RESEARCH PROGRESS REPORT

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Work Done in 1996

- Dilepton Productions from Heavy Quark Decays at RHIC
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  The emission of dileptons in high energy heavy-ion collisions provides an excellent probe of the property of dense hadronic matter such as the quark-gluon plasma and the hot hadronic gas. Due to the small cross sections of electromagnetic interactions, these dileptons once produced can escape the strong interacting volume of sizes which might be produced in heavy-ion collisions. The dilepton invariant mass spectrum holds the most promising signatures of the quark-gluon plasma such as thermal dileptons and the J/ψ suppression. However, the use of the dilepton probe is difficult for an obvious reason: it is sensitive to many different sources. In the low mass region, the resonance decays from the light hadrons constitute the main background. In the intermediate and high mass regions, the Drell-Yan dilepton production from the initial hard scattering is important. In high energy heavy-ion colliders such as RHIC and LHC, the heavy flavor quark production can be quite substantial and its subsequent decay can lead to a large combinatorial background for the dilepton spectrum. Therefore it is crucial to make a solid theoretical prediction on the contribution from heavy quark decays.

  In this work, we discuss the dimuon emission as the decay product of the heavy quarks (charm and bottom) produced in an initial hard scattering and in a thermalized quark-gluon plasma at RHIC energy. We include the next-to-leading order radiative corrections and nuclear shadowing effects. Indeed, some recent work has indicated that the dilepton production from the correlated charm decay is by far the dominant contribution. However, if the energetic charmed parton is subject to energy losses due to multiple secondary interactions in the dense matter produced in the collisions, the dilepton spectrum may be considerably softened. In contrast to the charm, the bottom decay can yield higher invariant mass lepton pairs even at rest due to the large bottom mass.

  We have taken into account the next-to-leading-order radiative corrections in perturbative QCD to the heavy quark production from both an initial hard parton-parton scattering and an ideal quark-gluon plasma. The parton fragmentation and the heavy hadron decay are handled by the ISAJET

Monte Carlo model. The cascade decay of the bottom quark, $b \to c \to s$ is also included in this model. We find that the thermal charm decay dominates the dilepton production in the low dilepton mass region (< 2 GeV), while the heavy quark production from the initial scattering takes over the intermediate and high mass regions (> 2 GeV). Our result also indicates the importance of the bottom quark in the high mass region (> 4 GeV) due to its large mass and cascade decay. If the initial scattering produced charm suffers a significant energy loss due to the secondary interaction, the bottom decay constitutes the major background for the thermal dileptons.

- Jet Quenching in the Opposite Direction of a Tagged Photon in High-Energy Heavy-Ion Collisions

  X.-N. Wang, Z. Huang and I. Sarcevic

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  Large transverse momentum jets, among many other hard processes in high-energy heavy-ion collisions, have been proposed as effective probes of the transient dense matter. For example, an enhanced acoplanarity and energy imbalance of two back-to-back jets can be used to study multiple scatterings of a parton inside a dense medium. Study of large p_T jets can also probe their energy loss due to inelastic scatterings inside a dense matter or a quark-gluon plasma. Because of the enormous background in high-energy heavy-ion collisions, the conventional calorimetric study cannot measure the jet energy to such an accuracy as required to determine the energy loss. Alternately, single-particle inclusive p_T-spectrum has been shown to be sensitive to the jet energy loss. Since the single-particle spectrum is a convolution of the jet production cross section and the jet fragmentation functions, the suppression of produced hadrons at a fixed p_T results from jet quenching with a wide range of initial transverse energies, thus making it difficult to measure directly the modification of jet fragmentation for a given transverse energy.

  In this work, we propose to study the jet quenching in high-energy heavy-ion collisions by measuring the p_T distribution of charged hadrons in the opposite direction of a tagged direct photon. A direct photon is produced by quark-antiquark annihilation or quark(antiquark)-gluon Compton scatterings in which a gluon or quark(antiquark) jet is also produced in the opposite direction of the photon. By tagging a direct photon with a given transverse energy E_T^γ, one can avoid the uncertainties associated with the jet production cross section. One can also determine the initial transverse energy of the produced jet, $E_T \approx E_T^\gamma$, from momentum conservation, modulo calculable corrections from initial state radiations. At collider energies and sufficiently large E_T^γ, the Cronin effect due to multiple scatterings during the initial interaction stage is also negligible . We use perturbative QCD to show that the p_T spectrum of charged hadrons with moderate p_T in the backward direction of a direct photon is a very good approximation of the jet fragmentation function which can thus be reliably extracted. We also study the sensitivity of the modification of the jet fragmentation functions in heavy-ion collisions to the energy loss of jets and the jet interaction mean-free-path inside a dense matter. We have also demonstrated that modification of the jet fragmentation function due to jet quenching can be used to obtain the energy loss and the mean-free-path of jet interaction inside the dense matter produced in high-energy heavy-ion collisions. The energy dependence of the energy loss in our calculation. In addition, the energy loss, dE/dx, might also depend on the distance that jet partons have traveled as indicated by a recent study. These dependences can be studied experimentally by varying the energy of the tagged photons in the collisions of different nuclei. These are the subjects of further investigations.

- Studying the Domain Structure of a Disoriented Chiral Condensate From a Wavelet Perspective

  Z. Huang, I. Sarcevic, R. Thews and X.-N. Wang

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  Recently, it has been suggested that in very high energy hadronic and heavy-ion collisions the rapid expansion of the collision debris in the longitudinal (beam) direction leads to supercooling in the interior of the interaction region, and as a result, domains of the "unconventionally" oriented vacuum configurations allowed by the chiral symmetry may be forme. Detection of this interesting phenomenon, the so-called Disoriented Chiral Condensate (DCC), would provide valuable information on the vacuum structure of the strong interaction and the nature of the chiral phase transition. Preliminary theoretical investigations on nonequilibrium dynamics using the classical linear σ-model have found some evidence for the growth of long wavelength pion modes, which may indeed lead to domain structure or cluster formation. Although the precise dimension of a typical domain or cluster is still under debate, it seems likely, especially in heavy-ion collisions, that many domains or clusters could be formed in the large interaction volume. If there are many uncorrelated small domains, the integrated probability distribution of the neutral pion fraction f emitted from a disoriented region, predicted to be $P(f) = 1/2\sqrt{f}$, would become Gaussian. This would follow from the Central Limit Theorem in statistics which states that the probability distribution of the sum of N independent identically distributed variables becomes Gaussian with width $\sim 1/N$ as N increases, independent of the original distribution. This makes the experimental search for the DCC signal a rather difficult task.

  In order to disentangle the DCC domain structure in high energy heavy-ion collisions, we propose a new method which emphasizes not only the behavior of the probability distribution in the full phase space region but also its fluctuation in rapidity η or azimuthal angle ϕ. In other words, one needs to study the "local" properties of the distribution in phase space if the DCC clusters are "localized" objects in phase space. It is a multiresolution analysis performed by a discrete wavelet transformation (DWT) which has been found effective in systematically detecting structures on various scales in turbulence, astrophysics, and multiparticle productions. We demonstrate that the DWT proves to be very useful in identifying and measuring the DCC domain structures *simultaneously* in terms of their size (in scale) and location (in space). Since it is likely that there are other physical scales accompanying the typical DCC domain scale in a physical process, the multiresolution feature of the DWT is essential for identification of the structures of interest. It acts like a mathematical microscope which can zoom in or out to various scales at each location. Due to the completeness and orthogonality of the DWT basis, there will be no information loss.

We show that the probability distributions of the neutral pion fraction for various rapidity-bin sizes have distinctive shapes in the case of a DCC and exhibit a delay in approaching the Gaussian distribution required by the Central Limit Theorem. We find the wavelet power spectrum for a DCC to exhibit a strong dependence on the scale while an equilibrium system and the standard dynamical models such as HIJING have a flat spectrum.

- Dilepton and Photon Productions from a Coherent Pion Oscillation

  Zheng Huang and Xin-Nian Wang

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  Recently, there has been some interest in the formation of a disoriented chiral condensate (DCC) in high energy hadronic and heavy-ion collisions. Preliminary studies have suggested that there may be a coherent pion field oscillation following a nonequilibrium second order phase transition which may lead to characteristic soft pion production. These pions are not assumed to reach a thermal equilibrium, rather, they behave collectively and a coherent field description is more relevant. The space-time evolution of the condensate field is mainly determined by the classical equation of motion for a low energy effective theory such as a linear or nonlinear σ model. Eventually, the "disoriented vacuum" relaxes back to normal vacuum by emitting physical pions. It is, however, difficult to obtain the information on its space-time evolution from the final hadron spectrum.

  In contrast, the electromagnetic signature is known to be an ideal probe of a dense hadronic matter owing to the fact that it escapes the strong interaction region once produced without further final state interactions and thus carries the information on the early dynamical evolution. In this work, we study the dilepton and direct photon production from the classical pion field in the context of a disoriented chiral condensate (DCC) or most generally a nonequilibrium pion cloud. We develop a general formalism for the dilepton and photon emissions in the presence of a classical electromagnetic current. As an example, we calculate the dilepton and photon spectra in an analytical solvable model where a general class of solutions are obtained by Blaizot and Krzywicki and by Huang and Suzuki. Since the electromagnetic current coincides with the third component of the isovector current, the isospin angular oscillation of the condensate field can be a significant source for the electromagnetic emission in the low mass (transverse momentum) region.

  We have studied the characteristic dilepton and photon emissions from the classical pion field oscillation in the QCD vacuum. The general analytical solution obtained in the nonlinear σ model is used to calculate the electromagnetic current density, which exhibits a light-front singularity and decreases rapidly as inverse square of the proper time due to a longitudinal expansion. The momentum and invariant mass spectra of the direct photon and dilepton are found to be a sensitive probe of the space-time evolution of the chiral condensate field.

Work in Progress

- Wavelet Jet Algorithm in High Energy Collisions

  Z. Huang, I. Sarcevic and R. Thews

  We propose to develop a background smoothing/suppression algorithm based on a discrete wavelet transformation (DWT) for high E_T jets in high energy heavy-ion collisions.

- Gluon Structure Function in Nuclei

  Z. Huang, H.-J. Lu and I. Sarcevic

  The gluon density in a nucleon/nucleus is the most important physical observables that govern the physics at high energy and low Bjorken x. We are currently interested in a unified picture of the nuclear gluon density evolution combining a nonperturbative Glauber approach and a perturbative recombination effect such as that in the GLR equation. The aim is to confront the theoretical ideas with experimental data on the nuclear shadowing, especially the saturation of the nuclear gluon density.