System size and energy dependence of high $p_T$ hadron production measured with PHENIX experiment at RHIC

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PHENIX has measured high transverse momentum ($p_T$) identified hadrons in different collision species and energies in the last five RHIC runs. The systematic study of the high $p_T$ hadron production provides an idea on interaction of hard scattered partons and the matter created in relativistic heavy ion collision. The $\eta/\pi^0$ ratio is measured in Au+Au collisions, which gives a hint on the system thermalization and particle production. A future measurement of hadron and photon measurement is discussed.

1. Introduction

One of the essential questions in relativistic heavy ion collisions is how the system is thermalized from the early stages of collisions. A recent theoretical implication of direct photon data from the PHENIX experiment\cite{1,2} says that the thermalization time of the partonic system is $\tau \sim 0.26\text{fm}/c$\cite{3}. It would imply that the partonic system is almost suddenly thermalized after initial collisions. This rapid thermalization is also suggested from a quark and kinetic energy scaling of strong elliptic flow measured by the PHENIX experiment\cite{4}. The collective behavior of partons may be realized already at an early stage when the collisional area is most anisotropy defined by the initial collision geometry.

One idea to investigate the state of the matter created is to measure the interaction of well-calibrated probe, such as hard scattered partons, with the matter. In high energy p+p collisions, high transverse momentum ($p_T$) hadrons are mostly produced from jets, the fragments of hard scattered partons. In the presence of a hot dense matter produced in relativistic heavy ion collisions, such partons may lose energy, and therefore the fragmentation function is modified. It may result in a different particle yield ratio as a function of momentum compared to p+p collisions. Hard scattered partons may also combine with partons in the medium, and produce mid-$p_T$ (2-5 GeV/c) particles. It is a different mechanism from the one expected in p+p collisions and can be said as an interaction of the partons with the medium as well\cite{5}.

A systematic study of identified hadron production at high $p_T$ provides many
intriguing information on the matter. In this presentation, the recent measurement on high $p_T$ identified hadrons at a mid-rapidity is reviewed and discussed. A possible future measurement is also presented.

2. Measurement of high $p_T$ $\pi^0$ production in Au+Au and Cu+Cu collisions

PHENIX has measured $p_T$ spectra of $\pi^0$ at different energies and different collision systems. Figure 1 shows the $p_T$ spectra of $\pi^0$ in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV for different centralities from RHIC Year-4 run. The measurement is extended up to 20 GeV/$c$, compared to year-2 run, with 900 M minimum bias collisions. Figure 2 shows the $p_T$ spectra of $\pi^0$ in Cu+Cu collisions at the same c.m.s. energy from RHIC Year-5 run. These measurement were made through $\pi^0 \rightarrow \gamma \gamma$ channel.

The change of the spectra shape as a function of centrality can quantitatively be evaluated using a nuclear modification factor ($R_{AA}$) defined as:

$$R_{AA} = \frac{(1/N_{coll})dN^{AuAu}/dydp_T}{<N_{coll}> (1/\sigma^{pp}_{inel})d\sigma/dydp_T}$$

where, $<N_{coll}>$ is the average number of binary nucleon-nucleon collisions. The ratio is expected to be unity if particles are produced just by hard scattering, and no nuclear effect is involved.
Figures 3 and 4 show $R_{AA}$ for $\pi^0$ in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV. The centrality in two plots are different (30-40% for Au+Au and 0-10% for Cu+Cu), but the number of participant nucleons are around same. It is seen that the suppression factors in the two systems are almost same. It is even clearly seen in the integrated $R_{AA}$ for $p_T > 7$ GeV/$c$ as shown in Fig. 3. At a high $p_T$ ($p_T > \sim 5$ GeV/$c$), $\pi^0$'s are mostly from jets, and therefore should essentially have the same slopes expected from a hard scattering, over centralities. The same $R_{AA}$ at the same number of participants would imply that the amount of the matter that hard scattered partons suffers in both systems are same even though the shape of collisional regions are different. Comparisons with some model calculations are also overlaid in the plot.

The energy dependence of hadron suppression has been measured in Cu+Cu collisions (Fig. 6). It turned out that the suppression is degraded as energy decreases, and the Cronin-like enhancement becomes visible. It suggests the energy loss is smaller in the lower c.m.s. energy, but it is also possible that the particle production at a lower energy does not completely follow the number of binary collision scaling in heavy ion collisions. The direct photon results confirmed that the probability of an initial hard scattering that produces high $p_T$ hadrons is scaled as the number of binary collisions only at $\sqrt{s_{NN}} = 200$ GeV. We should measure direct photons at lower energy as well to make a conclusive statement.

3. $\eta$ spectra and $\eta/\pi^0$ ratio in Au+Au collisions

PHENIX has measured $\eta$ in a wide $p_T$ range of from 1.5 GeV/$c$ to 15 GeV/$c$ via $\eta \rightarrow \gamma \gamma$ channel. Figure 7 shows the $\eta$ spectra over centralities in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The $\eta/\pi^0$ ratio has been particularly of interest for a direct
photon measurement. The value has been used to estimate the yield of $\eta$ from $\pi^0$ yield in case that they are not clearly observed. Surprisingly, the ratio in Au+Au is well described by PYTHIA [8] (Fig. 6), though copious "soft" $\eta$'s is expected in Au+Au collisions. This implies that either the thermal production of $\eta$ and $\pi^0$ is similar to the one expected from a hard scattering followed by fragmentation function, or the system is almost thermalized immediately after the collisions.
4. Future measurement of the particle production in PHENIX

One way to investigate the thermalization scenario is to measure the hadron spectra as a function of rapidity. A theoretical model on the rapid thermalization assumes an interaction of a nucleus with the strong color field created by the other incoming nucleus\(^{[10]}\). The model suggests that the amount of color potential receiving from the incoming nucleus depends on the rapidity, and thus predicts different temperature of hadrons at different rapidities. There is a prediction also for photon production\(^{[11]}\). The prediction says that the rapidity dependence of photon temperature is different depending on the system expansion scenarios.

The PHENIX experiment has an upgrade project to strengthen the PID and calorimetric capability at forward rapidity region. Figure\(^{[7]}\) shows a calorimeter that is going to be installed into the rapidity of \(y=1-2\) in 2011. The measurement at forward rapidity region would give hints on understanding the particle production mechanism at RHIC.

5. Summary

PHENIX has measured high transverse momentum \((p_T)\) identified hadrons in different collision species and energies in the last five RHIC runs. The systematic study of the high \(p_T\) hadron production provides an idea on interaction of hard scattered partons and the matter created in relativistic heavy ion collision. The \(\eta/\pi^0\) ratio is measured in Au+Au collisions, which gives a hint on the system thermalization and particle production.
Fig. 9. PHENIX nose cone calorimeter.

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