TIFR Annual Technical Report (2014-15)

Department of Theoretical Physics

High Energy Physics

Relativistic Viscous Hydrodynamics for Heavy-ion Collisions: A Comparison between the Chapman-Enskog and Grad Methods

Derivations of relativistic second-order dissipative hydrodynamic equations rely almost exclusively on the use of Grad's 14-moment approximation to write $f(x,p)$, the nonequilibrium distribution function in the phase space. An alternative Chapman-Enskog-like method, which, unlike Grad's, involves a small expansion parameter was considered. An expression for $f(x,p)$ was derived to second order in this parameter. It was shown analytically that while Grad's method led to the violation of the experimentally observed $1/\sqrt{m_T}$ scaling of the longitudinal femtoscopic radii, the alternative method did not exhibit such an unphysical behavior. Numerical results for hadron transverse-momentum spectra and femtoscopic radii obtained in these two methods, within the one-dimensional scaling expansion scenario, were compared with each other. Moreover, a rapid convergence of the Chapman-Enskog-like expansion up to second order was demonstrated. This led to an expression for $\delta f(x,p)$ which provided a better alternative to Grad's approximation, for hydrodynamic modeling of relativistic heavy-ion collisions.
[Rajeev S. Bhalerao, A. Jaiswal, S. Pal, and V. Sreekanth]

Characterizing Flow Fluctuations with Moments

A complete set of multiparticle correlation observables for ultrarelativistic heavy-ion collisions was presented. It included moments of the distribution of the anisotropic flow in a single harmonic, and also mixed moments, which contain the information on correlations between event planes of different harmonics. It was explained how all these moments can be measured using just two symmetric subevents separated by a rapidity gap. This presented a multi-pronged probe of the physics of flow fluctuations. For instance, it allowed to test the hypothesis that event-plane correlations are generated by non-linear hydrodynamic response. The method was illustrated with simulations of

events in A MultiPhase Transport (AMPT) model.
[Rajeev S. Bhalerao and S. Pal, with J. Y. Ollitrault (IPhT, Saclay)]

Spectra of Hadrons with Heavy Quarks using Overlap Formalism

Many new hadrons with one or more charm quarks have been recently discovered, and more are expected. The spectra of such hadrons were studied using overlap valence quarks on configurations with improved gluons and staggered sea quarks (HISQ). The finite cutoff corrections that occur due to the use of different formulations of the valence and sea quarks were investigated. The ratio of leptonic decay constants, $f_{D_s^*}/f_{D_s}$ was also estimated.
[Saumen Datta and Nilmani Mathur, with S. Basak (NISER), A. T. Lytle (TIFR & University of Glasgow), P. Majumdar (IACS), and M. Padmanath (University of Graz)]

Hadron Spectra and Δ_{mix} from Overlap Quarks on a HISQ Sea

Results of the continuing study on mixed-action hadron spectra and decay constants using overlap valence quarks on MILC's $2+1+1$ flavor HISQ gauge configurations were presented. This study was carried out on three lattice spacings, with charm and strange masses tuned to their physical values, and with $m_l/m_s = 1/5$. Results of an ongoing determination of the mixed-action parameter Δ_{mix}, which enters into chiral formulae for the masses and decay constants were presented.
[Saumen Datta and Nilmani Mathur, with S. Basak (NISER), A. T. Lytle (TIFR & University of Glasgow), P. Majumdar (IACS), and M. Padmanath (University of Graz)]

Bottomonia in Quark-Gluon Plasma

Quarkonia are very important probes of deconfinement and the formation of quark-gluon plasma in relativistic heavy ion collision experiments. In particular, very interesting results on bottomonia are available from Pb-Pb collisions in LHC. Behavior of bottomonia in equilibriated gluon plasma was studied by examining the thermal correlators, and the comparison of the Matsubara and screening correlators.
[Saumen Datta]

Enhancing Sensitivity to Neutrino Parameters at INO Combining Muon and Hadron Information

The design of the proposed iron calorimeter (ICAL) detector at the India-based Neutrino Observatory (INO) is primarily optimized to measure muon momentum. However the detector is also capable of measuring the hadron energy in each event, albeit with much lower resolution. It was demonstrated that the hadronic hits in the detector encode information on the inelasticty in the charged-current processes, the extraction of which would significantly improve the sensitivity of ICAL to the neutrino parameters. In particular, the analysis that uses hadron energy information can distinguish the normal and inverted mass hierarchies with $\Delta\chi^2 \approx 9$ with 10 years exposure at the 50 kt ICAL, which corresponds to about 40% improvement over the muon-only analysis.
[Amol Dighe, M. M. Devi, and T. Thakore, with S. Agarwalla (IOP)]

Simple Action for Finite Density Lattice QCD

It had earlier been shown that preservation of exact chiral invariance on the lattice is feasible only for a linear chemical potential term in the quark action for the overlap and the domain wall fermions. Investigations of QCD at finite density, and in particular of the QCD critical point, gain in terms of CPU time for the same computation by using such canonical Lagrange multiplier type linear term in the action for other fermions as well such as the simpler staggered quarks. It, however, has a problem of chemical potential dependent divergence. Using simulations of the quenched QCD with the staggered quarks on varying temporal lattices, it was demonstrated at two different temperatures how physical results are obtained for a variety of quark number susceptibilities in the continuum limit by using the same method of divergence subtraction.
[Rajiv V. Gavai and S. Sharma (University of Bielefeld)]

Criticality and the Equation of State of QCD

The baryon number density and the excess contribution to the pressure in Quantum Chromodynamics at finite chemical potential and temperature was obtained, by resumming the Taylor series expansion found in a lattice computation with two flavours of quarks at three different quark masses. The method proceeded by giving a critical chemical potential and limits on the critical exponent, and permits reliable estimations of the errors in resummed quantities. The baryon density and excess pressure were found to be insensitive to the quark mass. The bulk isothermal compressibility over a range of temperature and chemical potential was also reported.
[Sourendu Gupta and N. Karthik with P. Majumdar (IACS)]

Lambda Phenomena: the Lambda Points of Liquid Helium and Chiral QCD

The scaling of various thermodynamic variables near the chiral transition in a model of QCD was studied. Extraction of the universal scaling behaviour for these required a careful subtraction of the non-universal contribution to the free energy. This is similar to the superfluid transition of liquid Helium where the specific heat is finite at the critical point, but has a cusp. From this follows an interesting mixture of universal and non-universal features at the critical point. Through the CP symmetry of chiral QCD, this has implications for the fourth order baryon number susceptibility and susceptibilities of higher orders. The investigation of such a scaling is expected to show us whether $O(4)$ scaling is an accurate description of baryon-free QCD when the pion mass is realistic. [Sourendu Gupta and Rishi Sharma]

Excited-state Spectroscopy of Doubly Charmed Baryons from Lattice QCD

The ground and excited state spectra of doubly charmed baryons from lattice QCD with dynamical quark fields were presented. Calculations were performed on anisotropic lattices of size $16^3 \times 128$, with inverse spacing in temporal direction $1/a_t = 5.67(4)$ GeV and with a pion mass of about 390 MeV. A large set of baryonic operators that respect the symmetries of the lattice yet which retain a memory of their continuum analogues were used. These operators transform as irreducible representations of $SU(3)$ symmetry for flavor, $SU(4)$ symmetry for Dirac spins of quarks and $O(3)$ for spatial symmetry. The distillation method was utilized to generate baryon correlation functions which were analysed using the variational fitting method to extract excited states. The lattice spectra obtained had baryonic states with well-defined total spins up to $7/2$ and the pattern of low lying states did not support the diquark picture for doubly charmed baryons. On the contrary, the calculated spectra were remarkably similar to the expectations from models with an $SU(6) \times O(3)$ symmetry. Various spin dependent energy splittings between the extracted states were also evaluated. The mass splitting between B_c^*, which is yet to be discovered, and B_c meson was predicted to be about 80 ± 8 MeV. This may help in future discovery of B_c^* meson.
[Nilmani Mathur with R. Edwards (Jefferson Lab), M. Padmanath (University of Graz), M. Peardon (Trinity College, Dublin)]

Higgs Boson Decay Constraints on a Model with a Universal Extra Dimension

The impact of the latest available data on Higgs boson branching ratios on the minimal model with a universal extra dimension was investigated. Combining constraints from vacuum stability requirements – which restrict the cutoff of the theory – with these branching ratio measurements, realistic predictions for the signal strengths in this model could be made. These were compared

with data to find a lower bound of 1.3 TeV on the size parameter $1/R$ of the model at 95% confidence level – which is far more stringent than any other terrestrial bound obtained till now and is compatible with the dark matter constraints from the WMAP data.
[Sreerup Raychaudhuri with A. Datta (University of Calcutta) and A. Patra (Oklahoma State University)].

Anomalous Triple Gauge Vertices at the Large Hadron-Electron Collider

At a high energy ep collider, such as the Large Hadron-Electron Collider (LHeC) which is being planned at CERN, one can access the WW vertex exclusively in charged current events with a radiated photon, with no interference from the WWZ vertex. It was found that the azimuthal angle between the jet and the missing momentum in each charged current event is a sensitive probe of anomalous WW couplings. For quite reasonable values of integrated luminosity, the LHeC can extend the discovery reach for these couplings beyond all present experimental bounds.
[Sreerup Raychaudhuri with S. S. Biswal (Ravenshaw University) and M. Patra (University of Zurich)].

On Statistical Aspects of QJets

Jets arise in many important scattering processes encountered at the LHC. Therefore, much experimental and theoretical effort has recently gone into creating better tools for handling them. A new technique "Qjets", was invented to identify jets arising from the decay of boosted heavy particles as opposed to those arising from QCD, motivated by the observation that as jets are produced through a stochastic process there is an inherent ambiguity in their reconstruction. The Qjets procedure accounted for this ambiguity by considering many reconstructions of a jet at once, allowing one to assign a weight to each interpretation of the jet. Employing these weighted interpretations led to an improvement in the statistical stability of many measurements. The foundation for understanding the statistical properties of these sets of weighted measurements were laid down. It was also demonstrated how this method can be used to improve the reach of jet-based studies.
[Tuhin S. Roy with S. D. Ellis (University of Washington), A. Hornig (LANL), and D. Krohn (Harvard University)]

Generalized Supersoft Supersymmetry

A new framework of weak scale supersymmetry (namely, Generalized Supersoft Supersymmetry or GSS) was proposed as an alternative to the well studied framework of the Minimal Supersymmetric Standard Model or the MSSM. Models in GSS with D-type supersymmetry breaking and heavy

Dirac gauginos, are considerably less constrained by the LHC searches than the MSSM. These models also ameliorate the supersymmetric flavor and CP problems that plague MSSM. In previously considered models of D-type supersymmetry breaking, obtaining a natural size Higgsino mass parameter (namely, μ) was relatively complicated and contrived. Obtaining a 125 GeV for the mass of the lightest Higgs boson was also difficult. Additional issues arose from the fact that these models contained new scalars in the adjoint representation of the standard model, which might obtain negative squared-masses, breaking colour and generating too large a T-parameter. In GSS all these issues were solved, resulting in a viable and "natural" framework of weak scale supersymmetry, which arose from well-motivated microscopic theories.
[Tuhin S. Roy with A. E. Nelson (University of Washington)]

Neutrino-pair bremsstrahlung from nucleon-α versus nucleon-nucleon scattering

The impact of the nucleon-α P-wave resonances on neutrino-pair bremsstrahlung was studied. Because of the non-central spin-orbit interaction, it was found that these resonances lead to an enhanced contribution to the nucleon spin structure factor for temperatures $T \lesssim 4$ MeV. If the α-particle fraction is significant and the temperature is in this range, this contribution is competitive with neutron-neutron bremsstrahlung. It was proposed that this effect may be relevant for neutrino production in core-collapse supernovae or other dense astrophysical environments.
[Rishi Sharma with S. Bacca (TRIUMF & Manitoba University), and A. Schwenk (Darmstadt, Tech. Hochsch. & Darmstadt, EMMI)]

Bulk RS models, Electroweak Precision Tests and 125 GeV Higgs

The variants of the original Randall-Sundrum model with SM particles in the bulk and the Higgs on and off the TeV brane were considered in the light of a global fit to electroweak precision data. This analysis was done with taking the measured mass of the Higgs boson into account, and the impact of this information on the global fits was studied. The introduction of a custodial symmetry or a deformed metric helped lower the Kaluza-Klein particle masses and the fits had also been done by taking these into account. The results for the case of the deformed metric are novel and striking suggesting that the lowest Kaluza Klein excitation is in the 1.5 TeV mass range.
[K. Sridhar and A. M. Iyer, with S. K. Vempati (IISC)]

Probing the NMSSM via Higgs signatures from stop cascade decays at the LHC

Higgs signatures from the cascade decays of light stops are an interesting possibility in the next to minimal supersymmetric standard model (NMSSM). The potential reach of the light stop mass at

the 13 TeV run of the LHC was studied by means of five NMSSM benchmark points where this signature is dominant. These benchmark points were compatible with Higgs coupling measurements at the LHC, dark matter relic density and direct detection constraints. Single and di-lepton search strategies, as well as the jet-substructure technique to reconstruct the Higgs bosons were considered. It was found that one can probe stop masses up to 1.2 TeV with 300 fb^{-1} luminosity via the di-lepton channel, while with the jet-substructure method, stop masses up to 1 TeV can be probed with 300 fb^{-1} luminosity. The possibility of the appearance of multiple Higgs peaks over the background in the fat-jet mass distribution was also studied. It was concluded that such a possibility is viable only at the high luminosity run of 13 TeV LHC.
[A. Chakraborty with D. K. Ghosh, S. Mondal, S. Poddar, and D. Sengupta (IACS)]

Gravitational Rescue of Minimal Gauge Mediation

Gravity mediation supersymmetry breaking become comparable to gauge mediated supersymmetry breaking contributions when messenger masses are close to the GUT scale. By suitably tuning the gravity contributions one can then modify the soft supersymmetry breaking sector to generate a large stop mixing parameter and a light higgs mass of 125 GeV. In this kind of hybrid models, however the nice features of gauge mediation like flavour conservation etc, are lost. To preserve the nice features, gravitational contributions should become important for lighter messenger masses and should be important only for certain fields. This is possible when the hidden sector contains multiple (at least two) spurions with hierarchical vaccum expectation values. In this case, the gravitational contributions can be organised to be 'just right'. A complete model with two spurion hidden sector was presented where the gravitational contribution was from a warped flavour model in a Randall-Sundrum setting. Along the way, simple expressions were derived in order to handle renormalisation group equations when supersymmetry is broken by two different sectors at two different scales.
[A. M. Iyer, with V. S. Mummidi and S. K. Vempati (IISC)]

Quark Number Susceptibility in QCD Inspired Effective Models : Revisited with Fluctuation-dissipation Theorem

Quark Number Susceptibility (QNS) is routinely calculated in mean field models either through direct numerical differentiation of pressure with respect to chemical potential or as Taylor coefficients by expanding pressure as a function of chemical potential. On the other hand, according to the fluctuation-dissipation theorem (FDT), the QNS may also be obtained from the time-time component of the current-current correlator in the vector channel. It was shown that the temporal vector correlator associated with the fluctuations is modified due to the effective interaction in these model Lagrangians. This proves that the inclusion of implicit dependent terms through the mean

fields are not ad-hoc but actually consistent with the field theoretic point of view and consolidates FDT.

[A. Lahiri with S. K. Ghosh (Bose Institute), S. Majumder, M. G. Mustafa (SINP), S. Raha, and Ray (Bose Institute)]