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Nuclear Physics A 954 (2016) 371–392

NUCLEAR PHYSICS A

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# Study of reactions disclosing hidden charm pentaquarks with or without strangeness

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Received 26 February 2016; received in revised form 26 April 2016; accepted 26 April 2016

Available online 29 April 2016

## Abstract

We present results for five reactions, $\Lambda_b \to J/\psi K^- p$, $\Lambda_b \to J/\psi \eta \Lambda$, $\Lambda_b \to J/\psi \pi^- p$, $\Lambda_b \to J/\psi K^0 \Lambda$ and $\Xi_b^- \to J/\psi K^- \Lambda$, where combining information from the meson baryon interaction, using the chiral unitary approach, and predictions made for molecular states of hidden charm, with or without strangeness, we can evaluate invariant mass distributions for the light meson baryon states, and for those of $J/\psi p$ or $J/\psi \Lambda$. We show that with the present available information, in all of these reactions one finds

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http://dx.doi.org/10.1016/j.nuclphysa.2016.04.038

peaks where the pentaquark states show up. In the $\Lambda_b \to J/\psi K^- p$ and $\Lambda_b \to J/\psi \pi^- p$ reactions we show that the results obtained from our study are compatible with present experimental observations.


*Keywords:* Pentaquark reactions; Molecular states with hidden charm

## 1. Introduction

The recent observation of signals on the $J/\psi p$ mass distribution in the $\Lambda_b \to J/\psi p K^-$ decay [1,2], interpreting them in terms of two pentaquark states, $P_c(4380)$, $P_c(4450)$, with widths around 200 MeV and 40 MeV respectively, has stirred a lot of excitement in the hadron community. Soon after these results were reported a work was done [3], suggesting that these states could be molecular states of the type $\bar{D}^*\Sigma_c^*$ corresponding to spin parity $3/2^-$ and $5/2^-$ respectively. The latter assignment, was argued, would demand D-waves in $J/\psi p$, which could justify why the higher mass state is narrower than the first one. This might be contradicting the experimental assignments which were favored as having opposite parity, as $(3/2^-, 5/2^+)$, $(3/2^+, 5/2^-)$, $(5/2^+, 3/2^-)$, but the fact is that other assignments could not be ruled out. In [4] a state with $3/2^-$ of $\bar{D}^*\Sigma_c$–$\bar{D}^*\Sigma_c^*$ was associated to the narrow state, and nothing was concluded about the wide one. A different molecular assignment is done in [5], assuming $3/2^-$ $\bar{D}\Sigma_c^*$ for the lower mass state and $5/2^+$ $\bar{D}^*\Sigma_c$ for the higher mass state. There are more options since in [6], using sum rules, two states with $3/2^-, 5/2^+$ can be obtained, albeit with uncertainties of about 200 MeV in the mass. Other works followed, suggesting either a molecular nature, different types of pentaquark, or even rescattering effects, to explain the two observed structures.

Among the ideas proposed to explain the states, meson–baryon molecules have been suggested in [3–11]. Some type of pentaquark states of diquark–diquark–antiquark nature have been suggested in [12–16]. Other types, as compact diquark–triquark pentaquarks have been proposed in [17,18], $\bar{D}$-soliton states in [19], genuine multiquark states in [20,21]. Some papers have suggested that the peaks could be kinematical effects related to a triangle singularity [22–24]. Summaries of the theoretical and experimental work done can be seen in Refs. [25–28], and a thorough review on the subject has been presented in [29].

The present paper deals about suggesting reactions to see these and other partner states. Although the molecular picture is guiding the discussion, the results that we obtain are more general. The molecular nature is quite appealing, since predictions for states of hidden charm, that could be naturally associated to these observed states, had been done before. Indeed in [30,31] baryon states of hidden charm were found in the study of the interaction of the $\bar{D}\Sigma_c$–$\bar{D}\Lambda_c$, $\bar{D}^*\Sigma_c$–$\bar{D}^*\Lambda_c$ coupled channels, as main building blocks, together with decay channels in the light sector and the $\eta_c N$ and $J/\psi N$ states. Related studies followed and in [32] bound states of $\bar{D}\Sigma_c$ and $\bar{D}^*\Sigma_c$ were also found. In [33] an admixture of spin flavor symmetry in the light sector and Heavy Quark Spin symmetry, HQSS, was used and states of hidden charm similar to those predicted in [30,31] were found. Similar results to those of [30,31] were found in [34] using HQSS and the local hidden gauge approach to evaluate the matrix elements of HQSS. A quark model was used in [35] and also hidden charm baryon states were obtained. All these works get similar qualitative results, but differ in the values of the masses of the particles as much as 200 MeV up in [35] to 200 MeV down in [33] with respect to those found in [30,31,34]. More work on this is done in [36], where a mixture of Vector–Baryon, VB, and Pseudoscalar–Baryon