Hadronic decays of charmed meson at BESIII

Yu Lu(卢宇)
Central South University
On behalf of BESIII Collaboration
HFCPV-2022

$\tau - charm$ factory

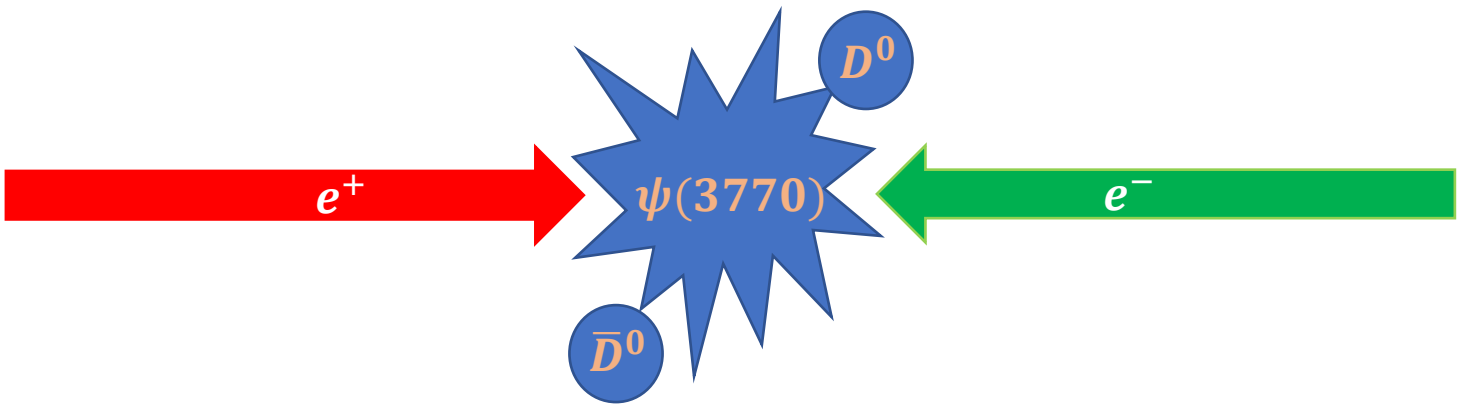
Beam energy: 1.0-2.3 GeV → Come to ~2.5 GeV in 2020

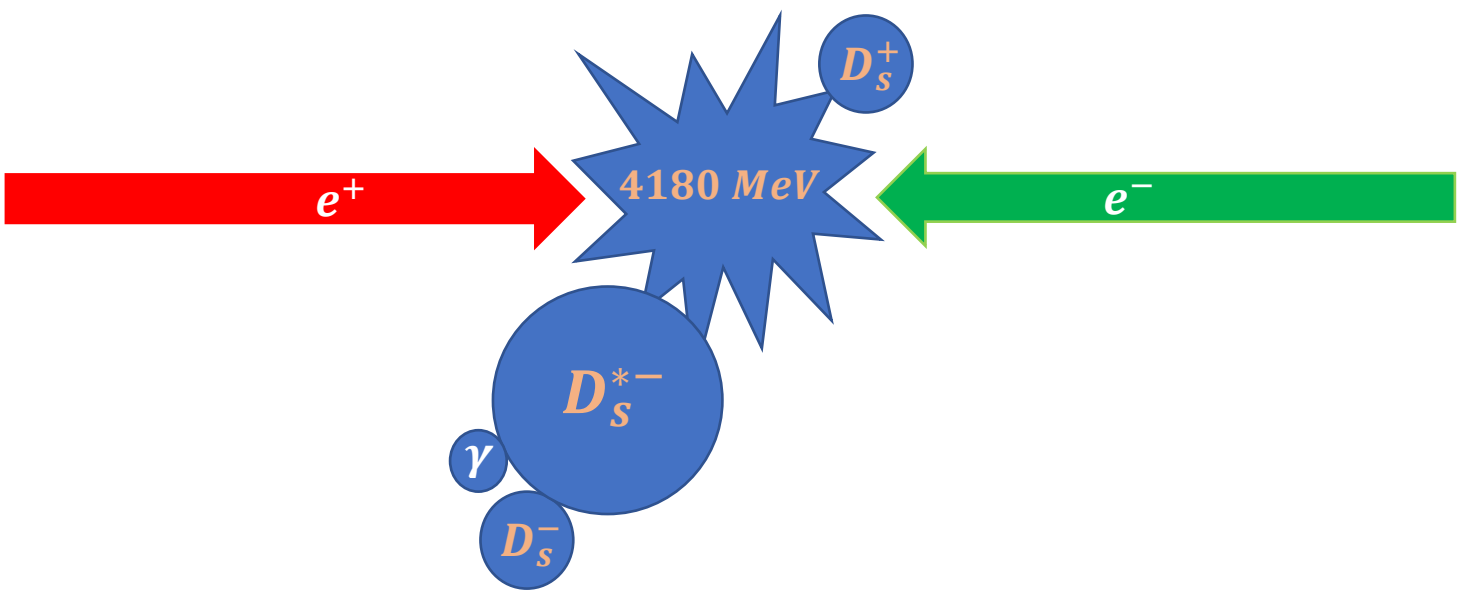
2004: started BEPCII upgrade, BESIII construction

2009 - now: BESIII physics run

- **1989-2004 (BEPC):**
  $L_{peak}=1.0\times10^{31}\ /cm^2s$
- **2009-now (BEPCII):**
  $L_{peak}= 1.0\times10^{33}/cm^2$(4/5/2016)

Charmed mesons are paired generated





Content

D_s^+ decays

- $\boldsymbol{D_s^+ \to \pi^+\pi^+\pi^-}$
- $\boldsymbol{D_s^+ \to \pi^+\pi^0\pi^0}$

Amplitude analysis

- $\boldsymbol{D_s^+ \to K_S^0 K_S^0 \pi^+}$
- $\boldsymbol{D_s^+ \to K_S^0 K^+ \pi^0}$

spectroscopy

- $\boldsymbol{D_s^+ \to \pi^+\pi^0\eta'}$
- $\boldsymbol{D_s^+ \to K^+K^-\pi^+\pi^+\pi^-}$

Strong phase measurement

- $\boldsymbol{D_s^+ \to K^+\pi^+\pi^-(\pi^0)}$

Branching fraction measurement

$D^{0/+}$ decays

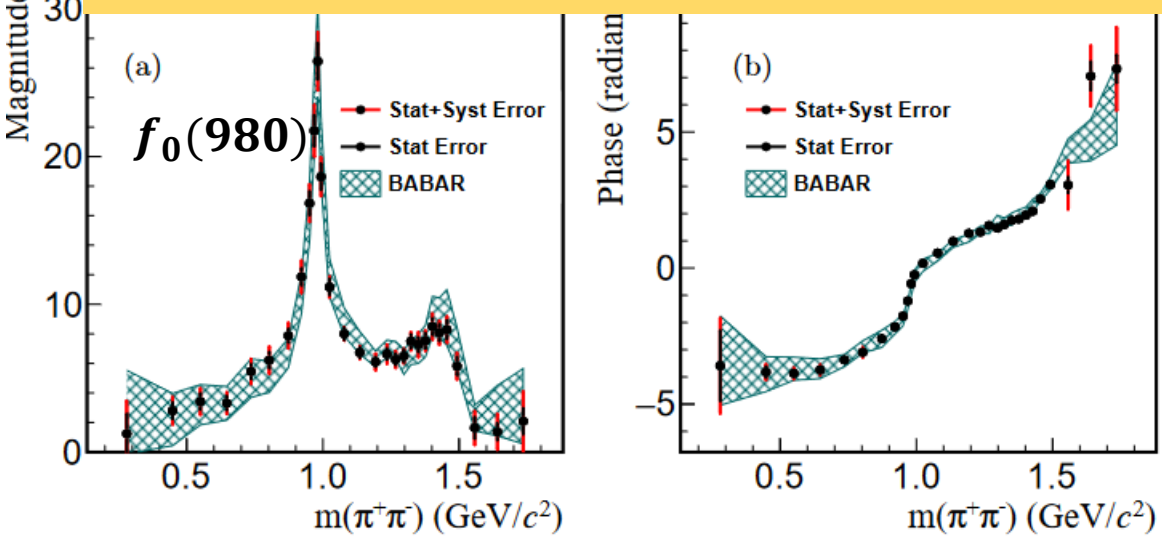
- $\delta_{K\pi}$
- $F_+^{4\pi}$
- Branching fractions of $D^{0/+} \to K_S^0\pi^{0/+}\omega$, $D^0 \to K^-\pi^+\omega$ and some channels with multi-pions
- Branching fractions of DCS decays $D^+ \to K^+\pi^0\pi^0/\eta$, $D^0 \to K^+\pi^-\pi^0(\pi^0)$
- Branching fractions of $D^0 \to K_L X$ ($X = \phi, \eta, \omega$ and η')

D_s^+ decays

Amplitude analysis of the $D_s^+ \to \pi^+\pi^+\pi^-$ decay

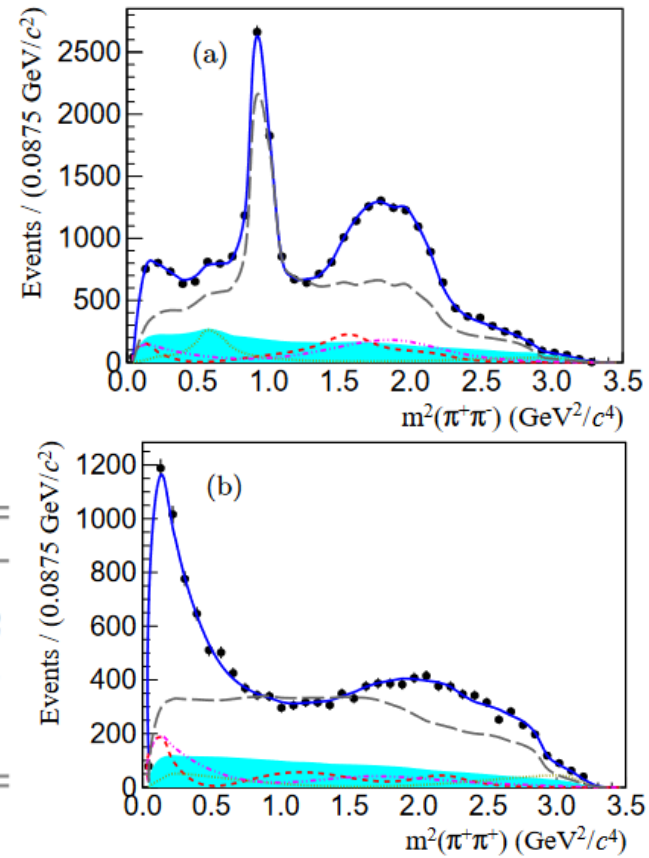
arXiv:2108.10050, accepted by PRD

$(\pi^+\pi^-)_{s-wave}$ scattering



Decay mode	Fit fraction (%)	Magnitude	Phase (radians)
$f_2(1270)\pi^+$	$10.5 \pm 0.8 \pm 1.2$	1. (Fixed)	0. (Fixed)
$\rho(770)\pi^+$	$0.9 \pm 0.4 \pm 0.5$	$0.13 \pm 0.03 \pm 0.04$	$5.44 \pm 0.25 \pm 0.62$
$\rho(1450)\pi^+$	$1.3 \pm 0.4 \pm 0.5$	$0.91 \pm 0.16 \pm 0.22$	$1.03 \pm 0.32 \pm 0.51$
$\mathcal{S}$ wave	$84.2 \pm 0.8 \pm 1.3$	Table III	Table III
Total	$96.8 \pm 2.4 \pm 3.5$		

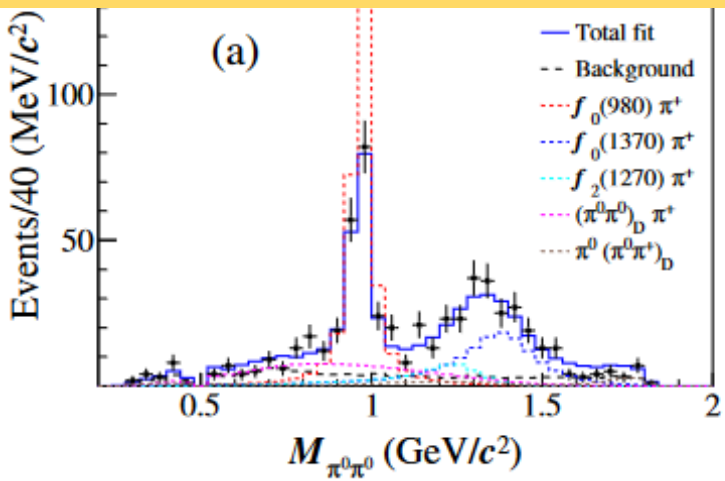
Projections

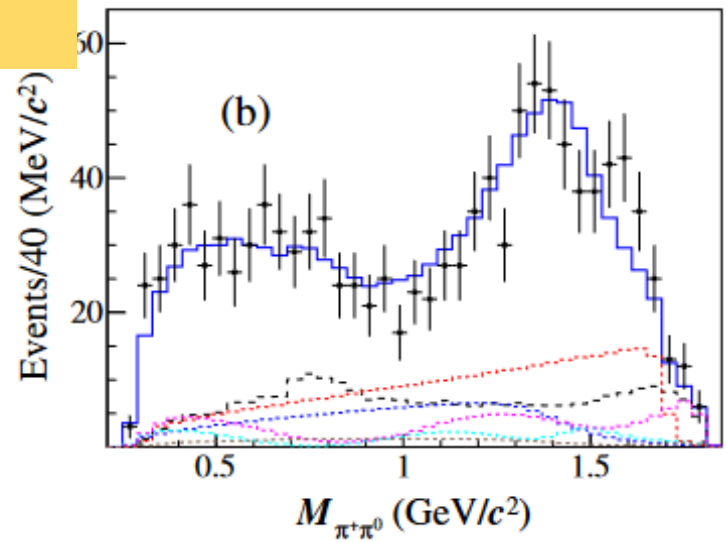


Amplitude analysis and branching fraction measurement of the decay $D_s^+ \to \pi^+\pi^0\pi^0$

JHEP01(2022)052

$(\pi^0\pi^0)_{s-wave}$ scattering

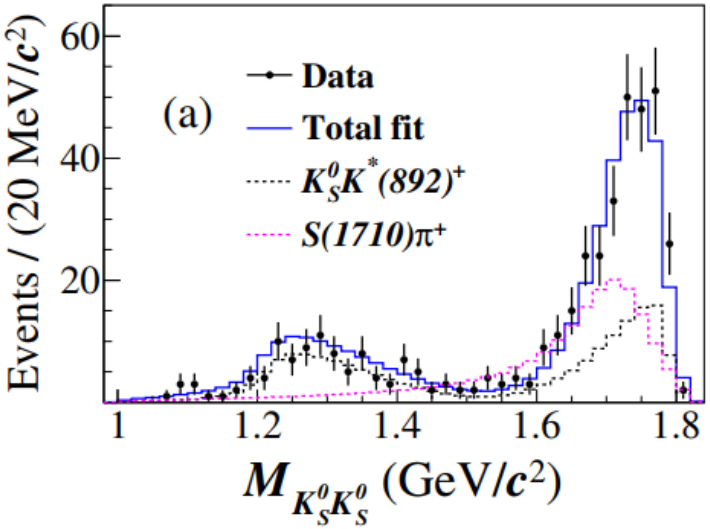


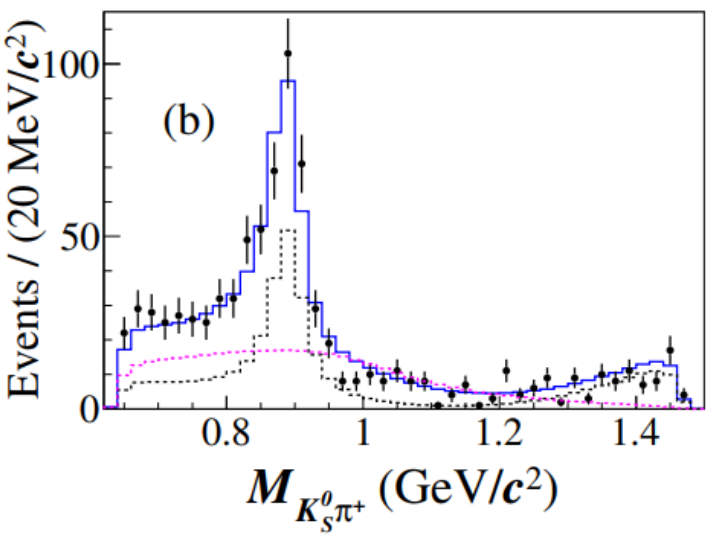


Intermediate process	BF (10^{-3})
$D_s^+ \to f_0(980)\pi^+,\ f_0(980) \to \pi^0\pi^0$	$2.8 \pm 0.4 \pm 0.4$
$D_s^+ \to f_0(1370)\pi^+,\ f_0(1370) \to \pi^0\pi^0$	$1.3 \pm 0.3 \pm 0.5$
$D_s^+ \to f_2(1270)\pi^+,\ f_2(1270) \to \pi^0\pi^0$	$0.5 \pm 0.2 \pm 0.3$
$D_s^+ \to \pi^+(\pi^0\pi^0)_D$	$1.1 \pm 0.4 \pm 0.2$
$D_s^+ \to (\pi^+\pi^0)_D\pi^0$	$0.3 \pm 0.1 \pm 0.1$
	BF listed on PDG [1] (10^{-3})
$D_s^+ \to f_0(980)\pi^+,\ f_0(980) \to \pi^+\pi^-$	6.1 ± 0.7
$D_s^+ \to f_0(1370)\pi^+,\ f_0(1370) \to \pi^+\pi^-$	3.5 ± 0.9
$D_s^+ \to f_2(1270)\pi^+,\ f_2(1270) \to \pi^+\pi^-$	1.2 ± 0.2

Study of the decay $D_s^+ \to K_S^0 K_S^0 \pi^+$ and observation of an isovector partner to $f_0(1710)$

Phys. Rev. D 105, L051103 (2022)





Amplitude	Phase	FF (%)
$D_s^+ \to K_S^0 K^*(892)^+$	0.0 (fixed)	$43.5 \pm 3.9 \pm 0.5$
$D_s^+ \to S(1710)\pi^+$	$2.3 \pm 0.1 \pm 0.1$	$46.3 \pm 4.0 \pm 1.2$

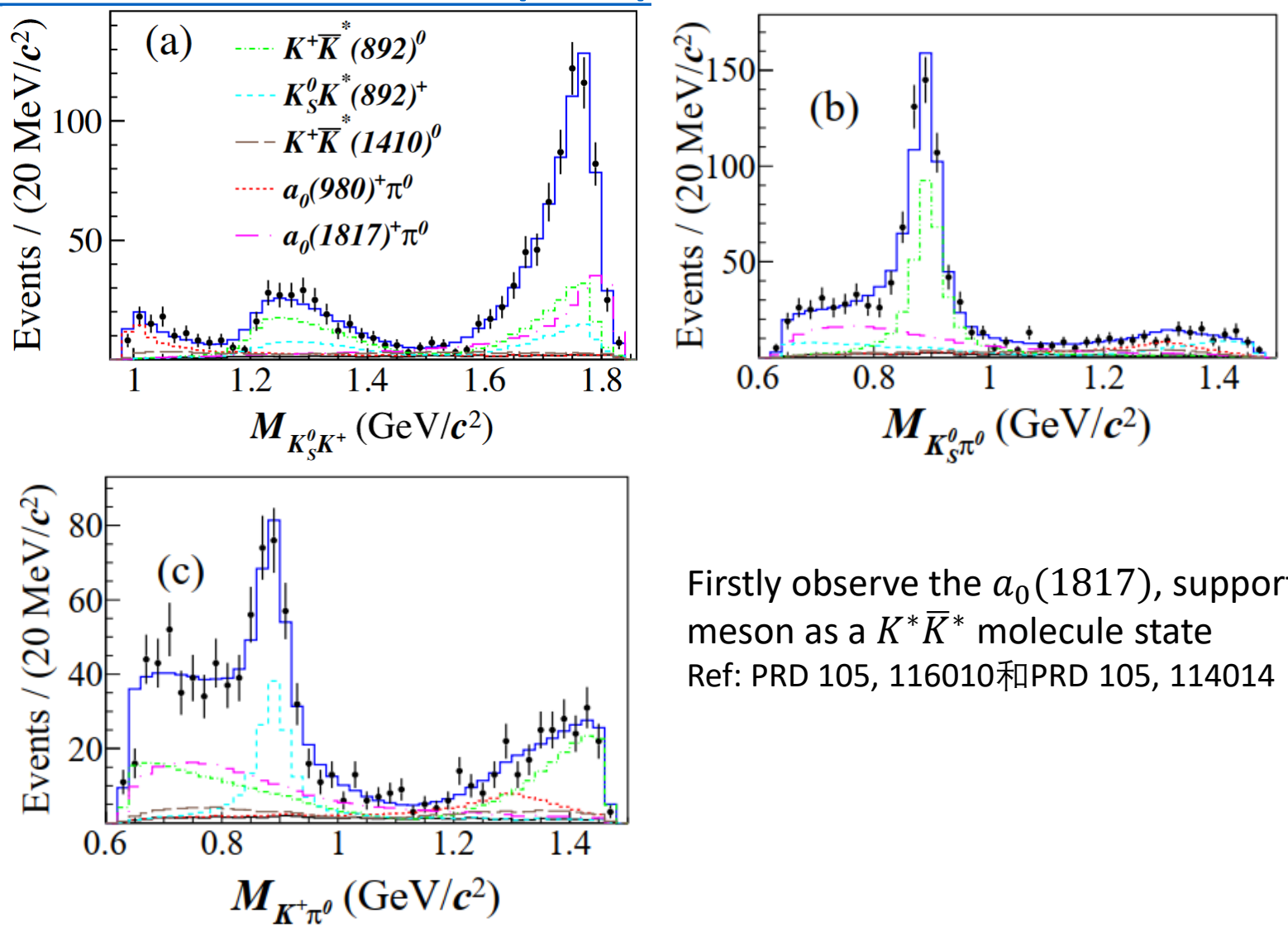
$$\mathcal{B}(D_s^+ \to K_S^0 K_S^0 \pi^+) = (0.68 \pm 0.04_{stat.} \pm 0.01_{syst.})\%$$

Amplitude	BF (10^{-3})
$D_s^+ \to K_S^0 K^*(892)^+ \to K_S^0 K_S^0 \pi^+$	$3.0 \pm 0.3 \pm 0.1$
$D_s^+ \to S(1710)\pi^+ \to K_S^0 K_S^0 \pi^+$	$3.1 \pm 0.3 \pm 0.1$

In this analysis, we can not distinguish the iso-scalar and iso-vector, therefore we use $S(1710)$ to represent their total contribution.

Observation of an a_0-like State with Mass of 1.817 GeV in the Study of $D_s^+ \to K_S^0 K^+ \pi^0$ Decays

Phys. Rev. Lett. 129, 182001 (2022)

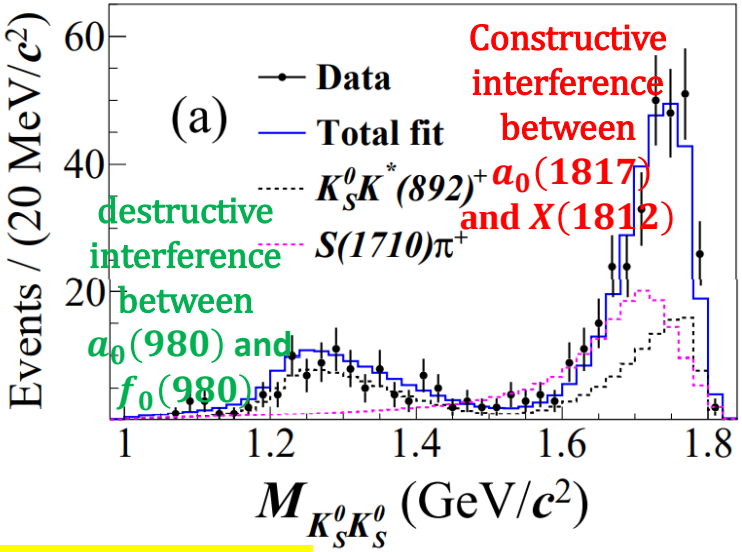


Firstly observe the $a_0(1817)$, support this meson as a $K^*\bar{K}^*$ molecule state

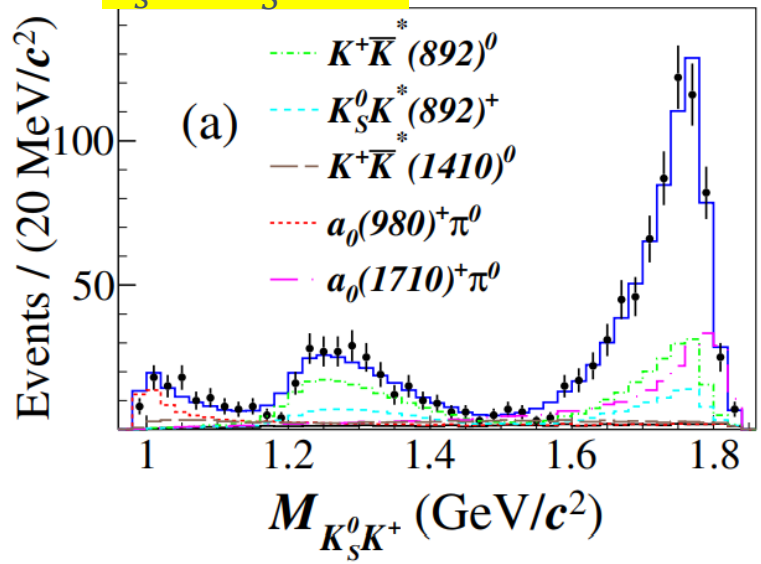
Ref: PRD 105, 116010和PRD 105, 114014

Recall the analysis of $D^+ \to K^-K^+\pi^+$

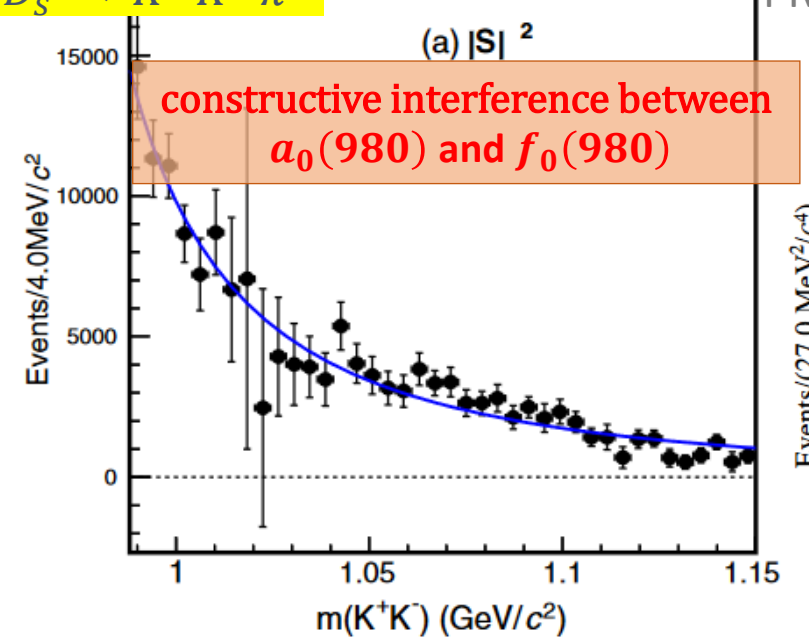
$D_s^+ \to K_S^0 K_S^0 \pi^+$ PRD 105, L051103 (2022)

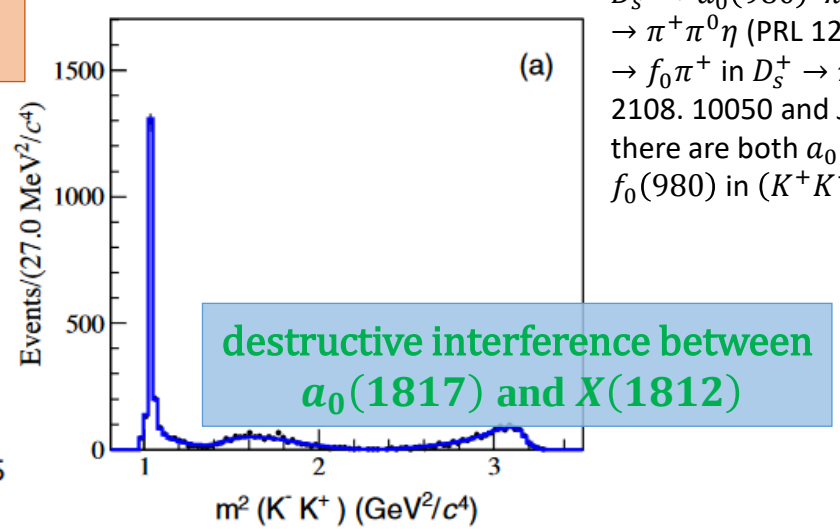


$D_s^+ \to K_S^0 K^+ \pi^0$ **PRL 129, 182001 (2022)**



$D_s^+ \to K^+K^-\pi^+$ PRD 104, 012016 (2021)



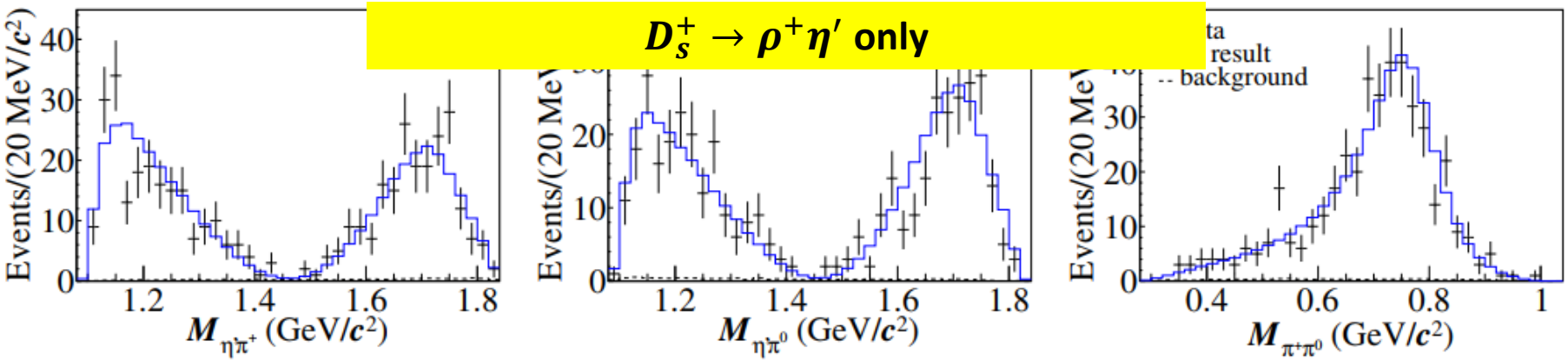


According to the measurement of $D_s^+ \to a_0(980)^0\pi^+$ in $D_s^+ \to \pi^+\pi^0\eta$ (PRL 123, 112001) and $D_s^+ \to f_0\pi^+$ in $D_s^+ \to \pi^+\pi^{+/0}\pi^{-/0}$ (aXiv: 2108. 10050 and JHEP01(2022)052), there are both $a_0(980)^0$ and $f_0(980)$ in $(K^+K^-)_{s-wave}$

Amplitude analysis and branching fraction measurement of $D_s^+ \to \pi^+\pi^0\eta'$

JHEP04(2022)058

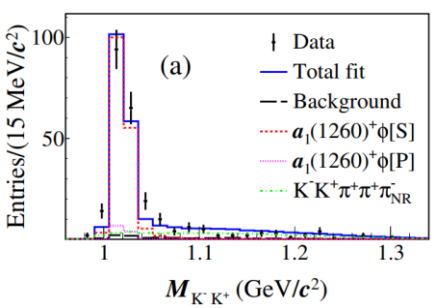
$D_s^+ \to \rho^+\eta'$ only

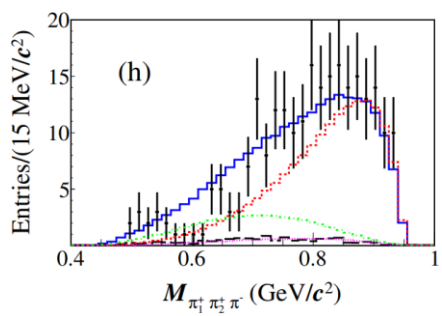


- $\mathcal{B}(D_s^+ \to \rho^+\eta') = \mathcal{B}(D_s^+ \to \pi^+\pi^0\eta') = (6.15 \pm 0.25_{stat.} \pm 0.18_{syst.})\%$, larger than theoretical prediction (about 3%) by 3σ

Amplitude analysis and branching fraction measurement of $D_s^+ \to K^+K^-\pi^+\pi^+\pi^-$

JHEP07(2022)051



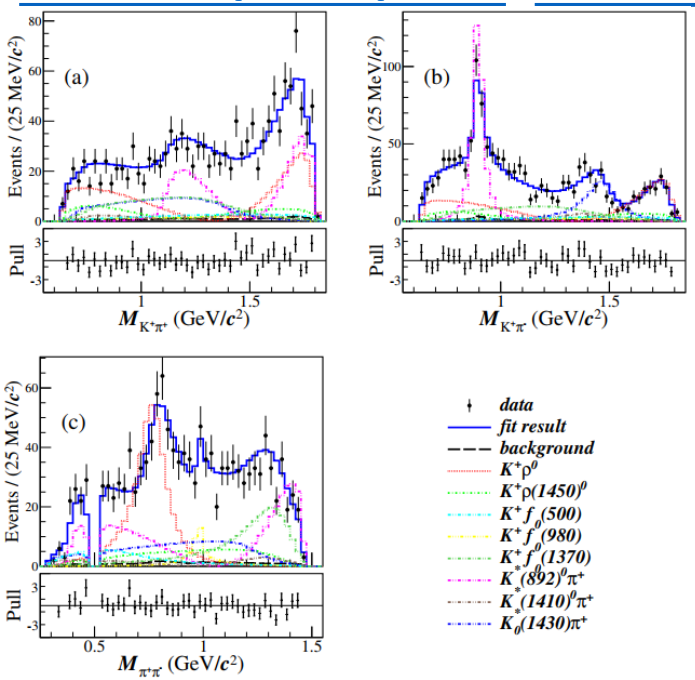


Amplitude	Phase	FF (%)	Significance (σ)
$D_s^+[S] \to a_1(1260)^+\phi$	0 (fixed)	$73.1 \pm 3.1 \pm 1.5$	> 10
$D_s^+[P] \to a_1(1260)^+\phi$	$1.47 \pm 0.19 \pm 0.03$	$5.0 \pm 1.7 \pm 0.7$	5.5
$D_s^+ \to a_1(1260)^+\phi$	...	$78.1 \pm 2.9 \pm 1.6$	...
$D_s^+ \to (K^-K^+\pi^+\pi^+\pi^-)_{NR}$	$1.99 \pm 0.12 \pm 0.17$	$21.8 \pm 2.9 \pm 0.8$	> 10

- $\mathcal{B}(D_s^+ \to K^+K^-\pi^+\pi^+\pi^-) = (6.60 \pm 0.47_{stat.} \pm 0.38_{syst.}) \times 10^{-3}$
- The first amplitude analysis for five body charmed decays at BESIII

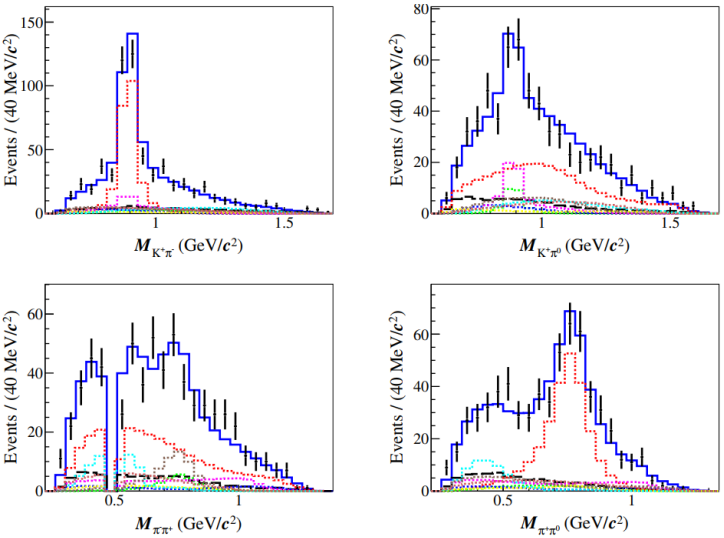
Amplitude analysis and branching fraction measurement of $D_s^+ \to K^+\pi^+\pi^-(\pi^0)$

JHEP08 (2022) 196 (JHEP09(2022)242)



$$\mathcal{B}(D_s^+ \to K^+\pi^+\pi^-) = \left(6.11 \pm 0.18_{stat.} \pm 0.11_{syst.}\right) \times 10^{-3}$$

Intermediate process	BF(10^{-3})	PDG(10^{-3})
$D_s^+ \to K^+\rho^0$	$1.99 \pm 0.20 \pm 0.22$	2.5 ± 0.4
$D_s^+ \to K^+\rho(1450)^0$	$0.78 \pm 0.20 \pm 0.17$	0.69 ± 0.64
$D_s^+ \to K^*(892)^0\pi^+$	$1.85 \pm 0.13 \pm 0.11$	1.41 ± 0.24
$D_s^+ \to K^*(1410)^0\pi^+$	$0.29 \pm 0.13 \pm 0.13$	1.23 ± 0.28
$D_s^+ \to K_0^*(1430)^0\pi^+$	$1.15 \pm 0.16 \pm 0.15$	0.50 ± 0.35
$D_s^+ \to K^+f_0(500)$	$0.43 \pm 0.14 \pm 0.24$	-
$D_s^+ \to K^+f_0(980)$	$0.27 \pm 0.08 \pm 0.07$	-
$D_s^+ \to K^+f_0(1370)$	$1.22 \pm 0.19 \pm 0.18$	-
$D_s^+ \to (K^+\pi^+\pi^-)_{NR}$	-	1.03 ± 0.34



$$\mathcal{B}(D_s^+ \to K^+\pi^+\pi^-\pi^0) = \left(9.75 \pm 0.54_{stat.} \pm 0.17_{syst.}\right) \times 10^{-3}$$

$$\mathcal{B}(D_s^+ \to K^+\omega) = \left(0.95 \pm 0.12_{stat.} \pm 0.06_{syst.}\right) \times 10^{-3}$$

$D^{0,+}$ decays

$\delta_{K\pi}$ measurement

Eur.Phys.J.C 82 (2022) 1009

Since the $D^0\bar{D}^0$ is $CP-odd$ generated, therefore

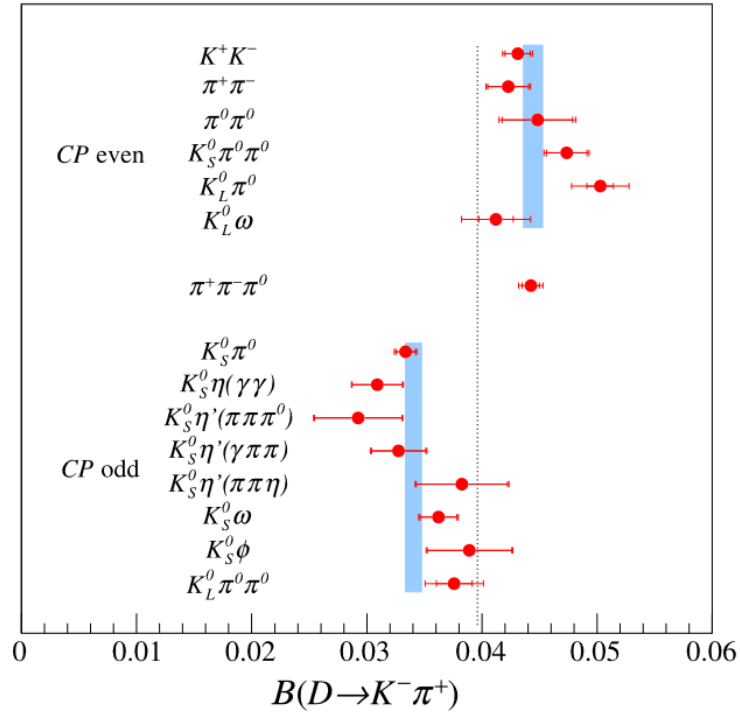
$$\mathcal{B}(D_- \to K^-\pi^+) = \frac{N(K^-\pi^+|T_+)}{2N_{D\bar{D}}\mathcal{B}(D^0 \to T_+)} \cdot \frac{1}{\epsilon(K^-\pi^+|T_+)}$$

Then the asymmetry of effective branching fraction is

$$\mathcal{A}_{K\pi} \equiv \frac{\mathcal{B}(D_- \to K^-\pi^+) - \mathcal{B}(D_+ \to K^-\pi^+)}{\mathcal{B}(D_- \to K^-\pi^+) + \mathcal{B}(D_+ \to K^-\pi^+)}$$

Therefore,

$$\mathcal{A}_{K\pi} = \frac{-2r_D^{K\pi}\cos\delta_D^{K\pi} + y}{1 + (r_D^{K\pi})^2}.$$



With tagged by self-conjugate channel, e.g $D \to \pi^+\pi^-\pi^0$

$$\mathcal{A}_{K\pi}^{\pi\pi\pi^0} \equiv \frac{\mathcal{B}(D_X \to K^-\pi^+) - \mathcal{B}(D_+ \to K^-\pi^+)}{\mathcal{B}(D_X \to K^-\pi^+) + \mathcal{B}(D_+ \to K^-\pi^+)}$$

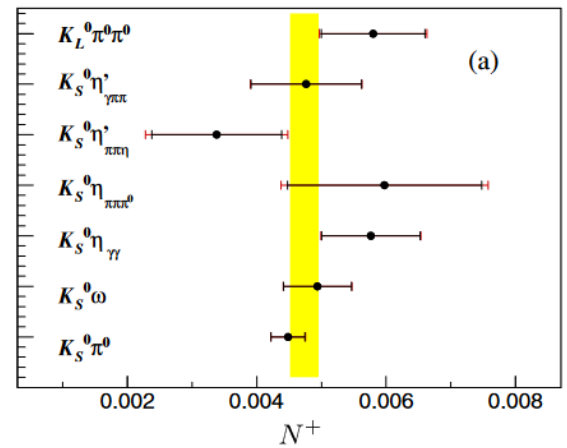
$$\mathcal{A}_{K\pi}^{\pi\pi\pi^0} = \frac{\left(-2r_D^{K\pi}\cos\delta_D^{K\pi} + y\right)F_+^{\pi\pi\pi^0}}{1 + (r_D^{K\pi})^2 + (1 - F_+^{\pi\pi\pi^0})\left(2r_D^{K\pi}\cos\delta_D^{K\pi} + y\right)}$$

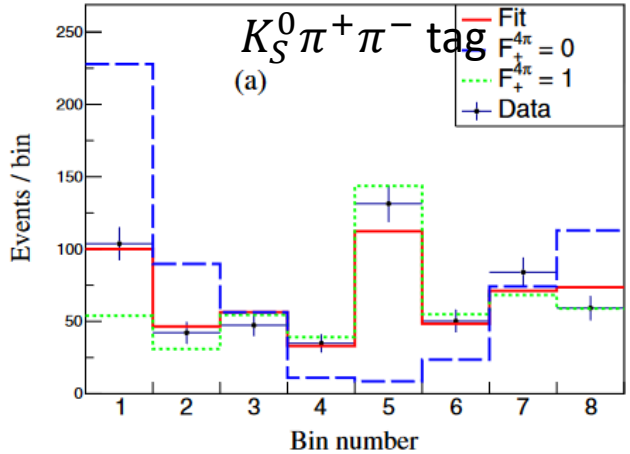
$$\mathcal{A}_{K\pi} = 0.132 \pm 0.011 \pm 0.007$$
$$\mathcal{A}_{K\pi}^{\pi\pi\pi^0} = 0.130 \pm 0.012 \pm 0.008.$$
$$\delta_D^{K\pi} = \left(187.6^{+8.9+5.4}_{-9.7-6.4}\right)^\circ$$

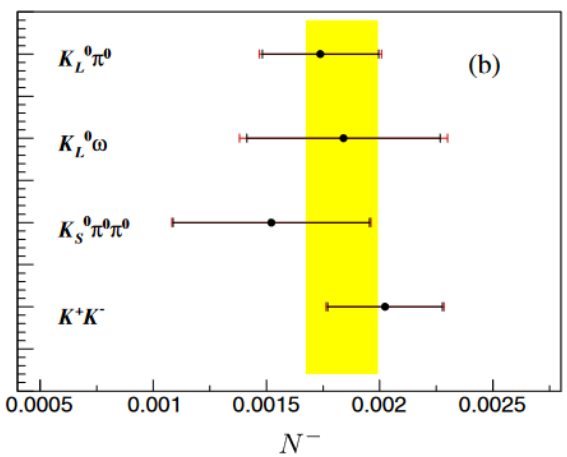
$F_+^{\pi\pi\pi^0}$ is the fraction of CP-even component in $D \to \pi^+\pi^-\pi^0$ decay

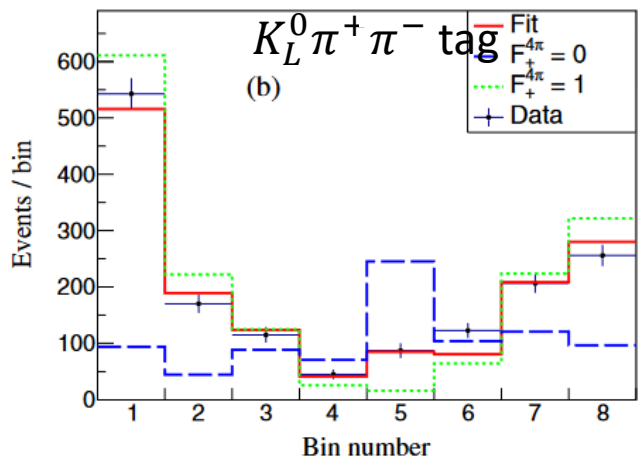
$F_+^{4\pi}$ measurement

PhysRevD.106.092004









$D \to \pi^+\pi^-\pi^0$ tag

$F_+^{4\pi} = 0.721 \pm 0.019 \pm 0.007$

$F_+^{4\pi} = 0.754 \pm 0.031 \pm 0.009$

$F_+^{4\pi} = 0.753 \pm 0.028 \pm 0.010,$

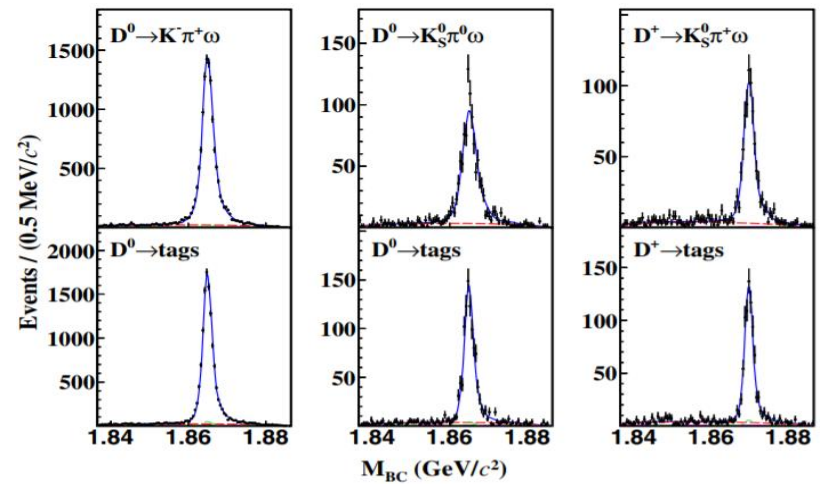
Combined:

$$F_+^{4\pi} = 0.735 \pm 0.015 \pm 0.005$$

Branching fractions of $D^{0/+} \to K_S^0 \pi^{0/+} \omega$, $D^0 \to K^- \pi^+ \omega$

PhysRevD.105.032009 (2022)

$D^0 \to K^- \pi^+ \omega$	$(3.392 \pm 0.044_{stat.} \pm 0.085_{syst.})\%$
$D^0 \to K_S^0 \pi^0 \omega$	$(0.848 \pm 0.046_{stat.} \pm 0.031_{syst.})\%$
$D^+ \to K_S^0 \pi^+ \omega$	$(0.707 \pm 0.041_{stat.} \pm 0.029_{syst.})\%$



Some channels with multi-pions

PhysRevD.106.092005 (2022)

Decay	ΔE_{sig} (MeV)	N_{DT}	ϵ_{sig} (%)	$\mathcal{B}_{sig}$ ($\times 10^{-4}$)
$\pi^+\pi^-\pi^0$	$(-62, 36)$	12792.6(120.1)	40.91	134.3(13)(16)
$\pi^+\pi^-2\pi^0$	$(-75, 37)$	3801.3(70.6)	16.29	100.2(19)(24)
$\pi^+\pi^-2\eta$	$(-37, 29)$	42.5(6.7)	2.14	8.5(13)(04)
$4\pi^0$	$(-105, 41)$	96.0(11.5)	5.41	7.6(09)(07)
$3\pi^0\eta$	$(-82, 40)$	155.3(14.7)	2.83	23.6(22)(17)
$2\pi^+2\pi^-\pi^0$	$(-52, 33)$	942.4(40.0)	11.70	34.6(15)(15)
$2\pi^+2\pi^-\eta$	$(-36, 28)$	48.5(7.8)	3.46	6.0(10)(06)
$\pi^+\pi^-3\pi^0$	$(-76, 39)$	182.7(20.9)	5.13	15.3(17)(13)
$2\pi^+2\pi^-2\pi^0$	$(-64, 36)$	350.0(22.9)	3.15	47.7(31)(21)
$2\pi^+\pi^-$	$(-30, 28)$	2579.0(57.6)	50.63	32.7(07)(05)
$\pi^+2\pi^0$	$(-96, 44)$	1963.9(51.6)	27.33	46.1(12)(09)
$2\pi^+\pi^-\pi^0$	$(-59, 35)$	4614.4(83.1)	25.42	116.5(21)(21)
$\pi^+3\pi^0$	$(-86, 39)$	573.7(30.2)	8.83	41.7(22)(13)
$3\pi^+2\pi^-$	$(-37, 33)$	462.1(28.7)	16.26	18.2(11)(10)
$2\pi^+\pi^-2\pi^0$	$(-74, 39)$	1207.1(45.4)	7.21	107.4(40)(30)
$2\pi^+\pi^-\pi^0\eta$	$(-51, 33)$	191.4(15.9)	3.17	38.8(32)(12)
$\pi^+4\pi^0$	$(-90, 41)$	56.7(10.4)	1.87	19.5(36)(23)
$\pi^+3\pi^0\eta$	$(-66, 37)$	79.7(10.9)	1.77	28.9(40)(22)
$3\pi^+2\pi^-\pi^0$	$(-49, 34)$	182.8(17.3)	5.02	23.4(22)(15)
$2\pi^+\pi^-3\pi^0$	$(-66, 37)$	185.9(17.0)	3.49	34.2(31)(16)

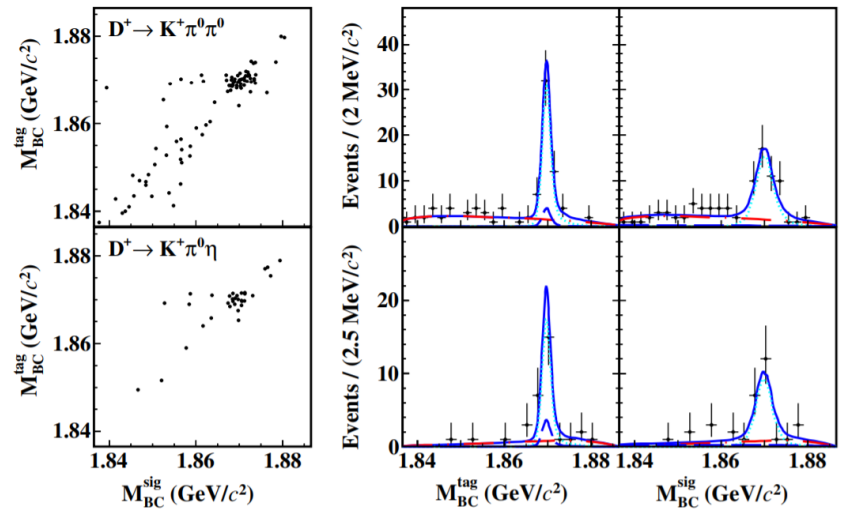
Also measure the CP-even fraction for some of channels

Decay	$M^-_{measured}$	$M^+_{measured}$	f_{CP+}
$D^0 \to \pi^+\pi^-\pi^0$	...	...	0.973 ± 0.017 [34]
$D^0 \to \pi^+\pi^-2\pi^0$	65.7 ± 11.1	169.8 ± 13.9	0.682 ± 0.077
$D^0 \to 4\pi^0$	...	...	1
$D^0 \to 3\pi^0\eta$	...	...	1
$D^0 \to 2\pi^+2\pi^-\pi^0$	37.8 ± 8.3	35.5 ± 6.6	0.438 ± 0.104
$D^0 \to \pi^+\pi^-3\pi^0$	$5.2^{+3.5}_{-2.8}$	$6.8^{+3.4}_{-2.7}$	$0.520^{+0.338}_{-0.269}$
$D^0 \to 2\pi^+2\pi^-2\pi^0$	$3.5^{+2.8}_{-2.1}$	15.9 ± 3.7	$0.790^{+0.269}_{-0.255}$

Branching fractions of $D^+ \to K^+\pi^0\pi^0/\eta$

JHEP09(2022)107

Decay mode	N_{DT}	ϵ_{sig} (%)	$\mathcal{B}_{sig}$ ($\times 10^{-4}$)
$D^+ \to K^+\pi^0\pi^0$	42.8 ± 7.2	18.08 ± 0.03	$2.1 \pm 0.4 \pm 0.1$
$D^+ \to K^+\pi^0\eta$	19.2 ± 5.0	20.50 ± 0.03	$2.1 \pm 0.5 \pm 0.1$
$D^+ \to K^{*+}\pi^0$	$16.6^{+6.6}_{-6.2}$	13.02 ± 0.03	$3.4^{+1.4}_{-1.3} \pm 0.1$
$D^+ \to K^{*+}\eta$	$10.9^{+4.4}_{-3.8}$	16.60 ± 0.04	$4.4^{+1.8}_{-1.5} \pm 0.2$

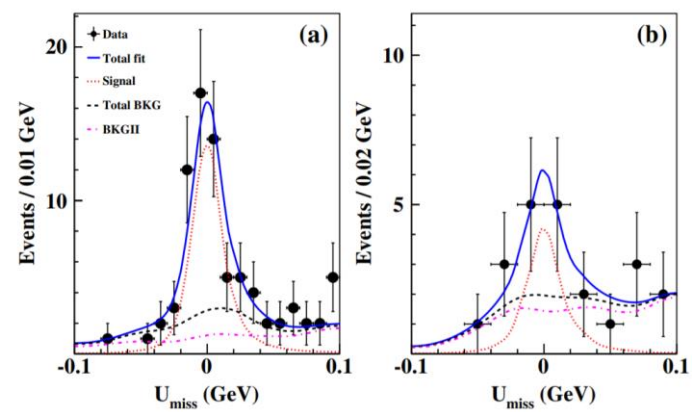


Branching fractions of $D^0 \to K^+\pi^-\pi^0(\pi^0)$

PhysRevD.105.112001 (2022)

$D^0 \to K^+\pi^-\pi^0$	$\left(3.13^{+0.60}_{-0.56}(stat.) \pm 0.15(syst.)\right) \times 10^{-4}$
$D^0 \to K^+\pi^-\pi^0\pi^0$	$< 3.6 \times 10^{-4}$ @90% CL.

Semi-leptonic decays are used for tag $\bar{D}^0$:



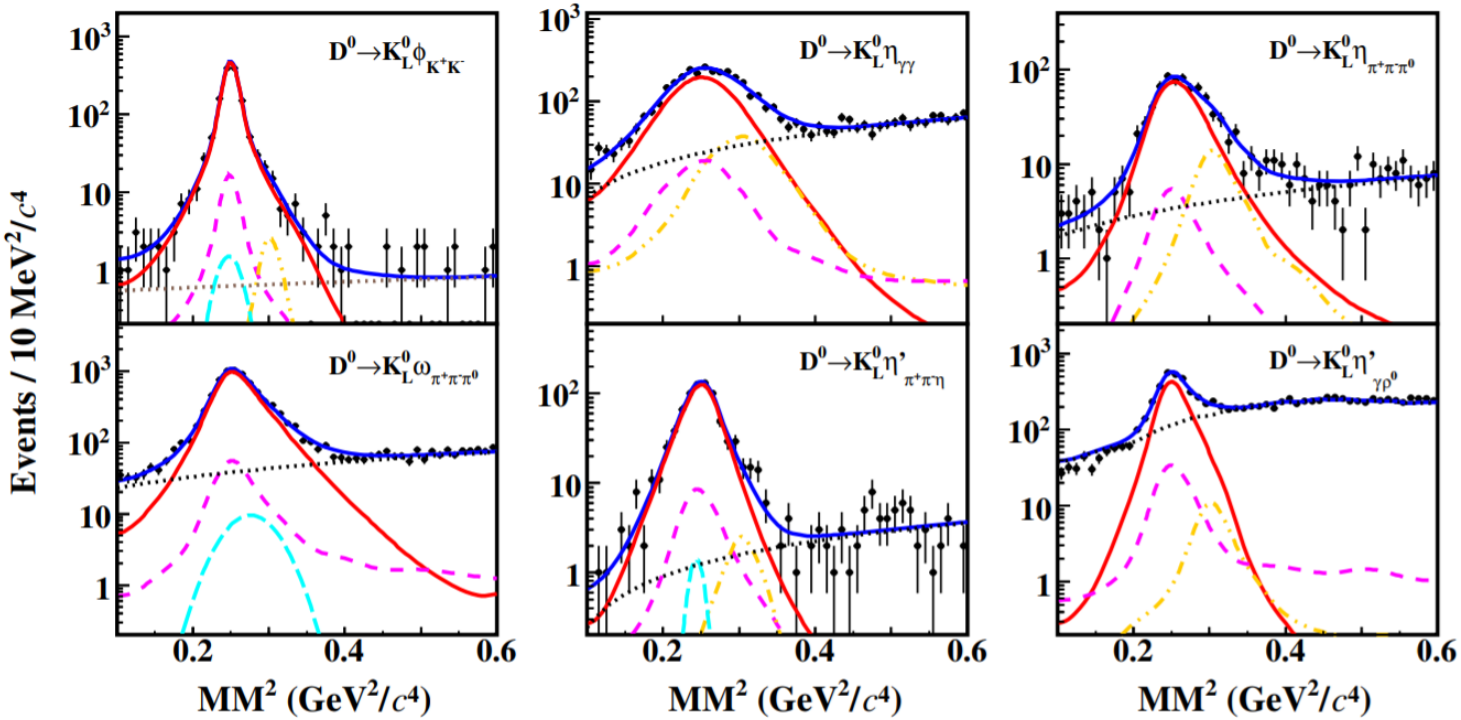
Branching fractions of $D^0 \to K_L X$ ($X = \phi, \eta, \omega$ and η')

PhysRevD.105.092010 (2022)

TABLE IV. Comparison of measured BFs and $K_S^0 - K_L^0$ asymmetries with theoretical calculations of Ref. [6]. $\mathcal{B}_{\rm exp}$ ($\mathcal{B}_{\rm FAT}$) and $\mathcal{R}(D^0)_{\rm exp}$ ($\mathcal{R}(D^0)_{\rm FAT}$) are the BFs and $K_S^0 - K_L^0$ asymmetries of the experimental measurements (theoretical calculations).

Decay	$\mathcal{B}_{\rm exp}$ (%)	$\mathcal{B}_{\rm FAT}$ (%)	Difference	$\mathcal{R}(D^0)_{\rm exp}$	$\mathcal{B}(D^0)_{\rm FAT}$	Difference
$D^0 \to K_L^0 \phi$	$0.414 \pm 0.021 \pm 0.010$	0.33 ± 0.03	2.2σ	-0.001 ± 0.047		2.4σ
$D^0 \to K_L^0 \eta$	$0.433 \pm 0.012 \pm 0.010$	0.40 ± 0.07	0.5σ	0.080 ± 0.022	0.113 ± 0.001	1.5σ
$D^0 \to K_L^0 \omega$	$1.164 \pm 0.022 \pm 0.028$	0.95 ± 0.15	1.4σ	-0.024 ± 0.031		4.4σ
$D^0 \to K_L^0 \eta'$	$0.809 \pm 0.020 \pm 0.016$	0.77 ± 0.07	0.5σ	0.080 ± 0.023		1.6σ

$$\mathcal{R}(D^0, X) = \frac{\mathcal{B}(D^0 \to K_S^0 X) - \mathcal{B}(D^0 \to K_L^0 X)}{\mathcal{B}(D^0 \to K_S^0 X) + \mathcal{B}(D^0 \to K_L^0 X)}$$



Summary

- With the data of $E_{cm} = 4.13 - 4.26$ GeV data, 8 analyses for D_s^+ hadronic decays are (going to) published this year.
- With the 2.93fb^{-1} of $\psi(3770)$ data, 7 analyses for $D^{0/+}$ hadronic decays are published this year.
- These analyses relate to amplitude analysis, spectroscopy, strong phase and branching fraction.
- In near future, BESIII will gather 20fb^{-1} of $\psi(3770)$ data, more result will come in next several year!

Thank you for your attention!