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Positive parity D_s mesons and Z_c^+ from lattice QCD

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Abstract. Two particularly interesting channels are presented: the positive parity D_s mesons and the exotic Z_c^+. In the D_s channel there was some tension between experiment and theory, as the $D_{s0}^*(2317)$ and $D_{s1}(2460)$, which were experimentally found below the DK and D^*K thresholds respectively, were theoretically supposed to be above threshold. We perform a lattice QCD simulation where we include not only $\bar{c}s$ but also $D^{(*)}K$ operators; this enables us to take into account the threshold effects. The extracted mases are found below threshold and match experimental values within error. We perform also a lattice QCD simulation of the exotic Z_c^+ channel, where experiments found several manifestly exotic states with at least two quark and two anti-quarks. In the operator basis we include all relevant scattering operators $J/\psi\pi$,$\eta_c\rho$, DD^*, $\psi(2S)\pi$, D^*D^*, $\psi(3770)\pi$, $\psi_{3--}\pi$ as well as additional diquark anti diquark operators. We are able to identify all scattering levels within the energy region of interest, however no additional level identifiable as a candidate for Z_c^+ is found.

Lattice QCD is the theory of the Strong interaction formulated in discrete Euclidean space time, specifically within a finite sized box with periodic boundary conditions. The pre-eminent advantage of lattice QCD is that it allows the nonperturbative calculation of correlator functions of hadronic operators in terms of fundamental quark and gluon degrees of freedom. From these correlator functions, the spectrum of hadrons in a given quantum channel can be extracted. However unlike in the continuum, the spectrum from a lattice simulation is discrete due to the periodic boundary conditions in space. Here recent results from lattice simulations of the positive parity D_s mesons and the $J^{PC} = 1^{+-}$ charmonium channel are presented.

The positive parity D_s mesons, especially the $D_{s0}(2317)$ and $D_{s1}(2460)$, are understood quite badly from a theoretical point of view. Experimentally they are seen below the $D^{(*)}K$ thresholds [1], however neither quark models nor lattice QCD studies have been able to reproduce this so far [2]. Early quenched lattice studies, that ignored sea quark contributions only took into account $\bar{q}q$ operators and found results consistent with the quark model – $D_{s0}(2317)$ and $D_{s1}(2460)$ appeared above DK and D^*K thresholds respectively [3]. Dynamical studies followed, thinking that the issue might have been in the lack of sea quark contributions, however when pion and kaon masses were taken to be close to physical, the states of interest again appeared to be above their respective thresholds [4].

We performed dynamical lattice QCD simulations at two distinct pion masses, $m_\pi = 266$MeV and 156MeV, using both $\bar{c}s$ and $D^{(*)}K$ operators in the construction of the correlator matrix in order to take into the account the effects of the threshold [5]. The discrete energy levels are in both cases obtained from the generalized eigenvalue problem [6]. When the scattering operators are not included in the analysis, we reproduce the previous results, where the $D_{s0}(2317)$ and $D_{s1}(2460)$ are above threshold. However when also the meson-meson scattering operators are included in the analysis, the above threshold energy level becomes two distinct levels - one above the respective threshold and one below. The Lüscher method [7,8] is used to obtain the phase shifts near and below threshold allowing to determine the position of the pole in the T matrix. We find [5] the $D_{s0}(2317)$ to be 78.9(5.4) MeV and 36.6(16.6) MeV below the DK threshold for the case of $m_\pi = 266$ MeV and the case of $m_\pi = 156$ MeV respectively. The $D_{s1}(2460)$ appears 93.2(4.7) MeV below threshold for $m_\pi = 266$ MeV and 44.2(9.9) MeV below threshold for $m_\pi = 156$ MeV. The lighter pion mass ensemble compares to experiment favorably: $m^{exp}_{D_{s0}(2317)} - m^{exp}_K - m^{exp}_D \approx 45.1$ MeV and $m^{exp}_{D_{s1}(2460)} - m^{exp}_K - m^{*exp}_D \approx 44.7$ MeV [1].

The $J^{PC} = 1^{+-}$ charmonium channel is interesting because experiments [9–11] recently discovered manifestly exotic hadrons – charged charmonium resonances. The first study of this channel [12], was focused on J/ψ and DD^* scattering below 4 GeV, however no candidate was found. Another study of this channel with lattice QCD appeared soon after, and was able to extract DD^* scattering parameters near threshold, however claimed to find no candidates for exotic hadrons [13].

We performed a comprehensive lattice QCD study of this channel using the ensemble with $m_\pi = 266$MeV. In the construction of the correlator matrix operators corresponding to all scattering states relevant on the lattice below 4.3 GeV: $J/\psi\pi$, $\eta_c\rho$, DD^*, $\psi(2S)\pi$, D^*D^*, $\psi(3770)\pi$, $\psi_{3--}\pi$ as well as additional diquark anti-diquark operators, $[\bar{c}\bar{u}]_{3_c}[cu]_{\bar{3}_c}$ were used. The obtained discrete energy levels were identified with their respective scattering states and no additional state which could be identified as a candidate for the exotic hadron, was found under 4.2 GeV [14].

For the case of the positive parity D_s mesons we have resolved a long standing issue between experiment and theory, by taking into account the $D^{(*)}K$ threshold effects. In the charmonium channel we did not find any candidates for the exotic hadrons, even though we included explicit diquark anti-diquark operators in the analysis. Further and more extensive studies of this channel would need to be performed to shed some light on the theoretical understanding of the exotic hadrons in the $J^{PC} = 1^{+-}$ charmonium channel.

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Izbrani spektroskopski rezultati kolaboracije Belle

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V prispevku smo poročali o izbranih rezultatih iz spektroskopskih eksperimentov, pred kratkim izvedenih s spektrometrom Belle, ki deluje na energijsko asimetričnem trkalniku elektronov in pozitronov KEKB v laboratoriju KEK, Tsukuba, Japonska.

Konstituentni kvark kot soliton v kiralnih kvarkovskih modelih

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Obravnavamo možnost, da lahko soliton z barionskim številom $1/3$, dobljenim v linearnem modelu sigma in v modelu Nambuja in Jona-Lasinija, identificiramo s konstituentnim kvarkom. V linearnem modelu sigma smo izpeljali potencial med dvema solitonoma, ki je podoben potencialom, ki se uporabljajo v modelih s konstituentnimi kvarki.

Mezoni D_s s pozitivno parnostjo in Z_c^+ v kromodinamiki na mreži

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Predstavljena sta dva še posebej zanimiva kanala: D_s mezoni s pozitivno parnostjo ter eksotični hadron Z_c^+. V kanalu z D_s je bilo nekaj napetosti med eksperimentom ter teorijo, saj je eksperiment našel stanji $D_{s0}^*(2317)$ in $D_{s1}(2460)$ pod pragom za sipanje mezonov DK in D^*K, medtem ko je teorija napovedala mase teh mezonov nad tem istim pragom. V kromodinamiki na mreži smo simulirali dotični kanal tako, da smo uporabili operatorje $\bar{c}s$ ter tudi $D^{(*)}K$. Upoštevajoč pojave na pragu sipanja smo izločili mase mezonov D_s s pozitivno parnostjo, ki se nahajajo pod pragom za sipanje in se v okviru napak ujemajo z eksperimentalnimi. Simulirali pa smo tudi eksotični kanal v katerem se nahaja Z_c^+. Uporabili smo vse relevantne dvomezonske sipalne operatorje $J/\psi\pi$,$\eta_c\rho$, DD^*, $\psi(2S)\pi$, D^*D^*, $\psi(3770)\pi$, $\psi_{3--}\pi$, kot tudi dodatne operatorje tipa dikvark anti-dikvark. Identificirali smo vse diskretne energijske nivoje, a nismo našli prepoznavnega kandidata za Z_c^+.