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Scattering phase shifts and resonances from lattice QCD

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Most of hadrons are hadronic resonances - they decay quickly via the strong interactions. Among all the resonances, only the ρ meson has been properly simulated as a resonance within lattice QCD up to know. This involved the simulation of the $\pi\pi$ scattering in p-wave, extraction of the scattering phase shift and determination of m_R and Γ via the Breit-Wigner like fit of the phase shift.

In the past year, we performed first exploratory simulations of $D\pi$, $D^*\pi$ and $K\pi$ scattering in the resonant scattering channels [1,2]. Our simulations are done in lattice QCD with two-dynamical light quarks at a mass corresponding to $m_\pi \simeq 266$ MeV and the lattice spacing $a = 0.124$ fm.

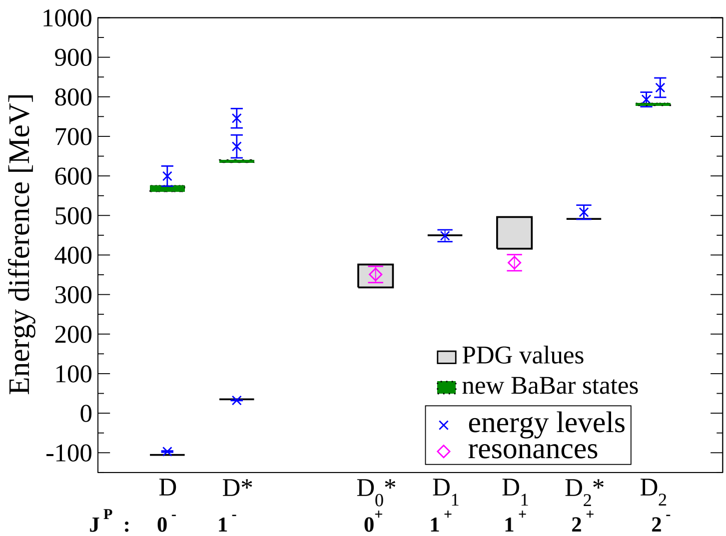

Fig. 1. Energy differences $\Delta E = E - \frac{1}{4}(M_D + 3M_{D^*})$ for D meson states in our simulation [1] and in experiment; the reference spin-averaged mass is $\frac{1}{4}(M_D + 3M_{D^*}) \approx 1971$ MeV in experiment. Magenta diamonds give resonance masses for states treated properly as resonances, while those extracted naively assuming $m_n = E_n$ are displayed as blue crosses [1].

The masses and widths of the broad scalar $D_0^*(2400)$ and the axial $D_1(2430)$ charmed-light resonances are extracted by simulating the corresponding $D\pi$ and $D^*\pi$ scattering on the lattice [1]. The resonance parameters are obtained using a Breit-Wigner fit of the elastic phase shifts. The resulting $D_0^*(2400)$ mass is 351 ± 21 MeV above the spin-average $\frac{1}{4}(m_D + 3m_{D^*})$, in agreement with the experimental value of 347 ± 29 MeV above. The resulting $D_0^* \to D\pi$ coupling $g^{lat} = 2.55 \pm 0.21$ GeV is close to the experimental value $g^{exp} = 1.92 \pm 0.14$ GeV, where g parametrizes the width $\Gamma \equiv g^2 p^\star/s$. The resonance parameters for the broad $D_1(2430)$ are also found close to the experimental values; these are obtained by appealing to the heavy quark limit, where the neighboring resonance $D_1(2420)$ is narrow. The simulation of the scattering in these channels incorporates quark-antiquark as well as $D^{(*)}\pi$ interpolators, and we use distillation method for contractions. The resulting D-meson spectrum is compared to the experimental one in Fig. 1.

In addition, the ground and several excited charm-light and charmonium states with various J^P are calculated using standard quark-antiquark interpolators. The lattice results for the charmonium are compared to the experimental levels in Fig. 2.

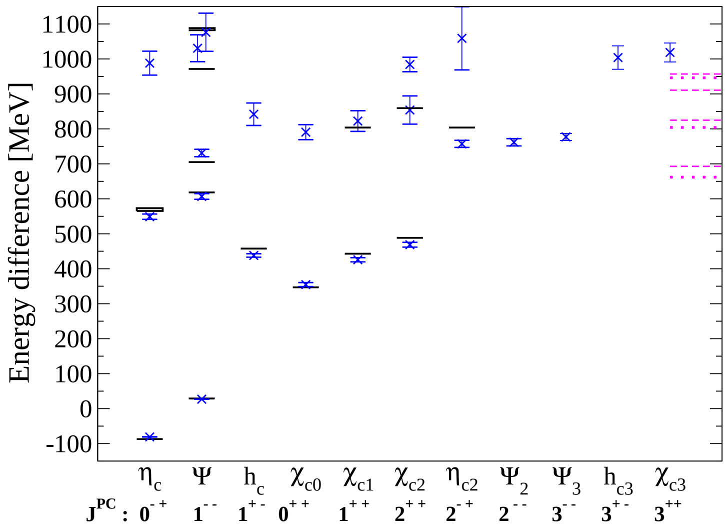

Fig. 2. Energy differences $\Delta E = E - \frac{1}{4}(M_{\eta_c} + 3M_{J\psi})$ for charmonium states in our simulation [1] and in experiment; reference spin-averaged mass is $\frac{1}{4}(M_{\eta_c} + 3M_{J\psi}) \approx 3068$ MeV in experiment. The magenta lines on the right denote relevant lattice and continuum $\bar{D}^{(*)}D^{(*)}$ thresholds.

We also simulated $K\pi$ scattering in s-wave and p-wave for both isospins $I = 1/2,\ 3/2$ using quark-antiquark and meson-meson interpolating fields [2]. Fig. 3 shows the resulting energy levels of $K\pi$ in a box. In all four channels we observe the expected $K(n)\pi(-n)$ scattering states, which are shifted due to the interaction. In both attractive $I = 1/2$ channels we observe additional states that are related

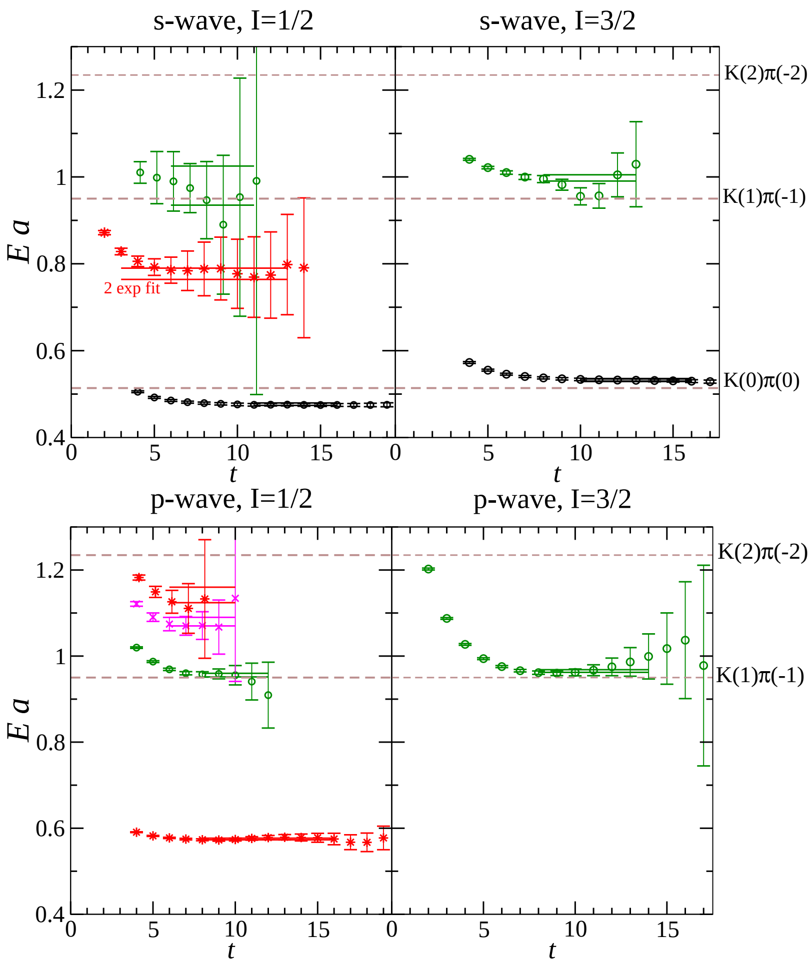

Fig. 3. The energy levels $E(t)a$ of the $K\pi$ in the box for all four channels (multiply by $a^{-1} = 1.59$ GeV to get the result in GeV). The horizontal broken lines show the energies $E = E_K + E_\pi$ of the non-interacting scattering states $K(n)\pi(-n)$ as measured on our lattice; $K(n)\pi(-n)$ corresponds to the scattering state with $p^* = \sqrt{n}\frac{2\pi}{L}$. Note that there is no $K(0)\pi(0)$ scattering state for p-wave. Black and green circles correspond to the shifted scattering states, while the red stars and pink crosses correspond to additional states related with resonances.

to resonances; we attribute them to $K_0^*(1430)$ in s-wave and $K^*(892)$, $K^*(1410)$ and $K^*(1680)$ in p-wave. We extract the elastic phase shifts δ at several values of the $K\pi$ relative momenta. The resulting phases exhibit qualitative agreement with the experimental phases in all four channels, as shown in Fig. 4. In addition to the values of the phase shifts shown in Fig. 4, we also extract the values of the phase shift close to the threshold, which are expressed in terms of the scattering lengths in [2].

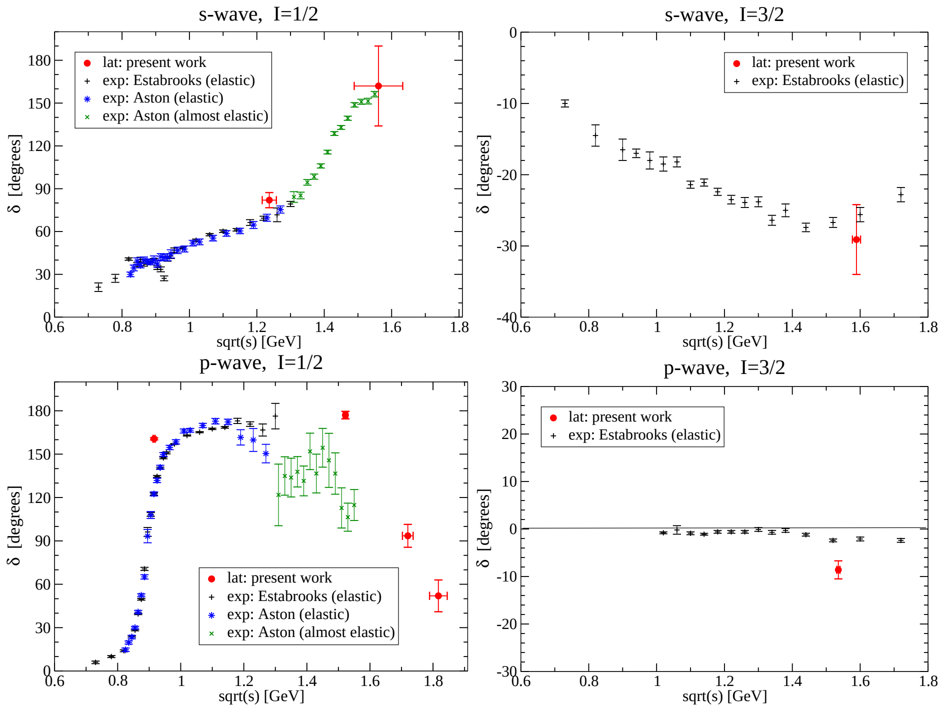

Fig. 4. The extracted $K\pi$ scattering phase shifts δ_ℓ^I in all four channels $l = 0, 1$ and $I = 1/2,\ 3/2$. The phase shifts are shown as a function of the $K\pi$ invariant mass $\sqrt{s} = M_{K\pi} = \sqrt{(p_\pi + p_K)^2}$. Our results (red circles) apply for $m_\pi \simeq 266$ MeV and $m_K \simeq 552$ MeV in our lattice simulation. In addition to the phases provided in four plots, we also extract the values of $\delta_0^{1/2,\ 3/2}$ near threshold $\sqrt{s} = m_\pi + m_K$, but these are provided in the form of the scattering length in the main text (as they are particularly sensitive to $m_{\pi,K}$). Our lattice results are compared to the experimental elastic phase shifts (both are determined up to multiples of 180 degrees).

We believe that these simulations of the $D\pi$, $D^*\pi$ and $K\pi$ scattering in the resonant channels represent encouraging step to simulate resonances properly from first principle QCD. There are many other exciting resonances waiting to be simulated along the similar lines.

References

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