Hidden-Charm Pentaquark Production in Weak Decays of Bottom Hadrons

Alexander Parkhomenko

P. G. Demidov Yaroslavl State University, Yaroslavl, Russia

22nd International Seminar on High Energy Physics "QUARKS-2024"
Pereslavl-Zalessky, Russia, May 20 — 24, 2024

Outline

- Introduction
- Pentaquark Production in Bottom Baryon Decays
- Pentaquark Production in B-Meson Decays
- Conclusions

Bottom Baryon Decays

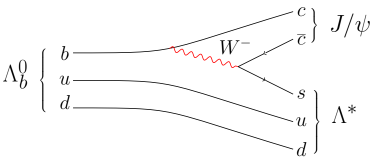
Introduction

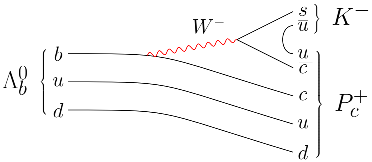
- Production, properties, and decays of heavy baryons are intensively studied both experimentally and theoretically
- Λ_b-baryon is a bound state of heavy b-quark and a pair of light u- and d-quarks
- It decays due to weak interactions
- Mass and lifetime of Λ_b-baryon

$$m_{\Lambda_b} = 5619.51 \pm 0.23\,\text{MeV}, \quad \tau_{\Lambda_b} = (1.466 \pm 0.010) \times 10^{-12}\,\text{sec}$$

- At present, experimentally known more than 40 decay channels with branching fractions exceeded 10^{-6}
- Exotic resonances are found in $\Lambda_b \to p + K^- + J/\psi$ and $\Lambda_b \to p + \pi^- + J/\psi$ decays
- They are interpreted as pentaquarks

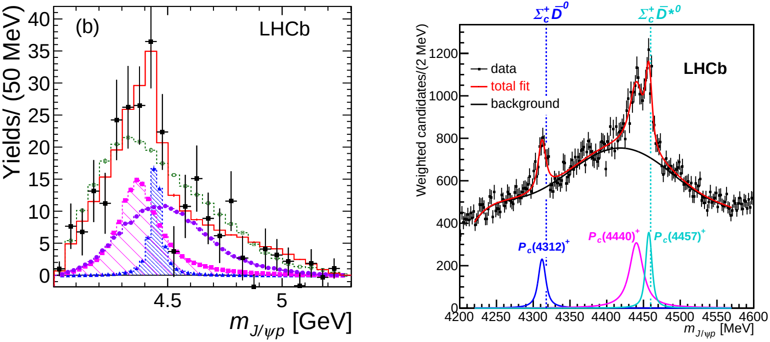
- In addition to the non-resonant channel, there are two different quasi-two-particle decay channels of Λ_b-baryon [LHCb Collab., Phys. Rev. Lett. 115 (2015) 072001]
  1. $\Lambda_b \to \Lambda^* + J/\psi$, where the Λ-hyperon or its excited states are produced and decay subsequently $\Lambda^* \to p + K^-$
  2. $\Lambda_b \to P_c^J + K^-$, where the P_c^J-pentaquark with spin J is produced and decays through the channel $P_c^J \to p + J/\psi$



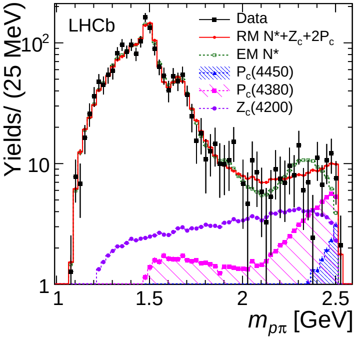


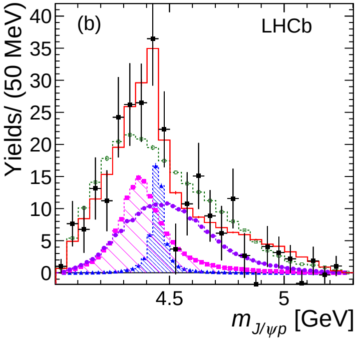
LHCb results on $\Lambda_b \to p + K^- + J/\psi$ decay

- In 2015, one narrow and one wide resonances interpreted as hidden-charm pentaquarks were found [LHCb Collab., Phys. Rev. Lett. 115 (2015) 072001]
- In 2019, three narrow pentaquark resonances were observed [LHCb Collab., Phys. Rev. Lett. 122 (2019) 222001]



- Evidence of these resonances was also pointed out in the other decay $\Lambda_b \to p + J/\psi + \pi^-$ [LHCb, PRL, 2016]
- Combined significance is calculated to be 3.1σ
- Contributions from pentaquarks are shown as shaded





Strange Ξ_b-baryons

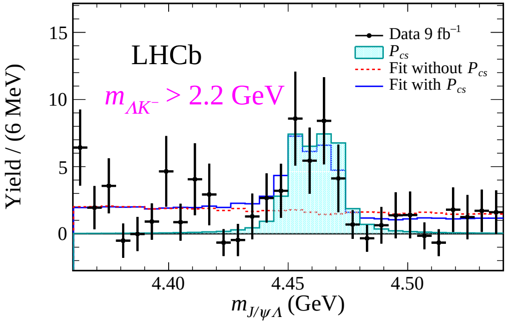
- Ξ_b-baryons are bound states of heavy b-quark, strange s-quark and one from u- or d-quarks
- Ξ_b^0- and Ξ_b^--baryons, having the quark content *bsu* and *bsd*, respectively, and entering the $SU(3)_F$anti-triplet together with Λ_b-baryon, are also decaying weakly

$$m_{\Xi_b^0} = 5791.9 \pm 0.5 \ \mathrm{MeV}, \quad \tau_{\Xi_b^0} = (1.480 \pm 0.030) \times 10^{-12} \ \mathrm{sec}$$
$$m_{\Xi_b^-} = 5797.0 \pm 0.6 \ \mathrm{MeV}, \quad \tau_{\Xi_b^-} = (1.572 \pm 0.040) \times 10^{-12} \ \mathrm{sec}$$

- Only 4 decay chanels of Ξ_b^0-baryon and 9 modes of Ξ_b^--baryon are measured experimentally
- In the $\Xi_b^- \to \Lambda^0 + J/\psi + K^-$ decay, there is an evidence of exotic resonance interpreted as pentaquark

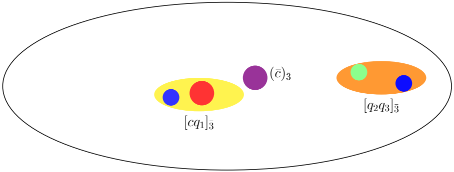
Evidence of strange $P_{cs}(4459)$ pentaquark

- Resonance is found in $\Xi_b^- \to \Lambda^0 + J/\psi + K^-$ decay [LHCb Collab., Sci. Bull. 66 (2021) 1278]
- Its mass $M_{P_{cs}} = 4458.8 \pm 2.9^{+4.7}_{-1.1}$ MeV and decay width $\Gamma_{P_{cs}} = 17.3 \pm 6.5^{+8.0}_{-5.7}$ MeV
- Two-resonance structure of the peak is not excluded
- Spin-parity is not defined
- Statistical significance is 3.1σ



Existing theoretical models of pentaquarks

- Several dynamical models of pentaquarks are suggested:
  1. baryon-meson model (molecular pentaquark);
  2. triquark-diquark model;
  3. diquark-diquark-antiquark model;
  4. ...
- For example, in the diquark-diquark-antiquark model, dynamics is determined by interaction of light diquark $[q_2 q_3]$, heavy diquark $[c q_1]$ and c-antiquark, where q_i is one of the light u-, d- or s-quarks [A. Ali et al., JHEP 10 (2019) 256]



Hadron classification under flavor $SU(3)_F$ group

- Pentaquark production can be studied based on the approximate flavor $SU(3)_F$ symmetry between light quarks
- Hadrons, being bound states of quarks and/or antiquarks, can be classified according to the flavor $SU(3)_F$ group irreducible representations
- Each multiplet includes particles with the same spin-parity J^P and approximately the same masses
- Within the multiplet, particles differ by the third isospin projection I_3 and strong hypercharge Y
- $SU(3)_F$ representations: singlet (1), triplet (3), anti-triplet ($\bar{3}$), sextet (6), anti-sextet ($\bar{6}$), octet (8), decuplet (10), anti-decuplet ($\overline{10}$), etc.

Triplets of Light Quarks and B-Mesons

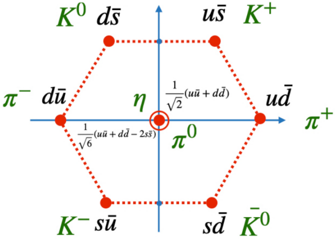
- $SU(3)_F$-triplet of light quarks $\quad q_i = (u, d, s)^T$
- $SU(3)_F$-anti-triplet of light antiquarks $\quad \bar{q}^i = (\bar{u}, \bar{d}, \bar{s})$
- b- and c-quarks and their antiquarks are $SU(3)_F$-singlets
- Pseudoscalar B-mesons with the spin-parity $J^P = 0^-$ form flavor triplet and anti-triplet

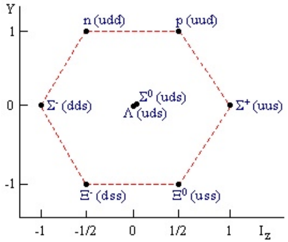
$$B_i\,(3) = \left(\bar{b}u,\ \bar{b}d,\ \bar{b}s\right)^T = \left(B^+,\ B^0,\ B_s^0\right)^T$$

$$\bar{B}^i\,(\bar{3}) = \left(\bar{u}b,\ \bar{d}b,\ \bar{s}b\right) = \left(B^-,\ \bar{B}^0,\ \bar{B}_s^0\right)$$

- Pseudoscalar mesons and ordinary baryons with spin-parity $J^P = 1/2^+$ are members of the $SU(3)_F$ octets

$$\mathcal{M}_i^j = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\frac{2\eta_8}{\sqrt{6}} \end{pmatrix} \qquad \mathcal{B}_i^j = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda^0}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda^0}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda^0}{\sqrt{6}} \end{pmatrix}$$





- Ordinary baryons with $J^P = 3/2^+$ are combined into the $SU(3)_F$ decuplet

Octet and decuplet of pentaquarks

- Octet of pentaquarks differs from ordinary baryons by the presence of $\bar{c}c$-pair which is the $SU(3)_F$-singlet

$$\mathcal{P}_i^j\left(J^P\right) = \begin{pmatrix} \frac{P_{\psi s}^{\Lambda 0}}{\sqrt{6}} + \frac{P_{\psi s}^{\Sigma 0}}{\sqrt{2}} & P_{\psi s}^{\Sigma +} & P_{\psi}^{N+} \\ P_{\psi s}^{\Sigma -} & \frac{P_{\psi s}^{\Lambda 0}}{\sqrt{6}} - \frac{P_{\psi s}^{\Sigma 0}}{\sqrt{2}} & P_{\psi}^{N0} \\ P_{\psi ss}^{\Xi' -} & P_{\psi ss}^{\Xi 0} & -\frac{2P_{\psi s}^{\Lambda 0}}{\sqrt{6}} \end{pmatrix}$$

- $P_c^+ \equiv P_{\psi}^{N+}$ and $P_{cs} \equiv P_{\psi s}^{\Lambda 0}$ are known experimentally
- $SU(3)_F$ decuplet of hidden-charm pentaquarks is described by totally symmetric third-rank tensor, $\mathcal{P}_{ijk}$, similarly to the decuplet of $J^P = 3/2^+$ ordinary baryons

$$\mathcal{P}_{111} = P_{\psi}^{\Delta ++},\ \mathcal{P}_{112} = P_{\psi}^{\Delta +}/\sqrt{3},\ \mathcal{P}_{122} = P_{\psi}^{\Delta 0}/\sqrt{3},\ \mathcal{P}_{222} = P_{\psi}^{\Delta -},$$
$$\mathcal{P}_{113} = P_{\psi s}^{\Sigma +}/\sqrt{3},\ \mathcal{P}_{123} = P_{\psi s}^{\Sigma 0}/\sqrt{6},\ \mathcal{P}_{223} = P_{\psi s}^{\Sigma -}/\sqrt{3},$$
$$\mathcal{P}_{133} = P_{\psi ss}^{\Xi 0}/\sqrt{3},\ \mathcal{P}_{233} = P_{\psi ss}^{\Xi -}/\sqrt{3},\ \mathcal{P}_{333} = P_{\psi sss}^{\Omega -}$$

$SU(3)_F$ classification of bottom baryons with $J^P = 1/2^+$

- Anti-triplet of bottom baryons

$$\mathcal{B}^{ij}\left(\bar{3}\right) = -\mathcal{B}^{ji}\left(\bar{3}\right) = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & \Lambda_b^0 & -\Xi_b^0 \\ -\Lambda_b^0 & 0 & \Xi_b^- \\ \Xi_b^0 & -\Xi_b^- & 0 \end{pmatrix}$$

$$\mathcal{B}_a\left(\bar{3}\right) = \frac{1}{\sqrt{2}}\varepsilon_{aij}\,\mathcal{B}^{ij}\left(\bar{3}\right) = \left(\Xi_b^-,\, \Xi_b^0,\, \Lambda_b^0\right)$$

- Sextet of bottom baryons

$$\mathcal{B}^{kl}\left(6\right) = \mathcal{B}^{lk}\left(6\right) = \frac{1}{\sqrt{2}}\begin{pmatrix} \sqrt{2}\,\Sigma_b^+ & \Sigma_b^0 & \Xi_b^{\prime 0} \\ \Sigma_b^0 & \sqrt{2}\,\Sigma_b^- & \Xi_b^{\prime -} \\ \Xi_b^{\prime 0} & \Xi_b^{\prime -} & \sqrt{2}\,\Omega_b^- \end{pmatrix}$$

Effective weak Hamiltonians

- $\mathcal{B} \to \mathcal{P} + \mathcal{M}$ decays considered are due to weak interactions

$$H_{\text{eff}}^{W} = \frac{G_F}{\sqrt{2}} \sum_{q=d,s} V_{cb} V_{cq}^{*} \left(C_1\, O_1^{(q)} + C_2\, O_2^{(q)} \right) + \mathrm{h.\,c.}$$

- G_F is the Fermi constant
- V_{ij} are Cabibbo-Kobayashi-Maskawa matrix elements
- C_i are Wilson coefficients
- Four-quark operators $O_i^{(q)}$, where $q = d,\ s$

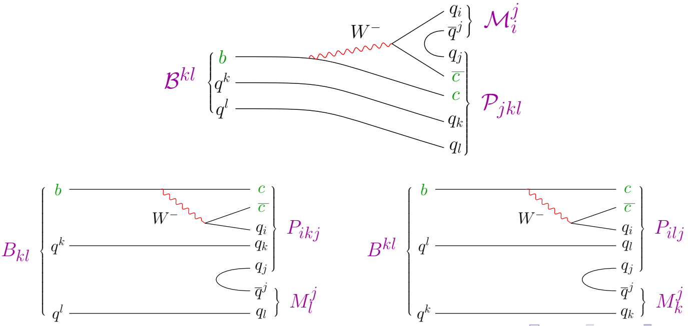
$$O_1^{(q)} = [\bar{q}_\alpha \gamma_\mu (1 - \gamma_5) c_\alpha]\, [\bar{c}_\beta \gamma^\mu (1 - \gamma_5) b_\beta]$$

$$O_2^{(q)} = [\bar{q}_\alpha \gamma_\mu (1 - \gamma_5) c_\beta]\, [\bar{c}_\beta \gamma^\mu (1 - \gamma_5) b_\alpha]$$

- $\alpha,\ \beta = 1,\ 2,\ 3$ are color indices
- Operators $O_i^{(q)}$ are flavor $SU(3)_F$ anti-triplets

Feynman diagrams for $\mathcal{B} \to \mathcal{P} + \mathcal{M}$ decay

- Three diagrams contribute to the decay amplitude
- Contribution of each is denoted by T_i ($i = 1, 2, 3$) for pentaquarks from the octet and t_i from the decuplet
- Heavy Quarks Symmetry (HQS) reduces their number to one, T_1 or t_1, which enters the upper diagram
- In this diagram, diquark is a spectator and moves from heavy baryon to pentaquark without changing its spin and parity



Decay amplitude

- General expression for the baryon decay amplitude into pentaquarks and mesons

$$\mathcal{A} = \left\langle \mathcal{P}\mathcal{M} \left| H_{\text{eff}}^{W} \right| \mathcal{B} \right\rangle$$

- Under $SU(3)_F$-group, effective weak Hamiltonian, H_{eff}^{W}, is the $SU(3)_F$ anti-triplet
- Particle called spurion can be used instead: $H_{\text{eff}}^{W} \to H\left(\bar{3}\right)^{i}$
- Decay process is replaced by the baryon-spurion scattering

$$\mathcal{B} + H\left(\bar{3}\right) \to \mathcal{P} + \mathcal{M} \quad \Longrightarrow \quad \mathcal{A} = \langle \mathcal{P}\,\mathcal{M} | H\left(\bar{3}\right) \mathcal{B} \rangle$$

- Decay amplitude $A^J_{t8}(q)$, where $q = d$ or s, of b-baryons from anti-triplet $\mathcal{B}_a$ and from sextet $\mathcal{B}^{kl}$ into pentaquarks from octet $\mathcal{P}^j_i$ and pseudoscalar mesons $\mathcal{M}^j_i$

$$
\begin{aligned}
A^J_{t8}(q) \quad = \quad & \left(T^J_1 - T^J_2\right)\left\langle \mathcal{P}^a_j \mathcal{M}^j_i \,|\, H\left(\bar{3}\right)^i \mathcal{B}_a \right\rangle + T^J_2 \left\langle \mathcal{P}^i_j \mathcal{M}^j_i \,|\, H\left(\bar{3}\right)^a \mathcal{B}_a \right\rangle \\
& + T^J_3 \left\langle \mathcal{P}^a_i \mathcal{M}^j_j \,|\, H\left(\bar{3}\right)^i \mathcal{B}_a \right\rangle - T^J_3 \left\langle \mathcal{P}^l_i \mathcal{M}^a_l \,|\, H\left(\bar{3}\right)^i \mathcal{B}_a \right\rangle \\
& + t^J_1 \left\langle \mathcal{P}^a_l \mathcal{M}^j_i \,|\, H\left(\bar{3}\right)^i \mathcal{B}^{kl} \right\rangle \varepsilon_{jka} + t^J_2 \left\langle \mathcal{P}^a_j \mathcal{M}^j_l \,|\, H\left(\bar{3}\right)^i \mathcal{B}^{kl} \right\rangle \varepsilon_{ika} \\
& + t^J_3 \left\langle \mathcal{P}^a_i \mathcal{M}^j_l \,|\, H\left(\bar{3}\right)^i \mathcal{B}^{kl} \right\rangle \varepsilon_{akj}
\end{aligned}
$$

- Decay amplitude $A^J_{t10}(q)$ of b-baryons from anti-triplet $\mathcal{B}_a$ and from sextet $\mathcal{B}^{kl}$ into pentaquarks from decuplet $\mathcal{P}_{ijk}$ and pseudoscalar mesons $\mathcal{M}^j_i$

$$
\begin{aligned}
A^J_{t10}(q) \quad = \quad & \overline{T}^J_2 \, \varepsilon^{kla} \left\langle \mathcal{P}_{ijk} \mathcal{M}^j_l \,|\, H\left(\bar{3}\right)^i \mathcal{B}_a \right\rangle \\
& + \bar{t}^J_1 \left\langle \mathcal{P}_{jkl} \mathcal{M}^j_i \,|\, H\left(\bar{3}\right)^i \mathcal{B}^{kl} \right\rangle + \bar{t}^J_2 \left\langle \mathcal{P}_{ijk} \mathcal{M}^j_l \,|\, H\left(\bar{3}\right)^i \mathcal{B}^{kl} \right\rangle
\end{aligned}
$$

Decay amplitudes of Λ_b-baryon

Decay modes	Amplitudes
$\Lambda_b^0 \to P_{\psi}^{N+}\pi^-$	$\Delta T = T_1 - T_2$
$\Lambda_b^0 \to P_{\psi}^{N0}\pi^0$	$-\frac{1}{\sqrt{2}}\,\Delta T$
$\Lambda_b^0 \to P_{\psi}^{N0}\eta$	$\frac{1}{2\sqrt{3}}\left[\sqrt{2}\cos\theta - 2(C_0 - 1)\sin\theta\right](\Delta T + 2T_3)$
$\Lambda_b^0 \to P_{\psi}^{N0}\eta'$	$\frac{1}{2\sqrt{3}}\left[2(C_0 - 1)\cos\theta + \sqrt{2}\sin\theta\right](\Delta T + 2T_3)$
$\Lambda_b^0 \to P_{\psi s}^{\Sigma 0}K^0$	$\frac{1}{\sqrt{2}}\,T_3$
$\Lambda_b^0 \to P_{\psi s}^{\Lambda}K^0$	$-\frac{1}{\sqrt{6}}\,(2\,\Delta T + T_3)$
$\Lambda_b^0 \to P_{\psi s}^{\Sigma -}K^+$	$-T_3$

- T_i ($i = 1,\, 2,\, 3$) is a strength of the i-th Feynman diagram in the total decay amplitude $\mathcal{A}_{t8}(d)$
- θ is the mixing angle between η- and η'-meson states
- C_0 is the coefficient relevant for $U(3)_F \to SU(3)_F$ symmetry breaking ($U(3)_F$-symmetry recovers at $C_0 = 0$)

b-baryon decay widths

- Definition of decay width

$$\Gamma(\mathcal{B} \to \mathcal{P} + \mathcal{M}) = \frac{1}{2M_{\mathcal{B}}} \frac{1}{2J+1} \sum_{\lambda} |\mathcal{A}|^2 \, \Phi^{(2)}$$

- $M_{\mathcal{B}}$ and J are the mass and spin of initial baryon
- $\Phi^{(2)}$ is the two-particle phase space
- As far as one decay width is known, decay widths of other particles from the b-baryon multiplet can be calculated
- After the difference in particle masses from the multiplet is neglected, the ratio of decay widths reduces to the ratio of decay amplitudes squared

$$\frac{\Gamma_2}{\Gamma_1} \simeq \frac{\sum_{\lambda} |A_2|^2}{\sum_{\lambda} |A_1|^2}$$

Numerical results for $R(\mathcal{P}\,\mathcal{M}/P_\psi^{N+}\,K^-)$

- Hidden-charm pentaquarks are observed in $\Lambda_b^0 \to P_\psi^{N+}\,K^-$
- Widths of other decay modes can be compared with $\Gamma(\Lambda_b^0 \to P_\psi^{N+}\,K^-)$ through the ratio

$$R(\mathcal{P}\,\mathcal{M}/P_\psi^{N+}\,K^-) = \Gamma(\mathcal{B} \to \mathcal{P}\,\mathcal{M})/\Gamma(\Lambda_b^0 \to P_\psi^{N+}\,K^-)$$

- Decays due to $\Delta S = -1$ transition (or $b \to s\bar{c}c$) are presented
- HQS limit is considered ($T_2 = T_3 = 0$ and $t_2 = t_3 = 0$)

Decay mode	$R(\mathcal{P}\,\mathcal{M}/P_\psi^{N+}\,K^-)$	Decay mode	$R(\mathcal{P}\,\mathcal{M}/P_\psi^{N+}\,K^-)$
$\Lambda_b^0 \to P_\psi^{N0}\bar{K}^0$	1	$\Lambda_b^0 \to P_{\psi s}^{\Lambda 0}\eta$	$\lvert 0.11 + 0.47\,(C_0 - 1)\rvert^2$
$\Lambda_b^0 \to P_{\psi s}^{\Lambda 0}\eta'$	$\lvert 0.66 + 0.08\,(C_0 - 1)\rvert^2$	$\Xi_b^0 \to P_{\psi s}^{\Sigma +}K^-$	1
$\Xi_b^0 \to P_{\psi s}^{\Sigma 0}\bar{K}^0$	$1/2$	$\Xi_b^0 \to P_{\psi ss}^{\Xi 0}\eta$	$\lvert 0.13 + 0.57\,(C_0 - 1)\rvert^2$
$\Xi_b^0 \to P_{\psi ss}^{\Xi 0}\eta$	$\lvert 0.13 + 0.57\,(C_0 - 1)\rvert^2$	$\Xi_b^0 \to P_{\psi s}^{\Lambda 0}\bar{K}^0$	$1/6$
$\Xi_b^- \to P_{\psi s}^{\Sigma -}\bar{K}^0$	1	$\Xi_b^- \to P_{\psi s}^{\Sigma 0}K^-$	$1/2$
$\Xi_b^- \to P_{\psi ss}^{\Xi -}\eta$	$\lvert 0.13 + 0.57\,(C_0 - 1)\rvert^2$	$\Xi_b^- \to P_{\psi ss}^{\Xi -}\eta'$	$\lvert 0.81 + 0.09\,(C_0 - 1)\rvert^2$
$\Xi_b^- \to P_{\psi s}^{\Lambda}(4459)^0 K^-$	$1/6$	$\Omega_b^- \to P_{\psi ss}^{\Xi' 0}K^-$	$\lvert t_1/T_1\rvert^2$
$\Omega_b^- \to P_{\psi ss}^{\Xi' -}\bar{K}^0$	$\lvert t_1/T_1\rvert^2$		

Numerical results for $R(\mathcal{P}\,\mathcal{M}/P_{\psi}^{N+}\,\pi^-)$

- Evidence of hidden-charm pentaquarks in $\Lambda_b^0 \to P_{\psi}^{N+}\,\pi^-$
- Widths of other decay modes can be also compared with $\Gamma(\Lambda_b^0 \to P_{\psi}^{N+}\,\pi^-)$ through the ratio

$$R(\mathcal{P}\,\mathcal{M}/P_{\psi}^{N+}\,\pi^-) = \Gamma(\mathcal{B} \to \mathcal{P}\,\mathcal{M})/\Gamma(\Lambda_b^0 \to P_{\psi}^{N+}\,\pi^-)$$

- Decays due to $\Delta S = 0$ transition (or $b \to d\bar{c}c$) are presented

Decay mode	$R(\mathcal{P}\,\mathcal{M}/P_{\psi}^{N+}\,\pi^-)$	Decay mode	$R(\mathcal{P}\,\mathcal{M}/P_{\psi}^{N+}\,\pi^-)$
$\Lambda_b^0 \to P_{\psi}^{N0}\pi^0$	$1/2$	$\Lambda_b^0 \to P_{\psi}^{N0}\eta$	$\lvert 0.07 - 0.57\,(C_0 - 1)\rvert^2$
$\Lambda_b^0 \to P_{\psi}^{N0}\eta'$	$\lvert 0.40 + 0.09\,(C_0 - 1)\rvert^2$	$\Lambda_b^0 \to P_{\psi s}^{\Lambda 0}K^0$	$2/3$
$\Xi_b^0 \to P_{\psi s}^{\Sigma+}\pi^-$	1	$\Xi_b^0 \to P_{\psi s}^{\Sigma 0}\pi^0$	$1/4$
$\Xi_b^0 \to P_{\psi ss}^{\Xi 0}K^0$	1	$\Xi_b^0 \to P_{\psi s}^{\Lambda 0}\eta$	$\lvert 0.03 + 0.23\,(C_0 - 1)\rvert^2$
$\Xi_b^0 \to P_{\psi s}^{\Lambda 0}\eta'$	$\lvert 0.16 + 0.04\,(C_0 - 1)\rvert^2$	$\Xi_b^0 \to P_{\psi s}^{\Sigma 0}\eta$	$\lvert 0.05 - 0.40\,(C_0 - 1)\rvert^2$
$\Xi_b^0 \to P_{\psi s}^{\Sigma 0}\eta'$	$\lvert 0.28 - 0.07\,(C_0 - 1)\rvert^2$	$\Xi_b^0 \to P_{\psi s}^{\Lambda 0}\pi^0$	$1/12$
$\Xi_b^- \to P_{\psi s}^{\Sigma -}K^0$	1	$\Xi_b^- \to P_{\psi s}^{\Sigma -}\eta$	$\lvert 0.07 - 0.57\,(C_0 - 1)\rvert^2$
$\Xi_b^- \to P_{\psi s}^{\Sigma -}\eta'$	$\lvert 0.40 + 0.09\,(C_0 - 1)\rvert^2$	$\Xi_b^- \to P_{\psi s}^{\Sigma -}\pi^0$	$1/2$
$\Xi_b^- \to P_{\psi s}^{\Sigma 0}\pi^-$	$1/2$	$\Xi_b^- \to P_{\psi s}^{\Lambda}(4459)^0\pi^-$	$1/6$
$\Omega_b^- \to P_{\psi ss}^{\Xi' -}\pi^0$	$\lvert t_1/T_1\rvert^2/2$	$\Omega_b^- \to P_{\psi ss}^{\Xi' 0}\pi^-$	$\lvert t_1/T_1\rvert^2$
$\Omega_b^- \to P_{\psi ss}^{\Xi' -}\eta$	$\lvert 0.07 - 0.57\,(C_0 - 1)\rvert^2\,\lvert t_1/T_1\rvert^2$	$\Omega_b^- \to P_{\psi ss}^{\Xi' -}\eta'$	$\lvert 0.40 + 0.09\,(C_0 - 1)\rvert^2\,\lvert t_1/T_1\rvert^2$

Remarks

- Quantum numbers of pentaquarks born in decays of bottom baryons are yet unknown and this produces difficalties in consistency check of $SU(3)_F$ symmetry predictions in decay width ratios
- Some input from theoretical models for pentaquark structure is required, in particular, quantum numbers of pentaquarks
- $SU(3)_F$ analysis done can be easily generalized on production of pentaquarks and light vector mesons
- Decay $\Omega_b^- \to P^{\Omega}_{\psi sss}(\to J/\psi\,\Omega) + \phi(\to K^+K^-,\, \mu^+\mu^-)$ could be of experimental interest at the LHC despite statistics of Ω_b^--baryon is rather low
- Note that $P^{\Omega}_{\psi sss}$-pentaquark is from the flavor $SU(3)_F$ decuplet

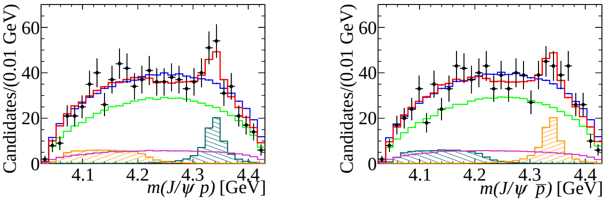
B-Meson Decays

[LHCb Collab., Phys. Rev. Lett. 128 (2022) 062001]

- Data of 2011 — 2018; correspond int. luminosity of 9 fb^{-1}
- No evidence is seen either for $P_c(4312)^+$ or glueball $f_J(2220)$
- Evidence for a Breit-Wigner shaped resonance is obtained

J^P	p $(\times 10^{-3})$	σ	M_0 (MeV)	Γ_0 (MeV)
$1/2^-$	0.5 ± 0.3	3.5 ± 0.1	$4335^{+3}_{-3} \pm 2$	$23^{+11}_{-8} \pm 14$
$1/2^+$	0.2 ± 0.1	3.7 ± 0.1	$4337^{+7}_{-4} \pm 2$	$29^{+26}_{-12} \pm 14$
$3/2^-$	0.3 ± 0.2	3.6 ± 0.1	$4337^{+5}_{-3} \pm 2$	$23^{+16}_{-9} \pm 14$
$3/2^+$	2 ± 1	3.1 ± 0.1	$4336^{+3}_{-2} \pm 2$	$15^{+9}_{-6} \pm 14$

- Limited sample size; impossible to distinguish among J^P



Mass Predictions for Unflavored Pentaquarks

J^P	JHEP 10 (2019) 256	AAAR
	$S_{ld} = 0,\ L = 0$	
$1/2^-$	3830 ± 34	4086 ± 42
	4150 ± 29	4162 ± 38
$3/2^-$	4240 ± 29	4133 ± 55
	$S_{ld} = 1,\ L = 0$	
$1/2^-$	4026 ± 31	4119 ± 42
	4346 ± 25	4166 ± 38
	4436 ± 25	4264 ± 41
$3/2^-$	4026 ± 31	4072 ± 40
	4346 ± 25	4300 ± 40
	4436 ± 25	4342 ± 40
$5/2^-$	4436 ± 25	4409 ± 40
	$S_{ld} = 0,\ L = 1$	
$1/2^+$	4030 ± 39	4030 ± 62
	4351 ± 35	4141 ± 44
	4430 ± 35	4217 ± 40
$3/2^+$	4040 ± 39	
	4361 ± 35	
	4440 ± 35	
$5/2^+$	4457 ± 35	4510 ± 57

J^P	JHEP 10 (2019) 256	AAAR
	$S_{ld} = 1,\ L = 1$	
$1/2^+$	4144 ± 37	3970 ± 50
	4209 ± 37	4174 ± 44
	4465 ± 32	4198 ± 50
	4530 ± 32	4221 ± 40
	4564 ± 33	4240 ± 50
	4663 ± 32	4319 ± 43
$3/2^+$	4187 ± 37	
	4250 ± 37	
	4508 ± 32	
	4570 ± 32	
	4511 ± 33	
	4566 ± 32	
	4656 ± 32	
$5/2^+$	4260 ± 37	4450 ± 44
	4581 ± 32	4524 ± 41
	4601 ± 32	4678 ± 44
	4656 ± 32	4720 ± 44
$7/2^+$	4672 ± 32	

Mass Predictions for Strange Pentaquarks

- Inclusion of strange quark(s) into the content makes spectrum of hidden-charm pentaquarks very rich
- They can be classsified according to their strangeness and color connection of four quarks
  - Singly-strange: $(\bar{c}_{\bar{3}}\,[cs]_{\bar{3}}\,[qq']_{\bar{3}})$ and $(\bar{c}_{\bar{3}}\,[cq]_{\bar{3}}\,[sq']_{\bar{3}})$
  - Doubly-strange: $(\bar{c}_{\bar{3}}\,[cs]_{\bar{3}}\,[sq]_{\bar{3}})$ and $(\bar{c}_{\bar{3}}\,[cq]_{\bar{3}}\,\{ss\}_{\bar{3}})$
  - Triply-strange: $(\bar{c}_{\bar{3}}\,[cs]_{\bar{3}}\,\{ss\}_{\bar{3}})$
- Can be produced in weak decays of Ξ_b- and Ω_b-baryons at the LHC
  - $\Xi_b^- \to P_{\psi s}^{\Lambda 0} + K^- \to J/\psi + \Lambda^0 + K^-$
  - $\Xi_b^{-,0} \to P_{\psi s}^{\Sigma 0,+} + K^- \to J/\psi + \Sigma^{0,+} + K^-$
  - $\Omega_b^- \to P_{\psi ss}^{\Xi' 0} + K^- \to J/\psi + \Xi'^0 + K^-$
  - $\Omega_b^- \to P_{\psi sss}^{\Omega -} + \phi \to J/\psi + \Omega^- + \phi$
- Ω_b-decays gives a new avenue to study pentaquarks with “bad” light diquarks ($S_{ld} = 1$)

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- Ω_b-decays gives a new avenue to study pentaquarks with "bad" light diquarks ($S_{ld} = 1$)

Masses of Singly-Strange ($\bar{c}_{\bar{3}}\,[cq]_{\bar{3}}\,[sq']_{\bar{3}}$) Pentaquarks

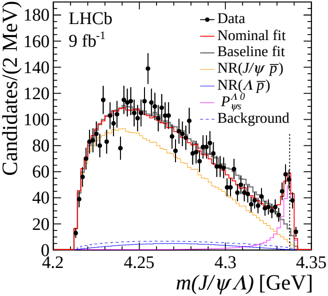
J^P	JHEP 10 (2019) 256	AAAR
	$S_{ld}=0,\ L=0$	
$1/2^-$	4112 ± 32	4094 ± 44
	4433 ± 26	4132 ± 43
$3/2^-$	4523 ± 26	4172 ± 47
	$S_{ld}=1,\ L=0$	
$1/2^-$	4230 ± 30	4128 ± 44
	4551 ± 25	4134 ± 42
	4641 ± 25	4220 ± 43
$3/2^-$	4230 ± 30	4031 ± 43
	4551 ± 25	4262 ± 43
	4641 ± 25	4303 ± 43
$5/2^-$	4641 ± 25	4370 ± 43
	$S_{ld}=0,\ L=1$	
$1/2^+$	4312 ± 37	4069 ± 56
	4633 ± 33	4149 ± 45
	4713 ± 33	4187 ± 44
$3/2^+$	4323 ± 37	
	4643 ± 33	
	4723 ± 33	
$5/2^+$	4740 ± 33	4549 ± 51

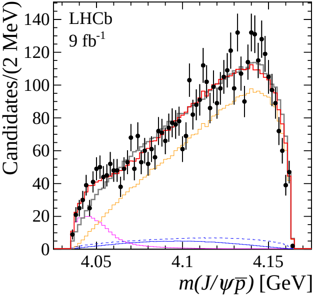
J^P	JHEP 10 (2019) 256	AAAR
	$S_{ld}=1,\ L=1$	
$1/2^+$	4348 ± 36	3929 ± 53
	4414 ± 36	4183 ± 45
	4669 ± 32	4159 ± 53
	4735 ± 32	4189 ± 44
	4768 ± 32	4201 ± 53
	4867 ± 32	4275 ± 45
$3/2^+$	4392 ± 36	
	4454 ± 36	
	4713 ± 32	
	4775 ± 32	
	4716 ± 32	
	4770 ± 32	
	4861 ± 32	
$5/2^+$	4465 ± 36	4409 ± 47
	4786 ± 32	4486 ± 45
	4806 ± 32	4639 ± 47
	4860 ± 32	4681 ± 47
$7/2^+$	4877 ± 32	

Structure $J/\psi\,\Lambda$ in $B^- \to J/\psi\,\Lambda\,\bar{p}$ Decay

[LHCb Collab., Phys. Rev. Lett. 131 (2023) 031901]

- New resonant structure called $P^{\Lambda}_{\psi s}(4338)^0$ in the $J/\psi\,\Lambda$ system is found with high statistical significance ($> 15\sigma$)
- $P^{\Lambda}_{\psi s}(4338)^0$ with preferred spin-parity $J^P = 1/2^-$ has the mass $M = 4338.2 \pm 0.7 \pm 0.4$ MeV and width $\Gamma = 7.0 \pm 1.2 \pm 1.3$ MeV
- $P^{\Lambda}_{\psi s}(4338)^0$ state is found at the $\Xi_c^+ D^-$ threshold
- No evidence is seen either for unflavored pentaquark or lower mass strange pentaquark $P^{\Lambda}_{\psi s}(4255)^0$



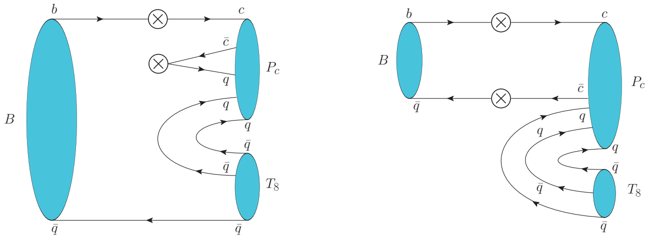


Masses of Singly-Strange ($\bar{c}_{\bar{3}}\,[cq]_{\bar{3}}\,[sq']_{\bar{3}}$) Pentaquarks

J^P	JHEP 10 (2019) 256	AAAR	J^P	JHEP 10 (2019) 256	AAAR
	$S_{ld}=0,\ L=0$			$S_{ld}=1,\ L=1$	
$1/2^-$	4112 ± 32	4094 ± 44	$1/2^+$	4348 ± 36	3929 ± 53
	4433 ± 26	4132 ± 43		4414 ± 36	4183 ± 45
$3/2^-$	4523 ± 26	4172 ± 47		4669 ± 32	4159 ± 53
	$S_{ld}=1,\ L=0$			4735 ± 32	4189 ± 44
$1/2^-$	4230 ± 30	4128 ± 44		4768 ± 32	4201 ± 53
	4551 ± 25	4134 ± 42		4867 ± 32	4275 ± 45
	4641 ± 25	4220 ± 43	$3/2^+$	4392 ± 36	
$3/2^-$	4230 ± 30	4031 ± 43		4454 ± 36	
	4551 ± 25	4262 ± 43		4713 ± 32	
	4641 ± 25	4303 ± 43		4775 ± 32	
$5/2^-$	4641 ± 25	4370 ± 43		4716 ± 32	
	$S_{ld}=0,\ L=1$			4770 ± 32	
$1/2^+$	4312 ± 37	4069 ± 56		4861 ± 32	
	4633 ± 33	4149 ± 45	$5/2^+$	4465 ± 36	4409 ± 47
	4713 ± 33	4187 ± 44		4786 ± 32	4486 ± 45
$3/2^+$	4323 ± 37			4806 ± 32	4639 ± 47
	4643 ± 33			4860 ± 32	4681 ± 47
	4723 ± 33		$7/2^+$	4877 ± 32	
$5/2^+$	4740 ± 33	4549 ± 51			

[Wei-Hao Han, Ji Xu, & Ye Xing, arXiv:2310.17125]

- Decays $B \to \mathcal{P}\bar{\mathcal{B}}$ are described by two diagrams
- Representations of pentaquarks $\mathcal{P}$ and antibaryons $\bar{\mathcal{B}}$ are assumed to be $SU(3)_F$ octet and anti-octet
- Decuplet and anti-decuplet were not considered



- Total B-meson decay amplitude contains three terms

$$\mathcal{A}_8 = c_1\, B_n H^n(3) \epsilon_{ijk} \mathcal{P}^k_l \epsilon^{ilm} \overline{\mathcal{B}}^j_m + c_2\, B_n H^l(3) \epsilon_{ijk} \mathcal{P}^k_l \epsilon^{inm} \overline{\mathcal{B}}^j_m$$
$$+ c_3\, B_n H^j(3) \epsilon_{ijk} \mathcal{P}^k_l \epsilon^{inm} \overline{\mathcal{B}}^l_m$$

- c_i are the universal amplitutes
- Corresponding sets of B-meson decay amplitudes are under check

Conclusions

- Weak decays of bottom baryons into hidden-charm pentaquarks and light mesons are considered
- $SU(3)_F$-classification of pentaquarks is presented
- $SU(3)_F$-invariant decay amplitudes are calculated with account of particles' $SU(3)_F$-multiplets and $SU(3)_F$-representation of the effective weak Hamiltonian
- Ratios of decay widths are discussed with a goal to specify the most promising for experimental searches decay modes with pentaquark production
- Similar analysis for the B-meson decays into hidden-charm pentaquark and ordinary antibaryon is breefly presented