TIFR Annual Report 2003-04
THEORETICAL PHYSICS

High Energy Physics

Highlights

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

If neutrinos from a supernova pass through the Earth before reaching the detector, their energy spectra were shown to allow identification of their mixing scenarios. Precise values of the solar neutrino mass and mixing parameters were determined from a global data analysis. The difference between the survival probabilities of muon neutrino and antineutrino beams at long baselines, was shown to probe the deviation from maximality of muon neutrino flavour mixing. In a nonminimal supergravity model the lightest supersymmetric particle was found to be the superpartner of the Higgs instead of a gauge boson, with very distinctive implications for dark matter experiments. Implications of an R-parity violating supersymmetric model, with an ultralight gravitino as the lightest supersymmetric particle, for the Large Hadron Collider were studied. The first computation of next-to-leading order QCD corrections to a process involving virtual graviton exchange in models of TeV-scale gravity was completed.

In Lattice Gauge Theory, a more reliable estimate of the location of the critical point in the QCD phase diagram was obtained. Improved estimates of the specific heat of and speed of sound in Quark Gluon Plasma were obtained. A new method to obtain the compressibility of QGP was proposed. The Taylor expansion in baryon chemical potential was used to probe QCD at finite baryon densities.

In Quantum Chromodynamics, the structure of strange quark stars was shown to depend more sensitively on the density dependence of the bag parameter than on colour superconductivity. It was found that η_c production in relativistic heavy-ion collisions and its decay rates offer a quantitative explanation of the low-mass dimuon enhancement observed in these collisions.

Beyond Standard Model Physics

Earth Matter Effects on Supernova Neutrino Spectra

The oscillation patterns generated when neutrinos from a supernova (SN) pass through the mantle as well as the core of the Earth were studied. The Earth matter effects on SN neutrinos can be identified at a single detector through peaks in the Fourier transform of their "inverse energy" spectrum. The positions of these peaks are independent of the SN models and therefore the peaks can be used as a robust signature of the Earth matter effects, which in turn can distinguish between different neutrino mixing scenarios. Whereas only one genuine peak is observable when the neutrinos traverse only the Earth mantle, traversing also the core gives rise to multiple peaks. The strengths and positions of these peaks were calculated analytically and their features were explored at a large scintillation detector as well as at a megaton water Cherenkov detector through Monte Carlo simulations. A simple algorithm to identify the peaks in the actual data was proposed and the chances of a peak identification as a function of the location of the SN in the sky were quantified. [Amol Dighe with M. Kachelriess, G. Raffelt and R. Tomas of MPI Physics, Munich]

Neutrino Mass Matrix

In analogy with the quark sector, texture zeros in the neutrino mass matrix have been shown to predict important relations between their mass and mixing parameters. In particular, three-neutrino mass matrices with two texture zeros were shown to be compatible with the observed maximal mixing angle of atmospheric neutrino only for hierarchical and inverted hierarchical neutrino masses, but not for degenerate ones. Moreover, for each of these two cases, the other mixing angles were uniquely predicted in terms of the three neutrino masses. [D.P. Roy with B.R. Desai and A. Vaucher of Univ. of California, Riverside]

Solar Neutrino Oscillation

The Solar Neutrino Observatory (SNO) and the KamLAND Reactor Neutrino experiments have established the presence of Solar Neutrino Oscillation with unambiguous mass and mixing parameters. The latest values of these parameters were estimated from a global analysis including the recent data from the salt phase of the SNO experiment. Moreover simulation studies of future KamLAND data were done to show how they will further improve the determination of these parameters. [D.P. Roy with A. Bandyopadhyay of SINP, Kolkata, S. Goswami and R. Gandhi of HRI, Allahabad, and S. Choubey and S. Petkov of SISSA, Trieste]

Atmospheric Neutrino Oscillation

Atmospheric neutrino oscillation predicts a distinctive distortion of the neutrino energy spectrum in the long baseline accelerator neutrino experiments, which cannot be measured however on an event by event basis. Therefore the knowledge of low energy neutrino scattering data was used to predict the resulting distortion in the outgoing muon energy spectrum, which is a directly measurable quantity. [D.P. Roy with E.A. Paschos and J.Y. Yu of Univ. of Dortmund and I. Scienbein of DESY, Hamburg]

Invisible Higgs Search at LHC

In many scenarios beyond the Standard Model the Higgs Boson can dominantly decay into an invisible channel, for which the standard Higgs search strategy will not work. In this case the associated production of Higgs with a Z boson was shown to provide a viable signature at the Large Hadron Collider in terms of dilepton events accompanied with a large missing transverse momentum. [D.P. Roy with M. Guchait and K. Mazumdar of DHEP, R.M. Godbole of IISc, Bangalore, and S. Moretti of Univ. of Southampton]

SUSY Dark Matter in Nonminimal Supergravity Models

The Lightest Supersymmetric Particle (LSP), a mixture of gauginos and higgsinos which are superpartners of gauge and Higgs Bosons, is a leading candidate for the dark matter of the universe. In the minimal supergravity model it is dominantly a U(1) gaugino, which generally leads to an over-abundance of cosmic dark matter. On the other hand, a nonminimal supergravity model was shown to give a higgsino dominated LSP, which generally leads to an under-abundance of cosmic dark matter. Nonetheless, the expected signals in the proposed dark matter detection experiments were found to be more favourable in this case compared to the minimal model. [D.P. Roy with U. Chattopadhyay of IACS, Kolkata]

Testing the Maximal Nature of Muon Neutrino Flavour Mixing

The small difference between the survival probabilities of muon neutrino and antineutrino beams, travelling through earth matter in a long baseline experiment such as MINOS or Off-Axis NUMI, is shown to measure the product of the deviation from maximality of the mixing of those states and the matrix element which mixes the electron-like neutrino with the third massive one. [Probir Roy with S. Choubey of SISSA, Italy]

Signature Factors of Neutrino Mixing

A careful study was made of convention dependence in the definition of neutrino mixing signatures. It was found that the same combination of signature factors always appears in

all expressions of measurable neutrino oscillation probabilities. [Probir Roy with S. Rakshit of Technion, Israel]

R-Parity Violating SUSY with an Ultralight Gravitino at LHC

Resonant slepton production at the Large Hadron Collider (LHC) in models with ultra-light gravitinos has been studied, where the slepton decays into a neutralino and a lepton, and the neutralino decays into a photon and a gravitino. By measuring the transverse masses of the $\gamma - G$ and the $\ell - \gamma - G$ subsystems, it is possible to accurately reconstruct both the slepton and neutralino masses. In some regions of the parameter space, the slepton decays directly into a lepton and a gravitino, giving an identical experimental topology to W production (ℓ, missing-E_T). A peak in the tail of the lepton-missing momentum transverse mass distribution of the W provides a signature for the process and an accurate measurement of the slepton mass. [K. Sridhar with B.C. Allanach, LAPP, Annecy, France and M. Guchait of DHEP]

NLO QCD Calculations of Graviton Exchange Processes in TeV-Scale Gravity Models

Next-to-leading order QCD corrections to the process $e^+e^- \to$ hadrons via photon-, Z- and graviton-exchange in TeV-scale gravity models have been calculated. The quantitative impact of these QCD corrections for searches of extra dimensions at a Linear Collider has been discussed. This is the first calculation in the models of TeV-scale gravity to be done at next-to-leading order in QCD. [K. Sridhar with P. Mathews of Hyderabad Univ. and V. Ravindran of HRI, Allahabad]

Lattice Gauge Theory

Critical Point in QCD Phase Diagram

Computing the 6th and 8th order susceptibilities, which require up to eight computations of quark propagator, i.e., eight inversions of the corresponding Dirac matrix, the convergence of the series expansion for the QCD free energy was investigated both below and above the chiral phase transition temperature for QCD with two light dynamical quarks. While the radius of convergence seemed to grow indefinitely at $0.9T_c$ and $1.05T_c$, a finite radius of convergence was indicated at lower temperatures of $0.8T_c$ and $0.7T_c$. Extrapolating the results from successive orders, an estimate of the critical point in the QCD phase diagram was obtained for lattices with four temporal sites. Our results indicate a shift towards larger μ and lower temperatures compared to earlier results on same-size lattices albeit using other methods. [R.V.Gavai and Sourendu Gupta]

Speed of Sound, Compressibility and Specific Heat of the Quark Gluon Plasma

The phenomenology of relativistic heavy ion collisions crucially depends on quantities such as the speed of sound or compressibility as a function of temperature. These can be obtained from lattice simulations. Using the differential method and one-loop-order perturbative couplings, simulations were made for $3.0 \geq T/T_c \geq 1.5$ in the quenched approximation of quantum chromodynamics. Our continnum results, obtained by using progressively larger lattices with diminishing lattice artifacts, permitted us to improve upon the existing computations of specific heat and speed of sound. Our estimates of specific heat at constant volume and speed of sound were found to be less than the ideal gas results, by about 20% and 10%, respectively, even at the highest T. A first attempt has been made to obtain compressibility by using a new method proposed by us. [R.V.Gavai, Sourendu Gupta and Swagato Mukherjee]

Taylor Expansions in Chemical Potential

Taylor expansions of operator expectation values in QCD with respect to chemical potentials of quarks were studied. Some Taylor coefficients are related through Maxwell's relations. The Taylor coefficients for the chiral condensate were measured up to the second order. Computations above the critical temperature showed that the chiral condensate, which is finite at finite quark masses, is independent of the chemical potential when the quark masses are less than the temperature. A Maxwell relation then shows that the isovector quark number susceptibility is independent of quark masses over the same range of masses. [Sourendu Gupta and Rajarshi Ray]

Quantum Chromodynamics

Strange Quark Stars

Strange quark stars were studied in the framework of the MIT bag model, allowing the bag parameter B to depend on the density of the medium. It was shown that this has a significant effect on the equation of state (EOS) of the strange quark matter (SQM) and hence on the resulting stellar structure curves. Specifically, it led to a stiffer EOS which gave rise to stars with larger masses and radii. The effect of colour superconductivity on the structure of strange stars had been studied by several authors. An important point which emerged from the present work was that the results depend more sensitively on the density dependence of B than on the phenomenon of colour superconductivity. More importantly, it was shown that certain stellar sequences, which are ruled out by the requirement of the stability of SQM if B is treated as a constant, are allowed if the density dependence of B is taken into consideration. [R.S. Bhalerao with N. Prasad of DAA]

History of Exotic Baryon (Pentaquark) States

The history of the recently observed exotic baryon resonances was traced back to its original prediction from Duality and Regge pole formalism by members of this group about thirty five years ago. The most favourable channels for the confirmation of these resonances were pointed out on the basis of this formalism. [D.P. Roy]

η_c Contribution to the Low-Mass Dimuon Enhancement in Heavy-Ion Collisions

Dilepton production in heavy ion collisions, in the intermediate mass region has consistently shown an excess over theoretical estimates. An attempt to understand this discrepancy was made by calculating, in Non-Relativistic QCD, the contribution of the η_c meson to this channel. It was found that η_c production and decay rates offer a satisfactory quantitative explanation of the discrepancy. [K. Sridhar with R. Basu of IMSc, Chennai]