EEF70

Workshop on Unquenched Hadron Spectroscopy:
Non-Perturbative Models and Methods of QCD vs. Experiment
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Book of Abstracts

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Speaker: **P. Alberto**

Title: *Pseudospin and spin symmetries in the Dirac equation for confining potentials with application to the Coulomb potential in* $1+1$ *dimensions*

In this paper, after revising the main features of pseudospin and spin symmetries of the Dirac equation with scalar S and vector V potentials, especially in case of confining potentials, we show some recent results in applying them to mean-field Coulomb potentials in 1+1 dimensions. We study both the cases where there are only scalar and vector potentials and when there is also a pseudoscalar potential, equivalent to a tensor potential in $3+1$ dimensions. The relations between the spin and pseudospin symmetry solutions, already described in previous papers through chiral and charge-conjugation transformations, are illustrated by comparing the $S=V$ and $S=-V$ solutions for this potential.

Speaker: **E. van Beveren**

Co-authors: G. Rupp, S. Coito

Title: *Unquenching weak substructure*

The unquenching approach of the Resonance Spectrum Expansion intends to make a clear connection between hypothetical quenched spectra for quark-antiquark systems and the observed resonances in two-particle amplitudes. However, the present poor status of experimental observation does not allow for detailed conclusions. Furthermore, the existence of dynamically generated resonances and threshold enhancements complicate even just the classification of the observed resonances and lead, moreover, to misidentifications. Several examples for strong and superstrong interactions are presented.

Speaker: **P. Bicudo**

Title: *Tetraquarks*

I briefly review tetraquarks with a personal perspective. I present the experimental candidates and paradigms for the stability of tetraquarks. The theoretical difficulties to model tetraquarks are highlighted.

Speaker: **A. Blin**

Co-author: N. Leite

Title: *Neutrinos and the average thermal evolution of the universe*

Starting after the end of inflation, we study the influence of neutrinos on the average evolution of the temperatures and densities of the main components in the standard cold dark matter (ΛCDM) universe. Concerning the dark components, we briefly discuss how dark energy can arise from conformal variations of the metric; dark matter is assumed to consist of neutralinos, usually assumed to be leading candidates for the lightest supersymmetric partners (LSP) and for WIMPs. The calculation can however be adapted to other dark matter candidates as well. Particle annihilation and decoupling processes and the transitions between eras dominated by the various components of the universe are considered, with particular attention to the difference due to the character of the neutrinos, Majorana or Dirac.

Speaker: **W. Broniowski**

Title: *Large-N_c Regge phenomenology*

The talk reviews some recent findings within the large-N_c Regge phenomenology concerning various form factors and features of the mesonic spectra.

Speaker: **T. Burns**

Title: *Meson mass splittings in unquenched quark models*

General results are obtained for meson mass splittings and mixings in unquenched (coupled-channel) quark models. The results are valid for all models in which the coupling between the valence and continuum channels is due to a non-flip, triplet operator, namely in which the initial quarks' spins are unchanged, and the created light quark-antiquark pair is coupled to spin triplet. This applies to the $^3P_0$ model, the flux tube model, the Cornell model, and, in the heavy quark limit, more general microscopic decay models. Loop theorems derived previously in perturbation theory, which apply in the limit that there are no spin splittings among the valence and continuum states, are generalised to the full coupled-channel system. The key results of the paper involve the more realistic calculation including the spin splittings among the valence and continuum states. Approximate formulae are obtained for the mass shifts of mesons below threshold due to their continuum coupling. These shifts induce spin-dependent splittings which renormalise the spin-spin, spin-orbit and tensor splittings of the valence spectra. The S-wave hyperfine splitting decreases, but its relation to the vector e^+e^- width is unchanged; this yields a prediction for the missing $\eta_b(3S)$. The ordinary (quenched) quark model result that the P-wave hyperfine splitting vanishes also survives unquenching. A ratio of P-wave mass splittings commonly used to infer the Lorentz structure of confinement is scarcely affected by unquenching.

Speaker: **M. Cardoso**

Co-author: P. Bicudo

Title: *A unitarised model for tetraquarks with a colour flip-flip potential*

In this work, a colour structure dependent flip-flop potential is developed for the two quarks and two antiquarks system. Then, this potential is applied to a microscopic quark model which, by integrating the internal degrees of freedom, is transformed into a model of mesons with non-local interactions. With this, the T matrix for the system is constructed and meson-meson scattering is studied. Tetraquarks states, interpreted as poles of of the T matrix, both bound states and resonances, are found. Special emphasis is given to the truly exotic $qq\bar{Q}\bar{Q}$ system, but some results for the crypto-exotic $qQ\bar{q}\bar{Q}$ are also presented.

Speaker: **M. Cardoso**

Co-authors: G. Rupp, E. van Beveren

Title: $X(3872)$ *electromagnetic decay in a coupled-channel model*

A multichannel Schrödinger equation with both quark-antiquark and meson-meson components, using a confining harmonic oscillator potential for the quark-antiquark states and

a delta-shell string-breaking potential, is applied to the $X(3872)$ and $c\bar{c}$ vector mesons. The model parameters are fitted to the experimental values of the masses of the $X(3872)$, J/ψ and $\psi(2S)$. The wave functions of these states are calculated and then used to calculate the electromagnetic decay widths of the $X(3872)$ into $J/\psi\gamma$ and $\psi(2S)\gamma$.

Speaker: **B. Golli**

Title: *Meson-cloud effects in nucleon resonances at low and intermediate energies*

The notion that the pion cloud plays an important role in the formation of nucleon resonances was first anticipated by João da Providência and João Urbano in 1978. We will review some most important results obtained by the Coimbra-Ljubljana collaboration (J. da Providência, M. Fiolhais, P. Alberto, and L. Amoreira; M. Rosina, S. Širca, and B. G.) studying nucleon resonances at low and intermediate energies in various quark models incorporating the pion cloud. In this research we have shown that the presence of a strong pion field in the nucleon and in the resonances manifests itself most clearly in the Q^2-behaviour of the electro-excitation amplitudes. For example, we have shown in one of our early works that the relatively strong contribution to the $E2$ amplitude for the $\Delta(1232)$ resonance almost entirely arises from the pion cloud. We have also been able to explain the intriguing zero-crossing of the $M1$ amplitude at $Q^2 \approx 0.5$ GeV^2 in the case of the Roper resonance as an interplay of the pion cloud contribution at low Q^2 and the quark contribution with the opposite sign at somewhat higher Q^2. I will further discuss higher P-, S- and D-wave resonances in a coupled-channel approach in which the effects of meson clouds involving higher-mass mesons are also included. We have found out that the eta-meson cloud strongly influences the properties of the lower $S11$ resonance, while the pion cloud has a more important contribution to the properties of the upper $S11$ resonance. In addition, the kaon cloud considerably influences the behaviour of the scattering and electro-production amplitudes above the Λ-K threshold. In the case of the D-wave resonances we have shown that the pion cloud provides almost equal strength to the $E1$ electro-excitation amplitudes of the lowest $D33$ resonances as the quark core. This strongly resembles the situation found for the $M1$ amplitude in the case of the $\Delta(1232)$ resonance. I will finally discuss the shift of the resonance positions with respect to the bare masses due to the meson self-energy as well as to the mixing of several channels. To conclude, I will critically examine the model dependence of the results and reliability of our conclusions.

Speaker: **A. Habersetzer**

Co-authors: D. Rischke, F. Giacosa

Title: *τ vector and axial-vector spectral functions in the extended linear σ model*

The extended Linear Sigma Model (eLSM) describes scalar, pseudoscalar, vector and axial-vector meson resonances, the glueball, and the tetraquark, as well as baryons, on the basis of a Lagrangian that is invariant under global chiral symmetry transformations and dilatation. In addition, for $N_F = 2$, we have now included the electroweak interaction on the basis of a local $SU(2)_L \times U(1)_Y$ symmetry. Thus we have all components available to compute the coherent amplitudes that yield the vector and axial-vector spectral functions of the weak τ decay with intermediate a_1 and ρ resonances. We find that within the framework of the eLSM the assumption that the ρ and a_1 meson resonances are quarkonia and chiral partners is valid. We will also see that the obtained weak spectral functions

give a nice illustration of Vector Meson Dominance in the weak sector of meson vacuum phenomenology.

Speaker: **B. Hiller**

Co-authors: A. A. Osipov, A. H. Blin

Title: *The three-flavour NJL Lagrangian with explicit symmetry-breaking interactions: scalar & pseudoscalar meson spectra and decays*

We extend the multi-interaction picture of an NJL-like Lagrangian to include all non-derivative interactions relevant at the scale of chiral symmetry breaking. In particular they include a whole set of current-quark-mass-dependent interactions which have the same N_c counting as the 't Hooft term. The impact on the spectra of the low-lying scalar and pseudoscalar mesons as well as their decays is discussed.

Speaker: **R. Kaminski**

Title: *What happened with the $f_0(500)/\sigma$ meson – theory and experiment*

The lightest scalar-isoscalar meson has recently been re-parametrized and became subject of a number of innovative works in QCD physics. After many years of problems with experimental determination of its parameters, this meson has been finally precisely described by means of theoretical dispersion relations with imposed crossing symmetry condition [1,2]. Fundamental importance of this meson for low-energy QCD opened up the possibility of, for example, constructive examination of its internal structure and study of delicate phenomena like CP violation via final strong pion-pion state interactions. Presented will be very interesting and spectacular rich history of this meson and of its almost rediscovery two years ago. Also proof of the uniqueness and correctness of the dispersion method used to obtain its parameters will be shown. Example of a successful application of this method in modification of coupled-channel $\pi\pi$, KK and $\eta\eta$ amplitudes fitted in past only to experimental data and not fulfilling crossing symmetry condition will be demonstrated. Several questions concerning the possibility of extending the dispersion method for study of low-energy QCD will be selected.

The described method and results, their uniqueness and precision should facilitate modification of often used incorrect $\pi\pi$ amplitudes. This should significantly increase the reliability of obtained results (e.g. in decays of heavy mesons) and accelerate research on other light mesons – candidates for being the lightest non-quark-antiquark states (e.g. $f_0(980)$ and $f_0(1500)$).

[1] R. Garcia-Martin, R. Kaminski, J. R. Pelaez, J. Ruiz de Elvira and F. J. Yndurain, *"The pion-pion scattering amplitude. IV: Improved analysis with once subtracted Roy-like equations up to 1100 MeV",* Phys. Rev. D **83**, 074004 (2011);
R. Garcia-Martin, R. Kaminski, J. R. Pelaez and J. Ruiz de Elvira, *"Precise determination of the $f_0(600)$ and $f_0(980)$ pole parameters from a dispersive data analysis",* Phys. Rev. Lett. **107**, 072001 (2011).

[2] I. Caprini, G. Colangelo and H. Leutwyler, *"Mass and width of the lowest resonance in QCD",* Phys. Rev. Lett. **96**, 132001 (2006).

Speaker: **K. Khemchandani**

Title: *Problems with meson spectroscopy involving perturbative loop corrections*

We study meson-meson scattering with a formalism which treats confined quark pairs and mesons on equal footing. Concretely, the interaction between the mesons proceeds through s-channel meson-exchange diagrams. Further, we develop a perturbative expansion of the model, and show that the resonance poles found in such a treatment, even by including contributions up to fourth order, do not coincide with those obtained with nonperturbative calculations. We show that the resonance predictions based on perturbative approximations in quark models are not reliable, especially in those cases where the coupling to the scattering channels is large.

Speaker: **F. Kleefeld**

Title: *Strong interactions with quarks and mesons – on unitarisation including bound states and non-Hermitian quantum theory*

Most recent theoretical ideas and developments allowing to set up a new standard model of particle physics based on quarks and mesons (and not on gluons) are presented. Key ingredients are the formalism of unitarisation including bound states strongly promoted by Everadus Johannes H. V. van Beveren and G. Rupp, and the presently developing formalism of non-Hermitian quantum theory promoted by the author allowing dynamical generation of constituent quark masses and asymptotic freedom without gluons.

Speaker: **C. Lang**

Title: *Hadron scattering from a lattice perspective*

Recent years have seen considerable progress in ab initio QCD calculations of hadron scattering threshold parameters and scattering phase shifts in the (elastic) resonance region. The lattice approach is becoming powerful enough to even predict states in the heavy quark sector. Methods and recent results for light quarks, heavy-light and heavy-heavy quark hadrons will be discussed.

Speaker: **S. Leitão**

Title: *Mesons in a covariant quark-constituent formalism*

In continuation of previous work [1], we are developing a covariant model in Minkowski space for all mesons that can be described as quark-antiquark bound states, using the framework of the Covariant Spectator Theory (CST). Our model incorporates both spontaneous chiral symmetry breaking and confinement and has already been used to compute dressed quark mass functions [2] and the pion electromagnetic form factor in the relativistic impulse approximation [3].

The kernel of the quark-antiquark bound-state equation contains a relativistic generalization of a linear confining potential. It is singular in momentum space, which makes the numerical solution of the bound-state equation more difficult. The same type of singularity is also present in the momentum-space Schrödinger equation, which is obtained in the nonrelativistic limit of the CST equation. Because exact solutions for the Schrödinger equation with a linear potential in coordinate space are known for S-waves, we used this as a test case to study different numerical methods to deal with this singularity. We found that a subtraction technique is able to completely remove all singularities from the bound-state equation, and that the singularity-free form of the momentum-space Schrödinger

equation is much easier to solve numerically, yielding accurate and stable results also in higher partial waves [4].

The same method has now been successfully applied also to the numerical solution of the relativistic CST bound-state equation, again for arbitrary partial waves. We studied cases where the relativistic kernel has a Lorentz scalar, vector, or mixed scalar-vector structure, improving on previous work [5] where the vector interaction was approximated by the time-like component only and retardation was neglected.

We will present results for the spectra of heavy quarkonia and heavy-light mesons, both using the relativistic CST equation and the nonrelativistic Schrdinger equation.

[1] F. Gross, J. Milana, Phys. Rev. D **43**, 2401 (1991); **45**, 969 (1992); **50**, 3332 (1994); C. Savkli, F. Gross, Phys. Rev. C **63**, 035208 (2001).
[2] E. P. Biernat, F. Gross, M. T. Peña, A. Stadler, Phys. Rev. D **89**, 016005 (2014).
[3] E. P. Biernat, F. Gross, M. T. Peña, A. Stadler, Phys. Rev. D **89**, 016006 (2014).
[4] A. Stadler, S. Leitão, M. T. Peña, E. P. Biernat, Few Body Syst. **55**, 701 (2014).
[5] F. Gross, M. Uzzo, Phys. Rev. C **59**, 1009 (1999).

Speaker: **X. Liu**

Title: *The initial-chiral-particle-emission mechanism and the predictions of charged charmonium-like structures*

In this talk, I will introduce how the initial-single-pion-emission (ISPE) mechanism is introduced to explain the charged bottomonium-like states $Z_b(10610)$ and $Z_b(10650)$. Later, I will illustrate the relation between the prediction of charged charmonium-like structures and the observed charged charmonium-like states $Z_c(3900)$ and $Z_c(4025)$. By the ISPE mechanism, more abundant phenomena of charged charmonium-like structures were predicted, which will be introduced in this talk.

Speaker: **A. Martínez Torres**

Title: $X(3872)$ *production in high-energy heavy-ion collisions*

We have determined the production cross sections of $X(3872)$ state in several reactions involving D and $\bar{D}^*$ mesons. The evaluation of the cross section of the processes involving $\bar{D}^*$ mesons requires the calculation of an anomalous vertex $X\bar{D}^*D$, which has been obtained by considering triangular loops motivated by the molecular nature of $X(3872)$.

Speaker: **J. Morais**

Co-authors: J. Moreira, B. Hiller, A. Osipov, A. Blin

Title: *The T-μ phase diagram of the NJL model in presence of explicit symmetry-breaking interactions*

It is shown that the strange quark mass undergoes a first-order transition in a generalized 3-flavor Nambu–Jona-Lasinio model Lagrangian which includes a complete set of explicit chiral-symmetry-breaking interactions. This transition occurs in a moderate chemical-potential region $\mu \sim 400$ MeV, in addition to the usual chiral transition associated with the light-quark sector. We discuss the implications for strange-quark-matter production.

Speaker: **J. Moreira**

Co-authors: B. Hiller, W. Broniowski, A. Blin

Title: *Non-uniform phases in a three-flavour 't Hooft extended Nambu–Jona-Lasinio model*

The possible existence of nonuniform phases in cold dense quark matter in the light quark sector (u, d and s) is addressed using the Nambu–Jona-Lasinio Model extended to include flavour-mixing 't Hooft determinant. The effect of changes in the coupling strengths of the model as well as that of the value of the current mass of the strange quark is discussed. It is seen that the inclusion of the strange sector actually catalyses the appearance of these nonuniform phases extending the domain for their appearance.

Speaker: **B. Moussallam**

Title: *Scalar mesons in isospin-violating τ decays*

It was noted long ago that the τ decay mode $\tau \to \eta\pi\nu$, which is isospin violating, provides a clean experimental probe of the nature of the $a_0(980)$ scalar meson. We reconsider this question from the point of view of analyticity and the dispersion relations that the form factors which describe the decay amplitude have to satisfy and derive relations with the $\eta\pi \to \eta\pi$ scattering phase shift and the $\eta\pi$ scalar radius.

Speaker: **F. Nerling**

Title: *Newest results from the COMPASS experiment at CERN*

The COMPASS experiment at the CERN-SPS studies the structure and the spectrum of hadrons by scattering high-energy hadrons and polarised muons off various fixed targets. While COMPASS focused on nucleon spin physics using 160 GeV/c polarised μ^+ beams on polarised deuteron and proton targets during the years 2002–2007 and 2010–2011, high-statistics data were taken with negative and positive 190 GeV/c hadron beams on a proton and nuclear targets in 2008 and 2009 for hadron spectroscopy. The muon programme includes measurements of the gluon contribution to the nucleon spin using longitudinal target polarisation as well as studies of transverse spin effects in the nucleon on a transversely polarised target. A major goal of the hadron physics programme is the search for new states, in particular the search for J^{PC} exotic states and glueballs. In addition, COMPASS measures low-energy QCD constants like, e.g., the electromagnetic polarisability of the pion. A selection of the most recent results will be discussed. Since 2012, in the COMPASS-II phase, the focus is on the three-dimensional structure of the nucleon via Drell-Yan reactions of π^- on transversely polarised protons and DVCS of μ^+ and μ^- on a liquid-hydrogen target. In parallel to DVCS, measurements of SIDIS on liquid hydrogen will also be pursued.

Speaker: **F. Nerling**

Title: *Prospectives of the PANDA experiment at FAIR*

The new Facility for Antiproton and Ion Research (FAIR) is under construction at GSI in Darmstadt (Germany), where the PANDA experiment represents the central part of the hadron physics programme. The multi-purpose PANDA detector in combination with an intense and high-quality anti-proton beam for creating a gluon-rich environment in

antiproton-proton collisions allows for coverage of a broad range of different aspects of QCD. Apart from the facility and the apparatus, an overview of the rich PANDA physics programme will be given, with focus on the unique possibilities for performing studies in the field of exotic hadrons.

Speaker: **A. Palano**

Title: *New results on charmonium physics from the BaBar experiment*

New results will be presented on charmonium spectroscopy and decays. In particular, the following topics will be discussed:

a) Dalitz-plot analysis of η_c decays produced in two-photon interactions;
b) Search for new charmonium states in double-charmonium final states;
c) Search for exotic states in $Y(4260)$ and B decays;
d) Dalitz-plot analysis of J/psi three-body decays.

Speaker: **A. Palano**

Title: *Recent LHCb spectroscopy results*

The latest years have seen a resurrection of interest in searches for exotic states motivated by tantalising observations by Belle and CDF. Using the data collected at *pp* collisions at 7 and 8 TeV by the LHCb experiment we present studies of the $X(3872)$ properties including its decay rate to $\psi(2S)\gamma$, as well as studies of putative states such as the $Z(4430)^+$ and similar in B decays. Using $B \to J/\psi\pi\pi$ decays we also study the nature of the $f_0(980)$ and $f_0(500)$ mesons. Spectroscopy results in states with open b and c flavour are also presented.

Speaker: **D. Parganlija**

Co-authors: F. Bruenner, A. Rebhan

Title: *Holographic glueball decay*

Glueball search is a main pillar of the experimental program for PANDA at FAIR. We present new results on two-pion and four-pion decay widths of scalar and tensor glueballs in the Sakai-Sugimoto model, a realisation of holographic QCD from first principles containing only one free coupling and a mass scale. Our results for the dilaton-dual field indicate the corresponding scalar glueball to be two times heavier than the rho meson.

Speaker: **J. Peláez**

Co-authors: J. Nebreda, A. P. Szczepaniak, J. A. Carrasco

Title: *Non-ordinary Regge trajectory of the σ meson*

We review how the Regge trajectory of an elastic resonance can be obtained just from its pole position and coupling, by means of a dispersive formalism. This allows to deal correctly with the finite widths of resonances in Regge trajectories. For the $\rho(770)$, the $f_2(1275)$ or the $f'(1525)$ mesons this method leads to the ordinary linear Regge trajectories with a universal slope. In contrast, for the $f_0(500)$ meson, the resulting Regge trajectory is non-linear and with much smaller slope. This is another strong indication of the non-ordinary nature of the lightest scalar meson.

Speaker: **M. Pelizaeus**

Title: *Recent results from charmonium spectroscopy at BES-III*

The BES-III experiment at the electron-positron collider BEPC-II in Beijing has collected large data samples of vector resonances in the charmonium energy region up to about 4.6 GeV. These data include the world's largest data samples of the $Y(4260)$ and $Y(4360)$ states produced in direct electron-positron annihilation, which will help us to understand the nature of these states. Furthermore in these data several exotic charged charmonium-like states — including the $Z_c(3900)^+$ in the process $e^+e^- \to J/\psi\pi^+\pi^-$ — have been observed. The states must contain at least four quarks, but their exact nature is currently debated.

In this talk recent results from these data samples and future plans of the experiment will be presented.

Speaker: **M. Pennington**

Title: *The brief life of a hadron: QCD unquenched*

The essence of hadrons beyond the ground state is that their lives are brief. This shapes their whole existence, their production and decay. Eef understood this. QCD is unquenched. The impact and implications of these ideas will be discussed.

Speaker: **C. Providência**

Co-authors: P. Costa, M. Ferreira

Title: *The QCD critical end point driven by an external magnetic field*

Presently the study of the phase diagram of QCD is the subject of both theoretical and experimental studies under extreme conditions of density and temperature. In particular, it is expected that the phenomenon of deconfinement occurs in relativistic heavy-ion collisions and in the interior of compact stars, two very different scenarios when isospin asymmetry is considered. While in heavy-ion collisions the proton fraction is presently not smaller than $\sim$0.4, much smaller proton fractions are expected in the interior of neutron stars. Also the understanding of the eect of an external magnetic eld on the structure of the QCD phase diagram is very important once extremely strong magnetic elds are relevant for compact objects like magnetars and are expected to aect measurements in heavy-ion collisions at very high energies or the behavior of the rst phases of the universe. Another degree of freedom that must be considered when discussing the QCD phase diagram is strangeness. In the interior of a neutron star it is expected that strangeness is present either in the form of hyperons, of a kaon condensate, or of a core of deconfined quark matter. Betaequilibrium is energetically favored and the Fermi pressure of neutrons is reduced if strangeness degrees of freedom are generated through the action of the weak interaction. On the other hand, the strong force governs heavy-ion collisions. In this presentation the location of the critical end point (CEP) in the QCD phase diagram is discussed under different scenarios. The effect of strangeness, isospin/charge asymmetry and an external magnetic eld is investigated. The discussion is performed within the 2+1-flavor Nambu–Jona-Lasinio model with Polyakov loop (PNJL). It is shown that isospin asymmetry shifts the CEP to larger baryonic chemical potentials and smaller temperatures. At large asymmetries the CEP disappears. However, a strong enough magnetic eld

drives the system into a rst-order phase transition.

[1] "Phase transition and critical end point driven by an external magnetic field in asymmetric quark matter", Pedro Costa, Márcio Ferreira, Hubert Hansen, Débora P. Menezes, Constança Providência, Phys. Rev. D **89** (2014) 056013.

Speaker: **H. Reinhardt**

Co-authors: D. Campagnari, J. Heffner

Title: *Hamiltonian approach to QCD in Coulomb gauge: deconfinement from confinement*

I will review recent results obtained within the Hamiltonian approach to QCD in Coulomb gauge. I will focus on the description of the deconfinement phase transition by compactifying one spatial dimension.

Speaker: **G. Rupp**

Co-authors: E. van Beveren, S. Coito

Title: *No serious meson spectroscopy without scattering*

Very recent unquenched lattice calculations indicate that including two-meson fields to describe mesonic resonances [1], besides the usual quark-antiquark operators, may give rise to very large changes in the predictions for central resonance masses, when compared to computations also with dynamical quarks but without meson-meson fields [2]. Moreover, even states stable with respect to OZI-allowed strong decay can be subject to sizable downwards mass shifts, when meson-meson fields corresponding to virtual OZI-allowed decay channels are taken into account [3]. For more details, see the talk by C. Lang at this workshop.

Similar large effects due to real or virtual strong decay have been predicted long ago by Eef van Beveren and collaborators, employing phenomenological unquenched ("unitarised") quark models, with coupled channels describing real or virtual strong two-meson decay. One of the main conclusions was that mesonic ground states and also other quasi-bound states below all OZI-allowed thresholds can undergo large shifts due to unitarisation [4]. Another big surprise was the straightforward description of the light scalar mesons as dynamical resonances, arising as extra, light states from normal $^3P_0$ $q\bar{q}$ seeds above 1.2 GeV [5]. More recently, $D_{s0}(2317)$ was successfully described as a scalar $c\bar{s}$ meson with a large subthreshold DK component [6], in full agreement with the very recent lattice finding in Ref. [3].

It is illusory to hope that such non-perturbative coupled-channel effects can be faithfully mimicked by either a redefinition of the constituent quark mass or a screening of the confining potential, as is sometimes claimed. This will be further demonstrated via additional concrete examples from recent work on $X(3872)$ [7] and axial-vector charm mesons [8]. Conclusions will be presented on the propects for realistic meson spectroscopy.

[1] S. Prelovsek, L. Leskovec, C. B. Lang, and D. Mohler, Phys. Rev. D **88** (2013) 054508.
[2] G. P. Engel, C. B. Lang, D. Mohler, and A. Schäfer, PoS Hadron **2013** (2013) 118 [arXiv:1311.6579 [hep.ph]].
[3] D. Mohler, C. B. Lang, L. Leskovec, S. Prelovsek, and R. M. Woloshyn, Phys. Rev. Lett. **111** (2013) 222001.
[4] E. van Beveren, C. Dullemond, and G. Rupp, Phys. Rev. D **21** (1980) 772; E. van Beveren, G. Rupp, T. A. Rijken, and C. Dullemond, Phys. Rev. D **27** (1983) 1527.

[5] E. van Beveren, T. A. Rijken, K. Metzger, C. Dullemond, G. Rupp, and J. E. Ribeiro, Z. Phys. C **30** (1986) 615.
[6] E. van Beveren and G. Rupp, Phys. Rev. Lett. **91** (2003) 012003.
[7] S. Coito, G. Rupp, and E. van Beveren, Eur. Phys. J. C **71** (2011) 1762; **73** (2013) 2351.
[8] S. Coito, G. Rupp, and E. van Beveren, Phys. Rev. D **84** (2011) 094020.

Speaker: **E. Santopinto**

Title: *Higher charmonia and bottomonia in an unquenched quark model*

I will review the results obtained with an unquenched quark model for charmonia and bottomonia.

Speaker: **P. J. Silva**

Co-authors: O. Oliveira, D. Dudal, P. Bicudo, N. Cardoso

Title: *Aspects of gluon propagation in Landau gauge: spectral densities and mass scales at finite temperature*

In this talk we discuss a method to extract the Källén-Lehmann spectral density of a particle (be it elementary or bound state) propagator and apply it to compute gluon spectral densities from lattice data. Furthermore, we also consider the interpretation of the Landau-gauge gluon propagator at finite temperature as a massive-type bosonic propagator.

Speaker: **A. Szczepaniak**

Title: *New opportunities and challenges in hadron spectroscopy*

In this talk I will discuss some of the latest theoretical, phenomenological and experimental results in hadron spectroscopy.

Speaker: **S. Takeuchi**

Co-authors: K. Shimizu, M. Takizawa

Title: *On the origin of the narrow peak and the isospin-symmetry breaking of the $X(3872)$*

The $X(3872)$ formation from the B decay and its decay into the two-meson state are investigated by employing a coupled-channel two-meson model with the $c\bar{c}$ state. This two-meson state consists of the $D^0\overline{D}^{*0}$, D^+D^{*-}, $J/\psi\rho$, and $J/\psi\omega$ channels. The energy-dependent decay widths of the ρ and ω mesons are taken into account. The interaction between D and $\overline{D}^*$ mesons is taken to be consistent with a lack of the $B\overline{B}^*$ bound state. The $D\overline{D}^*$-$c\bar{c}$ coupling is taken as a parameter to fit the $X(3872)$ mass. The coupling between the $D\overline{D}^*$ and J/ψ-vector-meson channels is determined with the help of a quark model.

It is found that the $J/\psi\rho$ and $J/\psi\omega$ peaks appear around the $D^0\overline{D}^{*0}$ threshold under reasonable assumptions and that their peaks are very narrow when they appear. It is also found that the large decay width of the ρ meson enhances the isospin-one component in the decay spectra in the $X(3872)$ energy region. The size of the $J/\psi\pi^3$ peak we calculated is 1.29–2.38 times as large as that of the $J/\psi\pi^2$. The isospin-symmetry breaking in the

present model comes from the difference in the meson masses and widths, which seems to give a sufficiently large isospin mixing to explain the experiments. Also, the results suggest that one can judge whether the $X(3872)$ is a bound state by looking into the ratio of the $D^0\overline{D}^{*0}$ decay fragment to that of the $J/\psi\rho$ at around the $D^0\overline{D}^{*0}$ threshold. Moreover, the relative importance of the $D\overline{D}^*$-$c\bar{c}$ coupling in the $X(3872)$ can be evaluated from the ratio of the D^+D^{*-} fragment to that of the $D^0\overline{D}^{*0}$ as well as from the ratio of the $J/\psi\pi^3$ peak size to that of the $J/\psi\pi^2$.

Part of this work has been published in Ref. [1]. We are submitting the manuscript [2].

[1] M. Takizawa and S. Takeuchi, *"$X(3872)$ as a hybrid state of charmonium and the hadronic molecule,"* Prog. Theor. Exp. Phys. **2013**, 0903D01 (2013).

[2] S. Takeuchi, K. Shimizu, and M. Takizawa, *"On the origin of the narrow peak and the isospin symmetry breaking of the $X(3872)$".*

Speaker: **M. Takizawa**

Title: *Summary of results on spectroscopy from Belle*

We shall present the results on the spectroscopy measured with the Belle detector at the KEKB asymmetric-energy e^+e^- collider.

Speaker: **Gy. Wolf**

Co-authors: P. Kovacs, Zs. Szep

Title: *Extended linear σ model at non-zero temperature and non-zero density*

We extended the linear sigma model with vector mesons. We calculated the vacuum phenomenology, masses and decay widths of the (pseudo)scalar and (pseudo)vector mesons. We obtained a very good description, with scalar meson masses all above 1 GeV. Furthermore we couple these meson fields with quarks and calculate high density and temperature behaviour of these mesons.

Speaker: **T. Wolkanowski-Gans**

Co-author: F. Giacosa

Title: *Dynamical generation of hadronic resonances*

A type of dynamical generation consists in the formation of multiple hadronic resonances from single seed states by incorporating hadronic loop contributions on the level of S-wave propagators. Along this line, we study the propagator poles within scalar theories and report on the status of our work: (i) In the framework of a simple quantum field theory describing the decay of $f_0(500)$ into two pions, we study the pole(s) trajectories. Besides the expected pole on the second Riemann sheet, we find — for a large enough coupling constant — a second, additional pole on the first Riemann sheet below the pion-pion threshold (i.e., a stable state emerges); (ii) Although the coupling constants might be large, we show why the one-loop resummation scheme is usually valid in the framework of hadronic resonances; (iii) We perform a numerical study of the pole(s) of $a_0(1450)$ and the isodoublet $K_0^\star(1450)$ by using as an input the results obtained in the extended linear sigma model (eLSM). Here, we do not find any additional poles besides the original ones. Thus we cannot obtain $a_0(980)$ and the $K_0^\star(800)$ as emerging states; (iv) We show preliminary results on the exotic resonance $X(3872)$.