Study of scalar and vector mesons in the charmed hadron decays at BESIII

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On behalf of BESIII Collaboration

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Outline

- Motivation
- BESIII charm dataset
- Hadronic decays
- Semi-leptonic Decay
- Summary & Outlook

Motivation-Quark model

[1] PRL 92 (2004), 102001
[2] PRD 75 (2007) 074015
[3] PRD 76 (2007) 094025
[4] PRD 83 (2011) 032003

- The constituent quark model has been very successful in explaining the composition of hadrons in the past few decades.
- The observed meson spectrum is described as bound $q\bar{q}$ states grouped into SU(n) flavor multiplets.
- The properties of pseudoscalar ($J^P = 0^-$) and vector ($J^P = 1^-$) mesons can be well explained, but the properties of scalar mesons ($S_0, J^P = 0^+$) is still controversial.

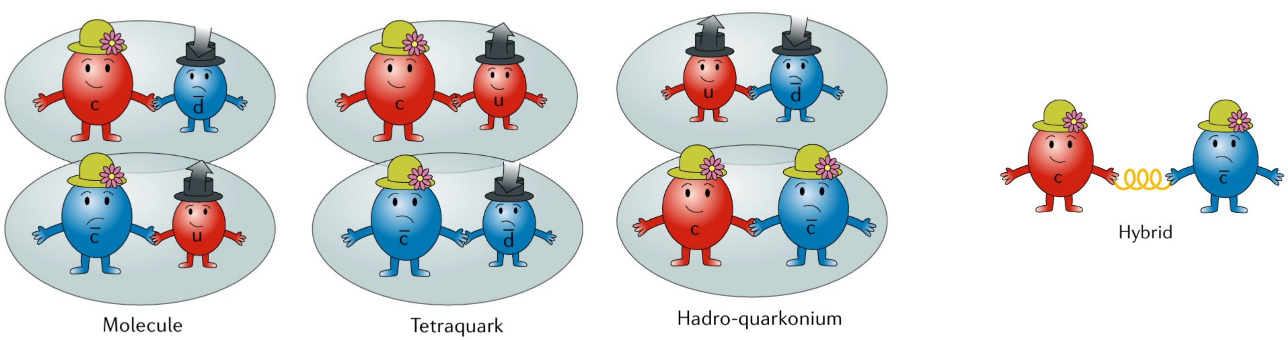
PDG: Tentative classification

	Γ [MeV]	isospin i	structure
$a_0(980)$	~ 50	1	$K\bar{K}, qq\bar{q}\bar{q}$
$f_0(980)$	~ 50	0	$K\bar{K}, qq\bar{q}\bar{q}$
$f_0(500)$	~ 800	0	$\pi\pi, qq\bar{q}\bar{q}$
$K_0^*(700)$	~ 600	$\frac{1}{2}$	$K\pi, qq\bar{q}\bar{q}$
$a_0(1450)$	265	1	$u\bar{d}, d\bar{u}, d\bar{d} - u\bar{u}$
$f_0(1370)$	~ 400	0	$d\bar{d} + u\bar{u}$
$f_0(1710)$	125	0	$s\bar{s}$
$K_0^*(1430)$	294	$\frac{1}{2}$	$u\bar{s}, d\bar{s}, s\bar{u}, s\bar{d}$

Motivation-Scalar mesons

[1] PRL 92 (2004), 102001
[2] PRD 75 (2007) 074015
[3] PRD 76 (2007) 094025
[4] PRD 83 (2011) 032003

- Puzzles: mass degeneracy between $\boldsymbol{a_0(980)}$ and $\boldsymbol{f_0(980)}$, broad width of $\boldsymbol{K(700)}$ and $\boldsymbol{f_0(500)}$.
- It is generally believed that they are not the ordinary $q\bar{q}$ state.
- Many interpretations: compact tetraquark $q^2\bar{q}^2$ state, molecule (K$\bar{K}$ bound) state, hybrid etc[1-4].



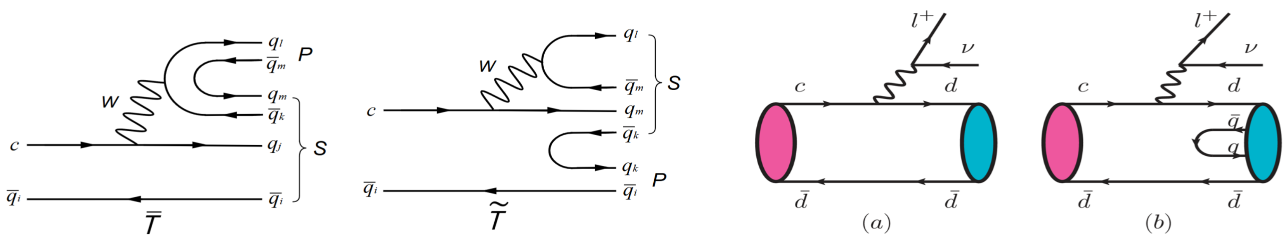
Motivation-Scalar mesons

[1] arXiv:2408.13942
[2] arXiv:2306.06091
[3] PRD 82, 034016 (2010)

- Charm mesons have abundant final state interactions, which the production of exotic states essentially involves, such as quark exchange, resonance formation, etc.

- Some examples:

1. There are more possible topological amplitudes for tetraquark, i.e. the branching fraction will be different from the $q\bar{q}$ structure[1].



2. Different quark structures have different mixing situations. The mixing angle facilitate a connection of all form factors in $D \to S_0 e^+ \nu_e$ decays under the SU(3) flavor symmetry[2].

3. In the SU(3) symmetry limit, the ratio of $\frac{\mathcal{B}(D^+ \to f_0(980) l^+ \nu_l) + \mathcal{B}(D^+ \to f_0(500) l^+ \nu_l)}{\mathcal{B}(D^+ \to a_0^0(980) l^+ \nu_l)}$ has different expectations for different quark explanations[3].

$\begin{cases} 1 & \text{two quark} \\ 3 & \text{tetra-quark} \end{cases}$

Motivation-vector meson ϕ

$\phi(1020)$ **DECAY MODES**

	Mode	*Fraction* (Γ_i / Γ)
Γ_1	$K^+ K^-$	$(49.1 \pm 0.5)\%$
Γ_2	$K_L^0 K_S^0$	$(33.9 \pm 0.4)\%$
Γ_3	$\rho\pi + \pi^+\pi^-\pi^0$	$(15.4 \pm 0.4)\%$

- Most ϕ measurements are performed in the e^+e^- annihilation and $K-p$ scattering, which may encounter challenges from complex background and various interferences.

A new, independent method is needed to cross-check ϕ measurements

- The $D^+_{(s)}$ decay products contain a large number of ϕ mesons, providing excellent experimental conditions for the study of ϕ mesons.
- The ϕ relative BF measurement can be obtained (by measuring the BF of $D^+_{(s)} \to \phi\pi^+$ in different final states of ϕ).

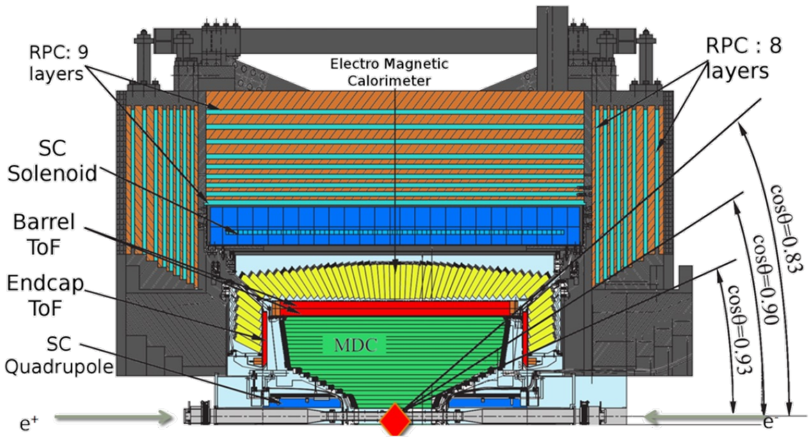
BESIII charm dataset

$D^{\pm,0}$: 20.3 fb^{-1} @E_{cm}=3.773 GeV

$D_s^{\pm}$: 7.33 fb^{-1} @E_{cm}=4.128 − 4.226GeV

$\Lambda_c^{\pm}$: 6.1 fb^{-1} @E_{cm}=4.600-4.843GeV

Pair-production near threshold

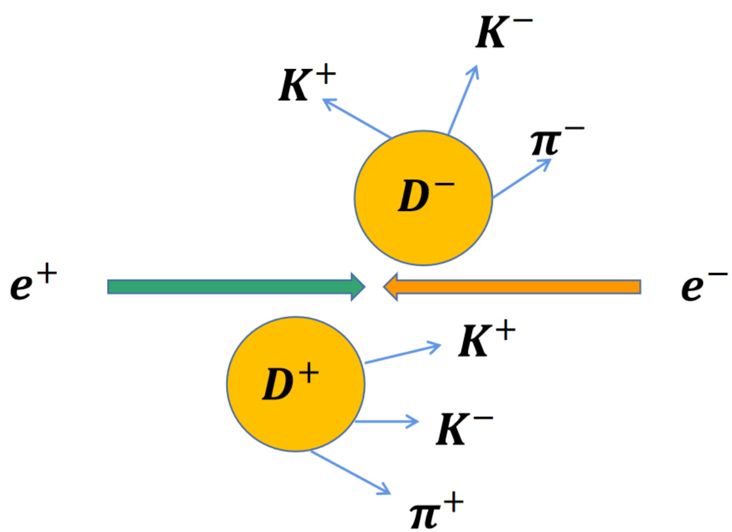


Single Tag (ST): reconstruct only one of the ($D\bar{D}$ or $\Lambda_c^+\bar{\Lambda}_c^-$)

- Relative high background
- Higher efficiency

Double Tag (DT): reconstruct both of the hadrons

- Clean samples
- Systematics in the tag side almost cancel out
- Absolute branching fraction measurement



in the hadronic decays

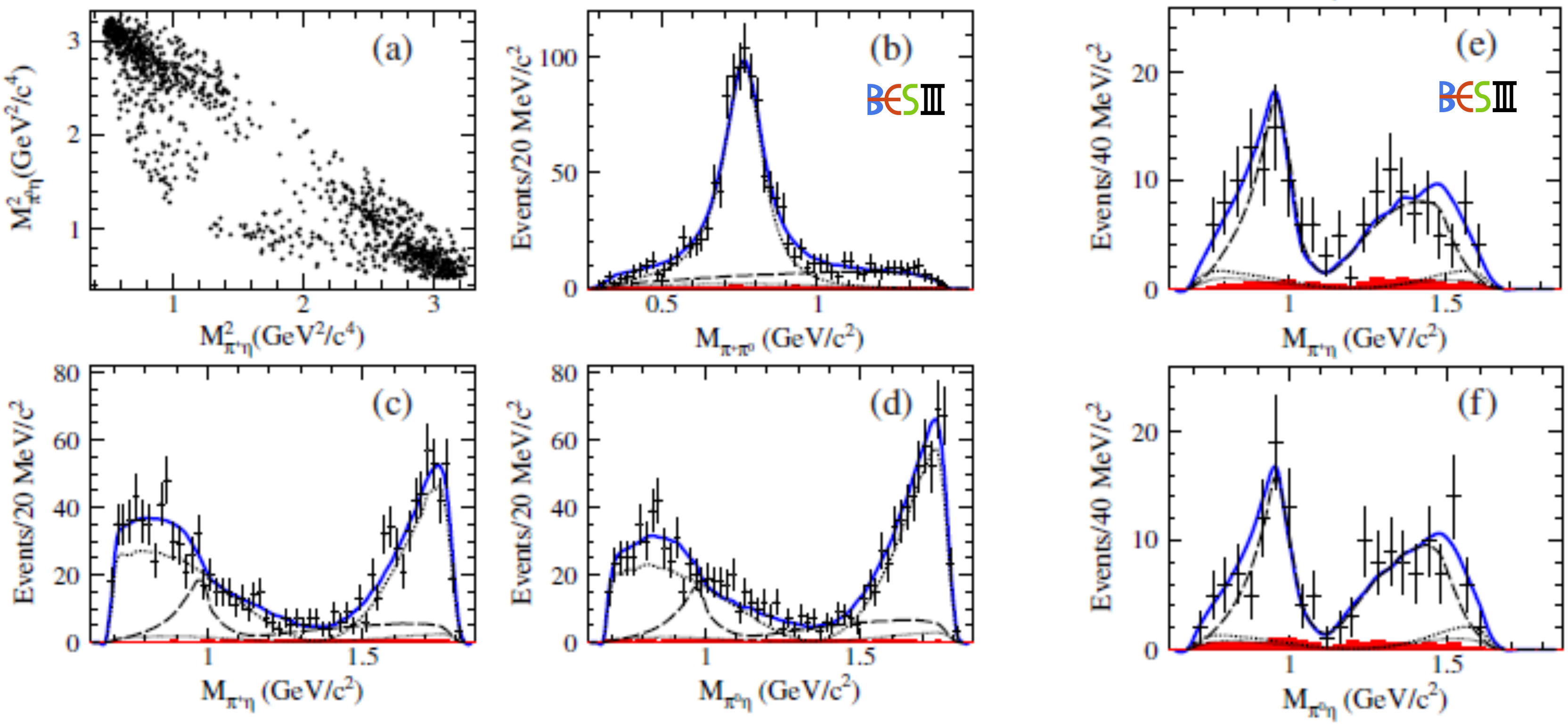
Amplitude analysis of $D_s^+ \to \pi^+\pi^0\eta$
- Observation of $D_s^+ \to a_0(980)\pi$

PRL123, 112001 (2019)

$D_s^+ \to \pi^+\pi^0\eta$

Full sample

Sub-sample with $M_{\pi^+\pi^0} > 1.0$ GeV/c^2

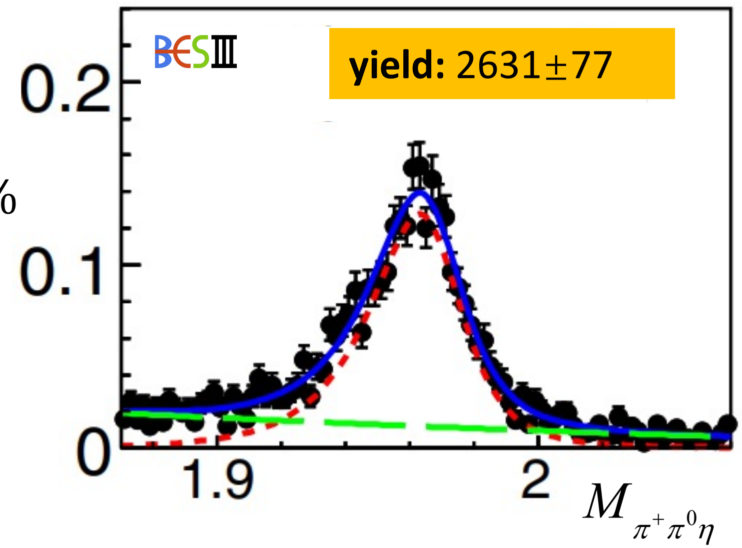


Dots with error bar: data; solid: total fit; dotted: $D_s^+ \to \rho^+\eta$; dashed: $D_s^+ \to a_0(980)\pi$ (**with a stat. significance of 16.2σ**).

Branching Fraction Results of $D_s^+ \to \pi^+\pi^0\eta$

PRL123, 112001 (2019)

Fit to the invariant mass $M_{\pi^+\pi^0\eta}$ to get the yield.



$$\mathcal{B}(D_s^+ \to \pi^+\pi^0\eta) = (9.50 \pm 0.28_{stat.} \pm 0.41_{syst.})\%$$

PDG value = $(9.2 \pm 1.2)\%$

BF(sub-mode n) = $\mathcal{B}(D_s^+ \to \pi^+\pi^0\eta) FF(n)$

Branching fraction (%)
$\mathcal{B}(D_s^+ \to \rho^+\eta) = 7.44 \pm 0.52_{stat.} \pm 0.38_{sys.}$
$\mathcal{B}(D_s^+ \to a_0(980)^+\pi^0)^* = 1.46 \pm 0.15_{stat.} \pm 0.23_{sys.}$
$\mathcal{B}(D_s^+ \to a_0(980)^0\pi^+)^* = 1.46 \pm 0.15_{stat.} \pm 0.23_{sys.}$

*here, $a_0(980) \to \pi\eta$

PDG value = $(8.9 \pm 0.9)\%$

First observation !

- $\mathcal{B}(D_s^+ \to a_0(980)^+\pi^0$ is larger than other measured pure W-annihilation decays ($D_s^+ \to p\bar{n}$, $D_s^+ \to \omega\pi^+$) by one order.

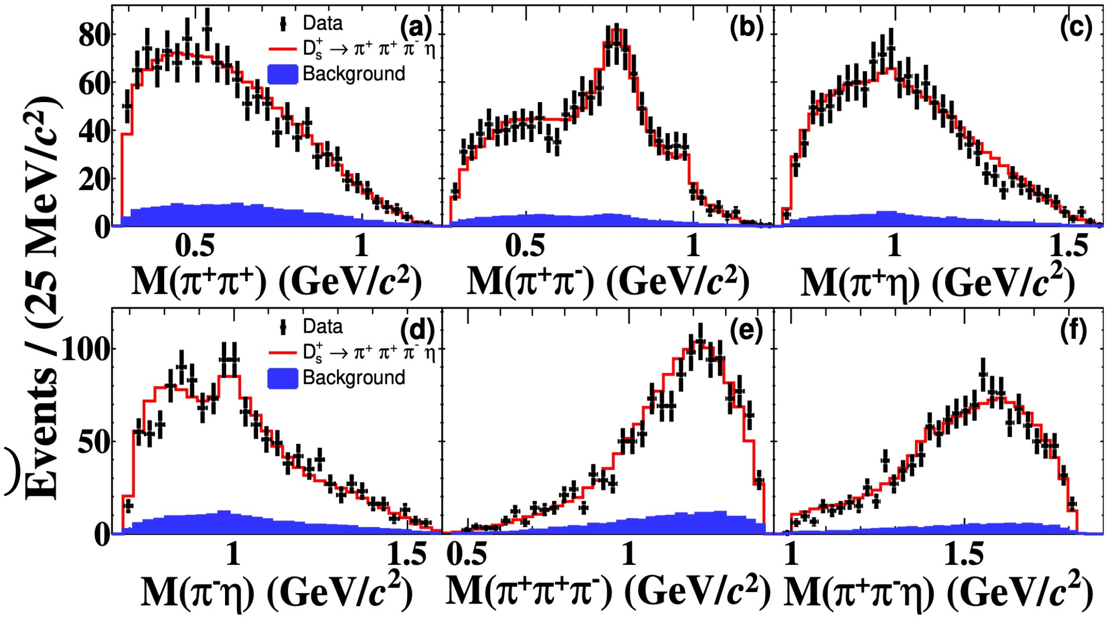
Amplitude analysis of $D_s^+ \to \pi^+\pi^+\pi^-\eta$

2139 events with purity > 85%

PRD 104, L071101 (2021)

$\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^-\eta)$
$=(3.12\pm0.13\pm0.09)\%$

$\mathcal{B}(D_s^+ \to a_0^+(980)\rho^0, a_0^+(980) \to \pi^+\eta)$
$=(0.21\pm0.08\pm0.05)\%$



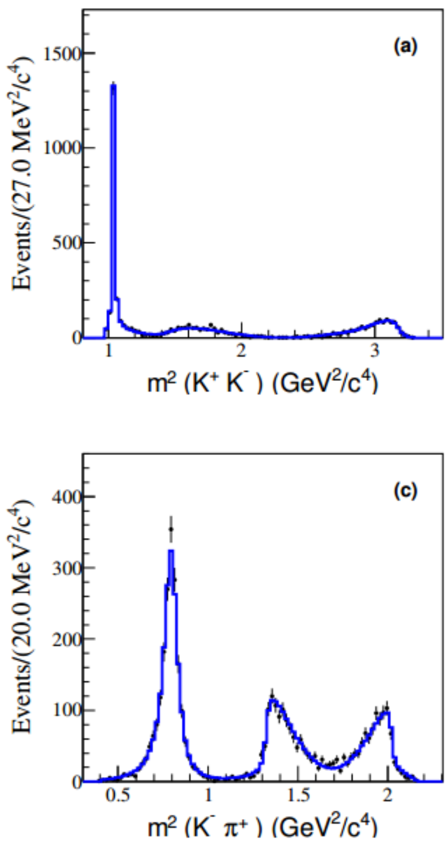
Amplitude	Phase	FF(%)
$a_1(1260)^+(\rho(770)^0\pi^+)\eta$	0.0(fixed)	$55.4\pm3.9\pm2.0$
$a_1(1260)^+(f_0(500)\pi^+)\eta$	$5.0\pm0.1\pm0.1$	$8.1\pm1.9\pm2.1$
$a_0(980)^+\rho(770)^0$	$2.5\pm0.1\pm0.1$	$6.7\pm2.5\pm1.5$
$\eta(1405)(a_0(980)^-\pi^+)\pi^+$	$0.2\pm0.2\pm0.1$	$0.7\pm0.2\pm0.1$
$\eta(1405)(a_0(980)^+\pi^-)\pi^+$	$0.2\pm0.2\pm0.1$	$0.7\pm0.2\pm0.1$
$f_1(1420)(a_0(980)^-\pi^+)\pi^+$	$4.3\pm0.2\pm0.4$	$1.9\pm0.5\pm0.3$
$f_1(1420)(a_0(980)^+\pi^-)\pi^+$	$4.3\pm0.2\pm0.4$	$1.7\pm0.5\pm0.3$
$[a_0(980)^-\pi^+]_S\pi^+$	$0.1\pm0.2\pm0.2$	$5.1\pm1.2\pm0.9$
$[a_0(980)^+\pi^-]_S\pi^+$	$0.1\pm0.2\pm0.2$	$3.4\pm0.8\pm0.6$
$[f_0(980)\eta]_S\pi^+$	$1.4\pm0.2\pm0.3$	$6.2\pm1.7\pm0.9$
$[f_0(500)\eta]_S\pi^+$	$2.5\pm0.2\pm0.3$	$12.7\pm2.6\pm2.0$

Larger than other w-annihilation decays.

How about $D_s^+ \to a_0^+(980)\rho^0$? Does it have the same branching fraction?

Amplitude analysis of $D_s^+ \to K^+K^-\pi^+$

Dalitz plot projections:



Black dots with error bars: data

Blue solid lines: fit results

PRD 104. 012016(2021)

The best precision at present

$$\mathcal{B}(D_s^+ \to K^+K^-\pi^+) = (5.47 \pm 0.08_{stat.} \pm 0.13_{syst.})\%$$

Process	BF (%)	
	BESIII (this analysis)	PDG
$D_s^+ \to \bar{K}^*(892)^0K^+$, $\bar{K}^*(892)^0 \to K^-\pi^+$	$2.64 \pm 0.06_{\rm stat} \pm 0.07_{\rm sys}$	2.58 ± 0.08
$D_s^+ \to \phi(1020)\pi^+$, $\phi(1020) \to K^+K^-$	$2.21 \pm 0.05_{\rm stat} \pm 0.07_{\rm sys}$	2.24 ± 0.08
$D_s^+ \to S(980)\pi^+$, $S(980) \to K^+K^-$	$1.05 \pm 0.04_{\rm stat} \pm 0.06_{\rm sys}$	1.14 ± 0.31
$D_s^+ \to \bar{K}_0^*(1430)^0K^+$, $\bar{K}_0^*(1430)^0 \to K^-\pi^+$	$0.16 \pm 0.03_{\rm stat} \pm 0.03_{\rm sys}$	0.18 ± 0.04
$D_s^+ \to f_0(1710)\pi^+$, $f_0(1710) \to K^+K^-$	$0.10 \pm 0.02_{\rm stat} \pm 0.03_{\rm sys}$	0.07 ± 0.03
$D_s^+ \to f_0(1370)\pi^+$, $f_0(1370) \to K^+K^-$	$0.07 \pm 0.02_{\rm stat} \pm 0.01_{\rm sys}$	0.07 ± 0.05
$D_s^+ \to K^+K^-\pi^+$ total BF	$5.47 \pm 0.08_{\rm stat} \pm 0.13_{\rm sys}$	5.39 ± 0.15

Both $a_0(980)$ and $f_0(980)$ decays to K^+K^- .
Impossible to separate them here

Isospin configurations:

$a_0(980)$ I=1 → ($|K^+K^- >$ - $|K^0\overline{K^0} >$)

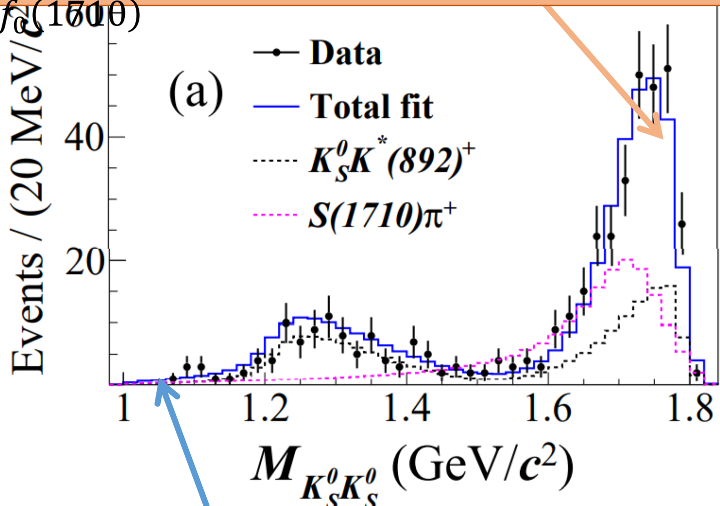
$f_0(980)$ I=0 → ($|K^+K^- >$ + $|K^0\overline{K^0} >$)

The comparison of K^+K^- and $K_S^0K_S^0$ spectrum will reveal more information!

Observation of new a_0-like triplet in D_s decays

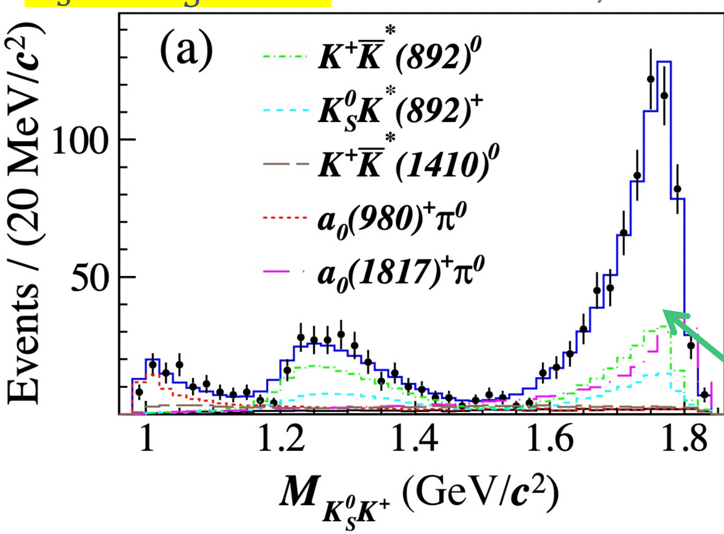
$D_s^+ \to K_S^0 K_S^0 \pi^+$ PRD 105, L051103

constructive interference: new neutral a_0-like and $f_0(1710)$



destructive interference: $a_0(980)$ and $f_0(980)$

$D_s^+ \to K_S^0 K^+ \pi^0$ PRL 129, 182001



new charged a_0-like in $K_S^0 K^+$ mass spectrum

[1] Eur. Phys. J. C 82, 225 (2022).
[2] Phys.Rev. D105, 114014 (2022).
[3] PRD 104, 072002 (2021)

A new a_0 isospin triplet!

Amplitude	BF (10^{-3})
$D_s^+ \to \bar{K}^*(892)^0 K^+$	$4.77 \pm 0.38 \pm 0.32$
$D_s^+ \to K^*(892)^+ K_S^0$	$2.03 \pm 0.26 \pm 0.20$
$D_s^+ \to a_0(980)^+ \pi^0$	$1.12 \pm 0.25 \pm 0.27$
$D_s^+ \to \bar{K}^*(1410)^0 K^+$	$0.88 \pm 0.21 \pm 0.19$
$D_s^+ \to a_0(1817)^+ \pi^0$	$3.44 \pm 0.52 \pm 0.32$

- Double tag method
- $D_s^+ \to a_0(1817)^+\pi^0$ is observed for the first time
- Significance $> 10\sigma$
- M=$1.817 \pm 0.008 \pm 0.020$ GeV/c^2
- Γ= $0.097 \pm 0.022 \pm 0.015$ GeV/c^2

- The isovector partner of $f_0(1710)$[1] or $X(1812)$?[2]
- Same resonance observed in η_c to $\pi\pi\eta$ by BaBar[3]?

Study of $D^+ \to K_S^0 a_0(980)^+$

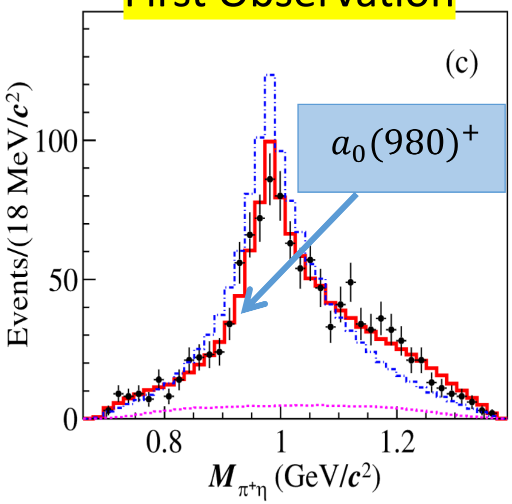
PRL 132, 131903 (2024)

[1]Phys. Rev. D 105, 033006 (2022).
[2]Phys. Rev. D 67, 034024 (2003).
[3] Phys. Rev. D 81, 074031 (2010)

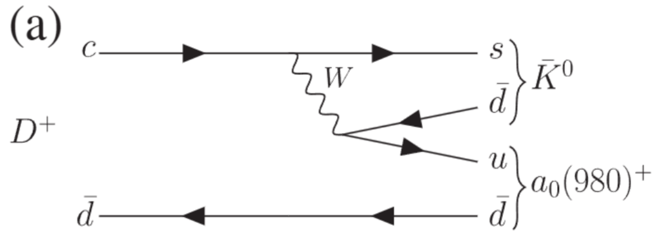
Among $D \to a_0(980)^+ P$, $D^+ \to K_S^0 a_0(980)^+$ is the only decay free of weak-annihilation contributions.

2.93fb^{-1}@E_{cm}=3.773 GeV
1113 candidates with 98.2% purity

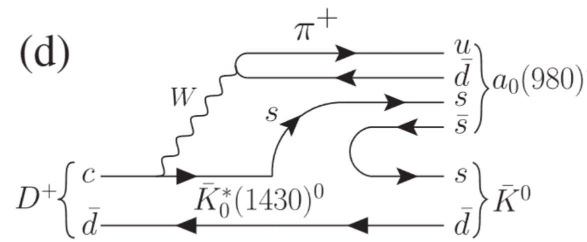
First Observation



two-quark state-
internal W-emission



tetraquark state-
rescattering



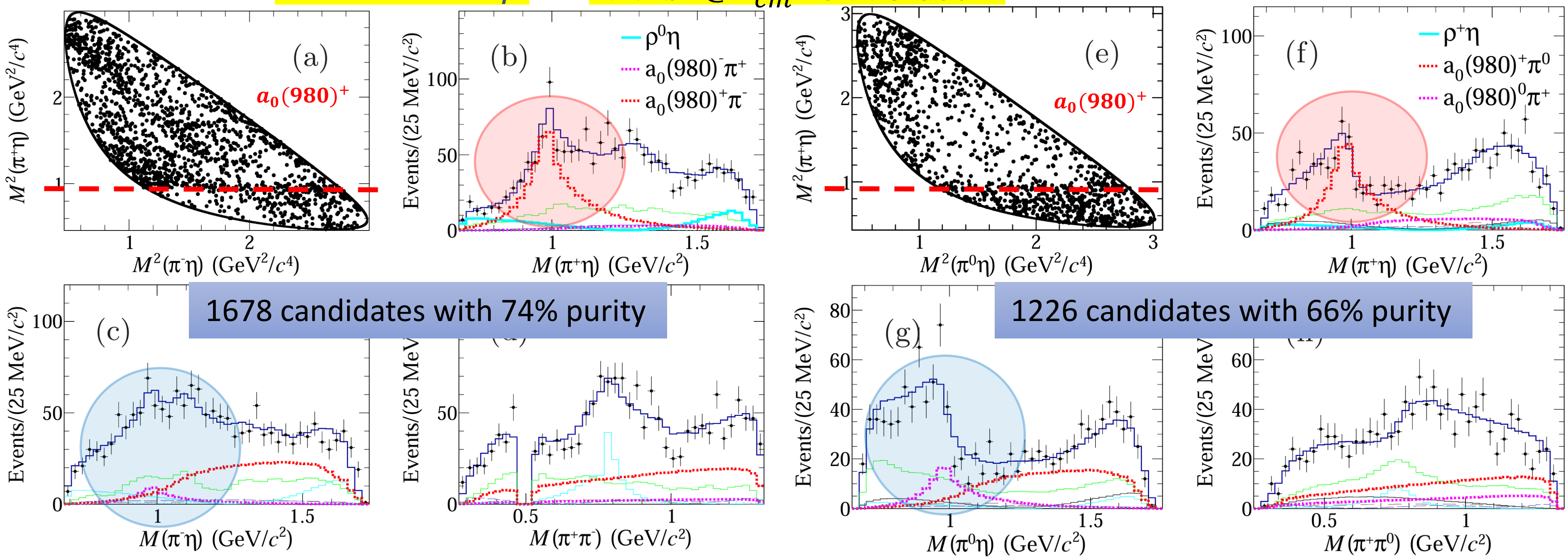
$$\mathcal{B}(D^+ \to K_S^0 \pi^+ \eta) = (1.27 \pm 0.04_{stat} \pm 0.03_{syst})\%$$

- $\mathcal{B}(D^+ \to K_S^0 a_0(980)^+, a_0(980)^+ \to \pi^+\eta) = (1.33 \pm 0.05_{stat} \pm 0.04_{syst})\%$
- Provide sensitive constraints in the extraction of contributions from external and internal W-emission diagrams of $D \to SP$
- Understand the inconsistency between theory and experiment of the $D \to a_0(980)^+ P$[1-3].

Observation of $D \to a_0(980)\pi$

arXiv:2404.09219

$D^0 \to \pi^+\pi^-\eta$ | 7.9fb^{-1}@E_{cm}=3.773 GeV | $D^+ \to \pi^+\pi^0\eta$



Amplitude	Phase (in unit rad)	FF (%)	Significance (σ)	BF ($\times 10^{-3}$)
$D^0 \to \rho^0\eta$	0 (fixed)	$15.2 \pm 1.7 \pm 1.0$	> 10	$0.19 \pm 0.02 \pm 0.01$
$D^0 \to a_0(980)^-\pi^+$	$0.06 \pm 0.16 \pm 0.12$	$5.9 \pm 1.3 \pm 1.0$	8.9	$0.07 \pm 0.02 \pm 0.01$
$D^0 \to a_0(980)^+\pi^-$	$-1.06 \pm 0.12 \pm 0.10$	$44.0 \pm 4.0 \pm 5.3$	> 10	$0.55 \pm 0.05 \pm 0.07$
$D^0 \to a_2(1320)^+\pi^-$	$-1.16 \pm 0.25 \pm 0.23$	$2.1 \pm 0.9 \pm 0.8$	4.5	$0.03 \pm 0.01 \pm 0.01$
$D^0 \to a_2(1700)^+\pi^-$	$0.08 \pm 0.17 \pm 0.23$	$5.5 \pm 1.8 \pm 2.7$	6.1	$0.07 \pm 0.02 \pm 0.03$
$D^0 \to (\pi^+\pi^-)_{S-\rm wave}\eta$	$-0.92 \pm 0.29 \pm 0.14$	$3.9 \pm 1.8 \pm 2.1$	5.3	$0.05 \pm 0.02 \pm 0.03$
$r_{+/-}$		$7.5^{+2.5}_{-0.8} \pm 1.7$	7.7^*	-
$D^+ \to \rho^+\eta$	$-4.03 \pm 0.19 \pm 0.13$	$9.3 \pm 3.0 \pm 2.1$	6.0	$0.20 \pm 0.07 \pm 0.05$
$D^+ \to (\pi^+\pi^0)_V\eta$	$-0.64 \pm 0.22 \pm 0.19$	$15.8 \pm 4.8 \pm 5.2$	4.7	$0.34 \pm 0.11 \pm 0.11$
$D^+ \to a_0(980)^+\pi^0$	0 (fixed)	$43.7 \pm 5.6 \pm 1.9$	9.1	$0.95 \pm 0.12 \pm 0.05$
$D^+ \to a_0(980)^0\pi^+$	$2.44 \pm 0.20 \pm 0.10$	$17.0 \pm 4.4 \pm 1.7$	7.9	$0.37 \pm 0.10 \pm 0.04$
$D^+ \to a_2(1700)^+\pi^0$	$0.92 \pm 0.20 \pm 0.14$	$4.2 \pm 2.1 \pm 0.7$	3.6	$0.09 \pm 0.05 \pm 0.02$
$D^+ \to a_0(1450)^+\pi^0$	$0.63 \pm 0.41 \pm 0.30$	$7.0 \pm 2.8 \pm 0.7$	4.7	$0.15 \pm 0.06 \pm 0.02$
$r_{+/0}$		$2.6 \pm 0.6 \pm 0.3$	4.0^*	-

The external W-emission dominates the $D \to a_0(980)\pi$ decays in the diquark scenario, contrary to expectations of its negligible contribution due to the very small $a_0(980)$ decay constant[1].

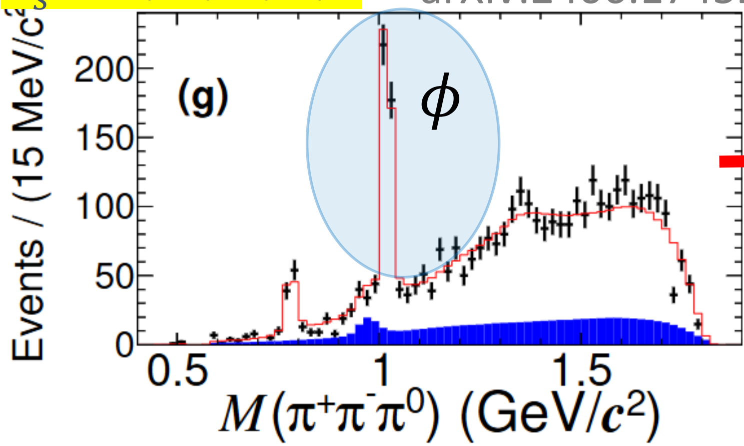
- $\mathcal{B}(D^0 \to \pi^+\pi^-\eta) = (1.24 \pm 0.04_{stat} \pm 0.03_{syst})\%$
- $\mathcal{B}(D^+ \to \pi^+\pi^0\eta) = (2.18 \pm 0.12_{stat} \pm 0.03_{syst})\%$
- $a_0(1817)$ is not observed in both channels

[1] Phys. Rev. D 105, 033006(2022).

Study of $D_s^+ \to \phi(\pi^+\pi^-\pi^0, K^+K^-)\pi^-$

$D_s^+ \to \pi^+\pi^-\pi^0\pi^+$

arXiv:2406.17452



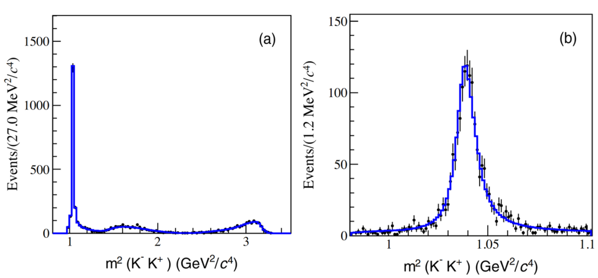
First Measurement

Component	Phase (rad)	FF (%)	BF (10^{-3})
$f_0(1370)\rho^+$	0.0(fixed)	$24.9 \pm 3.8 \pm 2.1$	$5.08 \pm 0.80 \pm 0.43$
$f_0(980)\rho^+$	$3.99 \pm 0.13 \pm 0.07$	$12.6 \pm 2.1 \pm 1.0$	$2.57 \pm 0.44 \pm 0.20$
$f_2(1270)\rho^+$	$1.11 \pm 0.10 \pm 0.10$	$9.5 \pm 1.7 \pm 0.6$	$1.94 \pm 0.36 \pm 0.12$
$(\rho^+\rho^0)_S$	$1.10 \pm 0.18 \pm 0.10$	$3.5 \pm 1.2 \pm 0.6$	$0.71 \pm 0.25 \pm 0.12$
$(\rho(1450)^+\rho^0)_S$	$0.43 \pm 0.18 \pm 0.17$	$4.6 \pm 1.3 \pm 0.8$	$0.94 \pm 0.27 \pm 0.16$
$(\rho^+\rho(1450)^0)_P$	$4.58 \pm 0.16 \pm 0.09$	$8.6 \pm 1.3 \pm 0.4$	$1.75 \pm 0.27 \pm 0.08$
$\phi((\rho\pi) \to \pi^+\pi^-\pi^0)\pi^+$	$2.90 \pm 0.15 \pm 0.18$	$24.9 \pm 1.2 \pm 0.4$	$5.08 \pm 0.32 \pm 0.10$
$\omega((\rho\pi) \to \pi^+\pi^-\pi^0)\pi^+$	$3.22 \pm 0.21 \pm 0.09$	$6.9 \pm 0.8 \pm 0.3$	$1.41 \pm 0.17 \pm 0.06$
$a_1^+(\rho^0\pi^+)_S\pi^0$	$3.78 \pm 0.16 \pm 0.12$	$12.5 \pm 1.6 \pm 1.0$	$2.55 \pm 0.34 \pm 0.20$
$a_1^0((\rho\pi)_S \to \pi^+\pi^-\pi^0)\pi^+$	$4.82 \pm 0.15 \pm 0.12$	$6.3 \pm 1.9 \pm 1.2$	$1.29 \pm 0.39 \pm 0.24$
$\pi(1300)^0((\rho\pi)_P \to \pi^+\pi^-\pi^0)\pi^+$	$2.22 \pm 0.14 \pm 0.08$	$11.7 \pm 2.3 \pm 2.2$	$2.39 \pm 0.48 \pm 0.45$

- $\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^-\pi^0|_{\text{non}-\eta}) = (2.04 \pm 0.08_{stat} \pm 0.05_{syst})\%$
- $\mathcal{B}(D_s^+ \to \phi\pi^+, \phi \to \pi^+\pi^-\pi^0) = (5.08 \pm 0.32 \pm 0.10)\times 10^{-3}$
- $\mathcal{B}(D_s^+ \to \phi\pi^+, \phi \to K^+K^-) = (2.21 \pm 0.05 \pm 0.07)\%$

$D_s^+ \to K^+K^-\pi^+$

PRD 104, 012016



- $\frac{\mathcal{B}(\phi\to\pi^+\pi^-\pi^0)}{\mathcal{B}(\phi\to K^+K^-)} = \mathbf{0.230 \pm 0.014_{stat} \pm 0.010_{syst}}$.
- Deviates from PDG value (0.313 ± 0.010) % by $> 4\sigma$.
- First measurement of R_ϕ in charmed mesons, and the lower than expected value motivates further studies.

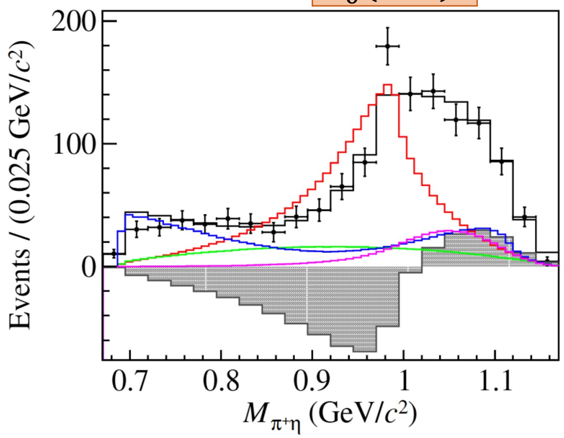
Observation of $\Lambda_c^+ \to \Lambda a_0(980)^+$

arXiv:2407.12270

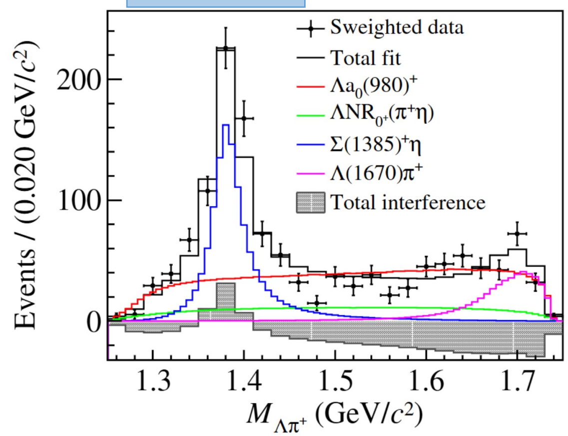
First observation

[1] J. Phys. G 36, 075005(2009).
[2] Phys. Lett. B 820, 136586 (2021).

$a_0(980)^+$



$\Sigma(1385)^+$



1312±45 events with 80% purity

Process	FF (%)	$\mathcal{S}$	α
$\Lambda a_0(980)^+$	$54.0 \pm 8.4 \pm 2.6$	13.1σ	$0.91^{+0.09}_{-0.18} \pm 0.08$
$\Sigma(1385)^+\eta$	$30.4 \pm 2.6 \pm 0.7$	22.5σ	$-0.61 \pm 0.15 \pm 0.04$
$\Lambda(1670)\pi^+$	$14.1 \pm 2.8 \pm 1.2$	11.7σ	$0.21 \pm 0.27 \pm 0.33$
ΛNR_{0^+}	15.4 ± 5.3	6.7σ	...

$$\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\eta)$$
$$= (1.94 \pm 0.07 \pm 0.11)\%$$

- Theoretical calculation of $\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+)$:

  1.9×10^{-4} $\Longrightarrow$ based on factorization and the pole model[1]

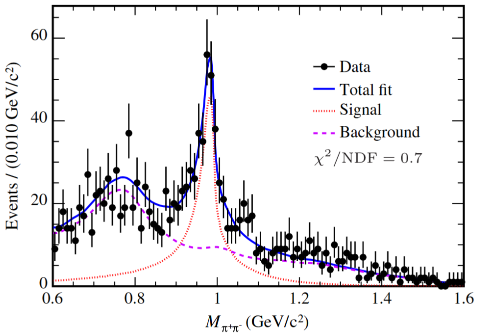
  1.7×10^{-3} $\Longrightarrow$ considering the rescattering $\Sigma(1385)^+\eta \to \Lambda a_0(980)^+$[2]

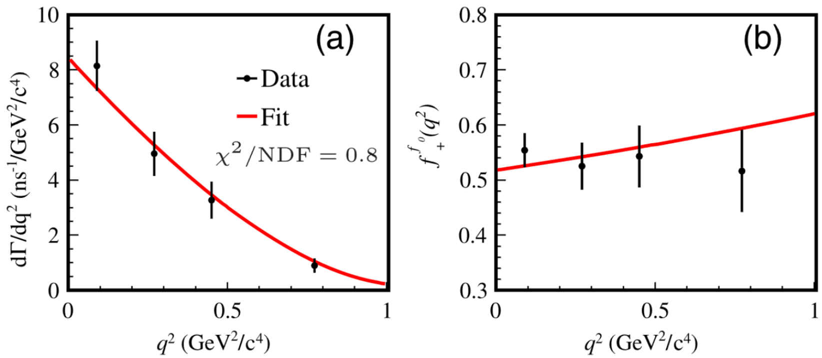
- We measure $\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+)$ =(1.23 ± 0.21)%, which is larger than theoretical calculations by 1-2 orders.
- The difference suggests some unknown decay mechanisms.

in the semi-leptonic decays

Study of $D_s^+ \to f_0(980)/f_0(500)e^+\nu_e$

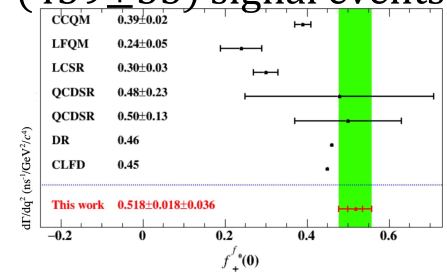
PRL 132, 141901(2024)





$D_s^+ \to \pi^+\pi^- e^+\nu_e$ 7.33fb⁻¹

(439±33) signal events



- $\mathcal{B}(D_s^+ \to f_0(980)e^+\nu_e, f_0(980) \to \pi^+\pi^-) = (1.72 \pm 0.13_{stat} \pm 0.10_{syst})\times 10^{-3}$

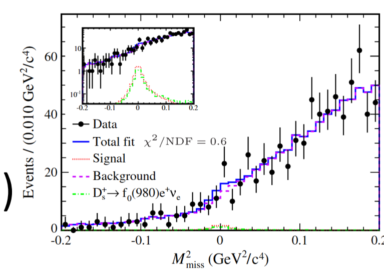
$\phi = (19.7 \pm 12.8)^\circ$($s\bar{s}$ is dominant based on $|f_0(980)\rangle = sin\phi \,|\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\rangle + cos\phi|s\bar{s}\rangle$)

- First form factor measurement with simple pole form and Flatte formula:

	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°

- $f_+^{f_0}(0)|V_{cs}|$=0.504 ± 0.017 ± 0.035

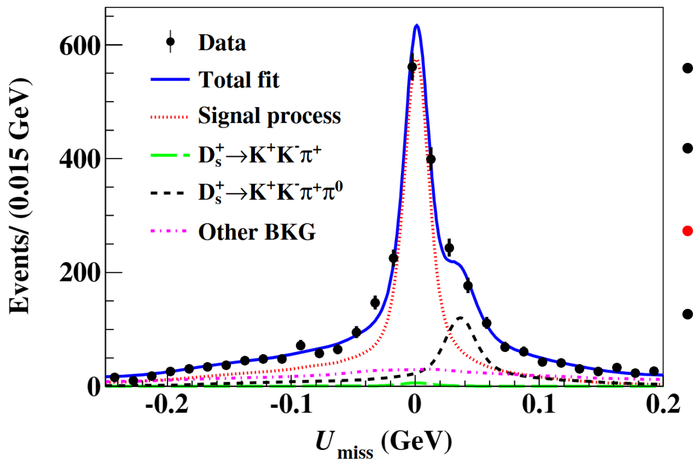
- Form factor $f_+^{f_0}(0)$=0.518 ± 0.018 ± 0.036(|V_{cs}|=0.97349 ± 0.00016 PDG)



- First search, $\mathcal{B}(D_s^+ \to f_0(500)e^+\nu_e, f_0(500) \to \pi^+\pi^-) < 3.3\times 10^{-4}$ at 90% confidence level.

Study of $D_s^+ \to f_0(980)/\phi\mu^+\nu_\mu$

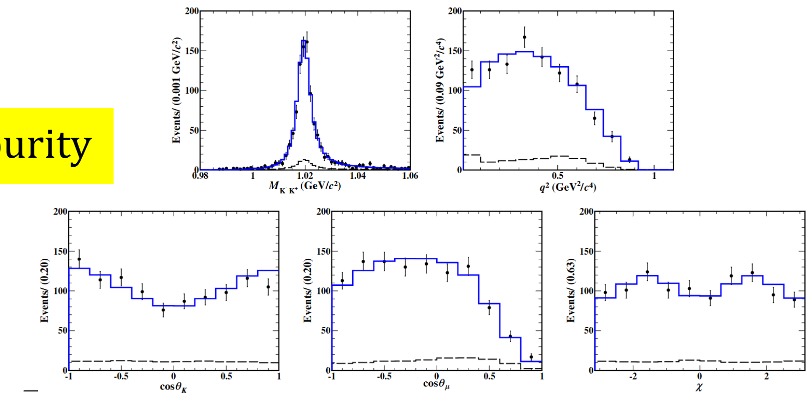
JHEP12(2023)072



$D_s^+ \to K^+K^-\mu^+\nu_\mu$

- Branching fraction measurement：(1175±68) signal events
- $\mathcal{B}(D_s^+ \to K^+K^-\mu^+\nu_\mu) = (1.11 \pm 0.04_{stat} \pm 0.04_{syst})\%$
- $\mathcal{B}(D_s^+ \to \phi\mu^+\nu_\mu) = (2.25 \pm 0.09_{stat} \pm 0.07_{syst})\%$
- $\mathcal{B}(D_s^+ \to \phi\mu^+\nu_\mu)/\mathcal{B}(D_s^+ \to \phi e^+\nu_e) = 0.94 \pm 0.08$

PDG



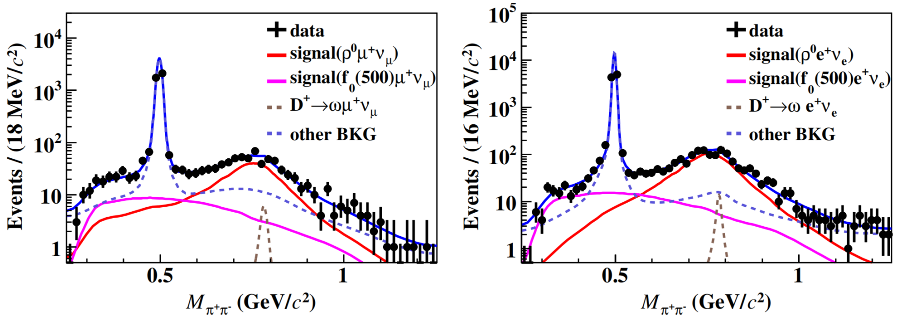
- Partial wave analysis：939 signal events, 80.2% purity
- First FF measurement based on simple pole
- ϕ dominate
- $r_V = \frac{V(0)}{A_1(0)}$=1.58 $\pm$ 0.17 $\pm$ 0.02
- $r_2 = \frac{A_2(0)}{A_1(0)}$=0.71 $\pm$ 0.14 $\pm$ 0.02
- No significant $f_0(980)$ contribution
- $\mathcal{B}(D_s^+ \to f_0(980)\mu^+\nu_\mu, f_0(980) \to K^+K^-) < 5.45\times10^{-4}$@90% $C.L.$ ($\sim 2.2\sigma$)

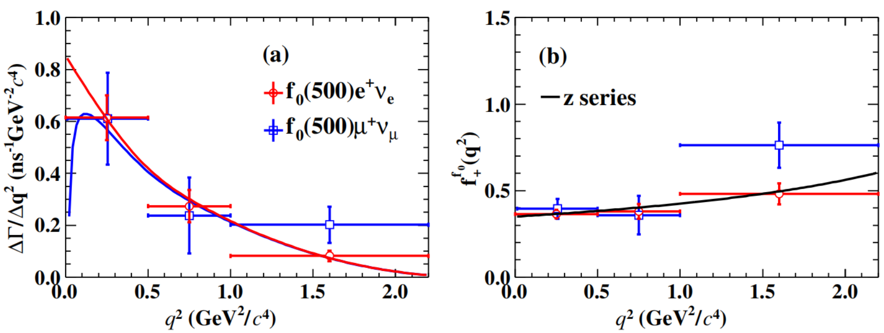
Experiments	r_V	r_2
PDG [41]	1.80±0.08	0.84±0.11
This analysis	1.58±0.17±0.02	0.71±0.14±0.02
BABAR [25]	1.807±0.046±0.065	0.816±0.036±0.030
FOCUS [57]	1.549±0.250±0.148	0.713±0.202±0.284
Theory	r_V	r_2
CCQM [5]	1.34±0.27	0.99±0.20
CQM [6]	1.72	0.73
LFQM [7]	1.42	0.86
LQCD [3]	1.72±0.21	0.74±0.12
HMχT [8]	1.80	0.52

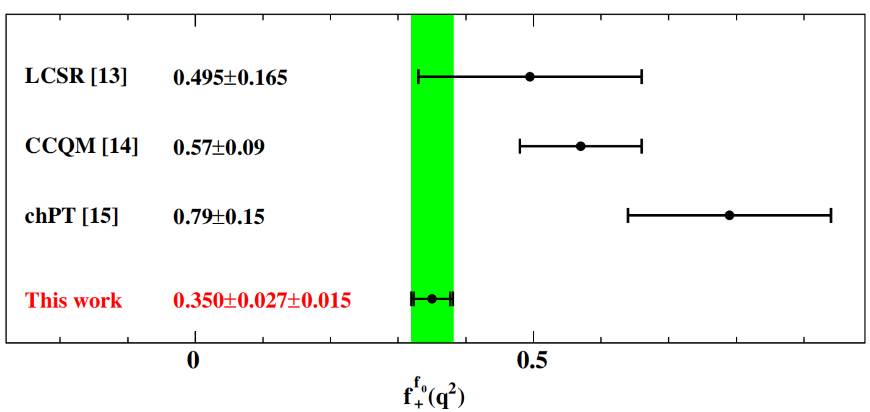
Study of $D^+ \to f_0(500) l^+ \nu_l$

arXiv:2401.13225

$D_s^+ \to \pi^+\pi^- l^+ \nu_l$ 2.93fb^{-1}
@E_{cm}=3.773 GeV







- First observation of $D^+ \to f_0(500)\mu^+\nu_\mu$
- First FF measurement of $D^+ \to f_0(500) l^+ \nu_l$

Signal mode	$N_{\rm obs}$	$\mathcal{S}$ (σ)	$\epsilon_{\rm sig}$ (%)	$\mathcal{B}_{\rm sig}(\times 10^{-3})$
$f_0(500)\mu^+\nu_\mu$	209 ± 38	5.9	18.93 ± 0.13	0.72 ± 0.13
$\rho^0\mu^+\nu_\mu$	496 ± 38	> 10	19.86 ± 0.13	1.64 ± 0.13
$f_0(500)e^+\nu_e$	412 ± 43	> 10	44.76 ± 0.25	0.60 ± 0.06
$\rho^0 e^+\nu_e$	1237 ± 47	> 10	44.12 ± 0.25	1.84 ± 0.07

- $f_+^{f_0}(0)|V_{cd}|$=0.0787 $\pm$ 0.0060 $\pm$ 0.0033
- $f_+^{f_0}(0)$=0.350 $\pm$ 0.027 $\pm$ 0.015

($|V_{cd}|$=0.22438 $\pm$ 0.00044 PDG)

- $\mathcal{B}(D^+ \to \rho^0\mu^+\nu_\mu)/\mathcal{B}(D^+ \to \rho^0 e^+\nu_e) = 0.88 \pm 0.10$
- $\mathcal{B}(D^+ \to f_0(500)\mu^+\nu_\mu)/\mathcal{B}(D^+ \to f_0(500)e^+\nu_e)$ $= 1.44 \pm 0.28$
- Consistent with the standard model expectation.

Summary & Outlook

- BESIII has the largest data samples at $D\bar{D}/\Lambda_c\bar{\Lambda}_c$ threshold.
- Light scalar mesons are studied systematically via charm decays.
- BFs and FF measurements help to understand the nature of light scalar mesons.
- The ϕ branching ratio is significant different from the PDG result.

Outlook

- Many BFs, amplitude analyses are being studied.
- ϕ decay will be precisely measured in charm decay.
- More scalar mesons could be studied via charm decays.

Thanks for your attention!