PROCEEDINGS OF SCIENCE

New direct and non-prompt photon yield and flow results from PHENIX in 200GeV Au+Au collision

Melinda Orosz[a,b,*]

[a] *University of Debrecen, Egyetem square 1 ,Debrecen, Hungary*
[b] *HUN-REN ATOMKI, Bem square 18/C, Debrecen, Hungary*

E-mail: orosz.melinda@atomki.hu

Direct photons produced in heavy ion collisions are penetrating probes and as such encode the entire space-time history of the collision, from the initial hard scattering till the final kinetic freeze-out. For the very same reason theoretical models are challenged to connect and balance many different production mechanisms. Simultaneous observation of large yields and large azimuthal asymmetries (elliptic flow) by PHENIX could so far not been reproduced quantitatively, a situation dubbed "direct photon puzzle". Using the 2014 200 GeV Au+Au data, which have ten times the statistics of earlier published results, and deploying the same analysis technique over the wide 0.8-10 GeV/c transverse momentum range, PHENIX re-measured both the direct and nonprompt photon yields and the direct photon elliptic flow in finer centrality bins than before.

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*Speaker

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1. Introduction

Direct photons have long been considered to be the golden probe to understand of the evolution of relativistic heavy-ion collisions, from the quark-gluon plasma (QGP) phase to the hadron-gas (HG) phase.

The penetrating photons encode information about the environment. High transverse momentum (p_T) direct photons are dominated by photons created from initial hard-scattering processes (prompt photons), meanwhile the low p_T region is dominated by radiation from the evolving partonic/hadronic medium (non-prompt photons, earlier often referred to summarily as "thermal" photons). Over the years, several theoretical models have been developed, and also various techniques and collision systems were used by the PHENIX experiment [4] [5] . From previous measurements, the so-called "direct photon puzzle" is already well established, and the latest data did confirm it. The "puzzle" is this: large invariant yields were seen, which indicate early emission, when the temperature is highest. At the same time, the elliptic and triangular flow found to be high too, but large flow indicates late emissions, since the velocity field takes time to build up. This "puzzle" can be seen on Fig.1, where none of the models can simultaneously describe the invariant yield and flow.

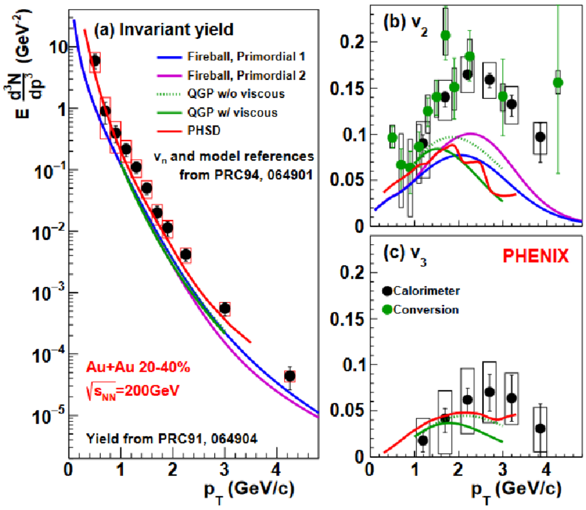


Figure 1: Comparison of the direct photon yields and v_2 and v_3 with all the different model used before. [1] [2] [3]

2. New measurement confirms earlier results

The PHENIX experiment already published direct photon measurements using different techniques: .internal conversion, external conversion far from the collision vertex, and real photons in calorimeters, all providing consistent results[2][7][8]. This time a new method has been applied: external conversion close to the vertex. The comparison between all four methods can be seen in Fig. 2. Its specificity is that the direct-photon measurement is based on the tracking and identification of e^- and e^+ from photon conversions in vertex detector (VTX) material. To correctly reconstruct and identify photon conversions at different VTX layers, a new track-reconstruction algorithm is developed. The new algorithm relies on the fact that the e^- and e^+ from a conversion have the same origin and that their momenta were initially parallel in radial direction. This additional constraint eliminates the need to assume the origin of the track. Electron identification included a signal in the Ring Imaging Cherenkov detector (RICH) and a high E/p ratio in the electromagnetic calorimeter (EMCal). Background from π^0 decays was estimated from the invariant mass of pairs of conversion photons and real photons detected in the EMCal.

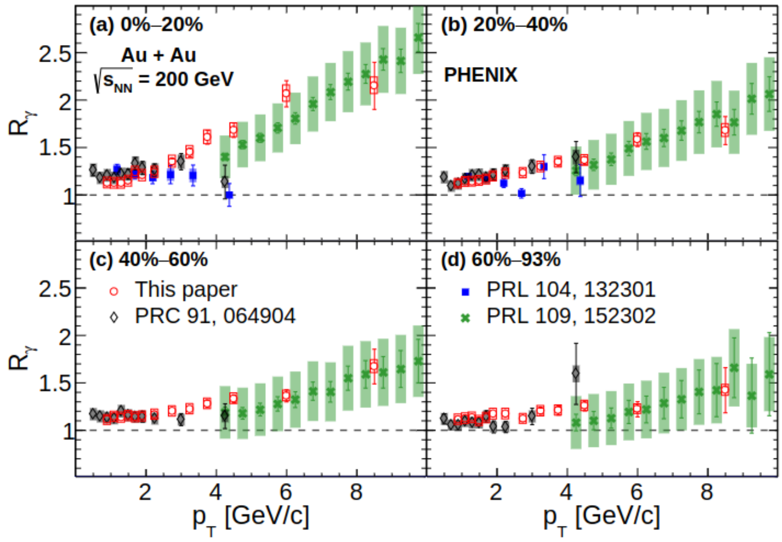


Figure 2: The ratio, $R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadr}}$, as a function of photon p_T in 0%–20%, 20%–40%, 40%–60% and 60%–93% centrality bins. The 2014 Au+Au data at $\sqrt{S_{NN}}$= 200 GeV (red markers) are compared to results from previous PHENIX publications for the same system and $\sqrt{S_{NN}}$, but different datasets and analysis techniques.[6][7]

3. Direct photon yields

The 2014 data have smaller statistical uncertainties than in previous publications at RHIC due to the increased luminosity and significantly larger amount of conversion material. The high statistics allows to divide the data sample into nine centrality bins, from 0%–10% to 80%–93%, 10% bins each, except for the last one which is slightly larger. The direct-photon spectra are calculated from R_γ and γ^{hadr} using: $\gamma^{dir} = (R_\gamma - 1)\gamma^{hadr}$, where R_γ is the ratio of inclusive to decay photons and γ^{hadr} is the estimated total decay photon yield, from all hadronic sources.

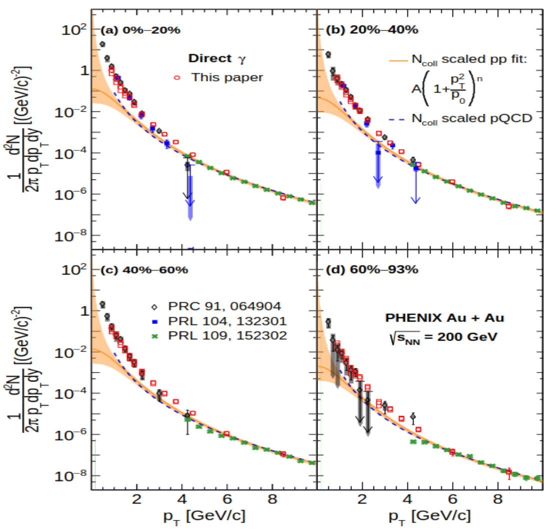
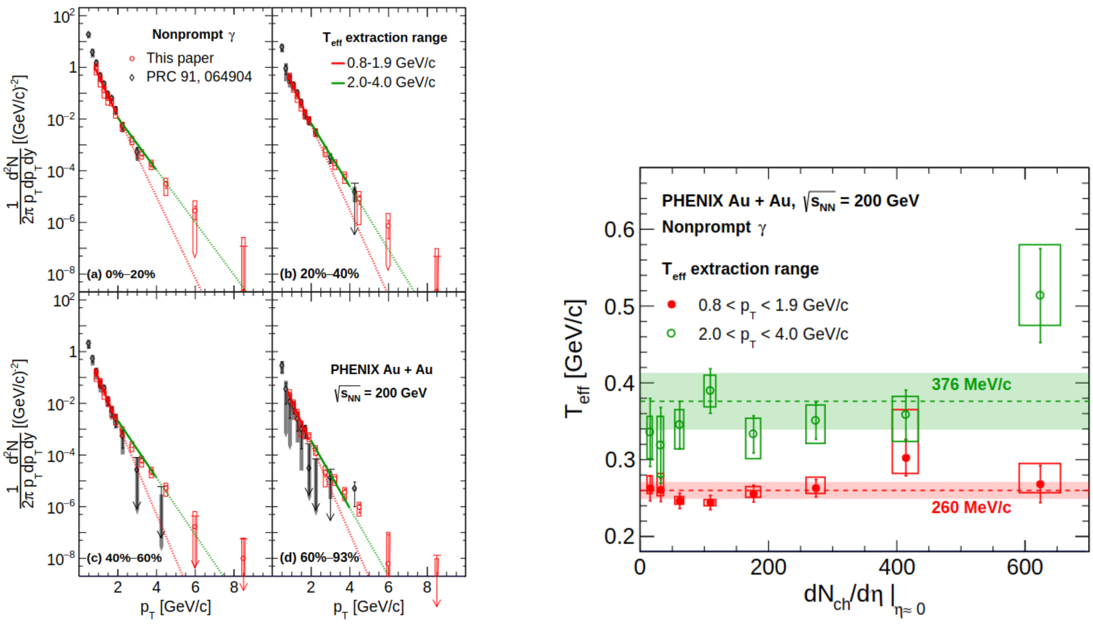


Figure 3: Invariant yield of direct photons as a function of conversion photon p_T in (a) 0%–20%, (b) 20%–40%, (c) 40%–60% and (d) 60%–93% centrality bins.[6]

In order to separate the prompt contribution, the p+p results are fitted. The fit agrees well with the perturbative quantum chromo-dynamics (pQCD) calculation above 2 GeV/c. As seen in Fig. 3 the direct-photon yield for p_T larger than 5 GeV/c is well described by the N_{coll}-scaled p+p result and pQCD calculations, which confirms that the high- p_T direct photons are predominately from initial hard-scattering processes. Below 4–5 GeV/c a clear direct-photon excess develops above the prompt component, gradually becoming larger towards lower p_T .

4. Nonprompt direct-photon excess, T_{eff}

To extract the direct-photon excess above the prompt-photon contribution, the N_{coll}-scaled p+p fit is subtracted from the Au+Au data. This excess is thought to be mostly due to the radiation that is emitted during the collision from the hot expanding fireball. The spectrum of nonprompt photons is shown in panel (a) in Fig.4, and it can be fitted with exponentials, suggesting thermal origin. Interestingly, while the exponent changes with the p_T region considered, it is independent of centrality. The data are very consistent in the region of overlap, the nonprompt direct-photon spectra are not described by a single exponential but rather have a continually increasing with p_T inverse slope, T_{eff}, shown in panel (b) on Fig.4. The T_{eff} depends on the fitted p_T range, but is almost independent of centrality.



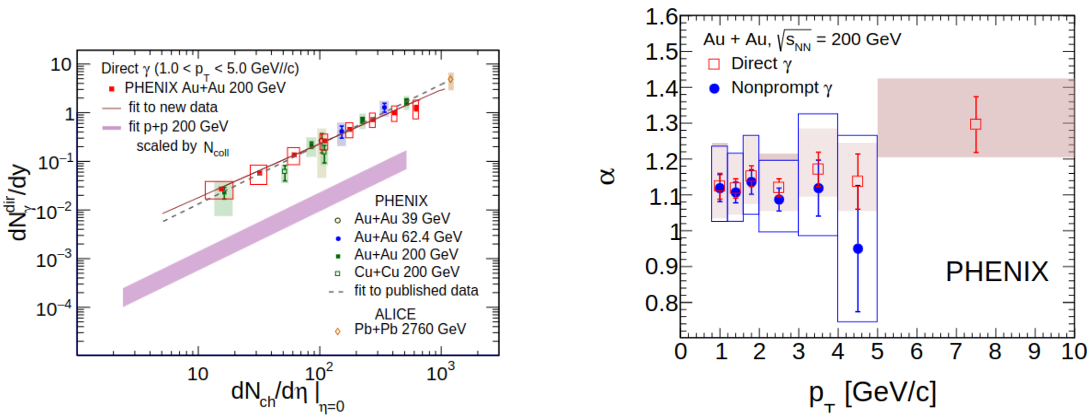
(a) (b)

Figure 4: (a) Nonprompt direct-photon yield as a function of conversion photon p_T in (a) 0%–20%, (b) 20%–40%, (c) 40%–60%, and (d) 60%–93% centrality bins, and (b) T_{eff} as a function of charged-particle multiplicity at midrapidity[6]

5. Scaling with multiplicity

In addition to investigating the p_T and system-size dependence of the shape of the nonprompt direct-photon spectra, the dependence of the yield on system size and p_T has also been studied. The integrated direct photon yield (1-5 GeV/c p_T region) scales with the function

$$\frac{dN_\gamma}{dy} = \int_{p_{T,min}}^{p_{T,max}} \frac{dN_\gamma^{dir}}{dp_T dy} dp_T = A \times (\frac{dN_{ch}}{d\eta})^\alpha \tag{1}$$



(a) (b)

Figure 5: (a) Integrated direct-photon yield (1–5 GeV/c) versus charged-particle multiplicity at midrapidity, compared to a previous compilation of data, and (b) scaling factors, α , extracted from fitting Eq.1. to integrated direct and nonprompt-photon yields as a function of $dN_{ch}/d\eta$ [6]

Panel (a) in Fig.5. shows good agreement with other direct-photon results, even though, the power obtained from the fit to the current data: $\alpha = 1.11 \pm 0.02 \pm 0.09$ is slightly smaller than before, and it is smaller than predicted [9][10]. The same scaling holds over vastly different collision energies and systems. Instead of the integrated yield (1-5 GeV/c) in panel (b) the powers obtained for narrow p_T bins are shown. The values of α for the non-prompt component are constant with no evidence of p_T dependence.

6. Elliptic flow

The observation of large azimuthal anisotropy combined with observations published earlier that the direct photon yields themselves are large, contradicts several existing interpretations where the large yields are provided at the very early production stage, when the temperature of the system is highest but the collective flow including azimuthal asymmetry is negligible. Conversely, the observed large anisotropy suggests that photon production occurs at very late stages of the collision when the collective flow of the system is fully developed, while the temperature and the corresponding thermal photon emission rates are already lower. In Fig.6. preliminary results from a recent analysis of direct photon elliptic flow are shown, in finer centrality bins than previously published. The elliptic flow of direct photons in the low p_T region ($1 < p_T < 4$ GeV/c) is large, and consistent with that of final state hadrons. These new results are consistent with earlier measurements, but put tighter constraints on future attempts to resolve the "direct photon puzzle".

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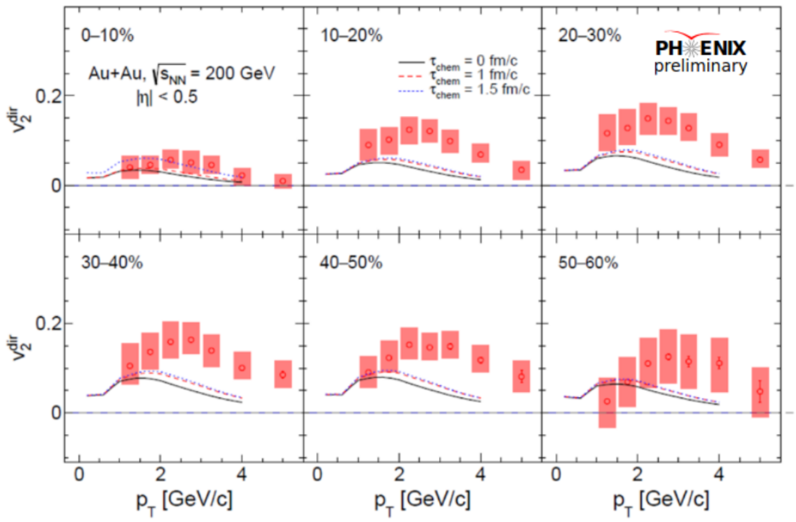

Figure 6: Direct photon elliptic flow in 10% wide centrality bin [11]

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