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Direct Photons at the PHENIX Experiment: From Large to Small Systems †

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Abstract: Direct photons are a unique probe to study the properties of the medium created in heavy ion collisions. Low transverse momentum (p_T) direct photons are of special interest since thermal photons are supposed to be dominant, while at high p_T direct photons come from initial hard scattering (pQCD). PHENIX has observed a large excess of direct photon yield as well as large azimuthal anisotropy at low p_T in Au+Au collisions at the c.m.s energy per nucleon pair $\sqrt{s_{NN}} = 200$ GeV. The mechanism to produce a large direct photon yield with a large elliptic anisotropy (v_2) is not well understood yet. PHENIX has made systematic measurements of direct photons with different collision energies and system configurations. It has been found that direct photon yield $dN_\gamma/d\eta$ is proportional to charge particle multiplicity $(dN_{ch}/d\eta)^{1.25}$. This behavior holds for beam energies measured both at RHIC and at the LHC in large systems. This scaling suggests that there is a transition from p+p to A+A system which could be understood with the analysis of smaller systems like p+Au and d+Au.

Keywords: direct photons; electromagnetic probes; photon scaling

1. Introduction

Due to the fact that photons do not interact strongly in heavy ion collisions, they can carry primordial information about the collision at the time of their production, namely temperature evolution and collective motion of the matter. Photons are very abundant in heavy ion collisions, however, most of them come from hadronic decays, mainly π^0 and η to $\gamma\gamma$. The so called direct photons are those which do not come from hadronic decays; they can be determined experimentally by subtracting from the total yield the expected fraction coming from hadron decays. In large systems and at low p_T, it is expected that the dominant source of direct photons is emission from the QGP and from the hadronic gas phase; whereas at high p_T, their origin is connected to initial state interactions produced in the hard scattering.

2. Challenges

The PHENIX experiment measured not only the direct photon yield but also its azimuthal anisotropy in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. A large yield and a large v_2 were found, which is challenging to theoretical models because a large yield implies early emission when the temperature is higher, but a large v_2 implies late emission when the flow is fully developed. Details can be found in [1]. In order to understand this observation, PHENIX has performed similar measurements on different datasets. In large systems, PHENIX has measured: Au+Au collisions at $\sqrt{s_{NN}} = 200, 62, 39$ GeV and Cu+Cu at $\sqrt{s_{NN}} = 200$ GeV. In small systems, PHENIX has measured: p+p, p+Au, d+Au (MB) at $\sqrt{s_{NN}} = 200$ GeV. We will discuss these measurements in the next sections.

3. Large Systems

3.1. *Yield*

The measurement of direct photon yield in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV is well established [2]. The yield follows the p+p signal scaled to the number of binary collision (N_{coll}) above 4 GeV/c in p_T, but there is a significant excess of the direct photon yield at p_T below 3 GeV/c. The excess has a nearly exponential shape. Recently, the direct photon yield at low p_T was measured in Au+Au collisions at 62.4 GeV and 39 GeV via the external conversion method [3]. A clear direct photon signal excess was found at low p_T compared to the pQCD prediction scaled by the N_{coll}. The results can be seen in Figure 1. Cu+Cu collisions at 200 GeV were also explored [4] via the internal conversion method. The direct photon yield for Cu+Cu minimum bias (MB) can be seen in the right panel of Figure 1. It shows that the Cu+Cu signal has a clear direct photon yield excess over the binary-scaled p+p baseline. Similar behavior is expected in other large systems, and it was recently reported in Pb+Pb 2760 GeV by the ALICE experiment [5].

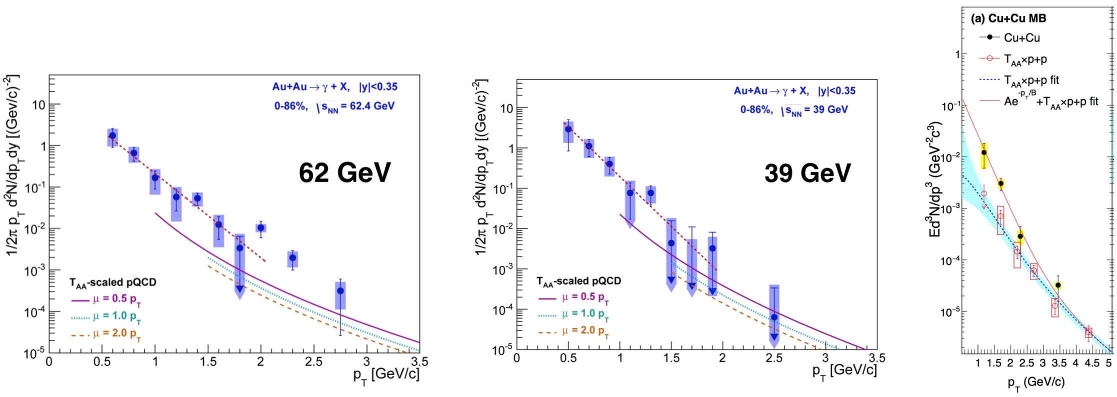

Figure 1. Low p_T direct photon yield for Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV (**left**), Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV (**middle**) and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV (**right**) [4].

3.2. *Scaling*

In order to compare the different collision systems and energies, and gain insight in the mechanism of the direct photon production, the yield was integrated. It can be represented as a function of the number of participants (N_{part}), but N_{part} has limitation because it saturates at the same value for similar system size at different beam energies. So instead of N_{part}, the number of charged particles (N_{ch}) was used. Figure 2 shows the integrated direct photon yield for $p_T > 1$ GeV/c (left) and $p_T > 5$ GeV/c (right) versus the number of charge particles, $dN_{ch}/d\eta$. In the plot there is data from Au+Au collisions at 200 GeV, 62 GeV, 39 GeV, Cu+Cu collisions at 200 GeV and Pb+Pb collisions at 2760 GeV from ALICE [5]. A universal scaling behavior of $dN_\gamma/d\eta$ with $(dN_{ch}/d\eta)^{1.25}$ is observed, independent of the system, energy or centrality for $p_T > 1$ GeV/c. The p+p fit scaled by the number of collisions is significantly lower. This scaling behavior can indicate that the low p_T direct photons are produced around the critical temperature when the transition from QGP to hadron gas happens. The integrated yield at hight p_T, $p_T > 5$ GeV/c, follows the p+p fit scaling by the number of collision for Au+Au data as expected, where the dominant photons are the ones that come from hard scattering.

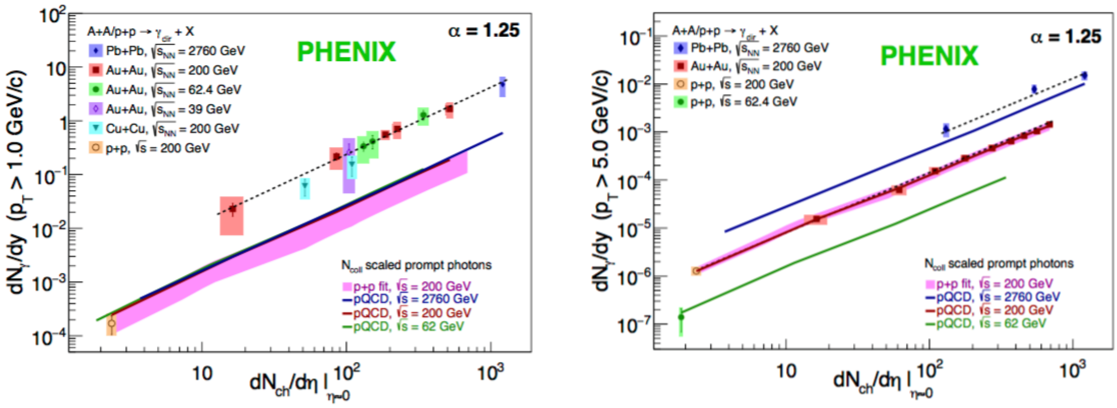

Figure 2. Integrated direct photon yield vs. $dN_{ch}/d\eta$ for different collision systems and energies, integrated in $p_T > 1$ GeV/c (**left**) and $p_T > 5$ GeV/c (**right**). The plots are from [3].

4. Small Systems

PHENIX has recently measured low momentum direct photon production in p+Au collisions at 200 GeV. While the p+Au MB direct photon signal is consistent with N_{coll} p+p scale, the most central p+Au show a hint of excess over the binary-scaled baseline, as seen in Figure 3. A previous measurement in small systems, d+Au [6] did not show a significant modification of the direct photon p_T distribution. These last data are consistent with the results from MB in p+Au collisions, Figure 3 left. Figure 4 left shows the ratio of the direct photon yield in p+Au to p+p scaled by the number of binary collisions as a funtion of p_T. The ratio shows a hint for a significant excess, which is compatible with theoretical calculations of thermal emission [7].

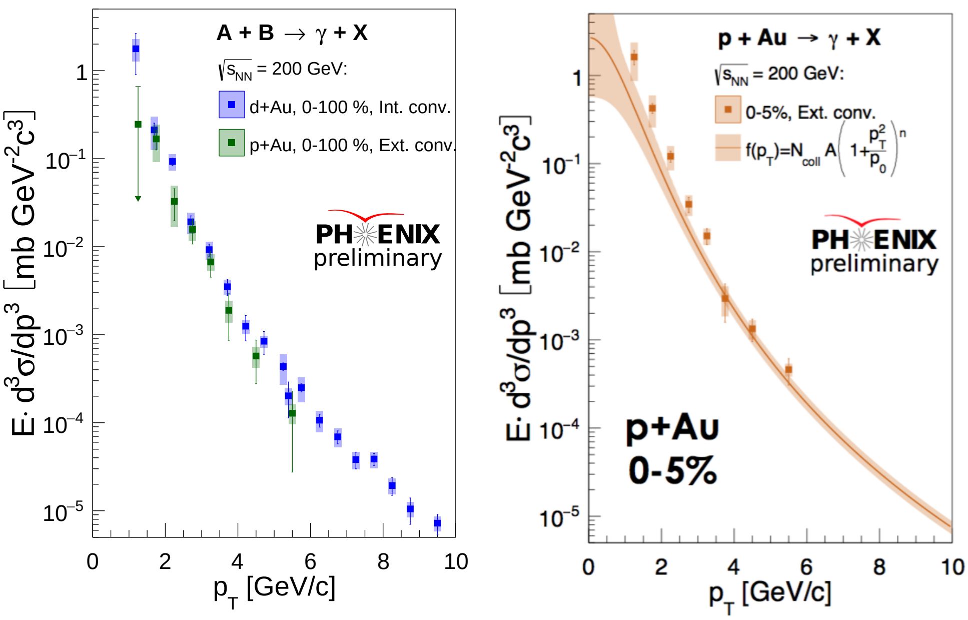

Figure 3. Direct photon yield at low p_T in d+Au and p+Au MB (**left**), and p+Au central collision at 200 GeV (**right**).

Going back to the integrated yields, the data from p+Au and d+Au are added to what was shown in Figure 2 left in Figure 4 right. The data from small systems indicate a transition from p+p like yields to large systems like yields in a narrow multiplicity range.

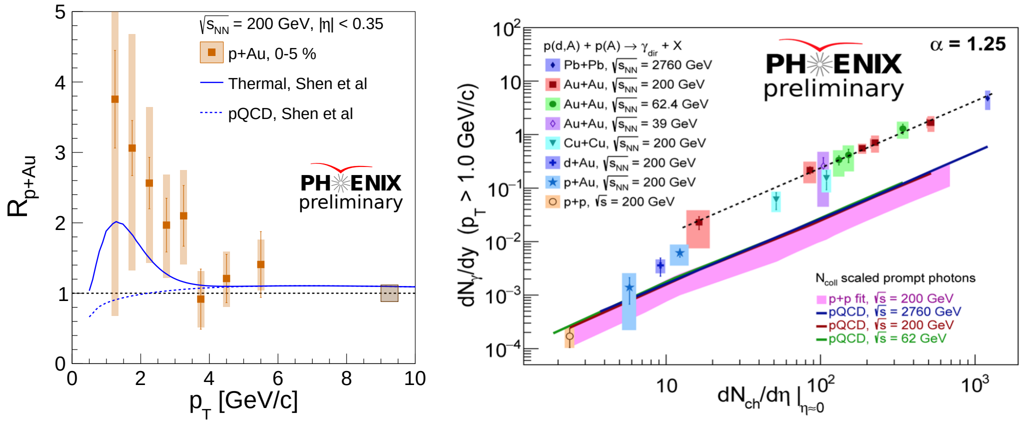

Figure 4. R_{p+Au} vs p_T for p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at 0–5 % centrality (**left**). Direct photon yield integrated above 1 GeV/c vs $dN_{ch}/d\eta$, compared with the large system data from small systems (**right**).

5. Conclusions

In order to understand better the low p_T direct photon signal, PHENIX has performed the measurement at different energies and systems: Au+Au collisions at 39 and 62.4 GeV, Cu+Cu collisions at 200 GeV. A unique scaling behavior of the integrated direct photon yield with respect to the $dN_{ch}/d\eta$ was observed with collision energies and different systems and centralities. This scaling may be an indication that direct photons are produced during the transition from QGP to the hadron gas. The hint of an excess in p+Au can indicate a possible formation of QGP droplets in the small systems. The data suggest the transition between p+p to A+A like yields in a narrow multiplicity range.

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