Multiple Parton Scattering in Nuclei: Heavy Quark Energy Loss and Modified Fragmentation Functions [1]

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The extraction of the initial gluon density from jet quenching pattern as measured at RHIC relies on the assumption that it is caused by parton multiple scattering and induced radiation. While such an assumption is based on a solid physical picture and is supported by a multitude of experimental data, it is still important to have additional and independent study of the consequences of parton energy loss. Quenching of heavy quark spectra has been proposed as a special probe because of the unique mass dependence of the energy loss and medium modification of the fragmentation functions. In this paper, we will apply the framework of twist expansion that was developed for the study of medium modification of parton fragmentation functions to heavy quarks.

Multiple parton scattering inside nuclei in generally is a higher twist process that involves multiple parton correlations. By dimensional counting, such higher twist processes are power-suppressed in terms of the momentum scale Q^2 involved. Therefore, one can have a systematic expansion of the cross section in $1/Q^2$. Since the probability of multiple scattering increases with the nuclear size, the leading higher twist contribution should be enhanced by $A^{1/3}$. Furthermore, multiple parton correlations involve only the intrinsic properties of the nuclei. They should be independent of the hard processes involved. This twist expansion is referred to as generalized factorization. Such framework has been applied to semi-inclusive DIS on nuclear targets to study nuclear modification of light (massless) quark fragmentation functions and effective parton energy loss. Because of the Landau-Pomeranchuk-Migdal interference, the phase space available for the induced gluon radiation is limited that is also proportional to $A^{1/3}$. The final twist-four contribution to the modified fragmentation functions is then proportional to $A^{2/3}/Q^2$. Such a quadratic dependence on nuclear size is indeed observed in semi-inclusive deep inelastic lepton-nucleus experiments.

In this paper, we will extend the study of modified fragmentation functions in nuclei to heavy quarks when they propagate through nuclear matter. We will derive the modified heavy quark fragmentation functions and the effective energy loss. To demonstrate the effect of quark mass, we will compare the results with the ones for light quarks. One of the most important effect is the reduction of gluon formation time when it is radiated from a slow heavy quark whose virtuality is not much larger than its mass. Such a reduction will effectively eliminate LPM effect and the nuclear size dependence of the modification will become linear in contrast to the case of a light quark. The second mass effect is the significant reduction of induced quark energy loss due to limited gluon radiation angle imposed by the mass. With detailed data analysis of experimental data both in the single electron channel and direct measurement of heavy mesons, one could learn more about the parton energy loss mechanism in dense matter.

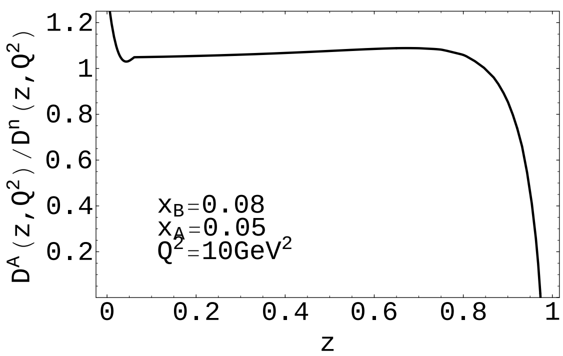

FIG. 1: Modification factor for the charm quark fragmentation function in a nucleus.

In this work, we elaborate the detailed derivation and focus on numerical calculations and discussions about modified heavy quark fragmentation functions. The paper is organized as follows. We resent the theoretical formalism of our calculation including the generalized factorization of twist-4 processes. We show in detail the calculation of different contributions to the modified heavy quark fragmentation function and energy loss due to multiple scattering. We then numerically evaluate and discuss the modified fragmentation functions of a heavy quark propagating in nuclei. We demonstrate the mass effects by discussing how the dependence on medium size changes from a linear to a quadratic dependence when the energy of the heavy quark and the momentum scale is increased, and the suppression of the energy loss for the heavy quark relative to a light quark due to "dead-cone" effect.

[1] B.-W. Zhang, E. Wang, and X.-N. Wang, Nucl. Phys. **A757**, 493 (2005), hep-ph/0412060.