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Preliminary results on direct photon-photon HBT measurements in $\sqrt{s_{NN}} = 62.4$ GeV and 200 GeV Au+Au collisions at RHIC

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Abstract We present the preliminary results on direct photon interferometry measurements in Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV and 200 GeV using the STAR (solenoidal tracker at RHIC) detector. Photons are reconstructed via e^+/e^- conversions in STAR Time Projection Chamber (TPC) and energy deposited by photons in STAR Barrel Electromagnetic Calorimeter (BEMC). The two-photon correlations are measured using (1) both photons measured with BEMC; (2) one photon from conversions and the other measured with BEMC. Both the methodologies and the possible constraints in the correlation function measurements are discussed.

Key words RHIC • HBT • interferometry • TPC • BEMC • photon

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Introduction

The information about the space-time structure of the emitting source created in elementary particle and heavy-ion collisions from the measured particle momenta can be extracted by the method of two-particle intensity interferometry techniques (Hanbury Brown-Twiss – HBT) [9, 10]. Experimentally, the two-particle correlation function (normalized to unity at large Q_{inv}) is obtained from the ratio,

$$C_2(Q_{\text{inv}}) = A(Q_{\text{inv}})/B(Q_{\text{inv}}) \quad (1)$$

where $A(Q_{\text{inv}})$ is the pair distribution in invariant momentum for particle-pairs from the same event, and $B(Q_{\text{inv}})$ is the corresponding distribution for pairs of particles taken from different events [11].

Historically, most of the HBT measurements in heavy-ion experiments have been done with the pions [2, 3] and also have been extended to kaons, protons and other heavier particles. Hadron correlations reflect the properties of the hadronic source, i.e. size of the system at the freeze-out time. The direct photons, which are emitted during all the stages of the collision, serve as a deep probe of the hot and dense matter. Hence, direct photon HBT correlations can provide the system sizes at all stages of heavy-ion collisions [13–15].

Direct photons emitted from the early hot phase of the relativistic heavy-ion collisions and their HBT correlations are an important signature of the quark-gluon plasma and its properties. Due to their electromagnetic nature of interaction, the photons have a clear advantage in such studies [5] as they weakly interact with the system and are free from Coulomb interactions, which one needs to correct for hadronic in HBT measurements.

The photon-photon Bose-Einstein interferometry of the direct photons provides information about the various stages of heavy-ion collisions [7]. However, it is difficult to extract the small yield of direct photons due to the large background of photons produced by electromagnetic decay of the hadrons (especially π^0s and η). It has been proposed that one can obtain the direct photon HBT signal using all produced photons [12]. Direct photon HBT correlations were observed at SPS energies [4].

In this paper, we present the preliminary results on direct photon interferometry at $\sqrt{s_{NN}}$ = 62.4 GeV and 200 GeV Au+Au collisions in the Solenoidal Tracker in RHIC (STAR) experiment at the Relativistic Heavy Ion Collider (RHIC) facility in Brookhaven National Laboratory, USA. We have analysed minimum bias events for both 62.4 GeV and 200 GeV datasets.

Photons are reconstructed using two techniques: (a) energy deposited by photons in the STAR Barrel Electromagnetic Calorimeter (BEMC) and (b) from conversions in STAR Time Projection Chamber (TPC) [6]. The photon correlation functions C_2 (Q_{inv}) are extracted using two ways: (1) both photons measured using BEMC and (2) one photon from conversions and the other measured with BEMC. The photon identification efficiency in TPC is low and the granularity of BEMC tower hinders the observation of two very close BEMC photons. The energy threshold of the photons reconstructed from BEMC is relatively large. So, the combination of BEMC-TPC photon pairs can help to provide a compromise between these individual photon detection limitations.

The STAR detector and experimental setup

The STAR detector is one of the two ongoing large-scale experiments at RHIC. The present analysis is based on the Au+Au collisions measured by STAR detector in Run-IV. In the following, we describe the detectors that are relevant to the present analysis. The Time Projection Chamber (TPC) is used in STAR as the primary tracking device. The TPC records the charged particle tracks, measures their momenta and hence provides the particle identification by measuring their ionization energy loss (dE/dx). Particles are identified for a momentum range of 100 MeV/c to greater than 1 GeV/c and the measured momenta ranges from 100 MeV/c to 30 GeV/c. TPC has an acceptance of $|\eta| < 1.8$ with full azimuthal coverage. Photon momentum reconstruction was done by the measured momenta of e^+/e^- pairs produced from conversions.

The Barrel Electromagnetic Calorimeter (BEMC) is the main detector in STAR for photon measurements [8]. For the RHIC Run-IV, 50% of the BEMC was installed and operational, covering an acceptance of $0 < \eta < 1$ and full azimuth. The BEMC is a lead-scintillator sampling electromagnetic calorimeter with equal volumes of lead and scintillator. The calorimeter has a depth of 20 radiation lengths at $\eta = 0$ and an inner radius of 220 cm.

The BEMC includes a total of 120 calorimeter modules, each subtending an angle of 6^0 in φ direction (~0.1 radian) and 1.0 unit in η direction. These calorimeter modules are mounted 60 in φ and 2 in η. Each module is divided into 40 towers with granularity $(\Delta\eta,\Delta\varphi) = (0.05,0.05)$. Two layers of gaseous Shower Maximum Detectors (SMDs) with two-dimensional readout are located at $5X_0$ inside the calorimeter module.

The SMD is a wire proportional counter-strip readout detector using gas amplification. While the BEMC towers provide precise energy measurements for isolated electromagnetic showers, the high spatial resolution of $(\Delta\eta,\Delta\varphi) = (0.007,0.007)$ provided by the SMDs is essential for γ identification, π^0 reconstruction and electron identification. The electromagnetic energy resolution of the calorimeter is $\delta E/E \sim 16\%/\sqrt{E}$ (GeV).

The STAR trigger detectors are the CTB and ZDCs but separate trigger settings are used for the data analysis of 62.4 GeV and 200 GeV Au+Au collisions.

Correlation analysis of BEMC photons at $\sqrt{s_{NN}}$ = 62.4 GeV

For the present analysis of two-photon correlation functions, we have used 1.8 M minimum-bias events of 62.4 GeV after the event quality cuts. The event quality cuts include (1) the selection of events with a collision vertex with ±30 cm measured along the beam axis from the center of TPC, and (2) the rejection of corrupted events with high spurious energy measurements. The details of energy reconstruction and measurements in BEMC can be found in Ref. [1]. The photon-like clusters in the calorimeter are taken in this analysis which do not have a TPC track pointing at them within the proximity of single tower $(\Delta\eta,\Delta\varphi) = (0.05,0.05)$.

The two-photon correlation function that is defined in Eq. (1) is calculated as the ratio of the distribution of photon pair invariant relative momenta, Q_{inv}.

During the study of correlations at small Q_{inv}, we need to understand the effects produced by splitting of a single electromagnetic shower into multiple showers, or merging of nearby showers into a single cluster. From the studies of opening angle between two-photon clusters measured in BEMC, it is found that the minimum angle that reduces cluster merging is ~0.02 radian.

The effects of cluster splitting have been studied with opening angle and cluster energy cuts. Since the splitting photons are spatially close we rejected all photon clusters from the same tower.

Further studies on two-photon correlation function with photons taken from different towers along with energy cuts are also carried out. The two-photon correlation functions with pairs having energy specifically above 0.4, 0.6 and 0.8 GeV are shown in Fig. 1.

It can be seen from Fig. 1 that photon energy cut helps to reduce large enhancement below 0.1 GeV/c. This enhancement is related with the lepton pairs from

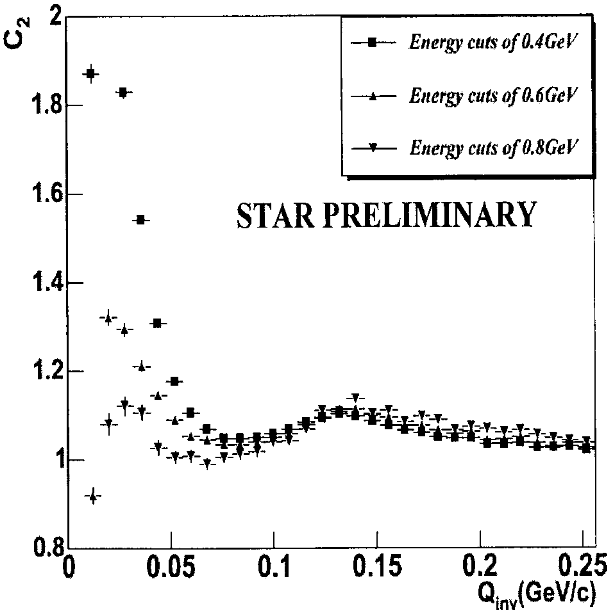

Fig. 1. Preliminary two-photon correlation function for neutral BEMC clusters with different energy cuts. Here BEMC clusters are selected from different adjacent towers. The region below the π^0 peak at $Q_{inv} \approx m_{\pi^0}$ is where the interference effects become significant.

the photon conversions in outer field cage of the TPC. We also see a clearly visible peak at $Q_{inv} \approx m_{\pi^0}$ due to the neutral pion decays. The energy cuts applied on the photon pairs reduce splitting but such cuts also require optimization as the correlation strength for direct photons is much less than the decayed ones. At present, we are studying how judiciously we can disentangle the apparatus effects, which mimic direct photon Bose-Einstein correlations.

We have also tested other properties of cluster splitting, like relative energy difference. In the case of erroneous cluster splitting one part is assigned more energy than the other. So, an effective cut to remove such pairs can help us to reduce splitting. We have studied the effects of two-particle energy asymmetry (alpha cut) |E1 − E2|/|E1 + E2| on correlation functions and found that in the case of STAR BEMC this cut is not effective in the removal of cluster splitting.

Correlation analysis of TPC-BEMC photons at $\sqrt{s_{NN}}$ = 200 GeV

In this analysis the TPC photons are reconstructed via e^+/e^- conversions. Electron and positron tracks are selected from particle identification by energy loss in the TPC. Some geometrical and quality cuts are applied to each e^+/e^- pair. For a converting primary photon, it is emitted from the primary vertex and converts into e^+/e^- pairs after traveling a certain distance, with a small opening angle between two daughter tracks. The trajectories of daughter tracks are two helices, thus the analysis cuts require that these two helices meet at a conversion point inside TPC or the inner cage if extended backward. The opening angle between the momenta of daughter tracks at the conversion point is required to be small. The momentum of the reconstructed photon, i.e. the sum of daughter tracks' momenta at conversion point, must point back to the primary vertex and the reconstructed photon invariant mass should be very small.

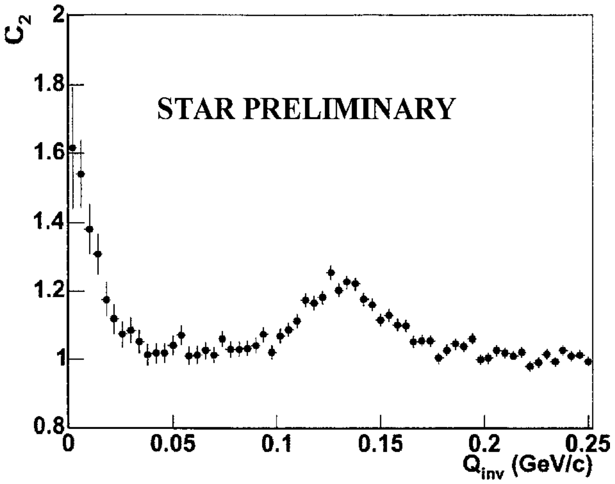

Fig. 2. Preliminary two-photon correlation function using the photon pairs from BEMC and TPC.

The BEMC photons are measured from the energy deposited in the electromagnetic calorimeter. The barrel BEMC towers are used to measure the energy of photons. The spatial position of the photons in the azimuthal and pseudorapidity directions are provided by the SMDs. Charged particles are removed by rejecting the BEMC clusters associated with any TPC charged tracks.

The correlation function shown in Fig. 2 uses one photon from BEMC while the other photon is reconstructed from TPC. There is a big unknown peak at small Q_{inv} region, with a magnitude greater than the theoretical limit of the direct photon HBT signal. This peak is insensitive to the geometrical and quality cuts of photons.

The study of the opening angle between photon pairs contributing to the low Q_{inv} region reveals that there might be some angular correlations between BEMC and TPC photons. Removing TPC photons with energy greater than 1 GeV substantially reduces the peak. But we do not see a similar behaviour of the correlation function when removing high-energy BEMC photons. Finally, in our simulation we observed a residual correlation from π^0 HBT correlation with a magnitude of a few percent, i.e. larger than the expected HBT signal, depending on the transverse-momentum range. This effect is still under study.

Conclusions

The current status of two-photon correlation functions, measured for the first time at RHIC using two independent methodologies, is presented. We have found an interesting correlation at low Q_{inv} and the challenge now remains to understand the apparatus effects and physics reasons behind such behaviour.

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