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

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In collaboration with Graeme Watt, arXiv: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 $Z \rightarrow \nu\ \nu$ 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

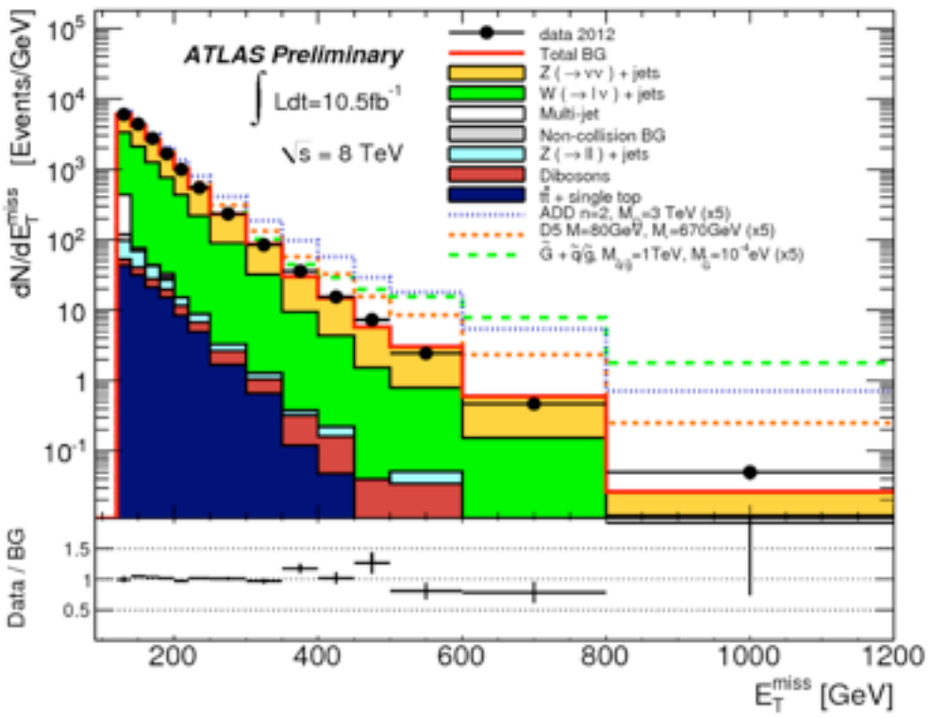
Motivation

• 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→ ν ν+jets is dominant background in many searches for new physics that involve jets and missing transverse energy

For example,

ATLAS-CONF-2012-147



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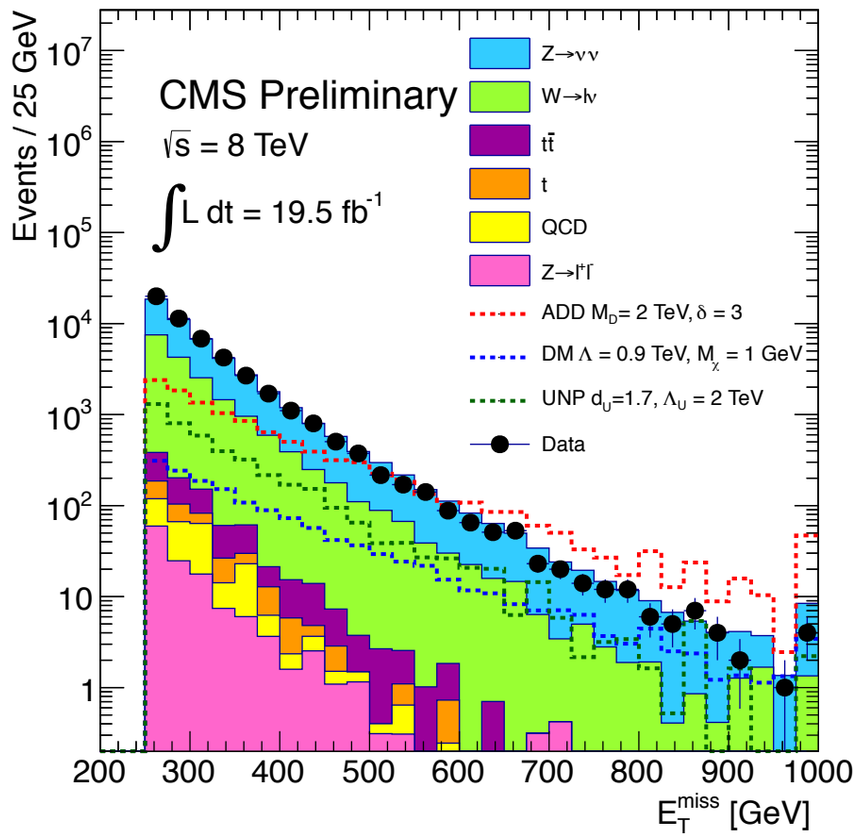
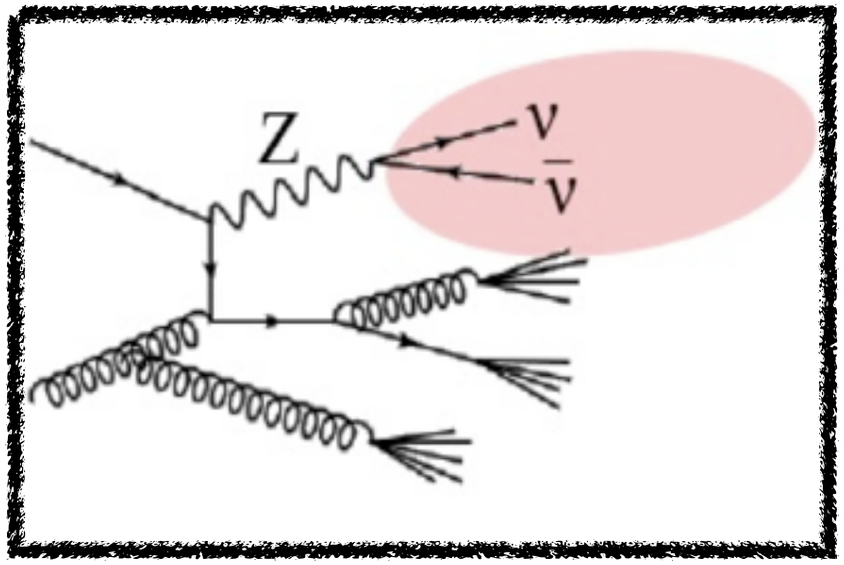
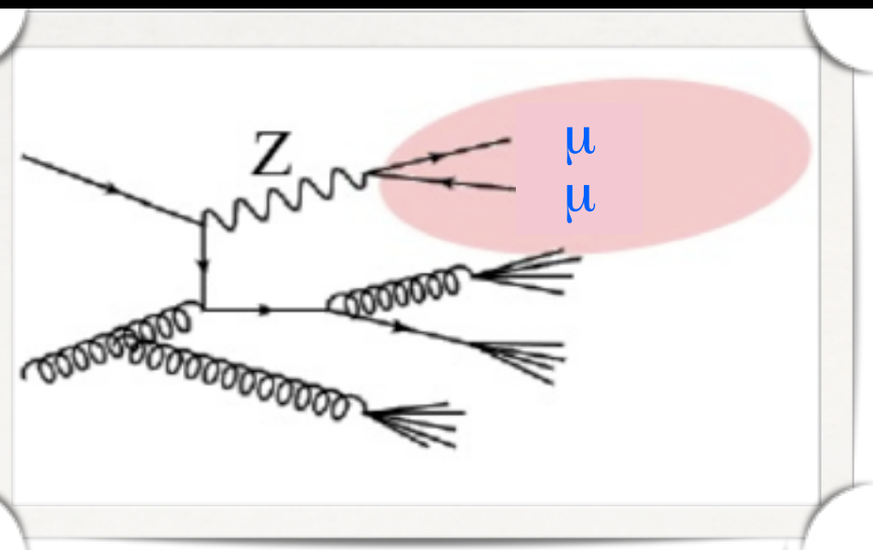


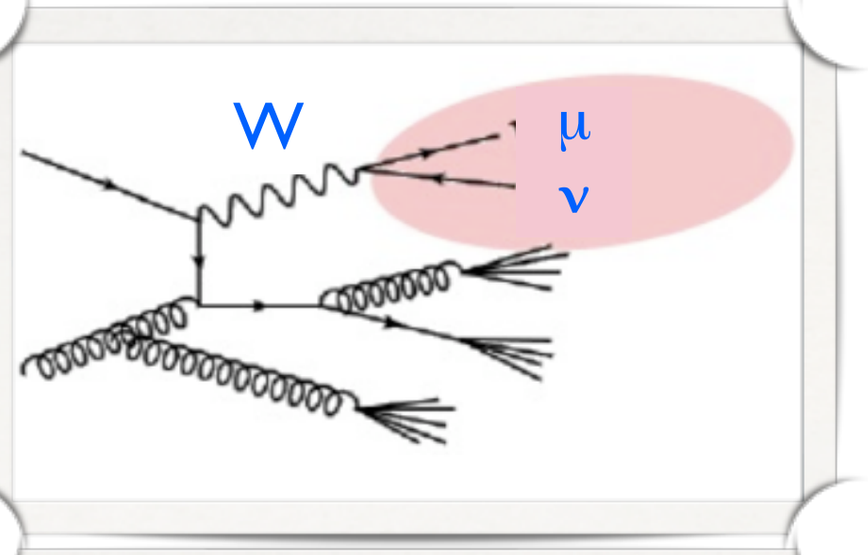
Searches for Large Extra Dimensions and dark matter, up to 70% of the background is from Z→ ν ν+jet events

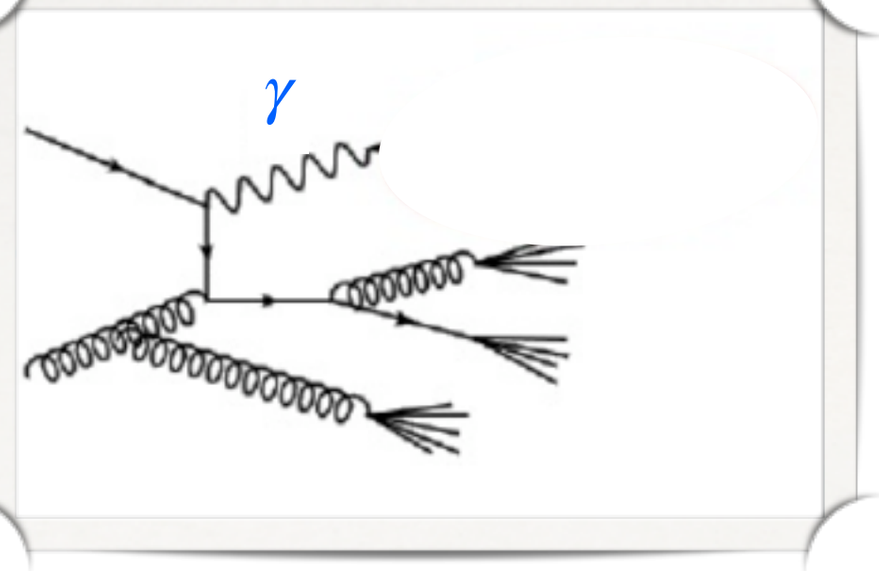
Data-driven methods to estimate Z-->νν+jets

Use V+jets, V = Z, W, γ









Data-driven methods to estimate Z-->νν+jets

- Fully reconstructable decay
- Clean, low background
- Theoretical input : ratio of branching fractions

$Z \to \nu\,\nu / Z \to ll$, well known

- Cons: low statistics

- Higher statistics
- But also more background from ttbar etc
- Theoretical input : ratio of W/Z cross section

- 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%.

Uncertainties on background estimates

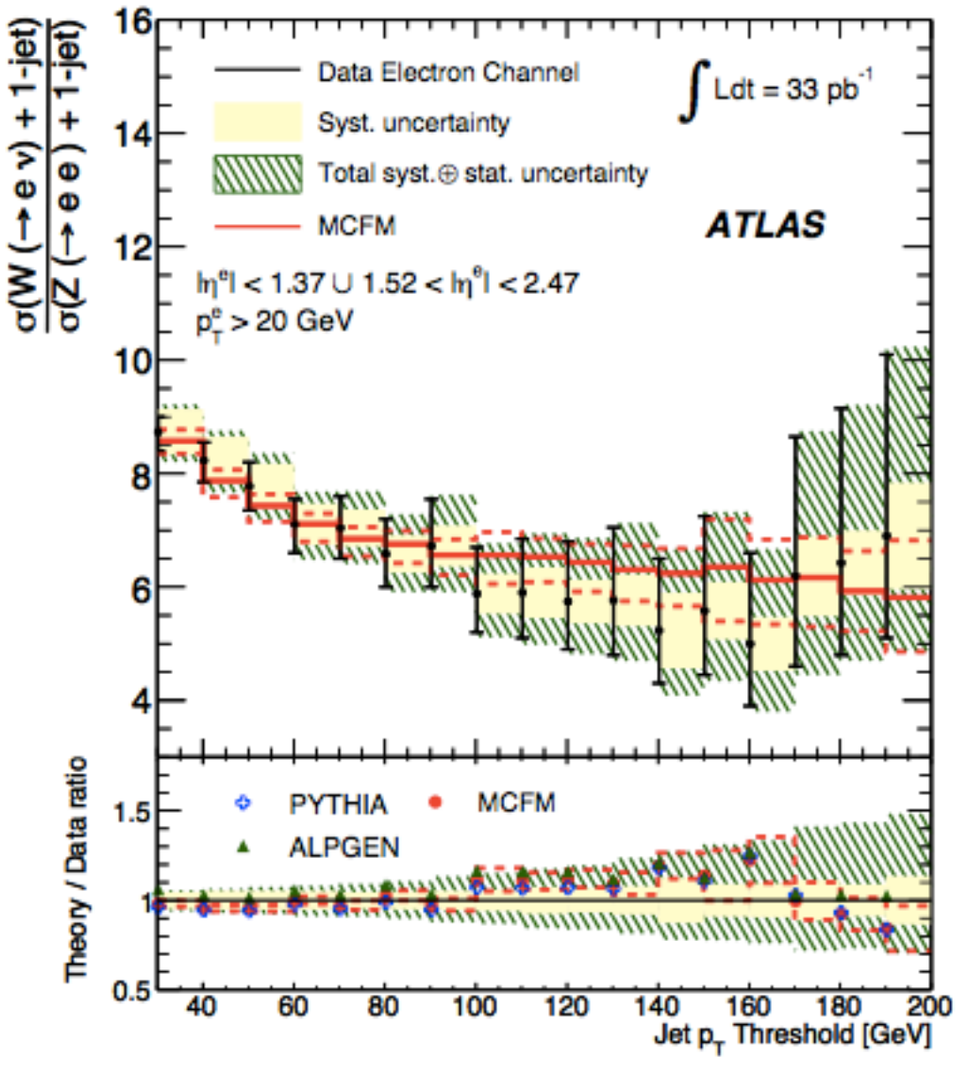
Relative systematic uncertainties (in%) for all signal regions (ATLAS, arXiv:1210.4491)

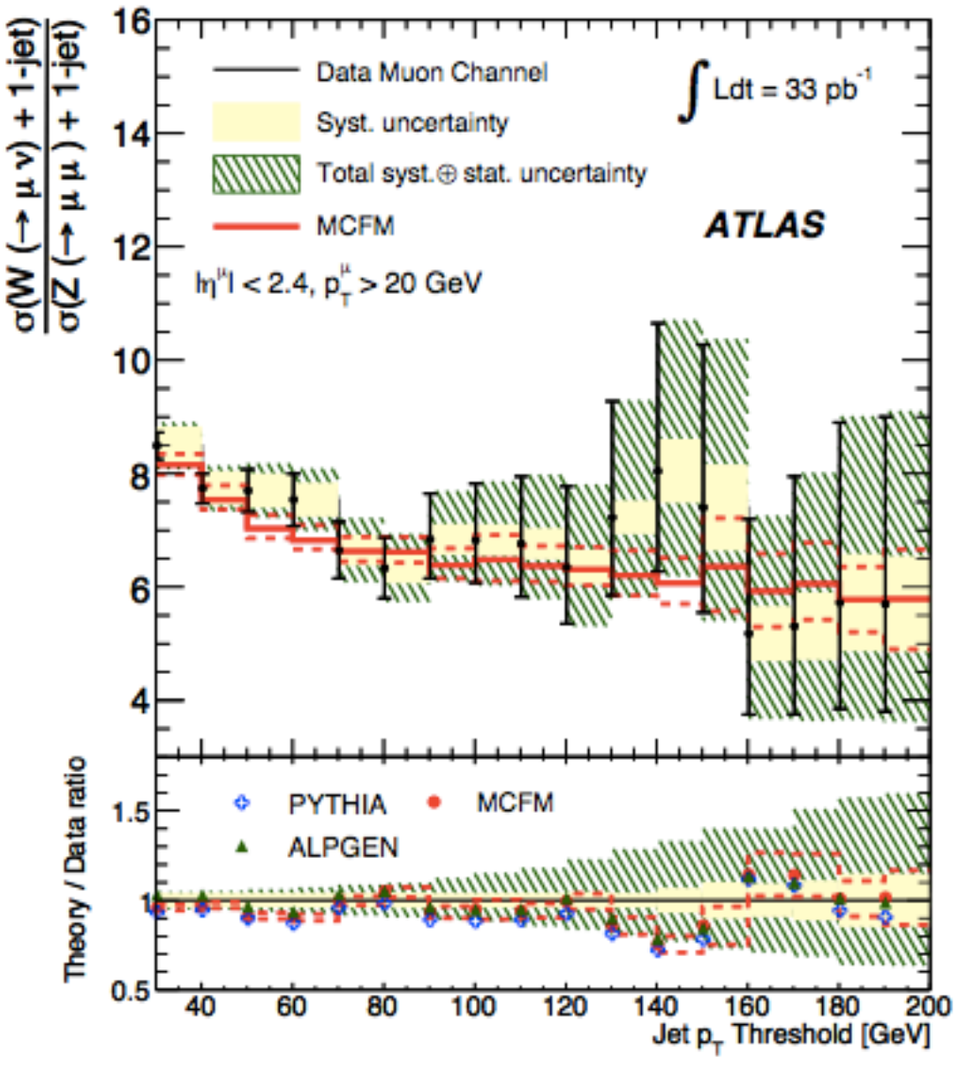
Source	SR1	SR2	SR3	SR4
JES/JER/$E_{\mathrm{T}}^{\mathrm{miss}}$	1.0	2.6	4.9	5.8
MC Z/W modelling	2.9	2.9	2.9	3.0
MC statistical uncertainty	0.5	1.4	3.4	8.9
$1 - f_{\mathrm{EW}}$	1.0	1.0	0.7	0.7
Muon scale and resolution	0.03	0.02	0.08	0.61
Lepton scale factors	0.4	0.5	0.6	0.7
Multijet BG in electron 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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- Study the behavior of the W+/W-, W+/Z, W-/Z, and W/Z ratios as a function of boson p_T and jet multiplicity
- Study the theoretical uncertainties on these ratios from;
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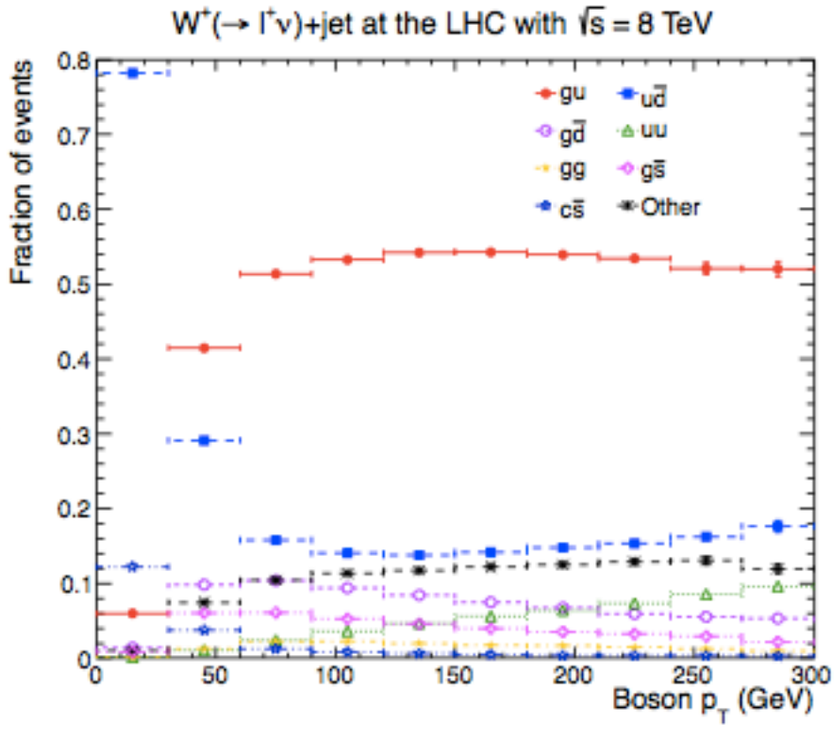
Used Madgraph at LO with N= 0,1,2,3,4 jets matched to Pythia with CTEQ6L1 PDFs

MCFM for the V+jet process with MSTW08 NLO PDFs

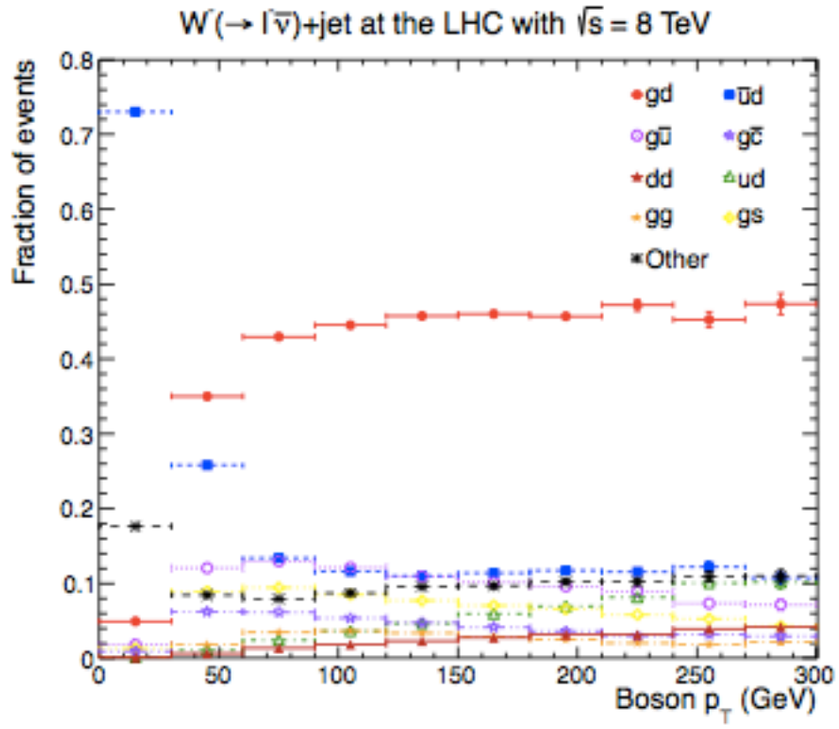
Jets defined as anti-k_T with $p_T > 10$, $|\eta| < 5$.

Flavor decomposition

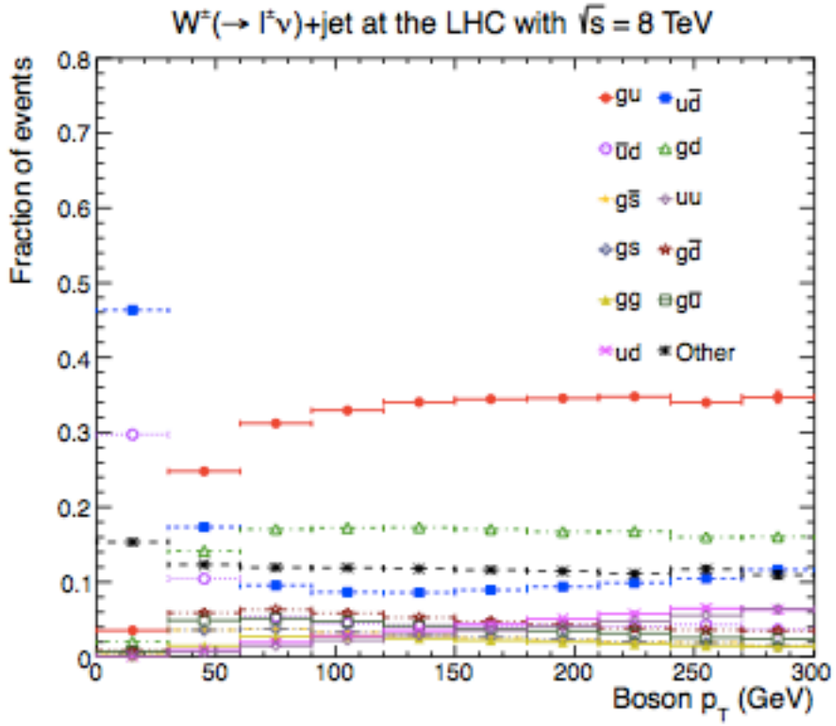
- Flavour decomposition for W+, W-, W, Z
- At high p_T, gu dominates W+ and Z, gd dominates W-.
- Flavor decomposition of W and Z very similar



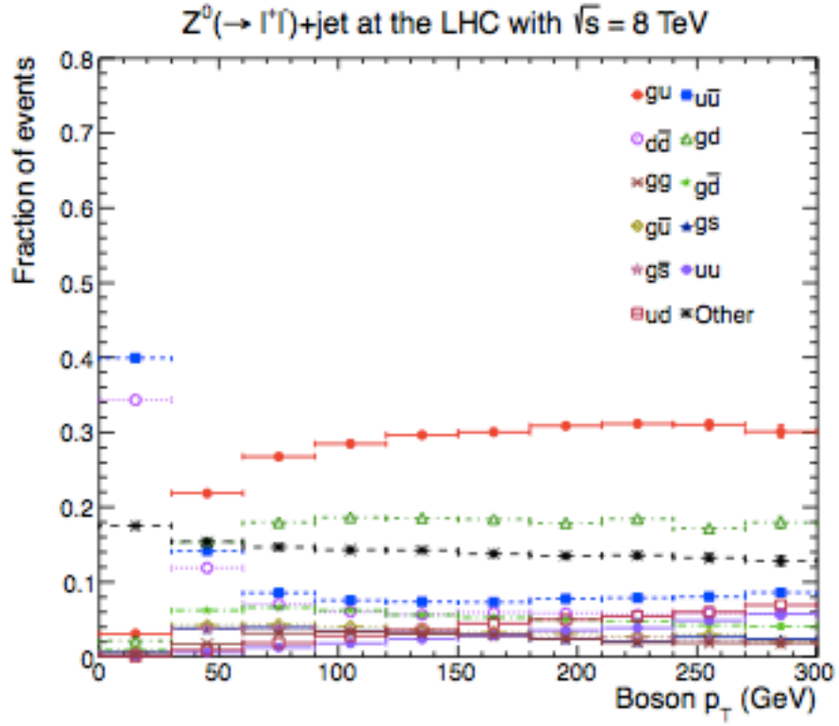
(a) W^+



(b) W^-



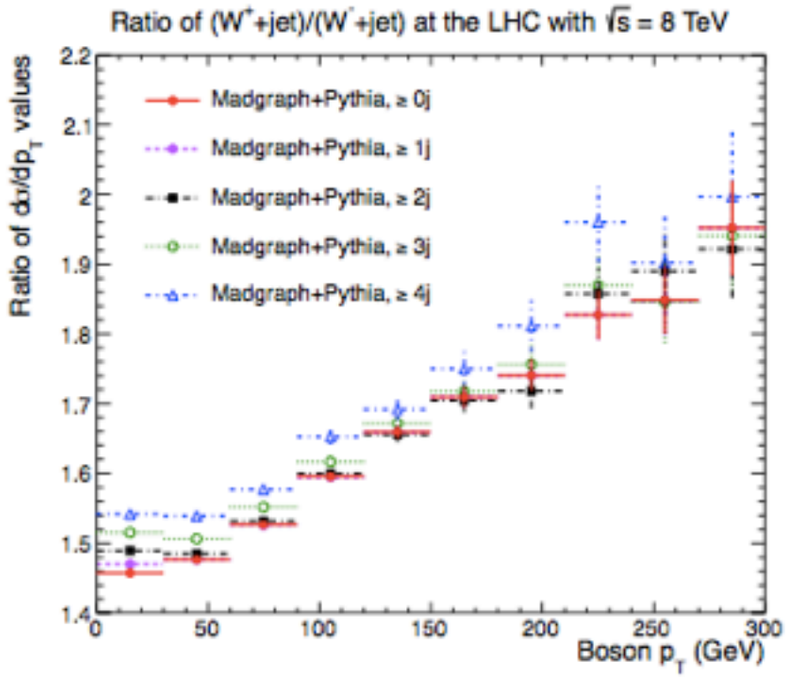
(c) $W^{\pm}$



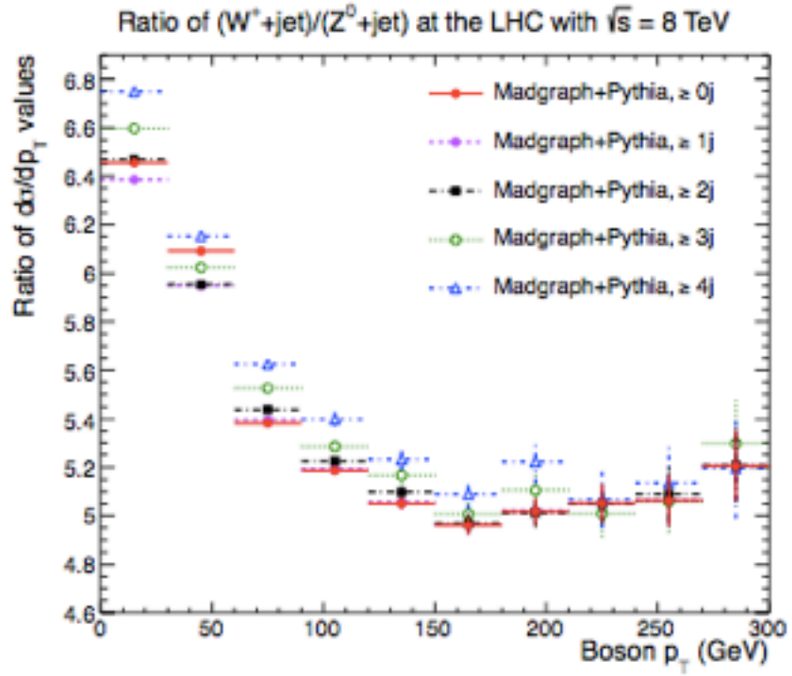
(d) Z^0

Dependence on jet multiplicity

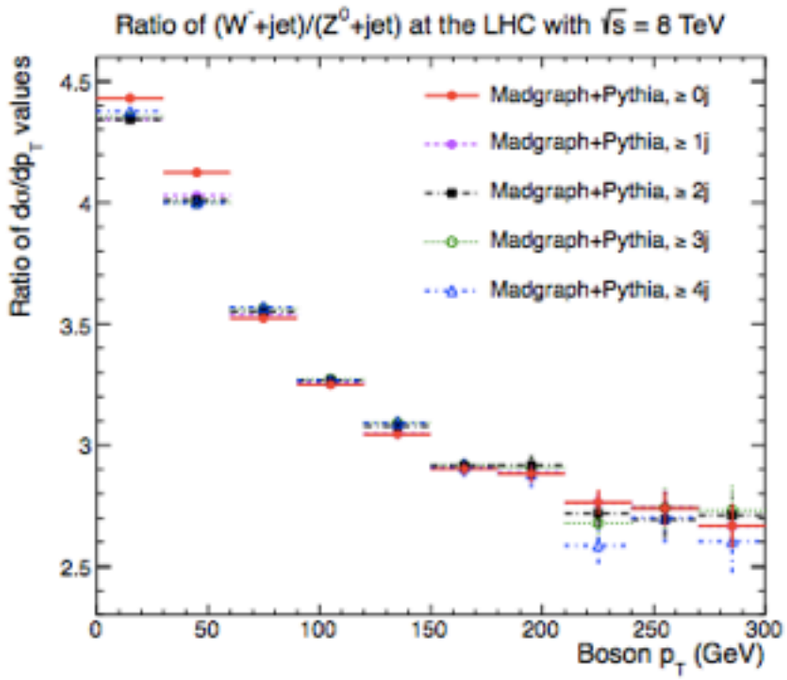
- Ratios have interesting dependence on boson p_T
- W+/W- tracks u/d ratio, increases going to higher boson p_T as higher x values are probed
- No strong dependence on jet multiplicity
- Slight increase in W+/W- with higher jet multiplicity, understood by the increase in partonic invariant mass and hence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



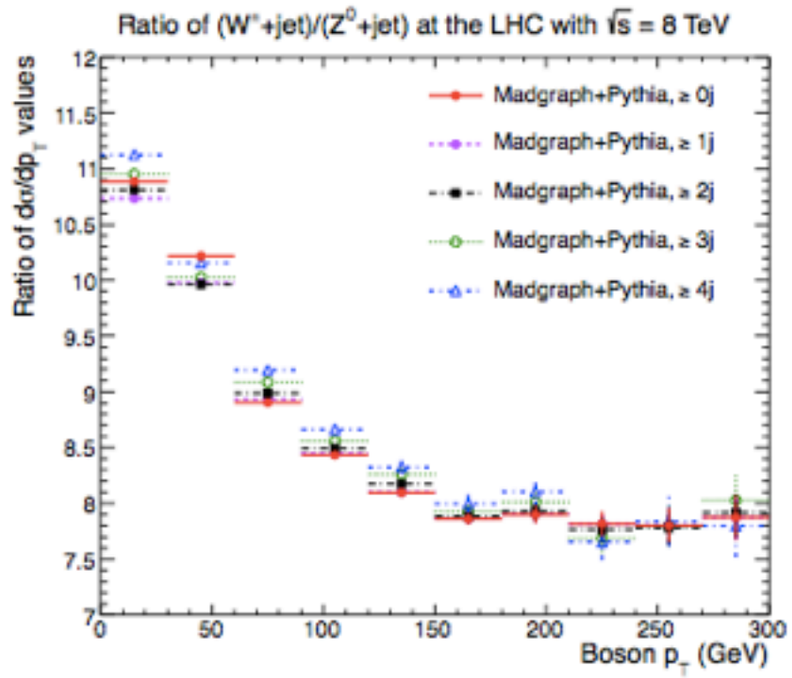
(a) W^+/W^-



(b) W^+/Z^0



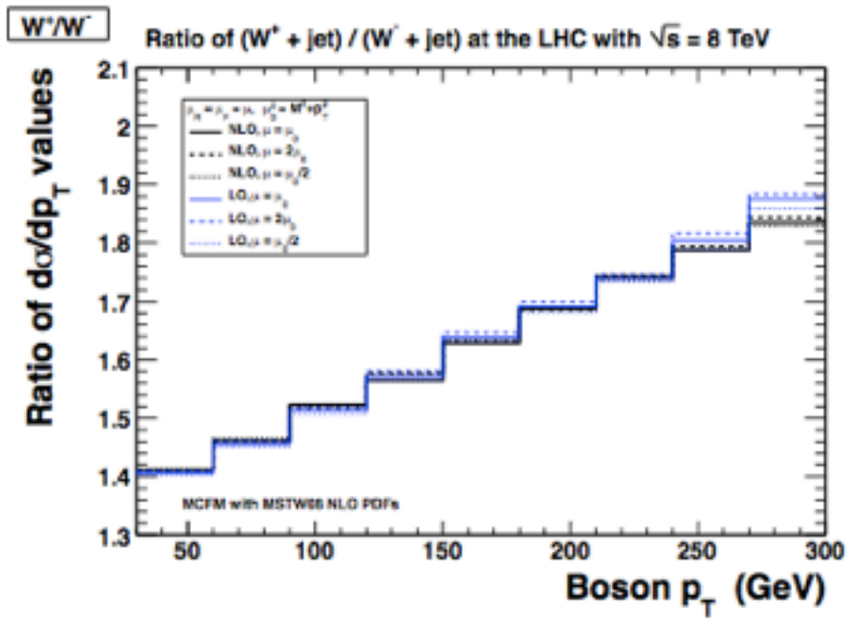
(c) W^-/Z^0



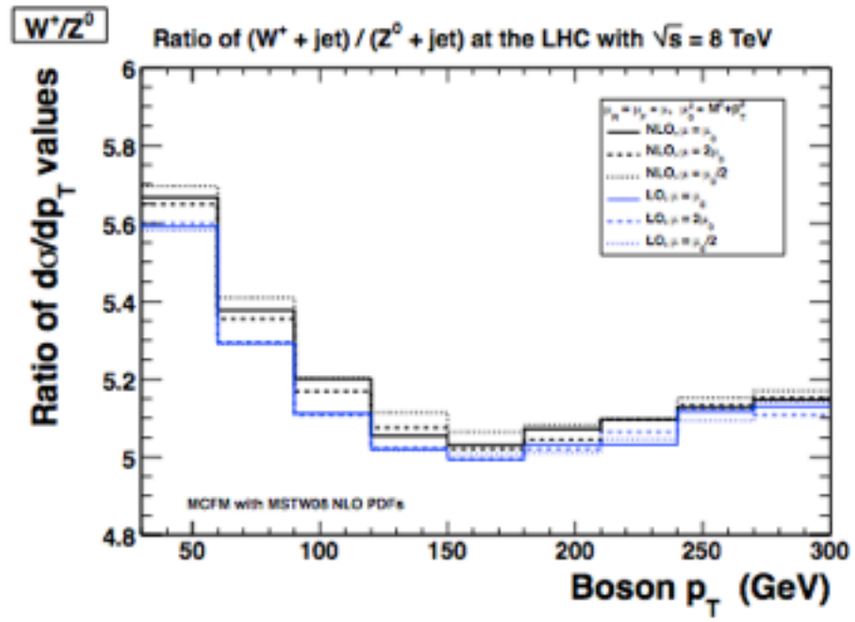
(d) $W^{\pm}/Z^0$

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.

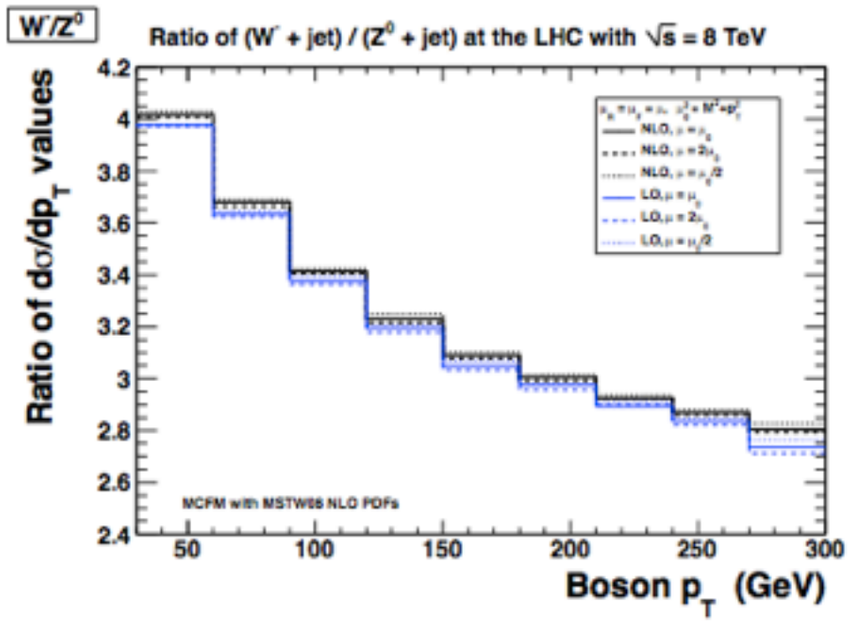


(a) W^+/W^-

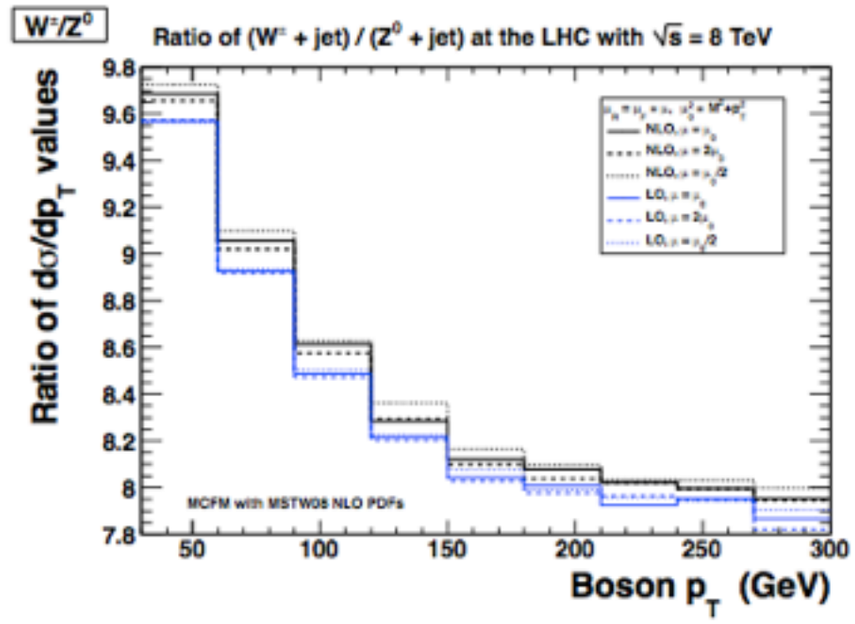


(b) W^+/Z^0

- 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



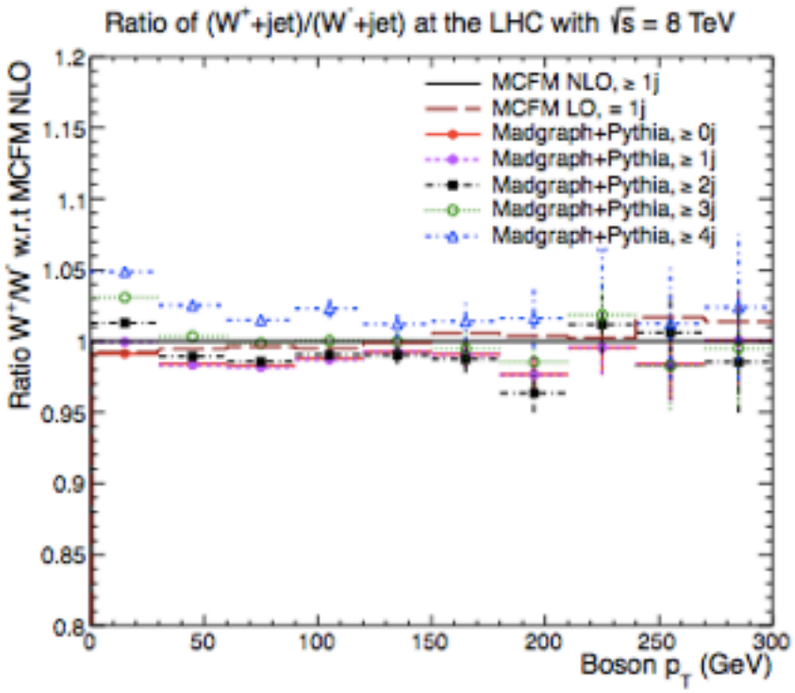
(c) W^-/Z^0



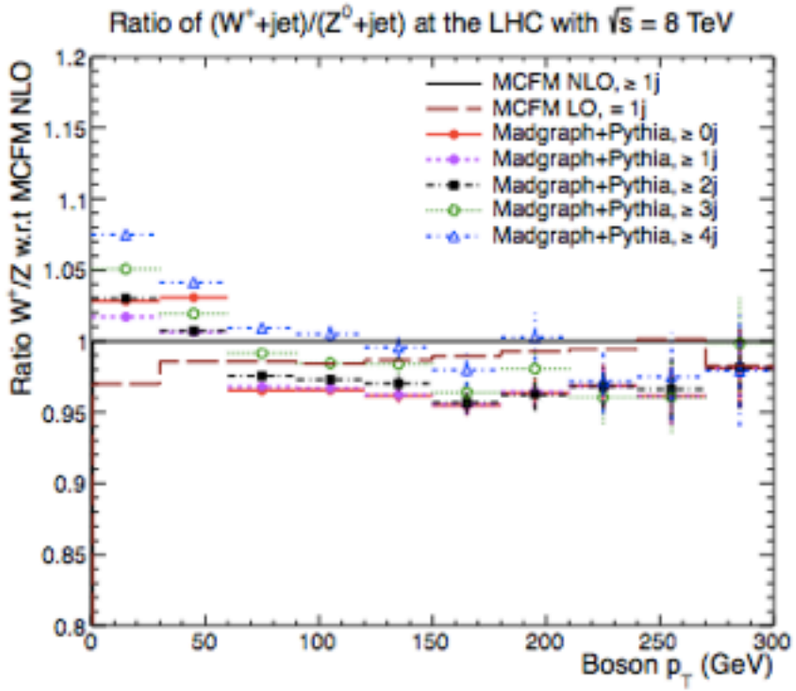
(d) $W^\pm/Z^0$

Comparing MCFM with Madgraph+Pythia

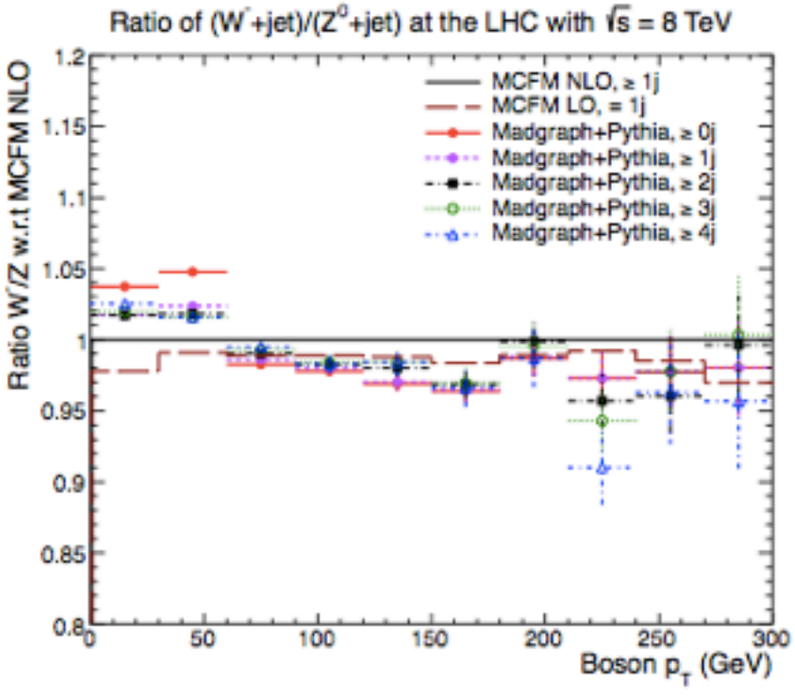
- Evaluate uncertainty from matching to a parton shower
- Compare Madgraph+pythia with NLO MCFM using same NLO PDFs
- A few percent difference at high boson p_T



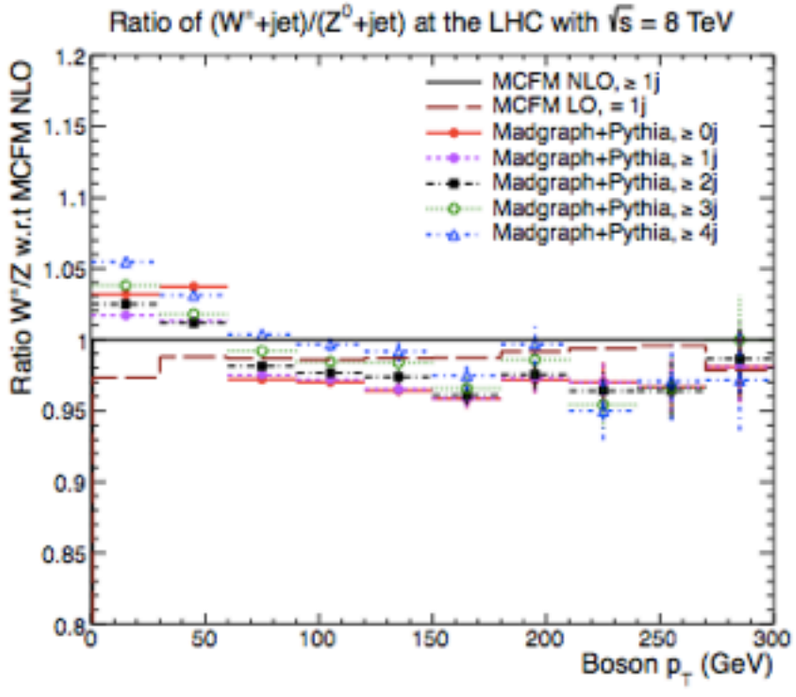
(a) W^+/W^-



(b) W^+/Z^0



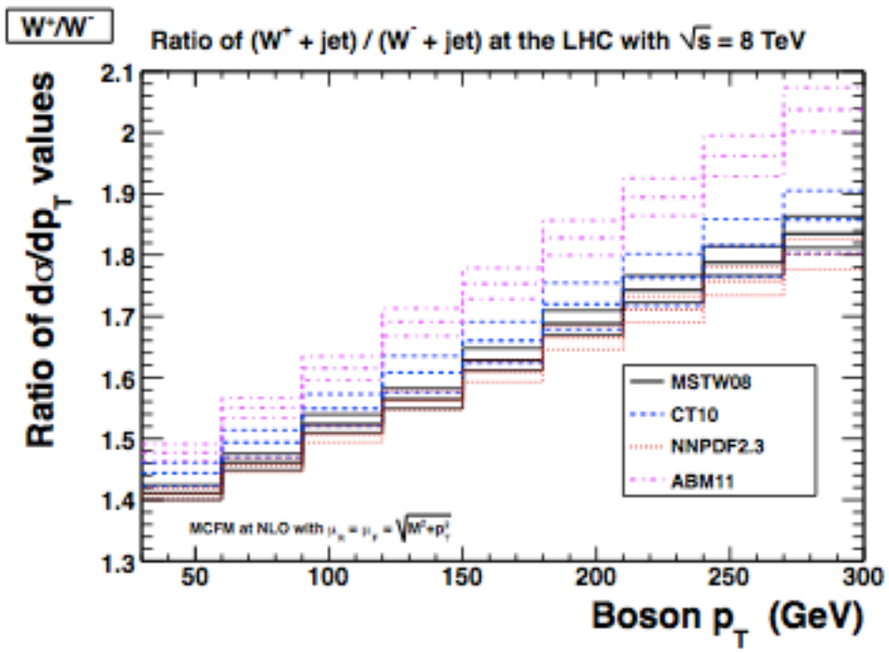
(c) W^-/Z^0



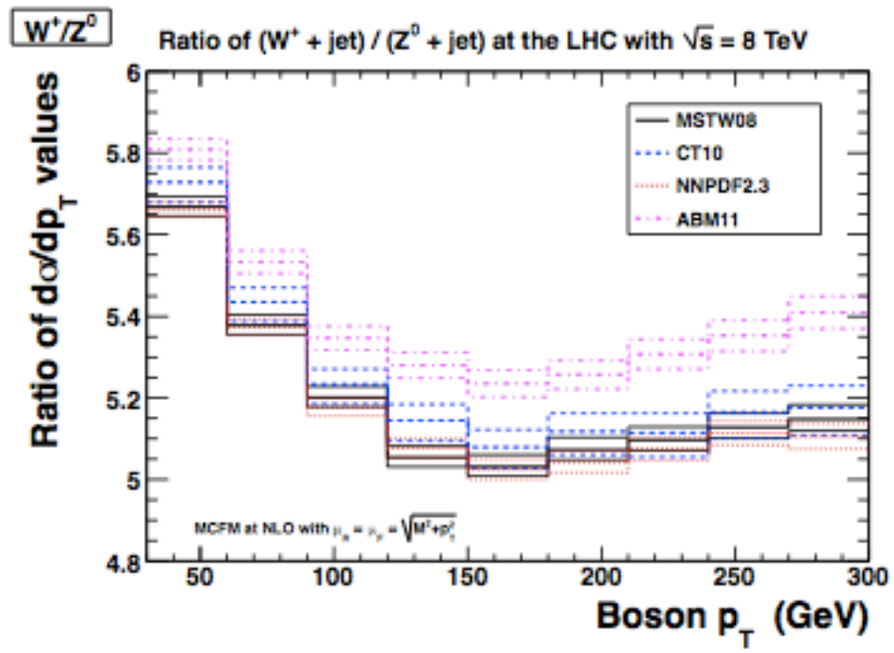
(d) $W^{\pm}/Z^0$

Dependence on PDFs

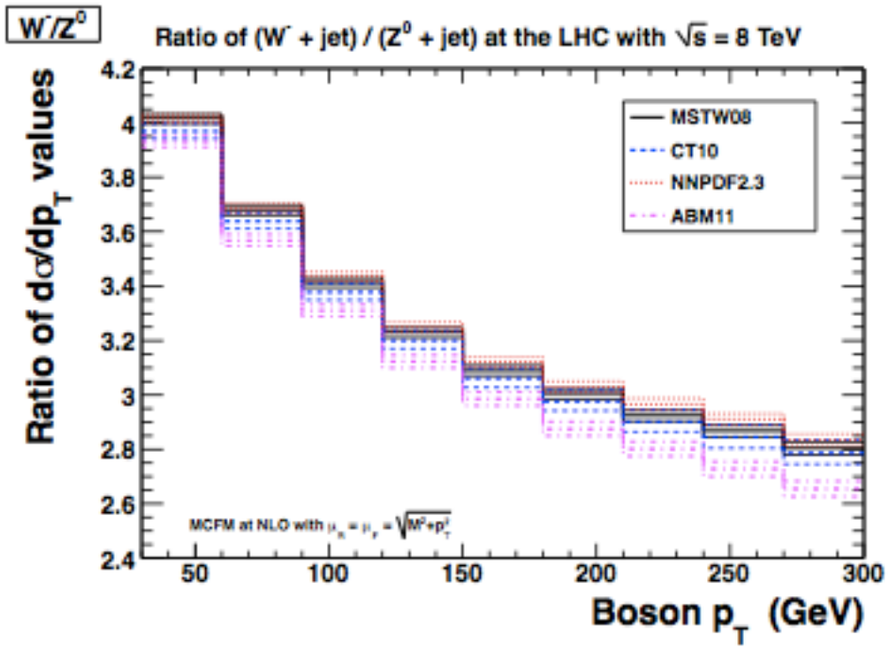
- Dependence of ratios on choice of PDFs; MSTW08, CT10, NNPDF2.3, ABM11
- W+/W- ratio most sensitive to PDFs
- PDF dependence cancels in $W^{\pm}/Z$ ratio



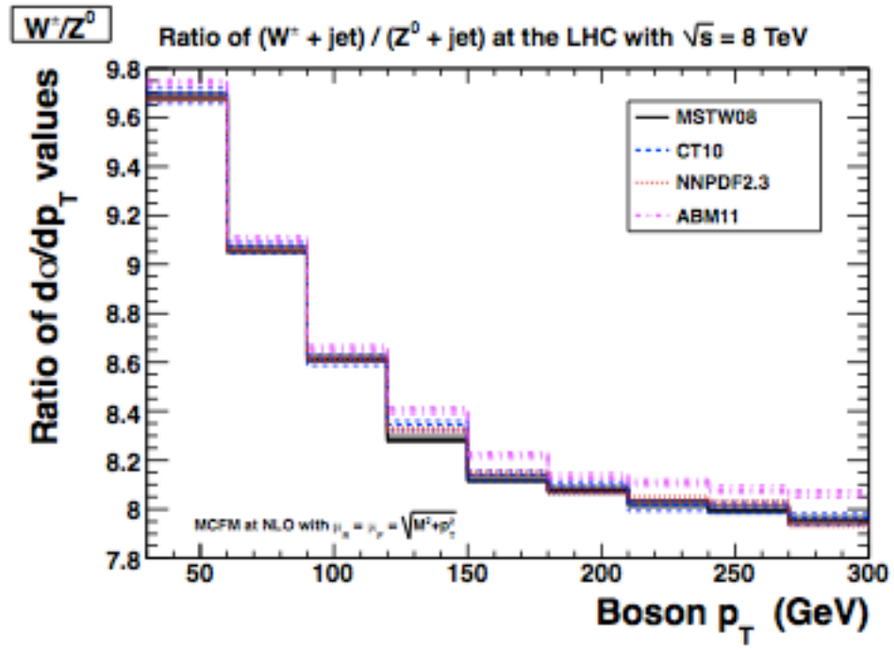
(a) W^+/W^-



(b) W^+/Z^0



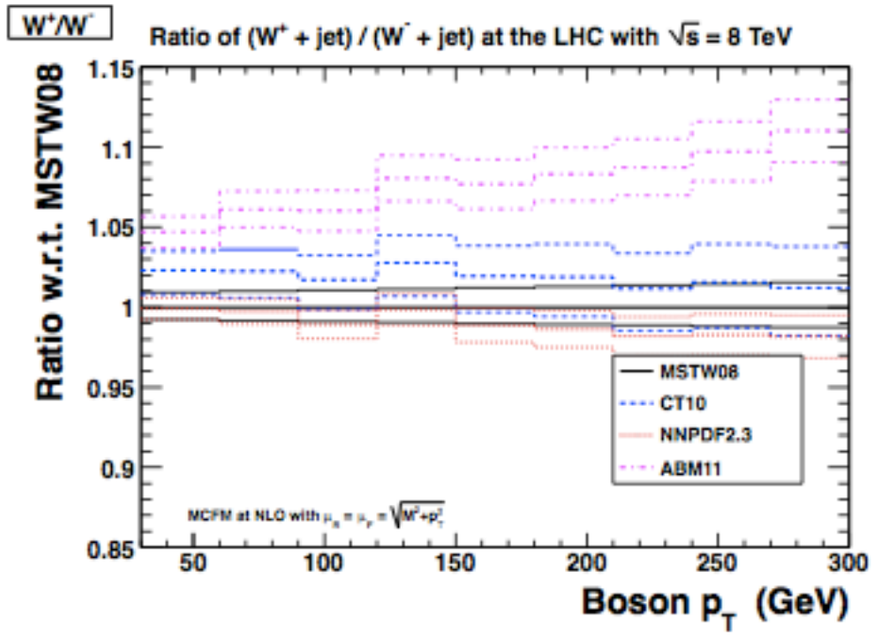
(c) W^-/Z^0



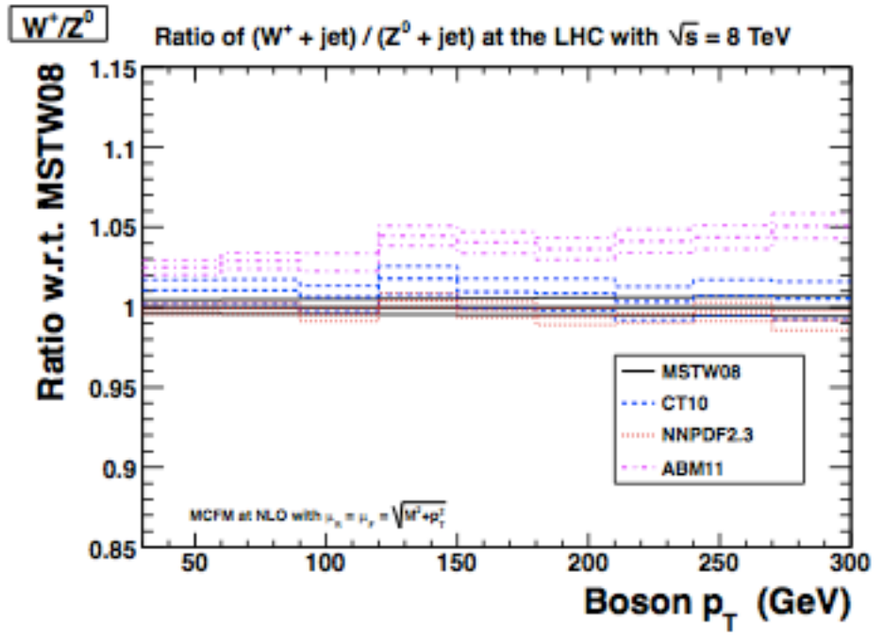
(d) $W^{\pm}/Z^0$

Dependence on PDFs

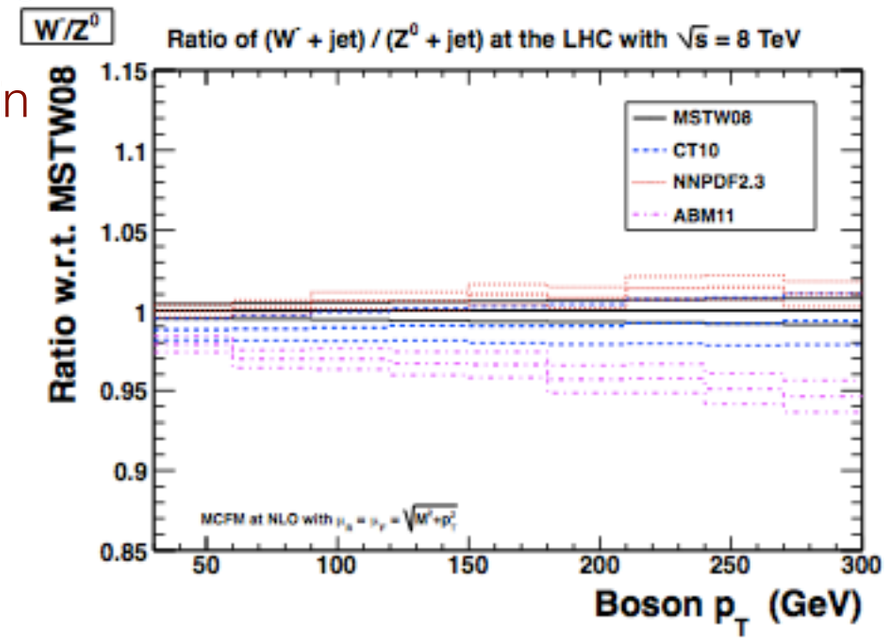
- Ratio w.r.t MSTW08
- Difference between ABM11 and MSTW08 grows with p_T, from 5% to 10%
- Separate W+/Z and W-/Z retain some sensitivity to PDFs
- PDF dependence cancels in $W^{\pm}/Z$ ratio (similar flavor decomposition for W and Z)



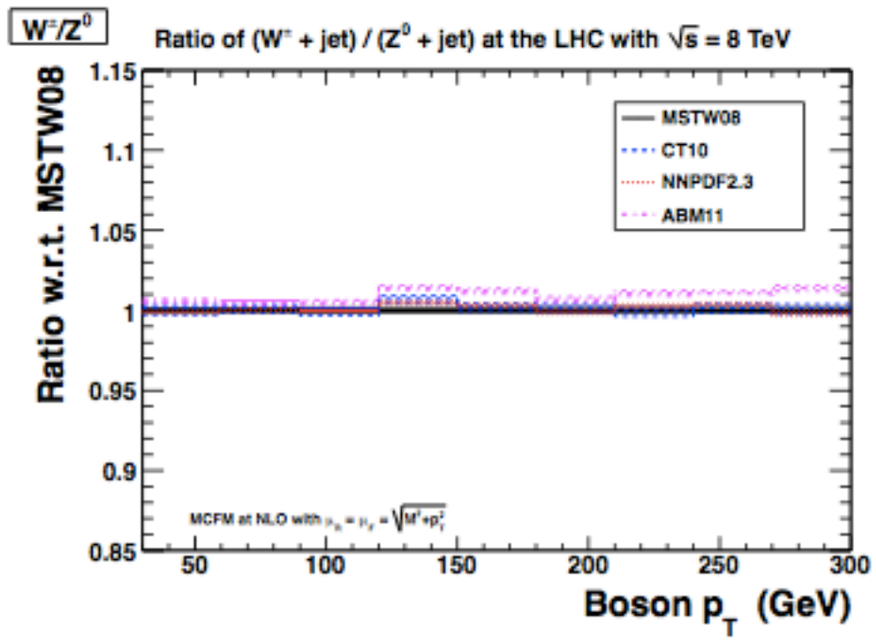
(a) W^+/W^-



(b) W^+/Z^0



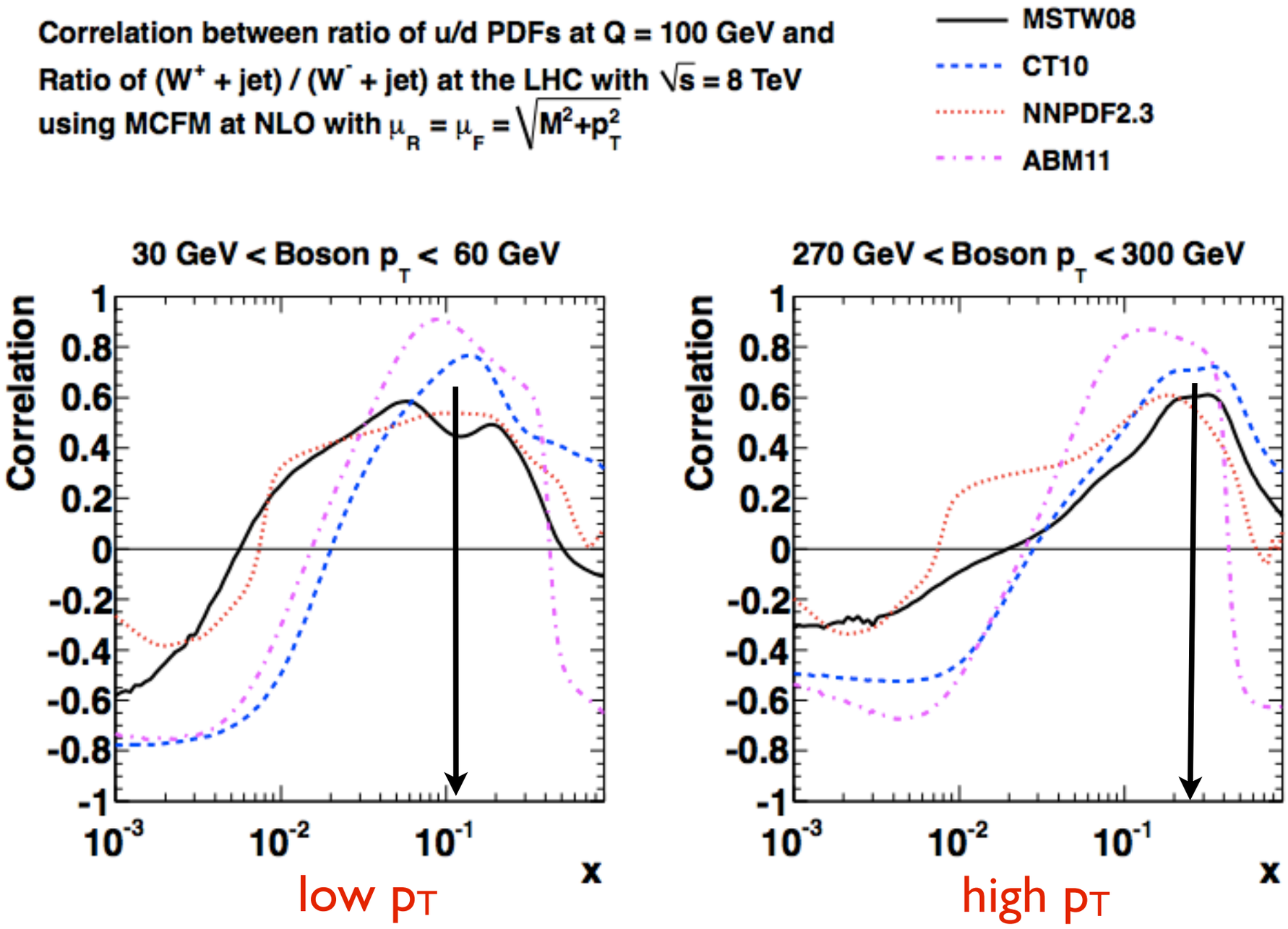
(c) W^-/Z^0



(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^+ + jet) / (W^- + jet) at the LHC with $\sqrt{s}$ = 8 TeV using MCFM at NLO with $\mu_R = \mu_F = \sqrt{M^2+p_T^2}$



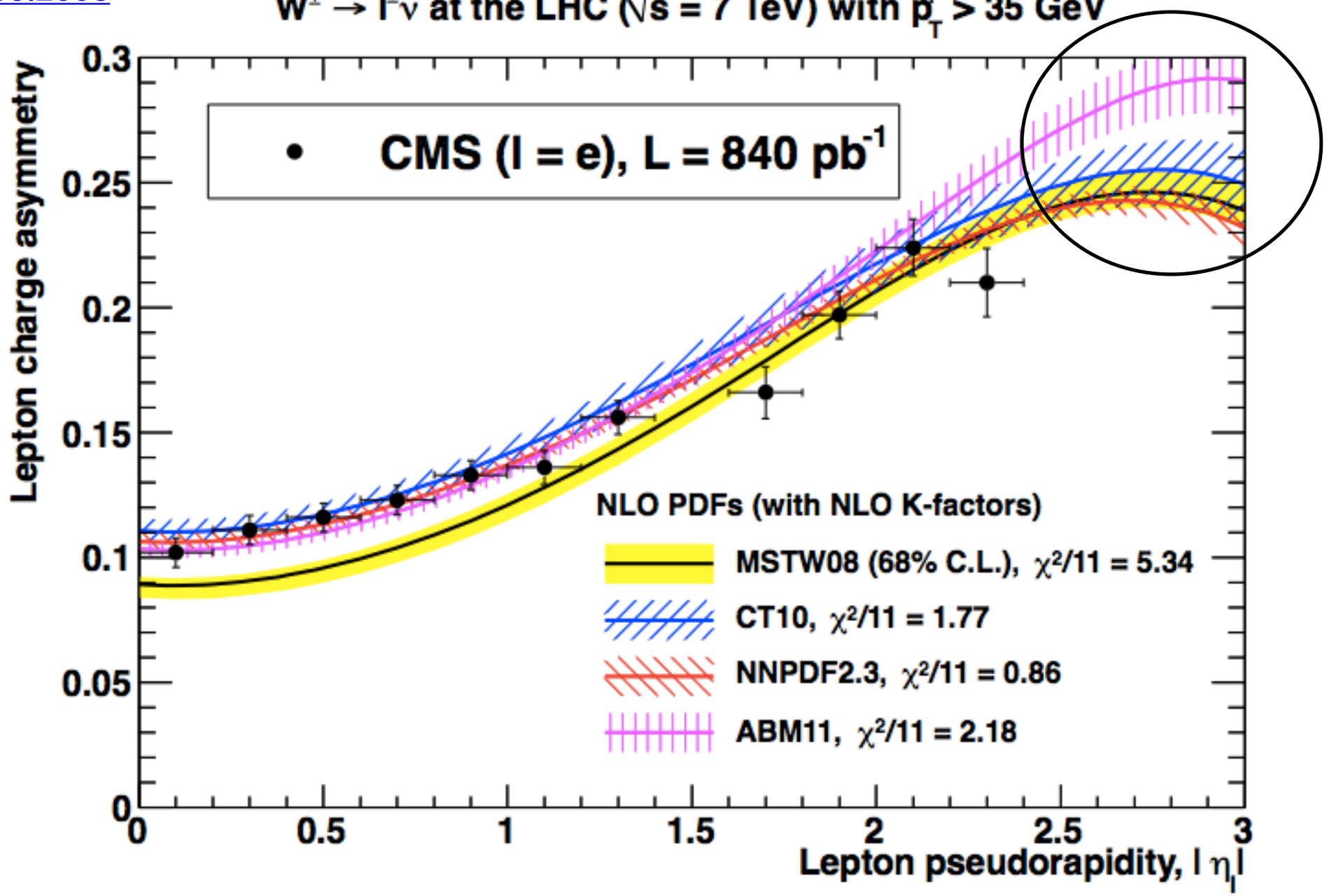
low p_T high p_T

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

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

arXiv:1206.2598

Probing higher values of x



- Measurement vs boson p_T complementary to measurement vs η_l.

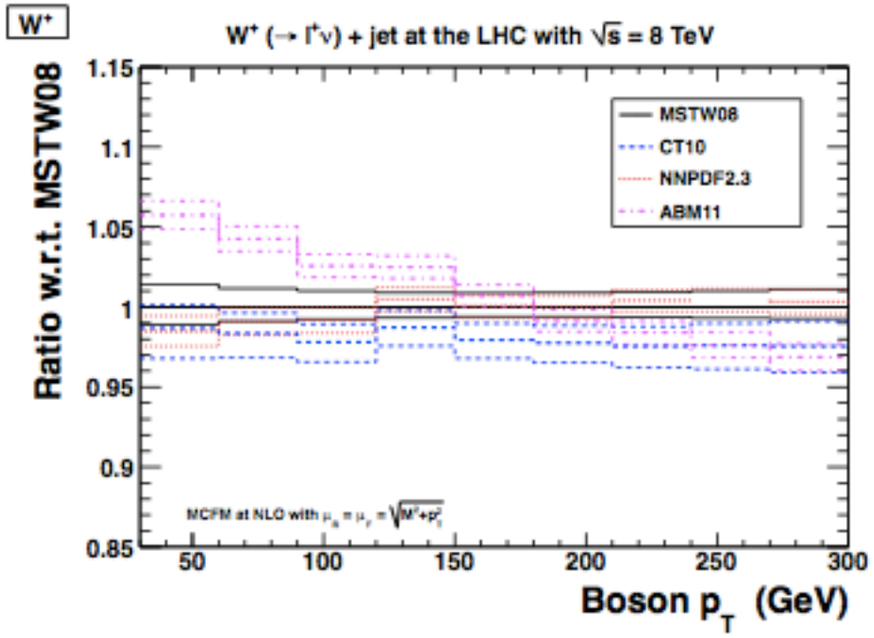
Higher order electroweak corrections

- 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.

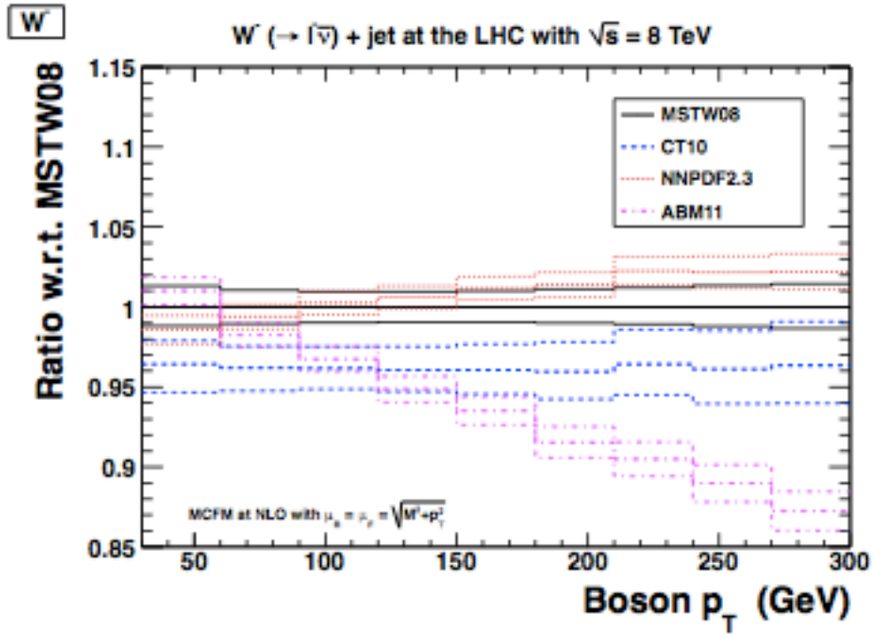
Summary

- Theoretical ratio W/Z is a key ingredient in the data-driven estimates of the $Z \rightarrow \nu\,\nu$ +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 < ~ 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.

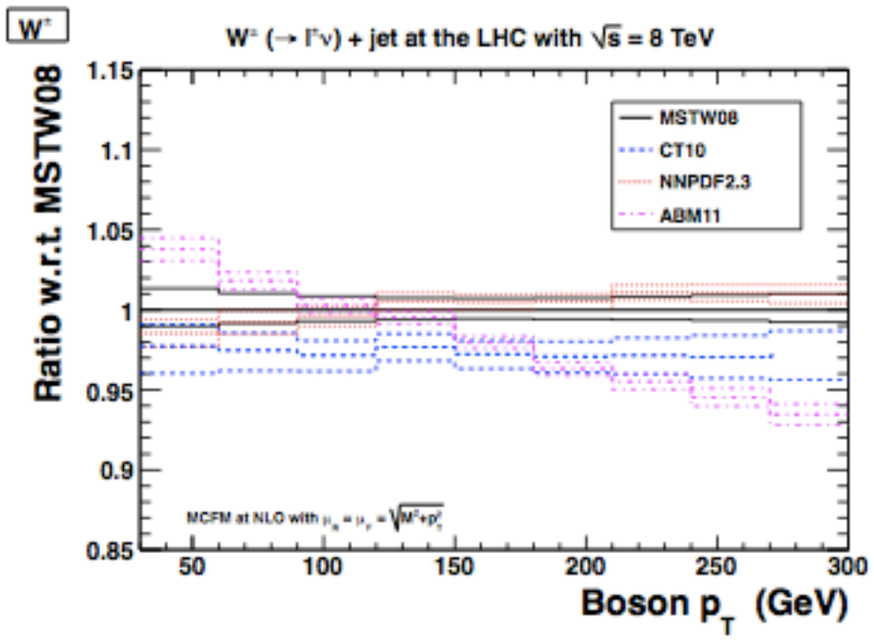
Backup



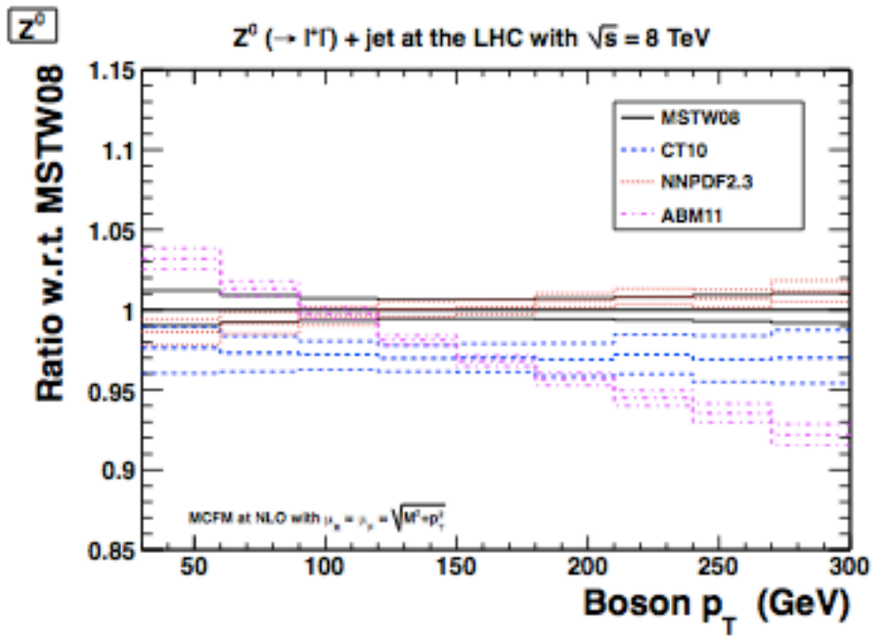
(a) W^+



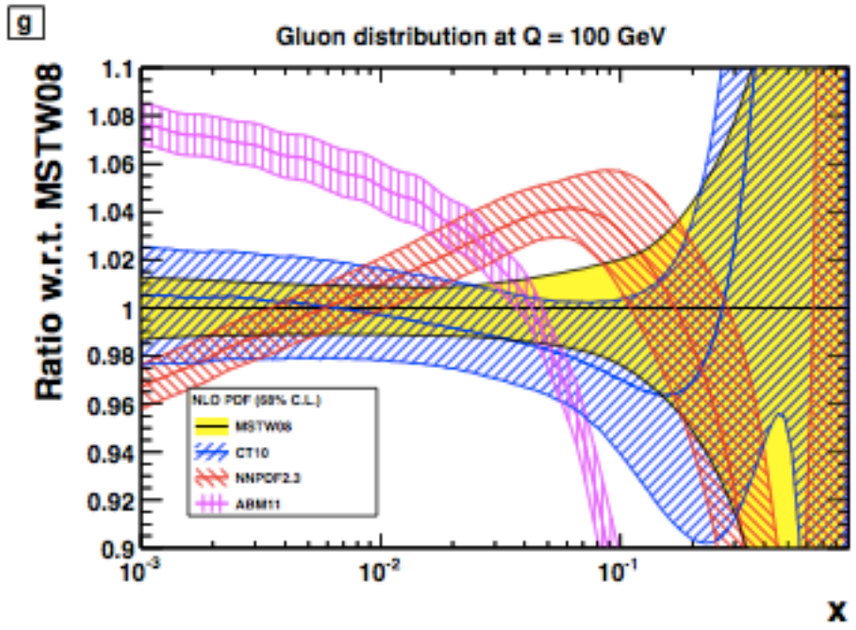
(b) W^-



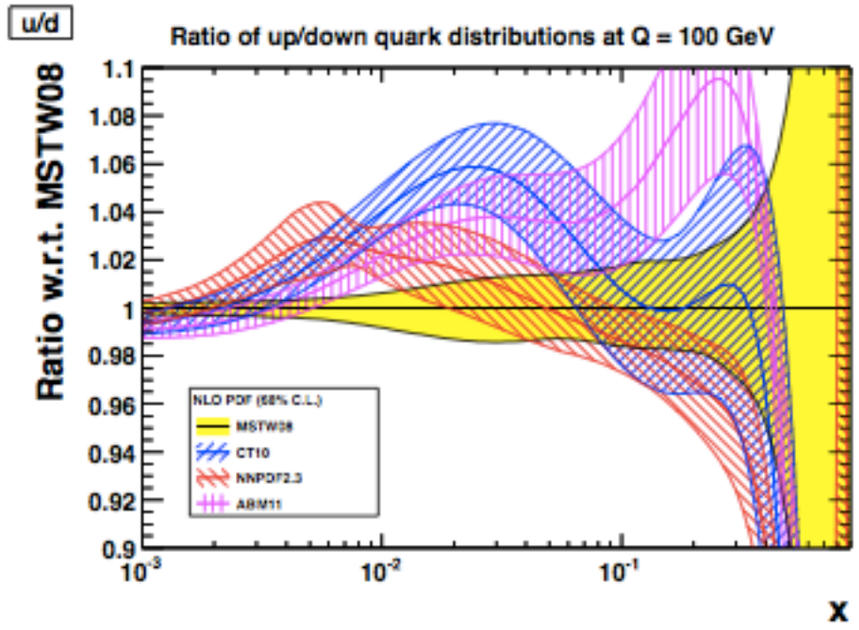
(c) $W^{\pm}$



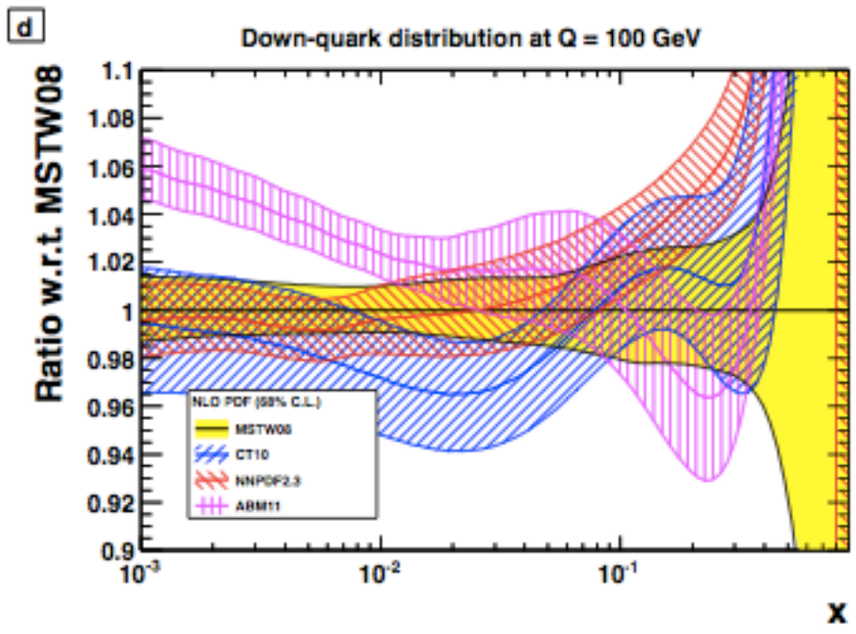
(d) Z^0



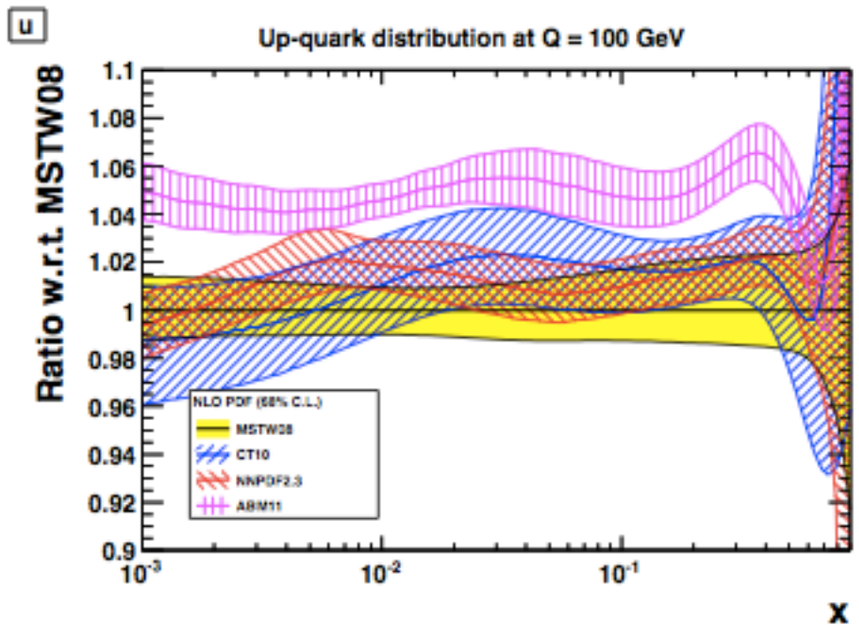
(a) Gluon distribution



(b) Ratio of up/down quark distributions



(c) Down-quark distribution



(d) Up-quark distribution