P and CP odd effects in hot and dense matter
Future Studies

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As Yogi Berra noted "predictions are hard, especially for the future"

Nevertheless, I will offer some thoughts

About the topic, including some general observations which you probably already know, but which are relevant to "future Studies".

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- Perhaps the central issue derives from the fact that what we can observe is a correlation predicted by the LPV (local parity violation) theory but is not in itself a parity odd operator. Observation of this correlation thus does not definitively prove LPV.
- Indeed, there have been several attempts to show that this correlation could arise from what we could loosely call “known physics”.

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- Therefore, the elucidation of the source of the observed effect requires considerable additional experimental and theoretical work, some of which I will try to describe.

- Many of the ideas have been given by others and I do not pretend to originality.

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- One class of experiments are those where the LPV theory would not predict an effect, but which it is reasonable to expect that the non LPV "background" effects should be present.
- Another class of experiments studies the behaviour of the LPV effect as the experimental parameters are varied. Clearly this study requires the theory to predict what the behaviour should be. To do this adequately in most cases is a considerable challenge to theorists.

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- Finally there is one class of experiment which might be definitive. This was suggested by Millo and Shuryak (arXive:09212.4894v 1 [hep-ph] Dec 2009).
- They argue that the parity violating region should exist after particles form and this could give rise to a parity violating decay. The example they list is $\eta \rightarrow \pi^{+}\pi^{-}$. Unfortnately, the branching ratio is estmated as .001. This is an experimental challenge!

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1. Experiments of the first class (LPV predicts no effect, but "background" can be expected.
   a) As sugested by Sergei, U-U collisions where the long axes of the football shape of the Uranium nuclei are parallel and normal to the line of flight.

      If the highest centrality (.5%) is selected, the impact parameter and hence the magnetic field should be near zero. There would however still be appreciable v_2 because of the nuclear shape. So LPV effect small, background "normal". A good test of the first class.

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- The correlation of the K_{short} mesons with charged pions should be zero from the LPV effect but as K_{shorts} are hadrons many of the background effects might be present. (The K_{shorts} are equally quark and anti quark).

- A similar but much more difficult experiment is the measurement of the correlation of π^0 mesons with charged pions. This is highly challenging and I do not see how to do it.

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2. Experiments of the second type in which the behaviour of the correlation is studied as the experimental parameters are varied.

- Perhaps the most interesting of these is the study of the effect as the energy of the collision is lowered. At a sufficiently low energy the collision should not be able to produce a "QGP"and the LPV effect should vanish (or be very much reduced).

  In a more general view, the energy dependence is a behaviour which can be compared with the theoretical predictons.

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b) Another experiment of the second type is the study of the effect (as also suggested by Sergei) of the effect as the colliding charges are varied, keeping the same baryon numbers in the collision (isotopes). According to the LPV theory this should display the dependence on the magnetic field (quadratic dependence for same masses). Of course there may well be geometric complications.

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c) The effect can be studied as a function of the colliding species. Again, this needs to be compared with a theory. This is complicated by the fact that the observed correlation depends not only on the LPV effect but also on the number of particles that do not pass through a parity violating region. Thus a rather complete theory of the entire collision is needed.

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d) Another interesting study would be to see how the effect shows up in the correlations of different (identified) particles. For example hyperons and even (with sufficient statistics) resonances. Clearly this also challenges the theory

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- Theoretical challenges

- Clearly, the elucidation of the interesting physics ofthis subject will require both experiment and theory developments.

  One of the most challenging will be the development of theories which describe the entire dynamical process of the collision.

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- Although a complete theory of the collision is probably not possible in the near term, even a partly phenomenolical analysis could be very useful.
- For example delineating experiments which could be compared with one another in the light of the theory (such as the variation of the magnetic field keeping baryon numbers constant) could be illuminating.

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- All of the above suggests that victory in the understanding of this fascianting effect will be, in “military” terms, the result of a long “infantry” battle advancing step by step until the weight of evidence becomes overwhelming, one way or another.

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- To summarize:
- A long program of experiment and comparison with theoretical models of the LPV effect and of other non LPV theories needs to be done if we are to understand

origin and physics of the correlations we have observed.

But the goal is a much more profound understanding of the nature of the new state(s) of hadronic matter discovered at RHIC