Multiple Parton Scattering in Nuclei: Beyond Helicity Amplitude Approximation *

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Suppression of jet production or jet quenching in high-energy nuclear collisions has been proposed as a good probe of the hot and dense medium that is produced during the violent collisions. The quenching of an energetic parton is caused by multiple scattering and induced parton energy loss during its propagation through the hot QCD medium. It suppresses the final leading hadron distribution giving rise to modified fragmentation functions and the final hadron spectra. Recent theoretical estimates all show that the effective parton energy loss is proportional to the gluon density of the medium. Therefore measurements of the parton energy loss will enable one to extract the initial gluon density of the produced hot medium. Strong suppression of high transverse momentum hadron spectra is indeed observed by experiments at the Relativistic Heavy-Ion Collider (RHIC) at the Brookhaven National Laboratory (BNL), indicating large parton energy loss in a medium with large initial gluon density. However, one cannot unambiguously extract the initial gluon density from the experiments of heavy-ion collisions alone because of the theoretical uncertainty in relating the parton energy loss to the initial gluon density. For this purpose, one has to rely on other complimentary experimental measurements such as parton energy loss in deeply inelastic scattering (DIS) of nuclear targets. One can then at least extract the initial gluon density in heavy-ion collisions relative to that in a cold nucleus.

Modified quark fragmentation function inside a nucleus in DIS and the effective parton energy loss has been derived recently by Guo and Wang. Generalized factorization of twist-four processes was applied to the inclusive process of jet fragmentation in DIS in order to derive the modified fragmentation functions. Taking into account of gluon bremsstrahlung induced by multiple parton scattering and the Landau-Pomeranchuck-Migdal (LPM) interference effect, one finds that the leading twist-four contributions to the modified fragmentation function and the effective parton energy loss depend quadratically on the nuclear size R_A. They also depend linearly on the effective gluon distribution in nuclei. One can also extend the study to parton propagation inside a hot QCD medium reproducing earlier results. This allows one to relate parton energy loss in both hot and cold nuclear medium.

We have extended an earlier study on gluon radiation induced by multiple parton scattering in DIS off a nuclear target with a complete calculation beyond the helicity amplitude (or soft radiation) approximation. Working within the framework of the generalized factorization of twist-four processes, we obtained a new correction to the modified parton fragmentation functions. Such a new correction essentially results in a new term in the modified splitting function which is proportional to $(1-z)$. In the limit of helicity amplitude approximation $(1-z) \to 0$, this term vanishes and we recover the early results.

The new correction we obtained in this paper comes from the gluon radiation process (residual final state radiation from a quark after incomplete cancellation by the initial state radiation) that is actually responsible for the photon radiation in QED. However, the leading correction beyond the helicity amplitude approximation does not come from this process itself. Rather, it comes from the interference between this process and the other gluon radiation processes that are responsible for the result in the helicity amplitude approximation. Though it is not dominant for induced gluon radiation in QCD, it still make a finite contribution to the modified fragmentation function for a quark propagating inside a nuclear medium and to the effective quark energy loss. We found that it reduces the effective quark energy loss by a factor of $5/6$.

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