

Hadronic Decays of Charmed Hadrons at BESIII

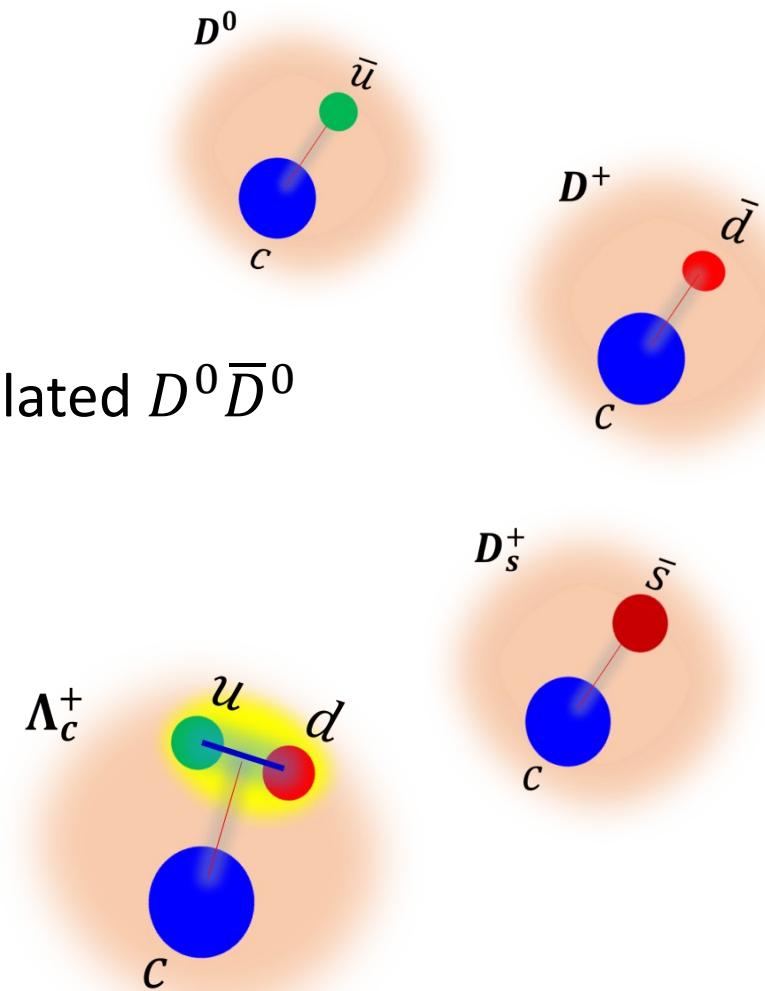
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on behalf of the BESIII Collaboration

第五届重味物理与量子色动力学研讨会

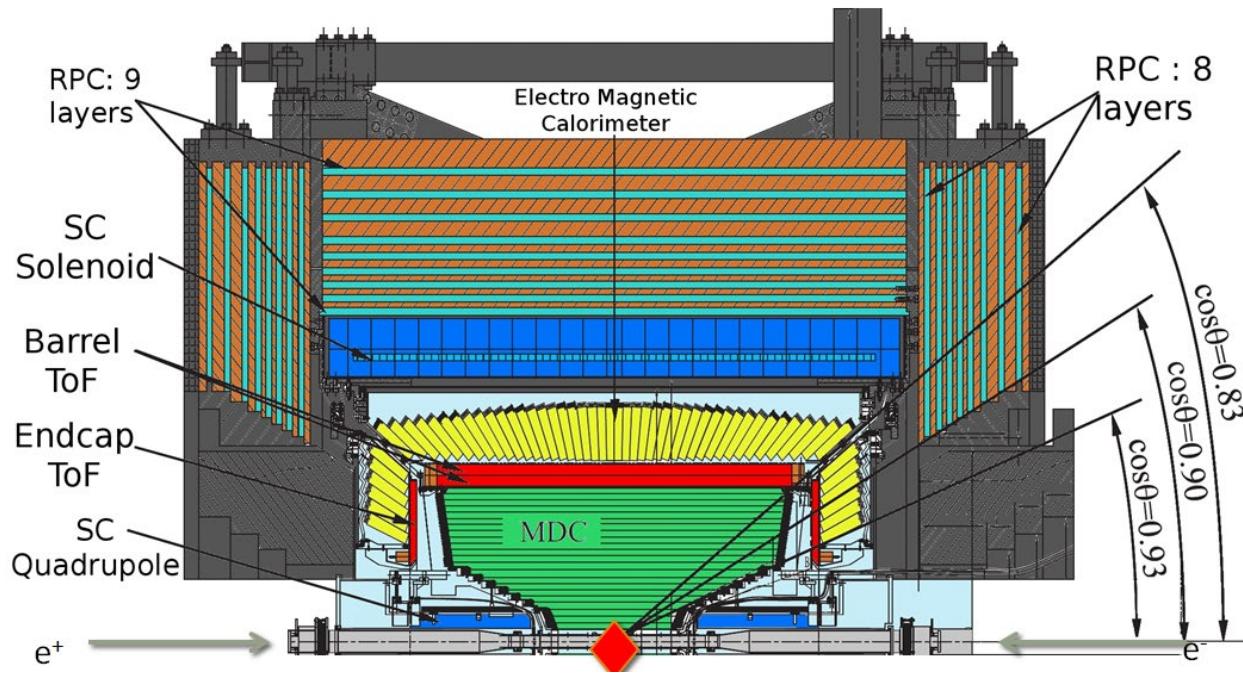
Outline

- BESIII detector and data
- Measurements with Quantum Correlated $D^0\bar{D}^0$
- Branching Fraction Measurements
- Amplitude Analyses
- Summary and Prospect



[Natl.Sci.Rev. 8 \(2021\) 11, nwab181](#)

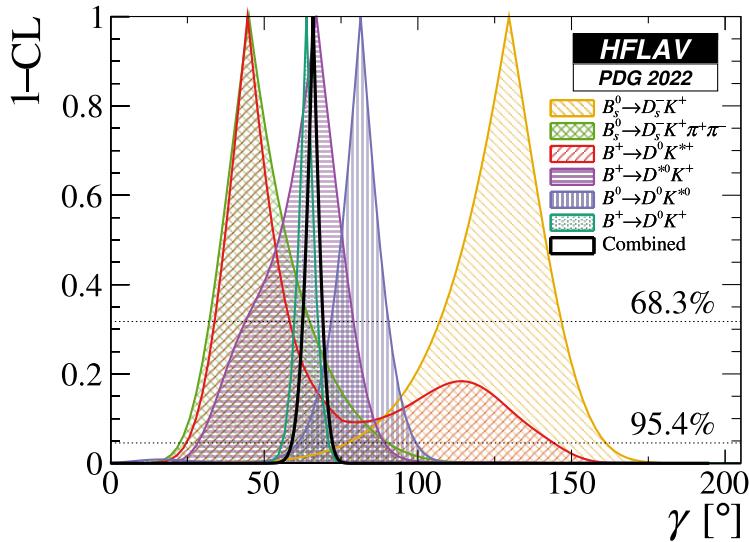
BESIII detector and Data Sample



\sqrt{s} (GeV)	Year	Luminosity (fb^{-1})	D^0 Yields	D^+ Yields	D_s^+ Yields	Λ_c^+ Yields
3.773	2010 – 2011(+2023)	$2.93 \rightarrow 8$	2.5M(2.7×)	1.7M(2.7×)		
4.009	2011	0.5			13 K	
4.18 – 4.23	2016, 2017, 2014, 2019	7.3			1.5M	
4.6(4.61 – 4.7)	2014(+2020)	$0.6 \rightarrow 4.5$				15 K(8×)

CKM Angle γ Measurement

- CKM unitary angle γ is important for the study of **CPV** and new physics



- CKMFitter: $(65.5^{+1.1}_{-2.7})^\circ$
- Direct measurement: $(65.9^{+3.3}_{-3.5})^\circ$
 - theoretical uncertainty free
 - statistical dominant

- Input from D meson decay is crucial for γ measurement

- GLW: $D \rightarrow (\text{quasi-})\text{CP} \Leftarrow F_+$ [PLB 265 \(1991\) 172-176](#)

$$\Gamma(B^\pm \rightarrow DK^\pm) \propto 1 + r_B^2 + 2(2F_+ - 1)\cos(\delta_B \pm \gamma)$$

- ADS: $D \rightarrow CF/DCS \Leftarrow R_D, r_D, \delta_D^f$ [PRD 63 \(2001\) 036005](#)

$$\Gamma(B^0 \rightarrow DK) \propto r_D^2 + r_B^{DK} + 2R_D r_D r_B^{DK} \cos(\delta_B^{DK} + \delta_D + \gamma)$$

- $CF/DCS: K\pi\pi^0, K\pi\pi\pi$

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

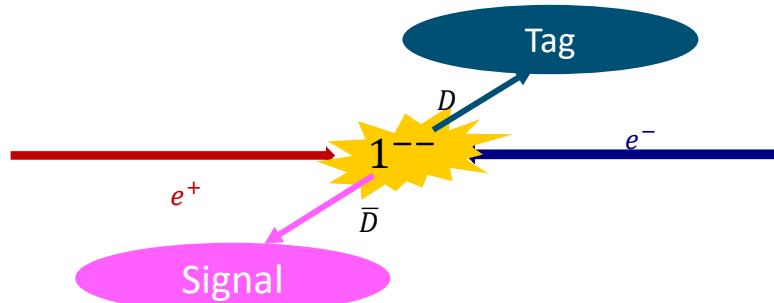
- BPGGSZ: $D \rightarrow K_{S,L}^0 h^+ h^- \Leftarrow c_i, s_i$ [arXiv:2006.12404](#)

$$N_{\pm i}^{\exp} (B^- \rightarrow K^- D_{K_{S,L}^0 \pi^- \pi^+})$$

$$= h_B^- \left[K_{\pm i} + r_B^2 K_{\mp i} + 2r_B \sqrt{K_i K_{-i}} \times [c_i \cos(\delta_B - \gamma) \pm s_i \sin(\delta_B - \gamma)] \right]$$

Measurements with Quantum-correlated $D^0\bar{D}^0$

- Quantum correlated $D^0\bar{D}^0$ recorded by sample at BESIII at $\psi(3770)$ resonance



$$|\psi(3770)\rangle \rightarrow \frac{1}{\sqrt{2}}(|D^0\rangle|\bar{D}^0\rangle - |\bar{D}^0\rangle|D^0\rangle)$$

- Double tag yields

$$N(S | T) \propto A_S^2 A_T^2 [(r_D^S)^2 + (r_D^T)^2 - 2 R_S R_T r_D^S r_D^T \cos(\delta_D^T - \delta_D^S)]$$

- Typical tag modes

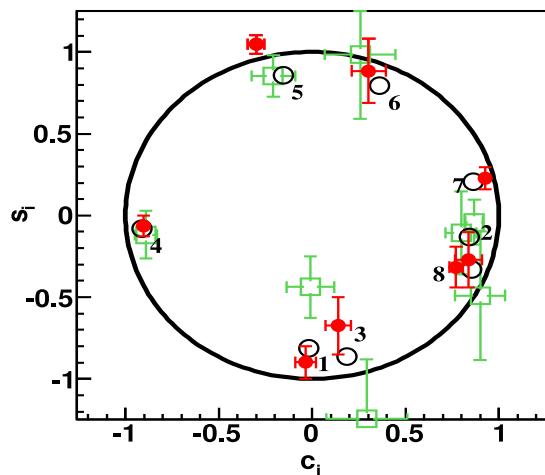
Flavor	$K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^-\pi^+, K^+e^-\bar{\nu}_e$
CP even	$K^+K^-, \pi^+\pi^-, K_S^0\pi^0\pi^0, K_L^0\pi^0, \pi^+\pi^-\pi^0$
CP odd	$K_S^0\pi^0, K_S^0\eta, K_S^0\omega, K_S^0\eta', K_L^0\pi^0\pi^0$
Mixed CP	$K_{S,L}^0\pi^+\pi^-$

Strong Phase Difference Parameter of $K_{S,L}^0 \pi^+ \pi^-$

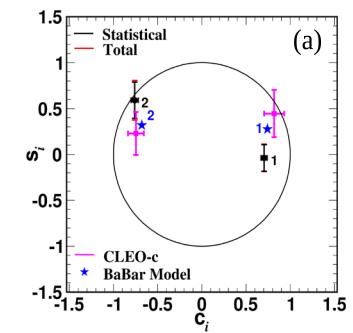
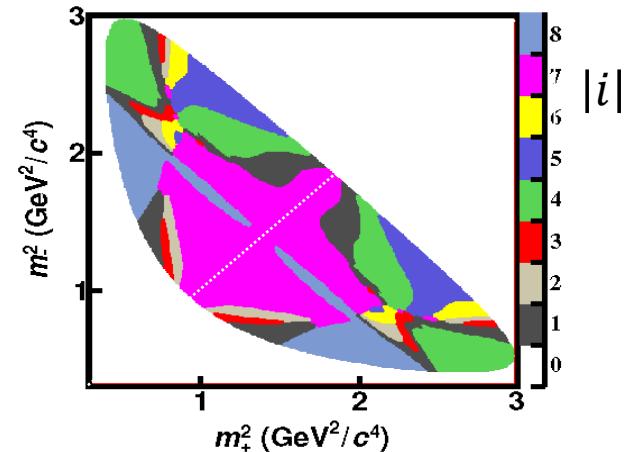
- The c_i and s_i are determined with DT yields in difference phase space interval

$$\cdot c_i = \frac{1}{\sqrt{K_i K_{-i}}} \int_i |A_f| |\bar{A}_f| \cos[\delta_D] dm_+^2 dm_-^2 \xrightarrow{\cos \rightarrow \sin} s_i$$

$$\cdot M'_{ij} = h'_{\text{corr}} \left[K_i K'_{-j} + K_{-i} K'_j + 2 \sqrt{K_i K'_{-j} K_{-i} K'_j} (\color{red}c_i c'_j + s_i s'_j) \right]$$



- BESIII [PRD 101, 112002 \(2020\)](#)
- CLEO-C [PRD 82, 112006 \(2010\)](#)
- Prediction based on model [PRD 98.112012\(2018\)](#)



$K_S^0 K^+ K^-$

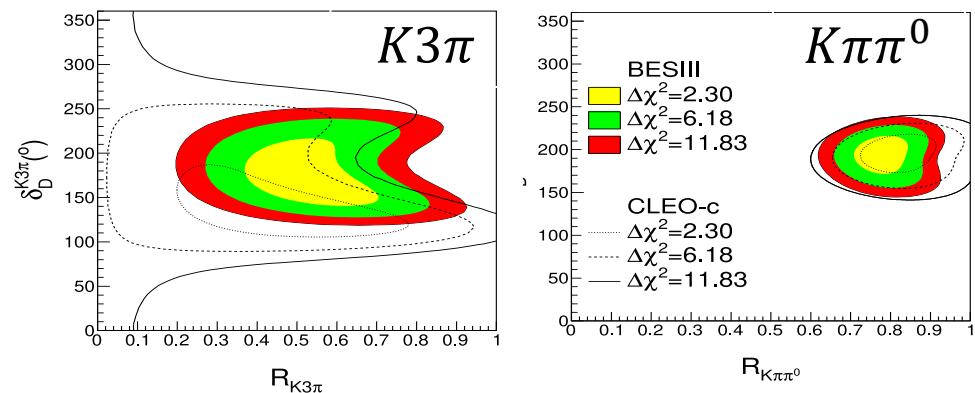
- Associated uncertainty on the γ measurement: $\sim 1^\circ$
- Significant improvement on $D^0 - \bar{D}^0$ mixing parameters

δ_D and R_D of $K^-\pi^+$, $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^-\pi^+$

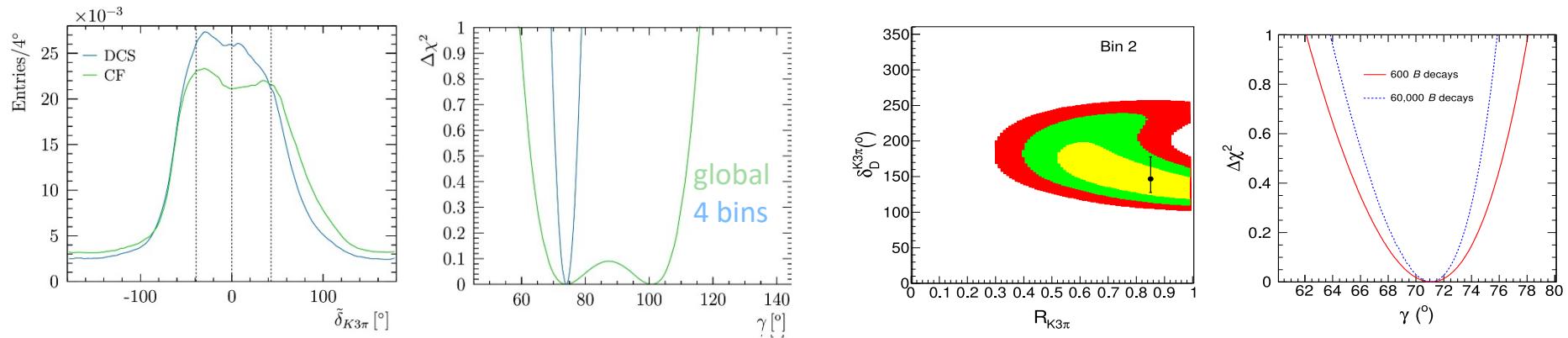
- Global hadronic parameters

Decay	δ_D^f ($^\circ$)	R_f
$K^-\pi^+$	$187.6^{+8.9+5.4}_{-9.7-6.4}$	-
$K^-\pi^+\pi^0$	196^{+14}_{-15}	0.78 ± 0.04
$K^-\pi^+\pi^-\pi^+$	167^{+31}_{-19}	$0.52^{+0.12}_{-0.10}$

JHEP 05 (2021) 164, EPJC 82, 1009 (2022)



- Hadronic parameters measurement in four bins for the $K^-\pi^+\pi^-\pi^+$



Higher sensitivity and breaking degeneracies

Uncertainty on γ measurement: $\sim 6^\circ$

CP Even Fraction F_+ of the Quasi- CP States

➤ $D \rightarrow \pi^+ \pi^- \pi^+ \pi^-$

[PRD 106, 092004 \(2022\)](#)

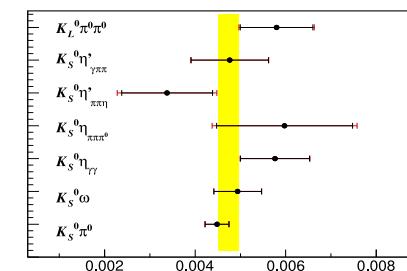
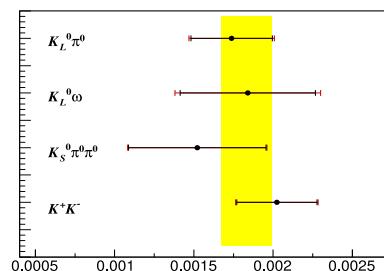
Tag mode $F_+^{4\pi}$

CP eigenstates $0.721 \pm 0.019 \pm 0.007$

$D \rightarrow \pi^+ \pi^- \pi^0$ $0.753 \pm 0.028 \pm 0.010$

$D \rightarrow K_{S,L}^0 \pi^+ \pi^-$ $0.754 \pm 0.031 \pm 0.009$

Combination $0.735 \pm 0.015 \pm 0.005$



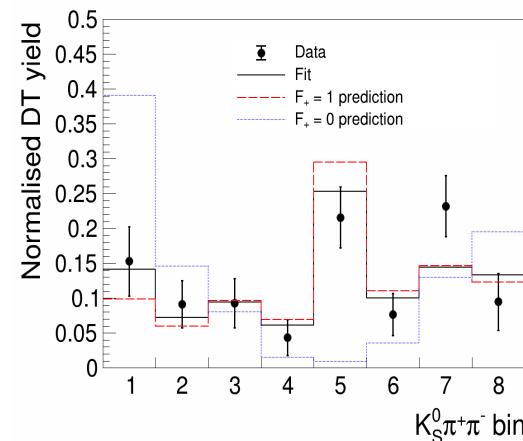
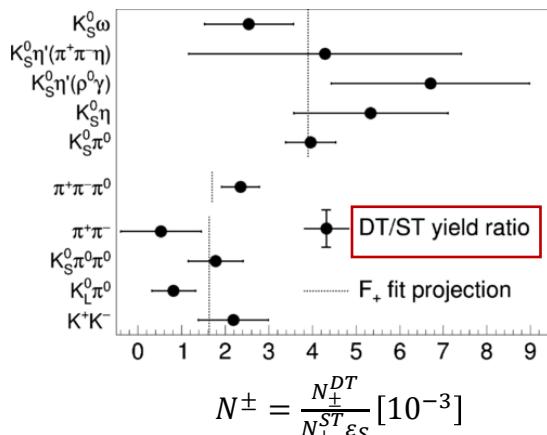
$$N^+ = \frac{N_+^{DT}}{N_+^{ST}}$$

$$N^- = \frac{N_-^{DT}}{N_-^{ST}}$$

$$F_+ = \frac{N^+}{N^+ + N^-}$$

Improved by a factor of 1.8, compared with CLEO-c result

➤ $D \rightarrow K^+ K^- \pi^+ \pi^-$ [PRD 107.032009](#)



- $F_+^{KK\pi\pi} = 0.730 \pm 0.037 \pm 0.021$
- First measurement
- Consistent with model prediction

Branching Fraction Measurements

➤ Motivations

- Input for the measurement of bottom hadron
- Calibration for non-perturbative QCD
- CP violation study, e.g. $A_{CP} = \frac{\Gamma(D \rightarrow f) - \Gamma(\bar{D} \rightarrow \bar{f})}{\Gamma(D \rightarrow f) + \Gamma(\bar{D} \rightarrow \bar{f})}$
- SU(3) breaking, e.g. $K_S^0 - K_L^0$ asymmetry

➤ Double tag method for the absolute branching fraction measurement

- $\mathcal{B} = \frac{N^{DT}}{N^{ST}\varepsilon^{sig}}$
- Quantum correlation effect need to be corrected for $D^0\bar{D}^0$

Branching Fraction: Kaonic

► $D^{0/+} \rightarrow K n \pi$ [PRD 106, 032002 \(2022\)](#)

Decay mode	$\mathcal{B}(10^{-3})$
$D^0 \rightarrow K_S^0 \pi^0 \pi^0 \pi^0$	$7.64 \pm 0.30 \pm 0.29$
$D^0 \rightarrow K^- \pi^+ \pi^0 \pi^0 \pi^0$	$9.54 \pm 0.30 \pm 0.31$
$D^0 \rightarrow K_S^0 \pi^+ \pi^- \pi^0 \pi^0$	$12.66 \pm 0.45 \pm 0.43$
$D^+ \rightarrow K_S^0 \pi^+ \pi^0 \pi^0$	$29.04 \pm 0.62 \pm 0.87$
$D^+ \rightarrow K_S^0 \pi^+ \pi^+ \pi^- \pi^0$	$15.28 \pm 0.57 \pm 0.60$
$D^+ \rightarrow K_S^0 \pi^+ \pi^0 \pi^0 \pi^0$	$5.54 \pm 0.44 \pm 0.32$
$D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0 \pi^0$	$4.95 \pm 0.26 \pm 0.19$

► $D^{0/+} \rightarrow K \pi \omega$ [PRD 105, 032009 \(2022\)](#)

	Measured	predicted
$\mathcal{B}(D^0 \rightarrow K^- \pi^+ \omega) (\%)$	$3.392 \pm 0.044 \pm 0.085$	Improved by a factor 7
$\mathcal{B}(D^0 \rightarrow K_S^0 \pi^0 \omega) (\%)$	$0.848 \pm 0.046 \pm 0.031$	
$\mathcal{B}(D^+ \rightarrow K_S^0 \pi^+ \omega) (\%)$	$0.707 \pm 0.041 \pm 0.029$	
$\frac{\mathcal{B}(D^0 \rightarrow K_S^0 \pi^0 \omega)}{\mathcal{B}(D^0 \rightarrow K^- \pi^+ \omega)}$	$0.23 \pm 0.01 \pm 0.01$	0.4
$\frac{\mathcal{B}(D^+ \rightarrow K_S^0 \pi^+ \omega)}{\mathcal{B}(D^0 \rightarrow K^- \pi^+ \omega)}$	$0.21 \pm 0.01 \pm 0.01$	0.9

► $D^0 \rightarrow K_L^0 X$ [PRD 105, 092010 \(2022\)](#)

Decay	$\mathcal{B}_{\text{exp}}(\%)$	$\mathcal{R}(D^0)$
$D^0 \rightarrow K_L^0 \phi$	$0.414 \pm 0.021 \pm 0.010$	-0.001 ± 0.047
$D^0 \rightarrow K_L^0 \eta$	$0.433 \pm 0.012 \pm 0.010$	0.080 ± 0.022
$D^0 \rightarrow K_L^0 \omega$	$1.164 \pm 0.022 \pm 0.028$	-0.024 ± 0.031
$D^0 \rightarrow K_L^0 \eta'$	$0.809 \pm 0.020 \pm 0.016$	0.080 ± 0.023

- Asymmetry between $\mathcal{B}(D^0 \rightarrow K_S^0 X)$ and $\mathcal{B}(D^0 \rightarrow K_L^0 X)$
 - $\mathcal{R}(D^0, X) = \frac{\mathcal{B}(D^0 \rightarrow K_S^0 X) - \mathcal{B}(D^0 \rightarrow K_L^0 X)}{\mathcal{B}(D^0 \rightarrow K_S^0 X) + \mathcal{B}(D^0 \rightarrow K_L^0 X)}$
- Indications $K_L^0 - K_S^0$ asymmetry(\mathcal{R}) for $K_L^0 \eta$ and $K_L^0 \eta'$

- Based on statistical isospin model [Nucl.Phys.B 122 \(1977\) 144-169](#)
- Large deviation from measured value
- Potential final-state interaction

Branching Fraction: Pionic

➤ D^0 decay with multiple pions(CS) [PRD 106, 092005 \(2022\)](#)

- First absolute measurement of 20 decay modes

Decay	$\mathcal{B}_{\text{sig}} (\times 10^{-4})$
$D^0 \rightarrow \pi^+ \pi^- \pi^0$	$134.3 \pm 13 \pm 16$
$D^0 \rightarrow \pi^+ \pi^- 2\pi^0$	$100.2 \pm 19 \pm 24$
$D^0 \rightarrow \pi^+ \pi^- 2\eta$	$8.5 \pm 13 \pm 04$
$D^0 \rightarrow 4\pi^0$	$7.6 \pm 09 \pm 07$
$D^0 \rightarrow 3\pi^0 \eta$	$23.6 \pm 22 \pm 17$
$D^0 \rightarrow 2\pi^+ 2\pi^- \pi^0$	$34.6 \pm 15 \pm 15$
$D^0 \rightarrow 2\pi^+ 2\pi^- \eta$	$6.0 \pm 10 \pm 06$
$D^0 \rightarrow \pi^+ \pi^- 3\pi^0$	$15.3 \pm 17 \pm 13$
$D^0 \rightarrow 2\pi^+ 2\pi^- 2\pi^0$	$47.7 \pm 31 \pm 21$
$D^+ \rightarrow 2\pi^+ \pi^-$	$32.7 \pm 07 \pm 05$
$D^+ \rightarrow \pi^+ 2\pi^0$	$46.1 \pm 12 \pm 09$
$D^+ \rightarrow 2\pi^+ \pi^- \pi^0$	$116.5 \pm 21 \pm 21$
$D^+ \rightarrow \pi^+ 3\pi^0$	$41.7 \pm 22 \pm 13$
$D^+ \rightarrow 3\pi^+ 2\pi^-$	$18.2 \pm 11 \pm 10$
$D^+ \rightarrow 2\pi^+ \pi^- 2\pi^0$	$107.4 \pm 40 \pm 30$
$D^+ \rightarrow 2\pi^+ \pi^- - \pi^0 \eta$	$38.8 \pm 32 \pm 12$
$D^+ \rightarrow \pi^+ 4\pi^0$	$19.5 \pm 36 \pm 23$
$D^+ \rightarrow \pi^+ 3\pi^0 \eta$	$28.9 \pm 40 \pm 22$
$D^+ \rightarrow 3\pi^+ 2\pi^- \pi^0$	$23.4 \pm 22 \pm 15$
$D^+ \rightarrow 2\pi^+ \pi^- 3\pi^0$	$34.2 \pm 31 \pm 16$

- $\mathcal{A}_{CP} = \frac{\mathcal{B}^+ - \mathcal{B}^-}{\mathcal{B}^+ + \mathcal{B}^-}$ are measured

- \mathcal{B}^\pm : branching fraction of $D \rightarrow f$ and $\bar{D} \rightarrow \bar{f}$
- No significant CP violation is observed

Decay	$B^+ (\times 10^{-4})$	$B^- (\times 10^{-4})$	$A_{CP} (\%)$
$\pi^+ \pi^- \pi^0$	134.8 ± 1.8	133.3 ± 1.8	$+0.6 \pm 0.9 \pm 0.4$
$\pi^+ \pi^- 2\pi^0$	97.6 ± 2.6	102.7 ± 2.7	$-2.5 \pm 1.9 \pm 0.7$
$2\pi^+ \pi^-$	33.1 ± 1.0	32.3 ± 1.0	$+1.2 \pm 2.2 \pm 0.6$
$\pi^+ 2\pi^0$	48.3 ± 1.8	43.2 ± 1.7	$+5.6 \pm 2.7 \pm 0.5$
$2\pi^+ \pi^- \pi^0$	116.7 ± 3.0	116.0 ± 3.0	$+0.3 \pm 1.8 \pm 0.8$
$2\pi^+ \pi^- 2\pi^0$	102.7 ± 5.6	111.6 ± 5.8	$-4.2 \pm 3.8 \pm 1.3$

Branching Fraction: VV

➤ $D^0 \rightarrow \phi\omega$ [PRL 128, 011803 \(2022\)](#)

- $\mathcal{B} = (6.48 \pm 0.96 \pm 0.40) \times 10^{-4}$

- First observation with significance of 6.2σ

Prediction	Mode
6.6×10^{-4}	Factorization model [PRD 81.114020(2010)]
3.5×10^{-5}	SU(3) symmetry with nonet symmetry [PRD 43, 843 (1991)]
$(1.41 \pm 0.09) \times 10^3$	Factorization-assisted topological-amplitude method [CPC 42, 063101 (2018)]
0.028 ± 0.004	Heavy quark effective Lagrangian and chiral perturbation theory [PRD 56.7207 (1997)]

- Polarization measurements

- $\frac{1}{\Gamma} \frac{d\Gamma}{dcos\theta_{\omega/K}} = \frac{3}{2} \left\{ \frac{1}{2} (1 - f_L) \sin^2 \theta_{\omega/K} + f_L \cos^2 \theta_{\omega/K} \right\}$

- Transverse polarized

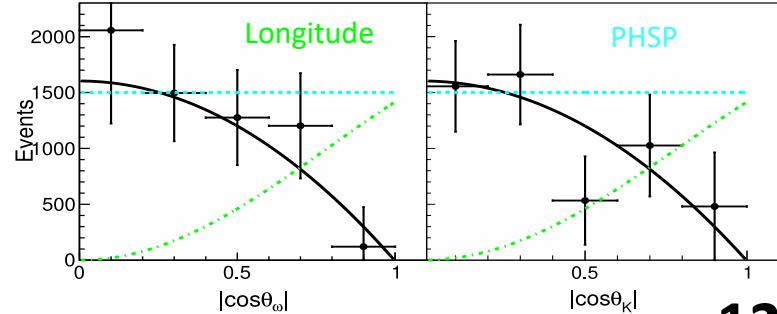
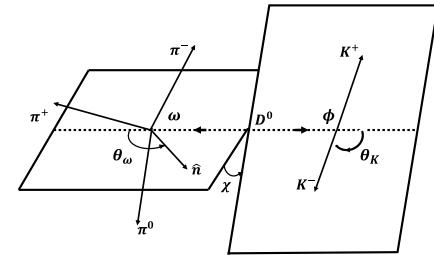
- $f_L < 0.24$ @ 95% CL

- Contradicts to the naive factorization and Lorentz invariant-based symmetry models

- [PRD 81, 114020 \(2010\)](#), [JHEP 03\(2014\)042](#)

- Consistent with explanation of FSI

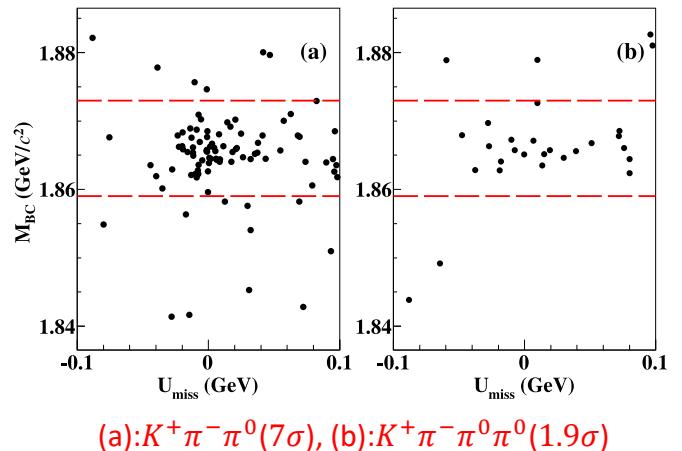
- [arXiv:2303.00535v2](#)



Branching Fraction: Doubly Cabibbo-suppressed(DCS) Decay

➤ $D^0 \rightarrow K^+ \pi^- \pi^0 (\pi^0)$ [PRD 105, 112001 \(2022\)](#)

- Previous results are from the $D^0 - \bar{D}^0$ mixing or coherent factor measurement
- $\mathcal{B}(K^+ \pi^- \pi^0) = [3.13^{+0.60}_{-0.56}(\text{stat}) \pm 0.15(\text{syst})] \times 10^{-4}$
- $\mathcal{B}(K^+ \pi^- \pi^0 \pi^0) < 3.6 \times 10^{-4}$ @ 90% CL.
 - $[1.84^{+1.19}_{-1.00}(\text{stat})] \times 10^{-4}$



➤ $D^+ \rightarrow K^+ \pi^0 \pi^0$ and $K^+ \pi^0 \eta$ [JHEP09\(2022\)107](#)

Decay mode	\mathcal{B}_{sig} ($\times 10^{-4}$)	Significance
$D^+ \rightarrow K^+ \pi^0 \pi^0$	$2.1 \pm 0.4 \pm 0.1$	8.8σ
$D^+ \rightarrow K^+ \pi^0 \eta$	$2.1 \pm 0.5 \pm 0.1$	5.5σ
$D^+ \rightarrow K^{*+} \pi^0$	$3.4^{+1.4}_{-1.3} \pm 0.1$	3.2σ
$D^+ \rightarrow K^{*+} \eta$	$4.4^{+1.8}_{-1.5} \pm 0.2$	2.7σ

Ignoring interference between the K^* and $K^+ \pi^0$

Decays	Measured($\tan^4 \theta_C$)	Predicted($\tan^4 \theta_C$)
$\frac{\mathcal{B}(D^+ \rightarrow K^+ \pi^0 \pi^0)}{\mathcal{B}(D^+ \rightarrow K^- \pi^+ \pi^+)}$	0.77 ± 0.14	$2/3$
$\frac{\mathcal{B}(D^+ \rightarrow K^+ \pi^0 \eta)}{\mathcal{B}(D^+ \rightarrow \bar{K}^0 \pi^+ \eta)}$	2.64 ± 0.68	1

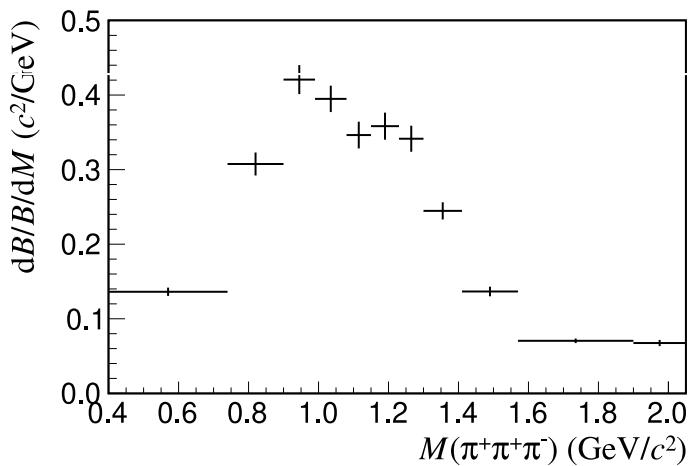
- θ_C : Cabibbo mixing angle
- $\frac{\mathcal{B}(D^+ \rightarrow K^+ \pi^0 \eta)}{\mathcal{B}(D^+ \rightarrow \bar{K}^0 \pi^+ \eta)}$ inconsistent with prediction based on isospins symmetry by 2.4σ [Nucl.Phys.B 122 \(1977\) 144-169](#)

First observation

Inclusive Decays of D

Decay Mode	\mathcal{B} (inclusive)	\mathcal{B}_{sum} (exclusive)	Difference
$D^0 \rightarrow K_S^0 X$ [arXiv:2302.14488]	$(32.78 \pm 0.13 \pm 0.27)\%$	$(31.68 \pm 0.32)\%$	$(1.10 \pm 0.41)\%$
$D^+ \rightarrow K_S^0 X$ [arXiv:2302.14488]	$(20.54 \pm 0.12 \pm 0.18)\%$	$(18.16 \pm 0.72)\%$	$(2.38 \pm 0.75)\%$
$D^0 \rightarrow \pi^+\pi^+\pi^- X$ [PRD107,032002(2023)]	$(17.60 \pm 0.11 \pm 0.22)\%$	$(16.05 \pm 0.47)\%$	$(1.55 \pm 0.53)\%$
$D^+ \rightarrow \pi^+\pi^+\pi^- X$ [PRD107,032002(2023)]	$(15.25 \pm 0.09 \pm 0.18)\%$	$(14.74 \pm 0.53)\%$	$(0.51 \pm 0.53)\%$
$D_s^+ \rightarrow \pi^+\pi^+\pi^- X$ [arXiv:2212.13072]	$(32.81 \pm 0.35 \pm 0.82)\%$	$(24.7 \pm 1.5)\%$	$(8.11 \pm 1.74)\%$

- Results from Inclusive measurements are larger
- Indications of unobserved decay modes
- $D_s^+ \rightarrow \pi^+\pi^+\pi^- X$
 - The partial \mathcal{B} as a function of $M(\pi^+\pi^-\pi^0)$ are measured to help study background $B^0 \rightarrow D^*D_s^+ (\rightarrow \pi^+\pi^+\pi^- X)$ for $B^0 \rightarrow D^*\tau^+ (\rightarrow \pi^+\pi^-\pi^+)$



Excited Charmed Meson Decays

➤ $D^{*0} \rightarrow D^0 e^+ e^-$ [PRD 104, 112012 \(2021\)](#)

- Observed for the first time with significance of 13.2σ
- $\frac{\mathcal{B}(D^{*0} \rightarrow D^0 e^+ e^-)}{\mathcal{B}(D^{*0} \rightarrow D^0 \gamma)} = (11.08 \pm 0.76 \pm 0.49) \times 10^{-3}$
 - Deviated from VMD model prediction of 6.7×10^{-3} by 4.8σ
- $\mathcal{B}(D^{*0} \rightarrow D^0 e^+ e^-) = (3.91 \pm 0.27 \pm 0.17 \pm 0.10) \times 10^{-3}$

➤ $D_s^{*+} \rightarrow D_s^+ \gamma$ and $D_s^{*+} \rightarrow D_s^+ \pi^0$ [PRD 107, 032011 \(2023\)](#)

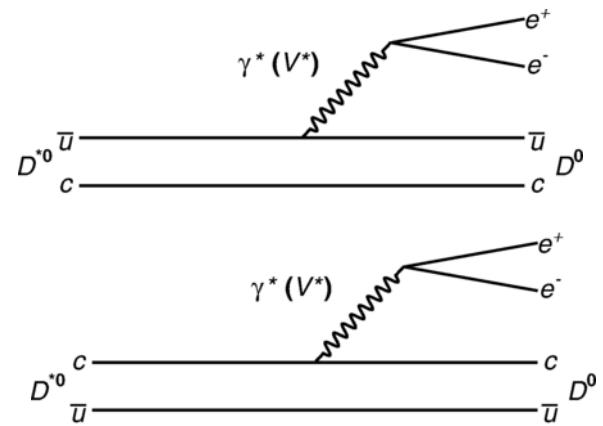
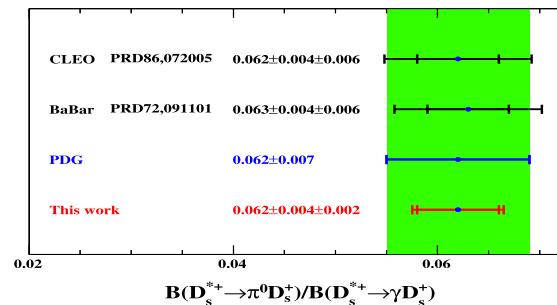


TABLE IV. Comparisons of the partial widths (Γ) and BFs (in brackets). The decay widths are in units of keV. The first two rows are from this work and the Particle Data Group, while the others are from various theoretical predictions. The superscript ^a denotes the value corresponding to $g = 0.52$, $\beta = 2.6 \text{ GeV}^{-1}$, and $m_c = 1.6 \text{ GeV}$; ^b denotes the values for a linear model; ^c denotes the value for $\kappa^q = 0.55$; and ^d denotes the values for (a) model.

	$\Gamma[\mathcal{B}]_{D_s^* \rightarrow D_s^+ \gamma}$	$\Gamma[\mathcal{B}]_{D_s^* \rightarrow D_s^+ \pi^0}$	$\mathcal{B}_{D_s^{*+} \rightarrow D_s^+ \pi^0} / \mathcal{B}_{D_s^{*+} \rightarrow D_s^+ \gamma}$
This work	$\dots [(93.57 \pm 0.38 \pm 0.22)\%]$	$\dots [(5.76 \pm 0.38 \pm 0.16)\%]$	$(6.16 \pm 0.43 \pm 0.18)\%$
PDG [17]	$\dots [(94.2 \pm 0.7)\%]$	$\dots [(5.9 \pm 0.7)\%]$	$(6.2 \pm 0.8)\%$
CM [14]	$3.53 \text{ [(92.7 \pm 0.7)\%]}$	$0.277_{-0.026}^{+0.028} \text{ [(7.3 \pm 0.7)\%]}$	$(7.9 \pm 0.8)\%$
χPT [2] ^a	4.5	\dots	\dots
χPT [3]	\dots	\dots	$8 \times 10^{-5} / \mathcal{B}(D^{*+} \rightarrow D^+ \gamma)$
χPT [4]	0.32 ± 0.30	\dots	
χPT [5]	\dots	$0.0081_{-0.0026}^{+0.0030}$	
LFQM [6] ^b	0.18 ± 0.01	\dots	
RQM [7] ^c	$0.321_{-0.008}^{+0.009}$	\dots	
QCDSR [8]	0.25 ± 0.08	\dots	
QCDSR [9]	0.59 ± 0.15	\dots	
NJLM [10]	0.09	\dots	
LQCD [11]	0.066 ± 0.026	\dots	
NRQM [12]	0.21	\dots	
NRQM [13] ^d	0.40	\dots	



The most precise measurement

Λ_c Decays

► $\Lambda_c^+ \rightarrow \Lambda K^+$ [PRD 106, L111101 \(2022\)](#)

- $\frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda K^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda \pi^+)} = (4.78 \pm 0.34 \pm 0.20)\%$
 - Significant difference from pure factorization approximation of $(7.34 \pm 0.14)\%$ [arXiv:2208.00557v1](#)
- $\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda K^+) = (0.621 \pm 0.044 \pm 0.026 \pm 0.034) \times 10^{-3}$
 - Consistent with prediction of Ref. [17]

► $\Lambda_c^+ \rightarrow \Sigma^0 K^+$ and $\Sigma^+ K_S^0$ [PRD 106, 052003 \(2022\)](#)

- $\frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 K^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 \pi^+)} = 0.0361 \pm 0.0073(\text{stat.}) \pm 0.0005(\text{syst.})$
- $\frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K_S^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \pi^+ \pi^+)} = 0.0106 \pm 0.0031(\text{stat.}) \pm 0.0004(\text{syst.})$
- $\frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 K^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K_S^0)} = 0.98 \pm 0.35(\text{stat.}) \pm 0.04(\text{syst.}) \pm 0.08(\text{ref.})$

Theoretical model	$\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda K^+) \times 10^{-3}$
SU(3) flavor symmetry [8]	1.4
Constituent quark model [14]	1.2
Current algebra [15]	1.06
Diquark picture [16]	0.18–0.39
SU(3) flavor symmetry [17]	0.46 ± 0.09

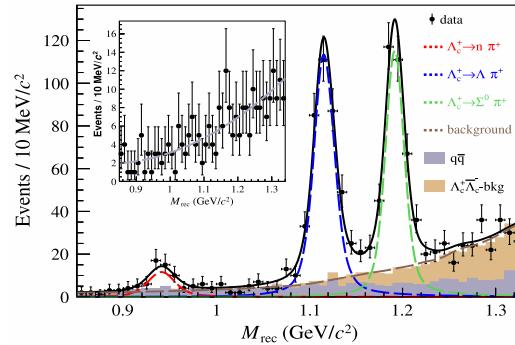
[8]. PRD 55, 7067 (1997)
[14]. PRD 49, 3417 (1994)
[15]. PRD 97, 074028 (2018).
[16]. CTP 40, 563 (2003).
[17]. PLB 776, 265 (2018).

	$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 K^+) (10^{-4})$	$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K_S^0) (10^{-4})$
QCD corrections	2(8)	2(4)
MIT bag model	7.2 ± 1.8	7.2 ± 1.8
Diagrammatic analysis	5.5 ± 1.6	9.6 ± 2.4
<i>SU(3)_F</i> flavor symmetry	5.4 ± 0.7	5.4 ± 0.7
IRA method	5.0 ± 0.6	6.2 ± 2.5
This work	$4.7 \pm 0.9_{\text{stat.}} \pm 0.1_{\text{syst.}} \pm 0.3_{\text{ref.}}$	$4.8 \pm 1.4_{\text{stat.}} \pm 0.2_{\text{syst.}} \pm 0.3_{\text{ref.}}$

Λ_c Decay

➤ $\Lambda_c^+ \rightarrow n\pi^+$ (SCS) [PRL 128, 142001 \(2022\)](#)

$\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+) \times 10^{-4}$	$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow p\pi^0)}$	Reference
4	2	PRD 55, 7067 (1997)
9	2	PRD 93, 056008 (2016)
11.3 ± 2.9	2	PRD 97, 073006 (2018)
8 or 9	4.5 or 8.0	PRD 49, 3417 (1994)
2.66	3.5	PRD 97, 074028 (2018)
6.1 ± 2.0	4.7	PLB 790, 225 (2019)
7.7 ± 2.0	9.6	JHEP 02 (2020) 165
$6.6 \pm 1.2 \pm 0.4$	> 7.2 @ 90% C.L.	this work



topological-diagram approach

➤ $\Lambda_c^+ \rightarrow n\pi^+\pi^0, n\pi^+\pi^-\pi^+$ (CS) and

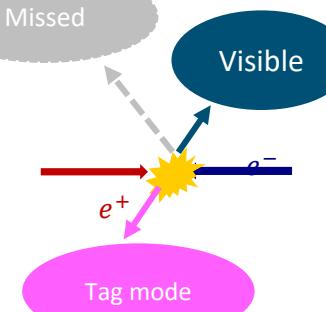
$\Lambda_c^+ \rightarrow nK^-\pi^+\pi^+$ (CF) [Chin. Phys. C47, 023001 \(2023\)](#)

Decay Mode	$\mathcal{B}(\%)$	Sig. (σ)
$\Lambda_c^+ \rightarrow n\pi^+\pi^0$	$(0.64 \pm 0.09 \pm 0.02)$	7.9
$\Lambda_c^+ \rightarrow n\pi^+\pi^-\pi^+$	$(0.45 \pm 0.07 \pm 0.03)$	7.8
$\Lambda_c^+ \rightarrow nK^-\pi^+\pi^+$	$(1.90 \pm 0.08 \pm 0.09)$	> 10

- $\frac{\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow nK^-\pi^+\pi^+)} = 0.24 \pm 0.04$
- Consistent with $|V_{cd}|/|V_{cs}| = (0.224 \pm 0.005)$

➤ $\bar{\Lambda}_c^- \rightarrow \bar{n} + X$ [arXiv:2210.09561](#)

- \bar{n} identification
 - Most energetic shower in the EMC
 - A data driven method for the better simulation of \bar{n} [Nucl.Instrum.Meth.A 1033 \(2022\) 166672](#)
- $\mathcal{B}(\bar{\Lambda}_c^- \rightarrow \bar{n} + X) = (33.5 \pm 0.7 \pm 1.2)\%$
- $\mathcal{B}(\Lambda_c^+ \rightarrow n + X) = (33.5 \pm 0.7 \pm 1.2)\%$
 - Ignoring CPV
- $\mathcal{B}_{exclusive}^{sum} \approx 25\%$
- 1/4 decay channels are not observed

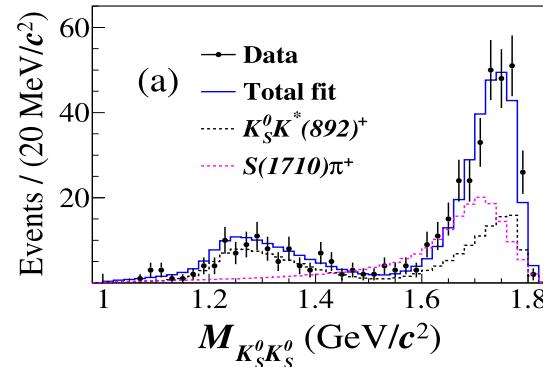
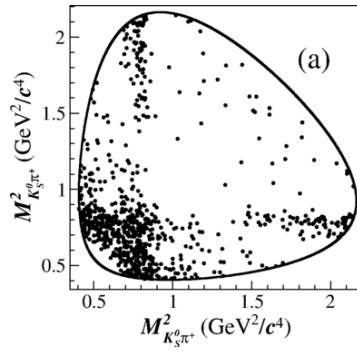


Amplitude Analysis

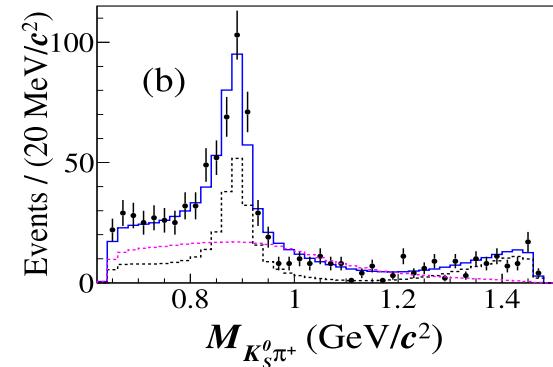
- Light meson or baryon spectroscopy
- Polarization of vector meson
 - $D \rightarrow VV$
- Optimization of binning scheme for the measurement of strong phase difference and CKM angle γ

Amplitude Analysis : $D_s^+ \rightarrow K_S^0 K_S^0 \pi^+$ PRD 105, L051103 (2022)

- A structure around 1.7 GeV, $S(1710)$, in $M(K_S^0 K_S^0)$



	S(1710)	$f_0(1710)$ PDG	difference
Mass (GeV/c ²)	$1.723 \pm 0.011 \pm 0.002$	1.704 ± 0.012	1.2σ
Width (GeV)	$0.140 \pm 0.014 \pm 0.004$	0.123 ± 0.018	0.7σ



Decay mode	Branching fraction (10^{-3})
$D_s^+ \rightarrow K_S^0 K_S^0 \pi^+$	$6.8 \pm 0.4_{stat} \pm 0.1_{syst}$
$D_s^+ \rightarrow K_S^0 K^*(892)^+$	$3.0 \pm 0.3_{stat} \pm 0.1_{syst}$
$D_s^+ \rightarrow S(980)\pi^+, S(980) \rightarrow K_S^0 K_S^0$	$< 0.18 @ 90\% \text{ C.L.}$
$D_s^+ \rightarrow S(1710)\pi^+$	$(3.1 \pm 0.3_{stat} \pm 0.1_{syst}) \times 10^{-3}$

- The $S(980)$ is observed in the $(D_s^+ \rightarrow S(980)\pi^+, S(980) \rightarrow K^+K^-)$ decay with significance $> 20\sigma$ [PRD 104, 012016 \(2021\)](#)
- Constructive interference between $a_0(980)^0$ and $f_0(980)^0$ for K^+K^-
- Destructive interference between $a_0(980)^0$ and $f_0(980)^0$ for $K_S^0 K_S^0$

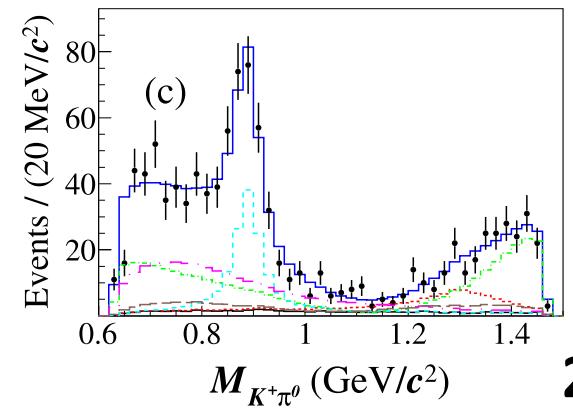
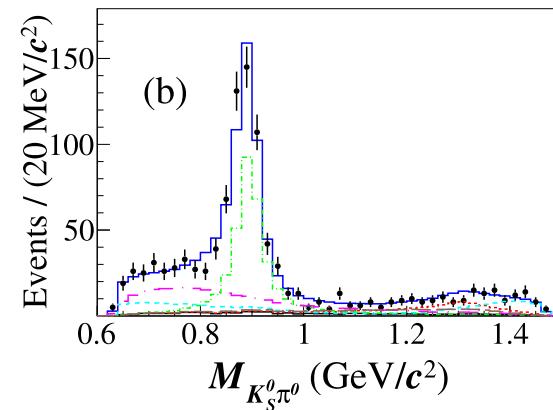
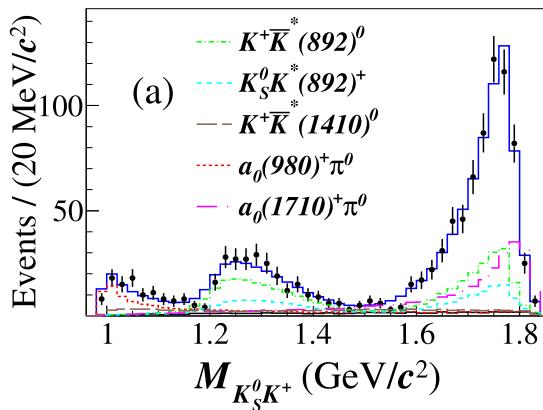
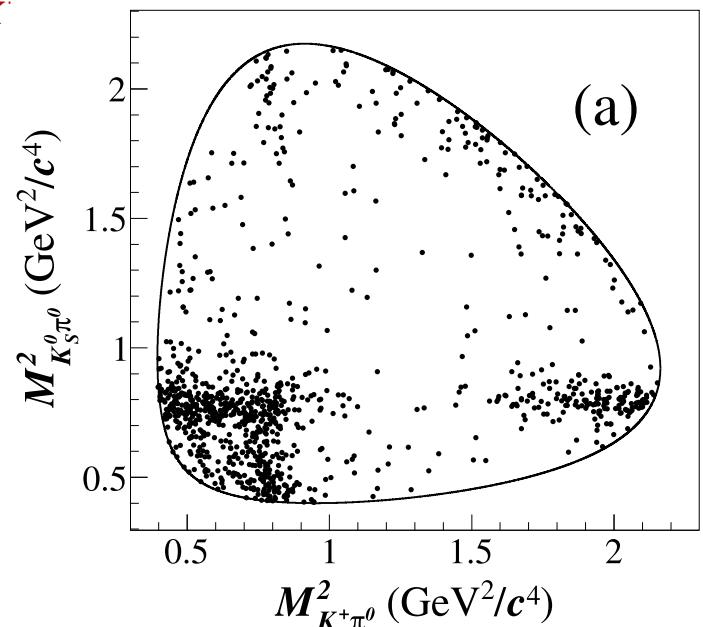
- One order of magnitude larger than expectation based on the isospin symmetry
- Constructive interference between $f_0(1710)$ and $a_0(1710)^0$
- A simultaneous amplitude analysis of $D_s^+ \rightarrow K^+K^-\pi^+$ and $D_s^+ \rightarrow K_S^0 K_S^0 \pi^+$ is desirable

Amplitude Analysis : $D_s^+ \rightarrow K_S^0 K^+ \pi^0$

PRL 129, 182001 (2022)

- First observation of a_0 -like state, $S(1817)^+$, in $M_{K_S^0 K^+}$:

- Mass: $(1.817 \pm 0.008_{stat} \pm 0.020_{syst}) \text{ GeV}/c^2$
- Width: $(0.097 \pm 0.022_{stat} \pm 0.015_{syst}) \text{ GeV}/c^2$
- Isospin-one partner of $f_0(1710) (\rightarrow K_S^0 K_S^0)$?
 - [EPJC 82, 225 \(2022\)](#)
 - $\mathcal{B}(D_s^+ \rightarrow a_0(1817)^+ \pi^0) = (3.44 \pm 0.52 \pm 0.32) \times 10^{-3}$
 - $\sim 100 \text{ MeV}$ difference in mass
- $\mathcal{B}(D_s^+ \rightarrow K_S^0 K^+ \pi^0) = (1.46 \pm 0.06_{stat} \pm 0.05_{syst})\%$.



Amplitude Analysis : $\Lambda_c^+ \rightarrow \Lambda\pi^+\pi^0$

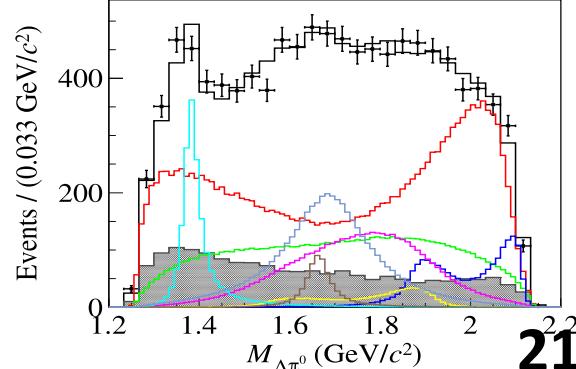
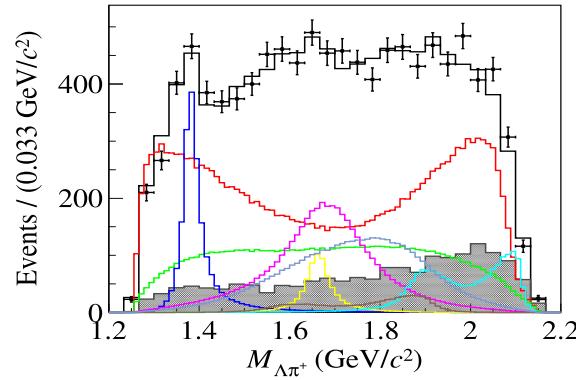
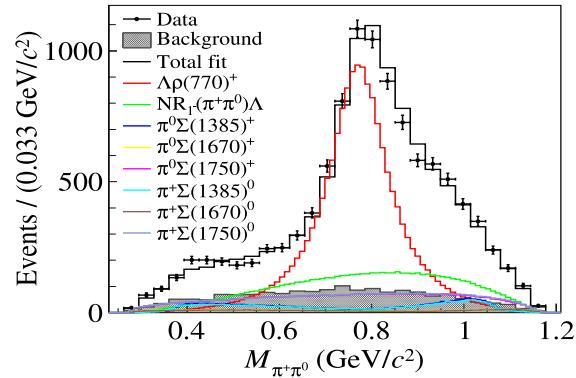
JHEP12(2022)033

	Theoretical calculation	This work	PDG
$10^2 \times \mathcal{B}(\Lambda_c^+ \rightarrow \Lambda\rho(770)^+)$	4.81 ± 0.58 [13]	4.0 [14, 15]	4.06 ± 0.52
$10^3 \times \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma(1385)^+\pi^0)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	5.86 ± 0.80
$10^3 \times \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma(1385)^0\pi^+)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	6.47 ± 0.96
$\alpha_{\Lambda\rho(770)^+}$	-0.27 ± 0.04 [13]	-0.32 [14, 15]	-0.763 ± 0.070
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]	-0.917 ± 0.089	—
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [17]	-0.79 ± 0.11	—

First observation

Consistent with predictions

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- [14] H.-Y. Cheng and B. Tseng, *Nonleptonic weak decays of charmed baryons*, *Phys. Rev. D* **46** (1992) 1042 [*Erratum ibid.* **55** (1997) 1697] [[INSPIRE](#)].
- [15] H.Y. Cheng and B. Tseng, *Erratum: Nonleptonic weak decays of charmed baryons*, *Phys. Rev. D* **55** (1997) 1697.
- [16] Y.K. Hsiao, Q. Yi, S.-T. Cai and H.J. Zhao, *Two-body charmed baryon decays involving decuplet baryon in the quark-diagram scheme*, *Eur. Phys. J. C* **80** (2020) 1067 [[arXiv:2006.15291](#)] [[INSPIRE](#)].
- [17] C.-Q. Geng, C.-W. Liu, T.-H. Tsai and Y. Yu, *Charmed baryon weak decays with decuplet baryon and SU(3) flavor symmetry*, *Phys. Rev. D* **99** (2019) 114022 [[arXiv:1904.11271](#)] [[INSPIRE](#)].



Other Results

➤ D^{+0}

- PWA of $D^0 \rightarrow K_L^0 \pi^+ \pi^-$: [arXiv:2212.09048](#)
- PWA of $D^+ \rightarrow K^+ K_S^0 \pi^0$:[PRD 104, 012006 \(2021\)](#):

➤ D_s

- Observation of the decay $D_s^+ \rightarrow \omega \pi^+ \eta$:[PRD 107, 052010 \(2023\)](#)
- PWA of $D_s^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$:[JHEP09\(2022\)242](#)
- PWA of $D_s^+ \rightarrow K^+ \pi^+ \pi^-$:[JHEP08\(2022\)196](#)
- PWA of $D_s^+ \rightarrow K^+ K^- \pi^+ \pi^+ \pi^-$:[JHEP07\(2022\)051](#)
- PWA of $D^{+s} \rightarrow \pi^+ \pi^0 \eta'$:[arXiv:2202.04232](#)
- PWA of $D_s^+ \rightarrow \pi^+ \pi^0 \pi^0$:[JHEP01\(2022\)052](#)
- PWA of $D_s^+ \rightarrow \pi^+ \pi^- \pi^+$:[PRD 106, 112006 \(2022\)](#)
- PWA of $D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \eta$:[PRD 104, L071101 \(2021\)](#)
- PWA of $D_s^+ \rightarrow K_S^0 \pi^+ \pi^0$:[JHEP06\(2021\)181](#)
- PWA of $D_s^+ \rightarrow K^- K^+ \pi^+ \pi^0$:[PRD 104, 032011 \(2021\)](#)
- PWA of $D_s^+ \rightarrow K_S^0 K^- \pi^+ \pi^+$:[PRD 103, 092006 \(2021\)](#)
- PWA of $D_s^+ \rightarrow K^+ K^- \pi^+$:[PRD 104, 012016 \(2021\)](#)

➤ Λ_c^+

- Measurement of branching fractions $\Lambda_c^+ \rightarrow \Sigma^+ K^+ K^-$, $\Sigma^+ \phi$, and $\Sigma^+ K^+ \pi^- (\pi^0)$: [arXiv:2304.09405](#)
- Branching fraction of $\Lambda_c^+ \rightarrow p \eta'$:[PRD 106, 072002 \(2022\)](#)

Summary and Prospect

- Many results related to the hadronic charmed decays are reported
 - Measurements with quantum correlated $D^0\bar{D}^0$ based on 2.93 fb^{-1}
 - Most sensitive results of strong phase difference of $D \rightarrow K_{S,L}^0\pi^+\pi^-$ for the γ measurement are reported
 - ...
 - Branching fraction measurements
 - Transverse polarization of $D \rightarrow \phi\omega$ is observed
 - Some of channels are still unobserved
 - ...
 - Amplitude analyses
 - Structures $S(1710) \rightarrow K_S^0K_S^0$ and $S(1817)^+ \rightarrow K_S^0K^+$ are observed
 - $D^+ \rightarrow K_S^0K_S^0\pi^+$ and $D_S^+ \rightarrow K_S^0K^+\pi^0$
 - ...
 - Prospect
 - More data will be available
 - 8 fb^{-1} data at 3.773 GeV has been released and 20 fb^{-1} data will be available in 2024
 - More progresses with more precise results will be reported

Backup

$K_{S,L}^0 \pi^+ \pi^-$

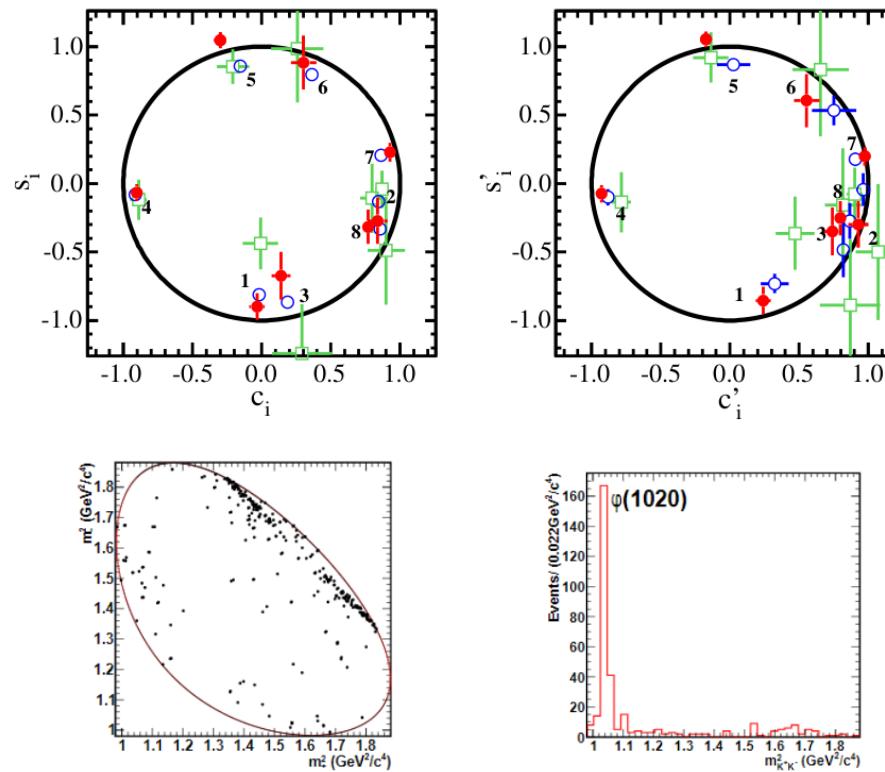


Figure: $K_S^0 K^+ K^-$ tagged with CP even modes and $m_{K^+ K^-}^2$ projection.

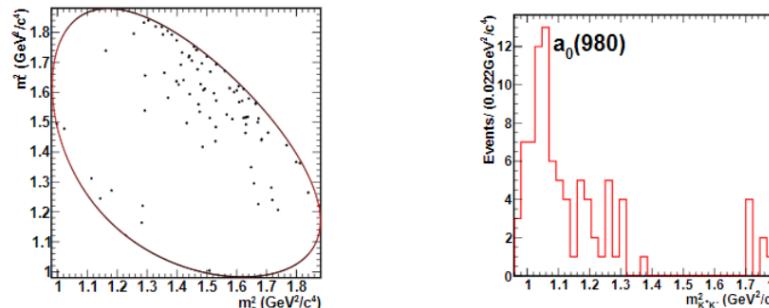
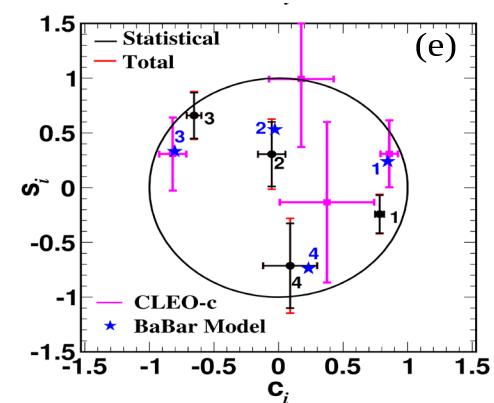
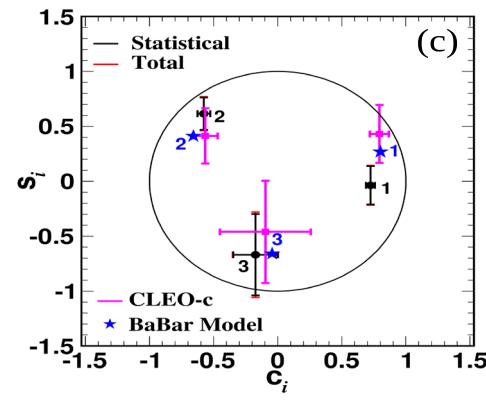
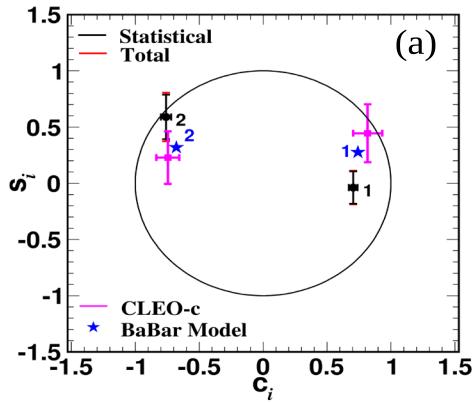
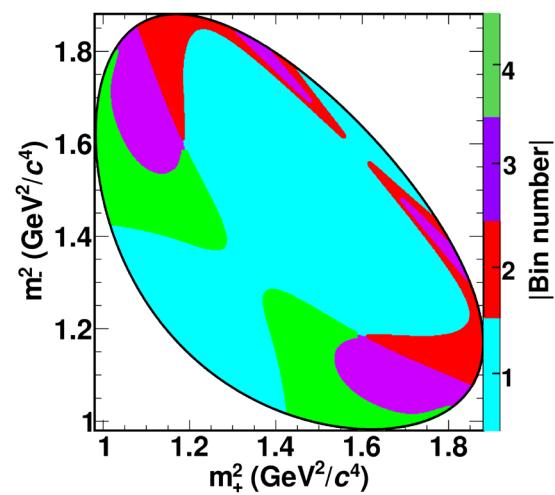
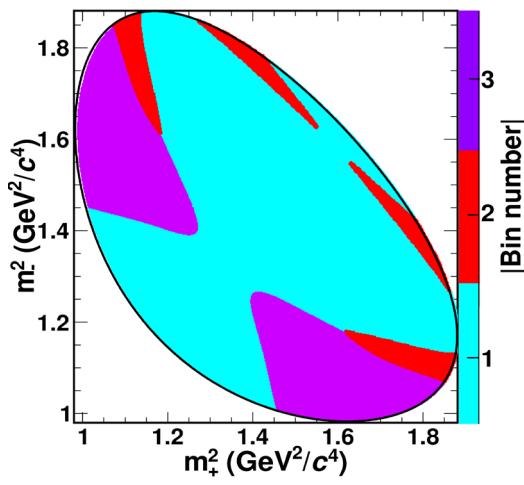
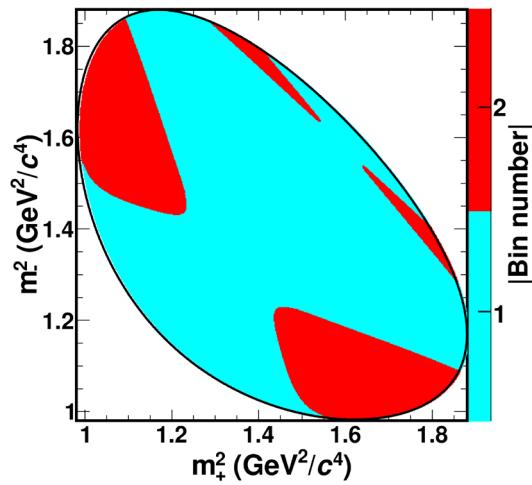


Figure: $K_S^0 K^+ K^-$ tagged with CP odd modes and $m_{K^+ K^-}^2$ projection.



Incorporate with the $K_S^0 \pi^+ \pi^-$, the uncertainty on the γ measurement: $\sim 1^\circ$

ADS rate and asymmetry (relative to the common decay):

$$\mathcal{R}_{DK} = \frac{\Gamma([K^+\pi^-]K^-) + \Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-) + \Gamma([K^+\pi^-]K^+)} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D) \cos \phi_3$$

$$\mathcal{A}_{DK} = \frac{\Gamma([K^+\pi^-]K^-) - \Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-) + \Gamma([K^+\pi^-]K^+)} = 2r_B r_D \sin(\delta_B + \delta_D) \sin \phi_3 / \mathcal{R}_{DK}$$

where $r_D = \left| \frac{\mathcal{A}(D^0 \rightarrow K^+\pi^-)}{\mathcal{A}(\bar{D}^0 \rightarrow K^+\pi^-)} \right| = 0.0613 \pm 0.0010$
and r_B was defined on p. 5 ⑨

Isospin for two body decay

$$\langle \bar{K}^0 \pi^+ | H_w^{n,L} | D^+ \rangle = A_{3/2} ,$$

$$\langle K^- \pi^+ | H_w^{n,L} | D^0 \rangle = \frac{1}{3} A_{3/2} + \frac{2}{3} A_{1/2} ,$$

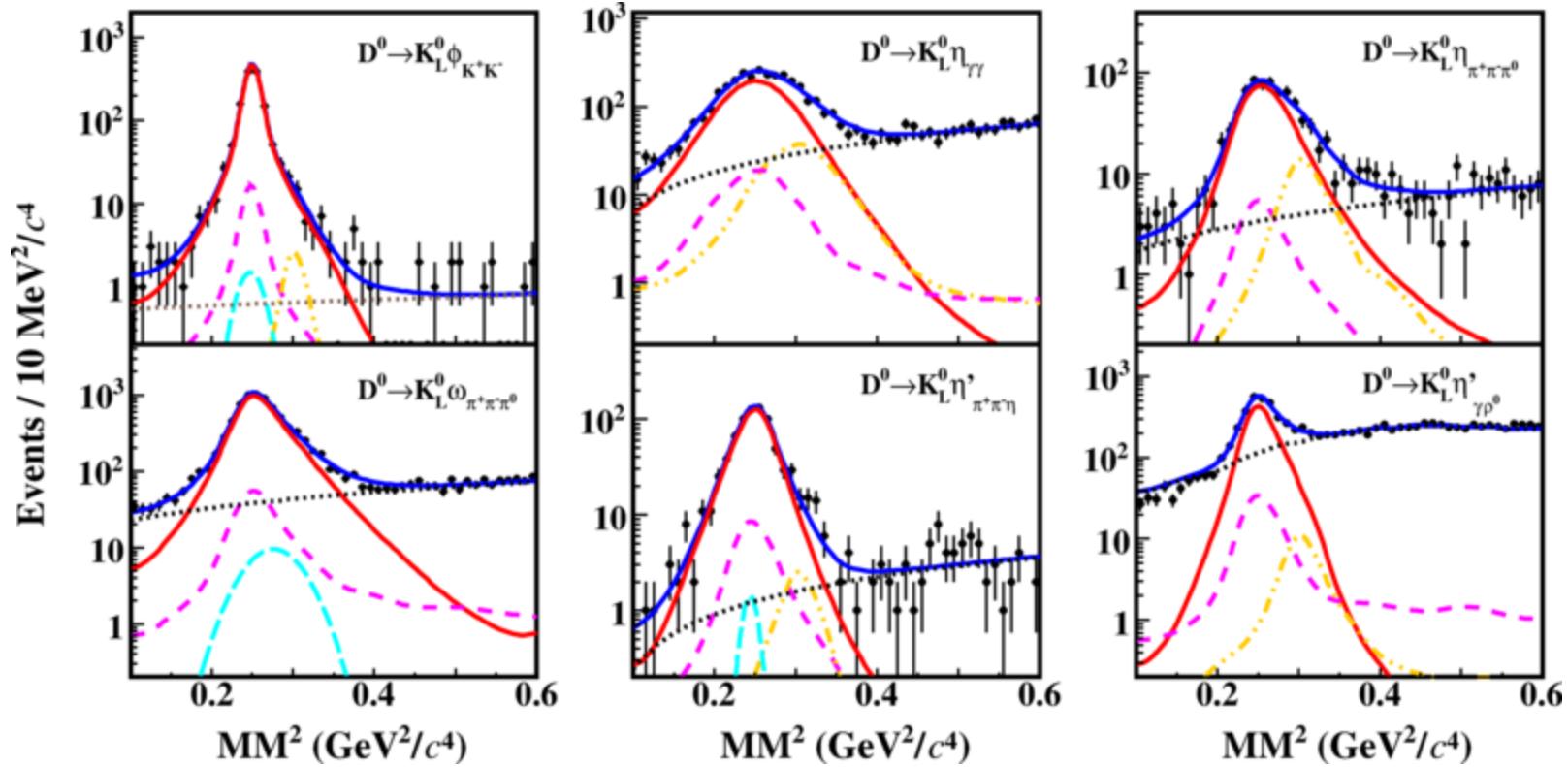
$$\langle \bar{K}^0 \pi^0 | H_w^{n,L} | D^0 \rangle = \frac{1}{3} \sqrt{2} (A_{3/2} - A_{1/2}) ,$$

Nuclear Physics B122 (1977) 144-169

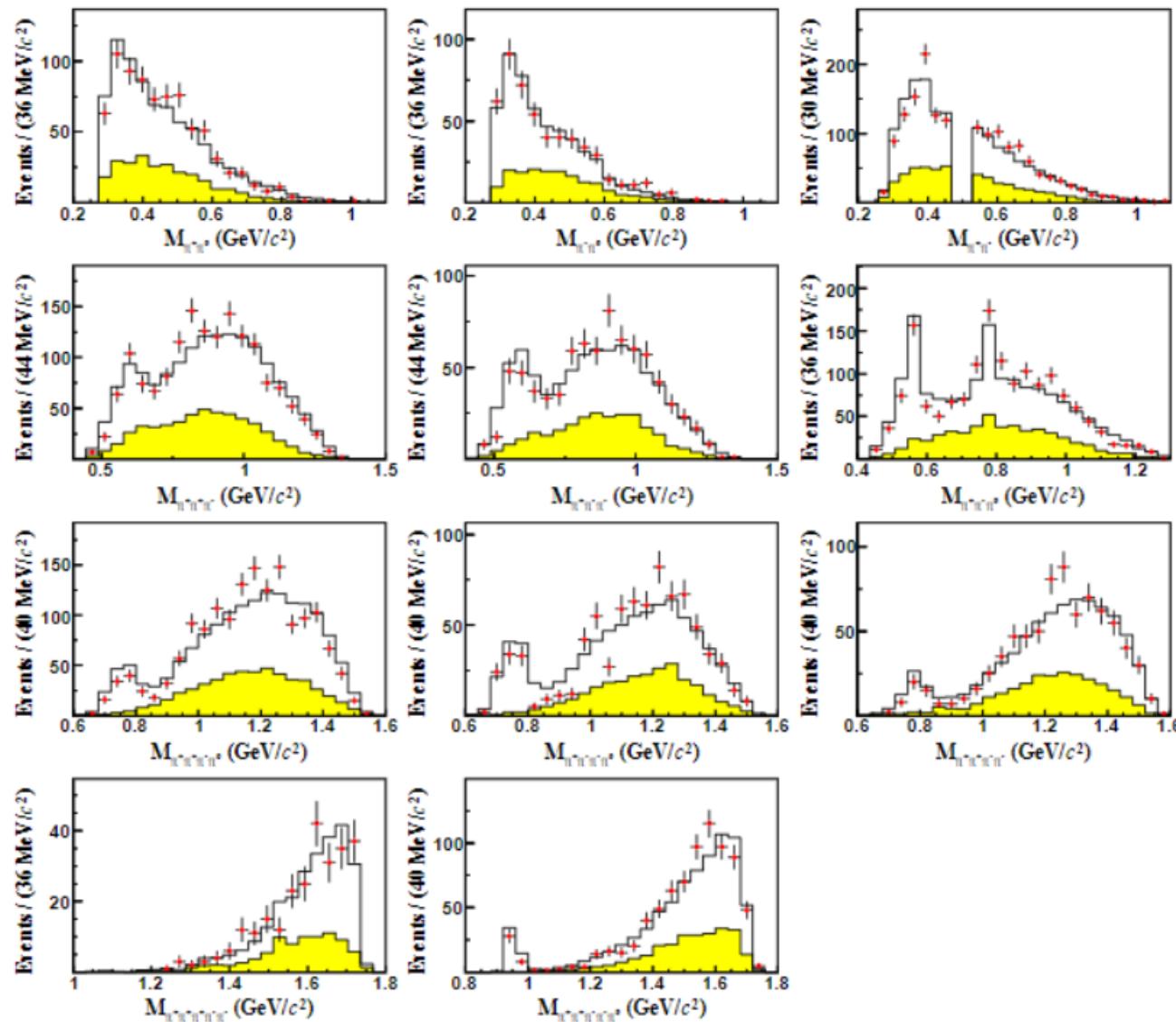
The charm-changing weak current is assumed to induce the quark transition *

$$c \leftrightarrow s \cos \theta_c - d \sin \theta_c , \quad (1)$$

Signal yields of $D^0 \rightarrow K_L^0 X$



Intermediates for $D^+ \rightarrow 3\pi^+ 2\pi^- \pi^0$



$D_s^- \rightarrow \pi^+ \pi^- \pi^- X$: binning

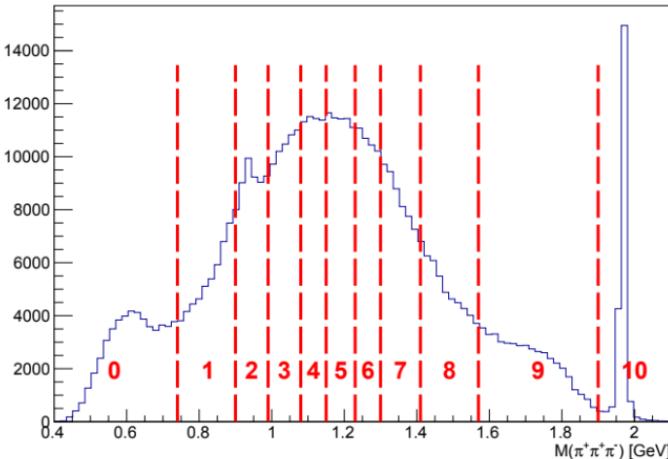
$M(\pi\pi\pi)$ bins

- We measure partial branching fraction of $D_s^- \rightarrow \pi\pi\pi X$ in 11 bins of $M(\pi\pi\pi)$

202 6 Double tag

203 6.1 Selection of three charged pions from the signal side

204 For one event, in the presence of the selected ST D_s^- candidates as described in the previous section, we
205 look at the rest of the event for one π^- and two π^+ (or c.c.) for the inclusive decay of $D_s^+ \rightarrow \pi^+ \pi^+ \pi^- X$.
206 The tracking and PID requirements on the selection pions are the same as those in §5.1. Also, charge
207 pion candidates with momenta below 100 MeV/c are rejected to suppress soft pion backgrounds from
208 $D^{*+} \rightarrow D^0 \pi^+$. In case that more than one π^- is reconstructed at the signal side, we select the one with the
209 largest $|p|$. When more than two π^+ is present at the signal side, we select the pion pairs with the largest
210 and second largest $|p|$ values.



https://indico.ihep.ac.cn/event/10988/contributions/6719/attachments/3032/3462/ds2pipipiX_20200922.pdf

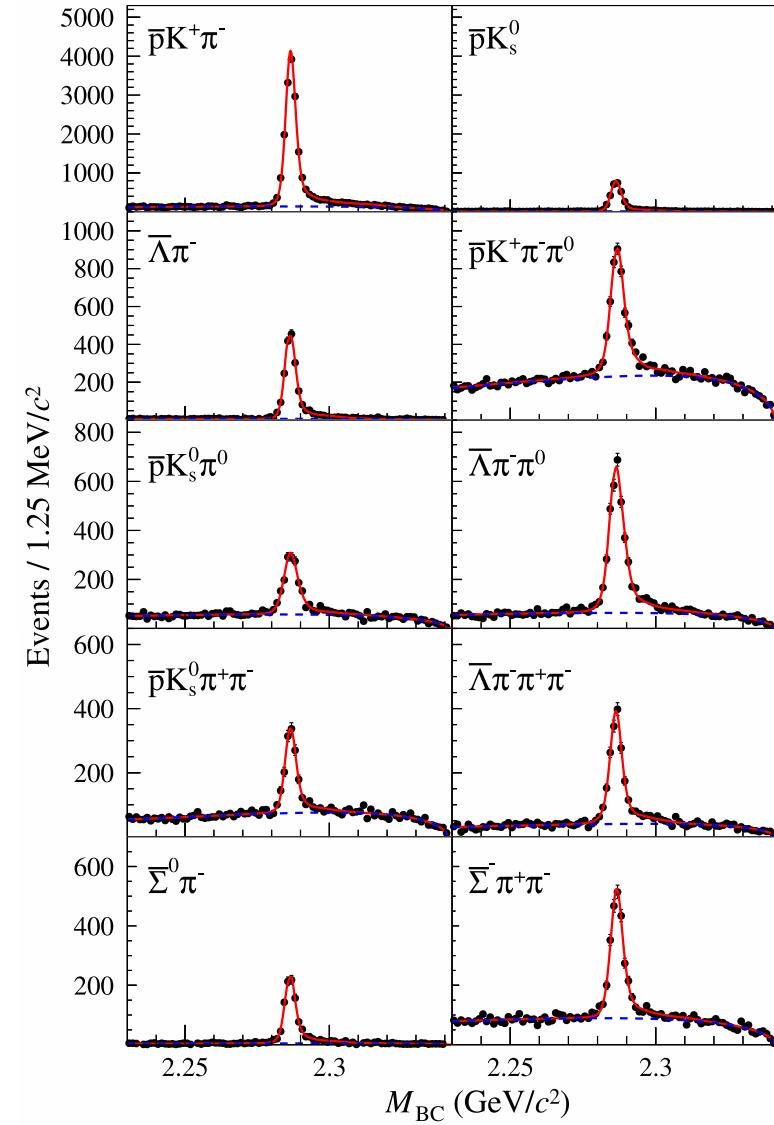
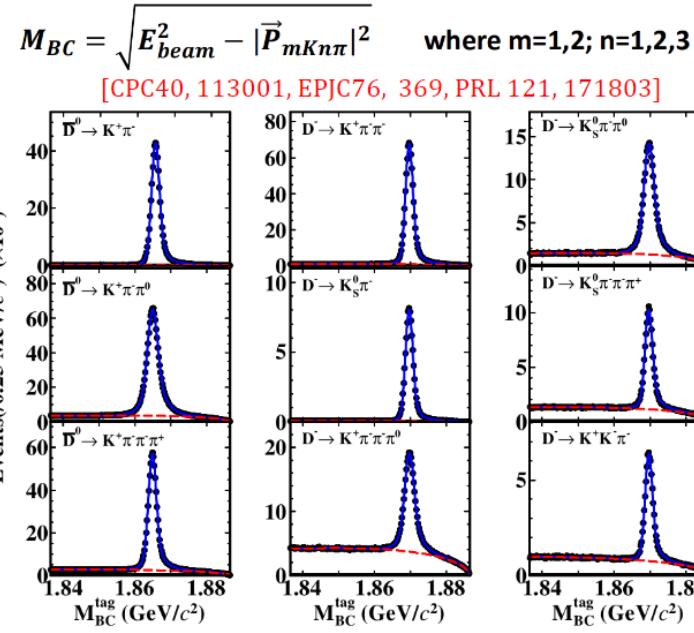
Refs for the $D_s^* \rightarrow D_s^+ \pi^0$

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Single tag mode

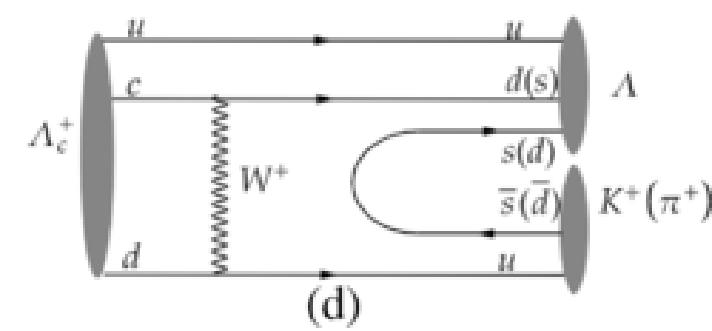
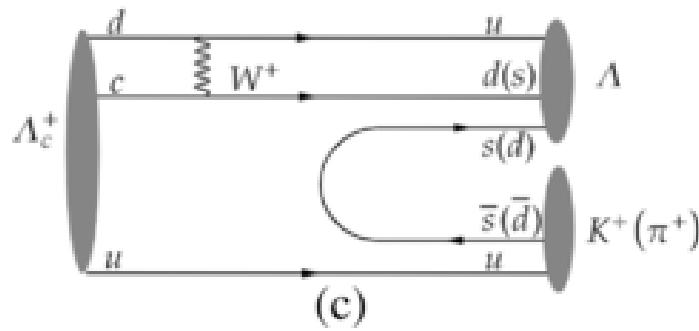
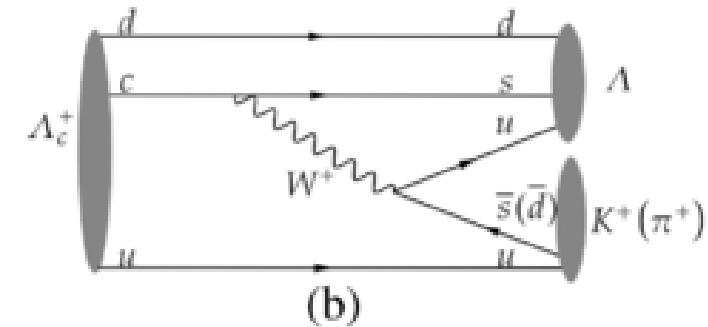
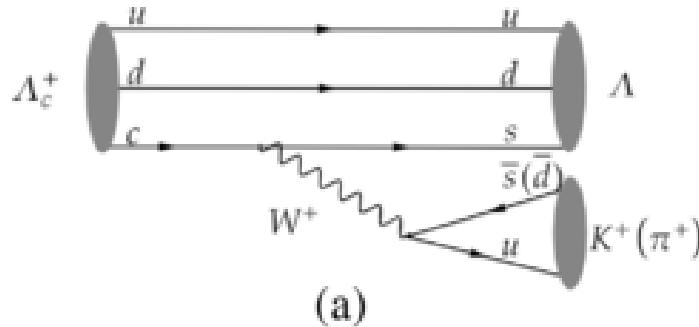
ST yields and efficiencies in data

Fitting: Signal shape \otimes Gaussian(sig) + ARGUS function(bkg)



7

$\Lambda_c^+ \rightarrow \Lambda K$



Summary

- Charm (semi-)leptonic decays provide precision calibration of LQCD; precision measurements of CKM matrix elements
- Charm hadronic decays are key labs to understand non-perturbative QCD; provide important inputs to model-independent determination of γ and charm mixing/CPV
- BESIII will collect 20 fb^{-1} data (17+3) at $\psi(3773)$ in next two years time.
→ a new era of precision charm physics

Thank you!

Coherence Factor Analysis of

- Treat $K3\pi$ like two-body decay with single effective strong phase δ_D .

$$\Gamma(B^- \rightarrow (K^+ 3\pi)_D K^-) \propto r_B^2 + (r_D^{K3\pi})^2 + 2R_{K3\pi} r_B r_D^{K3\pi} \cdot \cos(\delta_B + \delta_D^{K3\pi} - \gamma)$$

$$r_B = \left| \frac{A(B^- \rightarrow \bar{D}^0 K^-)}{A(B^- \rightarrow D^0 K^-)} \right| \quad r_D = \left| \frac{A(D^0 \rightarrow K^+ \pi^- \pi^+ \pi^-)}{A(\bar{D}^0 \rightarrow K^+ \pi^- \pi^+ \pi^-)} \right|$$

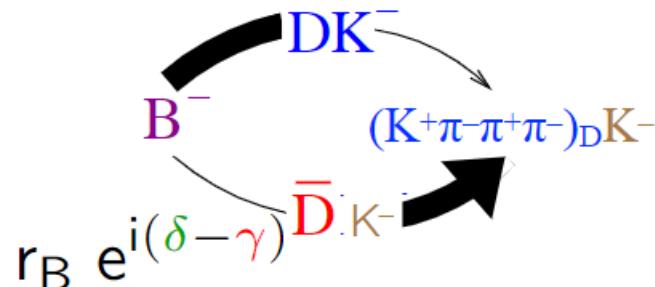
- $R e^{-i\delta_D} = \frac{1}{\mathcal{A}_\Omega \mathcal{B}_\Omega} \int_{\Omega} \langle f_p | \hat{H} | D^0 \rangle \langle f_p | \hat{H} | \bar{D}^0 \rangle^* \left| \frac{\partial^n \phi}{\partial(p_1 \dots p_n)} \right| d^n p.$

$$\mathcal{A}_\Omega \equiv \sqrt{\int_{\Omega} |\langle f_p | \hat{H} | D^0 \rangle|^2 \left| \frac{\partial^n \phi}{\partial(p_1 \dots p_n)} \right| d^n p}, \quad \mathcal{B}_\Omega \equiv \sqrt{\int_{\Omega} |\langle f_p | \hat{H} | \bar{D}^0 \rangle|^2 \left| \frac{\partial^n \phi}{\partial(p_1 \dots p_n)} \right| d^n p}$$

- Coherence factor $R < 1$;

CLEO-c input theory: Atwood, Soni: Phys.Rev. D68 (2003) 033003

CLEO-c data: Phys.Rev. D80 (2009) 031105, PLB 731 (2014) 197, Phys.Lett. B757 (2016) 520-527

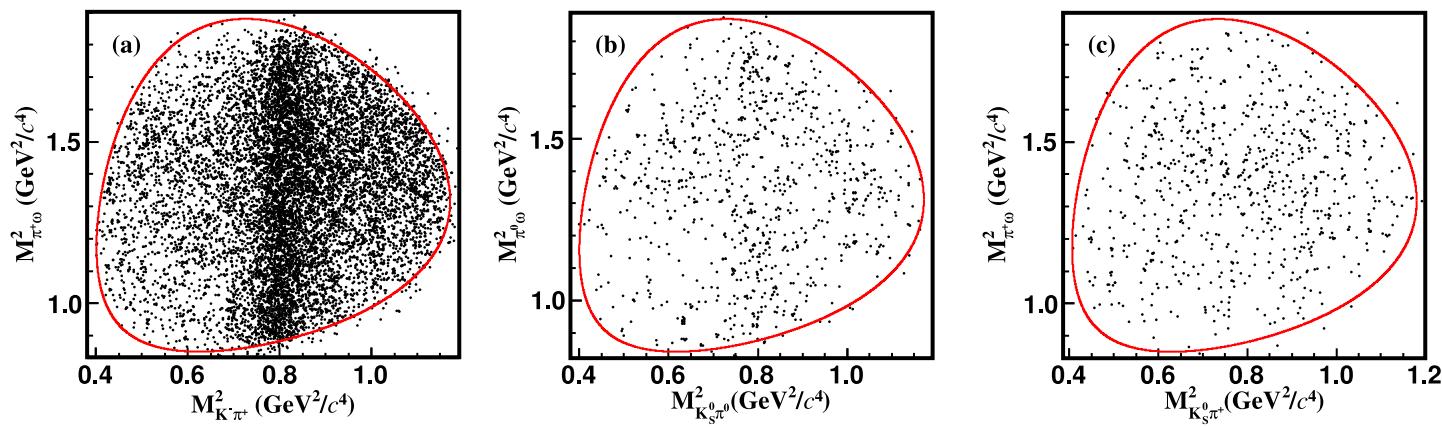


$R_{K3\pi}$ is the coherence factor introduced by Atwood & Soni, [PRD68 \(2003\) 033003](#)

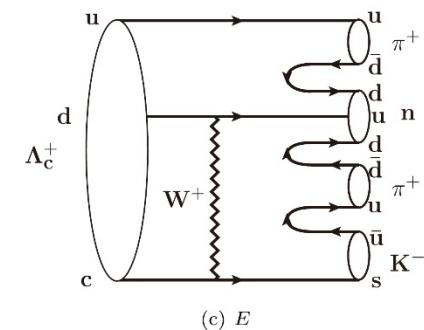
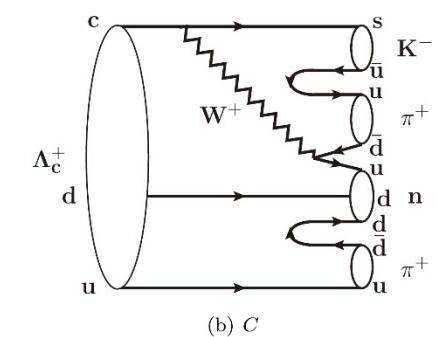
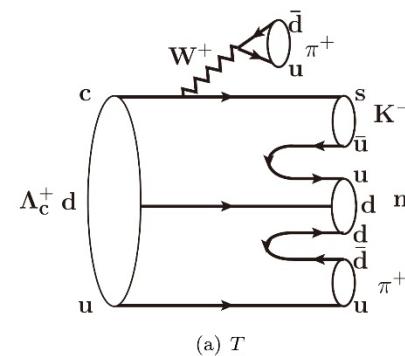
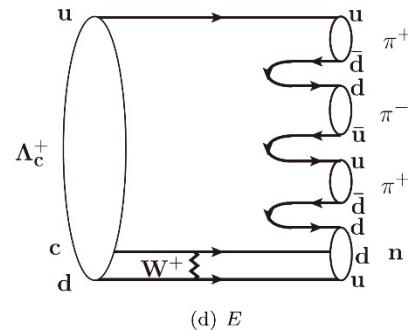
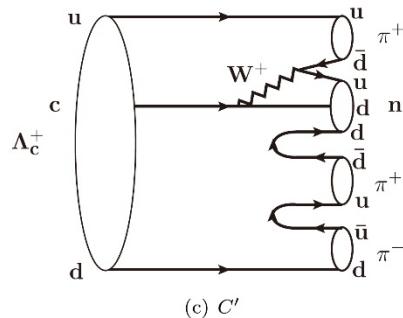
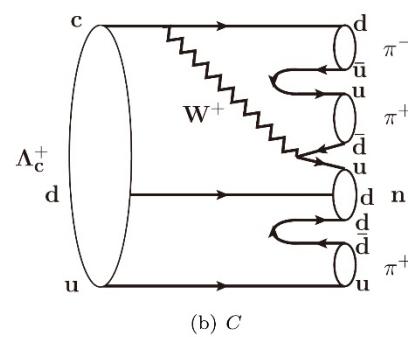
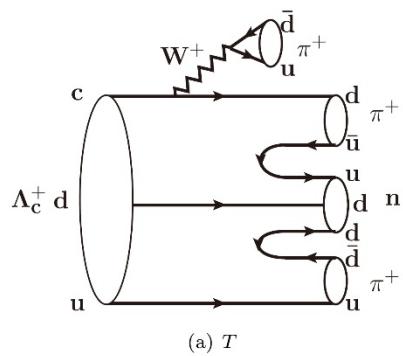
Also interesting in relation to charm mixing, see

- Bondar, Poluektov, Vorobiev: [PRD 82 \(2010\) 034033](#),
- Malde & Wilkinson [PLB701 \(2011\) 353-356](#),
- Malde, Thomas & Wilkinson [PRD91 \(2015\) no.9, 094032](#),
- Harnew & JR: [JHEP 1503 \(2015\) 169](#), [PLB 728 \(2014\) 296](#)
- LHCb: [PRL116 \(2016\) no.24, 241801](#)
- Evans et al: [PLB 757 \(2016\) 520](#)

$D^{0+} \rightarrow K\pi\omega$



Top. Diagram



$$D_s^+ \rightarrow K^+ K^+ \pi^+$$

TABLE XII.

The BFs measured in this analysis and quoted from PDG [7].

Process	BF (%)	
	BESIII (this analysis)	PDG
$D_s^+ \rightarrow K^*(892)^0 K^+, K^*(892)^0 \rightarrow K^- \pi^+$	$2.64 \pm 0.06_{\text{stat}} \pm 0.07_{\text{sys}}$	2.58 ± 0.08
$D_s^+ \rightarrow \phi(1020) \pi^+, \phi(1020) \rightarrow K^+ K^-$	$2.21 \pm 0.05_{\text{stat}} \pm 0.07_{\text{sys}}$	2.24 ± 0.08
$D_s^+ \rightarrow S(980) \pi^+, S(980) \rightarrow K^+ K^-$	$1.05 \pm 0.04_{\text{stat}} \pm 0.06_{\text{sys}}$	1.14 ± 0.31
$D_s^+ \rightarrow K_0^*(1430)^0 K^+, K_0^*(1430)^0 \rightarrow K^- \pi^+$	$0.16 \pm 0.03_{\text{stat}} \pm 0.03_{\text{sys}}$	0.18 ± 0.04
$D_s^+ \rightarrow f_0(1710) \pi^+, f_0(1710) \rightarrow K^+ K^-$	$0.10 \pm 0.02_{\text{stat}} \pm 0.03_{\text{sys}}$	0.07 ± 0.03
$D_s^+ \rightarrow f_0(1370) \pi^+, f_0(1370) \rightarrow K^+ K^-$	$0.07 \pm 0.02_{\text{stat}} \pm 0.01_{\text{sys}}$	0.07 ± 0.05
$D_s^+ \rightarrow K^+ K^- \pi^+ \text{ total BF}$	$5.47 \pm 0.08_{\text{stat}} \pm 0.13_{\text{sys}}$	5.39 ± 0.15

Decay channels required in [LHCb-PUB-2016-025]

Decay mode	Quantity	Status (2.93 fb^{-1})
$K_S^0\pi^+\pi^-$	c_i, s_i	Finished
$K_S^0K^+K^-$	c_i, s_i	Finished
$K^-\pi^+\pi^+\pi^-$	R, δ	Finished
$K^+K^-\pi^+\pi^-$	$F_+ \text{ or } c_i, s_i$	On going
$\pi^+\pi^-\pi^+\pi^-$	$F_+ \text{ or } c_i, s_i$	On going
$K^-\pi^+\pi^0$	R, δ	Finished
$K_S^0K^\pm\pi^\mp$	R, δ	...

Decay mode	Quantity	Status (2.93 fb^{-1})
$\pi^+\pi^-\pi^0$	F_+	On going
$K_S^0\pi^+\pi^-\pi^0$	$F_+ \text{ or } c_i, s_i$	On going
$K^+K^-\pi^0$	F_+	On going
$K^-\pi^+$	δ	Finished (Update)

- The precision will be improved with a factor ~ 2 compared with CLEOc's measurement