TIFR Annual Report (2012-13) - Department of Theoretical Physics

High Energy Physics

The QCD Critical Point : marching towards continuum

Whether the phase diagram of strongly interacting matter, governed by Quantum chromodynamics (QCD), has a critical point in the temperature (T) and baryon chemical potential μ_B plane, is an exciting question that has attracted many theorists, phenomenologists, and heavy ion experimentalists. Non-perturbative lattice QCD, defined on a discrete space-time lattice, has proved itself to be the most reliable technique for extracting such information from QCD. The TIFR group earlier proposed a new algorithm to locate the critical point, and employed it for dynamical QCD with two flavours of staggered fermions on lattices with temporal extensions of 4 and 6.

QCD with two light dynamical quarks was simulated on a still larger, $32^3 \times 8$, lattice at the same quark mass as before, which corresponds to a Goldstone pion mass of about 230 MeV. Employing the Taylor expansion method of the TIFR group, the radius of convergence of the series for the baryonic susceptibility was estimated by computing terms up to eighth order. Together with earlier results from the TIFR group, corresponding to the same physical parameters but on coarser lattices mentioned above, an attempt to approach the continuum limit was made. The very good agreement of results for $N_t = 8$ with those for $N_t = 6$ suggests the continuum limit to be in sight and the critical point estimate to be robust. [Saumen Datta, Rajiv V. Gavai and Sourendu Gupta]

More on the faster method of computation of quark number susceptibilities

The search for QCD critical point is one of the major experimental goals of many heavy ion collider experiments world wide. It, therefore, appears natural to have as precise a first principles determination of the QCD critical point theoretically as possible. In the TIFR group's method to do so, one ought to to compute ratios of as many higher orders of baryon number susceptibilities as possible for a precise estimation of the radius of convergence. Currently, one can go as far as the 8^{th} order, due to the ever-increasing number of cancelling terms and the resultant fluctuations.

By adding the chemical potential as a Lagrange multiplier for the point-split number density term, the quark number susceptibilities were computed in two flavor QCD for staggered fermions in a novel proposal. Since lesser number of quark propagators are required at any order, this method leads to faster computations with lesser fluctuations. A subtraction procedure was proposed to remove its inherent undesired (divergent) lattice term. Second order quark number susceptibility was computed at fixed temperatures but with a decreasing lattice cut-off size (a). It was found that the undesired lattice terms, which grow as a^{-2}, were indeed absent after subtraction, leading to a finite and correct answer. This thus opens up doors to more efficient computations of higher orders, and a better estimate of the location of the critical point. [Rajiv V. Gavai and Sayantan Sharma (University of Bielefeld)]

Screening of nucleonic charges in hot strongly interacting matter

The screening of nucleonic charges in gluonic medium was studied, both below and above the deconfinement transition temperature T_c, using lattice QCD. At temperatures of 1.5 T_c it was found that the screening of nucleonic sources is very similar to that expected in a weakly coupled gluonic system. At 0.95 T_c, a reduction of the difference between screening of positive parity and negative parity sources was seen, indicating a precursor of chiral symmetry restoration below T_c. [S. Datta, S. Gupta, N. Mathur, M. Padmanath with J. Maiti (Barasat Govt. College)]

Hadronic screening masses with improved valence quarks

The optimization of gauge link smearing was investigated by observing its effects on the infrared and ultraviolet components of gluon and quark fields. The meson and nucleon screening correlators and masses in finite temperature two flavour QCD was studied using smeared and thin-link quarks and it was seen that smearing improves taste symmetry. Varying the lattice spacing and quark masses, it was found that the screening lengths in the hot phase decrease systematically as taste symmetry breaking is reduced at T=0. Also, taste symmetry breaking in the hot phase improves super-linearly with improvement at T=0. It was found that the improved hadronic operators are consistent with weak-coupling predictions for $T > 1.5T_c$ (T_c is the finite temperature cross over). Consistent with this, there was evidence for the opening of a spectral gap of the Dirac operator immediately above T_c. [Nikhil Karthik and Sourendu Gupta]

The Flavor Structure of the Excited Baryon Spectra from Lattice QCD

Excited state spectra were calculated using lattice QCD for baryons that can be formed from u, d and s quarks, namely the N, Δ, Λ, Σ, Ξ and Ω families of baryons. Baryonic operators were constructed from continuum operators that transform as irreducible representations of $SU(3)_F$ symmetry for flavor, SU(4) symmetry for Dirac spins of quarks and O(3) symmetry for orbital angular momenta. Using these operators, the matrices of correlation functions

were calculated in order to extract excited states. The resulting lattice spectra have bands of baryonic states with well-defined total spins up to $J = 7/2$. Each state can be assigned a dominant flavor symmetry and the counting of states of each flavor and spin reflects the $SU(6) \times O(3)$ symmetry for the lowest negative-parity and positive-parity bands. States with strong hybrid content were identified through the dominance of chromo-magnetic operators. [Nilmani Mathur with Robert G. Edwards (Jefferson National Laboratory), David G. Richards (Jefferson National Laboratory) and Stephen J. Wallace (University of Maryland)]

The Δ_{mix} parameter in the overlap on domain-wall mixed action

The mixed-action parameter, Δ_{mix}, plays a crucial role to estimate errors in any mixed action calculation. A direct calculation of this mixed-action parameter with valence overlap fermions on a domain-wall fermion sea was undertaken. The calculation was performed on four ensembles of the 2+1-flavor domain-wall gauge configurations: $24^3 \times 64$ ($am_l = 0.005$, $a = 0.114fm$) and $32^3 \times 64$ ($am_l = 0.004, 0.006, 0.008$, $a = 0.085fm$). For pion masses close to $300MeV$, it was found that $\Delta_{mix} = 0.030(6)GeV^4$ at $a = 0.114fm$ and $\Delta_{mix} = 0.033(12)GeV^4$ at $a = 0.085fm$. These results were quite independent of the lattice spacing and were significantly smaller than the results for valence domain-wall fermions on Asqtad sea or those of valence overlap fermions on clover sea. Combining the results extracted from these two ensembles, $\Delta_{mix} = 0.030(6)(5)GeV^4$, where the first error is statistical and the second is the systematic error associated with the fitting method. [N. Mathur with M. Lujan (George Washington University) et al.]

Spectra of hadrons with one or more charm quarks, using chiral action

A plethora of new hadrons with one or more charm quarks have been recently discovered, and more are expected from LHCb. The spectra of such hadrons were studied by numerical methods of lattice QCD, using overlap valence quarks on configurations with improved gluons and staggered sea quarks (HISQ). The hyperfine splitting of 1S charmonia was obtained to be 114(3)(-2) MeV and 109(4)(-3) MeV, and the splitting (m(Ω_{ccc})-3/2 m(J/Ψ)) was found to be 110(20)(-10) MeV and 120(10) MeV, corresponding to lattices with spacings a = 0.09 and 0.06 fm respectively. The ratio of leptonic decay constants, $f_{D_s^*}/f_{D_s}$ was also estimated in this work. [S. Datta, N. Mathur M. Padmanath, with S. Basak (NISER), and P. Majumdar (IACS)]

New relativistic dissipative fluid dynamics from kinetic theory

A new derivation of the relativistic dissipative fluid dynamics was presented. Fluid dynamics equations were derived, starting with the Boltzmann equation where the collision term was generalized to include nonlocal effects via gradients of the phase-space distribution function. Comparisons were made with the corresponding equations obtained in the standard Israel-Stewart and related approaches. The present method generated all the second-order terms that are allowed by symmetry, some of which had been missed by the traditional

approaches based on Grad's 14-moment approximation, and the coefficients of other terms were altered. The first-order or Navier-Stokes equations too got modified. Significance of these findings was demonstrated in the framework of one-dimensional scaling expansion of the matter formed in relativistic heavy-ion collisions. [A. Jaiswal, R.S. Bhalerao and S. Pal]

Complete relativistic second-order dissipative hydrodynamics from the entropy principle

Relativistic dissipative hydrodynamic equations were derived invoking the second law of thermodynamics for the entropy four-current expressed in terms of the single-particle phase-space distribution function obtained from Grad's 14-moment approximation. This derivation was complete in the sense that all the second-order transport coefficients were uniquely determined within a single theoretical framework. In particular, this removed the long-standing ambiguity in the relaxation time for bulk viscosity thereby eliminating one of the uncertainties in the extraction of the shear viscosity to entropy density ratio from confrontation with the anisotropic flow data in relativistic heavy-ion collisions. In the one-dimensional scaling expansion, these transport coefficients were found to prevent the occurrence of cavitation even for rather large values of the bulk viscosity estimated in lattice QCD. [A. Jaiswal, R.S. Bhalerao and S. Pal]

Branching ratio of $B_s \to \tau\tau$

Motivated by the large like-sign dimuon charge asymmetry observed recently, whose explanation would require an enhanced decay rate of $B_s \to \tau\tau$, the constraints on this rate from the current data were calculated. Using an effective field theory approach, it was shown that a branching ratio as high as 15% may be allowed, which is orders of magnitude more than the Standard Model prediction. Specific models involving a scalar leptoquark and a light Z' gauge boson were explored and the limits on the enhancement they can provide were determined. [A. Dighe and D. Ghosh]

Constraining low-energy supersymmetry models

A critical study of two highly-constrained models of supersymmetry – the constrained minimal supersymmetric standard model (cMSSM), and the non-universal Higgs mass model (NUHM) – was performed in the light of the recent measurements of the Higgs boson and B decays. It was shown that these models are still allowed by the experimental data, even if one demands that there be a light stop particle. The only significant effects of all these constraints are to push the mass of the light stop higher, and to prefer the universal trilinear coupling A0 to be large and negative. The Higgs boson branching ratios to $WW, ZZ, \tau\tau$ and $\gamma\gamma$ in these models were calculated and it was shown that improved experimental limits on these could put them to the most stringent experimental tests yet. [A. Dighe, D. Ghosh, K. Patel, S. Raychaudhuri]

Reach of INO for measuring atmospheric neutrino mixing parameters

Using the detector resolutions and efficiencies obtained by the INO collaboration from a full-detector GEANT4-based simulation, the reach of this experiment for

the measurement of the atmospheric neutrino mixing parameters $\sin^2\theta_{23}$ and $|\Delta m^2_{32}|$ was determined. The sensitivity of this experiment to the octant of θ_{23}, and to its deviation from maximal mixing, was also explored. [A. Dighe and T. Thakore, with S. Choubey and A. Ghosh (HRI)]

Viability of the $\mu-\tau$ symmetry after results on non-zero reactor mixing angle

The $\mu-\tau$ interchange symmetry of the neutrino mass matrix in flavour basis predicts vanishing reactor mixing angle θ_{13}. Viability of such symmetry imposed as an approximate symmetry (1) on the neutrino mass matrix in the flavour basis (2) simultaneously on the charged lepton mass matrix and the neutrino mass matrix and (3) on the underlying Lagrangian was analyzed in the light of recent observation of a non-zero θ_{13}. It was shown that μ-τ symmetry breaking may be regarded as small only for the inverted or quasi-degenerate neutrino mass spectrum in case (1). The case (2) was found more restrictive and the requirement of relatively small breaking allows only the quasi-degenerate spectrum. If neutrinos obtain their masses from the type-I seesaw mechanism then even the hierarchical neutrino spectrum was found to be consistent with mildly broken μ-τ symmetry of the Lagrangian. [Ketan M. Patel with S. Gupta (Yosnei University, South Korea) and A. S. Joshipura (PRL, Ahmedabad)]

Testing Times for Supersymmetry: Looking Under the Lamp Post

A critical study was carried out for two highly-constrained models of supersymmetry - the constrained minimal supersymmetric standard model (cMSSM), and the non-universal Higgs mass model (NUHM) - in the light of the 125-126 GeV Higgs boson, the first observation of $B_s \to \mu\mu$ at the LHCb, and the updated $B \to \tau\nu$ branching ratio at BELLE. It was pointed out that these models are still allowed by the experimental data, even if a light stop is demanded with mass less than 1.5 TeV. The only significant effects of all these constraints were to push the mass of the light stop above 500 GeV, and to prefer the universal trilinear coupling A0 to be large and negative. The Higgs boson's branching ratios to WW, ZZ ,$\tau\tau$ and $\gamma\gamma$ were also calculated in these models and it was shown that improved experimental limits on these could put these models to the most stringent experimental tests yet. [Amol Dighe, Ketan M. Patel, Sreerup Raychaudhuri with D. Ghosh (INFN, Rome)]

Quark-Lepton Mass Relation and CKM mixing in an A4 Extension of the Minimal Supersymmetric Standard Model

An interesting mass relation between down type quarks and charged leptons was predicted within a minimal supersymmetric standard model based on the A4 flavor symmetry. A simple extension was proposed which provides an adequate full description of the quark sector. It was shown by adding a pair of vector-like up-quarks that how the CKM entries arise from deviations of the unitarity. Detailed analysis was performed on the most relevant observables in the quark sector, such as oscillations and rare decays of Kaons, Bd and Bs mesons. It was found that model predicts an inverted hierarchy for the neutrino masses leading

to a potentially observable rate of neutrinoless double beta decay. [Ketan M. Patel with S. Morisi (UW, Wurzburg), E. Peinado (INFN, Frascati), M. Nebot and J. W. F. Valle (IFIC, Valencia)]

Analysis of the experimental status of the constrained MSSM

A state-of-the-art analysis was carried out on the parameter space of the constrained MSSM (cMSSM), which is the most popular model of supersymmetry at the electroweak scale. This showed that the bulk of the parameter space of the model was still viable, with only some regions at the periphery being ruled out. It was predicted that if a Higgs boson of mass around 125 GeV were to be confirmed (as had already been hinted at in 2011), then very serious constraints would result.

Subsequently, such a discovery was indeed announced, and this leads, as predicted, to large chunks of the parameter space of this model being ruled out. [Diptimoy Ghosh and Sreerup Raychaudhuri (TIFR/DTP) with Monoranjan Guchait and Dipan Sengupta (TIFR/DHEP)]

Azimuthal angle asymmetries at the LHeC as a probe of the HWW coupling

The CP properties of a Higgs boson of mass 125 GeV, as announced in July 2012, cannot be easily measured at a purely hadronic machine like the LHC, for, among other reasons, the contributions induced by different Higgs vertices cannot be separated out. It was pointed out that at the proposed electron-proton collider using the LHC proton beam (the LHeC), there could be signals arising purely from the HWW vertex, whose CP properties can be studied by measuring asymmetries in the azimuthal angle distribution of jets in the final state. [Sudhansu S. Biswal and Sreerup Raychaudhuri (TIFR/DTP) with Rohini M. Godbole (IISc/CHEP, Bengaluru) and Bruce Mellado (U. of Wisconsin, Madison)]

Boosted jets as a probe of light Higgs bosons at the LHC

After the discovery of a 125 GeV Higgs boson at the LHC, the question naturally arises whether this is the only such particle, or one of a set of similar scalar particles. In the CP-violating version of supersymmetry, which is in some sense more natural, it is possible to have lighter Higgs bosons apart from the discovered one, which would go undetected by conventional techniques used at colliders like the LEP and LHC. It was shown that recently-discovered techniques for 'Higgs tagging' using boosted 'fat' jets with substructure, could be an efficient probe of such light Higgs bosons. [Sreerup Raychaudhuri with Biplob Bhattacherjee (Kavli IPMU, Tokyo), Amit Chakraborty and Dilip Kumar Ghosh (IACS, Kolkata)]

Compressed spectrum of minimal UED models in vacuum-stable scenarios

In minimal models with a Universal Extra Dimension, the coupling constants exhibit power-law running rather than logarithmic running because of the presence of multiple Kaluza-Klein thresholds. For a 125 GeV Higgs boson, the Higgs

potential destabilises at a fairly low scale, which must act as a cutoff for the theory. The consequence of such a low cutoff is a very compressed spectrum for the Kaluza-Klein excitations of the Standard Model fields, which makes most of the LHC signals proposed for such models unviable. It was shown than only signals with multiple leptons and missing transverse energy could be detected, if the parameters are favourable. [Anindya Datta (U. of Calcutta, Kolkata) and Sreerup Raychaudhuri (TIFR/DTP)]