北京谱仪III上粲介子半轻衰变中的轻强子研究

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湖南大学

第五届强子与重味物理理论与实验联合研讨会

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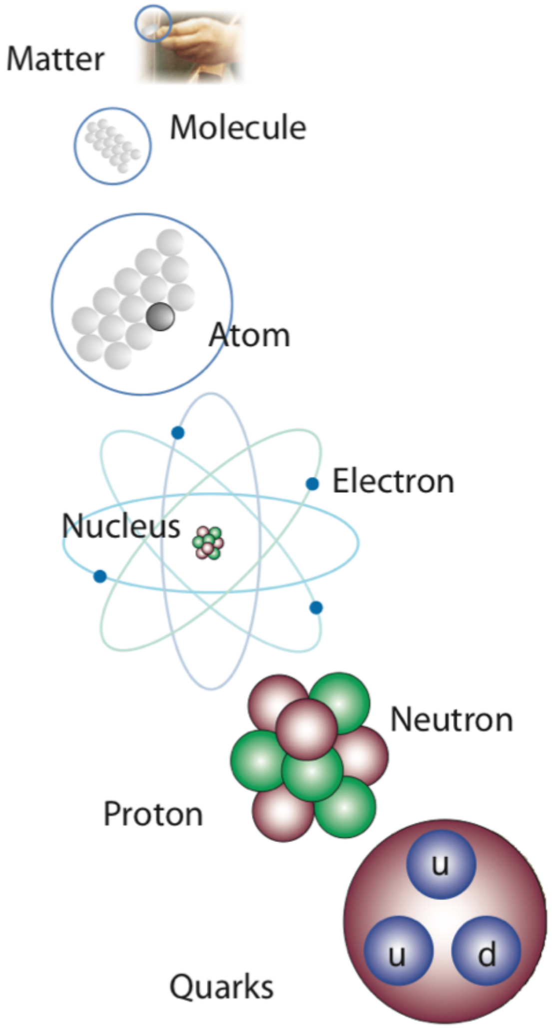
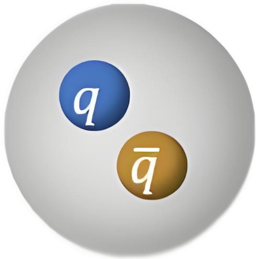
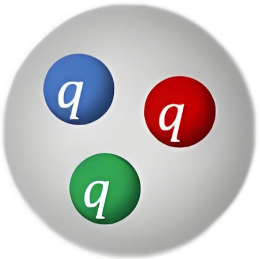
Content

Physics motivation

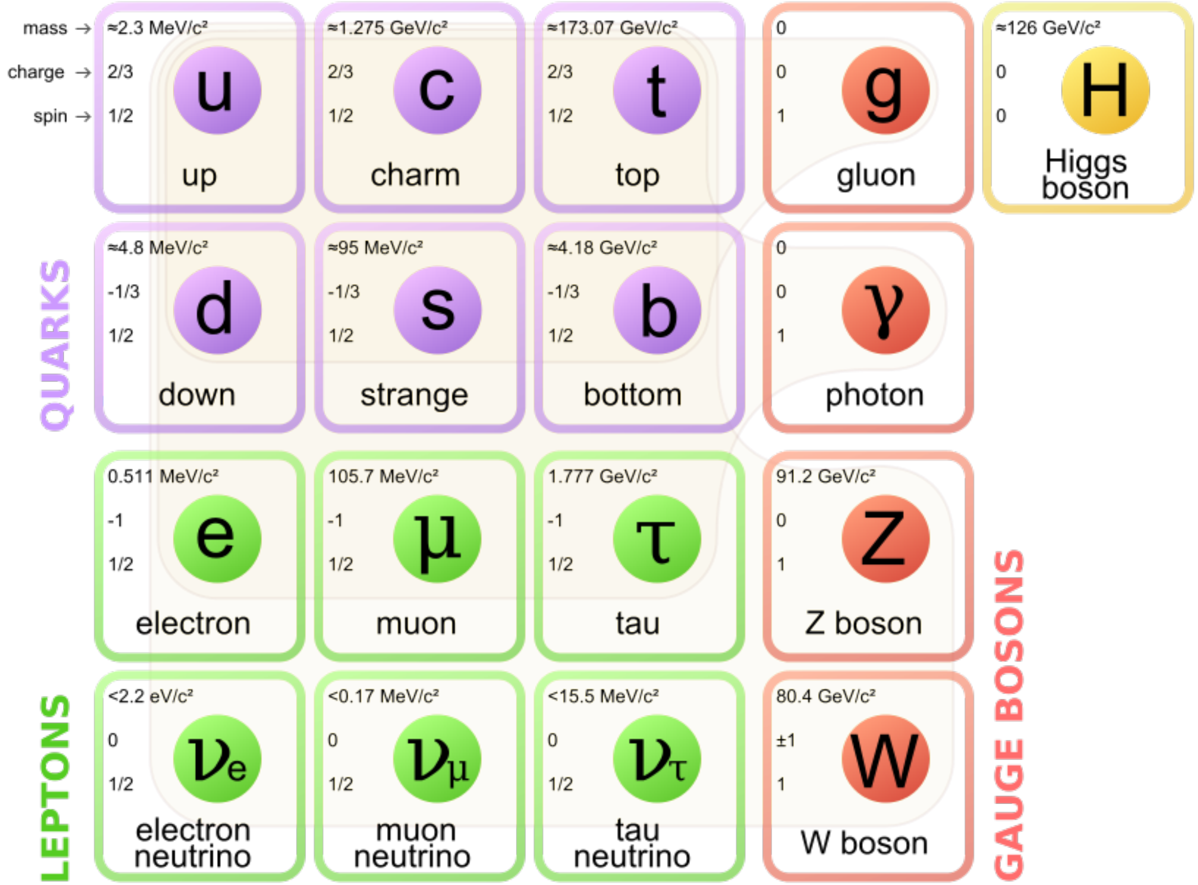




Meson

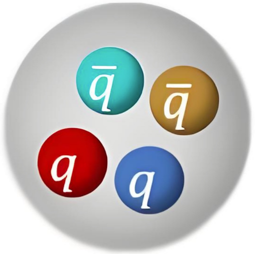


Baryon

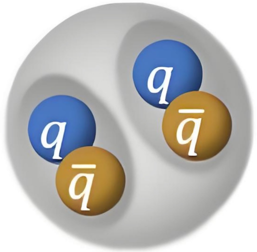


- **All matters are made out of quarks and leptons.**
- **Ordinary hadrons: Meson and Baryon.**

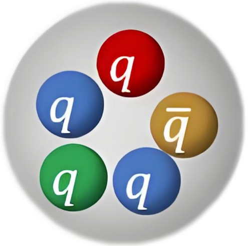
Physics motivation



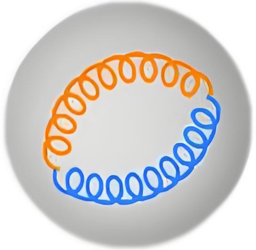
Tetraquark



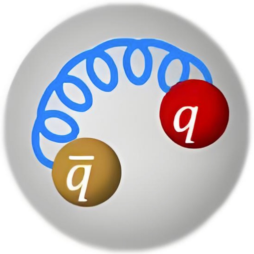
Hadronic molecules



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?

Physics motivation

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 a 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!

Physics motivation

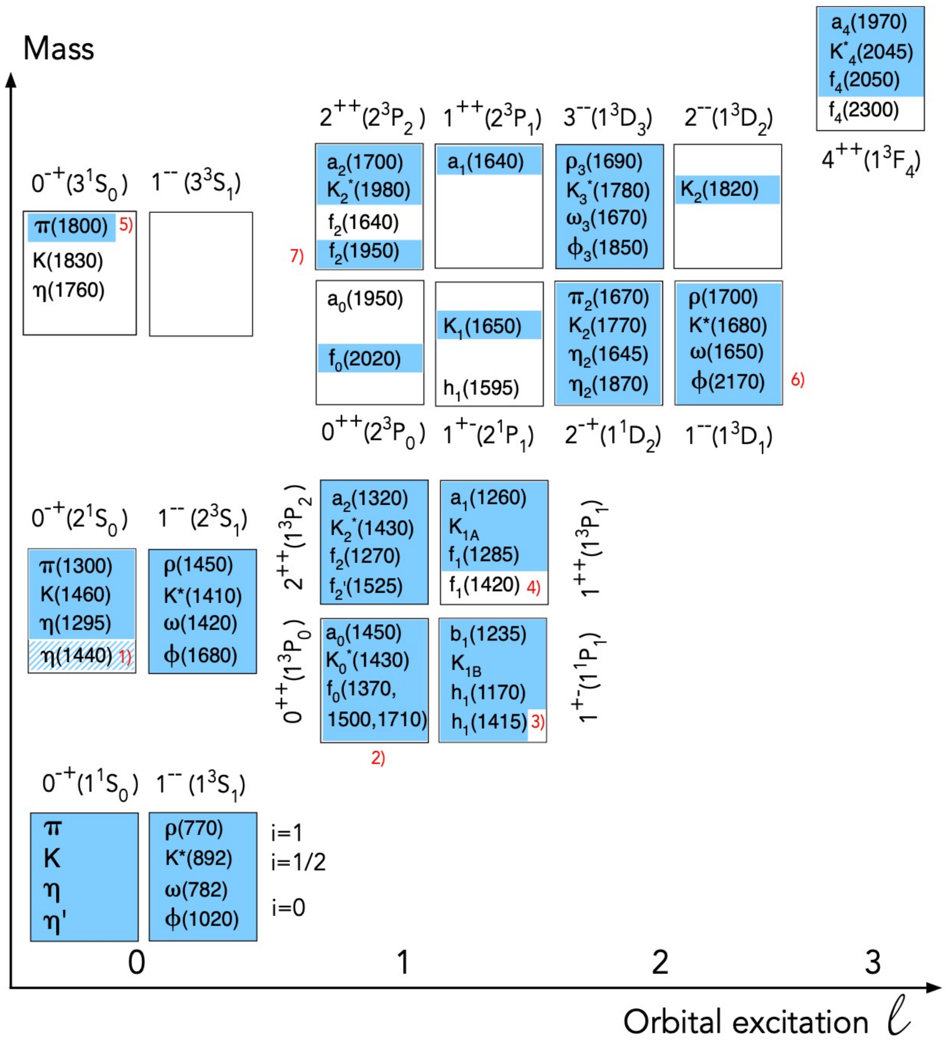
➢ **How about orbitally and radially excited states of strange and light mesons ?**

➔ $K_0^*(1430)$, $K^*(1410)$, $\boldsymbol{K_1(1270)}$, $K_1(1400)$, $\boldsymbol{K_2^*(1430)}$

➔ $f_0(1370)$, $f_0(1500)$, $\boldsymbol{f_1(1285)}$, $\boldsymbol{f_1(1420)}$, $f_2(1270)$

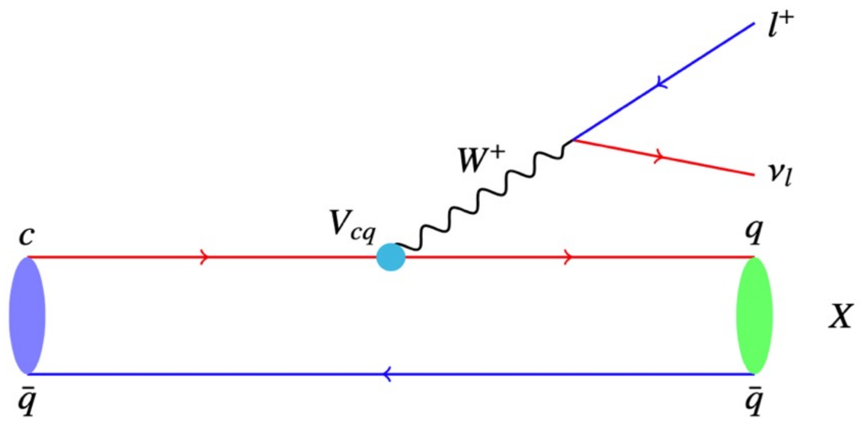
➔ $a_0(1450)$, $a_1(1260)$, $a_2(1320)$, $\boldsymbol{b_1(1235)}$, …

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



Physics motivation

??? ➠ **Why is the semi-leptonic decay of charmed meson?**



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

- **Clean environment:** hadrons ***X*** can be separated from leptons pair.
- **High statistics** of charmed meson at experiments.
- **Original purpose :**
  - Hadronic Form factor (FF) measurement ➔ **Test different QCD models (LQCD/QCDSR)**
  - $\mathcal{R}_{\mu/e} = \mathcal{B}(D_{(s)} \to X\mu^+\nu_\mu)/\mathcal{B}(D_{(s)} \to Xe^+\nu_e)$ measurement ➔ **Test lepton flavor universality (LFU)**

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Data sample

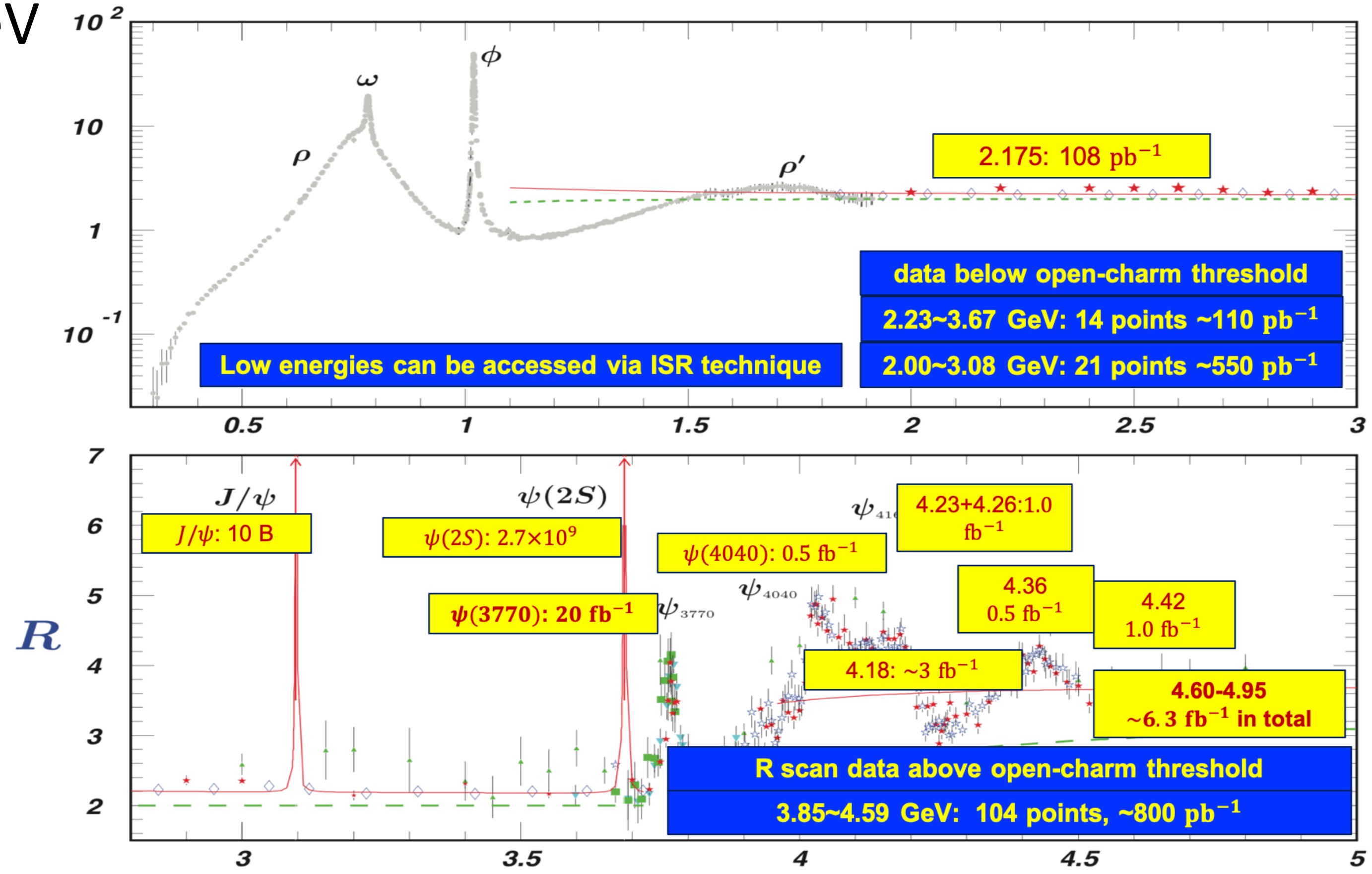
- Symmetric e^+e^- collider @2 – 5GeV
- Pair-production near threshold
- $D\bar{D}$@3.773GeV

  2.93 fb^{-1} 2010-2011

  4.99 fb^{-1} 2021-2022

  8.16 fb^{-1} 2021-2022

  4.19 fb^{-1} 2022-2024

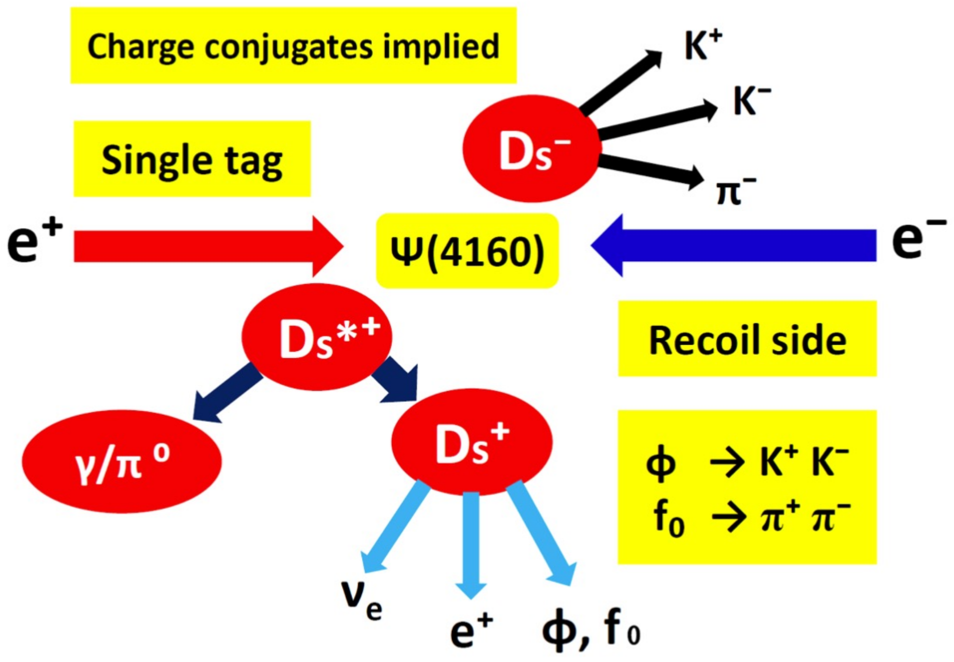


~20 fb^{-1} on the $\psi(3770)$ had been collected!

- $D_sD_s^*$ @4.13-4.23GeV: 7.33 fb^{-1}

Analysis method: Double Tag

Take Ds decay as an example (complicated case)



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

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

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

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

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

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

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

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

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

- 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**

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

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

- Point-like differential decay rate:

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

- Double differential decay rate:

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

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

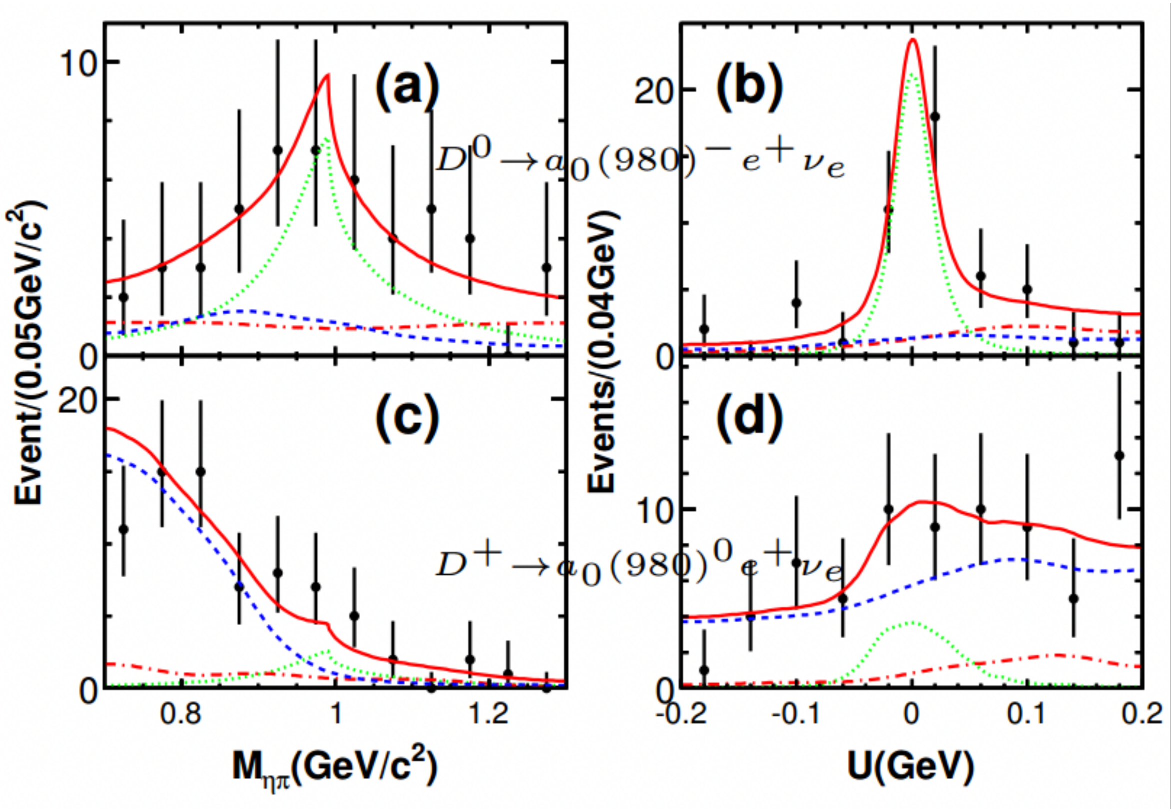
$$P(s) = \begin{cases} \dfrac{g_1\rho_{\pi\pi/\pi\eta}}{|m_0^2-s-i(g_1\rho_{\pi\pi/\pi\eta}+g_1\rho_{KK})|^2}, & \text{Flatte: } f_0(980)/a_0(980) \\ \dfrac{m_{f_0}\Gamma(s)}{(s-m_{f_0}^2)^2+m_{f_0}^2\Gamma^2(s)}, & \text{RBW: } f_0(500) \\ \dfrac{m_r\Gamma_{tot}(s)}{(m_r^2-s-g_1^2\frac{s-s_A}{m_r^2-s_A}z(s))^2+m_r^2\Gamma_{tot}^2(s)},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

Content

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

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

Study of the decay $D^0 \to a_0(980)^-(\eta\pi^-)e^+\nu_e$

Phys. Rev. D 111, L091501 (2025)

- 7.93 fb^{-1} data @ 3.773 GeV ➔ $N_{\text{sig}} = 51.8 \pm 10.0$
- **Updated BF measurement** of $D^0 \to a_0(980)^- e^+\nu_e$.

$\mathcal{B}(D^0 \to a_0(980)^- e^+\nu_e, a_0(980)^- \to (\eta\pi^-))$

$= (0.86 \pm 0.17 \pm 0.05)\times 10^{-4}$

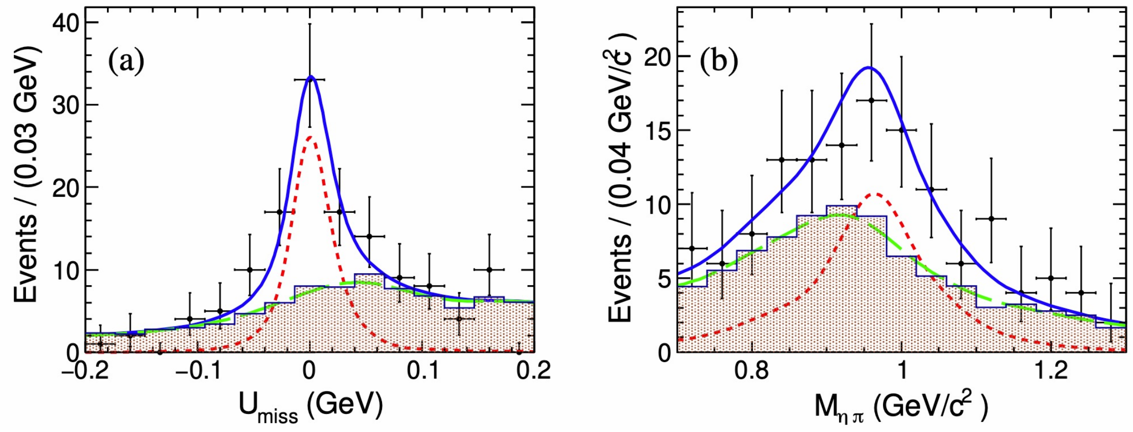
- **First FF measurement:**

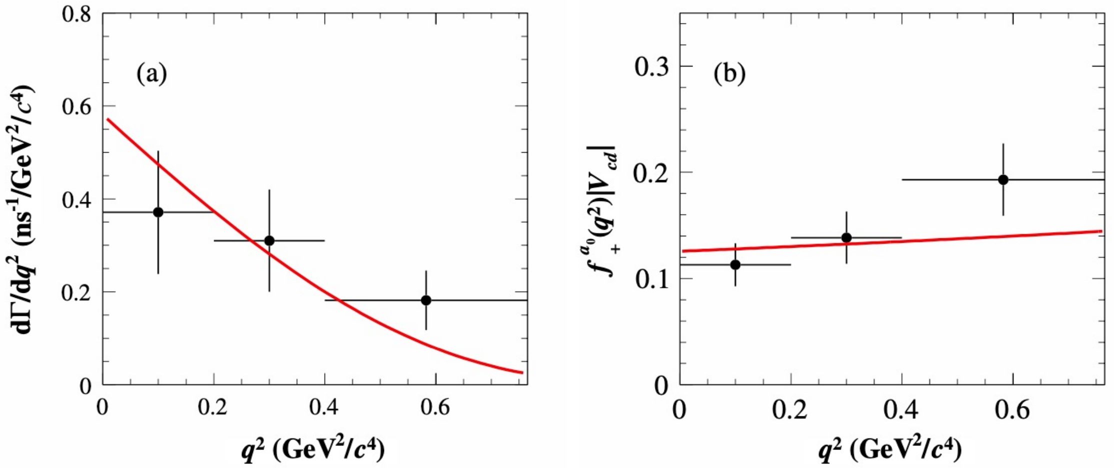
Single-pole form for FF and Bugg form for $a_0(980)^-$

➔ $f_+^{a_0}(0)|V_{cd}| = 0.126 \pm 0.013 \pm 0.003$

➔ $f_+^{a_0}(0) = 0.559 \pm 0.056 \pm 0.013$

ps: $|V_{cd}| = 0.22487 \pm 0.00068$ from SM global fit (PDG2024)





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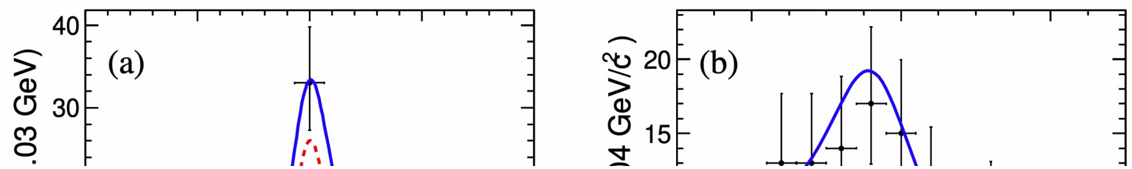

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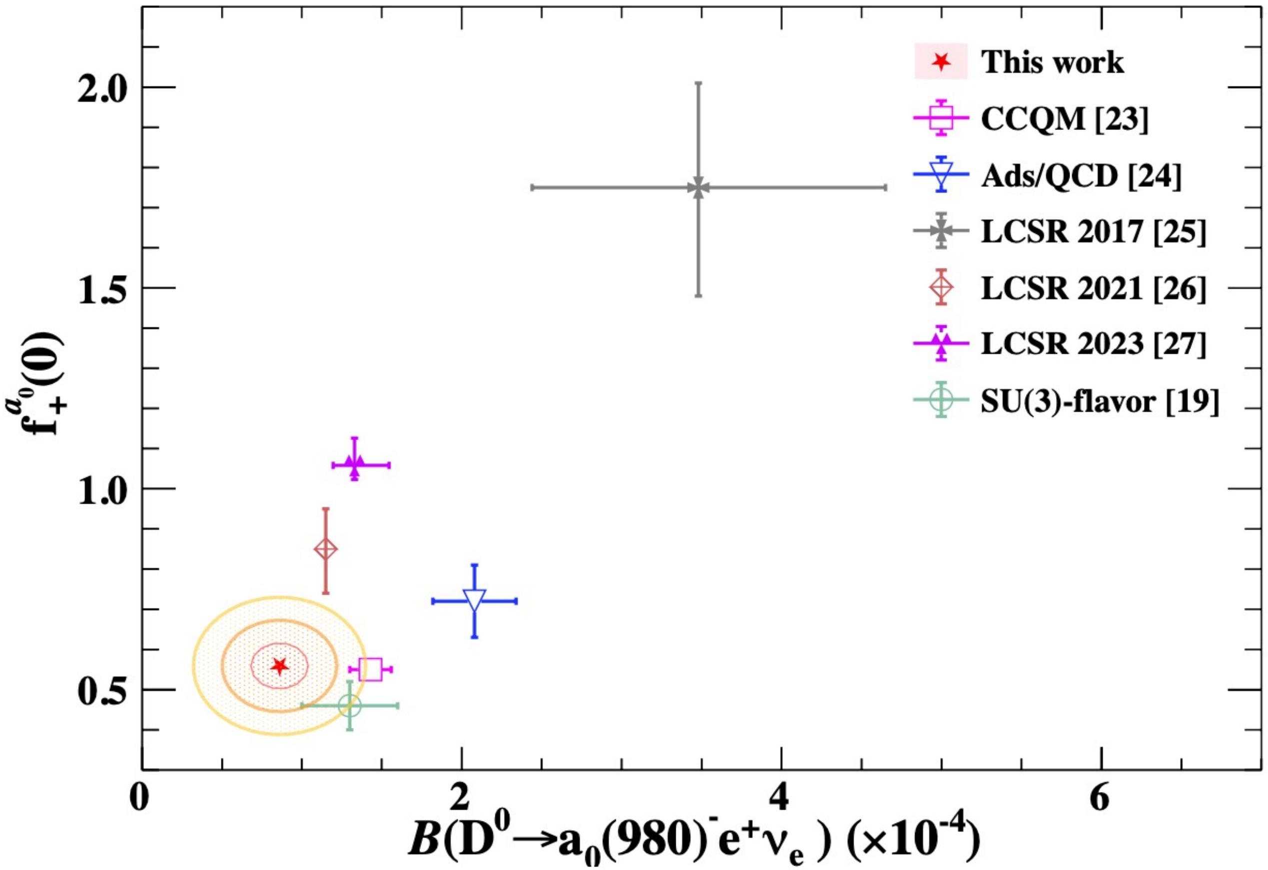


First observation of $D^+ \to f_0(500)e^+\nu_e$

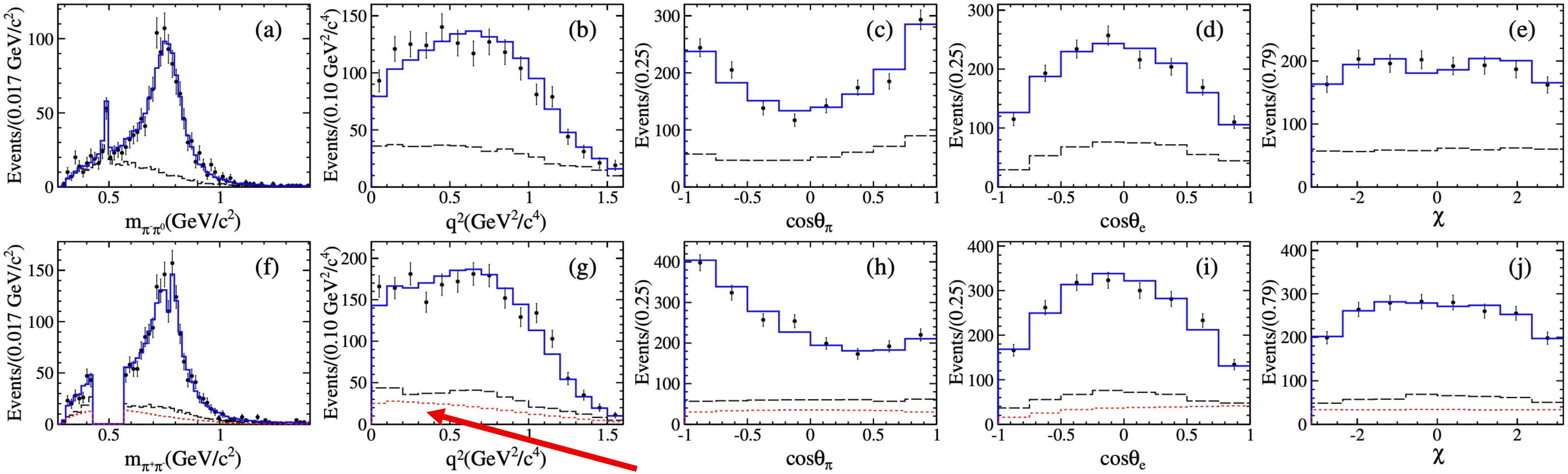
Phys. Rev. Lett. 122, 062001 (2019)

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

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

D^0

D^+



- 2.93 fb^{-1} data @ 3.773 GeV

$f_{f_0(500)} = (25.7 \pm 1.6 \pm 1.1)\%$

- $R = \frac{\mathcal{B}(D^+\to f_0(500)e^+\nu_e)+\mathcal{B}(D^+\to f_0(980)e^+\nu_e)}{\mathcal{B}(D^+\to a_0(980)e^+\nu_e)} > 2.7$@90% C.L.
- Favor tetraquark (R=3, PRD82, 034016(2010)) for f_0 and a_0

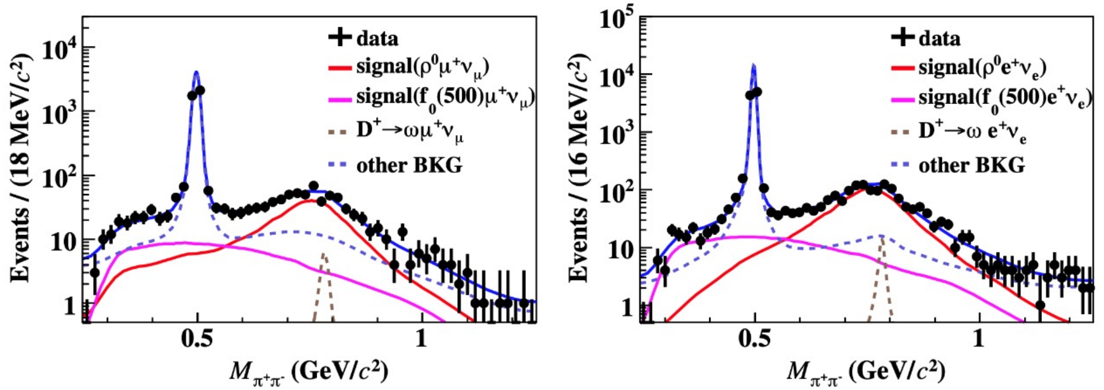
Signal mode	This analysis ($\times 10^{-3}$)
$D^0 \to \pi^-\pi^0 e^+\nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^0 \to \rho^- e^+\nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^+ \to \pi^-\pi^+ e^+\nu_e$	$2.449 \pm 0.074 \pm 0.073$
$D^+ \to \rho^0 e^+\nu_e$	$1.860 \pm 0.070 \pm 0.061$
$D^+ \to \omega e^+\nu_e$	$2.05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

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

Phys. Rev. D 110, 092008 (2024)

- $2.93\ \mathrm{fb}^{-1}$ data @ 3.773 GeV
- **First observation** of $D^+ \to f_0(500)(\pi^+\pi^-)\mu^+\nu_\mu$.

Signal mode	$N_{\rm obs}$	$\mathcal{S}\ (\sigma)$	$\epsilon_{\rm sig}\ (\%)$	$\mathcal{B}_{\rm sig}(\times 10^{-3})$
$f_0(500)\mu^+\nu_\mu$	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
$\rho^0 e^+\nu_e$	1237 ± 47	> 10	44.12 ± 0.25	1.84 ± 0.07



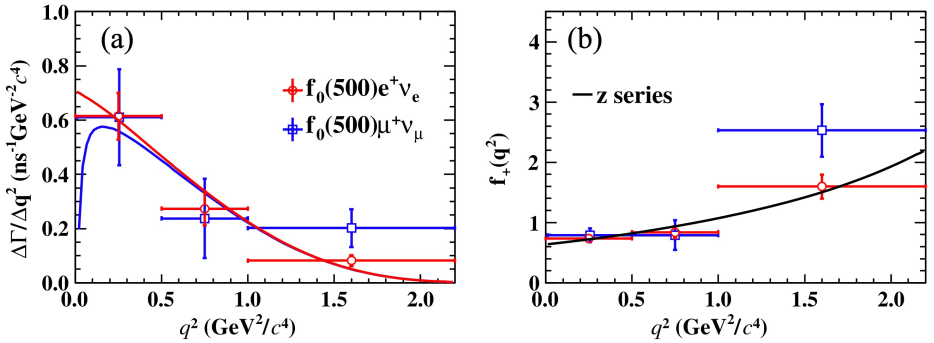
➔ The measured BF of $D^+ \to f_0(500)\ell^+\nu_\ell$ are closer to **tetraquark assumption**.
R.M. Wang et al, PRD107,056022 (2023)
Y.K. Hsiao et al, arXiv:2306.06091

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

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

➔ $f_+^{f_0}(0)|V_{cd}| = 0.143 \pm 0.014 \pm 0.011$

➔ $f_+^{f_0}(0) = 0.63 \pm 0.06 \pm 0.05$



ps: $|V_{cd}| = 0.22486 \pm 0.00067$ from SM global fit (PDG2022)

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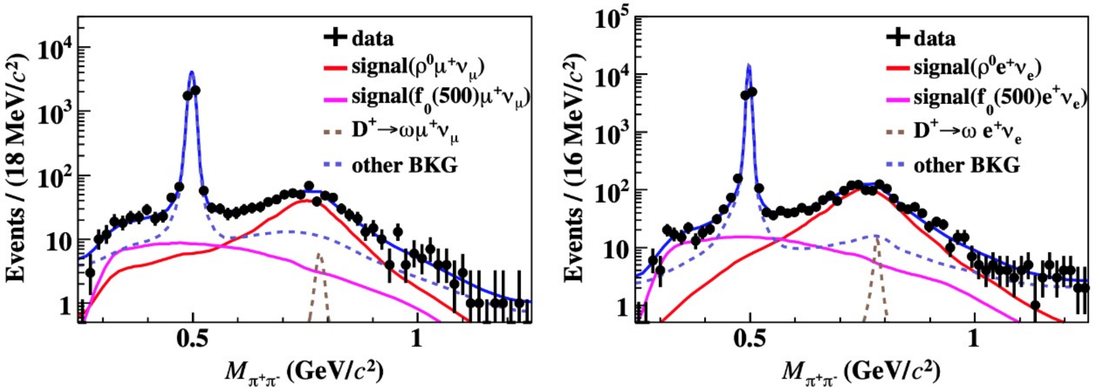

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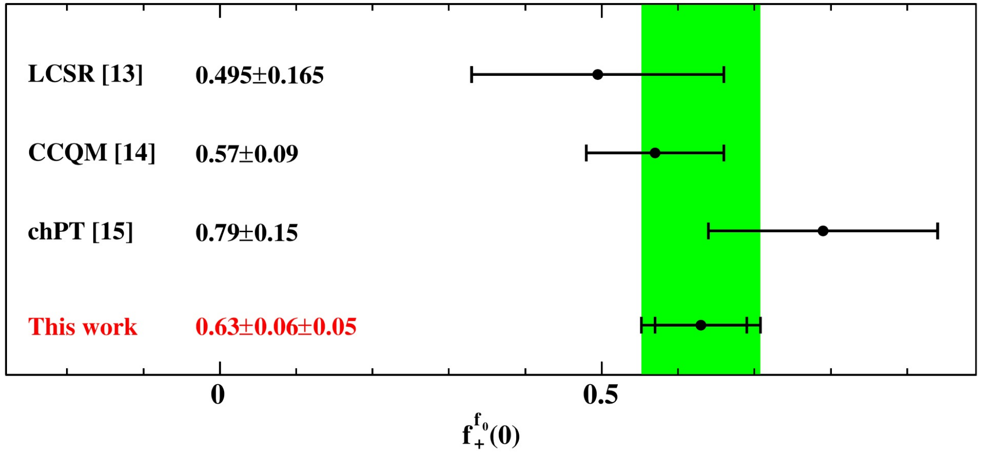


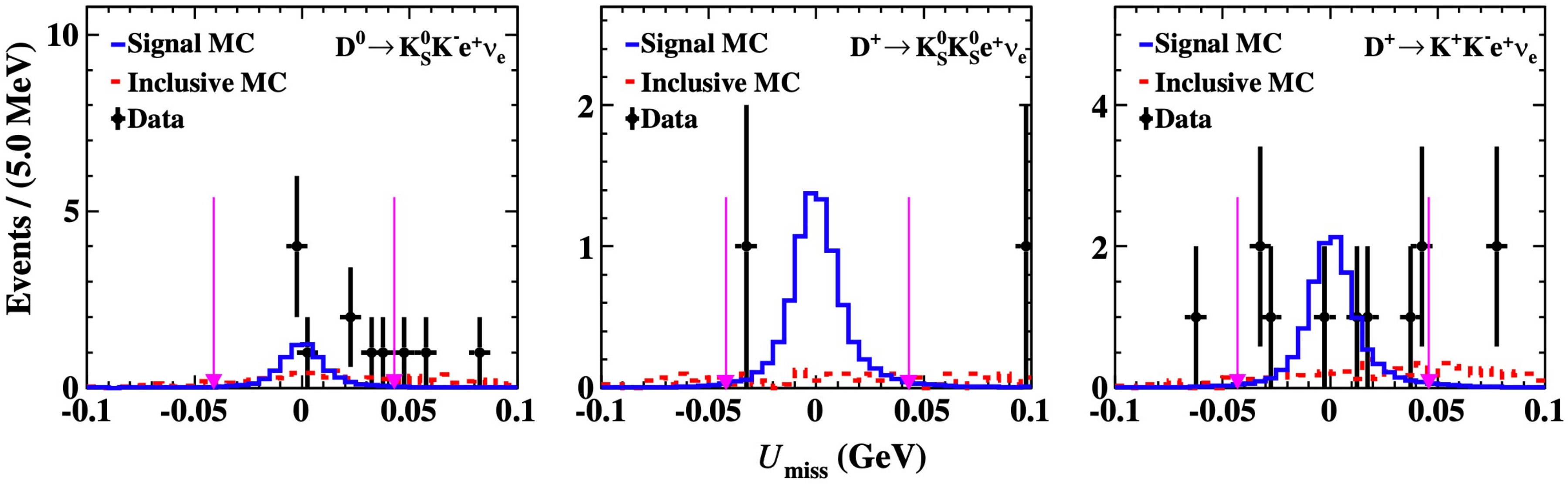
Search for the decay $D \to K\bar{K}e^+\nu_e$

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:

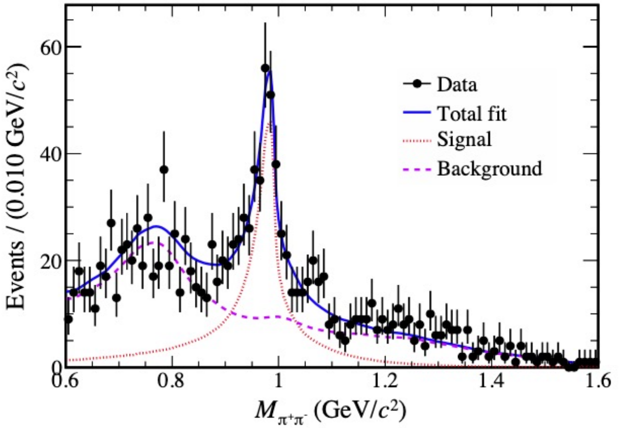
$$\mathcal{B}(D^0 \to K_S^0 K^- e^+ \nu_e) < 2.13\times10^{-5}$$

$$\mathcal{B}(D^+ \to K_S^0 K_S^0 e^+ \nu_e) < 1.54\times10^{-5}, \mathcal{B}(D^+ \to K^+ K^- e^+ \nu_e) < 2.10\times10^{-5}$$



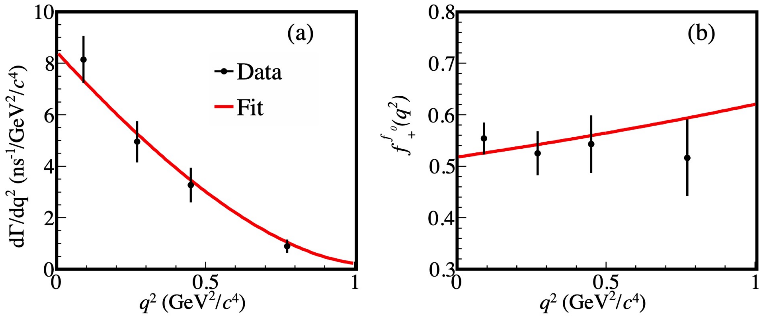
Study of the $f_0(980)$ and $f_0(500)$ through the decay $D_s^+ \to \pi^+\pi^- e^+\nu_e$

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

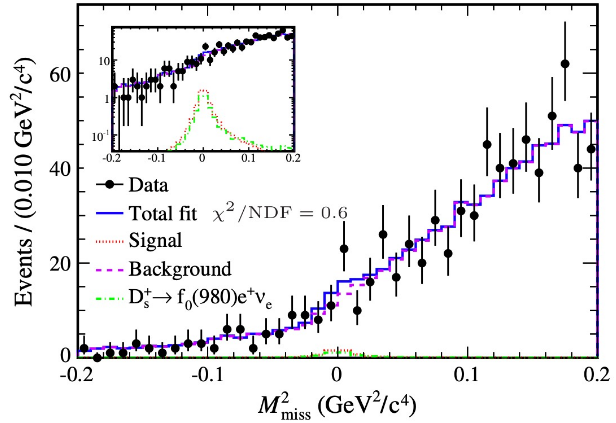


- 7.33 fb^{-1} data @ 4.128-4.226 GeV ➔ $N_{\text{sig}} = 439 \pm 33$
- $\mathcal{B}(D_s^+ \to f_0(980)e^+\nu_e, f_0(980) \to \pi^+\pi^-) = (1.72 \pm 0.13 \pm 0.10)\times 10^{-3}$
  - ➔ **$s\bar{s}$ is dominant** based on $|f_0(980)\rangle = \sin\phi|\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})\rangle + \cos\phi\,|s\bar{s}\rangle$

    $\phi = (19.7 \pm 12.8)^\circ$
- **First form factor measurement** with simple pole form:
  - ➔ $f_+^{f_0}(0)|V_{cs}| = 0.504 \pm 0.017 \pm 0.035$
  - ➔ $f_+^{f_0}(0) = 0.518 \pm 0.018 \pm 0.036$ ($|V_{cs}| = 0.97349 \pm 0.00016$ 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°	$(8^{+21}_{-8})^\circ$	—	$(56 \pm 7)^\circ$	31°



- **First search** of $D_s^+ \to f_0(500)e^+\nu_e, f_0(500) \to \pi^+\pi^-$ ($M_{\pi^+\pi^-} < 0.45$ GeV/c²)
- $\mathcal{B}(D_s^+ \to f_0(500)e^+\nu_e, f_0(500) \to \pi^+\pi^-) < 3.3\times 10^{-4}$

Study of the $f_0(980)$ and $f_0(500)$ through the decay $D_s^+ \to \pi^+\pi^- e^+\nu_e$

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

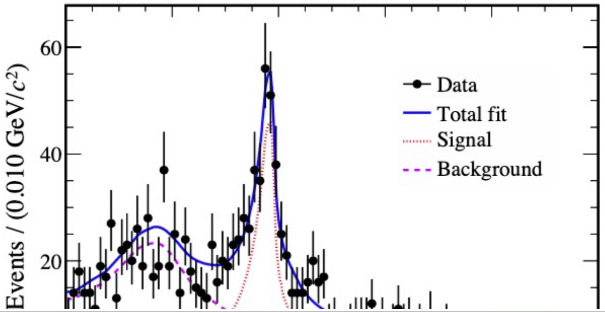
- 7.33 fb^{-1} data @ 4.128-4.226 GeV ➔ $N_{\text{sig}} = 439 \pm 33$
- $\mathcal{B}(D_s^+ \to f_0(980)e^+\nu_e, f_0(980) \to \pi^+\pi^-) = (1.72 \pm 0.13 \pm 0.10)\times 10^{-3}$

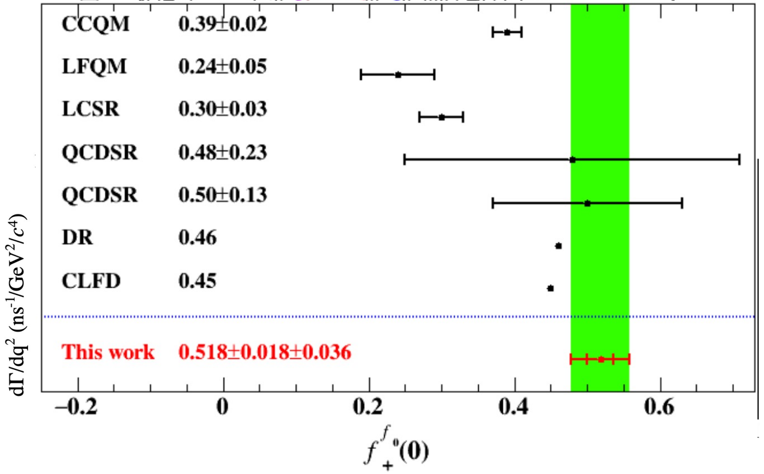
  ➔ **$s\bar{s}$ is dominant** based on $|f_0(980)\rangle = \sin\phi|\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\rangle + \cos\phi\,|s\bar{s}\rangle$

  $\phi = (19.7 \pm 12.8)^\circ$
- **First form factor measurement** with simple pole form:

  ➔ $f_+^{f_0}(0)|V_{cs}| = 0.504 \pm 0.017 \pm 0.035$

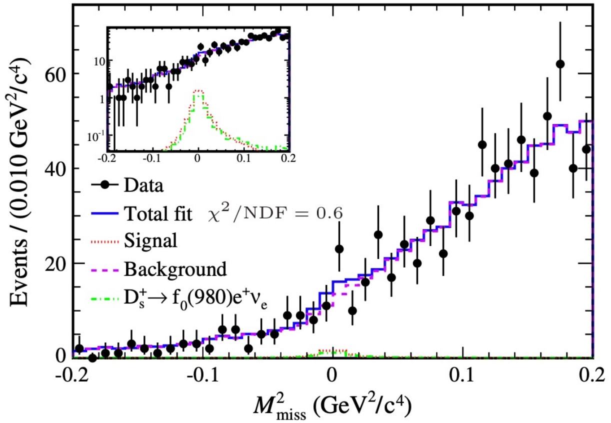
  ➔ $f_+^{f_0}(0) = 0.518 \pm 0.018 \pm 0.036$ ($|V_{cs}| = 0.97349 \pm 0.00016$ PDG2022)





	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°	$(8^{+21}_{-8})^\circ$	—	$(56 \pm 7)^\circ$	31°

- **First search** of $D_s^+ \to f_0(500)e^+\nu_e, f_0(500) \to \pi^+\pi^-$ ($M_{\pi^+\pi^-} < 0.45$ GeV/c²)
- $\mathcal{B}(D_s^+ \to f_0(500)e^+\nu_e, f_0(500) \to \pi^+\pi^-) < 3.3\times 10^{-4}$



Search for the $b_1(1235)$ in $D \to b_1(1235)e^+\nu_e$

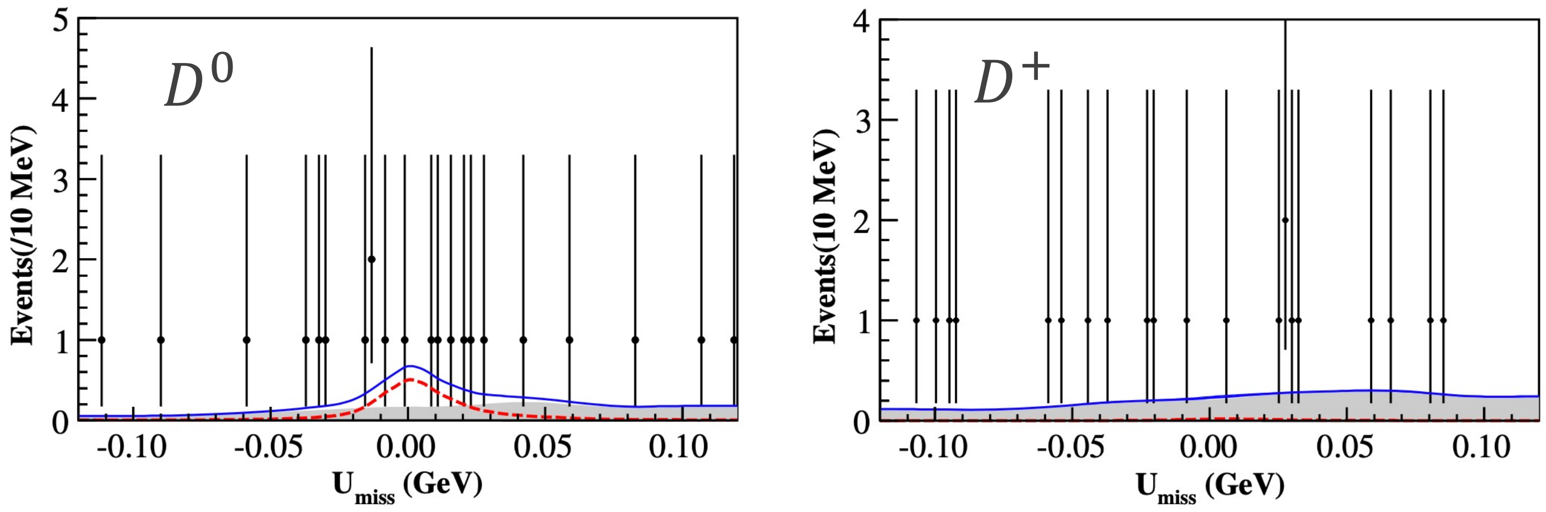
Phys. Rev. D 102, 112005 (2020)

- 2.93 fb^{-1} data @ 3.773 GeV
- First search and upper limit measurement on BF:

$\mathcal{B}(D^0 \to b_1(1235)^- e^+\nu_e, b_1(1235)^- \to \omega\pi^-) < 1.12\times10^{-4}$@90%C.L.

$\mathcal{B}(D^+ \to b_1(1235)^0 e^+\nu_e, b_1(1235)^0 \to \omega\pi^0) < 1.75\times10^{-4}$@90%C.L.

➔ Be comparable with the theoretical prediction [H. Y. Cheng and X. W. Kang, Eur. Phys. J. C 77, 587(2017)]



Search for the $b_1(1235)$ in $D \to b_1(1235)e^+\nu_e$

Phys. Rev. Lett. 136, 021801 (2026)

- 7.9 fb^{-1} data @ 3.773 GeV
- **First observation** ➔ $N_{\mathrm{sig}} = 35.6 \pm 8.9$

$\mathcal{B}(D^0 \to b_1(1235)^- e^+\nu_e, b_1(1235)^- \to \omega\pi^-)$

$= (0.72 \pm 0.18^{+0.06}_{-0.08})\times 10^{-4}$

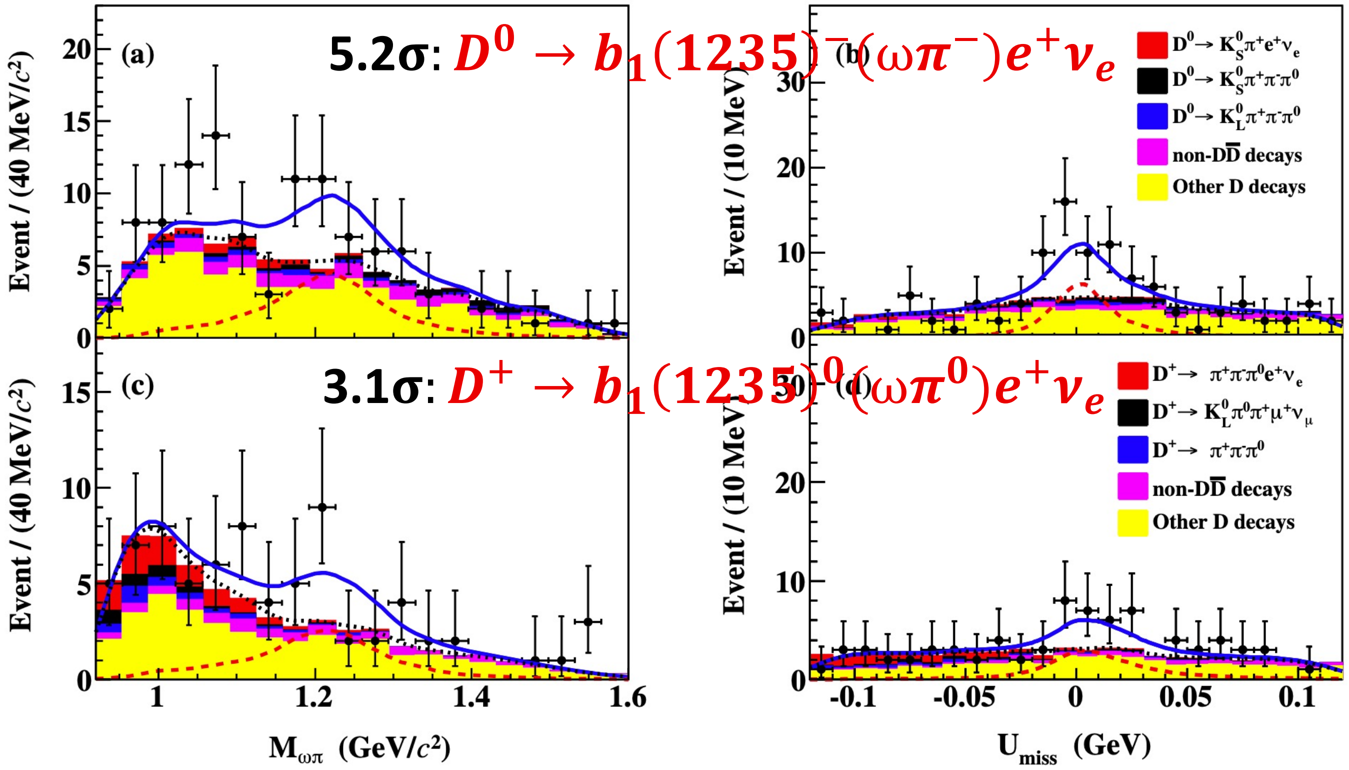
- **First evidence** ➔ $N_{\mathrm{sig}} = 17.5 \pm 6.7$

$\mathcal{B}(D^+ \to b_1(1235)^0 e^+\nu_e, b_1(1235)^0 \to \omega\pi^0)$

$= (1.16 \pm 0.44 \pm 0.16)\times 10^{-4}$

- **Isospin conservation check:**

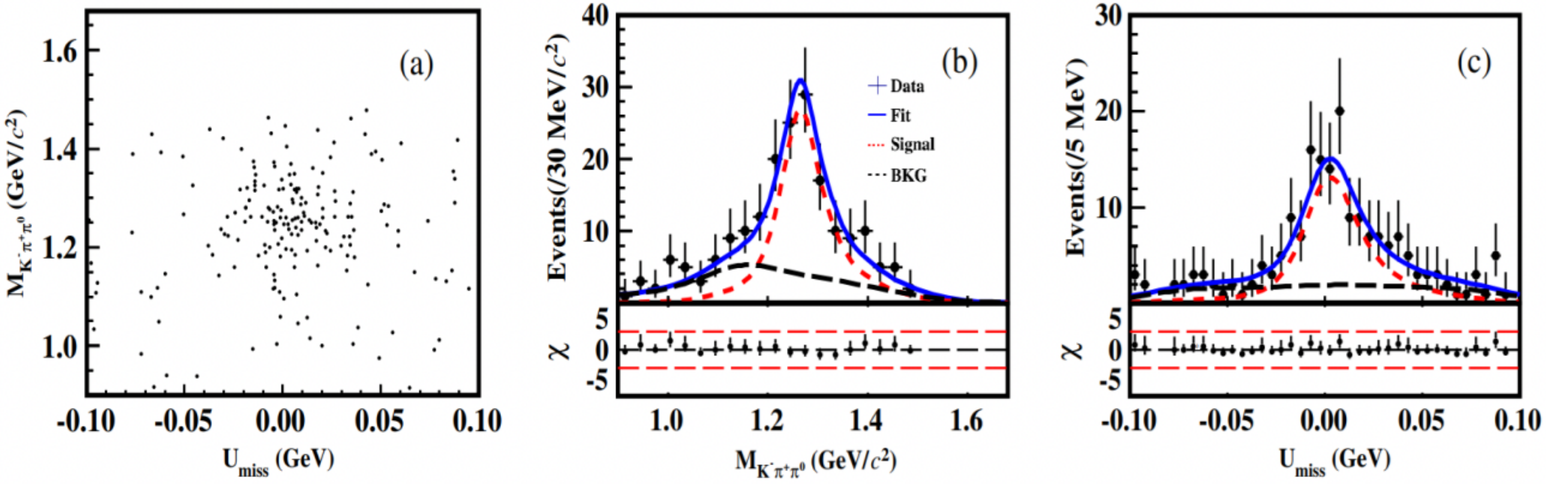
$$\frac{\Gamma(D^0\to b_1^- e^+\nu_e)}{2\Gamma(D^+\to b_1^0 e^+\nu_e)} = 0.78 \pm 0.19^{+0.04}_{-0.05}$$



First observation of $D^+ \to \overline{K}_1(1270)^0 e^+ \nu_e$

Phys. Rev. Lett. 123, 231801 (2019)

- 2.93 fb^{-1} data @ 3.773 GeV
- $N_{sig} = 119.7 \pm 13.3$ ($> 10\sigma$)
- Agree with $\theta_{K_1} \approx 33°$or 57°; disfavor negative sets



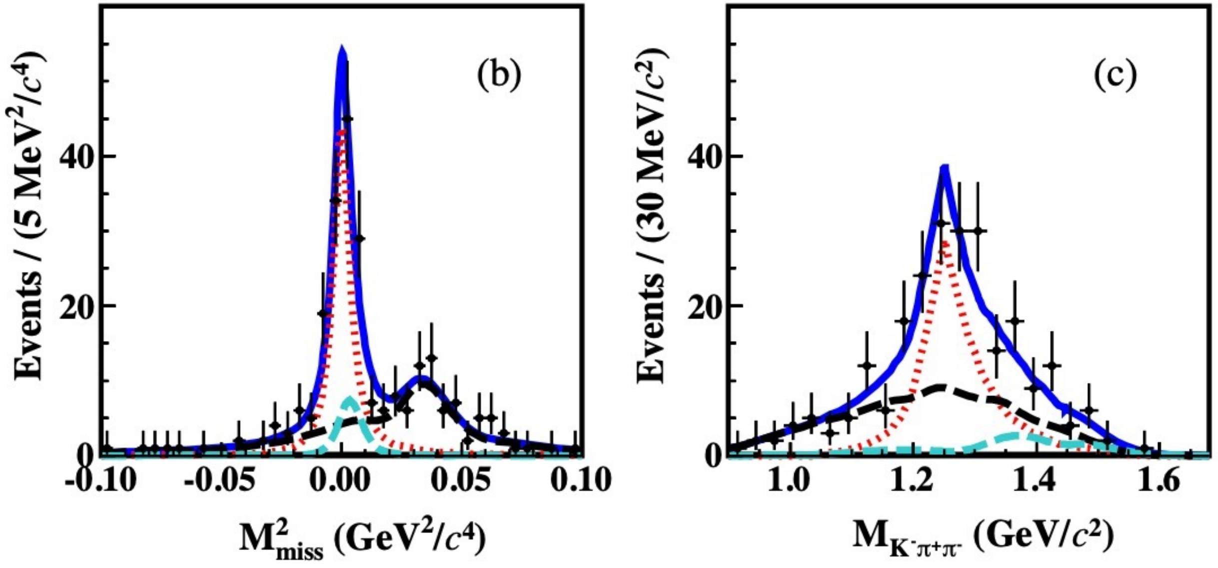
	$\mathcal{B}(D^+ \to \bar{K}_1(1270)^0 e^+ \nu_e)$
This work	$(2.30 \pm 0.26 \pm 0.18 \pm 0.25) \times 10^{-3}$
CLFQM[EPJC77,863(2017)]($\theta_{K_1} = 33°$)	$(3.20 \pm 0.40) \times 10^{-3}$
LCSR[JPG46,105006(2019)]($\theta_{K_1} < 0$)	$(17 \sim 21) \times 10^{-3}$

θ_{K_1} is the mixing angle of two states $K_{1A}(^1P_1)$ and $K_{1B}(^3P_1)$

First observation of $D^0 \to K_1(1270)^- e^+ \nu_e$

Phys. Rev. Lett. 127, 131801 (2021)

- 2.93 fb^{-1} data @ 3.773 GeV ➔ $N_{sig} = 109.0 \pm 12.5$ ($> 10\sigma$)
- $\mathcal{B}(D^0 \to K_1(1270)^- e^+ \nu_e) = (1.09 \pm 0.13^{+0.09}_{-0.16} \pm 0.12) \times 10^{-3}$
- Agree with $\theta_{K_1} \approx 33°$ or $57°$; disfavor negative sets
- $F_L = 0.50 \pm 0.17 \pm 0.08$ agree with LCSR [J. Phys. G 46, 105006 (2019)]



First decay dynamics study in $D \to \bar{K}_1(1270)e^+\nu_e$

Phys. Rev. Lett. 135, 091801 (2025)

- 20.3 fb^{-1} data @ 3.773 GeV ➔ $N_{SL}^{D^+(D^0)} = 1270 \pm 56\ (731 \pm 35)$
- $\mathcal{B}(D^+ \to \bar{K}_1(1270)^0 e^+\nu_e) = (2.27 \pm 0.11 \pm 0.07 \pm 0.07)\times10^{-3}$
- $\mathcal{B}(D^0 \to K_1(1270)^- e^+\nu_e) = (1.02 \pm 0.06 \pm 0.06 \pm 0.03)\times10^{-3}$
- First form factor measurement ($K_1(1400)$ is not observed)

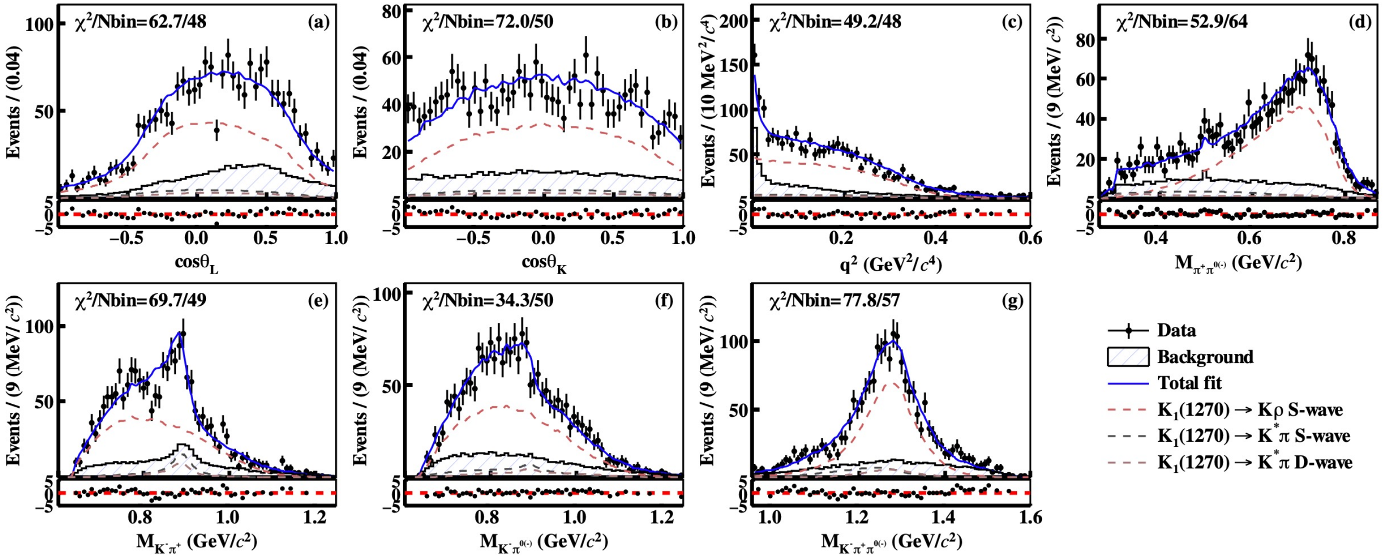
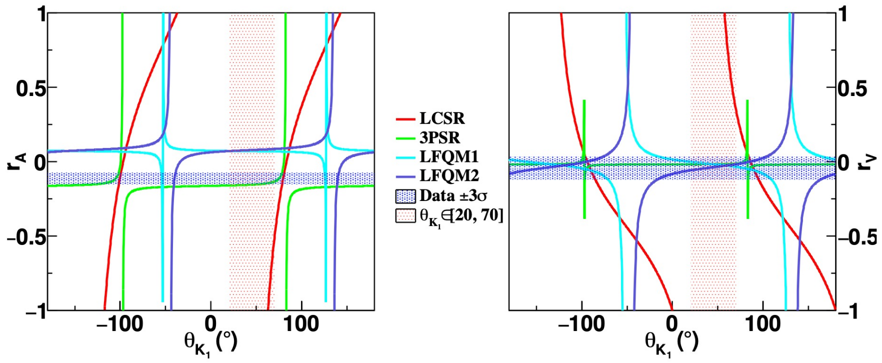


Table 2. Fitted parameters and fit fractions, where the first uncertainties are statistical and the second systematic.

Variable	Value
$r_A\ (\times10^{-2})$	$-11.2 \pm 1.0 \pm 0.9$
$r_V\ (\times10^{-2})$	$-4.3 \pm 1.0 \pm 2.4$
$f^{D^+}_{\rho K^-}$ (%)	$79.3 \pm 2.0 \pm 25.7$
$f^{D^+}_{\pi \bar{K}^*(892)}$ (%)	$10.9 \pm 1.2 \pm 3.0$
$f^{D^0}_{\rho K^-}$ (%)	$71.8 \pm 2.3 \pm 23.9$
$f^{D^0}_{\pi \bar{K}^*(892)}$ (%)	$19.5 \pm 1.9 \pm 5.2$
$m_{K_1(1270)}$ (MeV/c^2)	$1271 \pm 3 \pm 7$
$\Gamma_{K_1(1270)}$ (MeV)	$168 \pm 10 \pm 20$



$K^*(892)$ study in the decay $D^0 \to \bar{K}^0\pi^- e^+\nu_e$

JHEP 03 (2025) 197

- 7.93 fb^{-1} data @3.773GeV ➔ $N_{\rm sig} = 8752 \pm 132$
- Updated **BF** measurement:

  $\mathcal{B}(D^0 \to \bar{K}^0\pi^- e^+\nu_e) = (1.444 \pm 0.022 \pm 0.024)\%$

  $\mathcal{B}(D^0 \to K^*(892)^- e^+\nu_e) = (2.039 \pm 0.032 \pm 0.034)\%$

  $f_{\rm S-wave} = (5.87 \pm 0.32 \pm 0.16)\%$

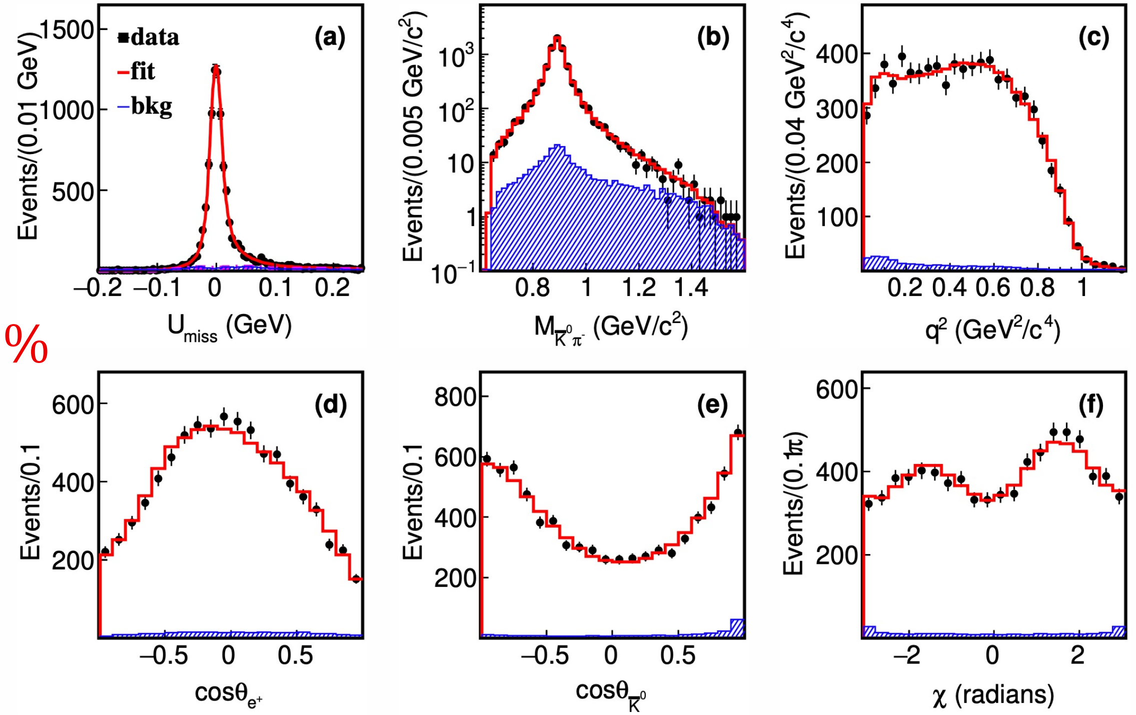
  $f_{\rm P-wave} = (94.15 \pm 0.32 \pm 0.16)\%$

- Updated **FF** measurement：

  $r_V = 1.48 \pm 0.05 \pm 0.02,$

  $r_2 = 0.70 \pm 0.04 \pm 0.02$

  $A_1(0) = 0.610 \pm 0.007 \pm 0.004$ (First measurement from this decay)



$|U_{\rm miss}| < 0.05$ GeV

$N_{\rm sig} \sim$ 8K, Bkg: ~4%

$K^*(892)$ study in the decay $D^0 \to K^-\pi^0\mu^+\nu_\mu$

Phys. Rev. Lett. 134, 011803 (2025)

- 7.93 fb^{-1} data @3.773GeV ➔ $N_{\mathrm{sig}} = 6436 \pm 119$
- **First BF** measurement and **LFU** test on this channel:

  $\mathcal{B}(D^0 \to K^-\pi^0\mu^+\nu_\mu) = (0.729 \pm 0.014 \pm 0.011)\%$

  $\mathcal{B}(D^0 \to K^*(892)^-\mu^+\nu_\mu) = (2.062 \pm 0.039 \pm 0.032)\%$

  $f_{S-\mathrm{wave}} = (5.76 \pm 0.35 \pm 0.29)\%$

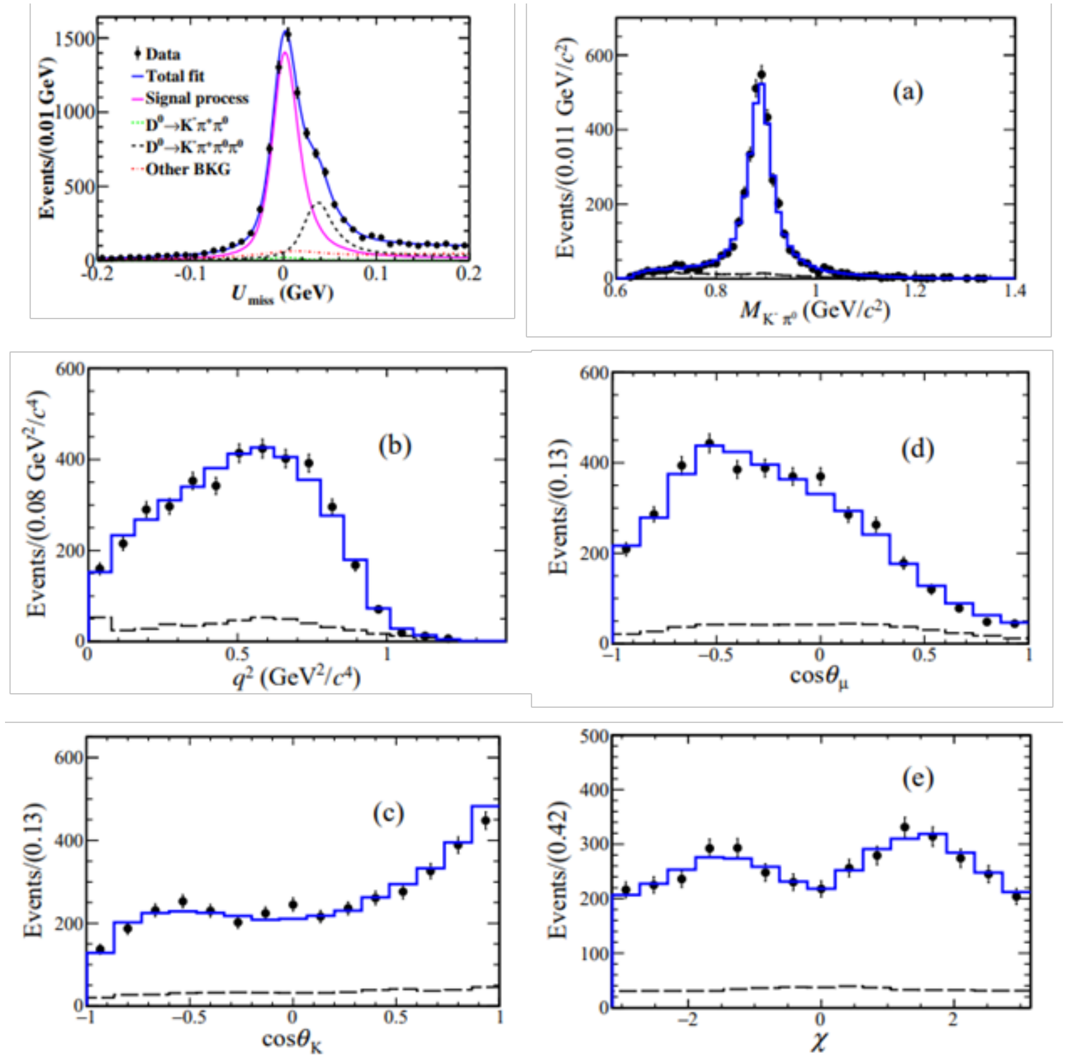
  $f_{P-\mathrm{wave}} = (94.24 \pm 0.35 \pm 0.29)\%$

  $\mathcal{R}^{\mu/e}_{K^*(892)^-} = 1.020 \pm 0.030 \pm 0.028$

- First **FF** measurement：

  $r_V = 1.37 \pm 0.09 \pm 0.03,$

  $r_2 = 0.76 \pm 0.06 \pm 0.02$



$|U_{\mathrm{miss}}| < 0.015$ **GeV**

$N^{SL}_{\mathrm{Event}} = 3375$, Bkg: $(12.6 \pm 0.7)\%$

$K^*(892)$ study in the decay $D^0 \to \overline{K}^0\pi^-\mu^+\nu_\mu$

Phys. Rev. Lett. 135, 111803 (2025)

- 7.9 fb^{-1} data @3.773GeV ➔ $N_{sig} = 6796 \pm 98$
- **First BF** measurement and **LFU** test on this channel:

$\mathcal{B}(D^0 \to \overline{K}^0\pi^-\mu^+\nu_\mu) = (1.373 \pm 0.020 \pm 0.023)\%$

$\mathcal{B}(D^0 \to K^*(892)^-e^+\nu_e) = (1.948 \pm 0.033 \pm 0.036)\%$

$\mathcal{R}^{\mu/e}_{K^*(892)^-} = 0.955 \pm 0.022 \pm 0.017$, $\mathcal{R}^{\mu/e}_{\overline{K}^0\pi^-} = 0.951 \pm 0.020 \pm 0.016$

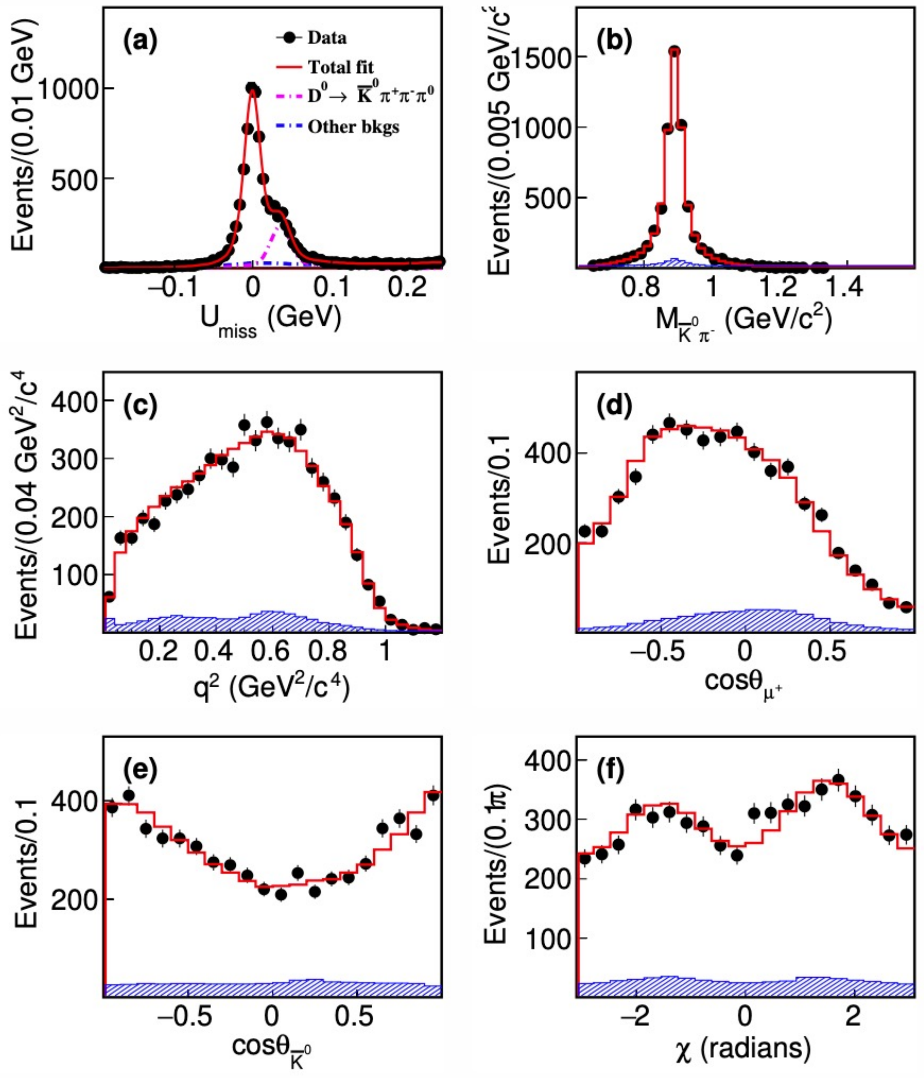
$f_{S-wave} = (5.35 \pm 0.87 \pm 0.71)\%$

$f_{P-wave} = (94.60 \pm 0.87 \pm 0.71)\%$

- **First FF** measurement at BESIII：

$r_V = 1.46 \pm 0.11 \pm 0.04$, $r_2 = 0.71 \pm 0.08 \pm 0.03$

$A_1(0) = 0.623 \pm 0.008 \pm 0.008$ (First measurement from this decay)



$|U_{miss}| < 0.02$ GeV
$N_{sig} \sim 6K$, Bkg: ~10%

$K^*(892)$ and $K_2^*(1430)$ study in the decay $D^0 \to K^-\pi^0 e^+\nu_e$

HUNAN UNIVERSITY

arXiv: 2603.00743 (Submitted to PRL)

- 20.3 fb^{-1} data @ 3.773 GeV ➔ $N_{\mathrm{sig}} = 28900 \pm 224$
- **First amplitude analysis give the observation of $K_2^*(1430)$ (7.9σ)**

$$f_{\mathcal{D}}(\%) = 0.16 \pm 0.05 \pm 0.02$$

$$\mathcal{B}(D^0 \to K_2^*(1430)e^+\nu_e) = (7.603 \pm 2.457 \pm 0.194)\times 10^{-4}$$

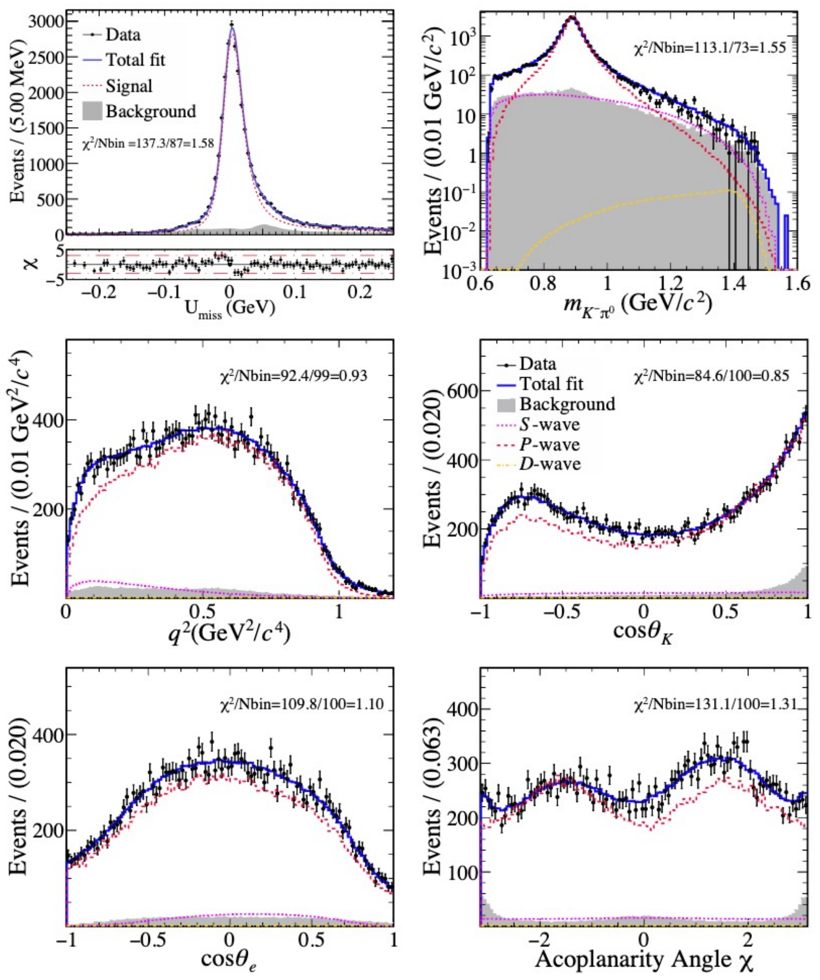
$$\mathcal{B}(D^0 \to K^*(892)^- e^+\nu_e, K^*(892)^- \to K^-\pi^0)$$

$$= (7.403 \pm 0.061 \pm 0.048\ )\times 10^{-3}$$

- **First test of isospin-breaking effect:**

$$\mathcal{R}_{K^{*-}} = \frac{\mathcal{B}(K^*(892)^- \to K^-\pi^0)}{\mathcal{B}(K^*(892)^- \to K_S^0\pi^-)} = \begin{cases} 1.09 \pm 0.02 \pm 0.02 \ (e \text{ channel}) \\ 1.07 \pm 0.02 \pm 0.03 \ (\mu \text{ channel}) \end{cases}$$

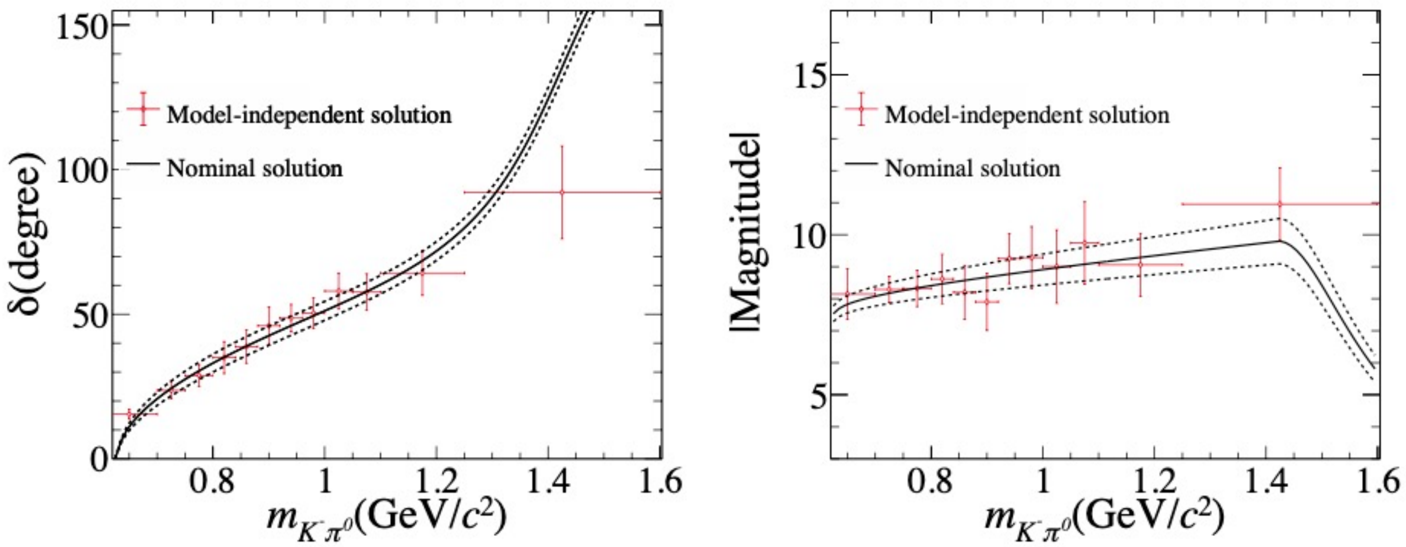
- LFU test： $\mathcal{R}_{\mu/e} = 0.928 \pm 0.020 \pm 0.012$ (~2.5% precision level)



~5% BKG level

$K_0^*(700)$ and $K_0^*(1430)$ study in the decay $D^0 \to K^-\pi^0 e^+\nu_e$

arXiv: 2603.00743 (Submitted to PRL)



Variable	Value
$r_S(\mathrm{GeV})^{-1}$	$-7.53 \pm 0.22 \pm 0.11$
$r_S^{(1)}$	$0.14 \pm 0.04 \pm 0.01$
$a_{S,\mathrm{BG}}^{1/2}\ (\mathrm{GeV}/c)^{-1}$	$1.98 \pm 0.10 \pm 0.13$
$b_{S,\mathrm{BG}}^{1/2}\ (\mathrm{GeV}/c)^{-1}$	$0.57 \pm 0.53 \pm 0.27$
$m_A(\mathrm{GeV}/c^2)$	$2.72 \pm 0.18 \pm 0.11$
$m_V(\mathrm{GeV}/c^2)$	$1.70 \pm 0.11 \pm 0.02$
r_V	$1.41 \pm 0.05 \pm 0.01$
r_2	$0.77 \pm 0.04 \pm 0.02$
$m_{K^*(892)^-}(\mathrm{MeV}/c^2)$	892.9 ± 0.2
$\Gamma^0_{K^*(892)^-}(\mathrm{MeV})$	$47.9 \pm 0.5 \pm 0.4$
$r_{\mathrm{BW}}\ (\mathrm{GeV}/c)^{-1}$	$3.38 \pm 0.17 \pm 0.16$
$r_{\mathcal{D}}(\mathrm{GeV})^{-4}$	$11.0 \pm 1.6 \pm 1.7$
$\phi_{\mathcal{D}}$ (degree)	$-16.9 \pm 7.7 \pm 3.0$
f_S (%)	$5.86 \pm 0.18 \pm 0.21$
$f_{\mathcal{P}}$ (%)	$93.97 \pm 0.19 \pm 0.21$
$f_{\mathcal{D}}$ (%)	$0.16 \pm 0.05 \pm 0.02$

- First measurement of the phase shift (magnitude) of the S-wave in a model-independent way in this channel.
- Additional measurement in a clean environment to constrain the pole parameters of the $K_0^*(700)$

$f_1(1285)$ and $f_1(1420)$ study in the decay $D_s^+ \to f_1 e^+ \nu_e$

arXiv: 2601.16938 (Submitted to PRD)

- 7.33 fb^{-1} data @ 4.128-4.226 GeV
- **First evidence of $D_s^+ \to f_1(1420) e^+ \nu_e$ ➔** $N_{\text{sig}} = 13.2^{+5.8}_{-5.0}$

$\mathcal{B}(D_s^+ \to f_1(1420) e^+ \nu_e \to K^+ K^- \pi^0) = (4.5^{+2.0}_{-1.7} \pm 0.4) \times 10^{-4}$

$\mathcal{B}(D_s^+ \to f_1(1420) e^+ \nu_e \to K^+ K^- \pi^0) < 7.6 \times 10^{-4}$@90%C.L.

- **First search of $D_s^+ \to f_1(1285) e^+ \nu_e$ (<1σ)**

$\mathcal{B}(D_s^+ \to f_1(1285) e^+ \nu_e \to \pi^+ \pi^- \eta) < 1.7 \times 10^{-4}$@90%C.L.

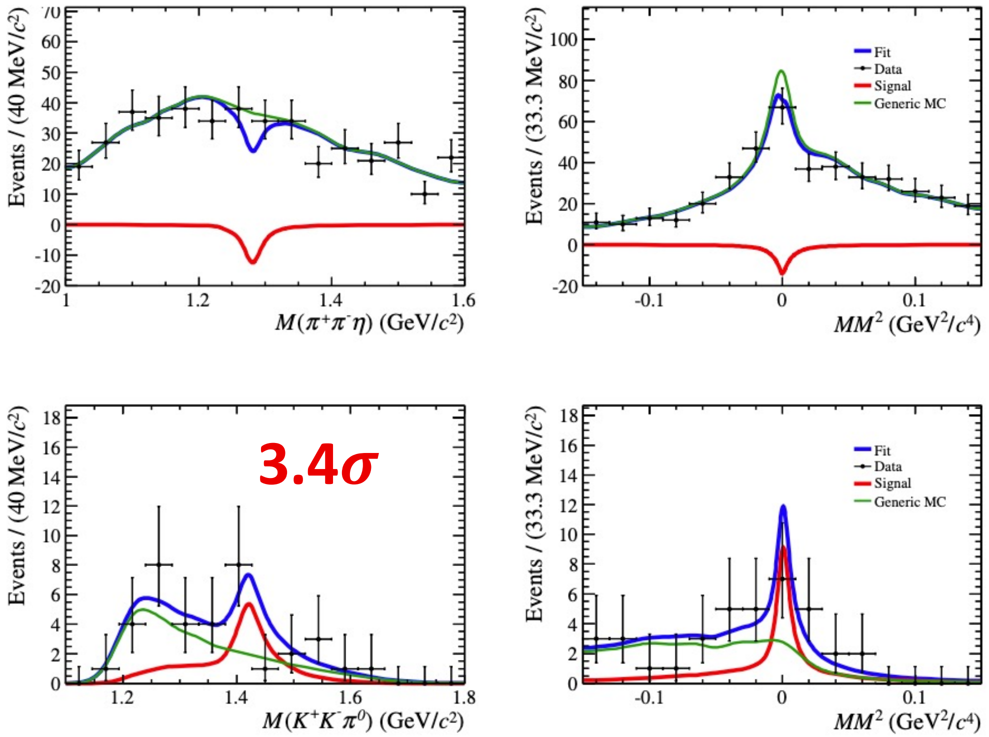
Unit ($\times 10^{-4}$)

Decay	Ref. [4]	Ref. [12]	Ref. [13]	Our result
$D_s^+ \to f_1(1285) e^+ \nu_e$	[0.6, 3.6]	8.6 ± 7.3	1.17 ± 0.18	< 5.0
$D_s^+ \to f_1(1420) e^+ \nu_e$	2.5 ± 0.5	2.1 ± 2.1	3.9 ± 0.4	–

[4] H. Y. Cheng *et al.*, Eur. Phys. J. C **77**, 587 (2017).

[12] Y. Qiao, Y. X. Liu, Y. G. Xu, and R. M. Wang, The European Physical Journal C **84** (2024).

[13] V. O. Galkin and I. S. Sukhanov, Phys. Rev. D **111**, 093001 (2025).



Content

Summary and prospect

Summary:

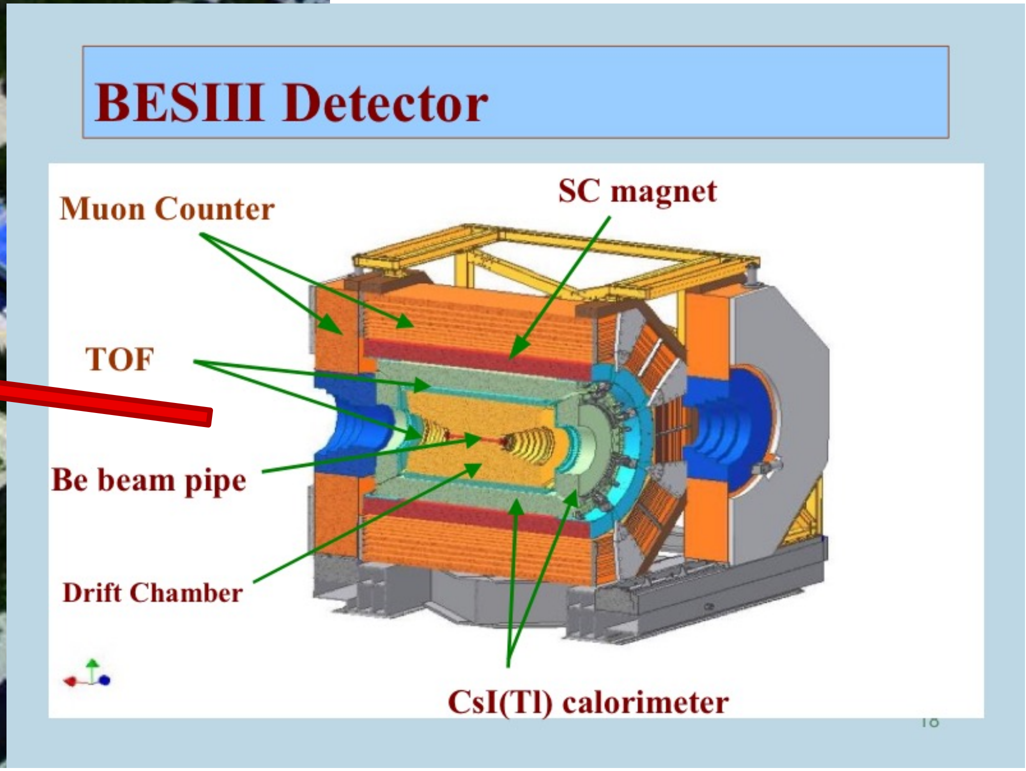
- BESIII has the largest data samples at $D\overline{D}/D_sD_s^*$ threshold.
- Scalar/axial-vector mesons are studied systematically via semi-leptonic charm decays.
- BFs/FF measurements help to test different QCD modes and understand their nature!

Prospect:

- BESIII has **20 fb^{-1}** @3.773 GeV in total now.
- More scalar/axial-vector/tensor mesons could be studied via semi-leptonic charm decays.
  - ➔ $\boldsymbol{K_0^*(700), K_0^*(1430), f_0(1370), f_0(1500), a_0(1450)}$ …
  - ➔ $\boldsymbol{K_1(1400), a_1(1260), b_1(1235), f_1(1285), f_1(1420)}$ …
  - ➔ $\boldsymbol{a_2(1320), f_2(1270), K_2^*(1430)}$ …
- More results are on the way!

Thank you!

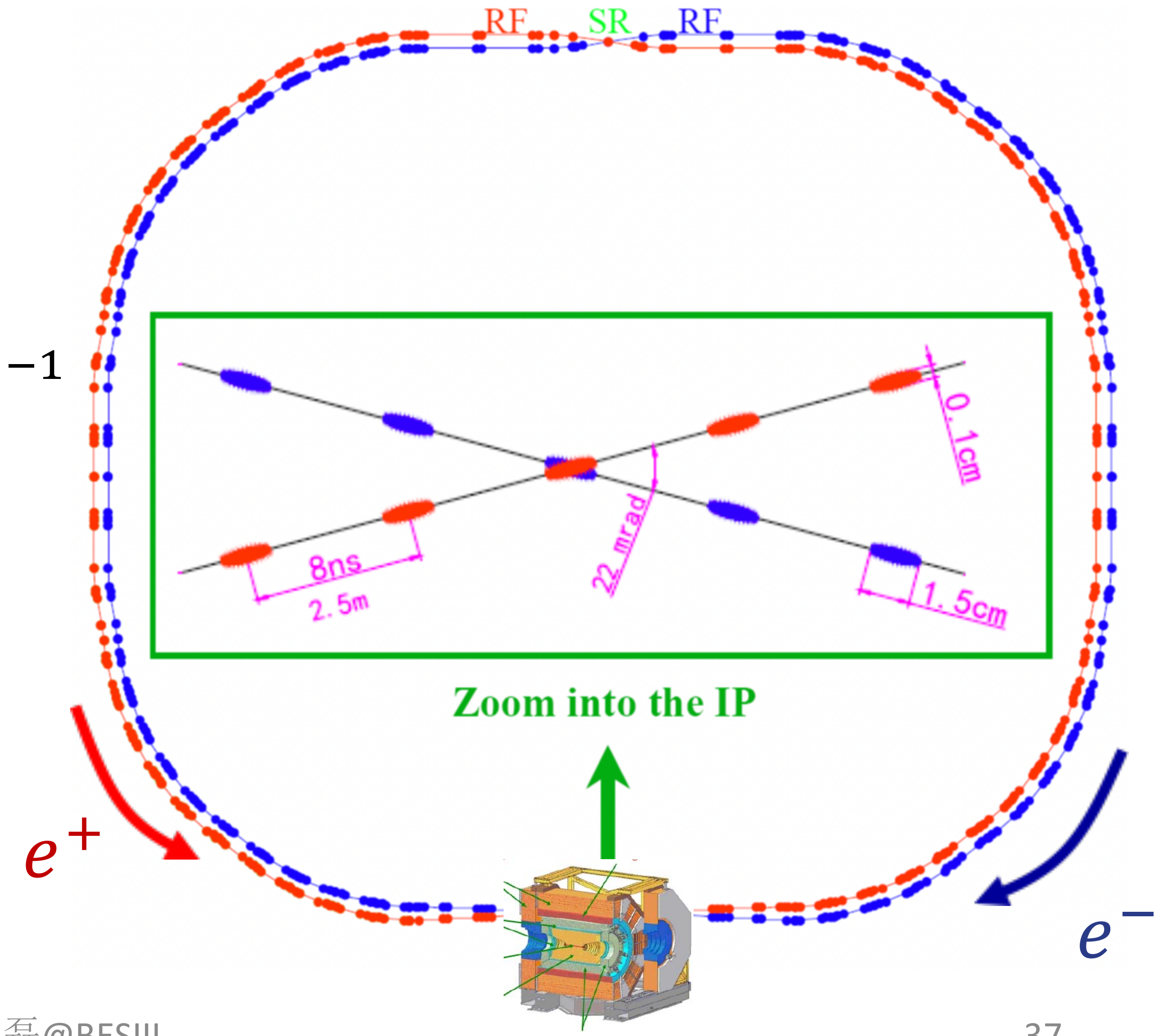
BESIII experiment



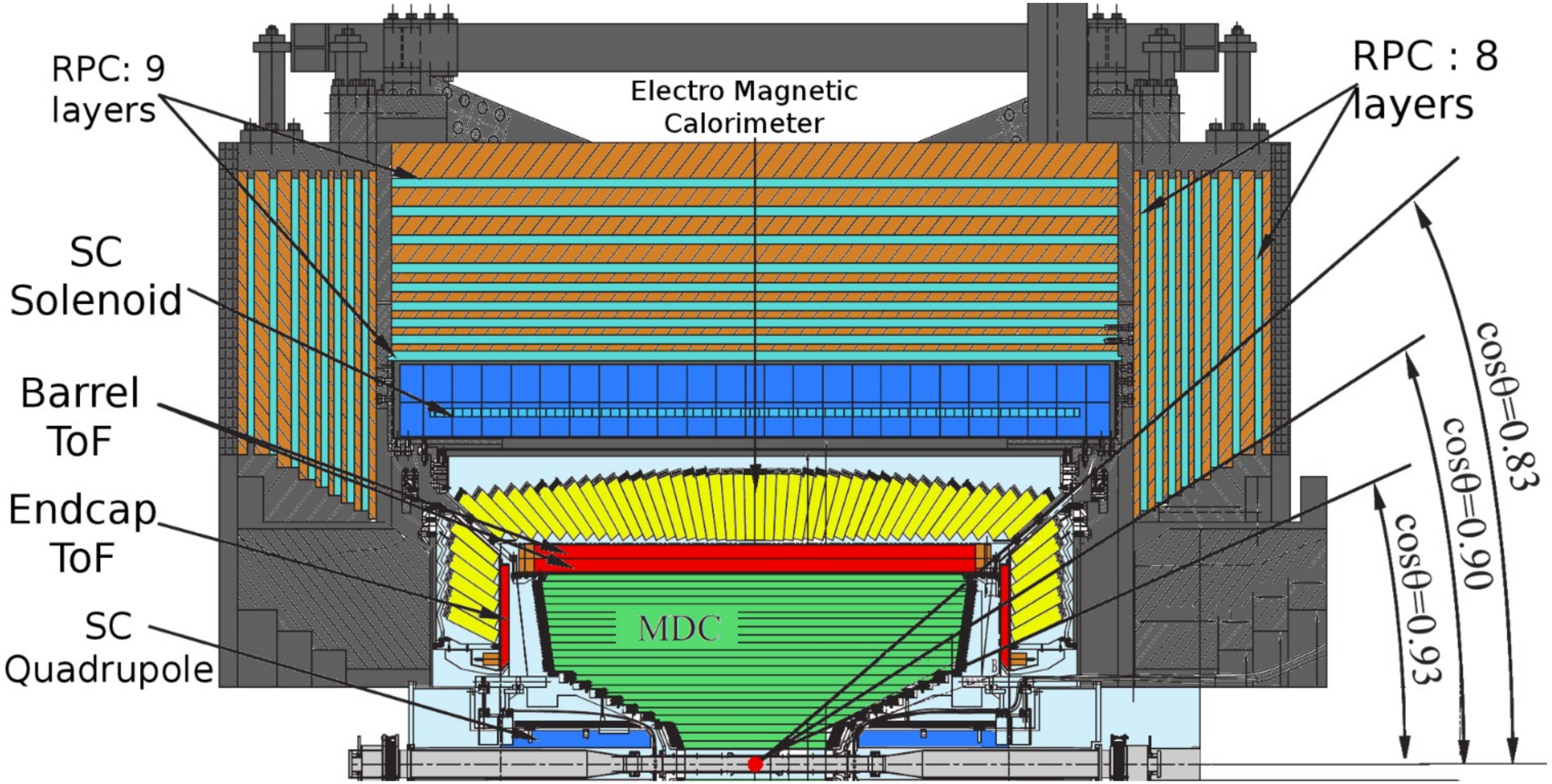
BEPCII collider

- Two ring symmetric e^+e^- collider
- Circumference: 240 m
- Design luminosity: $1\times10^{33}cm^{-2}s^{-1}$

  Achieved time: 5 April, 2016
- E_{cm}: 2 – 5 GeV
- Beam crossing angle: 22 mrad



BESIII detector



MDC

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

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

TOF

δt 80 ps Barrel

δt 110 ps Endcap

EMC

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

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

MUC

$\delta(xy) <$2 cm