Parton Propagation Through Strongly Interacting Matter

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Scientific Context

The interaction of energetic partons passing through strongly interacting systems has been a topic of study for over two decades. Anticipation of the advent of RHIC and LHC stimulated an accelerating amount of activity throughout the 1990's as proposed signatures of the quark gluon plasma appeared to be closely connected to energy loss of propagating partons. The suppression of high-p_T jets observed in the RHIC data to offer the strongest evidence to date of energetic partons losing energy in a hot and dense medium. Though the wealth of data on jet quenching at RHIC provides the first glimpse into jet interactions in a very hot medium, possibly the QGP, it is essential to understand the baseline effect of jet quenching in cold, "normal" nuclear matter.

In the past decade, two new sets of experimental data became available that provide important information on these baseline effects. First, a series of experiments exploiting the Drell-Yan process in high-energy p-A scattering were used to estimate the energy loss of quarks passing through cold nuclear matter. These experiments, using 800 GeV protons incident on a variety of nuclear targets, have lead to an extraction of an estimate for quark energy loss. Additionally, broadening of the transverse momentum distribution of Drell-Yan pairs, charmonia and bottomia produced off nuclei with 800-GeV protons provided crucial information about multiple interactions of high-energy quarks and gluons propagating through the nuclei.

More recently, measurements at HERMES using positron beams of 12 and 27 GeV have provided a rich new data set for deep inelastic scattering on light and medium-mass nuclear targets, with excellent hadron identification in the final state. The attenuation of hadrons in these measurements has been interpreted phenomenologically to yield the formation lengths of hadrons evolving from struck quarks. New theoretical activity has been stimulated by this data. However, the theoretical efforts to date explain the data using a variety of physical pictures which may not be compatible at root.

Finally, an experiment at Jefferson Lab will provide deep inelastic scattering data on a range of nuclei, detecting final-state hadrons. The first measurements took place in CLAS in early 2004 with a 5 GeV electron beam; future investigations with an upgraded facility will be feasible with an 11 GeV electron beam. These measurements will complement the HERMES data by providing lower energy measurements at high luminosity on targets from carbon to lead.

There are several theoretical issues underlying these studies. The struck quark, radiating gluons, interacts with the medium. The precise extent to which additional emitted gluons are stimulated by the medium is not yet known; this stimulation has been predicted to lead to the strong interaction analog of the Landau-Pomeranchuk-Migdal (LPM) effect. While medium-stimulated gluon emission is able to describe the published data, a full understanding of the kinematic range of its validity, and its completeness as a description of the underlying phenomena, requires more investigation. For instance, in this picture, the time of color neutralization which concludes the hadronization process is supposed to be much longer than the time of propagation through the nucleus, an assumption which will not hold for low energies.

The evolution of the struck quark into a hadron becomes relevant at lower energy scales, and the interaction of this evolving system with the medium is not well understood. It has been suggested that hadron attenuation may be related to the confinement scale of the medium; at early stages of hadron formation, color transparency may also be important. The restoration of the color field of the struck quark is analogous to a similar process in QED. Reliable calculations of these effects and their consequences for observables are needed to sort out which physical processes ultimately are relevant.

The evolution of the pre-hadron into a full hadron in the presence of an absorptive medium is a quantum-mechanical process. In some theoretical treatments, the process retains coherent features stemming from the evolution of the pre-hadron, and is described by the Schrödinger equation. In other treatments this stage is treated semi-classically, using coupled-channel transport equations to predict final state distributions. The assumptions are quite different, and each description possesses advantages and disadvantages.

In each of these issues, more theoretical work is needed. In addition to attenuation of hadrons by nuclear targets, the broadening of the hadron's transverse momentum as a function of several variables may discriminate among theoretical approaches. Development of techniques to transfer successful descriptions of the relevant parameters from cold nuclear systems to hot dense matter has already begun, but further work is needed.

This workshop topic is timely because of the convergence of relevant data from four international-scale laboratories: RHIC, Fermilab, HERA, and Jefferson Lab. It is particularly timely in view of its role in interpreting the RHIC data and predicting similar phenomena at LHC. It is interdisciplinary in the sense that it touches on topics in core nuclear physics (FSI, hadron propagation in nuclei, relativistic heavy ion nuclear physics, nuclear parton distributions, QCD factorization) as well as hadronic physics (formation length/hadronic sizes) and high energy physics (fragmentation functions, hadronization mechanisms), and connects to QED in the sense that there may be analogous phenomena in QCD (LPM effect, regeneration of truncated fields in high-energy scattering).

Workshop focus and goals:

The workshop will focus on a unified picture of jet quenching both in cold and in hot hadronic matter. Common features and differences in these two settings will be identified, both in experiment and theory, and connections between different theoretical descriptions will be examined.

The focus of the workshop is *to understand in-medium hadronization dynamics and partonic energy loss.* A minimal goal is to determine the primary reaction mechanism for the observed hadron attenuation in nuclear DIS experiments, and to understand the implications this holds for the interpretation of the observed jet quenching and mono-jet production at RHIC.

Within this narrow focus, the workshop will address questions such as the following:

- What is the role of coherence in parton and hadron transport? Examples: Can the final state be treated classically? Does color transparency play a measurable role?
- What relevant information can be meaningfully extracted from DIS data? Examples: formation length, production length, partonic energy loss, prehadron absorption cross sections.
- What experimental tools are needed to extract the above information? Examples: Q^2, z_h, and ν dependences of observables; correlations within the jet; correlations between slow and fast particles; p_T broadening; flavor dependences.
- How can the understanding of the DIS data be applied to hot dense matter? Examples: to calculate quark and gluon energy loss in-medium; to calculate the influence of finite hadron formation lengths on RHI observables; to specifically investigate jet quenching and mono-jet production as manifestations of the same processes that occur in DIS hadron production.

Organizers

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