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Low-p_{T} direct photon production in $p+p$ and $p+\mathrm{Au}$ collisions at $\sqrt{s_{NN}} = 200$ GeV

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The excess of direct photon production at low-p_{T} in heavy-ion collisions is often associated with the thermal radiation of the system. Direct photons are generated through the entire evolution of the collision system and once they are created they leave the system without further interaction. Recent measurements of collective phenomena in smaller collisions systems suggest a formation of strongly interacting medium in these systems. PHENIX has measured low-p_{T} direct photon production in $p+\mathrm{Au}$ collisions at $\sqrt{s_{NN}} = 200$ GeV and reports the results in this proceedings.

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Direct photons emerging from heavy-ion collisions are considered an important probe of the entire evolution of the colliding system. Unlike the hadron observables which mostly encode information at the freezout, direct photons have a much longer mean-free-path, hence, once they are created escape the medium without further interaction. Theory predicted that the created thermal medium in heavy-ion collisions would emit thermal radiation in forms of direct photons [1]. Experimental data shows a large low-p_{T} excess of direct photons compared to the N_{coll} -scaled pQCD expectations which is interpreted as thermal radiation of the system [2]. The thermal radiation would be a mixture of contributions from the partonic and hadronic phases and their dynamic evolution.

In contrast to heavy-ion collisions, where we expect to create a hot and strongly interacting medium, p+A collisions were considered to contain only cold nuclear effects. However, since the observation of long range correlation in high multiplicity $p+p$ and p+A collisions [3], similar to those in A + A collisions, this initial expectation is challenged. It is natural to ask, if the other signatures of the QGP are present in these collision systems. In case that a strongly interacting medium is created in these collisions, the medium should emit additional direct photons during its lifetime.

Figure 1 shows the PHENIX measurement of the direct photon double ratio R_γ of direct plus hadron decay photons over decay photons ($R_\gamma = (\gamma_d + \gamma_h)/\gamma_h$) in $p+p$ and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. PHENIX utilized a multiplicity trigger to increase the statistics of very high multiplicity events ($0-5\%$) in p+Au collisions. The new measurements in $p+p$ collisions are within experimental uncertainties consistent with earlier measurements of R_γ obtained using the virtual photon method. Results from minimum bias p+Au collisions are similarly consistent with R_γ from $p+p$ collisions, while for central p+Au collisions a hint of an enhancement is seen.

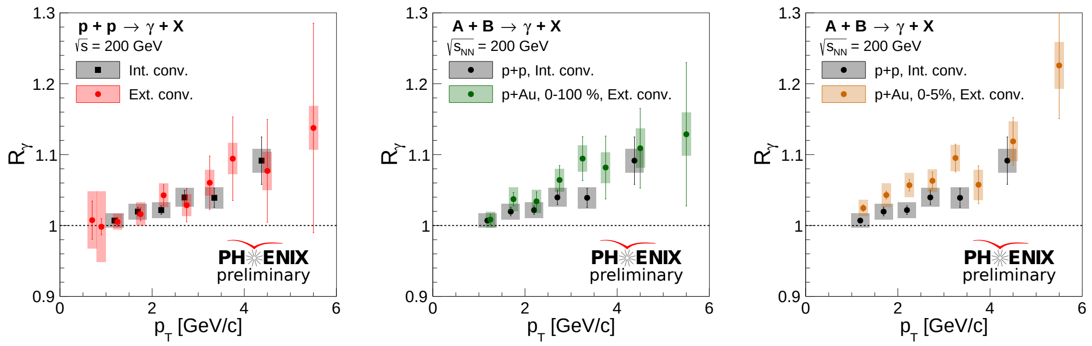

Figure 1: Direct photon fraction (R_γ) in $p+p$ (left panel) and minimum bias (middle panel) and central (right panel) p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

The invariant cross section is extracted from the double ratio (R_γ) as $\gamma_{\mathrm{d}} = (R_\gamma - 1)\gamma_{\mathrm{h}}$, where the γ_{d} and the γ_{h} are the yields of direct photons and photons from hadronic decays, respectively. Figure 2 shows the invariant cross section of the direct photons from various small systems ($p+p$, p+Au and d+Au) at $\sqrt{s_{NN}} = 200$ GeV. The new measurements are also compared with the previously published data from minimum bias d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [4].

The determination of the baseline from the $p+p$ data is important for studying the enhancement in heavy-ion collisions. The data are fitted with a pQCD inspired functional form: $f(x) =$

$A(1+x^2/x_0)^n$. We estimated the systematic uncertainties of the fit using the statistical and the systematical uncertainties on the data points, while also exploring different functional forms. The final systematic uncertainties are plotted an asymmetric band around the fit function shown in Figure 2.

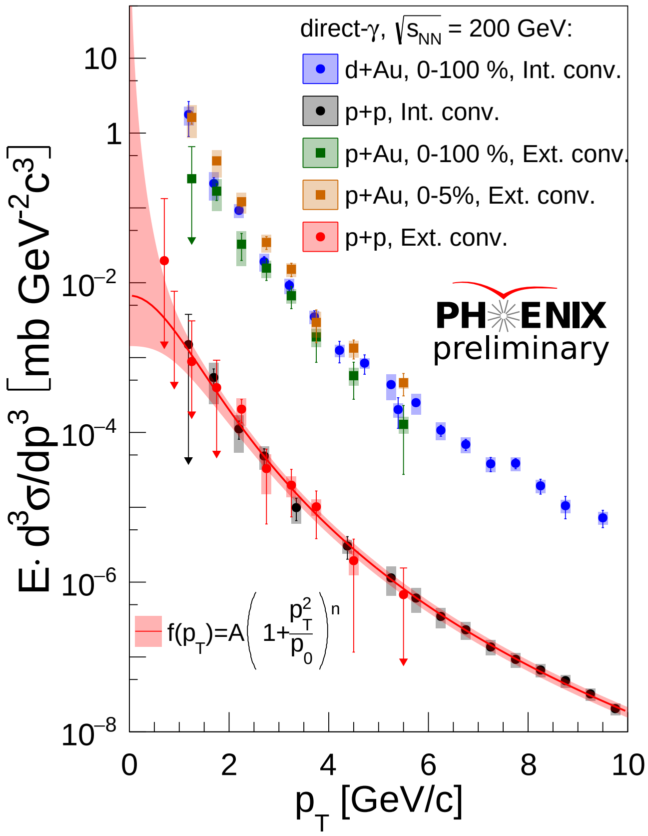

Figure 2: The direct photon invariant cross section measured by PHENIX in $p+p$, $p+\mathrm{Au}$ and $d+\mathrm{Au}$ collisions at $\sqrt{s_{NN}} = 200$ GeV.

In order to quantify the enhancement in these small systems we can calculate the nuclear modification factor (R_{AA}), shown in Figure 3. As reference for the ratio we use the fit function over the $p+p$ data described earlier. Both the R_{AA} for minimum bias and high multiplicity ($0-5\%$) $p+\mathrm{Au}$ collisions are consistent with unity within the experimental uncertainties. However, a hint of some enhancement is visible in the high multiplicity $p+\mathrm{Au}$ collisions. The experimental data are compared to theoretical predictions [5] for the same collision systems. The theory calculation shown as dotted line is the expectation for cold nuclear matter effects only, while the one shown as a solid line assumes that a small thermal medium is created that emits electromagnetic radiation. The current experimental data does not yet have the precision needed to distinguish between the two scenarios.

Another way to quantify possible thermal direct photon radiation is to integrated the direct photon yield in the excess region for p_T above 1 GeV/c. PHENIX presented these integrated yields for various heavy-ion collision systems as a function of the charged particle multiplicity in

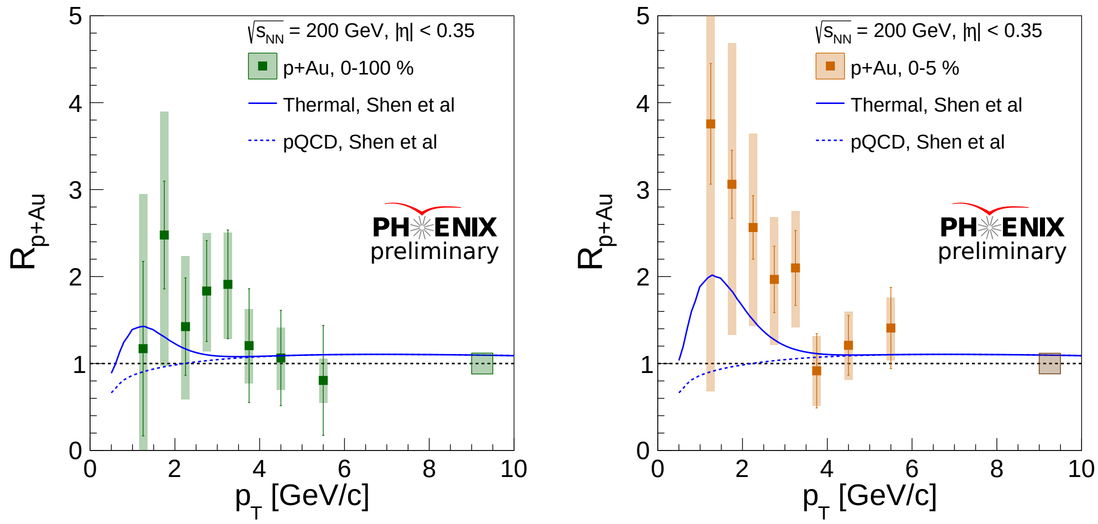

Figure 3: The nuclear modification factor of direct photons in $p+$Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The blue lines are the theoretical model predictions using only pQCD contributions and thermal photon production [5].

the mid-rapidity region [6]. The results are shown in Figure 4. They show a scaling behavior that takes the form $(dN/d\eta)^n$, where $n \approx 1.25$. The heavy-ion data show an enhancement by a factor of 10 above the integrated yield expected from direct photon production predicted by pQCD and scaled by $N_{\rm coll}$.

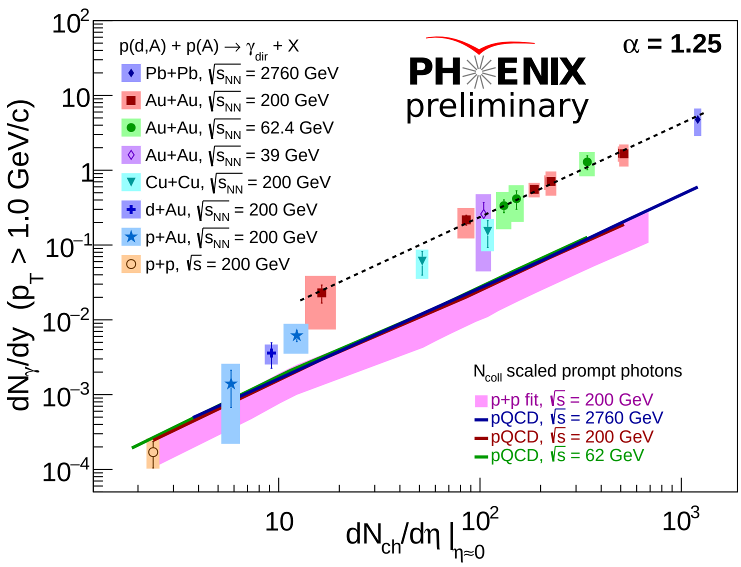

Figure 4: The integrated direct photon yield for $p_{\rm T} > 1$ GeV$/c$ from various systems as a function of the charged-particle multiplicity in the mid-rapidity region. The magenta band represents the $N_{\rm coll}$ -scaled $p+p$ data at $\sqrt{s} = 200$ GeVand the lines represent the $N_{\rm coll}$ -scaled pQCD calculations at different energies.

Comparing the integrated photon yields from heavy-ion collisions to the expected yields suggests that there could be a transition from $p+p$ like to A + A like yields to in the region of $(dN/d\eta) \sim$

$2-20$. This transition region is covered by data from p+Au and d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV as also shown in Fig. 4. The data from the minimum bias p+Au collisions are consistent with the N_{coll} -scaled $p+p$ collisions. However, the minimum bias d+Au and the high multiplicity p+Au data show some enhancement. This small enhancement could correspond to the turn on of the excess direct photon production that is clearly seen in heavy-ion collisions.

PHENIX presented a new measurement of the low-p_{T} direct photon yield in $p+p$ and p+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. For $p+p$ collisions, the measured double ratio is consistent with the previously measured data using the virtual photon method. For minimum bias p+Au collisions R_γ is also consistent with the N_{coll} scaled $p+p$ value. In contrast, there is a hint of a small enhancement in high multiplicity p+Au collisions. The integrated yield from various heavy-ion measurements suggests a "transition region" at low multiplicities, and the p+Au and d+Au measurements are consistent with such a transition. Further measurements of the direct photons in the high multiplicity events from collisions of small systems as well as the lower multiplicity heavy-ion collisions can help in understanding the origin of the excess in direct photon production.

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