



Detail study of the medium created in Au+Au collisions with high p_T probes by the PHENIX experiment at RHIC

Takao Sakaguchi, for the PHENIX Collaboration

Brookhaven National Laboratory, Upton, NY 11973, USA.

Abstract

Recent results on high p_T identified hadrons in Au+Au collisions from the PHENIX experiment are presented. The R_{AA} for π^0 and η are found to be very consistent. The second and fourth order collective flow of π^0 's have been measured and found that v_4/v_2^2 is consistent with the one observed in lower p_T region. Assuming the suppression of the π^0 yield at highest p_T arises from energy loss of partons, we found that the energy loss is L^3 dependent, where L is the path length of the partons in the medium. The $\delta p_T/p_T$'s of high p_T hadrons are computed from 39 GeV Au+Au over to 2.76 TeV Pb+Pb, and found that they vary by a factor of six. We have seen a smooth trend in $\delta p_T/p_T$ from RHIC energy to LHC energy when plotting against charged multiplicity of the systems.

Keywords: QGP, high p_T hadrons, energy loss

PACS: 25.75.-q, 25.75.Bh, 25.75.Ld

1. Introduction

The interaction of hard scattered partons with the medium created by heavy ion collisions (i.e., quark-gluon plasma, QGP) has been of interest since the beginning of the RHIC running [1]. A large suppression of the yields of high transverse momentum (p_T) hadrons which are the fragments of such partons was observed, suggesting that the matter is sufficiently dense to cause parton-energy loss prior to hadronization [2]. The PHENIX experiment [3] has been exploring the highest p_T region with single π^0 and η mesons, which are leading hadrons of jets, and thus provide a good measure of momentum of hard scattered partons. Here, we present the recent results obtained from Au+Au collisions in the Year-2007 run (0.81 nb^{-1}). Fig. 1(a) shows the nuclear modification factors R_{AA} ($\equiv (dN_{AA}/dydp_T)/(\langle T_{AA} \rangle d\sigma_{pp}/dydp_T)$) for π^0 and η 's in 200 GeV Au+Au collisions [4]. They are very consistent each other in spite of hidden strangeness contents in η mesons. This also implies that the fragmentation function is not modified by the medium for the p_T range we measured. Because η has four times larger mass compared to that of π^0 , one can resolve two photons decaying from η up to four times larger p_T of π^0 , resulting in a higher p_T reach with smaller systematic errors with η . The R_{AA} 's in Fig. 1(b) demonstrates that the π^0 yield from the Year-2007 run has smaller errors and is consistent with that from the Year-2004 run [5]. We used the same $p + p$ reference for R_{AA} 's from both Au+Au running.

2. Anisotropy of high p_T π^0 yield

2.1. Collective flow

The transition from anisotropy driven by hydrodynamic flow to anisotropy driven by jet quenching can be probed by the ratio of v_4/v_2^2 , where v_4 is the fourth order and v_2 is the second order flow. Perfect fluid hydrodynamics predicts

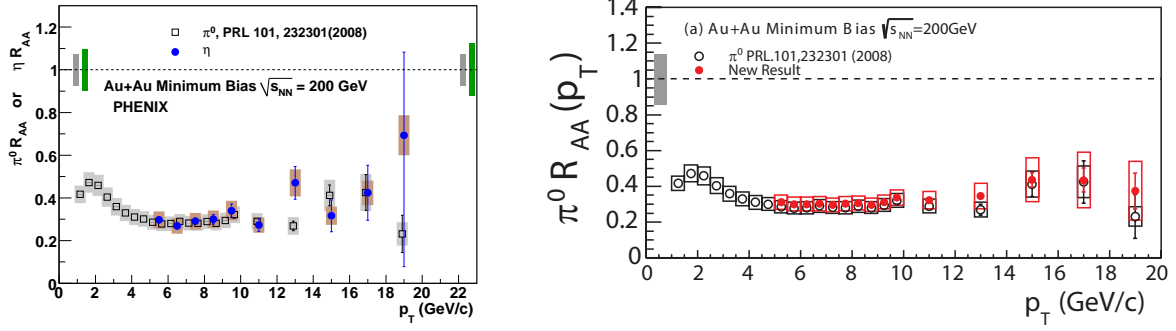


Figure 1. (a, left) R_{AA} for π^0 and η in minimum bias Au+Au collisions. (b, right) R_{AA} for π^0 from the RHIC Year-2004 run and Year-2007 run.

a value of 0.5 for this ratio [6]. The geometrical fluctuations and other dynamical fluctuations, as well as viscous damping, can increase the magnitude of the ratio, especially in central collisions [7]. At high p_T , the directions that maximize collective flow and jet quenching may not be the same [8, 9]. Therefore, this ratio could change in the p_T region where jet quenching begins to dominate. With the large statistics, we were able to measure the v_2 and v_4 of π^0 's with the same second-order event plane (Ψ_2) over a wide p_T range. Fig. 2(a) shows the $v_4(p_T)$ of π^0 in 200GeV Au+Au collisions [10]. We can see significant v_4 values even for $p_T > 5$ GeV/c. Fig. 2(b) shows the v_4/v_2^2 ratios for

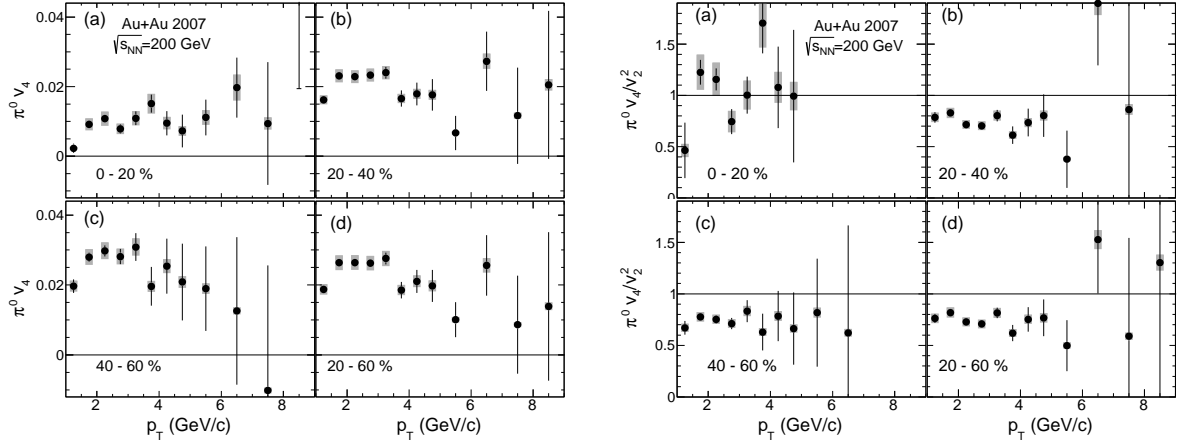


Figure 2. (a, left) v_4 of π^0 , and (b, right) v_4/v_2^2 for various centralities in 200GeV Au+Au collisions.

π^0 obtained in several centrality ranges [10]. The ratios are approximately independent of p_T , with values of ~ 0.8 - 1.0 depending on centrality selections. The constant ratios over the p_T are not trivial at all given several physics processes are involved, and may put additional constraint on dynamical description of the medium. The values for $p_T < \sim 5$ GeV/c are consistent with our prior observations of this ratio for inclusive charged hadron measurements [11].

2.2. Path-length dependence of yield suppression

Using the event plane information, we were also able to measure the R_{AA} of π^0 as a function of $\Delta\phi$ with respect to the event plane. Since the path length in the medium that partons traverse changes by the emission angle with respect to the event plane (especially in peripheral collision case), the angle dependence of the yields can be associated with the path length dependent energy loss of partons. We show the R_{AA} for in- and out-of event planes for π^0 's in 20-30% central 200 GeV Au+Au collisions in Fig. 3 [5]. Depending on the energy loss models, the powers of the path-length dependence change. The data favors an AdS/CFT-inspired (strongly coupled) model rather than a pQCD-inspired (weakly coupled) model, implying that the energy loss is L^3 dependent rather than L^2 dependence, where L denotes the path-length of partons in the medium.

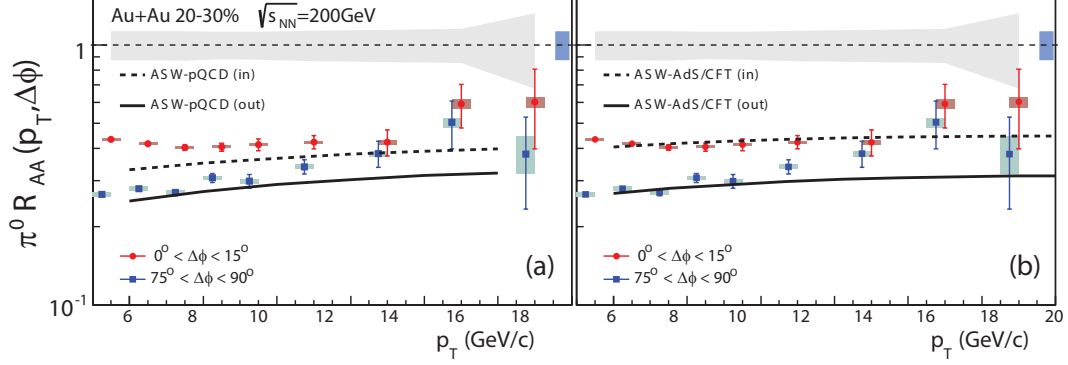


Figure 3. $R_{AA}(p_T, \Delta\phi)$ of π^0 in 20-30% centrality for in-plane and out-of-plane. Data are compared with a pQCD-inspired model (left), and an AdS/CFT-inspired model (right).

3. Fractional momentum loss of hadrons in A+A collisions

Experiments have been looking at the suppression of the yield at a given p_T to quantify the energy loss effect. However, the suppression is primarily the consequence of the reduction of momentum of hadrons which have exponential p_T distributions. We have statistically extracted the fractional momentum loss ($S_{\text{loss}} \equiv \delta p_T / p_T$, $\delta p_T \equiv p_T - p'_T$, where p_T is the transverse momentum of $p + p$ data, and p'_T is that of Au+Au data) of the partons using the hadron p_T spectra measured in $p + p$ and Au+Au collisions [5]. Fig. 4(a) depicts the method to compute the S_{loss} . Using this method, we computed the S_{loss} in Au+Au collisions at $\sqrt{s_{NN}} = 39, 62$, and 200 GeV as shown in Fig. 4(b) [12]. We also computed the S_{loss} in 2.76 TeV Pb+Pb collisions using charged hadron spectra measured by the ALICE experiment [13] as shown in Fig. 4(c). S_{loss} 's vary by a factor of six from 39 GeV Au+Au to 2.76 TeV Pb+Pb collisions. Naively, one

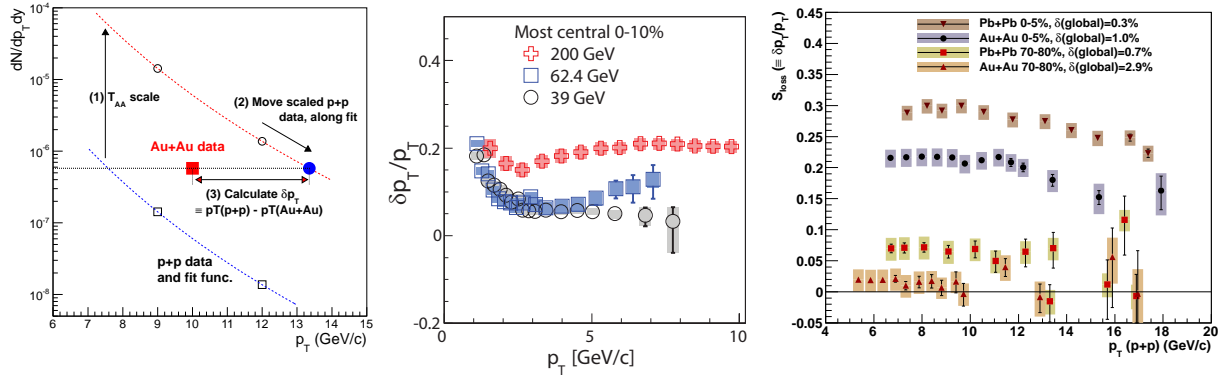


Figure 4. (a, left) Method of calculating average S_{loss} . We scaled the $p + p$ yield by T_{AA} corresponding to centrality selection of Au+Au data, shifted the $p + p$ points closest to Au+Au in yield, and calculated momentum difference of $p + p$ and Au+Au points. (b, middle) S_{loss} for π^0 for 0-10% centrality 39, 62, and 200 GeV Au+Au collisions. (c, right) S_{loss} for π^0 in 200 GeV Au+Au collisions and charged hadrons in 2.76 TeV Pb+Pb collisions.

expects that the energy loss is energy density dependent. We plotted the S_{loss} against charged multiplicity, $dN_{\text{ch}}/d\eta$, at $p_T(p + p) = 7 \text{ GeV}/c$, which is reasonably in hard scattering regime as shown in Fig. 5. We assume $dN_{\text{ch}}/d\eta$ well represents the energy density of the system. It is interesting to note that the trend of S_{loss} in Au+Au collisions points to the most central points in Pb+Pb collisions at LHC. The 62 GeV Au+Au point and the most peripheral ALICE point are off the trend. These features have not been found by looking at R_{AA} 's. In order to cross-check the new result, we have performed a power-law fit to the points on $\delta p_T / p_T$ vs $dN_{\text{ch}}/d\eta$, and compared the power with the result obtained from a different method [14]. We fitted the points of this work with $\delta p_T / p_T = \beta (dN_{\text{ch}}/d\eta)^\alpha$ assuming $dN_{\text{ch}}/d\eta \propto N_{\text{part}}$, and obtained α as 0.55 ± 0.06 . Assuming the spectra shape is power-law with the power n , one can write the relation

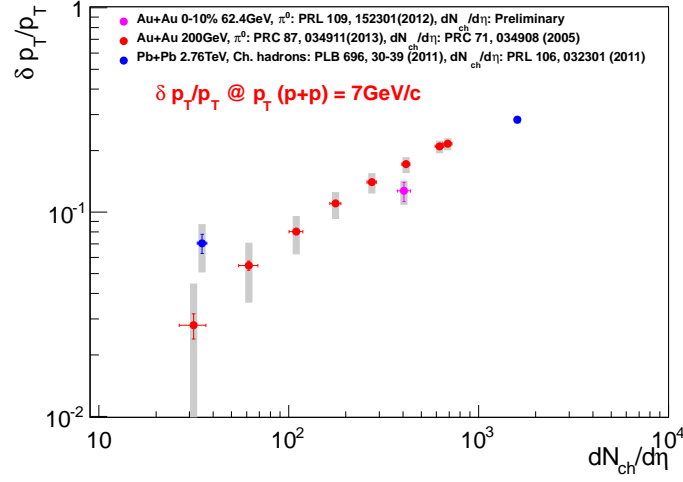


Figure 5. $\delta p_T/p_T$ as a function of $dN_{ch}/d\eta$ for π^0 in 200 GeV and 62.4 GeV Au+Au collisions measured by PHENIX and charged hadrons in 2.76 TeV Pb+Pb collisions measured by ALICE.

between S_{loss} and R_{AA} as:

$$S_{\text{loss}} \equiv \delta p_T/p_T = \beta N_{\text{part}}^\alpha, R_{AA} = (1 - S_{\text{loss}})^{n-2} = (1 - \beta N_{\text{part}}^\alpha)^{n-2}$$

Following this relation, we obtained the power α as 0.57 ± 0.13 from the fit to the integrated R_{AA} as a function of N_{part} in the literature [14]. Thus, we confirmed that the powers obtained by two methods are very consistent.

4. Summary

We presented the recent results on high p_T identified hadrons in Au+Au collisions from the PHENIX experiment. The R_{AA} for π^0 and η are found to be very consistent. The second and fourth order collective flow of π^0 's have been measured and found that v_4/v_2^2 is consistent with the one observed in lower p_T region, which is not trivial given several physics processes are involved. We found that the energy loss is L^3 dependent, where L is the path length of the partons in the medium. The $\delta p_T/p_T$'s of high p_T hadrons are computed from 39 GeV Au+Au over to 2.76 TeV Pb+Pb, and found that they vary by a factor of six. We have seen a smooth trend in $\delta p_T/p_T$ from RHIC energy to LHC energy when plotting against charged multiplicity of the systems. We performed power-law fit to the $\delta p_T/p_T$ vs $dN_{ch}/d\eta$, and obtained a power that is very consistent with the one obtained from the fitting to the integrated R_{AA} . We are going to add points from other systems to systematically investigate the $\delta p_T/p_T$.

References

- [1] X. -N. Wang, Phys. Rev. C **58**, 2321 (1998).
- [2] S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **91**, 072301 (2003).
- [3] K. Adcox *et al.* [PHENIX Collaboration], Nucl. Instrum. Meth. A **499**, 469 (2003).
- [4] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. C **82**, 011902 (2010).
- [5] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. C **87**, 034911 (2013).
- [6] N. Borghini and J. -Y. Ollitrault, Phys. Lett. B **642**, 227 (2006).
- [7] C. Gombaud and J. -Y. Ollitrault, Phys. Rev. C **81**, 014901 (2010).
- [8] J. Jia, Phys. Rev. C **87**, 061901 (2013).
- [9] X. Zhang and J. Liao, Phys. Rev. C **87**, 044910 (2013).
- [10] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. C **88**, 064910 (2013).
- [11] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **105**, 062301 (2010).
- [12] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **109**, 152301 (2012).
- [13] K. Aamodt *et al.* [ALICE Collaboration], Phys. Lett. B **696**, 30 (2011).
- [14] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **101**, 232301 (2008).