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Gluonic Content of the Pomeron *

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Abstract It is shown that the Pomeron could be regarded as a Reggeized Tensor Glueball with a trajectory of $\alpha_P(t) = 1.08 + 0.2\mathrm{GeV}^{-2}t$. Under this theory, the total cross section measured for pp elastic scattering at high energies is reproduced successfully. The best fits to experimental data lead to a $\Gamma_{\xi\to p\bar{p}} = 9 \pm 3\mathrm{MeV}$ and $\Gamma_\xi > 50\mathrm{MeV}$, and $J = 4$ for spin of the tensor glueball $m_\xi(2230)$ is precluded.

Key words Pomeron, gluon, glueball

In order to explain high energy elastic scattering and diffractive processes an imaginary object called Pomeron was introduced in hadron–hadron strong interaction by Pomeranchuk in 1958[1]. Pomeron has been playing a crucial role in explaining the asymptotic behavior of the hadron–hadron interaction in the framework of Regge theory[2]. To fit high energy experimental data the Pomeron requires a Regge trajectory $\alpha_P(t) = \alpha_P(0) + \alpha'_P \cdot t$ with $\alpha_P(0)$ greater than 1.0 which is larger than that for any existing hadron whose $\alpha_h(0)$ is less than 1.0. Moreover, comparing with all existing particles which have their own Regge trajectory, no physical particle has been, so far, found to lie on the Pomeron trajectory[3]. That is, no particle can be identified with the Pomeron, and the nature of the Pomeron remains unclear for a half centery.

Over years, a phenomenological Pomeron exchange model with a vector type Pomeron–nucleon coupling vertex, γ^μ, was proposed[4]

$$V^{\mathrm{P\text{-}N}} = \beta\gamma^\mu \cdot F(t), \tag{1}$$

where $F(t)$ is the isoscalar form factor and β is a parameter. This vertex has been used in a number of fits to high energy experimental data. Good fits to pp and $p\bar{p}$ elastic scattering[5] and diffractive dissociation as well as ρ–meson electroproduction[6] have been obtained with a value of $\beta = 6.0\mathrm{GeV}^{-1}$.

In our previous work[7], we have pointed out that the Pomeron is associated with

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gluonic content. We showed that a Pomeron may be related to the Regge trajectory defined by a light scalar glueball/sigma systems which involves complicated non-perturbative QCD. We derived the vertex parameter with non-perturbative QCD by assuming that the Pomeron is associated with a glueball/sigma type trajectory and using known properties of glueball and a conjecture of a light scalar glueball/sigma system. With these assumptions, a non-perturbative treatment of the Pomeron-nucleon vertex, $V^{P\text{-}N}$, has been carried out in terms of the glueball solutions obtained by QCD sum rules. We found $\beta = 6.6\text{GeV}^{-1}$ if the mean value of the quark mass is taken to be 6.0MeV. The result is compatible with the phenomenological value of 6.0GeV^{-1}.

In this report we show that the tensor glueball $\xi(2230)$ with quantum number $J^{PC} = 2^{++}$ could be one of the long-sought Pomeron members. This $\xi(2230)$ was first observed in the radiative decay of the J/ψ to $K\bar{K}$ by the MARK III collaboration[8]. Interest in the $\xi(2230)$ resurrected when the BES collboration[9] measured the reaction $J/\psi \to \gamma\xi$ and determined that this state has a mass of 2230MeV, nearly identical with the mass of 2^{++} tensor glueball predicted by various theories. In addition, the observed relative strength of each decay mode shows a remarkable flavor symmetry, which is one of the most important characheristics of a glueball state. However, the spin of $\xi(2230)$ is still uncertain, being either 2^{++} or 4^{++}, but will be determined by BES or other experiment groups.

As has been shown, Pomeron has a trajectory required by experimental data

$$\alpha_p(t) = 1.08 + 0.2\text{GeV}^{-2} \cdot t. \tag{2}$$

We claim that if $J = 2$ is confirmed, the $\xi(2230)$ satisfies the phenomenological spin-mass relation of Regge theory[10]

$$\alpha_\xi(t = m_\xi^2) = J_\xi, \tag{3}$$

where the mass of the tensor glueball $m_\xi = 2.23\text{GeV}$. Needless to say, the intercept of $\alpha_\xi(0) = 1.08$ certainly explain the asymptotic behavor of the total cross sections for high energy elastic scattering, $\sigma_t(s) \propto s^{\alpha_\xi(0)-1}$.

Let us consider pp elastic scattering denoted by $12 \to 34$ in s-channel. The corresponding t-channel process is, therefore, the $p\bar{p}$ scattering denoted by $1\bar{3} \to \bar{2}4$ via a formation and decay of the tensor glueball $\xi(2230)$. The t-channel helicity Feynman amplitude can be written as[11]

$$M_{\lambda_{\bar{2}}\lambda_4;\lambda_1\lambda_{\bar{3}}}(\bar{s}, \bar{t}) = -4mC_I 4\pi(2J_\xi + 1) < \lambda_{\bar{2}}\lambda_4 | M^{J_\xi}(\bar{s}) | \lambda_1\lambda_{\bar{3}} > d^{J_\xi}_{\lambda\lambda'}(z_t), \tag{4}$$

where $\lambda \equiv \lambda_1 - \lambda_{\bar{3}}$, $\lambda' = \lambda_{\bar{2}} - \lambda_4$, $C_I = \frac{1}{2}$ is the isospin factor, and

$$\langle \lambda_{\bar{2}}\lambda_4 | M^{J_\xi}(\bar{s}) | \lambda_1\lambda_{\bar{3}} \rangle = \frac{G^2 H^{J_\xi}_{\lambda_{\bar{2}}\lambda_4}(\bar{s}) H^{J_\xi}_{\lambda_1\lambda_{\bar{3}}}(\bar{s})}{\bar{s} - M_\xi^2 + iM_\xi \Gamma_{tot}} \tag{5}$$

with Γ_{tot} being the total width of the $\xi(2230)$. In Eq.(5), H denotes the form factor for ξpp vertex in the helicity basis. The G is coupling constant related to decay width $\Gamma_{\xi \to p\bar{p}}$. For the detailed explanation and the calculations we refer readers to our coming paper in Phys. Lett. B[11]. However, it should be emphased that the vertex H

proposed initially here is a relativistic and singularity free form factor satisfied the crossing symmetry transfered from t-channel to s-channel.

$$|H(t)|^2 = \left(\frac{t/4 - m^2}{q_r^2}\right)\left(\frac{e^{t_r/\lambda_t^2}}{R(-x_t) + e^{t/\lambda_t^2}}\right)^2\left(\frac{1 + e^{t_r/\lambda_s^2}}{R(x_s) + e^{-t/\lambda_s^2}}\right)^2, \tag{6}$$

where $q_r = m_\xi^2/4 - m^2$ is the square of the p-wave threshold behavior of a single $H(t)$, $x_i \equiv (t - 4m^2)/\lambda_i^2$, with i being s and t. m is the mass of baryon and $t_r = m_{res}^2$. The function $R(x)$ is defined by

$$R(ax) = \frac{1}{2}(1 + \tanh(ax)) = \frac{e^{ax}}{e^{ax} + e^{-ax}}. \tag{7}$$

Using Eqs. (3—7) we predict total cross section of pp elastic scattering at high energies as shown in Table 1.

Table 1 Comparison between the present predictions and experimental $\sigma_T^{pp}(s)$

$\sqrt{s}$/GeV	$\lambda_s(\Lambda)$/GeV	$\lambda_t(\Lambda)$/GeV	σ_T^{th}/mb	σ_T^{exp}/mb
15	3.66(0.84)	3.66(0.84)	67±40	39±3
	3.66(0.84)	3.73(0.60)	65±39	39±2
60	3.66(0.84)	3.66(0.84)	83±50	42±3
	3.66(0.84)	3.73(0.60)	81±49	42±3

The large uncertainty in our predictions reflects those of the $\Gamma_{\xi\to p\bar{p}}$. We emphased that the results are not sensitive to the range parameters. Conversely, from the known $\sigma_T^{exp}(s)$ we predict a $\Gamma_{\xi\to p\bar{p}}$ of 9 ± 3MeV, and from ratio of the branching ratios, a $\Gamma_\xi >$ 50MeV, which is consistent with conclusion of Ref.[12].

Our predictions also preclude the spin of tensor glueball to be 4 ($J = 4$), since if $J = 4$ the decay width Γ_ξ is too small ($\simeq$ 1MeV), a very unlikely possibility.

In summary, we regard the Pomeron as a Reggeized tensor glueball ξ(2230) with $J^{PC} = 2^{++}$, which lies on the Pomeron trajectory of $\alpha(t) = 1.08 + 0.2\text{GeV}^{-2}t$. The theory gives a good explanation of total cross section for pp elastic scattering at high energies, lending a strong support of gluonic content of the Pomeron. Of course, this interesting conclusion needs to be confirmed by experiments. Therefore, experimentally searching for glueball is an extremely interesting and important work. More work is needed to be done in future.

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Pomeron 的胶子内容*

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摘要 指出 Pomeron 可以被看作为具有 Regge 轨道 $\alpha_{\rm P}(t) = 1.08 + 0.2{\rm GeV}^{-2}t$ 的 Regge 化的胶子球. 理论成功地预言了实验上观测到的质子-质子弹性散射的总截面. 理论与实验的最好符合给出了张量胶子球到质子反质子道的衰变宽度为 9 ± 3MeV,其总宽度大于 50MeV. 并且排除了张量胶子球的自旋为 4 的可能性.

关键词 Pomeron 胶子 胶子球

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