Hadronic Charm Meson Decays @ BESIII

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On behalf of the BESIII Collaboration

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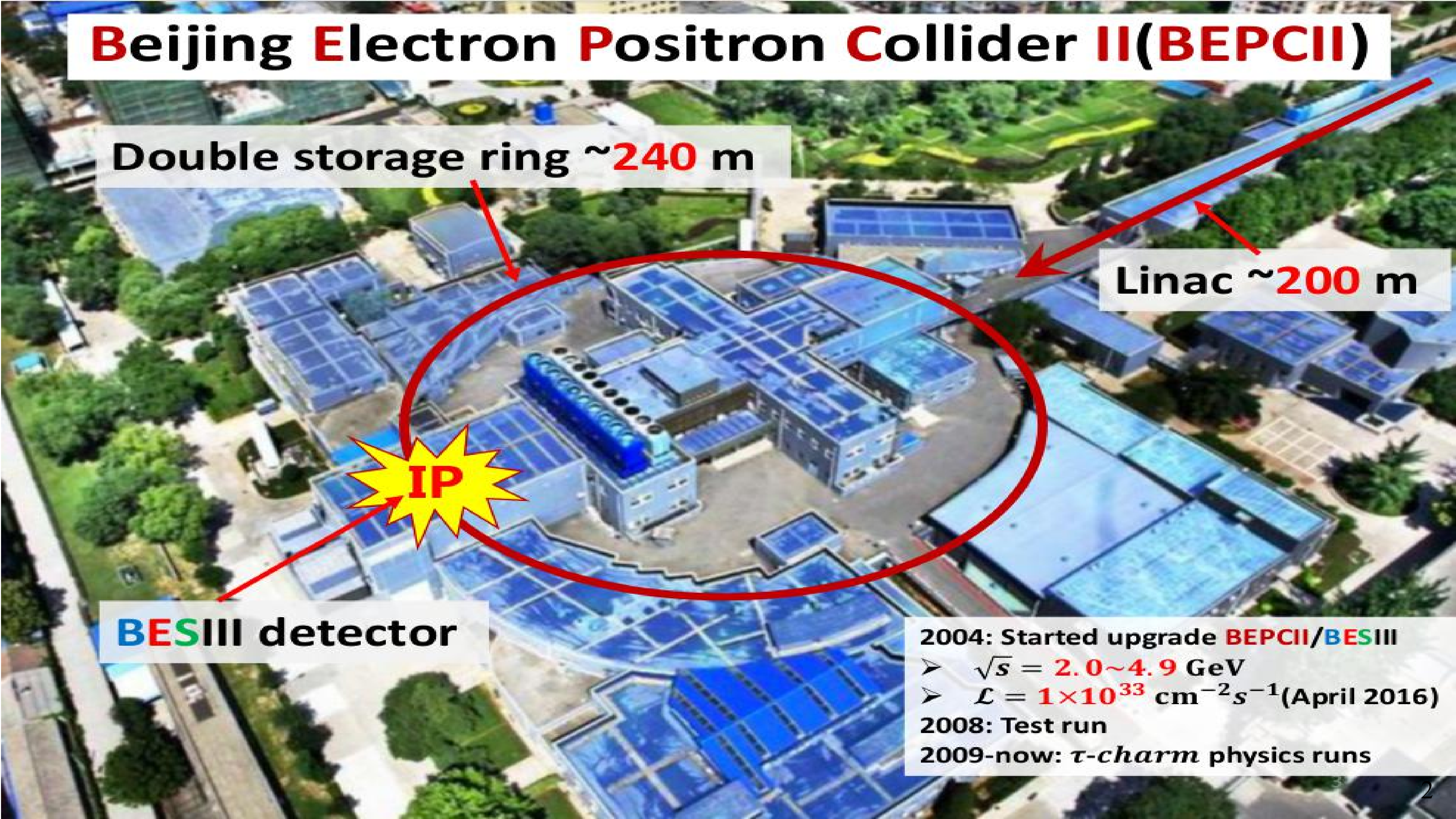
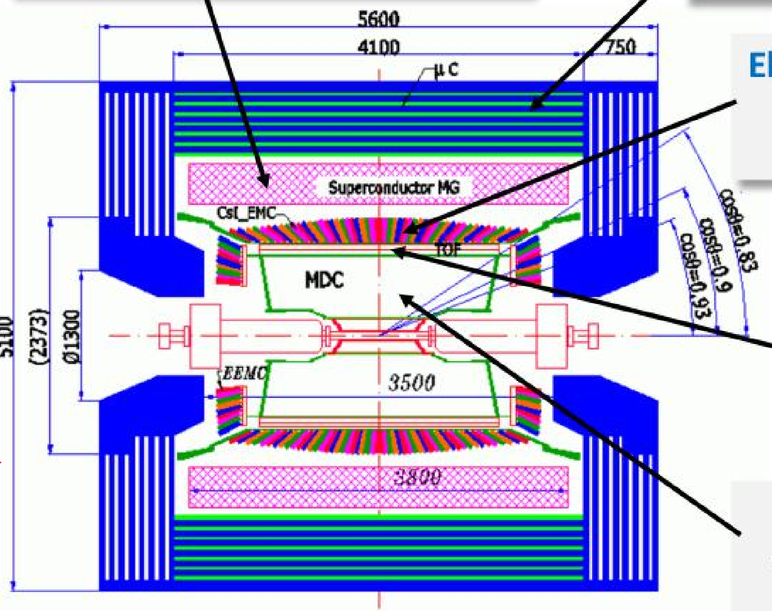
Outline

- Introduction
- Strong Phase Parameters
- Amplitude Analyses
- Absolute Branching Fractions
- Summary

Beijing Electron Positron Collider II(BEPCII)



Beijing Electron Positron Collider II(BEPCII)



Superconducting solenoid (1T)

RPC Muon Counter
9 layers (barrel) + 8 layers (end-caps)
93% coverage of the full solid angle

Electromagnetic CsI(Tl) Calorimeter
$\sigma_E/E < 2.5\%$ @ 1 GeV (barrel)
$\sigma_E/E < 5\%$ @ 1 GeV (end-caps)

Time-of-Flight
$\sigma_t = 90$ ps (barrel)
$\sigma_t = 120$ ps (end-caps)

Main Drift Chamber
$\sigma_{r\phi} = 130$ μm (single wire)
$\sigma_{pt}/p_t = 0.5\%$ @ 1 GeV

Charm Data and Analysis Method

BESIII

➢ Data production

Data samples	√s (GeV)	Int.$\mathcal{L}$(fb^{-1})	×CLEO-c
$D^0\bar{D}^0/D^-D^+$	3.773	2.93	3.6×
$D_sD_s^*$	4.178	3.19	5.3×
$D_sD_s^*$	4.189-4.226	3.13	-

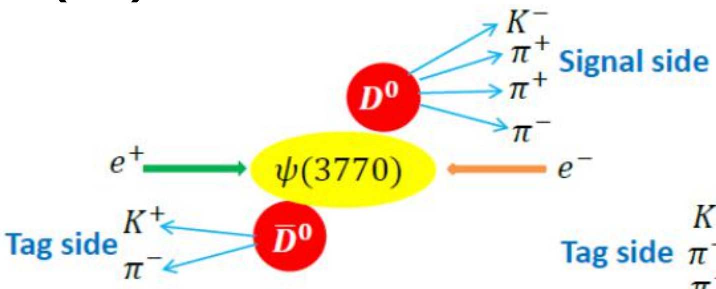
- Pair production @ threshold
- Quantum-correlated neutral D-meson pairs created in the decay of the $\Psi(3770)$ resonance
- Fully reconstructed event
- Clean background

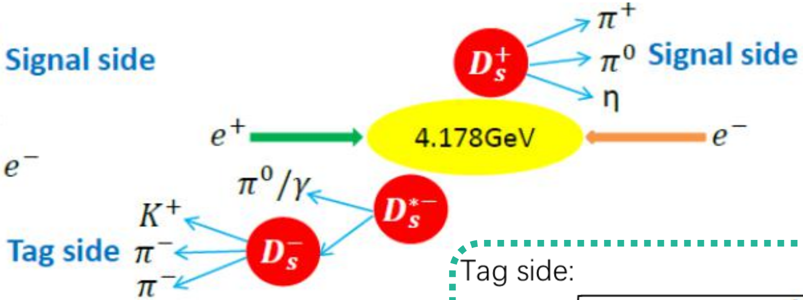
➢ Double Tagged (DT) Method

Tag side:

$$\Delta E = E_{\bar{D}} - E_{beam}$$

$$M_{BC} = \sqrt{E^2_{beam} - |\vec{p}_{\bar{D}}|^2}$$





Tag side:

$$M_{rec} = \sqrt{E_{cm} - \left(\sqrt{|\vec{p}_{D_s^+}|^2 + m^2_{D_s^+}}\right)^2 - |\vec{p}_{D_s^+}|^2}$$

Tag/Signal side:

$$E_{miss} = E_{beam} - \sum_f E_f \qquad \vec{p}_{miss} = -\vec{p}_{\bar{D}} - \sum_f \vec{p}_f$$

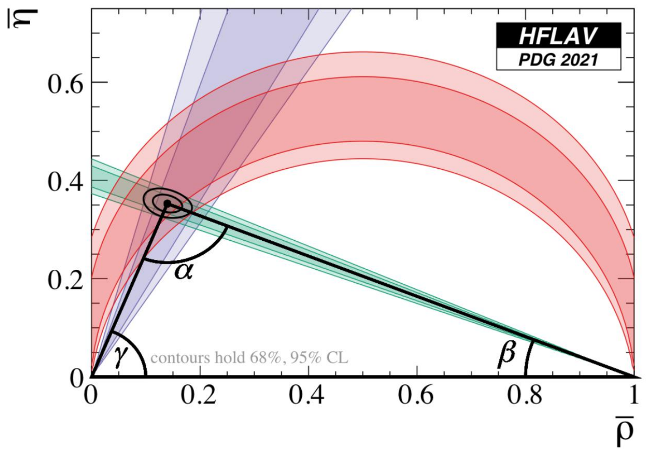
$$M^2_{miss} = E^2_{miss} - |\vec{p}_{miss}|^2 \qquad U_{miss} = E_{miss} - |\vec{p}_{miss}|$$

Double tag:

$$B(D \to f) = \frac{N_{sig}}{N^{tot}_{ST} \times \varepsilon}$$

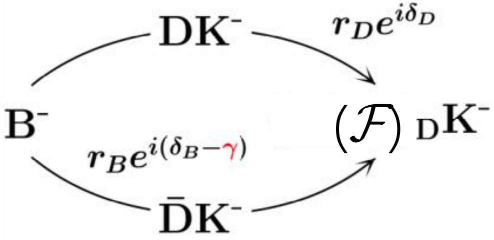
Strong Phase Difference

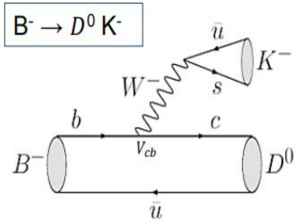
- **CKM angle $\gamma(\phi_3)$**

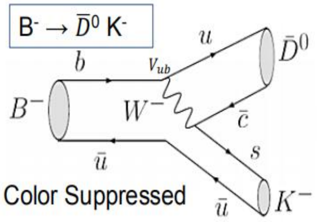


$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right) \quad (66.2^{+3.4}_{-3.6})^0$$

World average



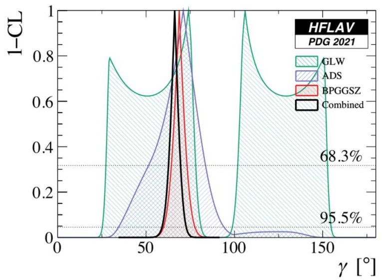


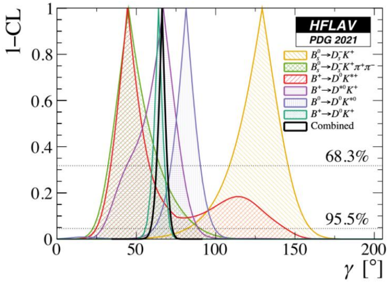


$$\frac{<B^- \to \bar{D}^0 K^->}{<B^- \to D^0 K^->} = r_B e^{i(\delta_B-\gamma)} \qquad \frac{<D \to \bar{f}>}{<D \to f>} = r_D e^{i\delta_D}$$

The strong-phase difference δ_D can be measured directly in the decays of quantum-correlated neutral D-meson pairs created in the decay of the $\Psi(3770)$ resonance, which ensures a binned model-independent measurement of the CKM angle $\gamma(\phi_3)$ with B decays.

Impact on γ





Works of hadronic parameters in BESIII

- **Strong-phase parameters in $D\to K_{S/L}\pi^+\pi^-$, $D\to K_{S/L}K^+K^-$**
  PRD 101, 112002(2020), PRL 124, 241802(2020)
  PRD 102, 052008(2020)
- **Strong-phase difference in $D\to K^-\pi^+\pi^+\pi^-$ and $D\to K^-\pi^+\pi^0$,**
  JHEP 05, 164(2021)

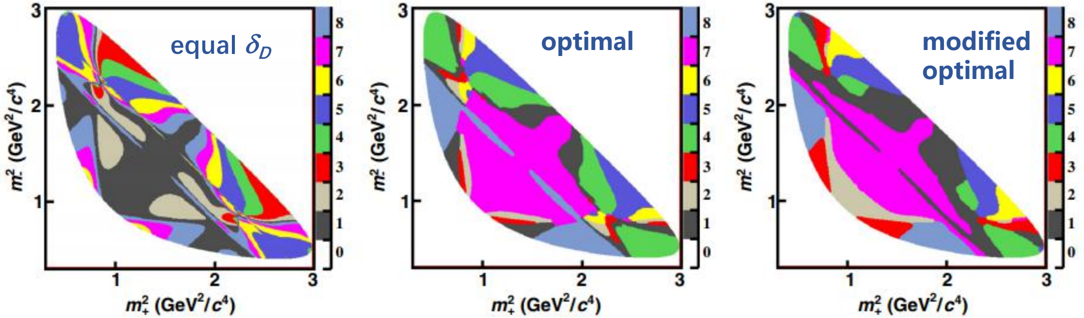
Strong-Phase Parameters in $D^0 \to K^0_{S/L}\pi^+\pi^-$

[Phys. Rev. Lett. 124, 241802 (2020)] [Phys. Rev. D 101, 112002 (2020)]

BESIII

$\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

- Self-conjugate multi-body decays (**GGSZ** approach)
- **Three-binning schemes** *[PRD 82, 112006(2010)]*
- The phase space is partitioned into **eight pairs** of irregularly shaped bins(i)



m_+^2, m_-^2 invariant mass square of $K_s\pi^+$, $K_s\pi^-$

- **2-D fits** are performed on all **DT** events.
- The comparison of the hadronic parameters c_i, s_i

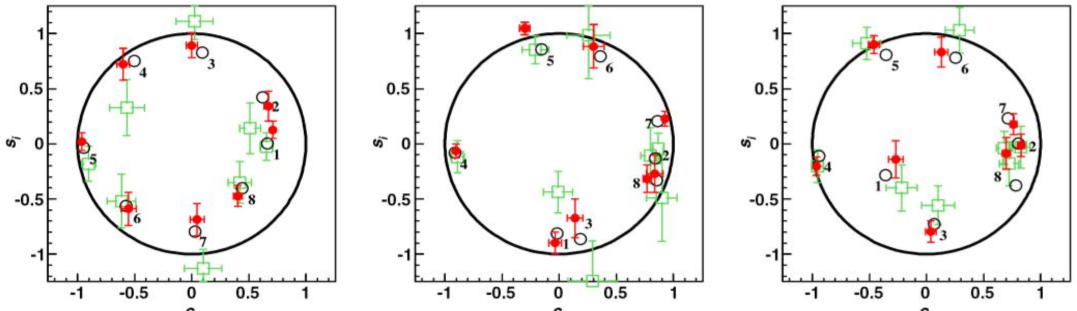
this work

expected values

(Phys.Rev.D 98 (2018) 112012)

CLEO-c results

(Phys.Rev.D 82 (2010) 112006)



c_i, s_i is the amplitude-weighted average of $\cos\Delta\delta_D$, $\sin\Delta\delta_D$ in the ith region of the Dalitz plot (D_i)

The decay model sensitivity to γ is expected to be around **1°**
(a factor of 3 smaller than previous measurements)

The **most precise** measurements to date of the strong-phase parameters c_i, s_i

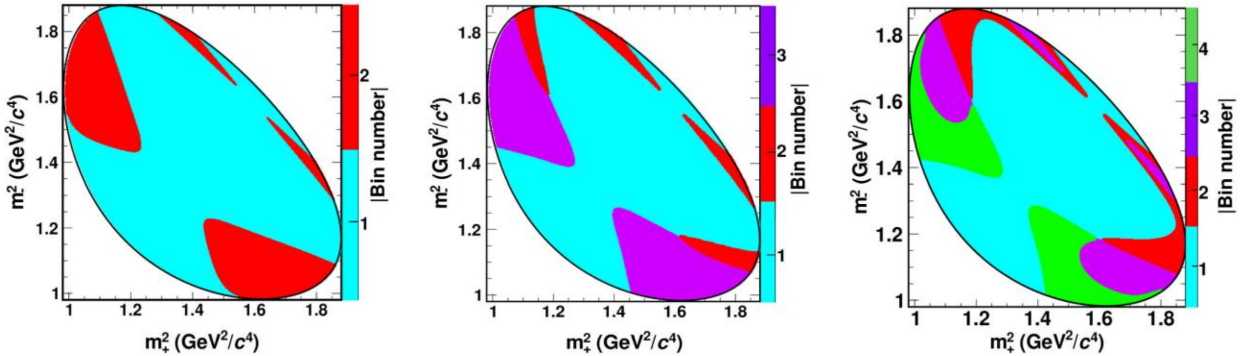
Back-up

Strong-Phase Difference in $D\to K^0_{S/L}K^+K^-$

Phys.Rev.D 102 (2020) 5, 052008

$\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

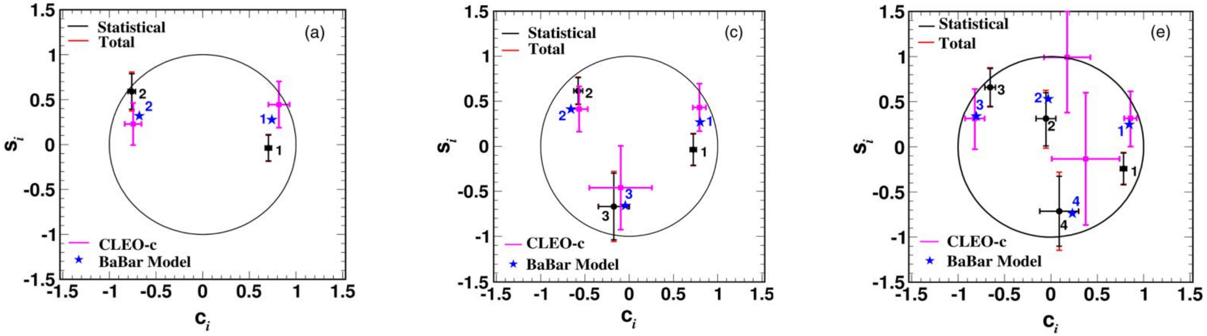
- Self-conjugate multi-body decays (**GGSZ** approach)
  - **Equal-$\Delta\delta_D$** binning scheme(***N*=2,3,4**) *[PRD 78, 034023 (2008)]*
  - The phase space is partitioned into **2/3/4 pairs** of irregularly shaped bins(i)



m^2_+, m^2_- invariant mass square of K_sK^+, K_sK^-

- **2-D fits** are performed on all **DT** events.
- The comparison of the hadronic parameters c_i, s_i

this work
BaBar model
Phys. Rev. D 78, (2008)034023
CLEO-c results
Phys. Rev.D 82 (2010) 112006



This is the most precise measurement to date of the strong-phase difference in these decays.

The decay model sensitivity to γ is expected to around 1.3°(N=3,4)

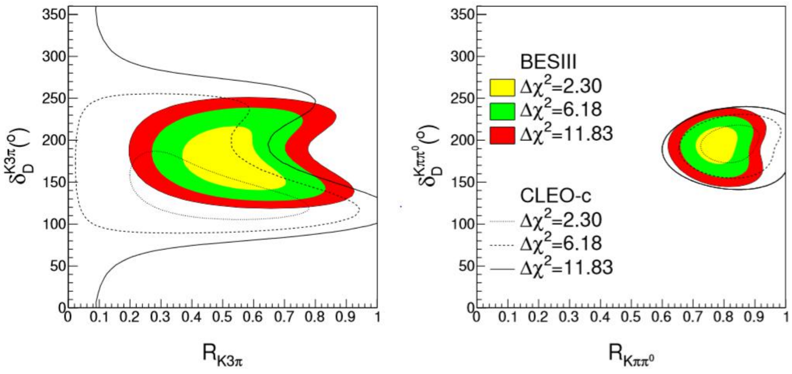
Strong-Phase Difference in $D\to K^-\pi^+\pi^+\pi^-$ and $D\to K^-\pi^+\pi^0$

$\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

JHEP 05, 164(2021)

- **Using multi-body $D\to K^- n\pi$ decays**
- **2-D fits** are performed on all **DT** events.
- **Global analysis** and **Equal-$\Delta\delta_D$ binning** scheme**(N=4)(Back-up)** *([Phys.Lett.B 802 (2020) 135188])*

Scans of $\Delta\chi^2$ in global 2-D parameter space



$R_{K3\pi} = 0.52^{+0.12}_{-0.10}$

$\delta_D^{K3\pi} = (167^{+31}_{-19})^o$

$r_D^{K3\pi} = (5.46 \pm 0.09)\times 10^{-2}$

$R_{K\pi\pi^0} = 0.78 \pm 0.04$

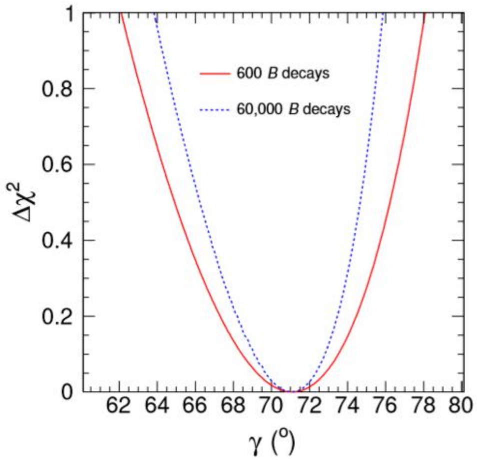
$\delta_D^{K\pi\pi^0} = (196^{+14}_{-15})^o$

$r_D^{K\pi\pi^0} = (4.40 \pm 0.11)\times 10^{-2}$

(Back-up)

The region of $(R_{K3\pi}, \delta_D^{K3\pi})$ parameter space encompassed by the 2σ and 3σ confidence intervals is significantly more constrained.

Impact of the results on the γ



600 suppressed B decays $\sim (71^{+7}_{-9})^o$

60,000 suppressed B decays $\sim (71^{+5}_{-7})^o$

Amplitude Analyses of $D_{(s)}$ Decays

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

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

$$D^+ \to K_S^0 K^+ \pi^0$$

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

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

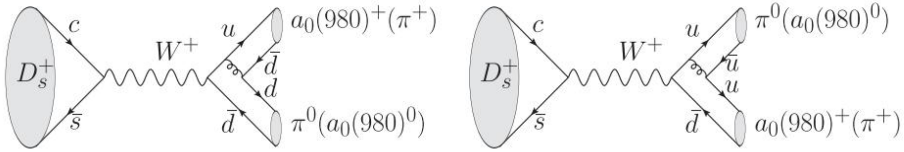
Dalitz Plot Analysis of $D_s^+ \to \pi^+\pi^0\eta$

BESIII

PRL123, 112001 (2019)

$\mathcal{L}$ = 3.19 fb^{-1} @ $\sqrt{s}$ = 4.178 GeV

- **W-annihilation dominant**

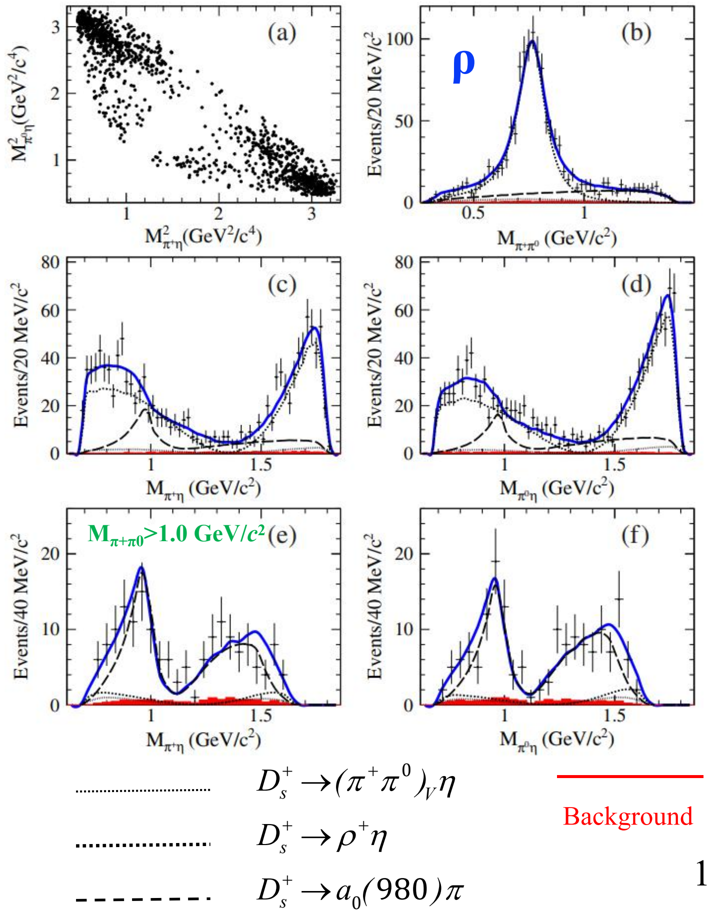


  - **1239 DT candidate events with 97.7% purity**
  - **Unbinned ML fit (χ^2/n_{dof} = 82.8/77)**

Amplitude	ϕ_n (rad)	FF$_n$	
$D_s^+ \to \rho^+\eta$	0.0 (fixed)	0.783±0.050±0.021	(20.0 σ)
$D_s^+ \to (\pi^+\pi^0)_V\eta$	0.612±0.172±0.342	0.054±0.021±0.025	(5.7 σ)
$D_s^+ \to a_0(980)\pi$	2.794±0.087±0.044	0.232±0.023±0.033	(16.2 σ)

- **Improved precision** $Br(D_s^+ \to \pi^+\pi^0\eta) = (9.50 \pm 0.28 \pm 0.41)\%$
- **First observation** $Br(D_s^+ \to a_0(980)^{+(0)}\pi^0,\ a_0(980)^{+(0)} \to \pi^{+(0)}\eta) = (1.46 \pm 0.15 \pm 0.23)\%$
- **Large *W*-annihilation rate in *SP* mode (estimated to be 0.84±0.23)**

Dalitz plot and fit projections



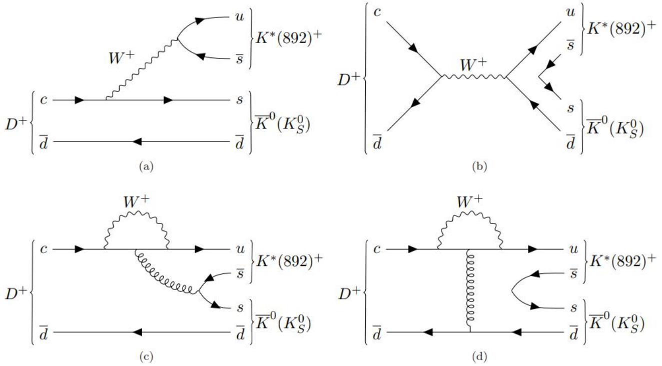
Dalitz Plot Analysis of $D^+ \to K_S^0 K^+ \pi^0$

BESIII

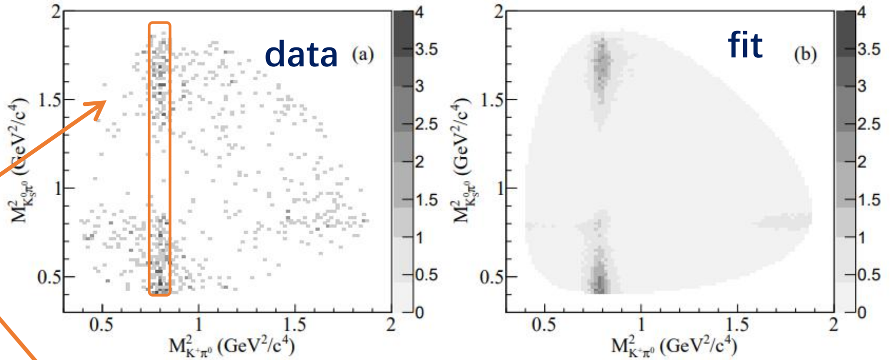
arXiv:2104.09131

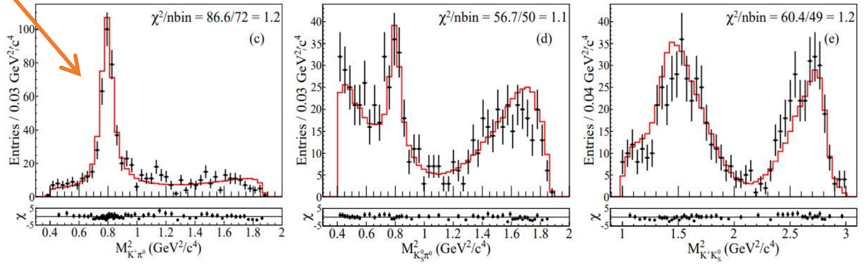
$\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

- **Topological diagrams contributing to the SCS decay of $D^+ \to K^*(892)^+ K_S^0$**



- **692 DT candidate events with 97.4% purity**
- **First amplitide analysis**





- **Nominal fitting results of Dalitz plot analysis**

Dominant

Amplitude	Magnitude	Phase ϕ (°)	FF (%)	Significance
$D^+ \to K^*(892)^+ K_S^0$	1.0 (fixed)	0.0 (fixed)	57.1 ± 2.6	$29.6\,\sigma$
$D^+ \to \bar{K}^*(892)^0 K^+$	0.41 ± 0.04	162 ± 10	10.2 ± 1.5	$11.6\,\sigma$
$D^+ \to (K^+\pi^0)_{S-\text{wave}} K_S^0$	2.02 ± 0.37	140 ± 14	3.9 ± 1.5	$5.2\,\sigma$
$D^+ \to (K_S^0\pi^0)_{S-\text{wave}} K^+$	3.14 ± 0.46	-173.7 ± 9.7	9.7 ± 2.6	$7.4\,\sigma$

BF	This work	PDG
$\frac{\mathcal{B}(D^+ \to K^*(892)^+(K^+\pi^0)K_S^0)}{\mathcal{B}(D^+\to K^+K_S^0\pi^0)}$	$(57.1 \pm 2.6_{\text{stat.}} \pm 4.2_{\text{syst.}})\%$	—
$\frac{\mathcal{B}(D^+\to \bar{K}^*(892)^0(K_S^0\pi^0)K^+)}{\mathcal{B}(D^+\to K^+K_S^0\pi^0)}$	$(10.2 \pm 1.5_{\text{stat.}} \pm 2.2_{\text{syst.}})\%$	—
$\mathcal{B}(D^+ \to K^*(892)^+ K_S^0)$	$(8.69 \pm 0.40_{\text{stat.}} \pm 0.64_{\text{syst.}} \pm 0.51_{\text{Br.}}) \times 10^{-3}$	$(17 \pm 8) \times 10^{-3}$
$\mathcal{B}(D^+ \to \bar{K}^*(892)^0 K^+)$	$(3.10 \pm 0.46_{\text{stat.}} \pm 0.68_{\text{syst.}} \pm 0.18_{\text{Br.}}) \times 10^{-3}$	$(3.74^{+0.12}_{-0.20}) \times 10^{-3}$

poorly measured before

- a factor of **4.6** improved!
- differs from the theoretical predictions by about **4 σ**
- agree with PDG value and theoretical calculation

Amplitude Analysis of $D_s^+ \to K_S^0 \pi^+ \pi^0$

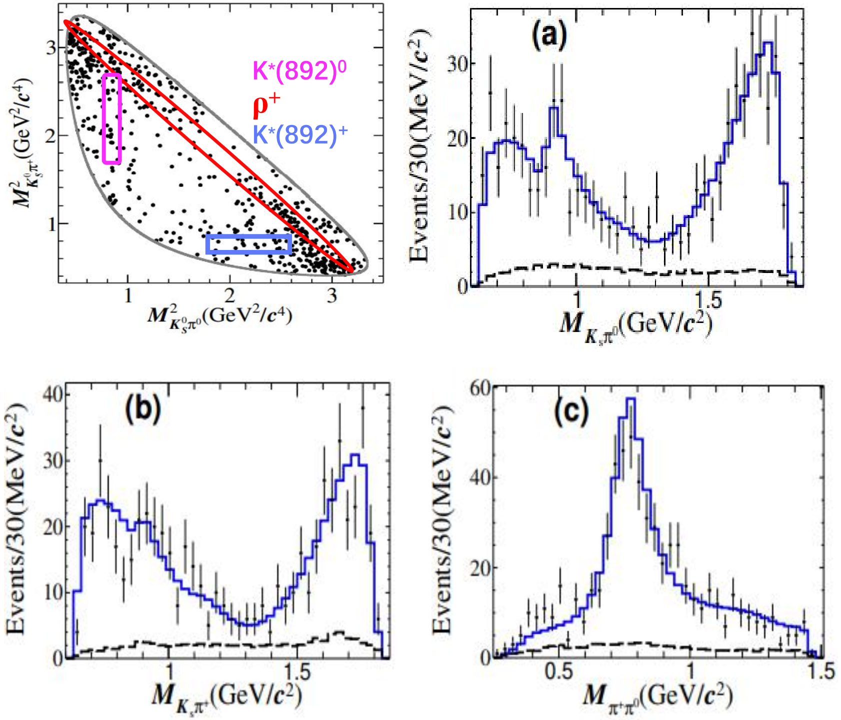
arXiv:2103.15098

BESIII

- Amplitude analysis of D_s^+ decay to a **3-body pseudoscalar meson** is a powerful tool for studying the *VP* channels of the **SCS D_s^+** decays
- 609 DT events with purity of 83.1%; Unbinned ML fit

$\mathcal{L}$ = 6.32 fb^{-1} @ $\sqrt{s}$ = 4.178-4.226 GeV

Dalitz plot and projections



- Amplitude analysis results

Amplitude	Magnitude (ρ_n)	Phase (ϕ_n)	FF (%)	Significance (σ)
$D_s^+ \to K_S^0\rho^+$	1.0(fixed)	0.0(fixed)	$50.2 \pm 7.2 \pm 3.9$	>10
$D_s^+ \to K_S^0\rho(1450)^+$	2.7 ± 0.5	$2.2 \pm 0.2 \pm 0.1$	$20.4 \pm 4.3 \pm 4.4$	>10
$D_s^+ \to K^*(892)^0\pi^+$	0.4 ± 0.1	$3.2 \pm 0.2 \pm 0.1$	$8.4 \pm 2.2 \pm 0.9$	5.0
$D_s^+ \to K^*(892)^+\pi^0$	0.3 ± 0.1	$0.2 \pm 0.2 \pm 0.2$	$4.6 \pm 1.4 \pm 0.4$	4.0
$D_s^+ \to K^*(1410)^0\pi^+$	0.8 ± 0.2	$0.2 \pm 0.3 \pm 0.1$	$3.3 \pm 1.6 \pm 0.5$	3.7

- BF measurement of $D_s^+ \to K_S^0 \pi^+ \pi^0$

$$Br(D_s^+ \to K_S^0\pi^+\pi^0) = (5.43 \pm 0.30_{stat.} \pm 0.15_{syst.}) \times 10^{-3}$$

Precision improved by a factor of 3 compared to CLEO-c result *[PRD 80, 112004(2009)].*

$$A_{CP} = \frac{Br(D_s^+) - Br(D_s^-)}{Br(D_s^+) + Br(D_s^-)} = (2.7 \pm 5.5_{stat.} \pm 0.9_{syst.}) \times 10^{-2}$$

No evidence for CPV

- BFs of intermediate processes

Intermediate process	BF (10^{-3})
$D_s^+ \to K_S^0\rho^+$	$2.73 \pm 0.42 \pm 0.22$
$D_s^+ \to K_S^0\rho(1450)^+$	$1.11 \pm 0.24 \pm 0.24$
$D_s^+ \to K^*(892)^0\pi^+$	$0.45 \pm 0.12 \pm 0.05$
$D_s^+ \to K^*(892)^+\pi^0$	$0.25 \pm 0.08 \pm 0.02$
$D_s^+ \to K^*(1410)^0\pi^+$	$0.18 \pm 0.09 \pm 0.03$

5σ off the theoretical prediction ***PRD 100, 093002(2019)***

Consistent with the theoretical prediction ***[PRD 84, 074019 (2011)]***

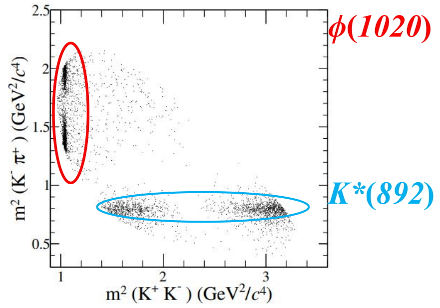
Amplitude Analysis of $D_s^+ \to K^+K^-\pi^+$

arXiv:2011.08041

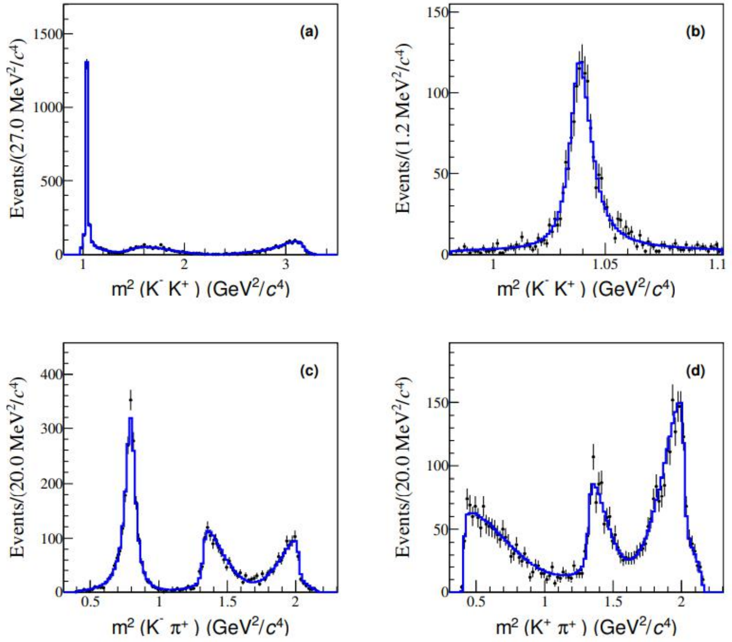
$\mathcal{L}$ = 3.19 fb^{-1} @ √s = 4.178 GeV

- **Obvious Differences between FFs of BaBar and CLEO-c**
- **4399 DT candidate events with 99.6% purity(BABAR(96307±369, 95%); CLEO-c(14400, 85%))**
- **Unbinned ML fit , χ^2/N_{dof} = 290/280**
- **Model- independent PWA in low K^+K^- mass region (Back-up)**

Amplitude	Magnitude (ρ)	Phase (ϕ)	FFs (%)	Significance (σ)
$D_s^+ \to \bar{K}^*(892)^0K^+$	1.0 (fixed)	0.0 (fixed)	48.3±0.9±0.6	> 20
$D_s^+ \to \phi(1020)\pi^+$	1.09±0.02±0.01	6.22±0.07±0.04	40.5±0.7±0.9	> 20
$D_s^+ \to S(980)\pi^+$	2.88±0.14±0.17	4.77±0.07±0.07	19.3±1.7±2.0	> 20
$D_s^+ \to \bar{K}_0^*(1430)^0K^+$	1.26±0.14±0.16	2.91±0.20±0.23	3.0±0.6±0.5	8.6
$D_s^+ \to f_0(1710)\pi^+$	0.79±0.08±0.14	1.02±0.12±0.06	1.9±0.4±0.6	9.2
$D_s^+ \to f_0(1370)\pi^+$	0.58±0.08±0.08	0.59±0.17±0.46	1.2±0.4±0.2	6.4



- **Dalitz plot projections**



- **Branching fraction measurement** $D_s^+ \to K^+K^-\pi^+$

$\mathcal{B}(D_s^+ \to K^+K^-\pi^+)$(%)	Collaboration
$5.55 \pm 0.14_{\rm stat} \pm 0.13_{\rm sys}$	CLEO [23]
$5.06 \pm 0.15_{\rm stat} \pm 0.21_{\rm sys}$	Belle [24]
$5.78 \pm 0.20_{\rm stat} \pm 0.30_{\rm sys}$	BaBar [25]
$5.47 \pm 0.08_{\rm stat} \pm 0.13_{\rm sys}$	BESIII(this analysis)

most precise at prescent

$$B(D_s^+ \to \overline{K}^*(892)^0K^+) = (3.94 \pm 0.12)\%$$
$$B(D_s^+ \to \phi(1020)\pi^+) = (4.60 \pm 0.17)\%$$

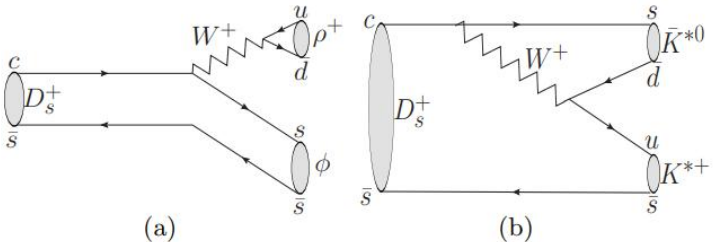
Consistent with theoretical prediction. *PRD 93, 114010 (2016)*

Amplitude Analysis of $D_s^+ \to K^- K^+ \pi^+ \pi^0$

arXiv:2103.02482

$\mathcal{L}$ = 6.32 fb^{-1} @ $\sqrt{s}$ = 4.178-4.226 GeV

- **Large BF of this CF decay with a large systematic uncertainty**
- **Study K_1 and f_1 mesons by $D_s^+ \to AP$; Study the 2-body $D_s^+ \to VV$($\phi\rho^+$, $\bar{K}^{*0}K^{*+}$)**



$Br(D_s^+ \to \phi\rho^+) = (8.4^{+1.9}_{-2.3})\%$ — *PRL 68 1279(1992)*

$Br(D_s^+ \to \overline{K}^{*0} K^{*+}) = (7.2 \pm 2.6)\%$ — *Z Phys. C 53 361(1992)*

- **Inconsistent between different experiments**

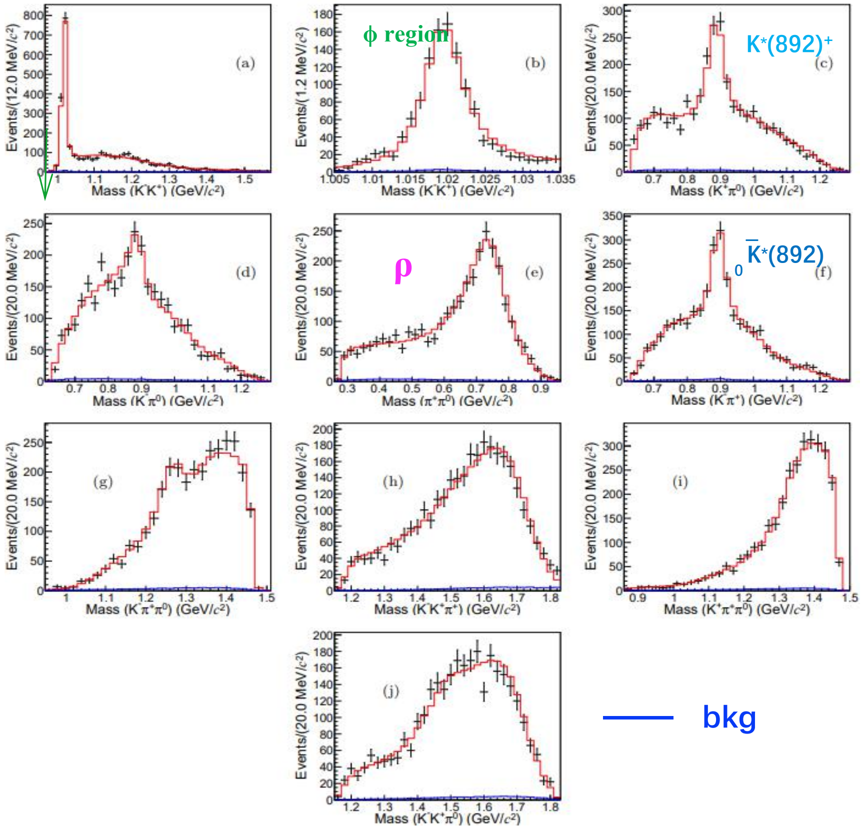
$R_{K_1(1270)}$	Process	Experiment
1.18 ± 0.43	$D^0 \to K^- K_1^+(1270)$	CLEO [19]
0.11 ± 0.06	$D^0 \to K^+ K_1^-(1270)$	CLEO [19]
0.19 ± 0.10	$D^0 \to K^-\pi^+\pi^+\pi^-$	BESIII [20]
0.24 ± 0.04	$D^0 \to K^-\pi^+\pi^+\pi^-$	LHCb [21]
0.45 ± 0.05	$B^+ \to J/\psi K^+\pi^+\pi^-$	Belle [22] (Fit 1)
0.30 ± 0.04	$B^+ \to J/\psi K^+\pi^+\pi^-$	Belle [22] (Fit 2)
0.38 ± 0.13	$K^- p \to K^-\pi^-\pi^+ p$	ACCMOR [23]
0.45 ± 0.14	$D^0 \to K^- K_1^+(1270)$	CLEO [24]

$$R_{K_1(1270)} \equiv \frac{Br(K_1(1270) \to K^*\pi)}{Br(K_1(1270) \to K\rho)}$$

[19] *PRD85, 122002 (2012)*
[20] *PRD95, 072010 (2017)*
[21] *EPJC78, 443 (2018)*
[22] *PRD83, 032005 (2011)*
[23] *NPB187, 1(1981)*
[24] *JHEP05, 143(2017)*

- 3088 DT candidate events with a purity of 97.5%
- First amplitude analysis ; Unbinned ML fit (χ^2/N_{dof} = 288.6/273)

Fit projections



Amplitude Analysis of $D_s^+ \to K^- K^+ \pi^+ \pi^0$

arXiv:2103.02482

- Fit results

Label	Amplitude	Phase (ϕ_n)	FF (%)	SS (σ)
I	$D_s^+[S] \to \phi\rho^+$	0.0 (fixed)	$42.64 \pm 1.30 \pm 0.77$	>20
II	$D_s^+[P] \to \phi\rho^+$	$1.64 \pm 0.05 \pm 0.02$	$8.58 \pm 0.69 \pm 0.37$	15.2
III	$D_s^+[D] \to \phi\rho^+$	$1.58 \pm 0.06 \pm 0.02$	$4.89 \pm 0.79 \pm 0.47$	8.4
	$D_s^+ \to \phi\rho^+$	···	$56.17 \pm 1.05 \pm 1.24$	···
IV	$D_s^+[S] \to \bar{K}^{*0} K^{*+}$	$1.13 \pm 0.06 \pm 0.03$	$15.49 \pm 0.81 \pm 0.36$	>20
V	$D_s^+[P] \to \bar{K}^{*0} K^{*+}$	$2.82 \pm 0.07 \pm 0.03$	$6.13 \pm 0.50 \pm 0.19$	16.2
VI	$D_s^+[D] \to \bar{K}^{*0} K^{*+}$	$1.76 \pm 0.07 \pm 0.03$	$4.00 \pm 0.47 \pm 0.34$	12.5
	$D_s^+ \to \bar{K}^{*0} K^{*+}$	···	$22.44 \pm 0.81 \pm 0.32$	···
VII	$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270) \to K^-\rho^+$	$5.36 \pm 0.06 \pm 0.10$	$9.81 \pm 0.80 \pm 0.46$	>20
	$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270)[S] \to \bar{K}^{*0}\pi^0$	···	$0.69 \pm 0.13 \pm 0.12$	···
	$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270)[S] \to K^{*-}\pi^+$	···	$1.27 \pm 0.27 \pm 0.25$	···
VIII	$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270)[S] \to K^*\pi$	$0.09 \pm 0.14 \pm 0.12$	$1.87 \pm 0.39 \pm 0.36$	7.2
	$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270)[D] \to \bar{K}^{*0}\pi^0$	···	$0.22 \pm 0.05 \pm 0.03$	···
	$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270)[D] \to K^{*-}\pi^+$	···	$0.41 \pm 0.10 \pm 0.05$	···
IX	$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270)[D] \to K^*\pi$	$1.62 \pm 0.15 \pm 0.12$	$0.64 \pm 0.16 \pm 0.08$	5.5
	$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270) \to K^*\pi$	···	$2.57 \pm 0.42 \pm 0.42$	···
	$D_s^+ \to \bar{K}_1^0(1400) K^+$, $\bar{K}_1^0(1400)[S] \to \bar{K}^{*0}\pi^0$	···	$2.67 \pm 0.36 \pm 0.17$	···
	$D_s^+ \to \bar{K}_1^0(1400) K^+$, $\bar{K}_1^0(1400)[S] \to K^{*-}\pi^+$	···	$4.90 \pm 0.65 \pm 0.29$	···
X	$D_s^+ \to \bar{K}_1^0(1400) K^+$, $\bar{K}_1^0(1400)[S] \to K^*\pi$	$5.66 \pm 0.08 \pm 0.05$	$7.23 \pm 0.95 \pm 0.41$	12.0
XI	$D_s^+ \to a_0^0(980)\rho^+$	$2.33 \pm 0.10 \pm 0.09$	$1.61 \pm 0.29 \pm 0.21$	6.0
	$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to K^{*-}K^+$	···	$0.87 \pm 0.17 \pm 0.07$	···
	$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to K^{*+}K^-$	···	$0.87 \pm 0.17 \pm 0.07$	···
XII	$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to K^{*\mp}K^\pm$	$5.14 \pm 0.10 \pm 0.05$	$1.35 \pm 0.28 \pm 0.11$	6.5
XIII	$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to a_0^0(980)\pi^0$	$5.77 \pm 0.14 \pm 0.07$	$0.65 \pm 0.24 \pm 0.12$	3.6
XIV	$D_s^+ \to \eta(1475)\pi^+$, $\eta(1475) \to a_0^0(980)\pi^0$	$0.98 \pm 0.08 \pm 0.06$	$3.28 \pm 0.38 \pm 0.25$	9.7

$$\frac{Br(D_s^+ \to \overline{K}_1^0(1270)K^+, \overline{K}_1^0(1270) \to K^{*-}\pi^+)}{Br(D_s^+ \to \overline{K}_1^0(1270)K^+, \overline{K}_1^0(1270) \to K^-\rho^+)} = 0.17 \pm 0.04$$

- BF measurements

$$Br(D_s^+ \to K^- K^+ \pi^+ \pi^0) = (5.42 \pm 0.10_{stat.} \pm 0.17_{syst.})\%$$

Precisions are significantly improved!

- BF for the intermediate processes

Dominant

Obtaining a much better precision than PDG value

Consistent with the theory prediction *PRD 49, 269(1994)*

Process	BF (%)
$D_s^+[S] \to \phi\rho^+$	$2.31 \pm 0.08 \pm 0.08$
$D_s^+[P] \to \phi\rho^+$	$0.45 \pm 0.04 \pm 0.02$
$D_s^+[D] \to \phi\rho^+$	$0.26 \pm 0.04 \pm 0.03$
$D_s^+ \to \phi\rho^+$	$3.06 \pm 0.08 \pm 0.12$
$D_s^+[S] \to \bar{K}^{*0} K^{*+}$	$0.84 \pm 0.05 \pm 0.03$
$D_s^+[P] \to \bar{K}^{*0} K^{*+}$	$0.33 \pm 0.03 \pm 0.01$
$D_s^+[D] \to \bar{K}^{*0} K^{*+}$	$0.21 \pm 0.03 \pm 0.02$
$D_s^+ \to \bar{K}^{*0} K^{*+}$	$1.21 \pm 0.05 \pm 0.04$
$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270) \to K^-\rho^+$	$0.50 \pm 0.04 \pm 0.03$
$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270)[S] \to K^*\pi$	$0.10 \pm 0.02 \pm 0.02$
$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270)[D] \to K^*\pi$	$0.04 \pm 0.01 \pm 0.01$
$D_s^+ \to \bar{K}_1^0(1270) K^+$, $\bar{K}_1^0(1270) \to K^*\pi$	$0.14 \pm 0.02 \pm 0.02$
$D_s^+ \to \bar{K}_1^0(1400) K^+$, $\bar{K}_1^0(1400) \to K^*\pi$	$0.39 \pm 0.05 \pm 0.03$
$D_s^+ \to a_0^0(980)\rho^+$	$0.07 \pm 0.02 \pm 0.01$
$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to K^{*\mp}K^\pm$	$0.07 \pm 0.02 \pm 0.01$
$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to a_0^0(980)\pi^0$	$0.04 \pm 0.01 \pm 0.01$
$D_s^+ \to \eta(1475)\pi^+$, $\eta(1475) \to a_0^0(980)\pi^0$	$0.17 \pm 0.02 \pm 0.01$

$$R_{K_1(1270)} \equiv \frac{Br(K_1(1270) \to K^*\pi)}{Br(K_1(1270) \to K\rho)} = 0.51 \pm 0.12_{stat.} \pm 0.09_{syst.}$$

This *R* value is consistent with the results using CLEO data *[JHEP 05, 143(2017)]* and Belle data (Fit 1) *[PRD 83, 032005(2011)]* within uncertainties.

Amplitude Analysis of other $D_{(s)}$ Decays

Amplitude analysis of $D^0 \to K_S^0 K^+ K^-$ **arXiv:2006.02800**

Amplitude analysis of $D^+ \to K_S \pi^+ \pi^+ \pi^-$ **PRD 100, 072008 (2019)**

Amplitude analysis of $D^0 \to K^- \pi^+ \pi^0 \pi^0$ **PRD 99, 092008 (2019)**

Amplitude analysis of $D_s^+ \to K_S^0 K^- \pi^+ \pi^+$ **PRD 103, 092006 (2021)**

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

Absolute Branching Fractions of $D_{(s)}$ Decays

BESIII

Fourteen exclusive hadronic $D^{0(+)}$ decays to η	**PRL 124, 241803 (2020)**
Two body $D^{0(+)} \to \phi P$ ($P = K^+$, $\pi^{+(0)}$, η)	**PLB 798, 135017 (2019)**
$D^+ \to K_{S/L} K^+ (\pi^0)$	**PRD 99, 032002 (2019)**
Inclusive decays $D^{0(+)} \to \phi X$	**PRD 100, 072006 (2019)**
Singly Cabiboo-suppressed decays $D \to \omega\pi\pi$	**PRD 102, 052003 (2020)**
$D^{0(+)} \to \eta\pi\pi$	**PRD 101, 052009 (2020)**
$D^{0(+)} \to \bar{K}K\pi\pi$	**PRD 102, 052006 (2020)**
$D_s \to K_{S/L} K^+$	**PRD 99, 112005 (2019)**
$D_s \to PP$	**JHEP 08, 146 (2020)**

- Some hadronic $D_{(s)}$ covered in "Radiative and Rare Charm Decays at BESIII"

Exclusive hadronic D Decays to η

BESIII

PRL 124,241803(2020)

$\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

- Key potential backgrounds in some LFU tests
- Known D^0/D^+ exclusive decays to η only account for 44%/16%
- Crucial to address the tensions found in LFU tests with semileptonic B decays
- First measurements, DT method, 2D unbinned ML fit

Absolute Branching Fractions

Decay		ΔE_{sig} (MeV)	N_{DT}	ϵ_{sig} (%)	$\mathcal{B}_{sig}$ ($\times10^{-4}$)
$D^0\to K^-\pi^+\eta$		(−37, 36)	6116.2 ± 81.8	14.22	185.3(25)(31)
$D^0\to K^0_S\pi^0\eta$		(−57, 45)	1092.7 ± 35.2	4.66	100.6(34)(30)
$D^0\to K^+K^-\eta$	5.5σ	(−27, 27)	13.1 ± 4.0	9.53	0.59(18)(05)
$D^0\to K^0_SK^0_S\eta$	2.8σ	(−29, 28)	7.3 ± 3.2	2.36	1.33(59)(18)
$D^0\to K^-\pi^+\pi^0\eta$		(−44, 36)	576.5 ± 28.8	5.53	44.9(22)(15)
$D^0\to K^0_S\pi^+\pi^-\eta$		(−33, 32)	248.2 ± 18.0	3.80	28.0(19)(10)
$D^0\to K^0_S\pi^0\pi^0\eta$		(−56, 41)	64.7 ± 9.2	1.58	17.6(23)(13)
$D^0\to \pi^+\pi^-\pi^0\eta$		(−57, 45)	508.6 ± 26.0	6.76	32.3(17)(14)
$D^+\to K^0_S\pi^+\eta$		(−36, 36)	1328.2 ± 37.8	6.51	130.9(37)(31)
$D^+\to K^0_SK^+\eta$	5.7σ	(−27, 27)	13.6 ± 3.9	4.72	1.85(52)(08)
$D^+\to K^-\pi^+\pi^+\eta$		(−33, 33)	188.0 ± 15.3	8.94	13.5(11)(04)
$D^+\to K^0_S\pi^+\pi^0\eta$	8.4σ	(−49, 41)	48.7 ± 9.7	2.57	12.2(24)(06)
$D^+\to \pi^+\pi^+\pi^-\eta$		(−40, 38)	514.6 ± 25.7	9.67	34.1(17)(10)
$D^+\to \pi^+\pi^0\pi^0\eta$		(−70, 49)	192.5 ± 17.1	3.86	32.0(28)(17)

others > 10σ

Agree with Belle results *[PRD98,030001(2018)][PRD102, 12002(2020)]* with 1.3σ, **with precision improved 2-fold!**

Greater than CLEO's results *[PRD98,030001(2018)] [PRL93,111801(2004)]* by 3.7σ

Charge-conjugated BFs and asymmetries

Decay	$\mathcal{B}^+_{sig}$ ($\times10^{-4}$)	$\mathcal{B}^-_{sig}$ ($\times10^{-4}$)	A^{sig}_{CP} (%)
$D^0\to K^-\pi^+\eta$	182.1 ± 3.5	189.1 ± 3.6	$-1.9\pm1.3\pm1.0$
$D^0\to K^0_S\pi^0\eta$	98.4 ± 4.8	106.3 ± 5.1	$-3.9\pm3.2\pm0.8$
$D^0\to K^-\pi^+\pi^0\eta$	41.7 ± 2.7	48.8 ± 3.2	$-7.9\pm4.8\pm2.5$
$D^0\to \pi^+\pi^-\pi^0\eta$	29.8 ± 2.2	33.3 ± 2.5	$-5.5\pm5.2\pm2.4$
$D^+\to K^0_S\pi^+\eta$	129.9 ± 5.3	132.3 ± 5.4	$-0.9\pm2.9\pm1.0$
$D^+\to \pi^+\pi^+\pi^-\eta$	35.4 ± 2.4	33.7 ± 2.4	$+2.5\pm5.0\pm1.6$

No evidence for *CP* violation is found

Summary

- Large $D_{(s)}$ samples near charm threshold
- Our results of hadronic parameters provide key inputs for the model-independent determination of the CKM angle γ of B decays.
- Amplitude analyses on 3-and 4-body hadronic decays, especially those with neutral mesons K_s^0, η, π^0 in the final states.
- Precise measurements of absolute branching fractions of hadronic $D_{(s)}$ decays can calibrate QCD calculations.
- Planning to take more data of $D_{(s)}$:

  20 fb^{-1} at 3.773 GeV ; 6 fb^{-1} at 4.178 GeV

  [Chinese Physics C Vol. 44, No. 4 (2020)]

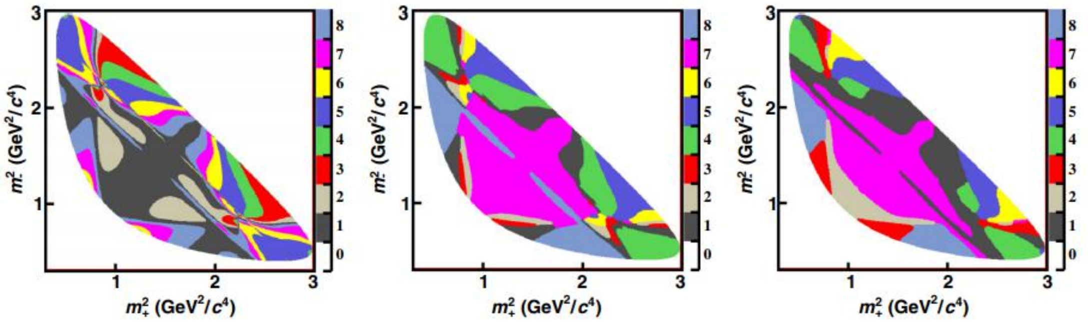
BACK UP

Strong-Phase Difference

Strong-Phase Difference

BESIII

Binning Schemes



m_+^2, m_-^2 ~ invariant mass square of $K_S\pi^+$, $K_S\pi^-$

equal-$\Delta\delta_D$:
according to regions of similar strong-phase difference $\Delta\delta_D$
optimal :
maximum sensitivity to γ in the presence of negligible background
(modified) optimal :
maximum sensitivity to γ in the presence of significant background

[PRD 82, 112006(2010)]

Hadronic Parameters c_i, s_i

c_i, s_i is the amplitude-weighted average of $\cos\Delta\delta_D$, $\sin\Delta\delta_D$ in the ith region of the Dalitz plot (D_i)

$$c_i = \frac{1}{\sqrt{F_i F_{-i}}} \int_i |f_D(m_+^2, m_-^2)||f_D(m_-^2, m_+^2)| \times \cos[\Delta\delta_D(m_+^2, m_-^2)] dm_+^2 dm_-^2$$

$$s_i = \frac{1}{\sqrt{F_i F_{-i}}} \int_i |f_D(m_+^2, m_-^2)||f_D(m_-^2, m_+^2)| \times \sin[\Delta\delta_D(m_+^2, m_-^2)] dm_+^2 dm_-^2,$$

F_i is the fraction of events found in the ith bin of the flavor-specific decay $D^0 \to K^0_{S/L}\pi^+\pi^-$, $D^0 \to K^0_{S/L}K^+K^-$

Strong-Phase Difference

Hadronic Parameters

$$R_S e^{-i\delta_D^S} = \frac{\int \mathcal{A}_S^*(\mathbf{x})\mathcal{A}_{\bar{S}}(\mathbf{x})\mathrm{d}\mathbf{x}}{A_S A_{\bar{S}}} \quad \text{and} \quad r_D^S = A_{\bar{S}}/A_S$$

R_S ~ coherence factor
r^S ~ amplitude ratio
δ^S ~ CP-conserving strong-phase difference
$A_S(x)$ ~ decay amplitude of $D^0 \to S$ at a point in multi-body phase space

Tag Mode

Flavour	Like sign	$K^-\pi^+\pi^+\pi^-$, $K^-\pi^+\pi^0$, $K^-\pi^+$
	Opposite sign	$K^+\pi^-\pi^-\pi^+$, $K^+\pi^-\pi^0$, $K^+\pi^-$
CP	Even	K^+K^-, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$, $K_L^0\pi^0$, $K_L^0\omega$, $\pi^+\pi^-\pi^0$
	Odd	$K_S^0\pi^0$, $K_S^0\eta$, $K_S^0\omega$, $K_S^0\eta'$, $K_S^0\phi$, $K_L^0\pi^0\pi^0$
Self-conjugate		$K_S^0\pi^+\pi^-$

Formalism and Measurement Strategy

decay rate

$$\Gamma(S|T) = \int\int |\mathcal{A}_S(\mathbf{x})\mathcal{A}_{\bar{T}}(\mathbf{y}) - \mathcal{A}_{\bar{S}}(\mathbf{x})\mathcal{A}_T(\mathbf{y})|^2 \mathrm{d}\mathbf{x}\mathrm{d}\mathbf{y}$$
$$= \left[A_S^2 A_{\bar{T}}^2 + A_{\bar{S}}^2 A_T^2 - 2R_S R_T A_S A_{\bar{S}} A_T A_{\bar{T}} \cos\left(\delta_D^T - \delta_D^S\right)\right]$$
$$= A_S^2 A_T^2 \left[(r_D^S)^2 + (r_D^T)^2 - 2R_S R_T r_D^S r_D^T \cos\left(\delta_D^T - \delta_D^S\right)\right]$$

T ~ tag mode S ~signal mode

CP tag

$$\Gamma(S|CP) = A_S^2 A_{CP}^2 \left(1 + (r_D^S)^2 - 2\lambda R_S r_D^S \cos\delta_D^S\right)$$

$$\rho_{CP\pm}^S = \frac{N(S|CP) + N(\bar{S}|CP)}{N(K^-\pi^+|CP) + N(K^+\pi^-|CP)} \cdot \frac{\mathcal{B}(D^0 \to K^-\pi^+) + \mathcal{B}(D^0 \to K^+\pi^-)}{\mathcal{B}(D^0 \to S) + \mathcal{B}(D^0 \to \bar{S})} \cdot \rho_{CP\pm}^{K\pi}$$

Flavour tag

$$\Gamma(S|S) = A_S^2 A_{\bar{S}}^2 \left[1 - R_S^2\right]$$

$$\rho_{T,LS}^S = \left(1 + (r_D^S/r_D^T)^2 - 2(r_D^S/r_D^T)R_S R_T \cos(\delta_D^T - \delta_D^S)\right) /$$
$$\left(1 + (r_D^S/r_D^T)^2 - R_T([y/r_D^T]\cos\delta_D^T - x/r_D^T]\sin\delta_D^T) - R_S([yr_D^S/(r_D^T)^2]\cos\delta_D^S - [xr_D^S/(r_D^T)^2]\sin\delta_D^S) + (x^2+y^2)/(r_D^T)^2\right)$$

Self-conjugate

$$Y_i^S = H\left(K_i + \left(r_D^S\right)^2 K_{-i} - 2r_D^S R_S \sqrt{K_i K_{-i}}\left[c_i\cos\delta_D^S - s_i\sin\delta_D^S\right]\right)$$

Strong-Phase Difference in $D \to K^- \pi^+ \pi^+ \pi^-$ and $D \to K^- \pi^+ \pi^0$

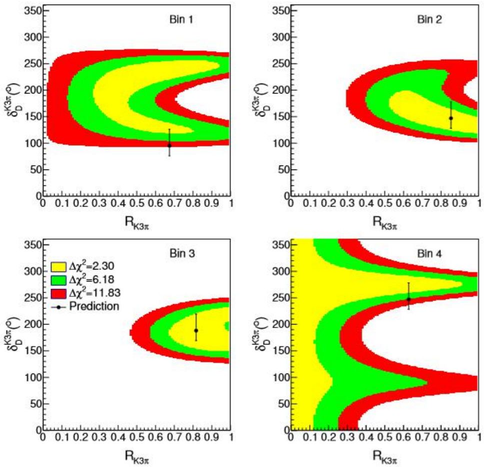
BESIII

$\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

arXiv:2103.05988

- Binned $D \to K^- \pi^+ \pi^+ \pi^-$ analysis (4-bins, *PLB802, 135188(2020)*)

Parameter	Global fit	Binned fit			
		Bin 1	Bin 2	Bin 3	Bin 4
$R_{K3\pi}$	$0.52^{+0.12}_{-0.10}$	$0.58^{+0.25}_{-0.33}$	$0.78^{+0.50}_{-0.21}$	$0.85^{+0.15}_{-0.12}$	$0.45^{+0.33}_{-0.37}$
$\delta_D^{K3\pi}$	$(167^{+31}_{-19})^\circ$	$(131^{+124}_{-16})^\circ$	$(150^{+37}_{-39})^\circ$	$(176^{+57}_{-21})^\circ$	$(274^{+19}_{-30})^\circ$
$r_D^{K3\pi}$ $(\times 10^{-2})$	5.46 ± 0.09	$5.44^{+0.45}_{-0.14}$	$5.80^{+0.14}_{-0.13}$	$5.75^{+0.41}_{-0.14}$	$5.09^{+0.14}_{-0.14}$
$R_{K\pi\pi^0}$	0.78 ± 0.04	0.80 ± 0.04			
$\delta_D^{K\pi\pi^0}$	$(196^{+14}_{-15})^\circ$	$(200 \pm 11)^\circ$			
$r_D^{K\pi\pi^0}$ $(\times 10^{-2})$	4.40 ± 0.11	4.41 ± 0.11			



Black dot with error bar denotes the prediction of model.

BESIII

Expected γ/ϕ_3 precision of the LHCb[1] and Belle II[2] experiments and their timescales

Runs	Collected / Expected integrated luminosity	Year attained	γ/ϕ_3 sensitivity
LHCb Run-1 [7, 8 TeV]	3 fb^{-1}	2012	8°
LHCb Run-2 [13 TeV]	6 fb^{-1}	2018	4°
Belle II Run	50 ab^{-1}	2025	1.5°
LHCb upgrade I [14 TeV]	50 fb^{-1}	2030	< 1°
LHCb upgrade II [14 TeV]	300 fb^{-1}	(>)2035	< 0.4°

2.93fb^{-1} @ $\sqrt{s}$ = 3.773 GeV $D^0\bar{D}^0$

$D \rightarrow K_{S/L}\pi^+\pi^-$ ~ **0.7°, 1.2°, 0.8°**

20 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV D^0D^0 in the future

~ 0.4°

[1] S. S. Malde, Technical Report, LHCb-PUB-2016-025 (2016)
[2] E. Kou et al. (Belle II Collaboration), PTEP 2019, 123C01 (2019)

Amplitude Analysis

Dalitz Plot Analysis of $D^0 \to K_S^0 K^+ K^-$

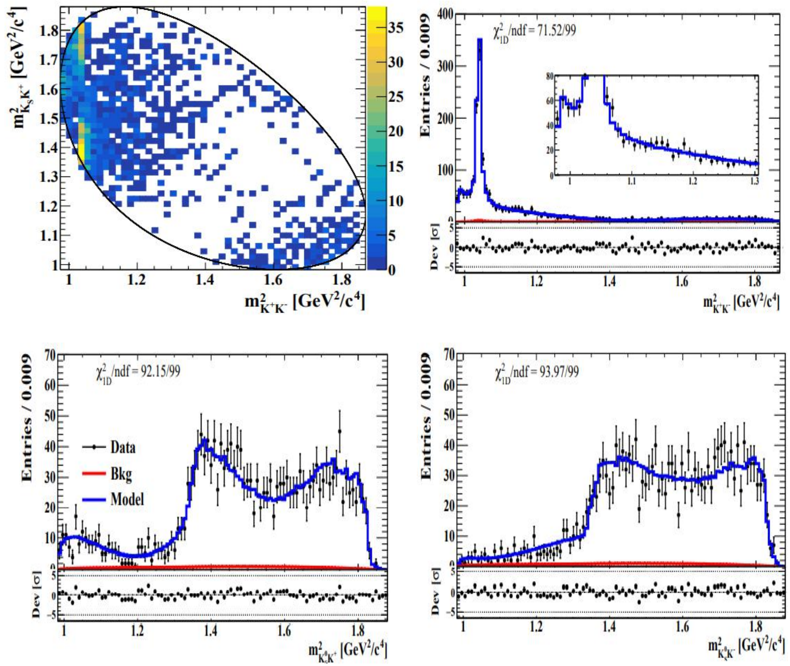
arXiv: 2006.02800

$\mathcal{L} = 2.93\ fb^{-1} @ \sqrt{s} = 3.773\ GeV$

- **1856±45** DT candidate events with **96.4%** purity
- Model selection ~ LASSO method *[J. R. Stat. Soc. Ser. B 58, 267 (1996)]*
- The Dalitz plot is well described by a set of six resonances
- Results of Dalitz plot analysis

Final state	Magnitude	Phase [rad]	Fit fraction [%]	Sign.[σ]
$a_0(980)^0 K_S^0$	1	0	$90 \pm 10 \pm 17$	>10
$a_0(980)^+ K^-$	$0.64^{+0.14}_{-0.08} \pm 0.09$	$2.94^{+0.19}_{-0.14} \pm 0.06$	$34 \pm 7 \pm 6$	>10
$\phi(1020) K_S^0$	$0.74^{+0.08}_{-0.04} \pm 0.08$	$1.67 \pm 0.08 \pm 0.19$	$48 \pm 2 \pm 3$	>10
$a_2(1320)^+ K^-$	$0.12 \pm 0.03 \pm 0.01$	$-2.92^{+0.21}_{-0.26} \pm 0.31$	< 2.3 (@90 % C.L.), CV = 1.4	3.9 } 5.9
$a_2(1320)^- K^+$	$0.09 \pm 0.03 \pm 0.02$	$-0.06 \pm 0.23 \pm 0.28$	< 1.6 (@90 % C.L.), CV = 0.8	3.5 } 5.9
$a_0(1450)^- K^+$	$0.16^{+0.12}_{-0.05} \pm 0.04$	$0.12 \pm 0.58 \pm 0.50$	< 13.2 (@90 % C.L.), CV = 2.2	3.5 } 5.9
Total			176 ± 20	

Dalitz plot and projections



- The coupling constant of $a_0(980)$ to $K\bar{K}$:

$$g_{K\bar{K}} = (3.77 \pm 0.24 \pm 0.35) GeV$$

The first measurement of absolute branching fraction:

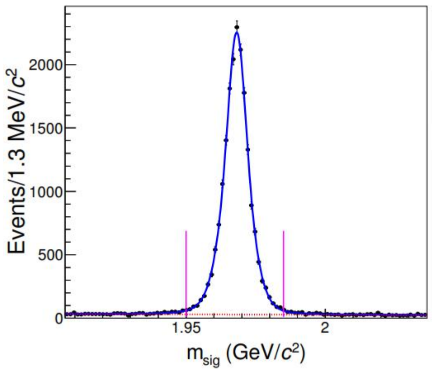
$$Br(D^0 \to K_S^0 K^+ K^-) = (4.51 \pm 0.05_{stat.} \pm 0.16_{sys.}) \times 10^{-3}$$

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

arXiv:2011.08041

$\mathcal{L}$ = 3.19 fb^{-1} @ $\sqrt{s}$ = 4.178 GeV

- A MVA method is used to suppress bkg.
- Fit to the signal D_s invariant mass after BDTG requirement



The area between the pink lines is the signal area of the sample for MIPWA

- Assuming that only S- and P-wave amplitudes are necessary at the low end of K^+K^- mass spectrum
- Angular distribution can be written as partial wave analysis

$$\frac{dN}{d\cos\Theta} = 2\pi\left|SY_0^0(\cos\Theta) + PY_1^0(\cos\Theta)\right|^2$$

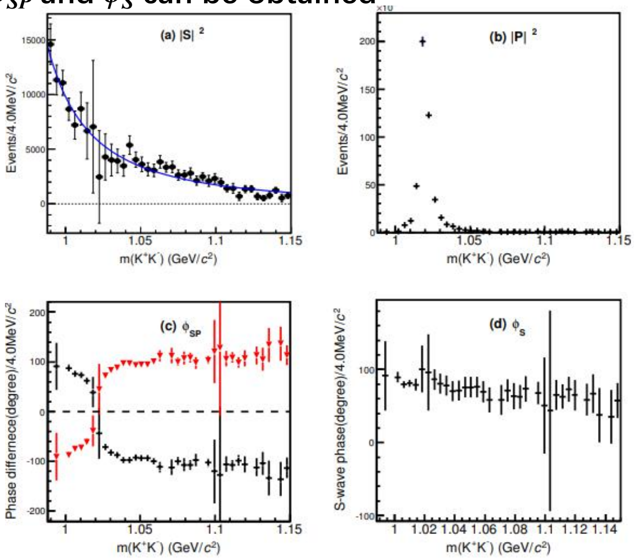
$$|S|^2 = \sqrt{4\pi}\left\langle Y_0^0\right\rangle - \sqrt{5\pi}\left\langle Y_2^0\right\rangle,$$

$$\cos\phi_{SP} = \frac{\left\langle Y_1^0\right\rangle}{\sqrt{(2\left\langle Y_0^0\right\rangle - \sqrt{5}\left\langle Y_2^0\right\rangle)\sqrt{5}\left\langle Y_2^0\right\rangle}}$$

$$|P|^2 = \sqrt{5\pi}\left\langle Y_2^0\right\rangle,$$

$S(P)$~amplitude of $S(P)$-wave
$\phi_{S(P)}$~phase of $S(P)$-wave
ϕ_{SP} ~phase difference between S-wave and P-wave

- Calculating $|S|^2$, ϕ_{SP} and $|P|^2$ in every mass interval of m(K^+K^-) in the threshold region, the distribution of $|S|^2$, $|P|^2$, ϕ_{SP} and ϕ_S can be obtained



- The lineshape of $S(980)$ is empirically parameterized by

$$A_{S(980)} = \frac{1}{m_0^2 - m^2 - im_0\Gamma_0\rho_{KK}}$$

- Fitting the distribution of $|S|^2$ in (a) with $|A_S(980)|^2$

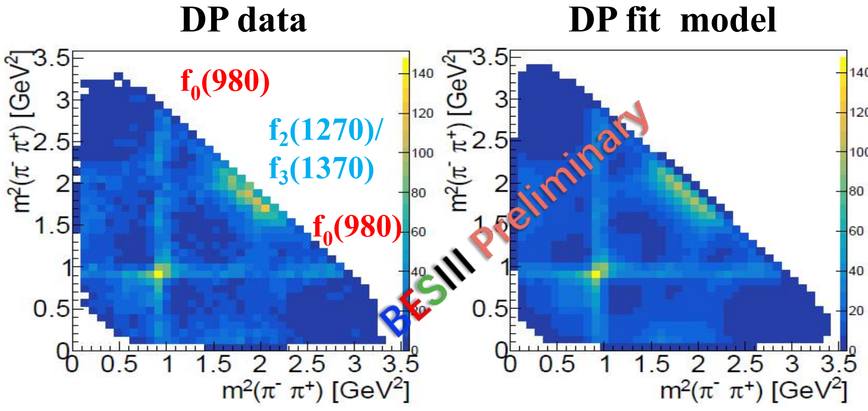
$$m_0 = (0.919 \pm 0.006_{\rm stat})\ \mathrm{GeV}/c^2$$
$$\Gamma_0 = (0.272 \pm 0.040_{\rm stat})\ \mathrm{GeV}.$$

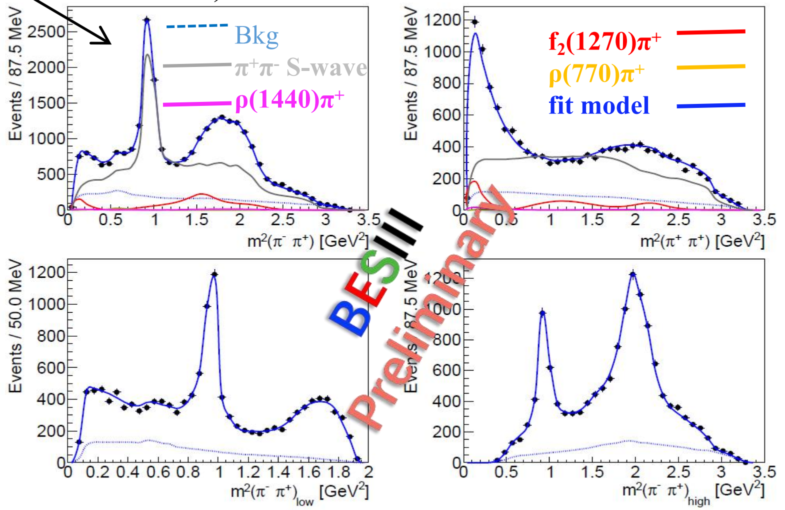
- Choose the black one in (c)

Amplitude Analysis of $D_s^+ \to \pi^+\pi^-\pi^+$

- **$f_0(980)$ resonance still needs to be better understood; Important input for the global study of $D_s \to VP$**
- **13.8 K** data events with **80%** purity in the signal region for DP analysis
- Dalitz Plot model: **unbinned ML fit** (χ^2/N_{dof} = **344/342**)
- Amplitude analysis results (**model- independent PWA in low $\pi^+\pi^-$ S-wave extraction**)

$\mathcal{L}$ = 3.19 fb^{-1} @ $\sqrt{s}$ = 4.178 GeV





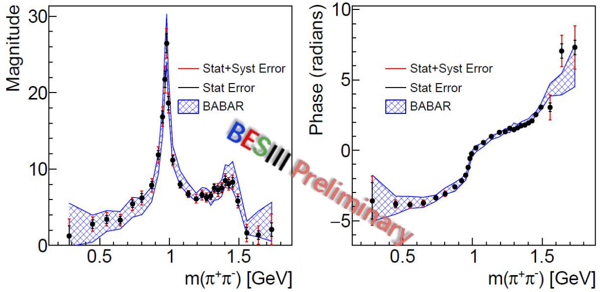
- Fit results by using **BABAR model** *[PRD 79, 032003 (2009)]:*

Decay mode	Decay fraction (%)	Amplitude	Phase (radians)
$f_2(1270)\pi^+$	10.52 ± 0.83 ± 1.15	1. (Fixed)	0. (Fixed)
$\rho(770)\pi^+$	0.87 ± 0.38 ± 0.52	0.13 ± 0.03 ± 0.04	5.44 ± 0.25 ± 0.62
$\rho(1450)\pi^+$	1.26 ± 0.40 ± 0.53	0.91 ± 0.16 ± 0.22	1.03 ± 0.32 ± 0.51
S-wave	84.15 ± 0.83 ± 1.30		
Total	96.80 ± 2.45 ± 3.50		

see next page

where **S-wave** is parameterized by an interpolation between the **N=29** control points also used by BABAR

- **With improved precision** our results are compatible with BABAR measurements *[PRD 79, 032003 (2009)]*



Amplitude Analysis of $D_s^+ \to \pi^+\pi^-\pi^+$

➢ Choice of signal Dalitz-plot model

Different fit models are tested, and **Fit 4** is chosen as the nominal fit model:

Decay Mode	Decay fraction (%) Fit **1**	Fit **2**	Fit **3**	Fit **4**	Fit **5**
$f_2(1270)\pi^+$	13.2 ± 0.6	12.5 ± 0.7	10.8 ± 0.8	10.5 ± 0.8	10.5 ± 0.7
$\rho(770)\pi^+$	—	1.[illegible] ± 0.5	—	0.9 ± 0.4	0.4 ± 0.2
$\rho(1450)\pi^+$	—	—	2.5 ± 0.5	1.3 ± 0.4	1.4 ± 0.3
$\omega(782)\pi^+$	—	—	—	—	0.3 ± 0.1
$(S\text{-wave})\pi^+$	87.7 ± 0.4	84.7 ± 0.7	85.7 ± 0.7	84.2 ± 0.8	84.1 ± 0.7
Total	100.9 ± 1.1	98.9 ± 2.0	99.0 ± 2.0	96.8 ± 2.4	96.8 ± 2.0
$-2\ln\mathcal{L}$	40401.2	40348.9	40321.4	40303.2	40276.7
Significance	—	6.9σ [Fit1 + $\rho(770)$]	8.7σ [Fit1 + $\rho(1450)$]	3.9σ [Fit3 + $\rho(770)$]	4.8σ [Fit4 + $\omega(782)$]
χ^2/ν	$\frac{433.0}{404-58} = 1.25$	$\frac{393.6}{404-60} = 1.14$	$\frac{350.0}{404-60} = 1.02$	$\frac{344.4}{404-62} = 1.01$	$\frac{335.2}{404-64} = 0.99$

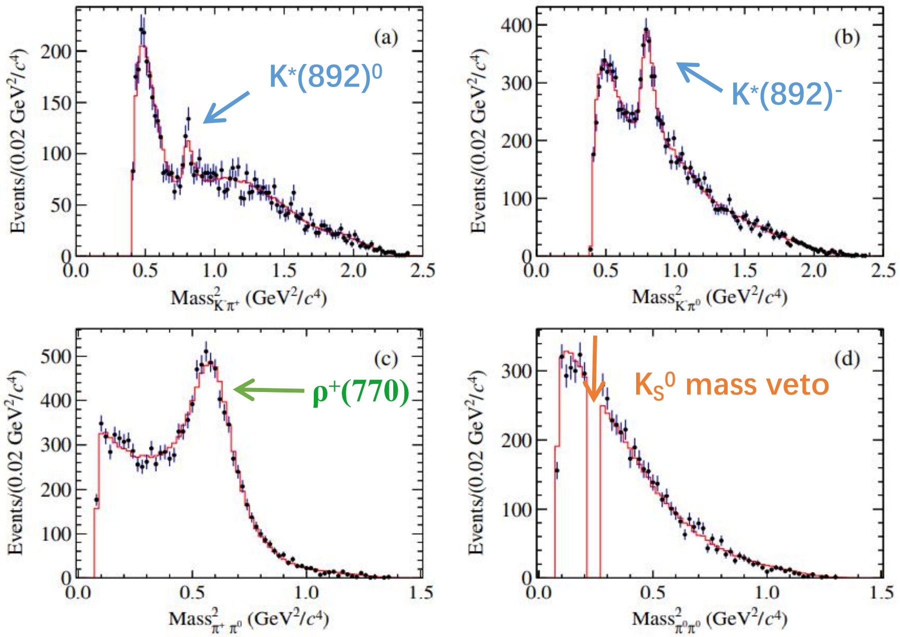
The results of **Fit 5** are considered as the systematic uncertainties on ω ("Alt. Fit")

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

RRD 99 092008(2019)

$\mathcal{L} = 2.93\ fb^{-1}$ @ $\sqrt{s} = 3.773$ GeV

- First amplitude analysis on this CF decay with large BF
- 5950 DT candidate events with a purity of 98.9%
- Unbinned ML fit results



Dominant

Amplitude mode	FF [%]	Phase [ϕ]	Significance [σ]
$D \to SS$			
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_S$	$6.92 \pm 1.44 \pm 2.86$	$-0.75 \pm 0.15 \pm 0.47$	>10
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_S$	$4.18 \pm 1.02 \pm 1.77$	$-2.90 \pm 0.19 \pm 0.47$	6.0
$D \to AP, A \to VP$			
$D \to K^-a_1(1260)^+, \rho^+\pi^0[S]$	$28.36 \pm 2.50 \pm 3.53$	0 (fixed)	>10
$D \to K^-a_1(1260)^+, \rho^+\pi^0[D]$	$0.68 \pm 0.29 \pm 0.30$	$-2.05 \pm 0.17 \pm 0.25$	6.1
$D \to K_1(1270)^-\pi^+, K^{*-}\pi^0[S]$	$0.15 \pm 0.09 \pm 0.15$	$1.84 \pm 0.34 \pm 0.43$	4.9
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[S]$	$0.39 \pm 0.18 \pm 0.30$	$-1.55 \pm 0.20 \pm 0.26$	4.8
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[D]$	$0.11 \pm 0.11 \pm 0.11$	$-1.35 \pm 0.43 \pm 0.48$	4.0
$D \to K_1(1270)^0\pi^0, K^-\rho^+[S]$	$2.71 \pm 0.38 \pm 0.29$	$-2.07 \pm 0.09 \pm 0.20$	>10
$D \to (K^{*-}\pi^0)_A\pi^+, K^{*-}\pi^0[S]$	$1.85 \pm 0.62 \pm 1.11$	$1.93 \pm 0.10 \pm 0.15$	7.8
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[S]$	$3.13 \pm 0.45 \pm 0.58$	$0.44 \pm 0.12 \pm 0.21$	>10
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[D]$	$0.46 \pm 0.17 \pm 0.29$	$-1.84 \pm 0.26 \pm 0.42$	5.9
$D \to (\rho^+K^-)_A\pi^0, K^-\rho^+[D]$	$0.75 \pm 0.40 \pm 0.60$	$0.64 \pm 0.36 \pm 0.53$	5.1
$D \to AP, A \to SP$			
$D \to ((K^-\pi^+)_{S\text{-wave}}\pi^0)_A\pi^0$	$1.99 \pm 1.08 \pm 1.55$	$-0.02 \pm 0.25 \pm 0.53$	7.0
$D \to VS$			
$D \to (K^-\pi^0)_{S\text{-wave}}\rho^+$	$14.63 \pm 1.70 \pm 2.41$	$-2.39 \pm 0.11 \pm 0.35$	>10
$D \to K^{*-}(\pi^+\pi^0)_S$	$0.80 \pm 0.38 \pm 0.26$	$1.59 \pm 0.19 \pm 0.24$	4.1
$D \to K^{*0}(\pi^0\pi^0)_S$	$0.12 \pm 0.12 \pm 0.12$	$1.45 \pm 0.48 \pm 0.51$	4.1
$D \to VP, V \to VP$			
$D \to (K^{*-}\pi^+)_V\pi^0$	$2.25 \pm 0.43 \pm 0.45$	$0.52 \pm 0.12 \pm 0.17$	>10
$D \to VV$			
$D \to K^{*-}\rho^+[S]$	$5.15 \pm 0.75 \pm 1.28$	$1.24 \pm 0.11 \pm 0.23$	>10
$D \to K^{*-}\rho^+[P]$	$3.25 \pm 0.55 \pm 0.41$	$-2.89 \pm 0.10 \pm 0.18$	>10
$D \to K^{*-}\rho^+[D]$	$10.90 \pm 1.53 \pm 2.36$	$2.41 \pm 0.08 \pm 0.16$	>10
$D \to (K^-\pi^0)_V\rho^+[P]$	$0.36 \pm 0.19 \pm 0.27$	$-0.94 \pm 0.19 \pm 0.28$	5.7
$D \to (K^-\pi^0)_V\rho^+[D]$	$2.13 \pm 0.56 \pm 0.92$	$-1.93 \pm 0.22 \pm 0.25$	>10
$D \to K^{*-}(\pi^+\pi^0)_V[D]$	$1.66 \pm 0.52 \pm 0.61$	$-1.17 \pm 0.20 \pm 0.39$	7.6
$D \to (K^-\pi^0)_V(\pi^+\pi^0)_V[S]$	$5.17 \pm 1.91 \pm 1.82$	$-1.74 \pm 0.20 \pm 0.31$	7.6
$D \to TS$			
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_T$	$0.30 \pm 0.21 \pm 0.30$	$-2.93 \pm 0.31 \pm 0.82$	5.8
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_T$	$0.14 \pm 0.12 \pm 0.10$	$2.23 \pm 0.38 \pm 0.65$	4.0
TOTAL	98.54		

- Measurement the BF

$$Br(D^0 \to K^-\pi^+\pi^0\pi^0) = (8.86 \pm 0.13_{stat.} \pm 0.19_{syst.})\%$$

Improved precision

Amplitude Analysis of $D^+ \to K_S \pi^+ \pi^+ \pi^-$

BESIII

PRD 100, 072008(2019)

$\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

- Measuring *D→AP* decay via this amplitude analysis
- **4559** DT candidate events with a purity of **97.5%**
- Unbinned ML fit

  Likelihood scan to determine the parameters $a_1(1260)^+$, $K(1460)^0$ and ω in the ρ-ω mixing (next page)

- Extracting the BFs by the PDG value

$$Br(D^+ \to K_S \pi^+ \pi^+ \pi^-) = (2.97 \pm 0.11)\%$$

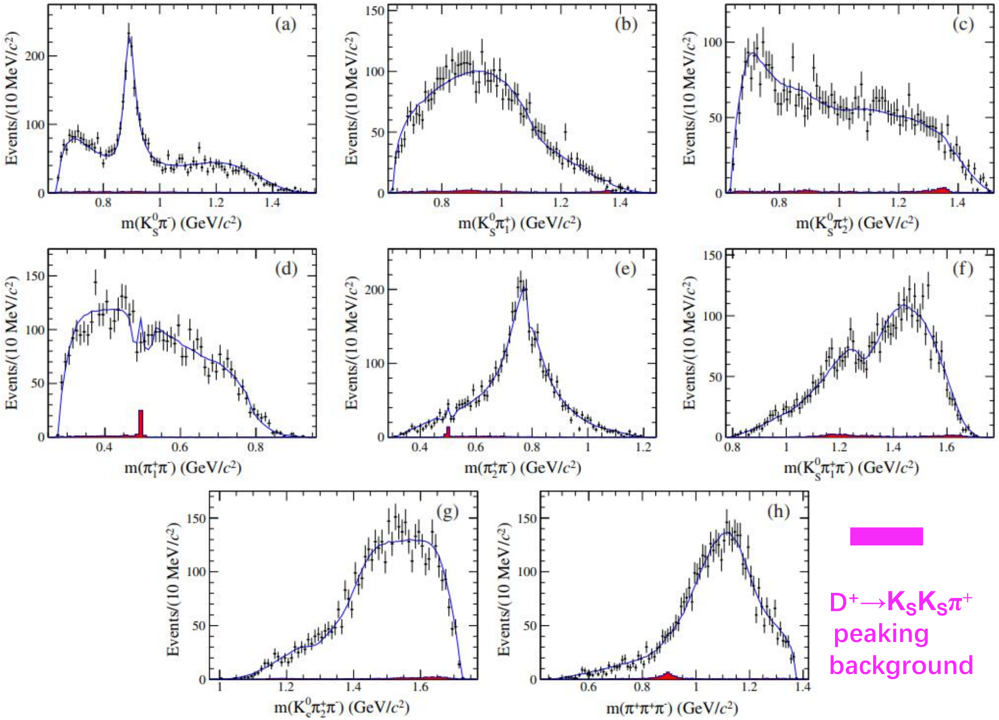
Component	Branching fraction (%)
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+)$	$1.197 \pm 0.062 \pm 0.120 \pm 0.044$
$D^+ \to K^0_S a_1(1260)^+(f_0(500)\pi^+)$	$0.163 \pm 0.021 \pm 0.053 \pm 0.006$
$D^+ \to \bar{K}_1(1400)^0(K^{*-}\pi^+)\pi^+$	$0.642 \pm 0.036 \pm 0.033 \pm 0.024$
$D^+ \to \bar{K}_1(1270)^0(K^0_S\rho^0)\pi^+$	$0.071 \pm 0.009 \pm 0.019 \pm 0.003$
$D^+ \to \bar{K}(1460)^0(K^{*-}\pi^+)\pi^+$	$0.202 \pm 0.018 \pm 0.031 \pm 0.007$
$D^+ \to \bar{K}(1460)^0(K^0_S\rho^0)\pi^+$	$0.024 \pm 0.006 \pm 0.015 \pm 0.009$
$D^+ \to \bar{K}_1(1650)^0(K^{*-}\pi^+)\pi^+$	$0.048 \pm 0.012 \pm 0.042 \pm 0.002$
$D^+ \to K^0_S\pi^+\rho^0$	$0.190 \pm 0.021 \pm 0.103 \pm 0.007$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$	$0.241 \pm 0.018 \pm 0.026 \pm 0.009$

dominant (first row)

Agree with *PRD 45, 2196(1992)* (first row)

Extracting the BFs for the first time (rows 2–4)

- Fit projections



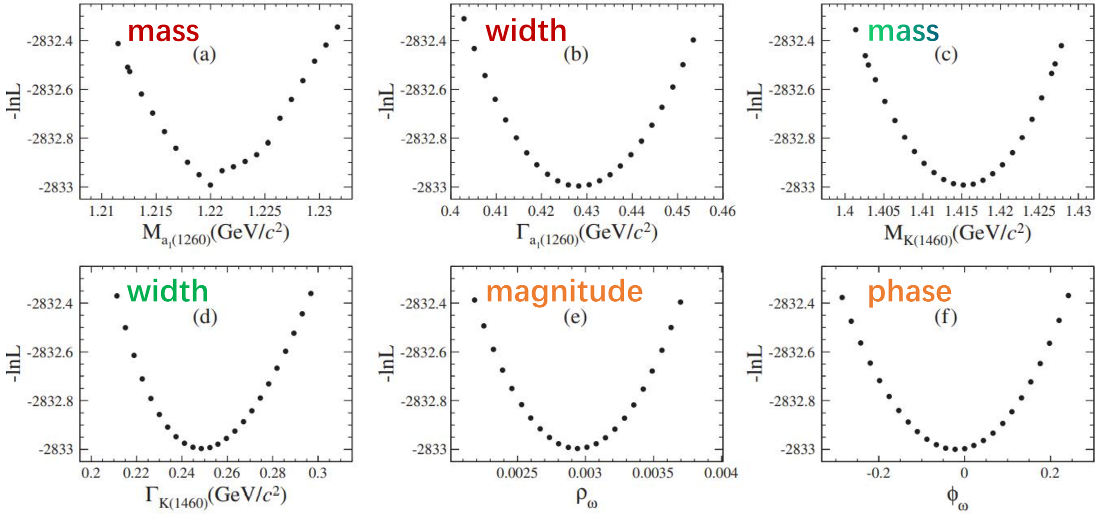
- Consistent with the previous measurements
- Precisions improved!
- ***D→Ka$_1$(1260)*** dominated in ***$D^{0(+)}$*** decays(Comparing the $D^0 \to K^-\pi^+\pi^-\pi^+$, *PRD95 072010(2017),EPJC78,443(2018)*)

  D→K$_1$(1400)π, the related BF in ***D^+*** is found to be **larger** than that in ***D^0*** by 1 order of magnitude.

Amplitude Analysis of $D^+ \to K_S \pi^+ \pi^+ \pi^-$

PRD 100, 072008(2019)

- Likelihood scan to determine the parameters of $a_1(1260)^+$, $K(1460)^0$ and ω in the ρ-ω mixing



$$m_{a_1(1260)^+} = 1220.0^{+9.5}_{-7.6}\ \mathrm{MeV}/c^2,$$
$$\Gamma_{a_1(1260)^+} = 428.2^{+23.0}_{-22.2}\ \mathrm{MeV}/c^2,$$
$$m_{\bar{K}(1460)^0} = 1415.2^{+11.8}_{-12.2}\ \mathrm{MeV}/c^2,$$
$$\Gamma_{\bar{K}(1460)^0} = 248.5^{+40.8}_{-33.4}\ \mathrm{MeV}/c^2,$$
$$\rho_\omega = (2.94 \pm 0.69) \times 10^{-3},$$
$$\phi_\omega = -0.02 \pm 0.23,$$

Amplitude Analysis of $D_s^+ \to K_S^0 K^- \pi^+ \pi^+$

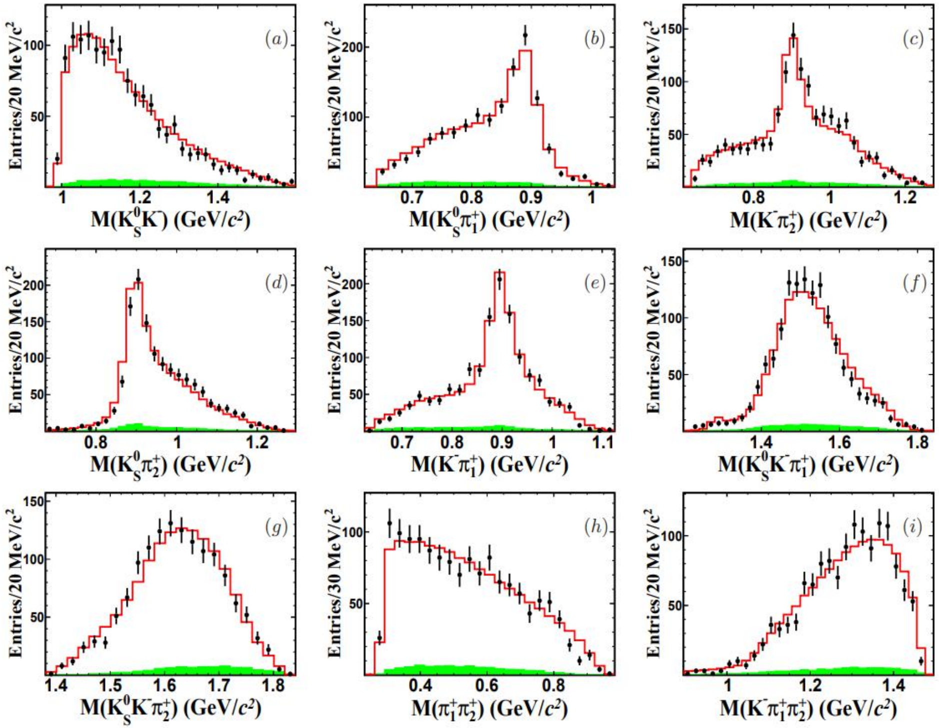
BESIII

PRD 103,092006(2010)

$\mathcal{L}$ = 6.32 fb^{-1} @ $\sqrt{s}$ = 4.178-4.226 GeV

- Measuring $D \to V\, V$ decay via this first amplitude analysis
- 1308 DT candidate events with a purity around 94.9%
- Unbinned ML fit

Fit projections



Combinatorial background

- BF measurements

$$Br(D_s^+ \to K_S^0 K^- \pi^+ \pi^+) = (1..46 \pm 0.05_{stat.} \pm 0.05_{syst.})\%$$

Using $Br(K_s^0 \to \pi^+ \pi^+) = (69.20 \pm 0.05)\%$

- BF for the intermediate processes

$K^*(892)^+ \to K_s^0 \pi^+$
$\overline{K}^*(892)^0 \to K^- \pi^+$
$a_0(980)^- \to K_s^0 K^-$

Dominant

$a_0(980)\pi$
K^*K

$a_0(980)\pi$ only

Process	BF(10^{-3}) This analysis	PDG
$D_s^+[S] \to K^*(892)^+ \overline{K}^*(892)^0$	5.01 ± 0.49 ± 0.78	
$D_s^+[P] \to K^*(892)^+ \overline{K}^*(892)^0$	1.10 ± 0.16 ± 0.10	
$D_s^+[D] \to K^*(892)^+ \overline{K}^*(892)^0$	0.65 ± 0.12 ± 0.10	
$D_s^+ \to K^*(892)^+ \overline{K}^*(892)^0$	5.93 ± 0.47 ± 0.74	7.98 ± 2.88
$D_s^+ \to K^*(892)^+ (K^-\pi^+)_{S-\mathrm{wave}}$	0.73 ± 0.17 ± 0.15	
$D_s^+ \to \overline{K}^*(892)^0 (K_S^0\pi^+)_{S-\mathrm{wave}}$	1.06 ± 0.16 ± 0.13	
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to a_0(980)^-\pi^+$	1.57 ± 0.39 ± 0.76	
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to \overline{K}^*(892)^0 K_S^0$	0.32 ± 0.10 ± 0.10	
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to K^*(892)^+ K^-$	0.32 ± 0.10 ± 0.10	
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to K^*(892) K$	0.72 ± 0.21 ± 0.14	
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to (K_S^0\pi^+)_{S-\mathrm{wave}} K^-$	3.44 ± 0.54 ± 1.10	
$D_s^+ \to f_1(1285)\pi^+, f_1(1285) \to a_0(980)^-\pi^+$	0.33 ± 0.08 ± 0.10	
$D_s^+ \to (K^*(892)^+K^-)_P\pi^+$, $(K^*(892)^+K^-)_P \to K^*(892)^+K^-$	1.58 ± 0.28 ± 0.26	
$D_s^+ \to K_S^0 K^- \pi^+ \pi^+$	14.60 ± 0.46 ± 0.48	16.50 ± 1.00

$$Br(D_s^+ \to K^*(892)^+ \overline{K}^*(892)^0) = (5.34 \pm 0.39_{stat.} \pm 0.64_{syst.})\%$$

Consistent with the current world averages much more precise

Absolute Branching Fractions

Absolute BFs of other D Decays I

BESIII

DT method $\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

SCS Decay of $D\to\omega\pi\pi$ *[PRD102,052003(2020)]*

Decay mode	$N_{SG}^{\omega/\eta}$	$f(\%)$	$N_{SB}^{\omega/\eta}$	N_{peak}^{BKGV}	N_{DT}^{sig}	Sig.	$\mathcal{B}^{int}$	$\mathcal{B}^{sig}(\times10^{-3})$	$\mathcal{B}_{PDG}(\times10^{-3})$
$D^0\to\omega\pi^+\pi^-$	908.0 ± 39.4	74.6 ± 1.5	610.5 ± 35.1	41.4 ± 2.5	411.2 ± 48.3	12.9σ	0.882	$1.33\pm0.16\pm0.12$	1.6 ± 0.5
$D^+\to\omega\pi^+\pi^0$	474.0 ± 42.8	73.3 ± 1.2	329.0 ± 34.3	...	232.9 ± 49.8	7.7σ	0.872	$3.87\pm0.83\pm0.25$	...
$D^0\to\omega\pi^0\pi^0$	20.2 ± 10.5	75.2 ± 5.6	22.1 ± 10.0	19.0 ± 1.2	-15.4 ± 13.0	0.6σ	0.862	<1.10	...
$D^0\to\eta\pi^+\pi^-$	151.3 ± 14.6	42.6 ± 0.9	115.0 ± 15.3	6.1 ± 0.2	96.2 ± 16.0	8.3σ	0.227	$1.06\pm0.18\pm0.07$	1.09 ± 0.16
$D^+\to\eta\pi^+\pi^0$	61.5 ± 14.3	41.4 ± 0.7	47.3 ± 16.4	...	41.9 ± 15.8	3.5σ	0.224	$2.47\pm0.93\pm0.16$	1.38 ± 0.35
$D^0\to\eta\pi^0\pi^0$	5.7 ± 3.8	40.6 ± 3.3	13.1 ± 4.8	2.0 ± 0.1	-1.6 ± 4.3	0.1σ	0.221	<2.38	0.38 ± 0.13

The product of the BFs of the intermediate states ω/η and π^0 in the subsequent decays of the *D* meson

Precision Improved ~ 2.1

Measured for the first time

Consistent with the previous measurements

DT method $\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

SCS Decay of $D\to\eta\eta(\pi)\pi$ *[PRD101,052009(2020)]*

Decay mode	N_{DT}	$\epsilon_{sig}(\%)$	$\mathcal{B}_{sig}$ $(\times10^{-3})$	$\mathcal{B}_{CLEO}$ $(\times10^{-3})$
$D^+\to\eta\eta\pi^+$	179 ± 15	24.96 ± 0.12	$2.96\pm0.24\pm0.10$	N/A
$D^+\to\eta\pi^+\pi^0$	381 ± 26	28.11 ± 0.13	$2.23\pm0.15\pm0.10$	$1.38\pm0.31\pm0.16$
$D^0\to\eta\pi^+\pi^-$	450 ± 25	39.98 ± 0.17	$1.20\pm0.07\pm0.04$	$1.09\pm0.13\pm0.09$

Measured for the first time

Consistent with CLEO's measurements with 2.2σ, 0.6σ

DT method $\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

Inclusive decays $D^{0(+)}\to\phi X$ *[PRD100, 072006(2019)]*

	This work	CLEO [2]	BES [1]
$D^+\to\phi X$	$1.135\pm0.034\pm0.031$	$1.03\pm0.10\pm0.07$	<1.8 (90% C.L.)
$D^0\to\phi X$	$1.091\pm0.027\pm0.035$	$1.05\pm0.08\pm0.07$	$1.71^{+0.76}_{-0.71}\pm0.17$

Consistent with previous measurements, but with much better precision

DT method $\mathcal{L}$ = 2.93 fb^{-1} @ $\sqrt{s}$ = 3.773 GeV

$D^{0(+)}\to K\bar{K}\pi\pi$ *[PRD102, 052006(2020)]*

Signal mode	ΔE_{sig}	N_{DT}^{fit}	$N_{K_S^0}^{sid}$	N_{DT}^{net}	ϵ_{sig} (%)	$\mathcal{B}_{sig}$ $(\times10^{-3})$	$\mathcal{B}_{PDG}$ $(\times10^{-3})$
$D^0\to K^+K^-\pi^0\pi^0$	$(-59,40)$	132.1 ± 13.9	...	132.1 ± 13.9	8.20 ± 0.07	$0.69\pm0.07\pm0.04$	...
$D^0\to K_S^0K_S^0\pi^+\pi^-$	$(-22,22)$	82.1 ± 9.7	37.8 ± 7.5	63.2 ± 10.4	5.14 ± 0.04	$0.53\pm0.09\pm0.03$	1.22 ± 0.23
$D^0\to K_S^0K^-\pi^+\pi^0$	$(-43,32)$	278.8 ± 18.8	166.1 ± 15.1	195.8 ± 20.3	6.38 ± 0.06	$1.32\pm0.14\pm0.07$	...
$D^0\to K_S^0K^+\pi^-\pi^0$	$(-44,33)$	124.0 ± 12.8	$9.5^{+3.7}_{-3.1}$	119.3 ± 12.9	7.94 ± 0.06	$0.65\pm0.07\pm0.02$	...
$D^+\to K^+K^-\pi^+\pi^0$	$(-39,30)$	1311.7 ± 40.4	...	1311.7 ± 40.4	12.72 ± 0.08	$6.62\pm0.20\pm0.25$	26^{+9}_{-8}
$D^+\to K_S^0K^+\pi^0\pi^0$	$(-61,44)$	35.9 ± 7.1	$3.8^{+2.8}_{-2.0}$	34.0 ± 7.2	3.77 ± 0.02	$0.58\pm0.12\pm0.04$	...
$D^+\to K_S^0K^-\pi^+\pi^+$	$(-22,21)$	505.0 ± 24.5	74.2 ± 10.3	467.9 ± 25.0	13.24 ± 0.08	$2.27\pm0.12\pm0.06$	2.38 ± 0.17
$D^+\to K_S^0K^+\pi^+\pi^-$	$(-21,20)$	284.6 ± 18.0	$15.3^{+4.9}_{-4.2}$	277.0 ± 18.2	9.39 ± 0.06	$1.89\pm0.12\pm0.05$	1.74 ± 0.18
$D^+\to K_S^0K_S^0\pi^+\pi^0$	$(-46,37)$	101.1 ± 11.3	42.0 ± 8.1	80.1 ± 12.0	3.84 ± 0.03	$1.34\pm0.20\pm0.06$	...

First direct measurement, > 8σ

First observation! Precision Improved

Absolute BFs of other $D_{(s)}$ Decays II

BESIII

ST method — $\mathcal{L}$ = 6.32 fb^{-1} @ √s = 4.178-4.226 GeV

$D_s \to PP$ [JHEP08,146(2020)]

Decay	n^i	$\bar{\varepsilon}^i$ (%)	R^i (%)	$\mathcal{B}^i$ (10^{-3})
$K^+\eta'$	675 ± 43	13.66 ± 0.20	$4.91 \pm 0.31 \pm 0.31$	$2.68 \pm 0.17 \pm 0.17 \pm 0.08$
$\eta'\pi^+$	9912 ± 113	14.19 ± 0.04	$69.4 \pm 0.8 \pm 3.8$	$37.8 \pm 0.4 \pm 2.1 \pm 1.2$
$K^+\eta$	1841 ± 114	26.21 ± 0.17	$2.97 \pm 0.18 \pm 0.06$	$1.62 \pm 0.10 \pm 0.03 \pm 0.05$
$\eta\pi^+$	19519 ± 192	25.86 ± 0.05	$31.94 \pm 0.33 \pm 0.49$	$17.41 \pm 0.18 \pm 0.27 \pm 0.54$
$K^+K^0_S$	35977 ± 206	31.47 ± 0.05	$27.55 \pm 0.18 \pm 0.50$	$15.02 \pm 0.10 \pm 0.27 \pm 0.47$
$K^0_S\pi^+$	2724 ± 83	32.27 ± 0.16	$2.035 \pm 0.062 \pm 0.042$	$1.109 \pm 0.034 \pm 0.023 \pm 0.035$
$K^+\pi^0$	2275 ± 149	27.96 ± 0.18	$1.373 \pm 0.090 \pm 0.033$	$0.748 \pm 0.049 \pm 0.018 \pm 0.023$
$K^+K^-\pi^+$	160262 ± 478	26.73 ± 0.02	100	54.5 ± 1.7

Consistent with PDG

Improved 3~5 times

Relative BFs	This work %	PDG [6] %
$\mathcal{B}(K^+\eta')/\mathcal{B}(\eta'\pi^+)$	$7.07 \pm 0.46 \pm 0.11$	4.2 ± 1.3
$\mathcal{B}(K^+\eta)/\mathcal{B}(\eta\pi^+)$	$9.31 \pm 0.58 \pm 0.10$	8.9 ± 1.6
$\mathcal{B}(K^0_S\pi^+)/\mathcal{B}(K^+K^0_S)$	$7.38 \pm 0.23 \pm 0.09$	8.12 ± 0.28
$\mathcal{B}(K^+\eta)/\mathcal{B}(K^+\eta')$	$60.6 \pm 5.4 \pm 3.6$	—
$\mathcal{B}(\eta\pi^+)/\mathcal{B}(\eta'\pi^+)$	$46.0 \pm 0.7 \pm 2.1$	—

Consistent with PDG within ~2σ

Improved precision

DT method — $\mathcal{L}$ = 3.19 fb^{-1} @ √s = 4.178 GeV

$D_s^+ \to K_{S/L} K^+$ [PRD99,112005(2019)]

$$\mathcal{B}(D_s^+ \to K_S^0 K^+) = (1.425 \pm 0.038 \pm 0.031)\%,$$
Consistent with PDG value

$$\mathcal{B}(D_s^+ \to K_L^0 K^+) = (1.485 \pm 0.039 \pm 0.046)\%$$
Mesurement first time

K_S^0-K_L^0 asymmetry measured in D_s *first time*

$$R(D_s^+ \to K^0K^+) = \frac{\mathcal{B}(D_s^+\to K_S^0K^+)-\mathcal{B}(D_s^+\to K_L^0K^+)}{\mathcal{B}(D_s^+\to K_S^0K^+)+\mathcal{B}(D_s^+\to K_L^0K^+)} = (-2.1 \pm 1.9 \pm 1.6)\%,$$

Direct *CP* asymmetry

$$A_{cp}(D_s^+ \to K_S^0K^+) = \frac{\mathcal{B}(D_s^+\to K_S^0K^+)-\mathcal{B}(D_s^-\to K_S^0K^-)}{\mathcal{B}(D_s^+\to K_S^0K^+)+\mathcal{B}(D_s^-\to K_S^0K^-)} = (0.6 \pm 2.8 \pm 0.6)\%,$$

$$A_{cp}(D_s^+ \to K_L^0K^+) = \frac{\mathcal{B}(D_s^+\to K_L^0K^+)-\mathcal{B}(D_s^-\to K_L^0K^-)}{\mathcal{B}(D_s^+\to K_L^0K^+)+\mathcal{B}(D_s^-\to K_L^0K^-)} = (-1.1 \pm 2.6 \pm 0.6)\%$$

ST method — $\mathcal{L}$ = 2.93 fb^{-1} @ √s = 3.773 GeV

$D^{0(+)} \to \phi P(P=K^+, \pi^{+(0)}, \eta)$ [PLB798,135017(2019)]

Decay mode	ΔE (GeV)	N^i_{sig}	ε^i (%)	$\mathcal{B}^i$ ($\times 10^{-4}$) (this work)	$\mathcal{B}_{ext}$ ($\times 10^{-4}$) (previsous)
$D^+ \to \phi\pi^+$	[−0.020, 0.019]	17527 ± 152	37.7 ± 0.1	$57.0 \pm 0.5 \pm 1.3$	53.7 ± 2.3 [4]
$D^+ \to \phi K^+$	[−0.019, 0.018]	12^{+28}_{-12}	23.7 ± 0.1	$0.062^{+0.144}_{-0.062} \pm 0.002$ < 0.21 at 90% CL	0.085 ± 0.011 [4,8,9]
$D^0 \to \phi\pi^0$	[−0.077, 0.035]	3333 ± 76	27.7 ± 0.1	$11.68 \pm 0.28 \pm 0.28$	13.2 ± 0.8 [4]
$D^0 \to \phi\eta$	[−0.040, 0.038]	102 ± 26	13.7 ± 0.1	$1.81 \pm 0.46 \pm 0.06$	1.4 ± 0.5 [4]

this work　　previsous

Consistent with the previous measurements with better precision

DT method — $\mathcal{L}$ = 2.93 fb^{-1} @ √s = 3.773 GeV

$D^+ \to K_{S/L} K^+(\pi^0)$ [PRD99,032002(2019)]

Signal mode	$\mathcal{B}(D^+)$ ($\times 10^{-3}$)	$\mathcal{B}(D^-)$ ($\times 10^{-3}$)	$\bar{\mathcal{B}}$ ($\times 10^{-3}$)	$\mathcal{B}$ (PDG) ($\times 10^{-3}$)	A_{CP} (%)
$K_S^0K^\pm$	$2.96 \pm 0.11 \pm 0.08$	$3.07 \pm 0.12 \pm 0.08$	$3.02 \pm 0.09 \pm 0.08$	2.95 ± 0.15	$-1.8 \pm 2.7 \pm 1.6$
$K_S^0K^\pm\pi^0$	$5.14 \pm 0.27 \pm 0.24$	$5.00 \pm 0.26 \pm 0.22$	$5.07 \pm 0.19 \pm 0.23$	⋯	$1.4 \pm 3.7 \pm 2.4$
$K_L^0K^\pm$	$3.07 \pm 0.14 \pm 0.10$	$3.34 \pm 0.15 \pm 0.11$	$3.21 \pm 0.11 \pm 0.11$	⋯	$-4.2 \pm 3.2 \pm 1.2$
$K_L^0K^\pm\pi^0$	$5.21 \pm 0.30 \pm 0.22$	$5.27 \pm 0.30 \pm 0.22$	$5.24 \pm 0.22 \pm 0.22$	⋯	$-0.6 \pm 4.1 \pm 1.7$

Consistent with the PDG value

Measured for the first time

For CPV, do not find a significant deviation from zero

List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^{\pm}$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

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