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Photon production of tensor mesons and the $J/\psi \to \eta K^* \bar{K}^*$ decay

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Outline

Introduction

Tensor mesons and the vector-vector interactions in the Chiral Unitary Approach

The $\gamma p \to p f_2(1270)$ reaction

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

Summary

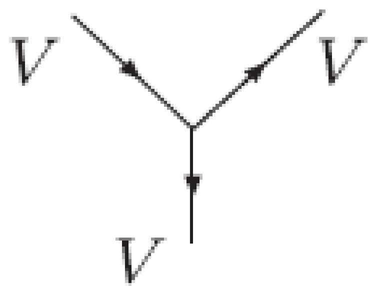
Hidden gauge interaction of vector mesons

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

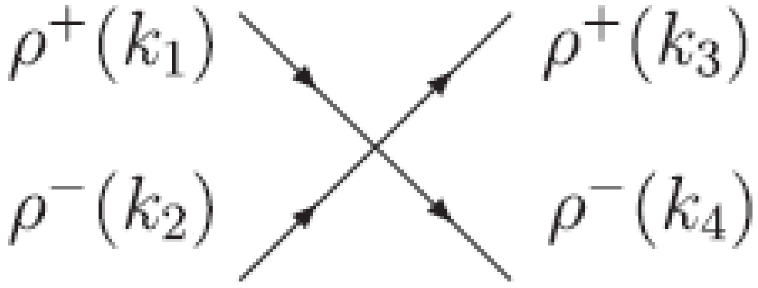
$$V_\mu = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu .$$

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

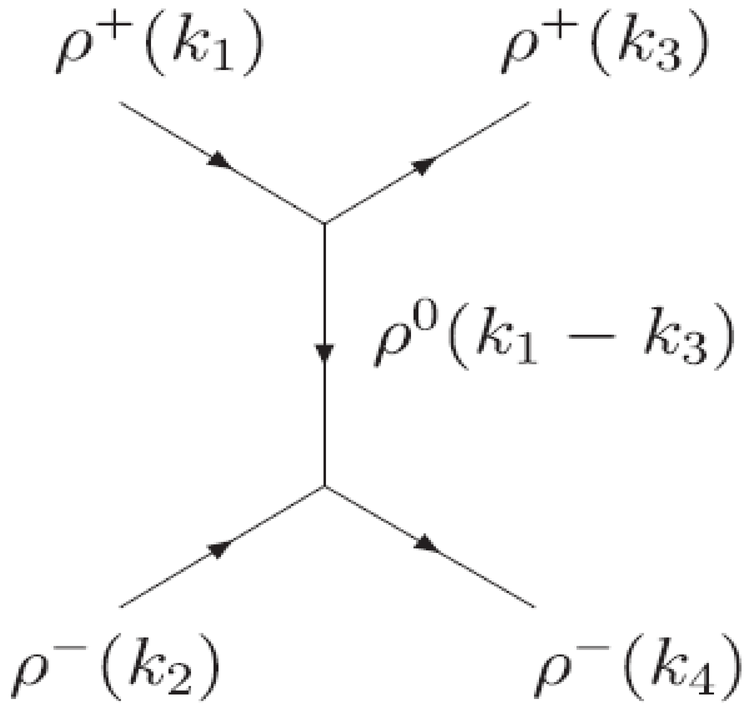
$$\mathcal{L}^{(3V)}_{III} = ig\langle(\partial_\mu V_\nu - \partial_\nu V_\mu)V^\mu V^\nu\rangle,$$



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

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

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

Dynamically generated states from Vector-Vector interactions

Pole positions and couplings to VV channels (In MeV)

$(1275, -i1)$ [spin = 2]

	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$	$\omega\phi$	$\phi\phi$
g	$(4733, -i53)$	$(10\,889, -i99)$	$(-440, i7)$	$(777, -i13)$	$(-675, i11)$

$(1525, -i3)$ [spin = 2]

	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$	$\omega\phi$	$\phi\phi$
g	$(10\,121, i101)$	$(-2443, i649)$	$(-2709, i8)$	$(5016, -i17)$	$(-4615, i17)$

$(1431, -i1)$ [spin = 2]

	ρK^*	$K^*\omega$	$K^*\phi$
g	$(10\,901, -i71)$	$(2267, -i13)$	$(-2898, i17)$

R. Molina, D. Nicmorus, and E. Oset, PRD 78, 114018 (2008).

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

The $\gamma p \to p f_2(1270)$ reaction

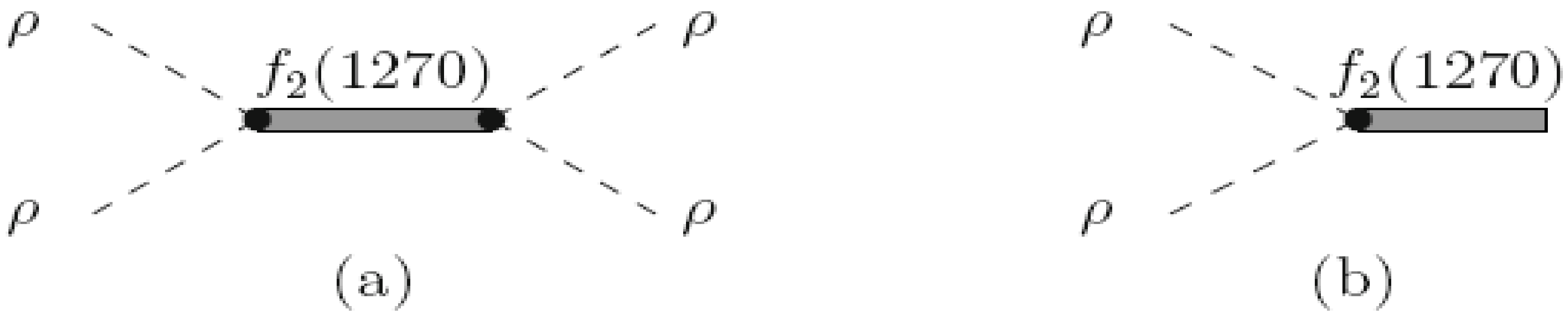
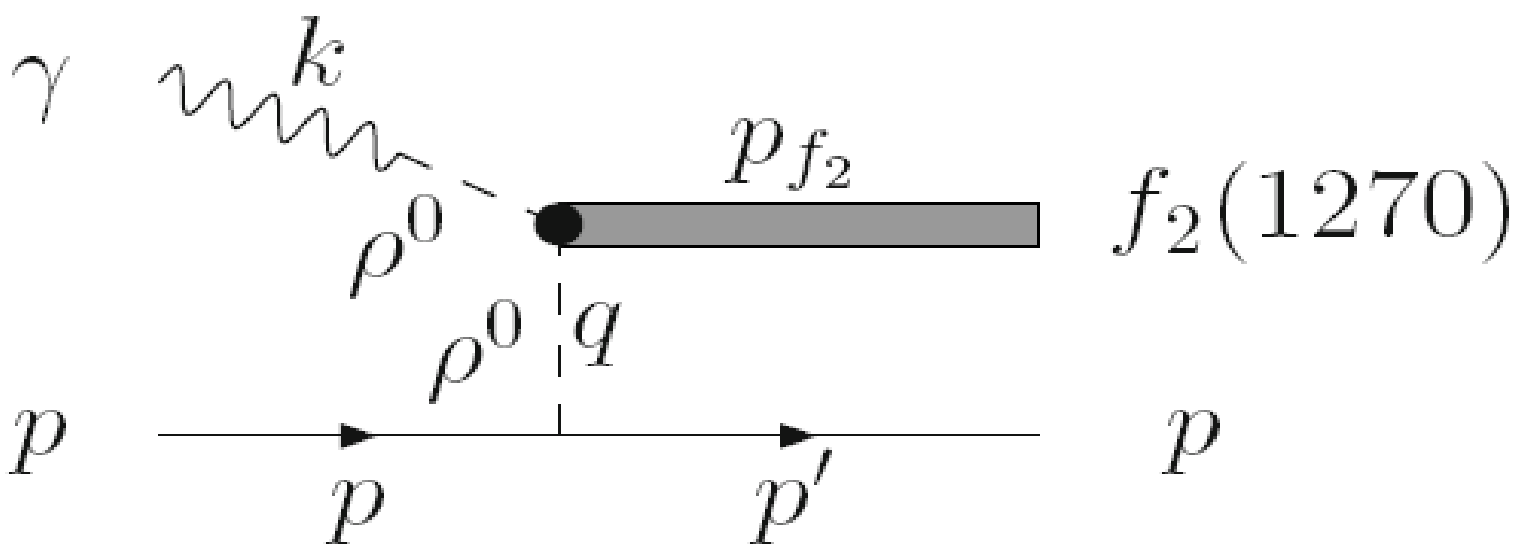


Fig. 1. (a) The $\rho\rho$ amplitude dominated by the $f_2(1270)$ pole; (b) representation of the $f_2(1270)$ coupling to $\rho\rho$.



Scattering amplitudes for γp -> $pf_2(1270)$ reaction

The γ-ρ^0 vertex

$$-it_{\rho^0\gamma} = \frac{-i}{\sqrt{2}}\frac{eM_\rho^2}{g}\epsilon_\mu(\rho)\epsilon^\mu(\gamma), \quad g = \frac{M_\rho}{2f}; \quad f = 93\,\mathrm{MeV}; \qquad \frac{e^2}{4\pi} = \frac{1}{137}$$

$$\mathcal{L}_{BBV} = g\left(\langle\bar{B}\gamma^\mu[V_\mu, B]\rangle + \langle\bar{B}\gamma^\mu B\rangle\langle V_\mu\rangle\right)$$

The ρ^0-p-p vertex $\quad -it_{\rho^0 pp} = i\frac{g}{\sqrt{2}}\bar{p}\gamma^\mu p\epsilon_\mu(\rho^0).$

$$T_{\gamma p\longrightarrow f_2(1270)p} = \frac{e\tilde{g}_T}{2}\frac{1}{q^2 - M_\rho^2}\left[\frac{1}{2}\epsilon_i(\gamma)\left(-g_{j\mu} + \frac{q_j q_\mu}{M_\rho^2}\right) + \frac{1}{2}\epsilon_j(\gamma)\left(-g_{i\mu} + \frac{q_i q_\mu}{M_\rho^2}\right) - \frac{1}{3}\epsilon_m(\gamma)\delta_{ij}\left(-g_{m\mu} + \frac{q_m q_\mu}{M_\rho^2}\right)\right] \langle M'|\gamma^\mu|M\rangle. \qquad (15)$$

More considerations

Tensor coupling for ρNN vertex

$$\mathcal{L}_{\rho NN} = -g_{\rho NN}\bar{N}\left(\gamma^{\mu} - \frac{\kappa_\rho}{2m_N}\sigma^{\mu\nu}\partial_\nu\right)\vec{\tau}\cdot\vec{\rho}_\mu N, \quad \frac{g^2_{\rho NN}}{4\pi} = 0.9, \quad \kappa_\rho = 6.1$$

Regge contributions

$$\frac{1}{q^2 - m_\rho^2} \quad \text{(normal)}$$

$$\rightarrow \widehat{f}\left(\frac{s}{s_0}\right)^{\alpha_\rho(t)-1} \Gamma(1-\alpha_\rho(t)) \quad \text{(Regge)},$$

$$\alpha_\rho(t) = 0.55 + 0.8t,$$

	ρNN vertex	ρ propagator
Model A	vector	normal
Model B	vector + tensor	normal
Model C	vector + tensor	Regge

Differential cross section for γp -> $pf_2(1270)$ -> $p\pi^+\pi^-$ reaction

$$\frac{d\sigma}{dt} = \frac{m_p^2}{16\pi s|\vec{k}|^2}\bar{\sum}\sum|T|^2. \quad t = q^2 = (p - p')^2$$

$$\frac{d^2\sigma}{dM_{\rm inv}dt} = \frac{m_p^2}{8\pi^2 s|\vec{k}|^2}\frac{M_{\rm inv}^2\Gamma_\pi}{|M_{\rm inv}^2 - M_{f_2}^2 + iM_{\rm inv}\Gamma_{f_2}|^2}\bar{\sum}\sum|T|^2$$

$$\Gamma_\pi(M_{\rm inv}) = \Gamma_\pi^{\rm on}\left(\frac{\tilde{q}}{\bar{q}}\right)^5\frac{M_{f_2}^2}{M_{\rm inv}^2}, \qquad \tilde{q} = \frac{\lambda^{1/2}(M_{\rm inv}^2, m_\pi^2, m_\pi^2)}{2M_{\rm inv}},$$

$$\Gamma_{f_2}(M_{\rm inv}) = 0.85\Gamma_{f_2}^{\rm on}\left(\frac{\tilde{q}}{\bar{q}}\right)^5\frac{M_{f_2}^2}{M_{\rm inv}^2} + 0.15\Gamma_{f_2}^{\rm on}, \qquad \bar{q} = \frac{\lambda^{1/2}(M_{f_2}^2, m_\pi^2, m_\pi^2)}{2M_{f_2}},$$

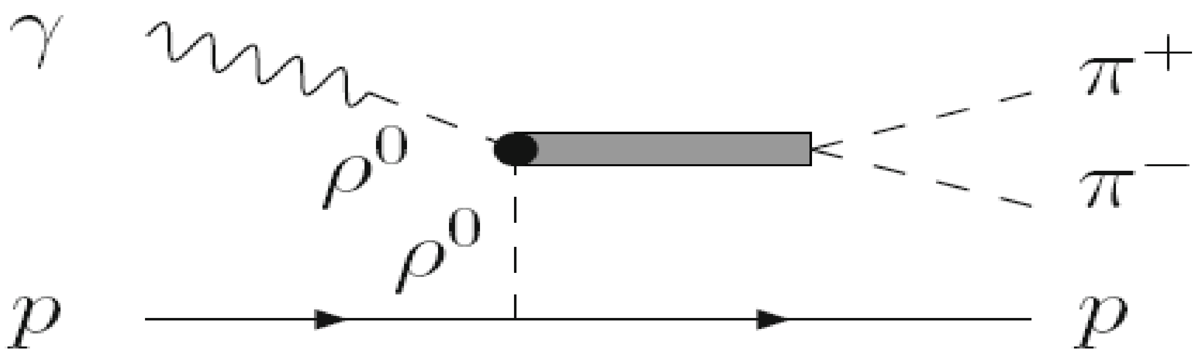
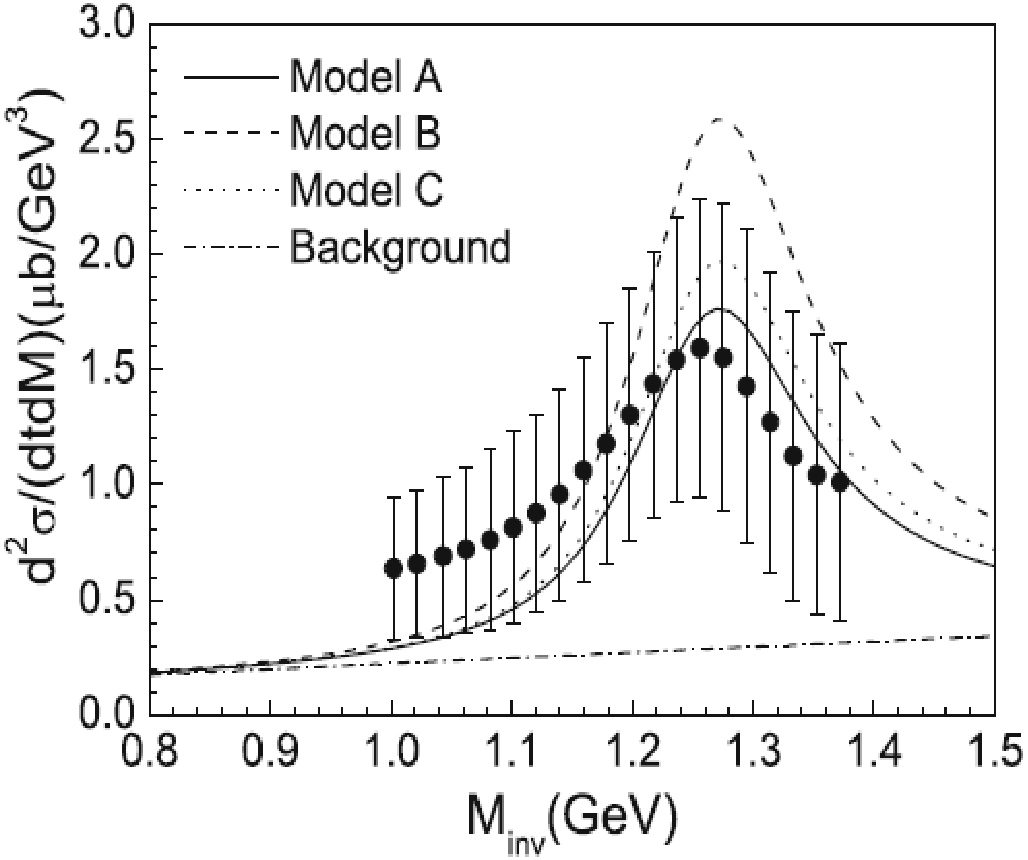
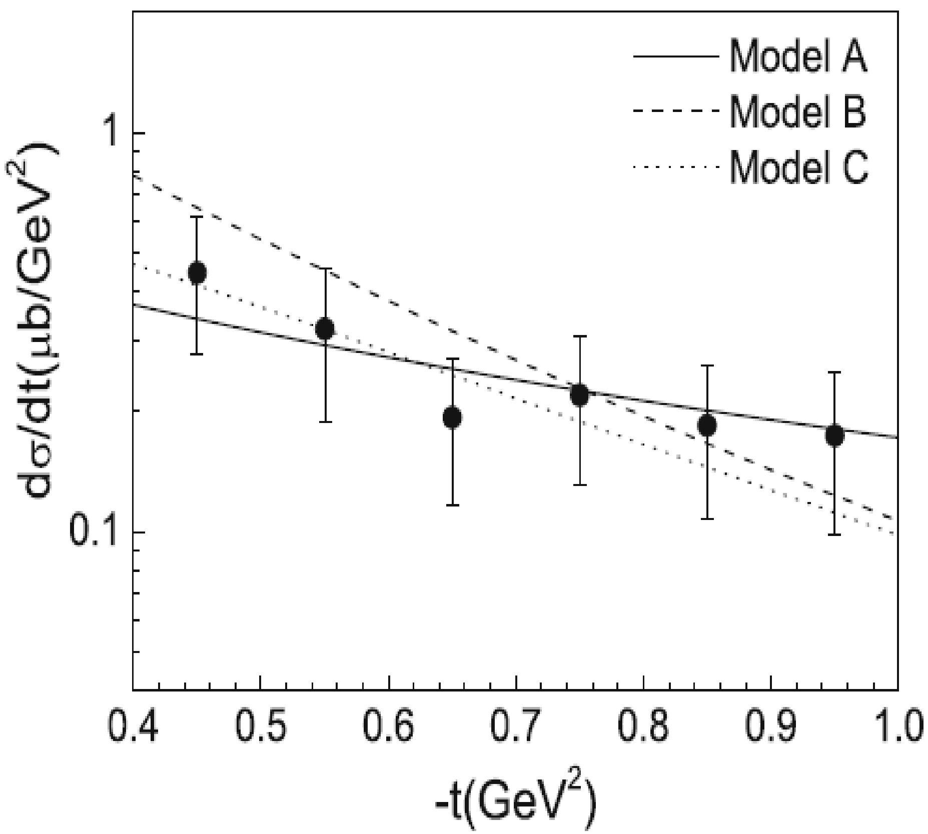


Fig. 3. Feynman diagram for the $\gamma p \to p\pi^+\pi^-$ reaction.

Numerical results for differential cross sections



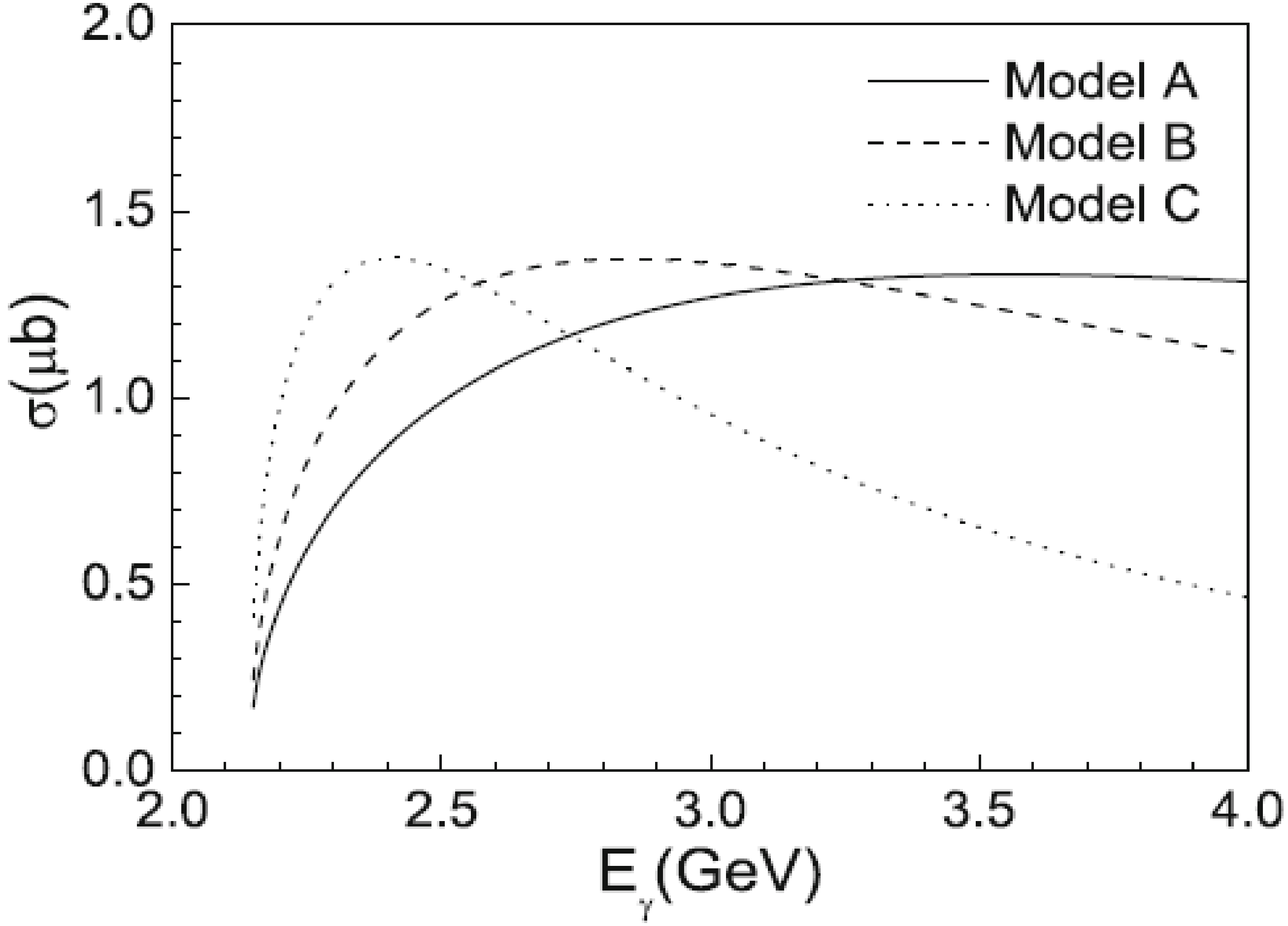


$$E_\gamma = 3.3 \text{ GeV } \textit{and } t = -0.55 \text{ GeV}^2$$

Background $$\frac{\mathrm{d}^2\sigma}{\mathrm{d}M_{\mathrm{inv}}\mathrm{d}t} = \frac{Cm_p^2}{2^8\pi^3 s|\vec{k}\,|^2}\tilde{q},$$

Data taken from CLAS Collaboration (M. Battaglieri et al.) PRD 80, 072 005 (2009).

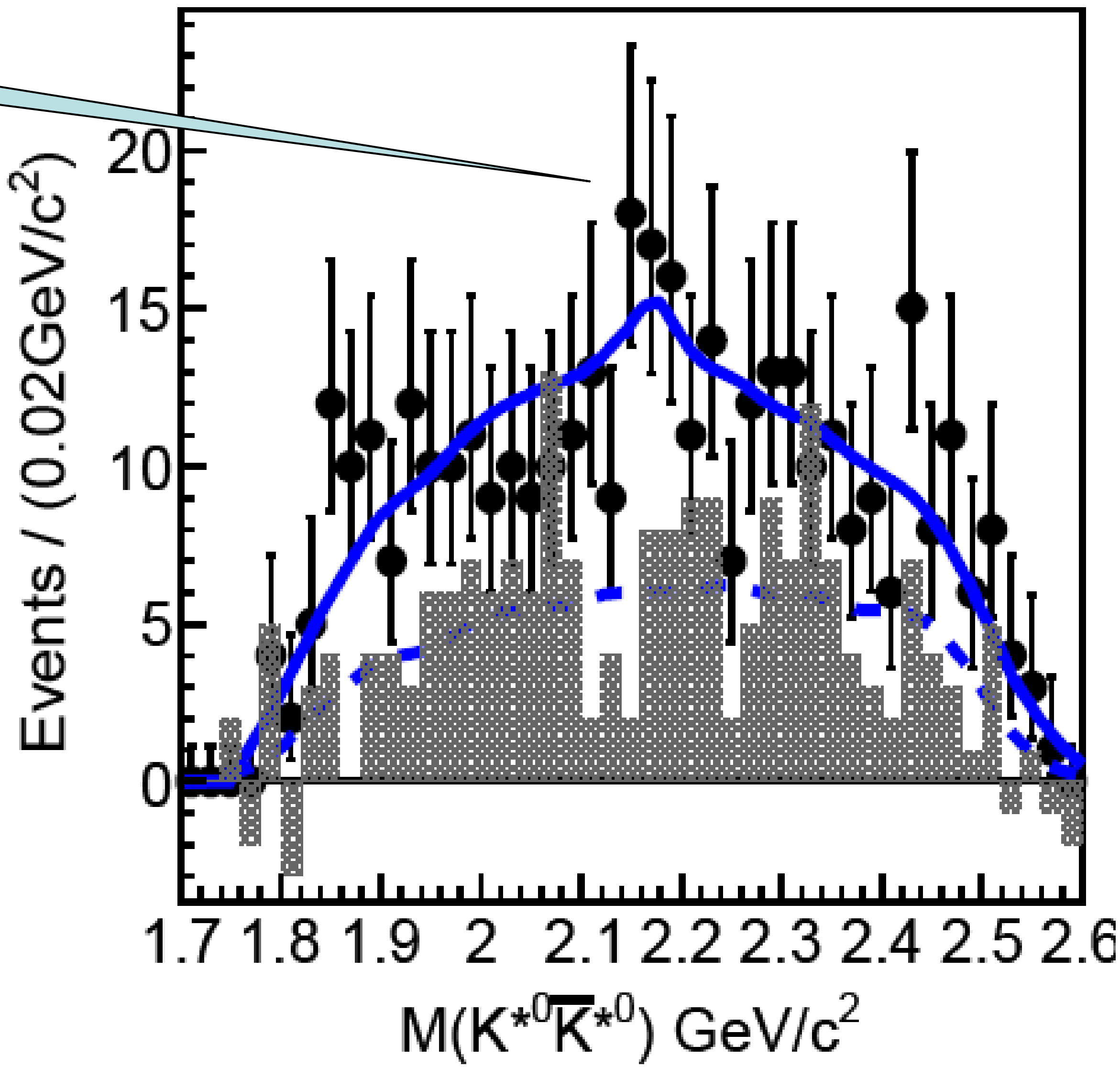
Numerical results for total cross sections



Ju-Jun Xie, and Eulogio Oset, EPJA 51, 111 (2015).

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

Y(2175) ?



No obvious enhancement near 2.175 GeV in the invariant mass spectrum of $K^{*0}K^{*0}$-bar is observed.

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

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 or pseudoscalar--pseudoscalar channels, which makes its observation difficult.

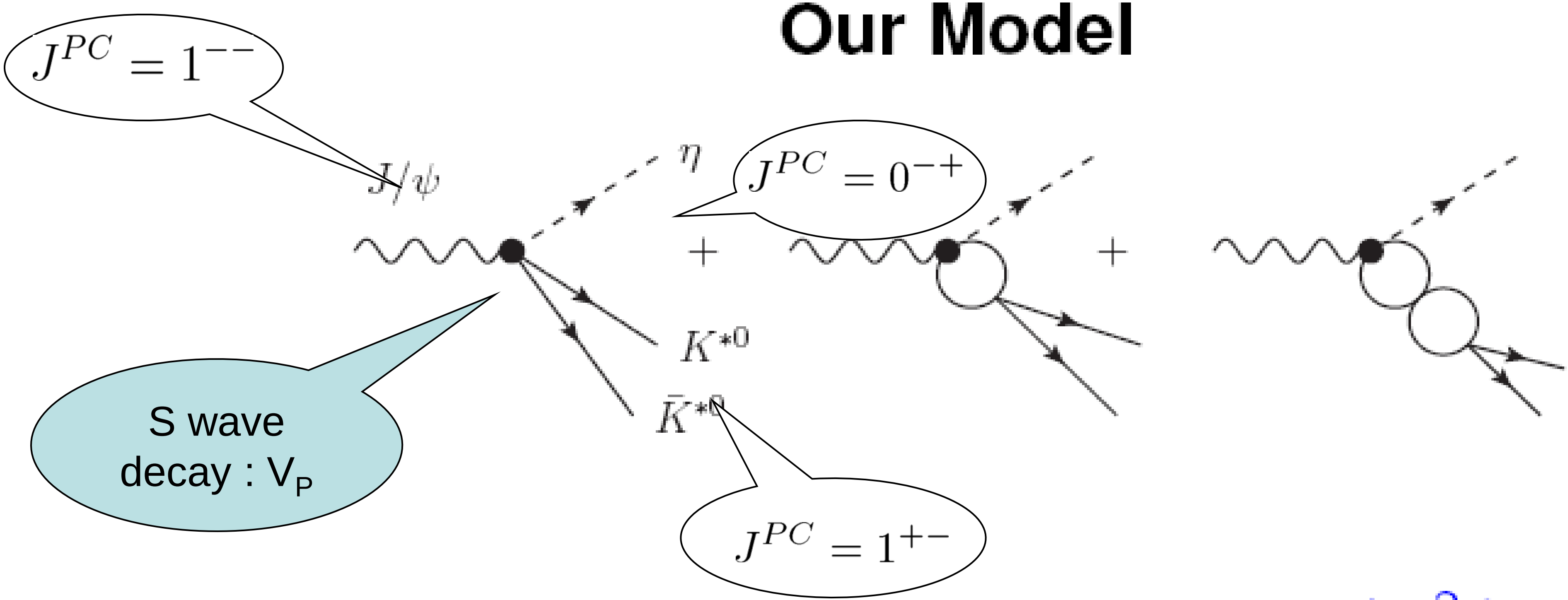
$$\text{Pole position}: \ (1802, -i39) \ \text{MeV}$$

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

$Y(2175)[\phi(2170)]$ with $I^G(J^{PC}) = 0^-(1^{--})$ does not couple to $K^*\bar{K}^*$

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

Our Model



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

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

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

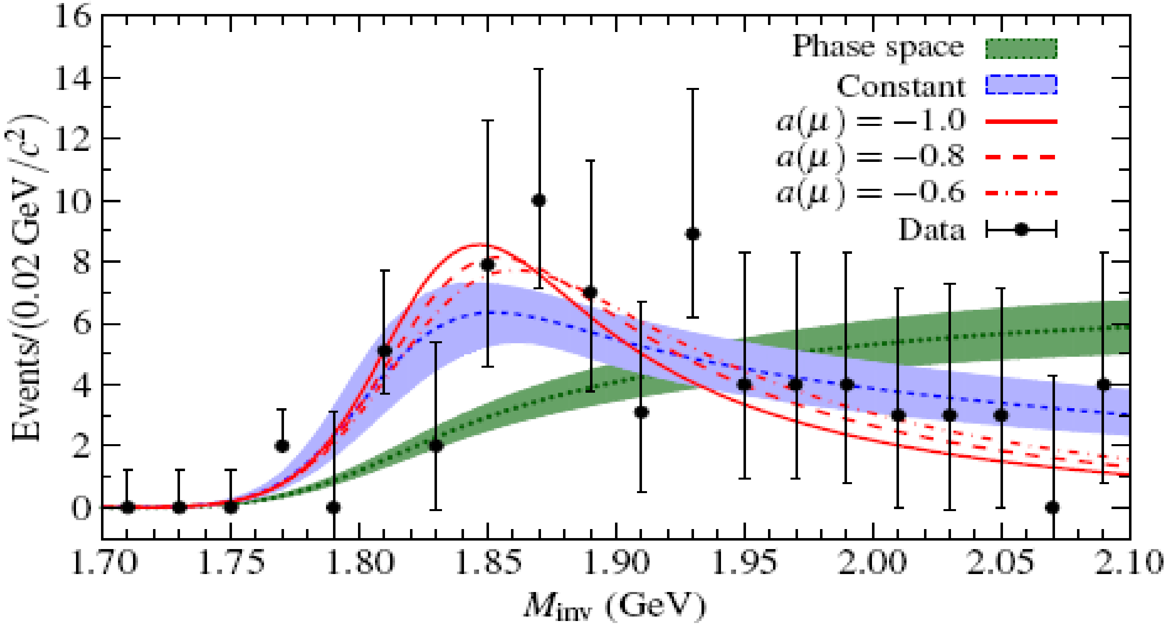
The constant *b* is determined by the masses of the vector mesons and its value turns out to be *b* = 6.8.

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

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

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

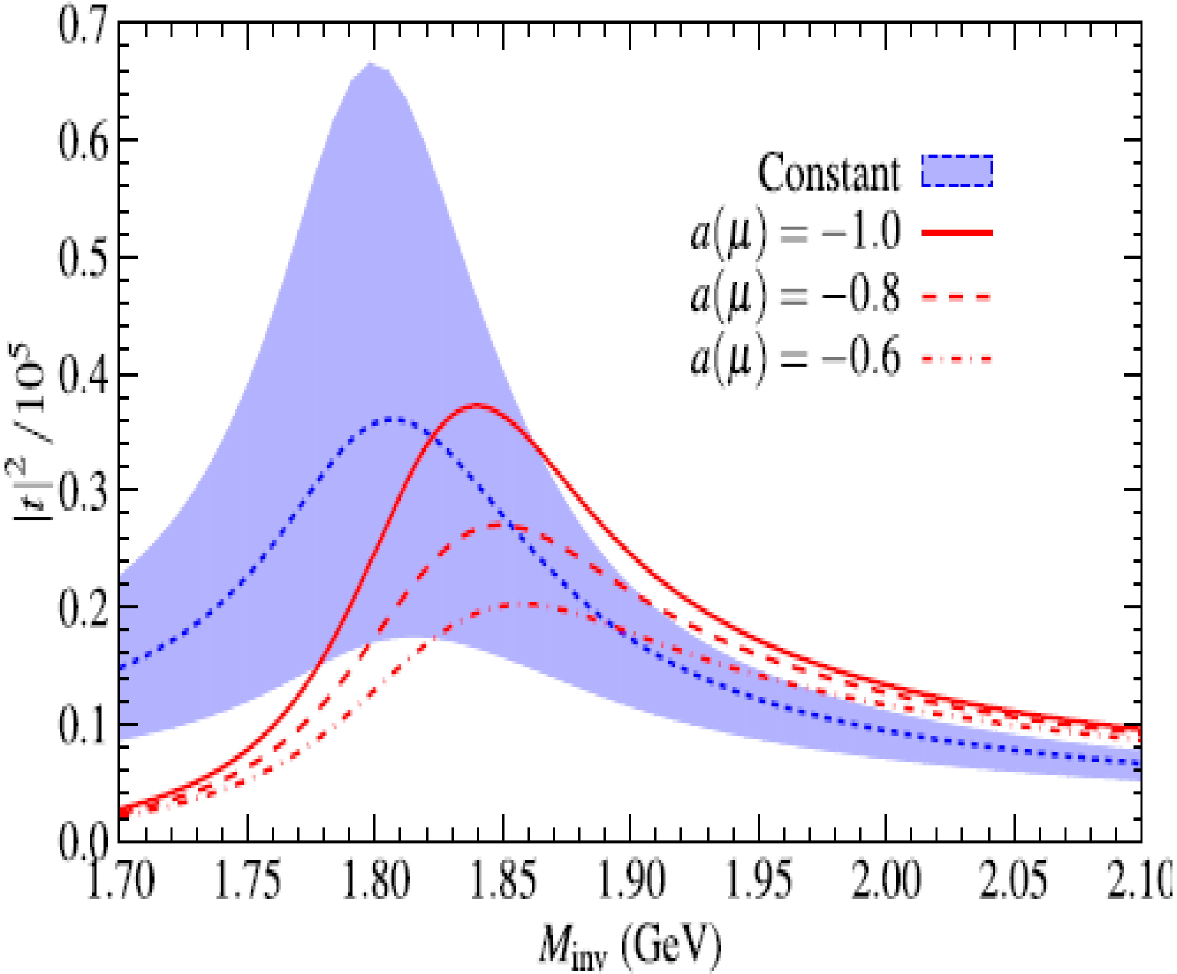
$$p_2 = \frac{\lambda^{1/2}(M_{\rm inv}^2, m_1^2, m_2^2)}{2M_{\rm inv}}.$$



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		0.56
Hidden gauge	53 ± 7	-0.8		0.47
Hidden gauge	67 ± 9	-0.6		0.42

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

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



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

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

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

$$16\pi^2 G(s, m_1^2, m_2^2)$$
$$= a(\mu) + \log\frac{m_1 m_2}{\mu^2} + \frac{\Delta}{2s}\log\frac{m_2^2}{m_1^2}$$
$$+ \frac{\nu}{2s}\left(\log\frac{s-\Delta+\nu}{-s+\Delta+\nu} + \log\frac{s+\Delta+\nu}{-s-\Delta+\nu}\right),$$

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

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

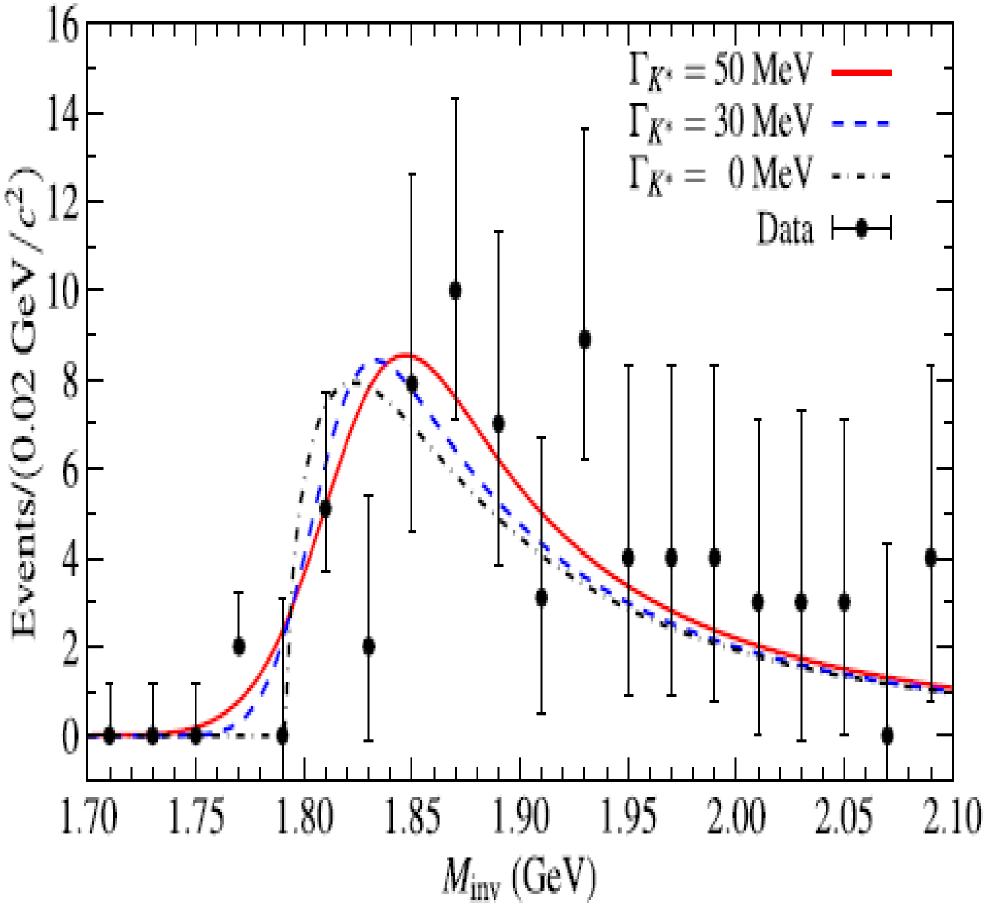
$$\mathcal{N} = \int_{m_-^2}^{m_+^2} dm_1^2\,\text{Im}\,\frac{1}{m_1^2 - m_{K^*}^2 + i\Gamma(m_1^2)m_1},$$

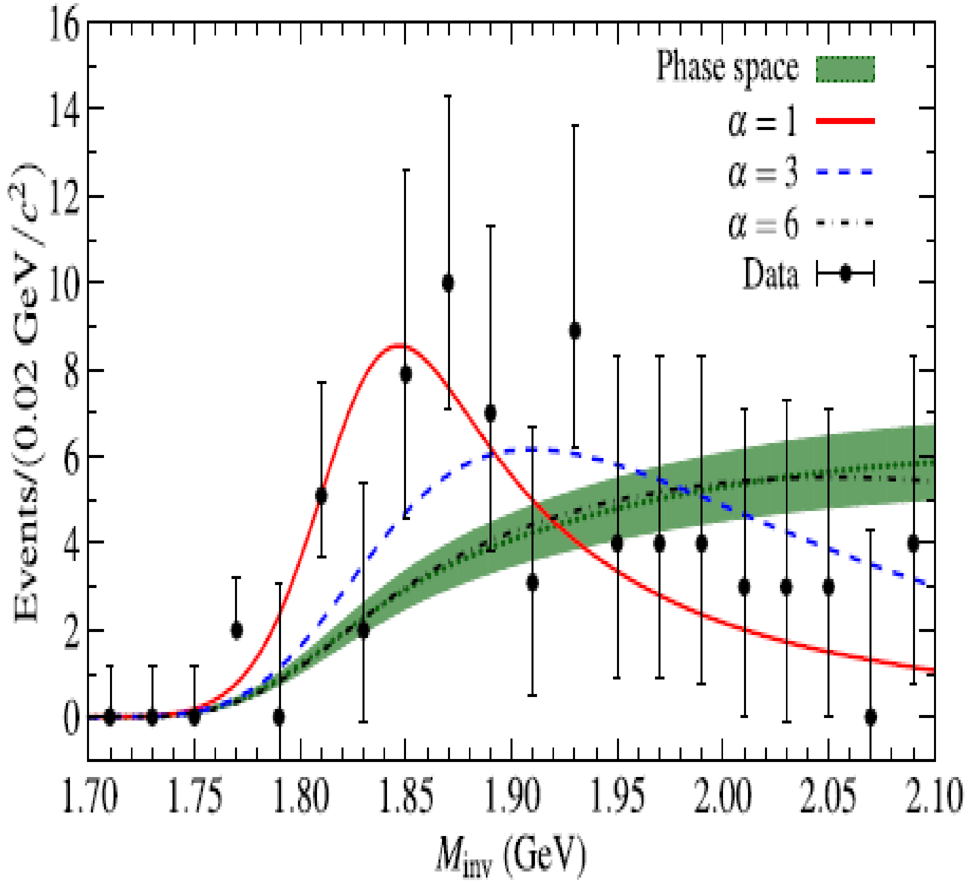
$$\Gamma(m_1^2) = \Gamma_{K^*}\frac{p^3(m_1^2)}{p^3(m_{K^*}^2)}, \qquad p(m_1^2) = \frac{\lambda^{1/2}(m_1^2, m_\pi^2, m_K^2)}{2m_1}.$$

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

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

More check





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

Summary

- The $f_2(1270)$, $f'_2(1525)$, and $K^*_2(1430)$ are dynamically generated states from the vector-vector interactions.
- The photon production processes could be used to check the nature of these tensor mesons.
- More experimental measurements of the $J/\Psi \to \eta K^* \bar{K}^*$ -bar can be used to study the possible $h_1(1800)$ state.

Thank you very much for your attention!