Direct Photons in PHENIX at RHIC

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Abstract.

PHENIX results on direct photon production in p+p, d+Au,Cu+Cu and Au+Au collisions are presented. Direct photon yield at high p_{T} is consistent with the dominance of the LO processes (inverse compton scattering and quark-antiquark annihilation). The low p_{T} direct photons exhibit an order of magnitude exponential enhancement consistent with thermal emission from QGP. The thermal nature of this enhancement is further confirmed by large elliptic flow of direct photons below $p_{\mathrm{T}} \sim 5 GeV/c$.

1. Introduction

Among the observables used to probe the high temperature and high density phase of heavy nucleus collisions direct photons are considered of particular interest. Nuclear modifications to the yield of direct photons reflects media effects on contributing production mechanisms. The anisotropy of high p_{T} photon production reflects the geometry of the medium. The emission from expanding media influences both the rate and azimuthal asymmetries of photon production at low to medium p_{T} (1-5GeV/c) [1, 2].

2. Direct photon measurements

The data presented in this paper are from p+p , d+Au , Cu+Cu and Au+Au data sets at $\sqrt{s_{NN}}$=200 GeV taken with the PHENIX detector [3] in 2004-2008. The PHENIX central arms, each covering ±0.35 units of pseudorapidity around midrapidity and 90° in azimuth, contain charged-particle tracking chambers and two kinds of electromagnetic calorimeters. The BBC and Zero-Degree Calorimeters (ZDC) were used for minimum bias event selection and centrality determination (when appropriate).

Direct photons yields, their flow and gamma-jet correlations are measured by statistical subtraction of the estimated meson (mainly π^0) decay photon contribution from the inclusive photon and γ-h samples. An alternative method for measuring direct photons is provided by the low-mass lepton e^+e^- pairs produced by a higher order QED correction to the real photon emission process. Any source of real photons must also emit virtual photons and their yield is related to that of real photons. In the low mass

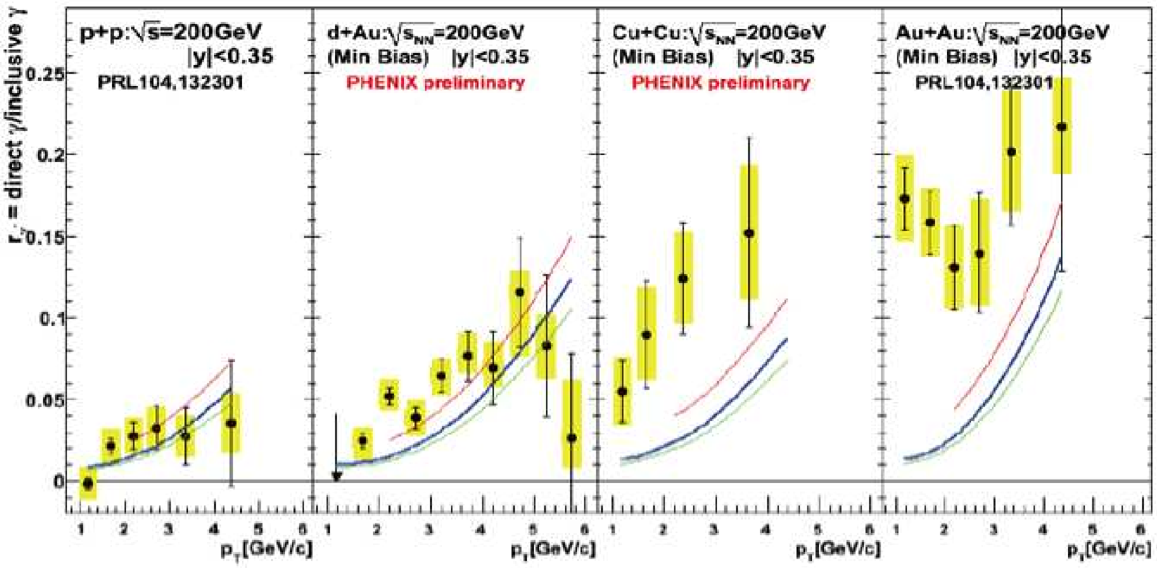

Figure 1. (color online) The fraction r_γ of direct photons in the inclusive photon yield as a function of p_T in p+p , d+Au , Cu+Cu and Au+Au (min. bias) collisions [1]. The error bars and the boxes represent statistical and systematic uncertainties, respectively. The curves are from an NLO pQCD calculation.

region, where the p_T of the e^+e^- pair is much greater than its mass ($m_{ee} \ll p_T$), the yield of the intermediate virtual photons is approximately the same as that of real photons. Therefore, in this quasi-real virtual photon region, the production of real direct photons can be deduced from measurements of e^+e^- pairs.

Figure 1 shows the fraction $r_\gamma = \frac{direct\ \gamma}{inclusive\ \gamma}$ of the direct photon component in p+p , d+Au , Cu+Cu and Au+Au collisions, respectively. The curves represent the expectations from a NLO pQCD calculation [4]. The three curves correspond (from top to bottom) to the theoretical scales set to $\mu = 0.5\ p_T$, p_T, and 2 p_T, respectively. While the fraction r_γ is consistent with the NLO pQCD calculation in p+p and d+Au, it is larger than the calculation in both Cu+Cu and Au+Au for $p_T < 5$ GeV/c.

The direct photon yield computed using the relation $dN_\gamma^{dir}(p_\mathrm{T}) = r_\gamma \times dN_\gamma^{incl}(p_T)$ is compared in Figure 2 to the direct photon data from [5, 6] and NLO pQCD calculations. In central Au+Au it shows excess over collision scaled $p + p$ data, and the shape of the excess is well described by a exponential with inverse slope $T \simeq 220$ MeV. If the direct photons in Au+Au collisions are of thermal origin, the inverse slope T is related to the initial temperature T_{init} of the dense matter. In hydrodynamical models, T_{init} is 1.5 to 3 times T due to the space-time evolution [7].

If photons are radiated inside an expanding matter having azimuthally anisotropic momentum distribution, their momenta add or subtract for radiation along or opposite to the motion. Neglecting pion mass, thermal photons must have the same or greater v_2 as pions [8]. An earlier low p_T measurements of photon flow (v_2) for π^0 and inclusive

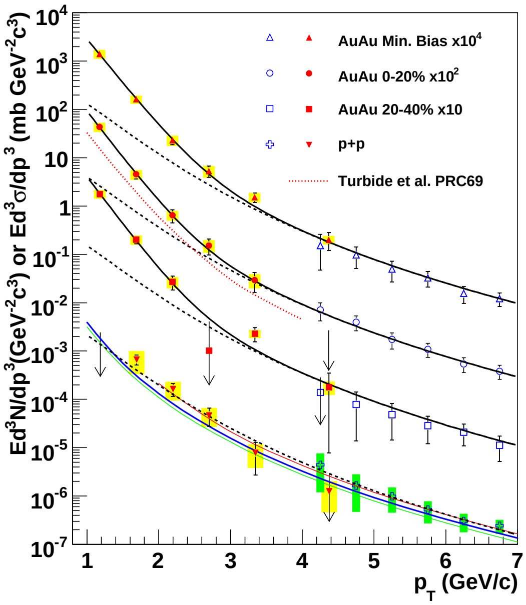

Figure 2. (color online) Invariant cross section ($p + p$) and invariant yield (Au+Au) of direct photons as a function of p_T [1, 5, 6]. The solid curves on the $p + p$ data represent NLO pQCD direct photon calculations [4]. The dashed curves on the Au+Au data show the $p + p$ fit scaled by T_{AA}. The solid curves on the Au+Au data are an exponential fit plus the T_{AA} scaled $p + p$ fit.

photons) has been published in [9]. Using the high statistics p+p and Au+Au data from 2007run PHENIX extended p_{T} range for v_2 measurements to 15 GeV/c and dramatically improved v_2 precision in the low to medium p_{T} range.

To correct for a large contribution from hadron decays, predominantly from π^0 (80%) and η (15%), and cluster merging for high p_{T} π^0 the elliptic v_2 flow of the direct photons was calculated as $v_2^{\gamma,dir} = \frac{R_\gamma(p_T)\times v_2^{\gamma,inc} - v_2^{\gamma,bg}}{R_\gamma(p_T)-1}$, where $N^{inc} = N^{meas} - N^{hadr}$ is for inclusive photons and $R_\gamma(p_T) = N^{inc}(p_T)/N^{bg}(p_T)$ is the direct photon excess ratio. The v_2 values for π^0 in minimum bias Au+Au events are compared to similar data for inclusive photons in Figure 3 left panel [2]. The v_2 data for direct photons in the most central Au+Au events are shown in the right panel in the same Figure.

Two sets of points (inclusive photons and π^0) are barely different in the thermal p_{T} range indicating the dominance of the component with flow values close to that of hadrons. Flow of photons drops at high p_{T} consistent with a growing contribution from hard scattering. Qualitative conclusions of the left panel are confirmed quantitatively in the right panel displaying subtraction data for direct photons in the most central Au+Au collisions. The meassured v_2 has value comparable to that of hadrons below $p_T \sim 5GeV/c$ and drops to zero at higher p_{T} as expected if LO processes (reverse compton scattering and quark-antiquark annihilation) dominate in that p_{T} range.

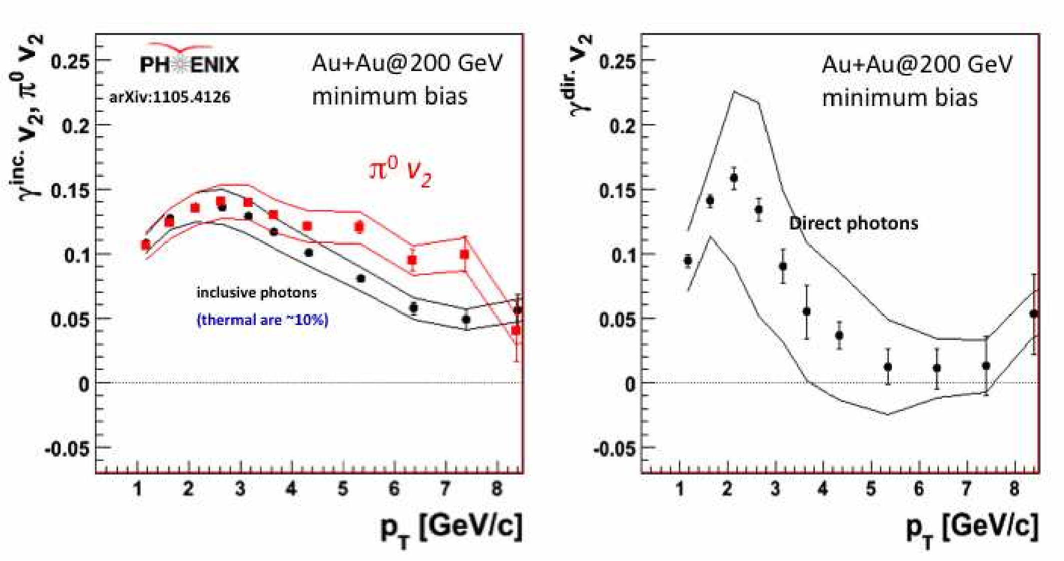

Figure 3. (color online) Left panel: Comparison between elliptic flow (v_2) of π^0 and inclusive photons in mim. bias $Au+Au$ collisions. Right panel: Direct photon flow in the most central $Au+Au$ collision computed a using subtraction procedure.

3. Summary

The direct photon production data accumulated by PHENIX confirm unique role of direct photons in probing prehistory of the sQGP and its properties. Consistency between high p_{T} yields of direct photons in $Au+Au$ collisions and collision scaled $p+p$ yield confirms LO dominance at high p_{T} and validity of collision scaling. The low p_{T} behavior of direct photons in central $Au+Au$ collisions is dramatically different from all other particles exhibiting an order of magnitude exponential enhancement as $p_T \to 0$ suggestive of thermal emission from the sQGP. The assumed thermal nature of low to medium p_{T} photons is further confirmed by the presense of a large flow of direct photons in p_{T} range below 5 GeV/c.

References

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