Measurements of D meson two body decays at BESIII

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NJU, IHEP

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Outline

1. Motivation
2. Measurements of $D^{\rightarrow}PP$ at BESIII
3. Measurements of $D^{\rightarrow}VP$ at BESIII
4. Measuremnt of D meson baryonic decay
5. Summary

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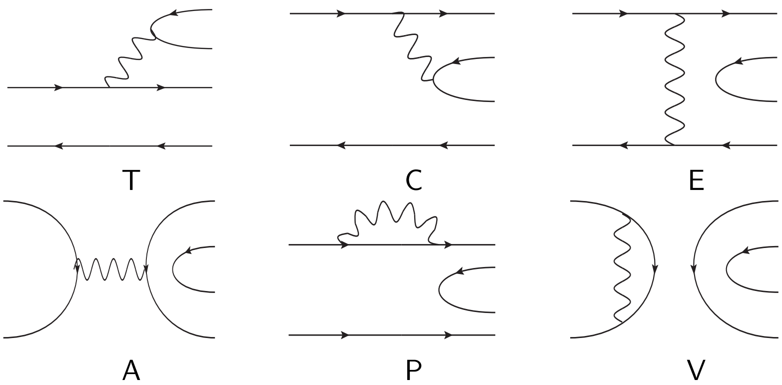
Diagrammatic approach for D meson two body decays

The mass of the charm quark is not heavy enough for a sensible heavy quark expansion as is done in B meson decays, and is not light enough for chiral perturbation theory.

Model independent diagrammatic approach:



Extraction of diagrammatic amplitudes

With enough measurements, the amplitudes and their relative phase for each diagram can be extracted.

PP		VP	
Mode	Representation	Mode	Representation
$D^0 \to K^-\pi^+$	$V_{cs}^* V_{ud}(T+E)$	$D^0 \to K^{*-}\pi^+$	$V_{cs}^* V_{ud}(T_V+E_P)$
$D^0 \to \bar{K}^0\eta$	$V_{cs}^* V_{ud}[\frac{1}{\sqrt{2}}(C+E)\cos\phi - E\sin\phi]$	$D_s^+ \to \phi\pi+$	$V_{cs}^* V_{ud} T_V$
$D^+ \to \pi^+\pi^-$	$V_{cd}^* V_{ud} A' + V_{cs}^* V_{us} T'$	$D^0 \to \rho^-\pi^+$	$V_{cd}^* V_{ud}(T'_V + E'_P)$
$D^0 \to K^0\pi^0$	$\frac{1}{\sqrt{2}} V_{cd}^* V_{us}(C'' - E'')$	$D^0 \to \phi K^0$	$V_{cd}^* V_{us} E''_V$

- Large amplitudes of E and A show sizable contribution from final state interaction which can not be factorized,
- Currently more inputs needed for determination of some amplitudes, especially A_P and A_V.
- Flavor SU(3) symmetry breaking effect: $T \neq T' \neq T''$

For factorization approach, measurements of the BF of D meson two body decays are also important inputs for the determination of some parameters.

Symmetry test

$K_{S/L}$ asymmetry due to the interference between CF and DCS amplitudes:

$$R(D^0)=\frac{\Gamma(D^0\to K_S\pi^0)-\Gamma(D^0\to K_L\pi^0)}{\Gamma(D^0\to K_S\pi^0)+\Gamma(D^0\to K_L\pi^0)}=2\tan^2\theta_C$$

$$R(D^+)=\frac{\Gamma(D^+\to K_S\pi^+)-\Gamma(D^+\to K_L\pi^+)}{\Gamma(D^+\to K_S\pi^+)+\Gamma(D^+\to K_L\pi^+)}=2\tan^2\theta_C Re(\frac{C''+A''}{C+T})$$

$$R(D_s^+)=\frac{\Gamma(D_s^+\to K_S K^+)-\Gamma(D_s^+\to K_L K^+)}{\Gamma(D_s^+\to K_S K^+)+\Gamma(D_s^+\to K_L K^+)}=2\tan^2\theta_C Re(\frac{C''+T''}{C+A})$$

Search for direct CP asymmetry via decays with at least two distinct decay amplitudes with non-trivial strong and weak phase differences.
Measurement from LHCb shows:

$$\Delta A_{CP}\equiv A_{CP}(K^+K^-)-A_{CP}(\pi^+\pi^-)=-(0.82\pm0.21\pm0.11)\%$$

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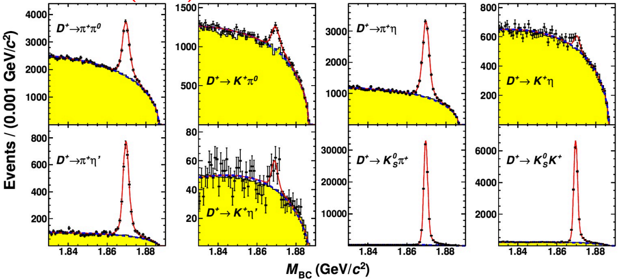
Measurements of the BFs of some $D \to PP$ decays

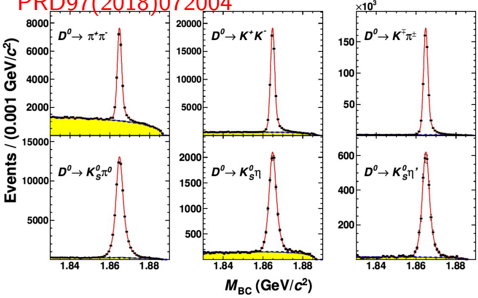
PRD97(2018)072004



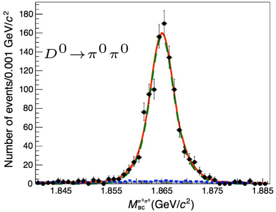
Mode	Diagram(s)	BF (10^{-3})	Mode	Diagram(s)	BF (10^{-3})
$D^+ \to K^0_S\pi^+$	T, C, C'', A''	$15.91\pm0.06\pm0.30$	$D^+ \to \pi^+\pi^0$	T', C'	$1.259\pm0.033\pm0.023$
$D^+ \to K^+\pi^0$	T'', A''	$0.231\pm0.021\pm0.006$	$D^+ \to \pi^+\eta$	T', C', A'	$3.790\pm0.070\pm0.068$
$D^+ \to K^+\eta$	T'', A''	$0.151\pm0.025\pm0.014$	$D^+ \to \pi^+\eta'$	T', C', A'	$5.12\pm0.14\pm0.21$
$D^+ \to K^+\eta'$	T'', A''	$0.164\pm0.051\pm0.024$	$D^+ \to K^0_S K^+$	T', A'	$3.183\pm0.029\pm0.060$

Measurements of the BFs of some $D \to PP$ decays

PRD97(2018)072004



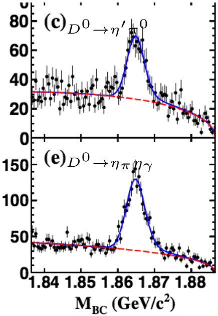
PRD91(2015)112015

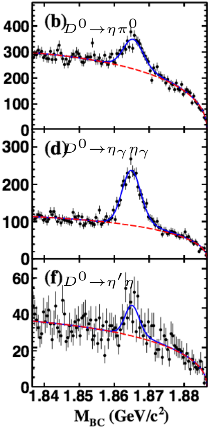


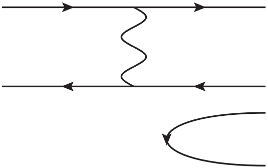
Mode	Diagram(s)	BF (10^{-3})	Mode	Diagram(s)	BF (10^{-3})
$D^0 \to K^{\mp}\pi^{\pm}$	T,E,T'',E''	$38.98\pm0.06\pm0.51$	$D^0 \to \pi^+\pi^-$	T',C'	$1.508\pm0.018\pm0.022$
$D^0 \to K^+K^-$	T',E'	$4.233\pm0.021\pm0.064$	$D^0 \to K^0_S\pi^0$	C,E,C'',E''	$12.39\pm0.06\pm0.27$
$D^0 \to K^0_S\eta$	C,E,C'',E''	$5.13\pm0.07\pm0.12$	$D^0 \to K^0_S\eta'$	C,E,C'',E''	$9.49\pm0.20\pm0.36$
$D^0 \to \pi^0\pi^0$	C',E'	$0.824\pm0.021\pm0.030$			

Measurements of the BFs of PP decays involving $\eta^{(\prime)}$

PRD91(2015)112015



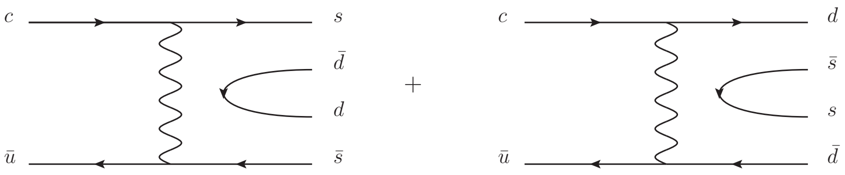




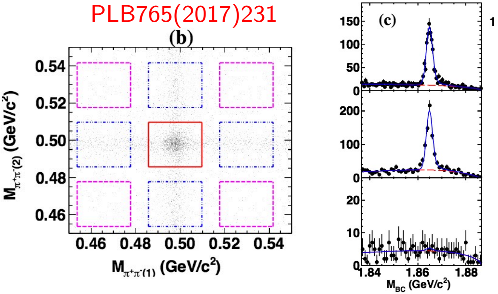
- Improve our understanding of the SE amplitude.
- Test the measured η/η' mixing angle.

Mode	Diagram(s)	BF (10^{-3})	Mode	Diagram(s)	BF (10^{-3})
$D^0\to\eta\pi^0$	C', E'	$0.58\pm0.05\pm0.05$	$D^0\to\eta\eta$	C', E'	$2.20\pm0.07\pm0.06$
$D^0\to\eta'\pi^0$	C', E'	$0.93\pm0.11\pm0.09$	$D^0\to\eta\eta'$	C', E'	$0.94\pm0.25\pm0.11$

Measurement of the BF of $D^0 \to K_S^0 K_S^0$



PLB765(2017)231



$$V_{cd}^* V_{ud} E_s' + V_{cs}^* V_{us} E_d'$$

With SU(3) symmetry:

$$V_{cd} = V_{us}$$

$$V_{cs} = V_{ud}$$

$$E_s' = -E_d'$$

Direct test of SU(3) symmetry breaking effect.

$$\mathcal{B}(D^0 \to K_S^0 K_S^0) = (0.167 \pm 0.011 \pm 0.011) \times 10^{-3}$$

Comparison of the measured BF (in 10^{-3}) with theoretical calculations

Modes	BF(BESIII)	BF(other)	BF(FSI)[1]	BF(diagrammatic)[2]	BF(pole)[3]	BF(FAT)[4]
$D^0 \to K^{\mp}\pi^{\pm}$	38.98 ± 0.51	39.4 ± 0.4	40.3	39.2 ± 1.7	39 ± 10	37.2
$D^0 \to \bar{K}^0(K^0)\pi^0$	24.78 ± 0.56	24.0 ± 0.8	13.5	23.7 ± 0.8	24 ± 7	24.2
$D^0 \to \bar{K}^0(K^0)\eta$	10.26 ± 0.28	9.7 ± 0.6	8.0	9.8 ± 0.5	8 ± 2	10.0
$D^0 \to \bar{K}^0(K^0)\eta'$	18.98 ± 0.82	19.0 ± 1.0	15.1	19.1 ± 0.9	19 ± 3	17.4
$D^+ \to \bar{K}^0(K^0)\pi^+$	31.82 ± 0.62	30.6 ± 1.2	25.1	31.0 ± 3.6	31 ± 20	32.4
$D^0 \to \pi^+\pi^-$	1.508 ± 0.028	1.421 ± 0.025	1.59	2.24 ± 0.10	2.2 ± 0.5	1.43
$D^0 \to K^+K^-$	4.233 ± 0.067	4.01 ± 0.07	4.56	1.92 ± 0.08	3.0 ± 0.8	4.19
$D^0 \to \pi^0\pi^0$	0.824 ± 0.037	0.84 ± 0.05	1.16	1.35 ± 0.05	0.8 ± 0.2	0.57
$D^0 \to \eta\pi^0$	0.58 ± 0.07	0.68 ± 0.07	0.58	0.75 ± 0.02	1.1 ± 0.3	0.94
$D^0 \to \eta'\pi^0$	0.93 ± 0.14	0.90 ± 0.14	1.7	0.74 ± 0.02	0.6 ± 0.2	0.65
$D^0 \to \eta\eta$	2.20 ± 0.09	1.67 ± 0.20	1.0	1.44 ± 0.08	1.3 ± 0.4	1.48

[1] F. Buccella et al. PRD51(1995)3478, PLB302(1993)319

[2] Hai-Yang Cheng and Cheng-Wei Chiang PRD81(2010)074021

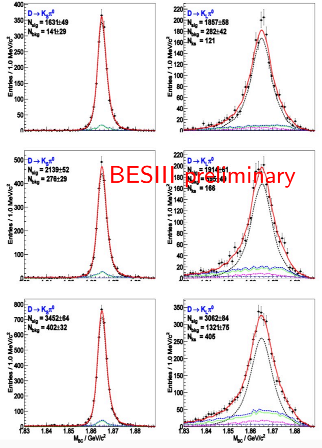
[3] Fu-Sheng Yu et al. PRD84(2011)074019

[4] H. N. Li et al. PRD86(2012)036012

Comparison of the measured BF (in 10^{-3}) with theoretical calculations

Modes	BF(BESIII)	BF(other)	BF(FSI)	BF(diagrammatic)	BF(pole)	BF(FAT)
$D^0 \to \eta\eta'$	0.94 ± 0.27	1.05 ± 0.26	2.2	1.19 ± 0.07	1.1 ± 0.1	1.54
$D^0 \to K^0 \bar{K}^0$	0.334 ± 0.032	0.34 ± 0.08	0.93	0	0.3 ± 0.1	0.36
$D^+ \to \pi^+ \pi^0$	1.259 ± 0.040	1.24 ± 0.06	1.7	0.88 ± 0.10	1.0 ± 0.5	0.89
$D^+ \to \pi^+ \eta$	3.790 ± 0.098	3.66 ± 0.22	3.6	1.48 ± 0.26	1.6 ± 1.0	3.39
$D^+ \to \pi^+ \eta'$	5.12 ± 0.25	4.84 ± 0.31	7.9	3.70 ± 0.37	5.5 ± 0.8	4.58
$D^+ \to \bar{K}^0 K^+$	6.37 ± 0.13	5.90 ± 0.30	8.6	5.46 ± 0.53	8.4 ± 1.6	5.95
$D^+ \to K^+ \pi^0$	0.231 ± 0.022	0.189 ± 0.025		0.159 ± 0.015	0.22 ± 0.04	0.197
$D^+ \to K^+ \eta$	0.151 ± 0.029	0.112 ± 0.018		0.098 ± 0.004	0.12 ± 0.02	0.066
$D^+ \to K^+ \eta'$	0.164 ± 0.056	0.183 ± 0.023		0.091 ± 0.017	0.10 ± 0.01	0.114

Study of asymmetry in $D^0 \to K_{S/L}\pi^0$



Hai-Yang Cheng and Cheng-Wei Chiang (PRD81(2010)074021) using diagrammatic approach:

$$R(D^0) = 2\tan^2\theta_C = 0.107$$

Di Wang, Fu-Sheng Yu et al. (PRD95(2017)073007) with FAT method considering the $D^0 - \bar{D}^0$ mixing effect:

$$R(D^0) = 2\tan^2\theta_C + y_D = 0.113 \pm 0.001$$

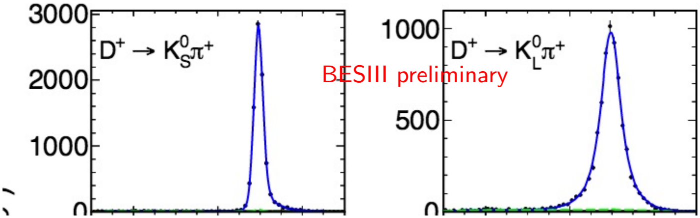
CLEOc's measurement:

$$R(D^0) = 0.108 \pm 0.025 \pm 0.024$$

BESIII's preliminary result with only statistical uncertainty:

$$R(D^0) = 0.1077 \pm 0.00125$$

Study of asymmetry in $D^+ \to K_{S/L}\pi^+$



Hai-Yang Cheng and Cheng-Wei Chiang (PRD81(2010)074021) using diagrammatic approach:

$$R(D^+) = 2\tan^2\theta_C Re(\frac{C'' + A''}{C + T}) = -0.019 \pm 0.016$$

Di Wang, Fu-Sheng Yu et al. (PRD95(2017)073007) with FAT method:

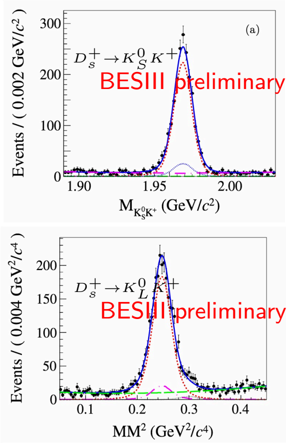
$$R(D^+) = 0.025 \pm 0.008$$

CLEOc's measurement:

$$R(D^+) = 0.022 \pm 0.016 \pm 0.018$$

BESIII's preliminary result:

$$R(D^+) = 0.001 \pm 0.009 \pm 0.009$$



Hai-Yang Cheng and Cheng-Wei Chiang (PRD81(2010)074021) using diagrammatic approach:

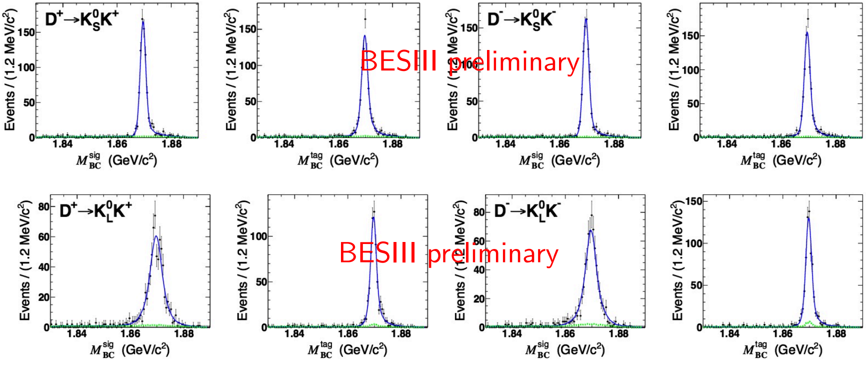
$$R(D_s^+) = 2\tan^2\theta_C Re(\frac{C'' + T''}{C + A}) = -0.008 \pm 0.007$$

Di Wang, Fu-Sheng Yu et al. (PRD95(2017)073007) with FAT method:

$$R(D_s^+) = 0.012 \pm 0.006$$

BESIII's preliminary result:

$$R(D_s^+) = -0.021 \pm 0.019 \pm 0.016$$



Mode	BF ($\times 10^{-3}$)	A_{CP} (%)
$D^\pm \to K^0_S K^\pm$	$3.02 \pm 0.09 \pm 0.08$	$-1.8 \pm 2.7 \pm 1.6$
$D^\pm \to K^0_L K^\pm$	$3.21 \pm 0.11 \pm 0.11$	$-4.2 \pm 3.2 \pm 1.2$

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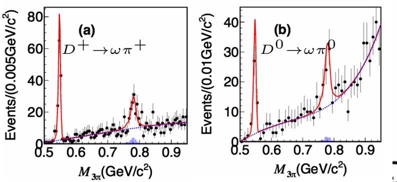
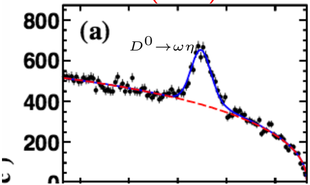
Observation of SCS decays $D^0 \to \omega\pi^0(\eta)$ and $D^+ \to \omega\pi^+$

PRL116(2016)082001



PRD97(2018)052005



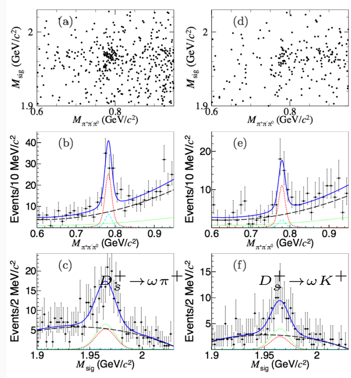
Mode	Diagram(s)	BF ($\times 10^{-3}$)
$D^+ \to \omega\pi^+$	T'_V, C'_P, A'_P, A'_V	$0.279 \pm 0.057 \pm 0.016$
$D^0 \to \omega\pi^0$	C'_P, C'_V, E'_P, E'_V	$0.117 \pm 0.034 \pm 0.007$
$D^0 \to \omega\eta$	C'_P, C'_V, E'_P, E'_V	$2.15 \pm 0.17 \pm 0.15$

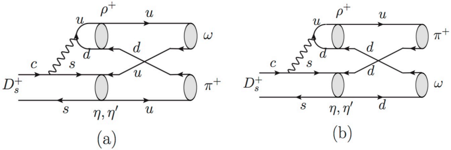
Q. Qin et al. (PRD89(2014)054006) predict $\mathcal{B}(D^0 \to \omega\pi^0) = 0.85 \times 10^{-3}$ without $\rho - \omega$ mixing and 0.18×10^{-3} with $\rho - \omega$ mixing.

Our result prefers the existence of $\rho - \omega$ mixing.

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

arXiv:1811:00392



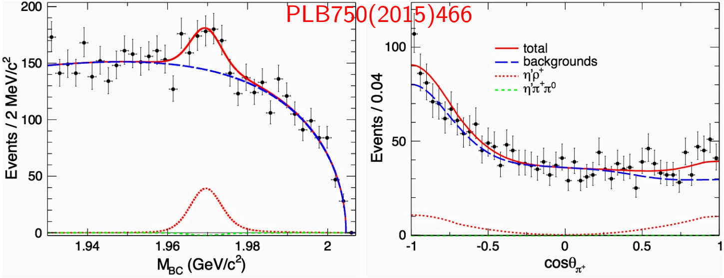


$\omega\pi^+$: large BF that can not be explained by $\phi - \omega$ mixing (10^{-4}), should be induced by FSI (Hai-Yang Cheng and Cheng-Wei Chiang (PRD81(2010)074021)).
ωK^+: Q. Qin et al. (PRD89(2014)054006) predict $\mathcal{B}D^0 \to \omega\pi^0 = 0.6 \times 10^{-3}$ without $\rho - \omega$ mixing and 0.07×10^{-3} with $\rho - \omega$ mixing. Our result prefers no $\rho - \omega$ mixing effect this time.

Mode	Diagram(s)	BF $(\times 10^{-3})$
$D_s^+ \to \omega\pi^+$	A_V, A_P	$1.77 \pm 0.32 \pm 0.12$
$D_s^+ \to \omega K^+$	C'_P, A'_P	$0.87 \pm 0.24 \pm 0.07$

Measurement of the absolute BF of $D_s^+ \to \eta' \rho^+$

Mode	Diagram(s)	BF(CLEO) (%)	BF(diagrammatic) (%)	BF(FAT) (%)
$D_s^+ \to \eta\rho^+$	T_P, A_P, A_V	8.9 ± 0.8	7.4 ± 0.7	8.2
$D_s^+ \to \eta'\rho^+$	T_P, A_P, A_V	12.2 ± 2.0	2.7 ± 0.2	1.7



In 2013, CLEO reported $\mathcal{B}(D_s^+ \to \eta' \pi^+ \pi^0) = (5.6 \pm 0.5 \pm 0.6)\%$.
Our result

$$\mathcal{B}(D_s^+ \to \eta' \rho) = 5.8 \pm 1.4 \pm 0.4.$$

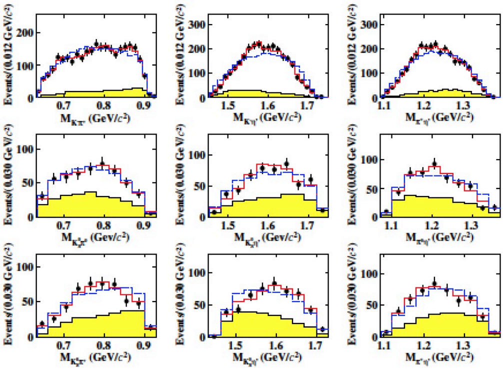
Comparison of the measured BF (in 10^{-3}) with theoretical calculations

Modes	BF(BESIII)	BF(other)	BF(FSI)	BF(diagrammatic)	BF(pole)	BF(FAT)[5]
$D^0 \to \omega\pi^0$	0.117 ± 0.035	<0.26	0.08	0.10 ± 0.18	0.08 ± 0.02	0.85
$D^0 \to \omega\eta$	2.15 ± 0.23	–	1.9	3.08 ± 1.42	1.2 ± 0.3	2.4
$D^+ \to \omega\pi^+$	0.279 ± 0.059	<0.34	0.35		0.3 ± 0.3	0.95
$D_s^+ \to \omega\pi^+$	1.77 ± 0.34	2.1 ± 0.9	0.0		0	3.0
$D_s^+ \to \omega K^+$	0.87 ± 0.25	–	0.72		1.8 ± 0.7	0.6
$D_s^+ \to \rho\eta'$	5.8 ± 1.5	12.2 ± 2.0	2.61		3.0 ± 0.5	1.7

[5] Q. Qin et al. PRD89(2014)054006

Measurements of the BFs of $D \to K\pi\eta'$

arXiv:1809.03750



Mode	BF ($\times 10^{-3}$)
$D^0 \to K^-\pi^+\eta'$	$6.43\pm0.15\pm0.31$
$D^0 \to K^0_S\pi^0\eta'$	$2.52\pm0.22\pm0.15$
$D^+ \to K^0_S\pi^+\eta'$	$1.90\pm0.17\pm0.13$

- No obvious $\bar{K}^{*0}$ signal.
- Phase space limited.
- Filling the space in the measurements of the BFs of D exclusive decays containing η'.

Mode	BF(FSI)	BF(diagrammatic)	BF(pole)	BF(FAT) $\times 10^{-3}$
$D^0 \to \bar{K}^{*0}\eta'$	0.05	0.12 ± 0.03	0.16 ± 0.05	0.18

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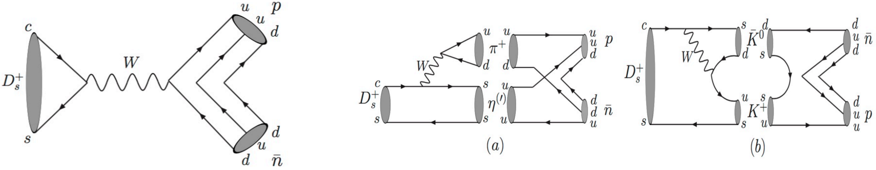

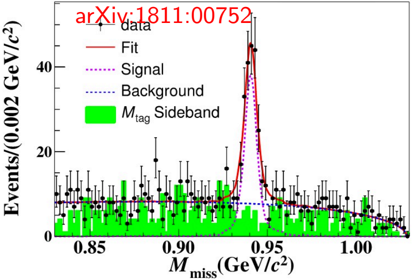

Only proceed via A diagram, highly suppressed (at the order of 10^{-6}).

CLEO reported $\mathcal{B}(D_s^+ \to p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$.

Chuan-Hung Chen et al. (PLB663(2008)326) considered the FSI effect which enhances the BF to $(0.8^{+2.4}_{-0.6}) \times 10^{-3}$.

Confirmed large BF $\mathcal{B}(D_s^+ \to p\bar{n}) = (1.21 \pm 0.10 \pm 0.06) \times 10^{-3}$.

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Summary

- $D \to PP$ decays have been widely studied and when carefully taking into consideration of the SU(3) symmetry breaking effect, theory can produce overall consistent results with experiments.
- More experimental inputs needed for $D \to VP$ decays, especially for the determination of weak annihilation amplitudes.
- Since the internal structure of light scalar mesons are still unknown, decays involving these products require the use of PWA method.
- BESIII will take more data on $D\bar{D}$ threshold and more results on D meson two body decays can be expected.

Thanks for your attention!