Measurement of low $p_T$ direct photon with virtual photon method in $\sqrt{s} = 200$ GeV p+p collisions at PHENIX

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1. Introduction

Direct photon is a powerful probe to investigate properties of Quark Gluon Plasma (QGP) since photons penetrate a dense and hot partonic matter created by heavy ion collisions. Special interest is in thermal photons from QGP, since they carry the thermodynamic information of the matter such as the temperature of the matter, degree of freedom and so on. Thermal photons are considered to be a primary contributor in the low $p_T$ region of the inclusive photon spectrum [1].

A measurement of ‘real’ direct photon using an electromagnetic calorimeter is notoriously difficult in the energy region below 4 GeV since the systematic errors cannot be reduced due to a large hadron background, particularly $\pi^0$. Recently, an alternative method using a ‘virtual’ direct photon measurement, i.e. a measurement of $e^+e^-$ pairs from ‘virtual’ direct photon decays was demonstrated to provide the photon yield with less systematic error in Au+Au collisions [2]. It is primarily because the $e^+e^-$ pair mass can be reconstructed with high resolution using the hit information from the drift chamber and components from hadron decays in the $e^+e^-$ pair mass distribution can be estimated reliably using a hadronic cocktail calculation which incorporates the measured yields of the mesons at PHENIX. The same method is applicable to the direct photon yield in p+p collisions, which serves as a reference to the direct photon yield in Au+Au collisions. The first result of the direct photon measurement with the virtual photon method in $\sqrt{s} = 200$ GeV p+p collisions at RHIC-PHENIX is presented and the comparison of the direct photon yields in p+p and Au+Au collisions is also shown in this report.

2. Analysis

For real events, the correlated pair mass distribution is obtained after combinatorial background subtraction using an event mixing method. However the cross pairs from decays with 4 electrons in the final state such as $\pi^0, \eta \rightarrow \gamma e^+e^- \rightarrow e^+e^- e^+e^-$ and from two independent decays in the same jet or the back-to-back jets still remain in the correlated pair mass distribution. The contribution of the cross pairs are evaluated using like-sign pair distributions and a Monte Carlo simulation since these pairs are clearly visible in like-sign pair distributions. Their contributions are about 20% in $100 < m_{ee} < 300$ MeV. After these background pairs are subtracted, remaining pairs are composed of the pairs from hadron decays and virtual photon decays.

The relation between the photon production and the associated $e^+e^-$ pair production is expressed by the Kroll-Wada formula, Eq. 1 in ref. [3].

$$\frac{d^2n_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi} \frac{1}{m_{ee}} \sqrt{1 - \frac{4m_{ee}^2}{m_{ee}^2}} \left(1 + \frac{2m_{ee}^2}{m_{ee}^2}\right) S d\nu, \quad (1)$$

where $\alpha$ is the fine structure constant, $m_e$ and $m_{ee}$ are the masses of the electron and the $e^+e^-$ pair, respectively, and $S$ is a process dependent factor. In the case of hadrons such as $\pi^0$ and $\eta$ Dalitz decays, $S$ is given as $S = |F_{DC}(m_{ee})|^2 \left(1 - \frac{m_{ee}^2}{M_{hadron}^2}\right)$, where $F$ denotes the form factor and $M_{hadron}$ is the mass of the parent hadron. The $S$ factor is zero for $m_{ee} > M_{hadron}$. On the other hand, the $S$ factor becomes unity for $m_{ee} \ll p_T$ in the case of virtual direct photon. It will be possible to extract the virtual direct photon component from the $e^+e^-$ pair mass spectra by utilizing the difference in $e^+e^-$ pair mass dependence of the $S$ factor. Therefore the $e^+e^-$ pair mass distribution for $m_{ee} < 300$ MeV and $p_T > 1.0$ GeV/c is focused on.

3. Result

Figure 1 show the $e^+e^-$ pair mass distributions in p+p and Au+Au collisions for several $p_T$ regions compared to the hadronic cocktail calculation.

Au+Au collisions for several $p_T$ regions. The symbols and lines show the real data and hadronic cocktail calculation, respectively. Enhancement of the $e^+e^-$ pair yield is clearly seen for $m_{ee} > 100$ MeV in Au+Au collisions. It is noted here that a small excess over the cocktail is also observed.
for p+p collisions in the high $p_T$ region.

The following function is used for fitting the data to determine the fraction of the virtual direct photon component in the $e^+e^-$ pair mass distribution.

\[ f(m_{ee}) = (1 - r) \cdot f_{\text{cocktail}}(m_{ee}) + r \cdot f_{\text{direct}}(m_{ee}). \] (2)

where $f_{\text{cocktail}}$ is the mass distribution from the decay of neutral hadrons estimated using the cocktail calculation and $f_{\text{direct}}$ is that from the virtual direct photon decays, and $r$ is the virtual direct photon fraction. The fit result in p+p collisions for $1.5 < p_T < 2.0$GeV/c is shown as a thick line in Fig. 2. Figure 3 shows the obtained fractions of the virtual direct photon component as a function of $p_T$ in p+p and Au+Au collisions. The symbols show the result and the lines are the expectations from next-to-leading-order perturbative QCD (NLO pQCD) calculations [4] with different theoretical scales. A clear excess above the NLO pQCD calculation is seen in Au+Au collisions while the result in p+p collisions is consistent with the NLO pQCD calculation.

Finally, the real direct photon yield is obtained by multiplying the inclusive photon yield to the virtual direct photon fraction. Figure 4 shows the direct photon spectra in p+p and Au+Au collisions as a function of $p_T$. The close and open symbols show the result from ‘virtual’ and ‘real’ photon analyses, respectively. The star symbol shows the p+p result and the triangle, circle and box symbols show the Au+Au results for minimum bias, centrality of 0-20% and 20-40%, respectively. This is the first time that the direct photon production in p+p collisions has been measured in $1.0 < p_T < 4.0$ GeV/c. The p+p result is well described by a modified power law function as shown by the dashed curve. The obtained yield in Au+Au collisions show an excess over the $N_{\text{coll}}$-scaled p+p fitted curve in the low $p_T$ region, where $N_{\text{coll}}$ is the number of nucleon-nucleon collisions. Fitting the result for Au+Au central collision with an exponential plus the $N_{\text{coll}}$-scaled p+p fitted curve provides the inverse slope parameter of $221 \pm 23 \pm 18$ MeV.

4. Summary and Outlooks

The direct photon measurements with a virtual photon method has been performed for p+p and Au+Au collisions at RHIC-PHENIX. An excess of the direct photon yield above a binary-scaled p+p result has been observed in Au+Au collisions. The excess is fitted with an exponential function with an inverse slope parameter of $221 \pm 23 \pm 18$ MeV. This result was submitted to Phys. Rev. Lett. [5]. Implications of the results are under various investigations.

The contribution from nuclear effects to the direct photon yield in the low $p_T$ region will be estimated using the data for Run-8 d+Au collisions and the analysis of the p+p data set with more statistics is now on going.

References