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A Study on the Pentaquark States

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These are preliminary lecture notes, intended only for distribution to participants

A Study on the Pentaquark States

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Introduction

• Exciting discovery of new particle Θ^+.

Reported mass of $\Theta^+ = 1540 \pm 10 MeV$ [LEPS Collab.: T. Nakano et al, Phys. Rev. Lett. **91**, 012002 (2003).]

Particle was identified in the K^+n invariant mass spectrum in the reaction

$$\gamma n \longrightarrow K^- + \Theta^+ \longrightarrow K^- + K^+ + n$$

having photon beam of energy upto $2.4 GeV$.

• Theoretical prediction of a narrow $s = +1$ baryon by DPP [D. Diakonov et al, Z. Phys. A **359**, 305 (1997).]

• Constituents of Θ^+ : $udud\bar{s}$.

Our Model for Predicting Θ^+ Mass

- Diquark formation takes place : [ud]

Diquark is a strongly correlated pair. In QCD, both the gluon exchange interaction and the instanton induced interaction favour the spin-singlet and color antisymmetric diquark combination,

$$[ud], I = 0$$

- We have two diquarks and one strange antiquark within the system. Now, the u and d couple together to form a diquark $[ud]_0$ (Scalar Boson). Its effective mass is being calculated following the idea of the effective mass of e^- in a crystal in condensed matter physics.

Mechanism of Effective Mass Approximation

Bare electrons in a lattice are affected by the force -∇V where, V is the crystal potential, and, the external force F :

$$m\frac{dv}{dt} = F - \frac{\partial V}{\partial r} \tag{1}$$

• The electron behaves as a quasiparticle. Single particle excitations are termed as quasiparticles. The effect of the crystal field should be contained in these quasiparticles.

• The dynamics of the quasiparticles is given by the equation,

$$m^*\frac{dv}{dt} = F \tag{2}$$

where, m^* is the effective mass of e^-. This effective mass reflects the inertia of e^- which is subject to the crystal field.

Dividing Eq.(1) by Eq.(2), we get

$$\frac{m}{m^*} = 1 - \frac{1}{F}\frac{\partial V}{\partial r} \tag{3}$$

- The effective mass of the diquark can be calculated as,

$$\frac{m[ud]}{m^*[ud]} = 1 - \frac{1}{F}\frac{\partial V}{\partial r} \tag{4}$$

m^* is the effective mass of the diquark.

- The interaction potential is,

$$V_{ij} = -\frac{\alpha}{r} + (F_i.F_j)(-\frac{1}{2}kr^2) \tag{5}$$

Here, $F_i.F_j = -2/3$ for qq interaction.

- Coupling constant $\alpha = (2/3)\alpha_s$. Therefore, Eq.(5) becomes,

$$V_{ij} = -\frac{\alpha}{r} + ar^2 \tag{6}$$

where, $a = k/3$.

- From Eq. (4),

$$\frac{m[ud]}{m^*[ud]} = 1 + \frac{\alpha}{2a < r^3 >} \tag{7}$$

• Input Values : •

- $m_u = m_d = 360 MeV$
- $\alpha = (2/3)\alpha_s = 0.393$, and $\alpha_s = 0.58$. [W. Lucha et al, Phys. Rep. **200**, 168 (1991).]
- $k = 241.5 MeV fm^{-2}$ [Ref.: R. K. Bhaduri et al, Phys. Rev. Lett. **44**, 1369 (1980)].
- $a = 0.003 GeV^3$.
- $< r >= 5.38 GeV^{-1}$ [Ref.: S. N. Banerjee et al, Int. J. Mod. Phys. A **2**, 1829 (1987)].
- $m^*[ud] = 506 MeV$

The decreasing contribution of effective mass of $\bar{s}$ has been assumed very small. Assuming the interaction span of s quark ($\simeq$ pentaquark radius) very large, only less than 10 percent of its mass decreases and, hence, has been neglected. We take the $\bar{s}$ quark mass also to be the same as that of the quasiparticle, i.e.,

$$m_s = 540 MeV$$

• Diquarks stand for building blocks, similar to the excitation states in crystals in condensed matter physics. These elementary excitations, simulating the effect of a many body interaction are such that they behave like scalar Bosons.

•These low lying excitations may be regarded as separate elementary entities, behaving as quasiparticles within the system. We presume that they do not interact with each other as well as the $\bar{s}$ quark to the first order of approximation. So, as in an ideal gas of quasiparticles their energies are additive.

L. D. Landau and E. M. Lifshitz, in *Satistical Physics* Vol. V, 3rd Ed., Part I (Butterworth and Heinemann, Moscow, 1997 ; pp. 216).

Summary of Result

Mass of Θ^+ is obtained to be equal to,

$$\begin{aligned} M(\Theta^+) &= (506 \times 2 + 540) MeV \\ &= 1552 Mev \end{aligned} \tag{8}$$

which is very close to the experimental value

$$M(\Theta^+) = 1540 \pm 10 MeV$$

THANK YOU VERY MUCH !