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SEARCH FOR OBSERVABLES SENSITIVE TO POSSIBLE RESONANCES IN THE PROTON-PROTON SYSTEM

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Within the framework of helicity amplitudes and their angular-momentum decomposition we examine the impact of possible resonances in the proton-proton system upon spin correlation observables at 90^0_{cm}. The sensitivity of the observables to the resonances is discussed in the region between 1 and 2 GeV/c.

1. Introduction

Significant structures observed in the excitation functions $\Delta\sigma_L$[1], $\Delta\sigma_T$[2], $A_{LL}(90^0_{cm})$[3] and $A_{NN}(90^0_{cm})$[4] in the proton-proton system still await an explanation. The existence of dibaryon resonances as suggested in Ref. 5 is far from being accepted. Exact amplitude analysis at 90^0_{cm} has recently been recommended[6] as a helpful method for studying this problem. Only three helicity amplitudes exist at 90^0_{cm}. Five experiments are, therefore, needed to determine the amplitudes completely. In fact, an incomplete subset of only three experiments allows one to determine the three moduli exactly[6]. Another argument concerning the convenience of the 90^0_{cm} geometry can be raised on the basis of non-resonant dynamics. With increasing energy, the *p-p* differential cross section becomes dominated by small *t* values. Therefore, resonant departures should be easier to detect at large momentum transfer.

In the present paper we examine the shape changes in spin correlation observables at 90^0_{cm} imposed by insertion of a resonance into the smooth background. This discussion illuminates the sensitivity of a single observable to the existence of resonance in the chosen partial wave. As most of the experiments concentrate on measuring only one observable, our analysis can be a guide for planning future measurements. Using some known facts about amplitude moduli in the region between 1 and 2 GeV/c, we discuss the sensitivity of spin correlation observables to the possible resonances. The analogous arguments can be made in other energy domains provided that some knowledge on amplitude moduli exists.

2. *Formalism*

The relations between the spin-correlation observables and the helicity amplitude components at 90^0_{cm} are shown to be[6]

$$\frac{d\sigma}{dt} = \frac{\pi}{4q^4} \cdot I,$$

$$I = |f|^2 + |g|^2 + |\Phi_3|^2,$$

$$I \cdot A_{NN} = |g|^2 + |\Phi_3|^2 - |f|^2 \tag{1}$$

$$I \cdot A_{SS} = |g|^2 - |f|^2 - |\Phi_3|^2$$

$$I \cdot A_{LL} = |\Phi_3|^2 - |J|^2 - |g|^2.$$

Here, q is the cm momentum and the helicity amplitude components are

$$(\Phi_1 - \Phi_2)/2 = f = \sum_{\substack{J \\ even}} (2J + 1) K_J M_J$$

$$(\Phi_1 + \Phi_2)/2 = g = \sum_{\substack{J \\ even}} A(J) K_J,$$

$$\Phi_3 = \sum_{\substack{J \\ even}} B(J) K_J + \sum_{\substack{J \\ odd}} C(J) M_{JJ},$$

$$(\Phi_4 = -\Phi_3;\ \Phi_5 = 0),$$

$$A(J) = JM_{J-1J} + (J+1) M_{J+1,J} - 2[J(J+1)]^{1/2} N_J,$$

$$B(J) = (J+1) M_{J-1,J} + J M_{J+1,J} + 2\,[J(J+1)]^{1/2} N_J, \tag{2}$$

$$K_J = \binom{-1/2}{J/2}$$

for even J,

$$C(J) = (J+1)\binom{-1/2}{J_-} + J\binom{-1/2}{J_+}$$

for odd J,

$$J_+ = (J+1)/2, \qquad J_- = (J-1)/2.$$

The symbols M_J, $M_{J+1,J}$, $M_{J-1,J}$, M_{JJ} and N_J are scattering matrix elements in the J representation and their connection[7] to phase-shifts is straightforward.

Now, we restrict our discussion to the case when a resonance occurs in a singlet state influencing only M_J, and examine its consequences upon the behaviour of f. Similar considerations apply to the relationship between M_{JJ} and Φ_3. The influence of a resonance in any singlet partial wave on the f component of helicity amplitudes becomes transparent if the resonant contribution is explicitly taken out from the non-resonant background. We start with the known relations[8]

$$\begin{aligned} M_J &= M_J^\infty + \eta_\infty e^{2i\delta_\infty} M_R, \\ M_R &= 2x/(\varepsilon - i), \\ \varepsilon &= 2\,(m_R - \sqrt{s})/\Gamma, \\ s &= 4\,(m_p^2 + q^2), \\ x &= \Gamma_{el}/\Gamma, \end{aligned} \tag{3}$$

where M_J^∞ is the background M matrix, η_∞ and δ_∞ are the background parameters; x, m_R, Γ and Γ_{el} are the resonance elasticity, mass, total and elastic width, respectively. Relations (2) and (3) combine into

$$f = f_\infty + f_R,$$

$$f_\infty = \sum_{\substack{J \\ \text{even}}} (2J+1)\, K_J\, M_\infty^J,$$

$$f_R = \frac{2\,(2J_R+1)\, K_{J_R}\, \eta_{J_R}^\infty\, x}{(\varepsilon^2+1)^{1/2}} \exp\left[i\left(2\delta_{J_R}^\infty + \operatorname{Arc\,tan}\frac{1}{\varepsilon}\right)\right].$$

Here, J_R is the resonant partial wave.

The resonant part of the f component completes a circle when the parameter ε changes from $+\infty$ to $-\infty$* and f_∞ is a constant. The behaviour of f as a function of energy can be easily followed in Fig. 1. The following statements are obvious from this figure:

1) The f component values lie on a circle in the complex plane.
2) The tangent at the point $\varepsilon = +\infty$ of the circle forms an angle $\Phi = 2\,\delta_{J_R}^{\infty}$ with respect to the horizontal axis.

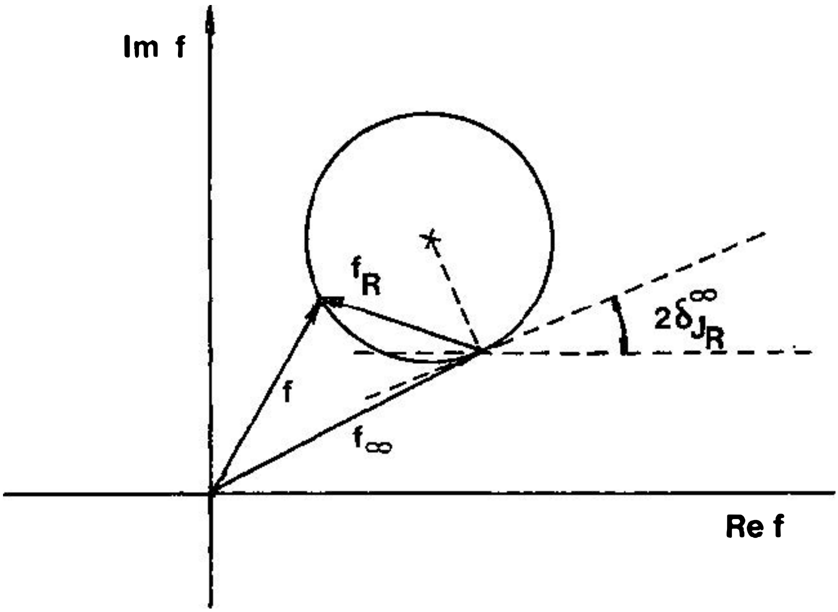

Fig. 1. Summation of the non-resonant (f_∞) and the resonant part (f_R) into the total contribution (f).

A resonance in any singlet partial wave induces a characteristic resonant pattern for the absolute value of the singlet amplitude f (increase and/or decrease). For example, if f_∞ is perpendicular to the resonant circle touching it from outside, a resonance will produce an increase of f. The rotation of such a resonant circle around the point $\varepsilon = +\infty$ by 180° will produce a minimum.

The dependence of the Φ_3 component on a possible resonance in M_{JJ} can be described in an analogous way.

3. *Sensitivity of observables*

The spin-correlation parameters $A_{NN}\,(90^0_{\rm cm})$, $A_{LL}\,(90^0_{\rm cm})$ and $A_{SS}\,(90^0_{\rm cm})$ are, in general, less sensitive to the existence of a resonance in the singlet channel than the absolute value of the f component. Such a qualitative statement can be reached

* Strictly speaking, ε can change from $-\infty$ to $2\,(m_R - 2\,m_p)/\Gamma$, so that the circle is not exactly closed.

by inspection of Eqs. (1). The resonant pattern appears only in the f-component of the nominator and denominator and is disturbed by the presence of the other smooth components $|g|^2$ and $|\Phi_3|^2$. The increase in sensitivity of the above parameters can, however, be achieved with at least two different mechanisms:

a) The non-resonant part of the $|f|^2$ is approximately cancelled in the nominator by the combination of the absolute values of the triplet parts.

b) The resonant decrease of the right side of Eqs. (1) coincides with the resonant enchancement of I; and the resonant enhancement of the right side of Eqs. (1) coincides with the resonant decrease of I.

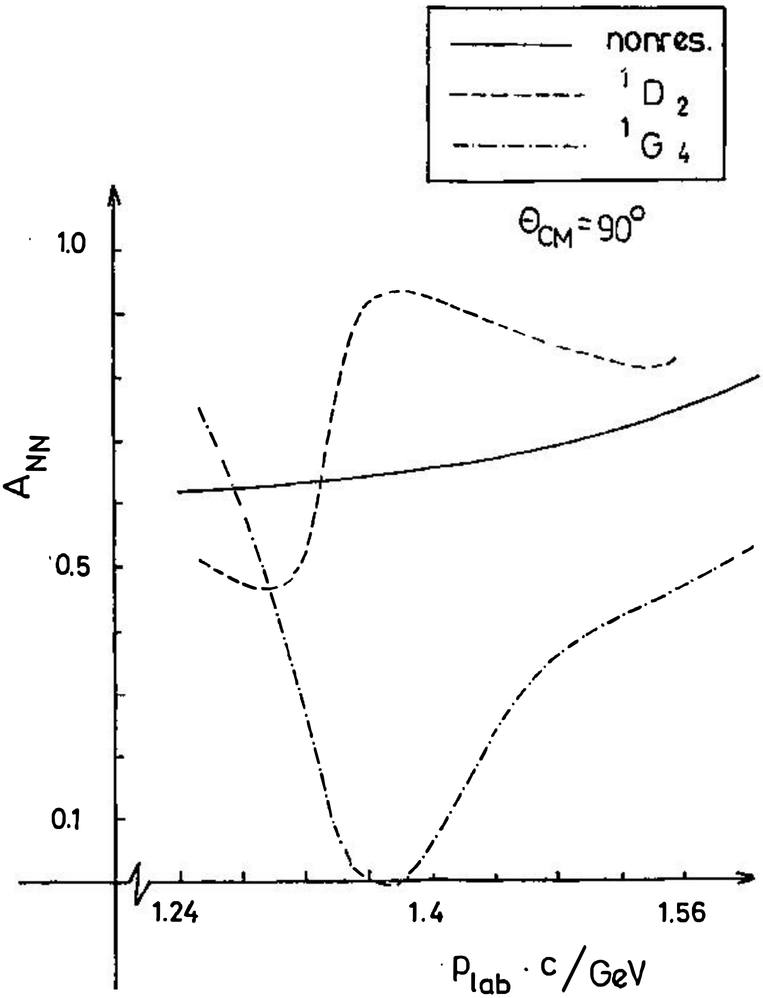

Fig. 2. The influence of the $^1D_2$ (dashed line) and $^1G_4$ (dash-dotted line) resonances upon A_{NN}. Hoshizaki[8] phase shifts have been used.

Obviously, the absolute values of all three components of helicity amplitudes have to be approximately known before a definite answer about the sensitivity of spin-correlation parameters to the possible resonances can be given. Our previous analysis[6] performed in the region between 1 and 2 GeV/c indicated that the absolute value of the Φ_3 amplitude dominated the other two. A similar result for the relationship among moduli of three amplitudes can be obtained from the Hoshizahi phase shifts[8]. The above relationship among the amplitude moduli has the following consequences. The change of the observable caused by a resonance in the singlet partial wave relative to the non-resonant contribution is much bigger for $A_{LL}(90^0_{cm})$ than it is for $A_{NN}(90^0_{cm})$ and $A_{SS}(90^0_{cm})$. (The absolute value of the non-resonant part of f is to a large extent cancelled by the difference of the absolute values of the triplet parts Φ_3 and g). Therefore, $A_{LL}(90^0_{cm})$ appears to be the most convenient parameter for the detection of the possible resonances in the spin singlet channels.

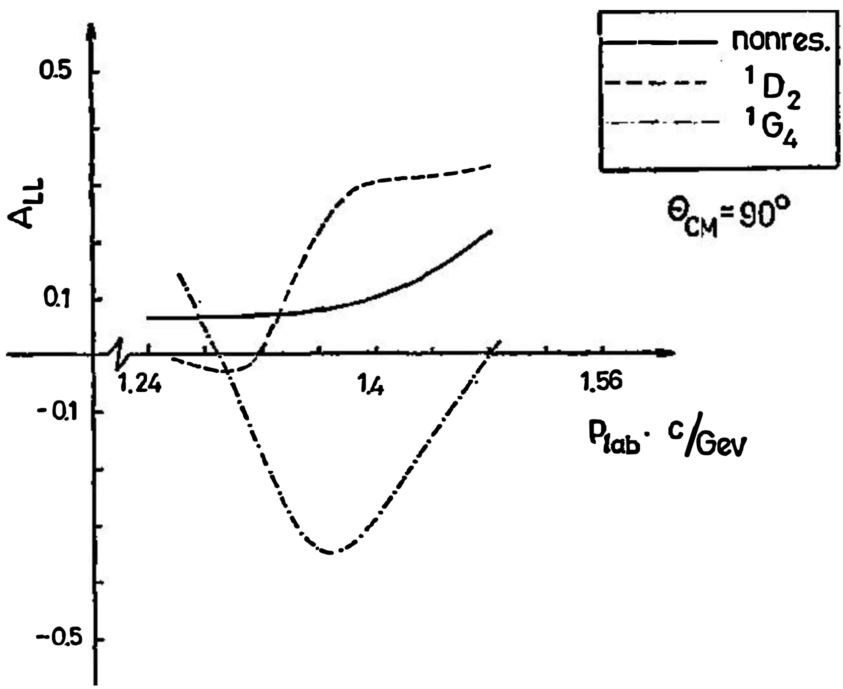

Fig. 3. The influence of the $^1D_2$ (dashed line) and $^1G_4$ (dash-dotted line) resonances upon A_{LL}. Hoshizaki phase shifts have been used.

A similar discussion can be made on the possible resonances in triplet-odd states (M_{JJ}). On the basis of equivalent arguments, we may conclude that $A_{LL}(90^0_{cm})$ is again the convenient observable in the region between 1 and 2 GeV/c when searching for a resonance in the triplet-odd part.

The above conclusions are numerically illustrated in the case when the phase shift analysis is applied. The spin correlation parameters are first calculated using only the non-resonant part of Hoshizahi's phase shifts[8]. The modification of the observable values caused by a resonance is afterwards determined in the following way. The existence of the Breit-Wigner resonance with parameters $x = 0.2$, $m_R =$ $= 2.2$ GeV and $\Gamma = 0.05$ GeV is postulated, first in the $^1D_2$ partial wave and then in the $^1G_4$ partial wave. Figs. 2 and 3 show the influence of the resonance upon the observables A_{NN} and A_{LL}. It is obvious that the relative change of A_{NN} and A_{SS} at certain points ($p_{lab} = 1.4$ GeV/c) for the $^1D_2$ resonance is of the order of 50% of the non-resonant value, while the change of A_{LL} for the same resonance is as high as 200% of the non-resonant value at the same p_{lab}.

The exposition made so far illustrates how to determine which observable is the most sensitive to the resonance existence. It does not provide, however, the criteria needed to claim the resonance. Single variable measurements, while extremely useful in the search, do not supply information necessary in the final identification.

4. *Conclusion*

Complete amplitude analysis can be performed with a reduced number of experiments at 90^0_{cm}. Such analysis should, in general, give the most precise information when looking for a resonance. We have searched for a single observable which would have an increased sensitivity to the presence of resonance. The existing knowledge of the amplitude moduli in the region between 1 and 2 GeV/c has been used. Within this range, we have found that the excitation function for $A_{LL}\,(90^0_{cm})$ is especially sensitive to the presence of a resonance in both the singlet and triplet-odd case.

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TRAŽENJE VARIJABLI KOJE SU OSJETLJIVE NA MOGUĆE REZONANCIJE U PROTON-PROTON SISTEMU

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U okviru helicitetnih amplituda i njihove dekompozicije po kutnoj količini gibanja ispituju se utjecaji mogućih rezonancija u proton-proton sistemu na spin korelacijske observable kod 90^0_{cm}. Diskutira se osjetljivost varijabli na rezonancije u području između 1 i 2 GeV/c.