The axial charge of Δ baryon in QCD

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The iso-vector axial-vector form factors of the $\Delta - \Delta$ transition are calculated in the framework of the Light-cone QCD sum rules method. Also, axial charge of Δ baryon is predicted.

Keywords— Baryon axial form factors, Δ, light-cone QCD sum rules

1 Introduction

The axial charge g_A is an important parameter for low-energy effective theories. It can also be viewed as an indicator of the phenomenon of spontaneous breaking of chiral symmetry of non-perturbative QCD [1]. Form factors describe how hadrons interact with each other and bring forth valuable information about the internal structure of the hadrons. As the form factors are non perturbative properties, they need to be calculated using a non-perturbative method. Light cone QCD sum rules [2–4] is one of the non-perturbative methods that have been applied to various properties of hadrons including their form factors. This method has been rather successful in determining hadron form factors at high Q^2. Using the LCSR, the isovector axial vector form factors of baryons have been calculated [5–7]. For Δ baryon isovector axial vector form factors have been studied using lattice QCD [8], chiral perturbation theory [9] and quark models [1,10–12].

2 The axial form factors

In the LCSR approach, we consider the following two-point correlation function:

$$\Pi_{\mu\nu}(p,q) = i \int d^4x e^{iqx} \langle 0|T[\eta^{\Delta}_{\mu}(0) A^3_{\nu}(x)]|\Delta(p,s)\rangle, \tag{1}$$

where $\eta_\Delta(x)$ is an interpolating current for the Δ baryon which has the form as

$$\eta^{\Delta}_{\mu}(0) = \frac{1}{\sqrt{3}}\epsilon^{abc}[2(u^{aT}(0)C\gamma_\mu d^b(0))u^c(0) + (u^{aT}(0)C\gamma_\mu u^b(0))d^c(0)]. \tag{2}$$

The axial transition form factors are defined by the matrix element which can be expressed in terms of four invariant transition factors as [8];

$$\langle \Delta(p',s')|A_\nu(x)|\Delta(p,s)\rangle = \frac{-i}{2}\overline{v}^{\alpha}(p',s')\Big[g_{\alpha\beta}\Big(g^A_1(q^2)\gamma_\nu\gamma_5 + g^A_3(q^2)\frac{q_\nu\gamma_5}{2M_\Delta}\Big) + \frac{q^\alpha q^\beta}{4M^2_\Delta}\Big(h^A_1(q^2)\gamma_\nu\gamma_5 + h^A_3(q^2)\frac{q_\nu\gamma_5}{2M_\Delta}\Big)\Big]v^{\beta}(p,s) \tag{3}$$

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where $A_\nu^3(x) = \frac{1}{2}[(\overline{u}(x)\gamma_\nu\gamma_5 u(x) - \overline{d}(x)\gamma_\nu\gamma_5 d(x)]$ is the isovector-axial vector current, $q = p' - p$, M_Δ is delta mass, v_α is a Rarita-Schwinger spinor for Δ baryon.

In order to calculate the correlation function, we need to know matrix element of the three quark operator. This matrix element can be expressed in terms of quark distribution amplitudes (DAs). DAs of the Δ are calculated in Refs. [13]. Further details of the sum rules calculations can be found in [6].

Choosing the relevant structures, we determine sum rules for the form factors g_1^A, g_3^A as:

$$\begin{aligned}
g_1^A(q^2)\frac{\lambda_\Delta}{M_\Delta - p'^2} &= -\frac{f_\Delta M_\Delta}{\sqrt{3}}\Bigg[\int_0^1 dx_2 \frac{1}{(q-px_2)^2}\int_0^{1-x_2} d_{x_1} 4V(x_1, x_2, 1-x_1-x_2) \\
&\quad - \int_0^1 dx_3 \frac{1}{(q-px_3)^2}\int_0^{1-x_3} d_{x_1}[-T + A - 2V](x_1, 1-x_1-x_3, x_3)\Bigg]
\end{aligned}$$

$$\begin{aligned}
g_3^A(q^2)\frac{\lambda_\Delta}{M_\Delta - p'^2} &= -\frac{f_\Delta M_\Delta}{\sqrt{3}}\Bigg[\int_0^1 dx_2 \frac{1}{(q-px_2)^2}\int_0^{1-x_2} d_{x_1}[2T + 4A + 8V](x_1, x_2, 1-x_1-x_2) \\
&\quad + \int_0^1 dx_3 \frac{1}{(q-px_3)^2}\int_0^{1-x_3} d_{x_1}[-3T + 3A + 2V](x_1, 1-x_1-x_3, x_3)\Bigg].
\end{aligned} \tag{4}$$

3 Results and Conclusions

In this section, we present our numerical predictions of the axial vector form factors of Δ baryon. To obtain the numerical results, we use the expressions of the Δ baryon DAs which are studied in [13]. Also, for the value of the residue of the Δ baryon, λ_Δ. We choose the value as $\lambda_\Delta = 0.038\ GeV^3$ from analysis of the mass sum rules [14].

In Fig.1, we plot the dependence of the form factors $g_1^A(Q^2)$ and $g_3^A(Q^2)$ on M^2 for two fixed values of Q^2 and for various values of s_0 in the range $2\ GeV^2 \leq s_0 \leq 4\ GeV^2$. From these figures, the predictions are quite stable with respect to variation of the Borel parameter for $s_0 = 2.5 \pm 0.5\ GeV^2$.

In Fig. 2, we present the form factors g_1^A and g_3^A as a function of Q^2. The qualitative behavior of the form factors agree with our expectations. Since only the leading twist DAs of the Δ baryons are known, it is not enough to determine the other form factors $h_1^A(Q^2)$ and $h_3^A(Q^2)$.

The axial form factor $g_1^A(Q^2)$ is the only one that can be extracted directly from the matrix element, and we can determine the axial charges at $Q^2 = 0$. However, in our case, the working region of the LCSR cannot extrapolate to the $Q^2 = 0$ directly. LCSR results more reliable at $Q^2 \geq 1\ GeV^2$. Therefore, the axial form factor is parameterized in terms of an exponential form

$$g_A(q^2) = g_A(0)\exp[-Q^2/M_A^2] \tag{5}$$

Fit Region (GeV^2)	$g_A(0)$	M_A (GeV)
$[1.0-10]$	-3.48	1.15
$[1.5-10]$	-2.64	1.24
$[2.0-10]$	-2.10	1.32

Table 1: The values of exponential fit parameters, g_A and M_A for axial form factors. The results include the fits from three region.

	[8]	[9]	[10]	[11]	[12]	This Work
g_A	-1.9 ± 0.1	-4.50	-4.47	-4.48	-4.30	-2.70 ± 0.6

Table 2: Different results from theoretical models which are Lattice QCD [8], ChPT [9], quark models [10–12] and also our model.

Our results are shown in Table I. For this fit form we have studied three fit regions $Q^2 \geq 1\ GeV^2$, $Q^2 \geq 1.5\ GeV^2$ and $Q^2 \geq 2\ GeV^2$.

In Table II, we present the different numerical results of the axial charge predicted from other theoretical models. As seen from table, our result is slightly larger than the result obtained from Lattice QCD [8], approximately two times smaller compared to the predictions of ChPT [9] and quark models [10–12]. There is no experimental result yet.

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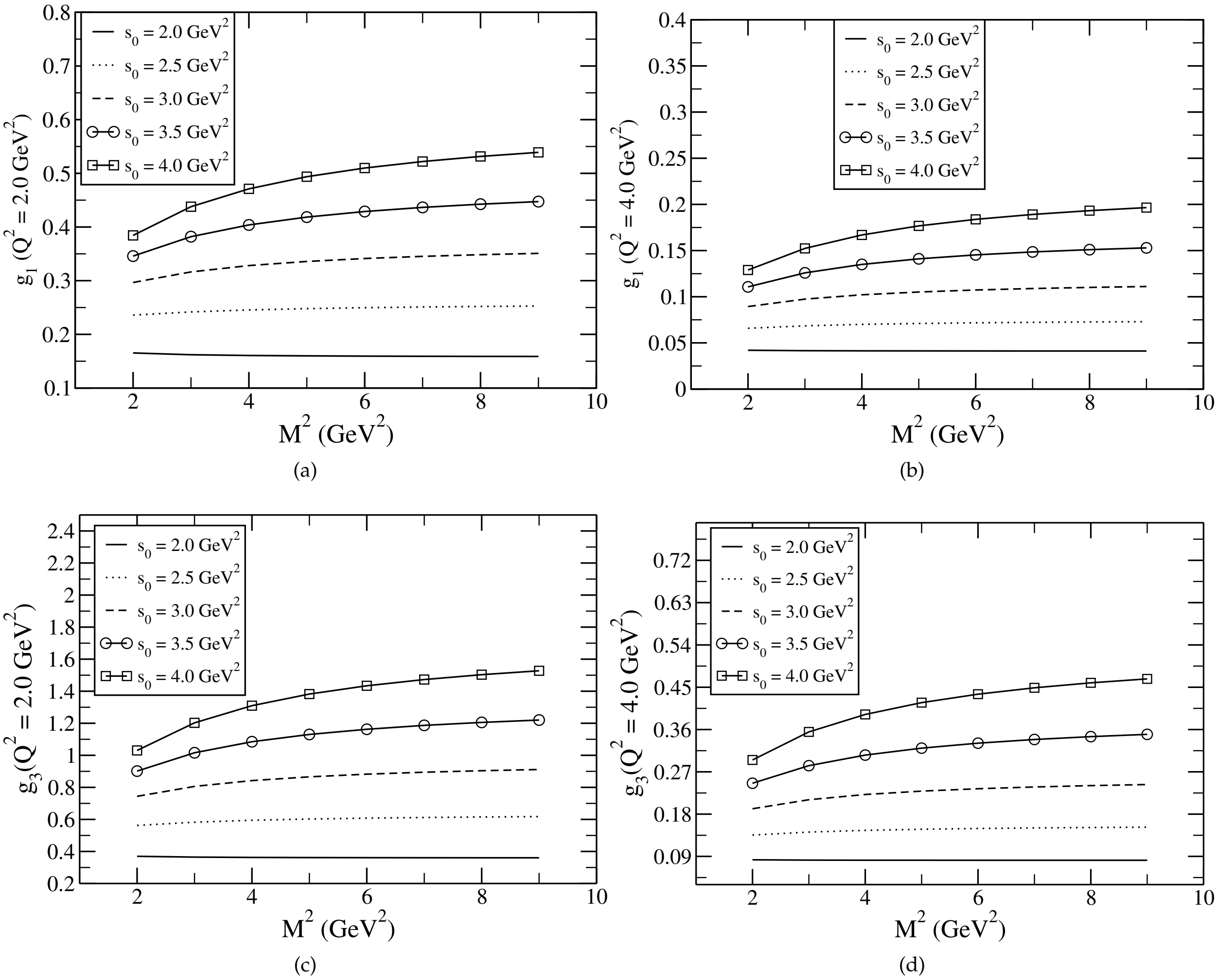
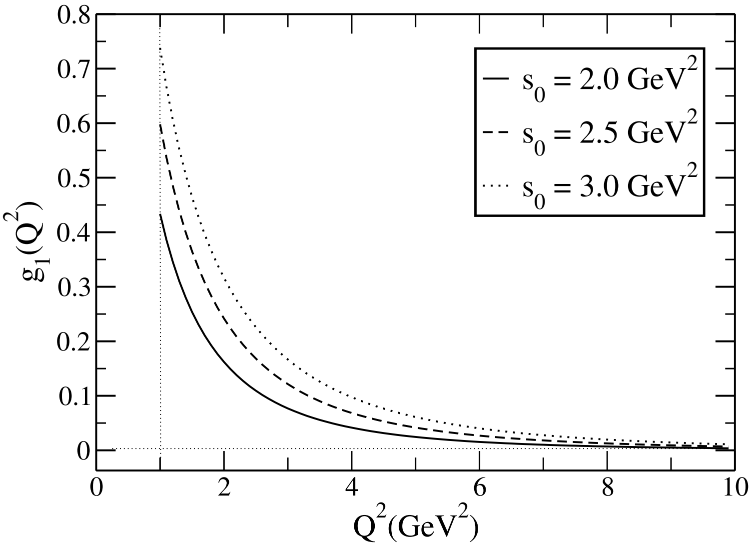
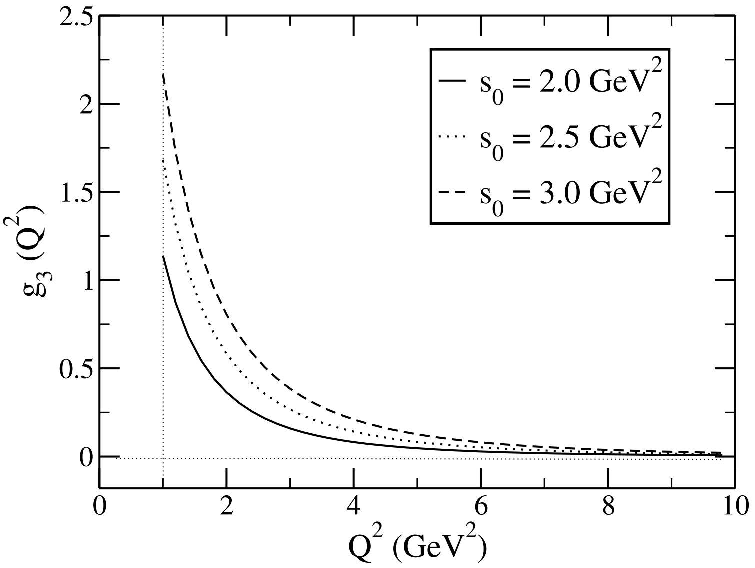


Figure 1: The dependence of the form factor g_1^A and g_3^A on the Borel parameter squared M^2 for the values of the continuum threshold $s_0 = 2.0\ GeV^2$, $s_0 = 2.5\ GeV^2$ $s_0 = 3.0\ GeV^2$, $s_0 = 3.5\ GeV^2$ and $s_0 = 4.0\ GeV^2$ and at the values $Q^2 = 2.0$ and $4.0\ GeV^2$.



(a)



(b)

Figure 2: The dependence of the form factors g_1^A and g_3^A on the Q^2 for the values of the continuum threshold $s_0 = 2.0\ GeV^2$, $s_0 = 3.0\ GeV^2$, $s_0 = 3.5\ GeV^2$ and the Borel parameter $M^2 = 3.0\ GeV^2$.