

Theoretical motivations for measuring the W/Z ratio at large boson transverse momentum

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In collaboration with Graeme Watt, [arXiv:1304.2424](https://arxiv.org/abs/1304.2424)

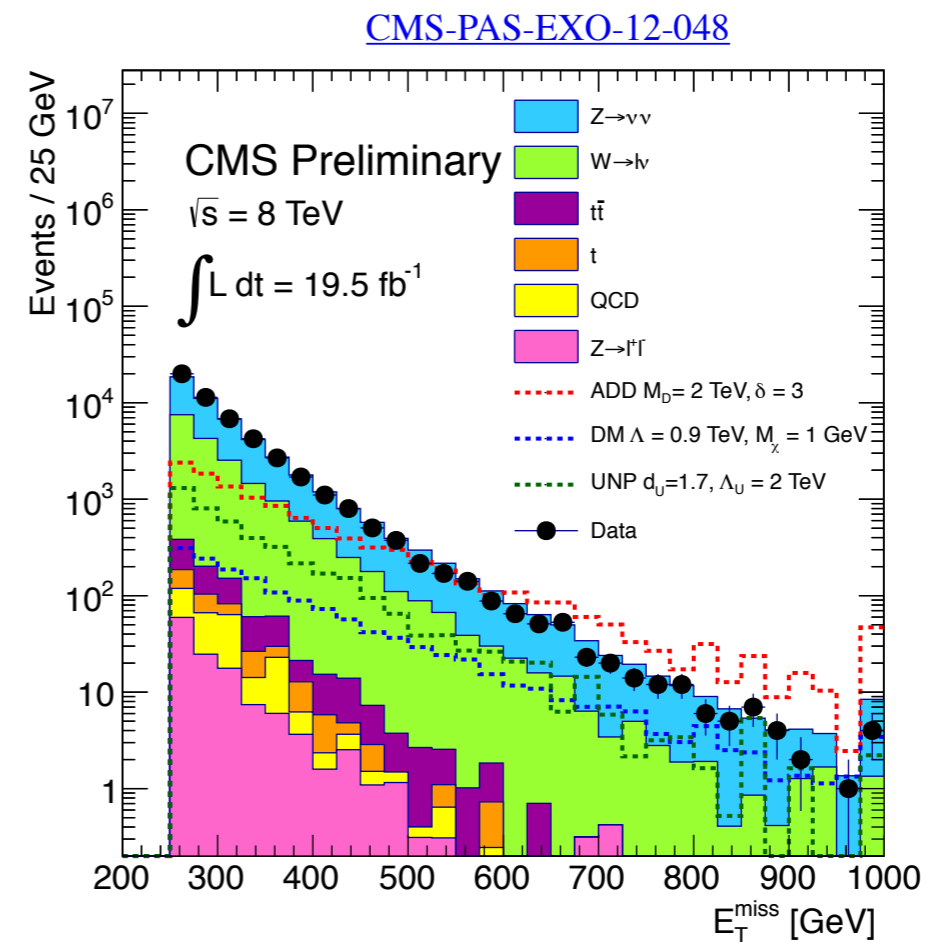
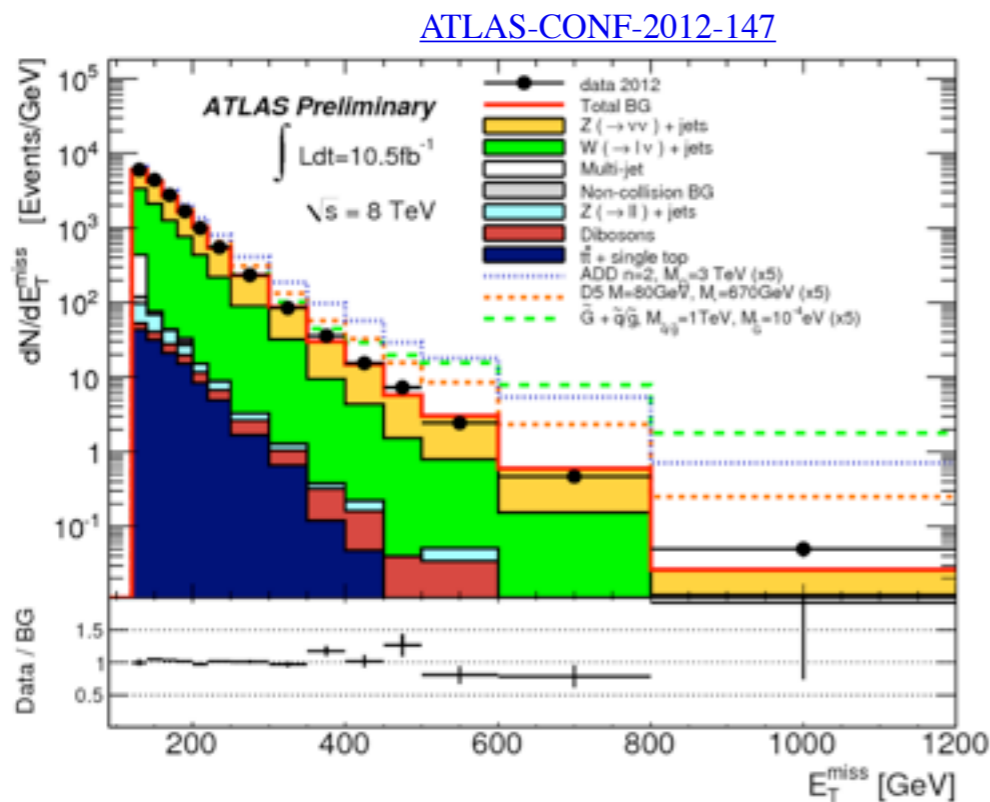
Outline

- Explain motivation for a precise measurement of the W/Z ratio at large boson p_T as a means of constraining the $Z \rightarrow \nu \bar{\nu}$ background
- Dependence of W and Z cross sections vs p_T on the flavor of the initial state partons
- Study the behavior of the W_+/W_- , W_+/Z , W_-/Z , and W/Z ratios as a function of boson p_T and on the jet multiplicity.
- Study the theoretical uncertainties on these ratios from;
 - Higher order QCD and EWK corrections
 - choice of PDF
- Investigate whether a measurement of these ratios has the potential to constrain PDFs

Motivation

- Many searches for physics beyond the SM involve production of new particles that can only be inferred from missing transverse energy (SUSY, Extra dimensions, WIMPs etc)
- $Z \rightarrow \nu \nu + \text{jets}$ is dominant background in many searches for new physics that involve jets and missing transverse energy

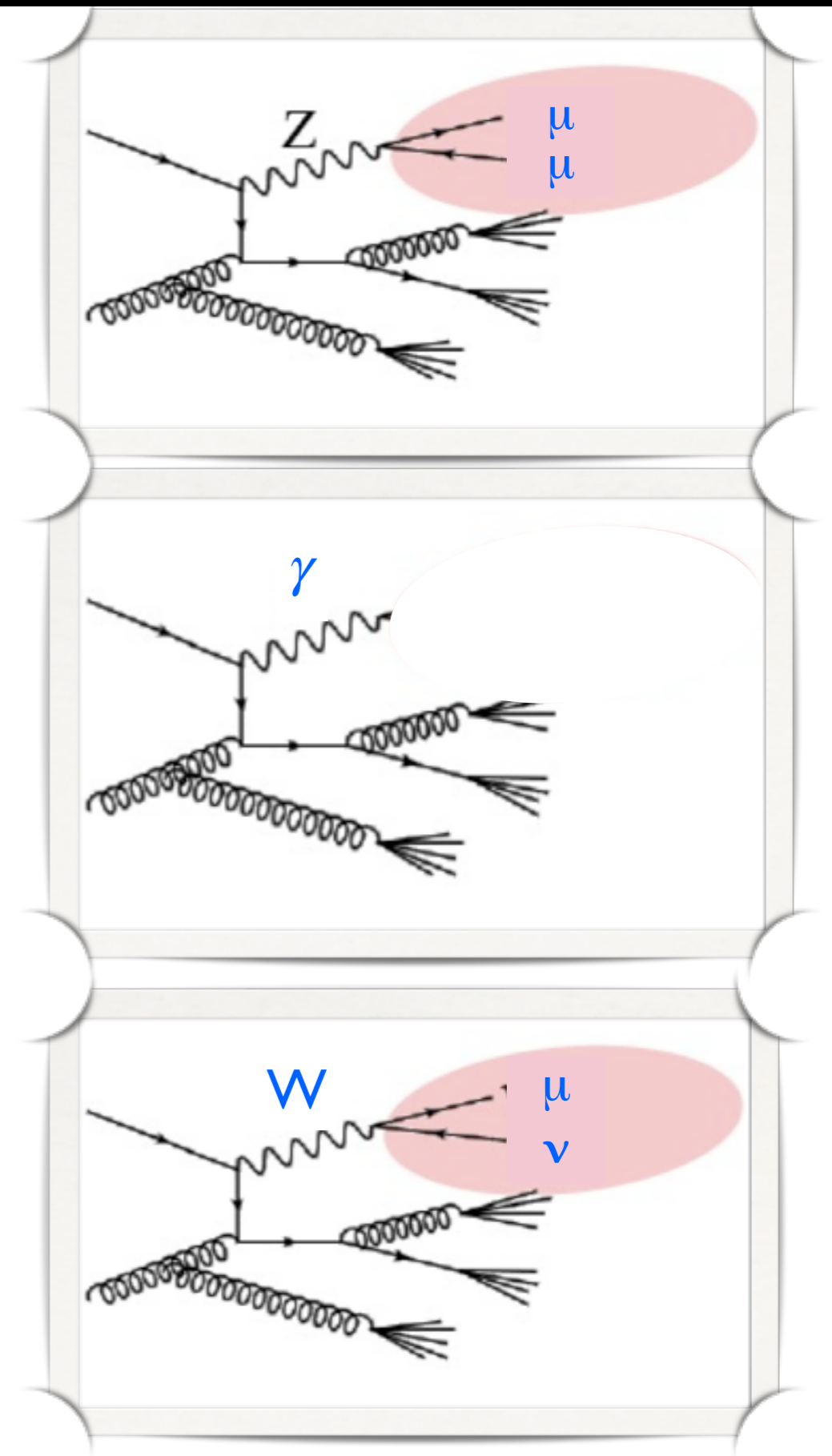
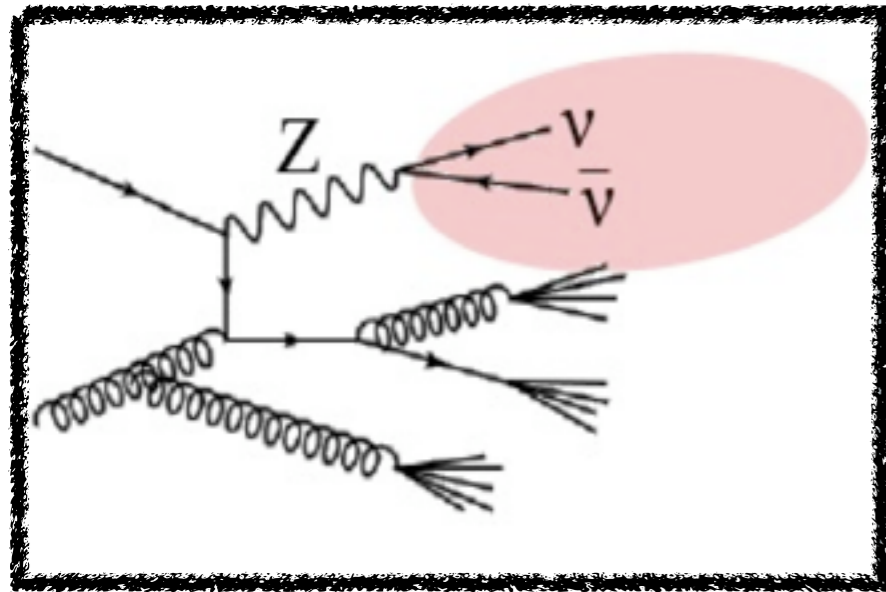
For example,



Searches for Large Extra Dimensions and dark matter, up to 70% of the background is from $Z \rightarrow \nu \nu + \text{jet}$ events

Data-driven methods to estimate $Z \rightarrow \nu\bar{\nu} + \text{jets}$

Use $V + \text{jets}$, $V = Z, W, \gamma$

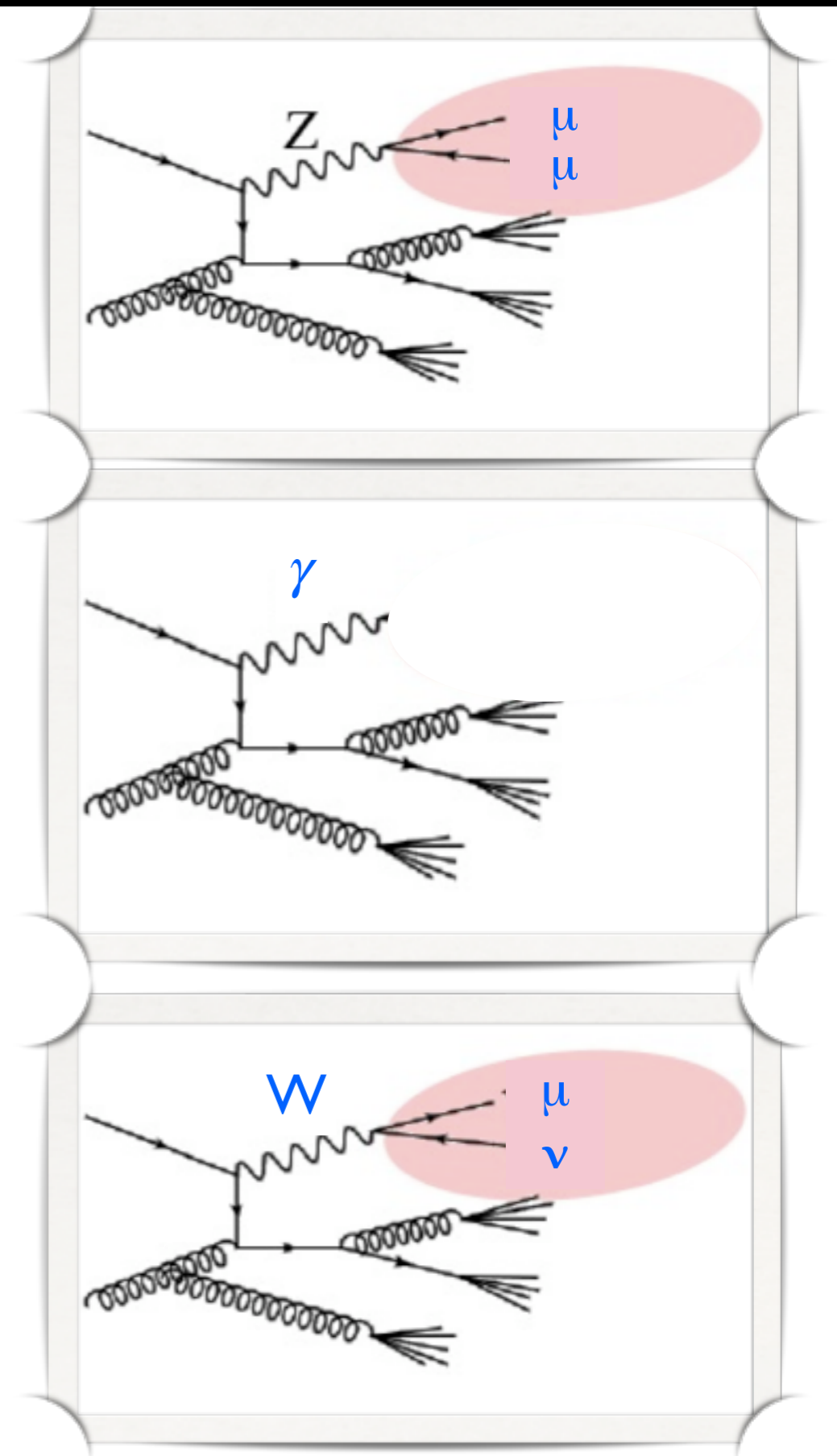


Data-driven methods to estimate $Z \rightarrow \nu\nu + \text{jets}$

- Fully reconstructable decay
- Clean, low background
- Theoretical input : ratio of branching fractions $Z \rightarrow \nu\nu / Z \rightarrow ll$, well known
- Cons: low statistics

- Higher statistics
- Theoretical input : ratio of Z/γ but this has large theoretical uncertainties. Studied in [arXiv:1106.1423](#), [arXiv:1206.6064](#), [arXiv:1107.2803](#). Currently, QCD uncertainties $< 10\%$, EWK $< 15\%$.

- Higher statistics
- But also more background from $t\bar{t}$ etc
- Theoretical input : **ratio of W/Z cross section**



Uncertainties on background estimates

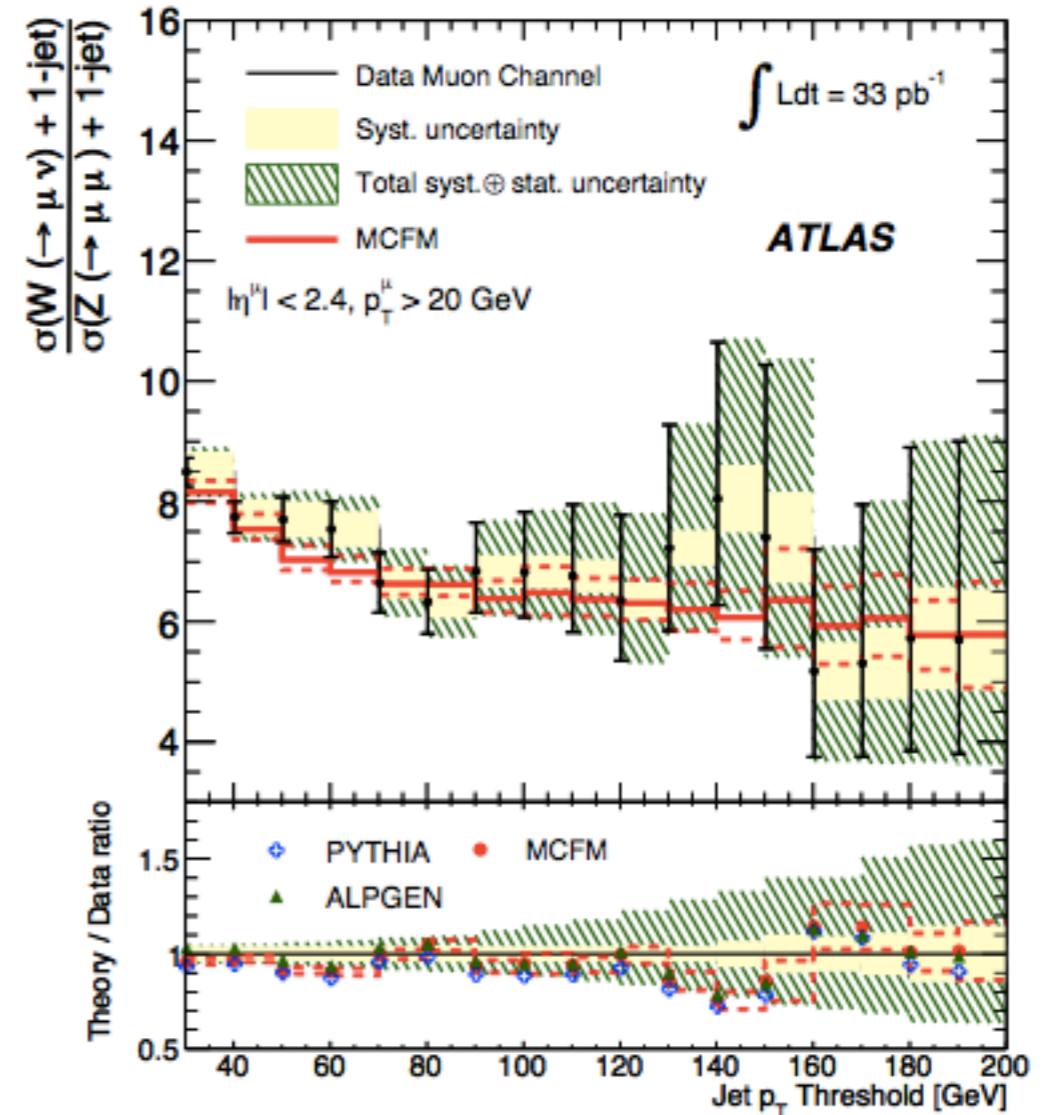
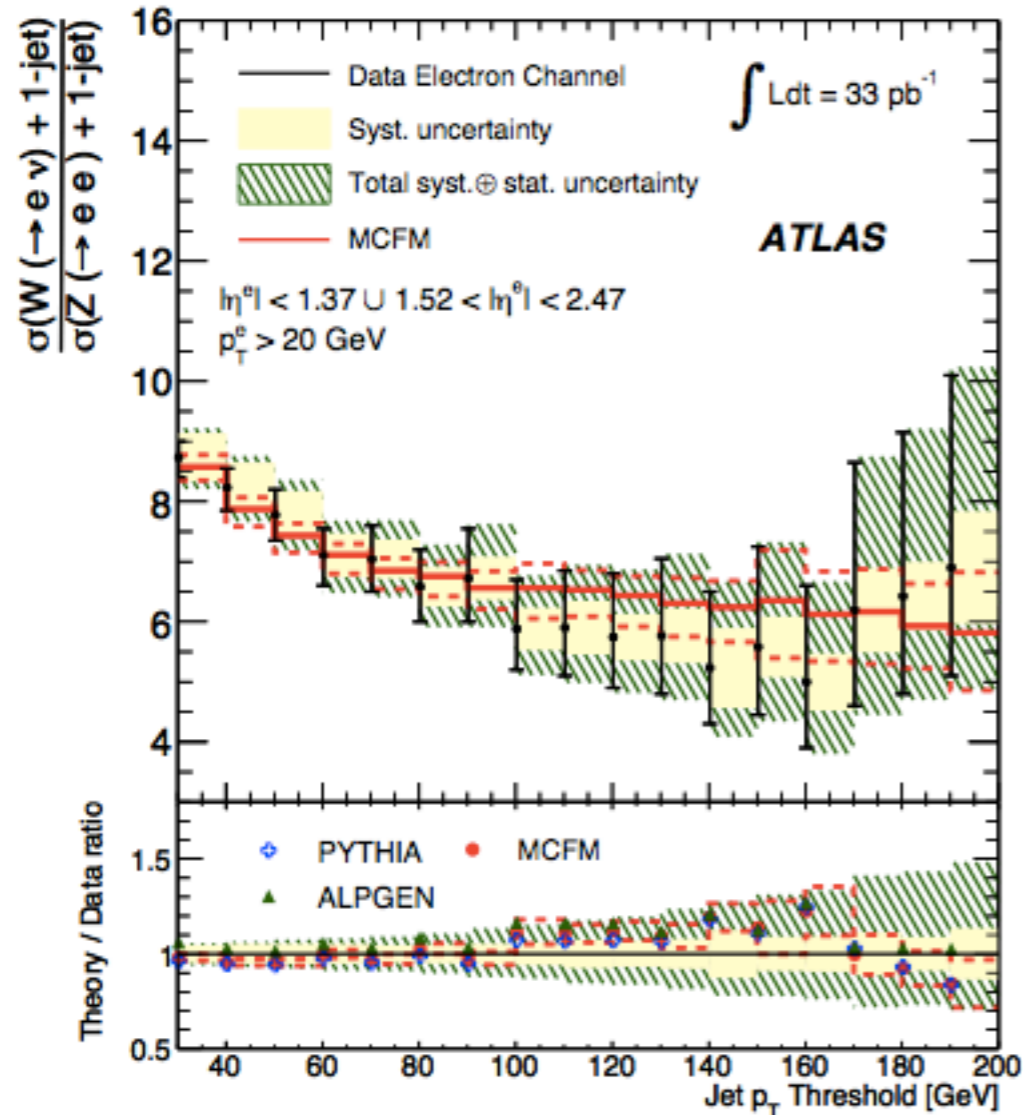
Relative systematic uncertainties (in%) for all signal regions (ATLAS, [arXiv:1210.4491](https://arxiv.org/abs/1210.4491))

Source	SR1	SR2	SR3	SR4
JES/JER/ E_T^{miss}	1.0	2.6	4.9	5.8
MC Z/W modelling	2.9	2.9	2.9	3.0
MC statistical uncertainty	0.5	1.4	3.4	8.9
$1 - f_{EW}$	1.0	1.0	0.7	0.7
Muon scale and resolution	0.03	0.02	0.08	0.61
Lepton scale factors	0.4	0.5	0.6	0.7
Multijet BG in electron CR	0.1	0.1	0.3	0.6
Di-boson, top, multijet, non-collisions	0.8	0.7	1.1	0.3
Total systematic uncertainty	3.4	4.4	6.8	11.1
Total data statistical uncertainty	0.5	1.7	4.3	11.8

Uncertainty on Z/W modelling taken from a comparison of ALPGEN and SHERPA

Ratio of W/Z vs jet p_T

ATLAS, arXiv:1108.4908



- W/Z ratio vs jet p_T threshold measured by ATLAS
- Searches for SUSY typically use variables like the missing H_T which is a vector sum of the p_T of jets above a certain threshold and numerically close to the boson p_T .

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Used Madgraph at LO with $N=0,1,2,3,4$ jets matched to Pythia with CTEQ6L1 PDFs

MCFM for the V +jet process with MSTW08 NLO PDFs

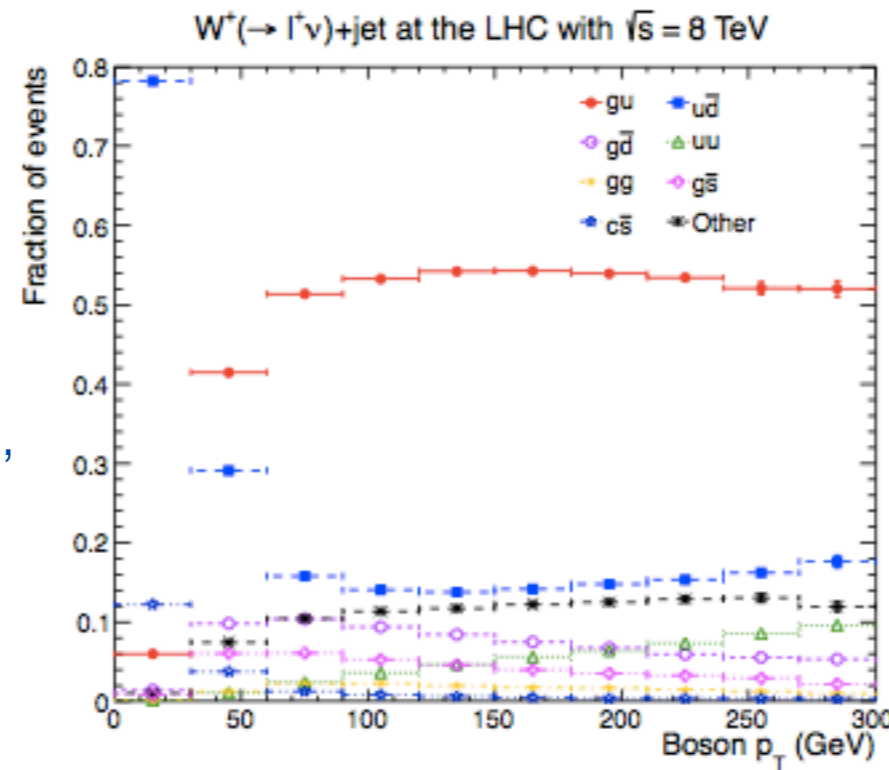
Jets defined as anti- k_T with $p_T > 10$, $|\eta| < 5$.

Flavor decomposition

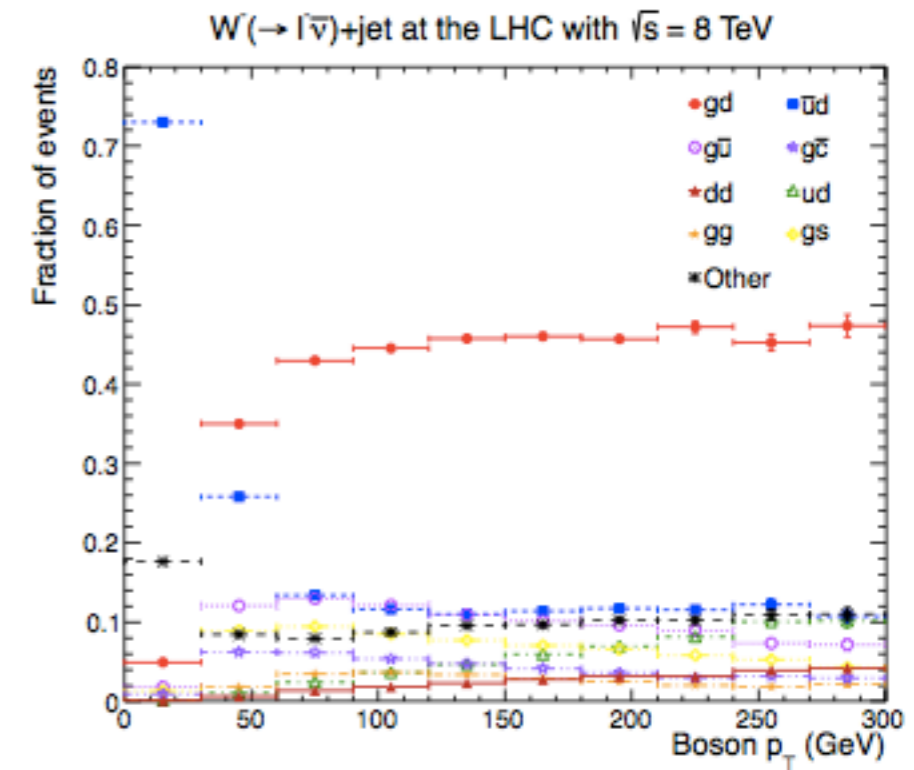
- Flavour decomposition for W^+ , W^- , W , Z

- At high p_T , gu dominates W^+ and Z , gd dominates W^- .

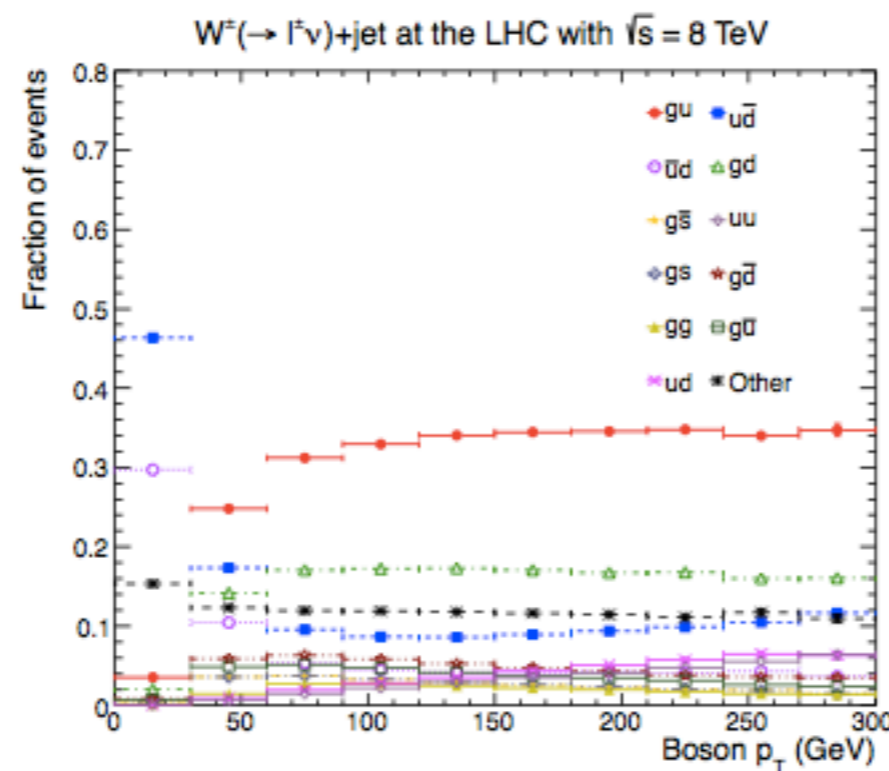
- Flavor decomposition of W and Z very similar



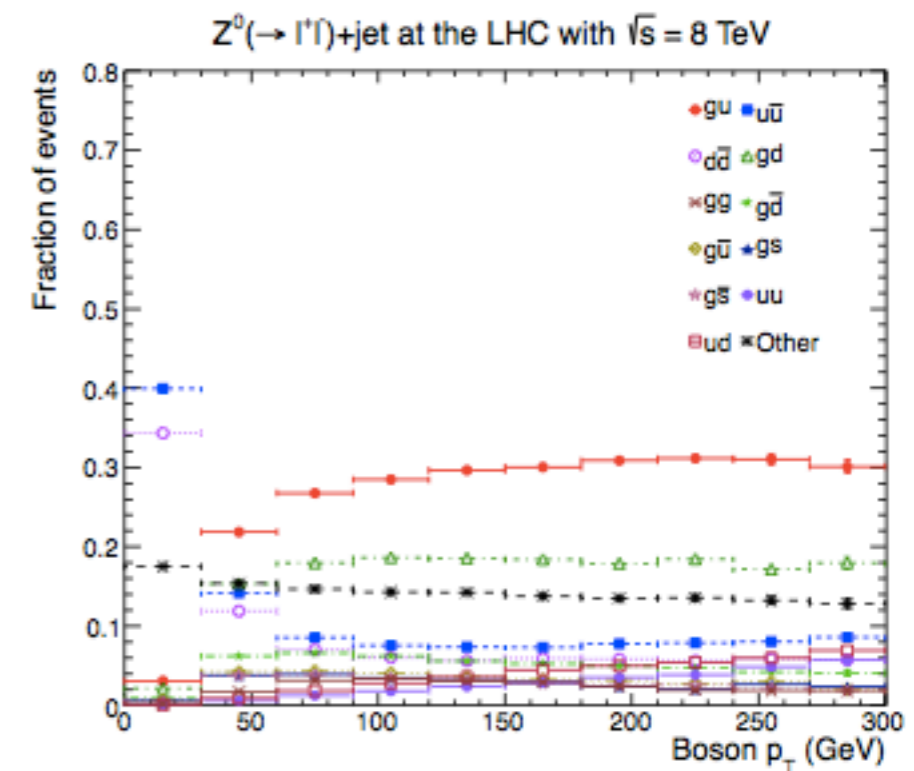
(a) W^+



(b) W^-



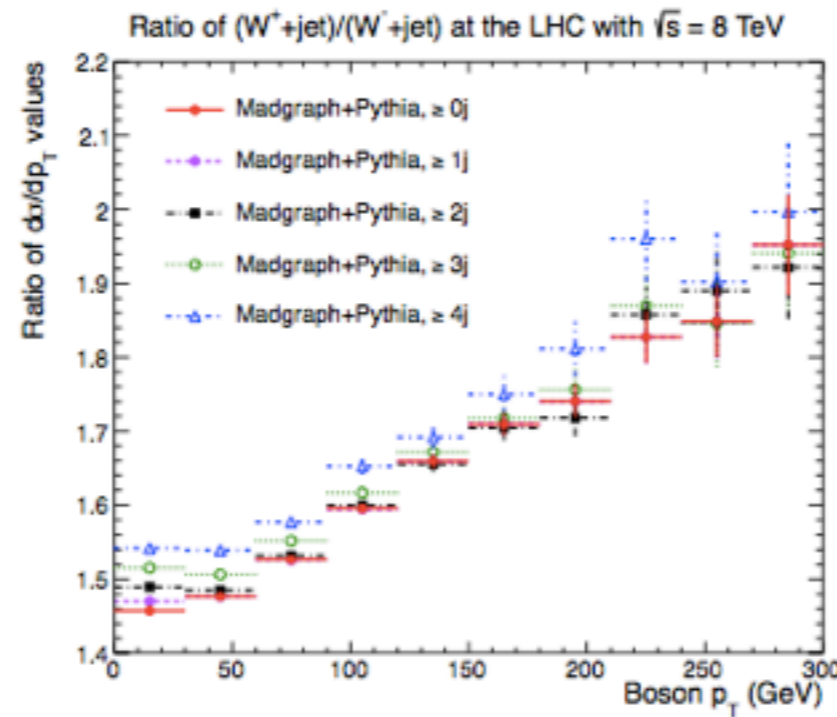
(c) W^\pm



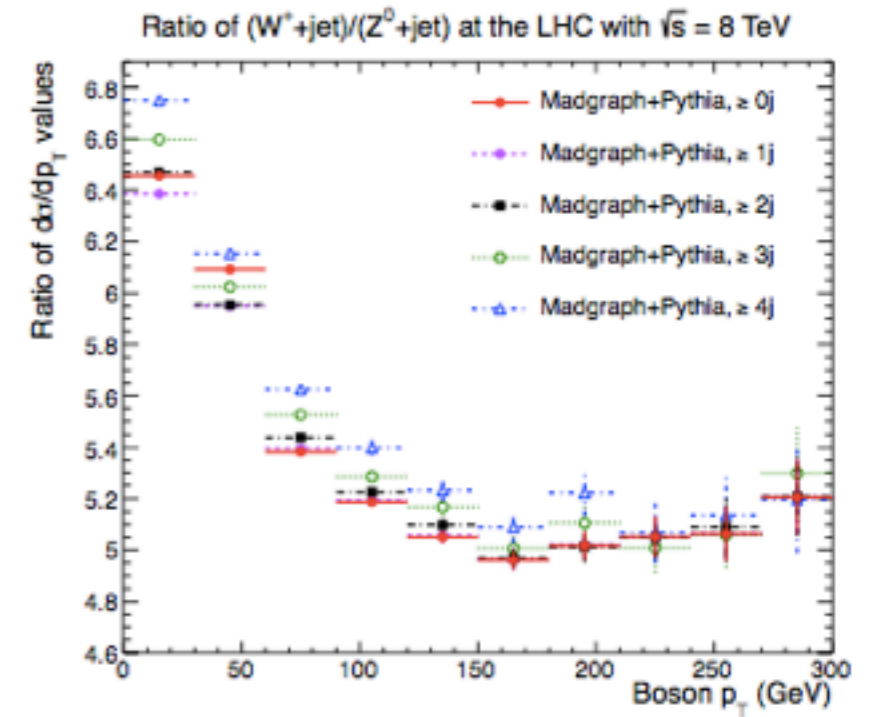
(d) Z^0

Dependence on jet multiplicity

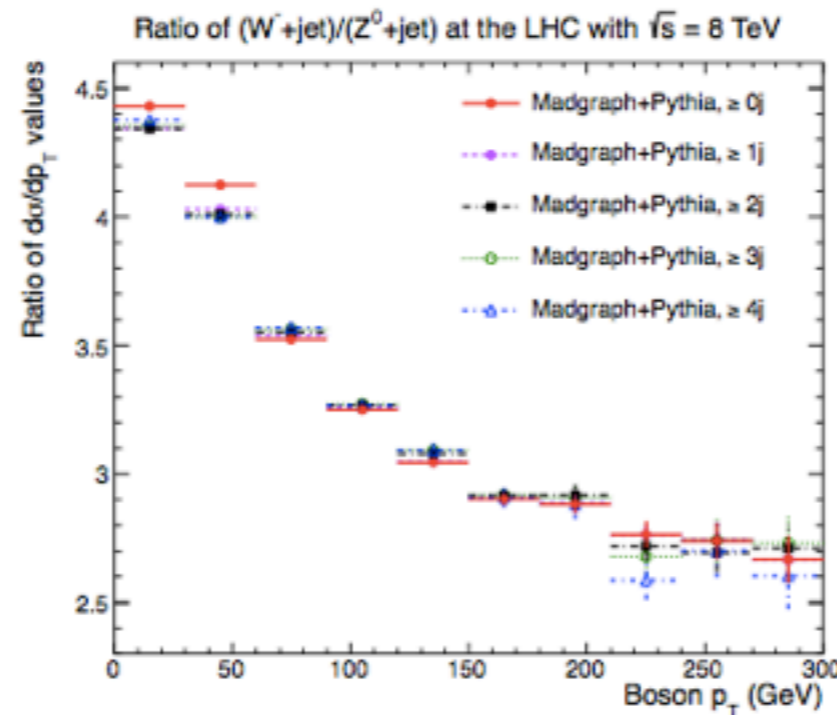
- Ratios have interesting dependence on boson p_T
- W^+/W^- tracks u/d ratio, increases going to higher boson p_T as higher x values are probed
- No strong dependence on jet multiplicity
- Slight increase in W^+/W^- with higher jet multiplicity, understood by the increase in partonic invariant mass and hence x



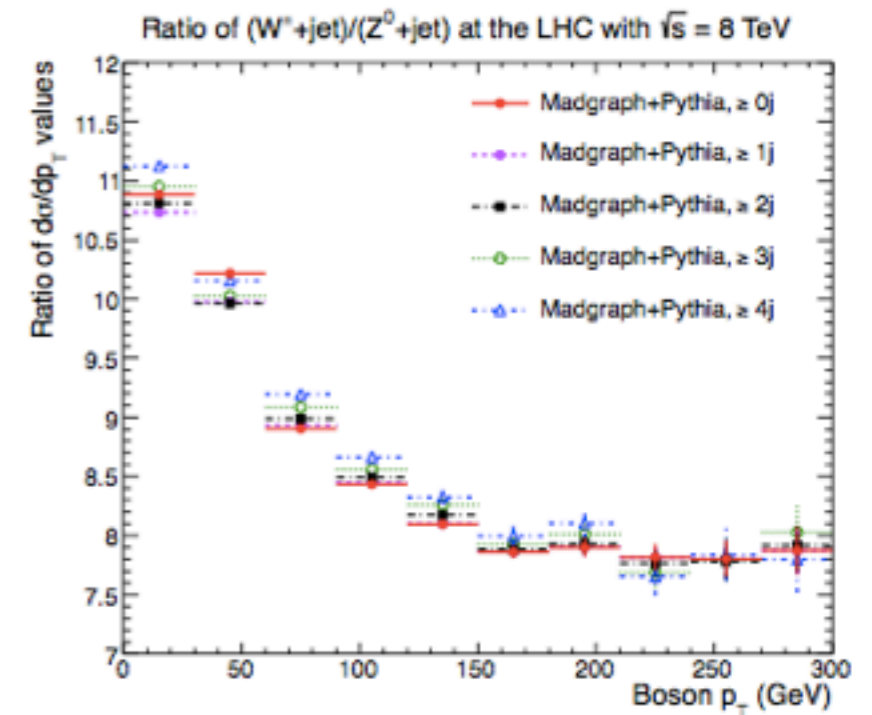
(a) W^+/W^-



(b) W^+/Z^0



(c) W^-/Z^0

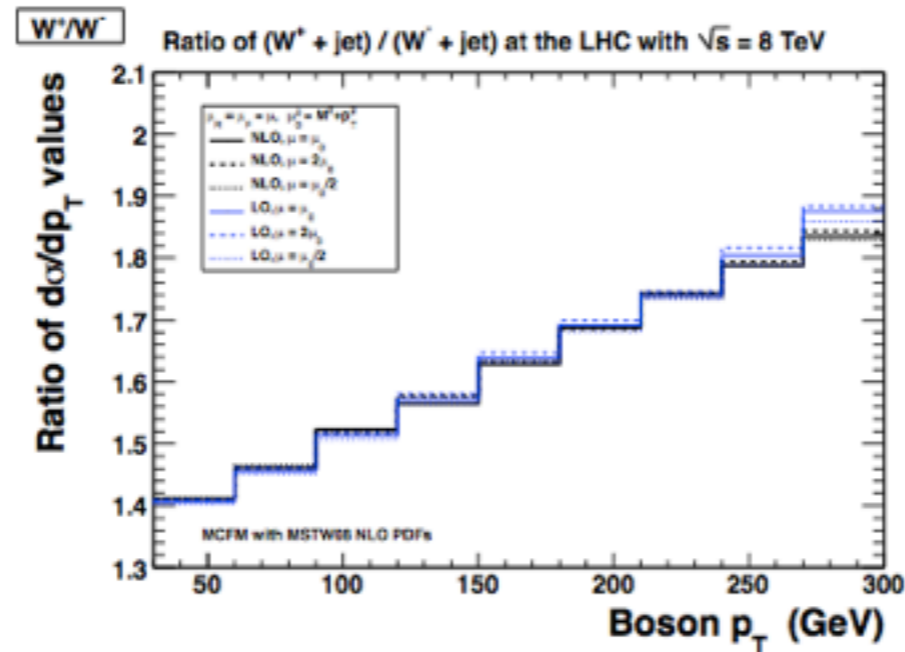


(d) W^\pm/Z^0

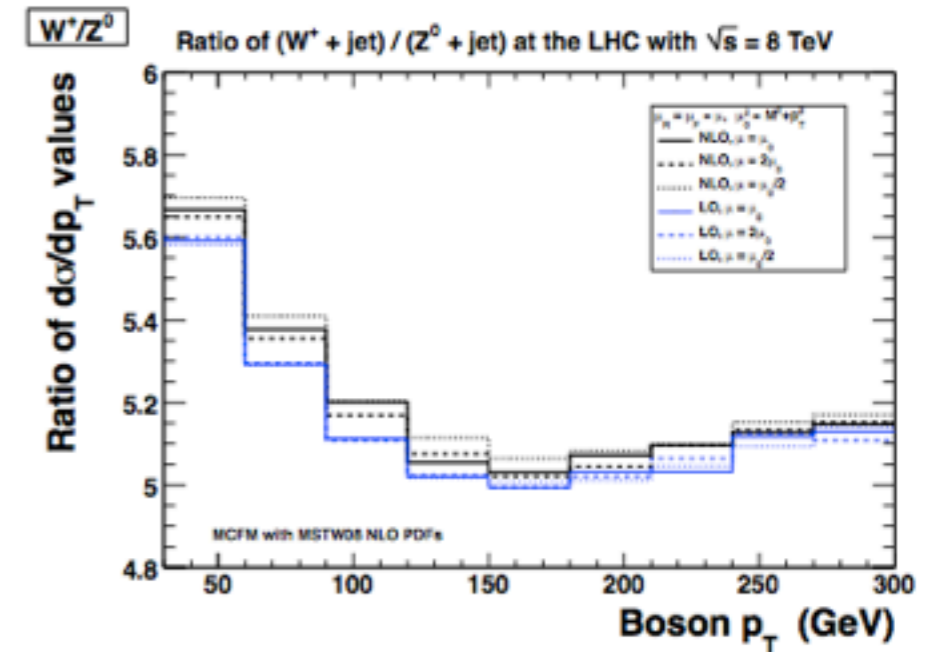
Ratios of boson p_T distributions : LO vs NLO

- Compare MCFM LO vs NLO with dynamic choice for renormalisation/factorisation scale, varied up and down by factor 2.

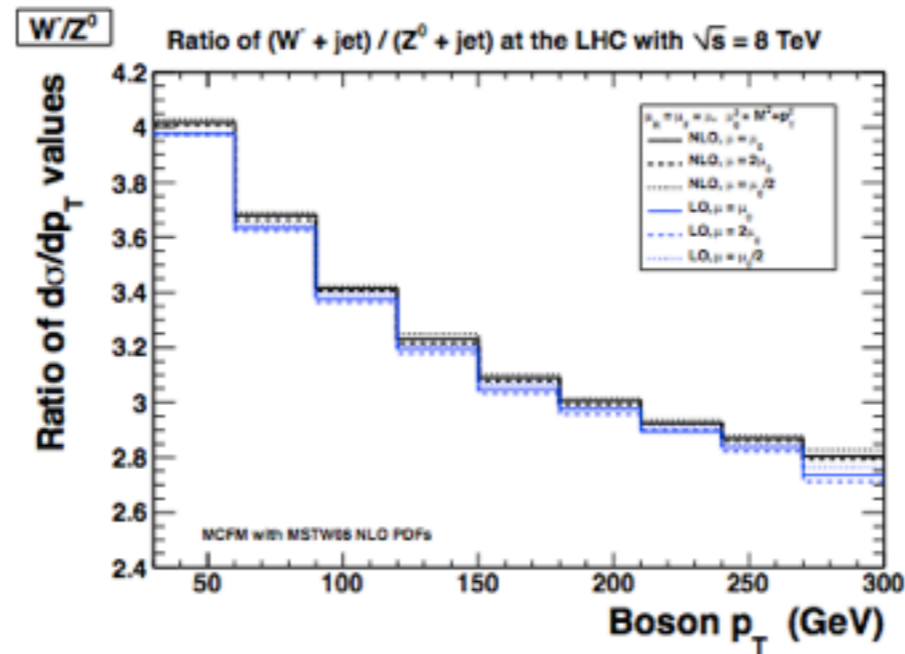
- Ratios have very small dependence on higher order corrections and scale choice
- Almost completely cancels in W^+/W^- , 1% or so in W/Z ratios



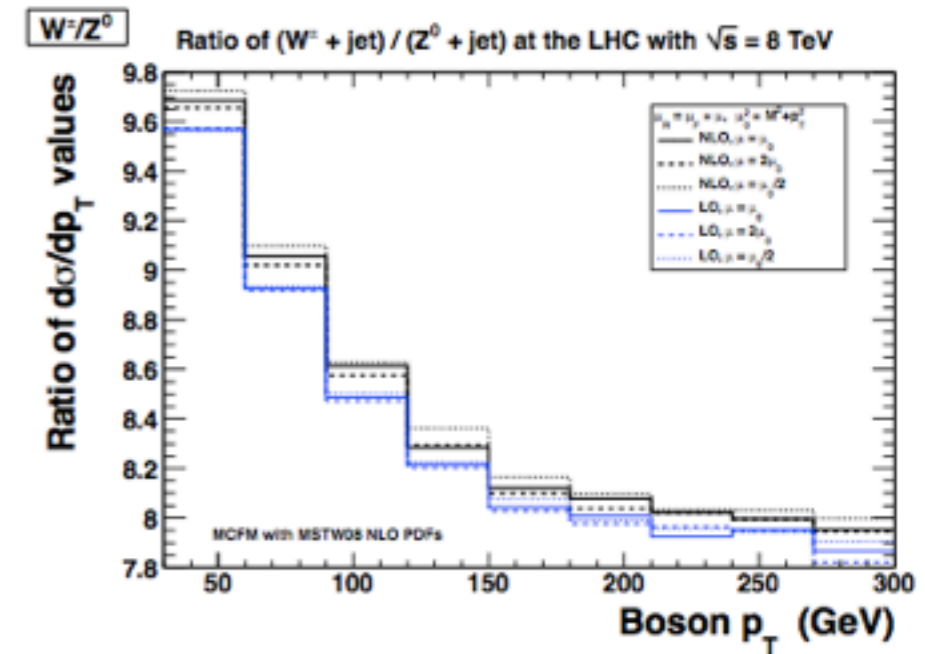
(a) W^+ / W^-



(b) W^+ / Z^0



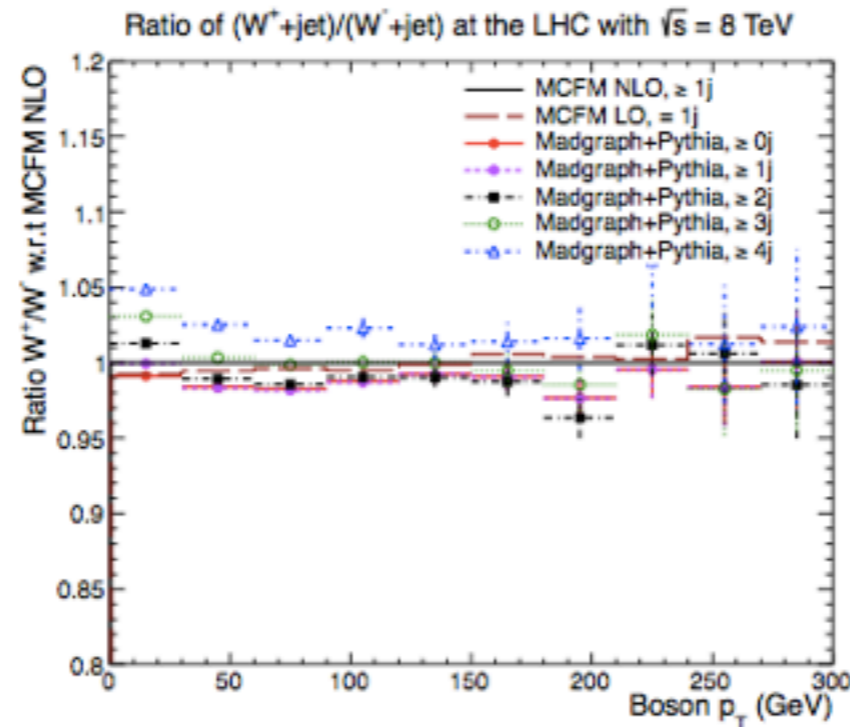
(c) W^- / Z^0



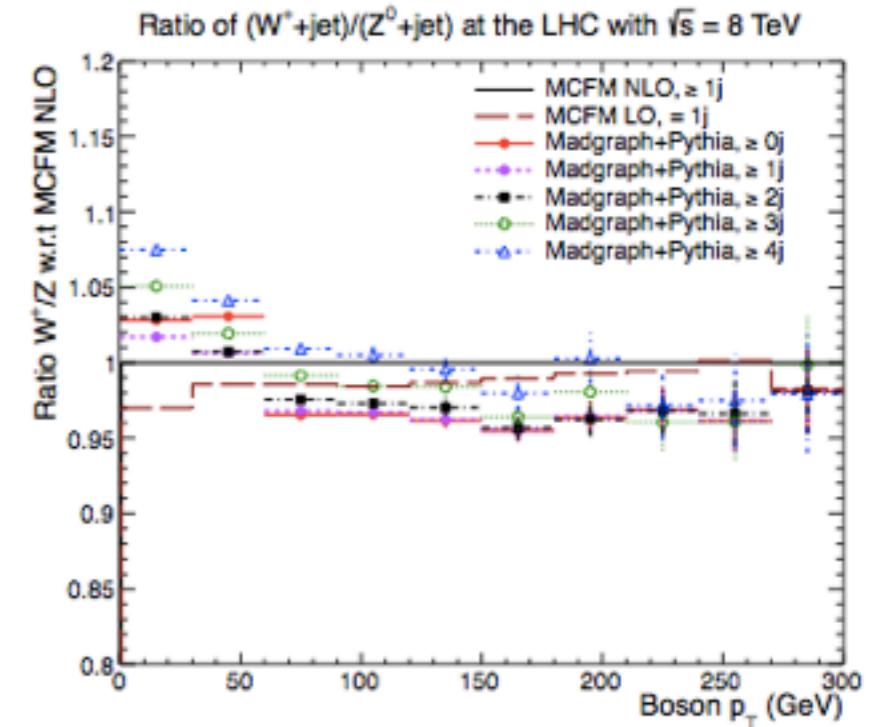
(d) W^\pm / Z^0

Comparing MCFM with Madgraph+Pythia

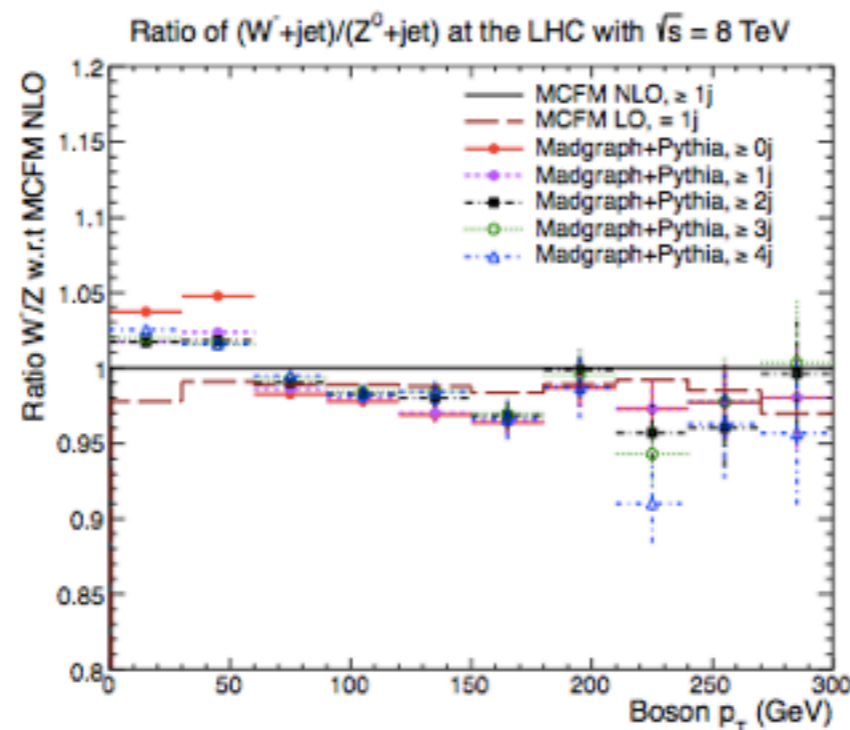
- Evaluate uncertainty from matching to a parton shower
- Compare Madgraph+pythia with NLO MCFM using same NLO PDFs
- A few percent difference at high boson p_T



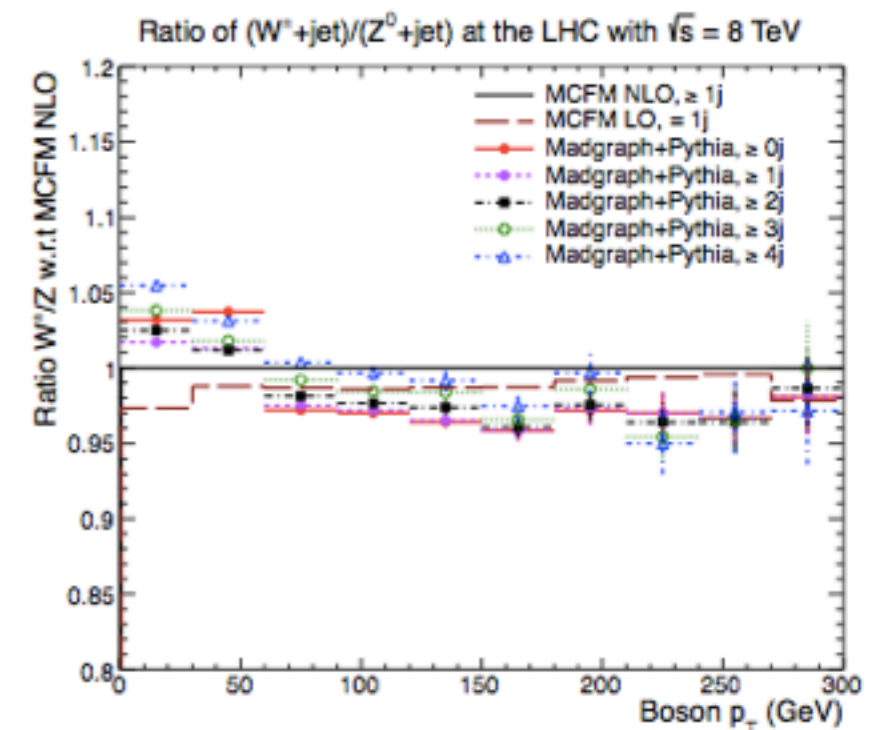
(a) W^+/W^-



(b) W^+/Z^0



(c) W^-/Z^0



(d) W^\pm/Z^0

Dependence on PDFs

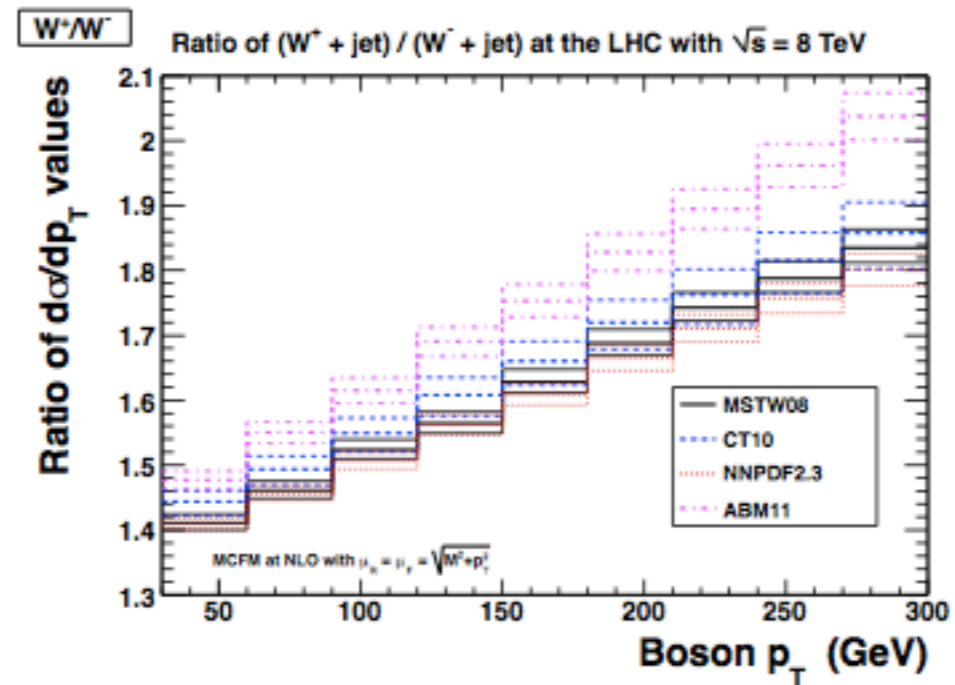
- Dependence of ratios on choice of PDFs; MSTW08, CT10, NNPDF2.3, ABM11

- W^+/W^- ratio most sensitive to

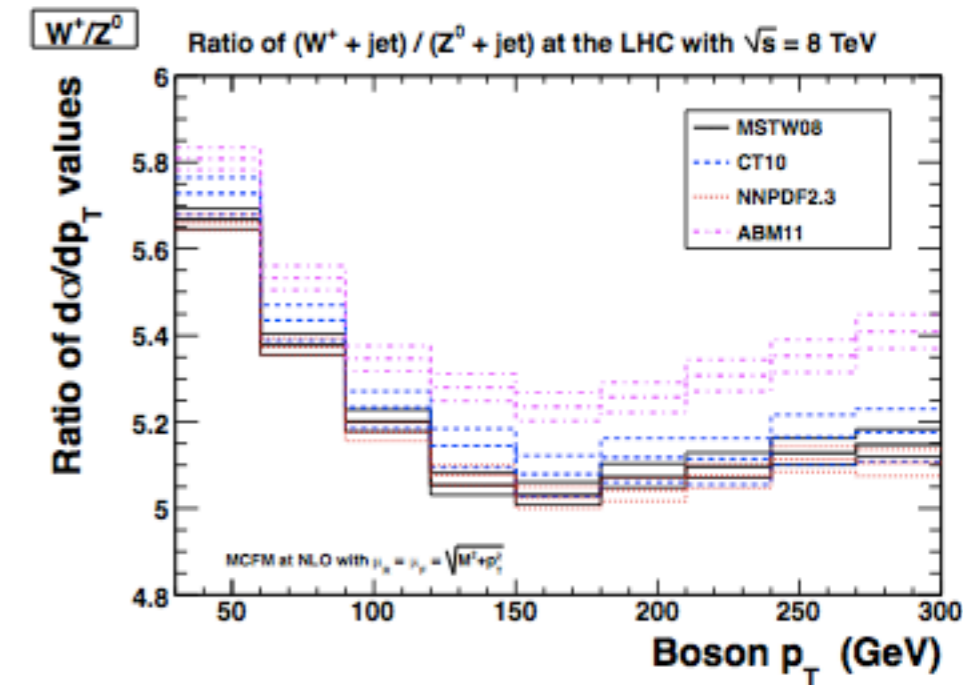
PDFs

- PDF dependence cancels in

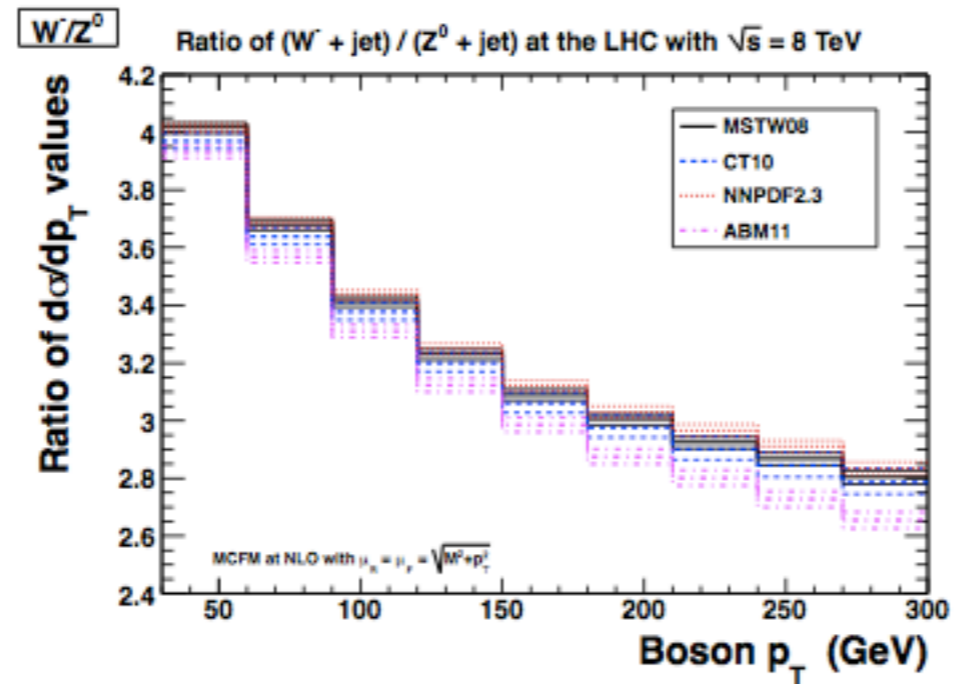
W^\pm/Z ratio



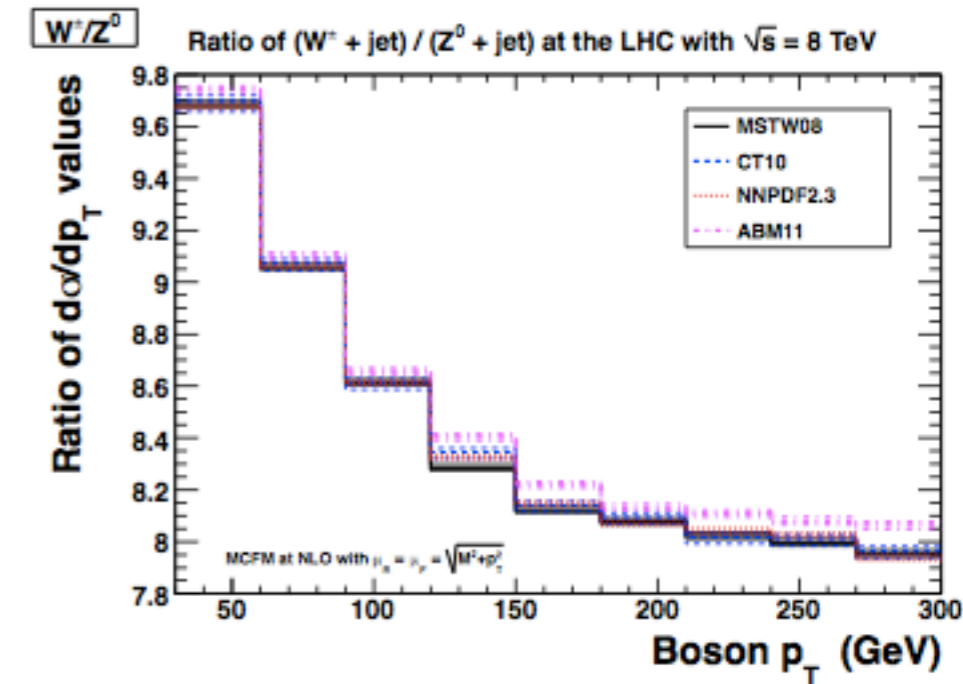
(a) W^+ / W^-



(b) W^+ / Z^0



(c) W^- / Z^0



(d) W^\pm / Z^0

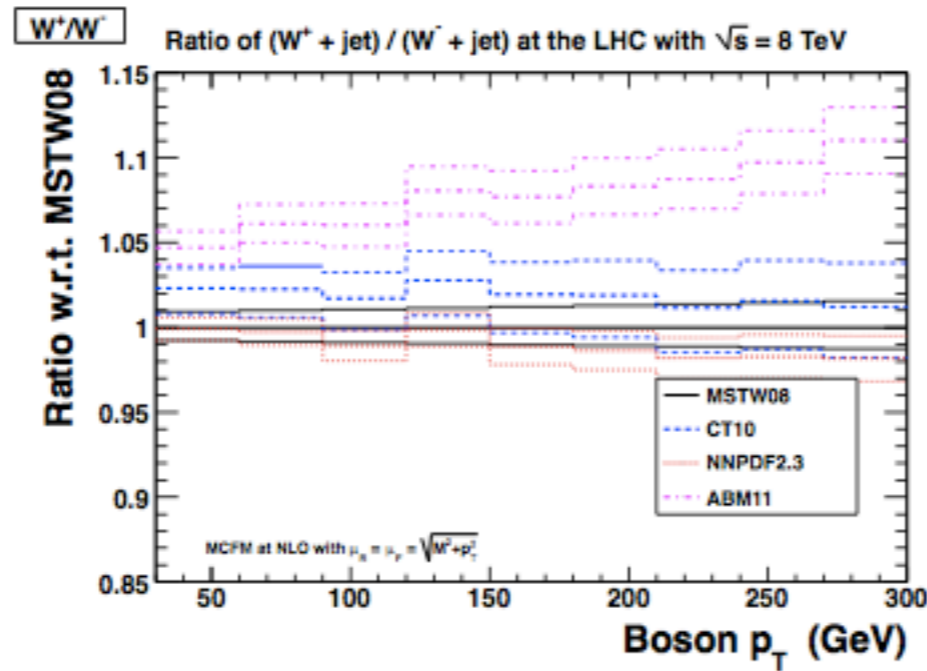
Dependence on PDFs

- Ratio w.r.t MSTW08
- Difference between ABM11 and MSTW08 grows with p_T , from 5% to 10%

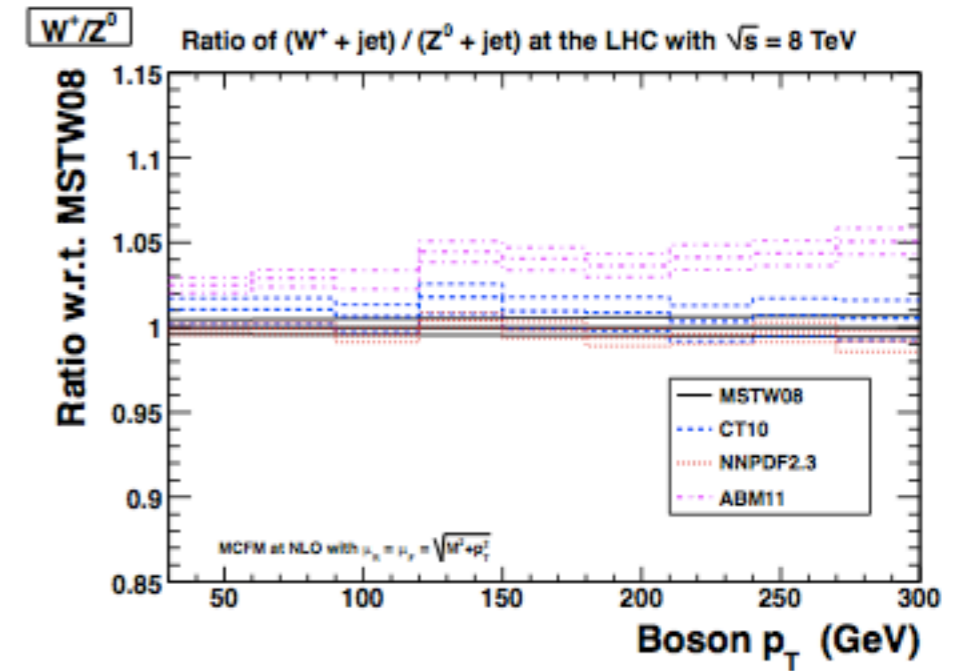
- Separate W^+/Z and W^-/Z

retain some sensitivity to PDFs

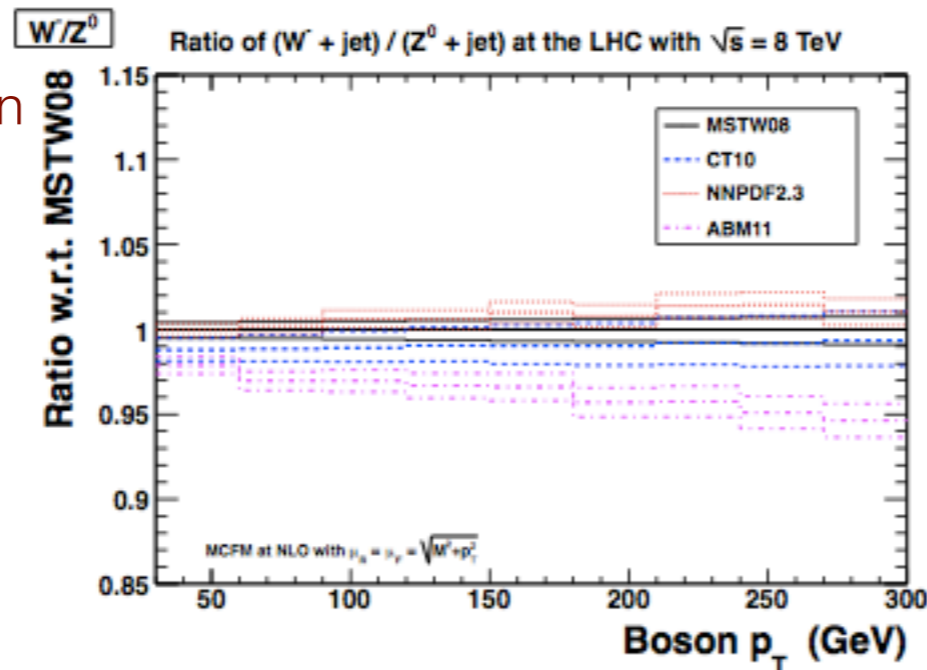
- PDF dependence cancels in W^\pm/Z ratio (similar flavor decomposition for W and Z)



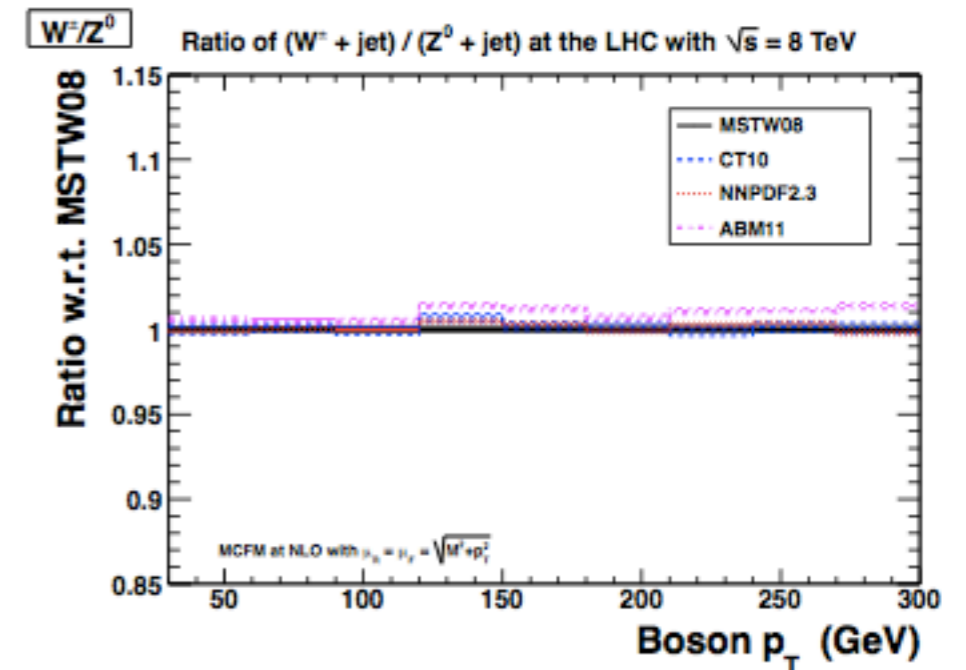
(a) W^+/W^-



(b) W^+/Z^0



(c) W^-/Z^0

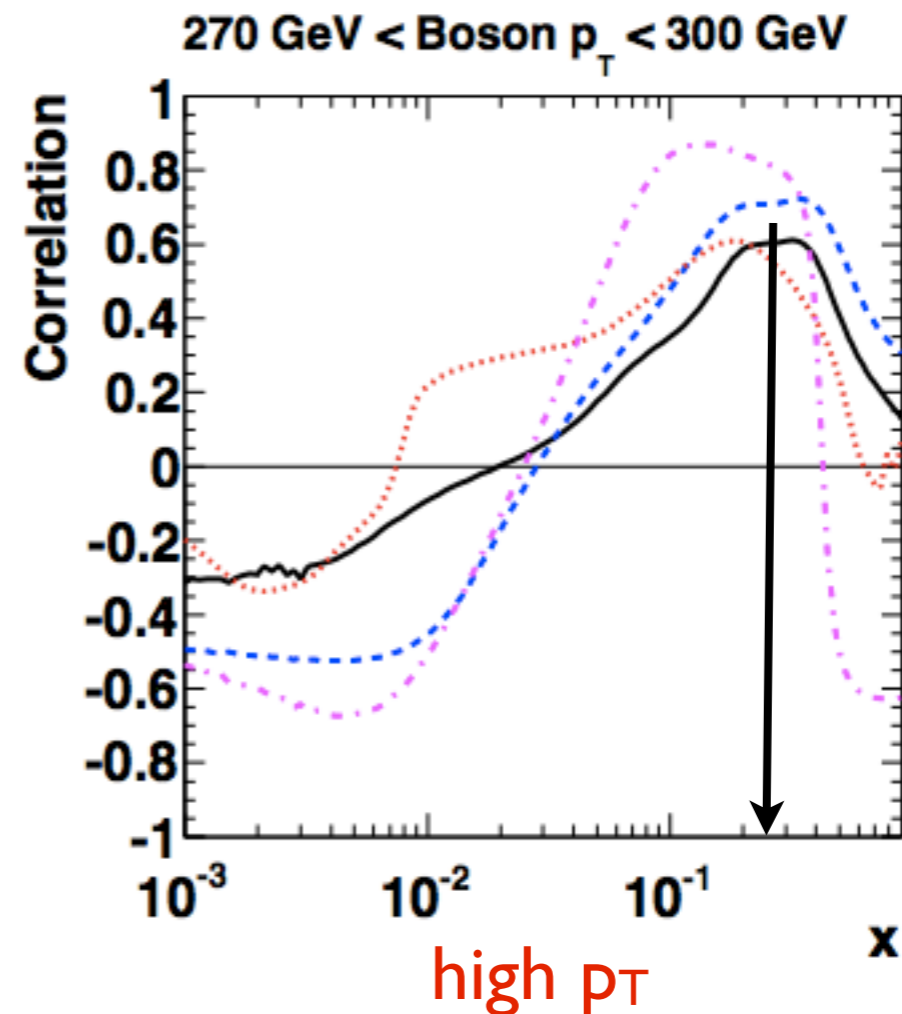
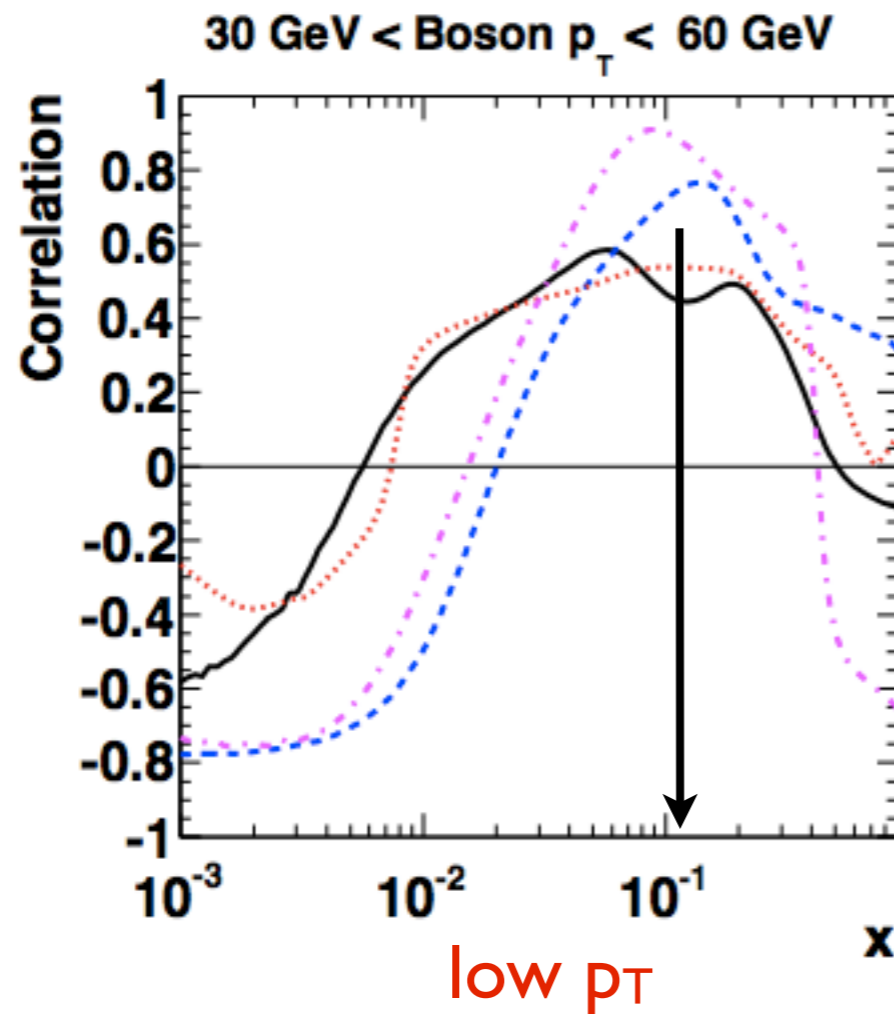


(d) W^\pm/Z^0

Potential PDF constraints from W^+/W^- ratio

Correlation between ratio of u/d PDFs at $Q = 100$ GeV and Ratio of $(W^+ + \text{jet}) / (W^- + \text{jet})$ at the LHC with $\sqrt{s} = 8$ TeV using MCFM at NLO with $\mu_R = \mu_F = \sqrt{M^2 + p_T^2}$

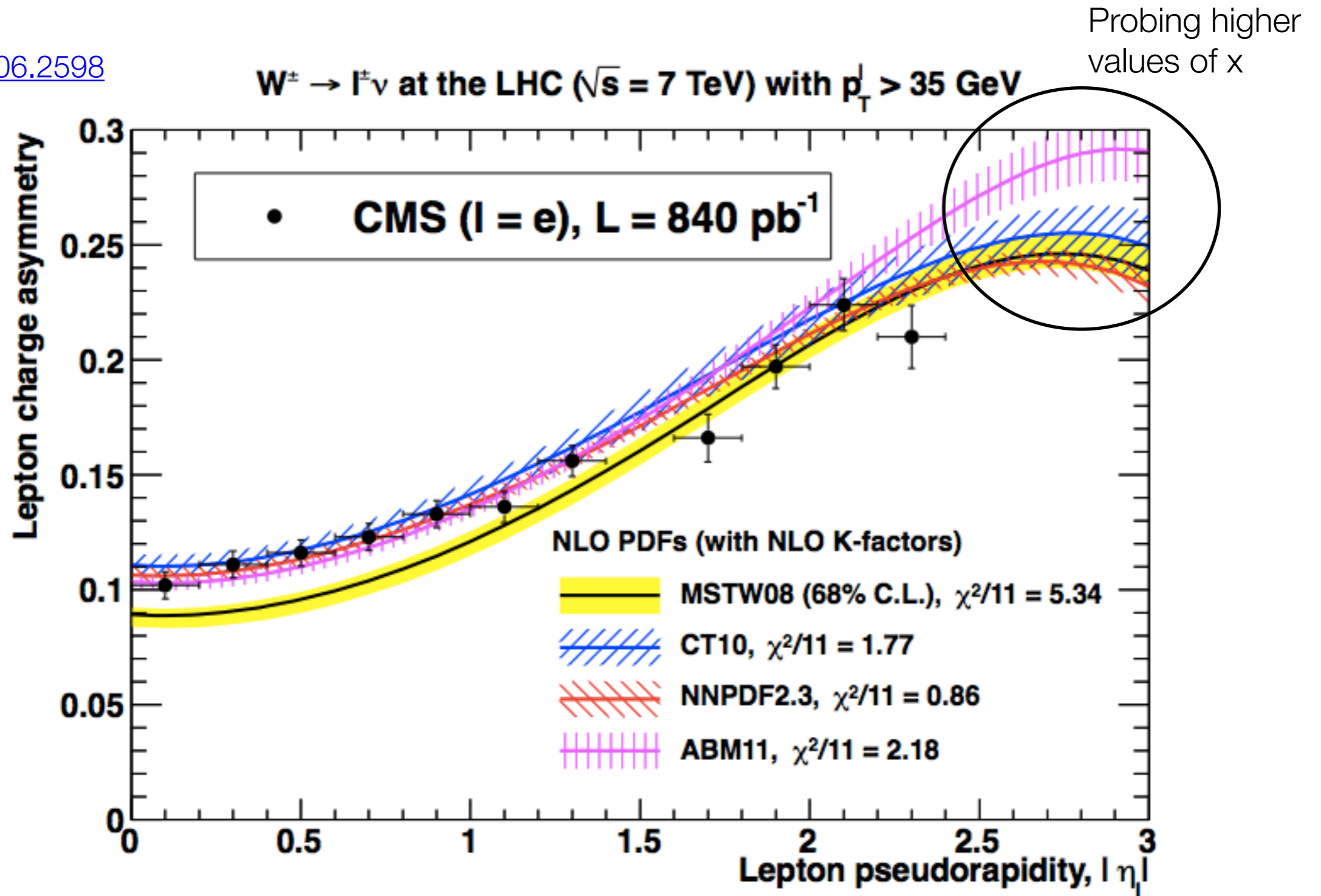
— MSTW08
- - - CT10
... NNP2.3
- . - ABM11



x range corresponding to strong correlation moves to higher x values (from $x \sim 0.1$ to $\sim 0.2-0.3$) as boson p_T is increased

Potential PDF constraints from W^+/W^- ratio

[arXiv:1206.2598](https://arxiv.org/abs/1206.2598)



- Measurement vs boson p_T complementary to measurement vs η_l .

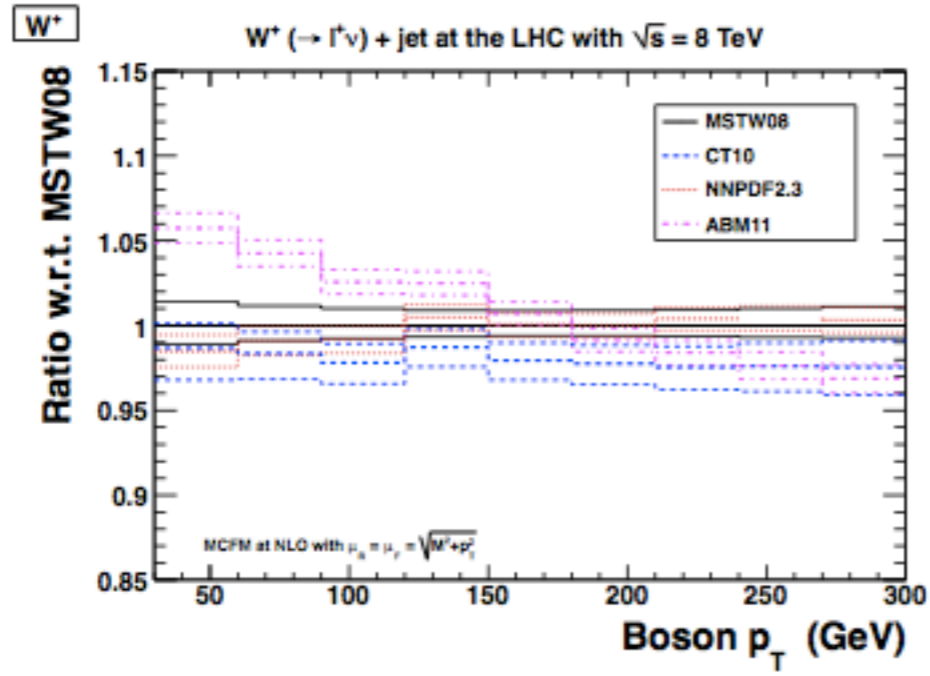
Higher order electroweak corrections

- Effect of large virtual electroweak Sudakov logarithms can reach up to a few tens of percent for $d\sigma/dp_T$ at very large boson p_T .
- Effect cancels almost completely in the W^+/W^- ratio.
- Decrease in W^+/Z and W^-/Z ratios by 4% at boson $p_T = 1$ TeV and by 7% at $p_T = 2$ TeV at the 14 TeV LHC. Smaller shift for boson p_T values considered in this study.
- Electroweak corrections on W/Z are smaller than γ/Z ratio, which increases by 13% at boson $p_T = 1$ TeV and by 22% at $p_T = 2$ TeV at the 14 TeV LHC.
- For sufficiently inclusive measurements, potential partial cancellations from real emission of soft W and Z bosons.
- Effect of real EWK corrections and extent of cancellation would need to be studied for realistic experiments cuts used in measurement.

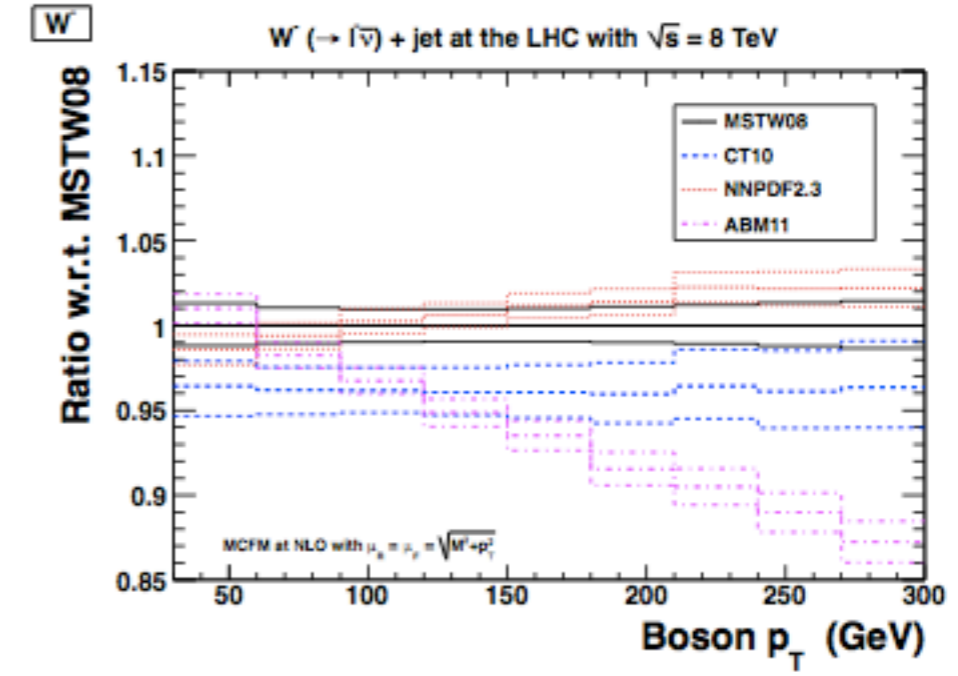
Summary

- Theoretical ratio W/Z is a key ingredient in the data-driven estimates of the $Z \rightarrow \nu \bar{\nu} + \text{jets}$ background in searches for new physics.
- Presented detailed study of the theoretical uncertainties on the 4 ratios; W^+/W^- , W^+/Z , W^-/Z and W/Z as a function of the boson p_T .
- Theoretical QCD and EWK uncertainties on W/Z ratio small, QCD uncertainties $< \sim 5\%$.
- W^+/W^- ratio measured as a function of boson p_T has negligible uncertainties from higher order QCD and EWK, hence can constrain u/d ratio in a complementary region of x to the W charge asymmetry measured as a function of η_l .

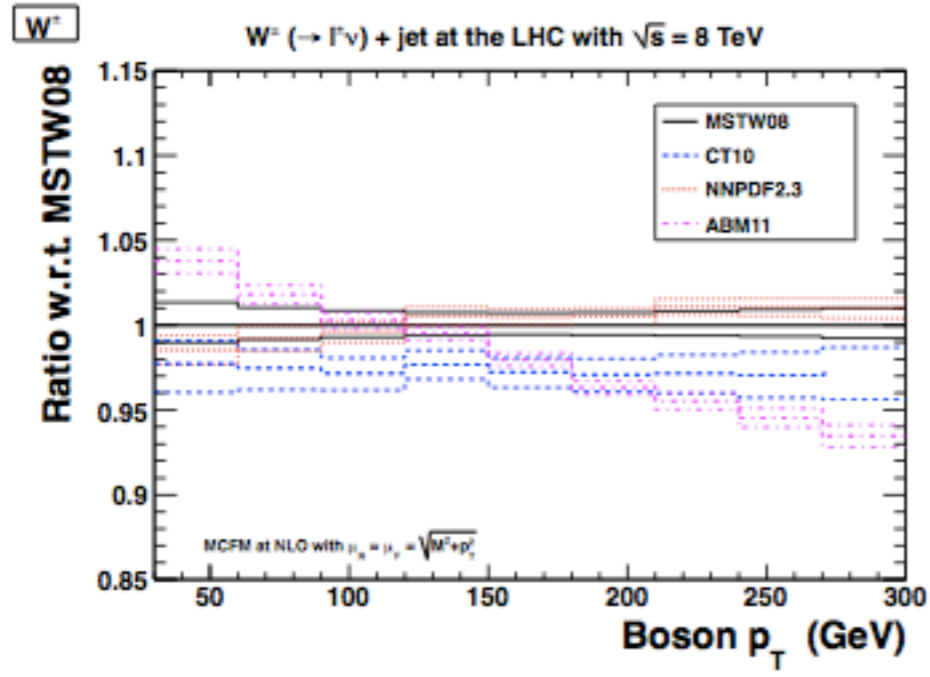
Backup



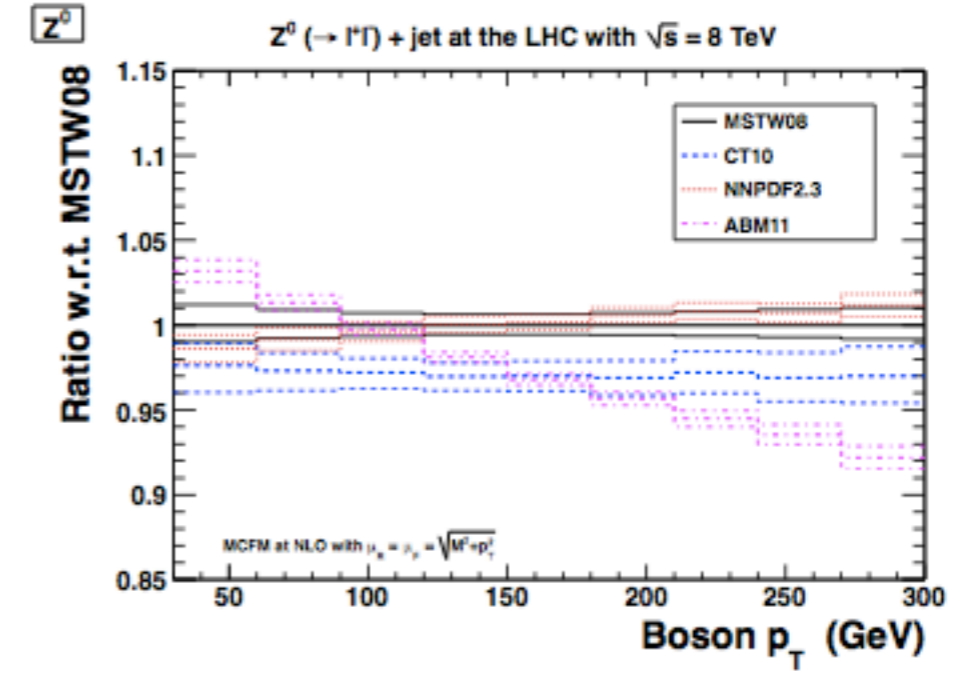
(a) W^+



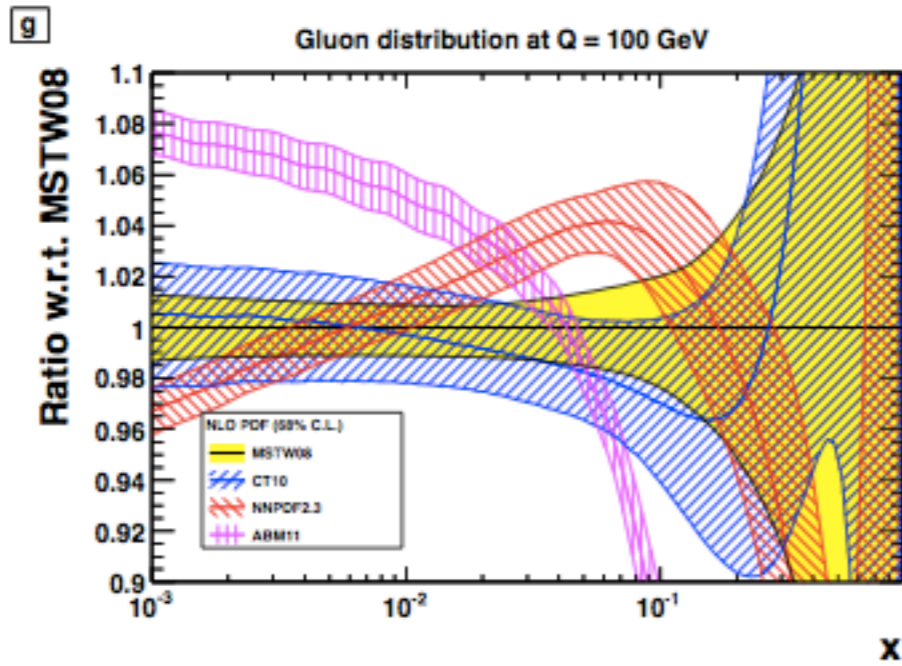
(b) W^-



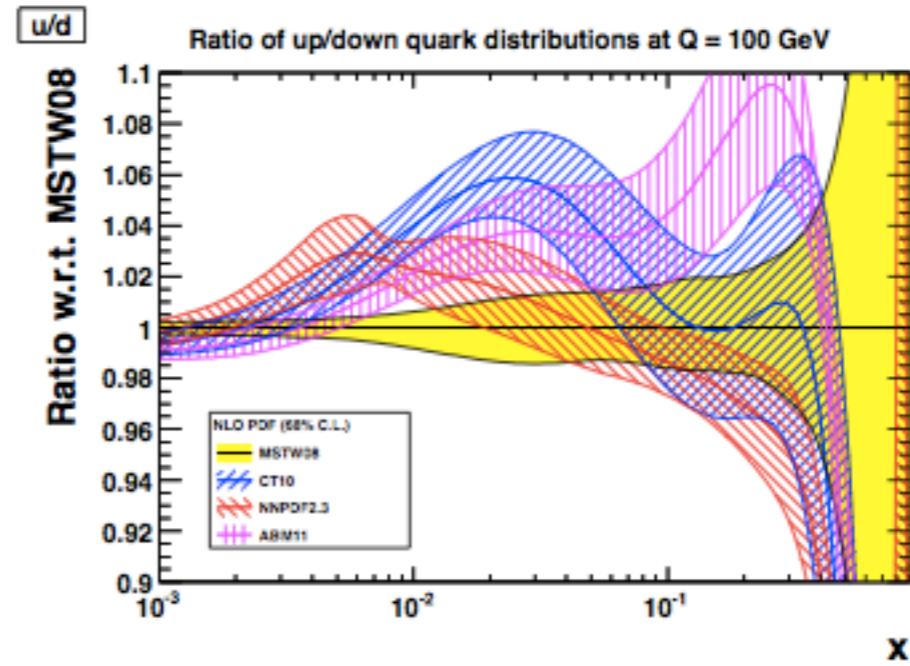
(c) W^\pm



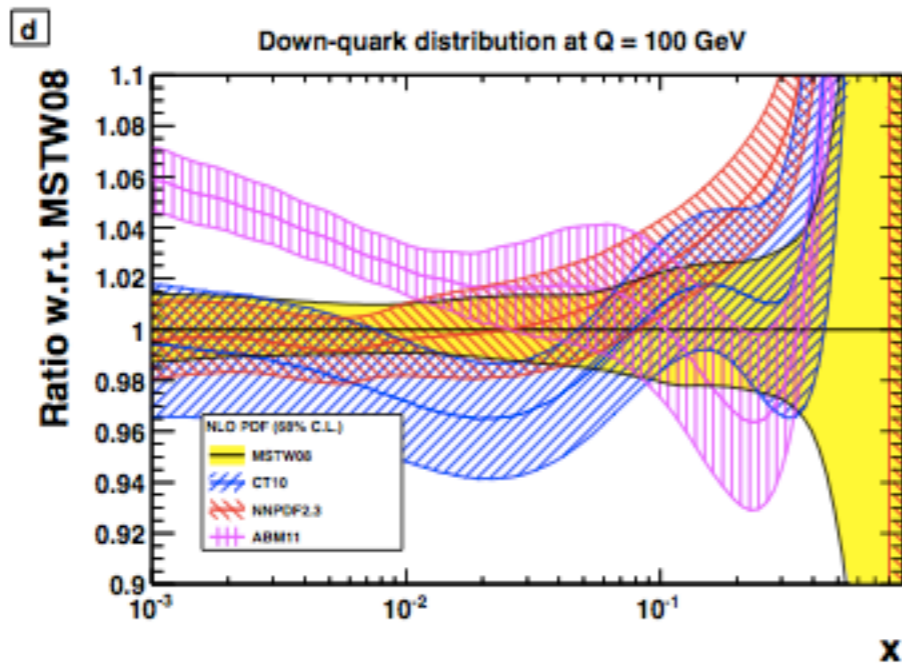
(d) Z^0



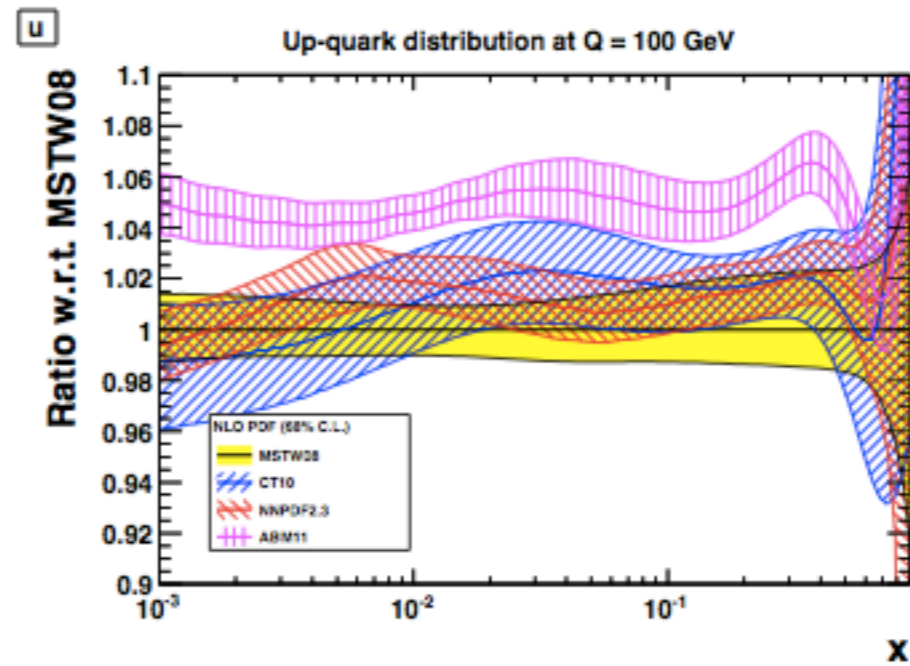
(a) Gluon distribution



(b) Ratio of up/down quark distributions



(c) Down-quark distribution



(d) Up-quark distribution