AlpGen and **SHERPA** in $Z/\gamma^* + jets$ at LHC

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Abstract
A study of **AlpGen** and **SHERPA** event generators in the production of $Z/\gamma^* + jets$ events at LHC is presented. Both generators implement a combined use of multi-parton tree level matrix element calculations and parton shower, but the prescriptions used to match the two approaches are different. We will show a collection of lepton and jet observables and how they change as the parameters that steer the matching prescription are altered. We will also show a comparison between the two algorithms when run with the default parameter choice. The study has been done using the Rivet analysis framework.

1 Introduction

The characterization of $Z/\gamma^* + jets$ production at LHC, with the vector boson decaying leptonically, will be one of the goals of the early LHC physics analyses; the rather clear leptonic signature will make these events easy to identify, and the vector boson kinematics will be reconstructed quite well even with a not perfectly calibrated/aligned detector: these signals will be very useful, for example, for the calibration of the calorimeter response using the balancing of the jets with the recoiling vector boson. Z bosons will be produced at the LHC with unprecedented rates, thus allowing a very precise determination of the vector boson mass and width; besides $Z/W + jets$ events represent a background for many new physics searches, such as SUSY.

For all these reasons it's extremely important to understand the different characteristics of the event generators that can produce these events, to understand the theoretical uncertainties connected to residual dependence on parameters such as the scale choice and to spot how the differences among the event generators on the market translate into the observables reconstructed in the experiments.

Several event generators exist that can produce $Z/\gamma^* + jets$ events. The **PYTHIA** [1] and **HERWIG** [2] event generators implement the LO calculation of the hard $2 \rightarrow 2$ process and then continue the evolution with the parton shower technique.

A different approach, which proved quite effective in describing Tevatron data, consists of the combination of matrix element (ME) tree level calculations for up to several partons in the final state and subsequent parton shower (PS), with care not to double count configurations that can be produced both from the matrix element and from the parton shower. **AlpGen** [3] and **SHERPA** [4] both implement this approach, but with significant differences.

2 Matching prescriptions

CKKW: The **SHERPA** event generator comes with its own ME calculator, called **AMEGIC++** [5] (A Matrix Element Generator In C++), and with its own PS, called **APACIC++** [6] (A Parton

CAscade in C++). In this event generator the CKKW prescription for matching ME and PS is implemented in full generality.

The CKKW prescription was originally proposed for e^+e^- collision [7], then it was extended to hadron collisions [8]. It's based on a separation of the phase space in a region for jet production, handled by the ME and a region for jet evolution, handled by the PS. The separation is determined using a $k_\perp$ measure; a configurable $k_\perp$ cutoff, $y_{cut} = Q^2_{cut}/E^2_{CM}$, is used to define the separation of the two regions; Q_{cut} is the only parameter of this matching prescription.

The first step of the CKKW matching prescription is the calculation of the ME cross sections for all the parton multiplicities we want to enter the final state. In this calculation y_{cut} is used to cutoff divergences: the cross section is calculated for parton configurations such that the minimum $k_\perp$ distance between two partons is above y_{cut}. In the ME cross section estimation a fixed value for α_S, ${\alpha_S}^{ME}$, is used.

The problem with ME calculation is that they are inclusive, so one cannot simply add ME cross sections for different final state parton multiplicities.

In the CKKW approach events produced according to the ME cross sections are reweighted with a Sudakov form factor weight. This makes ME cross sections exclusive. To calculate the Sudakov weight final state partons arising from the ME calculations are clustered back with a $k_\perp$ clustering till the core $2 \rightarrow 2$ process. In this way a series of splittings is reconstructed, that represent the splittings that would occur in a PS description of that final state. On this basis the Sudakov weight is calculated. An α_S correction is also applied to take into account that the splittings happened at scales different from Q_{cut}, as originally imposed in the ME calculation.

Below the scale y_{cut} the evolution is described by the PS alone, but with a veto to avoid emission above y_{cut}, that has been taken into account already in the ME.

MLM: The MLM prescription is implemented in **`AlpGen`**; it is similar to the CKKW prescription for what concerns the production of ME events and the reweighting of α_S but implements the Sudakov reweighting and the veto on the PS in a different way.

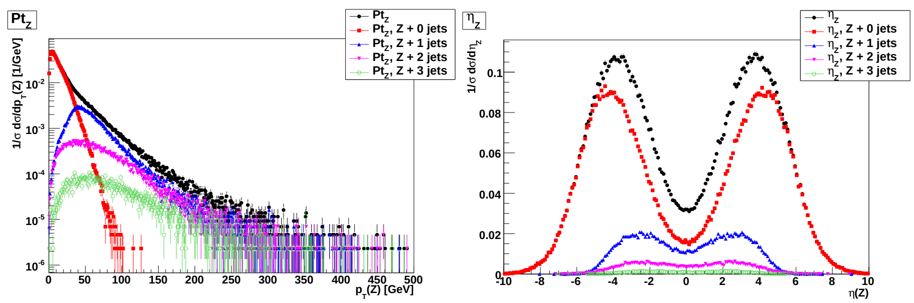
In the MLM approach a conventional PS program (**`PYTHIA`** or **`HERWIG`**) is used to shower events emerging from the ME. The shower is performed without any constraint. Partons resulting from the PS are clustered into jets with a cone algorithm. If all the jets match to all the partons generated from the ME the event is kept otherwise it is discarded. A special treatment is then needed for the events produced by the highest multiplicity ME, where additional jets, softer that the matched ones are allowed.

In this way the MLM prescription both reproduces the effect of the Sudakov reweighting and vetoes additional hard emission from the shower.

3 Analysis framework

Both programs were run with up to three additional partons from the matrix element. In order to better identify the effect of the different matching prescriptions we switched off the underlying event simulation.

We setup an analysis in the Rivet [9] analysis framework. Rivet is interfaced to a number



(a) (b)

Fig. 1: p_T spectrum (a) and η distribution (b) for events produced with **SHERPA**. The contribution from different jet multiplicities is put into evidence in color.

of event generators through the AGILe package; this means that one can run both **SHERPA** and **AlpGen** within Rivet and run exactly the same analysis code on them. Rivet analyses are actually run on the **HepMC** [10] record as it is produced from the generator.

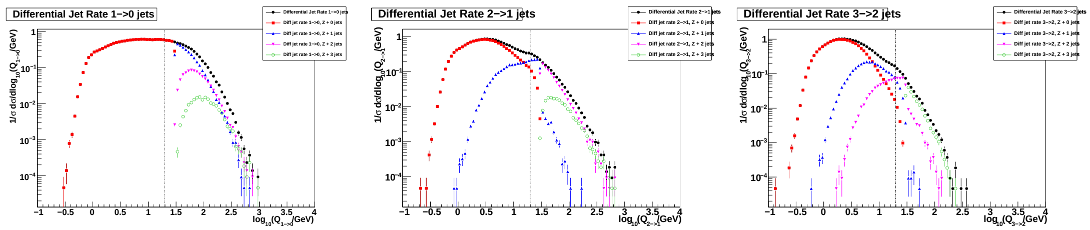
We run the analysis at hadron level, selecting final state particles with pseudorapidity η such that $|\eta| < 5$. We selected lepton pairs with an invariant mass between $66\,\mathrm{GeV}$ and $116\,\mathrm{GeV}$. Jets were reconstructed with the longitudinally invariant $k_\perp$ algorithm [11], as implemented in the **FastJet** package [12]. We set the pseudo-radius parameter of the $k_\perp$ algorithm to 0.4 and we set a minimum p_T for jets of 30 GeV.

4 Results for SHERPA

Fig. 1 shows the p_T (a) and η (b) distributions for the lepton pair produced in **SHERPA**. The contribution from different jet multiplicities is put into evidence in colour, while the overall contribution is in black. We observe that the high p_T tail of the distribution is due to the multiple jet contribution.

Fig. 2 shows differential jet rates in **SHERPA**. Differential jet rates are the distribution of the resolution parameter in the $k_\perp$ clustering, that makes an n jet event turn into an $n-1$ jet event. To compute differential jet rates one might think of running the $k_\perp$ clustering in exclusive mode with different values of the resolution parameter, looking for the parameter that makes on jet disappear, thus leading to the transition $n \to n-1$. Actually this is done more efficiently simply looking at the relevant recombinations in the clustering sequence when running $k_\perp$ clustering in inclusive mode. Those plots give a very detailed picture of how the phase space is filled. In particular one has to take care of what happens around the separation cut between the ME-filled region and the PS-filled region, marked with a vertical dashed line in the plots. The phase space above the line is filled by the ME, below by the PS. While the $1 \to 0$ transition looks quite smooth, some structure around the separation cut is present in the $2 \to 1$ and $3 \to 2$ plots. The effect is anyway moderate, and is due to mismatches that can occur close to the cut, due to the way the PS modifies the ME kinematics.

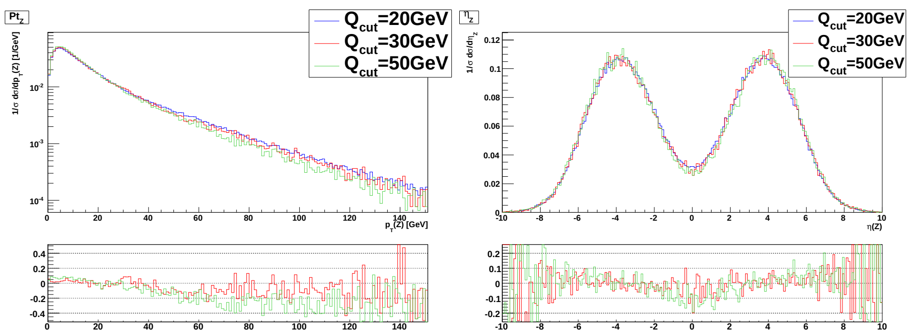
Fig. 3 shows how the p_T and η distribution of the lepton pair change if the value of the parameter Q_{cut} that steers the matching is changed. As Q_{cut} is increased the p_T spectrum tends



(a) (b) (c)

Fig. 2: Differential jet rates in **SHERPA**. (a) $1 \to 0$, (b) $2 \to 1$ (c), $3 \to 2$

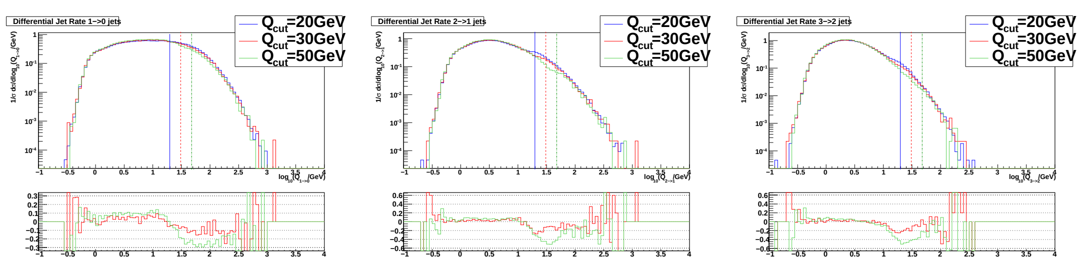
to be softer and the η distribution less central. This is probably due to the reduced phase space available for the ME as Q_{cut} is increased. Since the ME is responsible for the hardest parton kinematics, an increase in Q_{cut} results in slightly softer spectra.



(a) (b)

Fig. 3: p_T distribution (a) and η distribution (b) for the lepton pair in **SHERPA** with three different values of Q_{cut}.

Fig. 4 shows the Q_{cut} dependency in differential jet rate plots. Differences are observed in the transition region around Q_{cut}. The difference with respect to the default $20\,\mathrm{GeV}$ is at most 40%.



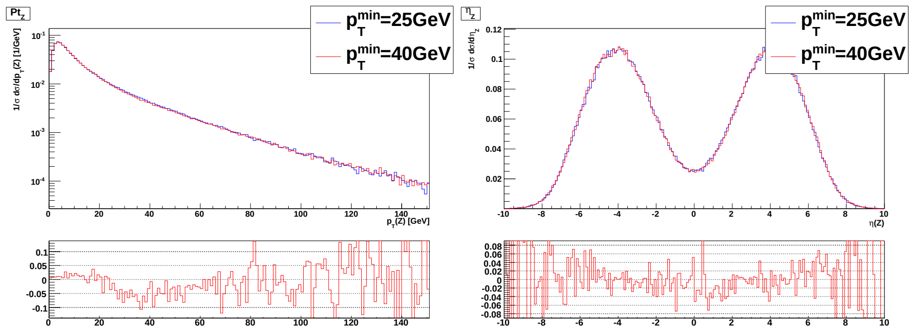
(a) (b) (c)

Fig. 4: Differential jet rates in **SHERPA** for three different values of Q_{cut}. (a) $1 \to 0$, (b) $2 \to 1$ (c), $3 \to 2$

5 Results for **AlpGen**

AlpGen sample has been showered using **PYTHIA**. We tried two different values for the minimum p_T in the cone algorithm that is used in **AlpGen** to steer the MLM matching: $25\,\mathrm{GeV}$ and $40\,\mathrm{GeV}$.

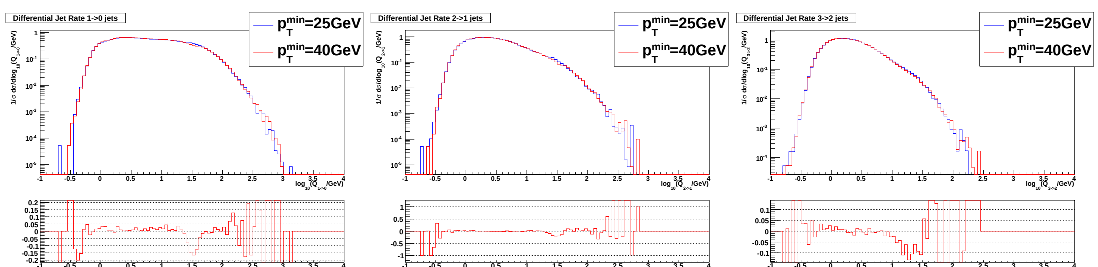
Fig. 5 shows the effect of this change on the lepton pair p_T and η spectra. The effect is almost negligible.



(a) (b)

Fig. 5: p_T distribution (a) and η distribution (b) for the lepton pair with three different values of p_T^{min} in **AlpGen**.

Fig. 6 shows differential jet rate plots for **AlpGen** for the two values of the minimum p_T in the internal cone algorithm. Also in this case the differences are concentrated in the region around p_T^{min}, that is effectively the value used in **AlpGen** to separate the ME and PS regions.

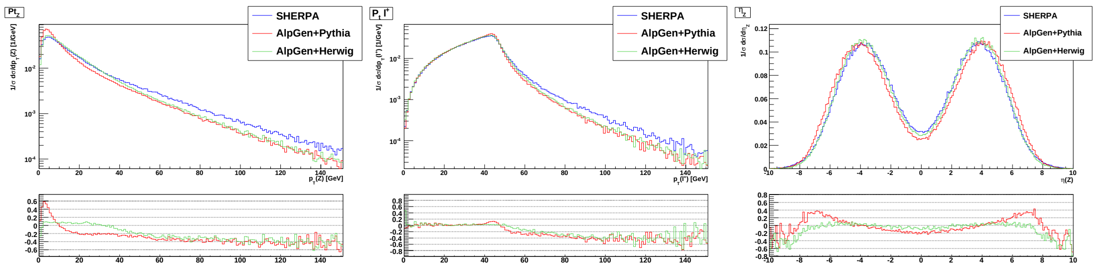


(a) (b) (c)

Fig. 6: Differential jet rates in **AlpGen**. (a) $1 \rightarrow 0$, (b) $2 \rightarrow 1$ (c), $3 \rightarrow 2$

6 A comparison between the two

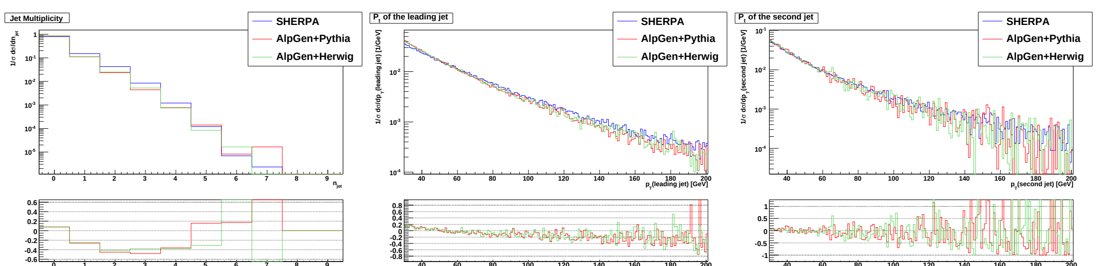
We made a comparison between **AlpGen** and **SHERPA** when run with the default settings. For **AlpGen** we used both **PYTHIA** and **HERWIG** as parton showers. Fig. 7 shows the p_T spectrum and the η distribution of the lepton pair and the p_T spectrum of one of the two leptons. We observe that **SHERPA** shows the hardest spectrum both for the lepton pair and the single lepton, while **AlpGen**+**PYTHIA** is the softest. This translates into the η distribution, with **SHERPA** showing the most central boson, and **AlpGen**+**PYTHIA** the less central.



(a) (b) (c)

Fig. 7: p_T distribution of the lepton pair (a), of the positive lepton (b) and η distribution for the lepton pair (c) in **SHERPA**, **AlpGen**+**PYTHIA** and **AlpGen**+**HERWIG**. Relative difference plots are with respect to **SHERPA**.

Fig. 8 shows the jet multiplicity, the hardest and the second jet spectra. **SHERPA** shows a higher mean jet multiplicity; this is consistent with the harder leptonic spectra, given that the Z boson recoils against the jets. Also the leading jet p_T spectrum is harder in **SHERPA**, while the spectrum for the second jet is similar.



(a) (b) (c)

Fig. 8: Jet multiplicity (a) and p_T spectrum for the hardest (a) and second (b) jet in **SHERPA**, **AlpGen**+**PYTHIA** and **AlpGen**+**HERWIG**. Relative difference plots are with respect to **SHERPA**.

7 Conclusion

A study **AlpGen** and **SHERPA** for the production of $Z/\gamma^* + jets$ has been done. A series of consistency checks have been performed with both generators to check the sensitivity to parameters that steer the matching prescription. No big dependencies were spotted. The two generators were compared when run with default settings. Some not negligible differences were spotted, both in the lepton and jet observables. **SHERPA** shows in general harder spectra, and also a higher mean jet multiplicity.

The analyses shown in this paper were performed with the Rivet Analysis framework.

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