NN resonance and the corrections to the Goldberger-Treiman relation

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Abstract. The relevance of the recent experimental observation of possible bound and resonant states in NN scattering to the Goldberger-Treiman (GT) relation is examined. It is pointed out that an S-wave resonance in NN scattering goes a long way towards accounting for the corrections to the GT relations. Values of the mass and width of the resonance capable of giving a reasonable fit for the GT relation are presented.

Keywords. Dispersion relation; Goldberger-Treiman relation; NN resonant intermediate state; elastic unitarity.

1. Introduction

Recent experimental observations on $Pd$ interactions at 5.55 GeV/c by Braun et al. (1976) show evidence for the existence of an $NN$ resonance at 2.85 GeV with a width $\Gamma = 39$ MeV and probably another one at 3.05 GeV. The existence of such $NN$ states (both bound as well as resonant) had been predicted earlier by Kalogeropoulos (1974a) and Shapiro (1972; see also Bogdanova et al. 1974) and an experimental observation by Kalogeropoulos (1974b, 1975) further supports the existence of two such $NN$ states near threshold; one at 1.897 GeV with a width of $25 \pm 6$ MeV and the other, a much narrower one at 1.932 GeV. That the existence of such resonant states could have an important role in accounting for the corrections to the GT relation (Goldberger and Treiman 1958a; we follow the notation of this article) had been conjectured by one of the authors (Sekhar Raghavan 1974). In this paper we wish to bring out the important role played by the $NN$ resonant states in improving the agreement between theory and experiment with reference to the GT relation.

Corrections to the GT relation have claimed the attention of several workers. The works most relevant to our approach are due to Pagels (1969) and Pagels and Zepeda (1972). They have concluded that the corrections to the GT relation, obtained by including the $3\pi$ intermediate state in the evaluation of the absorptive part \[ \text{abs}\langle N | \delta_{A, A'} | N \rangle \] have the wrong sign in addition to being smaller by more than an order of magnitude. In order to get over this difficulty they have conjectured a possible tripton resonance or a subtraction in the dispersion relation. Attempts have also been made (Jones and Scadron 1975 and references therein) in estimating the
electromagnetic corrections and contributions from $\rho\pi$ and $\sigma\pi$ intermediate states, which however lead to corrections which are very small.

The main objective of this paper is to bring out the importance of the contribution of a resonant $N\bar{N}$ intermediate state to the pion-nucleon vertex function, in evaluating the pion decay amplitude $F(-m_\pi^2)$, which in turn would account for the corrections to the GT relation. For this purpose we shall adopt the original approach of Goldberger and Treiman (1958a), wherein the role of $N\bar{N}$ intermediate state contribution to $\text{abs } F(-m_\pi^2)$ is clearly brought out. $F(-m_\pi^2)$ is related to the pion-nucleon vertex function and the nucleon axial vector form factors $a$ and $b$. The latter turn out to be real when the contribution of the single pion intermediate state alone is taken into account in estimating them. In a subsequent paper, Goldberger and Treiman (1958b) have pointed out the modification that would result if the $N\bar{N}$ intermediate state contribution are included as well. They conclude however that this modification would not affect their earlier conclusions provided the value of a particular integral (denoted by $J$) is large compared to $0.1$.

2. The method of Goldberger and Treiman

In order to present a cogent and clear picture we repeat here briefly the assumptions made in deriving the GT relation and the important steps of the derivation:

(i) The pion decay amplitude $F(-m_\pi^2)$ is assumed to satisfy an unsubtracted dispersion relation in the variable $\xi := (p_\pi + p_\nu)^2$

$$F(\xi) = \frac{1}{\pi} \int \frac{\text{Im}F(-\xi') d\xi'}{\xi' + \xi - i\epsilon}$$

(ii) In the evaluation of $\text{Im } F(\xi)$ all contributions ($3\pi$ and higher mass intermediate states) other than $N\bar{N}$ are assumed to be negligible. This leads to the following expression

$$\text{Im } F(\xi) = \text{Re} \left\{ K^*(\xi) \left[ a(\xi) - \frac{\xi}{2m} b(\xi) \right] \right\}$$

where $K(\xi)$ is the pion-nucleon vertex function, $m$ the nucleon mass and $a$ and $b$ are the nucleon axial vector form factors.

(iii) $a$ and $b$ are taken to be real (viz only the pion pole contribution is taken into account in estimating them), and one has

$$a = g_A; \quad b \left[ (q_N + q_{\bar{N}})^2 \right] = -\frac{\sqrt{2}G F(-m_\pi^2)}{[(q_N + q_{\bar{N}})^2 + m_\pi^2]}$$

where $g_A$ is the axial vector weak coupling constant and $G$ is the strong coupling constant.