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COUPLING OF THE POMERANCHUK PARTICLE TO THE PION
AND ITS DECAY WIDTH

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Chew and Frautschi ¹⁾, on the basis of their "celebrated plot", predicted a particle, the pomeron, which would lie on the vacuum trajectory with spin 2, parity + and mass around 1 GeV. In the following, analyzing the high-energy scattering data in the Regge pole approach, we estimate the coupling constant of the pomeron to two pions and consequently its decay width.

Consider the coupling of a spin 2 isoscalar particle, $\phi^{\mu\nu}$, to two pions. In the field theoretical language $\phi^{\mu\nu}$ is a traceless, symmetric tensor satisfying the subsidiary condition $\partial_\mu \phi^{\mu\nu} = 0$ and the Klein-Gordon equation $(\square^2 - m^2)\phi^{\mu\nu} = 0$ where m is the mass of the particle. The field $\phi^{\mu\nu}$ is coupled to the pion field φ through an effective interaction Lagrangian

$$\mathcal{L}_I = \frac{1}{2} \frac{f}{m} \phi^{\mu\nu} \partial_\mu \varphi^\alpha \partial_\nu \varphi^\alpha \quad (1)$$

where f is the coupling constant. We use the standard field theoretical expressions for Green's functions etc. only near the mass shell and expression (1) is given here only to define the coupling constant.

The matrix element $\mathcal{M}$ for the transition $\phi \rightarrow 2\pi$ can be written most conveniently in the rest-system of ϕ

$$\begin{aligned} \mathcal{M} &= \sqrt{\frac{3}{2}} \frac{f}{m} |\vec{q}|^2 \left[\left(\frac{\vec{\epsilon} \cdot \vec{q}}{|\vec{q}|} \right)^2 - \frac{1}{3} \right] (\pi^+ \pi^- + \pi^- \pi^+ + \pi^0 \pi^0) \\ &= \sqrt{\frac{2}{3}} \frac{f}{m} |\vec{q}|^2 P_2 \left(\frac{\vec{\epsilon} \cdot \vec{q}}{|\vec{q}|} \right) (\pi^+ \pi^- + \pi^- \pi^+ + \pi^0 \pi^0) \end{aligned} \quad (2)$$

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where $\vec{q}$ is the momentum of the pion in the centre-of-mass system, and $\vec{\epsilon}$ is a unit polarization vector; for convenience, we choose a state such that the component of the spin of the particle along $\vec{\epsilon}$ is zero. The factor

$$(\pi^+\pi^- + \pi^-\pi^+ + \pi^0\pi^0)$$

gives the charge structure of the decay products, i.e., we have $\frac{2}{3}\pi^+\pi^-$ and $\frac{1}{3}\pi^0$, which make an isotopic spin singlet.

With the above matrix element, the width for this decay channel is given by

$$\Gamma_{\pi\pi} = \frac{f^2}{20\pi} \frac{|\vec{q}|^5}{m^4} = \frac{f^2}{4\pi} \frac{(m^2 - 4\mu^2)^{\frac{5}{2}}}{m^4 \times 160} \quad (3)$$

where μ is the pion mass.

In the following we will consider the case of the Pomeranchuk particle. If such a particle exists, we will estimate its coupling constant to two pions using the high-energy cross-sections in the Regge pole approach. Using the factorization theorem ²⁾, $\sigma_{\pi\pi} = (\sigma_{\pi N})^2 / \sigma_{NN}$ we can find the high-energy $\pi\pi$ total cross-section, $\sigma_{\pi\pi}$, from the high-energy πN and NN total cross-sections. Now in the Regge pole approach the high-energy amplitude $T_{\pi\pi}$ for $\pi\pi$ elastic scattering will be dominated by the Regge pole of the Pomeranchuk particle. Thus, we will have

$$T_{\pi\pi} = \frac{1 + e^{-i\pi\alpha_P}}{2 \sin \pi\alpha_P} c(t) \frac{(2\alpha+1)}{5} P_{\alpha_P}(-\cos\theta_t) \quad (4)$$

where $\cos\theta_t = -s - 2\mu^2 - t/2q_t^2$ gives the scattering angle, $q_t = \sqrt{\frac{t}{4} - \mu^2}$ is the momentum of the pion in the crossed channel, and s is the invariant energy squared.

The coupling $c(t)$ is related to the field-theoretical coupling f of Eq. (1) when the pomeron is on the mass shell:

$$\frac{1 + e^{-i\pi\alpha_P}}{2 \sin\pi\alpha_P} c(t) \frac{(2\alpha_P + 1)}{5} P_{\alpha_P}(\cos\theta_t) \Big|_{t=m^2} = \frac{2}{3} \frac{f^2}{m^2} \frac{|\vec{q}|^4}{t} \frac{P_{\alpha_P}(\cos\theta_t)}{t - m^2}$$

or

$$\frac{f^2}{4\pi} = \frac{6 c(m^2) m^2}{(m^2 - 4\mu^2)^2 \eta \pi^2} \quad (5)$$

where $\eta = \left. \frac{d\alpha_P}{dt} \right|_{t=m^2}$ is the slope of the P trajectory. We will assume that this trajectory is a straight line with the slope $\eta = 1/m^2$.

Using the optical theorem we can determine $c(0)$. We have

$$\sigma_{\pi\pi} = \frac{\sqrt{s} T_{\pi\pi}(t=0)}{s} = \frac{3 c(0)}{20\mu^2} \quad (6)$$

To evaluate the coupling constant we need to extrapolate $c(t)$ from its value at $t=0$ to $t=m^2$. We observe that $c(t)$ is not a coupling constant but rather a partial wave scattering amplitude proportional to the coupling constant. Thus, we factor out from $c(t)$ a $(2q_t^2/s_0)^\alpha$ dependence, i.e., we define

$$c(t) = \left(\frac{2q_t^2}{s_0} \right)^\alpha \frac{s_0^2}{m^2} f^2 \eta \pi \beta(t)$$

where $\beta(4\mu^2) \neq 0$ and $\beta(m^2) = 1$. Now our amplitude has the right threshold behaviour and reduces to the exact field theoretical form at $t = m^2$. It is not

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completely unreasonable to assume that $\beta(t)$ as a "form factor", is a slowly varying function of t . We will extrapolate $\beta(t)$ as a constant. We will take $s_0 = 2M^2$ as seems to be indicated by the NN and πN diffraction pattern³⁾. Thus, we take

$$C(m^2) = \frac{m^4}{16\mu^2 M^2} C(0) \sim 3 \left(\frac{m}{\mu}\right)^4 C(0) \quad (7)$$

where M is the nucleon mass.

Using now Eqs. (7), (6) and (5) we find

$$\frac{f^2}{4\pi} \simeq 2.5 \frac{m^4}{M^2 \pi^2} \sigma_{\pi\pi} \quad (8)$$

with $\sigma_{\pi\pi} \sim 15$ mb and $m = M$ we find

$$\frac{f^2}{4\pi} \simeq 9.2$$

and

$$T_{\pi\pi} \sim 60 \text{ MeV}$$

We note that this width refers, of course, only to the partial decay of the pomeron into two pions. However, from phase space consideration we expect this to be practically the whole width. (From G invariance the next lightest mass decay mode will be decay into four pions.)

Recent experiments^{4),5)} have indicated the existence of a 2π resonance, the so-called f^0 resonance, with mass around 1250 MeV, probably $T = 0$, and spin greater than one⁵⁾. If we try to identify this particle with the pomeron then $T_{\pi\pi} \sim 140$ MeV⁶⁾.

In conclusion we remark that these numbers should be considered only in an order of magnitude sense. The main object of this note is to check roughly whether the Regge pole hypothesis correlates high and low energy phenomena in a consistent way.

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FOOTNOTES AND REFERENCES

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- 6) We have used here the same $s_0 (= 2M^2)$ for πN and NN scattering. The
present experimental indications are that the diffraction peak is wider
for πN than for NN . This would reduce somehow the value for $T_{\pi\pi}$.