Decay width of the $X(3842)$ as the $\psi_3(1^3D_3)$ state

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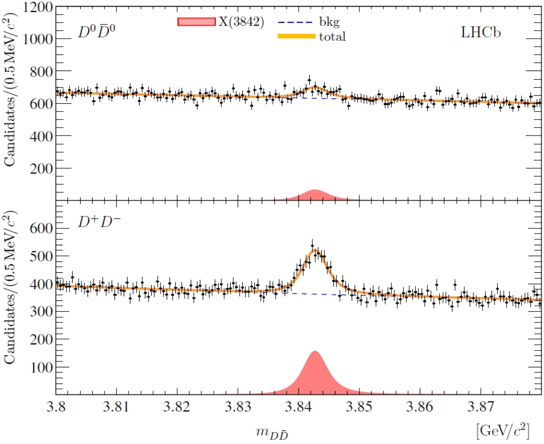
Outline

1. Background

- In 2019, a new bound state $X(3842)$ was discovered at LHCb, which is considered to spin triplet D wave charmonium $\psi_3(1^3D_3)$ with $J^{PC} = 3^{--}$.



R. Aaij *et al.*, (LHCb Collaboration), JHEP 07 (2019) 035.

2. Previous research

- Other works Different models have studied the decays of $X(3842)$. They had predicted the $\psi_3(1^3D_3)$ state to have a natural width $0.5 \sim 4$ MeV.

  T. Barnes and S. Godfrey, Phys. Rev. D 69, 054008 (2004)

  T. Barnes, S. Godfrey and E. S. Swanson, Phys. Rev. D 72, 054026 (2005)

  E. J. Eichten, K. Lane and C. Quigg, Phys. Rev. D 73, 014014 (2006)

  G.-L. Yu and Z.-G. Wang, Int. J. Mod. Phys. A 34, 1950151 (2019).

- Our works The Bethe-Salpeter (BS) equation is a relativistic dynamic equation used to describe bound state. By using the BS equation method, theoretical results were obtained that were in good agreement with experimental data.

  Chang, Chen, and Wang, Commun. Theor. Phys. 46, 467 (2006)

  Wang and Wang, Phys. Lett. B 697, 233 (2011)

  Wang, Jiang and Wang, J. High Energy Phys. 03, 209 (2016)

  Wang, Wang and Chang, J. High Energy Phys. 05, 006 (2022)

1. Bethe-Salpeter equation

- **Bethe-Salpeter equation**

  For meson consisting of quark and antiquark, the general Bethe-Salpeter equation in momentum space

$$(\not{p}_1 - m_1)\chi_P(q)(\not{p}_2 + m_2) = i\int \frac{d^4k}{(2\pi)^4} V(P,k,q)\chi_P(k). \qquad (2.1)$$

  $\chi_P(q)$ – BS wave function, $V(P,k,q)$ – interaction kernel.

- The meson momentum P and relative momentum q:

$$p_1 = \alpha_1 P + q, \qquad \alpha_1 = \frac{m_1}{m_1 + m_2},$$

$$p_2 = \alpha_2 P - q, \qquad \alpha_2 = \frac{m_2}{m_1 + m_2}.$$

E. E. Salpeter and H. A. Bethe , Phys. Rev. 84 (1951)

II. Model introduction

- Although BS equation is the relativistic dynamic equation, it is difficult to solve analytically

  such as, complete interacting kernel $V(P,k,q)$ of BS equation, it cannot be fully calculated.

- Reduced version is needed -(instantaneous version).

2. Salpeter equation

- Salpeter equation

The reduced (instantaneous) Bethe-Salpeter wave function

$$\varphi_p(q_\perp^\mu) \equiv i \int \frac{dq_p}{(2\pi)} \chi_P(q_\parallel^\mu, q_\perp^\mu), \tag{2.2}$$

and new integration kernel

$$\eta(q_\perp^\mu) \equiv \int \frac{k_T^2 dk_T ds}{(2\pi)^2} V(k_\perp, q_\perp) \varphi_P(k_\perp^\mu). \tag{2.3}$$

The useful notations

$$\omega_i = \sqrt{m_i^2 - p_{i\perp}^2}, \quad \Lambda_i^\pm(q_\perp) = \frac{1}{2\omega_i}\left[\frac{\not{P}}{M}\omega_i \pm J_i(m_i + \not{q}_\perp)\right],$$

$$\varphi_P^{\pm\pm}(q_\perp) = \Lambda_1^\pm(q_\perp)\frac{\not{P}}{M}\varphi_P(q_\perp)\frac{\not{P}}{M}\Lambda_2^\pm(q_\perp).$$

II. Model introduction

- Then, BS equations can be written as

$$\chi(q) = S(p_1)\eta(q_\perp)S(-p_2). \tag{2.4}$$

$S(p_1)$ and $S(-p_2)$ represent fermion and antifermion propagators, respectively.

$$-iS(p_1) = \frac{i\Lambda_1^+}{q_P + \alpha_1 M - \omega_1 + i\epsilon} + \frac{i\Lambda_1^-}{q_P + \alpha_1 M + \omega_1 - i\epsilon}$$
$$iS(-p_2) = \frac{i\Lambda_2^+}{q_P - \alpha_2 M + \omega_2 - i\epsilon} + \frac{i\Lambda_2^-}{q_P - \alpha_2 M - \omega_2 + i\epsilon}$$

- Further carry out a contour integration for the time-component q_P on both sides of equation (2.4), then obtain Salpeter wave function

$$\varphi(q_\perp) = \frac{\Lambda_1^+(q_\perp)\eta(q_\perp)\Lambda_2^+(q_\perp)}{M - \omega_1 - \omega_2} - \frac{\Lambda_1^-(q_\perp)\eta(q_\perp)\Lambda_2^-(q_\perp)}{M + \omega_1 + \omega_2}. \tag{2.5}$$

II. Model introduction

- Salpeter equation

To apply the complete set of the projection operators $\Lambda_i^{\pm}(q_\perp)$, then obtain the four equations

$$(M-\omega_1-\omega_2)\varphi_P^{++}(q_\perp)=\Lambda_1^{+}(q_\perp)\eta_P(q_\perp)\Lambda_2^{+}(q_\perp),$$
$$(M+\omega_1+\omega_2)\varphi_P^{--}(q_\perp)=\Lambda_1^{-}(q_\perp)\eta_P(q_\perp)\Lambda_2^{-}(q_\perp),$$
$$\varphi_P^{+-}(q_\perp)=\varphi_P^{-+}(q_\perp)=0.$$

E. E. Salpeter, PRD 87 (1952) 328.

C.-H. Chang, J.-K. Chen, and G.-L.Wang, Commun. Theor. Phys. 46, 467 (2006).

3. $^3P_0$ model

- The $^3P_0$ model (quark pair creation model) is a nonrelativistic model. This model is widely used in the Okubo-Zweig-Iizuka (OZI) allowed strong decays of a meson .

- In previous work, we have extended the $^3P_0$ model to the relativistic case

$$H_I = g \int d^3\vec{x}\bar{\psi}\psi\,|_{nonrel} \longrightarrow H_I = -ig \int d^4x\bar{\psi}\psi,$$

where, the input relativistic wave function ψ comes from a strict solution of the Salpeter equation.

$g = 2m_q\gamma$ is phenomenological parameters of the model, γ is dimensionless interaction strength.

Simonov Y A, Phys. Atom. Nucl., 2008, 71(6).

Danilkin I V, Simonov Y A, Phys. Rev. Lett., 2010, 105(10).

H.-F. Fu, G.-L. Wang, T-H. Wang, Int. J. Mod. Phys. A 27, 1250027 (2012).

T. Wang, G.-L. Wang, H.-F. Fu, , J. High Energy Phys. 07 (2013) 120.

1. Amplitude and form factors

- For the two-body strong decay $A \to B + C$, the Feynman diagram as follows

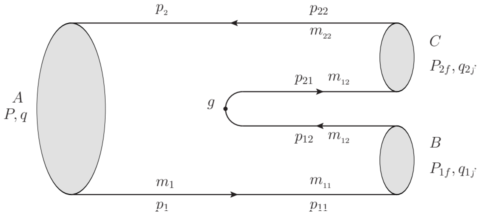


Figure: The Feynman diagram for the two-body strong decay process with a $^3P_0$ vertex.

- The transition matrix can be written as

$$\langle P_{1f} P_{2f} \mid S \mid P \rangle_{^3P_0} = (2\pi)^4 \delta^4 (P - P_{1f} - P_{2f}) \mathcal{M}_{^3P_0}$$
$$= -ig(2\pi)^4 \delta^4 (P - P_{1f} - P_{2f}) \int \frac{d^4 q}{(2\pi)^4} Tr\left[\chi_P(q) S_2^{-1}(-p_2) \bar{\chi}_{P_{2f}}(q_{2f}) \bar{\chi}_{P_{1f}}(q_{1f}) S_1^{-1}(p_1) \right]. \quad (3.1)$$

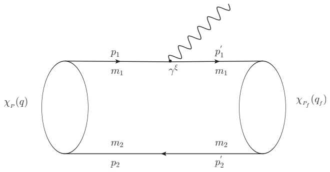
III. Transition amplitude and relativistic wave function

- Through the Feynman rule and related calculations, the decay amplitude can be written as

$$\mathcal{M}_{^3P_0} = g\int \frac{d^3q_\perp}{(2\pi)^3} Tr\left[\frac{\not{P}}{M}\varphi_{_P}^{++}(q_\perp)\frac{\not{P}}{M}\bar{\varphi}_{_{P_{2f}}}^{++}(q_{_{2f}\perp})\bar{\varphi}_{_{P_{1f}}}^{++}(q_{_{1f}\perp})\right]. \quad (3.2)$$

III. Transition amplitude and relativistic wave function

- For the EM decay of $A \to B\gamma$, the Feynman diagram as follows



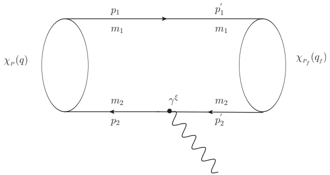


Figure: Feynman diagram for the transition $\chi_P \to \chi_{cJ}\gamma$. The diagram on the left and right show photons come from the quark and the antiquark, respectively.

- For the EM decay of $A \to B\gamma$, the transition matrix can be written as

$$\langle \chi_{cJ}(P_f, \epsilon_2)\gamma(k, \epsilon_0)|X(P, \epsilon_1)\rangle = (2\pi)^4\delta^4(P - P_f - k)\epsilon_{0\xi}\mathcal{M}^\xi. \qquad (3.3)$$

- Therefore, the decay amplitude can be written as

$$\mathcal{M}^{\xi} = \int \frac{d^3 q_{\perp}}{(2\pi)^3} Tr[Q_1 e \frac{\not{P}}{M} \bar{\varphi}_f^{++}(q_{\perp} + \alpha_2 P_{f_{\perp}}) \gamma^{\xi} \varphi_i^{++}(q_{\perp}) + Q_2 e \, \bar{\varphi}_f^{++}(q_{\perp} - \alpha_1 P_{f_{\perp}}) \frac{\not{P}}{M} \varphi_i^{++}(q_{\perp}) \gamma^{\xi}]. \quad (3.4)$$

- Considering nonrelativistic limitations, we only calculate the decay channel $X(3842) \to \chi_{c2}\gamma$ by E_1.

Chao-Hsi Chang, Jiao-Kai Chen, Xue-Qian Li, Guo-Li Wang, Commun. Theor. Phys. 43 (2005)

2. Relativistic wave function

- For $J^{PC}=3^{--}$ state, the relativistic wave function

$$\varphi_{3--}(q_\perp)=\epsilon_{\mu\nu\alpha}q_\perp^\mu q_\perp^\nu\Big[q_\perp^\alpha\Big(f_1+\frac{\not{P}}{M}f_2+\frac{\not{q}_\perp}{M}f_3+\frac{\not{P}\not{q}_\perp}{M^2}f_4\Big)$$
$$+M\gamma^\alpha\Big(f_5+\frac{\not{P}}{M}f_6+\frac{\not{q}_\perp}{M}f_7+\frac{\not{P}\not{q}_\perp}{M^2}f_8\Big)\Big], \qquad (3.5)$$

where, radial wave function $f_i\ (i=1,2,...8)$ is function of $-q_\perp^2$. The relationships between them as follows

$$f_1=\frac{q_\perp^2 f_3(\omega_1+\omega_2)+2M^2 f_5\omega_2}{M(m_1\omega_2+m_2\omega_1)},\quad f_2=\frac{q_\perp^2 f_4(\omega_1-\omega_2)+2M^2 f_6\omega_2}{M(m_1\omega_2+m_2\omega_1)},$$
$$f_7=\frac{M(\omega_1-\omega_2)}{m_1\omega_2+m_2\omega_1}f_5,\qquad f_8=\frac{M(\omega_1+\omega_2)}{m_1\omega_2+m_2\omega_1}f_6. \qquad (3.6)$$

T. Wang, H.-F. Fu, Y. Jiang, Q. Li, G.-L. Wang, Int. J. Mod. Phys. A 32, 1750035 (2017).

- The partial wave of 3^{--} state

The relativistic wave function in Eq.(3.5) for 3^{--} state is not a pure D wave. In terms of spherical harmonics Y_{lm}, we can rewrite

$$\epsilon_{\mu\nu\alpha} q_{\perp}^{\mu} q_{\perp}^{\nu} q_{\perp}^{\alpha} = 2i\sqrt{\frac{6\pi}{35}} \mid \vec{q} \mid^{3} (Y_{32} - Y_{3-2}), \tag{3.7}$$

so f_1 and f_2 terms are F wave.
Similarly, for the f_3 and f_4 terms,

$$\begin{aligned}\epsilon_{\mu\nu\alpha} q_{\perp}^{\mu} q_{\perp}^{\nu} q_{\perp}^{\alpha} \not{q}_{\perp} = i \mid \vec{q} \mid^{4} \Bigg[& \frac{4}{7}\sqrt{\frac{3\pi}{5}}(-Y_{21}\gamma^{+} + Y_{2-1}\gamma^{-}) + \frac{2}{7}\sqrt{\frac{6\pi}{5}}(-Y_{22} + Y_{2-2})\gamma^{\Delta} \\ & + \frac{2}{7}\sqrt{\frac{2\pi}{5}}(Y_{41}\gamma^{+} - Y_{4-1}\gamma^{-}) + \frac{4}{7}\sqrt{\frac{2\pi}{5}}(-Y_{42} + Y_{4-2})\gamma^{\Delta} \\ & + 2\sqrt{\frac{2\pi}{35}}(Y_{43}\gamma^{-} - Y_{4-3}\gamma^{+})\Bigg],\end{aligned} \tag{3.8}$$

where, $\gamma^{+} = -\frac{\gamma^1 + i\gamma^2}{\sqrt{2}}$, $\gamma^{-} = \frac{\gamma^1 - i\gamma^2}{\sqrt{2}}$ and $\gamma^{\Delta} = \gamma^3$. So f_3 and f_4 terms include D wave and G wave, they are $D - G$ mixing.

III. Transition amplitude and relativistic wave function

- The partial wave of 3^{--} state

The f_5 and f_6 terms are D wave, because,

$$\epsilon_{\mu\nu\alpha} q_\perp^\mu q_\perp^\nu \gamma_\perp^\alpha = 2i\sqrt{\frac{2\pi}{15}} \mid \vec{q} \mid^2 \left[\sqrt{2}(Y_{21}\gamma^+ - Y_{2-1}\gamma^-) + (Y_{22} - Y_{2-2})\gamma^\Delta\right]. \tag{3.9}$$

The f_7 and f_8 terms are F wave, since

$$\epsilon_{\mu\nu\alpha} q_\perp^\mu q_\perp^\nu \gamma_\perp^\alpha \not{q}_\perp = 2i \mid \vec{q} \mid^3 \left[\frac{2}{5}\sqrt{\frac{\pi}{7}} Y_{30}(\gamma^{+2} - \gamma^{-2}) + \frac{1}{5}\sqrt{\frac{6\pi}{7}}(-Y_{31}\gamma^+ + Y_{3-1}\gamma^-)\gamma^\Delta + \sqrt{\frac{2\pi}{105}}(Y_{32} - Y_{3-2})(2\gamma^+\gamma^- - \gamma^{\Delta 2}) + \sqrt{\frac{2\pi}{35}}(Y_{33}\gamma^- - Y_{3-3}\gamma^+)\gamma^\Delta\right]. \tag{3.10}$$

Then the complete D wave in Eq.(3.5) is

$$\epsilon_{\mu\nu\alpha} q_\perp^\mu q_\perp^\nu M\gamma^\alpha (f_5 + \frac{\not{P}}{M} f_6) - \frac{3}{7}\epsilon_{\mu\nu\alpha} q_\perp^\mu q_\perp^\nu M\gamma^\alpha \frac{\mid \vec{q} \mid^2}{M^2}(f_3 - \frac{\not{P}}{M} f_4).$$

The pure G wave in Eq.(3.5) is

$$\epsilon_{\mu\nu\alpha} q_\perp^\mu q_\perp^\nu q_\perp^\alpha (\frac{\not{q}_\perp}{M} f_3 + \frac{\not{P}\not{q}_\perp}{M^2} f_4) + \frac{3}{7}\epsilon_{\mu\nu\alpha} q_\perp^\mu q_\perp^\nu M\gamma^\alpha \frac{\mid \vec{q} \mid^2}{M^2}(f_3 - \frac{\not{P}}{M} f_4).$$

III. Transition amplitude and relativistic wave function

- For $J^{PC} = 0^-$ state, the relativistic wave function

$$\varphi_{0^-}(q_{f_\perp}) = M_f \left(\frac{\not{P}_f}{M_f} g_1 + g_2 + \frac{\not{q}_{f_\perp}}{M_f} g_3 + \frac{\not{P}_f \not{q}_{f_\perp}}{M_f^2} g_4 \right) \gamma^5, \quad (3.11)$$

The relationships between $g_i s$ as follows

$$g_3 = \frac{g_2 M_f (\omega_{2_f} - \omega_{1_f})}{(m_{1_f}\omega_{2_f} + m_{2_f}\omega_{1_f})}, \qquad g_4 = -\frac{g_1 M_f (\omega_{2_f} + \omega_{1_f})}{(m_{1_f}\omega_{2_f} + m_{2_f}\omega_{1_f})}. \quad (3.12)$$

Similarly, the relativistic 0^- state wave function is not a pure S wave (the terms including g_1 and g_2), but also contains a small component of P wave (terms including g_3 and g_4).

C. S. Kim and G.-L. Wang, Phys. Lett. B 584, 285 (2004).

III. Transition amplitude and relativistic wave function

- For $J^{PC}=2^{++}$ state, the relativistic wave function

$$\varphi_{2^{++}}(q_{f_\perp}) = \epsilon_{\mu\nu} q^{\mu}_{f_\perp}\Big[q^{\nu}_{f_\perp}\Big(h_1 + \frac{\not{P}_f}{M_f}h_2 + \frac{\not{q}_{f_\perp}}{M_f}h_3 + \frac{\not{P}_f \not{q}_{f_\perp}}{M_f^2}h_4\Big) + M_f\gamma^{\nu}\Big(h_5 + \frac{\not{P}_f}{M_f}h_6 + \frac{\not{q}_{f_\perp}}{M_f}h_7\Big) + \frac{i}{M_f}h_8\epsilon^{\mu\alpha\beta\gamma}P_{f\alpha}q_{f_\perp\beta}\gamma_\gamma\gamma_5\Big]. \quad (3.13)$$

The relationships between $h_i s$ as follows

$$h_1 = \frac{(q^2_{f_\perp}h_3 + M_f^2 h_5)(\omega_{1_f}+\omega_{2_f}) - M_f^2 h_5(\omega_{1_f}-\omega_{2_f})}{M_f(m_{1_f}\omega_{2_f}+m_{2_f}\omega_{1_f})}, \quad h_7 = \frac{M_f(\omega_{1_f}-\omega_{2_f})}{m_{1_f}\omega_{2_f}+m_{2_f}\omega_{1_f}}h_5,$$

$$h_2 = \frac{(q^2_{f_\perp}h_4 - M_f^2 h_6)(\omega_{1_f}-\omega_{2_f})}{M_f(m_{1_f}\omega_{2_f}+m_{2_f}\omega_{1_f})}, \qquad h_8 = \frac{M_f(\omega_{1_f}+\omega_{2_f})}{m_{1_f}\omega_{2_f}+m_{2_f}\omega_{1_f}}h_6. \quad (3.14)$$

In Eq. (3.13), the terms including h_5 and h_6 are P waves, those including h_3 and h_4 are $P-F$ mixing waves, others are D waves.

C. S. Kim and G.-L. Wang, Phys. Lett. B 584, 285 (2004).

III.Transition amplitude and relativistic wave function

- The form factors expression of amplitude

Integrate internal momentum $q_\perp$ over the initial and final state wave functions, and finishing the trace, then we obtain the decay amplitude described using form factor.

(1) For the strong decay $X(3842) \to D\bar{D}$

$$\mathcal{M}(X(3842) \to D\bar{D}) = \epsilon_{\mu\nu\alpha} P_f^{\mu} P_f^{\nu} P_f^{\alpha} t_1, \tag{3.15}$$

where t_1 is the form factor.

(2) For the EM decay $X(3842) \to \chi_{c2}(^3P_2)\gamma$,

$$\begin{aligned}\mathcal{M}^{\xi}(X(3842) \to \chi_{c2}(1P)\gamma) = {} & P^{\xi} \epsilon_{P_f P_f P_f} \epsilon_{f,PP} s_1 + + P^{\xi} \epsilon_{\rho\, P_f P_f} \epsilon^{\rho}_{f,P} s_2 + \epsilon^{\xi}_{P_f P_f} \epsilon_{f,PP} s_3 \\ & + \epsilon_{P_f P_f P_f} \epsilon^{\xi}_{f,P} s_4 + P^{\xi} \epsilon_{\rho\sigma P_f} \epsilon_f^{\rho\sigma} s_5 + \epsilon^{\xi}_{\rho\, P_f} \epsilon^{\rho}_{f,P} s_6 \\ & + \epsilon_{\rho P_f P_f} \epsilon_f^{\xi\rho} s_7 + \epsilon^{\xi}_{\rho\sigma} \epsilon_f^{\rho\sigma} s_8,\end{aligned} \tag{3.16}$$

For the EM decay, not all the form factors are independent, due to the Ward identity $(P_\xi - P_{f,\xi})\mathcal{M}^{\xi} = 0$, we have the following relations

$$s_3 = (M^2 - ME_f)s_1 + s_4, \quad s_6 = (M^2 - ME_f)s_2 + s_7, \quad s_8 = (M^2 - ME_f)s_5. \tag{3.17}$$

IV. Results and discussions

1. Strong decay widths

- Strong decay widths of $X(3842)$ as the $\psi_3(1^3D_3)$ state

The strong decay width of $X(3842)$ decays to $D^0\bar{D}^0$ and D^+D^- are calculated as

$$\Gamma[X(3842) \to D^0\bar{D}^0] = 1.27\ \text{MeV}, \quad \Gamma[X(3842) \to D^+D^-] = 1.08\ \text{MeV}. \qquad (4.1)$$

TABLE I: The strong decay widths (MeV) of the $X(3842) \to DD$, and the ratio of $\frac{\mathcal{B}[X(3842)\to D^+D^-]}{\mathcal{B}[X(3842)\to D^0\bar{D}^0]}$.

	[15]	[16]		[17]	[23]	[56]		Ours	EX[13]
$M_{(1^3D_3)}(MeV)$	3868	3849	3872	3806	$3762-3912$	3872	3902	3842.7	$3842.71^{+0.28}_{-0.28}$
$\Gamma(X(3842) \to D^+D^-)$					$2-3$	0.39	0.72	1.08	
$\Gamma(X(3842) \to D^0\bar{D}^0)$					$2.5-3.5$	0.47	0.84	1.27	
$\Gamma(X(3842) \to DD)$	0.82	2.27	4.04	0.5	$4.5-6.5$	0.86	1.56	2.35	$2.79^{+0.86}_{-0.86}$
$\frac{\Gamma(X(3842)\to D^+D^-)}{\Gamma(X(3842)\to D^0\bar{D}^0)}$					$0.85-0.90$	0.83	0.86	0.84	

2. EM decay width

- EM decay width of $X(3842)$ as 1^3D_3 state

$\psi_3(1^3D_3) \to \chi_{c2}(1P)\gamma$ is dominant in the EM decays of $\psi_3(1^3D_3)$, and the result is

$$\Gamma[X(3842) \to \chi_{c2}(1P)\gamma] = 288 \text{ keV}. \quad (4.2)$$

TABLE II: The radiative partial decay widths (keV) of the $X_{(1^3D_3)}(3842) \to \chi_{c2}\gamma$.

	[17]		[22]				[56]					
$Model$	NR	GI	NR	V	S	RE	SC^3			C^3		
$M_{(1^3D_3)}(MeV)$	3806	3849	3815				3815	3868	3972	3815	3868	3972
$\Gamma(X(3842) \to \chi_{c2}\gamma)$	272	296	252	163	170	156	199	329	341	179	286	299

	[57]			[58]		[59]			[60]		$Ours$
$Model$	NR	SN_0	SN_1	NR	MNR	CCP_v			NR	RE	BS
$M_{(1^3D_3)}(MeV)$	3799			3815	3813	3520	3653	3831	3805		3842.7
$\Gamma(X(3842) \to \chi_{c2}\gamma)$	272	284	223	340	302	138	246	432	271	298	288

3. Contributions of different partial waves of EM decay

- For $\psi_3(1D) \to \chi_{c2}\gamma$, for the initial state, compared to F and G waves, the D wave have the dominant contribution. And the main contribution of the final state comes from the P wave which provides the nonrelativistic result, and the relativistic correction (D and F wave in 2^{++} state) contribute relatively small.

TABLE III: The EM decay width (keV) of different partial waves for $X_{(1^3D_3)}(3842) \to \chi_{c2}(1P)\gamma$.

	2^{++}			
3^{--}	*complete*	P *wave*	D *wave*	F *wave*
complete	288	215	18.2	0.197
D *wave*	234	232	13.9	0.186
F *wave*	13.7	13.4	0.180	0.0187
G *wave*	0.540	0.245	0.00373	0.000358

4. Discussions

- We have estimated total decay width of $X(3842)$ can be estimated as.

$$\Gamma[X(3842)] \approx \Gamma(DD) + \Gamma(\chi_{c2}\gamma) + \Gamma(J/\psi\pi\pi) + \Gamma(ggg) + \Gamma(gg\gamma) = 2.87 \text{ MeV}.$$

  This result is in good agreement with the experimental data $2.79^{+0.86}_{-0.86}$ MeV.

- For the EM decay of $\psi_3(1D) \to \chi_{c2}\gamma$, using the non-relativistic result 232 keV, and the relativistic one 288 keV, we obtain the relativistic effect is 19%.

V. Summary

- We studied the decays of the new particle $X(3842)$ as $\psi_3(1^3D_3)$ by using the relativistic Bethe-Salpeter equation method and $^3P_0$ model. And estimated total decay width of $X(3842)$ is 2.87 MeV.

- Our results show that $\Gamma[X(3842) \to D^0\bar{D}^0] = 1.27\ \mathbf{MeV}$, $\Gamma[X(3842) \to D^+D^-] = 1.08\ \mathbf{MeV}$, this is the dominant strong decay channel. The decay ratio $\frac{\mathcal{B}[X(3842)\to D^+D^-]}{\mathcal{B}[X(3842)\to D^0\bar{D}^0]} = 0.84$, this indicating that the difference between the decay widths of $X(3842) \to D^0\bar{D}^0$ and $X(3842) \to D^+D^-$ is almost purely from the phase space difference.

- Decay width of the dominant EM decay channel $\Gamma[X(3842) \to \chi_{c2}(1P)\gamma] = 288\ \mathbf{keV}$. In addition, we calculated the contributions of different partial waves and obtained the relativistic effect 19%.

Thanks for your attention!