BLED WORKSHOPS
IN PHYSICS
VOL. 15, NO. 1
p. 40

Proceedings of the Mini-Workshop
Quark Masses and Hadron Spectra
Bled, Slovenia, July 6 - 13, 2014

News from Belle: selected spectroscopy results

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Abstract. This paper reports on selected recent results from the spectroscopy measurements performed with the experimental data collected by the Belle spectrometer, which has been operating at the KEKB asymmetric-energy e^+e^- collider in the KEK laboratory in Tsukuba, Japan.

1 Introduction

The Belle detector [1] at the asymmetric-energy e^+e^- collider KEKB [2] was operating between 1999 and 2010. During this time, the experiment has accumulated about 1 ab^{-1} of data. The KEKB collider, often called a *B-factory*, because for the most of its time it was operating around the $\Upsilon(4S)$ resonance, thus enabling Belle experiment to collect a sample of about 772 million pairs of $B\overline{B}$ mesons. However, the experiment has also accumulated substantial data samples at other Υ resonances, like $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(5S)$, as well as in the nearby continuum. In particular, the data samples at the $\Upsilon(4S)$ and $\Upsilon(5S)$ resonances are by far the largest available in the world, corresponding to integrated luminosities of 800 fb^{-1} and 123 fb^{-1}, respectively [3]. Large amount of collected experimental data and excellent detector performance enabled many interesting spectroscopic results, including discoveries of new charmonium(-like) and bottomonium(-like) hadronic states and studies of their properties. This report focuses on some of these results that triggered more interest at the workshop.

2 Charmonium and Charmonium-like States

There has been a renewed interest in charmonium spectroscopy since 2002. The attention to this field was first drawn by the discovery of the two missing $c\overline{c}$ states below the open-charm threshold, $\eta_c(2S)$ and $h_c(1P)$ [4,5] with $J^{PC}=0^{-+}$ and 1^{+-}, respectively, but even with the discoveries of new charmonium-like states (so called "XYZ" states).

2.1 The $X(3872)$ news

The story about the so called "XYZ" states began in 2003, when Belle reported on $B^+ \to K^+ J/\psi\pi^+\pi^-$ analysis, where a new state decaying to $J/\psi\pi^+\pi^-$ was discovered [7]. The new state, called $X(3872)$, was soon confirmed and also intensively

studied by the CDF, DØ and *BABAR* collaborations [8–17, 19–21], and recently also by the LHC experiments [22, 23]. So far it has been established that this narrow state ($\Gamma = (3.0^{+1.9}_{-1.4} \pm 0.9)$ MeV) has a mass of (3872.2 ± 0.8) MeV, which is very close to the $D^0\overline{D}^{*0}$ threshold [6]. Intensive studies of several $X(3872)$ production and decay modes were performed by Belle and other experiments to determine the $X(3872)$ properties. These studies suggested two possible J^{PC} assignments, 1^{++} and 2^{-+}, and establish the $X(3872)$ as a candidate for a loosely bound $D^0\overline{D}^{*0}$ molecular state. However, results provided substantial evidence that the $X(3872)$ state must contain a significant $c\bar{c}$ component as well.

As mentioned above, the Belle experiment has already finished collecting data and the final measured sample still does not allow Belle to completely distinguish between the two possible J^{PC} assignments, 1^{++} and 2^{-+}, although the latter case is not very likely. This was confirmed in 2013, when the quantum-number-assignment issue was finally resolved by the LHCb experiment [24]. They performed a full five-dimensional amplitude analysis of the angular correlations between the decay products in $B^+ \to X(3872)K^+$ decays, where $X(3872) \to J/\psi\pi^+\pi^-$ and $J/\psi \to \mu^+\mu^-$, they unambiguously determined 1^{++} assignment. This result also favours exotic explanations of the $X(3872)$ state.

3 Summary and Conclusions

Many new particles have already been discovered during the operation of the Belle experiment at the KEKB collider, and some of them are mentioned in this report. Some recent Belle results also indicate that analogs to exotic charmonium-like states can be found in $b\bar{b}$ systems. Although the operation of the experiment has finished, data analyses are still ongoing and therefore more interesting results on charmonium(-like) and bottomonium(-like) spectroscopy can still be expected from Belle in the near future. These results are eagerly awaited by the community and will be widely discussed at various occassions, in particular at workshops and conferences.

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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^+.