Mass spectra and electromagnetic decays of single bottom baryons

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Outline

Introduction

- Hadrons
- Quark Model: mesons ($q\bar{q}$), baryons (qqq)
  Exotics: tetraquarks ($qq\bar{q}\bar{q}$), pentaquarks ($qqqq\bar{q}$)
- Computation of mass spectra and electromagnetic decays of single bottom baryons

M. Gell-Mann, Phys. Lett. 8 (1964) 214

Motivation

- The study of the mass spectra as well as the decay properties of single bottom baryons is relevant in hadron physics
- In order to produce such states higher energy and higher beam luminosity are required
- Only a few single bottom baryons have been discovered. Many of them have to be discovered
- Our work can guide experimentalists: giving the mass range and identifying the more suitable channels where to look for new states

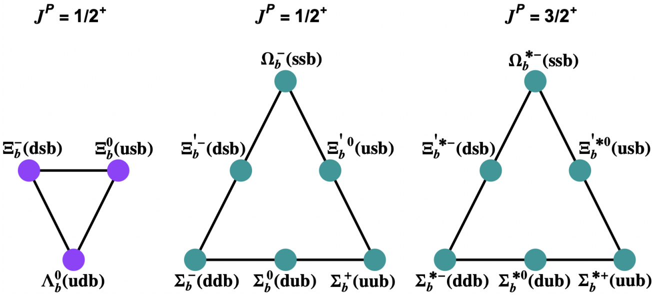
Experiments at LHC

LHCb

CMS
Compact Muon Solenoid

ATLAS
EXPERIMENT

Ground state single bottom baryons



Flavor wave functions

$\bar{3}$-plet

$$|\Xi_b^-, 1/2, -1/2\rangle : \quad = \quad \frac{1}{\sqrt{2}}(|dsb\rangle - |sdb\rangle) \tag{1}$$

$$|\Xi_b^0, 1/2, 1/2\rangle : \quad = \quad \frac{1}{\sqrt{2}}(|usb\rangle - |sub\rangle) \tag{2}$$

$$|\Lambda_b^0, 0, 0\rangle : \quad = \quad \frac{1}{\sqrt{2}}(|udb\rangle - |dub\rangle) \tag{3}$$

6-plet

$$|\Omega_b^-, 0, 0\rangle : \quad = \quad |ssb\rangle \tag{4}$$

$$|\Xi_b'^-, 1/2, -1/2\rangle : \quad = \quad \frac{1}{\sqrt{2}}(|dsb\rangle + |sdb\rangle) \tag{5}$$

$$|\Xi_b'^0, 1/2, 1/2\rangle : \quad = \quad \frac{1}{\sqrt{2}}(|usb\rangle + |sub\rangle) \tag{6}$$

$$|\Sigma_b^+, 1, 1\rangle : \quad = \quad |uub\rangle \tag{7}$$

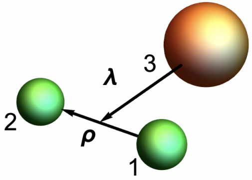
$$|\Sigma_b^-, 1, -1\rangle : \quad = \quad |ddb\rangle \tag{8}$$

$$|\Sigma_b^0, 1, 0\rangle : \quad = \quad \frac{1}{\sqrt{2}}(|udb\rangle + |dub\rangle) \tag{9}$$

Mass formula

The masses of the single bottom baryons are calculated as the eigenvalues of the Hamiltonian

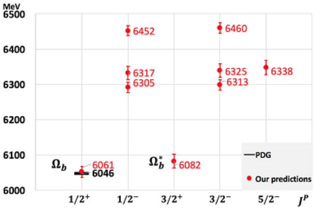
$$H = H_{\mathrm{h.o.}} + a_{\mathrm{S}} \mathbf{S}^2_{\mathrm{tot}} + a_{\mathrm{SL}} \mathbf{S}_{\mathrm{tot}} \cdot \mathbf{L}_{\mathrm{tot}} + a_{\mathrm{I}} \mathbf{I}^2 + a_{\mathrm{F}} \hat{\mathbf{C}}_2(SU_F(3))$$

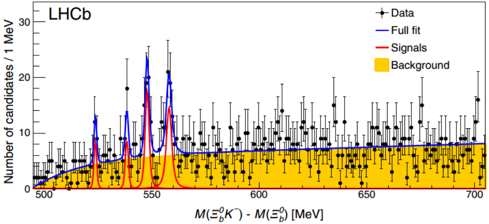


$$\begin{aligned} E^{3q} &= \sum_{i=1}^{3} m_i + \omega_\rho n_\rho + \omega_\lambda n_\lambda + a_{\mathrm{S}} [S_{\mathrm{tot}}(S_{\mathrm{tot}}+1)] \\ &+ a_{\mathrm{SL}} \frac{1}{2} \left[J(J+1) - L_{\mathrm{tot}}(L_{\mathrm{tot}}+1) - S_{\mathrm{tot}}(S_{\mathrm{tot}}+1) \right] \\ &+ a_{\mathrm{I}} [I(I+1)] + a_{\mathrm{F}} \frac{1}{3} [p(p+3) + q(q+3) + pq] \end{aligned} \quad (10)$$

E. Santopinto, A. Giachino, J. Ferretti, H. Garcia-Tecocoatzi, M.A. Bedolla, R. Bijker, E. Ortiz-Pacheco, EPJC 79(12), 1012 (2019)

Predictions for the Ω_b excited states



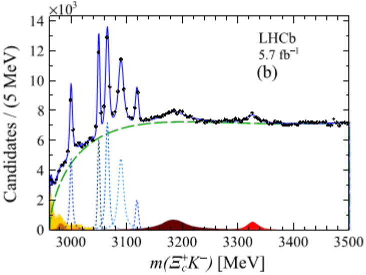


Experimental Mass	Experimental Width(MeV)	Predicted Width(MeV)
6316	< 4.2	1.14
6330	< 4.7	2.79
6340	< 1.8	0.62
6350	< 3.2	4.28

E. Santopinto, A. Giachino, J. Ferretti, H. García-Tecocoatzi, M.A. Bedolla, R. Bijker, and E. Ortiz-Pacheco, Eur. Phys. J. C (2019) 79:1012

LHCb Collaboration, PRL 124, 082002 (2020)

$\lvert l_\lambda = 2, l_\rho = 0, k_\lambda = 0, k_\rho = 0\rangle$	$^2D_{3/2}$	3315^{+15}_{-14}
$\lvert l_\lambda = 2, l_\rho = 0, k_\lambda = 0, k_\rho = 0\rangle$	$^2D_{5/2}$	3360^{+17}_{-16}
$\lvert l_\lambda = 2, l_\rho = 0, k_\lambda = 0, k_\rho = 0\rangle$	$^4D_{1/2}$	3330^{+25}_{-25}

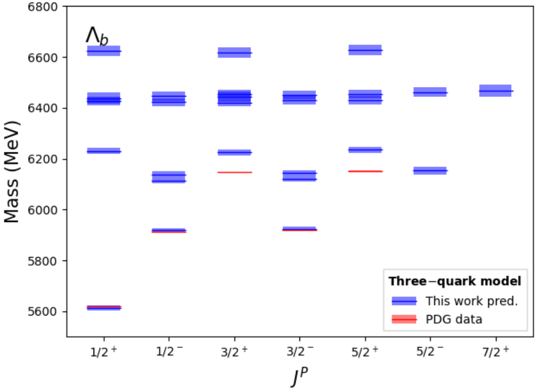


Experimental Mass of the $\Omega_c(3327)^0$	Experimental Width(MeV)	Predicted Width(MeV)
$3327.1 \pm 1.2 \pm 0.2$	20	16.2

H. Garcia-Tecocoatzi, A. Giachino, J. Li, A. Ramirez-Morales, and E. Santopinto, PRD 107, 034031 (2023)

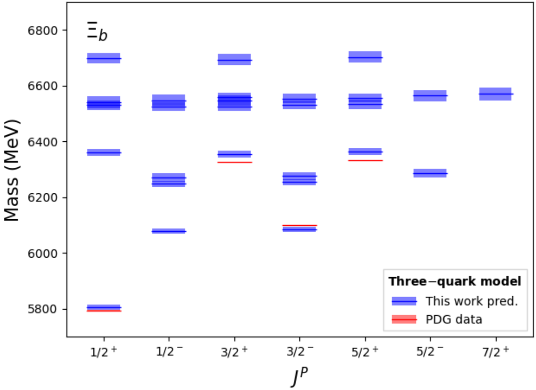
LHCb Collaboration, PRL 131, 131902 (2023)

Mass spectra of Λ_b



H. Garcia-Tecocoatzi, A. Giachino, A. Ramirez-Morales, A. Rivero-Acosta, E. Santopinto, and C. Vaquera, e-Print: 2307.00505 [hep-ph] (2023)

Mass spectra of Ξ_b



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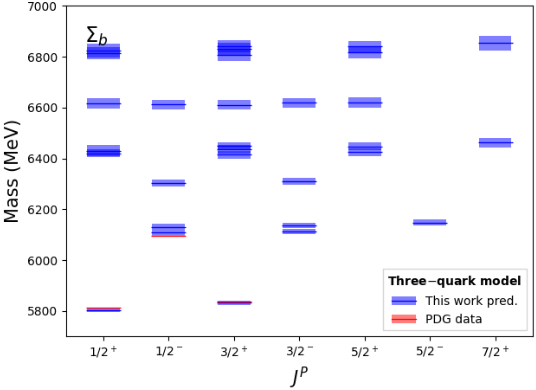
Mass spectra of Σ_b



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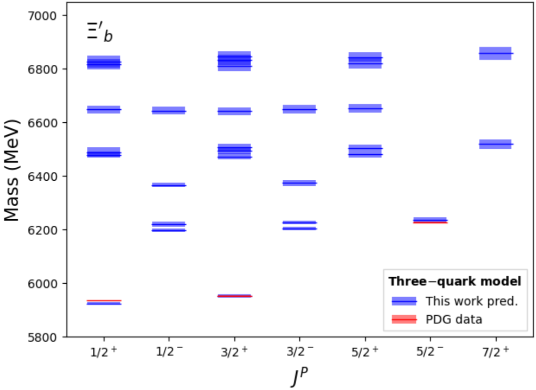
Mass spectra of Ξ'_b



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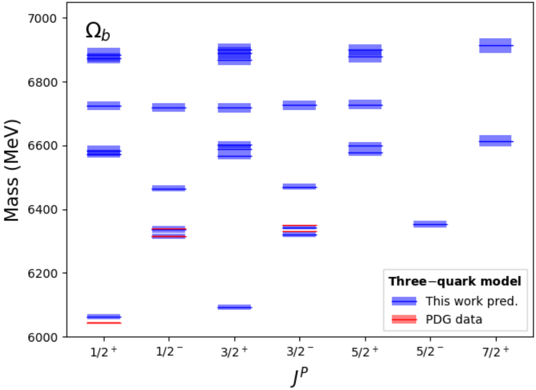
Mass spectra of Ω_b



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Electromagnetic interaction Hamiltonian

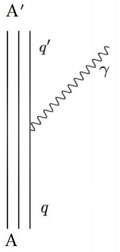
$$\mathcal{H}_{em} = 2\sqrt{\frac{\pi}{k_0}} \sum_{j=1}^{3} \mu_j \left[k s_{j,-} e^{-i\mathbf{k}\cdot\mathbf{r}_j} + \frac{1}{2}\left(p_{j,-} e^{-i\mathbf{k}\cdot\mathbf{r}_j} + e^{-i\mathbf{k}\cdot\mathbf{r}_j} p_{j,-}\right)\right] \quad (11)$$

$$k_0{}^2 = \frac{({M_A}^2 - {M_{A'}}^2)^2}{2({M_A}^2 + {M_{A'}}^2) + Q^2}$$

$$\mu_j = \frac{q_j}{2m_j}$$

Transition amplitude for a given helicity J_{A_z}

$$\mathcal{A}_{J_{A_z}} = \langle J_{A'}, J_{A_z} - 1 | \mathcal{H}_{\rm em} | J_A, J_{A_z} \rangle$$



Electromagnetic decay

Partial decay widths of the electromagnetic transitions

$$\Gamma_{em}(A \to A' + \gamma) = 2\pi\rho \frac{1}{(2\pi)^3} \frac{2}{2J_A + 1} \sum_{J_{A_z} > 0} \left| \mathcal{A}_{J_{A_z}} \right|^2, \tag{12}$$

In the rest frame of the initial baryon: $\rho = 4\pi \frac{E_{A'}}{M_A} k^2$

Energy of the final state: $E_{A'} = \sqrt{{M_{A'}}^2 + k^2}$

The energy of the photon: $k = \frac{{M_A}^2 - {M_{A'}}^2}{2M_A}$

Electromagnetic decay widths for Λ_b resonances

$\mathcal{F} = \bar{3}_f$				$\Lambda_b^0\gamma$	$\Sigma_b^0\gamma$	$\Sigma_b^{*}\gamma$
$\Lambda_b(nnb)$	J^P	$\vert l_\lambda, l_\rho, k_\lambda, k_\rho\rangle$	$^{2S+1}L_J$	KeV	KeV	KeV
$N=0$						
$\Lambda_b(5613)$	$\frac{1}{2}^+$	$\vert 0,0,0,0\rangle$	$^2S_{1/2}$	0	0	0
$N=1$						
$\Lambda_b(5918)$	$\frac{1}{2}^-$	$\vert 1,0,0,0\rangle$	$^2P_{1/2}$	64	0.4	0
$\Lambda_b(5924)$	$\frac{3}{2}^-$	$\vert 1,0,0,0\rangle$	$^2P_{3/2}$	65	0.5	0.1
$\Lambda_b(6114)$	$\frac{1}{2}^-$	$\vert 0,1,0,0\rangle$	$^2P_{1/2}$	15	519	3
$\Lambda_b(6137)$	$\frac{1}{2}^-$	$\vert 0,1,0,0\rangle$	$^4P_{1/2}$	9	6	76
$\Lambda_b(6121)$	$\frac{3}{2}^-$	$\vert 0,1,0,0\rangle$	$^2P_{3/2}$	16	1025	3
$\Lambda_b(6143)$	$\frac{3}{2}^-$	$\vert 0,1,0,0\rangle$	$^4P_{3/2}$	25	17	382
$\Lambda_b(6153)$	$\frac{5}{2}^-$	$\vert 0,1,0,0\rangle$	$^4P_{5/2}$	17	12	1023

$N = n_\rho + n_\lambda, \quad n_{\rho(\lambda)} = 2k_{\rho(\lambda)} + l_{\rho(\lambda)}, \quad l_{\rho(\lambda)}$ orbital angular momentum
$k_{\rho(\lambda)}$ is the number of nodes (radial excitations)

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Electromagnetic decay widths for Ξ_b resonances

$\mathcal{F} = \bar{3}_f$				$\Xi_b^0\gamma$	$\Xi_b^-\gamma$	$\Xi_b'^0\gamma$	$\Xi_b'^-\gamma$	$\Xi_b^{*0}\gamma$	$\Xi_b^{*-}\gamma$
$\Xi_b(snb)$	$\mathbf{J}^P$	$\vert l_\lambda, l_\rho, k_\lambda, k_\rho\rangle$	$^{2S+1}L_J$	KeV	KeV	KeV	KeV	KeV	KeV
$N = 0$									
$\Xi_b(5806)$	$\frac{1}{2}^+$	$\vert 0, 0, 0, 0\rangle$	$^2S_{1/2}$	0	0	0	0	0	0
$N = 1$									
$\Xi_b(6079)$	$\frac{1}{2}^-$	$\vert 1, 0, 0, 0\rangle$	$^2P_{1/2}$	122	126	1.1	0	0.2	0
$\Xi_b(6085)$	$\frac{3}{2}^-$	$\vert 1, 0, 0, 0\rangle$	$^2P_{3/2}$	125	126	1.3	0	0.2	0
$\Xi_b(6248)$	$\frac{1}{2}^-$	$\vert 0, 1, 0, 0\rangle$	$^2P_{1/2}$	19	28	494	9	2	0
$\Xi_b(6271)$	$\frac{1}{2}^-$	$\vert 0, 1, 0, 0\rangle$	$^4P_{1/2}$	11	17	5	0.1	75	1.4
$\Xi_b(6255)$	$\frac{3}{2}^-$	$\vert 0, 1, 0, 0\rangle$	$^2P_{3/2}$	20	29	950	17	3	0
$\Xi_b(6277)$	$\frac{3}{2}^-$	$\vert 0, 1, 0, 0\rangle$	$^4P_{3/2}$	33	49	14	0.3	363	7
$\Xi_b(6287)$	$\frac{5}{2}^-$	$\vert 0, 1, 0, 0\rangle$	$^4P_{5/2}$	23	34	10	0.2	945	17

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Electromagnetic decay widths for Σ_b resonances

$\mathcal{F}=6_f$ $\Sigma_b(nnb)$	J^P	$\vert l_\lambda, l_\rho, k_\lambda, k_\rho\rangle$	${}^{2S+1}L_J$	$\Sigma_b^{+}\gamma$ KeV	$\Sigma_b^{0}\gamma$ KeV	$\Sigma_b^{-}\gamma$ KeV	$\Lambda_b^{0}\gamma$ KeV	$\Sigma_b^{*+}\gamma$ KeV	$\Sigma_b^{*0}\gamma$ KeV	$\Sigma_b^{*-}\gamma$ KeV
$N=0$										
$\Sigma_b(5804)$	$\frac{1}{2}^+$	$\vert 0,0,0,0\rangle$	${}^2S_{1/2}$	0	0	0	150	0	0	0
$\Sigma_b(5832)$	$\frac{3}{2}^+$	$\vert 0,0,0,0\rangle$	${}^4S_{3/2}$	0.5	0	0.1	215	0	0	0
$N=1$										
$\Sigma_b(6108)$	$\frac{1}{2}^-$	$\vert 1,0,0,0\rangle$	${}^2P_{1/2}$	407	34	73	195	7	0.4	2
$\Sigma_b(6131)$	$\frac{1}{2}^-$	$\vert 1,0,0,0\rangle$	${}^4P_{1/2}$	13	0.8	3	111	36	4	5
$\Sigma_b(6114)$	$\frac{3}{2}^-$	$\vert 1,0,0,0\rangle$	${}^2P_{3/2}$	1202	89	252	202	7	0.4	2
$\Sigma_b(6137)$	$\frac{3}{2}^-$	$\vert 1,0,0,0\rangle$	${}^4P_{3/2}$	40	2	10	321	316	26	59
$\Sigma_b(6147)$	$\frac{5}{2}^-$	$\vert 1,0,0,0\rangle$	${}^4P_{5/2}$	29	2	7	217	1222	90	256
$\Sigma_b(6304)$	$\frac{1}{2}^-$	$\vert 0,1,0,0\rangle$	${}^2P_{1/2}$	247	15	62	424	103	6	26
$\Sigma_b(6311)$	$\frac{3}{2}^-$	$\vert 0,1,0,0\rangle$	${}^2P_{3/2}$	256	16	64	414	107	7	27

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Electromagnetic decay widths for Ξ'_b resonances

$\mathcal{F} = \mathbf{6}_f$ $\Xi'_b(snb)$	$\mathbf{J}^P$	$\vert l_\lambda, l_\rho, k_\lambda, k_\rho\rangle$	$^{2S+1}L_J$	$\Xi_b^0\gamma$ KeV	$\Xi_b^-\gamma$ KeV	$\Xi_b'^0\gamma$ KeV	$\Xi_b'^-\gamma$ KeV	$\Xi_b^{*0}\gamma$ KeV	$\Xi_b^{*-}\gamma$ KeV
$N=0$									
$\Xi'_b(5925)$	$\frac{1}{2}^+$	$\vert 0,0,0,0\rangle$	$^2S_{1/2}$	33	0.6	0	0	0	0
$\Xi'_b(5953)$	$\frac{3}{2}^+$	$\vert 0,0,0,0\rangle$	$^4S_{3/2}$	60	1.1	0.1	0.1	0	0
$N=1$									
$\Xi'_b(6198)$	$\frac{1}{2}^-$	$\vert 1,0,0,0\rangle$	$^2P_{1/2}$	65	1.2	78.2	71.1	0.4	0.6
$\Xi'_b(6220)$	$\frac{1}{2}^-$	$\vert 1,0,0,0\rangle$	$^4P_{1/2}$	40	0.7	0.9	1.4	11	9
$\Xi'_b(6204)$	$\frac{3}{2}^-$	$\vert 1,0,0,0\rangle$	$^2P_{3/2}$	69	1.3	157	167	0.4	0.7
$\Xi'_b(6226)$	$\frac{3}{2}^-$	$\vert 1,0,0,0\rangle$	$^4P_{3/2}$	117	2	3	4	57	54
$\Xi'_b(6237)$	$\frac{5}{2}^-$	$\vert 1,0,0,0\rangle$	$^4P_{5/2}$	83	1.5	2	3	157	168
$\Xi'_b(6367)$	$\frac{1}{2}^-$	$\vert 0,1,0,0\rangle$	$^2P_{1/2}$	644	12	19	28	7	11
$\Xi'_b(6374)$	$\frac{3}{2}^-$	$\vert 0,1,0,0\rangle$	$^2P_{3/2}$	637	12	20	29	8	12

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Electromagnetic decay widths for Ω_b resonances

$\mathcal{F} = \mathbf{6}_f$				$\Omega_b \gamma$	$\Omega_b^* \gamma$
$\Omega_b(ssb)$	$\mathbf{J}^P$	$\lvert l_\lambda, l_\rho, k_\lambda, k_\rho \rangle$	$^{2S+1}L_J$	KeV	KeV
$N = 0$					
$\Omega_b(6064)$	$\frac{1}{2}^+$	$\lvert 0,0,0,0 \rangle$	$^2S_{1/2}$	0	0
$\Omega_b(6093)$	$\frac{3}{2}^+$	$\lvert 0,0,0,0 \rangle$	$^4S_{3/2}$	0.1	0
$N = 1$					
$\Omega_b(6315)$	$\frac{1}{2}^-$	$\lvert 1,0,0,0 \rangle$	$^2P_{1/2}$	51	0.2
$\Omega_b(6337)$	$\frac{1}{2}^-$	$\lvert 1,0,0,0 \rangle$	$^4P_{1/2}$	0.5	8
$\Omega_b(6321)$	$\frac{3}{2}^-$	$\lvert 1,0,0,0 \rangle$	$^2P_{3/2}$	99	0.2
$\Omega_b(6343)$	$\frac{3}{2}^-$	$\lvert 1,0,0,0 \rangle$	$^4P_{3/2}$	1.7	38
$\Omega_b(6353)$	$\frac{5}{2}^-$	$\lvert 1,0,0,0 \rangle$	$^4P_{5/2}$	1.3	99
$\Omega_b(6465)$	$\frac{1}{2}^-$	$\lvert 0,1,0,0 \rangle$	$^2P_{1/2}$	12	4
$\Omega_b(6471)$	$\frac{3}{2}^-$	$\lvert 0,1,0,0 \rangle$	$^2P_{3/2}$	12	5

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Importance of the electromagnetic decay

Electromagnetic decay widths are particularly valuable in cases where the strong decays are suppressed

$\mathcal{F} = \mathbf{6}_F$				$\Xi_b K$	$\Xi_b' K$	$\Xi_b^* K$	$\Xi_b K^*$	$\Xi_b' K^*$	$\Xi_b^* K^*$	$\Omega_b \eta$	$\Omega_b^* \eta$	$\Omega_b \phi$	$\Omega_b^* \phi$	$\Omega_b \eta'$	$\Omega_b^* \eta'$	$\Xi_8 B$	$\Xi_{10} B$	Γ^{Strong}
$\Omega_b(ssb)$	$\mathbf{J}^P$	$\vert l_\lambda, l_\rho, k_\lambda, k_\rho\rangle$	${}^{2S+1}L_J$	MeV	MeV	MeV	MeV	MeV	MeV	MeV	MeV	MeV	MeV	MeV	MeV	MeV	MeV	
$N = 0$																		
$\Omega_b(6064)$	$\frac{1}{2}^+$	$\vert 0,0,0,0\rangle$	${}^2S_{1/2}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$\Omega_b(6093)$	$\frac{3}{2}^+$	$\vert 0,0,0,0\rangle$	${}^4S_{3/2}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

We suggest the $\Omega_b^* \to \Omega_b^- \gamma$ decay mode as a channel for the observation of the Ω_b^{*-} state

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Summary

- We calculated the mass spectra single bottom baryons up to the D-wave states
- We performed calculations for the electromagnetic decay widths of single bottom baryons from P-wave states to ground states
- Our predictions for the masses of single bottom baryons exhibit good agreement with the available experimental data

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Thank you for your attention!