Institute of High Energy Physics
Chinese Academy of Sciences

粲介子强子衰变振幅分析和分支比测量

报告人：李振轩

广西大学
中国科学院高能物理研究所

GUANGXI UNIVERSITY

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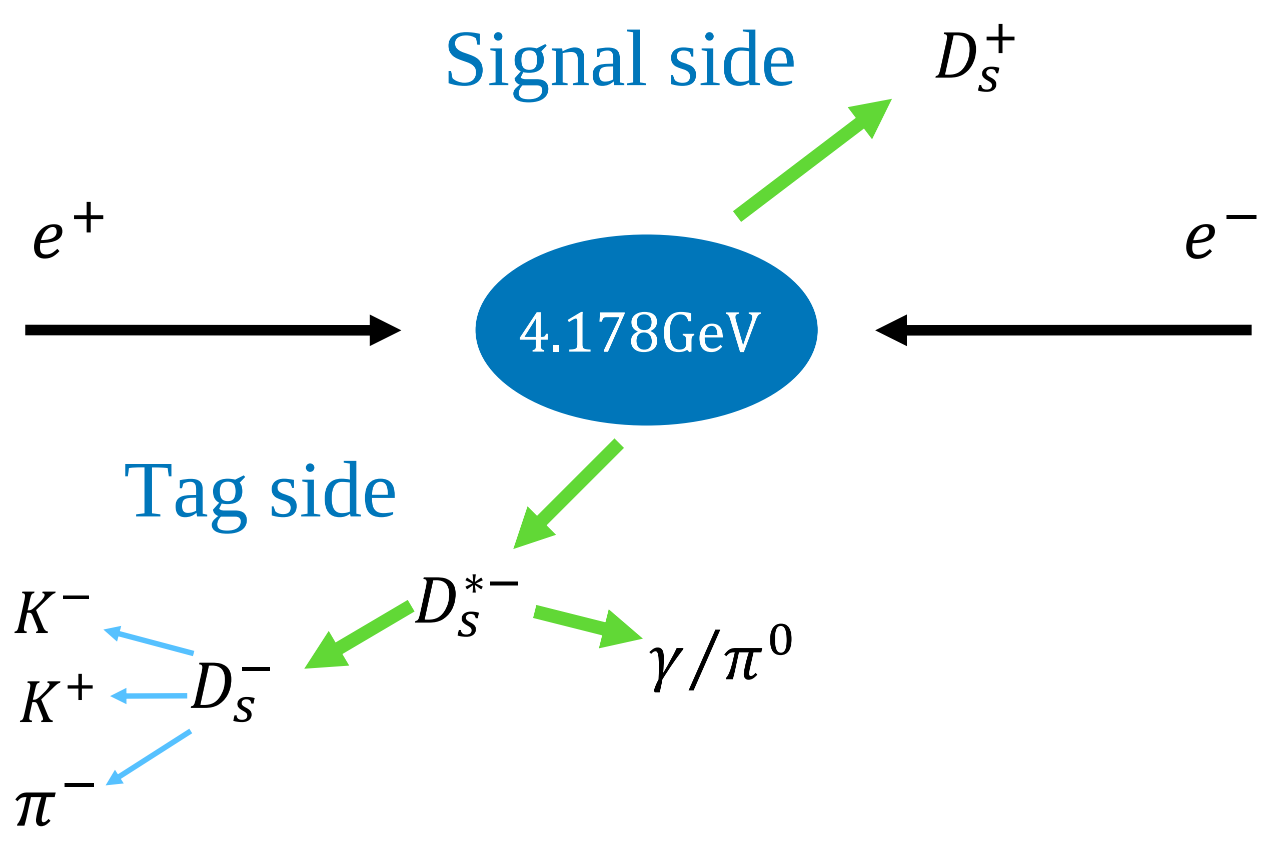
目录

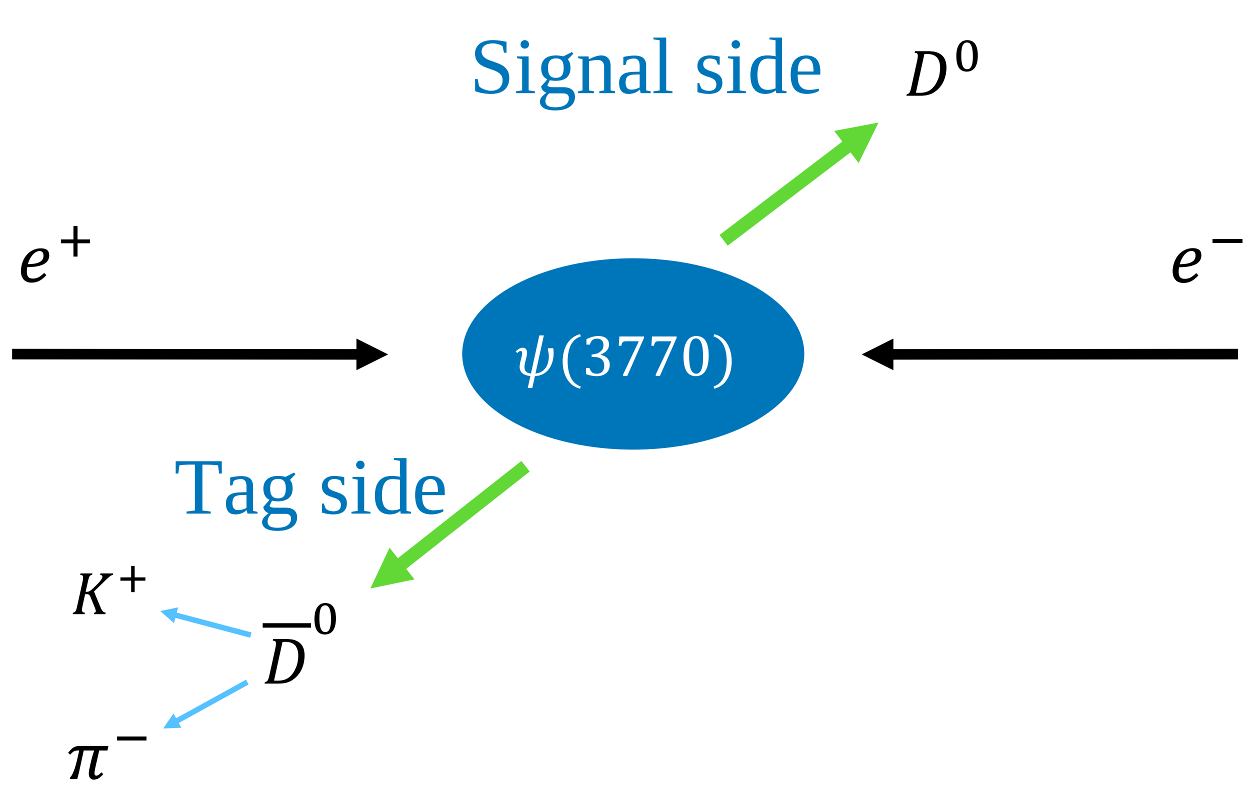
- ✓ 简介
- ✓ 振幅分析
- ✓ 分支比测量
- ✓ 总结

粲介子强子衰变

- 检验非微扰QCD理论
  - 测量二体衰变PP, VP, VV, SP, AP的分支比
  - 为研究$D^0\overline{D}^0$混合，CP破坏，SU(3)对称性破缺提供重要信息
- 深入理解强子谱
  - 为探讨轻标量介子结构，$a_1(1260), K_1(1270)$ 及非共振态S波的性质提供实验依据
- 提供精确的模拟模型
  - 有效提高其它粲介子分析，如强相位、形状因子、衰变常数等的测量精度

数据样本及双标记法





Datasets:

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

— D_s^+ : 6.32 fb^{-1} @ $E_{cm} = 4.178 - 4.226\text{GeV}$.

Single Tag (ST) : 重建单个 $D_{(s)}$ 介子

—相对较高的本底

— 更高的效率

Double Tag (DT) : 同时重建两侧的 $D_{(s)}$ 介子

— 非常低的本底水平，以用于不同衰变的研究

— 来自标记测的系统误差几乎可以消除

$$绝对分支比计算: \mathcal{B}_{sig} = \frac{N_{sig}^{\text{DT}}}{\Sigma_\alpha N_\alpha^{\text{ST}} \epsilon_{\alpha,sig}^{\text{DT}} / \epsilon_\alpha^{\text{ST}}}$$

目录

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- ✓ 分支比测量
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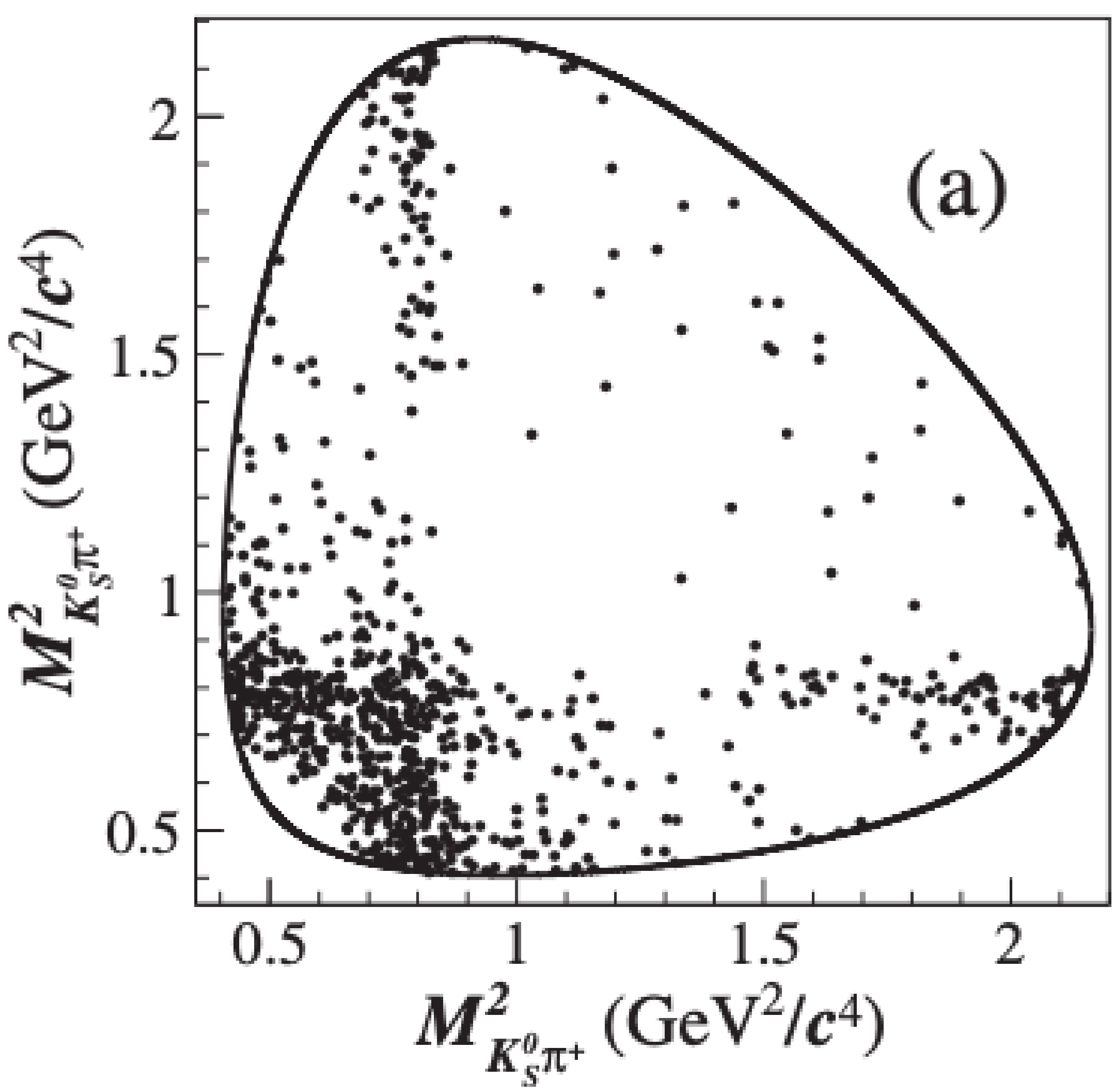
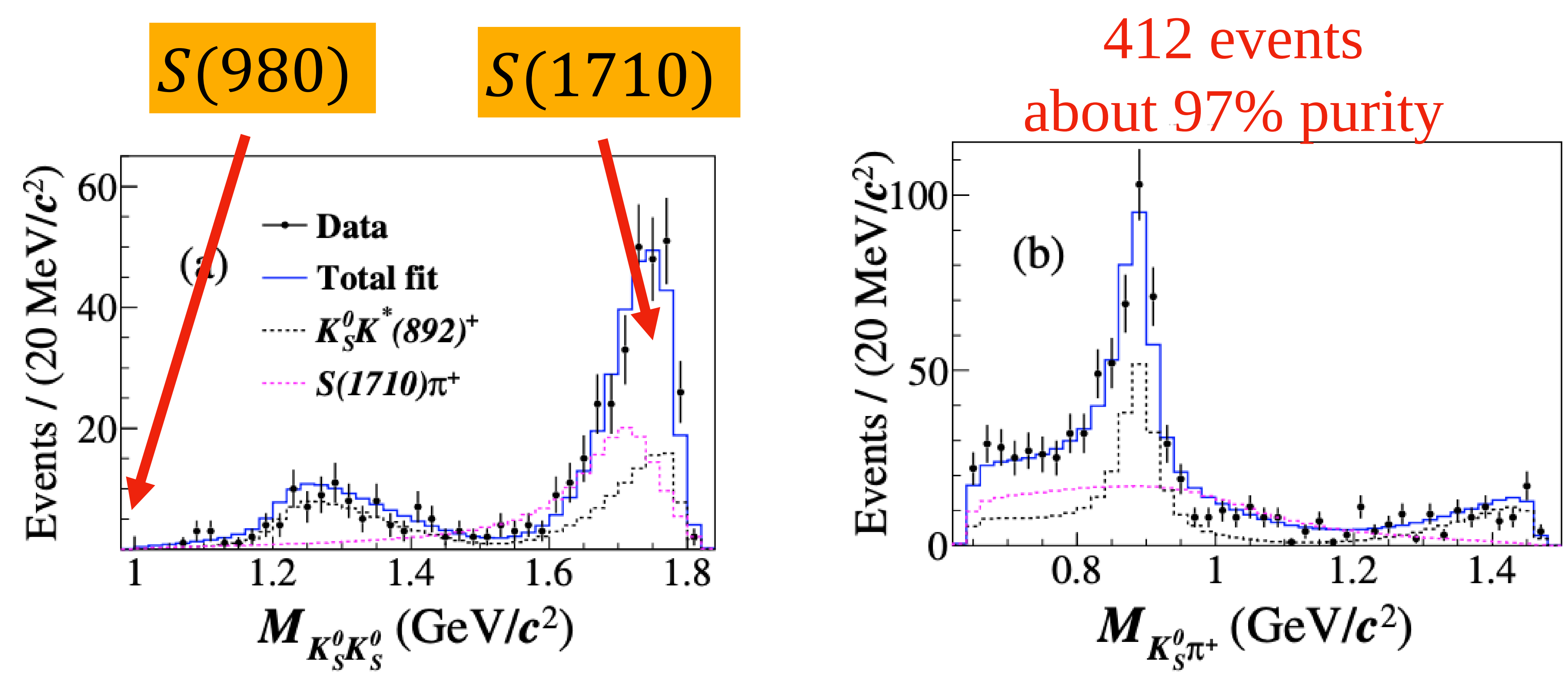
Amplitude analysis of $D_s^+ \to K_S^0 K_S^0 \pi^+$

[Phys. Rev. D 105, L051103 (2022)]

- 首次振幅分析
- 观测到了同位旋为1的态$a_0(1710)$

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





$S(1710)$: $f_0(1710)$ 与 $a_0(1710)$的混合:

- 相消干涉 $D_s^+ \to K^+K^-\pi^+$
  [PRD 104, 012016 (2021)]
- 相加干涉 $D_s^+ \to K_S^0 K_S^0 \pi^+$

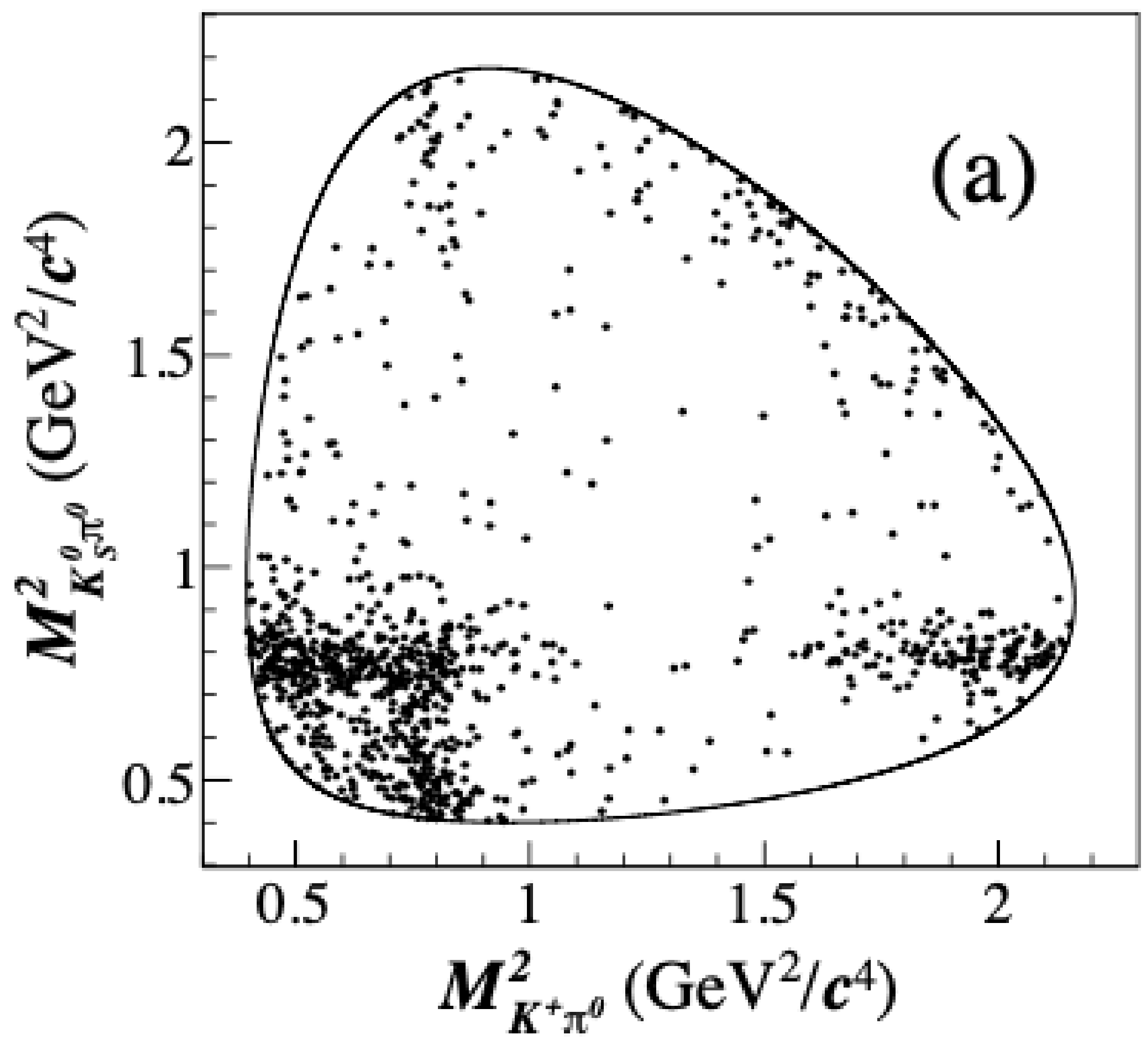
→ Consistent with the $K^*\bar{K}^*$ molecule hypothesis of $f_0(1710)$

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

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

arXiv:2204.09614 Submitted to PRL

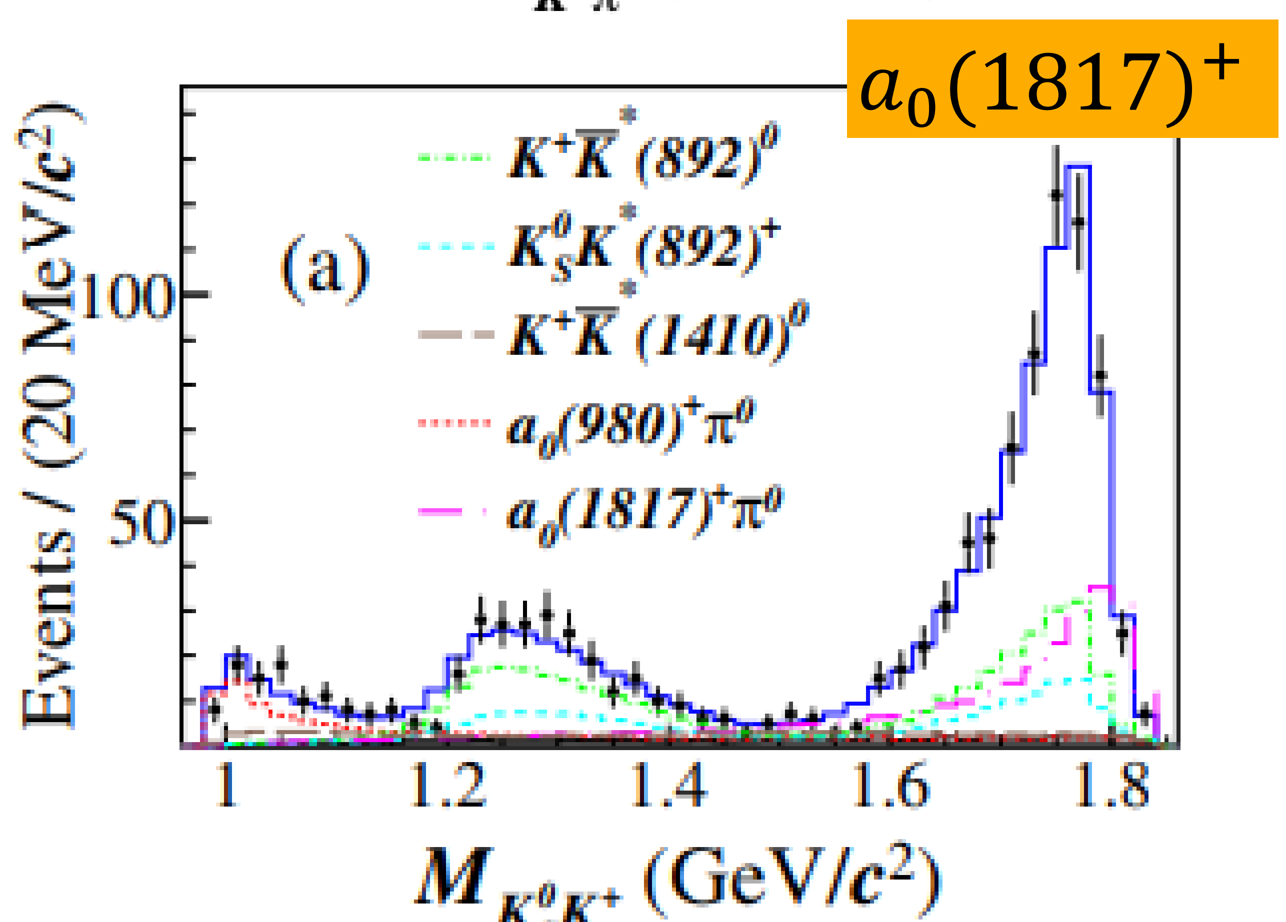
- 首次振幅分析
- 首次通过$K_S^0 K^+$衰变过程观测到$a_0(1817)^+$

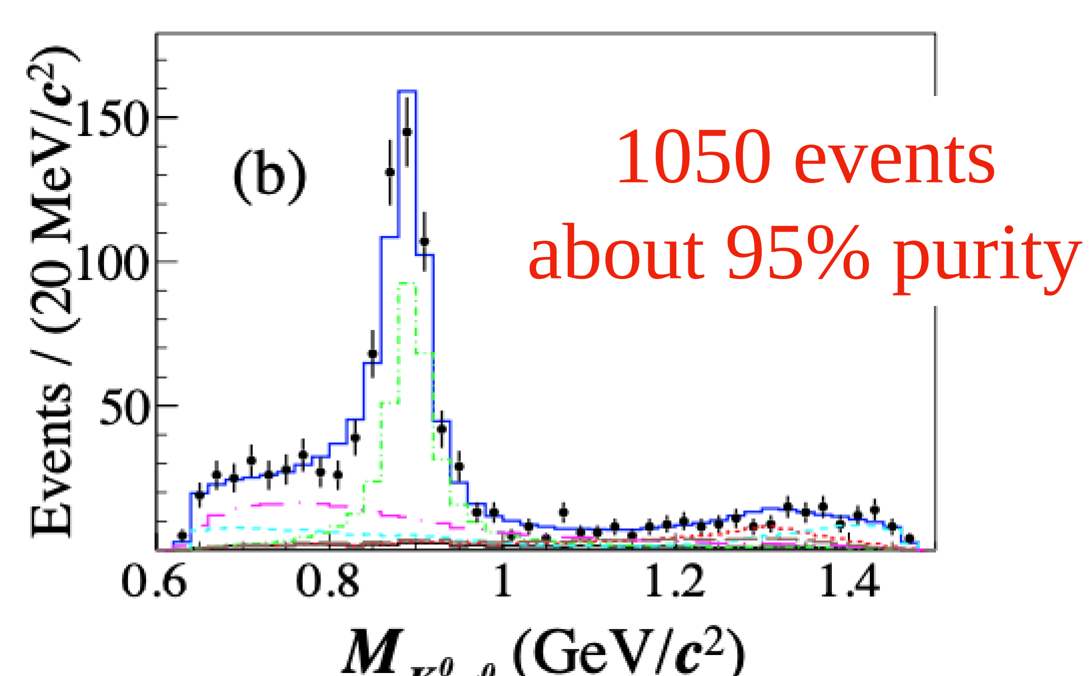


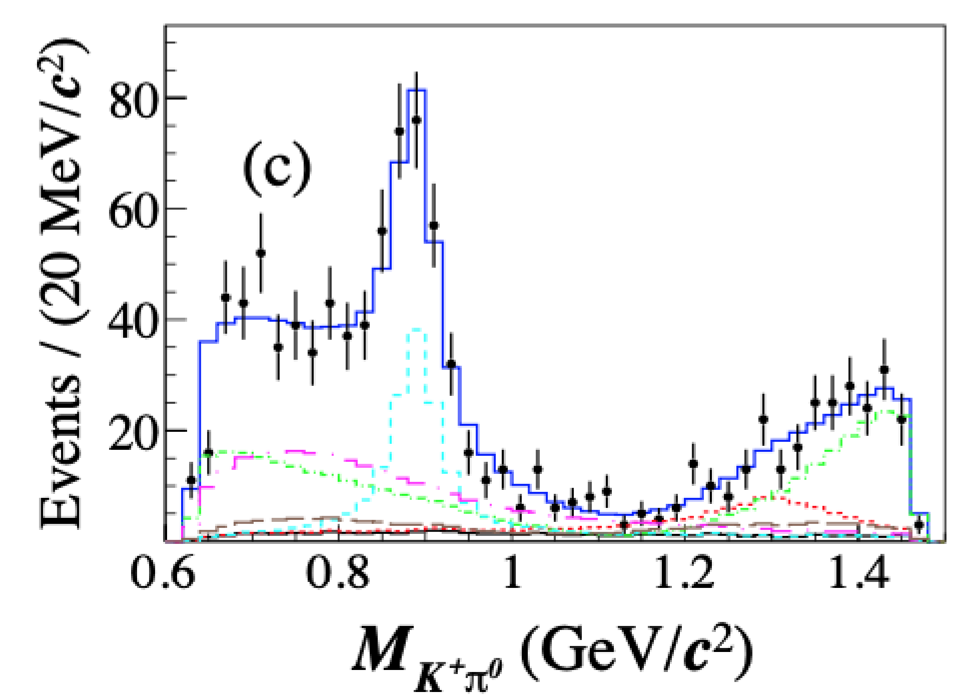
Amplitude	Phase (rad)	FF (%)	BF (10^{-3})	σ
$D_s^+ \to \bar{K}^*(892)^0 K^+$	0.0(fixed)	$32.7 \pm 2.2 \pm 1.9$	$4.77 \pm 0.38 \pm 0.32$	> 10
$D_s^+ \to K^*(892)^+ K_S^0$	$-0.16 \pm 0.12 \pm 0.11$	$13.9 \pm 1.7 \pm 1.3$	$2.03 \pm 0.26 \pm 0.20$	> 10
$D_s^+ \to a_0(980)^+ \pi^0$	$-0.97 \pm 0.27 \pm 0.25$	$7.7 \pm 1.7 \pm 1.8$	$1.12 \pm 0.25 \pm 0.27$	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
$D_s^+ \to a_0(1817)^+ \pi^0$	$-2.55 \pm 0.21 \pm 0.07$	$23.6 \pm 3.4 \pm 2.0$	$3.44 \pm 0.52 \pm 0.32$	> 10

与理论预测一致 Eur. Phys. J. C 82, 225 (2022)

$$M(a_0^+(1817)) = 1.817 \pm 0.008_{\text{stat.}} \pm 0.020_{\text{syst.}} \text{GeV}/c^2$$
$$\Gamma\ (a_0^+(1817)) = 0.097 \pm 0.022_{\text{stat.}} \pm 0.015_{\text{syst.}} \text{GeV}/c^2$$





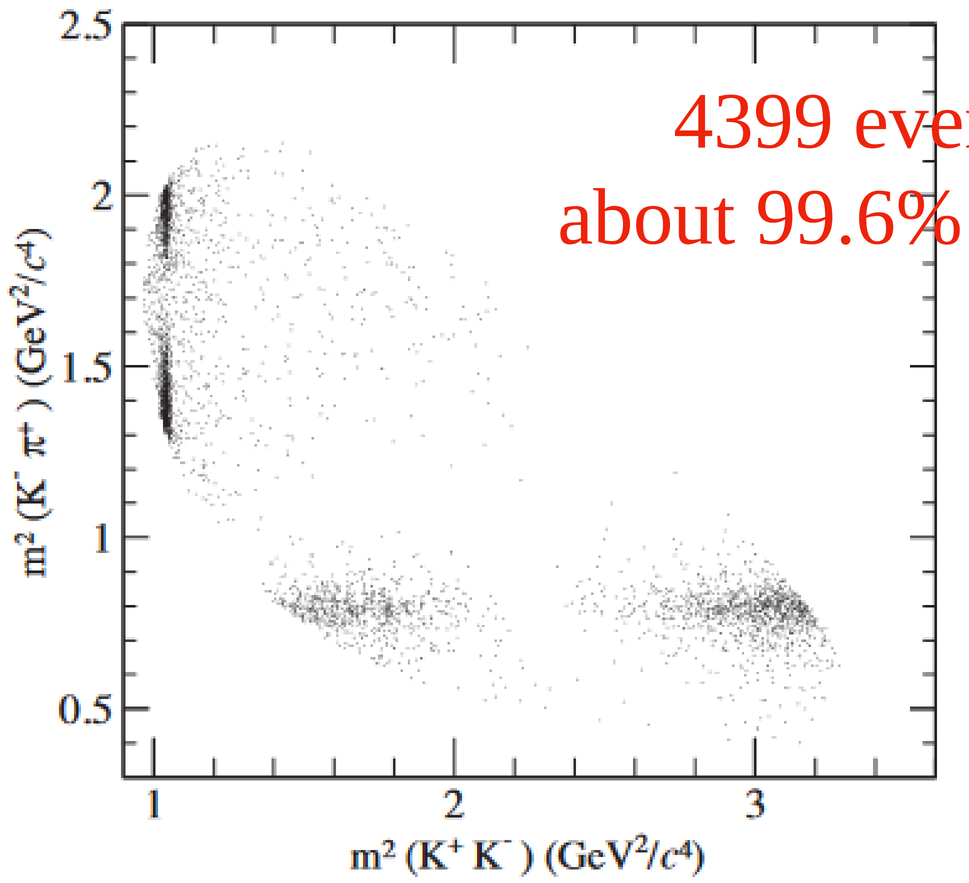


$$\mathcal{B}(D_s^+ \to K_S^0 K^+ \pi^0) = (1.46 \pm 0.06_{\text{stat.}} \pm 0.05_{\text{syst.}})\%$$

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

Phys. Rev. D 104, 012016 (2021)

- 在 K^+K^- 质量谱的低端进行模型无关的振幅分析，以此来确定K^+K^- S波的线形

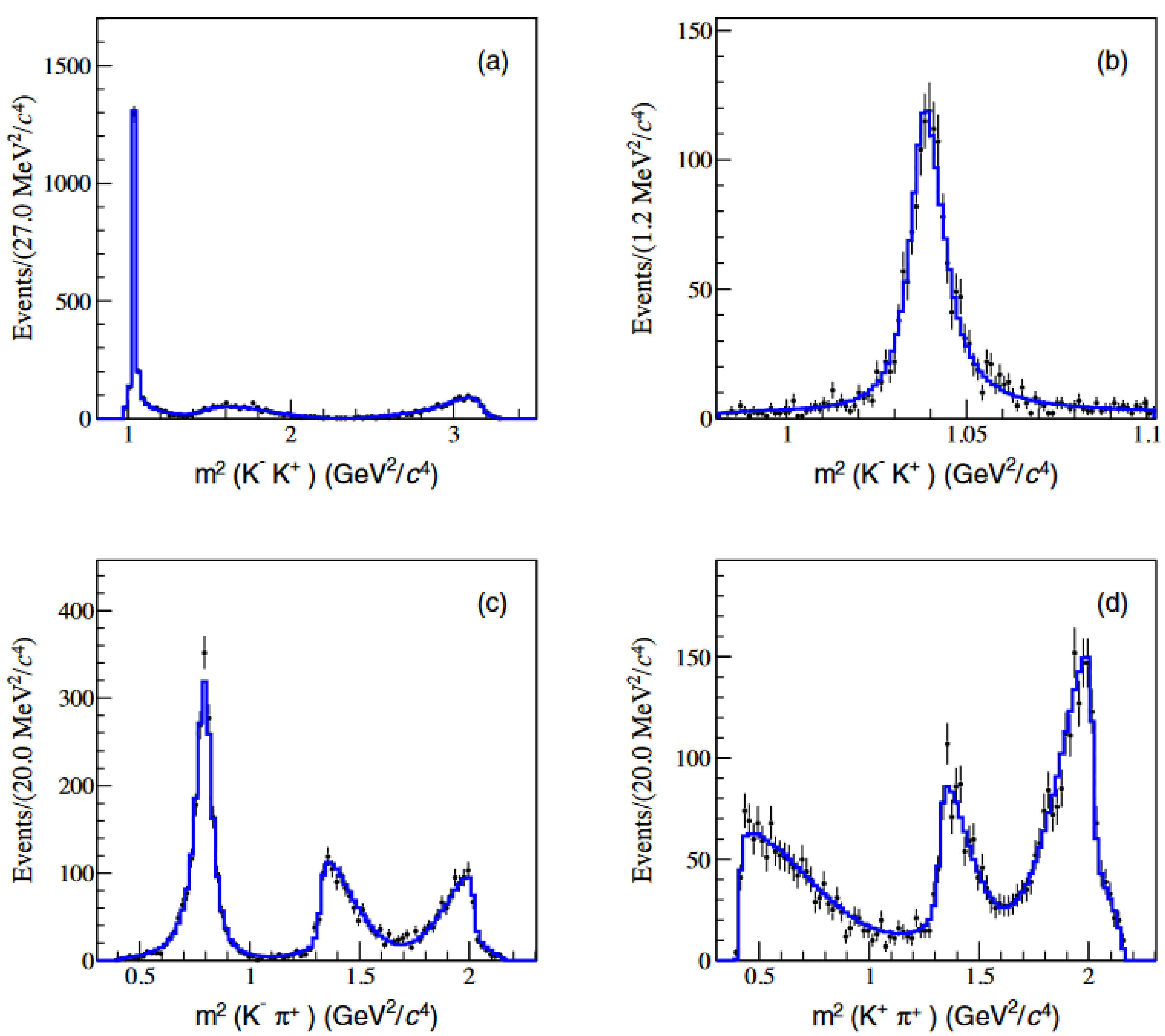


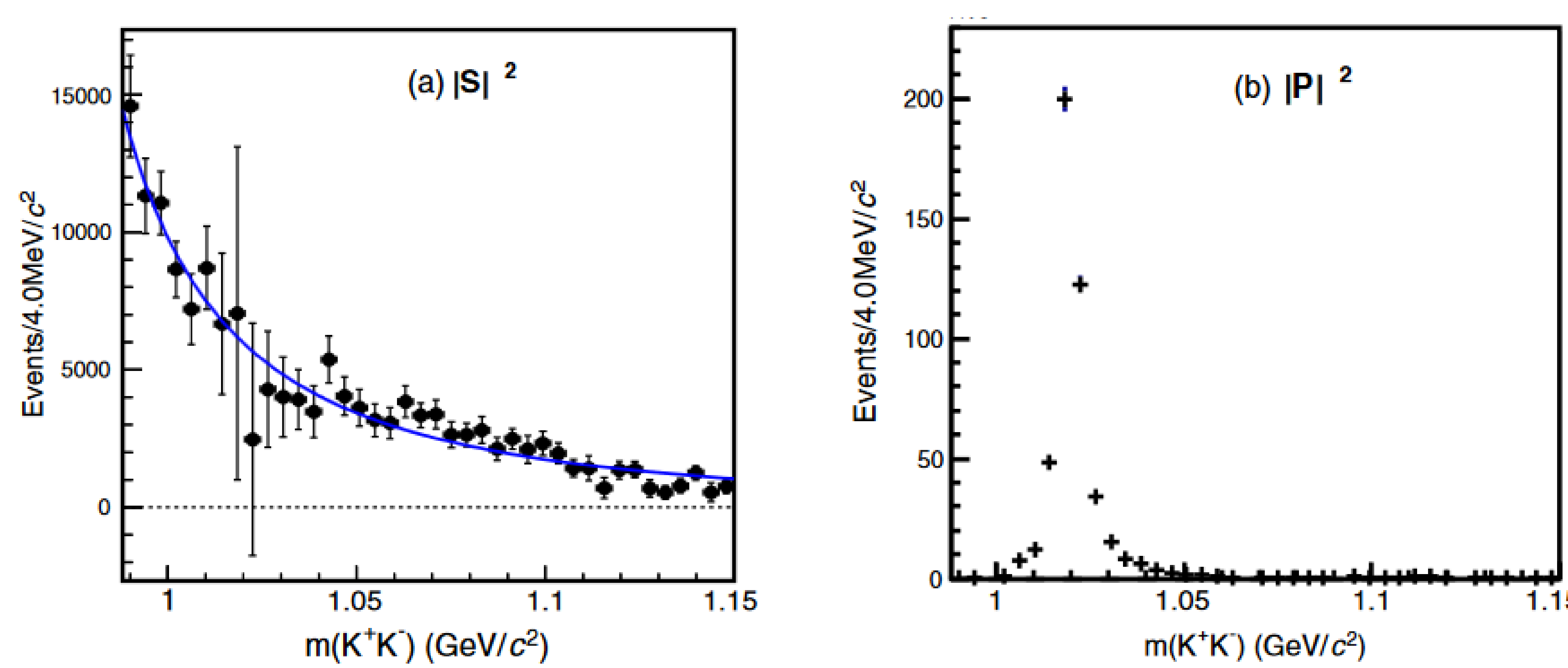
4399 events
about 99.6% purity

Amplitude	Magnitude (ρ)	Phase (ϕ)	FFs (%)	Significance (σ)
$D_s^+ \to \bar{K}^*(892)^0K^+$	1.0 (fixed)	0.0 (fixed)	$48.3 \pm 0.9 \pm 0.6$	>20
$D_s^+ \to \phi(1020)\pi^+$	$1.09 \pm 0.02 \pm 0.01$	$6.22 \pm 0.07 \pm 0.04$	$40.5 \pm 0.7 \pm 0.9$	>20
$D_s^+ \to S(980)\pi^+$	$2.88 \pm 0.14 \pm 0.17$	$4.77 \pm 0.07 \pm 0.07$	$19.3 \pm 1.7 \pm 2.0$	>20
$D_s^+ \to \bar{K}_0^*(1430)^0K^+$	$1.26 \pm 0.14 \pm 0.16$	$2.91 \pm 0.20 \pm 0.23$	$3.0 \pm 0.6 \pm 0.5$	8.6
$D_s^+ \to f_0(1710)\pi^+$	$0.79 \pm 0.08 \pm 0.14$	$1.02 \pm 0.12 \pm 0.06$	$1.9 \pm 0.4 \pm 0.6$	9.2
$D_s^+ \to f_0(1370)\pi^+$	$0.58 \pm 0.08 \pm 0.08$	$0.59 \pm 0.17 \pm 0.46$	$1.2 \pm 0.4 \pm 0.2$	6.4

$S(980)$: $f_0(980)$ 与 $a_0(980)$ 的混合

$\phi(1020)$





K^+K^- S-wave and P-wave lineshape

$\mathcal{B}(D_s^+ \to K^+K^-\pi^+) = (5.47 \pm 0.08_{\rm stat.} \pm 0.13_{\rm syst.})\%$

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

JHEP 04 (2022) 058

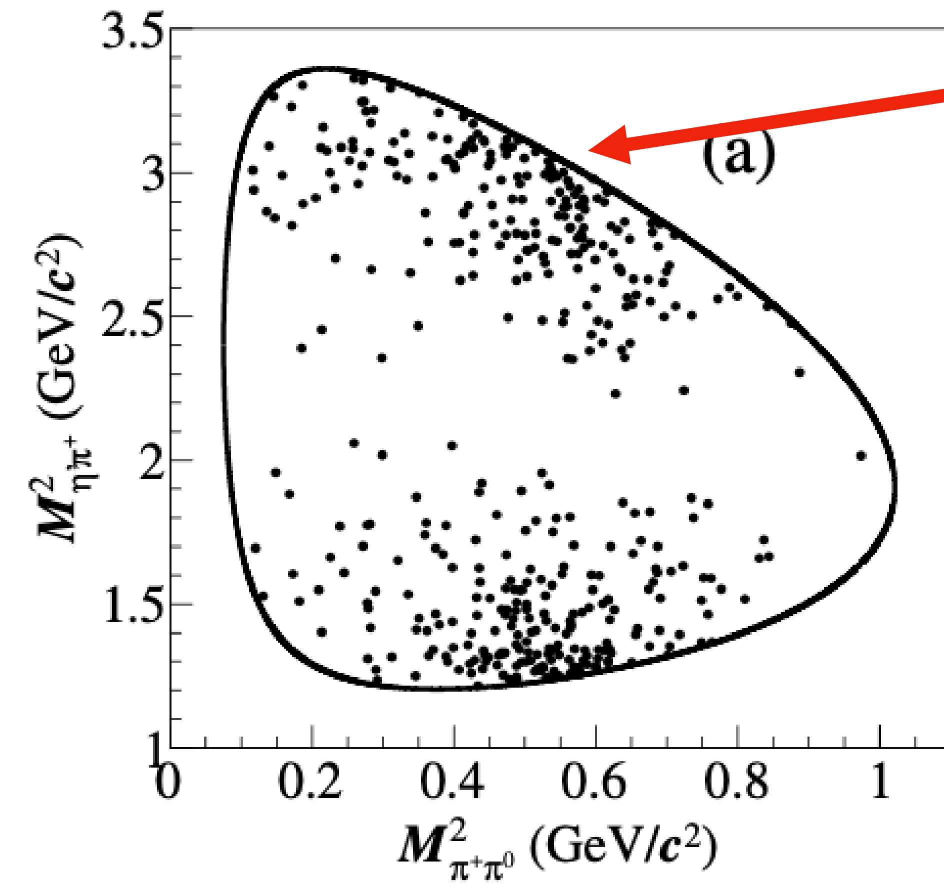
- 首次振幅分析
- 实验测量与理论预言间有较大偏差

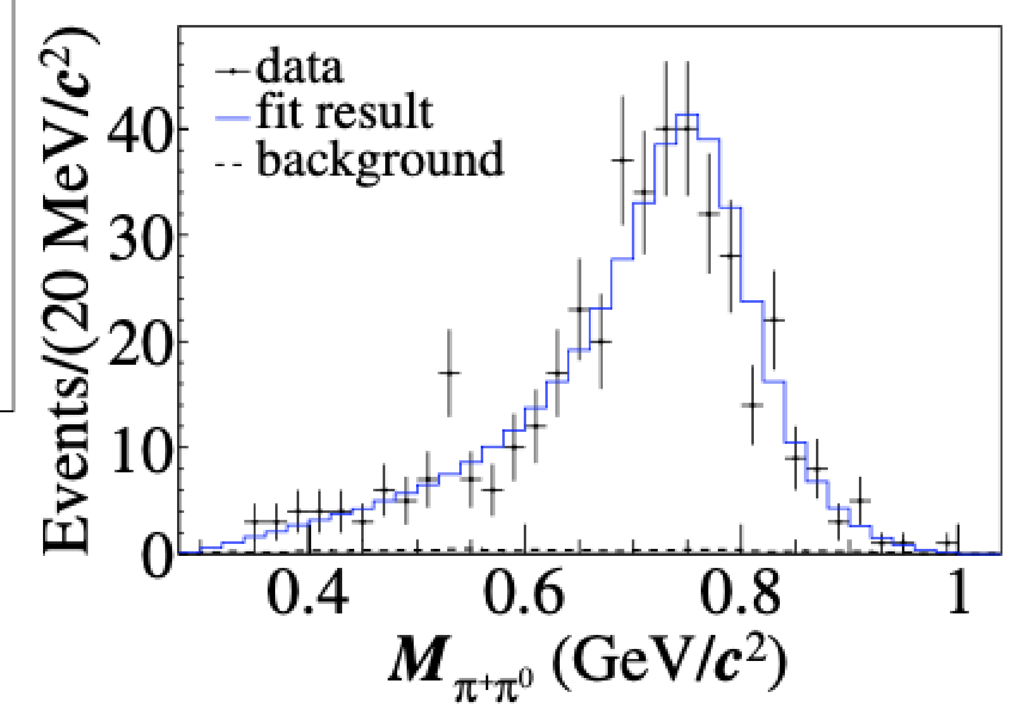
[1] Phys. Rev. D 84 (2011) 074019

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

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)	

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



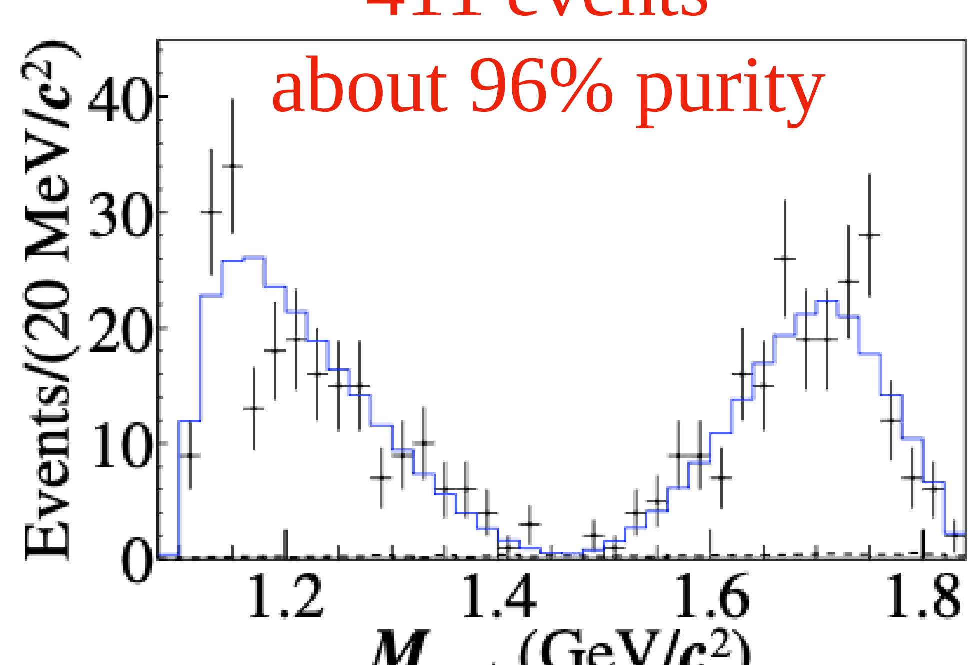


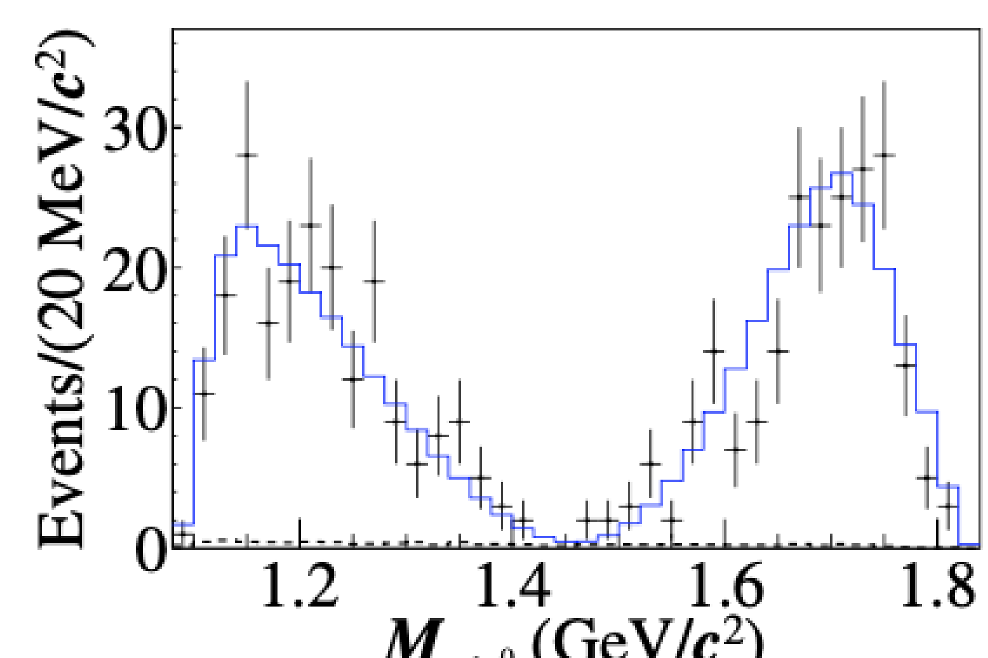
最高精度分支比测量:

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

411 events

about 96% purity





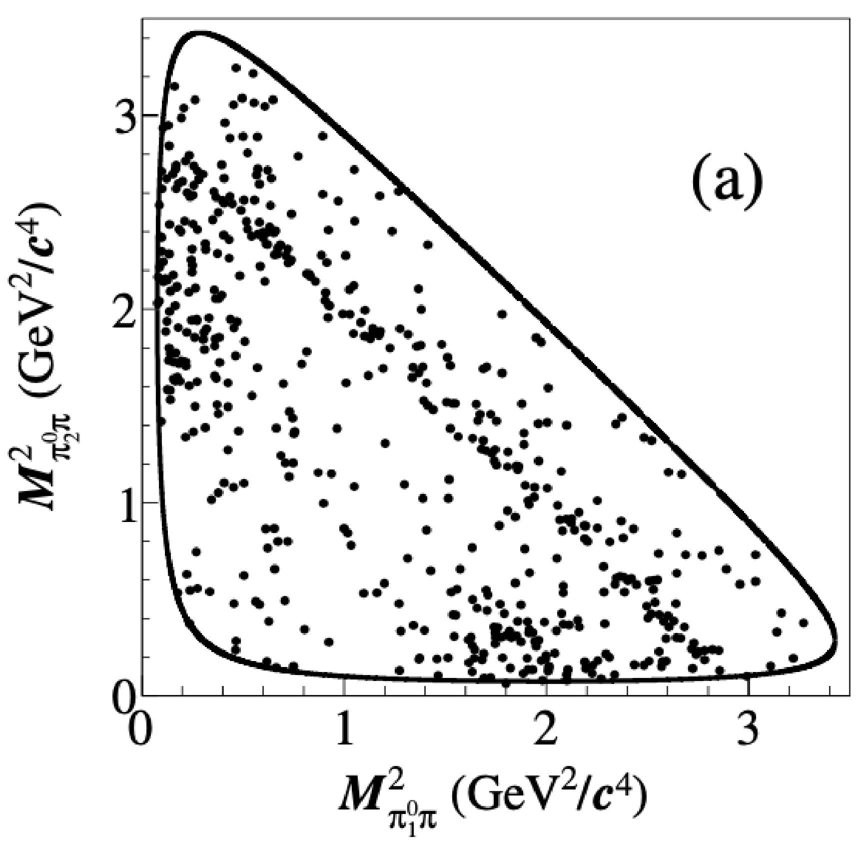
$\mathcal{B}(D_s^+ \to (\pi^+\pi^0)_S\eta') < 0.10\%$ @90%CL

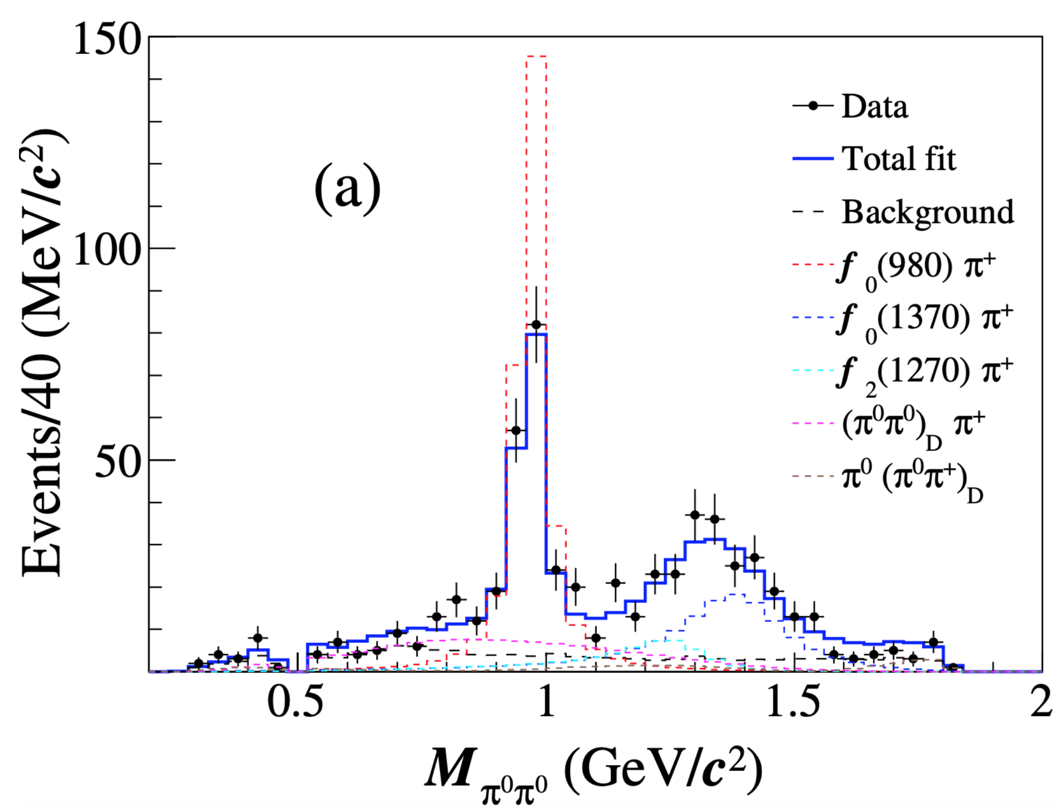
$\mathcal{B}(D_s^+ \to (\pi^+\pi^0)_P\eta') < 0.74\%$ @90%CL

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

JHEP 01 (2022) 052

- 首次振幅分析
- 首次通过$f_0(980) \to \pi^0\pi^0$测量了$D_s^+ \to f_0(980)\pi^+$分支比





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

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

没有$f_0(500)$的信号

$$R = \frac{f_{0(2)}(\pi^+\pi^-)}{f_{0(2)}(\pi^0\pi^0)}$$

$$R(f_0(980)) = 2.2 \pm 0.5$$
$$R(f_0(1370)) = 2.7 \pm 1.4$$
$$R(f_2(1270)) = 2.4 \pm 1.8$$

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

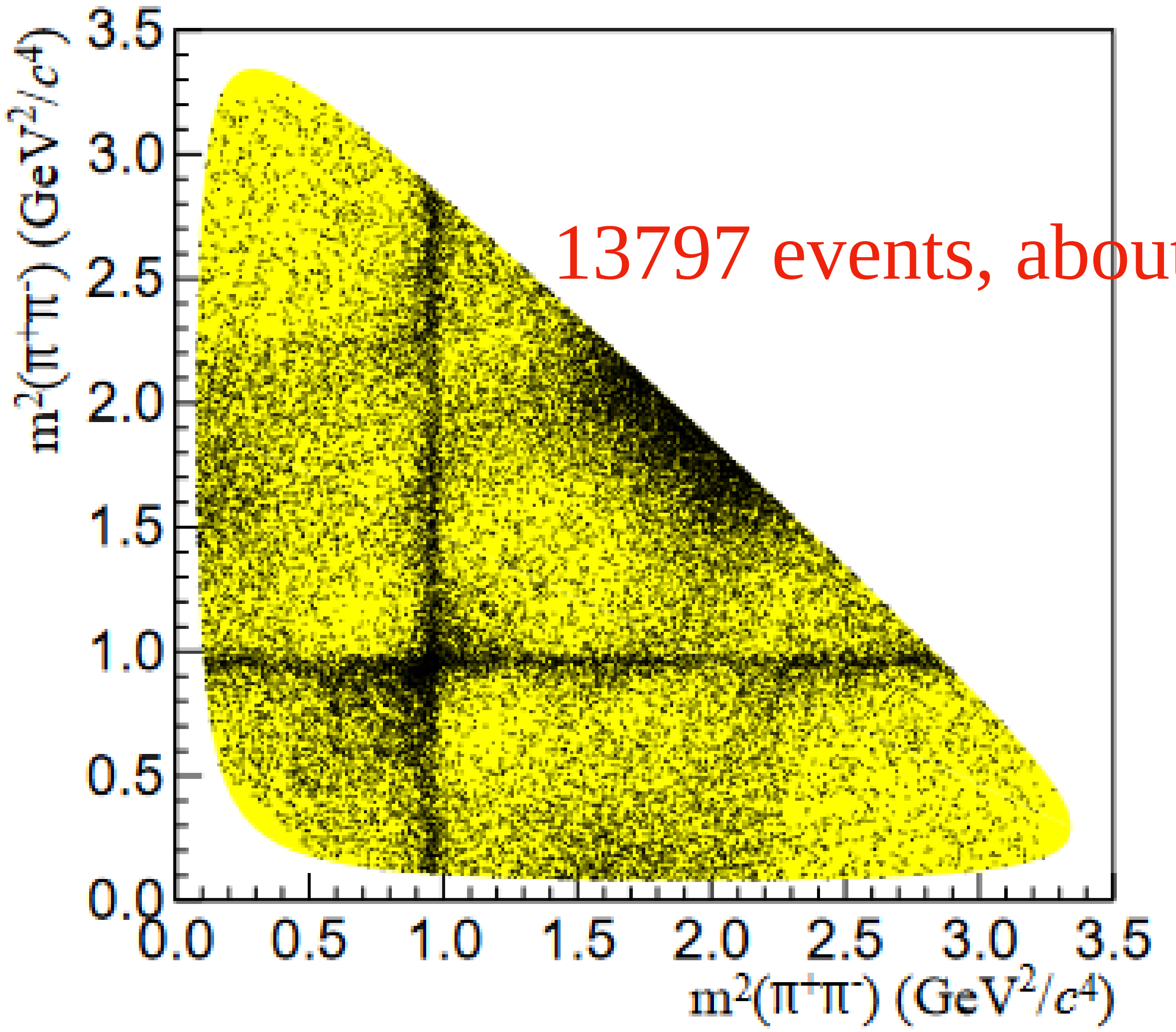
相较于PDG精度改进约2倍

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

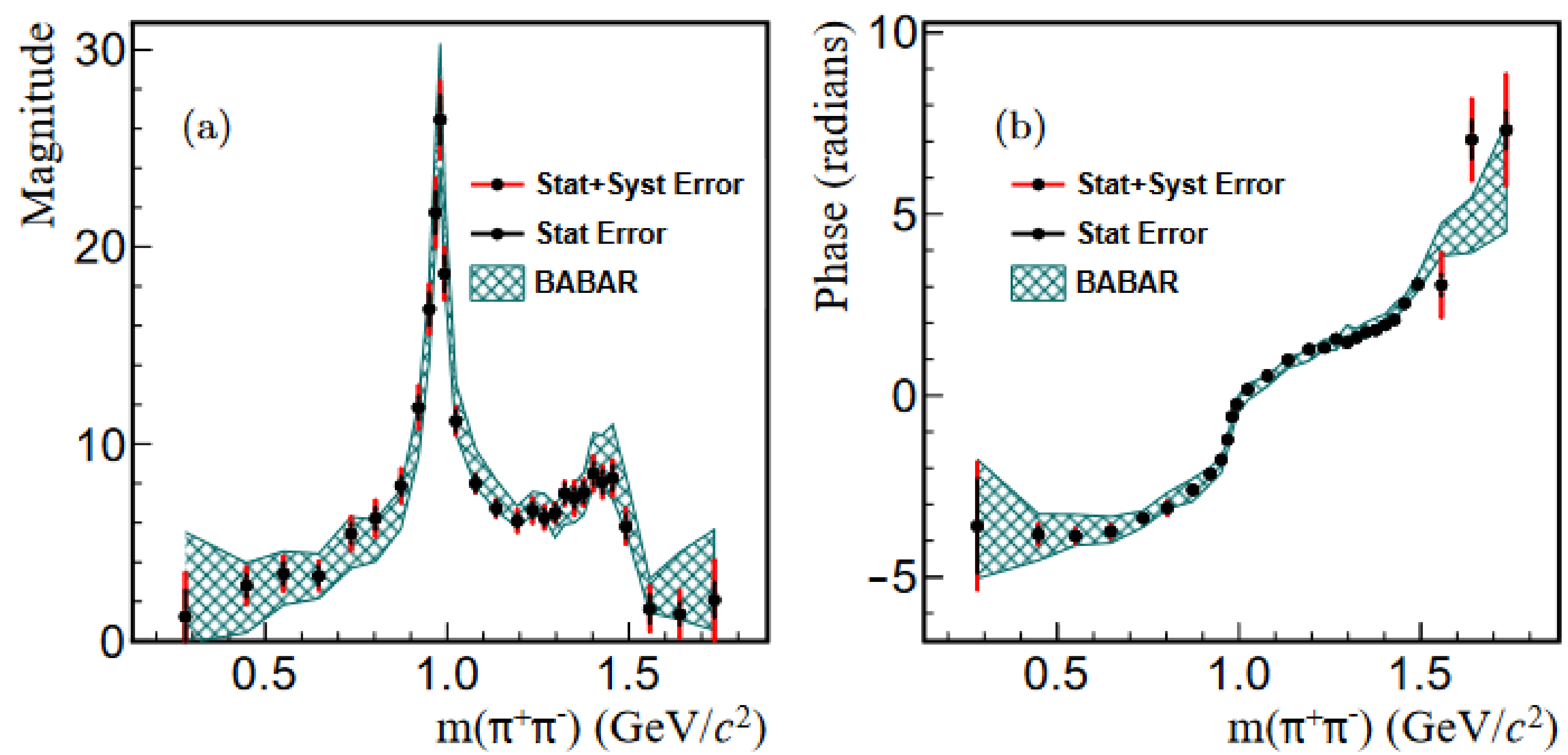
arXiv:2108.10050 Submitted to PRD

- 准模型无关方法
- 在此衰变中提供了对$\pi^+\pi^-$ S波的精确描述

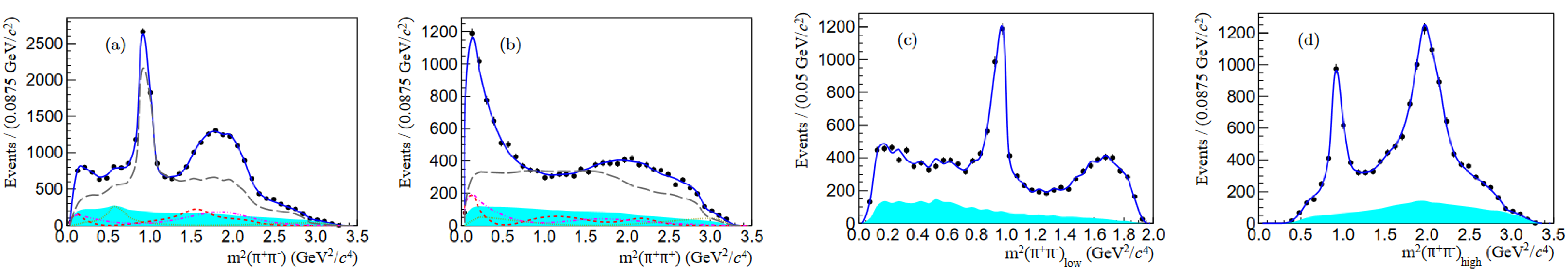
Decay mode	Fit fraction (%)	Magnitude	Phase (radians)
$f_2(1270)\pi^+$	$10.5 \pm 0.8 \pm 1.2$	1. (Fixed)	0. (Fixed)
$\rho(770)\pi^+$	$0.9 \pm 0.4 \pm 0.5$	$0.13 \pm 0.03 \pm 0.04$	$5.44 \pm 0.25 \pm 0.62$
$\rho(1450)\pi^+$	$1.3 \pm 0.4 \pm 0.5$	$0.91 \pm 0.16 \pm 0.22$	$1.03 \pm 0.32 \pm 0.51$
S wave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



13797 events, about 80% purity



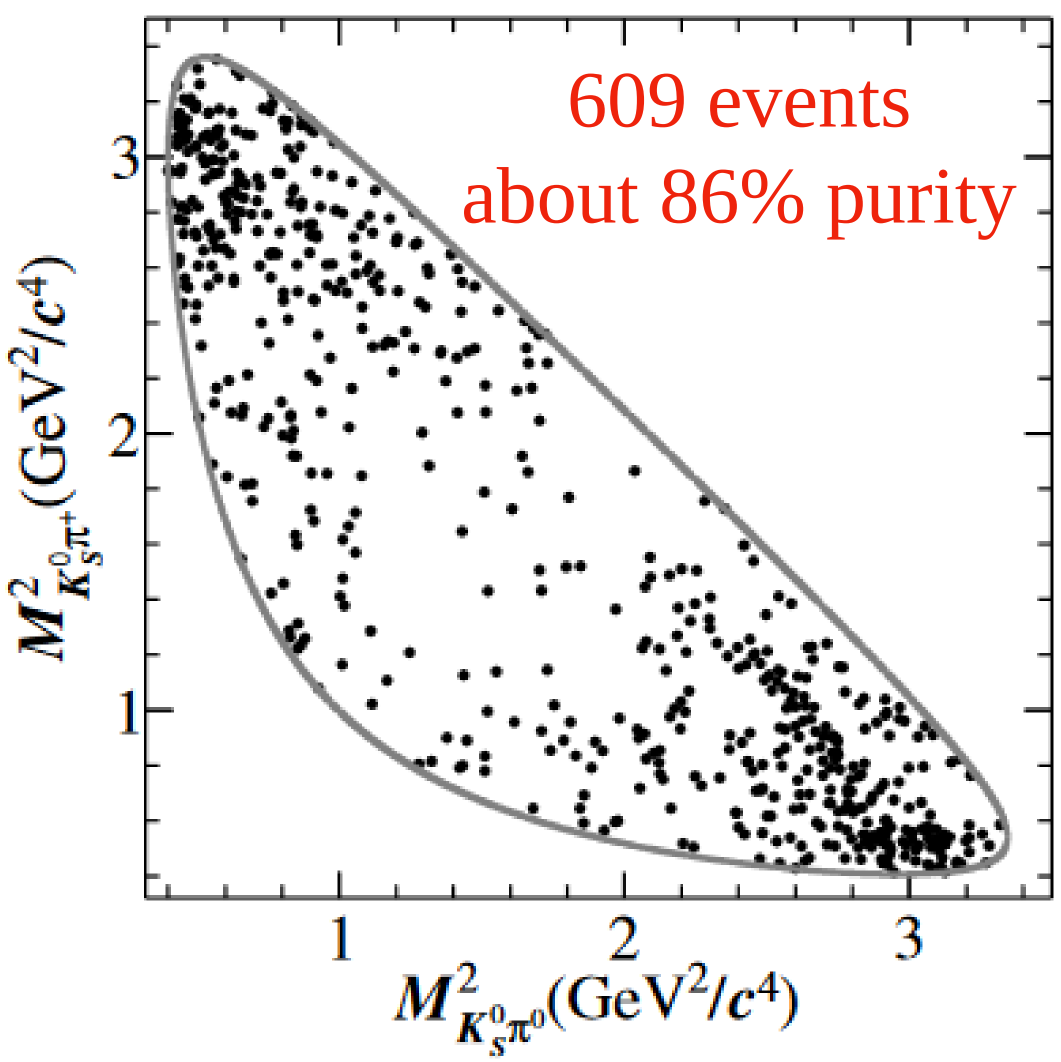
S波强度及相位



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

SCS   JHEP 06 (2021) 181

- $\mathcal{B}(D_s^+ \to VP)$帮助研究SU(3)对称性破缺效应



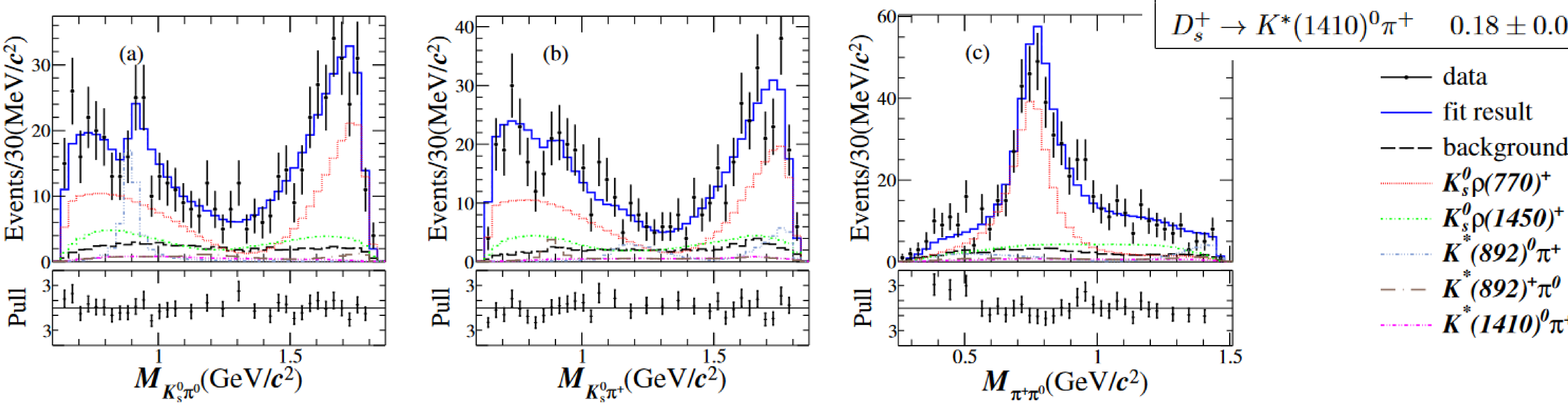
Amplitude	Magnitude (ρ_n)	Phase (ϕ_n)	FF (%)	Significance (σ)
$D_s^+ \to K_S^0\rho^+$	1.0(fixed)	0.0(fixed)	$50.2 \pm 7.2 \pm 3.9$	>10
$D_s^+ \to K_S^0\rho(1450)^+$	2.7 ± 0.5	$2.2 \pm 0.2 \pm 0.1$	$20.4 \pm 4.3 \pm 4.4$	>10
$D_s^+ \to K^*(892)^0\pi^+$	0.4 ± 0.1	$3.2 \pm 0.2 \pm 0.1$	$8.4 \pm 2.2 \pm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

$$\mathcal{B}\left(D_s^+ \to K_S^0\pi^+\pi^0\right) = \left(5.43 \pm 0.30_{\text{stat.}} \pm 0.15_{\text{syst.}}\right) \times 10^{-3}$$

精度改进约3倍

$$A_{CP} = \left(2.7 \pm 5.5_{\text{stat.}} \pm 0.9_{\text{syst.}}\right)\%$$

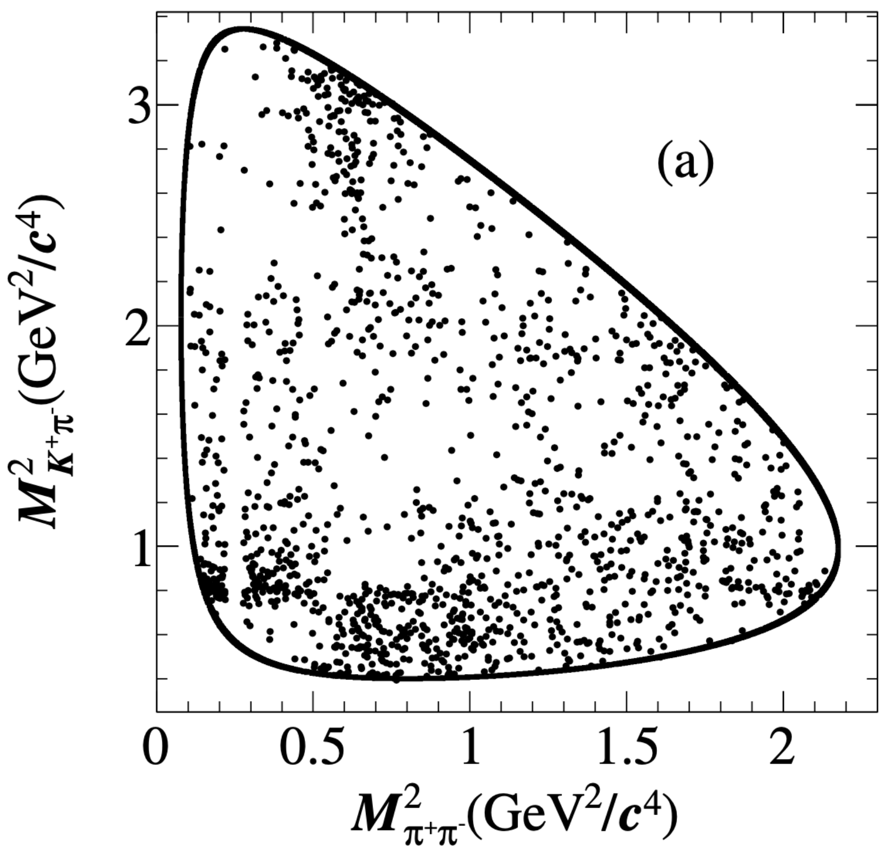
Intermediate process	BF (10^{-3})
$D_s^+ \to K_S^0\rho^+$	$2.73 \pm 0.42 \pm 0.22$
$D_s^+ \to K_S^0\rho(1450)^+$	$1.11 \pm 0.24 \pm 0.24$
$D_s^+ \to K^*(892)^0\pi^+$	$0.45 \pm 0.12 \pm 0.05$
$D_s^+ \to K^*(892)^+\pi^0$	$0.25 \pm 0.08 \pm 0.02$
$D_s^+ \to K^*(1410)^0\pi^+$	$0.18 \pm 0.09 \pm 0.03$



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

SCS　JHEP 08 (2022) 196

➢ 首次测量$\mathcal{B}(D_s^+ \to K^+f_0(500)\ ,K^+f_0(980)\ ,\ K^+f_0(1370))$



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

与PDG结果相比：

将非共振态替换为

$K^+f_0(500)\ ,K^+f_0(980)$

和 $K^+f_0(1370)$

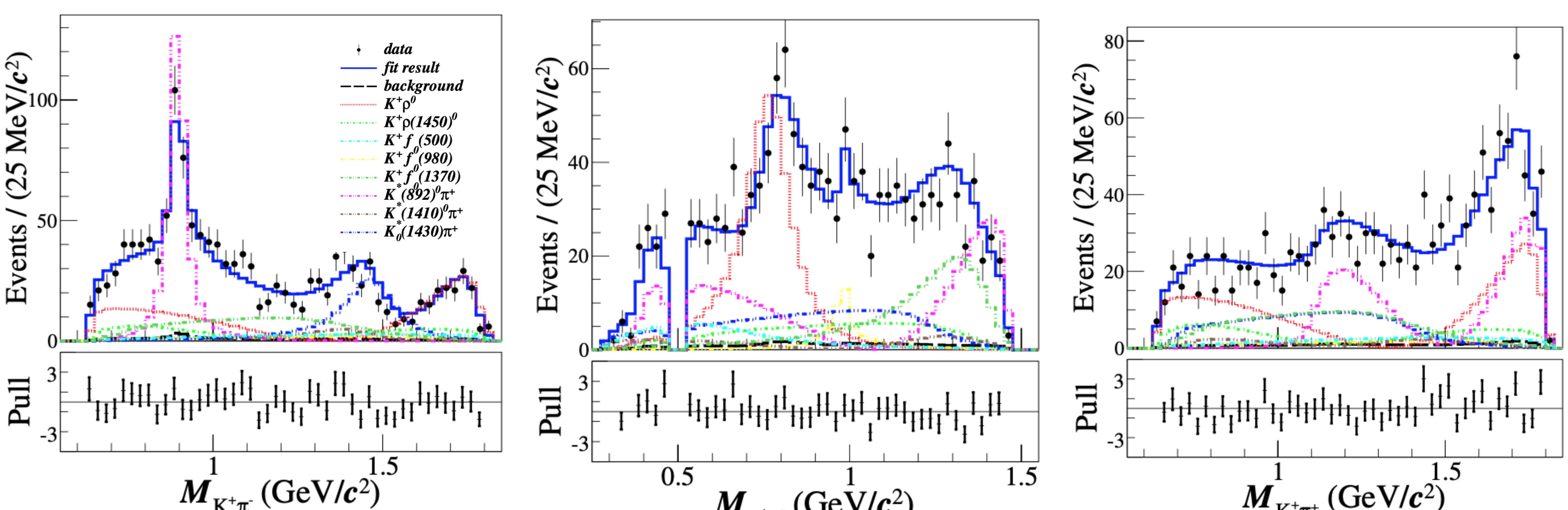
1356 events, about 95% purity

- Dominant processes:

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

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

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



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

无明显CP破缺

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

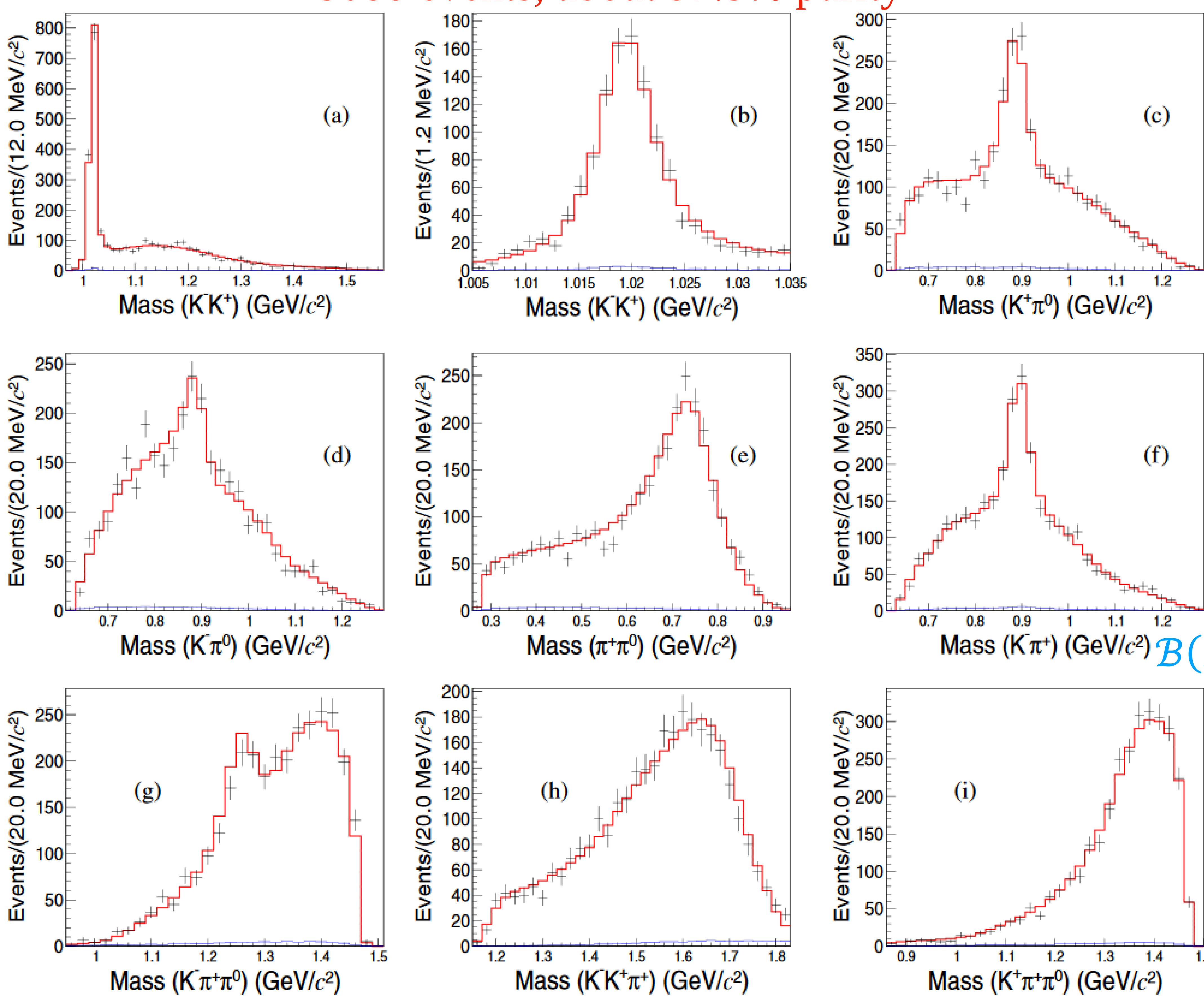
Phys. Rev. D 104, 032011 (2021)

- 首次振幅分析

- $R_{K_1(1270)} \equiv \frac{\mathcal{B}(K_1^0(1270)\to K^*\pi)}{\mathcal{B}(K_1^0(1270)\to K\rho)}$

$$= 0.99 \pm 0.15_{\text{stat.}} \pm 0.18_{\text{syst.}}$$

3088 events, about 97.5% purity



Amplitude	Phase (ϕ_n)	FF (%)
$D_s^+[S] \to \phi\rho^+$	0.0 (fixed)	$38.68 \pm 1.42 \pm 2.17$
$D_s^+[P] \to \phi\rho^+$	$-1.46 \pm 0.05 \pm 0.02$	$9.64 \pm 0.84 \pm 0.30$
$D_s^+[D] \to \phi\rho^+$	$1.46 \pm 0.07 \pm 0.04$	$3.36 \pm 0.75 \pm 0.27$
$D_s^+ \to \phi\rho^+$	...	$50.81 \pm 1.01 \pm 2.20$
$D_s^+[S] \to \bar{K}^{*0}K^{*+}$	$-2.15 \pm 0.06 \pm 0.05$	$16.32 \pm 0.95 \pm 0.33$
$D_s^+[P] \to \bar{K}^{*0}K^{*+}$	$-0.52 \pm 0.07 \pm 0.04$	$6.87 \pm 0.55 \pm 0.26$
$D_s^+[D] \to \bar{K}^{*0}K^{*+}$	$-1.57 \pm 0.08 \pm 0.03$	$3.34 \pm 0.55 \pm 0.18$
$D_s^+ \to \bar{K}^{*0}K^{*+}$	...	$23.15 \pm 0.89 \pm 0.74$
$D_s^+ \to \bar{K}_1^0(1270)K^+$, $\bar{K}_1^0(1270) \to K^-\rho^+$	$1.87 \pm 0.08 \pm 0.17$	$10.44 \pm 0.81 \pm 0.73$
$D_s^+ \to \bar{K}_1^0(1270)K^+$, $\bar{K}_1^0(1270)[S] \to \bar{K}^{*0}\pi^0$	...	$1.40 \pm 0.26 \pm 0.17$
$D_s^+ \to \bar{K}_1^0(1270)K^+$, $\bar{K}_1^0(1270)[S] \to K^{*-}\pi^+$	...	$2.60 \pm 0.48 \pm 0.31$
$D_s^+ \to \bar{K}_1^0(1270)K^+$, $\bar{K}_1^0(1270)[S] \to K^*\pi$	$-0.25 \pm 0.11 \pm 0.12$	$3.88 \pm 0.71 \pm 0.45$
$D_s^+ \to \bar{K}_1^0(1270)K^+$, $\bar{K}_1^0(1270)[D] \to \bar{K}^{*0}\pi^0$	...	$0.45 \pm 0.11 \pm 0.10$
$D_s^+ \to \bar{K}_1^0(1270)K^+$, $\bar{K}_1^0(1270)[D] \to K^{*-}\pi^+$	...	$0.86 \pm 0.20 \pm 0.17$
$D_s^+ \to \bar{K}_1^0(1270)K^+$, $\bar{K}_1^0(1270)[D] \to K^*\pi$	$1.52 \pm 0.11 \pm 0.15$	$1.34 \pm 0.31 \pm 0.27$
$D_s^+ \to \bar{K}_1^0(1270)K^+$, $\bar{K}_1^0(1270) \to K^*\pi$	...	$5.43 \pm 0.69 \pm 0.76$
$D_s^+ \to \bar{K}_1^0(1400)K^+$, $\bar{K}_1^0(1400)[S] \to \bar{K}^{*0}\pi^0$	...	$2.90 \pm 0.39 \pm 0.44$
$D_s^+ \to \bar{K}_1^0(1400)K^+$, $\bar{K}_1^0(1400)[S] \to K^{*-}\pi^+$	...	$5.37 \pm 0.73 \pm 0.82$
$D_s^+ \to \bar{K}_1^0(1400)K^+$, $\bar{K}_1^0(1400)[S] \to K^*\pi$	$-0.92 \pm 0.07 \pm 0.05$	$8.03 \pm 1.09 \pm 1.22$
$D_s^+ \to a_0^0(980)\rho^+$	$2.15 \pm 0.08 \pm 0.08$	$3.46 \pm 0.58 \pm 0.61$
$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to K^{*-}K^+$	...	$1.56 \pm 0.28 \pm 0.17$
$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to K^{*+}K^-$	...	$1.56 \pm 0.28 \pm 0.17$
$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to K^{*\mp}K^\pm$	$2.13 \pm 0.08 \pm 0.05$	$2.39 \pm 0.43 \pm 0.25$
$D_s^+ \to f_1(1420)\pi^+$, $f_1(1420) \to a_0^0(980)\pi^0$	$2.95 \pm 0.13 \pm 0.06$	$0.77 \pm 0.27 \pm 0.09$
$D_s^+ \to \eta(1475)\pi^+$, $\eta(1475) \to a_0^0(980)\pi^0$	$0.61 \pm 0.10 \pm 0.06$	$1.37 \pm 0.32 \pm 0.34$

$$\mathcal{B}(D_s^+ \to K^-K^+\pi^+\pi^0) = (5.42 \pm 0.10_{\text{stat.}} \pm 0.17_{\text{syst.}})\%$$

$$\mathcal{B}(D_s^+ \to \phi\rho^+) = (5.59 \pm 0.15_{\text{stat.}} \pm 0.30_{\text{syst.}})\%$$

Consistent (5.70%)

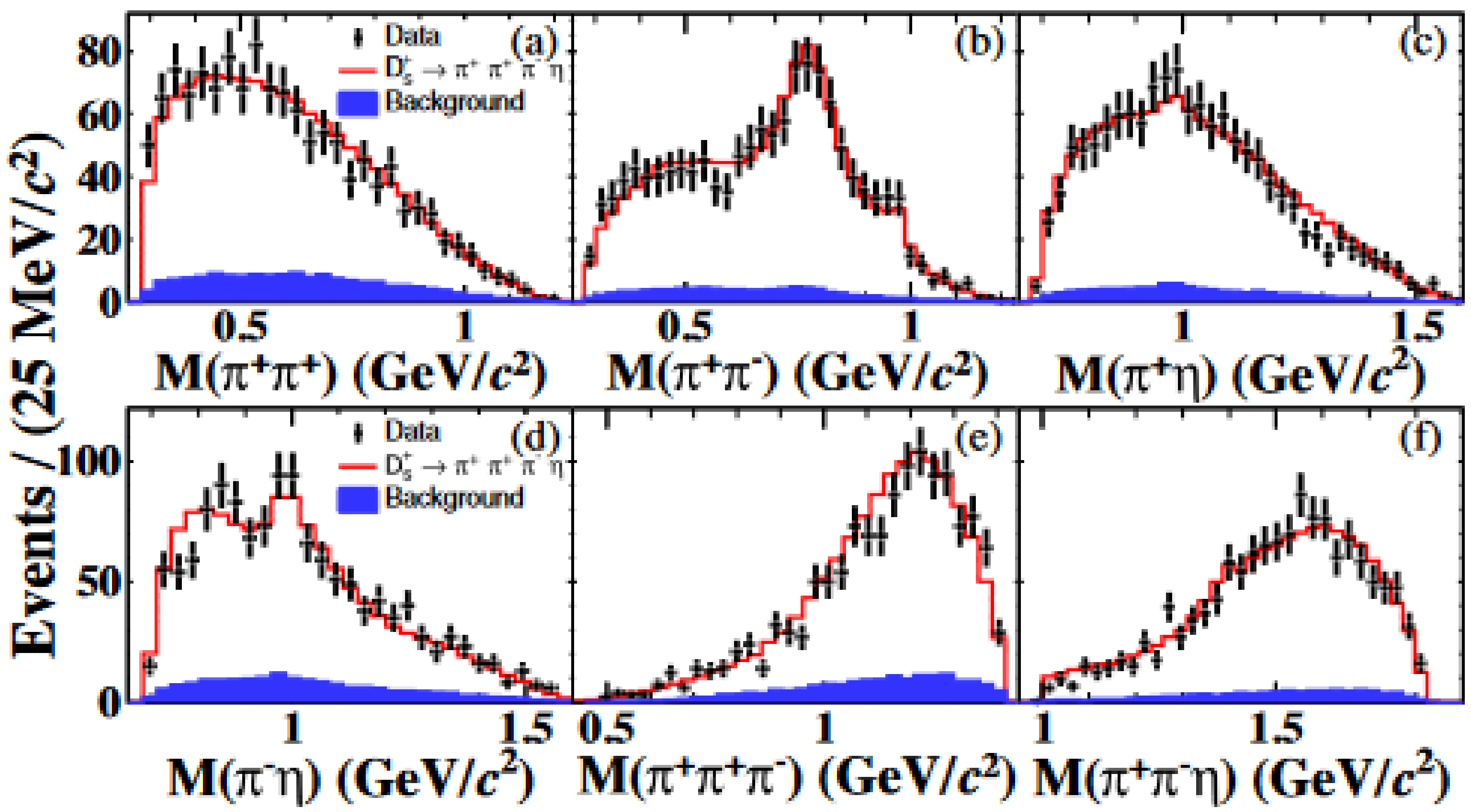
$$\mathcal{B}\left(D_s^+ \to \bar{K}^{*0}K^{*+}\right) = (5.64 \pm 0.23_{\text{stat.}} \pm 0.27_{\text{syst.}})\%$$

Much larger (1.50%)

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

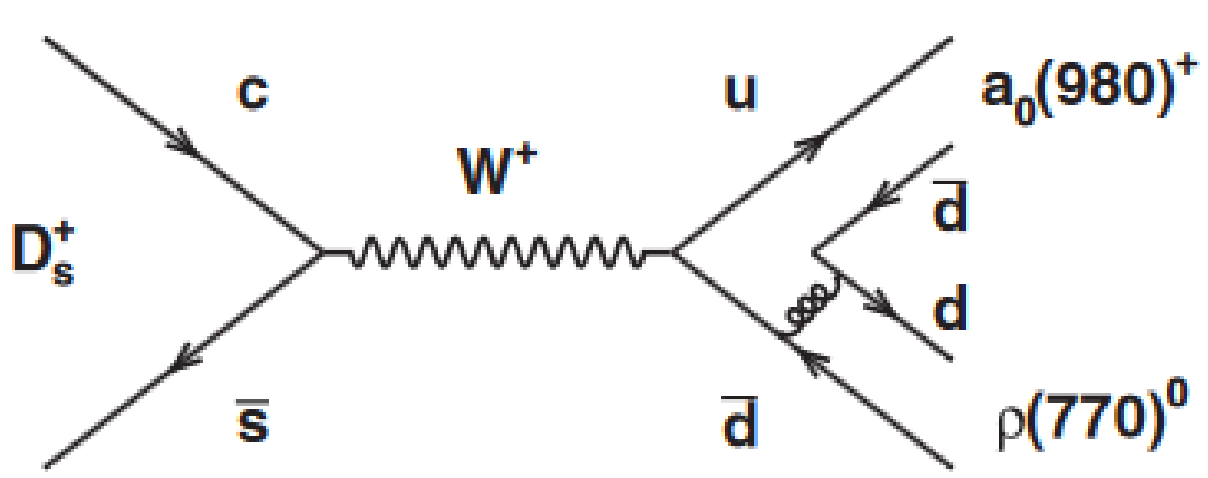
Phys. Rev. D 104, L071101 (2021)

- 首次振幅分析
- 观测到了纯湮灭过程 $D_s^+ \to a_0(980)^+\rho(770)^0$



1306 events, about 87% purity

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



$$\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^-\eta) = (3.12 \pm 0.13_{\text{stat.}} \pm 0.09_{\text{syst.}})\%$$

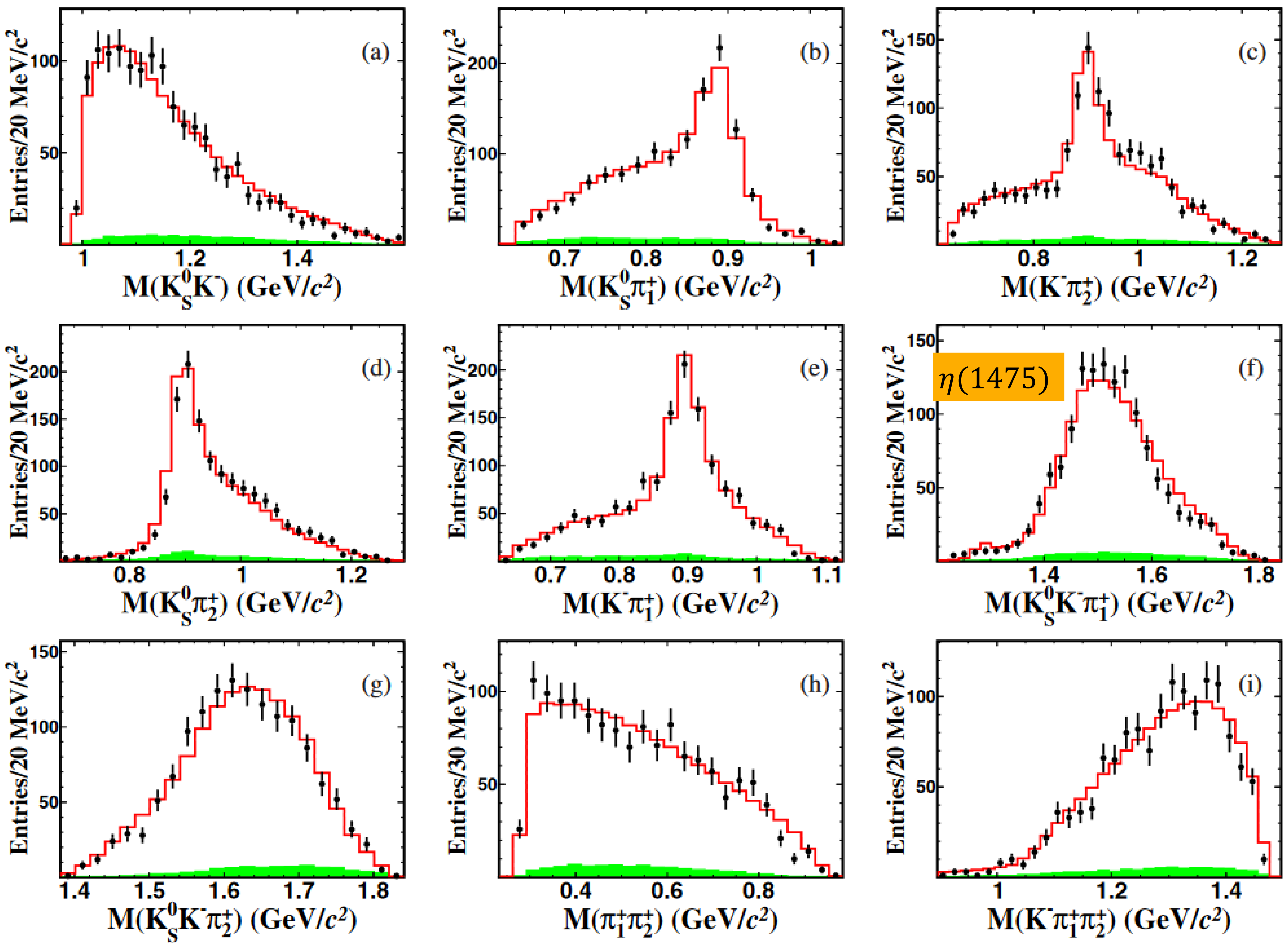
$$\mathcal{B}(D_s^+ \to a_0(980)^+\rho(770)^0, a_0(980)^+ \to \pi^+\eta) = (0.21 \pm 0.08_{\text{stat.}} \pm 0.05_{\text{syst.}})\%$$

比其它多数纯湮灭衰变高了一个量级

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

[Phys. Rev. D 103, 092006 (2021)](#)

- 首次振幅分析
- 与世界平均值一致，但精度更高



Dominant process, $\mathcal{B}(D_s^+ \to K^*(892)^+ \bar{K}^*(892)^0)$
$= (5.34 \pm 0.39_{\text{stat.}} \pm 0.64_{\text{syst.}})\%$

	FF(%)
$D_s^+[S] \to K^*(892)^+\bar{K}^*(892)^0$	$34.3 \pm 3.1 \pm 5.2$
$D_s^+[P] \to K^*(892)^+\bar{K}^*(892)^0$	$1.1 \pm 0.1 \pm 8.3$
$D_s^+[D] \to K^*(892)^+\bar{K}^*(892)^0$	$4.5 \pm 0.8 \pm 0.3$
$D_s^+ \to K^*(892)^+\bar{K}^*(892)^0$	$40.6 \pm 2.9 \pm 4.9$
$D_s^+ \to K^*(892)^+(K^-\pi^+)_{S\text{-wave}}$	$5.0 \pm 1.2 \pm 1.0$
$D_s^+ \to \bar{K}^*(892)^0(K_S^0\pi^+)_{S\text{-wave}}$	$7.3 \pm 1.1 \pm 0.9$
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to a_0(980)^-\pi^+$	$10.8 \pm 2.6 \pm 5.2$
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to \bar{K}^*(892)^0 K_S^0$	$2.2 \pm 0.6 \pm 0.2$
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to K^*(892)^+ K^-$	$2.2 \pm 0.6 \pm 0.2$
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to K^*(892) K$	$4.9 \pm 1.4 \pm 1.0$
$D_s^+ \to \eta(1475)\pi^+, \eta(1475) \to (K_S^0\pi^+)_{S\text{-wave}} K^-$	$23.6 \pm 3.6 \pm 7.5$
$D_s^+ \to f_1(1285)\pi^+, f_1(1285) \to a_0(980)^-\pi^+$	$2.2 \pm 0.5 \pm 0.2$
$D_s^+ \to (K^*(892)^+K^-)_P\pi^+$	$10.8 \pm 1.9 \pm 1.7$

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

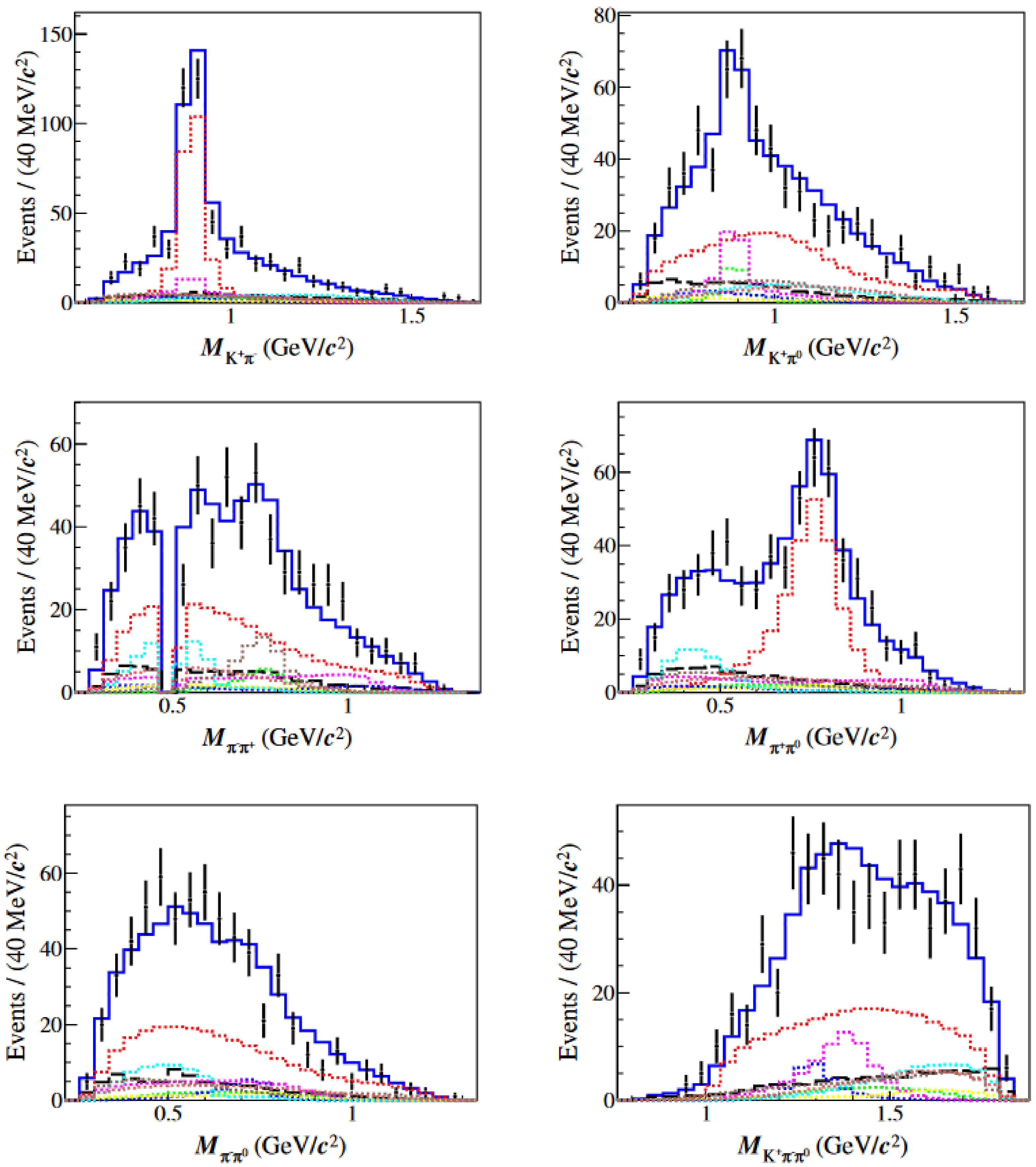
Amplitude analysis of $D_s^+ \to K^+\pi^+\pi^-\pi^0$

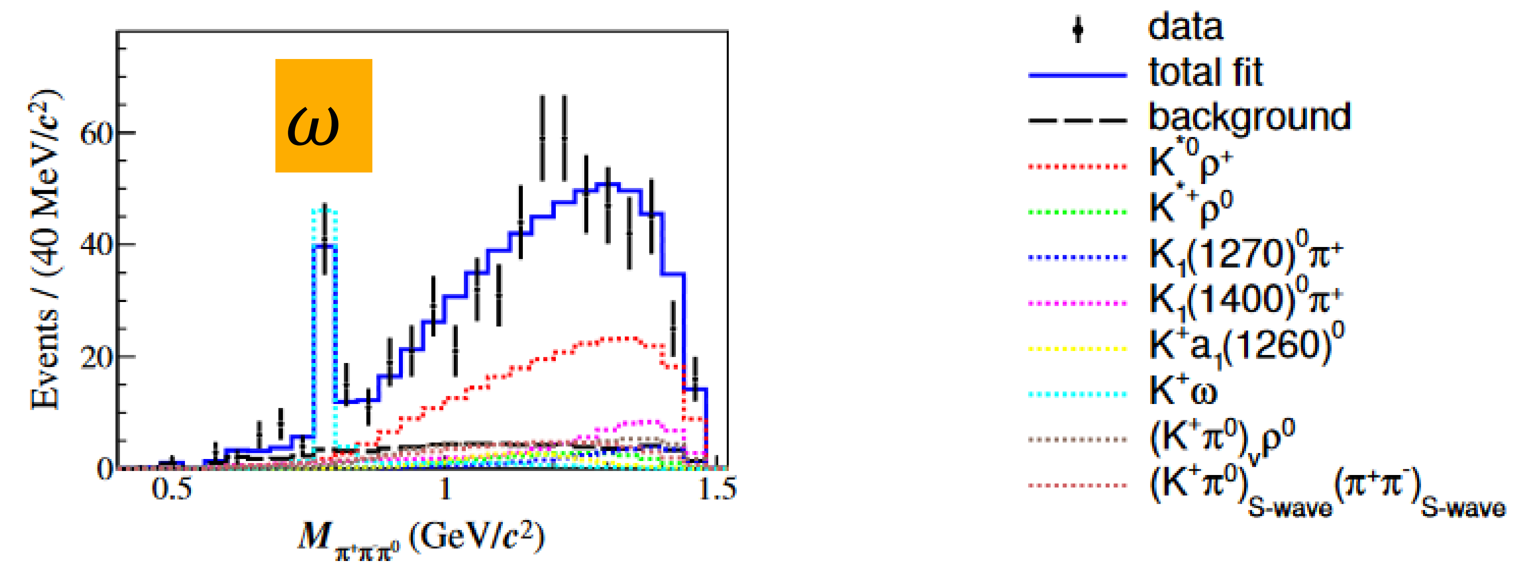
SCS

arXiv:2205.13759 Submitted to JHEP

- 首次振幅分析
- $\mathcal{B}(D_s^+ \to K^+\omega)$与BESIII此前测量一致 Phys. Rev. D 99, 091101 (2019)

630 events, about 87% purity





Amplitude	Phase (rad)	FF (%)	$S(\sigma)$
$D_s^+[S] \to K^{*0}\rho^+$	0.0 (fixed)	$14.5 \pm 2.2 \pm 0.6$	>10
$D_s^+[P] \to K^{*0}\rho^+$	$2.09 \pm 0.12 \pm 0.03$	$26.0 \pm 2.5 \pm 1.1$	>10
$D_s^+ \to K^{*0}\rho^+$	-	$40.5 \pm 2.8 \pm 1.5$	>10
$D_s^+[P] \to K^{*+}\rho^0$	$2.42 \pm 0.21 \pm 0.04$	$4.3 \pm 1.1 \pm 0.6$	6.8
$D_s^+ \to K^+\omega$	$0.57 \pm 0.23 \pm 0.10$	$9.7 \pm 1.5 \pm 0.6$	>10
$D_s^+ \to K_1(1270)^0(K^+\rho^-)[S]\pi^+$	$1.80 \pm 0.24 \pm 0.08$	$4.0 \pm 1.2 \pm 0.6$	5.5
$D_s^+ \to K_1(1400)^0(K^{*+}\pi^-)[S]\pi^+$	$-1.61 \pm 0.17 \pm 0.05$	$5.6 \pm 0.9 \pm 0.2$	-
$D_s^+ \to K_1(1400)^0(K^{*0}\pi^0)[S]\pi^+$	$-1.61 \pm 0.17 \pm 0.05$	$6.1 \pm 0.9 \pm 0.2$	-
$D_s^+ \to K_1(1400)^0(K^*\pi)[S]\pi^+$	-	$11.3 \pm 1.8 \pm 0.4$	8.9
$D_s^+ \to K^+a_1(1260)^0(\rho^+\pi^-)[S]$	$-1.19 \pm 0.25 \pm 0.22$	$1.9 \pm 0.7 \pm 0.9$	-
$D_s^+ \to K^+a_1(1260)^0(\rho^-\pi^+)[S]$	$-1.19 \pm 0.25 \pm 0.22$	$1.9 \pm 0.7 \pm 0.9$	-
$D_s^+ \to K^+a_1(1260)^0(\rho\pi)[S]$	-	$3.3 \pm 1.2 \pm 1.5$	3.8
$D_s^+[S] \to (K^+\pi^0)_V\rho^0$	$1.02 \pm 0.16 \pm 0.08$	$10.4 \pm 2.0 \pm 0.6$	6.6
$D_s^+ \to (K^+\pi^0)_{S-\text{wave}}(\pi^+\pi^-)_{S-\text{wave}}$	$-2.87 \pm 0.17 \pm 0.06$	$9.5 \pm 2.2 \pm 0.9$	6.0

$\mathcal{B}(D_s^+ \to K^+\pi^+\pi^-\pi^0) = (9.75 \pm 0.54_{\text{stat.}} \pm 0.17_{\text{syst.}}) \times 10^{-3}$

$A_{CP} = (6.6 \pm 5.4_{\text{stat.}} \pm 0.7_{\text{syst.}})\%$

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

JHEP 07 (2022) 051

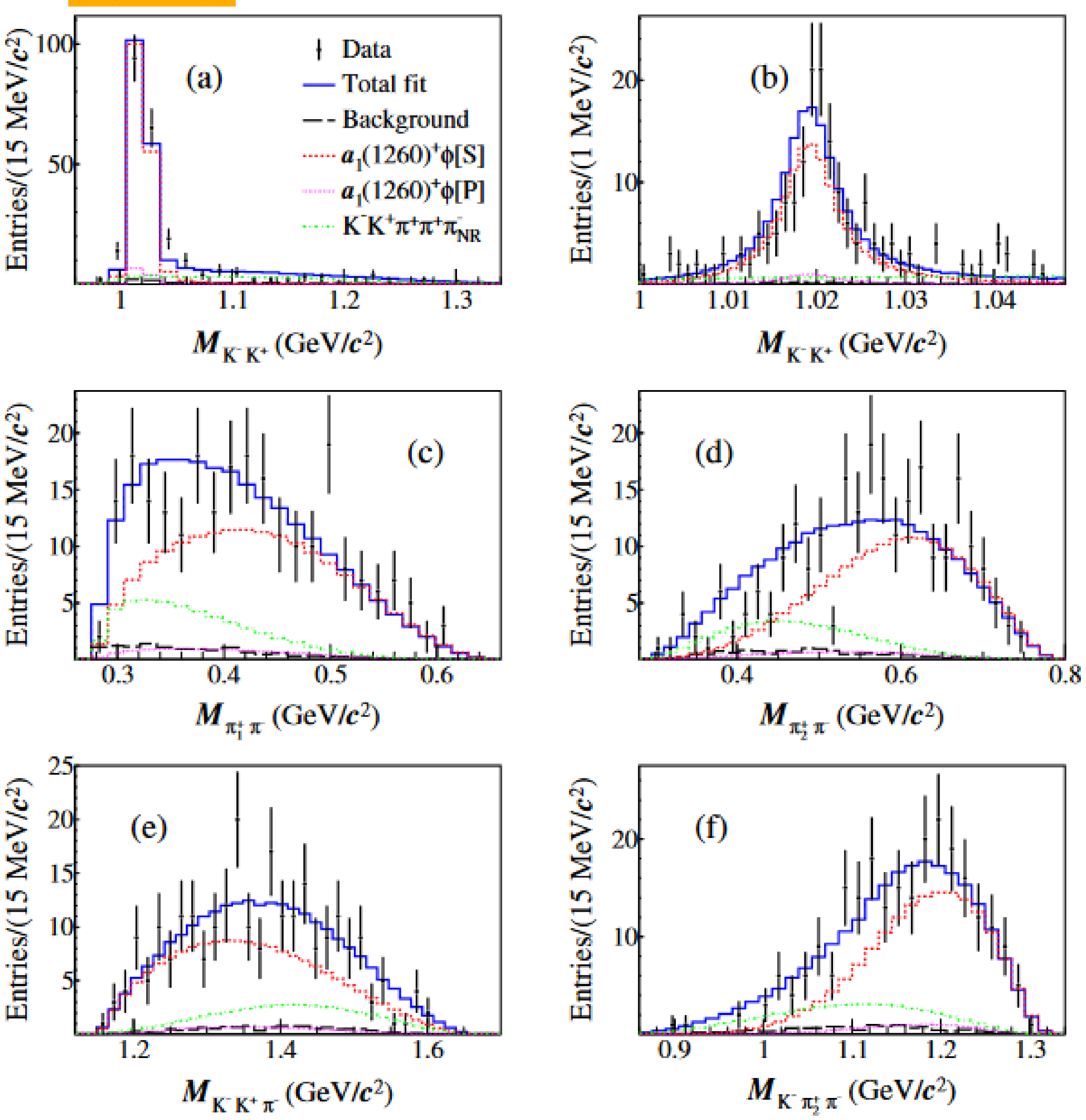
- 首次振幅分析
- 帮助研究 $D_s^+ \to AV$ 衰变过程

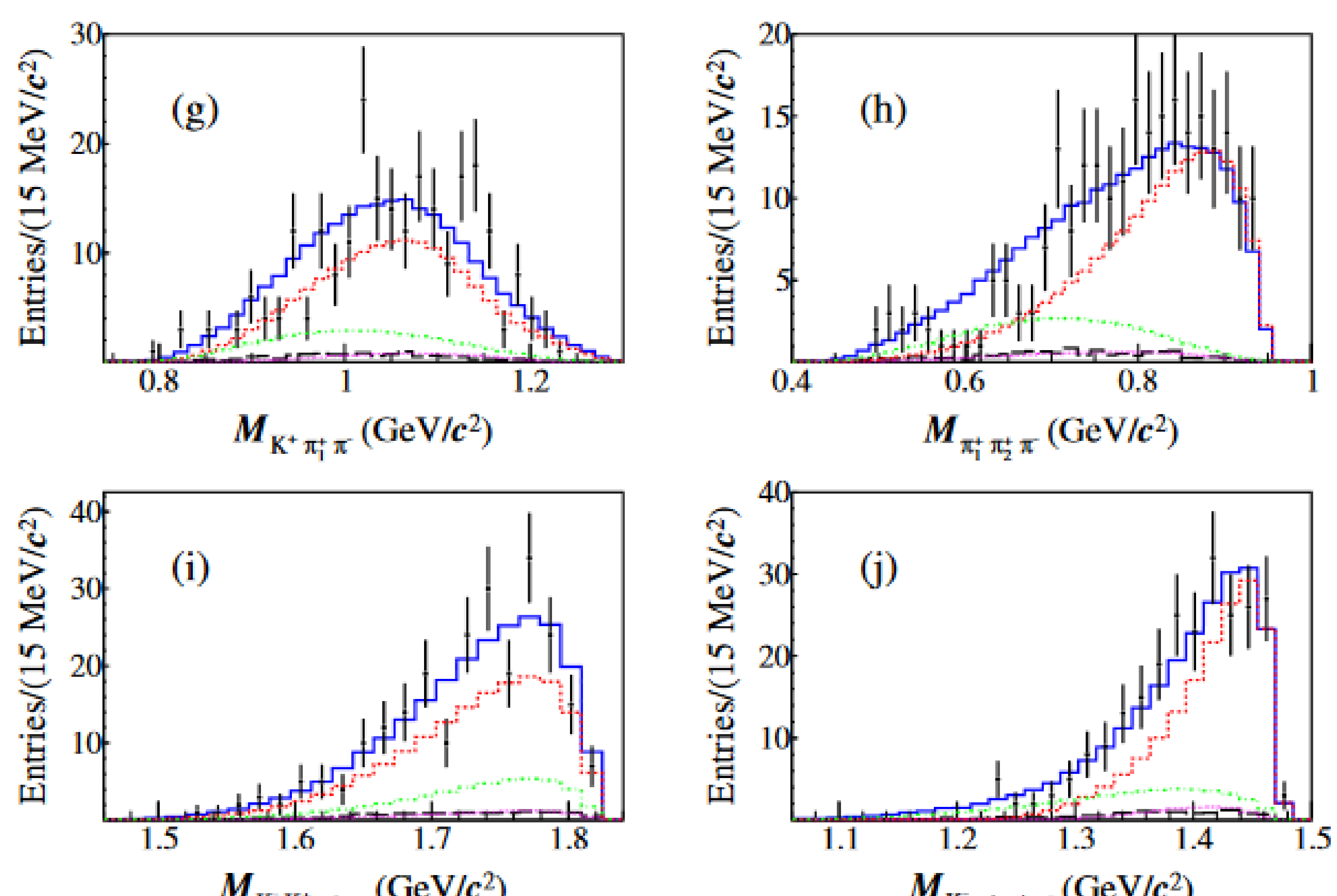
Dominated by $D_s^+ \to a_1(1260)^+\phi$

Amplitude	Phase	FF (%)	Significance (σ)
$D_s^+[S] \to a_1(1260)^+\phi$	0 (fixed)	$73.1\pm3.1\pm1.5$	>10
$D_s^+[P] \to a_1(1260)^+\phi$	$1.47\pm0.19\pm0.03$	$5.0\pm1.7\pm0.7$	5.5
$D_s^+ \to a_1(1260)^+\phi$	...	$78.1\pm2.9\pm1.6$	...
$D_s^+ \to (K^-K^+\pi^+\pi^+\pi^-)_{\mathrm{NR}}$	$1.99\pm0.12\pm0.17$	$21.8\pm2.9\pm0.8$	>10

$\phi(1020)$ 243 events, about 96% purity

$$\mathcal{B}(D_s^+ \to K^-K^+\pi^+\pi^+\pi^-) = (6.60 \pm 0.47_{\mathrm{stat.}} \pm 0.38_{\mathrm{syst.}}) \times 10^{-3}$$





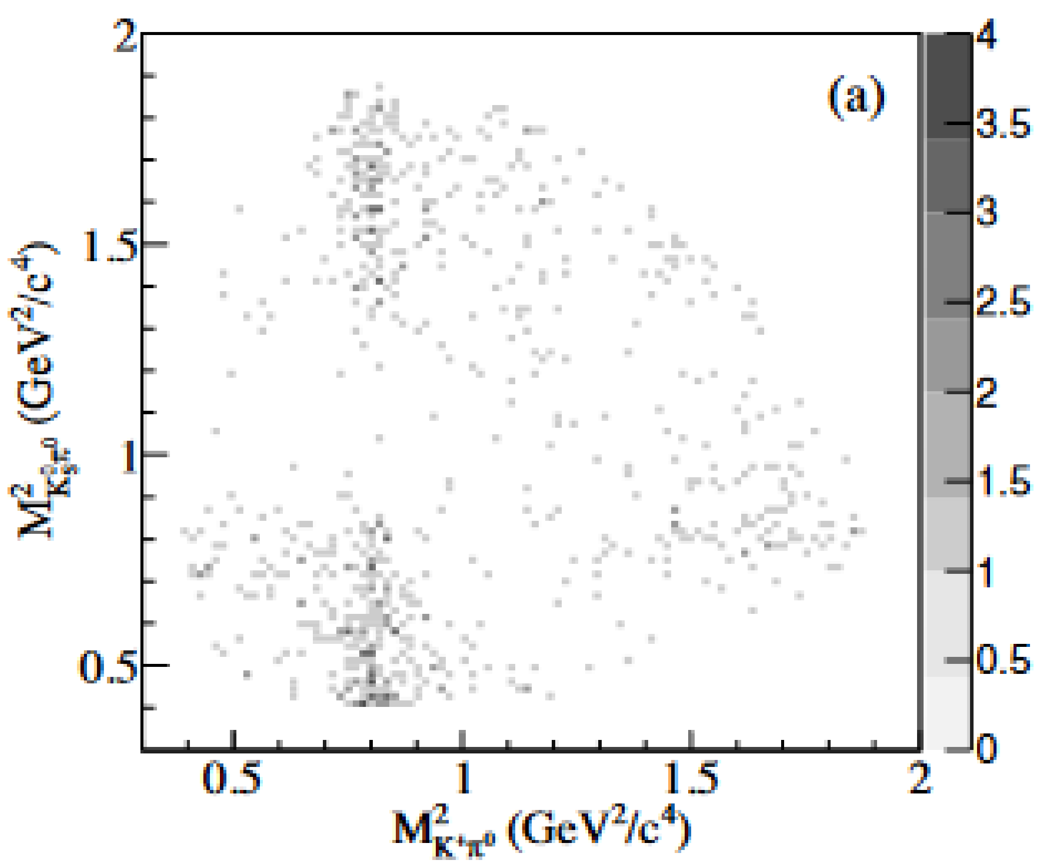
Amplitude analysis of $D^+ \to K^+ K_S^0 \pi^0$

SCS

Phys. Rev. D 104, 012006 (2021)

- 首次振幅分析
- $\mathcal{B}(D^+ \to K^*(892)^+ K_S^0)$与不同理论预言间的偏差约4$\sigma$

Model	$\mathcal{B}(D^+ \to K^*(892)^+ K_S^0)(\times 10^{-3})$
Pole	6.2 ± 1.2
FAT [mix]	5.5
TDA [tree]	5.02 ± 1.31
TDA [QCD-penguin]	4.90 ± 0.21
PDG	17 ± 8

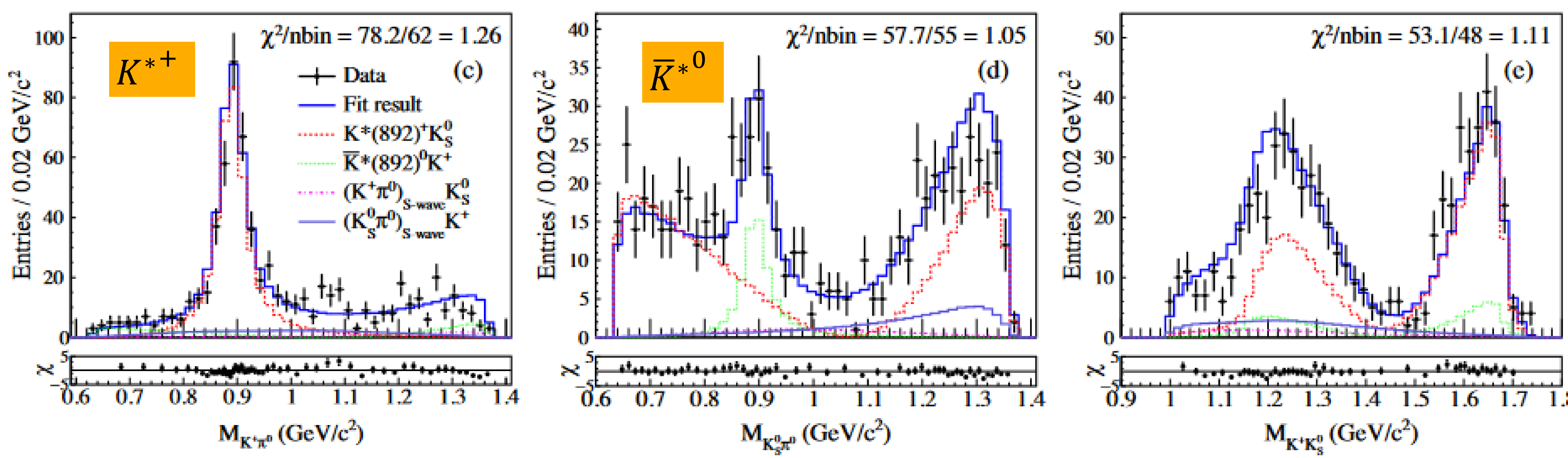


692 events, about 97.4% purity

Amplitude	Magnitude	Phase ϕ (°)	FF (%)	Significance
$D^+ \to K^*(892)^+ K_S^0$	1.0 (fixed)	0.0 (fixed)	57.1 ± 2.6	29.6σ
$D^+ \to \bar{K}^*(892)^0 K^+$	0.41 ± 0.04	162 ± 10	10.2 ± 1.5	11.6σ
$D^+ \to (K^+\pi^0)_{S\text{-wave}} K_S^0$	2.02 ± 0.37	140 ± 14	3.9 ± 1.5	5.2σ
$D^+ \to (K_S^0\pi^0)_{S\text{-wave}} K^+$	3.14 ± 0.46	-173.7 ± 9.7	9.7 ± 2.6	7.4σ

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

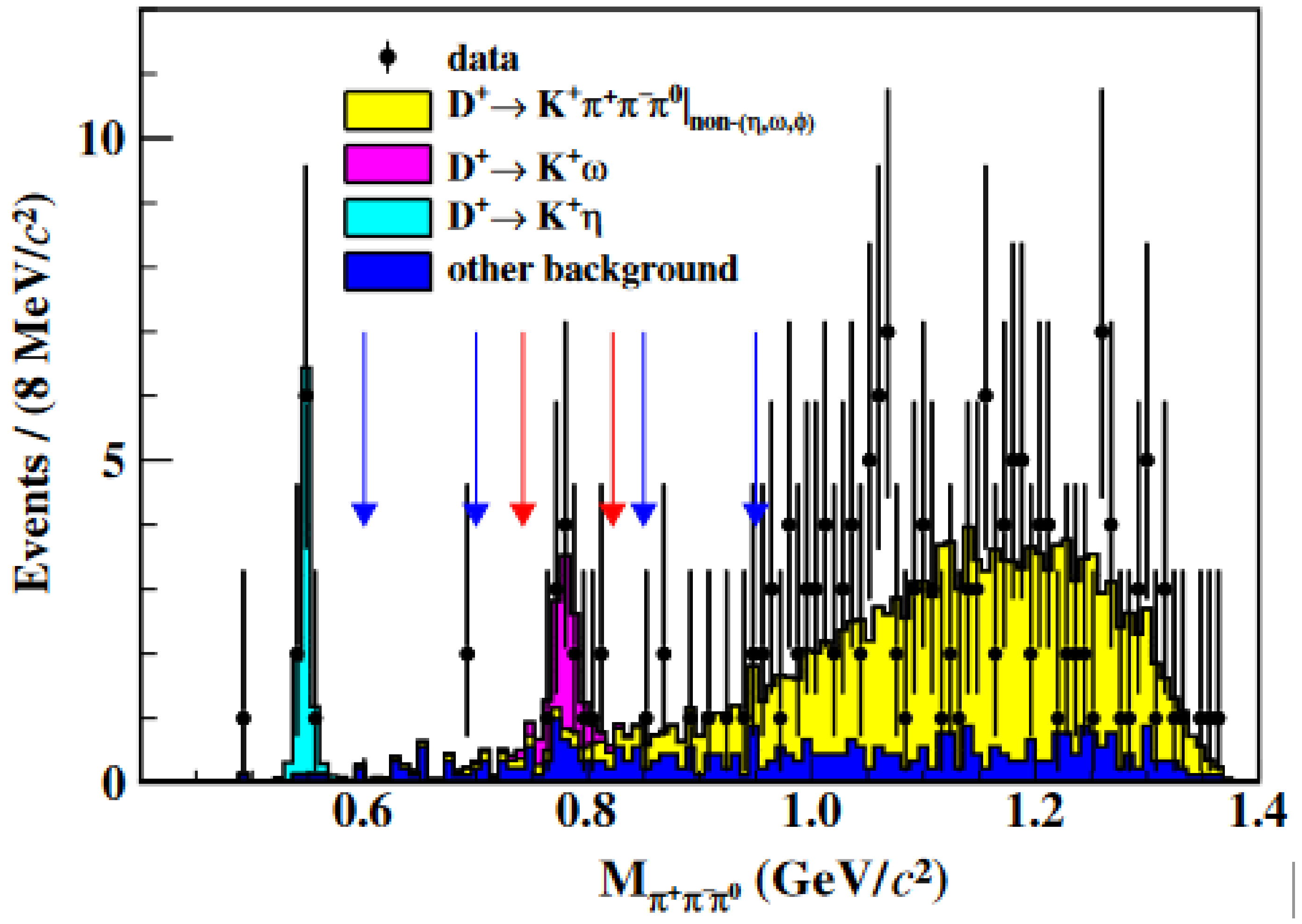
与此前测量及理论预测一致



目录

双卡压低衰变分支比测量

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



使用强子标记道:

$\mathcal{B}(D^+ \to K^+\pi^+\pi^-\pi^0) = (1.13 \pm 0.08_{stat.} \pm 0.03_{syst.}) \times 10^{-3}$

(移除 $D^+ \to K^+\omega, D^+ \to K^+\eta, D^+ \to K^+\phi$)

$\mathcal{B}(D^+ \to K^+\omega) = (5.7^{+2.5}_{-2.1\,stat.} \pm 0.2_{syst.}) \times 10^{-5}$

$A_{CP} = -0.04 \pm 0.06_{stat.} \pm 0.01_{syst.}$

$$\frac{\mathcal{B}(D^+ \to K^+\pi^+\pi^-\pi^0)}{\mathcal{B}(D^+ \to K^-\pi^+\pi^+\pi^0)} = (1.81 \pm 0.15)\%, \qquad (6.28 \pm 0.52)\tan^4\theta_C$$

Phys. Rev. L 125, 141802 (2020)

使用半轻标记道:

$\mathcal{B}(D^+ \to K^+\pi^+\pi^-\pi^0) = (1.03 \pm 0.12_{stat.} \pm 0.06_{syst.}) \times 10^{-3}$

Phys. Rev. D 104, 072005 (2021)

	$\mathcal{B}(\times 10^{-4})$	Ratio of DCS decay over Cabbibo-favored decay	**Phys. Rev. D 105, 112001 (2022)** **arXiv:2110.10999**
$D^0 \to K^+\pi^-\pi^0$	$3.13^{+0.60}_{-0.56\,stat.} \pm 0.15_{syst.}$	$(0.22 \pm 0.04)\%$	$(0.75 \pm 0.14)\tan^4\theta_C$
$D^0 \to K^+\pi^-\pi^0\pi^0$	< 3.6 90% CL	$< 0.40\,\%$	$1.37 \times \tan^4\theta_C$
$D^+ \to K^+\pi^0\pi^0$	$2.1 \pm 0.4_{stat.} \pm 0.1_{syst.}$	$(2.26 \pm 0.40) \times 10^{-3}$	$(0.78 \pm 0.14)\tan^4\theta_C$
$D^+ \to K^+\pi^0\eta$	$2.1 \pm 0.6_{stat.} \pm 0.1_{syst.}$	$(8.09 \pm 2.13) \times 10^{-3}$	$(2.79 \pm 0.64)\tan^4\theta_C$

分支比测量

- $D^{+(0)}$含多个π介子衰变 — arXiv:2206.13864
- $D^{+(0)}$含K介子和π介子衰变 — Phys. Rev. D 106, 032002 (2022)
- $D^{+(0)} \to K\bar{K}\pi\pi$ — Phys. Rev. D 102, 052006 (2020)
- $D^{+(0)}$含η介子衰变 — Phys. Rev. Lett. 124, 241803 (2020)
- $D^{+(0)} \to K\,\pi\,\omega$ — Phys. Rev. D 105, 032009 (2020)
- $D^{+(0)} \to \omega\,\pi\,\pi$ — Phys. Rev. D 102, 052003 (2020)
- $D^0 \to K_L X,\ X = \phi/\eta/\omega/\eta'$ — Phys. Rev. D 105, 092010 (2022)
- $D^0 \to \omega\,\phi$，极化测量 — Phys. Rev. Lett. 128, 011803 (2022)
- $D_s^+ \to P\,P$，二体衰变 — JHEP 08 (2020) 146

目录

总结

✓ **振幅分析**

- 观测到新的同位旋为1的粒子— $a_0(1817)$
- 检验不同理论模型
- 测量$D \to VP, AP, VV$ ... 过程分支比，帮助研究SU(3)对称性破缺等效应

✓ **分支比测量**

- 首次测量双卡压低过程$D^+ \to K^+\pi^+\pi^-\pi^0$
- 显著提高多个衰变道测量精度

✓ **未来目标**

- 利用 20 fb^{-1} $\psi(3770)$ 数据进一步研究D介子内部信息

Thanks for your attention!

Back up

$D^{+(0)}$ decays involving multiple pions

arXiv:2206.13864

Decay	$\Delta E_{\rm sig}$ (MeV)	$N_{\rm DT}$	$\epsilon_{\rm sig}$ (%)	$\mathcal{B}_{\rm sig}$ ($\times 10^{-4}$)
$\pi^+\pi^-\pi^0$	$(-62, 36)$	12792.6(120.1)	40.91	134.3(13)(16)
$\pi^+\pi^-2\pi^0$	$(-75, 37)$	3783.7(70.5)	16.29	99.8(19)(24)
$\pi^+\pi^-2\eta$	$(-37, 29)$	42.5(6.7)	2.14	8.5(13)(04)
$4\pi^0$	$(-105, 41)$	96.0(11.5)	5.41	7.6(09)(07)
$3\pi^0\eta$	$(-82, 40)$	155.3(14.7)	2.83	23.6(22)(17)
$2\pi^+2\pi^-\pi^0$	$(-52, 33)$	942.4(40.0)	11.70	34.6(15)(15)
$2\pi^+2\pi^-\eta$	$(-36, 28)$	48.5(7.8)	3.46	6.0(10)(06)
$\pi^+\pi^-3\pi^0$	$(-76, 39)$	182.7(20.9)	5.13	15.3(17)(13)
$2\pi^+2\pi^-2\pi^0$	$(-64, 36)$	350.0(22.9)	3.15	47.7(31)(21)
$2\pi^+\pi^-$	$(-30, 28)$	2614.3(58.0)	50.63	33.1(07)(05)
$\pi^+2\pi^0$	$(-96, 44)$	1968.0(51.7)	27.33	46.2(12)(09)
$2\pi^+\pi^-\pi^0$	$(-59, 35)$	4649.5(83.5)	25.42	117.4(21)(21)
$\pi^+3\pi^0$	$(-86, 39)$	573.7(30.2)	8.83	41.7(22)(13)
$3\pi^+2\pi^-$	$(-37, 33)$	462.1(28.7)	16.26	18.2(11)(10)
$2\pi^+\pi^-2\pi^0$	$(-74, 39)$	1207.1(45.4)	7.21	107.4(40)(30)
$2\pi^+\pi^-\pi^0\eta$	$(-51, 33)$	191.4(15.9)	3.17	38.8(32)(12)
$\pi^+4\pi^0$	$(-90, 41)$	56.7(10.4)	1.87	19.5(36)(23)
$\pi^+3\pi^0\eta$	$(-66, 37)$	79.7(10.9)	1.77	28.9(40)(22)
$3\pi^+2\pi^-\pi^0$	$(-49, 34)$	182.8(17.3)	5.02	23.4(22)(15)
$2\pi^+\pi^-3\pi^0$	$(-66, 37)$	185.9(17.0)	3.49	34.2(31)(16)

Decay	$\mathcal{B}^+_{\rm sig}(\times 10^{-4})$	$\mathcal{B}^-_{\rm sig}(\times 10^{-4})$	$\mathcal{A}^{\rm sig}_{CP}$ (%)
$\pi^+\pi^-\pi^0$	134.8 ± 1.8	133.3 ± 1.8	$+0.6 \pm 0.9 \pm 0.4$
$\pi^+\pi^-2\pi^0$	97.1 ± 2.6	102.3 ± 2.7	$-2.6 \pm 1.9 \pm 0.7$
$2\pi^+\pi^-$	33.5 ± 1.0	32.7 ± 1.0	$+1.2 \pm 2.1 \pm 0.6$
$\pi^+2\pi^0$	48.9 ± 1.8	43.4 ± 1.7	$+6.0 \pm 2.7 \pm 0.5$
$2\pi^+\pi^-\pi^0$	117.7 ± 3.0	116.8 ± 3.0	$+0.4 \pm 1.8 \pm 0.8$
$2\pi^+\pi^-2\pi^0$	102.7 ± 5.6	111.6 ± 5.8	$-4.2 \pm 3.8 \pm 1.3$

$D^{+(0)}$ decays involving kaons and pions [Phys. Rev. D 106, 032002 (2022)]

Signal mode	ΔE_{sig} (MeV)	N_{DT}^{fit}	$N_{K_S^0,sid}$	N_{DT}^{net}	ϵ_{sig} (%)	$\mathcal{B}_{sig}$ (10^{-3})
$D^0 \to K_S^0\pi^0\pi^0\pi^0$	$(-73, 34)$	913 ± 33	86 ± 11	870 ± 36	4.90 ± 0.04	$7.64 \pm 0.30 \pm 0.29$
$D^0 \to K^-\pi^+\pi^0\pi^0\pi^0$	$(-64, 33)$	1560 ± 48	$\cdots$	1560 ± 48	7.04 ± 0.06	$9.54 \pm 0.30 \pm 0.31$
$D^0 \to K_S^0\pi^+\pi^-\pi^0\pi^0$	$(-50, 30)$	1253 ± 40	134 ± 14	1186 ± 40	4.04 ± 0.04	$12.66 \pm 0.45 \pm 0.43$
$D^+ \to K_S^0\pi^+\pi^0\pi^0$	$(-63, 34)$	3513 ± 66	226 ± 19	3400 ± 66	7.51 ± 0.07	$29.04 \pm 0.62 \pm 0.87$
$D^+ \to K_S^0\pi^+\pi^+\pi^-\pi^0$	$(-45, 30)$	1097 ± 37	107 ± 14	1043 ± 38	4.38 ± 0.04	$15.28 \pm 0.57 \pm 0.60$
$D^+ \to K_S^0\pi^+\pi^0\pi^0\pi^0$	$(-43, 25)$	294 ± 22	19 ± 7	285 ± 23	3.30 ± 0.03	$5.54 \pm 0.44 \pm 0.32$
$D^+ \to K^-\pi^+\pi^+\pi^0\pi^0$	$(-54, 31)$	756 ± 39	$\cdots$	756 ± 39	9.80 ± 0.07	$4.95 \pm 0.26 \pm 0.19$
$D^0 \to K_S^0K_S^0\pi^0$	$(-45, 28)$	65 ± 10	118 ± 13	$6 \pm 13(<24.6)$	7.06 ± 0.11	<0.145

$D^{+(0)} \to K\bar{K}\pi\pi$

[Phys. Rev. D 102, 052006 (2020)]

Signal mode	ΔE_{sig}	N_{DT}^{fit}	$N_{K_S^0}^{sid}$	N_{DT}^{net}	ϵ_{sig} (%)	$\mathcal{B}_{sig}$ ($\times 10^{-3}$)	$\mathcal{B}_{PDG}$ ($\times 10^{-3}$)
$D^0 \to K^+K^-\pi^0\pi^0$	$(-59, 40)$	132.1 ± 13.9	$\dots$	132.1 ± 13.9	8.20 ± 0.07	$0.69 \pm 0.07 \pm 0.04$	$\dots$
$D^0 \to K_S^0K_S^0\pi^+\pi^-$	$(-22, 22)$	82.1 ± 9.7	37.8 ± 7.5	63.2 ± 10.4	5.14 ± 0.04	$0.53 \pm 0.09 \pm 0.03$	1.22 ± 0.23
$D^0 \to K_S^0K^-\pi^+\pi^0$	$(-43, 32)$	278.8 ± 18.8	166.1 ± 15.1	195.8 ± 20.3	6.38 ± 0.06	$1.32 \pm 0.14 \pm 0.07$	$\dots$
$D^0 \to K_S^0K^+\pi^-\pi^0$	$(-44, 33)$	124.0 ± 12.8	$9.5^{+3.7}_{-3.1}$	119.3 ± 12.9	7.94 ± 0.06	$0.65 \pm 0.07 \pm 0.02$	$\dots$
$D^+ \to K^+K^-\pi^+\pi^0$	$(-39, 30)$	1311.7 ± 40.4	$\dots$	1311.7 ± 40.4	12.72 ± 0.08	$6.62 \pm 0.20 \pm 0.25$	26^{+9}_{-8}
$D^+ \to K_S^0K^+\pi^0\pi^0$	$(-61, 44)$	35.9 ± 7.1	$3.8^{+2.8}_{-2.0}$	34.0 ± 7.2	3.77 ± 0.02	$0.58 \pm 0.12 \pm 0.04$	$\dots$
$D^+ \to K_S^0K^-\pi^+\pi^+$	$(-22, 21)$	505.0 ± 24.5	74.2 ± 10.3	467.9 ± 25.0	13.24 ± 0.08	$2.27 \pm 0.12 \pm 0.06$	2.38 ± 0.17
$D^+ \to K_S^0K^+\pi^+\pi^-$	$(-21, 20)$	284.6 ± 18.0	$15.3^{+4.9}_{-4.2}$	277.0 ± 18.2	9.39 ± 0.06	$1.89 \pm 0.12 \pm 0.05$	1.74 ± 0.18
$D^+ \to K_S^0K_S^0\pi^+\pi^0$	$(-46, 37)$	101.1 ± 11.3	42.0 ± 8.1	80.1 ± 12.0	3.84 ± 0.03	$1.34 \pm 0.20 \pm 0.06$	$\dots$

$D^{+(0)}$ decays involving η

Phys. Rev. L 124, 241803 (2020)

Decay	$\Delta E_{\rm sig}$ (MeV)	$N_{\rm DT}$	$\epsilon_{\rm sig}$ (%)	$\mathcal{B}_{\rm sig}$ ($\times 10^{-4}$)
$D^0 \to K^-\pi^+\eta$	$(-37, 36)$	6116.2 ± 81.8	14.22	185.3(25)(31)
$D^0 \to K^0_S\pi^0\eta$	$(-57, 45)$	1092.7 ± 35.2	4.66	100.6(34)(30)
$D^0 \to K^+K^-\eta$	$(-27, 27)$	13.1 ± 4.0	9.53	0.59(18)(05)
$D^0 \to K^0_SK^0_S\eta$	$(-29, 28)$	7.3 ± 3.2	2.36	1.33(59)(18)
$D^0 \to K^-\pi^+\pi^0\eta$	$(-44, 36)$	576.5 ± 28.8	5.53	44.9(22)(15)
$D^0 \to K^0_S\pi^+\pi^-\eta$	$(-33, 32)$	248.2 ± 18.0	3.80	28.0(19)(10)
$D^0 \to K^0_S\pi^0\pi^0\eta$	$(-56, 41)$	64.7 ± 9.2	1.58	17.6(23)(13)
$D^0 \to \pi^+\pi^-\pi^0\eta$	$(-57, 45)$	508.6 ± 26.0	6.76	32.3(17)(14)
$D^+ \to K^0_S\pi^+\eta$	$(-36, 36)$	1328.2 ± 37.8	6.51	130.9(37)(31)
$D^+ \to K^0_SK^+\eta$	$(-27, 27)$	13.6 ± 3.9	4.72	1.85(52)(08)
$D^+ \to K^-\pi^+\pi^+\eta$	$(-33, 33)$	188.0 ± 15.3	8.94	13.5(11)(04)
$D^+ \to K^0_S\pi^+\pi^0\eta$	$(-49, 41)$	48.7 ± 9.7	2.57	12.2(24)(06)
$D^+ \to \pi^+\pi^+\pi^-\eta$	$(-40, 38)$	514.6 ± 25.7	9.67	34.1(17)(10)
$D^+ \to \pi^+\pi^0\pi^0\eta$	$(-70, 49)$	192.5 ± 17.1	3.86	32.0(28)(17)

Decay	$\mathcal{B}^+_{\rm sig}$ ($\times 10^{-4}$)	$\mathcal{B}^-_{\overline{\rm sig}}$ ($\times 10^{-4}$)	$\mathcal{A}^{\rm sig}_{CP}$ (%)
$D^0 \to K^-\pi^+\eta$	182.1 ± 3.5	189.1 ± 3.6	$-1.9 \pm 1.3 \pm 1.0$
$D^0 \to K^0_S\pi^0\eta$	98.4 ± 4.8	106.3 ± 5.1	$-3.9 \pm 3.2 \pm 0.8$
$D^0 \to K^-\pi^+\pi^0\eta$	41.7 ± 2.7	48.8 ± 3.2	$-7.9 \pm 4.8 \pm 2.5$
$D^0 \to \pi^+\pi^-\pi^0\eta$	29.8 ± 2.2	33.3 ± 2.5	$-5.5 \pm 5.2 \pm 2.4$
$D^+ \to K^0_S\pi^+\eta$	129.9 ± 5.3	132.3 ± 5.4	$-0.9 \pm 2.9 \pm 1.0$
$D^+ \to \pi^+\pi^+\pi^-\eta$	35.4 ± 2.4	33.7 ± 2.4	$+2.5 \pm 5.0 \pm 1.6$

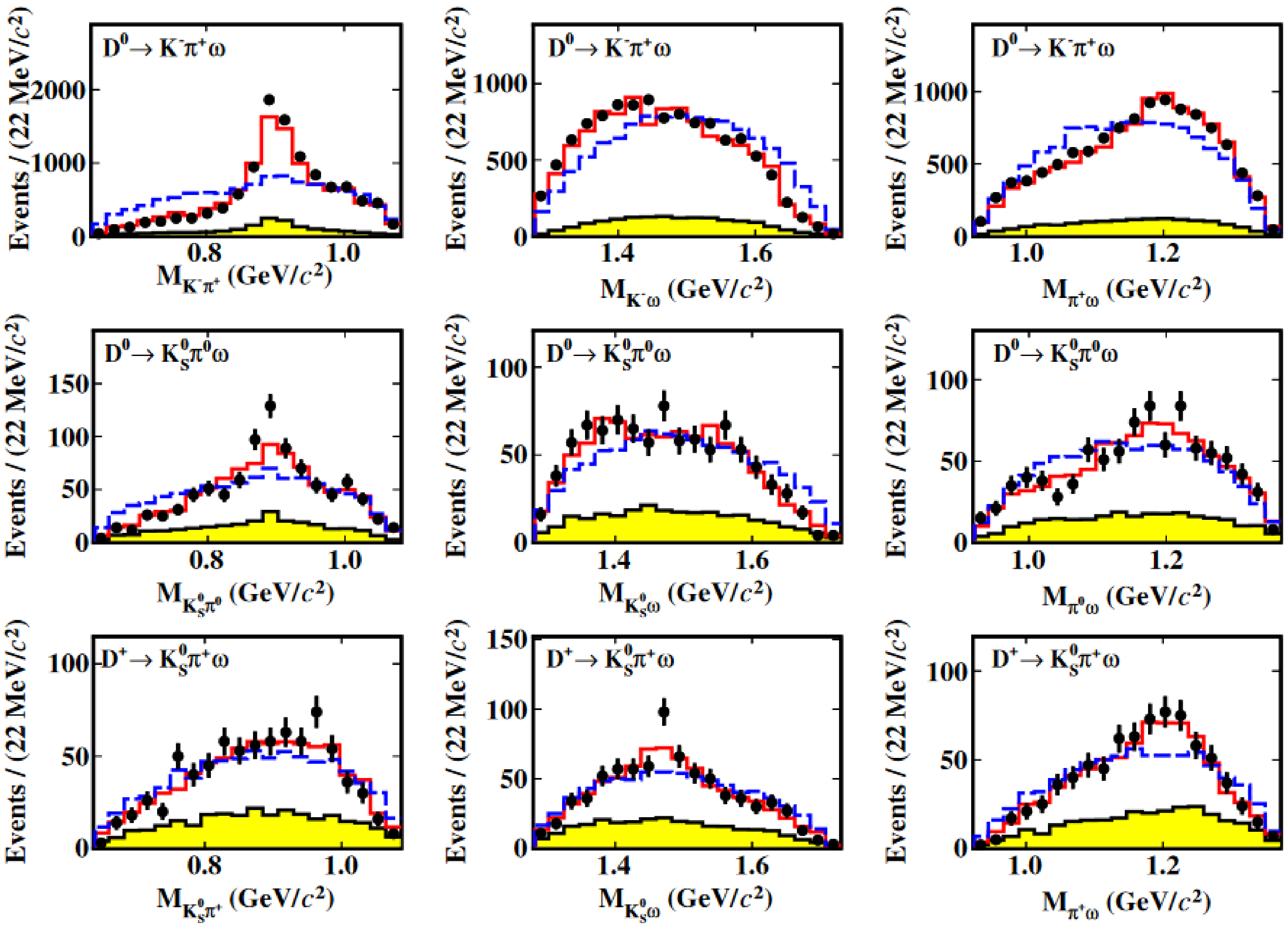
$D^{+(0)} \to K\,\pi\,\omega$

Phys. Rev. D 105, 032009 (2020)

$$\mathcal{B}(D^0 \to K^-\pi^+\omega) = \left(3.392 \pm 0.044_{stat.} \pm 0.085_{syst.}\right)\%$$

$$\mathcal{B}\left(D^0 \to K_S^0\pi^0\omega\right) = \left(0.848 \pm 0.046_{stat.} \pm 0.031_{syst.}\right)\%$$ First measurement!

$$\mathcal{B}\left(D^+ \to K_S^0\pi^+\omega\right) = \left(0.707 \pm 0.041_{stat.} \pm 0.029_{syst.}\right)\%$$ First measurement!



$$\mathcal{R}^0 \equiv \frac{\mathcal{B}\left(D^0 \to K_S^0\pi^0\omega\right)}{\mathcal{B}(D^0 \to K^-\pi^+\omega)} = 0.23 \pm 0.01_{stat.} \pm 0.01_{syst.}\ (0.4)$$

$$\mathcal{R}^+ \equiv \frac{\mathcal{B}\left(D^+ \to K_S^0\pi^+\omega\right)}{\mathcal{B}(D^0 \to K^-\pi^+\omega)} = 0.21 \pm 0.01_{stat.} \pm 0.01_{syst.}\ (0.9)$$

$D^{+(0)} \to \omega\pi\pi, \eta\pi\pi$

Phys. Rev. D 102, 052003 (2020)

SCS

Decay mode	$N_{\rm SG}^{\omega/\eta}$	$f(\%)$	$N_{\rm SB}^{\omega/\eta}$	$N_{\rm peak}^{\rm BKGV}$	$N_{\rm DT}^{\rm sig}$	Sig.	$\mathcal{B}^{\rm int}$	$\mathcal{B}^{\rm sig}(\times 10^{-3})$	$\mathcal{B}_{\rm PDG}(\times 10^{-3})$
$D^0 \to \omega\pi^+\pi^-$	908.0 ± 39.4	74.6 ± 1.5	610.5 ± 35.1	41.4 ± 2.5	411.2 ± 48.3	12.9σ	0.882	$1.33 \pm 0.16 \pm 0.12$	1.6 ± 0.5
$D^+ \to \omega\pi^+\pi^0$	474.0 ± 42.8	73.3 ± 1.2	329.0 ± 34.3	$\cdots$	232.9 ± 49.8	7.7σ	0.872	$3.87 \pm 0.83 \pm 0.25$	$\cdots$
$D^0 \to \omega\pi^0\pi^0$	20.2 ± 10.5	75.2 ± 5.6	22.1 ± 10.0	19.0 ± 1.2	-15.4 ± 13.0	0.6σ	0.862	< 1.10	$\cdots$
$D^0 \to \eta\pi^+\pi^-$	151.3 ± 14.6	42.6 ± 0.9	115.0 ± 15.3	6.1 ± 0.2	96.2 ± 16.0	8.3σ	0.227	$1.06 \pm 0.18 \pm 0.07$	1.09 ± 0.16
$D^+ \to \eta\pi^+\pi^0$	61.5 ± 14.3	41.4 ± 0.7	47.3 ± 16.4	$\cdots$	41.9 ± 15.8	3.5σ	0.224	$2.47 \pm 0.93 \pm 0.16$	1.38 ± 0.35
$D^0 \to \eta\pi^0\pi^0$	5.7 ± 3.8	40.6 ± 3.3	13.1 ± 4.8	2.0 ± 0.1	-1.6 ± 4.3	0.1σ	0.221	< 2.38	0.38 ± 0.13

$D^0 \to K_L X, \qquad X = \phi/\eta/\omega/\eta'$

Phys. Rev. D 105, 092010 (2022)

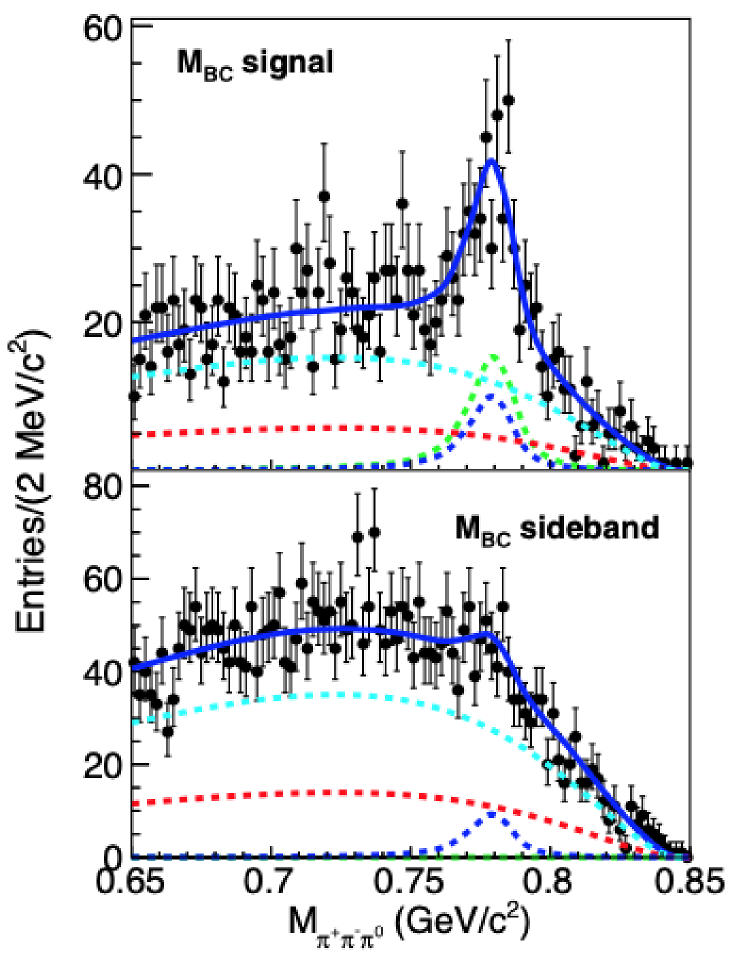
Decay	$\mathcal{B}_{\rm exp}$ (%)	$\mathcal{B}_{\rm FAT}$ (%)	Difference	$\mathcal{R}(D^0)_{\rm exp}$	$\mathcal{B}(D^0)_{\rm FAT}$	Difference
$D^0 \to K_L^0 \phi$	$0.414 \pm 0.021 \pm 0.010$	0.33 ± 0.03	2.2σ	-0.001 ± 0.047	0.113 ± 0.001	2.4σ
$D^0 \to K_L^0 \eta$	$0.433 \pm 0.012 \pm 0.010$	0.40 ± 0.07	0.5σ	0.080 ± 0.022		1.5σ
$D^0 \to K_L^0 \omega$	$1.164 \pm 0.022 \pm 0.028$	0.95 ± 0.15	1.4σ	-0.024 ± 0.031		4.4σ
$D^0 \to K_L^0 \eta'$	$0.809 \pm 0.020 \pm 0.016$	0.77 ± 0.07	0.5σ	0.080 ± 0.023		1.6σ

Decay	$\mathcal{B}^+_{\rm sig}$ (%)	$\mathcal{B}^-_{\rm sig}$ (%)	$\mathcal{A}^{\rm sig}_{CP}$ (%)
$D^0 \to K_L^0 \phi$	0.428 ± 0.029	0.405 ± 0.034	$2.7 \pm 5.4 \pm 0.7$
$D^0 \to K_L^0 \eta$	0.445 ± 0.018	0.421 ± 0.017	$2.8 \pm 2.9 \pm 0.4$
$D^0 \to K_L^0 \omega$	1.200 ± 0.030	1.121 ± 0.031	$3.4 \pm 1.9 \pm 0.6$
$D^0 \to K_L^0 \eta'$	0.789 ± 0.028	0.826 ± 0.028	$-2.2 \pm 2.5 \pm 0.4$

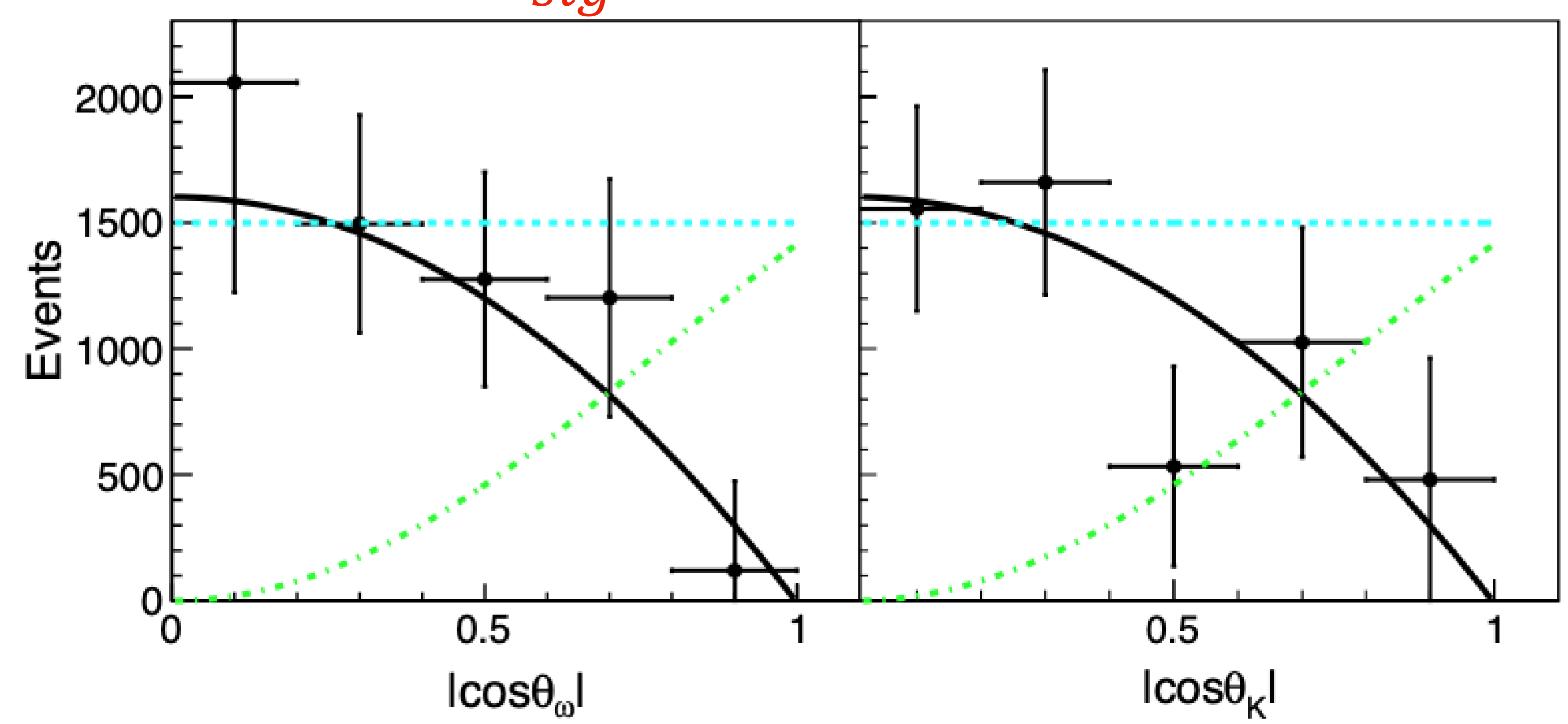
Polarizations in $D^0 \to \omega\phi$

[Phys. Rev. Lett. 128, 011803 (2022)](#)

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



$N_{sig} = 195.9 \pm 29.1$



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

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

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

with a significance of 6.3σ

Black dots: data

Black curves: fit results

Green: longitudinal

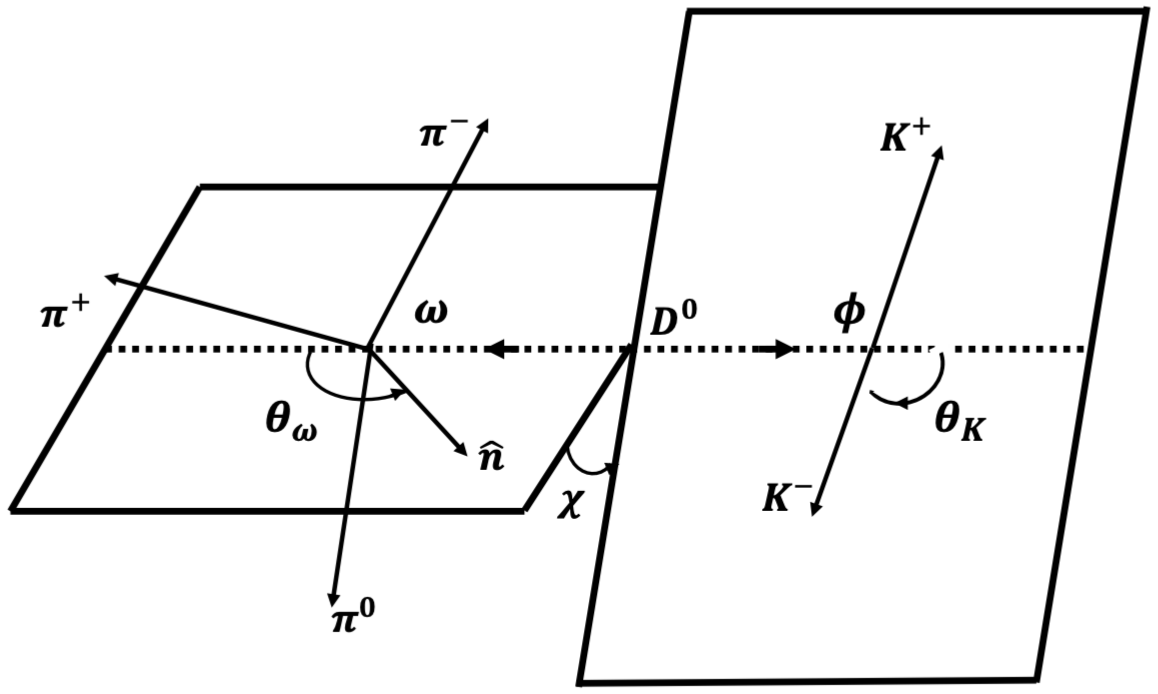
Cyan: PHSP

- ω and ϕ are transversely polarized

→ Contradict existing model predictions

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

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.

$D_s^+ \to P\ P$

JHEP 08 (2020) 146

Decay	PDG [6]	Cheng et al. [3] SU(3)	Cheng et al. [3] SU(3)-breaking	Cheng et al. [1]	Yu et al. [2]	Li et al. [4]	Wang et al. [5]
$K^+\eta'$	1.8 ± 0.6	1.23 ± 0.06	1.49 ± 0.08	1.07 ± 0.17	1.4 ± 0.4	1.92	3.1 ± 0.4
$\eta'\pi^+$	39.4 ± 2.5	—	—	38.2 ± 3.6	46 ± 6	34.4	46.7 ± 6.2
$K^+\eta$	1.77 ± 0.35	0.91 ± 0.03	0.86 ± 0.03	0.78 ± 0.09	0.8 ± 0.5	1.00	0.91 ± 0.20
$\eta\pi^+$	17.0 ± 0.9	—	—	18.2 ± 3.2	19 ± 5	16.5	19.6 ± 4.4
$K^+K_S^0$	15.0 ± 0.5	—	—	14.85 ± 1.60	15.0 ± 4.5	15.0	15.0 ± 1.6
$K_S^0\pi^+$	1.22 ± 0.06	1.20 ± 0.04	1.27 ± 0.04	1.365 ± 0.130	1.4 ± 0.3	1.105	1.04 ± 0.13
$K^+\pi^0$	0.63 ± 0.21	0.86 ± 0.04	0.56 ± 0.02	0.86 ± 0.09	0.5 ± 0.2	0.67	0.69 ± 0.03

$$\mathcal{B}(D_s^+ \to K^+\eta') = (2.68 \pm 0.17 \pm 0.17 \pm 0.08) \times 10^{-3},$$
$$\mathcal{B}(D_s^+ \to \eta'\pi^+) = (37.8 \pm 0.4 \pm 2.1 \pm 1.2) \times 10^{-3},$$
$$\mathcal{B}(D_s^+ \to K^+\eta) = (1.62 \pm 0.10 \pm 0.03 \pm 0.05) \times 10^{-3},$$
$$\mathcal{B}(D_s^+ \to \eta\pi^+) = (17.41 \pm 0.18 \pm 0.27 \pm 0.54) \times 10^{-3},$$
$$\mathcal{B}(D_s^+ \to K^+K_S^0) = (15.02 \pm 0.10 \pm 0.27 \pm 0.47) \times 10^{-3},$$
$$\mathcal{B}(D_s^+ \to K_S^0\pi^+) = (1.109 \pm 0.034 \pm 0.023 \pm 0.035) \times 10^{-3},$$
$$\mathcal{B}(D_s^+ \to K^+\pi^0) = (0.748 \pm 0.049 \pm 0.018 \pm 0.023) \times 10^{-3},$$

Relative BFs	This work	PDG [6]
$\mathcal{B}(K^+\eta')/\mathcal{B}(\eta'\pi^+)$	$7.07 \pm 0.46 \pm 0.11$	4.2 ± 1.3
$\mathcal{B}(K^+\eta)/\mathcal{B}(\eta\pi^+)$	$9.31 \pm 0.58 \pm 0.10$	8.9 ± 1.6
$\mathcal{B}(K_S^0\pi^+)/\mathcal{B}(K^+K_S^0)$	$7.38 \pm 0.23 \pm 0.09$	8.12 ± 0.28
$\mathcal{B}(K^+\eta)/\mathcal{B}(K^+\eta')$	$60.6 \pm 5.4 \pm 3.6$	—
$\mathcal{B}(\eta\pi^+)/\mathcal{B}(\eta'\pi^+)$	$46.0 \pm 0.7 \pm 2.1$	—