

Charm Decays

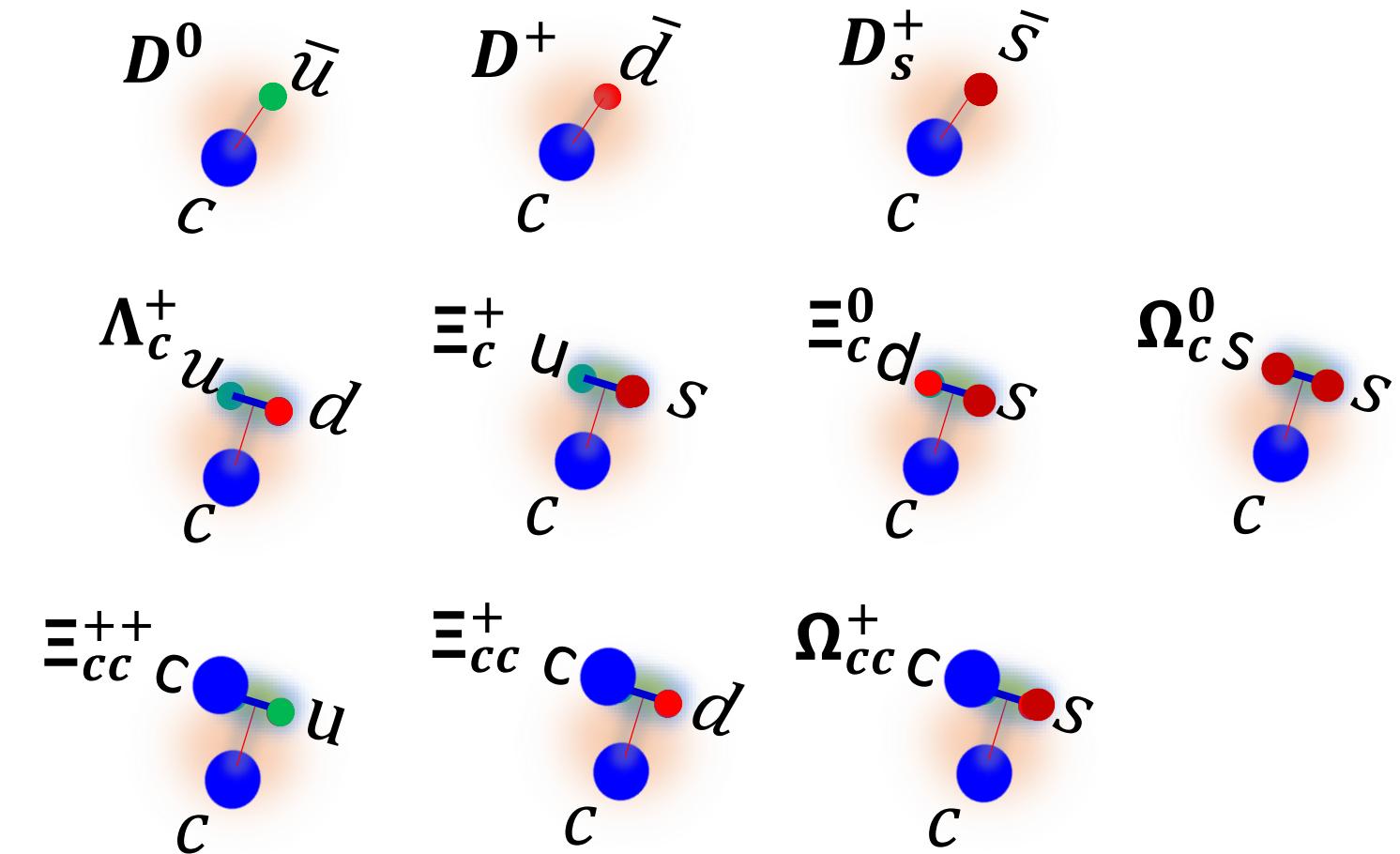
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Main contents

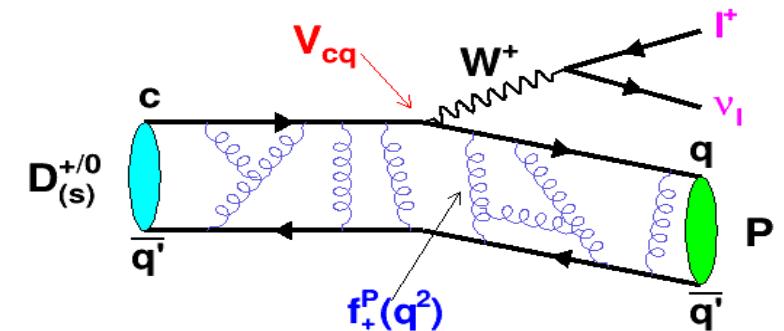
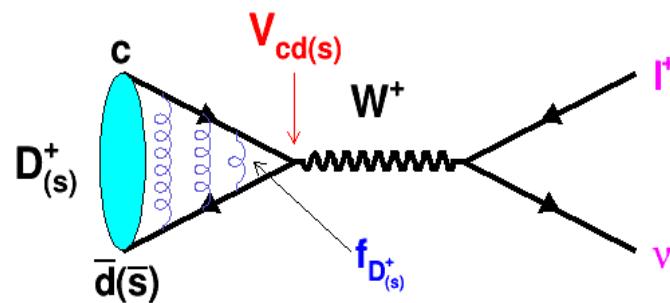
- Introduction
- Data samples
- (Semi)leptonic D decays
- Hadronic D decays
- Charmed baryon decays
- Summary



→ Selected topics in recent years, except $D^0\bar{D}^0$ mixing, CP violation and rare decays covered by Prasanth Krishnan's talk

(Semi)leptonic charm decays

Ideal bridge to access the strong and weak effects between quarks



$$\Gamma(D_{(s)}^+ \rightarrow \ell^+ \nu_\ell) = \frac{G_F^2}{8\pi} f_{D_{(s)}^+}^2 |V_{cd(s)}|^2 m_\ell^2 m_{D_{(s)}^+} \left(1 - \frac{m_\ell^2}{m_{D_{(s)}^+}^2}\right)^2$$

$$\frac{d\Gamma}{dq^2} = X \frac{G_F^2}{24\pi^3} |f_+(q^2)|^2 |V_{cq}|^2 |\vec{p}_h|^3$$

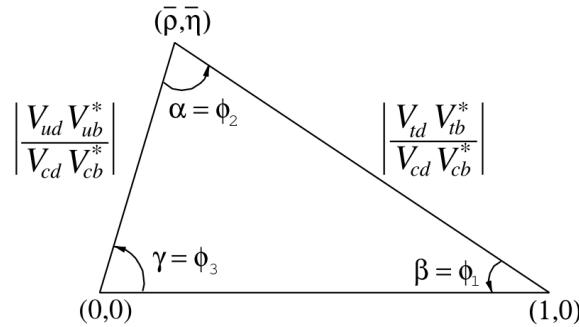
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} V_{us} V_{ub} \\ V_{cd} V_{cs} V_{cb} \\ V_{td} V_{ts} V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix elements: fundamental Standard Model (SM) parameters describing the mixing of quark fields due to weak interaction

- $|V_{cs}|$ and $|V_{cd}|$ → Test CKM matrix unitarity
- Decay constants and form factors → Calibrate LQCD calculations
- Branching fraction (BF) ratios → Test lepton flavor universality (LFU)

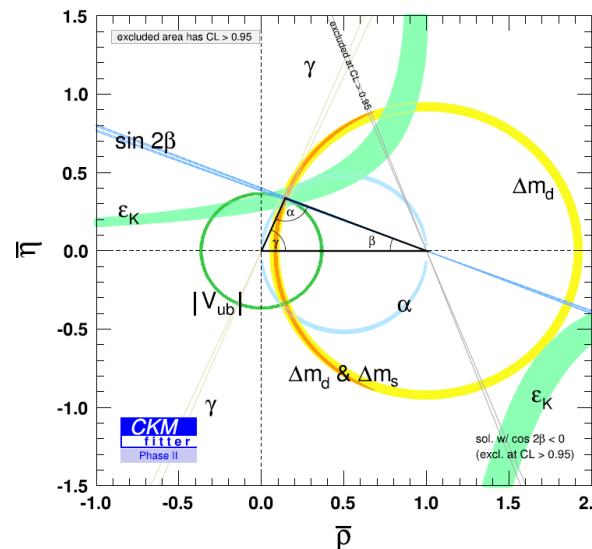
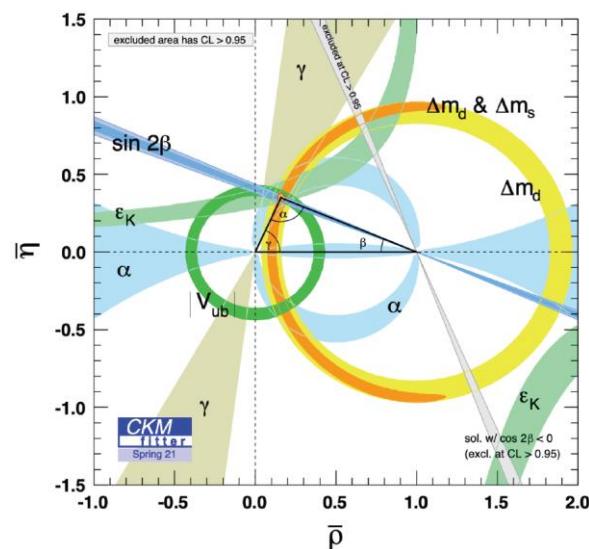
Search for new physics beyond the SM

Strong phase difference between hadronic D^0 and \bar{D}^0 decays



In B physics, precision measurements of CP violation phase angles α , β and γ offer powerful tests on the EW theories. Among them, the γ precision is the most urgent

Precision measurements of γ at LHCb and Belle II need input the strong phase differences of neutral D decays



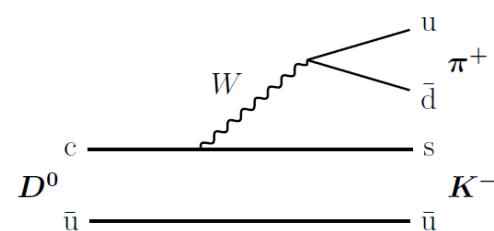
Quantum-correlated $e^+e^- \rightarrow \psi(3770) \rightarrow D^0\bar{D}^0$ pairs at BESIII offer an ideal opportunity to extract the strong phase differences between D^0 and \bar{D}^0

In the future 10-15 years, the statistical uncertainties of the γ measurements will reach at $\sim 1.5^\circ$ and 0.4° at Belle II and LHCb upgrade

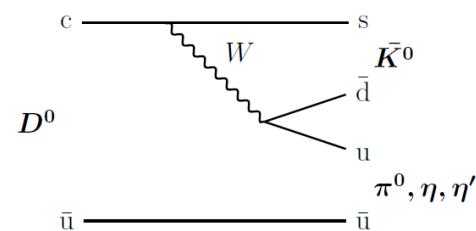
The constraint on the γ measurement before BESIII is only 2° . Improved measurements of strong phase differences are highly desirable

Amplitude analyses of hadronic charm decays

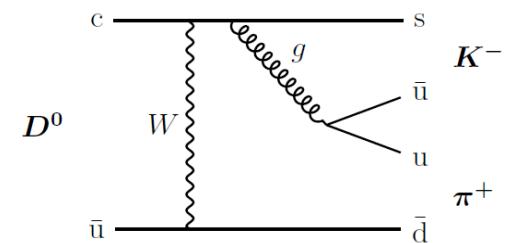
Typical Feynman diagrams of two-body hadronic D decays ($D \rightarrow VP, PP$ for example)



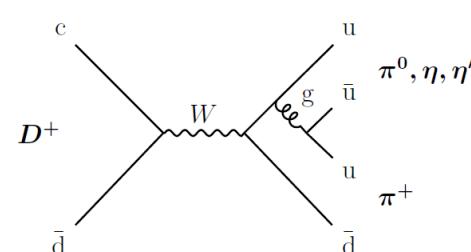
Tree



Color suppressed



W-exchange



Annihilation

Measurements of absolute BFs → test theoretical calculations of these BFs or decay asymmetry parameters, benefit the understanding of the quark SU(3) flavor symmetry and its break effect, help to deeply explore the effects of $D^0 - \bar{D}^0$ mixing and CP violation in the charm sector

Amplitude analysis of multi-body hadronic charm decays → mass and width of light hadrons which are beneficial to understand light hadron spectroscopy, more information of $D \rightarrow VP, PS, VV, TS, TP, AP\dots$

P, V, S, A, T denote pseudoscalar, vector, scalar, axial-vector and tensor mesons, respectively

Charmed baryon decays

- Knowledge is poor. Taking Λ_c^+ as example
- Λ_c^+ was observed in 1979
- Before 2014, all decays of Λ_c^+ are measured relative to $\Lambda_c^+ \rightarrow pK^-\pi^+$, which suffers large uncertainty of 25%, with data at high energy range. No absolute measurement using data produced at Λ_c^+ pair threshold
- Sum of the BFs of known Λ_c^+ decays is only about 60%
- Similar situation for the other charmed baryons Ξ_c^- , Ξ_c^0 , Ω_c^0 , Ξ_{cc}^{++} and Ξ_{cc}^+

Intensive studies of these charmed baryons, search for new decays and absolute BF measurements are important to fully explore charmed baryon decay mechanisms

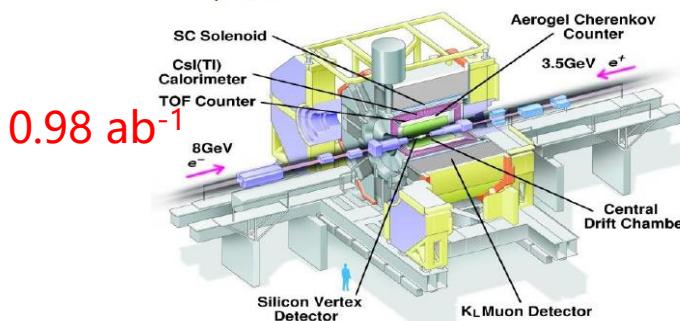
Λ_c^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S = -1$ final states			
$p\bar{K}^0$	(2.3 \pm 0.6) %		873
$pK^-\pi^+$	[a] (5.0 \pm 1.3) %		823
$p\bar{K}^*(892)^0$	[b] (1.6 \pm 0.5) %		685
$\Delta(1232)^{++}K^-$	(8.6 \pm 3.0) $\times 10^{-3}$		710
$\Lambda(1520)\pi^+$	[b] (1.8 \pm 0.6) %		627
$pK^-\pi^+$ nonresonant	(2.8 \pm 0.8) %		823
$p\bar{K}^0\pi^0$	(3.3 \pm 1.0) %		823
$p\bar{K}^0\eta$	(1.2 \pm 0.4) %		568
Hadronic modes with a hyperon: $S = -1$ final states			
$\Lambda\pi^+$	(1.07 \pm 0.28) %		864
$\Lambda\pi^+\pi^0$	(3.6 \pm 1.3) %		844
$\Lambda\rho^+$	< 5 %	CL=95%	636
$\Lambda\pi^+\pi^+\pi^-$	(2.6 \pm 0.7) %		807
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+} \rightarrow$	(7 \pm 4) $\times 10^{-3}$		688
$\Lambda\pi^+$	(5.5 \pm 1.7) $\times 10^{-3}$		688
$\Sigma(1385)^-\pi^+\pi^+$, $\Sigma^{*-} \rightarrow$			
$\Lambda\pi^-$	(1.1 \pm 0.5) %		524
$\Lambda\pi^+\rho^0$	(3.7 \pm 3.1) $\times 10^{-3}$		363
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+} \rightarrow \Lambda\pi^+$	< 8 $\times 10^{-3}$	CL=90%	807
$\Lambda\pi^+\pi^+\pi^-\pi^0$ total	(1.8 \pm 0.8) %		757
$\Lambda\pi^+\eta$	[b] (1.8 \pm 0.6) %		691
$\Sigma(1385)^+\eta$	[b] (8.5 \pm 3.3) $\times 10^{-3}$		570
$\Lambda\pi^+\omega$	[b] (1.2 \pm 0.5) %		517
$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω	< 7 $\times 10^{-3}$	CL=90%	757
$\Lambda K^+\bar{K}^0$	(4.7 \pm 1.5) $\times 10^{-3}$	S=1.2	443
$\Xi(1690)^0K^+$, $\Xi^{*0} \rightarrow \Lambda\bar{K}^0$	(1.3 \pm 0.5) $\times 10^{-3}$		286
$\Sigma^0\pi^+$	(1.05 \pm 0.28) %		825
$\Sigma^+\pi^0$	(1.00 \pm 0.34) %		827
$\Sigma^+\eta$	(5.5 \pm 2.3) $\times 10^{-3}$		713
$\Sigma^+\pi^+\pi^-$	(3.6 \pm 1.0) %		804
$\Sigma^+\rho^0$	< 1.4 %	CL=95%	575
$\Sigma^-\pi^+\pi^+$	(1.7 \pm 0.5) %		799
$\Sigma^0\pi^+\pi^0$	(1.8 \pm 0.8) %		803
$\Sigma^0\pi^+\pi^+\pi^-$	(8.3 \pm 3.1) $\times 10^{-3}$		763
$\Sigma^+\pi^+\pi^-\pi^0$	—		767
$\Sigma^+\omega$	[b] (2.7 \pm 1.0) %		569
Semileptonic modes			
$\Lambda e^+\nu_e$	[c] (2.0 \pm 0.6) %		871
$\Lambda\mu^+\nu_\mu$	(2.1 \pm 0.6) %		871
	(2.0 \pm 0.7) %		867
Inclusive modes			
e^+ anything	(4.5 \pm 1.7) %		—
$p e^+$ anything	(1.8 \pm 0.9) %		—
p anything	(50 \pm 16) %		6

Experiments and data samples

Belle @ KEKB



$e^+e^- : \sim 10.6 \text{ GeV } (\Upsilon(4S))$
 $\sigma(e^+e^- \rightarrow cc) = 1.3 \text{ nb}$
 $L_{\text{peak}} = 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

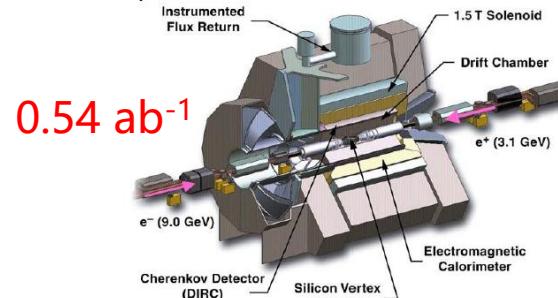


0.98 ab^{-1}

BaBar @ PEP-II

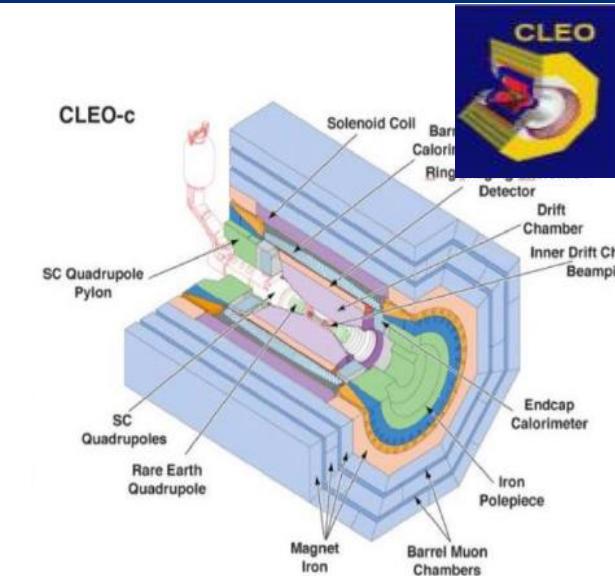


$e^+e^- : \sim 10.6 \text{ GeV } (\Upsilon(4S))$
 $\sigma(e^+e^- \rightarrow cc) = 1.3 \text{ nb}$
 $L_{\text{peak}} = 1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$



0.54 ab^{-1}

CLEO-c



$0.8 \text{ fb}^{-1} @ 3.774 \text{ GeV}$

$0.6 \text{ fb}^{-1} @ 4.170 \text{ GeV}$

BESIII @ BEPC II



$e^+e^- : 2-4.6 \text{ GeV}$

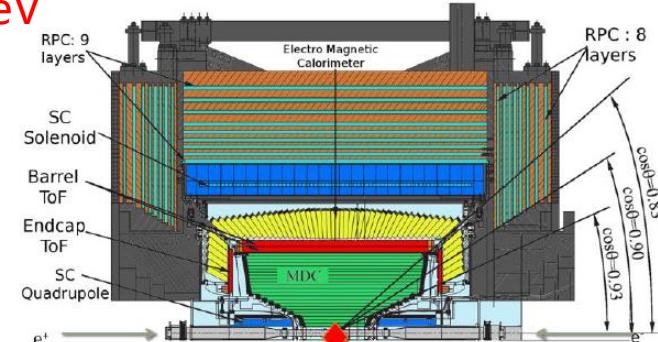
$\sigma(e^+e^- \rightarrow cc) = 3 \text{ nb}$

$L_{\text{peak}} = 1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

$2.93 \text{ fb}^{-1} @ 3.773 \text{ GeV}$

$7.33 \text{ fb}^{-1} @ 4.13-4.23 \text{ GeV}$

$4.50 \text{ fb}^{-1} @ 4.6-4.7 \text{ GeV}$



LHCb @ LHC



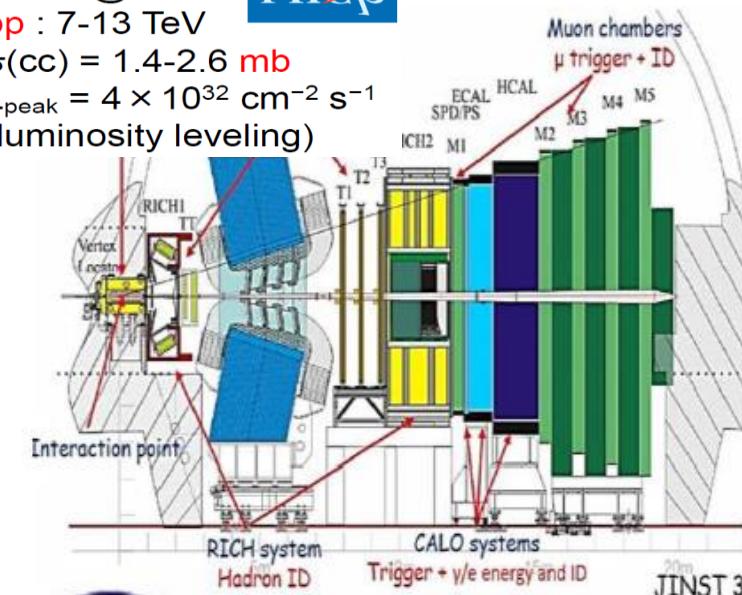
$pp : 7-13 \text{ TeV}$

$\sigma(cc) = 1.4-2.6 \text{ mb}$

$L_{\text{peak}} = 4 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

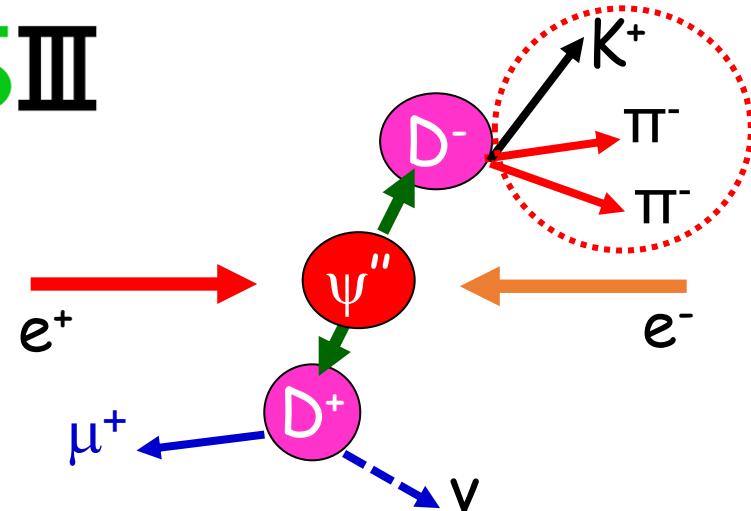
(luminosity leveling)

9 fb^{-1}



The world largest threshold hadron samples at BESIII

BESIII



Produced in pair → Double tag method
Low background → low systematic uncertainties
Quantum correlation for $\psi(3770) \rightarrow D^0 \bar{D}^0$ pairs

Yields of Singly Tagged (ST) charmed hadrons

E_{cm} (GeV)	Data taking year	L (fb^{-1})	ST D^0 yield	ST D^+ yield	ST D_s^+ yield	ST Λ_c^+ yield
3.773	2010-2011 (+2022)	2.93 ($\rightarrow 8$)	2.5M (2.7 \times)	1.7M (2.7 \times)		
4.009	2011	0.48			13K	
4.13-4.23	2016,2017,2012,2019	7.33			0.8M	
4.6-4.7	2014, 2020	4.5				0.12M

Total yields of various charmed hadrons at BESIII are lower than Belle and LHCb by 2-3 orders. However, BESIII, Belle and LHCb have complimentary advantages in various charm physics

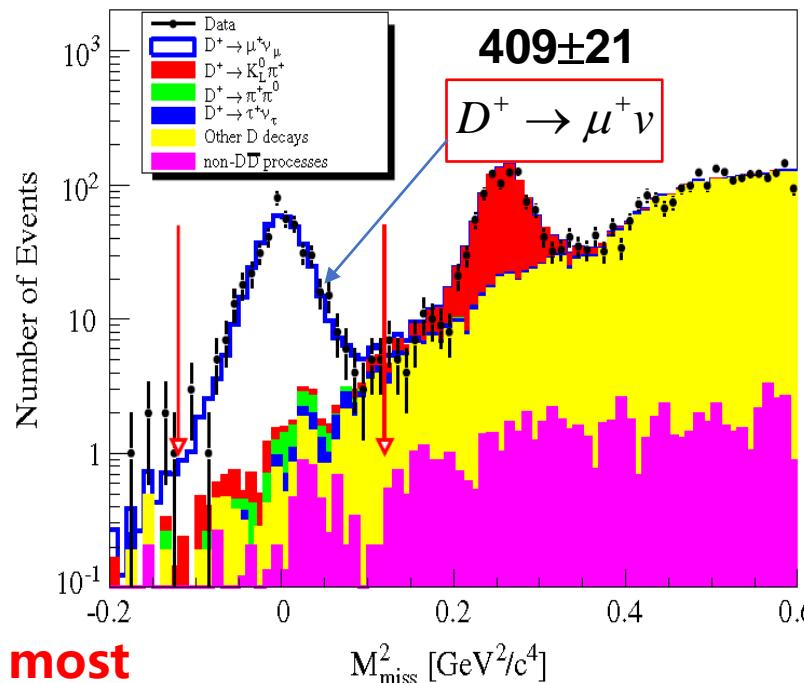
(Semi)leptonic D decays

- Leptonic D decays
- Semileptonic decays of $D \rightarrow Pe^+\nu_e$
- Semileptonic decays of $D \rightarrow Ve^+\nu_e$
- Semileptonic decays of $D \rightarrow Se^+\nu_e$
- Semileptonic decays of $D \rightarrow Ae^+\nu_e$

Studies of $D^+ \rightarrow l^+\nu_l$

BESIII

PRD89(2014)051104

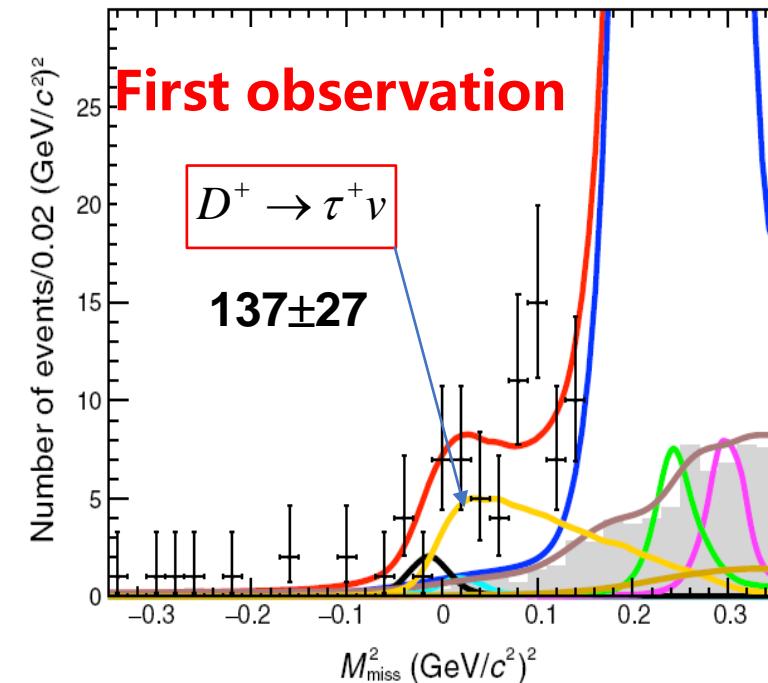


$$\mathcal{B}[D^+ \rightarrow \mu^+\nu] = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$$

$$f_{D^+}|V_{cd}| = 46.7 \pm 1.2 \pm 0.4 \text{ MeV}$$

Precision~2.7%

PRL123(2019)211802



$$\mathcal{B}[D^+ \rightarrow \tau^+\nu] = (1.20 \pm 0.24 \pm 0.12) \times 10^{-3}$$

$$f_{D^+}|V_{cd}| = 50.4 \pm 5.0 \pm 2.5 \text{ MeV}$$

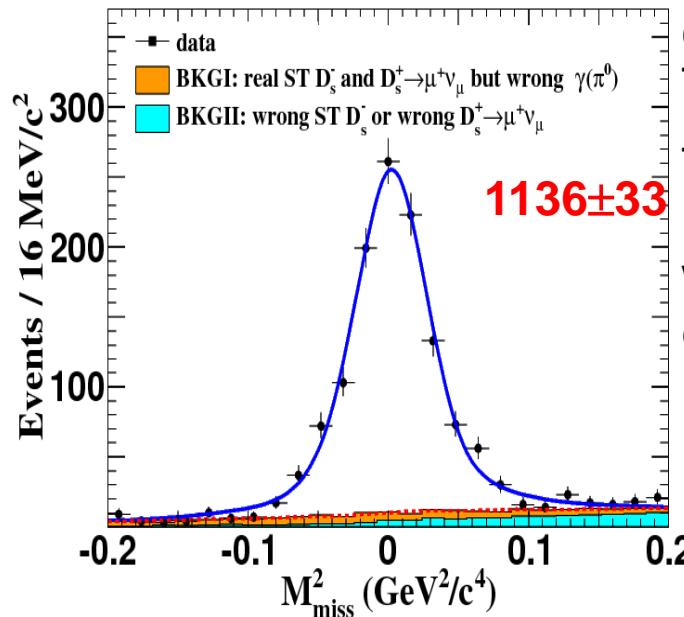
Precision~11%

Studies of $D_s^+ \rightarrow \mu^+\nu_\mu$

BESIII

3.19 fb⁻¹@4.18 GeV

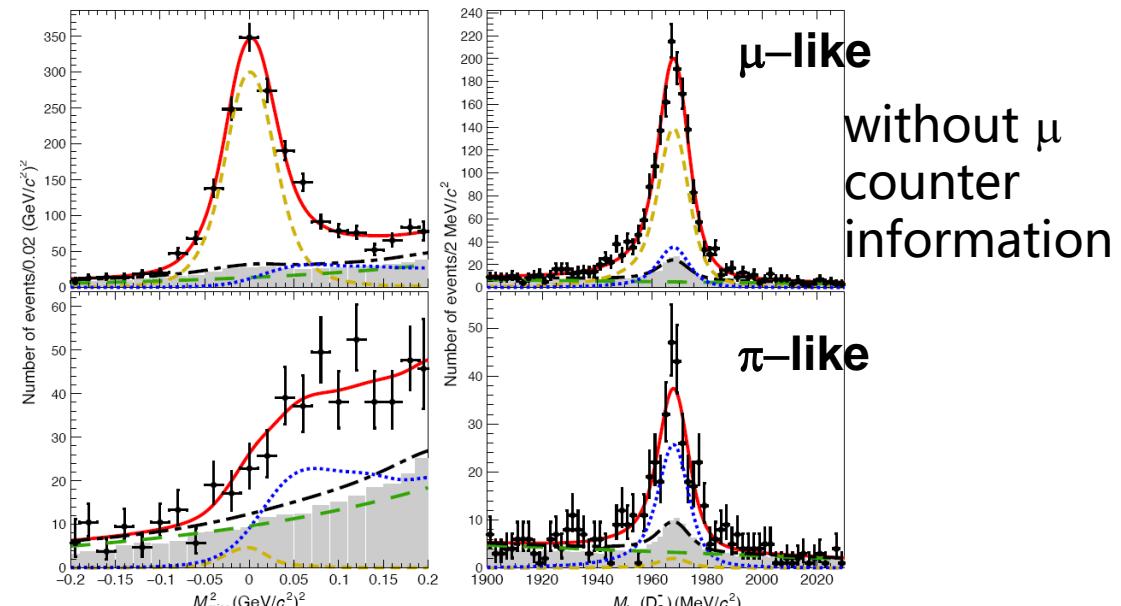
PRL122(2019)071802



Constrained fit
to matched and
un-matched
transition $\gamma(\pi^0)$
with μ
counter
information

6.3 fb⁻¹@4.18-4.23GeV

PRD104(2021)052009



2198±55

$$\mathcal{B}[D_s^+ \rightarrow \mu^+\nu] = (5.49 \pm 0.16 \pm 0.15) \times 10^{-3}$$

$$f_{D_s^+} |V_{cs}| = (246.2 \pm 3.6 \pm 3.5) \text{ MeV}$$

Precision~2.1%

$$\mathcal{B}[D_s^+ \rightarrow \mu^+\nu] = (5.35 \pm 0.13 \pm 0.16) \times 10^{-3}$$

$$f_{D_s^+} |V_{cs}| = (243.1 \pm 3.0 \pm 3.7) \text{ MeV}$$

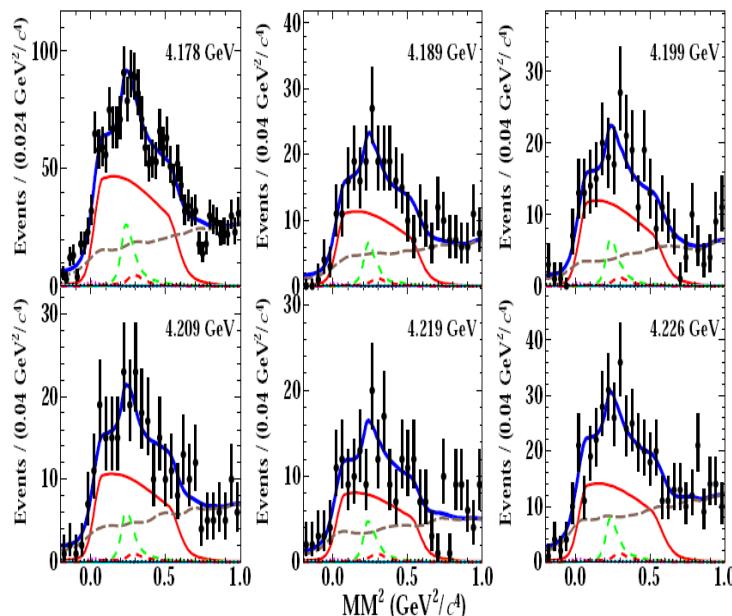
Precision~2.0%

Studies of $D_s^+ \rightarrow \tau^+\nu_\tau$

BESIII PRD104(2021)032001

$$D_s^+ \rightarrow \tau^+(\rho^+\nu)\nu$$

6.3 fb⁻¹



$$\text{B}[D_s^+ \rightarrow \tau^+\nu] = (5.29 \pm 0.25 \pm 0.20)\%$$

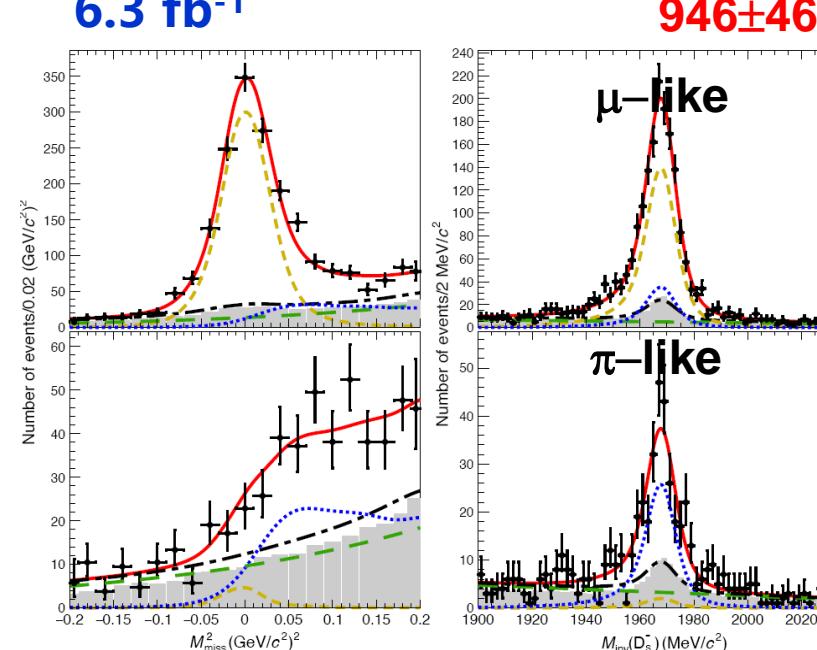
$$f_{D_s^+} |V_{cs}| = (244.8 \pm 5.8 \pm 4.8) \text{ MeV}$$

Precision~3.1%

PRD104(2021)052009

$$D_s^+ \rightarrow \tau^+(\pi^+\nu)\nu$$

6.3 fb⁻¹



$$\text{B}[D_s^+ \rightarrow \tau^+\nu] = (5.21 \pm 0.25 \pm 0.17)\%$$

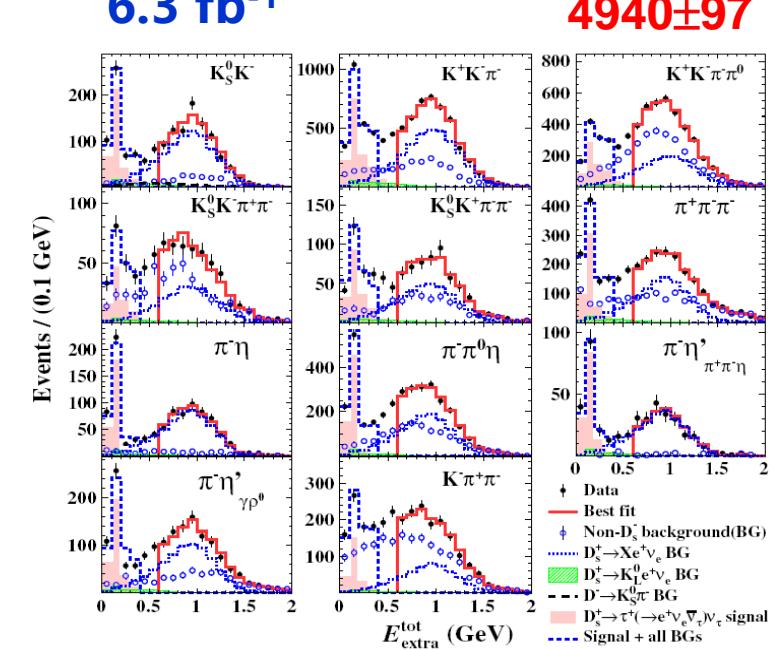
$$f_{D_s^+} |V_{cs}| = (243.0 \pm 5.8 \pm 4.0) \text{ MeV}$$

Precision~2.9%

PRL127(2021)171801

$$D_s^+ \rightarrow \tau^+(e^+\nu\nu)\nu$$

6.3 fb⁻¹

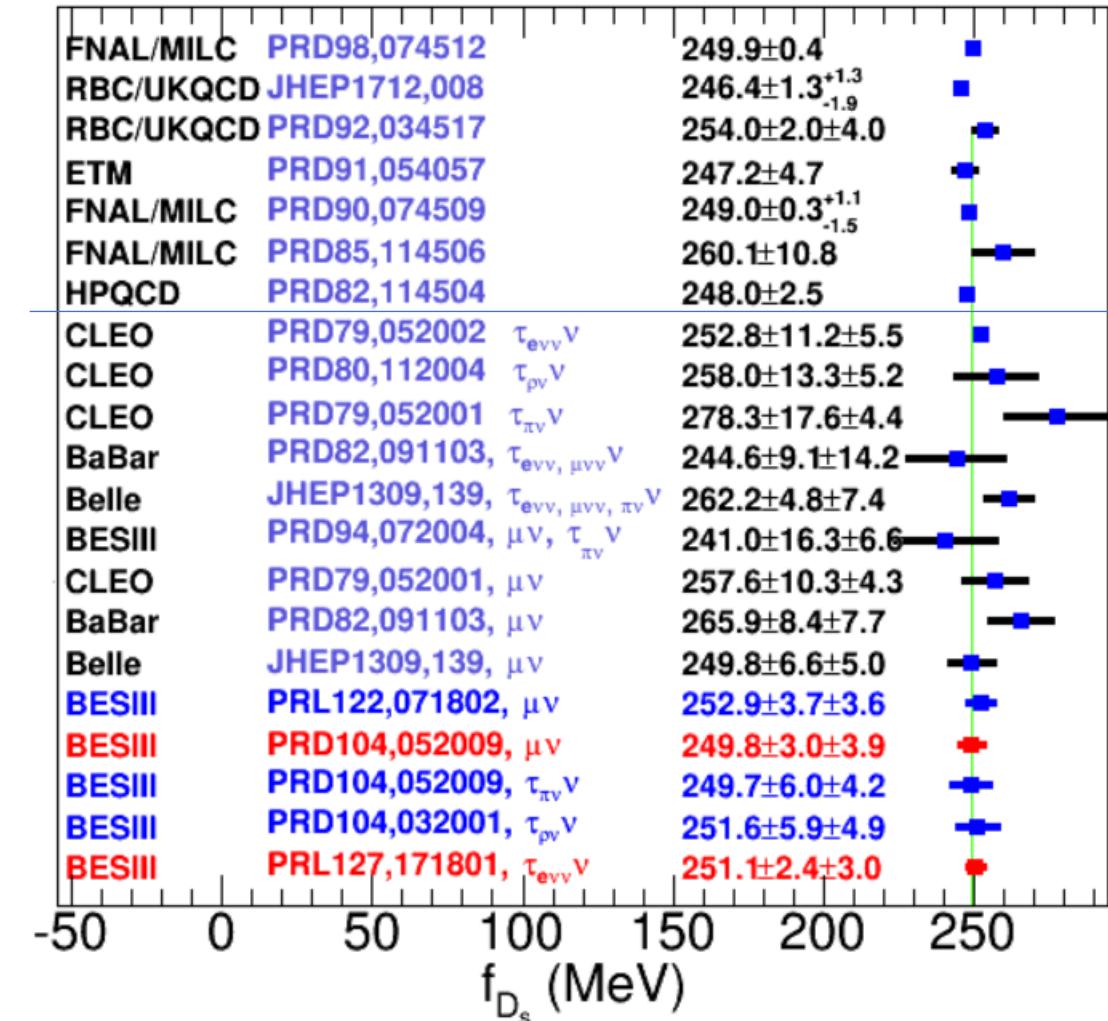
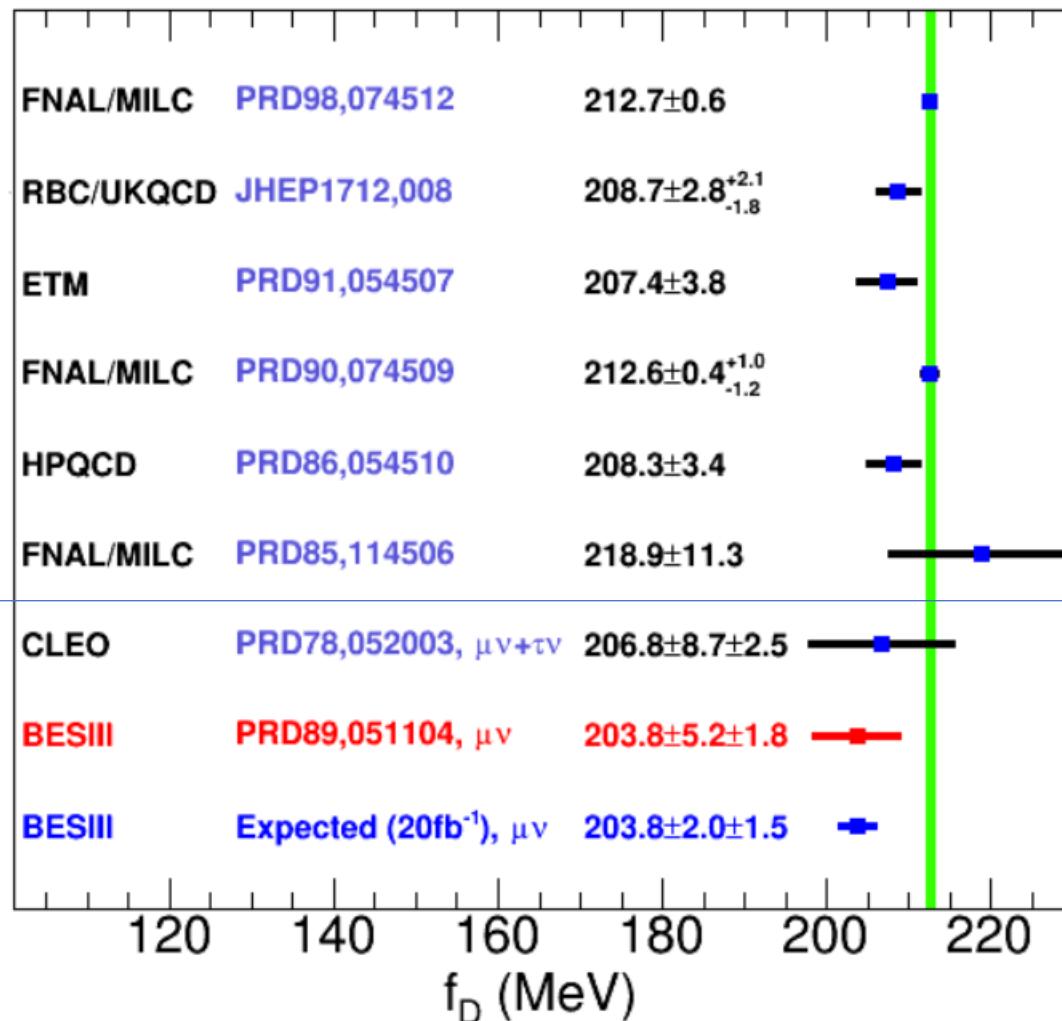


$$\text{B}[D_s^+ \rightarrow \tau^+\nu] = (5.27 \pm 0.10 \pm 0.12)\%$$

$$f_{D_s^+} |V_{cs}| = (244.4 \pm 2.3 \pm 2.9) \text{ MeV}$$

Precision~1.5%
The most precise to date

Comparisons of f_{D^+} and $f_{D_s^+}$



Studies of $D \rightarrow Pl^+\nu_l$ dynamics

Dynamic study

$$\frac{d\Gamma}{dq^2} = X \frac{G_F^2 |V_{cd(s)}|^2}{24\pi^3} p^3 |f_+(q^2)|^2 \longrightarrow f_+^{D \rightarrow P}(0) |V_{cs(d)}|$$

Form factor parameterizations:

– Single pole form

$$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{M_{\text{pole}}^2}}$$

– Modified pole

$$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{M_{\text{pole}}^2})(1 - \alpha \frac{q^2}{M_{\text{pole}}^2})}$$

– ISGW2

$$f_+(q^2) = f_+(q_{\max}^2) \left(1 + \frac{r_{\text{ISGW2}}^2}{12} (q_{\max}^2 - q^2)\right)^{-2}$$

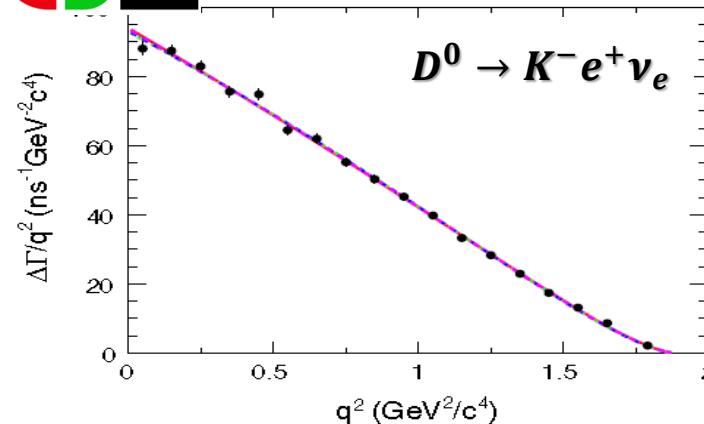
– Series expansion

$$f_+(t) = \frac{1}{P(t)\Phi(t, t_0)} a_0(t_0) \left(1 + \sum_{k=1}^{\infty} r_k(t_0) [z(t, t_0)]^k\right)$$

Studies of $c \rightarrow sl^+\nu_l$ semileptonic decays

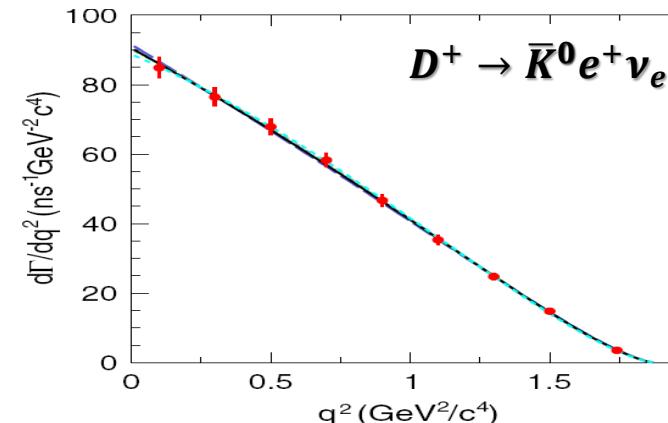
BES III

PRD92(2015)072012



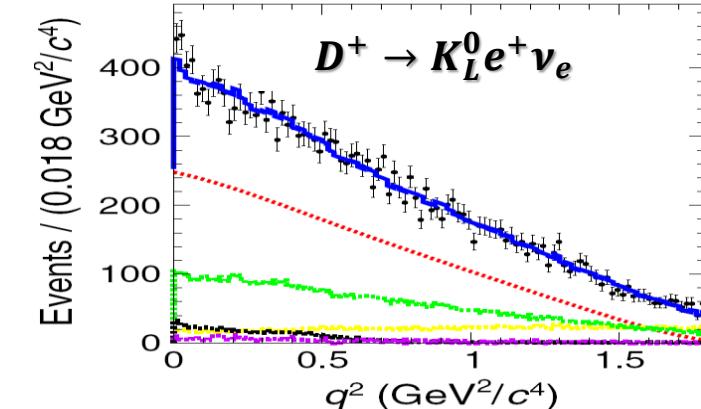
$$f_+^{D \rightarrow K}(0)|V_{cs}| = 0.717(03)(04)$$

PRD96(2017)012002



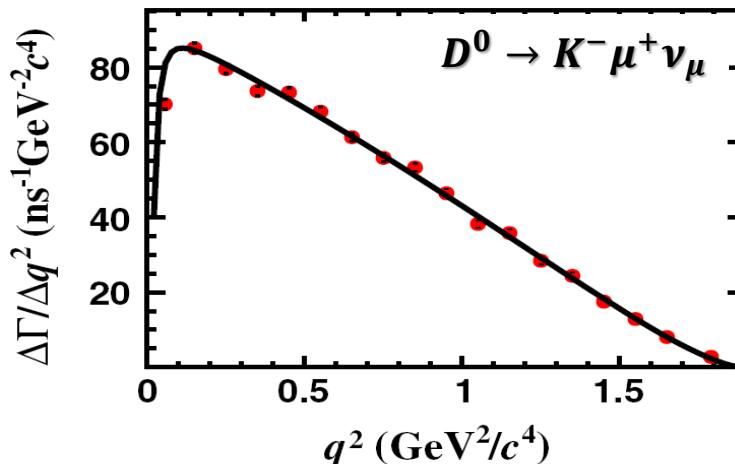
$$f_+^{D \rightarrow K}(0)|V_{cs}| = 0.705(04)(11)$$

PRD92(2015)112008



$$f_+^{D \rightarrow K}(0)|V_{cs}| = 0.728(06)(11)$$

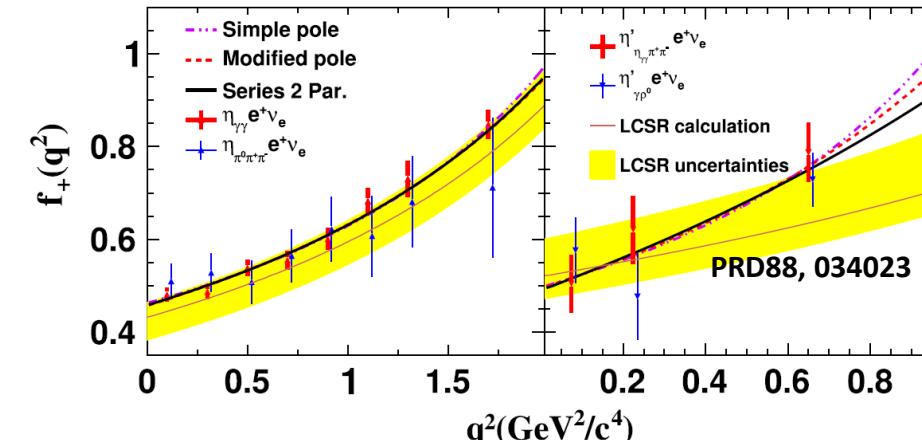
PRL122(2019)011804



$$f_+^{D \rightarrow K}(0)|V_{cs}| = 0.7148(38)(29)$$

$D_s^+ \rightarrow \eta^{(\prime)} e^+ \nu_e$

PRL123(2019)121801



$$f_+^{D_s \rightarrow \eta}(0)|V_{cs}| = 0.446(05)(04)$$

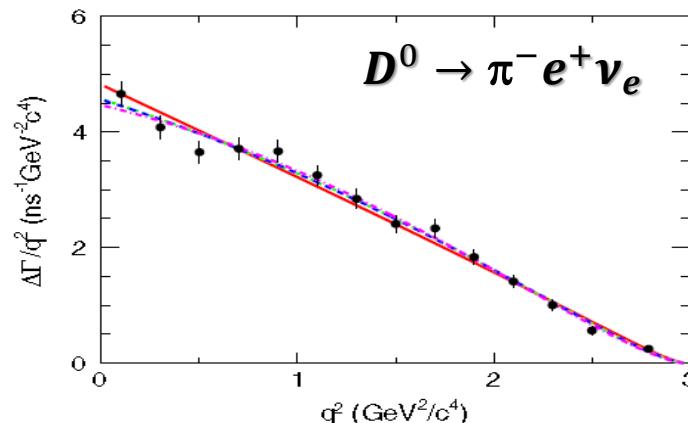
$$f_+^{D_s \rightarrow \eta'}(0)|V_{cs}| = 0.477(49)(11)^5$$

First extraction

Studies of $c \rightarrow dl^+\nu_l$ semileptonic decays

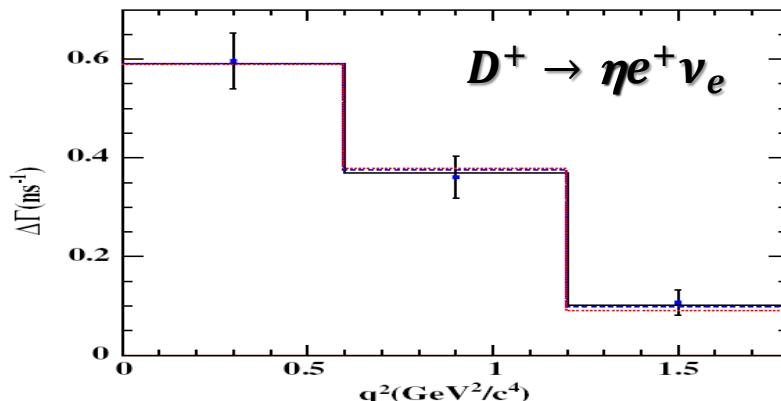
BESIII

PRD92(2015)072012



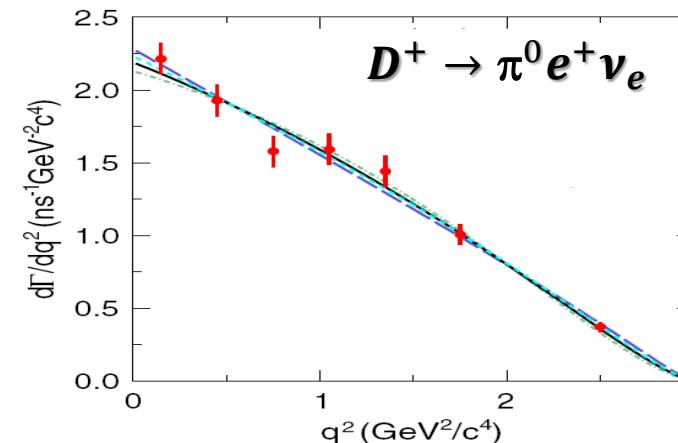
$$f_+^{D \rightarrow \pi}(0)|V_{cd}| = 0.144(02)(01)$$

PRD97(2018)092009



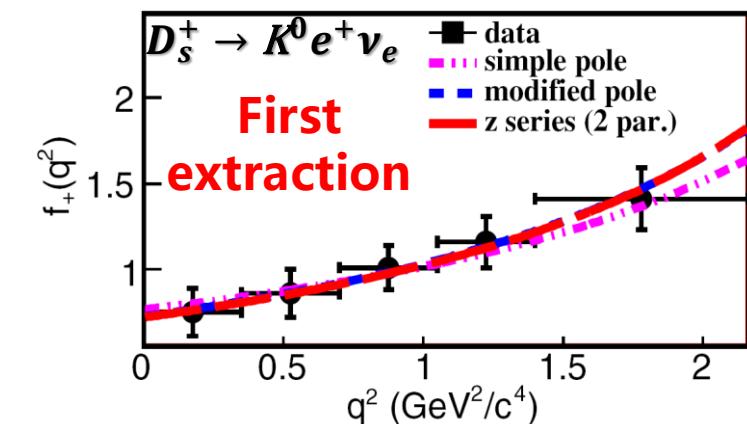
$$f_+^{D \rightarrow \eta}(0)|V_{cd}| = 0.079(06)(02)$$

PRD96(2017)012002



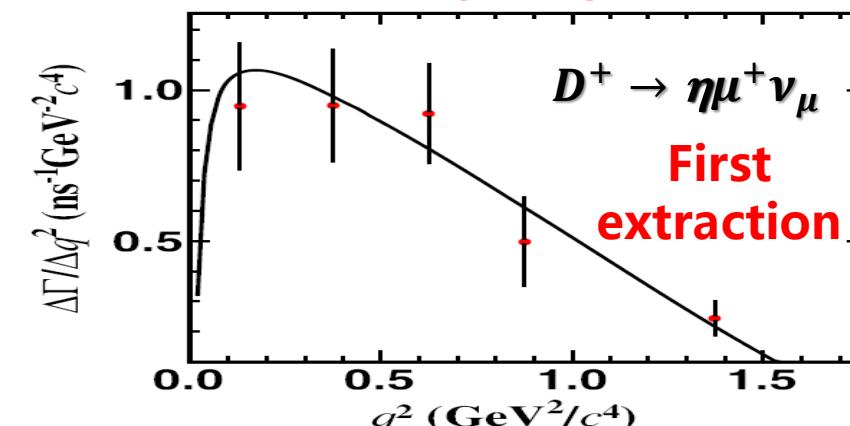
$$f_+^{D \rightarrow \pi}(0)|V_{cd}| = 0.140(03)(01)$$

PRL122(2019)061801



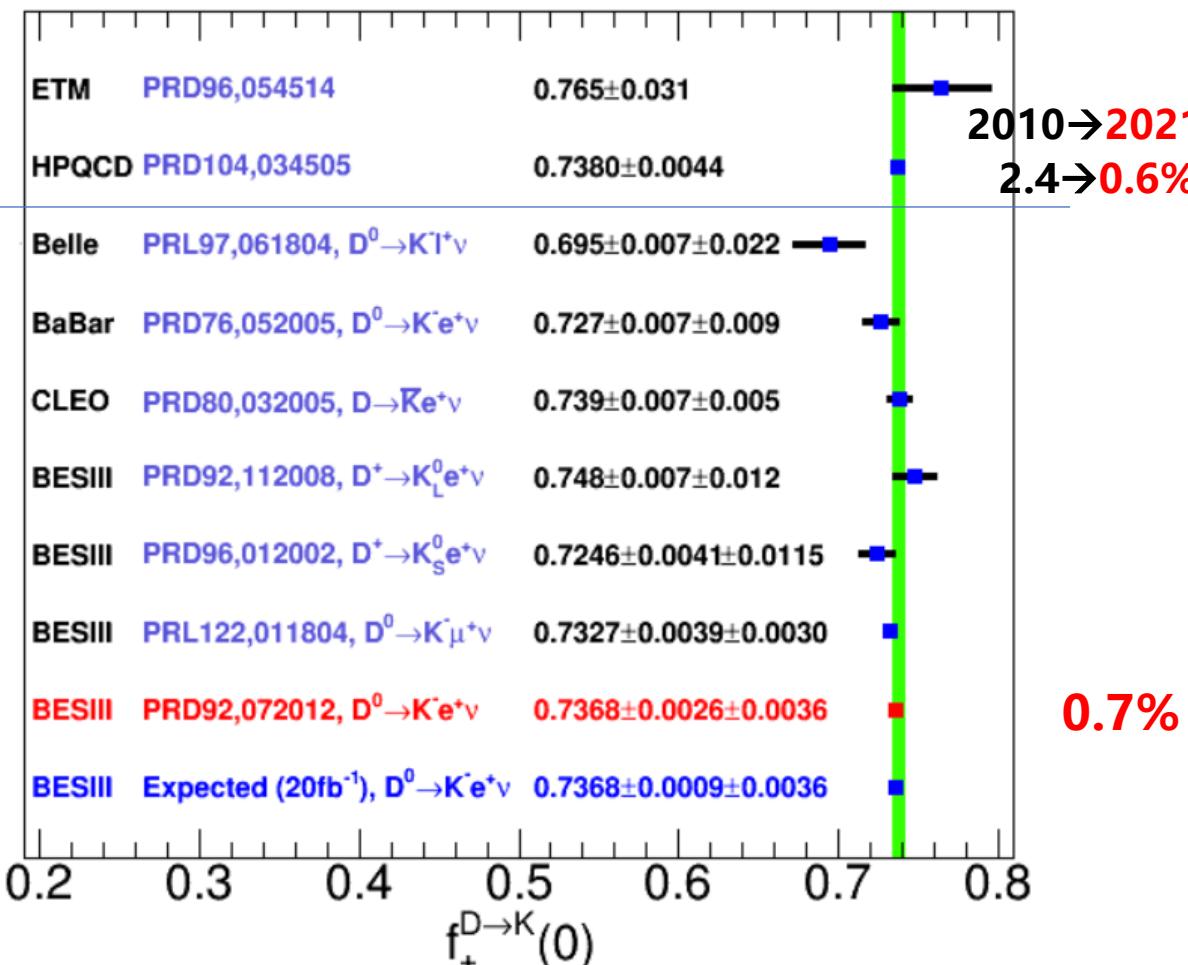
$$f_+^{D_s \rightarrow K}(0)|V_{cd}| = 0.162(19)(03)$$

PRL124(2020)231801

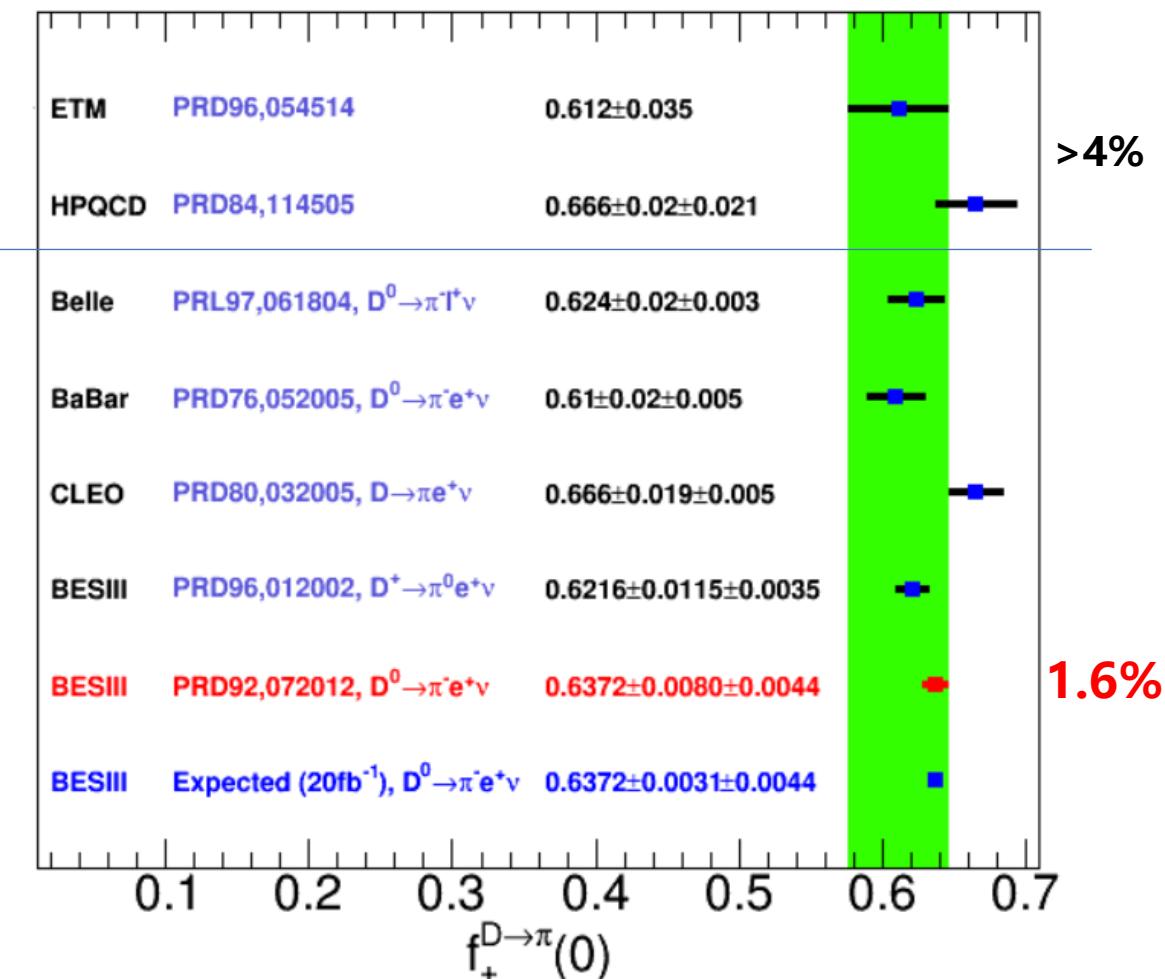


$$f_+^{D \rightarrow \eta}(0)|V_{cd}| = 0.087(08)(02)$$

Comparisons of $f_+^{D \rightarrow K}(0)$ and $f_+^{D \rightarrow \pi}(0)$

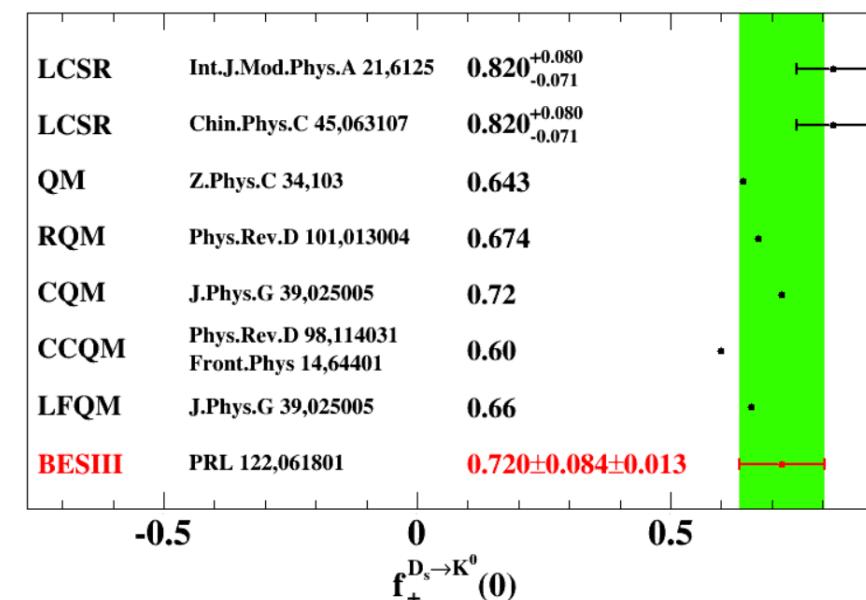
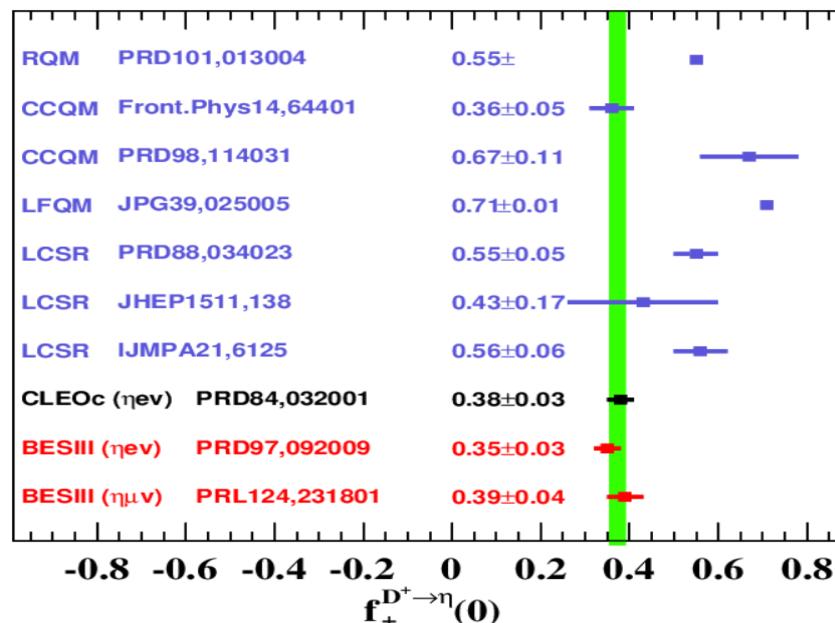
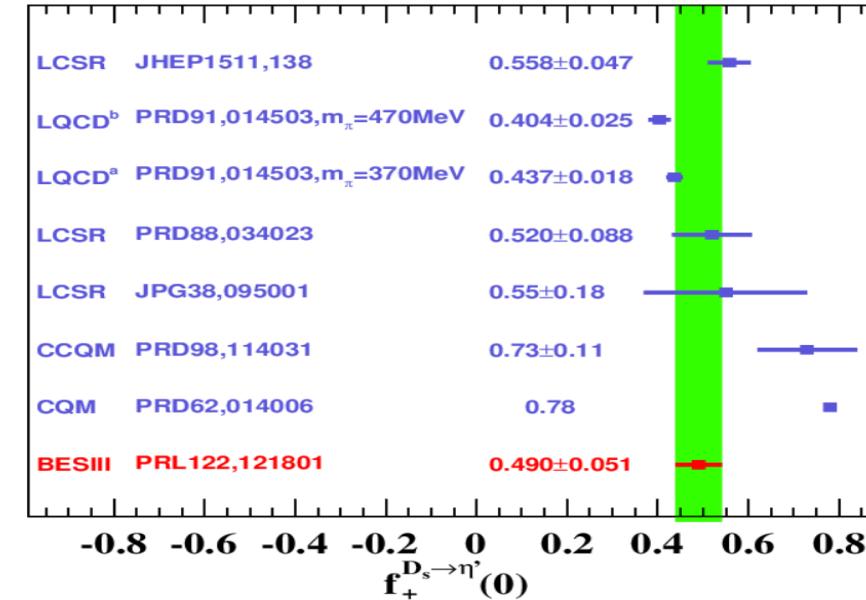
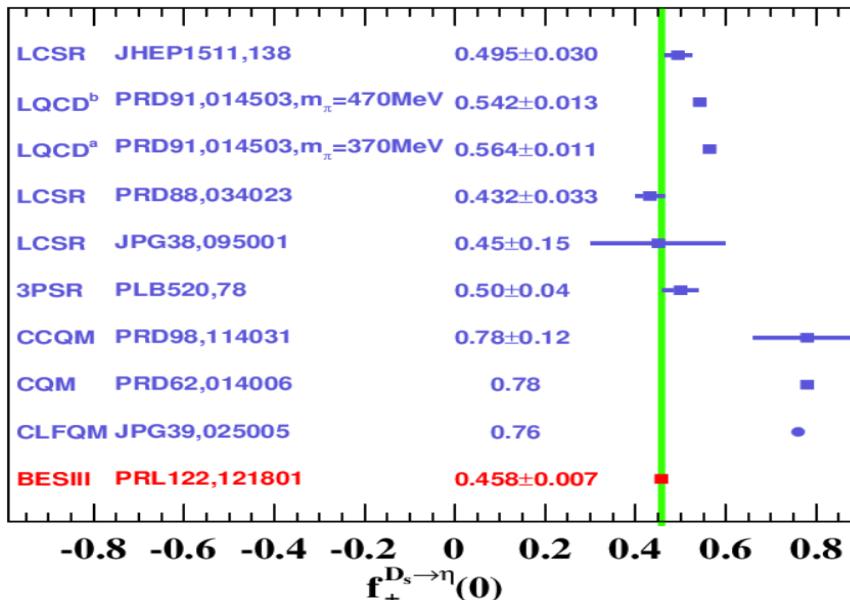


Experimental precision of $f_+^{D \rightarrow K}(0)$ is comparable to the latest LQCD precision

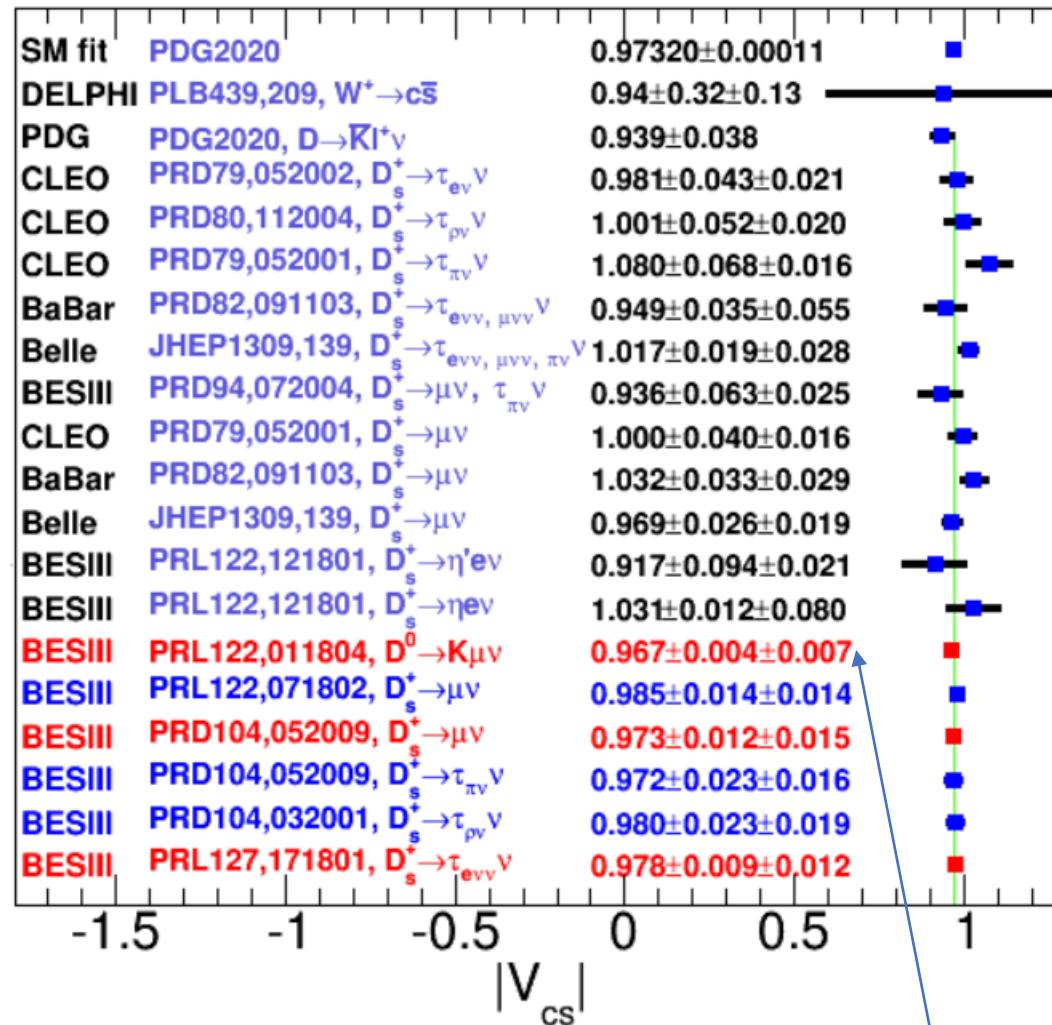


Experimental precision of $f_+^{D \rightarrow \pi}(0)$ is still dominated by statistical uncertainties

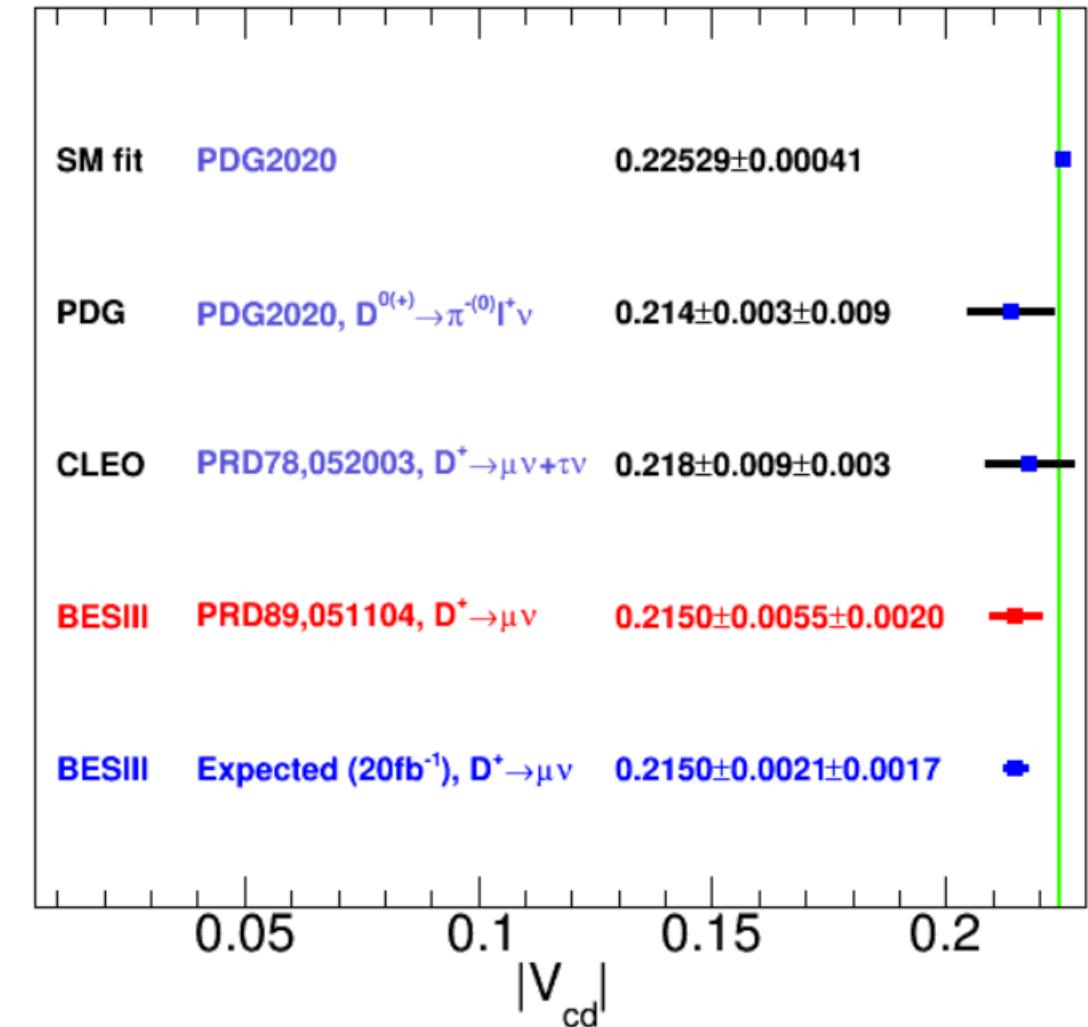
Comparisons of other $D \rightarrow P$ form factors



Comparisons of $|V_{cs}|$ and $|V_{cd}|$



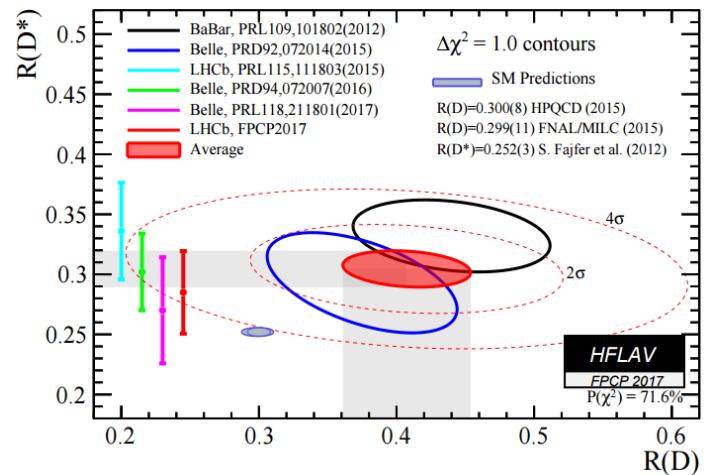
$f_+^{D \rightarrow K}(0)$ @ HPQCD²⁰²¹
precision: 2.4% → 0.6%



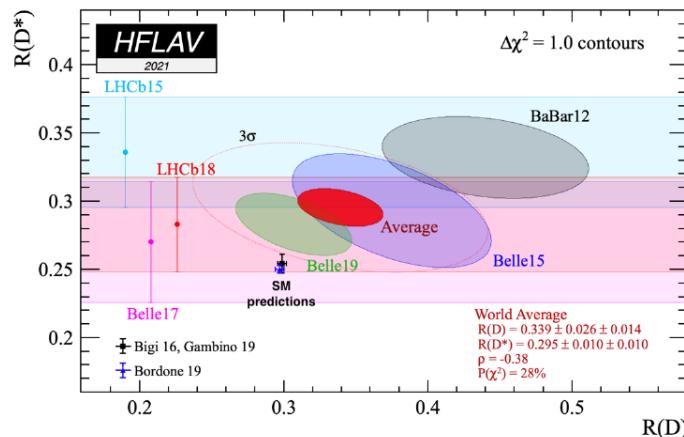
LFU tests in charm meson decays before BESIII

Tension in B physics

$$R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \bar{\nu}_\tau)}{\mathcal{B}(B \rightarrow D^{(*)} l \bar{\nu}_l)}$$



3.9 σ



3.3 σ

Tension in D physics

$$\mathcal{B}^{\text{PDG18}}[D^0 \rightarrow \pi^- \mu^+ \nu] = (0.237 \pm 0.024)\%$$

$$\frac{\Gamma^{\text{PDG18}}[D^0 \rightarrow \pi^- \mu^+ \nu]}{\Gamma^{\text{PDG18}}[D^0 \rightarrow \pi^- e^+ \nu]} = 0.82 \pm 0.08 \quad \text{SM prediction: } 0.985 \quad (2.1\sigma)$$

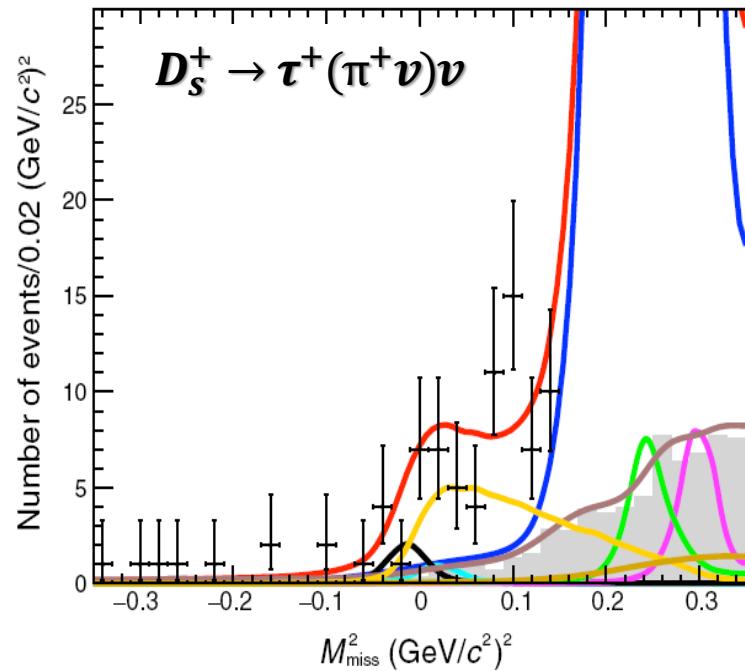
The knowledge of semimuonic charm meson decays is very poor

	D^0		D^+		D_s^+	
	K^-	4% ^{Belle}	\bar{K}^0	7% ^{FOCUS}	η	NA
$c \rightarrow sl^+ \nu$	K^{*-}	13% ^{FOCUS}	\bar{K}^{*0}	3% ^{CLEOc}	η'	NA
					ϕ	NA
					f_0	NA
$c \rightarrow dl^+ \nu$	π^-	10% ^{Belle}	π^0	NA	K^0	NA
	ρ^-	NA	ρ^0	17% ^{FOCUS}	K^{*0}	NA
			ω	NA		
			η	NA		
			η'	NA		

Tests of LFU in $D_{(S)}^+ \rightarrow l^+ \nu_l$

BESIII

PRL123(2019)211802



$$\mathcal{B}[D^+ \rightarrow \tau^+ \nu] = (1.20 \pm 0.24 \pm 0.12) \times 10^{-3}$$

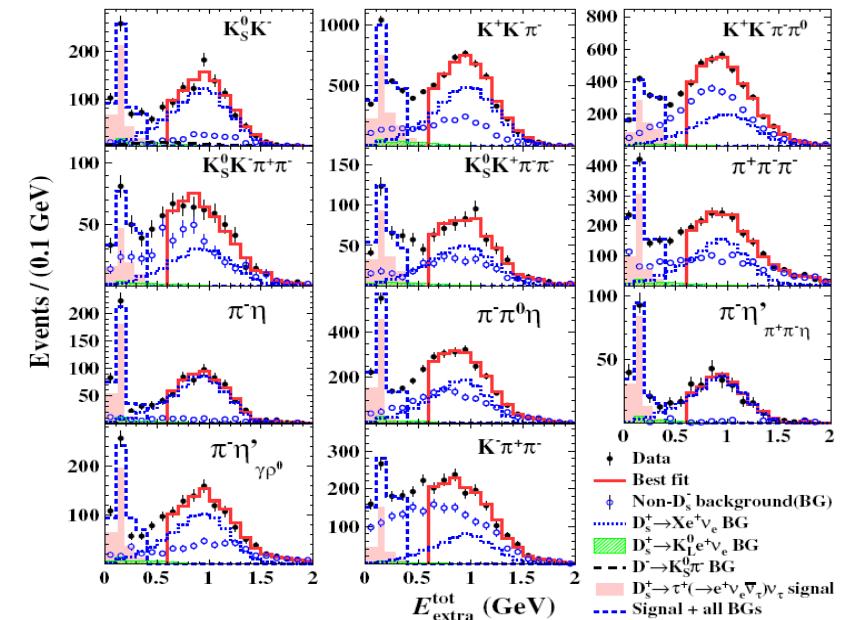
$$\mathcal{B}^{\text{PDG}}[D^+ \rightarrow \mu^+ \nu] = (3.74 \pm 0.17) \times 10^{-4}$$

$$R_D = \frac{\mathcal{B}[D^+ \rightarrow \tau^+ \nu]}{\mathcal{B}[D^+ \rightarrow \mu^+ \nu]} = 3.21 \pm 0.64 \pm 0.43$$

SM prediction: 2.67

PRL127(2021)171801

$D_s^+ \rightarrow \tau^+ (e^+ \nu \bar{\nu}) \nu$



Combined results:

$$\mathcal{B}[D_s^+ \rightarrow \mu^+ \nu] = (5.43 \pm 0.16) \times 10^{-3}$$

$$\mathcal{B}[D_s^+ \rightarrow \tau^+ \nu] = (5.33 \pm 0.12)\%$$

$$R_{D_s} = \frac{\mathcal{B}[D_s^+ \rightarrow \tau^+ \nu]}{\mathcal{B}[D_s^+ \rightarrow \mu^+ \nu]} = 9.82 \pm 0.36$$

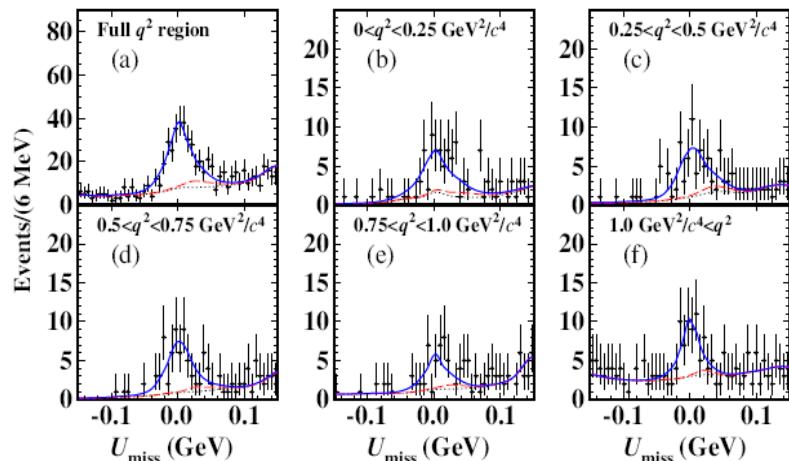
SM prediction: 9.75

Tests of LFU in $D \rightarrow (P, V)l^+\nu_l$

BESIII

$$D^+ \rightarrow \eta\mu^+\nu$$

PRD101(2020)072005



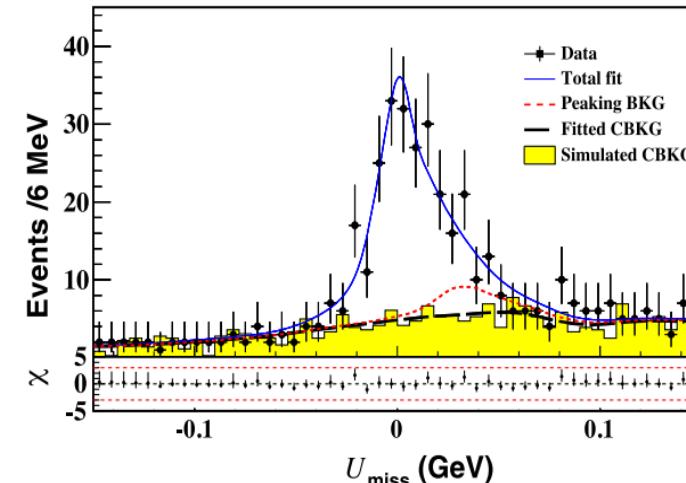
$$B[D^+ \rightarrow \eta\mu^+\nu] = (0.104 \pm 0.010 \pm 0.005)\%$$

$$R_{D\eta} = \frac{\Gamma[D^+ \rightarrow \eta\mu^+\nu]}{\Gamma[D^+ \rightarrow \eta e^+\nu]} = 0.91 \pm 0.13$$

First observations

$$D^+ \rightarrow \omega\mu^+\nu$$

PRD101(2020)072005



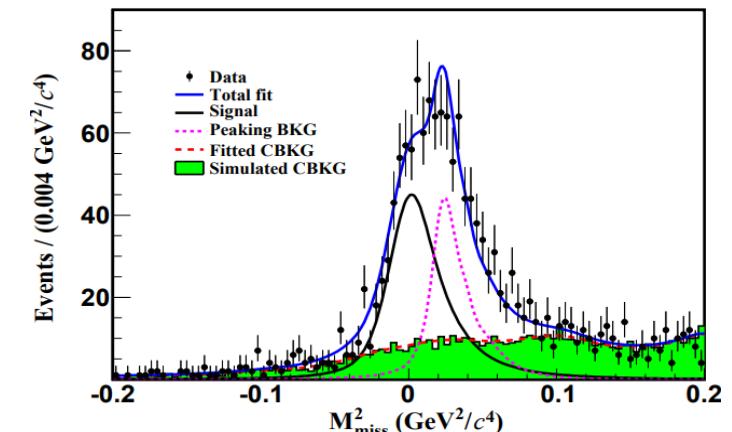
$$B[D^+ \rightarrow \omega\mu^+\nu] = (0.177 \pm 0.018 \pm 0.011)\%$$

$$R_{D\omega} = \frac{\Gamma[D^+ \rightarrow \omega\mu^+\nu]}{\Gamma[D^+ \rightarrow \omega e^+\nu]} = 1.05 \pm 0.14$$

SM predictions: 0.93-0.96

$$D^0 \rightarrow \rho^-\mu^+\nu$$

PRD104(2021)L091103



$$B[D^0 \rightarrow \rho^-\mu^+\nu] = (0.135 \pm 0.009 \pm 0.009)\%$$

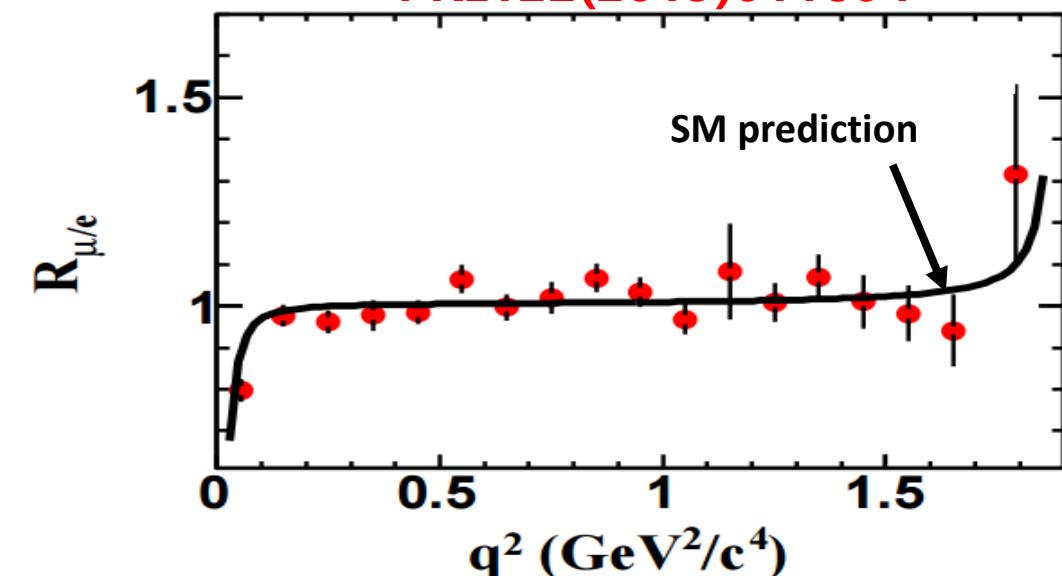
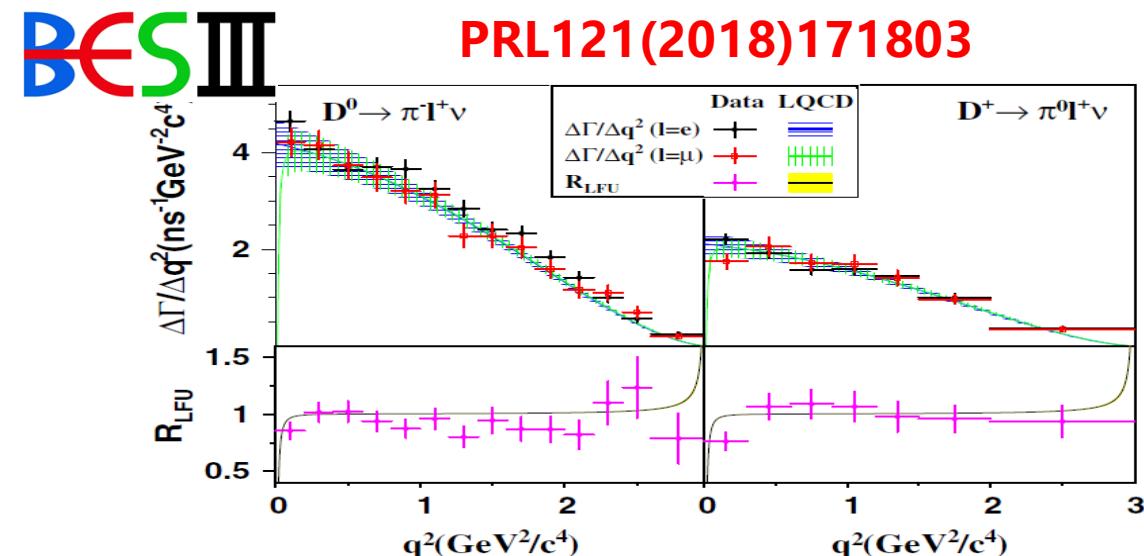
$$R_{D\rho} = \frac{\Gamma[D^+ \rightarrow \omega\mu^+\nu]}{\Gamma[D^+ \rightarrow \omega e^+\nu]} = 0.90 \pm 0.11$$

Summary of LFU tests at BESIII

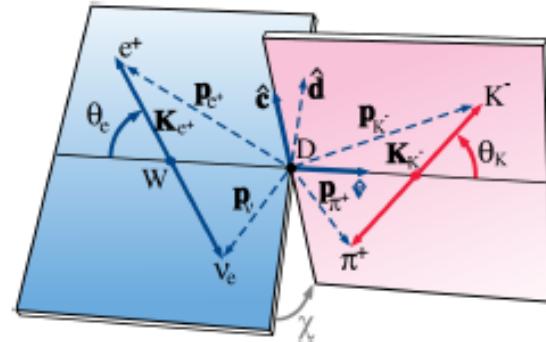
The $D^+ \rightarrow \tau^+\nu$ and six semimuonic D decays are observed for the first time. Five semimuonic charm decays are measured with better precision

	BF ratios	References
μ/e	$D^0 \rightarrow K^-$	$0.978 \pm 0.007 \pm 0.012$ PRL122(2019)011804
	$D^0 \rightarrow \pi^-$	$0.922 \pm 0.030 \pm 0.022$ PRL121(2018)171803
	$D^0 \rightarrow \rho^-$	0.90 ± 0.11 PRD104(2021)L091003
	$D^+ \rightarrow \bar{K}^0$	1.00 ± 0.03 EPJC76(2016)369
	$D^+ \rightarrow \pi^0$	$0.964 \pm 0.037 \pm 0.026$ PRL121(2018)171803
	$D^+ \rightarrow \omega$	1.05 ± 0.14 PRD101(2020)072005
	$D^+ \rightarrow \eta$	0.91 ± 0.13 PRL124(2020)231801
	$D_s^+ \rightarrow \eta$	0.86 ± 0.29
	$D_s^+ \rightarrow \eta'$	1.14 ± 0.68 PRD97(2018)012006
	$D_s^+ \rightarrow \phi$	1.05 ± 0.24
τ/μ	$\Lambda_c^+ \rightarrow \Lambda$	$0.96 \pm 0.16 \pm 0.04$ PLB767(2017)42
	$D^+ \rightarrow \tau^+\nu$	$3.21 \pm 0.64 \pm 0.43$ PRL123(2019)211802
	$D_s^+ \rightarrow \tau^+\nu$	9.67 ± 0.36 PRL127(2021)171801

No deviation greater than 1.7σ is found!



Studies of $D \rightarrow Ve^+\nu_e$ dynamics



- $m^2 = (p_{\pi^+} + p_{K^-})^2$
- $\cos(\theta_K) = \frac{\hat{v} \cdot \mathbf{K}_{K^-}}{|\mathbf{K}_{K^-}|}$
- $\cos(\chi) = \hat{c} \cdot \hat{d}$
- $q^2 = (p_{e^+} + p_{\nu_e})^2$
- $\cos(\theta_e) = -\frac{\hat{v} \cdot \mathbf{K}_{e^+}}{|\mathbf{K}_{e^+}|}$
- $\sin(\chi) = (\hat{c} \times \hat{v}) \cdot \hat{d}$

Decay rate depend on 5 variables and 3 form factors

$$d^5\Gamma = \frac{G_F^2 |V_{cs}|^2}{(4\pi)^6 m_D^2} X \beta \mathcal{I}(m^2, q^2, \theta_K, \theta_e, \chi) dm^2 dq^2 d\cos(\theta_K) d\cos(\theta_e) d\chi$$

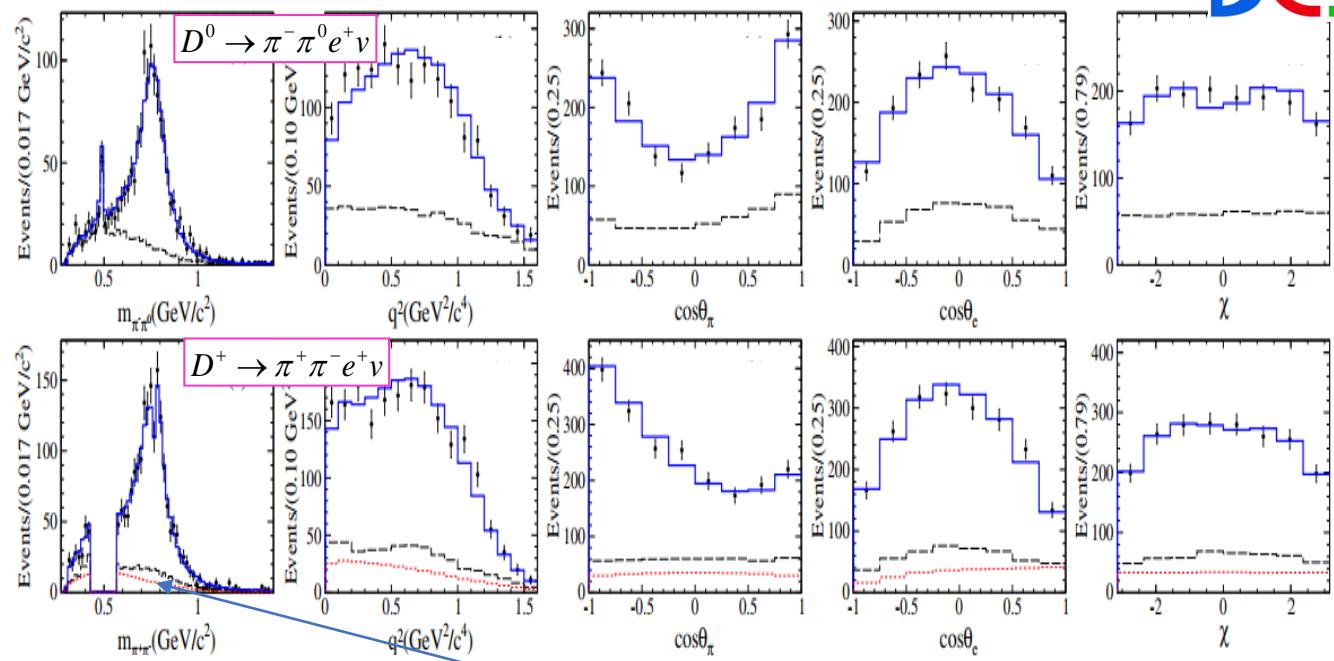
- $X = p_{K\pi} m_D$, $p_{K\pi}$ is the momentum of the $K\pi$ system in the D rest frame
 - $\beta = 2p^+/m$, p^+ is the breakup momentum of the $K\pi$ system in its rest frame
 - \mathcal{I} can be expressed in terms of helicity amplitudes $H_{0,\pm}$:
- $$H_0(q^2) = \frac{1}{2m_q} \left[(m_D^2 - m^2 - q^2)(m_D + m) \textcolor{red}{A}_1(q^2) - 4 \frac{m_D^2 p_{K\pi}^2}{m_D + m} \textcolor{red}{A}_2(q^2) \right]$$
- $$H_{\pm}(q^2) = (m_D + m) \textcolor{red}{A}_1(q^2) \mp \frac{2m_D p_{K\pi}}{m_D + m} \textcolor{blue}{V}(q^2)$$
- Vector form factor: $\textcolor{blue}{V}(q^2) = \frac{\textcolor{blue}{V}(0)}{1 - q^2/m_V^2}$; or: FF ratio $r_V = \textcolor{blue}{V}(0)/A_1(0)$
 - Axial-vector form factor: $\textcolor{red}{A}_1(q^2) = \frac{A_1(0)}{1 - q^2/m_A^2}$, $\textcolor{red}{A}_2(q^2) = \frac{A_2(0)}{1 - q^2/m_A^2}$; or: FF ratio $r_2 = A_2(0)/A_1(0)$

Analysis of $D^0(+) \rightarrow \pi\pi e^+\nu_e$ and observation of $D \rightarrow Se^+\nu_e$

PRL122(2019)062001

BESIII

PRL121(2018)081802



$$r_V = 1.695 \pm 0.083 \pm 0.051$$

$$r_2 = 0.845 \pm 0.056 \pm 0.039$$

Observation of $D^+ \rightarrow f_0(500) e^+\nu_e$

Signal mode	This analysis ($\times 10^{-3}$)
$D^0 \rightarrow \pi^-\pi^0 e^+\nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^0 \rightarrow \rho^- e^+\nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^+ \rightarrow \pi^-\pi^+ e^+\nu_e$	$2.449 \pm 0.074 \pm 0.073$
$D^+ \rightarrow \rho^0 e^+\nu_e$	$1.860 \pm 0.070 \pm 0.061$
$D^+ \rightarrow \omega e^+\nu_e$	$2.05 \pm 0.66 \pm 0.30$
$D^+ \rightarrow f_0(500) e^+\nu_e, f_0(500) \rightarrow \pi^+\pi^-$	$0.630 \pm 0.043 \pm 0.032$
$D^+ \rightarrow f_0(980) e^+\nu_e, f_0(980) \rightarrow \pi^+\pi^-$	<0.028

$$B_{D^0 \rightarrow a_0(980)^- e^+\nu_e} B_{a_0(980)^- \rightarrow \eta\pi^-} = (1.33^{+0.33}_{-0.29} \pm 0.09) \times 10^{-4}$$

$$B_{D^+ \rightarrow a_0(980)^0 e^+\nu_e} B_{a_0(980)^0 \rightarrow \eta\pi^0} = (1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4}$$

$$[B_{D^+ \rightarrow f_0(500)e^+\nu_e} + B_{D^+ \rightarrow f_0(980)e^+\nu_e}] / B_{D^+ \rightarrow a_0(980)^0 e^+\nu_e} > 2.7$$

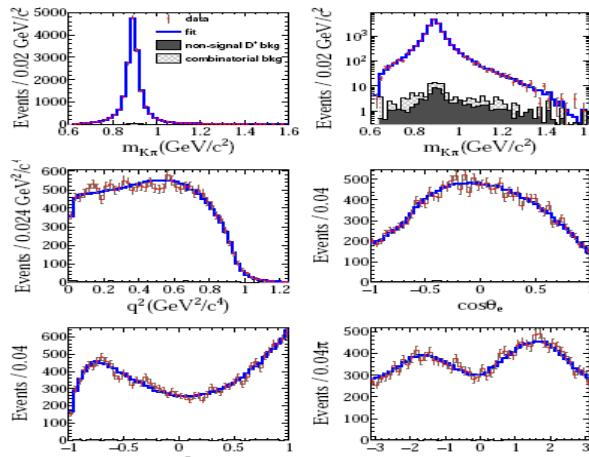
**Supports tetraquark assumption
for light mesons of a_0 and f_0**

Analyses of other $D \rightarrow Ve^+\nu_e$ dynamics

BESIII

$$D^+ \rightarrow \bar{K}^{*0} e^+ \nu_e$$

PRD94(2016)032001

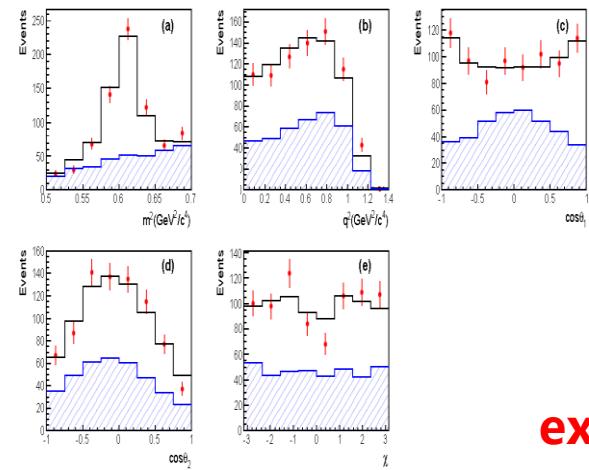


$$r_V = 1.411 \pm 0.058 \pm 0.007$$

$$r_2 = 0.788 \pm 0.042 \pm 0.008$$

$$D^+ \rightarrow \omega e^+ \nu_e$$

PRD92(2015)071101



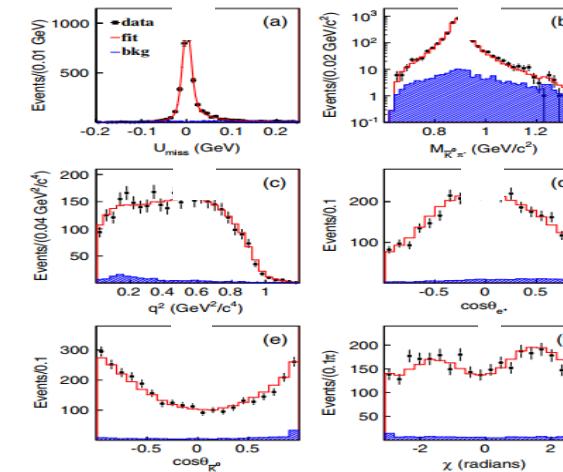
$$r_V = 1.24 \pm 0.09 \pm 0.06$$

First extraction

$$r_2 = 1.06 \pm 0.15 \pm 0.05$$

$$D^0 \rightarrow K^{*-} e^+ \nu_e$$

PRD99(2018)011103



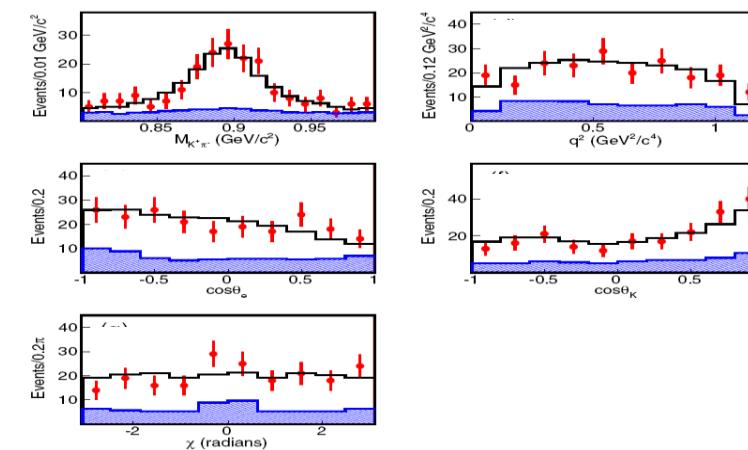
$$r_V = 1.46 \pm 0.07 \pm 0.02$$

$$r_2 = 0.67 \pm 0.06 \pm 0.01$$

First extraction

$$D_s^+ \rightarrow K^{*0} e^+ \nu_e$$

PRL122(2019)061801



$$r_V = 1.67 \pm 0.34 \pm 0.16$$

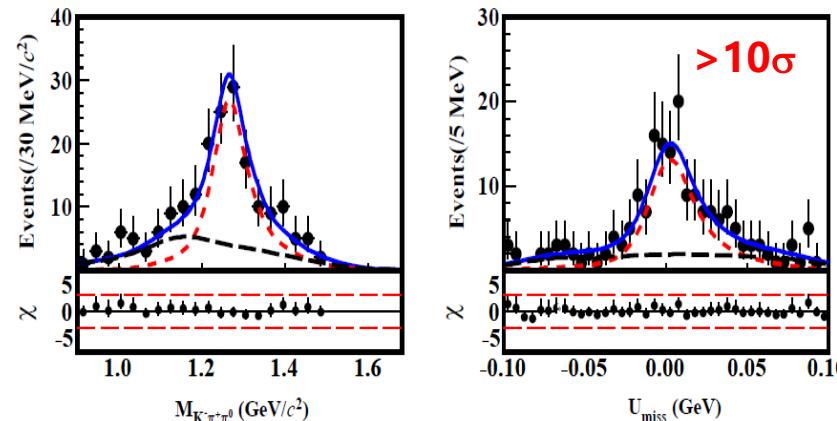
$$r_2 = 0.77 \pm 0.28 \pm 0.07$$

First extraction

Observation of $D \rightarrow Ae^+\nu_e$

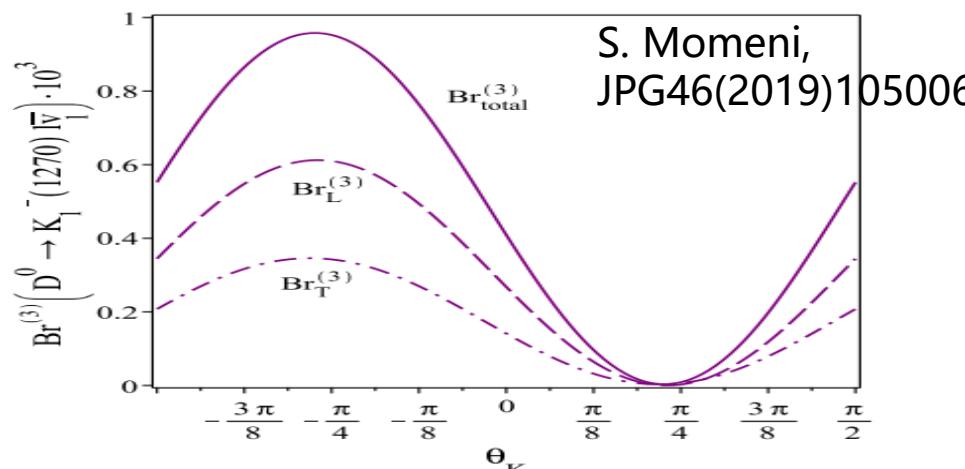
BESIII

$D^+ \rightarrow \bar{K}_1^0(1270)e^+\nu_e$ PRL123(2019)231801



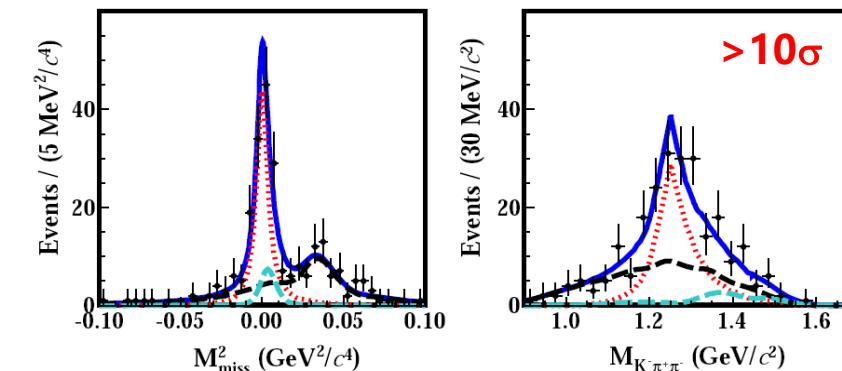
$$B_{D^+ \rightarrow \bar{K}_1^0(1270)e^+\nu_e} = (2.30 \pm 0.26 \pm 0.18 \pm 0.25) \times 10^{-3}$$

Helps to test various theoretical calculations which are sensitive to K_1 mixing angle



$D^0 \rightarrow K_1(1270)^-e^+\nu_e$

PRL127(2021)131801



$$B_{D^0 \rightarrow K_1(1270)^-e^+\nu_e} = (1.09 \pm 0.13 \pm 0.13 \pm 0.12) \times 10^{-3}$$

New window to explore the property and nature of K_1 and \bar{K}_1 mixing angle

Combined analysis of $D \rightarrow \bar{K}_1 e^+\nu_e$ and $B \rightarrow \gamma \bar{K}_1$ helps to constrain new physics effect in the studies of photon polarization in $b \rightarrow s\gamma$ process

Wei Wang et al. PRL125(2020)051802

See backup slides for more measurements of the semileptonic D decays at BESIII

Hadronic D decays

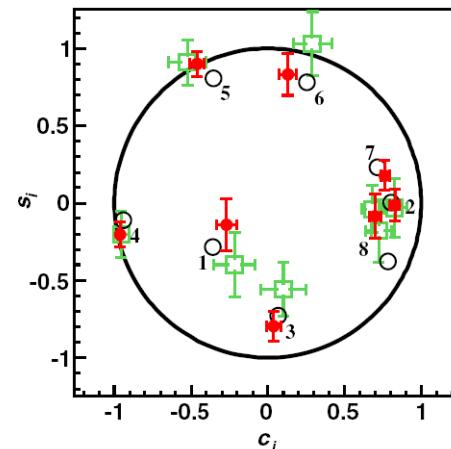
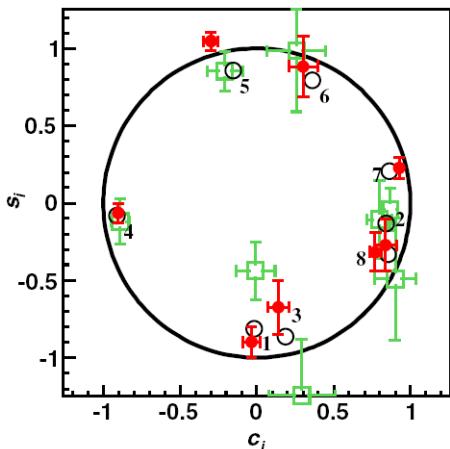
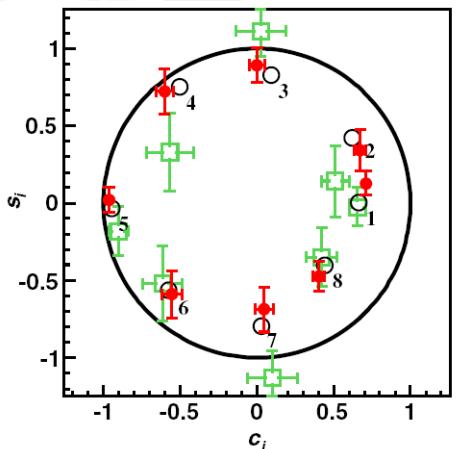
- Strong phase difference in neutral D decays
- Two-body decays $D^0 \rightarrow PP, VP, VV$
- Amplitude analyses of multi-body D decays
- Doubly Cabibbo-Suppressed (DCS) D decays
- Measurements of absolute BFs

Strong phase differences between D^0 and \bar{D}^0

BESIII

$D \rightarrow K_{S/L}^0 \pi^+ \pi^-$

PRL124(2020)241802

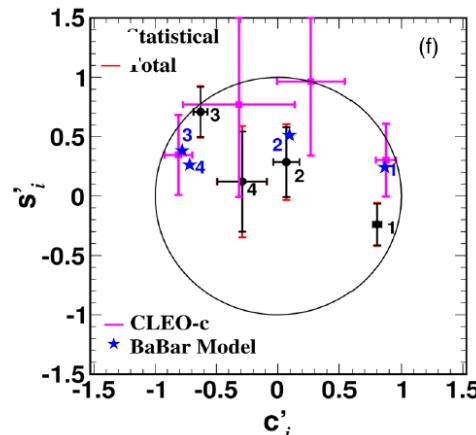
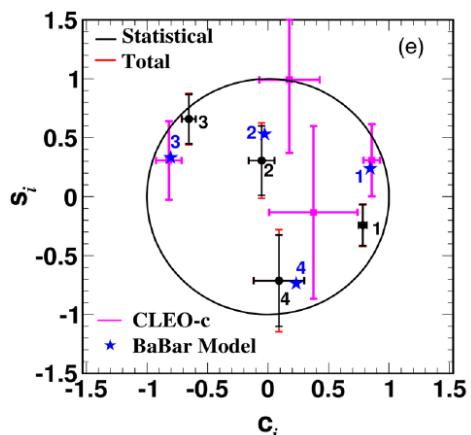


$e^+ e^- \rightarrow \Psi(3770) \rightarrow D^0 \bar{D}^0$ at 3.773 GeV

Constraint on γ measurement $\sim 0.9^\circ$

$D \rightarrow K_{S/L}^0 K^+ K^-$

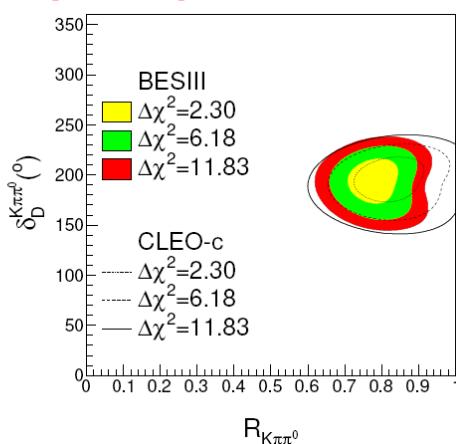
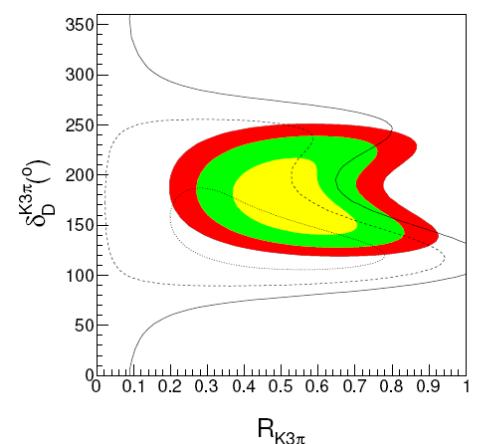
PRD102(2020)052008



Constraint on γ measurement $\sim 1.3^\circ$

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

JHEP05(2021)164



Constraint on γ measurement $\sim 6^\circ$

CP+ fraction in $D^0/\bar{D}^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$

Category	Decay modes
CP-even	K^+K^- , $K_S^0\pi^0\pi^0$, $K_L^0\pi^0$, $K_L^0\omega$
CP-odd	$K_S^0\pi^0$, $K_S^0\eta$, $K_S^0\eta'$, $K_S^0\omega$, $K_L^0\pi^0\pi^0$
Quasi CP-even	$\pi^+\pi^-\pi^0$
Mixed CP	$K_S^0\pi^+\pi^-$, $K_L^0\pi^+\pi^-$

$$M(4\pi, f) =$$

$$2N_{D\bar{D}}\mathcal{B}(4\pi)\mathcal{B}(\pi\pi\pi^0)\epsilon_{DT}[1 - (2F_+^{\pi\pi\pi^0} - 1)(2F_+^{4\pi} - 1)]$$

$$S(\pi\pi\pi^0) = 2N_{D\bar{D}}\mathcal{B}(\pi\pi\pi^0)\epsilon_{ST}[1 - (2F_+^{\pi\pi\pi^0} - 1)y]$$

$$F_+^{4\pi} = \frac{N^+ F_+^{\pi\pi\pi^0}}{N^{\pi\pi\pi^0} - N^+ + 2N^+ F_+^{\pi\pi\pi^0}}$$

$$M_i(4\pi, K_S^0\pi^+\pi^-) =$$

$$H[K_i + K_{-i} - 2\sqrt{K_i K_{-i}} c_i (2F_+^{4\pi} - 1)],$$

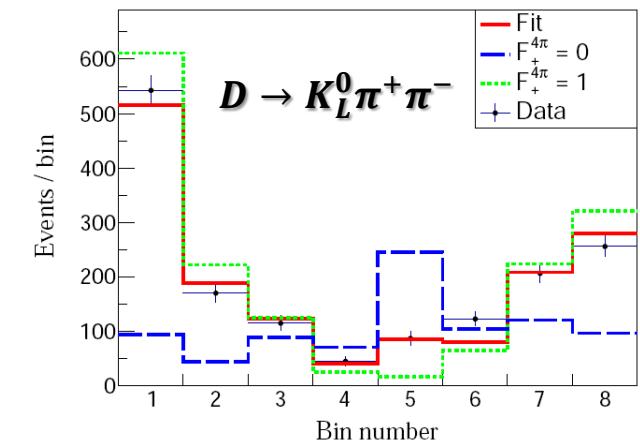
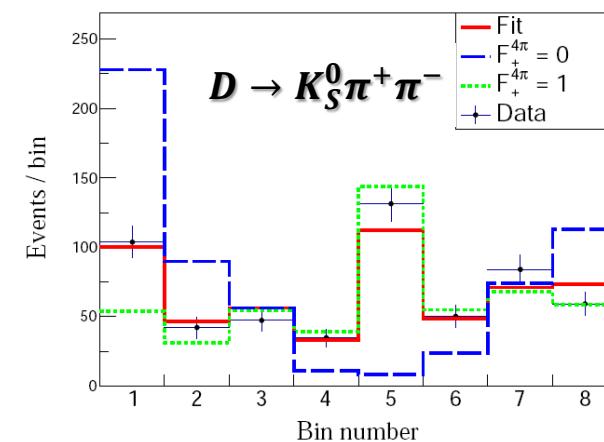
$$M'_i(4\pi, K_L^0\pi^+\pi^-) =$$

$$H'[K'_i + K'_{-i} + 2\sqrt{K'_i K'_{-i}} c'_i (2F_+^{4\pi} - 1)]$$

$$F_+^{4\pi} = \frac{N^+}{N^+ + N^-}$$

arXiv:2208.10098

BES III



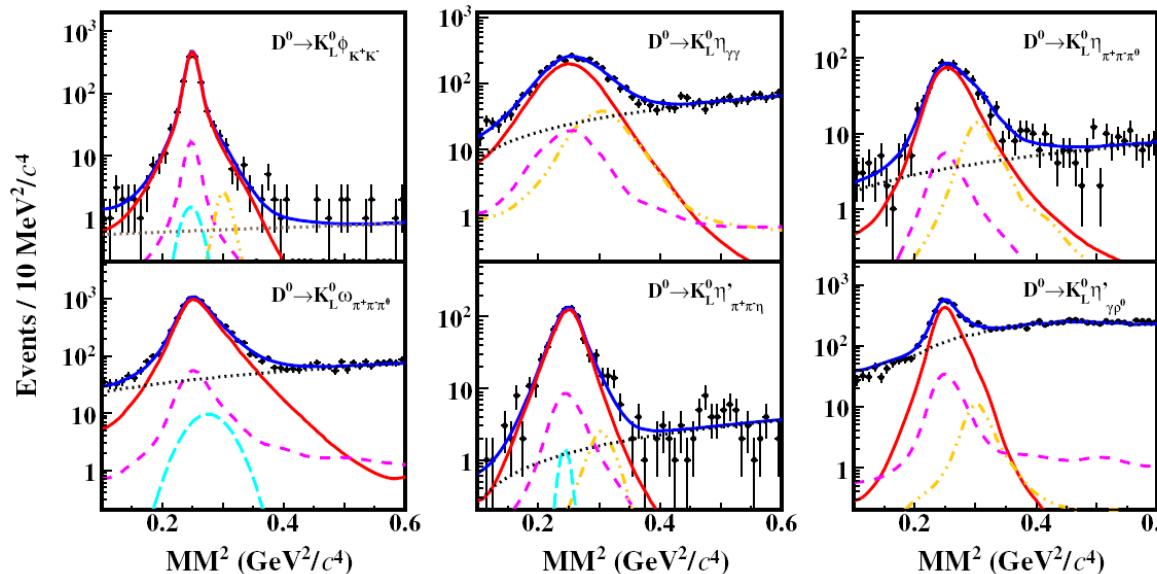
Tag modes	$F_+^{4\pi}$
CP eigenstates	$0.721 \pm 0.019 \pm 0.007$
$D \rightarrow \pi^+\pi^-\pi^0$	$0.753 \pm 0.028 \pm 0.010$
$D \rightarrow K_{S,L}^0\pi^+\pi^-$	$0.754 \pm 0.031 \pm 0.009$
Combination	$0.735 \pm 0.015 \pm 0.005$

Agrees with CLEO result, but with better precision

Measurements of $D^0 \rightarrow K_L^0\eta$, $K_L^0\eta'$, $K_L^0\omega$ and $K_L^0\phi$

BESIII

PRD104(2022)012003



First measurements of these decay BFs:

Decay	$\mathcal{B}_{\text{exp}} (\%)$	$\mathcal{B}_{\text{FAT}} (\%)$	Difference	$\mathcal{R}(D^0)_{\text{exp}}$	$\mathcal{B}(D^0)_{\text{FAT}}$	Difference	For VP final states, the asymmetries deviate with theoretical calculations
$D^0 \rightarrow K_L^0\phi$	$0.414 \pm 0.021 \pm 0.010$	0.33 ± 0.03	2.2σ	-0.001 ± 0.047		2.4σ	
$D^0 \rightarrow K_L^0\eta$	$0.433 \pm 0.012 \pm 0.010$	0.40 ± 0.07	0.5σ	0.080 ± 0.022		1.5σ	
$D^0 \rightarrow K_L^0\omega$	$1.164 \pm 0.022 \pm 0.028$	0.95 ± 0.15	1.4σ	-0.024 ± 0.031	0.113 ± 0.001	4.4σ	
$D^0 \rightarrow K_L^0\eta'$	$0.809 \pm 0.020 \pm 0.016$	0.77 ± 0.07	0.5σ	0.080 ± 0.023		1.6σ	

Asymmetries of BFs of D^0/\bar{D}^0 :

$$\mathcal{A}_{CP}^{\text{sig}} = \frac{\mathcal{B}_{\text{sig}}^+ - \mathcal{B}_{\text{sig}}^-}{\mathcal{B}_{\text{sig}}^+ + \mathcal{B}_{\text{sig}}^-}$$

Decay	$\mathcal{B}_{\text{sig}}^+ (\%)$	$\mathcal{B}_{\text{sig}}^- (\%)$	$\mathcal{A}_{CP}^{\text{sig}} (\%)$
$D^0 \rightarrow K_L^0\phi$	0.428 ± 0.029	0.405 ± 0.034	$2.7 \pm 5.4 \pm 0.7$
$D^0 \rightarrow K_L^0\eta$	0.445 ± 0.018	0.421 ± 0.017	$2.8 \pm 2.9 \pm 0.4$
$D^0 \rightarrow K_L^0\omega$	1.200 ± 0.030	1.121 ± 0.031	$3.4 \pm 1.9 \pm 0.6$
$D^0 \rightarrow K_L^0\eta'$	0.789 ± 0.028	0.826 ± 0.028	$-2.2 \pm 2.5 \pm 0.4$

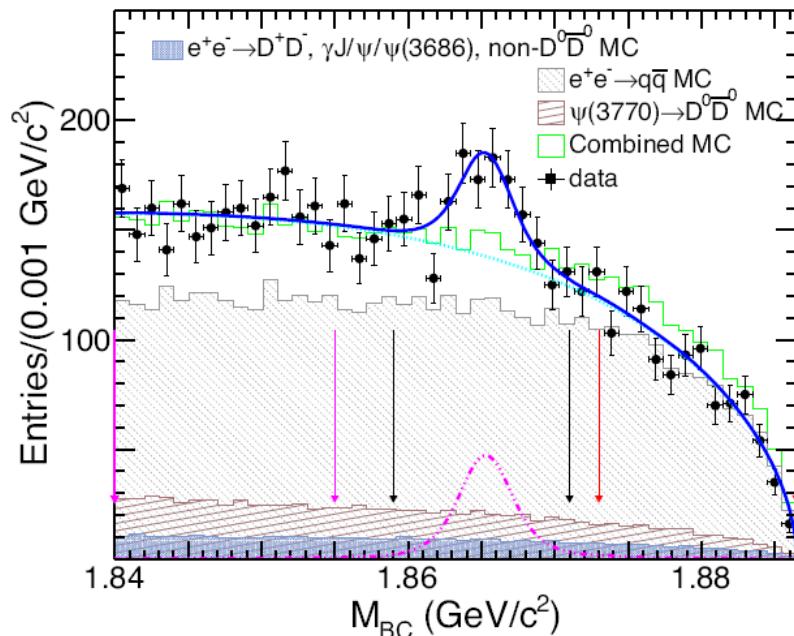
Asymmetries of BFs of $D^0 \rightarrow K_S^0 X$ and $K_L^0 X$:

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

Observation of $D^0 \rightarrow \omega\phi$

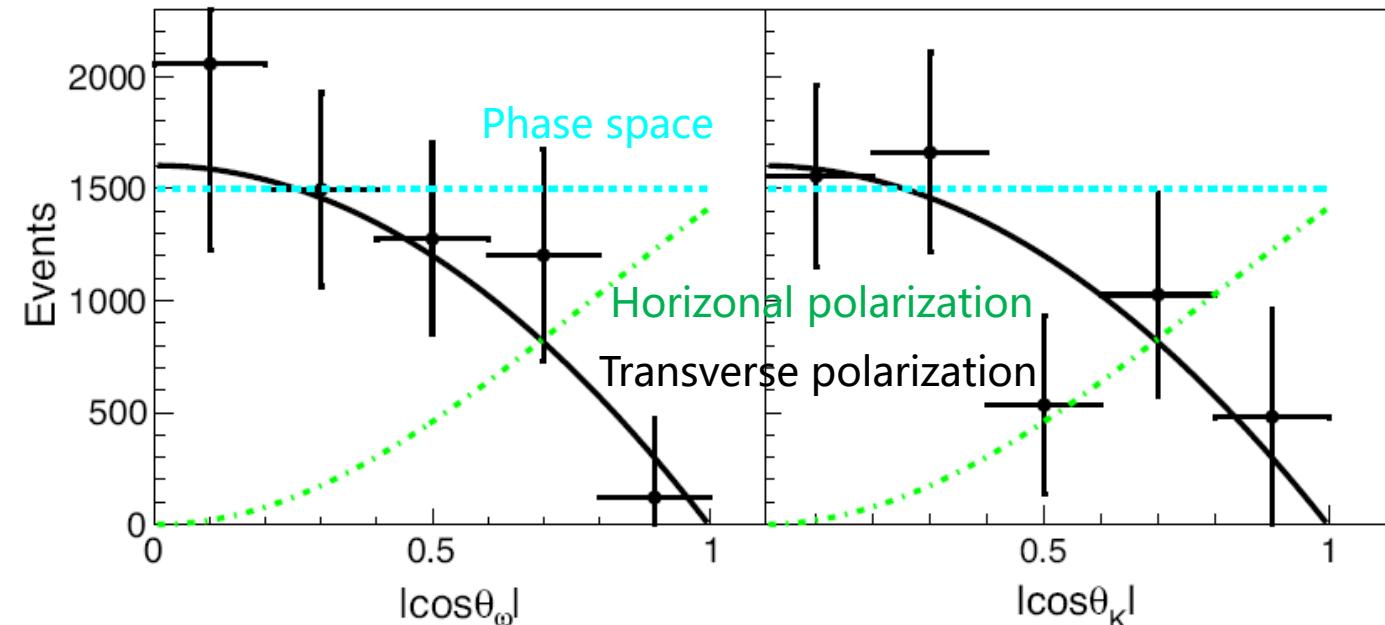
BESIII

PRL128(2022)011803



$$B[D^0 \rightarrow \omega\phi] = (6.48 \pm 0.96 \pm 0.40) \times 10^{-3}$$

Transverse polarization in $D^0 \rightarrow VV$ is found to deviate significantly with theoretical prediction

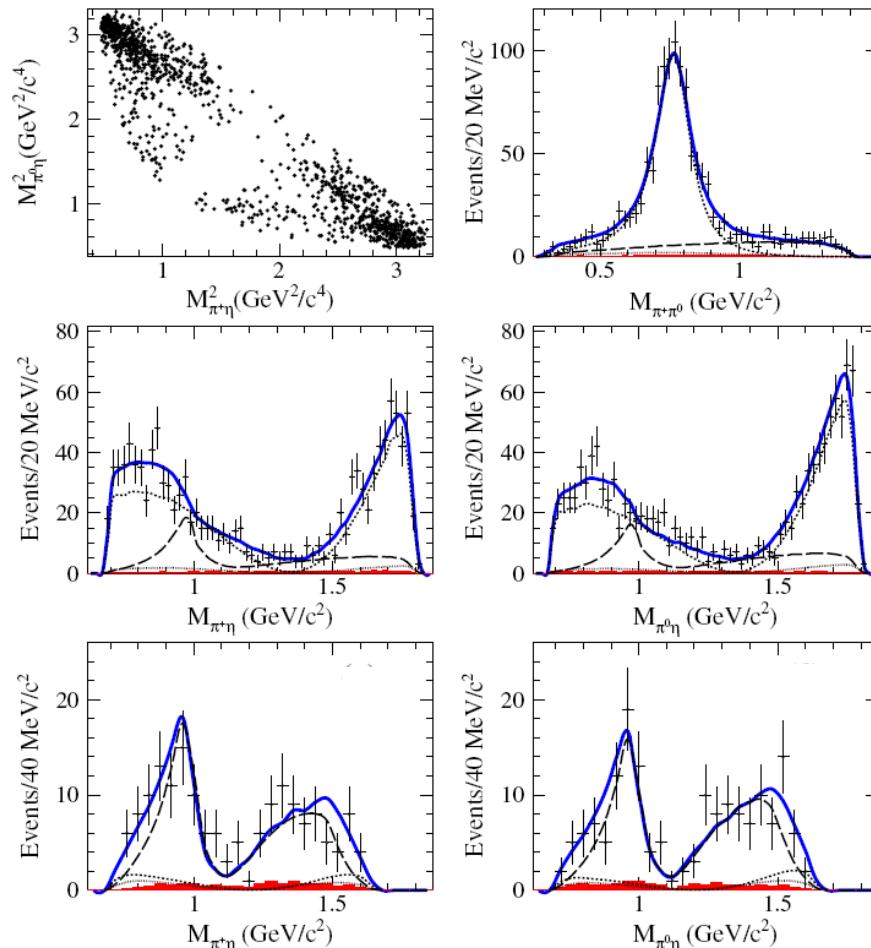


Benefits to explore the mechanisms of $D^0 - \bar{D}^0$ mixing and CP violation in theory

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

BESIII

PRL123(2020)112001



Amplitude	ϕ_n (rad)	FF_n
$D_s^+ \rightarrow \rho^+ \eta$	0.0 (fixed)	$0.783 \pm 0.050 \pm 0.021$
$D_s^+ \rightarrow (\pi^+ \pi^0)_V \eta$	$0.612 \pm 0.172 \pm 0.342$	$0.054 \pm 0.021 \pm 0.025$
$D_s^+ \rightarrow a_0(980) \pi$	$2.794 \pm 0.087 \pm 0.044$	$0.232 \pm 0.023 \pm 0.033$

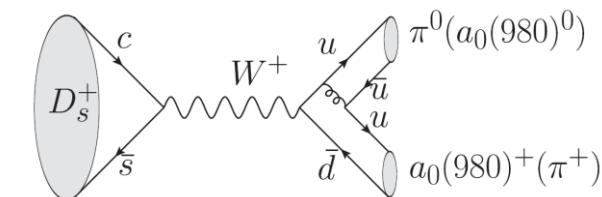
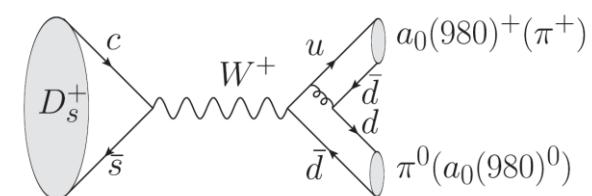
$$B_{D_s^+ \rightarrow \pi^+ \pi^0 \eta} = (9.50 \pm 0.28 \pm 0.41)\%$$

$$B_{D_s^+ \rightarrow \pi^+ \pi^0 \eta}^{\text{PDG18}} = (9.2 \pm 1.2)\%$$

$$B_{D_s^+ \rightarrow \rho^+ \eta} = (7.44 \pm 0.48 \pm 0.44)\%$$

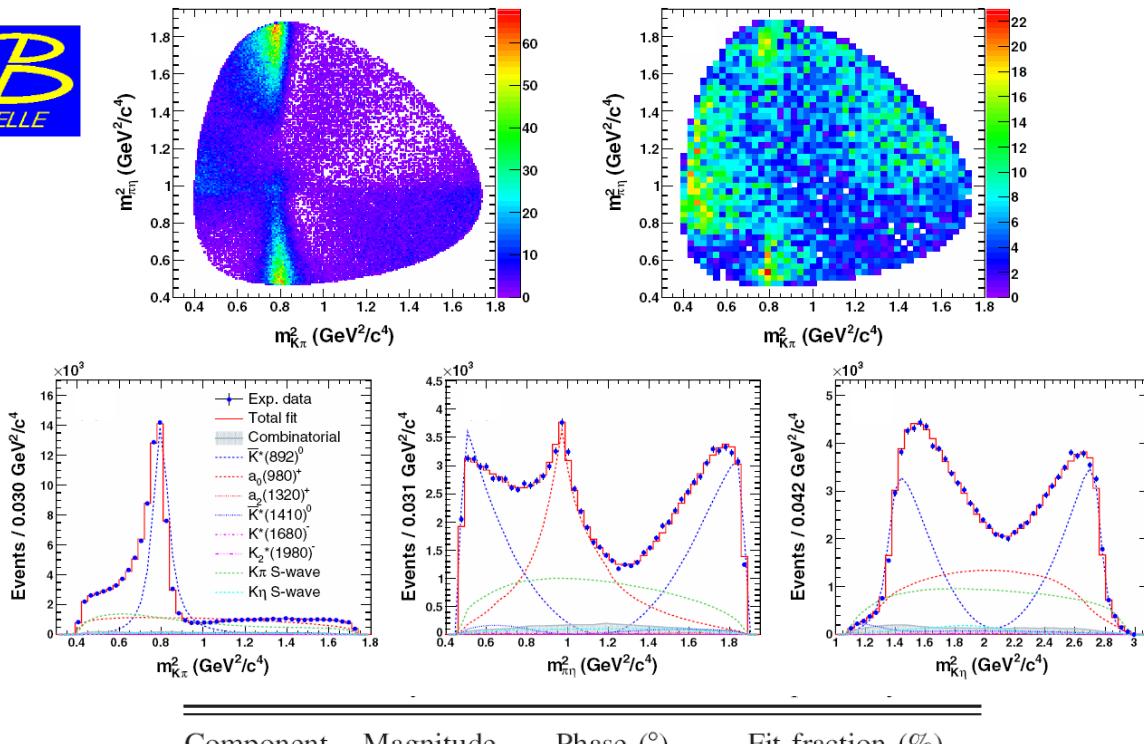
Observation of a W-annihilation process:

$$B_{D_s^+ \rightarrow a_0(980) \pi} = (2.20 \pm 0.22 \pm 0.34)\%$$



which is significantly greater than that of the known D annihilation decay by two orders of magnitude

Dalitz plot analysis of $D^0 \rightarrow K^-\pi^+\eta$ at Belle



Component	Magnitude	Phase (°)	Fit fraction (%)
$\bar{K}^*(892)^0$	1	0	$47.61 \pm 1.32^{+0.24+3.64}_{-0.49-2.71}$
$a_0(980)^+$	2.779 ± 0.032	310.3 ± 1.1	$39.28 \pm 1.50^{+1.58+4.38}_{-0.51-3.30}$
$K\pi$ S-wave	10.82 ± 0.23	50.0 ± 5.7	$31.92 \pm 1.21^{+1.47+2.75}_{-0.53-2.87}$
$K\eta$ S-wave	1.70 ± 0.082	113.8 ± 13.6	$3.37 \pm 0.50^{+0.77+3.20}_{-0.27-1.21}$
$a_2(1320)^+$	1.27 ± 0.079	283.4 ± 4.7	$0.74 \pm 0.09^{+0.06+0.37}_{-0.04-0.17}$
$\bar{K}^*(1410)^0$	4.84 ± 0.36	352.7 ± 2.8	$6.94 \pm 0.85^{+0.55+2.37}_{-1.61-3.22}$
$K^*(1680)^-$	2.56 ± 0.18	232.2 ± 6.6	$1.07 \pm 0.16^{+0.11+0.58}_{-0.10-0.36}$
$K_2^*(1980)^-$	9.29 ± 0.69	207.7 ± 4.0	$1.13 \pm 0.15^{+0.05+0.88}_{-0.05-0.98}$
Sum			$132.1 \pm 3.4^{+1.6+8.3}_{-0.7-4.5}$

PRD102(2020)012002

$$\frac{\mathcal{B}[D^0 \rightarrow K^-\pi^+\eta]}{\mathcal{B}[D^0 \rightarrow K^-\pi^+]} = 0.500 \pm 0.002 \pm 0.020 \pm 0.003_{\text{PDG}}$$

$$\mathcal{B}[D^0 \rightarrow K^-\pi^+\eta] = (1.973 \pm 0.009 \pm 0.079 \pm 0.018_{\text{PDG}})\%$$

This analysis confirms $\pi\eta'$ contribution for $a_0(980)$ in the three channel Flatte model with significance $>10\sigma$

$$\frac{\mathcal{B}[K^*(1680)^- \rightarrow K^-\eta]}{\mathcal{B}[K^*(1680)^- \rightarrow K^-\pi^0]} = 0.11 \pm 0.02 \pm 0.06 \pm 0.04_{\text{PDG}}$$

which is not consistent with the theoretical prediction under an assumption of a 1^3D_1 state

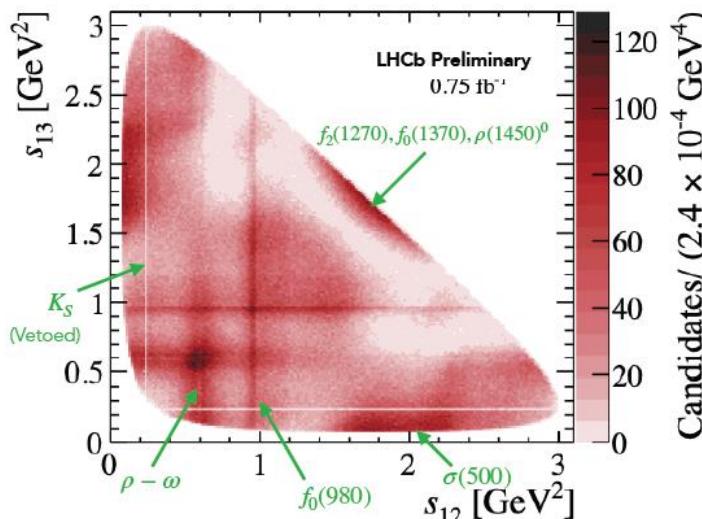
$$\mathcal{B}[D^0 \rightarrow \bar{K}^*(892)^0\eta] = (1.41 \pm 0.13)\%$$

which deviates from various theoretical calculations of (0.51-0.92)% by more than 3σ

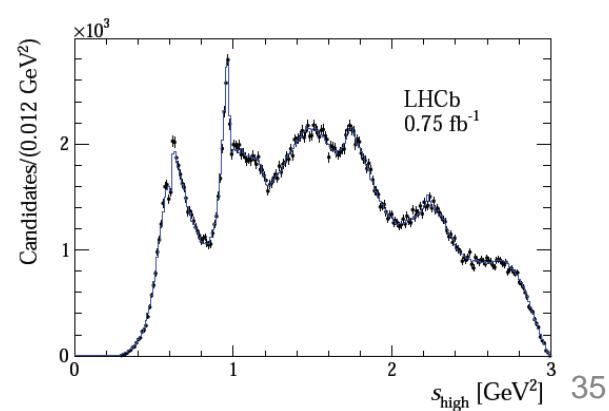
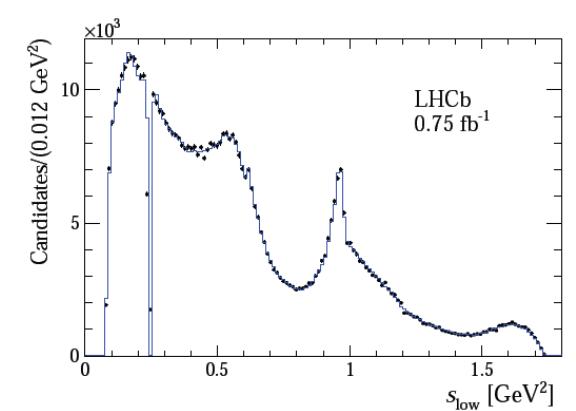
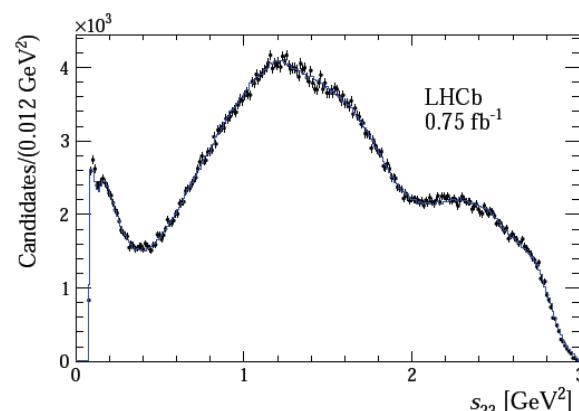
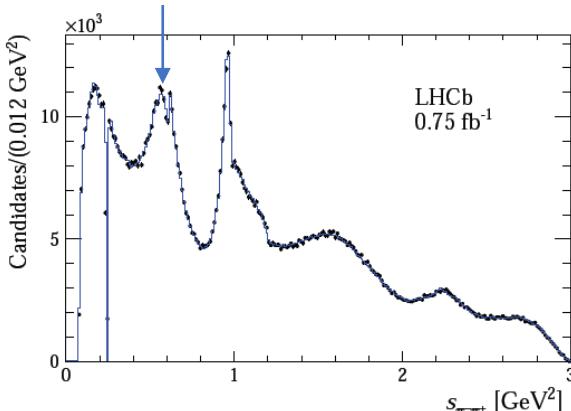
Dalitz plot analysis of $D^+ \rightarrow \pi^+ \pi^+ \pi^-$ at LHCb



arXiv:2208.03300



$\rho - \omega$ interference



Component	Magnitude	Phase [°]	Fit fraction [%]
$\rho(770)^0 \pi^+$	1 [fixed]	0 [fixed]	26.0 \pm 0.3 \pm 1.6 \pm 0.3
$\omega(782) \pi^+$	$(1.68 \pm 0.06 \pm 0.15 \pm 0.02) \times 10^{-2}$	$-103.3 \pm 2.1 \pm 2.6 \pm 0.4$	$0.103 \pm 0.008 \pm 0.014 \pm 0.002$
$\rho(1450)^0 \pi^+$	$2.66 \pm 0.07 \pm 0.24 \pm 0.22$	$47.0 \pm 1.5 \pm 5.5 \pm 4.1$	$5.4 \pm 0.4 \pm 1.3 \pm 0.8$
$\rho(1700)^0 \pi^+$	$7.41 \pm 0.18 \pm 0.47 \pm 0.71$	$-65.7 \pm 1.5 \pm 3.8 \pm 4.6$	$5.7 \pm 0.5 \pm 1.0 \pm 1.0$
$f_2(1270) \pi^+$	$2.16 \pm 0.02 \pm 0.10 \pm 0.02$	$-100.9 \pm 0.7 \pm 2.0 \pm 0.4$	$13.8 \pm 0.2 \pm 0.4 \pm 0.2$
S-wave			$61.8 \pm 0.5 \pm 0.6 \pm 0.5$
$\sum_i \text{FF}_i$			112.8
χ^2/ndof (range)	[1.47 - 1.78]		$-2 \log \mathcal{L} = 805622$

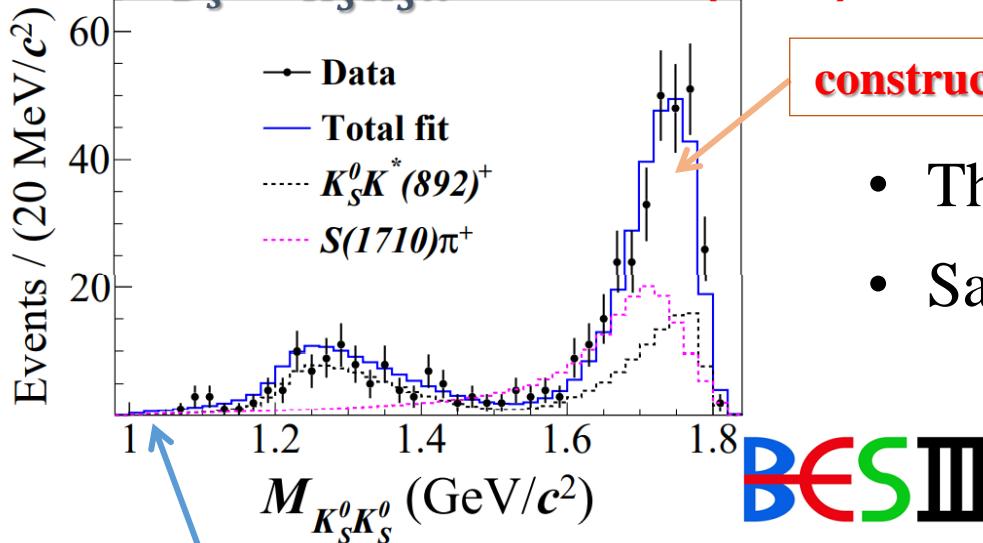
S-wave is dominated

	$\omega(782) \pi^+$	$\rho(1450)^0 \pi^+$	$\rho(1700)^0 \pi^+$	$f_2(1270) \pi^+$	S-wave
$\rho(770)^0 \pi^+$	-0.24 ± 0.06	5.1 ± 0.3	-5.8 ± 0.4	-0.3 ± 0.1	1.8 ± 0.4
$\omega(782) \pi^+$		0.05 ± 0.01	0.05 ± 0.01	0.046 ± 0.04	-0.04 ± 0.01
$\rho(1450)^0 \pi^+$				-4.0 ± 0.5	1.1 ± 0.1
$\rho(1700)^0 \pi^+$					-3.4 ± 0.5
$f_2(1270) \pi^+$					-1.6 ± 0.1

Large interference between ρ states

Amplitude analysis of $D_s^+ \rightarrow KK\pi$

$D_s^+ \rightarrow K_S^0 K_S^0 \pi^+$ PRD105(2022)L051103



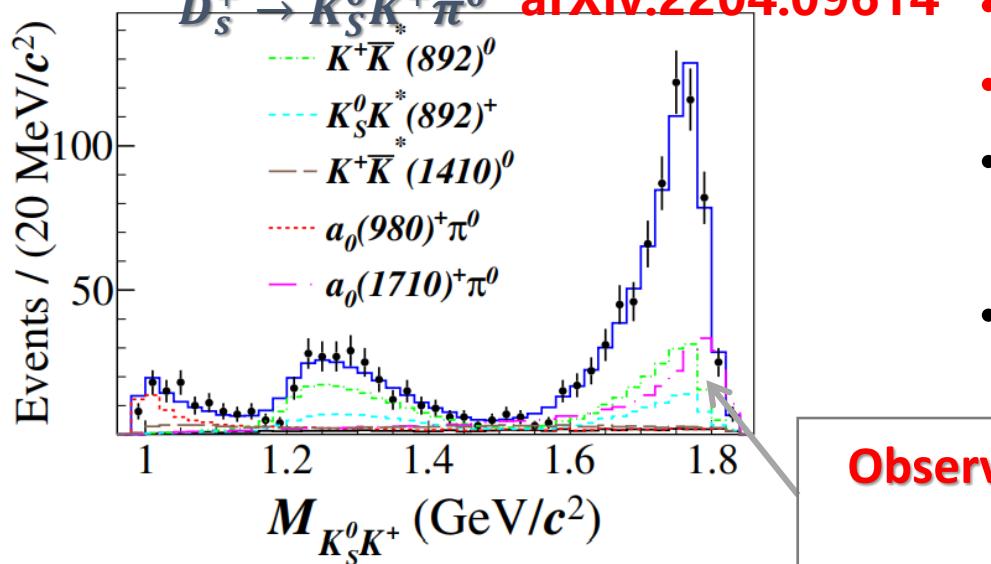
constructive interference: $a_0(1817)$ and $f_0(1710)$

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

PRD104(2021)072002

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

$D_s^+ \rightarrow K_S^0 K^+ \pi^0$ arXiv:2204.09614



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

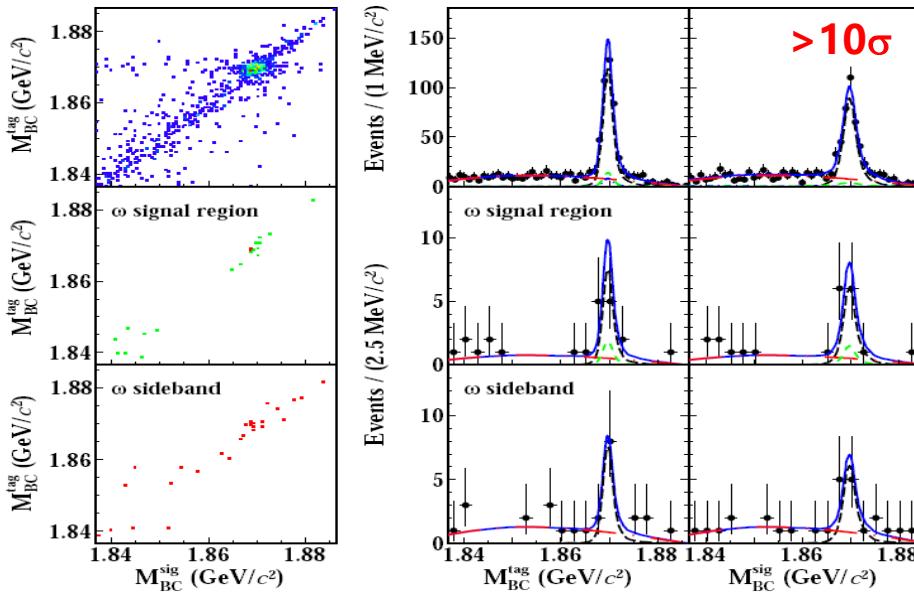
- $M = 1.817 \pm 0.008 \pm 0.020$ GeV/ c^2
- $\Gamma = 0.097 \pm 0.022 \pm 0.015$ GeV/ c^2
- $\mathcal{B}(D_s^+ \rightarrow a_0(1817)^+ \pi^0)$
 $= (3.44 \pm 0.52 \pm 0.32) \times 10^{-3}$
- Significance $> 10\sigma$

See backup slides for more amplitude analyses of multi-body hadronic D decays at BESIII

Observation of DCS decay $D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$

BESIII

PRL125(2020)241802



A very large BF:

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

$$B_{DCS}/B_{CF} = (6.28 \pm 0.52) \tan^4 \theta_C$$

θ_C is Cabibbo mixing angle

Naïve theoretical prediction:

$$B_{DCS}/B_{CF} \sim (0.5 - 2.0) \tan^4 \theta_C$$

Comparison of B_{DCS}/B_{CF} :

DCS mode	BF($\times 10^{-4}$)	CF mode	BF($\times 10^{-2}$)	Ratio($\times 10^{-3}$)
$D^0 \rightarrow K^+ \pi^-$	1.48 ± 0.07	$D^0 \rightarrow K^- \pi^+$	3.89 ± 0.04	3.80 ± 0.18
$D^0 \rightarrow K^+ \pi^- \pi^0$	3.01 ± 0.15	$D^0 \rightarrow K^- \pi^+ \pi^0$	14.2 ± 0.5	2.12 ± 0.13
$D^0 \rightarrow K^+ \pi^- \pi^- \pi^+$	2.45 ± 0.07	$D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$	8.11 ± 0.15	3.02 ± 0.10
$D^+ \rightarrow K^+ \pi^+ \pi^-$	5.19 ± 0.26	$D^+ \rightarrow K^- \pi^+ \pi^+$	8.98 ± 0.28	5.78 ± 0.34
$D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$	11.3 ± 0.8	$D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0$	6.25 ± 0.18	18.10 ± 1.5

Asymmetry of charge-conjugated BFs:

$$\mathcal{A}_{CP}^{D^\pm \rightarrow K^\pm \pi^\pm \pi^\mp \pi^0} = \frac{\mathcal{B}_{D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0} - \mathcal{B}_{D^- \rightarrow K^- \pi^- \pi^+ \pi^0}}{\mathcal{B}_{D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0} + \mathcal{B}_{D^- \rightarrow K^- \pi^- \pi^+ \pi^0}}$$

$$\mathcal{A}_{CP}^{D^\pm \rightarrow K^\pm \pi^\pm \pi^\mp \pi^0} = (-0.04 \pm 0.06_{\text{stat}} \pm 0.01_{\text{syst}})$$

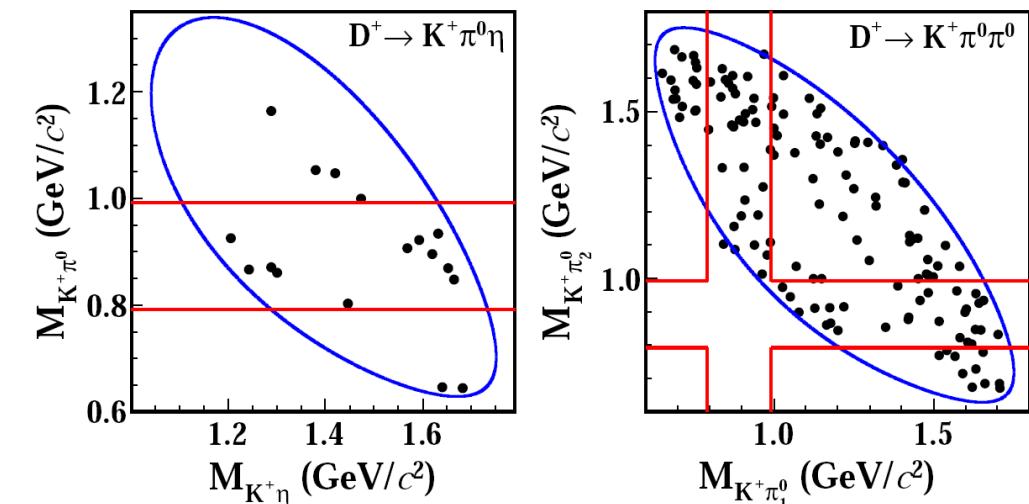
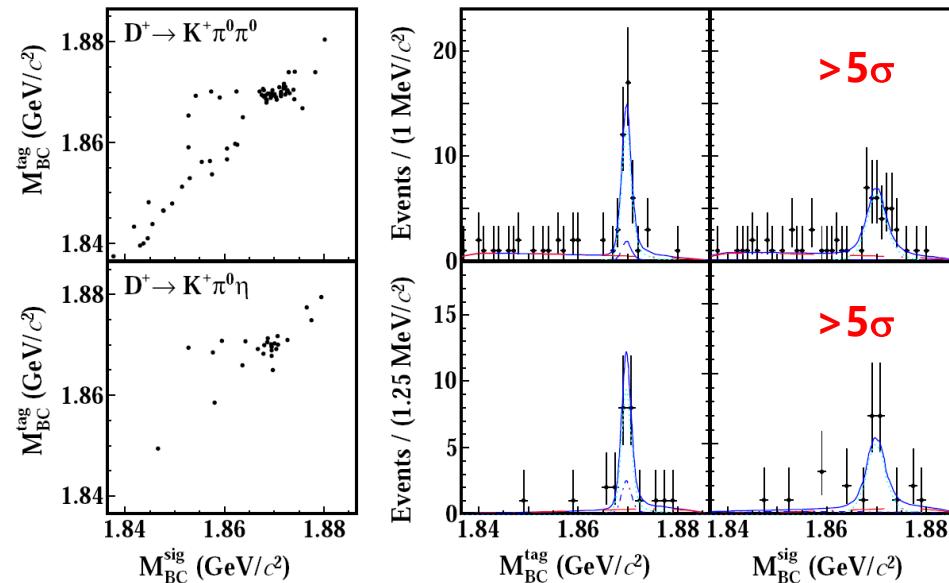
Evidence for $D^+ \rightarrow K^+ \omega$ (3.2σ):

$$\mathcal{B}(D^+ \rightarrow K^+ \omega) = (5.7^{+2.5}_{-2.1} \text{ stat} \pm 0.2_{\text{syst}}) \times 10^{-5}$$

Observation of DCS decays $D^+ \rightarrow K^+\pi^0\pi^0$ and $K^+\pi^0\eta$

BESIII

arXiv:2110.10999, accepted by JHEP



$$\frac{B[D^+ \rightarrow K^+\pi^0\pi^0]}{B[D^+ \rightarrow K^-\pi^+\pi^+]} = (2.26 \pm 0.40) \times 10^{-3}$$

$$B_{DCS}/B_{CF} = (0.78 \pm 0.14) \tan^4 \theta_C$$

$$\frac{B[D^+ \rightarrow K^+\pi^0\eta]}{B[D^+ \rightarrow \bar{K}^0\pi^+\eta]} = (8.09 \pm 2.13) \times 10^{-3}$$

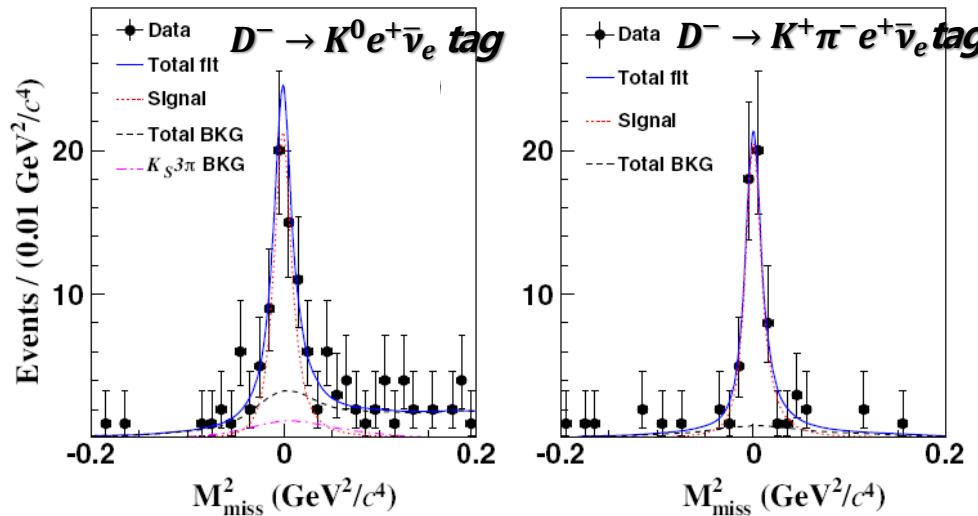
$$B_{DCS}/B_{CF} = (2.79 \pm 0.64) \tan^4 \theta_C$$

Decay mode	N_{DT}	$\epsilon_{sig} (\%)$	$\mathcal{B}_{sig} (\times 10^{-4})$
$D^+ \rightarrow K^+\pi^0\pi^0$	34.4 ± 6.4	18.22 ± 0.04	$2.1 \pm 0.4 \pm 0.1$
$D^+ \rightarrow K^+\pi^0\eta$	15.4 ± 4.4	20.66 ± 0.04	$2.1 \pm 0.6 \pm 0.1$
$D^+ \rightarrow K^{*+}\pi^0$	$10.4^{+5.7}_{-5.3}$	14.18 ± 0.04	$2.5^{+1.4}_{-1.3} \pm 0.1$
$D^+ \rightarrow K^{*+}\eta$	$9.8^{+4.0}_{-3.4}$	17.78 ± 0.07	$4.7^{+1.9}_{-1.6} \pm 0.2$

Studies of DCS D decays via semileptonic tags

BESIII

PRD104(2021)072005



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

$$B_{\text{DCS}}/B_{\text{CF}} = (5.73 \pm 0.73) \tan^4 \theta_C$$

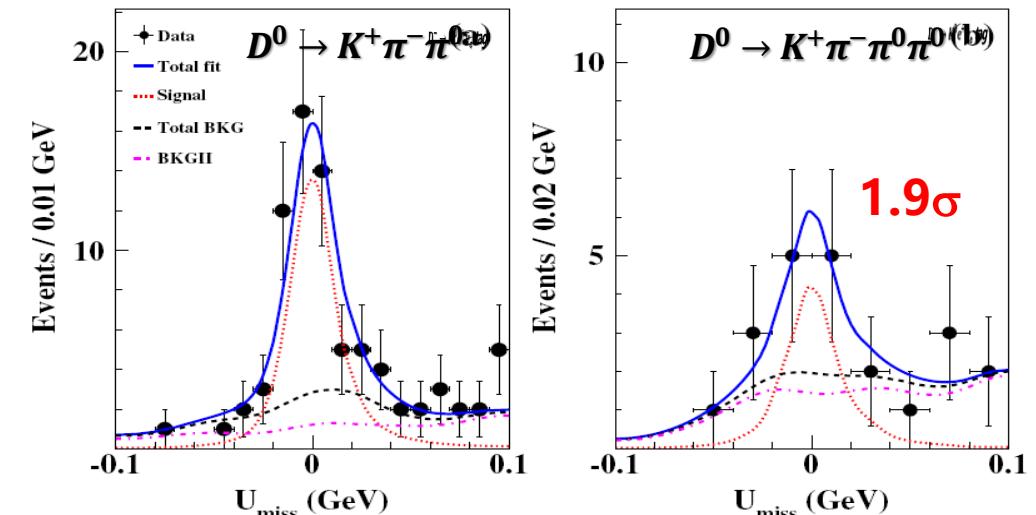
Confirms the results measured via hadronic tags

Combining the two results obtained with hadronic and semileptonic tags gives:

$$B_{D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0} = (1.10 \pm 0.07) \times 10^{-3}$$

$$B_{\text{DCS}}/B_{\text{CF}} = (6.11 \pm 0.42) \tan^4 \theta_C$$

PRD105(2022)112001



$$B_{D^0 \rightarrow K^+ \pi^- \pi^0} = (3.13 \pm 0.60 \pm 0.15) \times 10^{-4}$$

$$B_{\text{DCS}}/B_{\text{CF}} = (0.75 \pm 0.14) \tan^4 \theta_C$$

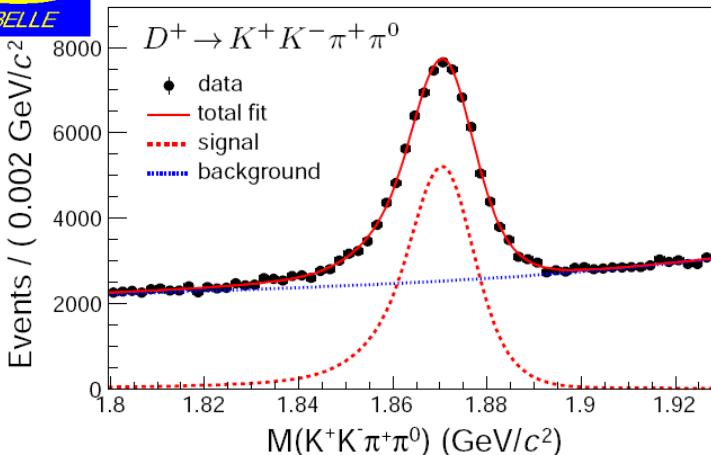
$$B_{D^0 \rightarrow K^+ \pi^- \pi^0 \pi^0} = (1.84^{+1.19}_{-1.10} \pm 0.11) \times 10^{-4}$$

$$B_{\text{DCS}}/B_{\text{CF}} < 1.37 \tan^4 \theta_C \quad @90\% \text{ CL}$$

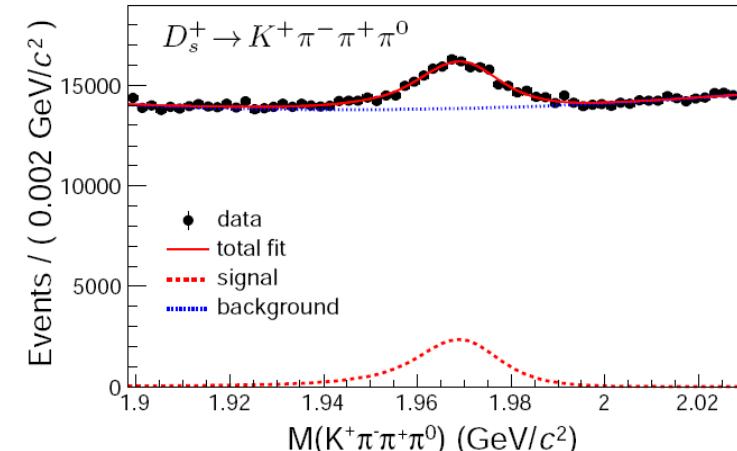
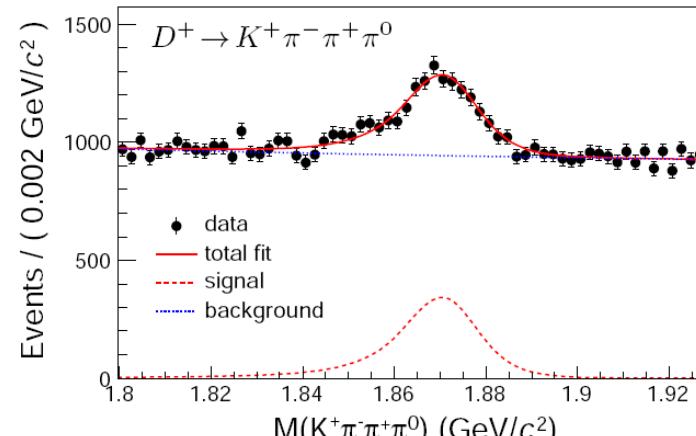
Direct measurement of DCS D^0 decays with negligible quantum correction effect

See backup slides for more measurements of BFs of hadronic D decays at BESIII

DCS D decay at Belle



arXiv:2205.02018



$$\frac{B[D^+ \rightarrow K^+ K^- \pi^+ \pi^0]}{B[D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0]} = (11.32 \pm 0.11 \pm 0.26)\%$$

$$B[D^+ \rightarrow K^+ K^- \pi^+ \pi^0] = (7.08 \pm 0.07 \pm 0.16 \pm 0.20_{\text{PDG}}) \times 10^{-3}$$

$$\frac{B[D^+ \rightarrow K^+ \pi^- \pi^+ \pi^0]^{\text{DCS}}}{B[D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0]} = (1.68 \pm 0.08 \pm 0.03)\%$$

$$B[D^+ \rightarrow K^+ \pi^- \pi^+ \pi^0]^{\text{DCS}} = (1.05 \pm 0.05 \pm 0.02 \pm 0.03_{\text{PDG}}) \times 10^{-3}$$

$$B_{\text{DCS}}/B_{\text{CF}} = (5.83 \pm 0.30) \tan^4 \theta_C$$

confirms the large BF of $D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$ at BESIII

$$\frac{B[D_s^+ \rightarrow K^+ \pi^- \pi^+ \pi^0]}{B[D_s^+ \rightarrow K^+ K^- \pi^+ \pi^0]} = (17.13 \pm 0.46 \pm 0.51)\%$$

$$B[D_s^+ \rightarrow K^+ \pi^- \pi^+ \pi^0] = (9.44 \pm 0.25 \pm 0.28 \pm 0.32_{\text{PDG}}) \times 10^{-3}$$

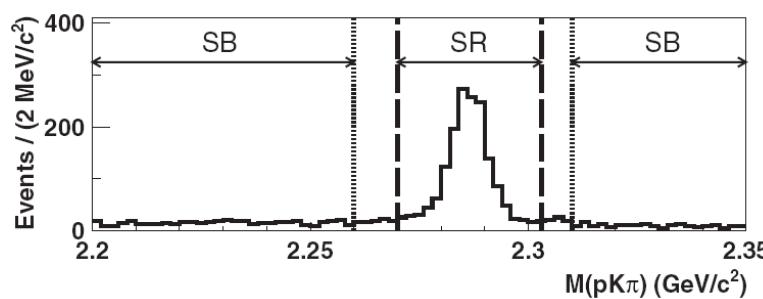
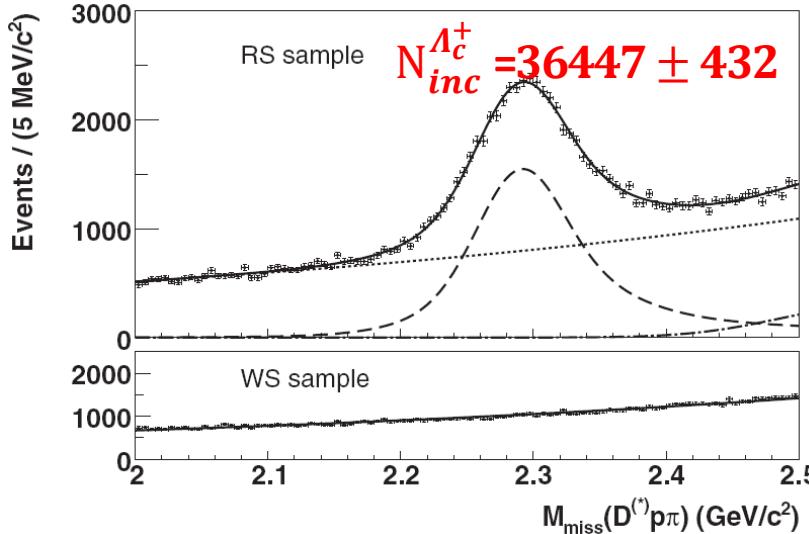
Charmed baryon decays

- Λ_c^+ decays
- Ξ_c^+ and Ξ_c^0 decays
- Ω_c^0 decays
- Ξ_{cc}^{++} and Ξ_{cc}^+ decays

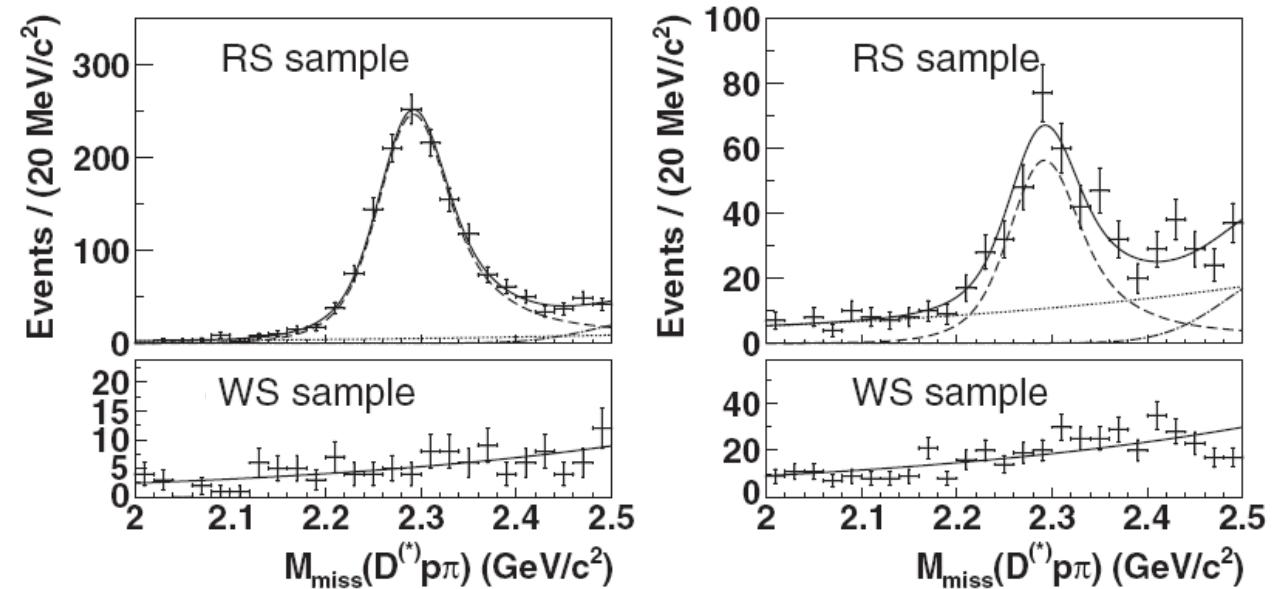
Absolute BF of $\Lambda_c^+ \rightarrow pK^-\pi^+$ at Belle



PRL113(2014)042002



$$\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+) = \frac{N(\Lambda_c^+ \rightarrow pK^-\pi^+)}{N_{\text{inc}}^{\Lambda_c} f_{\text{bias}} \epsilon(\Lambda_c^+ \rightarrow pK^-\pi^+)}$$



1359 ± 45

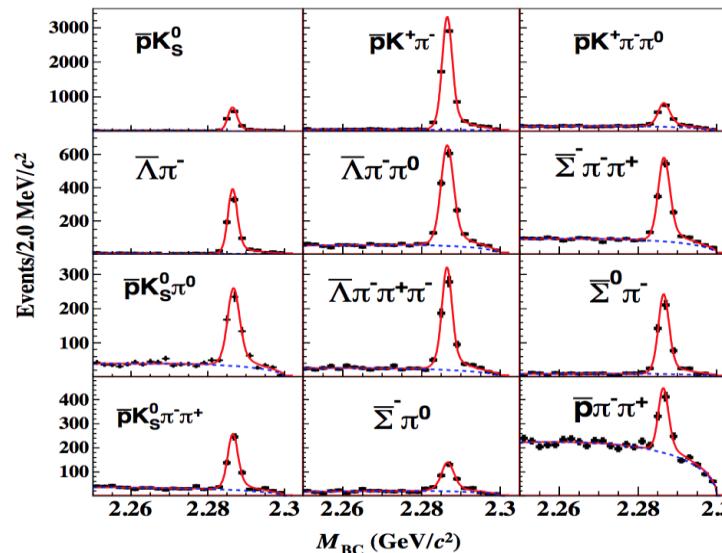
$$B[\Lambda_c^+ \rightarrow pK^-\pi^+] = (6.84 \pm 0.24^{+0.21}_{-0.27})\%$$

Much improved precision compared to the precision
of 25% of previous world average value

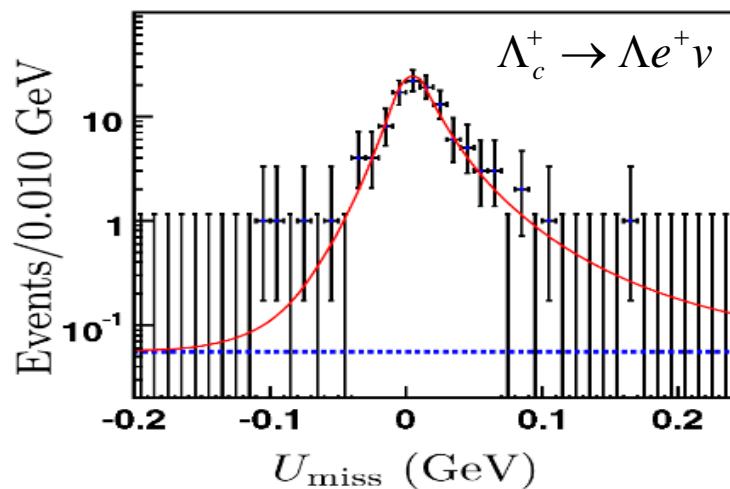
Absolute BFs of Λ_c^+ decays at BESIII

BESIII

PRL116(2016)052001



PRL115(2015)221805



Based on 0.57 fb⁻¹@4.6 GeV:

Hadronic decay

- $\Lambda_c^+ \rightarrow pK^-\pi^+ + 11$ CF modes PRL116(2016)052001
- $\Lambda_c^+ \rightarrow pK^+K^-, p\pi^+\pi^-$ PRL117(2017)232002
- $\Lambda_c^+ \rightarrow nK_s^0\pi^+$ PRL118(2017)112001
- $\Lambda_c^+ \rightarrow p\eta, p\pi^0$ PRD95(2017)111102(R)
- $\Lambda_c^+ \rightarrow \Sigma^-\pi^+\pi^+\pi^0$ PLB772(2017)388
- $\Lambda_c^+ \rightarrow \Xi^{0(*)}K^+$ PLB783(2018)200
- $\Lambda_c^+ \rightarrow \Lambda\eta\pi^+$ PRD99(2019)032010
- $\Lambda_c^+ \rightarrow \Sigma^+\eta, \Sigma^+\eta'$ CPC43(2019)083002
- $\Lambda_c^+ \rightarrow$ BP decay asymmetries PRD100(2019)07200
- $\Lambda_c^+ \rightarrow pK_s\eta$ PLB817(2021)136327

Semi-leptonic decay

- $\Lambda_c^+ \rightarrow \Lambda e^+\nu_e$ PRL115(2015)221805
- $\Lambda_c^+ \rightarrow \Lambda\mu^+\nu_\mu$ PLB767(2017)42

Inclusive decay

- $\Lambda_c^+ \rightarrow \Lambda X$ PRL121(2018)062003
- $\Lambda_c^+ \rightarrow e^+X$ PRL121(2018)251801
- $\Lambda_c^+ \rightarrow K_s^0X$ EPJC80(2020)935

Production

- $\Lambda_c^+ \Lambda_c^-$ cross section PRL120(2018)132001

Very productive for data taken in 35 days!

Impact on the world data of Λ_c^+

PDG2014

For example

PDG2020

Λ_c^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S = -1$ final states			
$p\bar{K}^0$	(2.3 ± 0.6) %	873	
$pK^-\pi^+$	[a] (5.0 ± 1.3) %	823	
$p\bar{K}^*(892)^0$	[b] (1.6 ± 0.5) %	685	
$\Delta(1232)^{++}K^-$	(8.6 ± 3.0) $\times 10^{-3}$	710	
$\Lambda(1520)\pi^+$	[b] (1.8 ± 0.6) %	627	
$pK^-\pi^+$ nonresonant	(2.8 ± 0.8) %	823	
$p\bar{K}^0\pi^0$	(3.3 ± 1.0) %	823	
$p\bar{K}^0\eta$	(1.2 ± 0.4) %	568	

Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

Λ_c^+ REFERENCES

We have omitted some papers that have been superseded by later experiments. The omitted papers may be found in our 1992 edition (Physical Review **D45**, 1 June, Part II) or in earlier editions.

AAIJ	19AG	PR D100 032001	R. Aaij <i>et al.</i>	(LHCb Collab.)
ABLIKIM	19AX	PR D100 072004	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
ABLIKIM	19X	CP C43 083002	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
ABLIKIM	19Y	PR D99 032010	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
AAIJ	18N	PR D97 091101	R. Aaij <i>et al.</i>	(LHCb Collab.)
AAIJ	18R	JHEP 1803 182	R. Aaij <i>et al.</i>	(LHCb Collab.)
AAIJ	18V	JHEP 1803 043	R. Aaij <i>et al.</i>	(LHCb Collab.)
ABLIKIM	18AF	PRL 121 251801	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	18E	PRL 121 062003	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
ABLIKIM	18Y	PL B783 200	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
BERGER	18	PR D98 112006	M. Berger <i>et al.</i>	(BELLE Collab.)
ABLIKIM	17D	PL B767 42	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
ABLIKIM	17H	PRL 118 112001	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
ABLIKIM	17Q	PR D95 111102	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
ABLIKIM	17Y	PL B772 388	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
PAL	17	PR D96 051102	B. Pal <i>et al.</i>	(BELLE Collab.)
ABLIKIM	16	PRL 116 052001	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
ABLIKIM	16U	PRL 117 232002	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
YANG	16	PRL 117 011801	S.B. Yang <i>et al.</i>	(BELLE Collab.)
ABLIKIM	15Y	PRL 115 221805	M. Ablikim <i>et al.</i>	(BESIII Collab.★)
ZUPANC	14	PRL 113 042002	A. Zupanc <i>et al.</i>	(BELLE Collab.)
LEES	11G	PR D84 072006	J.P. Lees <i>et al.</i>	(BABAR Collab.)

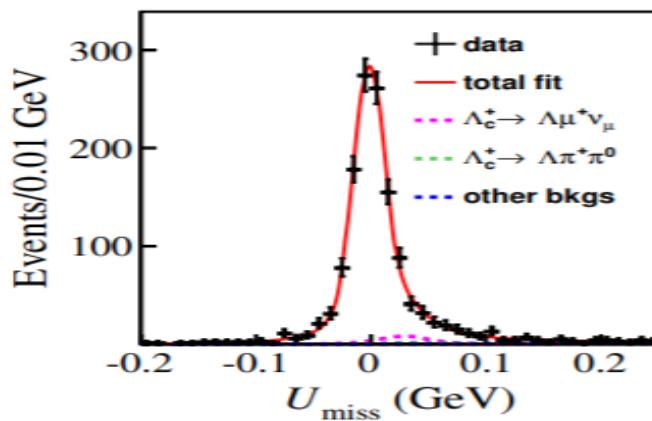
Hadronic modes with a p or n : $S = -1$ final states		
Γ_1	pK_S^0	(1.59 ± 0.08) %
Γ_2	$p\bar{K}^-\pi^+$	(6.28 ± 0.32) %
Γ_3	$p\bar{K}^*(892)^0$	[a] (1.96 ± 0.27) %
Γ_4	$\Delta(1232)^{++}K^-$	(1.08 ± 0.25) %
Γ_5	$\Lambda(1520)\pi^+$	[a] (2.2 ± 0.5) %
Γ_6	$pK^-\pi^+$ nonresonant	(3.5 ± 0.4) %
Γ_7	$pK_S^0\pi^0$	(1.97 ± 0.13) %
Γ_8	$nK_S^0\pi^+$	(1.82 ± 0.25) %
Γ_9	$p\bar{K}^0\eta$	(1.6 ± 0.4) %
Γ_{10}	$pK_S^0\pi^+\pi^-$	(1.60 ± 0.12) %
Γ_{11}	$pK^-\pi^+\pi^0$	(4.46 ± 0.30) %
Γ_{12}	$pK^*(892)^-\pi^+$	[a] (1.4 ± 0.5) %
Γ_{13}	$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$	(4.6 ± 0.8) %
Γ_{14}	$\Delta(1232)^{++}\pi^0$	seen
Γ_{15}	$pK^-2\pi^+\pi^-$	(1.4 ± 0.9) $\times 10^{-3}$
Γ_{16}	$pK^-\pi^+2\pi^0$	(1.0 ± 0.5) %

Much improved precision and new decay modes

Study of $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$ dynamics

BESIII

arXiv:2207.14149



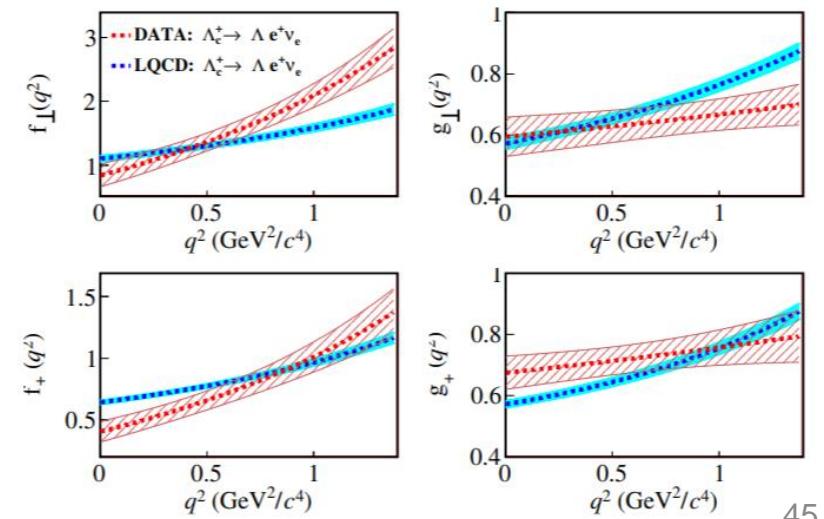
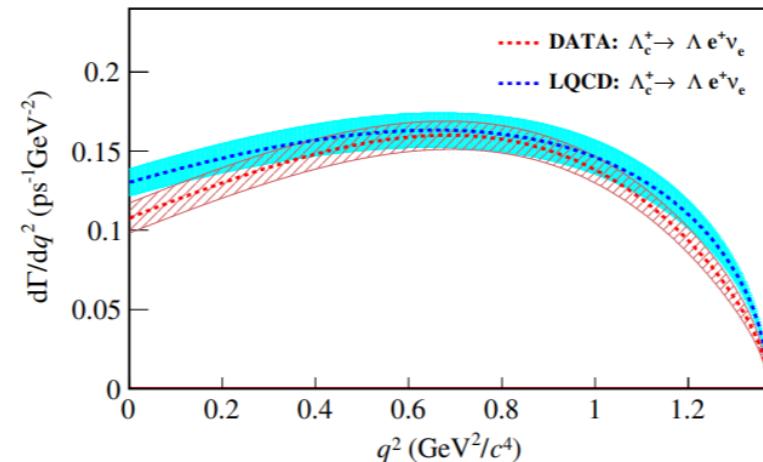
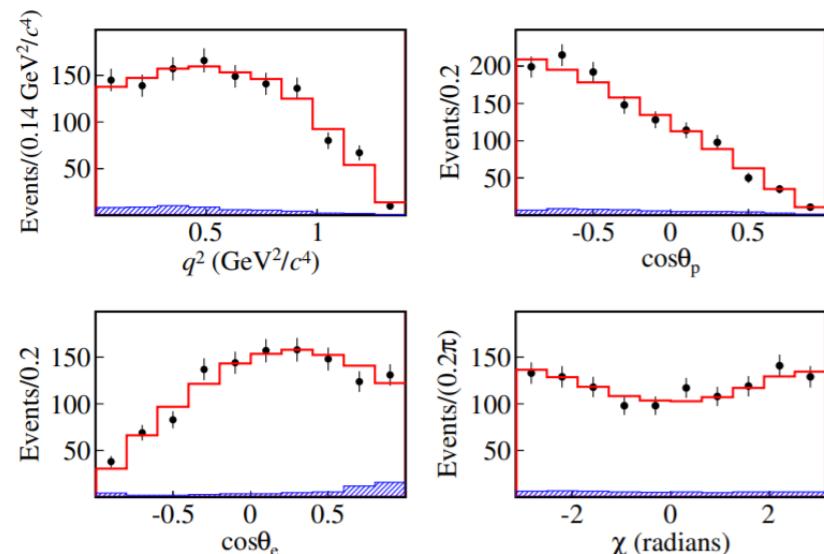
$$\mathcal{B}[\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e] = (3.56 \pm 0.11 \pm 0.07)\%$$

$$|V_{cs}| = 0.936 \pm 0.017 \pm 0.025_{\text{LQCD}}$$

	$\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e) [\%]$
Constituent quark model (HONR) [8]	4.25
Light-front approach [9]	1.63
Covariant quark model [10]	2.78
Relativistic quark model [11]	3.25
Non-relativistic quark model [12]	3.84
Light-cone sum rule [13]	3.0 ± 0.3
Lattice QCD [14]	3.80 ± 0.22
$SU(3)$ [15]	3.6 ± 0.4
Light-front constituent quark model [16]	3.36 ± 0.87
MIT bag model [16]	3.48
Light-front quark model [17]	4.04 ± 0.75
This work	$3.56 \pm 0.11 \pm 0.07$

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_e d\cos\theta_p d\chi} = \frac{G_F^2 |V_{cs}|^2}{2(2\pi)^4} \cdot \frac{Pq^2}{24M_{\Lambda_c}^2} \times$$

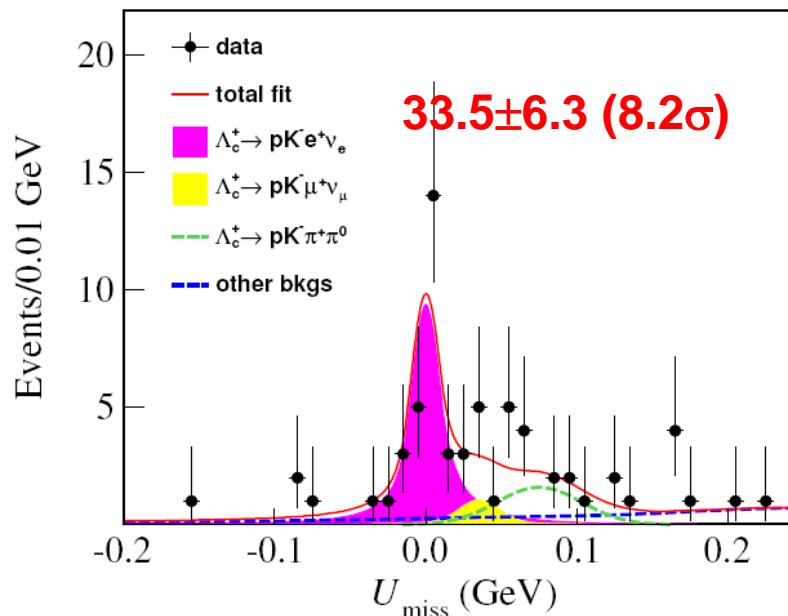
$$\left\{ \begin{aligned} & \frac{3}{8}(1 - \cos\theta_e)^2 |H_{\frac{1}{2}1}|^2 (1 + \alpha_\Lambda \cos\theta_p) \\ & + \frac{3}{8}(1 + \cos\theta_e)^2 |H_{-\frac{1}{2}-1}|^2 (1 - \alpha_\Lambda \cos\theta_p) \\ & + \frac{3}{4}\sin^2\theta_e [|H_{\frac{1}{2}0}|^2 (1 + \alpha_\Lambda \cos\theta_p) + |H_{-\frac{1}{2}0}|^2 (1 - \alpha_\Lambda \cos\theta_p)] \\ & + \frac{3}{2\sqrt{2}}\alpha_\Lambda \cos\chi \sin\theta_e \sin\theta_p \times \\ & [(1 - \cos\theta_e)H_{-\frac{1}{2}0}H_{\frac{1}{2}1} + (1 + \cos\theta_e)H_{\frac{1}{2}0}H_{-\frac{1}{2}-1}] \end{aligned} \right\}$$



Observation of $\Lambda_c^+ \rightarrow pK^-e^+\nu_e$

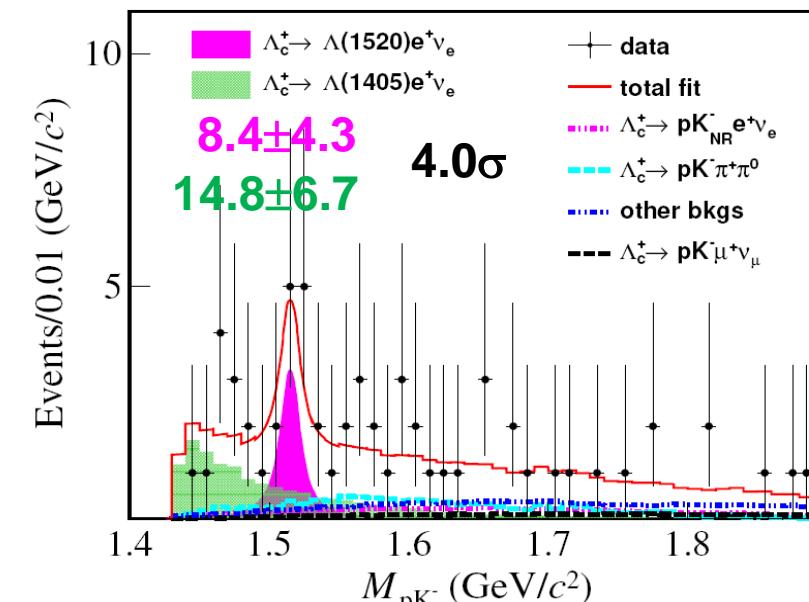
BESIII

arXiv:2207.11483



$$B[\Lambda_c^+ \rightarrow pK^-e^+\nu_e] = (8.2 \pm 1.5 \pm 0.6) \times 10^{-4}$$

Evidence of $\Lambda_c^+ \rightarrow \Lambda(1520)e^+\nu_e$ & $\Lambda_c^+ \rightarrow \Lambda(1405)e^+\nu_e$



$$B[\Lambda_c^+ \rightarrow \Lambda(1520)e^+\nu_e] = (0.99 \pm 0.51 \pm 0.10) \times 10^{-3}$$

$$B[\Lambda_c^+ \rightarrow \Lambda(1405)e^+\nu_e] = (1.69 \pm 0.70 \pm 0.16) \times 10^{-3}$$

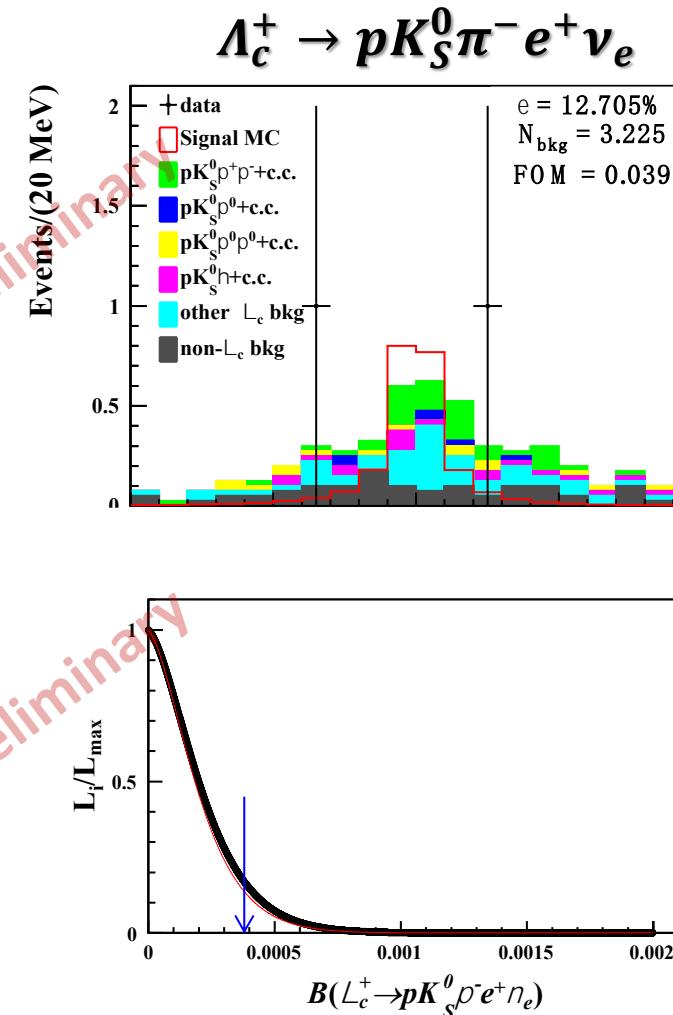
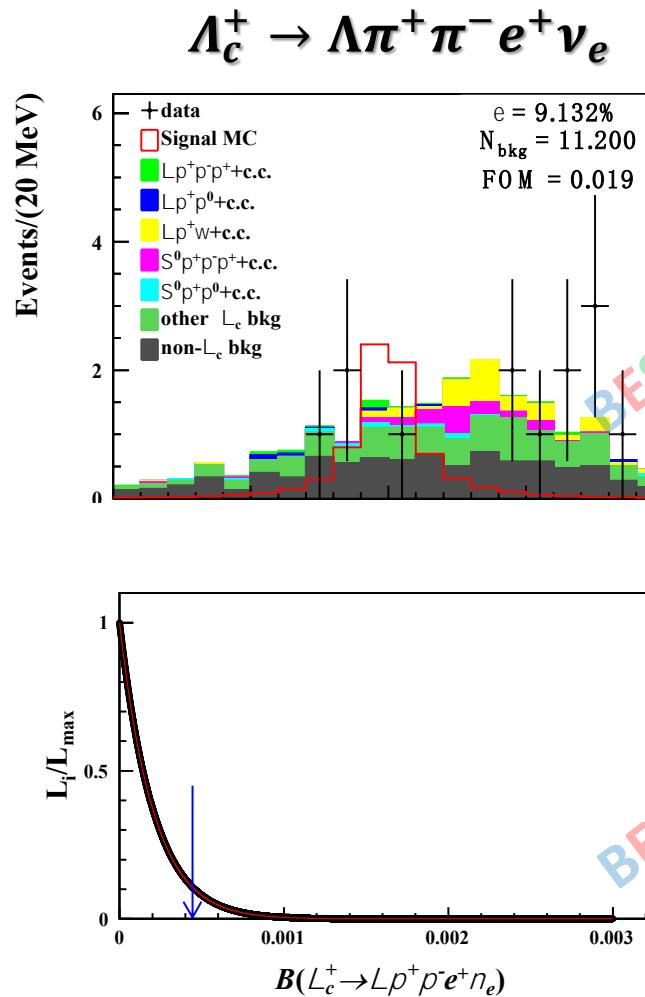
Larger data set helps to determine form factors in these decays

$$|V_{cs}| = 1.3 \pm 0.3 \pm 0.1_{\text{LQCD}}$$

	$\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda(1520)e^+\nu_e)$	$\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda(1405)e^+\nu_e)$	
Constituent quark model [7]	1.01	3.04	Ref. [7]: PRD93(2016)014021
Molecular state [8]	--	0.02	Ref. [8]: PRD93(2016)014021
Nonrelativistic quark model [9]	0.60	2.43	Ref. [9]: PRD95((2017)053005; 95(2017)099901E)
Lattice QCD [11, 12]	0.512 ± 0.082	--	Ref. [11]: PRD105(2022)L051505
Measurement	$0.99 \pm 0.51 \pm 0.10$	$1.69 \pm 0.76 \pm 0.16$	Ref. [12]: PRD105(2022)054511

Search for $\Lambda_c^+ \rightarrow \Lambda\pi^+\pi^-e^+\nu_e$ and $pK_S^0\pi^-e^+\nu_e$

BESIII



No significant signal is found and the upper limits on the BFs of these two decays are set at 90% CL:

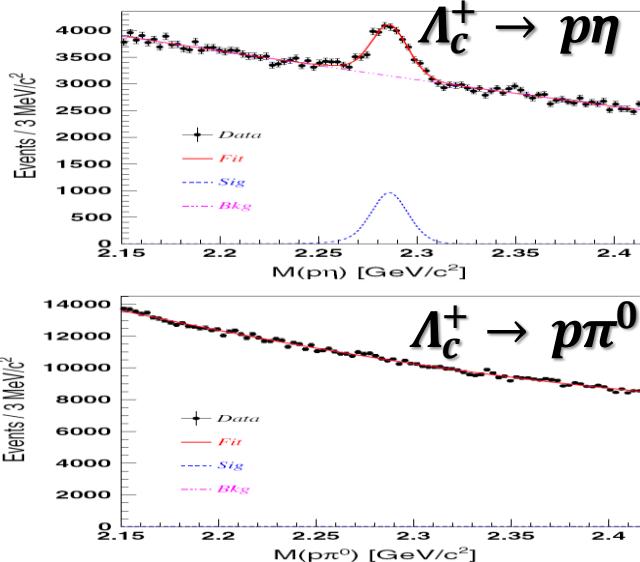
$$\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda\pi^+\pi^-e^+\nu_e) < 4.4 \times 10^{-4}$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow pK_S^0\pi^-e^+\nu_e) < 3.8 \times 10^{-4}$$

Studies of $\Lambda_c^+ \rightarrow ph$ ($h = \pi^0, \eta, \omega$) at Belle and LHCb



PRD103(2022)072004



$$\frac{B[\Lambda_c^+ \rightarrow p\eta]}{B[\Lambda_c^+ \rightarrow pK^-\pi^+]} = (2.258 \pm 0.077 \pm 0.122)\%$$

$$B[\Lambda_c^+ \rightarrow p\eta] = (1.42 \pm 0.05 \pm 0.11) \times 10^{-3}$$

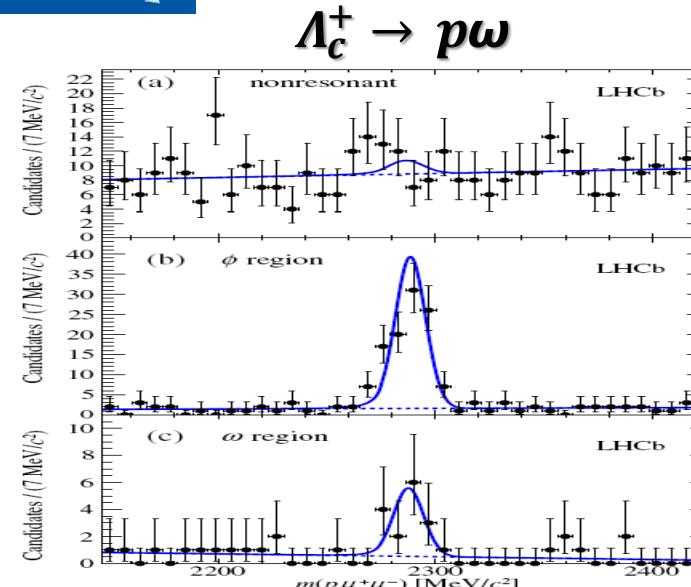
$$\frac{B[\Lambda_c^+ \rightarrow p\pi^0]}{B[\Lambda_c^+ \rightarrow pK^-\pi^+]} < 1.275 \times 10^{-3}$$

$$B[\Lambda_c^+ \rightarrow p\pi^0] < 8.0 \times 10^{-5} \quad @90\% \text{ CL}$$

agree with BESIII 2017 results, but with much better precision or sensitivity



PRD97(2018)091101

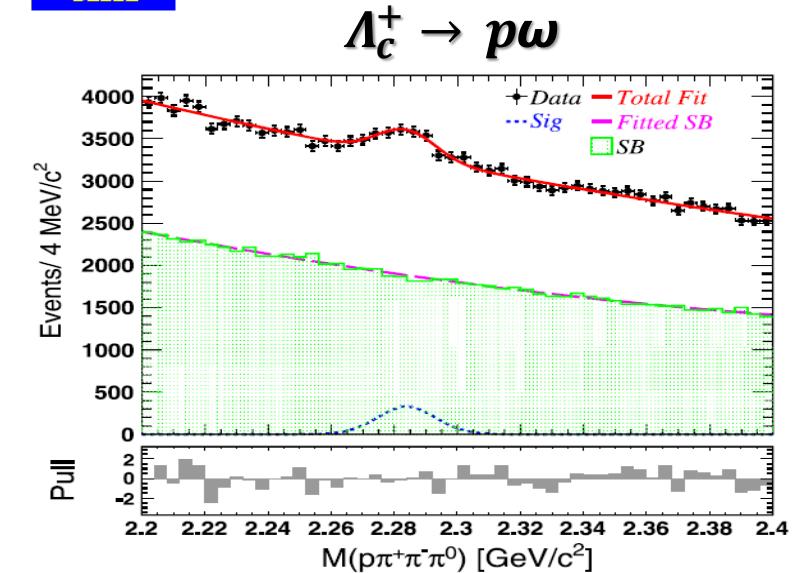


$$\frac{B[\Lambda_c^+ \rightarrow p\omega]B[\omega \rightarrow \mu^+\mu^-]}{B[\Lambda_c^+ \rightarrow p\phi]B[\phi \rightarrow \mu^+\mu^-]} = 0.23 \pm 0.08 \pm 0.03$$

$$B[\Lambda_c^+ \rightarrow p\omega] = (9.4 \pm 3.2 \pm 1.0 \pm 2.0) \times 10^{-4}$$



PRD104(2021)072008

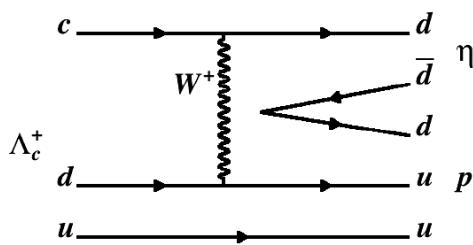
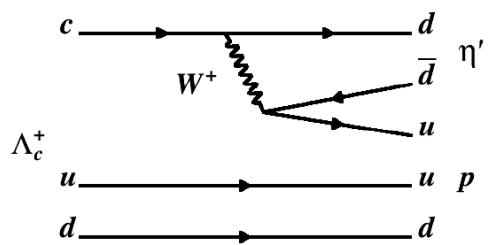


$$\frac{B[\Lambda_c^+ \rightarrow p\omega]}{B[\Lambda_c^+ \rightarrow pK^-\pi^+]} = (1.32 \pm 0.12 \pm 0.10)\%$$

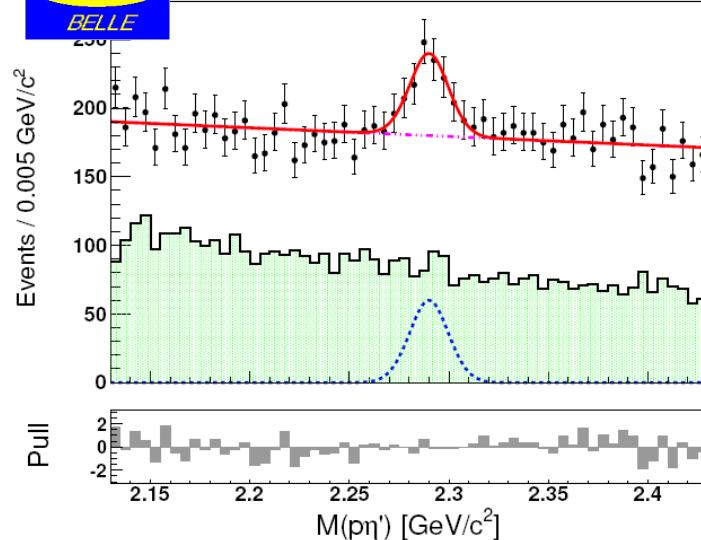
$$B[\Lambda_c^+ \rightarrow p\omega] = (8.27 \pm 0.75 \pm 0.62 \pm 0.42) \times 10^{-4}$$

Help to improve the theoretical calculations based on SU(3) flavor symmetry or QCD dynamics model predictions

Measurements of $\Lambda_c^+ \rightarrow p\eta'$ at Belle and BESIII



JHEP03(2022)090

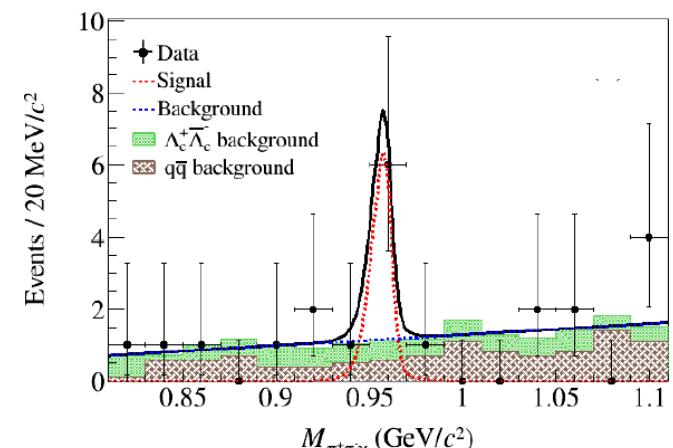
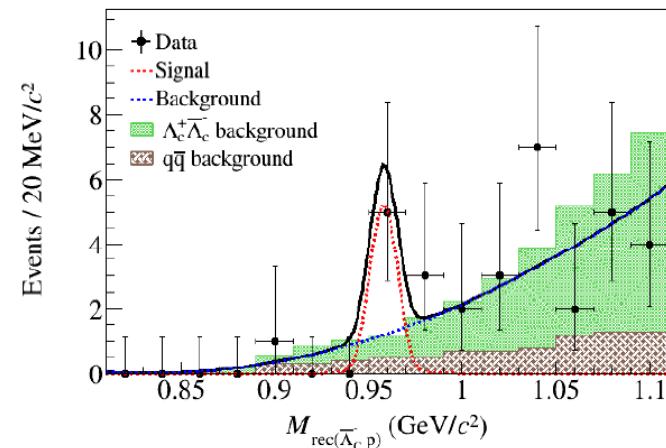


$$\frac{B[\Lambda_c^+ \rightarrow p\eta']}{B[\Lambda_c^+ \rightarrow pK^-\pi^+]} = (11.32 \pm 0.11 \pm 0.26) \times 10^{-3}$$

$$B[\Lambda_c^+ \rightarrow p\eta'] = (4.73 \pm 0.82 \pm 0.46 \pm 0.24_{\text{PDG}}) \times 10^{-4}$$



arXiv:2207.14461



$$\Lambda_c^+ \rightarrow p\eta' (10^{-4})$$

BESIII	$5.62^{+2.46}_{-2.04} \pm 0.26$
Belle [19]	4.73 ± 0.97
Sharma <i>et al.</i> [41]	$4 - 6$
Uppal <i>et al.</i> [42]	$0.4 - 2$
Geng <i>et al.</i> [17]	$12.2^{+14.3}_{-8.7}$

Ref. [17]: PLB790(2019)225

Ref. [19]: JHEP03(2022)090

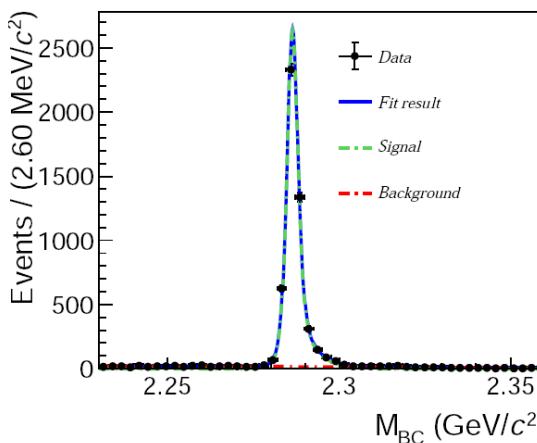
Ref. [41]: PRD55(1997)7067

Ref. [42]: PRD49(1994)3417

Study of $\Lambda_c^+ \rightarrow \Lambda K^+$

BESIII

arXiv:2208.04001



$$\frac{B[\Lambda_c^+ \rightarrow \Lambda K^+]}{B[\Lambda_c^+ \rightarrow \Lambda \pi^+]} = (4.78 \pm 0.34 \pm 0.20)\%$$

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

helps to clarify the tension between Belle and BaBar results:

$$\frac{B[\Lambda_c^+ \rightarrow \Lambda K^+]}{B[\Lambda_c^+ \rightarrow \Lambda \pi^+]}_{\text{Belle}} = (7.4 \pm 1.0 \pm 1.2)\%$$

PLB524(2002)33

$$\frac{B[\Lambda_c^+ \rightarrow \Lambda K^+]}{B[\Lambda_c^+ \rightarrow \Lambda \pi^+]}_{\text{BaBar}} = (4.4 \pm 0.4 \pm 0.3)\%$$

PRD75(2007)052002

Comparing to $\frac{B[\Lambda_c^+ \rightarrow p K^+ \pi^-]_{\text{DCS}}}{B[\Lambda_c^+ \rightarrow p K^- \pi^+]} = (0.82 \pm 0.12) \tan^4 \theta_C$

indicates that the Singly Cabibbo suppressed Λ_c^+ decays have more prominent non-factorizable effect

Comparing to $\frac{B[D^0 \rightarrow K^+ \pi^-]_{\text{DCS}}}{B[D^0 \rightarrow K^- \pi^+]} = (1.24 \pm 0.05) \tan^4 \theta_C$

$$\sqrt{\frac{B[D^+ \rightarrow K^+ \pi^+ \pi^-]_{\text{DCS}} B[D_s^+ \rightarrow K^+ K^+ \pi^-]_{\text{DCS}}}{B[D^+ \rightarrow K^- \pi^+ \pi^+] B[D_s^+ \rightarrow K^+ K^- \pi^+]}} = (1.25 \pm 0.08) \tan^4 \theta_C$$

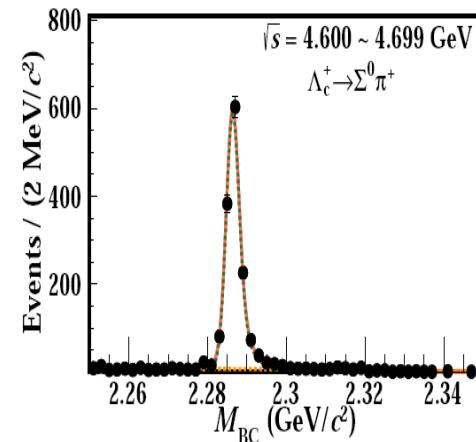
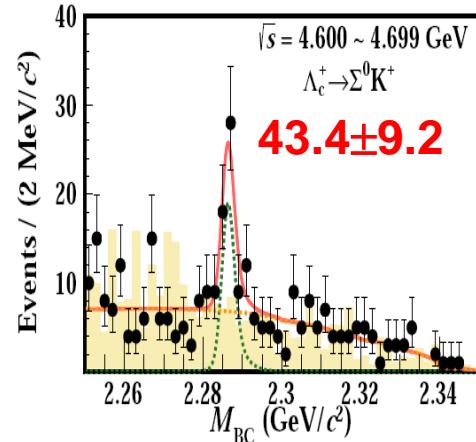
implies that the SU(3) flavor-symmetry breaking in charmed baryon system is more significant than charmed mesons

Theoretical predictions	$B(\Lambda_c^+ \rightarrow \Lambda K^+) (\times 10^{-3})$
$SU(3)$ 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

Studies of $\Lambda_c^+ \rightarrow \Sigma^0 K^+$ and $\Lambda_c^+ \rightarrow \Sigma^+ K_s^0$

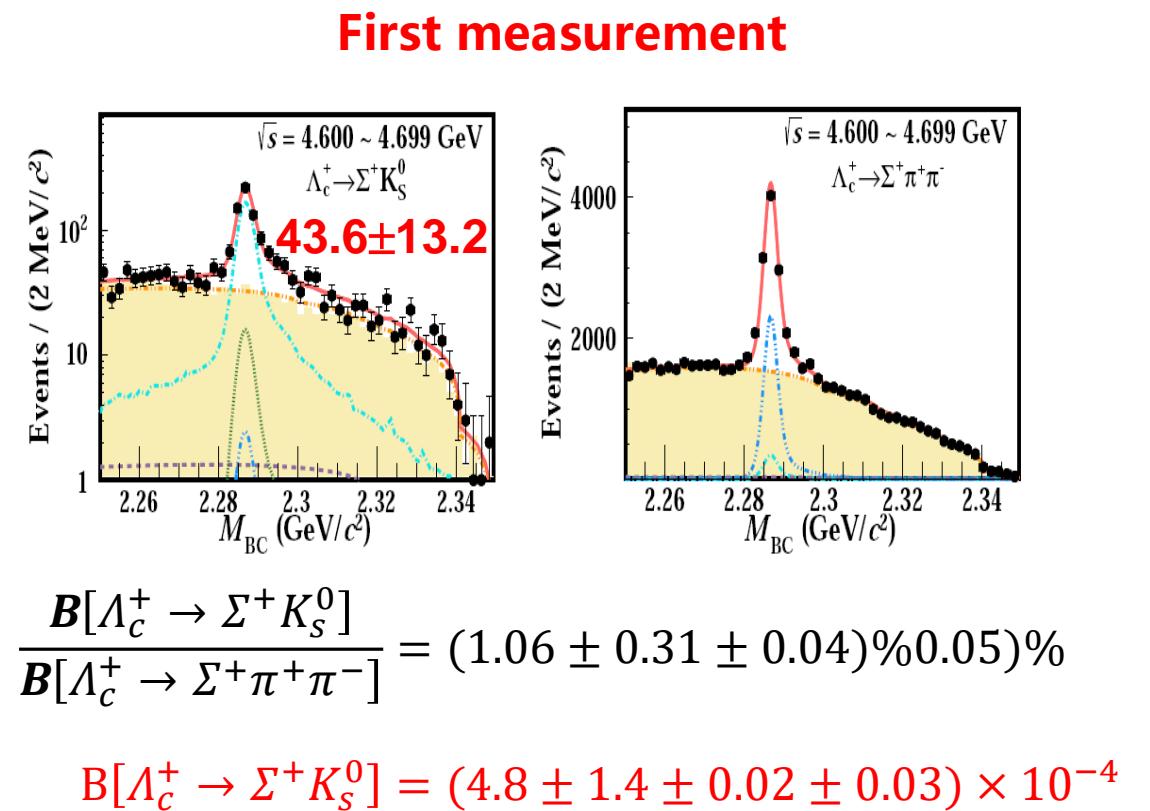
BESIII

arXiv:2207.10906



$$\frac{\mathcal{B}[\Lambda_c^+ \rightarrow \Sigma^0 K^+]}{\mathcal{B}[\Lambda_c^+ \rightarrow \Sigma^0 \pi^+]} = (3.61 \pm 0.73 \pm 0.05)\%$$

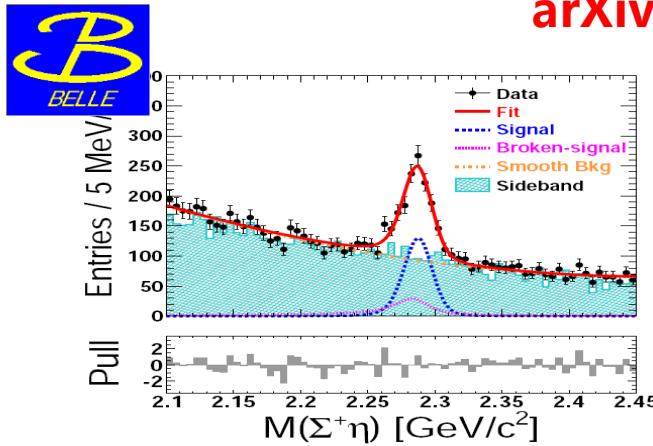
$$\mathcal{B}[\Lambda_c^+ \rightarrow \Sigma^0 K^+] = (4.7 \pm 0.9 \pm 0.1 \pm 0.3) \times 10^{-4}$$



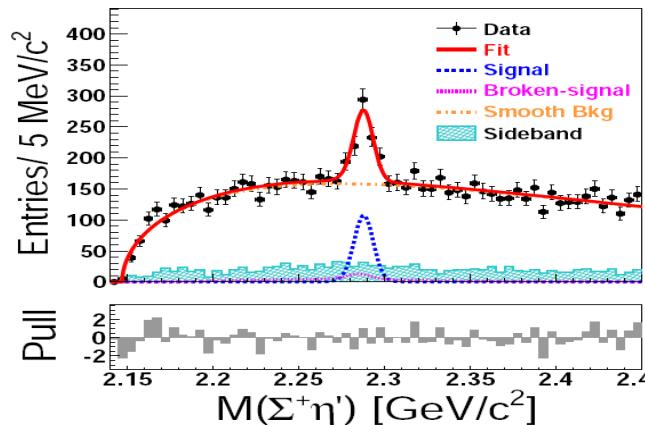
	$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 K^+)$	$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K_s^0)$
QCD corrections [2]	2(8)	2(4)
MIT bag model [3]	7.2 ± 1.8	7.2 ± 1.8
Diagrammatic analysis [4]	5.5 ± 1.6	9.6 ± 2.4
$SU(3)_F$ flavor symmetry [5]	5.4 ± 0.7	5.4 ± 0.7
IRA method [6]	5.0 ± 0.6	1.0 ± 0.4
PDG 2020 [28]	5.2 ± 0.8	/

$$\mathcal{B}[\Lambda_c^+ \rightarrow \Sigma^0 K^+]/\mathcal{B}[\Lambda_c^+ \rightarrow \Sigma^+ K_s^0] = 0.98 \pm 0.36$$

Mesurements of $\Lambda_c^+ \rightarrow \Sigma^+ h$ ($h = \pi^0, \eta, \eta'$) at Belle



arXiv:2208.10825

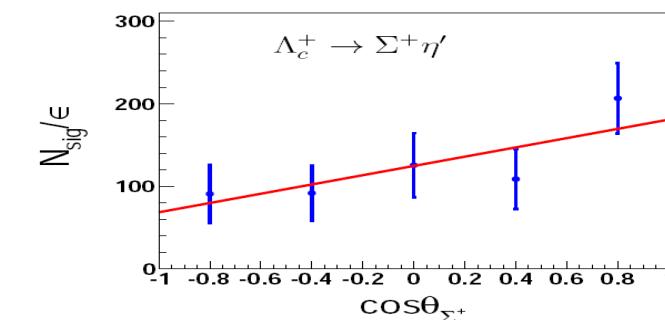
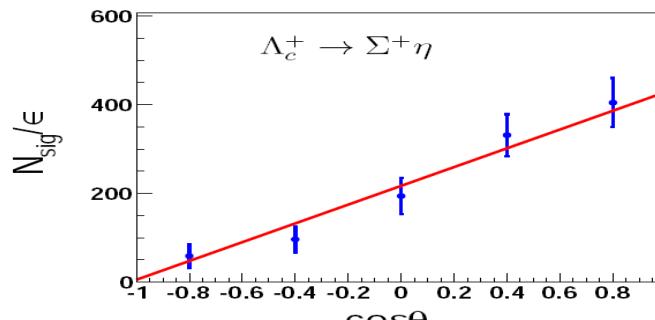
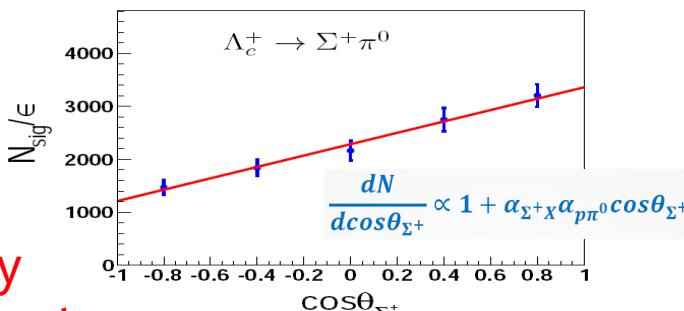


BFs:
$$\frac{B[\Lambda_c^+ \rightarrow \Sigma^+ \eta]}{B[\Lambda_c^+ \rightarrow \Sigma^+ \pi^0]} = 0.25 \pm 0.03 \pm 0.01$$

$$\frac{B[\Lambda_c^+ \rightarrow \Sigma^+ \eta']}{B[\Lambda_c^+ \rightarrow \Sigma^+ \pi^0]} = 0.33 \pm 0.06 \pm 0.02$$

$$B[\Lambda_c^+ \rightarrow \Sigma^+ \eta] = (3.14 \pm 0.35 \pm 0.11 \pm 0.25_{\text{PDG}}) \times 10^{-4}$$

$$B[\Lambda_c^+ \rightarrow \Sigma^+ \eta'] = (4.18 \pm 0.75 \pm 0.21 \pm 0.33_{\text{PDG}}) \times 10^{-4}$$



Decay parameters:

$$\alpha[\Sigma^+ \pi^0] = -0.48 \pm 0.02 \pm 0.02$$

$$\alpha[\Sigma^+ \eta] = -0.99 \pm 0.03 \pm 0.05$$

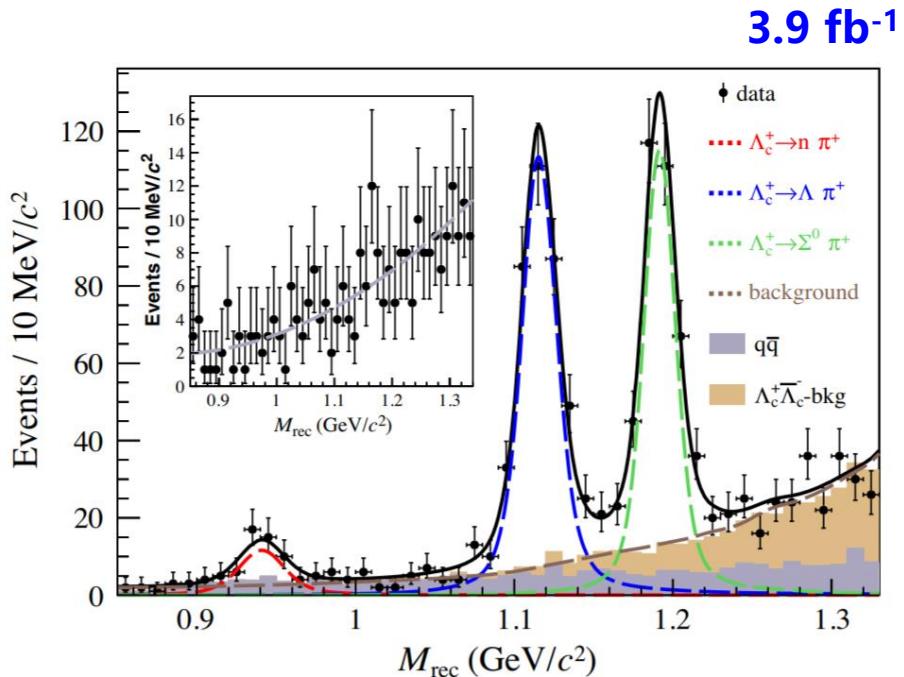
$$\alpha[\Sigma^+ \eta'] = -0.46 \pm 0.06 \pm 0.03$$

Decay	Körner [1]	Ivanov [2]	Zenczykowski [7]	Sharma [8]	Zou [10]	Geng [11]	Experiment [16]
$\Lambda_c^+ \rightarrow \Sigma^+ \eta$	0.16	0.11	0.90	0.57	0.74	0.32 ± 0.13	0.44 ± 0.20
$\Lambda_c^+ \rightarrow \Sigma^+ \eta'$	1.28	0.12	0.11	0.10	—	1.44 ± 0.56	1.5 ± 0.6
$\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$	0.70	0.43	0.39	-0.31	-0.76	-0.35 ± 0.27	-0.55 ± 0.11
$\Lambda_c^+ \rightarrow \Sigma^+ \eta$	0.33	0.55	0.00	-0.91	-0.95	-0.40 ± 0.47	—
$\Lambda_c^+ \rightarrow \Sigma^+ \eta'$	-0.45	-0.05	-0.91	0.78	—	$1.00^{+0.00}_{-0.17}$	—

Observation of $\Lambda_c^+ \rightarrow n\pi^+$

BESIII

PRL128(2022)142001



helps to test various theoretical calculations based on quark SU(3)-flavor symmetry

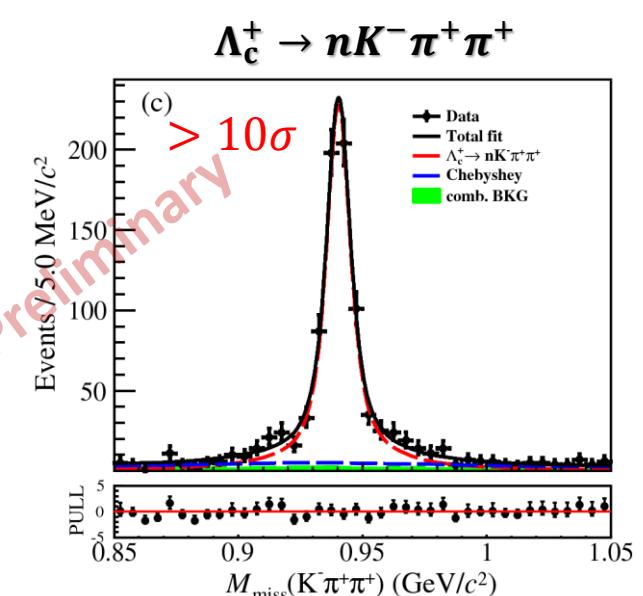
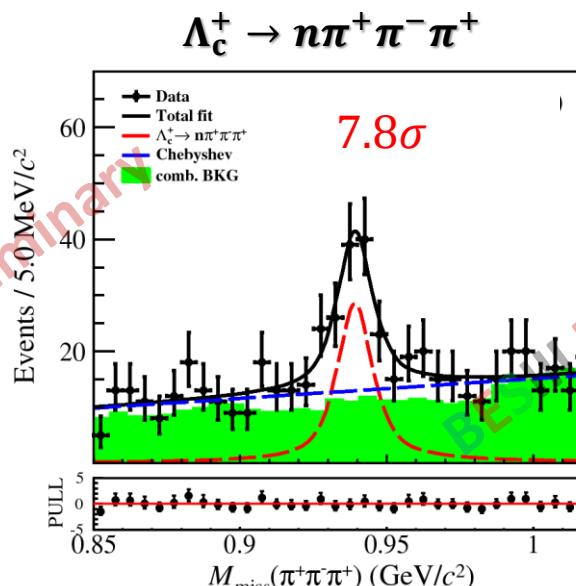
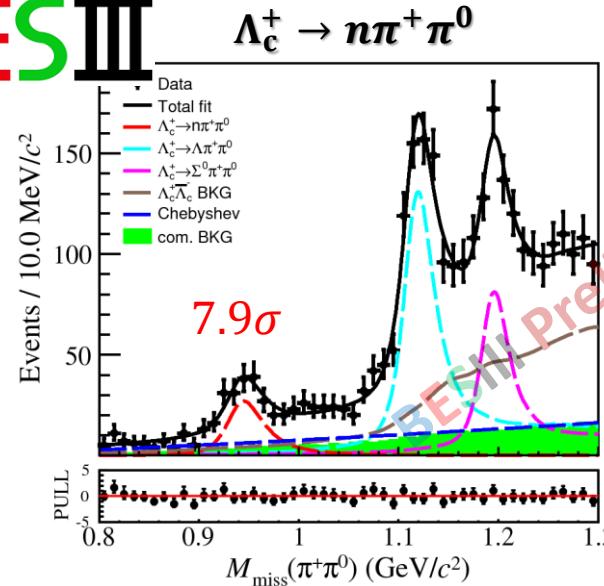
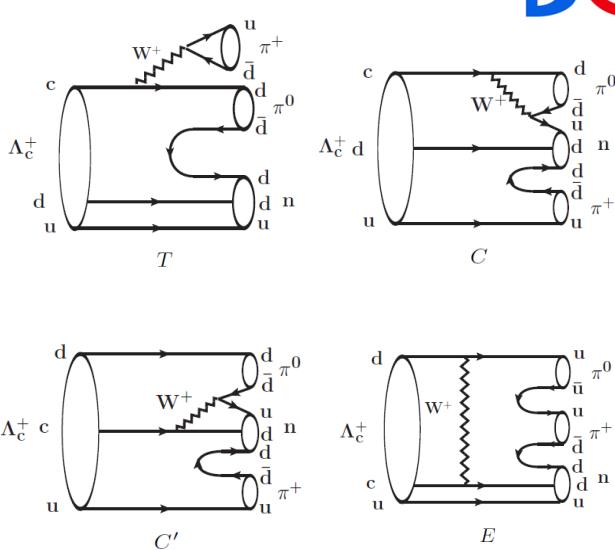
Decay	Yields	BF
$\Lambda_c^+ \rightarrow n\pi^+$	50 ± 9	$(6.6 \pm 1.2_{\text{stat}} \pm 0.4_{\text{syst}}) \times 10^{-4}$
$\Lambda_c^+ \rightarrow \Lambda\pi^+$	376 ± 22	$(1.31 \pm 0.08_{\text{stat}} \pm 0.05_{\text{syst}}) \times 10^{-2}$
$\Lambda_c^+ \rightarrow \Sigma^0\pi^+$	343 ± 22	$(1.22 \pm 0.08_{\text{stat}} \pm 0.07_{\text{syst}}) \times 10^{-2}$

$$\frac{B[\Lambda_c^+ \rightarrow n\pi^+]}{B[\Lambda_c^+ \rightarrow p\pi^0]} > 7.2 \quad @90\% \text{ CL}$$

$B(\Lambda_c^+ \rightarrow n\pi^+) \times 10^{-4}$	R	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

Observation of $\Lambda_c^+ \rightarrow n\pi^+\pi^0$, $n\pi^+\pi^-\pi^+$ and $nK^-\pi^+\pi^+$

BESIII



No theoretical calculation for the BFs of $\Lambda_c^+ \rightarrow n\pi^+\pi^0$, $\Lambda_c^+ \rightarrow n\pi^+\pi^-\pi^+$ and $\Lambda_c^+ \rightarrow nK^-\pi^+\pi^+$ were reported. These results may offer some inputs for theoretical research

$$R_1 = \frac{\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+\pi^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+)} = 9.7 \pm 2.2$$

PRL128 (2022) 142001

Decay mode	Yields	BF(%)	PDG value(%)
$\Lambda_c^+ \rightarrow n\pi^+\pi^0$	150.9 ± 21.4	$0.64 \pm 0.09_{\text{stat}} \pm 0.02_{\text{syst}}$	-
$\Lambda_c^+ \rightarrow n\pi^+\pi^-\pi^+$	120.6 ± 17.9	$0.45 \pm 0.07_{\text{stat}} \pm 0.03_{\text{syst}}$	-
$\Lambda_c^+ \rightarrow nK^-\pi^+\pi^+$	805.8 ± 33.1	$1.90 \pm 0.08_{\text{stat}} \pm 0.09_{\text{syst}}$	-

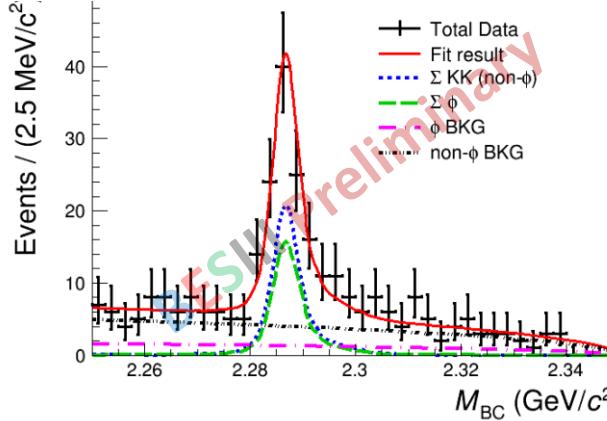
$$R_2 = \frac{\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow nK^-\pi^+\pi^+)} = 0.24 \pm 0.04$$

$$R_3 = \frac{\mathcal{B}(\Lambda_c^+ \rightarrow p\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow n\pi^+\pi^0)} = 0.72 \pm 0.13$$

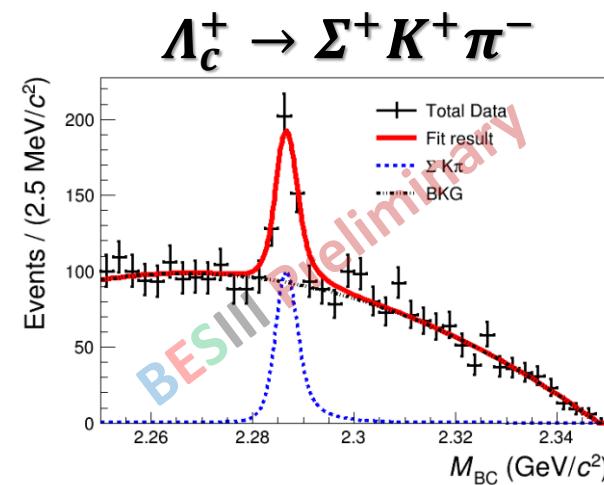
PDG

Studies of $\Lambda_c^+ \rightarrow \Sigma^+ K^+ \pi^-$, $\Sigma^+ K^+ K^-$ and $\Sigma^+ K^+ \pi^- \pi^0$

BESIII

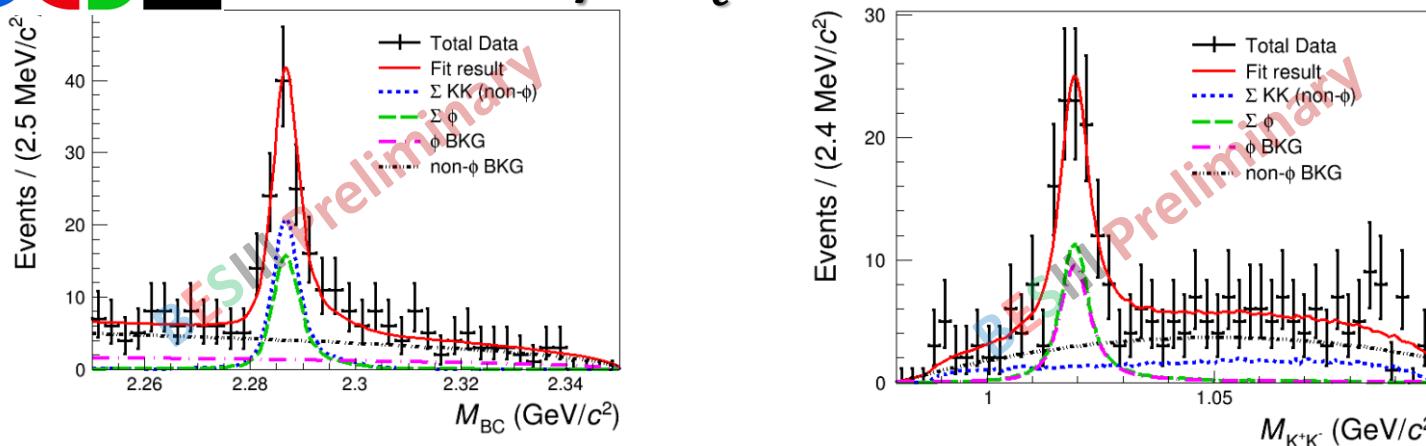


Study of $\Lambda_c^+ \rightarrow \Sigma^+ K^+ \pi^-$



$$\frac{B(\Lambda_c^+ \rightarrow \Sigma^+ K^+ \pi^-)}{B(\Lambda_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-)} = (4.51 \pm 0.52)\%$$

Statistical uncertainty only

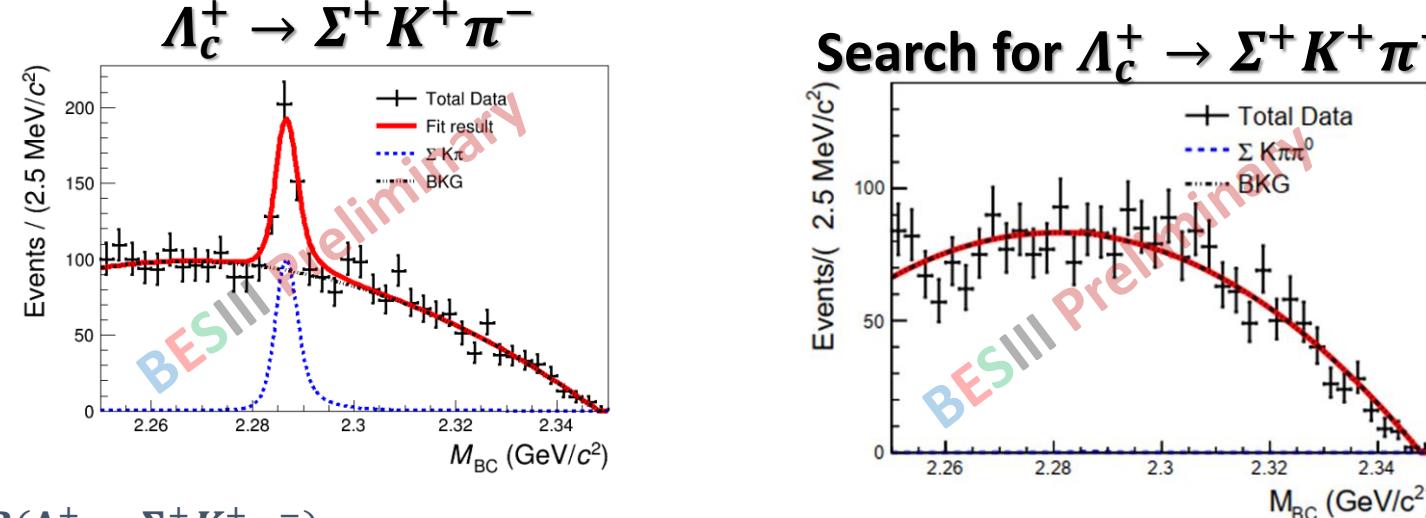


$$\frac{B(\Lambda_c^+ \rightarrow \Sigma^+ K^+ K^-)}{B(\Lambda_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-)} = (7.33 \pm 0.80)\%$$

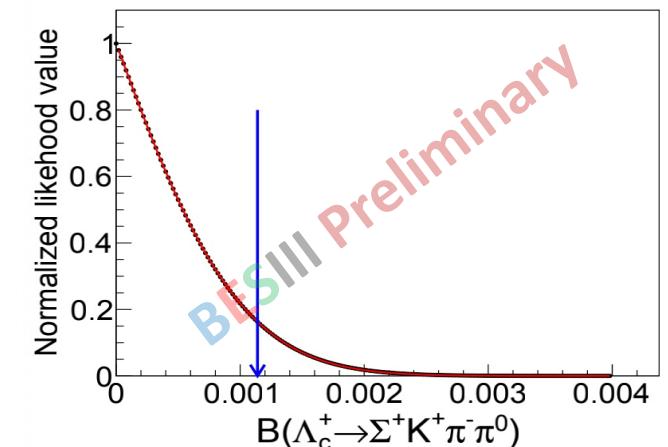
$$\frac{B(\Lambda_c^+ \rightarrow \Sigma^+ \phi)}{B(\Lambda_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-)} = (9.2 \pm 1.8)\%$$

$$\frac{B(\Lambda_c^+ \rightarrow \Sigma^+ K^+ K^- (\text{non-}\phi))}{B(\Lambda_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-)} = (4.38 \pm 0.79)\%$$

Statistical uncertainty only



$$B(\Lambda_c^+ \rightarrow \Sigma^+ K^+ \pi^- \pi^0) < 0.11\% \quad @90\% \text{ CL}$$

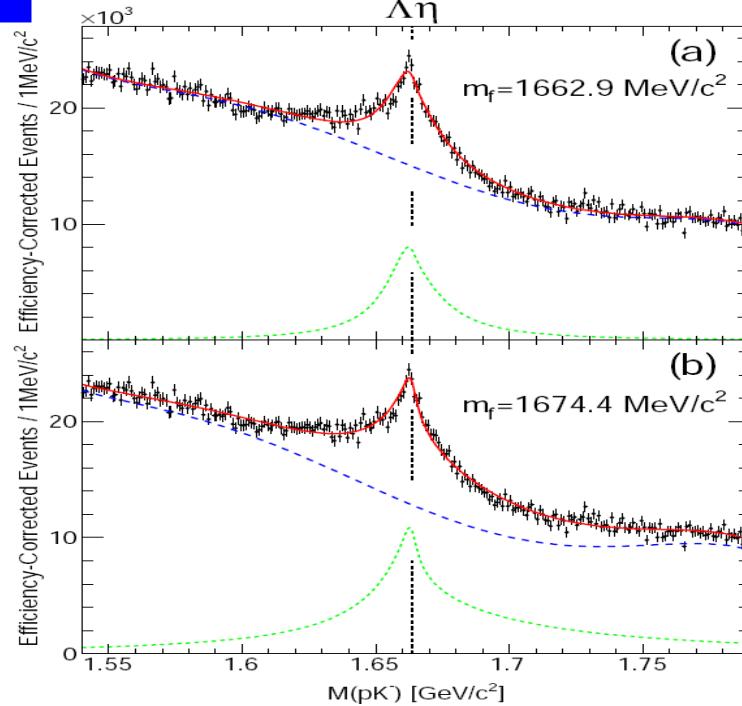


Study of $\Lambda_c^+ \rightarrow pK^-\pi^+$ at Belle



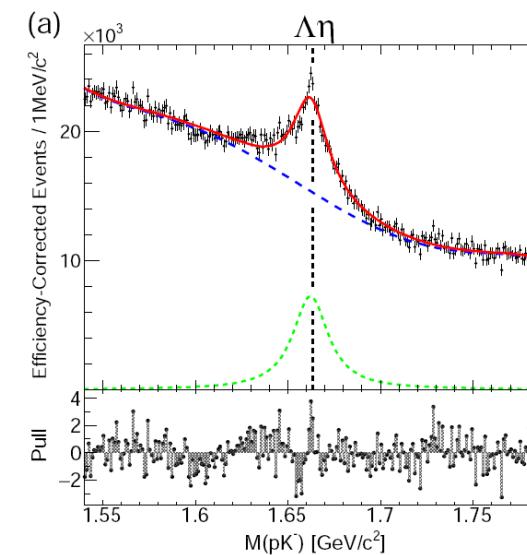
arXiv:2209.00050

1.5 M



$$\frac{dN}{dm} \propto |f(m)|^2 = \left| \frac{1}{m - m_f + \frac{i}{2}(\Gamma' + \bar{g}_{\Lambda\eta}k)} \right|^2$$

Observation of a threshold cusp at the $\Lambda\eta$ threshold in the pK^- mass spectrum



Breit-Wigner

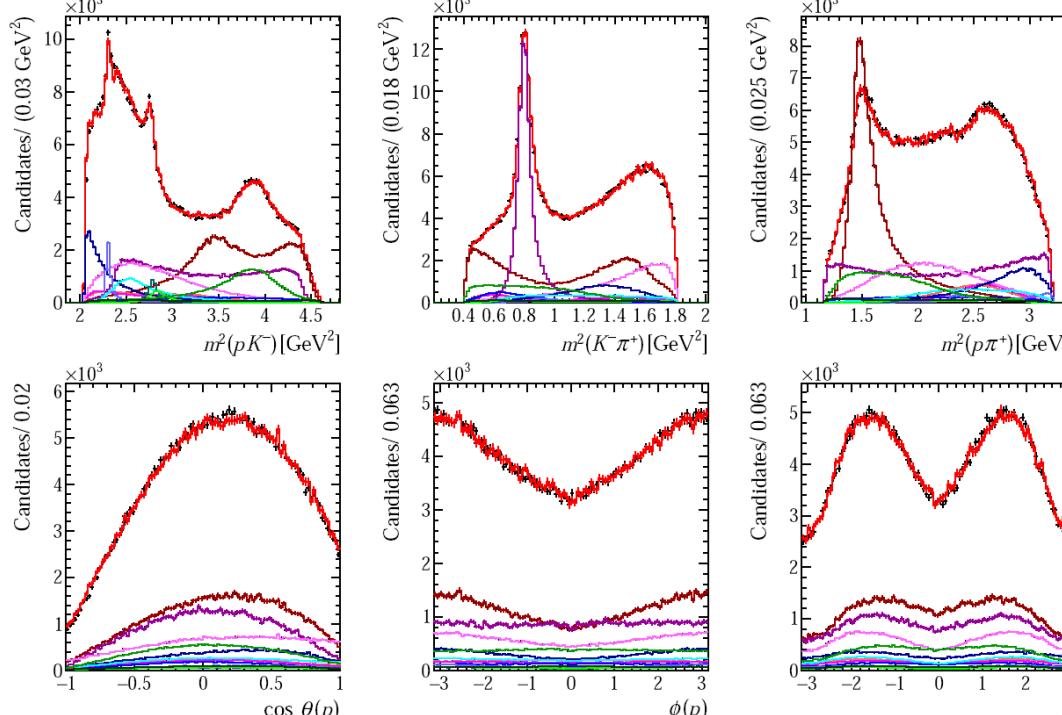
Breit-wigner with a complex constant added

The best fit is obtained with a coherent sum of a Flatt'e function and a constant background amplitude with the $\chi^2/\text{n.d.f} = 257/243$ ($p=0.25$), while the fits with Breit-Wigner functions are unfavored by more than 7σ

Amplitude analysis of $\Lambda_c^+ \rightarrow pK^-\pi^+$ at LHCb



arXiv:2208.03262



0.4M

Complete description of this decay

- | | | | |
|-----------------------|-------------------|-----------------------|-----------------------|
| — Data | — Model | — $\Delta(1232)^{++}$ | — $\Delta(1600)^{++}$ |
| — $\Delta(1700)^{++}$ | — $K^*(892)$ | — $K_0^*(1430)$ | — $K_0^*(700)$ |
| — $\Lambda(1405)$ | — $\Lambda(1520)$ | — $\Lambda(1600)$ | — $\Lambda(1670)$ |
| — $\Lambda(1690)$ | — $\Lambda(2000)$ | — Background | |

Observation of new state, identified as $\Lambda(2000)$, with spin of $1/2^-$, and mass and width

$$M = (1988 \pm 2 \pm 21) \text{ MeV}$$

$$\Gamma = (179 \pm 4 \pm 16) \text{ MeV}$$

Measured polarization components

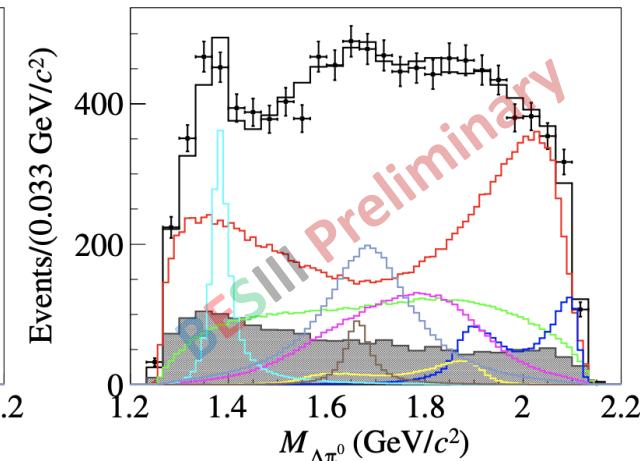
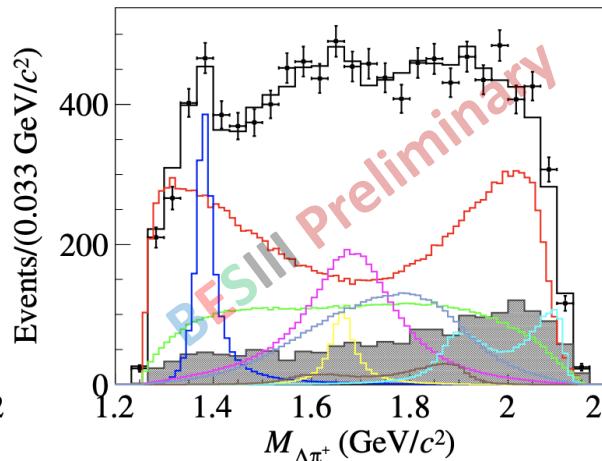
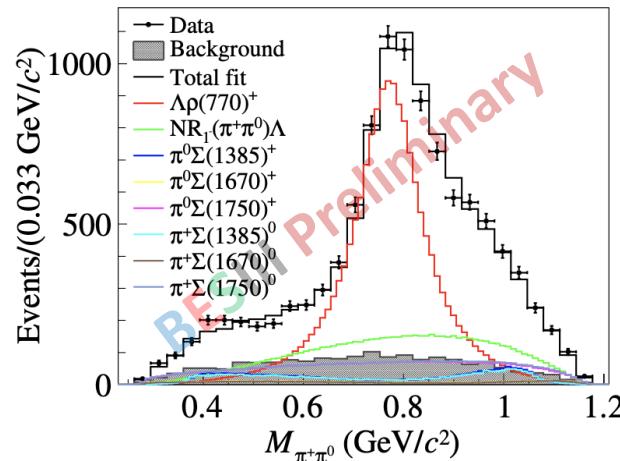
Component	Value (%)
P_x (lab)	$60.32 \pm 0.68 \pm 0.98 \pm 0.21$
P_y (lab)	$-0.41 \pm 0.61 \pm 0.16 \pm 0.07$
P_z (lab)	$-24.7 \pm 0.6 \pm 0.3 \pm 1.1$
P_x (\tilde{B})	$21.65 \pm 0.68 \pm 0.36 \pm 0.15$
P_y (\tilde{B})	$1.08 \pm 0.61 \pm 0.09 \pm 0.08$
P_z (\tilde{B})	$-66.5 \pm 0.6 \pm 1.1 \pm 0.1$

A large sensitivity to the polarization shows the $\Lambda_c^+ \rightarrow pK^-\pi^+$ decay to be the best probe for Λ_c^+ polarization

Amplitude analysis of $\Lambda_c^+ \rightarrow \Lambda\pi^+\pi^0$

BESIII

Theoretical calculations of BFs and decay asymmetry parameters:

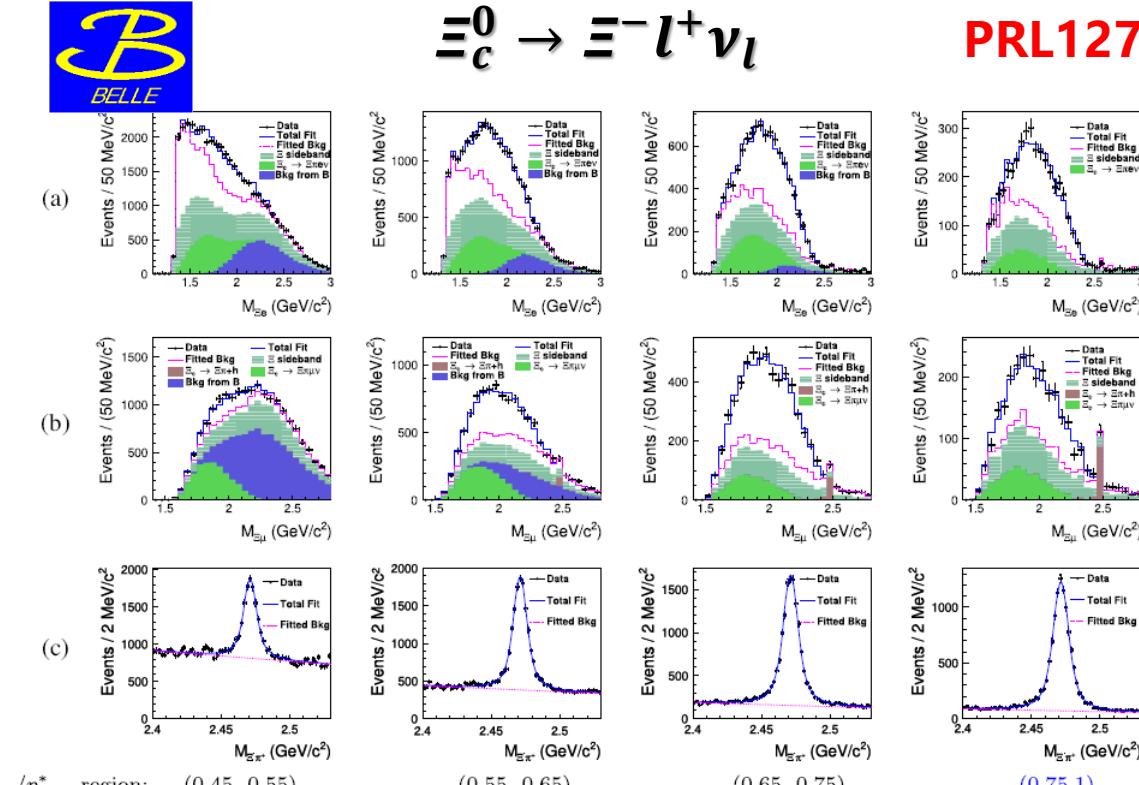


Amplitude analysis help to explore
 $\Lambda_c^+ \rightarrow B^*V$ and $\Lambda_c^+ \rightarrow B^*M$

	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 ± 0.066
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]	-0.917 ± 0.083	Ref. [13]: PRD 101 (2020) 053002
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [17]	-0.79 ± 0.11	Ref. [14,15]: PRD 46 (1992) 1042; 55 (1997) 1697

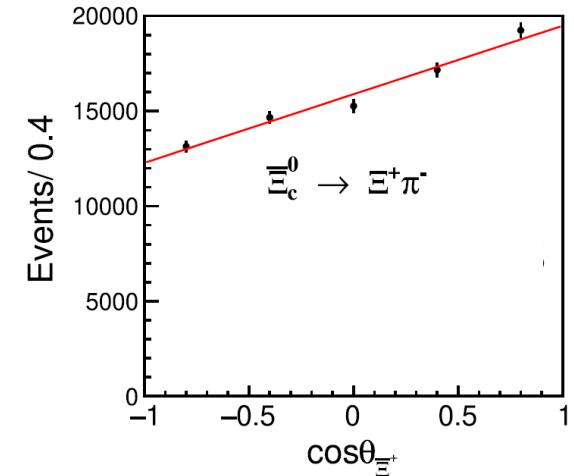
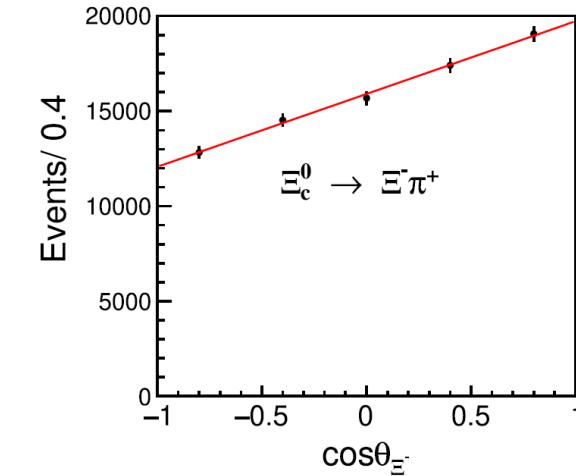
Ref. [16]: EPJC 80 (2020) 1067
 Ref. [17]: PRD 99 (2019) 114022

Studies of $\Xi_c^0 \rightarrow \Xi^- l^+ \nu_l$ and $\Xi_c^0 \rightarrow \Xi^- \pi^+$ at Belle



PRL127(2021)121803

$\Xi_c^0 \rightarrow \Xi^- \pi^+$



Decay parameter of $\Xi_c^0 \rightarrow \Xi^- \pi^+$:

$$\alpha = 0.63 \pm 0.03 \pm 0.01$$

Asymmetry of decay parameters:

$$\mathcal{A}_{CP} = (\alpha_{\Xi^- \pi^+} + \alpha_{\Xi^+ \pi^-}) / (\alpha_{\Xi^- \pi^+} - \alpha_{\Xi^+ \pi^-}) = 0.024 \pm 0.052 \pm 0.014$$

$$B[\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e] = (1.31 \pm 0.04 \pm 0.07 \pm 0.38_{\text{PDG}}) \times 10^{-3}$$

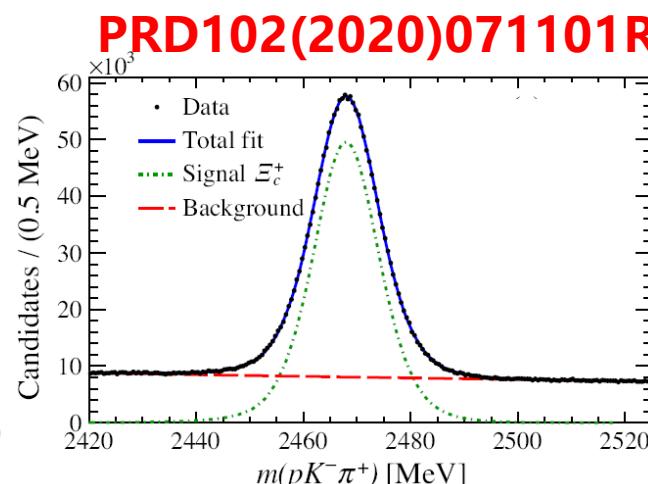
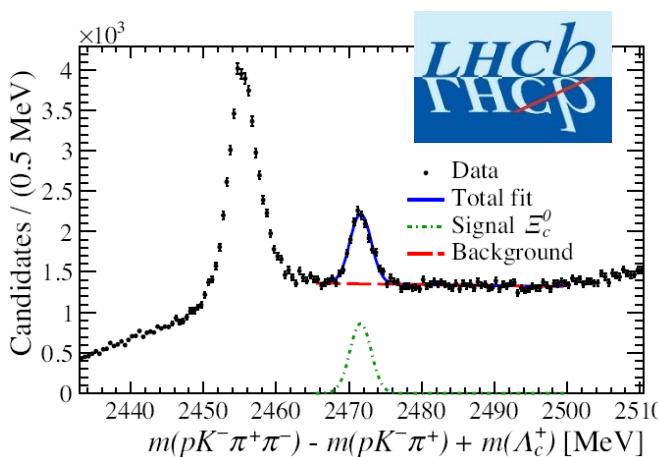
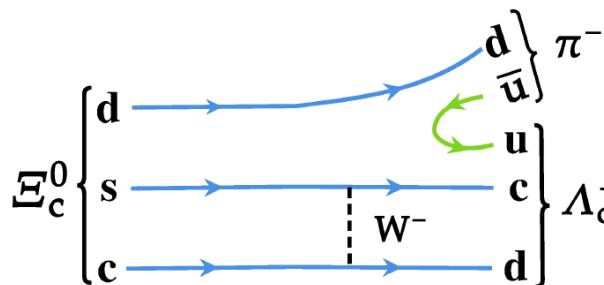
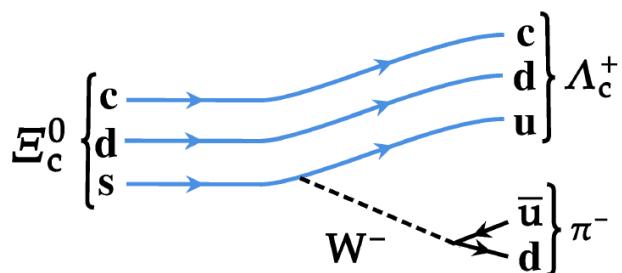
$$B[\Xi_c^0 \rightarrow \Xi^- \mu^+ \nu_\mu] = (1.27 \pm 0.06 \pm 0.10 \pm 0.37_{\text{PDG}}) \times 10^{-3}$$

$$\frac{B[\Xi_c^0 \rightarrow \Xi^- \mu^+ \nu_\mu]}{B[\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e]} = 1.03 \pm 0.05 \pm 0.07$$

consistent with prediction based on LFU, 0.962 ± 0.004 , within errors

CPC46(2022)011002

Measurements of $\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-$ at LHCb and Belle



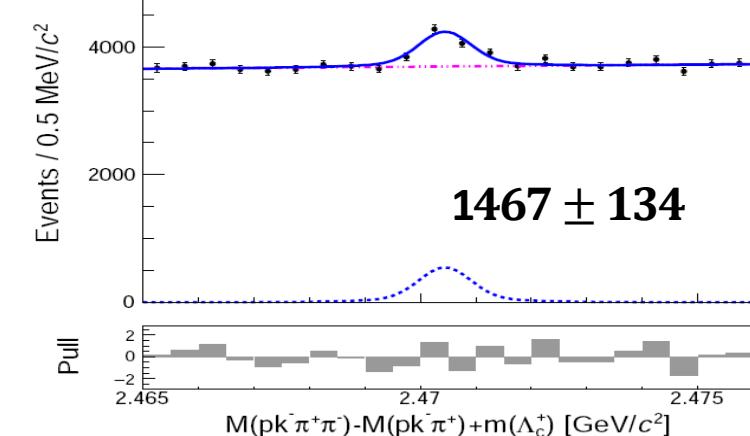
First measurement of BF of $\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-$

$$B[\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-] = (0.55 \pm 0.02 \pm 0.18)\%$$

$$B[\Xi_c^+ \rightarrow pK^-\pi^+] = (1.135 \pm 0.002 \pm 0.387)\%$$



arXiv:2206.08527



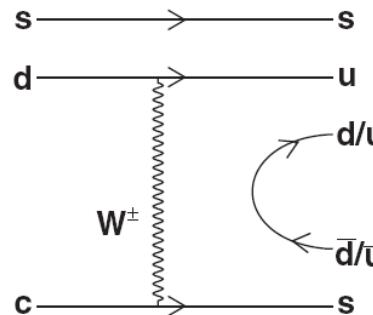
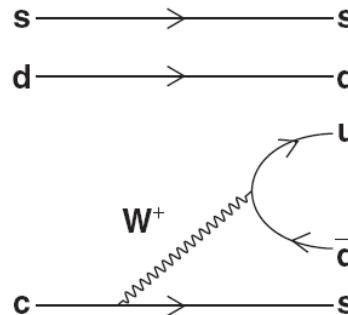
$$\frac{B[\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-]}{B[\Xi_c^0 \rightarrow \Xi^- \pi^+]} = 0.38 \pm 0.04 \pm 0.04$$

$$B[\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-] = (0.54 \pm 0.05 \pm 0.05 \pm 0.12_{\text{PDG}})\%$$

Important to test various theoretical calculations

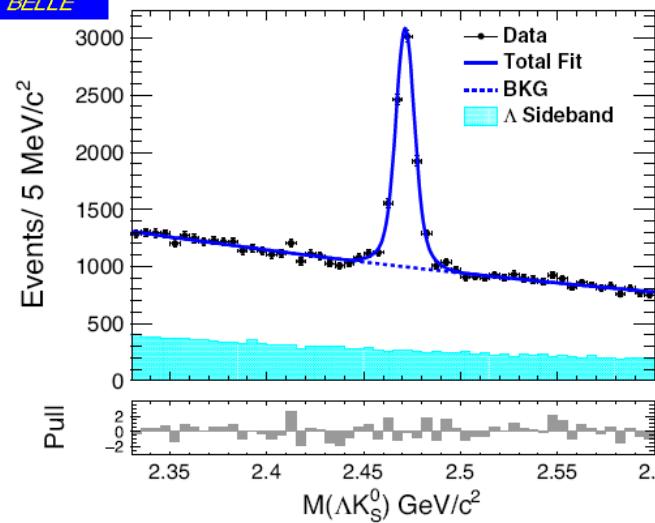
(CLY) ² ('92) [1]	Voloshin [3]	Gronau [4]	Faller [5]	(CLY) ² ('06) [6]
0.39	$> (0.25 \pm 0.15)$	1.34 ± 0.53	< 3.9	0.17

Measurements of $\Xi_c^0 \rightarrow \Lambda K_s^0$, $\Sigma^0 K_s^0$ and $\Sigma^+ K^-$ at Belle



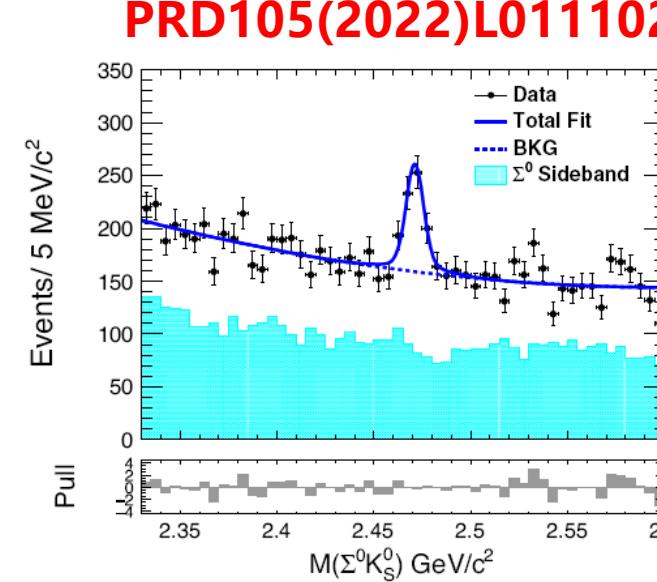
Theoretical calculations

Modes	Zou <i>et al.</i> [4]	Geng <i>et al.</i> [5]	Zhao <i>et al.</i> [6]
$\Xi_c^0 \rightarrow \Lambda \bar{K}^0$	13.3	10.5 ± 0.6	8.3 ± 5.0
$\Xi_c^0 \rightarrow \Sigma^0 \bar{K}^0$	0.4	0.8 ± 0.8	7.9 ± 4.8
$\Xi_c^0 \rightarrow \Sigma^+ K^-$	7.8	5.9 ± 1.1	22.0 ± 5.7



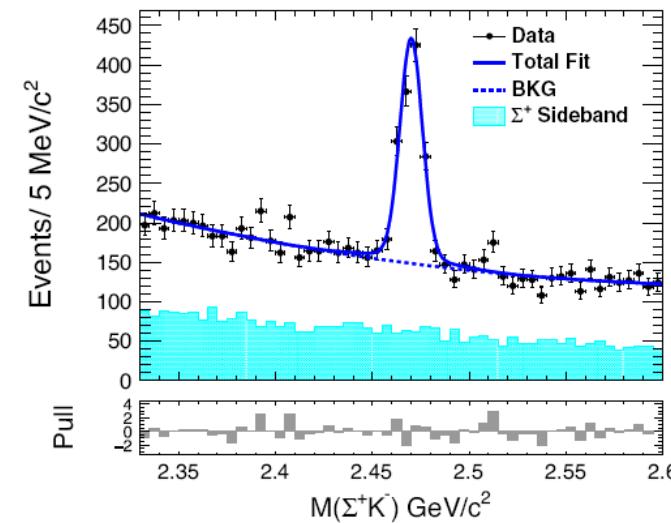
$$\frac{B[\Xi_c^0 \rightarrow \Lambda K_s^0]}{B[\Xi_c^0 \rightarrow \Xi^- \pi^+]} = (22.9 \pm 0.8 \pm 1.2)\%$$

$$B[\Xi_c^0 \rightarrow \Lambda K_s^0] = (3.27 \pm 0.11 \pm 0.17 \pm 0.73_{\text{PDG}}) \times 10^{-3}$$



$$\frac{B[\Xi_c^0 \rightarrow \Sigma^0 K_s^0]}{B[\Xi_c^0 \rightarrow \Xi^- \pi^+]} = (3.8 \pm 0.6 \pm 0.4)\%$$

$$B[\Xi_c^0 \rightarrow \Sigma^0 K_s^0] = (0.54 \pm 0.09 \pm 0.06 \pm 0.12_{\text{PDG}}) \times 10^{-3}$$



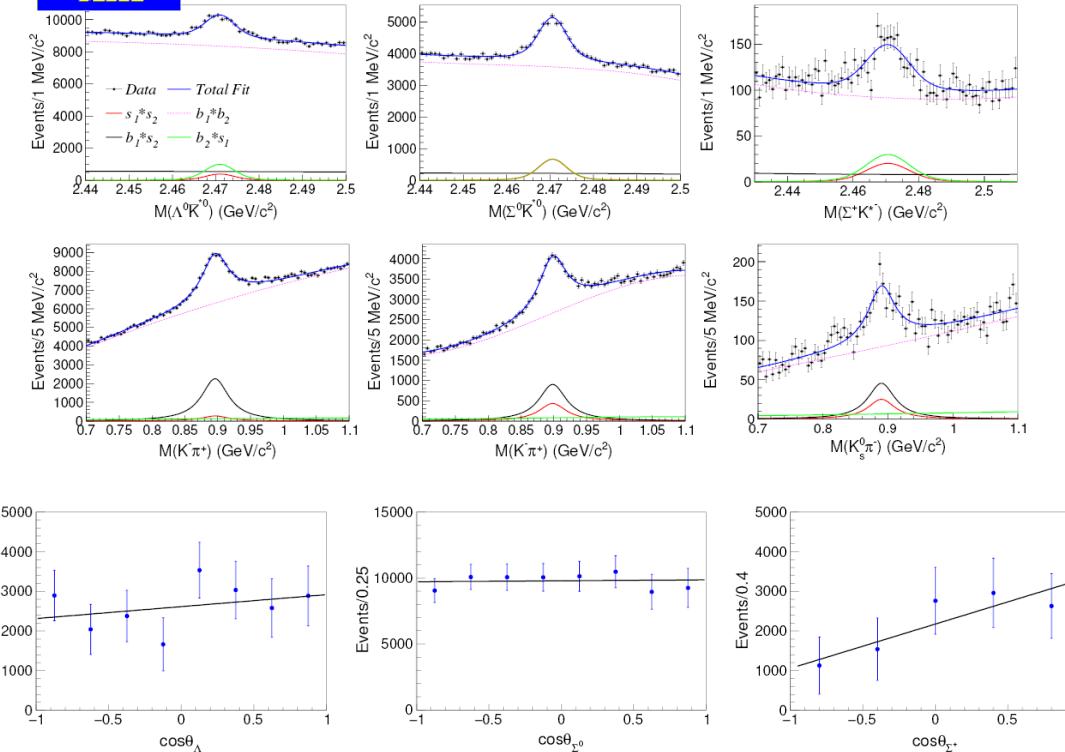
$$\frac{B[\Xi_c^0 \rightarrow \Sigma^+ K^-]}{B[\Xi_c^0 \rightarrow \Xi^- \pi^+]} = (12.3 \pm 0.7 \pm 1.0)\%$$

$$B[\Xi_c^0 \rightarrow \Sigma^+ K^-] = (1.76 \pm 0.10 \pm 0.14 \pm 0.39_{\text{PDG}}) \times 10^{-3}$$

Studies of $\Xi_c^0 \rightarrow \Lambda\bar{K}^{*0}$, $\Sigma^0\bar{K}^{*0}$ and Σ^+K^{*-} at Belle



JHEP06(2021)160



Decay parameters:

$\alpha(\Xi_c^0 \rightarrow \Lambda\bar{K}^{*0})\alpha(\Lambda \rightarrow p\pi^-)$	$0.115 \pm 0.164(\text{stat.}) \pm 0.031(\text{syst.})$
$\alpha(\Xi_c^0 \rightarrow \Sigma^0\bar{K}^{*0})\alpha(\Sigma^0 \rightarrow \gamma\Lambda)$	$0.008 \pm 0.072(\text{stat.}) \pm 0.008(\text{syst.})$
$\alpha(\Xi_c^0 \rightarrow \Sigma^+K^{*-})\alpha(\Sigma^+ \rightarrow p\pi^0)$	$0.514 \pm 0.295(\text{stat.}) \pm 0.012(\text{syst.})$
$\alpha(\Xi_c^0 \rightarrow \Lambda\bar{K}^{*0})$	$0.15 \pm 0.22(\text{stat.}) \pm 0.04(\text{syst.})$
$\alpha(\Xi_c^0 \rightarrow \Sigma^+K^{*-})$	$-0.52 \pm 0.30(\text{stat.}) \pm 0.02(\text{syst.})$

BFs:

$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \rightarrow \Xi^-\pi^+)$	$0.18 \pm 0.02(\text{stat.}) \pm 0.01(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda\bar{K}^{*0})$	$(3.3 \pm 0.3(\text{stat.}) \pm 0.2(\text{syst.}) \pm 1.0(\text{ref.})) \times 10^{-3}$
$\mathcal{B}(\Xi_c^0 \rightarrow \Sigma^0\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \rightarrow \Xi^-\pi^+)$	$0.69 \pm 0.03(\text{stat.}) \pm 0.03(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \rightarrow \Sigma^0\bar{K}^{*0})$	$(12.4 \pm 0.5(\text{stat.}) \pm 0.5(\text{syst.}) \pm 3.6(\text{ref.})) \times 10^{-3}$
$\mathcal{B}(\Xi_c^0 \rightarrow \Sigma^+K^{*-})/\mathcal{B}(\Xi_c^0 \rightarrow \Xi^-\pi^+)$	$0.34 \pm 0.06(\text{stat.}) \pm 0.02(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \rightarrow \Sigma^+K^{*-})$	$(6.1 \pm 1.0(\text{stat.}) \pm 0.4(\text{syst.}) \pm 1.8(\text{ref.})) \times 10^{-3}$

Theoretical calculations on branching fractions:

Channel	KK [26]	Zen [31]	HYZ [24]	GLT [7]
$\Xi_c^0 \rightarrow \Lambda\bar{K}^{*0}$	1.55	1.15	0.46 ± 0.21	1.37 ± 0.26
$\Xi_c^0 \rightarrow \Sigma^0\bar{K}^{*0}$	0.85	0.77	0.27 ± 0.22	0.42 ± 0.23
$\Xi_c^0 \rightarrow \Sigma^+K^{*-}$	0.54	0.37	0.93 ± 0.29	0.24 ± 0.17

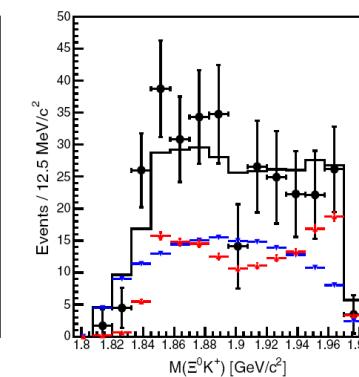
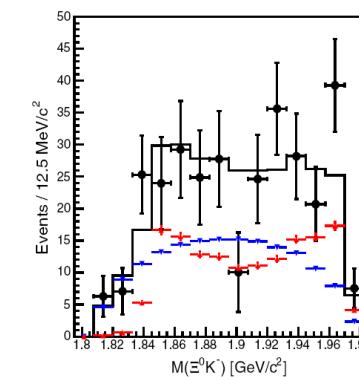
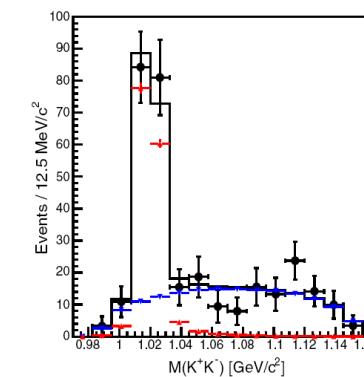
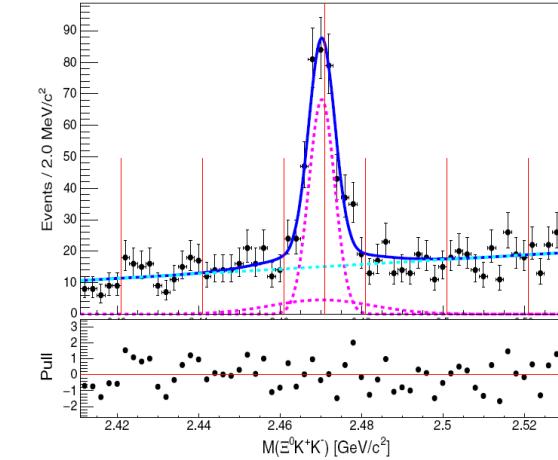
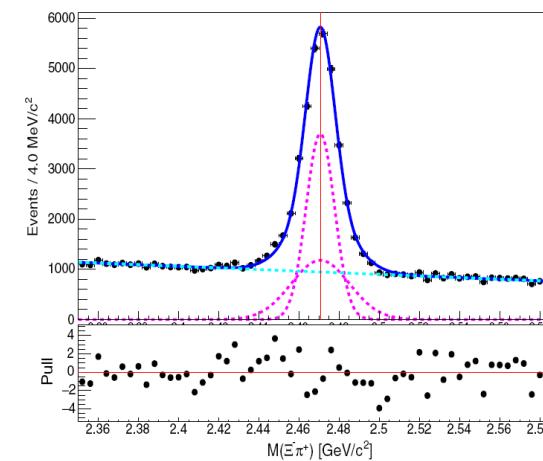
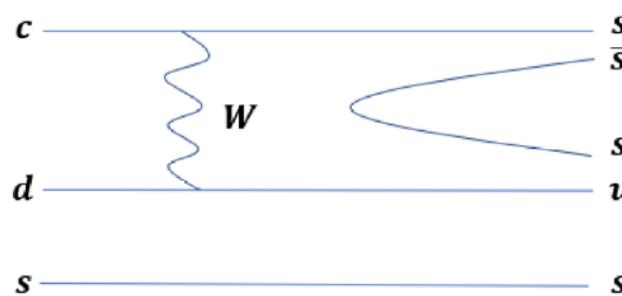
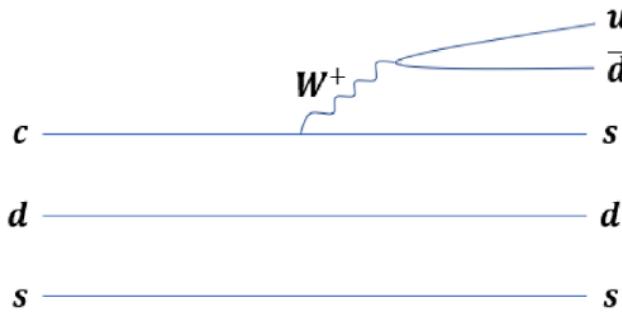
Theoretical calculations on decay parameters:

Channel	KK [26]	Zen [31]	GLT [7]
$\Xi_c^0 \rightarrow \Lambda\bar{K}^{*0}$	+0.58	+0.49	-0.67 ± 0.24
$\Xi_c^0 \rightarrow \Sigma^0\bar{K}^{*0}$	-0.87	+0.25	-0.42 ± 0.62
$\Xi_c^0 \rightarrow \Sigma^+K^{*-}$	-0.60	+0.51	$-0.76_{-0.24}^{+0.64}$

Measurement of $\Xi_c^0 \rightarrow \Xi^0 K^+ K^-$ at Belle



PRD103(2021)112002



$$\frac{B[\Xi_c^0 \rightarrow \Xi^0 \phi(\rightarrow K^+ K^-)]}{B[\Xi_c^0 \rightarrow \Xi^- \pi^+]} = (3.6 \pm 0.4 \pm 0.2)\%$$

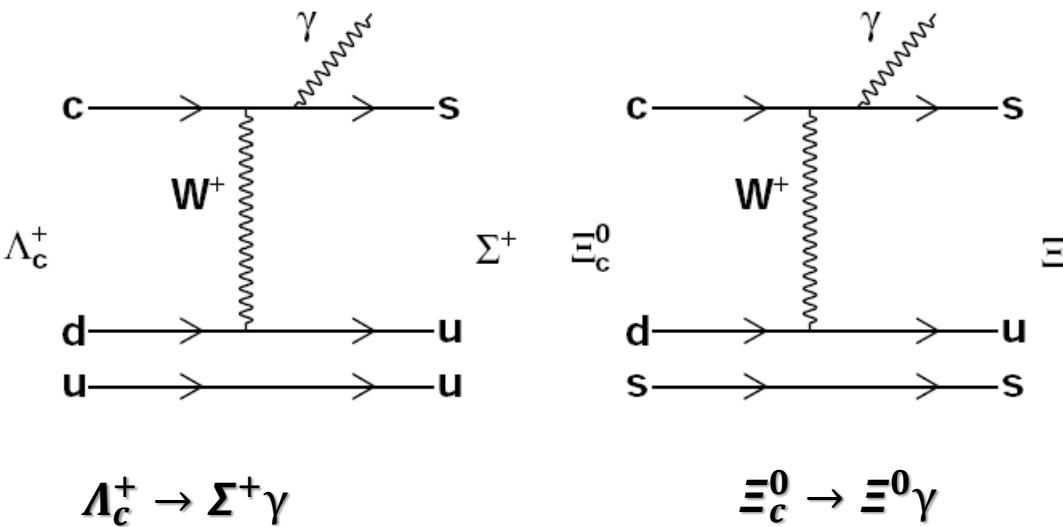
$$\frac{B[\Xi_c^0 \rightarrow \Xi^0 K^+ K^-]}{B[\Xi_c^0 \rightarrow \Xi^- \pi^+]} = (3.9 \pm 0.4 \pm 0.2)\%$$

non- ϕ

Search for $\Lambda_c^+ \rightarrow \Sigma^+ \gamma$ and $\Xi_c^0 \rightarrow \Xi^0 \gamma$ at Belle

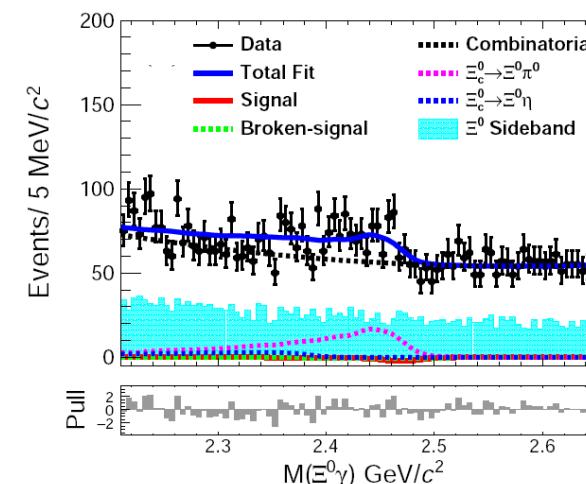
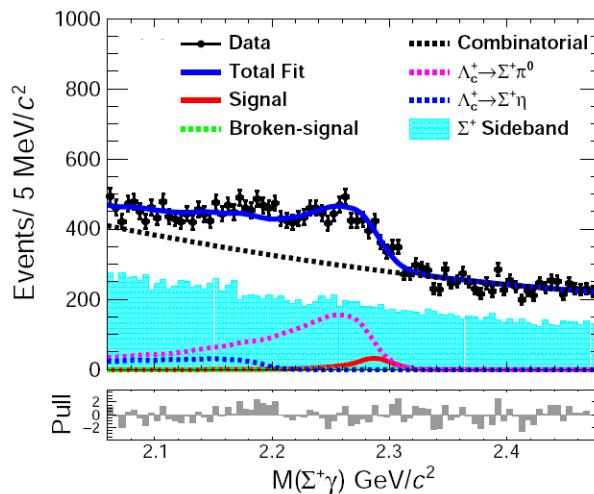


arXiv:2206.12517



2.2σ

$\Lambda_c^+ \rightarrow \Sigma^+ \gamma$



$$\frac{\mathcal{B}[\Lambda_c^+ \rightarrow \Sigma^+ \gamma]}{\mathcal{B}[\Lambda_c^+ \rightarrow p K^- \pi^+]} = (2.23 \pm 0.72 \pm 0.63) \times 10^{-3}$$

$$\frac{\mathcal{B}[\Lambda_c^+ \rightarrow \Sigma^+ \gamma]}{\mathcal{B}[\Lambda_c^+ \rightarrow p K^- \pi^+]} < 4.0 \times 10^{-3} \quad @90\% \text{ CL}$$

$$\mathcal{B}[\Lambda_c^+ \rightarrow \Sigma^+ \gamma] < 2.6 \times 10^{-4}$$

$$\frac{\mathcal{B}[\Xi_c^0 \rightarrow \Xi^0 \gamma]}{\mathcal{B}[\Xi_c^0 \rightarrow \Xi^- \pi^+]} < 1.2\%$$

$$\mathcal{B}[\Xi_c^0 \rightarrow \Xi^0 \gamma] < 1.8 \times 10^{-4} \quad @90\% \text{ CL}$$

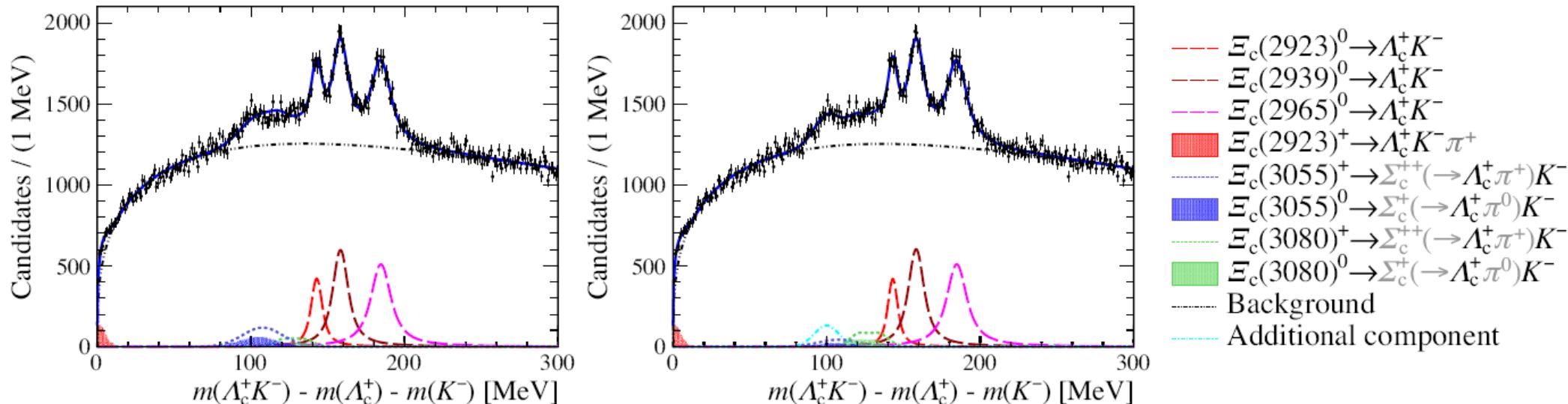
Modes	Kamal [4]	Uppal [5]	Cheng [6]
(I)	(II)		
$\Lambda_c^+ \rightarrow \Sigma^+ \gamma$	6.0	4.5	29.1
$\Xi_c^0 \rightarrow \Xi^0 \gamma$...	3.0	19.5
			4.8

Observation of new Ξ_c^0 baryons at LHCb



PRL124(2020)222001

$\Xi_c^0 \rightarrow \Lambda_c^+ K^-$



Observation of three new Ξ_c^0 baryons

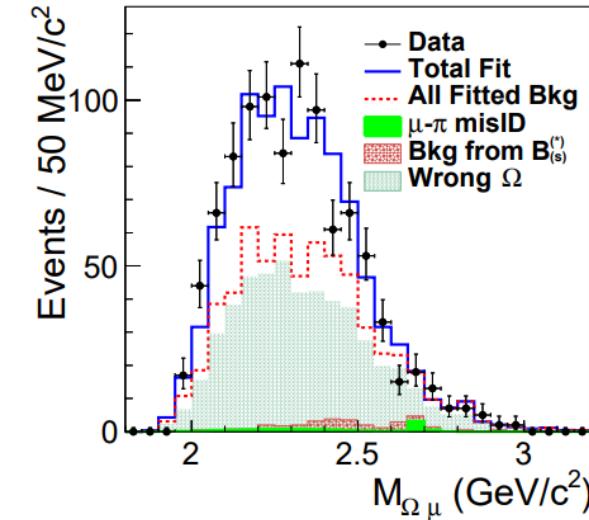
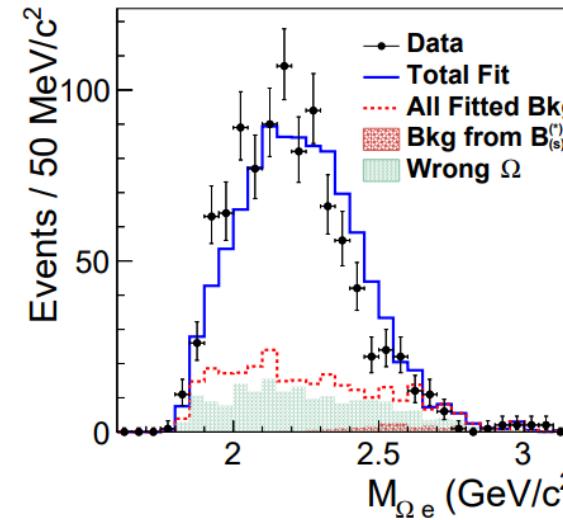
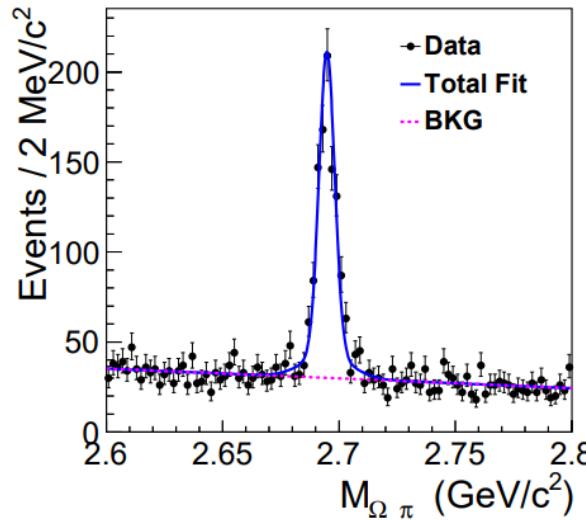
Resonance	Peak of ΔM [MeV]	Mass [MeV]	Γ [MeV]
$\Xi_c(2923)^0$	$142.91 \pm 0.25 \pm 0.20$	$2923.04 \pm 0.25 \pm 0.20 \pm 0.14$	$7.1 \pm 0.8 \pm 1.8$
$\Xi_c(2939)^0$	$158.45 \pm 0.21 \pm 0.17$	$2938.55 \pm 0.21 \pm 0.17 \pm 0.14$	$10.2 \pm 0.8 \pm 1.1$
$\Xi_c(2965)^0$	$184.75 \pm 0.26 \pm 0.14$	$2964.88 \pm 0.26 \pm 0.14 \pm 0.14$	$14.1 \pm 0.9 \pm 1.3$

Mass difference to Λ_c^+

Study of $\Omega_c^0 \rightarrow \Omega^- l^+ \nu_l$ at Belle



PRD105(2022)L091001



$$\frac{B[\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e]}{B[\Omega_c^0 \rightarrow \Omega^- \pi^+]} = 1.98 \pm 0.13 \pm 0.08$$

$$\frac{B[\Omega_c^0 \rightarrow \Omega^- \mu^+ \nu_\mu]}{B[\Omega_c^0 \rightarrow \Omega^- \pi^+]} = 1.94 \pm 0.18 \pm 0.10$$

$$\frac{B[\Omega_c^0 \rightarrow \Omega^- \mu^+ \nu_\mu]}{B[\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e]} = 1.02 \pm 0.10 \pm 0.02$$

consistent with prediction based on LFU, 1.02 ± 0.10 , within errors

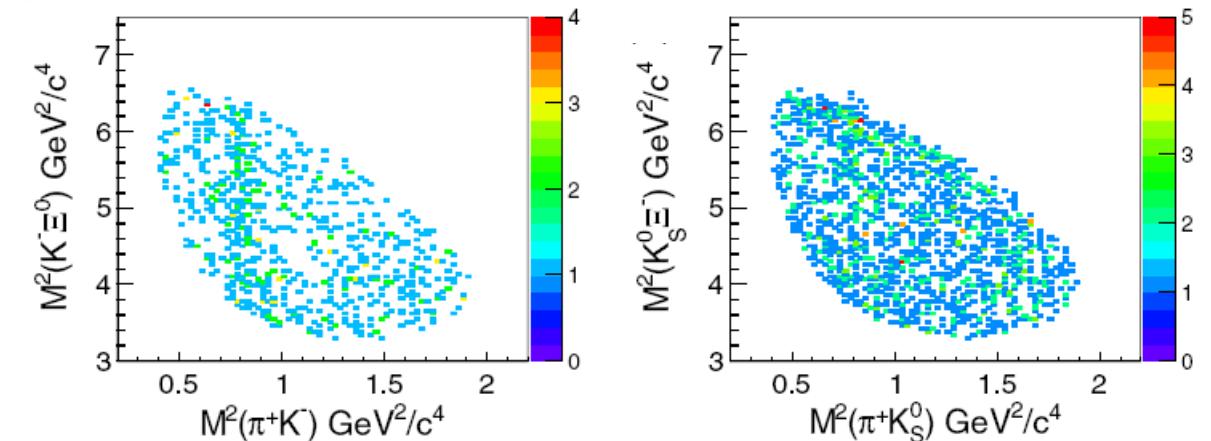
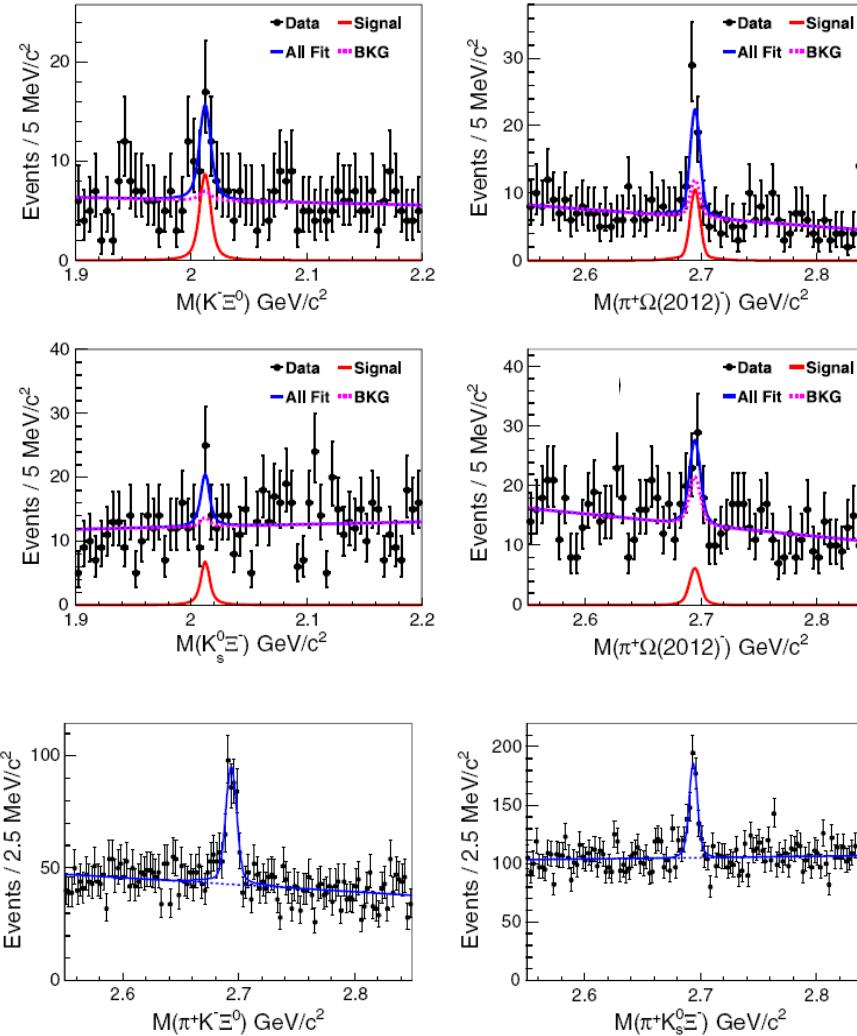
EPJC82(2022)11

Evidence for $\Omega_c^0 \rightarrow \pi^+ \Omega(2012)^- \rightarrow \pi^+ (K\Xi)^-$ at Belle



PRD104(2021)052005

4.2σ



$$\frac{B[\Omega_c^0 \rightarrow \pi^+ \Omega(2012)^-] B[\Omega(2012)^- \rightarrow \bar{K}^0 \Xi^-]}{B[\Omega_c^0 \rightarrow \pi^+ \bar{K}^0 \Xi^-]} = (5.5 \pm 2.8 \pm 0.7)\%$$

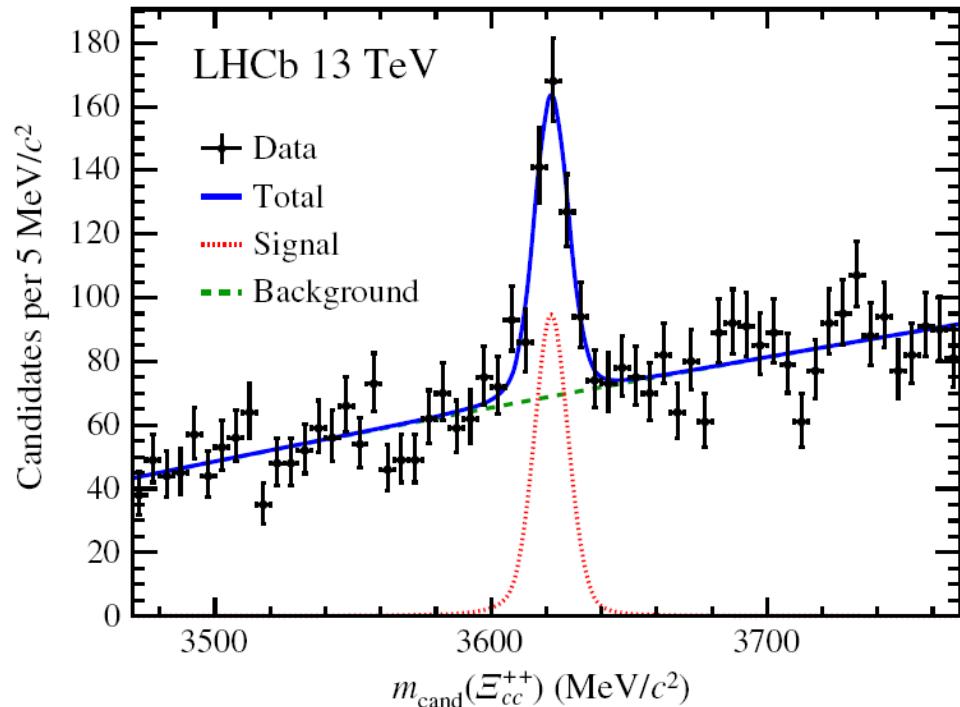
$$\frac{B[\Omega_c^0 \rightarrow \pi^+ \Omega(2012)^-] B[\Omega(2012)^- \rightarrow K^- \Xi^0]}{B[\Omega_c^0 \rightarrow \pi^+ K^- \Xi^0]} = (9.6 \pm 3.2 \pm 1.8)\%$$

$$\frac{B[\Omega_c^0 \rightarrow \pi^+ \Omega(2012)^-] B[\Omega(2012)^- \rightarrow (K\Xi)^-]}{B[\Omega_c^0 \rightarrow \pi^+ \Omega^-]} = (22.0 \pm 5.9 \pm 3.5)\%$$

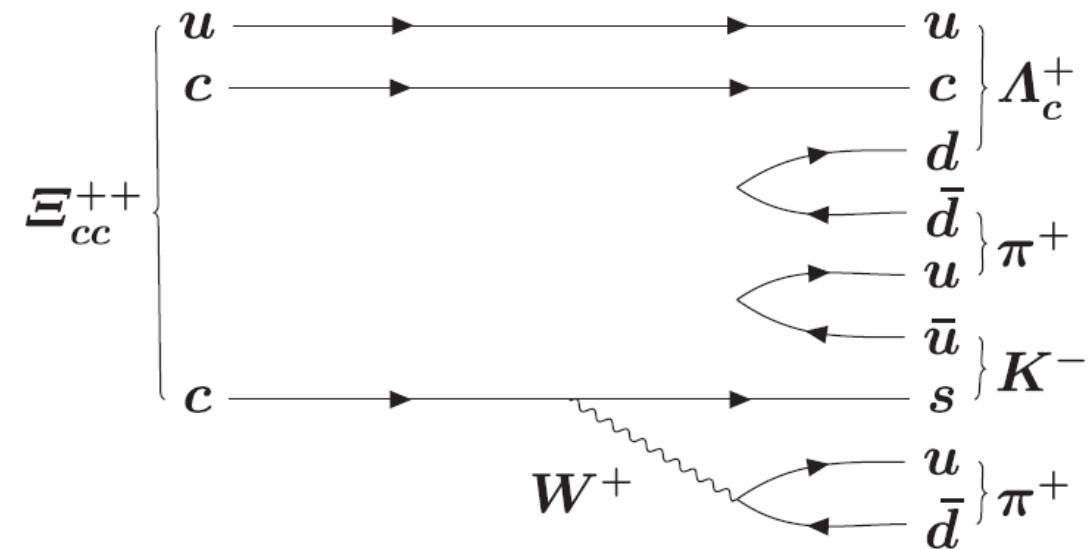
Observation of doubly charmed baryon Ξ_{cc}^{++} at LHCb

LHCb
THCP

PRL119(2017)112001



$$\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$$



Mass difference to Λ_c^+ : $1334.94 \pm 0.72(\text{stat.}) \pm 0.27(\text{syst.}) \text{ MeV}/c^2$,

Mass: $3621.40 \pm 0.72(\text{stat.}) \pm 0.27(\text{syst.}) \pm 0.14(\Lambda_c^+) \text{ MeV}/c^2$

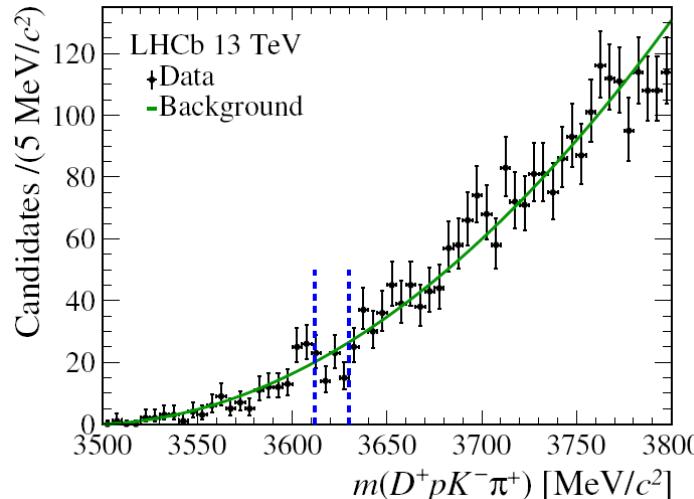
isospin partner to the Ξ_{cc}^{++} state reported previously by the SELEX Collaboration?

More studies of Ξ_{cc}^{++}/Ξ_{cc}^+ decays at LHCb



JHEP10(2019)124

$$\Xi_{cc}^{++} \rightarrow D^+ p K^- \pi^+$$

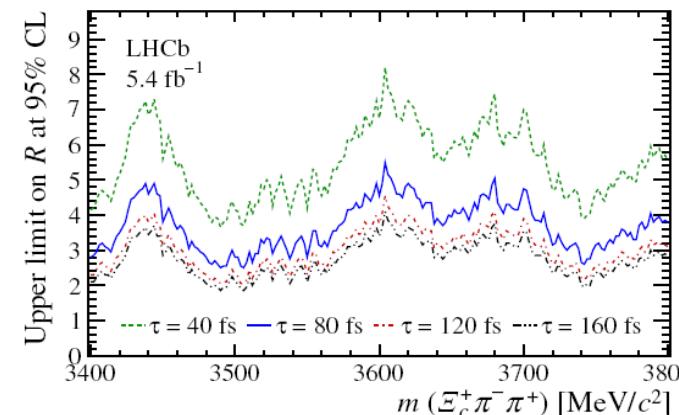
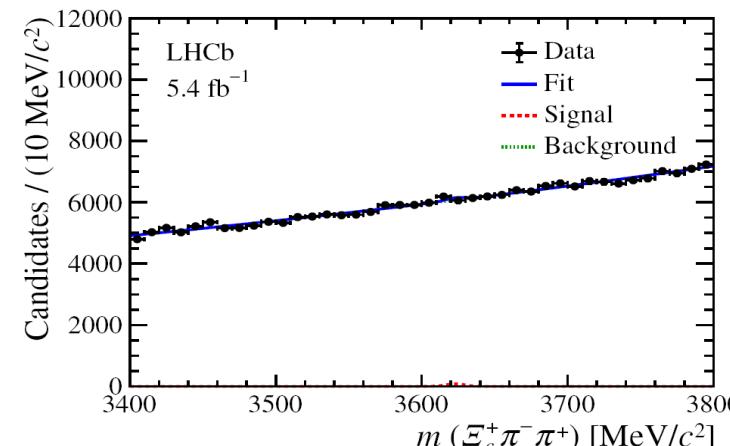


$$\frac{B[\Xi_{cc}^{++} \rightarrow D^+ p K^- \pi^+]}{B[\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+]} < 1.7\%$$

@90% CL

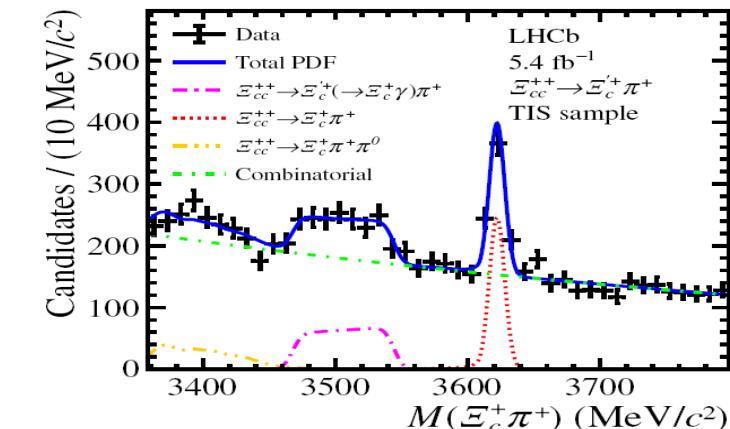
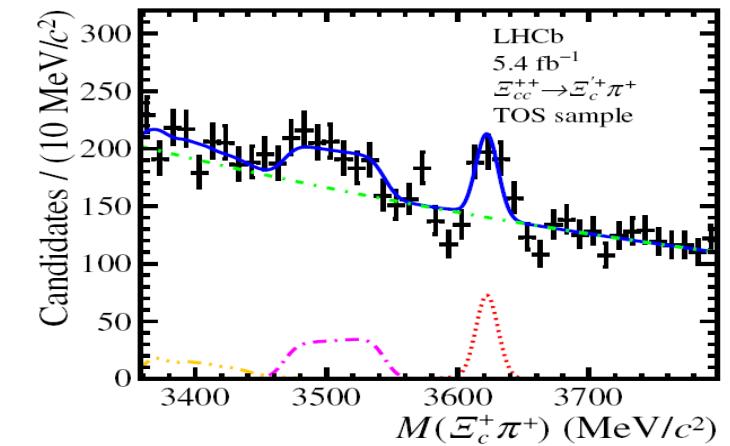
JHEP12(2021)107

$$\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^+ \pi^-$$



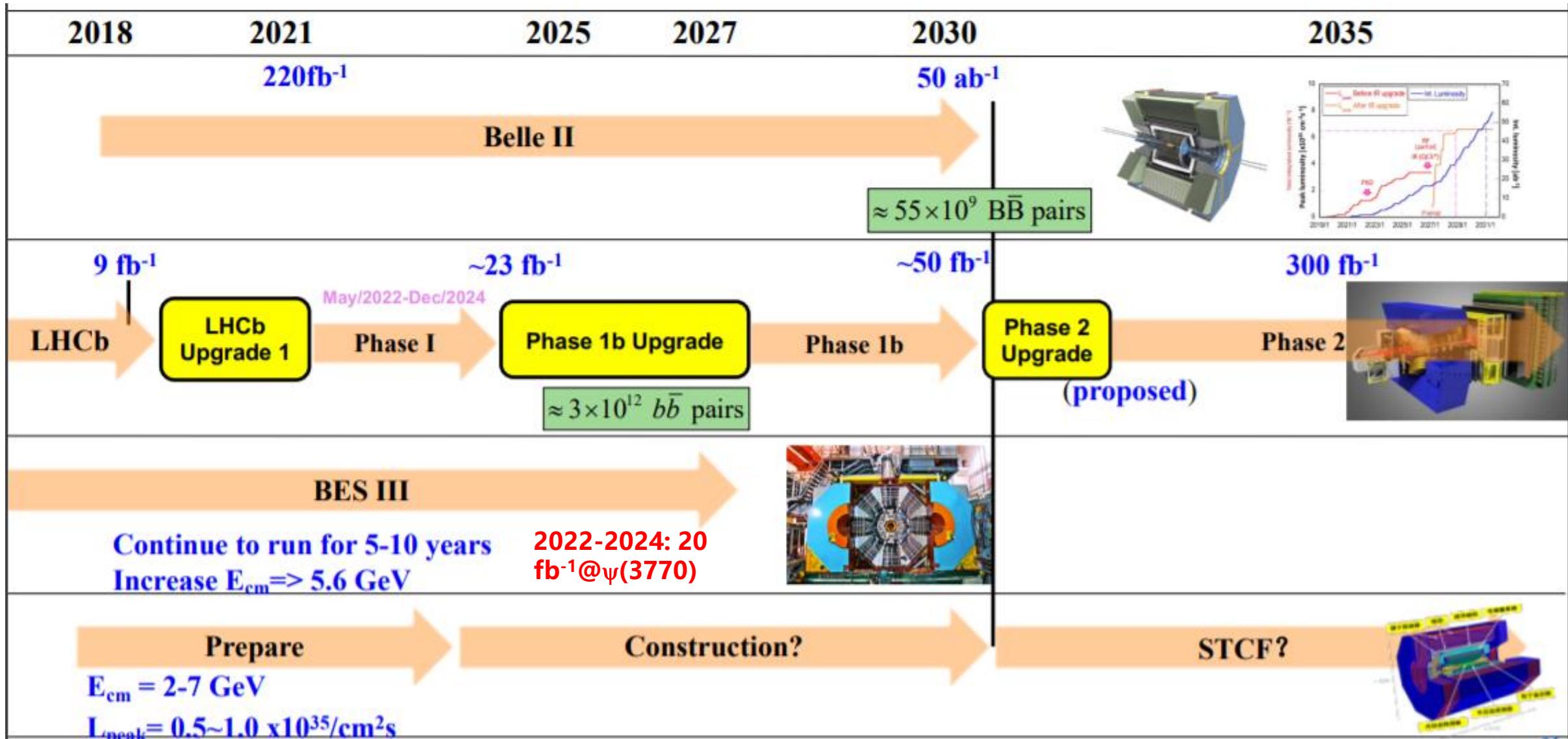
JHEP05(2022)038

$$\Xi_{cc}^{++} \rightarrow \Xi_c' \pi^+$$



$$\frac{B[\Xi_{cc}^{++} \rightarrow \Xi_c' \pi^+]}{B[\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+]} = 1.41 \pm 0.17 \pm 0.10$$

Future



Summary and prospects

- In recent years, many important results of charm decays were reported by BESIII, Belle, and LHCb.
- In the near future, more fruitful results are expected:
 - Precision of f_{D^+} , $f_{D_s^+}$, $|V_{cs}|$, $|V_{cd}|$, $f_+^{D \rightarrow K}(0)$ and $f_+^{D \rightarrow \pi}(0)$ reaches (0.5-1.0)% level;
 - Intensive LFU tests with (semi-)leptonic decays → the expected best precision is better than 1% for μ -e and 3% for τ - μ ;
 - Improved measurements of strong phase differences of neutral D decay → constrain the γ measurement to about 0.5° level;
 - Precision of the absolute BFs of the golden decays $D^0 \rightarrow K^- \pi^+$, $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$, $D^+ \rightarrow K^- \pi^+ \pi^+$, $D_s^+ \rightarrow K^+ K^- \pi^+$, and $\Lambda_c^+ \rightarrow p K^- \pi^+$ reaches better than 1.0% level;
 - Intensive measurements of more missing decay modes of known charmed hadrons;
 - Observations of more excited charmed hadron states?

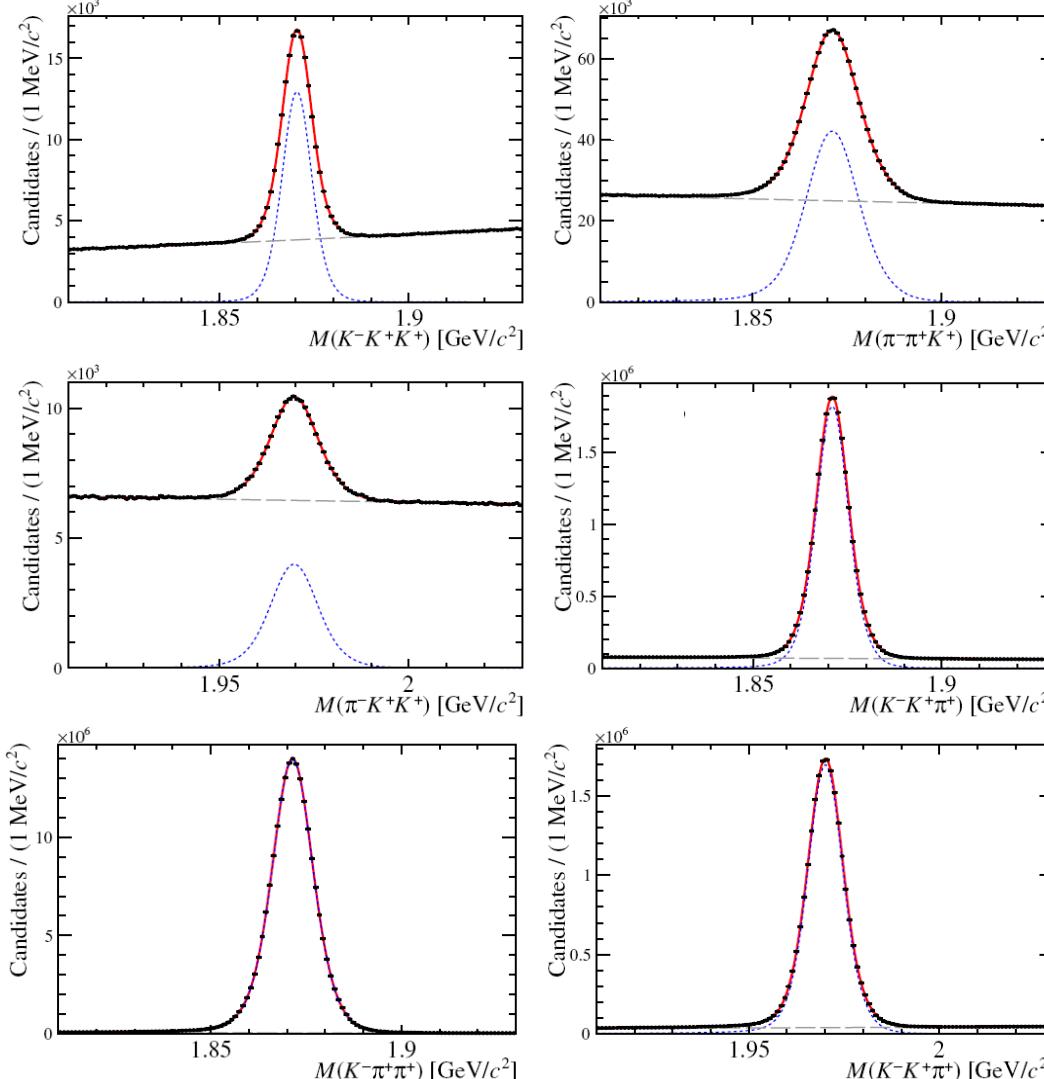
Thank you!

Backup slides

DCS D decay at LHCb



JHEP03(2019)176



Channel	$MagDown \ (\times 10^{-3})$
$\mathcal{B}(D^+ \rightarrow K^-K^+K^+)/\mathcal{B}(D^+ \rightarrow K^-\pi^+\pi^+)$	$0.653 \pm 0.004 \pm 0.005$
$\mathcal{B}(D^+ \rightarrow \pi^-\pi^+K^+)/\mathcal{B}(D^+ \rightarrow K^-\pi^+\pi^+)$	$5.220 \pm 0.013 \pm 0.028$
$\mathcal{B}(D_s^+ \rightarrow \pi^-K^+K^+)/\mathcal{B}(D_s^+ \rightarrow K^-K^+\pi^+)$	$2.333 \pm 0.033 \pm 0.030$
$\mathcal{B}(D^+ \rightarrow K^-K^+\pi^+)/\mathcal{B}(D^+ \rightarrow K^-\pi^+\pi^+)$	$103.00 \pm 0.03 \pm 0.85$
Channel	$MagUp \ (\times 10^{-3})$
$\mathcal{B}(D^+ \rightarrow K^-K^+K^+)/\mathcal{B}(D^+ \rightarrow K^-\pi^+\pi^+)$	$0.655 \pm 0.004 \pm 0.005$
$\mathcal{B}(D^+ \rightarrow \pi^-\pi^+K^+)/\mathcal{B}(D^+ \rightarrow K^-\pi^+\pi^+)$	$5.244 \pm 0.013 \pm 0.030$
$\mathcal{B}(D_s^+ \rightarrow \pi^-K^+K^+)/\mathcal{B}(D_s^+ \rightarrow K^-K^+\pi^+)$	$2.419 \pm 0.035 \pm 0.032$
$\mathcal{B}(D^+ \rightarrow K^-K^+\pi^+)/\mathcal{B}(D^+ \rightarrow K^-\pi^+\pi^+)$	$102.59 \pm 0.03 \pm 0.93$

$$B[D^+ \rightarrow K^+K^+K^-] = (5.87 \pm 0.02 \pm 0.04 \pm 0.18_{PDG}) \times 10^{-5}$$

$$B[D^+ \rightarrow \pi^-\pi^+K^+] = (4.70 \pm 0.01 \pm 0.02 \pm 0.15_{PDG}) \times 10^{-5}$$

$$B[D_s^+ \rightarrow \pi^-K^+K^+]^{DCS} = (1.293 \pm 0.013 \pm 0.014 \pm 0.040_{PDG}) \times 10^{-4}$$

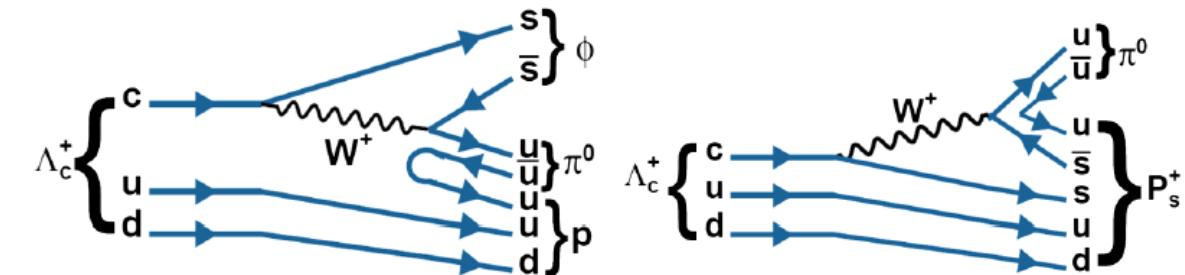
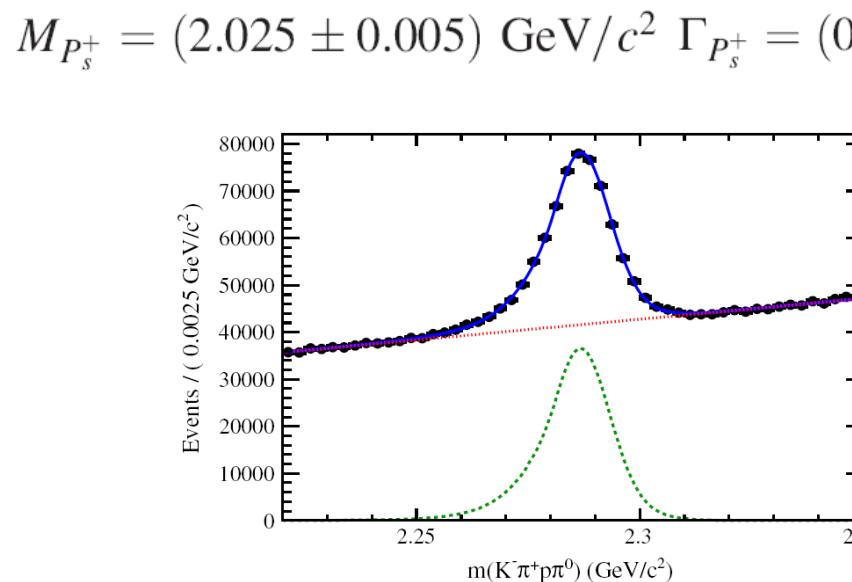
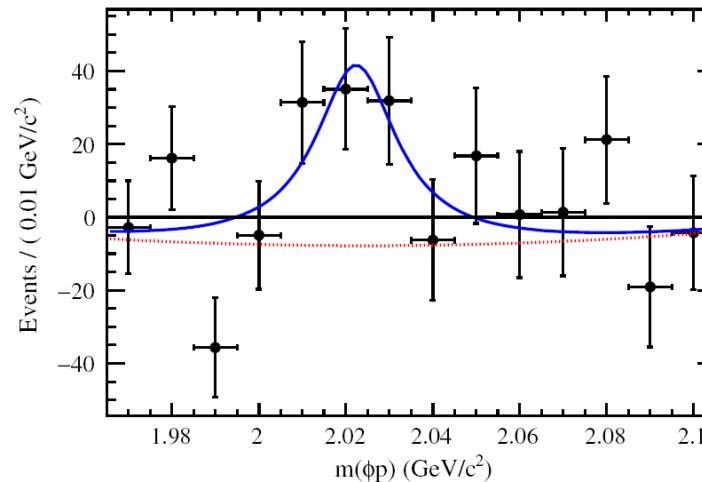
$$B[D^+ \rightarrow K^-K^+\pi^+] = (9.233 \pm 0.002 \pm 0.061 \pm 0.288_{PDG}) \times 10^{-5}$$

with significantly improved precision

Measurements of $\Lambda_c^+ \rightarrow ph^-h^+\pi^0$ at Belle



PRD96(2017)051102R



$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow \phi p\pi^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = (1.538 \pm 0.641^{+0.077}_{-0.100}) \times 10^{-3}$$

$$M_{P_s^+} = (2.025 \pm 0.005) \text{ GeV}/c^2 \quad \Gamma_{P_s^+} = (0.022 \pm 0.012) \text{ GeV}$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \phi p\pi^0) = (9.94 \pm 4.14^{+0.50}_{-0.65} \pm 0.37) \times 10^{-3}$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow P_s^+\pi^0) \times \mathcal{B}(P_s^+ \rightarrow \phi p) < 8.3 \times 10^{-5} \quad @90\% \text{ CL}$$

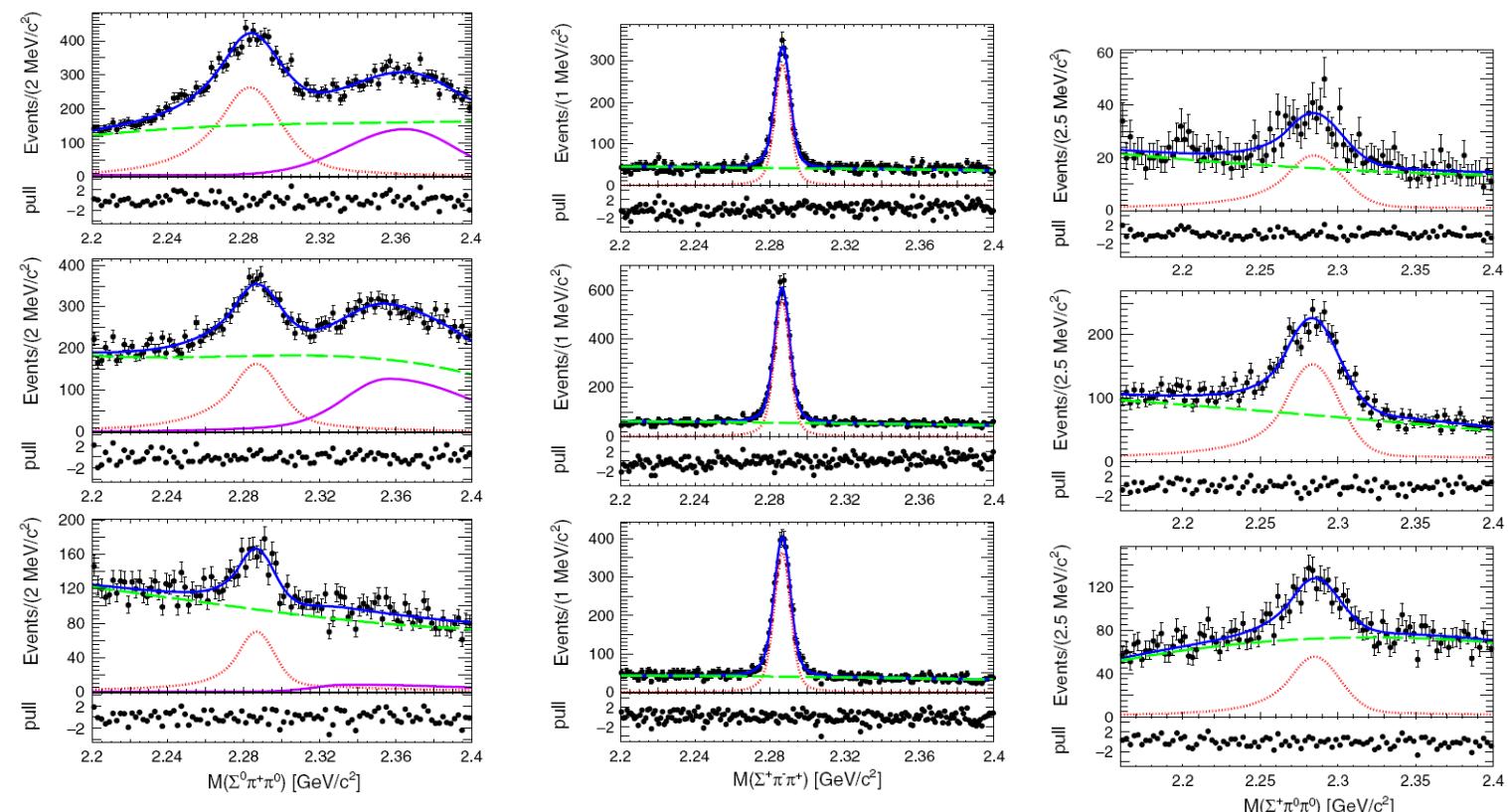
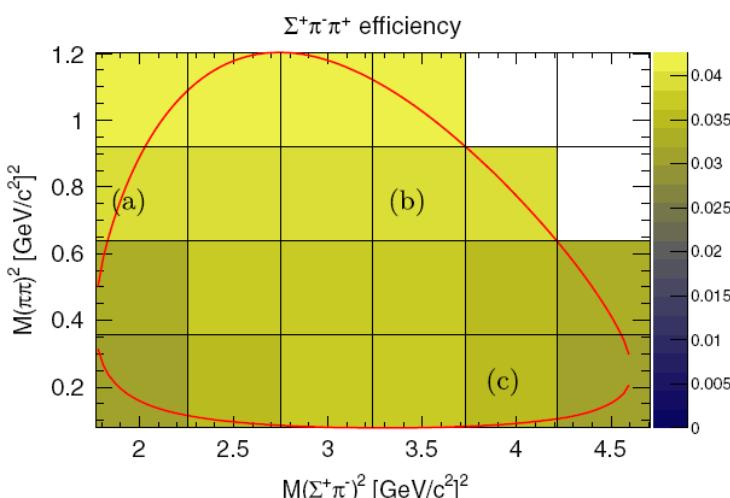
$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow K^-\pi^+p\pi^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow K^-\pi^+p)} = (0.685 \pm 0.007 \pm 0.018)$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow K^-\pi^+p\pi^0) = (4.42 \pm 0.05 \pm 0.12 \pm 0.16)\%$$

Measurement of the decays $\Lambda_c^+ \rightarrow \Sigma\pi\pi$ at Belle



PRD98(2018)112006



$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = 0.719 \pm 0.003 \pm 0.024,$$

$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0\pi^+\pi^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = 0.575 \pm 0.005 \pm 0.036,$$

$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+\pi^0\pi^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = 0.247 \pm 0.006 \pm 0.019.$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+\pi^-\pi^+) = 4.57 \pm 0.02 \pm 0.15 \pm 0.24\%,$$

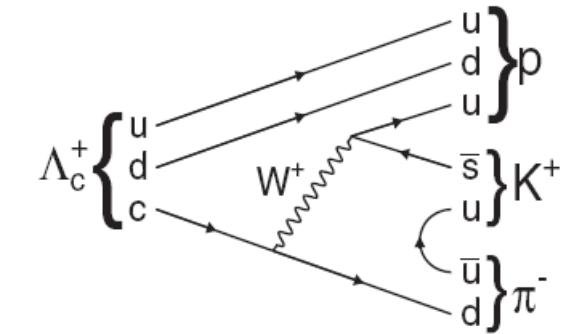
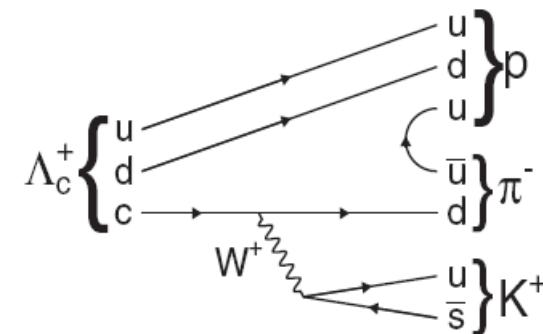
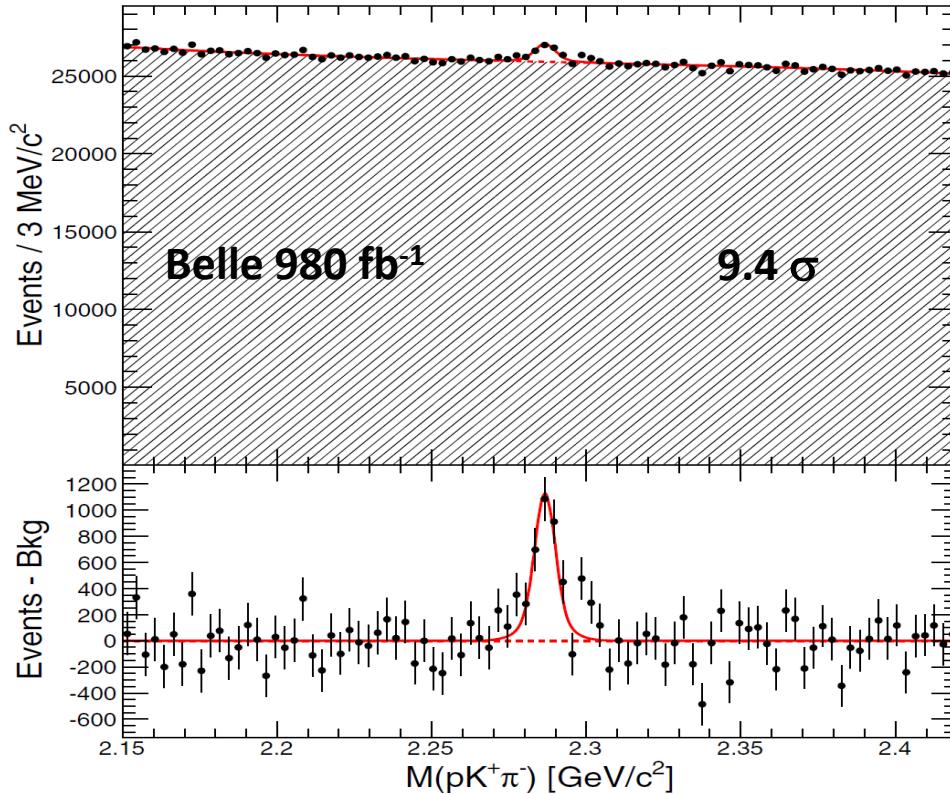
$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0\pi^+\pi^0) = 3.65 \pm 0.03 \pm 0.23 \pm 0.19\%,$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+\pi^0\pi^0) = 1.57 \pm 0.04 \pm 0.12 \pm 0.08\%.$$

Observation of DCS decay $\Lambda_c^+ \rightarrow p K^+ \pi^-$ at Belle



PRL117(2016)011801



- DCS decays of D/D_s were observed by Babar, Belle and LHCb
- The ratios of DCS decays to corresponding CF decays are important in constraining theoretical models in the study of flavor-SU(3) symmetry
- Belle reported the first observation of the DCS decay $\Lambda_c^+ \rightarrow p K^- \pi^+$

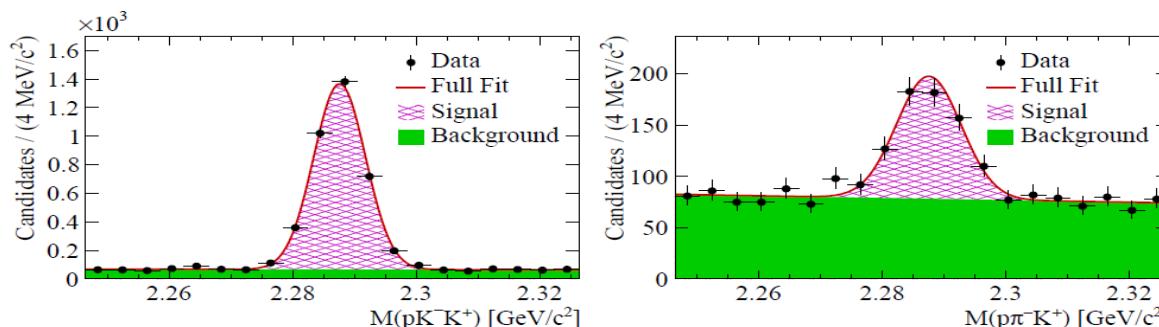
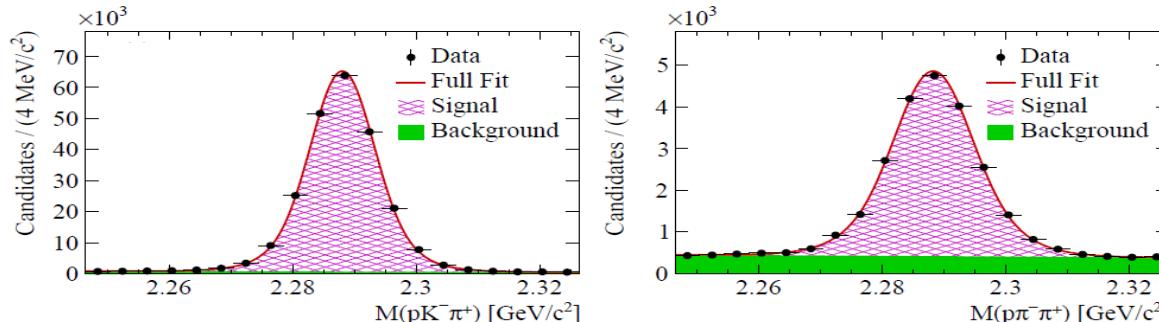
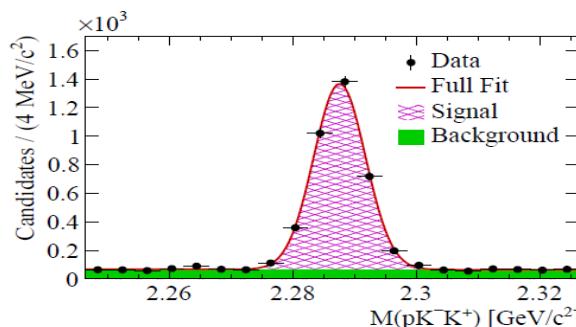
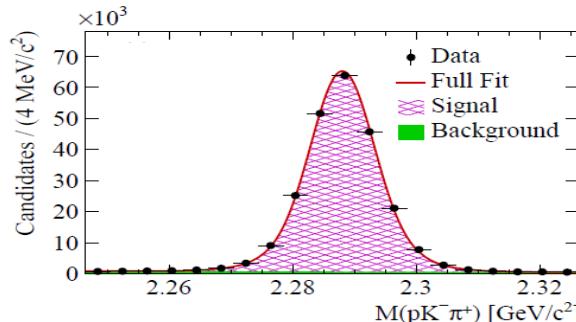
$$\frac{B[\Lambda_c^+ \rightarrow p K^+ \pi^-]}{B[\Lambda_c^+ \rightarrow p K^- \pi^+]} = (2.35 \pm 0.27 \pm 0.21) \times 10^{-3}$$

$$B_{\text{DCS}}/B_{\text{CF}} = (0.82 \pm 0.12) \tan^4 \theta_C$$

Studies of $\Lambda_c^+ \rightarrow ph^+h^-$ at LHCb



JHEP03(2018)043



$$\frac{B[\Lambda_c^+ \rightarrow p\pi^+\pi^-]}{B[\Lambda_c^+ \rightarrow pK^-\pi^+]} = (7.44 \pm 0.08 \pm 0.18)\%$$

$$\frac{B[\Lambda_c^+ \rightarrow pK^+K^-]}{B[\Lambda_c^+ \rightarrow pK^-\pi^+]} = (1.70 \pm 0.03 \pm 0.03)\%$$

$$\frac{B[\Lambda_c^+ \rightarrow pK^+\pi^-]_{DCS}}{B[\Lambda_c^+ \rightarrow pK^-\pi^+]} = (1.65 \pm 0.15 \pm 0.05) \times 10^{-3}$$

Lower than that from Belle at 2σ level

Combining the PDG value
of $B[\Lambda_c^+ \rightarrow pK^-\pi^+]$ gives:

$$B[\Lambda_c^+ \rightarrow p\pi^+\pi^-] = (4.72 \pm 0.05 \pm 0.11 \pm 0.25_{PDG}) \times 10^{-3}$$

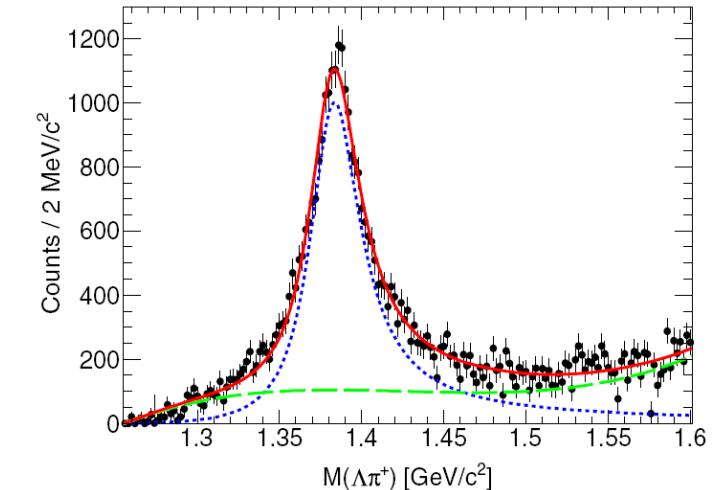
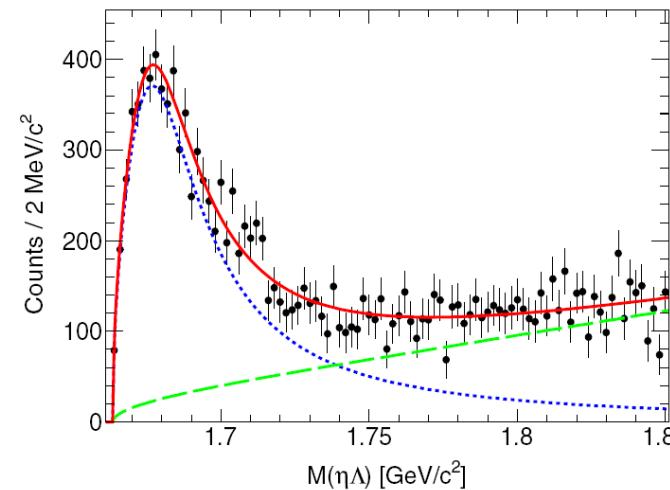
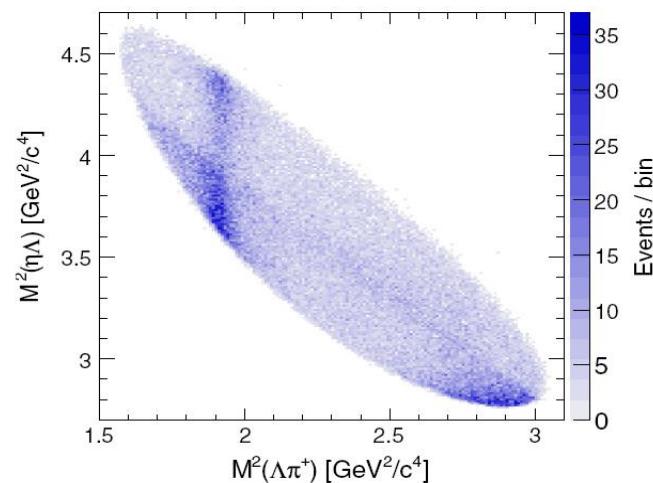
$$B[\Lambda_c^+ \rightarrow pK^+K^-] = (1.08 \pm 0.02 \pm 0.02 \pm 0.06_{PDG}) \times 10^{-3}$$

$$B[\Lambda_c^+ \rightarrow pK^+\pi^-] = (1.04 \pm 0.09 \pm 0.03 \pm 0.05_{PDG}) \times 10^{-4}$$

Study of $\Lambda_c^+ \rightarrow \Lambda\pi^+\eta$ and $\Lambda_c^+ \rightarrow \Sigma^0\pi^+\eta$ at Belle



PRD103(2021)052005



Resonances	Mass [MeV/ c^2]	Width [MeV]
$\Lambda(1670)$	$1674.3 \pm 0.8 \pm 4.9$	$36.1 \pm 2.4 \pm 4.8$
$\Sigma(1385)^+$	$1384.8 \pm 0.3 \pm 1.4$	$38.1 \pm 1.5 \pm 2.1$

Decay modes	$\mathcal{B}(\text{Decay mode})/\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)$
$\Lambda_c^+ \rightarrow \eta\Lambda\pi^+$	$0.293 \pm 0.003 \pm 0.014$
$\Lambda_c^+ \rightarrow \eta\Sigma^0\pi^+$	$0.120 \pm 0.006 \pm 0.010$
$\Lambda_c^+ \rightarrow \Lambda(1670)\pi^+$; $\Lambda(1670) \rightarrow \eta\Lambda$	$(5.54 \pm 0.29 \pm 0.73) \times 10^{-2}$
$\Lambda_c^+ \rightarrow \eta\Sigma(1385)^+$	$0.192 \pm 0.006 \pm 0.016$

$$\begin{aligned}\mathcal{B}(\Lambda_c^+ \rightarrow \eta\Lambda\pi^+) &= (1.84 \pm 0.02 \pm 0.09 \pm 0.09)\%, \\ \mathcal{B}(\Lambda_c^+ \rightarrow \eta\Sigma^0\pi^+) &= (7.56 \pm 0.39 \pm 0.62 \pm 0.39) \times 10^{-3}, \\ \mathcal{B}(\Lambda_c^+ \rightarrow \Lambda(1670)\pi^+) \times \mathcal{B}(\Lambda(1670) \rightarrow \eta\Lambda) \\ &= (3.48 \pm 0.19 \pm 0.46 \pm 0.18) \times 10^{-3},\end{aligned}$$

and

$$\mathcal{B}(\Lambda_c^+ \rightarrow \eta\Sigma(1385)^+) = (1.21 \pm 0.04 \pm 0.10 \pm 0.06)\%,$$

Other semileptonic D decays at BESIII

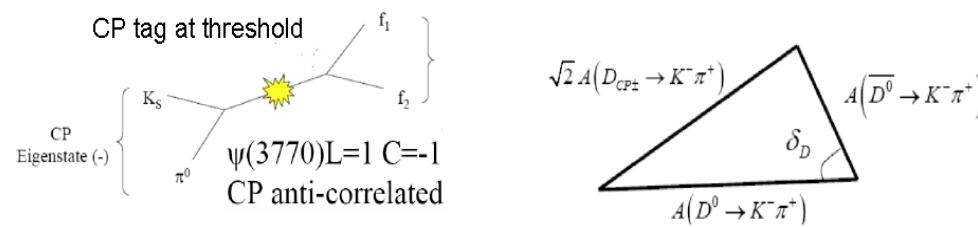
■ $D_s^+ \rightarrow \pi^0 e^+ \nu_e$	arXiv:2206.13870
■ $D_s^+ \rightarrow f_0 e^+ \nu_e$	PRD105(2022)L031101
■ $D^{0(+)} \rightarrow \bar{K} e^+ \nu_e$	PRD104(2021)052008
■ $D_s^+ \rightarrow \nu_e e X$	PRD104(2021)012003
■ $D_s^+ \rightarrow a_0(980)^0 e^+ \nu$	PRD104(2021)092004
■ $D^0 \rightarrow b_1(1235)^- e^+ \nu$	PRD101(2020)112005
■ $D_s^+ \rightarrow p \bar{p} e^+ \nu_e$	PRD100(2019)112008
■ $D_s^+ \rightarrow \gamma e^+ \nu_e$	PRD99(2019)072002
■ $D_s^+ \rightarrow \eta^{(\prime)} \mu^+ \nu$ and $\phi \mu^+ \nu$	PRD97(2018)012006
■ $D^+ \rightarrow \gamma e^+ \nu_e$	PRD95(2017)071102
■ $D^+ \rightarrow D^0 e^+ \nu_e$	PRD96(2016)092002
■ $D^+ \rightarrow \bar{K}^0 e^+ \nu_e$ via $\bar{K}^0 \rightarrow \pi^0 \pi^0$	CPC40(2016)113001
■ $D_s^+ \rightarrow l^+ \nu_l$ @ 4.009 GeV	PRD94(2016)072004
■ $D_s^+ \rightarrow \eta^{(\prime)} e^+ \nu_e$ @ 4.009 GeV	PRD94(2016)112003

Amplitude analyses of other hadronic D decays at BESIII

■ $D_s^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$	arXiv:2205.13759
■ $D_s^+ \rightarrow K^+ \pi^+ \pi^-$	arXiv:2205.08844, accepted by JHEP
■ $D_s^+ \rightarrow K^+ K^- \pi^+ \pi^+ \pi^-$	JHEP07(2022)051
■ $D_s^+ \rightarrow \eta \pi^+ \pi^+ \pi^-$	JHEP04(2022)058
■ $D_s^+ \rightarrow K_S^0 K_S^0 \pi^+$	PRD105(2022)L051103
■ $D_s^+ \rightarrow \pi^+ \pi^0 \pi^0$	JHEP01(2022)052
■ $D_s^+ \rightarrow \pi^+ \pi^+ \pi^-$	arXiv:2108.10050, under PRD review
■ $D_s^+ \rightarrow \eta \pi^+ \pi^+ \pi^-$	PRD104(2021)L071101
■ $D^+ \rightarrow K_S^0 K^+ \pi^0$	PRD104(2021)012006
■ $D_s^+ \rightarrow K_S^0 \pi^+ \pi^0$	JHEP06(2021)181
■ $D_s^+ \rightarrow K^+ K^- \pi^+ \pi^0$	PRD104(2021)032011
■ $D_s^+ \rightarrow K_S^0 K^- \pi^+ \pi^+$	PRD103(2021)092006
■ $D_s^+ \rightarrow K^+ K^- \pi^+$	PRD104(2021)012016
■ $D^0 \rightarrow K_S^0 K^+ K^-$	arXiv:2006.02800
■ $D^+ \rightarrow K_S^0 \pi^+ \pi^+ \pi^-$	PRD100(2019)072008
■ $D^0 \rightarrow K^- \pi^+ \pi^0 \pi^0$	PRD99(2019)092008
■ $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$	PRD95(2017)072010
■ $D^+ \rightarrow K_S^0 \pi^+ \pi^0$	PRD89(2014)052001

Strong phase parameters of neutral D decays

PLB734(2014)227



$$\mathcal{A}_{CP \rightarrow K\pi} = \frac{\mathcal{B}_{D_2 \rightarrow K^-\pi^+} - \mathcal{B}_{D_1 \rightarrow K^-\pi^+}}{\mathcal{B}_{D_2 \rightarrow K^-\pi^+} + \mathcal{B}_{D_1 \rightarrow K^-\pi^+}}.$$

$$2r \boxed{\cos \delta_{K\pi}} + y = (1 + R_{WS}) \cdot \mathcal{A}_{CP \rightarrow K\pi},$$

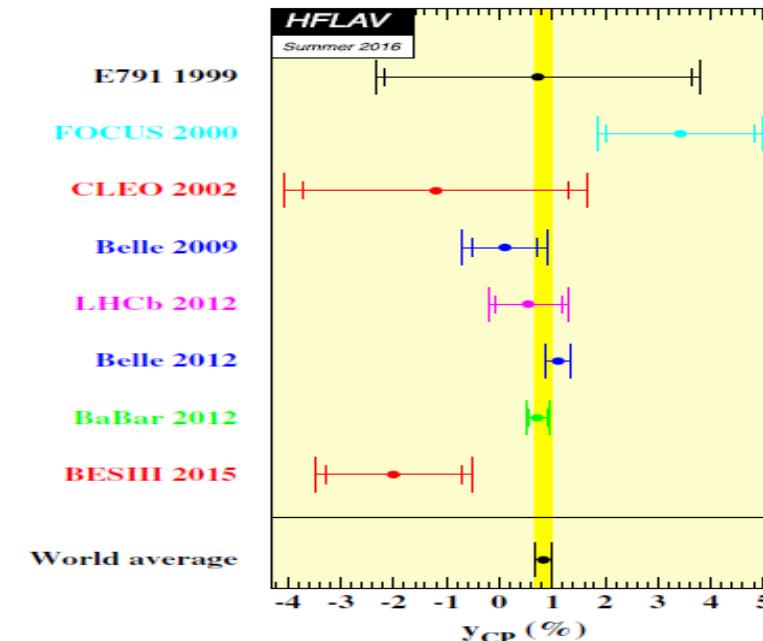
$$|D_1\rangle \equiv \frac{|D^0\rangle + |\overline{D}^0\rangle}{\sqrt{2}} \quad |D_2\rangle \equiv \frac{|D^0\rangle - |\overline{D}^0\rangle}{\sqrt{2}}.$$

$$A_{CP}^{K\pi} = (12.7 \pm 1.3 \pm 0.7)\%$$

$$\cos \delta_{K\pi} = 1.02 \pm 0.11 \pm 0.06 \pm 0.01$$

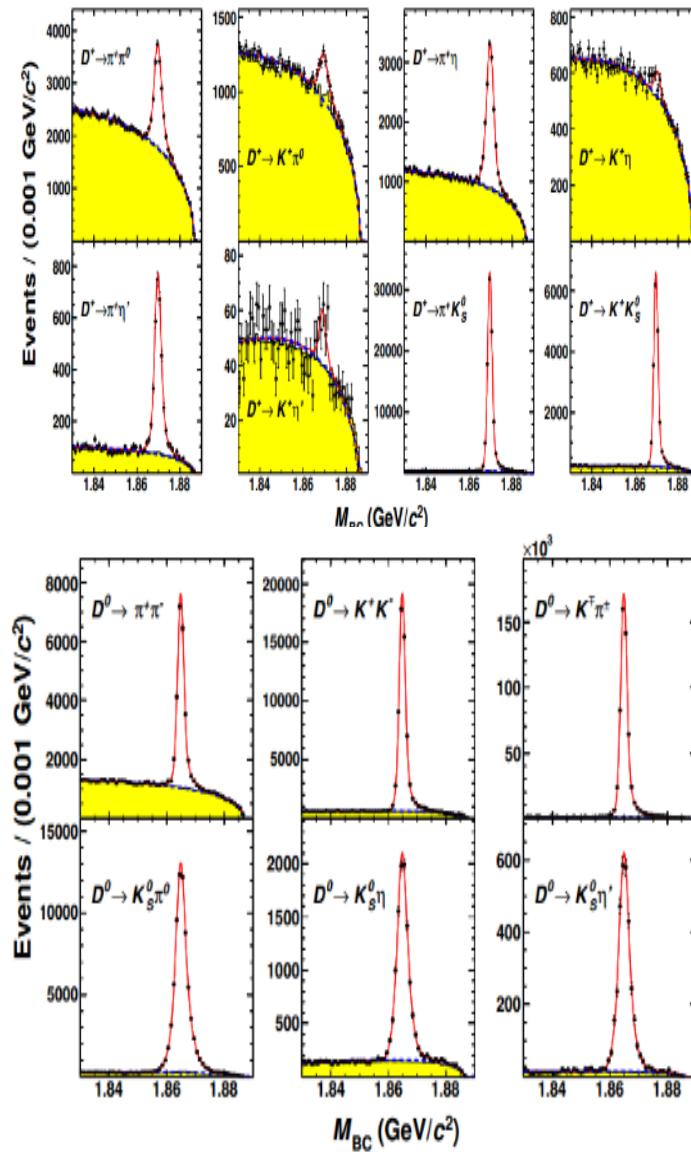
The most precise result to date

PLB744(2015)339

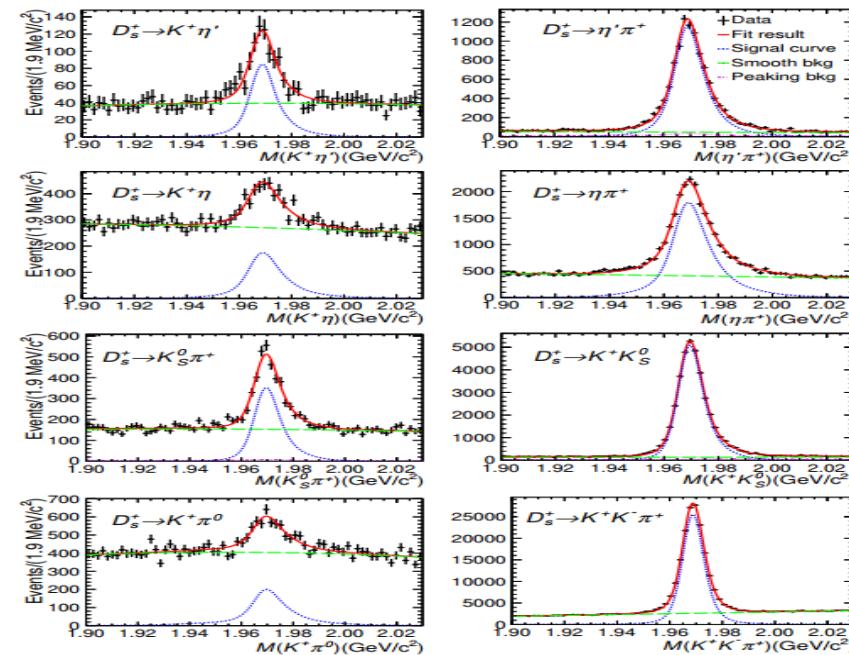


Branching fractions of $D \rightarrow PP$

PRD97(2018)072004



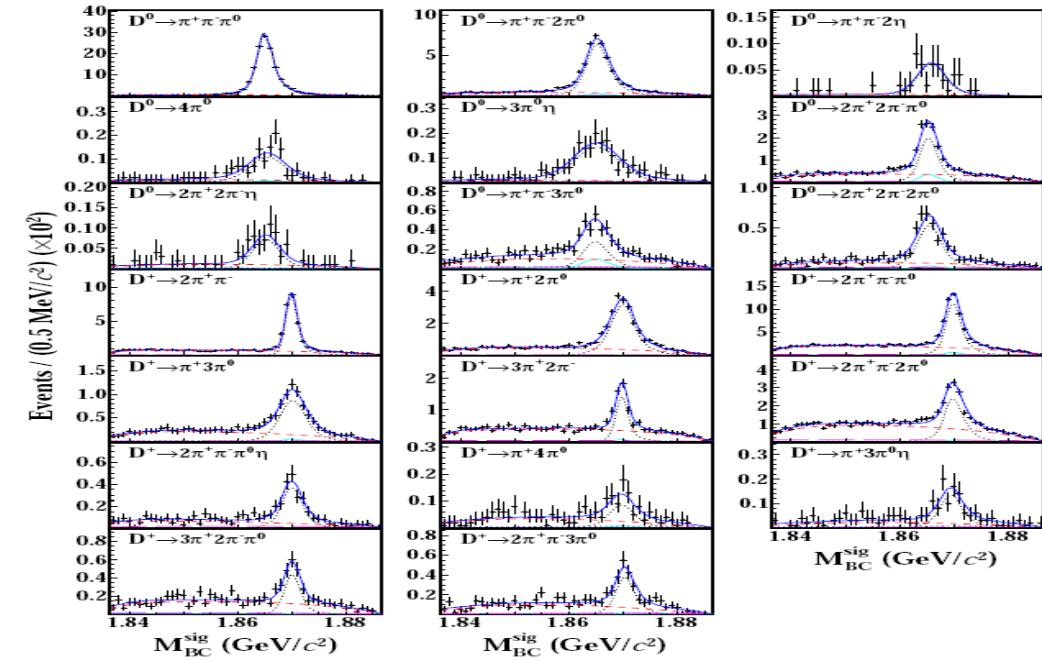
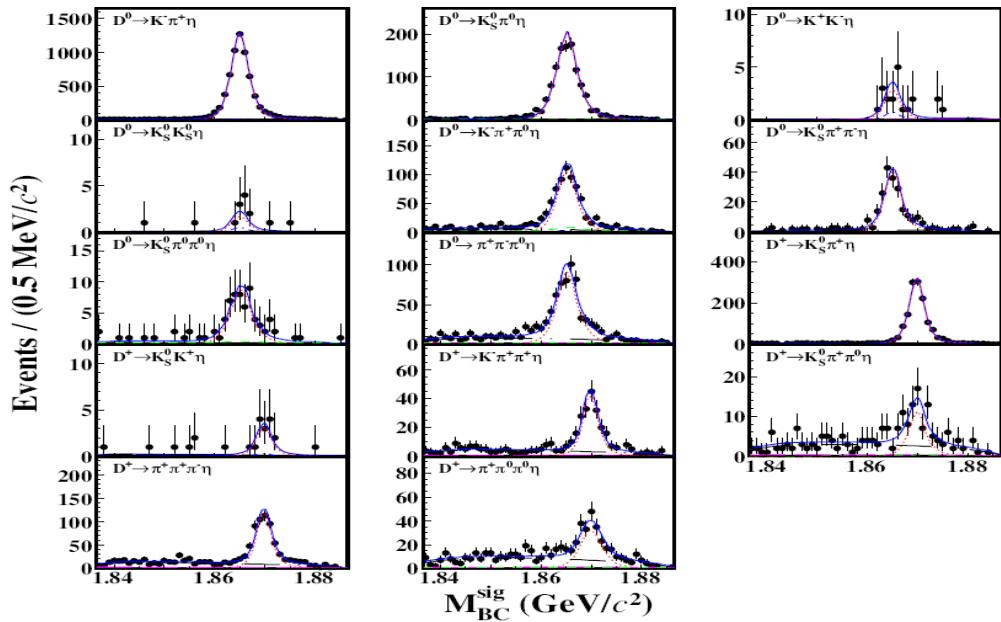
JHEP08(2020)146



Absolute BFs of hadronic D decays

PRL124(2020)241803

arXiv:2206.13864



Most of them are measured for the first time

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

Decay	ΔE_{sig} (MeV)	N_{DT}	ϵ_{sig} (%)	\mathcal{B}_{sig} ($\times 10^{-4}$)
$\pi^+ \pi^- \pi^0$	(-62, 36)	$12792.6(120.1)$	40.91	134.3(13)(16)
$\pi^+ \pi^- 2\pi^0$	(-75, 37)	$3783.7(70.5)$	16.29	99.8(19)(24)
$\pi^+ \pi^- 2\eta$	(-37, 29)	$42.5(6.7)$	2.14	8.5(13)(04)
$4\pi^0$	(-105, 41)	$96.0(11.5)$	5.41	7.6(09)(07)
$3\pi^0 \eta$	(-82, 40)	$155.3(14.7)$	2.83	23.6(22)(17)
$2\pi^+ 2\pi^- \pi^0$	(-52, 33)	$942.4(40.0)$	11.70	34.6(15)(15)
$2\pi^+ 2\pi^- \eta$	(-36, 28)	$48.5(7.8)$	3.46	6.0(10)(06)
$\pi^+ \pi^- 3\pi^0$	(-76, 39)	$182.7(20.9)$	5.13	15.3(17)(13)
$2\pi^+ 2\pi^- 2\pi^0$	(-64, 36)	$350.0(22.9)$	3.15	47.7(31)(21)
$2\pi^+ \pi^-$	(-30, 28)	$2614.3(58.0)$	50.63	33.1(07)(05)
$\pi^+ 2\pi^0$	(-96, 44)	$1968.0(51.7)$	27.33	46.2(12)(09)
$2\pi^+ \pi^- \pi^0$	(-59, 35)	$4649.5(83.5)$	25.42	117.4(21)(21)
$\pi^+ 3\pi^0$	(-86, 39)	$573.7(30.2)$	8.83	41.7(22)(13)
$3\pi^+ 2\pi^-$	(-37, 33)	$462.1(28.7)$	16.26	18.2(11)(10)
$2\pi^+ \pi^- 2\pi^0$	(-74, 39)	$1207.1(45.4)$	7.21	107.4(40)(30)
$2\pi^+ \pi^- \pi^0 \eta$	(-51, 33)	$191.4(15.9)$	3.17	38.8(32)(12)
$\pi^+ 4\pi^0$	(-90, 41)	$56.7(10.4)$	1.87	19.5(36)(23)
$\pi^+ 3\pi^0 \eta$	(-66, 37)	$79.7(10.9)$	1.77	28.9(40)(22)
$3\pi^+ 2\pi^- \pi^0$	(-49, 34)	$182.8(17.3)$	5.02	23.4(22)(15)
$2\pi^+ \pi^- 3\pi^0$	(-66, 37)	$185.9(17.0)$	3.49	34.2(31)(16)

Absolute BFs of other hadronic D decays at BESIII

■ BFs of $D^{0(+)} \rightarrow K3\pi$ and $K4\pi$	arXiv:2205.14031, accepted by PRD
■ DCS decays $D^0 \rightarrow K^-\pi^+\pi^0$ and $K^-\pi^+\pi^0\pi^0$	PRD105(2022)112001
■ $D^{0(+)} \rightarrow K_L(\omega, \phi, \eta, \eta')$	PRD105(2022)092010
■ $D^{0(+)} \rightarrow K\pi\omega$	PRD105(2022)032009
■ DCS decays $D^+ \rightarrow K^+\pi^0\pi^0$ and $K^+\pi^0\eta$	arXiv:2110.10999, submitted to JHEP
■ DCS decay $D^+ \rightarrow K^+\pi^+\pi^-\pi^0$ via SL method	PRD104(2021)072005
■ $D^{0(+)} \rightarrow KK\pi\pi$	PRD102(2020)052006
■ $D^{0(+)} \rightarrow \omega\pi\pi$	PRD102(2020)052003
■ $D^+ \rightarrow \eta\eta\pi^+$	PRD101(2020)052009
■ $D^{0(+)} \rightarrow \phi X$	PRD100(2019)072006
■ Two-body $D^{0(+)} \rightarrow \phi P$ decays	PLB798(2019)135017
■ $D_s^+ \rightarrow \omega K^+$ and $\omega\pi^+$	PRD99(2019)091101
■ $D_s^+ \rightarrow K_{S/L}^0 K^+$	PRD99(2019)032002
■ $D_s^+ \rightarrow p\bar{n}$	PRD99(2019)031101
■ $D^+ \rightarrow K_{S/L}^0 K^+(\pi^0)$	PRD99(2019)112005
■ $D^{0(+)} \rightarrow \bar{K}\pi\eta'$	PRD98(2018)092009
■ $D^0 \rightarrow \omega\eta$	PRD97(2018)052005
■ $D^0 \rightarrow 3\pi^0, 2\pi^0\eta, 2\eta\pi^0$	PLB781(2018)781
■ $D^{0(+)} \rightarrow K_S^0 X$	PLB765(2017)231
■ $D_s^+ \rightarrow \eta'X$ and $\eta'\rho^+ @ 4.009 \text{ GeV}$	PLB750(2016)466

Rare D decays at BESIII

■ $D^0 \rightarrow \pi^0 \nu \bar{\nu}$	PRD105(2022)L071102
■ $D^0 \rightarrow p e$	PRD105(2022)032006
■ $D^+ \rightarrow \Lambda e^+ , \Sigma e^+$	PRD101(2020)031102
■ $D^0 \rightarrow h h e^+ e^+$	PRD99(2019)112002
■ $D^+ \rightarrow h^+ h^0 e^+ e^-$	PRD97(2018)072015
■ $D^0 \rightarrow \gamma \gamma$	PRD91(2015)112015