Study of γ-charge correlation in heavy ion collisions

Prithwish Tribedy [1*] and Subhasis Chattopadhyay
Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata-700064, India

Aihong Tang
Physics Dept., Brookhaven National Laboratory, Upton, NY 11973, USA

Introduction

High energy heavy ion collisions produce realistic scenario for studying the phase transition from hadronic matter to Quark gluon plasma(QGP). Fluctuation of conserved quantities like isospin could be an important experimental signature for such phase transition. Since mostly produced charged particles and photons in heavy ion collision comprise charged pions and decay product of neutral pions respectively, $\gamma-$ch correlation addresses isospin fluctuation of pions. Moreover this phase transition is associated with restoration of QCD chiral symmetry. In such scenarios anomalous fluctuation in the relative pion production of different isospin is predicted to occur [1] through formation of domains of "Disoriented Chiral Condensate" (DCC). This is expected to appear in the form of $\gamma-$ch anticorrelation and has been searched previously in SPS (Pb+Pb) and Minimax (p+p) experiments. We present a method of studying $\gamma-$ch correlation study known detector and statistical effects involved in these measurements and suggest suitable robust observables $\Delta\nu_{\rm dyn}$ and $r_{m,1}$ sensitive to small $\gamma-$ch correlation signal.

Method

Variables to study $\gamma-$ch correlation are constructed based on moments of multiplicity distributions of photon and charged particles. It can be shown that such observables should contain ratios of factorial moments with powers of mean multiplicity to be robust explicit efficiency dependence [5]. We employ the generating function approach to study the sensitivity and the robustness of our observables defined as

$$G(z_{\rm ch}, z_\gamma) = \int_0^1 df\, \mathcal{P}(f) \sum_N P(N)\, [f z_\gamma + (1-f) z_{\rm ch}]^N \quad (1)$$

where $\mathcal{P}(f)$ and $P(N)$ are the event-by-event measured distribution of neutral pion fraction and total pion multiplicity respectively. Isospin symmetry for a pion gas corresponds to a generic case of pion productions for which $\mathcal{P}(f) = \delta(f-1/3)$. In case of DCC like events we have $\mathcal{P}(f) = 1/2\sqrt{f}$. Here $z_{\rm ch}$ and z_γ are variables to estimate moments accodring to the expression

$$\left.\frac{\partial^{m,n} G(z_{\rm ch}, z_\gamma)}{\partial z_{\rm ch}^m\, \partial z_\gamma^n}\right|_{z_{\rm ch}=z_\gamma=1} = \left\langle \frac{N_{\rm ch}!\ N_\gamma!}{(N_{\rm ch}-m)!\,(N_\gamma-n)!} \right\rangle$$

We consider two observables, $\nu_{dyn}^{\gamma-{\rm ch}}$ introduced in Ref [2] and is defined as

$$\nu_{dyn}^{\gamma-{\rm ch}} = \frac{\langle N_{\rm ch}(N_{\rm ch}-1)\rangle}{\langle N_{\rm ch}\rangle^2} + \frac{\langle N_\gamma(N_\gamma-1)\rangle}{\langle N_\gamma\rangle^2} - 2\frac{\langle N_{\rm ch} N_\gamma\rangle}{\langle N_\gamma\rangle\langle N_{\rm ch}\rangle}$$

Following the generating function approach it can be shown [5] that a modified form of this variable given by

$$\Delta\nu_{\rm dyn}^{\gamma-{\rm ch}} = \nu_{\rm dyn}^{\gamma-{\rm ch}} - \frac{1}{\sqrt{\langle N_{\rm ch}\rangle\,\langle N_\gamma\rangle}} \quad (2)$$

would make the variable more sensitive to signals of anti-correlation. The variable $r_{m,1}$, introduced in Ref[3] is defined as

$$r_{m,1}^{\gamma-{\rm ch}} = \frac{\langle N_{\rm ch}(N_{\rm ch}-1)..(N_{\rm ch}-m+1)\, N_\gamma\rangle\langle N_{\rm ch}\rangle}{\langle N_{\rm ch}(N_{\rm ch}-1)..(N_{\rm ch}-m)\rangle\langle N_\gamma\rangle}.$$

*Electronic address: ptribedy@vecc.gov.in

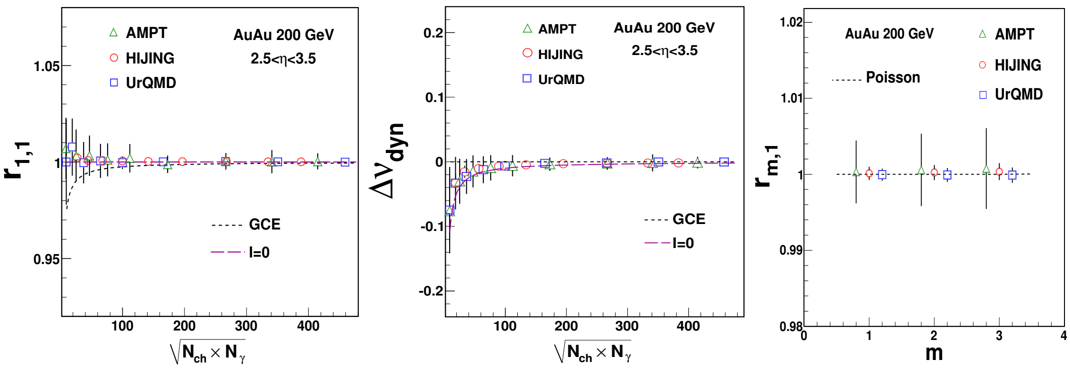

FIG. 1: Prediction of $r_{m,1}$ and $\Delta\nu_{\rm dyn}$ from different models relevant to heavy-ion collision. The curves represent the results from Ref[6] for different ensembles of Boltzmann gas of pions as described in the text. The markers are from different Monte-Carlo models. The error-bars are statistical.

which is 1 for Poisson case for all m and higher m show larger sensitivity to signal. In case of a scenario when x-fraction of events analyzed has DCC like fluctuation carried by y-fraction of total pions the effective generating function of eq.1 would be replaced by

$$G_{obs} = x\, G_{\rm DCC}\, G_{generic} + (1-x) G_{generic}$$

In that case the observables are become

$$\Delta\nu_{\rm dyn} \approx \frac{x}{5/9}\, y^2 \ , \ r^{\gamma-{\rm ch}}_{m,1} \approx 1 - \frac{mxy^2}{(m+1)} F(m, xy^2)$$

where the function $F(m,x)$ is given by

$$F(m,x) = \frac{1}{x + (1-x)\frac{2}{\sqrt{\pi}}\left(\frac{2}{3}\right)^{m+1}\frac{\Gamma(m+5/2)}{\Gamma(m+2)}}. \quad (3)$$

A functional fit of $r_{m,1}$ with m to experimental data by the above expression can restrict the contours of x and y.

Results and discussion

We have studied the behavior of observables from different models such as ideal Boltzmann gas of pions [6] for grand canonical ensemble (GCE), for a system of total isospin(I=0), monte-carlo models like HIJING, AMPT and UrQMD [4] which includes correlated productions such as resonances. Results for such non-DCC models are summarized in Fig.1. Relevant to heavy ion collision, we have also estimated the centrality dependance of our observables using an approach based on central limit theorem(CLT).

Summary and conclusion

We discuss a method for studying γ-charge correlation in heavy-ion collisions. One of the primary motivations for this study could be the search for DCC-like anti-correlation signals relevant to the ongoing heavy ion program at RHIC and LHC. We have studied the observables $\Delta\nu^{\gamma-{\rm ch}}_{\rm dyn}$ and $r^{\gamma-{\rm ch}}_{m,1}$ under different scenarios relevant to heavy-ion collisions. $\Delta\nu^{\gamma-{\rm ch}}_{\rm dyn}$ is either 0 or negative except for DCC case which gives positive value depending on the fraction x and y. $r^{\gamma-{\rm ch}}_{m,1}$ would show a particular functional dependance on m for DCC case which is distinct from all other scenarios.

Acknowledgement

A.T was supported by U.S. DOE under grants DE-AC02-98CH10886 and DE-FG02-89ER40531.

References

[1] J.D. Bjorken, What lies ahead?, SLAC-PUB-5673, 1991.
[2] C. Pruneau, S. Gavin and S. Voloshin, Phys. Rev. C **66**, 044904 (2002)
[3] T. C. Brooks *et al.* Phys. Rev. D **55**, 5667 (1997)
[4] X. N. Wang *et al.*, Phys. Rev. D **44**, 3501(1991), Z. W. Lin *et al.*, [nucl-th/0411110], S. A. Bass *et al.*, [nucl-th/9803035].
[5] P. Tribedy, S. Chattopadhyay and A. Tang, arXiv:1108.2495
[6] V. V. Begun, M. I. Gorenstein and O. A. Mogilevsky, Phys. Rev. C **82**, 024904 (2010) [arXiv:1004.2918 [nucl-th]].