Final state spin polarization in $pp \to p\Delta^+$

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Introduction

Measurements [1] of the total cross section for $pp \to pp\pi^0$ had generated considerable amount of excitement, as they were found to be more than five times the then available theoretical predictions [2]. This led to measurements of a complete set of polarization observables [3] in $\vec{p}\vec{p} \to pp\pi^0$ and to the advent of the Julich meson exchange model [4]. Hanhart [5] observed "As for as microscopic model calculations of the reaction $NN \to NN\pi$ are concerned one has to concede that the theory is definitely lagging behind the development of the experimental sector". More recently, Δ production and decay in proton-proton collisions are reported by the HADES collaboration [6].

A model independent theoretical approach [7] was advanced, following which further investigations [8] were also carried out. A comparison [9] of the empirically extracted amplitudes using this approach with the Julich model predictions identified not only the transitions in which the model was deficient, but also revealed the importance of taking into consideration the Δ contributions. A short coming in [9] was that the threshold Ss amplitude was assumed to have the same phase as the leading Ps amplitude. It was then shown [10] that the phase ambiguity can be removed through the measurements of final state spin obsevables.

The $NN \to N\Delta$ transition matrix was shown [11] to contain as many as 16 amplitudes, of which 10 are associated with second rank spin tensors. Attention was drawn by Ray [12] to the importance of the second rank spin tensors. They have also been used [13] in the context of studies on Δ excitation. Considerable attention has been given to Δ excitation in inelastic nucleon scattering as well [14]. Ramachandran and Vidya [15] have written the $NN \to N\Delta$ matrix using irreducible tensor techniques. The purpose of the present contribution is to use a model independent irreducible tensor formalism to discuss the final state spin polarization in $pp \to p\Delta^+$.

Theory

The reaction matrix $\mathcal{M}$ for $pp \to p\Delta^+$ may be written in the form

$$\mathcal{M} = \sum_{s_i=0}^{1} \sum_{s=1}^{2} \sum_{\Lambda=|s-s_1|}^{s+s_i} [S^{\Lambda}(s, s_i) \cdot \mathcal{M}^{\Lambda}(s, s_i)] \quad (1)$$

where the irreducible spin tensor operators are defined following [7] and the corresponding tensor amplitudes $\mathcal{M}^{\Lambda}_{\mu}(s, s_i)$ are expressible in terms of the partial wave amplitudes $M^{j}_{l_2 s; l_i s_i}$, which completely take care of the dependence on c.m. energy E. The $l_i = 0, 1$ denote the initial relative orbital angular momentum and $s_i = 0, 1$ denotes the initial channel spin whereas l_2 denotes the relative angular momentum between the proton and the Δ^+ and $s = 1, 2$ denotes the final channel spin. It follows that

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

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in terms of the partial wave amplitudes.

The density matrix ρ^f describing the spin polarization in the final state is then given by

$$\rho^f = \frac{1}{4}\mathcal{M}\mathcal{M}^\dagger = \frac{1}{4}\sum_{s,s',k}(S^k(s,s')\cdot t^k(s,s')) \quad (3)$$

in terms of the Fano statistical tensors

$$t^k_q(s,s') = \sum_{s_i,\Lambda,\Lambda'}(-1)^{s'-s_i}[\Lambda]^2[s']$$

$$W(s'\Lambda s\Lambda';s_ik)(\mathcal{M}^\Lambda(s,s_i)\otimes\mathcal{M}^{\dagger\Lambda'}(s',s_i))^k_q \quad (4)$$

The differential cross section is given by

$$\mathrm{Tr}\rho^f = \frac{1}{4}\sum_{s,s_i,\Lambda,\mu}|(\mathcal{M}^\Lambda_\mu(s,s_i)|^2 \quad (5)$$

If we choose conveniently the right handed transverse frame with the Z-axis along $\mathbf{p_i}\times\mathbf{p_2}$ and the X-axis along $\mathbf{p_i}$, the $\mathcal{M}^\Lambda_\mu(s,s_i)$ with odd μ will vanish. This in turn implies that t^k_q with odd q are zero. The t^k_q contain full information regarding Δ polarization and the polarization of the proton coming out with momentum $\mathbf{p_2}$ and the spin correlation between the two.

It would be worth while to measure experimentally, the differential cross section and the spin polarization in the final state as these measurements would lead to a better insight into Δ contribution in $pp \to pp\pi^0$.

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