VNI – An Event Generator for Deep-Inelastic Final States in a Space-Time Description of Shower Development and Hadronization

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VNI3.1 is a Monte Carlo implementation of a quantum kinetic approach to the description of high energy particle collisions, including e^+e^-, deep-inelastic ep and eA, hadron-hadron, hadron-nucleus and nucleus-nucleus collsions. In the case of deep-inelastic electron scattering off a proton or nucleus at HERA, the basic concept is the following [1]: The history of the triggering photon-proton (nucleus) hard scattering is traced back to the initial hadronic (nuclear) state and forward to the formation of colour-singlet pre-hadronic clusters and their decays into hadrons. The time evolution of the space-like initial-state shower and the time-like secondary partons are treated similarly, and cluster formation is treated using a spatial criterion motivated by confinement and a non-perturbative model for hadronization.

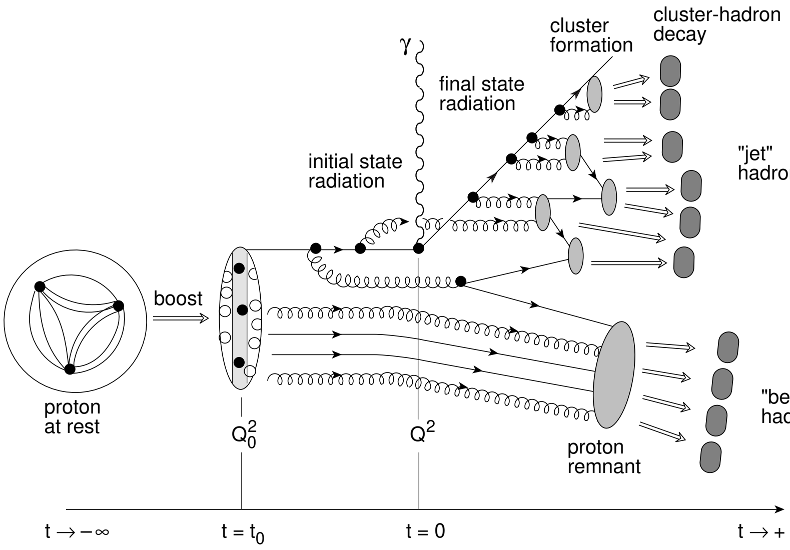
The central element in this approach is the use of QCD transport theory [2] and quantum field kinetics [3] to follow the evolution of a generally mixed multiparticle system of partons and hadrons in 7-dimensional phase-space $d^3rd^3kdk^0$. Included are both the perturbative QCD parton-cascade development [4, 5], and the phenomenological parton-hadron conversion model which has been proposed previously in Refs. [6, 7], in which a dynamical parton-cluster formation is considered as a local, statistical process that depends on the spatial separation and colour of nearest-neighbour partons, followed by the decay of clusters into hadrons. In contrast to the commonly-used momentum-space description, in the present approach the microscopic history of the dynamically-evolving particle system is traced in space-time *and* momentum space, so that the correlations of partons in space, time, and colour can be taken into account for both the perturbative cascade evolution and the non-perturbative hadronization. One strength of this approach lies in the possible extension of its applicability to the collision dynamics of complicated multi-particle systems, as in eA, pA and AA collisions, for which a causal time evolution in position space and momentum space is essential.

The model contains three main building blocks which generically embody high-energy collisions involving leptons, hadrons, or nuclei in colliders (for DIS ep collisions, the model components are illustrated in Fig. 1):

a. the *initial state* associated with the incoming collision partners (the beam particles), in particular the phenomenological construction of the hadron (nucleus) in terms of quark and gluon phase-space distributions;

b. the *parton cascade development* with mutual- and self-interactions of the system of quarks and gluons consisting of both the materialized partons from parton showers, and the spectator partons belonging to the remnants of the collided beam particles;

c. the *hadronization* of the evolving system in terms of parton coalescence to colour-neutral clusters as a local, statistical process that depends on the spatial separation and colour of nearest-neighbour partons, followed by the decay of clusters into hadrons according to the density of final hadron states.



Such a pragmatical division, which assumes complex interference between the different physics regimes to be negligible, is possible if the respective dynamical scales are such that the short-range hard interaction, with its associated perturbative parton evolution, and the non-perturbative mechanism of hadron formation occur on well-separated space-time scales. For DIS, this condition of validity requires $\min(W^2, Q^2) \geq L_c^{-2} \gg \Lambda_{QCD}^2$, meaning that the characteristic mass scale for the γp hard scattering and parton shower development (W^2, Q^2, or a combination of the two) is larger than the inverse 'confinement length scale' $L_c = O(1\, fm)$ separating perturbative and non-perturbative domains. Specifically, for DIS, in the small-x regime probed at HERA ($10^{-4} \lesssim x \lesssim 10^{-3}$), one has $60 \lesssim W \lesssim 300$ GeV for $10 \leq Q^2 \leq 300$ GeV^2, so that the above requirement is well satisfied. It is important to realize however, that in this model the interplay between perturbative and non-perturbative regimes is controlled locally by the space-time evolution of the mixed parton-hadron system itself, rather than by an arbitrary global division between parton and hadron degrees of freedom.

Recently the approach discussed above has been applied [1] in detail to deep-inelastic ep scattering at HERA, and will be applied in the future to more complicated situations, in particular the extension to eA collsions at HERA energy. It allows to map the history of the particle densities and associated spectra, including the rapidity, longitudinal and transverse distributions of particles, so that these may be compared with intuitive pictures of the space-time development of hadronic final states in DIS. They will also form the basis for investigating the effects of multiple parton scattering, energy-loss phenomena, parton shadowing, and other interesting effects in eA scattering which are not present in ep.

The aforementioned application to ep shows encouraging results for, e.g., inclusive hadron spectra in x_F and p_T, and the transverse energy flow, or, distributions of the mass M_X of the observed hadronic final state in events without a large rapidity gap, which can be used to estimate the background to the cross-section for LRG events.

As already mentioned, the new features of this approach open the way to future applications of the model to eA, pp, pA and AA collisions, where the novel features associated with high parton densities will become more marked. In this respect the possible eA experiments at HERA can play a key role since these collisions provide the 'cleanest' way of probing parton- and hadron- evolution in a nuclear medium, rather than in vacuum.

References

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