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NLO vector boson production with light jets

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Summary. — In this contribution we present recent progress in the computation of next-to-leading order (NLO) QCD corrections for the production of an electroweak vector boson in association with jets at hadron colliders. We focus on results obtained using the virtual matrix element library `BlackHat` in conjunction with `SHERPA`, focusing on results relevant to understanding the background to top production.

PACS `12.38.Bx` – Perturbative calculations.
PACS `14.70.Fm` – W bosons.
PACS `14.70.Hp` – Z bosons.

1. – Introduction

The production of a vector boson in association with several jets at the Large Hadron Collider (LHC) is an important background for other Standard Model processes as well as new physics signals. In particular, the production of a W boson in association with many jets is an important background for processes involving one or more top quarks.

Precise predictions for the backgrounds are crucial to measurement of top-quark processes. Vector boson production in association with multiple jets is also a very important background for many SUSY searches, as it mimics the signatures of many typical decay chains. Here we will discuss how polarisation information can be used as an additional handle to differentiate top pair production from "prompt" W-boson production [1]. More

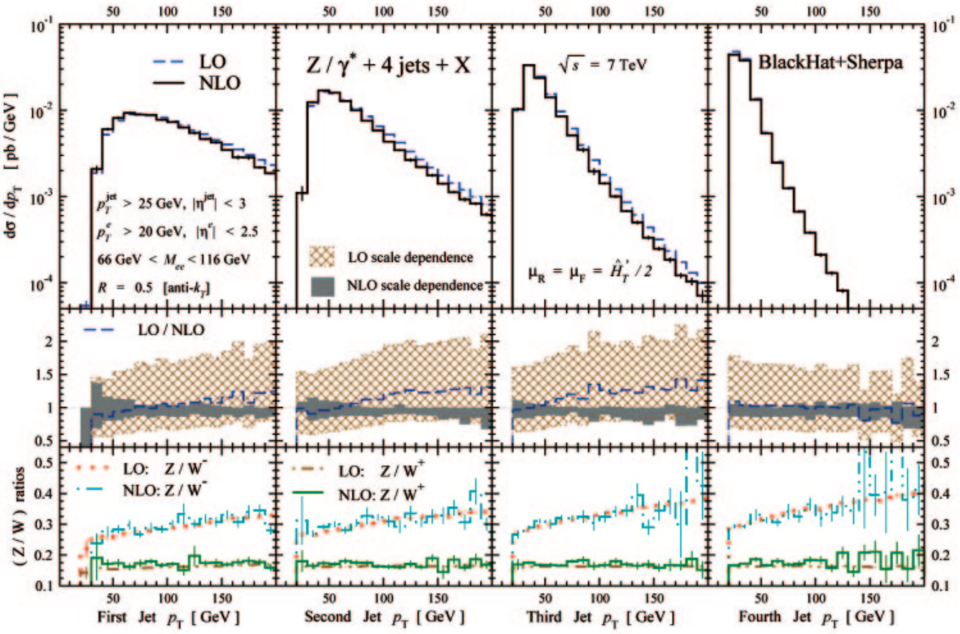

Fig. 1. – (Colour on-line) P_T distributions for the first four jets in Z+4 jets at the LHC with $\sqrt{s} = 7$ TeV, as well as ratios to W^+ and W^-. Details of the experimental cuts can be found in ref. [13].

generally, ratios of observables, for example for events containing a W boson *versus* those containing a Z boson, are expected to be better-behaved as many uncertainties cancel in such ratios. Precise calculation of ratios, along with measurement of one of the two processes in the ratio, can be used in data-driven techniques for estimating backgrounds.

2. – Recent results

In this contribution we present NLO results obtained by combining results from two programs, `SHERPA` [2-4] for the real emission and `BlackHat` [5] for the virtual emission. `SHERPA` is also used to perform the integration over the phase space of the virtual contribution. We also used `BlackHat` to supply the most complex tree-level matrix elements needed for the real emission contributions.

The calculation of virtual corrections to complex processes four of more final state objects was for a long time a highly non-trivial challenge. This situation has changed with the development of unitarity-based techniques (for a review see [6,7]). In particular, the inclusive production of a W boson in association with three jets has been computed at NLO by two independent groups with these techniques using different color approximations [8, 9] followed by a full color computation [10]. The same process with the W boson replaced by a Z boson, at the Tevatron, was computed shortly thereafter [11]. More recently, NLO results for the production of a W or a Z boson in association with four jets have been presented [12, 13]. These are the first NLO QCD calculations at hadron colliders involving five final state objects, including jets.

Figure 1 [13] shows the transverse momentum distributions of the first, second, third and fourth jets in events with a Z boson and at least four jets. In the top row of plots, the

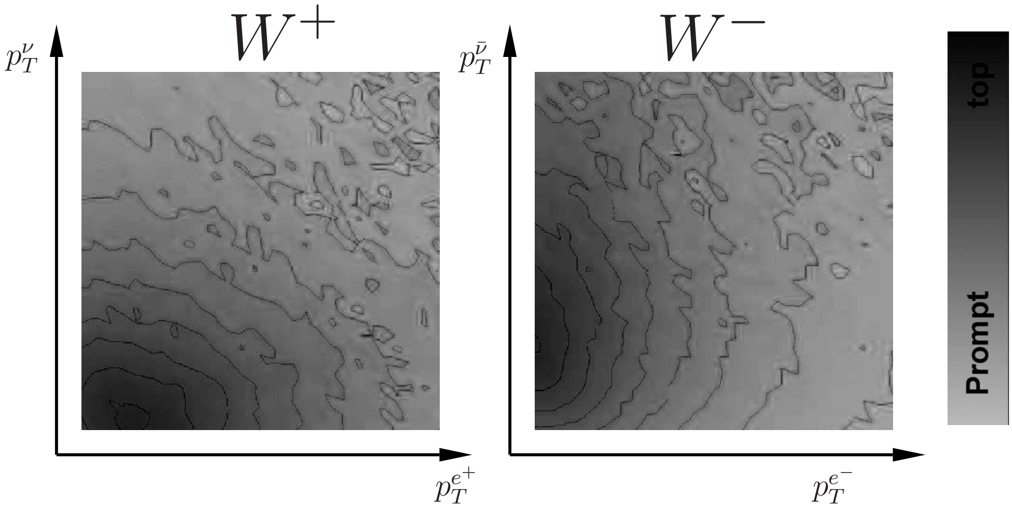

Fig. 2. – Density plots for the ratio of the LO cross sections for $pp \to t\bar{t} \to W^\pm + 3$ jets and $pp \to W^\pm + 3$ jets as a function of the lepton and neutrino transverse momentum.

dashed (blue) curve represents the LO result while the plain (black) line is the NLO result. The middle part of the plot shows the ratio to the NLO prediction. The bands display the scale variation obtained by varying the renormalisation and factorisation scale simultaneously by factors of $1/2$, $1/\sqrt{2}$, 1, $\sqrt{2}$ and 2. Clearly, the scale variation for the NLO result (in gray) is much smaller than that attributed to the LO result (in hashed orange). The bottom panels in this figure show the ratios between the W and Z boson processes. These ratios and their stability going from LO to NLO are important as they are used by experimenters to extrapolate from a measured control process into a signal process or region.

3. – W polarisation at the LHC

The fact that W bosons produced at low transverse momentum, moving mainly along the beamline, are predominantly polarised left-handed has been known for a long time [14]. More recently it has been recognized that the same is true for W bosons produced at large transverse momentum, and the mechanism has been described as well [1]. In contrast to the longitudinal effect which relies on angular momentum conservation, the transverse effect is more subtle and may be understood as properties of the matrix elements. The effective polarisation has been found to be relatively unaffected by NLO corrections [1]. This polarisation effect can be used as an additional handle to separate W bosons directly produced in conjunction with jets from those produced in the decay of a top or anti-top quark, as the latter are predominantly longitudinally polarised.

A left-handed W^+ that decays leptonically will preferentially emit the neutrino along its flight direction, whereas the positron will tend to be emitted in the opposite direction (in the W rest frame), resulting in a larger average transverse momentum for the neutrino than for the positron. The opposite effect happens in the case of the decaying left-handed W^- boson: the electron inherits a larger average transverse momentum than the anti-neutrino. This asymmetry in the transverse momentum of the decay products is not present if the vector boson is longitudinally polarised. Figure 2 illustrates the phenomenon in density plots for the ratio of W's arising from top-quark decays to those from prompt production at the LHC $\sqrt{s} = 7\,\text{TeV}$ and cuts chosen as in ref. [1]:

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_T^\nu \mathrm{d}p_T^l}\left(pp \to t\bar{t} \to W^\pm + 3 \text{ jets}\right) \Big/ \frac{\mathrm{d}^2\sigma}{\mathrm{d}p_T^\nu \mathrm{d}p_T^l}\left(pp \to W^\pm + 3 \text{ jets}\right).$$

One can see in the figure that in the case of the W^+ bosons, prompt production tends to populate more the region where the transverse momentum of the neutrino is larger than that of the positron, while the opposite effect is seen for the W^- boson. A suitable cut, or the addition of such information in statistical analysis tools such as boosted decision trees or neural networks could help discriminate between these two processes. The predominant left-handedness of prompt W bosons at the LHC with $p_T > 50\,\text{GeV}$ has been measured by the CMS collaboration [15] and found to be in good agreement with theoretical predictions [1].

4. – Conclusions

The field of NLO corrections for high-multiplicity final states has seen tremendous progress in the last few years, as exemplified by the first computations of $2 \to 5$ processes. This development is very timely as precise predictions are helpful for LHC measurements. In particular, as we discussed here, the left-handed polarisation of prompt W bosons in association with jets at the LHC may be useful as an additional handle to separate them from W bosons produced in the decay of heavy particles such as top quarks.

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