

BESIII上粲介子强子衰变的研究进展

董燎原（BESIII合作组）

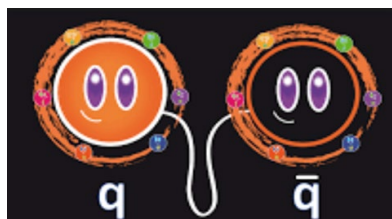
中国科学院高能物理研究所

2024年BESIII粲强子物理研讨会

2024/05/11 郑州大学和河南工业大学，河南郑州市

标准模型(SM)是当前描述微观世界最成功的模型,
量子色动力学(QCD)描述强相互作用, 是SM的两个组分之一

QCD的两个重要性质:



渐近自由



色禁闭

- ⊗ 高能下QCD的渐近自由得到实验精确检验(2004年获诺贝尔奖)
- ⊗ QCD**色禁闭本质**有待发展和检验
- ⊗ **低能下非微扰QCD理论不完善**, 理论工具结合实验观测

⇒ **提高低能QCD理论的预言能力!**

粲介子的强子衰变

- **研究粲夸克与末态轻夸克之间的强、弱作用的场所：**
 - 揭示动力学机制,检验SU(2)同位旋对称性和SU(3)味对称性
 - 检验并刻度理论计算非微扰效应的参数化方法和唯象模型
 - 为理论计算D衰变CP破坏和中性D介子混合提供实验输入
- **重味物理研究的基础：**
 - 标定其它粲强子衰变的分支比测量
 - 为B 物理研究提供关键输入
- **研究轻强子谱，发展和完善基于夸克模型的理论**

三. 研究进展

1. $20\text{fb}^{-1}\psi(3770)$ 数据

- 发布 2010-11, 2022, 和2023年 $\psi(3770)$ 数据(16fb^{-1})和单举MC样本
- 确保MC和数据的一致性, 以降低测量的系统误差。

Directory	Process	Cross section σ (nb)	Luminosity Scale	2010-11	2022	2023	2024
				2.93fb^{-1} round03-04	$\sim 5.0\text{fb}^{-1}$ $\downarrow N_{\text{evt}} (\times 10^6)$ round15	$\sim 8.1\text{fb}^{-1}$ round16	$\sim 4.2\text{fb}^{-1}$ round17
D0D0 ¹	$e^+e^- \rightarrow \psi(3770) \rightarrow D^0\bar{D}^0$	3.615^a	$80\times$	105.97×8	180.57×8	294.88×8	.
D+D- ²	$e^+e^- \rightarrow \psi(3770) \rightarrow D^+D^-$	2.830^a	$40\times$	82.96×4	141.36×4	230.84×4	.
ditau ²	$e^+e^- \rightarrow \tau^+\tau^-$	3.0	$40\times$	87.95×4	149.85×4	244.71×4	.
nonDD ²	$e^+e^- \rightarrow \psi(3770) \rightarrow \text{non-}D\bar{D}$	0.5	$40\times$	14.66×4	24.98×4	40.79×4	.
qq ²	$e^+e^- \rightarrow q\bar{q}$	16.86^b	$40\times$	495.47×4	842.15×4	1375.27×4	.
RR2S ²	$e^+e^- \rightarrow \gamma_{\text{ISR}}\psi(2S)$	3.4	$40\times$	99.68×4	169.83×4	277.34×4	.
RR1S ²	$e^+e^- \rightarrow \gamma_{\text{ISR}}J/\psi$	1.1	$40\times$	32.25×4	54.95×4	89.73×4	.
Bhabha ³	$e^+e^- \rightarrow e^+e^-$	520.5	$0.25\times$	381.5	650.0	1061.4	.
digamma ³	$e^+e^- \rightarrow \gamma\gamma$	24.7	$3\times$	217.2	370.1	604.4	.
dimu ³	$e^+e^- \rightarrow \mu^+\mu^-$	6.4	$15\times$	281.5	479.5	783.1	.

[a] Chin. Phys. C 42, 083001 (2018)

[b] Phys. Rev. D 76, 122002 (2007)

Round15
取数开始:
11-24-2021

round17
取数结束:
02-24-2024

- 更新衰变卡中 D^0 和 D^+ 衰变分支比到最新PDG值
- 增加20个 D^0 , 21个 D^+ 振幅分析产生子, 16个 D^0/D^+ Body3 产生子

所有 $\psi(3770)$ 数据($> 20\text{fb}^{-1}$)和相应单举MC样本预期7月BESIII合作组会正式发布!

2. 粲介子的强子衰变分支比测量

参考道分支比测量现状 PDG 2023

$D^0 \rightarrow K^- \pi^+$	$(3.937 \pm 0.030)\%$
$D^+ \rightarrow K^- \pi^+ \pi^+$	$(9.38 \pm 0.16)\%$
$D_s^+ \rightarrow K^+ K^- \pi^+$	$(5.37 \pm 0.10)\%$
$\Lambda_c^+ \rightarrow p K^- \pi^+$	$(6.26 \pm 0.29)\%$

分支比总和测量现状

$D^0 \rightarrow \text{anything}$	$< 80\%$
$D^+ \rightarrow \text{anything}$	$< 85\%$
$D_s^+ \rightarrow \text{anything}$	$< 60\%$
$\Lambda_c^+ \rightarrow \text{anything}$	$< 70\%$

研究现状:

- 实验上还未能完整理解粲强子的强子衰变
- 参考道测量精度不足 -> **重味物理研究的主要系统误差来源**

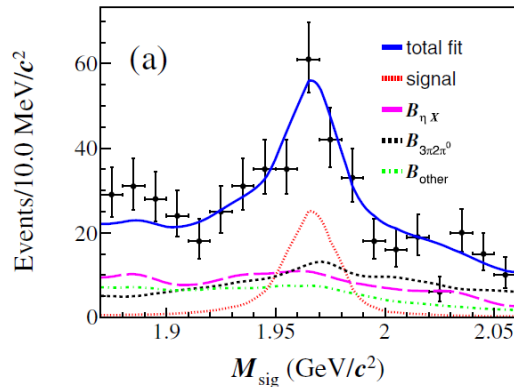
研究内容:

- 寻找并测量至今未被发现的Cabibbo允许和压低衰变
- 精确**测量关键参考道分支比**; 测量电荷宇称不对称性
- 测量 $D \rightarrow 3\pi X, \eta X, K_S^0 X$ 等单举衰变分支比, 为**测量轻子普适性参量 R_{D^*} 提供关键输入**。

• D_s^+ 强子衰变分支比测量

No significant CP -violating asymmetries of 15 hadronic D_s^+ decays are observed.

• Observation of $D_s^+ \rightarrow \omega\pi^+\eta$



PRD 107, 052010
(2023)

$$\mathcal{B}(D_s^+ \rightarrow \omega\pi^+\eta) = (0.54 \pm 0.12 \pm 0.04)\%$$

Accepted by JHEP (arXiv:2403.19256)

Mode	\mathcal{B} (%)	PDG \mathcal{B} (%)
$D_s^+ \rightarrow K_S^0 K^+$	$1.502 \pm 0.012 \pm 0.009$	1.453 ± 0.035
$D_s^+ \rightarrow K^+ K^- \pi^+$	$5.49 \pm 0.04 \pm 0.07$	5.37 ± 0.10
$D_s^+ \rightarrow K_S^0 K^+ \pi^0$	$1.47 \pm 0.02 \pm 0.02$	1.47 ± 0.07
$D_s^+ \rightarrow K_S^0 K_S^0 \pi^+$	$0.73 \pm 0.01 \pm 0.01$	0.71 ± 0.04
$D_s^+ \rightarrow K^+ K^- \pi^+ \pi^0$	$5.50 \pm 0.05 \pm 0.11$	5.50 ± 0.24
$D_s^+ \rightarrow K_S^0 K^+ \pi^+ \pi^-$	$0.93 \pm 0.02 \pm 0.01$	0.95 ± 0.08
$D_s^+ \rightarrow K_S^0 K^- \pi^+ \pi^+$	$1.56 \pm 0.02 \pm 0.02$	1.53 ± 0.08
$D_s^+ \rightarrow \pi^+ \pi^+ \pi^-$	$1.09 \pm 0.01 \pm 0.01$	1.08 ± 0.04
$D_s^+ \rightarrow \pi^+ \eta$	$1.69 \pm 0.02 \pm 0.02$	1.67 ± 0.09
$D_s^+ \rightarrow \pi^+ \pi^0 \eta$	$9.10 \pm 0.09 \pm 0.15$	9.5 ± 0.5
$D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \eta$	$3.08 \pm 0.06 \pm 0.05$	3.12 ± 0.16
$D_s^+ \rightarrow \pi^+ \eta'$	$3.95 \pm 0.04 \pm 0.07$	3.94 ± 0.25
$D_s^+ \rightarrow \pi^+ \pi^0 \eta'$	$6.17 \pm 0.12 \pm 0.14$	6.08 ± 0.29
$D_s^+ \rightarrow K_S^0 \pi^+ \pi^0$	$0.51 \pm 0.02 \pm 0.01$	0.54 ± 0.03
$D_s^+ \rightarrow K^+ \pi^+ \pi^-$	$0.620 \pm 0.009 \pm 0.006$	0.620 ± 0.019

在研: D_s^+ 介子强子衰变分支比测量:

$$D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \pi^0, D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \pi^0 \pi^0, D_s^+ \rightarrow \pi^+ \pi^0 \pi^0 \eta, D_s^+ \rightarrow K_S^0 \pi^+ \pi^+ \pi^-, D_s^+ \rightarrow K_S^0 K^+ \pi^0 \pi^0, D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \eta'$$

• $D \rightarrow \pi^+ \pi^- \pi^+ X$ 2.93fb^{-1} @3.773GeV

PRD 107, 032002 (2023)

$$\mathcal{B}(D^0 \rightarrow \pi^+ \pi^+ \pi^- X) = (17.60 \pm 0.11 \pm 0.22)\%$$

$$\mathcal{B}(D^+ \rightarrow \pi^+ \pi^+ \pi^- X) = (15.25 \pm 0.09 \pm 0.18)\%$$

• $D_s^+ \rightarrow \pi^+ \pi^- \pi^+ X$ 3.19fb^{-1} @4.178GeV

PRD 108, 032001 (2023)

$$\mathcal{B}(D_s^+ \rightarrow \pi^+ \pi^+ \pi^- X) = (32.81 \pm 0.35_{\text{stat}} \pm 0.63_{\text{syst}})\%$$

Larger than $B_{\text{exclusive}}^{\text{sum}}$ of $\sim 25\%$

→ missing decay modes ?

• $D \rightarrow K_S^0 X$ 2.93fb^{-1} @3.773GeV PRD 107, 112005 (2023)

Decay mode	PDG (%)	BESIII (%)	$B_{\text{exclusive}}^{\text{sum}}$ (%)
$D^+ \rightarrow K_S^0 X$	30.5 ± 2.5	$33.11 \pm 0.13 \pm 0.36$	31.68 ± 0.32
$D^0 \rightarrow K_S^0 X$	23.5 ± 2.0	$20.75 \pm 0.12 \pm 0.20$	18.16 ± 0.72

→ missing decay modes ?

- **$D \rightarrow K3\pi$ 、 $KK\pi\pi$ 四体衰变振幅分析不足，现有结果差异大**
 - $D \rightarrow VV$ 研究不足，导致矢量介子的极化研究缺乏
 - $D \rightarrow AP$ 现有结果冲突，无法理解轴矢量介子的衰变机制
 - 导致理论无法精确预期 D 衰变的 CP 破坏和 D^0 介子的混合
- **$D \rightarrow K4\pi$ 五体衰变至今无振幅分析研究**
 - $D \rightarrow AV$ 的实验结果极其缺乏
- **振幅分析可以系统理解强子谱**

3.1 D_S^+ 介子多体强子衰变的振幅分析

6.32fb⁻¹ between 4.178 – 4.226GeV

⊗ $D_S^+ \rightarrow K_S^0 K^+ \pi^0$ PRL 129, 182001 (2022)

Observation of $a_0(1817)^+$

$$m(a_0) = (1.817 \pm 0.008 \pm 0.020) \text{ GeV}/c^2$$

$$\Gamma(a_0) = (0.097 \pm 0.022 \pm 0.015) \text{ GeV}/c^2$$

$$\mathcal{B}(D_S^+ \rightarrow a_0(1817)^+ \pi^0, a_0(1817)^+ \rightarrow K_S^0 K^+) = (3.44 \pm 0.52 \pm 0.32) \times 10^{-4}$$

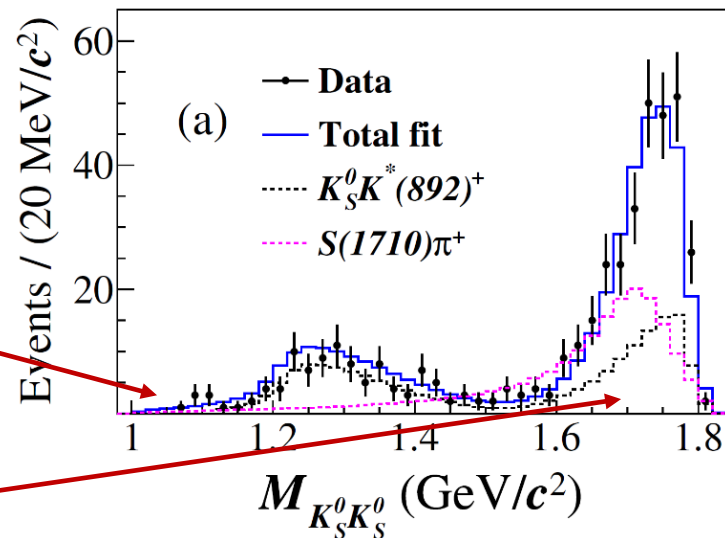
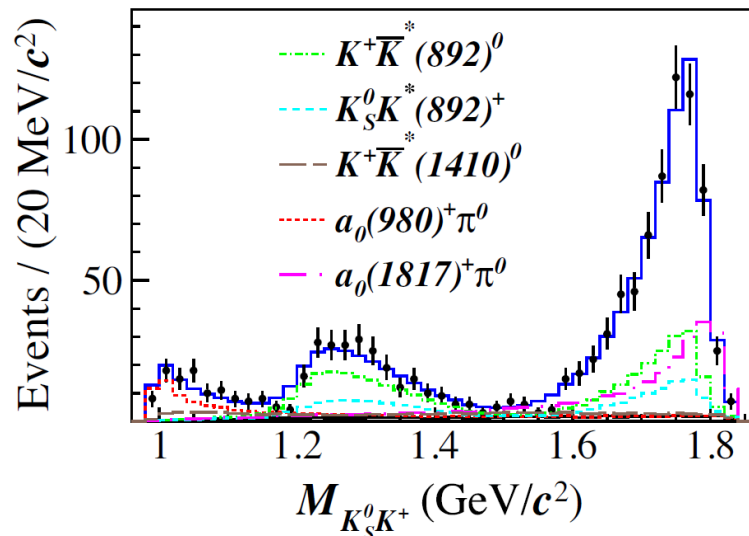
→ 结合 $D_S^+ \rightarrow K_S^0 K_S^0 \pi^+$ 的分析,
支持存在新的 a_0 同位旋三重态

⊗ $D_S^+ \rightarrow K_S^0 K_S^0 \pi^+$ PRD 105, L051103 (2022)

$$\mathcal{B}(D_S^+ \rightarrow S(980)\pi^+) < 1.8 \times 10^{-4} \quad \text{@ 90\% CL} \quad \rightarrow \quad \text{f}_0(980) \text{ 和 } a_0(980) \text{ 相消干涉}$$

$$\mathcal{B}(D_S^+ \rightarrow S(1710)\pi^+) = (0.31 \pm 0.03 \pm 0.01)\% \quad \rightarrow \quad \text{f}_0(1710) \text{ 和 } a_0(1710) \text{ 相加干涉}$$

$D_S^+ \rightarrow K^+ K^- \pi^+$, PRD 104, 012016 (2021)

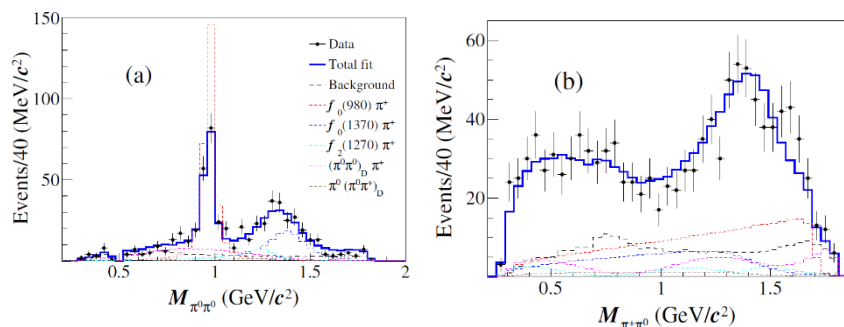


3.1 D_s^+ 介子三体强子衰变的振幅分析

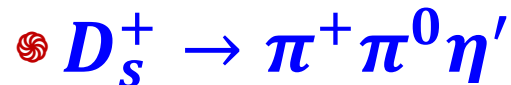
6.32fb⁻¹ between 4.178 – 4.226GeV



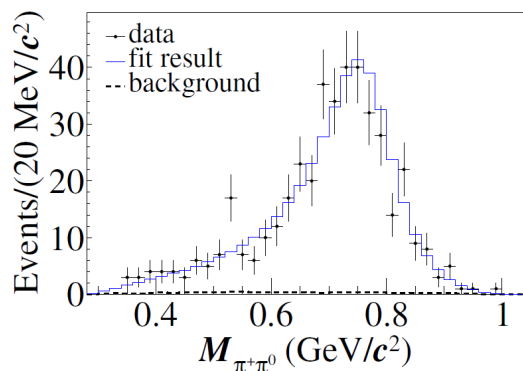
JHEP 01(2022)052



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



JHEP 04(2022)058

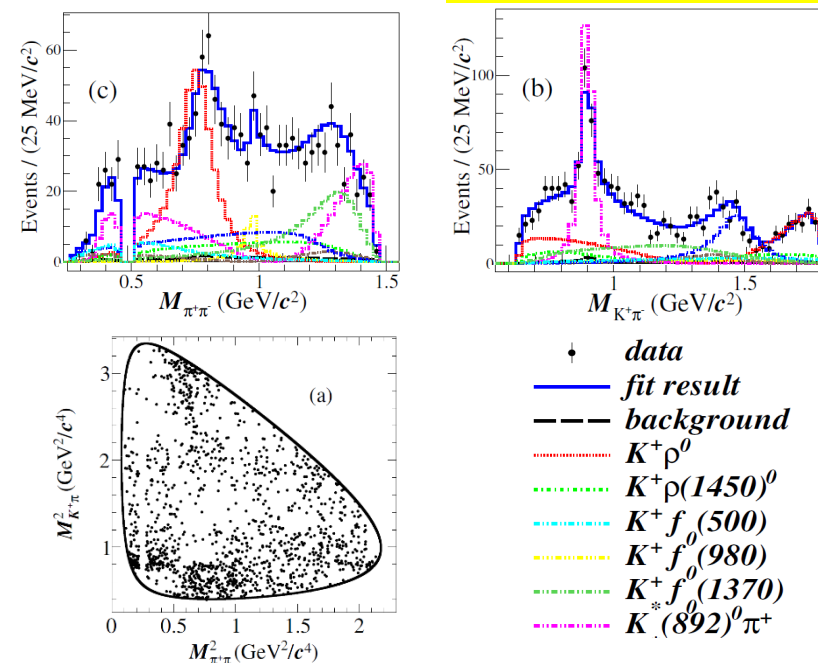


$$\mathcal{B}(D_s^+ \rightarrow \pi^+ \pi^0 \eta') = (6.15 \pm 0.25 \pm 0.18)\%$$

全部来自 $D_s^+ \rightarrow \rho^0 \eta'$



JHEP 08(2022)196



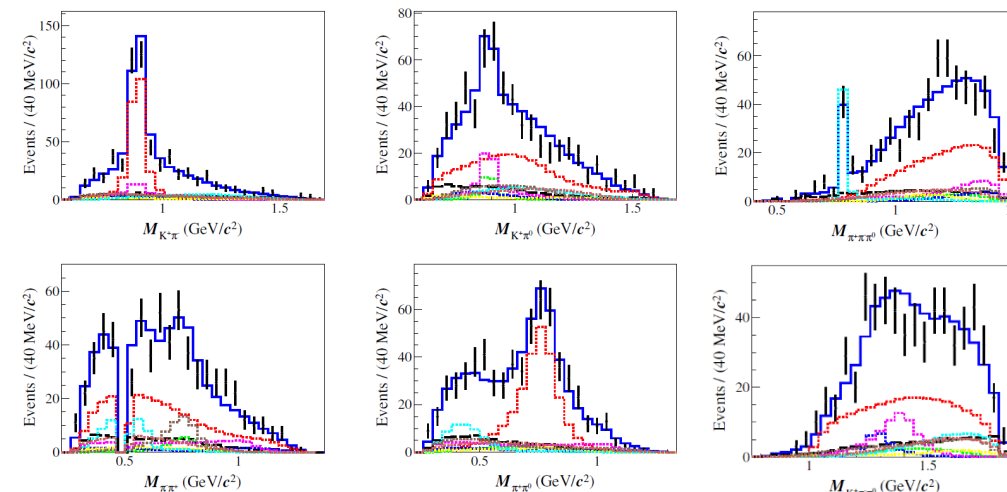
Intermediate process	BF(10 ⁻³)	PDG(10 ⁻³)
$D_s^+ \rightarrow K^+ \rho^0$	$1.96 \pm 0.19 \pm 0.23$	2.5 ± 0.4
$D_s^+ \rightarrow K^+ \rho(1450)^0$	$0.80 \pm 0.19 \pm 0.18$	0.69 ± 0.64
$D_s^+ \rightarrow K^*(892)^0 \pi^+$	$1.85 \pm 0.12 \pm 0.13$	1.41 ± 0.24
$D_s^+ \rightarrow K^*(1410)^0 \pi^+$	$0.27 \pm 0.13 \pm 0.15$	1.23 ± 0.28
$D_s^+ \rightarrow K_0^*(1430)^0 \pi^+$	$1.13 \pm 0.16 \pm 0.16$	0.50 ± 0.35
$D_s^+ \rightarrow K^+ f_0(500)$	$0.44 \pm 0.13 \pm 0.27$	—
$D_s^+ \rightarrow K^+ f_0(980)$	$0.27 \pm 0.08 \pm 0.07$	—
$D_s^+ \rightarrow K^+ f_0(1370)$	$1.22 \pm 0.18 \pm 0.57$	—

3.1 D_s^+ 介子多体强子衰变的振幅分析

6.32fb⁻¹ between 4.178 – 4.226GeV

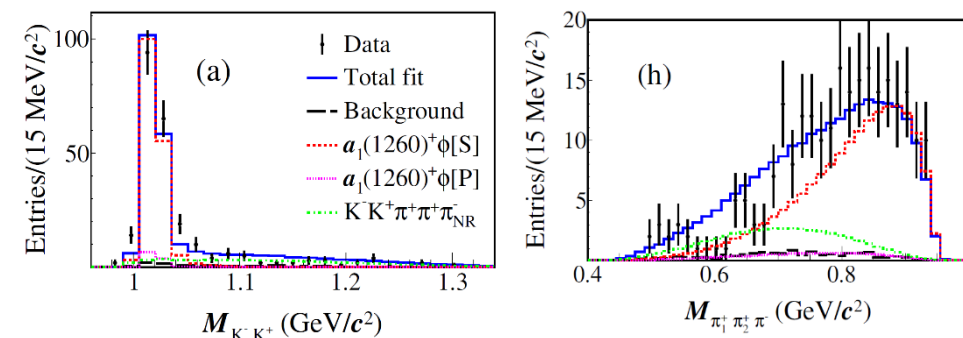
⊗ $D_s^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$ JHEP 09(2022)242

Intermediate process	BF (10 ⁻³)
$D_s^+[S] \rightarrow K^*(892)^0 \rho^+$	$1.41 \pm 0.23 \pm 0.07$
$D_s^+[P] \rightarrow K^*(892)^0 \rho^+$	$2.53 \pm 0.28 \pm 0.12$
$D_s^+ \rightarrow K^*(892)^0 \rho^+$	$3.95 \pm 0.35 \pm 0.17$
$D_s^+[P] \rightarrow K^*(892)^+ \rho^0$	$0.42 \pm 0.16 \pm 0.06$
$D_s^+ \rightarrow K^+ \omega$	$0.95 \pm 0.12 \pm 0.06$



⊗ $D_s^+ \rightarrow K^+ K^- \pi^+ \pi^- \pi^+$ JHEP 07(2022)051

Intermediate process	BF (10 ⁻³)
$D_s^+[S] \rightarrow a_1(1260)^+ \phi, a_1(1260)^+[S] \rightarrow \rho^0 \pi^+$	$4.82 \pm 0.40 \pm 0.29$
$D_s^+[P] \rightarrow a_1(1260)^+ \phi, a_1(1260)^+[S] \rightarrow \rho^0 \pi^+$	$0.34 \pm 0.11 \pm 0.05$
$D_s^+ \rightarrow a_1(1260)^+ \phi$	$5.15 \pm 0.41 \pm 0.32$
$D_s^+ \rightarrow (K^- K^+ \pi^+ \pi^+ \pi^-)_{NR}$	$1.44 \pm 0.22 \pm 0.10$



3.1 D_s^+ 介子多体强子衰变的振幅分析

BESIII的14个振幅分析
结果已收录到PDG

在研:

Amplitude analyses of

$$D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \pi^0$$

$$D_s^+ \rightarrow \pi^+ \pi^+ \pi^- \pi^0 \pi^0$$

$$D_s^+ \rightarrow \pi^+ \pi^0 \pi^0 \eta$$

$$D_s^+ \rightarrow K_S^0 K^+ \pi^+ \pi^-$$

更新

open charm 单举MC样本
@4.123-4.226 GeV:

包括 D^0 , D^+ 和 D_s^+ 分支比更新到PDG值, 增加20个 D^0 , 21个 D^+ 和**22** D_s^+ 振幅分析产生子。

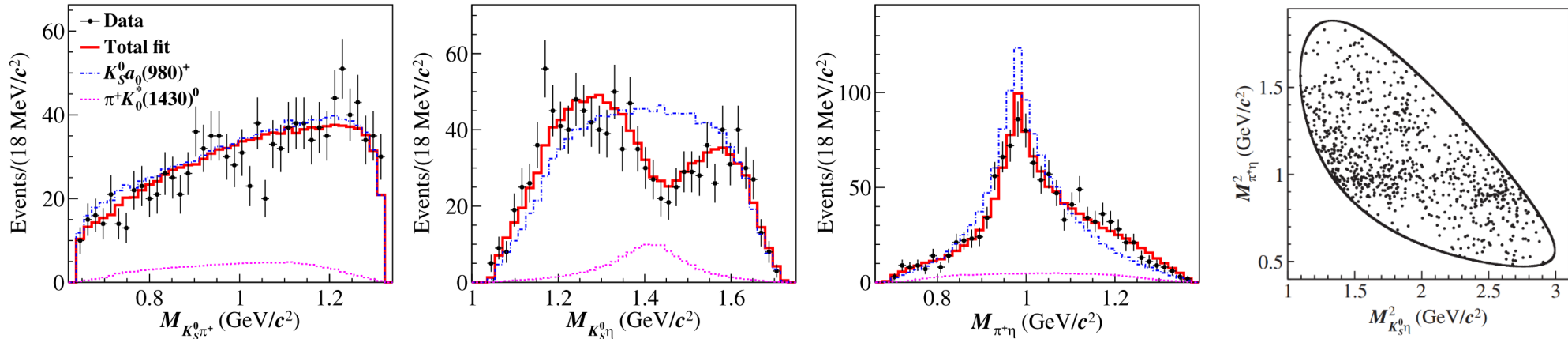
D_s^\pm Amplitude analyses

$D_s^+ \rightarrow K^+ K^- \pi^+$ partial wave analyses	Phys. Rev. D 104 (2021) 012016
$D_s^+ \rightarrow K^+ K_S^0 \pi^0$ partial wave analyses	Phys. Rev. Lett. 129 (2022) 182001
$D_s^+ \rightarrow 2 \pi^+ \pi^-$ partial wave analyses	Phys. Rev. D 106 (2022) 112006
$D_s^+ \rightarrow 2 \pi^+ \pi^- \eta$ partial wave analyses	Phys. Rev. D 104 (2021) L071101
$D_s^+ \rightarrow \pi^+ \pi^0 \eta'$ partial wave analyses.	JHEP 04 (2022) 058
$D_s^+ \rightarrow \pi^+ 2 \pi^0$ partial wave analyses.	JHEP 01 (2022) 052
$D_s^+ \rightarrow K^+ \pi^+ \pi^-$ partial wave analyses	JHEP 08 (2022) 196
$D_s^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$ partial wave analyses	JHEP 09 (2022) 242
$D_s^+ \rightarrow 2 K_S^0 \pi^+$ partial wave analyses	Phys. Rev. D 105 (2022) L051103
$D_s^+ \rightarrow K_S^0 K^- 2 \pi^+$ partial wave analyses	Phys. Rev. D 103 (2021) 092006
$D_s^+ \rightarrow K^- K^+ \pi^+ \pi^0$ partial wave analyses	Phys. Rev. D 104 (2021) 032011
$D_s^+ \rightarrow K^- K^+ 2 \pi^+ \pi^-$ partial wave analyses	JHEP 07 (2022) 051
Amplitude analysis of $D_s^+ \rightarrow K_S^0 \pi^+ \pi^0$	JHEP 06 (2021) 181
Amplitude analysis of $D_s^+ \rightarrow \pi^+ \pi^0 \eta$	Phys. Rev. Lett. 123 (2019) 112001

3.2 D 介子三体强子衰变的振幅分析

• $D^+ \rightarrow K_S^0 \pi^+ \eta$ PRL 132, 131903 (2024)

Observation of W-annihilation-free decay $D^+ \rightarrow K_S^0 a_0(980)^+ \pi^+ \eta$



$$\mathcal{B}(D^+ \rightarrow K_S^0 a_0(980)^+ \pi^+ \eta) = (1.33 \pm 0.05_{\text{stat}} \pm 0.04_{\text{syst}})\%$$

$$\mathcal{B}(D^+ \rightarrow \bar{K}_0^*(1430)^0 \pi^+, \bar{K}_0^*(1430)^0 \rightarrow K_S^0 \eta) = (0.14 \pm 0.02_{\text{stat}} \pm 0.02_{\text{syst}})\%$$

$$\mathcal{B}(D^+ \rightarrow K_S^0 \pi^+ \eta) = (1.27 \pm 0.04_{\text{stat}} \pm 0.03_{\text{syst}})\%$$

Provide sensitive constraints in the extraction of contributions from internal W-emission diagrams of $D \rightarrow SP$

在研: Amplitude analyses: $D^0 \rightarrow K_S^0 \pi^0 \eta$, $D^0 \rightarrow K^- \pi^+ \eta$, $D^+ \rightarrow K_S^0 K_S^0 K^+$, $D^0 \rightarrow K_S^0 / K_L^0 K^+ K^-$, $D^+ \rightarrow \pi^+ \eta \eta$, ...

3.2 D 介子三体强子衰变的振幅分析

Submitted to PRL (arXiv:2404.09219)



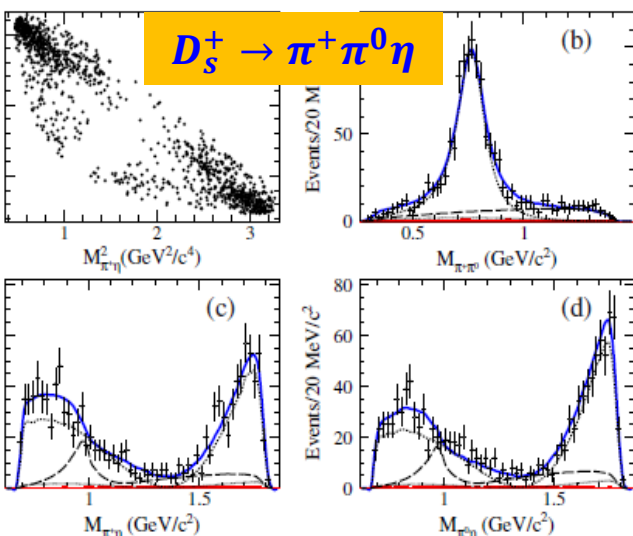
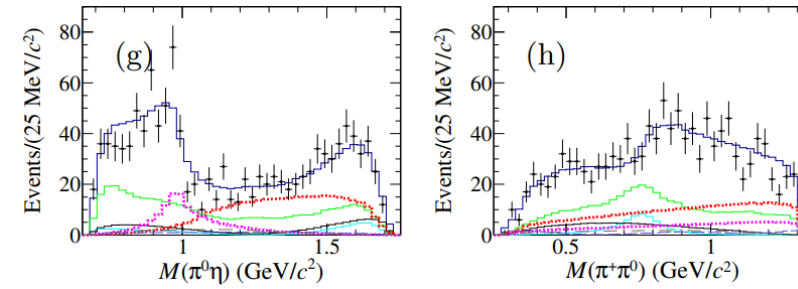
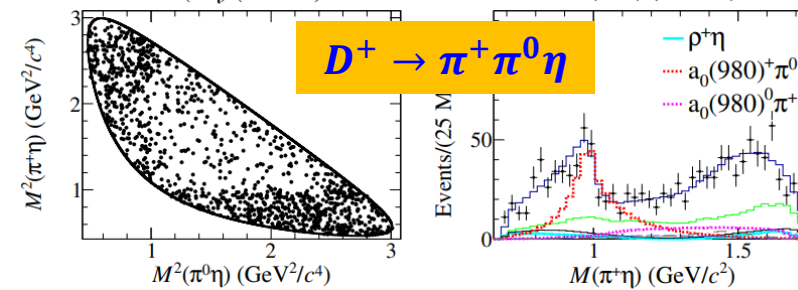
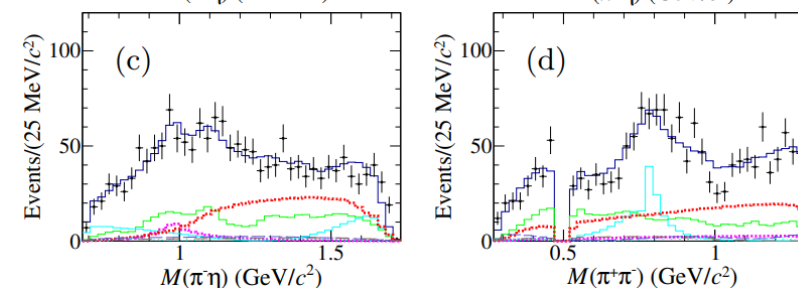
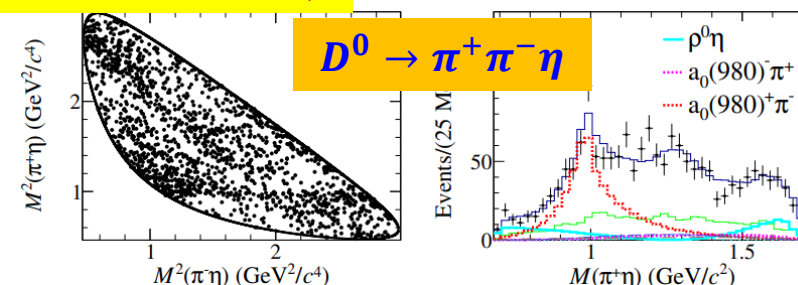
$7.9 \text{ fb}^{-1} @ 3.773 \text{ GeV}$

Observation of $D \rightarrow a_0(980)\pi$

$$\mathcal{B}(D^0 \rightarrow a_0(980)^+ \pi^-) / \mathcal{B}(D^0 \rightarrow a_0(980)^- \pi^+) = 7.5_{-0.8}^{\text{stat.}} \pm 1.7_{\text{sys.}}$$

$$\mathcal{B}(D^+ \rightarrow a_0(980)^+ \pi^0) / \mathcal{B}(D^+ \rightarrow a_0(980)^0 \pi^+) = 2.6 \pm 0.6_{\text{stat.}} \pm 0.3_{\text{sys.}}$$

→ Disagrees with theoretical predictions by orders of magnitudes



$3.19 \text{ fb}^{-1} @ 4.178 \text{ GeV}$

PRL 123, 112001 (2019)

Branching fraction (%)	
$\mathcal{B}(D_s^+ \rightarrow \rho^+ \eta)$	$7.44 \pm 0.52_{\text{stat.}} \pm 0.38_{\text{sys.}}$
$\mathcal{B}(D_s^+ \rightarrow a_0(980)^+ \pi^0)^*$	$1.46 \pm 0.15_{\text{stat.}} \pm 0.23_{\text{sys.}}$
$\mathcal{B}(D_s^+ \rightarrow a_0(980)^0 \pi^+)^*$	$1.46 \pm 0.15_{\text{stat.}} \pm 0.23_{\text{sys.}}$

*here, $a_0(980) \rightarrow \pi\eta$

3.3 D 介子四体强子衰变的振幅分析

$D^+ \rightarrow K_S^0 \pi^+ \pi^0 \pi^0$

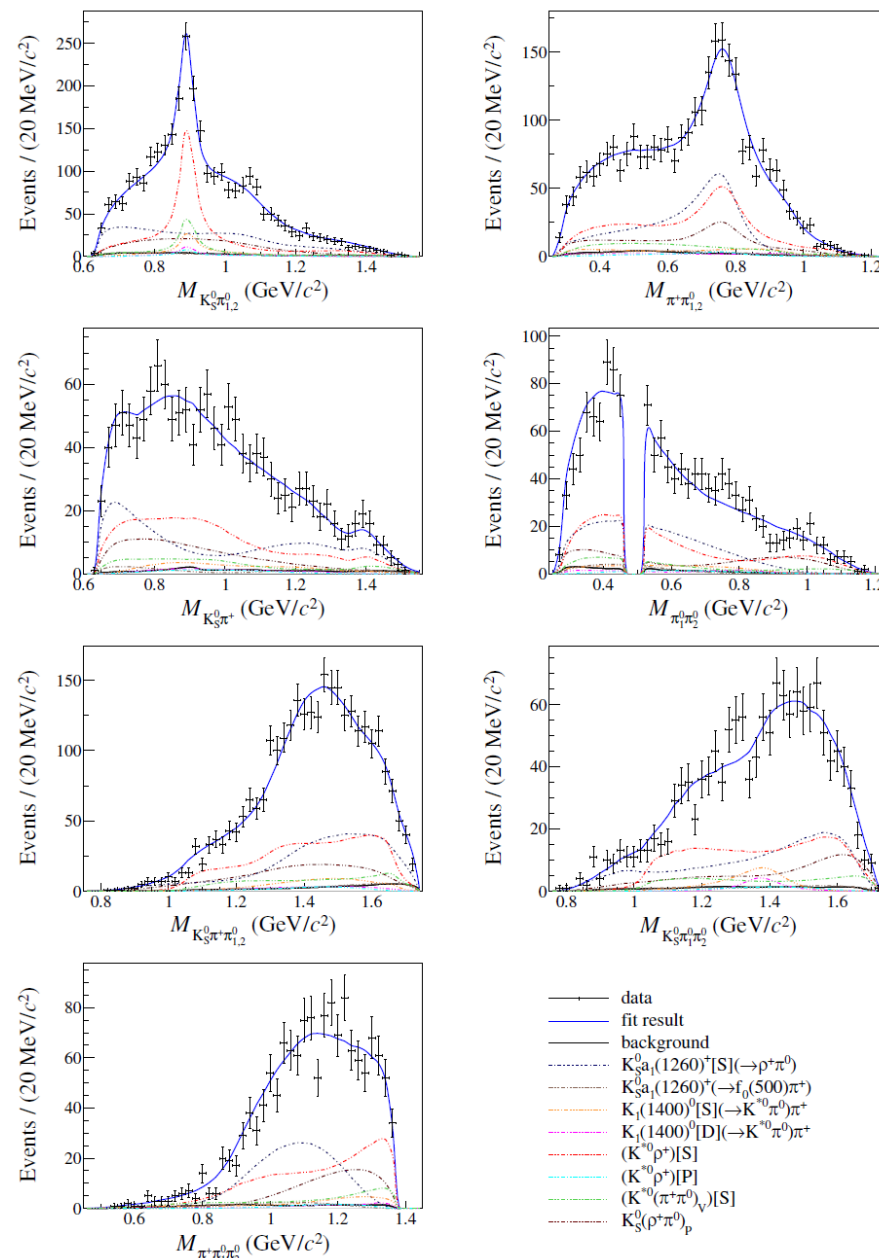
JHEP 09 (2023) 077

2.93 fb⁻¹ @3.773GeV

Intermediate process	BF ($\times 10^{-3}$)
$D^+ \rightarrow K_S^0 a_1(1260)^+[S](\rightarrow \rho^+ \pi^0)$	$8.66 \pm 1.04 \pm 1.24$
$D^+ \rightarrow K_S^0 a_1(1260)^+(\rightarrow f_0(500) \pi^+)$	$1.00 \pm 0.33 \pm 0.55$
$D^+ \rightarrow \bar{K}_1(1400)^0[S](\rightarrow \bar{K}^{*0} \pi^0) \pi^+$	$1.73 \pm 0.34 \pm 0.09$
$D^+ \rightarrow \bar{K}_1(1400)^0[D](\rightarrow \bar{K}^{*0} \pi^0) \pi^+$	$0.68 \pm 0.16 \pm 0.07$
$D^+ \rightarrow \bar{K}_1(1400)^0(\rightarrow \bar{K}^{*0} \pi^0) \pi^+$	$2.32 \pm 0.36 \pm 0.13$
$D^+[S] \rightarrow \bar{K}^{*0} \rho^+$	$9.20 \pm 0.80 \pm 0.45$
$D^+[P] \rightarrow \bar{K}^{*0} \rho^+$	$0.49 \pm 0.17 \pm 0.03$
$D^+ \rightarrow \bar{K}^{*0} \rho^+$	$9.70 \pm 0.81 \pm 0.47$

$\mathcal{B}(D^+ \rightarrow K_S^0 \pi^+ \pi^0 \pi^0) = (2.888 \pm 0.058_{\text{stat.}} \pm 0.069_{\text{syst.}})\%$

Here, \bar{K}^{*0} decays to $\bar{K}_S^0 \pi^0$,
 ρ^+ decays to $\pi^+ \pi^0$
 $f_0(500)$ decays to $\pi^0 \pi^0$



$D \rightarrow K3\pi$ 7个四体衰变振幅分析研究现状

$D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$	BESIII PRD95, 072010 (2017); LHCb EPJC 78, 443 (2018)
$D^0 \rightarrow K_S^0 \pi^+ \pi^- \pi^0$	在研 Collaboration meeting
$D^0 \rightarrow K^- \pi^+ \pi^0 \pi^0$	BESIII PRD99, 092008 (2019)
$D^0 \rightarrow K_S^0 \pi^0 \pi^0 \pi^0$	在研 memo review
$D^+ \rightarrow K_S^0 \pi^+ \pi^+ \pi^-$	BESIII PRD100, 072008(2019)
$D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0$	在研 memo review
$D^+ \rightarrow K_S^0 \pi^+ \pi^0 \pi^0$	BESIII JHEP 09, 077 (2023)

— data
— fit result
— background
- - - $K_S^0 a_1(1260)^+[S](\rightarrow \rho^+ \pi^0)$
- - - $K_S^0 a_1(1260)^+(\rightarrow f_0(500) \pi^+)$
- - - $K_1(1400)^0[S](\rightarrow \bar{K}^{*0} \pi^0) \pi^+$
- - - $K_1(1400)^0[D](\rightarrow \bar{K}^{*0} \pi^0) \pi^+$
- - - $(K^{*0} \rho^+)[S]$
- - - $(K^{*0} \rho^+)[P]$
- - - $(K^{*0}(\pi^+ \pi^0)_V)[S]$
- - - $K_S^0(\rho^+ \pi^0)_p$

3.3 D 介子四体强子衰变的振幅分析

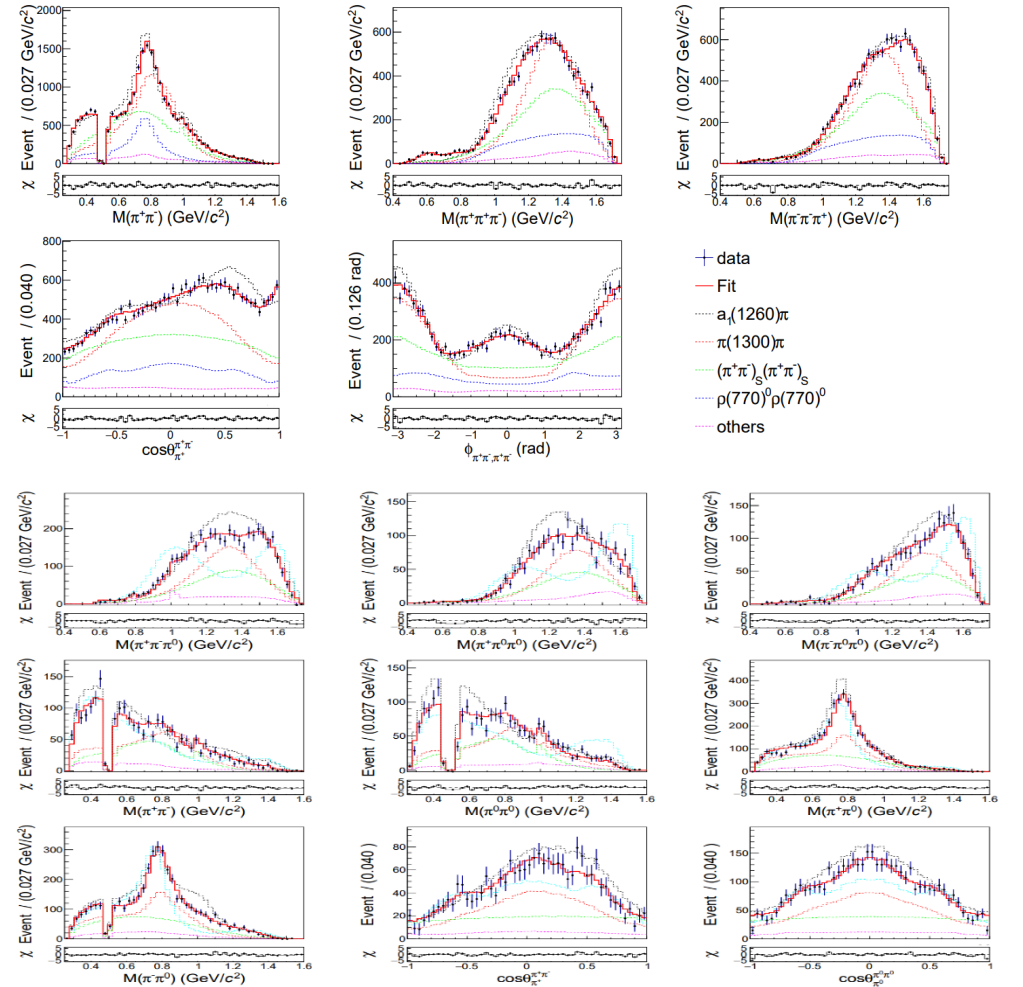
$D^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-, \pi^+ \pi^- \pi^0 \pi^0$

Accepted by CPC, arXiv:2312.02524

2.93 fb⁻¹ @3.773 GeV

Component	Branching fraction (%)	
	$\pi^+ \pi^- \pi^+ \pi^-$	$\pi^+ \pi^- \pi^0 \pi^0$
$D^0 \rightarrow a_1(1260)^+ \pi^-$	$0.566 \pm 0.024 \pm 0.008 \pm 0.110$	$0.546 \pm 0.027 \pm 0.011 \pm 0.069$
$D^0 \rightarrow a_1(1260)^- \pi^+$	$0.071 \pm 0.010 \pm 0.001 \pm 0.017$	$0.068 \pm 0.011 \pm 0.001 \pm 0.021$
$D^0 \rightarrow a_1(1260)^0 \pi^0$	-	$0.313 \pm 0.031 \pm 0.007 \pm 0.082$
$D^0 \rightarrow a_1(1640)^+ \pi^-$	$0.012 \pm 0.003 \pm 0.000 \pm 0.006$	$0.010 \pm 0.003 \pm 0.000 \pm 0.007$
$D^0 \rightarrow h_1(1170)^0 \pi^0$	-	$0.012 \pm 0.006 \pm 0.000 \pm 0.010$
$D^0 \rightarrow \pi(1300)^+ \pi^-$	$0.222 \pm 0.018 \pm 0.003 \pm 0.031$	$0.148 \pm 0.014 \pm 0.003 \pm 0.025$
$D^0 \rightarrow \pi(1300)^- \pi^+$	$0.162 \pm 0.016 \pm 0.002 \pm 0.028$	$0.108 \pm 0.011 \pm 0.002 \pm 0.021$
$D^0 \rightarrow \pi(1300)^0 \pi^0$	-	$0.221 \pm 0.027 \pm 0.005 \pm 0.033$
$D^0 \rightarrow \pi_2(1670)^0 \pi^0$	-	$0.010 \pm 0.002 \pm 0.000 \pm 0.004$
$D^0 \rightarrow \rho(770)^0 \rho(770)^0$	$0.193 \pm 0.013 \pm 0.003 \pm 0.022$	-
$D^0 \rightarrow \rho(770)^0 \rho(770)^0 [S]$	$0.012 \pm 0.004 \pm 0.000 \pm 0.003$	-
$D^0 \rightarrow \rho(770)^0 \rho(770)^0 [P]$	$0.067 \pm 0.007 \pm 0.001 \pm 0.006$	-
$D^0 \rightarrow \rho(770)^0 \rho(770)^0 [D]$	$0.159 \pm 0.015 \pm 0.002 \pm 0.017$	-
$D^0 \rightarrow \rho(770)^0 \rho(1450)^0$	$0.017 \pm 0.006 \pm 0.000 \pm 0.008$	-
$D^0 \rightarrow \rho(770)^0 \rho(1450)^0 [P]$	$0.007 \pm 0.003 \pm 0.000 \pm 0.003$	-
$D^0 \rightarrow \rho(770)^0 \rho(1450)^0 [D]$	$0.010 \pm 0.006 \pm 0.000 \pm 0.008$	-
$D^0 \rightarrow \rho(770)^+ \rho(770)^-$	-	$0.864 \pm 0.040 \pm 0.018 \pm 0.075$
$D^0 \rightarrow \rho(770)^+ \rho(770)^- [S]$	-	$0.124 \pm 0.019 \pm 0.003 \pm 0.033$
$D^0 \rightarrow \rho(770)^+ \rho(770)^- [P]$	-	$0.186 \pm 0.013 \pm 0.004 \pm 0.019$
$D^0 \rightarrow \rho(770)^+ \rho(770)^- [D]$	-	$0.342 \pm 0.029 \pm 0.007 \pm 0.024$
$D^0 \rightarrow \rho(770)^+ \rho(1450)^- [D]$	-	$0.016 \pm 0.008 \pm 0.000 \pm 0.016$

	Branching fractions	PDG
$D^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-$	$(0.688 \pm 0.010 \pm 0.010)\%$	$(0.756 \pm 0.020)\%$
$D^0 \rightarrow \pi^+ \pi^- \pi^0 \pi^0 (\text{non-}\eta)$	$(0.951 \pm 0.025 \pm 0.021)\%$	$(1.005 \pm 0.090)\%$



CP -even fractions	$F_+^{\pi^+ \pi^- \pi^+ \pi^-}$	$F_+^{\pi^+ \pi^- \pi^0 \pi^0} (\text{non-}\eta)$
	$(75.2 \pm 1.1_{\text{stat.}} \pm 1.5_{\text{syst.}})\%$	$(68.9 \pm 1.5_{\text{stat.}} \pm 2.4_{\text{syst.}})\%$

理论预期： $\frac{\text{双Cabibbo压低衰变分支比}}{\text{相应Cabibbo允许衰变分支比}} = \tan^4 \theta_c (\sim 0.29\%)$

θ_c 为 CKM Cabibbo 混合角

BESIII发现 $D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0$ 的比值**比理论预期高三倍**

衰变机制的差异，干涉效应？

PRL125, 141802 (2020)

探索更多双Cabibbo压低衰变

需要对相关衰变开展振幅分析，研究末态相互作用和内部共振结构，

理解双Cabibbo压低分支比异常的本质

2.93fb⁻¹ @3.773GeV

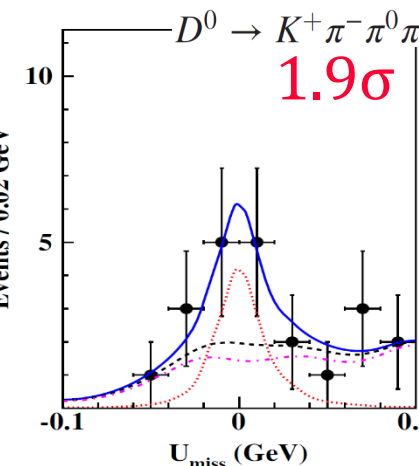
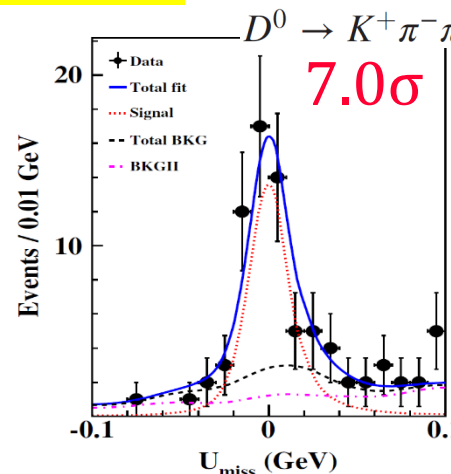


PRD 105, 112001 (2022)

$$\mathcal{B}(D^0 \rightarrow K^+ \pi^- \pi^0) =$$

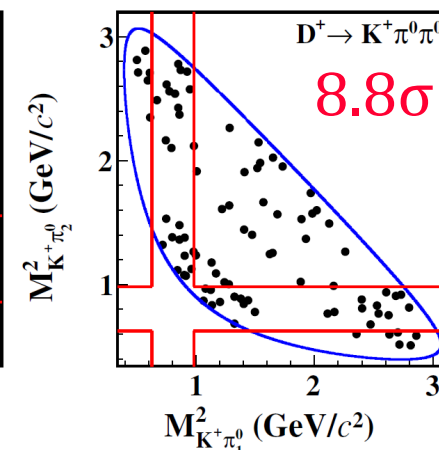
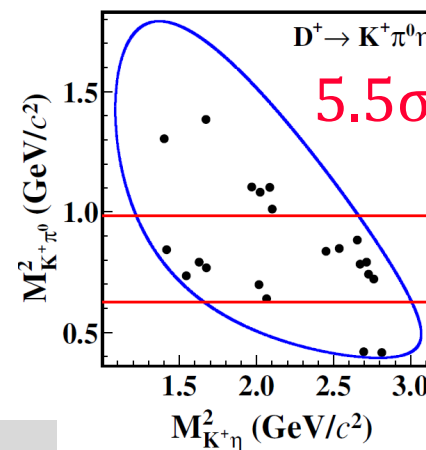
$$[3.13_{-0.56}^{+0.60}(\text{stat}) \pm 0.15(\text{syst})] \times 10^{-4}$$

$$\mathcal{B}(D^0 \rightarrow K^+ \pi^- \pi^0 \pi^0) < 3.6 \times 10^{-4} \text{ @ 90\% CL.}$$



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Decay mode	N_{DT}	$\epsilon_{sig} (\%)$	$\mathcal{B}_{sig} (\times 10^{-4})$
$D^+ \rightarrow K^+ \pi^0 \pi^0$	42.8 ± 7.2	18.08 ± 0.03	$2.1 \pm 0.4 \pm 0.1$
$D^+ \rightarrow K^+ \pi^0 \eta$	19.2 ± 5.0	20.50 ± 0.03	$2.1 \pm 0.5 \pm 0.1$
$D^+ \rightarrow K^{*+} \pi^0$	$16.6_{-6.2}^{+6.6}$	13.02 ± 0.03	$3.4_{-1.3}^{+1.4} \pm 0.1$
$D^+ \rightarrow K^{*+} \eta$	$10.9_{-3.8}^{+4.4}$	16.60 ± 0.04	$4.4_{-1.5}^{+1.8} \pm 0.2$



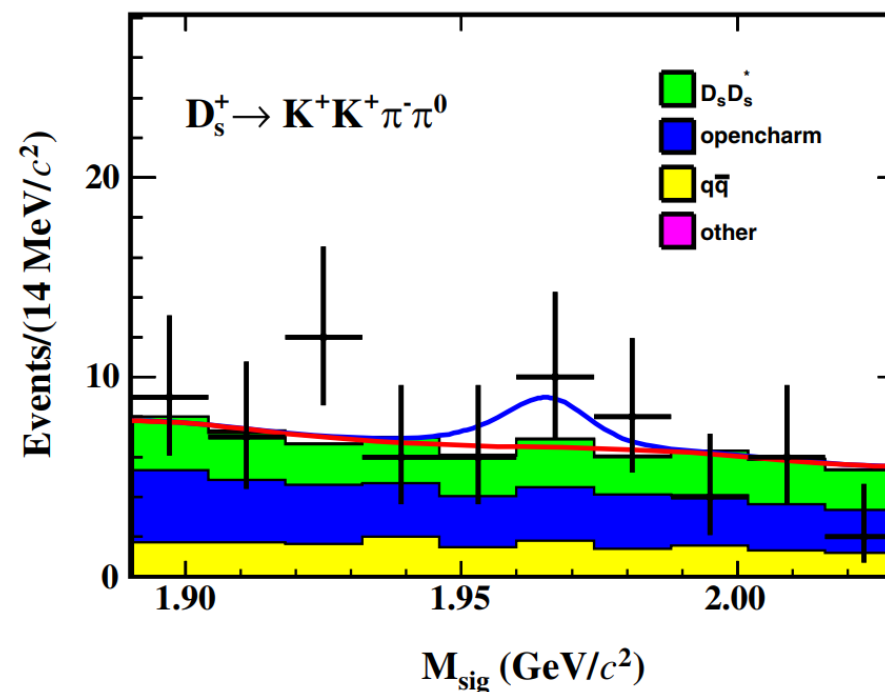
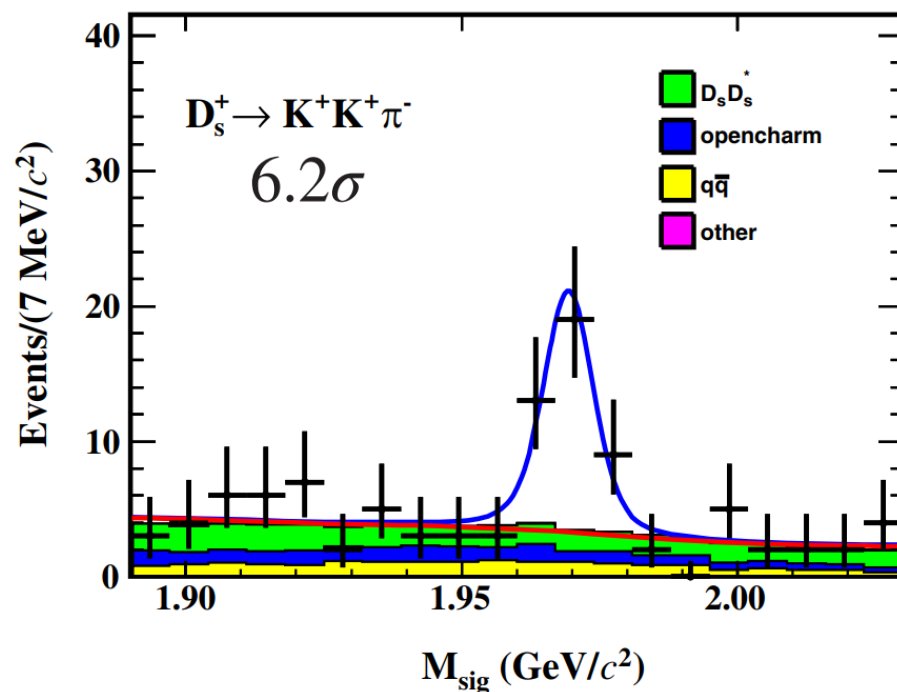
在研: Amplitude analyses of DCS decays:

$D^+ \rightarrow K^+ \pi^+ \pi^- \pi^0, D^+ \rightarrow K^+ \pi^+ \pi^-, D^+ \rightarrow K^+ \pi^0 \pi^0, D^+ \rightarrow K^+ \pi^0 \eta$

7.33fb⁻¹ between 4.128 – 4.226GeV

• $D_s^+ \rightarrow K^+ K^+ \pi^-, K^+ K^+ \pi^- \pi^0$

PRD 109, 032011 (2024)



DCS decay	$\mathcal{B}_{\text{DCS}}^{\text{this work}} (\times 10^{-4})$	CF decay	$\mathcal{B}_{\text{CF}}^{\text{PDG}} (\times 10^{-2})$	$\mathcal{B}_{\text{DCS}}^{\text{this work}} / \mathcal{B}_{\text{CF}}^{\text{PDG}} (\times 10^{-3})$	$\times \tan^4 \theta_C$
$D_s^+ \rightarrow K^+ K^+ \pi^-$	$1.24^{+0.28}_{-0.26} \pm 0.06$	$D_s^+ \rightarrow K^+ K^- \pi^+$	5.37 ± 0.10	$2.31^{+0.52}_{-0.48}$	$0.80^{+0.18}_{-0.16}$
$D_s^+ \rightarrow K^+ K^+ \pi^- \pi^0$	< 1.7	$D_s^+ \rightarrow K^+ K^- \pi^+ \pi^0$	5.50 ± 0.24	< 3.09	< 1.07

- 利用在阈值附近采集的粲介子样本，开展强子衰变研究，对
 - 检验并刻度理论计算非微扰效应的参数化方法和唯象模型，
 - 理解粲强子弱衰变机制，
 - 检验SU(3)味对称性和提高粲强子CP破坏的理论预言，**具有重要意义**
- BESIII开展了粲介子强子衰变的精密测量工作，进展顺利。
- 20fb⁻¹ $\psi(3770)$ 数据和相应inclusive MC样本(40x数据)7月发布。
预期有更多更好的BESIII粲物理成果发表。

谢谢!