Overview of hadronic decays of the charmed hadrons

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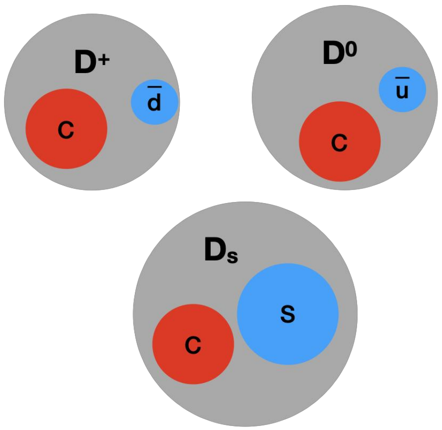
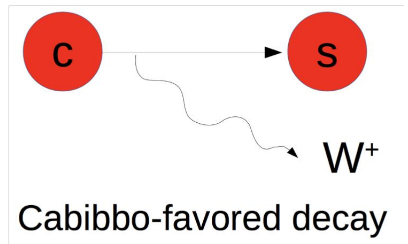
on behavier of BESIII Collaboration

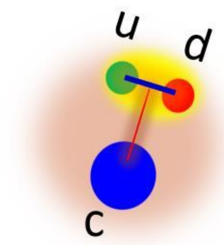
July 17-21 2023 @ **Charm 2023**, Siegen University, Germany

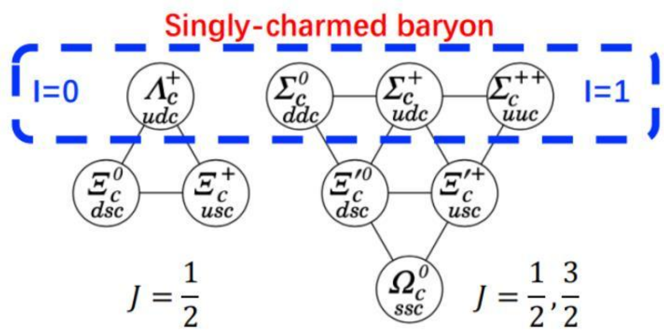
Outline

- Introduction of BESIII charm datasets
- Charmed meson (D^0, D^+, D_s^+)
  - Amplitude analysis
  - Doubly-Cabibbio-suppressed decays
  - New flavor tagging method (Belle II)
- Charmed baryon
  - Partial Wave Analysis
  - Decays With Neutron in final states
  - Singly-Cabibbo-suppressed decays
- Quantum correlated $D^0\bar{D}^0$ at BESIII
  - Determination of $\delta_D^{K\pi}$
  - CP-even fraction measurement
- Summary









- The lightest charmed hadrons ($D^0,\ D^+, D_s^+, \Lambda_c^+$) $\rightarrow$ study weak interaction
- b-hadrons and excited charmed hadrons decay to the lightest charmed hadrons
- The perturbative QCD is not applicable in the low energy region $\rightarrow$ Test low-energy non-perturbative QCD phenomenological model and LQCD calculations in charm region.

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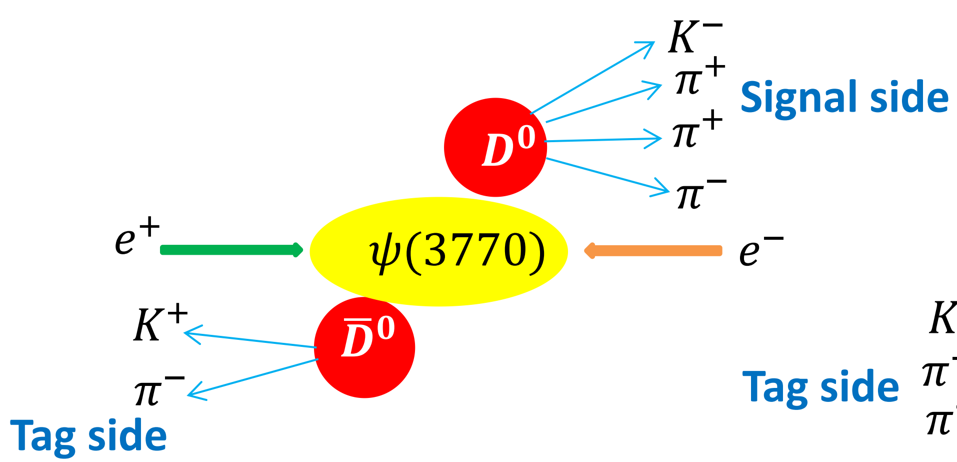
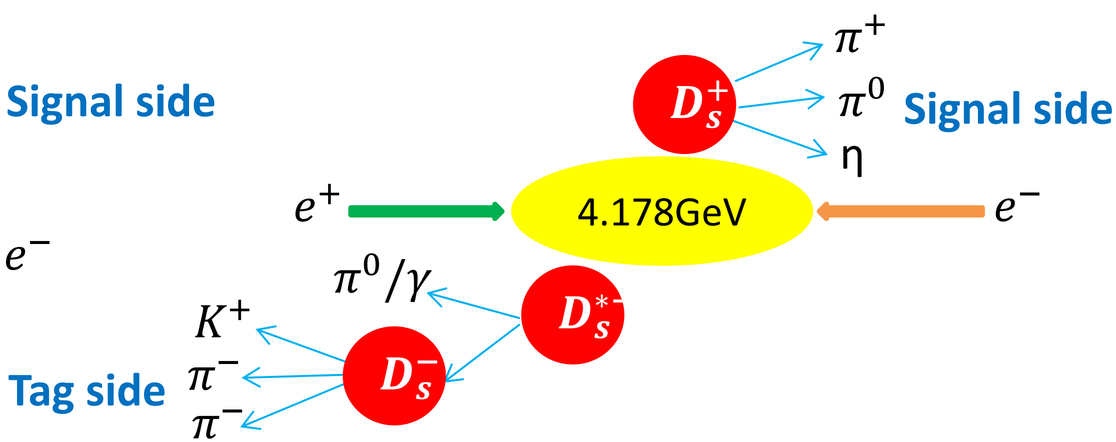
BESIII Dataset

- 7.9 fb^{-1} at Ecm = 3.773 GeV:
  $e^+e^- \to \psi(3770) \to D\bar{D}$ (totally 57M D^0 and 45M D^+)
- 7.33 fb^{-1} at Ecm = 4.128-4.226 GeV
  $e^+e^- \to D_s^{\pm}D_s^{*\mp}, D_s^{*\mp} \to \pi^0/\gamma D_s^{\mp}$ (~600k D_s)
- 4.5 fb^{-1} at Ecm = 4.600-4.699 GeV $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$

- **Single Tag (ST):** reconstruct only one of the hadron
- **Double Tag (DT):** reconstruct both of the hadrons
  access to absolute BFs; clean samples





(Charge-conjugate states are implied throughout this talk)

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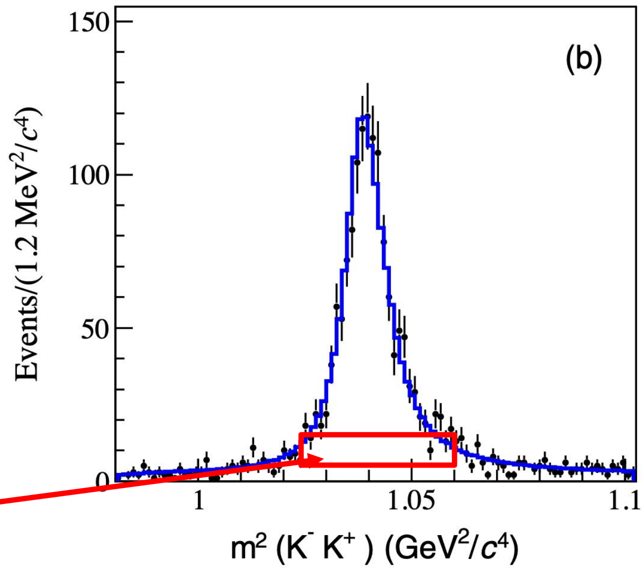
Why amplitude analysis?

Measuring intermediate resonance with considering interference

Interference of $D_s \to \phi\pi$ and other processes



The total amplitude $M(p_j)$ is the coherent sum of the sub-amplitude $A_n(p_j)$,

$$M(p_j) = \sum_n \rho_n e^{i\phi_n} A_n(p_j)$$

A bridge connecting theories (two-body) and experiments (three or four-body with e, μ, π, K, p as the final state particles)

Providing accurate models for simulation

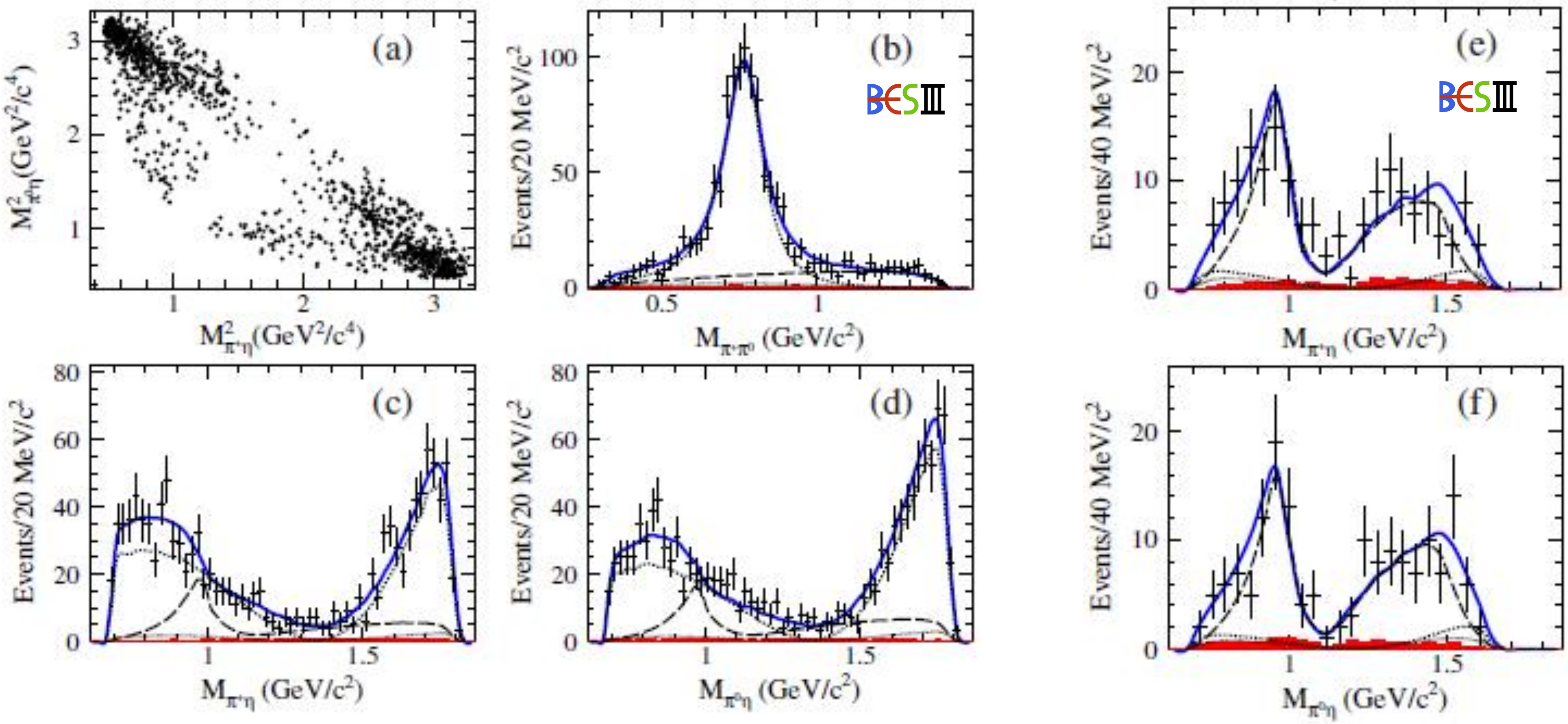
Amplitude analysis of $D_s^+ \to \pi^+\pi^0\eta$ - Observation of $D_s^+ \to a_0(980)\pi$

PRL123, 112001 (2019)

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

Full sample

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

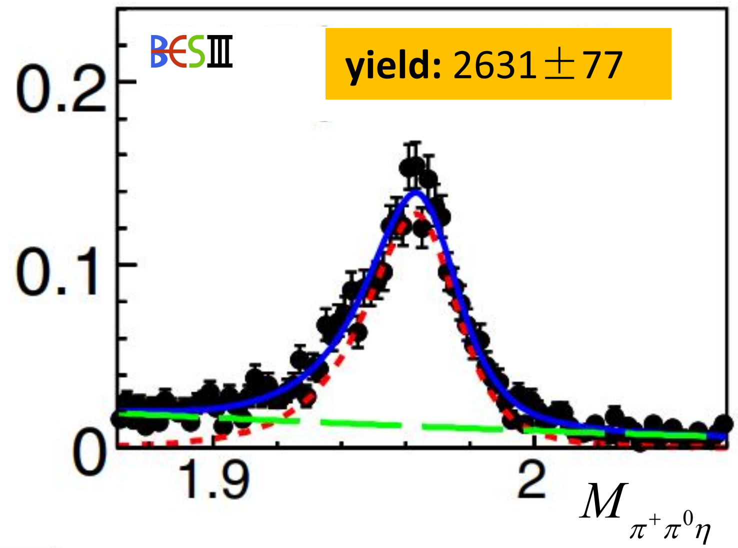


Dots with error bar: data; solid: total fit; dotted: $D_s^+ \to \rho^+\eta$; dashed: $D_s^+ \to a_0(980)\pi$ (**with a stat. significance of 16.2�**).

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

PRL123, 112001 (2019)

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



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

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

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

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

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

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

First observation !

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

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

2139 events with purity > 85%

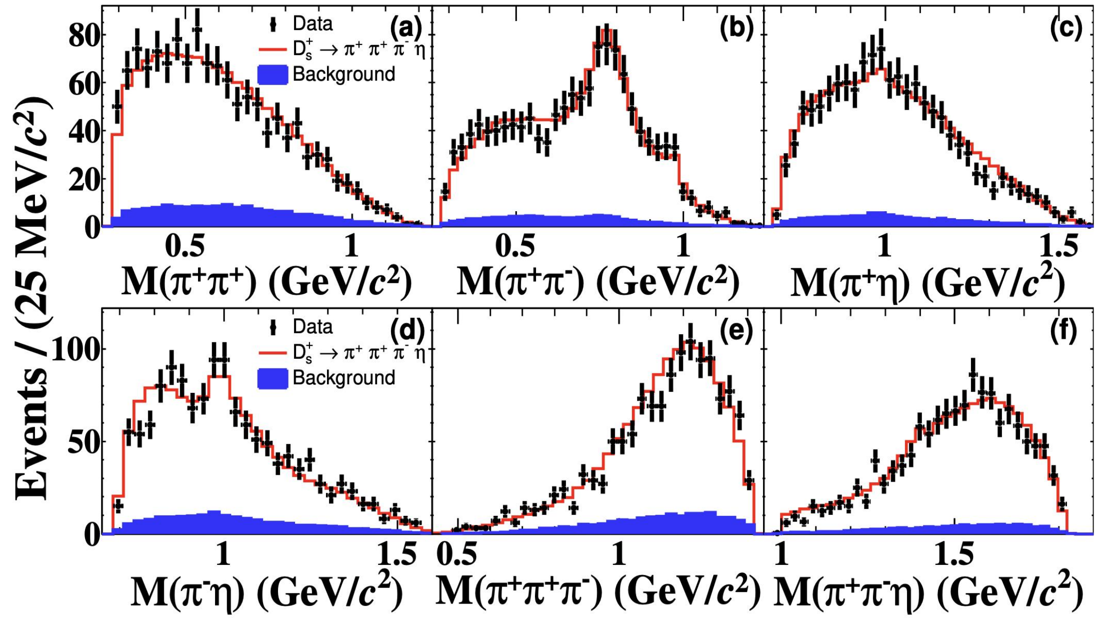
PRD 104, L071101 (2021)

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

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

Larger than other w-annihilation decays.

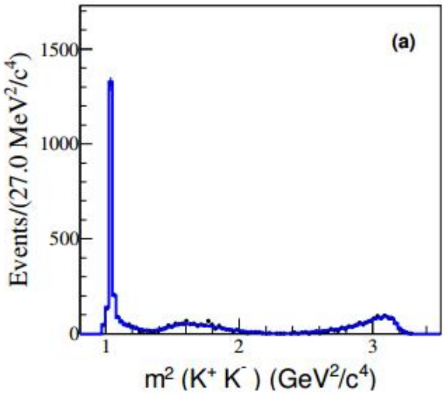
How about $D_s^+ \to a_0^+(980)\rho^0$? Does it have the same branching fraction?

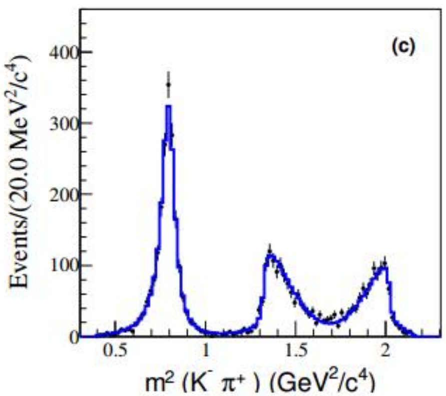


Amplitude	Phase	FF(%)
$a_1(1260)^+(\rho(770)^0\pi^+)\eta$	0.0(fixed)	$55.4\pm3.9\pm2.0$
$a_1(1260)^+(f_0(500)\pi^+)\eta$	$5.0\pm0.1\pm0.1$	$8.1\pm1.9\pm2.1$
$a_0(980)^+\rho(770)^0$	$2.5\pm0.1\pm0.1$	$6.7\pm2.5\pm1.5$
$\eta(1405)(a_0(980)^-\pi^+)\pi^+$	$0.2\pm0.2\pm0.1$	$0.7\pm0.2\pm0.1$
$\eta(1405)(a_0(980)^+\pi^-)\pi^+$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

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

Dalitz plot projections:





Black dots with error bars: data

Blue solid lines: fit results

PRD 104. 012016 (2021)

The best precision at present

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

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

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

Isospin configurations:

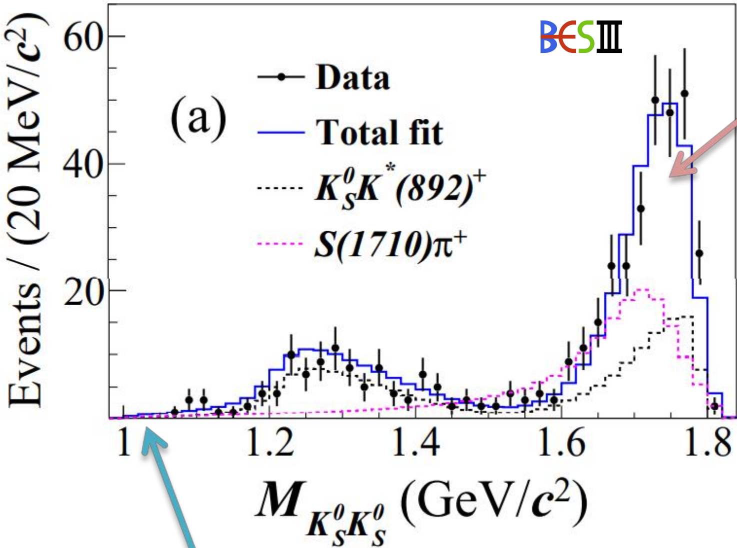
$a_0(980)$ I=1 $\to$ ($|K^+K^-\rangle$ - $|K^0\overline{K^0}\rangle$)

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

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

Observation of $a_0(1817)$ in D_s decays

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

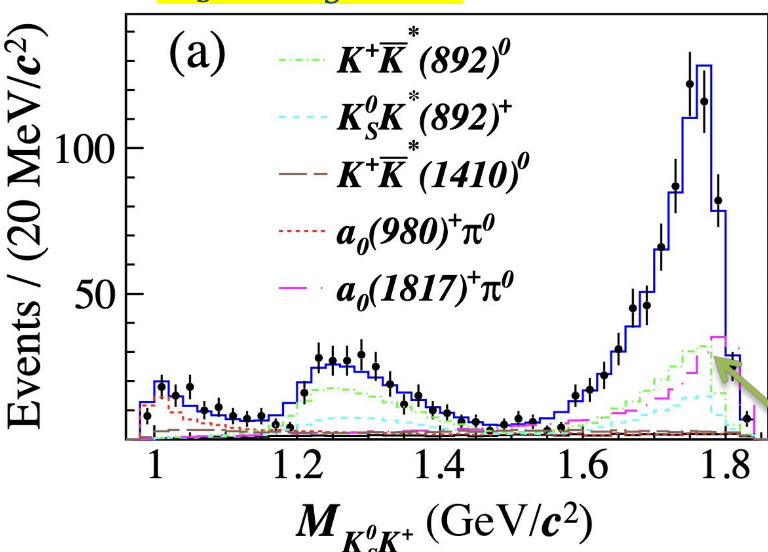


constructive interference: $a_0(1817)$ and $f_0(1710)$

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

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

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



PRD 104, 072002 (2021)

- M=$1.817 \pm 0.008 \pm 0.020$ GeV/c^2
- Γ= $0.097 \pm 0.022 \pm 0.015$ GeV/c^2
- $\mathcal{B}(D_s^+ \to a_0(1817)^+\pi^0)$ $= (3.44 \pm 0.52 \pm 0.32) \times 10^{-3}$
- Significance $> 10\sigma$

$a_0(1817)^+$ in $K_S^0 K^+$ mass spectrum

Studies of D_s decays

Amplitudes analyses:

$D_s^+ \to \pi^+\pi^0\eta$ Phys. Rev. Lett. **123**, 112001 (2019)

$D_s^+ \to K^+K^-\pi^+$ Phys. Rev. D 104, 112016 (2019)

$D_s^+ \to K^+K^-\pi^+\pi^0$ Phys. Rev. D 104, 032011 (2021)

$D_s^+ \to K_s^0K^-\pi^+\pi^+$ Phys. Rev. D 103 , 092006 (2021)

$D_s^+ \to \pi^+\pi^-\pi^+\eta$ Phys. Rev. D 104, L071101 (2021)

$D_s^+ \to K_S^0\pi^+\pi^0$ JHEP 06, 181 (2021)

$D_s^+ \to K_S^0K^+\pi^0$ Phys. Rev. Lett 129, 182001 (2022)

$D_s^+ \to K_S^0K_S^0\pi^+$, Phys. Rev. D 105, L051103 (2022)

$D_s^+ \to \pi^+\pi^0\eta'$ JHEP 04, 058 (2022)

$D_s^+ \to \pi^+\pi^-\pi^+$ Phys. Rev. D 106, 112006 (2022)

$D_s^+ \to \pi^+\pi^0\pi^0$ JHEP 01, 052 (2022)

$D_s^+ \to K^+\pi^+\pi^-$ JHEP 08, 196 (2022)

$D_S^+ \to K^+K^-\pi^+\pi^+\pi^-$ JHEP 07, 051 (2022)

$D_S^+ \to K^+\pi^+\pi^-\pi^0$ JHEP 09(2022) 242

$D_S^+ \to K^+\pi^+\pi^-$ JHEP 08(2022) 196

Amplitude analysis of five-body decays

Amplitude analysis of $D \to K\pi\pi\pi$

The measurement of the sub-modes in $D \to K\pi\pi\pi$ provides a window to study the decays $D \to AP$ and $D \to VV$ (*A*=axial-vector, *V*=vector).

- $a_1(1260)$, $K_1(1270)$,$K_1(1400)$ etc.
- polarization of $K^*\rho^*$etc.

1.$D^0 \to K^-\pi^+\pi^+\pi^-$ PRD 95, 072010 (2017)

2.$D^0 \to K^-\pi^+\pi^0\pi^0$ PRD 99, 092008 (2019)

3.$D^+ \to K_S^0\pi^+\pi^+\pi^-$ PRD 100, 072008 (2019)

4.$D^+ \to K_S^0\pi^+\pi^0\pi^0$ arXiv:2305.15879

Some other new amplitude analysis of D

$D^0 \to K_S^0K^+K^-$ arXiv:2006.02800

$D^0 \to K_L^0\pi^+\pi^-$ arXiv:2212.09048

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Observation of the DCSD $D^+ \to K^+\pi^+\pi^-\pi^0$

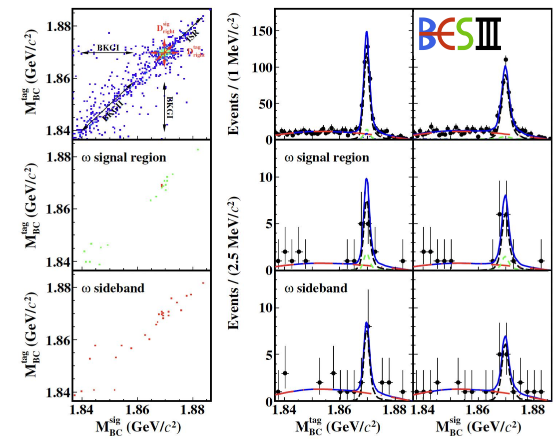
Use hadronic tags. 350 signal events

$$\mathcal{B}(D^+ \to K^+\pi^+\pi^-\pi^0) = (1.13 \pm 0.08 \pm 0.03) \times 10^{-3}$$

$$\frac{\mathcal{B}(D^+ \to K^+\pi^+\pi^-\pi^0)}{\mathcal{B}(D^+ \to K^-\pi^+\pi^+\pi^0)} = (1.81 \pm 0.15)\%$$

Corresponding to $(6.28 \pm 0.52)\ tan^4\theta_C$

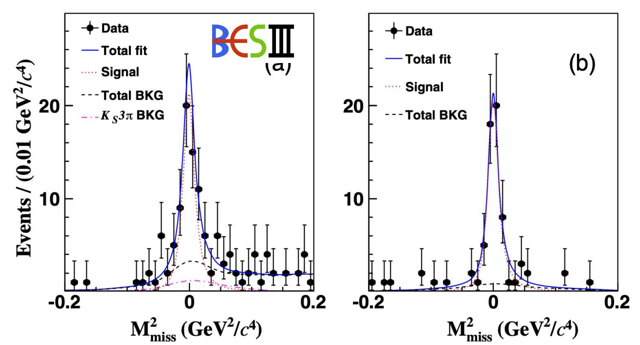
One order larger than normal



Use semileptonic tags. 112 signal events

$$\mathcal{B}(D^+ \to K^+\pi^+\pi^-\pi^0) = (1.03 \pm 0.12 \pm 0.06) \times 10^{-3}$$

First try of semileptonic tag at BESIII



PRD 104, 072005 (2021)

$D^+ \to K^+\pi^0\pi^0$ and $D^+ \to K^+\pi^0\eta$

$\mathcal{B}(D^+ \to K^+\pi^0\pi^0) = (2.1\pm0.4\pm0.1)\times10^{-4}$

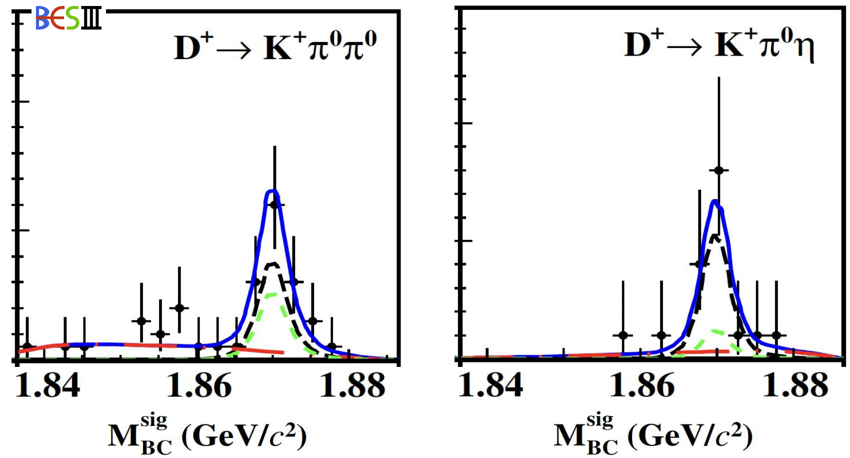
$\mathcal{B}(D^+ \to K^+\pi^0\eta) = (2.1\pm0.5\pm0.1)\times10^{-4}$

$$\frac{\mathcal{B}(D^+ \to K^+\pi^0\pi^0)}{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)} = (2.24 \pm 0.40) \times 10^{-3}$$

$(0.77 \pm 0.14)\ tan^4\theta_C$

$$\frac{\mathcal{B}(D^+ \to K^+\pi^0\eta)}{\mathcal{B}(D^+ \to \overline{K^0}\pi^+\eta)} = (8.01 \pm 1.97) \times 10^{-3}$$

$(2.64 \pm 0.68)\ tan^4\theta_C$



JHEP 09 (2022) 107

$D^0 \to K^+\pi^-\pi^0$ and $D^0 \to K^+\pi^-\pi^0\pi^0$

Can not distinguish D^0 and $\overline{D}^0$ in DCSD measurements with hadronic tag

$\mathcal{B}(D^0 \to K^+\pi^-\pi^0 = (3.13^{+0.60}_{-0.56} \pm 0.09) \times 10^{-4}$

$\mathcal{B}(D^0 \to K^+\pi^-\pi^0\pi^0) < 3.6 \times 10^{-4}$

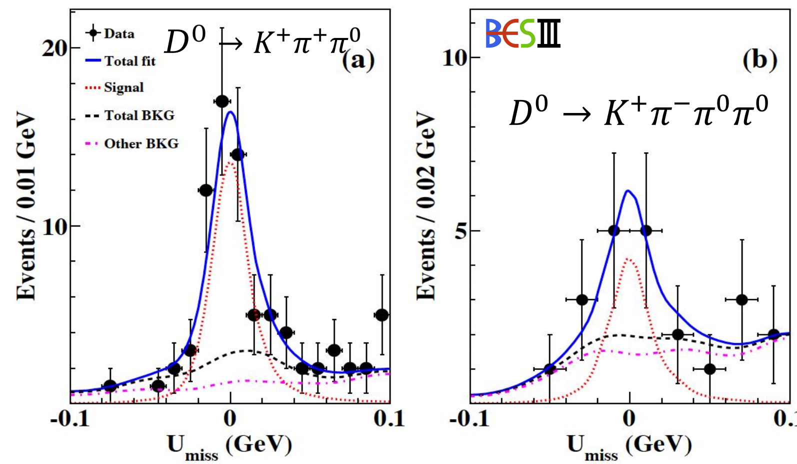
at the 90% C.L.

$$\frac{\mathcal{B}(D^0 \to K^+\pi^-\pi^0)}{\mathcal{B}(D^0 \to K^-\pi^+\pi^0)} = (0.22\pm0.44)\%$$

$(0.75\pm0.14)tan^4\theta_C$

$$\frac{\mathcal{B}(D^0 \to K^+\pi^-\pi^0\pi^0)}{\mathcal{B}(D^0 \to K^-\pi^+\pi^0\pi^0)} < 0.40\%$$

$< 1.37 \times tan^4\theta_C$



PRD105, 112001 (2022)

Measurement of the branching fractions for Cabibbo-suppressed decays $D^+ \to K^+K^-\pi^+\pi^0$ and $D^+_{(s)} \to K^+\pi^-\pi^+\pi^0$ at Belle

PRD 107, 033003 (2023)

Search for CP violation using T-odd correlations in $D^+_{(s)} \to K^+K^-\pi^+\pi^0$, $D^+_{(s)} \to K^+\pi^-\pi^+\pi^0$, and $D^+ \to K^-\pi^+\pi^+\pi^0$ decays

arXiv:2305.12806

Search for CP violation in $D^+_{(s)} \to K^+K^0_S h^+h^-$ $(h = K, \pi)$ decays and observation of the Cabibbo-suppressed decay $D^+_s \to K^+K^-K^0_S\pi^+$

arXiv:2305.11405

Measurement of the branching fraction and search for CP violation in $D^0 \to K^0_S K^0_S \pi^+\pi^-$ decays at Belle

PRD 107, 052001 (2023)

see Longke Li's talk at Charm 2023

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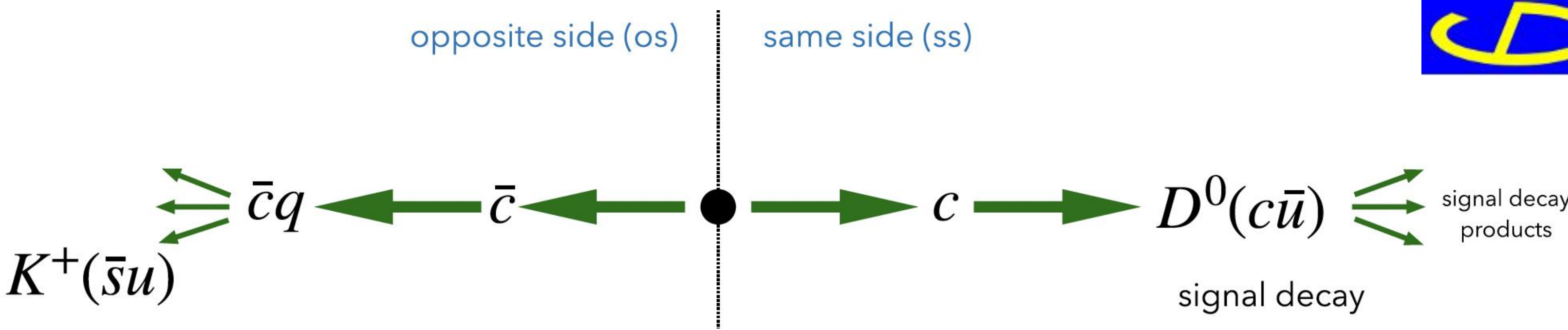
Novel method for the identification of the production flavor of neutral charmed mesons

Process: $e^+e^- \rightarrow$ two charm hadrons + fragmentation



CPV/mixing measurement → **flavor tagging:**

Standard approach: exclusive reconstruction of strong decay $D^{*+} \rightarrow D^0\pi^+$

New approach: exploit correlation between signal flavor and charge of particles reconstructed in the rest using BDT

# of tagged signal D^0 (125600 ± 350) + (127080 ± 280)

doubling the sample size!

PRD 107, 112010 (2023)

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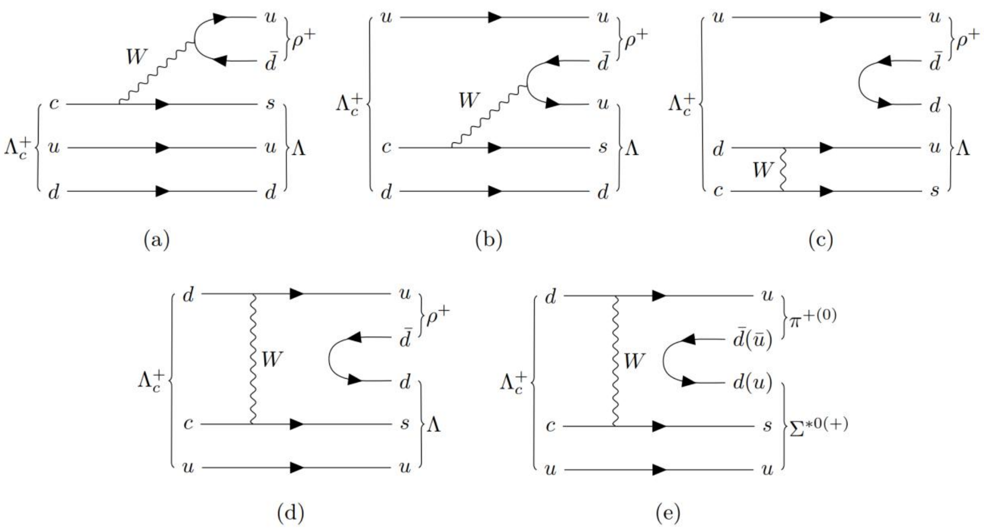
Partial wave analysis of the charmed baryon hadronic decay $\Lambda_c^+ \to \Lambda\pi^+\pi^0$



$\Lambda_c^+ \to \Lambda\rho^+$ consists of both factorizable(a) and non-factorizable(b-d) contributions.
$\Lambda_c^+ \to \Sigma(1385)\pi$ consists of pure non-factorizable(e) contribution.

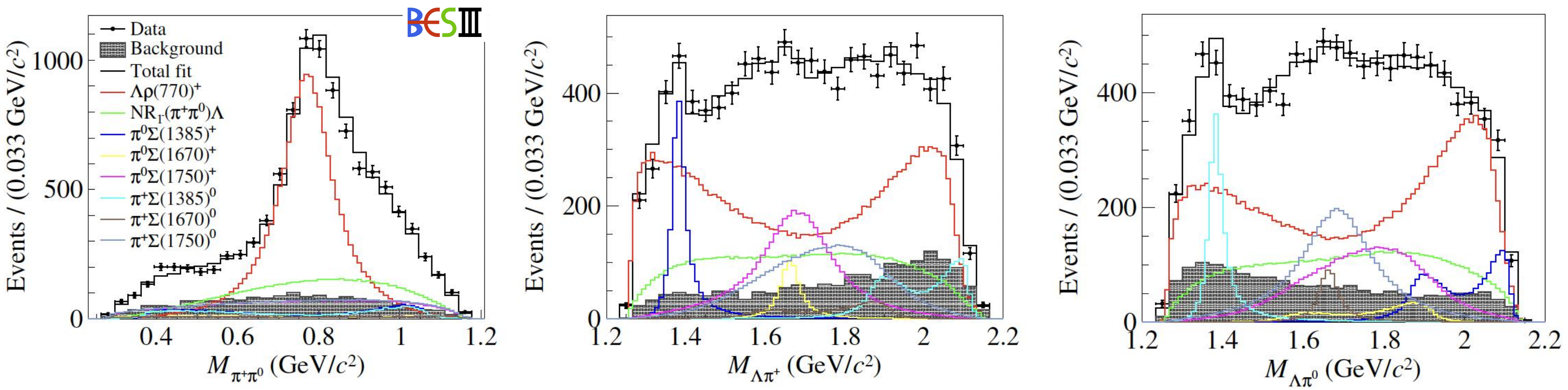
- Decay asymmetry parameters: relevant to the interference of the internal partial wave amplitudes.
- Provide important inputs to the theoretical calculations for non-factorizable.

Use new-developed Tensor Flow based package TF-PWA*.

(*BESIII Preliminary: https://github.com/jiangyi15/tf-pwa)

Partial wave analysis of the charmed baryon hadronic decay $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

JHEP12 (2022) 033



The first PWA of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

	Theoretical calculation		This work	PDG
$10^2 \times \mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)$	4.81 ± 0.58 [13]	4.0 [14, 15]	4.06 ± 0.52	< 6
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	5.86 ± 0.80	—
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+)$	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	—

The first measurement of the decay asymmetry parameters for the relevant resonance

Ref. [13]: PRD 101 (2020) 053002.
Ref. [14,15]: PRD 46 (1992) 1042; PRD 55 (1997) 1697.
Ref. [16]: EPJC 80 (2020) 1067.
Ref. [17]: PRD 99 (2019) 114022

- Introduction of BESIII charm datasets
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  - Amplitude analysis
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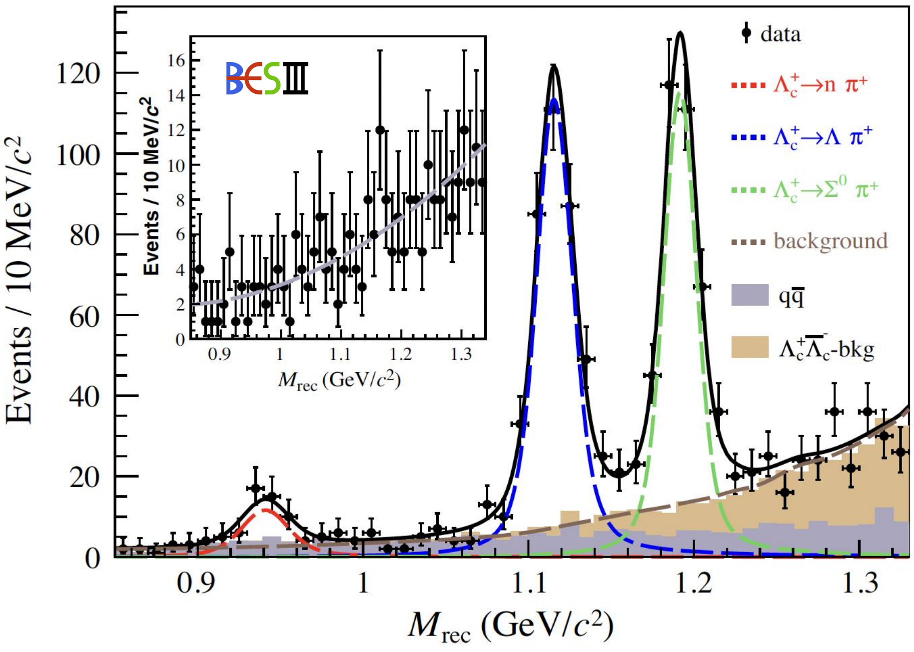
Measurement of the absolute branching fraction of the singly Cabibbo suppressed decays of $\Lambda_c^+ \to n\pi^+$

First measurement

$\mathcal{B}(\Lambda_c^+ \to n\pi^+)$
$=(6.6 \pm 1.2 \pm 0.4) \times 10^{-4}$

$\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+)$
$=(1.31 \pm 0.08 \pm 0.05) \times 10^{-2}$

$\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+)$
$=(1.22 \pm 0.08 \pm 0.07) \times 10^{-2}$



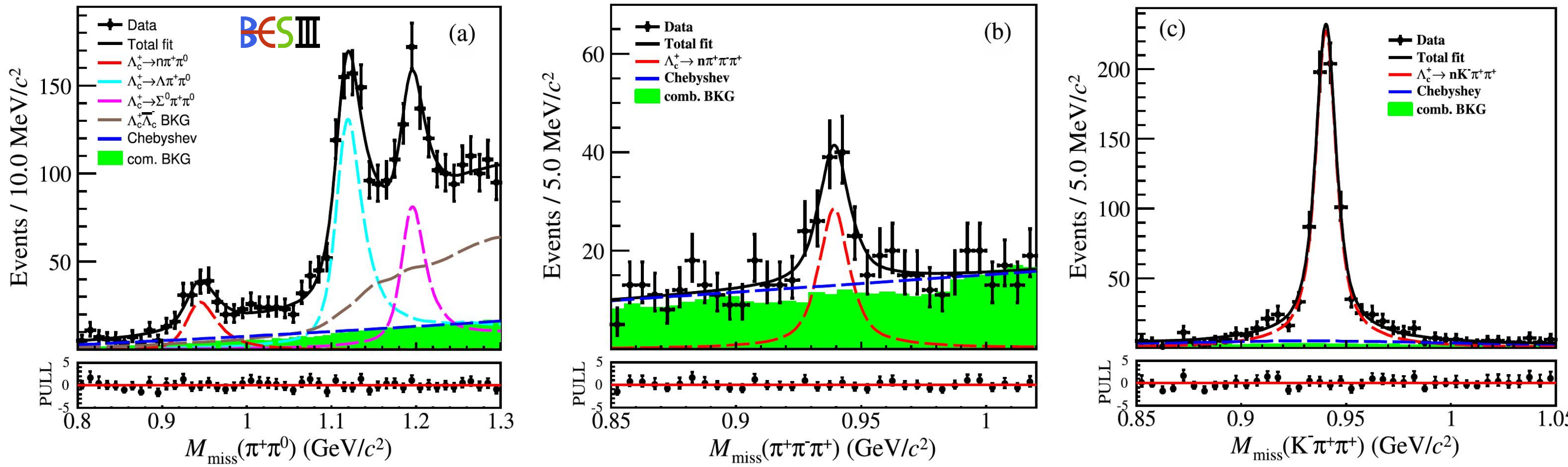
$\mathcal{B}(n\pi^+)/(p\pi^0)$> 7.2 at 90% C.L.

Use recoil mass to access neutron

- Disagrees with most predictions of the phenomenological models
- Nonfactorization contributions may be overestimated.

PRL 128, 142001 (2022)

Some other branching fractions about neutron final states



Signal decay		$\mathcal{B}$ (%)
$\Lambda_c^+ \to n\pi^+\pi^0$		$0.64 \pm 0.09 \pm 0.02$
$\Lambda_c^+ \to n\pi^+\pi^-\pi^+$	First Observation	$0.45 \pm 0.07 \pm 0.03$
$\Lambda_c^+ \to nK^-\pi^+\pi^+$		$1.90 \pm 0.08 \pm 0.09$

One order larger than $\mathcal{B}(n\pi^+)$.

$$\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)/\mathcal{B}(\Lambda_c^+ \to n\pi^0\pi^+) = 0.72 \pm 0.11$$

This result provides useful input to test of isospin.

CPC 47, 023001 (2023)

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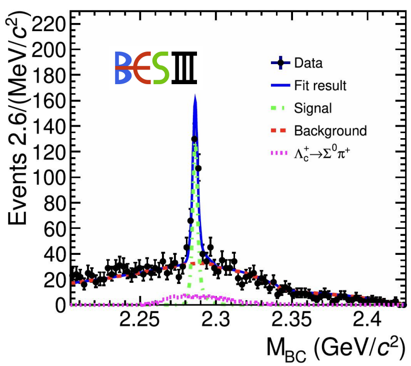
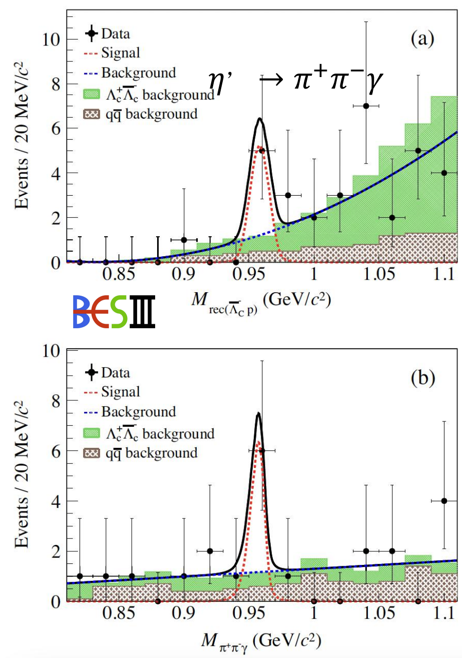
Some other branching fractions of the singly Cabibbo-suppressed decay of Λ_c^+

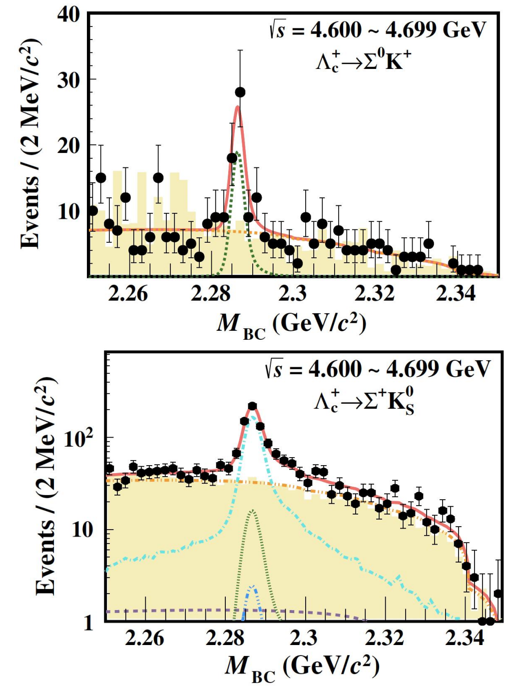


$\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)$
$= (6.21 \pm 0.44 \pm 0.26 \pm 0.34) \times 10^{-4}$

~40% Lower than SU(3) symmetry predictions, indicating the factorizable contributions are significantly underestimated.



$\mathcal{B}(\Lambda_c^+ \to \Lambda \eta')$
$=(5.62^{+2.46}_{-2.04} \pm 0.26) \times 10^{-4}$



First measurement

$\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+)$
$= (4.7 \pm 0.9 \pm 0.1 \pm 0.3) \times 10^{-4}$
$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S^0)$
$= (4.8 \pm 1.4 \pm 0.2 \pm 0.3) \times 10^{-4}$

PRD 106, L111101 (2022)

PRD 106, 072002 (2022)

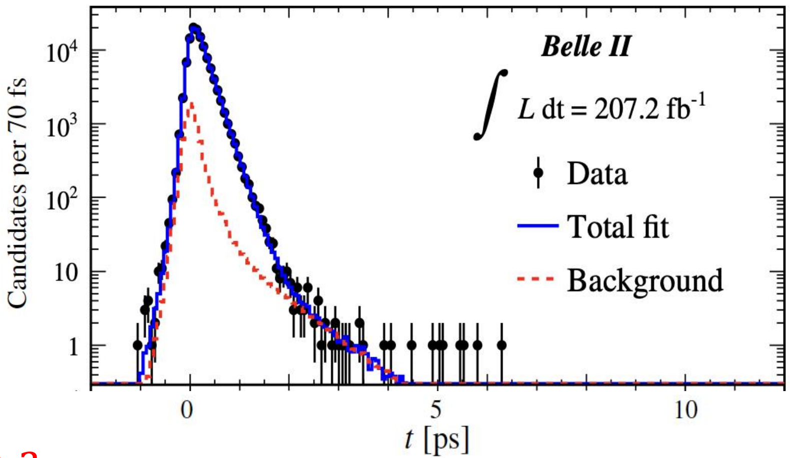
PRD106, 052003 (2022)

Measurement of the Λ_c^+ lifetime

PRL 130, 071802 (2023)

Use $\Lambda_c^+ \to pK^-\pi^+$ decays at high momentum (not from B decays)

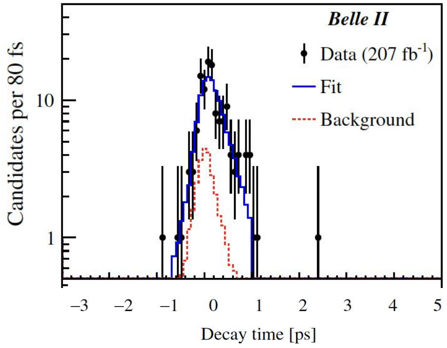
$$\tau(\Lambda_c^+) = 203.20 \pm 0.89 \pm 0.77 \text{ fs}$$



- World's best measurements
- Consistent with current world averages
- Tension with CLEO measurement remains

$$t = m_{\Lambda_c} \vec{L} \cdot \vec{p} / |\vec{p}|^2$$

Measurement of the Ω_c^0 lifetime



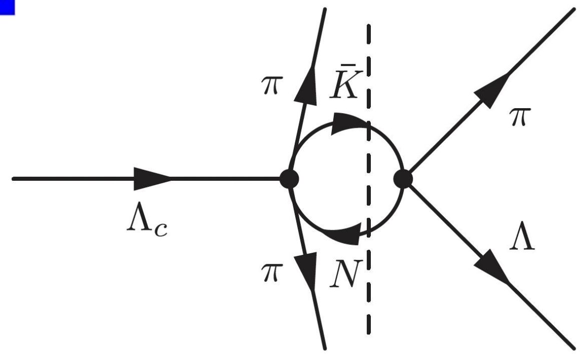
PRD 107, L031103 (2023)

$$\tau(\Omega_c^0) = 243 \pm 48(\text{stat}) \pm 11(\text{syst}) \text{ fs}.$$

Consistent with LHCb measurement

see Alan Schwartz's talk at Charm 2023

First Observation of $\Lambda\pi^+$ and $\Lambda\pi^-$ Signals near the $\bar{K}N(I=1)$ Mass Threshold in $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ Decay



$\overline{K} - N$ rescattering into $\Lambda\,\pi$

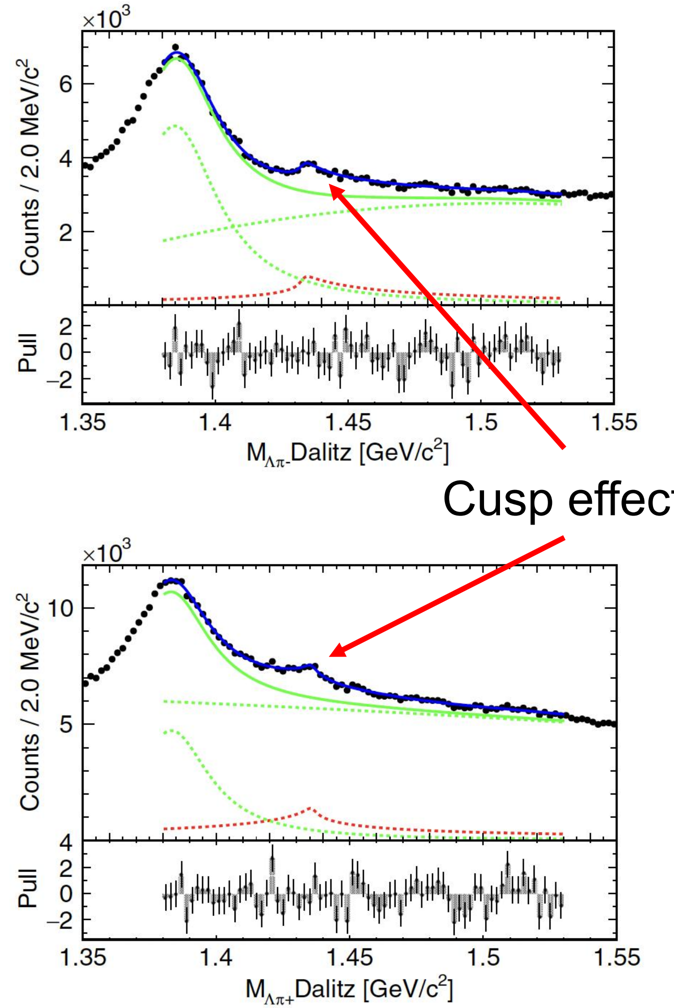
$$a + ib = \frac{g}{2(E_{\mathrm{BW}} - i\Gamma/2)}$$

Flatte parameterization

Scaling behavior

Mode	a (fm)	b (fm)
$\Lambda\pi^+$	0.48 ± 0.32	1.22 ± 0.83
$\Lambda\pi^-$	1.24 ± 0.57	0.18 ± 0.13

Interpretation as Σ^* is also tested



PRL130, 151903 (2023)

Measurements of branching fractions of $\Lambda_c^+ \to \Sigma^+\eta$ and $\Lambda_c^+ \to \Sigma^+\eta'$ and asymmetry parameters of $\Lambda_c^+ \to \Sigma^+\pi^0$, $\Lambda_c^+ \to \Sigma^+\eta$, and $\Lambda_c^+ \to \Sigma^+\eta'$

PRD 107, 032003 (2023)

Search for *CP* violation and measurement of branching fractions and decay asymmetry parameters for $\Lambda_c^+ \to \Lambda h^+$ and $\Lambda_c^+ \to \Sigma^0 h^+$ $(h = K, \pi)$

Science Bulletin 68 (2023) 583–592

Measurement of branching fractions of $\Lambda_c^+ \to pK_S^0K_S^0$ and $\Lambda_c^+ \to pK_S^0\eta$ at Belle

PRD 107, 032004 (2023)

First search for the weak radiative decays $\Lambda_c^+ \to \Sigma^+\gamma$ and $\Xi_c^0 \to \Xi^0\gamma$

PRD 107, 032001 (2023)

Measurement of the branching fraction of $\Xi_c^0 \to \Lambda_c^+\pi^-$ at Belle

PRD 107, 032005 (2023)

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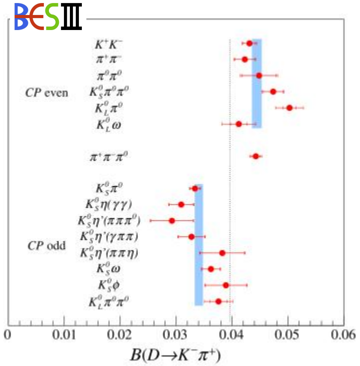
Determination of $\delta_D^{K\pi}$

EPJC 82 1009 (2022)

- An update measurement of the asymmetry between CP-odd and CP-even eigenstate decays into $K^-\pi^+$

30% more precise ！

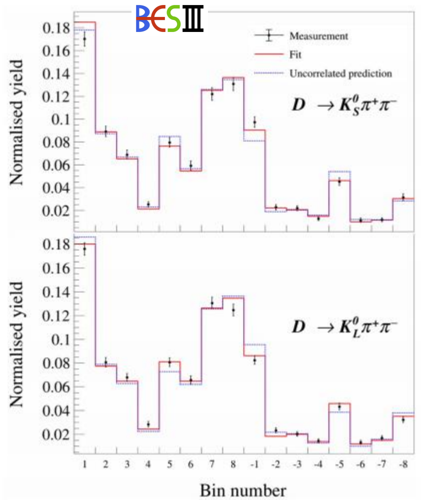


$$\mathcal{A}_{K\pi} \equiv \frac{\mathcal{B}(D_- \to K^-\pi^+) - \mathcal{B}(D_+ \to K^-\pi^+)}{\mathcal{B}(D_- \to K^-\pi^+) + \mathcal{B}(D_+ \to K^-\pi^+)} = \frac{-2r_D^{K\pi}\cos\delta_D^{K\pi} + y}{1 + \left(r_D^{K\pi}\right)^2} = 0.132 \pm 0.011 \pm 0.007$$

- Using the predominantly CP-even tag $D \to \pi^+\pi^-\pi^0$ and CP-odd eigenstate tags, we measured：

$$\mathcal{A}_{K\pi}^{\pi\pi\pi^0} \equiv \frac{\mathcal{B}(D_X \to K^-\pi^+) - \mathcal{B}(D_+ \to K^-\pi^+)}{\mathcal{B}(D_X \to K^-\pi^+) + \mathcal{B}(D_+ \to K^-\pi^+)} = \frac{\left(-2r_D^{K\pi}\cos\delta_D^{K\pi} + y\right)F_+^{\pi\pi\pi^0}}{1 + \left(r_D^{K\pi}\right)^2 + \left(1 - F_+^{\pi\pi\pi^0}\right)\left(2r_D^{K\pi}\cos\delta_D^{K\pi} + y\right)} = 0.130 \pm 0.012 \pm 0.008$$

- $\delta_D^{K\pi}$=$(187.6^{+8.9+5.4}_{-9.7-6.4})$

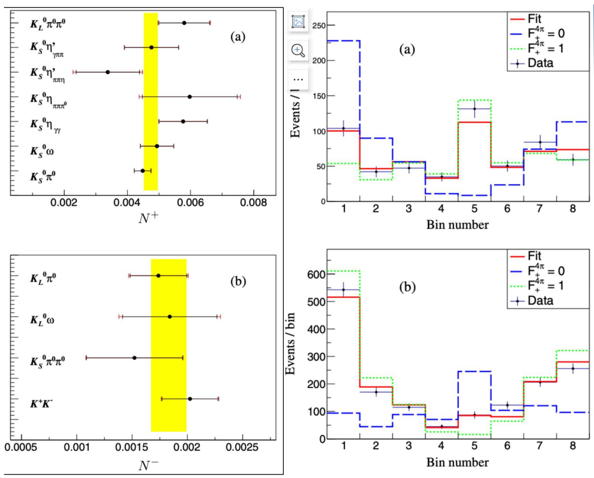


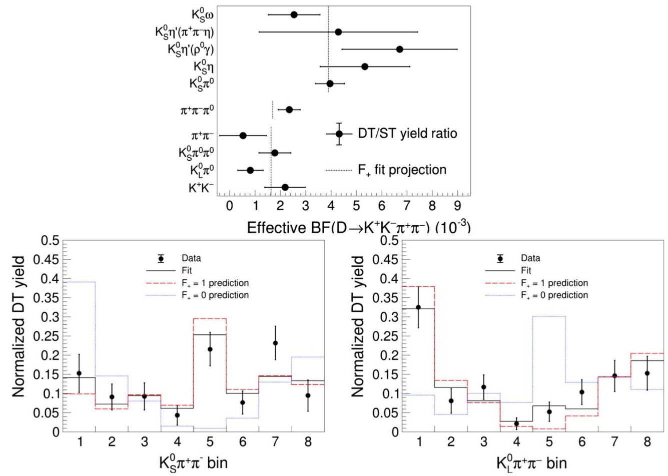
- With events containing both $D \to K^-\pi^+$ and $D \to K_{S,L}^0\pi^+\pi^-$ decays, which sensitive to $r_D^{K\pi}\cos\delta_D^{K\pi}$
- Studied in bins of phase space of the three-body decays
- Precision test of the theoretical prediction $\delta_D^{K\pi} = (183 \pm 5.7)°$[*]
- Most precise single measurements.
- $r_D^{K\pi}$, y and $F_+^{\pi\pi\pi^0}$ are constrained to measured values .

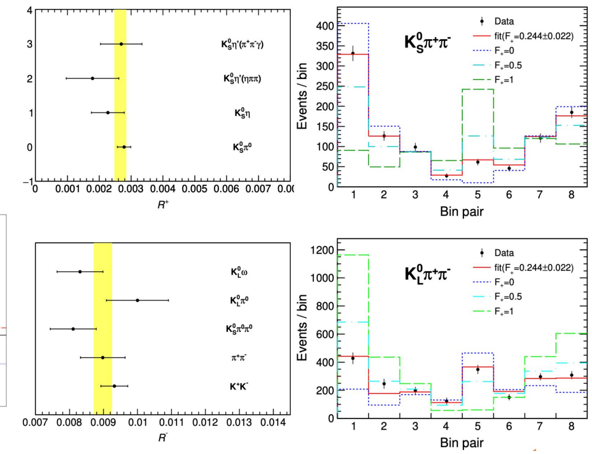
[*]PRD 99,113001(2019)

CP-even fraction measurement

BESIII







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

$F_+ = 0.735 \pm 0.015 \pm 0.005$

PRD 106 092004(2022)

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

$F_+ = 0.730 \pm 0.037 \pm 0.021$

PRD 107 032009(2023)

$D^0 \to K^0_S\pi^-\pi^+\pi^0$

$F_+ = 0.235 \pm 0.010 \pm 0.002$

arxiv:2305.03975

More

Decay mode	Quantities	Status (2.93 fb^{-1})
$K_S^0\pi^+\pi^-$	c_i, s_i	Finished(2020)
$K_S^0K^+K^-$	c_i, s_i	Finished(2021)
$K^-\pi^+\pi^+\pi^-$	R, δ	Finished(2020)
$K^+K^-\pi^+\pi^-$	F_+ or c_i, s_i	F_+Finished(2022),c_i, s_i on going
$\pi^+\pi^-\pi^+\pi^-$	F_+ or c_i, s_i	F_+Finished(2022),c_i, s_i on going
$K^-\pi^+\pi^0$	R, δ	Finished(2021)
$K_S^0K^\pm\pi^\mp$	R, δ	On going
$\pi^+\pi^-\pi^0$	F_+	On going
$K_S^0\pi^+\pi^-\pi^0$	F_+ or c_i, s_i	F_+Finished(2023),c_i, s_i on going
$K^+K^-\pi^0$	F_+	On going
$K^-\pi^+$	δ	Updated Finished (2022)

- Making progress in past few years.
- Many ongopng projects, eventually 20 fb^{-1} $\psi(3770)$ data samples.

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Summary

- **Comprehensive studies of D_s have been done.**
- **More precise measurements for D_0/D^+ decays in the near future with Belle II data (along with the new tagging method) and the new BESIII $\psi(3770)$ data.**
- **Many charmed baryon measurements are on going.**
- **BESIII can't access to "heavy" charmed baryons in short time. Need contributions from Belle II and LHCb.**

Thanks for your attention