Probing chiral dynamics by charged-pion correlations*

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High-energy nuclear collisions are expected to produce transient systems within which chiral symmetry is approximately restored and the matter is partially deconfined. The identification and exploration of such a novel matter phase is a major experimental goal and the efforts have intensified with the recent commisioning of the Relativistic Heavy Ion Collider at BNL.

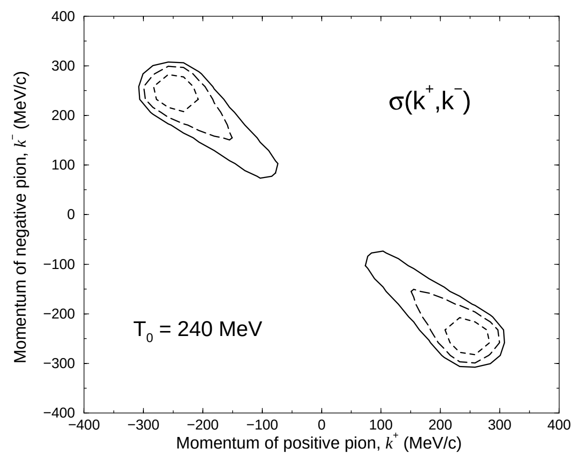
Through the past decade, it has been speculated that the rapid expansion of the collision zone, after an approximate restoration of chiral symmetry has occurred, may produce long-wavelength isospin-polarized agitations of the pionic field, commonly referred to as disoriented chiral condensates (DCC), which in turn should lead to anomalies in the resulting pion multiplicity distribution. However, the experimental search for the phenomenon has been hampered by the lack of signatures that are practically observable.

The present work identifies a novel observable that may be particularly suitable as an indicator of the DCC phenomenon, namely the approximate back-to-back correlation between oppositely charged soft pions.

The pionic degrees of freedom experience a rapidly changing environment that can be approximately accounted for by an in-medium effective mass depending both on the degree of agitation and on the chiral order parameter. Since the system is steadily cooling down while the order parameter reverts from its initial small value to its large vacuum value in a non-equilibrium fashion, the effective pion mass has then a correspondingly intricate evolution, displaying an overall decay towards the free mass overlaid by the effect of the rather regular oscillations by the relaxing order parameter. This time modulation of the effective mass may lead to parametric amplification those soft pionic modes with an energy near half the σ mass.

The effect is brought out most clearly in the simple case where the environment, and hence the effective mass, is spatially uniform, as is approximately the case in the interior of the collision zone. It is then obvious that although the time dependence of the mass may generate considerable agitation, this agency cannot add any net momentum. Thus the any pions produced by the mechanism must be formed pairwise and moving in opposite directions. Furthermore, by a similar reasoning, the time dependence of the mass does not add any change, so the produced pairs must be oppositely charged. Thus, the particles generated by an arbitrary time dependence in a uniform medium are charge-conjugate back-to-back pairs. This basic feature may be exploited as a probe of the chiral dynamcis.

When the environment has a spatial dependence, as is more realistic, the pions experience forces that tend to erode the clear back-to-back correlation pattern. We have examined this effect with a quantum-field treatment of a one-dimensional scenario, using a mass function that emulates the profiles obtained in more elaborate numerical simulations with the linear σ model. The resulting two-body correlation function for charge-conjugate pions is shown in the figure. The characteristic correlation structure is seen to be rather robust and so there is reason to hope that this signature may be experimentally observable.



Of course, this "signal" is partially obscured or eroded by a number of other processes and thus any attempt to extract it from the experimental data must take careful account of such "background" contributions.

One important issue concerns the possible presence of other agencies that may lead to a similar signal and thus forge the DCC signature. While there are many physically different sources of charge-conjugate pion pairs, fortunately only few lead to strong back-to-back correlations. Particularly important is the decay $\rho(770) \to \pi^+\pi^-$ but due to the high ρ mass, at least one of the pions has a momentum above 360 MeV$/c$ which is somewhat above the upper limit of the expected effect ($k_{\rm max} \approx 300$ MeV$/c$). Moreover, although $\eta(550)$ and $\omega(780)$ may both contribute soft $\pi^+\pi^-$ pairs, these all arise in three-body decays and thus they are only rather weakly correlated and so they should not pose a serious problem.

In conclusion, then, we suggest that the data now being taken at RHIC be analyzed for indications of the described signature in the large-angle correlation of soft charge-conjugate pion pairs. It may also be worthwhile to scrutinize existing SPS data for this signal. If indeed identified, this signal may offer a means for probing the degree of chiral restoration achieved and the subsequent DCC dynamics.

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