Recent BESIII results in open charm

Krishnakumar Ravindran

Indian Institute of Technology Madras, Chennai
(on behalf of BESIII collaboration)

WIN 2019, Bari, Italy

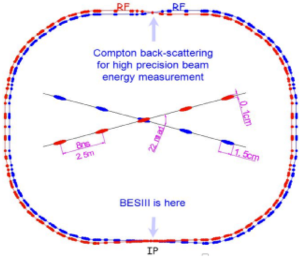
Outline

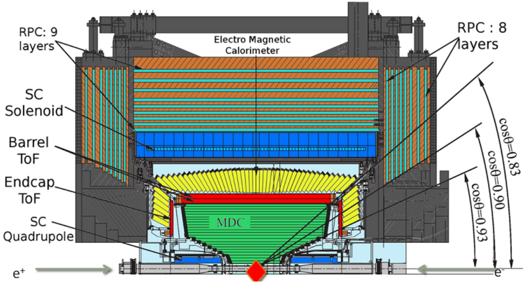
- BESIII experiments and dataset
- Latest results
  - (Semi)leptonic decays
  - Hadronic
  - Λ_c
- Summary

Also see **progress on charmonium and XYZ states at BESIII**- Xiaorong Zhou

Flavor and precision physics :Experiments- Bostjan Golob

BESIII experiment





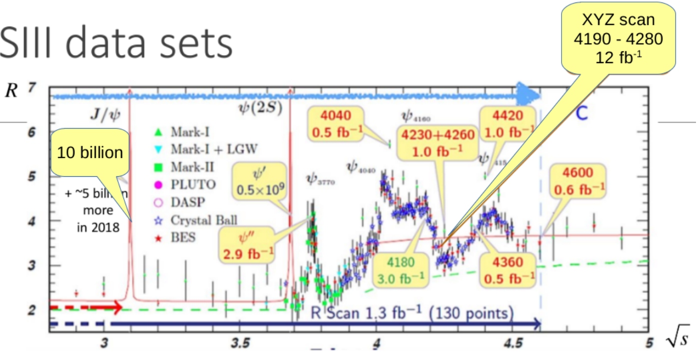
BEPCII

- Two ring symmetric e^+e^- collider; circumference: 240 m and with a design instantaneous luminosity of $1 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$.
- $\sqrt{s}$: 2 - 4.6 GeV.
- Beam crossing angle 22 mrad.

BESIII

- Hermeticity 93% of 4π
- MDC: σ_p/p= 0.5% at 1 GeV
- ToF system: σ = 80 ps (110 ps) in barrel (endcap)
- ECL: σ_E/E = 2.5 % at 1 GeV
- Superconducting solenoid (SSM): $\Rightarrow$ 1 T

BESIII data sets



$D^{0(+)}$ data

- $e^+e^- \to \psi(3770) \to D^0\bar{D}^0(D^+D^-)$.
- $\int \mathcal{L}dt = 2.93$ fb^{-1} at $\sqrt{s} = 3.774$ GeV.
- $N_{D^0\bar{D}^0}$: 10M, $N_{D^+D^-}$: 8M

D_s^+ data

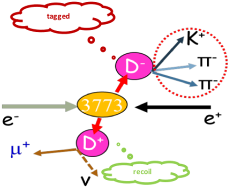
- $e^+e^- \to D_S D_S^{*-}, D_S^{*-} \to D_S^- \gamma$.
- $\int \mathcal{L}dt = 3.19$ fb^{-1} at $\sqrt{s} = 4.178$ GeV.
- $N_{D_s^+D_s^{*-}}$: 3M

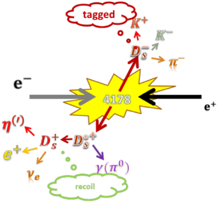
$\Lambda_c^+\Lambda_c^-$ data

- $e^+e^- \to \Lambda_c^+\Lambda_c^-$.
- $\int \mathcal{L}dt = 0.57$ fb^{-1} at $\sqrt{s} = 4.6$ GeV.

Singletag and doubletag techniques

Threshold production $\Rightarrow$ no other particles are produced along with a $D\bar{D}$, $D^0\bar{D}^0$, $\Lambda_c^+\Lambda_c^-$.





Single tag $\Rightarrow$ reconstruct only one D meson.

Double tag $\Rightarrow$ full reconstruction of events.

$$\Delta E = E_D - E_{beam}$$

$$\Delta M_{BC} = \sqrt{E_{beam}^2 - p_D^2}$$

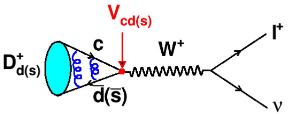
Advantages

- Absolute BF measurements possible.
- Full kinematic constraints: possible to reconstruct ν and K_L^0.
- Low background.

Disadvantage

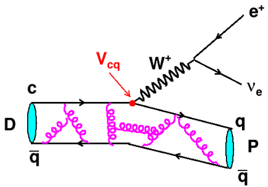
- Low reconstruction efficiency.

Leptonic decays of a $D^{\pm}, D_s^{\pm}$



$$\Gamma(D_s^+ \to l^+\nu_l) = \frac{G_F^2}{8\pi} f_{D_s^+}^2 |V_{cs}|^2 m_l^2 m_{D_s^+} \left(1 - \frac{m_l^2}{m_{D_s^+}^2}\right)^2$$

Semi leptonic decays of a $D^{\pm}, D_s^{\pm}$



∗ f function of four momentum of W

V_{cs}/V_{cd}

- Take $f^+_{D_s}/f^+_{D^+}$ from LQCD and get

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Test of unitarity.

$f^+_{D_s}/f^+_{D^+}$

- Input V_{cs}/V_{cd} get $f^+_{D_s}/f^+_{D^+}$.
- Test LQCD.
- Precision of experiments still limited compared to LQCD.

Lepton flavor universality(LFU)

- Hints of LFU violation in B decays (PRD 94, 072007 (2016), JHEP.08 (2017) 055).

$D_s^+ \to \mu^+\nu_\mu$ (PRL 122 071802 (2019))

- More precise measurement than previous BESIII result (PRD 94, 072004).
- $D_s^\pm$ reconstructed in 14 different ST modes.

$$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (5.49 \pm 0.16 \pm 0.15) \times 10^{-3}$$
$$f_{D_s^+}|V_{cs}| = 246.2 \pm 3.6 \pm 3.5 \text{ MeV}$$

Input $|V_{cs}|$: $0.97359^{+0.00010}_{-0.00011}$

$$f_{D_s^+} = 252.9 \pm 3.7 \pm 3.6 \text{ MeV}$$

Input $f_{D_s^+}$:0.249.9±0.4 MeV

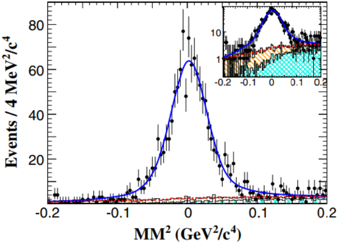
$$|V_{cs}| = 0.985 \pm 0.014 \pm 0.014$$

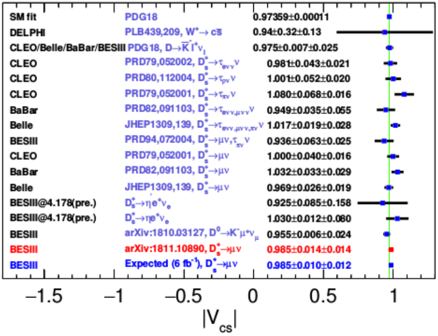
Using PDG value of $\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$

$$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)} = 9.98 \pm 0.52$$

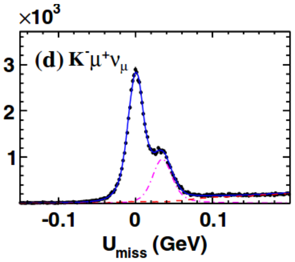
⋆ Consistent with SM prediction 9.74 ⇒ no evidence of LFU violation observed.

Analysis in $\tau^+\nu_\tau$ ongoing.





$D^0 \to K^- \mu^+ \nu_\mu$ (PRL 122(2019)011804)

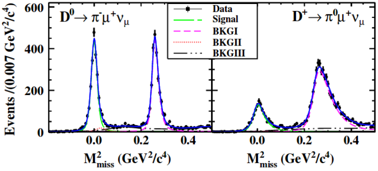


DT analysis with 3 pseudoflavor tags.

$$\mathcal{B}(D^0 \to K^- \mu^+ \nu_\mu) = (3.413 \pm 0.019 \pm 0.035)\%$$
$$f_+^K(0) = 0.7327 \pm 0.0039 \pm 0.0030$$
$$|V_{cs}| = 0.955 \pm 0.005 \pm 0.004 \pm 0.024$$

$$\mathcal{R}^0 = \frac{\mathcal{B}(D^0 \to K^- \mu^+ \nu_\mu)}{\mathcal{B}(D^0 \to K^- e^+ \nu_e)} = 0.974 \pm 0.007 \pm 0.012$$

$D^0 \to \pi^- \mu^+ \nu_\mu$ (PRL 121(2018)171803)



ST analysis with 3 pseudo-flavor tags for D^0 and 6 hadronic decay modes for D^+.

$$\mathcal{B}(D^0 \to \pi^- \mu^+ \nu_\mu) = (0.272 \pm 0.008 \pm 0.006)\%$$
$$\mathcal{B}(D^+ \to \pi^0 \mu^+ \nu_\mu) = (0.350 \pm 0.011 \pm 0.010)\%$$

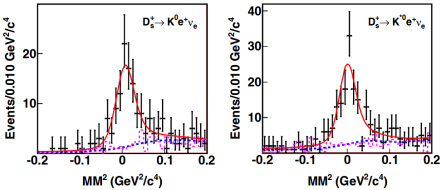
$$\mathcal{R}^0 = \frac{\mathcal{B}(D^0 \to \pi^- \mu^+ \nu_\mu)}{\mathcal{B}(D^0 \to \pi^- e^+ \nu_e)} = 0.922 \pm 0.030 \pm 0.022$$
$$\mathcal{R}^+ = \frac{\mathcal{B}(D^+ \to \pi^0 \mu^+ \nu_\mu)}{\mathcal{B}(D^+ \to \pi^0 e^+ \nu_e)} = 0.964 \pm 0.037 \pm 0.026$$

$$\mathcal{R}^0 = 0.985 \pm 0.002 \quad \text{(SM)}$$

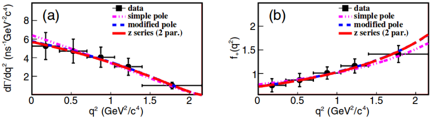
- ⋆ $\mathcal{R}^0$ and $\mathcal{R}^+$ are consistent with theoretical expectation of LFU within 1.7σ and 0.5σ.

$D_s^+ \to K^0 e^+ \nu_e$ and $K^{*0} e^+ \nu_e$ PRL 122, 061801 (2019)

- First measurement of form factor.
- DT analysis with 13 tag modes.
- Form factors from fit (least χ^2 fits) to differential decay rates in various q^2 bins.



	Values
$f_+^{D_s^+ \to K^0}(0)/f_+^{D^+ \to \pi^0}(0)$	$1.16 \pm 0.14(\text{stat}) \pm 0.02(\text{syst})$
$r_V^{D_s^+ \to K^{*0}}/r_V^{D^+ \to \rho^0}$	$1.13 \pm 0.26(\text{stat}) \pm 0.11(\text{syst})$
$r_2^{D_s^+ \to K^{*0}}/r_2^{D^+ \to \rho^0}$	$0.93 \pm 0.36(\text{stat}) \pm 0.10(\text{sys}$



$$f_+(0) = 0.720 \pm 0.084 \pm 0.013$$
$$r_V = V(0)/A_1(0) = 1.67 \pm 0.34 \pm 0.16$$
$$r_2 = A_2(0)/A_1(0) = 0.77 \pm 0.28 \pm 0.07$$

$$\mathcal{B}(D_S^+ \to K^0 e^+ \nu_e) = (3.25 \pm 0.38 \pm 0.16) \times 10^{-3}$$
$$\mathcal{B}(D_S^+ \to K^{*0} e^+ \nu_e) = (2.37 \pm 0.26 \pm 0.20) \times 10^{-3}$$

Hadronic decays

- Different final states possible: PP, VP, SP, AP ,TP...
- Absolute BF measurements.
- Testing asymmetry in decay of $D^0 \to K^0_{S,L} X$ (X $= \eta, \eta', \omega, \phi$).

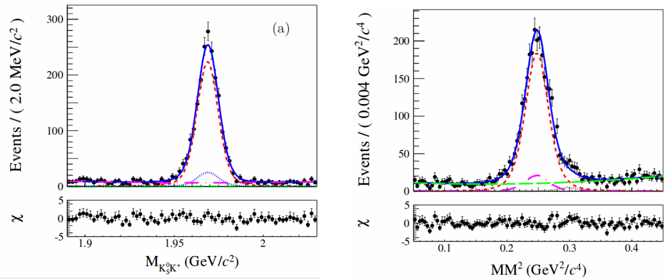
Amplitude analysis

- Theoretical treatment of weak decays of charm quark is very challenging
  - Not light enough to apply chiral perturbation theory reliably.
  - Not heavy enough to apply heavy quark expansion tools.
- Better understanding the resonant substructures of sub decay modes
  - Inputs phenomenological models for charm meson decays.
  - Explore various binning to measure c_i and s_i.

Analysis of $D_S^+ \to K_S^0 K^+$ and $D_S^+ \to K_L^0 K^+$ (arXiv:1903.04164)

Interference of $D \to \bar{K}^0 X$ (CF) and $D \to K^0 X$ (DCS) transitions results in measurable K_S^0-K_L^0 asymmetry. (PLB 349, 363, (1995))

Validation of various phenomenological models of K_S^0-K_L^0 asymmetry. (PRD 81 014026 (2010), PRD 81 074021 (2010), PRD 91 014019 (2015), PRD 92 014004 (2017))



$$MM^2 = (P_{e^+e^-} - P_{D_s^-} - P_\gamma - P_{K^+})^2$$

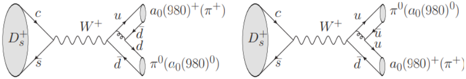
$\mathcal{B}(D_s^+ \to K_S^0 K^+) = (1.425 \pm 0.038 \pm 0.031)\%$ (consistent with WA)
$\mathcal{B}(D_s^+ \to K_L^0 K^+) = (1.485 \pm 0.039 \pm 0.046)\%$ (First measurement; consistent)

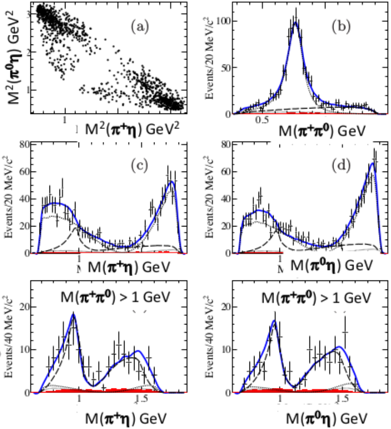
$$\frac{\mathcal{B}(D_s^+ \to K_S^0 K^+) - \mathcal{B}(D_s^+ \to K_L^0 K^+)}{\mathcal{B}(D_s^+ \to K_S^0 K^+) + \mathcal{B}(D_s^+ \to K_L^0 K^+)} = (-2.1 \pm 1.9 \pm 1.6)\%$$ (First measurement; consistent)

Amplitude analysis of $D_S^+ \to \pi^+\pi^0\eta$ (arXiv: 1903.04118)

First observation of pure W annihilation decays $D_S^+ \to a_0(980)^0\pi^+$ and $D_S^+ \to a_0(980)^+\pi^0$

1239 events with 97.7% purity.



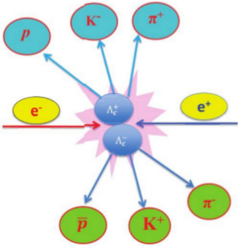


Amplitude	ϕ_n (rad)	FF$_n$
$D_s^+ \to \rho^+\eta$	0.0 (fixed)	$0.783 \pm 0.050 \pm 0.021$
$D_s^+ \to (\pi^+\pi^0)_V\eta$	$0.612 \pm 0.172 \pm 0.342$	$0.054 \pm 0.021 \pm 0.025$
$D_s^+ \to a_0(980)\pi$	$2.794 \pm 0.087 \pm 0.044$	$0.232 \pm 0.023 \pm 0.033$

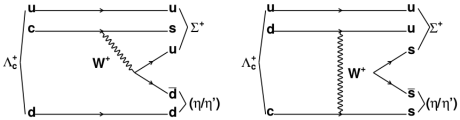
$$\mathcal{B}(D_S^+ \to \pi^+\pi^0\eta) = (9.50 \pm 0.28 \pm 0.41)\%$$
$$\mathcal{B}(D_S^+ \to a_0(980)^{+(0)}\pi^{0(+)}), (a_0(980)^{+(0)} \to \pi^{+(0)}\eta) = (1.46 \pm 0.15 \pm 0.23)\%$$

Λ_c physics

- Lightest in the family singly charmed meson: $\Sigma_c, \Xi_c, \Omega_c$.
- Proposed in 1975 and observed in 1980 by Mark II (PRL 44,10,(1980))
- Many observations and first measurement from LHCb, BaBar, Belle and BESIII $\Rightarrow$ resurgence in interest in charmed baryons.
- Precision test of strong and weak interaction complimentary to charmed meson.
- Charmed baryonic modes are the most favourable decay of beauty baryon.
- Known exclusive decays accounts only about 60% of the total BF



$\Lambda_c \to \Sigma^+\eta$ and $\Sigma^+\eta'$ (arXiv: 1811.08028)



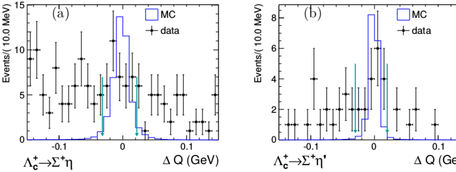
- CF decays proceeds through non-factorizable internal W emission and exchange.
- Singletag analysis with $\Lambda \to \Sigma^+\eta, \Sigma^+\eta', \Sigma^+\pi^0, \Sigma^+\pi^0$

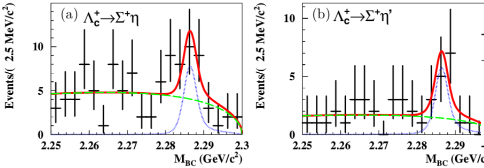
$$\mathcal{B}(\Lambda_c \to \Sigma^+\eta) = (0.41 \pm 0.19 \pm 0.05)\%$$
$$\mathcal{B}(\Lambda_c \to \Sigma^+\eta') = (1.34 \pm 0.53 \pm 0.21)\%$$

M_{BC} and ΔE as selection variable.

Additional variable
$\Delta Q \equiv \Delta E - k.(M_{p\pi^0} - m_{\Sigma^+})$.

K determined from 2D fit to ΔE vs $M_{p\pi^0}$ with linear function.

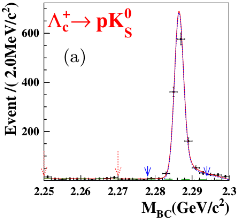




Decay mode	ΔQ (GeV)	N_i	ε_i (%)
(a) $\Lambda_c^+ \to \Sigma^+\eta$	[−0.032, 0.022]	14.6±6.6	7.80
(b) $\Lambda_c^+ \to \Sigma^+\eta'$	[−0.030, 0.020]	13.0±4.8	4.61
(c) $\Lambda_c^+ \to \Sigma^+\pi^0$	[−0.050, 0.030]	122.4±14.5	8.98
(d) $\Lambda_c^+ \to \Sigma^+\omega$	[−0.030, 0.020]	135.4±20.4	7.83

Weak decay asymmetries of $\Lambda_c \to pK_S^0, \Lambda\pi^+, \Sigma^+\pi^0, \Sigma^0\pi^+$ (arXiv: 1905.04707)

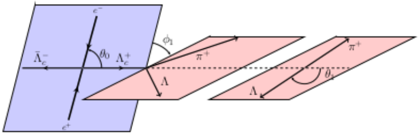
- First study of transverse polarisation of Λ_c^+.
- pK_S^0 and $\Sigma^0\pi^+$ asymmetry parameter. measured for the first time.



Decay asymmetry parameter for $\Lambda \to BP$: α_{BP}^+

$$\alpha_{BP}^+ = \frac{2Re(s.p)}{|s|^2+|p|^2}$$

s: parity violating s-wave amplitude p: parity conserving p-wave amplitude.



final state	α_{BP}^+
pK_S^0	0.18 $\pm$ 0.43 $\pm$ 0.14
$\Lambda\pi^+$	-0.80 $\pm$ 0.11 $\pm$ 0.02
$\Sigma^+\pi^0$	-0.57 $\pm$ 0.10 $\pm$ 0.07
$\Sigma^0\pi^+$	-0.73 $\pm$ 0.17 $\pm$ 0.07

$$\frac{dN}{dcos\theta_2} \propto 1 + \alpha_{\Lambda\pi^+(\Sigma^+\pi^0)}\alpha_{\Lambda(\Sigma^+)}\cos\theta_2$$

⋆ Negative sign of $\alpha_{\Sigma^+\pi^0}^+$ confirmed and deviates by 8σ from model predictions. (PRD 48, 4188 (1993), PRD 10, 1042 (1992), PRD 50, 5787, (1994))

⋆ No theoretical prediction consistent with experiment for $\alpha_{pK_S^0}^+$, $\alpha_{\Sigma^+\pi^0}^+$ and $\alpha_{\Sigma^0\pi^+}^+$.

Summary

In this talk

Leptonic decays

$D_s^+ \to \mu^+\nu_\mu$

Semi Leptonic decays

$D^0 \to K^-\mu^+\nu_\mu$
$D^0 \to \pi^-\mu^+\nu_\mu$
$D_s^+ \to K^{(*)0}e^+\nu_e$

Amplitude analyses

$D_S^+ \to \pi^+\pi^0\eta$

Λ_c

$\Lambda_c \to \Sigma^+\eta, \Sigma^+\eta'$
$\Lambda_c \to pK_S^0, \Lambda\pi^+, \Sigma^+\pi^0, \Sigma^0\pi^+$

Similar but not presented here

Mainly focused on BF and decay constant measurements.

$D_S^+ \to p\bar{n}$
(PRD 99, 031101 (2019))
$D_S^+ \to \omega\pi^+, D_S^+ \to \omega K^+$
(arXiv: 1811.00392)
$D^0 \to \bar{K}^0\pi^-e^+\nu_e,$
(PRD. 99 011103 (2019))
$D \to \pi\pi e\nu_e$
(PRL 122 062001 (2019))
$D^+ \to \eta^{(\prime)}e^+\nu_e$
(PRL 122 062001 (2019))
$D_s^+ \to \eta^{(\prime)}e^+\nu_e$
(PRL 122 121801 (2019))
$\Lambda_c^+ \to \Lambda\eta\pi^+, \Lambda\Sigma^+(1385)\eta$
(PRD 99 032010 (2019))

Many more open charm results in progress will appear soon.

Highlights

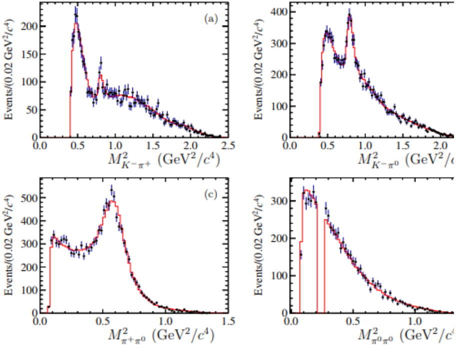
- Improved branching fraction measurements.
- LFU: no violation with current level of statistics.
- Decay asymmetry of $D_S^+ \to K_S^0K^+$ and $D_S^+ \to K_L^0K^+$ were measured for first time and is consistent with the theoretical prediction.
- Weak decay asymmetry of $\Lambda_c \to pK_S^0, \Lambda\pi^+, \Sigma^+\pi^0, \Sigma^0\pi^+$ were presented - theoretical value inconsistent with experiment.

Thank you

Amplitude analysis of $D^0 \to K^-\pi^+\pi^0\pi^0$ (arXiv: 1903.06316)

- $K3\pi$ modes with two or more π^0's are not measured so far.
- First amplitude analysis and $\mathcal{BF}$ measurement of this mode.

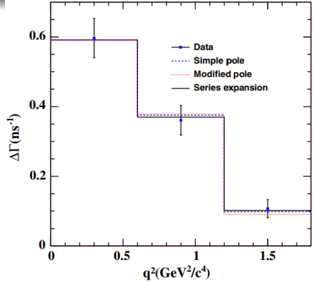
Amplitude mode	FF (%)	Phase (ϕ)	Significance (σ)
$D \to SS$			
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_S$	$6.92 \pm 1.44 \pm 2.86$	$-0.75 \pm 0.15 \pm 0.47$	> 10
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_S$	$4.18 \pm 1.02 \pm 1.77$	$-2.90 \pm 0.19 \pm 0.47$	6.0
$D \to AP, A \to VP$			
$D \to K^-a_1(1260)^+, \rho^+\pi^0[S]$	$28.36 \pm 2.50 \pm 3.53$	0 (fixed)	> 10
$D \to K^-a_1(1260)^+, \rho^+\pi^0[D]$	$0.68 \pm 0.29 \pm 0.30$	$-2.05 \pm 0.17 \pm 0.25$	6.1
$D \to K_1(1270)^-\pi^+, K^{*-}\pi^0[S]$	$0.15 \pm 0.09 \pm 0.15$	$1.84 \pm 0.34 \pm 0.43$	4.9
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[S]$	$0.39 \pm 0.18 \pm 0.30$	$-1.55 \pm 0.20 \pm 0.26$	4.8
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[D]$	$0.11 \pm 0.11 \pm 0.11$	$-1.35 \pm 0.43 \pm 0.48$	4.0
$D \to K_1(1270)^0\pi^0, K^-\rho^+[S]$	$2.71 \pm 0.38 \pm 0.29$	$-2.07 \pm 0.09 \pm 0.20$	> 10
$D \to (K^{*-}\pi^0)_A\pi^+, K^{*-}\pi^0[S]$	$1.85 \pm 0.62 \pm 1.11$	$1.93 \pm 0.10 \pm 0.15$	7.8
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[S]$	$3.13 \pm 0.45 \pm 0.58$	$0.44 \pm 0.12 \pm 0.21$	> 10
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[D]$	$0.46 \pm 0.17 \pm 0.29$	$-1.84 \pm 0.26 \pm 0.42$	5.9
$D \to (\rho^+K^-)_A\pi^0, K^-\rho^+[D]$	$0.75 \pm 0.40 \pm 0.60$	$0.64 \pm 0.36 \pm 0.53$	5.1
$D \to AP, A \to SP$			
$D \to ((K^-\pi^+)_{S\text{-wave}}\pi^0)_A\pi^0$	$1.99 \pm 1.08 \pm 1.55$	$-0.02 \pm 0.25 \pm 0.53$	7.0
$D \to VS$			
$D \to (K^-\pi^0)_{S\text{-wave}}\rho^+$	$14.63 \pm 1.70 \pm 2.41$	$-2.39 \pm 0.11 \pm 0.35$	> 10
$D \to K^{*-}(\pi^+\pi^0)_S$	$0.80 \pm 0.38 \pm 0.26$	$1.59 \pm 0.19 \pm 0.24$	4.1
$D \to K^{*0}(\pi^0\pi^0)_S$	$0.12 \pm 0.12 \pm 0.12$	$1.45 \pm 0.48 \pm 0.51$	4.1
$D \to VP, V \to VP$			
$D \to (K^{*-}\pi^+)_V\pi^0$	$2.25 \pm 0.43 \pm 0.45$	$0.52 \pm 0.12 \pm 0.17$	> 10
$D \to VV$			
$D \to K^{*-}\rho^+[S]$	$5.15 \pm 0.75 \pm 1.28$	$1.24 \pm 0.11 \pm 0.23$	> 10
$D \to K^{*-}\rho^+[P]$	$3.25 \pm 0.55 \pm 0.41$	$-2.89 \pm 0.10 \pm 0.18$	> 10
$D \to K^{*-}\rho^+[D]$	$10.90 \pm 1.53 \pm 2.36$	$2.41 \pm 0.08 \pm 0.16$	> 10
$D \to (K^-\pi^0)_V\rho^+[P]$	$0.36 \pm 0.19 \pm 0.27$	$-0.94 \pm 0.19 \pm 0.28$	5.7
$D \to (K^-\pi^0)_V\rho^+[D]$	$2.13 \pm 0.56 \pm 0.92$	$-1.93 \pm 0.22 \pm 0.25$	> 10
$D \to K^{*-}(\pi^+\pi^0)_V[D]$	$1.66 \pm 0.52 \pm 0.61$	$-1.17 \pm 0.20 \pm 0.39$	7.6
$D \to (K^-\pi^0)_V(\pi^+\pi^0)_V[S]$	$5.17 \pm 1.91 \pm 1.82$	$-1.74 \pm 0.20 \pm 0.31$	7.6
$D \to TS$			
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_T$	$0.30 \pm 0.21 \pm 0.30$	$-2.93 \pm 0.31 \pm 0.82$	5.8
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_T$	$0.14 \pm 0.12 \pm 0.10$	$2.23 \pm 0.38 \pm 0.65$	4.0
TOTAL	98.54		



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

$D^0 \to K^- a_1(1260) \Rightarrow$ dominant amplitude 28% of total fit fraction

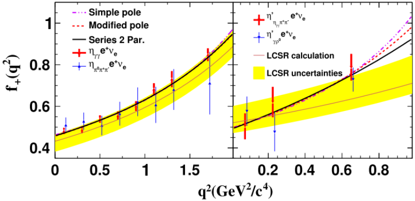
$D^+ \to \eta^{(\prime)} e^+ \nu_e$ (PRD 97(2018)092009)



$$\mathcal{B}(D^+ \to \eta e^+ \nu_e) = (10.74 \pm 0.81 \pm 0.51) \times 10^{-4}$$
$$\mathcal{B}(D^+ \to \eta' e^+ \nu_e) = (1.91 \pm 0.51 \pm 0.13) \times 10^{-4}$$
$$f_+^{D^+ \to \eta}(0)|V_{cd}| = (7.86 \pm 0.64 \pm 0.21) \times 10^{-2}$$

Fit to partial decay widths with various form factor models --→

QCD Light cone sum rules (LCSR)



$D_s^+ \to \eta^{(\prime)} e^+ \nu_e$ (PRL 122(2019)121801)

$$\mathcal{B}(D_s^+ \to \eta e^+ \nu_e) = (2.323 \pm 0.063 \pm 0.063)\ \%$$
$$\mathcal{B}(D_s^+ \to \eta' e^+ \nu_e) = (0.824 \pm 0.073 \pm 0.027)\ \%$$
$$f_+^{D_s^+ \to \eta}(0)|V_{cs}| = 0.446 \pm 0.005 \pm 0.004$$
$$f_+^{D_s^+ \to \eta'}(0)|V_{cs}| = 0.477 \pm 0.049 \pm 0.011$$

Model independent determination of Φ_p (PRL 122(2019)121801)

$$\frac{\Gamma(D_s^+ \to \eta' e^+ \nu_e)/\Gamma(D_s^+ \to \eta e^+ \nu_e)}{\Gamma(D^+ \to \eta' e^+ \nu_e)/\Gamma(D^+ \to \eta e^+ \nu_e)} \simeq \cot^4 \Phi_P$$

$$\Phi_P = (40.1 \pm 2.1 \pm 0.7)^\circ$$