High-$P_T$ Physics with Identified Particles

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Abstract

The suppression of high-$P_T$ particles in heavy ion collisions was one of the key discoveries at the Relativistic Heavy Ion Collider. This is usually parameterized by the average rate of momentum-transfer squared to this particle, $\hat{q}$. Here we argue that measurements of identified particles at high $P_T$ can lead to complementary information about the medium. The leading particle of a jet can change its identity through interactions with the medium. Tracing such flavor conversions could allow us to constrain the mean free path. Here we review the basic concepts of flavor conversions and discuss applications to particle ratios and elliptic flow. We make a prediction that strangeness is enhanced at high $P_T$ at RHIC energies while its elliptic flow is suppressed.

For the past decade high momentum particles and jets have been used to probe the quark gluon plasma (QGP) phase created at the Relativistic Heavy Ion Collider (RHIC). The energy loss of a fast parton suffered in the medium carries information about the typical momentum transfer $\mu$ along the path, more precisely about the transport coefficient $\hat{q} = \mu^2/\lambda$ [1, 2, 3, 4, 5, 6].

We have recently argued that the mean free path $\lambda$ of a fast parton could be determined separately by measuring the change in hadro-chemistry induced by the medium [7, 8].

Here we discuss a model based on conversions of the leading particle of a jet. Just as partons can lose energy through collisions and induced radiation, they can scatter through channels in which the identity of the fastest parton in the initial and final state are not the same. Examples are binary collisions like $q + \bar{q} \rightarrow g + g$ or $q + g \leftrightarrow g + q$ which can lead to conversions of quarks into gluons and vice versa. Here the first parton on each side has a large momentum (the leading jet parton) and the second parton in the initial state is a thermal parton from the quark gluon plasma. The rate of flavor conversions depends on the mean free path $\lambda$ of fast partons.

Conversions between quarks and gluons should obscure their different color factors coupling them to the medium. Instead of a relative factor 9/4 in $\hat{q}$ only an average color factor should be observable in a long enough medium. It was pointed out that a larger quenching for gluons could be reflected in more suppression of protons compared to pions given the preference of gluon to proton fragmentation in modern fragmentation functions [9]. Jet conversions should soften this effect and increase the proton to pion ration in central collisions [10, 11].

Fig. 1 shows the ratio of nuclear modification factors $R_{AA}$ for protons and pions with and without conversions between quarks and gluons taken into account [7]. Clearly, flavor conversions lead to less proton suppression.

Conversions had also been discussed before for photons and dileptons. Fast quarks and gluons can create real or virtual photons through Compton and annihilation processes with the medium, $q + g \rightarrow \gamma + g$, $q + \bar{q} \rightarrow \gamma + g$. It has been realized over the years that this process can make a large contribution to the overall yield of photons or dileptons [12, 13, 14, 15, 16, 17]. Fig.
Figure 1: Left panel: The nuclear modification factor $R_{AA}$ for direct photons with and without conversions switched on, calculated in the model introduced in [7] (preliminary PHENIX data from [18]). Right panel: The ratio of nuclear modification factors for protons and pions is approaching one if conversions are allowed.

Figure 2: $R_{AA}$ for neutral kaons with and without conversion processes allowed. The strangeness in the jet sample is driven towards equilibrium by coupling it chemically to the quark gluon plasma.

Also shows the nuclear modification factor for direct photons with and without jet conversions into photons from the computation described in [7] together with data from PHENIX.

Most recently we predicted an enhancement of strange hadrons from jet conversions at RHIC energies. This is driven by a strong chemical gradient between the jet sample at RHIC and the quark gluon plasma. While strangeness is equilibrated in the latter, it contributes only a small fraction ($<5\%$) to the former. Elastic channels like $g + g \rightarrow s + \bar{s}$ and in particular kick-out reactions like $g + s \rightarrow s + g$ can lead to an enrichment of strangeness in the jet sample. Obviously, for a sufficiently long medium the jet sample would be driven toward chemical equilibrium through interactions with the chemically equilibrated medium. Fig. 2 shows the expected nuclear modification factor for neutral kaons at RHIC. For the perturbative elastic rates chosen in [7] with a $K$ factor of 4 we see a clear enhancement extending above 10 GeV/c.

We have also checked the effect of conversions on heavy quark production [19]. We do not find any significant yields of charm or bottom quarks at high $P_T$ from these processes. The same
is true even at LHC energies. The reason is that thresholds and low center of mass energies suppress pair production in interactions of jets with the medium, and kick-out reactions suffer from small heavy quark densities in the medium to begin with. Even for charm at LHC we do not expect chemical equilibration and there is no large chemical gradient between heavy quarks in jets and the medium.

We have also studied the effect of flavor conversions on the azimuthal asymmetry $v_2$. It was first pointed out in Ref. [20] that photons from jet-medium interactions should be more abundantly produced in the direction where the medium is thicker, leading to a negative contribution to $v_2$. See [21] for comprehensive calculations of photon elliptic flow. It is important to realize that this mechanism is generally true for all particles produced in jet-medium interactions [22]. In particular, we expect it to hold for additional strange hadrons produced at RHIC. Fig. [3] shows the effect of flavor conversions on the azimuthal asymmetry $v_2$ of up, down and strange quarks as well as gluons. As predicted, conversions make light quarks and gluons behave similarly while there is a significant decrease in the $v_2$ of strange quarks due to the additional large yield with a negative contribution. Note that the total $v_2$ is determined from summing up all sources of particles both with positive and negative $v_2$. Fig. [4] shows the resulting azimuthal asymmetry $v_2$ that we expect for kaons at RHIC [22].

In summary, we have shown that jet conversions can lead to measurable signatures in hadron production at high $p_T$. We predict an enhancement of strange hadrons at high $p_T$ at RHIC and a suppression of their azimuthal asymmetry coefficient $v_2$.

Acknowledgments

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Figure 4: The resulting azimuthal asymmetry $v_2$ for kaons which is expected to be suppressed compared to that of pions. Data from [23, 24].

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