DTP Annual report 2013-2014

A. High energy physics

1. Particle production in relativistic heavy-ion collisions: A consistent hydrodynamic approach

Relativistic viscous hydrodynamic equations were derived by invoking the generalized second law of thermodynamics for two different forms of the non-equilibrium single-particle distribution function. Relaxation times in these two derivations were found to be identical for shear viscosity but different for bulk viscosity. These equations were used to study thermal dilepton and hadron spectra within longitudinal scaling expansion of the matter formed in relativistic heavy-ion collisions. For consistency, the same non-equilibrium distribution function was used in the particle production prescription as in the derivation of the viscous evolution equations. Appreciable differences were found in the particle production rates corresponding to the two non-equilibrium distribution functions. It was emphasized that an inconsistent treatment of the non-equilibrium effects influences the particle production significantly, which may affect the extraction of transport properties of quark-gluon plasma. [R.S. Bhalerao, A. Jaiswal, S. Pal, and V. Sreekanth]

2. Event-plane correlators

Correlators between event planes of different harmonics in relativistic heavy-ion collisions have the potential to provide crucial information on the initial state of the matter formed in these collisions. A new procedure for analyzing such correlators was presented. It is less demanding in terms of detector acceptance than the one used recently by the ATLAS collaboration to measure various two-plane and three-plane correlators in Pb-Pb collisions at LHC. It can also be used unambiguously for quantitative comparison between theory and data. This procedure was used to carry out realistic simulations within the transport model AMPT. Our theoretical results were in excellent agreement with the ATLAS data, in contrast with previous hydrodynamic calculations which only achieved qualitative agreement. Predictions were made for new correlators, in particular four-plane correlators, which can easily be analyzed with our new method. [R.S. Bhalerao, J.-Y. Ollitrault (IPhT, Saclay), and S. Pal]

3. The critical point in QCD phase diagram

The QCD phase diagram is expected to have a critical point in the temperature(T) baryon chemical potential ($_B$) plane. We used the method of radius of convergence of the Taylor series of baryon susceptibility, developed earlier in TIFR, and looked at fine lattices to estimate the continuum limit of the critical point. [with R. Gavai and S. Gupta]

4. Bottomonia in quark-gluon plasma

Quarkonia have constituted a very important probe of 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. I have studied behavior of bottomonia in equilibrated gluon plasma, by studying the thermal correlators, and comparison of the Matsubara and screening correlators.

5. Hadron energy response of the ICAL detector at INO

Interactions of atmospheric neutrinos in the iron calorimeter detector, to be constructed at INO, were simulated using a GEANT4 modeling of the detector. The detector response to hadrons propagating through it was investigated using the hadron hit multiplicity in the active detector elements. It was found that the shape of the hit multiplicity curve fits the Vavilov distribution. In terms of the Vavilov parameters, the calibration of hadron energy as a function of the hit multiplicity, and the hadron energy resolution as a function of hadron energy, were determined. It was shown that decreasing the iron plate thickness would not give any significant improvement in the hadron energy resolution. [A. Dighe and M. M. Devi, with A. Ghosh, S. Choubey (HRI), L. S. Mohan, D. Indumathi, M. V. N. Murthy (IMSc), D. Kaur, S. Kumar, M. Naimuddin (Delhi U.)]

6. Non-universality of indirect CP asymmetries in $D \to \pi\pi, KK$ decays

It was pointed out that, if the direct CP asymmetries in the $D \to \pi\pi$ and $D \to KK$ decays are unequal, the indirect CP asymmetries as measured in these modes are necessarily unequal. This non-universality of indirect CP asymmetries can be significant with the right amount of new physics contribution, a scenario that may be fine-tuned, but still viable. A model-independent fit to the current data allows different indirect CP asymmetries in the above two decays. This could even be contributing to the apparent tension between the difference CP asymmetries $\Delta A_{\rm CP}$ measured through the pion-tagged and muon-tagged data samples at the LHCb. [A. Dighe, D. Ghosh and B. Kodrani]

7. Supersymmetry search at the LHC

Supersymmetry search at the LHC: Since the Higgs boson discovery, the major focus of supersymmetry studies at the LHC has been the search for light stops. A combination of all direct and indirect constraints coming from experiment was imposed on (a) the constrained minimal supersymmetric Standard Model (cMSSM) and (b) the non-universal Higgs model (NUHM), together with the requirement of a light stop which would be discoverable at the LHC. Large parts of the parameter space of these models are ruled out thereby, but it was found that there remain enough points to make the stop search at the LHC viable, even if we impose the constraints from the Higgs boson branching ratios. [A. Dighe, D. Ghosh, K.M. Patel and S. Raychaudhuri]

8. Curing Divergences in Quark Number Susceptibility

Thermodynamics of a system with conserved charges, such as baryon or quark number, is obtained from first principles by introducing a term linear in the corresponding chemical potential, μ_B. A space-time lattice formulation, needed for computations relevant to relativistic heavy-ion collision experiments, showed presence of a quadratic divergence in the cut-off in the quark number susceptibility. It has been thought that this is a deficiency of the lattice formalism and therefore needs to be handled by suitably exploiting the freedom of modifying the linear term to an exponential in μ_B. It was shown that contrary to the textbook descriptions, the divergence is present in the continuum theory as well, and is merely faithfully represented in the lattice approach. Further, it was proposed to subtract it from the interacting quark-gluon theory (Quantum Chromodynamics) contributions. The divergences were demonstrated to be absent in this subtraction scheme by removing the cut-off. It was demonstrated to be computationally also a lot more efficient method. [Rajiv V. Gavai and Sayantan Sharma (University of Bielefeld)]

9. Strange Freezeout

It was argued that known systematics of hadron cross sections may cause different particles to freeze out of the fireball produced in heavy-ion collisions at different times. It was found that a simple model with two freezeout points is a better description of data than that with a single freezeout, while still remaining predictive. The resulting fits seem to present constraints on the late stage evolution of the fireball, including the tantalizing possibility that the QCD chiral transition influences the yields at $\sqrt{S}$=2700 GeV and the QCD critical point those at $\sqrt{S}$=17.3 GeV. [Work done in collaboration with Sandeep Chatterjee and Rohini Godbole of IISc, Bengaluru]

10. Fractal Structure of near-Threshold Quarkonium Production off Cold Nuclear Matter

Near-threshold production of quarkonium resonances in cold nuclear matter was investigated through a scaling theory with two exponents which are fixed by existing data on near-threshold J/psi production in proton-nucleus collisions. Interestingly, it seems possible to extend one of the multifractal dimensions to the production of other mesons in cold nuclear matter. The scaling theory can be tested and refined in experiments at the upcoming high-intensity FAIR accelerator complex in GSI. [Work done in collaboration with Partha Pratim Bhaduri of VECC, Kolkata].

11. On the thermalization of quarkonia at the LHC

Collisions of Pb ions at the Large Hadron Collider has provided us with rich data on the yields of the ground states of charmonia and bottomonia. In particular, we noted that the relative yields of $\Upsilon(3S)$, $\Upsilon(2S)$ and $\Upsilon(1S)$ mesons allows an extraction of a freezeout temperature of bottomonia in PbPb collisions, $T_f = 222^{+28}_{-29}$MeV. This suggests a very simple model for the evolution of bottomonia states through the QGP, which only requires that the transition rates between the states be rapid enough that they can come to equilibrium with the ambient thermal medium for a part of its existence. We analyzed the systematics of the bottomonium freezout temperature as a function of the centrality of the collisions. [Sourendu Gupta and Rishi Sharma]

12. Kaon mixing beyond the Standard Model

Kaon mixing is a CP-violating and FCNC process important for constraining both Standard Model (SM) and Beyond Standard Model (BSM) physics. Connecting theory models to the phenomenology of kaon mixing requires knowledge of hadronic matrix elements of four-quark operators between kaon states. Although the single required SM matrix element B_K has been subject to intensive study and is known to few-percent precision (or better), the 7 additional matrix elements required for full parameterization of generic BSM scenarios are less well-known. We computed and renormalized these matrix elements on an ensemble with inverse lattice spacing $a^{-1} \approx 1.75$ GeV, extending earlier results obtained on an ensemble with $a^{-1} \approx 2.31$ GeV. [A. Lytle, with P. Boyle, N. Garron, R. Hudspith, and C. Sachrajda]

13. Non-perturbative renormalization for improved staggered bilinears

The leading source of uncertainty in ongoing lattice calculations of B_K using staggered fermions comes from perturbative truncation of lattice to continuum matching factors. Non-perturbative determinations of these factors which avoids truncation uncertainty are therefore desirable. We performed a detailed study of general bilinear matching factors computed non-perturbatively in the RI scheme, and compared the results to those obtained in perturbation theory. This calculation is a stepping stone to the determination of matching factors of four-quark operators needed for B_K. [A. Lytle, with S. Sharpe]

14. Hadron spectra from overlap fermions on HISQ gauge configurations

There has recently been a resurgence of interest in heavy hadron spectroscopy, with the discovery of numerous hadrons with one or more heavy quarks. Results from the LHC and charm-bottom factories are expected to add to the excitement in this field in the near future. Direct lattice calculations involving heavy hadrons are challenging since the condition $am \ll 1$ is not generally satisfied. We reported on studies of the overlap action in the regime $am \lesssim 1$ using 2+1+1 flavor HISQ gauge configurations generated by the MILC collaboration, presenting preliminary results for charm spectra and strange spectra as well as leptonic decay constants D_s and D_s^*. We found encouraging results which suggest overlap valence on 2+1+1 flavor HISQ configurations is a promising formulation for lattice simulations involving light, strange, and charm quarks. The hadron masses were calculated on lattices of spatial size 3 fm and lattice spacings 0.12, 0.09 and 0.06 fm. [S. Basak (NISER), S. Datta, A.T. Lytle, M. Padmanath, P. Majumdar (IACS, Kolkata) and N. Mathur]

15. Excited-state spectroscopy of singly, doubly and triply-charmed baryons from lattice QCD

Energy spectra of the singly, doubly and triply charmed baryons were calculated for the first time using lattice QCD. A large set of baryonic operators that respect the symmetries of the lattice and are obtained after subduction from their continuum analogues were utilized. Using novel computational techniques correlation functions of these operators were generated and the variational method exploited to extract excited states. The spectra obtained have baryonic states with well-defined total spin up to 7/2 Fig. 1 and the low-lying states closely resemble the expectation from models with an SU(6) $\times$ O(3) symmetry. Various energy splittings between the extracted states, including splittings due to hyperfine as well as spin-orbit coupling, were considered and those were also compared against similar energy splittings at other quark masses. Using those splittings for doubly-charmed baryons we predicted the

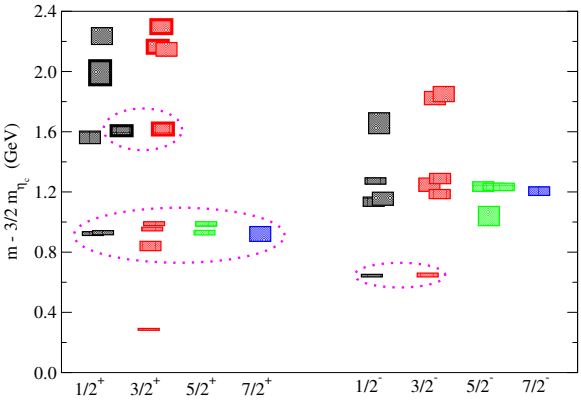

FIG. 1. Triply charmed baryons

mass splittings of $B_c^* - B_c$ to be about 80 ± 8 MeV, and furthermore, taking input of experimental B_c meson mass we predict mass of yet unknown $\Omega_{ccb} = 8050 \pm 10$ MeV. [M. Padmanath, R. Edwards (Jefferson Lab), N. Mathur and M. Peardon (Trinity College, Dublin)]

16. A Lattice Study of Quark and Glue Momenta and Angular Momenta in the Nucleon

We carried out a detailed calculation of the quark and glue momenta and angular momenta in the proton. These include the quark contributions from both the connected and disconnected insertions. The quark disconnected insertion loops were computed with Z_4noise, and the signal-to-noise was improved with unbiased subtractions. The glue operator is comprised of gauge-field tensors constructed from the overlap operator. The chirally extrapolated u and d quark momentum/angular momentum fraction was found to be 0.64(5)/0.70(5), the strange momentum/angular momentum fraction, 0.023(6)/0.022(7), and that of the glue, 0.33(6)/0.28(8). The previous study of quark spin on the same lattice revealed that it carries a fraction of 0.25(12) of proton spin. The orbital angular momenta of the quarks were then obtained from subtracting the spin from their corresponding angular momentum components. We found that the quark orbital angular momentum constitutes 0.47(13) of the proton spin with almost all of it coming from the disconnected insertions [N. Mathur with χ-QCD collaboration].

17. Noise reduction algorithm for Glueball correlators

Besides the usual mesons and baryons the theory of strong interaction also predicts states made of gluons, called glueballs. However, due to noisy gluon field operators the signal to noise ratio for glueballs in lattice QCD calculations are rather poor. We presented an error reduction method for obtaining glueball correlators from Monte Carlo simulations of SU(3) lattice gauge theory. We explored the scalar and tensor channels at three different lattice spacings. Using this method we can follow glueball correlators to temporal separations even up to 1 fermi. This is a significant improvement over existing methods for the signal to noise ratio in glueball correlators. This method will be followed up with a aim to predict glueball states precisely. [Pushan Majumdar (IACS, Kolkata), Nilmani Mathur and Sourabh Mandal (IACS, Kolkata)].

18. Invisible decays of low mass Higgs bosons in supersymmetric models

The discovery of a 126 GeV Higgs like scalar at the LHC along with the non observation of the supersymmetric particles, has in turn lead to constraining various supersymmetric models through the Higgs data. We considered the case of both MSSM, as well its extension containing an additional chiral singlet superfield, NMSSM. We concentrated on the case where we can identify the second lightest Higgs boson as the 126 GeV state discovered at the CERN LHC and consider the invisible decays of the low mass Higgs bosons in both MSSM and NMSSM. The invisible Higgs branching ratio being constrained by the LHC results, we found that in this case with the second lightest Higgs being the 126 GeV state, more data from the LHC is required to constrain the neutralino parameter space, compared to

the case when the lightest Higgs boson is the 126 GeV state [Monalisa Patra with P.N. Pandita (North Eastern Hill University, Shillong)]

19. 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, the $WW\gamma$ vertex can be accessed exclusively in charged current events with a radiated photon, with no interference from the WWZ vertex. We found that the azimuthal angle between the jet and the missing momentum in each charged current event is a sensitive probe of anomalous $WW\gamma$ couplings, and that for quite reasonable values of integrated luminosity, the LHeC can extend the discovery reach for these couplings beyond all present experimental bounds. [Monalisa Patra, Sreerup Raychaudhuri with Sudhansu S. Biswal (College of Basic Sciences, Orissa University of Agriculture and Technology)]

20. New Physics in $e^+ + e \to Z\gamma$ at the ILC with polarized beams: Explorations beyond conventional anomalous triple gauge boson coupling (M. Patra)

One of the most-studied signals for physics beyond the standard model in the production of gauge bosons in electron-positron collisions is that due to the anomalous triple gauge boson couplings in the $Z\gamma$ final state. The implications of this was studied for a 800GeV International Linear Collider, with polarized beams for signals that go beyond traditional anomalous triple neutral gauge boson couplings. It was found that a dimension-8 CP-conserving $Z\gamma Z$ vertex exists that has not mentioned in the literature. Added to that a correspondence between the triple gauge boson couplings and the four-point BSM contact interactions was established and the sensitivities on these anomalous couplings obtained with realistic polarization and luminosity. [Monalisa Patra with B. Ananthanarayan, Jayita Lahiri (Bangalore, Indian Institute of Science) and Saurabh D. Rindani (Ahmedabad, Physical Research Laboratory)]

21. Distinguishing Signatures of top-and bottom-type heavy vectorlike quarks at the LHC

An SU(2) vectorlike singlet quark with a charge either +2/3 (t') or -1/3 (b') is predicted in many extensions of the Standard Model. The mixing of these quarks with the top or bottom lead to Flavor Changing Yukawa Interactions and Neutral Current. The decay modes of the heavier mass eigenstates are therefore different from the Standard Model type chiral quarks. The Large Hadron Collider (LHC) will provide an ideal environment to look for the signals of these exotic quarks. Considering all decays, including those involving Z- and Yukawa interactions, we showed how one can distinguish between t' and b' from ratios of event rates with different lepton multiplicities. We also saw that the ability to reconstruct the Higgs boson with a mass around 125.5 GeV plays an important role in such differentiation. [Monalisa Patra with Aarti Girdhar (Ambedkar, Nat. Inst. Technol. and Harish-Chandra Res. Inst.) and Biswarup Mukhopadhyaya (Harish-Chandra Res. Inst.)]