Institute of High Energy Physics
Chinese Academy of Sciences

BESIII

Hadronic $D_{(s)}$ decays at BESIII

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On behalf of the BESIII Collaboration

FPCP, 23-27th May, 2022

OutLine

- ✓ Introduction
- ✓ Amplitude Analyses
- ✓ Branching Fractions
- ✓ Summary

Hadronic charm physics

✓ Strong phase measurement with quantum correlated $\psi(3770) \to D^0\bar{D}^0$ is crucial in the model-independent determinations of γ and charm mixing/direct CPV

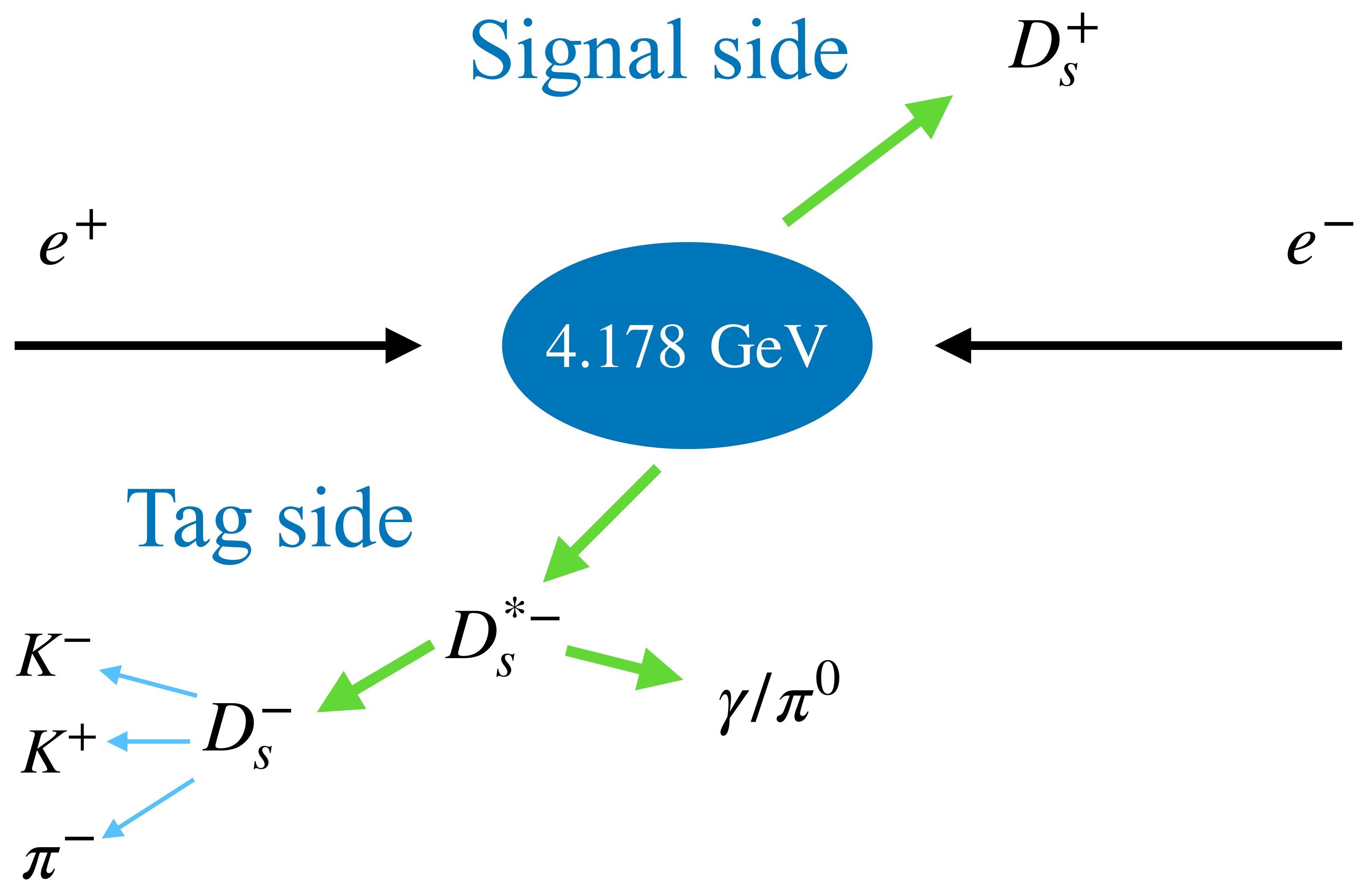
FPCP 2021: https://indico.ihep.ac.cn/event/12805/session/40/contribution/224/material/slides/0.pdf

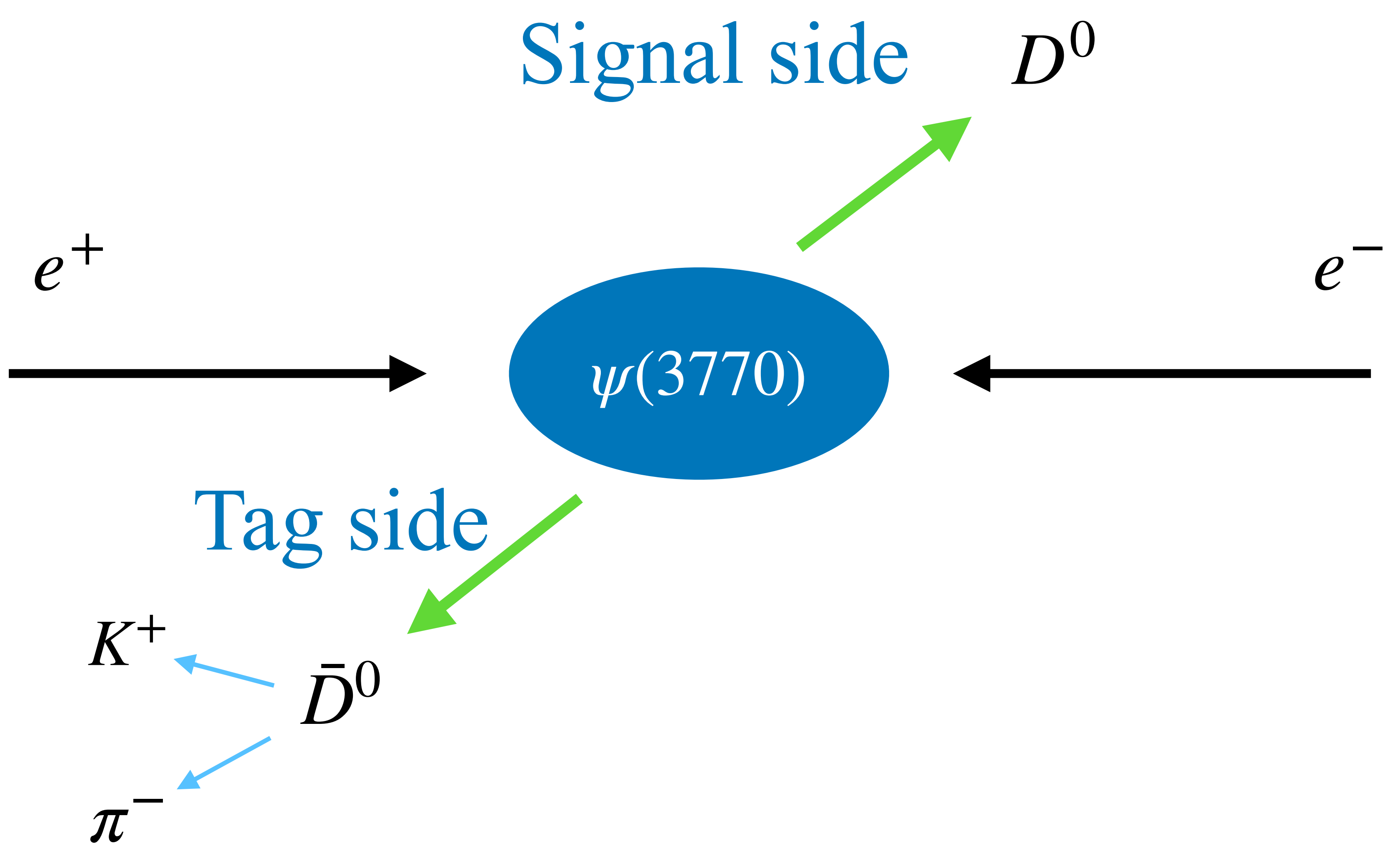
✓ Probe non-perturbative QCD

- Measure the branching fractions of two-body decays with *PP*, *VP*, *VV*, *SP* and *AP* final states
- Offer comprehensive information to explore the phenomenon of $D^0\bar{D}^0$ mixing, *CP* violation and SU(3)-flavor symmetry breaking

✓ Help to understand hadron spectroscopy

Datasets and double tag method





Datasets:

— $D^{+(0)}$: 2.93 fb^{-1} @ $E_{cm} = 3.773$ GeV. Collected in 2011

— D_s^+ : 6.32 fb^{-1} @ $E_{cm} = 4.178 - 4.226$ GeV. Collected in 2013-2017

Single Tag (ST) : reconstruct one $D_{(s)}$

— Relative high background

— Higher efficiency

Double Tag (DT) : reconstruct both $D_{(s)}$

— Clean background for study of various decays

— Systematics in the tag side almost cancel out

Absolute branching fraction via DT : $\mathscr{B}_{sig} = \dfrac{N_{sig}^{\text{DT}}}{\Sigma_\alpha N_\alpha^{\text{ST}} \epsilon_{\alpha,sig}^{\text{DT}} / \epsilon_\alpha^{\text{ST}}}$

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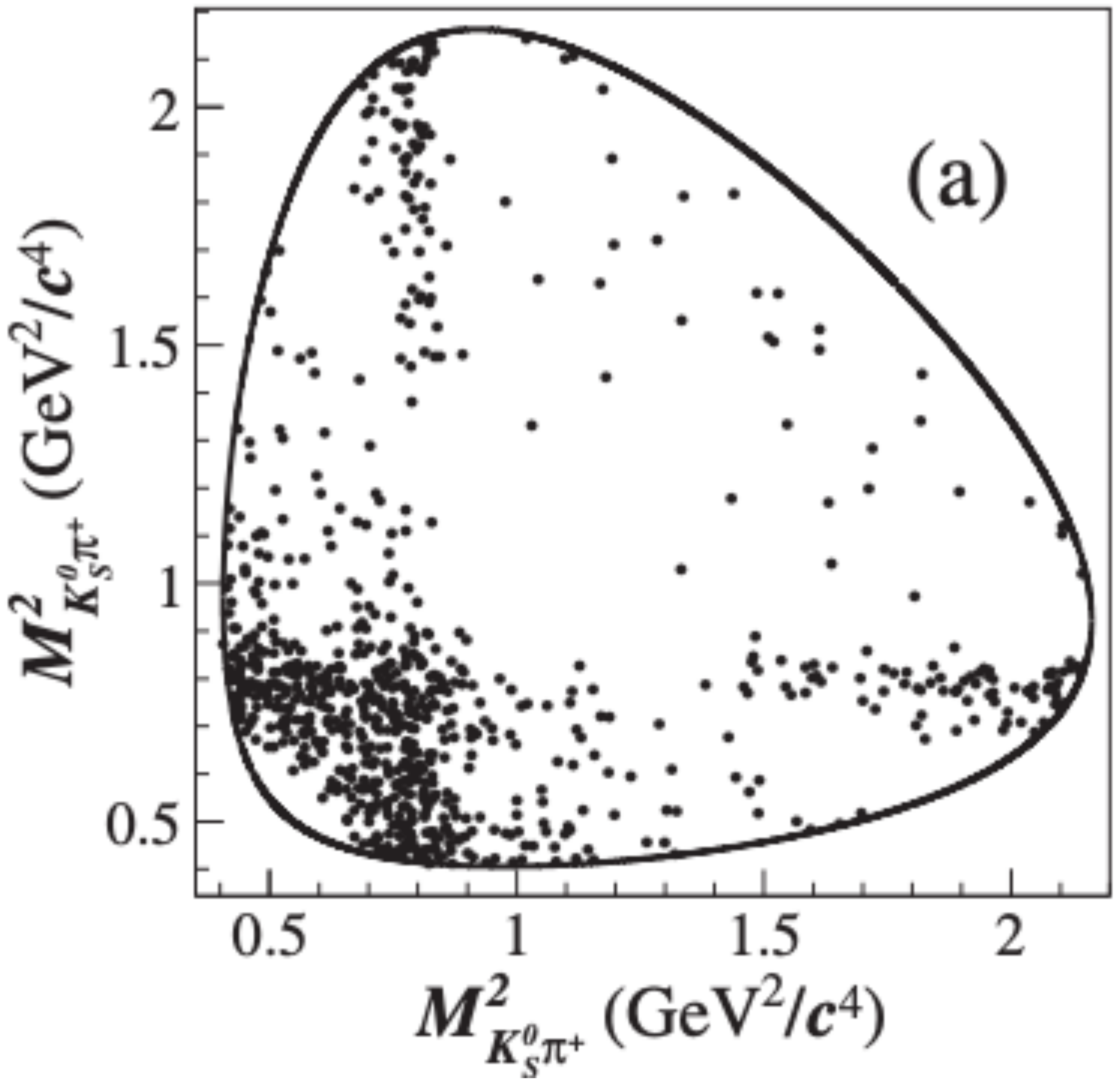
Amplitude analysis of $D_s^+ \to K_S^0 K_S^0 \pi^+$

Phys. Rev. D 105, L051103 (2022)

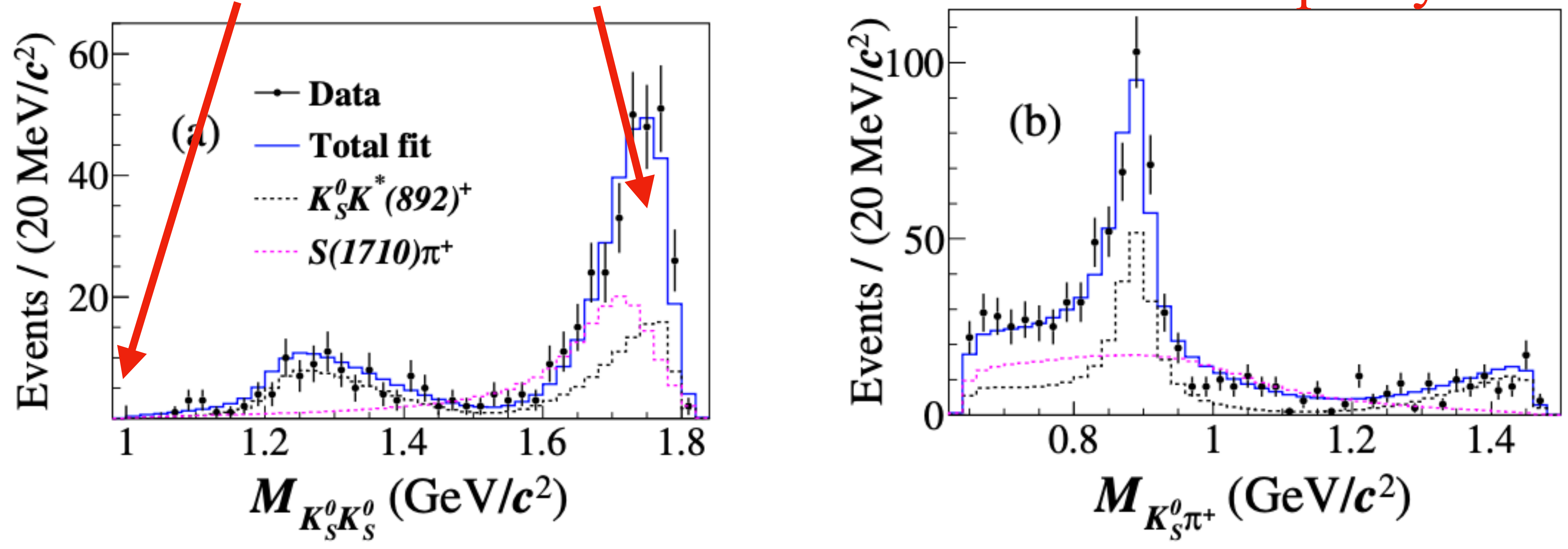
First amplitude analysis

Amplitude	Phase	FF (%)
$D_s^+ \to K_S^0 K^*(892)^+$	0.0 (fixed)	$43.5 \pm 3.9 \pm 0.5$
$D_s^+ \to S(1710)\pi^+$	$2.3 \pm 0.1 \pm 0.1$	$46.3 \pm 4.0 \pm 1.2$



$S(980)$ $S(1710)$

412 events
about 97% purity



Observation of isospin-one $a_0(1710)$

$S(1710)$: mixture of $f_0(1710)$ and $a_0(1710)$:

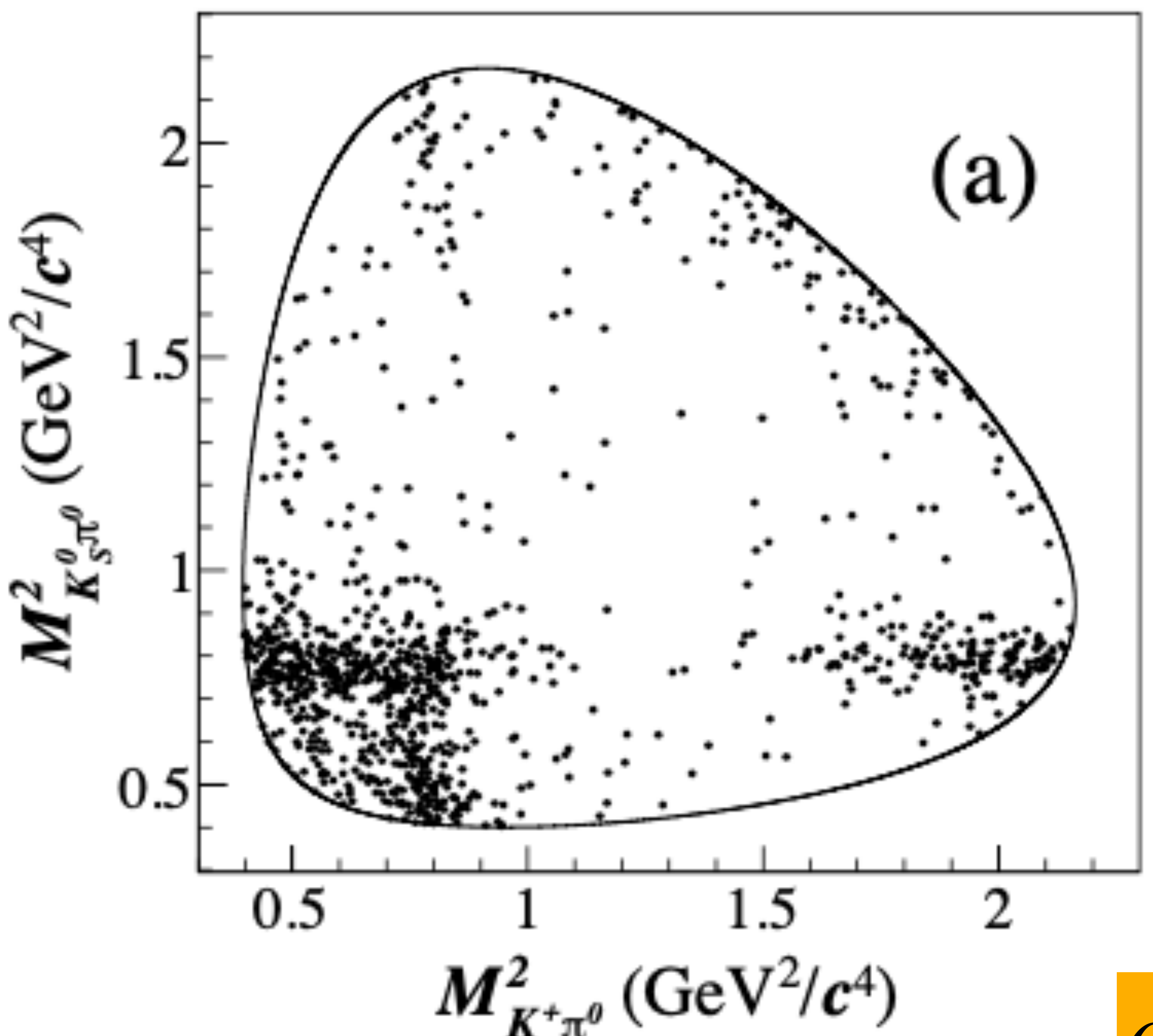
- Destructive interference in $D_s^+ \to K^+K^-\pi^+$
  PRD 104, 012016 (2021)
- Constructive interference in $D_s^+ \to K_S^0 K_S^0 \pi^+$

➡Consistent with the $K^*\bar{K}^*$ molecule hypothesis of $f_0(1710)$

$$\mathscr{B}(D_s^+ \to K_S^0 K_S^0 \pi^+) = (0.68 \pm 0.04_{\text{stat.}} \pm 0.01_{\text{syst.}})\,\%$$

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

arXiv:2204.09614



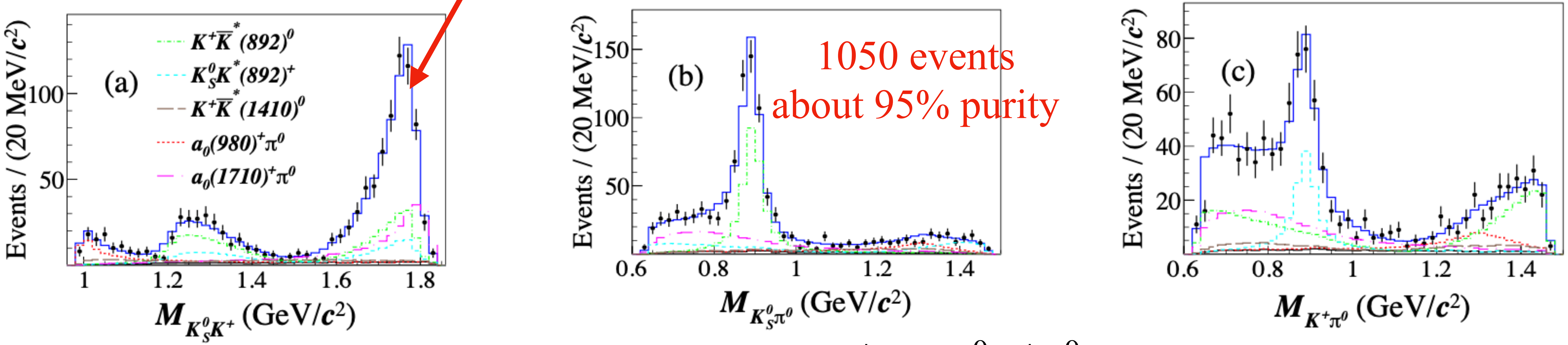
First amplitude analysis

Amplitude	Phase (rad)	FF (%)	BF (10^{-3})	σ
$D_s^+ \to \bar{K}^*(892)^0 K^+$	0.0(fixed)	$32.7 \pm 2.2 \pm 1.9$	$4.77 \pm 0.38 \pm 0.32$	> 10
$D_s^+ \to K^*(892)^+ K_S^0$	$-0.16 \pm 0.12 \pm 0.11$	$13.9 \pm 1.7 \pm 1.3$	$2.03 \pm 0.26 \pm 0.20$	> 10
$D_s^+ \to a_0(980)^+ \pi^0$	$-0.97 \pm 0.27 \pm 0.25$	$7.7 \pm 1.7 \pm 1.8$	$1.12 \pm 0.25 \pm 0.27$	6.7
$D_s^+ \to \bar{K}^*(1410)^0 K^+$	$0.17 \pm 0.15 \pm 0.08$	$6.0 \pm 1.4 \pm 1.3$	$0.88 \pm 0.21 \pm 0.19$	7.6
$D_s^+ \to a_0(1710)^+ \pi^0$	$-2.55 \pm 0.21 \pm 0.07$	$23.6 \pm 3.4 \pm 2.0$	$3.44 \pm 0.52 \pm 0.32$	> 10

Consistent with the prediction by Eur. Phys. J. C 82, 225 (2022)

$$M(a_0^+(1710)) = 1.817 \pm 0.008_{\text{stat.}} \pm 0.020_{\text{syst.}}\ \text{GeV}/c^2$$
$$\Gamma(a_0^+(1710)) = 0.097 \pm 0.022_{\text{stat.}} \pm 0.015_{\text{syst.}}\ \text{GeV}/c^2$$

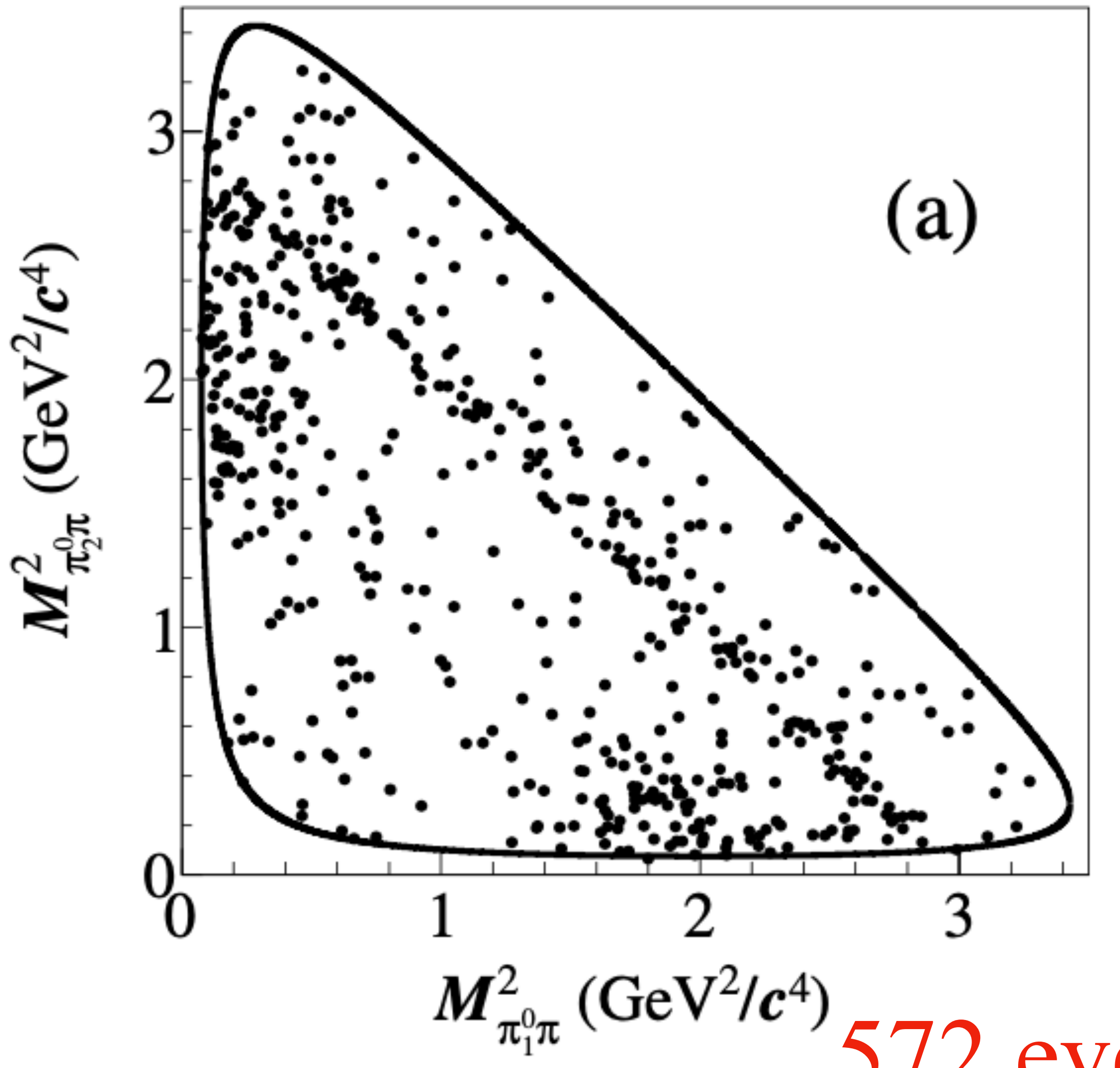
$a_0(1710)^+$

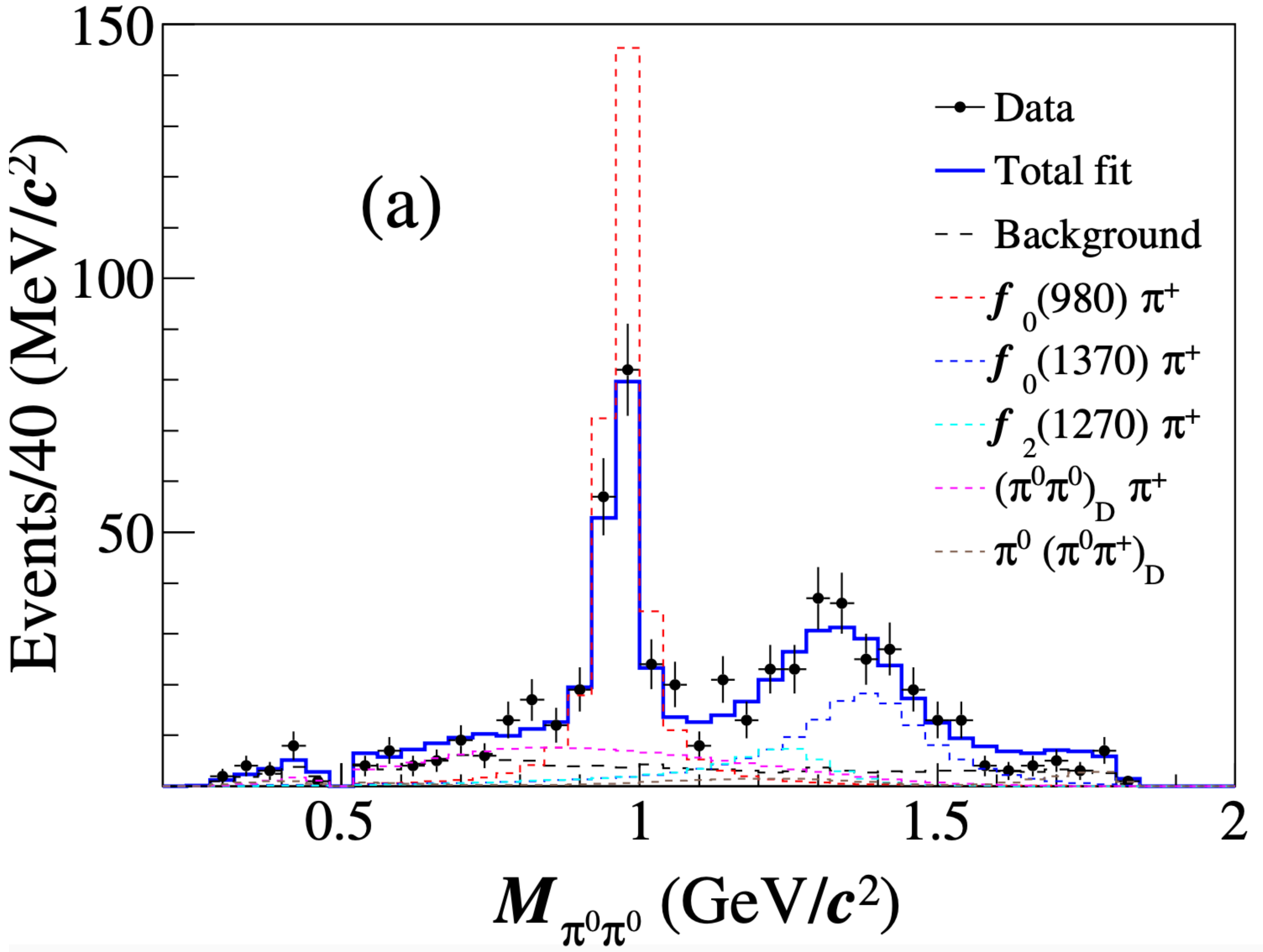


$$\mathscr{B}(D_s^+ \to K_S^0 K^+ \pi^0) = (1.46 \pm 0.06_{\text{stat.}} \pm 0.05_{\text{syst.}})\ \%$$

Amplitude analysis of $D_s^+ \to \pi^+\pi^0\pi^0$

JHEP01(2022)052





572 events, about 78% purity

Intermediate process	BF (10^{-3})
$D_s^+ \to f_0(980)\pi^+$, $f_0(980) \to \pi^0\pi^0$	$2.8 \pm 0.4 \pm 0.4$
$D_s^+ \to f_0(1370)\pi^+$, $f_0(1370) \to \pi^0\pi^0$	$1.3 \pm 0.3 \pm 0.5$
$D_s^+ \to f_2(1270)\pi^+$, $f_2(1270) \to \pi^0\pi^0$	$0.5 \pm 0.2 \pm 0.3$
$D_s^+ \to \pi^+(\pi^0\pi^0)_D$	$1.1 \pm 0.4 \pm 0.2$
$D_s^+ \to (\pi^+\pi^0)_D\pi^0$	$0.3 \pm 0.1 \pm 0.1$
	BF listed on PDG [1] (10^{-3})
$D_s^+ \to f_0(980)\pi^+$, $f_0(980) \to \pi^+\pi^-$	6.1 ± 0.7
$D_s^+ \to f_0(1370)\pi^+$, $f_0(1370) \to \pi^+\pi^-$	3.5 ± 0.9
$D_s^+ \to f_2(1270)\pi^+$, $f_2(1270) \to \pi^+\pi^-$	1.2 ± 0.2

First amplitude analysis

$$\mathcal{B}(D_s^+ \to f_0(980)\pi^+, f_0(980) \to \pi^0\pi^0)$$
$$= (2.8 \pm 0.4 \pm 0.4) \times 10^{-3}$$

Measured for the first time

No significant signal of $f_0(500)$

$R(f_0(980)) = 2.2 \pm 0.5$

$R(f_0(1370)) = 2.7 \pm 1.4$ $\quad R = \dfrac{f_{0(2)}(\pi^+\pi^-)}{f_{0(2)}(\pi^0\pi^0)}$

$R(f_2(1270)) = 2.4 \pm 1.8$

consistent with $D_s^+ \to \pi^+\pi^+\pi^-$

arXiv:2108.10050

$$\mathcal{B}(D_s^+ \to \pi^+\pi^0\pi^0) = (0.50 \pm 0.04_{\text{stat.}} \pm 0.02_{\text{syst.}})\,\%$$

Improved by a factor of two compared with PDG

Amplitude analysis of $D_s^+ \to \pi^+\pi^0\eta'$

JHEP04(2022)058

Decay		$\mathcal{B}(\%)$	
Theory	$D_s^+ \to \rho^+\eta'$	3.0 ± 0.5 [1]	1.7 [2] 1.6 [2]
Experiment	$D_s^+ \to \pi^+\pi^0\eta'$	$5.6 \pm 0.5 \pm 0.6$	CLEO
	$D_s^+ \to \rho^+\eta'$	$5.8 \pm 1.4 \pm 0.4$	BESIII
	$D_s^+ \to \pi^+\pi^0\eta'$ (nonresonant)	< 5.1 (90% confidence level)	BESIII

Large deviation between theoretical predictions and experimental measurements

[1] Phys. Rev. D 84 (2011) 074019

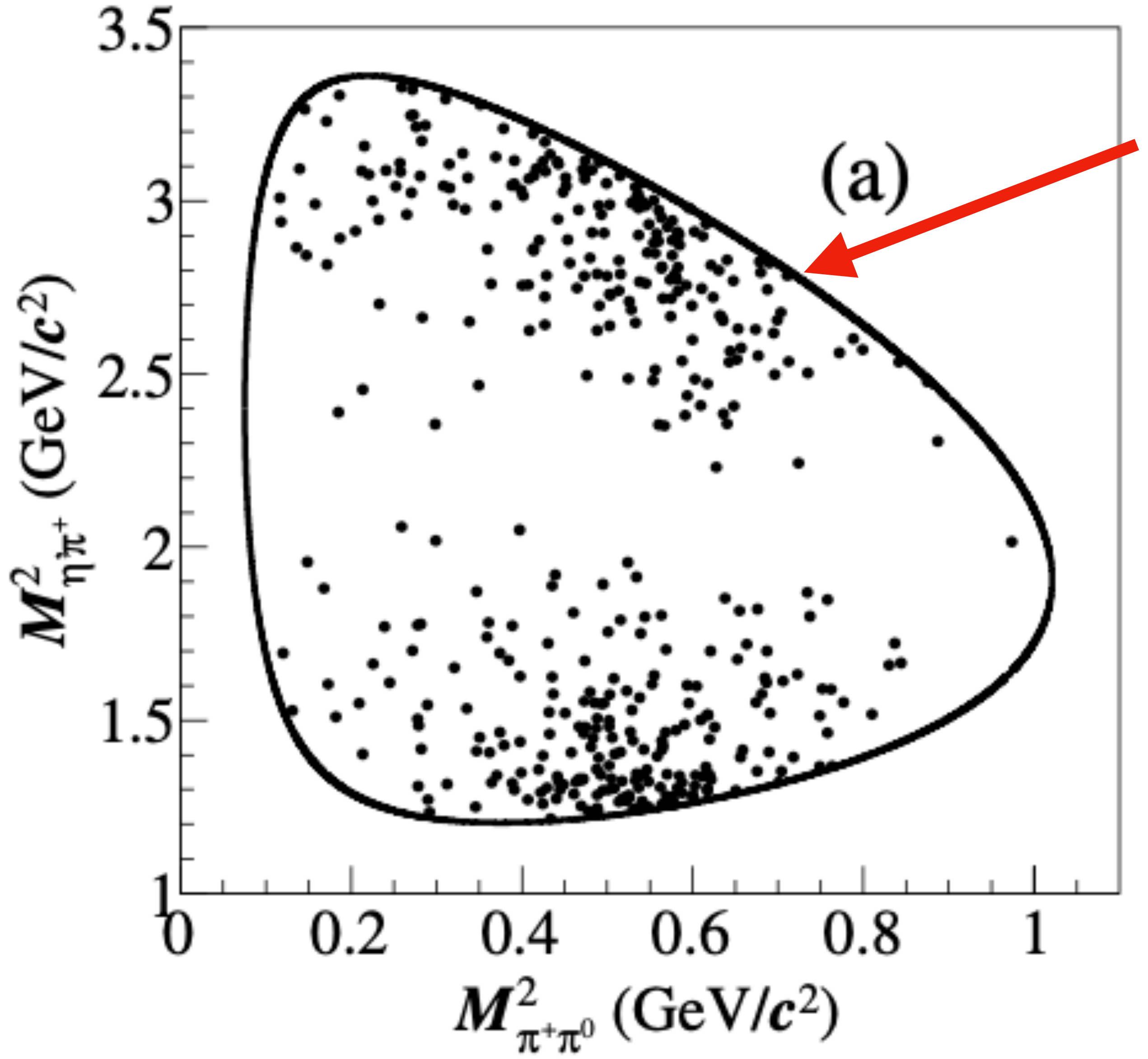
[2] Phys. Rev. D 89 (2014) 054006

Branching fraction measurement with best precision :

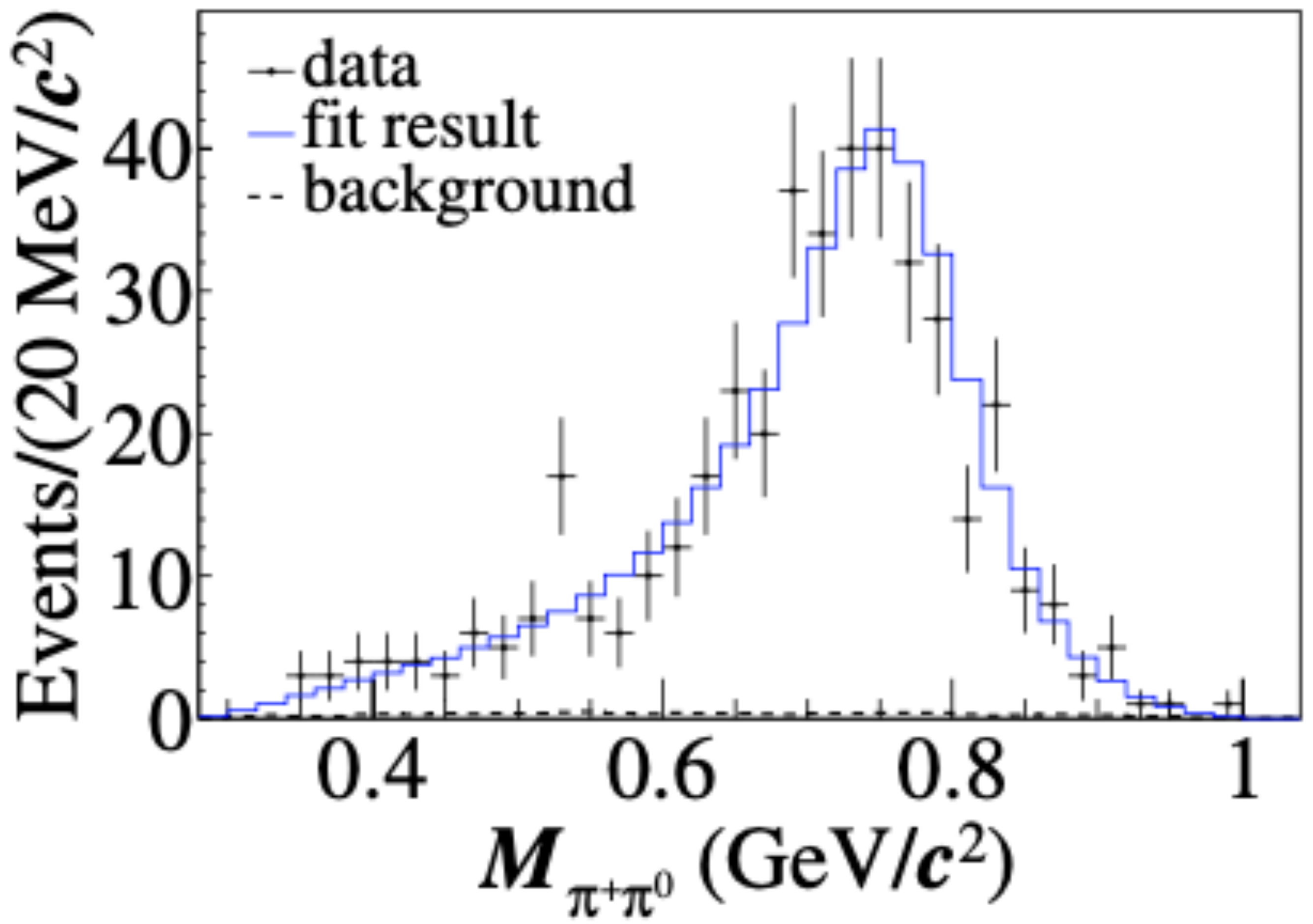
$\mathcal{B}(D_s^+ \to \pi^+\pi^0\eta') = (6.15 \pm 0.25_{\text{stat.}} \pm 0.18_{\text{syst.}})\,\%$

$\mathcal{B}(D_s^+ \to (\pi^+\pi^0)_S\eta') < 0.1\,\%$ @ 90% CL

$\mathcal{B}(D_s^+ \to (\pi^+\pi^0)_P\eta') < 0.74\,\%$ @ 90% CL

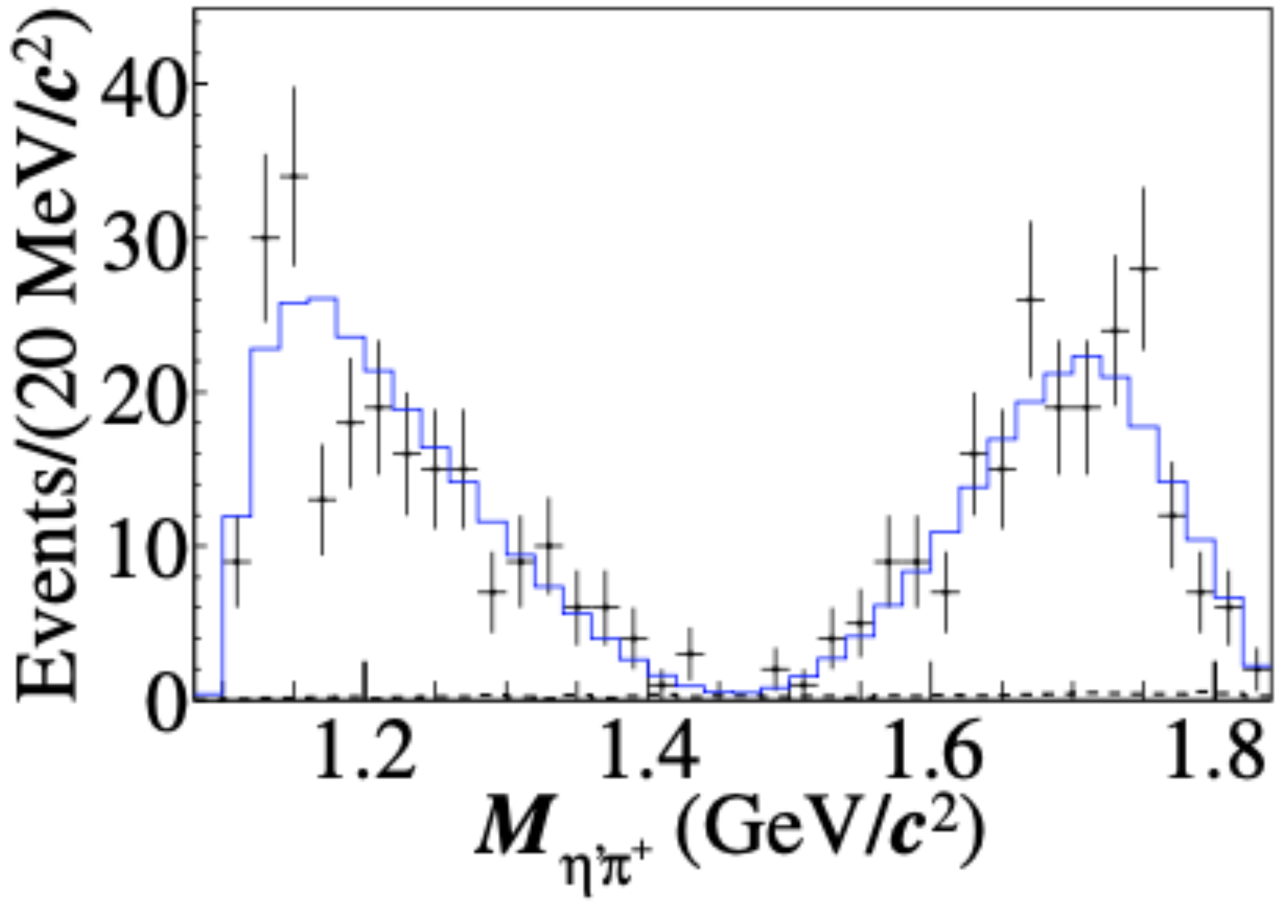


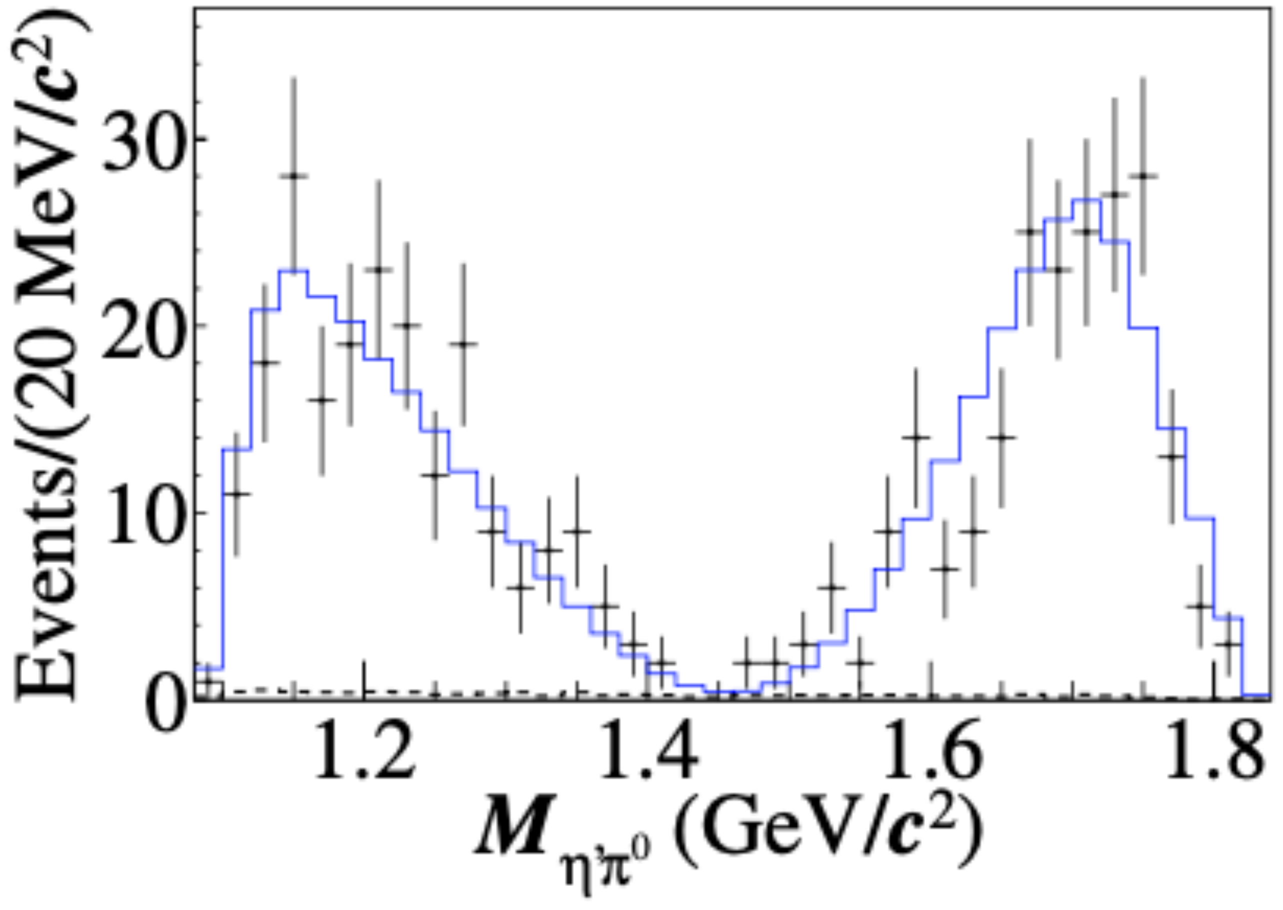
Only $D_s^+ \to \rho^+\eta'$ contributes



411 events
about 96% purity

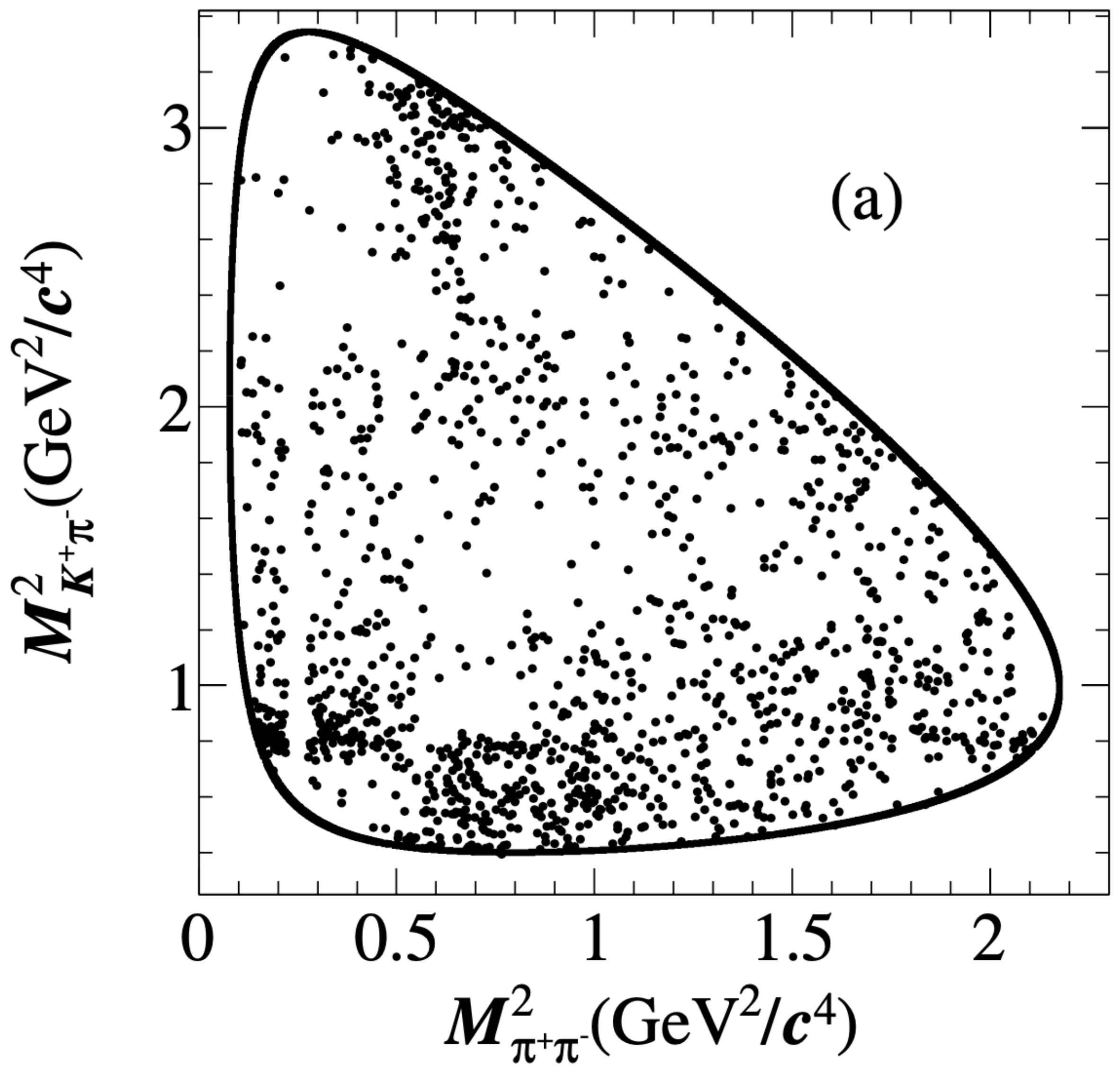
First amplitude analysis





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

arXiv:2205.08844



Intermediate process	BF(10^{-3})	PDG(10^{-3})
$D_s^+ \to K^+\rho^0$	$1.99 \pm 0.20 \pm 0.22$	2.5 ± 0.4
$D_s^+ \to K^+\rho(1450)^0$	$0.78 \pm 0.20 \pm 0.17$	0.69 ± 0.64
$D_s^+ \to K^*(892)^0\pi^+$	$1.85 \pm 0.13 \pm 0.11$	1.41 ± 0.24
$D_s^+ \to K^*(1410)^0\pi^+$	$0.29 \pm 0.13 \pm 0.13$	1.23 ± 0.28
$D_s^+ \to K_0^*(1430)^0\pi^+$	$1.15 \pm 0.16 \pm 0.15$	0.50 ± 0.35
$D_s^+ \to K^+f_0(500)$	$0.43 \pm 0.14 \pm 0.24$	-
$D_s^+ \to K^+f_0(980)$	$0.27 \pm 0.08 \pm 0.07$	-
$D_s^+ \to K^+f_0(1370)$	$1.22 \pm 0.19 \pm 0.18$	-
$D_s^+ \to (K^+\pi^+\pi^-)_{NR}$	-	1.03 ± 0.34

NR is replaced by $K^+f_0(500)$, $K^+f_0(980)$ and $K^+f_0(1370)$

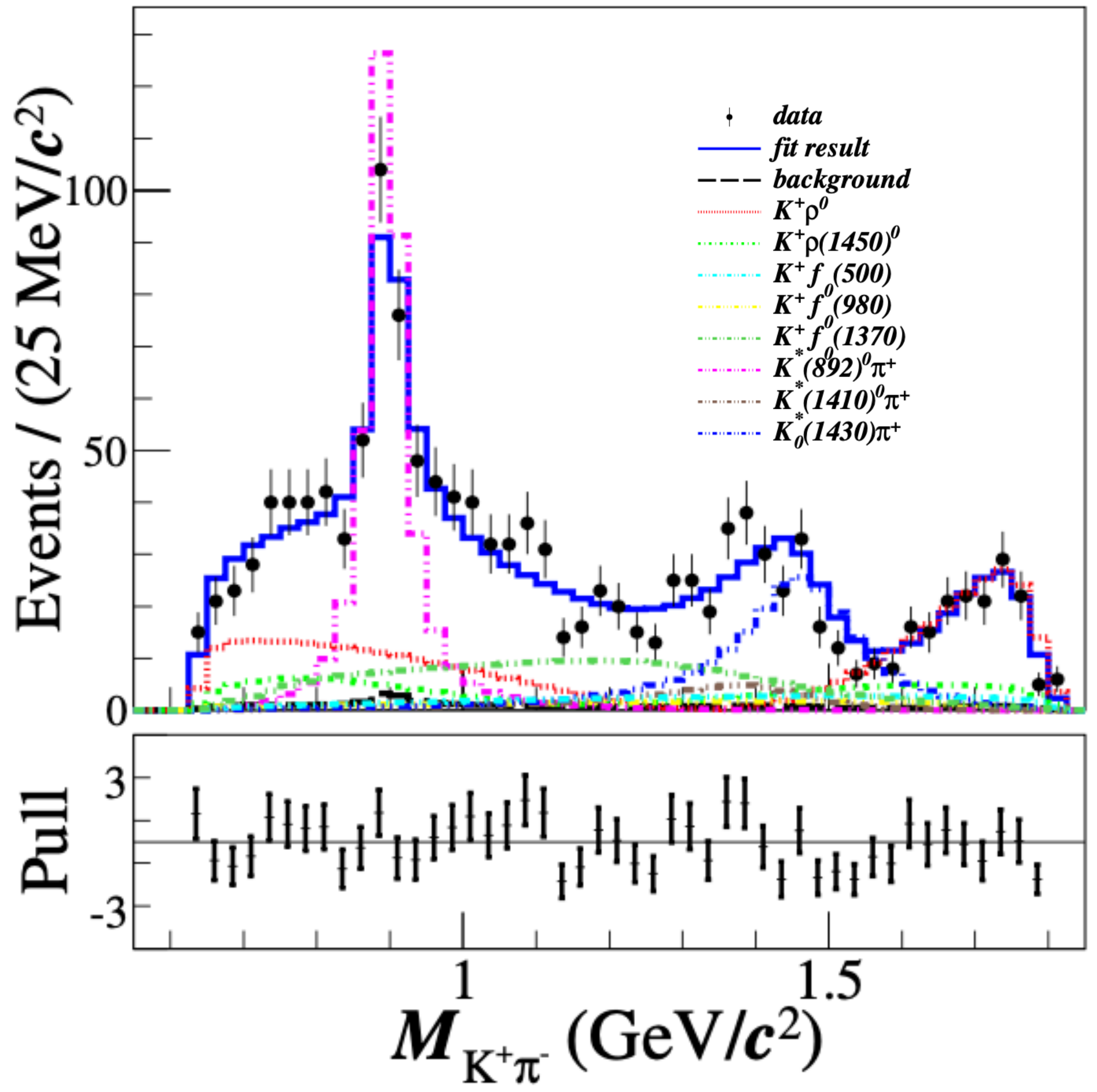
- Dominant processes:

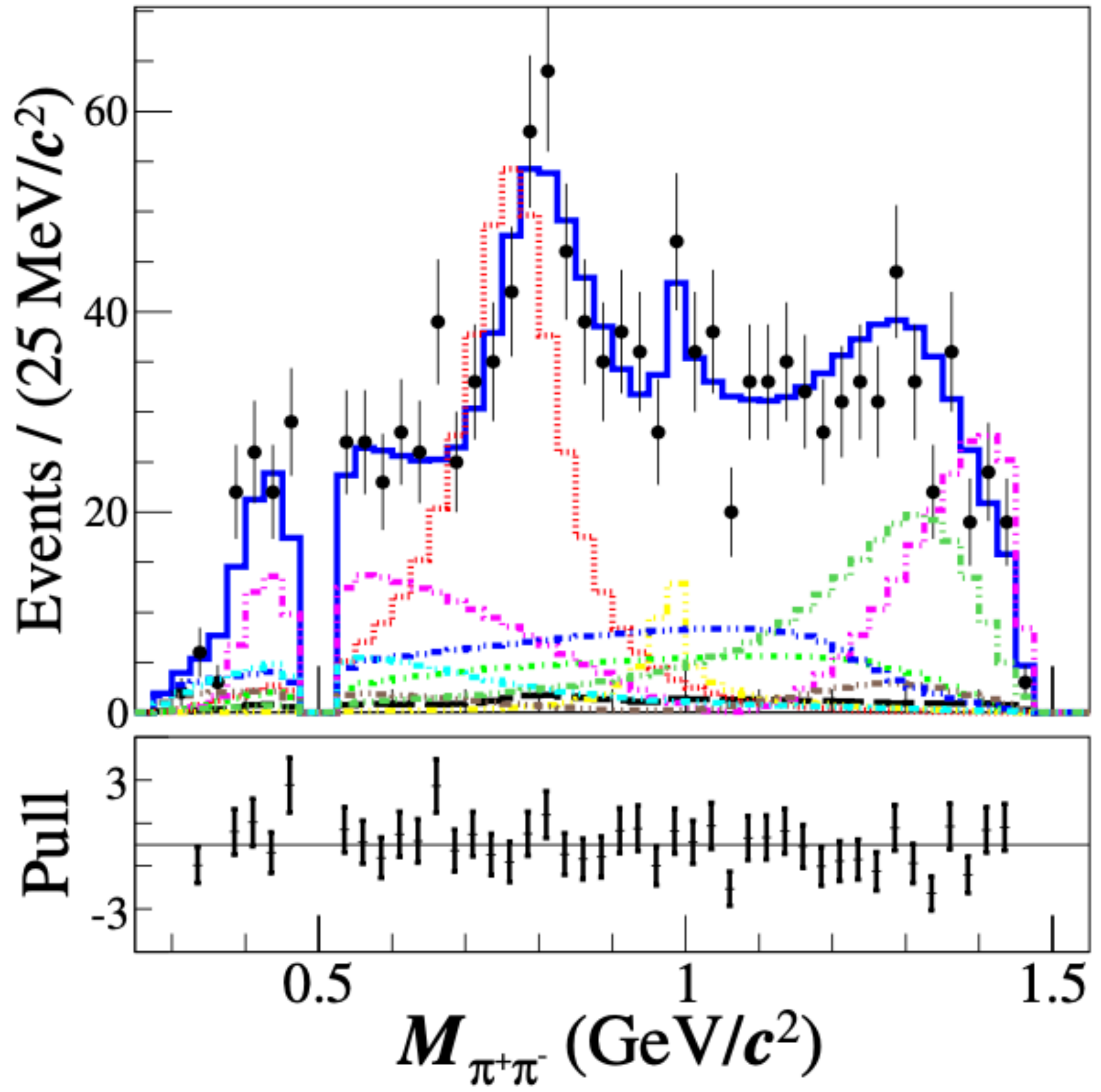
$\mathcal{B}(D_s^+ \to K^+\rho^0)$
$= (1.99 \pm 0.20_{\text{stat.}} \pm 0.22_{\text{syst.}}) \times 10^{-3}$

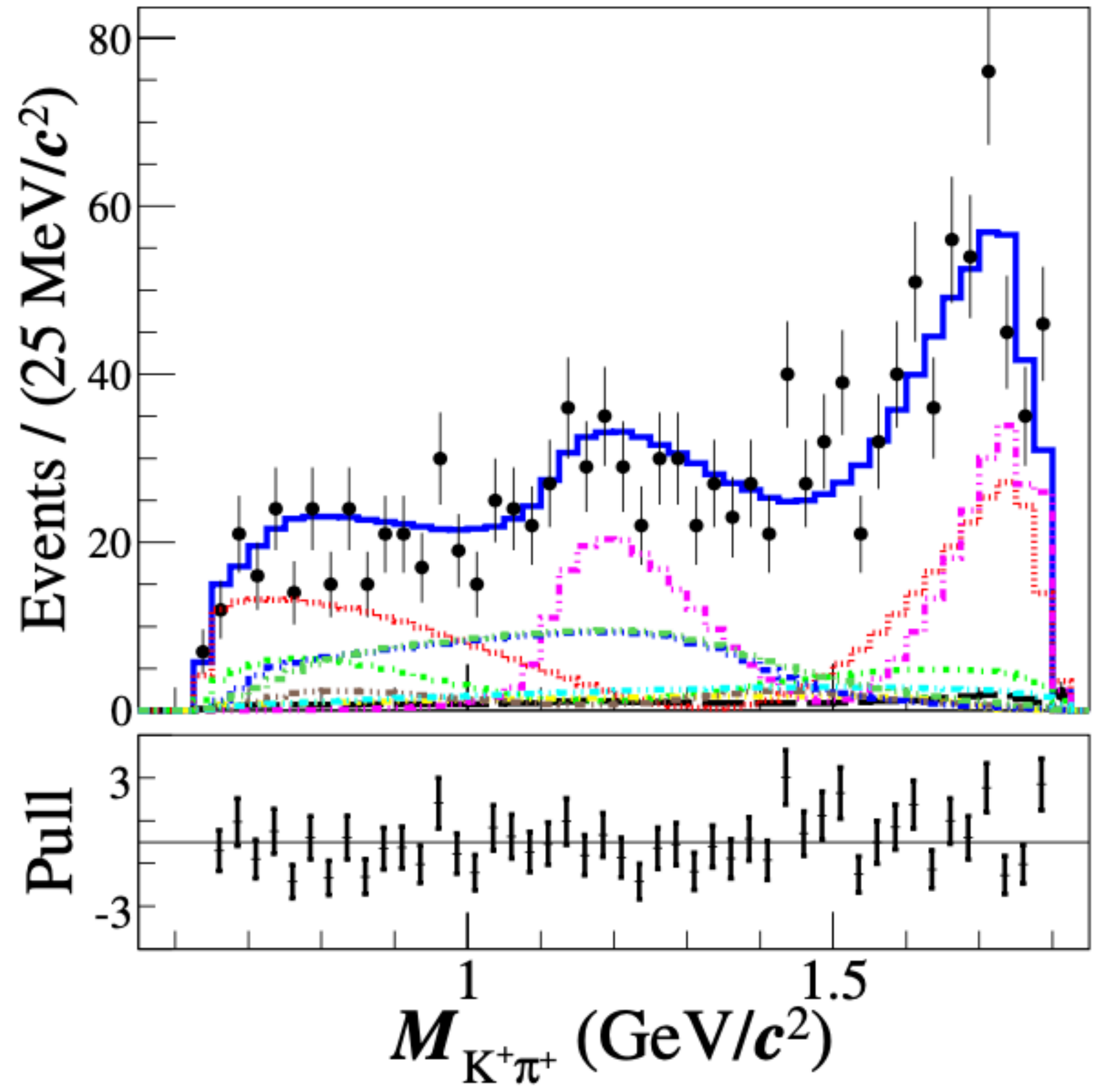
$\mathcal{B}(D_s^+ \to K^*(892)^0\pi^+)$
$= (1.85 \pm 0.13_{\text{stat.}} \pm 0.11_{\text{syst.}}) \times 10^{-3}$

Much more precise

1356 events, about 95% purity







$\mathcal{B}(D_s^+ \to K^+\pi^+\pi^-)$
$= (6.11 \pm 0.18_{\text{stat.}} \pm 0.11_{\text{syst.}}) \times 10^{-3}$

$$A_{CP} = \frac{\mathcal{B}(D_s^+) - \mathcal{B}(D_s^-)}{\mathcal{B}(D_s^+) + \mathcal{B}(D_s^-)} = (3.3 \pm 3.7_{\text{stat.}} \pm 1.3_{\text{syst.}})\,\%$$

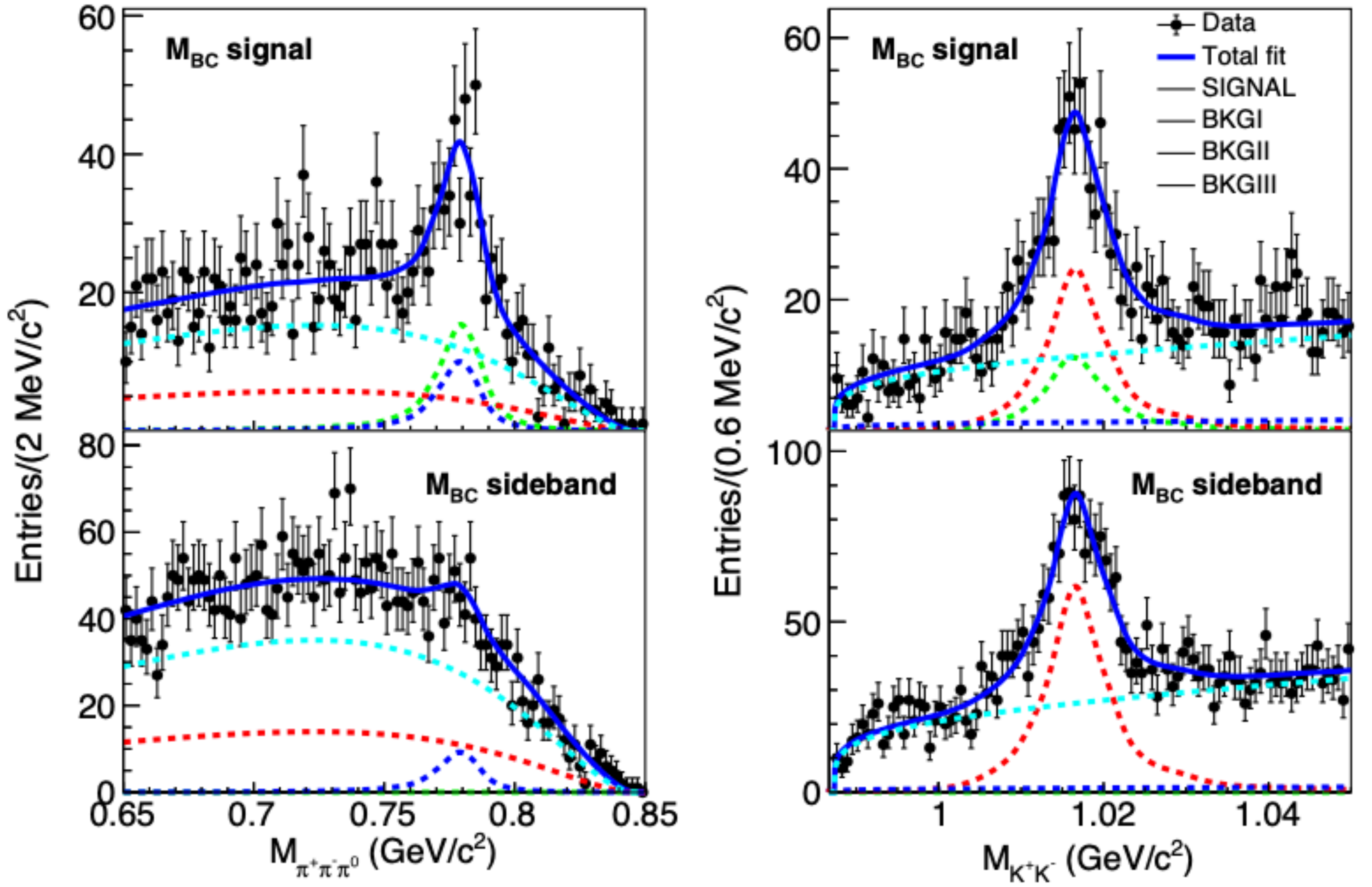
No significant CP violation

OutLine

Polarizations in $D^0 \to \omega\phi$

Phys. Rev. Lett. 128, 011803 (2022)

Single tag method — only one D^0 meson is reconstructed



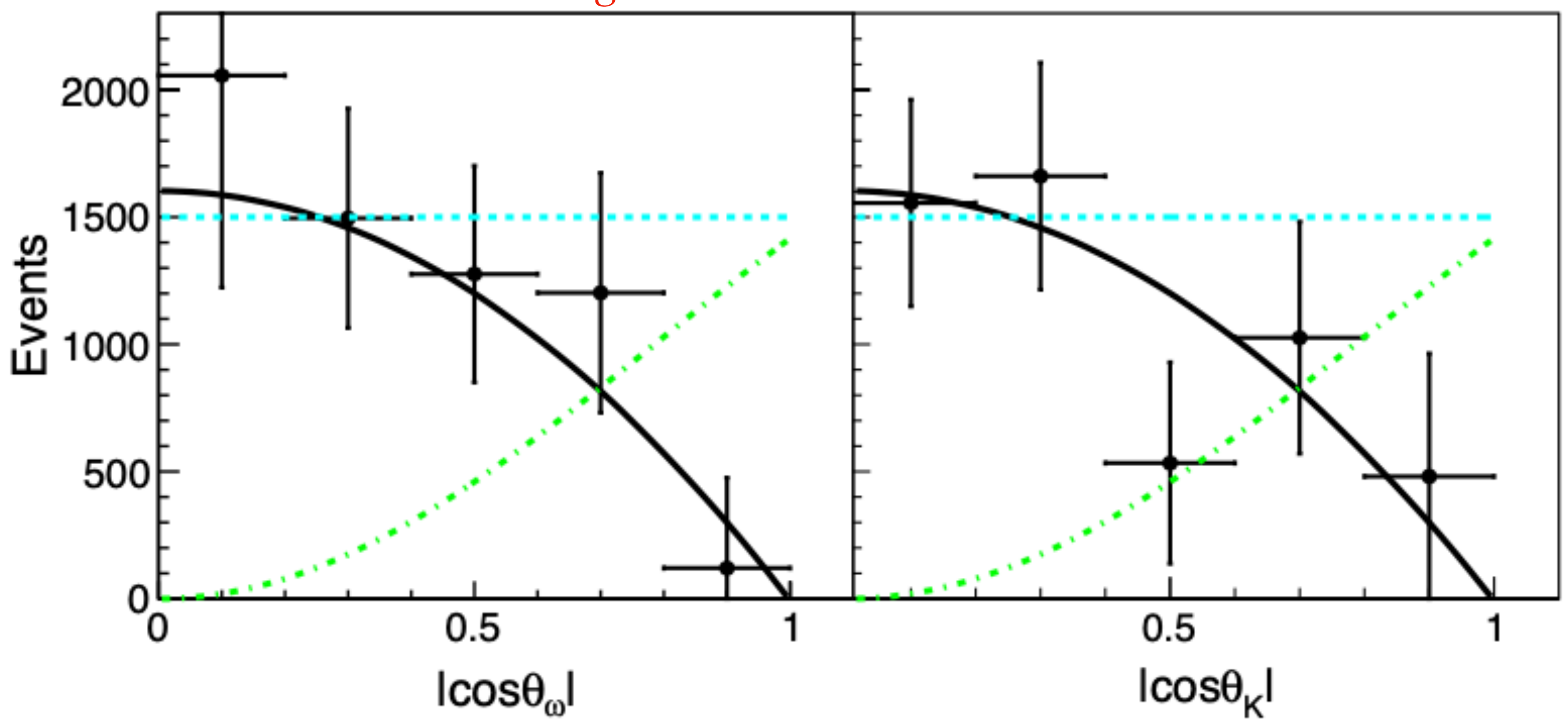
- $D^0 \to \omega\phi$ is observed for the first time:

  $\mathscr{B}(D^0 \to \omega\phi)$

  $= (6.48 \pm 0.96_{\text{stat.}} \pm 0.40_{\text{syst.}}) \times 10^{-4}$

  with a significance of 6.3σ

$N_{sig} = 195.9 \pm 29.1$



Black dots: data

Black curves: fit results

Green: longitudinal

Cyan: PHSP

- ω and ϕ are transversely polarized

➡ Contradict existing model predictions

Phys. Rev. D 81, 114020 (2010); J. High Energy Phys. 03 (2014) 042

Measurements of other $D_{(s)}$ decays

✓ Amplitude analysis of $D_s^+ \to \pi^+\pi^+\pi^-\eta$: **Phys. Rev. D 104, L071101 (2021)**

✓ Amplitude analysis of $D_s^+ \to \pi^+\pi^+\pi^-$: **arXiv:2108.10050, Submitted to PRD**

✓ Amplitude analysis of $D_s^+ \to K^+K^-\pi^+\pi^+\pi^-$: **arXiv:2203.06688, Submitted to JHEP**

✓ $\mathscr{B}(D^0 \to K_L^0 X,\ X = \phi/\eta/\omega/\eta')$: **arXiv:2202.13601, accepted by PRD**

✓ $\mathscr{B}(D^0 \to K^-\pi^+\omega)$: **Phys. Rev. D 105, 032009 (2022)**

✓ $\mathscr{B}(D^+ \to K^+\pi^0\pi^0)$: **arXiv:2110.10999, Submitted to JHEP**

✓ $\mathscr{B}(D^0 \to K^+\pi^-\pi^0)$: **arXiv:2203.01555, Submitted to PRD**

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Summary

✓ **Amplitude analyses show great power**

- Establishment of isospin-one particle — $a_0(1710)$
- Validation of various theories

✓ **Large samples for precise measurements**

- Puzzle of $P \to VV$ polarization

✓ **Bright future of Hadronic *D* decays**

- Lots of results are ready to be published
- 20 fb^{-1} $\psi(3770)$ data at BESIII by next year **CPC 44, 040001 (2020)**

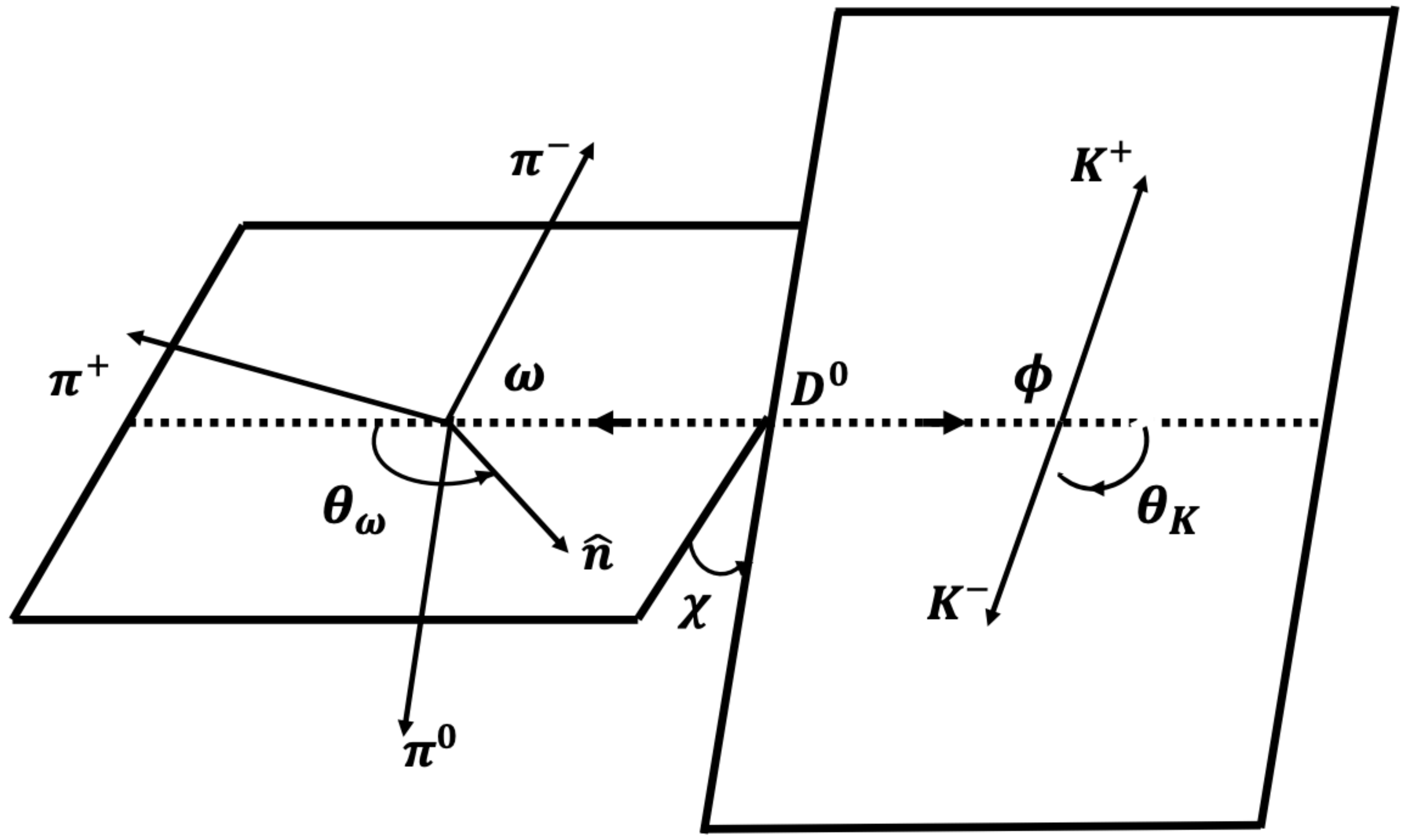
Thanks for your attention!

Back up

Tag modes of DT analyses

	$D_s^+ \to K_S^0 K_S^0 \pi^+$	$D_s^+ \to K_S^0 K^+ \pi^0$	$D_s^+ \to \pi^+ \pi^0 \pi^0$	$D_s^+ \to \pi^+ \pi^0 \eta'$	$D_s^+ \to K^+ \pi^+ \pi^-$
$D_s^- \to K^- K^+ \pi^-$	✔	✔	✔	✔	✔
$D_s^- \to K_S^0 K^- \pi^0$			✔	✔	✔
$D_s^- \to K^+ K^- \pi^- \pi^0$	✔	✔		✔	✔
$D_s^- \to K_S^0 K^- \pi^- \pi^+$	✔	✔	✔	✔	✔
$D_s^- \to K_S^0 K^+ \pi^- \pi^-$	✔	✔	✔	✔	✔
$D_s^- \to \pi^- \pi^- \pi^+$	✔	✔		✔	✔
$D_s^- \to \pi^- \eta$					✔
$D_s^- \to \pi^- \pi^0 \eta$				✔	✔
$D_s^- \to \pi^- \eta'$	✔	✔	✔	✔	✔
$D_s^- \to K_S^0 K^-$	✔	✔	✔	✔	✔
$D_s^- \to K^- \pi^+ \pi^-$	✔	✔	✔	✔	

Definitions in $D^0 \to \omega\phi$



θ_ω is the angle between $\mathbf{p}^\omega_{\pi^+} \times \mathbf{p}^\omega_{\pi^-}$ and $-\mathbf{p}^\omega_{D^0}$ in the ω rest frame, and θ_K is the angle between $\mathbf{p}^\phi_{K^-}$ and $-\mathbf{p}^\phi_{D^0}$ in the ϕ rest frame. Here, $\mathbf{p}^\omega_{\pi^+}$, $\mathbf{p}^\omega_{\pi^-}$, $\mathbf{p}^\phi_{K^-}$, and $\mathbf{p}^{\omega/\phi}_{D^0}$ are the momenta of the π^+, π^-, K^-, and D^0 in the rest frame of either the ω or ϕ meson, respectively.