



Electroweak Physics at LHCb



EPS 2015, Vienna, Austria

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On behalf of the LHCb collaboration

European Organisation for Nuclear Research (CERN)

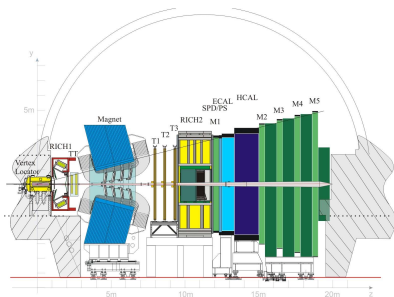
23rd July 2015

Introduction

- LHCb has an exciting programme studying the physics of **electroweak boson production**.
 - ▶ In different regimes these measurements are **sensitive to pQCD, PDFs, and allow precision tests of Standard Model**.
 - ▶ Also allows backgrounds to be constrained for other processes - like **top quark production** in the forward region (see Roger Barlow's talk on Saturday!)
- This talk will cover:
 - ▶ the LHCb detector,
 - ▶ **W and Z production** in the forward region,
 - ▶ **boson + jet** production,
- Lots of material not covered today (proton-lead collisions, $Z \rightarrow \tau\tau\dots$)!

The LHCb Detector

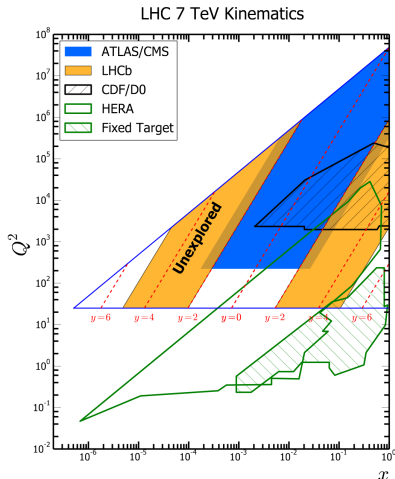
- Single arm spectrometer, fully instrumented in **forward region** ($2.0 < \eta < 4.5$). Designed for **flavour physics**.
- LHCb overlap with GPDs in $2.0 < \eta < 2.5$, precision coverage unique for LHCb $2.5 < \eta < 4.5$.
 - ▶ allows **complementary studies** in **QCD** and **EW** physics to ATLAS and CMS. The region of overlap also allows comparison of results.



- Excellent vertex resolution (VELO) (0.01-0.05 mm in transverse plane),
- Tracking detectors, ECAL, HCAL, Muon chambers,
- **Ring Imaging Cherenkov (RICH)** detectors for particle ID,
- Dedicated triggers for EW analyses - e.g. single lepton ($p_T > 10$ GeV).

W & Z production in the forward region

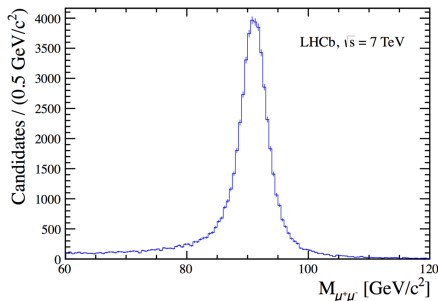
- Main theory uncertainty on **benchmark Standard Model Processes** comes from uncertainties in **parton distribution functions (PDFs)**.



- LHCb is sensitive to previously **unexplored** region of **low x -high Q^2** phase space.
- Can use measurements at LHCb to **constrain PDFs**.
- PDF uncertainties reduced in some cross-section ratios - can also **probe the standard model**.

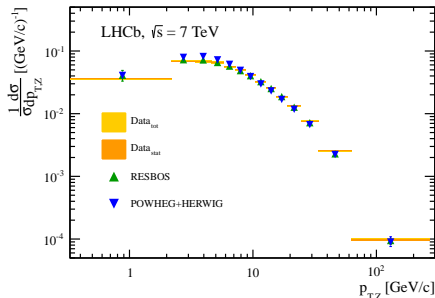
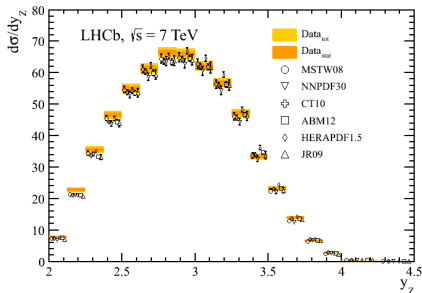
$Z \rightarrow \mu\mu$ production in the forward region

- 1 fb^{-1} data at $\sqrt{s} = 7 \text{ TeV}$.
- Study $pp \rightarrow Z(\rightarrow \mu\mu)X$.
- Fiducial Acceptance:
 - ▶ $p_T(\mu) > 20 \text{ GeV}$,
 - ▶ $2.0 < \eta(\mu) < 4.5$,
 - ▶ $60 < M(\mu\mu) < 120 \text{ GeV}$.
- $\sim 99\%$ purity in $\mu\mu$ final state.
- Efficiencies taken from data using tag and probe methods.
- Dominant uncertainties on cross-section from luminosity (1.7%) and beam energy (1.3%).



Source	Uncertainty (%)
Statistical	0.39
Trigger efficiency	0.07
Identification efficiency	0.23
Tracking efficiency	0.53
FSR	0.11
Purity	0.22
GEC efficiency	0.26
Systematic	0.68
Beam energy	1.25
Luminosity	1.72
Total	2.27

$Z \rightarrow \mu\mu$ production in the forward region

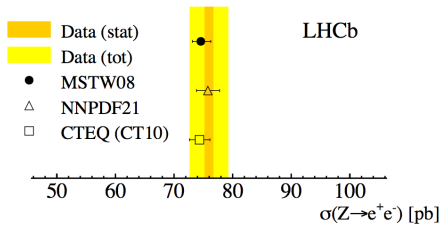


- Very good agreement with **NNLO predictions** in the rapidity distribution - very sensitive to PDF effects.
- Very good agreement with different **NLO predictions** in the transverse momentum distribution - sensitive to higher orders in pQCD.

$Z \rightarrow ee$ production in the forward region

JHEP05 (2015) 109, JHEP02 (2013) 106

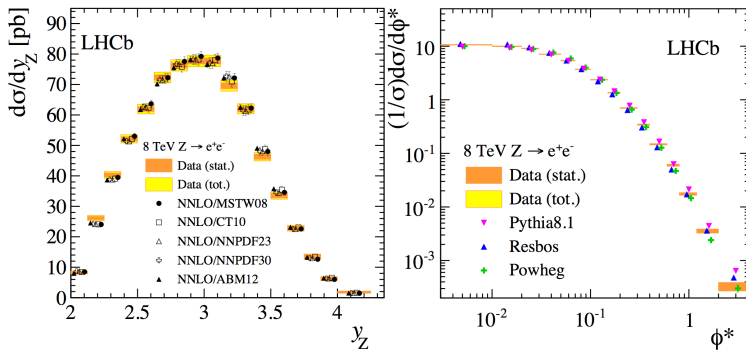
- 1 fb^{-1} at $\sqrt{s} = 7 \text{ TeV}$ and
 2 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$
- Study $pp \rightarrow Z(\rightarrow ee)X$.
- Fiducial Acceptance:
 - ▶ $p_T(e) > 20 \text{ GeV}$,
 - ▶ $2.0 < \eta(e) < 4.5$,
 - ▶ $60 < M(ee) < 120 \text{ GeV}$.



- **> 90% purity** in ee final state.
- Overall cross-section measurement in **good agreement with measured cross-sections in muon final state.**

$Z \rightarrow ee$ production in the forward region

JHEP05 (2015) 109, JHEP02 (2013) 106



- Data show good agreement with theory for both fixed order and ME+PS simulation.
- Agreement seen for multiple PDF sets.
- Agreement seen in both rapidity and ϕ^* distributions.
 - ▶ $\phi^* \equiv \tan\left(\frac{\pi - \Delta\phi}{2}\right) / \cosh\left(\frac{\Delta\eta}{2}\right) \approx \frac{p_T}{M}$

$W \rightarrow \mu\nu$ production in the forward region

arXiv:1505.07024

- 1 fb⁻¹ data at $\sqrt{s} = 7$ TeV.

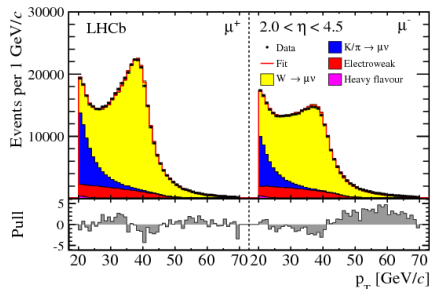
- Fiducial Acceptance:

- ▶ $p_T(\mu) > 20\text{GeV}$,
- ▶ $2.0 < \eta(\mu) < 4.5$.

- Extract signal by fitting the muon transverse momentum distribution.

- Signal purity of about 77%.

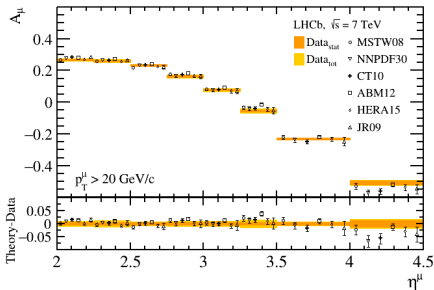
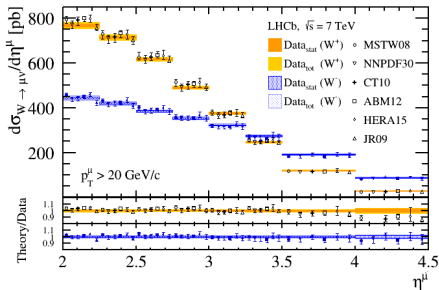
- Largest uncertainty after luminosity and beam due to reconstruction efficiencies ($\sim 1.2\%$). Uncertainty from template shapes is typically 0.3-0.4%.



$W \rightarrow \mu\nu$ production in the forward region

arXiv:1505.07024

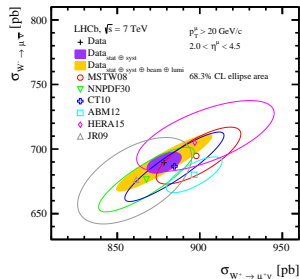
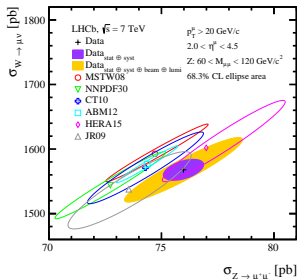
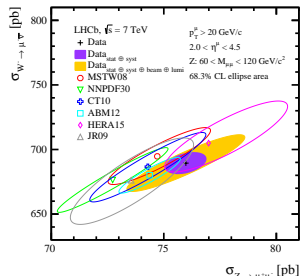
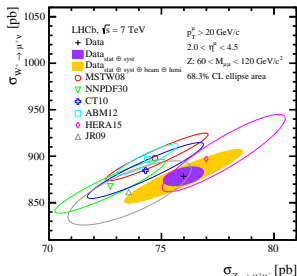
- Measure cross-section as a function of the lepton η .
- Also measure the **Lepton charge asymmetry**, $A_\mu = \frac{\sigma(W^+) - \sigma(W^-)}{\sigma(W^+) + \sigma(W^-)}$
- Many **experimental uncertainties cancel** in A_μ so we can perform a **high precision measurement**.
- Lepton charge asymmetry is particularly sensitive to PDFs.
- See **excellent agreement with NNLO Standard Model predictions**.



W and Z production ratios

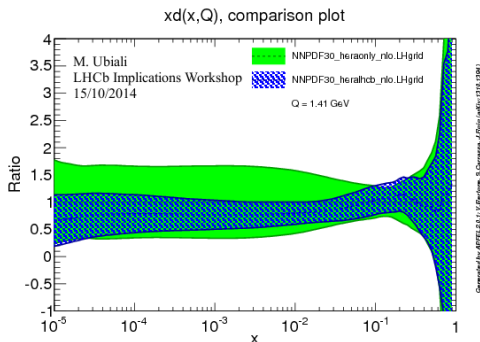
- Ratios of W and Z production cross-sections cancel many experimental and theoretical (scale) uncertainties.

- Sensitivity to PDFs remains in some ratios (W^+/W^-).



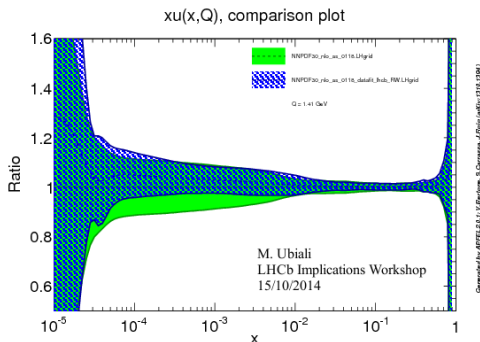
Impact of LHCb results on PDFs

- Many LHCb run 1 results on electroweak boson production now included in PDF fits.
- Large impact on pre-LHC PDF knowledge.
- Shown here NNPDF down quark PDF and uncertainties (normalised so central value pre-LHC is unity):
 - ▶ Green: PDF fit using pre-LHC data
 - ▶ Blue: PDF fit using pre-LHC data and LHCb data

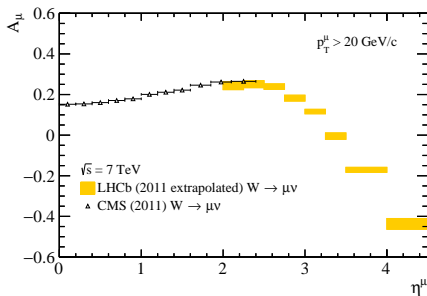
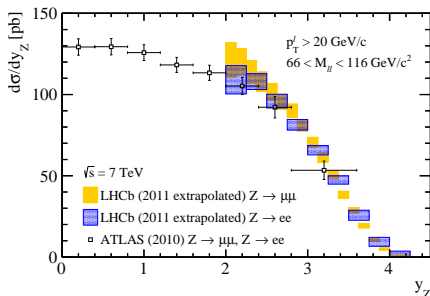


Impact of LHCb results on PDFs

- Even when results from other LHC experiments are included in PDF fits, LHCb still noticeably reduces PDF uncertainties.
- Shown here NNPDF up quark PDF and uncertainties:
 - ▶ Green: PDF fit with LHC data (but no LHCb data)
 - ▶ Blue: PDF fit with LHC data (including LHCb data)

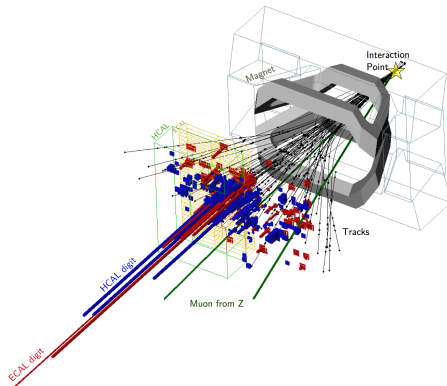


- **Extrapolate LHCb results** as a function of (pseudo)rapidity, to account for different ATLAS and CMS fiducial acceptances.
- Dominant uncertainty in extrapolation tends to be from scale variation at low η , and PDF uncertainties at high η .

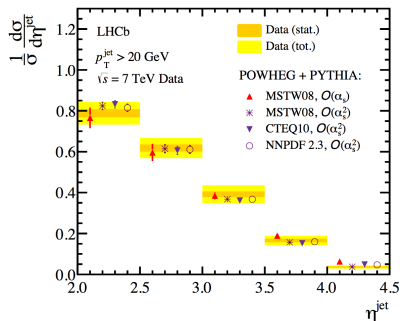
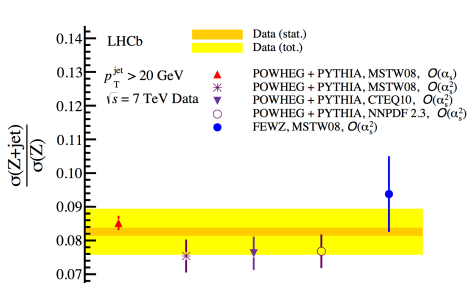


- See **very good agreement** in region of overlap between **ATLAS**, **CMS** and **LHCb** results.
- **LHCb** extends the GPD results into a **previously unexplored region** of phase space which can be used to constrain PDFs.

- Vector boson + jet measurements probe pQCD, test PDFs in the forward region, and constrain backgrounds in other key measurements.
- Reconstruct jets using **anti- k_T algorithm**, with r-parameter $R = 0.5$.
- **Jet energy resolution typically $\sim 15\%$** for jets with $p_T < 100$ GeV.
- We also have excellent b and c -tagging of jets, and $W + b, c$ jet results - see Roger Barlow's talk on Saturday!



- Analysis uses 1fb^{-1} of $\sqrt{s} = 7$ TeV data,
- In addition to fiducial acceptance for $Z \rightarrow \mu\mu$, require $p_T^{\text{jet}} > 20(10)$ GeV, $2.0 < \eta^{\text{jet}} < 4.5$, $\Delta R(\mu, \text{jet}) > 0.4$.

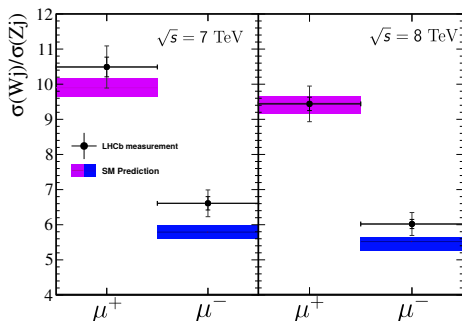


- Dominant uncertainty from Jet Energy Scale.
- Results in good agreement with theoretical predictions from NLO ME+PS predictions.

Ratio of W +jet and Z +jet production cross-sections

arXiv:1505.04051

- Analysis uses both 7 and 8 TeV data collected at LHCb.
- In addition to standard W and Z fiducial acceptance, require jets to have: $p_T^{\text{jet}} > 20$ GeV, $2.2 < \eta^{\text{jet}} < 4.2$, $\Delta R(\mu, \text{jet}) > 0.5$.
- Also make additional requirement $p_T(\mu + \text{jet}) > 20$ GeV in W +jet events.
- Extract signal purity by fitting isolation of muons produced by boson decay - dominant uncertainty from templates used.
- Very good agreement between LHCb data and theoretical predictions using MCFM and CT10 PDFs.

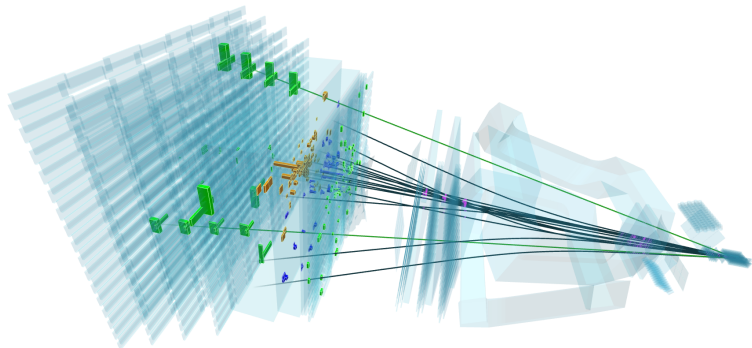


Looking Forward

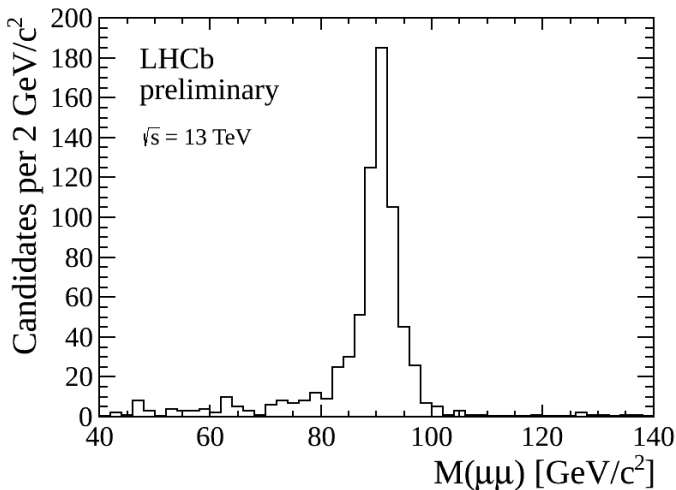
- More exciting results to come from further analysis of the run-1 data.
- and we have $\sqrt{s} = 13$ TeV data on disc



Event 885617570
Run 157596
Sat, 11 Jul 2015 02:01:18



Looking Forward



- LHCb is looking forward to the years ahead.

Summary

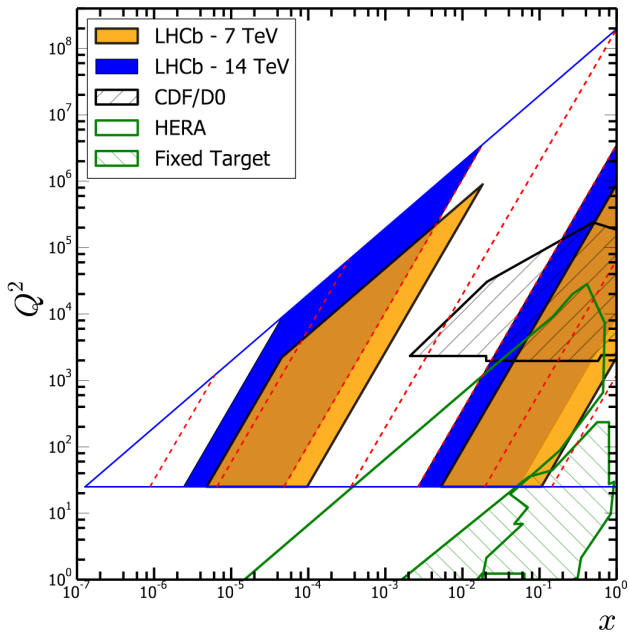
- LHCb occupies a **unique region of phase space** at the LHC, allowing **complementary measurements** to **ATLAS and CMS**.
- EW measurements at LHCb can be used to:
 - ▶ **constrain PDFs** in previously unexplored regions.
 - ▶ **test the standard model** using ratios of benchmark processes which are very well predicted.
- LHCb results of EW boson production show **good agreement** with **Standard Model** predictions and measurements by the **GPDs**.
- LHCb results of EW boson + jet production show good agreement with the Standard Model, and also provide tests of PDFs.
- LHCb is looking forward to Run 2 measurements.

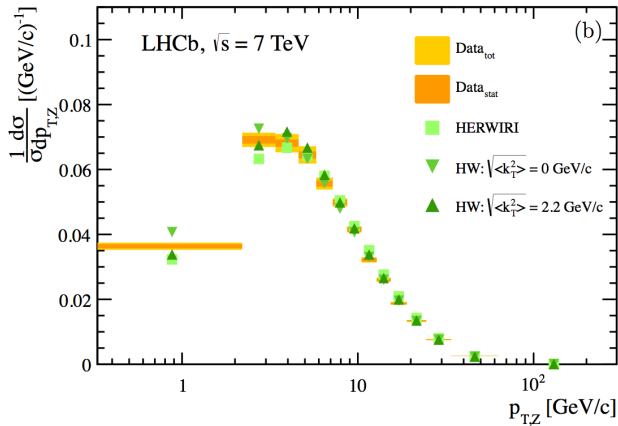
Material Not Covered Today

- Z production in proton-lead collisions, [JHEP09 \(2014\) 030](#)
- $Z \rightarrow \tau\tau$, [JHEP01 \(2013\) 111](#)
- Limits on neutral Higgs boson production using ditau final states, [JHEP05 \(2013\) 132](#)
- $Z + \text{jet}$, [JHEP01 \(2014\) 033](#)
- $Z + b\text{-jet}$, [JHEP01 \(2015\) 064](#)
- $Z + D$ meson, [JHEP04 \(2014\) 091](#)

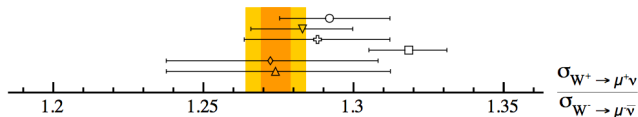
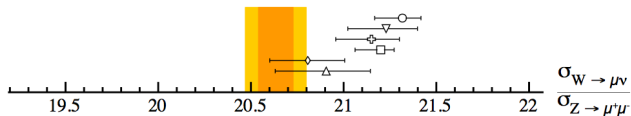
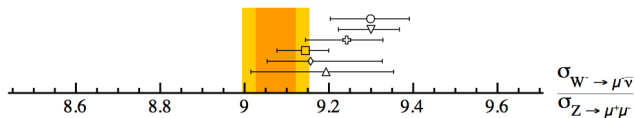
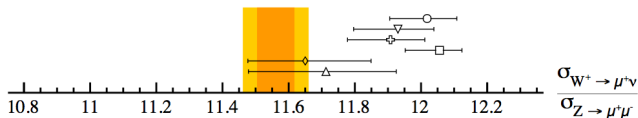
BACKUP SLIDES

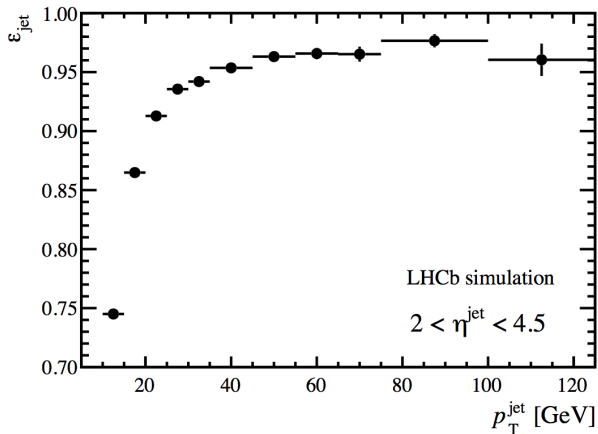
LHCb Kinematics

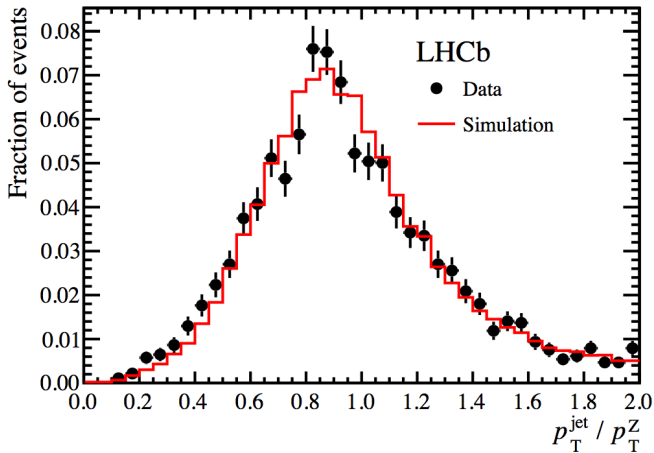


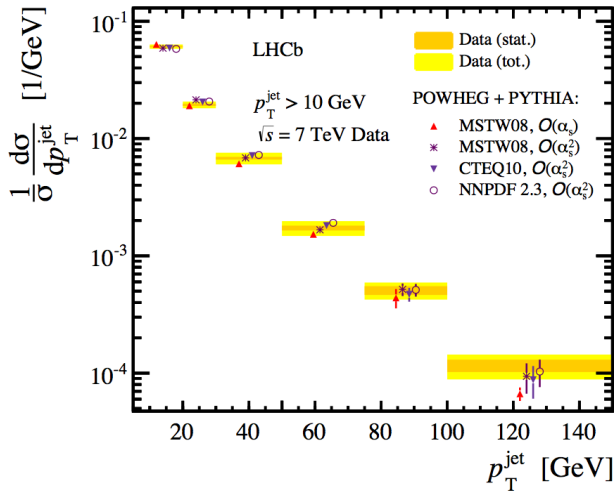


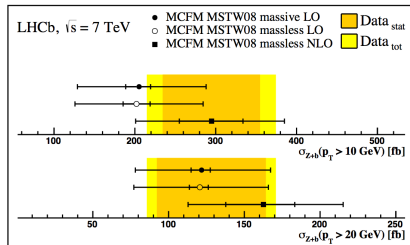
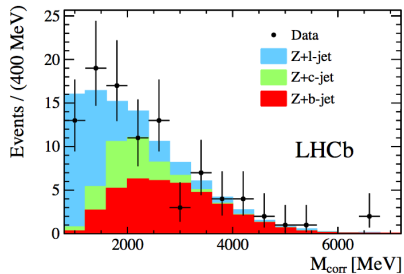
LHCb, $\sqrt{s} = 7$ TeV \circ MSTW08 \square ABM12 $p_T^\mu > 20$ GeV/c
 Data_{stat} ∇ NNPDF30 \diamond HERA15 $2.0 < \eta^\mu < 4.5$
 Data_{tot} \oplus CT10 \triangle JR09 Z: $60 < M_{\mu\mu} < 120$ GeV/c²











- CT10 - arXiv:1101.0561
- NNPDF30 - arXiv:1410.8849
- MSTW08 - arXiv:0901.0002
- ABM12 - arXiv:1310.3059
- HERA1.5 - arXiv:0911.0884
- JR09 - arXiv:0810.4274