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PHENIX Measurements of Beam Energy Dependence of Direct Photon Emission

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In this talk the PHENIX collaboration presents new measurements of low momentum direct photons from Cu+Cu at 200 GeV and Au+Au at 62.4 GeV and 39 GeV. A large excess of direct photons over the scaled p+p yield is found. The comparison of the new data with data from Au+Au at 200 GeV and ALICE data from 2.76 TeV reveals that at low-p_T the spectra of direct photons and their integrated yield above 1 GeV/c follow a universal scaling as a function of the charged-particle multiplicity, $(dN_{ch}/d\eta)^{\alpha}$, with $\alpha = 1.25$, independent of collision centrality or center of mass energy. The observed scaling properties suggests that the emission source has similar properties for all observed systems.

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In collision of heavy ions one expects that after the initial contact of the ions the system rapidly thermalizes within less than one fm/c and forms a droplet of QGP that expands hydrodynamically, hadronizes and eventually freezes out after about 10 fm/c. Heavy ion collisions at RHIC would cover a range from initial temperatures of around 400 MeV to freezout temperatures of about 150 MeV. During the full expansion and cool down electromagnetic radiation is emitted as photons and dileptons. Their properties can provide information about the produced matter and its time evolution.

In this talk we focus on photon measurements by PHENIX. The main experimental challenge is to extract the photons of interest, those directly emitted from the hot and interacting matter, from the different background sources, most prominently photons that arise from π^0 and η decays long after the collision. Another important background component is prompt photon emission from hard scattering processes during the initial contact before QGP is created. PHENIX uses several techniques to measure photons. The methods include measurements of (i) the energy deposit in the electromagnetic calorimeters, these are most valuable at high p_T, (ii) photon conversions to e^+e^- pairs in the detector material, which utilize the charge particle tracking, the ring imaging Cerenkov counters and the calorimeter, give low p_T coverage, and (iii) virtual photons in form of e^+e^- pairs that are extrapolated to zero pair mass provide an alternative way to access low p_T. Results from the three different methods are found to be consistent.

For p_T above 3 GeV/c the direct photon spectra measured for Au+Au at 200 GeV agree well with those from p+p, once scaled by the number of binary collisions N_{coll}. However, below 3 GeV/c a substantial enhancement is found with a nearly exponential shape and an inverse slope of approximately 240 MeV [1, 2]. The same data exhibits a significant anisotropy of low p_T direct photons with respect to the reaction plane, which has been interpreted as indication for emission from radially expanding matter [3, 4]. These data have been compared to a variety of different theoretical calculations. Calculations of thermal photon emission from QGP and the hot hadron gas generally fall short in simultaneously describing the yield and the anisotropy. The discrepancy with the data reflects the tension between the need to have early emission to generate a large yield, but late emission to get a sizable Doppler shift. This tension has triggered a number of ideas for new contributions, including non equilibrium radiation from the glasma, enhanced thermal radiation due to large magnetic fields, modified formation time, or extended emission at the phase boundary, to name a few.

In order to provide new insights PHENIX has varied the system size and the geometry by changing the collision system, center-of-mass energy, and centrality. Fig. 1 shows new data from Au+Au collision at 39 and 62.4 GeV [5] and from Cu+Cu collisions at 200 GeV [6]. The minimum bias spectra from these data are compare to pQCD calculations and p+p data. All systems show a significant enhancement at low p_T.

We adopted measuring the system size through the multiplicity density of produced charge particles ($dN_{ch}/d\eta$). This has the advantage that it is an experimental observable and can be used across different $\sqrt{s}$, since it not only measures the volume but also the energy density. In trying to better understand the interplay between system size and hard scattering processes we compare N_{coll} with $dN_{ch}/d\eta$ in Fig. 2 for four different beam energies. We find that for all energies N_{coll} is approximately proportional to $(dN_{ch}/d\eta)^{5/4}$ with a $\sqrt{s_{NN}}$ dependent proportionality factor, the specific yield, which varies logarithmically with $\sqrt{s_{NN}}$ as shown in the insert. In the following

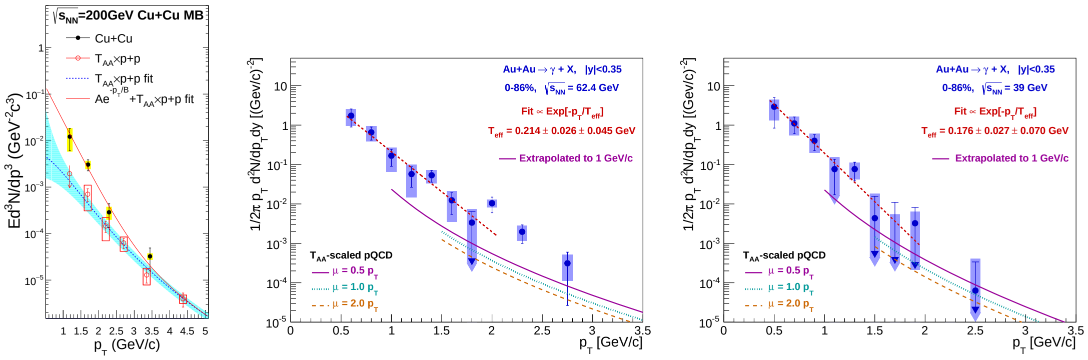

Figure 1: Direct photon spectra from Cu+Cu at $\sqrt{s_{NN}}$ = 200 GeV and from Au+Au at $\sqrt{s_{NN}}$ = 62.4 GeV and 39 GeV. All data are from minimum bias triggered events.

$(dN_{ch}/d\eta)^{5/4}$ is used to scale direct photon data for different system sizes.

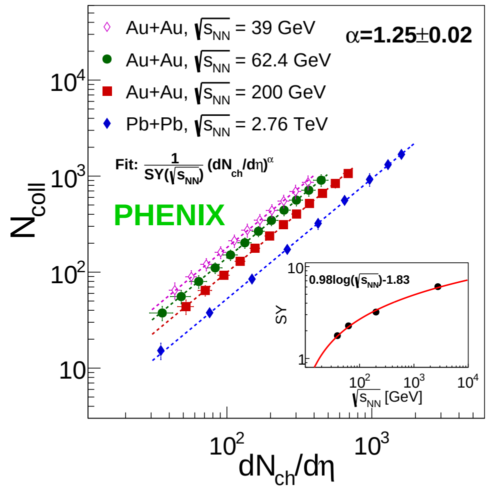

Figure 2: Relation of N_{coll} and $dN_{ch}/d\eta|_{\eta=0}$ for four beam energies. All the data are consistent with a power law scaling with an exponent of α = 1.25.

Fig. 3 presents the invariant direct photon yield normalized to $(dN_{ch}/d\eta)^{5/4}$ as function of p_T for a large number of data sets [2, 3, 6, 7, 8, 9, 10]. Let us focus first on panel (b) with p+p and Au+Au data at 200 GeV. Since at fixed collision energy $(dN_{ch}/d\eta)^{5/4}$ is proportional to N_{coll}, above 3 GeV/c all data fall on top of each other. At lower p_T the p+p data follow the fit to the p+p data and the pQCD calculation [11]. In contrast, the Au+Au data show an excess above the p+p fit with a nearly exponential shape. Surprisingly all centrality selections fall on top of each other. Panel (a) shows the new minimum bias Au+Au data at 39 and 62.4 GeV in the same presentation and p+p data from the ISR for 62.4 GeV. Again the pQCD calculation is consistent with the p+p data, but below 3 GeV/c there is a significant excess of photons in Au+Au. Within uncertainties the excess at 39 and 62.4 GeV is the same and is also consistent with the one found at 200 GeV. In Panel (c) data from central collisions for 62.4 and 200 GeV Au+Au, 200 GeV Cu+Cu and for 2.76 TeV Pb+Pb data from ALICE are compared. At high p_T ALICE and PHENIX data are different and, as expected, the pQCD calculations are consistent with the data. However, at low p_T all data again fall on top of each other.

In order to bring out some of the features of the data more clearly we integrate the yield above 1 GeV/c, which is dominated by the excess, and above 5 GeV/c, which is dominated by hard

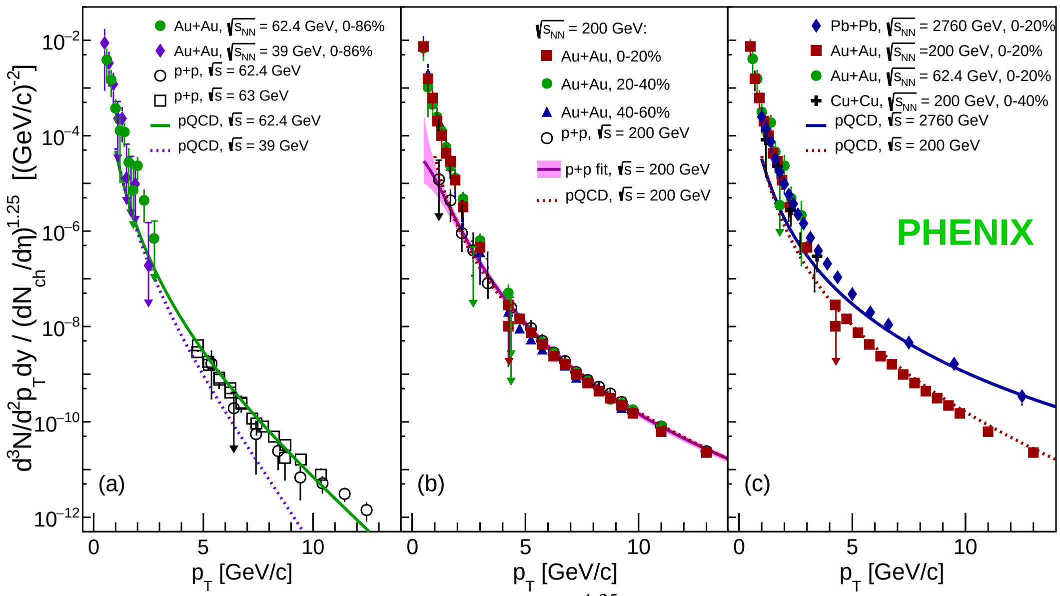

Figure 3: Direct photon spectra normalized by $(dN_{ch}/d\eta)^{1.25}$ for Au+Au at 39 and 64.2 GeV (a) and (b) at 200 GeV; panel (c) compares for different A+A systems at different $\sqrt{s_{NN}}$. Panels (a) and (b) also show p+p data . All panels show pQCD calculations for the corresponding $\sqrt{s}$. The errors shown are the quadratic sum of systematic and statistical uncertainties. Uncertainties on the $dN_{ch}/d\eta$ are not included.

processes. Panel (a) of Fig. 4 shows the integrated yield above 1 GeV/c as a function of $dN_{ch}/d\eta$. Each data set from Fig. 3 is now collapsed to one point. The dashed line gives $A(dN_{ch}/d\eta)^{5/4}$ with the normalization constant A fitted to the data. Also shown is the integrated yield from p+p data and the p+p fit scaled by N_{coll} for the corresponding $dN_{ch}/d\eta$. Visibly the scaled p+p yield follows the same trend, but at a factor of 10 lower yield. Integrated yields from the pQCD calculations scaled by N_{coll} are also shown for three energies. The universal scaling behavior of low p_T direct photon emissions from the heavy ion collisions indicates that the source of the photons may be similar for these systems. The difference compared to the scaled p+p integrated yield suggests that there may be a transition from p+p like to A+A like low p_T direct photon yields somewhere in the range around $dN_{ch}/d\eta$ of 10. PHENIX data from p+Au and d+Au, that were also shown at this conference [12], cover the $dN_{ch}/d\eta$ and support the conjecture that there may be a transition.

Turning to the integrated yield above 5 GeV/c presented on panel (b) of Fig. 4 gives a different picture. Less data is shown because there are fewer data sets that reaches beyond 5 GeV/c. For 200 GeV, all integrated yields, Au+Au, p+p and pQCD fall on the same trend $(dN_{ch}/d\eta)^{5/4}$, which is equivalent to N_{coll} scaling. At 2760 GeV, three data sets are available above 5 GeV/c. They show the same $(dN_{ch}/d\eta)^{5/4}$ scaling, but about 30% above the pQCD calculation.

In summary, the thermal photon puzzle discovered in Au+Au at 200 GeV remains unresolved. The data show large photon yields with large azimuthal anisotropy, which is difficult for theoretical models to reconcile. PHENIX has discovered a universal scaling of the low p_T direct photon yield with $(dN_{ch}/d\eta)^{5/4}$ independent of centrality and $\sqrt{s_{NN}}$ from 39 GeV to 2760 GeV. It seems to hold down to a system size of $dN_{ch}/d\eta$ about 20. At fixed $\sqrt{s_{NN}}$ the scaling is equivalent to N_{coll} scaling at low p_T and high p_T. The scaled A+A yield is a factor of 10 larger than expected from p+p. PHENIX data from p+A and d+Au indicate a rapid onset of direct photon excess around $dN_{ch}/d\eta$

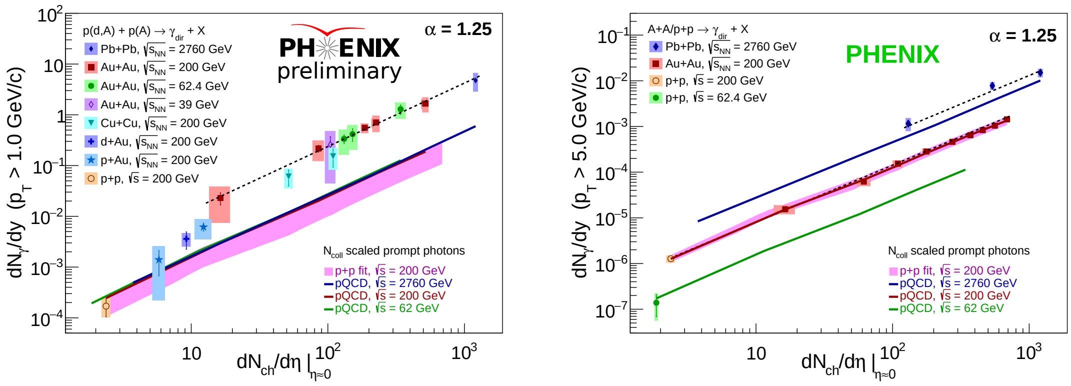

Figure 4: The left plot shows the data on the direct photon yield, integrated above 1.0 GeV/c in p_T, vs. $dN_{ch}/d\eta$, for many data sets. The right plot shows the yield integrated above 5.0 GeV/c in p_T. Details are reproted in the text.

of 5 to 20. More PHENIX data varying size and geometry to be finalized/analyzed including small systems (p+Au, d+Au, ^{3}He+Au) and large systems (Au+Au and Cu+Au)

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