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# A New Relativistic and Singularity Free Form Factor of Baryon Vertex *

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**Abstract** A new relativistic and singularity free form factor for baryon vertex is suggested. The form factor satisfies the crossing symmetry of scattering amplitude transfered from t-channel to s-channel for strong interaction processes.

**Key words** formfactor, baryon, coupling vertex

It is well known that a baryon consists of quarks and gluons and thus, is a composite system with a volume occupied in space. That is, baryon is not a point-like, structureless, fundamental particle but a sizeable object in space with a quark-gluon structure. Accordingly, when treating an interacting physical process involved a baryon a form factor describing the internal quark-gluon structure of the baryon must be used, which has been shown to be crucial in improving dramatically the theoretical description of experimental observables. The form factors having been most commonly using so far are of multipole type, $[\lambda^2/(\lambda^2-q^2)]^n$, or its variants, with $n$ being the multipole order, $q$ the four momentum transfer to the vertex and $\lambda$ a momentum-space range. In the absence of microscopic calculations of the form factor, $\lambda$ was customarily treated as a free parameter having its value determined from fitting experimental data, but with some strong controversies[1].

However, the form factors used so far does not satisfy the crossing symmetry required by $s$-matrix, since it must be an analytic function and analytically continued from one channel to other channel[2]. For example, when studying the asymptotic behavior of scattering amplitude for strong interacting processes at high energies[3], the t-channel $(a+\bar{c}\rightarrow\bar{b}+d)$ amplitude, $F^{t}_{a+\bar{c}\rightarrow\bar{b}+d}(s,\ t)$, must be transfered into the amplitude in the s-channel $(a+b\rightarrow c+d)$, $F^{s}_{a+b\rightarrow c+d}(s,\ t)$, and the two amplitudes are required to satisfy the crossing symmetry relation

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$$A^{(t)}_{a+\bar{c}\to\bar{b}+d}(s_t,\ t_t,\ u_t) = A^{(s)}_{a+b\to c+d}(t,\ s,\ u), \tag{1}$$

with $s$, $t$, $u$ being the Mandelstam variables, and $s_t = t$, $t_t = s$. Unfortunately, all of commonly used form factors becomes singular in $t$ when it passes from s-channel, where $s > 0$, $t < 0$, to t-channel, where $t_t > 0$, $s_t < 0$, or reverse. They all are, therefore, unsuitable to analyses involving channel crossing.

To overcome this difficulty, we suggest a new relativistic and singularity free form factor $H(t)$ in this note, which must satisfy the following physical requirements

(1) It should be an analytic function of $t$ so that it can be continued analytically from s-channel to t-channel and vice verse.

(2) Since in the t-channel, $t_t > 0$ and in the s-channel $t \leqslant 0$, it should behave as the following

$$H^2(t) \xrightarrow{t\to\pm\infty} 0. \tag{2}$$

(3) It should neither diverge with $t\to\pm\infty$, nor has a pole in the $t$ and it must be normalized according to

$$H^2(t = m^2_{res}) = 1. \tag{3}$$

Therefore, the form factor may have the form as the following

$$|H(t)|^2 = \left(\frac{t/4 - m^2}{q^2_r}\right)\left(\frac{e^{t_r/\lambda^2_t}}{R(-x_t) + e^{t/\lambda^2_t}}\right)^2 \cdot \left(\frac{1 + e^{-t_r/\lambda^2_s}}{R(x_s) + e^{-t/\lambda^2_s}}\right)^2, \tag{4}$$

where $m^2_{res}/4 - m^2 = q^2_r$ is the square of the resonance threshold behavior of a single $H(t)$, $x_i \equiv (t - 4m^2)/\lambda^2_i$ with i being s or t, $m$ is the mass of baryon and $t_r = m^2_{res}$. The function $R(ax)$ is defined by

$$R(ax) = \frac{1}{2}\,(1 + \tanh(ax)) = \frac{e^{ax}}{e^{ax} + e^{-ax}}. \tag{5}$$

Obviously, it rapidly changes from 0 into 1 as $x$ goes from negetive values ($x < 0$) into positive one ($x > 0$), with a controling the transition speed at $x = 0$ as shown in fig.1.

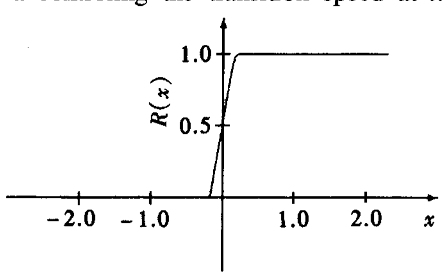


Fig 1

That is, with $a = 10$, $R(x)$ will be very close to a step function but does not have the discontinuity of the latter.

Combining Eqs.(2) and (3) shows that in the s-channel

$$|H(t)|^2 \propto [1 + \exp(t/\lambda^2_t)]^{-2}[\exp(-t/\lambda^2_s)]^{-2}, \tag{6}$$

and here, the $\lambda_s$ controls the form factor $H(t)$ in Eq.(5). When $t$ increases and becomes larger than $4m^2$, the $[H(t)]^2$ behave as

$$|H(t)|^2 \propto [\exp(t/\lambda_t^2)]^{-2}[1+\exp(-t/\lambda_s^2)]^{-2}, \tag{7}$$

and hence, in the t-channel $\lambda_t$ controls the $H(t)$. Note that our proposed form factor here has no singularity in $t$. Particularly, when one studies on mass shell behavior, $t = m_{res}^2$, one has the $H(t) = 1$. This is the normalization of form factor used to date.

With this form factor defined by Eqs(4, 5), the pp elastic scattering experimental data has been reproduced successfully in Ref.(4), and the Pomeson as a Reggeized glueball was discussed. The results showed that the leading contribution to the Pomeron may come from the bound states of gluons-glueballs.

It should be pointed out that like the form factors used commonly such as monopole, exponential-and dipole-form factor, the form of our form factor proposed in this note, Eq.(5), is not unique, but it is singularity free form factor, the only one can be used to analyses involving channel crossing. It also give a most likely result of commonly used form factors for different purpose in different physical processes with a good stability as $\lambda$ variation[4].

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# 一个新的相对论的无奇异点的重子顶点形状因子*

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**摘要**　提出了一个新的、相对论的、无奇异点的重子顶点形状因子．这个形状因子满足强相互作用过程中，散射振幅从 $t$ 道到 $s$ 道变化的交叉对称性．

**关键词**　形状因子　重子　顶点相互作用

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