Elliptic flow of direct photons in Au+Au collisions at 200 GeV *

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Abstract The rapidity dependence of the elliptic flow of direct photons in Au+Au collisions at $\sqrt{s_{\rm NN}}=$ 200 GeV are predicted, based on a three-dimensional ideal hydrodynamic description of the hot and dense matter. The rapidity dependence of the elliptic flow $v_2(y)$ of direct photons (mainly thermal photons) is very sensitive to the initial energy density distribution along longitudinal direction, which provides a useful tool to extract the realistic initial condition from measurements.

Key words thermal photons, elliptic flow, hydrodynamics

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1 Introduction

The deconfined matter, a quark gluon plasma (QGP), has been expected to appear in relativistic heavy ion collisions. Various signatures have been proposed to verify its existence [1].

Collective flow, in particular elliptic flow, is an effective probe to investigate bulk properties of the QGP in nucleus-nucleus collisions at relativistic energies. In non-central collisions the overlapping reaction zone of two colliding nuclei has an anisotropic shape, like an almond, in the transverse plane. This leads to a preferred flow direction parallel to the impact parameter, and therefore the initial spatial anisotropy is carried over to momentum-space anisotropy [2].

In high energy heavy ion collisions, thermal photons can be produced during the whole history of the evolution of the hot and dense matter. Moreover the mean free path of photons is much larger than the transverse size of the bulk matter. As a result, thermal photons can provide the inner information of the QGP.

In this paper, we investigate the second Fourier coefficient of azimuthal momentum distribution, the so-called elliptic flow coefficient v_2, for thermal photons in Au+Au collisions at $\sqrt{s_{\rm NN}}=200$ GeV, under different initial conditions. In Sec. 2 we will introduce basic formula for the production of thermal photons and that for calculating elliptic flow. In Sec. 3, we will show our results on v_2 of thermal photons in whole rapidity range in Au+Au collisions at $\sqrt{s_{\rm NN}}=200$ GeV. Section 4 is devoted to summary of our results.

2 Thermal photons production and elliptic flow

Transverse momentum spectra of thermal photons can be written as

$$\frac{{\rm d}N}{{\rm d}y{\rm d}^2p_{\rm t}}=\int{\rm d}^4x\Gamma(E^*,T), \tag{1}$$

with $\Gamma(E^*,T)$ being the Lorentz invariant thermal photons emission rate which covers the contributions from the QGP phase [3] and hadron gas (HG) phase [4], ${\rm d}^4x=\tau\,{\rm d}\tau\,{\rm d}x\,{\rm d}y\,{\rm d}\eta_{\rm s}$ being the volume-element, and $E^*=p^\mu u_\mu$ the photon energy in the local rest frame. Here p^μ is the photon's four momentum in the laboratory frame, T and u^μ are the temperature and the local fluid velocity, respectively, to be taken from the hydrodynamic calculations mentioned above. We

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only consider thermal photon radiation from the region with energy density above $e^{\rm th}$.

The triple differential spectrum can be written as a Fourier series,

$$\frac{\mathrm{d}^3N}{\mathrm{d}y\,\mathrm{d}^2p_\mathrm{t}}=\frac{\mathrm{d}^2N}{2\pi p_\mathrm{t}\,\mathrm{d}p_\mathrm{t}\,\mathrm{d}y}\left(1+\sum_{n=1}^{\infty}2v_n\cos(n\phi)\right), \quad (2)$$

where ϕ is the azimuthal angle of photon's momentum with respect to the reaction plane, which is defined to be the plane containing the impact parameter and beam axis. The elliptic flow is quantified by the second harmonic coefficient v_2

$$v_2(p_\mathrm{t},y)=\frac{\int\mathrm{d}\phi\cos(2\phi)\mathrm{d}^3N/\mathrm{d}y\,\mathrm{d}^2p_\mathrm{t}}{\int\mathrm{d}\phi\mathrm{d}^3N/\mathrm{d}y\,\mathrm{d}^2p_\mathrm{t}}. \quad (3)$$

In previous work [5], we have investigate the p_t dependence of elliptic flow in various centrality and the centrality dependence of integrated elliptic flow with full 3D ideal hydrodynamic calculation [6, 7] in Au+Au collisions at $\sqrt{s_\mathrm{NN}}=200$ GeV. In the following we discuss the rapidity dependence of elliptic flow for different initial condition.

3 Results and discussion

In this work, we still use the full 3D ideal hydrodynamic calculation [6, 7] to describe the space-time evolution of the hot and dense matter created in Au+Au collisions at RHIC. In this calculation, the local thermal equilibrium is assumed to be reached at the initial time $\tau_0=0.6$ fm/c. The impact parameters corresponding to different centralities in Au+Au collisions at RHIC, which are estimated with Glauber model, are 3.2, 5.5, 7.2, 8.5, 9.7, 10.8, and 11.7 fm for 0%–10%, 10%–20%, $\cdots$ and 60%–70% centrality, respectively.

Here we have introduce an additional initial condition based on flux tubes (string picture) as realized by the EPOS model [8] at the same initial time τ_0. For the two initial conditions, the EPOS one and the one we have been using so far – a parameterized initial condition based Glauber model – we take the same hydrodynamic equations and equations of state. The initial energy density from the two scenarios has been plotted as a function space-time rapidity η in Fig. 1, where dashed lines is based on parameterized initial condition one and dotted lines from EPOS initial conditions. One can see the energy density decreases very rapidly with η in EPOS initial condition while it has a plateau for $|\eta|<2.5$ in parameterized initial condition. In two dimensional hydrodynamics this plateau is assumed for the whole η region. The EPOS initial condition gives many similar results compared to the parameterized initial condition, i.e., the measured p_t-spectra of direct photons can also be well reproduced, and the same p_t-dependence and centrality dependence of elliptic flow of thermal photons has been observed. But a very different rapidity dependence of elliptic flow can be obtained based on the two initial conditions.

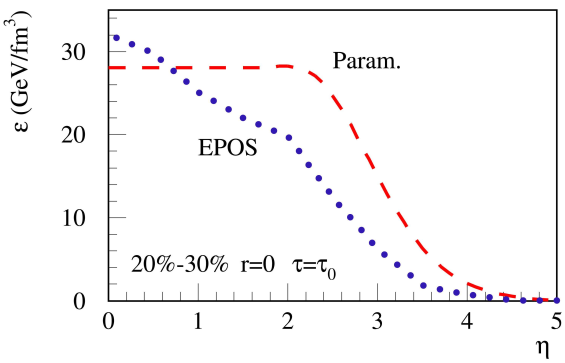

Fig. 1. (Color online) energy density as a function of space-time η; Dashed lines from parameterized initial condition and dotted lines from EPOS initial condition.

In Fig. 2 and Fig. 3 show the rapidity distributions of dn/dy and the v_2 of thermal photons produced from the two kinds of initial conditions at the same centrality, respectively. Solid lines are results of thermal photons emitted respectively from space-time rapidity $\eta=0,\pm1,\pm2,\cdots$. Dashed lines are over all η results. One can see that thermal photons from each η source have momentum rapidity $y\sim\eta$, similar to 1D Bjorken flow. The rapidity distribution of thermal photon production is an overlapping from different η sources. Due to this reason, different initial conditions give quite similar dn/dy of thermal photons. The over all elliptic flow $v_2(y)$ is more like a dn/dy-weighted average v_2 from different η sources. Both dn/dy and v_2 from each η source decrease rapidly when energy density decreases. So the obtained $v_2(y)$ almost keep the same shape of the initial $\epsilon(\eta)$: A rapid decrease of elliptic flow along longitudinal direction is obtained from EPOS initial condition where the energy density decreases very rapidly with η while a plateau of $v_2(y)$ at midrapidity region is roughly kept from the parameterized initial condition. A similar observation has already been made concerning the rapidity dependence of elliptic flow of hadrons.

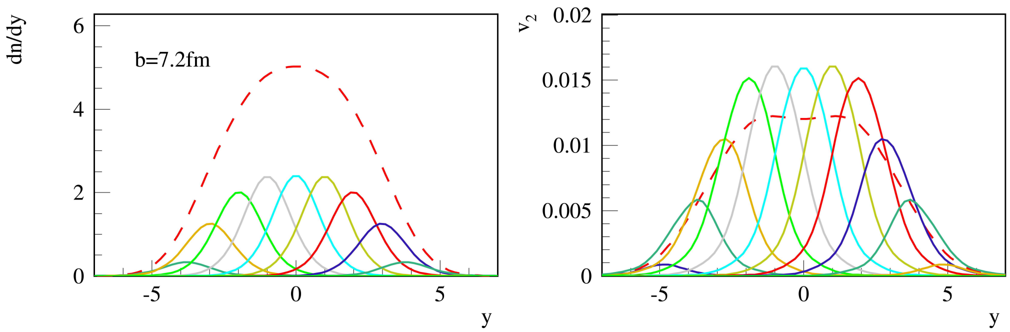

Fig. 2. (Color online) Rapidity distributions of $\mathrm{d}n/\mathrm{d}y$ and the v_2 of thermal photons calculated with parameterized initial condition. Solid lines are results of thermal photons emitted respectively from space-time rapidity $\eta=0,\pm1,\pm2,\cdots$. Dashed lines are over all η results.

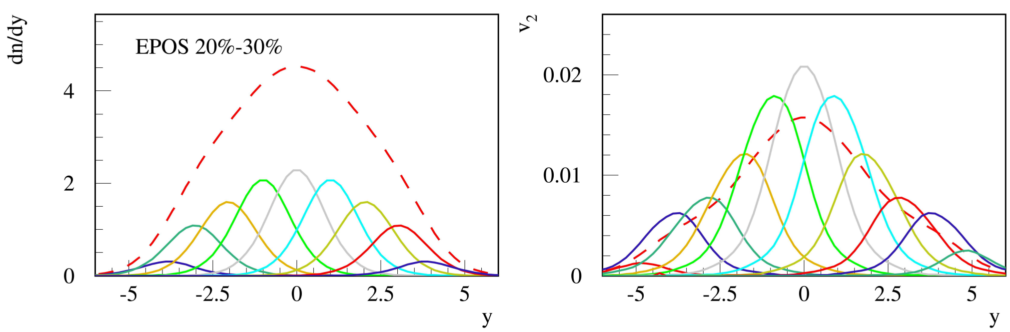

Fig. 3. (Color online) Rapidity distributions of $\mathrm{d}n/\mathrm{d}y$ and the v_2 of thermal photons calculated with EPOS initial condition. Solid lines are results of thermal photons emitted respectively from space-time rapidity $\eta=0,\pm1,\pm2,\cdots$. Dashed lines are over all η results.

4 Conclusion

Based on a fully three-dimensional ideal hydrodynamic description of the evolution of hot and dense matter created in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}=200$ GeV, with two kind of initial condition, we found the rapidity dependence of elliptic flow of thermal photons $v_2(y)$ can "remember" the initial energy density along the longitudinal direction $\epsilon_0(\eta_{\mathrm{s}})$, i.e., a plateau at midrapidity can be obtained from the parameterized initial condition based on Glauber model, while a rapid decrease of elliptic flow along rapidity is obtained from EPOS initial conditions.

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References

1 Harris J W, Muller B Ann. Rev. Nucl. Part. Sci., 1996, **46**: 71

2 Ollitrault J Y. Phys. Rev. D, 1992, **46**: 229; Phys. Rev. D, 1993, **48**: 1132

3 Arnold P, Moore G, Yaffe L G. J. High Energy Phys., 2001, **0111**: 057; J. High Energy Phys., 2001, **0112**: 9

4 Turbide S, Rapp R, Gale C. Phys. Rev. C, 2004, **69**: 014903

5 LIU F-M, Hirano T, Werner K, ZHU Y. Nucl.Phys.A, 2009, **830**:587C-590C

6 Hirano T. Phys. Rev. C, 2002, **65**: 011901

7 Hirano T, Tsuda K. Phys. Rev. C, 2002, **66**: 054905

8 Werner K, Hirano T, Karpenko Iu, Pierog T, Porteboeuf S, Bleicher M, Haussler S. J. Phys. G: Nucl. Part. Phys., 2009, **36**: 064030; arXiv:0907.5529