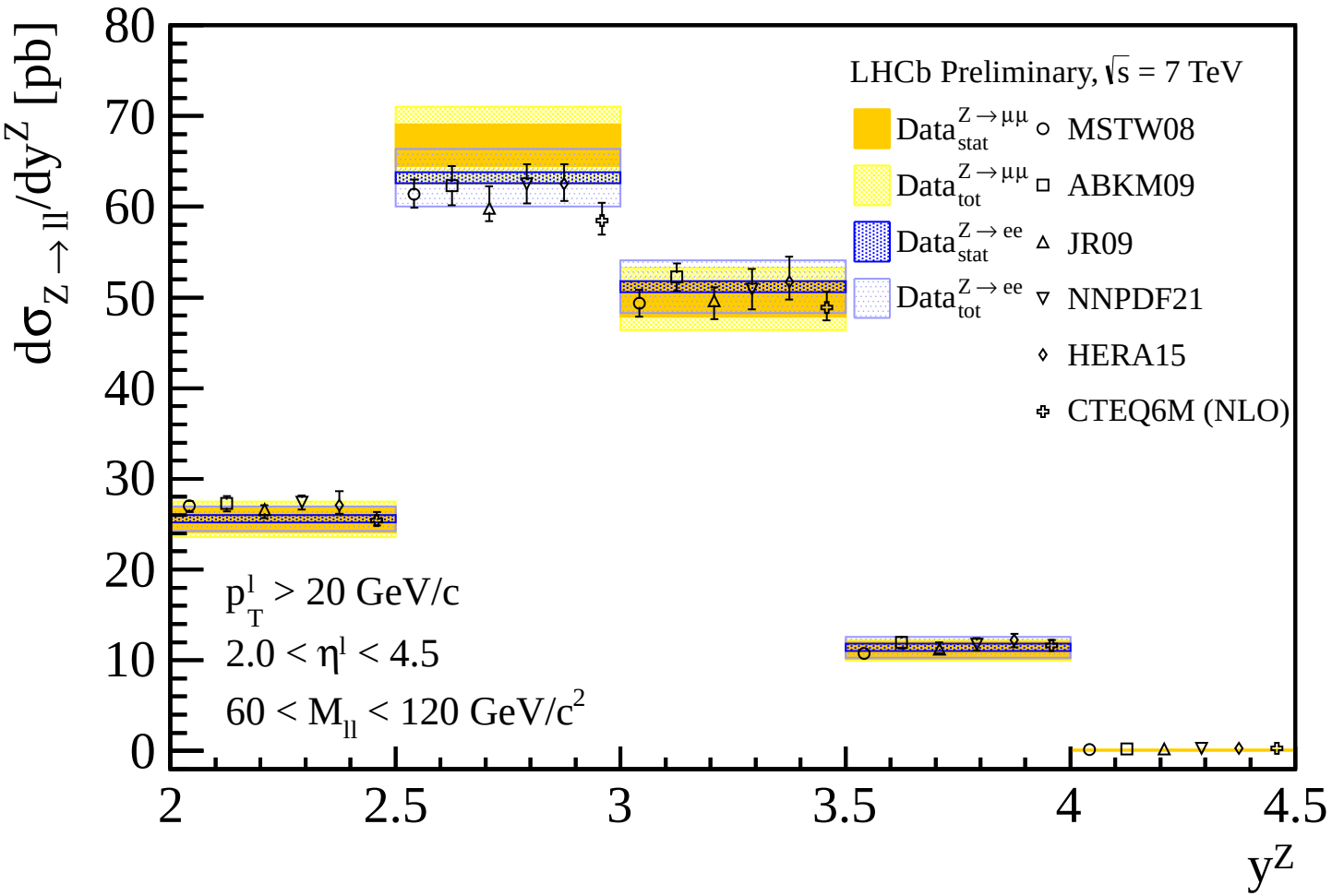
LHCb-CONF-2012-011



- Results in muon and electron channels are consistent with each other and NNLO predictions.
- For τ analysis see LHCb-CONF-2011-041.

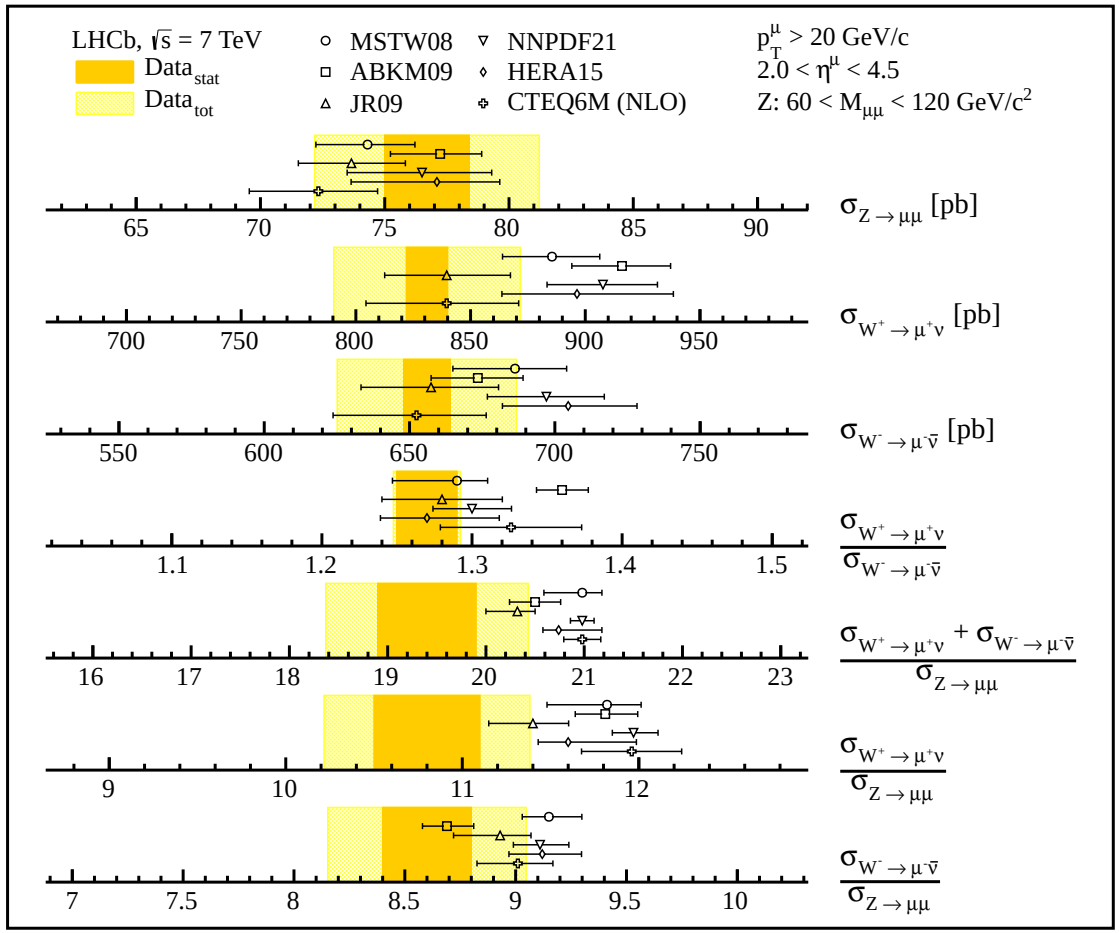
Cross-section measurements

LHCb-CONF-2012-011



Cross-section measurements

LHCb-PAPER-2012-008

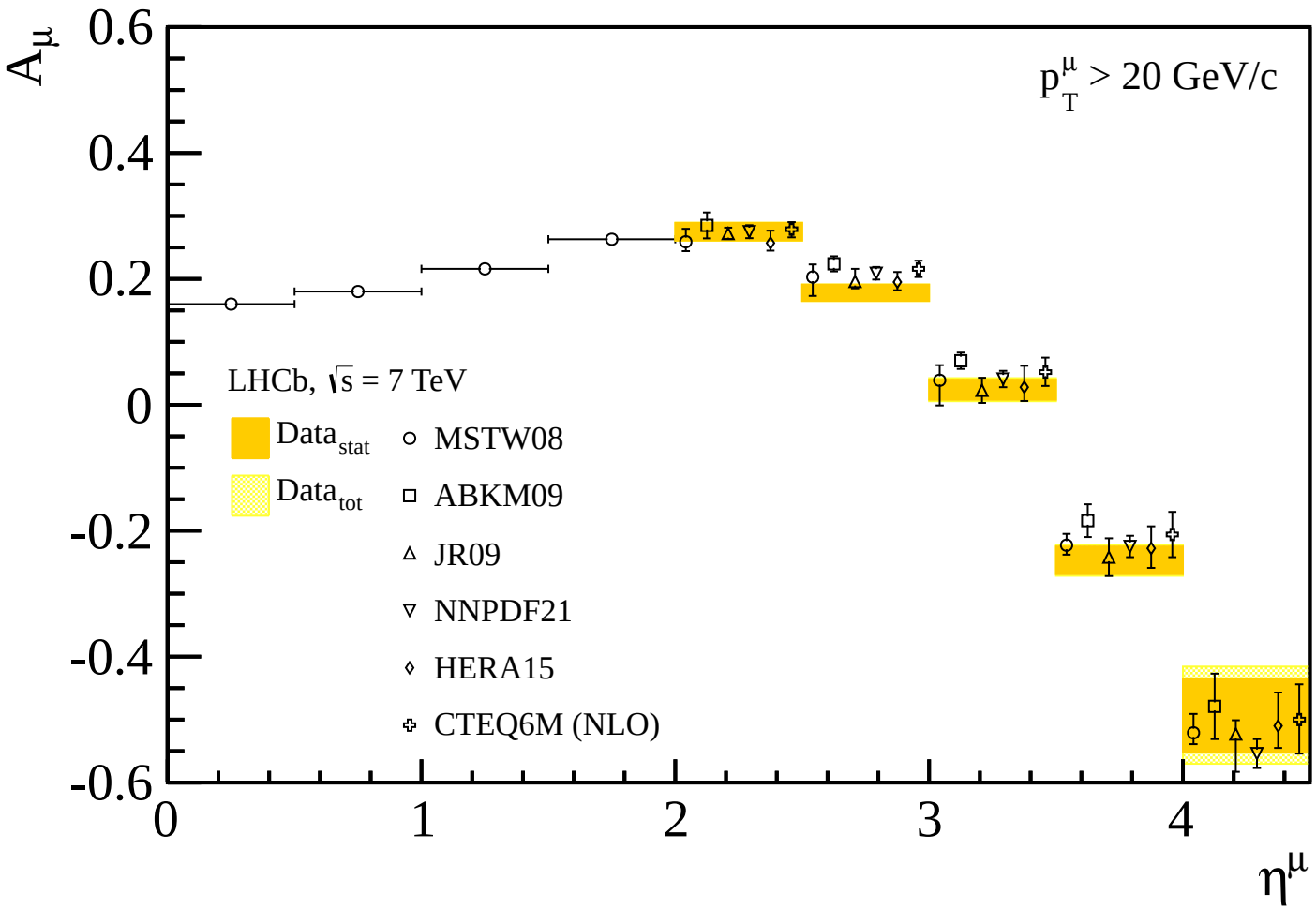


- Different ratios allow us to make precision tests of the standard model, whereas others allow us to further constrain PDFs.

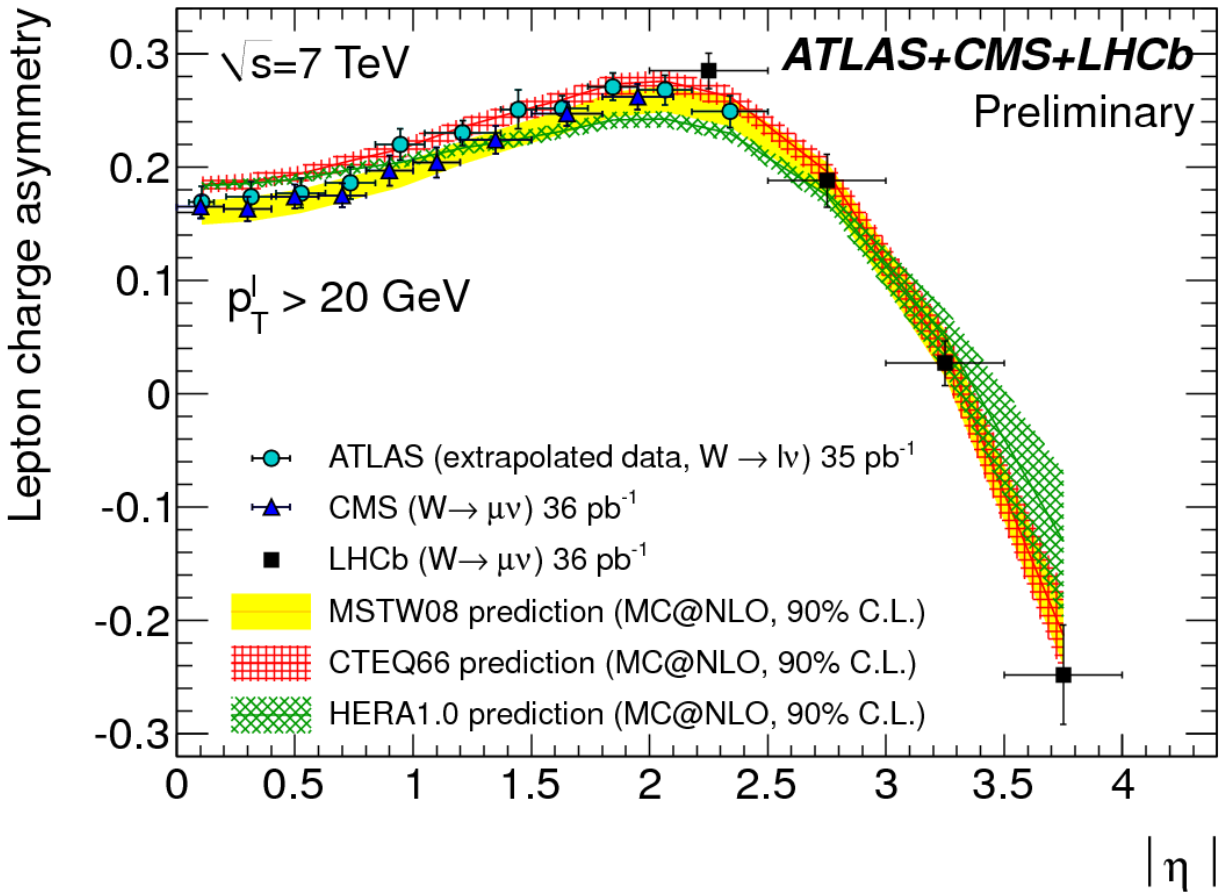
Muon charge asymmetry

LHCb-PAPER-2012-008

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



Combined lepton charge asymmetry



Low Mass Drell-Yan

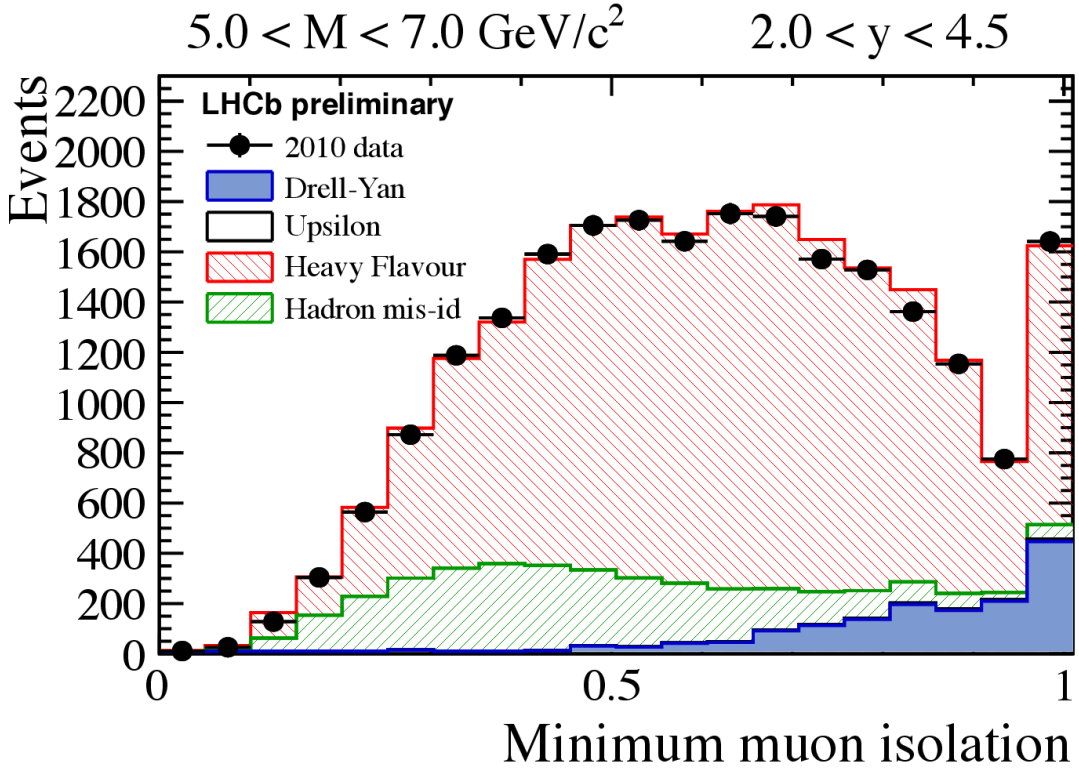
LHCb-CONF-2012-013

- 2010: $\int \mathcal{L} \mathrm{dt} = 37\ \mathrm{pb}^{-1}$
- Dimuon trigger: $p_T(\mu) > 2.5$ GeV.
- Acceptance:
  - $2.0 < \eta(\mu) < 4.5$,
  - $5 < M(\mu\mu) < 120$ GeV (with upsilon veto),
  - $p(\mu) > 10$ GeV,
  - $p_T(\mu) > 3$ GeV (and for $M(\mu\mu) > 40$ GeV, require $p_T(\mu) > 15$ GeV),
- Quantify signal fraction using isolation variable. Define muon isolation to be $\frac{p_T(\mu)}{p_T(\mu-\mathrm{jet})}$, where the μ-jet is the jet containing the muon.

Low Mass Drell-Yan

LHCb-CONF-2012-013

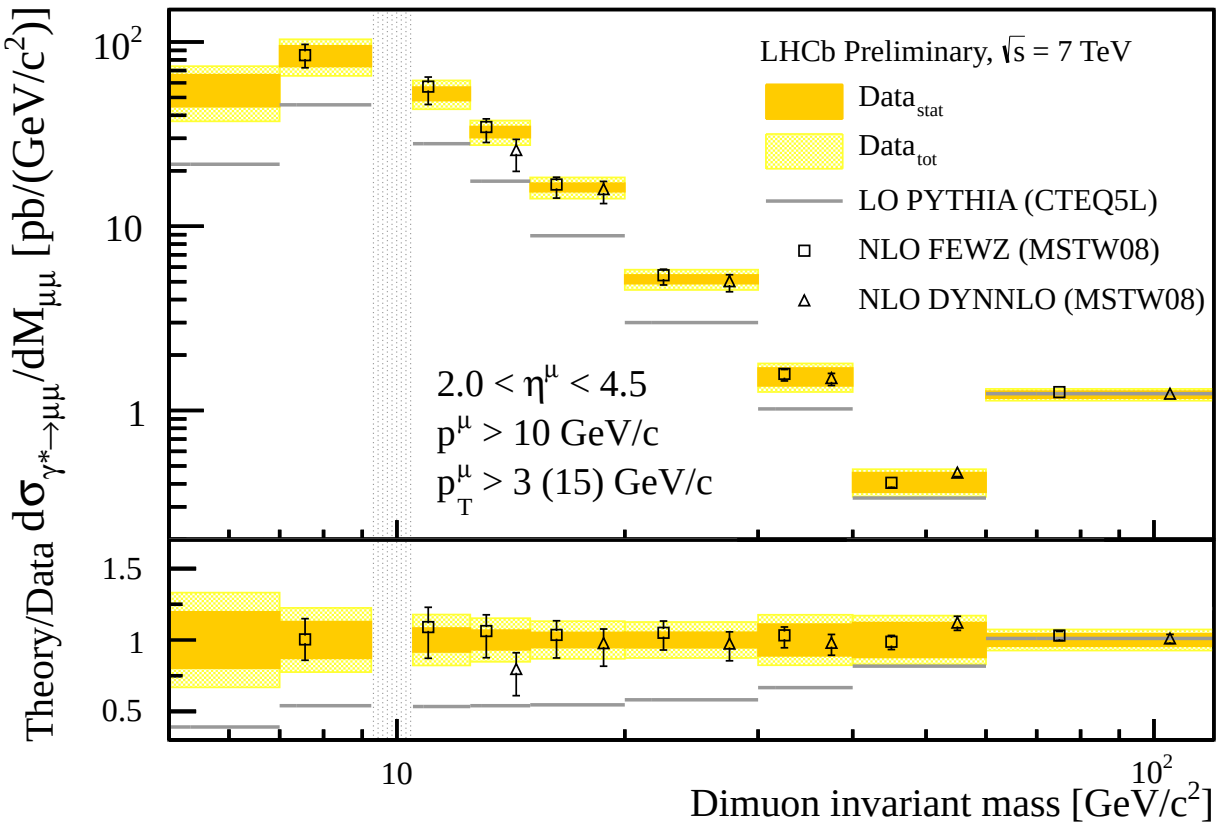
- Determine signal fraction by fitting the isolation of the least isolated muon in each candidate event.
- Purity varies from $\sim 7\%$ (at low mass) to $\sim 100\%$.
- Main systematic at low mass comes from this fit.
- signal template from MC,



- background templates
  from data: heavy flavour, K/π mis-ID,
  from MC: upsilon

Low Mass Drell-Yan

LHCb-CONF-2012-013

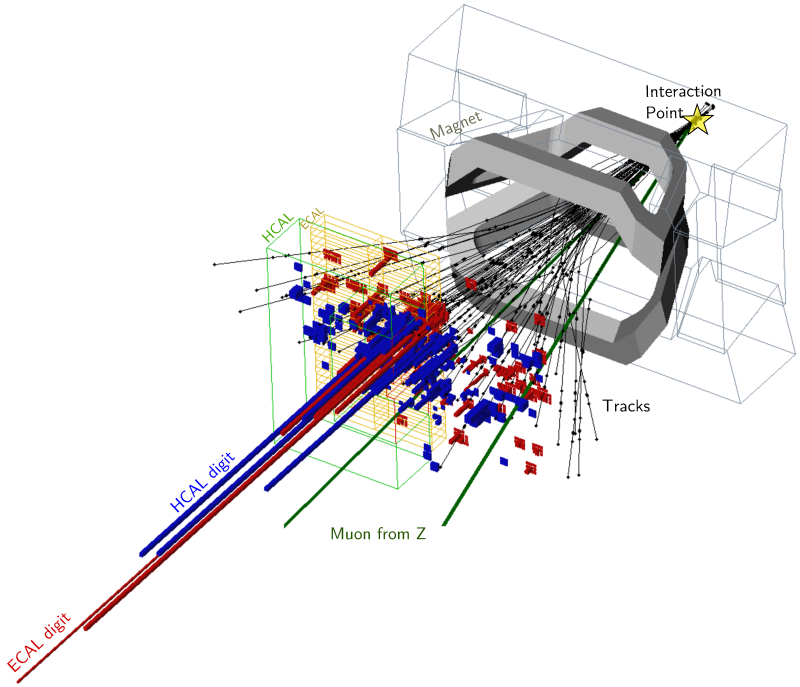


While the PYTHIA predictions agree in shape but are too low in normalisation, reasonable agreement is found with NLO predictions where the calculations are available.

Jet Production in Z events

LHCb-CONF-2012-016

- We use a particle flow algorithm, that uses as much information as possible from tracking to reconstruct jets.

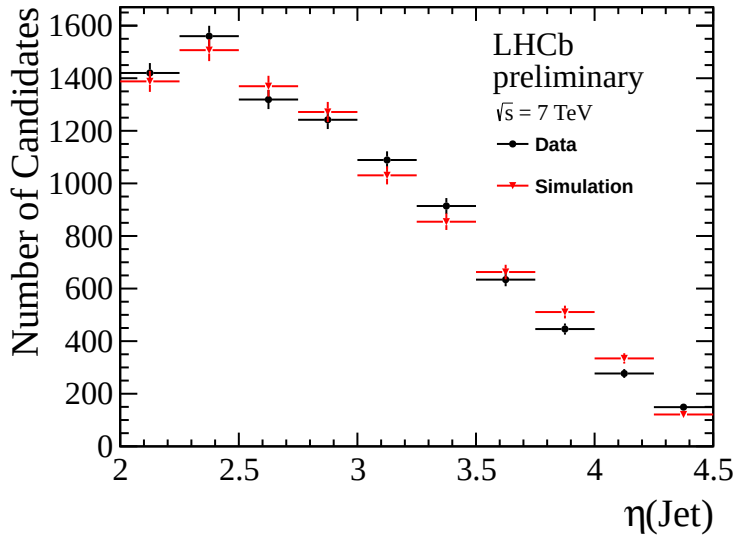


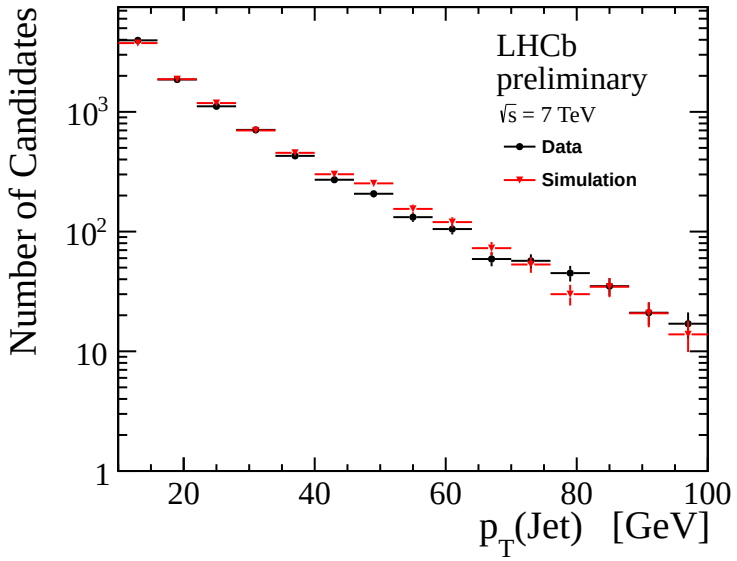
- Reconstruct jets with anti-k_T algorithm, using R=0.5.
- Correct jets to the hadron-level.
- Jet Energy Resolution is currently $\sim 17\%$ at $p_T(\text{Jet}) = 30$ GeV.

Jet Production in Z events

LHCb-CONF-2012-016

- 2011: $\int \mathcal{L} dt = 1$ fb^{-1}
- Acceptance:
  - Same as $Z \to \mu\mu$ analysis (for Z production),
  - p_T(Jet)$>$ 10 GeV,
  - $2.0 < \eta(\text{Jet}) < 4.5$,
  - $\Delta R(\mu, \text{Jet}) > 0.4$
- No significant increase in background above level in inclusive Z production
- Plots on this slide at detector level - not corrected for detection efficiencies. LHCb has the potential to make good jet measurements, and our simulation describes the data well.



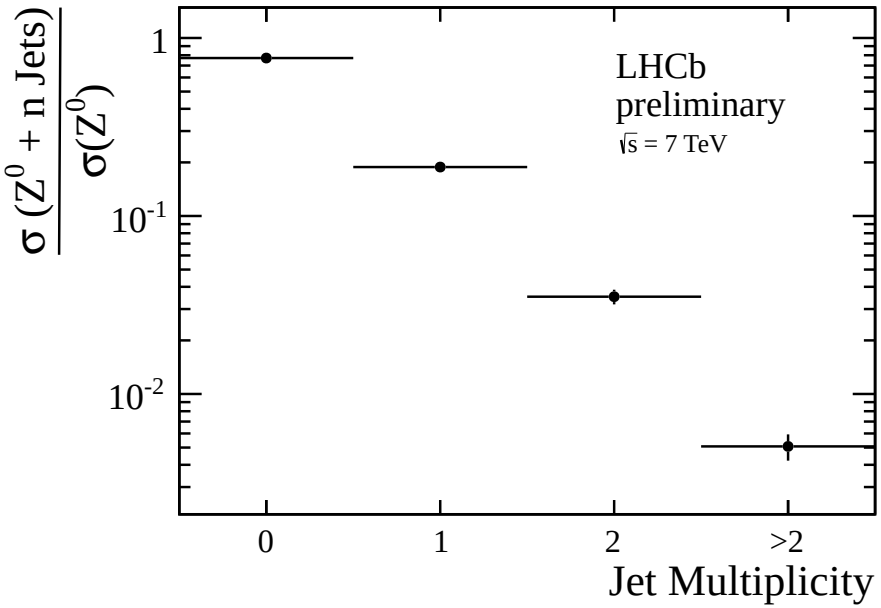


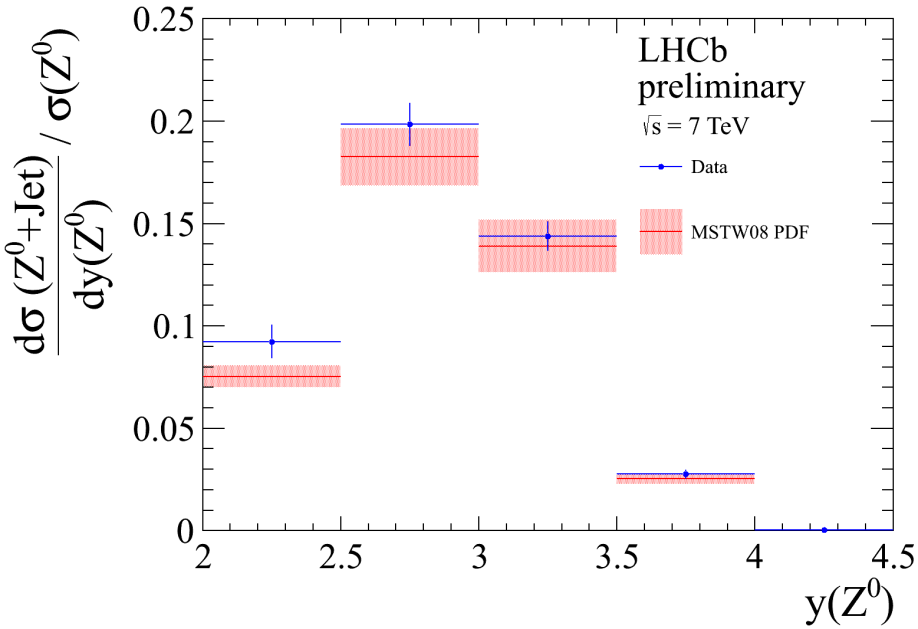
Jet Production in Z events

LHCb-CONF-2012-016

- We measure the cross-section ratio of Z+Jet production to Z production. We compare this to a theory prediction from FEWZ using MSTW08 PDFs (NLO theory predictions for the Z+Jet process).

$$\sigma(Z + \text{Jet})/\sigma(Z) = 0.229 \pm 0.006(stat.) \pm 0.009(syst.) \text{ (LHCb prelim.)}$$
$$0.212\ ^{+\ 0.006}_{-\ 0.009}(P.D.F.) \pm 0.016(scale) \text{ (Theory)}$$





Outlook

- Update W, Z cross-sections in muon final states with 2011 data,
  - statistical error reduced by factor 5,
  - statistically limited systematic errors also reduced.
- Update $Z \rightarrow \tau\tau$ measurement, adding hadronic τ decay modes.
- Update Drell-Yan production analysis, using 2011 data and including region above Z production resonance.
- Measurement of A_{FB} and $\sin^2(\theta_W)$.
- More measurements of jet production, including jet tagging.
- Top production in the forward region.

- Repeat analyses with 2012 data, making measurements at $\sqrt{s} = 8$ TeV.

Conclusion

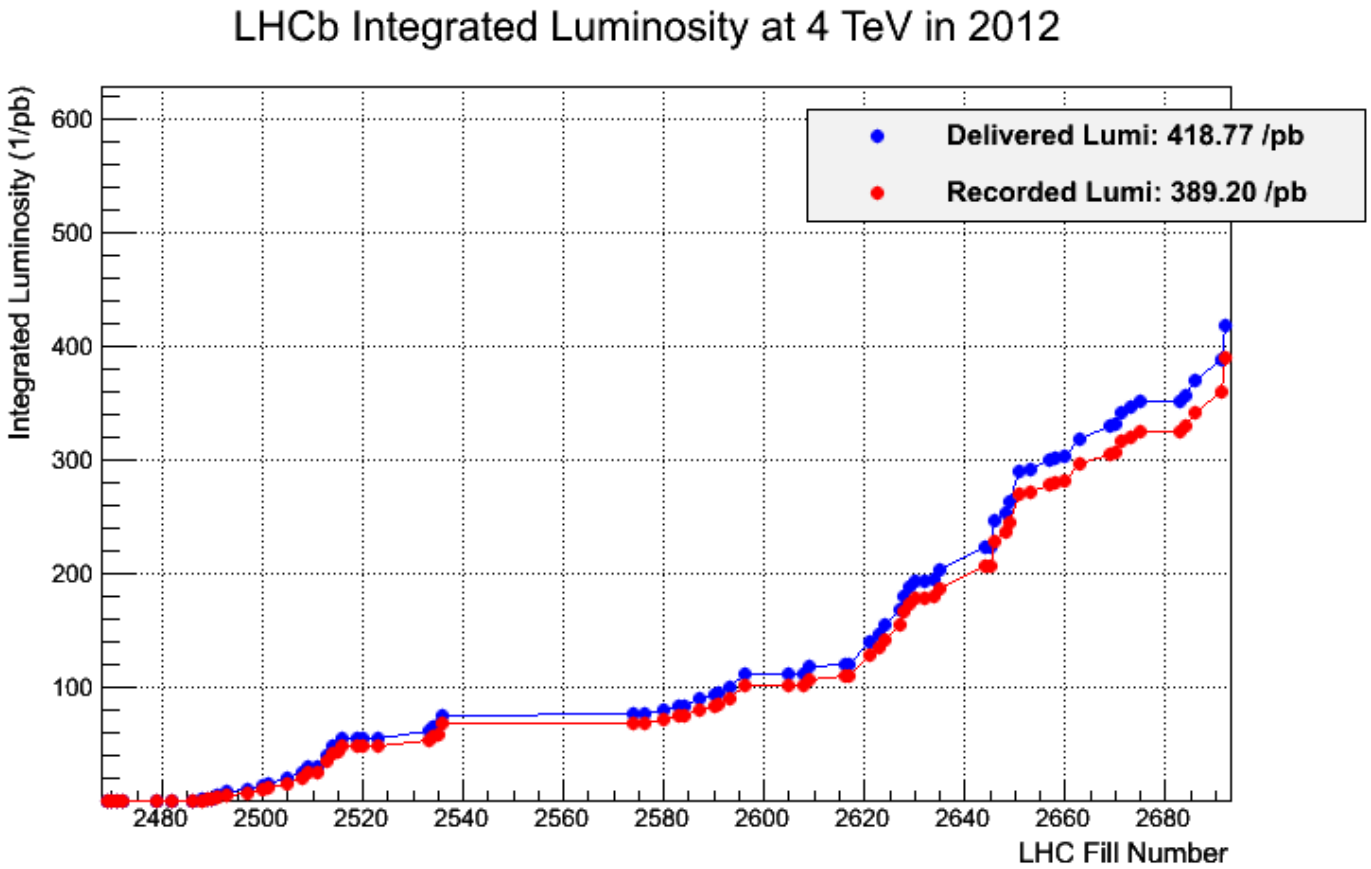
- LHCb operates in a unique region of phase space that allows us to make interesting Electroweak measurements that are complementary to those made by the GPDs.
- Measurements at LHCb can be used to constrain parton distribution functions.
- LHCb have presented results for Z production (in electron, muon and tau channels) and Z+Jet production, W production, and Drell-Yan production (in muon channels).

- Many interesting measurements to come.

- Thank you for your attention!

BACKUP SLIDES

Data Taken by LHCb in 2012



- note: low number of average interactions (~ 1.5) due to luminosity levelling

Systematic Uncertainties in W, Z and Jet Production

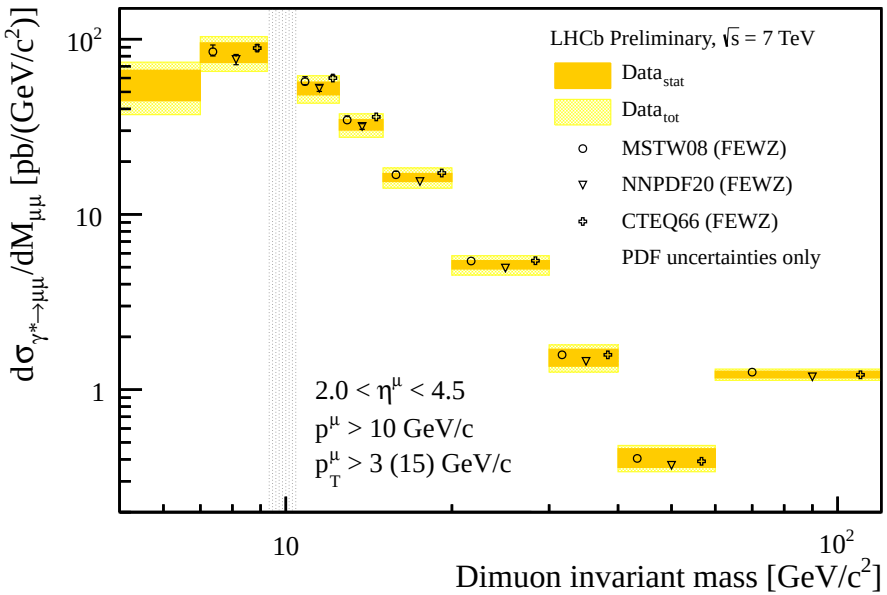
LHCb-PAPER-2012-008, LHCb-CONF-2012-016

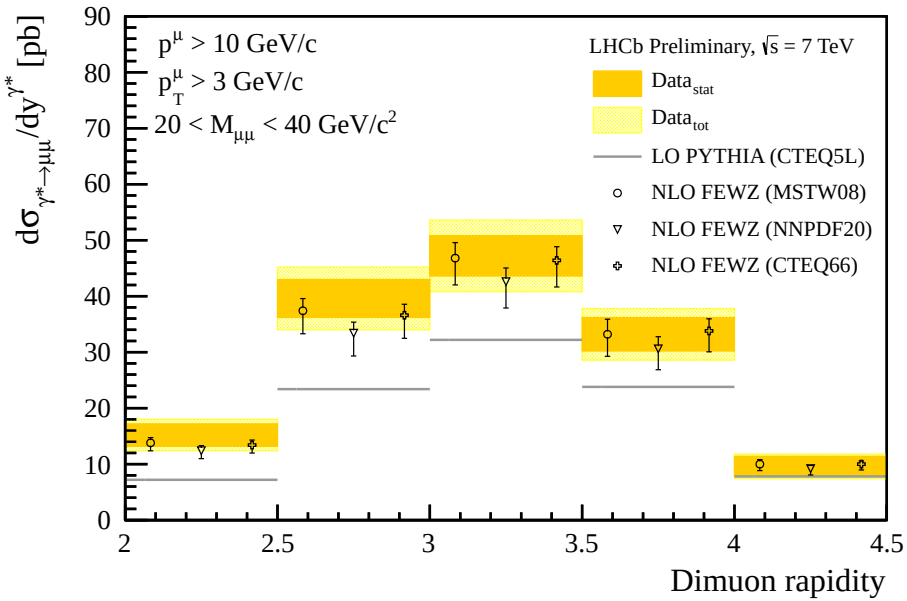
Source	$\Delta\sigma_{Z\to\mu\mu}$ (%)	$\Delta\sigma_{W^+\to\mu^+\nu}$ (%)	$\Delta\sigma_{W^-\to\mu^-\bar{\nu}}$ (%)
Signal purity	±0.1	±1.2	±0.9
Template shape (fit)	–	±0.9	±1.0
Efficiency (trigger, tracking, muon id)	±4.3	±2.2	±2.0
Additional selection	–	±1.8	±1.7
FSR correction	±0.02	±0.01	±0.02
Total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

Jet Multiplicity Bin	Z^0 + 0 jet	Z^0 + 1 jet	Z^0 + 2 jet	Z^0 + $\geq$ 3 jet
Jet Multiplicity Bin-to-Bin Migration Syst. (%)	0.2	1.0	2.9	9.7
GEC and Trigger Syst. (%)	0.3	0.9	1.5	3.8
μ ID Syst. (%)	0.2	0.6	0.9	1.4
μ Trk Syst. (%)	0.5	1.3	4.0	3.6
Jet Energy Correction Syst. (%)	1.0	2.6	7.0	11.0
Jet Energy Resolution Syst. (%)	0.1	0.6	1.7	3.6
Jet ID Syst. (%)	0.3	0.8	1.6	2.9
Total Syst. Uncertainty (%)	1.2	3.4	9.1	16

Drell-Yan Production

LHCb-CONF-2012-013





$Z \to \tau\tau$

LHCb-CONF-2011-041

- 2010+2011 Data: 248 pb^{-1}
- Important cross-check of results in muon channel.
- Sensitive to new physics models which increase τ production.
- An important test of lepton universality at LHC energy scales.

- Different channels for the τ decays: $\mu\mu$, $e\mu$

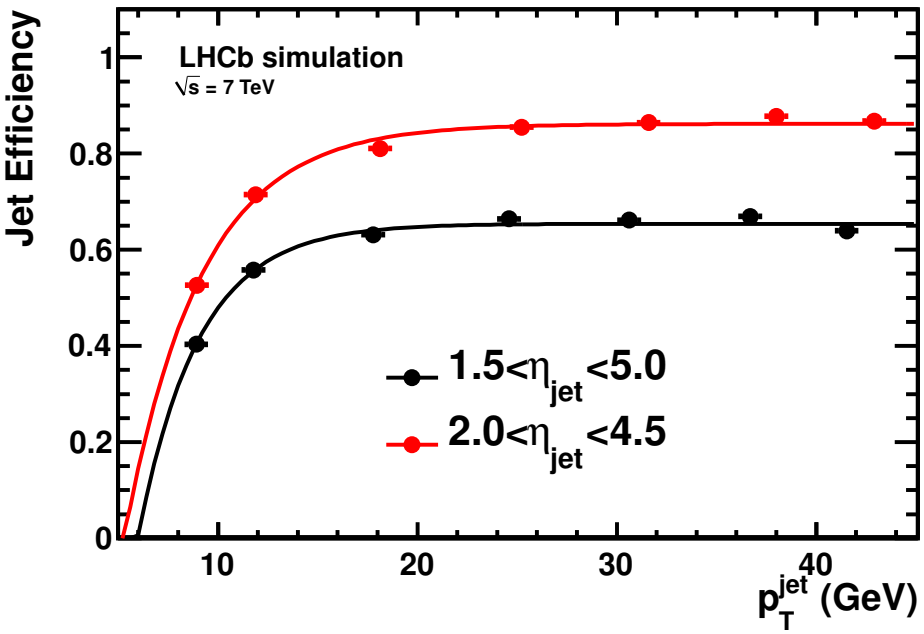
- Fiducial acceptance:
  - Same cuts on taus as on muons in $Z \to \mu\mu$ analysis:
- Also make cuts in analysis (which are corrected for) to improve purity of sample:
  - One muon with $p_T > 20$ GeV and another oppositely signed muon or electron with $p_T > 5$ GeV,
  - $2.0 < \eta(\text{lepton}) < 4.5$,
  - Isolated leptons,
  - $\Delta\phi(\text{lepton 1, lepton 2}) > 2.7$ radians,
  - for $\mu\mu$: the muons must not have similar p_T and must be displaced and require $M(\mu\mu) < 80$ GeV.

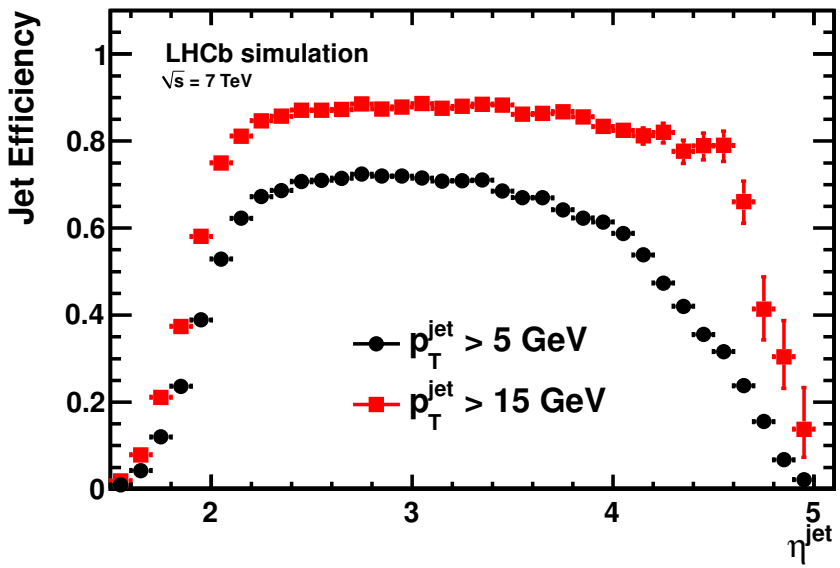
	$e\mu$		$\mu\mu$	
	2010 data	2011 data	2010 data	2011 data
Number of events	10	71	4	29
Estimated background	1.9 ± 0.5	10.6 ± 2.7	1.1 ± 0.3	6.1 ± 2.0
$\epsilon_{trigger}$	0.73 ± 0.01	0.78 ± 0.01	0.81 ± 0.01	0.86 ± 0.01
ϵ^{μ}_{track}	0.84 ± 0.02		0.84 ± 0.02	
ϵ^{e}_{track}	0.80 ± 0.03		-	-
ϵ^{μ}_{id}	0.991 ± 0.002		0.991 ± 0.002	
ϵ^{e}_{id}	0.962 ± 0.01		-	-
ϵ_{sel}	0.46 ± 0.03		0.172 ± 0.014	
ϵ	0.215 ± 0.017	0.230 ± 0.019	0.097 ± 0.009	0.103 ± 0.010
Acceptance	0.249 ± 0.012		0.386 ± 0.009	
Luminosity (pb^{-1})	37.5 ± 1.3	210.4 ± 12.6	37.5 ± 1.3	208.9 ± 12.5
Branching Ratio	0.062		0.030	
FSR Correction	0.7 ± 0.1			
Cross-section (pb)	$79 \pm 9 \pm 8 \pm 4$		$89 \pm 15 \pm 10 \pm 5$	

Combined measurement gives:

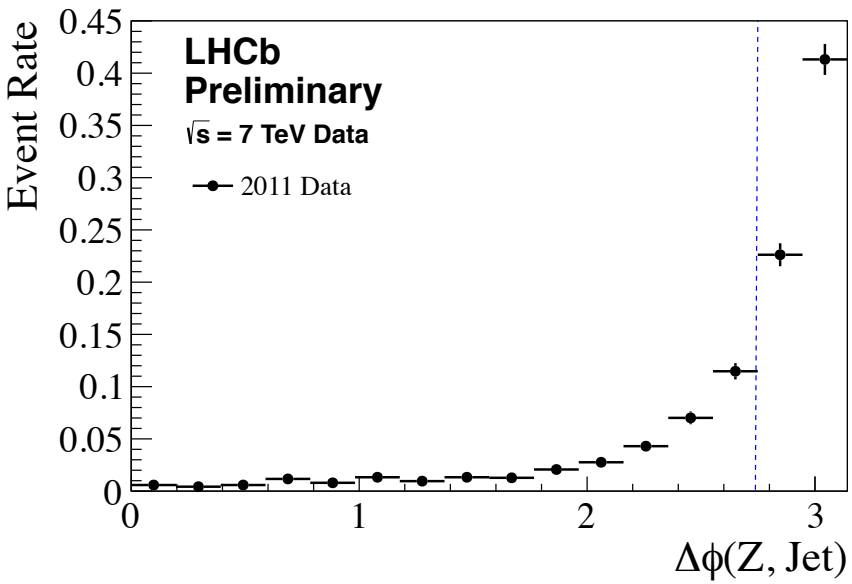
$$\frac{\Gamma(Z \to \tau\tau)}{\Gamma(Z \to \mu\mu)} = 1.09 \pm 0.17$$

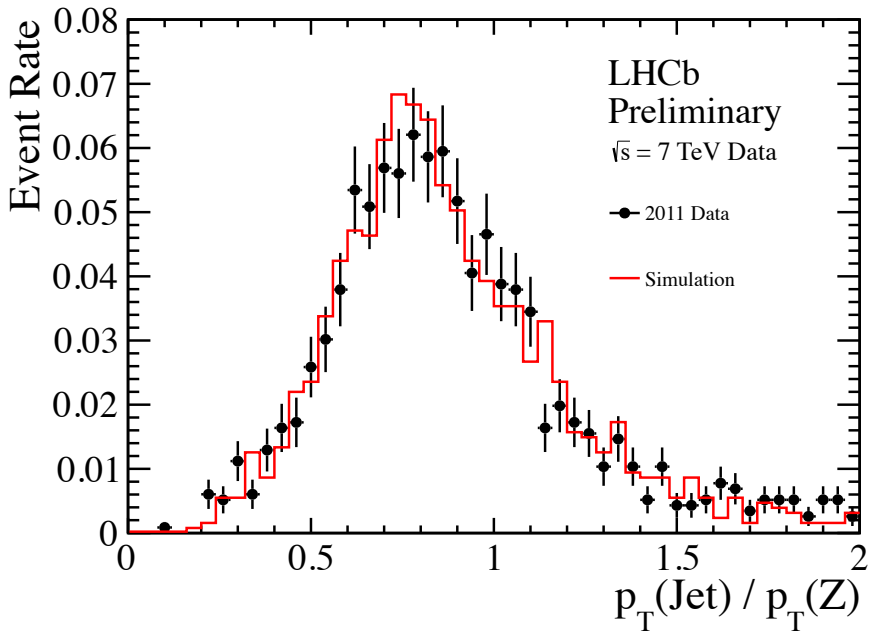
Jet Reconstruction at LHCb





Jet Reconstruction at LHCb





Jet Reconstruction at LHCb