Theoretical description of the $J/\psi \to \eta(\eta')h_1(1380), \eta(\eta')h_1(1170)$ and $J/\psi \to \pi^0 b_1(1235)^0$ and $\chi_{cJ} \to \phi h_1(1380)$ reactions

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In collaboration with

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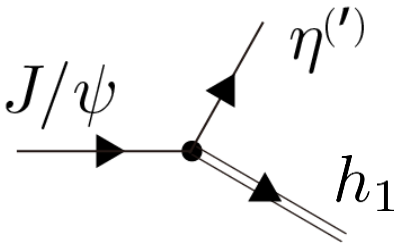
Phys. Rev. D99 (2019) no.9, 094020
arXiv:1904.08271 (accepted in Phys. Lett. B)

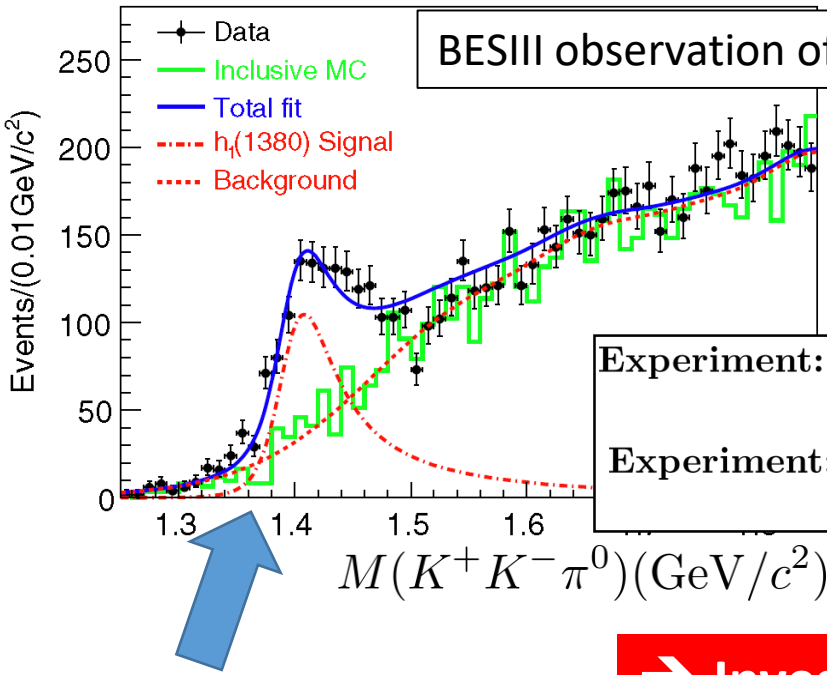
Axial vector with negative C from J/ψ



J^{PC} of h_1 = 1^{+-}

Good process to see isoscalar Axial-Vector mesons

$J/\psi \to \eta' K^+ K^- \pi^0$



BESIII observation of $h_1(1380)$

BESIII Collab. [PRD98(2018)072005]

Experiment: $\mathrm{Br}^{\mathrm{exp}}(J/\psi \to \eta' h_1(1380), h_1(1380) \to K^{*+}K^- + c.c. \text{ in } K^+K^-\pi^0) = (1.51 \pm 0.09 \pm 0.21) \times 10^{-4}$

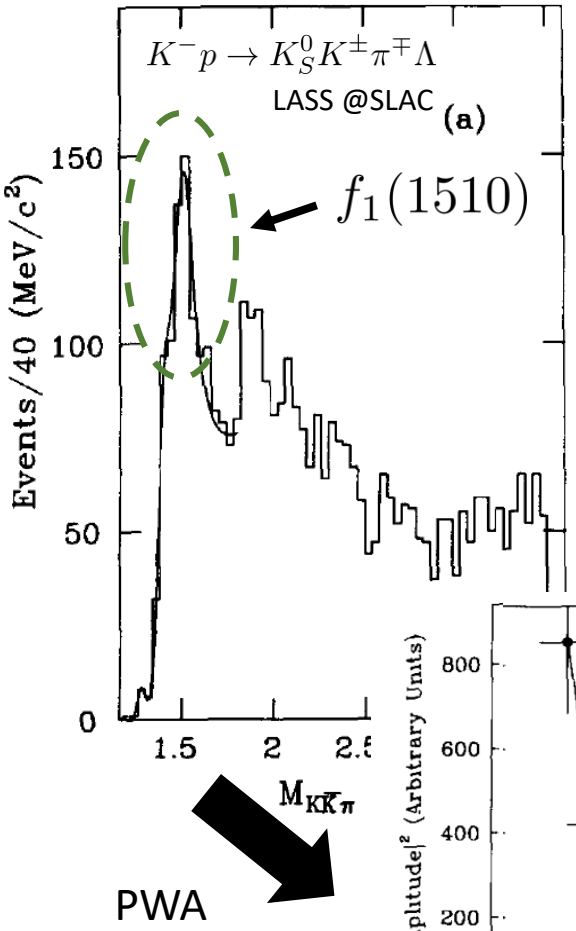
Experiment: $\mathrm{Br}^{\mathrm{exp}}(J/\psi \to \eta' h_1(1380), h_1(1380) \to K^*\bar{K} + c.c. \text{ in } K^0_S K^\pm \pi^\mp) = (2.16 \pm 0.12 \pm 0.29) \times 10^{-4}$

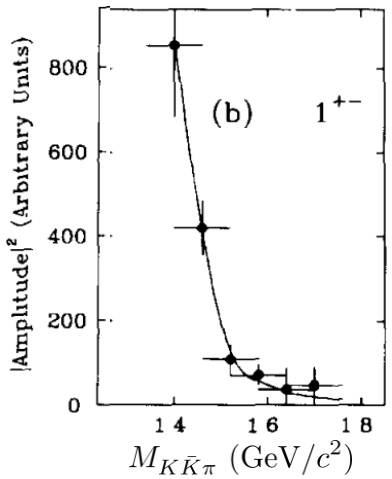
$h_1(1380)$ peak around 1.4 GeV

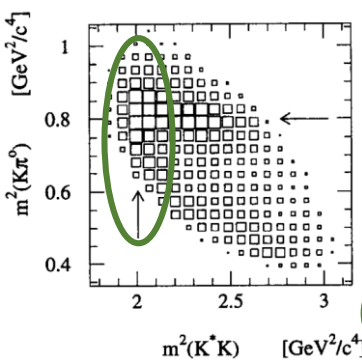
➔ **Investigation on the basis of hardonic molecular axial-vector meson**

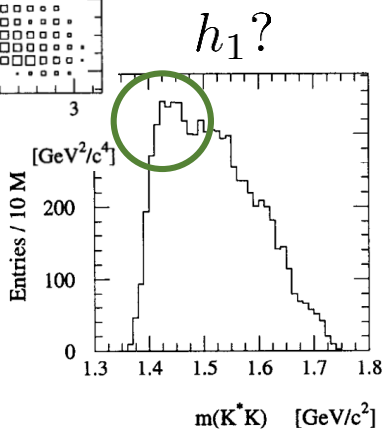
Observation of $h_1(1380)$

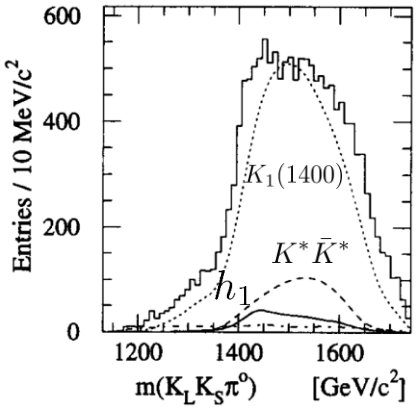
$h_1(1415)$
was $h_1(1380)$
in the latest PDG

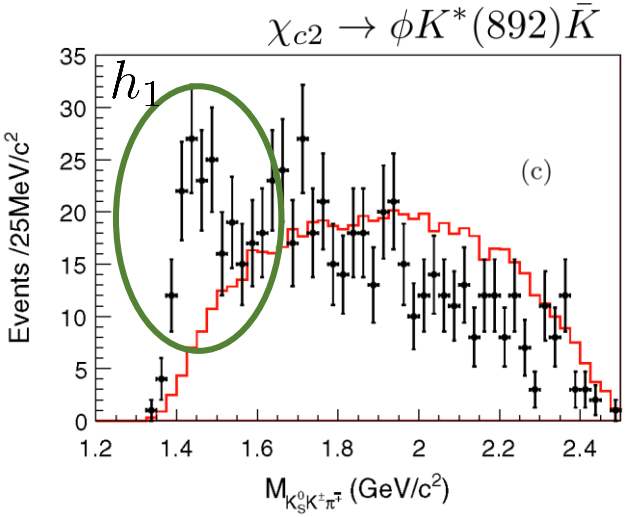








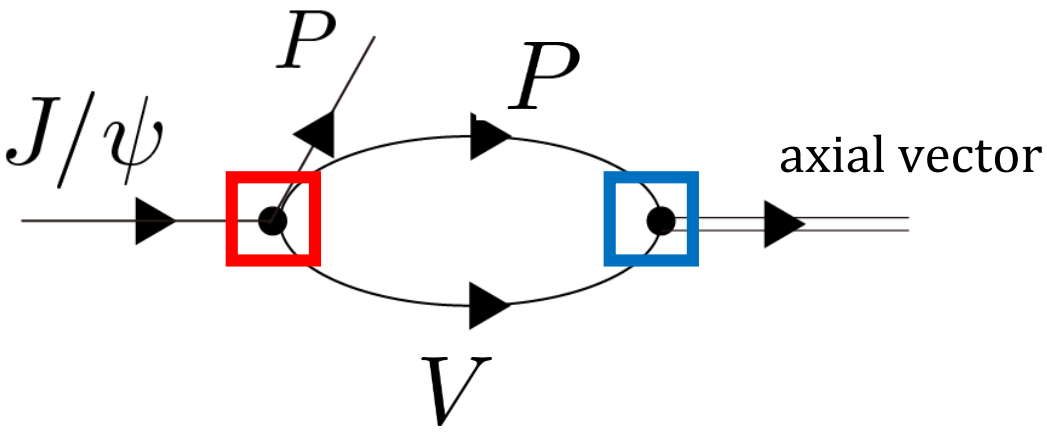




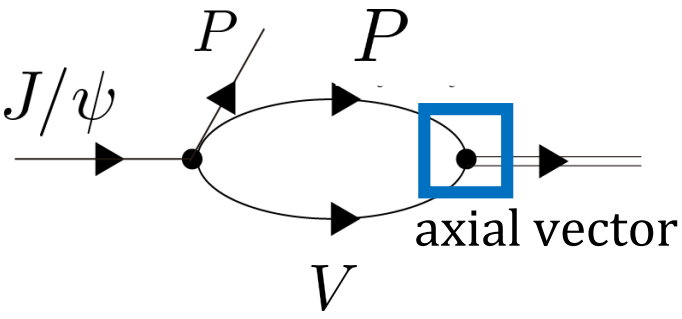
(Left): PLB 201 (1988) 573
(Middle): PLB 415 (1997) 280
(Right): PRD 91, 112008 (2015)

$J/\psi \rightarrow$ pseudoscalar + axial vector

$\eta h_1(1170), \eta' h_1(1170), \eta h_1(1380),$
$\boldsymbol{\eta' h_1(1380)}, \pi^0 b_1(1235)^0$



Coupling to axial-vector meson



-- Chiral unitary approach with channel coupling ($I = 0,1; C = \pm$)

Roca-Oset-Singh, Phys. Rev. D72, 014002(2005)

Axial vector mesons (h1(1170),h1(1380),b1(1235)) as pseudoscalar-vector bound state

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

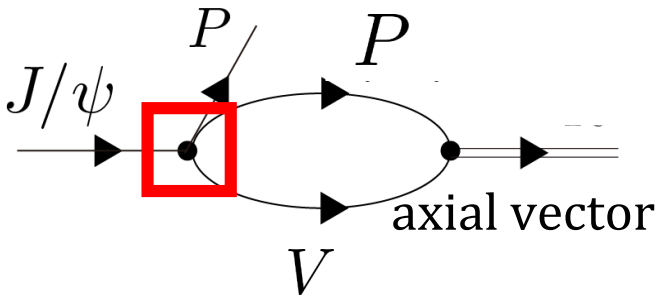
v : from chiral Lagrangian

coupled channel $\begin{cases} h_1(1170, 1380) : (\bar{K}^* K)_{I=0,C=-}, \phi\eta, \omega\eta, \rho\pi \\ b_1(1235) : (\bar{K}^* K)_{I=1,C=-}, \phi\pi, \omega\pi, \rho\eta \end{cases}$

$t_{ij} \sim \dfrac{g_{iR} g_{jR}}{s - s_R} + \text{non res.}$: coupling constant $g_{R,PV}$ from residue of pole

$\begin{cases} R = h_1(1170, 1380), b_1(1225) \\ PV = \bar{K}^* K, K^* \bar{K}, \eta\phi, \eta\omega, \pi\rho, \pi\omega, \eta\rho \end{cases}$

Primary J/ψ decay vertex



$$A_1 J/\psi_\mu \mathrm{tr}[PPV^\mu]$$

$$\beta A_1 J/\psi_\mu \mathrm{tr}[PP]\mathrm{tr}[V^\mu]$$

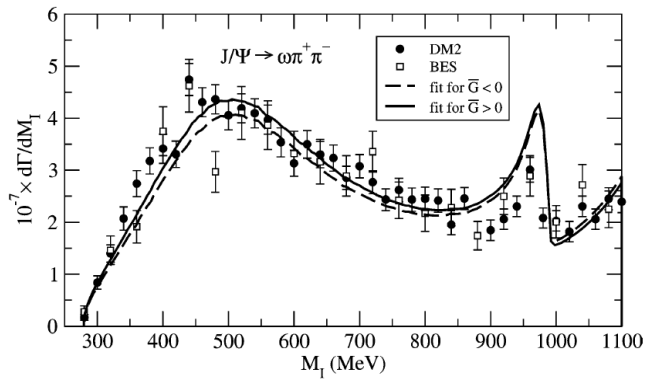
$$P = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{3}}\eta + \frac{1}{\sqrt{6}}\eta' & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{3}}\eta + \frac{1}{\sqrt{6}}\eta' & K^0 \\ K^- & \bar{K}^0 & -\frac{1}{\sqrt{3}}\eta + \sqrt{\frac{2}{3}}\eta' \end{pmatrix}$$

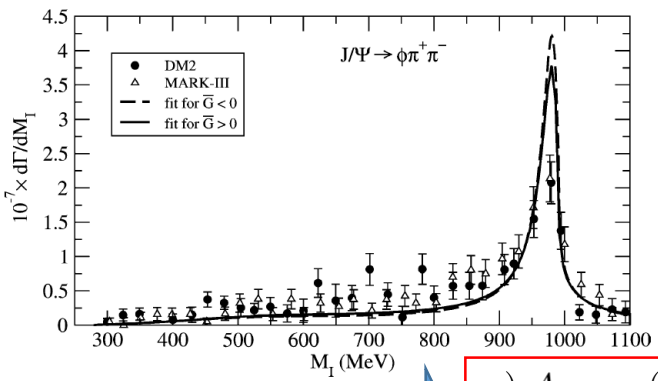
$$V = \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & \rho^+ & K^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}$$

A_1, β : parameters to be fixed

: use parameters determined with the $J/\psi \to \omega\pi^+\pi^-, \phi\pi^+\pi^-$ data

Roca *et al.*, NPA744(2004)127

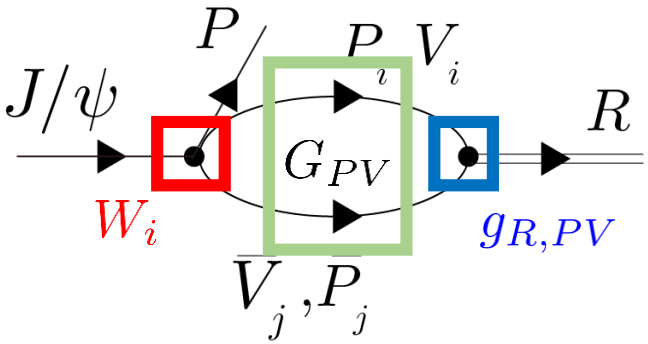




a) $A_1 = -(0.032 \pm 0.001); \quad \beta = 0.0927$

b) $A_1 = -(0.015 \pm 0.001); \quad \beta = 0.165$

Decay amplitude



$$
\begin{aligned}
t_{J/\psi,\,\eta' h_1} &= A_1[-2\,W_{K^{*+}K^-\eta'}\,G_{K^*\bar{K}}\,g_{h_1,(K^*\bar{K})_{I=0}} + W_{\phi\eta\eta'}\,G_{\phi\eta}\,g_{h_1,\phi\eta} \\
&\quad + W_{\omega\eta\eta'}\,G_{\omega\eta}\,g_{h_1,\omega\eta} - \sqrt{3}\,W_{\rho^+\pi^-\eta'}\,G_{\rho\pi}\,g_{h_1,(\rho\pi)_{I=0}}] \\
t_{J/\psi,\,\eta h_1} &= A_1[2\,W_{\eta\omega\eta}\,G_{\omega\eta}\,g_{h_1,\omega\eta} + 2\,W_{\eta\phi\eta}\,G_{\phi\eta}\,g_{h_1,\phi\eta} \\
&\quad - \sqrt{3}\,W_{\eta\rho^+\pi^-}\,G_{\rho\pi}\,g_{h_1,(\rho\pi)_{I=0}}] \\
t_{J/\psi,\,\pi^0 b_1} &= A_1[-2\,W_{\pi^0 K^{*+}K^-}\,G_{K^*\bar{K}}\,g_{b_1,(K^*\bar{K})_{I=1}} + 2\,W_{\pi^0\phi\pi^0}\,G_{\phi\pi}\,g_{b_1,\phi\pi} \\
&\quad + 2\,W_{\pi^0\omega\pi^0}\,G_{\omega\pi}\,g_{b_1,\omega\pi} + W_{\pi^0\rho^0\eta}\,G_{\rho\eta}\,g_{b_1,\rho\eta}]
\end{aligned}
$$

Branching fractions of $J/\psi \to PR$

	branching fraction (a)	branching fraction (b)
$\mathrm{Br}[J/\psi \to \eta' h_1(1380)]$	2.35×10^{-3}	5.16×10^{-4}
$\mathrm{Br}[J/\psi \to \eta h_1(1380)]$	3.65×10^{-5}	1.02×10^{-5}
$\mathrm{Br}[J/\psi \to \eta' h_1(1170)]$	5.35×10^{-4}	1.18×10^{-4}
$\mathrm{Br}[J/\psi \to \eta h_1(1170)]$	9.49×10^{-4}	2.08×10^{-4}
$\mathrm{Br}[J/\psi \to \pi^0 b_1(1235)^0]$	1.23×10^{-3}	2.77×10^{-4}

a) $A_1 = -(0.032 \pm 0.001)$; $\beta = 0.0927$
b) $A_1 = -(0.015 \pm 0.001)$; $\beta = 0.165$

Br. of $J/\psi \to \pi b_1(1235)$ (PDG)

$\mathrm{Br}[J/\psi \to \pi b_1(1235)] \sim (1.77 \pm 0.4) \times 10^{-3}$

Good agreement with parameter set (a)

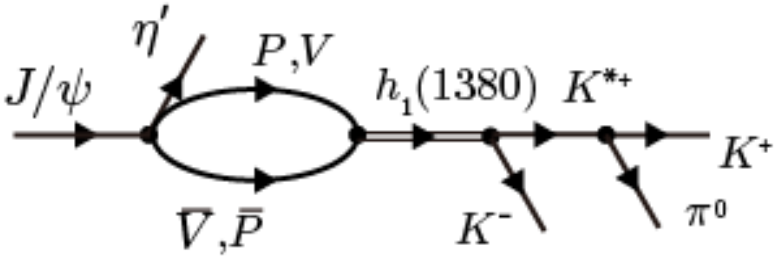
Experiment: $\mathrm{Br}^{\mathrm{exp}}(J/\psi \to \eta' h_1(1380), h_1(1380) \to K^{*+}K^- + c.c. \text{ in } K^+K^-\pi^0) = (1.51 \pm 0.09 \pm 0.21) \times 10^{-4}$

Experiment: $\mathrm{Br}^{\mathrm{exp}}(J/\psi \to \eta' h_1(1380), h_1(1380) \to K^* \bar{K} + c.c. \text{ in } K_S^0 K^{\pm}\pi^{\mp}) = (2.16 \pm 0.12 \pm 0.29) \times 10^{-4}$

$J/\psi \to \eta' h_1(1380)$ with $h_1(1380) \to K^{*+}K^- + c.c.$ in $K^+K^-\pi^0$

Experiment: $\mathrm{Br}^{\mathrm{exp}}(J/\psi \to \eta' h_1(1380), \boxed{h_1(1380) \to K^{*+}K^- + c.c. \text{ in } K^+K^-\pi^0})$
$= (1.51 \pm 0.09 \pm 0.21) \times 10^{-4}$

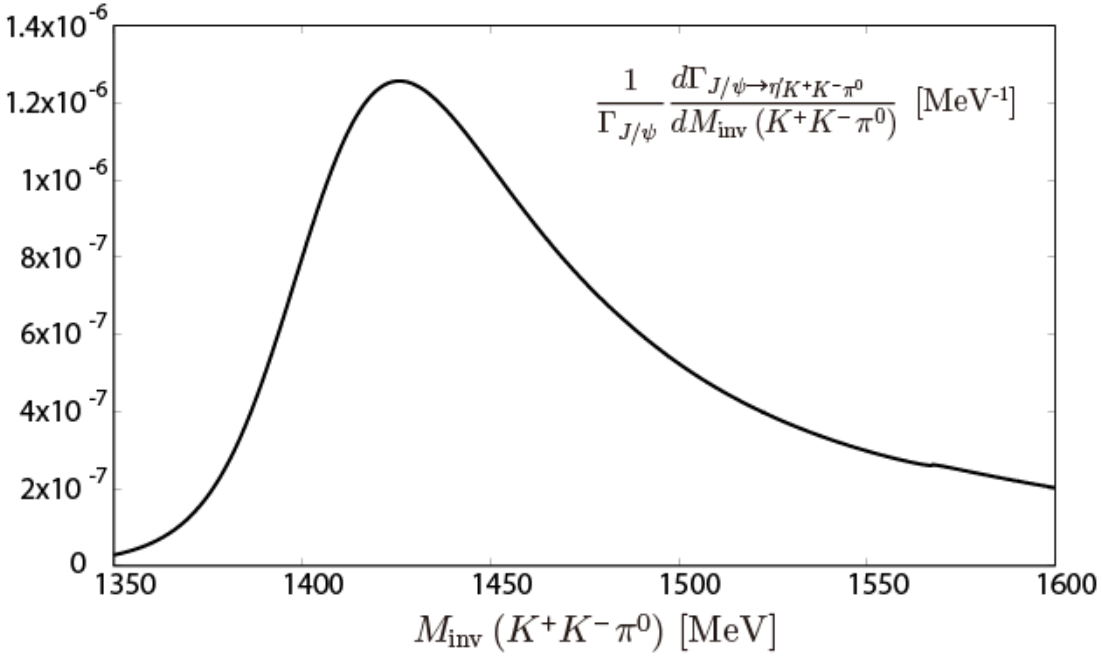
Experiment: $\mathrm{Br}^{\mathrm{exp}}(J/\psi \to \eta' h_1(1380), \boxed{h_1(1380) \to K^* \bar{K} + c.c. \text{ in } K^0_S K^\pm \pi^\mp})$
$= (2.16 \pm 0.12 \pm 0.29) \times 10^{-4}$

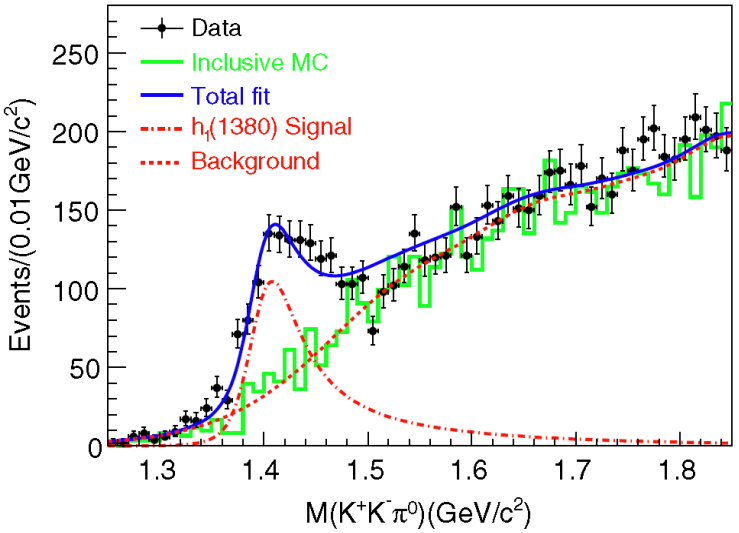


$$t' = t_{J/\psi,\eta' h_1} \frac{g_{h_1,(K^*\bar{K})_{I=0}}}{2} \frac{1}{M^2_{\mathrm{inv}}(K^+K^-\pi^0) - M^2_{h_1} + iM_{h_1}\Gamma_{h_1}} \cdot \frac{1}{M^2_{\mathrm{inv}}(\pi^0 K^+) - M^2_{K^{*+}} - iM_{K^*}\Gamma_{K^*}} \frac{1}{\sqrt{3}} g_{K^*,K\pi}\, \vec{\epsilon}_{J/\psi} \cdot \vec{\tilde{p}}_K$$

$$\left[\Gamma_{K^*} = \Gamma^0_{K^*} \left(\frac{\tilde{p}_{K^*}}{\tilde{p}^0_{K^*}}\right)^3\right]$$

$M_{\rm inv}(K^+K^-\pi^0)$ distribution





$$2\times{\rm Br}(J/\psi\to\eta' h_1(1380), h_1(1380)\to K^{*+}K^-, K^{*+}\to K^+\pi^0) = 3.31\times10^{-4}$$

Experiment: ${\rm Br}^{\rm exp}(J/\psi\to\eta' h_1(1380), h_1(1380)\to K^{*+}K^- + c.c.\ {\rm in}\ K^+K^-\pi^0)$
$= (1.51\pm0.09\pm0.21)\times10^{-4}$

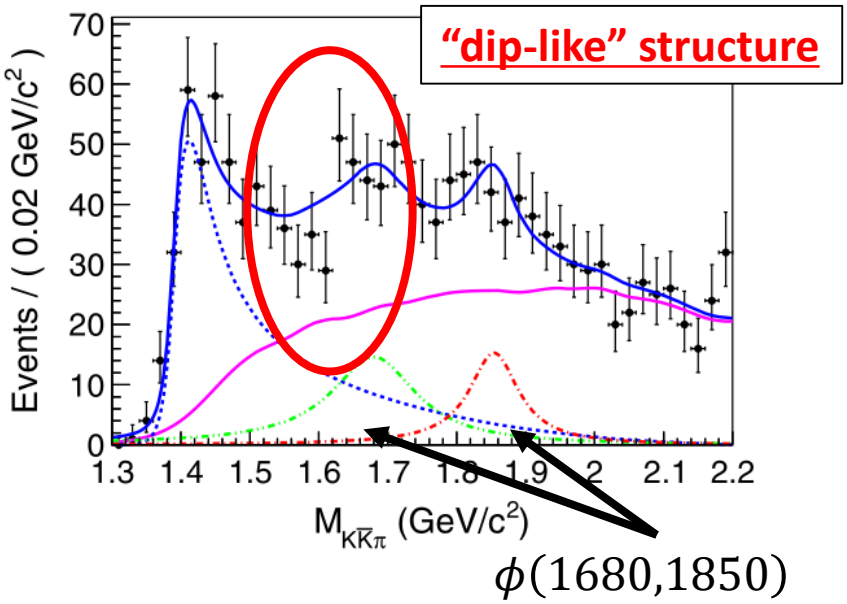
Experiment: ${\rm Br}^{\rm exp}(J/\psi\to\eta' h_1(1380), h_1(1380)\to K^*\bar{K} + c.c.\ {\rm in}\ K^0_S K^\pm\pi^\mp)$
$= (2.16\pm0.12\pm0.29)\times10^{-4}$

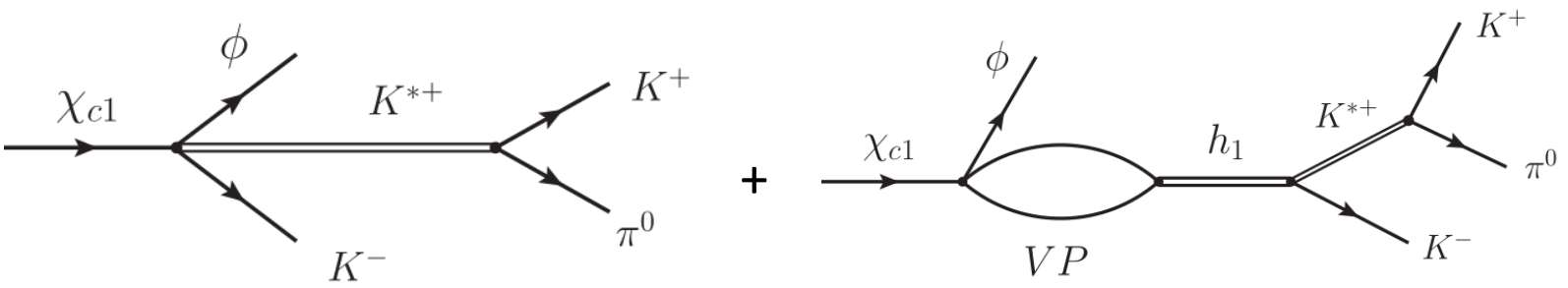
Fair agreement with experiment

$\chi_{cJ} \to \phi h_1(1380)$ reactions

$K\bar{K}\pi$ distribution in $\chi_{cJ} \to \phi K\bar{K}\pi$ in $(J = 1,2)$

[Phys. Rev. D 91, 112008 (2015) by BESIII]





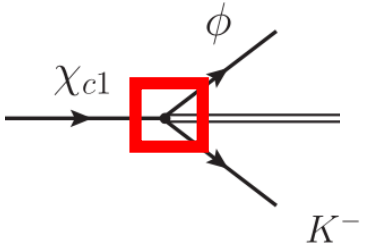
$$\mathcal{A}_{\chi_{cJ},\phi\pi K\bar{K}} \sim h_{PV}\left[1 + g_{h1,PV}\, g_{h_1,K^*\bar{K}}\, G_{K^*\bar{K}}\, D_{h_1}(m_{K^*\bar{K}})\right] D_{K^*}(m_{\pi K})$$

Unavoidable interference

-- strength and pattern of interference~ $g_{h1,PV}$

$$H_{\rm int} = g\chi_{cJ}{\rm tr}\left[VVP\right]$$

➔ratio of VVP coupling can be fixed

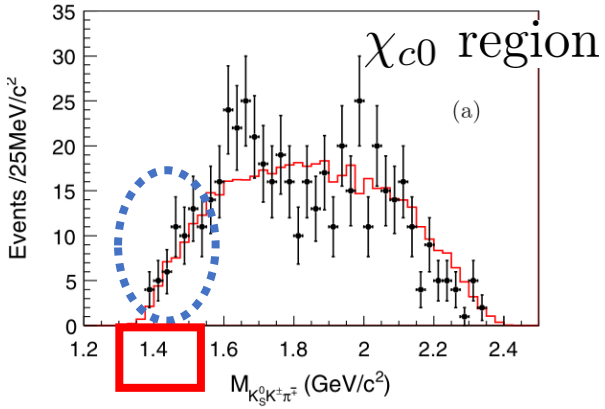


-- Structure of χ_{cJ}-VVP vertex

$$J^{PC}(\chi_{cJ}) = 0, 1, 2^{++}$$

○ p-wave vertex is required to conserve parity

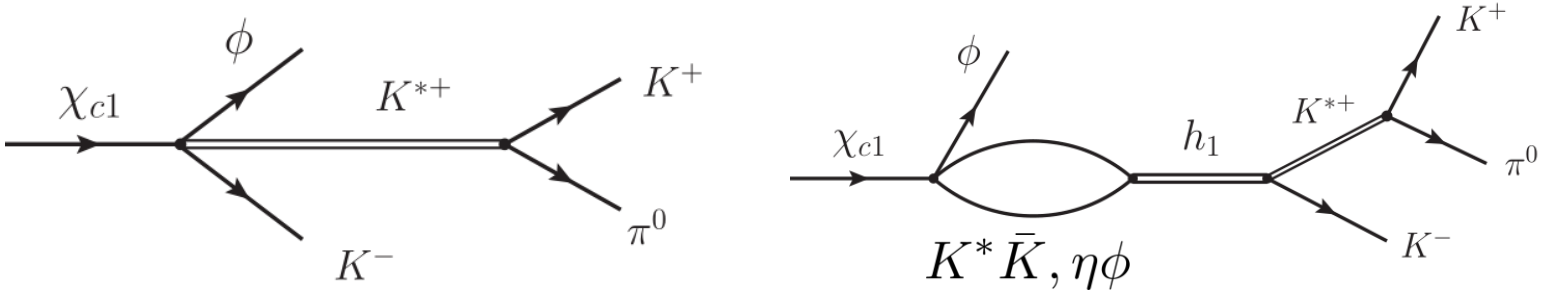
$$J = 0 \Rightarrow (\vec{\epsilon}_{\phi} \times \vec{\epsilon}_{K^*}) \cdot \vec{p}_i \ [i = \phi, K^*, \bar{K}]$$



s-wave $K^*\bar{K}$ [$\sim h_1(1380)$] is forbidden

$$J = 1 \Rightarrow (\vec{\epsilon}_{\chi_{c1}} \cdot \vec{p}_i)(\vec{\epsilon}_{\phi} \cdot \vec{\epsilon}_{K^*}) \ [i = \phi, K^*, \bar{K}]$$

s-wave$K^*\bar{K}$ [$\sim h_1(1380)$] is allowed



$K^*\bar{K}$ from χ_{c1}

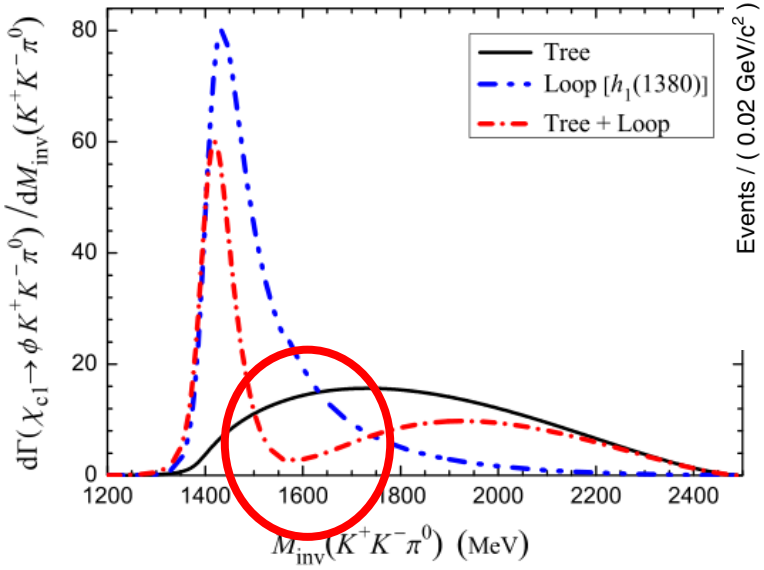
$K^*\bar{K}$ from h_1

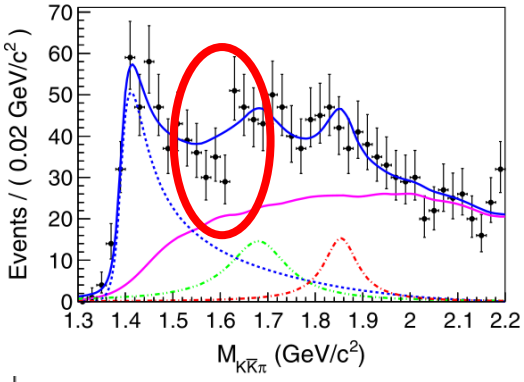
$$T = h_{K^{*+}K^-} + D_{h_1}(M_{\rm inv}(K^{*+}K^-))$$
$$[h_{K^*\bar{K}}\, g^2_{h_1,K^*\bar{K}}\, G_{K^*\bar{K}}(M_{\rm inv}(K^{*+}K^-))$$
$$+ 2\, h_{\phi\eta}\, g_{h_1,\phi\eta}\, g_{h_1,K^*\bar{K}}\, G_{\phi\eta}(M_{\rm inv}(K^{*+}K^-))\,]$$

$$\overline{\sum}\sum |t|^2 = B\vec{p}^{\,2}_{\phi}\tilde{p}^{\,2}_{K^+}|D_{K^*}|^2|T|^2$$

$$\frac{\mathrm{d}^2\Gamma}{\mathrm{d}M_{\rm inv}(K^{*+}K^-)\,\mathrm{d}M_{\rm inv}(K^+\pi^0)} = \frac{1}{(2\pi)^5}\, p_\phi\, p_{K^-}\, \tilde{p}_{K^+}\, \frac{1}{4M^2_{\chi_{c1}}}\, \overline{\sum}\sum |t|^2$$

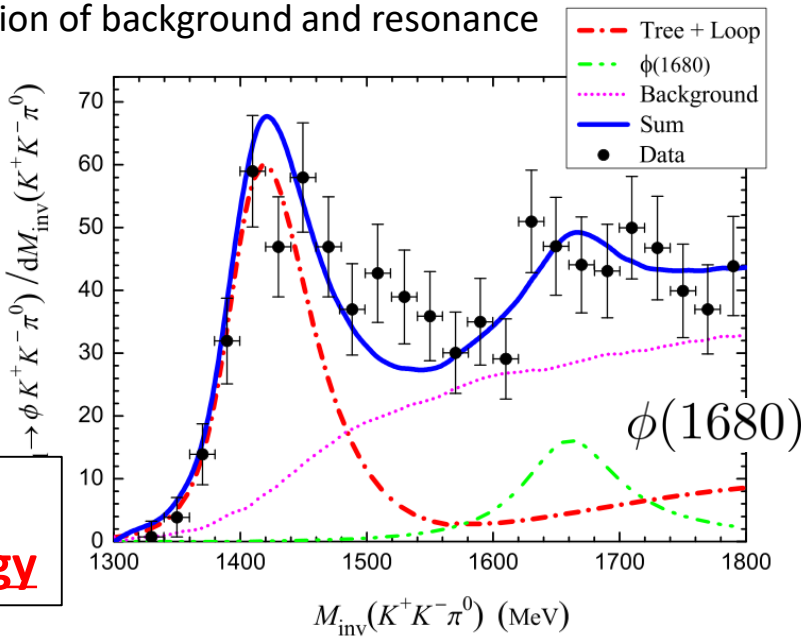
Mass distribution of $K^+K^-\pi^0$



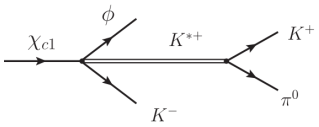


Rapid decrease at 1.6GeV

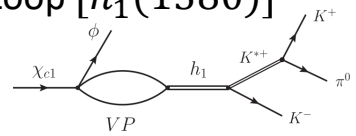
-- inclusion of background and resonance



Tree



Loop [$h_1(1380)$]



"dip" structure at the same energy

Support for the molecular picture of $h_1(1380)$

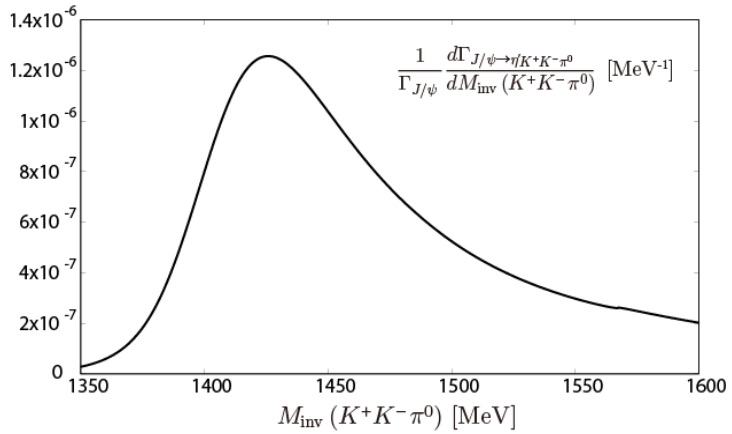
Summary

Study of charmonia ($J/\psi, \chi_{cJ}$) decay into meson+axial vector with the hadronic molecular picture of axial vector

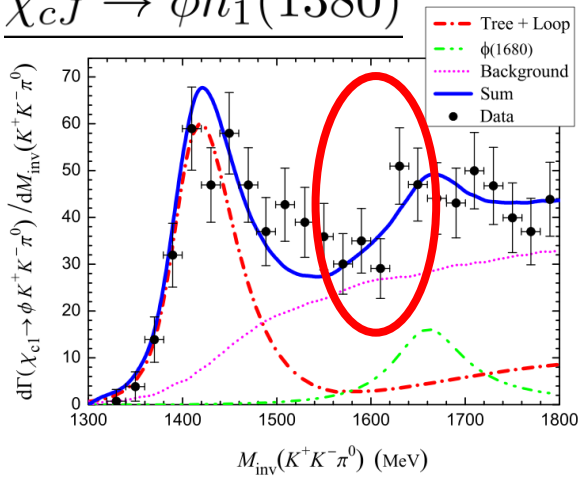
- Theoretical description of $J/\psi \to \eta^{(\prime)} h_1, \pi b_1(1235)$, $\chi_{cJ} \to \phi h_1(1380)$

	branching fraction (a)	branching fraction (b)
$\mathrm{Br}[J/\psi \to \eta' h_1(1380)]$	2.35×10^{-3}	5.16×10^{-4}
$\mathrm{Br}[J/\psi \to \eta h_1(1380)]$	3.65×10^{-5}	1.02×10^{-5}
$\mathrm{Br}[J/\psi \to \eta' h_1(1170)]$	5.35×10^{-4}	1.18×10^{-4}
$\mathrm{Br}[J/\psi \to \eta h_1(1170)]$	9.49×10^{-4}	2.08×10^{-4}
$\mathrm{Br}[J/\psi \to \pi^0 b_1(1235)^0]$	1.23×10^{-3}	2.77×10^{-4}

$J/\psi \to \eta' h_1(1380), h_1(1380) \to K^+K^-\pi^0$



$\chi_{cJ} \to \phi h_1(1380)$



See Poster
by Sheng-Juan Jiang
18:00, today

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for your attention!!