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QUARK MODEL PREDICTIONS FOR THE DECAY DISTRIBUTIONS OF STRANGE BARYONS PRODUCED IN THE REACTIONS $\frac{1}{2}^+\frac{1}{2}^+ \to \frac{1}{2}^+\frac{3}{2}^+$

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The quark model is used to predict the joint decay distributions of pairs of strange baryons produced in the reactions $\frac{1}{2}^+\frac{1}{2}^+ \to \frac{1}{2}^+\frac{3}{2}^+$ with polarized target. For reactions with particles polarized perpendicularly to the reaction plane it is possible to make absolute predictions using data obtained from reactions with unpolarized particles. Relations between the statistical tensors provide a method of evaluating the additivity angle for the $^3/_2{}^+$ isobar, if the polarization of the target in the reaction plane is not zero.

1. *Introduction*

The additive quark model is useful for the investigation decay distributions of particles in two body reactions (*cf.* Ref. [1–8]).

In this paper we present the predictions of this model for the decay distributions or particles produced in the reactions

$$BB \to BB^* \tag{1}$$

with polarized target. Here B is a $1/2^+$ baryon and B^* is a $3/2^+$ resonance. Up to now a similar analysis has not yet been performed, because in all processes (1), in which the decays of the baryons B and B^* conserve parity, there are only two measurable independent statistical tensors components T_0^2 and T_2^2. In this case the quark model predicts only that the component T_2^2 is independent of the target polarization.

If, however, in the examined reactions (1) the $1/2^+$ baryon decays without conserving parity (as is the case for the weak decays of strange baryons), we can measure all the tensors $T^{J_1J_2}_{M_1M_2}$ with J_1 and J_2 odd (*cf. e. g.* [10]). Then for reactions (1) with unpolarized target only 11 independent tensor components are not equal zero. All the tensors with $J = 3$ vanish (*cf.* Ref. [10]). In the case of the polarized target there are 35 measurable independent tensor components expressed by six independent complex scalar amplitudes.

We have found 35 linear relations between these tensors and tensors measurable in the reactions with unpolarized particles. All the components $T^{J_1J_2}_{M_1M_2}$ with M_1+M_2 even for re-

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actions with polarized target can be calculated if we know the tensors for unpolarized target. Therefore for reactions (1) with particles polarized perpendicularly to the reaction plane it is possible to predict decay distributions using data obtained from reactions with unpolarized particles.

The tensor components $T^{J_1J_2}_{M_1M_2}$ with M_1+M_2 odd are proportional to the polarization in the reaction plane P. They can also be expressed by tensor components measureble in the reactions without polarization. In this case the 16 obtained relations depend still on one parameter, namely on the additivity angle ψ for the $3/2^+$ isobar (*cf. e. g.* [5]). These relations may be used to evaluate the additivity angle and, on the other hand, to check the quark model predictions. All these relations expressing the tensors with polarized target by the tensors with unpolarized target are presented in Sections 2 and 3. Besides, there are also 6 relations between different tensor components with polarized target.

In the Appendix we give the expressions for the statistical tensors in terms of the quark — quark amplitudes.

2. *Relations between statistical tensors with M_1+M_2 even*

The method of deriving of the quark model formulae for statistical tensors was already discussed *e. g.* in Refs [3], [5], [9], (for a review of properties of statistical tensors *cf.* Ref. [11]. Therefore we give here only the final results, *i. e.* the relations between statistical tensors for processes (1). All calculations are done in the transversity frame, *i. e.* with the spin projection on the normal to the reaction plane. The density matrix for the initial baryon can be written in the form

$$\varrho = \frac{1}{2}\begin{pmatrix} 1+P_n & -iPe^{-i\alpha} \\ iPe^{i\alpha} & 1-P_n \end{pmatrix}. \tag{2}$$

Here P_n is the target polarization along the normal to the scattering plane, P is the polarization in the scattering plane, and α is the angle between the beam direction and the polarization vector in the scattering plane.

For the tensor components $T^{J_1J_2}_{M_1M_2}$ with M_1+M_2 even one obtains the following linear relations

$$T^{12}_{11}(P_n) = T^{12}_{11}(P_n = 0)+\sqrt{\frac{3}{5}}\, T^{11}_{11}(P_n = 0)\cdot P_n, \tag{3}$$

$$T^{12}_{1-1}(P_n) = T^{12}_{1-1}(P_n = 0)+\sqrt{\frac{3}{5}}\, T^{11}_{1-1}(P_n = 0)\cdot P_n, \tag{4}$$

$$T^{11}_{11}(P_n) = T^{11}_{11}(P_n = 0)+\frac{1}{\sqrt{15}}\, T^{12}_{11}(P_n = 0)\cdot P_n, \tag{5}$$

$$T^{11}_{1-1}(P_n) = T^{11}_{1-1}(P_n = 0)+\frac{1}{\sqrt{15}}\, T^{12}_{1-1}(P_n = 0)\cdot P_n, \tag{6}$$

$$T^{12}_{02}(P_n) = T^{12}_{02}(P_n = 0), \tag{7}$$

$$T^{02}_{02}(P_n) = T^{02}_{02}(P_n = 0), \tag{8}$$

$$T^{12}_{00}(P_n) = T^{12}_{00}(P_n = 0) + \frac{2}{\sqrt{5}} T^{11}_{00}(P_n = 0) \cdot P_n, \tag{9}$$

$$T^{11}_{00}(P_n) = T^{11}_{00}(P_n = 0) + \left(\frac{\sqrt{5}}{3} T^{10}_{00}(P_n = 0) + \frac{2}{3\sqrt{5}} T^{12}_{00}(P_n = 0)\right) P_n, \tag{10}$$

$$T^{10}_{00}(P_n) = T^{10}_{00}(P_n = 0) + \frac{1}{\sqrt{5}} T^{11}_{00}(P_n = 0) \cdot P_n, \tag{11}$$

$$T^{02}_{00}(P_n) = T^{02}_{00}(P_n = 0) + \frac{2}{\sqrt{5}} T^{01}_{00}(P_n = 0) \cdot P_n, \tag{12}$$

$$T^{01}_{00}(P_n) = T^{01}_{00}(P_n = 0) + \left(\frac{5}{6\sqrt{10}} + \frac{2}{3\sqrt{5}} T^{02}_{00}(P_n = 0)\right) P_n, \tag{13}$$

$$T^{13}_{13}(P_n) = T^{13}_{13}(P_n = 0) = 0, \tag{14}$$

$$T^{13}_{11}(P_n) = 2\sqrt{\frac{2}{5}}\, T^{12}_{11}(P_n = 0) \cdot P_n, \tag{15}$$

$$T^{13}_{1-1}(P_n) = 2\sqrt{\frac{2}{5}}\, T^{12}_{1-1}(P_n = 0) \cdot P_n, \tag{16}$$

$$T^{13}_{1-3}(P_n) = T^{13}_{1-3}(P_n = 0) = 0, \tag{17}$$

$$T^{13}_{02}(P_n) = T^{12}_{02}(P_n = 0) \cdot P_n, \tag{18}$$

$$T^{03}_{02}(P_n) = T^{02}_{02}(P_n = 0) \cdot P_n, \tag{19}$$

$$T^{13}_{00}(P_n) = \frac{3}{\sqrt{5}} T^{12}_{00}(P_n = 0) \cdot P_n, \tag{20}$$

$$T^{03}_{00}(P_n) = \frac{3}{\sqrt{5}} T^{02}_{00}(P_n = 0) \cdot P_n. \tag{21}$$

These relations are independent of the polarization in the scattering plane P.

From these relations we see that all the tensor components determining the decay distributions with the target polarized perpendiculary to the reaction plane are expressed by the tensors $T^{J_1 J_2}$ $(P_n = 0)$ measured without polarized target. Because $T^2_2 = \sqrt{2}\, T^{02}_{02}$, we see from Eq. (8) that T^2_2 is independent of the target polarization. It is the only interesting result of the quark model for reactions (1), if only the even — M tensor components are measured. Because all the tensor components with $M_1 + M_2$ odd are proportional to the polarization in the reaction plane P (see the Appendix) we see from Eqs (3)–(21) that for processes (1) without polarization ($P_n = P = 0$) only 11 tensor components are not equal zero. All the tensors $T^{J_1 3}_{M_1 M_2}(P_n = P = 0)$ vanish (*cf.* Ref. [10]). Besides there are no linear relations between tensors $T^{J_1J_2}_{M_1M_2}(P_n = P = 0)$. There are still two relations of this type expressing a combination of tensor components with $P_n \neq 0$ by tensor components with $P_n = 0$

$$T^{11}_{11}(P_n) - \frac{1}{2\sqrt{6}} T^{13}_{11}(P_n) = T^{11}_{11}(P_n = 0), \tag{22}$$

$$T^{11}_{1-1}(P_n) - \frac{1}{2\sqrt{6}} T^{11}_{1-1}(P_n) = T^{11}_{1-1}(P_n = 0). \tag{23}$$

3. *Relations between statistical tensors with M_1+M_2 odd*

For the tensor components $T^{J_1J_2}_{M_1M_2}$ with M_1+M_2 odd one obtains the following linear relations

$$T^{12}_{12}(P) = -i\sqrt{\frac{3}{5}}\, T^{11}_{11}(P_n = 0) P e^{i(\alpha+\varphi)}, \tag{24}$$

$$T^{12}_{10}(P) = i\,\frac{1}{2}\sqrt{\frac{6}{5}}\, P\left(T^{12}_{11}(P_n = 0) e^{-i(\alpha+\varphi)} + T^{12}_{1-1}(P_n = 0) e^{i(\alpha+\varphi)}\right), \tag{25}$$

$$T^{12}_{1-2}(P) = -i\sqrt{\frac{3}{5}}\, T^{11}_{1-1}(P_n = 0) P e^{-i(\alpha+\varphi)}, \tag{26}$$

$$T^{11}_{10}(P) = i\,\frac{1}{\sqrt{30}}\, P\left(T^{12}_{11}(P_n = 0) e^{-i(\alpha+\varphi)} + T^{12}_{1-1}(P_n = 0) e^{i(\alpha+\varphi)}\right), \tag{27}$$

$$T^{10}_{10}(P) = i\,\frac{1}{\sqrt{10}}\, P\left(T^{11}_{1-1}(P_n = 0) e^{i(\alpha+\varphi)} + T^{11}_{11}(P_n = 0) e^{-i(\alpha+\varphi)}\right), \tag{28}$$

$$T^{12}_{01}(P) = -i\sqrt{\frac{3}{10}}\, T^{11}_{00}(P_n = 0) e^{i(\alpha+\varphi)}, \tag{29}$$

$$T^{11}_{01}(P) = i\,\frac{1}{3\sqrt{10}}\, P\left(T^{12}_{00}(P_n = 0) - 5\, T^{10}_{00}(P_n = 0)\right) e^{i(\alpha+\varphi)} + i\,\frac{1}{\sqrt{15}}\, P T^{12}_{02}(P_n = 0) e^{-i(\alpha+\varphi)}, \tag{30}$$

$$T^{02}_{01}(P) = -i\sqrt{\frac{3}{10}}\, T^{01}_{00}(P_n = 0) e^{i(\alpha+\varphi)}, \tag{31}$$

$$T^{01}_{01}(P) = iP\left(\frac{1}{3\sqrt{10}}\, T^{02}_{00}(P_n = 0) - \frac{\sqrt{5}}{12}\right) e^{i(\alpha+\varphi)} + i\,\frac{1}{\sqrt{15}}\, P T^{02}_{02}(P_n = 0) e^{-i(\alpha+\varphi)}, \tag{32}$$

$$T^{13}_{12}(P) = -iP T^{12}_{11}(P_n = 0) e^{i(\alpha+\varphi)}, \tag{33}$$

$$T^{13}_{10}(P) = -iP\sqrt{\frac{3}{10}}\left(T^{12}_{1-1}(P_n = 0) e^{i(\alpha+\varphi)} + T^{12}_{11}(P_n = 0) e^{-i(\alpha+\varphi)}\right), \tag{34}$$

$$T^{13}_{1-2}(P) = -iP T^{12}_{1-1}(P_n = 0) e^{-i(\alpha+\varphi)}, \tag{35}$$

$$T^{13}_{03}(P) = -iP\sqrt{\frac{3}{2}}\, T^{12}_{02}(P_n = 0) e^{i(\alpha+\varphi)}, \tag{36}$$

$$T^{03}_{03}(P) = -iP\sqrt{\frac{3}{2}}\, T^{02}_{02}(P_n = 0)e^{i(\alpha+\psi)}, \tag{37}$$

$$T^{13}_{01}(P) = -iP\left(\sqrt{\frac{3}{5}}\, T^{12}_{00}(P_n = 0)e^{i(\alpha+\psi)} + \frac{1}{\sqrt{10}}\, T^{12}_{02}(P_n = 0)e^{-i(\alpha+\psi)}\right), \tag{38}$$

$$T^{03}_{01}(P) = -iP\left(\sqrt{\frac{3}{5}}\, T^{02}_{00}(P_n = 0)e^{i(\alpha+\psi)} + \frac{1}{\sqrt{10}}\, T^{02}_{02}(P_n = 0)e^{-i(\alpha+\psi)}\right). \tag{39}$$

They, in turn, do not depend on P_n.

As seen from these formulae it is possible to determine all the tensors $T^{J_1J_2}(P \neq 0)$ if we know $T^{J_1J_2}(P = 0)$ and the additivity angle ψ.

Relations (24)–(39) enable one to determine the additivity angle and, besides, may serve as a check of the additive quark model.

We have still two relations between tensor components with $P \neq 0$ involving the additivity angle

$$T^{13}_{10}(P) = \frac{1}{2}\sqrt{\frac{6}{5}}\,(T^{13}_{1-2}(P)e^{2i(\alpha+\psi)} + T^{13}_{12}(P)e^{-2i(\alpha+\psi)}), \tag{40}$$

$$T^{10}_{10}(P) = -\frac{1}{\sqrt{6}}\,(T^{12}_{1-2}(P)e^{2i(\alpha+\psi)} + T^{12}_{12}(P)e^{-2i(\alpha+\psi)}). \tag{41}$$

Further there is still a relation independent of P or ψ

$$3T^{11}_{10} = T^{12}_{10} = -T^{13}_{10} \tag{42}$$

but all three components appearing here are zero unless $P \neq 0$.

Finally, the quark model predicts that the following two complex components ($= 0$ for $P = 0$) have the same phases:

$$\text{phase of } T^{12}_{01} = \text{phase of } T^{02}_{01}. \tag{43}$$

This exhausts the list of quark model predictions for our reaction (1).

The author would like to thank Dr A. Kotański for suggesting the problem and many helpful discussions.

APPENDIX

Using the similar method to that described in Ref. [5] we obtain for the statistical tensor components with M_1+M_2 even

$$T^{12}_{11} = -\frac{1}{4}\sqrt{\frac{3}{2}}\,(f_7f_2^* + f_3f_0^* + (f_7f_2^* - f_3f_0^*)P_n), \tag{A.1}$$

$$T^{12}_{1-1} = -\frac{1}{4}\sqrt{\frac{3}{2}}\,(f_7f_4^* + f_5f_0^* + (f_5f_0^* - f_7f_4^*)P_n). \tag{A.2}$$

$$T^{11}_{11} = \frac{1}{4\sqrt{10}} \left(5(f_3 f_0^* - f_7 f_2^*) - (f_3 f_0^* + f_7 f_2^*) P_n\right). \tag{A.3}$$

$$T^{11}_{1-1} = -\frac{1}{4\sqrt{10}} \left(5(f_5 f_0^* - f_7 f_4^*) + (f_7 f_4^* + f_5 f_0^*) P_n\right), \tag{A.4}$$

$$T^{12}_{02} = \frac{\sqrt{3}}{4} (f_4 f_2^* - f_3 f_5^*), \tag{A.5}$$

$$T^{02}_{02} = \frac{\sqrt{3}}{4} (f_3 f_5^* + f_4 f_2^*), \tag{A.6}$$

$$T^{12}_{00} = \frac{1}{4\sqrt{2}} (|f_2|^2 - |f_3|^2 + |f_4|^2 - |f_5|^2 + |f_7|^2 - |f_0|^2) + \frac{1}{2\sqrt{2}} (|f_2|^2 + |f_3|^2 - |f_4|^2 - |f_5|^2) P_n, \tag{A.7}$$

$$T^{11}_{00} = \frac{5}{4\sqrt{10}} (|f_2|^2 + |f_3|^2 - |f_4|^2 - |f_5|^2) + \frac{1}{\sqrt{10}} \Big(|f_2|^2 - |f_3|^2 + |f_4|^2 - |f_5|^2 - \\ - \frac{1}{4} |f_7|^2 + \frac{1}{4} |f_0|^2 \Big) P_n, \tag{A.8}$$

$$T^{10}_{00} = \frac{1}{2\sqrt{2}} \left(|f_2|^2 - |f_3|^2 + |f_4|^2 - |f_5|^2 - \frac{1}{2} |f_7|^2 + \frac{1}{2} |f_0|^2 \right) + \\ + \frac{1}{4\sqrt{2}} (|f_2|^2 + |f_3|^2 - |f_4|^2 - |f_5|^2) P_n, \tag{A.9}$$

$$T^{02}_{00} = \frac{1}{4\sqrt{2}} (|f_2|^2 + |f_3|^2 + |f_4|^2 + |f_5|^2 - |f_7|^2 - |f_0|^2) + \\ + \frac{1}{2\sqrt{2}} (|f_2|^2 - |f_3|^2 - |f_4|^2 + |f_5|^2) P_n, \tag{A.10}$$

$$T^{01}_{00} = \frac{5}{4\sqrt{10}} (|f_2|^2 - |f_3|^2 - |f_4|^2 + |f_5|^2) + \\ + \frac{1}{\sqrt{10}} \left(|f_2|^2 + |f_3|^2 + |f_4|^2 + |f_5|^2 + \frac{1}{4} |f_7|^2 + \frac{1}{4} |f_0|^2 \right) P_n, \tag{A.11}$$

$$T^{13}_{13} = 0, \tag{A.12}$$

$$T^{13}_{11} = -\frac{1}{2} \sqrt{\frac{3}{5}} (f_3 f_0^* + f_7 f_2^*) P_n. \tag{A.13}$$

$$T^{13}_{1-1} = -\frac{1}{2} \sqrt{\frac{3}{5}} (f_7 f_4^* + f_5 f_0^*) P_n, \tag{A.14}$$

$$T^{13}_{1-3} = 0, \tag{A.15}$$

$$T^{13}_{02} = \frac{\sqrt{3}}{4} (f_4 f_2^* - f_3 f_5^*) P_n, \tag{A.16}$$

$$T_{00}^{13}=\frac{3}{4\sqrt{10}}(|f_2|^2-|f_3|^2+|f_4|^2-|f_5|^2+|f_7|^2-|f_0|^2)P_n, \tag{A.17}$$

$$T_{02}^{03}=\frac{\sqrt{3}}{4}(f_3f_5^*+f_4f_2^*)P_n, \tag{A.18}$$

$$T_{00}^{03}=\frac{3}{4\sqrt{10}}(|f_2|^2+|f_3|^2+|f_4|^2+|f_5|^2-|f_7|^2-|f_0|^2)P_n. \tag{A.19}$$

For the statistical tensor components with M_1+M_2 odd one obtains

$$T_{12}^{12}=-i\,\frac{1}{4}\sqrt{\frac{3}{2}}(f_3f_0^*-f_7f_2^*)Pe^{i(\alpha+\varphi)}, \tag{A.20}$$

$$T_{10}^{12}=-i\,\frac{3}{8\sqrt{5}}P((f_3f_0^*+f_7f_2^*)e^{-i(\alpha+\varphi)}+(f_7f_4^*+f_5f_0^*)e^{i(\alpha+\varphi)}), \tag{A.21}$$

$$T_{1-2}^{12}=-i\,\frac{1}{4}\sqrt{\frac{3}{2}}(f_7f_4^*-f_5f_0^*)Pe^{-i(\alpha+\varphi)}, \tag{A.22}$$

$$T_{10}^{11}=-i\,\frac{1}{8\sqrt{5}}P((f_3f_0^*+f_7f_2^*)e^{-i(\alpha+\varphi)}+(f_7f_4^*+f_5f_0^*)e^{i(\alpha+\varphi)}), \tag{A.23}$$

$$T_{10}^{10}=-i\,\frac{1}{8}P((f_5f_0^*-f_7f_4^*)e^{i(\alpha+\varphi)}+(f_7f_2^*-f_3f_0^*)e^{-i(\alpha+\varphi)}), \tag{A.24}$$

$$T_{01}^{12}=-i\,\frac{\sqrt{3}}{8}P(|f_2|^2+|f_3|^2-|f_4|^2-|f_5|^2)e^{i(\alpha+\varphi)}, \tag{A.25}$$

$$T_{01}^{11}=i\,\frac{1}{4\sqrt{5}}P\left(\left(\frac{3}{2}(-|f_2|^2+|f_3|^2-|f_4|^2+|f_5|^2)+|f_7|^2-|f_0|^2\right)e^{i(\alpha+\varphi)}+\right.$$
$$\left.+(f_4f_2^*-f_3f_5^*)e^{-i(\alpha+\varphi)}\right), \tag{A.26}$$

$$T_{01}^{02}=-i\,\frac{\sqrt{3}}{8}(|f_2|^2-|f_3|^2-|f_4|^2+|f_5|^2)Pe^{i(\alpha+\varphi)}, \tag{A.27}$$

$$T_{01}^{01}=-i\,\frac{1}{4\sqrt{5}}P\left(\left(\frac{3}{2}(|f_2|^2+|f_3|^2+|f_4|^2+|f_5|^2)+|f_7|^2+|f_0|^2\right)e^{i(\alpha+\varphi)}-\right.$$
$$\left.-(f_3f_5^*+f_4f_2^*)e^{-i(\alpha+\varphi)}\right), \tag{A.28}$$

$$T_{12}^{13}=i\,\frac{1}{4}\sqrt{\frac{3}{2}}P(f_3f_0^*+f_7f_2^*)e^{i(\alpha+\varphi)}, \tag{A.29}$$

$$T_{10}^{13}=i\,\frac{3}{8\sqrt{5}}P((f_5f_0^*+f_7f_4^*)e^{i(\alpha+\varphi)}+(f_7f_2^*+f_3f_0^*)e^{-i(\alpha+\varphi)}), \tag{A.30}$$

$$T^{13}_{1-2} = i\,\frac{1}{4}\sqrt{\frac{3}{2}}\,P(f_7 f_4^* + f_5 f_0^*)e^{-i(\alpha+\psi)}, \tag{A.31}$$

$$T^{13}_{03} = i\,\frac{3}{4\sqrt{2}}\,(f_3 f_5^* - f_4 f_2^*)Pe^{i(\alpha+\psi)}, \tag{A.32}$$

$$T^{03}_{03} = -i\,\frac{3}{4\sqrt{2}}\,(f_3 f_5^* + f_4 f_2^*)Pe^{i(\alpha+\psi)}, \tag{A.33}$$

$$T^{13}_{01} = i\,\frac{1}{4}\sqrt{\frac{3}{10}}\,P((-|f_2|^2+|f_3|^2-|f_4|^2+|f_5|^2-|f_7|^2+|f_0|^2)e^{i(\alpha+\psi)} + $$
$$+(f_3 f_5^* - f_4 f_2^*)e^{-i(\alpha+\psi)}), \tag{A.34}$$

$$T^{03}_{01} = -i\,\frac{1}{4}\sqrt{\frac{3}{10}}\,P(|f_2|^2+|f_3|^2+|f_4|^2+|f_5|^2-|f_7|^2-|f_0|^2)e^{i(\alpha+\psi)} + $$
$$+(f_3 f_5^* + f_4 f_2^*)e^{-i(\alpha+\psi)}). \tag{A.35}$$

Here $f_1, f_2, f_3, f_4, f_5, f_0$ and f_7 are linear combinations scalar amplitudes, and ψ is the additivity angle for the $^3/_2{}^+$ isobar.

Some of the formulae in this paper were simplified by the normalization condition

$$\left(|f_2|^2+|f_3|^2+|f_4|^2+|f_5|^2+\frac{1}{2}|f_7|^2+\frac{1}{2}|f_0|^2\right)+\frac{P_n}{2}(|f_2|^2-|f_3|^2-|f_4|^2+|f_5|^2)=1. \tag{A.36}$$

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