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THEORETICAL PHYSICS

High Energy Physics

Highlights

The production of the Kaluza-Klein excitation of the gluon in a modified Randall-Sundrum model has been studied. The one-loop decay of a Z-boson into photon and a graviton in a model of large extra dimensions has been calculated.

Evasion of the decade-long "Grossman bound" was shown to be possible in presence of flavor dependent new physics interactions, since these can enhance the lifetime differences in neutral B meson systems over their standard model values.

The interplay between the lower bound on the branching ratio of $B \to K\mu^+\mu^-$ and the upper bound on that of $B_s \to \mu^+\mu^-$ was used to point out the tension between them in the presence of scalar/pseudoscalar new physics operators.

Four was shown to be the maximum number of texture zeroes allowed by the data in the neutrino Yukawa coupling matrix within the Type-I seesaw.

An accurate measurement of the neutrino mixing angle θ_{13} was shown to be capable of discrimination among different symmetries at the high scale in MSSM in spite of the RG running of angles.

The reach of various long baseline experiments was calculated for i) detecting sterile neutrino mixing for an arbitrary number of sterile neutrinos, and ii) constraining CPT violating parameters .

A formalism was developed to analyze the nonlinear collective effects arising from the neutrino-neutrino interactions inside a supernova in the complete three-flavor framework. Using it, the step-like feature in the electron neutrino survival probabiliy during the neutronization burst of an O-Ne-Mg supernova was analytically explained.

The collective effects in supernova neutrino oscillations were shown to be capable of distinguishing between the neutrino mass hierarchies even for vanishingly small θ_{13}.

It was pointed out that a nonzero baryonic chemical potential violates the exact chiral symmetry of the overlap fermions. Optimal range of a parameter of the overlap fermions was found numerically to make computer simulations cheaper in CPU time.

A new hydrodynamical formulation which includes dissipation in heavy-ion collisions was shown to give interesting new flow patterns which could be distinguished from previous results in some experiments, and therefore to have impact on studies of deconfinement in

QCD.

It was shown that the topological structure of the phase diagram of QCD is strongly constrained by the results of lattice simulations performed earlier by the Indian Lattice Gauge Theory Initiative (ILGTI).

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

Direct production of Kaluza-Klein gluons in the Bulk Randall-Sundrum Model at the Tevatron

Informed by the duality between a theory of gravity in a anti-de Sitter space and a conformal gauge theory on the boundary of this space, a new avatar of the Randall-Sundrum model has been proposed where the Higgs is localised in 4-dimensional spacetime whereas all other SM particles are free to propagate in higher dimensions. The Kaluza-Klein excitations of the gluon, with its huge decay branching fraction into top-antitop pairs, provides the most distinctive signature for this model. A study of the production of this KK gluon at the Run II of Tevatron has been a carried out and a bound of 800 GeV on the mass of this particle has been derived. [K. Sridhar, Manoranjan Guchait with F. Mahmoudi (Uppsala Univ. Sweden)]

Associated production of Kaluza-Klein gluons with a top pair at the LHC

The production of the KK gluon in the modified Randall-Sundrum model in association with a top-antitop pair at the LHC has been studied and the kinematic reach of this process at the LHC has been discussed. [K. Sridhar, Manoranjan Guchait with F. Mahmoudi (Uppsala Univ. Sweden)]

One-loop decay of a Z to a photon and graviton

The amplitudes for the decay of a Z boson into a photon and a graviton Kaluza-Klein tower, via loops mediated by top quarks, bottom quarks and W bosons, have been computed. [K. Sridhar with B. Allanach and J. Skitrall (DAMTP, Cambridge)]

Possibility of large lifetime differences in neutral B meson systems

It was shown that in the presence of flavor dependent new physics interactions, lifetime differences in the neutral B meson systems can be enhanced over their standard model values, thus evading the decade-long "Grossman bound". In models with third generation scalar leptoquarks, it was explicitly shown that the lifetime differences can be enhanced up to 5 times, and hence their measurement at upcoming experiments becomes possible. [Amol Dighe with Anirban Kundu and Soumitra Nandi (Calcutta U.)]

Scalar/pseudoscalar new physics contribution to $b \to s\mu\mu$ decays

It was shown that the upper bound on the branching ratio of $B_s \to \mu^+\mu^-$ sets a strong constraint on the possible scalar/pseudoscalar operator contribution to the branching ratio of $B \to K\mu^+\mu^-$. Consequently in multi-Higgs models, an order of magnitude enhancement of $B(B_s \to \mu^+\mu^-)$ is ruled out if $B(B \to K\mu^+\mu^-)$ is greater than its standard model prediction by more than a few per cent. It was also pointed out that the scalar/pseudoscalar operators cannot lower $B(B \to K\mu^+\mu^-)$ below its standard model prediction. [Ashutosh Kumar Alok and Amol Dighe with S. Uma Sankar (IIT Bombay)]

Four Zero Neutrino Yukawa Textures

Within the Type I seesaw framework, four was shown to be the maximum number of texture zeroes permitted in the neutrino Yukawa coupling matrix by the observed mixing pattern and the assumption that no neutrino mass vanishes. All such allowed four-zero textures were classified into two categories with three classes each. The different classes, in general, were shown to admit CP violation both at low and high energies and constraints were obtained for low energy physics in each case. The role of these four zero textures in establishing a connection between leptogenesis and low energy data was analysed in detail. In each case a complete specification was made of the parameters relevant for leptogenesis in terms of light neutrino masses and mixing angles together with the unknown heavy right-handed neutrino masses. [Probir Roy with G. C. Branco, D. E-Costa and M. N. Rebelo (IST, Lisbon)]

Radiatively broken symmetries of nonhierarchical neutrinos

Symmetry-based ideas, such as the quark-lepton complementarity (QLC) principle and the tri-bimaximal mixing (TBM) scheme, predict specific neutrino mixing patterns at the high scale of grand unification. Renormalization group (RG) evolution down to a laboratory scale tends to break these symmetries. In the context of the minimal supersymmetric standard model (MSSM), it was shown that an accurate measurement of the neutrino mixing angle θ_{13} enables discrimination among different symmetries at the high scale in spite of the RG evolution. [Amol Dighe and Probir Roy with Srubabati Goswami (HRI, Allahabad)]

CPT violation in long baseline neutrino experiments

Possible signals of CPT violation in neutrinos were explored in the complete three-flavor framework. Employing a systematic expansion in small parameters, the CPT violating contributions to the survival probabilities of neutrinos were analytically estimated. The combinations of CPT violating parameters that are relevant for long baseline experiments were identified, and the reach of these experiments in constraining the parameters was estimated. [Amol Dighe and Shamayita Ray]

Signatures of heavy sterile neutrinos at long baseline experiments

The question of whether there are signals of sterile neutrinos that are hidden with all the current data, but are possible at the planned long baseline experiments, was explored. An analytical approximation scheme was developed which exploited the observed smallness of some of the neutrino mixing parameters, and neutrino flavor transformations were calculated using perturbation theory with these small parameters, in the complete three neutrino framework. The reach of various long baseline experiments was calculated, and the analysis was extended to a general case where the number of sterile neutrino species can be arbitrary. [Amol Dighe and Shamayita Ray]

Collective three-flavor oscillations of supernova neutrinos

Neutrinos and antineutrinos emitted from a core collapse supernova interact among themselves, giving rise to nonlinear flavor conversion effects that are significant near the neutrinosphere. A formalism to analyze these collective effects in the complete three-flavor framework was developed, which analytically describes phenomena like vacuum/MSW oscillations, synchronized oscillations, bipolar oscillations and spectral split in three flavors. It was demonstrated that the flavor conversions may be "factorized" into two-flavor oscillations with hierarchical frequencies. For a typical supernova density profile, an approximate separation of regions where distinctly different flavor conversion mechanisms operate was identified, and the interplay between collective and MSW effects was demonstrated. [Basudeb Dasgupta and Amol Dighe]

Spectral split in prompt supernova neutrino burst

For O-Ne-Mg core supernovae, the matter density profile can be so shallow that the usual MSW matter effects occur within the dense-neutrino region close to the neutrino sphere. In this case the ν_e flavor survival probability during the neutronization burst shows a step-like feature. This feature was explained analytically as a "MSW prepared spectral split." Using a three-flavor treatment, it was shown that the step-like feature actually consists of two

narrowly spaced splits, with the split energies determined by two combinations of flavor-lepton numbers that are conserved under collective oscillations. [Basudeb Dasgupta and Amol Dighe with Alessandro Mirizzi and Georg G. Raffelt (Max Planck Inst., Munich)]

Identifying neutrino mass hierarchy at extremely small θ_{13}

Collective neutrino flavor transformations deep inside a supernova are sensitive to the neutrino mass hierarchy even at extremely small values of the neutrino mixing angle θ_{13}. Exploiting this effect, it was shown that a comparison of the antineutrino signals from a galactic supernova in two megaton class water Cherenkov detectors, one of which is shadowed by the Earth, will enable us to distinguish between the hierarchies even if θ_{13} is vanishingly small. [Basudeb Dasgupta and Amol Dighe with Alessandro Mirizzi (Max Planck Inst., Munich)]

Lattice Gauge Theory

QCD Equation of State from Lattice

The equation of state of QCD was calculated numerically on lattice, using Monte Carlo simulation with a strange quark and two degenerate light quarks such that the pion mass is about 220 MeV. Different lattice spacings and spacings were utilized to extrapolate to the infinite volume continuum theory. A study of quark condensates and renormalized Polyakov loops indicated that the chiral symmetry restoration and deconfinement transition occur simultaneously in QCD. The conformal symmetry breaking just above the deconfinement transition was carefully investigated. Bulk thermodynamic quantities like pressure, energy density and entropy density were calculated. [Saumen Datta with N. Christ (Columbia U.), F. Karsch (BNL) and E. Laermann (Bielefeld), et al.]

Thermodynamics of the ideal overlap quarks on the lattice

The location, and even the existence, of the critical point in the $\mu_B - T$ phase diagram of quantum chromodynamics (QCD), where μ_B is the baryonic chemical potential, is expected to depend crucially on the number of light flavours N_f and the nature of chiral symmetries on the lattice. Popular choices of lattice fermion break these chiral symmetries at least partially (staggered fermions) or fully (Wilson fermions). The overlap fermion, also called the Neuberger-Dirac, operator respects chiral symmetry at the expense of being highly non-local. Although computationally very expensive, these fermions are likely to play a strong role in this area in future, thanks to their exact chiral symmetry.

The thermodynamics of ideal gas of overlap quarks was investigated both analytically

and numerically for both zero and nonzero baryon chemical potential. Any μ_B^2-divergence was shown analytically to be absent for a class of actions with nonzero chemical potential. It was also shown that nonzero μ_B violates the exact chiral invariance. While the parameter M of the Neuberger-Dirac operator was shown to be irrelevant in the continuum limit, as expected, it was shown numerically that the continuum limit can be reached on relatively coarser lattices for certain ranges of M. Numerical limitations of the existing method of introduction of chemical potential were demonstrated. Finally we also showed that the energy density for the massive overlap fermions has the correct continuum limit. (R.V. Gavai With Debasish Banerjee and Sayantan Sharma]

The phase structure of QCD

The phase structure of baryonic matter was investigated using a symmetry analysis to determine the order parameters which should be used and then depending only on the constraints from thermodynamics. Interestingly, when two flavours of light quarks are taken into account, this turns out to determine the structure of the full phase diagram almost completely: in particular predicting which phases coexist in first order phase transitions, and the chatracter of each critical point. Quantitative work using QCD, which is time-consuming and expensive, can therefore be carried out more easily. When the strange quark is taken into account there remain three different possible structures for the phase diagram. Quantitative computations will have to decide between well-defined choices. [Sourendu Gupta]

Relativistic diffusion

In relativity the diffusion equation seems to violate the principle of causality: that all influences propagate at speeds not exceeding that of light. The kinetic equations, on the other hand, have causality built in. It was checked that a reduction of the kinetic equations to the continuum limit contain subleading corrections which restore causality, and restrict the domain of use of the diffusion equation. These subleading corrections give rise to new transport coefficients, which were connected by sum rules to the microscopic physics. This approach provides a microscopic model for subleading corrections to the Navier-Stokes equations of fluid mechanics. [Sourendu Gupta]

Quantum Chromodynamics

Aspects of Causal Viscous Hydrodynamics

The phenomenology of freely expanding fluids having different material properties and evolving through the Israel-Stewart (IS) causal viscous hydrodynamics was investigated. Results were compared with those obtained in the relativistic Eckart-Landau-Navier-Stokes

(ELNS) acausal viscous hydrodynamics. A definition of thermalization time which could be self-consistently determined in viscous hydrodynamics, was given through the analysis of scaling invariants. Solutions for one-dimensional boost-invariant flows were constructed. Expansion of viscous fluids was found to be slower than that of one-dimensional ideal fluid, resulting in entropy production. At late times, these flows were reasonably well approximated by solutions obtained in ELNS hydrodynamics. Estimates of initial energy densities from observed final values were strongly dependent on the dynamics chosen. For the same material, and the same final state, IS hydrodynamics gave the smallest initial energy density. Fluctuations about these one-dimensional boost-invariant backgrounds were studied; they were damped in ELNS hydrodynamics but could become sound waves in IS hydrodynamics. [R.S. Bhalerao and Sourendu Gupta]