Two-Body Hadronic $D_{(s)}$ Decays at BESIII

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On behalf of BESIII Collaboration

Hefei, 6th - 9th, April, 2023

2023年BESIII粲强子研讨会

Outline

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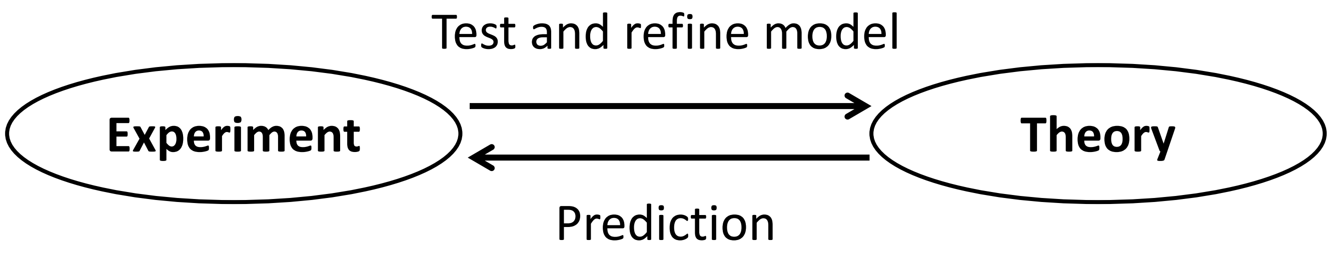
  - Measurement of W-Annihilation processes
  - $D \to \omega\phi$
  - Other works
- **Summary**

Motivation

Hadronic decays of charmed meson (weak and strong interaction)

- **To understand non-perturbative QCD**
- **To test flavor SU(3) symmetry and final-state-interaction effects**

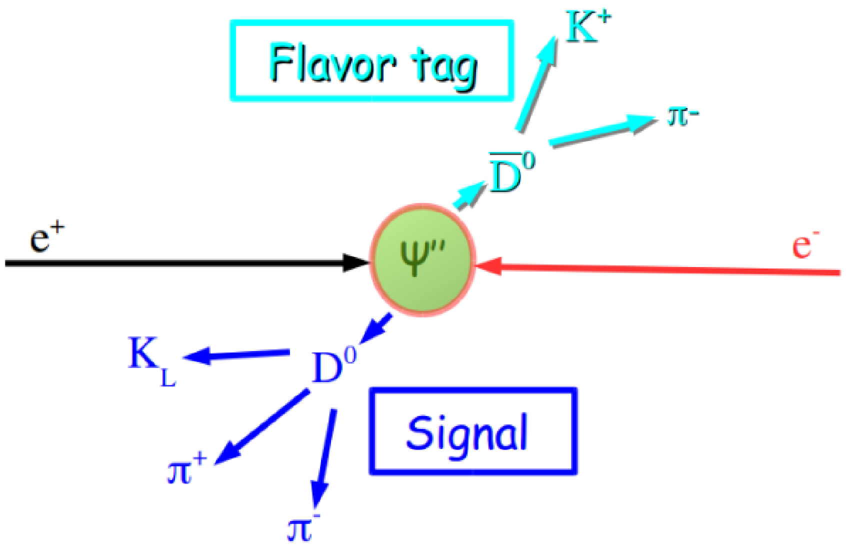


Branching fraction
Asymmetry
Strong phase
…

D meson production @ BESIII

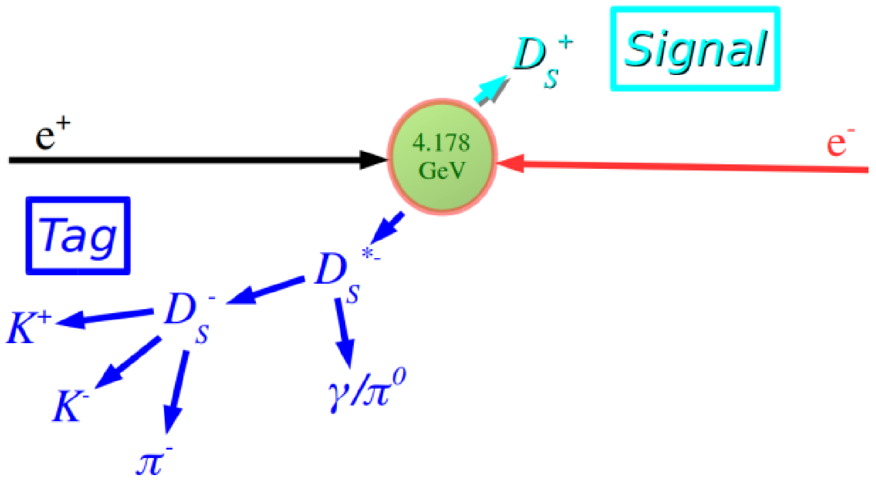
➢ **D meson pair production near threshold @ BESIII**

E_{cm} (GeV)	Pair Production	ST D Yields	Luminosity
3.773	$D^0\bar{D}^0, D^+D^-$	$2.5\text{M } D^0, 1.7\text{M } D^\pm$	2.93 fb^{-1}
4.13~4.23	$D_s^\pm D_s^{*\mp}$	$0.8\text{M } D_s^\pm$	7.33 fb^{-1}



➢ **Analysis technique**

- **Single Tag (ST): reconstruct one D**
  - Relative high efficiency and signal yields
  - Relative high background
- **Double Tag (DT): reconstruct both D**
  - Clean background
  - Full kinematic constraint
  - Absolute branching fraction measurement $\mathcal{B}_{sig} = \frac{N_{sig}^{DT}}{\Sigma_\alpha N_\alpha^{ST}\epsilon_{\alpha,sig}^{DT}/\epsilon_\alpha^{ST}}$
  - Quantum correlated $D^0\bar{D}^0$ analysis



BEPCII & BESIII

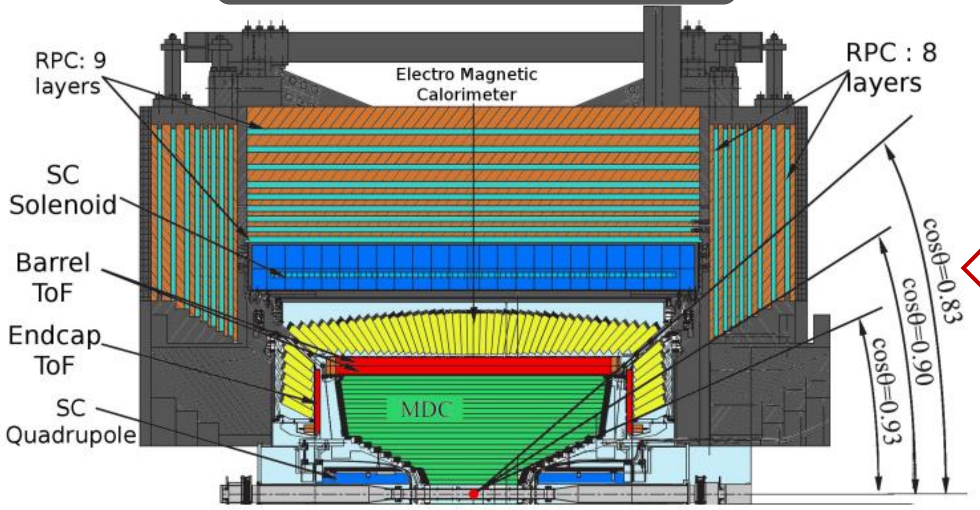
MDC: small cell & Gas:
$He/C_3H_8(60/40)$, 43 layers
$\sigma_p/p = 0.5\%@1GeV$,
$\sigma_{dE/dx} = 6\%$

TOF: Barrel: $\sigma_T = 100ps$
endcap: $\sigma_T = 110ps$
(60ps for endcap after upgraded to MRPC in 2015)

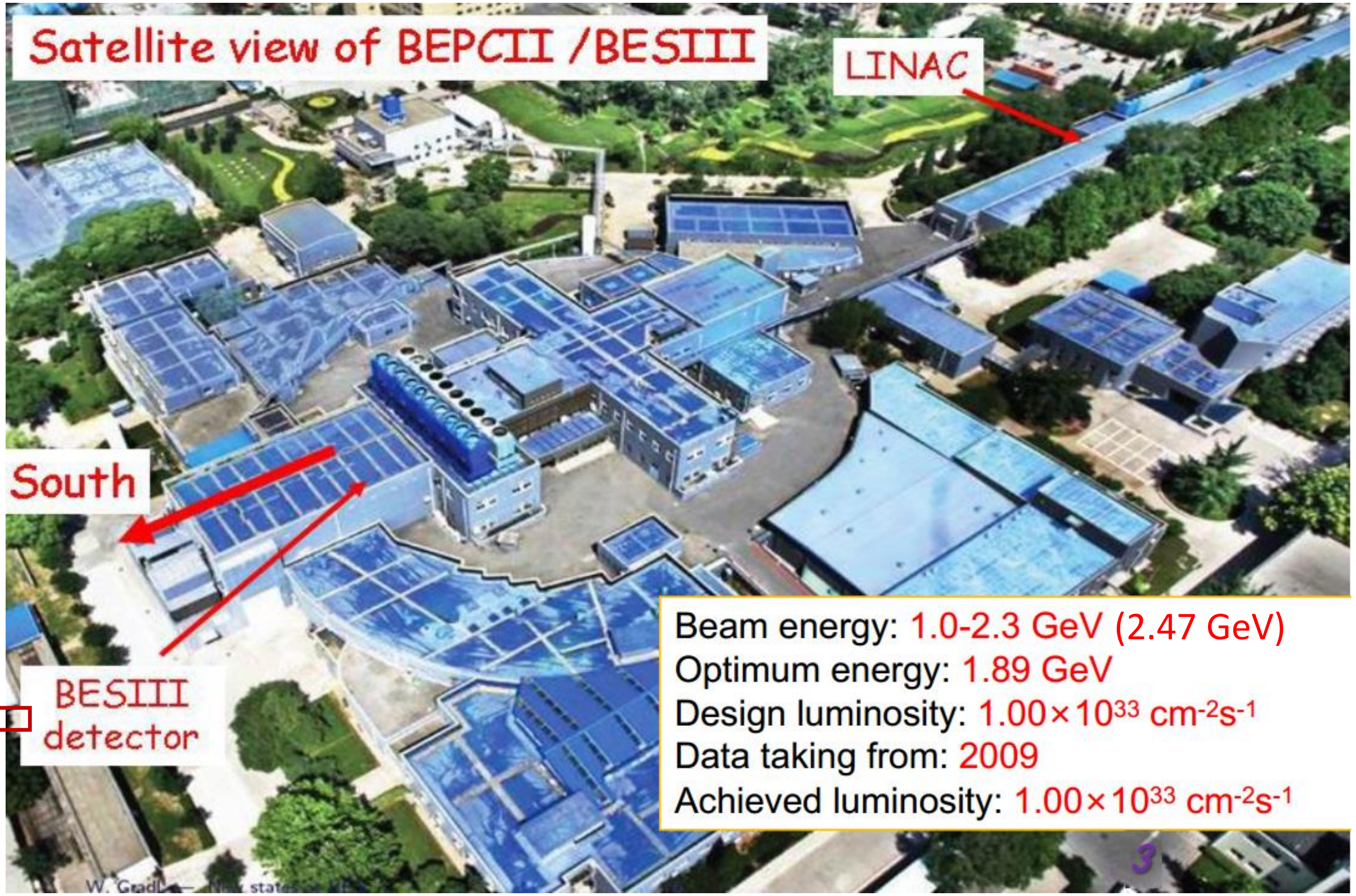
EMC: CsI crystal. 28cm
$\Delta E/E = 2.5\%@1GeV$,
$\sigma_z = 0.6cm/\sqrt{E}$

MUC: 9layers RPC
(8 layers in Endcap)
$\sigma_{R\phi} = 1.4\sim1.7cm$

Magnet: 1T Super conducting



[Nucl. Instr. Meth. A614, 345(2010)]



$K_S^0 - K_L^0$ Asymmetry in D Meson Decays

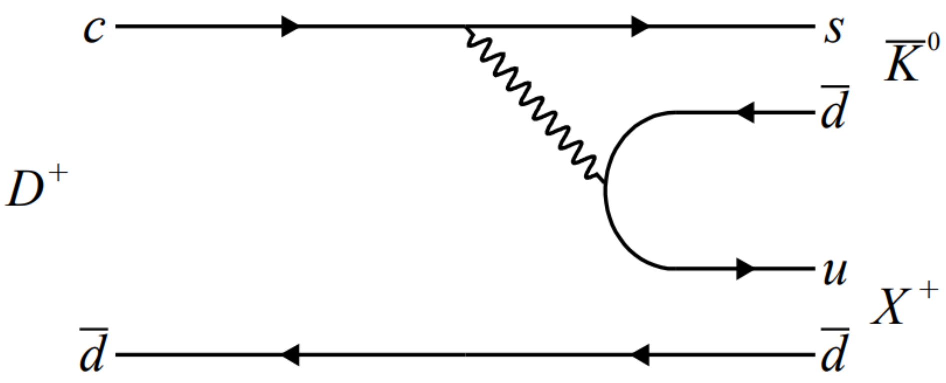
- **Interference between Cabibbo-favored (CF) and doubly Cabibbo-suppressed (DCS) amplitudes**
- **Advantage of BESIII: Full kinematic constraint → measurement of the decays with K_L^0**

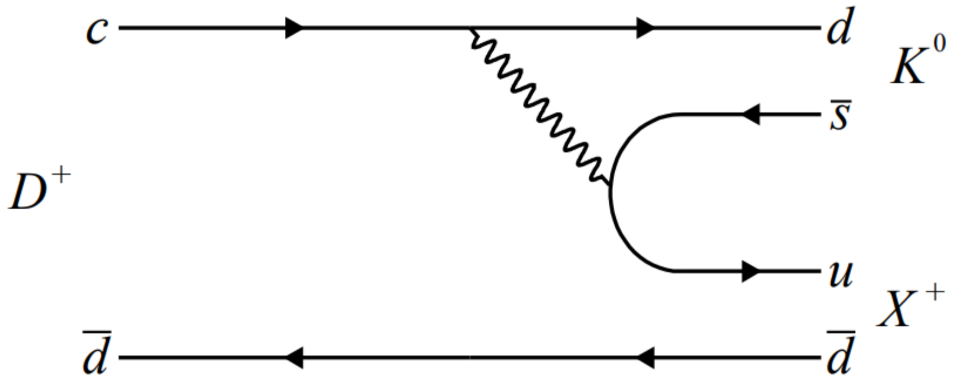
$$R(D \to K_{S,L}^0\pi) = \frac{\mathcal{B}(D \to K_S^0\pi) - \mathcal{B}(D \to K_L^0\pi)}{\mathcal{B}(D \to K_S^0\pi) + \mathcal{B}(D \to K_L^0\pi)} \sim -2r\cos\delta$$

$$\frac{A(D \to K^0\pi)}{A(D \to \overline{K}^0\pi)} = re^{i\delta}$$

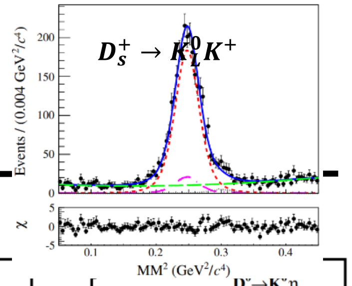
strong phase (δ)

$r \sim\lambda^2\sim 0.05$

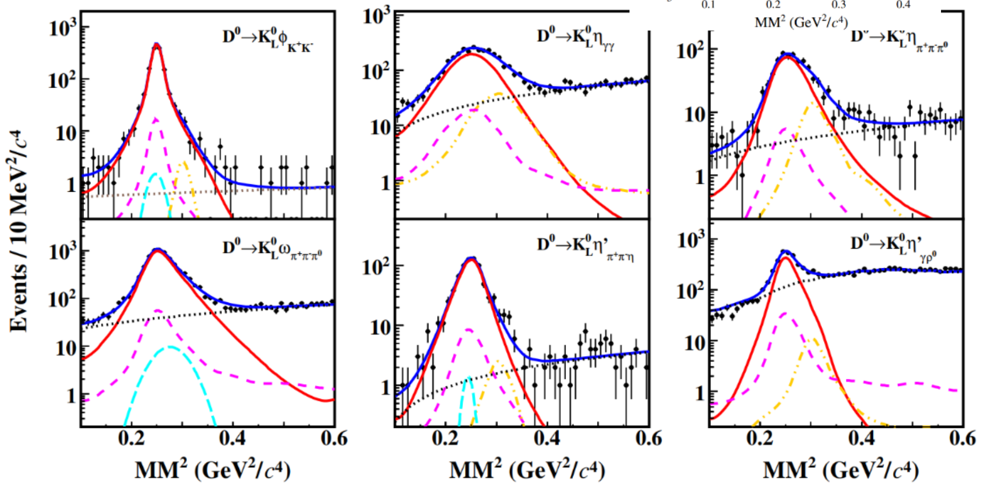




$K_S^0 - K_L^0$ Asymmetry in D Meson Decays



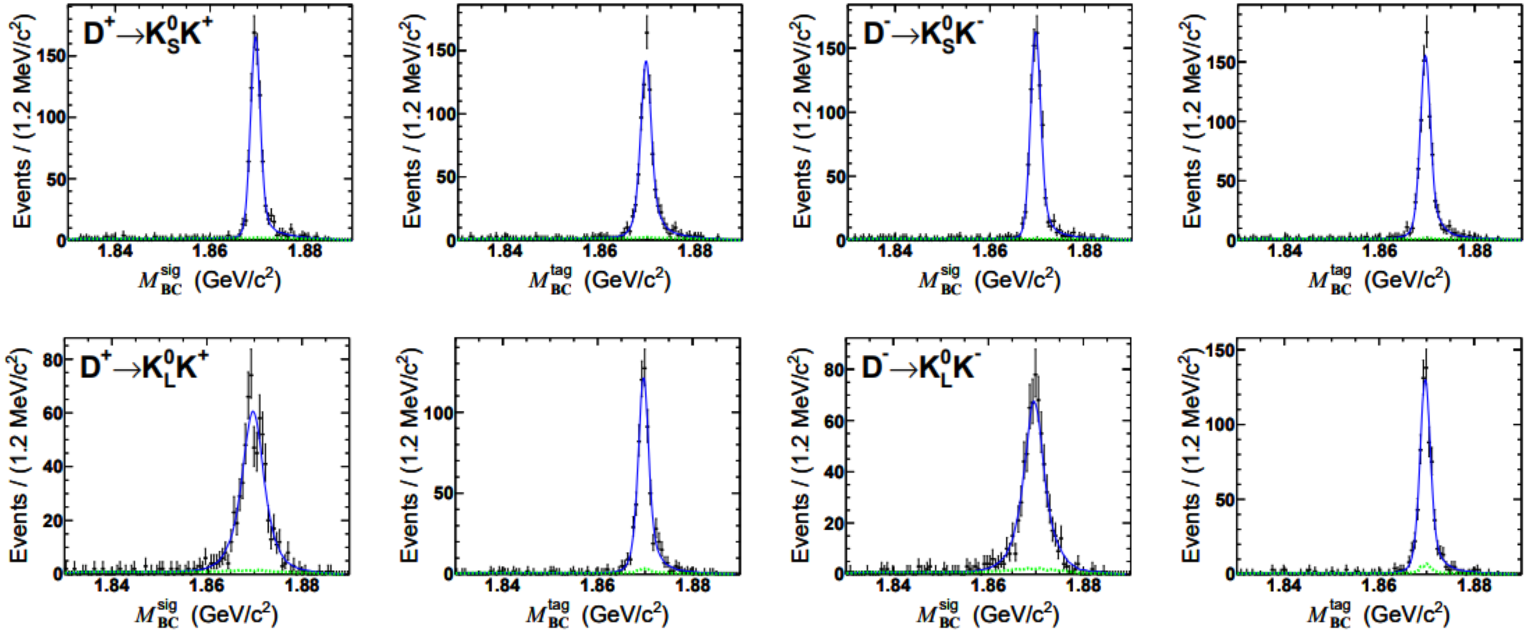
- Extract K_L^0 signal from missing mass square
- $R(D^0 \to K_{S,L}^0 P)$: consistent with the prediction under U-spin symmetry $\sim 2\lambda^2 \sim 0.1$
- $R(D^0 \to K_{S,L}^0 V)$: different with $K_{S,L}^0 P$ case (caused by W-ex amplitude?)
- $R(D_s^+ \to K_{S,L}^0 K^+)$: consistent with prediction within 2σ (precision need to be improved)



channel	Branching fraction (%)	$R(D \to K_{S,L}^0 f)$	Data Sample	Reference
$D^0 \to K_L^0 \eta$	$0.433 \pm 0.012 \pm 0.010$	0.080 ± 0.022	$2.93\ \text{fb}^{-1}$ @ 3.773 GeV	[PRD 105, 092010 (2022)]
$D^0 \to K_L^0 \eta'$	$0.809 \pm 0.020 \pm 0.016$	0.080 ± 0.023		
$D^0 \to K_L^0 \omega$	$1.164 \pm 0.022 \pm 0.028$	-0.024 ± 0.031		
$D^0 \to K_L^0 \phi$	$0.414 \pm 0.021 \pm 0.010$	-0.001 ± 0.047		
$D_s^+ \to K_S^0 K^+$	$1.425 \pm 0.038 \pm 0.031$	$-0.021 \pm 0.019 \pm 0.016$	$3.19\ \text{fb}^{-1}$ @ 4.178 GeV	[PRD 99, 112005 (2019)]
$D_s^+ \to K_L^0 K^+$	$1.485 \pm 0.039 \pm 0.046$			

Measurement of $D^+ \to K^0_{S,L}K^+$

- **Branching fractions of $D^+ \to K^0_{S,L}K^+(\pi^0)$ are measured and CPV is searched**
- **DT method with 2.93 fb^{-1} data @ $E_{cm} = 3.773$ GeV**
- **Direction of K^0_L in EMC is used in analysis**

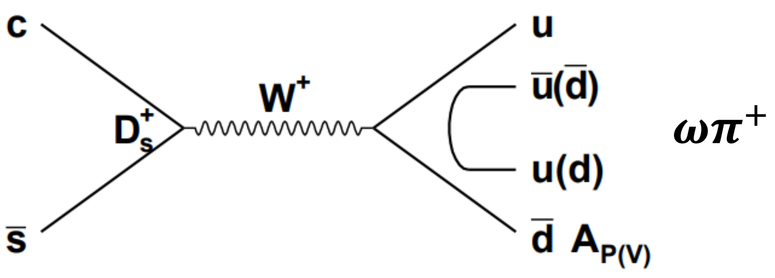


[PRD 99, 032002 (2019)]

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

$D_s^+ \to \omega\pi^+, \omega K^+$

- **Observation of W-Annihilation decay $D_s^+ \to \omega\pi^+$ and evidence of $D_s^+ \to \omega K^+$**

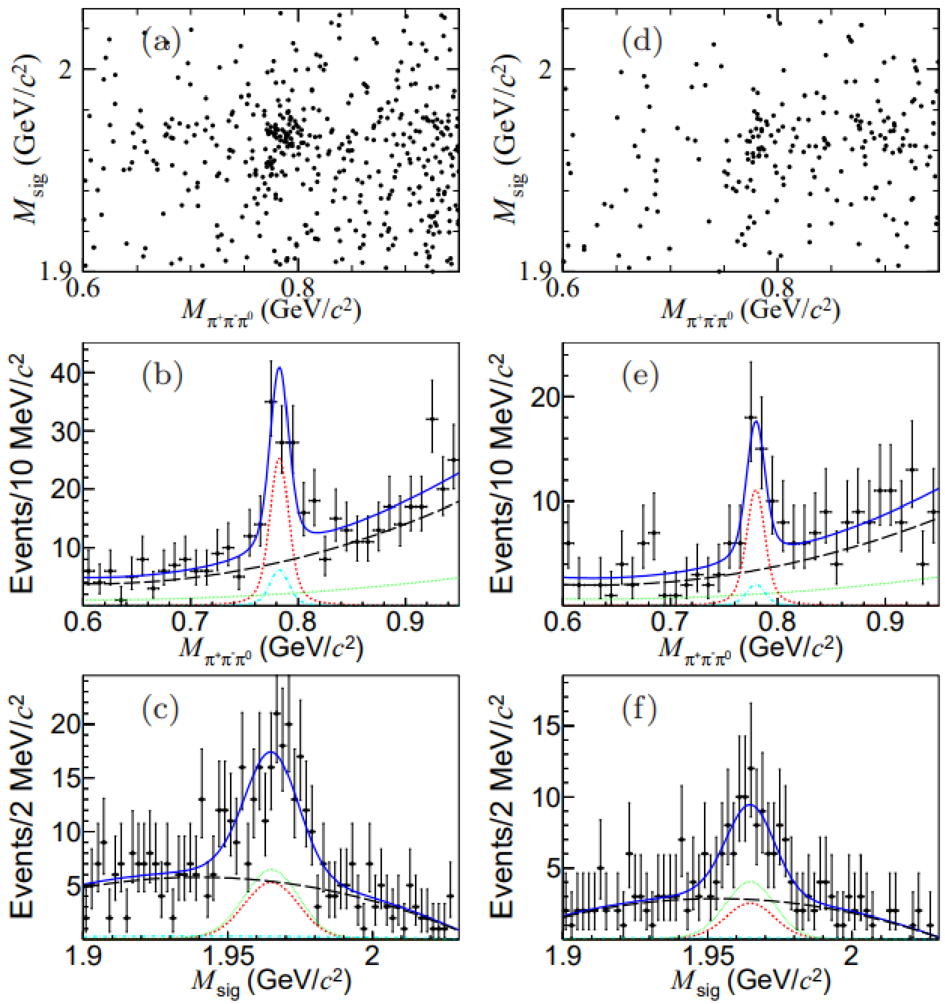


- **DT method with 3.19 fb^{-1} data @ $E_{cm} = 4.178\ GeV$**

[PRD 99, 091101(R) (2019)]

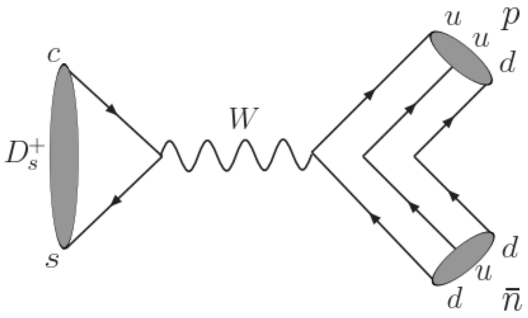
Channel	Branching fraction (10^{-3})	Significance
$D_s^+ \to \omega\pi^+$	$1.77 \pm 0.32 \pm 0.13$	6.7σ
$D_s^+ \to \omega K^+$	$0.87 \pm 0.24 \pm 0.08$	4.4σ

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



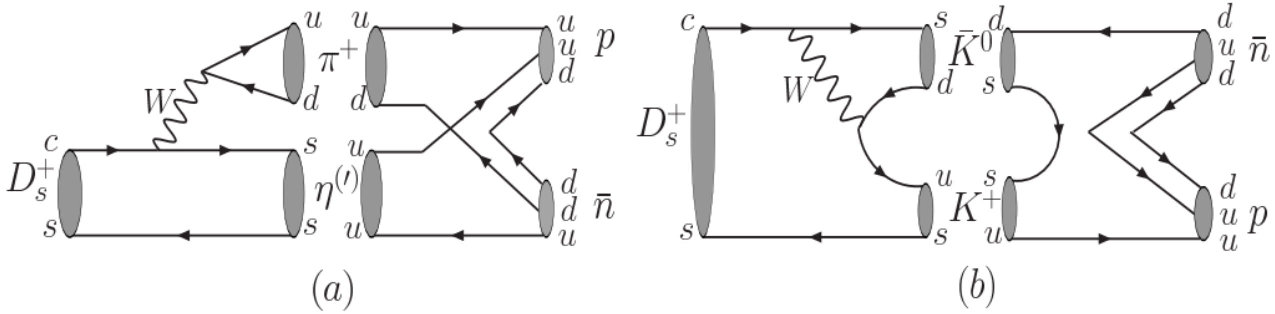
$D_s^+ \to p\bar{n}$

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



(a) Short-distance effects

helicity suppression



(b) Long-distance effects

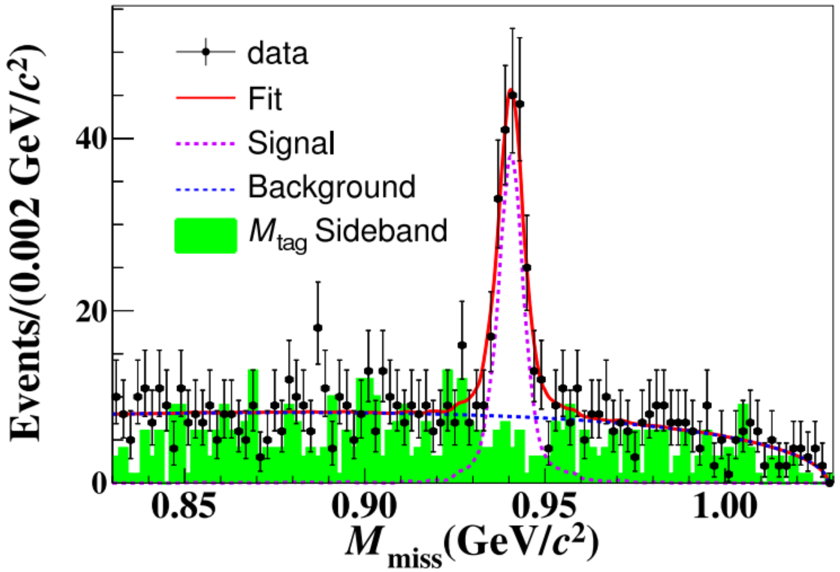
Enhance by long-distance effect

- **DT method with 3.19 fb^{-1} data @ $E_{cm} = 4.178$ GeV**

[PRD 99, 031101(R) (2019)]

Channel	Branching fraction (10^{-3})	Significance
$D_s^+ \to p\bar{n}$	$1.21 \pm 0.10 \pm 0.05$	>10σ

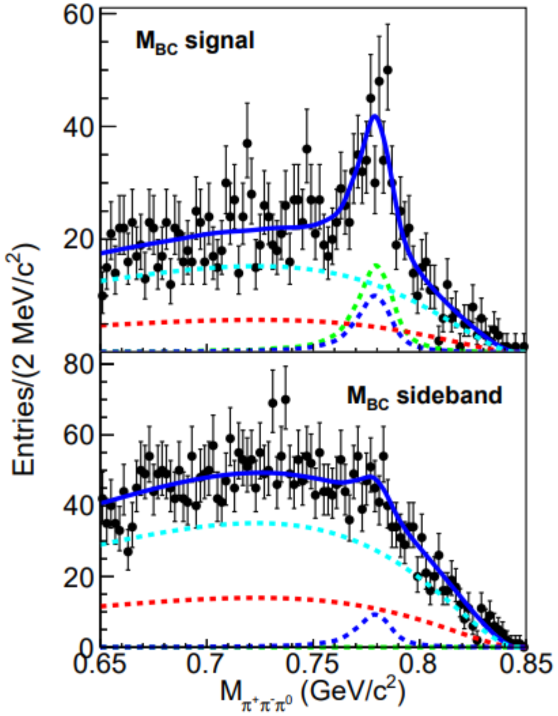
Confirm the result from CLEO's measurement

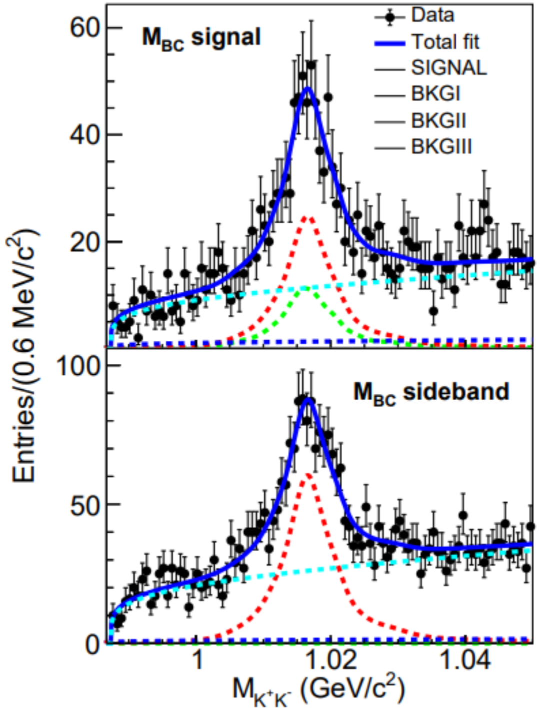


$D^0 \to \omega\phi$

- Branching fraction of $D^0 \to \omega\phi$ are measured for the first time
- ST method with 2.93 fb^{-1} data @ $E_{cm} = 3.773$ GeV

$$BF = (6.48 \pm 0.96 \pm 0.40) \times 10^{-4} \quad 6.3\sigma$$



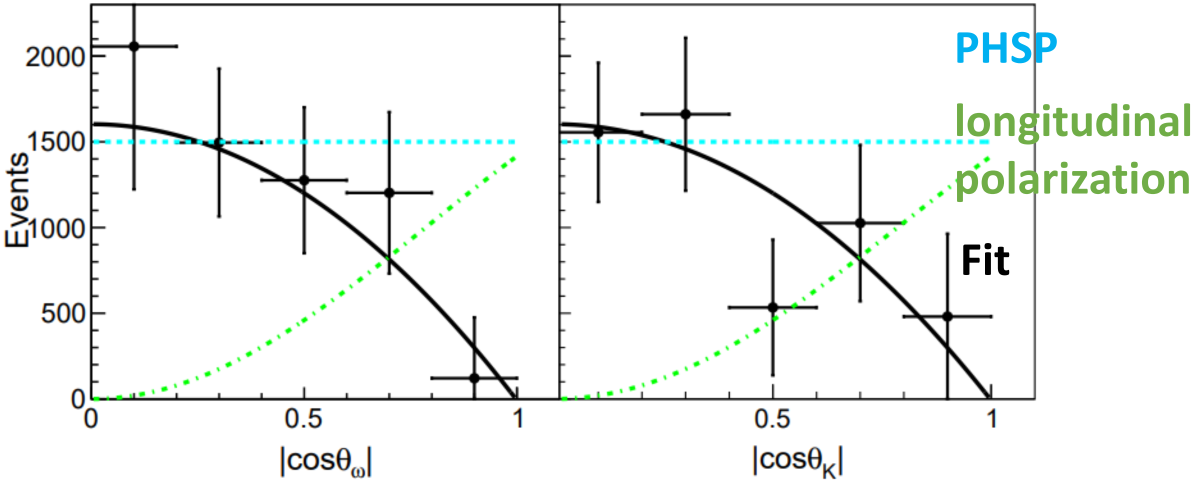


- Upper limit on longitudinal polarization faction $f_L < 0.24$ @ 95% C.L.

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta} = \frac{3}{2}\{\frac{1}{2}(1-f_L)\sin^2\theta + f_L\cos^2\theta\}$$

$$f_L = H_0^2/(H_0^2 + H_-^2 + H_+^2)$$

[PRL 128, 011803 (2022)]



$D^{+,0} \to PP(P = \pi, K, \eta, \eta')$

- The branching fractions of 14 $D^{+,0}$ two-body hadronic decays are measured
- ST method with 2.93 fb^{-1} data @ $E_{cm} = 3.773$ GeV $\quad \mathcal{B}(D \to P_1 P_2) = \frac{N_{\mathrm{net}}}{2 \times N^{\mathrm{tot}}_{D\bar{D}} \times \varepsilon \times \mathcal{B}_{\mathrm{sub}}},$

[PRD 97, 072004 (2018)]

Mode	N_{net}	ϵ (%)	$\mathcal{B}$ ($\times 10^{-3}$)	$\mathcal{B}_{\mathrm{PDG}}$ ($\times 10^{-3}$)
$D^+ \to \pi^+\pi^0$	$10\,108 \pm 267$	49.0 ± 0.3	$1.259 \pm 0.033 \pm 0.023$	1.24 ± 0.06
$D^+ \to K^+\pi^0$	1834 ± 168	48.2 ± 0.4	$0.232 \pm 0.021 \pm 0.006$	0.189 ± 0.025
$D^+ \to \pi^+\eta$	$11\,636 \pm 215$	47.0 ± 0.3	$3.790 \pm 0.070 \pm 0.068$	3.66 ± 0.22
$D^+ \to K^+\eta$	439 ± 72	44.6 ± 0.3	$0.151 \pm 0.025 \pm 0.014$	0.112 ± 0.018
$D^+ \to \pi^+\eta'$	3088 ± 83	21.5 ± 0.2	$5.12 \pm 0.14 \pm 0.024$	4.84 ± 0.31
$D^+ \to K^+\eta'$	87 ± 25	18.8 ± 0.2	$0.164 \pm 0.051 \pm 0.024$	0.183 ± 0.023
$D^+ \to K^0_S\pi^+$	$93\,883 \pm 352$	51.4 ± 0.2	$15.91 \pm 0.06 \pm 0.30$	15.3 ± 0.6
$D^+ \to K^0_S K^+$	$17\,704 \pm 151$	48.5 ± 0.1	$3.183 \pm 0.029 \pm 0.060$	2.95 ± 0.15
$D^0 \to \pi^+\pi^-$	$21\,107 \pm 249$	66.0 ± 0.3	$1.508 \pm 0.018 \pm 0.022$	1.421 ± 0.025
$D^0 \to K^+K^-$	$56\,359 \pm 272$	62.8 ± 0.3	$4.233 \pm 0.021 \pm 0.064$	4.01 ± 0.07
$D^0 \to K^\mp\pi^\pm$	$534\,135 \pm 759$	64.7 ± 0.1	$38.98 \pm 0.06 \pm 0.51$	39.4 ± 0.4
$D^0 \to K^0_S\pi^0$	$66\,552 \pm 302$	37.1 ± 0.2	$12.39 \pm 0.06 \pm 0.27$	12.0 ± 0.4
$D^0 \to K^0_S\eta$	9485 ± 126	32.0 ± 0.1	$5.13 \pm 0.07 \pm 0.12$	4.85 ± 0.30
$D^0 \to K^0_S\eta'$	2978 ± 61	12.7 ± 0.1	$9.49 \pm 0.20 \pm 0.36$	9.5 ± 0.5

$D_s^+ \to PP(P = \pi, K, \eta, \eta')$

- The branching fractions of 7 D_s^+ two-body hadronic decays are measured
- ST method with 6.32 fb^{-1} data @ $E_{cm} = 4.18 \sim 4.23$ GeV

$$R^i = \frac{\mathcal{B}^i}{\mathcal{B}^{K^+K^-\pi^+}} = \frac{n^i \cdot \bar{\varepsilon}^{K^+K^-\pi^+}}{n^{K^+K^-\pi^+} \cdot \bar{\varepsilon}^i \cdot \mathcal{B}^i_{\text{final-state}}}.$$

[JHEP 08, 146 (2020)]

Decay	n^i	$\bar{\varepsilon}^i$ (%)	R^i (%)	$\mathcal{B}^i$ (10^{-3})
$K^+\eta'$	675 ± 43	13.66 ± 0.20	$4.91 \pm 0.31 \pm 0.31$	$2.68 \pm 0.17 \pm 0.17 \pm 0.08$
$\eta'\pi^+$	9912 ± 113	14.19 ± 0.04	$69.4 \pm 0.8 \pm 3.8$	$37.8 \pm 0.4 \pm 2.1 \pm 1.2$
$K^+\eta$	1841 ± 114	26.21 ± 0.17	$2.97 \pm 0.18 \pm 0.06$	$1.62 \pm 0.10 \pm 0.03 \pm 0.05$
$\eta\pi^+$	19519 ± 192	25.86 ± 0.05	$31.94 \pm 0.33 \pm 0.49$	$17.41 \pm 0.18 \pm 0.27 \pm 0.54$
$K^+K_S^0$	35977 ± 206	31.47 ± 0.05	$27.55 \pm 0.18 \pm 0.50$	$15.02 \pm 0.10 \pm 0.27 \pm 0.47$
$K_S^0\pi^+$	2724 ± 83	32.27 ± 0.16	$2.035 \pm 0.062 \pm 0.042$	$1.109 \pm 0.034 \pm 0.023 \pm 0.035$
$K^+\pi^0$	2275 ± 149	27.96 ± 0.18	$1.373 \pm 0.090 \pm 0.033$	$0.748 \pm 0.049 \pm 0.018 \pm 0.023$
$K^+K^-\pi^+$	160262 ± 478	26.73 ± 0.02	100	54.5 ± 1.7

Uncertainty from BF of Ds->KKpi

Reference channel

$D \to PV$

- ST method with 2.93 fb^{-1} data @ $E_{cm} = 3.773$ GeV

[PRD 97, 052005 (2018)]

Decay mode	This work (10^{-3})	PDG [3] (10^{-3})
$D^0 \to \omega\eta$	$2.16 \pm 0.17 \pm 0.15$	–
$D^0 \to \eta\pi^0$	$0.59 \pm 0.05 \pm 0.05$	0.68 ± 0.07
$D^0 \to \eta'\pi^0$	$0.92 \pm 0.11 \pm 0.09$	0.90 ± 0.14
$D^0 \to \eta\eta$	$2.20 \pm 0.07 \pm 0.11$	1.67 ± 0.20
$D^0 \to \eta'\eta$	$0.93 \pm 0.24 \pm 0.10$	1.05 ± 0.26

[PLB 798, 135017 (2019)]

Decay mode	$\mathcal{B}^i (\times 10^{-4})$	
$D^+ \to \phi\pi^+$	$57.0 \pm 0.5 \pm 1.3$	
$D^+ \to \phi K^+$	$0.062^{+0.144}_{-0.062} \pm 0.002$ < 0.21 at 90% CL	evidence
$D^0 \to \phi\pi^0$	$11.68 \pm 0.28 \pm 0.28$	
$D^0 \to \phi\eta$	$1.81 \pm 0.46 \pm 0.06$	

- DT method with 2.93 fb^{-1} data @ $E_{cm} = 3.773$ GeV

[PRL 116, 082001 (2016)]

Mode	This work	Previous measurements	
$D^+ \to \omega\pi^+$	$(2.79 \pm 0.57 \pm 0.16) \times 10^{-4}$	$< 3.4 \times 10^{-4}$ at 90% C.L.	**5.5σ**
$D^0 \to \omega\pi^0$	$(1.17 \pm 0.34 \pm 0.07) \times 10^{-4}$	$< 2.6 \times 10^{-4}$ at 90% C.L.	**4.1σ**
$D^+ \to \eta\pi^+$	$(3.07 \pm 0.22 \pm 0.13) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$	
$D^0 \to \eta\pi^0$	$(0.65 \pm 0.09 \pm 0.04) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$	

BFs of $\omega\pi$ ~ 1 order lower than $\eta\pi$

Summary

- **D meson pair production data near threshold at BESIII provide a clean environment to measure the absolute branching fractions of D meson decays**

- **Based current data (2.93 $\mathbf{fb^{-1}}$ @ 3.773 GeV, 6.32 $\mathbf{fb^{-1}}$ @ 4.18~4.23 GeV), most of two-body hadronic D meson decays have been measured**
  - **The branching fraction reach to 10^{-4} for D decays and 10^{-3} for Ds decays**
  - **Only 10^{-2} sensitivity for asymmetry measurement.**

- **8 $\mathbf{fb^{-1}}$ (2.7x) data @ 3.773 GeV is ready and 20 $\mathbf{fb^{-1}}$ (6.8x) data @ 3.773 GeV is expected to be acquired at next year**

Thank you!