CASCADE

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Abstract
CASCADE is a full hadron-level Monte Carlo event generator for ep, γp, pp and $p\bar{p}$ processes.

CASCADE uses the unintegrated parton distribution functions convoluted with off-mass shell matrix elements for the hard scattering. The CCFM [1] evolution equation is an appropriate description valid for both small and moderate x which describes parton emission in the initial state in an angular ordered region of phase space. For inclusive quantities it is equivalent to the BFKL and DGLAP evolution in the appropriate asymptotic limits. The angular ordering of the CCFM description makes it directly applicable for Monte Carlo implementation. The following processes are available: $\gamma^* g^* \to q\bar{q}(Q\bar{Q})$ $\gamma g^* \to J/\psi g$, $g^* g^* \to q\bar{q}(Q\bar{Q})$ and $g^* g^* \to h^0$.

A detailed description of CASCADE, the source code and manual can be found under [2]. A discussion of different unintegrated gluon densities can be found in [3–5].

The unintegrated gluon density $x\mathcal{A}_0(x, k_\perp, \bar{q})$ is a function of the longitudinal momentum fraction x the transverse momentum of the gluon $k_\perp$and the scale (related to the angle of the gluon) $\bar{q}$. Given this distribution, the generation of a full hadronic event is separated into three steps:

- The hard scattering process is generated,

$$\sigma = \int dk_{t\,1}^2 dk_{t\,2}^2 dx_1 dx_2 \mathcal{A}(x_1, k_{t\,1}, \bar{q}) \mathcal{A}(x_2, k_{t\,2}, \bar{q}) \sigma(g_1^* g_2^* \to X)\,, \tag{1}$$

  with X being $q\bar{q}$, $Q\bar{Q}$, $J/\psi g$ or h^0 states. The hard cross section is calculated using the off-shell matrix elements given in [6] for $q\bar{q}$ and $Q\bar{Q}$, $\gamma g^* \to J/\psi g$ in [7] and for Higgs production $g^* G^* \to h^0$ in [8]. The gluon momentum is given in Sudakov representation:

$$k = x_g p_p + \bar{x}_g p_e + k_t \simeq x_g p_p + k_t\,. \tag{2}$$

  where the last expression comes from the high energy approximation ($x_g \ll 1$), which then gives $-k^2 \simeq k_t^2$.
- The initial state cascade is generated according to CCFM in a backward evolution approach.
- The hadronization is performed using the Lund string fragmentation implemented in PYTHIA [9].

The backward evolution there faces one difficulty: The gluon virtuality enters in the hard scattering process and also influences the kinematics of the produced quarks and therefore the maximum angle allowed for any further emission in the initial state cascade. This virtuality is only known after the whole cascade has been generated, since it depends on the history of the gluon evolution (as $\bar{x}_g$ in eq.(2) may not be neglected for exact kinematics). In the evolution equations itself it does not enter, since there only the longitudinal energy fractions z and the transverse momenta are involved. This problem can only approximately be overcome by using $k^2 = k_t^2/(1 - x_g)$ for the virtuality which is correct in the case of no further gluon emission in the initial state. This problem is further discussed in [5, 10]

The CCFM evolution equations have been solved numerically [11] using a Monte Carlo method. Several sets of un-integrated gluon densities are available which have the input parameters were fitted to describe the structure function $F_2(x, Q^2)$ in the range $x < 5 \cdot 10^{-3}$ and $Q^2 > 4.5$ GeV^2 as measured at H1 [12] and ZEUS [13].

Also the unintegrated gluon densities described in [5] including non-linear terms [14] are available within CASCADE.

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