Hadronic Decays of Charm hadrons at BESIII

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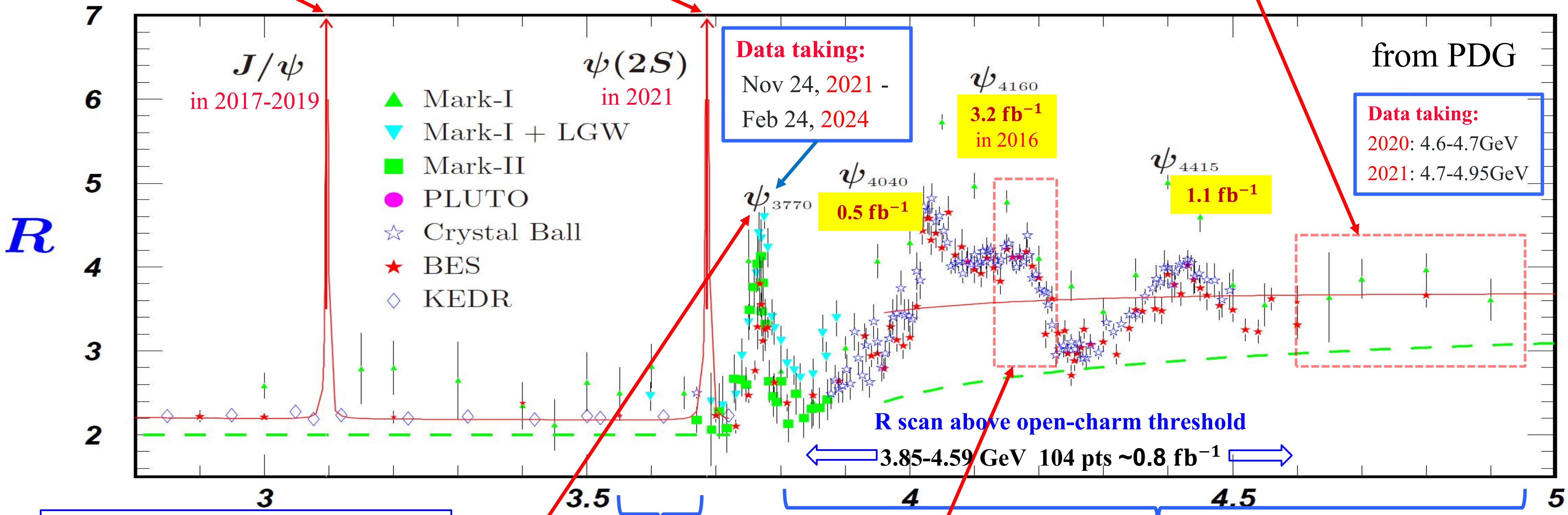
Datasets (totally ~50 fb^{-1} from 1.84 – 4.95 GeV)

BESIII

10B: light hadron, hyperon

2.7B: charmonium

6.4 fb^{-1}: ~1.0M $\Lambda_c^+\bar{\Lambda}_c^-$ pairs produced @4.5995-4.9509 GeV



R scan below open-charm threshold
1.84-1.97 GeV 13 pts ~25 pb^{-1}
2.00-3.08 GeV 21 pts ~550 pb^{-1}
2.23-3.67 GeV 14 pts ~110 pb^{-1}

Tau mass scan

3.8-4.96 GeV: ~22.5 fb^{-1}, XYZ, $D_s^+D_s^-$, $\Lambda_c^+\bar{\Lambda}_c^-$ …

7.33 fb^{-1}: ~6.5M $D_s^+D_s^-$ pairs produced @4.128-4.226 GeV

20.3 fb^{-1}: ~73.3M $D^0\bar{D}^0$ pairs produced @3.773 GeV
~57.4M D^+D^- pairs produced @3.773 GeV

Data taking plan
Mar 2025 - Jul 2025: $\psi(3686)$; Oct 2025-Jul 2026: 4.7 GeV;
Oct 2026 - Aug 2028: 4.2-5.0 GeV; Sep 2028-Jul 2030 :5.0-5.6 GeV

Charmed mesons hadronic decays

Measurements of the BFs

→ Are important component of heavy-flavor physics program.

→ Probe and calibrate non-perturbative QCD

→ Understand SU(3) flavor symmetry and its breaking effect

→ Test theoretical calculations of BFs and improve theoretical predictions of *CP* violation

Amplitude analysis of multi-body decays

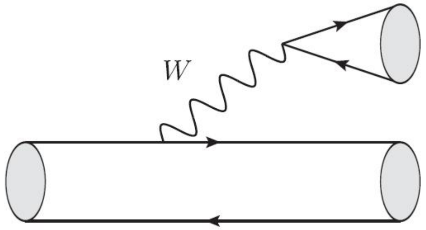
→ Information of $D \to VP, PP, SP, SV, VV, AP, AV, TP\ldots$

→ Light hadron spectroscopy

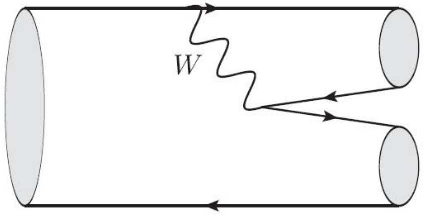
P: pseudo-scalar
V: vector
S: scalar
A: axial-vector
T: tensor

Topological Diagrammatic for D/D_s^+ decays:

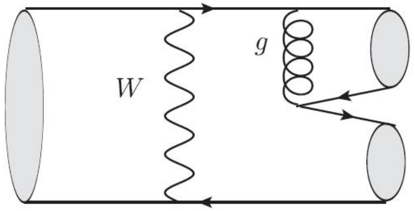
H.-Y. Cheng, *et al.* PRD 85,034036



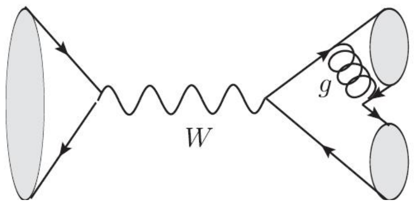
Color-allowed tree T



Color-suppressed tree C



W-exchange E



W-annihilation A

Calculation is not reliable, need exp. input

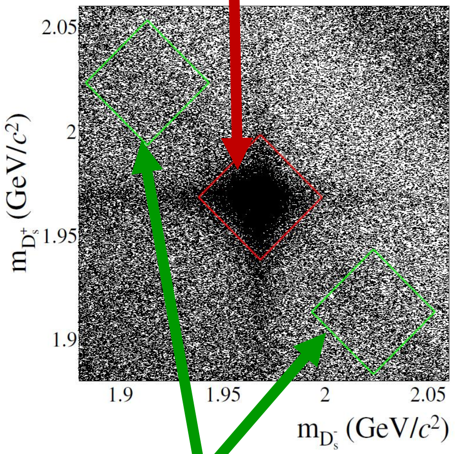
BF of D_s^+ hadronic decays

BESIII

BF Measurement of D_s^+ hadronic decays

JHEP05(2024)335, 7.33fb^{-1}@$4.128-4.226$GeV

42965 events in signal region



14728 events in combined sideband

Mode	$\mathcal{B}$ (%)	$\mathcal{A}_{CP}$ (%)
$D_s^+\to K_S^0K^+$	$1.502\pm0.012\pm0.009$	$0.29\pm0.50\pm0.21$
$D_s^+\to K^+K^-\pi^+$	$5.49\pm0.04\pm0.07$	$0.48\pm0.26\pm0.24$
$D_s^+\to K_S^0K^+\pi^0$	$1.47\pm0.02\pm0.02$	$-0.85\pm1.97\pm0.46$
$D_s^+\to K_S^0K_S^0\pi^+$	$0.73\pm0.01\pm0.01$	$1.14\pm1.58\pm0.44$
$D_s^+\to K^+K^-\pi^+\pi^0$	$5.50\pm0.05\pm0.11$	$-0.66\pm0.91\pm0.33$
$D_s^+\to K_S^0K^+\pi^+\pi^-$	$0.93\pm0.02\pm0.01$	$2.00\pm2.37\pm0.70$
$D_s^+\to K_S^0K^-\pi^+\pi^+$	$1.56\pm0.02\pm0.02$	$-0.24\pm1.05\pm1.07$
$D_s^+\to \pi^+\pi^+\pi^-$	$1.09\pm0.01\pm0.01$	$-0.88\pm1.17\pm0.38$
$D_s^+\to \pi^+\eta$	$1.69\pm0.02\pm0.02$	$-0.44\pm0.89\pm0.19$
$D_s^+\to \pi^+\pi^0\eta$	$9.10\pm0.09\pm0.15$	$1.05\pm1.45\pm0.62$
$D_s^+\to \pi^+\pi^+\pi^-\eta$	$3.08\pm0.06\pm0.05$	$2.42\pm2.85\pm0.78$
$D_s^+\to \pi^+\eta'$	$3.95\pm0.04\pm0.07$	$-0.59\pm0.76\pm0.20$
$D_s^+\to \pi^+\pi^0\eta'$	$6.17\pm0.12\pm0.14$	$-1.60\pm2.57\pm0.64$
$D_s^+\to K_S^0\pi^+\pi^0$	$0.51\pm0.02\pm0.01$	$-2.17\pm4.65\pm1.10$
$D_s^+\to K^+\pi^+\pi^-$	$0.620\pm0.009\pm0.006$	$1.81\pm2.01\pm0.45$

Agree with PDG with much improved precision

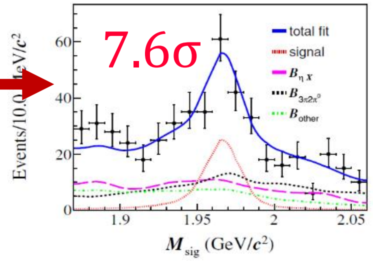
17 Amplitude analyses published

$D_s^+\to K^+K^-\pi^+$	Phys. Rev. D **104** (2021) 012016
$D_s^+\to K_S^0K^+\pi^0$	Phys. Rev. Lett. **129** (2022) 182001
$D_s^+\to \pi^+\pi^+\pi^-$	Phys. Rev. D **106** (2022) 112006
$D_s^+\to \pi^+\pi^+\pi^-\eta$	Phys. Rev. D **104** (2021) L071101
$D_s^+\to \pi^+\pi^0\eta'$	**JHEP 04** (2022) 058
$D_s^+\to \pi^+\pi^0\pi^0$	**JHEP 01** (2022) 052
$D_s^+\to K^+\pi^+\pi^-$	**JHEP 08** (2022) 196
$D_s^+\to K^+\pi^+\pi^-\pi^0$	**JHEP 09** (2022) 242
$D_s^+\to K_S^0K_S^0\pi^+$	Phys. Rev. D **105** (2022) L051103
$D_s^+\to K_S^0K^-\pi^+\pi^+$	Phys. Rev. D **103** (2021) 092006
$D_s^+\to K^+K^-\pi^+\pi^0$	Phys. Rev. D **104** (2021) 032011
$D_s^+\to K^+K^-\pi^+\pi^+\pi^-$	**JHEP 07** (2022) 051
$D_s^+\to K_S^0\pi^+\pi^0$	**JHEP 06** (2021) 181
$D_s^+\to \pi^+\pi^0\eta$	Phys. Rev. Lett. **123** (2019) 112001
$D_s^+\to \pi^+\pi^+\pi^-\pi^0$	Phys. Rev. Lett. **134** (2025) 011904
$D_s^+\to \pi^+\pi^+\pi^-\pi^0\pi^0$	Phys. Rev. Lett. **134** (2025) 201902
$D_s^+\to K_S^0K_L^0\pi^+$	Phys. Rev. Lett. **135** (2025) 161902
$D_s^+\to \pi^+\pi^0\pi^0\eta$	**to be submitted soon**

Observation of $D_s^+\to\omega\pi^+\eta$

PRD 107, 052010 (2023), 7.33fb^{-1}@$4.128-4.226$GeV

$$\mathcal{B}(D_s^+\to\omega\pi^+\eta)=(0.54\pm0.12\pm0.04)\%$$



分支比测量和振幅分析为理解D_s^+介子强子衰变机制提供了完整的实验信息

Amplitude analysis of $D_s^+ \to \pi^+\pi^+\pi^-\pi^0$

$7.33\,\mathrm{fb}^{-1}$ @ $4.128-4.226\,\mathrm{GeV}$, PRL 134, 011904 (2025)

1552 candidates with >75% purity

Observation of $D_s^+ \to f_0(980)\rho(770)^+$

(Mainly involves W-external-emission diagram)

$$\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^-\pi^0|_{\mathrm{non}-\eta}) = (2.04 \pm 0.08_{\mathrm{stat.}} \pm 0.05_{\mathrm{syst.}})\%$$

$$\mathcal{B}(D_s^+ \to \eta\pi^+) = (1.56 \pm 0.09_{\mathrm{stat.}} \pm 0.04_{\mathrm{syst.}})\%$$

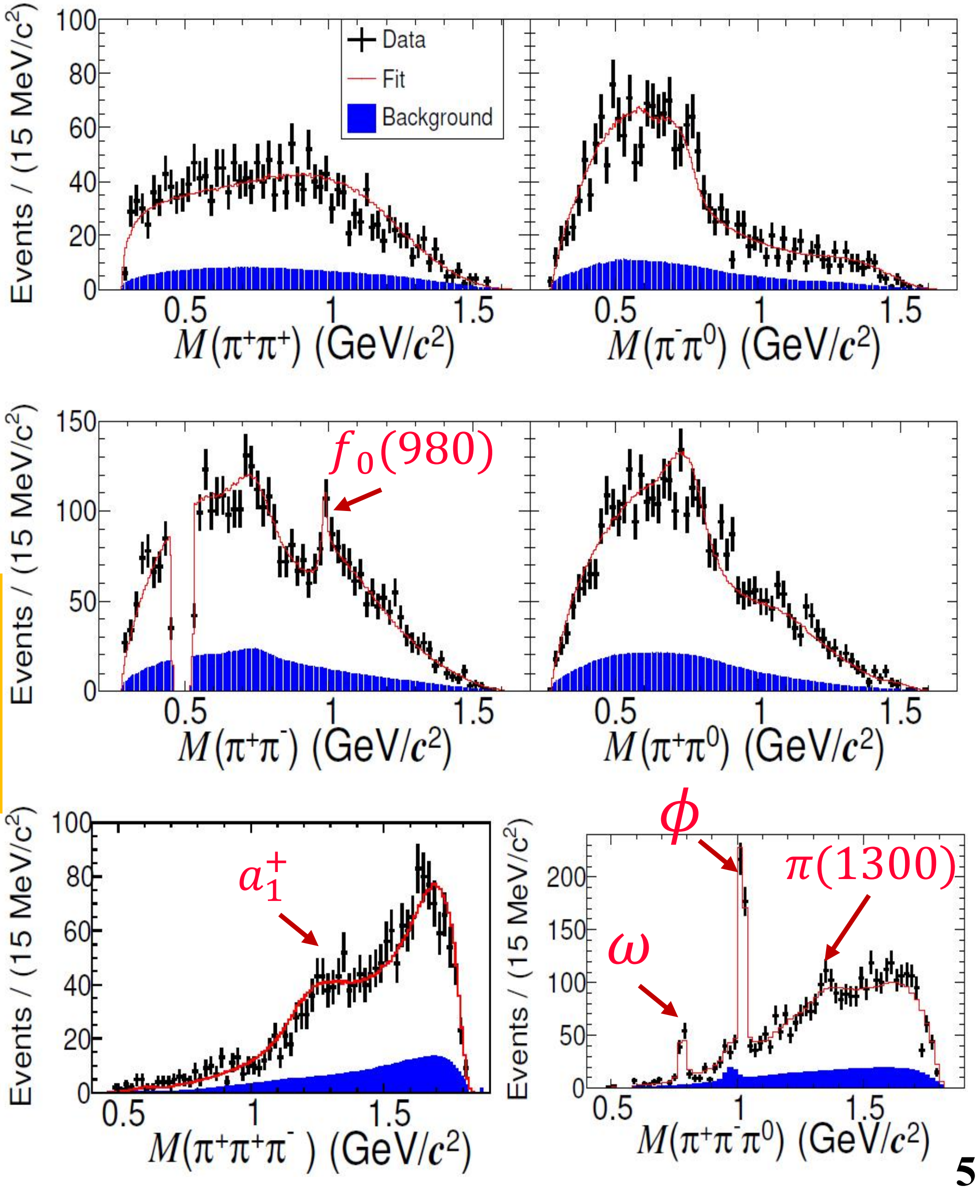
$$\frac{\mathcal{B}(\phi(1020) \to \pi^+\pi^-\pi^0)}{\mathcal{B}(\phi(1020) \to K^+K^-)} = 0.230 \pm 0.014_{\mathrm{stat.}} \pm 0.010_{\mathrm{syst.}}$$

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

Deviates from PDG value (0.313±0.010) by >4σ

Component	Phase (rad)	BF (10^{-3})
$f_0(1370)\rho^+$	0.0(fixed)	$5.08 \pm 0.80 \pm 0.43$
$f_0(980)\rho^+$	$3.99 \pm 0.13 \pm 0.07$	$2.57 \pm 0.44 \pm 0.20$
$f_2(1270)\rho^+$	$1.11 \pm 0.10 \pm 0.10$	$1.94 \pm 0.36 \pm 0.12$
$(\rho^+\rho^0)_S$	$1.10 \pm 0.18 \pm 0.10$	$0.71 \pm 0.25 \pm 0.12$
$(\rho(1450)^+\rho^0)_S$	$0.43 \pm 0.18 \pm 0.17$	$0.94 \pm 0.27 \pm 0.16$
$(\rho^+\rho(1450)^0)_P$	$4.58 \pm 0.16 \pm 0.09$	$1.75 \pm 0.27 \pm 0.08$
$\phi((\rho\pi) \to \pi^+\pi^-\pi^0)\pi^+$	$2.90 \pm 0.15 \pm 0.18$	$5.08 \pm 0.32 \pm 0.10$
$\omega((\rho\pi) \to \pi^+\pi^-\pi^0)\pi^+$	$3.22 \pm 0.21 \pm 0.09$	$1.41 \pm 0.17 \pm 0.06$
$a_1^+(\rho^0\pi^+)_S\pi^0$	$3.78 \pm 0.16 \pm 0.12$	$2.55 \pm 0.34 \pm 0.20$
$a_1^0((\rho\pi)_S \to \pi^+\pi^-\pi^0)\pi^+$	$4.82 \pm 0.15 \pm 0.12$	$1.29 \pm 0.39 \pm 0.24$
$\pi(1300)^0((\rho\pi)_P \to \pi^+\pi^-\pi^0)\pi^+$	$2.22 \pm 0.14 \pm 0.08$	$2.39 \pm 0.48 \pm 0.45$

W-annihilation decay
$BF = (1.92 \pm 0.30) \times 10^{-3}$ **(PDG)**

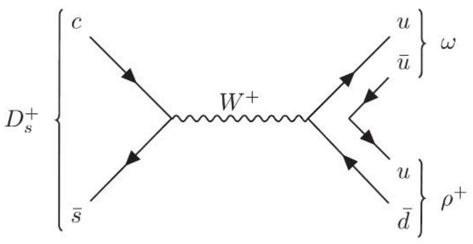


Amplitude analysis of $D_s^+ \to \pi^+\pi^+\pi^-\pi^0\pi^0$

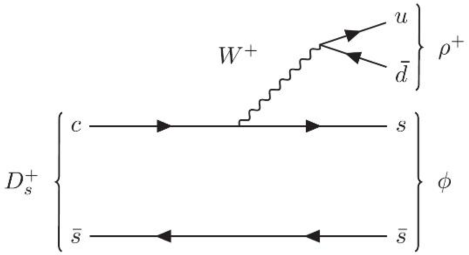
7.33fb^{-1} @ $4.128 - 4.226$GeV, PRL 134, 201902 (2025)

1888 candidates with >79% purity

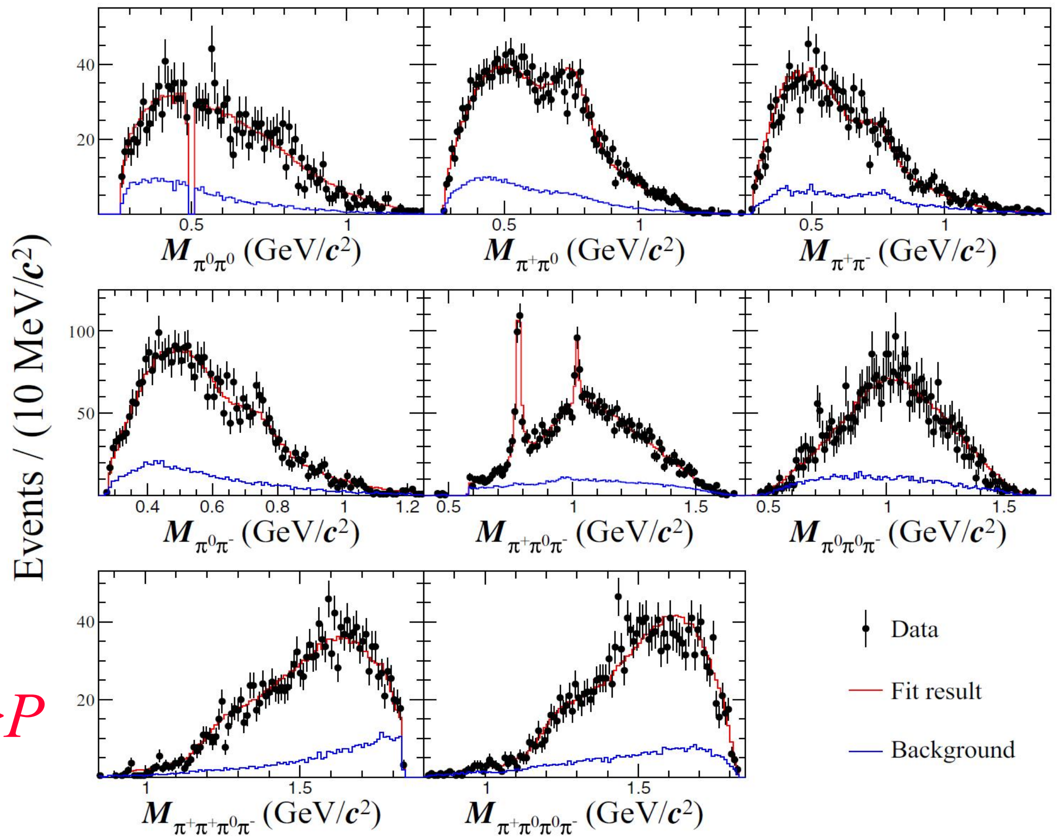
Observation of $D_s^+ \to \omega\rho(770)^+$



Pure W-annihilation



Pure W-external emission



Amplitude	BF (%)
$D_s^+ \to \rho(1450)^+\pi^0,\ \rho(1450)^+ \to \omega\pi^+$	$0.39 \pm 0.04\ ^{+0.03}_{-0.03}$
$D_s^+[S] \to a_1(1260)^0\rho^+,\ a_1(1260)^0[S] \to \rho^+\pi^-$	$0.23 \pm 0.02\ ^{+0.01}_{-0.01}$
$D_s^+[P] \to a_1(1260)^0\rho^+,\ a_1(1260)^0[S] \to \rho^+\pi^-$	$0.50 \pm 0.04\ ^{+0.02}_{-0.02}$
$D_s^+ \to a_1(1260)^0\rho^+,\ a_1(1260)^0 \to \rho^+\pi^-$	$0.50 \pm 0.04\ ^{+0.02}_{-0.02}$
$D_s^+[S] \to a_1(1260)^0\rho^+,\ a_1(1260)^0[S] \to \rho^-\pi^+$	$0.16 \pm 0.02\ ^{+0.01}_{-0.01}$
$D_s^+[P] \to a_1(1260)^0\rho^+,\ a_1(1260)^0[S] \to \rho^-\pi^+$	$0.17 \pm 0.01\ ^{+0.01}_{-0.01}$
$D_s^+ \to a_1(1260)^0\rho^+,\ a_1(1260)^0 \to \rho^-\pi^+$	$0.33 \pm 0.02\ ^{+0.02}_{-0.02}$
$D_s^+[S] \to a_1(1260)^+\rho^0,\ a_1(1260)^+[S] \to \rho^+\pi^0$	$0.41 \pm 0.05\ ^{+0.05}_{-0.05}$
$D_s^+[P] \to a_1(1260)^+\rho^0,\ a_1(1260)^+[S] \to \rho^+\pi^0$	$0.31 \pm 0.04\ ^{+0.02}_{-0.02}$
$D_s^+ \to a_1(1260)^+\rho^0,\ a_1(1260)^+ \to \rho^+\pi^0$	$0.73 \pm 0.07\ ^{+0.07}_{-0.07}$
$D_s^+ \to b_1(1235)^+\pi^0,\ b_1(1235)^+[S] \to \omega\pi^+$	$0.53 \pm 0.05\ ^{+0.03}_{-0.03}$
$D_s^+ \to b_1(1235)^0\pi^+,\ b_1(1235)^0[S] \to \omega\pi^0$	$0.72 \pm 0.06\ ^{+0.05}_{-0.05}$

Polarization puzzle

Amplitude	BF (%)
$D_s^+[S] \to \omega\rho^+$	$0.30 \pm 0.07\ ^{+0.02}_{-0.03}$
$D_s^+[P] \to \omega\rho^+$	$0.25 \pm 0.04\ ^{+0.04}_{-0.04}$
$D_s^+[D] \to \omega\rho^+$	$0.52 \pm 0.07\ ^{+0.04}_{-0.07}$
$D_s^+ \to \omega\rho^+$	$0.99 \pm 0.08\ ^{+0.05}_{-0.07}$
$D_s^+[S] \to \phi\rho^+$	$3.32 \pm 0.29\ ^{+0.19}_{-0.17}$
$D_s^+[P] \to \phi\rho^+$	$0.63 \pm 0.12\ ^{+0.05}_{-0.06}$
$D_s^+ \to \phi\rho^+$	$3.98 \pm 0.33\ ^{+0.21}_{-0.19}$

D>S>P (for $D_s^+ \to \omega\rho^+$)

S>P>D (for $D_s^+ \to \phi\rho^+$)

Naive prediction: PRL 128,011803

transverse dominates than longitudinal in charm decays

$$\frac{\mathcal{B}(\phi(1020) \to \pi^+\pi^-\pi^0)}{\mathcal{B}(\phi(1020) \to K^+K^-)} = 0.222 \pm 0.019_{\text{stat}} \pm 0.016_{\text{syst}}$$

Taking from $D_s^+ \to K^+K^-\pi^+\pi^0$
BESIII, PRD 104, 032011 (2021)

Deviates from PDG value (0.313±0.010) by $>3\sigma$

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

BESIII

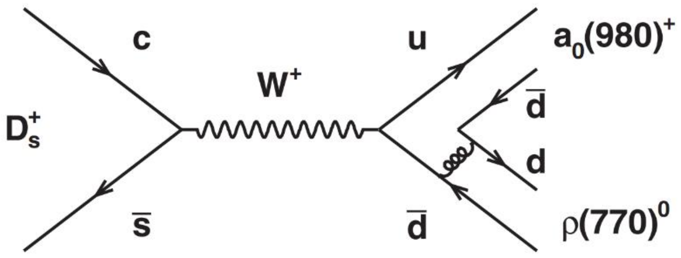
- $D_s^+ \to \eta\pi^+\pi^+\pi^-$

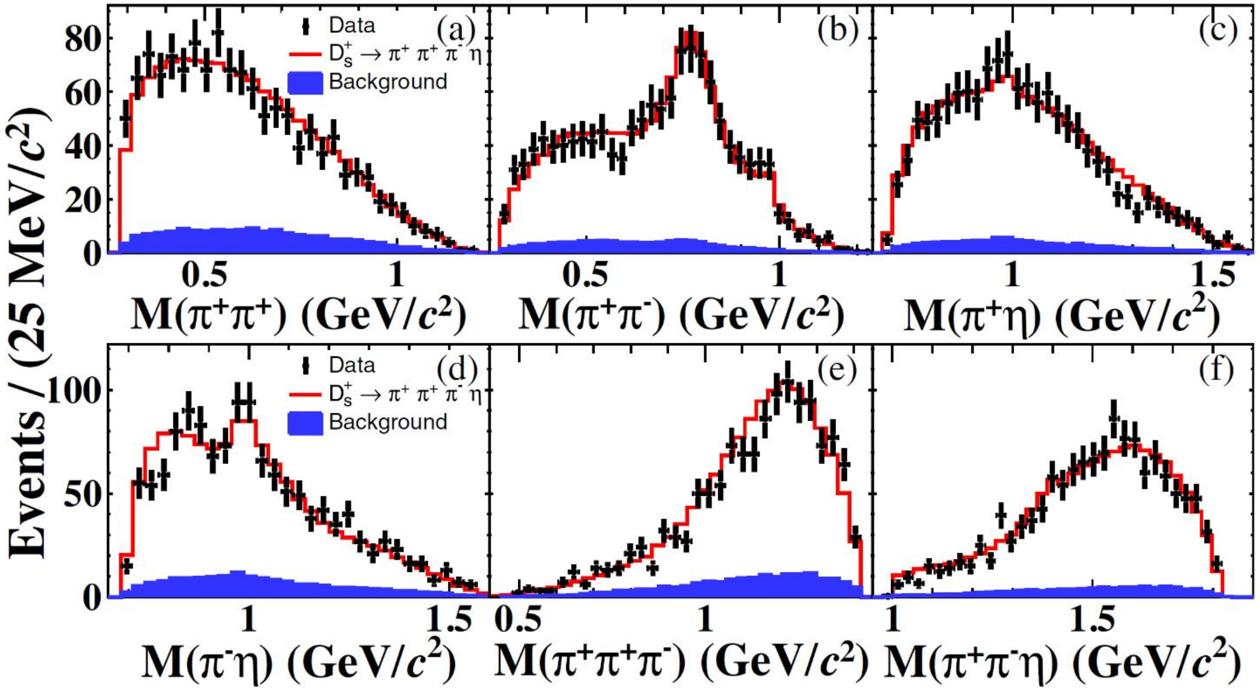
PRD 104, L071101 (2021)

$6.32\,\text{fb}^{-1}@\boldsymbol{E}_{\textbf{cm}} = 4.178-4.226\,\text{GeV}$

1306 candidates with >85% purity

Observe W-annihilation decay $D_s^+ \to a_0(980)^+\rho(770)^0$





- First measurement:

$$\mathcal{B}_{D_s^+\to\eta\pi^+\pi^+\pi^-} = (3.12 \pm 0.13 \pm 0.09)\%$$

- Dominant process:

$$\mathcal{B}_{D_s^+\to a_1(1260)^+\eta,\, a_1(1260)^+\to\rho^0\pi^+} = (1.73 \pm 0.14 \pm 0.08)\%$$

- W-annihilation contribution:

$$\mathcal{B}_{D_s^+\to a_0(980)^+\rho^0,\, a_0(980)^+\to\eta\pi^+} = (0.21 \pm 0.08 \pm 0.05)\%$$

Significantly larger than the BFs of most other measured pure W-annihilation decays

Amplitude analysis of $D_s^+ \to K_S^0 K_L^0 \pi^+$

7.33fb^{-1} @ $4.128-4.226\text{GeV}$

PRL 135, 161902 (2025)

2310 candidates with >78% purity

Measurement of $\phi \to K_S^0 K_L^0$

$$\mathcal{B}_{D_s^+ \to K_S^0 K_L^0 \pi^+} = (1.86 \pm 0.06_{\text{stat}} \pm 0.03_{\text{syst}})\%$$

Amplitude	Phase (rad)	BF (%)
$D_s^+ \to \phi\pi^+$	0.0 (fixed)	$1.31 \pm 0.05 \pm 0.03$
$D_s^+ \to K_L^0 K^*(892)^+$	$1.10 \pm 0.20 \pm 0.20$	$0.36 \pm 0.03 \pm 0.02$
$D_s^+ \to K_S^0 K^*(892)^+$	$-1.93 \pm 0.20 \pm 0.25$	$0.27 \pm 0.02 \pm 0.02$

$$\frac{\mathcal{B}(\phi(1020) \to K_S^0 K_L^0)}{\mathcal{B}(\phi(1020) \to K^+ K^-)} = (0.593 \pm 0.023_{\text{stat}} \pm 0.014_{\text{syst}} \pm 0.016_{\phi\pi})$$

Taking from PDG $\mathcal{B}(D_s^+ \to \phi\pi^+, \phi \to K^+K^-)$

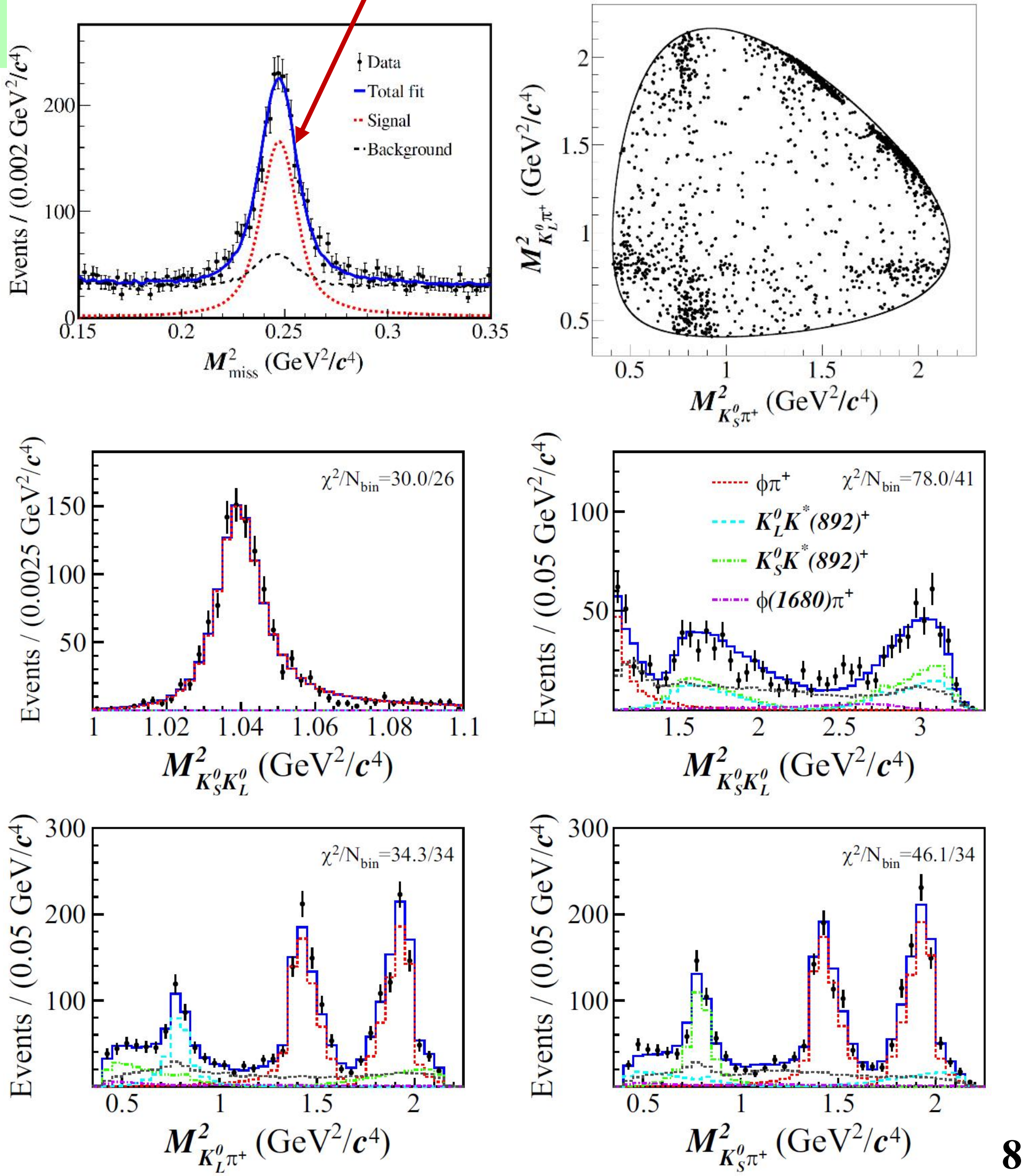
Deviates from PDG value (0.740±0.031) by $>3\sigma$

First observation of $K_S^0 - K_L^0$ asymmetry

$$\frac{\mathcal{B}(D_s^+ \to K_S^0 K^*(892)^+) - \mathcal{B}(D_s^+ \to K_L^0 K^*(892)^+)}{\mathcal{B}(D_s^+ \to K_S^0 K^*(892)^+) + \mathcal{B}(D_s^+ \to K_L^0 K^*(892)^+)} = (-14.5 \pm 5.1_{\text{stat}} \pm 1.8_{\text{syst}})\%$$

Model	DAT(F4)	DAT(F1′)
$D_s^+ \to \bar{K}^0 K^{*+}$	-0.164 ± 0.032	-0.159 ± 0.028

Predictions by H.-Y. Cheng *et al.*, PRD109, 073008（2024）

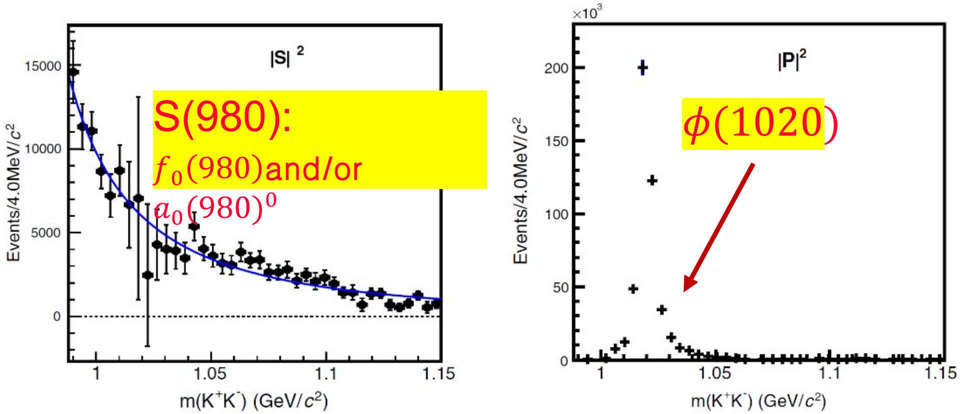


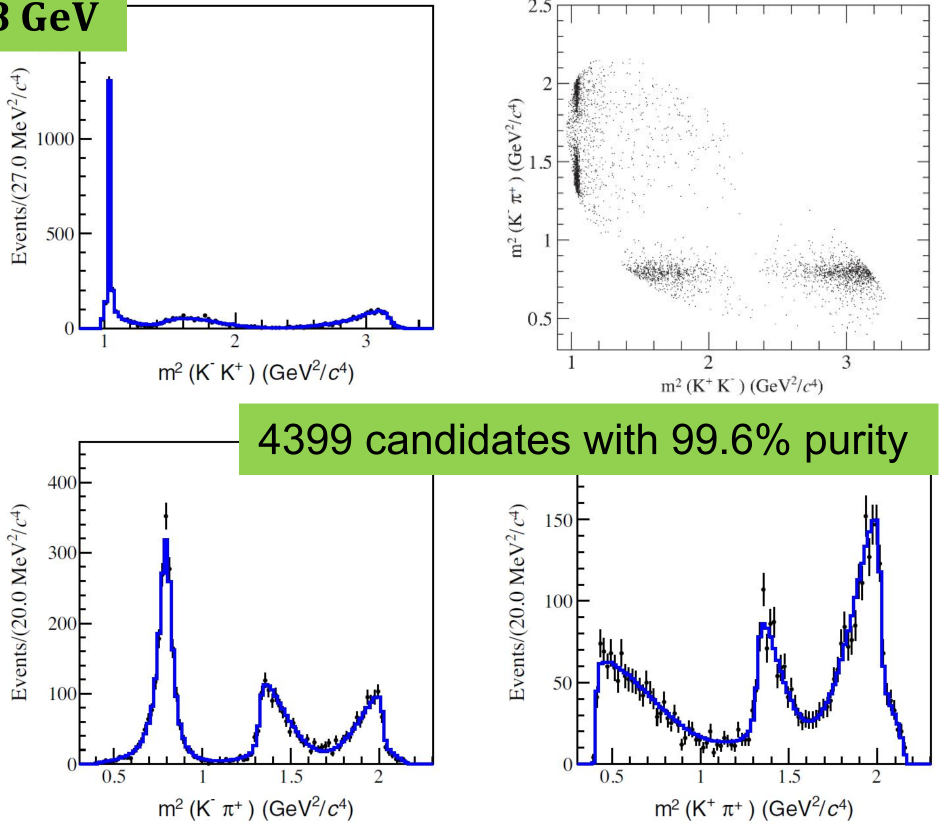
Amplitude analysis of $D_s^+ \to K^+K^-\pi^+$

$D_s^+ \to K^+K^-\pi^+$ PRD 104, 012016 (2021) $3.19\,\mathrm{fb}^{-1}@E_{\mathrm{cm}} = 4.178$ GeV

Gold normalization channel, 4399 candidates with 99.6% purity.

Model-independent PWA to determine the KK S-wave line shape:





Measured BFs and quoted from PDG:

Process	BF (%)	PDG 2024
$D_s^+ \to \bar{K}^*(892)^0K^+$, $\bar{K}^*(892)^0 \to K^-\pi^+$	$2.64 \pm 0.06_{\mathrm{stat}} \pm 0.07_{\mathrm{sys}}$	2.58 ± 0.06
$D_s^+ \to \phi(1020)\pi^+$, $\phi(1020) \to K^+K^-$	$2.21 \pm 0.05_{\mathrm{stat}} \pm 0.07_{\mathrm{sys}}$	2.21 ± 0.06
$D_s^+ \to S(980)\pi^+$, $S(980) \to K^+K^-$	$1.05 \pm 0.04_{\mathrm{stat}} \pm 0.06_{\mathrm{sys}}$	1.11 ± 0.19
$D_s^+ \to \bar{K}_0^*(1430)^0K^+$, $\bar{K}_0^*(1430)^0 \to K^-\pi^+$	$0.16 \pm 0.03_{\mathrm{stat}} \pm 0.03_{\mathrm{sys}}$	0.18 ± 0.03
$D_s^+ \to f_0(1710)\pi^+$, $f_0(1710) \to K^+K^-$	$0.10 \pm 0.02_{\mathrm{stat}} \pm 0.03_{\mathrm{sys}}$	0.07 ± 0.03
$D_s^+ \to f_0(1370)\pi^+$, $f_0(1370) \to K^+K^-$	$0.07 \pm 0.02_{\mathrm{stat}} \pm 0.01_{\mathrm{sys}}$	0.07 ± 0.03
$D_s^+ \to K^+K^-\pi^+$ total BF	$5.47 \pm 0.08_{\mathrm{stat}} \pm 0.13_{\mathrm{sys}}$	5.37 ± 0.10

BFs of Intermediate processes:

$$\mathcal{B}(D_s^+ \to \bar{K}^*(892)^0K^+) = (3.94 \pm 0.12)\%$$

$$\mathcal{B}(D_s^+ \to \phi(1020)\pi^+) = (4.60 \pm 0.17)\%$$

Consistent with latest calculations:

Hai-Yang Cheng *et al.*,

Phys. Rev. D **109**, 114027 (2024)

Amplitude analysis of $D_s^+ \to K_S^0 K^+ \pi^0, K_S^0 K_S^0 \pi^+$

BESIII

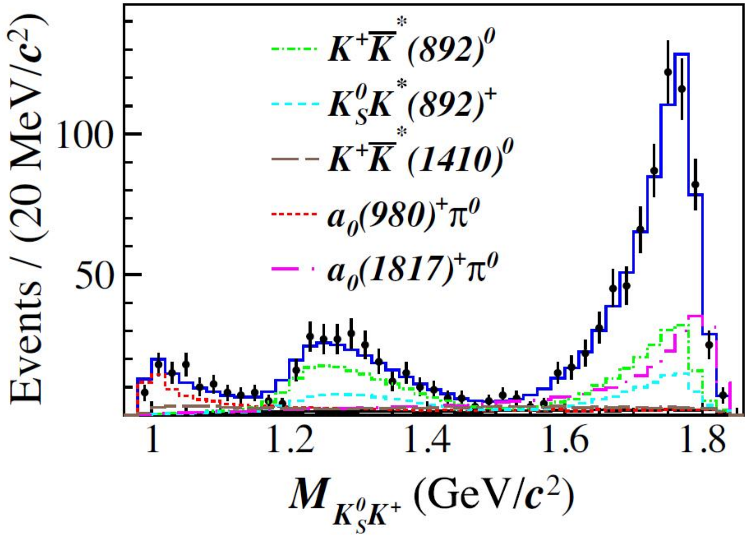
6.32fb^{-1} between $4.178 - 4.226\text{GeV}$

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

Observation of $a_0(1817)^+$

$$m(a_0) = (1.817 \pm 0.008 \pm 0.020)\ \text{GeV}/c^2$$
$$\Gamma(a_0) = (0.097 \pm 0.022 \pm 0.015)\ \text{GeV}/c^2$$
$$\mathcal{B}(D_s^+ \to a_0(1817)^+\pi^0, a_0(1817)^+ \to K_S^0 K^+) = (3.44 \pm 0.52 \pm 0.32) \times 10^{-4}$$

→ 结合$D_s^+ \to K_S^0 K_S^0 \pi^+$的分析，支持存在新的$a_0$同位旋三重态



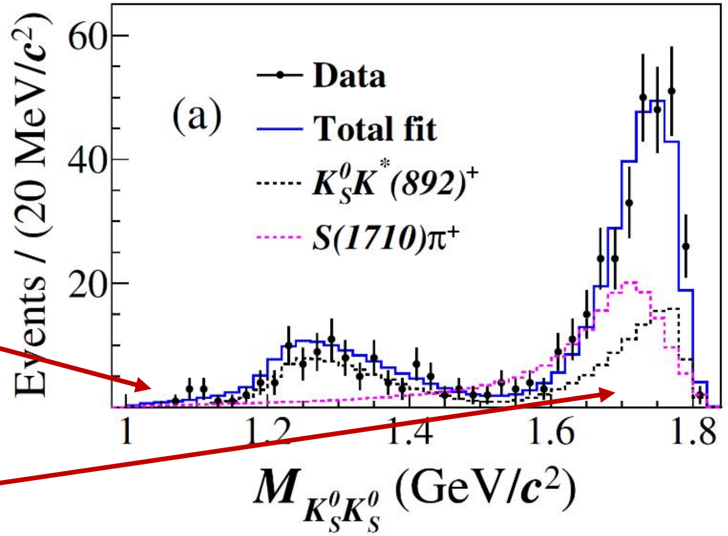
$D_s^+ \to K_S^0 K_S^0 \pi^+$ PRD 105, L051103 (2022)

$$\mathcal{B}(D_s^+ \to S(980)\pi^+) < 1.8 \times 10^{-4}$$ @ 90% CL → $f_0(980)$和$a_0(980)$ 相消干涉

$$\mathcal{B}(D_s^+ \to S(1710)\pi^+) = (0.31 \pm 0.03 \pm 0.01)\%$$

比预期值大1个量级 → $f_0(1710)$和$a_0(1710)$ 相加干涉

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



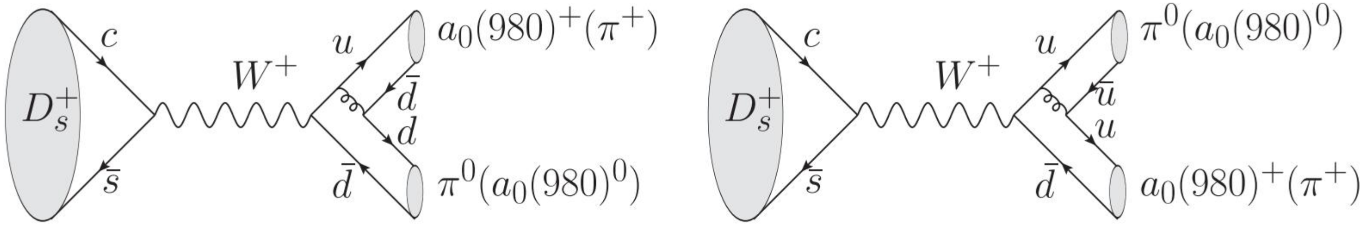
Amplitude analysis of $D_s^+ \to \pi^+\pi^0\eta$

- $D_s^+ \to \pi^+\pi^0\eta$ PRL 123, 112001 (2019)

$3.19\,\mathrm{fb}^{-1}$@$E_{cm} = 4.178$ GeV

1239 candidates with 97.7% purity

Observe W-annihilation decay:



$$\mathcal{B}(D_s^+ \to a_0(980)^{+(0)}\pi^{0(+)}, a_0(980)^{+(0)} \to \pi^{+(0)}\eta) = (1.46 \pm 0.15_{\rm stat} \pm 0.23_{\rm sys})\%$$

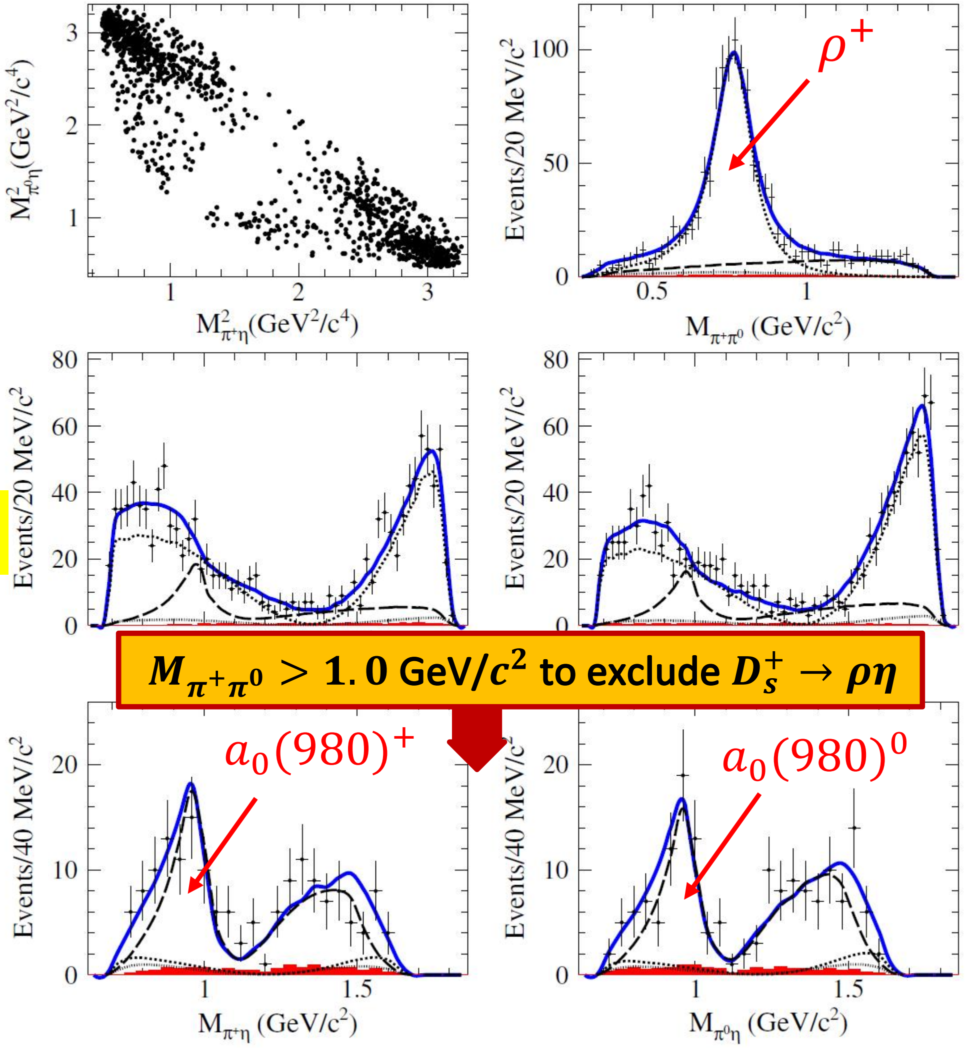
Significantly larger than other W-annihilation decays by one order

- BF measurement:

$$B(D_s^+ \to \pi^+\pi^0\eta) = (9.50 \pm 0.28 \pm 0.41)\%$$

- Dominant process:

$$B(D_s^+ \to \rho^+\eta) = (7.44 \pm 0.48 \pm 0.44)\%$$



Amplitude analysis of $D^0 \to \pi^+\pi^-\eta$, $D^+ \to \pi^+\pi^0\eta$

BESIII

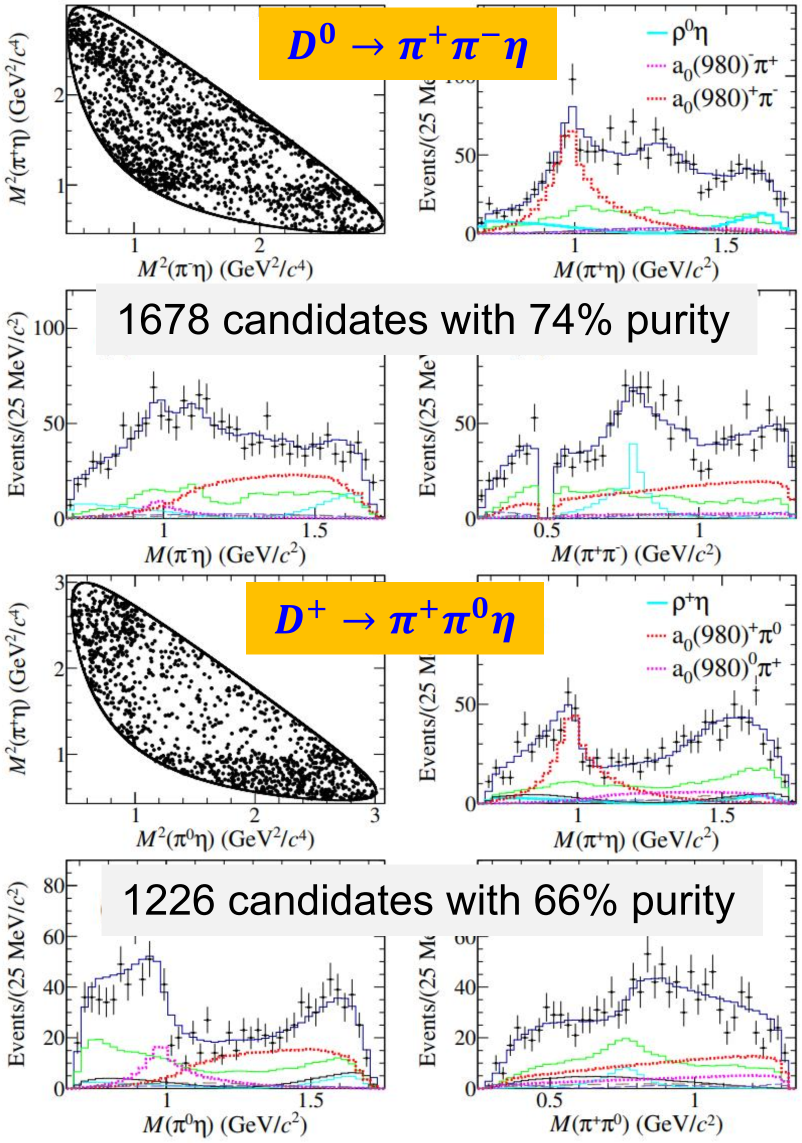
Observation of $D \to a_0(980)\pi$

$7.9\ \text{fb}^{-1}@E_{\text{cm}} = 3.773\text{GeV}$,
PRD 110, L111102 (2024)

$\mathcal{B}(D^0 \to \pi^+\pi^-\eta) = (1.24 \pm 0.04 \pm 0.03)\%$

$\mathcal{B}(D^+ \to \pi^+\pi^0\eta) = (2.18 \pm 0.12 \pm 0.03)\%$

Amplitude	Phase (in unit rad)	BF ($\times 10^{-3}$)
$D^0 \to \rho^0\eta$	0 (fixed)	$0.19 \pm 0.02 \pm 0.01$
$D^0 \to a_0(980)^-\pi^+$	$0.06 \pm 0.16 \pm 0.12$	$0.07 \pm 0.02 \pm 0.01$
$D^0 \to a_0(980)^+\pi^-$	$-1.06 \pm 0.12 \pm 0.10$	$0.55 \pm 0.05 \pm 0.07$
$D^0 \to a_2(1320)^+\pi^-$	$-1.16 \pm 0.25 \pm 0.23$	$0.03 \pm 0.01 \pm 0.01$
$D^0 \to a_2(1700)^+\pi^-$	$0.08 \pm 0.17 \pm 0.23$	$0.07 \pm 0.02 \pm 0.03$
$D^0 \to (\pi^+\pi^-)_{S-\text{wave}}\eta$	$-0.92 \pm 0.29 \pm 0.14$	$0.05 \pm 0.02 \pm 0.03$
$D^+ \to \rho^+\eta$	$-4.03 \pm 0.19 \pm 0.13$	$0.20 \pm 0.07 \pm 0.05$
$D^+ \to (\pi^+\pi^0)_V\eta$	$-0.64 \pm 0.22 \pm 0.19$	$0.34 \pm 0.11 \pm 0.11$
$D^+ \to a_0(980)^+\pi^0$	0 (fixed)	$0.95 \pm 0.12 \pm 0.05$
$D^+ \to a_0(980)^0\pi^+$	$2.44 \pm 0.20 \pm 0.10$	$0.37 \pm 0.10 \pm 0.04$
$D^+ \to a_2(1700)^+\pi^0$	$0.92 \pm 0.20 \pm 0.14$	$0.09 \pm 0.05 \pm 0.02$
$D^+ \to a_0(1450)^+\pi^0$	$0.63 \pm 0.41 \pm 0.30$	$0.15 \pm 0.06 \pm 0.02$



$$\mathcal{B}(D^0 \to a_0(980)^+\pi^-)/\mathcal{B}(D^0 \to a_0(980)^-\pi^+) = 7.5^{+2.5}_{-0.8}{}_{\text{stat.}} \pm 1.7_{\text{syst.}}$$
$$\mathcal{B}(D^+ \to a_0(980)^+\pi^0)/\mathcal{B}(D^+ \to a_0(980)^0\pi^+) = 2.6 \pm 0.6_{\text{stat.}} \pm 0.3_{\text{syst.}}$$

→ Disagrees with theoretical predictions by orders of magnitude

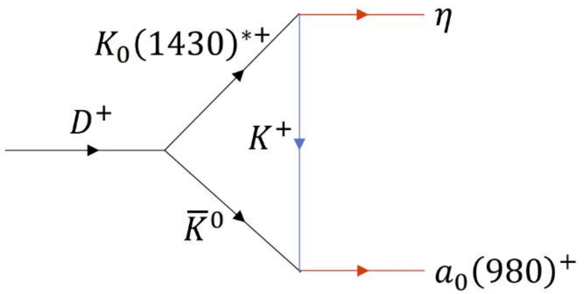
Amplitude analysis of $D^+ \to \pi^+\eta$

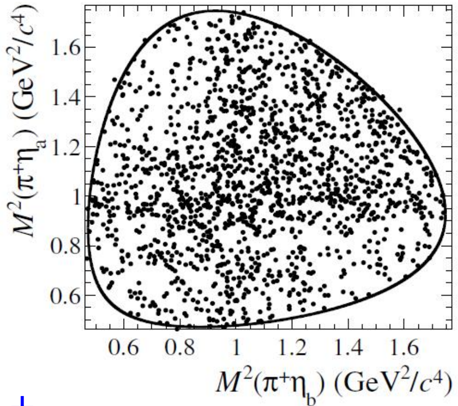
arXiv: 2505.12086

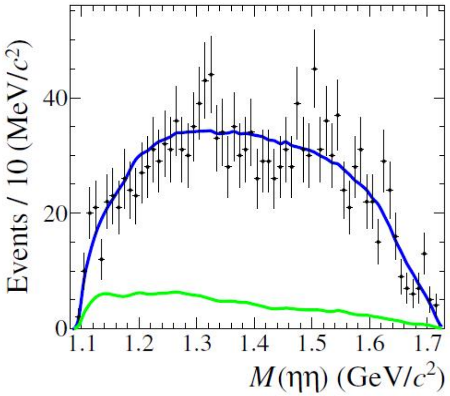
20.3fb^{-1} @3.773GeV

1624 candidates with 85% purity

- First observation of an altered $a_0(980)$ line-shape due to triangle loop rescattering







Fit1: $P_{a_0(980)}$ three-channel coupled Flatte formulae, the fitted pole position is inconsistent with previous measurement.

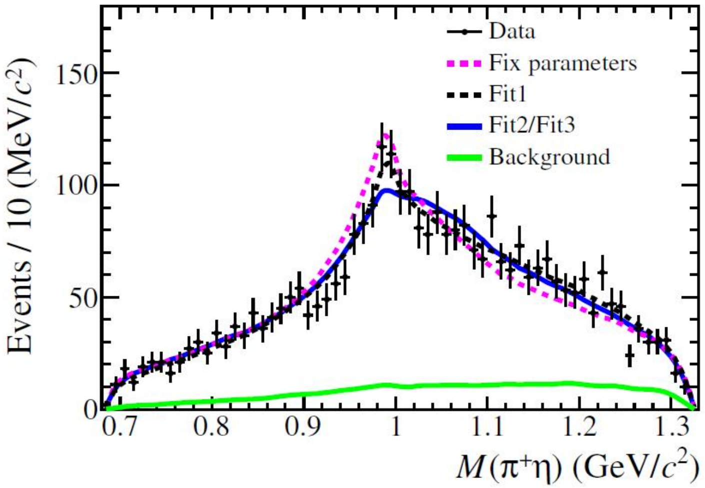
To consider the rescattering process $D^+ \to \bar{K}_0^*(1430)^0 K^+ \to a_0(980)^+\eta$

we perform Fit2 and Fit3

Fit2: $(1 + |C|e^{i\phi_C}A_{\text{loop}})P_{a_0(980)}$

Fit3: $(1 + |C|A_{\text{loop}})P_{a_0(980)}$ with ϕ_C fixed to zero.

$$|C| = 0.113 \pm 0.015_{\text{stat.}} \pm 0.048_{\text{syst.}}$$



Fit2 and Fit3 give good descriptions of the altered $a_0(980)$ line-shape.

- **BF**

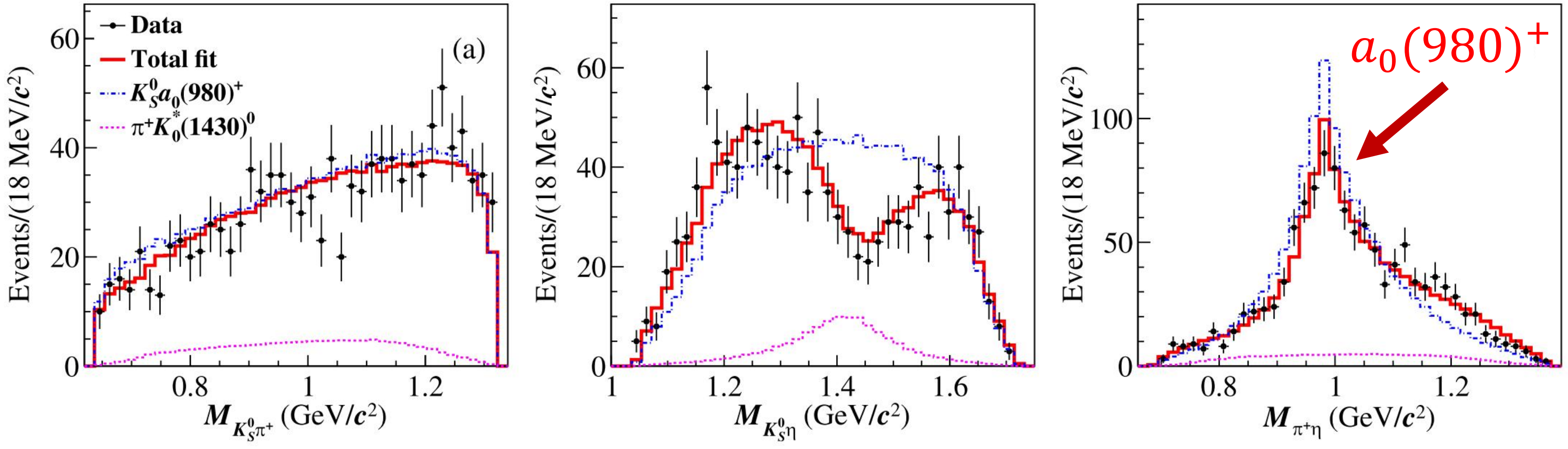
$$\left.\begin{array}{r}\mathcal{B}(D^+ \to \pi^+\eta\eta) \\ \mathcal{B}(D^+ \to a_0(980)^+\eta)\ \mathcal{B}(a_0(980)^+ \to \pi^+\eta)\end{array}\right\} = (3.67 \pm 0.12_{\text{stat.}} \pm 0.06_{\text{syst.}}) \times 10^{-3}$$

Amplitude analysis of $D^+ \to K_S^0\pi^+\eta$

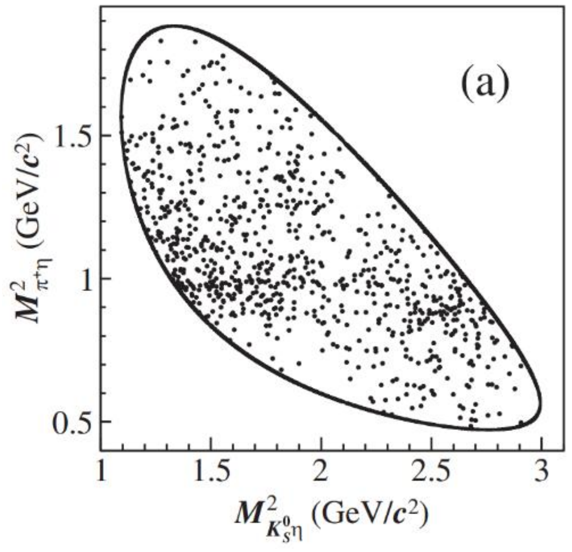
PRL 132, 131903 (2024)

2.93fb^{-1} @3.773GeV

Observation of *W*-annihilation-free decay $D^+ \to K_S^0 a_0(980)^+$



1113 candidates with 98% purity

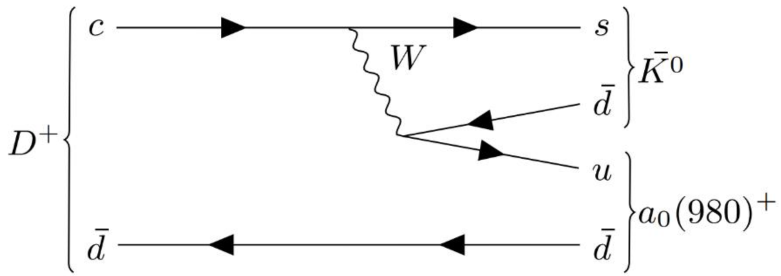


$$\mathcal{B}(D^+ \to K_S^0 a_0(980)^+, a_0(980)^+ \to \pi^+\eta) = (1.33 \pm 0.05_{\text{stat}} \pm 0.04_{\text{syst}})\%$$

$$\mathcal{B}(D^+ \to \bar{K}_0^*(1430)^0\pi^+,\ \bar{K}_0^*(1430)^0 \to K_S^0\eta) = (0.14 \pm 0.02_{\text{stat}} \pm 0.02_{\text{syst}})\%$$

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

Provide sensitive constraints in the extraction of contributions from internal W-emission diagrams →



Amplitude analysis of $D^+ \to K^-\pi^+\pi^-\pi^0$

$D^+ \to K^-\pi^+\pi^-\pi^0$ Golden tag mode

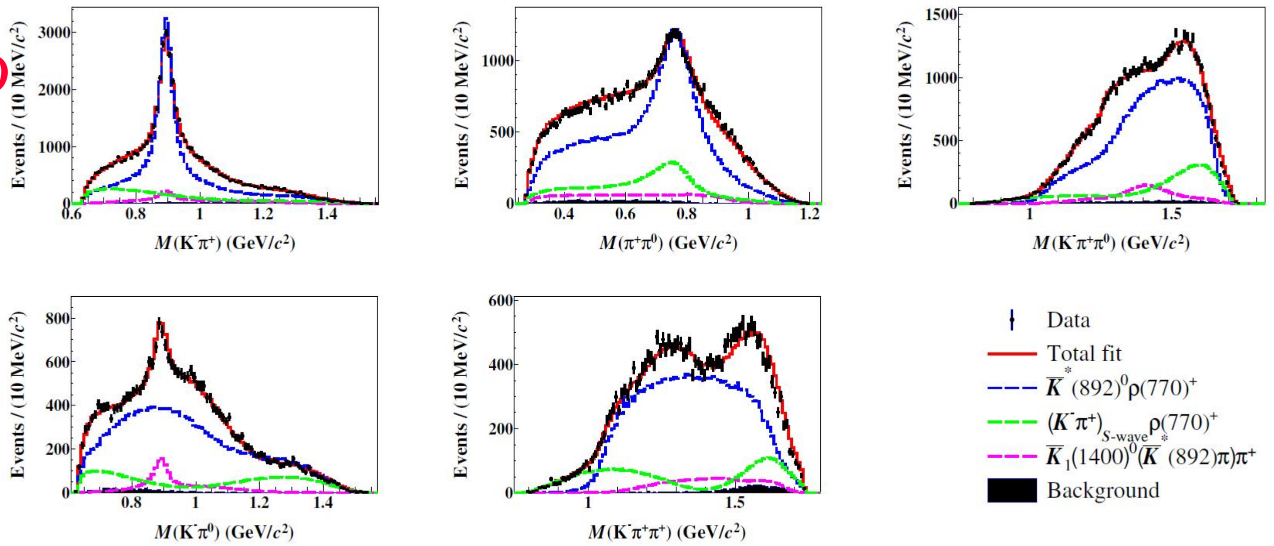
$7.9\,\mathrm{fb}^{-1}$ @3.773GeV，JHEP05(2025)195

Amplitude	Phase (rad)	FFs (%)
$D^+[S] \to \bar{K}^*(892)^0\rho(770)^+$	0.0(fixed)	$66.5 \pm 1.1 \pm 3.0$
$D^+[P] \to \bar{K}^*(892)^0\rho(770)^+$	$1.45 \pm 0.04 \pm 0.08$	$1.9 \pm 0.2 \pm 0.2$
$D^+ \to \bar{K}^*(892)^0\rho(770)^+$	–	$68.4 \pm 1.1 \pm 2.6$
$D^+ \to \bar{K}_1(1270)^0[S]\pi^+$, $\bar{K}_1(1270)^0 \to K^-\rho(770)^+$	$-0.09 \pm 0.03 \pm 0.03$	$3.8 \pm 0.3 \pm 0.3$
$D^+ \to \bar{K}_1(1400)^0[S]\pi^+$	$0.40 \pm 0.02 \pm 0.04$	$7.5 \pm 0.2 \pm 0.3$
$D^+ \to \bar{K}_1(1400)^0[D]\pi^+$	$-2.42 \pm 0.04 \pm 0.04$	$0.5 \pm 0.1 \pm 0.1$
$D^+ \to \bar{K}_1(1400)^0\pi^+$, $\bar{K}_1(1400)^0 \to \bar{K}^*(892)\pi$	–	$7.3 \pm 0.2 \pm 0.3$
$D^+ \to \bar{K}(1460)^0\pi^+$, $\bar{K}(1460)^0 \to \bar{K}^*(892)\pi$	$0.41 \pm 0.04 \pm 0.07$	$5.1 \pm 0.2 \pm 0.3$
$D^+ \to \bar{K}^*(1680)^0\pi^+$, $\bar{K}^*(1680)^0 \to \bar{K}^*(892)\pi$	$1.13 \pm 0.04 \pm 0.09$	$3.8 \pm 0.4 \pm 0.8$
$D^+ \to (K^-\pi^+)_{S-\mathrm{wave}}\rho(770)^+$	$2.90 \pm 0.02 \pm 0.04$	$18.3 \pm 0.7 \pm 0.7$
$D^+ \to \bar{K}(1460)^0\pi^+$, $\bar{K}(1460)^0 \to K^-[\pi^+\pi^0]^{L=1}\pi$	$-1.29 \pm 0.08 \pm 0.06$	$8.6 \pm 0.8 \pm 0.5$
$D^+ \to \bar{K}(1460)^0\pi^+$, $\bar{K}(1460)^0 \to [K^-\pi]^{L=1}\pi$	$-2.31 \pm 0.07 \pm 0.06$	$3.4 \pm 0.5 \pm 0.3$

S>P>D

$$\mathcal{B}(D^+ \to K^-\pi^+\pi^+\pi^0) = (6.35 \pm 0.04_{\mathrm{stat.}} \pm 0.07_{\mathrm{syst.}})\%$$

Decay channel and Collaboration	$\mathcal{B}(D^+ \to \bar{K}^*(892)^0\rho(770)^+)$ $(\times 10^{-2})$
$D^+ \to K^-\pi^+\pi^+\pi^0$, current analysis	$6.52 \pm 0.11 \pm 0.26$
$D^+ \to K^-\pi^+\pi^+\pi^0$, MARK-III [4]	$7.2 \pm 1.8 \pm 2.1$
$D^+ \to K_S^0\pi^+\pi^0\pi^0$, BESIII [21]	$5.82 \pm 0.49 \pm 0.29$



$D \to K3\pi$ 7个四体衰变振幅分析研究现状

$D^0 \to K^-\pi^+\pi^+\pi^-$	BESIII PRD95, 072010 (2017); LHCb EPJC 78, 443 (2018)
$D^0 \to K_S^0\pi^+\pi^-\pi^0$	在研：memo审核阶段
$D^0 \to K^-\pi^+\pi^0\pi^0$	BESIII PRD99, 092008 (2019)
$D^0 \to K_S^0\pi^0\pi^0\pi^0$	在研：memo审核阶段
$D^+ \to K_S^0\pi^+\pi^+\pi^-$	BESIII PRD100, 072008(2019)
$D^+ \to K^-\pi^+\pi^+\pi^0$	BESIII **JHEP05 (2025) 195**
$D^+ \to K_S^0\pi^+\pi^0\pi^0$	BESIII JHEP 09 (2023) 077

Amplitude analysis of $D^0 \to \pi^+\pi^-\pi^+\pi^-, \pi^+\pi^-\pi^0\pi^0$

BESIII

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

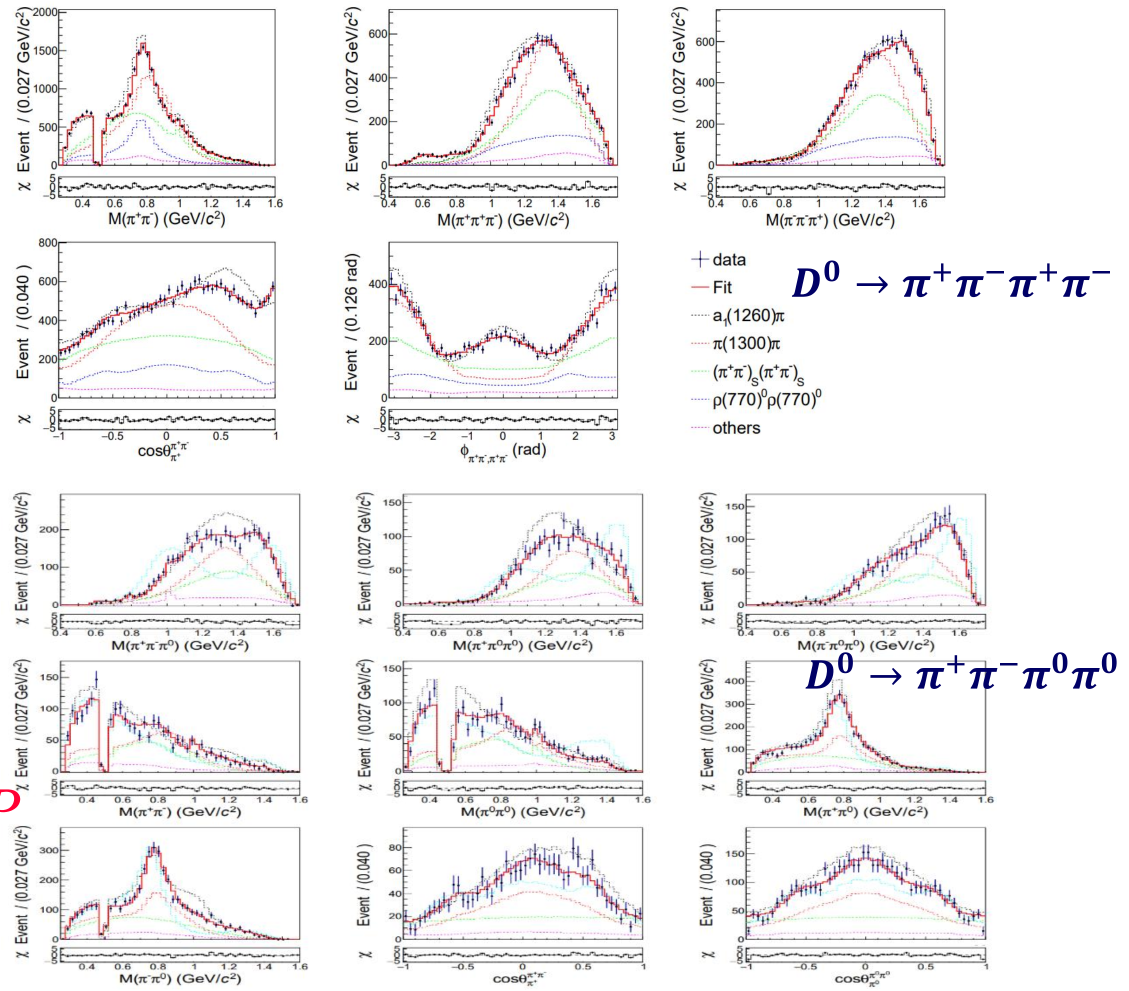
CPC 48, 083001 (2024)

2.93 fb^{-1} @3.773GeV

Component	Branching fraction (%)	
	$\pi^+\pi^-\pi^+\pi^-$	$\pi^+\pi^-\pi^0\pi^0$
$D^0 \to a_1(1260)^+\pi^-$	0.566 ± 0.024 ± 0.008 ± 0.110	0.546 ± 0.027 ± 0.011 ± 0.069
$D^0 \to a_1(1260)^-\pi^+$	0.071 ± 0.010 ± 0.001 ± 0.017	0.068 ± 0.011 ± 0.001 ± 0.021
$D^0 \to a_1(1260)^0\pi^0$	-	0.313 ± 0.031 ± 0.007 ± 0.082
$D^0 \to a_1(1640)^+\pi^-$	0.012 ± 0.003 ± 0.000 ± 0.006	0.010 ± 0.003 ± 0.000 ± 0.007
$D^0 \to h_1(1170)^0\pi^0$	-	0.012 ± 0.006 ± 0.000 ± 0.010
$D^0 \to \pi(1300)^+\pi^-$	0.222 ± 0.018 ± 0.003 ± 0.031	0.148 ± 0.014 ± 0.003 ± 0.025
$D^0 \to \pi(1300)^-\pi^+$	0.162 ± 0.016 ± 0.002 ± 0.028	0.108 ± 0.011 ± 0.002 ± 0.021
$D^0 \to \pi(1300)^0\pi^0$	-	0.221 ± 0.027 ± 0.005 ± 0.033
$D^0 \to \pi_2(1670)^0\pi^0$	-	0.010 ± 0.002 ± 0.000 ± 0.004
$D^0 \to \rho(770)^0\rho(770)^0$	0.193 ± 0.013 ± 0.003 ± 0.022	-
$D^0 \to \rho(770)^0\rho(770)^0[S]$	0.012 ± 0.004 ± 0.000 ± 0.003	-
$D^0 \to \rho(770)^0\rho(770)^0[P]$	0.067 ± 0.007 ± 0.001 ± 0.006	-
$D^0 \to \rho(770)^0\rho(770)^0[D]$	0.159 ± 0.015 ± 0.002 ± 0.017	-
$D^0 \to \rho(770)^0\rho(1450)^0$	0.017 ± 0.006 ± 0.000 ± 0.008	-
$D^0 \to \rho(770)^0\rho(1450)^0[P]$	0.007 ± 0.003 ± 0.000 ± 0.003	-
$D^0 \to \rho(770)^0\rho(1450)^0[D]$	0.010 ± 0.006 ± 0.000 ± 0.008	-
$D^0 \to \rho(770)^+\rho(770)^-$	-	0.864 ± 0.040 ± 0.018 ± 0.075
$D^0 \to \rho(770)^+\rho(770)^-[S]$	-	0.124 ± 0.019 ± 0.003 ± 0.033
$D^0 \to \rho(770)^+\rho(770)^-[P]$	-	0.186 ± 0.013 ± 0.004 ± 0.019
$D^0 \to \rho(770)^+\rho(770)^-[D]$	-	0.342 ± 0.029 ± 0.007 ± 0.024
$D^0 \to \rho(770)^+\rho(1450)^-[D]$	-	0.016 ± 0.008 ± 0.000 ± 0.016

D>S>P ($\rho(770)^0\rho(770)^0$)

D>S>P ($\rho(770)^+\rho(770)^-$)



	Branching fractions	PDG
$D^0 \to \pi^+\pi^-\pi^+\pi^-$	(0.688 ± 0.010 ± 0.010)%	(0.756 ± 0.020)%
$D^0 \to \pi^+\pi^-\pi^0\pi^0$(non-$\eta$)	(0.951 ± 0.025 ± 0.021)%	(1.005 ± 0.090)%

CP-even fractions

$F_+^{\pi^+\pi^-\pi^+\pi^-}$	$F_+^{\pi^+\pi^-\pi^0\pi^0}$(non-$\eta$)
$(75.2 \pm 1.1_{\text{stat.}} \pm 1.5_{\text{syst.}})\%$	$(68.9 \pm 1.5_{\text{stat.}} \pm 2.4_{\text{syst.}})\%$

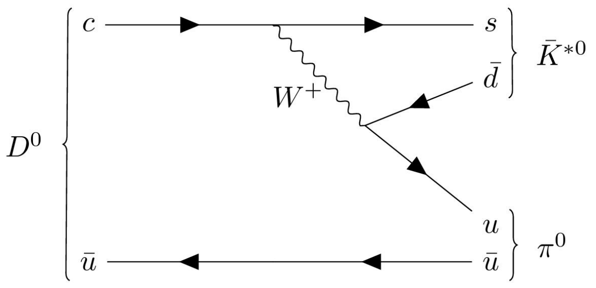
Amplitude analysis of $D^0 \to K_S^0\pi^0\pi^0$

BESIII

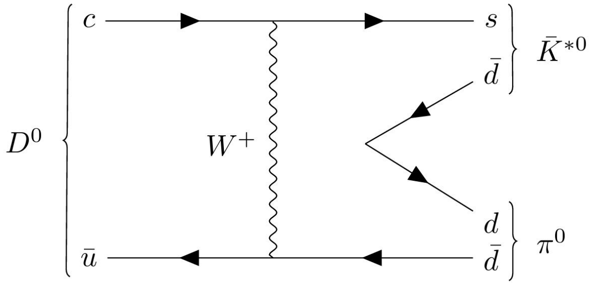
20.3fb^{-1} @ 3.773GeV, arxiv:2510.25111

19117 candidates with >93% purity

Dominant contribution $D^0 \to \bar{K}^*(892)^0\pi^0$

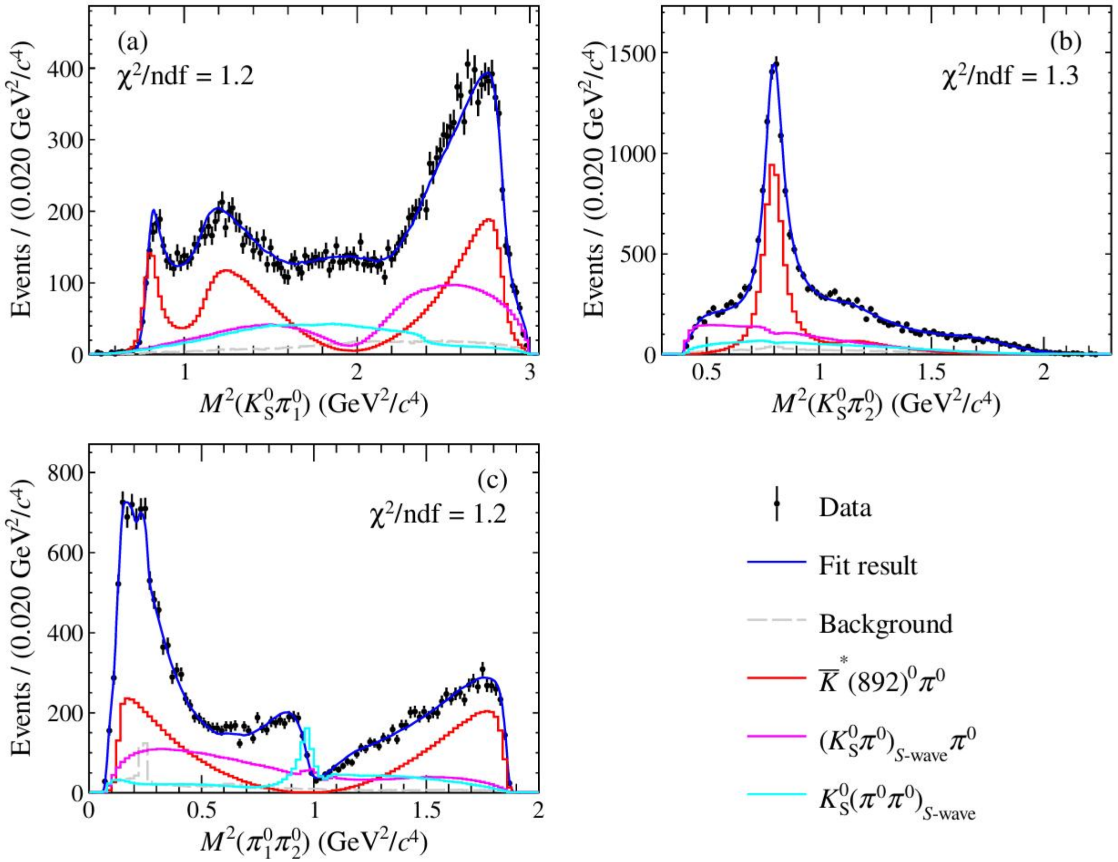


W-internal emission



W-exchange

Amplitude	$\mathcal{B}(D^0 \to \bar{K}^{*0}\pi^0)$ (%)
TDA	3.61±0.18
FAT [mix]	3.25
pole	2.9±1.0
CLEO [from $D^0 \to K^-\pi^+\pi^0$]	2.74±0.23(stat.)±0.41(syst.)
CLEO [from $D^0 \to K_S^0\pi^0\pi^0$]	4.16±0.37(stat.)±0.33(syst.)
This work	2.46 ± 0.06(stat.) ± 0.04(syst.)



Precise BF measurement of $D^0 \to K_S^0\pi^0\pi^0$

$$\mathcal{B}(D^0 \to K_S^0\pi^0\pi^0) = (1.026 \pm 0.008_{\text{stat.}} \pm 0.009_{\text{syst.}})\%$$

consistent with PDG value $(0.91 \pm 0.11)\%$
with precision improved by a factor of 10

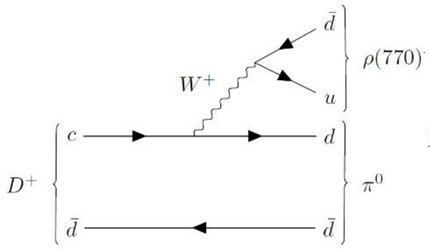
Amplitude analysis of $D^+ \to \pi^+\pi^0\pi^0$

BESIII

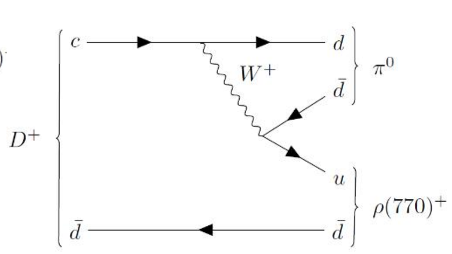
First observation of $D^+ \to \rho(770)^+\pi^0$

$20.3\,\text{fb}^{-1}$ @ 3.773GeV, arxiv:2512.12397

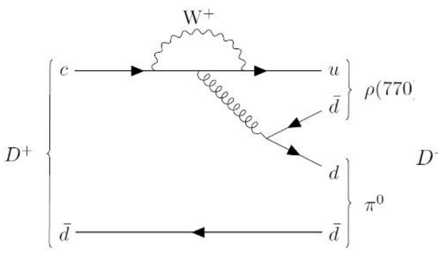
13498 candidates with >87% purity



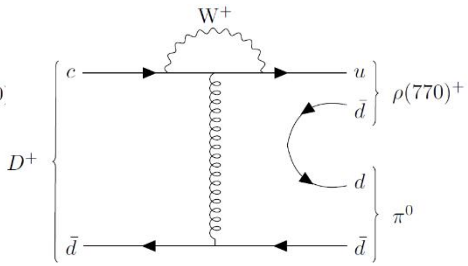
W-external emission



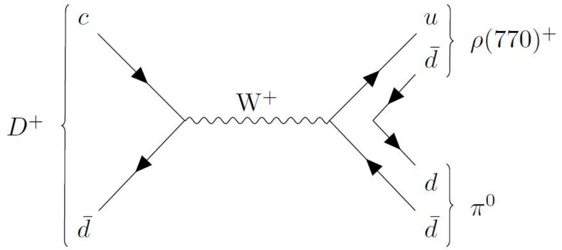
W-internal emission



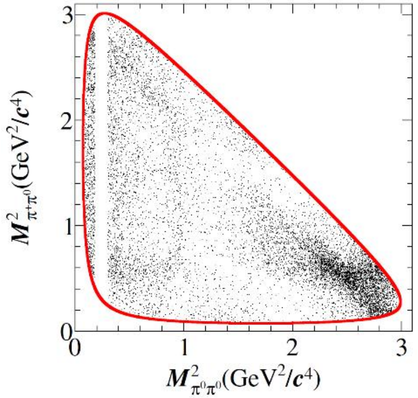
QCD penguin

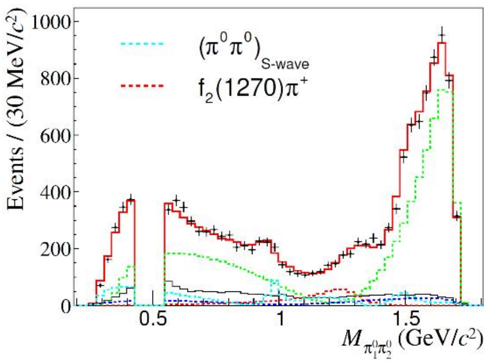


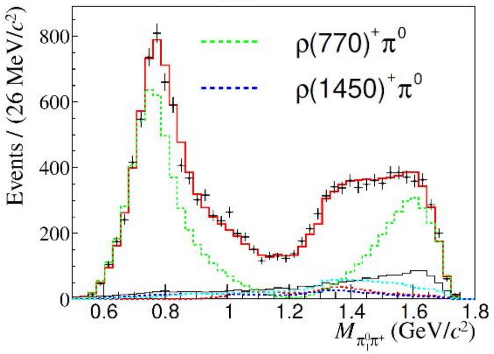
QCD penguin exchange

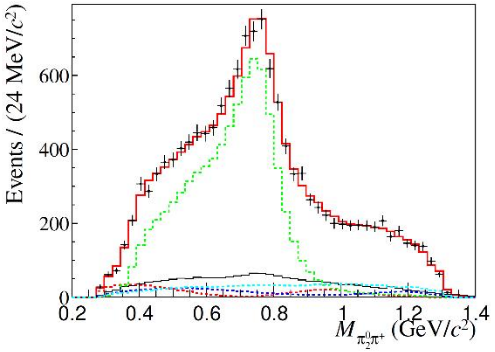


W-annihilation









$$\mathcal{B}(D^+ \to \rho(770)^+\pi^0) = (3.08 \pm 0.10_{\text{stat.}} \pm 0.05_{\text{syst.}})\%$$

CP asymmetry

Decay mode	D^+(%)	D^-(%)	$\mathcal{A}_{\text{FF}}$(%)
$D^{+(-)} \to \rho(770)^{+(-)}\pi^0$	$64.3 \pm 2.3 \pm 0.9$	$63.2 \pm 2.1 \pm 0.6$	$0.9 \pm 1.8 \pm 0.6$
$D^{+(-)} \to \rho(1450)^{+(-)}\pi^0$	$4.9 \pm 0.8 \pm 0.8$	$5.6 \pm 0.8 \pm 0.8$	$-7.2 \pm 6.8 \pm 6.8$
$D^{+(-)} \to f_2(1270)\pi^{+(-)}$	$4.3 \pm 0.4 \pm 0.2$	$4.7 \pm 0.4 \pm 0.2$	$-5.0 \pm 5.7 \pm 2.7$
$D^{+(-)} \to (\pi^0\pi^0)_{S-\text{wave}}\pi^{+(-)}$	$11.6 \pm 0.9 \pm 0.5$	$11.4 \pm 0.9 \pm 0.5$	$0.8 \pm 1.8 \pm 1.1$

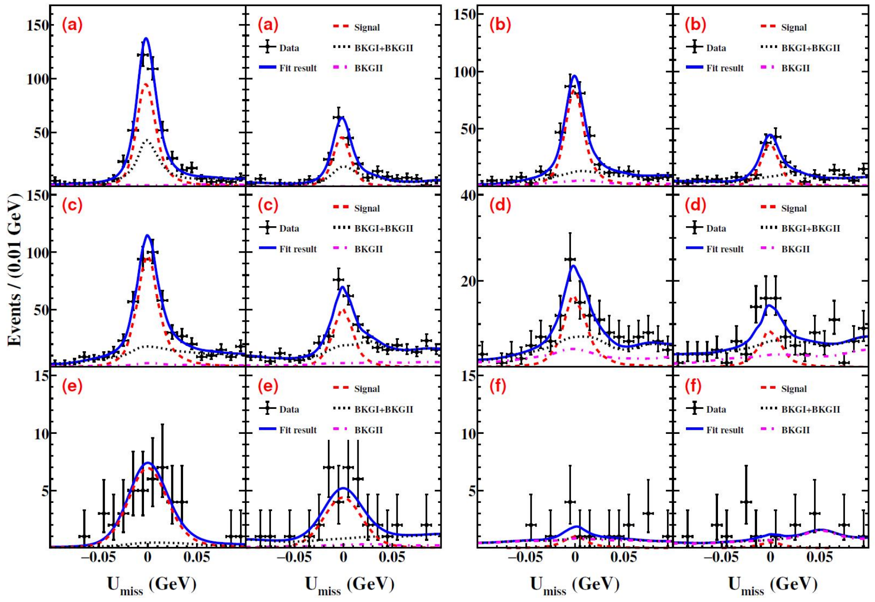
$$A_{\text{CP}} = (-1.4 \pm 1.0_{\text{stat.}} \pm 0.6_{\text{syst.}})\%$$

No evidence for *CP* violation is observed!

Doubly Cabibbo-suppressed Decays

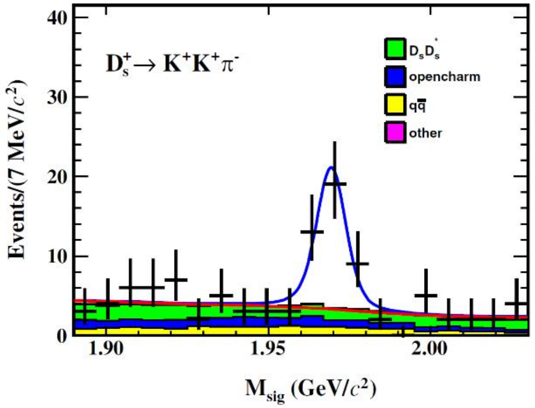
$R = \mathcal{B}(DCS)/\mathcal{B}(CF) \sim (0.5 - 2.0)\tan^4\theta_C$

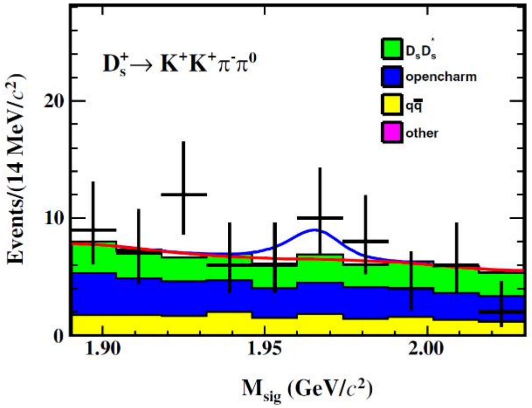
JHEP06(2025)220, 20.3fb^{-1} @ 3.773GeV



Signal decay	$\mathcal{B}_{\rm DCS}^{\rm This\ work}$ $(\times 10^{-4})$	$\mathcal{B}_{\rm DCS}^{\rm PDG}$ $(\times 10^{-4})$	$\mathcal{B}_{\rm DCS}^{\rm This\ work}/\mathcal{B}_{\rm CF}$ (%)	$\times \tan^4\theta_C$
$D^0 \to K^+\pi^-$	$1.30 \pm 0.09 \pm 0.04$	1.50 ± 0.07	0.328 ± 0.027	1.14 ± 0.09
$D^0 \to K^+\pi^-\pi^-\pi^+$	$2.38 \pm 0.19 \pm 0.12$	2.65 ± 0.06	0.289 ± 0.028	1.00 ± 0.10
$D^0 \to K^+\pi^-\pi^0$	$3.06 \pm 0.21 \pm 0.10$	3.06 ± 0.16	0.212 ± 0.021	0.74 ± 0.07
$D^0 \to K^+\pi^-\pi^0\pi^0$	$1.40 \pm 0.27 \pm 0.09$	< 3.6	0.158 ± 0.036	0.55 ± 0.12
$D^0 \to K^+\pi^-\eta$	$1.04 \pm 0.16 \pm 0.08$	–	0.555 ± 0.092	1.93 ± 0.32
$D^0 \to K^+\pi^-\pi^0\eta$	< 0.7	–	< 1.78	< 6.19
$D^+ \to K^+\pi^+\pi^-$	$4.50 \pm 0.12 \pm 0.35$	4.91 ± 0.09	0.480 ± 0.019	1.67 ± 0.07
$D^+ \to K^+\pi^+\pi^-\eta$	$1.56 \pm 0.22 \pm 0.04$	–	–	–
$D^+ \to K^+(\pi^+\pi^-\eta)_{\rm non-\eta'}$	$0.67 \pm 0.18 \pm 0.02$	–	5.0 ± 1.4	17.3 ± 4.8
$D^+ \to K^+K^+K^-$	$0.51 \pm 0.05 \pm 0.01$	0.614 ± 0.011	–	–
$D^+ \to K^+\eta\eta$	$0.59 \pm 0.23 \pm 0.02$	–	–	–

PRD 109, 032011 (2024) , 7.33fb^{-1} @ 4.178 – 4.226GeV





$$\mathcal{B}_{D_s^+\to K^+K^+\pi^-} = (1.24^{+0.28}_{-0.26}(\text{stat}) \pm 0.06(\text{syst})) \times 10^{-4}$$

$$\mathcal{B}_{D_s^+\to K^+K^+\pi^-\pi^0} < 1.7 \times 10^{-4}$$

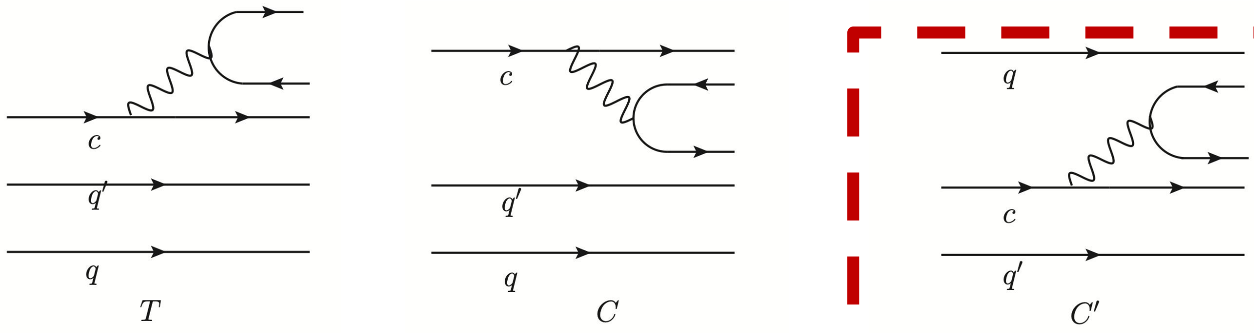
DCS decay	$\mathcal{B}_{\rm DCS}^{\rm this\ work}/\mathcal{B}_{\rm CF}^{\rm PDG}$ $(\times 10^{-3})$	$\times \tan^4\theta_C$
$D_s^+ \to K^+K^+\pi^-$	$2.31^{+0.52}_{-0.48}$	$0.80^{+0.18}_{-0.16}$
$D_s^+ \to K^+K^+\pi^-\pi^0$	< 3.09	< 1.07

Charmed baryon decay

- Λ_c^+ may reveal more information of strong- and weak-interactions in charm region complementary to D/D_s^+

  → Most charmed baryons eventually decay to Λ_c^+

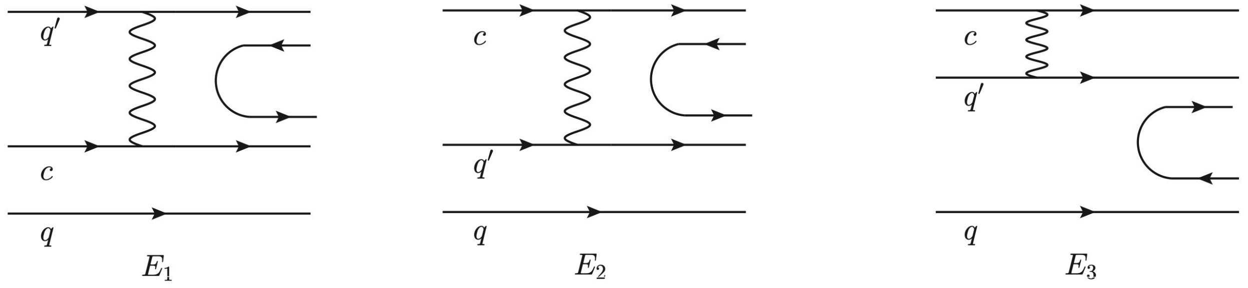
Topological Diagrams for Λ_c^+ decays:



W-emission T **internal W-emission C** **inner W-emission C'**

H.-Y. Cheng *et al.*, Chinese Journal of Physics, 78(2022) 324-362

Non-factorization amplitude
→ Calculation is not reliabale, need exp. input



W-exchange E_1, E_2 and E_3

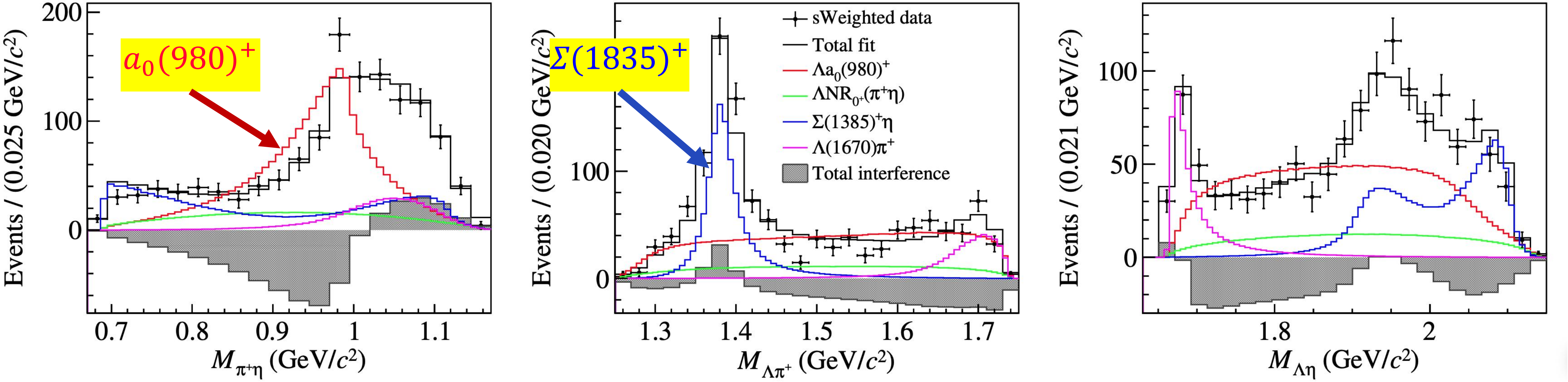
Observation $a_0(980)^+$ in $\Lambda_c^+ \to \Lambda\pi^+\eta$

BESIII

6.1fb^{-1} @ 4.600 – 4.843GeV PRL 134, 021901(2025)

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

1312 ± 45 signal events with 80% purity



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

$\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+, a_0(980)^+ \to \pi^+\eta) = (\mathbf{1.05 \pm 0.16 \pm 0.05}_{stat} \pm \mathbf{0.07}_{ext})\%$

$\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+) = (1.23 \pm 0.21)\%$

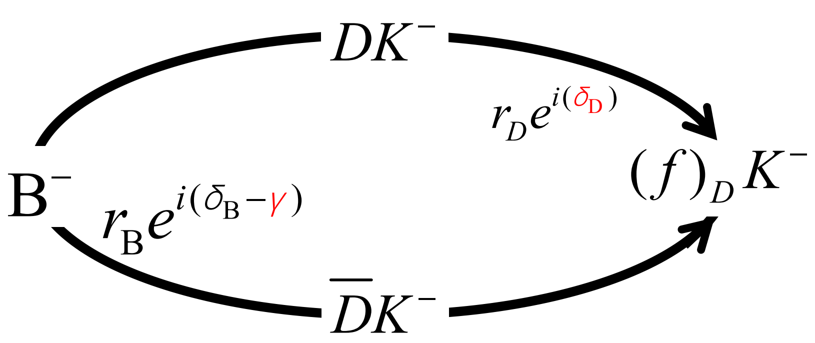
Process	FF (%)	$\mathcal{S}$	α
$\Lambda a_0(980)^+$	$54.0 \pm 8.4 \pm 2.6$	13.1σ	$-0.91^{+0.18}_{-0.09} \pm 0.08$
$\Sigma(1385)^+\eta$	$30.4 \pm 2.6 \pm 0.7$	22.5σ	$-0.61 \pm 0.15 \pm 0.04$
$\Lambda(1670)\pi^+$	$14.1 \pm 2.8 \pm 1.2$	11.7σ	$0.21 \pm 0.27 \pm 0.33$
ΛNR_{0+}	15.4 ± 5.3	6.7σ	...

Larger than theoretical calculation by 1-2 orders.

Strong-phase inputs for γ measurement

BESIII

- **CKM angle γ can be determined directly in $B^{\pm} \to DK^{\pm}$ (golden mode) decay**



→ **Phase-space integrated decay rate:**

$$\Gamma(B^{\mp} \to DK^{\mp}) \propto (r_D^f)^2 + r_B^2 + 2r_B r_D^f R_D^f \cos(\delta_B \mp \gamma - \delta_D^f)$$

- r_D^f: Magnitude ratio between $D^0 \to f$ and $\overline{D}^0 \to f$ amplitudes
- R_D^f: Coherence factor
- δ_D^f: Strong-phase difference between $D^0 \to f$ and $\overline{D}^0 \to f$ amplitudes

May limit precision to γ

- **Extract γ using different *D* decays:**

→ Self-conjugate decays (e.g. $K_S^0 h^+ h^-$): "GGSZ " → c_i, s_i (amplitude-weighted cos[sin]$\Delta\delta_D$ in phase-space i)

[PRD 68 (2003) 054018; PRD 67 (2003) 071301]

→ CF and DCS decays (e.g. $K\pi$, $K\pi\pi^0$, $K\pi\pi\pi$): "ADS" → δ_D^f, R_D^f

[PRL 78 (1997) 3257; PRD 63 (2001) 036005]

→ (Quasi-)*CP* eigenstates (e.g. h^+h^-): "GLW" → *CP* fraction F_+; ...

[PLB 265 (1991) 172; PLB 253 (1991) 483]

- *D* strong-phase parameters provide the crucial inputs for γ measurement

Quantum Correlated $D^0\overline{D}^0$ pairs

$7.13\ \mathrm{fb}^{-1}$ @4.13 – 4.23 GeV
PRL 135, 171901 (2025)

BESIII

- Studies of quantum correlations in

  $e^+e^- \to \gamma^* \to XD\overline{D}$

  → Quantum correlated C-odd $D^0\overline{D}^0$ pairs used at $\psi(3770)$ for D-decay strong phase measurements

- First observation of quantum correlations in $e^+e^- \to XD\overline{D}$ and C-even constrained $D\overline{D}$ pairs

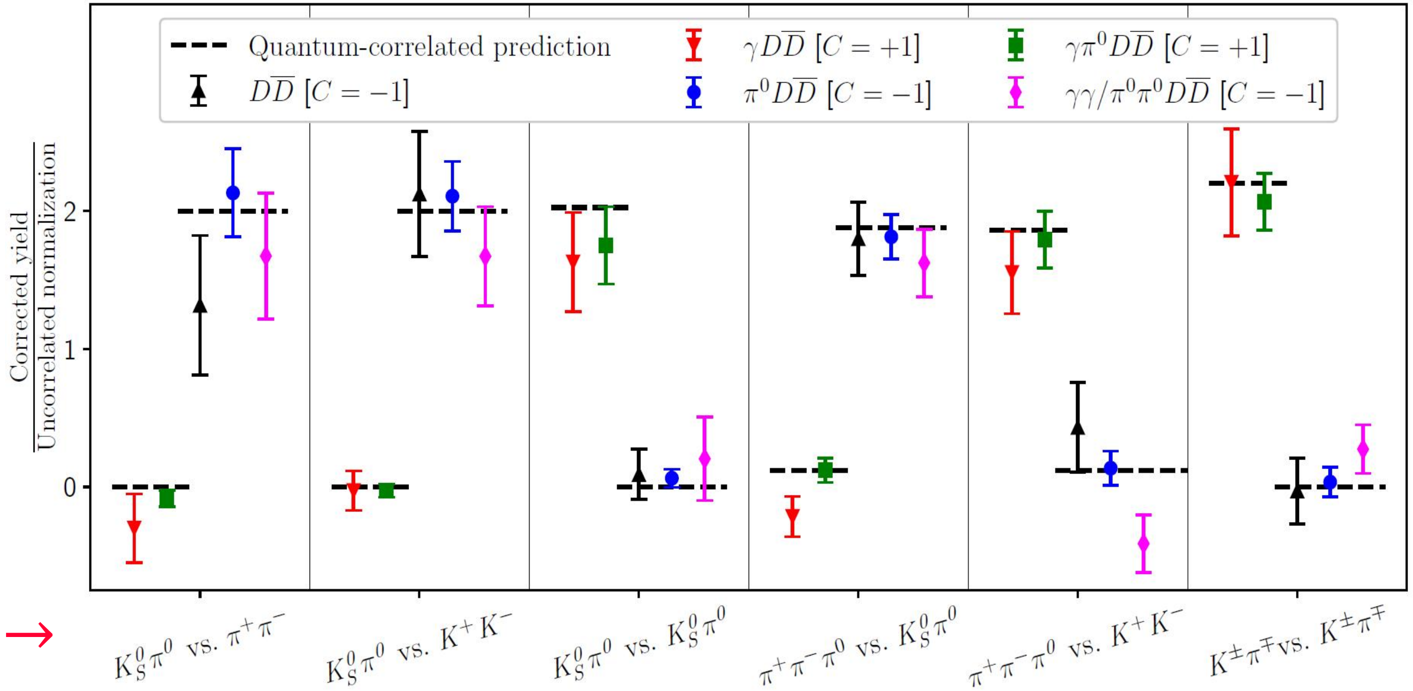
$$C_\gamma = -1$$
$$C_{\pi^0} = +1$$

Production mechanism	C
$e^+e^- \to D\overline{D}$	-1
$e^+e^- \to D^*\overline{D} \to D\overline{D}\,\gamma$	$+1$
$e^+e^- \to D^*\overline{D} \to D\overline{D}\,\pi^0$	-1
$e^+e^- \to D^*\overline{D}^* \to D\overline{D}\,\gamma\gamma$	-1
$e^+e^- \to D^*\overline{D}^* \to D\overline{D}\,\pi^0\gamma$	$+1$
$e^+e^- \to D^*\overline{D}^* \to D\overline{D}\,\pi^0\pi^0$	-1

$$\hat{C}\,|D\overline{D}\rangle = \kappa C_{\mathrm{exp}}\,|D\overline{D}\rangle - (1-\kappa)C_{\mathrm{exp}}\,|D\overline{D}\rangle$$

Production mechanism	κ
$D\overline{D}$	1.015 ± 0.066
$D^*\overline{D} \to \gamma D\overline{D}$	1.044 ± 0.044
$D^*\overline{D} \to \pi^0 D\overline{D}$	1.028 ± 0.024
$D^*\overline{D}^* \to \gamma\pi^0 D\overline{D}$	1.027 ± 0.017
$D^*\overline{D}^* \to \gamma\gamma/\pi^0\pi^0 D\overline{D}$	0.963 ± 0.060

κ=1: coherent
κ=0.5: incoherent



$D\overline{D} \to$ CP eigenvalue: -1, -1, +1, -1, +1, -

Measurement of $\delta_{K\pi}$

$7.13\ \mathrm{fb}^{-1}$ @4.13 – 4.23 GeV
PRD 112, 072006 (2025)

BESIII

- $\delta_{K\pi}$ is the strong-phase difference between $D^0 \to K^-\pi^+$ and $D^0 \to K^+\pi^-$ decays

$$r^D_{K\pi} e^{-i\delta^D_{K\pi}} = \frac{A(\overline{D}^0 \to K^-\pi^+)}{A(D^0 \to K^-\pi^+)},$$ $r^D_{K\pi}$ is the magnitude of the ratio

$\rightarrow$ is an key input for measurements of the charm mixing parameters and CKM angle γ

- Use the quantum correlated pairs to measure $\delta_{K\pi}$

$\rightarrow$ CP tags (K^+K^-, $\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $K^0_S\pi^0$) ($r_{K\pi}cos\delta_{K\pi}$)

$\rightarrow$ $K^0_S\pi^+\pi^-$ tags ($r_{K\pi}cos\delta_{K\pi}$ and $r_{K\pi}sin\delta_{K\pi}$)

Source	Observable	Value
$D \to CP$	$r^D_{K\pi}\cos\delta^D_{K\pi}$	$-0.070 \pm 0.008 \pm 0.0015$
$D \to K^0_S\pi^+\pi^-$	$r^D_{K\pi}\cos\delta^D_{K\pi}$	$-0.044 \pm 0.014 \pm 0.0018$
$D \to K^0_S\pi^+\pi^-$	$r^D_{K\pi}\sin\delta^D_{K\pi}$	$-0.022 \pm 0.017 \pm 0.0031$

- Extract $\delta_{K\pi}$

$$\delta^D_{K\pi} = \left(192.8^{+11.0+1.9}_{-12.4-2.4}\right)^\circ$$

agree with global average $\delta^D_{K\pi} = (190.2 \pm 2.8)^\circ$ [LHCb, CERN-LHCb-CONF-2024-004]

- BESIII combination (combined fit with BESIII measurement using $2.93\ \mathrm{fb}^{-1}$ $\psi(3770)$ data)

$$\delta^D_{K\pi} = \left(189.2^{+6.9+3.4}_{-7.4-3.8}\right)^\circ$$

$\delta^D_{K\pi} = \left(187.6^{+8.9+5.4}_{-9.7-6.4}\right)^\circ$ [BESIII, EPJC 82,1009(2022)]

Strong-phase measurement of $D^0 \to K^0_{S/L}\pi^+\pi^-$

BESIII

7.93 fb^{-1} @3.773 GeV, JHEP 06(2025)086

- Measurement of $D^0 \to K^0_{S/L}\pi^+\pi^-$ strong phase parameters:

  $c_i[s_i] \equiv$ amplitude-weighted cos[sin]$\Delta\delta_D$ in phase-space i

  → is an key input for direct measurement of CKM angle γ

- Impact on the γ measurement

  Model-predicted $c_i'(s_i') - c_i(s_i)$ between $K^0_S\pi^+\pi^-$ and $K^0_L\pi^+\pi^-$

  → Uncertainty: 0.9° with constraints
  → Uncertainty: 1.5° without constraints
  } with optimal binning

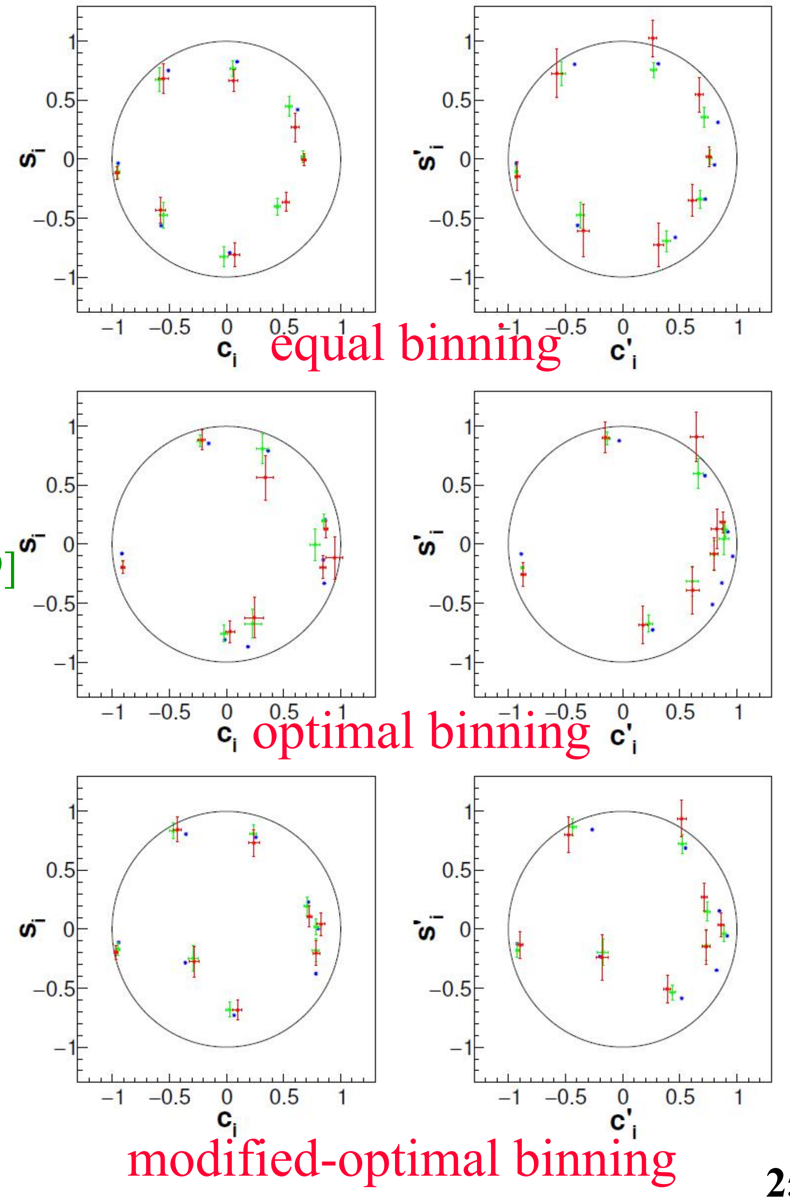
  Statistical uncertainty of current γ measurement: 5.1° [LHCb, JHEP02(2021)169]

- Expected γ precision

  Belle II [PTEP 2019, 123C01 (2019)]:
  1.5° with 50 ab^{-1}
  LHCb [LHCb-PUB-2016-025 (2016)]:
  < **1°** with 50 fb^{-1}, phase-1 upgrade (2030),
  < **0.4°** with 300 fb^{-1}, phase-2 upgrade (>2035)

Uncertainties due to strong-phases in $D \to K^0_S h^+h^-$ decays with 20fb^{-1}data → 0.5°

BESIII white paper



Summary and Prospects

BESIII

- BESIII made **significant contributions** to charmed flavor physics and hadron physics.

- Charm hadronic decays are key labs to understand non-perturbative QCD;
  study the properties of light hadron ($a_0(980)$, $f_0(980)$, $f_0(500)$…);
  and provide crucial inputs to model-independent determination of γ and charm mixing/CPV

  Strong-phase measurement: 0.9° on γ ($<0.5^\circ$ with $20\mathrm{fb}^{-1}$)

- BESIII's Future prospects

  → More interesting results are coming using $20.3\ \mathrm{fb}^{-1}$ $\psi(3770)$ data.

  → BEPCII-U will extend the lifetime of BESIII (**will continue to run till ~2030**).
  3× luminosity above 4 GeV & max energy to 5.6 GeV

谢谢！