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Studies of D_s^{**} spectroscopy with a Dalitz plot analysis of $B_s^0 \to \bar{D}^0 K^- \pi^+$ decays

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A study of the $B_s^0 \to \bar{D}^0 K^- \pi^+$ Dalitz plot is presented using $3.0\,\text{fb}^{-1}$ of data recorded by LHCb. A structure at $m(\bar{D}^0 K^-) \sim 2.86\,\text{GeV}/c^2$ was found to be an admixture of spin-1 and spin-3 resonances. This is the first observation of a spin-3 particle containing a heavy quark and the first time a spin-3 particle has been seen to be produced in a B decay. The masses and widths of these two states and of the $D_{s2}^*(2573)^-$ resonance are measured. In addition, product branching fractions are reported for the decays via all of the $\bar{D}^0 K^-$ and $K^-\pi^+$ resonances that contribute to the Dalitz plot. The $D_{s2}^*(2573)^-$ resonance is confirmed to be spin 2.

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1. Introduction

In addition to yielding measurements of the branching fractions of B_s^0 decays via several $\bar{D}^0 K^-$ and $K^-\pi^+$ resonances, a Dalitz plot analysis of $B_s^0 \to \bar{D}^0 K^- \pi^+$ decays is of interest for studying D_s^{**} meson spectroscopy.

Of the previously observed D_s^{**} states, the six lightest states are generally understood [1] to constitute the 1S (D_s^-, D_s^{*-}) and 1P ($D_{s0}^*(2317)^-$, $D_{s1}(2460)^-$, $D_{s1}(2536)^-$, $D_{s2}^*(2573)^-$) families of states. A further three states have been observed [2–4]: the $D_{s1}^*(2700)^-$, $D_{sJ}^*(2860)^-$ and $D_{sJ}(3040)^-$ mesons. Of these three heavier states, the first has known spin-parity, 1^-, while the second and third are known to have natural and unnatural spin-parity, respectively. Various interpretations of these states have been offered in the literature [5–8].

Since the $D_{s0}^*(2317)^-$ mass lies below the DK threshold [9] and only states of natural spin-parity decay to a $\bar{D}^0 K^-$ final state, the states that would be expected to feature in the $B_s^0 \to \bar{D}^0 K^- \pi^+$ Dalitz plot are the $D_{s2}(2573)^-$, $D_{s1}^*(2700)^-$ and $D_{sJ}^*(2860)^-$ mesons. Of these three resonances, the $D_{sJ}^*(2860)^-$ is of most interest, since it has unknown spin-parity. An overview of this Dalitz plot analysis is given here; full details can be found in Refs. [10, 11].

2. Analysis

The analysis was performed on $3.0\,\text{fb}^{-1}$ of data collected by LHCb. Candidate $\bar{D}^0$ mesons were reconstructed from the $K^+\pi^-$ final state. A fit to the $\bar{D}^0 K^- \pi^+$ invariant mass distribution was used to determine a window around the signal peak and the yields of all significant contributions within that window. The invariant mass fit is shown in Fig. 1. The signal and $B^0 \to \bar{D}^0 K^- \pi^+$ shapes are each modelled with the sum of two Crystal Ball [12] functions which share a common mean and have tails on opposite sides. The combinatorial background is modelled using a linear function. Smoothed histograms are used to describe the shapes of backgrounds due to $B_s^0 \to \bar{D}^{*0} K^- \pi^+$, $B^0 \to \bar{D}^{(*)0}\pi^+\pi^-$ and $\Lambda_b^0 \to \bar{D}^{(*)0}\bar{p}\pi^+$ decays. These shapes are determined from simulated decays reweighted to account for the known Dalitz plot distributions of the background decays [13, 14] and particle identification and misidentification probabilities. Events that fall within the signal window, $5334 < m(\bar{D}^0 K^- \pi^+) < 5397\,\text{MeV}/c^2$, were retained for the Dalitz plot analysis. The Dalitz plot distribution of these events is shown in Fig. 2. The fit to the Dalitz plot was performed using the `Laura++` package [15].

The combinatorial background contribution to the Dalitz plot was modelled by events falling in the upper sideband of the $\bar{D}^0 K^- \pi^+$ invariant mass distribution, $5500 < m(\bar{D}^0 K^- \pi^+) < 5900\,\text{MeV}/c^2$. Peaking backgrounds due to $B^0 \to \bar{D}^0 \pi^+ \pi^-$ and $\Lambda_b^0 \to \bar{D}^0 \bar{p}\pi^+$ were modelled using simulated data weighted to match the Dalitz plot distributions seen in previous analyses [13, 14].

The signal model was composed of various resonant and non-resonant contributions summed coherently in the isobar formalism [16–18]. The $\bar{K}^*(892)^0$, $\bar{K}^*(1410)^0$, $\bar{K}_2^*(1430)^0$ and $\bar{K}^*(1680)^0$ resonances were included in $m(K^-\pi^+)$. The $K^-\pi^+$ S-wave was modelled by the LASS shape [19], which includes the $\bar{K}_0^*(1430)^0$ resonance and a non-resonant term, and the $\bar{K}_0^*(1950)^0$ resonance. In $m(\bar{D}^0 K^-)$, components were included for the $D_{s2}^*(2573)^-$ and $D_{s1}^*(2700)^-$ states and for a non-resonant S-wave. Various spin compositions were tested for the $D_{sJ}^*(2860)^-$ region. Three "virtual"

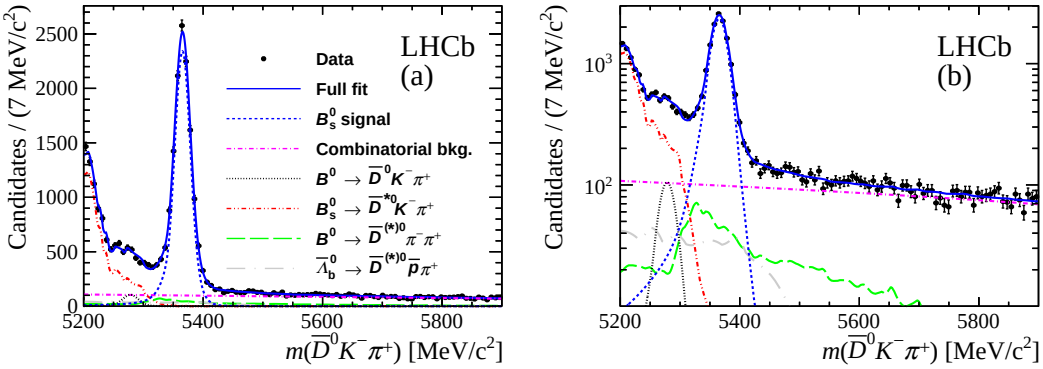

Figure 1: Results of the fit to the three-body $\bar{D}^0 K^- \pi^+$ invariant mass distribution shown on (a) linear and (b) logarithmic scales. Data points are shown in black, the full fit as a solid blue line and components as described in the legend.

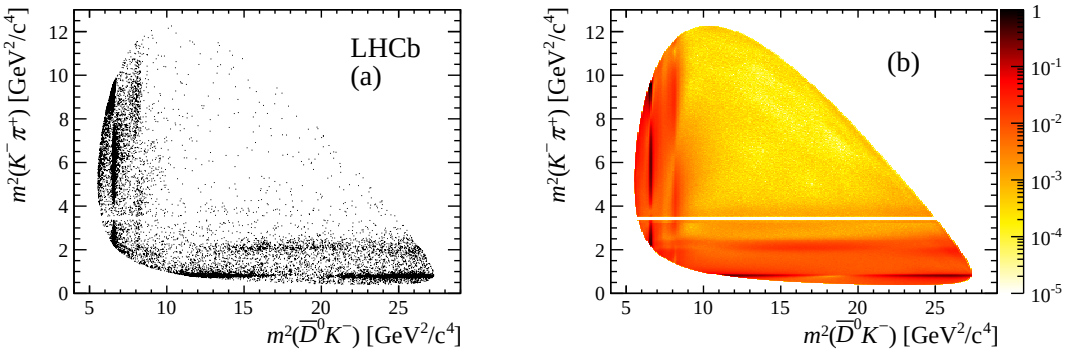

Figure 2: The distribution across the Dalitz plot of (a) $B_s^0 \to \bar{D}^0 K^- \pi^+$ candidates in the signal window and (b) the fit model in arbitrary units. The unpopulated horizontal band is due to a veto around the D^0 mass.

components, mediated by resonances whose pole masses are outside the Dalitz plot phase space, were also included in the signal model: D_s^{*-} and $D_{s0}^*(2317)^-$ in $m(\bar{D}^0 K^-)$ and B^{*+} in $m(\bar{D}^0 \pi^+)$.

The signal model was multiplied by an efficiency function to account for variations in efficiency across the phase space. This function was determined from simulated data and corrected for known discrepancies between data and simulation in track reconstruction, particle identification and the trigger.

Mass distributions and projections of the fit result are shown in Fig. 3. The dominant fit components are the $\bar{K}^*(892)^0$, $D_{s2}^*(2573)^-$, LASS and $m(\bar{D}^0 K^-)$ non-resonant terms.

For the $m(\bar{D}^0 K^-) \sim 2.86\,\text{GeV}/c^2$ region, all combinations of one or two resonances up to spin 3 were considered. The fit including both spin-1 and spin-3 components offered the best description of the data. The best fits without either the spin-1 or spin-3 component are compared to the nominal fit in Fig. 4. The significances of the spin-1 and spin-3 states were found to be in excess of 10 standard deviations when systematic uncertainties are taken into account. A similar analysis confirms that the $D_{s2}^*(2573)^-$ is spin 2.

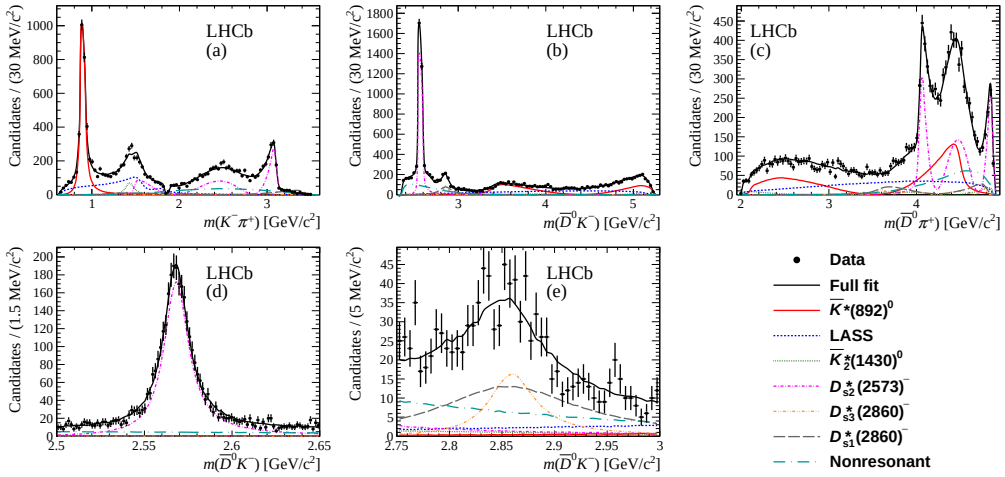

Figure 3: Distributions of the (a) $m(K^-\pi^+)$, (b) $m(\bar{D}^0 K^-)$ and (c) $m(\bar{D}^0\pi^+)$ invariant masses, with zooms of $m(\bar{D}^0 K^-)$ around (d) the $D_{s2}^*(2573)^-$ resonance and (e) the $D_{sJ}^*(2860)^-$ region. The projections of the Dalitz plot fit are overlaid. Data points are shown in black, the full fit as a solid black line and major components as described in the legend.

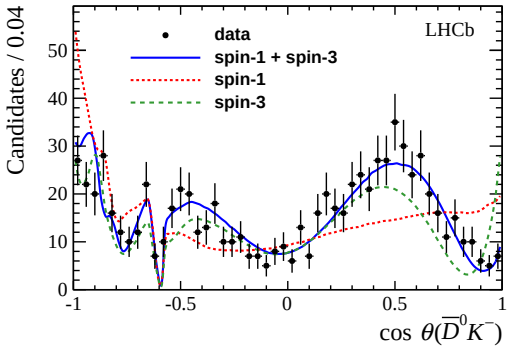

Figure 4: Projections of the data and the fit results with alternative models onto the cosine of the helicity angle of the $\bar{D}^0 K^-$ system for $2.77 < m(\bar{D}^0 K^-) < 2.91\,\text{GeV}/c^2$. The data are shown as black points, the nominal fit model as a solid blue line and the alternative fit models as described in the legend.

3. Results

The previously observed $D_{sJ}^*(2860)^-$ state was found to consist of at least two resonances, one spin-1 and the other spin-3, with a significance in excess of ten standard deviations. The masses and widths of the $D_{s2}^*(2573)^-$, $D_{s1}^*(2860)^-$ and $D_{s3}^*(2860)^-$ states were determined to be:

$$
\begin{aligned}
m(D_{s2}^*(2573)^-) &= 2568.39 \pm 0.29 \pm 0.19 \pm 0.18\,\text{MeV}/c^2\,,\\
\Gamma(D_{s2}^*(2573)^-) &= 16.9 \pm 0.5 \pm 0.4 \pm 0.4\,\text{MeV}/c^2\,,\\
m(D_{s1}^*(2860)^-) &= 2859 \pm 12 \pm 6 \pm 23\,\text{MeV}/c^2\,,\\
\Gamma(D_{s1}^*(2860)^-) &= 159 \pm 23 \pm 27 \pm 72\,\text{MeV}/c^2\,,\\
m(D_{s3}^*(2860)^-) &= 2860.5 \pm 2.6 \pm 2.5 \pm 6.0\,\text{MeV}/c^2\,,\\
\Gamma(D_{s3}^*(2860)^-) &= 53 \pm 7 \pm 4 \pm 6\,\text{MeV}/c^2\,,
\end{aligned}
$$

where the first uncertainty is statistical, the second is due to experimental systematic effects and the third arises from model variations. Product branching fractions (or upper limits) were also calculated for the decay chains via all of the resonant contributions to the Dalitz plot. Where the branching fraction of the resonance decay was known, a branching fraction was also reported for the two-body decay to that resonance. Full results can be found in Ref. [11].

4. Summary

A structure at $m(\bar{D}^0 K^-) \sim 2.86\,\text{GeV}/c^2$ was found to be an admixture of spin-1 and spin-3 resonances with significance in excess of 10 standard deviations. This is the first observation of a spin-3 particle containing a heavy quark and the first observation of a spin-3 particle produced in a B decay. In addition, the $D_{s2}^*(2573)^-$ meson was confirmed to be spin 2 and branching fractions were reported for each of the resonant contributions to the Dalitz plot.

Acknowledgments

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References

[1] K.A. Olive *et al.* (Particle Data Group), *Review of particle physics*, *Chin. Phys.* **C38** (2014) 090001.

[2] B. Aubert *et al.* (BABAR Collaboration), *Observation of a new D_s meson decaying to DK at a mass of* $2.86\,GeV/c^2$, *Phys. Rev. Lett.* **97** (2006) 222001 [hep-ex/0607082].

[3] B. Aubert *et al.* (BABAR Collaboration), *Study of D_{sJ} decays to D^*K in inclusive e^+e^- interactions*, *Phys. Rev.* **D80** (2009) 092003 [hep-ex/0908.0806].

[4] R. Aaij *et al.* (LHCb Collaboration), *Study of D_{sJ} decays to $D^+K^0_S$ and D^0K^+ final states in pp collisions*, *JHEP* **10** (2012) 151 [hep-ex/1207:6016].

[5] E.S. Swanson, *The new heavy mesons: a status report*, *Phys. Rept.* **429** (2006) 243 [hep-ph/0601110].

[6] J.L. Rosner, *Hadron spectroscopy: theory and experiment*, *J. Phys.* **G34** (2007) S127 [hep-ph/0609195].]

[7] E. Klempt and A. Zaitsev, *Glueballs, hybrids, multiquarks: experimental facts versus QCD inspired concepts*, *Phys. Rept.* **454** (2007) 1 [hep-ph/0708.4016].]

[8] P. Colangelo, F. De Fazio, F. Giannuzzi, and S. Nicotri, *New meson spectroscopy with open charm and beauty*, *Phys. Rev.* **D86** (2012) 054024 [hep-ph/1207.6940].]

[9] B. Aubert *et al.* (BABAR Collaboration), *Observation of a narrow meson decaying to $D_s^+\pi^0$ at a mass of* $2.32\,GeV/c^2$, *Phys. Rev. Lett.* **90** (2003) 242001 [hep-ex/0304021].

[10] R. Aaij *et al.* (LHCb Collaboration), *Observation of overlapping spin-1 and spin-3 $\bar{D}^0K^-$ resonances at mass* $2.86\,GeV/c^2$, *Phys. Rev. Lett.* **113** (2014) 162001 [hep-ex/1407.7574].

[11] R. Aaij *et al.* (LHCb Collaboration), *Dalitz plot analysis of $B_s^0 \to \bar{D}^0 K^- \pi^+$ decays*, *Phys. Rev.* **D90** (2014) 072003 [hep-ex/1407.7712].

[12] T. Skwarnicki, *A study of the radiative cascade transitions between the Upsilon-prime and Upsilon resonances*, PhD thesis, Institute of Nuclear Physics, Krakow, 1986

[13] R. Aaij *et al.* (LHCb Collaboration), *Measurement of the branching fractions of $B_s^0 \to \bar{D}^0 K^- \pi^+$ and $B^0 \to \bar{D}^0 K^- \pi^+$*, *Phys. Rev.* **D87** (2013) 112009 [hep-ex/1304.6317].

[14] R. Aaij *et al.* (LHCb Collaboration), *Studies of beauty baryon decays to $D^0 ph$ and $\Lambda_c^+ h$ final states*, *Phys. Rev.* **D89** (2014) 032001 [hep-ex/1311.4823].

[15] Laura++ Dalitz plot fitting package, http://laura.hepforge.org/

[16] G.N. Fleming, *Recoupling effects in the isobar model. 1. General formalism for three-pion scattering*, *Phys. Rev.* **135** (1964) B551.

[17] D. Morgan, *Phenomenological analysis of $I = \frac{1}{2}$ single-pion production processes in the energy range 500 to 700 MeV*, *Phys. Rev.* **166** (1968) 1731.

[18] D. Herndon, P. Soding, and R. J. Cashmore, *A generalised isobar model formalism*, *Phys. Rev.* **D11** (1975) 3165.

[19] D. Aston *et al.* (LASS Collaboration), *A study of $K^- \pi^+$ scattering in the reaction $K^- p \to K^- \pi^+ n$ at 11 GeV/c*, *Nucl. Phys.* **B296** (1988) 493.