Energy Dependence of Jet Quenching and Life-time of the Dense Matter in High-energy Heavy-ion Collisions

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The discovery of jet quenching in central $Au + Au$ collisions at the Relativistic Heavy-ion Collider (RHIC) at Brookhaven National Laboratory has provided clear evidence for the formation of strongly interacting dense matter. The observed jet quenching includes suppression of single hadron spectra at high p_T, disappearance of back-to-back correlation of high p_T hadrons and the azimuthal anisotropy of high p_T hadron spectra in non-central $Au + Au$ collisions. The absence of these jet quenching phenomena in $d + Au$ collisions proves that they are indeed due to final state interaction. Detailed analyses further indicate that they are caused by parton energy loss as predicted. Using the parton energy loss extracted from experimental data, one can conclude that the initial gluon density in central $Au + Au$ collisions at $\sqrt{s} = 200$ GeV is about 30 times higher than that in a cold nucleus.

The observed strong suppression of high p_T hadrons at RHIC is in sharp contrast to the results of $Pb + Pb$ collisions at the SPS energy. Data from the WA98 experiment show no or little suppression of high p_T (up to about 4 GeV/c) pions . Even if one takes into account the possible uncertainty in the reference $p+p$ data, the suppression allowed by the data is still significantly less than in $Au + Au$ collisions at RHIC, while the total charged multiplicities or the inferred initial parton densities only differ by a factor of 2. This implies that additional physics is at play in the energy dependence of the suppression of single hadron spectra in high-energy heavy-ion collisions. It could be the energy dependence of the Cronin effect due to initial state multiple scattering, the thermalization time and finite lifetime of the dense matter that limits the parton energy loss.

In this brief report [1], we explore the sensitivity of the final high p_T hadron suppression to the lifetime of the dense matter as well as the dependence on the colliding energy. We will study the high p_T hadron suppression at $\sqrt{s} = 17.2$, 62.4, 200 and 5500 GeV. We focus, in particular, on both neutral pion and charged hadron suppression at $\sqrt{s} = 62.4$ GeV and study the constraint on the lifetime by the measurement of hadron spectrum suppression.

The flat p_T dependence of the nuclear modification factor $R_{AA}(p_T)$ for neutral pions at large p_T in $Au+Au$ collisions at $\sqrt{s} = 200$ GeV, as shown in the Fig. 1 implies a strong energy-dependence of the parton energy loss. The flatness of the modification factor at this energy is actually a coincidence, as the combined effect of the energy dependence of the parton energy loss and the power-law behavior of the initial jet spectra. Using the same energy dependence of the parton energy loss but with a reduced amplitude due to smaller initial gluon density at $\sqrt{s} = 62.4$ GeV, the nuclear modification factor is found to decrease with p_T and even becomes smaller than the modification factor at $\sqrt{s} = 200$ GeV at high $p_T > 10$ GeV/c. This is simply a consequence of the energy dependence of jet spectrum shape. The initial jet spectra at $\sqrt{s} = 62.3$ GeV are much steeper than those at 200 GeV. The same amount of energy loss leads to a larger suppression of the final hadron spectra at 62.3 GeV than at 200 GeV. As one increases the colliding energy, the power-law spectra for the initial jet production become flatter, and the same parton energy loss will lead to less suppression of the final hadrons. As shown in the same figure, the nuclear modification factor at the LHC energy $\sqrt{s} = 5.5$ TeV is smaller than at 200 GeV in the intermediate p_T region, due to larger initial gluon density. However, the modification factor $R_{AA}(p_T)$ increases with p_T due to the flatter power-law spectra of jet production at LHC.

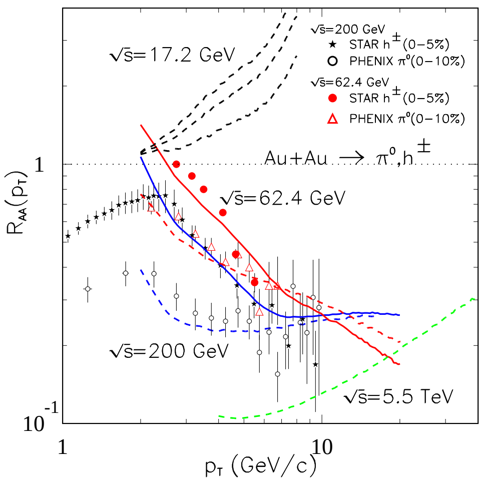

FIG. 1: Nuclear modification factors for charged hadrons (solid) and neutral pions (dashed) in 0-5% central $Au + Au$ collisions at $\sqrt{s} = 17.3$, 62.4, 200, 5500 GeV. The lifetime $\tau_f = 0,1,2$ fm/c (from top to bottom) is assumed for calculations at $\sqrt{s} = 17.2$ GeV. For other energies τ_f is assumed to be larger than the system size.

[1] X.-N. Wang, Phys. Rev. **C70**, 031901 (2004), nucl-th/0405029.