Kaon and pion fluctuations from small disoriented chiral condensates

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Enhancement of Ω and $\overline{\Omega}$ baryon production in Pb+Pb collisions at a center-of-mass energy of 17A GeV can be explained by the formation of many small disoriented chiral condensate regions. This explanation implies that neutral and charged kaons as well as pions must exhibit novel isospin fluctuations. We compute the distribution of the fraction of neutral pions and kaons from such regions. We then propose robust statistical observables that can be used to extract the novel fluctuations from background contributions in $\pi^0\pi^{\pm}$ and $K_S^0K^{\pm}$ measurements at the Brookhaven Relativistic Heavy Ion Collider and the CERN Large Hadron Collider.

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I. INTRODUCTION

Heavy ion collisions at the Brookhaven Relativistic Heavy Ion Collider (RHIC) at center-of-mass energies up to 200A GeV and the CERN Large Hadron Collider (LHC) at 5.5A TeV may produce matter in which chiral symmetry is restored. One possible consequence of the restoration and the subsequent rebreaking of chiral symmetry is the formation of disoriented chiral condensates (DCCs)—transient regions in which the average chiral order parameter differs from its value in the surrounding vacuum [1–3].

Measurements of Ω and $\overline{\Omega}$ baryon enhancement [4] at 17A GeV at the CERN SPS can be explained by the production of many small DCC regions within individual collision events [5]. If true, this explanation has two important consequences. First, the DCC regions must be rather small, with a size of about 2 fm. Such a size is consistent with predictions based on dynamical simulations of the two-flavor linear σ model [6]. More startling is the second implication that the evolution of the condensate can have a significant effect on *strange* particle production. The importance of strange degrees of freedom in describing chiral restoration has long been appreciated [7–11], but simulations of the three-flavor linear σ model had suggested that strange kaon fields are much less important than the pion fields [12]. Nevertheless, the Ω and $\overline{\Omega}$ data demand that we explore without prejudice techniques for measuring kaon fluctuations.

In this paper we study pion and kaon isospin fluctuations in the presence of many small DCCs. In the next section we compute probability distributions that describe the DCC contribution to these fluctuations. Pion fluctuations due to many small DCCs have been addressed by Amado and Lu [13] and Chow and Cohen [14], although the distribution we compute is new. Ours is the first work to study kaon fluctuations. In Sec. III we combine the DCC fluctuations with a contribution from a random thermal background. In Sec. IV we discuss how the size and number of DCCs vary with impact parameter, target, and projectile size. In Sec. V we assess robust statistical observables that can be used to measure the impact of many small DCCs at RHIC and LHC. In particular, we obtain a dynamic isospin fluctuation observable analogous to the dynamic charge observable used to measure net charge fluctuations at RHIC [15]. Of the quantities considered, this observable isolates the DCC effect from other sources of fluctuations best.

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 $\langle\sigma\rangle \sim \langle \overline{u}u + \overline{d}d\rangle$ that is a scalar isopin singlet. However, chiral symmetry implies that σ is degenerate with a pseudoscalar isospin triplet of fields with the same quantum numbers as the pions. In reality, chiral symmetry is only approximate and the 140 MeV pion mass is different from the 800 ± 400 MeV mass of the leading σ candidate [16]. Nevertheless, lattice calculations exhibit a dramatic drop of $\langle\sigma\rangle$ near T_c at finite quark masses.

A 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_π of neutral pions compared to the total that satisfies the probability distribution

$$\rho_1(f_\pi) = \frac{1}{2 f_\pi^{1/2}}, \quad 0 < f_\pi \leqslant 1 \tag{1}$$

[17–19]. Such isospin fluctuations constitute the primary signal for DCC formation. The enhancement of baryon-antibaryon pair production is a secondary effect due to the relation between baryon number and the topology of the pion condensate field [20].

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. The more realistic case of $m_s \sim 100$ MeV is between these extremes, so that $\langle\sigma\rangle \sim \langle \cos\theta(\overline{u}u + \overline{d}d) + \sin\theta(\overline{s}s)\rangle$. The mixing angle θ is highly uncertain since it depends on the σ mass together with the π, K, η, and η' masses and the $\eta - \eta'$ mixing angle [9]. A disoriented condensate can evolve by radiating

π, K, η, and η' mesons, with the neutral pion fraction satisfying Eq. (1). Schäffner-Bielich and Randrup find that the kaon fluctuations from a single large DCC satisfy [12]

$$\rho_1(f_K)=1, \quad 0\leqslant f_K\leqslant 1, \tag{2}$$

where $f_K=(K^0+\overline{K}^0)/(K^++K^-+K^0+\overline{K}^0)$. Moreover, the condensate fluctuations can now produce strange baryon pairs [5]. Linear σ 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 kaon condensation at high baryon density [21], bubble formation [22], or decay of the Polyakov loop condensate [23].

Why does the DCC's size matter? Pion measurements in individual collision events can distinguish DCC isospin fluctuations from a thermal background only if the disoriented region is sufficiently large [2]. DCCs 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 study neutral and charged pion fluctuations [19], wavelet [24], and HBT signals [2,25] to extract detailed information. In contrast, for small domains ($R<3$ fm [2]) DCC signals are hidden by fluctuations due to ordinary incoherent production mechanisms. This holds even if many such regions are produced per event. DCC mesons from small regions may have momenta of a few hundred MeV, nearer the pp mean value. Different regions would not add coherently to alter HBT, nor would their small spatial structures affect wavelet analyses.

Importantly, baryon pair enhancement is substantial only if there are many small incoherent regions. The large winding numbers that produce baryon-antibaryon pairs require many small regions with random relative orientations of the pion field. To describe strange antibaryon enhancement, Kapusta and Wong assume roughly 100 DCC regions of size of roughly 2 fm [5]. Topological models of baryon-antibaryon pair production successfully describe e^+e^- and hadronic collision data [26]. The connection of DCCs to topological pair production was pointed out in Ref. [20]; see also Ref. [27].

II. FLUCTUATIONS IN NEUTRAL DCC MESONS

In this section we will compute the statistical distribution of the ratio of neutral to total number of mesons, first for kaons and then for pions. In both cases the limit that the number of DCC domains becomes large is taken. It is natural that this limit results in a Gaussian distribution for both kaons and pions on account of the central limit theorem. In the next section these distributions will be folded together with a random or thermal source which most likely would comprise the bulk of the mesons in a high-energy heavy-ion collision.

A. Kaons

Define $f=(K^0+\overline{K}^0)/(K^++K^-+K^0+\overline{K}^0)$. To an excellent approximation the number of neutral kaons is equal to twice the number of short-lived neutral kaons K_S that are more readily measurable in high-energy heavy-ion collisions. The fraction f ranges from 0 to 1.

The statistical distribution in f for a single domain is $\rho_1(f)=1$. The distribution for n randomly oriented, independent domains is

$$\rho_n(f)=\int\prod_{k=1}^{n} df_k\rho_1(f_k)\,\delta\!\left(f-\frac{1}{n}\sum_{j=1}^{n} f_j\right). \tag{3}$$

The Dirac δ function can be represented as an integral. Then ρ_n can be written as

$$\rho_n(f)=\int_{-\infty}^{\infty}\frac{dz}{2\pi}e^{-ifz}\left[\int_0^1 dx\rho_1(x)e^{ixz/n}\right]^n. \tag{4}$$

Since $\rho_1(f)=1$, the integration over x can be done, resulting in a one-dimensional integral

$$\rho_n(f)=\frac{n}{\pi}\int_{-\infty}^{\infty}dt\left(\frac{\sin t}{t}\right)^n\cos[n(1-2f)t]. \tag{5}$$

The integral can be evaluated and expressed in terms of a finite sum:

$$\rho_n(f)=n^2\sum_{0\leqslant k<n(1-f)}(-1)^k\frac{[n(1-f)-k]^{n-1}}{k!(n-k)!}. \tag{6}$$

It is useful to have a simple analytic formula for ρ_n in the limit that $n\gg 1$. In this limit the factor $(\sin t/t)^n$ in the integral formula is strongly peaked at $t=0$. Let us write this factor as $\exp[-F(t)]$ with a view towards a saddle point approximation. We get

$$F(0)=F'(0)=0,$$
$$F''(0)=n/3, \tag{7}$$
$$e^{-F(t)}\approx e^{-nt^2/6}.$$

Use of this approximation yields the asymptotic formula

$$\rho_n(f)=\sqrt{\frac{6n}{\pi}}\exp[-6n(f-1/2)^2]. \tag{8}$$

The distribution is strongly peaked around $f=1/2$ as one might expect.

Figure 1 shows the evolution of $\rho_n(f)$ with n. It goes from a flat distribution for $n=1$ to a Gaussian sharply peaked at $f=1/2$ as n becomes large compared to 1. In fact a Gaussian is a very good representation for $n>2$.

B. Pions

Define $f=\pi^0/(\pi^++\pi^-+\pi^0)$. To a good approximation the number of neutral pions is equal to half the number of photons. Therefore, to this level of precision, it is not necessary to identify each π^0 via its decay into 2γ. The fraction f ranges from 0 to 1.

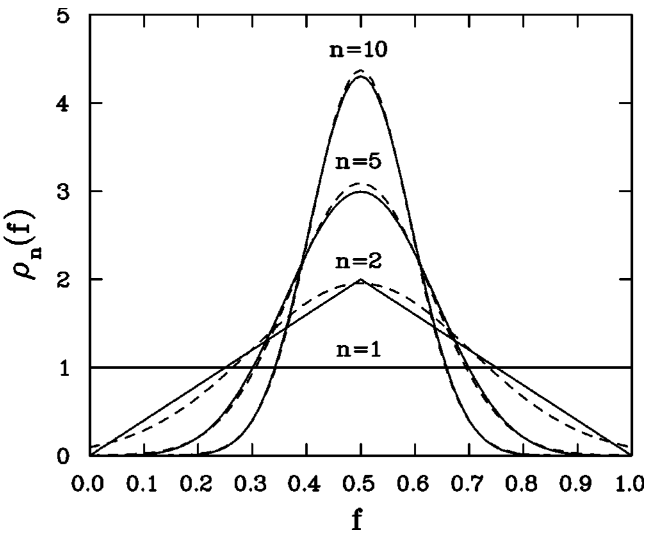

FIG. 1. The probability distribution for the ratio of neutral to total number of DCC kaons from n domains. The dashed curves represent Gaussian distributions [from Eqs. (6) and (8)].

The statistical distribution in f for a single domain is $\rho_1(f)=1/2\sqrt{f}$. The distribution for n randomly oriented, independent domains can be computed along the same lines as for kaons

$$\rho_n(f)=\int_{-\infty}^{\infty}\frac{dz}{2\pi}e^{-ifz}\left[\int_0^1\frac{dx}{2\sqrt{x}}e^{ixz/n}\right]^n. \tag{9}$$

Since pions from DCCs have been extensively studied we shall be content to evaluate the distribution in the large n limit. This is accomplished by expanding the exponential in the x integration to second order in $1/n$, evaluating the resulting integrals, and exponentiating. Thus

$$\int_0^1\frac{dx}{2\sqrt{x}}e^{ixz/n}\approx\exp\left[i\frac{z}{3n}-\frac{2z^2}{45n^2}\right]. \tag{10}$$

The z integral can then be done, yielding a Gaussian centered at $f=1/3$:

$$\rho_n(f)=\sqrt{\frac{45n}{4\pi}}\exp[-45n(f-1/3)^2/4]. \tag{11}$$

III. FOLDING DCCS AND THERMAL MESONS

In a more realistic scenario some kaons will come from the decay or realignment of DCC domains and some will come from more conventional sources. We shall refer to the latter as random or thermal, even though that may be a bit of a misnomer. What we mean by random or thermal is that the distribution of kaons from non-DCC sources is

$$\rho_0(f_0)=\frac{1}{2\pi\sigma_0^2}\exp[-(f_0-1/2)^2/2\sigma_0^2]. \tag{12}$$

For a completely random source the width σ_0 is related to the total number N_{random} of non-DCC kaons by

$$\sigma_0^2=\frac{1/2(1-1/2)}{N_{\mathrm{random}}}=\frac{1}{4N_{\mathrm{random}}}. \tag{13}$$

Now let us assume that a fraction α_K of all kaons come from non-DCC sources and the remaining fraction $\beta_K=1-\alpha_K$ come from $n\gg1$ independent DCC domains. Letting N denote the total number of kaons, we have $N_{\mathrm{random}}=\alpha_K N$ and $N_{\mathrm{DCC}}=\beta_K N$. Folding together two Gaussians gives a Gaussian:

$$\rho_K(f)=\int df_0 df_n\rho_0(f_0)\rho_n(f_n)\delta(f-\alpha_K f_0-\beta_K f_n)$$
$$=\frac{1}{\sqrt{2\pi\Delta_K^2}}\exp[-(f-1/2)^2/2\Delta_K^2]. \tag{14}$$

The net width is

$$\Delta_K^2=\frac{\alpha_K}{4N}+\frac{\beta_K^2}{12n}=\frac{1}{4N}+\left\{\frac{\beta_K^2}{12n}-\frac{\beta_K}{4N}\right\}. \tag{15}$$

The expression in curly brackets at the end represents the difference between the actual width and the width the distribution would have if there was no contribution from DCC kaons. This change in the width may be positive or negative, depending on the parameters.

An analogous analysis can be given for pions. This results in the distribution

$$\rho_\pi(f)=\int df_0 df_n\rho_0(f_0)\rho_n(f_n)\delta(f-\alpha_\pi f_0-\beta_\pi f_n)$$
$$=\frac{1}{\sqrt{2\pi\Delta_\pi^2}}\exp[-(f-1/3)^2/2\Delta_\pi^2] \tag{16}$$

with a net width of

$$\Delta_\pi^2=\frac{2\alpha_\pi}{9N}+\frac{2\beta_\pi^2}{45n}=\frac{2}{9N}+\left\{\frac{2\beta_\pi^2}{45n}-\frac{2\beta_\pi}{9N}\right\}. \tag{17}$$

As with the kaons, the last expression in curly brackets represents the difference between the actual width and the width the distribution would have if there was no contribution from DCC pions. Note that the fractions α_K and α_π need not be the same.

IV. VOLUME OR SURFACE SCALING?

The issue we wish to address is whether the number of DCC mesons (kaons or pions) scales with the volume or surface area of the system. This is an important issue when studying the impact parameter dependence or the dependence on the size of the projectile and target nuclei.

In this paper we follow Ref. [5] and assume that the collision process somehow forms many independent domains with a typical size $\xi\sim2$ fm. For such small domains, it is reasonable to assume that the size does not change appreciably with collision energy or total system volume (unless collisions are sufficiently peripheral that the overlap area is comparable to the domain size). The number of domains n is given by the ratio of the two volumes: $n=V_{\rm system}/V_{\rm DCC}$. The numbers of DCC kaons or pions, $N_{\rm DCC}$, scale in the same way with n or $V_{\rm system}$ because the size of individual domains is fixed. The numbers then depend on the extra energy associated with the formation of each domain. Each domain has a volume energy that depends on the mechanism that produced it. In linear σ models adjusted to fit the meson masses, the energy density inside distinct domains can differ by $\epsilon \sim 20$ MeV/fm^3 for two flavors [1] and a much larger amount for three flavors [9]. The number of pions or kaons then scales as the energy available for particle production, $\epsilon\xi^3 n$.

Observe that the same scaling $\propto n$ would hold if the up and down quark masses were zero, although for very different reasons. In this limit QCD has perfect SU(2) flavor symmetry and the volume energy of a uniform domain is independent of the orientation of the chiral field. With no volume energy difference between domains, the energy for particle production must come entirely from the misalignment of the condensate between adjacent domains. The number of DCC pions would then be proportional to the total surface energy between domains. Let us analyze the scaling of the excess surface energy quantitatively. Consider a cube with sides of length L into which fit $n=(L/l)^3$ cubic domains, each with sides of length l. Assuming that each domain is oriented independently of its neighbors, the total surface energy scales with the total surface area, which is $3(L/l+1)\times(L^2/l^2)$. With $L \gg l$, and with the domain size l fixed, the total surface area, energy, and therefore number of DCC mesons scale with n to the power of one. Thus $N_{\rm DCC}\propto n \propto V_{\rm system}$ no matter whether one imagines the excess energy being associated with domain interfaces or with domain interiors.

V. STATISTICAL ANALYSIS

Detection of small incoherent DCC regions in high energy heavy ion collisions requires a statistical analysis in the $\pi^0\pi^\pm$ or the $K_S^0K^\pm$ channels. Neutral mesons can be detected by the decays $\pi^0\rightarrow\gamma\gamma$ or $K_S^0\rightarrow\pi^+\pi^-$. The analysis we propose is sensitive to correlations due to isospin fluctuations. We expect these correlations to vary when DCC regions increase in abundance or size as centrality, ion-mass number A, or beam energy are changed. Correlation results combined with other signals, such as baryon enhancement [5], can be used to build a circumstantial case for DCC production.

Correlations of $\pi^0\pi^\pm$ and $K_S^0K^\pm$ can be determined by measuring the robust isospin covariance,

$$R_{c0}=\frac{\langle N_cN_0\rangle-\langle N_c\rangle\langle N_0\rangle}{\langle N_c\rangle\langle N_0\rangle}, \tag{18}$$

where N_0 and N_c are the number of neutral and charged mesons. We take $N_0=N_{\pi^0}$ and $N_c=N_{\pi^+}+N_{\pi^-}$ for pion fluctuations and $N_0=2N_{K_S^0}$ and $N_c=N_{K^+}+N_{K^-}$ for kaon fluctuations. The ratio (18) has two features that are convenient for experimental determination. First, this observable is independent of detection efficiency as are the "robust" ratios discussed in Ref. [28]. 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. Observe that robust quantities are not affected by the unobserved K_L^0, since the strong-interaction eigenstates K^0 and $\overline{K}^0$ are a superposition K_L^0 and K_S^0 until their decay well outside the collision region. Second, since Eq. (18) is obtained from a statistical analysis, individual $\pi^0\rightarrow\gamma\gamma$ or $K_S^0\rightarrow\pi^+\pi^-$ need not be fully reconstructed in each event. This feature is crucial because it would be extraordinarily difficult—if not impossible—to reconstruct a low momentum π^0 in heavy-ion collisions except on a statistical basis.

Next we define robust variance

$$R_{aa}=\frac{\langle N_a^2\rangle-\langle N_a\rangle^2-\langle N_a\rangle}{\langle N_a\rangle^2}, \tag{19}$$

where $a=c$ or 0. To see why Eq. (19) is robust, denote the probability of detecting each meson ϵ and the probability of missing it $1-\epsilon$. For a binomial distribution the average number of measured particles is $\langle N_a\rangle^{\rm expt}=\epsilon\langle N_a\rangle$ while the average square is $\langle N_a^2\rangle^{\rm expt}=\epsilon^2\langle N_a^2\rangle+\epsilon(1-\epsilon)\langle N_a\rangle$. We then find

$$R_{aa}^{\rm expt}=R_{aa}, \tag{20}$$

independent of ϵ [29]; the proof that Eq. (18) is robust is similar. The ratios (18) and (19) are strictly robust only if the efficiency ϵ is independent of multiplicity. Further properties and advantages of these and similar quantities are discussed in Ref. [29].

To study DCC fluctuations we define the dynamic isospin observable

$$\nu_{\rm dyn}^{c0}=R_{cc}+R_{00}-2R_{c0}. \tag{21}$$

Analogous observables have been employed to study net charge fluctuations in particle physics [30,31] and were considered in a heavy ion context in Refs. [15,32]. This quantity can be written in terms of

$$\nu^{c0}=\left\langle\left(\frac{N_0}{\langle N_0\rangle}-\frac{N_c}{\langle N_c\rangle}\right)^2\right\rangle. \tag{22}$$

To isolate the dynamical isospin fluctuations from other sources of fluctuations, one obtains Eq. (21) by subtracting from Eq. (22) the uncorrelated Poisson limit $\nu_{\rm stat}^{c0}=\langle N_0\rangle^{-1}+\langle N_c\rangle^{-1}$. Indeed, we show in Eq. (27) below that the quantity (21) depends primarily on the fluctuations of the neutral fraction f, while the individual ratios (18) and (19) have additional contributions.

We illustrate the effect of DCCs on the dynamic isospin fluctuations by writing $N_0=fN$ and $N_c=(1-f)N$. Small fluctuations on f or N results in the changes

$$\frac{\Delta N_0}{\langle N_0\rangle}=\frac{\Delta N}{\langle N\rangle}+\frac{\Delta f}{\langle f\rangle},$$
$$\frac{\Delta N_c}{\langle N_c\rangle}=\frac{\Delta N}{\langle N\rangle}-\frac{\Delta f}{1-\langle f\rangle}. \tag{23}$$

We obtain the average

$$\frac{\langle \Delta N_0^2\rangle}{\langle N_0\rangle^2}=v+\frac{2c}{\langle N\rangle\langle f\rangle}+\frac{\Delta^2}{\langle f\rangle^2}. \tag{24}$$

Here the contribution of the variance of the total number of mesons is $v\equiv\langle\Delta N^2\rangle/\langle N\rangle^2$ and the charge-total covariance is $c\equiv\langle\Delta N\Delta f\rangle$. DCC formation primarily effects the charge fluctuation contribution, $\Delta^2\equiv\langle(\Delta f)^2\rangle$, from Eq. (15) or (17). Similarly,

$$\frac{\langle \Delta N_c^2\rangle}{\langle N_c\rangle^2}=v-\frac{2c}{\langle N\rangle(1-\langle f\rangle)}+\frac{\Delta^2}{(1-\langle f\rangle)^2}, \tag{25}$$

and

$$R_{c0}=v+\left(\frac{1}{\langle f\rangle}-\frac{1}{1-\langle f\rangle}\right)\frac{c}{\langle N\rangle}-\frac{\Delta^2}{(1-\langle f\rangle)^2}, \tag{26}$$

where R_{c0} is given by Eq. (18). Using Eq. (21) we get

$$\nu_{\rm dyn}^{c0}=\frac{1}{\langle f\rangle(1-\langle f\rangle)}\left(\frac{\Delta^2}{\langle f\rangle(1-\langle f\rangle)}-\frac{1}{\langle N\rangle}\right). \tag{27}$$

This observable isolates the isospin fluctuations, whereas the individual R_{ab} depend on the fluctuations in total meson number, v and c as well.

We estimate the effect of DCC on the dynamical fluctuations (27) using Eqs. (15) and (17). We take $\langle N\rangle=N_K$ for kaons and $\langle N\rangle=N_\pi$ for pions; these are the total number of mesons of the indicated kind. For kaons

$$\nu_{\rm dyn}^{c0}(K\ {\rm DCC})=4\beta_K\left(\frac{\beta_K}{3n}-\frac{1}{N_K}\right), \tag{28}$$

and for pions

$$\nu_{\rm dyn}^{c0}(\pi\ \ {\rm DCC})=4.5\beta_\pi\left(\frac{\beta_\pi}{5n}-\frac{1}{N_\pi}\right). \tag{29}$$

These quantities can be positive or negative depending on the magnitude of β compared to the number of domains per kaon. In fact the dynamical fluctuation may even be positive for one kind of meson and negative for the other.

How big is the DCC effect compared to alternative sources of fluctuations? In the absence of DCCs $\alpha=1$ and $\beta=0$ so that Eq. (29) implies $\nu_{\rm dyn}^{c0}\equiv 0$ for both pions and kaons. On the other hand, in models that treat nuclear collisions as a superposition of independent nucleon-nucleon collisions, each nucleon-nucleon collision contributes an amount ν_{c0}^{pp} to the overall fluctuations. Consequently, M nucleon-nucleon collisions can contribute an amount ν_{c0}^{pp}/M to the total $\nu_{\rm dyn}^{c0}$ [34]. While little is known from pp experiments about kaon fluctuations, HIJING and RQMD models yield negative values of ν_{c0}^{pp}. For kaons, HIJING simulations of central Au+Au at 200A GeV yield $\nu_{\rm dyn}^{c0}\approx-0.002$ for 47 K^+ and 44 K_S^0 on average [33]. The onset of a DCC contribution to $\nu_{\rm dyn}^{c0}$ can substantially change this value. A detailed analysis of this problem within microscopic models will appear elsewhere [34].

VI. DISCUSSION AND CONCLUSION

Reference [5] argued that the anomalous abundance and transverse momentum distributions of Ω and $\overline{\Omega}$ baryons in central collisions between Pb nuclei at 17A GeV at the CERN SPS is evidence that they are produced as topological defects arising from the formation of many domains of disoriented chiral condensates (DCCs) with an average domain size of about 2 fm. Motivated by this interpretation, we have studied the effect of DCCs on the distribution of the fractions of neutral kaons and pions. We showed that the distributions are accurately described by Gaussians with centroids at $f=1/2$ and 1/3, respectively, once the number of domains exceeds just a few. Folding together kaons or pions arising from DCCs with other sources that are Gaussian distributed results once again in Gaussians. These may have a width that is greater or less than a purely random source without DCC formation.

The DCC pioneers [17–19,1] had hoped that a large percentage of pions might be emitted from just a few big domains, on the order of 5 to 8 fm (kaons were not considered). Such large domains have been ruled out at SPS [3], but remain possible at RHIC. More conservatively, as the number of domains grow and their average size diminishes, the impression left on the fluctuations in the neutral fraction becomes more subtle and less unique. For many small domains, statistical measurements of both neutral kaons (pions) and charged kaons (pions) are needed. Since not every hadron emitted can possibly be detected with 100% efficiency, and since the experimental techniques that identify K_S, $K^\pm$, π^0, and $\pi^\pm$ are very different, we have identified robust observables that are essentially independent of all these uncertainties. In particular, we propose that the dynamical isospin observable (21) can be parametrized as in Eqs. (28) and (29). DCC effects can appear as changes in the magnitude of the dynamical isospin observable as centrality is varied. We emphasize that similar consequence may follow from any mechanism that produces many small domains that decay to pions and kaons, such as the Polyakov loop condensate [23]. We anxiously await what RHIC will have to say.

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