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THEORETICAL PHYSICS

High Energy Physics

Highlights

It was shown that the recent astrophysical data on dark matter relic density favours the lightest superparticle being the superpartner of Higgs (Higgsino) instead of the superpartner of the gauge boson, which can be detected at a future 3 TeV electron-positron collider.

Quark-lepton complementarity was shown to be consistent with quasidegenerate neutrinos if a nontrivial role is played by the Majorana phases.

The computation of next-to-leading order QCD corrections to virtual graviton exchange processes for warped extra dimensions has been completed.

The implications of the existence of a minimal length scale for TeV-scale gravity models in jet + missing energy channels at hadron colliders has been studied.

New bounds on the combination of bilinear and trilinear R-parity violating parameters from neutron, mercury and deuteron electric dipole moment have been obtained.

It was shown that the matter produced in the early stages of nucleus-nucleus collisions at the Relativistic Heavy-Ion Collider is incompletely thermalized.

It was shown that the high temperature phase of QCD contains weakly interacting quarks.

a) The quark gluon plasma (QGP) phase was shown be a "quark liquid" of strongly interacting quasi-particles with the quantum numbers of quarks, b) Existence of a simple pattern in nonlinear quark number susceptibilities was demonstrated.

High Energy Physics

Research in High Energy Physics was carried out in the broad areas of Beyond Standard Model Physics, Lattice Gauge Theory and Quantum Chromodynamics.

Beyond Standard Model Physics

Higgsino LSP Scenario

It was shown that the recent astrophysical data on dark matter relic density favours supersymmetry models, where the lightest superparticle (LSP) is the superpartner of Higgs (Higgsino) instead of the superpartner of the gauge boson. It can be detected at a future 3 TeV electron-positron collider called CLIC and also in dark matter experiments as line gamma rays from the galactic centre [D. P. Roy and P. Konar with Utpal Chattopadhyay of IACS, Kolkata, Debajyoti Choudhury of Delhi University and Manuel Drees of University of Bonn, Germany].

Charged Higgs Boson

The Charged Higgs boson (H^+) carries the distinctive hallmark of Supersymmetric Models since it does not have a Standard Model analogue. In the Minimal Supersymmetric Standard Model, it is expected to be heavier than the top quark. A detailed simulation of the signature for such a heavy charged Higgs boson search at the large hadron collider (LHC) was carried out in its tau decay channel using the distinctive prediction for the tau polarization (D. P. Roy with M. Guchait of DHEP and R. Kinnunen of Helsinki University, Finland).

In popular exensions of the MSSM involving CP nonconservation or an extra Higgs singlet it was shown that the H^+ can be lighter than the top quark and it can have a novel decay mode into W^+ and a neutral Higgs boson [D. P. Roy with Rohini Godbole of IISc, Bangalore].

Discriminating between supersymmetry and large extra dimensions

The production of an electron or a muon pair with a large missing energy at an e+e- linear collider was discussed as a means distinguishing the minimal supersymmetry scenario from that with large extra dimensions for parameter ranges yielding comparable cross sections for both. Analyses in terms of event shape variables, specifically sphericity and thrust, were shown to enable a clear discrimination in this regard. [Partha Konar and Probir Roy]

Neutrino mixing from a high scale supersymmetric theory

A supersymmetric model was constructed with nonrenormalizable interactions in the hidden sector generating (through an array of gauge singlet chiral superfields) lepton-nonconserving mass terms for both right-chiral sneutrinos and Majorana neutrinos as well as nearly flavour-diagonal supersymmetry-breaking A-terms giving rise to the observed bi-large neutrino mixing pattern. [Probir Roy with B. Mukhopadhyaya and R. Srikanth of HRI, Allahabad]

Phase effects in neutrino conversions during a supernova shock wave

Neutrinos escaping from a core collapse supernova a few seconds after bounce pass through the shock wave, where they may encounter one or more resonances corresponding to Δm^2_{atm}. The neutrino mass eigenstates in matter stay coherent between these multiple resonances, giving rise to oscillations in the survival probabilities of neutrino species. We pointed out these novel "phase effects", and provided an analytic approximation to them that relates the density profile of the shock wave to the oscillation pattern. The phase effects can be strong if the multiple resonances encountered by neutrinos are semi-adiabatic. These effects would manifest themselves in oscillations in the observed neutrino spectra for certain neutrino mixing scenarios. [Basudeb Dasgupta, Amol Dighe]

Quark-lepton complementarity with quasidegenerate Majorana neutrinos

We implemented a basis independent formulation of quark-lepton complementarity at a high scale for quasidegenerate Majorana neutrinos. We showed that even with the renormalization group evolution in the minimal supersymmetric standard model, the scenario can be consistent with the data provided a nontrivial role is played by the Majorana phases. Correlated constraints were found on these phases and the neutrino mass scale using the current data. We also indicated how future accurate measurements of the mixing angles can serve as tests of this scenario and restrict the values of the Majorana phases. [Amol Dighe, Probir Roy, Srubabati Goswami of HRI, Allahabad]

Extra dimensions

1) The project of computing next-to-leading order QCD corrections to dilepton production in hadron collisions with virtual graviton exchange has been completed. This has been done in the framework of i) the ADD model of large extra dimensions and, ii) the RS model of warped extra dimensions. Detailed numerical studies of these corrections at the Tevatron and the LHC energies have been performed and the insensitivity of the NLO cross-section to

QCD scale-variation has been explicitly demonstrated. [K. Sridhar with Prakash Mathews of SINP, Kolkata and V. Ravindran, of HRI, Allahabad].

2) Models of gravity suggest the existence of a minimal length scale. The bounds on the low-energy quantum gravity scale in the ADD model have been shown to be considerably weakened because of the existence of such a minimal length scale. This has been done by studying the production of real gravitons in association with QCD jets at hadron colliders. [K. Sridhar with Gautam Bhattacharyya of SINP, Kolkata and Kumar Rao of PRL, Ahmedabad]

Flavour Changing Higgs decays in Supersymmetry with Minimal Flavour Violation

Flavor-changing Higgs decays provide a complementary channel for Higgs discovery in the critical mass range of light Higgs between 90-130 GeV, as compared to the dominant decay mode in this mass range. Within the minimal flavor violation scenario, taking into account existing experimental constraints, it is shown that the branching fraction can reach $O(10^{-4})$. [Rishikesh Vaidya with Abdesslam Arhrib of faculte des Sciences et Techniques, Tange Morocco, Dilip Ghosh of University of Delhi, and Otto Kong of National Central University, Taiwan]

Neutron, Mercury and Deuteron electric dipole moments from Supersymmetry without R-parity

Bounds on the bilinear and trilinear R-parity violating terms that contribute to EDM of neutron, Mercury and Deuteron at one-loop level have been obtained. It is found that there exist CKM-phase induced R-parity violating contributions which are as strong as the ones with complex R-parity violating parameters. [Rishikesh Vaidya with Otto Kong of National Central University, Tawian]

Quantum Chromodynamics and Lattice Gauge Theory

Incomplete Equilibration of Quark-Gluon Plasma

It has been shown that RHIC data, in particular those on the anisotropic flow coefficients v_2 and v_4, suggest that the matter produced in the early stages of nucleus-nucleus collisions was incompletely thermalized. The parameter $(1/S)(dN/dy)$, where S is the transverse area of the collision zone and dN/dy the multiplicity density has been shown to be a measure of the degree of equilibration and serves as a control parameter which can be varied experimentally by changing the system size, the centrality or the beam energy. Predictions were made for

Cu–Cu collisions at RHIC as well as for Pb–Pb collisions at the LHC. [R.S. Bhalerao with J.-P. Blaizot, N. Borghini and J.-Y. Ollitrault of Saclay, France]

Simple patterns for non-linear susceptibilities near T_c

Quark number susceptibilities in QCD are interesting because they are measurable through event-to-event fluctuations of conserved quantities in heavy-ion collisions. Generalized quark number susceptibilities, namely non-linear susceptibilities (NLS) have been investigated upto the eighth order in QCD with 2 flavours of dynamical quarks using TIFR's CRAY X1.

It is found that in the hadronic phase that different operators have vacuum expectation values of similar order. Above T_c, a simple pattern, in which the NLS are dominated by the operators with a single quark loop, is shown to result. In the vicinity of T_c, quite unexpectedly, the NLS are dominated by a composite operator which is made up of appropriate numbers of fermion loops with two γ_0 insertions in each. Our observation suggests that it may be possible to write down effective long-distance theories in which this composite bosonic operator is treated as a field operator whose expectation value shows the correct cross over behaviour. [R.V.Gavai and Sourendu Gupta]

A new method for the equation of state, specific heat, and speed of sound in QCD

A new method of lattice simulation to calculate the equation of state in relativistic heavy-ion collisions is proposed which gives positive pressure over the entire temperature range thereby solving the problem of negative pressure which resulted in older lattice simulations.

Using it on temporal lattices of 8, 10 and 12 sites, continuum values of the pressure, P, energy density, ϵ, entropy density, s, the specific heat, C_v, and the speed of sound, c_s, in quenched QCD, for $0.9 \leq T/T_c \leq 3$ have been obtained. This is the first direct estimate of c_s and C_v below T_c in QCD.

The results obtained from this approach have also been compared to dimensional reduction and a conformal symmetric theory at high-temperature. The pressure determined through dimensional reduction agrees with these results almost all the way down to T_c. Data on the entropy density, s/T^3, agrees well with the strong coupling result from AdS/CFT in a window of temperatures, $1.5 \leq T/T_c \leq 3$. [R.V.Gavai, Sourendu Gupta and S. Mukherjee]

Fluctuations, strangeness and quasi-quarks in heavy-ion collisions from lattice QCD

Using simulations of QCD with dynamical quarks, measurements of diagonal susceptibilities for the baryon number, χ_B, electrical charge, χ_Q, third component of isospin, χ_I, strangeness,

χ_S, and hypercharge, χ_Y, as well as the off-diagonal χ_{BQ}, χ_{BY}, χ_{BS}, have been made. It is shown that the ratios of susceptibilities in the high temperature phase are robust variables, independent of lattice spacing, and therefore yield predictions which can be meaningfully compared with experiments.

Strangeness production and flavour symmetry-breaking matrix elements at finite temperature have also been investigated. The Wróblewski parameter, which is defined as a ratio of produced strange quark-antiquark pairs to that of similar pairs of up and down quarks, has been obtained in a dynamical QCD computation for the first time. This shows strong dependence on the actual strange quark mass, m_s, in the vicinity of T_c. Since $m_s \simeq T_c$, it seems that part of this sensitivity could be attributed purely to kinematics.

One outstanding question about the high temperature phase of QCD is the nature of flavoured excitations. There is ample evidence that quarks are liberated at sufficiently high temperature— the continuum limit of lattice computations of screening masses are consistent with the existence of such a Fermi gas for $T \geq 2T_c$, quantitative agreement between weak coupling estimates of the susceptibilities and our lattice data also confirms this and the equation of state at very high temperature also testifies to this. However, comparison of lattice results and weak coupling computations of these quantities fail for $T < 2T_c$. Results on the cross correlations χ_{BQ}, χ_{BY}, χ_{BS} and χ_{QY} have been obtained and have been used to explore the charge and baryon number of objects that carry flavour. It is seen that the baryon number of flavour-carrying objects immediately above the QCD crossover temperature, T_c, are 1/3 and the charges are -1/3 or 2/3. Furthermore, these objects are almost pure flavour— anything carrying u flavour has only tiny admixtures of d and s flavours, etc. In the high temperature phase of QCD the different flavour quantum numbers are thus excited in linkages which are exactly the same as one expects from quarks. The QCD plasma phase appears to be a "quark liquid" in the sense that the quasi-particles carry the quantum numbers of quarks, but the interactions between them are too strong for the system to be treated in weak coupling theory. [R.V.Gavai and Sourendu Gupta]