Charm meson decays:

spectroscopy and strong phase distribution

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Outline

Introduction

Amplitude analysis of charmed meson decays at BESIII

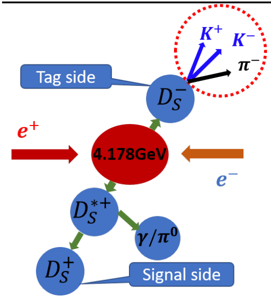
$D_S^+ \to \pi^+\pi^-\pi^+$ [arXiv: 2108.10050]
$D_S^+ \to K_S^0\pi^+\pi^0$ [JHEP 06 (2021) 181]
$D^+ \to K^+K_S^0\pi^0$ [PRD 104 (2021) 012006]
$D_S^+ \to \pi^+\pi^+\pi^-\eta$ [arXiv:2106.13536]
$D_S^+ \to K^-K^+\pi^+\pi^0$ [PRD 104 (2021) 032011]

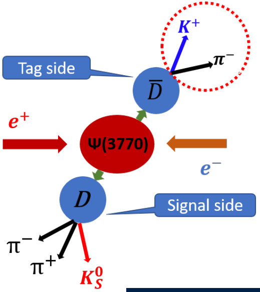
Strong phase parameters in neutral $D\bar{D}$ meson decays at BESIII

Phase variation across $D \to K_S^0\pi^+\pi^-$ Dalitz plot [PRD 101 (2020) 112002]
Phase variation in $D \to K3\pi$ phase space [JHEP 05 (2021) 164]

Summary

Charm data at BESIII

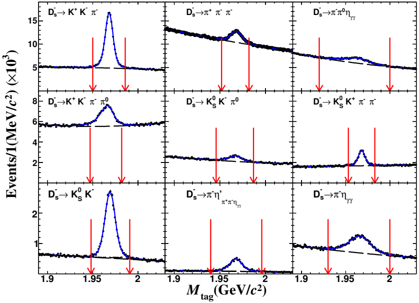




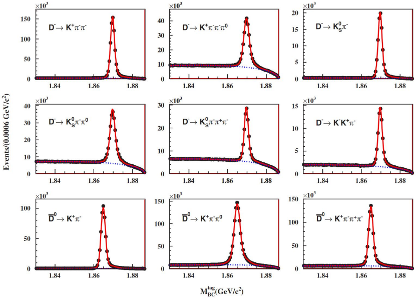
- $D_S^{*+}D_S^-$: $6.32\ \mathrm{fb}^{-1}$ at energy points 4.178-4.226 GeV
- $D\bar{D}$: $2.93\ \mathrm{fb}^{-1}$ at $\psi(3770)$ peak
- Single tag (ST): reconstruct one $D_{(S)}$
- Double tag (DT): $D_{(S)}$ in the other side
- Absolute branching fraction measurements
- Systematics in the tag side almost cancel out

Single tag $D_{(S)}$ samples at BESIII

D_S^- [JHEP 06 (2021) 181]



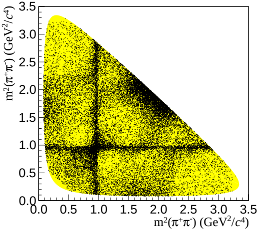
D^- / D^0 [PRD 97 (2018) 072015]



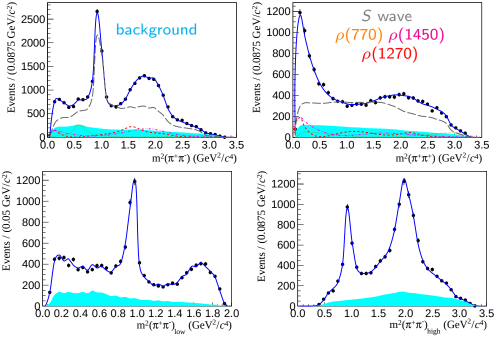
- Large ST samples by reconstructing hadronic decays with large branching fractions in the tag side
- Clean environment for amplitude analyses as continuum background is highly suppressed

Amplitude analysis of $D_S^+ \to \pi^+\pi^-\pi^+$

[arXiv: 2108.10050]



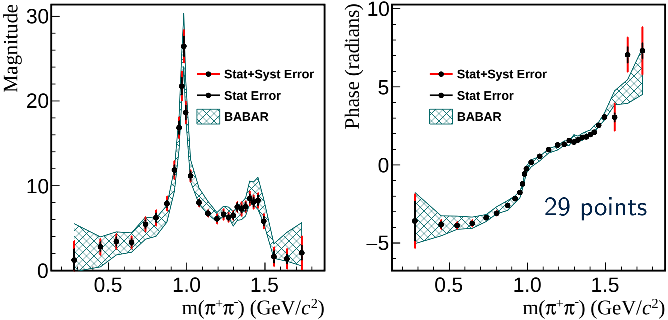
13797 signal events, ~ 80% purity



Decay mode	Fit fraction (%)	Magnitude	Phase (rad.)
$f_2(1270)\pi^+$	10.5 ± 0.8 ± 1.2	1. (Fixed)	0. (Fixed)
$\rho(770)\pi^+$	0.9 ± 0.4 ± 0.5	0.13 ± 0.03 ± 0.04	5.44 ± 0.25 ± 0.62
$\rho(1450)\pi^+$	1.3 ± 0.4 ± 0.5	0.91 ± 0.16 ± 0.22	1.03 ± 0.32 ± 0.51
S wave	84.2 ± 0.8 ± 1.3		
Total	96.8 ± 2.4 ± 3.5		

- Dominant by $\pi^+\pi^-$ *S*-wave contribution

Amplitude analysis of $D_S^+ \to \pi^+\pi^-\pi^+$

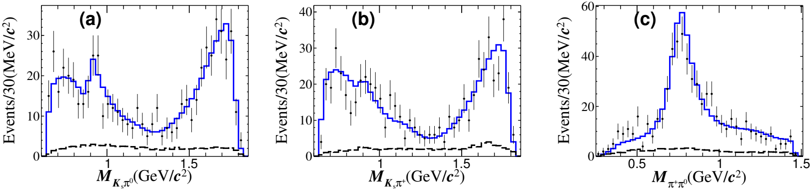


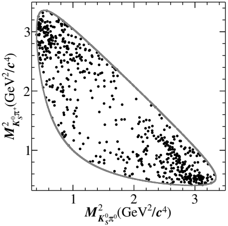
29 points

- Extract dominant $\pi^+\pi^-$ S-wave contribution with model-independent PWA [PRD 73 (2006) 032004]
- Consistent with the BABAR measurement with an improved precision [PRD 79 (2009) 032003]

Amplitude analysis of $D_S^+ \to K_S^0\pi^+\pi^0$

607 signal events with full dataset, background ~ 20% [JHEP 06 (2021) 181]





Amplitude	Magnitude (ρ_n)	Phase (ϕ_n)	FF (%)	(σ)
$K_S^0\rho^+$	1.0(fixed)	0.0(fixed)	$50.2 \pm 7.2 \pm 3.9$	>10
$K_S^0\rho(1450)^+$	2.7 ± 0.5	$2.2 \pm 0.2 \pm 0.1$	$20.4 \pm 4.3 \pm 4.4$	>10
$K^*(892)^0\pi^+$	0.4 ± 0.1	$3.2 \pm 0.2 \pm 0.1$	$8.4 \pm 2.2 \pm 0.9$	5.0
$K^*(892)^+\pi^0$	0.3 ± 0.1	$0.2 \pm 0.2 \pm 0.2$	$4.6 \pm 1.4 \pm 0.4$	4.0
$K^*(1410)^0\pi^+$	0.8 ± 0.2	$0.2 \pm 0.3 \pm 0.1$	$3.3 \pm 1.6 \pm 0.5$	3.7

- Singly Cabibbo suppressed, precision measurement help to study the SU(3) breaking effects and test the theoretical predictions (see next slide)

Amplitude analysis of $D_S^+ \to K_S^0\pi^+\pi^0$

Channel($\times 10^{-3}$)	PDG	Y.L. Wu *et al.* [1]	H.Y. Cheng *et al.* [2]	F.S. Yu *et al.*[3]
$K^0\rho^+$	–	9.1 ± 7.7	11.47 ± 0.48	7.5 ± 2.1
$K^*(892)^0\pi^+$	2.13 ± 0.36	3.3 ± 3.5	3.65 ± 0.24	1.5 ± 0.7
$K^*(892)^+\pi^0$	–	1.3 ± 1.3	1.02 ± 0.07	0.1 ± 0.1

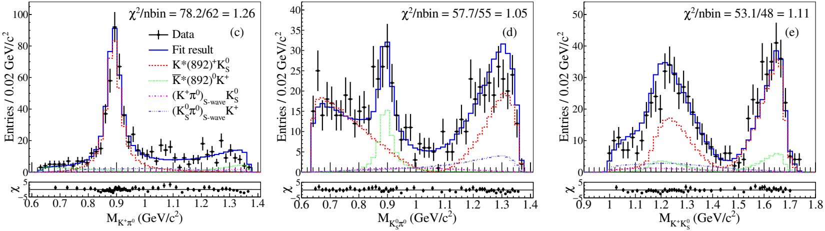
Table: [1] [EPJC 42 (2005) 391]; [2] [PRD 100 (2019) 093002]; [3] [PRD 84 (2011) 074019]

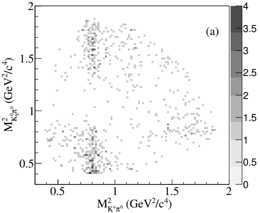
- Measured $\mathcal{B}$ are marginally consistent with Ref.[3]
    - $\mathcal{B}(D_S^+ \to K_S^0\pi^+\pi^0) = (5.43 \pm 0.30 \pm 0.15) \times 10^{-3}$
    - $\mathcal{B}(D_S^+ \to K^0\rho^+) = (5.46 \pm 0.84 \pm 0.44) \times 10^{-3}$
    - $\mathcal{B}(K^*(892)^0\pi^+) = (2.71 \pm 0.72 \pm 0.30) \times 10^{-3}$
    - $\mathcal{B}(K^*(892)^+\pi^0) = (0.75 \pm 0.24 \pm 0.06) \times 10^{-3}$
- $A_{CP} = \frac{\mathcal{B}(D_S^+ \to K_S^0\pi^+\pi^0) - \mathcal{B}(D_S^- \to K_S^0\pi^-\pi^0)}{\mathcal{B}(D_S^+ \to K_S^0\pi^+\pi^0) - \mathcal{B}(D_S^- \to K_S^0\pi^-\pi^0)} = (2.7 \pm 5.5 \pm 0.9)\%$

Amplitude analysis of $D^+ \to K^+ K_S^0 \pi^0$

692 signal events with background less than 2%

[PRD 104 (2021) 012006]



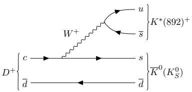


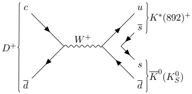
Amplitude	Magnitude	Phase ϕ ($^\circ$)	FF (%)	Significance
$K^*(892)^+ K_S^0$	1.0 (fixed)	0.0 (fixed)	57.1 ± 2.6	29.6 σ
$K^*(892)^0 K^+$	0.41 ± 0.04	162 ± 10	10.2 ± 1.5	11.6 σ
$(K^+\pi^0)_S K_S^0$	2.02 ± 0.37	140 ± 14	3.9 ± 1.5	5.2 σ
$(K_S^0\pi^0)_S K^+$	3.14 ± 0.46	−173.7 ± 9.7	9.7 ± 2.6	7.4 σ

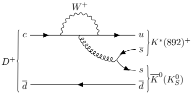
- Dominant by $K^*(892)^+ K_S^0$, provides important data to test theoretical QCD predictions and associated *CP* violating effects in the charmed SCS 2-body decays (see next slide)

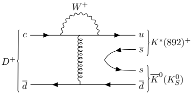
Amplitude analysis of $D^+ \to K^+ K_S^0 \pi^0$

- $\mathcal{B}(D^+ \to K^*(892)^+ K_S^0)$ contributed by color-favoured tree diagram, W-annihilation diagram and penguin diagrams
  - Pole model: $(6.2 \pm 1.2) \times 10^{-3}$ [PRD 84 (2011) 074019]
  - Factorization: 5.5×10^{-3} [PRD 89 (2014) 054006]
  - Topological diagram (tree-level): $(5.02 \pm 1.31) \times 10^{-3}$ [PRD 93 (2016) 114010]
  - Topological diagram (penguin): $(4.90 \pm 0.21) \times 10^{-3}$ [PRD 100 (2019) 093002]





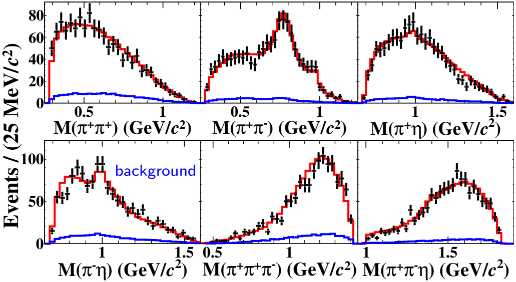




BF	This work	PDG
$\mathcal{B}(D^+ \to K^*(892)^+ K_S^0)$	$(8.69 \pm 0.40_{\rm stat.} \pm 0.64_{\rm syst.} \pm 0.51_{\rm Br.}) \times 10^{-3}$	$(17 \pm 8) \times 10^{-3}$
$\mathcal{B}(D^+ \to K^*(892)^0 K^+)$	$(3.10 \pm 0.46_{\rm stat.} \pm 0.68_{\rm syst.} \pm 0.18_{\rm Br.}) \times 10^{-3}$	$(3.74^{+0.12}_{-0.20}) \times 10^{-3}$

- $\mathcal{B}(D^+ \to K^*(892)^+ K_S^0)$ consistent with pole model prediction
- $\mathcal{B}(D^+ \to K^*(892)^0 K^+)$ agrees well with the predictions in above works

Amplitude analysis of $D_S^+ \to \pi^+\pi^+\pi^-\eta$

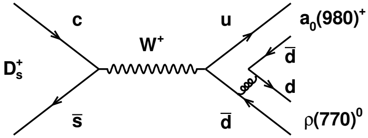


Amplitude	Phase	FF(%)
$a_1(1260)^+(\rho(770)^0\pi^+)\eta$	0.0(fixed)	$55.4 \pm 3.9 \pm 2.0$
$a_1(1260)^+(f_0(500)\pi^+)\eta$	$5.0 \pm 0.1 \pm 0.1$	$8.1 \pm 1.9 \pm 2.1$
$a_0(980)^+\rho(770)^0$	$2.5 \pm 0.1 \pm 0.1$	$6.7 \pm 2.5 \pm 1.5$
$\eta(1405)(a_0(980)^-\pi^+)\pi^+$	$0.2 \pm 0.2 \pm 0.1$	$0.7 \pm 0.2 \pm 0.1$
$\eta(1405)(a_0(980)^+\pi^-)\pi^+$	$0.2 \pm 0.2 \pm 0.1$	$0.7 \pm 0.2 \pm 0.1$
$f_1(1420)(a_0(980)^-\pi^+)\pi^+$	$4.3 \pm 0.2 \pm 0.4$	$1.9 \pm 0.5 \pm 0.3$
$f_1(1420)(a_0(980)^+\pi^-)\pi^+$	$4.3 \pm 0.2 \pm 0.4$	$1.7 \pm 0.5 \pm 0.3$
$[a_0(980)^-\pi^+]_S\pi^+$	$0.1 \pm 0.2 \pm 0.2$	$5.1 \pm 1.2 \pm 0.9$
$[a_0(980)^+\pi^-]_S\pi^+$	$0.1 \pm 0.2 \pm 0.2$	$3.4 \pm 0.8 \pm 0.6$
$[f_0(980)\eta]_S\pi^+$	$1.4 \pm 0.2 \pm 0.3$	$6.2 \pm 1.7 \pm 0.9$
$[f_0(500)\eta]_S\pi^+$	$2.5 \pm 0.2 \pm 0.3$	$12.7 \pm 2.6 \pm 2.0$

[arXiv:2106.13536]

- First measurement
- 2139 signal events, $\sim$ 85% purity
- $\mathcal{B}(D_S^+ \to \pi^+\pi^+\pi^-\eta) = (3.12 \pm 0.13 \pm 0.09)\%$
- Dominant by $\mathcal{B}(D_S^+ \to a_1(1260)^+(\rho(770)^0\pi^+)\eta) = (1.73 \pm 0.14 \pm 0.08)\%$
- Help background estimation in semileptonic B decays for R_{D^*} measurement [PRL 120 (2018) 171802]
- Observation of $a_0(980)^+\rho(770)^0$, $a_0(980)^+ \to \pi^+\eta$ with $> 7\sigma$ significance

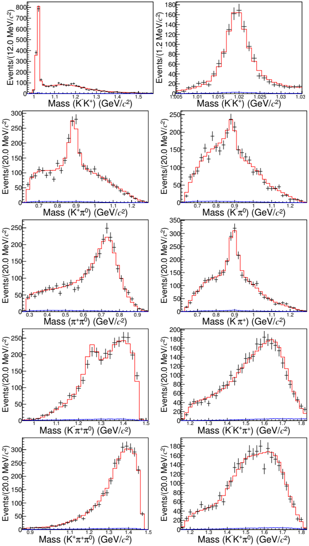
Amplitude analysis of $D_S^+ \to \pi^+\pi^+\pi^-\eta$



- $D_S^+ \to a_0(980)^+\rho(770)^0$ (VS state) is a W-annihilation transition
- $\mathcal{B} = (0.21 \pm 0.08 \pm 0.05)\%$, similar as $D_S^+ \to a_0(980)^+\pi^0$ (SP), is much larger than the pure WA processes $\mathcal{B}_{D_S^+ \to \pi^0\pi^+} = 0.037\%$ (PP) and $\mathcal{B}_{D_S^+ \to \rho^0\pi^+} = 0.019\%$ (VP)
- Final-state rescattering may play an important role [EPJC 80 (2020) 895]
- Helpful to interpret the $a_0(980)^+$ state [Prog. Theor. Exp. Phys. 2020 (2020) 083C01]

Amplitude analysis of $D_S^+ \to K^- K^+ \pi^+ \pi^0$ [PRD 104 (2021) 032011]

~ 3000 signal events, background less than 3%



Process	$\mathcal{B}_{\mathrm{BESIII}}(\%)$	$\mathcal{B}_{\mathrm{PDG}}(\%)$
$[\phi\rho^+]_S$	$2.10 \pm 0.09 \pm 0.13$	
$[\phi\rho^+]_P$	$0.52 \pm 0.05 \pm 0.02$	
$[\phi\rho^+]_D$	$0.18 \pm 0.04 \pm 0.02$	
$\phi\rho^+$	$2.75 \pm 0.07 \pm 0.15$	
Resonance Corrected	$5.59 \pm 0.15 \pm 0.30$	$8.4^{+1.9}_{-2.3}$
$[\bar{K}^{*0}K^{*+}]_S$	$0.88 \pm 0.05 \pm 0.03$	
$[\bar{K}^{*0}K^{*+}]_P$	$0.37 \pm 0.03 \pm 0.02$	
$[\bar{K}^{*0}K^{*+}]_D$	$0.18 \pm 0.03 \pm 0.01$	
$\bar{K}^{*0}K^{*+}$	$1.25 \pm 0.05 \pm 0.06$	
Resonance Corrected	$5.64 \pm 0.23 \pm 0.27$	7.2 ± 2.6
$\bar{K}_1^0(1270)K^+$,		
$\bar{K}_1^0(1270) \to K^-\rho^+$	$0.57 \pm 0.05 \pm 0.04$	
$\bar{K}_1^0(1270)[S] \to K^*\pi$	$0.21 \pm 0.04 \pm 0.03$	
$\bar{K}_1^0(1270)[D] \to K^*\pi$	$0.07 \pm 0.02 \pm 0.01$	
$\bar{K}_1^0(1270) \to K^*\pi$	$0.29 \pm 0.04 \pm 0.04$	
$\bar{K}_1^0(1400)K^+$,		
$\bar{K}_1^0(1400) \to K^*\pi$	$0.44 \pm 0.06 \pm 0.07$	
$a_0^0(980)\rho^+$	$0.19 \pm 0.03 \pm 0.03$	
$f_1(1420)\pi^+$,		
$f_1(1420) \to K^{*\mp}K^\pm$	$0.13 \pm 0.02 \pm 0.01$	
$f_1(1420) \to a_0^0(980)\pi^0$	$0.04 \pm 0.01 \pm 0.01$	
$\eta(1475)\pi^+$,		
$\eta(1475) \to a_0^0(980)\pi^0$	$0.07 \pm 0.02 \pm 0.02$	
$K^-K^+\pi^+\pi^0$	$5.42 \pm 0.10 \pm 0.17$	6.3 ± 0.6

Amplitude analysis of $D_S^+ \to K^- K^+ \pi^+ \pi^0$

- Dominant by the $D_S^+ \to VV$ processes $\phi\rho^+$ and $\bar{K}^{*0}K^{*+}$
- $R_{K_1(1270)} = \frac{K_1^0(1270)\to K^*\pi}{K_1^0(1270)\to K\rho}$ is determined to be $0.99 \pm 0.15 \pm 0.18$, consistent with [LHCb, JHEP 02 (2019) 126] and [CLEO, PRD 85 (2012) 12202]
- Favor the prediction of $R_{K_1(1270)} = 1$ under narrow width approximation for $K_1^0(1270)$ and CP conservation [NPR 36(2) (2019) 125]

$R_{K_1(1270)}$	Process	Ref.
0.81 ± 0.10	$D^0 \to K^+K^-\pi^+\pi^-$	[LHCb, JHEP 02 (2019) 126]
1.18 ± 0.43	$D^0 \to K^-K_1^+(1270)$	[CLEO, PRD 85 (2012) 12202]
0.11 ± 0.06	$D^0 \to K^+K_1^-(1270)$	[CLEO, PRD 85 (2012) 12202]
0.19 ± 0.10	$D^0 \to K^-\pi^+\pi^+\pi^-$	[BESIII, PRD 95 (2017) 072010]
0.24 ± 0.04	$D^0 \to K^-\pi^+\pi^+\pi^-$	[LHCb, EPJC 78 (2018) 443]
0.45 ± 0.05	$B^+ \to J/\psi K^+\pi^+\pi^-$	[Belle, PRD 83 (2011) 032005]
0.30 ± 0.04	$B^+ \to J/\psi K^+\pi^+\pi^-$	[Belle, PRD 83 (2011) 032005]
0.38 ± 0.13	$K^-p \to K^-\pi^-\pi^+p$	[ACCMOR, NPB 187 (1981) 1]
0.45 ± 0.14	$D^0 \to K^-K_1^+(1270)$	[CLEO, JHEP 05 (2017) 143]

Introduction

Amplitude analysis of charmed meson decays at BESIII

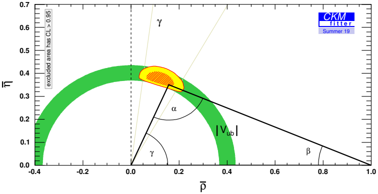
- $D_S^+ \to \pi^+\pi^-\pi^+$ [arXiv: 2108.10050]
- $D_S^+ \to K_S^0\pi^+\pi^0$ [JHEP 06 (2021) 181]
- $D^+ \to K^+K_S^0\pi^0$ [PRD 104 (2021) 012006]
- $D_S^+ \to \pi^+\pi^+\pi^-\eta$ [arXiv:2106.13536]
- $D_S^+ \to K^-K^+\pi^+\pi^0$ [PRD 104 (2021) 032011]

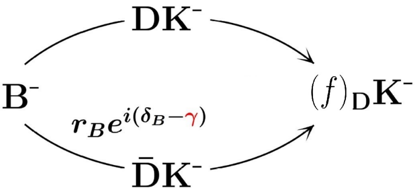
Strong phase parameters in neutral $D\bar{D}$ meson decays at BESIII

- Phase variation across $D \to K_S^0\pi^+\pi^-$ Dalitz plot [PRD 101 (2020) 112002]
- Phase variation in $D \to K3\pi$ phase space [JHEP 05 (2021) 164]

Summary

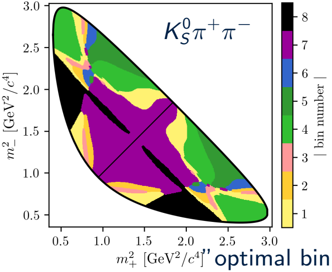
Inputs to the determination of CKM angle γ





- $\gamma = (72.1^{+5.4}_{-5.7})^\circ$, $\gamma_{\text{ind.}} = (65.66^{+0.90}_{-2.65})^\circ$(CKM fitter)
- Interference between the two paths into same final states, depends on the B and D decay parameters, i.e. strong phase parameters
- Extracting γ with multi-body D decays have advantage with exploiting strong-phase variations in phase space:
  - Self-conjugate decays (eg. $K_S^0 h^+ h^-$): "BPGGSZ" [PRD 68 (2003) 054018; PRD 67 (2003) 071301; A. Bondar] $\Rightarrow c_i,\ s_i$
  - DCS decays (eg. $K\pi\pi\pi$): "ADS" [PRL 78 (1997) 3257; PRD 63 (2001) 036005] $\Rightarrow \delta_D\ R_D$
  - Other methods...

Phase variation in $D \to K_S^0\pi^+\pi^-$



"optimal binning"
[JHEP 02 (2021) 169]

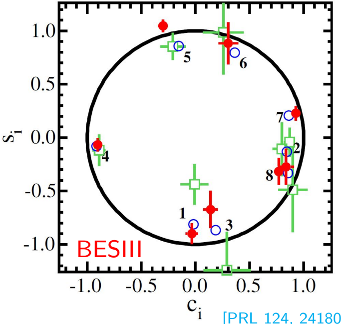
- The phase difference of the amplitude $\mathcal{A}_D(m_+^2,\ m_-^2)$ and $\mathcal{A}_D(m_-^2,\ m_+^2)$ $\Rightarrow \Delta\delta_D(m_+^2,\ m_-^2)$
- $\Delta\delta_D$ varies across the Dalitz plane
- Idea: divide the Dalitz plot into bins $\Rightarrow$bin averaged $\Delta\delta_D$
    - $c_i = \int dp \mathcal{A}_D(m_+^2,\ m_-^2)\mathcal{A}_D(m_-^2,\ m_+^2) \cos \Delta\delta_D(m_+^2,\ m_-^2)$
    - $s_i = \int dp \mathcal{A}_D(m_+^2,\ m_-^2)\mathcal{A}_D(m_-^2,\ m_+^2) \sin \Delta\delta_D(m_+^2,\ m_-^2)$
- Model-independent

- Quantum correlated C-odd $D^0\bar{D}^0$ produced at BESIII

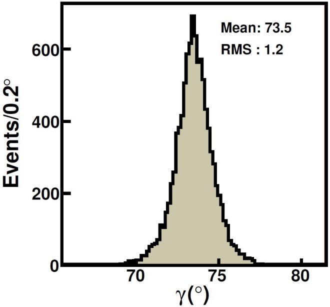
$$e^+e^- \to \psi(3770) \to D^0\bar{D}^0$$

- CP tags (eg. $\pi\pi\pi^0$, $K_S^0\pi^0$): information of c_i
- Self tags (tagged by itself): information of $c_i,\ s_i$

Measurement of c_i and s_i in $D \to K_S^0\pi^+\pi^-$



[PRL 124, 241802 (2020)]
[PRD 101, 112002 (2020)]

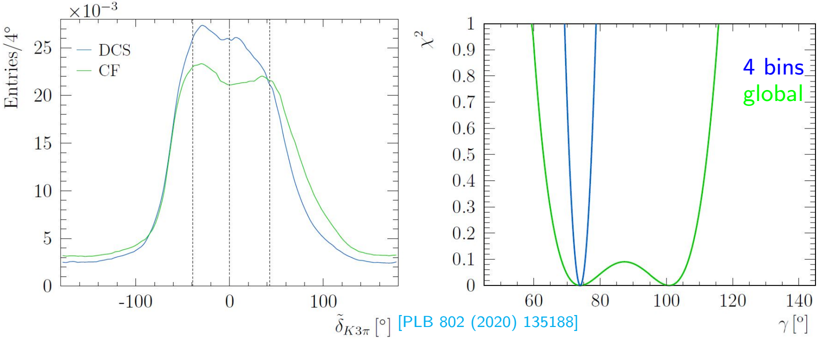


Contribution to δ_γ

- Improvement of the γ sensitivity compare to that with only CLEO-c inputs [PRD 82, 112006 (2010)]
- BESIII uncertainties of $K_S^0\pi^+\pi^-$ contribute around 1° in the latest LHCb measurement, leading to the best single measurement of γ (5 °) [JHEP 02 (2021) 169]
- $K_S^0K^+K^-$ is measured with a similar method, see [PRD 102, 052008 (2020)]

Phase variation in $D \to K3\pi$ phase space

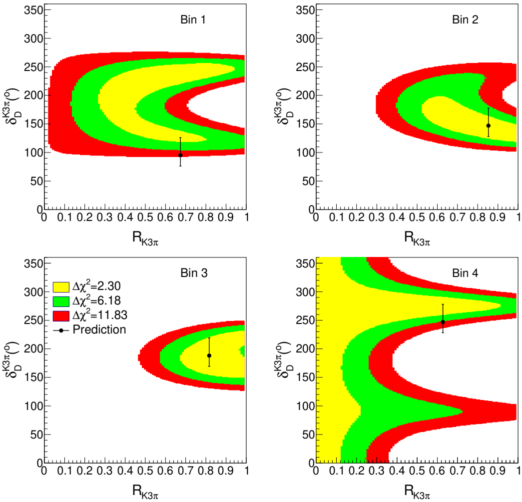
- $D \to K3\pi$ is rich of resonances, $\delta_D^{K3\pi}$ varies in phase space regions
- Divide the phase space according to LHCb model of the DCS and CF decay [EPJC 78, 443 (2018)]



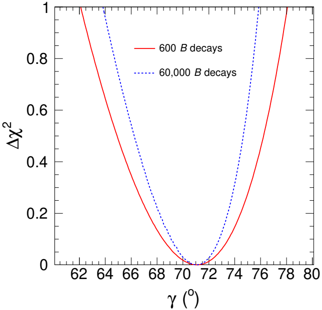
[PLB 802 (2020) 135188]

- Model-independent measurement, only binning method depends on the DCS and CF model of $D \to K3\pi$ [EPJC 78 (2018) 443]

Results of binned $\delta_D^{K3\pi}$ and $R_{K3\pi}$ at BESIII



[JHEP 05 (2021) 164]



- $\delta_{\rm LHCb}^{\rm Run1\&2} = (^{+7}_{-9})^\circ$, $(^{+5}_{-7})^\circ$ comes from BESIII
- $\delta_{\rm LHCb}^{K_S^0\pi\pi} \sim 5^\circ$ [JHEP 02 (2021) 169]

- Significant improvement compare to CLEO-c results [PLB 802 (2020) 135188]

Summary

- Amplitude analysis of $D_{(S)}$ decays with "double-tag" method at BESIII
  - Contain rich physics, eg. SU(3) breaking effect, final state interaction
  - Test the theoretical calculation approaches
  - Provide inputs for the LFU tests with B semileptonic decays
  - More results not in this talk:
    - $D_S^+ \to K^+K^-\pi^+$ [PRD 104 (2021) 012016]
    - $D_S^+ \to K_S^0K^-\pi^+\pi^+$[PRD 103 (2021) 092006]
- Quantum correlated measurement at BESIII with neutral $D\bar{D}$
  - Give access to the strong phase variations in multi-body D decays
  - Inputs for CKM angle γ measurement
  - Inputs for charm mixing and CP violation studies [arXiv: 2106.03744]
- 20 fb^{-1} $\psi(3770)$ data at BESIII in the near future [CPC 44, 040001 (2020)]

Thanks!

Dalitz plot analysis

- **Amplitude analysis:**
  - **Unbinned maximum likelihood Fit:**
  - **PDF =** $f_s S + (1 - f_s)B = \epsilon(p_j)R_4(p_j)[f_s \frac{|A_{D_s}(a_i,p_j)|^2}{\int \varepsilon(p_j)|A_{D_s}(a_i,p_j)|^2 R_4(p_j)dp_j} + (1 - f_s)\frac{B_\epsilon(p_j)}{\int B(p_j)R_4(p_j)dp_j}]$

Bkg function (RooNDKeysPdf)

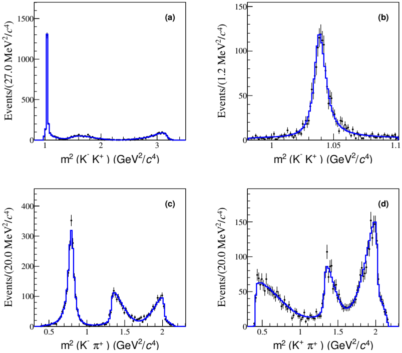
Acceptance function

MC integration

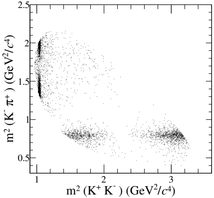
$$B_\epsilon = B/\epsilon$$

  - $\mathrm{A}_{\mathrm{D_s}\to\mathrm{sig}} = \Sigma_\mathrm{n} \mathrm{c_n} \mathrm{A_n}, \mathrm{c_n} = \rho_n e^{i\phi_n}$
  - **Covariant tensor formalism**
  - $\mathrm{A_n} = \mathrm{P_n^1 P_n^2 S_n F_n^1 F_n^2 F_n^{D_s}}$, $\mathrm{P_n^i}$ **propagator,** $\mathrm{F_n^i}$ **barrier,** $\mathrm{S_n}$ **angular distribution.**
  - **Log-likelihood:**
    - $\mathrm{lnL_{total}} = \Sigma_k^{\mathrm{N}_{data}} \log(f_s S(p_k) + (1 - f_s)B(p_k))$

Amplitude analysis of $D_S^+ \to K^+K^-\pi^+$



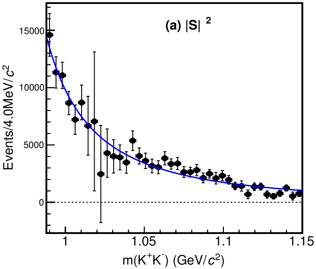
- The "golden" normalization mode for other D_S^+ decays
- Free of background



[PRD 104 (2021) 012016]

	FF(%)(BESIII)	FF(%)(CLEO)	FF(%)(BaBar)
$\bar{K}^*(892)^0K^+$	48.3±0.9±0.6	47.4±1.5±0.4	47.9±0.5±0.5
$\phi(1020)\pi^+$	40.5±0.7±0.9	42.2±1.6±0.3	41.4±0.8±0.5
$S_0(980)\pi^+$	19.3±1.7±2.0	28.2±1.9±1.8	16.4±0.7±2.0
$\bar{K}_0^*(1430)^0K^+$	3.0±0.6±0.5	3.9±0.5±0.5	2.4±0.3±1.0
$f_0(1710)\pi^+$	1.9±0.4±0.6	3.4±0.5±0.3	1.1±0.1±0.1
$f_0(1370)\pi^+$	1.2±0.4±0.2	4.3±0.6±0.5	1.1±0.1±0.2
$\sum$ FF(%)	110.2±0.6±2.0	129.5±4.4±2.0	110.2±0.6±2.0
Events	4399	12226±122	96307±369

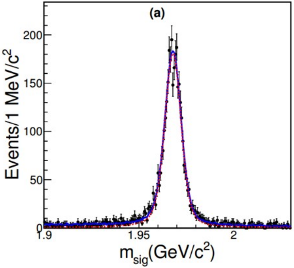
Amplitude analysis of $D_S^+ \to K^+K^-\pi^+$



- Extract K^+K^- S-wave ($S(980)$) from model-independent PWA
- $A_{S(980)} = \dfrac{1}{m_0^2 - m^2 - i m_0 \Gamma_0 \rho_{KK}}$

$$m_0 = (0.919 \pm 0.006_{\mathrm{stat}} \pm 0.030_{\mathrm{stat}})\ \mathrm{GeV}/c^2,$$

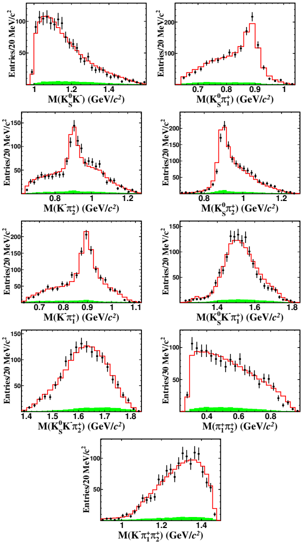
$$\Gamma_0 = (0.272 \pm 0.040_{\mathrm{stat}} \pm 0.024_{\mathrm{stat}})\ \mathrm{GeV}.$$



- $\mathcal{B}_{K^+K^-\pi^+} = (5.47 \pm 0.08 \pm 0.13)\%$, best measurement up to date
- $\mathcal{B}_{\bar{K}^*(892)^0 K^+} = (3.94 \pm 0.12)\%$, $\mathcal{B}_{\phi(1020)\pi^+} = (4.60 \pm 0.17)\%$, consistent with theoretical prediction [PRD 93, 114010 (2016)]

Amplitude analysis of $D_S^+ \to K_S^0 K^- \pi^+ \pi^+$

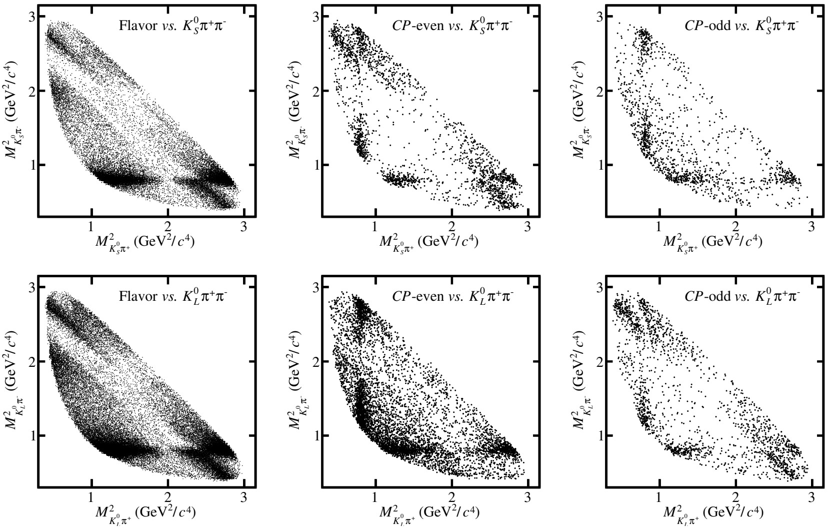
[PRD 103 (2021) 092006]



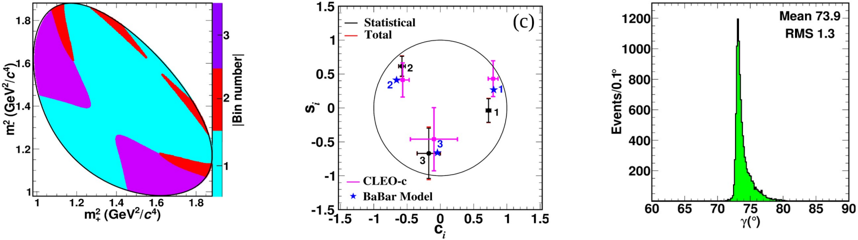
Process	BF(10^{-3})	
	This analysis	PDG
$[K^*(892)^+\overline{K}^*(892)^0]_S$	$5.01 \pm 0.49 \pm 0.78$	
$[K^*(892)^+\overline{K}^*(892)^0]_P$	$1.10 \pm 0.16 \pm 0.10$	
$[K^*(892)^+\overline{K}^*(892)^0]_D$	$0.65 \pm 0.12 \pm 0.10$	
$K^*(892)^+\overline{K}^*(892)^0$	$5.93 \pm 0.47 \pm 0.74$	7.98 ± 2.88
$K^*(892)^+(K^-\pi^+)_S$	$0.73 \pm 0.17 \pm 0.15$	
$\overline{K}^*(892)^0(K_S^0\pi^+)_S$	$1.06 \pm 0.16 \pm 0.13$	
$\eta(1475)\pi^+$, $\eta(1475) \to a_0(980)^-\pi^+$	$1.57 \pm 0.39 \pm 0.76$	
$\eta(1475)\pi^+$, $\eta(1475) \to \overline{K}^*(892)^0 K_S^0$	$0.32 \pm 0.10 \pm 0.10$	
$\eta(1475)\pi^+$, $\eta(1475) \to K^*(892)^+ K^-$	$0.32 \pm 0.10 \pm 0.10$	
$\eta(1475)\pi^+$, $\eta(1475) \to K^*(892) K$	$0.72 \pm 0.21 \pm 0.14$	
$\eta(1475)\pi^+$, $\eta(1475) \to (K_S^0\pi^+)_S K^-$	$3.44 \pm 0.54 \pm 1.10$	
$f_1(1285)\pi^+$, $f_1(1285) \to a_0(980)^-\pi^+$	$0.33 \pm 0.08 \pm 0.10$	
$K_S^0K^-\pi^+\pi^+$	$14.60 \pm 0.46 \pm 0.48$	16.50 ± 1.00

- Improved determination of $\mathcal{B}(K_S^0K^-\pi^+\pi^+)$ and $\mathcal{B}(K^*(892)^+\overline{K}^*(892)^0)$

DT events of $D \to K_S^0\pi^+\pi^-$



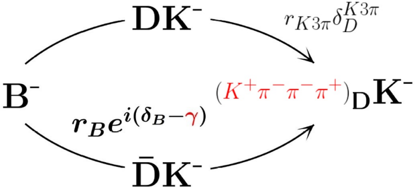
Measurement of c_i and s_i in $D \to K_S^0 K^+ K^-$



[PRD 102, 052008 (2020)]

- Improvement of the γ sensitivity with CLEO-c inputs (3.2-3.9)$^\circ$ ($K_S^0 K^+ K^-$)) [PRD 82, 112006 (2010)]

ADS method with multi-body D decays

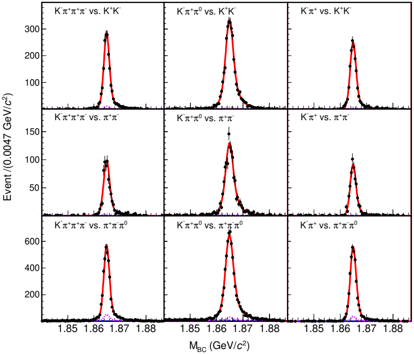


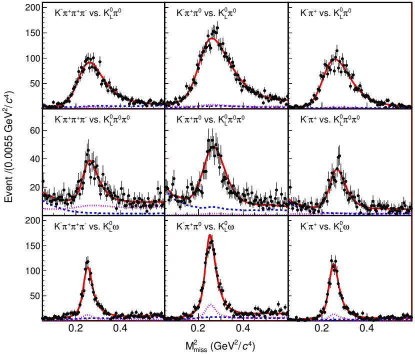
- Both DCS and CF processes contribute to $B^\mp \to (K^\pm 3\pi)_D K^\mp$
- Phase-space integrated decay rate

$$\Gamma(B^\mp \to (K^\pm 3\pi)_D K^\mp) \propto r_{K3\pi}^2 + r_B^2 + 2 r_B R_{K3\pi} r_{K3\pi} \cos(\delta_B \pm \gamma - \delta_D^{K3\pi})$$

- $R_S e^{-i\delta_D^S} = \frac{\int \mathcal{A}_S^*(\mathbf{x})\mathcal{A}_{\bar{S}}(\mathbf{x})\mathrm{d}\mathbf{x}}{A_S A_{\bar{S}}}$, coherence factor and strong phase
- R indicates the intermediate resonances, $0 < R < 1$ for $K3\pi$ and $K\pi\pi^0$, $R = 1$ for $K\pi$

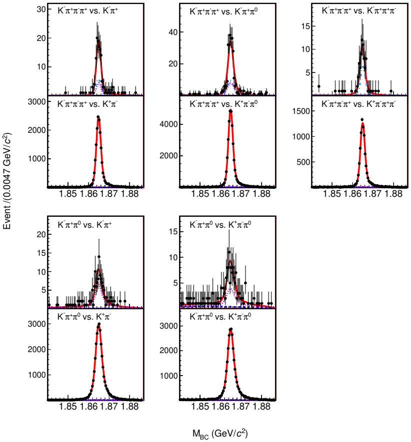
Back-up: $K3\pi/K\pi\pi^0$ DT modes

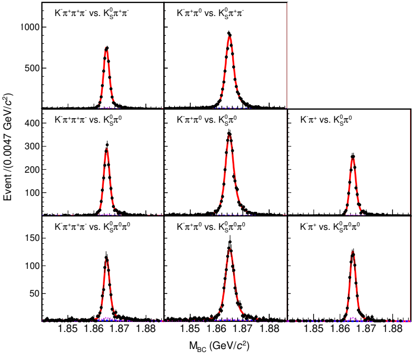




[JHEP 05 (2021) 164]

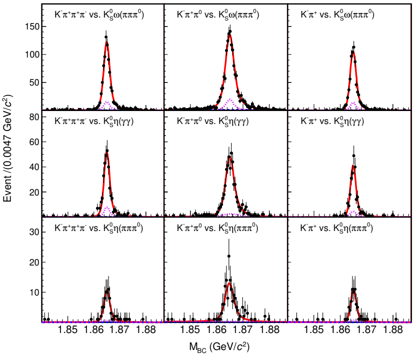
Back-up: $K3\pi/K\pi\pi^0$ DT modes

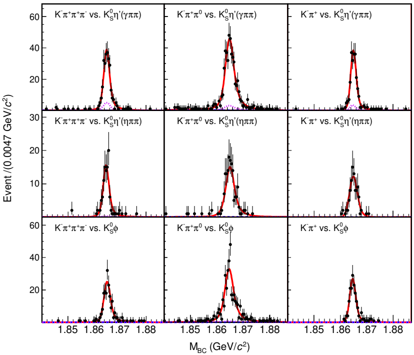




[JHEP 05 (2021) 164]

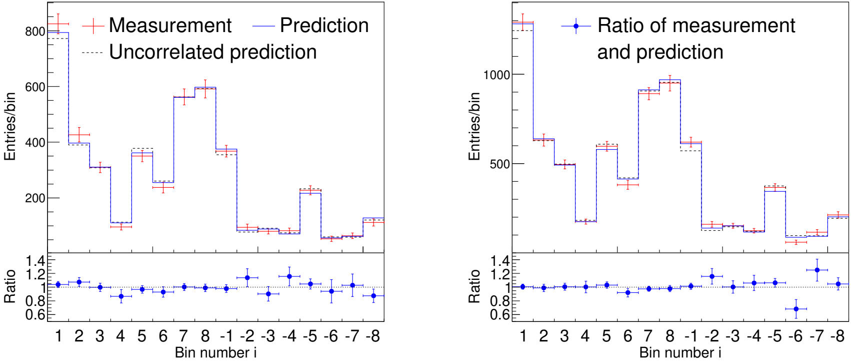
Back-up: $K3\pi/K\pi\pi^0$ DT modes





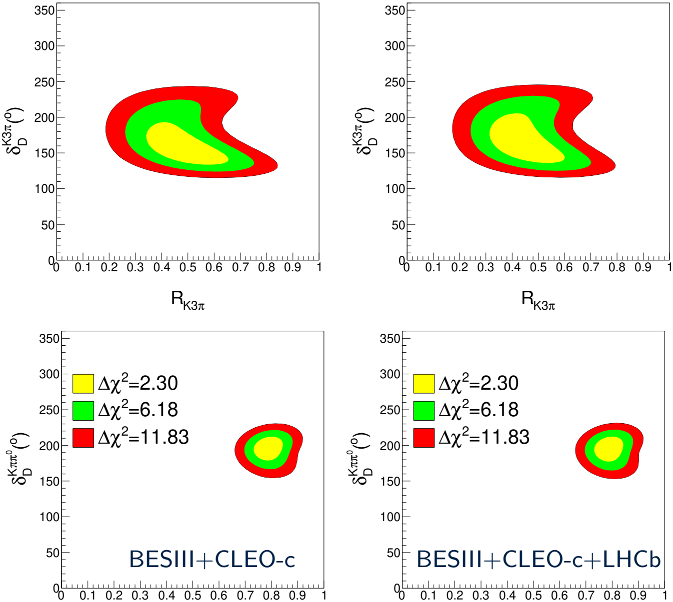
[JHEP 05 (2021) 164]

Back-up: $K_S^0\pi^+\pi^-$ tag for $K3\pi/K\pi\pi^0$



[JHEP 05 (2021) 164]

Back-up: Combination of $\delta_D^{K3\pi}$ and $R_{K3\pi}$



Back-up: Combination of binned $\delta_D^{K3\pi}$ and $R_{K3\pi}$