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A New Frontier of Modern Physics Research*

—— Pomeron as a Reggeized Tensor Glueball

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Abstract: We propose that the Pomeron is a Regge trajectory of tensor glueballs with the lightest member having a mass in the 2.2 GeV region and the quantum numbers $I^G J^{PC} = 0^+ 2^{++}$. By using the well-established high-energy proton-proton elastic scattering differential cross sections, we show that our conjecture is fully consistent with the observed ξ production data.

Key words: pomeron; glueball; proton-proton scattering; quantum chromodynamic

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1 Introduction

Before the development of the quantum chromodynamics (QCD) field theory, Regge theory[1] was successfully used in describing and predicting hadron-hadron elastic scattering and diffractive dissociation. Although Regge theory is not a field theory, it is based upon a set of postulates (or axioms) about the S-matrix, which is belie ved to govern the strong interaction physics. Consequently, the Regge theory can not be completely unrelated to QCD. In Regge theory, mesons and baryons are organized into families of trajectory (the Regge trajectories). These trajectories play an important role in hadronic dynamics. The most tantalizing prediction of the theory is that when the interaction energy approaches to infinity only one trajectory contributes to hadron-hadron elastic scattering. This unique trajectory is called the Pomeron trajectory, named after physicist I. Y. Pomeranchuk. The constituent members of the Pomeron trajectory all have the quatum numbers of a vacuum except their spins which follow the Regge-trajectory spin rule.

Although no particles that fit the required Pomeron prescription were observed during the heydays of the Regge theory, many new particles have been discovered due to a new generation of accelerators. Some of these particles exhibit the characteristics of the glueballs predicted only by the QCD theory. As a result of this progress, there is a surge of interests in understanding the success of the Regge theory through connecting glueballs with the Pomeron. Because glueballs are bound states of the gluons, they can only be understood in terms of nonperturbative QCD. An establishment of the Pomeron/Glueball link would guide us using the experience learned from the Regge theory to devise new approaches to nonpertubative QCD.

2 The Regge Theory and Pomeron

Unlike QCD, the Regge theory does not make

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use of gauge particles. Instead, it explores the consequences of a set of fundamental postulates of the S-matrix, which the strong interaction physics must obey. The most relevant postulates are the Lorentz invariance, the unitarity, and the analyticity of the S-matrix.

The Regge theory was motivated by the experimental observation that at high energies ($s \gg 1$ GeV^2) the hadron-hadron elastic scattering and diffractive dissociation are mainly diffractive. Because exchanging a particle in t-channel will give rise to a forward-peaking, diffractive amplitude in the s-channel, the Regge theory conjectures that the high-energy hadronic dynamics is driven by t-channel exchanges.

There is, however, an important difference between the Regge theory and the meson-exchange model used in medium-energy physics. It can be shown that the exchange of a particle of spin J in the t-channel will necessarily lead to a total cross section $\sigma^{tot}(s) \sim s^{J-1}$, which diverges with s for $J > 1$. Hence, the naive particle-exchange model will lead to divergent energy-dependent cross sections, which has to be rescued by introducing energy-cutoff form factors. Regge theory overcame this difficulty by not using particle exchanges but by using trajectory exchanges with each trajectory carrying a running spin, $\alpha(t)$, depending on the value of the exchanged 4-momentum t. As a result, the Regge theory gives $\sigma^{tot} \sim s^{\alpha(0)-1}$. The cross section no longer diverges with s because all trajectories associated with the known particles have $\alpha(0) < 1$. On the other hand, this last inequality also implies that the contribution of most trajectories will die off at high energies.

However, it is observed[2] experimentally that the total cross sections do not vanish asymptotically. In fact, they rise slowly as s increases (see Fig. 1). If one is to attribute this rise to the exchange of a single Regge trajectory, then it follows that this trajectory must have $\alpha(0) \gtrsim 1$. In order to further account for the fact that at high energies $\sigma_{pp} = \sigma_{p\bar{p}}$, $\sigma_{\pi^+p} = \sigma_{\pi^-p}$, and $\sigma_{hp} = \sigma_{\bar{h}p}$ as a whole, Pomeranchuk further conjectured that this trajectory must carry the quantum numbers of vacuum[3] (i.e., $B = Q = S = I = 0$ and $P = G = C = +$) with the exception of its spin $\alpha(t)$, which is not identically zero but is t-dependent. This unique trajectory has later been named the Pomeron trajectory (sometimes called Pomeron, P, for briefness).

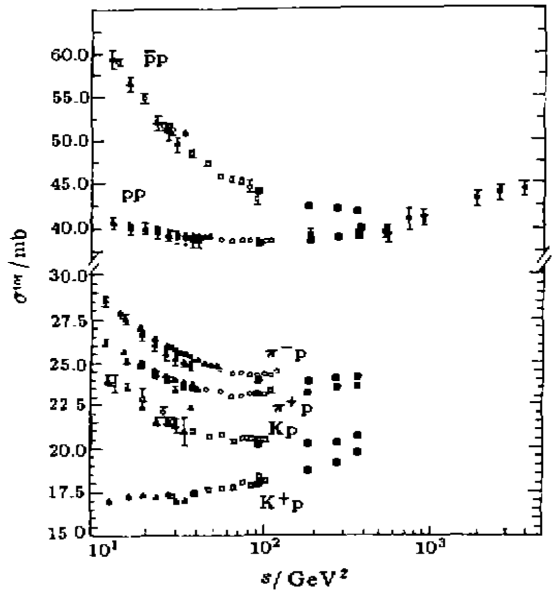

Fig. 1 Energy dependence of the experimental $\sigma_{tot}(s)$ for pp and p̄p elastic scattering at high energies.

The analytic property of the scattering amplitude requires $\alpha(t)$ to be a complex-valued function of t in general. The connection of a trajectory to a physical particle having mass m and spin J is $\mathrm{Re}[\alpha(t=m^2)] = J$. Because many particles can lie on the same trajectory, the exchange of a trajectory is in fact the exchange of a family of particles. In this respect, a trajectory (sometimes also called a Reggeon) can be considered as a family of reggeized particles.

3 Gluonic Content of the Pomeron

Phenomenological fits to the pp cross sections have led to the following linear form for the Pomeron trajectory[4]:

$$\alpha(t) = \alpha(0) + \alpha' t , \tag{1}$$

where $\alpha(0) = 1.08$ and $\alpha' = 0.20 - 0.25$, indicating that the lightest Pomeron should have a spin $J = \mathrm{Re}[\alpha] = 2$, a mass $M = \sqrt{t} = 1.9-2.2$ GeV, and a positive parity.

Recent experimental data on large rapidity gap events at HERA gave some evidence for the existence of the Pomeron. We caution, however, that Pomeron in these events is associated with large Q^2. It is the so-called "hard" Pomeron and is, therefore, not the original (or the "soft") Pomeron encountered in the Regge theory, which is associated with small Q^2. In terms of QCD, the hard Pomeron is in the perturbative (pQCD) regime while the soft Pomeron is nonperturbative (NpQCD). The evolution from hard to soft Pomeron or vice versa is still an unresolved problem at this time. The availability of high-quality data from DESY, TJNL, and FNL can also provide means to explore the dynamics of the Pomeron exchange. One should, however, keep in mind the difference between soft and hard Pomerons when analyzing the data.

The idea of modeling the Pomeron with two gluons was originated by Low[5]. The model was further developed by Nussinov[6] who considered more than two gluons. Subsequent more sophisticated considerations led to the development of BKFL[7] and DGLAP[8] equations. All these models use pQCD and all gave an $\alpha_P(0) \gg 1$, indicating that soft Pomeron must be modeled with NpQCD. There are many studies of diffractive processes using hard or semi-hard Pomeron models, which could be found in the literature[9].

We now list the arguments in favor of the assertion that Pomeron could be a glueball.

(1) Because particles that carry vacuum quantum numbers cannot be the conventional mesons and baryons, it follows that the Pomeron, if exists, would most likely be exotic particles.

(2) In QCD, the simplest model for vacuum exchange with properties similar to that of the Pomeron is two interacting gluons. This was emphasized by Nachtmann who stated that the "two-gluon Pomeron" has all properties that a Pomeron should possess[5,6].

(3) As mentioned above, models involving gluons but not gluonic bound states do not give the correct value of $\alpha(0)$. Consequently, glueballs are the viable candidates.

Scalar glueballs have been studied extensively[1-14]. The coupling strength between a scalar glueball and nucleon has been also derived with QCD sum rule techniques[10]. However, Eq. (1) rules out spin-0 (the scalar) glueballs. Moreover, Levin argued that the process due to exchanging scalar particle is not diffractive and becomes less important as energy increases. Consequently, scalar glueball cannot be the Pomeron and from the discussion given after Eq. (1) the 2^{++} tensor glueball is favored.

The first model for soft Pomeron was the Donnachie-Landshoff (DL) model. However, the DL model does not have gluonic bound state in it[12]. It gives[12,13] a coupling vertex of the Pomeron to the nucleon, of the form $3\beta\gamma^\mu F_1(t)$, which has the character of a vector coupling, γ^μ, implying that the Pomeron behaves like an isoscalar photon. Here, β is the coupling strength and the factor 3 comes from quark counting rule since there are 3 quarks inside the nucleon, and, finally $F_1(t)$ is the nucleon isoscalar form factor given[12,14] by

$$F_1(t) = \frac{4M_p^2 - 2.8t}{4M_p^2 - t}\left(1 - \frac{t}{t_0}\right)^{-2} \tag{2}$$

with $t_0 = 0.71$ GeV^2. One can immediately see two serious problems with the DL model. Firstly, the γ^μ coupling is dubious as it changes sign under charge conjugation, thus, in contradiction to the vacuum character of the Pomeron. Secondly, the form factor $F_1(t)$ has pole-singularities in t and is manifestly not crossing symmetric. In our view, the DL model was only constructed to fit the s-channel data and ignored the analyticity. There are other criticisms of the DL model and can be found in Ref. [15].

In summary, it is reasonable to believe

Pomeron being a glueball. The only viable candidate seems to be the tensor glueball with quantum numbers $I^G J^{PC}=0^+2^{+-}$ and a mass in the 2 GeV region.

4 Pomeron and Tensor Glueball

In 1986, MARK Ⅲ collaboration[16] at SLAC observed narrow resonances, named ξ, in the decay of J/Ψ to K_SK_S and K^+K^- channels. It was reported that $M_\xi=2\ 230\pm15$ MeV and $\Gamma_\xi=18^{+23}_{-15}\pm10$ and $26^{+26}_{-16}\pm7$ MeV, and that $J^{PC}=(\text{even})^{++}$. At the same time, Alde et al. also observed[17] a broad enhancement ($\Gamma\leq150$ MeV) at $M=2\ 220$ MeV in the reaction $\pi^-p\to nX$, $X\to\eta\eta'$. The ξ was also seen[18] in $K^0_SK^0_S$ and in the WA91 collaboration[19] at CERN. However, it was not seen in Υ decays and in inclusive B decays. In 1996, BES collaboration[20] at BEPC reported the observation of ξ(2 230) in the radiative decay of the J/Ψ to $\bar{p}p$, K^+K^-, $K^0_SK^0_S$, $\pi^+\pi^-$ two-body channels. It was also reported that the data suggest a spin ≥2. However, the ξ(2 230) was not seen in experiments $\bar{p}p\to K^+K^-$, K_SK_S, $\Phi\Phi$, $\pi^+\pi^-$. In our opinion, these seemingly contradictory experimental results could be an indication that the two-body decay channels is only a small fraction of the total ξ(2 230) decay. Indeed, the uncertainty on all the measured total width of ξ is of the same size as statistical errors. Measuring all the decay modes of the ξ, including a repetition of the BEPC experiment with a much improved statistics, will help clarify the situation.

The existence of a tensor glueball 2^{++} in the mass region of 2.2 GeV is expected from many theoretical considerations[21]. A mass-relation analysis of all the observed isoscalar tensor states indicates that while most of the tensor states are $\bar{q}q$ — glue hybrid states, the ξ(2 230) admits a pure glueball solution.

Since the BEPC collaboration observed ξ in the $J/\Psi\to\gamma\xi$; $\xi\to\bar{p}p$ reaction and since the $\bar{p}p$ channel is related to the pp channel by crossing symmetry, it is of value to investigate contributions by ξ to high-energy pp scattering. In particular, because pp elastic scattering is purely a diffractive process in which no quantum numbers are exchanged between the colliding particles, it creates ideal conditions for investigating the Pomeron.

The idea of the analysis[22] of Liu and Ma is that if the Regge-exchange of ξ can describe the observed pp elastic scattering as prescribed by the Pomeron, then the agreement would be a strong indication that the ξ(2 230) meson is a Pomeron and a glueball. In the following, we elucidate the key results of that work[22].

The s-channel pp elastic scattering is shown by the diagram in Fig. 2. The corresponding t - channel $p\bar{p}$ scattering is shown in Fig . 3 . The

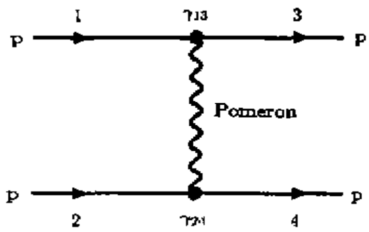

Fig. 2 Schematic representation of the Pomeron exchange model for pp elastic scattering at high energy in s-channel.

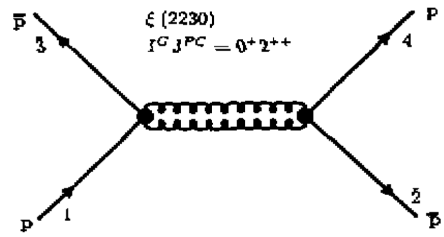

Fig. 3 Schematic representation of pp elastic scattering in t-channel via the formation and decay of the tensor glueball ξ(2 230).

crossing symmetry relation (omitting spins) is

$$A_{pp\to pp}(s,t)=A_{p\bar{p}\to\bar{p}p}(t,s)\ . \tag{3}$$

It is very important to notice the ordering of Mandelstam variables s, t in Eq. (3). This equation shows that the scattering amplitude in the s-channel, $A_{pp\to pp}$, can be obtained from the calculations of the t-channel amplitude $A_{p\bar{p}\to pp}$ by analytical continuation, and vice versa.

It is, however, physically more transparent to start with the Regge amplitude in the t-channel, which has a clear identification with the Feynman diagram of formation and decay of the exchanged particle (see below and Fig. 3). The t-channel Regge amplitude in the helicity basis is

$$A^{(t)}_{\lambda_{\bar 2}\lambda_4;\lambda_1\lambda_{\bar 3}}(\bar s,\bar t) = C_1 \frac{-4\pi^2(2\alpha+1)\beta_{\mathcal{M}}(t)(-1)^{\alpha+\lambda}\frac{1}{2}[1-(-1)^{\alpha}]}{\sin\pi(\alpha+\lambda)} \cdot d^{\alpha}_{\lambda\lambda'}(z_t) \, , \tag{4}$$

where $C_1 = 1/2$, $\bar s = t$, $\bar t = s$. The $\beta_{\mathcal{M}}(t) \equiv \beta_{\lambda_{\bar 2}\lambda_4\lambda_1\lambda_{\bar 3}}(\bar s = t)$ is the Regge residue. The λ_i is the helicity of the particle i, and $\alpha \equiv \alpha(t)$ is the trajectory spin. In Eq. (4), we have introduced for clarity the variables $\bar s \equiv t$ and $\bar t \equiv s$ which denote, respectively, the total c. m. energy and the momentum transfer in the t-channel.

The crossing-symmetry relations between spin-dependent amplitudes are

$$A^{(s)}_{(pp\to pp)\lambda_3\lambda_4;\lambda_1\lambda_2}(s,t) = \mathscr{U}_{\lambda_3\lambda_4\lambda_1\lambda_2;\lambda'_{\bar 2}\lambda'_4\lambda'_1\lambda'_{\bar 3}} A^{(t)}_{(p\bar p\to p\bar p)\lambda'_{\bar 2}\lambda'_4;\lambda'_1\lambda'_{\bar 3}}(\bar s,\bar t) \, . \tag{5}$$

Since there are five independent helicity amplitudes, $\mathscr{U}$ is a 5×5 unitary matrix.

The Feynman amplitude due to exchanging $\xi(2\,230)2^{++}$ is

$$A^{(t)}_{\lambda_{\bar 2}\lambda_4;\lambda_1\lambda_{\bar 3}}(t,s) = -4M_\xi^2 \frac{4\pi\,(2J_\xi+1)}{2} \langle\lambda_{\bar 2}\lambda_4|\mathscr{M}^{J_\xi}(t)|\lambda_1\lambda_{\bar 3}\rangle d^{J_\xi}_{\lambda\lambda'}(z_t) \, , \tag{6}$$

with

$$\langle\lambda_{\bar 2}\lambda_4|\mathscr{M}^{J_\xi}(t)|\lambda_1\lambda_{\bar 3}\rangle = \frac{G_\lambda H^{J_\xi}_{\lambda_{\bar 2}\lambda_4}(t) G_\lambda H^{J_\xi}_{\lambda_1\lambda_{\bar 3}}(t)}{t - M_\xi^2 - iM_\xi\Gamma^\xi_{tot}} \, , \tag{7}$$

where $\lambda = \lambda_1 - \lambda_{\bar 3}$, $\lambda' = \lambda_{\bar 2} - \lambda_4$, and $H(t)$ denotes the form factor of the $\xi p\bar p$ coupling vertex in the helicity basis and G is the coupling constant. Furthermore, $M_\xi = 2.23$ GeV, $\Gamma^\xi_{tot} = 15\pm9$ MeV are the mass and the total decay width of $\xi(2\,230)$.

The reggeization of ξ-exchange was realized through projecting the discrete spin value of J_ξ onto the continuous spin α of the Regge trajectory and the result is[22]

$$\beta_{\mathcal{M}}(t) = -\mathrm{Re}[\alpha']\, 4M_p^2 G_\lambda H_{\lambda_{\bar 2}\lambda_4,J_\xi}(t) \cdot G_\lambda H_{J_\xi,\lambda_1\lambda_{\bar 3}}(t) \, . \tag{8}$$

Eq. (8) gives a Feynman description of the "residue factorization" used extensively in the Regge theory, which also answers why we prefer to start with the t-channel amplitude. We may also notice that the factorization of the Regge residue β is achieved at the same time of the reggeization.

The GH is directly related to the partial decay width $\Gamma_{\xi\to p\bar p}$ through:

$$\frac{1}{2}\Gamma_{\xi\to p\bar p} = \mathrm{Im}\,[\Pi_\xi(t)] = \frac{1}{2}\frac{M_p^2}{M_\xi^2}\frac{|\boldsymbol{q}_t|}{16\pi^2}\sum_{\lambda_p\lambda_{\bar p}}|G_\lambda H_{\lambda_p\lambda_{\bar p},J_\xi}(q_t^2)|^2 , \tag{9}$$

with $q_t^2 = M_\xi^2/4 - M_p^2$ (which we denote t_r) and $\lambda = \lambda_p - \lambda_{\bar p}$. Eq. (9) shows that the vertex GH can be obtained from calculating the self-energy $\Pi_\xi(t)$ of the tensor state or from measuring $\Gamma_{\xi\to p\bar p}$. Conversely, one can determine GH from pp scattering and to use it to predict $\Gamma_{\xi\to p\bar p}$. The relevant equations are[22]

$$\sigma^{T}_{tot} = \frac{1}{2s}\sum_{\lambda_3\lambda_4,\lambda_1\lambda_2}\mathrm{Im}[\mathscr{A}^{(s)}_{\lambda_3\lambda_4,\lambda_1\lambda_2}]|_{t=0} = \frac{1}{2s}\mathrm{Im}(4\mathscr{A}^{(s)}_1 + 8\mathscr{A}^{(s)}_5)|_{t=0} \, . \tag{10}$$

and

$$\frac{d\sigma^T}{dt} = \frac{1}{16\pi s^2}\sum_{\lambda_3\lambda_4,\lambda_1\lambda_2}|\mathscr{A}^{(s)}_{\lambda_3\lambda_4,\lambda_1\lambda_2}|^2 = \frac{1}{16\pi s^2}(4|\mathscr{A}^{(s)}_1|^2 + 4|\mathscr{A}^{(s)}_3|^2 + 8|\mathscr{A}^{(s)}_5|^2) \, . \tag{11}$$

In the above equations, $\mathscr{A}^{(s)}_i\ (i=1,3,5)$ are three of the five independent helicity amplitudes corresponding respectively to $(\lambda_3\lambda_4;\lambda_1\lambda_2) = (++;++)$, $(--;+-)$, $(++;+-)$. The second equality in Eqs. (10) and (11) is due to crossing symmetry properties of the amplitudes.

It is advantageous to model the form factor H in the LS-basis because in this latter basis the form factor has a well-known $|\boldsymbol{q}|^L$ threshold behavior that can be explicitly incorporated into the model.

The helicity basis is related to the LS-basis by a unitary transformation. Hence,

$$\sum_{\lambda} | G_{\lambda} H_{\lambda_p \lambda_{\bar{p}}, J_\xi}(t) |^2 = \sum_{LS} | G_{LS} F_{LS}(t) |^2, \quad (12)$$

where F_{LS} and G_{LS} denote, respectively, the form factor and the coupling constant in the LS basis. For the p$\bar{\text{p}}$ system with $J^{PC}=2^{++}$, the parity conservation leads to $L=1$, 3 and $S=1$ only. If the form factor is defined in such a way that $F_{L,S=1}(t=M_\xi^2)=1$, then

$$\Gamma_{\xi \to p\bar{p}} \propto (g^2_{L=1,S=1} + g^2_{L=3,S=1}) . \quad (13)$$

We have pointed out that the form factor in the DL model is singular. It has two poles in the variable t: one at $t=4M_p^2$, the other at $t=0.71$ GeV^2. Although these t-poles occur at $t>0$ and do not cause trouble in fitting the s-channel pp scattering (where $t\leq 0$), they do prevent the use of the DL form factor in the crossed (i.e., the p$\bar{\text{p}}$) channel where $t>0$. Hence, the DL model is not good for Regge analysis where analyticity and crossing symmetry of the amplitude are required. Liu and Ma used the following crossing-symmetric and singularity-free form factor[22]:

$$[F_L(t)]^2 = \left(\frac{t/4 - M_p^2}{t_r/4 - M_p^2}\right)^L \cdot$$

$$\left[\frac{e^{t_r/\lambda_t^2}}{R(-x_t) + e^{t/\lambda_t^2}}\right]^2 \left[\frac{1 + e^{-t_r/\lambda_s^2}}{R(x_s) + e^{-t/\lambda_s^2}}\right]^2, \quad (14)$$

where $t_r \equiv M_\xi^2$. The first numerator $(t/4-M_p^2)^L$ (to be denoted f_L) equals to q^{2L}. It gives the threshold q^L-dependence of the F_L. Thus, it is easy to see that $F_L(t_r)\equiv 1$.

In Eq. (14), $x_s \equiv (t-2M_p^2)/\lambda_s^2$ and $x_t \equiv (t-2M_p^2)/\lambda_t^2$. The function R is defined by

$$R(x) = \frac{1}{2}(1+\tanh(ax)) = \frac{e^{ax}}{e^{ax}+e^{-ax}} , \quad (15)$$

which is analytic and rapidly changes from 0 to 1 when x changes from (0) to 0, with a controling the transition speed at $x=0$. With $a>10$, R will be very close to a step function but does not have the discontinuity of the latter. In fact, R and F_L are infinitely differentiable. Consequently, the form factor is a continuous function of t. Because it does not have singularity in either s- or t-channels, it can be used to make analytic continuation of the scattering amplitude between the direct and crossed channels.

In the physical domain of the t-channel (i.e., $t>4M_p^2$), $[F(t)]^2 \propto f_L[\exp(t/\lambda_t^2)]^{-2} \times [1+\exp(-t/\lambda_s^2)]^{-2} \sim t^L \exp(-2t/\lambda_t^2) \to 0$ when $t\to +\infty$, exhibiting the correct energy behavior in the t-channel. We can see that in the t-channel the λ_t controls the form factor. In the s-channel, $t\leq 0$. Hence, $R(-x_t)\simeq 1$ and $R(x_s)\simeq 0$. It follows that

$$[F(t)]^2 \propto \frac{f_L}{(1+e^{t/\lambda_t^2})^2 (e^{-t/\lambda_s^2})^2} \xrightarrow{t \to -\infty} \frac{t^L}{(e^{-t/\lambda_s^2})^2} . \quad (16)$$

Hence, λ_s controls the form factor in the s-channel.

The $[F_L(t)]^2$ of Eq. (16) is the counterpart of $F_1(t)$ of the DL model. A first-order expansion of the denominator in the last equation gives $\exp(-t/\lambda_s^2) \simeq (1 - t/\lambda_s^2)$. Comparing this with Eq. (2), we see that λ_s^2 plays the role of t_0. This comparison also shows that the $(1-t/t_0)$ of the DL form factor is just an ad-hoc parametrization. The deficiency of using the monopole form factor was discussed in more detail in Ref. [22]. As to the first denominator $(4M_p^2-t)$ in Eq. (2), we note that it has its roots in the kinematical singularities in the t-channel, which must be removed from analytic amplitudes. Many methods of regularization are given in the literature. In Ref. [22] the regularization was achieved through the use of Eq. (14) where the threshold behavior q^{2L} cancels out the kinematical singularity. In brief, although the poles of the DL form factor do not lead to numerical trouble in fitting the s-channel data, their existence is not consistent with the analyticity and would lead to difficulties in interpreting correctly the values of the parameters obtained.

Equations (10) – (15) were applied to the analysis of pp elastic scattering at high energies.

The results of predicted partial decay width $\Gamma_{\xi\to p\bar{p}}$ from the measured pp total and differential cross sections are given in Table 1. The width are about 1.5 to 2 MeV. This narrow width may explain why it can only be determined with certainty by means of high-statistics measurements.

We note that the BES collaboration cited nearly equal branching ratios for the four observed decay modes of ξ. Using these equal branching ratios and the above $\Gamma_{\xi\to p\bar{p}}=1.5-2.0$ MeV, we conclude that the total decay width Γ^{ξ}_{tot} is, at least, 8 MeV. In subsequent publications[23] the BES collaboration also reported the observation of $\xi\to\pi^0\pi^0$, $\eta\eta$, $\eta\eta'$. Assuming again equal branching ratios, we will have $\Gamma_{\xi\to p\bar{p}}$ increased to $\sim$ 14 MeV, which is still compatible with the published estimates[20].

The 2-body decay is most likely only a small part of the total decay of the ξ. When all the many-body decay channels are included, such as $\xi\to 4\pi$, the Γ^{tot}_{ξ} could turn out to be very large. Because at the present time the reported width in each decay channel is almost exactly equal to the experimental resolution width and because of the still unsettled experimental situation mentioned at the beginning of this section, it is of capital importance that ξ(2 230) be measured with much more improved resolution.

The spin of the ξ has not been suggested to be identified with 4 because of an insufficient statistics that prevented one from either making or rejecting this identification. Our calculations also tend to favor $J_\xi=2$ and exclude $J_\xi=4$. This is because by parity conservation the lowest partial wave for a $J=4$ particle coupled to a $p\bar{p}$ system must be $L=3$. Table 1 shows that the contribution from $L=3$ (i.e. $g_{L=3,S=1}$) is already very small in the case with $J_\xi=2$; inferring that $J_\xi=4$ being a very unlikely possibility.

Table 1 Predictions of decay width of the tensor glueball into $p\bar{p}$ channel, $\Gamma_{\xi\to p\bar{p}}$, from the measured pp cross sections at $\sqrt{s}=53$ and 62 GeV

$\sqrt{s}$/GeV	λ_s/GeV	λ_t/GeV	$g_{L=1,S=1}$	$g_{L=3,S=1}$	$\Gamma_{\xi\to p\bar{p}}$/MeV
53	0.65 — 0.67	3.43 — 3.44	1.13 — 1.14	0.295 — 0.299	1.85 — 1.86
62	0.66 — 0.68	3.25 — 4.07	1.07 — 1.19	0.277 — 0.360	1.65 — 2.08

5 Conclusions

The soft Pomeron predicted by the Regge theory cannot be conventional mesons or baryons, neither can it be scalar glueballs. It is most likely to be a Regge trajectory of tensor glueballs. Our model of 2^{++}-exchange is compatible with the high-energy pp data and predicts important result about the width of the ξ meson. In view of the fact that only the Pomeron trajectory dominates the high-energy pp scattering and that only exotic particles such as the tensor glueballs can carry the quantum numbers of a vacuum, it is reasonable to expect that the Pomeron is Reggeized tensor glueballs with its lightest constitutent being the ξ(2 230) which has the quantum numbers $I^GJ^{PC}=0^+2^{++}$.

The tensor-glueball exchange theory can be further tested in other diffractive processes such as diffractive dissociation, vector meson electroproduction from the proton, and virtual Compton scattering, etc., processes in which the Pomeron exchange is believed to be dominant.

References:

[1] Regge T. Introduction to Complex Orbital Momenta[J]. Nuovo Cimento, 1959, 14: 951—976.

[2] Donnachie A, Landshoff P V. Proton Structure Function at Small Q^2[J]. Z Phys, 1994, C61: 139—145.

[3] Foldy L F, Peierls R F. Isotopic Spin of Exchange System[J]. Phys Rev, 1963, 130: 1 585—1 600.

[4] Donnachie A, Landshoff P V. Diffractive Deep Inelastic Lepton Scattering[J]. Phys Lett, 1987, B191: 309—314.

[5] Low F E. Model of the Bare Pomeron[J]. Phys Rev, 1975, D12: 163—173.

[6] Nussinov S. Perturbative Recipe for Quark-gluon Theories and Some of its Application[J]. Phys Rev, 1976, D14: 246—257.

[7] Balitskii Y Y, Lipatov L N. The Pomeranch Singularity in Quantum Chromodynamics[J]. Sov J Nucl Phys, 1978, 28: 822—829.

[8] Altarelli G, Parisi G. Asymptotic Freedom in Parton Language[J]. Nucl Phys, 1977, B126: 298—318.

[9] Laget J M, Mendez Galain R. Exclusive Photo- and Electroproduction of Vector Mesons at Large Momentum Transfer [J]. Nucl Phys, 1995, A581: 397—428.

[10] Kisslinger L S, Ma W M. Pomeron and the Reggeized Glueball/Sigma[J]. Phys Lett, 2000, B485: 367—372.

[11] Close F E, Glennys F R, Zhenping Li. Determining the Gluonic Content of Isoscalar Mesons[J]. Phys Rev, 1997, D55: 5 749—5 766.

[12] Donnachie A, Landshoff P V. Elastic Scattering and Diffraction Dissociation[J]. Nucl Phys, 1984, B244: 322—336.

[13] Landshoff P V, Nachtmann O. Vacuum Structure and Diffraction Scattering[J]. Z Phys, 1987, C35: 405—416.

[14] Donnachie A, Landshoff P V. Multigluon Exchange in pp Scattering Scattering[J]. Phys Lett, 1983, B123: 345—348.

[15] Levin E. An Introduction to Pomerons[Z]. DESY, 98—120, TAUP—2522/98, Aug. 1998.

[16] Baltkusaitis R M, Becker J J, Blaylock G T, *et al*. Observation of a Narrow $K\bar{K}$ State in J/Ψ Radiative Decays[J]. Phys Rev Lett, 1986, 56: 107—110.

[17] Alde D M, Binon F, Brieman C, *et al*. 2.22GeV/c^2 $\eta\eta$ Structure Observed in 38 GeV/c and 100 GeV/c π^- p Collisions [J]. Phys Lett, 1986, B177: 120—124.

[18] Aston D, Awaji N, Bienz T, *et al*. Evidene for $J^{PC}=4^{++}$ $K\bar{K}$ State at 2.2 GeV/c^2 from K^-p Interactions at 11 GeV/c [J]. Phys Lett, 1988, B215: 199—204.

[19] Abatzis S, Antinori F, Barberis D, *et al*. Observation of a Narrow Scalar Meson at 1 450 MeV in the Reaction pp→pf($\pi^+\pi^-\pi^+\pi^-$)[J]. Phys Lett, 1994, B324: 509—514.

[20] Bai J Z, Chen G P, Chen H F, *et al*. BES Collaboration, "Studies of ξ(2 230) in J/ψ Radiative Decays"[J]. Phys Rev Lett, 1996, 76: 3 502—3 504.

[21] Burakovbsky L. Scalar Glueball Mass in Regge Phenomenology[J]. Phys Rev, 1998, D58: 057503-1—057503-4.

[22] Liu L C, Ma W X. The ξ(2 230) Meson Trajetory and the Pomeron[J]. J Phys, 2000, G26: L59—61.

[23] Bai J Z, Bain J G, Chai Z W, *et al*. BES Collaboration. "Experimental Study of J/ψ Radiative Decay to $\pi^0\pi^0$"[J]. Phys Rev Lett, 1998, 81: 1179—1182.

现代物理学研究中的一个新的前沿*

——坡密子是一个雷其化的张量胶子球

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摘　要：提出了坡密子就是质量～2.2 GeV、量子数为 $I^GJ^{PC}=0^+2^{++}$ 的张量胶子球的雷其轨迹．高能质子-质子弹性散射微分截面的研究表明，这个猜想与张量胶子球的实验材料完全一致的．

关键词：坡密子；胶子球；质子质子散射；量子色动力学

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