PROCEEDINGS OF SCIENCE

Recent LHCb results on pentaquark candidates

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The recent LHCb results related to searches for pentaquark candidates are reported. There are evidences for two new pentaquark candidates $P_c(4337)^+$ and $P_{cs}(4459)^0$ obtained from amplitude analysis of $B_s^0 \to J/\psi p\overline{p}$ and $\Xi_b^- \to J/\psi \Lambda K^-$ decays, respectively.

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1. Introduction

Beyond the naive quark model, the exotic hadrons, such as pentaquarks containing four quarks and one antiquark, are expected from the theory of QCD. The observation of three pentaquark candidates at LHCb [1], $P_c(4312)^+$, $P_c(4440)^+$, and $P_c(4457)^+$, indicates the interesting physics related to the thresholds of the charmed mesons and baryons.

The evidences for new structure $P_c(4337)^+$ in $B_s^0 \to J/\psi p\overline{p}$ decays and $P_{cs}(4459)^0$ in $\Xi_b^- \to J/\psi \Lambda K^-$ decays found at LHCb are present.

2. Evidence for $P_c(4337)^+$ in $B_s^0 \to J/\psi p\overline{p}$ decays

The $B_s^0 \to J/\psi p\overline{p}$ decays are first observed using $5.2fb^{-1}$ data collected by the LHCb experiment [2]. The measured branching fraction of $B_s^0 \to J/\psi p\overline{p}$ decays, much higher than the expectation without resonant contributions, indicates the possible pentaquark candidates in $J/\psi p$ system, and glueball or enhancement in $p\overline{p}$ system. The $J/\psi p$ mass distribution in the range [4040,4440] MeV is sensitive to the search for $P_c(4312)^+$, while the $p\overline{p}$ mass distribution for the possible glueball candidate $f_J(2220)$. The thresholds of $\Lambda_c^+\overline{D}^0$ and $\Lambda_c^+\overline{D}^{*0}$, around which possible structures might be, are also covered in $B_s^0 \to J/\psi p\overline{p}$ decays.

An amplitude analysis of flavour-untagged $B_s^0 \to J/\psi p\overline{p}$ decays is performed using $9fb^{-1}$ data collected at LHCb [3]. About 800 signals are reconstructed with purity of 85%. There are hints of horizontal and vertical bands in the region around (18.8-19.0) GeV^2 as present in the $m^2(J/\psi p)$ and $m^2(J/\psi\overline{p})$ distributions, respectively, as shown in Dalitz plot in Figure 1.

The amplitude model is constructed using helicity formalism under the assumption of CP symmetry conservation. Three interfering decay chains are considered in the amplitude model: $B_s^0 \to J/\psi X(\to p\overline{p})$, $B_s^0 \to P_c^+(\to J/\psi p)\overline{p}$, and $B_s^0 \to P_c^-(\to J/\psi\overline{p})p$, as J/ψ is reconstructed by $\mu^+\mu^-$ pair. Since there is no flavour identification for B_s^0 or $\overline{B}_s^0$, the amplitude analysis is sensitive to the sum of the possible contributions from P_c^+ and P_c^- states and not sensitive to different couplings for the P_c^+ and P_c^- states.

The baseline model includes a nonresonant (NR) contribution $X \to p\overline{p}$ with spin-parity quantum number equal to $J^P = 1^-$, which has S waves in both X's production and decay. The higher values of orbital momentum for X contributions are suppressed due to low $Q-$value in the decay. Models including different NR contributions with other quantum numbers are excluded as a result of significantly worse values of $-2\log\mathcal{L}$ with respect to the $J^P = 1^-$ hypothesis. The fit results of the baseline model are in blue as shown in Figure 2. The baseline model does not describe data well, as discrepancies found in $cos\theta_p$, $m(J/\psi p)$ and $m(J/\psi\overline{p})$ distributions.

In addition to the contributions in the baseline mode, the default model includes two contributions $P_c^+ \to J/\psi p$ and $P_c^- \to J/\psi\overline{p}$ with the same masses, widths and couplings. The projections of angular and mass distributions are improved as shown in Figure 2. Different J^P hypotheses for P_c are tested and the signal significance in the range of 3.1 to 3.7σ provides the evidence for a new pentaquark candidate. Due to the limited sample size, none of the J^P hypotheses can be excluded at 95% confidence level using the CL$_s$ method. The mass and width of this new pentaquark candidate $P_c(4337)^+$ are measured to be $M_{P_c} = 4337^{+7+2}_{-4-2}$ MeV and $\Gamma_{P_c} = 29^{+26+14}_{-12-14}$ MeV, respectively. There

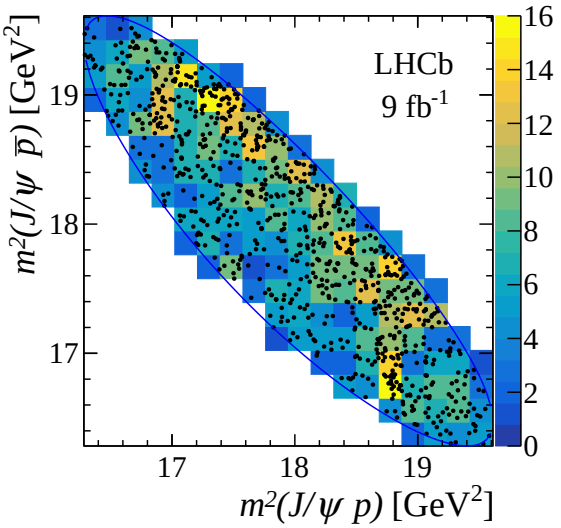

Figure 1: Dalitz distribution for reconstructed candidates (black dots) within the B_s^0 signal region. The colour scale represents the number of candidates in each Dalitz plot interval.

is no evidence for either $P_c(4313)^+$, or the glueball state $f_J(2220)$, or threshold enhancement in $p\overline{p}$ system.

3. Evidence for $P_{cs}(4459)^0$ in $\Xi_b^- \to J/\psi\Lambda K^-$ decays

The $\Xi_b^- \to J/\psi\Lambda K^-$ decays are first observed using $3fb^{-1}$ data collected by the LHCb experiment [4]. The strange counterparts of P_c^+s, denoted as P_{cs}^0, are predicted in several papers and has been suggested to search for in $\Xi_b^- \to J/\psi\Lambda K^-$ decays. The excited Ξ^- spectrum in a mass range of [1.61,2.70] GeV, can be studied in $\Xi_b^- \to J/\psi\Lambda K^-$ decays.

An amplitude analysis of the $\Xi_b^- \to J/\psi\Lambda K^-$ decays is performed using $9fb^{-1}$ data collected at LHCb [5]. About 1750 signals are reconstructed with purity of 80%. The $\Xi(1690)^-$ and $\Xi(1820)^-$ resonances are obvious, while no clear hint for P_{cs}^0 in the Dalitz plot Figure 3.

The amplitude model is constructed using helicity formalism, following a similar strategy in amplitude analysis of $\Lambda_b^0 \to J/\psi pK^-$ decays [6]. Two interfering decay chains are considered in the amplitude model: $\Xi_b^- \to J/\psi\Xi^{*-}(\to \Lambda K^-)$ and $\Xi_b^- \to P_{cs}^0(\to J/\psi\Lambda)K^-$, as J/ψ is reconstructed by $\mu^+\mu^-$ pair and Λ is reconstructed by proton and π^-.

The default amplitude model includes four excited Ξ^{*-} resonances, $\Xi(1690)^-$, $\Xi(1820)^-$, $\Xi(1950)^-$ and $\Xi(2030)^-$, NR(ΛK^-) contribution with spin-parity quantum number equal to $J^P = 1/2^-$, and a single P_{cs}^0 contribution. The default model can describe data well, as shown in Figure 4. A statistical significance of 4.3σ for $P_{cs}(4459)^0$ is obtained, while 3.1σ including systematic uncertainties and look-elsewhere effect. This is the first evidence for the hidden-charm pentaquark with strangeness. The mass and width of this new pentaquark candidate $P_{cs}(4459)^0$ are measured to be $M_{P_{cs}} = 4458.8 \pm 2.9^{+4.7}_{-1.1}$ MeV and $\Gamma_{P_{cs}} = 17.3 \pm 6.5^{+8.0}_{-5.7}$ MeV, respectively. Two Ξ^{*-} states, $\Xi(1690)^-$ and $\Xi(1820)^-$, are observed for the first time in Ξ_b^- decays. Due to the limited sample size, the spin-parity quantum number of P_{cs}^0 and Ξ^{*-} resonances can not be determined.

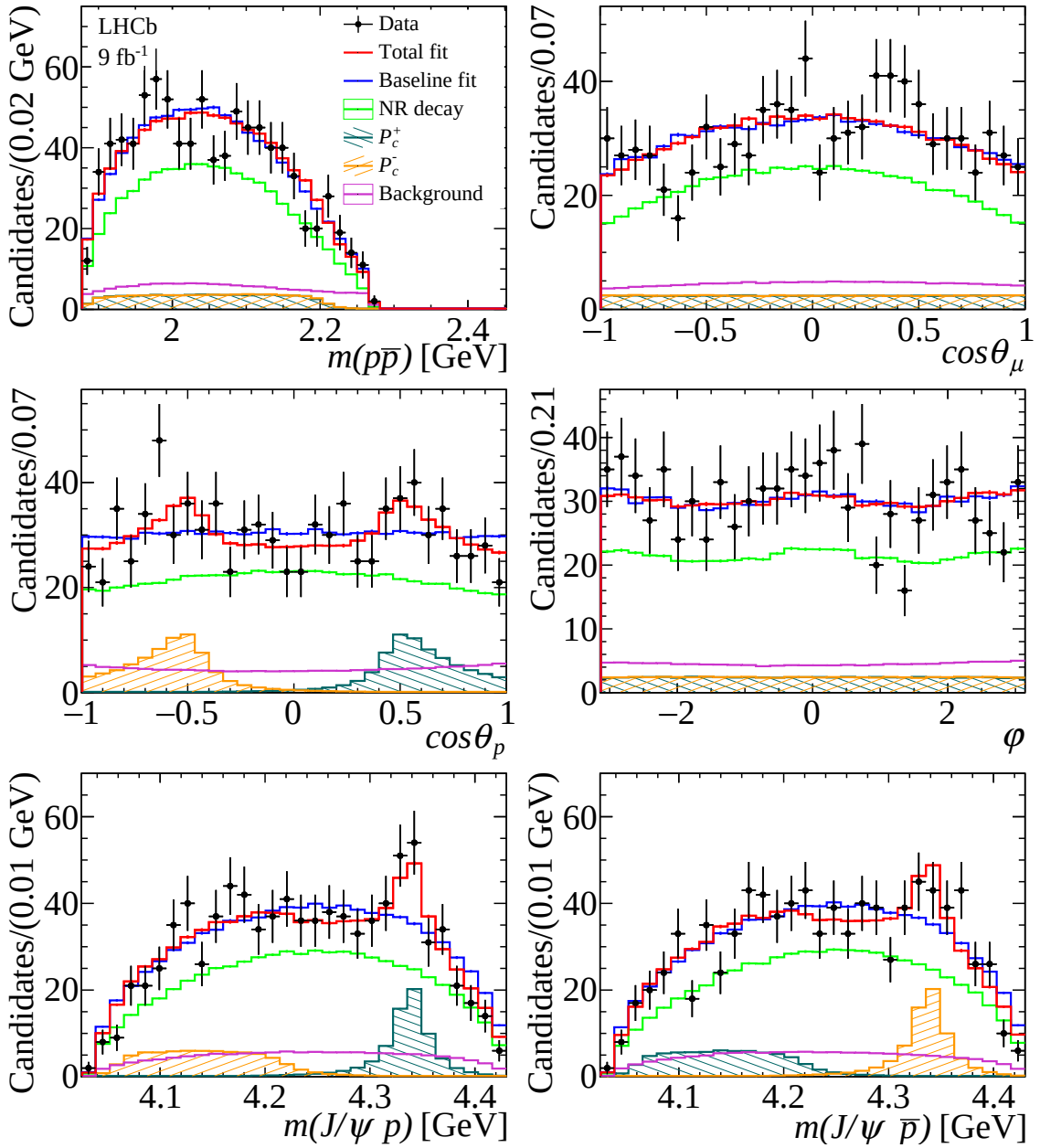

Figure 2: One-dimensional projections of the angular $(\cos\theta_\mu, \cos\theta_p, \varphi)$ and invariant-mass distributions $(m(p\overline{p}), m(J/\psi p), m(J/\psi\overline{p}))$, superimposed with the results of the fit from the baseline model (blue) and the default model (red) comprising a NR term and the P_c contribution.

4. Summary

In summary, there are evidences for two new pentaquark candidates $P_c(4337)^+$ and $P_{cs}(4459)^0$ in $B_s^0 \to J/\psi p\overline{p}$ and $\Xi_b^- \to J/\psi\Lambda K^-$ decays, respectively. The $P_c(4312)^+$ observed in [1] is not confirmed, and no evidence for possible glueball candidate $f_J(2220)$ and enhancement in $p\overline{p}$ system from amplitude analysis of $B_s^0 \to J/\psi p\overline{p}$ decays.

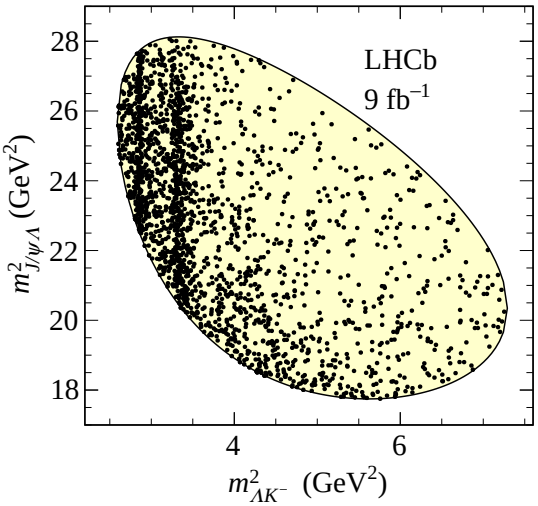

Figure 3: Dalitz plot for all candidates within ±15 MeV of the known Ξ_b^- mass. The yellow area shows the kinematically allowed region.

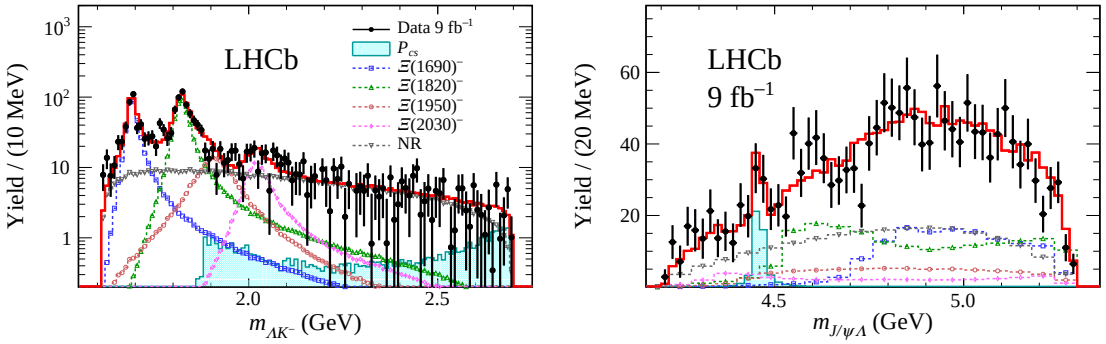

Figure 4: One-dimensional projections of mass distributions (a) $m_{\Lambda K^-}$ and (b) $m_{J/\psi\Lambda}$ superimposed with the results of the fit with the P^0_{cs} contribution.

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