The origin of spikes in dijet production

1 Spikes in the `POWHEG BOX` dijet generator

When showering dijet events produced by the `POWHEG BOX` with `PYTHIA`, generated using the Born suppression factor rather than a generation cut, it happens that events with very large weight and fairly large transverse momenta pop up from time to time, making it difficult to construct smooth histograms. We have investigated the origin of these events, and found a modification of the `POWHEG BOX` that avoids them.

The problem is due to the treatment of $q \to qg$ and $g \to q\bar{q}$ splittings in the `POWHEG BOX`. In order to minimize the number of generated configurations, the `POWHEG BOX` always generates the $q \to qg$ and $g \to q\bar{q}$ configurations, and never generates the $q \to gq$ and $g \to \bar{q}q$ ones. The transverse momentum in final-state radiation is defined to be

$$p_{\mathrm{T}}^2 = 2E^2 \left(1 - \cos\theta\right) , \tag{1}$$

where θ is the angle between the splitting partons, and E is the energy of the emitted parton (i.e. parton k in the $i \to jk$ splitting), both in the partonic centre of mass. Notice that, if the final-state partons are back to back, p_{T}^2 is large. Furthermore, p_{T}^2 is large also if the recoiling parton has small energy, and relatively large angle θ. This region, however, has small impact in the `POWHEG BOX`. If the emitter is a quark, a soft quark yields no infrared singularities, and thus the region of soft quarks is power suppressed. If the emitter is a gluon, the `POWHEG BOX` suppresses this region with a factor of the form

$$\frac{E_{\mathrm{em}}^p}{E_{\mathrm{em}}^p + E^p} , \tag{2}$$

where p is a positive number (usually 2) (the emitter is a gluon only if also the emitted parton is a gluon in the `POWHEG BOX`).

In case of jet production, when using the Born suppression factor instead of a generation cut, the above scheme can yield to events with large weights and large transverse momenta after showering. They are produced as follows: an underlying Born event is produced with very small transverse momentum, corresponding to a $2 \to 2$ parton scattering at very small angle. Because of the Born suppression factor, these events are rarely produced, and have a large weight (proportional to the inverse of the suppression factor).

Suppose now that a splitting process takes place, where a final-state parton, for example a gluon, splits into two partons $q\bar{q}$, with $\bar{q}$ carrying most of the energy of the incoming gluon, and q is soft and at a large angle. This event is phase-space suppressed. However, since the splitting pair has a small mass, its matrix element has no further suppression. According to the definition of the radiation transverse momentum in FSR in `POWHEG BOX`, this event has large transverse momentum, according to eq. (1). When passing the event to `PYTHIA`, further jets with relatively large transverse momentum may be produced. This event would pass the jet cuts, and have a large weight.

2 Fixing the problem

A patch that avoids this problem has been implemented in the SVN revision 2169. In order to activate the fix, the user should put the line:

```
doublefsr 1
```

in the powheg.input file. If not present, or different from 1, the program behaves exactly as before.

In the `doublefsr 1` mode the program does the following:

- Considers all splitting processes, including $q \to gq$ and $g \to \bar{q}q$, and not only the $q \to qg$ and $g \to q\bar{q}$.
- Suppresses all splitting processes with a factor proportional to eq. (2). Thus both processes $i \to jk$ and $i \to kj$ are present, with suppressions

  $$\frac{E_j^p}{E_j^p + E_k^p}\,, \qquad \text{and} \qquad \frac{E_k^p}{E_j^p + E_k^p}\,, \tag{3}$$

  respectively. Since the two splitting processes are equivalent and the sum of the two suppression factors is one, one gets back the correct result.

The above prescription is formally correct, and avoids the problem of the original `POWHEG BOX` scheme. Notice that the original prescription was not incorrect. However, it turned out to be not practical for a large number of events, where spikes were showing up, and too much statistics would have been required to smooth them away.

3 Modification of the `scalup` prescription

We have also studied in the past a modification of the `scalup` assignment that gets rid of the spike problem. Rather than using the `scalup` value provided by the `POWHEG BOX`, we suggested to recompute its value, and assign it the minimum transverse momentum among all the transverse momenta of the final-state partons with respect to each others, and with respect to the incoming beam, computed in the centre-of-mass frame.

4 Effects in the output

We have collected a number of results that document the effect of the new scheme with respect to the old one. We have made three comparisons:

- We have compared the NLO output of the two versions, and found no appreciable difference.
- We have compared the output of the two versions at the Les Houches event level. We see small differences.
- We have compared the output of the program with the `doublefsr 1` feature enabled, showered with PYTHIA 6 at the parton level, with the same output where the proposed modification of the `scalup` prescription is applied. In this case, we find variation of the distribution below 10%, especially at small transverse momentum.

In view of the fact that the modification of the `scalup` prescription does not spoil the NLO accuracy and the leading logarithmic accuracy of the program, we conclude that these variations represent a true uncertainty associated to shower effects at subleading (i.e. beyond the hardest jet) level.