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Light Scalar Mesons in Semi-leptonic Decay of Charm Meson at BESIII

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第七届强子谱与强子结构会议

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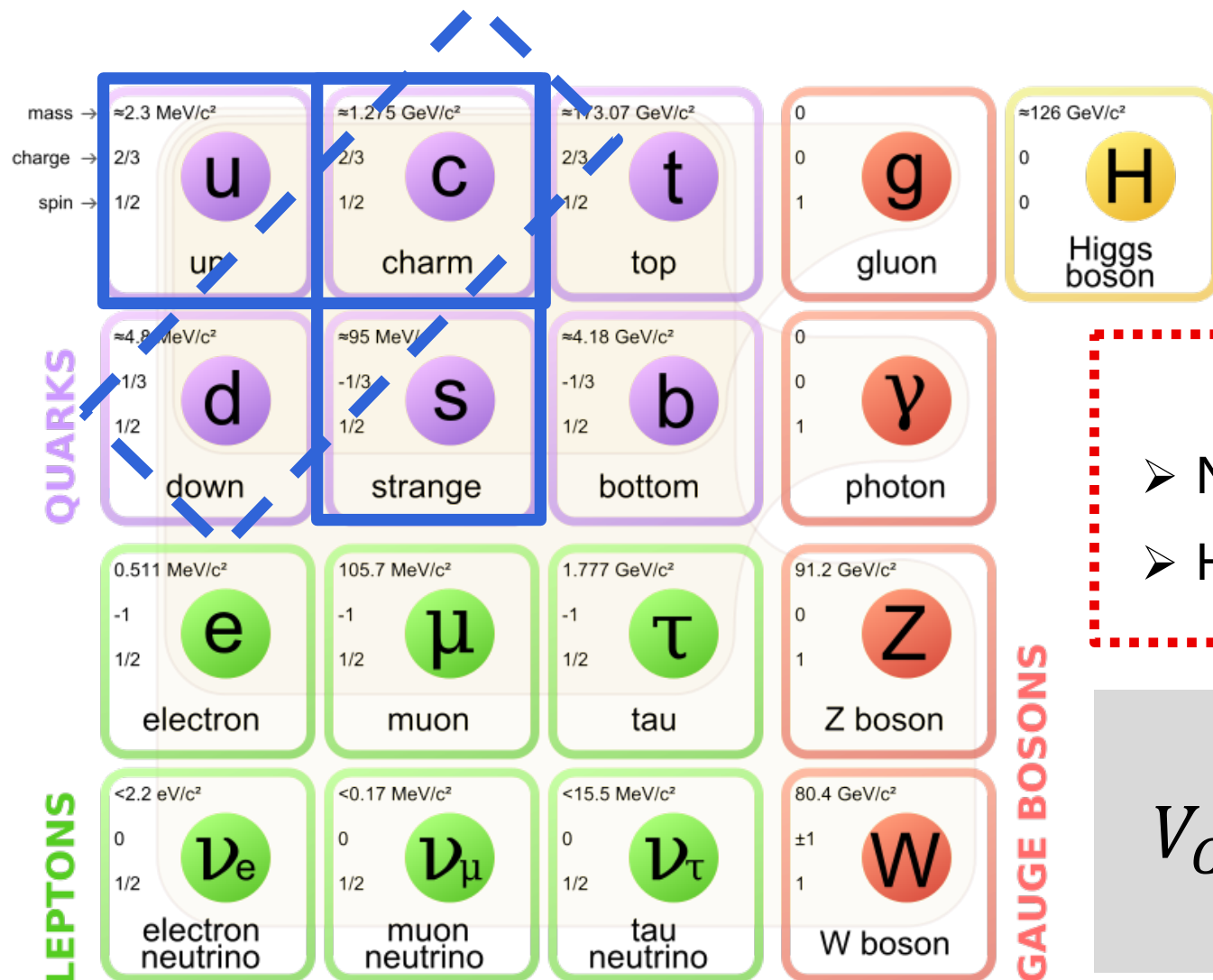
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Summary and prospect



Charm physics

- Nonperturbative region -> **QCD**
- High precision frontier -> **SM test**

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



➤ Hadronic **Form factor (FF)** -> **Test different QCD models (LQCD/QCDSR)**

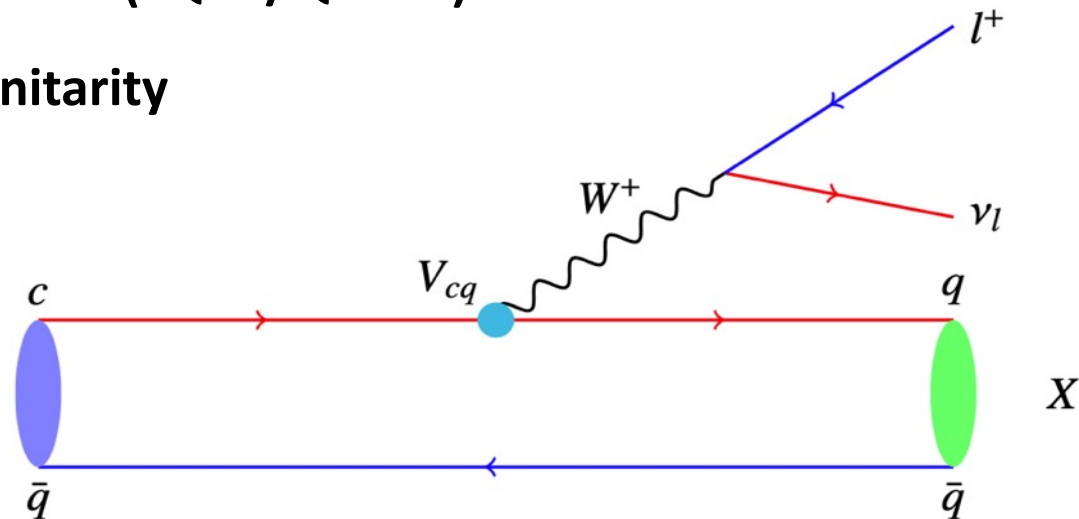
➤ CKM matrix elements $V_{cd(s)}$ -> **Test CKM matrix unitarity**

➤ $\mathcal{B}(D_{(s)} \rightarrow X \mu^+ \nu_\mu) / \mathcal{B}(D_{(s)} \rightarrow X e^+ \nu_e)$

-> **Lepton flavor universality (LFU) test.**

➤ Branching fraction and FF measurement

-> **Good laboratory for light scalar mesons study**



$$A(D \rightarrow X \ell \nu) = \frac{G_F}{\sqrt{2}} V_{cq}^* \nu \gamma_\mu (1 - \gamma_5) \ell \langle X | \bar{q} \gamma^\mu (1 - \gamma_5) c | D_{(s)} \rangle$$

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

$$\Gamma(D_{(s)} \rightarrow V \ell^+ \nu_\ell) \propto |V_{cd(s)}|^2 \mathfrak{I}(A_1(q^2), A_2(q^2), V(q^2)) dq^2$$

Light scalar mesons $f_0(500)$, $f_0(980)$ and $a_0(980)$

- Play an important role in the dynamics of the spontaneous breaking of QCD chiral symmetry and in the origin of pseudoscalar meson masses.
- Help to understand the confinement of quarks.
- Their nontrivial quark structure has remained controversial for many years!
- Interpretations: $q\bar{q}$ mixture; tetraquark; molecule, etc.
- Semi-leptonic D decay is an ideal probe for their nature.

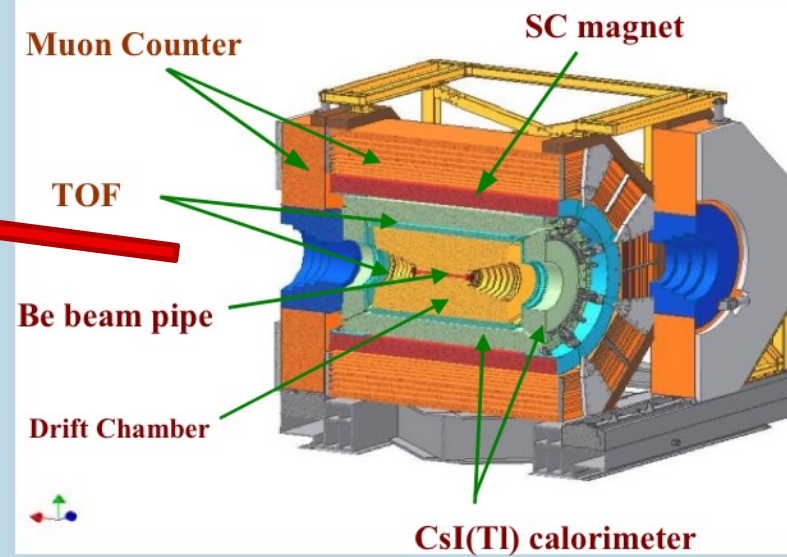
Jose R. Pelaez, *Physics Reports* 658 (2016) 1,
**“From controversy to precision on the sigma meson:
a review on the status of the non-ordinary $f_0(500)$ resonance”**

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

BESIII experiment

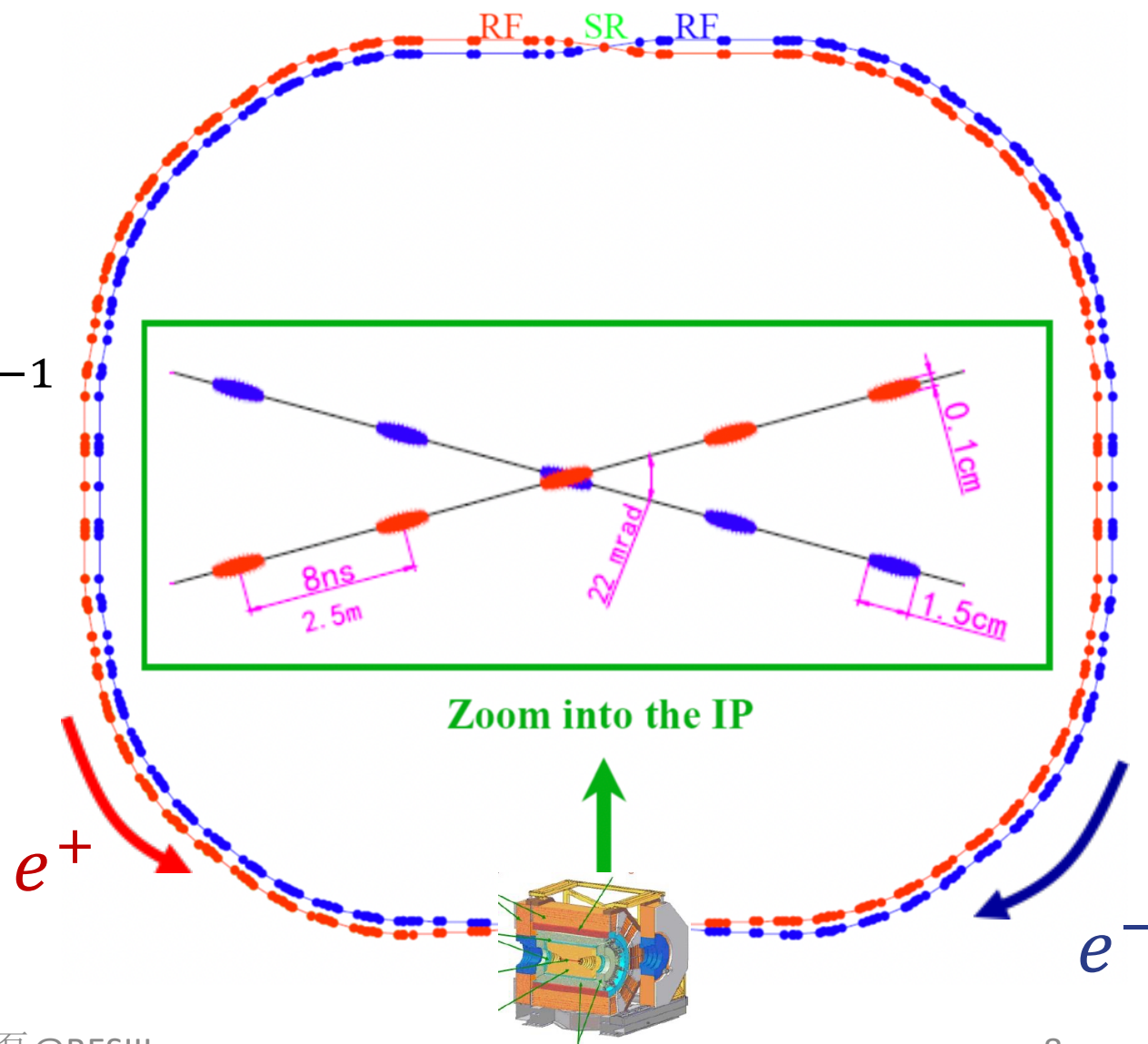


BESIII Detector

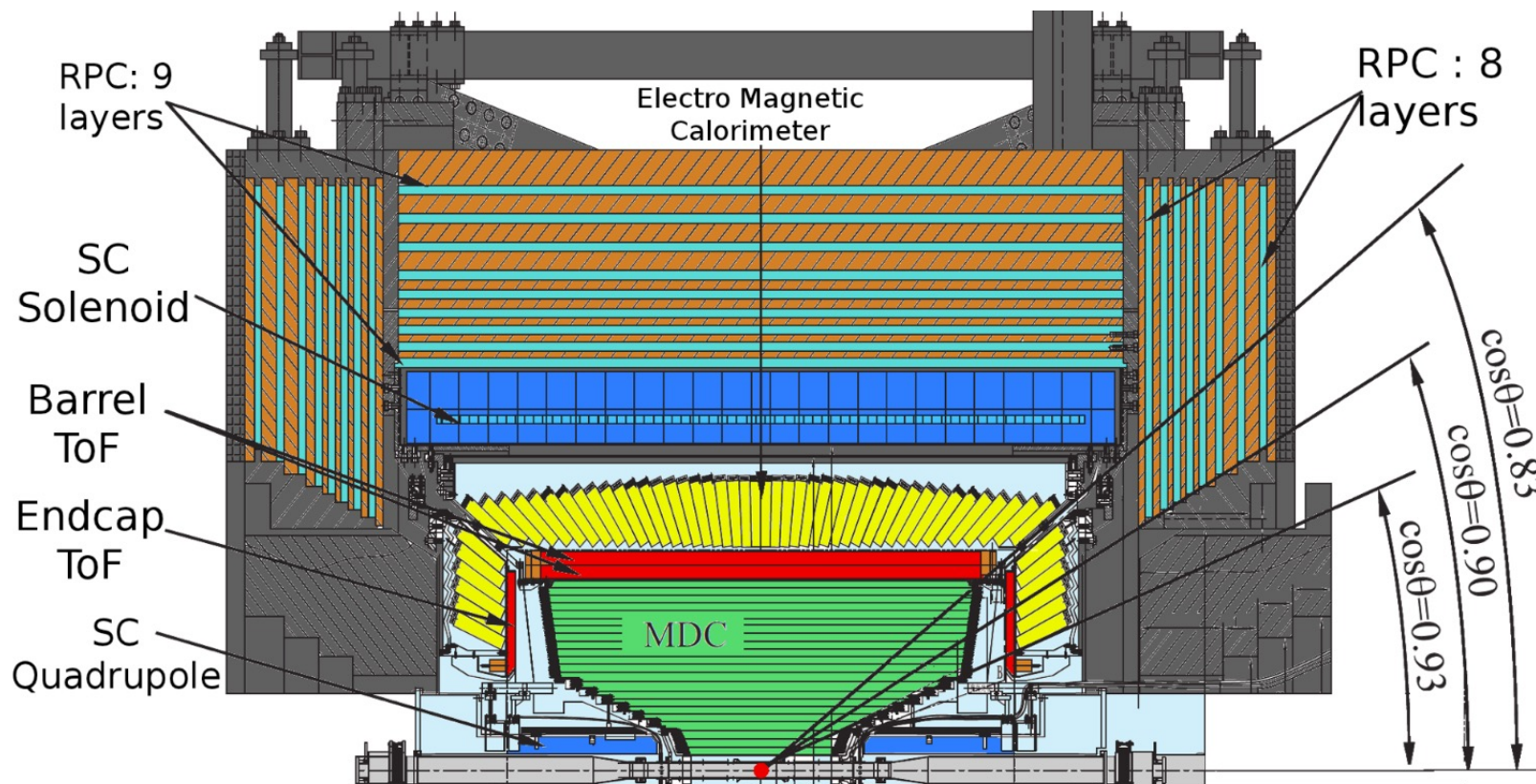


BEPCII collider

- Two ring symmetric e^+e^- collider
- Circumference: 240 m
- Design luminosity: $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
- Achieved time: 5 April, 2016
- E_{cm} : 2 – 5 GeV
- Beam crossing angle: 22 mrad



BESIII detector



MDC

$$\frac{\delta p}{p} < 0.5\% \text{ @1 GeV}$$

$$\frac{\delta(dE/dx)}{dE/dx} < 6\%$$

TOF

$$\delta t \text{ 80 ps Barrel}$$

$$\delta t \text{ 110 ps Endcap}$$

EMC

$$\frac{\delta E}{E} < 2.5\% \text{ @1 GeV}$$

$$\delta z = 0.6/\sqrt{E}$$

MUC

$$\delta(xy) < 2 \text{ cm}$$

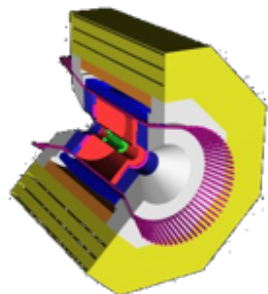
BESIII Collaboration

Political Map of the World, November 2011

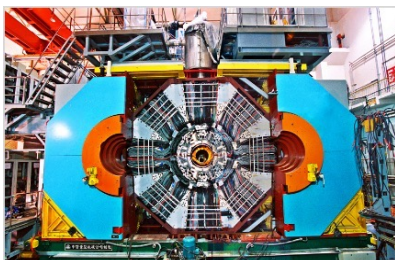


Data sample

CLEO-c



BESIII



- Symmetric e^+e^- collider
- E_{cm} : 2 – 5 GeV
- Charm collected through pair-production near threshold

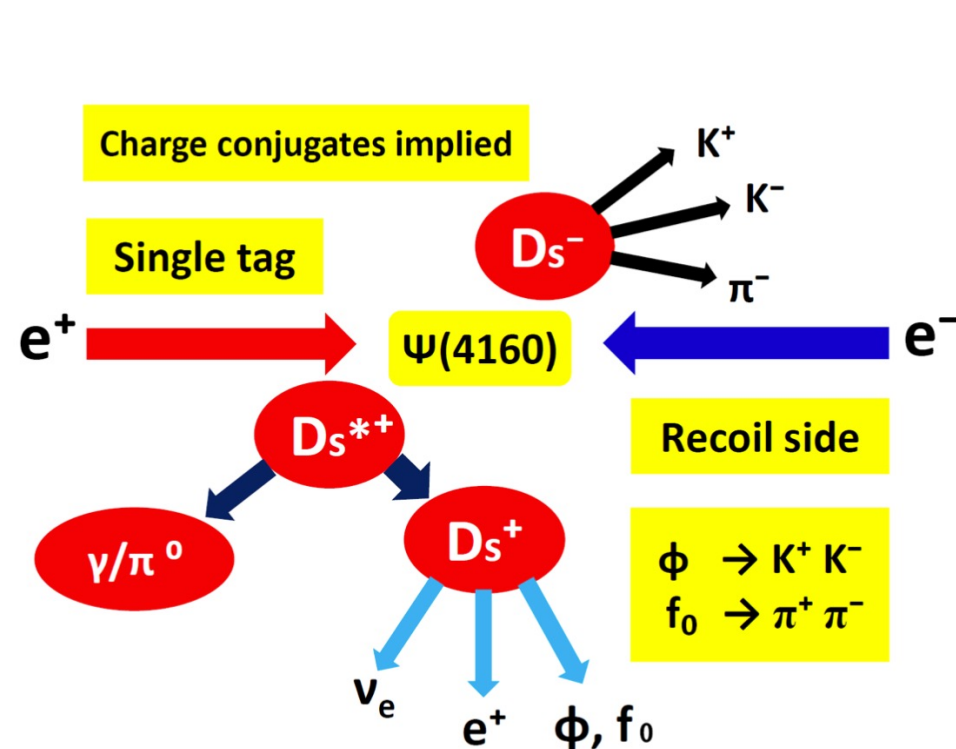


Belle, Belle-II

- Asymmetric e^+e^- collider
- E_{cm} : 10.8 GeV
- Charm collected through $b\bar{b}$ decays and $c\bar{c}$

Experiment	Data size	Energy region	Time
BESIII	$D^{+(0)}: 7.9 \text{ fb}^{-1}$ $D_s^+: 7.33 \text{ fb}^{-1}$	3.773 GeV 4.123-4.223 GeV	2010/2011/2021 2013-2017
CLEO-c	$D^{+(0)}: 0.82 \text{ fb}^{-1}$ $D_s^+: 0.6 \text{ fb}^{-1}$	3.770 GeV 4.170 GeV	Till 2008
BABAR	468 fb^{-1}	Near $\Upsilon(4S)$	Till 2008
Belle	976 fb^{-1}	Near $\Upsilon(4S)$	Till 2010

Take Ds decay as an example (complicated case)



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

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

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

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

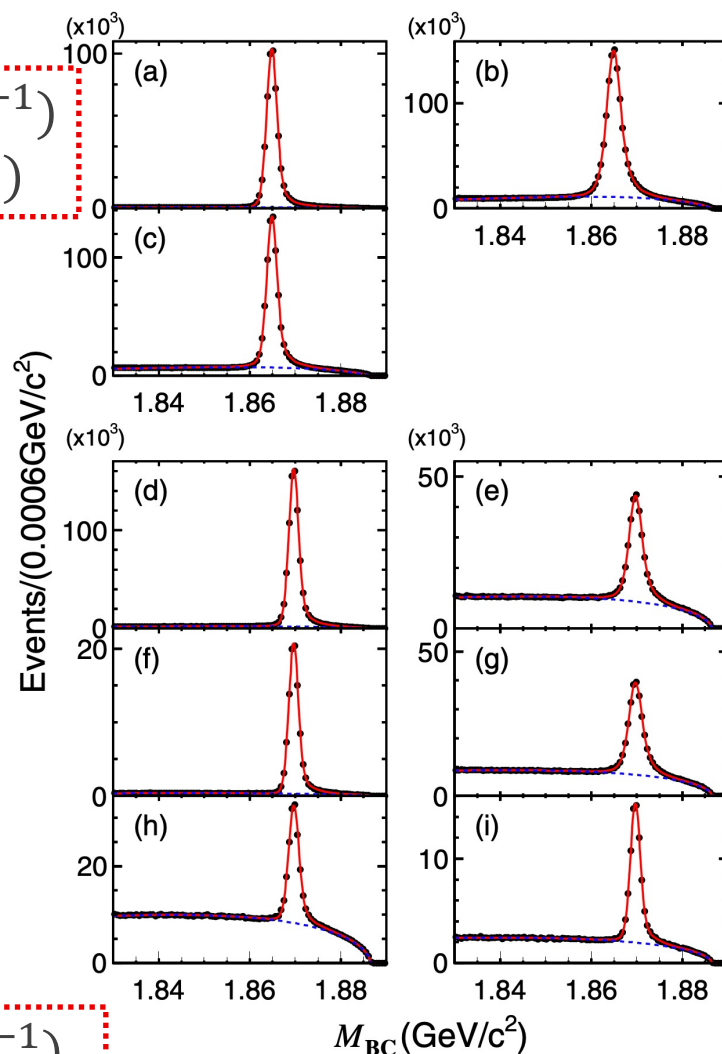
$$\mathcal{B}_{sig} = \frac{N_{sig}}{\mathcal{B}_\gamma \sum_\alpha N_{tag}^\alpha \epsilon_{sig}^\alpha / \epsilon_{tag}^\alpha}$$

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

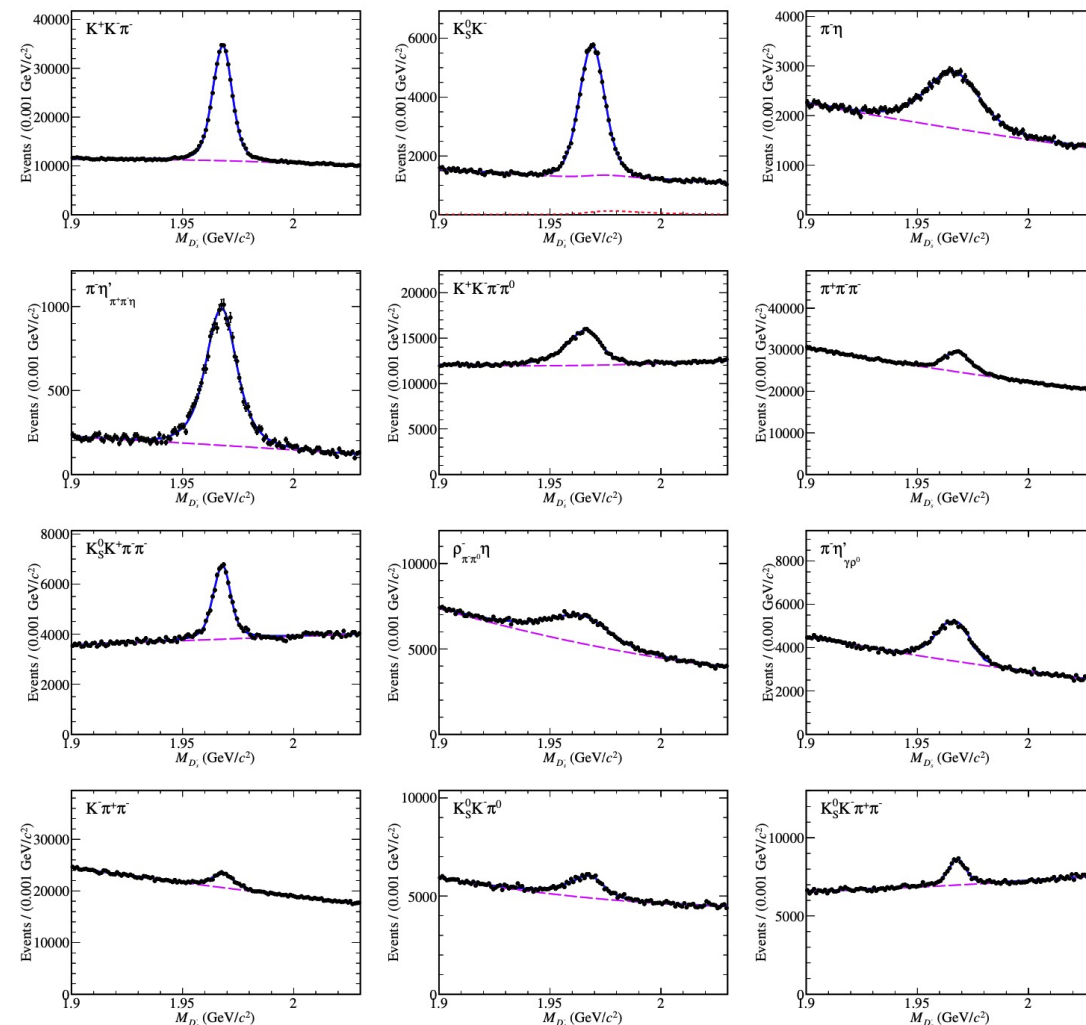
$$M_{miss}^2 = E_{miss}^2 - |\vec{p}_{miss}|^2$$

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))

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

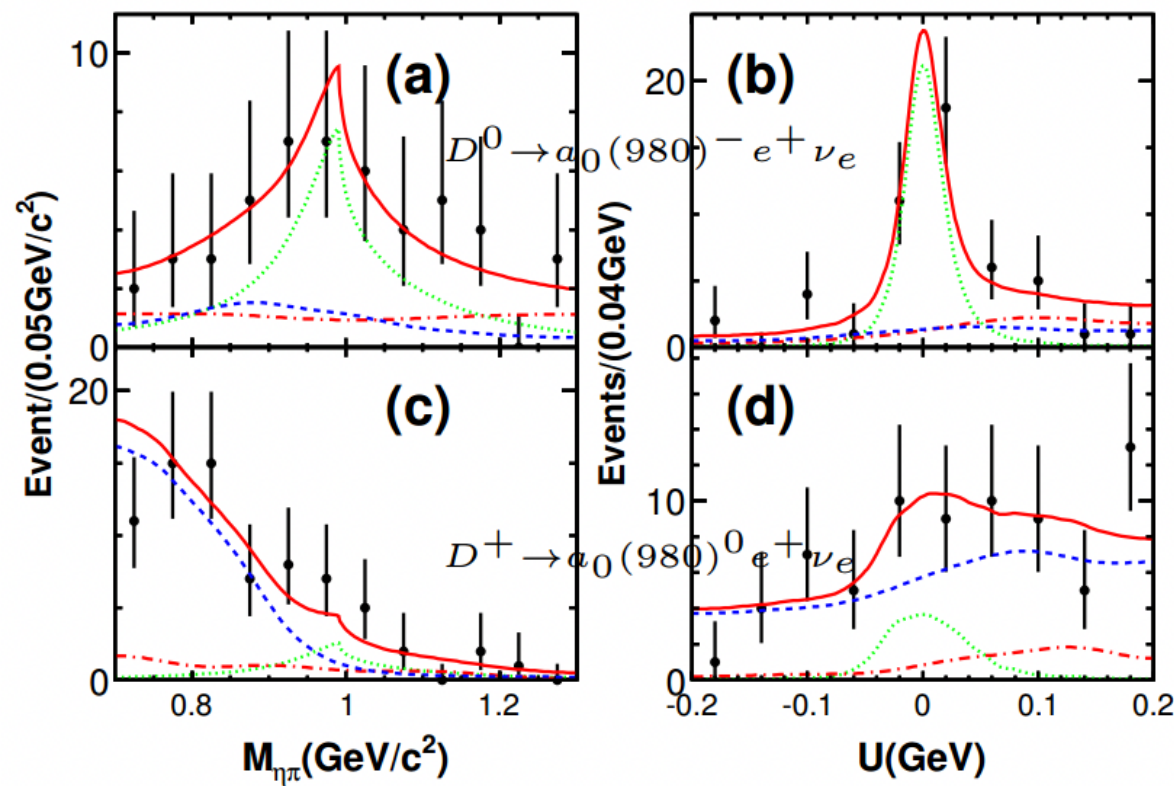
$$P(s) = \begin{cases} \frac{g_1 \rho_{\pi\pi/\pi\eta}}{|m_0^2 - s - i(g_1 \rho_{\pi\pi/\pi\eta} + g_1 \rho_{KK})|^2}, & \text{Flatte: } f_0(980)/a_0(980) \\ \frac{m_{f_0} \Gamma(s)}{(s - m_{f_0}^2)^2 + m_{f_0}^2 \Gamma^2(s)}, & \text{RBW: } f_0(500) \\ \frac{m_r \Gamma_{tot}(s)}{(m_r^2 - s - g_1^2 \frac{s-s_A}{m_r^2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



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
- $N_{sig}^{D^0} = 25.7^{+6.4}_{-5.7}$
- $N_{sig}^{D^+} = 10.2^{+5.0}_{-4.1}$
- BFs 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

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

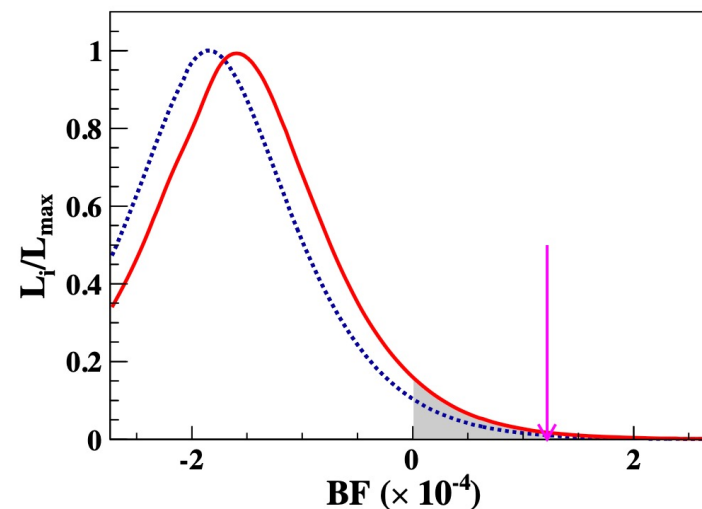
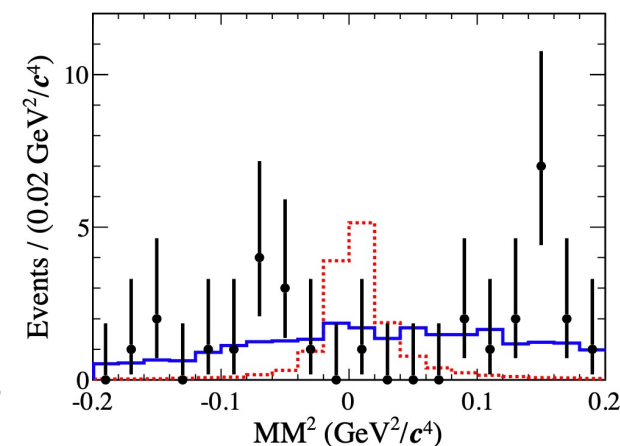
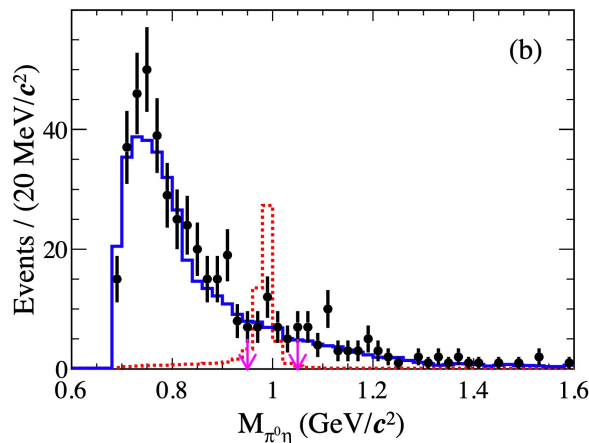
➤ No significant signal is observed.

An upper limit is determined at 90%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.



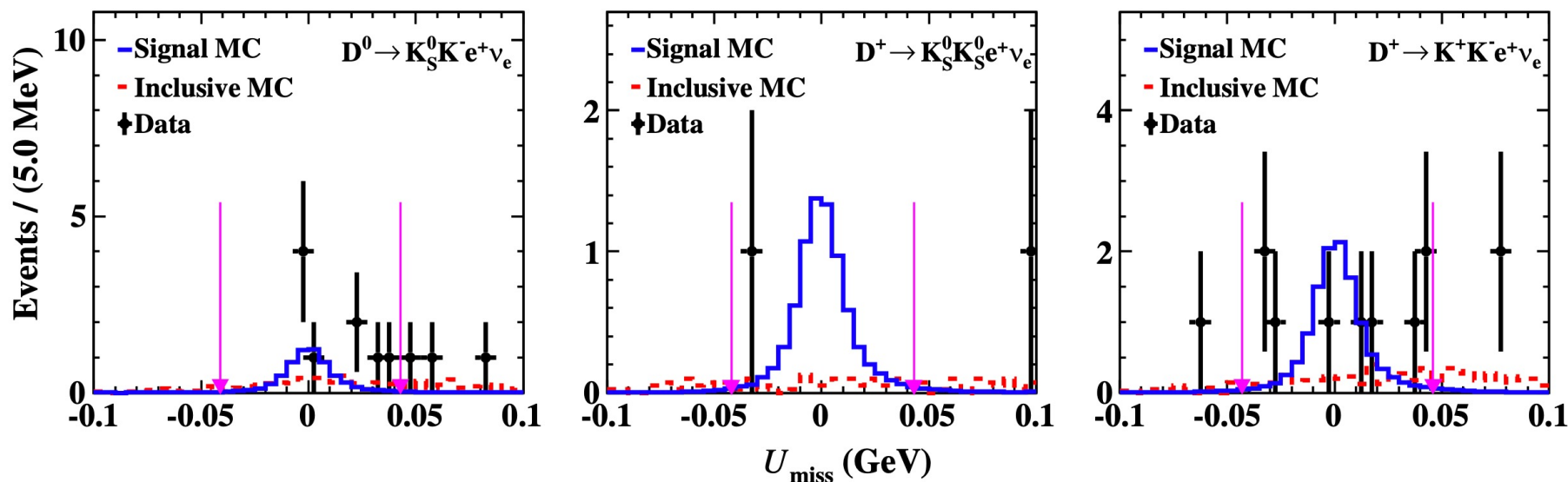
Search for the decay $D \rightarrow K\bar{K}e^+\nu_e$

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:

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

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

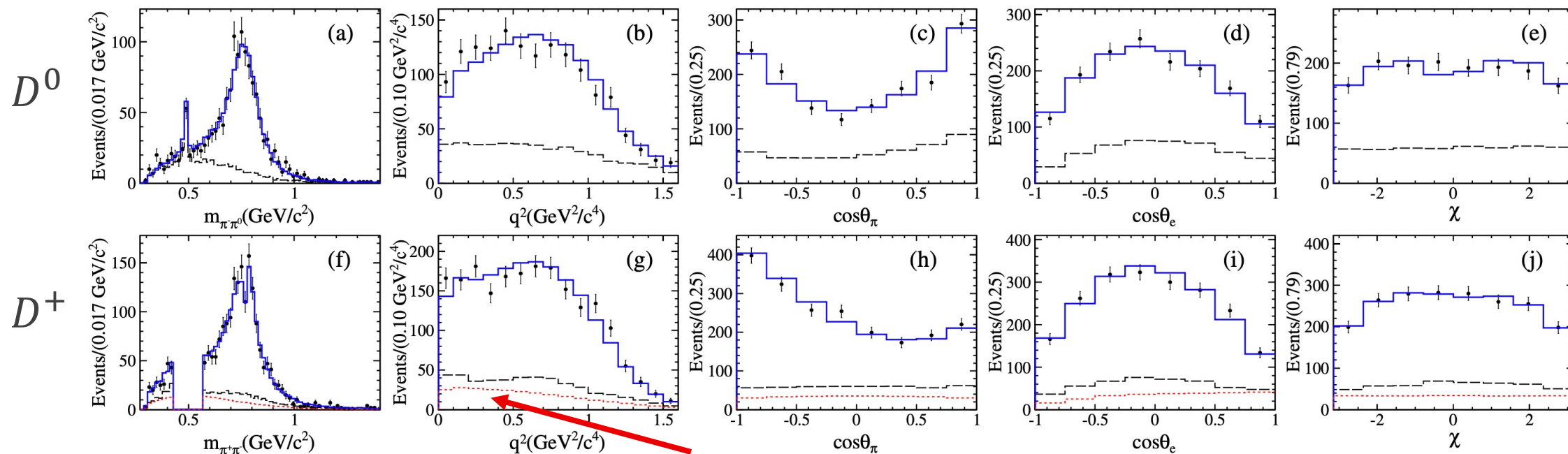


First observation of $D^+ \rightarrow f_0(500)e^+\nu_e$

Phys. Rev. Lett. 122, 062001 (2019)

$$N_{sig}^{D^0} = 1498 \text{ (Bkg: } \sim 33.3\%)$$

$$N_{sig}^{D^+} = 2017 \text{ (Bkg: } \sim 23.8\%)$$



➤ 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

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 $f_0(500)$)

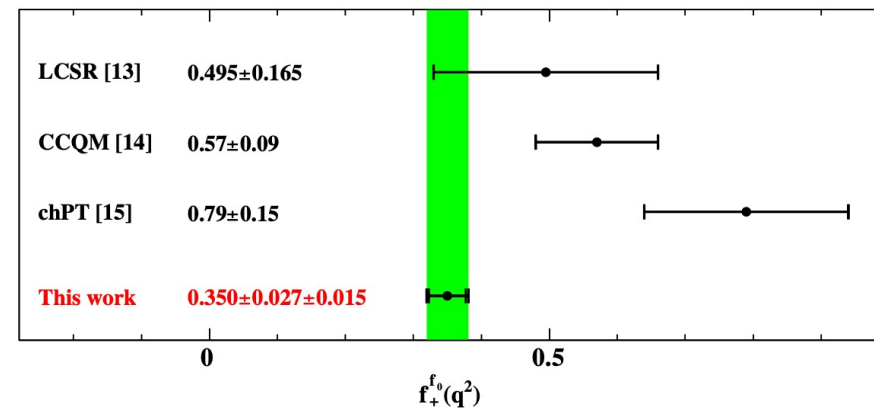
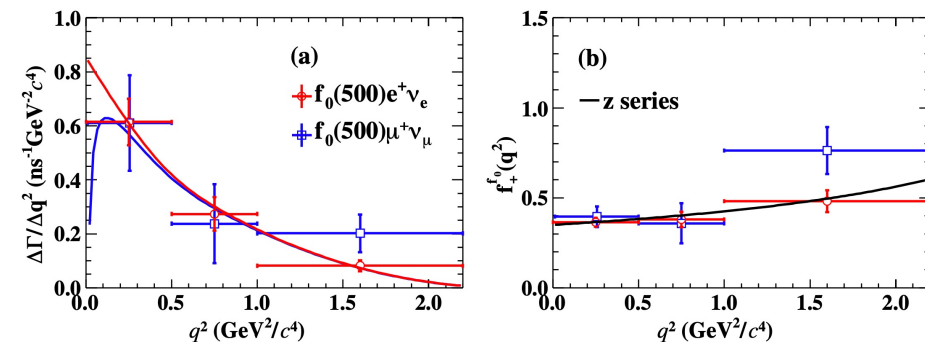
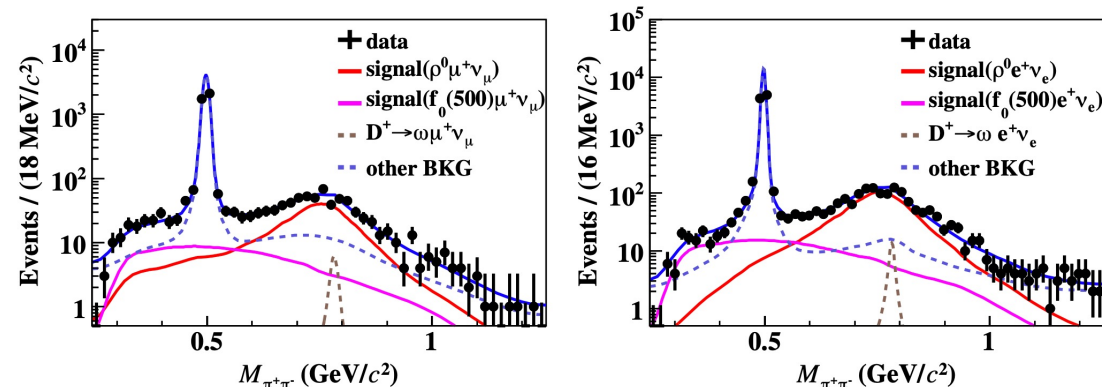
$$\rightarrow f_+^{f_0}(0)|V_{cd}| = 0.0787 \pm 0.0060 \pm 0.0033$$

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

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

2024/4/29

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

➤ 6.32 fb⁻¹ data @ 4.178-4.226 GeV

➤ $N_{sig}^{f_0(980)} = 54.8 \pm 10.1$ (7.8 σ significance)

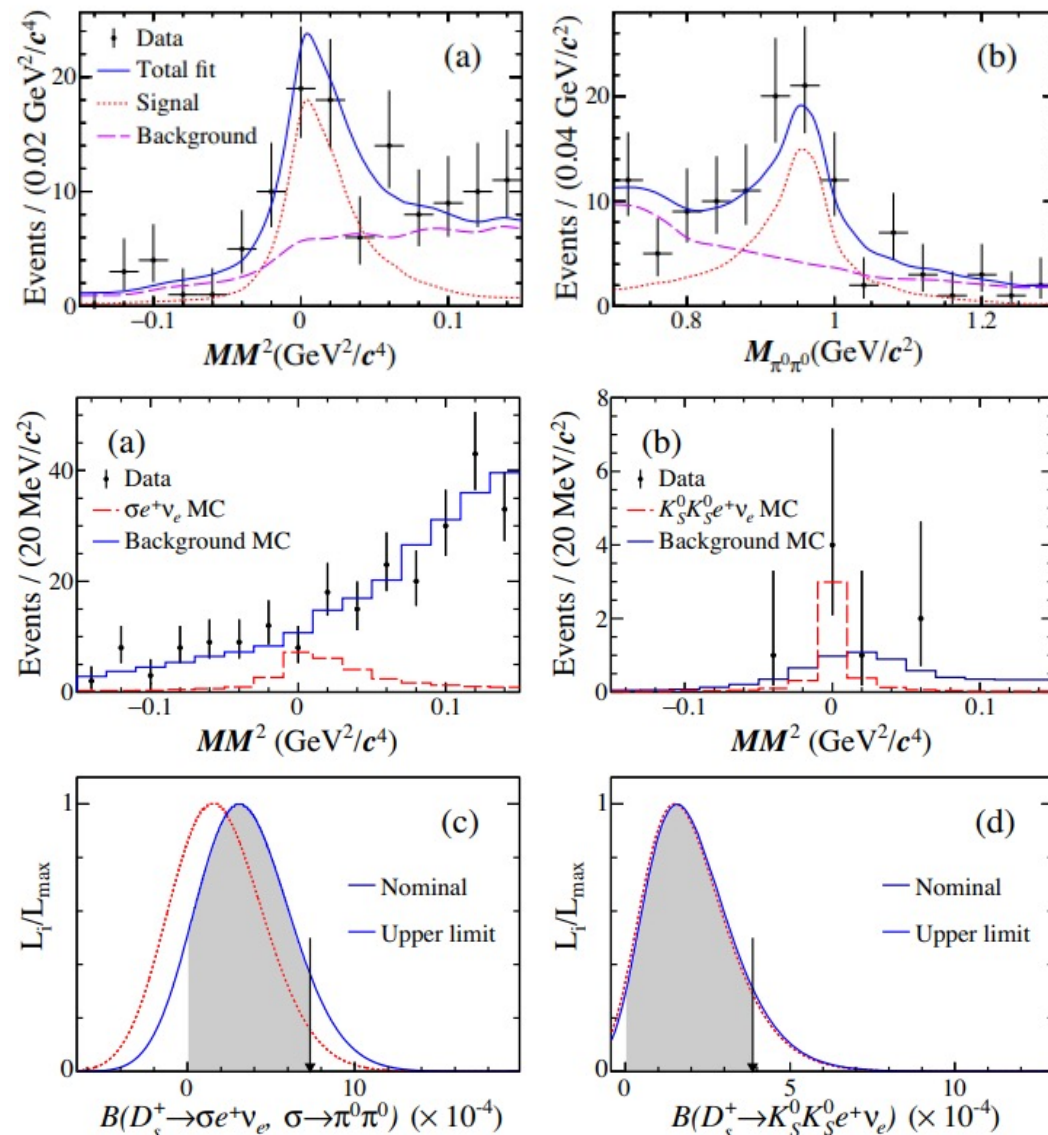
➤ First BFs Measurement:

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

➤ No significant signal:

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

➤ BFs help to understand the nature of the $f_0(500)$ and $f_0(980)$, and test different theoretical calculations.



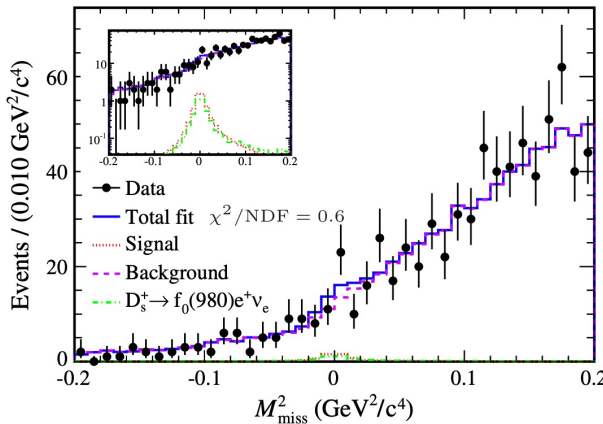
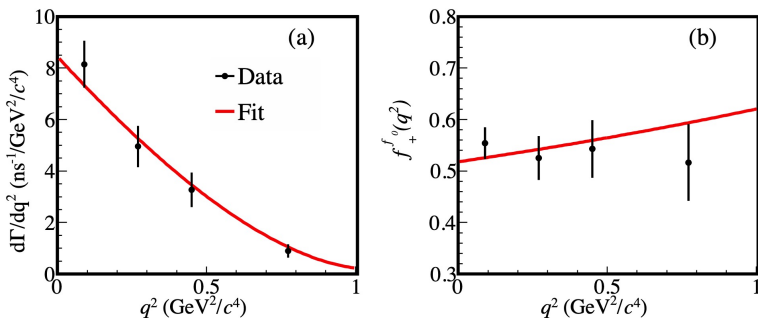
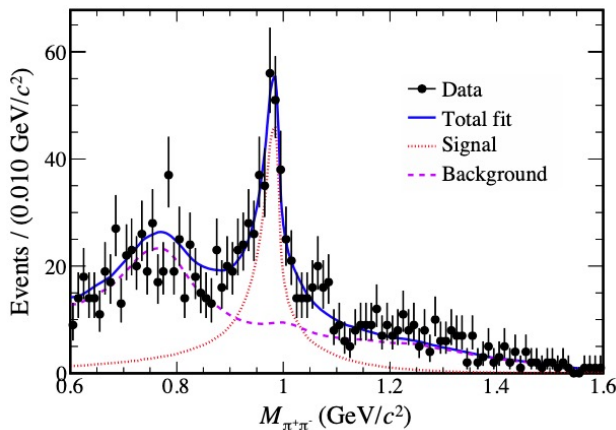


Phys. Rev. Lett. 132, 141901 (2024)

- 7.33 fb^{-1} data @ 4.128-4.226 GeV $\rightarrow N_{sig} = 439 \pm 33$
- $\mathcal{B}(D_s^+ \rightarrow f_0(980)e^+ \nu_e, f_0(980) \rightarrow \pi^+ \pi^-) = (1.72 \pm 0.13 \pm 0.10) \times 10^{-3}$
 $\rightarrow$ **$s\bar{s}$ 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 in theory	...	$(32 \pm 4.8)^\circ$	$(41.3 \pm 5.5)^\circ$	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 $f_0(980)$ through the decay $D_s^+ \rightarrow K^+ K^- \mu^+ \nu_\mu$

JHEP12(2023)072

➤ 7.33 fb⁻¹ data @ 4.128-4.226 GeV

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

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

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

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

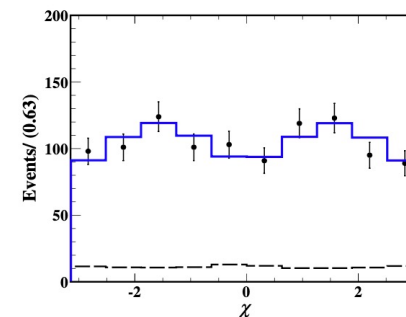
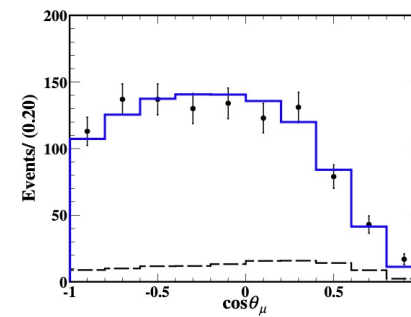
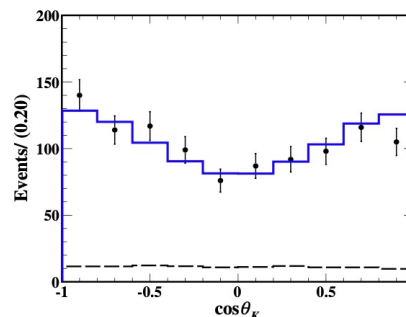
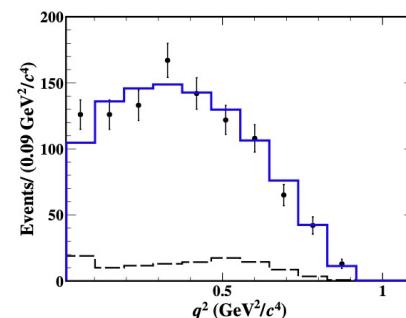
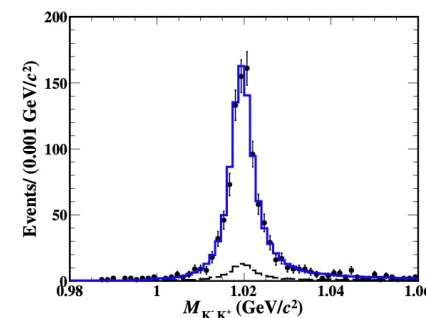
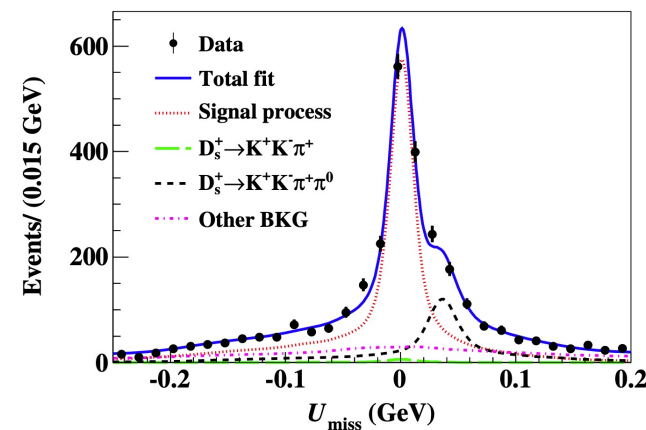
➤ **First FF measurement** based on single pole parameterization:

➤ PWA 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	$1.58 \pm 0.17 \pm 0.02$	$0.71 \pm 0.14 \pm 0.02$
<i>BABAR</i> [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
HM χ T [8]	1.80	0.52



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$|U_{miss}| < 0.02 \text{ GeV}$
939 signal events with $(9.8 \pm 0.7)\%$ Bkg

Light scalar mesons via semi-leptonic D 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

More hadrons via semi-leptonic D decays at BESIII

LIGHT UNFLAVORED MESONS ($S = C = B = 0$)

For $I = 1$ (π, ρ, ω): $u \bar{d}, (u \bar{u} - d \bar{d})/\sqrt{2}, d \bar{u}$;

for $I = 0$ ($\eta, \eta', h, h', \omega, \phi, f, f'$): $c_1(u \bar{u} + d \bar{d}) + c_2(s \bar{s})$

STRANGE MESONS ($S = \pm 1, C = B = 0$)

$K^+ = u \bar{s}, K^0 = d \bar{s}, \bar{K}^0 = \bar{d} s, K^- = \bar{u} s$, similarly for K^{*} 's

• $K_0^*(700)$ aka κ ; was $K_0^*(800)$	$1/2(0^+)$
• $K^*(892)$	$1/2(1^-)$
• $K_1(1270)$	$1/2(1^+)$
• $K_1(1400)$	$1/2(1^+)$
• $K^*(1410)$	$1/2(1^-)$
• $K_0^*(1430)$	$1/2(0^+)$
• $K_2^*(1430)$	$1/2(2^+)$
• $K(1460)$	$1/2(0^-)$

• $f_0(500)$ aka σ ; was $f_0(600), f_0(400 - 1200)$	$0^+(0^{++})$
• $\rho(770)$	$1^+(1^{--})$
• $\omega(782)$	$0^-(1^{--})$
• $\eta'(958)$	$0^+(0^{-+})$
• $f_0(980)$	$0^+(0^{++})$
• $a_0(980)$	$1^-(0^{++})$
• $\phi(1020)$	$0^-(1^{--})$
• $h_1(1170)$	$0^-(1^{+-})$
• $b_1(1235)$	$1^+(1^{+-})$
• $a_1(1260)$	$1^-(1^{++})$
• $f_2(1270)$	$0^+(2^{++})$
• $f_1(1285)$	$0^+(1^{++})$
• $\eta(1295)$	$0^+(0^{-+})$
• $\pi(1300)$	$1^-(0^{-+})$
• $a_2(1320)$	$1^-(2^{++})$
• $f_0(1370)$	$0^+(0^{++})$

• $\pi_1(1400)$	$1^-(1^{-+})$
• $\eta(1405)$	$0^+(0^{-+})$
• $h_1(1415)$ was $h_1(1380)$	$0^-(1^{+-})$
• $f_1(1420)$	$0^+(1^{++})$
• $\omega(1420)$	$0^-(1^{--})$
• $f_2(1430)$	$0^+(2^{++})$
• $a_0(1450)$	$1^-(0^{++})$
• $\rho(1450)$	$1^+(1^{--})$
• $\eta(1475)$	$0^+(0^{-+})$
• $f_0(1500)$	$0^+(0^{++})$
• $f_1(1510)$	$0^+(1^{++})$
• $f_2'(1525)$	$0^+(2^{++})$
• $f_2(1565)$	$0^+(2^{++})$
• $\rho(1570)$	$1^+(1^{--})$
• $h_1(1595)$	$0^-(1^{+-})$

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 D decay.
- 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 light hadrons could be studied via semi-leptonic D decay.
- More results are on the way!

Thank you!