PENTAQUARK PRODUCTION IN WEAK DECAYS OF BOTTOM BARYONS

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INTRODUCTION

Λ_b-baryon is a bound state of heavy b-quark and a pair of light u- and d-quarks. Its mass and lifetime are $m_{\Lambda_b} = 5619.51 \pm 0.23$ MeV and $\tau_{\Lambda_b} = (1.466 \pm 0.010) \times 10^{-12}$ sec, respectively. As Λ_b decays due to weak interections, it has such large lifetime. More than 40 decay modes with branching fractions exceeded 10^{-6} are experimentally found. Exotic resonances are found in $\Lambda_b \to p + K^- + J/\psi$ and $\Lambda_b \to p + \pi^- + J/\psi$ decays and they are consistent with the pentaquark model. Evidence of a strange pentaquark is also announced in $\Xi_b^- \to \Lambda + K^- + J/\psi$ decay of the Ξ_b^--baryon, $SU(3)_F$-partner of Λ_b.

HADRON MULTIPLETS

In flavor $SU(3)_F$-group, light quarks belong to triplet $q^a = (u,\, d,\, s)^T$ while heavy quarks are singlets. Hadrons, being bound states of quarks and/or antiquarks, can be classified accordingly. Light pseudoscalar (vector) mesons with $J^P = 0^-\ (1^-)$ are combined into octets and ordinary baryons with $J^P = 1/2^+$ and $J^P = 3/2^+$ are collected into the octet and decuplet, respectively.

Octet of hidden-charm pentaquarks differs from the ordinary-baryon octet by the presence of $SU(3)_F$-singlet $\bar{c}c$-pair:

$$\mathcal{P}_{ij} = \begin{pmatrix} \frac{P_{\Sigma^0}}{\sqrt{2}} + \frac{P_\Lambda}{\sqrt{6}} & P_{\Sigma^+} & P_p \\ P_{\Sigma^-} & \frac{P_\Lambda}{\sqrt{6}} - \frac{P_{\Sigma^0}}{\sqrt{2}} & P_n \\ P_{\Xi^-} & P_{\Xi^0} & -\frac{2P_\Lambda}{\sqrt{6}} \end{pmatrix}$$

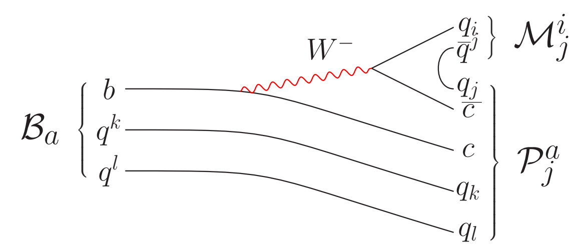
The same is true for the decuplet $\mathcal{P}_{ijk}$ of pentaquarks: $\mathcal{P}_{111} = P_{\Delta_{10}^{++}}$, $\mathcal{P}_{112} = P_{\Delta_{10}^{+}}/\sqrt{3}$, $\mathcal{P}_{122} = P_{\Delta_{10}^{0}}/\sqrt{3}$, $\mathcal{P}_{222} = P_{\Delta_{10}^{-}}$, $\mathcal{P}_{113} = P_{\Sigma_{10}^{+}}/\sqrt{3}$, $\mathcal{P}_{123} = P_{\Sigma_{10}^{0}}/\sqrt{6}$, $\mathcal{P}_{223} = P_{\Sigma_{10}^{-}}/\sqrt{3}$, $\mathcal{P}_{133} = P_{\Xi_{10}^{0}}/\sqrt{3}$, $\mathcal{P}_{233} = P_{\Xi_{10}^{-}}/\sqrt{3}$, $\mathcal{P}_{333} = P_{\Omega_{10}^{-}}$. Bottom baryons with $J^P = 1/2^+$ belong either antitriplet $\mathcal{B}_a = (\Xi_b^-,\, \Xi_b^0,\, \Lambda_b^0)$ or sextet $\mathcal{B}^{kl}$.

CONCLUSIONS

1. Weak decays of bottom baryons into hidden-charm pentaquarks and light mesons are considered based on $SU(3)_F$-symmetry
2. $SU(3)_F$-invariant decay amplitudes are calculated with account of $SU(3)_F$-multiplets of hadrons and $SU(3)_F$-antitriplet representation of the effective weak Hamiltonian
3. Predictions for decay-width ratios are presented and the most promising for experimental searches modes with pentaquark production are specified

THEORETICAL ANALYSIS

Three diagrams contribute to the decay amplitude. Heavy Quark Symmetry (HQS) reduces their number to one only in which light diquark goes from heavy baryon to the pentaquark without changing its spin and parity, as shown. In other two, quarks from light diquark are separated and enter both light meson and pentaquark.



Decay amplitude of bottom baryons $\mathcal{A} = \langle \mathcal{P}\mathcal{M} \left| H_{\rm eff}^W \right| \mathcal{B} \rangle$ is determined by the effective weak Hamiltonian, $H_{\rm eff}^W$, responsable for the $b \to sc\bar{c}$ and $b \to dc\bar{c}$ transitions. Some representative amplitudes due to $b \to dc\bar{c}$ transition are presented in the Table.

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

Here, 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, and C_0 is the coefficient relevant for $U(3)_F \to SU(3)_F$ symmetry breaking ($U(3)_F$-symmetry recovers at $C_0 = 0$).

As far as one decay width is known, decay widths of other particles from the b-baryon multiplet can be calculated. After differences in particle masses from multiplets are neglected, the ratio of decay widths is as follows: $\Gamma_2/\Gamma_1 \simeq \sum_\lambda |A_2|^2 / \sum_\lambda |A_1|^2$.

NUMERICAL RESULTS

Hidden-charm pentaquarks are found in $\Lambda_b^0 \to P_p K^-$ and $\Lambda_b^0 \to P_p \pi^-$ decays. In decays due to $b \to s\bar{c}c$ transition, decay widths can be compared with $\Gamma(\Lambda_b^0 \to P_p K^-)$ through the ratio $R(\mathcal{P}\,\mathcal{M}/P_p\,K^-) = \Gamma(\mathcal{B} \to \mathcal{P}\,\mathcal{M})/\Gamma(\Lambda_b^0 \to P_p\,K^-)$.

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

They are obtained in the HQS limit ($T_2 = T_3 = 0$ and $t_2 = t_3 = 0$). The ratio of the experimentally seen strange pentaquark to unflavored pentaqurk is marked in red. As far as spin-paritiyes of pentaqurks are determined, this ratio allows to check applicability of $SU(3)_F$- and HQS-symmetry in pentaquark sector.

In the same limit for decays due to the $b \to d\bar{c}c$ transition, the other ratio, $R(\mathcal{P}\,\mathcal{M}/P_p\,K^-) = \Gamma(\mathcal{B} \to \mathcal{P}\,\mathcal{M})/\Gamma(\Lambda_b^0 \to P_p\,K^-)$, can be used.

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

Suppression factor (in red) for this strange pentaquark search is the same and it is a matter of statistics for its evidence in such a decay mode.

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