Spin determination of $\Xi(1690)^-$ and $\Xi(1820)^-$ produced in $\bar{p}p$ annihilation

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Recently [1] the PANDA collaboration studied the feasibility to determine the spin and parity of the $\Xi(1690)^-$and $\Xi(1820)^-$ resonances in the ΛK^- system produced in $\bar{p}p$ collisions via the reaction channel $\bar{p}p \to \bar{\Xi}^+\Lambda K^-$. The purpose of this contribution is to study these reactions using a model-independent irreducible tensor formalism developed earlier. This study leads us to identify the partial-wave amplitude which would be zero if $\Xi(1690)^-$ or $\Xi(1820)^-$ had spin-1/2, when these resonances are produced at threshold (s-wave production).

We first analyse the reaction $\bar{p}p \to \bar{\Xi}^+\Xi^{*-}$, where Ξ^* denotes either of the intermediate resonances: $\Xi(1690)^-$ or $\Xi(1820)^-$. Using our irreducible formalism, details of which can be found in [2] and references therein, the reaction matrix can be written as

$$\mathcal{M} = \sum_{s_i=0}^{1}\sum_{s}\sum_{\lambda=|s-s_i|}^{s+s_i}\left(S^\lambda(s,s_i)\cdot\mathcal{M}^\lambda(s,s_i)\right),$$

where $s = 0,1$ if Ξ^* has spin-1/2, while $s = 0,1,2,3$ if Ξ^* has spin-3/2. The irreducible spin tensor operators are defined following [3] and the corresponding tensor amplitudes $\mathcal{M}^\lambda_\mu(s,s_i)$ can be in turn written down in terms of the partial wave amplitudes $\mathcal{M}^j_{l_2 s;l_i s_i}$, which depend only on the c.m. energy E. We have

$$\mathcal{M}^\lambda_\mu(s,s_i) = \sum_{l,l_2,j}(-1)^{s_i-j}W(s_i l_i s l_2; j\lambda)$$
$$[j]^2[s]^{-1}\mathcal{M}^j_{l_2 s;l_i s_i}\left(Y_{l_2}(\hat{\mathbf{p}}_2)\otimes Y_{l_i}(\hat{\mathbf{p}}_i)\right)^\lambda_\mu,$$

where we follow the notations used in [2,3] and $\mathbf{p}_i$ and $\mathbf{p}_2$ are the initial and final c.m. momenta. For threshold production of the Ξ^*, we assume $l_2 = 0$. Since parity is conserved, $(-1)^{l_i} = (-1)^{l_2}$.

The reaction matrix for $\bar{p}p \to \bar{\Xi}^+\Lambda K^-$, following [4] can be written as

$$\mathcal{M} = \sum_{s_f}\sum_{s_i=0}^{1}\sum_{\lambda=|s_f-s_i|}^{s_f+s_i}\left(S^\lambda(s_f,s_i)\cdot\mathcal{M}^\lambda(s_f,s_i)\right),$$

where $s_f = 0,1$ if Ξ^* has spin-1/2, while $s_f = 1,2$ if Ξ^* has spin-3/2 and the irreducible amplitudes

$$\mathcal{M}^\lambda_\mu(s_f,s_i) = \sum_{l_f,l,L_f,j_f,j,l_i} g_\alpha \mathcal{M}^j_{l(l_f s_f)j_f;l_i s_i}$$
$$\times\left(\left(Y_{l_f}(\hat{\mathbf{p}}_f)\otimes Y_l(\hat{\mathbf{q}})\right)^{L_f}\otimes Y_{l_i}(\hat{\mathbf{p}}_i)\right)^\lambda_\mu \quad (1)$$

are written in terms of the partial-wave amplitudes, $\mathcal{M}^j_{l(l_f s_f)j_f;l_i s_i}$, with g_α being geometrical factors. In the above equation, $\mathbf{p}_i = p_i\hat{\mathbf{p}}_i, \mathbf{p}_f = p_f\hat{\mathbf{p}}_f$ denote, respectively, the initial and final momenta associated with the relative motion of the Ξ^* and Λ, while $\mathbf{q} = q\hat{\mathbf{q}}$ denotes the K^- momentum in c.m. At threshold, we assume $l, l_f = 0,1$. If we denote l' to be the relative angular momentum between the Λ and K^-, then $l' = 0,1$ if Ξ^* has spin-1/2, while $l' = 1,2$ if Ξ^* has spin-3/2. We now use the relation derived in [2] to relate the angular momenta l', l_2 for $\bar{p}p \to \bar{\Xi}^+\Xi^{*-}$ with the angular momenta l_f, l for $\bar{p}p \to \bar{\Xi}^+\Lambda K^-$, viz.,

$$\left(Y_{l'}(\hat{\mathbf{q}}')\otimes Y_{l_2}(\hat{\mathbf{p}}_2)\right)^{L_f}_{M_f} = \sum_{L=0}^{l'}\sum_{L'=0}^{l_2}\sum_{l,l_f=0}^{1} F$$
$$\times\, C(LL'l;000)\, C(l'-L, l_2-L', l_f; 000)$$
$$\times\left\{\begin{matrix} L & L' & l \\ l'-L & l_2-L' & l_f \\ l' & l_2 & L_f \end{matrix}\right\}\left(Y_l(\hat{\mathbf{q}})\otimes Y_{l_f}(\hat{\mathbf{p}}_f)\right)^{L_f}_{M_f},$$

where $\mathbf{q}'$ is the relative momentum between the Λ and the K^- and F is a factor whose

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expression can be found in [2] and irrelevant for our subsequent conclusions. From the above expression, using the properties of the Clebsch-Gordan coefficients and the 9-j symbol, we clearly see that the partial-wave amplitude corresponding to $l_2 = 0$ *cannot* contribute to $l = l_f = 1$, if Ξ^* has spin-1/2 (in which case, $l' = 0, 1$) but it *can* contribute *only* to a Ξ^* which has a spin-3/2, because $l' = 2$ is an allowed angular momentum quantum number in this case and hence the partial-wave amplitude in eq. (1) can have $l = l_f = 1$.

Any observable measured for the reaction $\bar{p}p \to \bar{\Xi}^+ \Lambda K^-$ will be a bilinear in the reaction amplitudes given by eq (1). That is, they will involve real and imaginary parts of $\mathcal{M}^\lambda \mathcal{M}^{\lambda' *}$. If any of these observables, say, $O(\hat{\mathbf{q}}, \hat{\mathbf{p}}_f)$, are measured as a function of $\hat{\mathbf{q}}$ and $\hat{\mathbf{p}}_f$, then

$$\int O(\hat{\mathbf{q}}, \hat{\mathbf{p}}_f)\, Y_{2m}(\hat{\mathbf{q}}) Y_{2m'}(\hat{\mathbf{p}}_f)\, d\Omega_{\hat{\mathbf{p}}_f} d\Omega_{\hat{\mathbf{q}}} \qquad (2)$$

for any m, m' would be zero if Ξ^* had spin-1/2. This is because, the only way in which the observable $O(\hat{\mathbf{q}}, \hat{\mathbf{p}}_f)$ could contain a $Y_{2m}(\hat{\mathbf{q}})$ and a $Y_{2m'}(\hat{\mathbf{p}}_f)$ so that the orthogonality of the Y_{lm}s will not make the integral in eq. (2) zero is for it to contain an $l = 1$ and an $l_f = 1$ inside it. This is possible only if Ξ^* has spin-3/2, as we saw earlier.

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