Hadronic Charm Meson Decays @ BESIII

Chuangxin Lin
(On behalf of the BESIII Collaboration)
Sun Yat-sen University (SYSU)

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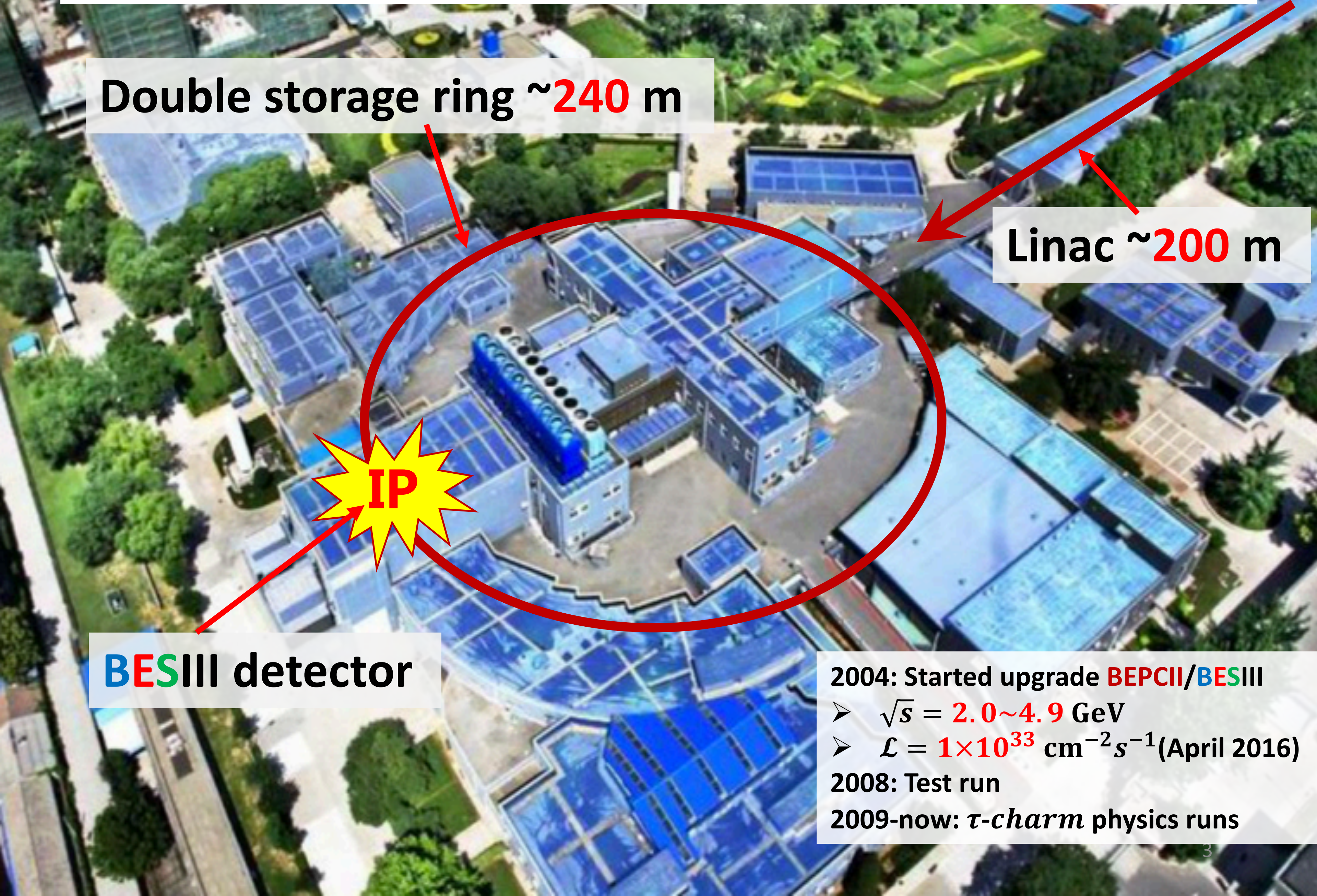
Outline

- Introduction
- Strong-phase parameters in $D^0/\bar{D}^0$ decay
- Amplitude analysis of D_s^+ and D^0 decay
- Branching fractions (BFs) of D_s^+ and D^+/D^0 decay
- Summary

Beijing Electron Positron Collider II(BEPCII)



2004: Started upgrade BEPCII/BESIII

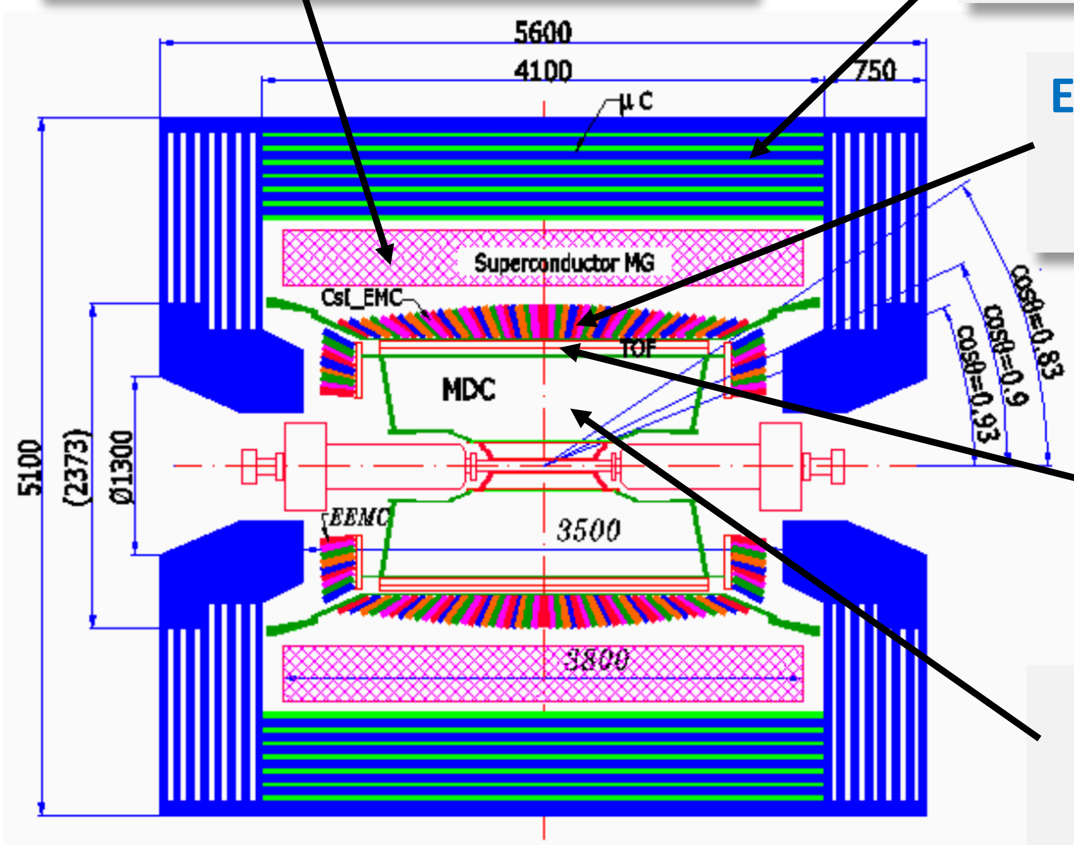
- $\sqrt{s} = 2.0\sim4.9$ GeV
- $\mathcal{L} = 1\times10^{33}$ $\mathrm{cm}^{-2}s^{-1}$(April 2016)

2008: Test run

2009-now: τ-$charm$ physics runs

Beijing Spectrometer(BESIII) Experiment

Superconducting solenoid (1T)



RPC Muon Counter

9 layers (barrel) + 8 layers (end-caps)

93% coverage of the full solid angle

Electromagnetic CsI(Tl) Calorimeter

$\sigma_E/E < 2.5\%$ @ 1 GeV (barrel)

$\sigma_E/E < 5\%$ @ 1 GeV (end-caps)

Time-of-Flight

$\sigma_t = 90$ ps (barrel)

$\sigma_t = 120$ ps (end-caps)

Main Drift Chamber

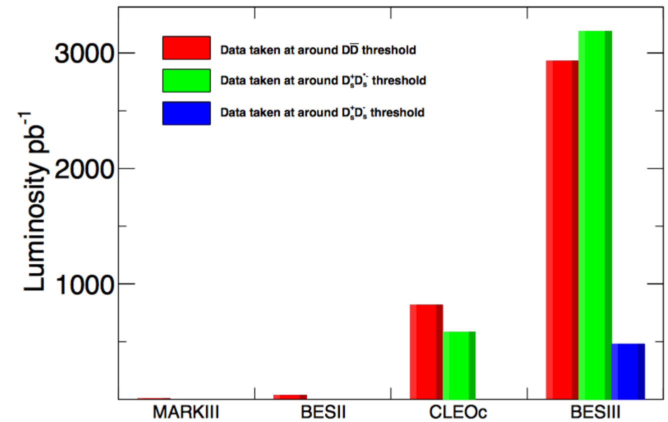
$\sigma_{r\phi} = 130$ μm (single wire)

$\sigma_{pt}/p_t = 0.5\%$ @ 1 GeV

Charm data and analysis method

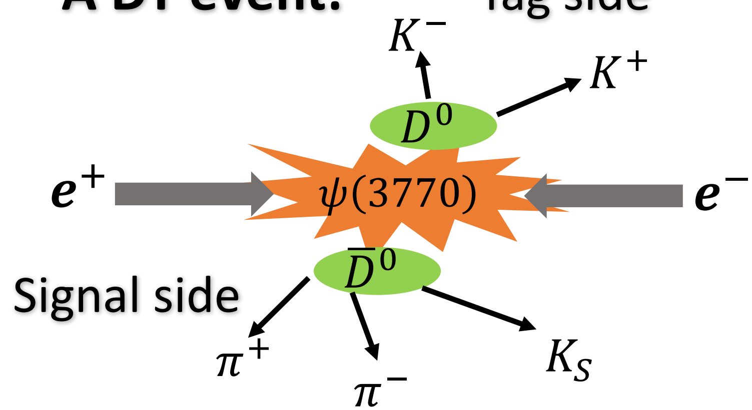
- **Data produced near threshold without accompanying particles:**

Data samples	$\sqrt{s}$ (GeV)	Int. $\mathcal{L}$ (fb^{-1})	x CLEO-c
$D\bar{D}$	3.773	2.93	3.6x
$D_s\bar{D}_s^*$	4.178	3.19	5.3x
$D_s\bar{D}_s^*$	4.189 – 4.226	3.18	-



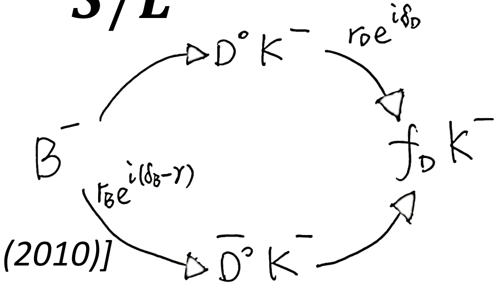
- Single tag (**ST**): $\mathcal{B}(D \to f) = \frac{N_{\text{sig}}}{2 \times N_{D\bar{D}}^{tot} \times \epsilon}$
  - For partial reconstruct, few bkg channels.
- Double tag (**DT**): $\mathcal{B}(D \to f) = \frac{N_{\text{sig}}}{N_{ST}^{tot} \times \epsilon}$
  - DT provides clean samples for amplitude analysis and BFs measurement.

A DT event:

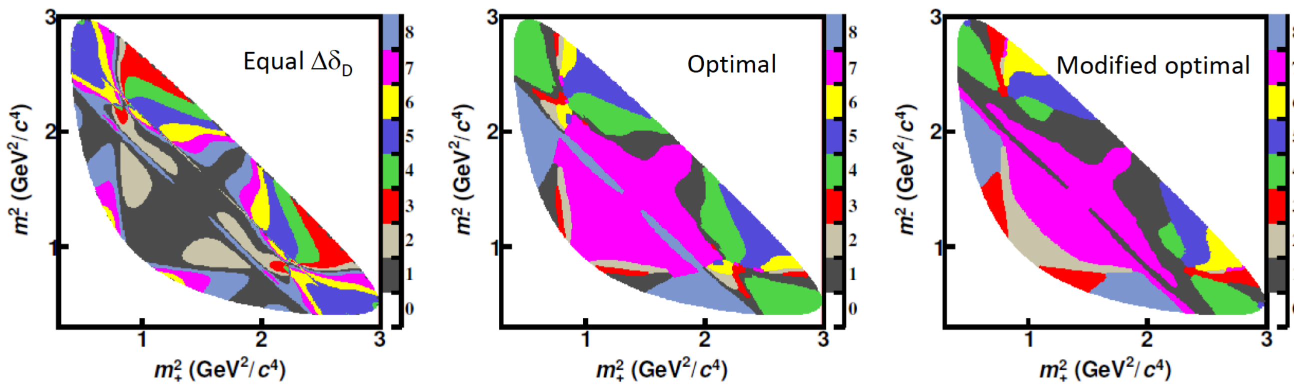


Strong-phase parameters in $D^0 \to K^0_{S/L}\pi^+\pi^-$

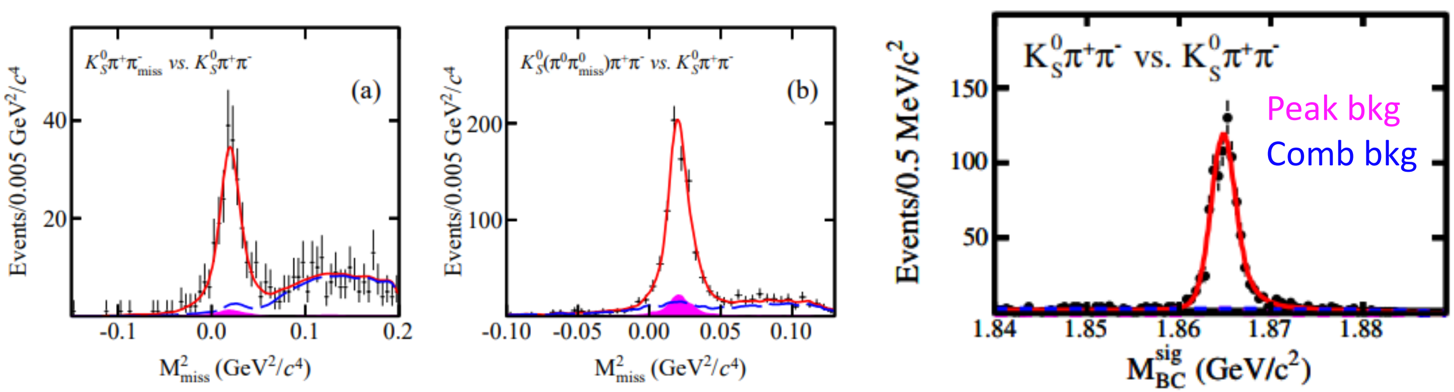
[Phys. Rev. Lett. 124, 241802 (2020)] *[Phys. Rev. D 101, 112002 (2020)]*



- Use self-conjugate multi-body decays (**GGSZ approach**):
  - $D^0 \to K_S h^+ h^-$ $(h = K, \pi)$ *[Phys. Rev. D 68, 054018 (2003)]*
  - Three Binning schemes are used in this work *[Phys. Rev. D 82,112006 (2010)]*

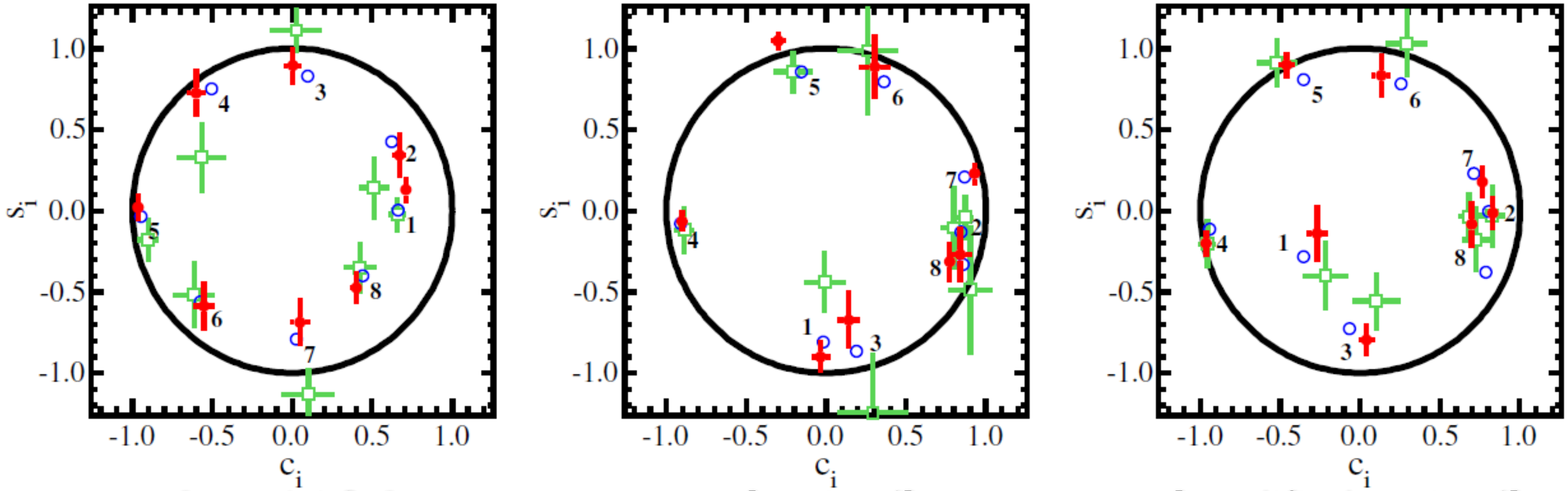


- 2-D fits are performed on all DT events, K_L and ν in DT events are missed.
- **To improve the statistics of $K_S\pi\pi$ vs $K_S\pi\pi$, two partially-reconstruction methods are used by missing 1 $\pi^\pm$ from D and missing 1 π^0 from K_S**



Strong-phase parameters $c_i^{(\prime)}$ and $s_i^{(\prime)}$

Red: this work
Blue: expected values [Phys. Rev. D 98, 110212(2018)]
Green: CLEO-c results



[Equal $\Delta\delta_D$] [optimal] [modified optimal]

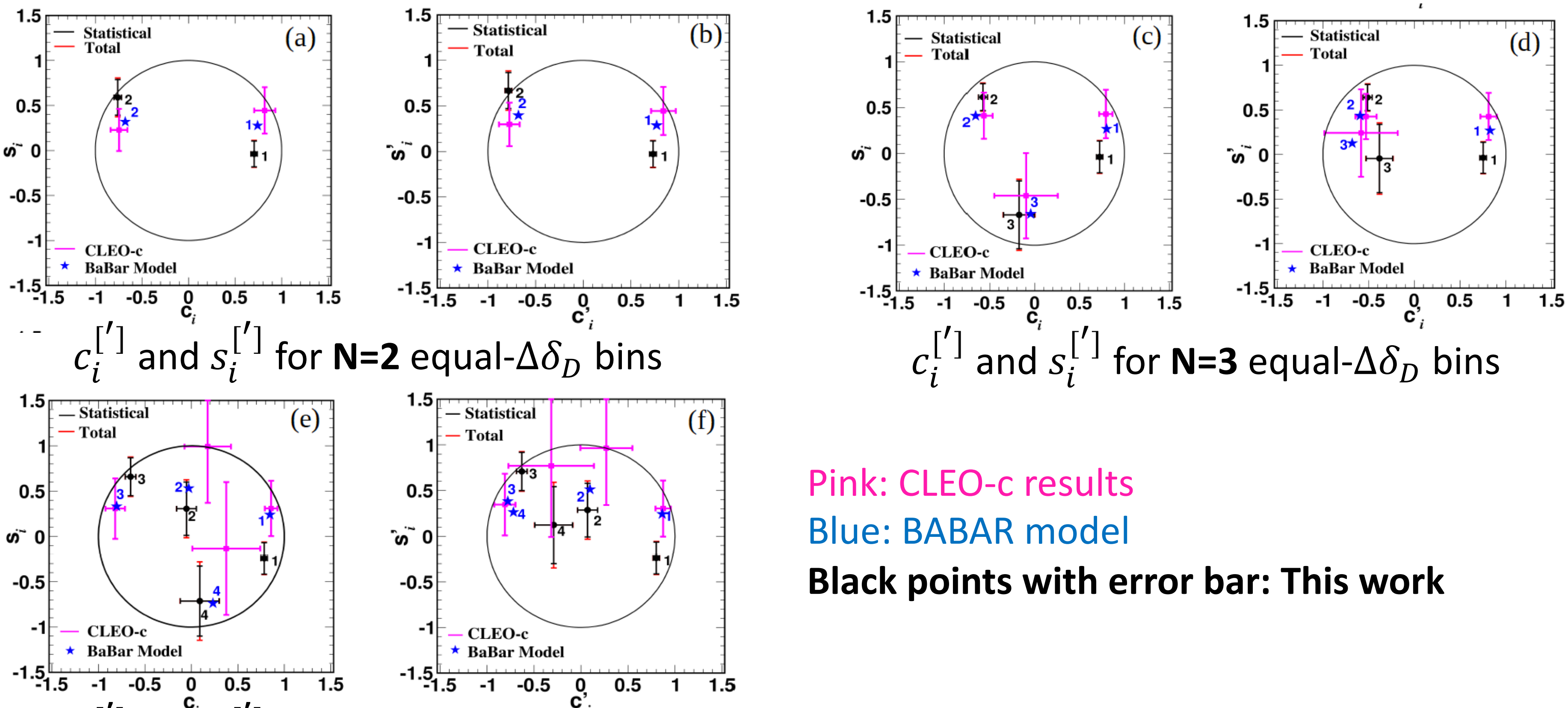
- The **most precise** measurements to date.
- The strong-phase parameters are limited by statistical uncertainty.
- A factor of **~2.5 (1.9)** and **~2.8 (2.2)** more precise for c_i (s_i) and c_i' (s_i') than previous results, respectively.
- **The associated uncertainty on γ is reduced from ~4° to ~1° in $B^- \to D(K_S\pi\pi)K^-$ [GGSZ].**
- The improved result is important input for γ measurement by B decay.

see back up for c_i' (s_i')

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

[arXiv: 2007.07959]

- Using the equal $\Delta\delta_D$ binning scheme (**GGSZ approach**):



$c_i^{[\prime]}$ and $s_i^{[\prime]}$ for **N=2** equal-$\Delta\delta_D$ bins

$c_i^{[\prime]}$ and $s_i^{[\prime]}$ for **N=3** equal-$\Delta\delta_D$ bins

$c_i^{[\prime]}$ and $s_i^{[\prime]}$ for **N=4** equal-$\Delta\delta_D$ bins

Pink: CLEO-c results

Blue: BABAR model

Black points with error bar: This work

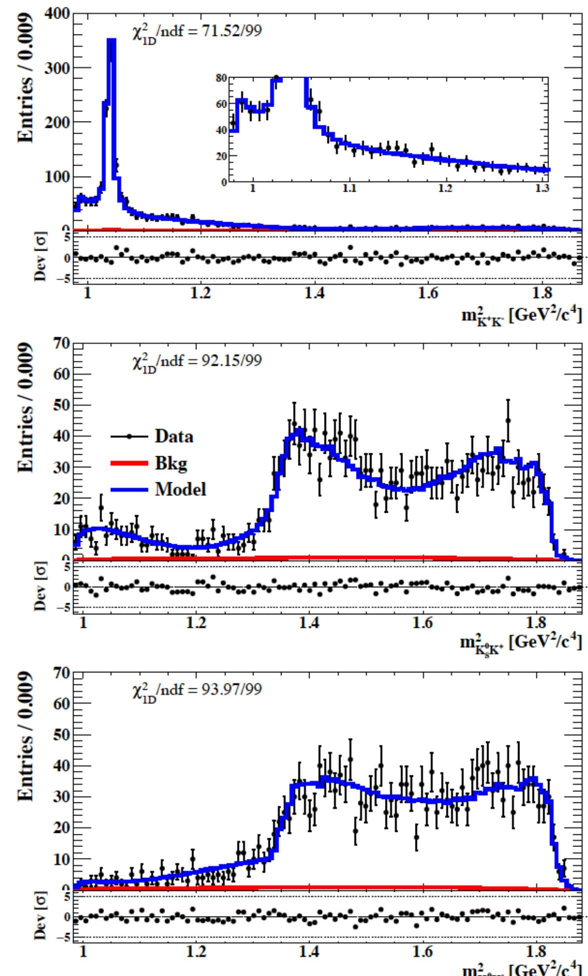
- Still limited by statistical uncertainty
- The **best precision** for strong-phase parameters of $D^0 \to K^0_{S/L} K^+ K^-$ decay.
- Determination of charm-mixing parameters and search for CP violation.

Dalitz plot analysis of $D^0 \to K_S^0 K^+ K^-$

[arXiv: 2006.02800]

- Using **1856±45** flavor-tagged signal events with a purity of 96.37%.
- The Dalitz plot (DP) is well described by a set of six resonances.

- The DP projections:
  Full dots are data
  Blue line is amplitude model



Results from DP analysis:

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

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

$$g_{K\bar{K}} = (3.77 \pm 0.24(\text{stat.}) \pm 0.35(\text{sys.}))\text{GeV}$$

- The **first absolute measurement**:

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

Systematically limited

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

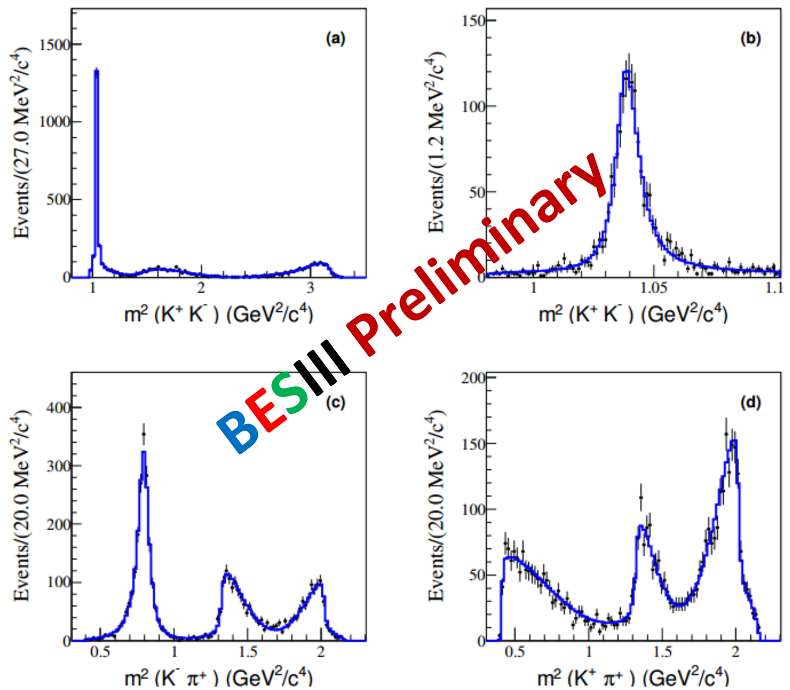
*[Phys. Lett. B **351**, 591 (1995)]*
*[Phys. Rev. D **79**, 072008 (2009)]*
*[Phys. Rev. D **83**, 052001 (2011)]*

- Provide inputs for theory and refine theoretical models.
- An obvious difference on BFs of $S(980)\pi^+$ between BABAR and CLEO.

- The DP projections:

Black dots with error bars: data

Blue solid lines: projection of result



Comparison with BABAR and CLEO results:

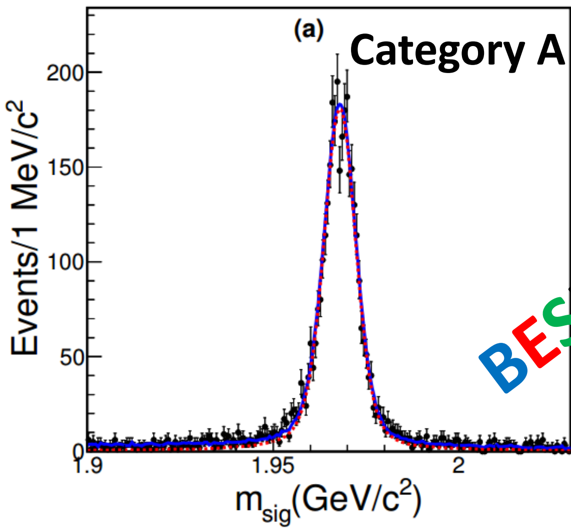
Amplitude	BABAR	CLEO	BESIII (this analysis)
$D_s^+ \to \bar{K}^*(892)^0 K^+$	47.9±0.5±0.5	47.4±1.5±0.4	48.3±0.9±0.6
$D_s^+ \to \phi(1020)\pi^+$	41.4±0.8±0.5	42.2±1.6±0.3	40.5±0.7±0.9
$D_s^+ \to S(980)\pi^+$	16.4±0.7±2.0	28.2±1.9±1.8	19.3±1.7±2.0
$D_s^+ \to \bar{K}_0^*(1430)^0 K^+$	2.4±0.3±1.0	3.9±0.5±0.5	3.0±0.6±0.5
$D_s^+ \to f_0(1710)\pi^+$	1.1±0.1±0.1	3.4±0.5±0.3	1.9±0.4±0.6
$D_s^+ \to f_0(1370)\pi^+$	1.1±0.1±0.2	4.3±0.6±0.5	1.2±0.4±0.2
$\sum FF(\%)$	110.2±0.6±2.0	129.5±4.4±2.0	114.2±1.7±2.3
χ^2/NDF	2843/2291=1.2	170/117=1.5	290/280=1.04
Events	96307 ± 369(purity 95%)	14400(purity 85%)	4397(purity 99.6%)

Background free

- **BESIII results are closer to BABAR's.**

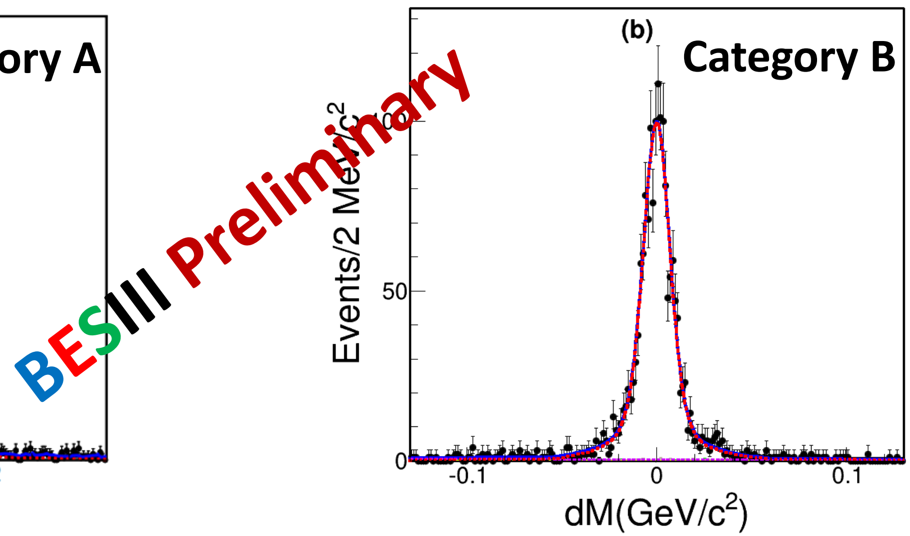
BF measurement of $D_s^+ \to K^+K^-\pi^+$

$D_s^- \to$ other tag && $D_s^+ \to K^+K^-\pi^+$



Fit of mass of Ds from signal side

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



Fit of mass difference of Ds from signal side and tag side

DT yield (A and B): 5148 ± 77

BFs results:

$\mathcal{B}(D_s^+ \to K^+K^-\pi^+) = (5.47 \pm 0.08_{\rm stat} \pm 0.13_{\rm sys})\%$ ➡ The **best precision** up to now!

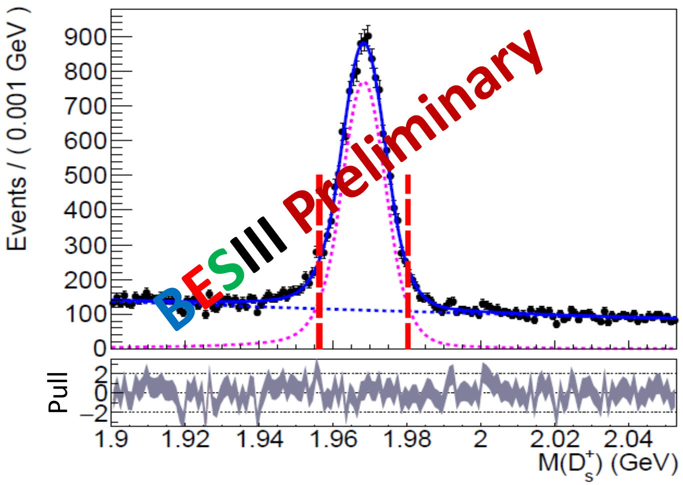
$\mathcal{B}(D_s^+ \to \bar{K}^*(892)^0 K^+) = (3.94 \pm 0.12)\%$
$\mathcal{B}(D_s^+ \to \phi(1020)\pi^+) = (4.60 \pm 0.17)\%$ ➡ Consistent with theoretical predictions

*[Phys. Rev. D **93**, 114010 (2016)]*

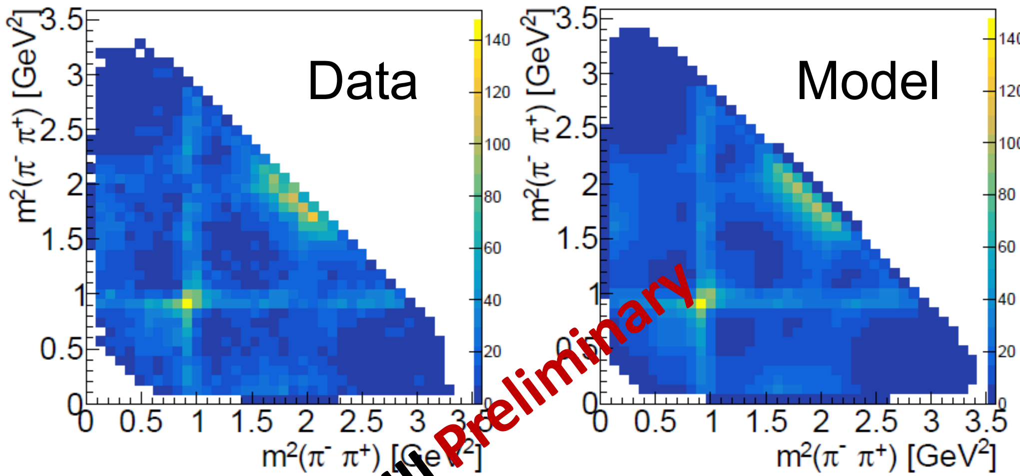
Dalitz plot analysis of $D_s^+ \to \pi^+\pi^-\pi^+$

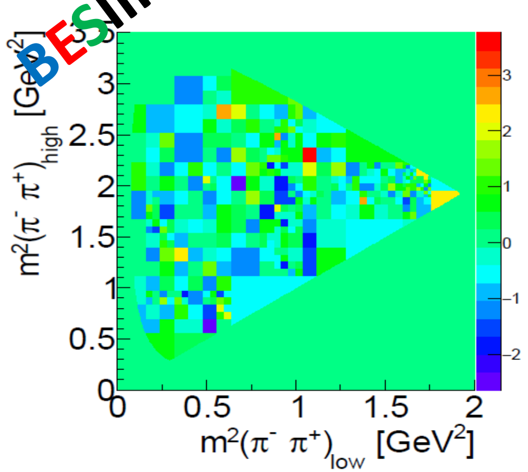
- $f_0(980)$ resonance still needs to be better understood. *[Phys. Rev. D 93 (2016) 114010]*
- Important input for the global study of $D_s \to VP$.

13.8 K data events with 80% signal purity in the signal region for DP analysis.



Dalitz plot:





- Unbinned ML fit with likelihood function depending on DP position (x, y) for each event.

Results of $D_s^+ \to \pi^+\pi^-\pi^+$

- Fit results by using the BABAR model.

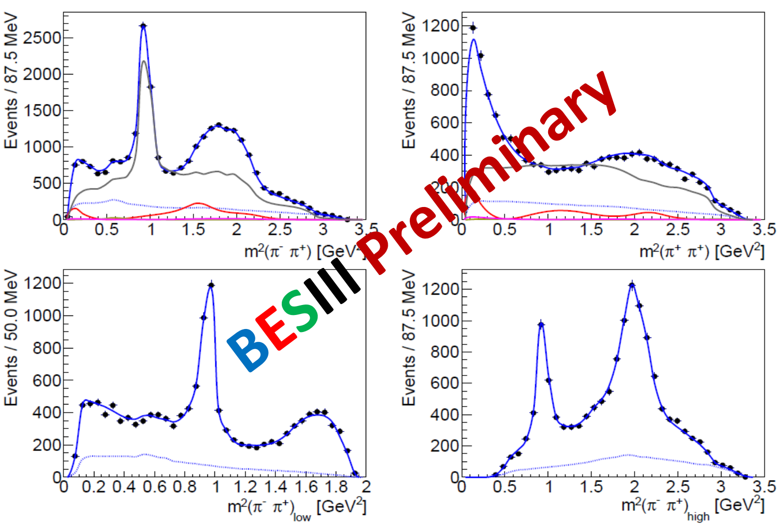
See back-up for other models tested *[Phys. Rev. D 79, 032003 (2009)]*

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

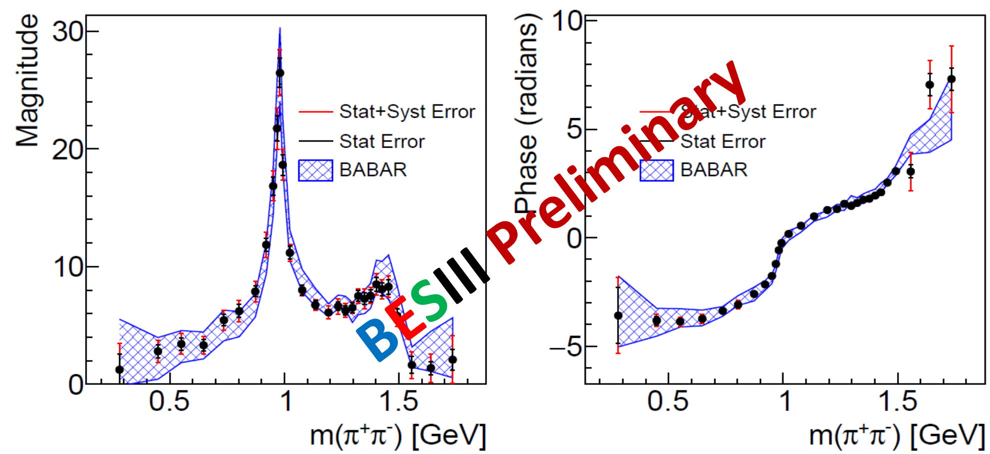
S-wave is parametrized by an interpolation between the **N=29** control points also used by BABAR:

$$A_{S\text{-wave}}(m_{\pi\pi}) = \mathrm{Interp}(c_k(m_{\pi\pi})e^{i\phi_k(m_{\pi\pi})})_{k=1,\dots,N}$$

Blue dashed: background, Gray: $\pi^+\pi^-$ *S*-wave, Red: $f_2(1270)\pi$, Yellow: $\rho(770)\pi$, Magenta: $\rho(1450)\pi$, Blue: full model



- With **improved precision**, our results are compatible with BABAR measurements:



[Phys. Rev. D 79, 032003 (2009)]

BFs of $D_s^+ \to PP$

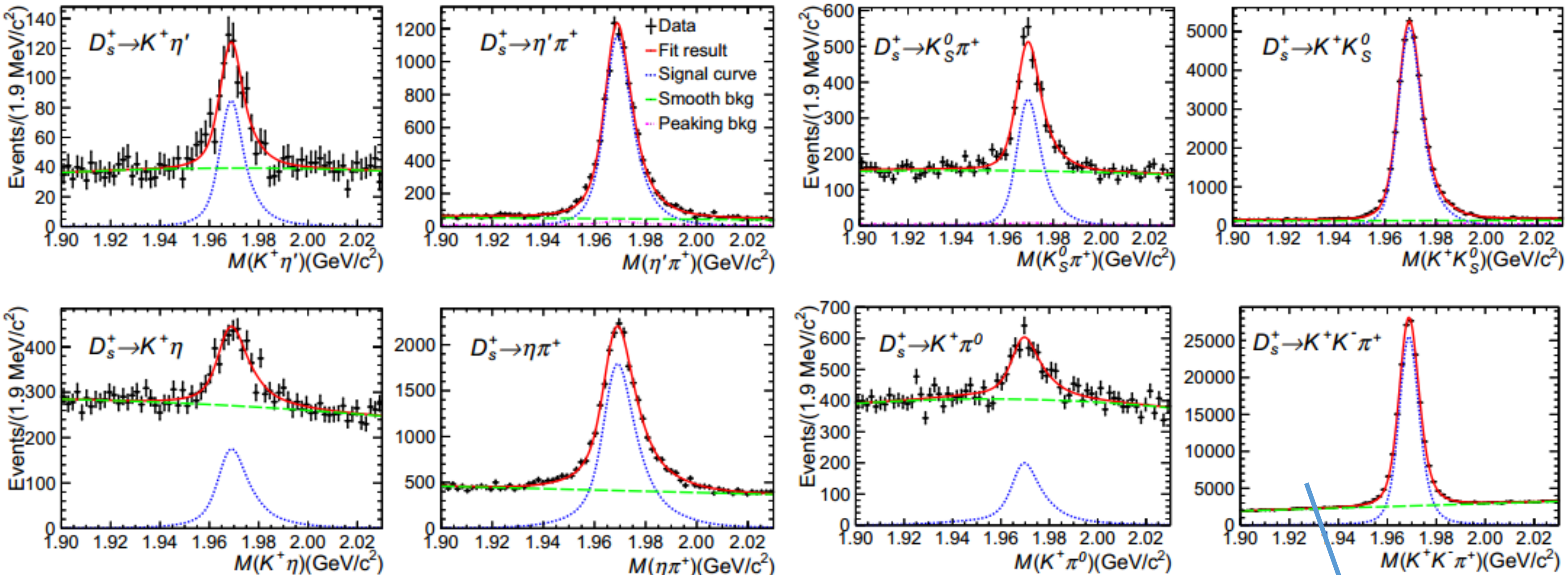
[arXiv:2005.05072 accepted by JHEP]

- Crucial calibrations to different theoretical models
- Explore SU(3) asymmetries for D_s^+ meson

Using 6.37 fb^{-1} DsDs* data at $E_{cms} = 4.178 - 4.226$ GeV

Seven channels:

Fit of invariant mass of D_s^+



Normalization mode

☐ Relative BFs compared with PDG

Relative BFs	This work	PDG [6]
$\mathcal{B}(K^+\eta')/\mathcal{B}(\eta'\pi^+)$	$7.07 \pm 0.46 \pm 0.11$	4.2 ± 1.3
$\mathcal{B}(K^+\eta)/\mathcal{B}(\eta\pi^+)$	$9.31 \pm 0.58 \pm 0.10$	8.9 ± 1.6
$\mathcal{B}(K_S^0\pi^+)/\mathcal{B}(K^+K_S^0)$	$7.38 \pm 0.23 \pm 0.09$	8.12 ± 0.28
$\mathcal{B}(K^+\eta)/\mathcal{B}(K^+\eta')$	$61.7 \pm 5.5 \pm 3.6$	–
$\mathcal{B}(\eta\pi^+)/\mathcal{B}(\eta'\pi^+)$	$46.90 \pm 0.71 \pm 2.04$	–

Precisions significantly improved

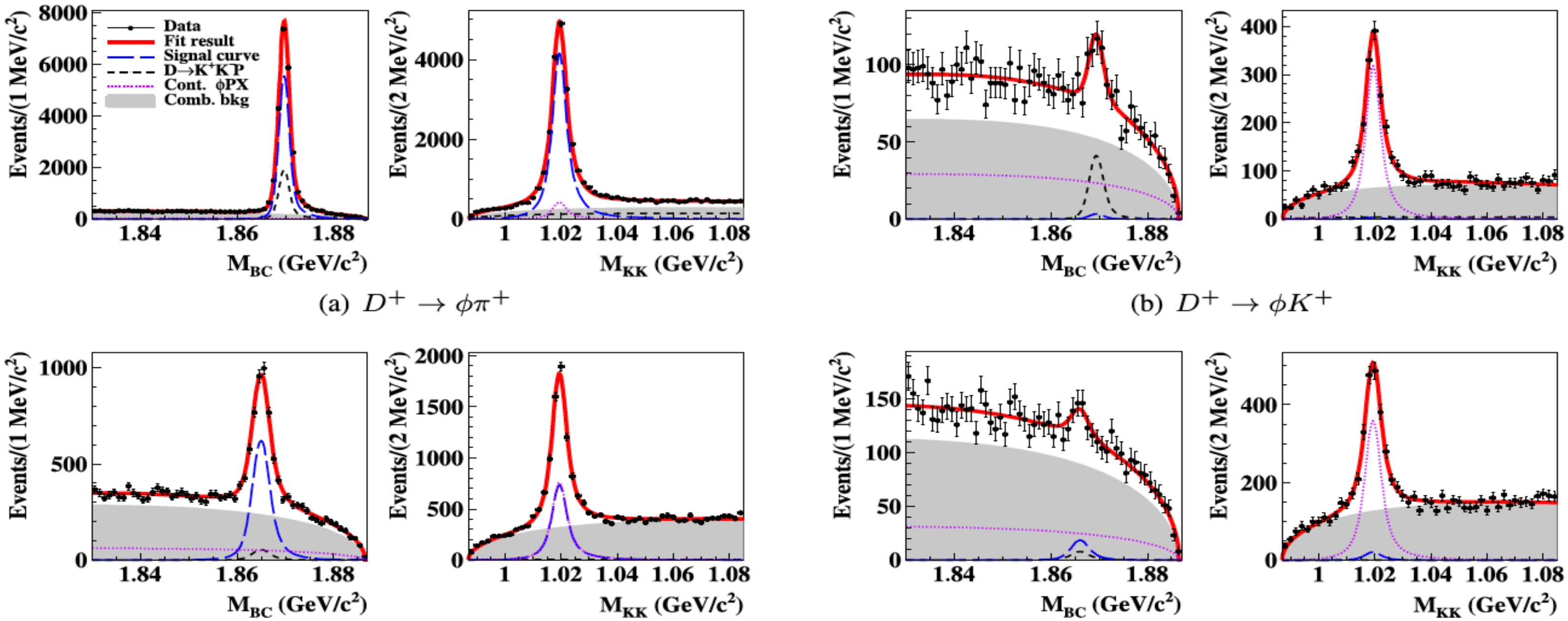
First measurement

BFs of $D \to \phi P$

- Precision measurement of absolute BFs of $D \to \phi P$ [Phys. Lett. B 798 (2019) 135017]
- Explore and check isospin symmetry between ***u*** and ***d*** quarks.

Four channels:

2D Fit for M_{BC} vs. M_{KK}



(a) $D^+ \to \phi\pi^+$ (b) $D^+ \to \phi K^+$

(c) $D^0 \to \phi\pi^0$ (d) $D^0 \to \phi\eta$

- **BFs compared with PDG ➡ Precisions significantly improved**

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

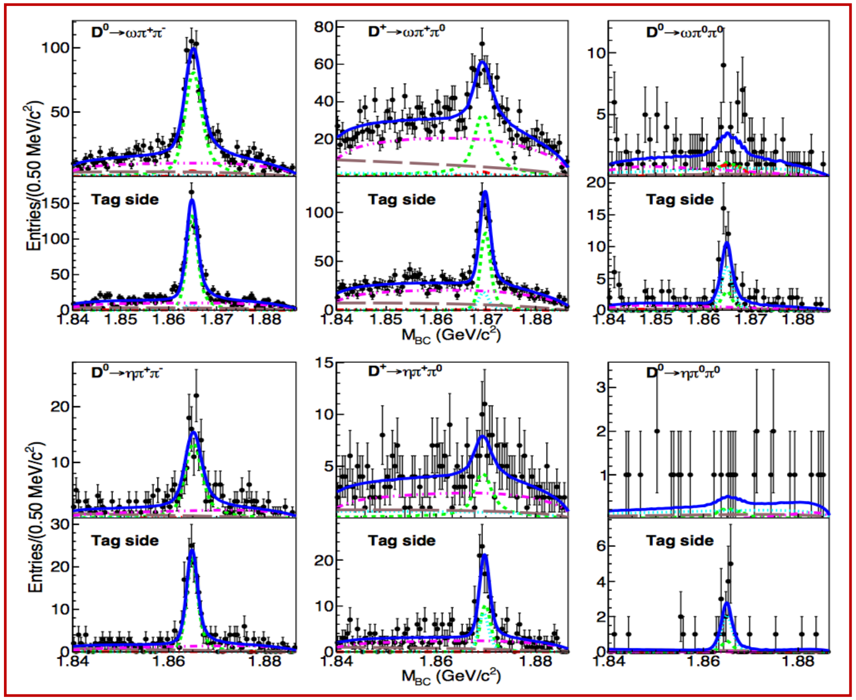
$\mathcal{B}(D^0 \to \phi\pi^0)/\mathcal{B}(D^+ \to \phi\pi^+) = (20.49 \pm 0.50 \pm 0.45)\%$ ➡ **Support isospin symmetry**

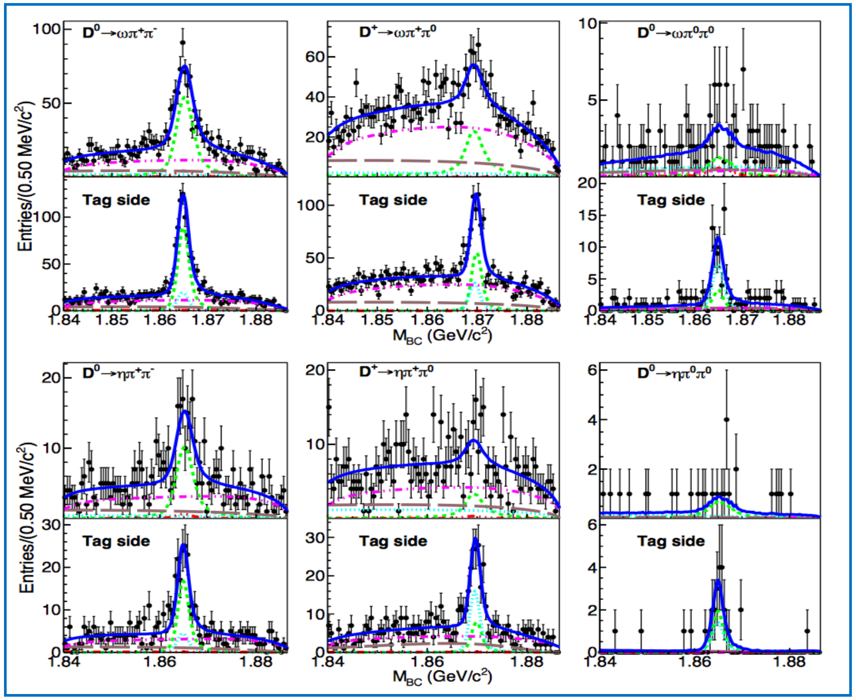
BFs of $D \to \omega\pi\pi$

[arXiv:2007.02542]

- Precision measurement of absolute BFs of SCS decay $D \to \omega\pi\pi$.
- Important inputs for ***B*** decays.

Signal region **2D Fit for M_{BC}^{tag} vs. M_{BC}^{sig}** **Sideband region**





- **Results of this work: Six channels**

Precisions significantly improved

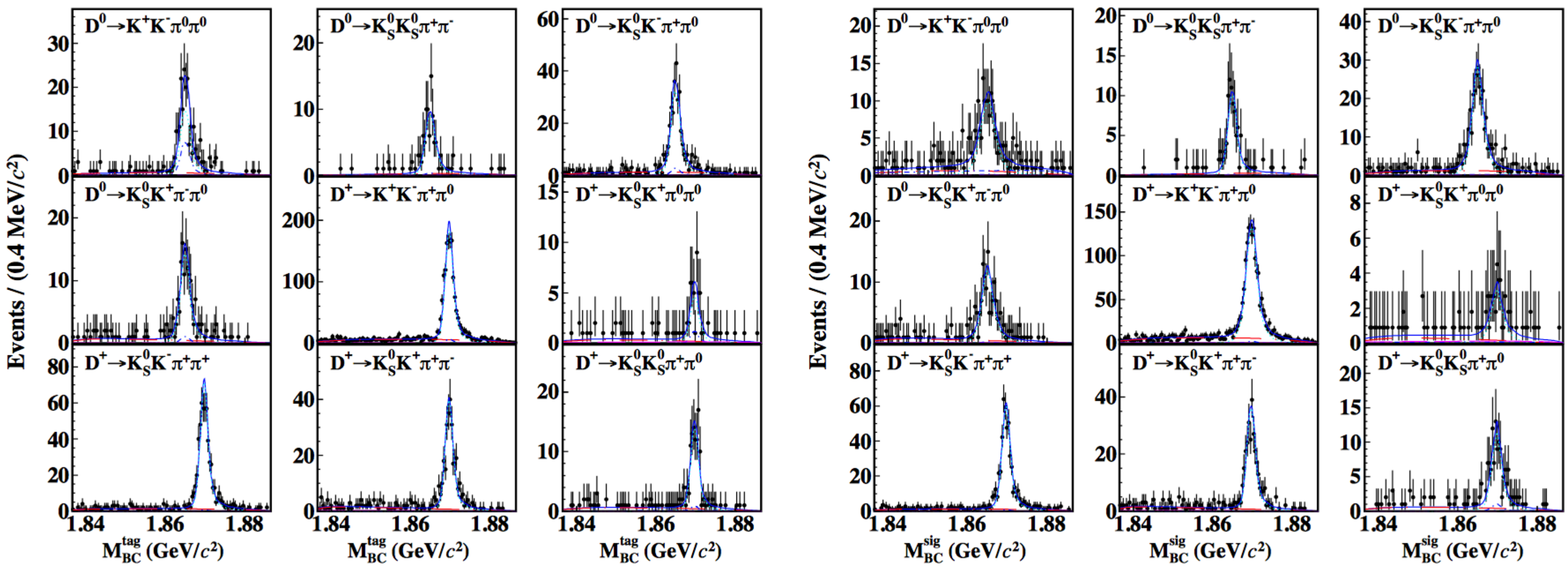
Decay mode	$N_{\rm SG}^{\omega/\eta}$	f (%)	$N_{\rm SB}^{\omega/\eta}$	$N_{\rm peak}^{\rm BKGV}$	$N_{\rm DT}^{\rm sig}$	Sig.	$\mathcal{B}^{\rm int}$	$\mathcal{B}^{\rm sig}$ $(\times 10^{-3})$	$\mathcal{B}_{\rm PDG}$ $(\times 10^{-3})$
$D^0 \to \omega\pi^+\pi^-$	908.0 ± 39.4	74.6 ± 1.5	610.5 ± 35.1	41.4 ± 2.5	411.2 ± 48.3	12.9σ	0.882	$1.33 \pm 0.16 \pm 0.12$	1.6 ± 0.5
$D^+ \to \omega\pi^+\pi^0$	474.0 ± 42.8	73.3 ± 1.2	329.0 ± 34.3	—	232.9 ± 49.8	7.7σ	0.872	$3.87 \pm 0.83 \pm 0.25$	—
$D^0 \to \omega\pi^0\pi^0$	20.2 ± 10.5	75.2 ± 5.6	22.1 ± 10.0	19.0 ± 1.2	-15.4 ± 13.0	0.6σ	0.862	< 1.10	—
$D^0 \to \eta\pi^+\pi^-$	151.3 ± 14.6	42.6 ± 0.9	115.0 ± 15.3	6.1 ± 0.2	96.2 ± 16.0	8.3σ	0.227	$1.06 \pm 0.18 \pm 0.07$	1.09 ± 0.16
$D^+ \to \eta\pi^+\pi^0$	61.5 ± 14.3	41.4 ± 0.7	47.3 ± 16.4	—	41.9 ± 15.8	3.5σ	0.224	$2.47 \pm 0.93 \pm 0.16$	1.38 ± 0.35
$D^0 \to \eta\pi^0\pi^0$	5.7 ± 3.8	40.6 ± 3.3	13.1 ± 4.8	2.0 ± 0.1	-1.6 ± 4.3	0.1σ	0.221	< 2.38	0.38 ± 0.13

First measurement

BFs of $D \to K\bar{K}\pi\pi$

- Precision measurement of absolute BFs of $D \to K\bar{K}\pi\pi$. *[arXiv:2007.10563]*
- Explore $D\bar{D}$ mixing, CP violation and quark SU(3)-flavor asymmetry.

2D Fit for M_{BC}^{tag} vs. M_{BC}^{sig}



Results of this work: Nine channels **Precisions significantly improved**

Signal mode	ΔE_{sig} (MeV)	N_{DT}^{net}	ϵ_{sig} (%)	$\mathcal{B}_{sig}$ ($\times 10^{-3}$)	$\mathcal{B}_{PDG}$ ($\times 10^{-3}$)
$D^0 \to K^+K^-\pi^0\pi^0$	$(-59, 40)$	132.1 ± 13.9	8.20 ± 0.07	$0.69 \pm 0.07 \pm 0.04$	–
$D^0 \to K_S^0K_S^0\pi^+\pi^-$	$(-22, 22)$	62.5 ± 10.4	5.14 ± 0.04	$0.52 \pm 0.09 \pm 0.03$	1.22 ± 0.23
$D^0 \to K_S^0K^-\pi^+\pi^0$	$(-43, 32)$	195.8 ± 20.3	6.38 ± 0.06	$1.32 \pm 0.14 \pm 0.07$	–
$D^0 \to K_S^0K^+\pi^-\pi^0$	$(-44, 33)$	119.3 ± 12.9	7.94 ± 0.06	$0.65 \pm 0.07 \pm 0.02$	–
$D^+ \to K^+K^-\pi^+\pi^0$	$(-39, 30)$	1311.7 ± 40.4	12.72 ± 0.08	$6.62 \pm 0.20 \pm 0.25$	26^{+9}_{-8}
$D^+ \to K_S^0K^+\pi^0\pi^0$	$(-61, 44)$	34.7 ± 7.2	3.77 ± 0.02	$0.59 \pm 0.12 \pm 0.04$	–
$D^+ \to K_S^0K^-\pi^+\pi^+$	$(-22, 21)$	467.9 ± 26.6	13.24 ± 0.08	$2.27 \pm 0.12 \pm 0.06$	2.38 ± 0.17
$D^+ \to K_S^0K^+\pi^+\pi^-$	$(-21, 20)$	279.6 ± 18.1	9.39 ± 0.06	$1.91 \pm 0.12 \pm 0.05$	1.74 ± 0.18
$D^+ \to K_S^0K_S^0\pi^+\pi^0$	$(-46, 37)$	80.4 ± 12.0	3.84 ± 0.03	$1.34 \pm 0.20 \pm 0.06$	–

Five channels are observed for the first time.

BFs of exclusive hadronic $D \to \eta X$

[Phys. Rev. Lett. 124, 241803 (2020)]

- Key potential backgrounds in some Lepton Flavor Universality (LFU) tests
- Known D^0/D^+ exclusive decays to η only account for 44% / 16%
- Crucial to address the tensions found in LFU tests with semi-leptonic ***B*** decays
- Search for CP violation in hadronic ***D*** decays

14 absolute BFs of this work: All 14 channels are first measured

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

Six charge-conjugated BFs and asymmetries

Decay	$\mathcal{B}^+_{\text{sig}}$ ($\times 10^{-4}$)	$\mathcal{B}^-_{\text{sig}}$ ($\times 10^{-4}$)	$\mathcal{A}^{\text{sig}}_{CP}$ (%)
$D^0 \to K^-\pi^+\eta$	182.1 ± 3.5	189.1 ± 3.6	$-1.9 \pm 1.3 \pm 1.0$
$D^0 \to K^0_S\pi^0\eta$	98.4 ± 4.8	106.3 ± 5.1	$-3.9 \pm 3.2 \pm 0.8$
$D^0 \to K^-\pi^+\pi^0\eta$	41.7 ± 2.7	48.8 ± 3.2	$-7.9 \pm 4.8 \pm 2.5$
$D^0 \to \pi^+\pi^-\pi^0\eta$	29.8 ± 2.2	33.3 ± 2.5	$-5.5 \pm 5.2 \pm 2.4$
$D^+ \to K^0_S\pi^+\eta$	129.9 ± 5.3	132.3 ± 5.4	$-0.9 \pm 2.9 \pm 1.0$
$D^+ \to \pi^+\pi^+\pi^-\eta$	35.4 ± 2.4	32.7 ± 2.4	$+2.5 \pm 5.0 \pm 1.6$

No evidence of CP violation found

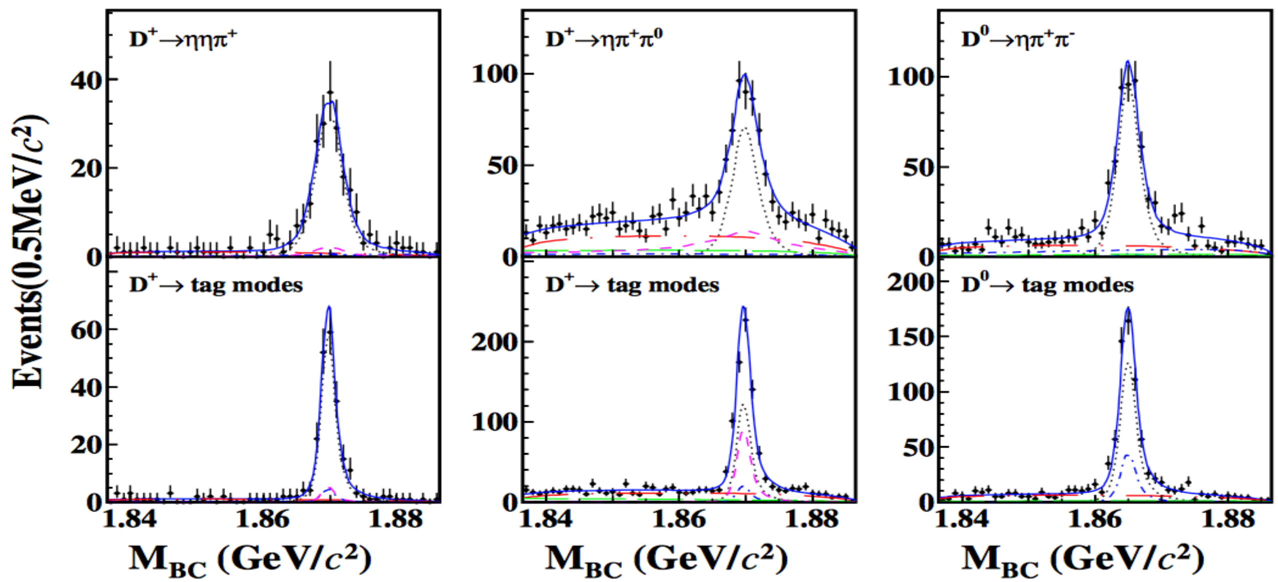
BFs of $D^+ \to \eta\eta\pi^+$ and $D \to \eta\pi\pi$

[Phys. Rev. D 101, 052009 (2020)]

- Clarify the gaps between inclusive and known $D \to \eta X$ decay rates.
- Provide important inputs for charm and $\boldsymbol{B}$ physics.

Three channels:

2D Fit for M_{BC}^{tag} vs. M_{BC}^{sig}



☐ **Results of this work:**

Precisions significantly improved

Decay mode	N_{DT}	$\epsilon_{sig}(\%)$	$\mathcal{B}_{sig}$ $(\times 10^{-3})$	$\mathcal{B}_{CLEO}$ $(\times 10^{-3})$
$D^+ \to \eta\eta\pi^+$	179 ± 15	24.96 ± 0.12	$2.96 \pm 0.24 \pm 0.10$	N/A
$D^+ \to \eta\pi^+\pi^0$	381 ± 26	28.11 ± 0.13	$2.23 \pm 0.15 \pm 0.10$	$1.38 \pm 0.31 \pm 0.16$
$D^0 \to \eta\pi^+\pi^-$	450 ± 25	39.98 ± 0.17	$1.20 \pm 0.07 \pm 0.04$	$1.09 \pm 0.13 \pm 0.09$

First observation

No evidence of CP violation found

Summary

White Paper of BESIII
[Chin. Phys. C 44, 040001 (2020)]

➢ **Measurement of strong-phase parameters**

- $D^0 \to K^0_{S/L}\pi^+\pi^-$: **Best precision, important**
- $D^0 \to K^0_{S/L}K^+K^-$: **input for γ angle**

➢ **Amplitude analysis of D^0 and D_s^+**

- $D^0 \to K_S^0 K^+K^-$: **First absolute measurement**
- $D_s^+ \to K^+K^-\pi^+, \pi^+\pi^-\pi^+$: **Best precision**

➢ **BFs of D_s^+ and D^+/D^0 decay**

- **First measurement:**

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

  $D^+ \to \eta\eta\pi^+$

  $D \to K\bar{K}\pi\pi$: **5** channels

  $D \to \eta X$: **14** channels

- **Best precision:**

  $D_s^+ \to PP$: **7** channels

  $D \to \phi P$: **4** channels

  $D \to \omega\pi\pi, \eta\pi\pi$: **5** channels

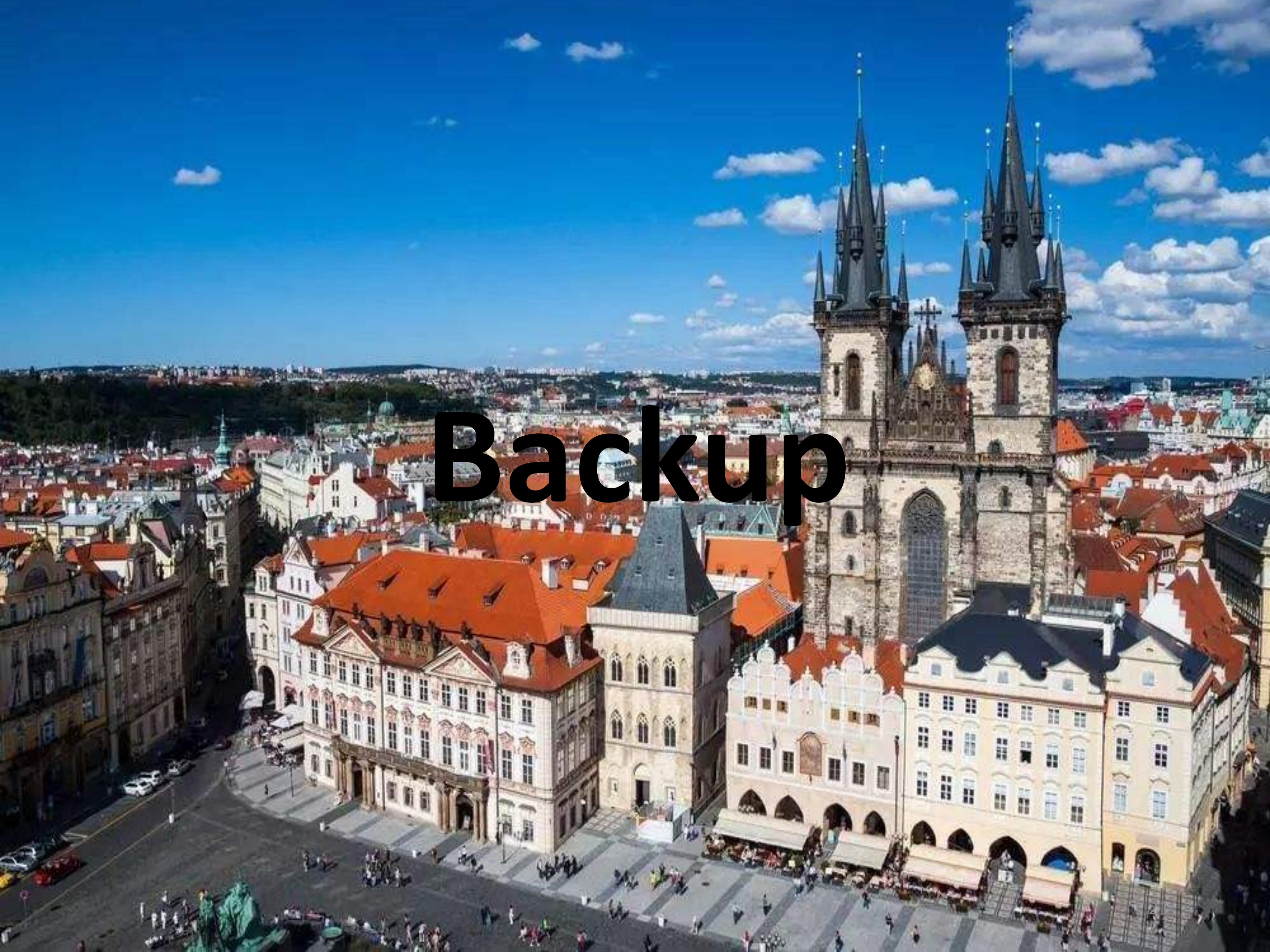
  $D \to K\bar{K}\pi\pi$: **4** channels

☐ **Test the theory**

- Check SU(3) asymmetry
- Support isospin symmetry
- No CP violation found

17 fb^{-1} $\psi(3770)$ data will be collected in the next two years.
More results in $D_{(s)}$ hadronic decays are coming...

谢谢！


Backup

Signal yield of $D^0 \to K^0_{S/L}\pi^+\pi^-$

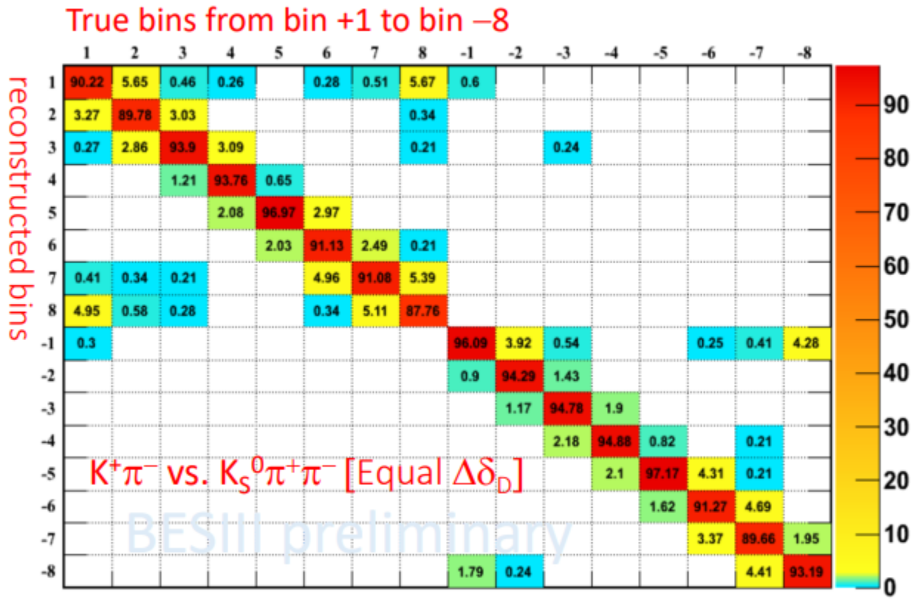
Mode	$N_{\rm ST}$	$N^{\rm DT}_{K^0_S\pi^+\pi^-}$	$N^{\rm DT}_{K^0_L\pi^+\pi^-}$
Flavor tags			
$K^+\pi^-$	549373 ± 756	4740 ± 71	9511 ± 115
$K^+\pi^-\pi^0$	1076436 ± 1406	5695 ± 78	11906 ± 132
$K^+\pi^-\pi^-\pi^+$	712034 ± 1705	8899 ± 95	19225 ± 176
$K^+e^-\bar{\nu}_e$	458989 ± 5724	4123 ± 75	
CP-even tags			
K^+K^-	57050 ± 231	443 ± 22	1289 ± 41
$\pi^+\pi^-$	20498 ± 263	184 ± 14	531 ± 28
$K^0_S\pi^0\pi^0$	22865 ± 438	198 ± 16	612 ± 35
$\pi^+\pi^-\pi^0$	107293 ± 716	790 ± 31	2571 ± 74
$K^0_L\pi^0$	103787 ± 7337	913 ± 41	
CP-odd tags			
$K^0_S\pi^0$	66116 ± 324	643 ± 26	861 ± 46
$K^0_S\eta_{\gamma\gamma}$	9260 ± 119	89 ± 10	105 ± 15
$K^0_S\eta_{\pi^+\pi^-\pi^0}$	2878 ± 81	23 ± 5	40 ± 9
$K^0_S\omega$	24978 ± 448	245 ± 17	321 ± 25
$K^0_S\eta'_{\pi^+\pi^-\eta}$	3208 ± 88	24 ± 6	38 ± 8
$K^0_S\eta'_{\gamma\pi^+\pi^-}$	9301 ± 139	81 ± 10	120 ± 14
$K^0_L\pi^0\pi^0$	50531 ± 6128	620 ± 32	
Mixed CP tags			
$K^0_S\pi^+\pi^-$	188912 ± 756	899 ± 31	3438 ± 72
$K^0_S\pi^+\pi^-_{\rm miss}$		224 ± 17	
$K^0_S(\pi^0\pi^0_{\rm miss})\pi^+\pi^-$		710 ± 34	

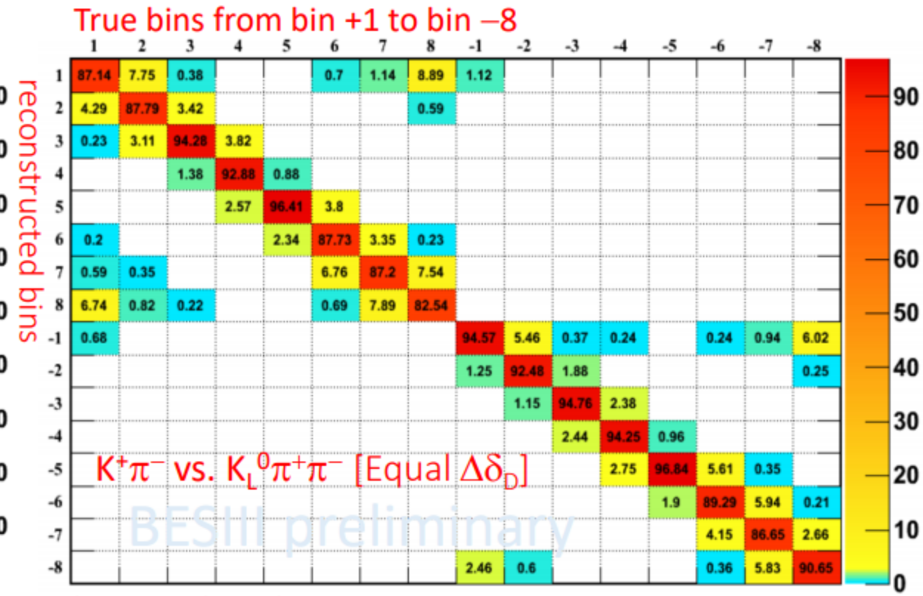
- ✓ Add 5 new CP tag decay modes
- ✓ The yield of DT $K_S\pi\pi$ *vs* $K_S\pi\pi$ is doubled by using partially reconstructed samples
- ✓ Compared to CLEO's

[Phys. Rev. D 82,112006 (2010)]

DT event mode	Scale to CLEO's
CP-even vs $K_S\pi\pi$	5.3
CP-odd vs $K_S\pi\pi$	9.2
$K_S\pi\pi$ *vs* $K_S\pi\pi$	3.9
$K_L\pi\pi$ *vs* $K_S\pi\pi$	2.9

Bin migration effects of $D^0 \to K^0_{S/L}\pi^+\pi^-$





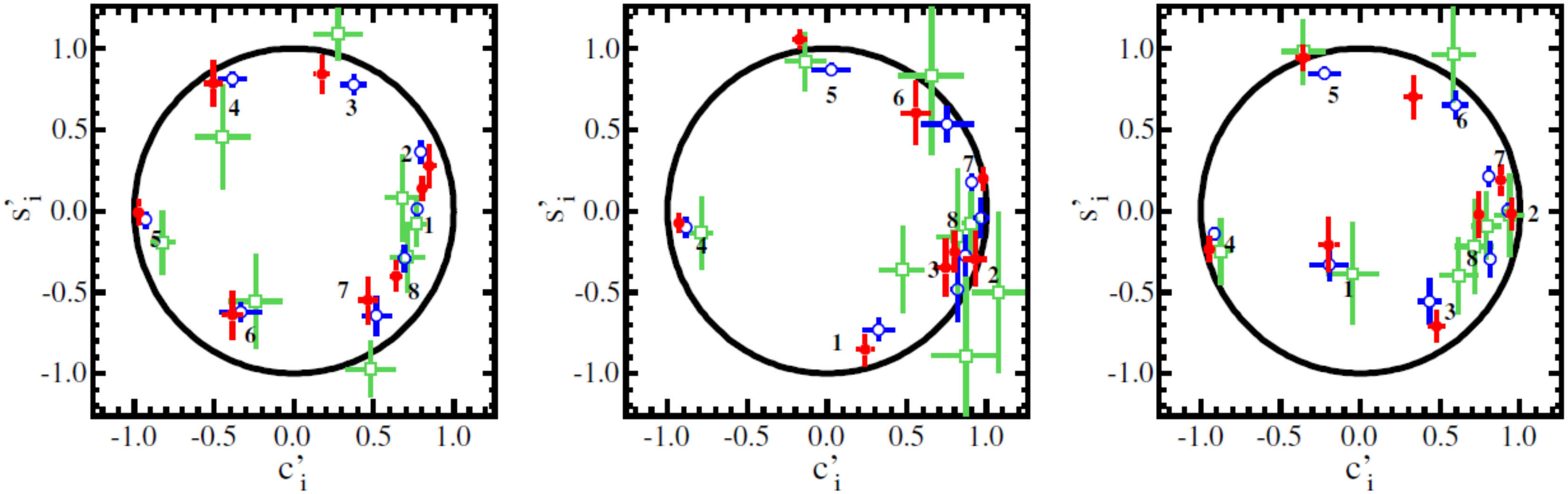
In above tables, the blank places stand for the bin migrations where are less than 0.2%.

- Because of the resolution of data on DP, bin migration effects are considered in fit as the efficiency matrix.

$$N_i^{\exp\prime\pm} = h_{CP\pm}\sum_j^8 \epsilon_{ij}^{CP\prime}(K'_j \mp 2c'_j\sqrt{K'_jK'_{-j}} + K'_{-j}),$$

- Neglecting bin migration leads to $\sim 0.7\sigma_{stat}$ in c_i and $\sim 0.3\sigma_{stat}$ in s_i

Strong-phase parameters c_i' and s_i'



[Equal $\Delta\delta_D$] [optimal] [modified optimal]

Red: this work Blue: expected values Green: CLEO-c results

[Phys. Rev. D 98, 110212(2018)]

- The strong-phase parameters are limited by statistical uncertainty.
- A factor of ~2.8 (2.2) more precise for c_i' (s_i') than previous results.
- **The improved result is important input for γ measurement by $B^- \to D(K_L\pi\pi)K^-$ [GGSZ].**

S-wave of $D_s^+ \to \pi^+\pi^-\pi^+$

Point #	Mass (GeV/c^2)	Amplitude	Phase (radians)
1	0.28	$1.23 \pm 1.34 \pm 1.79$	$-3.59 \pm 1.29 \pm 1.19$
2	0.448	$2.80 \pm 0.55 \pm 0.76$	$-3.82 \pm 0.20 \pm 0.21$
3	0.55	$3.42 \pm 0.54 \pm 0.70$	$-3.87 \pm 0.15 \pm 0.15$
4	0.647	$3.32 \pm 0.46 \pm 0.56$	$-3.74 \pm 0.15 \pm 0.13$
5	0.736	$5.45 \pm 0.49 \pm 0.70$	$-3.38 \pm 0.12 \pm 0.12$
6	0.803	$6.22 \pm 0.55 \pm 0.73$	$-3.10 \pm 0.13 \pm 0.14$
7	0.873	$7.88 \pm 0.46 \pm 0.73$	$-2.60 \pm 0.12 \pm 0.10$
8	0.921	$11.85 \pm 0.57 \pm 0.94$	$-2.16 \pm 0.12 \pm 0.10$
9	0.951	$16.84 \pm 0.80 \pm 0.98$	$-1.77 \pm 0.11 \pm 0.10$
10	0.968	$21.74 \pm 1.05 \pm 1.41$	$-1.21 \pm 0.11 \pm 0.10$
11	0.981	$26.45 \pm 1.23 \pm 1.55$	$-0.58 \pm 0.11 \pm 0.07$
12	0.993	$18.64 \pm 0.89 \pm 0.98$	$-0.25 \pm 0.10 \pm 0.09$
13	1.024	$11.17 \pm 0.55 \pm 0.47$	$0.17 \pm 0.10 \pm 0.11$
14	1.078	$8.00 \pm 0.42 \pm 0.18$	$0.55 \pm 0.10 \pm 0.07$
15	1.135	$6.74 \pm 0.36 \pm 0.25$	$0.98 \pm 0.09 \pm 0.07$
16	1.193	$6.10 \pm 0.32 \pm 0.46$	$1.28 \pm 0.09 \pm 0.03$
17	1.235	$6.63 \pm 0.38 \pm 0.53$	$1.32 \pm 0.10 \pm 0.03$
18	1.267	$6.27 \pm 0.39 \pm 0.43$	$1.56 \pm 0.11 \pm 0.09$
19	1.297	$6.50 \pm 0.42 \pm 0.25$	$1.47 \pm 0.10 \pm 0.06$
20	1.323	$7.50 \pm 0.47 \pm 0.39$	$1.60 \pm 0.10 \pm 0.07$
21	1.35	$7.27 \pm 0.49 \pm 0.69$	$1.75 \pm 0.10 \pm 0.11$
22	1.376	$7.53 \pm 0.51 \pm 0.45$	$1.80 \pm 0.10 \pm 0.13$
23	1.402	$8.49 \pm 0.56 \pm 0.68$	$1.94 \pm 0.10 \pm 0.07$
24	1.427	$8.08 \pm 0.57 \pm 0.57$	$2.09 \pm 0.11 \pm 0.12$
25	1.455	$8.28 \pm 0.63 \pm 0.64$	$2.54 \pm 0.09 \pm 0.09$
26	1.492	$5.82 \pm 0.60 \pm 0.67$	$3.07 \pm 0.10 \pm 0.12$
27	1.557	$1.64 \pm 0.72 \pm 0.89$	$3.05 \pm 0.30 \pm 0.84$
28	1.64	$1.38 \pm 0.57 \pm 1.07$	$7.06 \pm 0.52 \pm 0.98$
29	1.735	$2.09 \pm 0.89 \pm 1.82$	$7.32 \pm 0.51 \pm 1.44$

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

$$A_{S\text{-wave}}(m_{\pi\pi}) = \mathrm{Interp}(c_k(m_{\pi\pi})e^{i\phi_k(m_{\pi\pi})})_{k=1,\ldots,N}$$

Dalitz plot model of $D_s^+ \to \pi^+\pi^-\pi^+$

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

Decay Mode	Decay fraction (%)				
	Fit **1**	Fit **2**	Fit **3**	Fit **4**	Fit **5**
$f_2(1270)\pi^+$	13.2 ± 0.6	12.5 ± 0.7	10.8 ± 0.8	10.5 ± 0.8	10.5 ± 0.7
$\rho(770)\pi^+$	—	1.7 ± 0.5	—	0.9 ± 0.4	0.4 ± 0.2
$\rho(1450)\pi^+$	—	—	2.5 ± 0.5	1.3 ± 0.4	1.4 ± 0.3
$\omega(782)\pi^+$	—	—	—	—	0.3 ± 0.1
$(\mathcal{S}\text{-wave})\pi^+$	87.7 ± 0.4	84.7 ± 0.7	85.7 ± 0.7	84.2 ± 0.8	84.1 ± 0.7
Total	100.9 ± 1.1	98.9 ± 2.0	99.0 ± 2.0	96.8 ± 2.4	96.8 ± 2.0
$-2\ln\mathcal{L}$	40401.2	40348.9	40321.4	40303.2	40276.7
Significance	—	6.9σ [Fit1 + $\rho(770)$]	8.7σ [Fit1 + $\rho(1450)$]	3.9σ [Fit3 + $\rho(770)$]	4.8σ [Fit4 + $\omega(782)$]
χ^2/ν	$\frac{433.0}{404-58} = 1.25$	$\frac{393.6}{404-60} = 1.14$	$\frac{350.0}{404-60} = 1.02$	$\frac{344.4}{404-62} = 1.01$	$\frac{335.2}{404-64} = 0.99$

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