Strange Fluctuations at RHIC

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Robust statistical observables can be used to extract the novel isospin fluctuations from background contributions in $K_0^0 K^\pm$ measurements in nuclear collisions. To illustrate how this can be done, we present new HIJING and UrQMD computations of these observables.

1. INTRODUCTION

Relativistic nuclear collisions can produce matter in which chiral symmetry is restored. One possible consequence of this restoration is the formation of disoriented chiral condensates (DCC) – transient regions in which the average chiral order parameter differs from its value in the surrounding vacuum. Previous efforts to describe DCC signals have focused on pion production. In Ref. [1], Gavin and Kapusta explored the possible influence of DCC on kaon production, inspired by an explanation by Kapusta and Wong [2] of measurements of $\Omega$ and $\Omega$ baryon enhancement at the CERN SPS, as discussed by Wong in these proceedings.

If true, Ref. [2] implies that the evolution of the condensate has a substantial strange component and, therefore, can produce kaon isospin fluctuations. A further implication is that the DCC regions must be rather small, with a size of about 2 fm, in accord with predictions based on dynamical simulations of the two flavor linear sigma model. Such a size is consistent with WA98 results reported here, which reveal no evidence of large DCC domains in neutral and charged pions. In this talk we study kaon isospin fluctuations in the presence of many small DCC; both kaon and pion fluctuations were addressed in [1]. In the next section we discuss how DCC may lead to kaon fluctuations and propose statistical observables to detect them. In sec. 3 we present work in progress on event generator simulations to understand the magnitude and centrality dependence of these observables in the absence of DCC.

2. STRANGE DCC

To illustrate how a strange DCC can form, we first consider QCD with only up and down quark flavors. Equilibrium high temperature QCD respects chiral symmetry if the quarks are taken to be massless. This symmetry is broken below $T_c \sim 150$ MeV by the formation of a chiral condensate $\sigma$ that is a scalar isospin singlet. However, chiral symmetry implies that $\sigma$ is degenerate with a pseudoscalar isospin triplet of fields with the same quantum numbers as the pions.

DCC can form when a heavy ion collision produces a high energy density quark-gluon...
system that then rapidly expands and cools through the critical temperature. Such a system can initially break chiral symmetry along one of the pion directions, but must then evolve to the \( T = 0 \) vacuum by radiating pions. A single coherent DCC radiates a fraction \( f_\pi \) of neutral pions that satisfies the probability distribution \( \rho_1(f_\pi) = \{2f_\pi^{1/2}\}^{-1} \). Such isospin fluctuations constitute the primary signal for DCC formation in the pion sector. The enhancement of baryon-antibaryon pair production in [2] is a secondary effect due to the relation between baryon number and the topology of the pion condensate field.

This two flavor idealization only applies if the strange quark mass \( m_s \) can be taken to be infinite. Alternatively, if we take \( m_s = m_u = m_d = 0 \), then the chiral condensate would be an up-down-strange symmetric scalar field. For a realistic \( m_s \), a disoriented condensate can evolve by radiating \( \pi, K, \eta \) and \( \eta' \) mesons. Kaon fluctuations from a single large DCC would satisfy \( \rho_1(f_K) = 1 \), where \( f_K = (K_0 + \bar{K}_0)/(K_+ + K_- + K_0 + \bar{K}_0) \) [5]. Moreover, the condensate fluctuations can now produce strange baryon pairs [2]. Linear sigma model simulations indicate that pion fluctuations dominate three-flavor DCC behavior, while the fraction of energy imparted to kaon fluctuations is very small due to the kaons’ larger mass. On the other hand, domain formation may be induced by other mechanisms such as bubble formation or decay of the Polyakov loop condensate [3].

Detection of small incoherent DCC regions in high energy heavy ion collisions requires a statistical analysis in the \( \pi^0\pi^\pm \) or the \( K^0_S K^\pm \) channels. Neutral mesons can be detected by the decays \( \pi^0 \rightarrow \gamma\gamma \) or \( K^0_S \rightarrow \pi^+\pi^- \). The analysis we propose in [1] is sensitive to correlations due to isospin fluctuations. We expect these correlations to vary when DCC regions increase in abundance or size as centrality. Correlations of \( K^0_S K^\pm \) are reflected in the isospin variance,

\[ \nu = \left\langle \left( \frac{N_0}{\langle N_0 \rangle} - \frac{N_c}{\langle N_c \rangle} \right)^2 \right\rangle, \]

where \( N_0 \) and \( N_c \) are the number of neutral and charged mesons. For a single DCC, we find \( \nu \rightarrow 4\left\langle (2f_K - 1)^2 \right\rangle = 4/3 \). In contrast, an uncorrelated thermal source yields

\[ \nu_{\text{stat}} = \langle N_0 \rangle^{-1} + \langle N_c \rangle^{-1} = 4\langle N_K \rangle^{-1}, \]

with \( N_K = N_c + N_0 \). The dynamic isospin observable [1]

\[ \nu_{\text{dyn}} = \nu - \nu_{\text{stat}} \]

is convenient for experimenters, because this quantity is independent of detection efficiency [4] as discussed in Pruneau’s talk. Robust observables are useful for DCC studies because charged and neutral particles are identified using very different techniques and, consequently, are detected with different efficiency.

Why does the DCC’s size matter? Searches for structure in individual events – as conducted by WA98 – can distinguish DCC isospin fluctuations from a thermal background only if the disoriented region is sufficiently large. DCC can then be the dominant source of pions at low transverse momenta, since \( \langle p_t \rangle \sim 1/R \) for a coherent region of size \( R \). Experiments focusing on low \( p_t \) can then find anomalous events. For small domains as inferred in [2], this event structure is hard to distinguish from conventional fluctuations. However, statistical observables such as (3) can signal even a small DCC contribution for a sufficiently large event sample.
In Ref. [1], we compute the exact distribution of kaons due to many small DCC regions. For \( n \gg 1 \) domains, this distribution tends toward a Gaussian of mean \( \langle f \rangle = 1/2 \) and isospin variance \( \nu_{\text{dcc}} = 4/3n \). In a nuclear collision, the best we can hope is that a fraction \( \beta \) of kaons come from the decay or realignment of DCC domains, with the remainder \( \alpha = 1 - \beta \) from thermal sources. Folding together the thermal and the \( n \)-DCC distributions, we find

\[
\nu = \alpha^2 \nu_{\text{dcc}} + \beta^2 \nu_{\text{stat}},
\]

which implies

\[
\nu_{\text{dyn}} = 4\beta(\beta/3n - 1/\langle N_K \rangle).
\]

(4)

This quantity can be positive or negative depending on the magnitude of \( \beta \) compared to the number of domains per kaon.

### 3. FLUCTUATIONS IN COLLISIONS

We now discuss work in progress using event generators to simulate conventional sources of kaon fluctuations. In the absence of DCC, \( \beta = 0 \) so that \( \nu_{\text{dyn}}^0 = 0 \), see eq. (4). On the other hand, incomplete equilibration in nuclear collisions can result in dynamical correlations not described above. In particular, correlations at the \( NN \) level can affect \( \nu_{\text{dyn}} \). To explore how this might occur, we use HIJING and UrQMD to estimate the influence of conventional collision geometry and dynamics on the centrality dependence. To establish the relevance of these models, we show in fig. 1 the dynamic charge fluctuations \( \nu^{\pi^+\pi^-}_{\text{dyn}} \) and \( \nu^{K^+K^-}_{\text{dyn}} \) for pions and kaons as functions of the number of participants \( M \) computed from 300,000 HIJING, HIJING/\( BB \) and 50,000 UrQMD events for Au+Au at 200 \( \text{AGeV} \) in the rapidity range \(-0.5 < y < 0.5\). The uncertainties shown are statistical. Observe that all models give nearly the same values of \( \nu^{\pm}_{\text{dyn}} \). STAR data in Pruneau’s talk in these proceedings is in reasonable agreement with this data.

Figure 2 (left) shows the dynamic isospin observable as a function of \( M \) from HIJING, HIJING/\( BB \) and UrQMD. The large disagreement between the HIJING variants and UrQMD is astonishing, given the similarity of the charge fluctuations. To understand the contribution of collision dynamics to \( \nu_{\text{dyn}}^0 \), we compare our simulations to the wounded nucleon model (WNM). This model implies \( \nu_{\text{wnm}} \approx 2\nu_{pp}/M \), where \( M \) is the number of participants. The value in pp collisions \( \nu_{pp} \) is determined from pp simulations. The

![Figure 1: Dynamic charge fluctuations for \( \pi^+\pi^- \) (left) and \( K^+K^- \) (right).](image)
WNM curves in fig. 2 agree with HIJING and HIJING/B (the upper sets of points), but disagree with central UrQMD (the lower points). These trends may stem from the inclusion of rescattering in UrQMD but not in HIJING.

To illustrate the possible scenario for the onset of DCC effects, we estimate $\nu_{\text{dyn}}$ by adding DCC and wounded-nucleon contributions to the kaon variance and using (3) to find
$$\nu_{\text{dyn}} = \beta^2 \nu_{\text{dcc}} + (1 - \beta)^2 \nu_{\text{wnm}}.$$ We assume that the fraction of DCC kaons $\beta$ exhibits a threshold behavior above an impact parameter $b_0$, $\beta = \beta_0 [1 - (b/b_0)^2]$, where $b_0$ and $\beta_0$ are ad hoc constants. In fig. 2, we show estimates assuming that 10 domains contribute kaons in the range $-0.5 < y < 0.5$ for $b_0 \sim 6$ fm, taking the dcc fraction $\beta_0 \sim 20\%$.

In summary, we have argued that measurements of $K^0 K^\mp$ correlations may probe a variety of interesting phenomena, especially 2+1 flavor DCC. The robust statistical variable $\nu_{\text{dyn}}$ is sensitive to DCC even if domains are small. In addition, we have estimated $\nu_{\text{dyn}}$ in the absence of DCC using HIJING and UrQMD event generators. We find that isospin fluctuations distinguish between these models, while charge fluctuations do not.

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