Testing the light scalar meson as a non-$q\bar{q}$ state in semileptonic D decays

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Introduction

Light scalar meson (S_0)

- S_0 with masses below 1 GeV

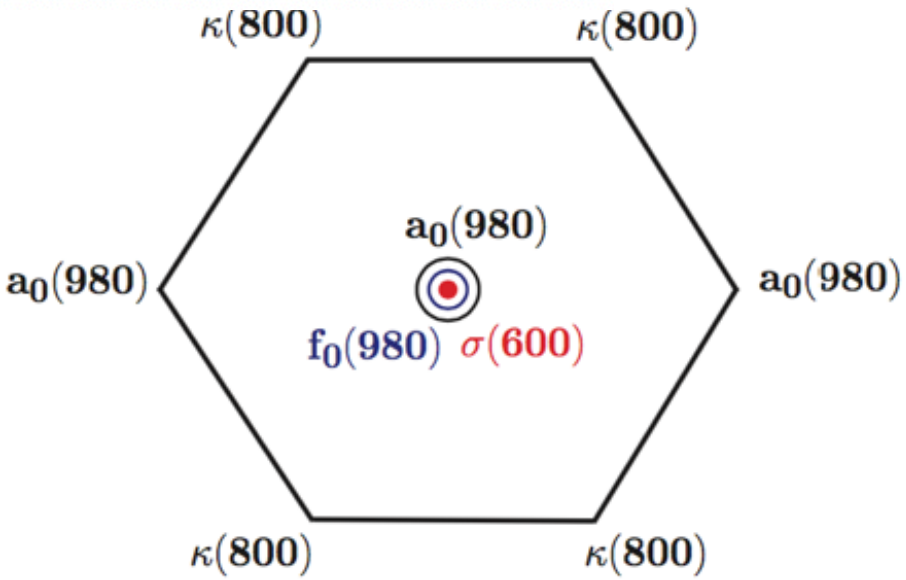
$f_0 \equiv f_0(980)$, $\sigma_0 \equiv f_0(500)$, $a_0 \equiv a_0(980)$, $\kappa \equiv K_0^*(700)$

- Controversially, regarded as

the normal p-wave meson ($q\bar{q}$),

exotic tetraquark [compact $q^2\bar{q}^2$ bound state or

molecular M_1M_2 bound state.]

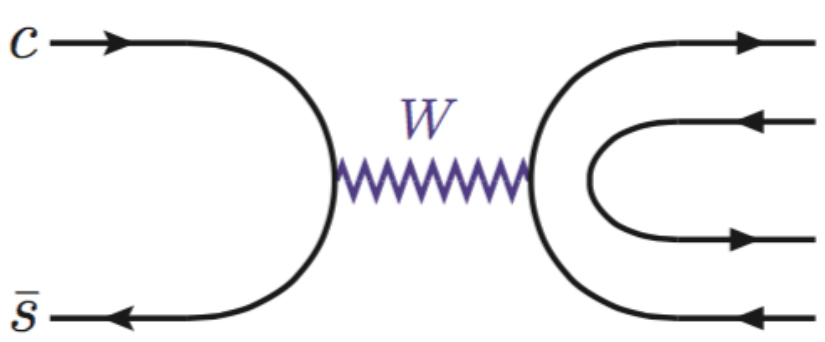


Introduction

- BESIII presented that

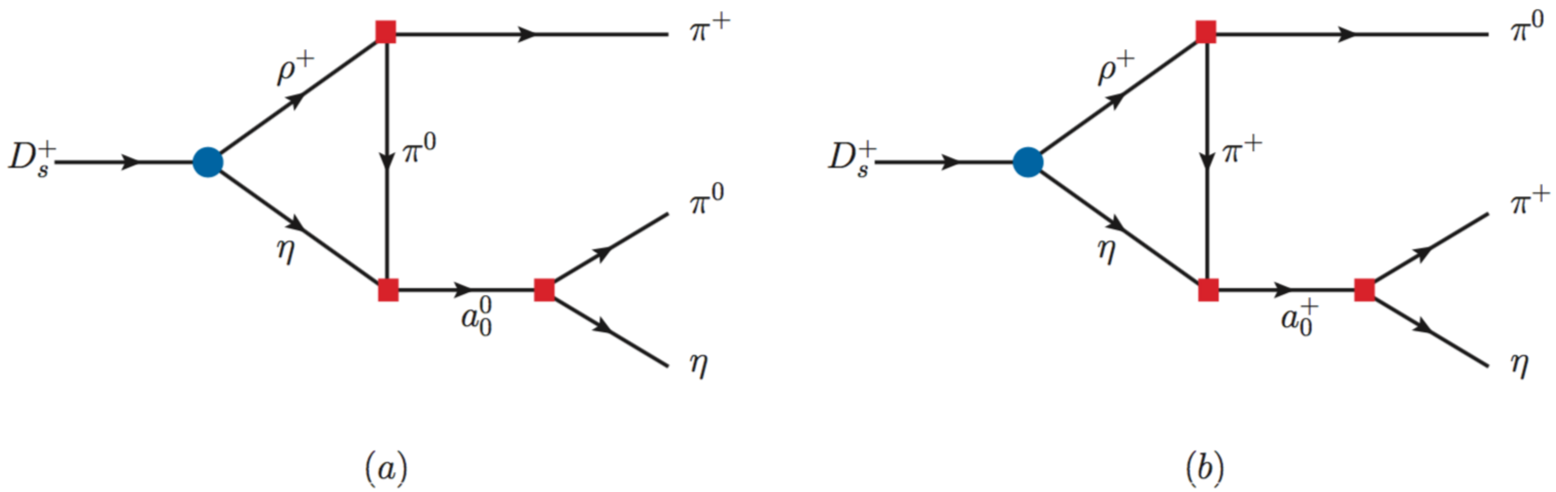
$\mathcal{B}(D_s^+ \to \pi^{+(0)} a_0^{0(+)}, a_0^{0(+)} \to \pi^{0(+)}\eta) = (1.46 \pm 0.15 \pm 0.23) \times 10^{-2}$

"Amplitude analysis of $D_s^+ \to \pi^+\pi^0\eta$ and first observation of the pure W-annihilation decays $D_s^+ \to a_0(980)^+\pi^0$ and $D_s^+ \to a_0(980)^0\pi^+$," [PRL123,112001 (2019)]



$D_s^+ \to a_0^{0(+)}\pi^{+(0)}, a_0^{0(+)} \to \pi^{0(+)}\eta$

Triangle rescattering as FSI [Hsiao, Yu, Ke, EPJC80, 895 (2020)]



$$\mathcal{B}(D_s^+ \to a_0^{0(+)}\pi^{+(0)}) = (1.7 \pm 0.2 \pm 0.1) \times 10^{-2},$$

$$\mathcal{B}(D_s^+ \to \pi^{+(0)}(a_0^{0(+)} \to)\pi^{0(+)}\eta) = (1.4 \pm 0.1 \pm 0.1) \times 10^{-2},$$

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

large interference with a relative phase of 180°

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

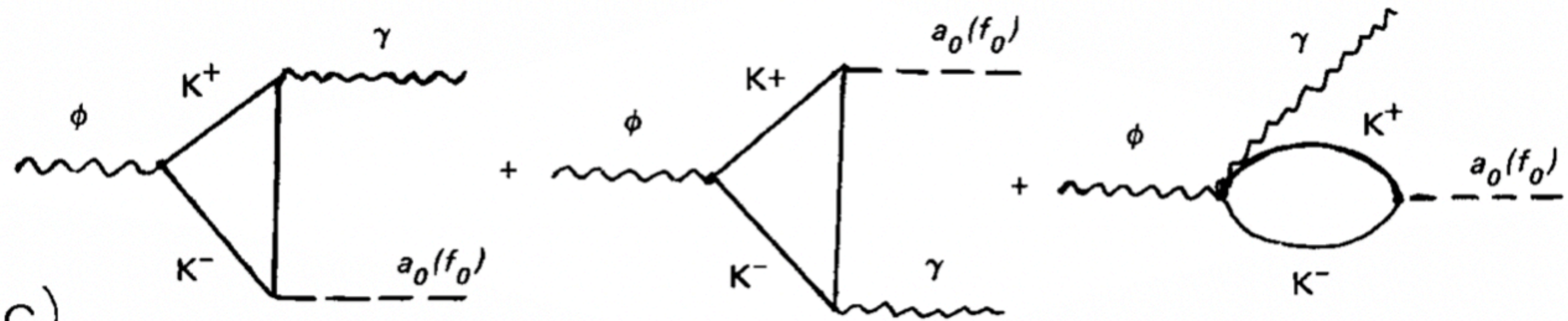
$\mathcal{A}_a(\rho^+ \to \pi^+\pi^0) = -\mathcal{A}_b(\rho^+ \to \pi^0\pi^+)$

30% cancellation to the total branching ratio.

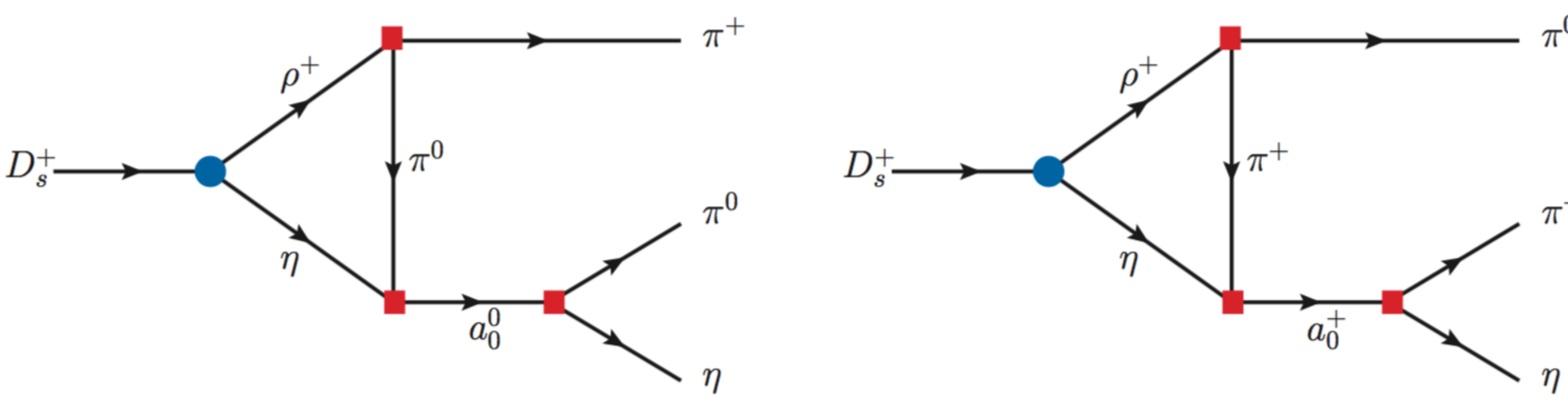
$\mathcal{B}(\phi \to a_0\gamma) \sim 10^{-4}$ from the kaon-loop calculation.

[Achasov, Ivanchenko, NPB315, 465 (1989)],

"On a Search for Four Quark States in Radiative Decays of ϕ Meson."



(c)



(a) (b)

• BESIII has recently measured that

1. PRD105, 3 (2022)

$\mathcal{B}(D_s^+ \to f_0 e^+ \nu_e, f_0 \to \pi^0\pi^0) = (7.9 \pm 1.4 \pm 0.3) \times 10^{-4}$,

$\mathcal{B}(D_s^+ \to \sigma_0 e^+ \nu_e, \sigma_0 \to \pi^0\pi^0) < 6.4 \times 10^{-4}$ (90% C.L.).

2. PRL132, 141901 (2024) [arXiv:2303.12927]

$\mathcal{B}(D_s^+ \to f_0 e^+ \nu_e, f_0 \to \pi^+\pi^-) = (1.72 \pm 0.13 \pm 0.10) \times 10^{-3}$

$\mathcal{B}(D_s^+ \to \sigma_0 e^+ \nu_e, \sigma_0 \to \pi^+\pi^-) < 3.3 \times 10^{-4}$ (90% C.L.).

Form factor (FF), extracted as

$f^+(0)|V_{cs}| = 0.504 \pm 0.017 \pm 0.035$, $f^+(0) = f^+(p^2)$ at $p^2 = 0$,

$|V_{cs}|$ the $c \to s$ CKM matrix element,

test the model calculations

TABLE I. Comparison of the FF at $q^2 = 0$ between our measurement and various theoretical predictions.

	This work	CLFD [6]	DR [6]	QCDSR [7]	QCDSR [8]	LCSR [9]	LFQM [11]	CCQM [12]
$f_+^{f_0}(0)$	$0.518 \pm 0.018_{\rm stat} \pm 0.036_{\rm syst}$	0.45	0.46	0.50 ± 0.13	0.48 ± 0.23	0.30 ± 0.03	0.24 ± 0.05	0.39 ± 0.02
Difference (σ)	—	—	—	0.1	0.2	4.3	4.3	2.8
ϕ in theory	—	$(32 \pm 4.8)^\circ$	$(41.3 \pm 5.5)^\circ$	35°	$(8^{+21}_{-8})^\circ$	—	$(56 \pm 7)^\circ$	31°

- a_0, f_0, and σ_0 in $q\bar{q}$ and $q^2\bar{q}^2$ pictures

$SU(3)$ relations, mixing scenarios

$|\theta| \simeq 20^\circ$ for $q\bar{q}$, $|\theta| < 10^\circ$ for $q^2\bar{q}^2$,

FFs for $q\bar{q}$ and $q^2\bar{q}^2$ can be very different

- extracting $f^+(0)$ from the data,

calculating $\mathcal{B}(D \to S_0 e^+ \nu, S_0 \to M_1 M_2)$

compared to the data

used to test the two quark contents

S_0 formation in weak decays, such as

- $D \to S_0 P$ [H. Y. Cheng, PRD67, 034024 (2003)],

"Hadronic D decays involving scalar mesons,"

- $D, B \to S_0 e^+ \nu$ [Wang, Lu, PRD82, 034016 (2010)],

"Distinguishing two kinds of scalar mesons from heavy meson decays,"

- $\bar{B}^0_{(s)} \to J/\psi(f_0, \sigma_0)$ [Stone, Zhang, PRL (2013)], *"Use of $B \to J/\psi f_0$ decays to discern the $q\bar{q}$ or tetraquark nature of scalar mesons,"*

$D \to S_0 e^+ \nu_e$ and $D \to S_0 e^+ \nu_e, S_0 \to M_1 M_2$

• Used to investigate the quark constituents of the scalar meson:

1. Wang, Lu, PRD82, 034016 (2010), *"Distinguishing two kinds of scalar mesons from heavy meson decays."*

2. Achasov, Kiselev, Shestakov, PRD102, 016022 (2020), *"Semileptonic decays $D \to \pi^+\pi^- e^+ \nu_e$ and $D_s \to \pi^+\pi^- e^+ \nu_e$ as the probe of constituent quark-antiquark pairs in the light scalar mesons"*

3. Achasov, Kiselev, Shestakov, PRD104, 016034 (2021), *"Semileptonic decays $D \to \eta\pi e\nu$ in the $a_0(980)$ region,"* taking $a_0(980)$ as a tetraquark.

Amplitudes of $D \to S_0 e^+ \nu_e, S_0 \to M_1 M_2$

- $\mathcal{M}(D \to S_0 e^+ \nu_e) = \frac{G_F}{\sqrt{2}} V_{cq} \langle S_0 | \bar{q} \gamma_\mu (1-\gamma_5) c | D \rangle \bar{u}_\nu \gamma_\mu (1-\gamma_5) v_e,$
- $\langle S_0 | (\bar{q} c) | D \rangle = i (p_D + p_{S_0})_\mu f^+(p^2) + i \frac{m_D^2 - m_{S_0}^2}{p^2} p_\mu [f^0(p^2) - f^+(p^2)],$
- FFs with the double and single pole representations:

Becirevic, Kaidalov, PLB478, 417 (2000),

"Comment on the heavy $\to$ light form-factors."

$f^+(p^2) = \frac{f(0)}{(1-p^2/m_{\mathrm{A}}^2)^2}$, $f^0(p^2) = \frac{f(0)}{1-p^2/m_{\mathrm{B}}^2}$,

$f(0)$: $f(p^2)$ at $p^2 = 0$, pole masses: m_{A} and m_{B}.

FFs with 2 possible quark contents of S_0

- $q\bar{q}$:

$$|n\bar{n}\rangle \equiv |\sqrt{1/2}(u\bar{u} + d\bar{d})\rangle$$

$$|f_0\rangle = \cos\theta_I |s\bar{s}\rangle + \sin\theta_I |n\bar{n}\rangle,$$

$$|\sigma_0\rangle = -\sin\theta_I |s\bar{s}\rangle + \cos\theta_I |n\bar{n}\rangle,$$

$$|a_0^0\rangle = |\sqrt{1/2}(u\bar{u} - d\bar{d})\rangle,\ |a_0^-\rangle = |d\bar{u}\rangle,$$

- FFs with $q\bar{q}$: $D^+ \to d\bar{d} \to S_0,\ D_s^+ \to s\bar{s} \to S_0,$

$$f_n \equiv |n\bar{n}\rangle,\ f_s \equiv |s\bar{s}\rangle$$

$$\langle f_0, \sigma_0|(\bar{d}c)|D^+\rangle = (\sin\theta_I, \cos\theta_I) \times \langle f_n|(\bar{d}c)|D^+\rangle,$$

$$\langle a_0^0|(\bar{d}c)|D^+\rangle = \sqrt{1/2}\langle a_0^-|(\bar{d}c)|D^0\rangle = -\langle f_n|(\bar{d}c)|D^+\rangle,$$

$$\langle f_0, \sigma_0, a_0^0|(\bar{s}c)|D_s^+\rangle = (\cos\theta_I, -\sin\theta_I, 0) \times \langle f_s|(\bar{s}c)|D_s^+\rangle.$$

- $q^2\bar{q}^2$:

$$|n\bar{n}s\bar{s}\rangle \equiv |\sqrt{1/2}(u\bar{u}+d\bar{d})s\bar{s}\rangle,$$

$$|f_0\rangle = \cos\theta_{II}|n\bar{n}s\bar{s}\rangle + \sin\theta_{II}|u\bar{u}d\bar{d}\rangle,$$

$$|\sigma_0\rangle = -\sin\theta_{II}|n\bar{n}s\bar{s}\rangle + \cos\theta_{II}|u\bar{u}d\bar{d}\rangle,$$

$$|a_0^0\rangle = |\sqrt{1/2}(u\bar{u}-d\bar{d})s\bar{s}\rangle,\ |a_0^-\rangle = |d\bar{u}s\bar{s}\rangle.$$

- FFs with $q^2\bar{q}^2$: need extra quark pair from $g \to q\bar{q}$

$$F_{ns} \equiv |n\bar{n}s\bar{s}\rangle,\ F_{ud} \equiv |u\bar{u}d\bar{d}\rangle,$$

$$\langle f_0|(\bar{d}c)|D^+\rangle = \cos\theta_{II}\langle F_{ns}|(\bar{d}c)|D^+\rangle + \sin\theta_{II}\langle F_{ud}|(\bar{d}c)|D^+\rangle,$$

$$\langle \sigma_0|(\bar{d}c)|D^+\rangle = -\sin\theta_{II}\langle F_{ns}|(\bar{d}c)|D^+\rangle + \cos\theta_{II}\langle F_{ud}|(\bar{d}c)|D^+\rangle,$$

$$\langle a_0^0|(\bar{d}c)|D^+\rangle = \sqrt{1/2}\langle a_0^-|(\bar{d}c)|D^0\rangle = -\langle F_{ns}|(\bar{d}c)|D^+\rangle,$$

$$\langle f_0,\sigma_0,a_0^0|(\bar{s}c)|D_s^+\rangle = (\cos\theta_{II}, -\sin\theta_{II}, 0)\times\langle F_{ns}|(\bar{s}c)|D_s^+\rangle.$$

• Calculating $D \to S_0 e^+ \nu, S_0 \to M_1 M_2$ as a four-body decay, instead of using $\mathcal{B} \simeq \mathcal{B}(D \to S_0 e^+ \nu)\mathcal{B}(S_0 \to M_1 M_2)$.

• Resonant amplitudes of $S_0 \to M_1 M_2$:

Flatté formula for f_0 and a_0, Breit-Wigner model for σ_0,

1. $\mathcal{R}_{f_0} \equiv \mathcal{R}(f_0 \to \pi\pi) = \frac{C_{f_0 \to \pi\pi}}{m_{f_0}^2 - t - i m_{f_0}(g_{f_0\pi\pi}\rho_{\pi\pi} + g_{f_0 KK}\rho_{KK})}$,

$\rho_{M_1 M_2} \equiv [(1 - m_+^2/t)(1 - m_-^2/t)]^{1/2}$, $m_\pm = m_{M_1} \pm m_{M_2}$,

$\langle M_1 M_2 | S_0 \rangle \equiv C_{S_0 \to M_1 M_2}$ for $S_0 \to M_1 M_2$ strong decay.

LHCb, PRD86, 052006 (2012),

"Analysis of the resonant components in $B_s \to J/\psi \pi^+ \pi^-$,"

LHCb, PRD92, 032002 (2015),

"Dalitz plot analysis of $B^0 \to \overline{D}^0 \pi^+ \pi^-$ decays."

2. $\mathcal{R}_{a_0} \equiv \mathcal{R}(a_0 \to \pi\eta) = \frac{C_{a_0\to\pi\eta}}{m_{a_0}^2 - t - i(g_{a_0\pi\eta}^2 \rho_{\pi\eta} + g_{a_0 KK}^2 \rho_{KK})}$,

BaBar, PRD72, 052008 (2005),

"Dalitz plot analysis of $D^0 \to \bar{K}^0 K^+ K^-$,"

BESIII, arXiv:2006.02800 [hep-ex],

"Analysis of the decay $D^0 \to K_S^0 K^+ K^-$,"

3. $\mathcal{R}_{\sigma_0} \equiv \mathcal{R}(\sigma_0 \to \pi\pi) = \frac{C_{\sigma_0\to\pi\pi}}{m_{\sigma_0}^2 - t - i\, m_{\sigma_0}\Gamma_{\sigma_0}}$,

$\Gamma_{\sigma_0} \equiv (\rho_{\pi\pi}/\bar{\rho}_{\pi\pi})\Gamma_{\sigma_0}^0$, $\bar{\rho}_{\pi\pi} = \rho_{\pi\pi}(t)$ at $t = m_{\sigma_0}^2$,

LHCb, PRD87, 052001 (2013),

"Analysis of the resonant components in $\bar{B}^0 \to J/\psi\pi^+\pi^-$."

- **Amplitude of $D \to S_0 e^+\nu, S_0 \to M_1 M_2$:**

$\mathcal{M} = \mathcal{R}_{S_0}\mathcal{M}(D \to S_0 e^+ \nu_e)$.

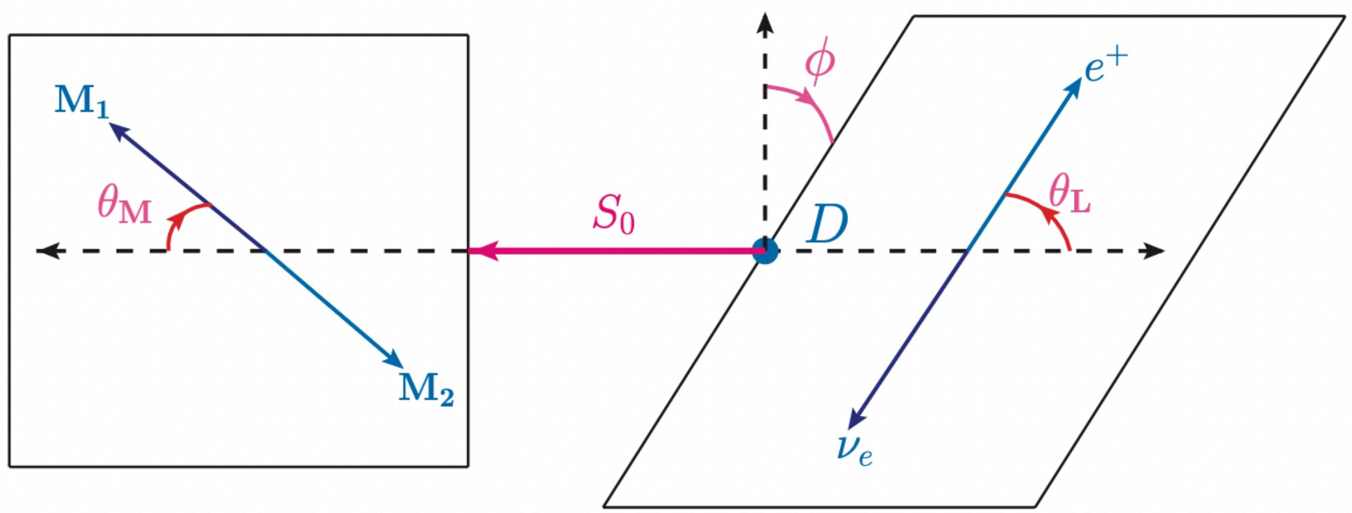
Phase space $D(p_D) \to S_0(p_{S_0})e^+(p_e)\nu(p_\nu), S_0(p_{S_0}) \to M_1(p_1)M_2(p_2)$

$$d\Gamma = \frac{|\bar{\mathcal{M}}|^2}{4(4\pi)^6 m_D^3} X \alpha_{\mathbf{M}} \alpha_{\mathbf{L}}\, ds\, dt\, d\cos\theta_{\mathbf{M}}\, d\cos\theta_{\mathbf{L}}\, d\phi$$

$$X = [(m_D^2 - s - t)^2/4 - st]^{1/2},$$

$$\alpha_{\mathbf{M}} = \lambda^{1/2}(t, m_1^2, m_2^2)/t,\ \alpha_{\mathbf{L}} = \lambda^{1/2}(s, m_e^2, m_\nu^2)/s$$

$$\lambda(a,b,c) = a^2 + b^2 + c^2 - 2ab - 2bc - 2ca.$$



The allowed regions of the variables:

$(m_e + m_\nu)^2 \le s \le (m_D - \sqrt{t})^2,$

$(m_1 + m_2)^2 \le t \le (m_D - m_e - m_\nu)^2,$

$0 \le \theta_{\mathbf{M},\mathbf{L}} \le \pi$, and $0 \le \phi \le 2\pi$.

Theoretical inputs

- Mixing angle:

$\theta_I = (158.7 \pm 4.0)^\circ$, Klempt, PLB820, 136512 (2021),

"Scalar mesons and the fragmented glueball."

$\theta_{II} = (174.6^{+3.4}_{-3.2})^\circ$, Maiani, Piccinini, Polosa, Riquer,

PRL93, 212002 (2004), *"A New look at scalar mesons."*

- Parameters in the denominator of $\mathcal{R}_{S_0}$

$(m_{f_0}, g_{f_0\pi\pi}) = (940, 199 \pm 30)$ MeV, $g_{f_0KK} = (3.0 \pm 0.3) g_{f_0\pi\pi}$,

$(m_{a_0}, g_{a_0\pi\eta}) = (999, 324 \pm 15)$ MeV, $g^2_{a_0KK} = (1.03 \pm 0.14) g^2_{a_0\pi\eta}$,

$(m_{\sigma_0}, \Gamma^0_{\sigma_0}) = (500, 500)$ MeV.

- $C_{S_0 \to M_1 M_2}$

$C_{f_0 \to \pi^+\pi^-} = \sqrt{2} C_{f_0 \to \pi^0\pi^0} = (1.5 \pm 0.1)$ GeV,

$C_{a_0^{-(0)} \to \pi^{-(0)}\eta} = (2.5 \pm 0.2)$ GeV,

$C_{\sigma_0 \to \pi^+\pi^-} = \sqrt{2} C_{\sigma_0 \to \pi^0\pi^0} = (3.9 \pm 0.1)$ GeV.

Numerical results

We determine $F^{D\to S_0} \equiv f(0)$ for $D \to S_0$:

$|F^{D_s^+\to f_0}_{q\bar{q},q^2\bar{q}^2}| = (0.52 \pm 0.02, 0.53 \pm 0.02)$,

agreeing with the experimental value of

0.52 ± 0.04 by BESIII,

justifying our determination.

decay channel	our work: $(q\bar{q}, q^2\bar{q}^2)$	experimental data
$10^4\mathcal{B}(D_s^+ \to f_0 e^+\nu_e, f_0 \to \pi^+\pi^-)$	$(16.9 \pm 1.2 \pm 0.7,\ 17.2 \pm 1.3 \pm 0.7)$	17.1 ± 1.6 [48]
$10^4\mathcal{B}(D_s^+ \to f_0 e^+\nu_e, f_0 \to \pi^0\pi^0)$	$(8.4 \pm 0.6 \pm 0.4,\ 8.6 \pm 0.7 \pm 0.4)$	7.9 ± 1.4 [49]
$10^4\mathcal{B}(D_s^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^+\pi^-)$	$(20.3 \pm 1.8 \pm 0.5,\ 0.58^{+1.43}_{-0.57} \pm 0.01)$	< 3.3 [48]
$10^4\mathcal{B}(D_s^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^0\pi^0)$	$(10.7 \pm 1.0 \pm 0.3,\ 0.29^{+0.72}_{-0.29} \pm 0.01)$	< 7.3 [49] (< 1.7 [48])†
$10^4\mathcal{B}(D^0 \to a_0^- e^+\nu_e, a_0^- \to \pi^-\eta)$	$(1.8 \pm 0.2 \pm 0.2,\ 0.8 \pm 0.1 \pm 0.1)$	1.3 ± 0.3 [8]
$10^4\mathcal{B}(D^+ \to a_0^0 e^+\nu_e, a_0^0 \to \pi^0\eta)$	$(2.4 \pm 0.2 \pm 0.3,\ 1.0 \pm 0.1 \pm 0.1)$	1.7 ± 0.7 [8]
$10^5\mathcal{B}(D^+ \to f_0 e^+\nu_e, f_0 \to \pi^+\pi^-)$	$(1.3 \pm 0.1 \pm 0.1, 2.9 \pm 0.7 \pm 0.2)$	< 2.8 [87]
$10^4\mathcal{B}(D^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^+\pi^-)$	$(5.4 \pm 0.5 \pm 0.1,\ 6.2 \pm 0.9 \pm 0.1)$	6.3 ± 0.5 [87]

• From the mixing, we obtain

$F^{D_s^+\to\sigma_0}_{(q\bar{q},q^2\bar{q}^2)} = -(\tan\theta_I, \tan\theta_{II}) \times F^{D_s^+\to f_0}$

$= (0.22 \pm 0.01, 0.037 \pm 0.032)$, leading to

$\mathcal{B}^{D_s^+\to\sigma_0\to\pi^+\pi^-}_{(q\bar{q},q^2\bar{q}^2)} \equiv \mathcal{B}_{(q\bar{q},q^2\bar{q}^2)}(D_s^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^+\pi^-)$

$= (20.3 \pm 1.8 \pm 0.5, 0.58^{+1.43}_{-0.57} \pm 0.01) \times 10^{-4}$,

$\mathcal{B}^{D_s^+\to\sigma_0\to\pi^0\pi^0}_{(q\bar{q},q^2\bar{q}^2)} \equiv \mathcal{B}_{(q\bar{q},q^2\bar{q}^2)}(D_s^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^0\pi^0)$

$= (10.7 \pm 1.0 \pm 0.3, 0.29^{+0.72}_{-0.29} \pm 0.01) \times 10^{-4}$,

respecting isospin symmetry.

• Compared to the data:

$\mathcal{B}(D_s^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^+\pi^-) < 3.3 \times 10^{-4}$,

$\mathcal{B}(D_s^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^0\pi^0) < 6.4 \times 10^{-4}$ or 1.7×10^{-4}.

• 9σ (10σ) deviations

Excluding the possibility that S_0 is a ordinary $q\bar{q}$ meson.

Semileptonic $D^{+(0)}$ decays

- Form factors: $F^{D_s^+\to F_{ns}}$, $F^{D^+\to F_{ns}}$, $F^{D^+\to F_{ud}}$

$$(F_{q^2\bar{q}^2}^{D_s^+\to f_0}, F_{q^2\bar{q}^2}^{D_s^+\to \sigma_0}) = (\cos\theta_{II}, -\sin\theta_{II}) \times F^{D_s^+\to F_{ns}}$$

$$F_{q^2\bar{q}^2}^{D^+\to a_0^0} = -F^{D^+\to F_{ns}}, \; F_{q^2\bar{q}^2}^{D^0\to a_0^-} = -\sqrt{2}F^{D^+\to F_{ns}}$$

$$F_{q^2\bar{q}^2}^{D^+\to f_0} = \cos\theta_{II} F^{D^+\to F_{ns}} + \sin\theta_{II} F^{D^+\to F_{ud}}$$

$$F_{q^2\bar{q}^2}^{D^+\to \sigma_0} = -\sin\theta_{II} F^{D^+\to F_{ns}} + \cos\theta_{II} F^{D^+\to F_{ud}}$$

$$F^{D^+\to F_{ud}} = \sqrt{2}F^{D^+\to F_{ns}} \; [SU(3)_f \text{ assumption}]$$

- Experimental data:

$$\mathcal{B}(D^0 \to a_0^- e^+\nu_e, a_0^- \to \pi^-\eta) = (1.3 \pm 0.3) \times 10^{-4},$$

$$\mathcal{B}(D^+ \to a_0^0 e^+\nu_e, a_0^0 \to \pi^0\eta) = (1.7 \pm 0.7) \times 10^{-4},$$

$$\mathcal{B}(D^+ \to f_0 e^+\nu_e, f_0 \to \pi^+\pi^-) < 2.8 \times 10^{-5},$$

$$\mathcal{B}(D^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^+\pi^-) = (6.3 \pm 0.5) \times 10^{-4}.$$

• $\bar{B}_s^0 \to J/\psi(f_0, \sigma_0)$, $\bar{B}^0 \to J/\psi(f_0, \sigma_0)$,

through $\bar{B}_s^0 \to s\bar{s} \to (f_0, \sigma_0)$ and $\bar{B}^0 \to d\bar{d} \to (f_0, \sigma_0)$.

• Proposed to distinguish between the quark content of

S_0 being quark-antiquark or tetraquark [Stone, Zhang, PRL (2013)].

• The following measurement of $\bar{B}_s^0 \to J/\Psi f_0, f_0 \to \pi^+\pi^-$

suggests the mixing angle to be less than $7.7°$,

LHCb, PRD89, 092006 (2014), *"Measurement of resonant and*

CP components in $\bar{B}_s^0 \to J/\psi\pi^+\pi^-$ *decays,"*

consistent with the tetraquark interpretation.

Summary

- We obtained

$$\mathcal{B}_{(q\bar{q})}^{D_s^+\to\sigma_0\to\pi^+\pi^-} = (20.3 \pm 1.8 \pm 0.5) \times 10^{-4},$$
$$\mathcal{B}_{(q\bar{q})}^{D_s^+\to\sigma_0\to\pi^0\pi^0} = (10.7 \pm 1.0 \pm 0.3) \times 10^{-4},$$

in comparison with the data:

$$\mathcal{B}(D_s^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^+\pi^-) < 3.3 \times 10^{-4},$$

$$\mathcal{B}(D_s^+ \to \sigma_0 e^+\nu_e, \sigma_0 \to \pi^0\pi^0) < 6.4 \times 10^{-4}\ (1.7 \times 10^{-4}).$$

- It has leaded to the 9σ (10σ) deviations:

not favoring S_0 as a ordinary $q\bar{q}$ meson.

Thank You