Hadronic Decays of $D^{0(+)}$ and D_s^+ at BESIII

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(On behalf of the BESIII collaboration)

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Outline

- Introduction
  - The BESIII experiment
  - Production near threshold and tag technique
- Hadronic decays of $D_{(s)}$
  - Observation of pure *W*-annihilation decays:
    $D_s^+ \to p\bar{n},\ D_s^+ \to \omega\pi^+,\ D_s^+ \to a_0(980)\pi$
  - Amplitude analysis of $D \to K\pi\pi\pi$:
    $D^0 \to K^-\pi^+\pi^+\pi^-,\ D^0 \to K^-\pi^+\pi^0\pi^0,\ D^+ \to K_s^0\pi^+\pi^+\pi^-$
  - Measurement of the branching fractions(BFs) of
    $D \to PP,\ D_s^+ \to K_{S,L}^0 K^+,\ D^+ \to K_{S,L}^0 K^+(\pi^0)$
    (P= pseudo-scalar)
- Summary

The BESIII Experiment

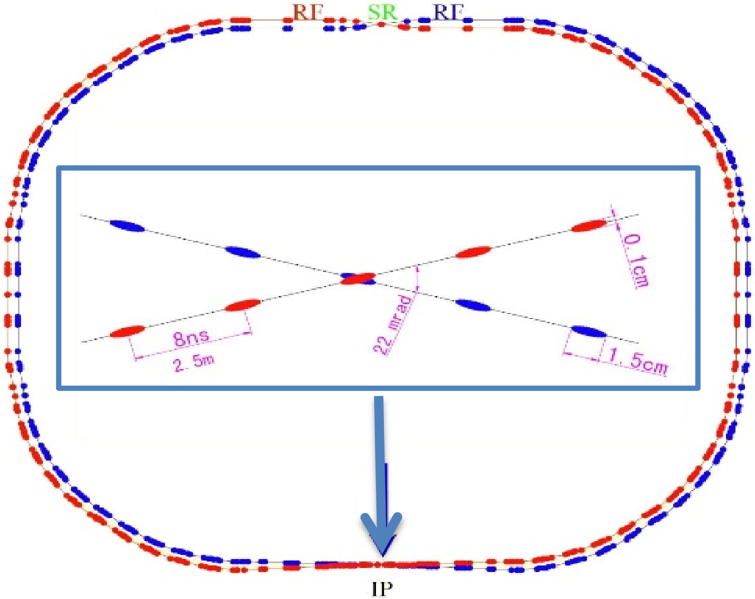
Beijing-Electron-Positron Collider II (BEPCII)

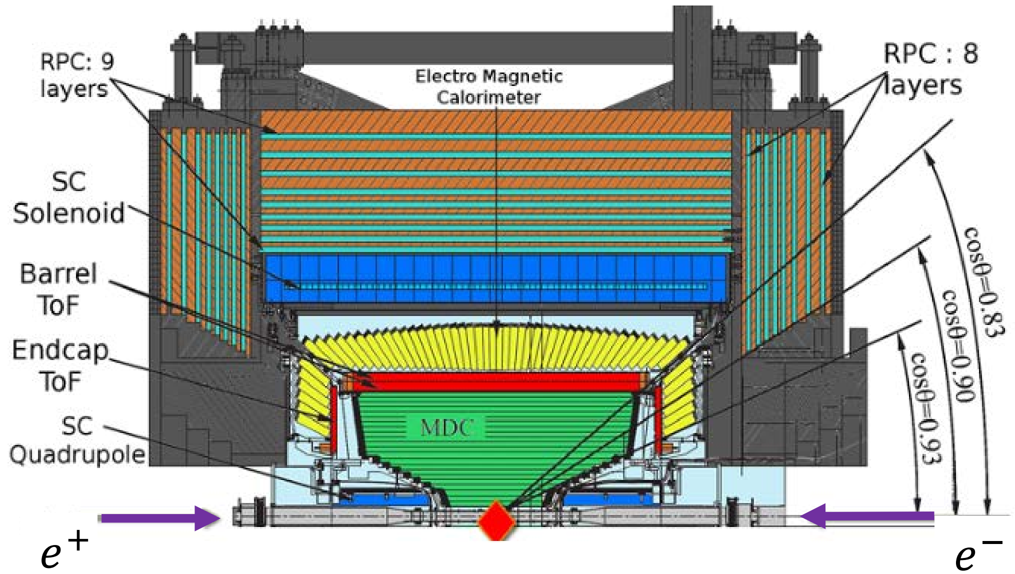
- e^+e^- collisions with $\sqrt{s} = 2.0 - 4.6GeV$
- Direct production of charmonia
- Designed Luminosity

  $\mathcal{L} = 1 \times 10^{33} cm^{-2} s^{-1}$
  was achieved in April 2016.

BESIII detector

- 93% coverage of the full solid angle
- Main drift chamber $\sigma_p/p = 0.5\%@1GeV$
- Time-of-flight system $\sigma_T = 100ps$ in Barrel
- Elmg. Calorimeter $\Delta E/E = 2.5\%@1GeV$
- Superconducting 1T magnet
- Muon system (RPC)





Production near threshold and tag technique

Dataset used in this talk:

- 2.93 fb^{-1} at Ecm = 3.773 GeV (~3.6x larger than CLEO's):
  D are produced via $e^+e^- \to \psi(3770) \to D\bar{D}$
- 3.19 fb^{-1} at Ecm = 4.178 GeV (~5.3x larger than CLEO's):
  D_s are produced mostly via $e^+e^- \to D_s^{\pm}D_s^{*\mp}, D_s^{*\mp} \to \pi^0/\gamma D_s^{\mp}$

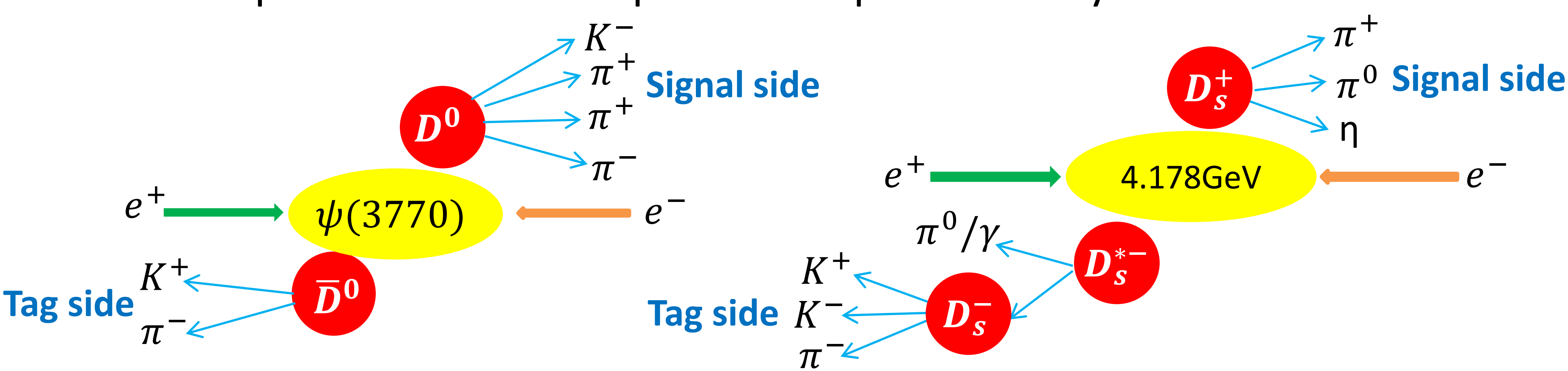
$N_{D^0\bar{D}^0}$ = $(10,597\pm28\pm98)\times10^3$
$N_{D^+D^-}$ = $(8,296\pm31\pm65)\times10^3$
produced

$N_{D_s^*D_s}$ ~ 3M produced

Two ways to study $D_{(s)}$ decays:

- **Single Tag (ST):** reconstruct only one of the $D\bar{D}$ $(D_s^+D_s^-)$
- **Double Tag (DT):** reconstruct both of $D\bar{D}$ $(D_s^+D_s^-)$

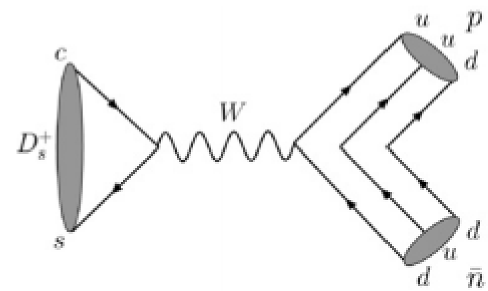
DT provides access to absolute BFs.
DT provides clean samples for amplitude analysis.



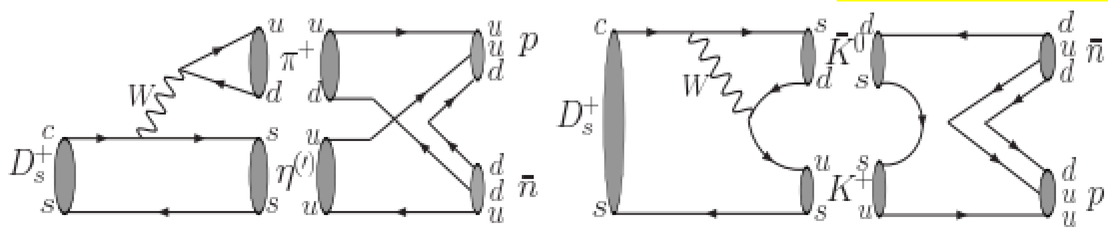
(Charge-conjugate states are implied throughout this talk)

Observation of pure *W*-annihilation decay $D_s^+ \to p\bar{n}$

- $D_s^+ \to p\bar{n}$ is the only baryonic decay of charmed meson and can proceed only through *W*-annihilation process,
  - Short-distance expected: BF~10^{-6}
  - Long-distance enhance to: BF~10^{-3}



C.H. Chen, et al. PLB663(2008)326



The large BF (~10^{-3}) indicates large final state interaction(FSI) effect and is important to understand the dynamical enhancement of *W*-annihilation.

- First evidence was reported by CLEO with a signal of 13.0 ± 3.6 events with $\mathrm{BF} = (1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$ (PRL100, 181802(2008)).

Observation of $D_s^+ \to p\bar{n}$

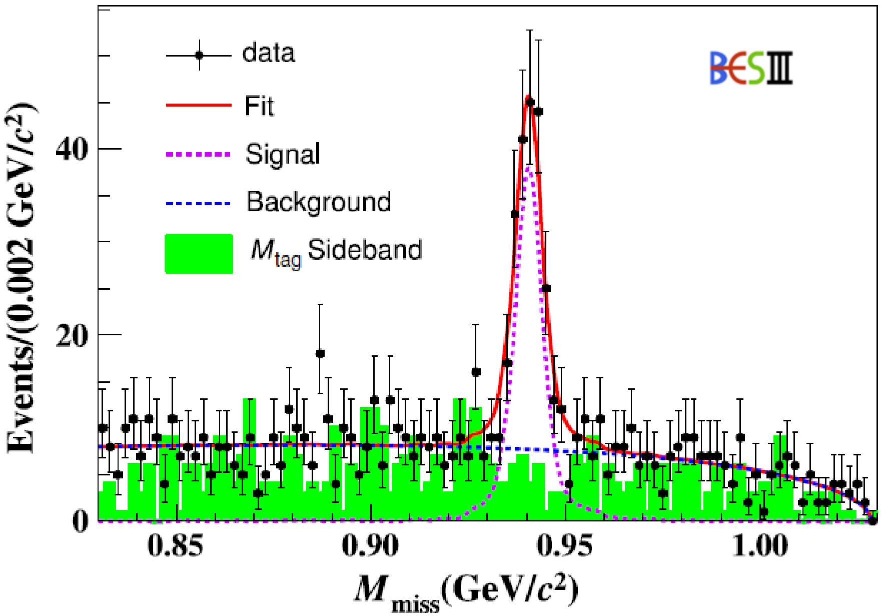
PRD 99, 031101(R) (2019)

Tag modes:

$K_S^0K^-$, $K^-K^+\pi^-$, $K_S^0K^-\pi^0$, $K^-K^+\pi^-\pi^0$, $K_S^0K^+\pi^-\pi^-$, $\pi^-\pi^+\pi^-$, $\pi^-\eta$, $\rho^-\eta$, $\pi^-\eta'$ (with $\eta' \to \pi^+\pi^-\eta$), $\pi^-\eta'$ (with $\eta' \to \gamma\pi^+\pi^-$) and $K^-\pi^+\pi^-$.

Total ST yield ~0.35M

Fit to the mass of missing particle M_{miss} to get the DT yield.



BESIII confirms it is indeed large:

$$BF = (1.21 \pm 0.10 \pm 0.05) \times 10^{-3}$$

- Confirm CLEO's measurement with greatly improved precision.
- Consistent with "long-distance" expectation (PLB663, 326).

Observation of pure *W*-annihilation decays $D_s^+ \to \omega\pi^+$, $D_s^+ \to a_0(980)\pi$

- $D_s^+ \to \omega\pi^+$, $D_s^+ \to a_0(980)\pi$ can proceed only via *W*-annihilation process:
  - factorizable short-distance contribution is helicity suppressed,
  - non-factorizable long-distance contribution induced by FSI dominate,

  which makes the input from experimental measurement to be the unique method to determine the *W*-annihilation amplitude.

- With the measured BF of $D_s^+ \to \omega\pi^+$ as one of the inputs , Q. Qin et al. (PRD89, 054006) predicts:

$\mathcal{B}(D_s^+ \to \omega K^+) = 0.6 \times 10^{-3}, \mathrm{A_{CP}}(D_s^+ \to \omega K^+) = -0.6 \times 10^{-3}$ (without $\rho - \omega$ mixing)

$\mathcal{B}(D_s^+ \to \omega K^+) = 0.07 \times 10^{-3}, \mathrm{A_{CP}}(D_s^+ \to \omega K^+) = -2.3 \times 10^{-3}$ (with $\rho - \omega$ mixing)

Among the largest expected A_{CP} observed in charmed decays

- $D_s^+ \to \omega\pi^+$: Evidence by CLEO, BF= $(2.1 \pm 0.9 \pm 0.1) \times 10^{-3}$ with a signal of 6.0 ± 2.4 events.

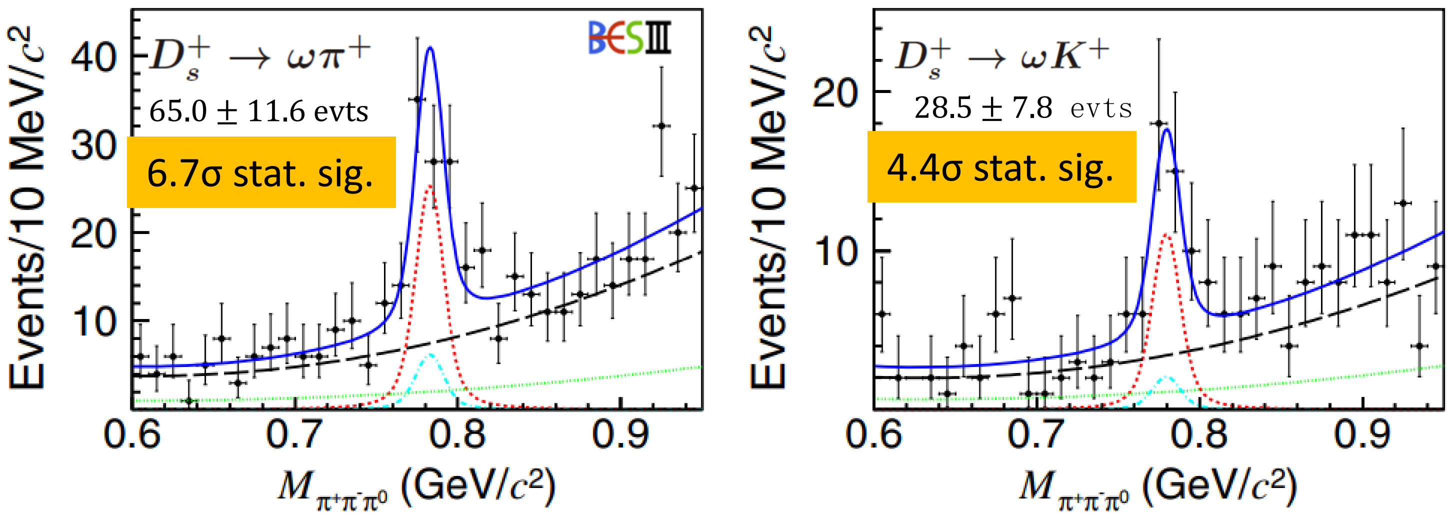
  $D_s^+ \to \omega K^+$: CLEO set an UL = 2.4×10^{-3} @90% C.L. (PRD80, 051102(R) (2009))

Observation of $D_s^+ \to \omega\pi^+$ and $D_s^+ \to \omega K^+$

PRD 99, 091101(R) (2019)

- Tag modes: $D_s^- \to K_S^0 K^-$, $D_s^- \to K^+K^-\pi^-$. Total ST yield ~ 0.167M.
- Double tag: average mass of two D_s mesons closest to the PDG value.

Fit to the invariant mass $M_{\pi^+\pi^-\pi^0}$ to get the DT yield:



Consistent with CLEO's measurement, but more precise.

$$\mathcal{B}(D_s^+ \to \omega\pi^+) = (1.77 \pm 0.32_{\rm stat.} \pm 0.13_{\rm sys.}) \times 10^{-3},$$
$$\mathcal{B}(D_s^+ \to \omega K^+) = (0.87 \pm 0.24_{\rm stat.} \pm 0.08_{\rm sys.}) \times 10^{-3}.$$

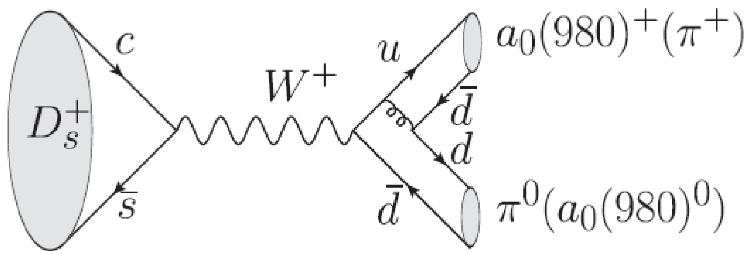
First observation !

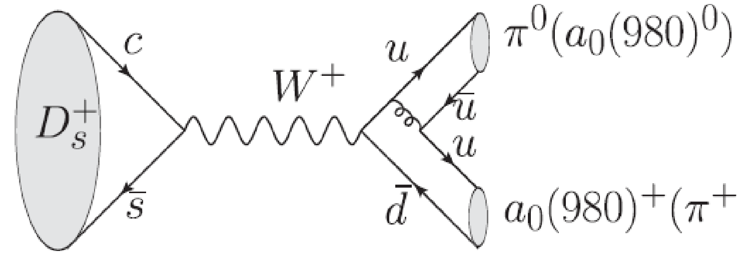
- The measurement of $D_s^+ \to \omega K^+$ implies the $\rho - \omega$ mixing is negligible.

(PRD89, 054006)

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

$D_s^+ \to a_0(980)^{+(0)}\pi^{0(+)}$ **W-annihilation topology diagrams:**





Events are selected with double tag:

- Tag modes:

$$D_s^- \to K_S^0 K^-, D_s^- \to K^+K^-\pi^-, D_s^- \to K_S^0 K^-\pi^0, D_s^- \to K^+K^-\pi^-\pi^0,$$
$$D_s^- \to K_S^0 K^+\pi^-\pi^-, D_s^- \to \pi^-\eta_{\gamma\gamma}, D_s^- \to \pi^-\eta'_{\pi^+\pi^-\eta}$$

- Multi-variate analysis is performed to suppress the background from fake η.

A sample of 1239 events with purity $(97.7 \pm 0.5)\%$ is used to perform the amplitude analysis.

Observation of $D_s^+ \to a_0(980)\pi$

PRL 123, 112001 (2019)

Phases, and fit fractions (FFs) for intermediate processes:

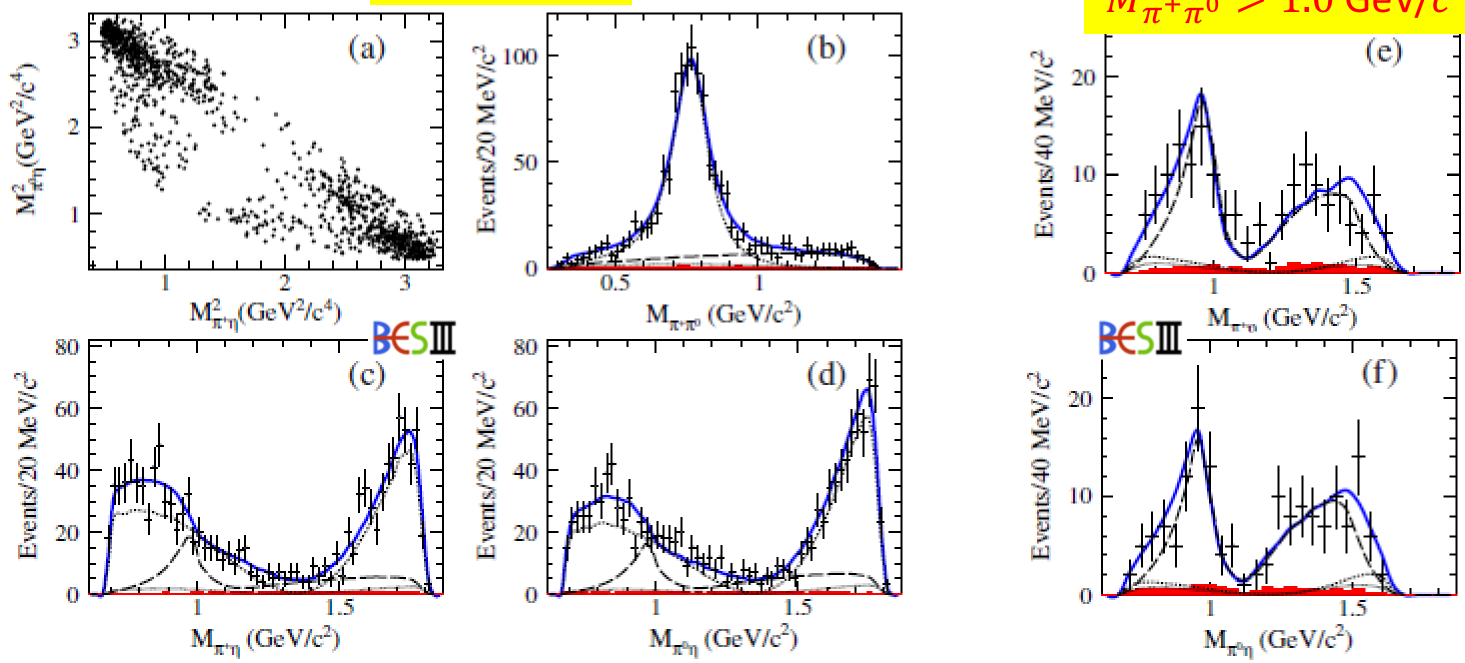
Amplitude	ϕ_n (rad)	FF$_n$
$D_s^+ \to \rho^+\eta$	0.0 (fixed)	$0.783 \pm 0.050 \pm 0.021$
$D_s^+ \to (\pi^+\pi^0)_V\eta$	$0.612 \pm 0.172 \pm 0.342$	$0.054 \pm 0.021 \pm 0.025$
$D_s^+ \to a_0(980)\pi$	$2.794 \pm 0.087 \pm 0.044$	$0.232 \pm 0.023 \pm 0.033$

The amplitudes agree with: $A(D_s^+ \to a_0(980)^+\pi^0) = -A(D_s^+ \to a_0(980)^0\pi^+)$ within stat. uncertainty, thus we set the magnitudes to be the same with the phase difference fixed to π.

Full sample

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

Dalitz plot & Projections:

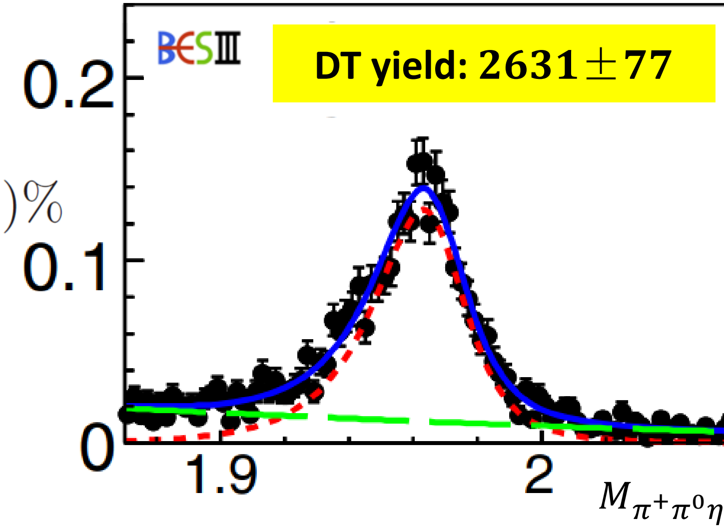


Dots with error bar: data; solid: total fit; dashed: $D_s^+ \to \rho^+\eta$; dotted: $D_s^+ \to (\pi^+\pi^0)_V\eta$; long dashed: $D_s^+ \to a_0(980)\pi$ (**with a stat. significance of 16.2σ**).

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

PRL 123, 112001 (2019)

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



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

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

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

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

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

First observation !

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

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

This provides theoretical challenge in understanding such a large *W*-annihilation contribution in $D \to SP$ (*S*=scalar; *P*=pseudo-scalar).

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

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

  both of them are important in learning the CPV in charm decays but less effective experimental measurements.

- The knowledge of sub-modes can be widely used in many measurements:

  Branching fraction measurement
  Strong phase measurement
  CKM unitary triangle measurement

- There are seven $D \to K\pi\pi\pi$ modes:

  $D^0 \to K^-\pi^+\pi^+\pi^-, K^-\pi^+\pi^0\pi^0, K_S^0\pi^+\pi^-\pi^0, K_S^0\pi^0\pi^0\pi^0$ and $D^+ \to K^-\pi^+\pi^+\pi^0, K_S^0\pi^+\pi^+\pi^-, K_S^0\pi^+\pi^0\pi^0$.

  Previous measurements of sub-modes in $D^0 \to K^-\pi^+\pi^+\pi^-, K_S^0\pi^+\pi^-\pi^0$ and $D^+ \to K^-\pi^+\pi^+\pi^0, K_S^0\pi^+\pi^+\pi^-$ have been perform by Mark III and E691.
  Both measurements are affected by low statistics.

- In this talk, we report the amplitude analysis results of

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

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

PRD95,072010

Double tag: The D^0 is reconstructed by $K^-\pi^+\pi^+\pi^-$ with $\bar{D}^0$ reconstructed by $K^+\pi^-$.

A sample of 15912 events with purity ~99.4% is used to perform the amplitude analysis.

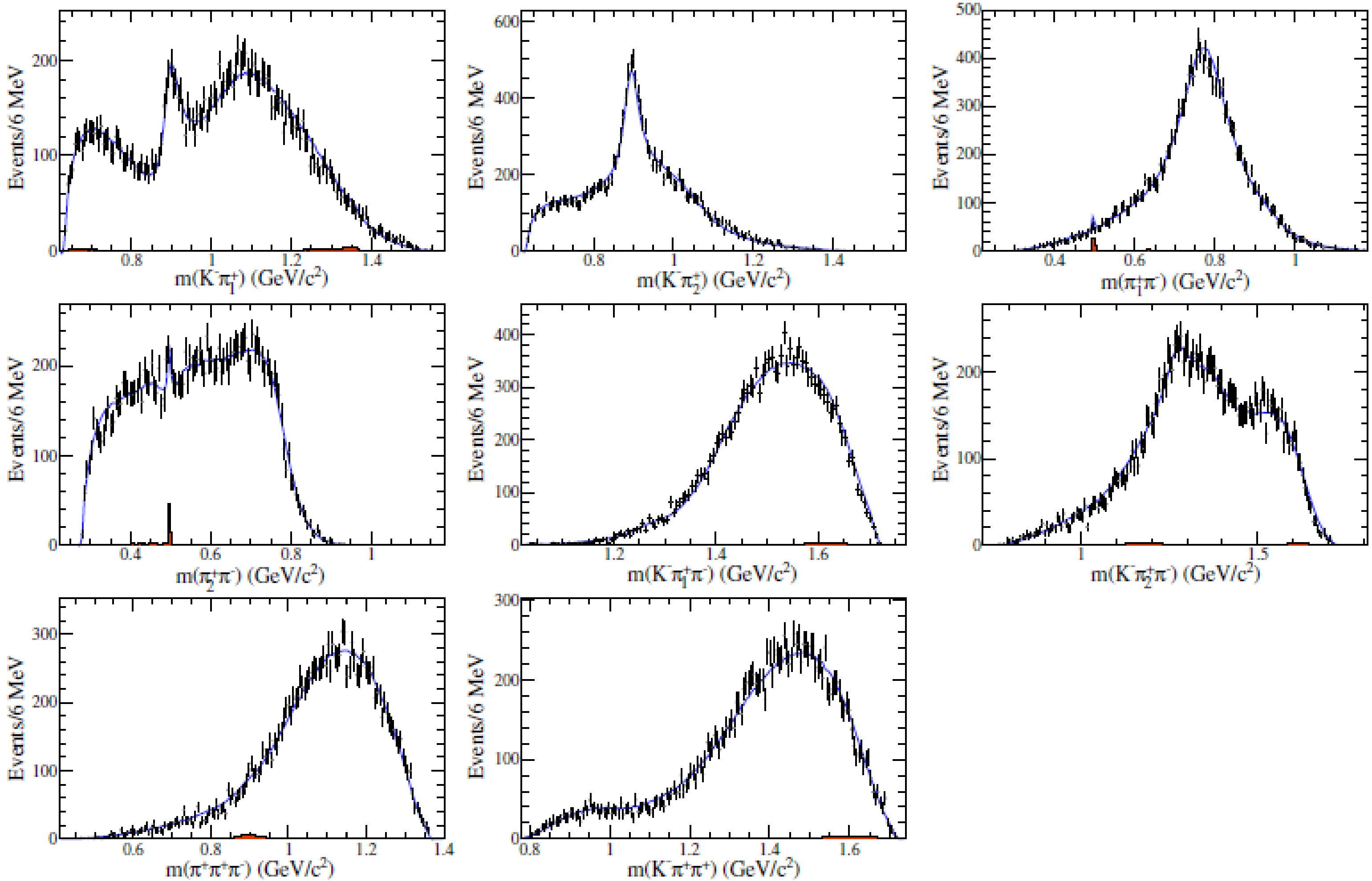
The data can be described with 23 amplitudes:

Amplitude	ϕ_i	Fit fraction (%)
$D^0[S] \to \bar{K}^*\rho^0$	$2.35 \pm 0.06 \pm 0.18$	$6.5 \pm 0.5 \pm 0.8$
$D^0[P] \to \bar{K}^*\rho^0$	$-2.25 \pm 0.08 \pm 0.15$	$2.3 \pm 0.2 \pm 0.1$
$D^0[D] \to \bar{K}^*\rho^0$	$2.49 \pm 0.06 \pm 0.11$	$7.9 \pm 0.4 \pm 0.7$
$D^0 \to K^- a_1^+(1260),\ a_1^+(1260)[S] \to \rho^0\pi^+$	0(fixed)	$53.2 \pm 2.8 \pm 4.0$
$D^0 \to K^- a_1^+(1260),\ a_1^+(1260)[D] \to \rho^0\pi^+$	$-2.11 \pm 0.15 \pm 0.21$	$0.3 \pm 0.1 \pm 0.1$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270)[S] \to \bar{K}^{*0}\pi^-$	$1.48 \pm 0.21 \pm 0.24$	$0.1 \pm 0.1 \pm 0.1$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270)[D] \to \bar{K}^{*0}\pi^-$	$3.00 \pm 0.09 \pm 0.15$	$0.7 \pm 0.2 \pm 0.2$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270) \to K^-\rho^0$	$-2.46 \pm 0.06 \pm 0.21$	$3.4 \pm 0.3 \pm 0.5$
$D^0 \to (\rho^0 K^-)_{\mathrm{A}}\pi^+,\ (\rho^0 K^-)_{\mathrm{A}}[D] \to K^-\rho^0$	$-0.43 \pm 0.09 \pm 0.12$	$1.1 \pm 0.2 \pm 0.3$
$D^0 \to (K^-\rho^0)_{\mathrm{P}}\pi^+$	$-0.14 \pm 0.11 \pm 0.10$	$7.4 \pm 1.6 \pm 5.7$
$D^0 \to (K^-\pi^+)_{\text{S-wave}}\rho^0$	$-2.45 \pm 0.19 \pm 0.47$	$2.0 \pm 0.7 \pm 1.9$
$D^0 \to (K^-\rho^0)_{\mathrm{V}}\pi^+$	$-1.34 \pm 0.12 \pm 0.09$	$0.4 \pm 0.1 \pm 0.1$
$D^0 \to (\bar{K}^{*0}\pi^-)_{\mathrm{P}}\pi^+$	$-2.09 \pm 0.12 \pm 0.22$	$2.4 \pm 0.5 \pm 0.5$
$D^0 \to \bar{K}^{*0}(\pi^+\pi^-)_{\mathrm{S}}$	$-0.17 \pm 0.11 \pm 0.12$	$2.6 \pm 0.6 \pm 0.6$
$D^0 \to (\bar{K}^{*0}\pi^-)_{\mathrm{V}}\pi^+$	$-2.13 \pm 0.10 \pm 0.11$	$0.8 \pm 0.1 \pm 0.1$
$D^0 \to ((K^-\pi^+)_{\text{S-wave}}\pi^-)_{\mathrm{A}}\pi^+$	$-1.36 \pm 0.08 \pm 0.37$	$5.6 \pm 0.9 \pm 2.7$
$D^0 \to K^-((\pi^+\pi^-)_{\mathrm{S}}\pi^+)_{\mathrm{A}}$	$-2.23 \pm 0.08 \pm 0.22$	$13.1 \pm 1.9 \pm 2.2$
$D^0 \to (K^-\pi^+)_{\text{S-wave}}(\pi^+\pi^-)_{\mathrm{S}}$	$-1.40 \pm 0.04 \pm 0.22$	$16.3 \pm 0.5 \pm 0.6$
$D^0[S] \to (K^-\pi^+)_{\mathrm{V}}(\pi^+\pi^-)_{\mathrm{V}}$	$1.59 \pm 0.13 \pm 0.41$	$5.4 \pm 1.2 \pm 1.9$
$D^0 \to (K^-\pi^+)_{\text{S-wave}}(\pi^+\pi^-)_{\mathrm{V}}$	$-0.16 \pm 0.17 \pm 0.43$	$1.9 \pm 0.6 \pm 1.2$
$D^0 \to (K^-\pi^+)_{\mathrm{V}}(\pi^+\pi^-)_{\mathrm{S}}$	$2.58 \pm 0.08 \pm 0.25$	$2.9 \pm 0.5 \pm 1.7$
$D^0 \to (K^-\pi^+)_{\mathrm{T}}(\pi^+\pi^-)_{\mathrm{S}}$	$-2.92 \pm 0.14 \pm 0.12$	$0.3 \pm 0.1 \pm 0.1$
$D^0 \to (K^-\pi^+)_{\text{S-wave}}(\pi^+\pi^-)_{\mathrm{T}}$	$2.45 \pm 0.12 \pm 0.37$	$0.5 \pm 0.1 \pm 0.1$

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

PRD95,072010

Fit projections:



Points with error bars: data, curves: fit, red histograms: background.

For the two identical π^+, we require $\mathrm{m}(\pi_1^+\pi^-) > \mathrm{m}(\pi_2^+\pi^-)$.

Branching Fraction Results of $D^0 \to K^-\pi^+\pi^+\pi^-$

PRD95,072010

Results of branching fractions for different components：

Component	Branching fraction (%)	PDG value (%)
$D^0 \to \bar{K}^{*0}\rho^0$	$0.99 \pm 0.04 \pm 0.04 \pm 0.03$	1.05 ± 0.23
$D^0 \to K^- a_1^+(1260)(\rho^0\pi^+)$	$4.41 \pm 0.22 \pm 0.30 \pm 0.13$	3.6 ± 0.6
$D^0 \to K_1^-(1270)(\bar{K}^{*0}\pi^-)\pi^+$	$0.07 \pm 0.01 \pm 0.02 \pm 0.00$	0.29 ± 0.03
$D^0 \to K_1^-(1270)(K^-\rho^0)\pi^+$	$0.27 \pm 0.02 \pm 0.04 \pm 0.01$	
$D^0 \to K^-\pi^+\rho^0$	$0.68 \pm 0.09 \pm 0.20 \pm 0.02$	0.51 ± 0.23
$D^0 \to \bar{K}^{*0}\pi^+\pi^-$	$0.57 \pm 0.03 \pm 0.04 \pm 0.02$	0.99 ± 0.23
$D^0 \to K^-\pi^+\pi^+\pi^-$	$1.77 \pm 0.05 \pm 0.04 \pm 0.05$	1.88 ± 0.26

stat. uncertainty from FF

sys. uncertainty from FF

uncertainties related to BF($D^0 \to K^-\pi^+\pi^+\pi^-$) in PDG

Macro Gersabeck, Experimental Charm Physics, 2018 Weihai High-Energy Physics School.

- First study of this decay in this millennium
- Paving the way for time-dependent amplitude analysis

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

Double tag: The D^0 is reconstructed by $K^-\pi^+\pi^0\pi^0$ with $\bar{D}^0$ reconstructed by $K^+\pi^-$.

PRD99,092008 (2019)

A sample of 5950 events with purity ~99% is used to perform the amplitude analysis.

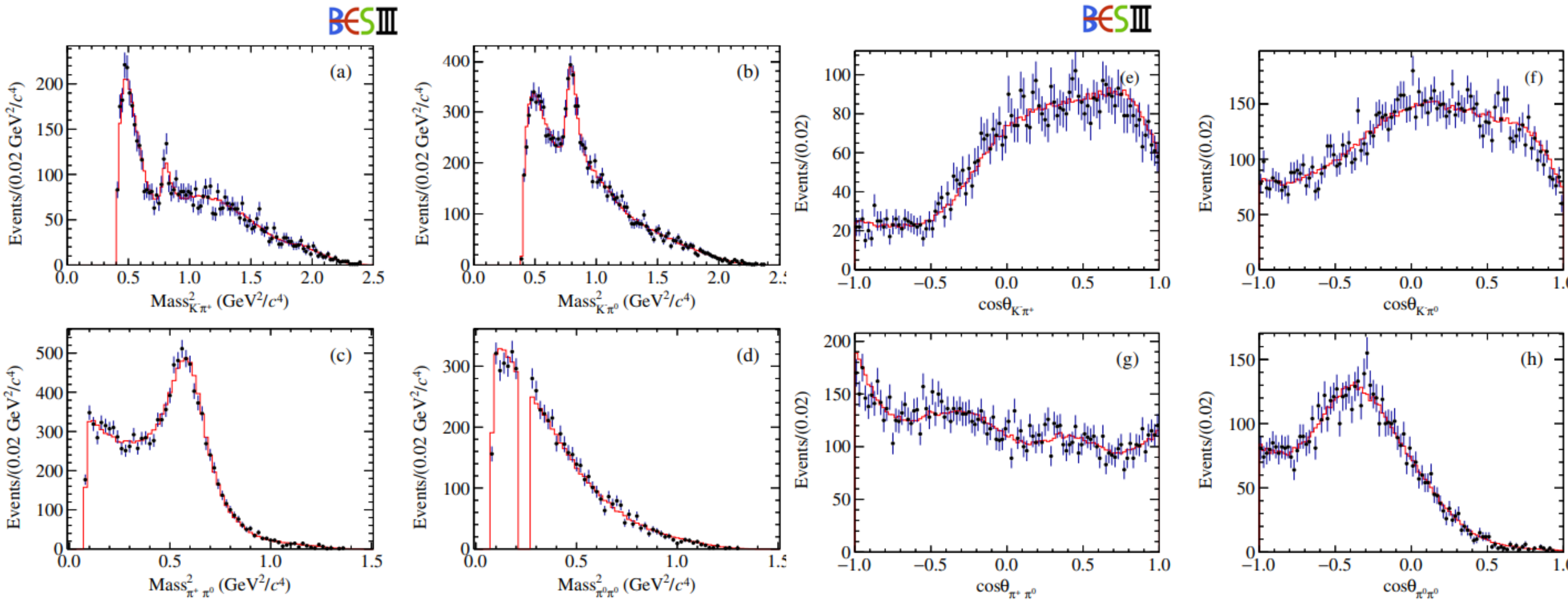
The data can be described with 26 amplitudes:

Amplitude mode	FF(%)	Phase (ϕ)
$D \to SS$		
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_S$	$6.92 \pm 1.44 \pm 2.86$	$-0.75 \pm 0.15 \pm 0.47$
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_S$	$4.18 \pm 1.02 \pm 1.77$	$-2.90 \pm 0.19 \pm 0.47$
$D \to AP, A \to VP$		
$D \to K^-a_1(1260)^+, \rho^+\pi^0[S]$	$28.36 \pm 2.50 \pm 3.53$	0 (fixed)
$D \to K^-a_1(1260)^+, \rho^+\pi^0[D]$	$0.68 \pm 0.29 \pm 0.30$	$-2.05 \pm 0.17 \pm 0.25$
$D \to K_1(1270)^-\pi^+, K^{*-}\pi^0[S]$	$0.15 \pm 0.09 \pm 0.18$	$1.84 \pm 0.34 \pm 0.43$
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[S]$	$0.39 \pm 0.18 \pm 0.30$	$-1.55 \pm 0.20 \pm 0.26$
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[D]$	$0.11 \pm 0.11 \pm 0.13$	$-1.35 \pm 0.43 \pm 0.48$
$D \to K_1(1270)^0\pi^0, K^-\rho^+[S]$	$2.71 \pm 0.38 \pm 0.29$	$-2.07 \pm 0.09 \pm 0.20$
$D \to (K^{*-}\pi^0)_A\pi^+, K^{*-}\pi^0[S]$	$1.85 \pm 0.62 \pm 1.11$	$1.93 \pm 0.10 \pm 0.15$
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[S]$	$3.13 \pm 0.45 \pm 0.58$	$0.44 \pm 0.12 \pm 0.21$
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[D]$	$0.46 \pm 0.17 \pm 0.29$	$-1.84 \pm 0.26 \pm 0.42$
$D \to (\rho^+K^-)_A\pi^0, K^-\rho^+[D]$	$0.75 \pm 0.40 \pm 0.60$	$0.64 \pm 0.36 \pm 0.53$
$D \to AP, A \to SP$		
$D \to ((K^-\pi^+)_{S\text{-wave}}\pi^0)_A\pi^0$	$1.99 \pm 1.08 \pm 1.55$	$-0.02 \pm 0.25 \pm 0.53$
$D \to VS$		
$D \to (K^-\pi^0)_{S\text{-wave}}\rho^+$	$14.63 \pm 1.70 \pm 2.41$	$-2.39 \pm 0.11 \pm 0.35$
$D \to K^{*-}(\pi^+\pi^0)_S$	$0.80 \pm 0.38 \pm 0.26$	$1.59 \pm 0.19 \pm 0.24$
$D \to K^{*0}(\pi^0\pi^0)_S$	$0.12 \pm 0.27 \pm 0.27$	$1.45 \pm 0.48 \pm 0.51$
$D \to VP, V \to VP$		
$D \to (K^{*-}\pi^+)_V\pi^0$	$2.25 \pm 0.43 \pm 0.45$	$0.52 \pm 0.12 \pm 0.17$
$D \to VV$		
$D[S] \to K^{*-}\rho^+$	$5.15 \pm 0.75 \pm 1.28$	$1.24 \pm 0.11 \pm 0.23$
$D[P] \to K^{*-}\rho^+$	$3.25 \pm 0.55 \pm 0.41$	$-2.89 \pm 0.10 \pm 0.18$
$D[D] \to K^{*-}\rho^+$	$10.90 \pm 1.53 \pm 2.36$	$2.41 \pm 0.08 \pm 0.16$
$D[P] \to (K^-\pi^0)_V\rho^+$	$0.36 \pm 0.19 \pm 0.27$	$-0.94 \pm 0.19 \pm 0.28$
$D[D] \to (K^-\pi^0)_V\rho^+$	$2.13 \pm 0.56 \pm 0.92$	$-1.93 \pm 0.22 \pm 0.25$
$D[D] \to K^{*-}(\pi^+\pi^0)_V$	$1.66 \pm 0.52 \pm 0.61$	$-1.17 \pm 0.20 \pm 0.39$
$D[S] \to (K^-\pi^0)_V(\pi^+\pi^0)_V$	$5.17 \pm 1.91 \pm 1.82$	$-1.74 \pm 0.20 \pm 0.31$
$D \to TS$		
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_T$	$0.30 \pm 0.21 \pm 0.32$	$-2.93 \pm 0.31 \pm 0.82$
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_T$	$0.14 \pm 0.12 \pm 0.10$	$2.23 \pm 0.38 \pm 0.65$

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

PRD99,092008 (2019)

Fit projections:



Points with error bars: data, red histograms: fit.

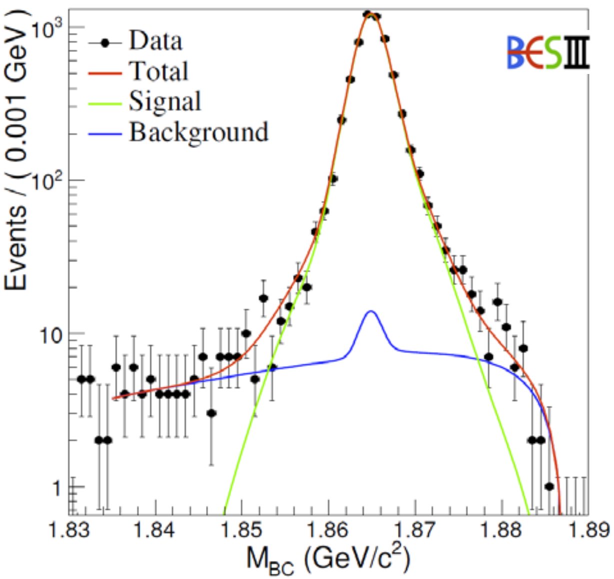
Branching Fraction Results of $D^0 \to K^-\pi^+\pi^0\pi^0$

PRD99,092008 (2019)

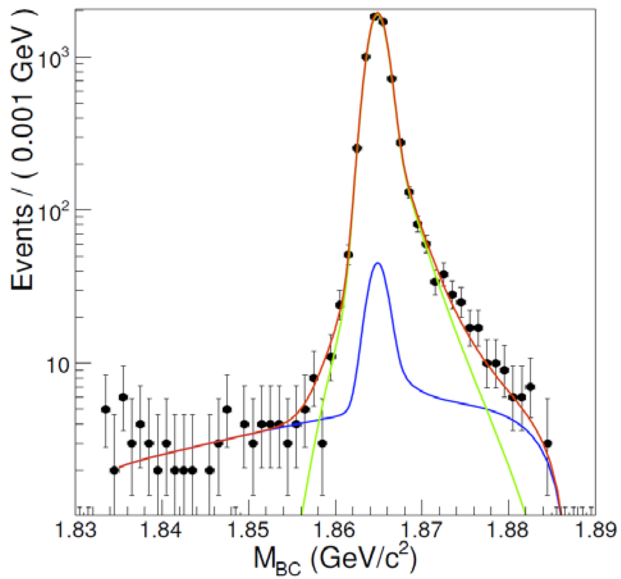
Fits to M_{BC} distributions of DT and ST data：

Beam-Constrained Mass: $M_{\mathrm{BC}} = \sqrt{E_{\mathrm{beam}}^2 - |\vec{p}_D|^2}$

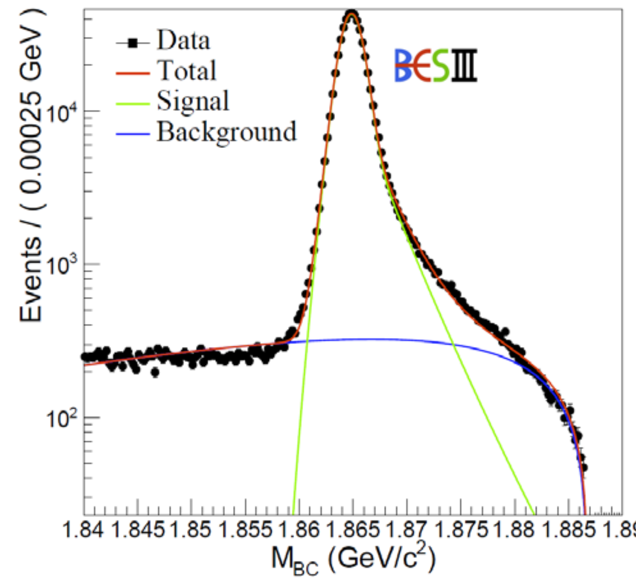
Signal: M_{BC} peaks at D mass



DT $(K^-\pi^+\pi^0\pi^0)$



DT $(K^+\pi^-)$



ST

DT yield = 6101 ± 83 ; ST yield = 534581 ± 769 .

The amplitude analysis result is used to determine the detection efficiency.

$$\mathcal{B}(D^0 \to K^-\pi^+\pi^0\pi^0) = (8.86 \pm 0.13(\mathrm{stat}) \pm 0.19(\mathrm{syst}))\%$$

First measurement

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

PRD100,072008 (2019)

Double tag: The D^+ is reconstructed by $K_S^0\pi^+\pi^+\pi^-$ with D^- reconstructed by $K^+\pi^-\pi^-$.

A sample of 4559 events with purity ~97.5% is used to perform the amplitude analysis.

The data can be described with 12 amplitudes:

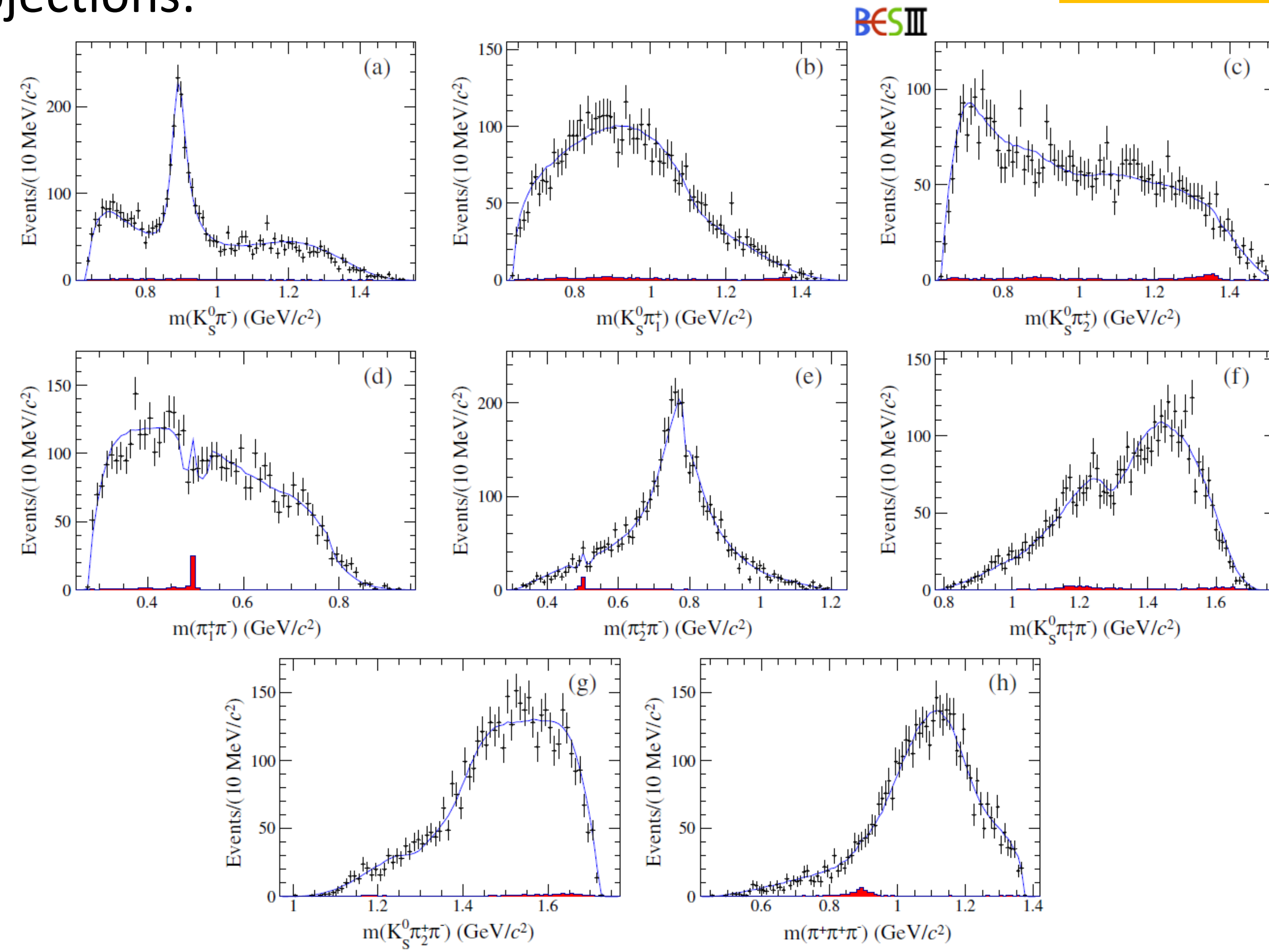
BESIII

Amplitude	ϕ	Fit fraction
$D^+ \to K_S^0 a_1(1260)^+, a_1(1260)^+ \to \rho^0\pi^+[S]$	0.000(fixed)	$0.567 \pm 0.020 \pm 0.044$
$D^+ \to K_S^0 a_1(1260)^+, a_1(1260)^+ \to f_0(500)\pi^+$	$-2.023 \pm 0.068 \pm 0.113$	$0.050 \pm 0.006 \pm 0.007$
$D^+ \to \bar{K}_1(1400)^0\pi^+, \bar{K}_1(1400)^0 \to K^{*-}\pi^+[S]$	$-2.714 \pm 0.038 \pm 0.051$	$0.380 \pm 0.013 \pm 0.014$
$D^+ \to \bar{K}_1(1400)^0\pi^+, \bar{K}_1(1400)^0 \to K^{*-}\pi^+[D]$	$3.431 \pm 0.137 \pm 0.117$	$0.015 \pm 0.004 \pm 0.005$
$D^+ \to \bar{K}_1(1270)^0\pi^+, \bar{K}_1(1270)^0 \to K_S^0\rho^0[S]$	$-0.418 \pm 0.070 \pm 0.087$	$0.036 \pm 0.004 \pm 0.002$
$D^+ \to \bar{K}(1460)^0\pi^+, \bar{K}(1460)^0 \to K_S^0\rho^0$	$-1.850 \pm 0.120 \pm 0.223$	$0.014 \pm 0.004 \pm 0.003$
$D^+ \to (K_S^0\rho^0)_A[D]\pi^+$	$2.328 \pm 0.097 \pm 0.068$	$0.011 \pm 0.003 \pm 0.002$
$D^+ \to K_S^0(\rho^0\pi^+)_P$	$1.656 \pm 0.083 \pm 0.056$	$0.031 \pm 0.004 \pm 0.010$
$D^+ \to (K^{*-}\pi^+)_A[S]\pi^+$	$1.962 \pm 0.047 \pm 0.073$	$0.132 \pm 0.011 \pm 0.011$
$D^+ \to (K^{*-}\pi^+)_A[D]\pi^+$	$0.989 \pm 0.158 \pm 0.229$	$0.013 \pm 0.004 \pm 0.004$
$D^+ \to (K_S^0(\pi^+\pi^-)_S)_A\pi^+$	$-2.935 \pm 0.060 \pm 0.125$	$0.051 \pm 0.004 \pm 0.003$
$D^+ \to ((K_S^0\pi^-)_S\pi^+)_P\pi^+$	$1.864 \pm 0.069 \pm 0.288$	$0.022 \pm 0.003 \pm 0.003$

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

PRD100,072008 (2019)

Fit projections:



Points with error bars: data, red histograms: fit, green histograms: background estimated from MC.

For the two identical π^+, we require $\mathrm{m}(\pi_1^+\pi^-) < \mathrm{m}(\pi_2^+\pi^-)$.

Branching fraction results of $D^+ \to K_S^0\pi^+\pi^+\pi^-$

PRD100,072008 (2019)

The preliminary results of branching fractions for different components：

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

stat. uncertainty from FF

sys. uncertainty from FF

uncertainties related to BF($D^+ \to K_S^0\pi^+\pi^+\pi^-$) in PDG

- The measurements of the decays with $K_1(1270)$ and $K_1(1400)$ involved provide some experimental information in understanding the mixture of the two excited Kaons.

PLB707,116

- $\boldsymbol{D^+ \to \bar{K}_1(1400)^0\pi^+}$ is found to be larger, unlike what we saw in the two D^0 cases.

Measurement of the Branching Fractions of $D \to PP$

- The analysis of $D \to PP$ modes provides materials for the study of SU(3) breaking effect.
- Most of the $D \to PP$ decays have been studied by CLEO in 2010 , other measurements come from Belle , BABAR and CDF , etc.

Branching fraction results of $D \rightarrow PP$

PRD97,072004

BFs of $D \rightarrow PP$ are obtained using ST method:

Mode	$\mathcal{B}$ $(\times 10^{-3})$	$\mathcal{B}_{\mathrm{PDG}}$ $(\times 10^{-3})$
$D^+ \rightarrow \pi^+\pi^0$	$1.259 \pm 0.033 \pm 0.023$	1.24 ± 0.06
$D^+ \rightarrow K^+\pi^0$	$0.232 \pm 0.021 \pm 0.006$	0.189 ± 0.025
$D^+ \rightarrow \pi^+\eta$	$3.790 \pm 0.070 \pm 0.068$	3.66 ± 0.22
$D^+ \rightarrow K^+\eta$	$0.151 \pm 0.025 \pm 0.014$	0.112 ± 0.018
$D^+ \rightarrow \pi^+\eta'$	$5.12 \pm 0.14 \pm 0.024$	4.84 ± 0.31
$D^+ \rightarrow K^+\eta'$	$0.164 \pm 0.051 \pm 0.024$	0.183 ± 0.023
$D^+ \rightarrow K_S^0\pi^+$	$15.91 \pm 0.06 \pm 0.30$	15.3 ± 0.6
$D^+ \rightarrow K_S^0K^+$	$3.183 \pm 0.029 \pm 0.060$	2.95 ± 0.15
$D^0 \rightarrow \pi^+\pi^-$	$1.508 \pm 0.018 \pm 0.022$	1.421 ± 0.025
$D^0 \rightarrow K^+K^-$	$4.233 \pm 0.021 \pm 0.064$	4.01 ± 0.07
$D^0 \rightarrow K^\mp\pi^\pm$	$38.98 \pm 0.06 \pm 0.51$	39.4 ± 0.4
$D^0 \rightarrow K_S^0\pi^0$	$12.39 \pm 0.06 \pm 0.27$	12.0 ± 0.4
$D^0 \rightarrow K_S^0\eta$	$5.13 \pm 0.07 \pm 0.12$	4.85 ± 0.30
$D^0 \rightarrow K_S^0\eta'$	$9.49 \pm 0.20 \pm 0.36$	9.5 ± 0.5

- The results from BESIII are consistent with the world average values within uncertainties. The BFs of $D^+ \rightarrow \pi^+\pi^0, K^+\pi^0, \pi^+\eta, \pi^+\eta', K_S^0\pi^+, K_S^0K^+$ and $D^0 \rightarrow K_S^0\pi^0, K_S^0\eta, K_S^0\eta'$ are determined with improved precision.

$D_s^+ \to K_S^0 K^+$ and $K_L^0 K^+$

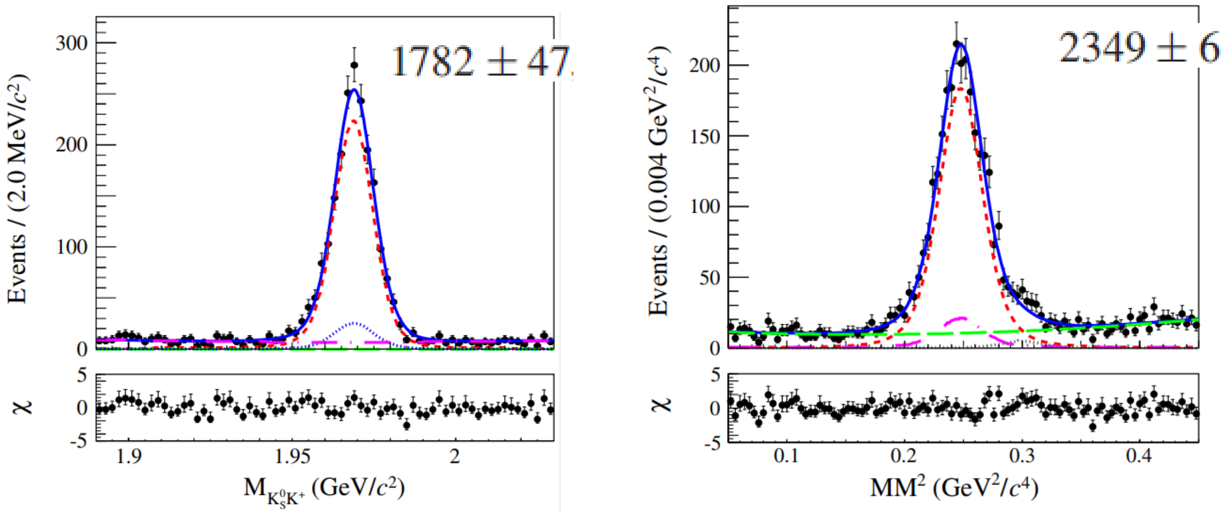
PRD99,112005 (2019)

As in $D \to K^0\pi$ and $D \to \bar{K}^0\pi$ could interfere,

So can the CF and DCS amplitudes in Ds decays: $D_s^+ \to K_S^0 K^+$ and $K_L^0 K^+$

Such interferences effect could also lead to CPV:

$A_{CP} \sim 10^{-3}$, predicted by F.S. Yu et al. (PRL 119, 181802(2017)).



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

$\mathcal{B}(D_s^+ \to K_L^0 K^+) = (1.485 \pm 0.039_{\text{stat.}} \pm 0.046_{\text{syst.}})\%$ 1st measurement

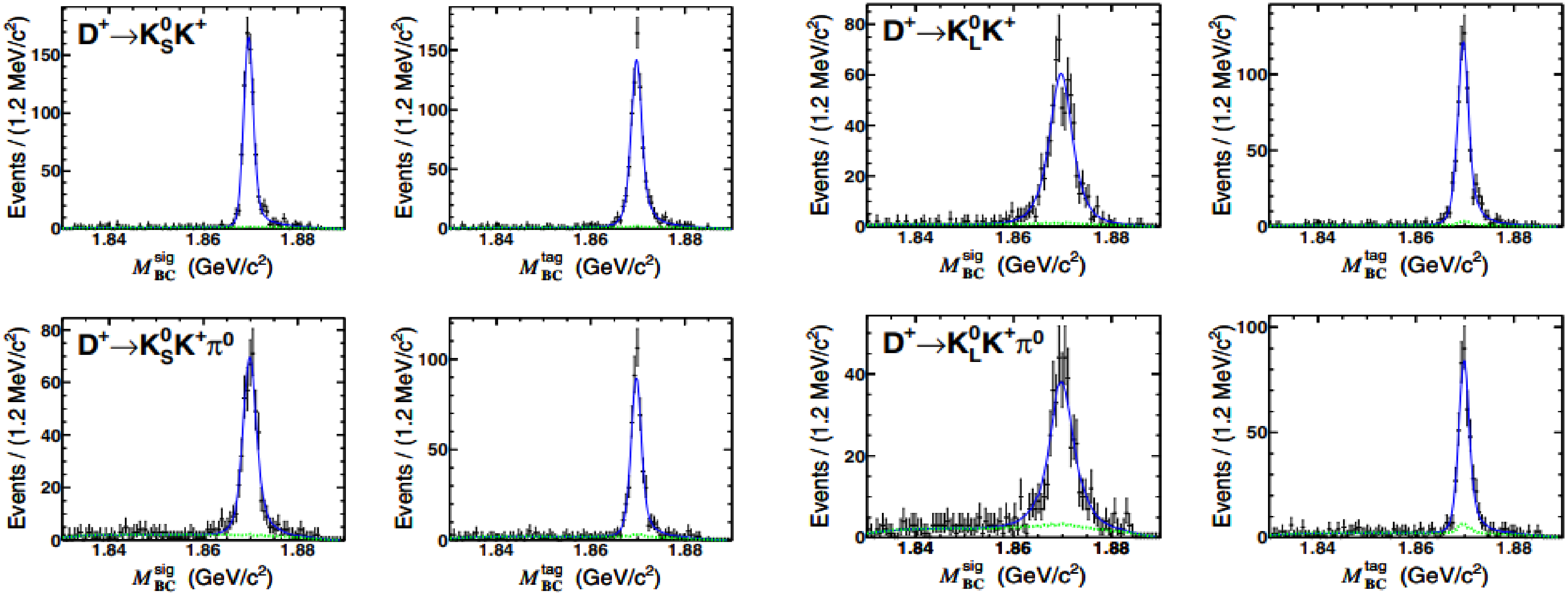
K_S^0-K_L^0 asymmetry $\dfrac{\mathcal{B}(D \to K_S^0 K) - \mathcal{B}(D \to K_L^0 K)}{\mathcal{B}(D \to K_S^0 K) + \mathcal{B}(D \to K_L^0 K)} = (-2.1 \pm 1.9 \pm 1.6)\%.$

$A_{CP}(D_s^\pm \to K_S^0 K^\pm) = (0.6 \pm 2.8 \pm 0.6)\%$ and $A_{CP}(D_s^\pm \to K_L^0 K^\pm) = (-1.1 \pm 2.6 \pm 0.6)\%$

$D^+ \to K_S^0 K^+$, $K_S^0 K^+ \pi^0$, $K_L^0 K^+$ and $K_L^0 K^+ \pi^0$

PRD99,032002 (2019)

As looked for similar final states, but in D^+ decays,
So added an additional π^0 .



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

1st measurements!

Summary

BESIII provides large data samples close to charm related threshold to study the $D_{(s)}$ hadronic decays:

- Observation of pure *W*-annihilation decays $D_s^+ \to p\bar{n}, D_s^+ \to \omega\pi^+, D_s^+ \to a_0(980)\pi$
  - Our results on $D_s^+ \to p\bar{n}, D_s^+ \to \omega\pi^+$ confirm CLEO's measurements with greatly improved precision.
  - Our results on $D_s^+ \to a_0(980)\pi$ are larger than other measured pure *W*-annihilation decays ($D_s^+ \to p\bar{n}, D_s^+ \to \omega\pi^+$) by one order.
- Amplitude analysis of $D \to K\pi\pi\pi$:
  - Amplitudes analyses of $D^0 \to K^-\pi^+\pi^+\pi^-$, $D^0 \to K^-\pi^+\pi^0\pi^0, D^+ \to K_S^0\pi^+\pi^+\pi^-$ are performed.

$$\mathcal{B}(D^0 \to K^-\pi^+\pi^0\pi^0) = (8.86 \pm 0.13(\text{stat}) \pm 0.19(\text{syst}))\%$$

- Branching fractions of $D \to PP$:

  The BFs of 14 decay modes, $D_s^+ \to K_{S,L}^0 K^+$ and $D^+ \to K_{S,L}^0 K^+(\pi^0)$ are obtained.

More measurements in $D_{(s)}$ hadronic decays are coming.

Thank you for your attention!