JIMMY4: Multiparton Interactions in HERWIG for the LHC

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1 JIMMY

The basic ideas of the eikonal model implemented in JIMMY are discussed in a previous publication [1]. The model derives from the observation that for partonic scatters above some minimum transverse momentum, $\hat{p}_T^{\rm min}$, the values of the hadronic momentum fraction x which are probed decrease as the centre-of-mass energy, s, increases, and since the proton structure function rises rapidly at small x [2], high parton densities are probed. Thus the perturbatively-calculated cross section grows rapidly with s. However, at such high densities, the probability of more than one partonic scattering in a single hadron-hadron event may become significant. Allowing such multiple scatters reduces the total cross section, and increases the activity in the final state of the collisions.

1.1 Model Assumptions

The JIMMY model assumes some distribution of the matter inside the hadron in impact parameter (b) space, which is independent of the momentum fraction, x. The multiparton interaction rate is then calculated using the cross section for the hard subprocess, the conventional parton densities, and the area overlap function, $A(b)$. For cross sections other than QCD $2 \rightarrow 2$ scatters, JIMMY makes use of approximate formula, valid when all cross sections except QCD $2 \rightarrow 2$ are small, which is true in most cases of interest this approximation is described in details elsewhere [3].

1.2 Standard Jimmy

The starting point for the multiple scattering model is the assertion that, at fixed impact parameter, b, different scatters are independent, so obey Poission statistics. It is then straightforward to show that the cross section for events in which there are n scatters of type a is given by

$$\sigma_n = \int \mathrm{d}^2 b \, \frac{(A(b)\sigma_{\rm a})^n}{n!} \, \mathrm{e}^{-A(b)\sigma_{\rm a}}, \tag{1}$$

where $\sigma_{\rm a}$ is the parton–parton cross section and $A(b)$ is the matter density distribution, obeying

$$\int \mathrm{d}^2b\, A(b) = 1. \tag{2}$$

It is straightforward to show that the inclusive cross section for scatters of type a is $\sigma_{\rm a}$ and the total cross section for events with at least one scatter of type a is

$$\sigma_{\rm tota} = \int \mathrm{d}^2b \left(1 - \mathrm{e}^{-A(b)\sigma_{\rm a}}\right). \tag{3}$$

These can then be combined to give the probability that an event has exactly n scatters of type a, given that it has at least 1 scatter of type a,

$$P_n = \frac{\int \mathrm{d}^2b\, \frac{(A(b)\sigma_{\rm a})^n}{n!}\, \mathrm{e}^{-A(b)\sigma_{\rm a}}}{\int \mathrm{d}^2b\, (1 - \mathrm{e}^{-A(b)\sigma_{\rm a}})}, \qquad n \geq 1. \tag{4}$$

This is the probability distribution pretabulated (as a function of $\sqrt{s}$) by Jimmy.

Jimmy's procedure can then be summarized as:

1. Give all events cross section $\sigma_{\rm tota}$.
2. In a given event, choose n according to Eq. (4).

It is interesting to note that Jimmy's procedure, despite integrating over b once-and-for-all at initialization time, correctly reproduces the correlation between different scatters, whose physical origin is a b-space correlation: small cross section scatters are more likely to come from events with a large overlap and hence be accompanied by a larger-than-average number of large cross section scatters.

1.3 Two Different Scattering Types

We consider the possibility that there are two different scattering types, but that the cross section for the second type, $\sigma_{\rm b}$, is small enough that events with more than one scatter of type b are negligible. The probability distribution for number of scatters of type a, n, in events with at least one of type b is given by [3]

$$P(n|m \geq 1) = \frac{\int \mathrm{d}^2b\, \frac{(A(b)\sigma_{\rm a})^n}{n!}\, \mathrm{e}^{-A(b)\sigma_{\rm a}} \left(1 - \mathrm{e}^{-A(b)\sigma_{\rm b}}\right)}{\int \mathrm{d}^2b\, (1 - \mathrm{e}^{-A(b)\sigma_{\rm b}})}, \qquad n \geq 0. \tag{5}$$

Since $\sigma_{\rm b}$ is small, we can expand the exponentials and obtain

$$P(n|m \geq 1) \approx \int \mathrm{d}^2b\, A(b)\, \frac{(A(b)\sigma_{\rm a})^n}{n!}\, \mathrm{e}^{-A(b)\sigma_{\rm a}}, \qquad n \geq 0. \tag{6}$$

Note that this expression is independent of $\sigma_{\rm b}$. It is therefore ideal for implementing into Jimmy. The Monte Carlo implementation of this procedure is straightforward:

1. Give all events cross section $\sigma_{\rm b}$.

2. In a given event choose n according to Eq. (**??**).

3. Generate 1 scatter of type b and $n-1$ of type a.

There is one important difference between the cases in which b is distinct from a and b is a subset of a: some of the $n-1$ scatters of type a could also be of type b. Although this is a small fraction of the total, it can be phenomenologically important. As each scatter of type a is generated, a check is made as to whether it is also of type b. The mth scatter of type b generated so far is rejected with probability $1/m$. This ensures that the proposed algorithm is continuous at the boundary of **b**.

When using JIMMY at the LHC, the tuneable parameters are those described previously [1], with the obvious exception of those parameters which only concern the photon. Those remaining are therefore the minimum transverse momentum of a hard scatter, the proton structure, and the effective radius of the proton. Details on how to adjust these parameter can be found elsewhere [3].

References

[1] J. M. Butterworth, J. R. Forshaw and M. H. Seymour, Z. Phys. C **72** (1996) 637 [arXiv:hep-ph/9601371].

[2] S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. C **21** (2001) 443 [arXiv:hep-ex/0105090];
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[3] "JIMMY4 - Multiparton Interactions in HERWIG at the LHC" J. M. Butterworth and M. H.Seymour, in preparation. See `http://www.cedar.ac.uk/hepforge/jimmy`