BESIII上粲介子强子衰变分支比测量

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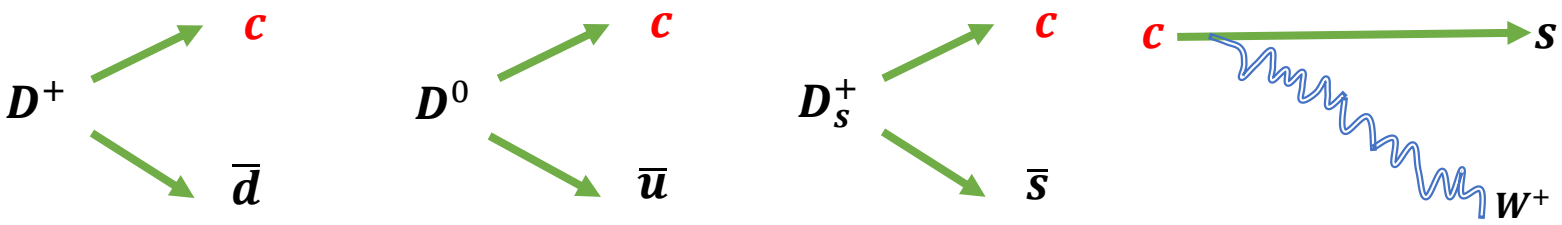
2024年 BESIII 粲强子物理研讨会

Outline

- Introduction
- BESIII charm dataset
- D_s meson hadronic decays
- D meson hadronic decays
- Summary & Outlook

Charm hadronic physics

The lightest charmed hadrons(D^+, D^0, D_s^+):



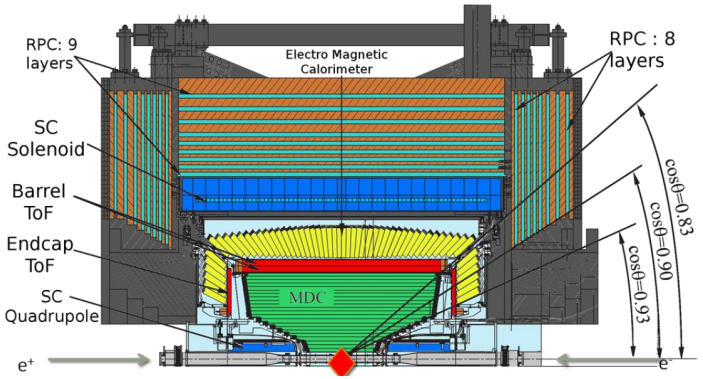
- Probe the weak decay mechanisms
- Understand SU(3) flavor symmetry and its breaking effect
- Explore CP violation effect
- Probe non-perturbative QCD in the low energy region
- As important inputs for the B physics
- Test theoretical calculations of BFs or decay asymmetry parameters

BESIII charm dataset

D : ~20fb^{-1} @E_{cm}=3.773 GeV.

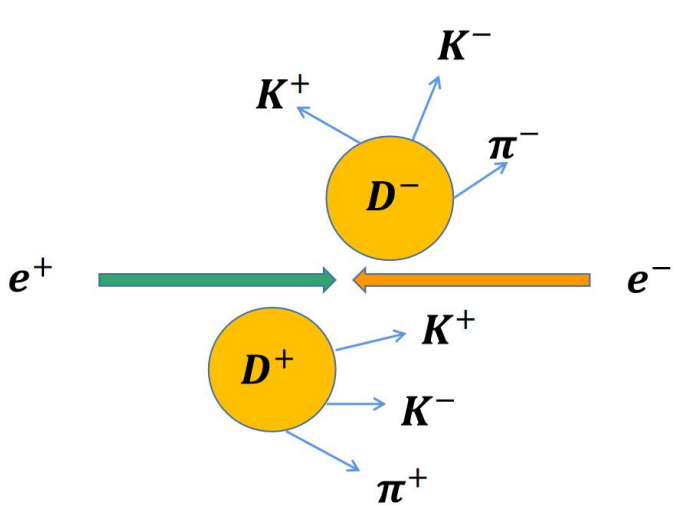
2.93fb^{-1}. Collected in 2010-2011.

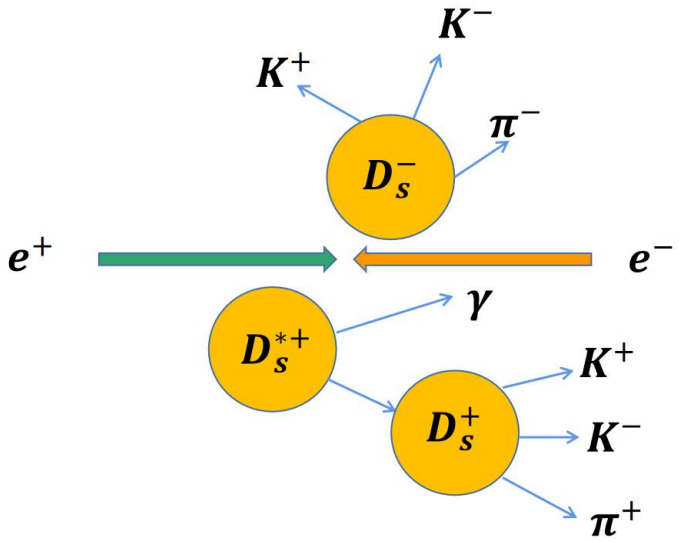
~17fb^{-1}. Collected in 2021-2024.



D_s: 7.33fb^{-1} @E_{cm}=4.128 − 4.226GeV. Collected in 2013-2017.

Double Tag (DT): reconstruct both of the hadrons.





access to absolute BFs; clean samples

D_s meson hadronic decays

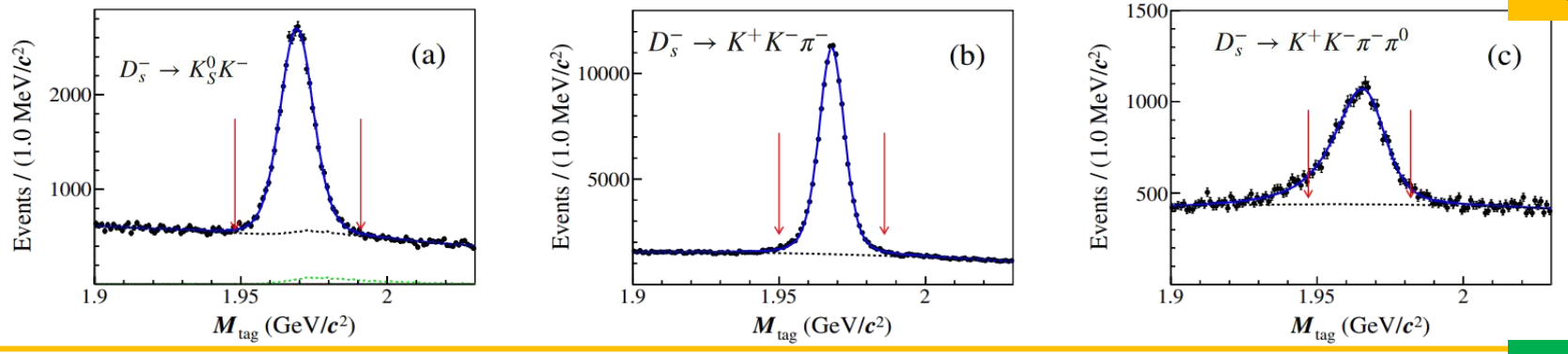
$D_s^+ \to \omega\pi^+\eta$

Phys. Rev. D
107, 052010 (2023)

Method: Double Tag
Data: 7.33 fb^{-1} 4.128 - 4.226 GeV

--the first observation and the BF measurement

tag



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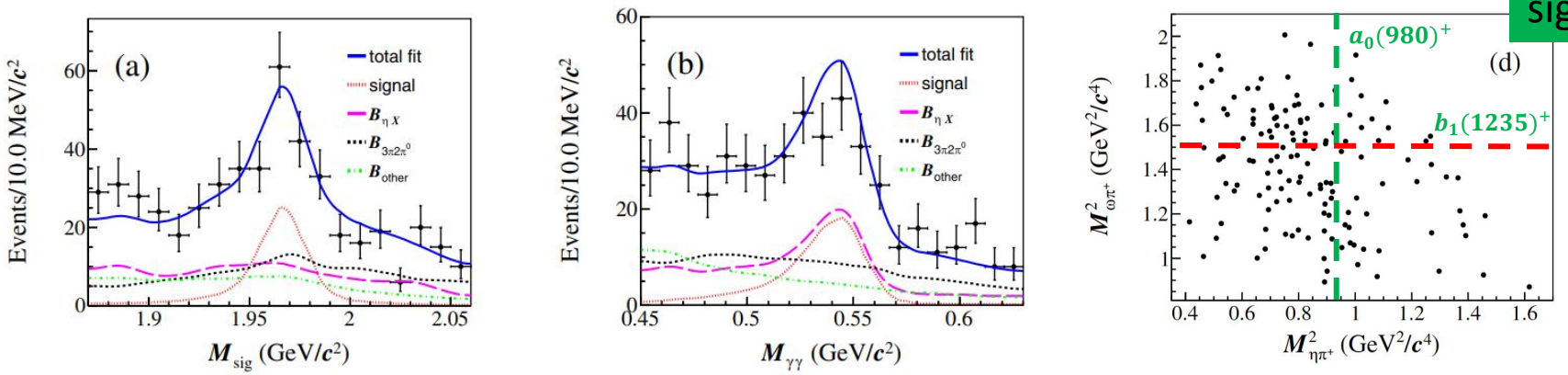


78±16 signal events with a statistical significance of 7.6σ.

$$\mathcal{B}(D_s^+ \to \omega\pi^+\eta) = (0.54 \pm 0.12 \pm 0.04)\%$$

$D_s^+ \to K^+K^+\pi^-(\pi^0)$

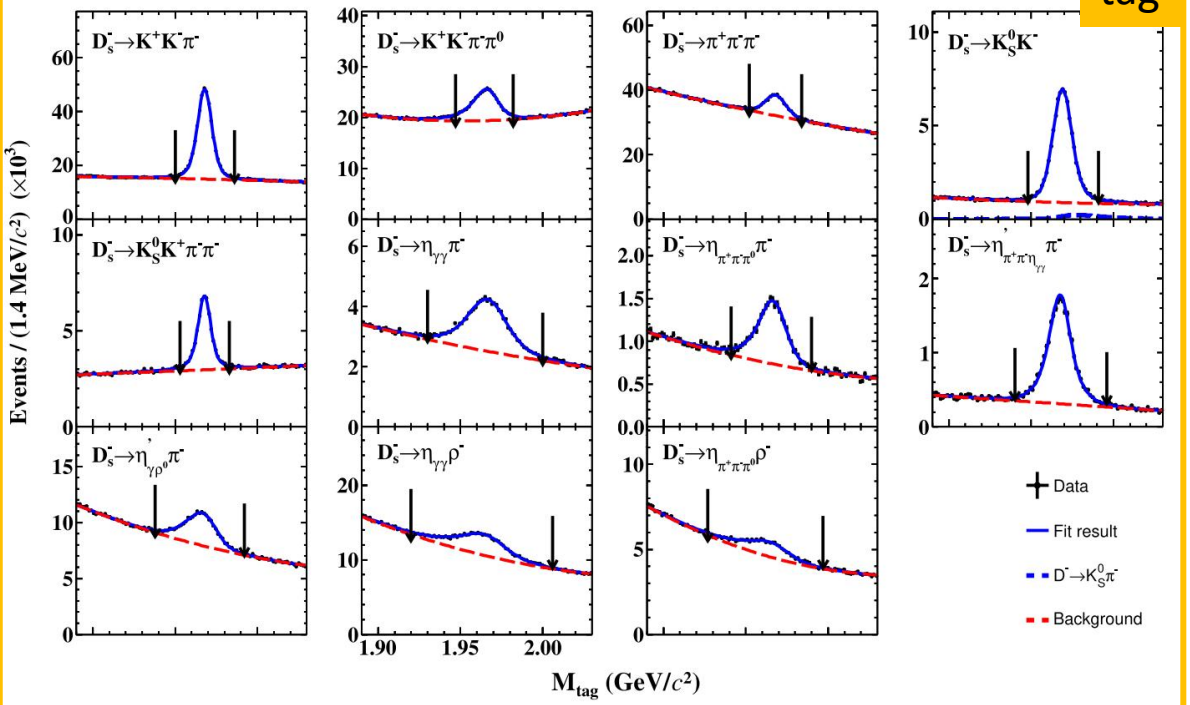
Phys. Rev. D
109, 032011 (2024)

Method: Double Tag

Data: 7.33 fb^{-1} 4.128 - 4.226 GeV

--Doubly Cabibbo-suppressed (DCS) decays

tag



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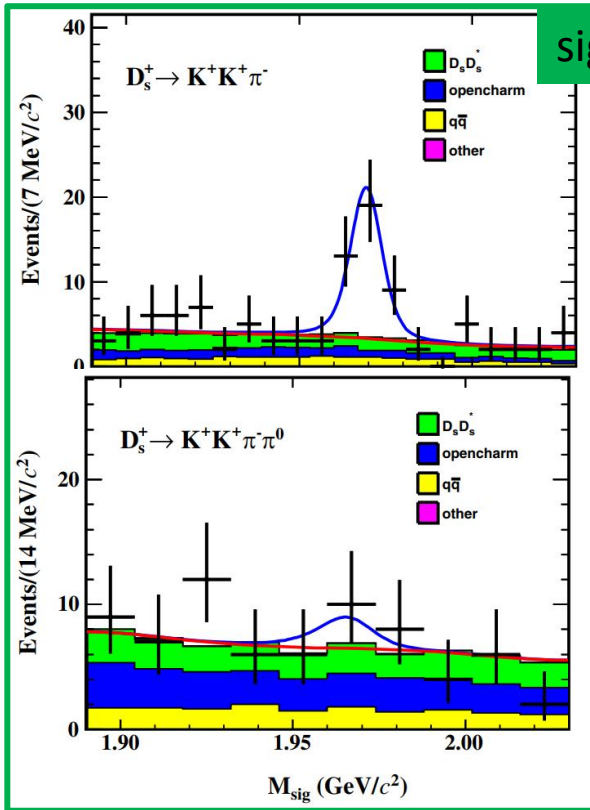


DCS decay	$\mathcal{B}_{\rm DCS}^{\rm this\ work}$ ($\times 10^{-4}$)	CF decay	$\mathcal{B}_{\rm CF}^{\rm PDG}$ ($\times 10^{-2}$)	$\mathcal{B}_{\rm DCS}^{\rm this\ work}/\mathcal{B}_{\rm CF}^{\rm PDG}$ ($\times 10^{-3}$)	$\times \tan^4\theta_C$
$D_s^+ \to K^+K^+\pi^-$	$1.24^{+0.28}_{-0.26} \pm 0.06$	$D_s^+ \to K^+K^-\pi^+$	5.37 ± 0.10	$2.31^{+0.52}_{-0.48}$	$0.80^{+0.18}_{-0.16}$
$D_s^+ \to K^+K^+\pi^-\pi^0$	< 1.7	$D_s^+ \to K^+K^-\pi^+\pi^0$	5.50 ± 0.24	< 3.09	< 1.07

$D_s^+ \to K^+K^+\pi^-$: $33.3^{+7.6}_{-6.9}$ signal events, $D_s^+ \to K^+K^+\pi^-\pi^0$: No significant signal.

$D_s^{*+} \to D_s^+\pi^0 / D_s^{*+} \to D_s^+\gamma$

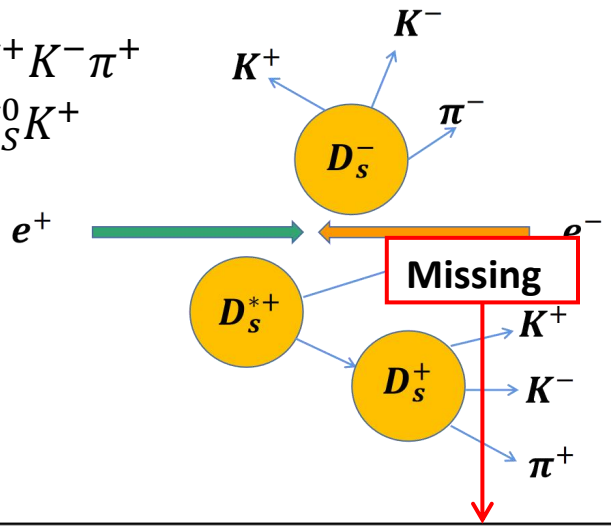
Phys. Rev. D
107, 032011 (2023)

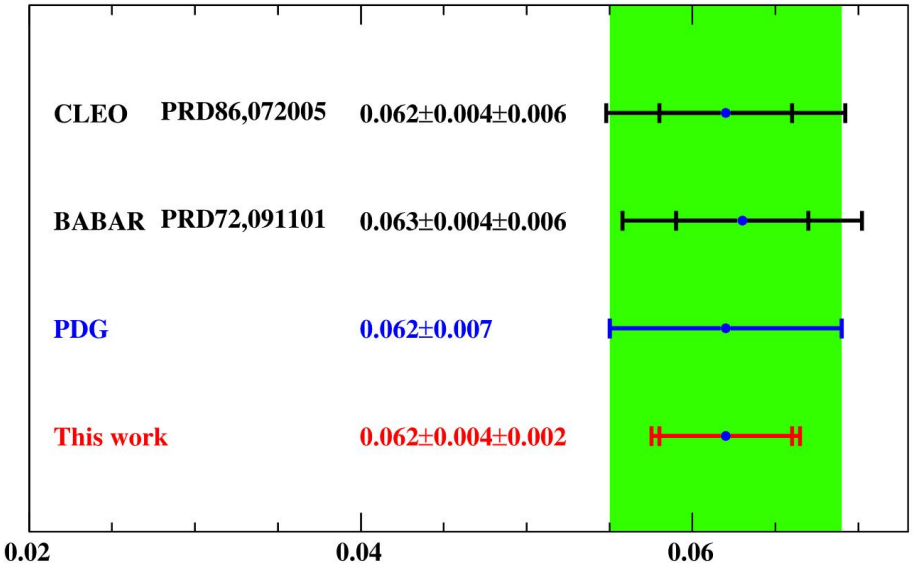
Method: Double Tag

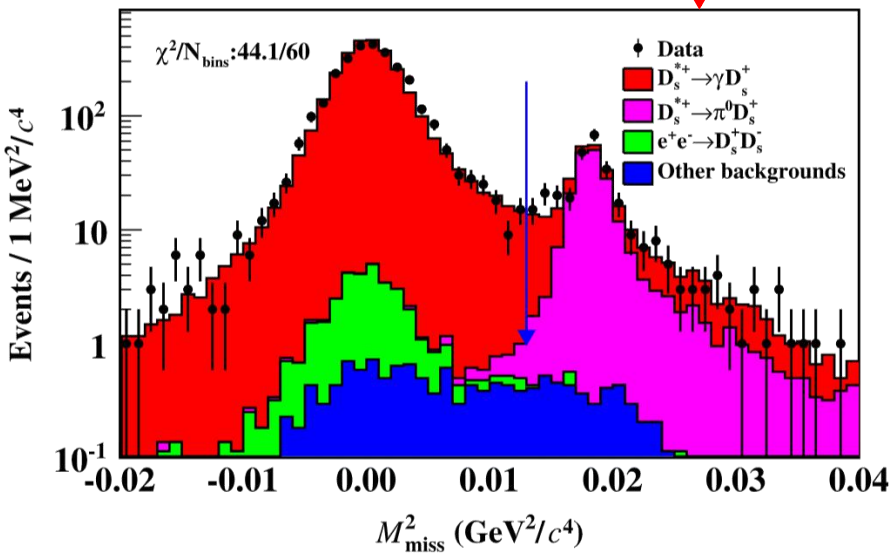
Data: 7.33 fb^{-1} 4.128 - 4.226 GeV

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

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







$$\frac{\mathcal{B}(D_s^{*+} \to D_s^+\pi^0)}{\mathcal{B}(D_s^{*+} \to D_s^+\gamma)} = (6.16 \pm 0.43 \pm 0.18)\%$$

using the world average value of
$\mathcal{B}(D_s^{*+} \to D_s^+e^+e^-)$=(0.67±0.16)%

$$\mathcal{B}(D_s^{*+} \to D_s^+\gamma) = (93.57 \pm 0.38 \pm 0.22)\%$$
$$\mathcal{B}(D_s^{*+} \to D_s^+\pi^0) = (5.76 \pm 0.38 \pm 0.16)\%$$

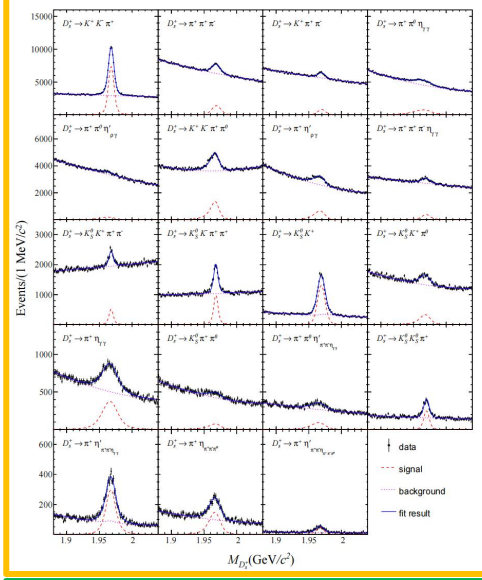
D_s^+ hadronic decays

Accepted by JHEP!
arXiv:2403.19256

Method: Double Tag
Data: 7.33 fb^{-1} 4.128 - 4.226 GeV

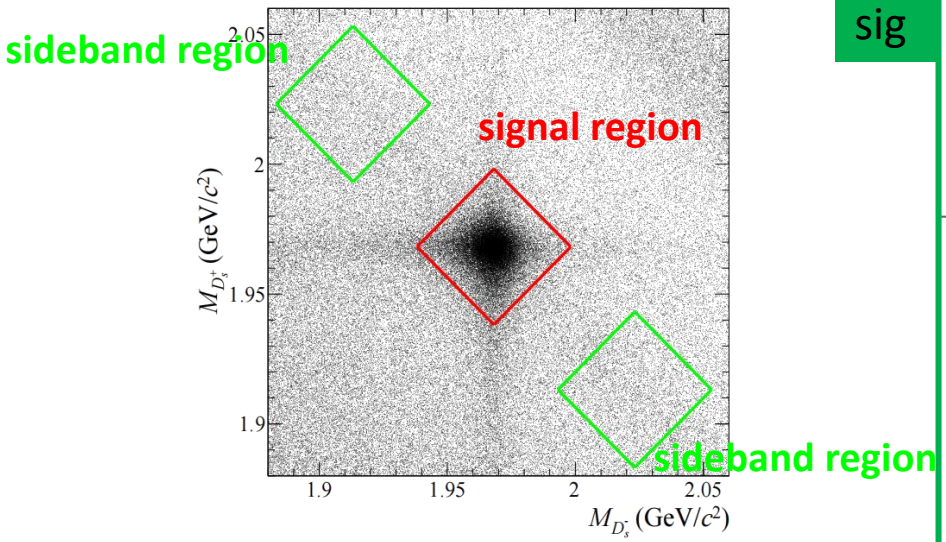
Global fit
15 decay modes (19 final states)

tag



Mode
$D_s^+ \to K_S^0 K^+$
$D_s^+ \to K^+ K^- \pi^+$
$D_s^+ \to K_S^0 K^+ \pi^0$
$D_s^+ \to K_S^0 K_S^0 \pi^+$
$D_s^+ \to K^+ K^- \pi^+ \pi^0$
$D_s^+ \to K_S^0 K^+ \pi^+ \pi^-$
$D_s^+ \to K_S^0 K^- \pi^+ \pi^+$
$D_s^+ \to \pi^+ \pi^+ \pi^-$
$D_s^+ \to \pi^+ \eta\ (\eta \to \gamma\gamma)$
$D_s^+ \to \pi^+ \pi^0 \eta\ (\eta \to \gamma\gamma)$
$D_s^+ \to \pi^+ \pi^+ \pi^- \eta\ (\eta \to \gamma\gamma)$
$D_s^+ \to \pi^+ \eta\ (\eta \to \pi^+ \pi^- \pi^0)$
$D_s^+ \to \pi^+ \eta'\ (\eta' \to \pi^+ \pi^- \eta,\ \eta \to \gamma\gamma)$
$D_s^+ \to \pi^+ \pi^0 \eta'\ (\eta' \to \pi^+ \pi^- \eta,\ \eta \to \gamma\gamma)$
$D_s^+ \to \pi^+ \eta'\ (\eta' \to \pi^+ \pi^- \eta,\ \eta \to \pi^+ \pi^+ \pi^0)$
$D_s^+ \to \pi^+ \eta'\ (\eta' \to \rho\gamma,\ \rho \to \pi^+ \pi^-)$
$D_s^+ \to \pi^+ \pi^0 \eta'\ (\eta' \to \rho\gamma,\ \rho \to \pi^+ \pi^-)$
$D_s^+ \to K_S^0 \pi^+ \pi^0$
$D_s^+ \to K^+ \pi^+ \pi^-$

sig



Mode	$\mathcal{B}$ (%)	PDG $\mathcal{B}$ (%)
$D_s^+ \to K_S^0 K^+$	$1.502 \pm 0.012 \pm 0.009$	1.453 ± 0.035
$D_s^+ \to K^+ K^- \pi^+$	$5.49 \pm 0.04 \pm 0.07$	5.37 ± 0.10
$D_s^+ \to K_S^0 K^+ \pi^0$	$1.47 \pm 0.02 \pm 0.02$	1.47 ± 0.07
$D_s^+ \to K_S^0 K_S^0 \pi^+$	$0.73 \pm 0.01 \pm 0.01$	0.71 ± 0.04
$D_s^+ \to K^+ K^- \pi^+ \pi^0$	$5.50 \pm 0.05 \pm 0.11$	5.50 ± 0.24
$D_s^+ \to K_S^0 K^+ \pi^+ \pi^-$	$0.93 \pm 0.02 \pm 0.01$	0.95 ± 0.08
$D_s^+ \to K_S^0 K^- \pi^+ \pi^+$	$1.56 \pm 0.02 \pm 0.02$	1.53 ± 0.08
$D_s^+ \to \pi^+ \pi^+ \pi^-$	$1.09 \pm 0.01 \pm 0.01$	1.08 ± 0.04
$D_s^+ \to \pi^+ \eta$	$1.69 \pm 0.02 \pm 0.02$	1.67 ± 0.09
$D_s^+ \to \pi^+ \pi^0 \eta$	$9.10 \pm 0.09 \pm 0.15$	9.5 ± 0.5
$D_s^+ \to \pi^+ \pi^+ \pi^- \eta$	$3.08 \pm 0.06 \pm 0.05$	3.12 ± 0.16
$D_s^+ \to \pi^+ \eta'$	$3.95 \pm 0.04 \pm 0.07$	3.94 ± 0.25
$D_s^+ \to \pi^+ \pi^0 \eta'$	$6.17 \pm 0.12 \pm 0.14$	6.08 ± 0.29
$D_s^+ \to K_S^0 \pi^+ \pi^0$	$0.51 \pm 0.02 \pm 0.01$	0.54 ± 0.03
$D_s^+ \to K^+ \pi^+ \pi^-$	$0.620 \pm 0.009 \pm 0.006$	0.620 ± 0.019

greement with the world-average value

much improved precision!!!

D_s^+ hadronic decays

Accepted by JHEP!
arXiv:2403.19256

Method: Double Tag
Data: 7.33 fb^{-1} 4.128 - 4.226 GeV

Numbers of producted $D_s^+ D_s^-$ pairs:

$\sqrt{s}$ (GeV)	$N^{D_s^+ D_s^-}$ ($\times 10^5$)
4.128 and 4.157	6.29±0.06±0.01
4.178	31.79±0.24±0.06
4.189	5.51±0.05±0.01
4.199	4.92±0.05±0.01
4.209	5.07±0.05±0.01
4.219	4.32±0.04±0.01
4.226	6.82±0.07±0.02

Provides important input for the relative BF measurements of BESIII.

$\mathcal{A}_{CP}$ calculation

Mode	$\mathcal{A}_{CP}$ (%)	PDG $\mathcal{A}_{CP}$ (%)
$D_s^\pm \to K_S^0 K^\pm$	$0.29 \pm 0.50 \pm 0.21$	0.09 ± 0.26
$D_s^\pm \to K^+ K^- \pi^\pm$	$0.48 \pm 0.26 \pm 0.24$	-0.5 ± 0.9
$D_s^\pm \to K_S^0 K^\pm \pi^0$	$-0.85 \pm 1.97 \pm 0.46$	-2 ± 6
$D_s^\pm \to K_S^0 K_S^0 \pi^\pm$	$1.14 \pm 1.58 \pm 0.44$	3 ± 5
$D_s^\pm \to K^+ K^- \pi^\pm \pi^0$	$-0.66 \pm 0.91 \pm 0.33$	0.0 ± 3.0
$D_s^\pm \to K_S^0 K^\pm \pi^+ \pi^-$	$2.00 \pm 2.37 \pm 0.70$	-6 ± 5
$D_s^\pm \to K_S^0 K^\mp \pi^\pm \pi^\pm$	$-0.24 \pm 1.05 \pm 1.07$	4.1 ± 2.8
$D_s^\pm \to \pi^\pm \pi^+ \pi^-$	$-0.88 \pm 1.17 \pm 0.38$	-0.7 ± 3.1
$D_s^\pm \to \pi^\pm \eta$	$-0.44 \pm 0.89 \pm 0.19$	0.3 ± 0.4
$D_s^\pm \to \pi^\pm \pi^0 \eta$	$1.05 \pm 1.45 \pm 0.62$	-1 ± 4
$D_s^\pm \to \pi^\pm \pi^+ \pi^- \eta$	$2.42 \pm 2.85 \pm 0.78$	-
$D_s^\pm \to \pi^\pm \eta'$	$-0.59 \pm 0.76 \pm 0.20$	-0.9 ± 0.5
$D_s^\pm \to \pi^\pm \pi^0 \eta'$	$-1.60 \pm 2.57 \pm 0.64$	0 ± 8
$D_s^\pm \to K_S^0 \pi^\pm \pi^0$	$-2.17 \pm 4.65 \pm 1.10$	3 ± 6
$D_s^\pm \to K^\pm \pi^+ \pi^-$	$1.81 \pm 2.01 \pm 0.45$	4 ± 5

No significant asymmetries are observed.

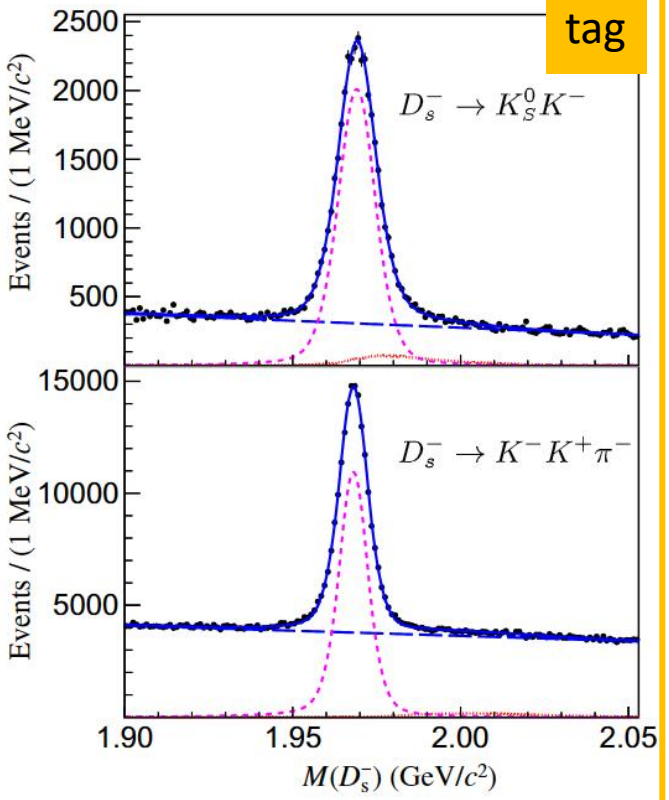
Achieved the desired goal of D_s^+ BF measurement!

$D_s^+ \to \pi^+\pi^+\pi^-X$

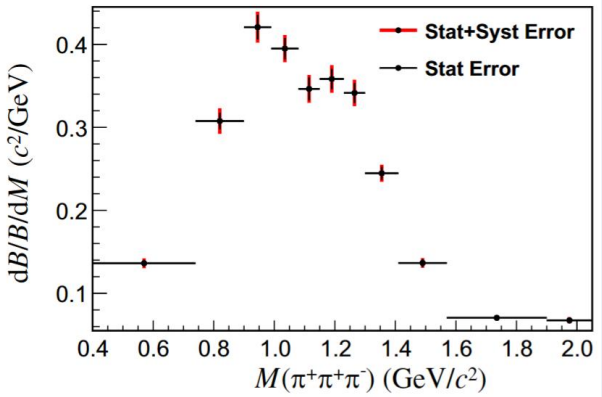
Phys. Rev. D
108, 032001 (2023)

Method: Double Tag
Data: 3.19 fb^{-1} 4.178 GeV

tag



Partial BF results: 11 intervals



$M(\pi^+\pi^+\pi^-)$ interval	$\Delta\mathcal{B}_{3\pi X,i}$ (%)
1	$4.63 \pm 0.14 \pm 0.14$
2	$4.92 \pm 0.16 \pm 0.19$
3	$3.79 \pm 0.13 \pm 0.10$
4	$3.55 \pm 0.12 \pm 0.09$
5	$2.42 \pm 0.10 \pm 0.07$
6	$2.87 \pm 0.10 \pm 0.09$
7	$2.39 \pm 0.09 \pm 0.07$
8	$2.69 \pm 0.09 \pm 0.07$
9	$2.19 \pm 0.08 \pm 0.05$
10	$2.32 \pm 0.07 \pm 0.05$
11	$1.01 \pm 0.04 \pm 0.04$

Major exclusive decay modes :

Decay mode	$\mathcal{B}$ (%)
$D_s^+ \to \eta'\rho^+$	4.6 ± 1.2
$D_s^+ \to \pi^+\pi^+\pi^-\eta$	3.1 ± 0.2
$D_s^+ \to \eta'\pi^+$	3.2 ± 0.2
$D_s^+ \to \eta\pi^+\pi^0$	2.6 ± 0.1
$D_s^+ \to \omega\pi^+\pi^0$	2.5 ± 0.6
$D_s^+ \to \phi a_1(1260)^+(\to \pi^+\pi^+\pi^-)$	1.2 ± 0.1
$D_s^+ \to K^+K^-\pi^+\pi^+\pi^-$ nonresonant	0.14 ± 0.02
$D_s^+ \to \eta\pi^+$	0.46 ± 0.03
$D_s^+ \to \omega\pi^+$	0.17 ± 0.03
$D_s^+ \to \omega\pi^+\pi^+\pi^-$	1.6 ± 0.5
$D_s^+ \to \pi^+\pi^+\pi^-$	1.08 ± 0.04
$D_s^+ \to \phi\pi^+$	0.72 ± 0.03
$D_s^+ \to \phi\rho^+$	0.97 ± 0.05
$D_s^+ \to \pi^+\pi^+\pi^+\pi^-\pi^-$	0.79 ± 0.08
$D_s^+ \to \tau^+\nu_\tau$	0.72 ± 0.01
$D_s^+ \to K^0\pi^+\pi^+\pi^-$	0.6 ± 0.2
$D_s^+ \to \eta' e^+\nu_e$	0.10 ± 0.01
$D_s^+ \to \eta'\mu^+\nu_\mu$	0.10 ± 0.01
Sum	24.7 ± 1.5

$\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^-X) = (32.81 \pm 0.35 \pm 0.63)\%$ → Difference : 8.11%

There exist unobserved decay modes having at least three charged pions.

D meson hadronic decays

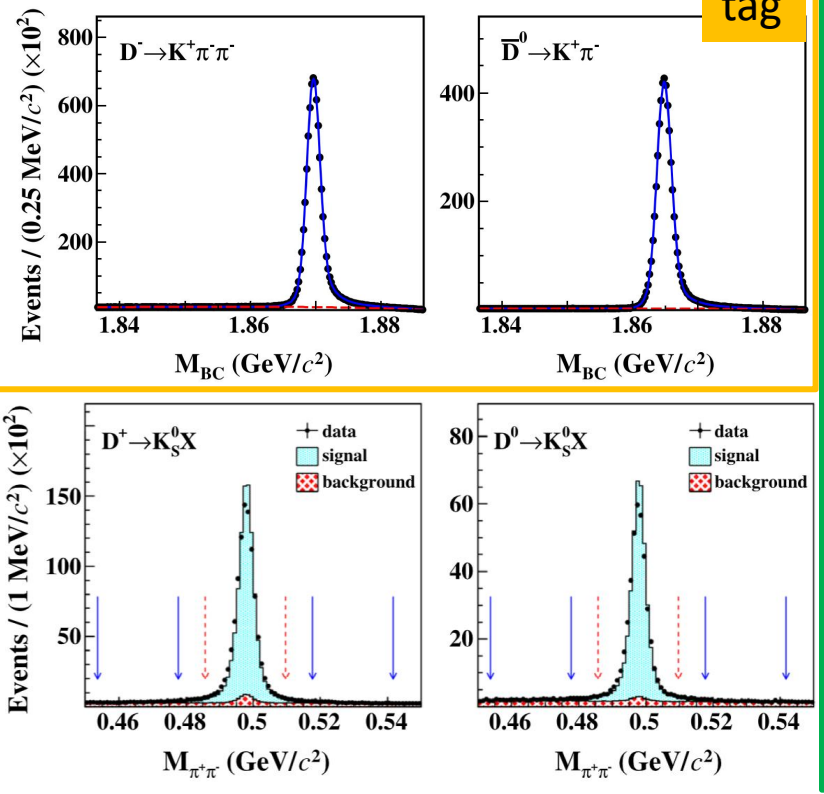
$D^+(D^0) \to K^0_S X$

Phys. Rev. D
107, 112005 (2023)

Method: Double Tag
Data: 2.93 fb^{-1}

-- Improved measurement of the branching fractions

tag



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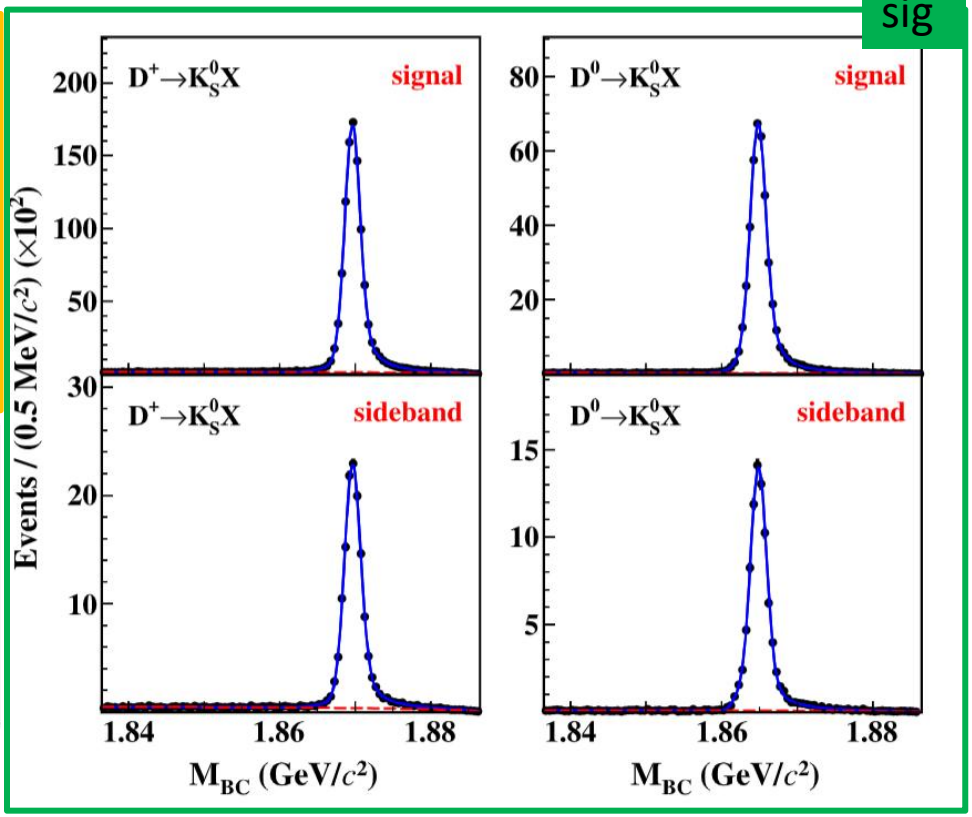


Decay mode	BES (%) [2]	PDG (%) [3]	This study (%)
$D^+ \to K^0_S X$	$30.25 \pm 2.75 \pm 1.65$	30.5 ± 2.5	$33.11 \pm 0.13 \pm 0.36$
$D^0 \to K^0_S X$	$23.80 \pm 2.40 \pm 1.50$	23.5 ± 2.0	$20.75 \pm 0.12 \pm 0.20$

Exclusive decay
$(31.68 \pm 0.32)\%$
$(18.16 \pm 0.72)\%$

Difference
$(1.43 \pm 0.44)\%$
$(2.59 \pm 0.76)\%$

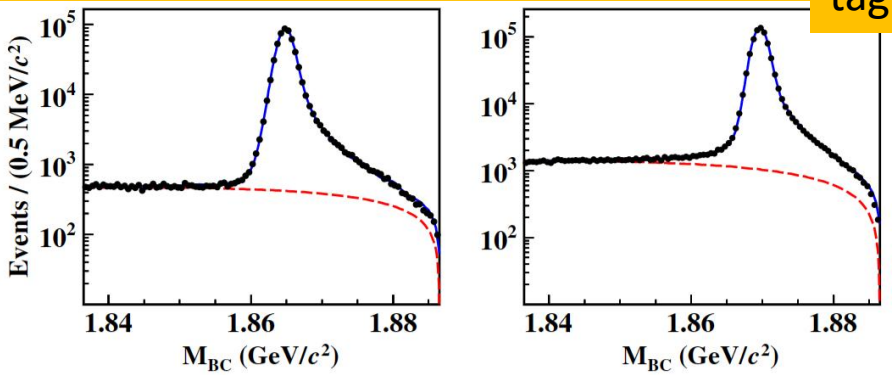
Some missing decay modes involving for K^0_S both D^+ and D^0 yet to be observed.

$D^+(D^0) \to \pi^+\pi^+\pi^-X$

Phys. Rev. D
107, 032002 (2023)

Method: Double Tag
Data: 2.93 fb^{-1}

tag



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

i	$N_{\rm prod}$	$d\mathcal{B}_{\rm sig}$ (%)
1	1747.1 ± 111.1	0.22 ± 0.01
2	9683.3 ± 245.1	1.19 ± 0.03
3	17890.3 ± 349.6	2.20 ± 0.04
4	27671.6 ± 366.3	3.41 ± 0.05
5	33224.6 ± 340.2	4.09 ± 0.04
6	20383.9 ± 251.5	2.51 ± 0.03
7	5772.7 ± 155.4	0.71 ± 0.02
8	2661.8 ± 97.8	0.33 ± 0.01
9	2032.0 ± 81.1	0.25 ± 0.01
10	2803.0 ± 80.2	0.35 ± 0.01
Total	123870.2 ± 744.7	15.25 ± 0.09

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

i	$N_{\rm prod}$	$d\mathcal{B}_{\rm sig}$	$d\mathcal{B}_{\rm sig}^{\rm corr}$ (%)
1	1541.3 ± 89.9	0.28 ± 0.02	0.28 ± 0.02
2	9349.1 ± 206.0	1.71 ± 0.04	1.70 ± 0.04
3	14235.8 ± 271.8	2.60 ± 0.05	2.66 ± 0.05
4	22130.5 ± 295.0	4.04 ± 0.05	4.08 ± 0.05
5	24638.2 ± 264.9	4.50 ± 0.05	4.51 ± 0.05
6	16850.4 ± 207.4	3.07 ± 0.04	3.14 ± 0.04
7	4228.6 ± 127.5	0.77 ± 0.02	0.80 ± 0.02
8	1730.9 ± 113.7	0.32 ± 0.02	0.31 ± 0.02
9	676.1 ± 69.6	0.12 ± 0.01	0.11 ± 0.01
Total	95381.0 ± 598.9	...	17.60 ± 0.11

$\mathcal{B}(D^0 \to \pi^+\pi^+\pi^-X) = (17.60 \pm 0.11 \pm 0.22)\%$

Exclusive decay : $(16.05 \pm 0.47)\%$

Difference: 1.55%

$\mathcal{B}(D^+ \to \pi^+\pi^+\pi^-X) = (15.25 \pm 0.09 \pm 0.18)\%$

Exclusive decay : $(14.74 \pm 0.53)\%$

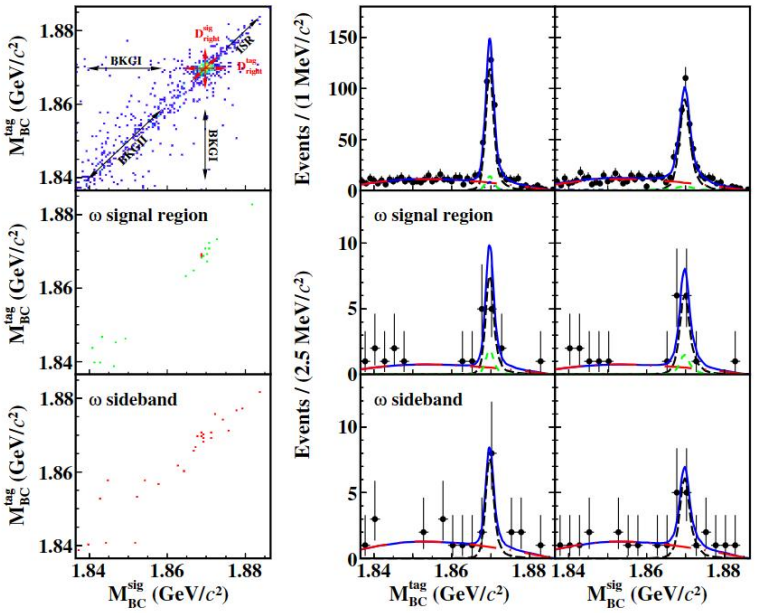
Difference: 0.51%

some exclusive decays are not measured or some known exclusive decays are overestimated.

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

Phys. Rev. Lett.
125, 141802 (2020)

--Doubly Cabibbo-suppressed (DCS) decays



First observation

350 ± 22 DT events

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

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

corresponds to $(6.28\pm0.52)\times tan^4\theta_C$

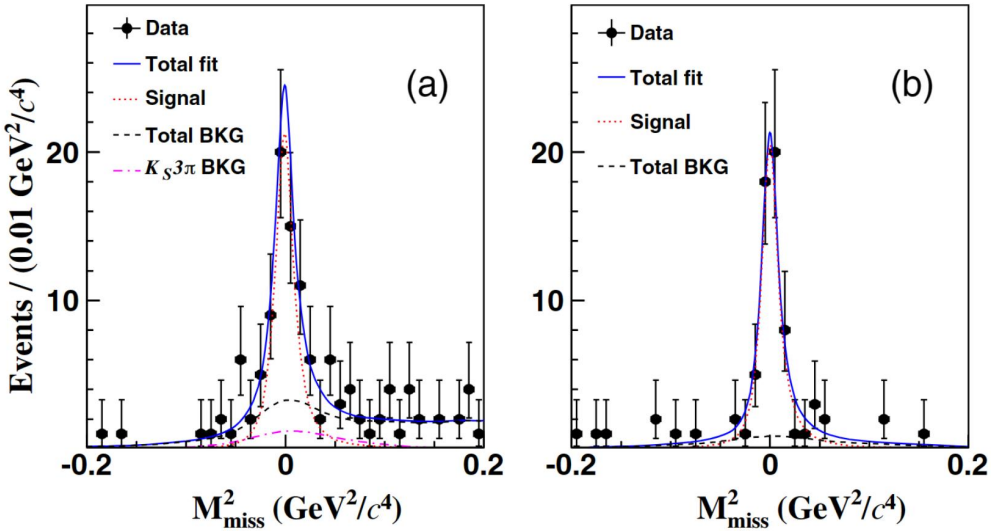
$$\mathcal{B}(D^+ \to K^+\omega) = (5.7^{+2.5}_{-2.1} \pm 0.2) \times 10^{-5}$$

Phys. Rev. D
104, 072005 (2021)

First try of semileptonic tag at BESIII

112 ± 12 DT events

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



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

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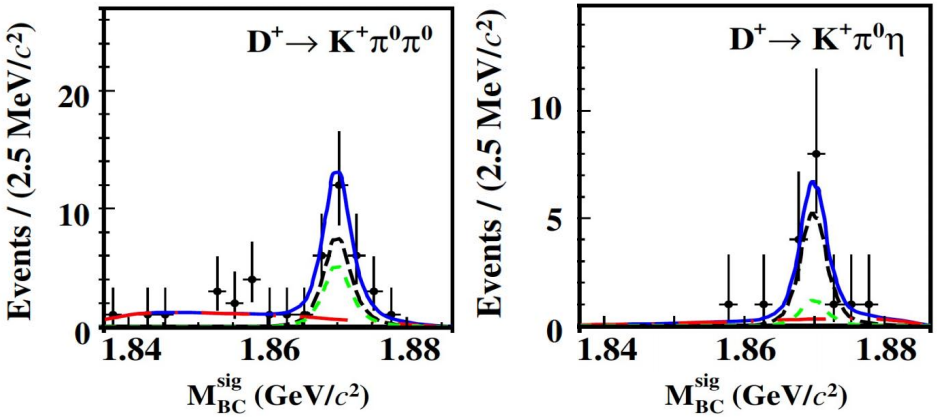
Method: Double Tag

Data: 2.93 fb^{-1}

First observation

--Doubly Cabibbo-suppressed (DCS) decays



$$\mathcal{B}(D^+ \to K^+\pi^0\pi^0) = (2.1 \pm 0.4 \pm 0.1) \times 10^{-4}$$
$$\mathcal{B}(D^+ \to K^+\pi^0\eta) = (2.1 \pm 0.5 \pm 0.1) \times 10^{-4}$$

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

$(0.77\pm0.14)\times tan^4\theta_C$

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

$(2.64\pm0.68)\times tan^4\theta_C$

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

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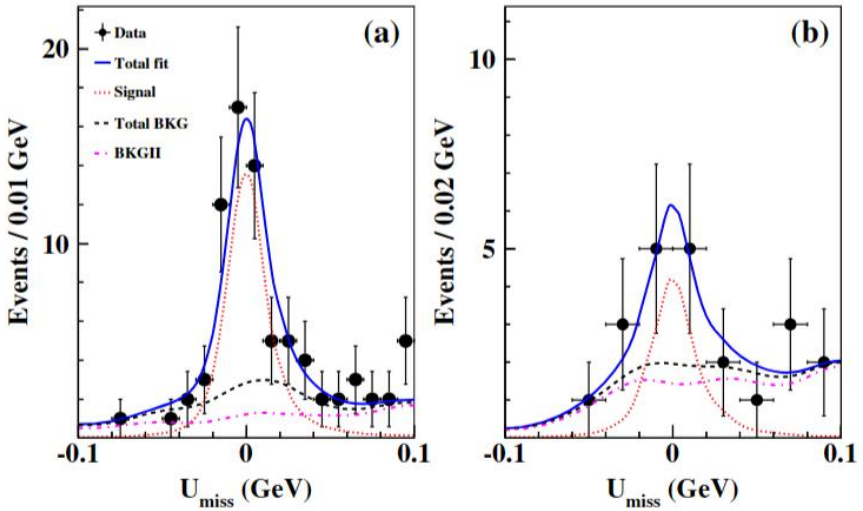

$$\mathcal{B}(D^0 \to K^+\pi^-\pi^0) = (3.13^{+0.6}_{-0.56} \pm 0.09) \times 10^{-4}$$
$$\mathcal{B}(D^0 \to K^-\pi^+\pi^0) < 3.6 \times 10^{-4}$$

$$\frac{\mathcal{B}(D^0 \to K^+\pi^-\pi^0)}{\mathcal{B}(D^0 \to K^-\pi^+\pi^0)} = (0.22 \pm 0.44)\%$$

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

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

$<1.37\times tan^4\theta_C$

Summary & Outlook

D_s hadronic decay:

- D_s^+ have been studied comprehensively.
- The desired D_s^+ BF measurement target is achieved.
- Enter the leak filling stage.

D hadronic decay:

- More inclusive decay results are published.
- 20 fb^{-1} data at BESIII will be released soon.
- Many BFs, amplitude analyses and strong-phase mesurements of D are being studied.

Thanks for your attention!