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Properties of Ξ hyperons and Ξ photoproduction process

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Abstract. In spite of the early efforts for studying Ξ resonances, we still do not have enough information on the properties of these resonances. The number of observed Ξ resonances is much smaller than the quark model predictions, and the predicted mass spectrum shows serious model-dependence. Furthermore, the spin-parity quantum numbers are not known for most observed resonances and the parity of the ground state Ξ has never been measured. In this talk, we review the issue in the Ξ spectrum and present a model for Ξ photoproduction which emphasizes the role of high-spin hyperon resonances.

Compared to the case of the non-strange resonances and strangeness −1 resonances, the information on the Ξ spectrum and the properties of Ξ resonances are very rare. This is because they are very difficult to produce from the photon-nucleon or the nucleon-nucleon scattering as the Ξ baryons have strangeness $S = -2$. Therefore, the kaon-nucleon reactions or the Σ-hyperon induced reactions are required to investigate multi-strangeness baryons like the Ξ baryons. Because of the lack of kaon factories, no significant progress in multi-strangeness physics has been made since the late 1980s.

However, there are recent interests in multi-strangeness baryon physics due to the construction of the J-PARC and the CLAS12 upgrade at the JLab. The investigation on multi-strangeness baryons is expected to give a new window to understand the structure of baryons and to constrain the properties of $S = -1$ baryons through the studies on the production mechanisms of the Ξ baryons.

Although most models can describe the mass spectra of the ground states of octet and decuplet baryons, they predict very different and even contradictory predictions on the spectrum of Ξ resonances [1]. This is because the structure of excited Ξ baryons heavily depends on the dynamics of the constituents of baryons while the spectra of the ground octet and decuplet states are the consequence of the flavor SU(3) symmetry and the symmetry breaking terms. Therefore, it is very interesting and important problem to understand the Ξ spectrum. Given in Table 1 are the predictions on the spectra of low-lying Ξ and Ω baryons in various hadron models, which shows that the predicted masses are highly model-dependent. Here, several comments are made in order.

– The experimentally observed low masses of the $\Xi(1620)$ and $\Xi(1690)$ are puzzles in quark models. The recent BABAR experiment showed that the spin-parity of the $\Xi(1690)$ is $1/2^-$ [2]. All quark models predict higher masses for this state and the existence of the $\Xi(1620)$ is quite puzzling.
– In the soliton model, the $\Xi(1690)$ has $j^P = 1/2^-$ and the existence of the $\Xi(1620)$ is required. Furthermore, these are claimed to be the analogous states to the $\Lambda(1405)$ [**?**]. Confirming the existence of the one-star-rated $\Xi(1620)$ at the current experimental facilities are, therefore, highly required.
– In the soliton model, several hyperon resonances of the same spin but of opposite parity form doublets and the mass difference between the members is about 300 MeV [1]. This can be verified by the present experimental data in PDG [3]. Furthermore, this pattern is seen also in heavy quark baryons.
– The quark models predict that the lowest states of $\Omega(1/2^-)$ and $\Omega(3/2^-)$ are (almost) degenerate. But in the soliton model, the mass difference between the two is about 140 MeV.

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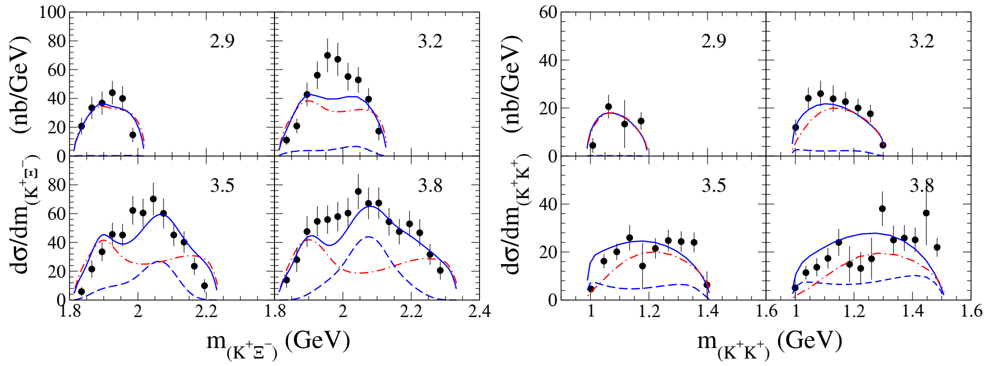
Table 1. Low-lying Ξ and Ω baryon spectrum of spin 1/2 and 3/2 predicted by the non-relativistic quark model of Chao *et al.* (CIK), relativized quark model of Capstick and Isgur (CI), Glozman-Riska model (GR), large N_c analysis, algebraic model (BIL), and QCD sum rules (SR). The recent quark model prediction (QM) and the Skyrme model results (SK) are given as well. The mass is given in the unit of MeV.

State	CIK [4]	CI [5]	GR [6]	Large-N_c [7–11]	BIL [12]	SR [13,14]	QM [15]	SK [1]
$\Xi(\frac{1}{2}^+)$	1325	1305	1320		1334	1320 (1320)	1325	1318
	1695	1840	1798	1825	1727		1891	1932
	1950	2040	1947	1839	1932		2014	
$\Xi(\frac{3}{2}^+)$	1530	1505	1516		1524		1520	1539
	1930	2045	1886	1854	1878		1934	2120
	1965	2065	1947	1859	1979		2020	
$\Xi(\frac{1}{2}^-)$	1785	1755	1758	1780	1869	1550 (1630)	1725	1614
	1890	1810	1849	1922	1932		1811	1660
	1925	1835	1889	1927	2076			
$\Xi(\frac{3}{2}^-)$	1800	1785	1758	1815	1828	1840	1759	1820
	1910	1880	1849	1973	1869		1826	
	1970	1895	1889	1980	1932			
$\Omega(\frac{1}{2}^+)$	2190	2220	2068	2408	2085		2175	2140
	2210	2255	2166		2219		2191	
$\Omega(\frac{3}{2}^+)$	1675	1635	1651		1670		1656	1694
	2065	2165	2020	1922	1998		2170	2282
	2215	2280	2068	2120	2219		2182	
$\Omega(\frac{1}{2}^-)$	2020	1950	1991	2061	1989		1923	1837
$\Omega(\frac{3}{2}^-)$	2020	2000	1991	2100	1989		1953	1978

These observations show that the investigation of multi-strangeness baryons gives another window to understand the baryon structure. In addition, the studies on the production mechanisms of Ξ baryons give a tool to constrain the properties of $S = -1$ hyperon resonances. The investigation to understand the production mechanisms of the Ξ baryons was recently initiated by the CLAS Collboration at JLab using the reaction of $\gamma p \to K^+K^+\Xi^-$ [16]. Theoretical investigation also started only recently [17–19]. In the analysis on the possible production mechanisms, it was shown that the most important contribution comes from the intermediate $S = -1$ hyperon resonances of $j^P = 1/2^-, 3/2^+, 5/2^-$, and $7/2^+$ [17,20]. Furthermore, through the list of PDG on the $S = -1$ hyperons, it can be found that many hyperon resonances in the mass of around 2 GeV have high spins. Therefore, it is necessary to develop a formalism to include high spin resonances for understanding the production process.

Based on the conventional Rarita-Schwinger formalism, neglecting the ambiguities arising from the off-shell nature of the intermediate hyperon resonances, one can construct a general formalism for high spin resonances [21]. Based on this formalism, the study on the role of high spin hyperon resonances in Ξ photoproduction was performed and the results for the invariant mass distribution of the $K^+\Xi^-$ pair and the K^+K^+ pair in the reaction of $\gamma p \to K^+K^+\Xi^-$ are shown in Fig. 1. Here, the dot-dashed lines are the results of Ref. [17] which considers the $\Lambda(1800)$ of $j^P = 1/2^-$ and the $\Lambda(1890)$ of $j^P = 3/2^+$. The result of this model for the $K^+\Xi^-$ invariant mass distribution evidently shows that the contribution from a resonance at a mass of around 2 GeV is missing. Among the hyperon resonances listed in the PDG, the $\Sigma(2030)$ of $j^P = 7/2^+$ is the most probable state that can represent such resonances. The contribution from the $\Sigma(2030)$ is shown by the dashed lines in Fig. 1, which shows that this can explain the gap between the results of Ref. [17] and the experimental data as shown by the solid lines. This investigation shows that the properties of high spin hyperon resonances can be studied through the analyses of the production processes of the Ξ baryons.

In summary, we have shown that the investigation of Ξ baryons and their production processes can open a way to learn about the baryon structure and the properties of $S = -1$ hyperon resonances of high spins. Studies on the Ξ spectrum can reveal the dynamics of the constituents that cannot be seen in non-strangeness baryons. Although more sophisticated models for the production mechanisms



(a) (b)

Fig. 1. Invariant mass distribution (a) of the $K^+\Xi^-$ pair and (b) of the K^+K^+ pair in the reaction of $\gamma p \to K^+K^+\Xi^-$. The number in the right upper corner of each graph indicates the incident photon energy in GeV. The dot-dashed lines are the results of Ref. [17] which includes only spin-1/2 and -3/2 hyperon resonances. The solid lines are the results of the present model, while the dashed lines show the contributions from the $\Sigma(2030)7/2^+$. Experimental data are from Ref. [16].

of the Ξ baryons are needed, the production is mostly governed by the intermediate $S = -1$ hyperon resonances and this can be used to constrain the parameters of hyperon resonances, in particular, of high spins.[1]

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[1] For the determination of the parity of the ground Ξ baryon in a model-independent way, see Ref. [22].