TIFR Annual Report 2000-01
THEORETICAL PHYSICS

High Energy Physics

Lattice Gauge Theory

Dimensional Reduction in Hot QCD

The quark-gluon plasma phase of QCD is currently of great experimental interest due to 1) the recent announcement that the CERN heavy ion program may have seen this phase, and 2) the start of the BNL Relativistic Heavy Ion Collider. The new experiments at higher colliding energies will soon begin to demand much more detailed information on the high-temperature phase. Whether the theory simplifies considerably by exhibiting dimensional reduction at the temperatures accessible to these experiments has important observational consequences. Screening masses were obtained for the first time from glueball-like correlators in QCD with four light dynamical flavours of quarks in the temperature range $1.5T_c \leq T \leq 3T_c$, where T_c is the temperature at which the chiral transition occurs, along with pion-like and sigma-like screening masses. These latter ones obstruct perturbative dimensional reduction since the lowest glueball screening mass is heavier than them. The extrapolation of our results indicates that this obstruction may remain till temperatures of $10T_c$ or higher ($T \approx$ 1–1.4 GeV) and therefore affect the entire range of temperatures expected to be reached even at highest colliding energy of the Large Hadron Collider. [R. V. Gavai and Sourendu Gupta]

Smoother Approach to Scaling

Long-distance physics, such as the confinement of quarks in quantum chromodynamics or the determination of the phase structure of QCD at nonzero temperatures, is conveniently studied using the lattice regularization. There is a lot of freedom in defining a lattice field theory. In particular, a variety of different choices of the lattice action correspond to the same quantum field theory in the continuum. Suppressing lattice monopoles and vortices by introducing large chemical potentials for them in the Wilson action for the $SU(2)$ lattice gauge theory, the nature of its deconfinement phase transition was investigated on $N_\sigma^3 \times N_\tau$ lattices for $N_\tau = 4$, 5, 6 and 8 and $N_\sigma =$ 8–16. Using finite size scaling theory, critical indices were obtained which showed excellent agreement with universality. The critical couplings at which the transition occurred for $N_\tau = 4$, 5, 6 and 8 lattices exhibited a lot smoother approach to scaling than the Wilson action itself. [R. V. Gavai]

Quark Number Susceptibilities and Strangeness

Fully non-perturbative computations of quark number susceptibilities are important for several reasons. First, there have been attempts to link them directly to experimental measurements of event-to-event fluctuations in particle production. Second, experimental observations of a relative enhancement of strange quarks have been attributed to the formation of a QCD plasma. This hypothesis can be quantitatively tested against the computation of the strange quark susceptibility. Finally, earlier results showed that physics at finite chemical potential is not weak-coupling physics. In an extensive systematic study of such susceptibilities, it was shown that strangeness susceptibility jumps across the phase transition and grows rapidly with temperature above T_c. Our precise results on quark number susceptibilities over a wide range of temperatures and quark masses showed that they differ significantly from the ideal gas expectations. These deviations increase with mass and decrease at higher T. As a result, the relative strangeness enhancement seen in heavy-ion collisions is expected to increase with temperature. Clear evidence was obtained in support of the hypothesis of "dynamical confinement" in the high temperature phase of the plasma but it was also shown to become increasingly less useful picture for higher temperatures. [R. V. Gavai and Sourendu Gupta]

Finite Temperature QCD with Two Light Quarks

A hybrid molecular dynamics algorithm (R algorithm of Gottlieb et al. Phys. Rev. D35, 2531) was implemented as a program to simulate QCD in the high temperature regime (deconfined phase) with two light dynamical quarks. This is a physically very interesting region now, with the relativistic heavy ion collider at BNL probing this region for signatures of Quark Gluon Plasma. Measurements are being performed of quark number susceptibility and various screening lengths in our simulation as signatures of this high temperature phase of QCD. This work extends the work done by Gavai and Gupta for the quenched case to the more realistic case of two light fermions. These results already show significant departure from those of the quenched theory. [R. V. Gavai, Sourendu Gupta and Pushan Majumdar]

A Precise Determination of T_c in QCD from Scaling

Existing lattice data on the QCD phase transition were analyzed in renormalized perturbation theory. In quenched QCD it was found that T_c scales for lattices with only three time slices, and that $T_c/\Lambda_{\overline{MS}} = 1.15 \pm 0.05$. A preliminary estimate in QCD with two flavours of dynamical quarks showed that this ratio depends on the quark mass. For realistic quark masses $T_c/\Lambda_{\overline{MS}}$ was estimated to be 0.49 ± 0.02. The equation of state in quenched QCD at 1-loop order in renormalised perturbation theory was investigated. [Sourendu Gupta]

Beyond Standard Model Physics

Electroweak Symmetry Breaking and Baryogenesis in Supersymmetric Standard Model

The minimal supersymmetric standard model (MSSM) offers natural explanations for electroweak symmetry breaking and baryogenesis with a relatively light Higgs boson. The latter seems to be ruled out, however, by the recent LEP limit on the Higgs boson mass over a significant region of the parameter space — the so-called low $\tan\beta$ region. It has been shown that this conflict can be avoided in a simple and well-motivated extension of this model, called the next-to-minimal supersymmetric standard model (NMSSM). That can naturally explain the electroweak symmetry breaking and baryogenesis while satisfying the LEP limit for practically any value of $\tan\beta$. [D. P. Roy with M. Bastero-Gil and S. F. King (Southampton Univ., UK), C. Huganie (RAL, UK) and S. Vempati (PRL, Ahmedabad)].

Investigations on Focus Point Supersymmetry

The minimal supergravity model is known to exhibit what is called a focus point phenomenon over a wide range of $\tan\beta$. This means that the naturalness of electroweak symmetry breaking can be achieved even for very large scalar masses, in the multi-TeV scale. Two investigations in this scenario have been completed. The first one showed that the scenario naturally leads to an inverted mass hierarchy of the scalar quarks, where the top squark is significantly lighter than the squarks and sleptons of the first two generations. This was shown to imply a distinctive SUSY signal at the Large Hadron Collider LHC. [U. Chattopadhyay and D.P. Roy with Anindya Datta and Asheshkrishna Datta (HRI, Allahabad) and Amitava Datta (Jadavpur University, Kolkata)].

The second work addressed one of the longstanding problems of the supergravity model — i.e. the fact that model predictions on the electric dipole moments (EDM) of electron and neutron exceed the experimental limits unless one assumes unnaturally small SUSY phase. It was shown that the large masses of the first generation sleptons and squarks in this scenario help reconcile the resulting electron and neutron EDMs with the experimental limits without assuming unnaturally small SUSY phase angles for intermediate values of $\tan\beta(\sim 5)$. [U. Chattopadhyay and D.P. Roy with T. Ibrahim (Alexandria University, Egypt)].

Supersymmetric Lepton Flavour Violation

The occurrence of a significant amount of supersymmetric lepton flavour violation at laboratory energies is shown to be observable in an e^+e^- linear collider with the distinct final state $\tau\mu$ + 3 jets + missing E_T with some case studies presented quantitatively. The role of pair-produced charginos turns out to be crucial and has been taken into account. [Probir Roy with M. Guchait (Saha Inst., Kolkata) and J. Kalinowski (University of Warsaw, Poland)]

Characteristic Signals of Anomaly Mediated Supersymmetry Breaking

Though the minimal model of anomaly mediated supersymmetry breaking has been significantly constrained by recent experimental and theoretical work, there are still allowed regions of the parameter space for moderate to large values of $\tan\beta$. It has been shown that these regions will be comprehensively probed in a $\sqrt{s} = 1$ TeV e^+e^- linear collider. Diagnostic signals to this end are studied by zeroing in on a unique and distinct feature of a large class of models in this genre: a neutral winolike Lightest Supersymmetric Particle closely degenerate in mass with a winolike chargino. The pair production processes $e^+e^- \to \tilde{e}_L^\pm \tilde{e}_L^\mp$, $\tilde{e}_R^\pm \tilde{e}_R^\mp$, $\tilde{e}_L^\pm \tilde{e}_R^\mp$, $\tilde{\nu}\bar{\tilde{\nu}}$, $\tilde{\chi}_1^0\tilde{\chi}_2^0$, $\tilde{\chi}_2^0\tilde{\chi}_2^0$ are all considered at $\sqrt{s} = 1$ TeV corresponding to the proposed TESLA linear collider in two natural categories of mass ordering in the sparticle spectra. The signals analysed comprise multiple combinations of fast charged leptons (any of which can act as the trigger) plus displaced vertices X_D (any of which can be identified by a heavy ionizing track terminating in the detector) and/or associated soft pions with characteristic momentum distributions. [Probir Roy and Sourov Roy with D. K. Ghosh (Taiwan National University, Taiwan) and A. Kundu (Jadavpur University, Kolkata)]

Signals of anomaly mediated supersymmetry breaking in $e\gamma$ collision were studied. The associated production $e^-\gamma \to \tilde{\chi}_1^-\tilde{\nu}$ has been considered corresponding to an e^+e^- CM energy of 1 TeV. Now, if one considers the decay of $\tilde{\nu}$ into $\tilde{\chi}_1^\pm + e^\mp$ and the characteristic dacay of $\tilde{\chi}_1^\pm$ into $\tilde{\chi}_1^0 + \pi^\pm$, then finally there will be a fast $e^\pm$ trigger, displaced vertices from the heavily ionizing tracks of the charginos and/or two visible soft $\pi^\pm$ with their impact parameters resolved. Depending on the choices of the parameter space, one can get a cross section of the order of 10-20 fb. This is a very interesting signal because here one gets a single electron and two soft pions while in the case of the e^+e^- linear collider two soft pions are always associated with an even number of charged leptons. [Debajyoti Choudhury (HRI, Allahabad) and Sourov Roy]

The effect of bilinear R-parity violation in the context of Anomaly Mediated Supersymmetry Breaking is investigated. The characteristic decay mode of the lighter chargino in the R-parity conserving AMSB model is $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 + \pi^\pm$ with a branching ratio $\sim 98\%$. But, when one includes R-parity violation through the bilinear terms $\epsilon L \cdot H_2$ in the superpotential, then there can be additional two-body decay modes of the lighter chargino, e.g. into $\nu + W^\pm$ or $\mu^\pm(\tau^\pm) + Z$, with appreciable branching ratios. This can cause major changes in AMSB signals in various collider experiments. These changed signals of AMSB with R-parity violation are studied in the context of an e^+e^- linear collider. [Sourov Roy]

Muon g-2, Minimal Supergravity and AMSB

In minimal supergravity as well as in minimal Anomaly Mediated Supersymmetry Breaking scenarios a detailed analysis using the $(\text{g-2})_\mu$ data, available in the year 2000, has been performed for the $\mu < 0$ case. For both of the models, it was found that only the $\mu > 0$ situation could survive and this is a very important constraint which muon (g-2) data could impose on such supersymmetric models. Very interestingly, the upper limits of the relevant superpartner masses found for both the models, would be very much accessible to the Large

Hadronic Collider. [Utpal Chattopadhyay, Dilip Kumar Ghosh and Sourov Roy].

Along with $(g-2)_\mu$ the significance of other constraints for $\mu > 0$, such as from $b \to s+\gamma$ and from the occurrence of the lightest neutralino as a cold dark matter candidate has been discussed. The $b \to s + \gamma$ constraint which has special signatures within AMSB models reduces the total available parameter space further. [Utpal Chattopadhyay and Pran Nath (CERN, Switzerland and Northeastern University, U.S.A.)]

The above investigation has been further extended by considering CP violating phases in the $(g-2)_\mu$ result. The combined effects due to the recent $(g-2)_\mu$ data and the limits from the electric dipole moments of electron and neutron have been analysed. The valid larger CP phase regions have been identified. [Utpal Chattopadhyay with Tarek Ibrahim (Alexandria University, Egypt) and Pran Nath (CERN, Switzerland and Northeastern University, U.S.A.)]

Signals of Large Extra Dimensions

The possibility that one could have extra compact dimensions as large as a mm has stimulated great interest in the possible experimental manifestations of these at high-energy colliders. In a programme initiated over the last three years a systematic study of a whole host of scattering processes observable at present or future colliders was undertaken. As a part of these studies, dijet production in proton-antiproton collisions was undertaken and using experimental results from the Tevatron, bounds of the effective string scale in the models of large extra dimensions was obtained. This is the most stringent bound as yet available from present collider data.

Another interesting theoretical scenario that has attracted a lot of attention recently is that of warped extra dimensions. The implications of this scenario for high-energy experiments has also been studied. [K. Sridhar]

Quantum Chromodynamics

Cold and Dense Quark Matter

The low-temperature and high-baryon-number-density region of the QCD phase diagram was investigated. A model for the first-order phase transition between the quark-gluon plasma and the recently proposed colour superconducting phase was presented. Some numerical results for the activation energy and other physical parameters of the droplets of Cooper pairs, at various temperatures and densities, were obtained. They provide support to the prevalent ideas of the phase structure of QCD in the above region. [R. S. Bhalerao with R. K. Bhaduri (McMaster Univ., Canada)]