Production of Heavy Tetraquarks in Rare Exclusive Higgs Boson Decays

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Introduction

Rare exclusive Higgs boson decays are important because they can additionally test models for describing bound states of quarks, provide new information about Higgs boson properties, including coupling constants with heavy quarks, and become a source for searching New Physics beyond the Standard Model.

David d'Enterria and Dung Van Le, Rare and exclusive few-body decays of the Higgs, Z, W bosons, and the top quark, J. Phys. G: Nucl. Part. Phys. 52 053001 (2025)

The aim of the work is to study process of Higgs boson decay into tetraquark $T_{cc\bar{c}\bar{c}}$ plus a photon:

$$H \to T_{cc\bar{c}\bar{c}} + \gamma$$

This work is a continuation of our research cycle on studying of rare Higgs boson decays into heavy quark bound states:

Faustov R. N., Martynenko F. A., Martynenko A. P. Higgs boson decay to the pair of S-and P-wave B c mesons, EPJ A. V. 58., P.4 (2022).

Faustov R. N., Martynenko A. P., Martynenko F. A. Relativistic corrections to paired production of charmonium and bottomonium in decays of the Higgs boson, PRD, V. 107., P. 056002 (2023).

Martynenko F.A., Martynenko A.P., Eskin A.V., Production of dileptonic bound states in the Higgs boson decay, PRD, V. 110, 056016 (2024).

I.N. Belov, A.V. Berezhnoy, A.E. Dorokhov, A.K. Likhoded, A.P. Martynenko, F.A. Martynenko, Higgs boson decay to paired Bc: Relativistic and one-loop corrections, Nuclear Physics A, V. 1015, 122285 (2021).

Experimental Researches

Studying of rare Higgs boson decays into heavy quarkonium pair:

The CMS Collaboration, Search for Higgs boson decays into Z and J/Ψ and for Higgs and Z boson decays into J/Ψ or Υ pairs in pp collisions at $\sqrt{s} = 13TeV$, Phys. Lett. B, 842, 137534 (2023)

Experimental observation of heavy tetraquark candidates:

S. K. Choi, S. L. Olsen, K. Abe, T. Abe, et al. (Belle Collaboration), Observation of a narrow charmoniumlike state in exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\Psi$ decays, Phys. Rev. Lett. 91, 262001 (2003), https://doi.org/10.1103/PhysRevLett.91.262001.

R. Aaij, et al. (LHCb Collaboration), Observation of structure in the J/Ψ-pair mass spectrum, Sci. Bull. 65, 1983 (2020), https://doi.org/10.1016/j.scib.2020.08.032.

M. Ablikim1, M. N. Achasov, P. Adlarson, S. Ahmed, M. Albrecht, R. Aliberti, A. Amoroso, Q. An, Anita et al. (BESIII Collaboration), Observation of a Near-Threshold Structure in the K^{+} Recoil-Mass Spectra in $e^{+}e^{-} \to K^{+}(D_S^{-} D^{*0} + D_S^{*-} D^{0})$, Phys. Rev. Lett. 126, 102001 (2021);

Rare processes of Higgs boson decays with production of tetraquarks may be observed at future colliders, such as CLIC, FCC-hh.

Theoretical Studies

Theoretical prediction on tetraquark mass spectrum

R. N. Faustov, V. O. Galkin, E. M. Savchenko, Heavy tetraquarks in the relativistic quark model, Universe 7, 94 (2021),

A. V. Berezhnoy, A. V. Luchinsky and A. A. Novoselov, Tetraquarks Composed of 4 Heavy Quarks, Phys. Rev. D 86, 034004 (2012)

Calculation of the cross sections for tetraquarks production in proton-proton interactions, in electron-positron annihilation, and in B-meson decays

H. X. Chen, W. Chen, X. Liu, S. L. Zhu, The hidden-charm pentaquark and tetraquark states, Phys. Rep. 639, 1-121 (2016),

A. V. Berezhnoy, A. K. Likhoded, A. V. Luchinsky, and A. A. Novoselov, Production of J/Ψ-meson pairs and $4c$ tetraquark at the LHC, Phys. Rev. D 84, 094023 (2011);

V. R. Debastiani and F. S. Navarra, A non-relativistic model for the $[cc][\bar{c}\bar{c}]$ tetraquark, Chinese Physics C 43, 1, 013105 (2019);

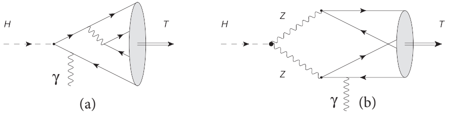
Q.-F. Lu, D.-Y. Chen and Y.-B. Dong, Masses of fully heavy tetraquarks $QQ\bar{Q}\bar{Q}$ in an extended relativized quark model, Eur. Phys. J. C 80:871 (2020)

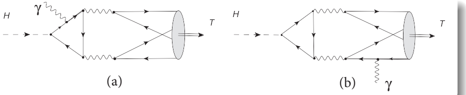
J. Wu, Y. R. Liu, K. Chen, X. Liu and S. L. Zhu, Heavy-flavored tetraquark states with the $QQ\bar{Q}\bar{Q}$ configuration, Phys. Rev. D, 97, 094015, (2018)

The aim of our work is to expand the field of study of processes with the formation of a tetraquark to the case of Higgs boson decay.

Production Amplitudes

Different mechanisms are possible for production of two quark - antiquark pairs ($c\bar{c}$) in the Higgs boson decay: quark-gluon, ZZ-boson, quark-gluon loop ...





"Quark-gluon mechanism"is characterized by initial decay of Higgs boson into quark - antoquark pair ($c\bar{c}$):

$$V_{Hc\bar{c}} = m_c(\sqrt{2}G_F)^{1/2},$$

"ZZ-boson mechanism"is defined by initial decay $H \to Z + Z$. Each Z boson produces quark - antiquark pair ($c\bar{c}$):

$$V_{HZZ} = \frac{2e}{\sin(2\theta_W)} M_Z g^{\alpha\beta}, \quad V_{Zc\bar{c}} = -M_Z(\sqrt{2}G_F)^{1/2}\gamma^\mu \left(\frac{1}{2}(1-\gamma^5) - 2Q_c \sin^2(\theta_W)\right)$$

V. I. Borodulin, R. N. Rogalev and S. R. Slabospitsky, CORE: COmpendium of RElations: Version 3.1, e-Print: arXiv:1702.08246v2 [hep-ph].

Tetraquark Formation

The color structure of the tetraquark state $(cc\bar{c}\bar{c})$ can be either of the hadronic type of molecule or of the diquark-antidiquark type. Pairs of quarks in the color antitriplet state are attracted to each other, and in the color sextet state they repel each other.

In our consideration the formation of a tetraquark occurs from pairs (cc) and $(\bar{c}\bar{c})$. Both pairs have spin $S = 1$ and are in antisymmetric color state.

$c + c + \bar{c} + \bar{c} \rightarrow$	$(cc)\, +$	$(\bar{c}\bar{c}) \rightarrow$	$(cc\bar{c}\bar{c})$
free quarks, antiquarks			tetraquark
$p_1,\ p_2,\ q_1,\ q_2$	Total P	Total Q	Total T
	relative p	relative q	relative p, q, t

Tetraquark can be formed with spin $S_T = 0,\ 1,\ 2$. We consider below only vector tetraquark $S_T = 1$.

Kinematics

Four - momenta of quarks and antiquarks: $p_{1,2} = \frac{1}{2}P \pm p, \quad q_{1,2} = \frac{1}{2}Q \pm q,$

Four momenta of diquark and antidiquark: $P = \frac{1}{2}T + t, Q = \frac{1}{2}T - t$

Theoretical Framework

Decay width for the process $H \to T + \gamma$:

$$\frac{d\Gamma_{H\to T+\gamma}}{d\Omega} = \frac{|\mathbf{T}|}{32\pi^2 M_H^2}\left|M_{H\to T+\gamma}\right|^2$$

We take into account relativistic corrections in interaction amplitudes $\sim \frac{p^2}{m^2}, \frac{q^2}{m^2}, \frac{t^2}{m^2}$.

Interaction amplitude in quasipotential approach can be presented as a convolution of relativistic wave function of tetraquark with production amplitude of free quarks and antiquarks, and a photon:

$$M_{H\to T+\gamma} = \int \frac{d\mathbf{p}}{(2\pi)^2}\int \frac{d\mathbf{q}}{(2\pi)^2}\int \frac{d\mathbf{t}}{(2\pi)^2}\Psi_T^{\lambda_1\lambda_2\lambda_3\lambda_4}(p,q,t)\,T_{H\to cc\bar{c}\bar{c}\gamma}^{\lambda_1\lambda_2\lambda_3\lambda_4}(p,q,t,T,k)$$

Tetraquark Wave Function

The transformation law of wave function from a moving reference frame to the rest frame was developed in the case of two - particle bound state:

- S. J. Brodsky, J. R. Primack, The electromagnetic interactions of composite systems, Ann. Phys. 52, 315 (1969);
- R. N. Faustov, Relativistic wave function and form factors of the bound system, Ann. Phys. 78, 176 (1973);

We expand this technique to the case of four - particle bound state.

Tetraquark wave function is obtained by solving of quasipotential equation with Nonrelativistic interaction potential of quarks and antiquarks in the four - particle bound state:

$$\Delta V(\boldsymbol{\rho}, \boldsymbol{\lambda}, \boldsymbol{\sigma}) = \Delta V^{C}(\boldsymbol{\rho}, \boldsymbol{\lambda}, \boldsymbol{\sigma}) + \Delta V^{conf}(\boldsymbol{\rho}, \boldsymbol{\lambda}, \boldsymbol{\sigma}),$$

$$\Delta V^{C}(\boldsymbol{\rho}, \boldsymbol{\lambda}, \boldsymbol{\sigma}) = \Big[-\frac{2\alpha_{s12}}{3\rho} - \frac{2\alpha_{s34}}{3\lambda} - \frac{4\alpha_{s13}}{3}\frac{1}{|\boldsymbol{\sigma} + \frac{m_4}{m_{34}}\boldsymbol{\lambda} - \frac{m_2}{m_{12}}\boldsymbol{\rho}|} - \frac{4\alpha_{s14}}{3}\frac{1}{|\boldsymbol{\sigma} - \frac{m_3}{m_{34}}\boldsymbol{\lambda} - \frac{m_2}{m_{12}}\boldsymbol{\rho}|} - \frac{4\alpha_{s23}}{3}\frac{1}{|\boldsymbol{\sigma} + \frac{m_4}{m_{34}}\boldsymbol{\lambda} + \frac{m_1}{m_{12}}\boldsymbol{\rho}|} - \frac{4\alpha_{s24}}{3}\frac{1}{|\boldsymbol{\sigma} - \frac{m_3}{m_{34}}\boldsymbol{\lambda} + \frac{m_1}{m_{12}}\boldsymbol{\rho}|}\Big],$$

$$\Delta V^{conf}(\boldsymbol{\rho}, \boldsymbol{\lambda}, \boldsymbol{\sigma}) = \Big[\frac{1}{2}A|\boldsymbol{\rho}| + \frac{1}{2}A|\boldsymbol{\lambda}| + A|\boldsymbol{\sigma} + \frac{m_4}{m_{34}}\boldsymbol{\lambda} - \frac{m_2}{m_{12}}\boldsymbol{\rho}| + A|\boldsymbol{\sigma} - \frac{m_3}{m_{34}}\boldsymbol{\lambda} - \frac{m_2}{m_{12}}\boldsymbol{\rho}| + A|\boldsymbol{\sigma} + \frac{m_4}{m_{34}}\boldsymbol{\lambda} + \frac{m_1}{m_{12}}\boldsymbol{\rho}| + A|\boldsymbol{\sigma} - \frac{m_3}{m_{34}}\boldsymbol{\lambda} + \frac{m_1}{m_{12}}\boldsymbol{\rho}| + B\Big],$$

ZZ-boson Mechanism

As a result, sum of all four production amplitudes in the case of ZZ-boson mechanism takes the following general form:

$$M_{T+\gamma} = \frac{e^4}{4\sin^2(2\theta_W)M_Z m^2}\int d\mathbf{p}d\mathbf{q}d\mathbf{t}\Psi_0(\mathbf{p},\mathbf{q},\mathbf{t})D_Z^{\alpha\lambda}(k_1)D_Z^{\alpha\sigma}(k_2)\frac{N(p,t)N(q,t)}{\frac{1}{4}(M_H^2-\frac{3}{4}M_T^2)-m^2}\times$$
$$Tr\{\hat{\Pi}_1^V(p,t)\hat{\varepsilon}_\gamma(\hat{p}_1+\hat{k}+m)\Gamma^\lambda_{Zc\bar{c}}\hat{\Pi}_2^V(q,t)\Gamma^\sigma_{Zc\bar{c}}+\hat{\Pi}_1^V(p,t)\Gamma^\lambda_{Zc\bar{c}}\hat{\Pi}_2^V(q,t)\Gamma^\sigma_{Zc\bar{c}}(\hat{p}_2+\hat{k}+m)\hat{\varepsilon}_\gamma+$$
$$\hat{\Pi}_1^V(p,t)\Gamma^\lambda_{Zc\bar{c}}(-\hat{q}_1-\hat{k}+m)\hat{\varepsilon}_\gamma\hat{\Pi}_2^V(q,t)\Gamma^\sigma_{Zc\bar{c}}+\hat{\Pi}_1^V(p,t)\Gamma^\lambda_{Zc\bar{c}}\hat{\Pi}_2^V(q,t)\hat{\varepsilon}_\gamma(-\hat{q}_2-\hat{k}+m)\Gamma^\sigma_{Zc\bar{c}}\}$$

Normalization factor:

$$N(p,t) = \left[\frac{\epsilon(\mathbf{p}+\mathbf{t}/2)}{m}\frac{(\epsilon(\mathbf{p}+\mathbf{t}/2)+m)}{2m}\frac{\epsilon(\mathbf{p}-\mathbf{t}/2)}{m}\frac{(\epsilon(\mathbf{p}-\mathbf{t}/2)+m)}{2m}\right]^{-1/2}$$

Projection operators on the state of pairs (cc), $(\bar{c}\bar{c})$ with $S=1$. Additional relativistic factors appear as a result of Lorentz transformation.

$$\hat{\Pi}_i^V = [\frac{\hat{v}-1}{2}-\hat{v}\frac{(\epsilon(\mathbf{p}+\frac{\mathbf{t}}{2})-m)}{2m}-\frac{(\hat{p}+\frac{\hat{t}}{2})}{2m}]\hat{\varepsilon}_i(1+\hat{v})[\frac{\hat{v}+1}{2}-\hat{v}\frac{(\epsilon(\mathbf{p}-\frac{\mathbf{t}}{2})-m)}{2m}+\frac{(\hat{p}-\frac{\hat{t}}{2})}{2m}]$$

ZZ-boson Mechanism

Decay width, corresponding to sum of four amplitudes of ZZ-boson mechanism taking into account leading order relativistic corrections $\omega_p =< \mathbf{p}^2/m^2 >$, $\omega_q =< \mathbf{q}^2/m^2 >$, $\omega_t =< \mathbf{t}^2/m^2 >$:

$$\Gamma(H \to ZZ \to \gamma + T) = \frac{256\pi^3\alpha^4 r_3^2(r_2^2 - r_3^2)|\Psi(0,0,0)|^2}{\sin^2 2\theta_W M_Z^8 r_2^3 (4 - r_3^2)^2 (2r_2^2 - r_3^2 - 4)^2 [\frac{1}{4}(r_2^2 - \frac{3}{4}r_3^2) - r_1^2 r_3^2]^2} \times$$

$$\Big[3N_2^2 + 2N_3^2(vv_\gamma)^2 - N_1^2(vv_\gamma)^2\Big], \quad (vv_\gamma) = \frac{(r_2^2 - r_3^2)}{2r_3^2}, \; v = \frac{T}{M_T}, \; v_\gamma = \frac{k}{M_T}.$$

Numerator of interaction amplitude is defined in terms of particles mass ratios

$$r_1 = \frac{m}{M_T}, \quad r_2 = \frac{M_H}{M_Z}, \quad r_3 = \frac{M_T}{M_Z}$$

$$\mathcal{N}_{T+\gamma} = N_1(v\varepsilon_\gamma)(v_\gamma\varepsilon_T) + N_2(\varepsilon_\gamma\varepsilon_T) + N_3\varepsilon_{\mu\nu\sigma\lambda}v^\mu v_\gamma^\nu \varepsilon_T^\sigma \varepsilon_\gamma^\lambda, \quad N_1 = 4(1-2a_z)(1 - \frac{7}{48}r_2^2 + \frac{7}{48}r_3^2 - \frac{1}{192}r_2^2 r_3^2)\omega_t,$$

$$N_2 = 4(1-2a_z)\omega_t\left[r_3^{-1}(-\frac{1}{2}\frac{r_2^2}{r_3} - \frac{1}{96}\frac{r_2^4}{r_3}) + \frac{1}{4} - \frac{1}{24}r_2^2 + \frac{1}{128}r_2^4 + \frac{1}{32}r_3^2 - \frac{1}{192}r_3^2 r_2^2\right],$$

$$N_3 = 32 - 2r_2^2 - 4r_3^2 + \frac{1}{2}r_2^2 r_3^2 - a_z(1-a_z) + (\omega_p + \omega_q)\Big[-\frac{112}{3} + \frac{7}{3}r_2^2 + \frac{14}{3}r_3^2 - \frac{7}{12}r_2^2 r_3^2 +$$

$$a_z(1-a_z)(\frac{224}{3} + \frac{2}{3}r_2^2 + \frac{4}{3}r_3^2 - \frac{1}{6}r_2^2 r_3^2)\Big] + \omega_t\Big[-\frac{61}{3} + \frac{59}{48}r_2^2 + \frac{67}{24}r_3^2 - \frac{65}{192}r_2^2 r_3^2 +$$

$$a_z(1-a_z)(\frac{122}{3} - \frac{1}{2}r_2^2 - r_3^2 + \frac{1}{8}r_2^2 r_3^2)\Big],$$

Quark - gluon Mechanism

In the case of quark-gluon mechanism there are 10 amplitudes. Total decay width of vector tetraquark production taking into account leading relativistic corrections is defined by expression:

$$\Gamma(H\to Q\bar{Q}\to\gamma+T)=\frac{2048\pi^3\alpha^2\alpha_s^2}{9M_Z^8\sin^2 2\theta_W}\frac{\left(1-\frac{r_3^2}{r_2^2}\right)^3}{r_3^5 r_2}|\Psi(0,0,0)|^2\times$$
$$\left[10+4\frac{r_3^2}{r_2^2}+(\omega_p+\omega_q)\left(\frac{11}{2}+4\frac{r_3^2}{r_2^2}\right)+\omega_t\left(-\frac{1}{12}+\frac{4}{3}\frac{r_3^2}{r_2^2}\right)\right]^2.$$

Numerator of sum of all quark-gluon amplitudes have the form:

$$\mathcal{N}_{\mathcal{M}}=\frac{512}{3M_T^2M_H^2}\left[10+4\frac{r_3^2}{r_2^2}+(\omega_p+\omega_q)\left(\frac{11}{2}+4\frac{r_3^2}{r_2^2}\right)+\omega_t\left(-\frac{1}{12}+\frac{4}{3}\frac{r_3^2}{r_2^2}\right)\right]\varepsilon_{\mu\nu\lambda\sigma}v^\mu v_\gamma^\nu\varepsilon_T^\lambda\varepsilon_\gamma^\sigma.$$

Order of decay width is determined by coupling constants:

$$\Gamma(H\to Q\bar{Q}\to\gamma+T)\sim\alpha^2\alpha_s^2$$
$$\Gamma(H\to ZZ\to\gamma+T)\sim\alpha^4$$

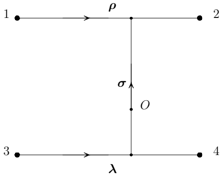
Tetraquark Wave Function

Tetraquark wave function at the origin $\Psi(0,0,0)$ is an important parameter of the theory. To obtain it we use variation approach with Gaussian wave functions. In terms of Jacobi coordinates the four particle bound state wave function have the form:

A.V. Eskin, A.P. Martynenko, F.A. Martynenko, Mass spectrum of heavy tetraquarks in variational approach, e-Print: 2505.05993 [hep-ph]

$$\Psi(\boldsymbol{\rho},\boldsymbol{\lambda},\boldsymbol{\sigma}) =$$

$$\sum_{I=1}^{K} C_I e^{-\frac{1}{2}\left[A_{11}(I)\boldsymbol{\rho}^2+2A_{12}(I)\boldsymbol{\rho}\boldsymbol{\lambda}+A_{22}(I)\boldsymbol{\lambda}^2+2A_{13}(I)\boldsymbol{\rho}\boldsymbol{\sigma}+2A_{23}(I)\boldsymbol{\lambda}\boldsymbol{\sigma}+A_{33}(I)\boldsymbol{\sigma}^2\right]},$$



where $A_{ij}(I)$ is the matrix of nonlinear variation parameters, C_I - are linear variation parameters.

Fourier transformation to momentum representation gives:

$$\Psi(\mathbf{p},\mathbf{q},\mathbf{t}) = \sum_{I=1}^{K} \frac{C_I}{\sqrt{\mathcal{N}}(detA)^{3/2}(2\pi)^{\frac{9}{2}}} e^{-\frac{1}{2detA}[\mathbf{p}^2(A_{22}A_{33}-A_{23}^2)+\mathbf{q}^2(A_{11}A_{33}-A_{13}^2)+\mathbf{t}^2(A_{11}A_{22}-A_{12}^2)]}$$

$$e^{-\frac{1}{2detA}[2\mathbf{pt}(A_{12}A_{23}-A_{13}A_{22})+2\mathbf{qt}(A_{12}A_{13}-A_{11}A_{23})+2\mathbf{pq}(A_{13}A_{23}-A_{12}A_{33})]}.$$

Relativistic Parameters

Finally, value of wave function at the origin in analytic form is determined by variation parameters:

$$\Psi(0,0,0)=\frac{1}{\sqrt{<\Psi|\Psi>}}\sum_{I=1}^{K}C_I\frac{1}{16\sqrt{2}\pi^{\frac{9}{2}}}\frac{1}{det\tilde{Q}(I)^{\frac{3}{2}}}\frac{1}{detA(I)^{\frac{3}{2}}},$$

matrix elements $\tilde{Q}$ are also defined by $A_{ij}(I)$ and C_I.
Relativistic corrections have the form of momenta integrals with square of tetraquark wave function. They can be calculated within the framework of variation approach.
Integrals over relative momenta takes the form:

$$\langle\frac{\mathbf{p}^2}{m^2}\rangle=\int\Psi(\mathbf{p},\mathbf{q},\mathbf{k})\frac{\mathbf{p}^2}{m^2}\frac{d\mathbf{p}d\mathbf{q}d\mathbf{k}}{(2\pi)^9}=\sum_{I=1}^{K}\frac{3C_I}{\sqrt{\mathcal{N}}}\frac{(\tilde{Q}_{22}\tilde{Q}_{33}-\tilde{Q}_{23}^2)}{detA(I)^{\frac{3}{2}}det\tilde{Q}(I)^{\frac{5}{2}}m^2}\times$$

$$\Big[Erf\Big(\sqrt{\frac{m^2det\tilde{Q}}{2(\tilde{Q}_{22}\tilde{Q}_{33}-\tilde{Q}_{23}^2)}}\Big)-\frac{\sqrt{2}}{3\sqrt{\pi}}\frac{m^3(det\tilde{Q})^{3/2}}{(\tilde{Q}_{22}\tilde{Q}_{33}-\tilde{Q}_{23}^2)^{3/2}}\Big(1+\frac{3(\tilde{Q}_{22}\tilde{Q}_{33}-\tilde{Q}_{23}^2)}{m^2det\tilde{Q}}\Big)e^{-\frac{m^2det\tilde{Q}}{2(\tilde{Q}_{22}\tilde{Q}_{33}-\tilde{Q}_{23}^2)}}\Big],$$

where $erf(t)$ is standard Gaussian error function.

Numerical Results

Decay	Non-relativistic Br_{nr}	Relativistic Br_{rel}
$H \to ZZ \to T + \gamma$	$0.38 \cdot 10^{-14}$	$0.61 \cdot 10^{-14}$
$H \to Q\bar{Q} \to T + \gamma$	$0.15 \cdot 10^{-8}$	$0.21 \cdot 10^{-8}$
$H \to quark - loop \to T + \gamma$	$0.32 \cdot 10^{-11}$	$0.50 \cdot 10^{-11}$

Taking into account relativistic effects leads to significant increase of total decay width.

Numerical values of relativistic parameters and wave function at the origin for $(cc\bar{c}\bar{c})$ tetraquark:

$$\Psi(0,0,0) = 0.10 \ GeV^{9/2},$$

$$\omega_p = \langle \frac{\mathbf{p}^2}{m^2} \rangle = 0.18, \ \omega_q = \langle \frac{\mathbf{q}^2}{m^2} \rangle = 0.18, \ \omega_t = \langle \frac{\mathbf{t}^2}{m^2} \rangle = 0.12.$$

Branching ratio $Br_{H \to T+\gamma}$ turns out to be greater then $Br_{H \to J/\Psi + J/\Psi} = 0.21 \cdot 10^{-9}$

Thank You!