Non-central interactions in $\overline{\mathrm{p}}\mathrm{p} \to \bar{\Lambda}\Lambda$

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INTRODUCTION

It is now well known that in the annihilation reaction, $\overline{\mathrm{p}}\mathrm{p} \to \bar{\Lambda}\Lambda$, the singlet contribution to the $\Lambda\bar{\Lambda}$ in the final state is suppressed. A meson-exchange model [1] explains this by assuming that the tensor interaction is dominant at the distances involved in the reaction, which is about 1 fm. In this paper, we explore this issue more closely especially since this reaction becomes relevant in the context of future experimental setups like PANDA [2]. To do this, we use model-independent irreducible tensorial techniques developed earlier [3].

FORMALISM

The irreducible formalism employed is identical to the one used for pion-production in NN collisions [3], with the momenta and angular quantum numbers associated with the pion set equal to zero. The matrix $\mathbf{M}$ in spin-space for $\overline{\mathrm{p}}\mathrm{p} \to \bar{\Lambda}\Lambda$ may be expressed in terms of the initial and final state-channel spins, $s_i, s_f = 0, 1$ as

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

with the irreducible reaction amplitudes in channel-spin space given by

$$M^{\lambda}_{\mu}(s_f, s_i) = \sum_{l_f, l_i, j} g_\alpha M^{j}_{l_f s_f; l_i s_i}(E) \times \left(Y_{l_f}(\hat{\mathbf{p}}_f) \otimes Y_{l_i}(\hat{\mathbf{p}}_i) \right)^{\lambda}_{\mu}, \tag{2}$$

in terms of the partial-wave amplitudes $M^{j}_{l_f s_f; l_i s_i}(E)$, which are functions of the c. m. energy E and the geometrical factors, g_α. The notations here follow [3]. We can express also $\mathbf{M}$ given by eq. (1) similar to that of the Wolfenstein-amplitudes for NN elastic scattering, in terms of the individual Pauli spin-operators as

$$\begin{aligned}\mathbf{M} =& A + B\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2 + (\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2) \cdot \mathbf{U} + \\ & (\boldsymbol{\sigma}_1 - \boldsymbol{\sigma}_2) \cdot \mathbf{V} + (\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2) \cdot \mathbf{W} + \\ & \left((\boldsymbol{\sigma}_1 \otimes \boldsymbol{\sigma}_2)^2 \cdot \mathcal{T}^2(1,1) \right),\end{aligned} \tag{3}$$

where $A = \mathcal{T}^0_0(0,0)$, $B = -\frac{1}{\sqrt{3}}\mathcal{T}^0_0(1,1)$, $\mathrm{U}^1_\mu = \frac{1}{2}\left[\mathcal{T}^1_\mu(1,0) + \mathcal{T}^1_\mu(0,1)\right]$, $\mathrm{V}^1_\mu = \frac{1}{2}\left[\mathcal{T}^1_\mu(1,0) - \mathcal{T}^1_\mu(0,1)\right]$, $\mathrm{W}^1_\mu = \frac{i}{\sqrt{2}}\mathcal{T}^1_\mu(1,1)$ in terms of the irreducible amplitudes,

$$\mathcal{T}^{\lambda}_{\mu}(\lambda_1, \lambda_2) = \sum_{s_f, s_i} G(s_f, s_i; \lambda_1, \lambda_2) M^{\lambda}_{\mu}(s_f, s_i) \tag{4}$$

where G are geometrical factors. The initial state spin density matrix is given by $\rho^i = \frac{1}{4}\left[1 + \left(\overrightarrow{\sigma_1} \cdot \vec{P}\right)\right]\left[1 + \left(\overrightarrow{\sigma_2} \cdot \vec{Q}\right)\right]$ in terms of the beam and target polarizations $\vec{P}$ and $\vec{Q}$ and the density matrix ρ^f characterizing the final spin-state is $\rho^f = \boldsymbol{M}\rho^i\boldsymbol{M}^\dagger$, which can be recast in terms of the irreducible Fano statistical tensors t^k_q as

$$\rho^f = \sum_{s_f, s'_f, k} \left(S^k(s_f, s'_f) \cdot t^k(s_f, s'_f) \right), \tag{5}$$

with

$$t^{k''}_{q''}(s_f, s'_f) = \sum_{s_i, s'_i} \sum_{\lambda, \lambda', \lambda''} \sum_{k, k'} G_1(P^k(s_i, s'_i) \otimes (M^{\lambda}(s_f, s_i) \otimes M^{\lambda'}(s'_f, s'_i))^{\lambda''})^{k''}_{q''}, \tag{6}$$

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where G_1 are geometrical factors and the channel-spin polarization tensors

$$P_q^k(s_i, s_i') = \frac{1}{2}[s_i'] \sum_{k_1,k_2} (-1)^{k_1+k_2-k} [k_1][k_2] \left\{ \begin{array}{ccc} \frac{1}{2} & \frac{1}{2} & s_i \\ \frac{1}{2} & \frac{1}{2} & s_i' \\ k_1 & k_2 & k \end{array} \right\} \left(P^{k_1} \otimes Q^{k_2}\right)_q^k . \tag{7}$$

From eqs. (5) and (6), we can immediately see that the singlet contribution to the differential cross section is nothing but $t_0^0(0,0)$ and the triplet contribution to the differential cross section is $t_0^0(1,1)$, so that the differential cross section is

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \mathrm{Tr}\, \rho^f = \sum_{s_f=0,1} (2s_f+1)\, t_0^0(s_f, s_f) . \tag{8}$$

The unpolarized differential cross section is recovered by putting $k_1 = k_2 = 0$ in eq. (7). The non-central interactions can now be investigated by introducing [4] projection-cum-spin flip operator

$$S_{\frac{1}{2},\frac{1}{2}}(l_f s_f; j; l_i s_i) = \sum_{\lambda_1=0}^{1} \sum_{\lambda_2=0}^{1} \sum_{\lambda} G_2 \times \left[S^\lambda(l_f, l_i) \cdot \tau^{(\lambda_1\lambda_2)\lambda}(\mathbf{S}_1, \mathbf{S}_2) \right] . \tag{9}$$

The notations used in the above equation are same as those used in [4]. We can now re-express eq. (3) as

$$\mathbf{M} = \sum_{l_f,s_f,j,l_i,s_i} M^j_{l_f s_f; l_i s_i} S_{\frac{1}{2},\frac{1}{2}}(l_f s_f; j; l_i s_i) . \tag{10}$$

We can now in general define an effective interaction for this reaction through

$$\langle \mathbf{r}_f | V_{\mathrm{eff}} | \mathbf{r}_i \rangle = \sum_{\lambda_1,\lambda_2,\lambda} \left(\sigma^{\lambda_1} \otimes \sigma^{\lambda_2}\right)^\lambda \cdot \left\langle \mathbf{r}_f \left| V^{(\lambda_1\lambda_2)\lambda} \right| \mathbf{r}_i \right\rangle , \tag{11}$$

where

$$\left\langle \mathbf{r}_f \left| V_\mu^{(\lambda_1\lambda_2)\lambda} \right| \mathbf{r}_i \right\rangle = \sum_{l_f,s_f,j,l_i,s_i} G_2 \times \left\langle r_f \left| V^j_{l_f s_f; l_i s_i} \right| r_i \right\rangle \left\langle \hat{\mathbf{r}}_f \left| S_\mu^\lambda(l_f, l_i) \right| \hat{\mathbf{r}}_i \right\rangle , \tag{12}$$

with $\left\langle r_f \left| V^j_{l_f s_f; l_i s_i} \right| r_i \right\rangle$ being the radial non-local terms. Thus the term $\lambda_1 = \lambda_2 = \lambda = 0$ in eq. (13) defines the spin-independent central interaction, while terms with $\lambda_1 = \lambda_2$ but $\lambda \neq 0$ lead to spin-dependent central interactions. The remaining terms will now correspond to spin-dependent noncentral interactions and these will include spin-orbit interactions when the choice $S_q^k(l,l) = \tau_q^k(\mathbf{L})$ is made. Thus, it is interesting to note that the irreducible tensor amplitudes $\mathcal{T}_\mu^\lambda(\lambda_1, \lambda_2)$ readily admit interpretation in terms of a variety of central and noncentral interactions including spin-orbit interactions thus allowing us to further explore the sensitivity of the singlet and triplet differential cross sections (and also the various spin observables) to the different forms of interactions in the context of the reaction, $\bar{\mathrm{p}}\mathrm{p} \to \bar{\Lambda}\Lambda$. This is achieved by expressing these observables in terms of the irreducible tensor amplitudes. These results will be discussed in detail in the contribution.

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