TIFR Annual Report 2006-07
THEORETICAL PHYSICS

High Energy Physics

Highlights

Quark-lepton complementarity was shown to be consistent with quasi-degenerate neutrinos if Majorana phases play a nontrivial role.

Strengths of flavour-dependent long-range leptonic forces were constrained using data from the solar neutrino and reactor experiments, to obtain bounds that are orders of magnitude stronger than the earlier ones.

Corrections to tri-bimaximal (TBM) neutrino mixing pattern were calculated from renormalization group (RG) and Planck scale effects.

The CRAY X1 was used to obtain the screening lengths in quark-gluon plasma from which genuine interaction effects could be discerned for the first time. A gap was shown to open across the phase transition in the eigenvalue spectrum of the quark operator evaluated on thermal ensembles created in QCD with two flavours of staggered quarks.

High-scale symmetries of non-hierarchical neutrinos were shown to be protected from significant changes due to RG evolution in the MSSM, by appropriate constraints on Majorana phases.

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

Quark-Lepton Complementarity with Quasi-degenerate Majorana Neutrinos

A basis-independent formulation of quark-lepton complementarity was implemented at a high scale for quasi-degenerate Majorana neutrinos. It was shown that even with the renormalization group (RG) evolution in the minimal supersymmetric standard model

(MSSM), 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. It was indicated how future accurate measurements of the mixing angles can serve as tests of this scenario and restrict the values of the Majorana phases. [A. Dighe and Probir Roy with S. Goswami (HRI, Allahabad and TUM, Munich)]

Flavour-dependent Long-Range Leptonic Forces

Flavour-dependent long-range (LR) leptonic forces, like those mediated by the $L_e - L_\mu$ or $L_e - L_\tau$ gauge bosons, constitute a minimal extension of the standard model that preserves its renormalizability. The impact of such interactions on the solar neutrino oscillations when the interaction range R_{LR} is much larger than the Earth-Sun distance was studied. A complete three-generation analysis was performed and crucial effects like the non-decoupling of solar and atmospheric mass scales even for a vanishing θ_{13}, and a possible resonant enhancement of θ_{13}, were pointed out. Using data from the solar neutrino experiments and KamLAND, the couplings of these long-range forces were constrained. The bounds obtained were orders of magnitude stronger than those obtained from astronomical observations and tabletop gravity experiments. [A. Bandyopadhyay and A. Dighe with A. Joshipura (PRL, Ahmedabad)]

Corrections to Tri-bimaximal Neutrino Mixing from RG and Planck Scale Effects

Corrections to tri-bimaximal (TBM) neutrino mixing pattern from RG running and from Planck scale effects were calculated. It was shown that while the RG effects are negligible in the standard model (SM), for quasi-degenerate neutrinos and large $\tan\beta$ in the MSSM all three mixing angles may change significantly. In both these cases, the direction of the modification of θ_{12} is fixed, while that of θ_{23} is determined by the neutrino mass ordering. The Planck scale effects can also change θ_{12} up to a few degrees in either direction for quasi-degenerate neutrinos. The usual constraints on neutrino masses, Majorana phases or $\tan\beta$ stemming from RG running arguments can then be relaxed. [A. Dighe with S. Goswami (HRI, Allahabad) and W. Rodejohann (MPI, Heidelberg)]

Extending the Slepton Mass Reach at the Large Hadron Collider

It was shown how the measurement of the Drell-Yan dilepton distribution, emanating from slepton pair-production at the LHC, as a function of transverse sphericity or circularity S_T, would extend the slepton mass reach to 500 GeV from 100 fb^{-1} of data. [Probir Roy with M. Guchait (DHEP) and S. Chakrabarti (C.E.N. Saclay, France)]

Radiatively Broken Symmetries of Non-hierarchical Neutrinos

Symmetry relations, based on ideas such as quark-lepton complementarity or tri-bimaximal mixing, were argued to be applicable at a high scale ($\sim 10^{12}$ GeV) from which renormalization group evolution (in the MSSM) down to laboratory energies would be necessary for comparison with experimental data. For non-hierarchical neutrinos, these relations tend generally to get spoilt as a consequence. It was shown how suitable constraints on the Majorana phases would save such relations vis-a-vis the extant experimental data. Specifically, a preference for the phase in the 1-2 sector to be near π (i.e. $m_1 \sim -m_2$) was found. It was shown how future measurements of θ_{12} and θ_{13} would help discriminate among various competing symmetry scenarios. [A. Dighe and Probir Roy with S. Goswami (HRI, Allahabad)]

Lattice Gauge Theory

Towards Continuum Limit of Screening Lengths with Chiral Fermions

Screening of currents in a medium is studied in order to extract information on its excitations. For exciting mesons with specific quantum numbers from the vacuum, simplest forms of currents with those quantum numbers are chosen. They should exhibit deconfinement related changes above the QCD phase transition temperature (T_c), while yielding the known spectrum at low temperatures. Earlier studies have shown that this indeed does happen in the vector and axial-vector channels — the screening above T_c is due to nearly non-interacting quark-antiquark pairs in the medium. The scalar and pseudo-scalar screening masses show more complicated behaviour with strong deviations from the ideal Fermi gas, and a strong temperature dependence. This puzzling behaviour is generic for different types and number of light quarks.

The mesonic screening correlators at $T = 2T_c$, where T_c is the QCD phase transition temperature, were studied using overlap Fermions in the quenched approximation of lattice QCD. These fermions have exact chiral and flavour symmetry on the lattice unlike those used earlier. As a price though, they are computationally expensive. Using lattices with temporal extents (N_t) up to 8 on our CRAY X1, *both* the pseudoscalar and vector screening masses were shown to have very small deviations from the ideal gas result and almost no variation with the lattice spacing a. The small deviations of the masses from the ideal gas values are thus genuine effects of interactions. Corresponding momentum space correlators were compared with the ideal gas limit. [R.V. Gavai and Sourendu Gupta with R. Lacaze (CEA, Saclay)]

Eigenvalues and Eigenvectors of the Staggered Dirac Operator at Finite Temperature

The eigenvalues and eigenvectors of the staggered Dirac operator evaluated on thermal ensembles created in QCD with two flavours of staggered quarks were examined. As the temperature T varied between $0.75T_c$ and $2T_c$, the renormalized quark mass was kept constant. It was shown that across the phase transition a gap opens in the eigenvalue spectrum. A clear crossover from low to high temperature behaviour is evidenced by an increase in the lowest eigenvalue by three orders of magnitude in the neighbourhood of T_c. This becomes sharper in the neighbourhood of T_c with increasing spatial size of the lattice.

For finite-volume lattices in the low-temperature phase the eigenvectors are extended, but generic field configurations in the high-temperature phase give rise to localized eigenstates. Examining measures of the stability of such localization, it was found that at finite volumes localization occurs through Mott's mechanism of the formation of mobility edges. However, the band gap between the localized and extended states appeared to scale to zero in the limit of large volume. [R.V. Gavai and Sourendu Gupta with R. Lacaze (CEA, Saclay)]

Quantum Chromodynamics

Eccentricity Fluctuations and Elliptic Flow at RHIC

The central issue at the Relativistic Heavy-Ion Collider (RHIC) is whether the quark-gluon matter produced in nucleus-nucleus collisions at RHIC attains thermalization or not. The elliptic flow scaled by the eccentricity of the overlap zone, v_2/ε, is one of the key observables at RHIC as well as LHC, because if it is found to be independent of the system size, one has a strong indication of thermalization. It is clear that both v_2 and ε need to be determined accurately. Various definitions of v_2 and ε were discussed. How these quantities are affected by the fluctuations in nucleon positions at the instant of the collision, was studied. An appropriate choice of definitions for comparison with experimental data was suggested. [R.S. Bhalerao with J.-Y. Ollitrault (Saclay, France)]