Jet fragmentation via recombination of parton showers

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The fragmentation and hadronization process of QCD (quantum chromodynamics) jets has been under investigation for many decades. Partons (quarks or gluons) created by hard (large momentum transfer) processes are not eligible final states since they carry color charges. Rather, such partons have to turn into systems of hardons. They are called jets since they exhibit large boosts in the direction of the original parton, due to the large total momentum carried in the lab frame. Jets have historically been observed in e^{+}+e^{-} collisions, e+p collisions, and p+p collisions. Over the past few years they have been found in A+A (nucleus-nucleus) collisions at the Large Hadron Collider (LHC) and the Relativistic Heavy Ion Collider (RHIC).

The fragmentation of a single parton into a jet of hadrons involves both perturbative and non-perturbative processes. Initially the parton is off-shell and radiates, building up an entire parton shower. This process is modelled based on perturbative principles in many jet shower Monte Carlo generators, like PYTHIA or HERWIG. In A+A collisions the parton shower may be modified due to the presence of quark gluon plasma (QGP), and Monte Carlo simulations describing jet-medium interaction on the parton level are currently being developed. Several models are available to describe the step of hadronizing the parton shower into hadrons. The most successful ones, developed for jets in the vacuum, i.e. not specifically for jets in A+A collisions, are the Lund string model and the cluster hadronization model. None of these are derived from first principles, but they are phenomenologically very successful. In this project [1], carried out as part of our commitment to the JET collaboration, we have developed a new model for hadronization of parton showers, which is based on a hybrid approach including quark recombination and string fragmentation. The advantage of using quark recombination to model hadronization lies in the fact that it is straight forward to generalize to A+A collisions. Recombination of quarks has successfully described many aspects of hadron production in nuclear collisions.

We assume that the Wigner function of the parton shower is provided by a shower Monte Carlo. For our first study [1] we used PYTHIA to estimate the Wigner function of vacuum jets. We used standard PYTHIA to generate showers with a fixed jet energy in momentum space. We introduced the average life-time of intermediate states in their rest frame based on their virtuality. This allowed us to reconstruct expectation values for the space-time positions of the partons in the shower at the end of their perturbative evolution. For each parton we then postulate Gaussian wave packets of a certain width to arrive at a factorized Wigner function for the shower. Gluons are split into quark-antiquark pairs using their remnant virtuality.

We then use the established quark recombination formalism, which allows us to calculate the probability of a quark-anti-quark pair coalescencing into a meson, or a quark triplet coalescencing into a baryon, using the Wigner function of the quarks, and the Wigner function of the bound state. We model hadrons using harmonic oscillator Wigner functions, both for ground and excited states. The parameters of the ground state Wigner functions are fitted to experimentally measured charge radii. We then apply Monte Carlo techniques to decide which partons in a given shower recombine into hadrons. Partons far apart from others in phase-space, e.g. leading partons with large momentum, have small probabilities to recombine. In our model these remnant partons are still connected by strings, and we apply string fragmentation, executed by PYTHIA, to hadronize those remnant partons. Fig. 1 shows results from our model for an ensemble of 100 GeV vacuum showers compared to PYTHIA string fragmentation. We reproduce both the longitudinal and transverse momentum distributions of various hadron species. In the future we will allow recombination of shower partons of jets embedded in QGP with thermal partons. First studies provide promising results.

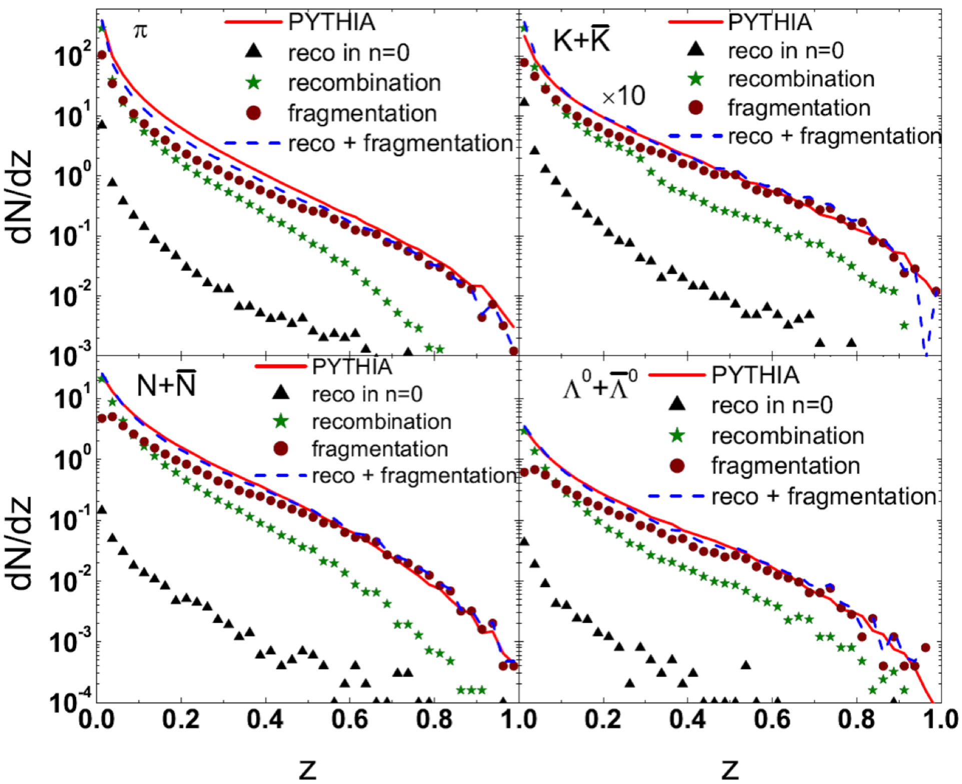

FIG. 1. Longitudinal momentum distribution dN/dz in terms of the momentum fraction z of the jet for (clockwise from top left) pion, kaons, Lambdas, and nucleons in 100 GeV quark jets. We show the results from the recombination and string hybrid model discussed here (blue dashed line) compared to pure PYTHIA string fragmentation (red solid line). We also show contributions from remnant strings (brown dots), recombination (green stars), and recombination only into ground state hadrons (black triangles).

[1] Kyong Chol Han, Rainer J. Fries, and C.M. Ko, Phys. Rev. C **93**, 045207 (2016).