Open Charm at BESIII

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on behalf of the BESIII collaboration

31st Rencontres de Blois, June 2-7, 2019, Blois

Outline

- BEPCII and BESIII
- The tagging method
- Charmed baryons
- Hadron decays (Amplitude analyses)
- BSM searches
- (Semi-)Leptonic decays
- Summary

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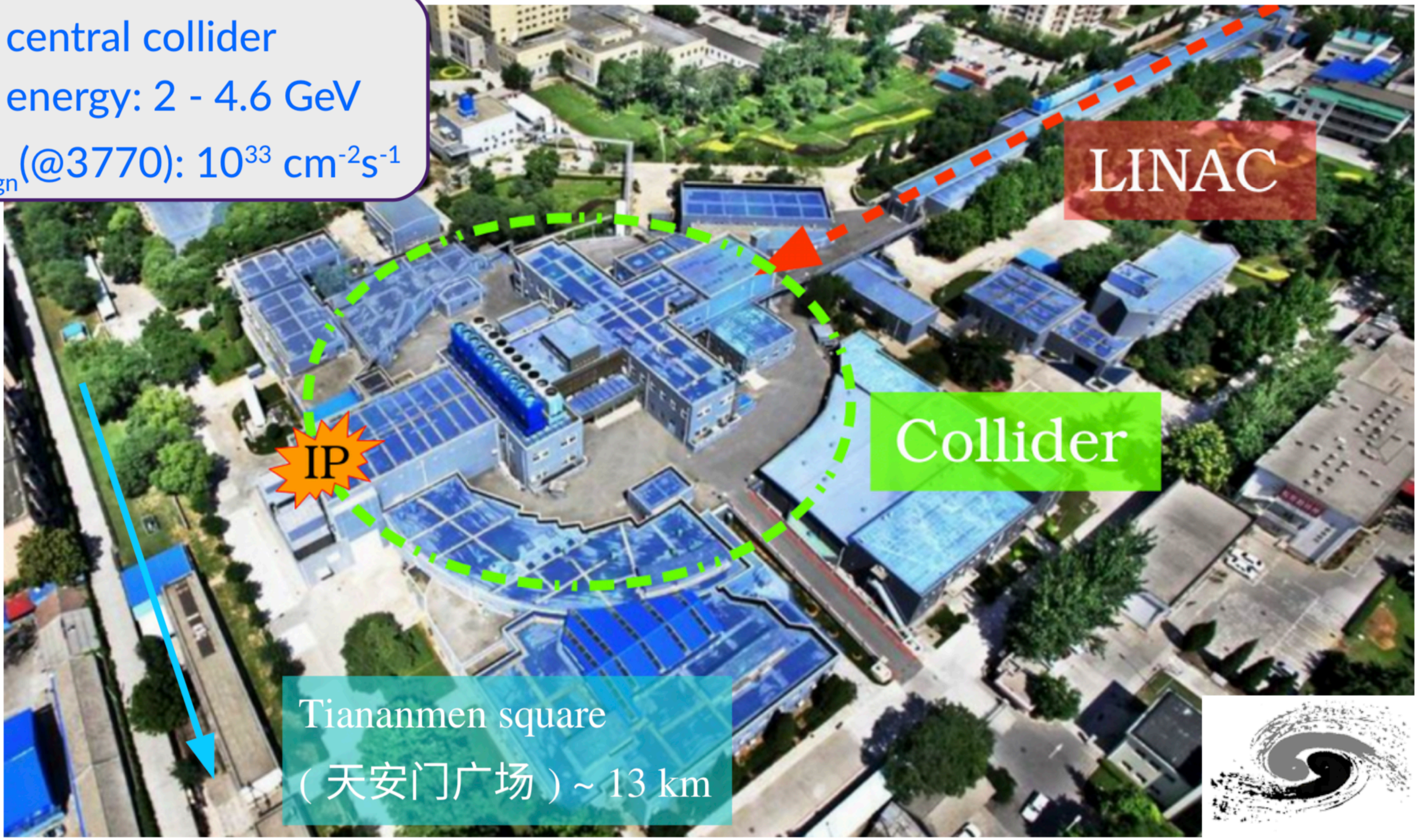
BEPCII @ IHEP (Beijing, PRC)

e^+e^- central collider
CM energy: 2 - 4.6 GeV
L_{design}(@3770): 10^{33} cm^{-2}s^{-1}



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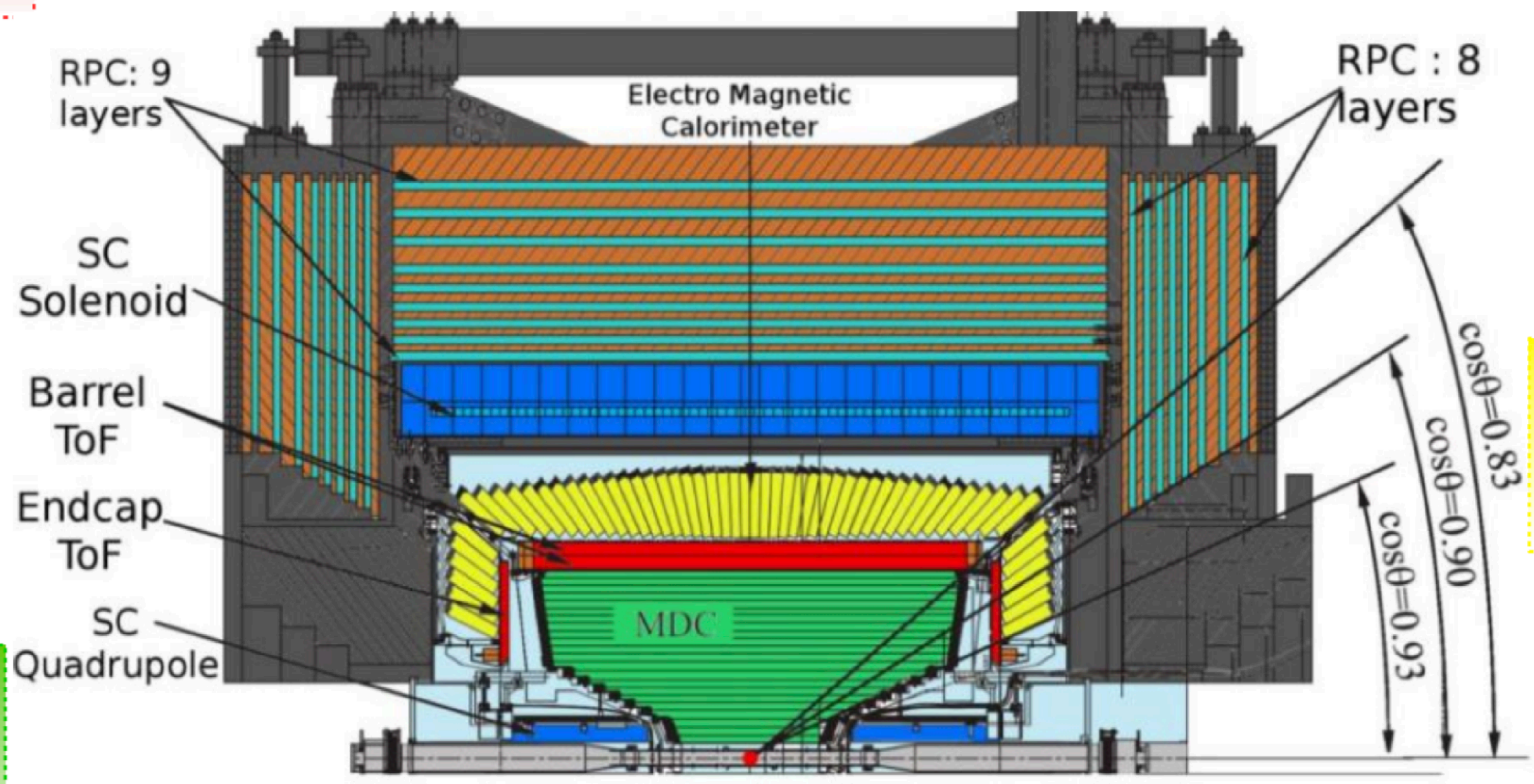
BESIII @ BEPCII

Time Of Flight:
σ_t (barrel) = 90 ps
σ_t (endcap) = 110 ps

1 Tesla Magnetic field

Muon counters:
$\delta_{r\varphi}$ = 1.4 cm – 1.7 cm



Electromagnetic Calorimeter:
$dE/\sqrt{E}$ (1 GeV) = 2.5 %

Main Drift Chamber:
σ_x (1 GeV/c) ~ 130 μm
dp/p (1 GeV/c) = 0.5 %

29

hermetic

barrel $|\cos\theta| < 0.83$

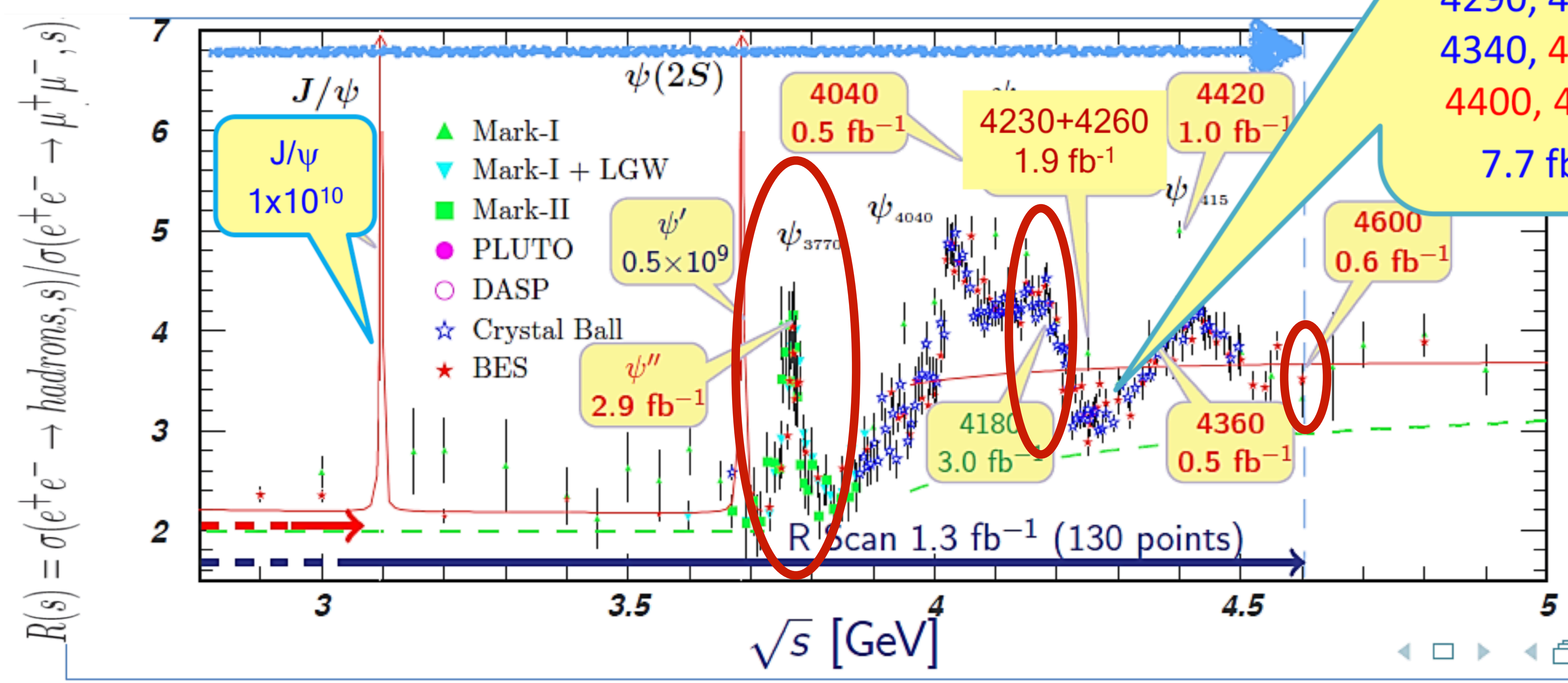
endcap $0.85 < |\cos\theta| < 0.93$

Collected datasets

Optimised for flavour physics in the tau-charm region

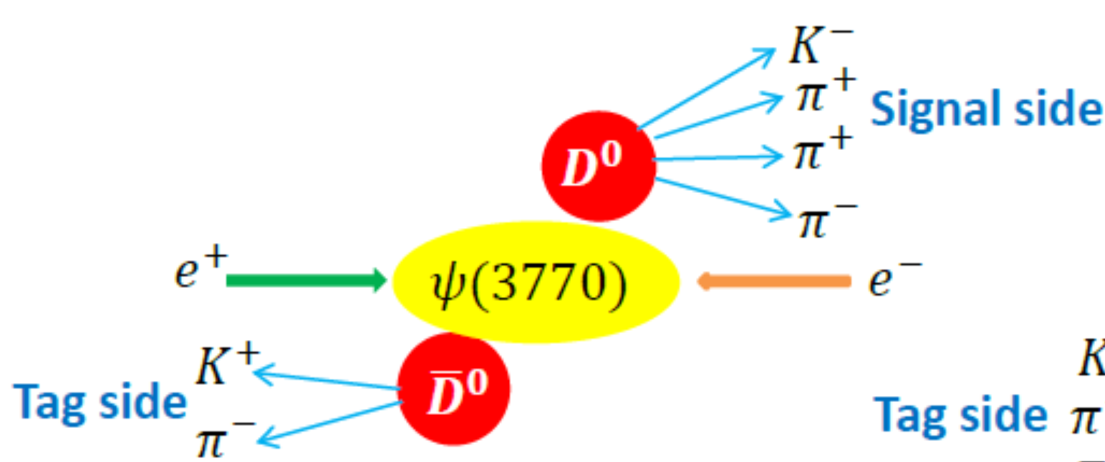
4130, 4160, 4190, 4200, 4210, 4220, 4236, 4245, 4270, 4280, 4290, 4315, 4340, 4380, 4400, 4440

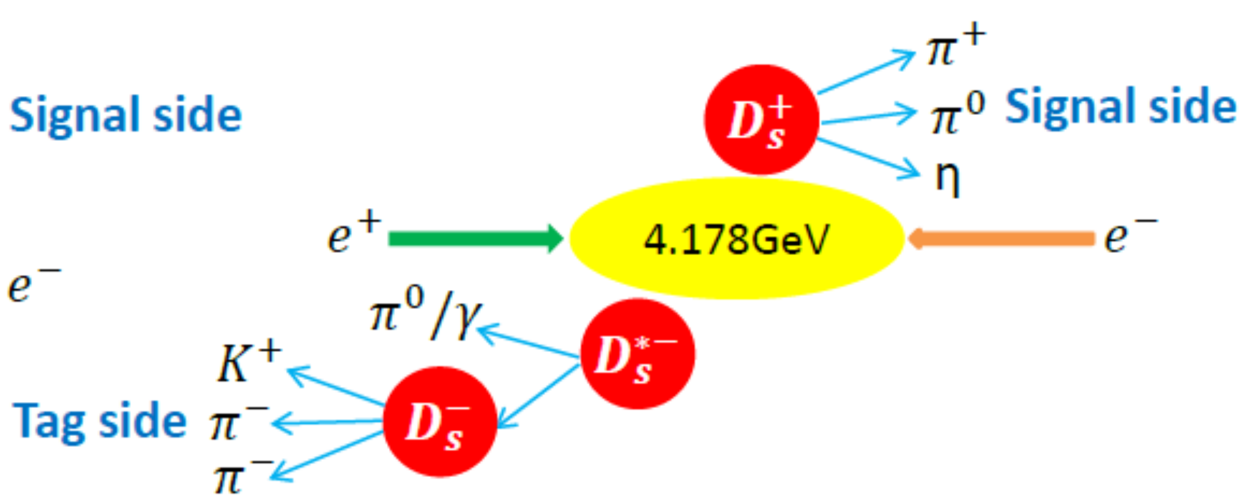
7.7 fb^{-1}



Tagging method for charm@threshold

- Single tag: fully reconstruct the signal $D_{(S)}$, Λ_c
- Double tag:
  - Fully reconstruct the tag $D_{(S)}$, Λ_c taking advantage of kinematic constrains
  - Search for the signal mode in the recoil system
  - Possible to measure absolute Branching Fraction





@ threshold = full kinematic constraint of the decays

Excellent for neutral and invisible particles

$$\Delta E = E_D - E_{\mathrm{Beam}}$$

$$M_{\mathrm{BC}} = \sqrt{E_{\mathrm{Beam}}^2 - p_D^2}$$

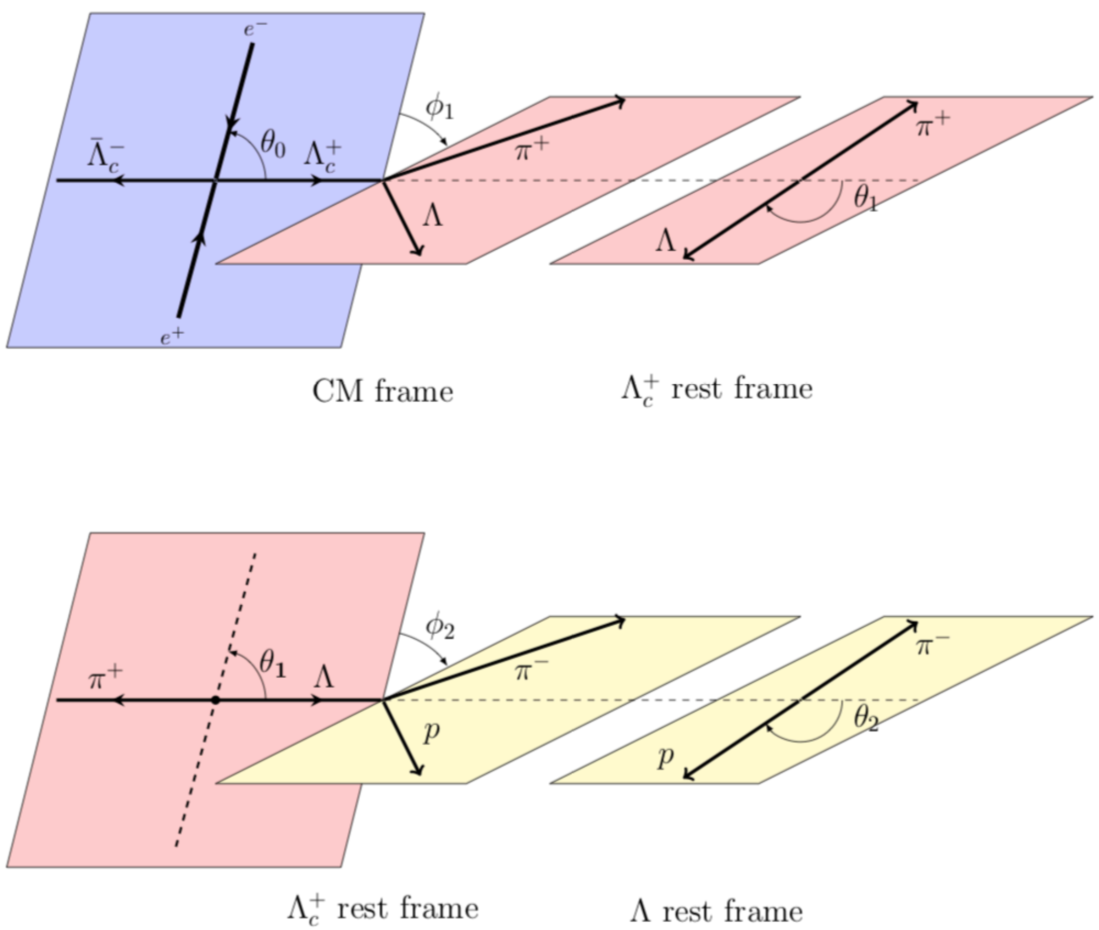
Weak Decay Asymmetries of $\Lambda^+_c \to pK^0_S$, $\Lambda\pi^+$, $\Sigma^+\pi^0$, and $\Sigma^0\pi^+$

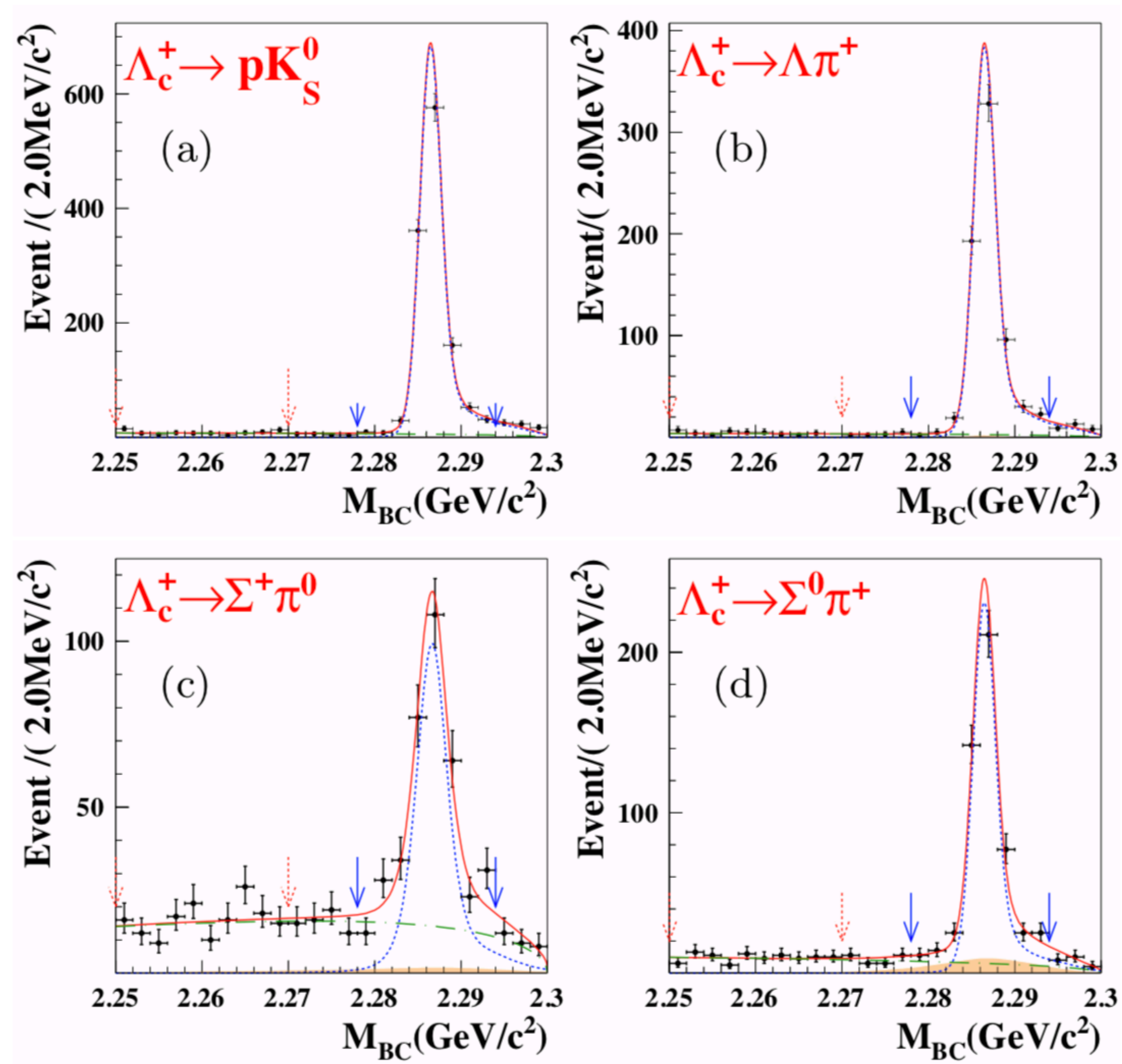
567 pb^{-1}@4600 MeV

arXiv:1905.04707

- Measure the weak asymmetry $\alpha^+_{BP} \equiv \frac{2\mathrm{Re}(s\cdot p)}{|s|^2+|p|^2}$ via a full angular analysis carried out simultaneously on the 4 signal modes

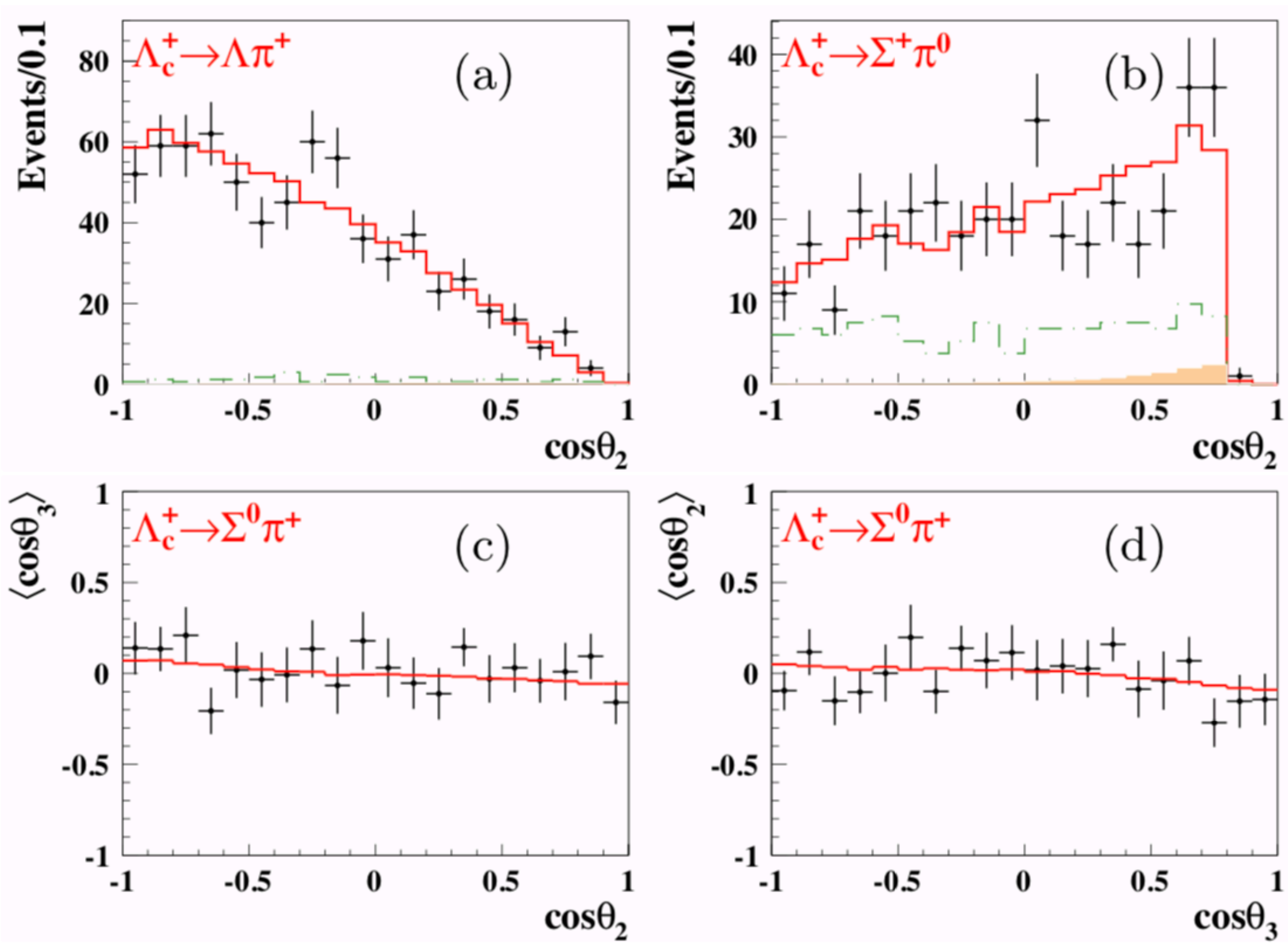
- Single tag method

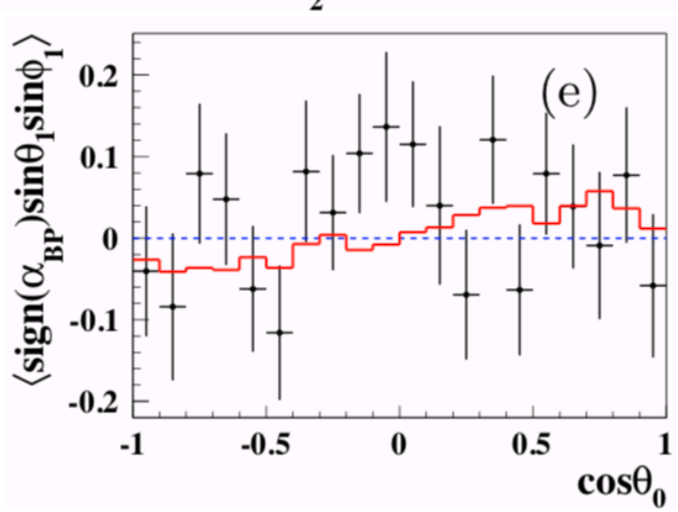




Results

arXiv:1905.04707





Decay asymmetry parameters α^+:

new

$\Lambda^+_c \to pK^0_S$: 0.18 ± 0.43(stat) ± 0.14(syst)

$\Lambda^+_c \to \Lambda\pi^+$: −0.80 ± 0.11(stat) ± 0.02(syst)

$\Lambda^+_c \to \Sigma^+\pi^0$: −0.57 ± 0.10(stat) ± 0.07(syst) best

$\Lambda^+_c \to \Sigma^0\pi^+$: −0.73 ± 0.17(stat) ± 0.07(syst)

new

$\alpha^+_{\Sigma+\pi 0}$: negative sign rules out several positive predictions

$\alpha^+_{\Sigma\pi}$ results agree well: hyperon isospin symmetry

First study of Λc transverse polarisation

$$\mathcal{P}_T(\cos\theta_0) \equiv \sqrt{1-\alpha_0^2}\cos\theta_0\sin\theta_0\sin\Delta_0$$

in unpolarised e+e−collisions

$\sin\Delta_0 = -0.28 \pm 0.13 \pm 0.03$

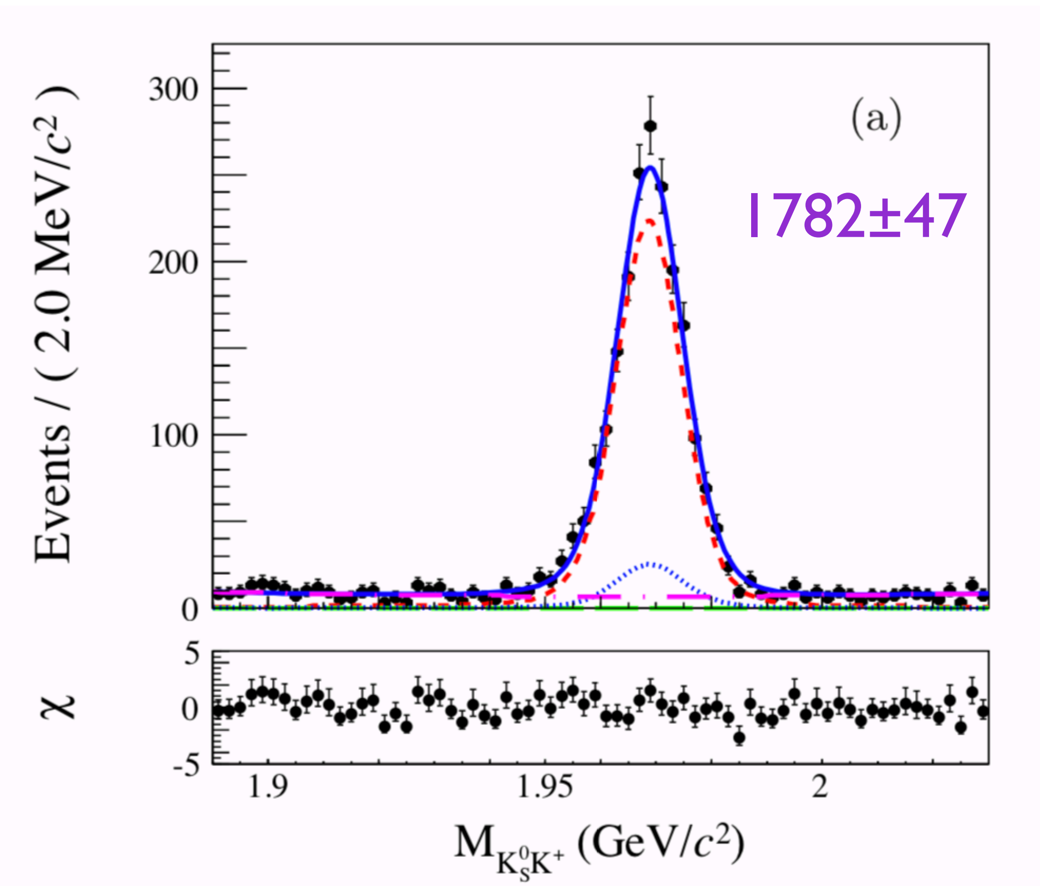
Effect with a 2.1σ statistical significance

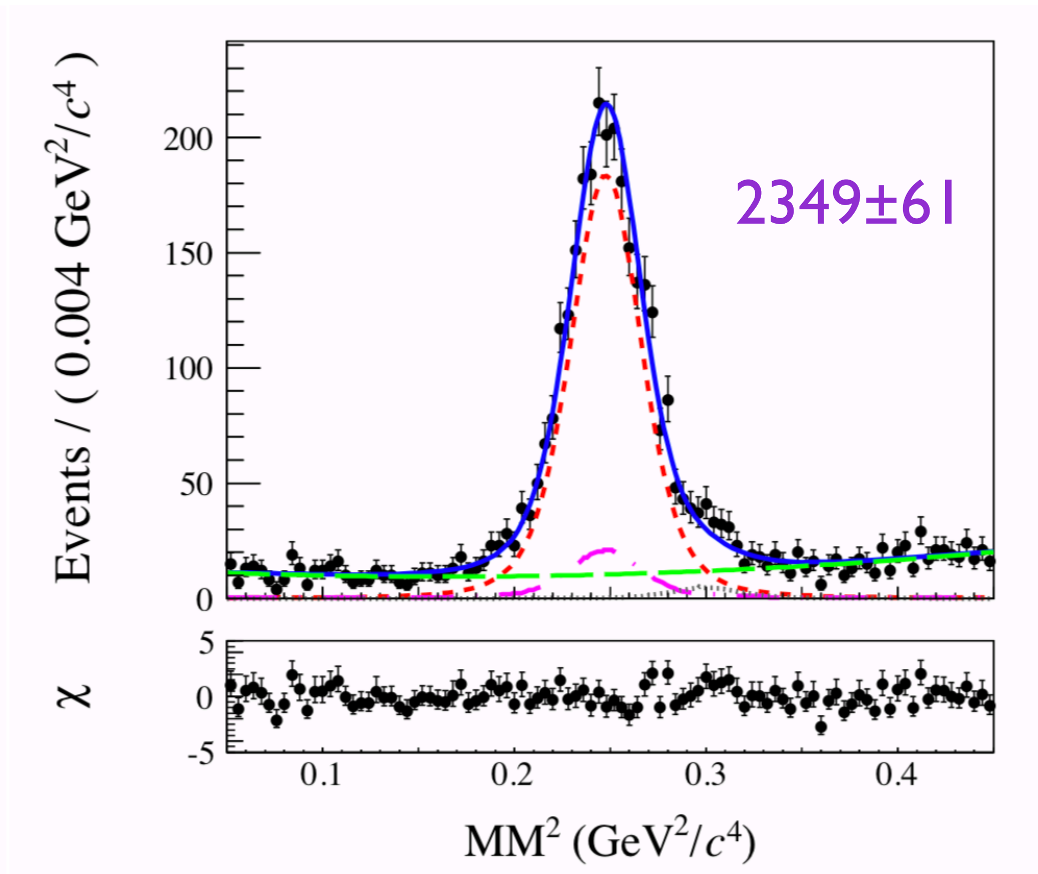
Study of the Decays $D^+_s \to K^0_S K^+$ and $K^0_L K^+$

3.19 fb^{-1}@4178 MeV

arXiv:1903.04164

- Double tag analysis $e^+e^- \to D^{*\pm}_s D^{\mp}_s \to \gamma D^+_s D^-_s$





Tag mode
$K^+K^-\pi^-$
$K^-\pi^+\pi^-$
$\pi^+\pi^-\pi^-$
$K^+K^-\pi^-\pi^0$
$\pi^-\eta'_{\gamma\rho^0}$
$\rho^-\eta$
$K^0_S K^-\pi^+\pi^-$
$K^0_S K^+\pi^-\pi^-$
$K^0_S K^-\pi^0$
$K^0_S K^0_S\pi^-$
$\pi^-\eta$
$\pi^-\eta'_{\pi^+\pi^-\eta}$
$\pi^-\eta_{\pi^+\pi^-\pi^0}$

$\mathcal{B}(D^+_s \to K^0_S K^+) = (1.425 \pm 0.038_{\rm stat.} \pm 0.031_{\rm syst.})\%$ $\mathcal{B}(D^+_s \to K^0_L K^+) = (1.485 \pm 0.039_{\rm stat.} \pm 0.046_{\rm syst.})\%$

$A_{CP}(D^+_s \to K^0_S K^+)$ = (0.6±2.8(stat)±0.6(syst))% $A_{CP}(D^+_s \to K^0_L K^+)$ = (-1.1±2.6(stat)±0.6(syst))%

K_S-K_L asymmetry

$$\frac{\mathcal{B}(D^+_s \to K^0_S K^+) - \mathcal{B}(D^+_s \to K^0_L K^+)}{\mathcal{B}(D^+_s \to K^0_S K^+) + \mathcal{B}(D^+_s \to K^0_L K^+)} = (-2.1 \pm 1.9_{\rm stat.} \pm 1.6_{\rm syst.})\%$$

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Amplitude Analysis of $D^0 \to K^-\pi^+\pi^0\pi^0$

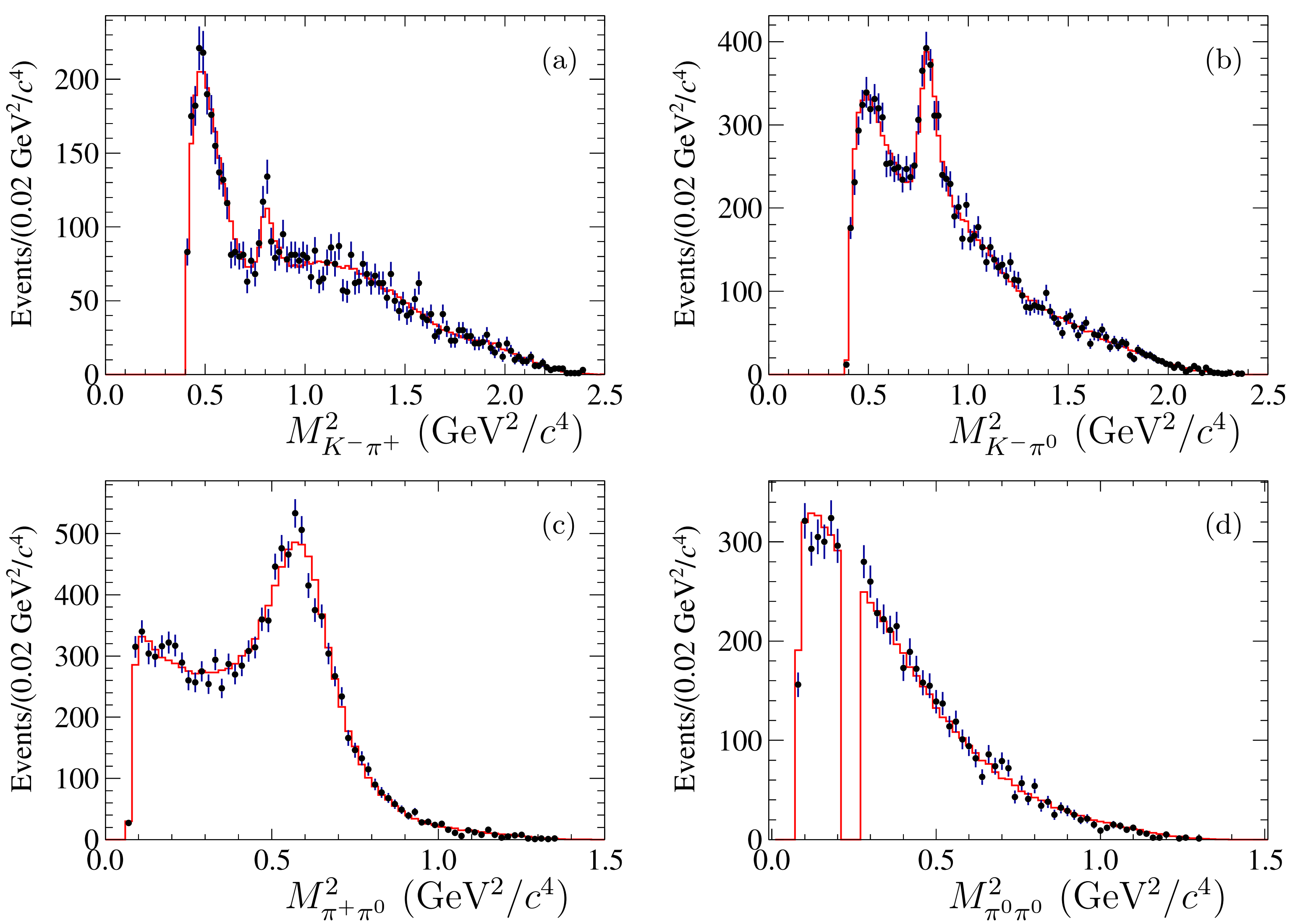
2.93 fb^{-1}@3773 MeV

arXiv:1903.06316

- Double tag analysis: tag mode: $\bar{D}^0 \to K^+\pi^-$
- 6100 events with 99% purity used for amplitude analysis
- $B(D^0 \to K^-\pi^+\pi^0\pi^0)$ = (8.86 0.13(stat) 0.19(syst))%

First measurement of $D^0 \to K\pi\pi\pi$ with more than one π^0

The dominant amplitude is $K^- a_1(1260)^+$



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

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

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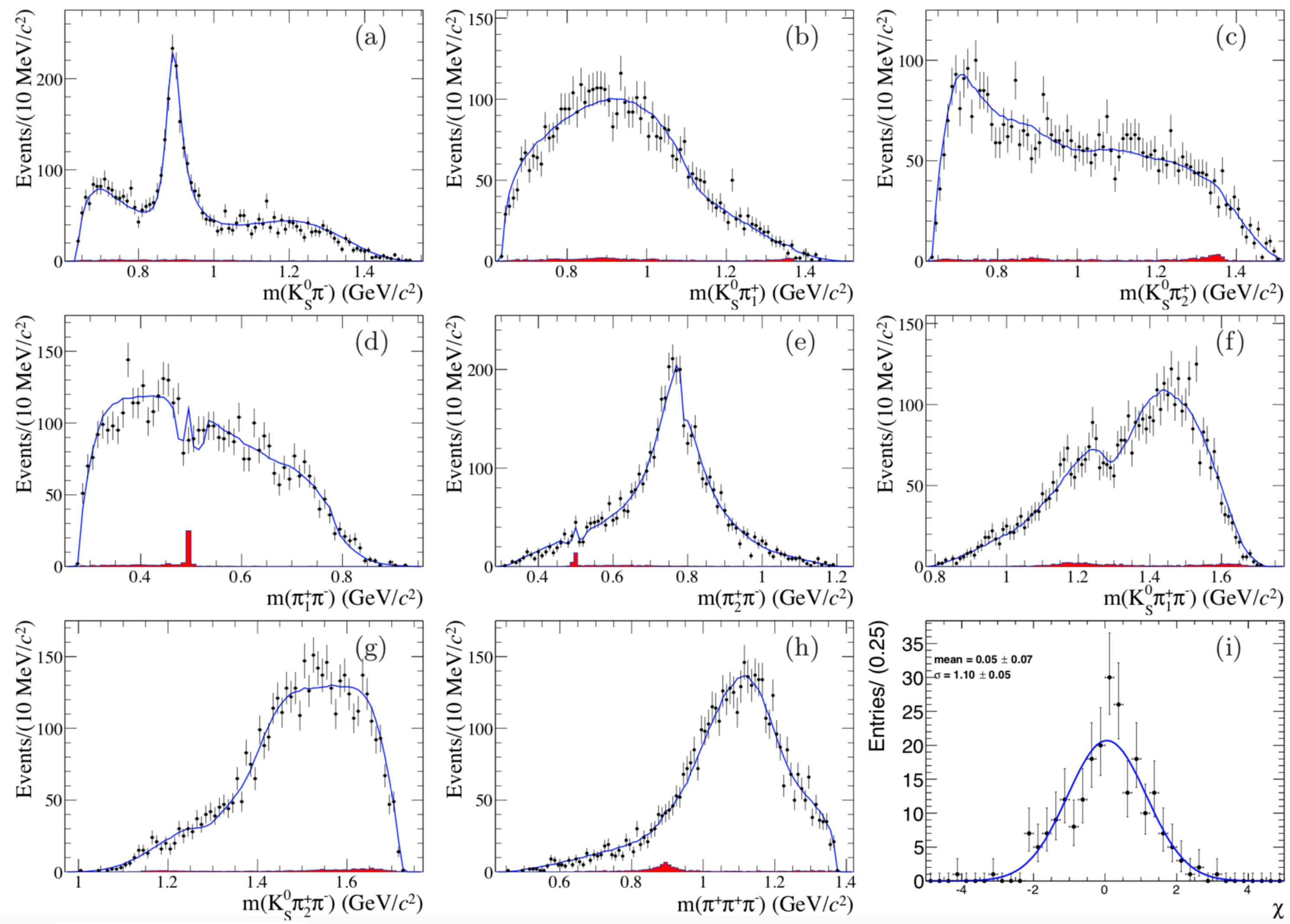
2.93 fb^{-1}@3773 MeV

arXiv:1901.05936

- Double tag analysis: tag mode $D^- \to K^+\pi^-\pi^-$
- 4559 events with 97.5% purity used for amplitude analysis
- BF of the components determined as well, with significantly improved precision



The dominant amplitude is $K^0_S a_1(1260)^+$

Comparing with $D^0 \to K^-\pi^+\pi^+\pi^-$: larger contribution for $D^+ \to \bar{K}_1(1400)^0\pi^+$ by an order of magnitude

Amplitude	Significance (σ)	Phase	FF
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+[S])$	> 10	0.0 (fixed)	$0.384 \pm 0.021 \pm 0.029$
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+[D])$	4.3	$-1.55 \pm 0.16 \pm 0.22$	$0.004 \pm 0.002 \pm 0.001$
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+)$	-	-	$0.403 \pm 0.021 \pm 0.029$
$D^+ \to K^0_S a_1(1260)^+(f_0(500)\pi^+)$	> 10	$-1.82 \pm 0.08 \pm 0.10$	$0.055 \pm 0.007 \pm 0.017$
$D^+ \to \bar{K}_1(1400)^0(K^{*-}\pi^+[S])\pi^+$	> 10	$-2.68 \pm 0.05 \pm 0.07$	$0.221 \pm 0.012 \pm 0.018$
$D^+ \to \bar{K}_1(1400)^0(K^{*-}\pi^+[D])\pi^+$	> 10	$-2.24 \pm 0.10 \pm 0.07$	$0.015 \pm 0.002 \pm 0.001$
$D^+ \to \bar{K}_1(1400)^0(K^{*-}\pi^+)\pi^+$	-	-	$0.216 \pm 0.012 \pm 0.011$
$D^+ \to \bar{K}_1(1270)^0(K^0_S\rho^0[S])\pi^+$	9.7	$-0.56 \pm 0.09 \pm 0.11$	$0.024 \pm 0.003 \pm 0.007$
$D^+ \to \bar{K}(1460)^0(K^{*-}\pi^+)\pi^+$	> 10	$-2.50 \pm 0.07 \pm 0.06$	$0.068 \pm 0.006 \pm 0.002$
$D^+ \to \bar{K}(1460)^0(K^0_S\rho^0)\pi^+$	6.1	$-2.65 \pm 0.18 \pm 0.25$	$0.008 \pm 0.002 \pm 0.005$
$D^+ \to \bar{K}_1(1650)^0(K^{*-}\pi^+[S])\pi^+$	6.5	$0.95 \pm 0.14 \pm 0.22$	$0.016 \pm 0.004 \pm 0.009$
$D^+ \to (K^0_S\rho^0[S])_A\pi^+$	> 10	$-1.88 \pm 0.08 \pm 0.05$	$0.057 \pm 0.007 \pm 0.023$
$D^+ \to (K^0_S\rho^0[D])_A\pi^+$	7.0	$2.77 \pm 0.12 \pm 0.14$	$0.008 \pm 0.002 \pm 0.001$
$D^+ \to (K^0_S\rho^0)_A\pi^+$	-	-	$0.064 \pm 0.007 \pm 0.030$
$D^+ \to (K^0_S(\pi^+\pi^-)_S)_A\pi^+$	> 10	$-3.08 \pm 0.06 \pm 0.04$	$0.064 \pm 0.005 \pm 0.007$
$D^+ \to ((K^0_S\pi^+)_{S-\mathrm{wave}}\pi^-)_P\pi^+$	> 10	$2.10 \pm 0.08 \pm 0.28$	$0.017 \pm 0.003 \pm 0.004$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$ non-resonance	-	-	$0.081 \pm 0.006 \pm 0.006$

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Amplitude analysis of $D^+_s \to \pi^+\pi^0\eta$ and …

3.19 fb^{-1}@4178 MeV

arXiv:1903.04118

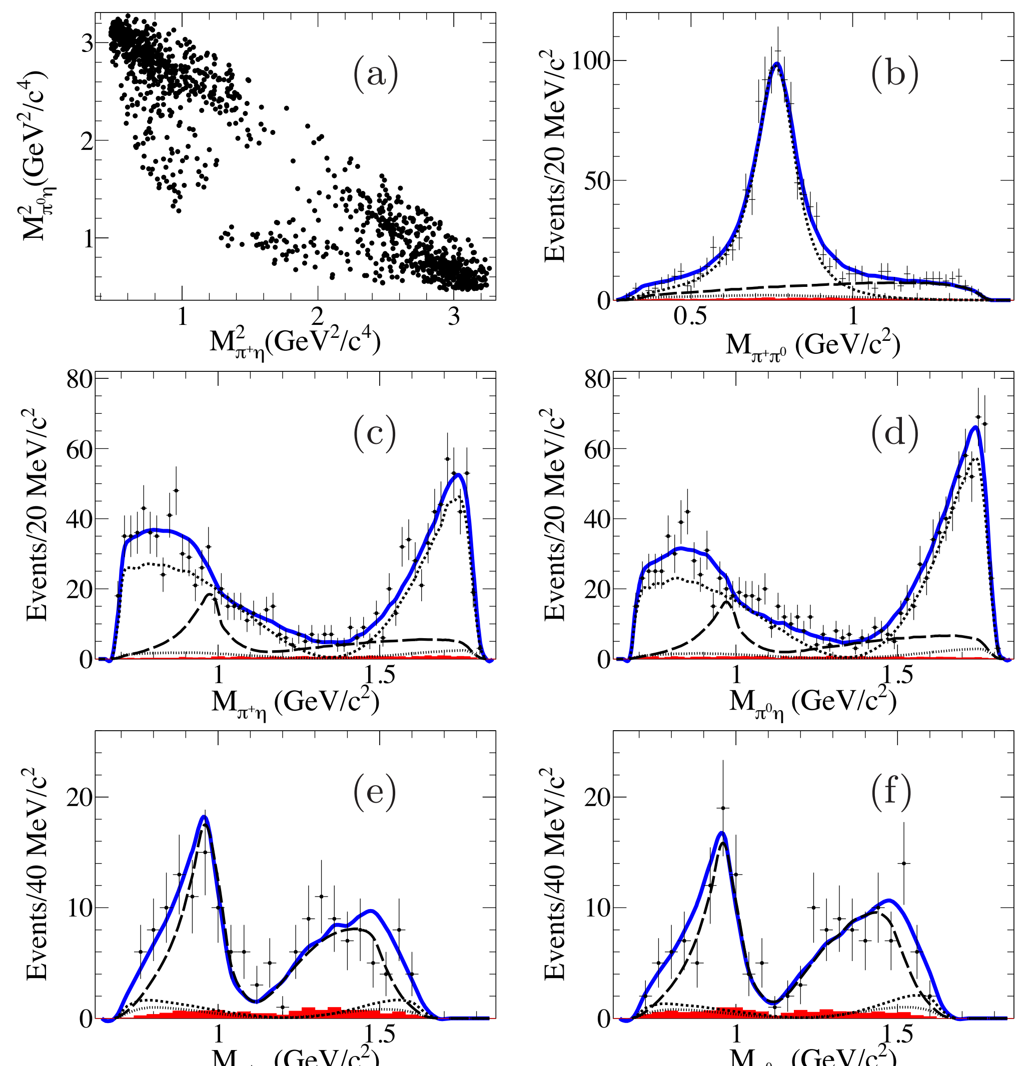
- Double tag analysis: tag modes $D^-_s \to K^0_S K^-$; $D^-_s \to K^+K^-\pi^-$; $D^-_s \to K^0_S K^-\pi^0$; $D^-_s \to K^+K^-\pi^-\pi^0$; $D^-_s \to K^0_S K^-\pi^-\pi^-$; $D^-_s \to \pi^-\eta$
- 1239 events with 97.7% purity used for amplitude analysis

First amplitude analysis

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

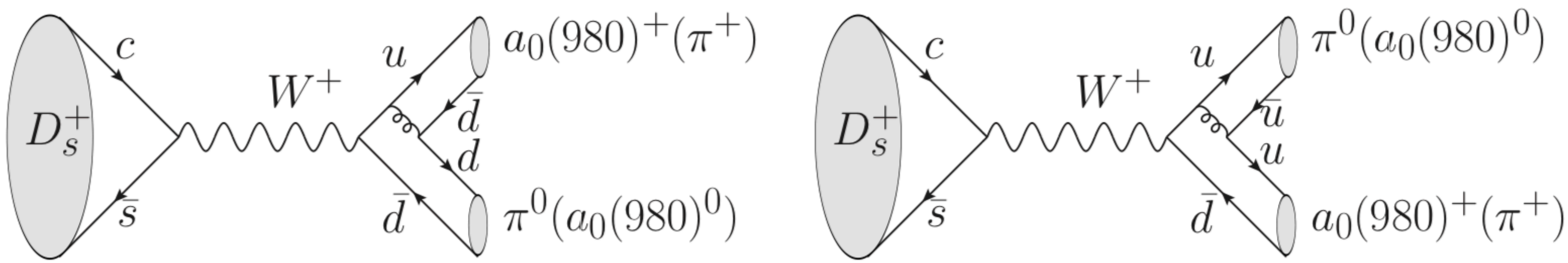
$B(D^+_s \to \pi^+\pi^0\eta) = (9.50 \pm 0.28(\text{stat}) \pm 0.41\ (\text{syst}))\%$

Best precision measurement



… a first observation of the pure W-annihilation decays $D^+_s \to a_0(980)^+\pi^0$ and $D^+_s \to a_0(980)^0\pi^+$

arXiv:1903.04118



First observation with a statistical significance 16.2 σ

$$\mathcal{B}(D_s^+ \to a_0(980)^{+(0)}\pi^{0(+)}, a_0(980)^{+(0)} \to \pi^{+(0)}\eta) = (1.46 \pm 0.15_{\text{stat.}} \pm 0.23_{\text{sys.}})\%$$

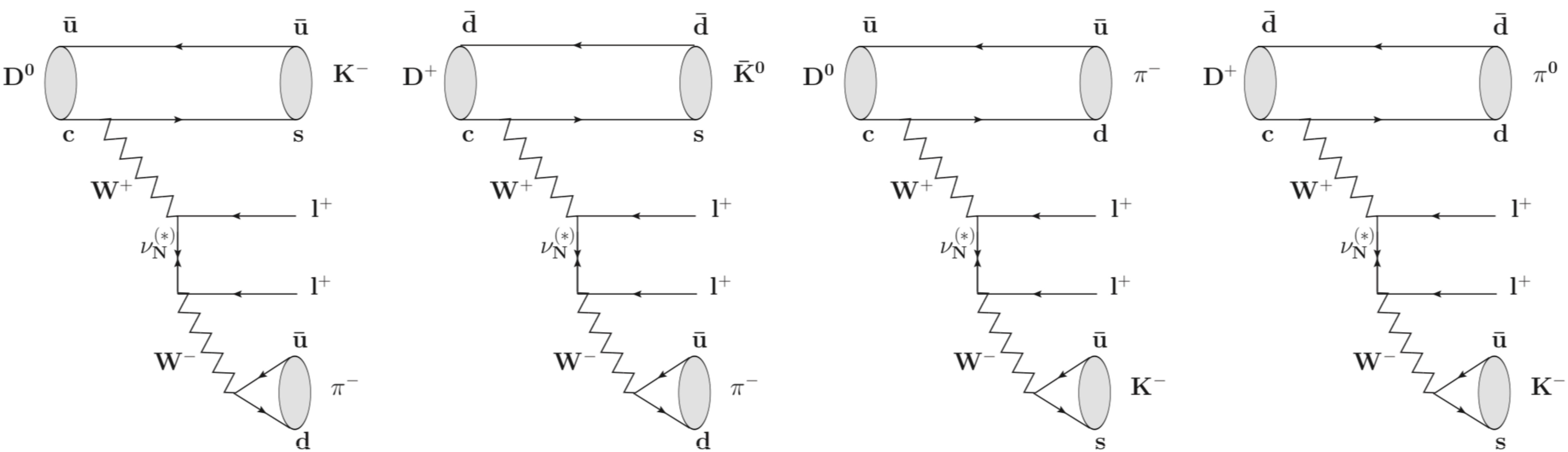
An order of magnitude larger than other W-annihilation decays

Search for heavy Majorana neutrino in lepton number violating decays of D→Kπe⁺e⁺

2.93 fb^{-1}@3773 MeV

arXiv:1902.02450

- Single tag analysis
- See-saw mechanism $m_\nu \sim y_\nu^2 v^2 / m_N$
- LNV process: exchange a single Majorana neutrino



(a) $D^0 \to K^-\pi^-l^+l^+$ (CF) (b) $D^+ \to \bar{K}^0\pi^-l^+l^+$ (CF) (c) $D^0 \to K^-\pi^-l^+l^+$ (DCS) (d) $D^+ \to K^-\pi^0l^+l^+$ (DCS)

Upper limits

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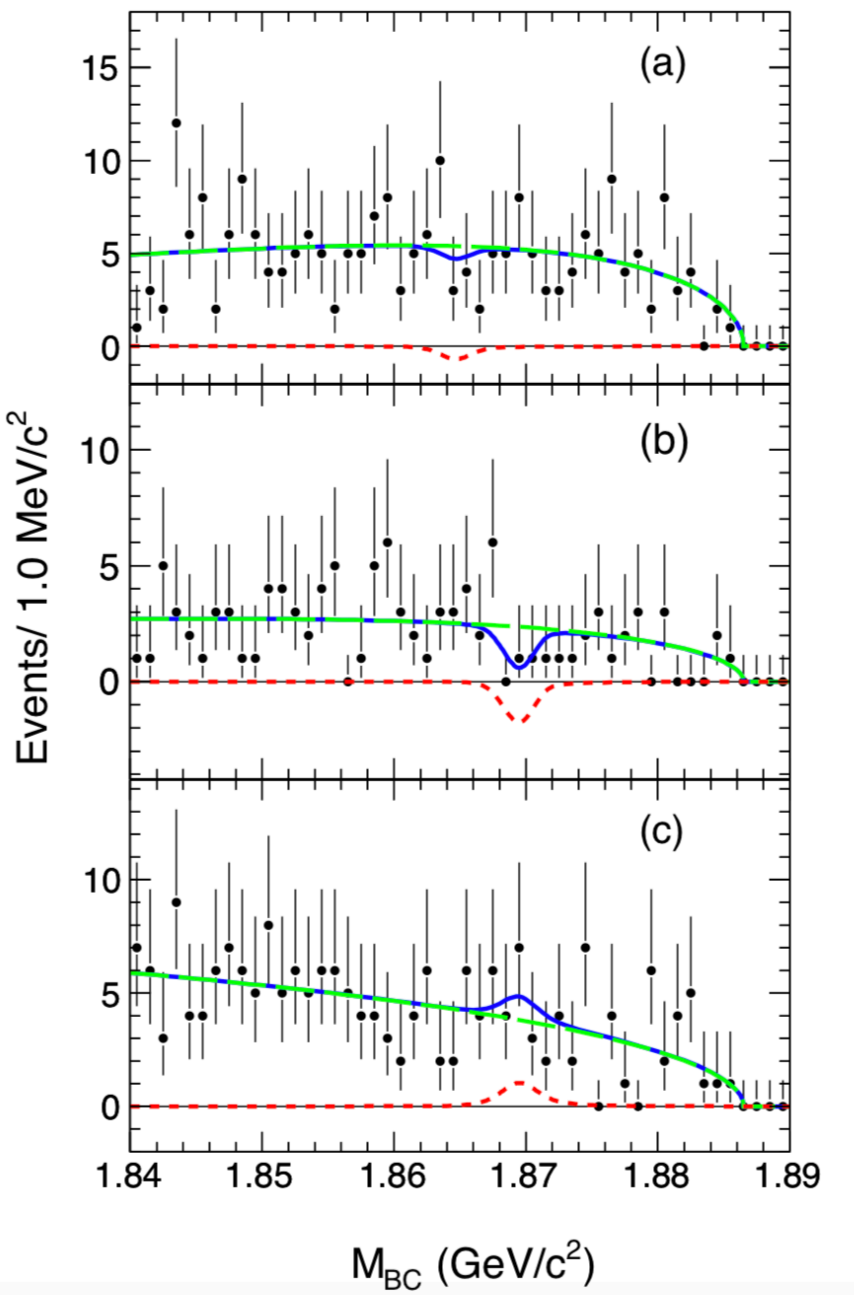
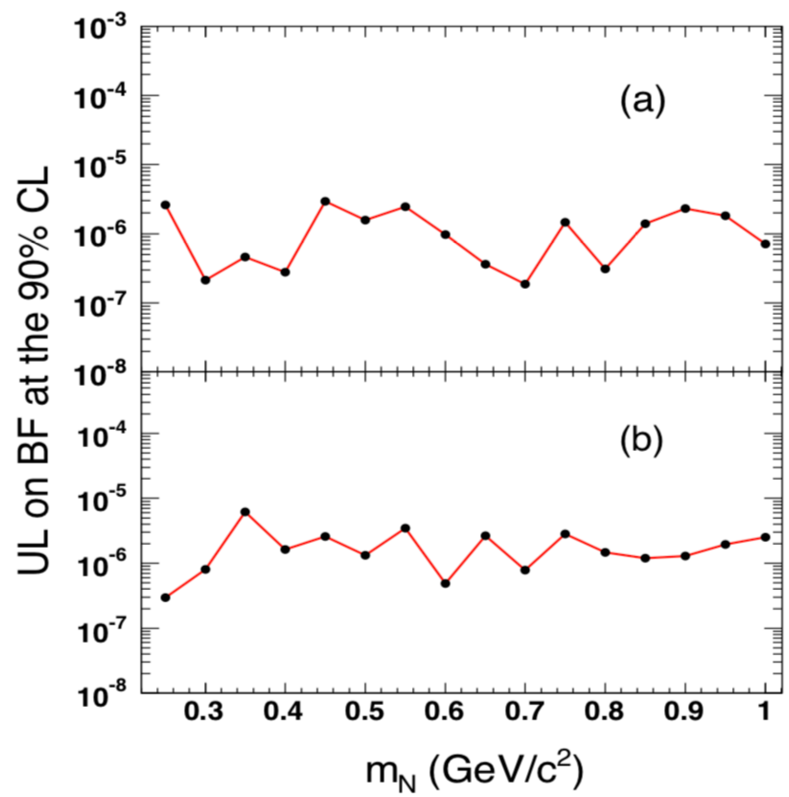
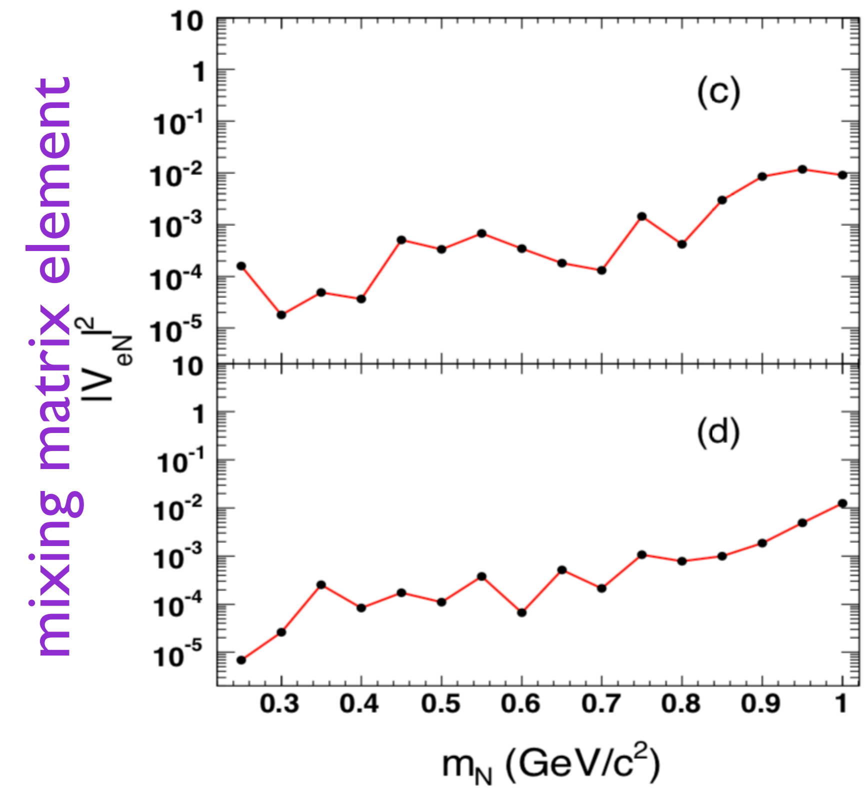


Different Majorana neutrino mass assumptions m_N in the decays $D^0 \to K^- e^+ \nu_N (\pi^- e^+)$ and $D^+ \to K^0_S e^+ \nu_N (\pi^- e^+)$





$B(D^0 \to K^- \pi^- e^+ e^+) < 2.7 \times 10^{-6}$ @90% CL

$B(D^+ \to K^0_S \pi e^+ e^+) < 3.3 \times 10^{-6}$ @90% CL

$B(D^+ \to K^- \pi^0 e^+ e^+) < 8.5 \times 10^{-6}$ @90% CL

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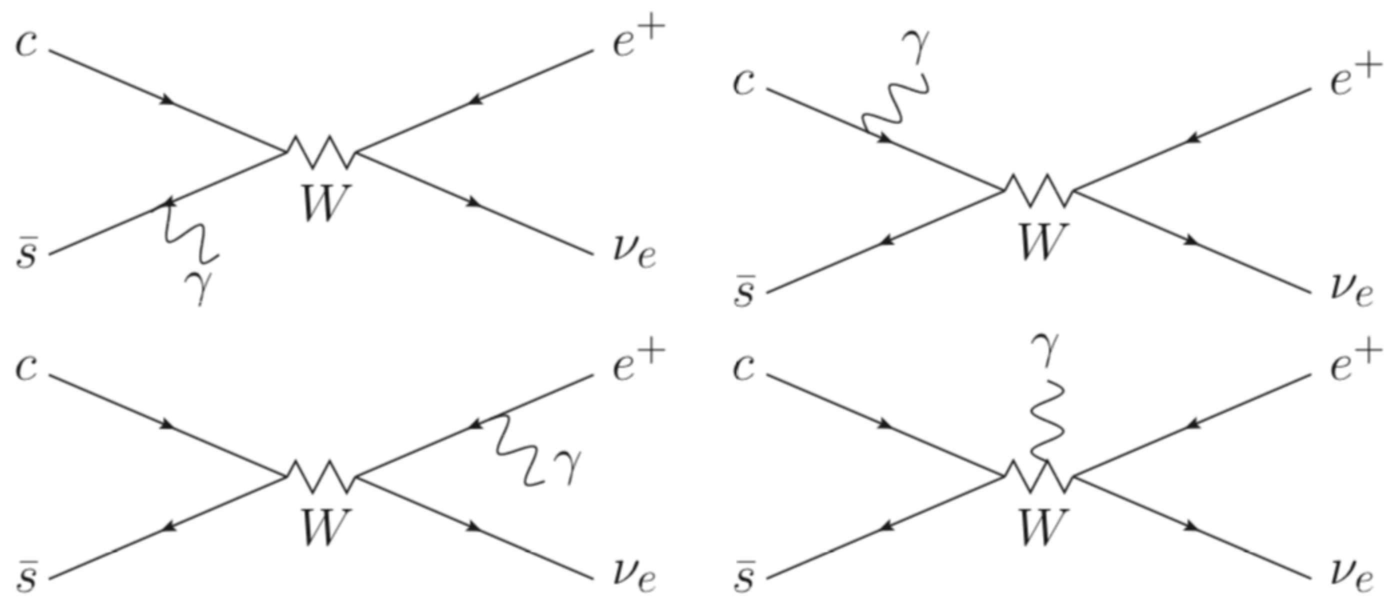
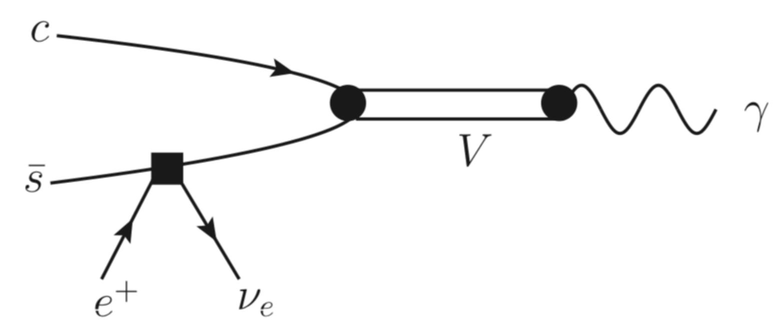
First search for the decay $D^+_s \to \gamma e^+ \nu_e$

No helicity suppression. The BFs are predicated to be in the range 10^{-5}-10^{-3} in various models.

3.19 fb^{-1}@4178 MeV

Phys. Rev. D 99, 072002 (2019) *arXiv:1902.03351*

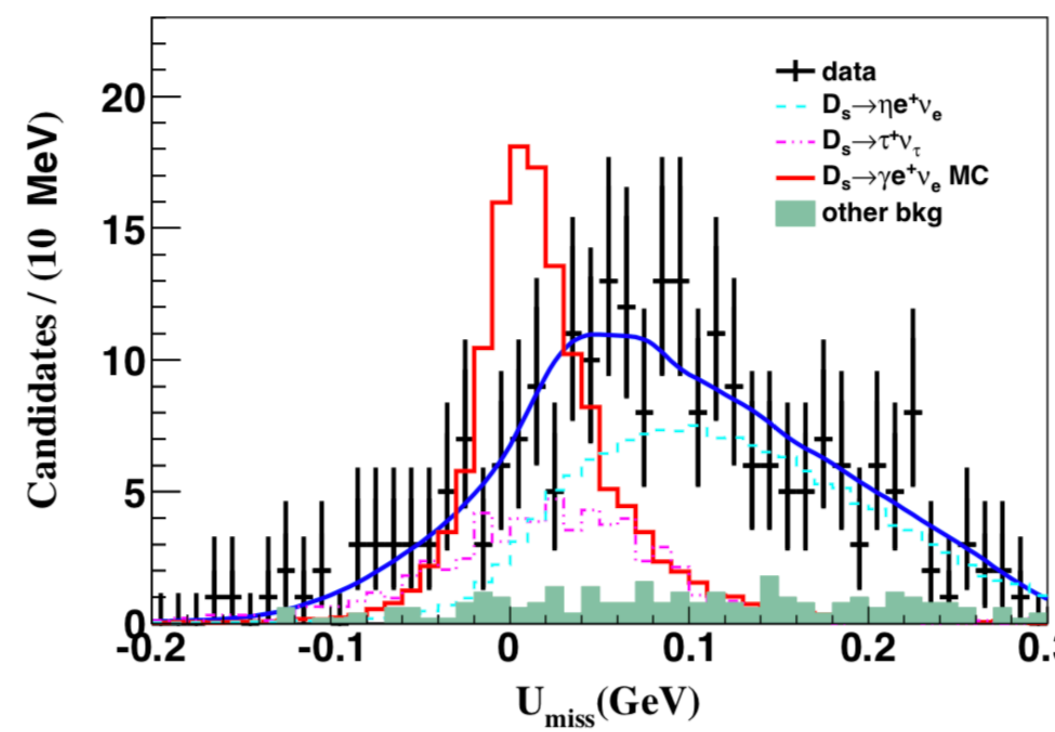




Long distance contribution via vector meson suggested by Yang and Yang, Mod. Phys. Lett. A 27, 1250120 (2012) may further enhance the BF

Double tag analysis with 14 tag modes

$K^+K^-\pi^-$	$K^0_S K^-$
$\pi^+\pi^-\pi^-$	$K^0_S K^-\pi^0$
$K^-\pi^+\pi^-$	$K^0_S K^+\pi^-\pi^-$
$K^+K^-\pi^-\pi^0$	$\eta_{\gamma\gamma}\pi^-$
$K^0_S K^-\pi^+\pi^-$	$K^0_S K^0_S \pi^-$
$\eta'_{\gamma\rho^0}\pi^-$	$\eta_{\pi^0\pi^+\pi^-}\pi^-$
$\eta_{\gamma\gamma}\rho^-$	$\eta'_{\eta_{\gamma\gamma}\pi^+\pi^-}\pi^-$



Upper limit $B(D^+_s \to \gamma e^+ \nu_e) < 1.3 \times 10^{-4}$ at the 90% C.L.

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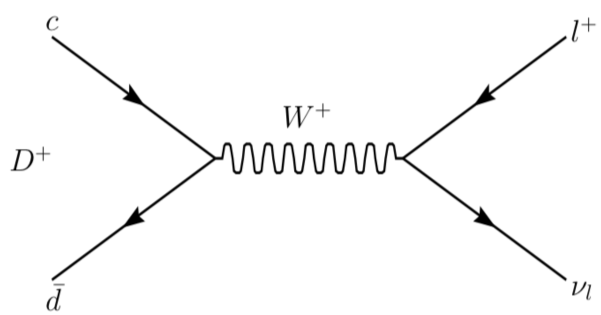
Search for $D^+ \to \tau^+ \nu_\tau$

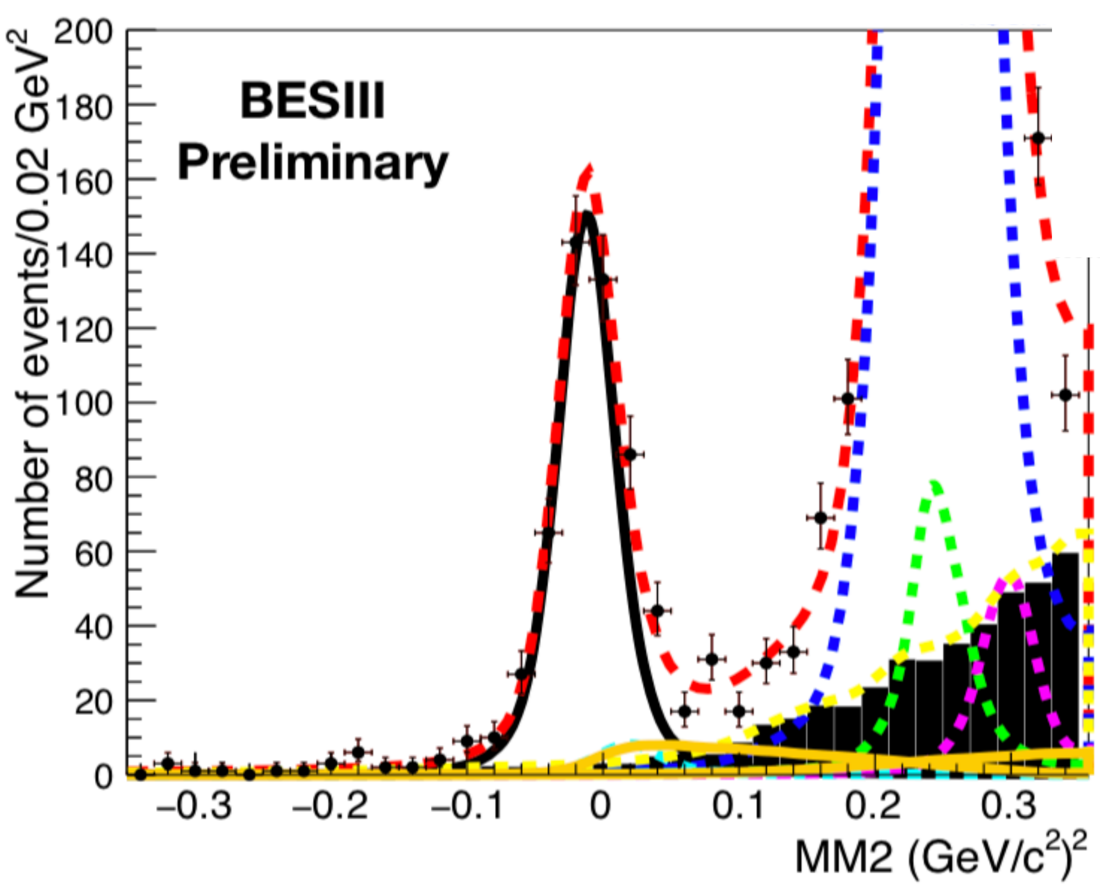
2.93 fb^{-1}@3773 MeV



$$\Gamma(D^+ \to \ell^+ \nu_\ell) = \frac{G_F^2}{8\pi} f_{D^+}^2 |V_{cd}|^2 m_\ell^2 M_{D^+} \left(1 - \frac{m_\ell^2}{M_{D^+}^2}\right)^2$$

BF < 1.2 ×10^{-3} @ 90% CL by CLEO with 818 pb^{-1}
PRD 78, 052003(2008)

- Double tag analysis



Tag modes, i
$K^+\pi^-\pi^-$
$K^+\pi^-\pi^-\pi^0$
$K_S^0\pi^-$
$K_S^0\pi^-\pi^0$
$K_S^0\pi^-\pi^-\pi^+$
$K^+K^-\pi^-$

137±27 events

First evidence with
> 4σ significance

$$\mathcal{B}(D^+ \to \tau^+\nu_\tau) = \frac{N_{\rm DT}}{\mathcal{B}(\tau^+ \to \pi^+\bar{\nu_\tau}) \cdot \sum_i N_{\rm tag}^i \cdot (\epsilon_{\rm DT}^i/\epsilon_{\rm tag}^i)}$$

$$\mathcal{B}(D^+ \to \tau^+\nu_\tau) = (1.20 \pm 0.24_{\rm stat}) \times 10^{-3}$$

$$f_{D^+}|V_{cd}| = 50.4 \pm 5.0_{\rm stat}\ \text{MeV}$$

$R_{\tau/\mu} = \Gamma(D^+ \to \tau^+\nu_\tau)/\Gamma(D^+ \to \mu^+\nu_\mu) = 3.21 \pm 0.64$, SM prediction is 2.66±0.01

Other recent results on hadronic decays and charm baryons

- M. Ablikim *et al.* (BESIII collaboration), Measurement of the absolute branching fractions of $\Lambda^+_c \to \Lambda\eta\pi^+$ and $\Sigma(1385)^+\eta$, Phys. Rev. D 99, 032010 (2019), arXiv:1812.10731

- M. Ablikim *et al.* (BESIII collaboration), Evidence for the decays of $\Lambda^+_c \to \Sigma^+\eta$ and $\Sigma^+\eta'$, arXiv:1811.08028

- M. Ablikim *et al.* (BESIII collaboration), Measurements of the absolute branching fractions and CP asymmetries for $D^+ \to K^0_{S,L}K(\pi^0)$, Phys. Rev. D 99, 032002 (2019), arXiv:1812.05400

- M. Ablikim *et al.* (BESIII collaboration), Observation of $D^+_s \to p\bar{n}$ and confirmation of its large branching fraction, Phys. Rev. D 99, 031101 (2019), arXiv:1811.00752

- M. Ablikim *et al.* (BESIII collaboration), Observation of the W-Annihilation Decay $D^+_s \to \omega\pi^+$ and Evidence for $D^+_s \to \omega K^+$, Phys. Rev. D 99, 091101 (2019), arXiv:1811.00392

Other recent results on (semi-)leptonic decays

- M. Ablikim *et al.* (BESIII collaboration), Measurement of the Dynamics of the Decays $D^+_s \to \eta^{(\prime)} e^+ \nu_e$, Phys. Rev. Lett. 122, 121801 (2019) arXiv:1901.02133

- M. Ablikim *et al.* (BESIII collaboration), Study of the decay $D^0 \to \bar{K}^0 \pi^- e^+ \nu_e$, Phys. Rev. D 99, 011103 (2019), arXiv:1811.11349

- M. Ablikim *et al.* (BESIII collaboration), Determination of the pseudoscalar decay constant $f_{D^+_s}$ via $D^+_s \to \mu^+ \nu_\mu$, Phys. Rev. Lett. 122, 071802 (2019), arXiv:1811.10890

- M. Ablikim *et al.* (BESIII collaboration), First measurement of the form factors in $D^+_s \to K^0 e^+ \nu_e$ and $D^+_s \to K^{*0} e^+ \nu_e$ decays, Phys. Rev. Lett. 122, 061801 (2019), arXiv:1811.02911

- M. Ablikim *et al.* (BESIII collaboration), Study of the $D^0 \to K^- \mu^+ \nu_\mu$ dynamics and test of lepton flavor universality with $D^0 \to K^- \ell^+ \nu_\ell$ decays, Phys. Rev. Lett. 122, 011804 (2019), arXiv:1810.03127

- M. Ablikim *et al.* (BESIII collaboration), Observation of $D^+ \to f_0(500) e^+ \nu_e$ and Improved Measurements of $D \to \rho e^+ \nu_e$, Phys. Rev. Lett. 122, 062001 (2019), arXiv:1809.06496

Summary

- Very rich charm programme @ BESIII
- The unique tagging technique allows for absolute BF measurements, rare decays searches
- Very high purity charm samples for amplitude analyses
- A lot of new results: either a completely new results or significantly improving previous measurements

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BACKUP

Variables & systematics $\Lambda^+_c \to BP$ decays

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

$$\langle\cos\theta_i\rangle = -\frac{1}{6}\alpha^+_{\Sigma^0\pi^+}\alpha_\Lambda\cos\theta_j$$

$$\mathcal{W} \propto 1 + \alpha_0\cos^2\theta_0 + \mathcal{P}_T\alpha^+_{BP}\sin\theta_1\sin\phi_1$$

$$\langle\sin\theta_1\sin\phi_1\rangle = \frac{\int_0^{2\pi}\int_{-1}^{1}\sin\theta_1\sin\phi_1\mathcal{W}\mathrm{d}\cos\theta_1\mathrm{d}\phi_1}{\int_0^{2\pi}\int_{-1}^{1}\mathcal{W}\mathrm{d}\cos\theta_1\mathrm{d}\phi_1}$$

Source	α^+_A	α^+_B	α^+_C	α^+_D	$\sin\Delta_0$	Δ^B_1	Δ^C_1	Δ^D_1
Reconstruction	0.00	0.00	0.00	0.01	0.00	0.8	0.0	0.0
$\pi^0\pi^0$ veto	0.01	0.00	0.01	0.00	0.00	0.0	0.2	0.0
ΔE signal region	0.07	0.01	0.02	0.05	0.02	0.3	0.1	0.1
M_{BC} signal region	0.12	0.01	0.05	0.02	0.02	0.5	0.4	0.1
Bkg subtraction	0.03	0.01	0.05	0.04	0.02	0.3	0.3	0.0
Total	0.14	0.02	0.07	0.07	0.03	1.0	0.6	0.2

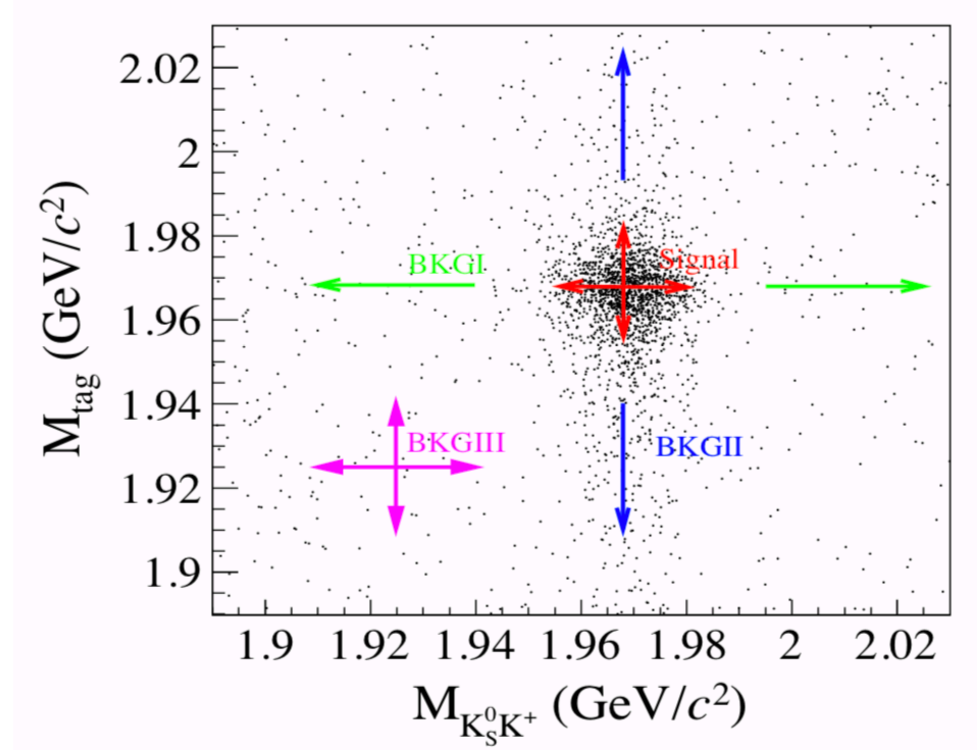
Systematics for $D^+_s \to K^0_S K^+$ and $K^0_L K^+$

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

$$N^i_{\rm ST} = 2 \times N_{D_s^{*\pm} D_s^{\mp}} \times \mathcal{B}^i_{\rm tag} \times \epsilon^i_{\rm ST}$$

$$N^i_{\rm DT} = 2 \times N_{D_s^{*\pm} D_s^{\mp}} \times \mathcal{B}^i_{\rm tag} \times \mathcal{B}_{\rm sig} \times \epsilon^i_{\rm DT}$$

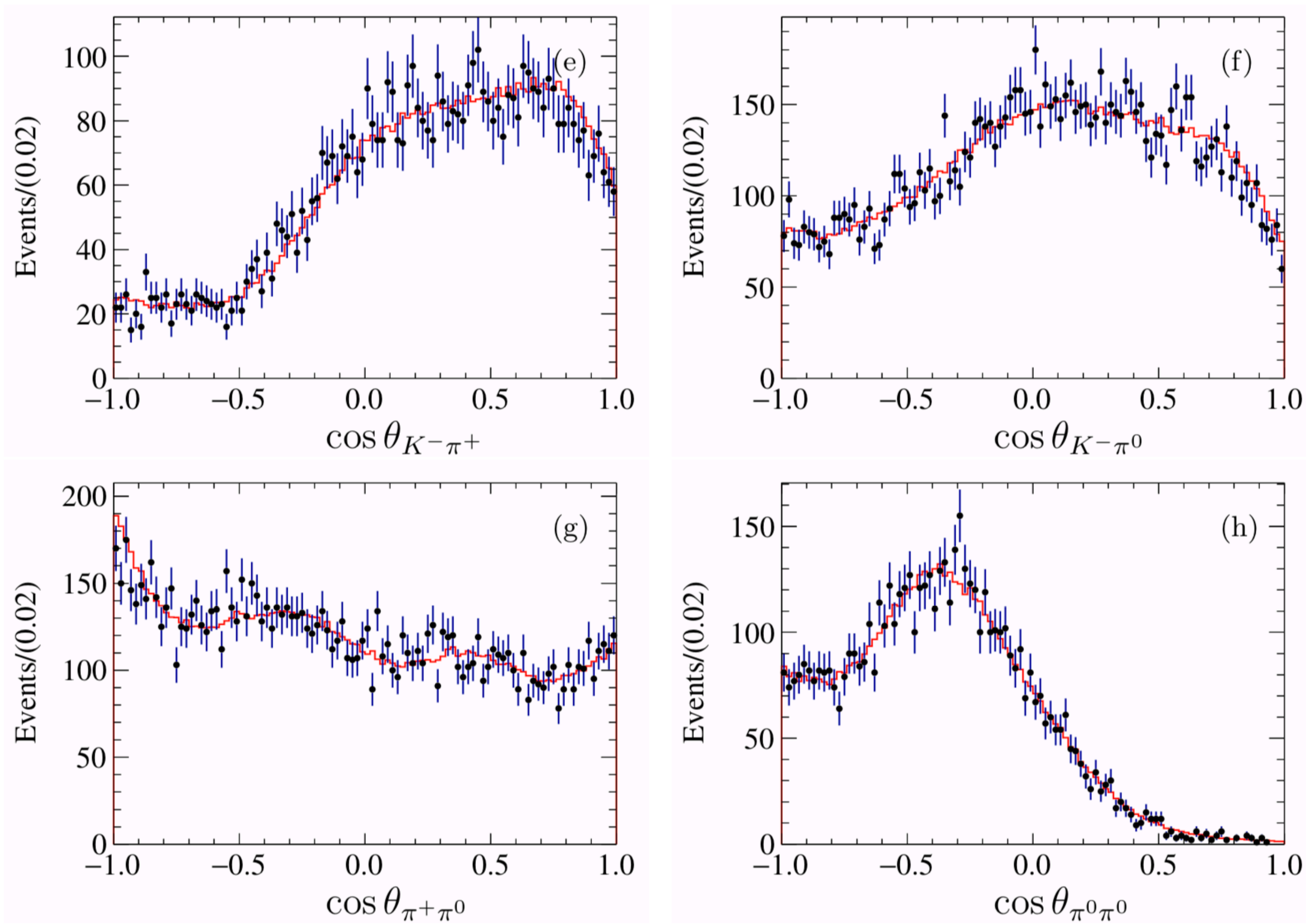
$$\mathcal{B}_{\rm sig} = \frac{N^{\rm tot}_{\rm DT}}{\sum_i N^i_{\rm ST} \times \epsilon^i_{\rm DT}/\epsilon^i_{\rm ST}}$$



Source	$\mathcal{B}(D_s^+ \to K_S^0 K^+)$	$\mathcal{B}(D_s^+ \to K_L^0 K^+)$	$R(D_s^+ \to K_{S,L}^0 K^+)$	$A_{\rm CP}(D_s^\pm \to K_S^0 K^\pm)$	$A_{\rm CP}(D_s^\pm \to K_L^0 K^\pm)$
K^+/K^- tracking	0.5	0.5	-	0.4	0.4
K^+/K^- PID	0.5	0.5	-	0.4	0.4
K_S^0 reconstruction	1.5	-	0.7	-	-
Photon selection and kinematic fit	-	2.0	1.0	-	-
Extra photon energy requirement	-	0.6	0.3	-	-
Extra charged track requirement	0.6	0.6	-	-	-
ST $M(D_s)$ fit	0.9	0.9	-	-	-
DT fit	0.8	-	0.4	-	-
MM^2 fit	-	1.5	0.7	-	-
MC statistics	0.3	0.3	0.2	0.2	0.2
Effect of $\mathcal{B}(D_s^* \to \gamma D_s)$	-	0.7	0.3	-	-
Effect of $e^+e^- \to D_s^+ D_s^-$	-	0.4	0.2	-	-
Tag-side bias	0.3	0.5	0.3	-	-
total	2.2	3.1	1.6	0.6	0.6

Amplitude Analysis of $D^0 \to K^-\pi^+\pi^0\pi^0$

- cosines of helicity angles



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

TABLE IV. FF systematic uncertainties (in units of statistical standard deviations) for: (I) the amplitude model, (II) background, (III) experimental effects, and (IV) fit bias. The total uncertainty is obtained by adding all contributions in quadrature.

Amplitude mode	I	II	III	IV	Total
$D \to SS$					
$D \to (K^-\pi^+)_S(\pi^0\pi^0)_S$	1.518	1.258	0.072	0.235	1.987
$D \to (K^-\pi^0)_S(\pi^+\pi^0)_S$	1.524	0.835	0.078	0.004	1.740
$D \to AP, A \to VP$					
$D \to K^-a_1(1260)^+, \rho^+\pi^0[S]$	1.293	0.436	0.030	0.363	1.412
$D \to K^-a_1(1260)^+, \rho^+\pi^0[D]$	0.938	0.368	0.024	0.284	1.046
$D \to K_1(1270)^-\pi^+, K^{*-}\pi^0[S]$	1.643	1.175	0.160	0.182	2.035
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[S]$	1.562	0.567	0.034	0.036	1.662
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[D]$	0.989	0.541	0.035	0.068	1.201
$D \to K_1(1270)^0\pi^0, K^-\rho^+[S]$	0.713	0.221	0.098	0.172	0.772
$D \to (K^{*-}\pi^0)_A\pi^+, K^{*-}\pi^0[S]$	1.253	1.254	0.076	0.237	1.790
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[S]$	1.145	0.524	0.022	0.162	1.278
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[D]$	0.865	1.468	0.052	0.106	1.708
$D \to (\rho^+K^-)_A\pi^0, K^-\rho^+[D]$	1.249	0.812	0.084	0.186	1.504
$D \to AP, A \to SP$					
$D \to ((K^-\pi^+)_S\pi^0)_A\pi^0$	1.377	0.372	0.102	0.164	1.439
$D \to VS$					
$D \to (K^-\pi^0)_S\rho^+$	1.308	0.252	0.070	0.476	1.416
$D \to K^{*-}(\pi^+\pi^0)_S$	0.381	0.549	0.023	0.166	0.689
$D \to K^{*0}(\pi^0\pi^0)_S$	0.880	0.417	0.078	0.232	1.005
$D \to VP, V \to VP$					
$D \to (K^{*-}\pi^+)_V\pi^0$	0.688	0.752	0.033	0.273	1.056
$D \to VV$					
$D \to K^{*-}\rho^+[S]$	0.980	1.354	0.059	0.371	1.713
$D \to K^{*-}\rho^+[P]$	0.425	0.506	0.031	0.348	0.747
$D \to K^{*-}\rho^+[D]$	1.365	0.598	0.049	0.398	1.543
$D \to (K^-\pi^0)_V\rho^+[P]$	0.695	1.223	0.027	0.140	1.414
$D \to (K^-\pi^0)_V\rho^+[D]$	1.335	0.848	0.237	0.401	1.649
$D \to K^{*-}(\pi^+\pi^0)_V[D]$	0.751	0.894	0.049	0.074	1.171
$D \to (K^-\pi^0)_V(\pi^+\pi^0)_V[S]$	0.818	0.443	0.046	0.211	0.955
$D \to TS$					
$D \to (K^-\pi^+)_S(\pi^0\pi^0)_T$	1.171	0.936	0.084	0.273	1.528
$D \to (K^-\pi^0)_S(\pi^+\pi^0)_T$	0.803	0.188	0.068	0.018	0.828

TABLE V. Phase, ϕ, systematic uncertainties (in units of statistical standard deviations) for: (I) the amplitude model, (II) background, (III) experimental effects, and (IV) fit bias. The total uncertainty is obtained by adding all contributions in quadrature.

Amplitude mode	I	II	III	IV	Total
$D \to SS$					
$D \to (K^-\pi^+)_S(\pi^0\pi^0)_S$	3.137	0.093	0.043	0.030	3.139
$D \to (K^-\pi^0)_S(\pi^+\pi^0)_S$	2.330	0.850	0.044	0.109	2.483
$D \to AP, A \to VP$					
$D \to K^-a_1(1260)^+, \rho^+\pi^0[S]$	0.000	0.000	0.000	0.000	0.000
$D \to K^-a_1(1260)^+, \rho^+\pi^0[D]$	1.194	0.761	0.081	0.479	1.497
$D \to K_1(1270)^-\pi^+, K^{*-}\pi^0[S]$	0.953	0.820	0.054	0.124	1.264
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[S]$	1.051	0.556	0.029	0.565	1.316
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[D]$	1.002	0.483	0.045	0.121	1.120
$D \to K_1(1270)^0\pi^0, K^-\rho^+[S]$	2.007	0.188	0.079	0.847	2.188
$D \to (K^{*-}\pi^0)_A\pi^+, K^{*-}\pi^0[S]$	1.208	0.706	0.048	0.455	1.472
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[S]$	1.711	0.365	0.053	0.214	1.750
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[D]$	1.501	0.605	0.051	0.187	1.630
$D \to (\rho^+K^-)_A\pi^0, K^-\rho^+[D]$	1.195	0.613	0.133	0.611	1.482
$D \to AP, A \to SP$					
$D \to ((K^-\pi^+)_S\pi^0)_A\pi^0$	2.039	0.410	0.045	0.446	2.127
$D \to VS$					
$D \to (K^-\pi^0)_S\rho^+$	3.159	0.471	0.053	0.216	3.201
$D \to K^{*-}(\pi^+\pi^0)_S$	1.207	0.258	0.045	0.156	1.245
$D \to K^{*0}(\pi^0\pi^0)_S$	0.938	0.476	0.062	0.116	1.060
$D \to VP, V \to VP$					
$D \to (K^{*-}\pi^+)_V\pi^0$	1.260	0.471	0.032	0.490	1.432
$D \to VV$					
$D \to K^{*-}\rho^+[S]$	1.995	0.154	0.070	0.712	2.125
$D \to K^{*-}\rho^+[P]$	1.612	0.214	0.035	0.864	1.842
$D \to K^{*-}\rho^+[D]$	1.586	1.108	0.051	0.588	2.022
$D \to (K^-\pi^0)_V\rho^+[P]$	1.429	0.324	0.023	0.128	1.471
$D \to (K^-\pi^0)_V\rho^+[D]$	0.401	0.832	0.133	0.666	1.146
$D \to K^{*-}(\pi^+\pi^0)_V[D]$	1.445	1.313	0.040	0.190	1.962
$D \to (K^-\pi^0)_V(\pi^+\pi^0)_V[S]$	1.354	0.213	0.041	0.726	1.551
$D \to TS$					
$D \to (K^-\pi^+)_S(\pi^0\pi^0)_T$	2.544	0.724	0.057	0.189	2.653
$D \to (K^-\pi^0)_S(\pi^+\pi^0)_T$	1.533	0.718	0.050	0.135	1.699

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Systematic uncertainties for $D^+_s \to \pi^+\pi^0\eta$

Systematic uncertainties for the amplitude analysis are considered from five sources: (I) line-shape parameterizations of the resonances, (II) fixed parameters in the amplitudes, (III) the background level and distribution in the Dalitz plot, (IV) experimental effects, and (V) the fitter performance. We determine these systematic un-

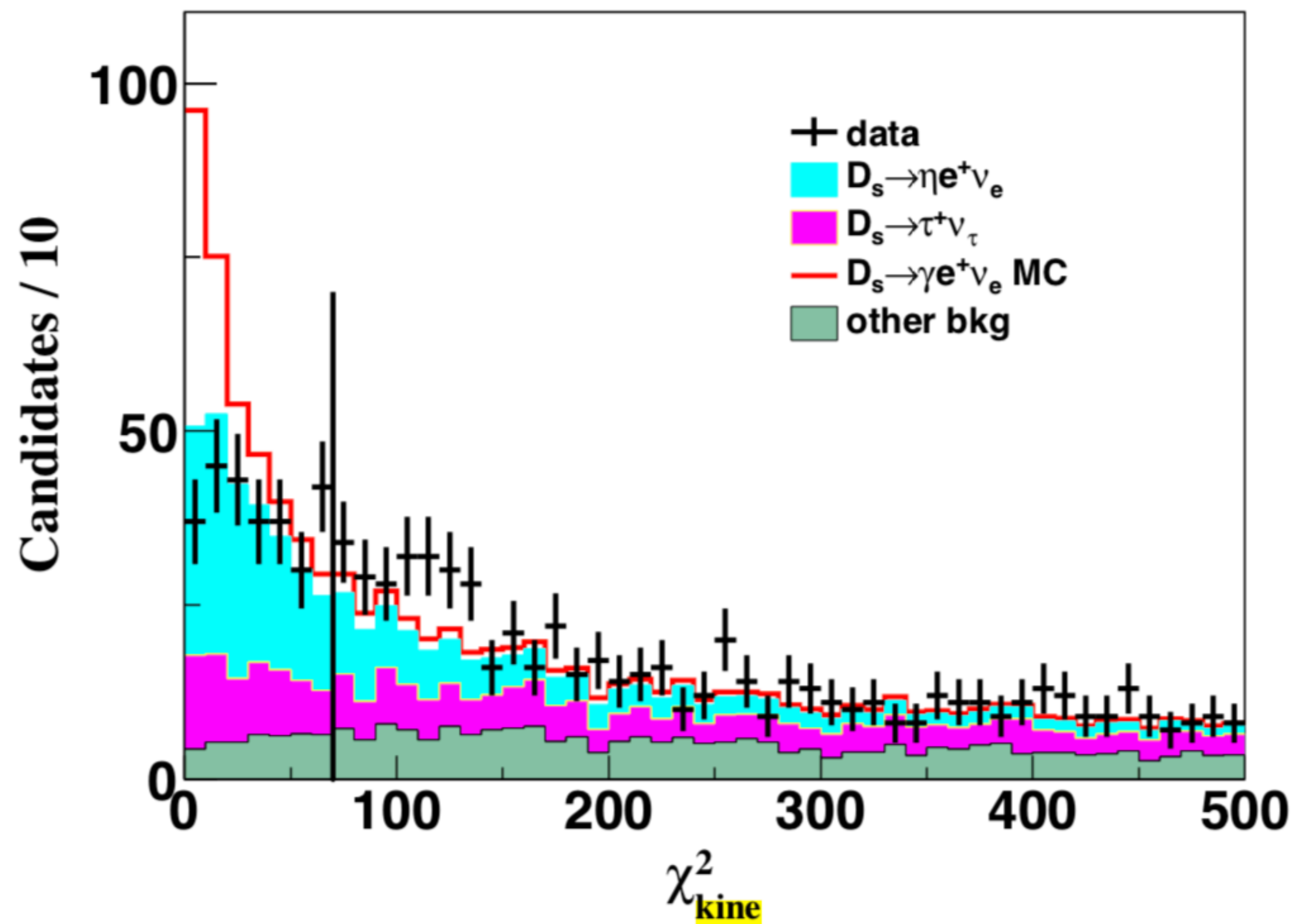
Amplitude		Source					
		I	II	III	IV	V	Total
$D_s^+ \to \rho^+\eta$	FF	0.06	0.34	0.13	0.12	0.15	0.41
$D_s^+ \to (\pi^+\pi^0)_V\eta$	ϕ	–	1.97	0.18	0.03	0.17	1.99
	FF	0.61	1.03	0.12	0.06	0.08	1.21
$D_s^+ \to a_0(980)\pi$	ϕ	–	0.41	0.07	0.28	0.09	0.51
	FF	0.58	1.31	0.02	0.06	0.11	1.45

Systematic uncertainties for D→Kπe+e+

Source	Relative systematic uncertainty (%)		
	$D^0 \to K^-\pi^-e^+e^+$	$D^+ \to K^0_S\pi^-e^+e^+$	$D^+ \to K^-\pi^0e^+e^+$
e Tracking	2.0	2.0	2.0
e PID	2.0	2.0	2.0
K/π Tracking	2.0	1.0	1.0
K/π PID	1.0	0.5	0.5
K^0_S selection	–	1.5	–
π^0 selection	–	–	2.0
$N_{D\bar{D}}$	1.0	0.9	0.9
Cited BF	–	0.1	0.0
ΔE requirement	0.7	0.7	0.4
FSR recovery	0.6	0.8	0.6
Efficiency modeling	3.6	4.3	4.7
Fitting $M_{\rm BC}$	...	...	...
Total	5.3	5.7	6.1

Systematic uncertainties for $D^+_s \to \gamma e^+ \nu_e$

Source	Relative uncertainty (%)
ST yields	0.4
Form factor model	11
e^+ tracking & PID	0.4
Photon selection	1
$E^{\max}_{\gamma\,\mathrm{extra}}$	1.1
$N^{\mathrm{extra}}_{\mathrm{char}}$	0.9
χ^2_{kine}	11
FSR	0.3
U_{miss} fit	10
Tag bias	0.5
Total	18.6



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Systematic uncertainties: $D^+ \to K^0_S\pi^+\pi^+\pi^-$

TABLE V. Systematic uncertainties of FFs for amplitudes and components. The different sources include (I) masses and widths of the intermediate resonances, (II) effective radius of intermediate resonances and D^+, (III) parameters in the $K^0_S\pi^+$ S-wave parameterization, (IV) parameters in $\rho-\omega$ mixing parameterization, (V) line shape of the $f_0(500)$, (VI) effect from peaking background, (VII) effect from general background, and (VIII) fit procedure.

Amplitude and component	Source ($\sigma_{\rm stat}$)								
	I	II	III	IV	V	VI	VII	VIII	total
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+[S])$	0.299	0.831	0.496	0.069	0.877	0.215	0.023	0.143	1.367
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+[D])$	0.137	0.335	0.032	0.078	0.014	0.028	0.054	0.085	0.386
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+)$	0.301	0.885	0.529	0.054	0.870	0.217	0.014	0.125	1.406
$D^+ \to K^0_S a_1(1260)^+(f_0(500)\pi^+)$	0.534	0.538	2.369	0.050	0.553	0.215	0.097	0.085	2.410
$D^+ \to \bar{K}_1(1400)^0\pi^+(K^{*-}\pi^+[S])$	1.260	0.094	0.306	0.003	0.093	0.177	0.174	0.060	1.328
$D^+ \to \bar{K}_1(1400)^0\pi^+(K^{*-}\pi^+[D])$	0.286	0.099	0.216	0.007	0.041	0.027	0.042	0.078	0.386
$D^+ \to \bar{K}_1(1400)^0\pi^+(K^{*-}\pi^+)$	0.857	0.078	0.221	0.002	0.066	0.123	0.119	0.063	0.910
$D^+ \to \bar{K}_1(1270)^0\pi^+(K^0_S\rho^0[S])$	1.151	0.274	1.511	0.071	0.480	0.172	0.061	0.086	1.990
$D^+ \to \bar{K}(1460)^0(K^{*-}\pi^+)\pi^+$	0.288	0.081	0.162	0.001	0.048	0.016	0.016	0.071	0.351
$D^+ \to \bar{K}(1460)^0(K^0_S\rho^0)\pi^+$	0.365	0.546	2.288	0.044	0.374	0.194	0.153	0.058	2.423
$D^+ \to \bar{K}_1(1650)^0\pi^+(K^{*-}\pi^+[S])$	1.836	0.862	0.077	0.007	0.164	0.095	0.195	0.063	2.049
$D^+ \to (K^0_S\rho^0[S])_A\pi^+$	0.644	0.758	3.139	0.036	0.124	0.154	0.037	0.058	3.300
$D^+ \to (K^0_S\rho^0[D])_A\pi^+$	0.188	0.248	0.334	0.044	0.010	0.072	0.001	0.092	0.474
$D^+ \to (K^0_S\rho^0)_A\pi^+$	0.863	0.876	4.287	0.031	0.131	0.236	0.066	0.078	4.469
$D^+ \to (K^0_S(\pi^+\pi^-)_S)_A\pi^+$	0.751	0.318	0.933	0.035	0.243	0.548	0.363	0.149	1.432
$D^+ \to ((K^0_S\pi^+)_{S-{\rm wave}}\pi^-)_P\pi^+$	0.347	0.073	1.422	0.014	0.128	0.259	0.039	0.086	1.497
$D^+ \to K^0_S\pi^+\pi^+\pi^-$ non-resonance	0.604	0.256	0.191	0.025	0.153	0.580	0.327	0.078	0.969

TABLE IV. Systematic uncertainties of phases for amplitudes. The different sources include (I) masses and widths of the intermediate resonances, (II) effective radius of intermediate resonances and D^+, (III) parameters in the $K^0_S\pi^+$ S-wave parameterization, (IV) parameters in the $\rho-\omega$ mixing parameterization, (V) line shape of the $f_0(500)$, (VI) effect from peaking background, (VII) effect from general background, and (VIII) fit procedure.

Amplitude	Source ($\sigma_{\rm stat}$)								
	I	II	III	IV	V	VI	VII	VIII	total
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+[D])$	0.317	0.413	1.221	0.059	0.273	0.042	0.057	0.061	1.412
$D^+ \to K^0_S a_1(1260)^+(f_0(500)\pi^+)$	0.265	0.343	1.110	0.262	-	0.220	0.058	0.071	1.243
$D^+ \to \bar{K}_1(1400)^0\pi^+(K^{*-}\pi^+[S])$	0.872	0.362	1.006	0.131	0.257	0.003	0.051	0.058	1.412
$D^+ \to \bar{K}_1(1400)^0\pi^+(K^{*-}\pi^+[D])$	0.393	0.252	0.451	0.068	0.062	0.001	0.097	0.149	0.679
$D^+ \to \bar{K}_1(1270)^0\pi^+(K^0_S\rho^0[S])$	1.135	0.349	0.123	0.021	0.012	0.131	0.121	0.121	1.213
$D^+ \to \bar{K}(1460)^0(K^{*-}\pi^+)\pi^+$	0.786	0.032	0.152	0.049	0.128	0.028	0.092	0.054	0.820
$D^+ \to \bar{K}(1460)^0(K^0_S\rho^0)\pi^+$	0.573	0.022	1.249	0.023	0.261	0.070	0.062	0.139	1.409
$D^+ \to \bar{K}_1(1650)^0\pi^+(K^{*-}\pi^+[S])$	1.171	0.166	0.948	0.026	0.089	0.066	0.118	0.051	1.526
$D^+ \to (K^0_S\rho^0[S])_A\pi^+$	0.539	0.307	0.217	0.015	0.061	0.007	0.115	0.050	0.672
$D^+ \to (K^0_S\rho^0[D])_A\pi^+$	0.173	0.278	1.057	0.038	0.273	0.045	0.057	0.100	1.147
$D^+ \to (K^0_S(\pi^+\pi^-)_S)_A\pi^+$	0.254	0.508	0.442	0.072	0.010	0.058	0.092	0.050	0.733
$D^+ \to ((K^0_S\pi^+)_{S-{\rm wave}}\pi^-)_P\pi^+$	0.142	0.226	3.309	0.083	0.192	0.027	0.059	0.125	3.330