# CASCADE

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

A detailed description of CASCADE is given in [2], the source code of CASCADE and a manual can be found under: `http://www.desy.de/~jung/cascade/`. A description and discussion of the CCFM unintegrated gluon densities used in CASCADE can be found in [3, 4] 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 factorization scale $\bar{q}$. A general discussion of unintegrated gluon densities is given in [5–8].

The matrix elements for heavy quark [9, 10] and Higgs [11] production in $k_t$-factorization are available since long. The $k_\perp$-factorisation approach can be used all the way up to high transferred-momentum scales. As an illustration in Fig. 1 we present a numerical calculation for the transverse momentum spectrum of top-antitop pair production at the LHC [5]. Small-$x$ effects are not large in this case. Rather, this process illustrates how $k_\perp$-factorisation works in the region of finite $x$ and large virtualities of the order of the top quark mass. It is interesting to note that even at LHC energies the transverse momentum distribution of top quark pairs calculated from $k_\perp$-factorisation is similar to what is obtained from a full NLO calculation (including parton showers, MC@NLO [12]), with CASCADE giving a somewhat harder spectrum, Fig. 1.

However, to use CASCADE for standard processes at the LHC, $g^*g^* \to W/ZQ\bar{Q}$ production [13, 14] and quark induced processes [15] ($q^*g \to qg$) needed to be calculated in the $k_t$-factorization approach. First results from these calculations are given in [16].

The QCD-Compton process needs special attention: First, we are dealing with light partons, and collinear and soft regions have to be avoided. This is done by applying a cut on the transverse momentum $p_t^{cm}$ of any of the outgoing $q$ or $g$ in the laboratory frame. Secondly, unintegrated quark distributions had to be determined. Since the aim is mainly to cover the forward or backward region at LHC, only the valence quarks are considered, avoiding any complication with double counting of sea-quarks and gluon contributions.The unintegrated quark density is obtained from a full CCFM evolution of valence quarks (taken at $Q_0$ from CTEQ 5 [17]) treating correctly the full kinematics during the evolution. Only the $q \to qg$ splitting functions were included, which are finite for small $x$.

For all processes, the initial state parton shower is obtained from a deconvolution of the CCFM unintegrated parton densities, obeying the angular ordering constraint. The angular ordering is essential for the $x$ dependence of the unintegrated parton densities. However, during

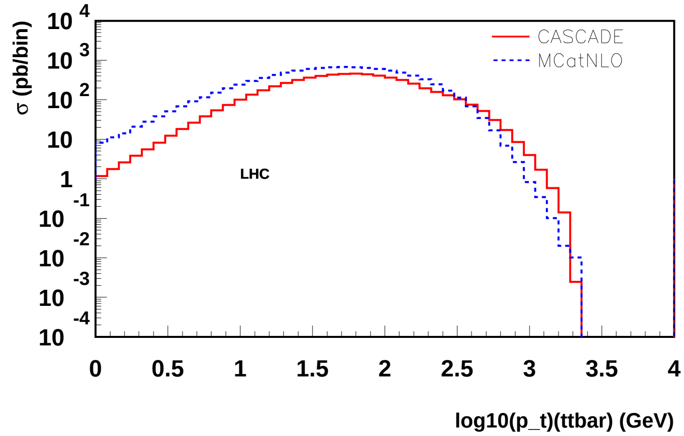


Fig. 1: Comparison of transverse momentum distribution of $t\bar{t}$ pairs calculated from CASCADE with the NLO calculation MC@NLO at LHC energies.

the initial state cascade, the emitted parton can also undergo a further time-like cascade. This time-like showering is now included, where the maximum virtuality of the showering partons is set by the transverse momentum of the parent parton. The time-like cascade follows again angular ordering, but it does not change (except from kinematics) the angular ordering of the initial state cascade, which is constrained by the unintegrated parton density.

New developments to properly model the dense partonic system have lead to the introduction of a absorptive boundary simulating effectively the saturation effect coming from non-linear evolution equations. The absorptive boundary at small $x$ suppresses the small $k_t$ region of the unintegrated gluon density. The initial parameters for these uPDFs have to be determined from fits to measurements [18] and yield a similarly good $\chi^2$. These uPDFs are available in CASCADE (version 2.0.2), allowing the study of saturation effects with final state observables.

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