Results on Photon Production in Au+Au Collisions at RHIC

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The status of the search for direct photons in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV and $\sqrt{s_{NN}} = 200$ GeV with the PHENIX experiment is presented. Within errors, no excess of direct photons was found in a first analysis pass done on a limited data set. Significantly reduced systematic and statistical uncertainties are expected in future analyses.

1. Introduction

The aim of this analysis is to search for direct photons, i.e. photons that are not produced in hadron decays such as $\pi^0 \rightarrow \gamma\gamma$ or $\eta \rightarrow \gamma\gamma$. Direct photons are generally subdivided into prompt photons from initial hard parton scatterings and thermal photons from a possible quark-gluon plasma and from the hadron gas.

Prompt photons are produced before a possible quark-gluon plasma has formed. Above a transverse momentum of $p_T \approx 3-5$ GeV prompt photons are expected to be the dominant source of direct photons in Au+Au collisions at RHIC. In p+p reactions direct photons are used to obtain information about the gluon distribution in the proton since their production in p+p is dominated by quark-gluon Compton scattering ($gq \rightarrow \gamma q$). By measuring direct photons in Au+Au at RHIC one is sensitive to modifications of the parton distribution functions in the nucleus (*nuclear shadowing*) [1].

The agreement between perturbative QCD calculations and experimental direct photon data in p+p and p+A can be improved if a momentum component k_T of the initial partons transverse to the beam axis is introduced in the calculations [2]. In nucleus-nucleus collisions one expects a stronger k_T than in p+p due to e.g. multiple soft scatterings of the incoming nucleons. As demonstrated in [3] the magnitude of this intrinsic k_T can be constrained by measurement of direct photons in nuclear collisions.

Thermal photons are produced over almost the entire evolution of a nucleus-nucleus collision: in a possible quark-gluon plasma phase and in the later hadron gas phase. The strongest contribution from thermal photons is expected roughly in the range $p_T \approx 1-5$ GeV. Theoretically, the entire hydrodynamical evolution of a nucleus-nucleus reaction needs to be modeled to describe thermal photon production. A comparison of these models with data constrains the initial temperature of the reaction system. In order to obtain information about the existence of a quark-gluon plasma one needs to compare models with and without phase transition to the data [4].

*for the full PHENIX Collaboration author list and acknowledgements, see Appendix "Collaborations" of this volume.

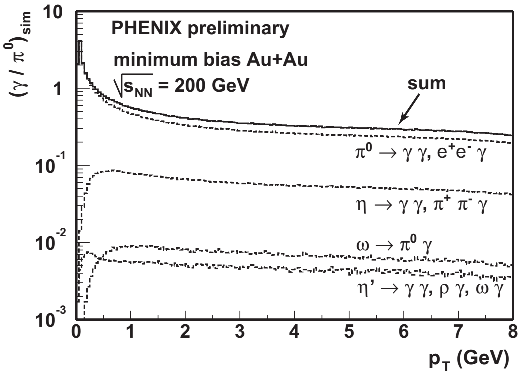

Figure 1. Simulation result for the γ/π^0 ratio in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions expected from hadronic decays.

The first observation of direct photons in heavy ion collisions was achieved at the CERN SPS by the WA98 experiment [5]. At RHIC, a substantial suppression of π^0 production at high p_T in central reactions was found that was not present at SPS energies [6]. The reduced background from neutral pions could result in a clearer direct photon signal at RHIC. Moreover, the passage of quark jets through the excited nuclear medium might be an important new source of direct photons at RHIC, such that the subdivision of direct photons into prompt and thermal photons would have to be extended [7].

2. Data Analysis

Direct photon measurements (even in p+p) are generally considered to be very challenging. It is therefore an advantage of the PHENIX experiment that photons can be measured in different ways: directly with an electromagnetic calorimeter and also via their conversions in e^+e^--pairs. Here we focus on the photon measurement with the electromagnetic calorimeter (EMCal) of the PHENIX experiment. The biggest experimental uncertainties in photon measurements with calorimeters are generally background from hadrons that are misidentified as photons and errors of the energy scale of the detector. In heavy ion collisions an additional uncertainty results from the high multiplicity environment leading to overlapping showers in the detector.

In p+p reactions direct photons at sufficiently high p_T are usually identified on an event-by-event basis with the help of certain isolation cuts. This is more difficult in heavy ion reactions and therefore the approach in this analysis is to try to find direct photons on a statistical basis. The inclusive photons (hadron decay photons and direct photons) are measured and then the background of photons from hadron decays is subtracted.

The PHENIX EMCal consists of two sub-detectors, a lead-scintillator calorimeter (PbSc, 6 sectors) and a lead-glass calorimeter (PbGl, 2 sectors). The lead-glass detector was previously used in the WA98 experiment. Each sector covers a pseudorapidity range of $|\eta| < 0.35$ and an azimuthal angle of $\phi \approx 22.5°$. Both sub-detectors are highly segmented $(\Delta\phi \times \Delta\eta \approx 0.01 \times 0.01)$ such that the two decay photons of a π^0 are well separated

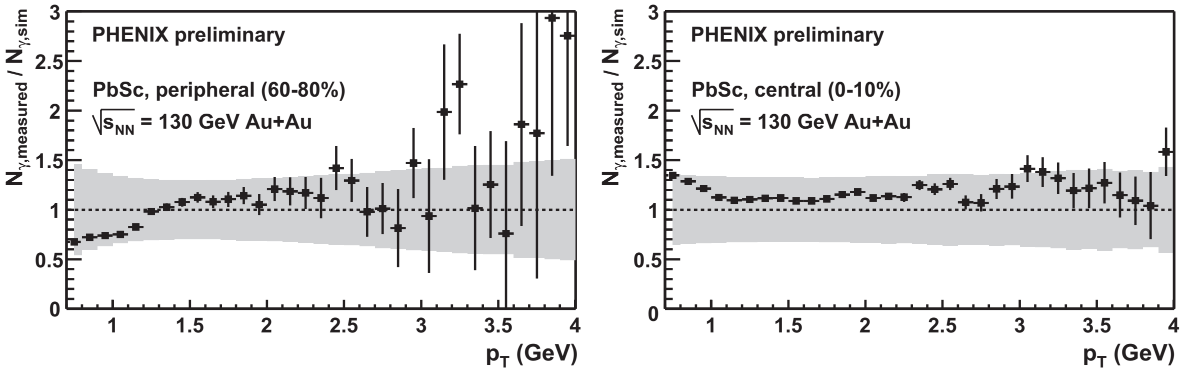

Figure 2. Ratio of measured photons to expected background photons from hadron decays in Au+Au at $\sqrt{s_{NN}} = 130$ GeV. The centrality classes are specified by fractions of the total geometrical Au+Au cross section. The shaded band indicates the systematic error.

up to neutral pion momenta of $p_T \approx 20$ GeV. The different detection mechanisms of the two sub-detectors (measurement of scintillation light in PbSc and detection of Cherenkov photons in PbGl) result in a different response to hadrons. Thus, PbSc and PbGl provide photon measurements with different systematics.

The extraction of the inclusive photon spectra starts by identifying photon-like hits in the EMCal. Hadrons on the average produce showers with larger lateral extensions than photons. Thus, cuts on the shower shape are used to identify photons both in PbSc and PbGl. In addition, the time-of-flight of the showers is used as an identification criterion. The next analysis step is the subtraction of background from charged hadrons, neutrons, anti-neutrons, and particles not coming from the vertex. This is done statistically and not on an event-by-event basis. In order to determine the background of charged hadrons in the sample of photon-like hits, identified tracks from the PHENIX tracking system are projected to the EMCal surface. Random associations between photons and charged tracks are corrected for by an event-mixing technique. Above photon transverse momenta of $p_T \approx 1.5$ GeV the background of charged hits in the photon-like sample is found to be less than 10%. The background of neutrons and anti-neutrons in the sample of neutral EMCal hits, that is obtained after subtracting the charged background, has to be determined from simulation. The assumed input spectra of neutrons and anti-neutrons needed in the simulation are estimated based on measured p and $\bar{p}$ spectra. The contribution of neutrons and anti-neutrons to all neutral EMCal hits is found to be less than 6%. In the last analysis step a photon efficiency correction is applied which takes the energy resolution of the detector, shower overlaps and photon losses due to identification cuts into account.

The expected photons from hadron decays are determined in a simulation that takes the measured neutral pion spectrum as input. Exactly the same data set is used for the neutral pion and the photon analysis. The neutral pion spectra obtained in this analysis agree with those presented in [8] within the current systematic error of 25%. An η-spectrum has not yet been measured. Therefore m_T-scaling is assumed for the η and

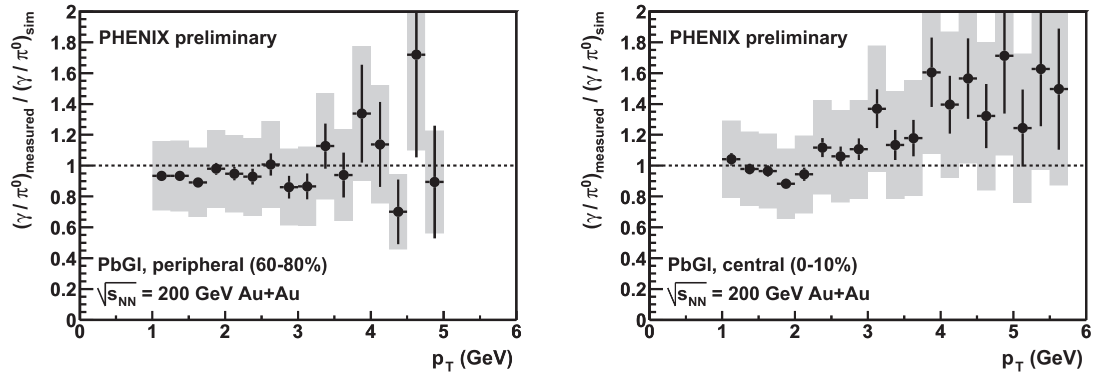

Figure 3. Measured over expected γ/π^0 ratio in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The shaded boxes represent the estimated 1σ absolute systematic errors of the data points.

other hadrons. The result of the hadron decay simulation is shown in Figure 1.

3. Results

In order to search for non-hadronic photon sources the ratio of all measured photons to the expected background photons from hadron decays is shown as a function of p_T for Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV (Figure 2) and 200 GeV (Figure 3).

The results in Figure 2 are from an analysis that is similar to the one described in the previous section, but the charged background was determined from simulation and not from real data. The statistics in the 130 GeV data is small compared to the 200 GeV data such that the shape of the π^0 spectrum is not as well constrained as in the 200 GeV analysis. In Figure 3 the results for Au+Au at $\sqrt{s_{NN}} = 200$ GeV are presented in terms of the ratio of the measured γ/π^0 ratio to the simulated γ/π^0 ratio. In the γ/π^0 ratio systematic errors partially cancel. The current systematic errors are dominated by uncertainties of the photon and neutral pion reconstruction efficiencies.

As can been seen from Figures 2 and 3 no direct photon signal is observed within current errors both in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV and $\sqrt{s_{NN}} = 200$ GeV. The systematic uncertainties are expected to be reduced significantly in the future with further analysis.

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