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ABSTRACT BOOK

PARALLEL SESSION C

Strangeness of the nucleon from lattice QCD

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We present lattice QCD results concerning the light and strange quark content of the Nucleon (see Ref .[1]). The strangeness of the nucleon is an important source of uncertainty in the computation of the cross section between dark matter and ordinary nuclear matter. The direct computation of the corresponding matrix elements is known to be challenging, in particular because singlet quantities are very noisy on the lattice. Using an improved method, we obtain accurate results for the light and strange quark content.

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Baryon wave functions from lattice QCD

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I describe an ongoing project by the QCDSF collaboration to calculate baryon wave functions at small inter-quark separation using lattice QCD. Preliminary results are presented for the wave functions at the origin and momentum fractions carried by the valence quarks in the nucleon and its negative parity partner, $N^*(1535)$. The calculations are done using two flavors of dynamical (clover) fermions on lattices of different volume and pion masses down to $m_\pi \simeq 170$ MeV.

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Renormalization of operators for excited-state hadrons in lattice QCD

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One of the primary aims of lattice QCD is to compute accurately the spectrum of hadronic excitations from first principles. However, obtaining an accurate resolution of excited states using methods of lattice QCD is not a trivial problem due to faster decay of excited-states correlation functions in Euclidean space in comparison with those of ground states. To overcome this difficulty, anisotropic lattices with a finer temporal discretization are used.

To go beyond the spectrum, in order to study the properties of the states, one needs to compute corresponding matrix elements. Thus, for example, the quark distribution amplitudes in mesons are given by matrix elements of quark bilinear operators, while in baryons, the corresponding quark distribution amplitudes are related to matrix elements of three-quark operators. However, to relate the matrix elements calculated on the lattice to those in the continuum, and hence measured experimentally, it is necessary to evaluate matching coefficients. In this work, we calculate the matching coefficients using perturbation theory for the improved anisotropic-clover fermion action used for our studies of excited states.

The H-dibaryon in Lattice QCD

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With the advent of powerful massive parallel computers and the improvement of computational algorithms, the last five years have witnessed an impressive progress in dynamical Lattice QCD simulations of the interactions between baryons. Among these, a remarkable impact in the nuclear physics community has been achieved by recent calculations of two-baryon binding energies in the strange sector, in particular, in the channel where the H-dibaryon would appear. The NPLQCD collaboration [1] performed simulations at different lattice volumes, allowing for an infinite volume extrapolation of the H binding energy, although at unphysical values of the light quark masses [2]. Simultaneously, independent simulations performed by the HAL QCD collaboration in the SU(3) limit, also found a bound state in this particular channel [3]. The most recent result for the binding energy of the I=0, J = 0 *uuddss* state, as quoted by NPLQCD in Ref. [4], is $B^{(\infty)} = 13.2(1.8)(4.0)$ MeV, obtained with a pion mass of 389 MeV.

The aim of the talk is to present the results generated by the NPLQCD collaboration for the H-dibaryon system, along with the formalism and analysis techniques used. I will also discuss different chiral extrapolations in the light-quark masses of the lattice results [5, 6].

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Three particles in a finite volume

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The nature of the Roper resonance $N(1440)$ has been an open question for decades. It is quite unnatural – at least, from the point of view of the quark models – that its mass turns out to be lower than that of the negative-parity ground state $N(1535)$. Up to now, numerous calculations of the excited spectrum of the nucleon, see e.g., [2, 3, 4] have not resolved the issue. The Roper is a resonance and not a stable state which would correspond to an isolated energy level in lattice simulations. This, in particular, means that the energy levels measured on the lattice will be volume-dependent and the true resonance pole position should be extracted from the volume-dependent spectrum.

The case of the elastic low-lying resonances on the lattice has been adressed in detail in the literature. Namely, the Lüscher formula [5] enables one to uniquely relate the discrete energy levels in a finite box to the elastic scattering phase shift in the infinite volume, measured at the same energy. This eventually opens the way for the extraction of the parameters of the elastic resonances – their masses and widths – in the lattice QCD.

The case of the inelastic resonances, however, is more complicated. The Roper resonance, for example, has a significant decay rate into the three and more particle final states. *A priori,* one may expect significant finite-volume effects in this decay, which can not be evaluated by using the standard Lüscher approach. Hence, it is highly desirable to construct a framework that will allow one to systematically calculate the finite-volume effects, coming from the tree-body final states.

In this talk, we present a generalized version of the Lüscher formula, which includes three-particle inelastic channels, see also [1]. Our approach is formulated within the non-relativistic potential scattering theory. The Faddeev equations in a finite volume are derived. We also prove that, even in the presence of the three-particle intermediate states, the discrete spectrum in a finite box is determined by the infinite-volume elements of the scattering S-matrix up to corrections, exponentially suppressed at large volumes.

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Lattice QCD at the CSSM

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A review is presented of some of the QCD research being undertaken by the CSSM Lattice collaboration. The CSSM is investigating a variety of hadronic physics, including baryonic resonance spectroscopy and background magnetic field studies. Using correlation matrix analysis techniques we isolate candidate states for the Roper[1] and the $\Lambda(1405)$ [2] on the lattice. By applying a uniform background magnetic field we investigate the nucleon magnetic moment and polarisability. The shape of baryonic wave functions are also explored[3].

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Charmed Bottom Hadron Spectroscopy

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The arena of doubly and triply heavy hadrons remains experimentally unexplored to a large extent. This has led to a great deal of theoretical effort being put forth in the calculation of mass spectra in this sector. Although the detection of such heavy particle states may lie beyond the reach of experiments for some time, it is interesting to compare results between lattice QCD computations and continuum theoretical models. Several recent lattice QCD calculations exist for both doubly and triply charmed as well as doubly and triply bottom hadrons. In this work we present the first lattice calculation of the mass spectrum of doubly and triply heavy hadrons including both charm and bottom quarks. The wide range of quark masses in these systems require that the various flavors of quarks be treated with different lattice actions. We use domain wall fermions for 2+1 flavors (up down and strange) of sea and valence quarks, a relativistic heavy quark action for the charm quarks, and non-relativistic QCD for the heavier bottom quarks. The calculation of the ground state spectrum is presented and compared to current continuum calculations. A future outlook includes treating the bottom quarks as relativistic in addition to the charm.

Correlations and fluctuations of conserved charges from lattice QCD

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We present the full results of the Wuppertal-Budapest lattice QCD collaboration on flavor diagonal and non-diagonal quark number susceptibilities with 2+1 staggered quark flavors, in a temperature range between 125 and 400 MeV [1]. The light and strange quark masses are set to their physical values. Lattices with Nt=6, 8, 10, 12, 16 are used. We perform a continuum extrapolation of all observables under study. A Symanzik improved gauge and a stout-link improved staggered fermion action is utilized. All results are compared to the Hadron Resonance Gas model predictions: good agreement is found in the temperature region below the transition.

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Spontaneous electromagnetic superconductivity of QCDxQED vacuum in strong magnetic field

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We show that in a background of a very strong magnetic field a QCDxQED vacuum may turn into a new phase characterized by anisotropic electromagnetic superconductivity [1, 2]. The phase transition should take place at a critical magnetic field B_c of the hadronic strength ($eB_c \approx 0.6\,\mathrm{GeV}^2$, or, equivalently, $B_c \approx 10^{16}$ Tesla).

The physical mechanism of the exotic vacuum superconductivity is as follows: in strong magnetic field the dynamics of virtual quarks and antiquarks is effectively one-dimensional because these electrically charged particles tend to move along the lines of the magnetic field. In one spatial dimension a gluon-mediated attraction between a quark and an antiquark of different flavors inevitably leads to formation of a colorless spin-triplet bound state (a vector analogue of the Cooper pair) with quantum numbers of an electrically charged rho meson. Such quark-antiquark pairs condense to form an anisotropic inhomogeneous superconducting state similar to the Abrikosov vortex lattice in a type-II superconductor. The onset of the superconductivity of the charged rho mesons should also induce an inhomogeneous superfluidity of the neutral rho mesons.

The ground state of the superconducting phase is a complicated honeycomblike superposition of superconductor and superfluid vortex lattices surrounded by overlapping charged and neutral condensates [3]. The Meissner effect in this new ground state is absent because the superconductivity is realized only along the axis of the magnetic field. The vacuum superconductivity should survive at very high temperatures of typical Quantum Chromodynamics (QCD) scale of $10^{12}\,\mathrm{K}$, making it a "high-temperature" superconductor. We discuss similarities and differences between the superconducting state of vacuum and conventional superconductivity, and between the magnetic–field–induced vacuum superconductivity in QCDxQED and electric–field–induced Schwinger pair production in QED.

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Canonical Transformations in Gauge Theories with Non-Trivial Backgrounds

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An intriguing connection exists between the formulation of a gauge theory in the presence of a non-trivial background and canonical transformations w.r.t. the Batalin-Vilkovisky bracket associated with the Slavnov-Taylor identity of the model. The classical background-quantum splitting is non-trivially deformed at the quantum level by a field and antifield redefinition, generated by a canonical transformation.

The approach is valid both perturbatively and non-perturbatively, since it only relies on the functional symmetries of the theory. Thus it could pave the way for an algebraic strategy to the implementation of the Background Field Method on the lattice and in the non-perturbative approaches to QCD, based on the Schwinger-Dyson equations. As an application, we compute the renormalization group equation in the presence of a generic background in the case of a SU(2) instanton and explicitly calculate the one-loop deformation of the background-quantum splitting in lowest order in the instanton background.

Based on [1],[2].

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High precision measurement of the form factors of the semileptonic decays $K^{\pm} \to \pi^0 l^{\pm} \nu$ (Kl3)

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Semileptonic kaon decays offer the most precise determination of the CKM matrix element —Vus—. The experimental precision is however limited by the knowledge of the form factors of this decay, since these enter both the phase space integral and the detector acceptances. The NA48/2 experiment presents new measurements of the form factors of the semileptonic decays of charged kaons, based on 4.3 million Ke3 and 3.5 million Kmu3 decays, both with negligible background. The result matches the precision of the current world average on the vector and scalar form factors and allows to significantly reduce the form factor uncertainty on —Vus—. In addition, the comparison of both channels sets tight constraints on lepton flavor violation and other possible new physics.

Baryon properties from the covariant Faddeev equation

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We show results on vector-meson, nucleon and delta/omega-baryon masses and form factors and their evolution with the current-quark mass using a covariant generalized Bethe-Salpeter equation approach, as an extension of the results showed in [1, 2, 3]. The interaction kernel is truncated to a dressed gluon exchange. We study the model dependence of our results with the quark-gluon dressing to assess the validity of the truncation.

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A light-front coupled-cluster method for quantum field theories

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The Hamiltonian eigenvalue problem for bound states of a quantum field theory is formulated in terms of Dirac's light-front coordinates [1, 2] and then approximated by the exponential-operator technique of the standard coupled-cluster method [3, 4]. This approximation [5] eliminates any need for the usual approximation of Fock-space truncation. Instead, the exponential operator is truncated and the terms retained are determined by a set of nonlinear integral equations. These equations are solved simultaneously with an effective eigenvalue problem in the valence sector, where the number of constituents is small. Matrix elements can be calculated, with extensions of techniques from standard coupled-cluster theory.

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Relevance of glueball bound states in the Yang Mills plasma within a many-body T-matrix approach

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The strongly coupled phase of Yang-Mills plasma with gauge group $SU(N)$ is studied in a T-matrix approach. The existence of lowest-lying glueballs, interpreted as color singlet bound states of two transverse gluons (quasi-particles in the many-body setup), is analyzed in a non-perturbative scattering formalism with the input of lattice-QCD evaluated static potentials. The relevance of the colored symmetric and antisymmetric octet channels at finite temperature is also discussed. The equation of state of the system is computed for several gauge groups and compared to pure gauge lattice data [1, 2, 3].

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Size matters - Nonlinear effects in the Glasma evolution

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The evolution of quantum fluctuations in the 'glasma', created immediately after the collision of heavy nuclei, is of great importance for the early time dynamics in relativistic heavy ion collisions [1]. In this talk we focus on the impact of boost non-invariant fluctuations which exhibit exponential amplification due to the presence of plasma instabilities [2, 3]. We present a detailed numerical study of this unstable regime along with analytical considerations. We find that the presence of plasma instabilities leads to an enhancement of non-linear interactions among initially small fluctuations on compartively short time scales. These non-linear interactions give rise to an enhanced growth of fluctuations in a large momentum region, which exceeds by far the originally unstable band such that non-linear amplification is parametrically as important as the primary instability. While this phenomenon is well known for scalar quantum field theories [4, 5], we present an analytical discussion of these non-linear effects in a non-abelian gauge theory within the framework of two-particle irreducible (2PI) effective action techniques. We demonstrate that the dependence on the strong coupling constant α_S is only logarithmic in accordance with results from classical statistical lattice simulations. We comment briefly on the impact on bulk obervables and possible implications for different thermalization scenarios [6, 7].

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Holographic Pomeron and the Schwinger Mechanism

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We revisit the problem of dipole-dipole scattering via exchanges of soft Pomerons in the context of holographic QCD with confinement [1, 2]. In the confined Euclidean background geometry [3], most part of string worldsheet stays at the infrared (IR) end point in the holographic direction, so that the problem effectively reduces to the flat space one with an effective string tension at the IR end point. We show that a single closed string exchange contribution to the eikonalized dipole-dipole scattering amplitude yields a Regge behavior of the elastic amplitude, and calculate the corresponding slope and intercept. We provide a physical interpretation of the semi-classical worldsheets driving the Regge behavior for $(-t) > 0$ in terms of worldsheet instantons [4]. The latter describe the Schwinger mechanism for string pair creation by an electric field, where the longitudinal electric field $E_L = \sigma_T \tanh(\chi/2)$ at the origin of this non-perturbative mechanism is induced by the relative rapidity χ of the scattering dipoles. Our analysis naturally explains the diffusion in the impact parameter space encoded in the Pomeron exchange. In our picture, it is due to the Unruh temperature of accelerated strings under the electric field. We also argue for the existence of a "micro-fireball" in the middle of the transverse space due to the soft Pomeron exchange, which may be at the origin of the thermal character of multiparticle production in ep/pp collisions. After summing over uncorrelated multi-Pomeron exchanges, we find that the total dipole-dipole cross section obeys the Froissart unitarity bound.

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Hadrons as Holograms

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Over the last years the gauge/string correspondence has begun to provide new insight into the infrared dynamics of hadrons. In this talk we present our recent work and results in this area. In particular, we discuss the emergence of universal Regge-type trajectories in dynamical gravity duals [1] and the holographic representation of multiquark correlations [2] in the light baryon [3] and scalar-meson sectors [4]. Moreover, we derive and analyze several hadron correlation function which provide detailed predictions and a challenging testing ground for both AdS/QCD and top-down gravity duals [5]. The results are confronted with QCD information from hadron spectroscopy, the lattice, the operator product expansion and low-energy theorems.

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Anomalous AVV* amplitudes in soft-wall AdS/QCD models

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I will present the study of the anomalous sector of QCD [1]. We analyzed the VVA Green's function in soft-wall holographic models. We also studied the relation proposed by Son and Yamamoto between the AVV* Green's function and the VV-AA correlator [2].

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Deeply Virtual Compton Scattering from Gauge/Gravity Duality

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We use gauge/gravity duality to study deeply virtual Compton scattering (DVCS) in the limit of high center of mass energy at fixed momentum transfer, corresponding to the limit of low Bjorken x, where the process is dominated by the exchange of the pomeron. Using conformal Regge theory we review the form of the amplitude for pomeron exchange, both at strong and weak 't Hooft coupling. At strong coupling, the pomeron is described as the graviton Regge trajectory in AdS space, with a hard wall to mimic confinement effects. This model agrees with HERA data in a large kinematical range. The behavior of the DVCS cross section for very high energies, inside saturation, can be explained by a simple AdS black disk model. In a restricted kinematical window, this model agrees with HERA data as well.

Refs. [1]

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Light-Front Holography – A New Approach to Non-Perturbative QCD

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Gauge/gravity duality leads to a simple, analytical, and phenomenologically compelling non-perturbative approximation to the full light-front QCD Hamiltonian. This approach, called "Light-Front Holography", successfully describes the spectroscopy of light-quark meson and baryons, their elastic and transition form factors, and other hadronic properties. The bound-state Schrödinger and Dirac equations of the soft-wall AdS/QCD model predict linear Regge trajectories which have the same slope in orbital angular momentum L and radial quantum number n for both mesons and baryons. Light-front holography connects the fifth-dimensional coordinate of AdS space z to an invariant impact separation variable ζ in $3+1$ space at fixed light-front time. A key feature is the determination of the frame-independent light-front wave-functions of hadrons – the relativistic analogs of the Schrödinger wavefunctions of atomic physics which allow one to compute form factors, transversity distributions, spin properties of the valence quarks, jet hadronization, and other hadronic observables. One thus obtains a one-parameter color-confining model for hadron physics at the amplitude level. AdS/QCD also predicts the form of the non-perturbative effective coupling $\alpha_s^{AdS}(Q)$ and its β-function with an infrared fixed point which agrees with the effective coupling $\alpha_{g_1}(Q^2)$ extracted from measurements of the Bjorken sum rule below $Q^2 < 1$ GeV^2. This is consistent with a flux-tube interpretation of QCD where soft gluons with virtualities $Q^2 < 1$ GeV^2 are sublimated into a color-confining potential for quarks. We discuss a number of phenomenological hadronic properties which support this picture.

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