

Future of V +jets physics theory programme

Marek Schönherr

IPPP, Durham University



THE
ROYAL
SOCIETY

Future of V +jets physics theory programme

There is no V +jets theory programme.

However, there are individuals who choose to work on related topics from time to time.

Future of V +jets physics theory programme

There is no V +jets theory programme.

However, there are individuals who choose to work on related topics from time to time.

Future of V+jets physics theory programme

There are various aspects:

fixed-order calculations ✓

analytic resummations ✓

parton showers and event generators ✗ → Frank's talk

Disclaimer: small and biased selection, many more interesting developments!

Overview

① Current status

② Future developments

Current status

① Current status

② Future developments

Current status

There are two aspects of vector boson production that are typically treated separately by experiments, but are not so disjoint in the theory world.

Inclusive W and Z production:

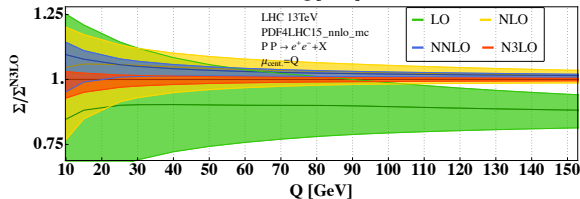
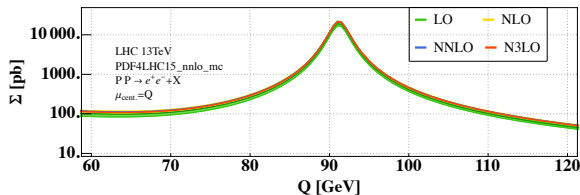
- $N^3\text{LO}_{\alpha_s} + N^2\text{LO}_{\alpha_s\alpha} + \text{NLO}_\alpha$ inclusive cross section
- $(N^3\text{LL}' + N^2\text{LO})_{\alpha_s} + (\text{NLL} + \text{NLO})_\alpha$ q_\perp spectrum

$W/Z/\gamma$ production in association with jets:

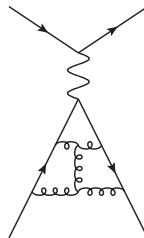
- $N^2\text{LO}_{\alpha_s} + \text{NLO}_\alpha$ $V+j$ observables
- $\text{NLO}_{\alpha_s} + \text{NLO}_\alpha$ $V+2,(3)j$ observables
- $\text{NLO}_{\alpha_s} + \text{LO}_\alpha$ $V+4,(5)j$ observables
- $\text{LO}_{\alpha_s} + \text{LO}_\alpha$ $V+6,7,8,(9)j$ observables
- polarised cross sections (V pol.) tricky, not clear gain in nominal accuracy is not off-set by loss of off-shell effects

Current status – inclusive cross section

Duhr, Dulat, Mistlberger '20; Duhr, Mistlberger '21; Chen et.al. '21, '22



$$pp \rightarrow l^+l^- + X$$



example diagram

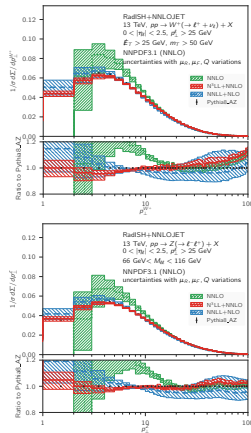
Current status – $p_T(V)$ distribution

Bizon et.al. '19; Camarda, Cieri, Ferrera '21; Ju, MS '21

Small- q_T resummation

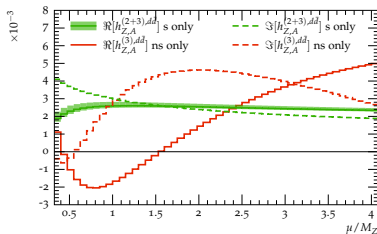
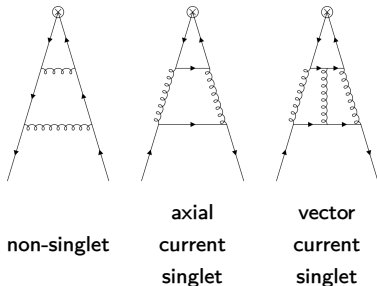
- state-of-the-art is $N^3LL^{(\prime)}+N^2LO$ in QCD
- uncertainties at $\mathcal{O}(5\%)$ at small q_T
- typically fully differential in lepton kinematics, including off-shell effects
- resummation of initial state QED effects for on-shell production at $NLL+NLO$

Cieri, Ferrera, Sborlini '18



Current status – $p_T(V)$ distribution

Ju, MS '21

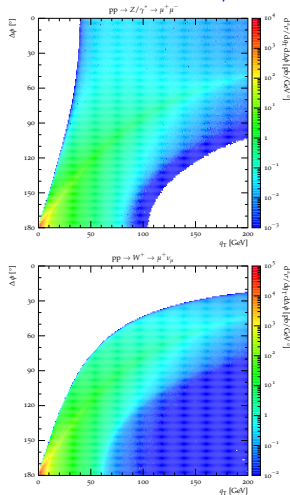


- total singlet contribution about 10% of second order coefficients
 - total singlet contribution same size as third order coefficients
- ⇒ **singlet contribution non-negligible at N³LL at the latest**

Current status – $p_T(V)$ ratios

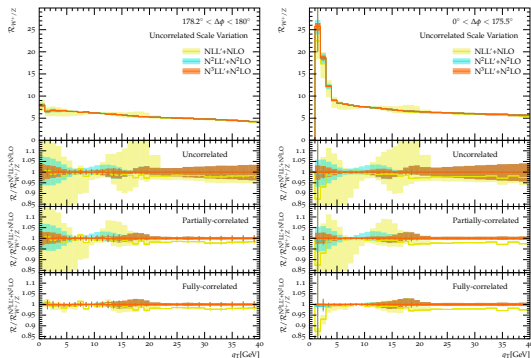
- fiducial regions for W^\pm and Z measurements differ
 → must be accounted for when calculating cross section ratios
- if ratios to be applied to data, it helps to have these ratios as differentially as possible
 → multi-differential distribution
- due to presence of neutrino in W process, only transverse observables useful
 → choose q_T and $\Delta\phi$

Ju, MS '21



Current status – $p_T(V)$ ratios

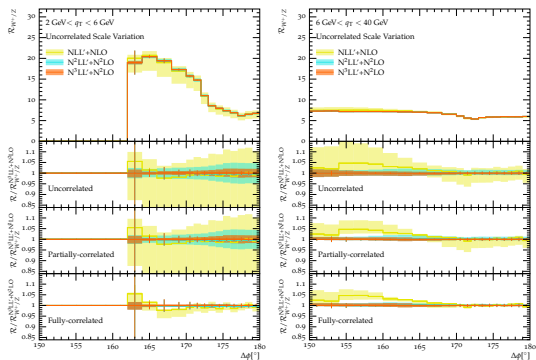
Ju, MS '21



- W^\pm/Z , W^+/W^- ratios depend on phase space region
- strong influence of differing fiducial volumes
- multi-differential predictions help to account for effects

Current status – $p_T(V)$ ratios

Ju, MS '21



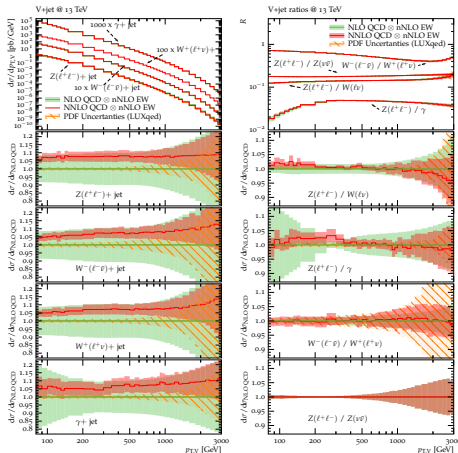
- W^\pm/Z , W^+/W^- ratios depend on phase space region
- strong influence of differing fiducial volumes
- multi-differential predictions help to account for effects

Current status – $p_T(V)$ at large p_T

Lindert et.al. '17

Large- q_T distributions

- state-of-the-art is $N^2LO_{\alpha_s} + NLO_{\alpha}$
 $+ N^2LL_{\alpha}$
- currently used to reweight MCs in DM searches
- same accuracy generically for $V+jet$ topologies

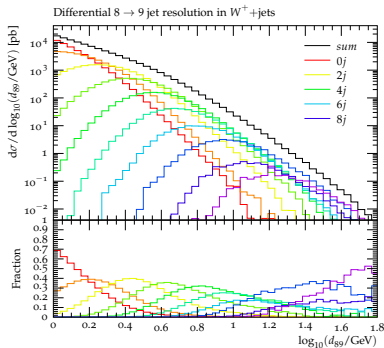


Current status – $V+$ multijets

Höche, Prestel, Schulz '19

$V+0-9j$ @ LO

- SHERPA/COMIX+PYTHIA MEPS@LO merged sample
- ME level event samples publicly available
- re-read-in for SHERPA to be developed



$pp \rightarrow X + n \text{ jets}$	cross section [pb]									
X / n	0	1	2	3	4	5	6	7	8	9
W^+	9908(29)	2523(8)	1067(7)	404(4)	148(1)	49.3(5)	15.8(2)	5.2(2)	1.30(8)	0.330(6)
W^-	7496(21)	1898(6)	760(4)	278(2)	94(1)	29.8(3)	9.29(9)	2.71(7)	0.63(2)	0.170(3)
Z	1661(3)	464(1)	193.6(8)	72.2(3)	25.7(2)	8.61(8)	2.74(3)	0.82(2)	0.211(3)	0.057(1)

Future developments

① Current status

② Future developments

Future developments

Uptake of recent developments:

Most of the recent developments have not made it into the experiments yet. Either because uptake takes a while, they are not provided publically, are computationally too costly,

... and in the future ↻

Future developments

Disclaimer: **My take!** Who knows who is working on what.



Fixed-order calculations:

- full $N^2LO_{\alpha_s\alpha}$, possibly also N^2LO_α , for inclusive V production
- $N^2LO_{\alpha_s}$ very likely for V+2j, maybe for V+3j



Event generators:

- NLL showers (needed to match non-trivial processes at N^2LO)
- $N^2LO + NLL$ for V+1j, possibly included in multijet merging



In all likelihood, the above give the same answer as the Delphic oracle.

Thank you!

Backup