Dilepton Interferometry at different collision energies

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The goal of nuclear collision at relativistic energy is to create and study a novel state of matter, properties of which are governed by deconfined quarks and gluons. Such a phase of matter is called as Quark Gluon Plasma (QGP). The existence of QGP has been predicted by lattice QCD at high temperatures and densities. One of the most important observables for studying different aspects of Heavy Ion Collision (HIC) is the momentum correlation between two identical particles. This gives the information of the space-time structure of the particle emitting source created in HIC through two-particle intensity (Hanbury-Brown-Twiss (HBT)) interferometry [1]. Compared to real photons, the virtual photon (dilepton) can be used more effectively to study specific stages of evolution in heavy-ion collisions because of the availability of an additional kinematic variable, the invariant mass (M). Generally the transverse momentum (k_T) spectra get affected by flow and k_T integrated invariant mass spectra remain unaltered by flow. This suggests that the analysis of correlations between two virtual photon (dilepton) with appropriate selection of M and k_T window can be used to characterize different phases of HIC [2, 3] very efficiently.

The Bose-Einstein correlation function, C_2, for two virtual photons can be written as,

$$C_2(\vec{k_1},\vec{k_2}) = \frac{P_2(\vec{k_1},\vec{k_2})}{P_1(\vec{k_1})P_1(\vec{k_2})} \qquad (1)$$

where $\vec{k_i}$ is the three momentum of the particle i and $P_1(\vec{k_i})$ & $P_2(\vec{k_1},\vec{k_2})$ represent the one- and two- particle inclusive lepton pairs transverse momentum spectra respectively [3].

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The correlation function, C_2 has been evaluated for different invariant mass windows as a function of q_{side} and q_{out}. q_{out} and q_{side} are given by $q_{out} = (k_{1T}^2 - k_{2T}^2)/f(k_{1T},k_{2T})$ and $q_{side} = (2k_{1T}k_{2T}\sqrt{1-\cos^2(\Delta\psi)})/f(k_{1T},k_{2T})$, where

$$f(k_{1T},k_{2T}) = \sqrt{k_{1T}^2 + k_{2T}^2 + 2k_{1T}k_{2T}\cos(\Delta\psi)}$$

where $\Delta\psi = \psi_1 - \psi_2$ ψ_is are the angles made by k_{iT} with the x-axis.

The source dimensions can be obtained by parameterizing the calculated correlation function with the empirical (Gaussian) form

$$C_2 = 1 + \lambda\exp(-R_i^2 q_i^2). \qquad (2)$$

where the subscript i stand for *out* and *side* and λ represents the degree of chaoticity of the source. In the present case the value of λ will be 1/3 for a fully chaotic source.

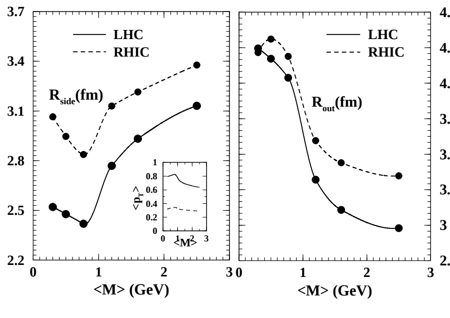

FIG. 1: R_{side} and R_{out} as a function of $\langle M\rangle = (M_1+M_2)/2$ for RHIC & LHC. M_1 and M_2 defines the width of the M window.

While the radius (R_{side}) corresponding to q_{side} is closely related to the transverse size of the system and considerably affected by the collectivity, the radius (R_{out}) corresponding to q_{out} measures both the transverse size and duration of particle emission. The extracted R_{side} and R_{out} for different M are shown in Fig. 1 for RHIC (dashed line) and LHC (solid line). The R_{side} shows non-monotonic dependence on M, it reduces with M, reaches its minimum value at $M \sim m_\rho$ and then increases again at high $\langle M \rangle$ approaching values close to the corresponding R_{side} for the QGP phase. In the absence of radial flow, R_{side} is independent of M. With the radial expansion of the system a rarefaction wave moves toward the center of the cylindrical geometry as a consequence the radial size of the emission zone decreases with time. The variation of R_{side} with $\langle M \rangle$ brings out the fact that the size of the emission zone is larger at early times and smaller at late time. And the larger dip in the variation of R_{side} with M around ρ-mass region at LHC is due to larger collectivity at LHC compared to RHIC.

The $R_{\rm out}$ probes both the transverse dimension and the duration of emission. Therefore, unlike R_{side}, it does not remain constant even in the absence of radial flow. The large M regions are populated by lepton pairs from early partonic phase where the effect of flow is small and the duration of emission is also small - resulting in smaller values of R_{out}. For lepton pair from $M \sim m_\rho$ the flow is large which could have resulted in a dip as in R_{side} in this M region. However, R_{out} probes the duration of emission too which is large for hadronic phase. The larger duration compensates the reduction of $R_{\rm out}$ due to flow in the hadronic phase resulting in a bump in $R_{\rm out}$ in this region of M.

The quantities $R_{\rm out}$ and $R_{\rm side}$ are proportional to the average size of the system. However, in the ratio, R_{out}/R_{side} some of the uncertainties associated with the space time evolution get canceled out. The quantity, R_{out}/R_{side} gives the duration of particle emission for various domains of M. Figure 2 shows the nonmonotonic variation of the ratio, R_{out}/R_{side} and the difference, $R_{diff} = \sqrt{R_{out}^2 - R_{side}^2}$ as a function of $\langle M \rangle$ for RHIC at $\sqrt{s_{NN}} = 200$ GeV (dashed line) and LHC at $\sqrt{s_{NN}} = 2.76$ TeV (solid line). The smaller values of both the quantities, particularly at high mass region, reflect the contributions from the early partonic phase of the system. The peak around ρ- mass reflects dominance of the contribution from the late hadronic phase as discussed before. Because of the large duration of particle emission at LHC the value of the ratio at the ρ peak is larger at LHC than RHIC.

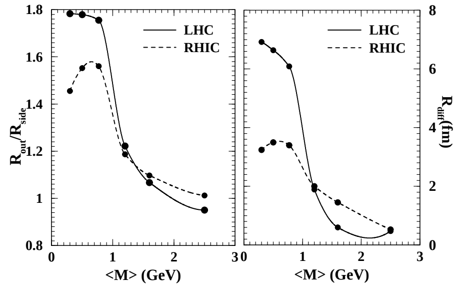

FIG. 2: The ratio R_{out}/R_{side} and the difference R_{diff} as a function of $\langle M \rangle$ for RHIC and LHC energies respectively.

In summary, a comparative study of the dilepton pair correlation functions has been evaluated for RHIC as well as LHC energy. Results obtained are qualitatively similar but quantitatively different. The quantitative difference in the ratio, R_{out}/R_{side} at RHIC and LHC reflects larger collectivity at LHC than RHIC.

References

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