

Evidence for $a_0(980)$ as tetraquark from the triangle rescattering $D_s^+ \rightarrow \pi^+\pi^0\eta$ decay

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BES-BELLE-LHCb 联合讨论会 2019

2019.11.02

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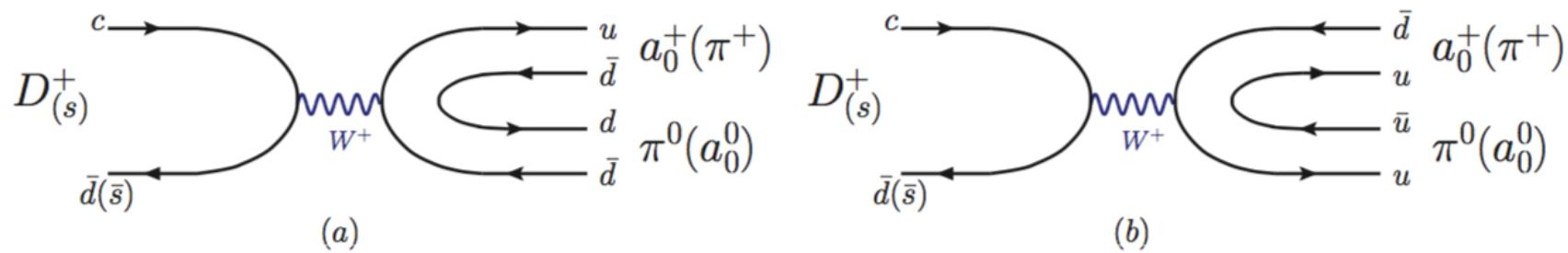
arXiv:1909.07327

Outline:

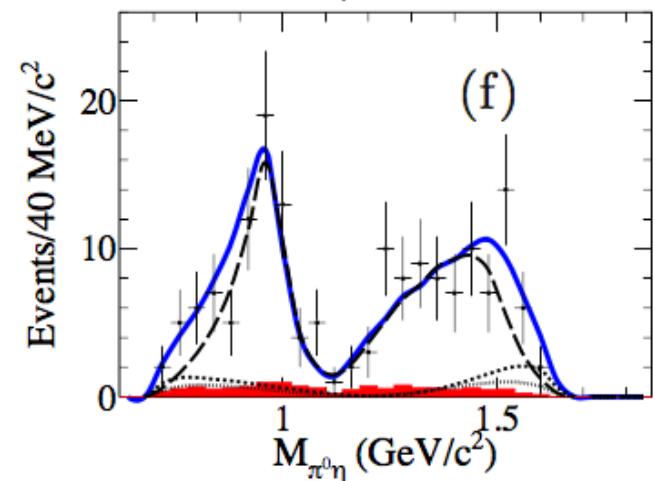
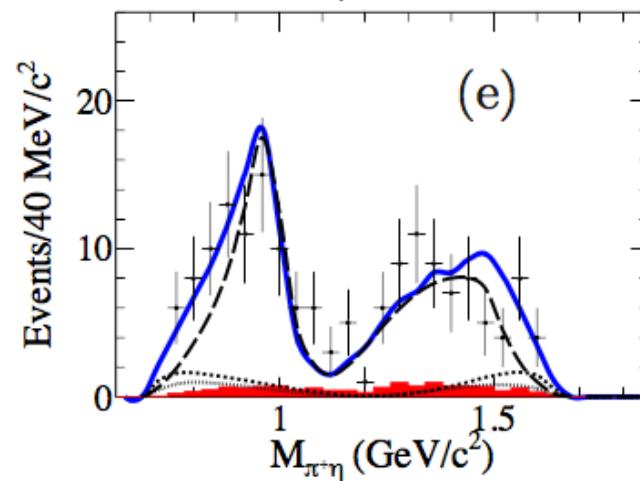
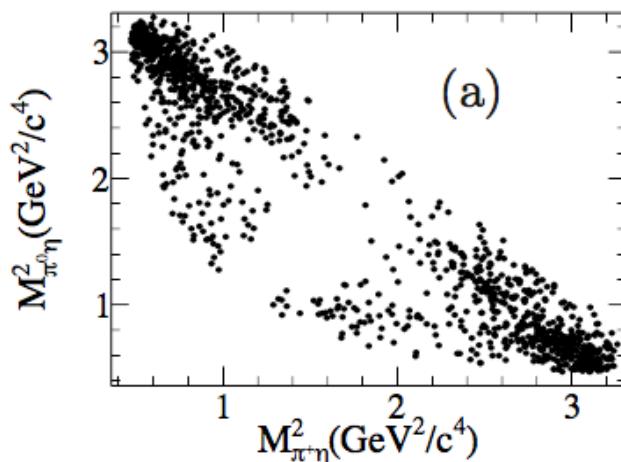
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Motivation

- Observation (BESIII, PRL112001 (2019), arXiv:1903.04118 [hep-ex])
 $\mathcal{B}(D_s^+ \rightarrow \pi^{+(0)}(a_0^{0(+)} \rightarrow) \pi^{0(+)} \eta) = (1.46 \pm 0.15 \pm 0.23) \times 10^{-2}$,
 $a_0 \equiv a_0(980)$, claimed as the W -annihilation process.



with the assumption that a_0 is a p-wave scalar meson.



- Theoretical difficulties

The spectator quark \bar{s} in D_s^+ needs elimination.

The productions of $a_0^{+,0}$, equal sizes.

$$\mathcal{B}(D_s^+ \rightarrow \pi^+ \rho^0) = (2.0 \pm 1.2) \times 10^{-4}$$

$$\mathcal{B}(D_s^+ \rightarrow \pi^{+(0)}(a_0^{0(+)} \rightarrow) \pi^{0(+)} \eta) = 1.46 \times 10^{-2}$$

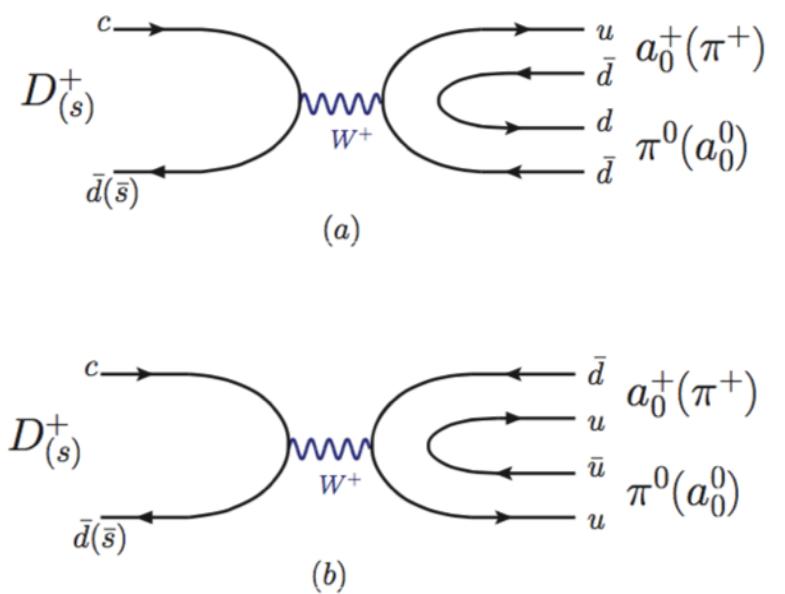
$$\mathcal{B}(D_s^+ \rightarrow \pi^+ \eta) = (1.70 \pm 0.09) \times 10^{-2}$$

$$\mathcal{B}(D_s^+ \rightarrow \pi^+ f_0(980)) \sim O(10^{-2})$$

- Estimation

$$\begin{aligned} & \mathcal{B}(D^+ \rightarrow \pi^{+(0)}(a_0^{0(+)} \rightarrow) \pi^{0(+)} \eta) \\ & \simeq \left(\frac{f_D}{f_{D_s}} \right)^2 \left(\frac{|V_{cd}|}{|V_{cs}|} \right)^2 \frac{\tau_D}{\tau_{D_s}} \left(\frac{m_{D_s}}{m_D} \right)^3 \times \mathcal{B}(D_s^+ \rightarrow \pi^{+(0)}(a_0^{0(+)} \rightarrow) \pi^{0(+)} \eta) \\ & \simeq 1.2 \times 10^{-3} \end{aligned}$$

disapproved by data: $\mathcal{B}(D^+ \rightarrow \pi^+ \pi^0 \eta) = (1.38 \pm 0.35) \times 10^{-3}$



Scalar mesons below 1 GeV

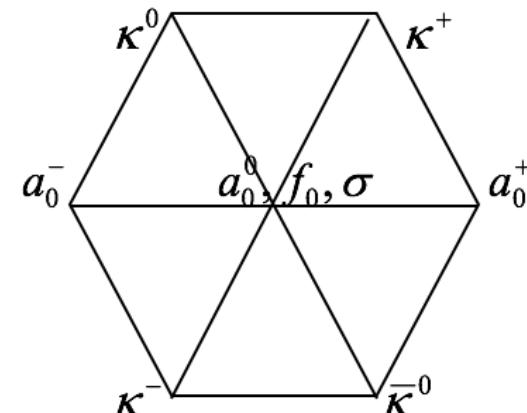
- Controversial identifications

a_0^+ , $a_0^{0,+}$, $f_0(980)$

p-wave $(u\bar{d})$, $(u\bar{u} - d\bar{d})/\sqrt{2}$, $s\bar{s}$

compact $s\bar{s}(u\bar{d})$, $s\bar{s}(u\bar{u} - d\bar{d})/\sqrt{2}$,

$s\bar{s}(u\bar{u} + d\bar{d})/\sqrt{2}$ tetraquarks



$$\sigma = u\bar{d}\bar{u}\bar{d}$$

$$f_0 = s\bar{s} \cancel{(u\bar{u} + d\bar{d})}/\sqrt{2}$$

$$a_0^0 = \cancel{s\bar{s}}(u\bar{u} - d\bar{d})/\sqrt{2},$$

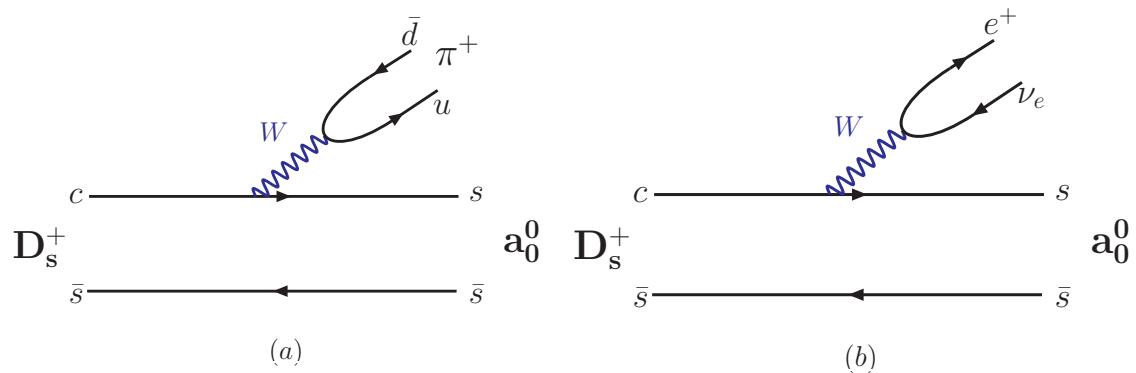
$$a_0^+ = u\bar{d}\cancel{s\bar{s}}$$

$$a_0^- = d\bar{u}\cancel{s\bar{s}}$$

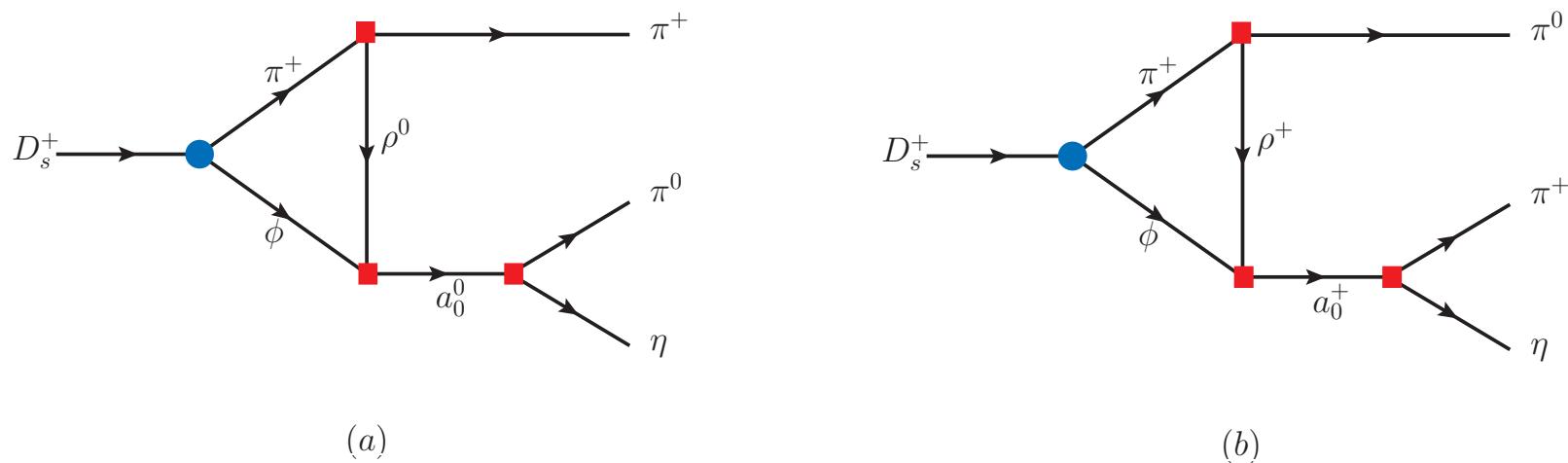
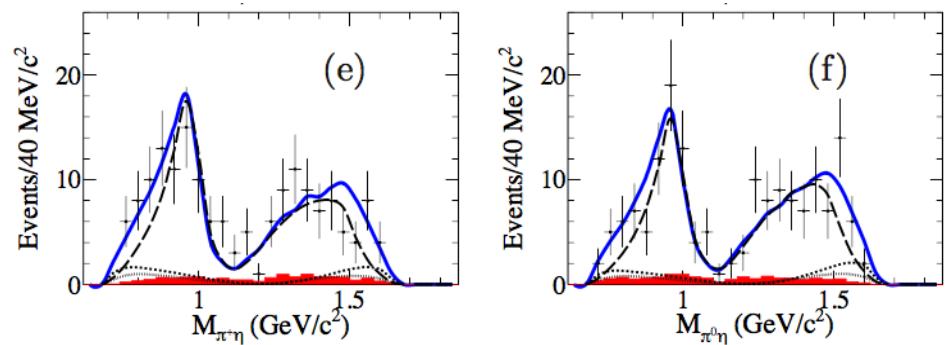
$$\kappa^+ = u\bar{s}\cancel{d\bar{d}}, \quad \kappa^0 = d\bar{s}\cancel{u\bar{u}}, \quad \kappa^- = s\bar{u}\cancel{d\bar{d}}$$

**Since you have eliminated the impossible,
whatever remains, however improbable,
must be the truth.**

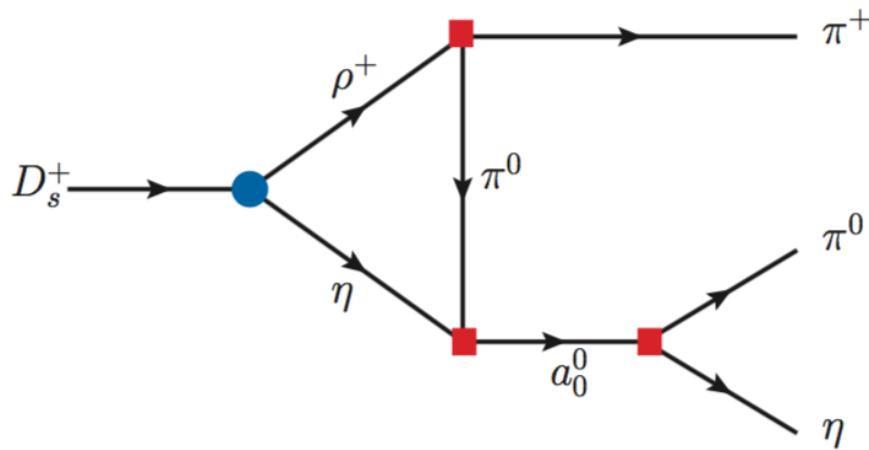




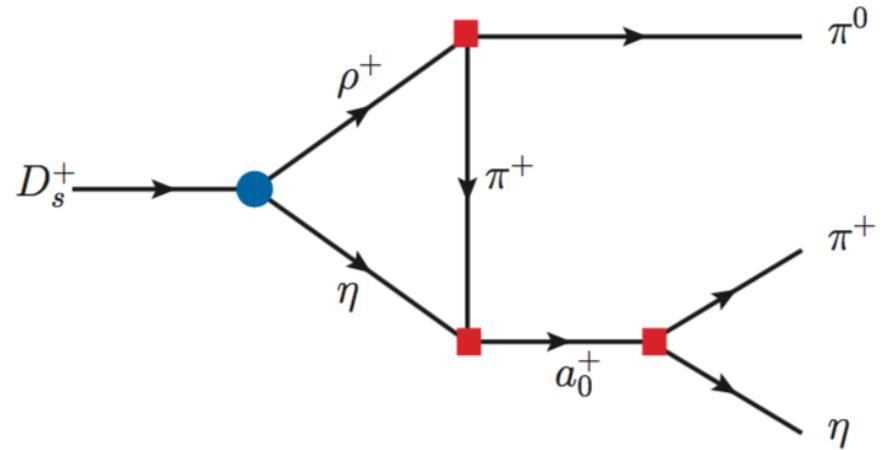
- not for a_0^+
- constraint from $D_s^+ \rightarrow a_0^0 e^+ \nu_e$
- $\phi \rightarrow a_0 \gamma$



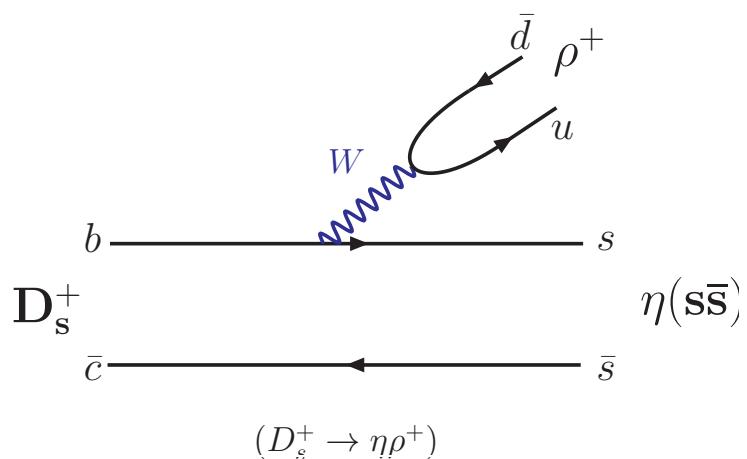
- $\mathcal{B}(D_s^+ \rightarrow \eta\rho^+) = (8.9 \pm 0.8)\%$
- Is a_0 still a tetraquark?

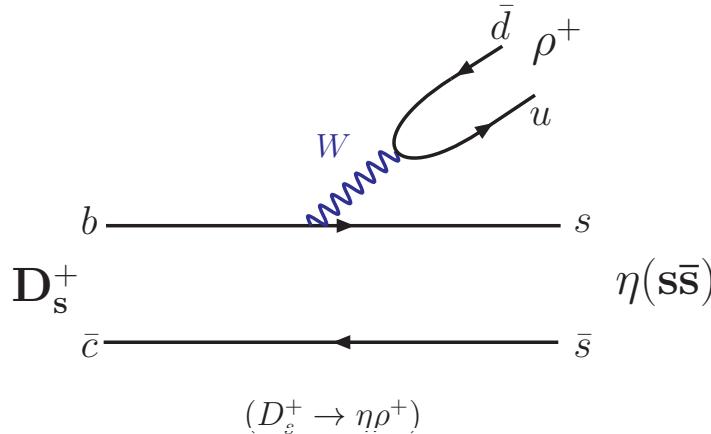


(a)



(b)





$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} V_{cs} V_{ud} [c_1^{eff} (\bar{u}d)(\bar{s}c) + c_2^{eff} (\bar{s}d)(\bar{u}c)]$$

$$\mathcal{A}(D_s^+ \rightarrow \eta\rho^+) = \frac{G_F}{\sqrt{2}} V_{cs} V_{ud} a_1 \langle \rho^+ | (\bar{u}d) | 0 \rangle \langle \eta | (\bar{s}c) | D_s^+ \rangle$$

$$\langle \eta | (\bar{s}c) | D_s^+ \rangle = (p_{D_s} + p_\eta)_\mu F_+(t) + q_\mu F_-(t)$$

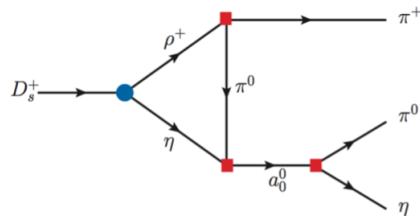
$$\langle \rho^+ | (\bar{u}d) | 0 \rangle = m_\rho f_\rho \epsilon_\mu^*$$

$$F(t) = \frac{F(0)}{1 - a(t/m_{D_s}^2) + b(t^2/m_{D_s}^4)}$$

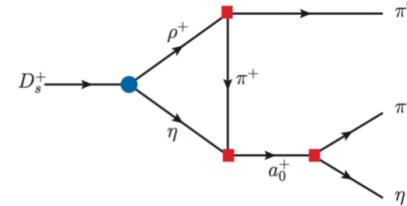
$$a_1 = 1.02 \pm 0.05 \qquad \bullet \; \mathcal{B}(D_s^+ \rightarrow \eta\rho^+) = (8.9 \pm 0.8)\%$$

$$\mathcal{A}(a_0 \rightarrow \eta\pi) = g_{a_0\eta\pi}$$

$$\mathcal{A}(\rho^+ \rightarrow \pi^+\pi^0) = g_{\rho\pi\pi} \epsilon \cdot (p_{\pi^+} - p_{\pi^0})$$



(a)



(b)

$$\mathcal{A}_{a+b} \equiv \mathcal{A}(D_s^+ \rightarrow \pi^+ (a_0^0 \rightarrow) \pi^0 \eta + \pi^0 (a_0^+ \rightarrow) \pi^+ \eta) = \mathcal{A}_a + \mathcal{A}_b ,$$

$$\mathcal{A}_a \equiv \mathcal{A}(D_s^+ \rightarrow \pi^+ (a_0^0 \rightarrow) \pi^0 \eta) = \frac{1}{m_{12}^2 - m_{a_0^0}^2 + im_{a_0^0}\Gamma_{a_0^0}}$$

$$\times i \int \frac{d^4 q_3}{(2\pi)^4} \frac{\hat{\mathcal{A}}_a}{(q_1^2 - m_{\rho^+}^2 + i\epsilon)(q_2^2 - m_\eta^2 + i\epsilon)(q_3^2 - m_{\pi^0}^2)} F_a^2(q_3^2) ,$$

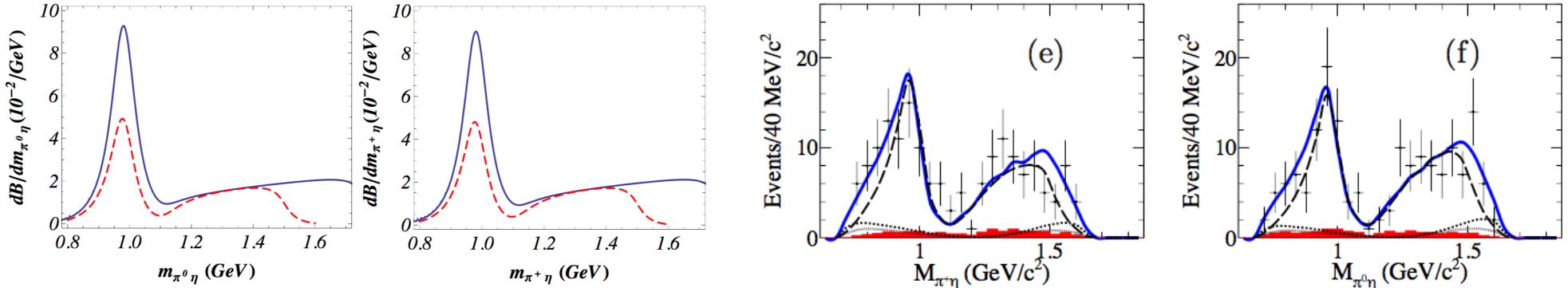
$$\mathcal{A}_b \equiv \mathcal{A}(D_s^+ \rightarrow \pi^0 (a_0^+ \rightarrow) \pi^+ \eta) = \frac{1}{m_{23}^2 - m_{a_0^+}^2 + im_{a_0^+}\Gamma_{a_0^+}}$$

$$\times i \int \frac{d^4 q_3}{(2\pi)^4} \frac{\hat{\mathcal{A}}_b}{(q_1^2 - m_{\rho^+}^2 + i\epsilon)(q_2^2 - m_\eta^2 + i\epsilon)(q_3^2 - m_{\pi^+}^2)} F_b^2(q_3^2) ,$$

$$\hat{\mathcal{A}}_{a(b)} = \mathcal{A}(D_s^+ \rightarrow \eta \rho^+) \mathcal{A}(\eta \pi^{0(+)} \rightarrow a_0^{0(+)}) \mathcal{A}_{a(b)}(\rho^+ \rightarrow \pi^{+(0)} \pi^{0(+)}) \mathcal{A}(a_0^{0(+)} \rightarrow \eta \pi^{0(+)}) ,$$

$$F_{a(b)}(q_3^2) = (m_{\pi^{0(+)}}^2 - \Lambda^2)/(q_3^2 - \Lambda^2) ,$$

$$\Lambda = (1.6 \pm 0.2) \text{ GeV}$$



$$\mathcal{B}(D_s^+ \rightarrow a_0^{0(+)} \pi^{+(0)}) = (1.7 \pm 0.4) \times 10^{-2},$$

$$\mathcal{B}(D_s^+ \rightarrow \pi^{+(0)} (a_0^{0(+)} \rightarrow) \pi^{0(+)} \eta) = (1.5 \pm 0.3) \times 10^{-2},$$

$$\mathcal{B}(D_s^+ \rightarrow \pi^{+(0)} (a_0^{0(+)} \rightarrow) \pi^{0(+)} \eta) = (1.46 \pm 0.15 \pm 0.23) \times 10^{-2}$$

- $D_s^+ \rightarrow \pi^+ (a_0^0 \rightarrow) \pi^0 \eta$ and $D_s^+ \rightarrow \pi^0 (a_0^+ \rightarrow) \pi^+ \eta$

large interference with a relative phase of 180°

$$\rho^+(q_4) \rightarrow \pi^0(q_3)\pi^+(q_4 - q_3), \quad \rho^+(q_4) \rightarrow \pi^+(q_3)\pi^0(q_4 - q_3)$$

$$\mathcal{A}_a(\rho^+ \rightarrow \pi^+ \pi^0) = -\mathcal{A}_b(\rho^+ \rightarrow \pi^0 \pi^+)$$

30% cancellation to the total branching ratio.

Summary

- By explaining $\mathcal{B}(D_s^+ \rightarrow \pi^+(a_0^0 \rightarrow) \pi^0 \eta, \pi^0(a_0^+ \rightarrow) \pi^+ \eta)$ as large as 10^{-2} , we have provided the evidence that a_0 is a tetraquark.
- Apart from $\phi \rightarrow a_0 \gamma$, there rarely exists the decay for a_0 in association with $s\bar{s}$ and $q\bar{q}$ both, which makes the observation by BESIII important.

Thank You