# High $p_{\mathrm{T}}$ direct photon spectra and azimuthal anisotropy measurements in 200 GeV Au+Au collisions at RHIC-PHENIX

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**Abstract.**

Direct photons are a powerful probe to study the property of Quark Gluon Plasma (QGP) in high energy heavy ion collisions. In non-central collisions, the anisotropy of the collision region produces the different pressure gradients and particle density that results in different anisotropy of particle emission, depending on the production processes of photons. Therefore, an azimuthal anisotropy parameter, $v_2$ is a powerful tool to explore the source of direct photons. We report on the latest direct photon analysis of nuclear modification factor in $\sqrt{s_{NN}}$ = 200 GeV and 62.4 GeV Au+Au collisions, and $v_2$ at high $p_{\mathrm{T}}$ in 200 GeV Au+Au collisions at RHIC-PHENIX (Run4). We also present the analysis status, using a larger statistics and better reaction plane information from a new detector available from RHIC Run7 data.

## 1. Introduction

In the heavy ion collision experiment at the Relativistic Heavy-Ion Collider (RHIC), the strong suppression is observed at large transverse momenta ($p_{\mathrm{T}}$) hadron yields in central Au+Au collisions when compared to the p+p scaled the number of binary nucleon-nucleon collisions[1]. The observed high $p_{\mathrm{T}}$ suppression is implemented as a consequence of the energy loss of hard-scattered partons going through the high density matter[2]. On the other hand, non-suppression of the high $p_{\mathrm{T}}$ direct photon yield is observed in Au+Au collisions[3]. Photons can carry out information on the states where they are emitted because they do not interact strongly with any other particles, and thus direct photons are one of the most effective probes to study properties of hot dense medium at initial state of heavy ion collisions

Although measurements of direct photons as penetrating probes allow us more study about thermodynamical quantities such as temperature and number of degrees of freedom, there are many photon sources in addition to hard scattered photons in heavy

‡ For the full list of PHENIX authors and acknowledgments, see Appendix 'Collaborations ' of this volume

ion collisions. In non-central collisions, the shape of collision region would have spatial anisotropy like ellipsoid. The different pressure gradients and particle density in the participant part which causes different anisotropy of particle emission, depending on the production processes of photons.

The second harmonic coefficient parameter $v_2$ of the azimuthal distribution of the particles produced in heavy ion collisions is defined by

$$\frac{dN}{d(\phi - \Psi_{RP})} \propto 1 + 2v_2 \cos(2(\phi - \Psi_{RP})) \quad (1)$$

where $\phi$ is the emission angle of the particle and $\Psi_{RP}$ is the direction of the reaction plane which is determined by another anisotropy existing in the forward particle flow.

If more particles are emitted to the short axis direction of the ellipsoid, they should make positive sign $v_2$. The photons from initial Compton-like hard scattering are expected to show zero $v_2$ if they do not interact with the hot dense matter. The $v_2$ of photons from parton fragmentation would have the similar $v_2$ to the hadrons due to the hadron suppression in high $p_{\rm T}$. On the other hand, the photons produced by Bremsstrahlung of hard-scattered partons should have negative sign $v_2$, because the partons emitted to the large ellipsoidal axis of the collision region would produce more Bremsstrahlung photons.

## 2. Analysis Method

The data sets are in Au+Au collisions at RHIC-PHENIX in Run4. The event trigger and centrality definition are given by the Beam-Beam Counters (BBC, $|\eta|$=3.1$\sim$3.9) and the Zero Degree Calorimeters (ZDC, $|\eta|$=2 mrad). The reaction plane is determined by the two BBCs.

Photons are detected by Electro Magnetic Calorimeter (EMCal) which has an acceptance of -0.35 $< \eta <$ 0.35 and $\pi$ radians in azimuth. Photon candidate clusters are selected by their time-of-flight and the corresponding shower profiles in the EMCal.

$\pi^0$ is reconstructed by making invariant mass distribution of $2\gamma$. In order to subtract the combinatorial background, mixed pair distribution is constructed from different events with similar centrality, z-vertex position, and reaction plane angle. We also estimated the distribution of well known hadrons besides $\pi^0$ for example, $\eta$, $\omega$, $\eta^{'}$ and $\rho$. We assumed that these particles follow $m_{\rm T}$ scaling, the hadron decay photon distribution are generated by a Monte-Carlo simulation.

## 3. Direct Photon Analysis

The direct photon yields measured in heavy ion collisions by PHENIX, and they are in good agreement with a NLO pQCD calculation scaled by the number of binary nucleon collisions within experimental errors and theoretical uncertainties[3]. The nuclear modification factors ($R_{\rm AA}$) which reflect medium effect in nuclear-nuclear collisions, defined as the ratio of Au+Au yield to p+p yield normalized by the number of binary

nucleon collisions are presented in $\sqrt{s_{NN}} = 200$ GeV and 62.4 GeV. Figure.1 and 2 show the direct photon $R_{\rm AA}$ in 200 GeV and 62.4 GeV with NLO pQCD prediction curve. These figures indicate non suppression of direct photon yield at Au+Au collision in 5 to 8 GeV/c or 12 GeV/c, then strong confirmation is provided that large suppression of high $p_{\rm T}$ hadrons caused by parton energy loss in the hot dense medium. On the other hand, a little suppression is observed at high $p_{\rm T}$ direct photon analysis recently. This effect may be due to difference of cross section among p+n, n+n, p+p (isospin effect).

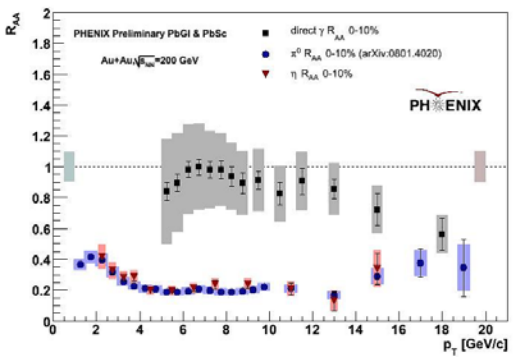


**Figure 1.** Nuclear modification factor of $\pi^0$, $\eta$, and direct photon in Au+Au 200 GeV. In 5 to 12 GeV/c region, parton energy loss in the medium seems to be origin of hadron suppression. Above 12 GeV/c, direct photon yield may be suppressed by isospin effect.

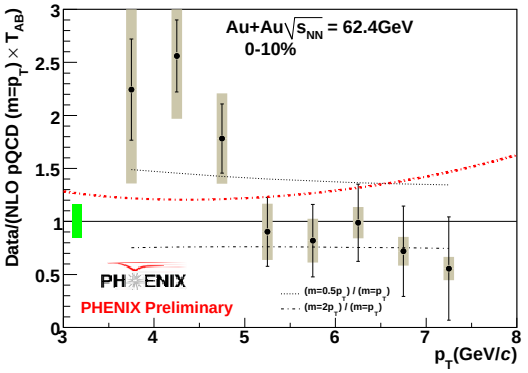


**Figure 2.** Divided direct photon spectra by scaled NLO pQCD calculation. Red line shows fitted prediction curve to Run5 p+p data and scaled by 62.4/200 ($x_{\rm T}$ scaling). If we compared red line with data, we can see a little suppression of direct photon yield in high $p_{\rm T}$ .

## 4. Direct photon $v_2$

Direct photon $v_2$ is estimated from,

$$v_2^{\rm direct} = \frac{R \cdot v_2^{\rm inclusive} - v_2^{\rm BG}}{R-1}, \qquad R = N^{\rm inclusive}/N^{\rm BG} \tag{2}$$

where $v_2^{\rm direct}$, $v_2^{\rm inclusive}$, and $v_2^{\rm BG}$ are direct photon $v_2$, inclusive photon $v_2$ and hadron decay back ground $v_2$. $N^{\rm BG}$ and $N^{\rm inclusive}$ are the number of photons originating from hadronic decay ($\pi^0$, $\eta$, $\omega$, $\eta^{'}$, $\rho$) and all of the measured photon respecting.

Figure.3 shows the direct photon $v_2$ and $\pi^0 v_2$. The direct photon $v_2$ is consistent with zero within statistical and systematic errors. The result supports that the large fraction part of direct photons come from initial Compton-like hard scattering in order. To study the effect of another emission source, it is necessary to do more detail calculation with larger statistics and compared with other analysis results.

Although we can see the first measurement of direct photon $v_2$ in run4, direct photon $v_2$ analysis needs more accuracy to compare with theoretical predictions which would be

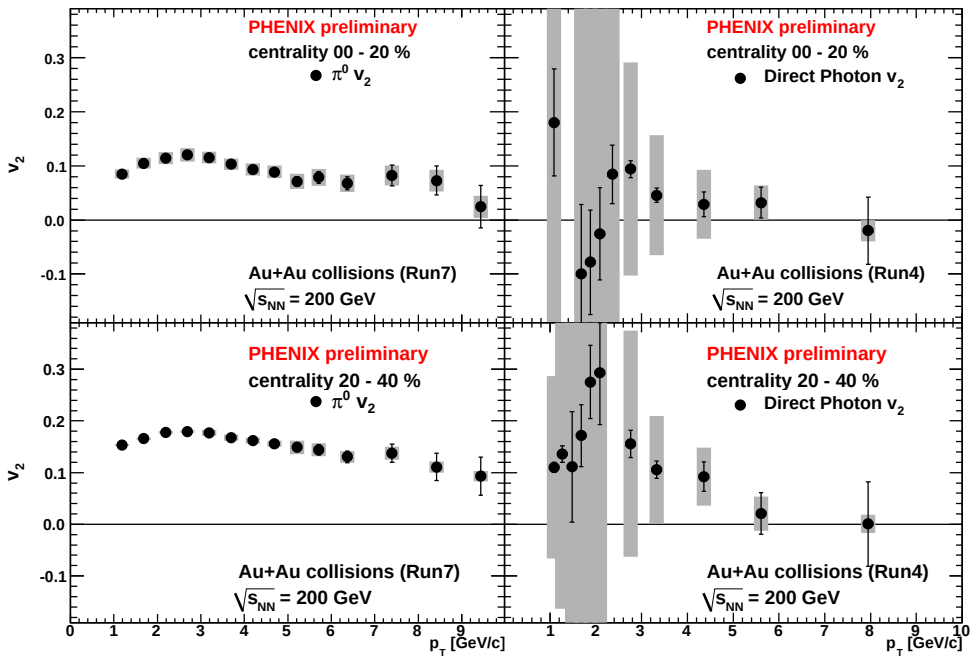


**Figure 3.** $\pi^0$ and direct photon $v_2$ in Au+Au $\sqrt{s_{NN}}$ = 200 GeV. $\pi^0 v_2$ is meacured by Run7 data set and reaction plane detector. Direct photon $v_2$ is estimated by Run4 data set.

realized in high statistics. In the Run7, about 3 times statistics are collected at $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions in PHENIX. We can show the measured $\pi^0 v_2$ result with a part of Run7 statistics ($\sim$ 1.8B events) in Figure.3. In this analysis, reaction plane angle is defined by reaction plane detector (RXNP) which has about twice resolution of BBC.

## 5. Summary

In conclusion, the direct photon of nuclear modification factor is measured in $\sqrt{s_{NN}}$ = 200 GeV and 62.4 GeV Au+Au collisions, and elliptic flow parameter ($v_2$) is measured in 200 GeV in Au+Au collisions at RHIC-PHENIX. Within statistical and systematic errors, the direct photons $v_2$ is consistent with zero. This result supports to the hard scattered photon existence in high $p_{\rm T}$ region and consistent with the contention of $R_{AA}$ analysis. We showed the isospin effect maybe existing in direct photon. Direct photon $v_2$ needs more accuracy to compare with theoretical predictions. Finally, the update of $\pi^0 v_2$ which is estimated from high statistics and resolution of reaction plane angle in Run7 is reported.

## References

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