Interpreting the peak structures around 1800 MeV in the BES data on $J/\psi \to \phi \pi^+ \pi^-, \to \gamma \omega \phi$

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with

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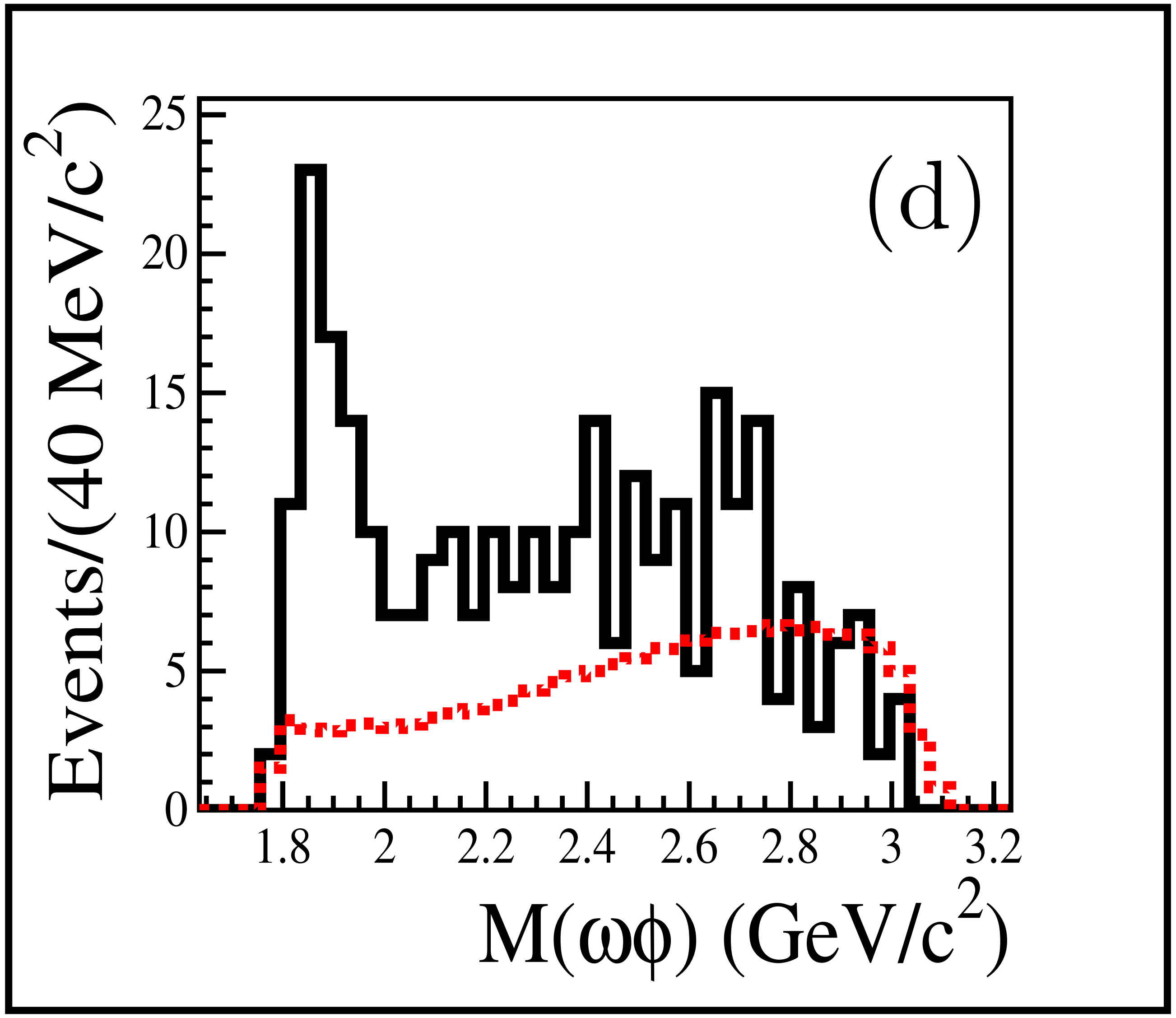
Based on: (1) Phys.Rev. D84 (2011) 074027
(2) Phys.Lett. B719 (2013) 388-393

The 7th International Symposium on Chiral Symmetry in Hadrons and Nuclei

Oct.27-30, 2013, Beihang university, China

Observation of a Near-Threshold Enhancement in the $\omega\phi$ Mass Spectrum from the Doubly OZI-Suppressed Decay $J/\psi \to \gamma\omega\phi$



PHYSICAL REVIEW LETTERS
PRL **96,** 162002 (2006)

0^{++} Resonance

M =1812+19-26±18 MeV
Γ=105±20±28 MeV

Known spectrum of (isoscalar) scalars

- $f_0(600)$
- $f_0(980)$
- $f_0(1370)$
- $f_0(1500)$
- $f_0(1710)$
- $f_0(2200)$
- $f_0(2330)$

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Q. Zhao and B. -S. Zou,
Phys. Rev. D **74,** 114025 (2006): enhancement found,
strength much smaller that the data,
$f_0(1710)$ $\omega\phi$ not known at that time

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More explanations:

tetraquark: B. A. Li, Phys. Rev. D 74, 054017 (2006).

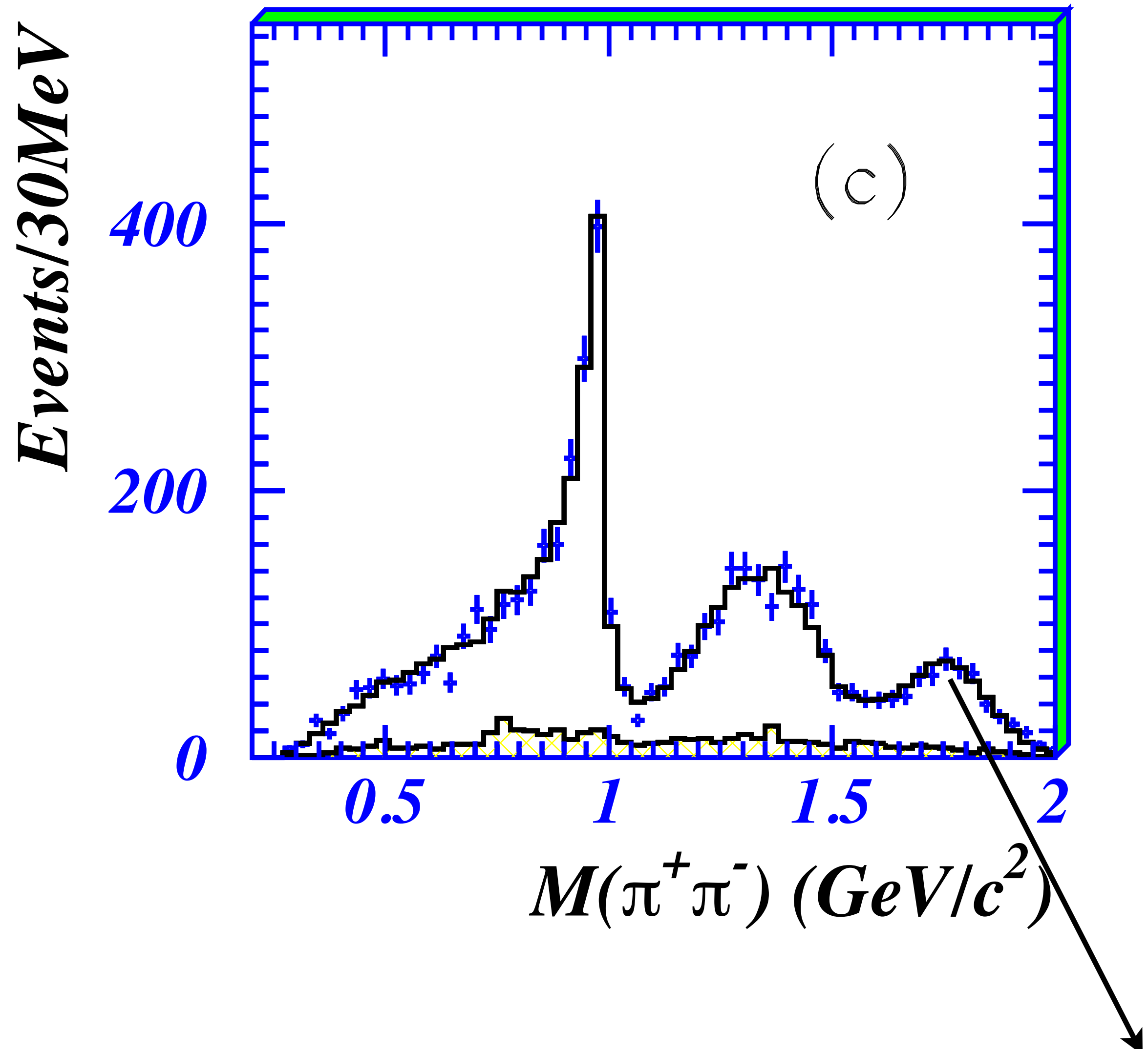
hybrid: K. -T. Chao, hep-ph/0602190.

Glueball: P. Bicudo, S. R. Cotanch, F. J. Llanes-Estrada and D. G. Robertson, Eur. Phys. J. C 52, 363 (2007).

Q. Zhao and B. -S. Zou,
Phys. Rev. D **74,** 114025 (2006): enhancement found,
strength much smaller that the data,
$f_0(1710)$ $\omega\phi$ not known at that time

Sometime ago.

Observation of a peak structure in the $\pi^+\pi^-$ Mass Spectrum was reported in $J/\psi \to \pi^+\pi^-\phi$ (also Doubly OZI-Suppressed) Decay



Ref: BES Collaboration, Phys. Lett. B 607 (2005) 243-253.

f_0(1790)

Peculiarity: Its decay to K anti-K is suppressed.

Thus, it can't be the known f_0(1710) (known to decay with a large branching ratio to K anti-K, decay to pions is suppressed).

- The quantum numbers ($J^{\pi c}=0^{++}$, I=0) of the states found in $J/\psi \rightarrow \pi^+\pi^-\phi$ and $J/\psi \rightarrow \gamma\omega\phi$ are same.

- There masses are very similar.

- Is it the same state showing up in the two cases?

- The answer is a "No" (as also analyzed by BES).

- **It seems from BES' work that there are 3 scalar resonances: f_0(1710), f_0(1790), f_0(1800).**

- **We show that there are only two states. That the enhancement seen in the J/ψ→$\gamma\omega\phi$ decay is the manifestation of the known f_0(1710).**

- **And the scalar resonance found in two pion spectrum is indeed a new state "f_0(1790)", distinct to the f_0(1710).**

- **We explain, why the decay of the latter one (f_0(1790)) to K-anti-K is suppressed.**

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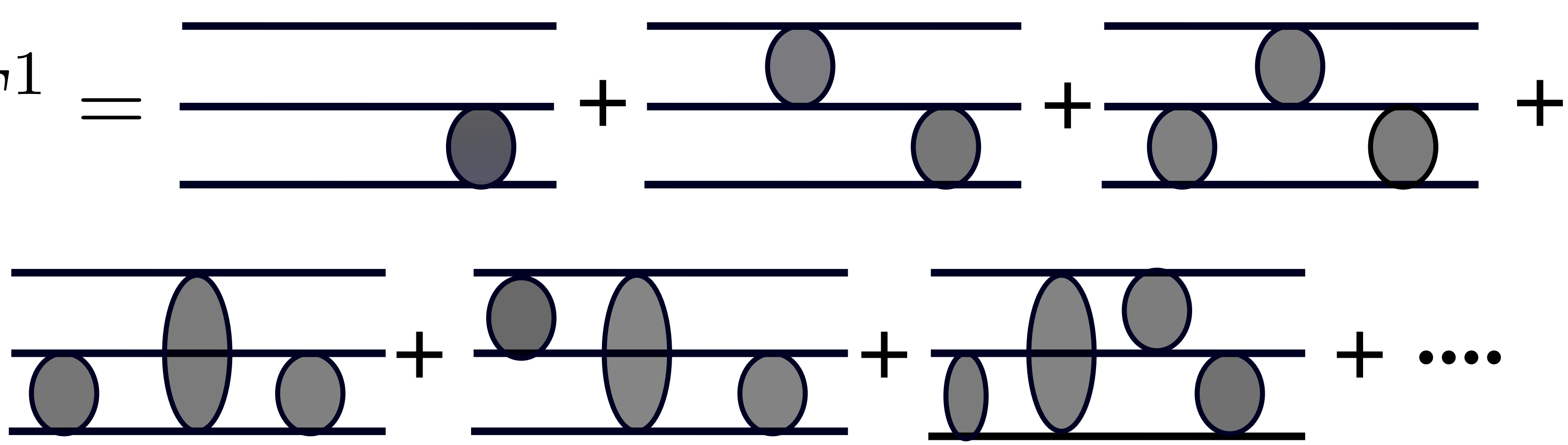
Supporting the existence of $f_0(1790)$ distinct to $f_0(1710)$

- We find a "π-π-$f_0(980)$" molecular interpretation for the $f_0(1790)$.

Formalism of the study in a nutshell:

- Obtaining Potentials from lowest order Chiral Lagrangians.
- Solving coupled channel Bethe salpeter equations to get two-body T-matrices.
- Solving Faddeev equations $T = T^1 + T^2 + T^3$ for the $\pi K\bar{K}$ system

$T^1 =$



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FORMALISM OF THE STUDY IN A NUTSHELL:

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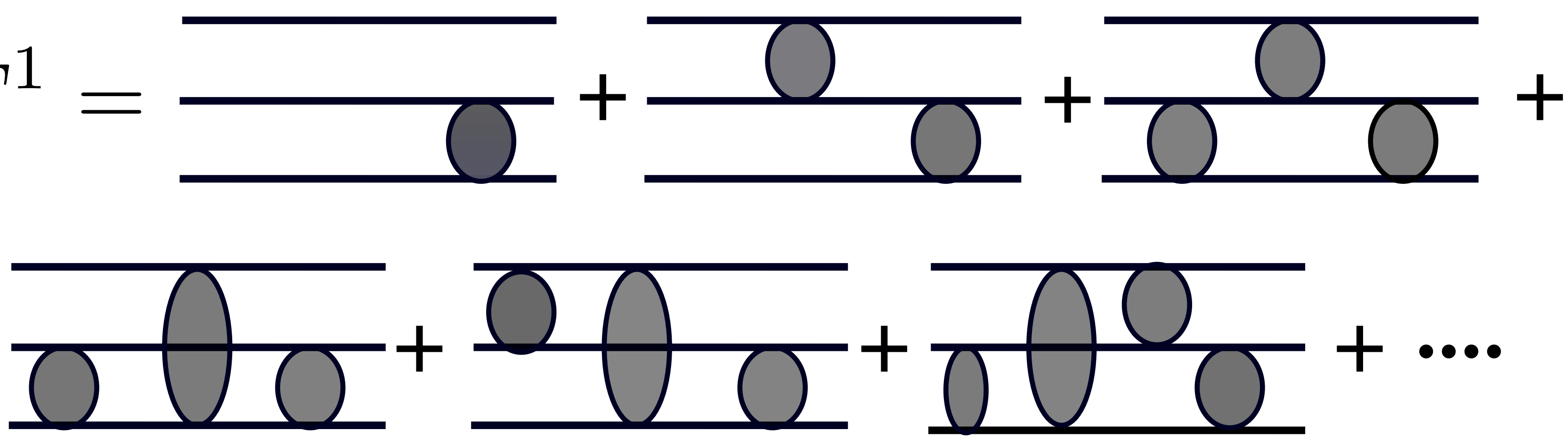

f_0(980)

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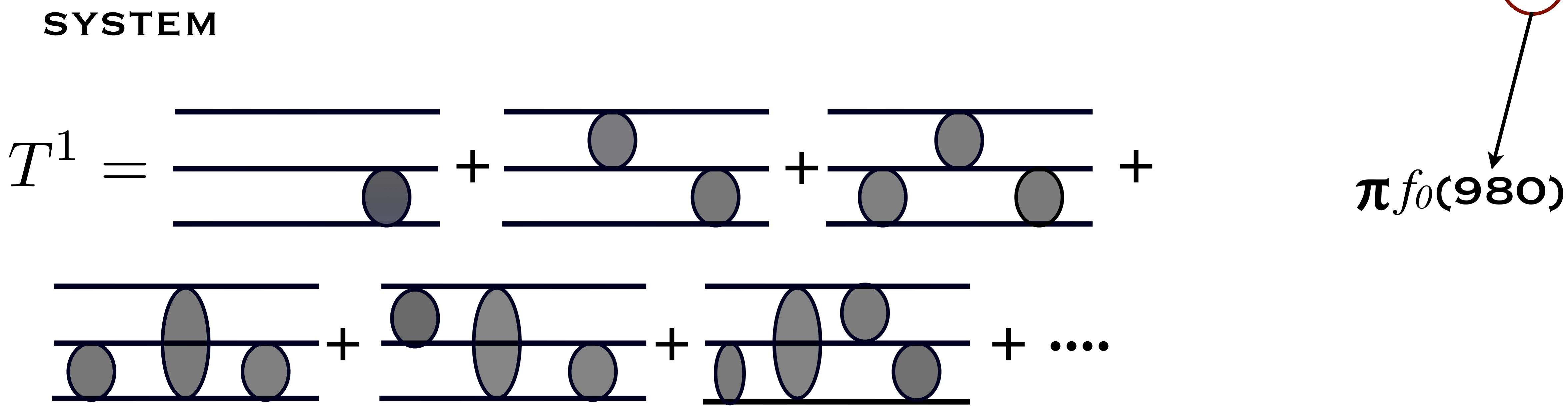

Supporting the existence of ***f*₀(1790) distinct to *f*₀(1710)**

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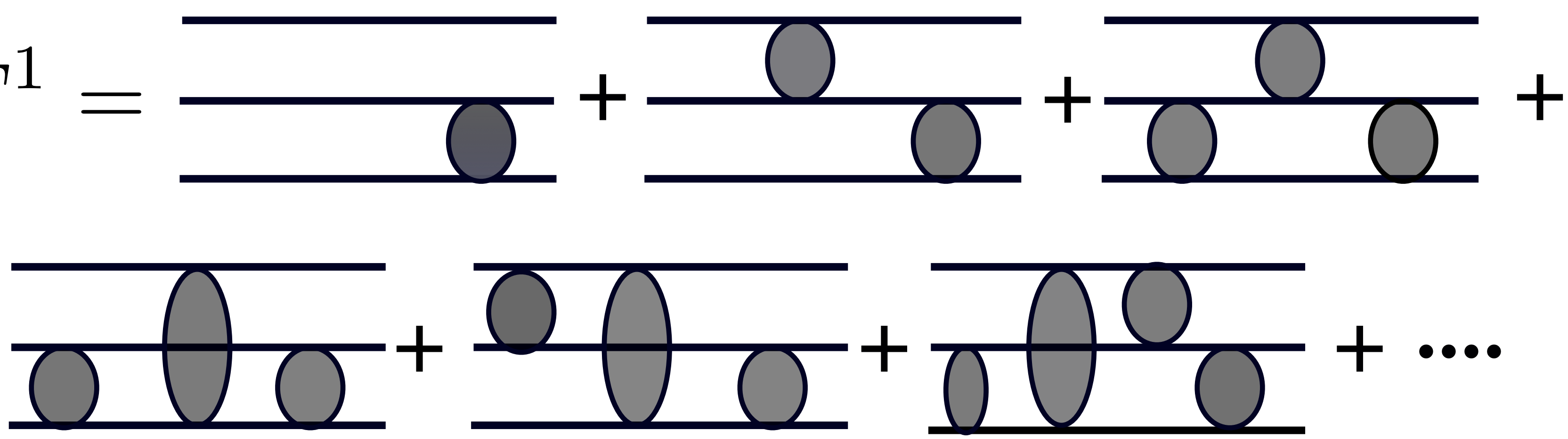
$T^1 =$ 

πf_0(980)

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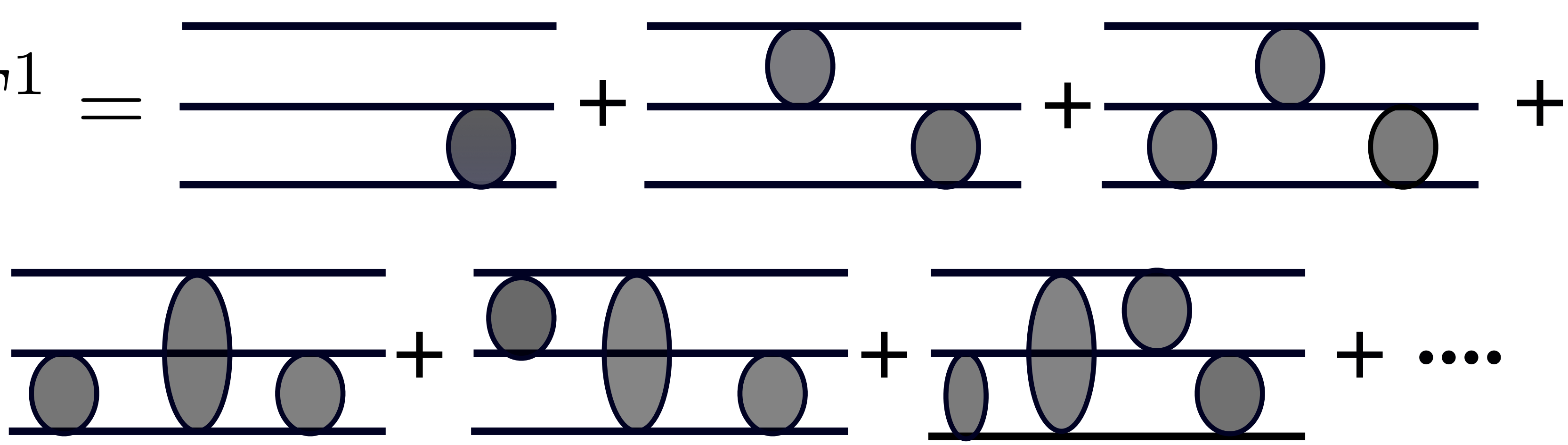

$\pi K\bar{K}$ → $\pi f_0(980)$ → $\pi(1300)$

Supporting the existence of f_0(1790) distinct to f_0(1710)

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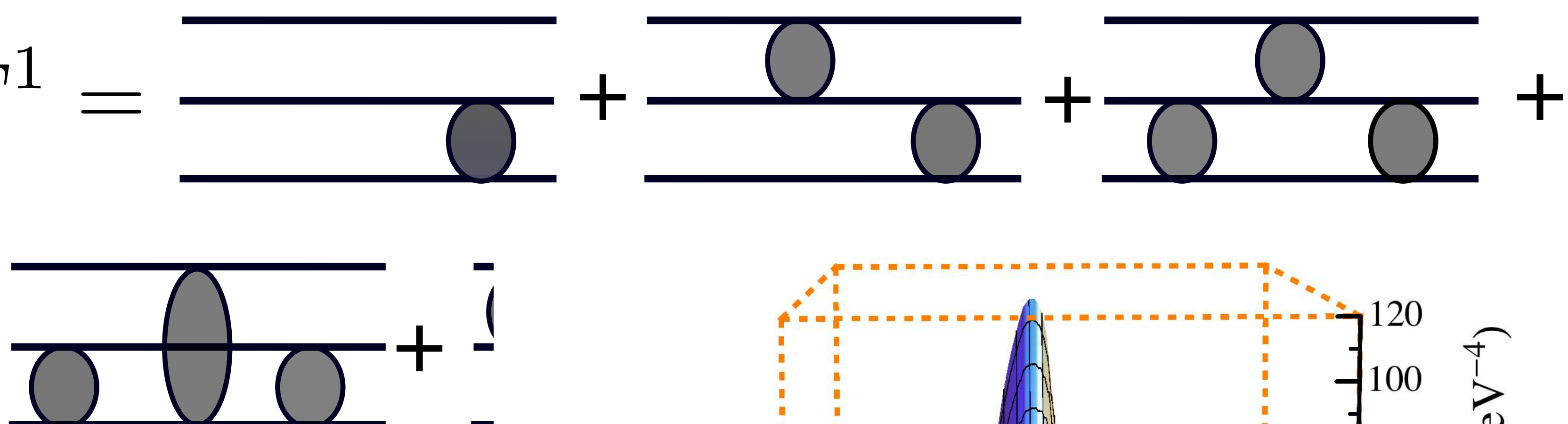

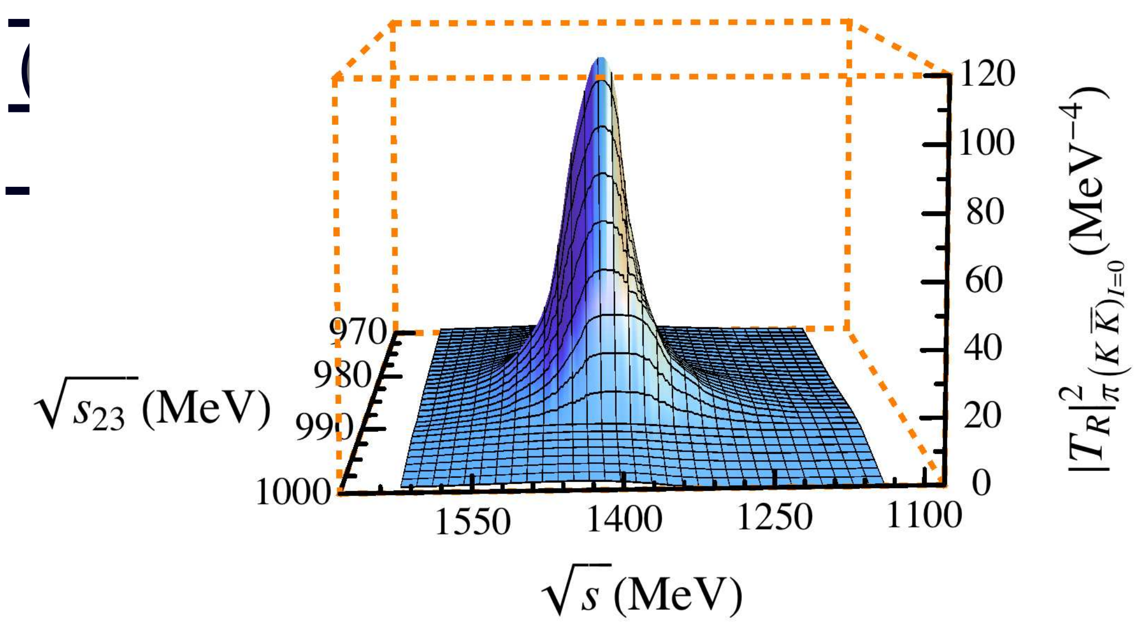

$K\bar{K}$ → π f_0(980) → π(1300)

Supporting the existence of $f_0(1790)$ distinct to $f_0(1710)$

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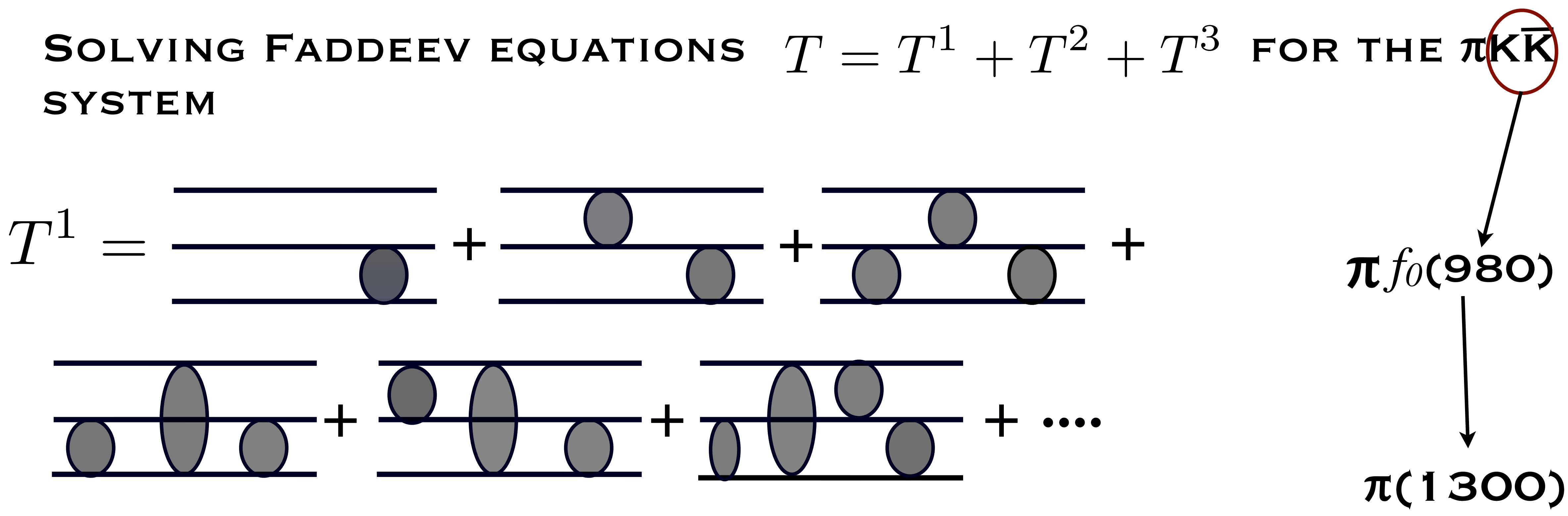
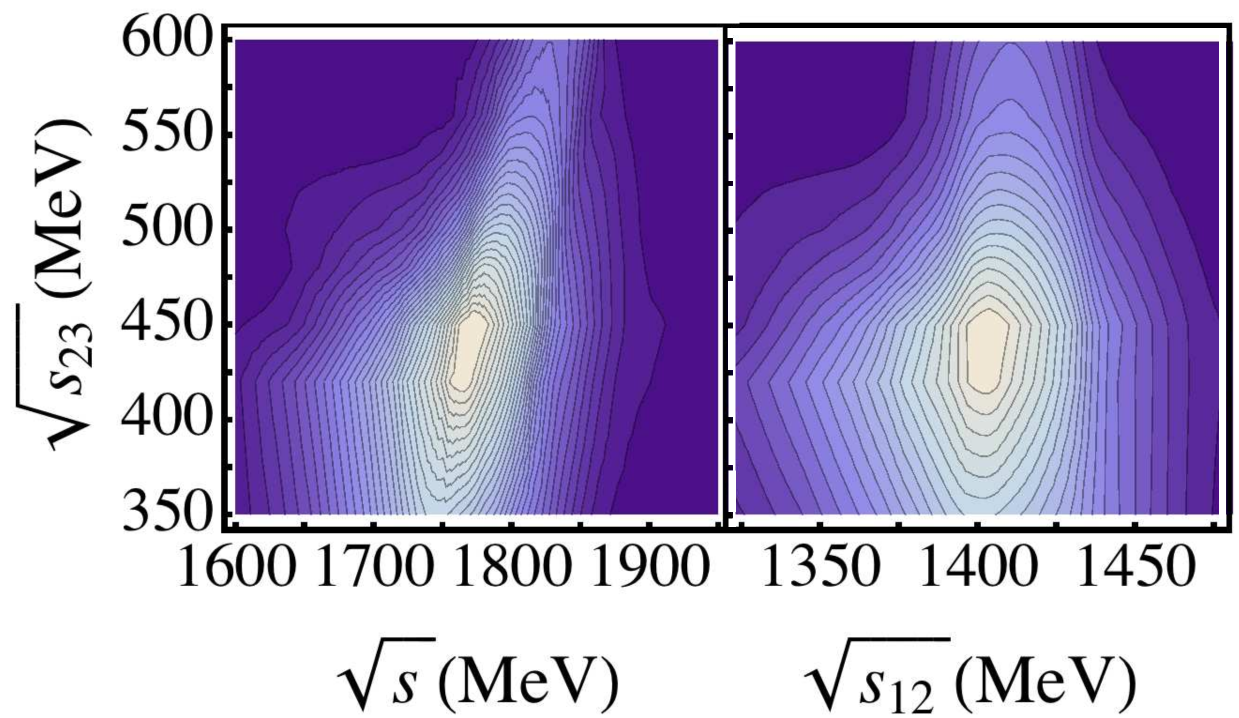
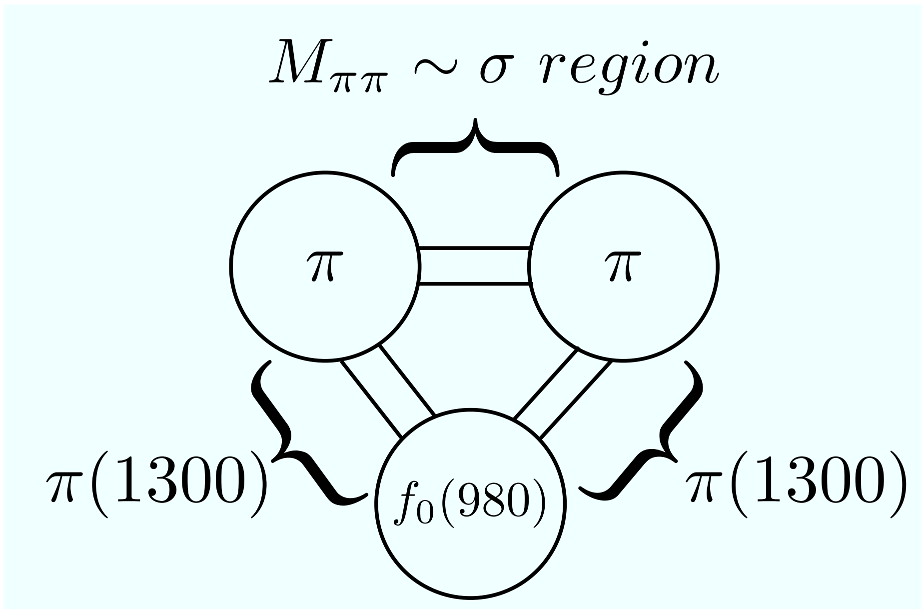


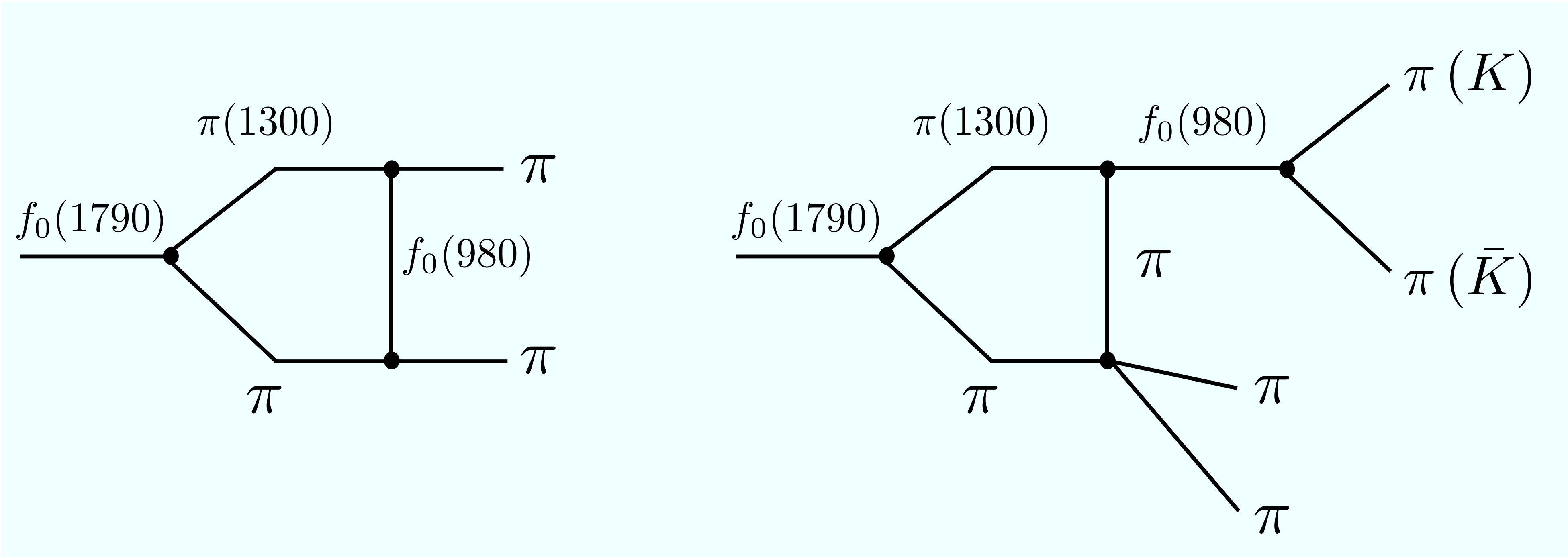
Supporting the existence of f_0(1790) distinct to f_0(1710)

- Solve Faddeev equations again for $\pi\,\pi\,f_0$ (980) system.



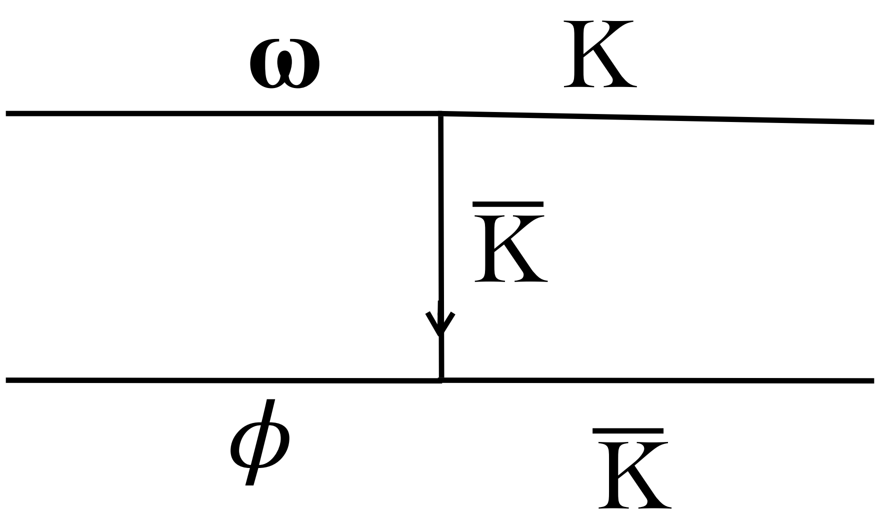


Supporting the existence of $\boldsymbol{f_0}$**(1790) distinct to** $\boldsymbol{f_0}$**(1710)**



- Decay mechanisms for $\boldsymbol{f_0}$**(1790)** to pions
- Decay to K anti-K suppressed
- The resonance structure found in the $\boldsymbol{\omega\phi}$ mass spectrum cannot be related with $\boldsymbol{f_0}$**(1790).**

The J/ψ→γωφ decay: Flaw in the Bes' interpretation?



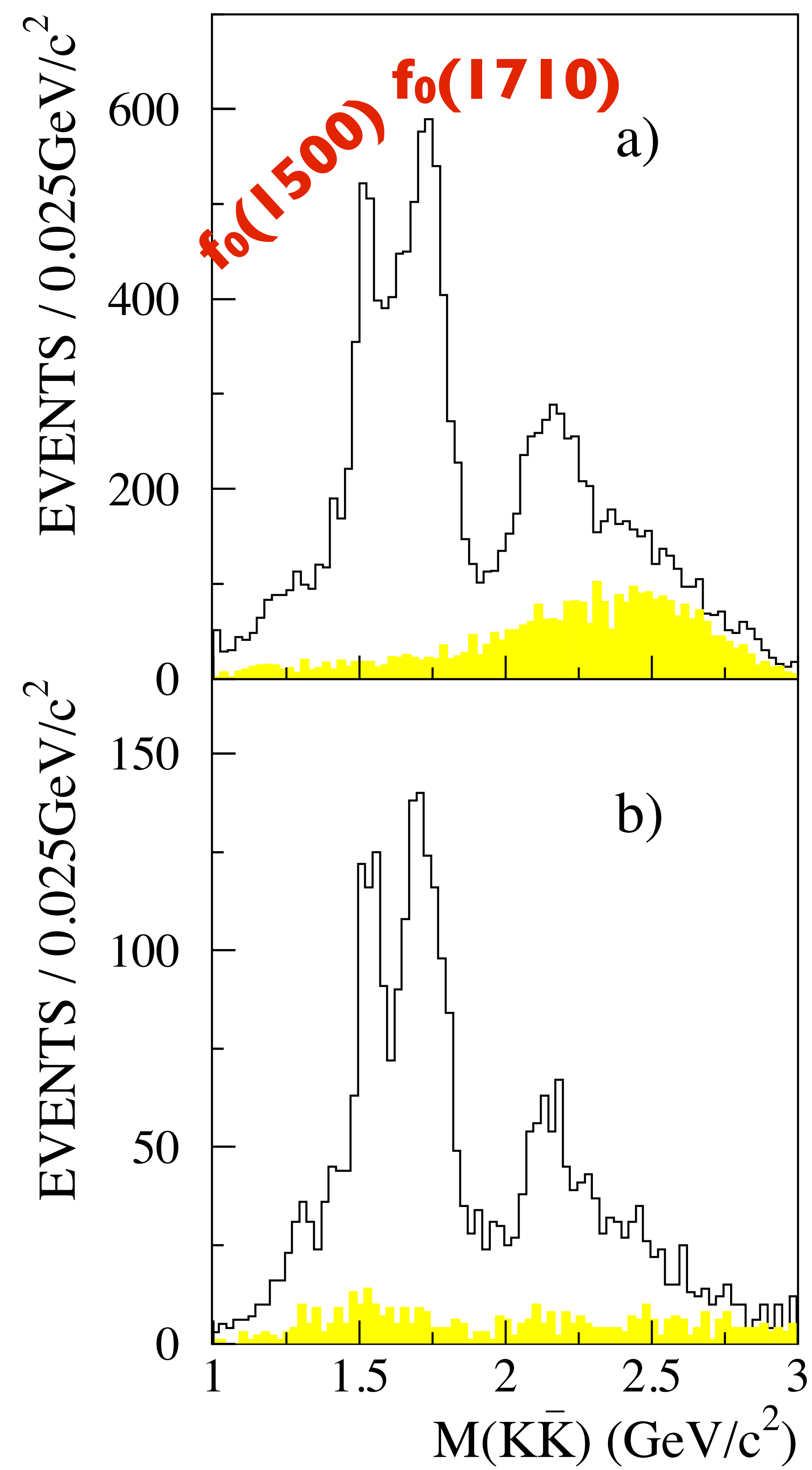
→ 0^{++}

↓

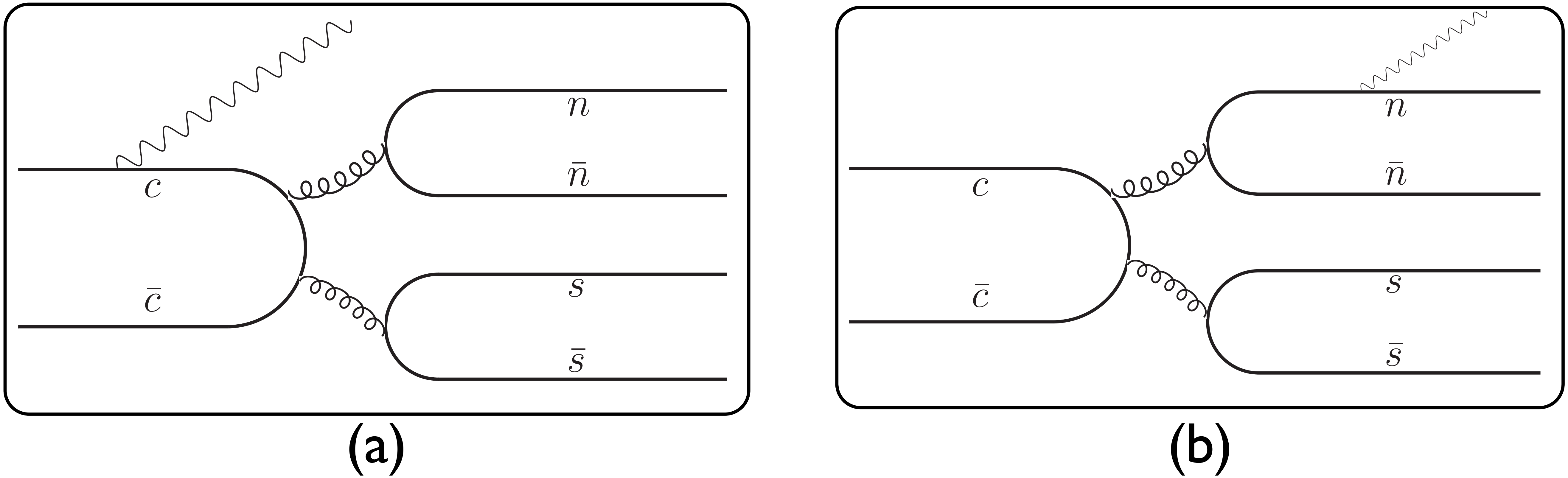
$J/\Psi \rightarrow \gamma K\bar{K}$

should also show a peak around 1800 MeV

Ref: J. Z. Bai et al. [BES Collaboration], Phys. Rev. D 68, 052003 (2003)



Formalism to study this process:



Two mechanisms of the J/Ψ radiative decays.

- Diagram (b) has been shown to be suppressed *(see: Phys Rept. 174 (1989) 67, Eur. Phys. J. A44 (2010) 305, etc.).*

- DIAGRAM (A) → SU(3) FLAVOR SINGLET FINAL STATE.

- VECTOR MESONS FINAL STATE INTERACTION WRITTEN IN TERMS OF A T-MATRIX OBTAINED USING EFFECTIVE FIELD THEORY FOLLOWING *Ref: L. S. Geng and E. Oset, Phys. Rev. D79 (2009) 074009,* WHERE $f_0(1710)$ HAS BEEN FOUND AS A DYNAMICALLY GENERATED RESONANCE.

Formalism:

- To get an SU(3) singlet in the final state we write:

$$M = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} \\ d\bar{u} & d\bar{d} & d\bar{s} \\ s\bar{u} & s\bar{d} & s\bar{s} \end{pmatrix}$$

- It is then easy to show that $M \cdot M = M \times (u\bar{u} + d\bar{d} + s\bar{s})$ ➡ Tr[M.M] gives an SU(3) flavor singlet.

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

- In effective field theory approach one writes the vector fields as

- and calculates Tr[V.V]

$$\mathrm{VV}_{\mathrm{SU(3)\ singlet}} = \rho^0\rho^0 + \rho^+\rho^- + \rho^-\rho^+ + \omega\omega + K^{*+}K^{*-} + K^{*0}\bar{K}^{*0} + K^{*-}K^{*+} + \bar{K}^{*0}K^{*0} + \phi\phi$$

Formalism:

- isospin projections of different VV channels:

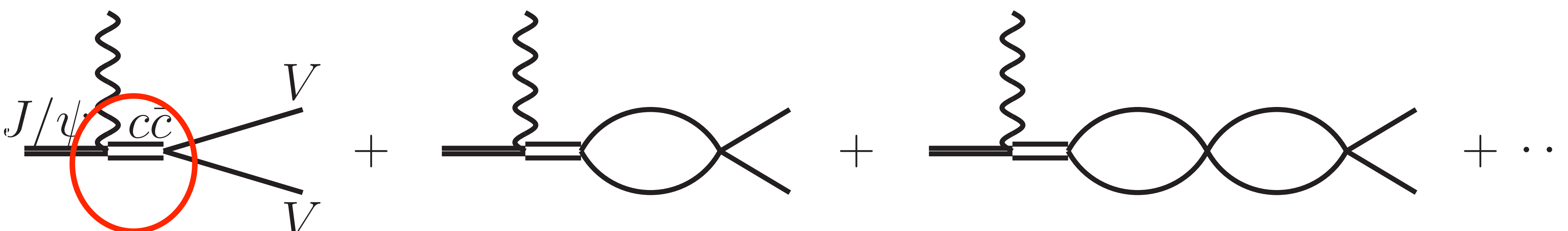
$$|\rho\rho\rangle_{I=0} = -\frac{1}{\sqrt{6}}|\rho^0\rho^0 + \rho^+\rho^- + \rho^-\rho^+\rangle,$$

$$|K^*\bar{K}^*\rangle_{I=0} = -\frac{1}{2\sqrt{2}}|K^{*+}K^{*-} + K^{*0}\bar{K}^{*0} + K^{*-}K^{*+} + \bar{K}^{*0}K^{*0}\rangle$$

$$|\omega\omega\rangle_{I=0} = \frac{1}{\sqrt{2}}|\omega\omega\rangle,$$

$$|\phi\phi\rangle_{I=0} = \frac{1}{\sqrt{2}}|\phi\phi\rangle,$$

- USING THESE STATES, AND RELATING TR[M.M] WITH TR[V.V], WE CAN CALCULATE THE WEIGHT FACTOR FOR THE HADRONIZATION OF THE Q ANTI-Q TO DIFFIERENT STATES.



$A\omega_j$

$$t_{J/\Psi\to\gamma\phi\omega} = A\sum_{j=1}^{4} w_j G_j t_{j\to\phi\omega}$$

loop function

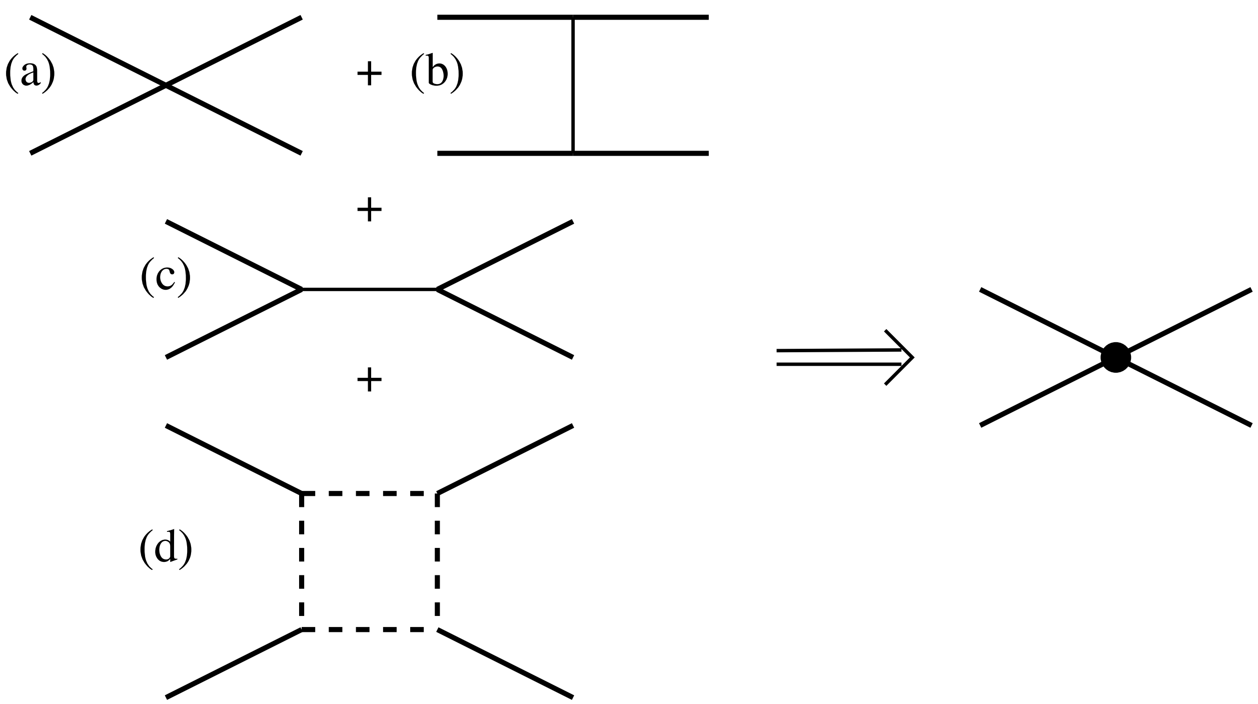
weight of the overlap function between the hadron and quark states

Formalism:

$$t_{J/\Psi\to\gamma\phi\omega} = A\sum_{j=1}^{4} w_j G_j t_{j\to\phi\omega}$$

Vector-Vector meson Amplitude → Ref: Geng and Oset, Phys.Rev.D79, (2009) 074009.

Kernerl → Bethe-Salpeter Equation



- $f_0(1710)$ found as dynamically generated state

- Use the coupling of the channels to the corresponding pole in the complex plane)

$$t_{i\to j} = \frac{g_i g_j}{s - M_R^2 + i M_R \Gamma_R}$$

Formalism:

- With the $J/\Psi \to \gamma\omega\phi$ amplitude we calculate the $\omega\phi$ mass distribution as

$$\frac{d\Gamma}{dM_{\rm inv}} = \frac{1}{(2\pi)^3}\frac{1}{4M^2_{J/\Psi}}\; p_\gamma \bar{q}_\omega \mid t_{J/\Psi\to\gamma\phi\omega} \mid^2$$

$\omega\phi$ invariant mass

where,

$$p_\gamma = \frac{\lambda^{1/2}\left(M^2_{J/\Psi}, 0, M^2_{\rm inv}\right)}{2M_{J/\Psi}}$$

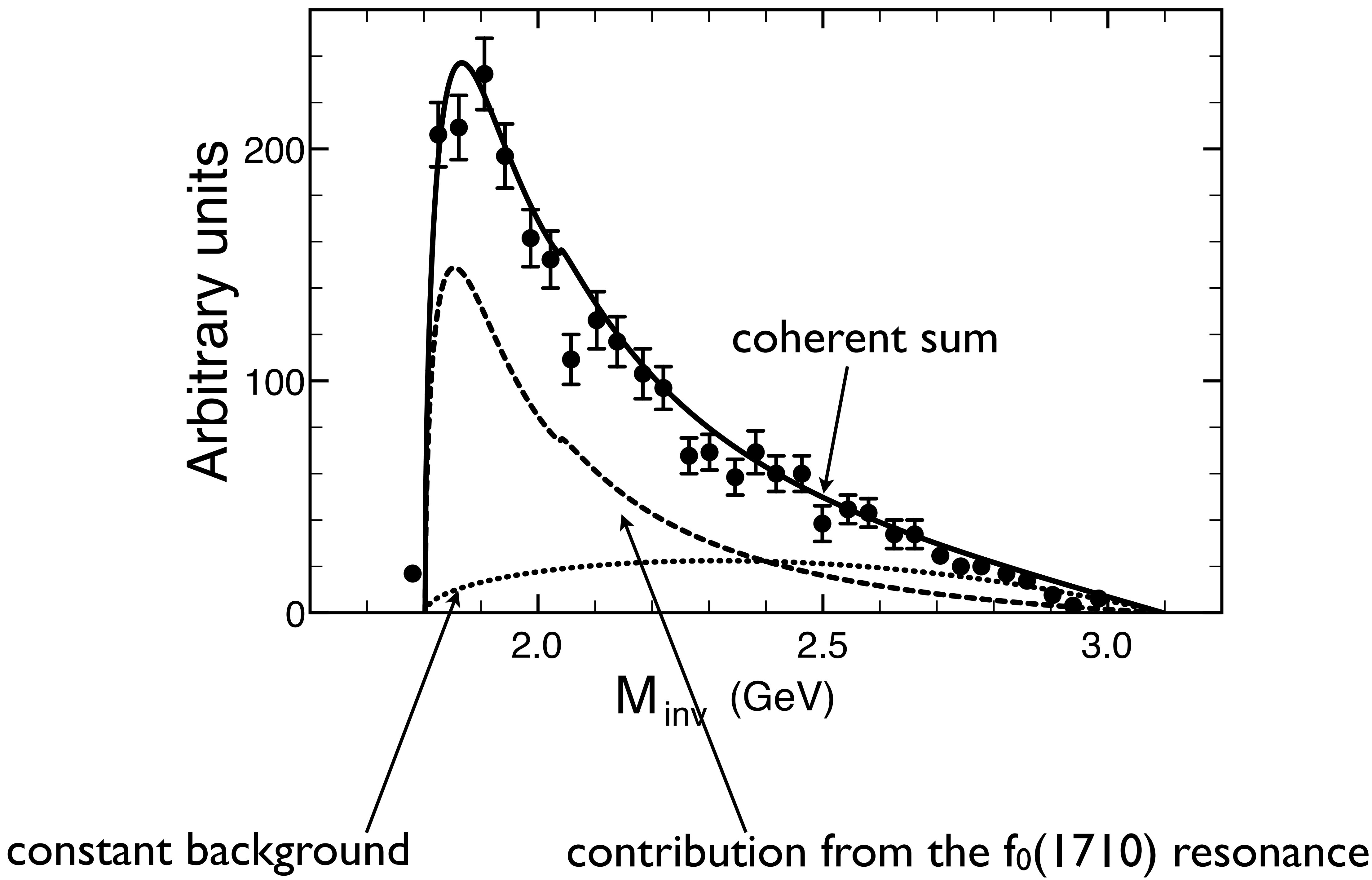
photon momentom in the J/Ψ rest frame

$$\bar{q}_\omega = \frac{\lambda^{1/2}\left(M^2_{\rm inv}, m^2_\omega, m^2_\phi\right)}{2M_{\rm inv}}$$

ω momentom in the $\omega\phi$ rest frame

Results:

$\omega\phi$ mass distribution



Results:

- We also calculated the Branching ratio of the $J/\Psi \to \gamma\omega\phi$ amplitude

$$\frac{B\left(J/\Psi \to \gamma R \to \gamma\phi\omega\right)}{B\left(J/\Psi \to \gamma f_0\right)} = 0.14^{+0.12}_{-0.07}.$$

from exptl data

Our result: $0.15^{+0.07}_{-0.04}$

Summary:

- We argue that the cross section enhancements found in the data on the $J/\psi \to \gamma\omega\phi$ and the $J/\psi \to \pi^+\pi^-\phi$ decay in the similar energy region are due to two distinct resonances.

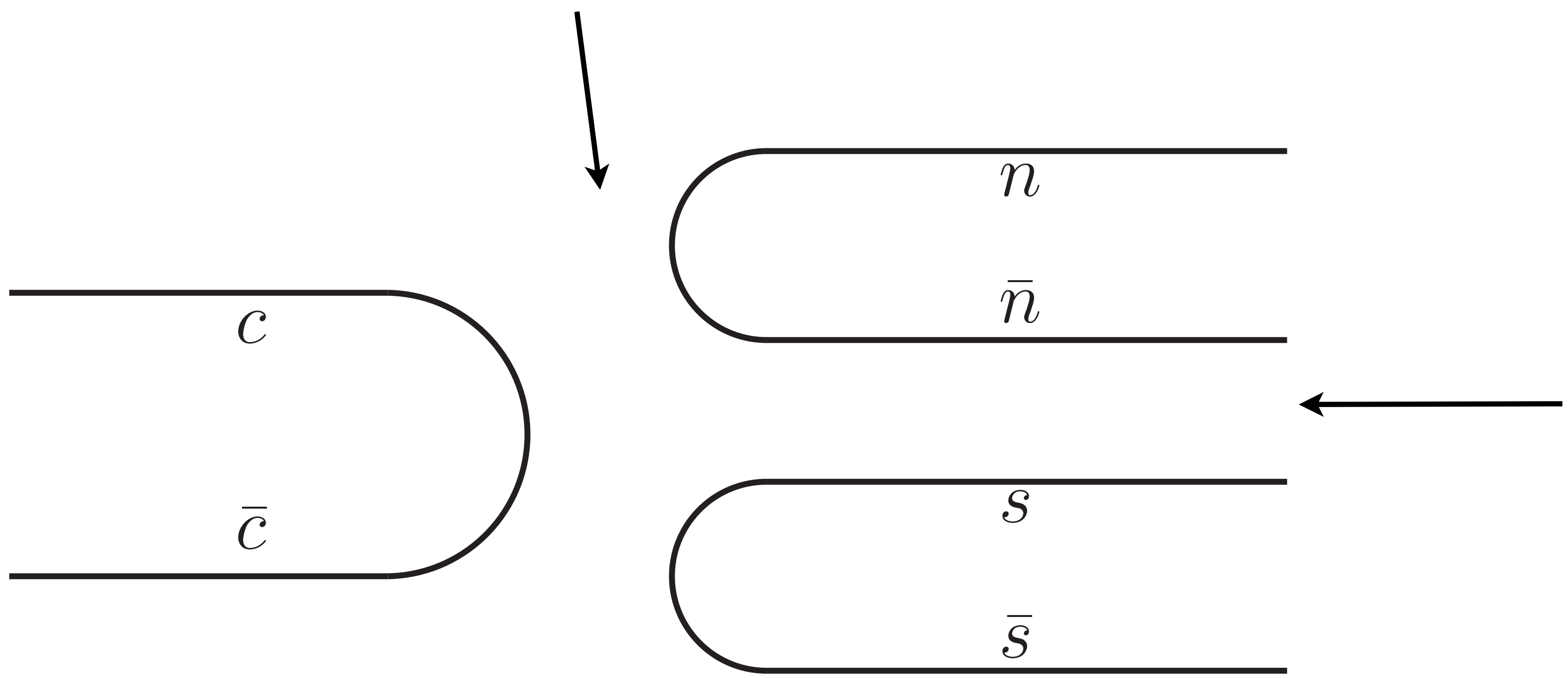
- We find a scalar resonance in the $\pi\pi$ $f_0(980)$ system with the properties very similar to the $f_0(1790)$ found in the $\pi^+\pi^-$ spectrum in the $J/\psi \to \pi^+\pi^-\phi$ decay.

- We find an explanation of the suppressed decay of $f_0(1790)$ to K-anti-K channel.

- Further, we interpret the peak near 1800 MeV in the $J/\psi \to \gamma\omega\phi$ decay as the signature of the $f_0(1710)$ resonance which is dynamically generated within the effective field theory calculations of the VV systems.

Summary:

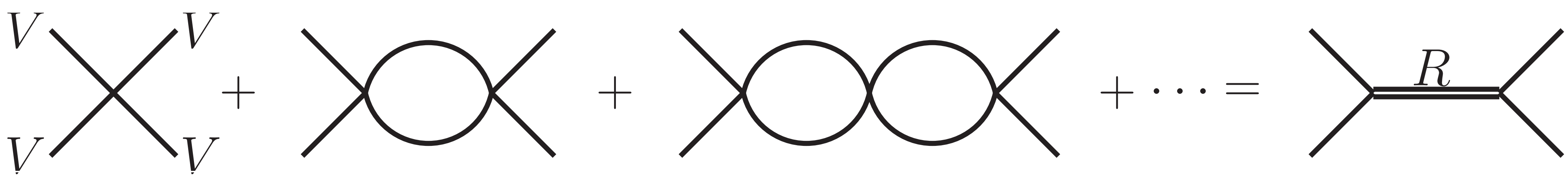
- This explains why no peak is seen in the K anti-K mass distribution near 1800 MeV.
- We can reproduce the experimental data (mass distribution and branching ratio) obtained by the BES collaboration.
- Thus, there are two scalar resonances in 1700-1800 MeV region: $f_0(1710)$ and $f_0(1790)$.



- Doubly OZI suppressed

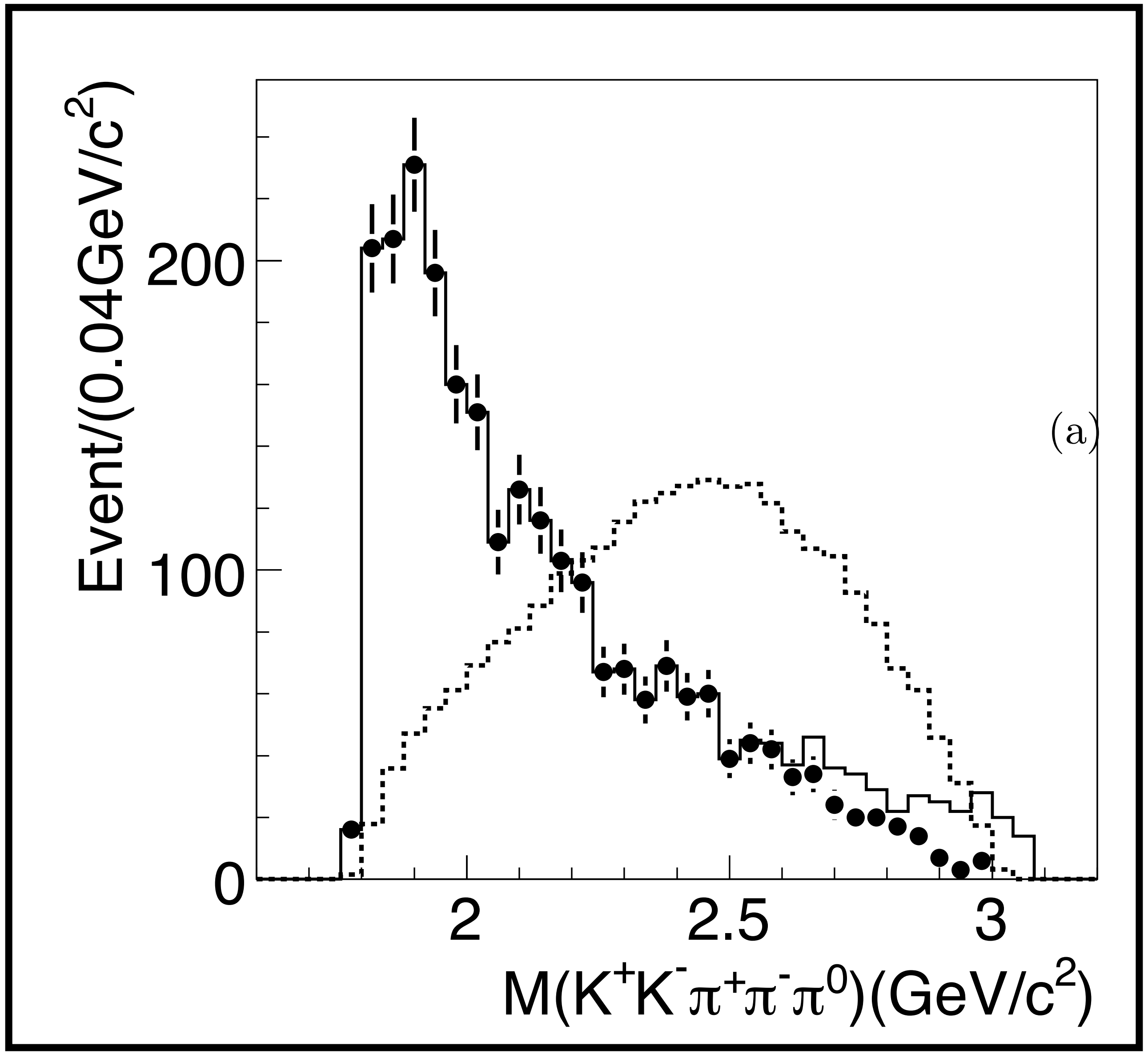
Formalism

- $f_0(1710)$ has been found to arise due to two vector meson dynamics. (Ref: L. S. Geng and E. Oset, Phys. Rev. D79 (2009) 074009).



- It was found to couple dominantly to the K^* anti-K^* channel.

- Coupled channels: ρρ,ωω,ΦΦ,*K** *anti-K**,ωΦ.



arXiv:1209.4813 [hep-ex]

M =1795±7+23-5 MeV

Γ=95±10+78-34 MeV

Higher statistics Results from BESIII