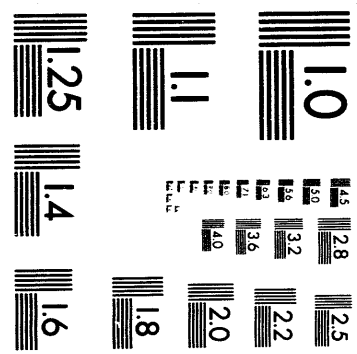

1 of 1

DOE/ER/40328--T2

1 Introduction

Nuclear physics is now a many-faceted field involving not only the study of nuclei but also properties of matter under extreme conditions and the interactions and dynamics of strongly interacting particles. The main focus of this group has been the study of high temperature and density matter, as well as the properties of ordinary nuclear matter. We have been working on problems which range from the properties of matter near and slightly above nuclear matter density to the properties of matter at energy densities where the electroweak degrees of freedom are important. With the advent of experiments at the AGS and at CERN, and with the construction of RHIC well underway and exciting possibilities at LHC in CERN, we are all extremely enthusiastic about the future of the field.

The main subject of research in our group has been and remains understanding the physics of matter at energy densities greater than 0.15 GeV/fm^3. Theory encompasses the relativistic many-body/quantum field theory aspects of QCD and the electroweak interactions at these high energy densities, both in and out of thermal equilibrium. Applications range from neutron stars/pulsars to QCD and electroweak phase transitions in the early universe, from baryon number violation in cosmology to the description of nucleus-nucleus collisions at CERN and at Brookhaven.

We have been involved in recent activity to understand the properties of matter at energy densities where the electroweak W and Z boson degrees of freedom are important. This problem has applications to cosmology and has the potential to explain the baryon asymmetry produced in the big bang at energies where the particle degrees of freedom will soon be experimentally probed. This problem is interesting for nuclear physics because many of the techniques used in many-body physics of nuclei and the quark-gluon plasma may be extended to this new problem.

We have been interested in problems related to multiparticle production. This includes work on production of particles in heavy ion collisions, the small x part of the nuclear and hadron wave function, and multiparticle production induced by instantons in weakly coupled theories. These problems have applications in the heavy ion program at RHIC and the deep inelastic scattering experiments at HERA.

The plan of this progress report is as follows. In section 2 we review the most important work of the group in the past year; research prior to August 1992 was summarized extensively in the proposal of July 1992. In section 3 we discuss the research now in progress and plans for investigations in the next year. In section 4 we list those personnel who have been supported by the grant in the past year, including postdoctoral research associates, graduate students, and visitors. In section 5 we list all publications of the group since August 1992. In section 6 we list the oral presentations of the principal investigators and postdoctoral research associates in the same time frame. Finally in section 7 we make a few remarks about the proposed budget.

In the past year we have been active in the physics community not only through research and regular university teaching but also by the following activities:

Joseph Kapusta

Co-organizer (with E. Shuryak) of *Strong Interactions at Finite Temperature*, to be held at the Institute for Theoretical Physics at the University of California in Santa Barbara, August - December 1993.

Larry McLerran

Director of Theoretical Physics Institute, University of Minnesota, 1989 - 1992

General Member of Aspen Institute for Physics, 1990 - present.

Member of Experimental Program Advisory Committee at Stanford Linear Accelerator Center, 1990 - 1992

International Advisory Committee for *Quark Matter 1993*, Uppsala, Sweden, 1993.

Organizing committee for the NATO Advanced Study Institute *Hot and Dense Nuclear Matter*, Bodrum, Turkey, 1993

Organizer of *B+L Not*, Aspen, Colorado, 1993

Organizing Committee for *Aspen High Energy Physics Meeting*, Aspen, Colorado, 1994

2 Review of Recent Work

2.1 Non-Relativistic Many-Body Theory

Paul Ellis has been working on problems in non-relativistic many body theory. The standard theory of effective interactions for use in shell model calculations yields an effective interaction, R, which is non-Hermitian (a real, but non-symmetric matrix). Shell model codes on the other hand are invariably designed for Hermitian matrices. The transformation of R to Hermitian form is known. Paul Ellis, Kenji Suzuki and Ryoji Okamoto (Kyushu) and Jifa Hao, Zibang Li and Tom Kuo (Stony Brook) have carried out the first investigations on this topic. Using realistic G-matrices with second order perturbation corrections it was found that the exact Hermitian effective interaction, W, can be well approximated by $\frac{1}{2}(R + R^{\dagger})$. The accuracy of this approximation is determined by the eigenvalues, μ^2, of the operator $\omega^{\dagger}\omega$, where ω is the operator which maps the model space states onto the excluded space. Both a formal bound and a model calculation show that if the values of μ^2 are small, or state independant, W is well approximated by $\frac{1}{2}(R + R^{\dagger})$ and the non-Hermiticity is small.

In effective interaction theory, methods have been introduced to sum the folded diagram series to all orders, but these methods are able to yield only certain of the exact eigenvalues. This restriction is not present in the exact representation of the complete many-body problem as a series of non-folded and folded diagrams since this contains information regarding all of the true eigenvalues. Given a model space of dimension d it should be possible to obtain any selection of d eigenvalues from the complete set of true eigenvalues. Paul Ellis, Kenji Suzuki and Ryoji Okamoto (Kyushu) and Tom Kuo (Stony Brook) have shown that this is indeed possible. The formalism requires generalization of the Lee-Suzuki iteration method to the case where the unperturbed model-space energies are non-degenerate. A condition was derived for the convergence of the iteration scheme and this depended on the choice of the model space projection operators. Two choices were examined, in the first the projection operators were defined in terms of the unperturbed states and in the second they were defined in terms of the eigenfunctions obtained at each stage of the iteration. As illustrated by calculations with a simple model, the second procedure gave the better convergence properties.

Different normalization conditions for RPA amplitudes have been obtained recently for use with energy-dependent interactions. Paul Ellis, Klaas Allaart, W.J.W. Geurts and G.A. Rijsdijk (Amsterdam) and Jifa Hao and Tom Kuo (Stony Brook) have shown that these conditions are equivalent. A third method, which has a wider applicability, was also discussed.

Finite temperature many-body theory is inherently more difficult than the corresponding zero-temperature formalism so it is important to assess the accuracy of many-body approximations. Paul Ellis, S.Y. Tsay Tzeng (Taipei), Tom Kuo (Stony Brook) and Eivind Osnes (Oslo) have addressed this question by studying the Lipkin model which has been widely used as a testing ground for many-body theory at $T = 0$. The exact solution for the grand potential was computed from which the number of particles and the internal energy could be obtained. The results were compared with Hartree-Fock (HF) calculations and with calculations which included in addition the particle-particle hole-hole ring diagrams (random phase approximation). This calculation is far from trivial since there are several self-consistency conditions to be satisfied. Further it is necessary to exactly satisfy the appropriate thermodynamic relations, which required derivatives of the HF energies and wavefunctions. For special values of the parameters the HF theory shows a "phase transition" to a non-interacting system, this, however, is an artefact of the approach since no such behavior is seen in the exact results. In general we found that HF yields a very good approximation over the entire temperature range. The ring diagrams yield a small improvement, particularly at the high temperature end, so that the complete result is in remarkably good agreement with the exact calculations.

2.2 Cold Dense Nuclear Matter

Paul Ellis, Erik Heide, Serge Rudaz and Madappa Prakash (Stony Brook) have been examining the implications of different choices of the renormalization scale in the relativistic Hartree approximation for neutron-rich matter and finite nuclei, following their previous work with nuclear matter. Physical results would be independant of this scale if they had embarked on a complete renormalization program which accounted for all the important physical effects, but, of course, they cannot claim that this is the case. Within the confines of the relativistic Hartree approximation they have previously found that nuclear matter favors values of $\mu/M = 0.79$ and 1.25. The observed masses of neutron stars do not distinguish different values of μ/M; however, for finite nuclei they find that the phenomenology with $\mu/M = 0.79$, with a sigma mass of about 600 MeV, is favored since it provides remarkably good agreement with the binding energies and charge distributions for O, Ca and Pb. The spin-orbit splittings are a little small at about 70% of the experimental values, but this is typical of relativistic Hartree approximations. Changing the renormalization scale μ/M from 1.0 to 0.79 can be viewed as choosing the effective three and four body scalar self-couplings to be zero at a point which correspond to 60% of equilibrium nuclear matter density, rather than in the vacuum. They have also studied the effect of the two-loop Fock diagrams (matter contributions only) with emphasis on the rho contribution including both vector and tensor couplings to the nucleon. Conceivably this could influence the coupling constants determined at low density and therefore modify the neutron star predictions. In practice they found that the exchange diagram has little impact on the bulk properties of neutron stars.

2.3 Covariant Non-Local Hadronic Field Theories

The central assumption of a hadronic field theory is that colored quark and gluon degrees of freedom reduce at low temperatures and densities to fewer color scalar or hadronic degrees of freedom. Attempts to describe hadronic reactions and matter using renormalizable local interactions face difficulties, both formally due to the need to include high-spin hadrons, and practically due to large pair amplitudes arising from point interactions in vacuum and medium. But it is well established that the lighter hadrons are extended systems without a distinct core or center (In heavy hadrons, heavy quarks supply such a center, analogous to the nucleus of an atom). Thus quantitative descriptions of hadronic scattering and production have to include additional information about the underlying degrees of freedom beyond what can be accommodated in a renormalizable local interaction.

A. Vischer and P. Siemens showed that an extended (non-local) n-point vertex differs topologically from a point interaction, even in the short range limit, because it realizes the Lorentz boost symmetry differently. In this limit the extended interaction survives on rays in Minkowski space, not just points. The extended vertices depend on invariants in a domain which is simply connected. The extended Minkowski structure produces a long distance divergence in certain diagrams. They discussed the consequences of extended vertices for covariant hadronic field theories. A further investigation of this result with respect to possible experimental consequences is underway.

2.4 QCD Sum Rules

Vladimir Eletsky (visitor), Paul Ellis and Joe Kapusta have studied the behavior of the color electric and magnetic condensates at low temperatures using hadrons as the proper degrees of freedom. Due to the preferred rest frame arising from the thermal bath, Lorentz non-scalar operators contribute to the correlator of two isovector vector currents. They have calculated these contributions, saturating the amplitude of the correlator by pions and vector mesons. The temperature dependence of the average gluonic stress tensor is estimated in the chiral limit to be $\langle \mathbf{E}^2 + \mathbf{B}^2 \rangle_T = \frac{\pi^2}{10} b T^4$. At a normalization point $\mu = 0.5$ GeV they obtain $b \approx 1.1$. Since $\langle \mathbf{B}^2 - \mathbf{E}^2 \rangle_T \simeq \langle \mathbf{B}^2 - \mathbf{E}^2 \rangle_0$, they get for the T dependence of the condensates of the chromomagnetic field , $\langle \mathbf{B}^2 \rangle_T = \langle \mathbf{B}^2 \rangle_0 + \frac{b\pi^2}{20} T^4$. The corresponding result for the chromoelectric field is $\langle \mathbf{E}^2 \rangle_T = \langle \mathbf{E}^2 \rangle_0 + \frac{b\pi^2}{20} T^4$. The temperature dependance is rather weak at low temperatures. Their result for b agrees with a calculation of the second moment of the quark distribution function in the pion due to Belyaev and Blok [Sov. J. Nucl. Phys. **43**, 450 (1986)], while lattice predictions give the opposite sign.

Vladimir Eletsky has used soft pions to study the (low) temperature dependance of four quark condensates. It was pointed out that the factorization hypothesis does not yield correct results; additional terms were identified by using an identity for the commutators of four quark fields and operators.

Vladimir Eletsky and B. L. Ioffe (ITEP, Moscow) have given a careful analysis of current correlators in QCD at finite temperature, T, pointing out that at low T hadronic, rather than quark-gluon, degrees of freedom should be considered and discussing the poles and continua that arise in the dispersion relations. PCAC and current algebra indicate that, in general, to order T^2 the poles do not move so that it is possible to define T-dependant resonance masses.

Vladimir Eletsky and B. L. Ioffe have also examined the recent experimental data on the $D^+ - D^0$ and $D^{*+} - D^{*0}$ mass differences. Making corrections for photon exchange and the electromagneitc hyperfine splitting, one is left with the hadronic part of the isospin splittings. This can be analyzed by standard QCD sum rule techniques for the appropriate correlators. This yields a mass splitting $m_d - m_u = 3 \pm 1$ MeV, in agreement with previous estimates, and $\gamma \equiv \frac{\langle \bar{d}d \rangle}{\langle \bar{u}u \rangle} - 1 = -(2.5 \pm 1) \times 10^{-3}$, which is significantly smaller than the usual value.

2.5 Hot Hadronic Matter

C. Song has been studying properties of hot hadronic matter as part of his PhD thesis. He has studied the temperature dependence of the effective masses of vector mesons (ρ and ω) and axial-vector mesons (A_1) with the use of an effective chiral Lagrangian. The effective masses at finite temperature are determined from the pole positions of the propagators and from the inverses of the static screening lengths. The results may be viewed as an extrapolation of known hadronic interactions to temperatures up to a deconfinement/chiral symmetry restoring transition or crossover.

Even though they are different numerically, both the pole mass and the screening mass show qualitatively similar behaviour at finite temperature. As temperature increases, the effective mass of the ρ meson increases and gets close to the A_1 meson mass which decreases. This mass degeneracy at finite temperature might suggest chiral symmetry restoration. The ω meson mass is not changed much and remains almost constant at finite temperature. Even if the ρ and ω meson had exactly the same mass at zero temperature, these masses become different as temperature increases. Thus the Zweig rule, which prohibits the flavor changing interaction at zero temperature, may not work anymore at finite temperature.

V. Eletsky, J. Kapusta and R. Venugopalan have calculated the electric screening mass in hot hadronic matter using two different approaches, chiral perturbation theory and the relativistic virial expansion. They also calculate the electric screening mass, for non interacting charged bosons with mass m, on a lattice to study likely finite size effects in lattice gauge theory simulations of continuum QCD. Besides being of intrinsic physical interest, their calculation of the electric screening mass is also illustrative, because the above mentioned techniques may be used to compute dispersion relations and other response functions. The virial and chiral perturbation theory results for the electric screening mass agree very well for low temperatures (below 80 MeV) but differ at higher temperatures. On the lattice, it is shown that for a lattice of given size, the continuum can be properly represented only for a window in the ratio T/m. The advantages and disadvantages of each of these approaches in calculating response functions is clearly outlined in their work.

2.6 The Parton Cascade Model

Klaus Geiger has been developing the parton cascade model of ultrarelativistic nuclear collisions. The *parton cascade model* provides a realistic simulation of high energy nuclear collisions of heavy nuclei on the basis of the microscopic dynamics of quarks and gluons. It has been developed in the last 2 years and has been successfully applied to shed some light on expected new aspects of ultra-relativistic heavy ion physics. The parton cascade model describes nuclear reactions at very high energies in terms of the time development of a large many-particle system consisting of quarks and gluons. The dynamical evolution is carried out in full 6-dimensional phase-space by solving a kinetic equation for the distribution functions of these partons. The development of this many-body system of quarks and gluons in phase-space is simulated in real time on the basis of perturbative quantum chromodynamics, embedded in a framework provided by relativistic transport theory and statistical physics. For example, a collision of two gold nuclei at a beam energy of 40 TeV (a typical collider experiment) involves about 25000 particles, each of which is followed through space and time as the particles interact with each other. An extensive analysis has been done of the physics output of this model, including the degree of thermal and chemical equilibrium attained, collective flow of matter, and dilepton emission.

2.7 Relativistic Hydrodynamics of the Quark Gluon Plasma

The space time development of matter produced in high energy nuclear collisions is explored using a fully three dimensional hydrodynamic model (albeit with cylindrical symmetry) developed by R. Venugopalan , M. Prakash, M. Kataja and P. V. Ruuskanen. Various initial conditions and equations of state are investigated. The contribution to the spectra of charged negatives from resonance decays is considered. A significant finding is the coupling between longitudinal and transverse flows. This may be seen, for instance, in the rapidity dependence of the transverse momentum distributions. It is also observed that the extreme Landau and Bjorken initial conditions result in virtually identical results for the rapidity and p_T spectra of charged negatives.

Extensive comparisons were done comparing boost-invariant and boost-noninvariant hydrodynamical initial conditions for ultrarelativistic heavy ion collisions by D. K. Srivastava, J. Alam, S. Chakrabarty, B. Sinha and S. Raha. It was possible to define a rapidity shift parameter which allows one to distinquish the various possibilities usually considered in the literature.

2.8 Photon and Dilepton Production

A large fraction (35%) of the papers written by our group for refereed journals in the last 12 month period was devoted to electromagnetic signals of quark-gluon plasma and hot hadronic matter. These can be classified into single photon production, dilepton production, and two-photon interferometry.

The number of photons emitted by the parton processes $qq \to g\gamma$ and $gq(\bar{q}) \to q(\bar{q})\gamma$ were computed by H. Nadeau assuming boost invariant initial conditions in two limiting cases: hydrodynamic expansion of quark-gluon plasma (collision dominated) and free-streaming plasma (collisionless). The photon spectrum at high transverse momentum was essentially identical. The reason is that electromagnetic signals are emitted primarily when the system is most hot and dense. The parton phase space distributions in these two models of the dynamics are the same initially. They do diverge as time goes on, but when they become noticeably different the energy density has already fallen so much that the high p_T part of the photon spectrum is no longer affected. Estimates also show that these 'direct' or 'thermal' photons will exceed those from meson decay above a p_T of 5 GeV, making them a good probe of parton dynamics at high energy density.

It is also important to understand the emission rates for photons from hadronic matter since eventually all partons must hadronize. This problem was addressed by C. Song in his PhD work. He used the same effective chiral Lagrangian discussed in section 2.5 to calculate the elementary processes $\pi\rho \to \pi\gamma$, $\pi\pi \to \rho\gamma$ and $\rho \to \pi\pi\gamma$ at finite temperature. The emission rates are compared with those obtained without the A_1 meson. For $\pi\rho \to \pi\gamma$ and $\pi\pi \to \rho\gamma$ reactions the photon emission rates are increased with the inclusion of the A_1 meson in intermediate states. There is a small increase of the emission rate from ρ meson decay. The temperature dependences of the emission rates were determined for all reactions. As temperature decreases, the thermal emission rates are reduced and effects of the A_1 meson also decrease. Even though the effect of A_1 meson is relatively big in the $\pi\pi \to \rho\gamma$ reaction, the $\pi\rho \to \pi\gamma$ reaction dominates other reactions at all temperatures. At low temperature the vector meson decay process becomes comparable to the other reactions.

High energy photons are most copiously produced during the early hot and dense state of the plasma. However, the quark-gluon plasma expands, cools, and undergoes a possibly first order phase transition to a hot hadronic gas. A large background to the photons from quark-gluon plasma might then be obtained from photons produced by hadronic reactions during the mixed and the hadronic phases and from the decay of mostly π^0 and η mesons. The thermal photon spectrum at energies reached at SPS, RHIC and LHC has been obtained by J. Alam, D. K. Srivastava, B. Sinha and D. N. Basu by taking realistic initial conditions and accounting for the hydrodynamical transverse expansion of the system. It is found that at SPS and RHIC energies, the photons produced during the mixed phase and the hadronic phase get boosted to larger transverse momenta and become comparable to those from the quark-gluon plasma. However at LHC energies, even though the transverse kick received by the photons produced at later times is substantial, the very high initial temperatures likely at LHC insure that the photons having transverse momenta of more than 4 GeV/c are predominantly produced in the quark-gluon plasma.

Five papers were written by various members of the group on dilepton production in high energy nucleus-nucleus collisions. The results can be summarized as follows. K. Geiger and J. Kapusta used the parton cascade model to calculate the spectrum of dileptons for masses bigger than about 3 GeV. The Drell Yan, pre-equilibrium, and equilibrium yields can all be calculated within this model to the same degree of accuracy. It includes contributions up to order $\alpha\alpha_s$ plus higher order QCD corrections associated with the emission and absorption of soft partons. There is a definite enhancement of the dilepton yield for masses up to 10 GeV as compared to pp collisions scaled up by $A^{4/3}$. This means that dileptons with masses between 3 and 10 GeV provide valuable information about the dynamics of partons at the very earliest times and very highest energy and entropy densities. Dileptons with invariant mass less than about 2 or 3 GeV get big contributions from the hot hadronic matter during the expansion stage of the collision (C. Gale, P. Lichard). J. Kapusta and D. K. Srivastava examined the effect of supercooling of quark-gluon plasma below T_c, followed by nucleation and growth of hadronic bubbles. This increases the entropy of the system and enhances the dilepton yield in the region of the ρ and ϕ mesons by about a factor of 2.

D. K. Srivastava and J. Kapusta extensively studied the possibility of using photon interferometry as a detailed probe of the early parton dynamics in collisions at RHIC and LHC. Unlike hadron interferometry, photons can carry out information directly from the early hot matter. Unlike single photons, which really only have one variable, p_T, photon pairs have many more. It turns out that one may distinquish photon pairs coming from the plasma stage from photon pairs coming from the later and cooler hadron phase. This may allow us to infer the detailed space-time evolution of the entire collision. Photon interferometry would play a role complementary to dileptons. Due to these studies, P. Braun-Munzinger (Stony Brook) and H. Gutbrod (CERN) are considering very seriously the experimental possibilities for experiments at RHIC and LHC.

2.9 Dynamics of the QCD Phase Transition

L. Csernai, J. Kapusta, G. Kluge and E. Zabrodin investigated various problems related to the dynamics of a first-order phase transition from quark-gluon plasma to hadronic matter in the baryon-free region in ultra-relativistic heavy ion collisions. These include nucleation, growth and fusion of hadronic bubbles in either the Bjorken longitudinal hydrodynamic expansion model or the Cooper-Frye-Schonberg spherical hydrodynamic expansion model. With reasonable input parameters the conversion of one phase into the other is relatively close to the idealized adiabatic Maxwell construction, although one can choose parameters such that the conversion is strongly out of equilibrium.

In any first order phase transition, one phase may supercool or superheat, thereby nucleating bubbles or droplets of the other phase. If the bubbles nucleated are of a critical radius, beyond which they are stable, they grow at an exponential rate which is the dynamical prefactor in the nucleation rate. A. Vischer and R. Venugopalan have computed the dynamical prefactor for the case where both viscous damping and thermal dissipation are significant. This result, which generalizes previous work on nucleation by Langer and Turski, Kawasaki, and Csernai and Kapusta, may be applied to study the growth of bubbles or droplets in condensed matter systems as well as in the baryon-rich region in heavy ion collisions.

2.10 Electroweak Phase Transition

The physics of the electroweak phase-transition opens up the possibility of generating the baryon asymmetry of the universe (BAU) at the electroweak scale of 1 TeV. The necessary conditions to achieve this BAU, baryon-number violating processes, CP-violation and non-equilibrium, are provided in the standard model in combination with the dynamics of the domain walls. A better understanding of the structure and interactions dominating the domain walls is necessary to further confirm or reject the possibility of creating the BAU at the phase-transition.

In the electroweak phase transition, bubbles of the true phase are nucleated and propagate into the false phase. B. Liu, N. Turok and L. Mclerran computed the velocity of these bubble walls using a kinetic theory treatment and found that the bubbles typically have a velocity of order (.1-.9)c where c is the speed of light.

P. Huet, K. Kajantie, R. Leigh, B. Liu and L. Mclerran have recently shown that the propagation of these wall is hydrodynamically stable for the range of velocities of physical interest. This is unlike the case for ordinary burning fronts which do have a convective instability. They also investigated the QCD case, which also looks stable, but with the uncertainties in the calculation cannot be claimed as a certainty.

M. Carrington and J. Kapusta applied recent advances in equilibrium and nonequilibrium finite temperature field theory to the dynamics of the electroweak phase transition in the early universe. The equation of state and the parameters that enter the nucleation rate, including the pre-exponential factor, are calculated in the one-loop plus ring-diagram approximation in the standard model. The velocity of bubble growth is taken from the aforementioned calculation of Liu, Turok and McLerran. They computed the temperature, average bubble size, bubble density and fraction of space which has been converted from the high temperature symmetric phase to the low temperature asymmetric phase as functions of time. Compared to the idealized adiabatic Maxwell construction of phase equilibrium, the start of the phase transition is siginificantly delayed, but then completes in a much shorter time interval.

To understand baryogenesis at the electroweak phase transition, the properties of fermions near the phase transition bubble wall must be understood. In a two step procedure, A. Ayala-Mercado, J. Jalilian-Marian, L. McLerran and A. Vischer studied static solutions of the equations of motion for the electroweak sector in the classical mean-field approximation across the domain wall and investigated the dynamical problem through approximated versions of the Dyson equations leading to generalized relativistic Vlassov equations. First results of the mean-field study indicate the possible formation of a 2-dimensional Fermi gas trapped in the domain wall.

5 Publications

5.1 Publications in Refereed Journals and Preprints Submitted for Publication in Refereed Journals

An * denotes a paper which was included in last year's report as a preprint or as a paper submitted for publication.

*1. "Nucleation of Relativistic First-Order Phase Transitions", Phys. Rev. **D46**, 1379 (1992) [L. P. Csernai and J. Kapusta].

*2. "Dynamics of the QCD Phase Transition", Phys. Rev. Lett., **69**, 737 (1992) [L. P. Csernai and J. Kapusta].

*3. "Screening of Static QED Electric Fields in Hot QCD", Phys. Rev. **D46**, 4749 (1992) [J. Kapusta].

*4. "Thermalization in Ultrarelativistic Nuclear Collisions - I. Parton Kinetics and Quark Gluon Plasma Formation", Phys. Rev. **D46**, 4965 (1992) [K. Geiger].

*5. "Thermalization in Ultrarelativistic Nuclear Collisions - II. Entropy Production and Energy Densities at RHIC and LHC", Phys. Rev. **D46**, 4986 (1992) [K. Geiger].

*6. "Particle Production in High Energy Nuclear Collisions - A Parton Cascade / Cluster Hadronization Model", Phys. Rev. **D47**, 133 (1992) [K. Geiger].

*7. "Bubble Nucleation and Growth at a Baryon Number Producing Phase Transition", Phys. Rev. **D46**, 2668 (1992) [B. H. Liu, L. McLerran and N. Turok].

*8. "Anharmonicity of the Nuclear Matter Ground State", Phys. Lett. **B285**, 183 (1992) [S. Rudaz, P. J. Ellis, E. K. Heide and M. Prakash].

*9. "Implicat[illegible]s of a Modified Glueball Potential for Nuclear Matter", Phys. Lett. **B293**, 259 (1992) [E. K. Heide, S. Rudaz and P. J. Ellis].

*10. "Nuclear Equation of State with Momentum-Dependent Interactions", Phys. Rev. **C46**, 736 (1992) [L. P. Csernai, G. Fai, C. Gale and E. Osnes].

*11. "Semi-Hard Collisions in Monte Carlo Quark-Gluon String Model", Phys. Rev. **D46**, 4873 (1992) [N. S. Amelin, E. F. Staubo and L. P. Csernai].

*12. "$U_A(1)$ Goldberger-Treiman Relation and the Proton Spin Problem", Phys. Rev. **D46**, 5078 (1992) [K.-T. Chao, J. R. Wen and H.-Q. Zheng].

*13. "Particle Composition and Clustering in Hadron-Hadron Collisions", Z. Phys. **C55**, 441 (1992) [C. Gao and J. Pan].

*14. "Some Problems on the Charmonium $^1P_1$ State", Phys. Lett. **B301**, 282 (1993) [K.-T. Chao, Y.-B. Ding and D.-H. Qiu].

15. "Four-Quark Condensates at $T = 0$", Phys. Lett. **B299**, 111 (1993) [V. L. Eletsky].

16. "Three-Body Initial States in Dilepton Production from Dense Partonic and Hadronic Decays", TPI-MINN-92/51, submitted for publication [P. Lichard].

17. "On the Current Correlators in QCD at Finite Temperature", Phys. Rev. **D47**, 3083 (1993) [V. L. Eletsky].

18. "Lectures on B+L Violation at High Temperature in Electroweak Theory", TPI-MINN-92/65, submitted for publication [L. McLerran].

19. "Estimates of $m_d - m_u$ and $\langle \bar{d}d \rangle - \langle \bar{u}u \rangle$ from QCD Sum Rules for D and D^* Isospin Mass Differences", TPI-MINN-92/69, submitted for publication [V. L. Eletsky and B. L. Ioffe].

20. "Transverse Flow Effects on High Energy Photons Emitted by Expanding Quark-Gluon Plasma", TPI-MINN-93/7, Phys. Rev. **D**, in press [Jan-e Alam, D. K. Srivastava, B. Sinha and D. N. Basu].

21. "Photon Interferometry of Quark-Gluon Dynamics", Phys. Lett. **B307**, 1 (1993) [D. K. Srivastava and J. Kapusta].

22. "Supercooling and Final State Effects on Dilepton Spectra", TPI-MINN-93/11, Phys. Rev. **C**, in press [D. K. Srivastava and J. Kapusta].

23. "History of Quark-Gluon Plasma Evolution from Photon Interferometry", TPI-MINN-93/14, Phys. Rev. **C**, in press [D. K. Srivastava and J. Kapusta].

24. "Hydrodynamics of Ultra-Relativistic Heavy Ion Collisions– Considerations of Boost-Non-Invariance and Stopping", TPI-MINN-93/17, Annals of Phys., in press [D. K. Srivastava, Jan-e Alam, S. Chakrabarty, B. Sinha and S. Raha].

25. "Screening Mass from Chiral Perturbation Theory, Virial Expansion and the Lattice", TPI-MINN-93/22, submitted for publication [V. L. Eletsky, J. I. Kapusta and R. Venugopalan].

26. "Dilepton Production in Nucleon-Nucleon Reactions with and without Hadronic

Inelasticities", TPI-MINN-93/18, submitted for publication [C. Gale and K. Haglin].

27. "Lepton Pairs from Thermal Mesons", TPI-MINN-93/19, submitted for publication [C. Gale and P. Lichard].

28. "Hydrodynamics of Ultrarelativistic Nuclear Collisions", NUC-MINN-93/13-T, submitted for publication [R. Venugopalan, M. Prakash, M. Kataja and P. V. Ruuskanen].

29. "Fidelity of Photon Interferometry for Recording Evolution Of Nascent Quark-Gluon Plasma", TPI-MINN-93/30, submitted for publication [D. K. Srivastava].

30. "Temperature Dependence of Electric and Magnetic Gluon Condensates", Phys. Rev. **D47**, 895 (1993) [V. L. Eletsky, P. J. Ellis and J. I. Kapusta].

31. "Normalization for the Random Phase Approximation with Energy-dependant Interactions", Phys. Rev. **C47**, 895 (1993) [K. Allaart, P. J. Ellis, W. J. W. Geurts, J. Hao, T. T. S. Kuo and G. A. Rijsdijk].

32. "Hermitian Effective Interactions Derived from the Paris and Bonn Potentials", Nucl. Phys. **A**, in press [T. T. S. Kuo, P. J. Ellis, J. Hao, Z. Li, K. Suzuki, R. Okamoto and H. Kumagai].

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3. "Reaction Dynamics of Ultrarelativistic Heavy Ion Collisions within the Parton Cascade Model", *Proc. 9th Winter Workshop on Nuclear Dynamics* (Key West, FL, 1993) to appear [K. Geiger].

4. "How fast is Equilibration in Hot Hadronic Matter?", to appear in *Proc. of Interdisciplinary Worshop on Transport Theory* (Les Houches, France, February 1993), TPI-MINN-93-36/T [Madappa Prakash, Manju Prakash, R. Venugopalan and G. Welke].

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