第十届手征有效场论研讨会
（南京）

The 10th Workshop on Chiral Effective Field Theory
(Nanjing)

廣西大學
GUANGXI UNIVERSITY

A Study of $X(6900)$ as a $[cc][\bar{c}\bar{c}]$ Tetraquark State Decaying into $2J/\psi$

Duo-Duo Lu, Shao-Zhou Jiang

School of Physical Science and Technology, Guangxi University

ABSTRACT

In this work, the decay width of $X(6900)\to 2J/\psi$ has been calculated within a covariant quark model, assuming its structure is described by the diquark-antidiquark model. The possible quantum numbers $J^{PC}=0^{-+}$, 0^{--}, 1^{-+}, 1^{--} are considered. However, the quantum numbers $J^{PC}=0^{--}$, 1^{--} do not allow decay in this channel in the lowest-order perturbation theory. The corresponding decay widths for $J^{PC}=0^{-+}$ and $J^{PC}=1^{-+}$ are $\Gamma = 60\sim120$ MeV and $1.0\sim1.4$ MeV respectively. The quantum number $J^{PC}=0^{-+}$ is consistent with the experimental observations.

INTRODUCTION

Since the experimental discovery of the first exotic hadron state $X(3872)$ in 2003, a large number of new hadronic states have been observed. This work studies the recently discovered fully heavy tetraquark state candidate $X(6900)$ and calculates its decay width for the process $X(6900)\to 2J/\psi$ to compare with experimental results. The corresponding experimental values are presented in the table on the right.

Collaboration	Model	m	Γ	Observed Channel
LHCb	No-Interference	$6905\pm11\pm7$	$80\pm19\pm33$	$2J/\psi$
	Interference	$6886\pm11\pm11$	$168\pm33\pm69$	
ATLAS	Model A	$6860\pm30^{+10}_{-20}$	$110\pm50^{+20}_{-10}$	$2J/\psi$
	Model B	$6910\pm10\pm10$	$150\pm30\pm10$	
CMS	Interference	6847^{+44+48}_{-28-20}	191^{+66+25}_{-49-17}	$2J/\psi$
	No-Interference	$6927\pm9\pm4$	$122^{+24}_{-21}\pm18$	

THEORETICAL METHOD

This work uses the covariant quark model, which is widely used to calculate hadron decays and electromagnetic properties, to calculate the decay width of $X(6900)\to 2J/\psi$. The effective interaction Lagrangian is written in the form

$$\mathcal{L}_{\rm int} = g_X X(x)\cdot J_X(x) + g_{J/\psi}\psi_\mu(x)\cdot J^\mu_{J/\psi}(x) + \text{H.c.}$$

The four-quark current and vector meson current are defined as follows

$$J_X(x)=\int d^4x_1\ldots\int d^4x_4\,\delta\Big(x-\sum_{i=1}^{4}w_ix_i\Big)\Phi_X\Big(\sum_{i<j}(x_i-x_j)^2\Big)j_{4c}(x_1,x_2,x_3,x_4)$$

$$J^\mu_{J/\psi}(x)=\int d^4y\,\Phi_{J/\psi}(y^2)\bar{c}_a(x+y/2)\gamma^\mu c_a(x-y/2)$$

All four-quark current j_{4c} used in this article are as follows

$$J^{PC}=0^{-+}:\quad j_1=i[c_a^TCc_b][\bar{c}_a\gamma^5C\,\bar{c}_b^T]+i[c_a^TC\gamma^5c_b][\bar{c}_aC\,\bar{c}_b^T]$$

$$J^{PC}=0^{--}:\quad j_2=[c_a^TCc_b][\bar{c}_a\gamma^5C\,\bar{c}_b^T]-[c_a^TC\gamma^5c_b][\bar{c}_aC\,\bar{c}_b^T]$$

$$J^{PC}=1^{-+}:\quad j_3^\mu=i[c_a^TC\gamma^\mu\gamma^5c_b][\bar{c}_a\gamma^5C\,\bar{c}_b^T]+i[c_a^TC\gamma^5c_b][\bar{c}_a\gamma^\mu\gamma^5C\,\bar{c}_b^T]$$

$$J^{PC}=1^{--}:\quad j_4^\mu=[c_a^TC\gamma^\mu\gamma^5c_b][\bar{c}_a\gamma^5C\,\bar{c}_b^T]-[c_a^TC\gamma^5c_b][\bar{c}_a\gamma^\mu\gamma^5C\,\bar{c}_b^T]$$

The Fourier transform of the function Φ_X is

$$\Phi_X(y_1^2+y_2^2+y_3^2)=\prod_{i=1}^{3}\int\frac{d^4k_i}{(2\pi)^4}\phi_X(k_1^2+k_2^2+k_3^2)e^{-i(k_1\cdot y_1+k_2\cdot y_2+k_3\cdot y_3)}$$

Choosing the Gaussian form of the ϕ_X

$$\phi_X(k^2)=e^{k^2/\Lambda_X^2}$$

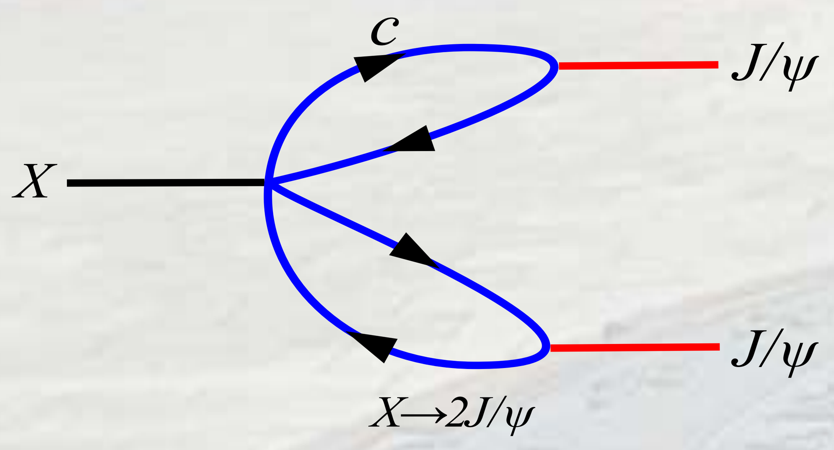
The coupling constant g_X is determined by the normalization condition called the compositeness condition

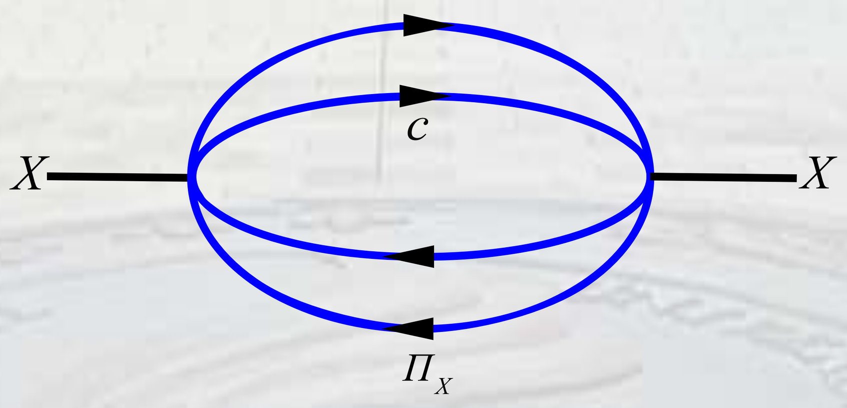
$$1-g_X^2\frac{d\Pi_X(s)}{ds}\bigg|_{s=m_X^2}=0$$

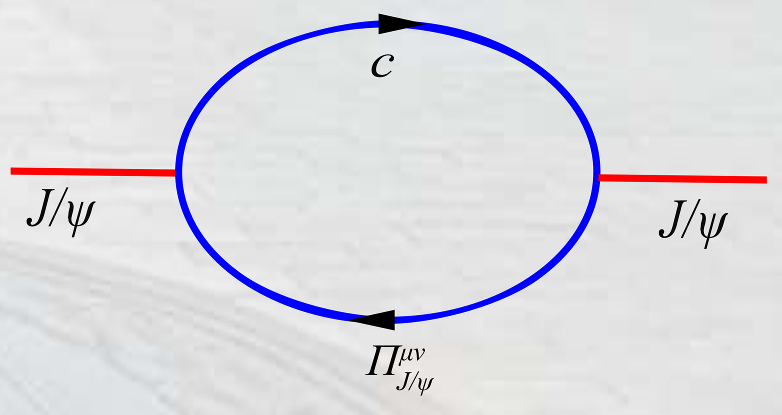
The function Π_X is defined as

$$\Pi_X(p^2)=i\int d^4x e^{ip\cdot x}\langle 0|TJ_X(x)J_X^\dagger(0)|0\rangle \quad \text{spin } 0$$

$$\Pi_X^{\mu\nu}(p^2)=i\int d^4x e^{ip\cdot x}\langle 0|TJ_X^\mu(x)J_X^{\nu\dagger}(0)|0\rangle \quad \text{spin } 1$$







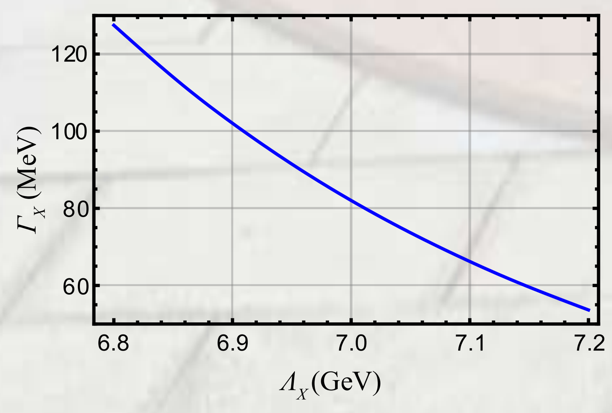
$$J^{PC}=0^{-+}\qquad \Gamma=\frac{I^2}{8\pi}\left(\frac{m_X^2}{4}-m_{J/\psi}^2\right)^{3/2}$$

$$J^{PC}=1^{-+}\qquad \Gamma=\frac{K_1^2}{192\pi}\frac{(m_X^2/4-m_{J/\psi}^2)^{3/2}}{m_{J/\psi}^2}$$

$$J^{PC}=0^{--},\ 1^{--}\qquad \Gamma=0$$

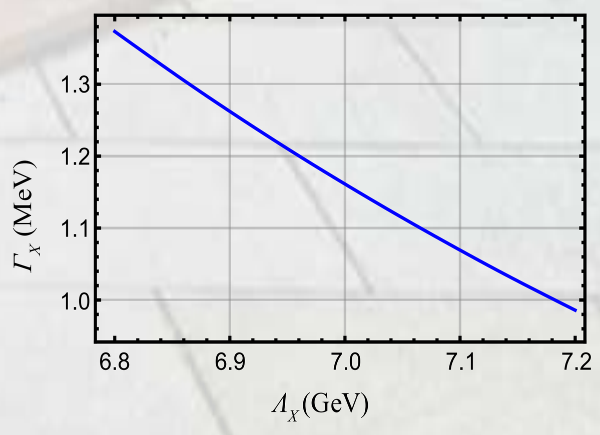
These three Feynman diagrams constitute the core part of the calculations in this work, the most complicated one is the three-loop banana diagram, and the calculation results of the Feynman diagram for the decay process are shown on the left.

NUMERICAL RESULTS



Numerical Result in $J^{PC}=0^{-+}$

The figure on the left shows the decay width curve for the process $X(6900)\to 2J/\psi$, which decreases smoothly. The decay width Γ_X varies from 60 to 120 MeV for $\Lambda_X = 6.8\sim7.2$ GeV, which is consistent with experiments. In contrast, the figure on the right shows that Γ_X is on the scale of 1 MeV, which is clearly inconsistent with experiments.



Numerical Result in $J^{PC}=1^{-+}$

SUMMARY AND CONCLUSION

This work employs the covariant quark model, which incorporates infrared confinement in an effective way, in order to study the decay process $X(6900)\to 2J/\psi$. By treating the $X(6900)$ as a tetraquark state with a diquark-antidiquark configuration, the corresponding transition matrix element and decay width are calculated. The results show that if the quantum number of $X(6900)$ is $J^{PC}=0^{--}$ or 1^{--}, the state cannot decay into $2J/\psi$ within the lowest-order perturbation approximation.

勤恳樸诚 厚學致新

Diligence and Sincerity, Profound Learning and Innovation

Email :1696675387@qq.com