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Nuclear Physics A 954 (2016) 294–307

NUCLEAR PHYSICS A

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Hadron–hadron correlation and interaction from heavy–ion collisions

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Received 15 March 2016; received in revised form 10 May 2016; accepted 10 May 2016

Available online 16 May 2016

Abstract

We investigate the $\Lambda\Lambda$ and K^-p intensity correlations in high-energy heavy–ion collisions. First, we examine the dependence of the $\Lambda\Lambda$ correlation on the $\Lambda\Lambda$ interaction and the $\Lambda\Lambda$ pair purity probability λ. For small λ, the correlation function needs to be suppressed by the $\Lambda\Lambda$ interaction in order to explain the recently measured $\Lambda\Lambda$ correlation data. By comparison, when we adopt the λ value evaluated from the experimentally measured Σ^0/Λ ratio, the correlation function needs to be enhanced by the interaction. We demonstrate that these two cases correspond to the two analyses which gave opposite signs of the $\Lambda\Lambda$ scattering length. Next, we discuss the K^-p correlation function. By using the local $\bar{K}N$ potential which reproduces the kaonic hydrogen data by SIDDHARTA, we obtain the K^-p correlation function. We find that the K^-p correlation can provide a complementary information to the K^-p elastic scattering amplitude.

Keywords: Hadron–hadron interaction; Two-particle intensity correlation; Heavy–ion collisions; Scattering length; Resonance

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http://dx.doi.org/10.1016/j.nuclphysa.2016.05.010
0375-9474/

1. Introduction

Interactions between hadrons are basic ingredients in nuclear and hadron physics. We need nucleon–nucleon (NN), hyperon–nucleon (YN) and hyperon–hyperon (YY) interactions to theoretically investigate normal nuclear and hypernuclear structure and nuclear matter equation of state (EOS). $\Lambda\Lambda$ interaction is one of the key interactions in exotic hadron physics and neutron star physics. First, $\Lambda\Lambda$ interaction is closely related to the existence of the dihyperon, the H particle ($uuddss$). While it seems improbable that there is a bound H state below the $\Lambda\Lambda$ threshold, H may exist as a resonance state. The deeply bound H [1] was ruled out by the observation of the double Λ hypernucleus ${}^{\ 6}_{\Lambda\Lambda}\mathrm{He}$ in the Nagara event [2,3], and the upper bound of loosely bound H production is found to be very small; it is much lower than the anti-deuteron ($\Upsilon(1S, 2S) \to \bar{d}X$) production at the KEKB e^+e^- collider [4], and much lower than various theoretical predictions [5] at the Large Hadron Collider at CERN [6]. By comparison, a bump structure above the $\Lambda\Lambda$ threshold was experimentally observed at KEK [7], and a bound H state found in recent ab initio calculations in the SU(3) limit with unphysical quark masses [8,9] could evolve into a resonance by the SU(3) breaking effects [10]. The H around the $\Lambda\Lambda$ threshold should have the molecule nature of $\Lambda\Lambda$, and information on $\Lambda\Lambda$ interaction is decisive. The $\Lambda\Lambda$ interaction is also important in neutron star physics, especially to solve the "hyperon puzzle". Hyperons are expected to appear in the core of heavy neutron stars, whereas the hyperonic equations of state of neutron star matter are generally too soft to support $2M_\odot$ neutron stars [11]. If the $\Lambda\Lambda$ interaction is repulsive enough at high densities, it may be possible to support massive neutron stars. Contrary to its importance, information on the $\Lambda\Lambda$ interaction is very limited. There is only one uniquely identified double Λ hypernucleus, ${}^{\ 6}_{\Lambda\Lambda}\mathrm{He}$, observed in Nagara event [2,3].[1] The bond energy $\Delta B_{\Lambda\Lambda}$ provides precious information, but it is not enough to determine the shape of the $\Lambda\Lambda$ potential.

Recent developments in exotic hadron physics demand deeper understanding of meson–baryon (MB) and meson–meson (MM) interactions. There have been exciting developments in the spectroscopy of hadron resonances, starting with the discovery of $D_{sJ}(2317)$ [14] and $X(3872)$ [15] in the charmed meson sector. Recently, new states are also observed in the bottom sector, such as $Z_b^{\pm}(10610)$ and $Z_b^{\pm}(10650)$ [16] and in the baryon sector, $P_c^+(4380)$ and $P_c^+(4450)$ [17]. These states cannot be explained by the simple quark model and are considered to be candidates of exotic hadrons. Among others, the hadronic molecules are closely related to the hadron–hadron interactions. One of the typical examples of hadronic molecules is the $\Lambda(1405)$ baryon resonance which appears near the $\bar{K}N$ threshold. It is considered as a $\bar{K}N$ quasi-bound state in the $\bar{K}N$-$\pi\Sigma$ coupled-channel analyses [18,19] (see Refs. [20,21] for recent reviews). The structure of $\Lambda(1405)$ is closely related to the strength and energy dependence of the $I = 0$ $\bar{K}N$ interaction. The uncertainty of the $\bar{K}N$ scattering amplitude at around the threshold is reduced by the high precision data of the kaonic hydrogen by SIDDHARTA [22] combined with the K^-p scattering data [23,24]. Because the low energy K^-p scattering data was accumulated by old bubble chamber experiments with relatively large experimental uncertainties, new and accurate information is desired to further sharpen the description of the $\bar{K}N$ amplitude. Precise knowledge of the $\bar{K}N$ interaction is also important for the study of kaonic atoms [25] and possible $\bar{K}$ bound states in nuclei [26–28].

[1] Binding energies of other double hypernuclear candidates are found to be consistently explained by using the $\Lambda\Lambda$ interactions which fit the bond energy of ${}^{\ 6}_{\Lambda\Lambda}\mathrm{He}$ [12,13].