FELIX and astroparticle physics: even more than the cosmic ray connection

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SUMMARY

It is emphasized that the formalisms of finite-temperature field theory and non-equilibrium field theory relevant for the theoretical investigation of part of the FELIX program have a central role in the study of the interface between particle physics and cosmology. In as much as FELIX will test these formalisms, it will also contribute to our understanding of the early universe.

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As a detector with full acceptance, including the far forward region, FELIX is ideally suited to obtain data of great importance for the interpretation of cosmic-ray events, one of the most exciting subjects of "astroparticle physics" (the interface between particle physics and cosmology). This cosmiray connection is discussed in detail in the *FELIX working documents* in Ref. [1]. In the present *working document* I would like to emphasize another aspect of the FELIX program that can bring important insight into issues relevant for the study of astroparticle physics. In fact, one of the central themes of astroparticle physics is the use of the formalisms of finite-temperature field theory and non-equilibrium field theory[1] for the investigation of the theories describing ordinary particle physics in the conditions of high temperatures and/or high densities that are believed to have occurred in the early universe, and these extreme conditions are rather similar to the ones realized in ultrarelativistic collisions of hadrons or nuclei. The formalisms of finite-temperature field theory and non-equilibrium field theory are indeed widely used in the theoretical investigation of part of the FELIX program. In a sense FELIX will test these formalisms (or at least the different versions of these formalisms that have been debated in the literature) and the lessons learned will provide much needed input for our investigations of the early universe.

Like a few other experiments of its generation, FELIX will be probing the

[1]Here and in the following "field theory" will stand for both "quantum field theory" and "classical field theory" unless explicitly qualified.

physics of the chiral/deconfinement phase transition of quantum chromodynamics, and FELIX will be doing this from its unique perspective as a full acceptance detector. Acceptance in the far forward region (with its implications for "small-x" studies discussed, *e.g.*, in the *FELIX working documents* in Ref. [2]) will also render accessible to FELIX the QCD regime of very high parton densities, thereby providing one more opportunity for the study of relativistic quantum gauge theories in extreme regimes.

Of course, some of the theoretical ideas used in the discussion of the early universe (and the extreme regimes that characterize it) have already been tested in some condensed matter experiments; for example, the measurements on superfluid He-3-B reported in the recent Ref. [3] have dramatically confirmed the prediction of topological-defect formation at certain temperature-induced phase transitions. However, it is important to realize that the high-temperature and high-density regimes of the relativistic gauge theories describing particle physics have never been significantly probed in controlled laboratory experiments.

The general point about the relevance of the FELIX agenda for the study of the early universe is perhaps best illustrated by the similitude between FELIX studies of disoriented chiral condensates[2] (portions of the collision

[2]Disoriented chiral condensates also provide a meeting point for the two major areas in which FELIX has relevance for astroparticle physics, *i.e.* cosmic-ray physics and early-universe phase transitions. In fact, on one hand disoriented chiral condensates are directly linked to the presence of a chiral phase transition and on the other hand the only (however faint and debatable) available experimental evidence for disoriented chiral condensates comes from the centauro and anti-centauro cosmic-ray data [1].

region in which the chiral order parameter is temporarily chirally rotated with respect to its orientation in ordinary vacuum [4, 5]) and some related studies of cosmological issues. In particular, the debate concerning the proper theoretical description of the formation of disoriented chiral condensates at a chiral phase transition has been progressing quite in parallel with the corresponding debate in the context of investigations of early-universe phase transitions [14]. On the disoriented-chiral-condensate side it is important to establish whether non-equilibrium quantum field theory [6, 7, 8] is to be used in the analysis of the chiral phase transition or a quasi-equilibrium description within finite-temperature quantum field theory is preferable [9], and both in the non-equilibrium and in the finite-temperature quantum frameworks it is still unclear what is the best way to handle certain possibly-significant non-perturbative effects [7, 8, 9, 10]. Moreover, while quantum effects are of course present, it has been argued that much simpler analyses within finite-temperature [11] or non-equilibrium [12, 13] classical field theory could suffice for most applications. The predictions concerning the amount of disoriented chiral condensate formed at a chiral phase transition can change substantially from one approach to the other.

Because of the above-mentioned analogies, the same problems have been encountered in the context of investigations of early-universe phase transitions. For example, discussions of non-equilibrium vs. thermal approaches can be found in [6, 15, 16], while the handling of non-perturbative contributions is discussed in [17, 18, 19, 20, 21]. Predictions of central importance for cosmology depend rather sensitively on the choice of formalism; for example, substantially different results are found by the various approaches in the study of the electroweak phase transition (the temperature-induced phase transition of the standard model of electroweak interactions), which has recently attracted a lot of interest because of possible implications for baryogenesis. Clearly, important progress would be achieved if FELIX helps us establish which formalisms are most effective in the study of the phase transitions undergone by the relativistic gauge theories that describe particle physics.

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