Role of the $h_1(1800)$ and $f_1(1285)$ states in the J/ψ decays

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Outline

Introduction

$K^*\bar{K}^*$ and $K^*\bar{K}$ interactions in the Chiral Unitary Approach

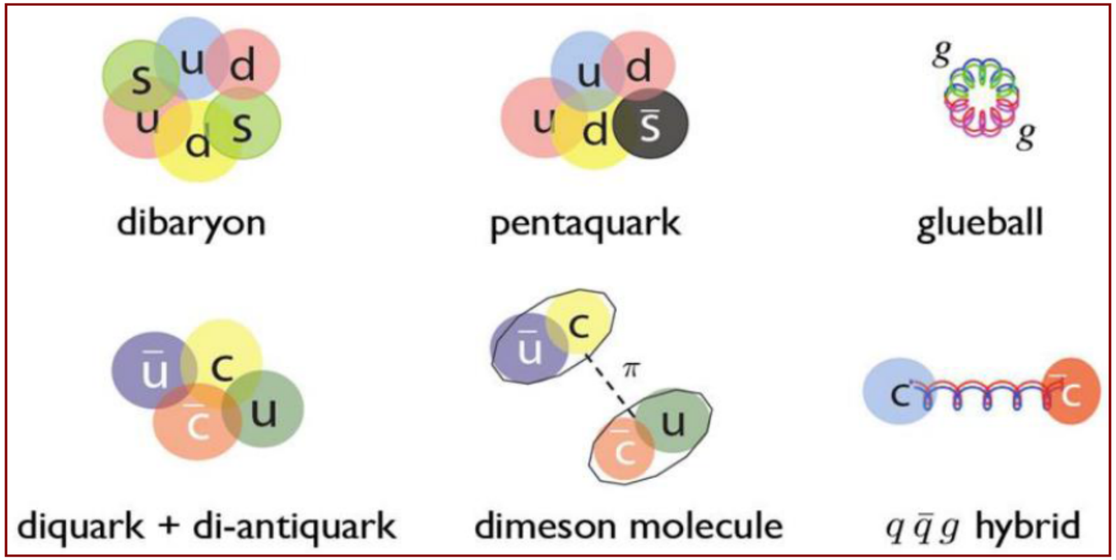
Signature of an h_1 state in the $J/\psi \to \eta h_1(1800) \to \eta K^{*0}\bar{K}^{*0}$ decay

The $J/\psi \to \phi \bar{K} K^*$ decay and the $f_1(1285)$ state

Summary

Hadrons: normal & exotic

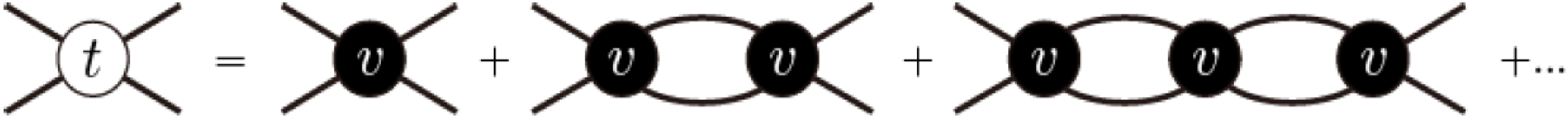
- Quark model: hadrons are composed from 2 (meson) quarks or 3 (baryon) quarks



- QCD does not forbid hadrons with $N_{quarks} \neq 2, 3$
  - Glueball: $N_{quarks} = 0$ (gg, ggg, …)
  - Hybrid: $N_{quarks} = 2$ (or more) + excited gluon
  - Multiquark state: $N_{quarks} > 3$
  - Molecule: bound state of more than 2 hadrons
  - …

From Cheng-Ping Shen.

Hadronic molecules



$$t = v + vgv + vgvgv + \ldots = v + vgt \quad (g: \text{ two body loop function})$$

$$= [1 - vg]^{-1} v$$

<u>v : from chiral Lagrangian</u>

Example <u>Λ(1405)</u> as KbarN molecular state

$P_c(4312)$

$P_c(4440)$?

$P_c(4457)$

Hadronic molecules

Feng-Kun Guo, Christoph Hanhart, Ulf-G. Meißner, Qian Wang, Qiang Zhao, and Bing-Song Zou
Rev. Mod. Phys. **90**, 015004 – Published 8 February 2018

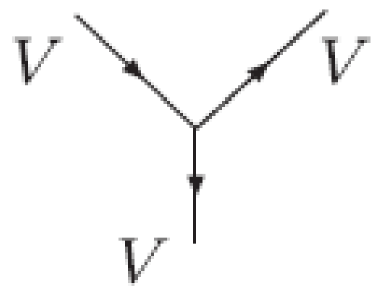
Vector-Vector interactions

$$\mathcal{L}_{III} = -\frac{1}{4}\langle V_{\mu\nu}V^{\mu\nu}\rangle, \quad V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - ig[V_\mu, V_\nu],$$

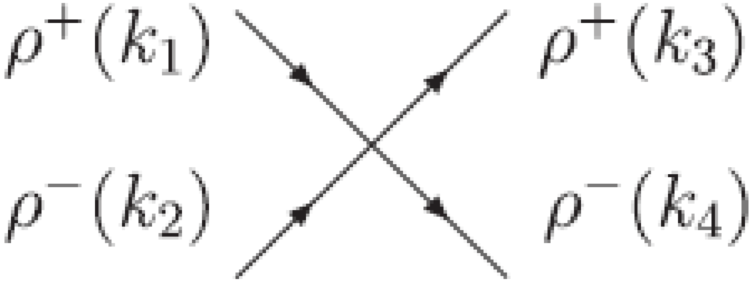
$$V_\mu = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu .$$

$$\mathcal{L}^{(c)}_{III} = \frac{g^2}{2}\langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu\rangle,$$

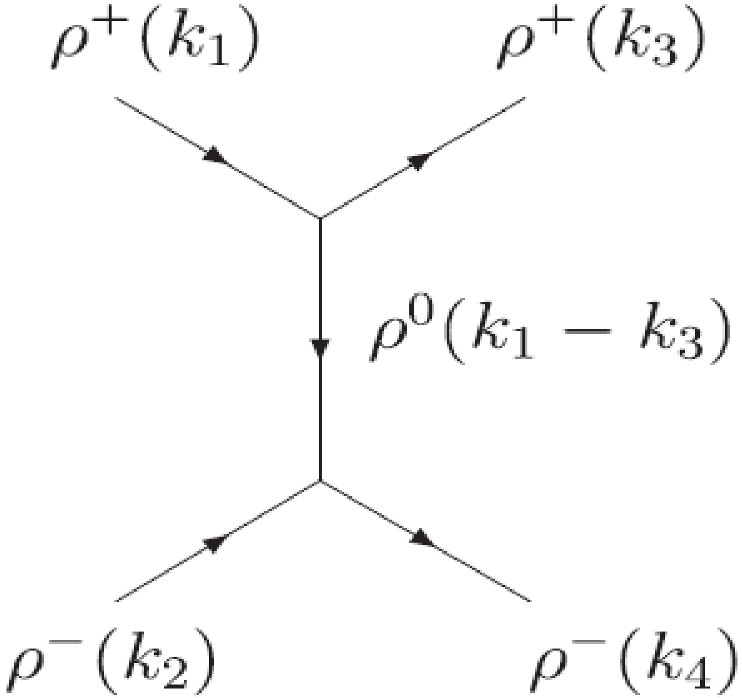
$$\mathcal{L}^{(3V)}_{III} = ig\langle(\partial_\mu V_\nu - \partial_\nu V_\mu)V^\mu V^\nu\rangle,$$



Vector-Vector scattering amplitudes



Contact term of the $\rho\rho$ interaction.



Vector exchange diagram for $\rho^+\rho^- \to \rho^+\rho^-$.

Potential (Kernel) V

G: two vectors loop function

$$T = (1 - VG)^{-1} V$$

$$G = i \int \frac{d^4 q}{(2\pi)^4} \frac{1}{q^2 - M_{V_1}^2 + i\epsilon} \frac{1}{(P-q)^2 - M_{V_2}^2 + i\epsilon}$$

An h_1 state in $K^*\bar{K}^*$ system

$$h_1: \;\; I^G(J^{PC}) = 0^-(1^{+-})$$

The pseudoscalar--vector channels are allowed, but their thresholds are far away. They can contribute to the width, but have little effect in the energy of the interacting *VV* components.

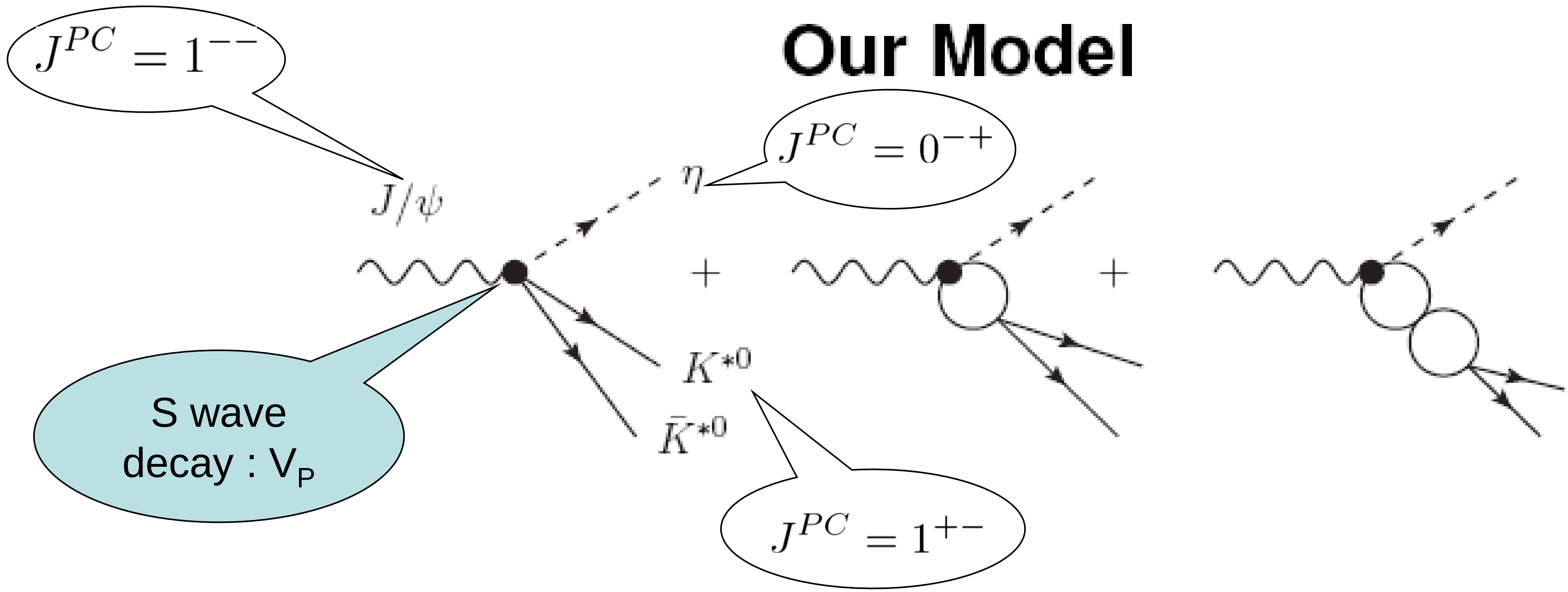
It cannot couple to other vector--vector because of Charge parity, which makes its observation difficult.

$$\text{Pole position}: \;\; (1802, -i39) \;\; \text{MeV}$$

$$\text{Coupling}: \;\; g^R_{K^*\bar{K}^*} = (8034, -i2542) \;\; \text{MeV}$$

L. S. Geng, and E. Oset, PRD 79, 074009 (2009).

Our Model



$$
\begin{aligned}
t_P &= V_P\left(1+\tilde{G}(M^2_{\text{inv}})t(M^2_{\text{inv}})\right) = V_P\frac{t(M^2_{\text{inv}})}{v(M^2_{\text{inv}})} \\
t &= v + v\tilde{G}t = v(1+\tilde{G}t) = (1-v\tilde{G})^{-1}v \\
v &= g^2\left(9 + b\left(1-\frac{3M^2_{\text{inv}}}{4m^2_{K^*}}\right)\right)
\end{aligned}
$$

L.S. Geng *et al.*, Phys. Rev. D **79**, 074009 (2009).

Ju-Jun Xie *et al.*, Phys. Lett. B **728**, 319 (2014).

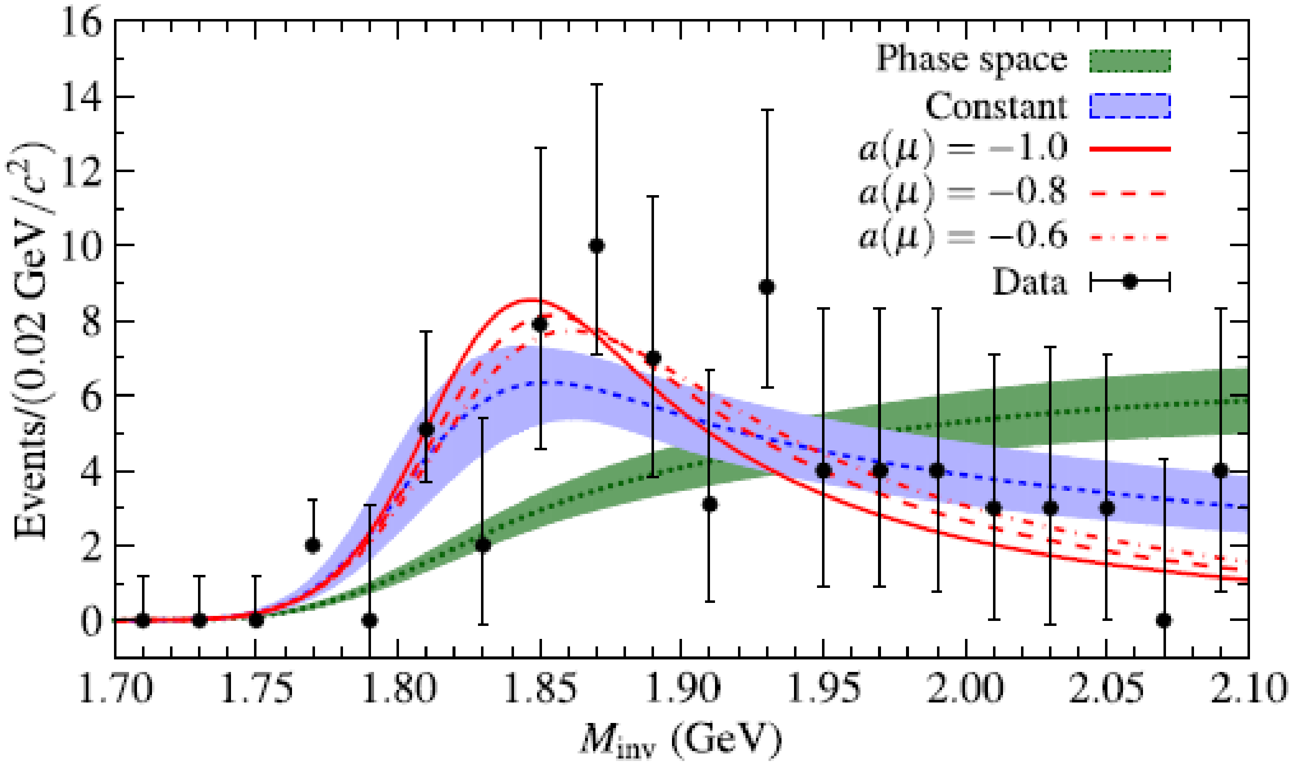
The constant *b* is determined by the masses of the vector mesons and its value turns out to be *b* = 6.8.

$J/\psi \to \eta K^{*0} \bar{K}^{*0}$ decay

$$\frac{d\Gamma}{dM_{\rm inv}} = \frac{C}{\left|v(M_{\rm inv}^2)\right|^2} \frac{p_1 \tilde{p}_2}{M_{J/\psi}} \left|t(M_{\rm inv}^2)\right|^2$$

$$p_1 = \frac{\lambda^{1/2}(M_{J/\psi}^2, m_\eta^2, M_{\rm inv}^2)}{2M_{J/\psi}},$$

$$p_2 = \frac{\lambda^{1/2}(M_{\rm inv}^2, m_1^2, m_2^2)}{2M_{\rm inv}}.$$

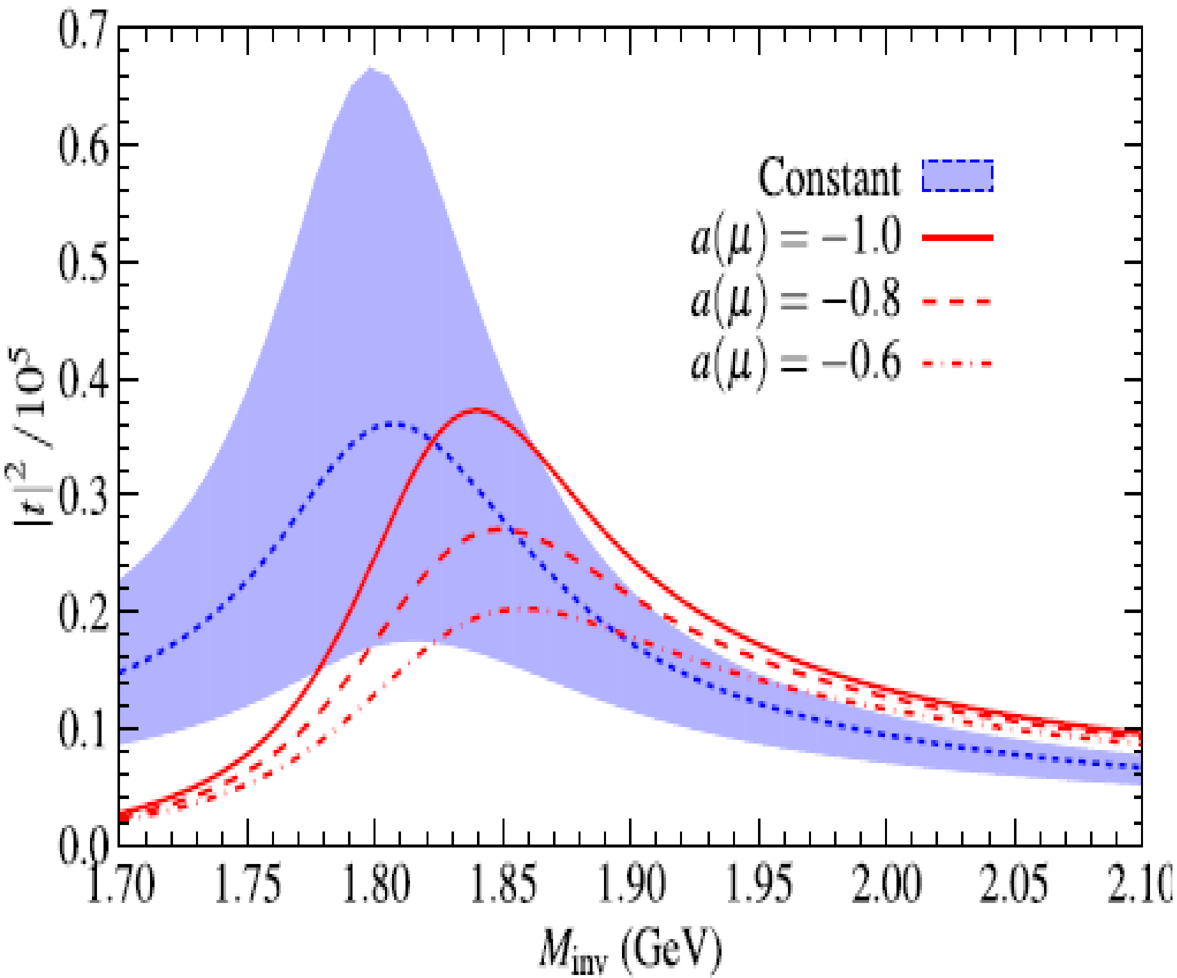


M. Ablikim *et al.* (BES Collaboration), PLB685, 27 (2010).

Values of some of the parameters used or determined in this work.

Potential	C (GeV^{-1})	a_μ	v/g^2	χ^2/d.o.f.
Constant	42 ± 6	-0.8	-6.2 ± 1.2	0.45
Hidden gauge	42 ± 6	-1.0	Eq. (8)	0.56
Hidden gauge	53 ± 7	-0.8	Eq. (8)	0.47
Hidden gauge	67 ± 9	-0.6	Eq. (8)	0.42

The modulus squared $|t|^2$ for $K^*\bar{K}^* \to K^*\bar{K}^*$



$$\tilde{G}(s) = \int_{m_-^2}^{m_+^2} dm_1^2 dm_2^2 \, \omega(m_1^2)\omega(m_2^2) G(s, m_1^2, m_2^2),$$

$$16\pi^2 G(s, m_1^2, m_2^2)$$

$$= a(\mu) + \log\frac{m_1 m_2}{\mu^2} + \frac{\Delta}{2s}\log\frac{m_2^2}{m_1^2}$$

$$+ \frac{\nu}{2s}\left(\log\frac{s-\Delta+\nu}{-s+\Delta+\nu} + \log\frac{s+\Delta+\nu}{-s-\Delta+\nu}\right),$$

$$\Delta = m_2^2 - m_1^2, \qquad \nu = \lambda^{1/2}(s, m_1^2, m_2^2),$$

$$\omega(m_1^2) = \frac{1}{\mathcal{N}} \operatorname{Im} \frac{1}{m_1^2 - m_{K^*}^2 + i\Gamma(m_1^2) m_1},$$

$$\mathcal{N} = \int_{m_-^2}^{m_+^2} dm_1^2 \operatorname{Im} \frac{1}{m_1^2 - m_{K^*}^2 + i\Gamma(m_1^2) m_1},$$

$$\Gamma(m_1^2) = \Gamma_{K^*} \frac{p^3(m_1^2)}{p^3(m_{K^*}^2)}, \qquad p(m_1^2) = \frac{\lambda^{1/2}(m_1^2, m_\pi^2, m_K^2)}{2m_1}.$$

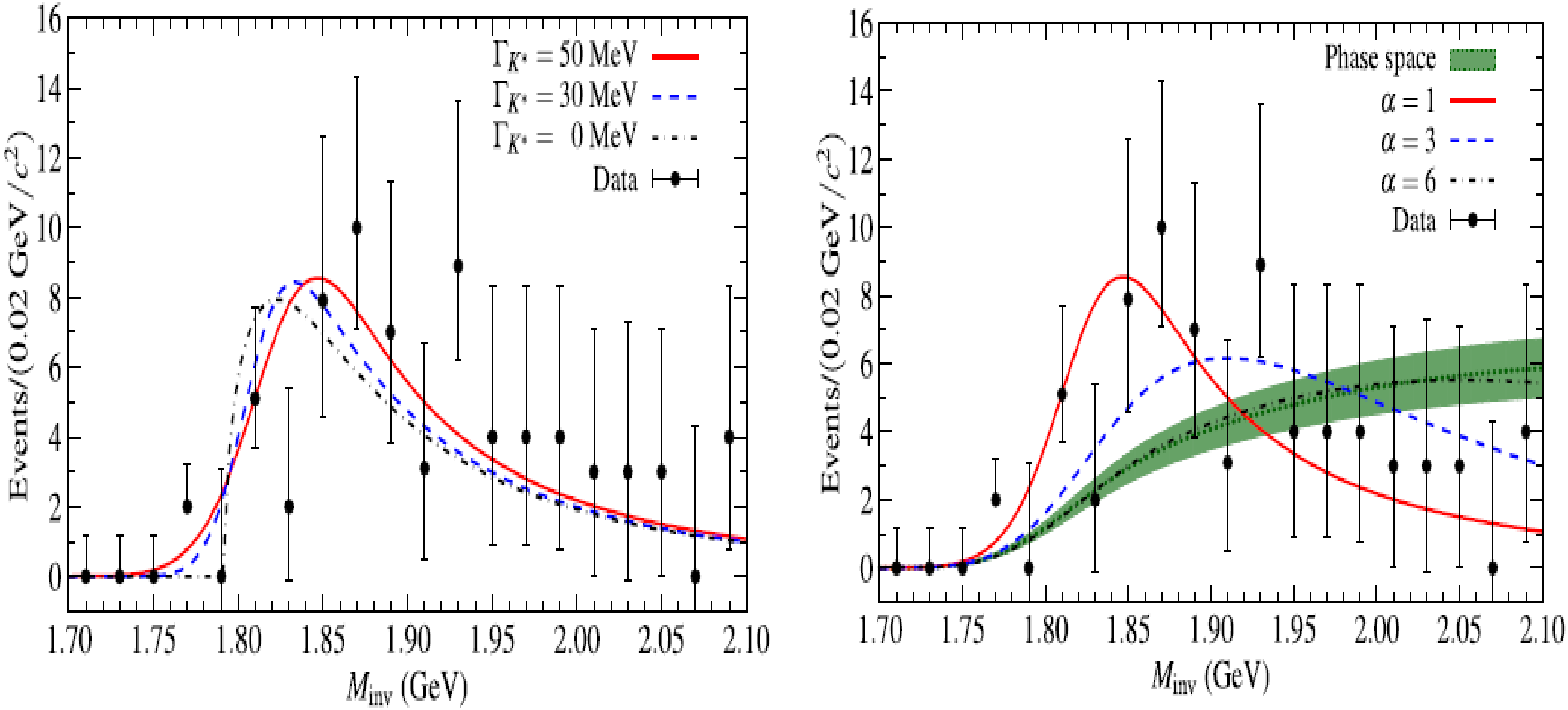
$$t = v + v\tilde{G}t = v(1+\tilde{G}t) = (1 - v\tilde{G})^{-1} v = \left(v^{-1} - \tilde{G}\right)^{-1}$$

$$v = \left(9 + b\left(1 - \frac{3M_{\rm inv}^2}{4m_{K^*}^2}\right)\right) g^2$$

$$s = M_{\rm inv}^2 \qquad m_\pm = m_{K^*} \pm 2\Gamma_{K^*}$$

$$\Gamma_{K^*} = 50 \text{ MeV}$$

More check



$$a(\mu) = -1 \qquad g^2 \to g^2/\alpha$$

Ju-Jun Xie, M. Albaladejo, and E. Oset, PLB728, 319 (2014).

$f_1(1285)$ $\quad I^G(J^{PC}) = 0^+(1^{++})$

$f_1(1285)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	4π	$(33.5^{+2.0}_{-1.8})$ %	S=1.3
Γ_2	$\pi^0\pi^0\pi^+\pi^-$	$(22.3^{+1.3}_{-1.2})$ %	S=1.3
Γ_3	$2\pi^+2\pi^-$	$(11.2^{+0.7}_{-0.6})$ %	S=1.3
Γ_4	$\rho^0\pi^+\pi^-$	$(11.2^{+0.7}_{-0.6})$ %	S=1.3
Γ_5	$\rho^0\rho^0$	seen	
Γ_6	$4\pi^0$	$< 7 \times 10^{-4}$	CL=90%
Γ_7	$\eta\pi^+\pi^-$	(35 ± 15) %	
Γ_8	$\eta\pi\pi$	$(52.0^{+1.8}_{-2.1})$ %	S=1.2
Γ_9	$a_0(980)\pi$ [ignoring $a_0(980) \to K\overline{K}$]	(38 ± 4) %	
Γ_{10}	$\eta\pi\pi$ [excluding $a_0(980)\pi$]	(14 ± 4) %	
Γ_{11}	$K\overline{K}\pi$	(9.1 ± 0.4) %	S=1.1
Γ_{12}	$K\overline{K}^*(892)$	not seen	
Γ_{13}	$\pi^+\pi^-\pi^0$	$(3.0 \pm 0.9) \times 10^{-3}$	
Γ_{14}	$\rho^\pm\pi^\mp$	$< 3.1 \times 10^{-3}$	CL=95%
Γ_{15}	$\gamma\rho^0$	(5.3 ± 1.2) %	S=2.9
Γ_{16}	$\phi\gamma$	$(7.5 \pm 2.7) \times 10^{-4}$	
Γ_{17}	$\gamma\gamma^*$		

$f_1(1285)$ $I^G(J^{PC}) = 0^+(1^{++})$

$$\mathcal{L}_{VVPP} = -\frac{1}{4f^2} Tr\left([V^\mu, \partial^\nu V_\mu][P, \partial_\nu P]\right)$$

$$t = \frac{v}{1 - vG},$$

Pole position : $(1282, -i0)$ MeV

Coupling : $g^R_{K^*\bar{K}} = (7555, -i0)$ MeV

where v is the $\bar{K}K^* \to \bar{K}K^*$ transition potential and G is the loop function for the propagators of the $\bar{K}$ and K^*

L. Roca, and E. Oset, “Low lying axial-vector mesons as dynamically generated resonances ”, Phys. Rev. D 72, 014002 (2005).

F. Aceti, J.M. Dias and E. Oset, “f1(1285) decays into a0(980)π0, f0(980)π0 and isospin breaking," Eur. Phys. J. A 51, 48 (2015).

R. Molina, M. Döring and E. Oset, “Determination of the compositeness of resonances from decays: the case of the B0s-> J/ψ f1(1285)," Phys. Rev. D 93, 114004 (2016).

$f_1(1285)$ in the unitized chiral perturbation theory

TABLE II. Pole positions and couplings in the $(S, I) = (0, 0)$ channel.

	$h_1(1170)$		$h_1(1380)$		$f_1(1285)$	
	LO	NLO	LO	NLO	LO	NLO
$\sqrt{s}$	$918 - i17$	$925 - i29$	$1244 - i7$	$1257 - i0$	$1286 - i0$	$1289 - i0$
$\frac{1}{\sqrt{2}}(\bar{K}^*K + K^*\bar{K})$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$7219 + i0$	$7884 + i0$
$\phi\eta$	$-46 + i13$	$69 - i102$	$-3309 + i47$	$-5963 - i38$	$\cdots$	$\cdots$
$\omega\eta$	$-24 + i28$	$711 - i427$	$3019 - i22$	$2642 - i47$	$\cdots$	$\cdots$
$\rho\pi$	$3452 - i1681$	$3576 - i1909$	$650 - i961$	$134 - i233$	$\cdots$	$\cdots$
$\frac{1}{\sqrt{2}}(\bar{K}^*K - K^*\bar{K})$	$-784 + i499$	$-1488 + i757$	$6137 + i183$	$6435 + i35$	$\cdots$	$\cdots$

PHYSICAL REVIEW D **90,** 014020 (2014)

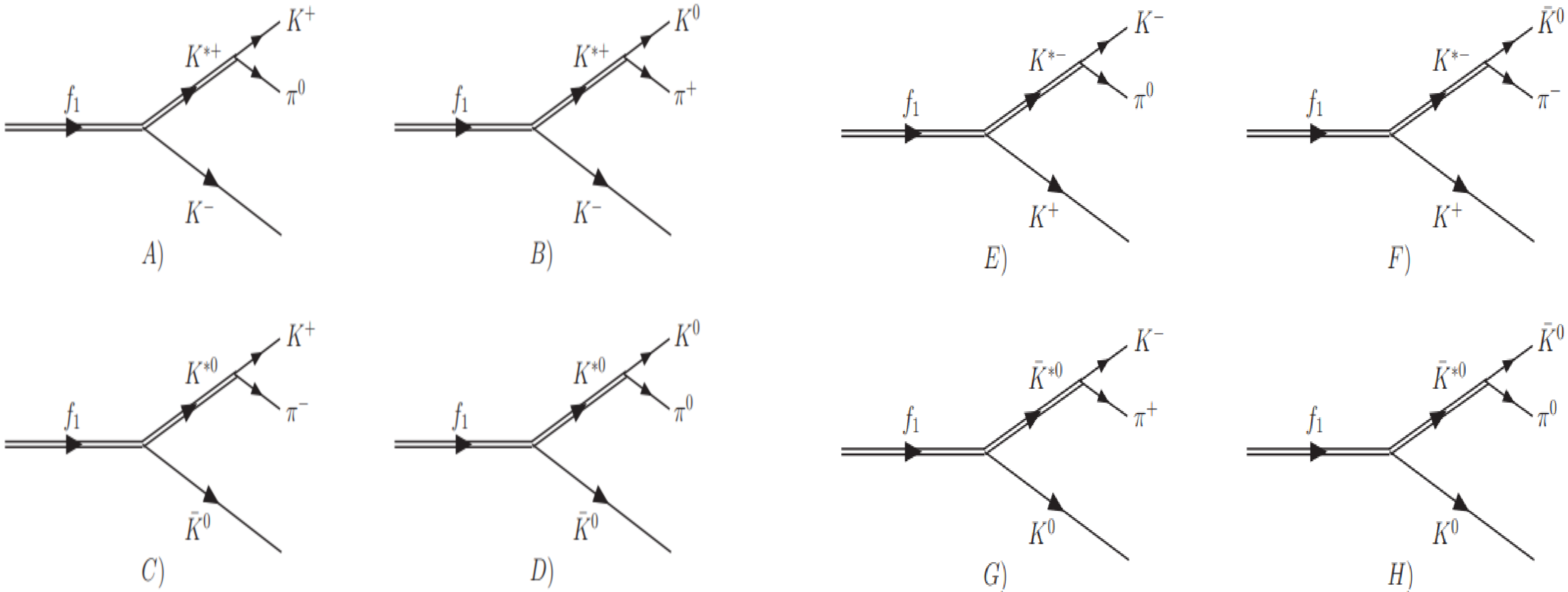
Pseudoscalar meson and vector meson interactions and dynamically generated axial-vector mesons

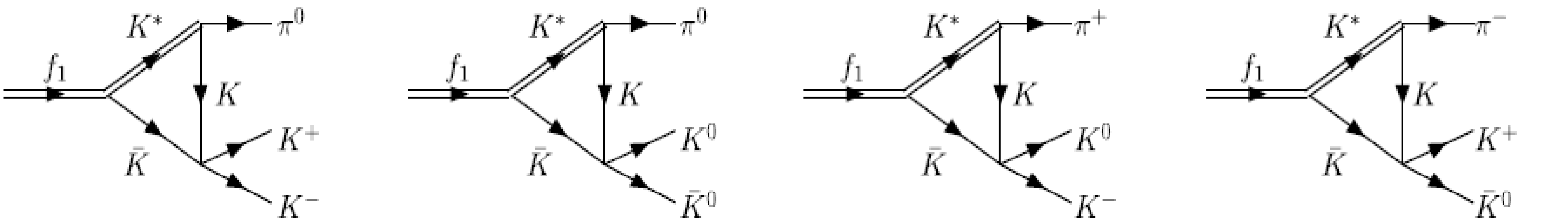
Yu Zhou, Xiu-Lei Ren, Hua-Xing Chen, and Li-Sheng Geng*

$f_1(1285) \to \pi K \bar{K}$ decay

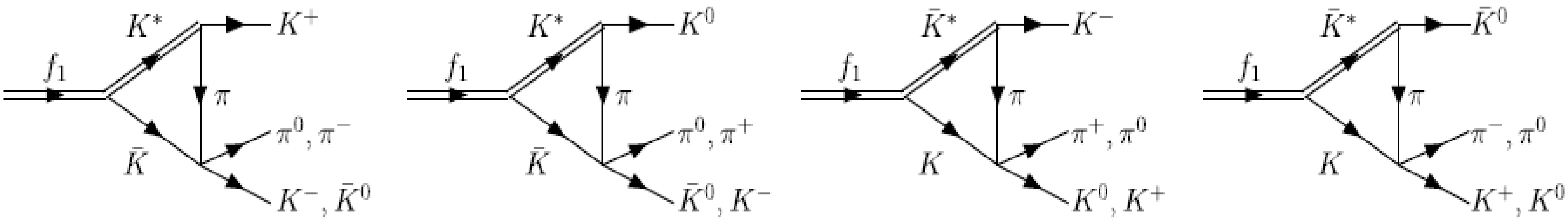
$$\frac{1}{\sqrt{2}}(K^*\bar{K} - \bar{K}^*K) = -\frac{1}{2}(K^{*+}K^- + K^{*0}\bar{K}^0$$
$$-K^{*-}K^+ - \bar{K}^{*0}K^0)\ .$$

We take the convention $CK^* = -\bar{K}^*$,





$A)$



$B)$

$$\Gamma = 6\frac{1}{64\pi^3 M_{f_1}} \int\int d\omega_{K^+} d\omega_{K^-} \overline{\sum}|M|^2 \qquad (24)$$
$$\times\, \theta(1-\cos^2\theta_{K\bar{K}})\theta(M_{f_1}-\omega_{K^+}-\omega_{K^-}-m_\pi),$$

where M is the full amplitude of the process $f_1(1285) \to \pi^0 K^+ K^-$ including the FSIs,

$$M = M_{\text{tree}} + M_{\text{FSI}}^{K\bar{K}} + M_{\text{FSI}}^{\pi K}, \qquad (25)$$

Theory

$$Br[f_1(1285) \to \pi K\bar{K}] = (7.2 \sim 7.8)\%$$

Experiment

$$Br[f_1(1285) \to \pi K\bar{K}] = (9.0 \pm 0.4)\%$$

F. Aceti, J.J. Xie and E. Oset, “The K-bar K pi decay of the f1(1285) and its nature as a K* K-bar molecule," Phys. Lett. B750, 609 (2015).

Invariant mass distributions

$$\frac{d\Gamma}{dM_{K^+K^-}} = \frac{M_{K^+K^-}}{64\pi^3 M_{f_1}^2}\int d\omega_{K^+}\overline{\sum}|M|^2\theta(1-\cos^2\theta_{K\bar{K}})\times \theta(M_{f_1}-\omega_{K^+}-\omega_{K^-}-m_\pi)\theta(\omega_{K^-}-m_K), \quad (31)$$

$$\frac{d\Gamma}{dM_{\pi^0K^+}} = \frac{M_{\pi^0K^+}}{64\pi^3 M_{f_1}^2}\int d\omega_{K^+}\overline{\sum}|M|^2\theta(1-\cos^2\theta_{K\bar{K}})\times \theta(M_{f_1}-\omega_{K^+}-\omega_{K^-}-m_\pi)\theta(\omega_{K^-}-m_K), \quad (32)$$

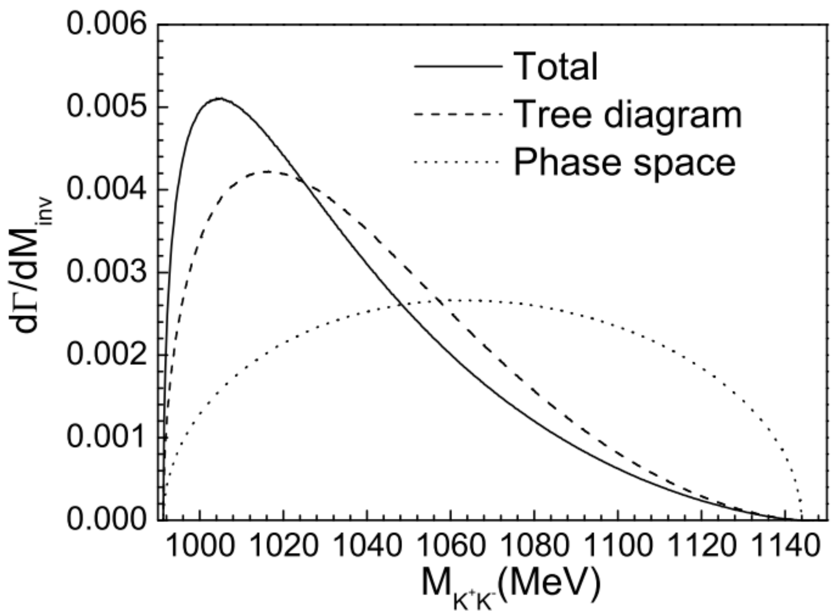


FIG. 3: The mass distribution $\frac{d\Gamma}{dM_{K^+K^-}}$ for $f_1(1285) \to \pi^0K^+K^-$ as a function of the invariant mass of the K^+K^- system.

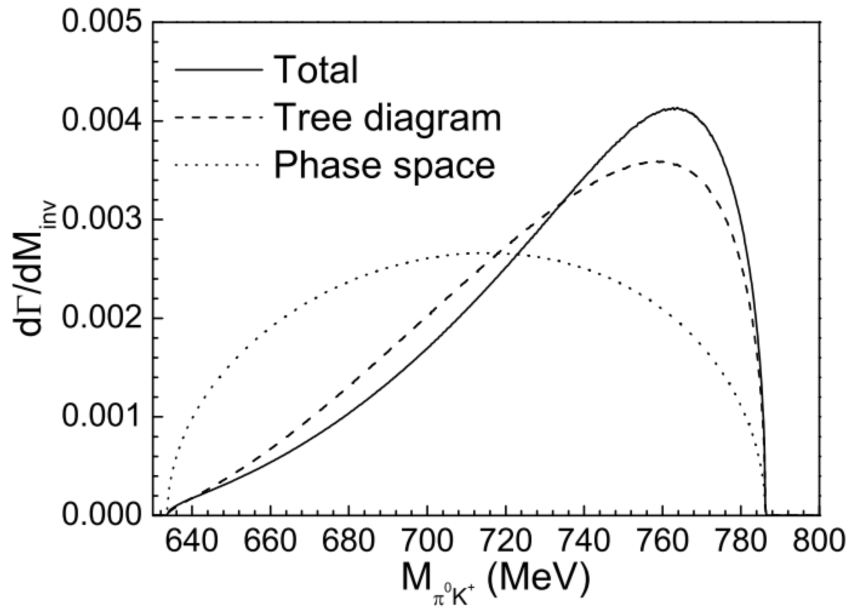
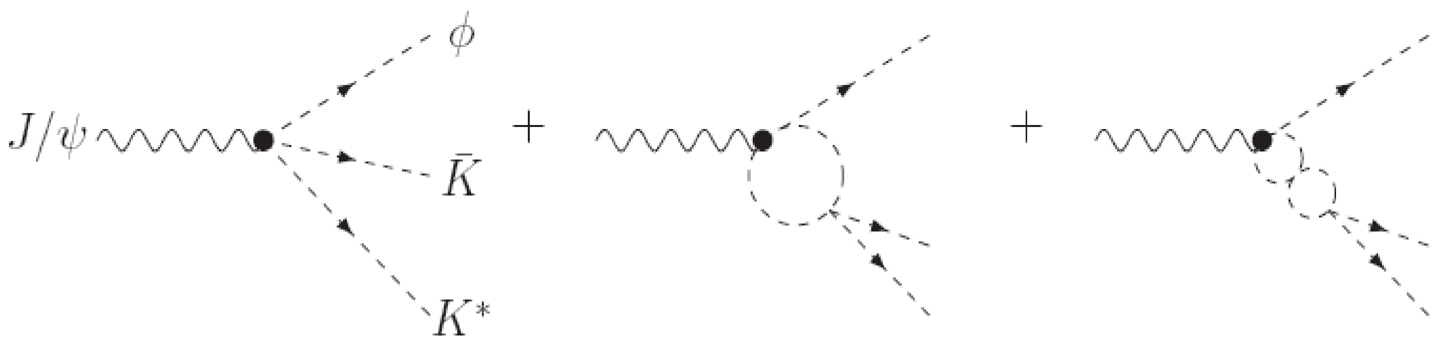


FIG. 4: The mass distribution $\frac{d\Gamma}{dM_{\pi^0K^+}}$ for $f_1(1285) \to \pi^0K^+K^-$ as a function of the invariant mass of the π^0K^+ system.

F. Aceti, J.J. Xie and E. Oset, “The K-bar K pi decay of the f1(1285) and its nature as a K* K-bar molecule," Phys. Lett. B750, 609 (2015).

$J/\psi \to \phi \bar{K} K^*$ and $J/\psi \to \phi f_1(1285)$ deacys



$$T_{J/\psi \to \phi \bar{K} K^*} = V_P C_s \left[1 + G(M_{\rm inv}^2) t(M_{\rm inv}^2) \right] = V_P C_s \frac{t(M_{\rm inv})}{v(M_{\rm inv})},$$

$$\frac{d\Gamma_{J/\psi \to \phi \bar{K} K^*}}{dM_{\rm inv}} = \frac{V_p^2}{(2\pi)^3} \frac{M_{\rm inv}}{8 M_{J/\psi}^3} \left| \frac{t(M_{\rm inv})}{v(M_{\rm inv})} \right|^2 \times \int_{M_{\phi\bar{K}}^{\rm min}}^{M_{\phi\bar{K}}^{\rm max}} \overline{\sum} \sum C_s^2 M_{\phi\bar{K}} dM_{\phi\bar{K}}$$

$$C_s = \epsilon_{ijk} \varepsilon_i(J/\psi) \varepsilon_j(\phi) \varepsilon_k(K^*).$$

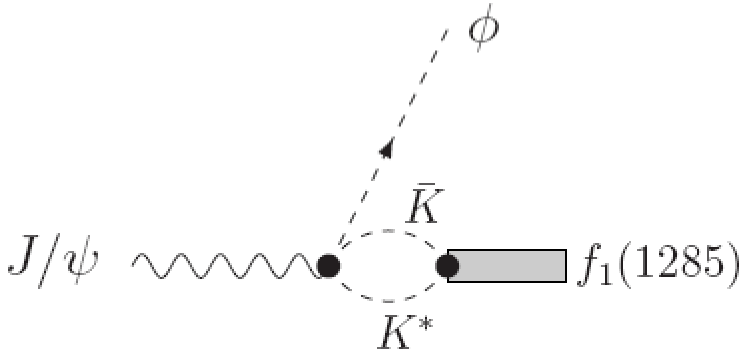
$$\overline{\sum} \sum C_s^2 = \frac{2}{3}\left(3 + \frac{p_\phi^2}{m_\phi^2} + \frac{p_{K^*}^2}{m_{K^*}^2}\right), \quad (4)$$

where p_ϕ and and p_{K^*} are the ϕ and K^* momenta in the J/ψ rest frame, respectively,

$$p_\phi = \frac{\lambda^{1/2}(M_{J/\psi}^2, m_\phi^2, M_{\rm inv}^2)}{2M_{J/\psi}}, \quad (5)$$

$$p_{K^*} = \frac{\lambda^{1/2}(M_{J/\psi}^2, m_{K^*}^2, M_{\phi\bar{K}}^2)}{2M_{J/\psi}}, \quad (6)$$

$J/\psi \to \phi \bar{K} K^*$ and $J/\psi \to \phi f_1(1285)$ deacys

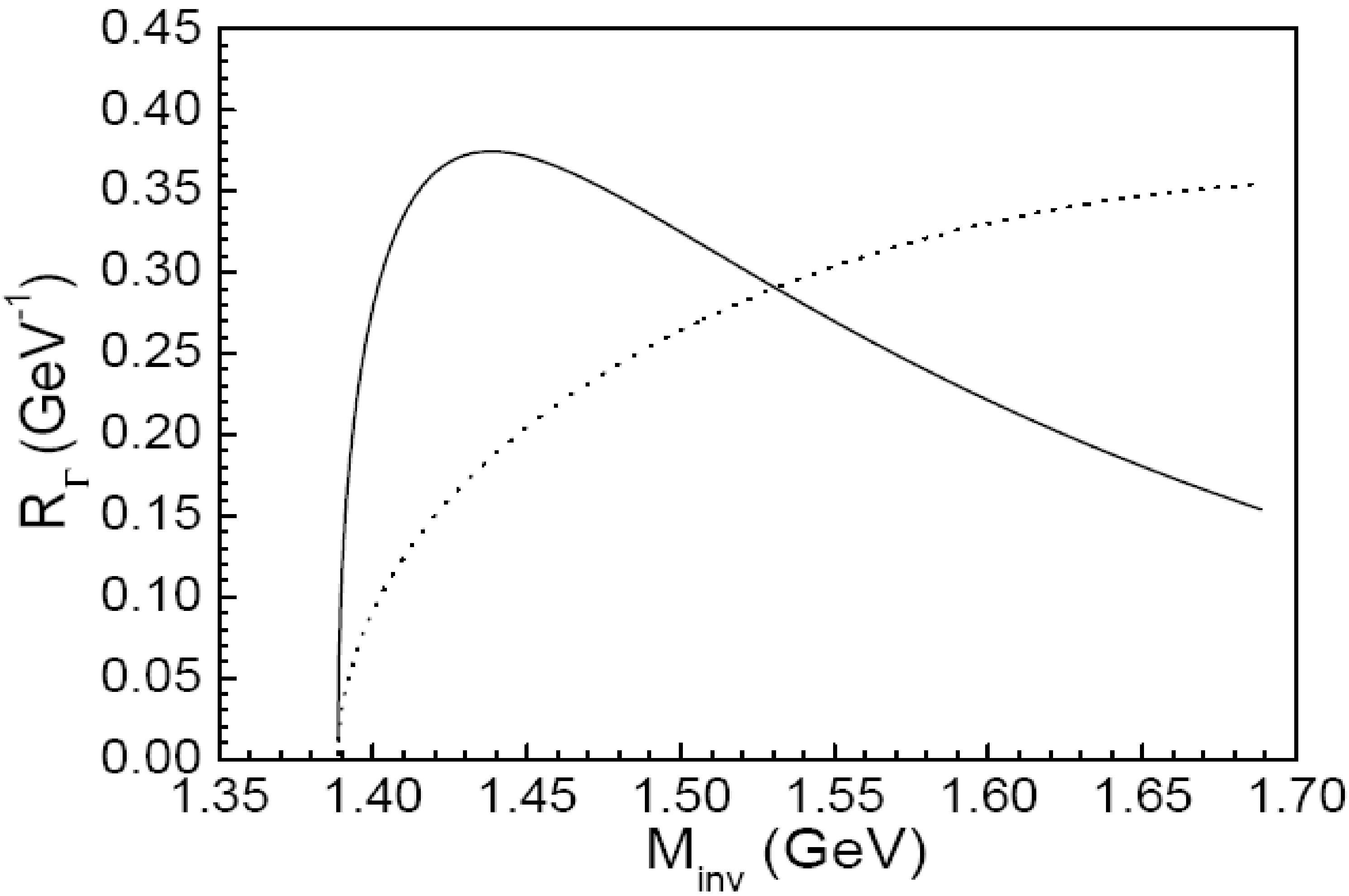


$$T_{J/\psi \to \phi f_1(1285)} = V_P C'_s G(M_{f_1}) g_{f_1}.$$

$$\Gamma_{J/\psi \to \phi f_1(1285)} = \frac{V_P^2}{8\pi} \frac{G^2(M_{f_1}) g_{f_1}^2 p'_\phi}{M_{J/\psi}^2} \overline{\sum} \sum C_s'^2 \qquad C'_s = \epsilon_{ijk} \varepsilon_i(J/\psi) \varepsilon_j(\phi) \varepsilon_k(f_1).$$

$$\overline{\sum} \sum C_s'^2 = \frac{2}{3}\left(3 + \frac{p_\phi'^2}{M_{f_1}^2} + \frac{p_\phi'^2}{m_\phi^2}\right), \qquad p'_\phi = \frac{\lambda^{1/2}(M_{J/\psi}^2, m_\phi^2, M_{f_1}^2)}{2M_{J/\psi}}.$$

$$R_\Gamma = \frac{d\Gamma_{J/\psi\to\phi\bar{K}K^*}/dM_{\rm inv}}{\Gamma_{J/\psi\to\phi f_1(1285)}}.$$



The dotted curve stands for the phase space.

Ju-Jun Xie and E. Oset, PLB753, 591, (2016).

Summary

- The $h_1(1800)$ and $f_1(1285)$ are dynamically generated states from the vector-vector and pseudoscalar-vector interactions.

- More experimental measurements of the J/ψ decays can be used to study the $h_1(1800)$ and $f_1(1285)$ states.

Thank you very much for your attention!