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DYNAMICAL SYMMETRY BREAKING AS THE ORIGIN OF THE POMERANCHUK SINGULARITY*

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ABSTRACT

We consider the viewpoint that Reggeons are built out of Reggeized quarks and that an O(2) symmetry between two kinds of quarks ("heavy" and "light") is dynamically broken by their interaction. The Goldstone boson thus generated is associated with the Pomeron, and it is argued that it naturally has a smaller slope than the other Reggeons which are ordinary bound states of the quarks.

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The spectrum of boson Regge singularities has the peculiar feature of containing a number of "ordinary" Reggeons ($\rho, A_2, f, \ldots$) with intercepts around J=1/2 or lower and slopes close to 1 $(\mathrm{GeV}/c)^{-2}$ and one peculiar object, the Pomeron, with intercept J=1 and slope about 1/4 to 1/3 of the ordinary trajectories. Chew and Rosenzweig[1] have proposed a model which identifies the Pomeron ($\underset{\sim}{P}$) with the next leading vacuum trajectory (f) and explains its intercept and small slope by significant curvature of the $\underset{\sim}{P}$-f object near t=0. Quigg and Rabinovici[2] have made an analysis of meson-baryon cross section data from 6 to 280 GeV/c and find no good evidence for this $\underset{\sim}{P}$-f coincidence.

From the point of view of Reggeon field theory the $\underset{\sim}{P}$ is a gapless singularity with Reggeon energy, E=1-J, vanishing at zero Reggeon momentum.[3] All other Reggeons have a nonzero energy gap $\Delta>0$, and trajectory: $E(\vec{q}) = \alpha' \vec{q}^{\,2} + \Delta$. Such a situation is highly suggestive of a bound state spectrum with a Goldstone boson arising from the breaking of an underlying continuous symmetry and a series of ordinary bound states to be identified with the usual Reggeons. Several people have taken up this theme by studying the Reggeon field theory for the Pomeron suggested originally by Gribov,[4] and asking how the $\underset{\sim}{P}$ field operator might acquire a nonzero vacuum expectation value and give rise to Goldstone excitations.[5] A thorough study of this possibility in ordinary Reggeon field theory reveals no reason why the Pomeron gap $\Delta_P = 1-\alpha_P(0)$ should be zero except for special values of the parameters in the Reggeon lagrangian.[6,7]

This suggests that one ought to look into the origin of Regge singularities as bound states of some constituents. In the same spirit as one thinks of the ordinary hadrons as bound states of quark degrees of freedom, we would like to think of Reggeons as bound states of the same degrees of freedom which are now realized off the mass shell and for complex angular momentum, as is appropriate for a Reggeon. Since fermion degrees of freedom appear to Reggeize in non-Abelian gauge theories,[8] such a theory may well underlie our approach.

So let us consider a set of quark Reggeon fields $\chi_i(\vec{x}, \tau)$ which are two component spinor fields in rapidity, τ, and impact parameter, $\vec{x}$, space. The label i encompasses color and some set of flavors. We want to imagine that among these flavor labels there is an O(2) symmetry. For example, it could mix an SU(3) triplet of u, d, s quarks with some triplet of U, D, S quarks. We'll call these two sets rotated into one another by the O(2), heavy and light. A free Reggeon lagrangian invariant under O(2) rotations $U(\theta) = \exp i\tau_2\theta;\ \tau_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$ is

$$\mathscr{L}_\chi = \frac{i}{2}\tilde{\chi}^+ \frac{\overleftrightarrow{\partial}}{\partial t}\chi + i\frac{\beta_0}{2}\tilde{\chi}^+ \sigma_3 \underset{\sim}{\sigma}\cdot\overleftrightarrow{\underset{\sim}{\partial}}\chi - \Delta_0\tilde{\chi}^+\chi \quad , \tag{1}$$

where $\tilde{\chi}$ is the transpose in heavy-light space. The σ matrices operate in the spin space of two component spinors and $\underset{\sim}{\sigma} = (\sigma_1, \sigma_2)$ operates in the two dimensional momentum space of the Reggeons. The free propagator[9]

$$S(E, \underset{\sim}{q}) = 1/E - \beta_0\sigma_3\underset{\sim}{\sigma}\cdot\underset{\sim}{q} - \Delta_0 \tag{2}$$

describes the usual doublet of positive and negative parity fermion Reggeons with intercept $\alpha_0 = 1 - \Delta_0$.

As a simple interaction, which is just renormalizable in two dimensional transverse space, we choose a scalar Reggeon $\phi(\vec{x}, \tau)$ to provide

$$\mathscr{L}_I = -\frac{\lambda_0}{2}\tilde{\chi}^+\chi(\phi^{+2} + \phi^2) \tag{3}$$

plus its free propagation

$$\mathscr{L}_\phi = \frac{i}{2}\phi^+\frac{\overleftrightarrow{\partial}}{\partial t}\phi - \alpha_0'\nabla\phi^+\cdot\nabla\phi - \delta_0\phi^+\phi \ . \tag{4}$$

Now we seek a solution to this O(2) symmetric Reggeon field theory which has a proper self energy for the fermion propagator $\Sigma(E, q) = \Sigma_I(E, q) + \tau_3\Sigma_3(E, q)$ where Σ_I and Σ_3 are invariant under O(2) rotations.[10] A term like Σ_3 breaks the heavy-light symmetry and gives rise to a Goldstone boson. To see this consider the proper vertex function of two quarks and the conserved O(2) current

$$(\rho, \underset{\sim}{J}) = \left(\tilde{\chi}^{+} \tau_2 \chi ,\ \tilde{\chi}^{+} \sigma_3 \underset{\sim}{\sigma} \tau_2 \chi\right) \ .$$

The vertex function satisfies the Ward identity

$$E\Gamma_{\rho}(E, \underset{\sim}{q}; E_1, \underset{\sim}{q}_1) - \underset{\sim}{q}\underset{\sim}{\Gamma}(E, \underset{\sim}{q}; E_1, \underset{\sim}{q}_1) = \tau_2 S^{-1}(E_1, \underset{\sim}{q}_1) - S^{-1}(E_1 - E, \underset{\sim}{q}_1 - \underset{\sim}{q}) \tau_2 \ . \quad (5)$$

As $E, \underset{\sim}{q} \to 0$, this means

$$\lim_{E, \underset{\sim}{q} \to 0} E\Gamma_{\rho} - \underset{\sim}{q}\underset{\sim}{\Gamma} = -2i\, \tau_1 \Sigma_3(E_1, \underset{\sim}{q}_1) \qquad (6)$$

and that the proper vertex may be written as

$$(\Gamma_{\rho}, \underset{\sim}{\Gamma}) = \left(\Gamma_{\rho}^{\text{Reg}}, \underset{\sim}{\Gamma}^{\text{Reg}}\right) + \frac{(1, a\underset{\sim}{q})}{E - a\underset{\sim}{q}^2} (-i \tau_1 \Gamma_1) \ , \qquad (7)$$

where

$$\Gamma_1(E, \underset{\sim}{q}; E_1, \underset{\sim}{q}_1) \Big|_{E, \underset{\sim}{q}=0} = 2\Sigma_3(E_1, \underset{\sim}{q}_1) \ , \qquad (8)$$

and Γ^{Reg} has no pole at E, q=0.

So if a symmetry breaking solution exists, then a Goldstone boson appears in the $\tilde{\chi}^{+} \tau_1 \chi$ channel. It has Regge trajectory $\alpha(t) = 1 + at$, and we identify it to be the Pomeron.

To find out whether such a solution is possible we look at the proper self energy Σ_3 to lowest order in λ_0. In D transverse dimensions this is

$$\Sigma_3(E, \underset{\sim}{q}) = \frac{-\lambda_0^2}{2(4\pi^2)^D} \int \frac{dE_1 d^D k_1\, dE_2 d^D k_2\, \Sigma_3(E_1, \underset{\sim}{k}_1) \left[(E_1 - \beta_0 \sigma_3 \underset{\sim}{\sigma} \cdot \underset{\sim}{k}_1 - \Delta_0 - \Sigma_I)^2 - \Sigma_3^2\right]^{-1}}{\left[E_2 - \alpha_0' \underset{\sim}{k}_2^2 - \delta_0 + i\epsilon\right] \left[E - E_1 - E_2 - \alpha_0' (\underset{\sim}{q} - \underset{\sim}{k}_1 - \underset{\sim}{k}_2)^2 - \delta_0 + i\epsilon\right]}$$

(9)

We seek a solution of the form $\Sigma_3(E,\underset{\sim}{q}) = A(E+b_0\underset{\sim}{q}^2)^{-\eta}$ for large E and $\underset{\sim}{q}^2$ with $\eta>0$.[11] Similarly for Σ_I. This only works for D=2, where the coupling λ_0/α_0' is dimensionless, and requires to lowest order in λ_0

$$\eta = \lambda_0/4\pi\alpha_0' \quad \text{and} \quad b_0 = \alpha_0' \frac{4\pi\alpha_0'}{\lambda_0} \tag{10}$$

At least in this crude approximation there is a symmetry breaking solution for every $\lambda_0>0$ at the physical dimensions D=2.

The Goldstone boson associated with this symmetry breaking couples only to the off diagonal channel $\tilde{\chi}^+\tau_1\chi = \chi_H^+\chi_L + \chi_L^+\chi_H$ where H and L label eigenvalues of the proper self energy. All other Reggeons couple to general mixtures of light and heavy quarks. The spectrum of ordinary Reggeons near t=0 ($\underset{\sim}{q}^2$=0) should be strongly determined near $E\approx 1/2$ ($J\approx 1/2$) by both heavy and light quarks so that the hadrons which lie on those trajectories will couple strongly to the $\underset{\sim}{P}$ trajectory there. Away from t=0 and $J\approx 1/2$ perhaps only light or only heavy quarks will be important. As we expect the mass m_H at which the heavy trajectory α_H reaches J=1/2 to be much larger than m_L where α_L=1/2, the slopes of these trajectories satisfy $\alpha_H' < \alpha_L'$, since their intercepts ought to be nearby. Since the $\underset{\sim}{P}$ is determined as a mixture of heavy and light only, its slope will be determined by the usual combination

$$\alpha_P' = \alpha_H'\alpha_L'/\alpha_H' + \alpha_L' \ , \tag{11}$$

while other Reggeons will have their slope determined by the light quarks primarily, so

$$\alpha_R' = \alpha_L'/2 \ .$$

Thus

$$\alpha_P'/\alpha_R' = \left(2\alpha_H'/\alpha_L'\right)/\left(1+\alpha_H'/\alpha_L'\right) \tag{12}$$

and should be small. If we take $\alpha'_P/\alpha'_R \approx 1/3$ and ask that $m_L \approx 300$ MeV and $m_H \approx 1.5$ GeV, then $\Delta_L \approx 0.7$ and $\Delta_H \approx 0.9$ making our picture of nearby singularities in the E plane for $\tilde{q}^2 \approx 0$ consistent.

From this picture also emerges a constant triple $\tilde{P}$ vertex and, yet, through a field theory which satisfies Reggeon unitarity a special (broken) symmetry allows a simple pole $\left[E - \alpha'_P \tilde{q}^2\right]^{-1}$ to emerge for the Pomeron. The details of this and several technical issues connected with the building of Reggeons from quarks and symmetry breaking will appear in an expanded version of this note.

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