Ratios of W and Z cross sections at large boson p_T (as a constraint on PDFs and background to new physics)

Graeme Watt

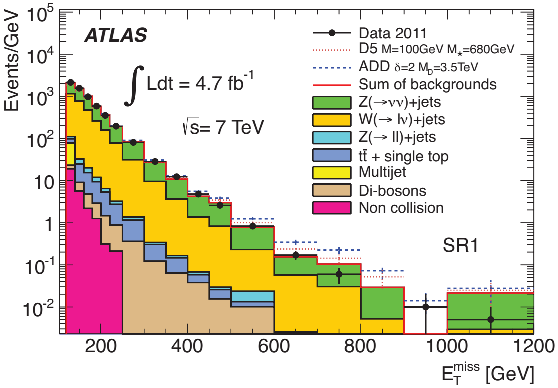
Institut für Theoretische Physik, Universität Zürich

PDF4LHC Meeting
CERN, Geneva, 17th April 2013

In collaboration with Sarah Alam Malik, arXiv:1304.2424.

$Z(\to \nu\bar{\nu})$+jets background to new physics

- Many searches for new physics (SUSY, LEDs, WIMPs, . . .) involve looking for missing transverse energy with jets.
- Major irreducible SM background is $Z(\to \nu\bar{\nu})$+jets.



[ATLAS, arXiv:1210.4491]

Data-driven methods to estimate $Z(\to \nu\bar{\nu})$+jets

Idea: Measure process X with similar kinematic properties, then correct by ratio of $Z(\to \nu\bar{\nu})$+jets to X taken from theory.

1. $Z(\to \ell\ell)$+jets. Only need to multiply by $(Z \to \nu\bar{\nu})/(Z \to \ell\ell)$ ratio of branching fractions, but large statistical uncertainty.
2. γ+jets. More statistics, but Z/γ ratio has larger theoretical uncertainties. Studied by Z. Bern *et al.* [arXiv:1106.1423, arXiv:1206.6064] ($\Rightarrow$ $< 10\%$ QCD and $< 15\%$ EW uncertainties). Also study of Z/γ ratio by S. Ask *et al.* [arXiv:1107.2803].
3. $W(\to \ell\nu)$+jets. More statistics than $Z(\to \ell\ell)$+jets, but $t\bar{t}$ background. Smaller theoretical uncertainties on Z/W ratio.

All three methods have relative advantages and disadvantages.
$\Rightarrow$ Best to use all three methods to cross-check each other.

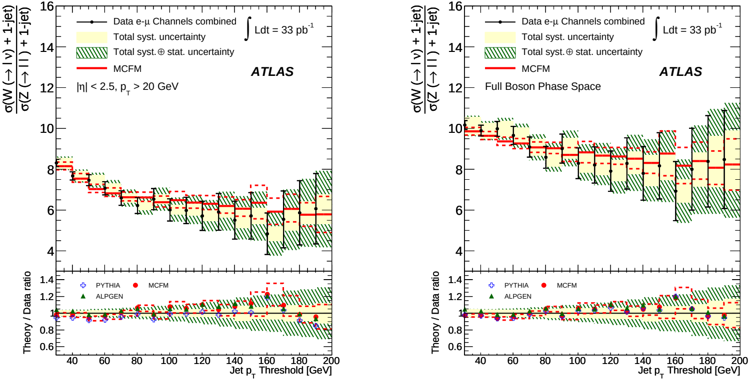
Uncertainties on background estimates [ATLAS, arXiv:1210.4491]

Relative systematic uncertainties for all signal regions (in percent):

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

- "MC Z/W modelling" from comparing ALPGEN and SHERPA.

Ratio of W+1-jet to Z+1-jet [ATLAS, arXiv:1108.4908]



- Dedicated ratio measurement validates theory predictions.
- SUSY searches typically use event variables such as $\not\!\!H_{\mathrm{T}}$, a vector sum of the jets above a certain p_T threshold [CMS, arXiv:1106.4503], numerically close to boson p_T for V+jets.

Goals of our study [S. Malik, G.W., arXiv:1304.2424]

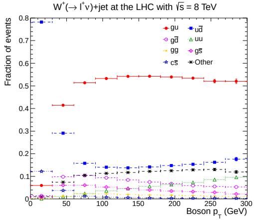
- Examine the behaviour of various cross-section ratios (W^+/W^-, W^+/Z, W^-/Z and $W^\pm/Z$) versus boson p_T.
- Study the theoretical uncertainties on these ratios at large values of the boson p_T in more detail than previously.
- Motivate a dedicated measurement to validate theoretical predictions (and possibly help to reduce uncertainties).
- Investigate if we can learn anything new about PDFs from these ratios measured as a function of the boson p_T.

Codes used for $W^+(\to \ell^+\nu)$, $W^-(\to \ell^-\bar{\nu})$ and $Z^0(\to \ell^+\ell^-)$

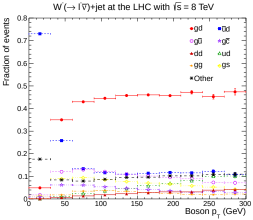
$p_T^{\rm jet} > 10$ GeV, $|\eta^{\rm jet}| < 5$, anti-k_T jets with $R = 0.5$, no lepton cuts.

- MADGRAPH at LO with $N = \{0, 1, 2, 3, 4\}$ jets matched to PYTHIA (using the MLM prescription) and CTEQ6L1 PDFs.
- MCFM for the V+jet process with MSTW08 NLO PDFs.

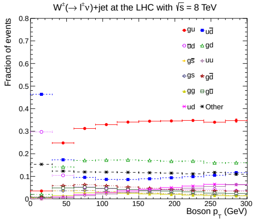
Flavour decomposition using MADGRAPH+PYTHIA



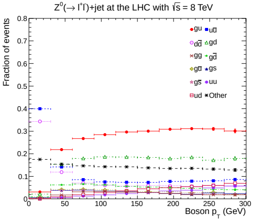
$W^+ \Rightarrow gu$



$W^- \Rightarrow gd$

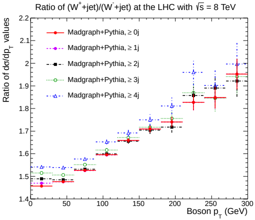


$W^\pm \Rightarrow gu, gd$

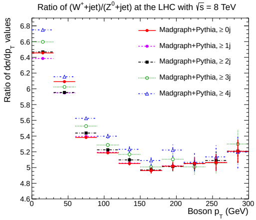


$Z^0 \Rightarrow gu, gd$

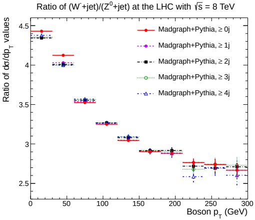
Dependence of cross-section ratios on jet multiplicity



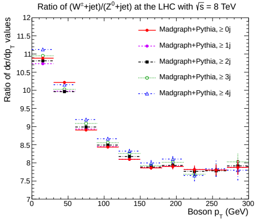
W^+/W^-



W^+/Z^0

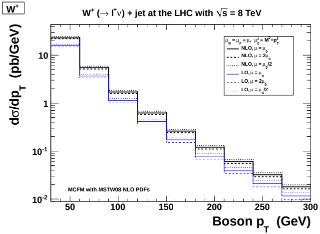


W^-/Z^0

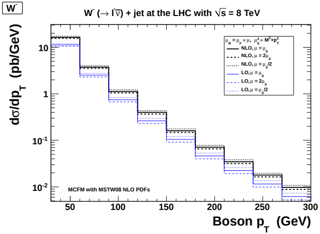


$W^\pm/Z^0$

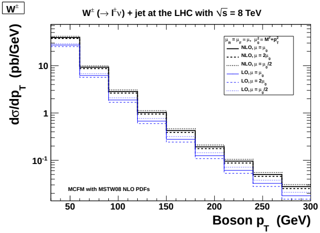
Differential cross sections, $\mathrm{d}\sigma/\mathrm{d}p_T$, for the V+jet process



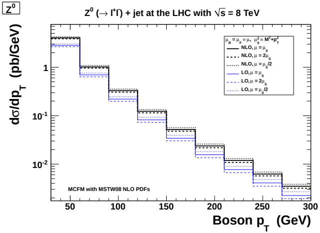
W^+



W^-

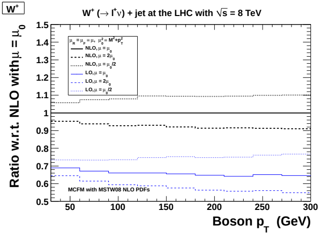


$W^\pm$

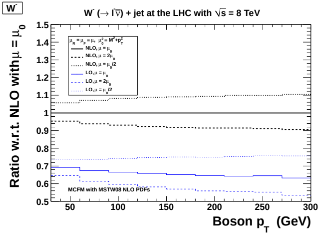


Z^0

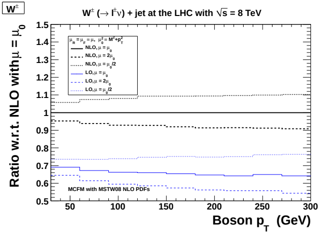
$\mathrm{d}\sigma/\mathrm{d}p_T$, normalised to the central NLO prediction



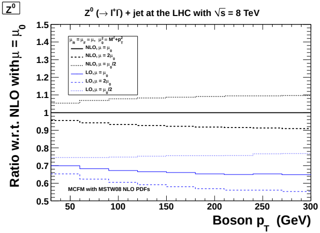
W^+



W^-

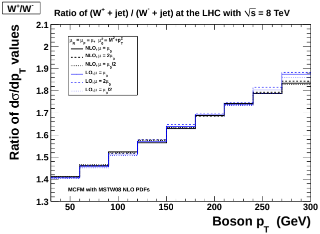


$W^\pm$

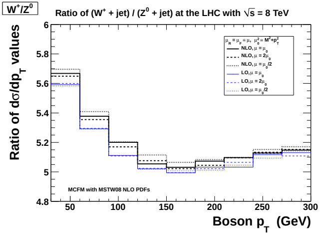


Z^0

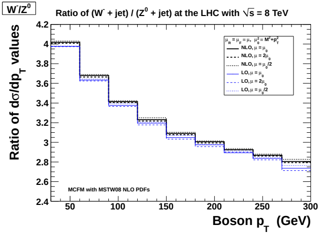
Ratios of boson p_T distributions for the V+jet process



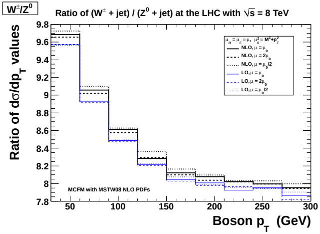
W^+/W^-



W^+/Z^0

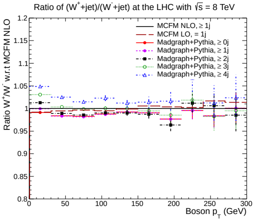


W^-/Z^0

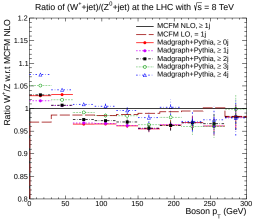


$W^\pm/Z^0$

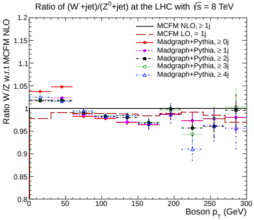
Compare MCFM (CTEQ6L1) and MADGRAPH+PYTHIA



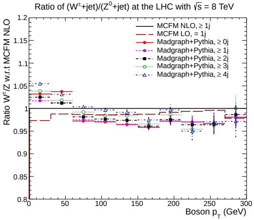
W^+/W^-



W^+/Z^0

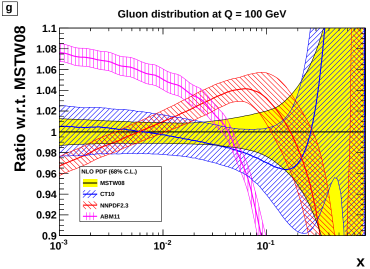


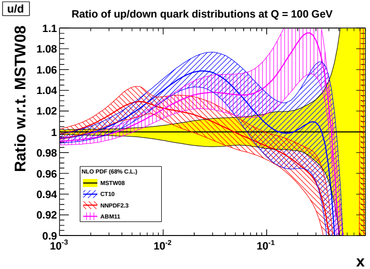
W^-/Z^0



$W^\pm/Z^0$

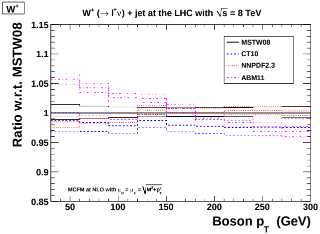
Gluon distribution and u/d ratio versus x



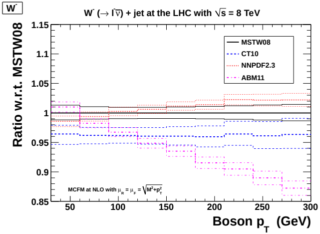


- Consider four NLO PDF sets (**MSTW08**, CT10, NNPDF2.3, ABM11) with $\alpha_S(M_Z^2) = \{0.1202, 0.1180, 0.1190, 0.1180\}$.
- Envelope of predictions using **MSTW08**, CT10 and NNPDF2.3 includes implicit $\alpha_S(M_Z^2) \approx 0.119 \pm 0.001$ uncertainty.
- x dependence of gluon $\Rightarrow$ p_T dependence of $\mathrm{d}\sigma/\mathrm{d}p_T$.
- x dependence of u/d ratio $\Rightarrow$ p_T dependence of W^+/W^- ratio.

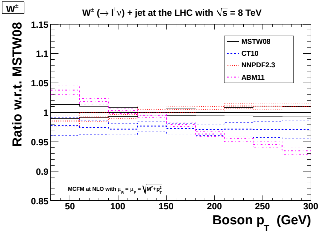
PDF dependence of differential cross sections, $\mathrm{d}\sigma/\mathrm{d}p_T$



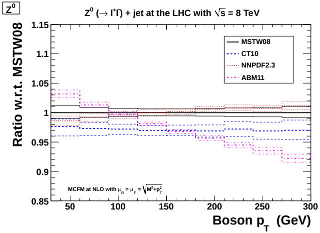
W^+



W^-

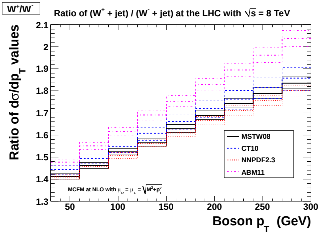


$W^\pm$

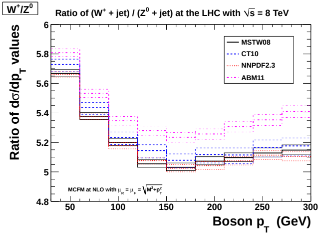


Z^0

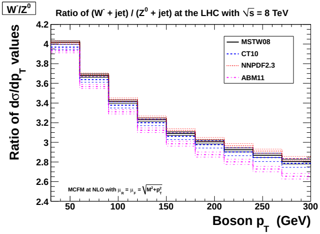
PDF dependence of ratios of boson p_T distributions



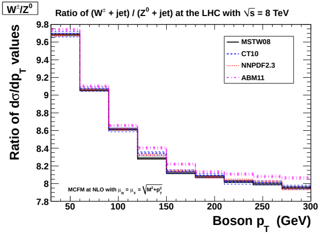
W^+/W^-



W^+/Z^0

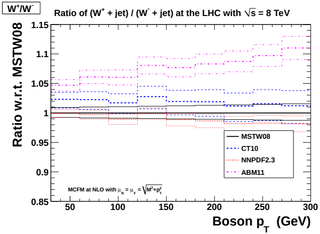


W^-/Z^0

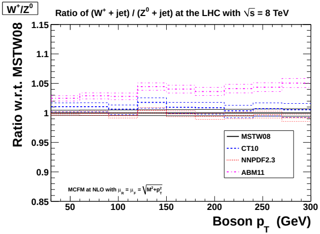


$W^\pm/Z^0$

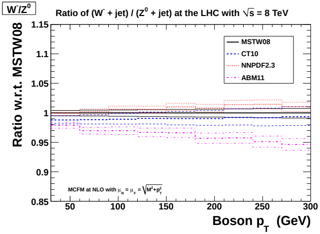
PDF dependence of ratios relative to MSTW08



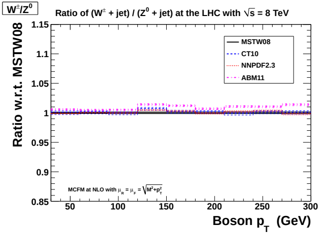
W^+/W^-



W^+/Z^0

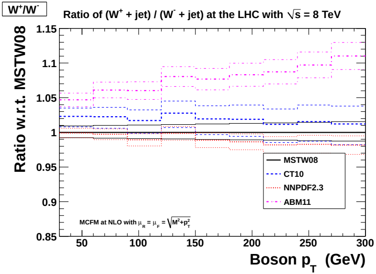


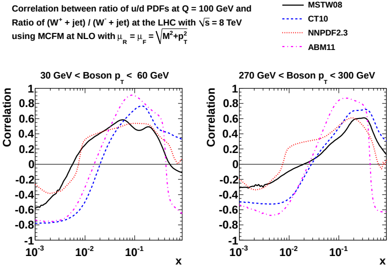
W^-/Z^0

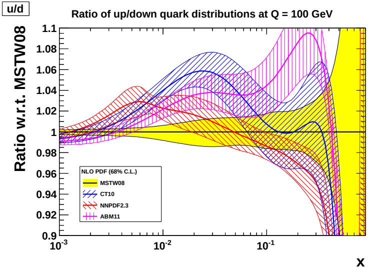


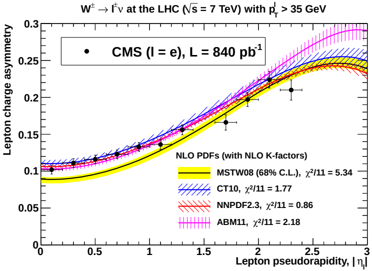
$W^\pm/Z^0$

Potential PDF constraints from W^+/W^- versus p_T^W







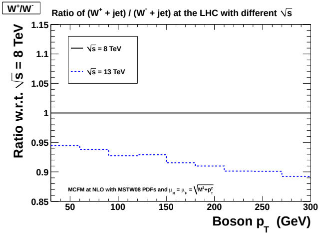


- Measurements versus p_T^W and versus $|\eta_\ell|$ are complementary.

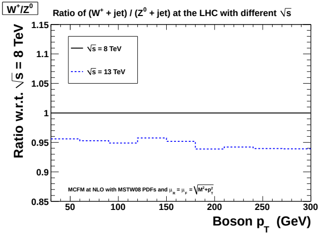
Higher-order electroweak corrections

- Effect of large virtual electroweak Sudakov logarithms of $\hat{s}/M_V^2$ can reach up to a few tens of percent for $\mathrm{d}\sigma/\mathrm{d}p_T$ at very large boson p_T [Denner *et al.*, arXiv:0906.1656, arXiv:1103.0914].
- Effect cancels in W^+/W^- ratio [Kühn *et al.*, arXiv:0708.0476].
- Decrease in W^+/Z and W^-/Z (and hence $W^\pm/Z$) ratios by 4% at boson $p_T = 1$ TeV and by 7% at $p_T = 2$ TeV at the 14 TeV LHC [Kühn *et al.*, arXiv:0708.0476].
- Smaller electroweak corrections 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 [Kühn *et al.*, hep-ph/0508253].
- Potential partial cancellation from real emission of soft W and Z bosons for sufficiently inclusive measurements [Baur, hep-ph/0611241; Stirling, Vryonidou, arXiv:1212.6537], but small effect expected for typical experimental cuts.

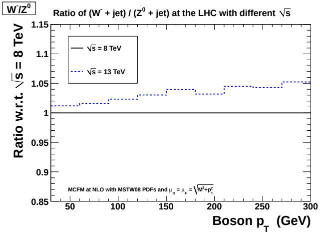
Double ratios at different $\sqrt{s}$ [see Mangano, Rojo, arXiv:1206.3557]



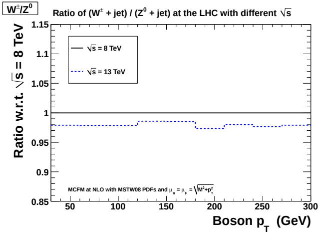
W^+/W^-



W^+/Z^0



W^-/Z^0



$W^\pm/Z^0$

Summary [S. Malik, G.W., arXiv:1304.2424]

- Theoretical $(W^{\pm} + \mathrm{jets})/(Z + \mathrm{jets})$ ratio is a key ingredient in data-driven estimates of the $Z(\to \nu\bar{\nu}) + \mathrm{jets}$ background.
- Presented detailed study of theoretical uncertainties on W^+/W^-, W^+/Z, W^-/Z and $W^{\pm}/Z$ ratios versus boson p_T.
- Theoretical QCD and EW uncertainties on $W^{\pm}/Z$ ratio both smaller than for γ/Z ratio: estimate QCD uncertainties to be less than 5%. Useful to check using NLO calculations for higher jet multiplicities, preferably with matching to a parton shower.
- $\mathrm{d}\sigma/\mathrm{d}p_T$ can potentially constrain gluon, but large higher-order QCD uncertainties (need NNLO) and electroweak corrections.
- W^+/W^- ratio measured as a function of p_T^W has negligible uncertainties from higher-order QCD and EW, and hence can constrain u/d ratio in a complementary region of x to the $W(\to \ell\nu)$ charge asymmetry measured as a function of η_ℓ.