BESIII上粲介子半轻衰变到矢量介子和标量介子末态的研究

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2024年11月09日@洛阳

Content

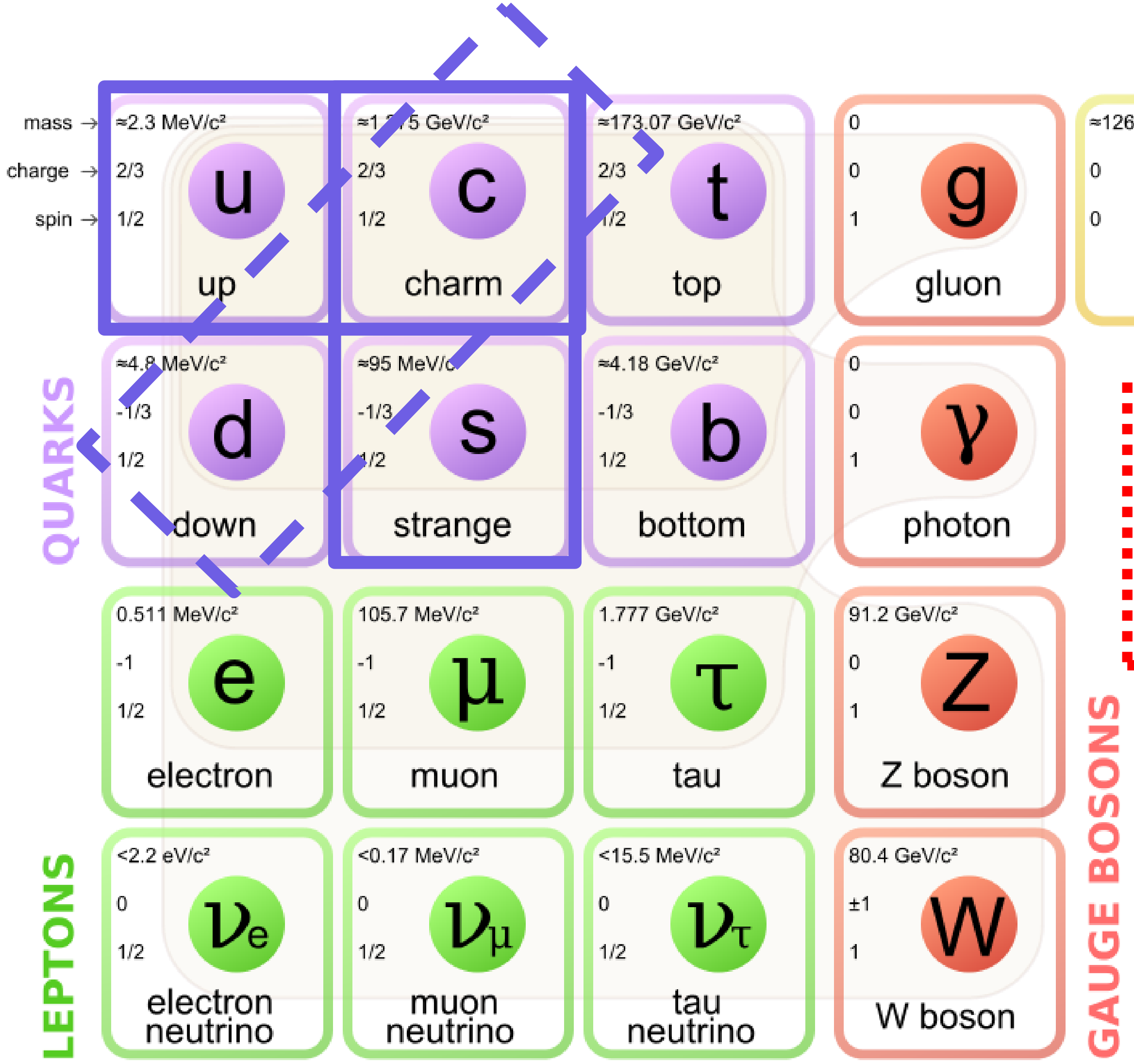
01 Physics motivation ✓

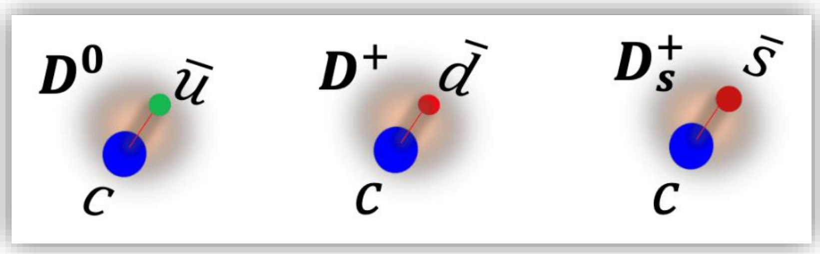
02 Data and analysis method

03 Results in review

04 Summary and prospect

Physics motivation





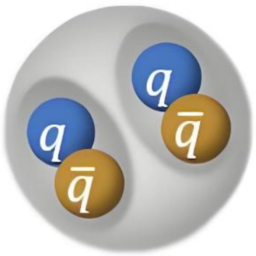
Charm physics

- **QCD**: Non-perturbative energy region
- **Standard Model test**: High-precision ➔ New Physics

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

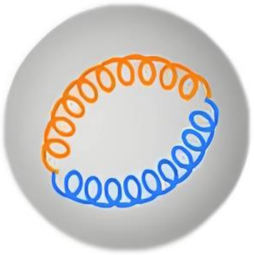
Physics motivation

Tetraquark

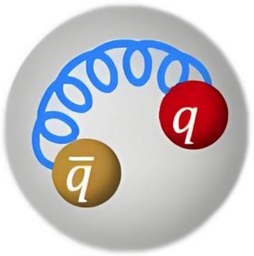


Hadronic molecules

Pentaquark



Glueball



hybrid

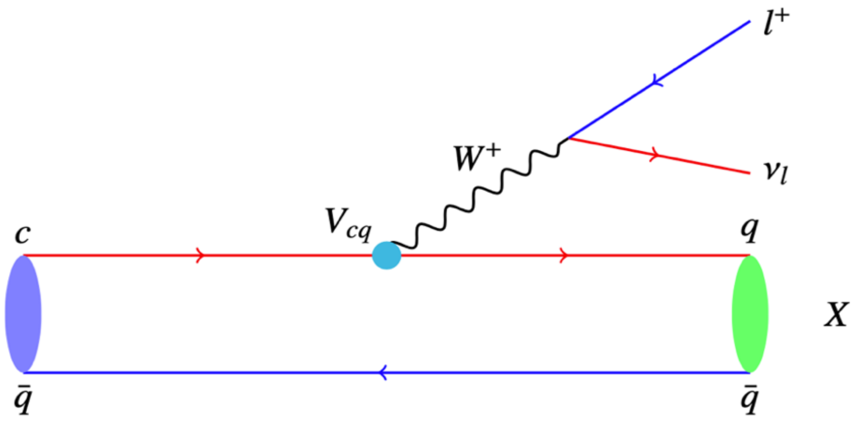
- **Quark model allows for them.**
- **How about scalar mesons:**

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

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

Physics motivation

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



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

- **Clean environment:** hadrons ***X*** can be separated from leptons pair.
- **High statistics** of charmed meson at experiments.
  - CKM matrix elements $|V_{cs}|/|V_{cd}|$ meaurements ➔ **Test the unitarity of the CKM matrix (New Physics).**
  - $\mathcal{R}_{\mu/e} = \mathcal{B}(D_{(s)} \to X\mu^+\nu_\mu)/\mathcal{B}(D_{(s)} \to Xe^+\nu_e)$ measurement ➔ **Test lepton flavor universality (LFU)**
  - Hadronic Form factor (FF) measurements ➔ **Test different QCD models (LQCD)**

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Data sample

- Symmetric e^+e^- collider @2 – 5GeV
- Pair-production near threshold
- $D\overline{D}$@3.773GeV: **~20.3 fb^{-1}**

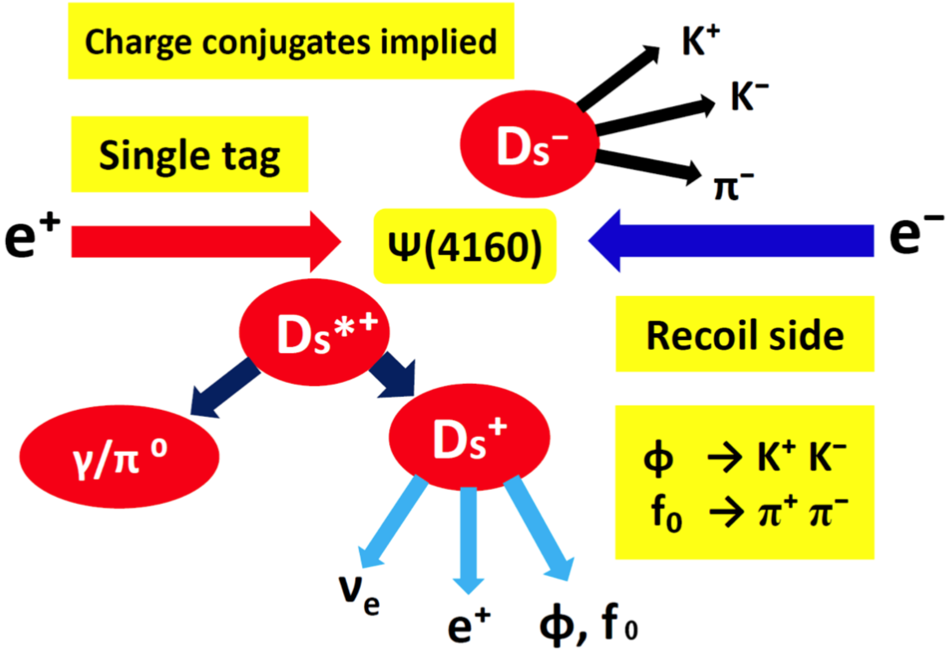
2.93 fb^{-1}@2010-2011; 4.99 fb^{-1}@2021-2022; 8.16 fb^{-1}@2021-2022; 4.19 fb^{-1}@2022-2024

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

E_{cm}(GeV)	Data taking year	$\mathcal{L}(\mathrm{fb}^{-1})$	ST D^0	ST D^+	ST D_s^+
3.773	2010-11➔2022-24	2.93➔20.3	2.7 M (~7 ×)	1.7 M (~7 ×)	
4.13-4.23	2012,2016-17,2019	7.33			0.8 M

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)

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

Analysis method： Maximum Likelihood Method

- Minimize the negative log-likelihood function.:

$$NLL = -\sum_{i=1}^{N} \ln \frac{\omega(\xi_i\ ,\eta)}{\sigma_s}$$

$\omega(\xi_i\ ,\eta)$ is the decay intensity， σ_s is the normalization factor, using signal Monte Carlo samples：

$$\sigma_s = \int d\xi\ \omega(\xi\ ,\eta)\ \epsilon(\xi) \ \propto \ \frac{1}{N_{selected}} \sum_{k=1}^{N_{selected}} \frac{\omega(\xi_k\ ,\eta)}{\omega(\xi_k\ ,\ \eta_0)}$$

- When the background is low, it can be directly subtracted in the NLL. ：

$$NLL = (-lnL_{data}) - (-lnL_{bkg})$$

- background is high ：

$$-\sum_{i=1}^{N} \ln\left((1-f_b)\frac{\omega(\xi_i,\eta)}{\int d\xi_i \omega(\xi_i,\eta)\epsilon(\xi_i)} + f_b \frac{B_\epsilon(\xi_i)}{\int d\xi_i B_\epsilon(\xi_i)\epsilon(\xi_i)} \right),$$

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

$$\Gamma(D_{(s)} \to V \ell^+ \nu_\ell) \propto |V_{cd(s)}|^2 \mathfrak{I}(A_1(q^2), A_2(q^2), V(q^2), \ldots) dm^2 dq^2 d\cos(\theta_h) d\cos(\theta_\ell) d\chi$$

V: ρ, ω, K^*, ϕ

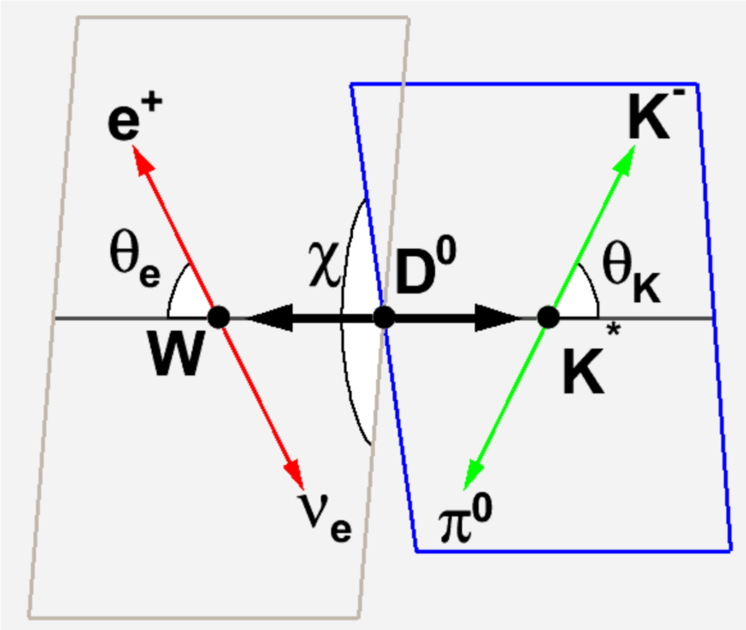
Theoretical： Phys. Rev. **137**, B438(1965), Phys.Reive.D 46,5040(1992)

- The decay intensity $\mathfrak{I}$ can include components of S/P/D wave processes.
- Unbinned maximum likelihood method.

  (implemented based on the RooFit framework).
- Form factor (single pole parameterization, double pole ...)

$$A_i(q^2) = \frac{A_i(0)}{1 - q^2/M_A^2} \qquad V(q^2) = \frac{V(0)}{1 - q^2/M_V^2}$$

$$r_V = \frac{V(0)}{A_1(0)} \qquad r_2 = \frac{A_2(0)}{A_1(0)}$$



c -> s semi-leptonic decay: $D^+ \to \bar{K}^{*0} e^+ \nu_e$

Phys. Rev. D 94, 032001(2016)

- 2.93fb^{-1} data @3.773GeV
- $N_{sig} = 18262$ (background Level: 0.8%)
- $\mathcal{B}(D^+ \to K^-\pi^+ e^+\nu_e) = (3.77 \pm 0.03 \pm 0.08)\%$
- $\mathcal{B}(D^+ \to \bar{K}^{*0} e^+\nu_e) = (5.31 \pm 0.05 \pm 0.12)\%$

  $f_{\text{S-wave}} = (6.05 \pm 0.22 \pm 0.18)\%$

  $f_{P-wave} = (93.93 \pm 0.22 \pm 0.18)\%$
- Form factor：

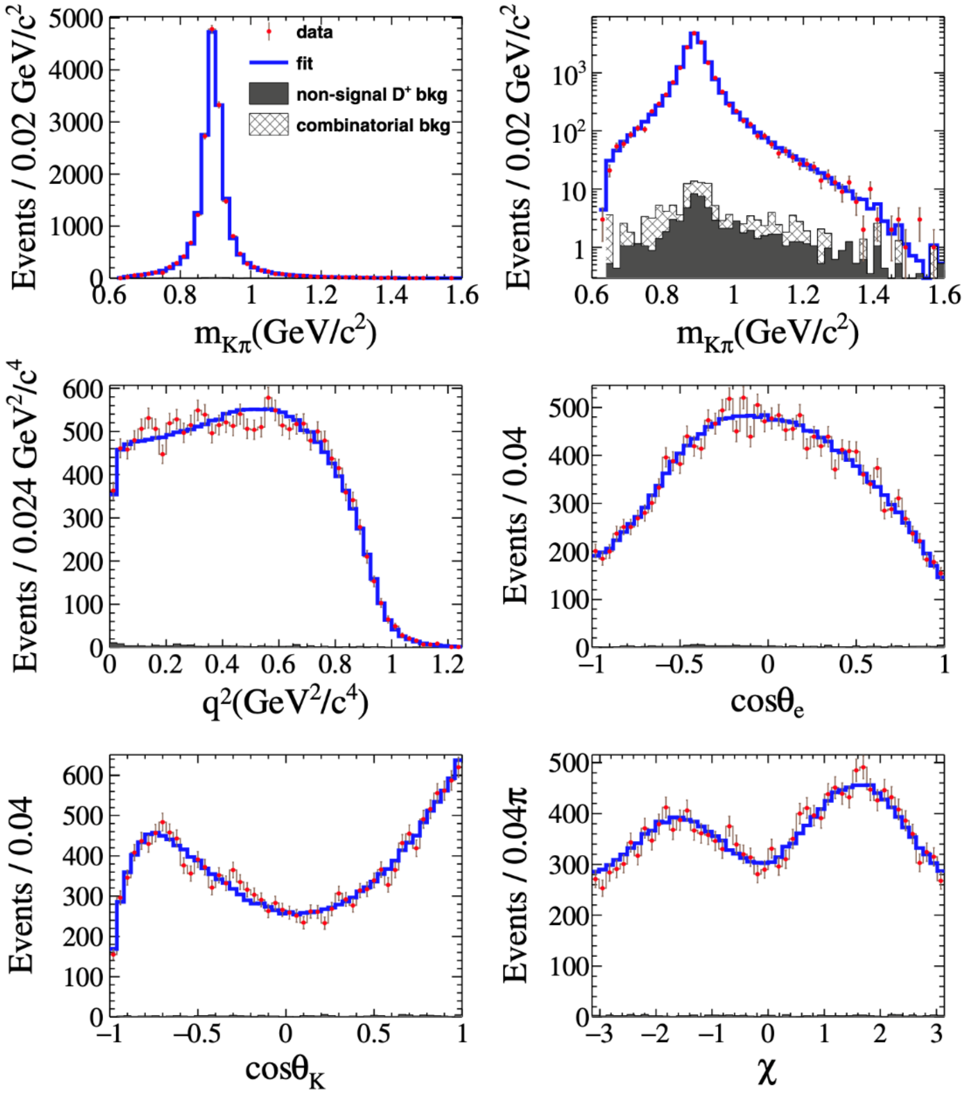
  $r_V = 1.411 \pm 0.058 \pm 0.007,$

  $r_2 = 0.788 \pm 0.042 \pm 0.008$

  input $G_f, \tau_{D^+}, |V_{cs}|$ ➔

$A_1(0) = 0.589 \pm 0.010 \pm 0.012$ (Zero-width)

$A_1(0) = 0.619 \pm 0.011 \pm 0.013$ (Considering width)



c -> s semi-leptonic decay: $D^0 \to K^{*-} e^+ \nu_e$

Phys. Rev. D 99, 0111003(R)(2019)

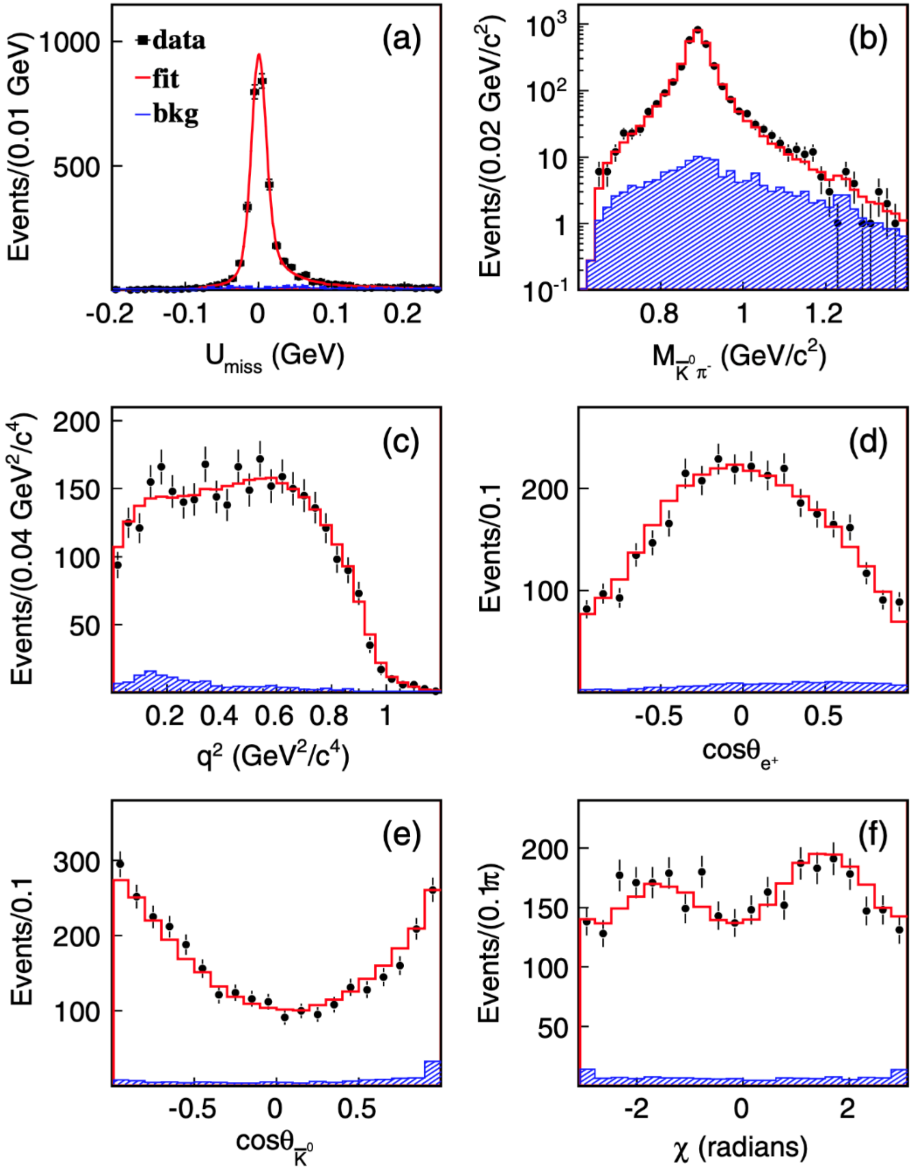
- 2.93fb^{-1} $data\ @3.773GeV$
- $N_{sig} = 3112 \pm 64$ (background level: 6.0%)
- $\mathcal{B}(D^0 \to \bar{K}^0 \pi^- e^+ \nu_e)$= $(1.434 \pm 0.029 \pm 0.032)\%$
- $\mathcal{B}(D^0 \to K^{*-} e^+ \nu_e)$= $(2.02 \pm 0.04 \pm 0.04)\%$

  $f_{\text{S-wave}} = (5.51 \pm 0.97 \pm 0.62)\%$

  $f_{P-wave} = (94.52 \pm 0.97 \pm 0.76)\%$
- First measurement of the form factor. :

  $r_V = 1.46 \pm 0.07 \pm 0.02,$

  $r_2 = 0.67 \pm 0.06 \pm 0.01$



c -> s semi-leptonic decays: $D^0 \to K^{*-}\mu^+\nu_\mu$

arXiv:2403.10877 (Accepted in PRL)

- $7.93\ \text{fb}^{-1}$ data @$3.773GeV$
- $N_{sig} = 6436 \pm 119$ (background level: 12.6%)
- $\mathcal{B}(D^0 \to K^-\pi^0\mu^+\nu_\mu) = (0.729 \pm 0.014 \pm 0.011)\%$
- $\mathcal{B}(D^0 \to K^{*-}\mu^+\nu_\mu) = (2.062 \pm 0.039 \pm 0.032)\%$

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

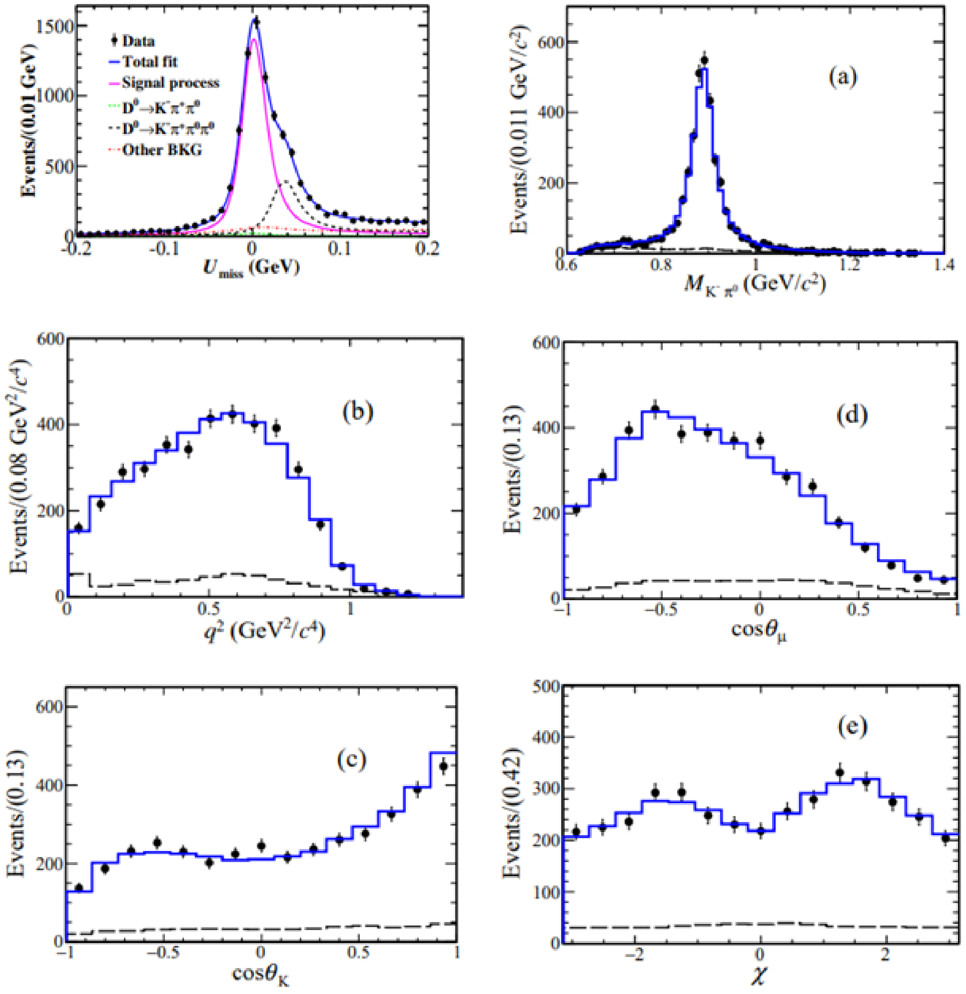
  $f_{P-wave} = (94.24 \pm 0.35 \pm 0.29)\%$

  $\mathcal{B}(D^0 \to K^{*-}\mu^+\nu_\mu)/\mathcal{B}(D^0 \to K^{*-}e^+\nu_e) = 0.96 \pm 0.08$

- First measurement of the form factor. :

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

  $r_2 = 0.76 \pm 0.06 \pm 0.02$



c -> s semi-leptonic decays: $D^+ \to \bar{K}^{*0} e^+ \nu_e$

J. High Energ. Phys. 10, 199 (2024)

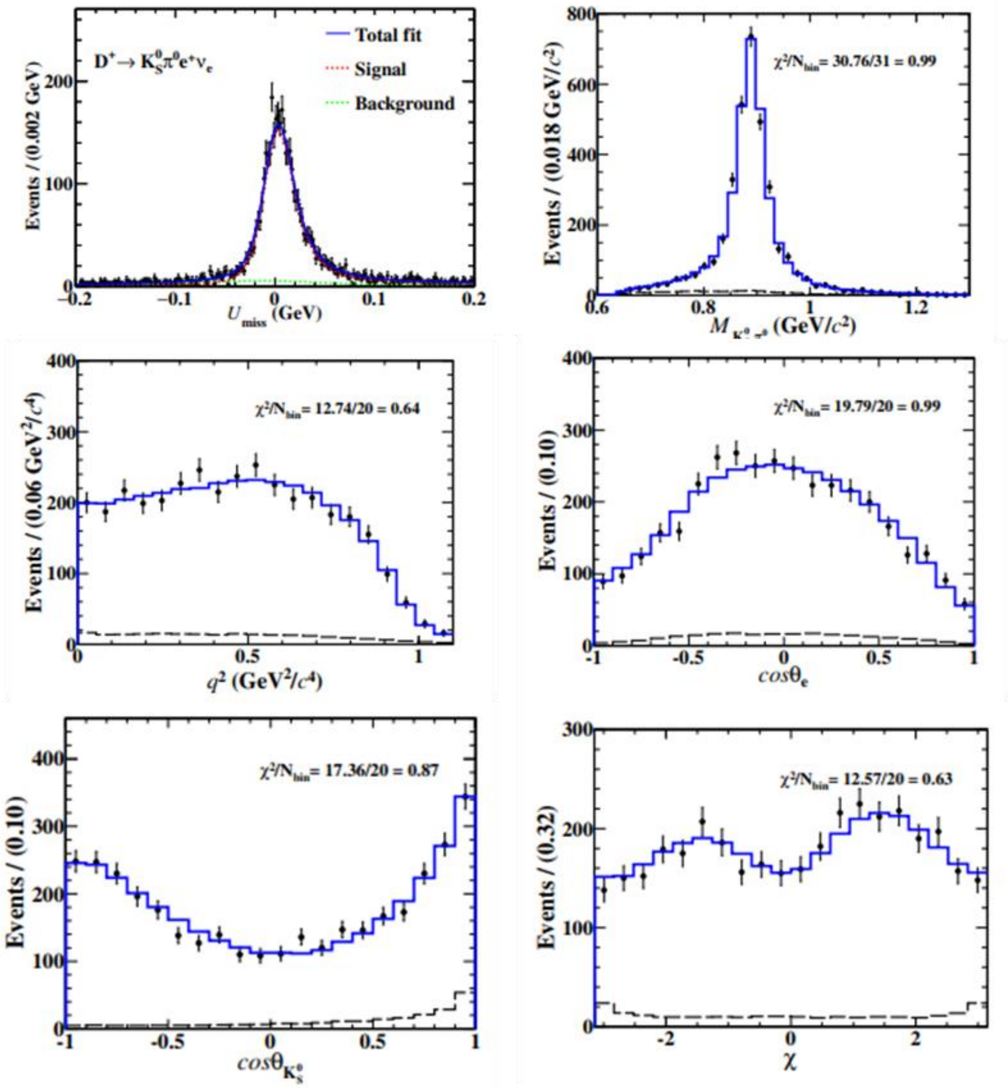
- 7.93 fb^{-1} data @3.773GeV
- $N_{sig} = 3852 \pm 75$ (background level: 6.54%)
- $\mathcal{B}(D^+ \to K_S^0 \pi^0 e^+ \nu_e)$= $(0.881 \pm 0.017 \pm 0.016)\%$
- $\mathcal{B}(D^+ \to \bar{K}^{*0}\, e^+ \nu_e)$= $(4.97 \pm 0.011 \pm 0.012)\%$

  $f_{S-\mathrm{wave}} = (5.41 \pm 0.35 \pm 0.37)\%$

  $f_{P-wave} = (93.88 \pm 0.27 \pm 0.29)\%$
- Measurement of the form factor.：

  $r_V = 1.43 \pm 0.07 \pm 0.03,$

  $r_2 = 0.72 \pm 0.06 \pm 0.02$



c -> s semi-leptonic decay: $D_s^+ \to K^+K^-\mu^+\nu_\mu$

JHEP12(2023)072

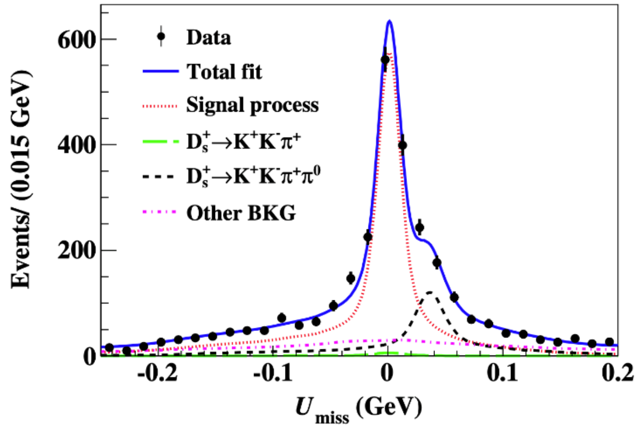
- 7.33 fb^{-1} data @ 4.13-4.23 GeV
- $N_{\text{sig}} = 1725 \pm 68$ for BF measurement

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

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

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

- **First FF measurement** based on single pole parameterization:
  - **Partial wave analysis** is performed ➔ ϕ dominate
  - **μ mass** is considered in the formula



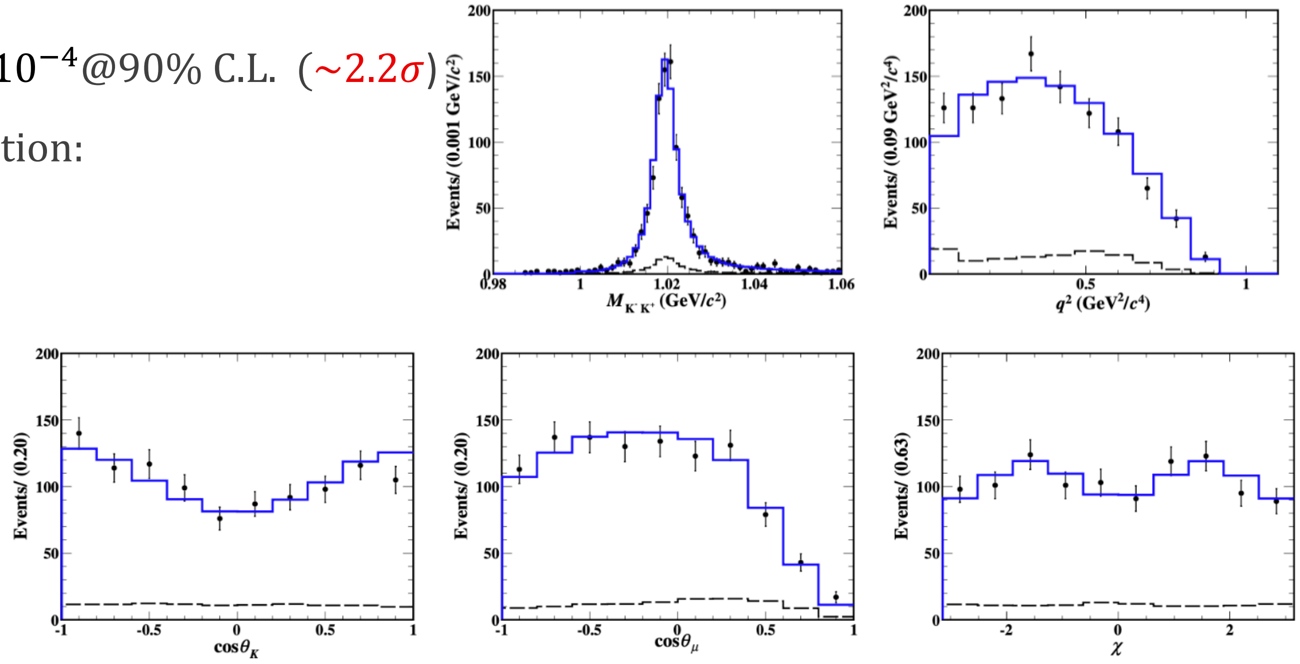


Table 5. Measured FF ratios and comparison with previous measurements.

Experiments	r_V	r_2
PDG [42]	1.80±0.08	0.84±0.11
This analysis	1.58±0.17±0.02	0.71±0.14±0.02
BABAR [25]	1.807±0.046±0.065	0.816±0.036±0.030
FOCUS [58]	1.549±0.250±0.148	0.713±0.202±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

$|U_{\text{miss}}| < 0.02$ GeV

$N_{\text{Event}}^{D_s^+} = 939$, Bkg: $(9.8 \pm 0.7)\%$

c -> d semi-leptonic decays : $D_s^+ \to K^{*0} e^+ \nu_e$

Phys. Rev. Lett. 122, 061801 (2019)

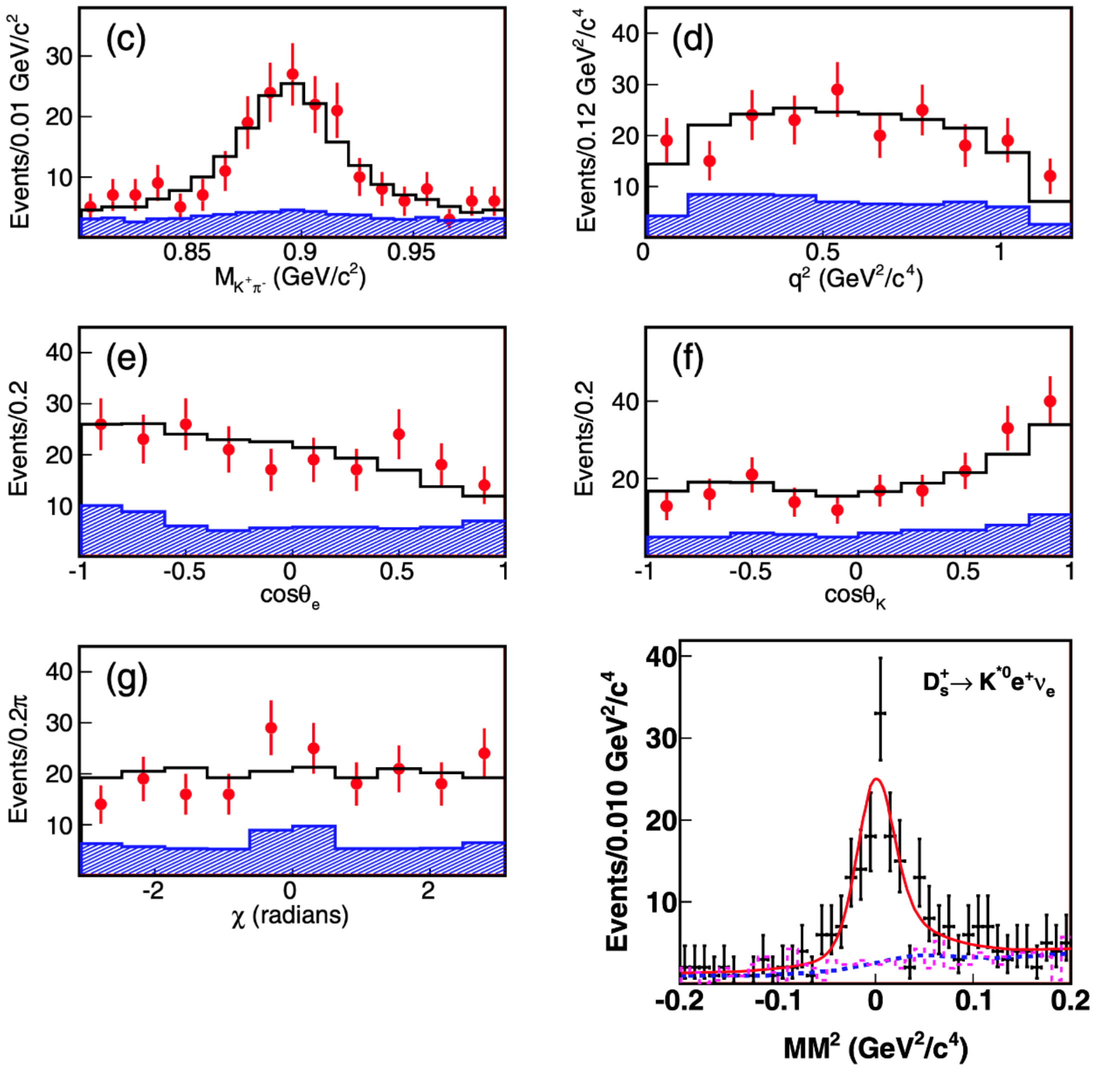
- 3.19 fb^{-1}data @4.18 GeV
- $N_{sig}(D_s^+ \to K^{*0} e^+ \nu_e) = 155.0 \pm 17.2$
- $\mathcal{B}(D_s^+ \to K^{*0} e^+ \nu_e) = (2.37 \pm 0.26 \pm 0.20) \times 10^{-3}$
- Consistent with multiple theoretical calculations：

  $r_V = 1.67 \pm 0.34 \pm 0.16,\ r_2 = 0.77 \pm 0.28 \pm 0.07$
- Consistent with the expectations of Lattice QCD and U-spin

  (d ↔ s) symmetry: Form factors are insensitive to spectator quarks

Use BESIII and CLEO measurement

	Values
$f_+^{D_s^+ \to K^0}(0)/f_+^{D^+ \to \pi^0}(0)$	$1.16 \pm 0.14 \pm 0.02$
$r_V^{D_s^+ \to K^{*0}}/r_V^{D^+ \to \rho^0}$	$1.13 \pm 0.26 \pm 0.11$
$r_2^{D_s^+ \to K^{*0}}/r_2^{D^+ \to \rho^0}$	$0.93 \pm 0.36 \pm 0.10$

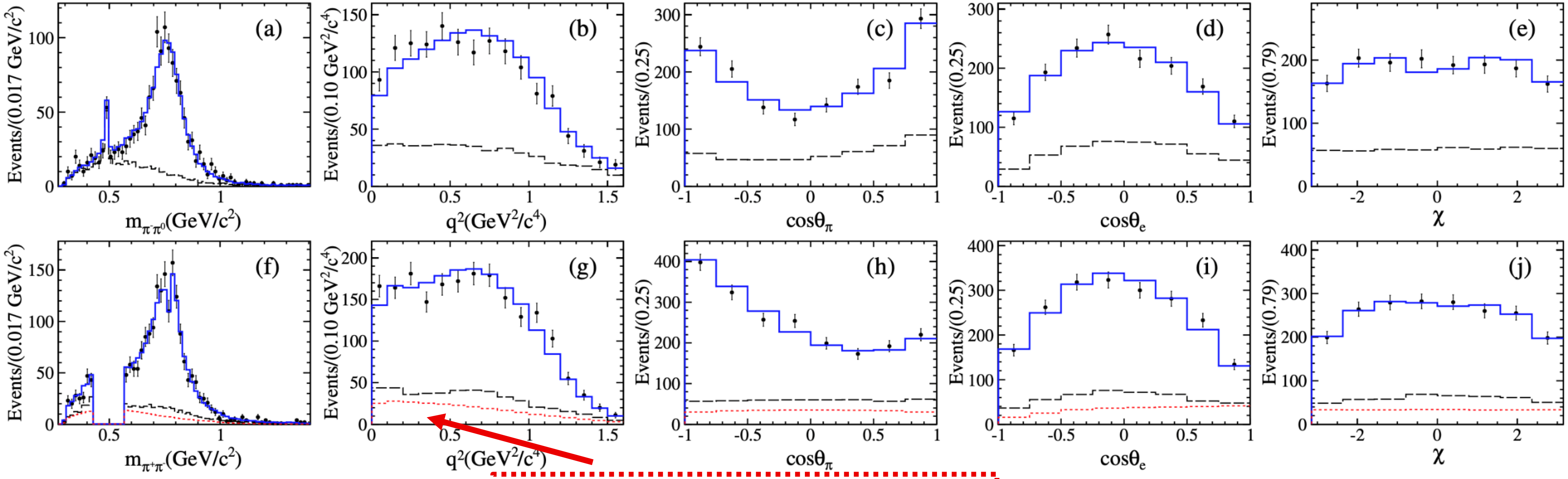


c -> d semi-leptonic decay : $D \to \rho\, e^{+}\nu_e$

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

$|U_{miss}| < 0.06$ GeV ➔ $N^{D^0}_{\text{Event}} = 1498$, Bkg: $(33.28 \pm 0.87)\%$; $N^{D^+}_{\text{Event}} = 2017$, Bkg: $(23.82 \pm 0.69)\%$

D^0 / D^+



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

- 2.93 fb^{-1} data @ 3.773 GeV
- $R = \frac{\mathcal{B}(D^+\to f_0(500)e^+\nu_e)+\mathcal{B}(D^+\to f_0(980)e^+\nu_e)}{\mathcal{B}(D^+\to a_0(980)e^+\nu_e)} > 2.7@90\%CL$

(W. Wang, PRD82, 034016(2010), Model independently way)

➔ BF results favor tetra-quark for f_0 and a_0

- $D \to \rho$: $r_V = 1.695 \pm 0.083 \pm 0.051,\ r_2 = 0.845 \pm 0.056 \pm 0.039$

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

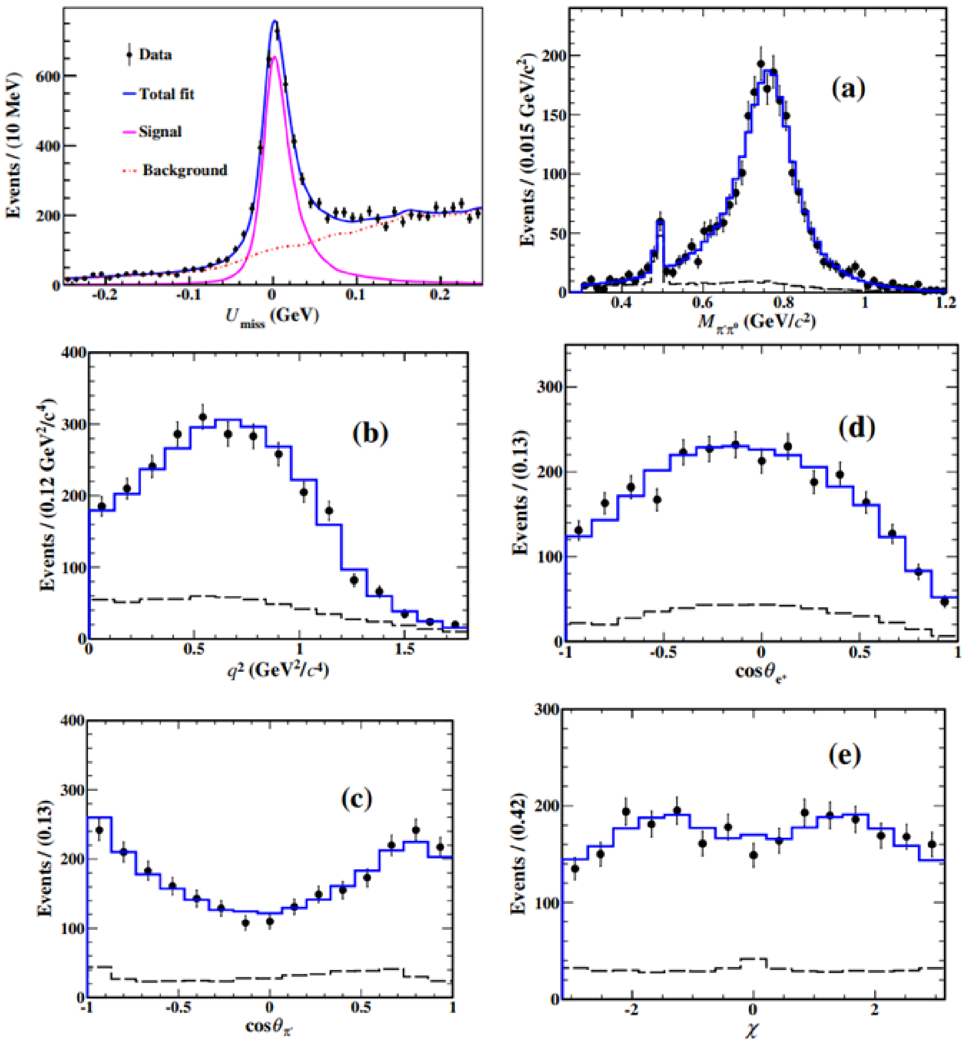
c -> d semi-leptonic decays : $D^0 \to \rho^- e^+ \nu_e$

arXiv:2409.04276 (Submitted to PRD)

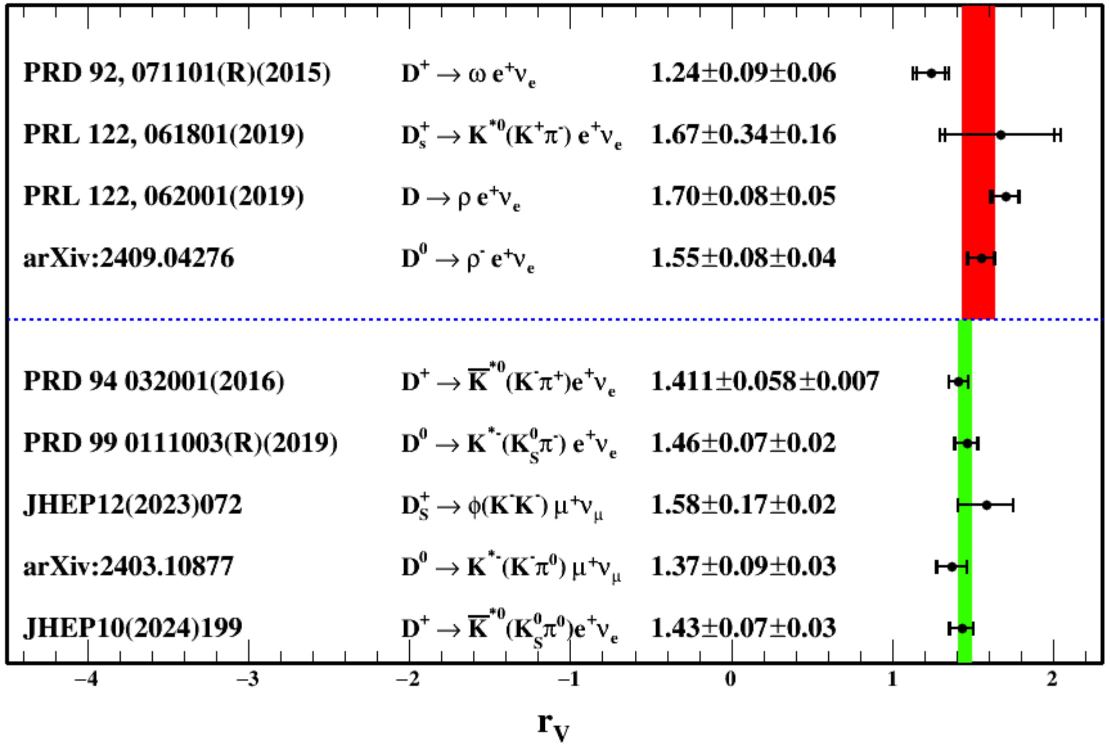
- 7.93fb^{-1} data @3.773GeV
- $N_{sig} = 3337 \pm 77$ (background level: 18.7%)
- $\mathcal{B}(D^0 \to \rho^- e^+ \nu_e) = (1.439 \pm 0.033 \pm 0.027) \times 10^{-3}$
- Form factor measurement:

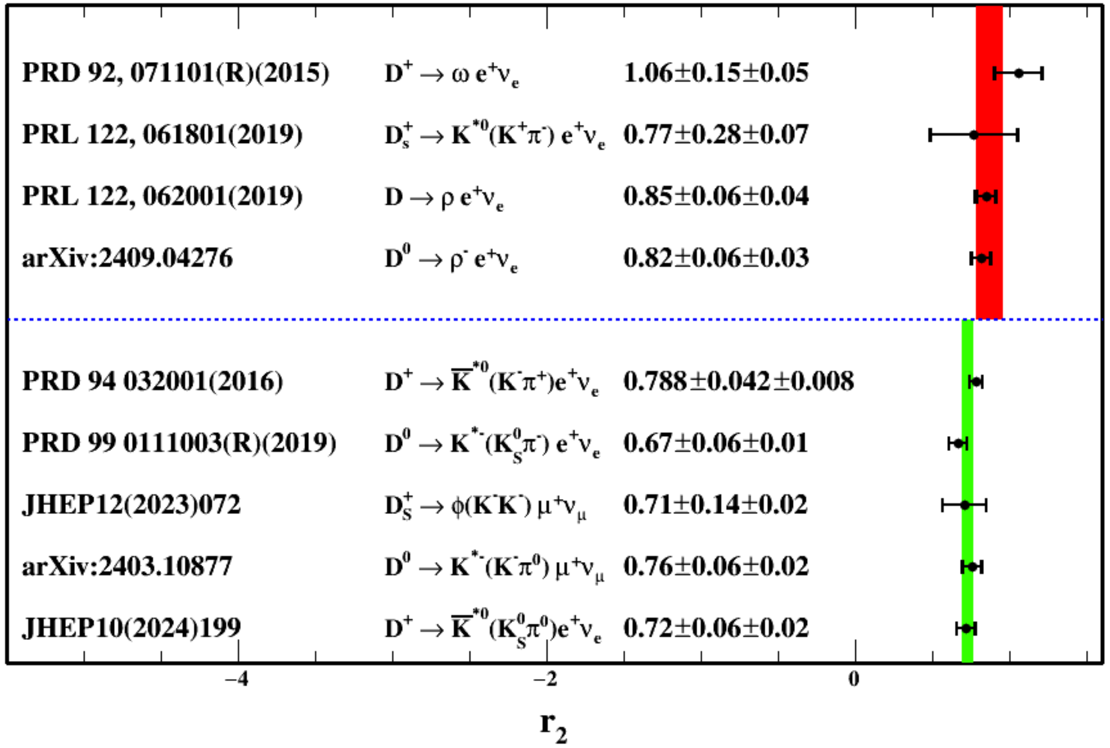
  $r_V = 1.548 \pm 0.079 \pm 0.041$,

  $r_2 = 0.823 \pm 0.056 \pm 0.026$



Comparisons of r_V and r_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:

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

- Double differential decay rate:

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

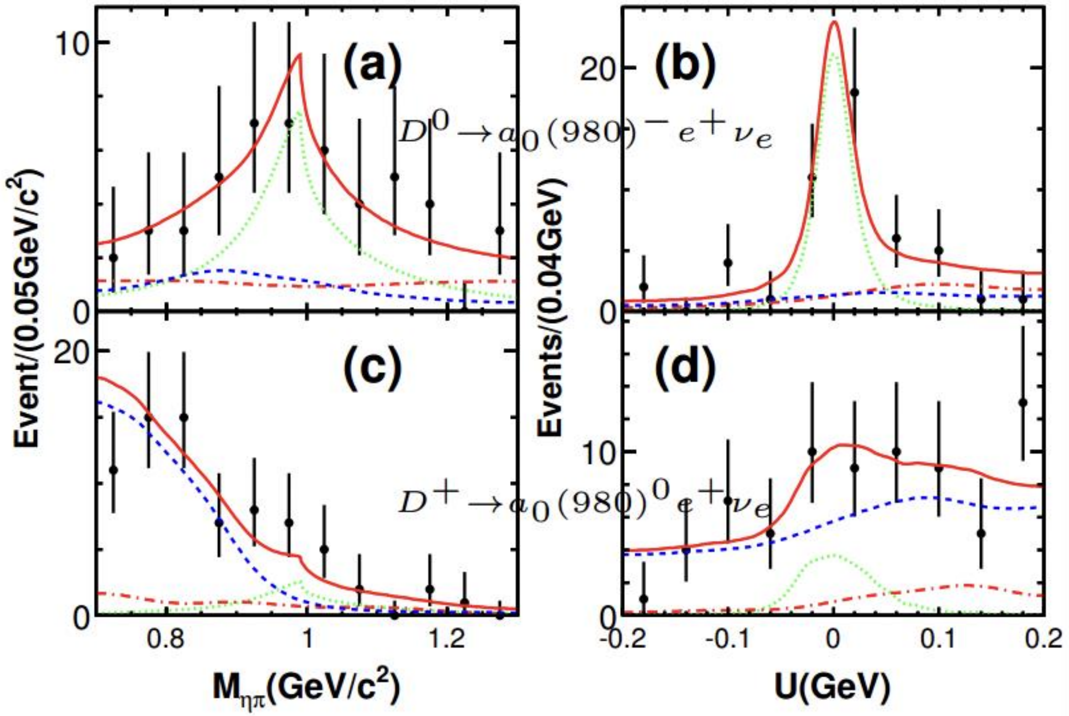
$$\frac{d^2\Gamma(D_{(s)} \to S\ell^+\nu_\ell)}{ds\,dq^2} = \frac{G_F^2 |V_{cd(s)}|^2}{192\pi^4 m_{D_{(s)}}^3} \lambda^{\frac{3}{2}}\left(m_{D_{(s)}}^2, s, q^2\right) |f_+(q^2)|^2 P(s)$$

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

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
- $N_{\mathrm{sig}}^{D^0} = 25.7^{+6.4}_{-5.7}$
- $N_{\mathrm{sig}}^{D^+} = 10.2^{+5.0}_{-4.1}$
- Branching fraction (BF) help to understand the nature of the $a_0(980)$

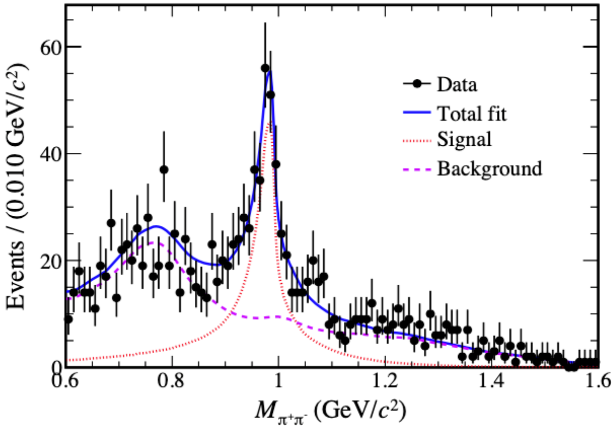


Decay	BF ($\times 10^{-4}$)	Significance
$D^0 \to a_0(980)^- e^+ \nu_e,\ a_0(980)^- \to \eta\pi^-$	$1.33^{+0.33}_{-0.29} \pm 0.09$	6.4σ
$D^+ \to a_0(980)^0 e^+ \nu_e,\ a_0(980)^0 \to \eta\pi^0$	$1.66^{+0.81}_{-0.66} \pm 0.11$ < 3.0 (90% C.L.)	2.9σ

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

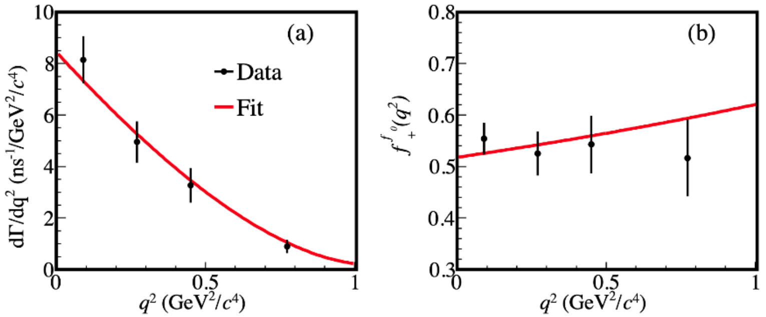
HUNAN UNIVERSITY

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

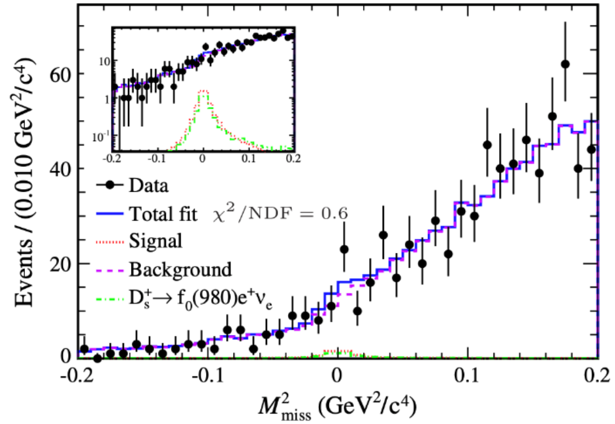


- 7.33 fb^{-1} data @ 4.128-4.226 GeV ➔ $N_{\mathrm{sig}} = 439 \pm 33$
- $\mathcal{B}(D_s^+ \to f_0(980)e^+\nu_e, f_0(980) \to \pi^+\pi^-) = (1.72 \pm 0.13 \pm 0.10) \times 10^{-3}$
  - ➔ **$s\bar{s}$ is dominant** based on $|f_0(980)\rangle = \sin\phi \left|\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\right\rangle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

    $\phi = (19.7 \pm 12.8)^\circ$
- **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]
$f_+^{f_0}(0)$	$0.518 \pm 0.018_{\mathrm{stat}} \pm 0.036_{\mathrm{syst}}$	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 $D_s^+ \to \pi^+\pi^- e^+\nu_e$

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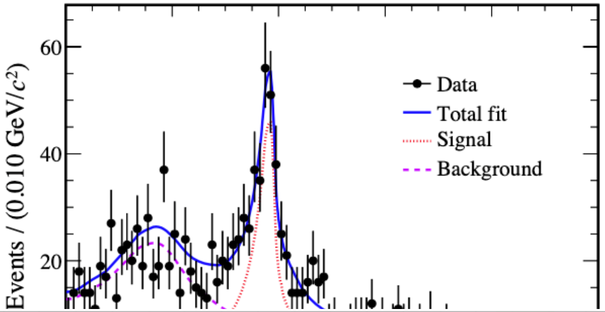

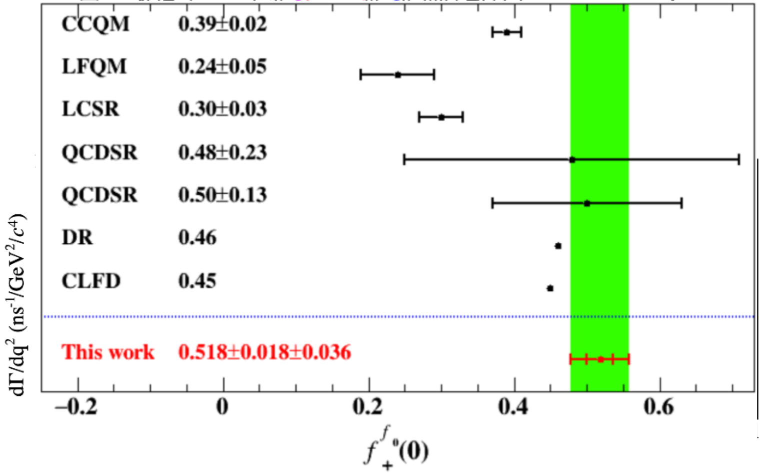

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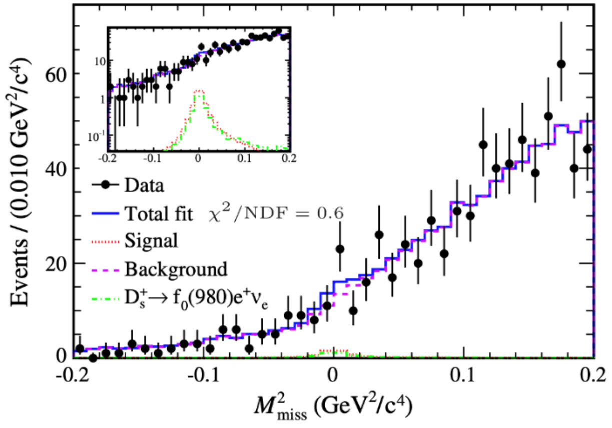

Study of the decay $D^+ \to f_0(500)\ell^+\nu_\ell$

arXiv: 2401.13225 (Accepted in PRD)

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

Signal mode	N_{obs}	$\mathcal{S}$ (σ)	ϵ_{sig} (%)	$\mathcal{B}_{\mathrm{sig}}(\times 10^{-3})$
$f_0(500)\mu^+\nu_\mu$	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
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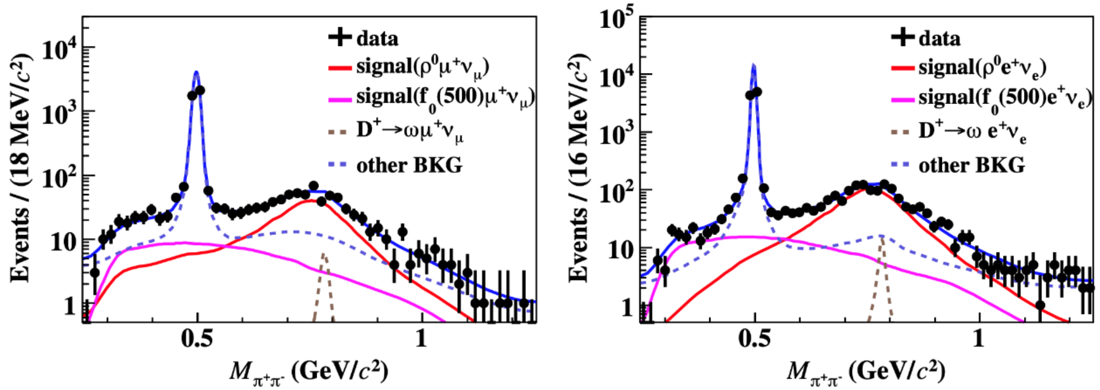


➔ The measured BF of $D^+ \to f_0(500)\ell^+\nu_\ell$ are closer to **tetraquark assumption**.
R.M. Wang et al, PRD107,056022 (2023)
Y.K. Hsiao et al, arXiv:2306.06091

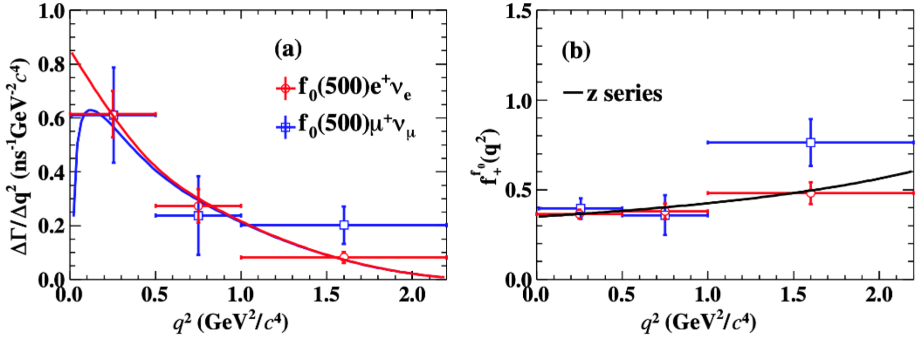
- **First FF measurement** of $D^+ \to f_0(500)(\pi^+\pi^-)\ell^+\nu_\ell$.

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

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

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

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



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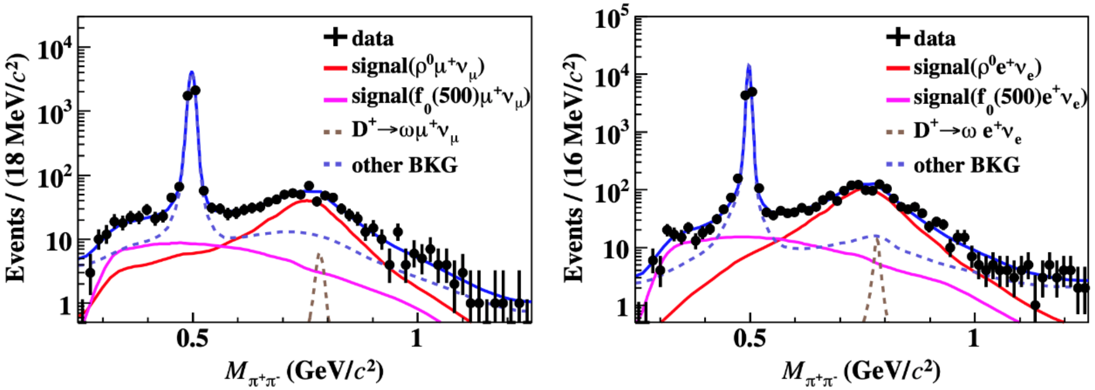

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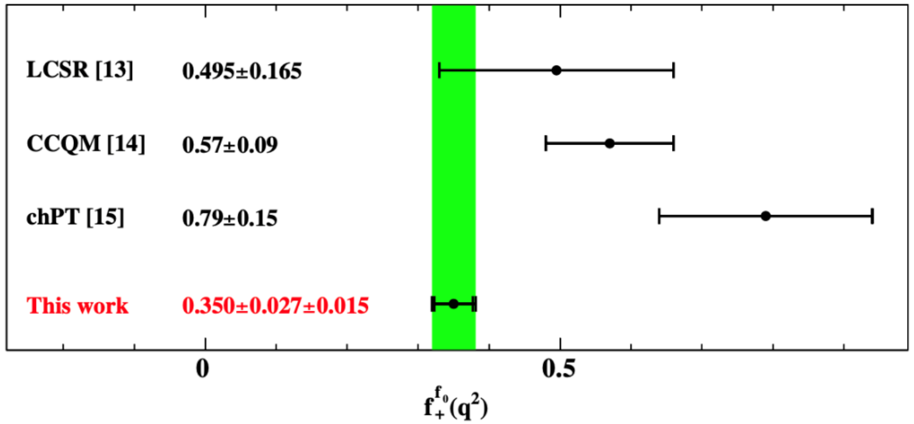

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Content

01 **Physics motivation ✓**

02 **Data and analysis method ✓**

03 **Results in review ✓**

04 **Summary and prospect ✓**

Summary and prospect

- Summary

BESIII have performed high-precision measurements on charm meson semi-leptonic decays to vector mesons (ρ, ω, K^*, ϕ) and scalar mesons ($f_0(500), f_0(980)$, $a_0(980)$)using the unique advantage of charm meson pair produced at threshold .

  - Absolute branching fraction measurements using double-tagging method
  - Hadronic form factors measurements through amplitude analysis.
  - Can help to measure CKM matrix elements$|\boldsymbol{V_{cs}}|/|\boldsymbol{V_{cd}}|$
  - Help to understand the nature of light scalar mesons

- prospect

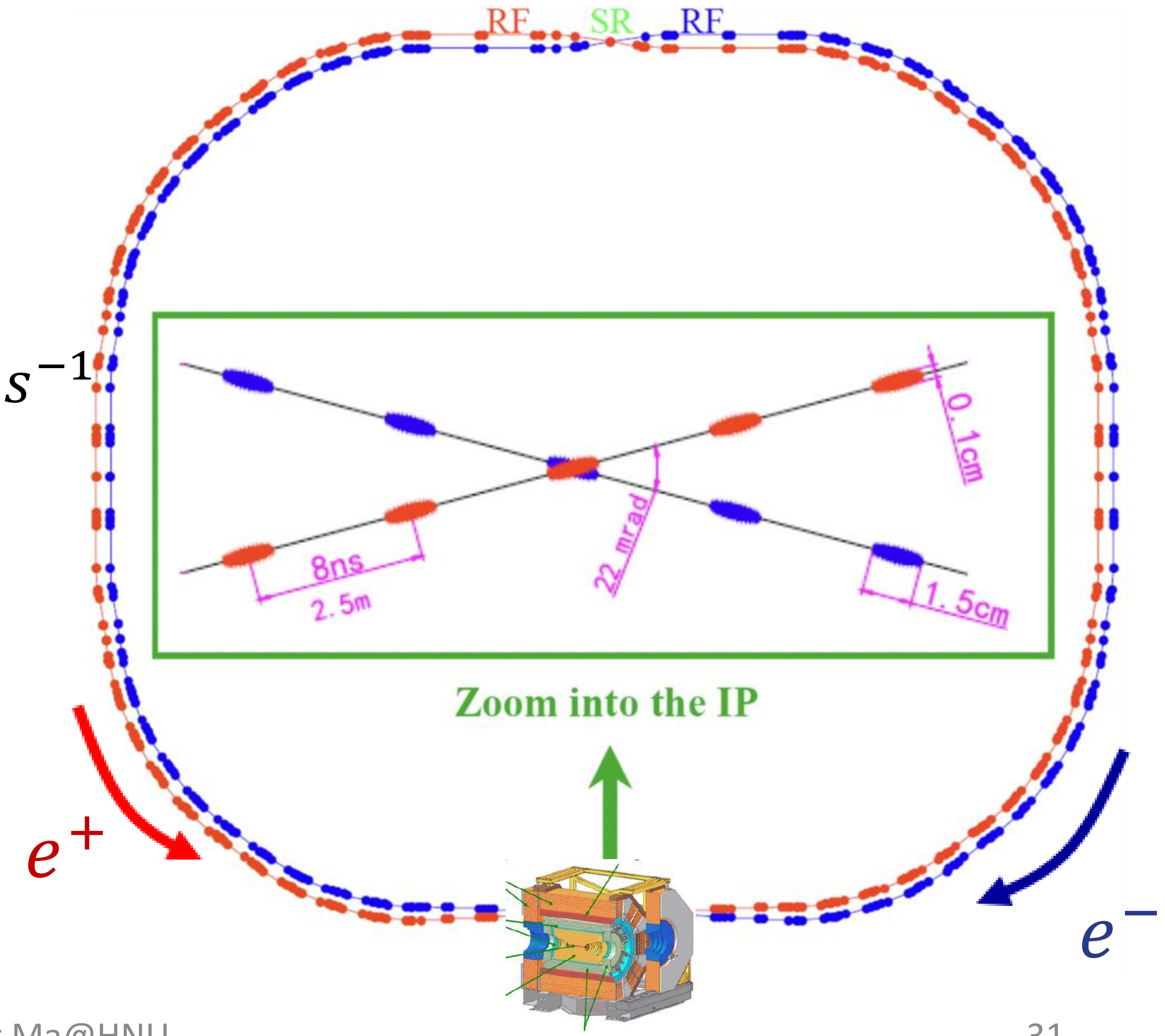
  - BESIII has ~**20 fb^{-1}** @3.773 GeV in total now.
  - More studies are on the way, especially the muon channels.
  - More jointed measurements of multiple channels

BESIII experiment

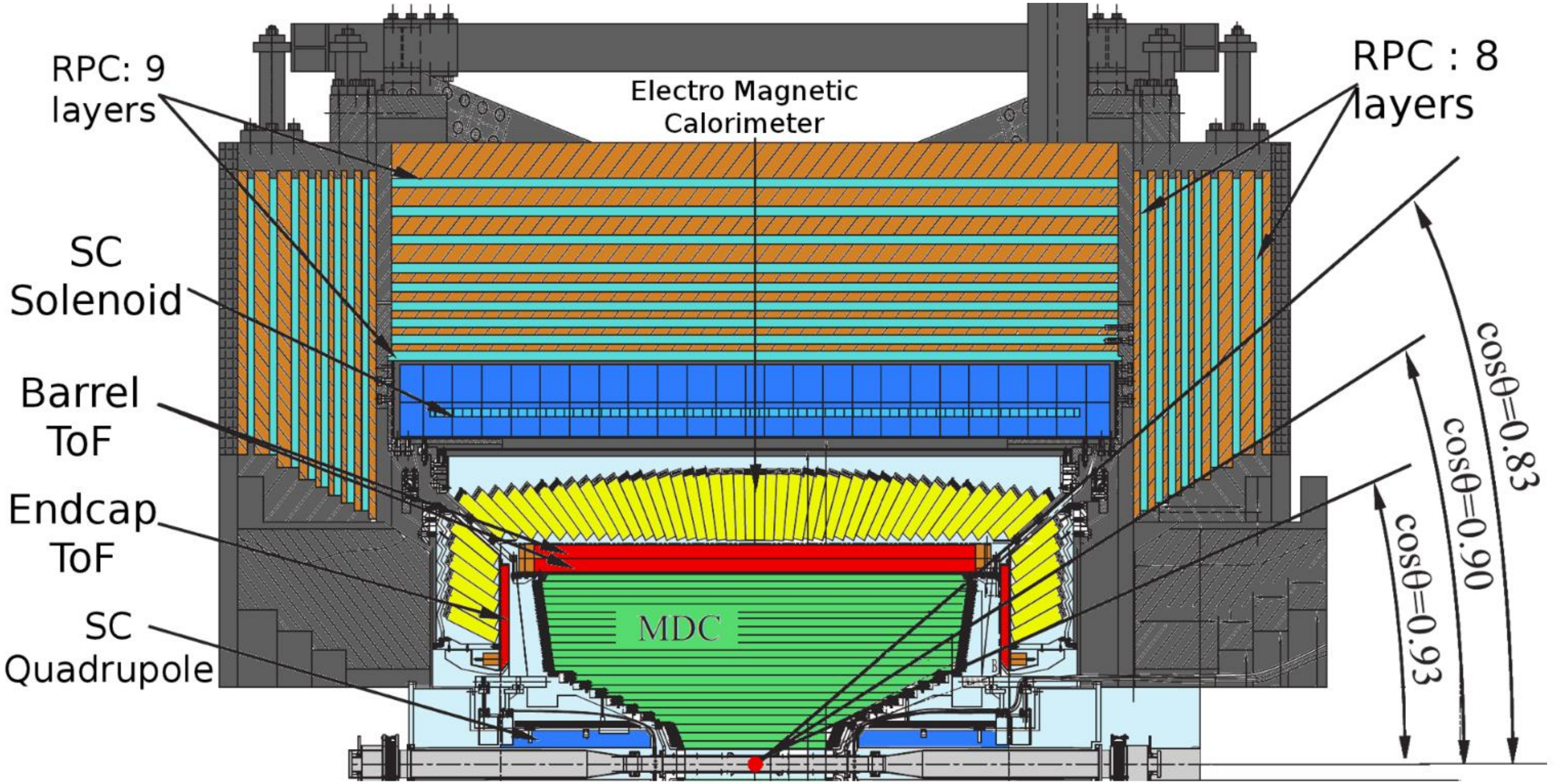
BEPCII collider

- Two ring symmetric e^+e^- collider
- Circumference: 240 m
- Design luminosity: $1 \times 10^{33} cm^{-2} s^{-1}$

  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