“粲强子衰变和标准模型的精确检验”2025夏季研讨会

D/D_s^+强子衰变的绝对分支比测量

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中国贵阳

绝对分支比的测量方法

我们使用双标记方法来获取绝对分支比，主要通过以下两个途径进行测量：

- 通过公式计算：

$$\mathcal{B}_i = \frac{\sum N_{DT,ij}}{\sum N_{ST,j}\epsilon_{DT,ij}/\epsilon_{ST,j}}$$

  - $N_{DT,ij}$：来自于双标记道 i 和 j的产额
  - $N_{ST,j}$：来自于单标记道j的产额
  - $\epsilon_{DT,ij}$：来自于双标记道 i 和 j的效率
  - $\epsilon_{ST,j}$：来自于单标记道j的的效率

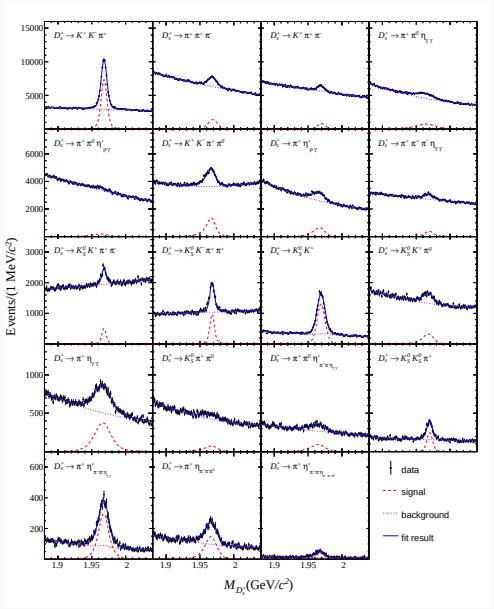
- 联合拟合：我们通过一个极大似然法的拟合来获取分支比和$D\bar{D}$总对数，可以显著降低统计误差：

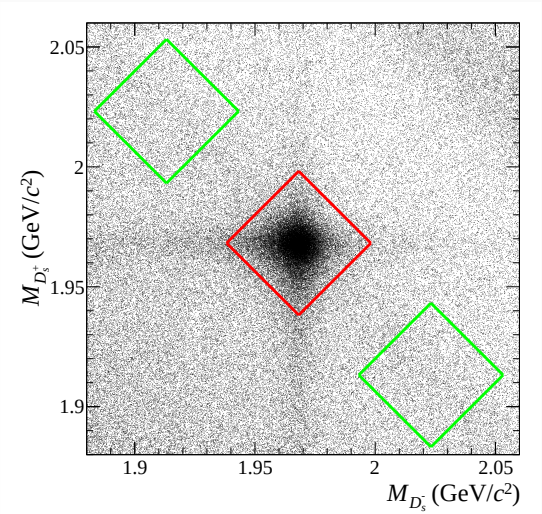
$$\mathcal{L} = \frac{1}{\sqrt{2\pi\,|\det \mathbf{V}|}} \exp\left[(\mathbf{E}-\mathbf{N})(\mathbf{V})^{-1}(\mathbf{E}-\mathbf{N})^{T}/2\right]$$

  - $\mathbf{N}$ 是产额矩阵
  - $\mathbf{V}$ 是误差矩阵
  - $\mathbf{E}$ 是效率修正矩阵：$\mathbf{E} = \mathbf{CY}$
    - $\mathbf{C}$ 表示效率矩阵
    - $\mathbf{Y}$ 是期望产额矩阵：
    - 对于单标而言：$Y_{i,e} = N_{D\bar{D},e}\mathcal{B}_i$
    - 对于双标而言：$Y_{ij,e} = N_{D\bar{D},e}\mathcal{B}_i\mathcal{B}_j$

Measurement of absolute branching fractions of D_s^+ hadronic decays

Data: 7.33 fb^{-1} $\sqrt{s}$=4.128 - 4.226 GeV JHEP05(2024)335





联合拟合方法

15个衰变道（19个衰变末态）

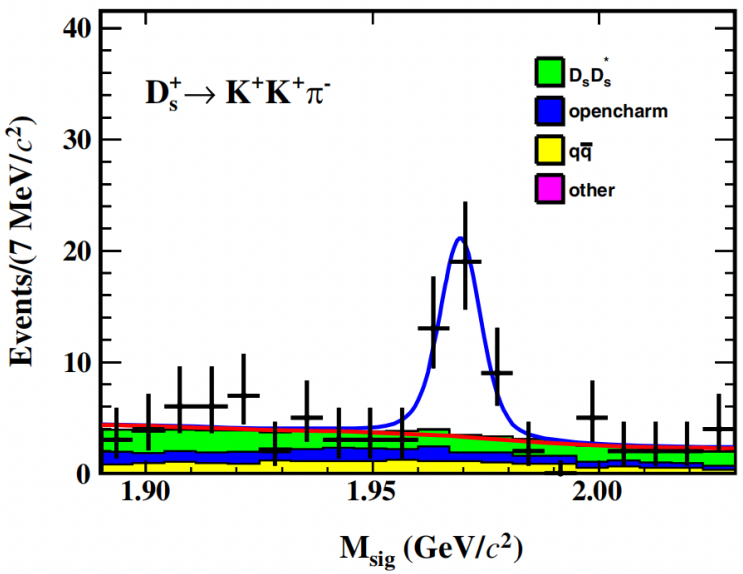
Mode	$\mathcal{B}$ (%)	PDG $\mathcal{B}$ (%)
$D_s^+ \to K_S^0 K^+$	1.502 ± 0.012 ± 0.009	1.453 ± 0.035
$D_s^+ \to K^+ K^- \pi^+$	5.49 ± 0.04 ± 0.07	5.37 ± 0.10
$D_s^+ \to K_S^0 K^+ \pi^0$	1.47 ± 0.02 ± 0.02	1.47 ± 0.07
$D_s^+ \to K_S^0 K_S^0 \pi^+$	0.73 ± 0.01 ± 0.01	0.71 ± 0.04
$D_s^+ \to K^+ K^- \pi^+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

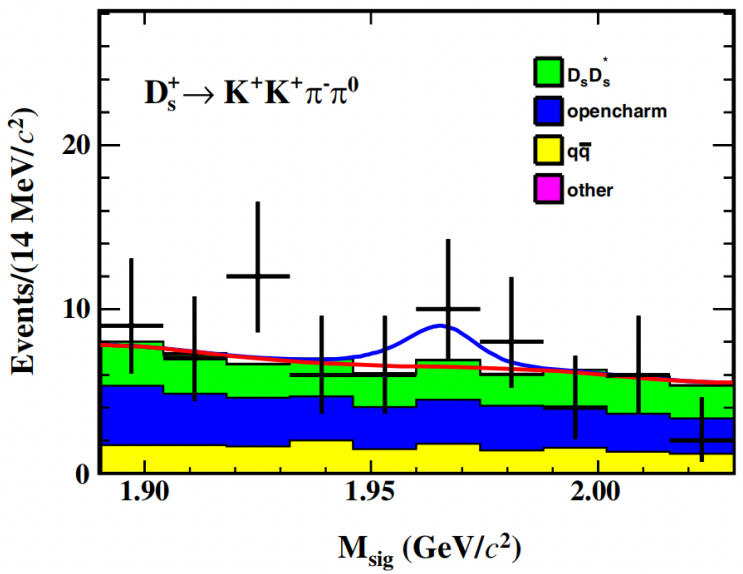
15个衰变道的分支比均精度显著提升

Study of the doubly Cabibbo-suppressed decays $D_s^+ \to K^+K^+\pi^-$ and $D_s^+ \to K^+K^+\pi^-\pi^0$

Data: 7.33 fb^{-1} $\sqrt{s}$=4.128 - 4.226 GeV Phys. Rev. D 109, 032011 (2024)

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

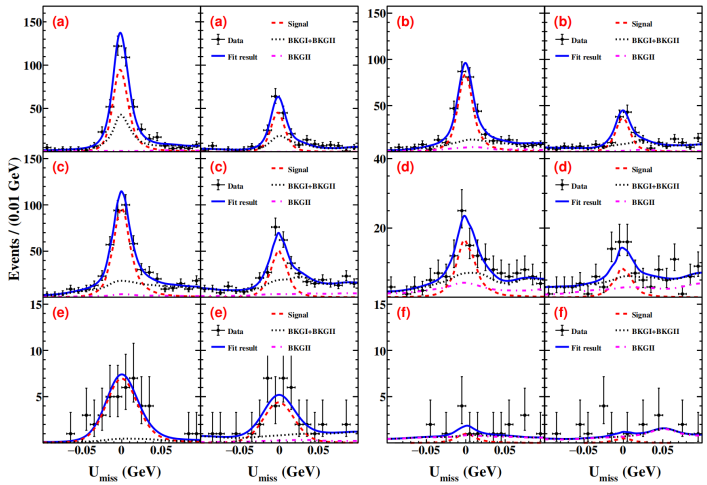


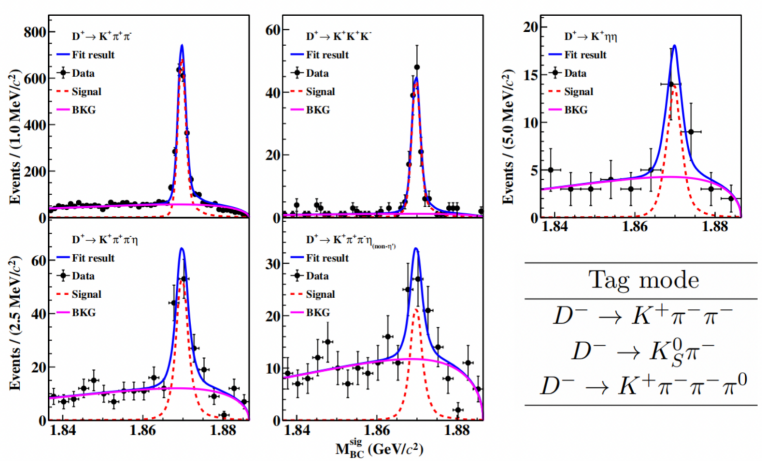


DCS decay	$\mathcal{B}_{\rm DCS}^{\rm this\ work}$ ($\times 10^{-4}$)	CF decay	$\mathcal{B}_{\rm CF}^{\rm PDG}$ ($\times 10^{-2}$)	$\mathcal{B}_{\rm DCS}^{\rm this\ work}/\mathcal{B}_{\rm CF}^{\rm PDG}$ ($\times 10^{-3}$)	$\times \tan^4\theta_C$
$D_s^+ \to K^+K^+\pi^-$	$1.24^{+0.28}_{-0.26} \pm 0.06$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

Measurement of the branching fractions of doubly Cabibbo-suppressed D decays

Data: 20.3 fb^{-1} $\sqrt{s}$=3.773 GeV JHEP06(2025)220





$$\mathcal{B}_{\rm sig} = \frac{N_{\rm DT}}{2\, N_{D^0\bar{D}^0}\, \epsilon_{\rm DT}\, \mathcal{B}_{\rm SL}},$$

$\mathcal{B}_{\rm SL}$:
$\mathcal{B}(D^0 \to K^+ e^- \bar{\nu}_e)$,
$\mathcal{B}(D^0 \to K^+ \mu^- \bar{\nu_\mu})$

Tag mode
$D^- \to K^+\pi^-\pi^-$
$D^- \to K^0_S\pi^-$
$D^- \to K^+\pi^-\pi^-\pi^0$

$$\mathcal{B}_{\rm sig} = N_{\rm DT}/(N_{\rm ST}^{\rm tot}\, \epsilon_{\rm sig}),$$

$$\epsilon_{\rm sig} = \frac{\sum_i (N_{\rm ST}^i\, \epsilon_{\rm DT}^i/\epsilon_{\rm ST}^i)}{N_{\rm ST}^{\rm tot}},$$

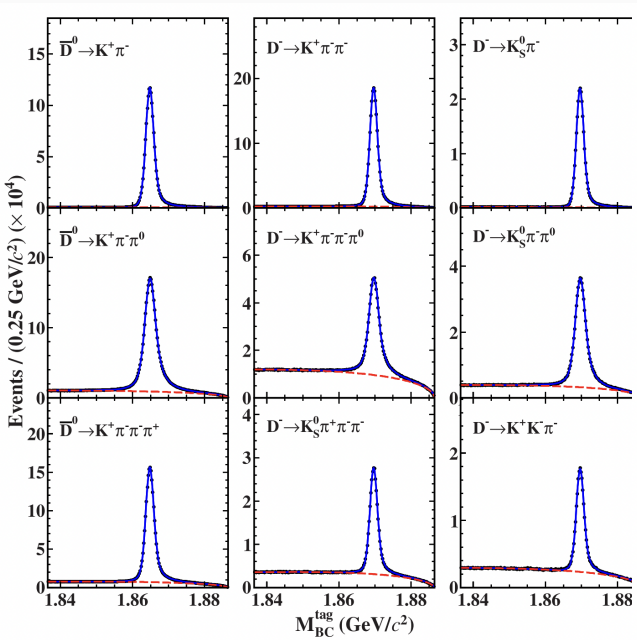
Signal decay	$\mathcal{B}_{\rm DCS}^{\rm This\ work}$ ($\times 10^{-4}$)	$\mathcal{B}_{\rm DCS}^{\rm PDG}$ ($\times 10^{-4}$)	$\mathcal{B}_{\rm CF}^{\rm PDG}$ ($\times 10^{-2}$)	$\mathcal{B}_{\rm DCS}^{\rm This\ work}/\mathcal{B}_{\rm CF}$ (%)	$\times \tan^4\theta_C$
$D^0 \to K^+\pi^-$	$1.30 \pm 0.09 \pm 0.04$	1.50 ± 0.07	3.947 ± 0.030	0.328 ± 0.027	1.14 ± 0.09
$D^0 \to K^+\pi^-\pi^-\pi^+$	$2.38 \pm 0.19 \pm 0.12$	2.65 ± 0.06	8.22 ± 0.14	0.289 ± 0.028	1.00 ± 0.10
$D^0 \to K^+\pi^-\pi^0$	$3.06 \pm 0.21 \pm 0.10$	3.06 ± 0.16	14.4 ± 0.6	0.212 ± 0.021	0.74 ± 0.07
$D^0 \to K^+\pi^-\pi^0\pi^0$	$1.40 \pm 0.27 \pm 0.09$	< 3.6	8.86 ± 0.23	0.158 ± 0.036	0.55 ± 0.12
$D^0 \to K^+\pi^-\eta$	$1.04 \pm 0.16 \pm 0.08$	–	1.88 ± 0.05	0.555 ± 0.092	1.93 ± 0.32
$D^0 \to K^+\pi^-\pi^0\eta$	< 0.7	–	0.449 ± 0.027	< 1.78	< 6.19
$D^+ \to K^+\pi^+\pi^-$	$4.50 \pm 0.12 \pm 0.35$	4.91 ± 0.09	9.38 ± 0.16	0.480 ± 0.019	1.67 ± 0.07
$D^+ \to K^+\pi^+\pi^-\eta$	$1.56 \pm 0.22 \pm 0.04$	–	–	–	–
$D^+ \to K^+(\pi^+\pi^-\eta)_{\rm non-\eta'}$	$0.67 \pm 0.18 \pm 0.02$	–	0.135 ± 0.012	5.0 ± 1.4	17.3 ± 4.8
$D^+ \to K^+K^+K^-$	$0.51 \pm 0.05 \pm 0.01$	0.614 ± 0.011	–	–	–
$D^+ \to K^+\eta\eta$	$0.59 \pm 0.23 \pm 0.02$	–	–	–	–

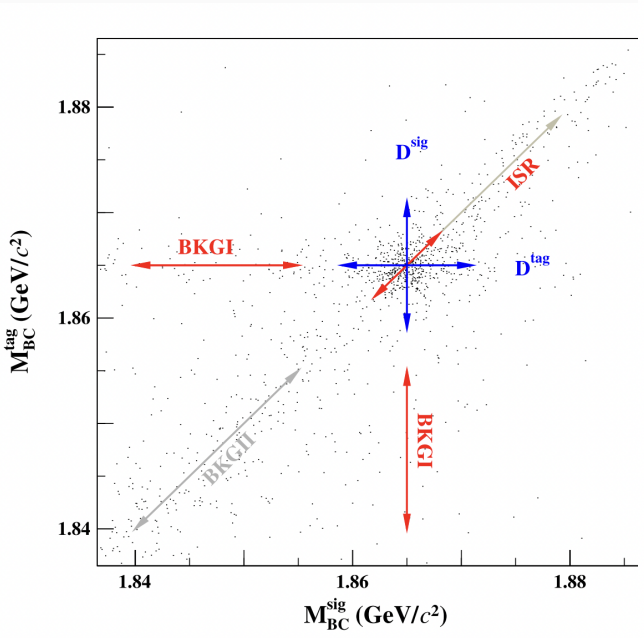
Investigated for the first time:

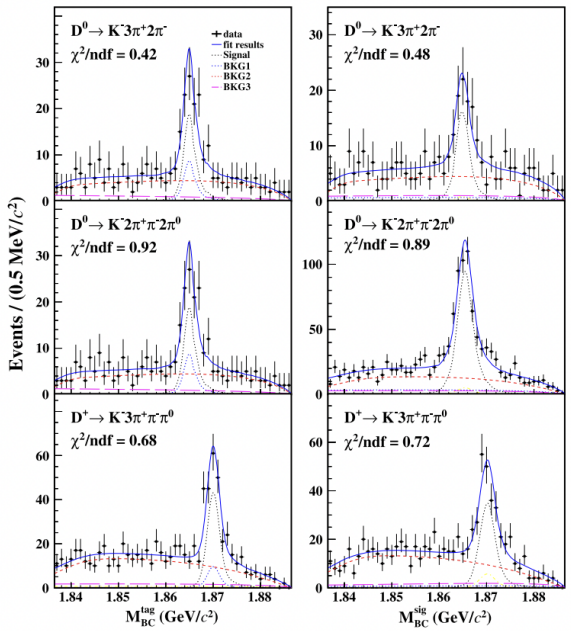
- $D^0 \to K^+\pi^-\eta$
- $D^0 \to K^+\pi^-\pi^0\eta$
- $D^+ \to K^+\eta\eta$
- $D^+ \to K^+\pi^+\pi^-\eta$
- $D^+ \to K^+(\pi^+\pi^+\eta)_{\rm non-\eta'}$

Measurements of BFs of $D^0 \to K^-3\pi^+2\pi^-$, $D^0 \to K^-2\pi^+\pi^02\pi^0$ and $D^+ \to K^-3\pi^+\pi^-\pi^0$

Data: 7.9 fb^{-1} $\sqrt{s}$=3.773 GeV Phys. Rev. D 112, 012001



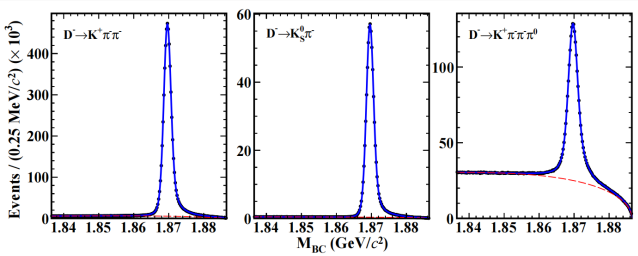




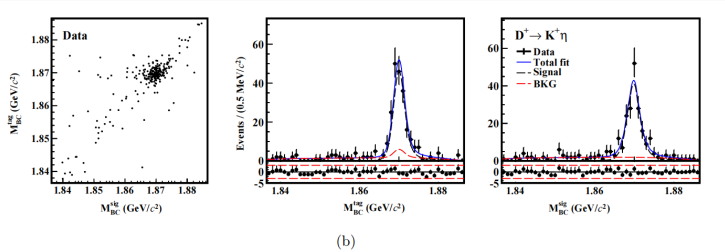
Signal decay	$\mathcal{B}_{\rm sig}(\times 10^{-4})$	$\mathcal{B}_{\rm FOCUS}(\times 10^{-4})$
$D^0 \to K^-3\pi^+2\pi^-$	$1.35 \pm 0.23 \pm 0.08$	$2.2 \pm 0.5 \pm 0.3$
$D^0 \to K^-2\pi^+\pi^-2\pi^0$	$19.0 \pm 1.1 \pm 1.5$	$\cdots$
$D^+ \to K^-3\pi^+\pi^-\pi^0$	$6.57 \pm 0.69 \pm 0.33$	$\cdots$

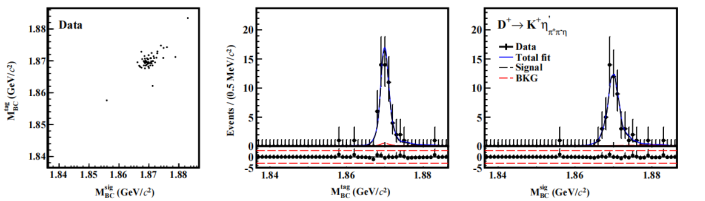
Measurements of the absolute branching fractions of the doubly Cabibbo-suppressed decays $D^+ \to K^+\pi^0$, $D^+ \to K^+\eta$ and $D^+ \to K^+\eta'$

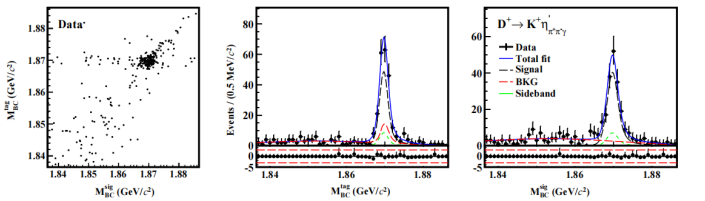
Data: 20.3 fb^{-1} $\sqrt{s}$=3.773 GeV arXiv:2506.15533v1

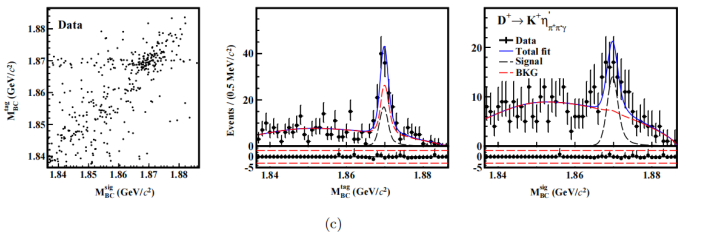


分支比精度显著提升

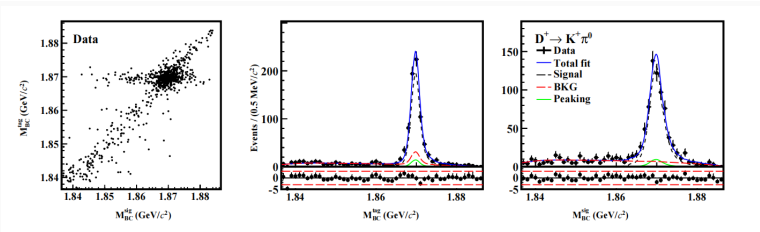






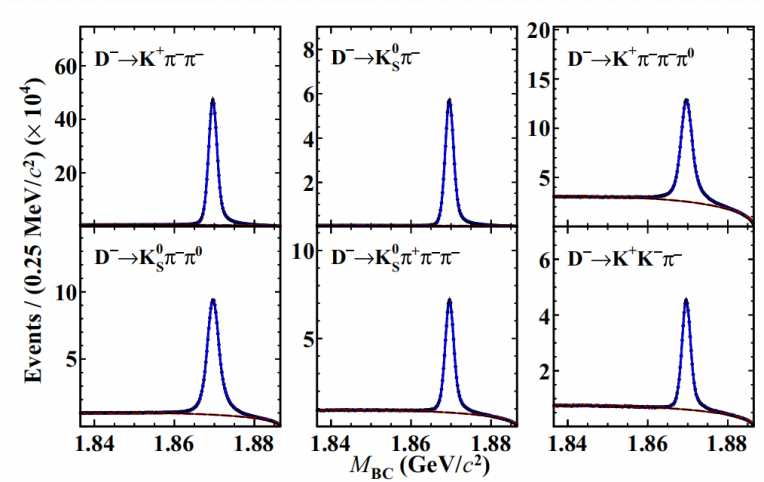


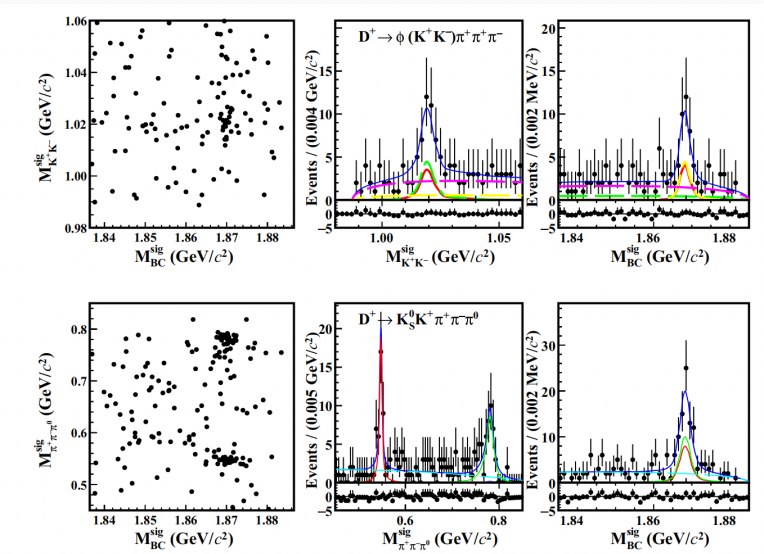
Signal decay	$D^+ \to K^+\pi^0$	$D^+ \to K^+\eta$	$D^+ \to K^+\eta'$
CLEO [8]	$2.28 \pm 0.36 \pm 0.17$	...	...
Belle [9]	...	$1.15 \pm 0.16 \pm 0.05$	$1.87 \pm 0.19 \pm 0.05$
BaBar [10]	$2.52 \pm 0.47 \pm 0.26$	...	...
BESIII [11]	$2.32 \pm 0.21 \pm 0.06$	$1.51 \pm 0.25 \pm 0.14$	$1.64 \pm 0.51 \pm 0.24$
PDG [12]	2.08 ± 0.21	1.25 ± 0.16	1.85 ± 0.20
DASU(3)L [1]	1.59 ± 0.15	0.98 ± 0.04	0.91 ± 0.17
TASU(3)B [2]	2.54 ± 0.06	1.04 ± 0.01	1.07 ± 0.01
GFRE [3]	2.2 ± 0.4	1.2 ± 0.2	1.0 ± 0.1
FDWC [4]	1.97	0.66	1.14
This work	$1.45 \pm 0.06 \pm 0.06$	$1.17 \pm 0.10 \pm 0.03$	$1.88 \pm 0.15 \pm 0.06$

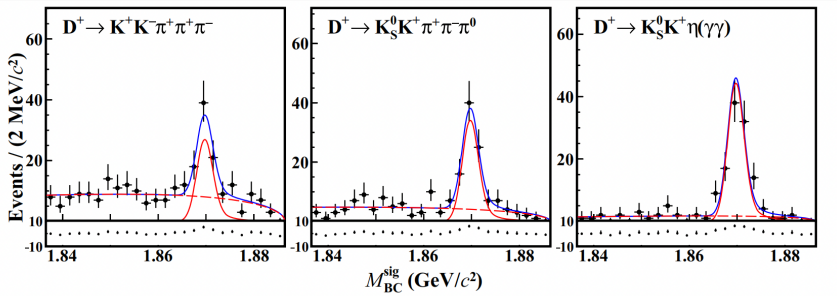


Measurement of the branching fractions of $D^+ \to K^+K^-\pi^+\pi^+\pi^-$, $\phi\pi^+\pi^+\pi^-$, $K^0_S K^+\pi^+\pi^-\pi^0$, $K^0_S K^+\eta$, and $K^0_S K^+\omega$ decays

Data: 20.3 fb^{-1} $\sqrt{s}$=3.773 GeV Phys. Rev. D 111, 092005 (2025)





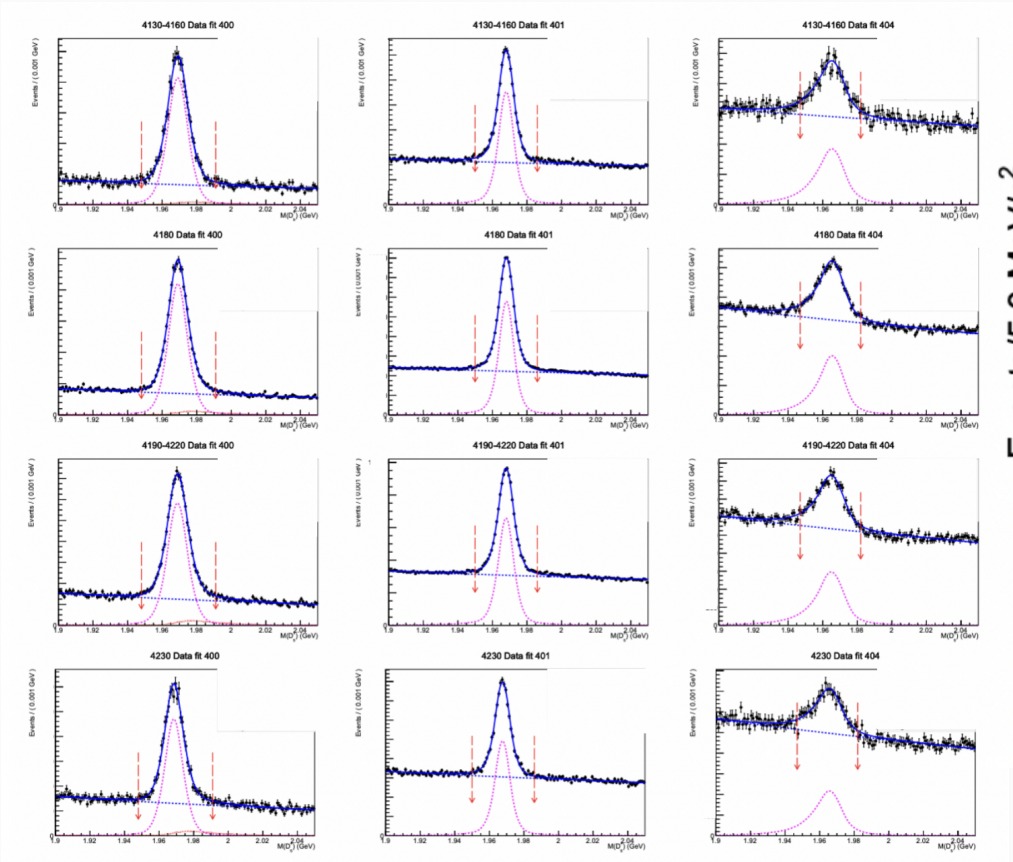


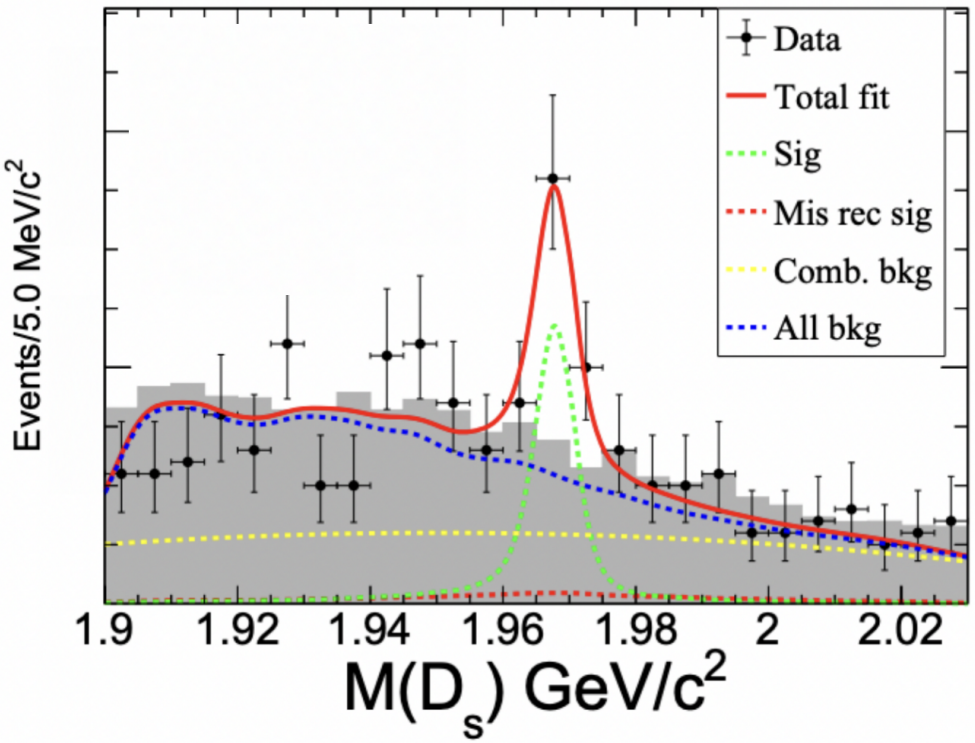
Signal decay	Resonance source	Fraction (%)
$D^+ \to K^+K^-\pi^+\pi^+\pi^-$	$K^+K^-\pi^+\pi^+\pi^-$	60.0 ± 14.0
	$\phi\pi^+\pi^+\pi^-$	40.0 ± 14.0
$D^+ \to K^0_S K^+\pi^+\pi^-\pi^0$	$K^0_S K^+\eta$	26.9 ± 9.2
	$K^0_S K^+\omega$	73.1 ± 9.2
$D^+ \to K^0_S K^+\omega$	$\bar{K}^0_1 K^+$	56.2 ± 2.4 [20]
	$K^+_1 K^0_S$	43.8 ± 2.4 [20]

mode	$\mathcal{B}(10^{-4})$	
$D^+ \to K^+K^-\pi^+\pi^+\pi^-$	$0.66 \pm 0.11 \pm 0.03$	
$D^+ \to \phi\pi^+\pi^+\pi^-$	$0.54 \pm 0.19 \pm 0.02$	First
$D^+ \to K^0_S K^+\pi^+\pi^-\pi^0$	$2.51 \pm 0.34 \pm 0.14$	First
$D^+ \to K^0_S K^+\eta$	$2.27 \pm 0.22 \pm 0.05$	
$D^+ \to K^0_S K^+\omega$	$2.02 \pm 0.35 \pm 0.10$	First

First observation of $D_s^+ \to \pi^+\pi^-\pi^+\eta'$

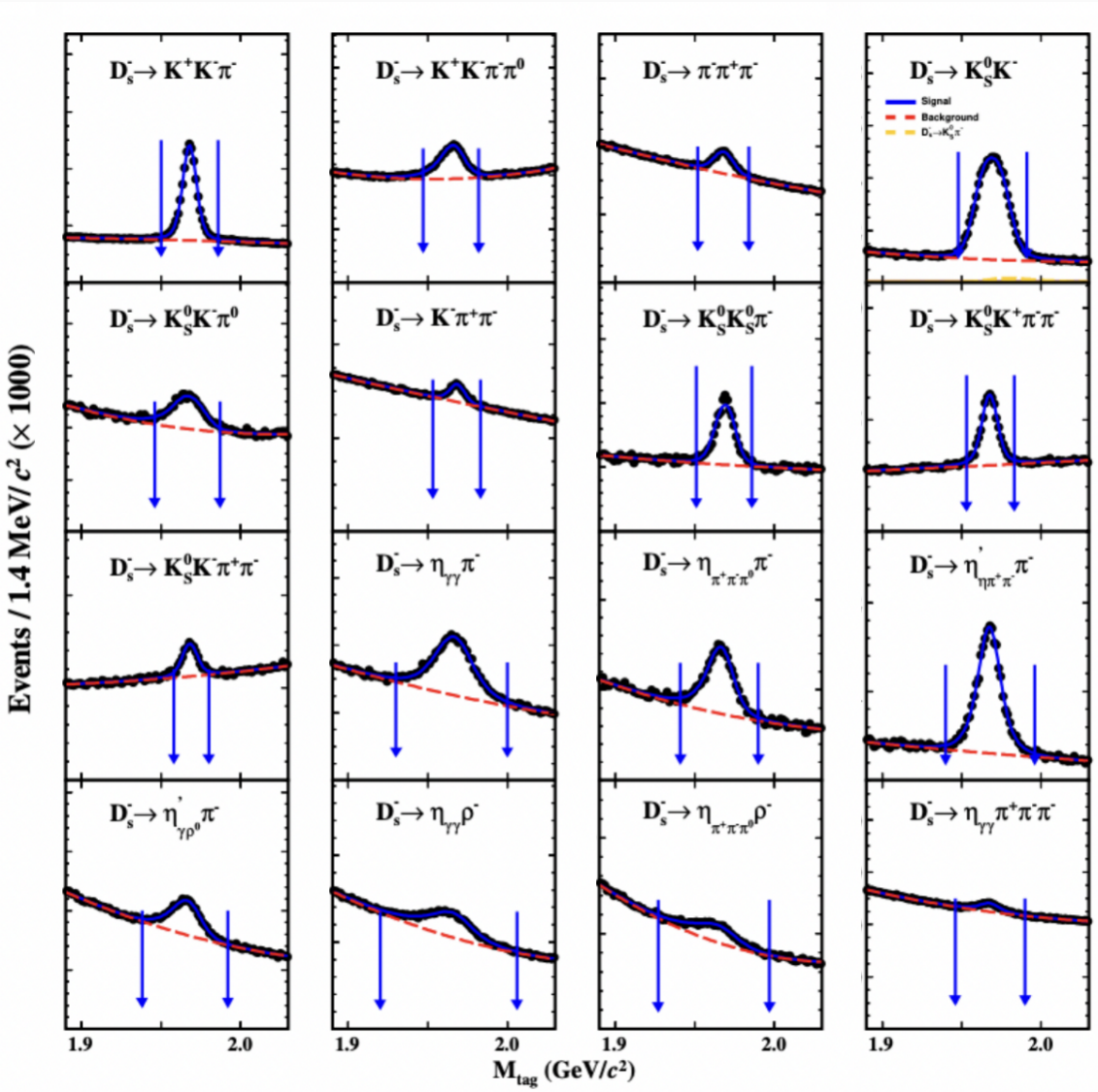
Data: 7.33 fb^{-1} $\sqrt{s}$=4.128 - 4.226 GeV BAM-00696

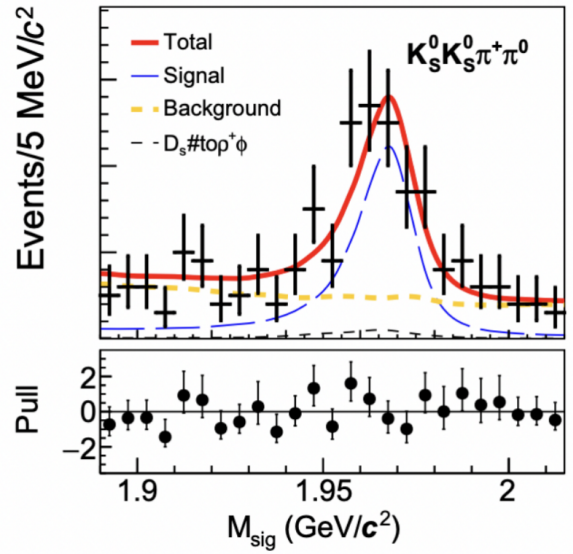


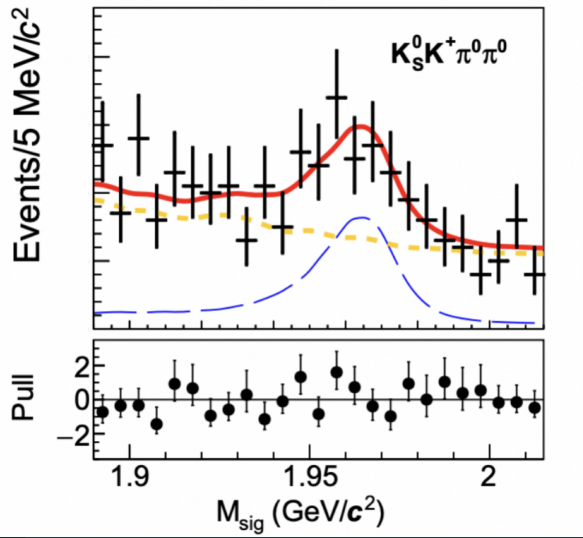


Measurement of branching fractions of $D_s^+ \to K_S^0 K_S^0 \pi^+ \pi^0$ and $K_S^0 K^+ \pi^0 \pi^0$

Data: 7.33 fb^{-1} $\sqrt{s}$=4.128 - 4.226 GeV (BAM-00852)

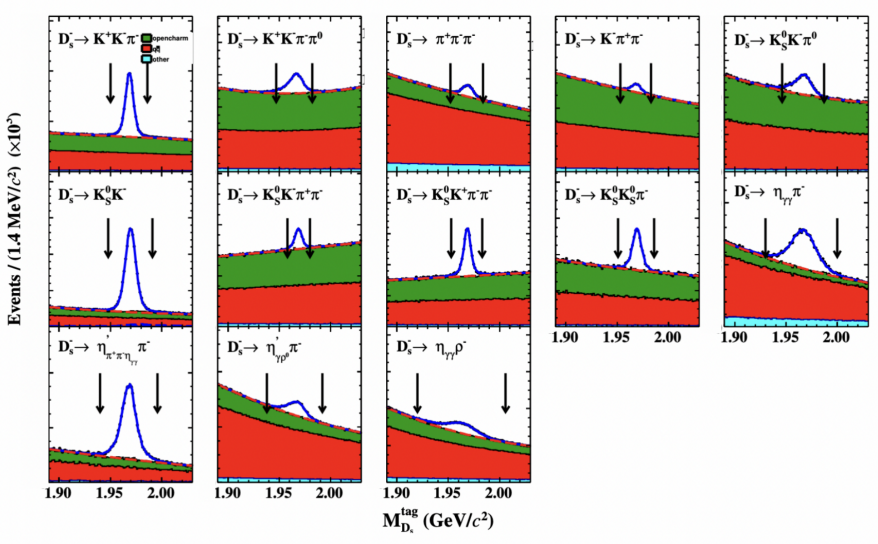


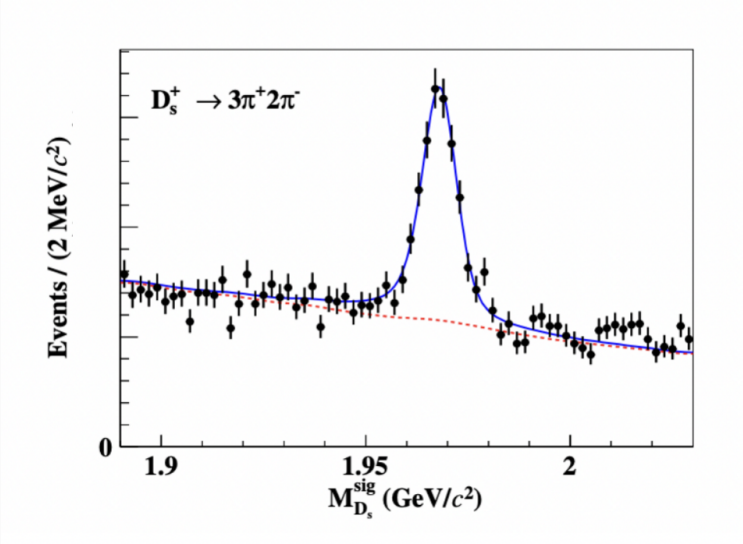


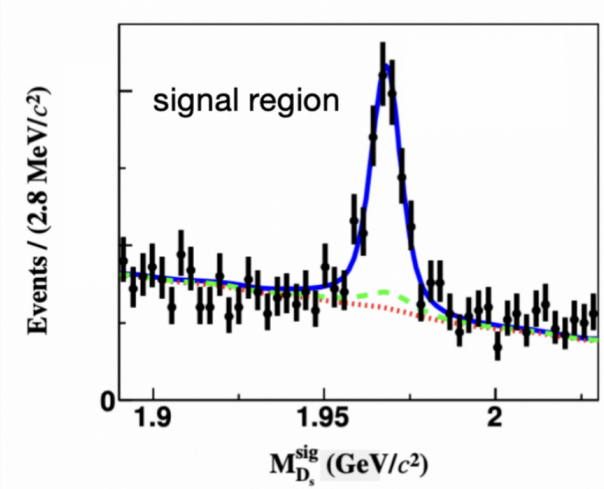


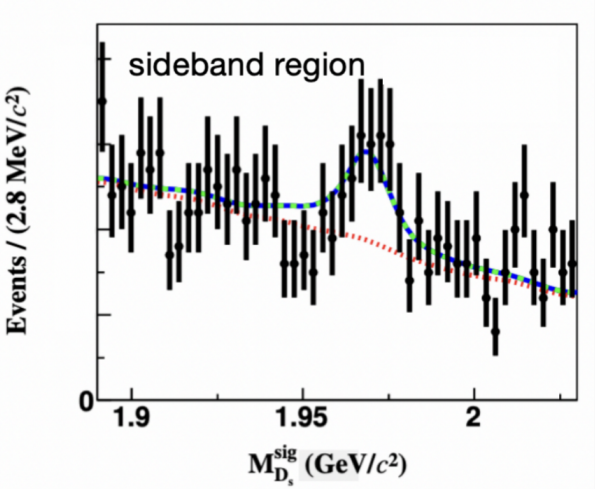
Measurements of $D_s^+ \to K_S^0 2\pi^+\pi^-$ and $D_s^+ \to 3\pi^+ 2\pi^-$

Data: 7.33 fb^{-1} $\sqrt{s}$=4.128 - 4.226 GeV (BAM-01028)



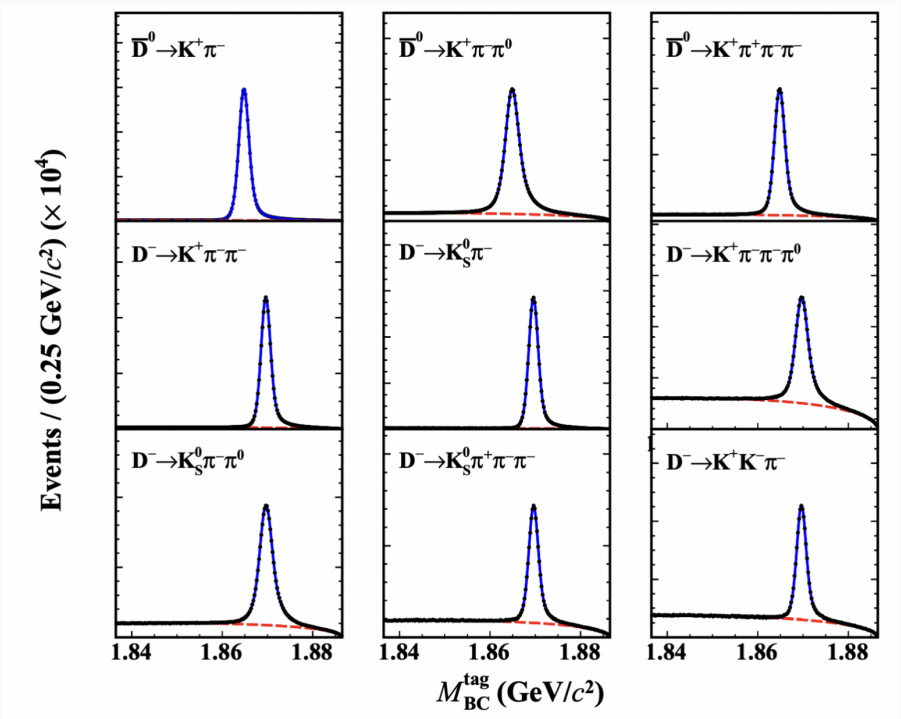


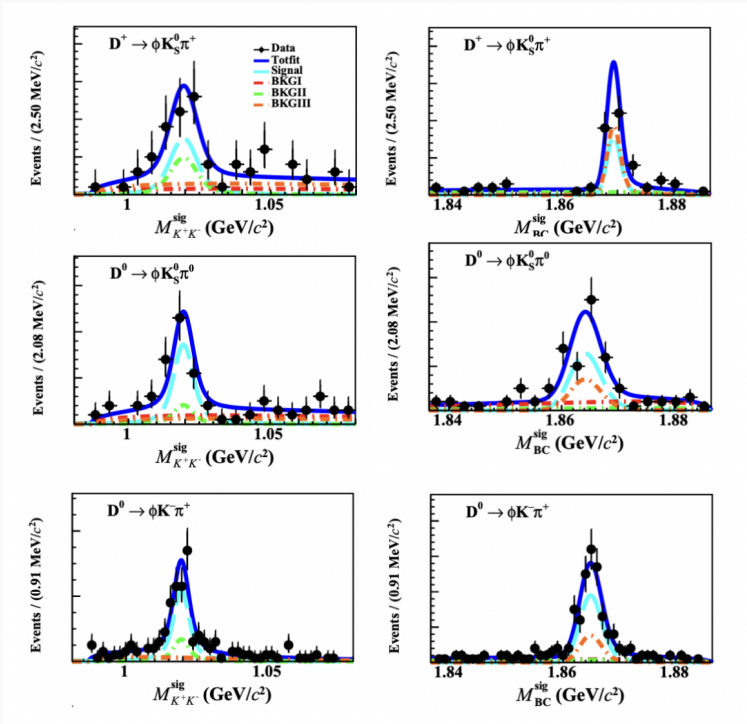


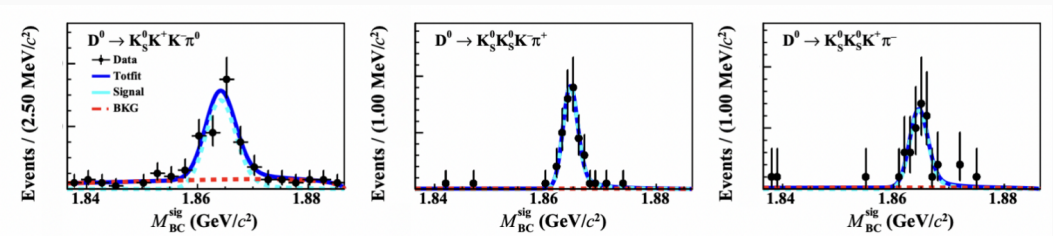


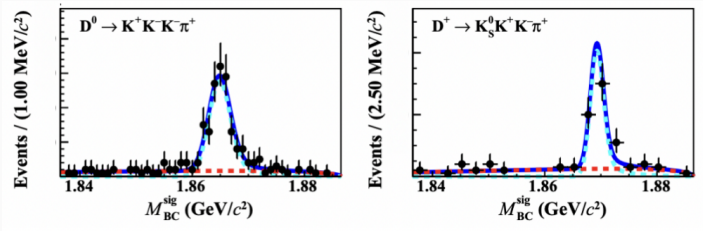
Measurements of absolute branching fractions of $D^{0(+)} \to KKK\pi$ decays

Data: 20.3 fb^{-1} $\sqrt{s}$=3.773 GeV (BAM-00851)





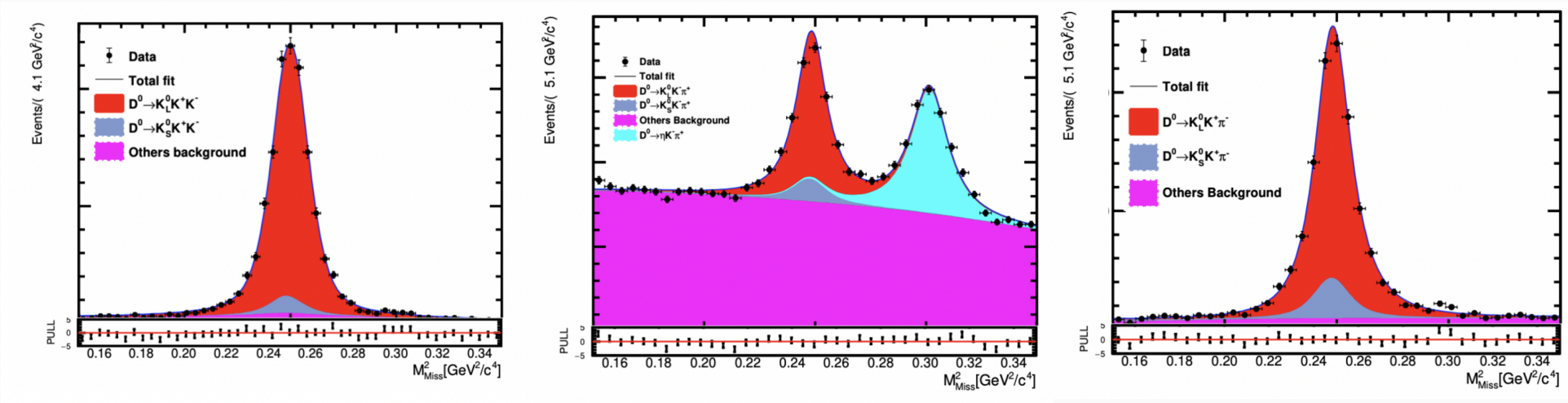




Measurements of BFs of $D^0 \to K^0_L K^+ K^-$, $K^0_L K^- \pi^+$ and $K^0_L K^+ \pi^-$

Data: 8 fb^{-1} $\sqrt{s}$=3.773 GeV (BAM-00859)

$$M^2_{miss} = (\sqrt{s} - E_{K^\pm} - E_{K^\mp,\pi^\mp})^2 - |\vec{P}_{tag} + \vec{P}_{K^\pm} + \vec{P}_{K^\mp,\pi^\mp}|^2$$



Signal mode:

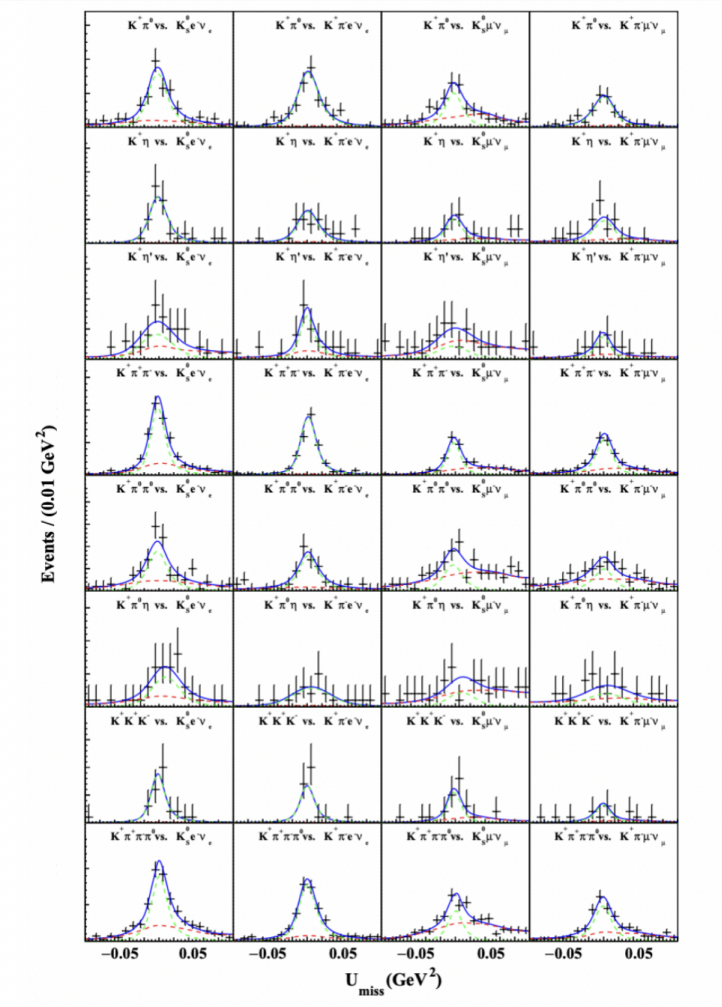
- $D^0 \to K^0_L K^+ K^-$
- $D^0 \to K^0_L K^- \pi^+$
- $D^0 \to K^0_L K^+ \pi$

Tag mode:

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

Measurement of doubly Cabibbo-suppressed D^+ decays with semileptonic tags

Data: 20.3 fb^{-1} $\sqrt{s}$=3.773 GeV charm memo review



$$U_{\rm miss} \equiv \left(E_{\rm beam} - E_{K_S^0/K^+\pi^-} - E_\ell\right) - \left|\vec{p}_D - \vec{p}_{K_S^0/K^+\pi^-} - \vec{p}_\ell\right|,$$

预期产额的构建:

$$N_{\rm SL,DCS} = 2N_{D^+D^-}\mathcal{B}_{\rm SL}\mathcal{B}_{\rm DCS}\epsilon_{\rm SL,DCS}\,,$$

Signal mode:

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

Tag mode:

- $D^- \to K_S^0 e^-\bar{\nu}_e$
- $D^- \to K^+\pi^- e^-\bar{\nu}_e$
- $D^- \to K_S^0\mu^-\bar{\nu}_\mu$
- $D^- \to K^+\pi^-\mu^-\bar{\nu}_\mu$

Measurements of the absolute D^0/D^+ hadronic branching fractions

Data: 20.3 fb^{-1} $\sqrt{s}$=3.773 GeV charm memo review

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