



北京谱仪III上轻标量介子的研究

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第二届强子物理新发展研讨会 暨 强子物理在线论坛100期特别活动

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Content

01

Physics motivation ✓

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Data and analysis method

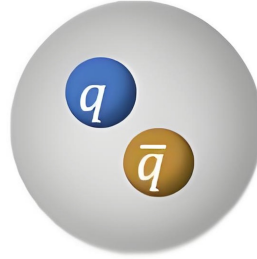
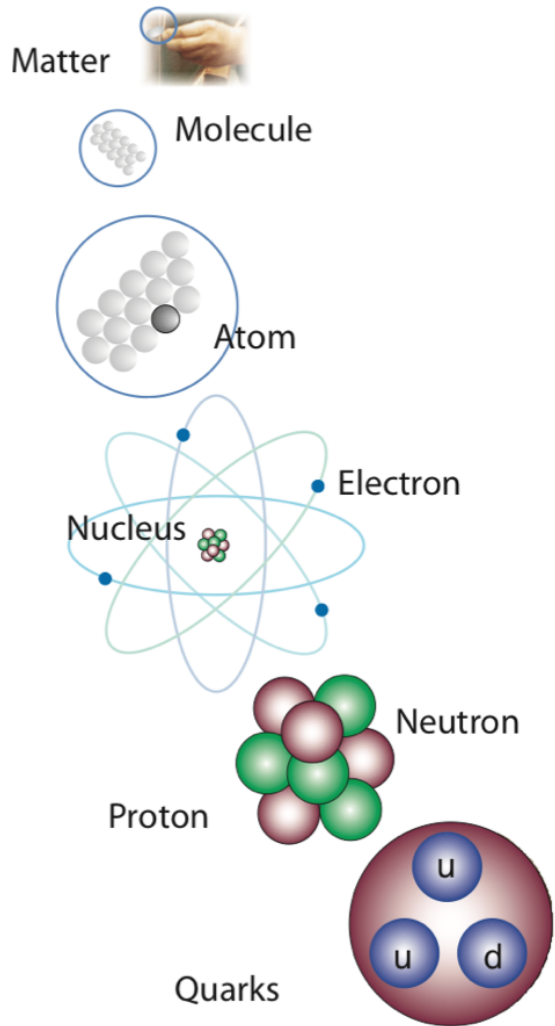
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Summary and prospect

Physics motivation



Meson



Baryon

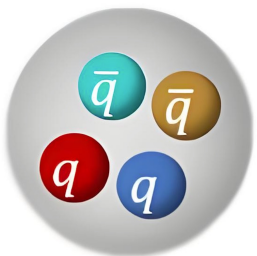
mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	u up	c charm	t top	g gluon	H Higgs boson
	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	d down	s strange	b bottom	γ photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	e electron	μ muon	τ tau	Z Z boson	
	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$1/2$	$1/2$	$1/2$	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

QUARKS

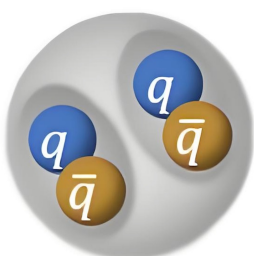
LEPTONS

GAUGE BOSONS

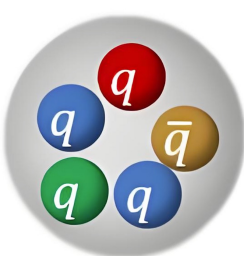
- All matters are made out of quarks and leptons.
- Ordinary hadrons: Meson and Baryon.



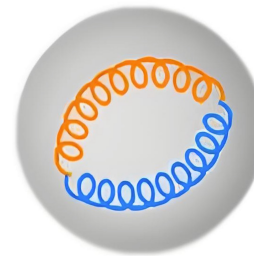
Tetraquark



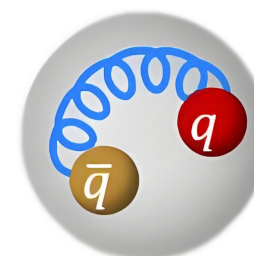
Hadronic molecules



Pentaquark



Glueball



hybrid

➤ Quark model allows for them.

➤ How about scalar mesons:

$f_0(500)$, $K^*(700)$, $f_0(980)$ and $a_0(980)$, etc

→ $q\bar{q}$ mixture, tetraquark, hadronic molecule or hybrid?

Jose R. Pelaez, *Physics Reports* 658 (2016) 1,
**“From controversy to precision on the sigma meson:
a review on the status of the non-ordinary $f_0(500)$ resonance”**

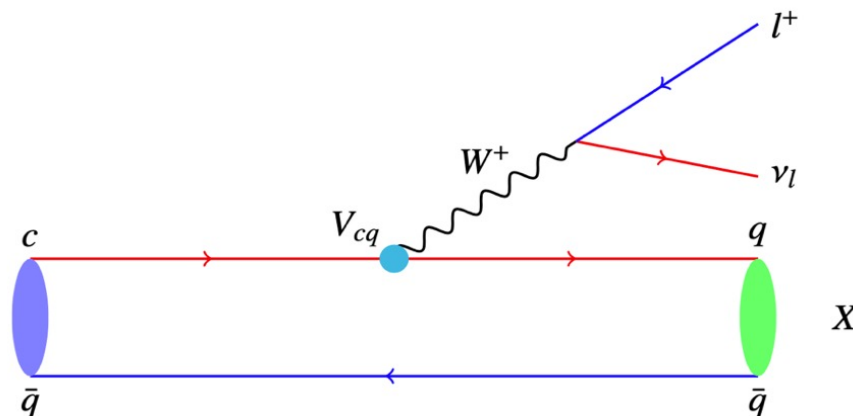
For researchers outside the field, it may be **surprising** that despite having established Quantum Chromodynamics (QCD) as the fundamental theory of the Strong Interaction 40 years ago, the spectrum of lowest mass states, and particularly that of scalar mesons, may be **still under debate**. Actually, light scalar mesons have been a puzzle in our understanding of the Strong Interaction for almost six decades. This may be even **more amazing** given the fact that they play a very relevant role within nuclear and hadron physics, as in the nucleon-nucleon attraction and in the spontaneous breaking of chiral symmetry, both of them fundamental features of the Strong Interaction. The relatively poor theoretical understanding of hadrons at low energies causes little surprise since it is textbook knowledge that QCD becomes non-perturbative at low energies and does not allow for precise calculations of the light hadron spectrum. However, **young** and not so young people outside the field are often **unaware** of the fact that even basic empirical properties such as the existence of many of the lightest mesons and resonances are **still actively discussed**, even if they were suggested much before QCD was proposed. Moreover, it is often the case that

Scalar mesons $f_0(500)$, $K^*(700)$, $f_0(980)$ and $a_0(980)$

- Their nontrivial quark structure has remained controversial for many years!
- Many interpretations: $q\bar{q}$ mixture, tetraquark, molecule, and hybrid etc.
- They play an important role in the dynamics of the spontaneous breaking of QCD chiral symmetry and in the origin of pseudoscalar meson masses.
- They can help to understand the confinement of quarks.

★ Semi-leptonic decay of charmed meson is an ideal probe for their nature!

??? $\Rightarrow$ Why is semi-leptonic decay of charmed meson?



$$\Gamma(D_{(s)} \rightarrow S \ell^+ \nu_\ell) \propto |V_{cd(s)}|^2 |f_+(q^2)|^2 dq^2$$

- **Clean environment:** hadrons X can be separated from leptons pair.
- **High statistics** of charmed meson at experiments.
- Besides, the branching fraction (BF) measurement of semi-leptonic decay can be used to achieve:
 - Hadronic Form factor (FF) measurement $\rightarrow$ **Test different QCD models (LQCD/QCDSR)**
 - $\mathcal{R}_{\mu/e} = \mathcal{B}(D_{(s)} \rightarrow X \mu^+ \nu_\mu) / \mathcal{B}(D_{(s)} \rightarrow X e^+ \nu_e)$ measurement $\rightarrow$ **Test lepton flavor universality (LFU)**

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Data sample

➤ Symmetric e^+e^- collider @2 – 5GeV

➤ Pair-production near threshold

➤ $D\bar{D}$ @3.773GeV

2.93 fb⁻¹ 2010-2011

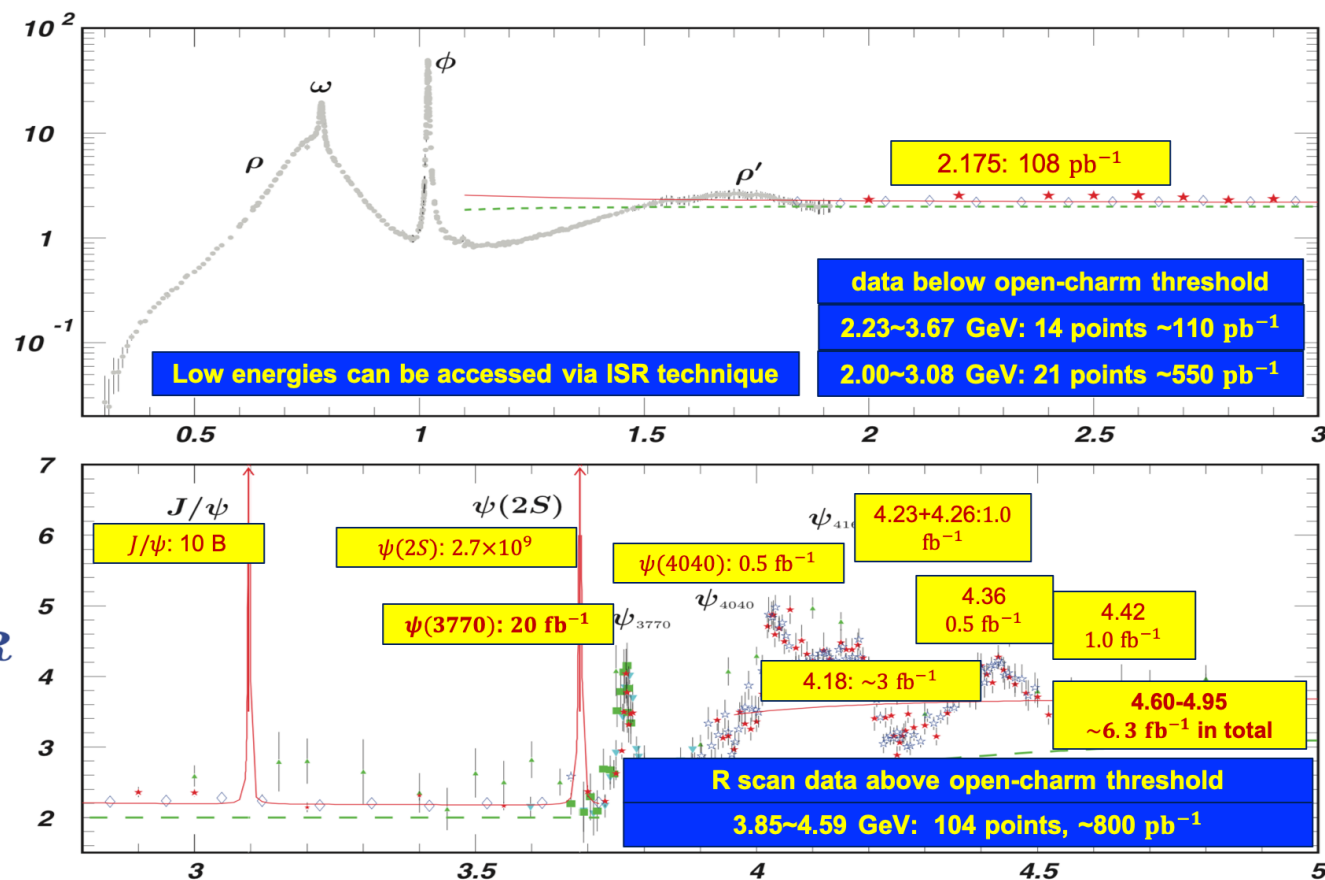
4.99 fb⁻¹ 2021-2022

8.16 fb⁻¹ 2021-2022

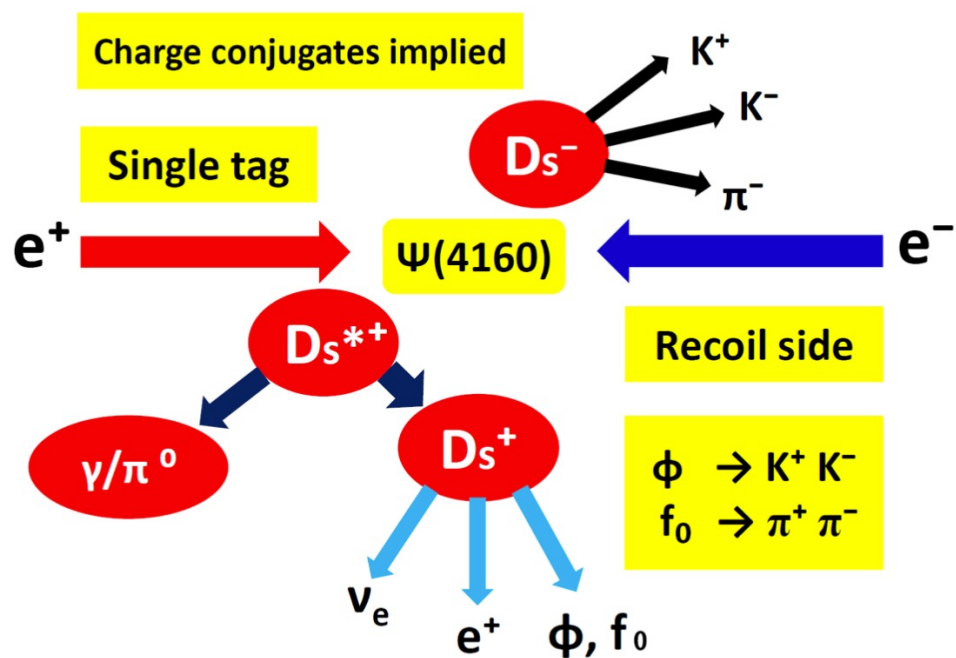
4.19 fb⁻¹ 2022-2024

~20 fb⁻¹ on the $\psi(3770)$ had been collected!

➤ $D_S D_S^*$ @4.13-4.23GeV: 7.33 fb⁻¹



Take Ds decay as an example (complicated case)



$$\mathcal{B}_\gamma(D_S^{*-} \rightarrow \gamma D_S^-)$$

$$N_{tag} = 2N_{D_S^+ D_S^-} \mathcal{B}_{tag} \epsilon_{tag}$$

$$N_{sig} = 2N_{D_S^+ D_S^-} \mathcal{B}_{tag} \mathcal{B}_{sig} \mathcal{B}_\gamma \epsilon_{sig}$$

$$\mathcal{B}_{sig} = \frac{N_{sig}}{\mathcal{B}_\gamma N_{tag} \epsilon_{sig} / \epsilon_{tag}}$$

$$\mathcal{B}_{sig} = \frac{N_{sig}}{\mathcal{B}_\gamma \sum_\alpha N_{tag}^\alpha \epsilon_{sig}^\alpha / \epsilon_{tag}^\alpha}$$

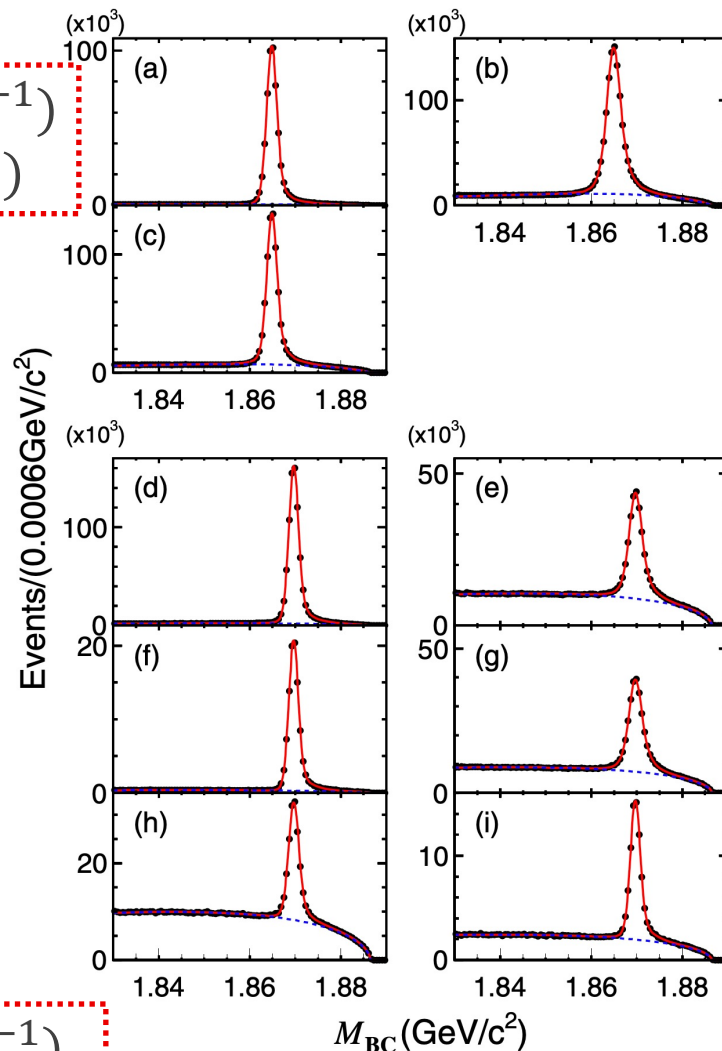
- Mature method
- Absolute BF measurement
- Low background
- Systematic cancellation (tag)

$$U_{miss} = E_{miss} - |\vec{p}_{miss}|$$

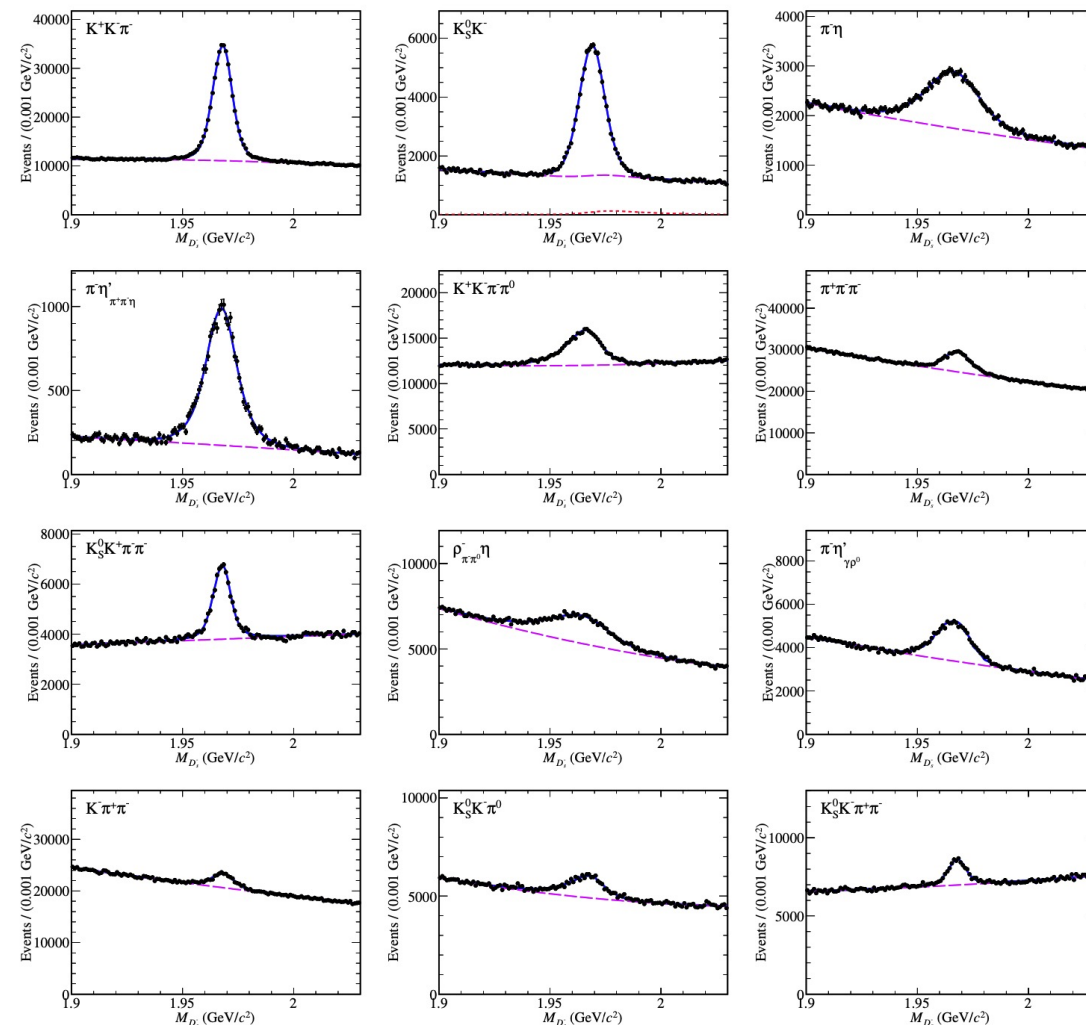
$$M_{miss}^2 = E_{miss}^2 - |\vec{p}_{miss}|^2$$

Analysis method: Single Tag sample

D^0 : ~ 2.76 M (2.93 fb^{-1})
 D^0 : ~ 6.31 M (7.9 fb^{-1})



D^+ : ~ 1.57 M (2.93 fb^{-1})
 D^+ : ~ 4.15 M (7.9 fb^{-1})



D_S : 0.77 M

The differential decay rate of $D_{(s)} \rightarrow S \ell \nu_\ell$

$$\Gamma(D_{(s)} \rightarrow S \ell^+ \nu_\ell)/dq^2 \propto |V_{cd(s)}|^2 |f_+(q^2)|^2$$

$$S: a_0(980), f_0(500), f_0(980)$$

- Use least χ^2 method to fit the measured partial decay width in different q^2 bin.
- Taking the correlations among q^2 bins into account.
- FF in different form (The width needs to be considered ?)

– **Single pole form**

$$f_+(q^2) = \frac{f_+(0)}{1 - q^2/M_{pole}^2}$$

– **Modified pole model**

$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{M_{pole}^2}\right) \left(1 - \alpha \frac{q^2}{M_{pole}^2}\right)}$$

– **ISGW2 model**

$$f_+(q^2) = f_+(q_{max}^2) \left(1 + \frac{r^2}{12} (q_{max}^2 - q^2)\right)^{-2}$$

– **Series expansion model**

$$f_+(t) = \frac{1}{P(t)\Phi(t, t_0)} a_0(t_0) \left(1 + \sum_{k=1}^{\infty} r_k(t_0) [z(t, t_0)]^k\right)$$

The differential decay rate of $D_{(s)} \rightarrow S \ell \nu_\ell$

- Point-like differential decay rate:

$$\frac{d\Gamma(D_{(s)} \rightarrow S \ell^+ \nu_\ell)}{dq^2} = \frac{G_F^2 |V_{cd(s)}|^2}{24\pi^3} p_{f_0}^3 |f_+(q^2)|^2$$

- Double differential decay rate:

(N.N.Achasov *et al.*, PRD102,016022(2020); W. Wang, PLB759,501(2016))

$$\frac{d^2\Gamma(D_{(s)} \rightarrow S \ell^+ \nu_\ell)}{ds dq^2} = \frac{G_F^2 |V_{cd(s)}|^2}{192\pi^4 m_{D_{(s)}}^3} \lambda^{\frac{3}{2}}(m_{D_{(s)}}^2, s, q^2) |f_+(q^2)|^2 P(s)$$

$$P(s) = \begin{cases} \frac{g_1 \rho_{\pi\pi/\pi\eta}}{|m_0^2 - s - i(g_1 \rho_{\pi\pi/\pi\eta} + g_1 \rho_{KK})|^2}, & \text{Flatte: } f_0(980)/a_0(980) \\ \frac{m_{f_0} \Gamma(s)}{(s - m_{f_0}^2)^2 + m_{f_0}^2 \Gamma^2(s)}, & \text{RBW: } f_0(500) \\ \frac{m_r \Gamma_{tot}(s)}{(m_r^2 - s - g_1^2 \frac{s - s_A}{m_r^2 - s_A} Z(s))^2 + m_r^2 \Gamma_{tot}^2(s)}, & \text{Bugg: } f_0(500) \end{cases}$$

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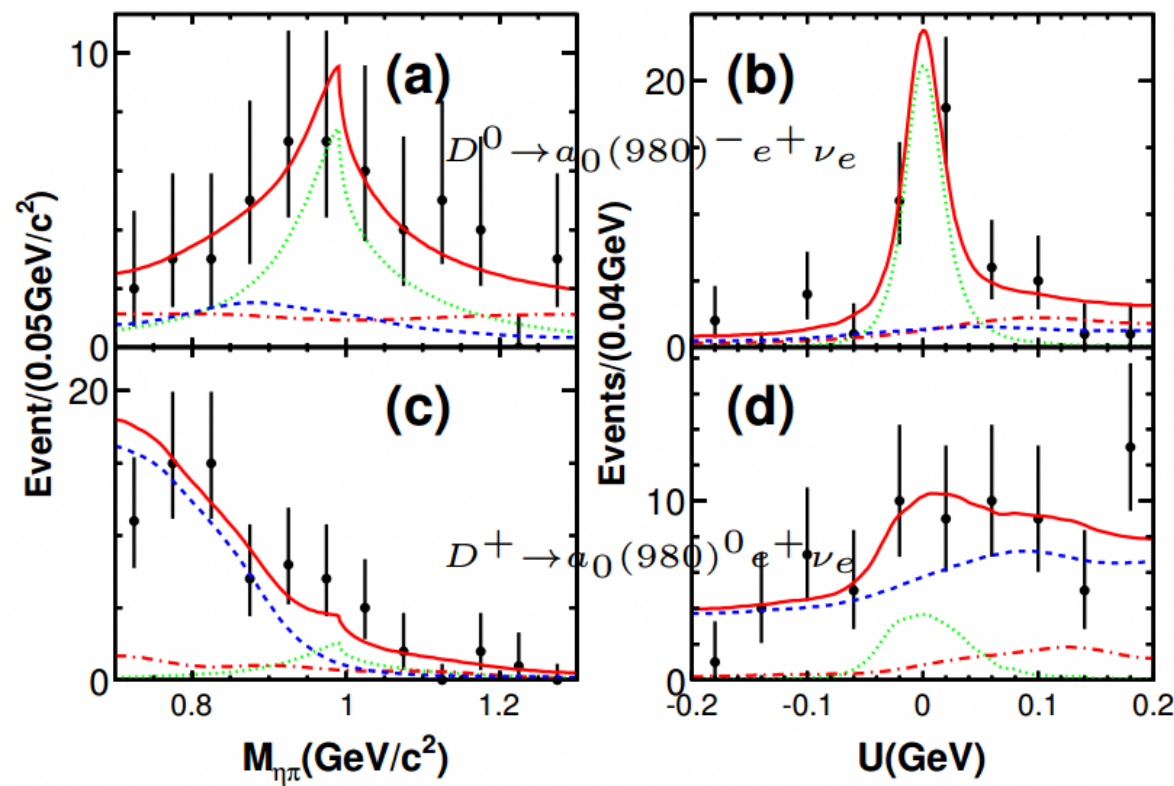
04

Summary and prospect

First observation of $D^0 \rightarrow a_0(980)^- e^+ \nu_e$

Phys. Rev. Lett. 121, 081802 (2018)

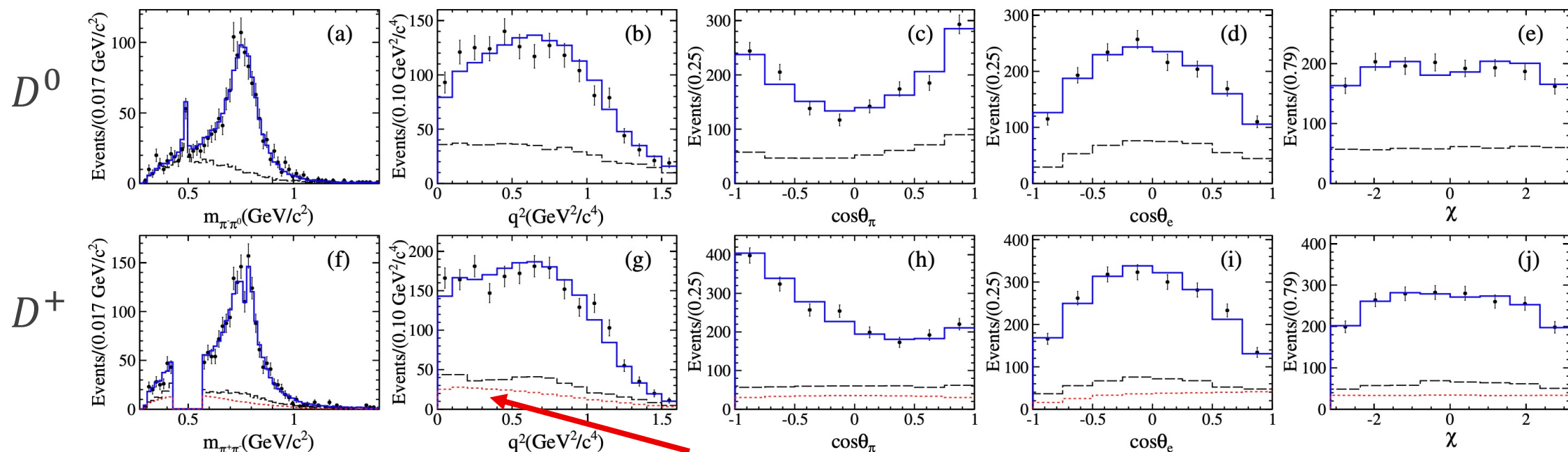
- 2.93 fb⁻¹ data @ 3.773 GeV
- $N_{\text{sig}}^{D^0} = 25.7^{+6.4}_{-5.7}$
- $N_{\text{sig}}^{D^+} = 10.2^{+5.0}_{-4.1}$
- Branching fraction (BF) help to understand the nature of the $a_0(980)$



Decay	BF ($\times 10^{-4}$)	Significance
$D^0 \rightarrow a_0(980)^- e^+ \nu_e, a_0(980)^- \rightarrow \eta \pi^-$	$1.33^{+0.33}_{-0.29} \pm 0.09$	6.4σ
$D^+ \rightarrow a_0(980)^0 e^+ \nu_e, a_0(980)^0 \rightarrow \eta \pi^0$	$1.66^{+0.81}_{-0.66} \pm 0.11$ < 3.0 (90% C.L.)	2.9σ

First observation of $D^+ \rightarrow f_0(500)e^+\nu_e$

Phys. Rev. Lett. 122, 062001 (2019) $|U_{\text{miss}}| < 0.06 \text{ GeV} \rightarrow$ $N_{\text{Event}}^{D^0} = 1498, \text{Bkg: } (33.28 \pm 0.87)\%$
 $N_{\text{Event}}^{D^+} = 2017, \text{Bkg: } (23.82 \pm 0.69)\%$



➤ 2.93 fb^{-1} data @ 3.773 GeV $f_{f_0(500)} = (25.7 \pm 1.6 \pm 1.1)\%$

➤ $R = \frac{\mathcal{B}(D^+ \rightarrow f_0(500)e^+\nu_e) + \mathcal{B}(D^+ \rightarrow f_0(980)e^+\nu_e)}{\mathcal{B}(D^+ \rightarrow a_0(980)e^+\nu_e)} > 2.7 @ 90\% CL$

➤ Favor tetraquark (R=3, PRD82, 034016(2010)) for f_0 and a_0

Signal mode	This analysis ($\times 10^{-3}$)
$D^0 \rightarrow \pi^- \pi^0 e^+ \nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^0 \rightarrow \rho^- e^+ \nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^+ \rightarrow \pi^- \pi^+ e^+ \nu_e$	$2.449 \pm 0.074 \pm 0.073$
$D^+ \rightarrow \rho^0 e^+ \nu_e$	$1.860 \pm 0.070 \pm 0.061$
$D^+ \rightarrow \omega e^+ \nu_e$	$2.05 \pm 0.66 \pm 0.30$
$D^+ \rightarrow f_0(500)e^+\nu_e, f_0(500) \rightarrow \pi^+\pi^-$	$0.630 \pm 0.043 \pm 0.032$
$D^+ \rightarrow f_0(980)e^+\nu_e, f_0(980) \rightarrow \pi^+\pi^-$	< 0.028

Search for the decay $D_s^+ \rightarrow a_0(980) e^+ \nu_e$

Phys. Rev. D. 103, 092004 (2021)

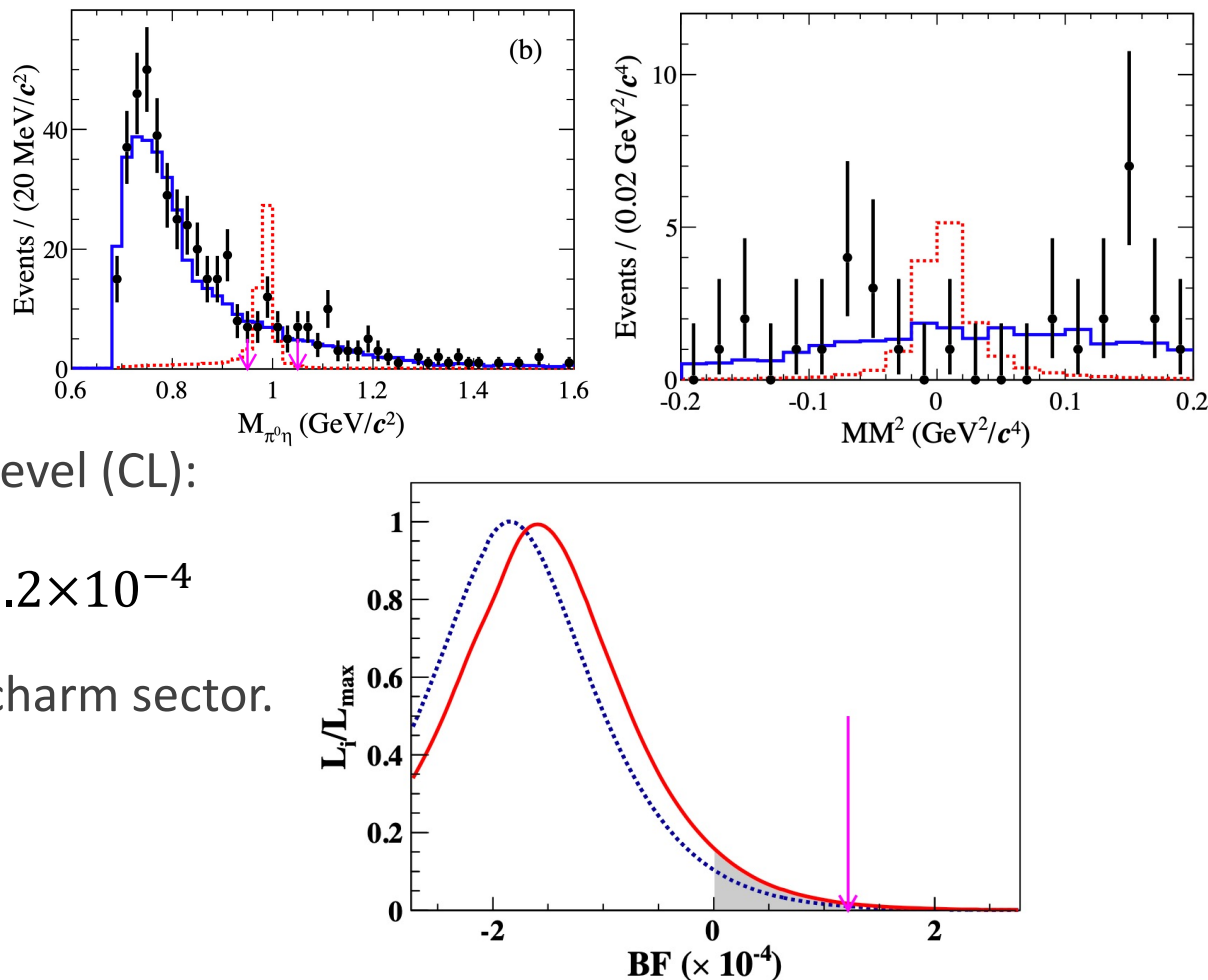
- 6.33 fb⁻¹ data @ 4.178-4.226 GeV
- No significant signal is observed.

An upper limit is determined at 90% confidence level (CL):

$$\mathcal{B}(D_s^+ \rightarrow a_0(980) e^+ \nu_e, f_0(980) \rightarrow \pi^0 \eta) < 1.2 \times 10^{-4}$$

- First study of $a_0(980) - f_0(980)$ mixing in the charm sector.

No obvious isospin violation is observed.



Phys. Rev. D. 105, L031101 (2022)

- 6.32 fb⁻¹ data @ 4.178-4.226 GeV
- $N_{\text{sig}}^{f_0(980)} = 54.8 \pm 10.1$ (7.8 σ significance)

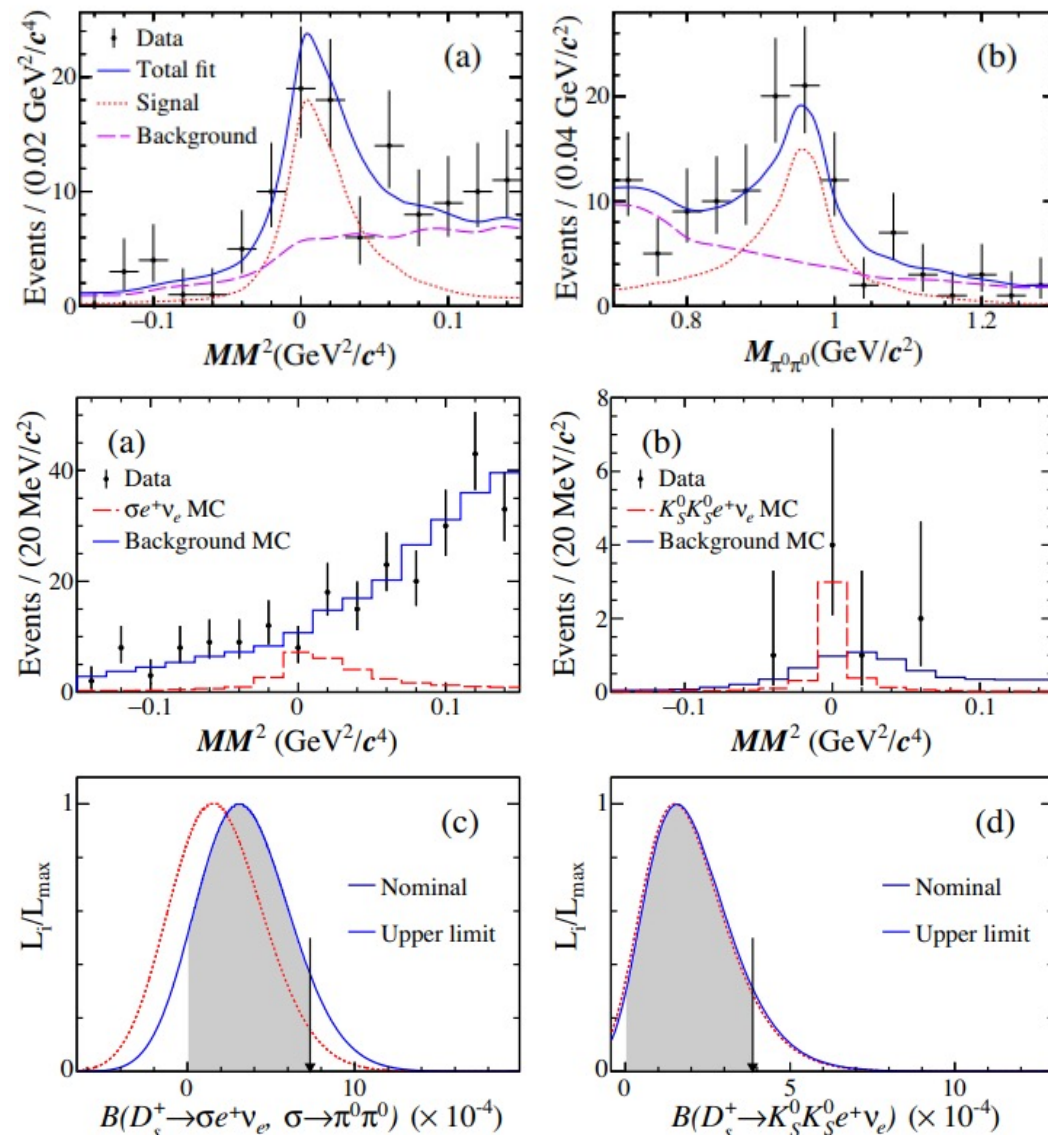
- First BF's Measurement:

$$\begin{aligned} \mathcal{B}(D_s^+ \rightarrow f_0(980)e^+ \nu_e, f_0(980) \rightarrow \pi^0 \pi^0) \\ = (7.9 \pm 1.4 \pm 0.4) \times 10^{-4} \end{aligned}$$

- No significant signal:

$$\begin{aligned} \mathcal{B}(D_s^+ \rightarrow f_0(500)e^+ \nu_e, f_0(500) \rightarrow \pi^0 \pi^0) &< 7.3 \times 10^{-4} \\ \mathcal{B}(D_s^+ \rightarrow K_S^0 K_S^0 e^+ \nu_e) &< 3.8 \times 10^{-4} \end{aligned}$$

- BF's help to understand the nature of the $f_0(500)$ and $f_0(980)$, and test different theoretical calculations.



JHEP12(2023)072

➤ 7.33 fb⁻¹ data @ 4.128-4.226 GeV

➤ $N_{\text{sig}} = 1725 \pm 68$ for BF measurement

$$\mathcal{B}(D_s^+ \rightarrow \phi \mu^+ \nu_\mu) = (2.25 \pm 0.09 \pm 0.07) \times 10^{-2}$$

$$\mathcal{B}(D_s^+ \rightarrow \phi \mu^+ \nu_\mu) / \mathcal{B}(D_s^+ \rightarrow \phi e^+ \nu_e) = 0.94 \pm 0.08 \rightarrow \text{No LFU violation}$$

$$\mathcal{B}(D_s^+ \rightarrow f_0(980) \mu^+ \nu_\mu) \cdot \mathcal{B}(f_0(980) \rightarrow K^+ K^-) < 5.45 \times 10^{-4} @ 90\% \text{ C.L. } (\sim 2.2\sigma)$$

➤ First FF measurement based on single pole parameterization:

➤ Partial wave analysis is performed $\rightarrow \phi$ dominate

➤ μ mass is considered in the formula

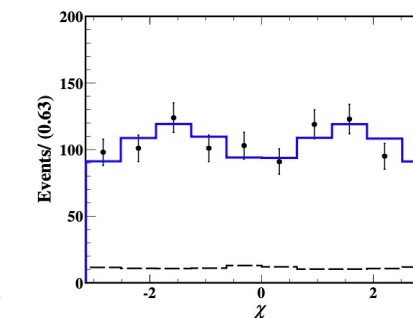
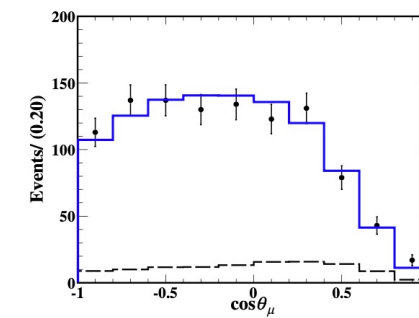
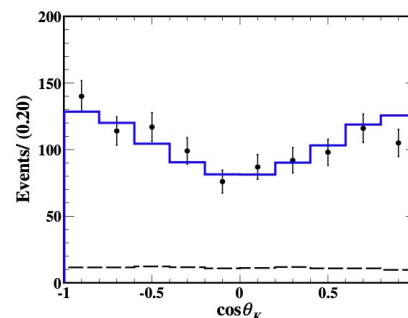
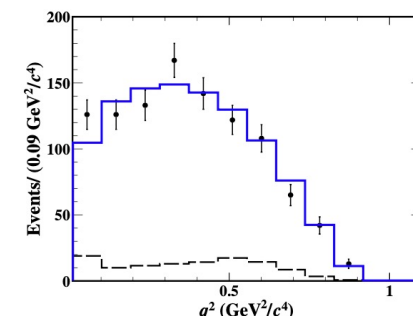
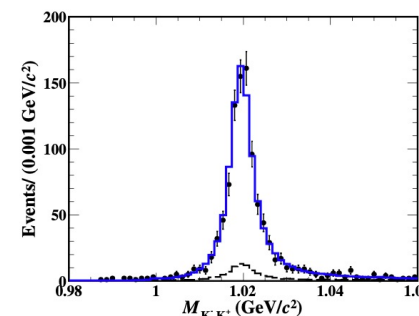
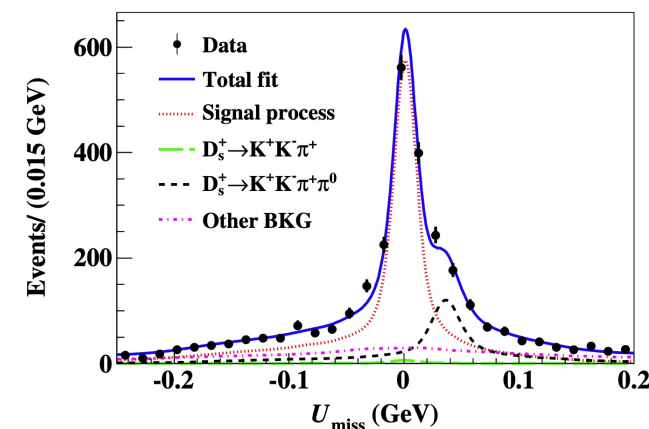


Table 5. Measured FF ratios and comparison with previous measurements.

Experiments	r_V	r_2
PDG [42]	1.80 ± 0.08	0.84 ± 0.11
This analysis	$1.58 \pm 0.17 \pm 0.02$	$0.71 \pm 0.14 \pm 0.02$
BABAR [25]	$1.807 \pm 0.046 \pm 0.065$	$0.816 \pm 0.036 \pm 0.030$
FOCUS [58]	$1.549 \pm 0.250 \pm 0.148$	$0.713 \pm 0.202 \pm 0.284$
Theory	r_V	r_2
CCQM [5]	1.34 ± 0.27	0.99 ± 0.20
CQM [6]	1.72	0.73
LFQM [7]	1.42	0.86
LQCD [3]	1.72 ± 0.21	0.74 ± 0.12
HMχT [8]	1.80	0.52

$|U_{\text{miss}}| < 0.02 \text{ GeV}$
 $N_{\text{Event}}^{D_s^+} = 939, \text{Bkg: } (9.8 \pm 0.7)\%$

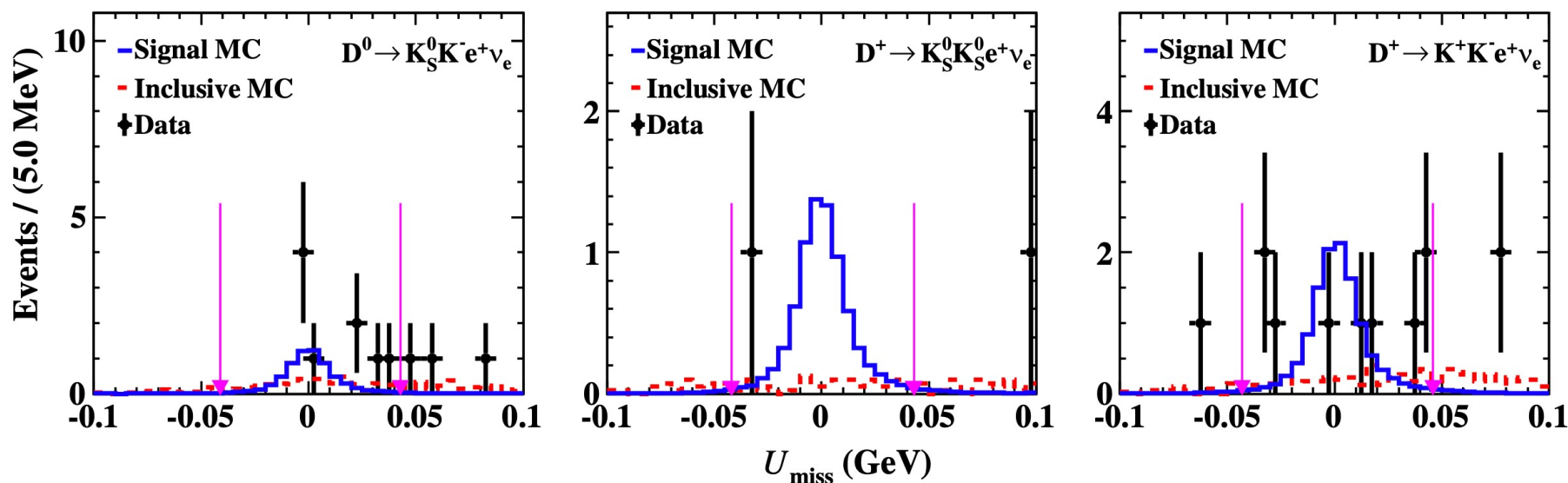
Search for the decay $D \rightarrow K\bar{K}e^+\nu_e$

Phys. Rev. D. 109, 072003 (2024)

- 7.9 fb⁻¹ data @ 3.773 GeV [2010,2011,2021]
- No significant signal is observed, upper limits are determined at 90%CL assuming $a_0(980)$ contribution:

$$\mathcal{B}(D^0 \rightarrow K_S^0 K^- e^+ \nu_e) < 2.13 \times 10^{-5}$$

$$\mathcal{B}(D^+ \rightarrow K_S^0 K_S^0 e^+ \nu_e) < 1.54 \times 10^{-5}, \mathcal{B}(D^+ \rightarrow K^+ K^- e^+ \nu_e) < 2.10 \times 10^{-5}$$



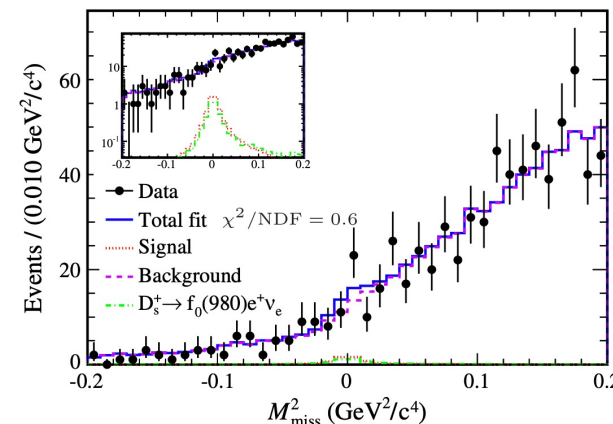
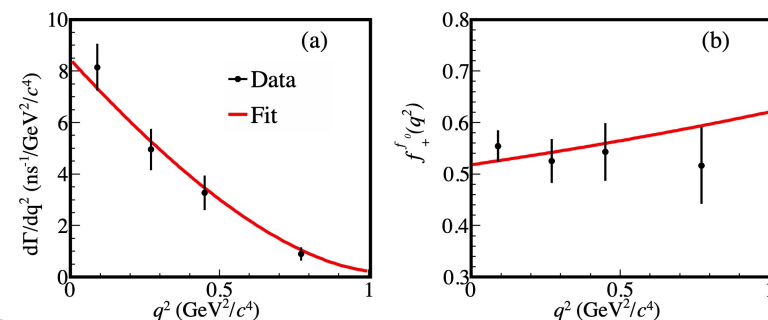
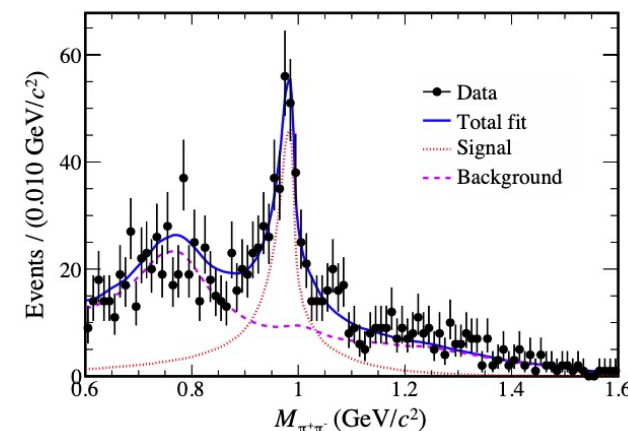


Phys. Rev. Lett. 132, 141901 (2024)

- 7.33 fb^{-1} data @ 4.128-4.226 GeV $\rightarrow N_{\text{sig}} = 439 \pm 33$
- $\mathcal{B}(D_s^+ \rightarrow f_0(980)e^+ \nu_e, f_0(980) \rightarrow \pi^+ \pi^-) = (1.72 \pm 0.13 \pm 0.10) \times 10^{-3}$
 $\rightarrow$ **$s\bar{s}$ is dominant** based on $|f_0(980)\rangle = \sin \phi |\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\rangle + \cos \phi |s\bar{s}\rangle$
 $\phi = (19.7 \pm 12.8)^\circ$
- **First form factor measurement with simple pole form:**
 $\rightarrow f_+^{f_0}(0) |V_{cs}| = 0.504 \pm 0.017 \pm 0.035$
 $\rightarrow f_+^{f_0}(0) = 0.518 \pm 0.018 \pm 0.036$ ($|V_{cs}| = 0.97349 \pm 0.00016$ PDG2022)

	This work	CLFD [6]	DR [6]	QCDSR [7]	QCDSR [8]	LCSR [9]	LFQM [11]	CCQM [12]
$f_+^{f_0}(0)$	$0.518 \pm 0.018_{\text{stat}} \pm 0.036_{\text{syst}}$	0.45	0.46	0.50 ± 0.13	0.48 ± 0.23	0.30 ± 0.03	0.24 ± 0.05	0.36 ± 0.02
Difference (σ)	—	1.7	1.4	0.1	0.2	4.3	4.3	2.8
ϕ	$\phi = (19.7 \pm 12.8)^\circ$	$(32 \pm 4.8)^\circ$	$(41.3 \pm 5.5)^\circ$	35°	$(8_{-8}^{+21})^\circ$	—	$(56 \pm 7)^\circ$	31°

- **First search of $D_s^+ \rightarrow f_0(500)e^+ \nu_e, f_0(500) \rightarrow \pi^+ \pi^-$ ($M_{\pi^+ \pi^-} < 0.45 \text{ GeV}/c^2$)**
- $\mathcal{B}(D_s^+ \rightarrow f_0(500)e^+ \nu_e, f_0(500) \rightarrow \pi^+ \pi^-) < 3.3 \times 10^{-4}$



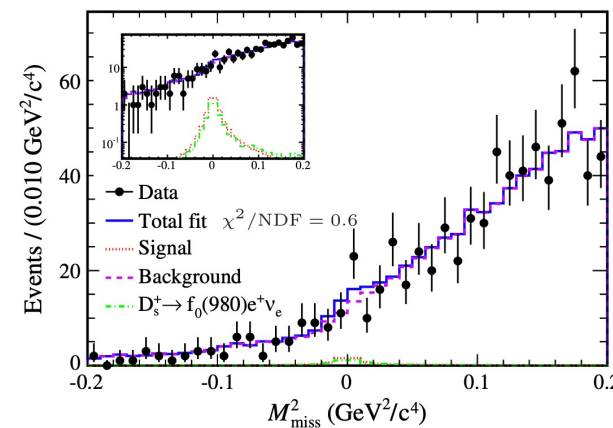
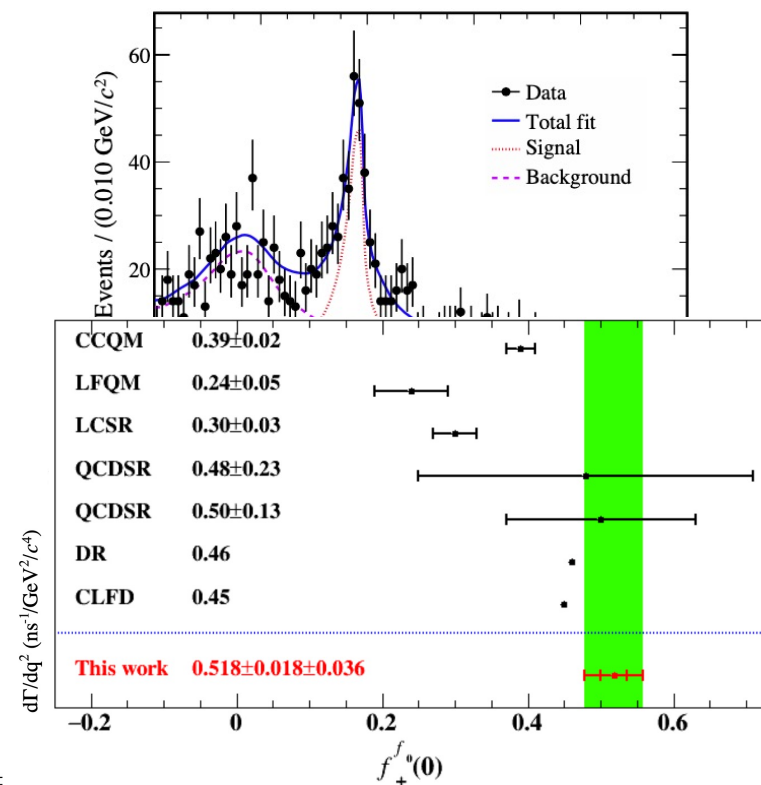


Phys. Rev. Lett. 132, 141901 (2024)

- 7.33 fb^{-1} data @ 4.128-4.226 GeV $\rightarrow N_{\text{sig}} = 439 \pm 33$
- $\mathcal{B}(D_s^+ \rightarrow f_0(980)e^+ \nu_e, f_0(980) \rightarrow \pi^+ \pi^-) = (1.72 \pm 0.13 \pm 0.10) \times 10^{-3}$
 $\rightarrow$ **$s\bar{s}$ is dominant** based on $|f_0(980)\rangle = \sin \phi |\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\rangle + \cos \phi |s\bar{s}\rangle$
 $\phi = (19.7 \pm 12.8)^\circ$
- **First form factor measurement** with simple pole form:
 $\rightarrow f_+^{f_0}(0) |V_{cs}| = 0.504 \pm 0.017 \pm 0.035$
 $\rightarrow f_+^{f_0}(0) = 0.518 \pm 0.018 \pm 0.036$ ($|V_{cs}| = 0.97349 \pm 0.00016$ PDG2022)

	This work	CLFD [6]	DR [6]	QCDSR [7]	QCDSR [8]	LCSR [9]	LFQM [11]	CCQM [12]
$f_+^{f_0}(0)$	$0.518 \pm 0.018_{\text{stat}} \pm 0.036_{\text{syst}}$	0.45	0.46	0.50 ± 0.13	0.48 ± 0.23	0.30 ± 0.03	0.24 ± 0.05	0.36 ± 0.02
Difference (σ)	—	1.7	1.4	0.1	0.2	4.3	4.3	2.8
ϕ	$\phi = (19.7 \pm 12.8)^\circ$	$(32 \pm 4.8)^\circ$	$(41.3 \pm 5.5)^\circ$	35°	$(8_{-8}^{+21})^\circ$	—	$(56 \pm 7)^\circ$	31°

- **First search** of $D_s^+ \rightarrow f_0(500)e^+ \nu_e, f_0(500) \rightarrow \pi^+ \pi^-$ ($M_{\pi^+ \pi^-} < 0.45 \text{ GeV}/c^2$)
- $\mathcal{B}(D_s^+ \rightarrow f_0(500)e^+ \nu_e, f_0(500) \rightarrow \pi^+ \pi^-) < 3.3 \times 10^{-4}$



Study of the decay $D^+ \rightarrow f_0(500)\ell^+\nu_\ell$

arXiv: 2401.13225 (Submitted to PRL)

- 2.93 fb⁻¹ data @ 3.773 GeV
- First observation of $D^+ \rightarrow f_0(500)(\pi^+\pi^-)\mu^+\nu_\mu$.

Signal mode	N_{obs}	$\mathcal{S}$ (σ)	ϵ_{sig} (%)	$\mathcal{B}_{\text{sig}} (\times 10^{-3})$
$f_0(500)\mu^+\nu_\mu$	209 ± 38	5.9	18.93 ± 0.13	0.72 ± 0.13
$\rho^0\mu^+\nu_\mu$	496 ± 38	> 10	19.86 ± 0.13	1.64 ± 0.13
$f_0(500)e^+\nu_e$	412 ± 43	> 10	44.76 ± 0.25	0.60 ± 0.06
$\rho^0e^+\nu_e$	1237 ± 47	> 10	44.12 ± 0.25	1.84 ± 0.07

- First FF measurement of $D^+ \rightarrow f_0(500)(\pi^+\pi^-)\ell^+\nu_\ell$.

(Based Z series expansion for FF and Bugg form for $f_0(500)$)

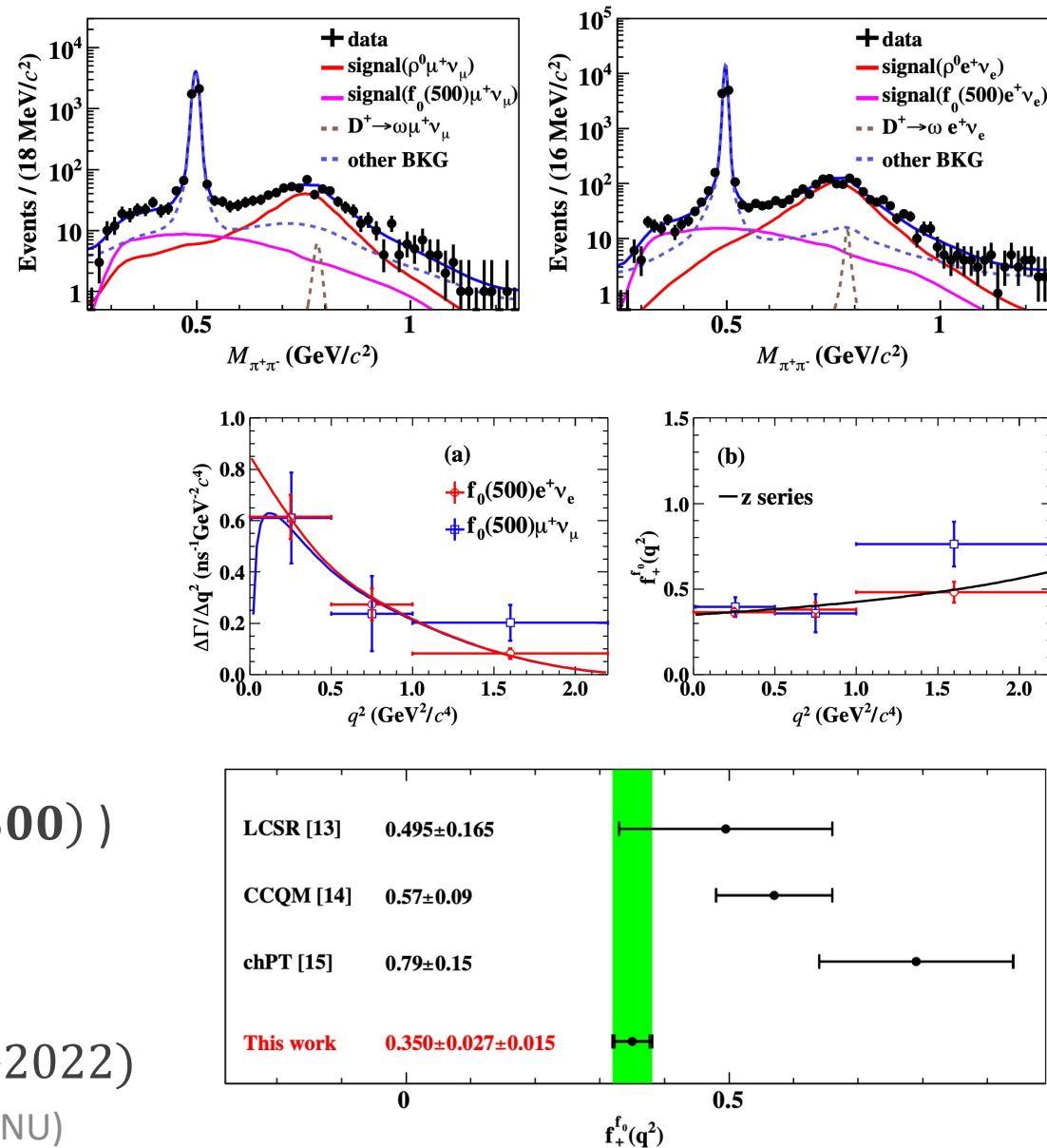
$$\rightarrow f_+^{f_0}(0)|V_{cd}| = 0.0787 \pm 0.0060 \pm 0.0033$$

$$\rightarrow f_+^{f_0}(0) = 0.350 \pm 0.027 \pm 0.015$$

ps: $|V_{cd}| = 0.22438 \pm 0.00044$ from SM global fit (PDG2022)

2024/July/02

Shulei Zhang (HNU)



Content

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Physics motivation ✓

02

Data and analysis method ✓

03

Results in review ✓

04

Summary and prospect ✓

Light scalar mesons via semi-leptonic charm decays at BESIII

Channel	Publication	Status
$D^0 \rightarrow a_0(980)^-(\eta\pi^-)e^+\nu_e$	<i>PRL 121, 081802(2018)</i>	Update in process (Draft review)
$D^+ \rightarrow a_0(980)^0(\eta\pi^0)e^+\nu_e$	<i>PRL 121, 081802(2018)</i>	Update in process (Group review)
$D \rightarrow a_0(980)(\eta\pi)\mu^+\nu_\mu$	No	In process (Group review)
$D \rightarrow a_0(980)(K\bar{K})e^+\nu_e$	<i>PRD 109, 072003(2024)</i>	Published
$D^+ \rightarrow f_0(500)(\pi^+\pi^-)e^+\nu_e$	<i>PRL 122, 062001(2019)</i>	Update in process (Group review)
$D^+ \rightarrow f_0(500)(\pi^+\pi^-)\mu^+\nu_\mu$	<i>arXiv: 2401.13225</i>	Submitted to PRL
$D^+ \rightarrow f_0(980)(\pi^+\pi^-)e^+\nu_e$	<i>PRL 122, 062001(2019)</i>	Update in process (Group review)
$D_s^+ \rightarrow a_0(980)^0(\eta\pi^0)e^+\nu_e$	<i>PRD 103, 092004(2021)</i>	Published
$D_s^+ \rightarrow f_0(980)(\pi^0\pi^0)e^+\nu_e$	<i>PRD 105, L031101(2022)</i>	Published
$D_s^+ \rightarrow f_0(500)(\pi^0\pi^0)e^+\nu_e$	<i>PRD 105, L031101(2022)</i>	Published
$D_s^+ \rightarrow f_0(980)(\pi^+\pi^-)e^+\nu_e$	<i>PRL 132, 141901(2024)</i>	Published
$D_s^+ \rightarrow f_0(980)(\pi^+\pi^-)\mu^+\nu_\mu$	No	In process (Memo review)
$D_s^+ \rightarrow f_0(980)(K^+K^-)e^+\nu_e$	No	In process (Draft review)
$D_s^+ \rightarrow f_0(980)(K^+K^-)\mu^+\nu_\mu$	<i>JHEP12(2023)072</i>	Published

Summary:

- BESIII has the largest data samples at $D\bar{D}/D_S D_S^*$ threshold.
- Light scalar mesons are studied systematically via semi-leptonic charm decays.
- BF and FF measurements help to understand the nature of light scalar mesons.

Prospect:

- BESIII has **20 fb⁻¹** @3.773 GeV in total now.
- More scalar mesons could be studied via semi-leptonic charm decays.
 - $K^*(700)$, $K_0^*(1430)$, $f_0(1370)$, $f_0(1500)$, $a_0(1450)$
- More results are on the way!

Thank you!