Recent results of semi-leptonic $D \to A$ decays at BESIII

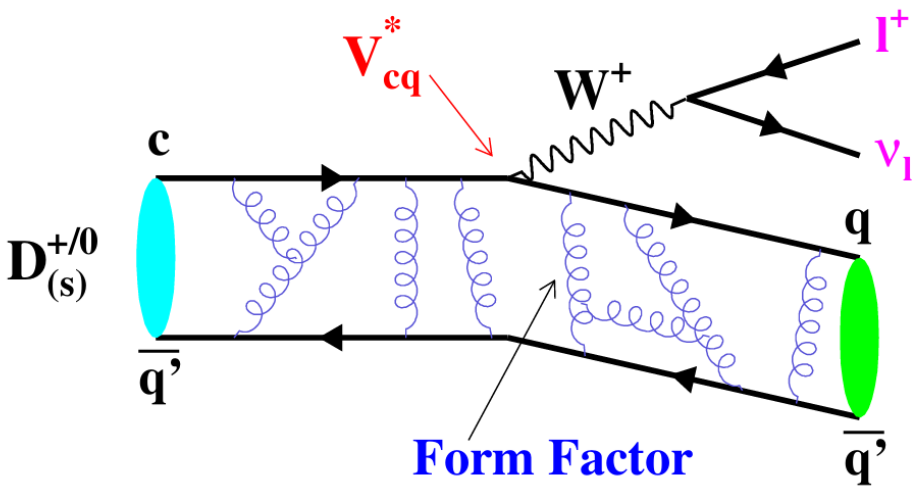
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BESIII 粲强子研讨会2026, 成都

Motivations

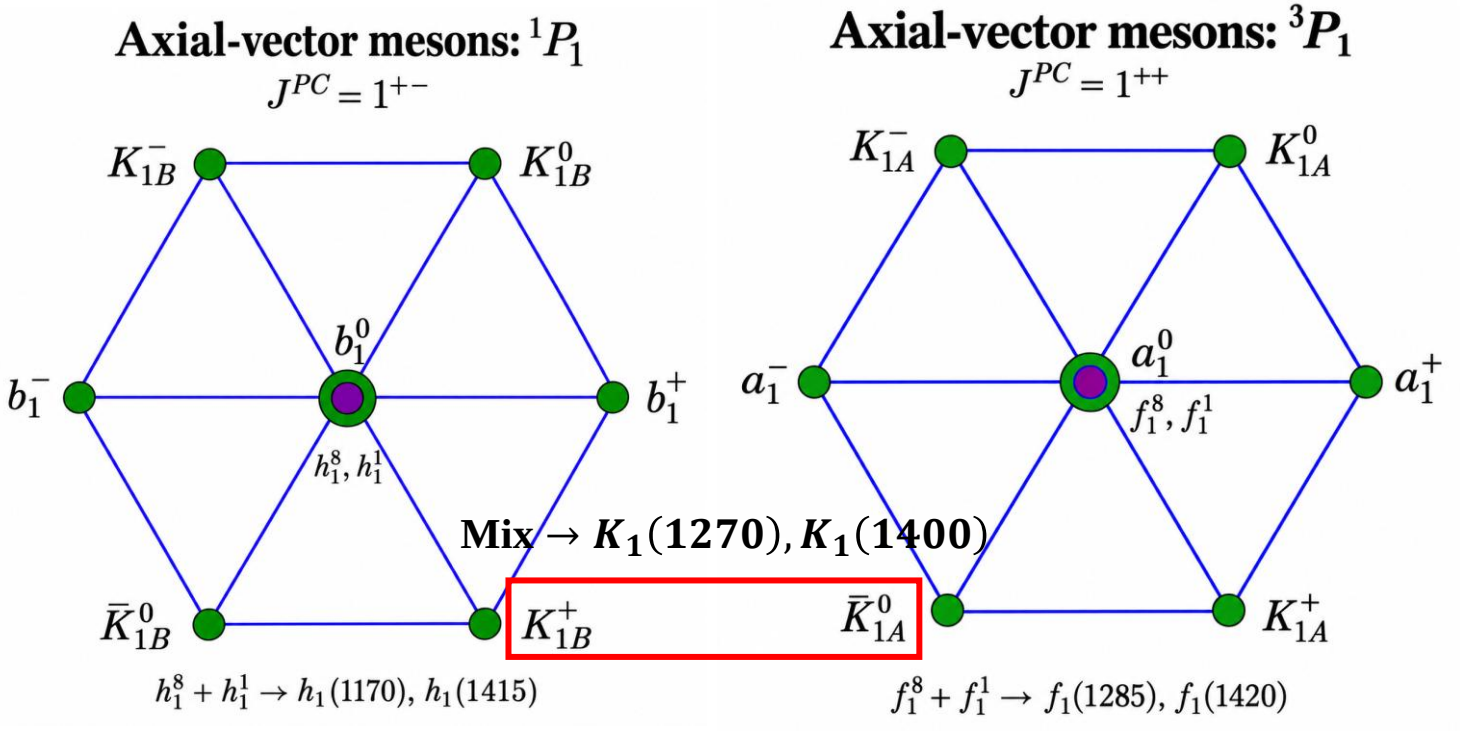
$$M_{fi} = \frac{G_F}{\sqrt{2}} V_{cq} \times \langle P, S, V, A | q\gamma_\mu(1-\gamma_5)c | D \rangle \times \bar{u}_\nu \gamma^\mu (1-\gamma_5) \nu_{\ell^+}$$



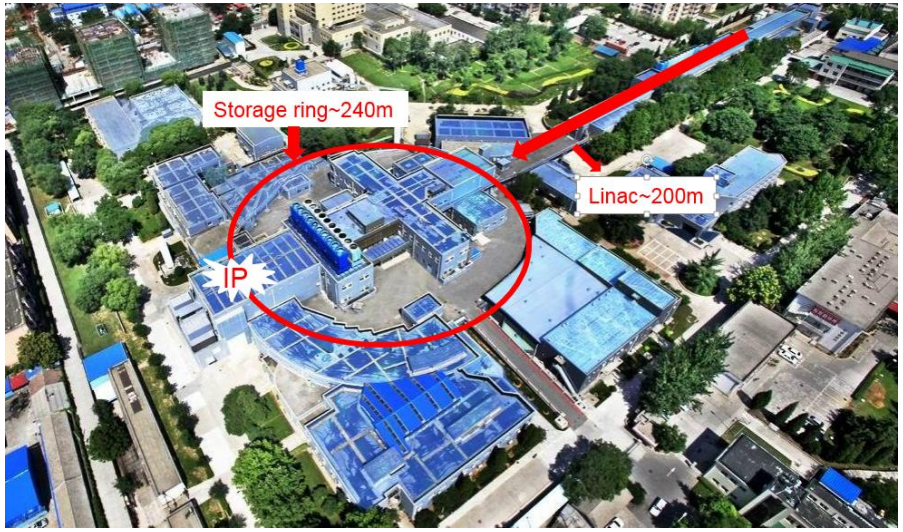
- Determination of $|V_{cq}|$: Validation of Unitary of CKM matrix & Basic parameters of SM
- Extraction of Form Factors: Test & Calibrate various theoretical calculations, e.g. LQCD
- Search for BSM: lepton flavor universality & BSM scalar/vector/tensor contributions

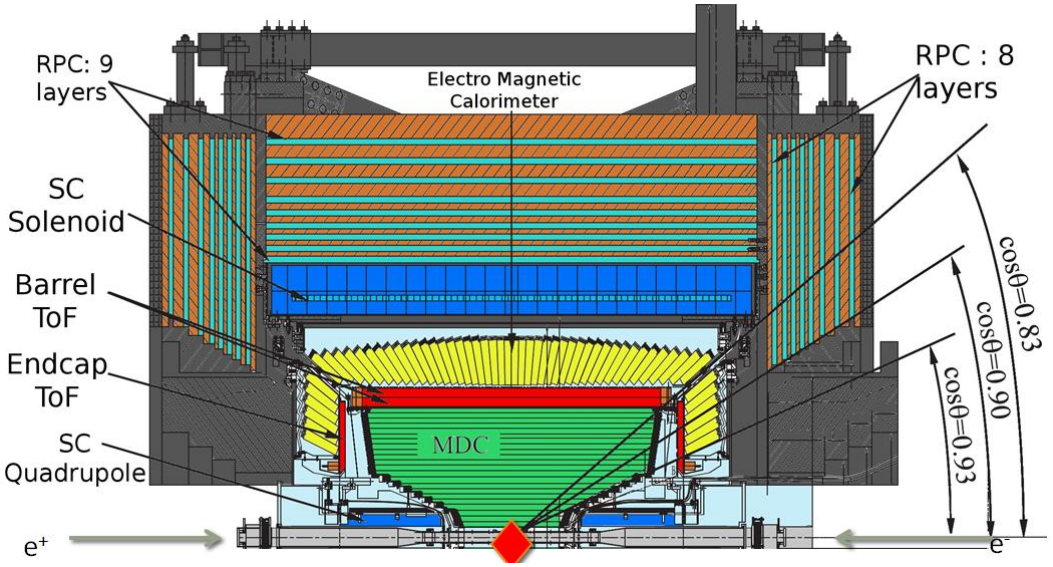
Motivations

- Axial-Vector mesons between $1.0 - 1.5$ GeV
- Conventional quark model: $q\bar{q}$, $J^P = 1^+$ can be formed by $S = 0/1$ & $L = 1$, two SU(3) $8 \oplus 1$
- Mixing between two octet & single/octet, study of SU(3) breaking effects



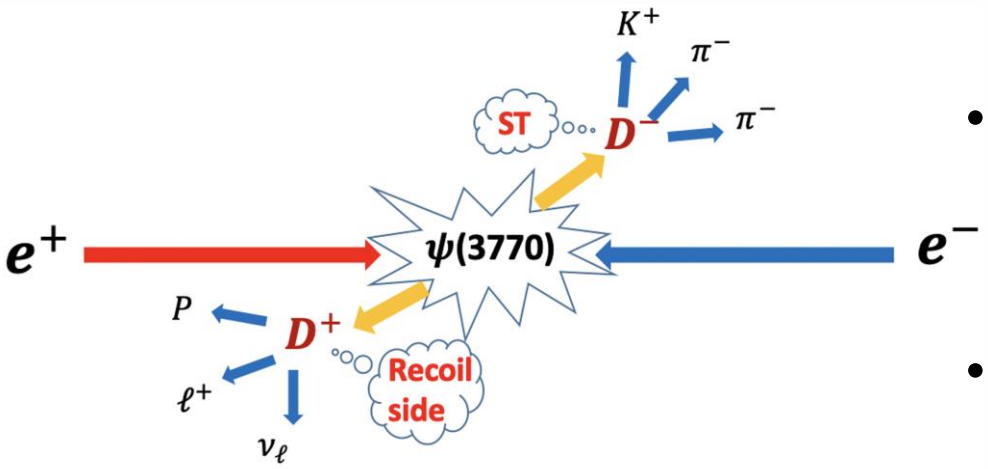
BESIII experiment





- $\sqrt{s} = (1.85 - 4.95)$ GeV
- Peak luminosity: $1.1 \times 10^{33}\ cm^{-2}s^{-1}$ @3.773 GeV
- MDC: $\sigma_p/P = 0.5\%$ @ 1 GeV; $\sigma_{dE/dx} = 6\%$
- TOF: $\sigma_T = 68(110)$ ps for barrel(endcap); endcap upgraded in 2015 $\sigma_T = 110 \rightarrow 68$ ps
- EMC: $\sigma_E/E = 2.5\%$ (5%) for barrel(endcap)

Dataset & Double tag method



- e^+e^- annihilations data near threshold → Double-tag method & Clean environment
- Undetectable neutrinos → extract the (semi-)leptonic signals with

$$U_{miss} = E_{miss} - |\vec{p}_{miss}|, \mathrm{M}^2_{miss} = E^2_{miss} - \left|\vec{P}_{miss}\right|^2$$

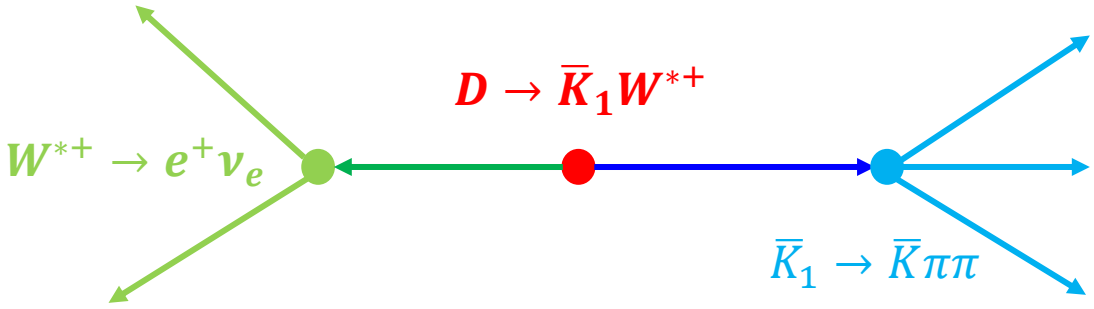
- Branching fraction with double tag method: $B = \frac{N_{DT}}{N_{ST}\epsilon_{DT}/\epsilon_{ST}}$

→ cancel most of systematic uncertainties due to ST

Data sample	$E_{\rm cm}$ (GeV)	$\mathcal{L}_{\rm int}$ ($\rm fb^{-1}$)	Single tag yields ($\times 10^6$)
$e^+e^- \to \psi(3770) \to D\bar{D}$	3.773	20.3	$\bar{D}^0$ ~16.9; D^- ~11.0
$e^+e^- \to D_s^{\pm}D_s^{*\mp}$	4.128-4.226	7.33	D_s^- ~0.8
$e^+e^- \to D_s^{*+}D_s^{*-}$	4.237-4.669	10.64	D_s^- ~0.12

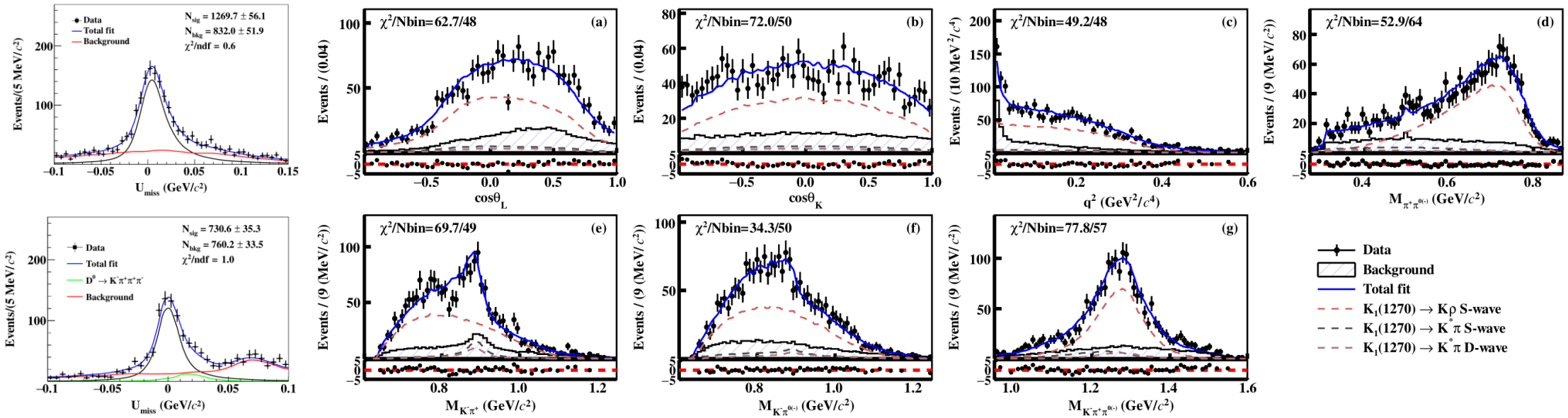
Decay formalism of $D \to Ae^+\nu_e, A \to P_1P_2P_3$

$$M = (V-A)^{\mu\eta} \cdot \left[\sum_{\lambda_{W^*}} \epsilon^*(\lambda_{W^*})_\mu \epsilon(\lambda_{W^*})_\rho\right] \cdot \left[\sum_{\lambda_{\bar{K}_1}} \epsilon^*(\lambda_{\bar{K}_1})_\eta \epsilon(\lambda_{\bar{K}_1})_\sigma\right] \cdot R_{\bar{K}_1} \cdot J^\sigma \cdot [\bar{u}_\nu \gamma^\rho (1-\gamma_5) \nu_l]$$



- More independent kinematic variables of **five body** semi-leptonic decay → general formalism is required!
- $D \to \bar{K}_1 W^{*+}$: $\langle \bar{K}_1 | s\gamma_\mu(1-\gamma_5) | D \rangle$, cited from PRD 104, 053003 (2021) → $V_{1,2}$ & $A \to r_A = \frac{A(0)}{V_1(0)}$ & $r_V = \frac{V_2(0)}{V_1(0)}$
- $\bar{K}_1 \to \bar{K}\pi\pi$: Constructed in covariant tensor formalism, following Eur. Phys. J. A 16, 537(2003)
- $m_e \to 0$: $q^\mu[\bar{u}_\nu \gamma_\mu (1-\gamma_5)\nu_l] = 0$ is used.

First study of $D^{0(+)} \to K^-\pi^+\pi^{-(0)}e^+\nu_e$

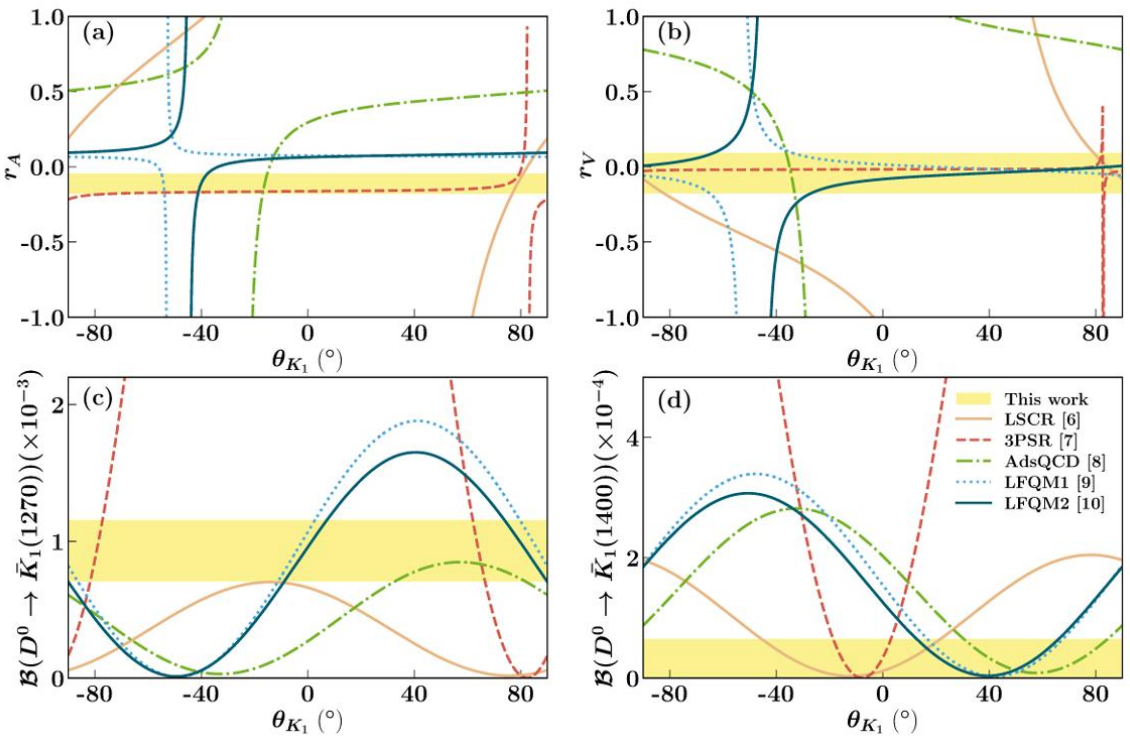


- PRL 111 091801 (2025), based on 20.3 fb^{-1} data sample @3.773 GeV, $\sum N_{DT}$~2.0 K
- Improve BFs measurement of $D \to \bar{K}_1(1270)e^+\nu_e$ & First upper limit on $D \to \bar{K}_1(1400)e^+\nu_e$

  $\mathrm{B}(D^+ \to \bar{K}_1^0(1270)e^+\nu_e) = (2.27 \pm 0.11 \pm 0.07 \pm 0.07) \times 10^{-3}$; $B(D^+ \to \bar{K}_1^0(1400)e^+\nu_e) < 1.4 \times 10^{-4}$

  $\mathrm{B}(D^0 \to K_1^-(1270)e^+\nu_e) = (1.02 \pm 0.06 \pm 0.06 \pm 0.03) \times 10^{-3}$; $B(D^0 \to K_1^-(1400)e^+\nu_e) < 0.7 \times 10^{-4}$
- First FFs measurement: $r_A = (-11.2 \pm 1.0 \pm 0.9) \times 10^{-2}$ & $r_V = (-4.3 \pm 1.0 \pm 2.5\ ) \times 10^{-2}$
- Component: $K\rho(770)$ & $K^*(892)\pi \to B(K_1(1270) \to K^*\pi)/B(K_1(1270) \to K\rho) = (20.3 \pm 2.1 \pm 8.7)\%$

First study of $D^{0(+)} \to K^-\pi^+\pi^{0(-)}e^+\nu_e$



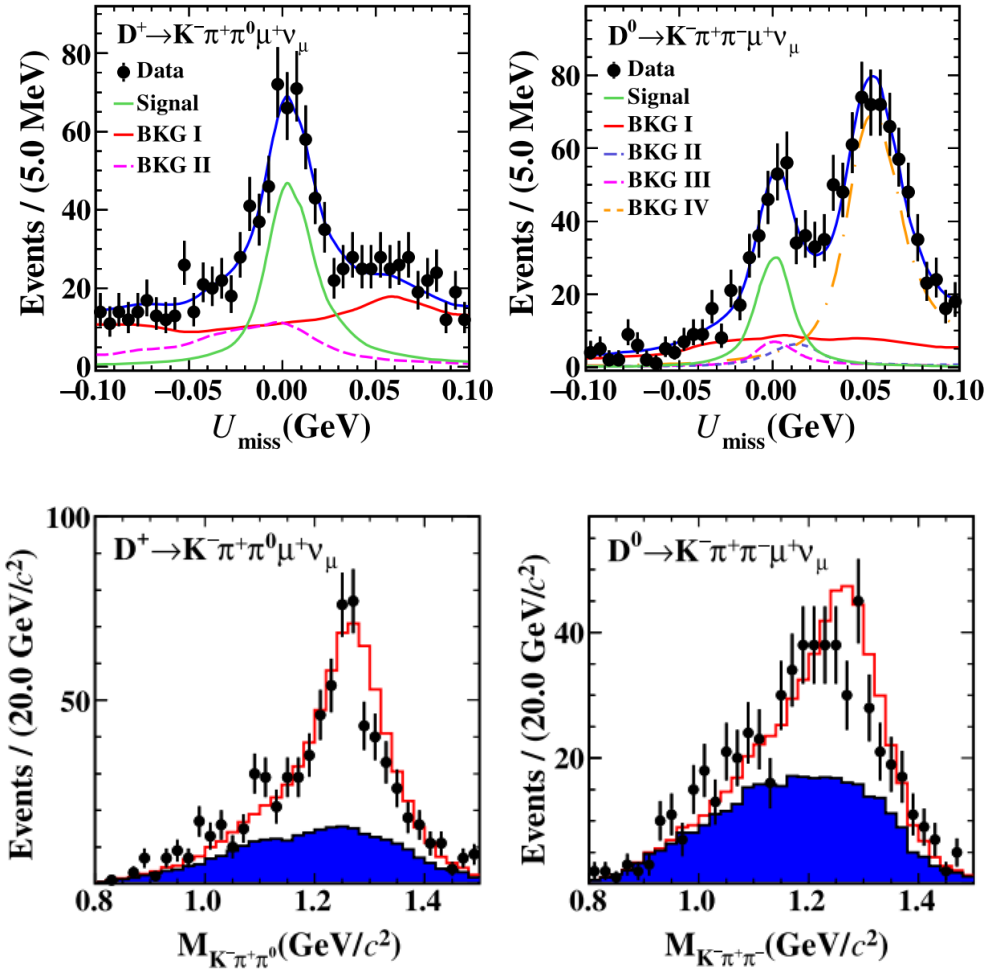
- $K_{1A}\,(^1P_1)$ & $K_{1B}(^3P_1)$ mix into $K_1(1270)$ & $K_1(1400)$
- FFs are sensitive to the mixing angle θ_{K_1}:

$$f_{K_1(1270)} = f_{K_{1A}} \sin\theta_{K_1} + f_{K_{1B}} \cos\theta_{K_1}$$

$$f_{K_1(1400)} = f_{K_{1A}} \cos\theta_{K_1} - f_{K_{1B}} \sin\theta_{K_1}$$

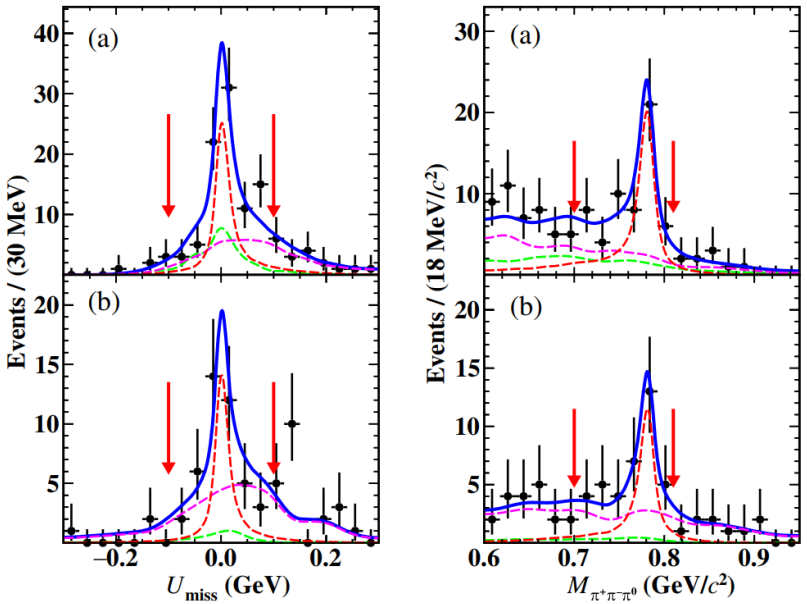
- Three unknow pars. $(f_{K_{1A}}, f_{K_{1B}}, \theta_{K_1})$ & Two equations
  → Determine θ_{K_1} requires one parameter input!
- However, for all theoretical predictions, we have four observables to give stringent test on them without assuming the value of θ_{K_1}.

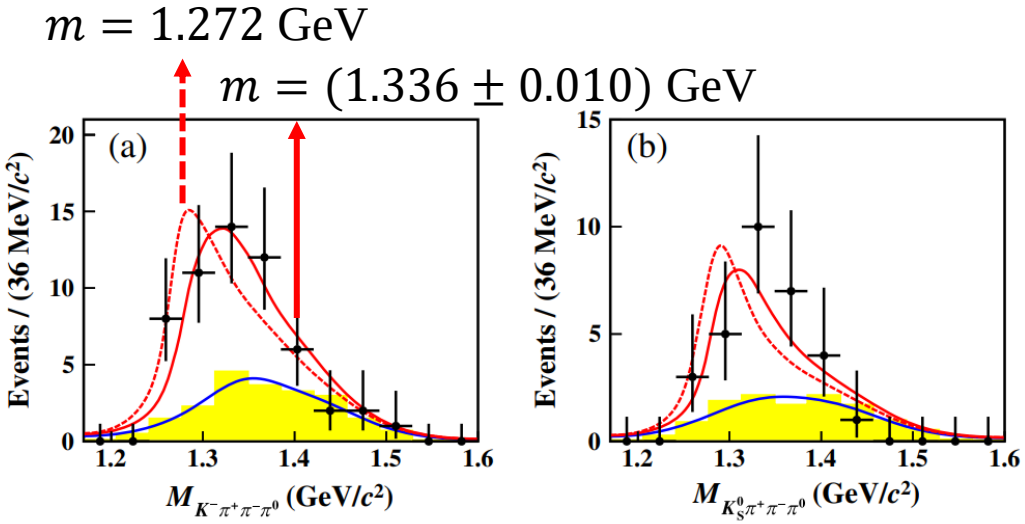
Observation of $D \to \bar{K}_1(1270)\mu^+\nu_\mu$



- PRD 111, L071101 (2025), based on 7.93 fb^{-1} data sample @3.773 GeV, N_{DT}~0.6 K
- $B\left(D^+ \to \bar{K}_1^0(1270)\mu^+\nu_\mu\right) = (2.36 \pm 0.20^{+0.18}_{-0.27} \pm 0.48) \times 10^{-3}$,
  $B\left(D^0 \to K_1^-(1270)\mu^+\nu_\mu\right) = \left(0.78 \pm 0.11^{+0.05}_{-0.09} \pm 0.15\right) \times 10^{-3}$
- LFU test: $R_{D^0} = 0.74 \pm 0.13^{+0.08}_{-0.13}$, $R_{D^+} = 1.03 \pm 0.14^{+0.11}_{-0.15}$
- Isospin test: $1.22 \pm 0.10^{+0.06}_{-0.09}$

Observation of $D \to \bar{K}\omega e^+\nu_e$





- PRL 137 091802 (2026), based on 20.3 fb^{-1} data sample @3.773 GeV, $\sum N_{DT}$~60
- Two pole structure of $K_1(1270)$: $M_{K^*\pi}$~1.2 GeV & $M_{\rho K}$~1.28 GeV, lower pole is suppressed in $K\omega$ with threshold 1.28 GeV
- Float mass fit $m = (1336 \pm 10)$ MeV, significantly larger than 1272 MeV, favor two pole exist

Towards absolute BFs of $K_1(1270)$

$$B_{3body} = B_{K\rho} + B_{K^*\pi} + B_{KX^0(\pi^+\pi^-)} = (1 - B_{K\omega})$$

- Define $\alpha \equiv B_{K^*\pi}/B_{K\rho} = (20.3 \pm 2.1 \pm 8.7)\%$
- Assume $B_{KX^0(\pi^+\pi^-)} \ll 1$

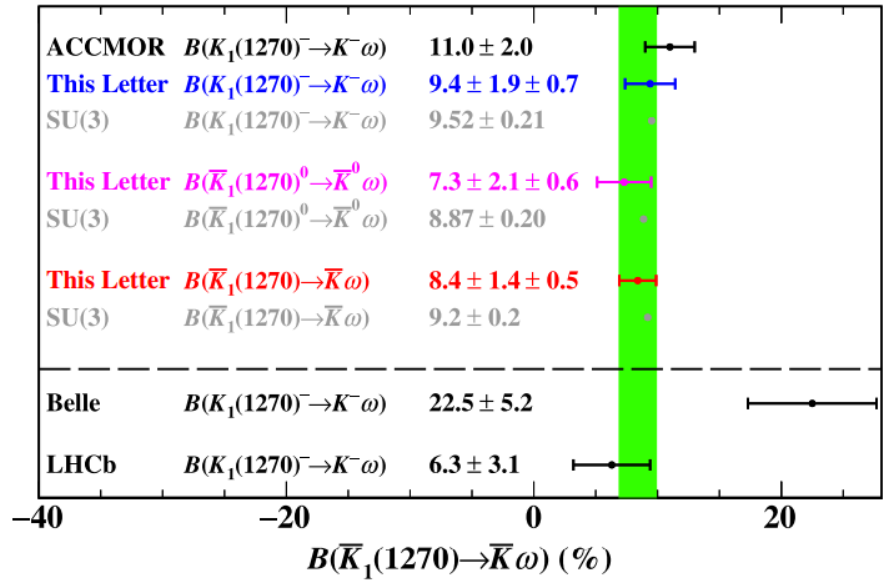
$$B_{K_1\to K^+\pi^-\pi^+} = \frac{1}{3} \times B_{K_1\to K\rho} + \frac{4}{9} \times B_{K_1\to K^*\pi} = \frac{3+4\alpha}{9(1+\alpha)} B_{3body}$$

$$B_{K_1\to K^+\pi^-\pi^0} = \frac{2}{3} \times B_{K_1\to K\rho} + \frac{4}{9} \times B_{K_1\to K^*\pi} = \frac{6+4\alpha}{9(1+\alpha)} B_{3body}$$

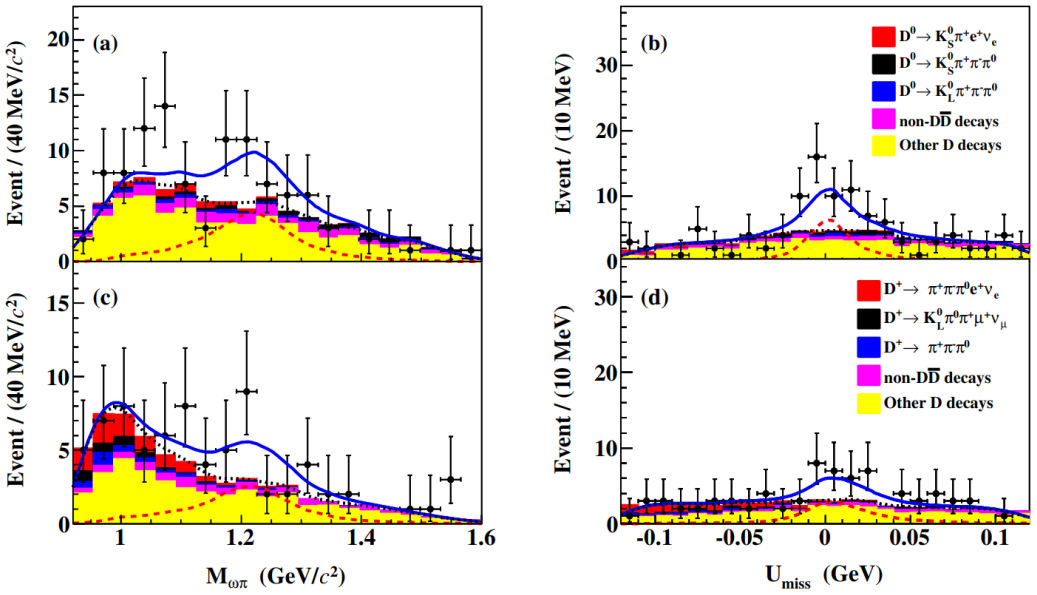
$$\gamma_+ \equiv \frac{B_{K_1\to K^+\pi^-\pi^+}}{B_{K^+\omega}} = (3.4^{+0.8}_{-0.7} \pm 0.3) \;\&\; \gamma_0 \equiv \frac{B_{K_1\to K^+\pi^-\pi^0}}{B_{\bar{K}^0\omega}} = (7.9^{+2.4}_{-2.1} \pm 0.7)$$

$$\gamma_+ B_{K^+\omega} = \frac{3+4\alpha}{9(1+\alpha)}(1 - B_{K^+\omega})$$

$$\gamma_0 B_{K^0\omega} = \frac{6+4\alpha}{9(1+\alpha)}(1 - B_{K^0\omega})$$

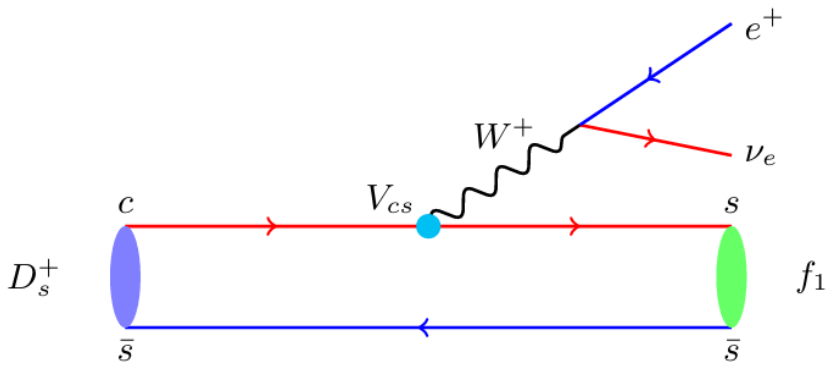


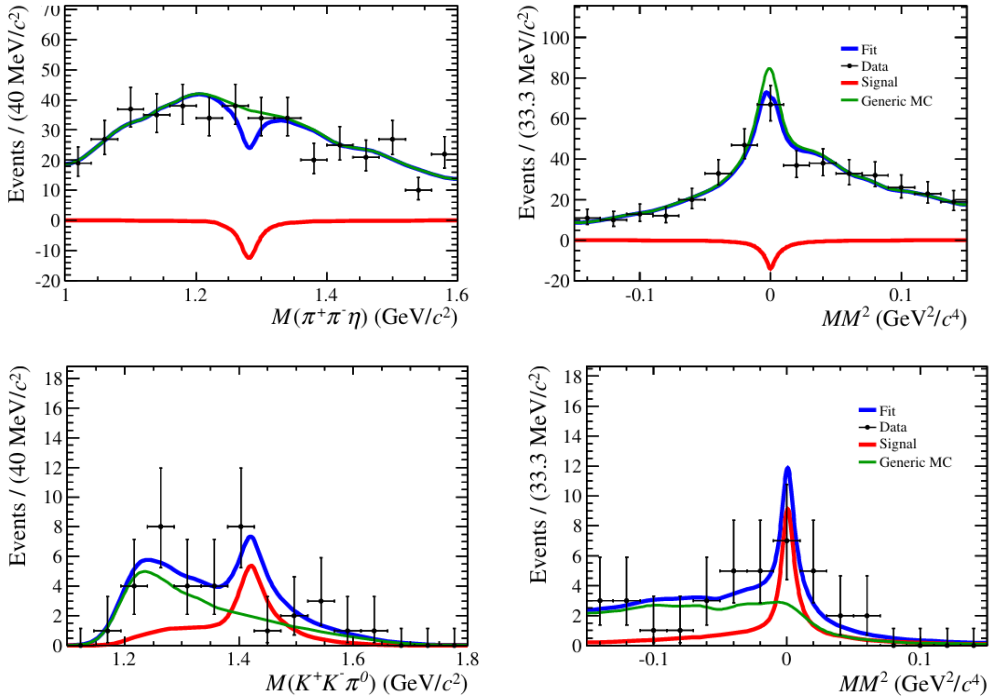
Observation of $D \to b_1(1235)e^+\nu_e$



- PRL 136, 021801 (2026), based on 7.93 fb^{-1} data sample @3.773 GeV, N_{DT}~60
- First observation of $D \to b_1(1235)e^+\nu_e$
- $B(D^0 \to b_1(1235)^-e^+\nu_e) \times B(b_1(1235)^- \to \omega\pi^-) = (0.72 \pm 0.18^{+0.06}_{-0.08}) \times 10^{-4}$
- $B(D^+ \to b_1(1235)^0e^+\nu_e) \times B(b_1(1235)^0 \to \omega\pi^0) = (1.16 \pm 0.44 \pm 0.16) \times 10^{-4}$
- Isospin test: $0.78 \pm 0.19^{+0.04}_{-0.05}$

Search for $D_s^+ \to f_1(1285/1420)e^+\nu_e$

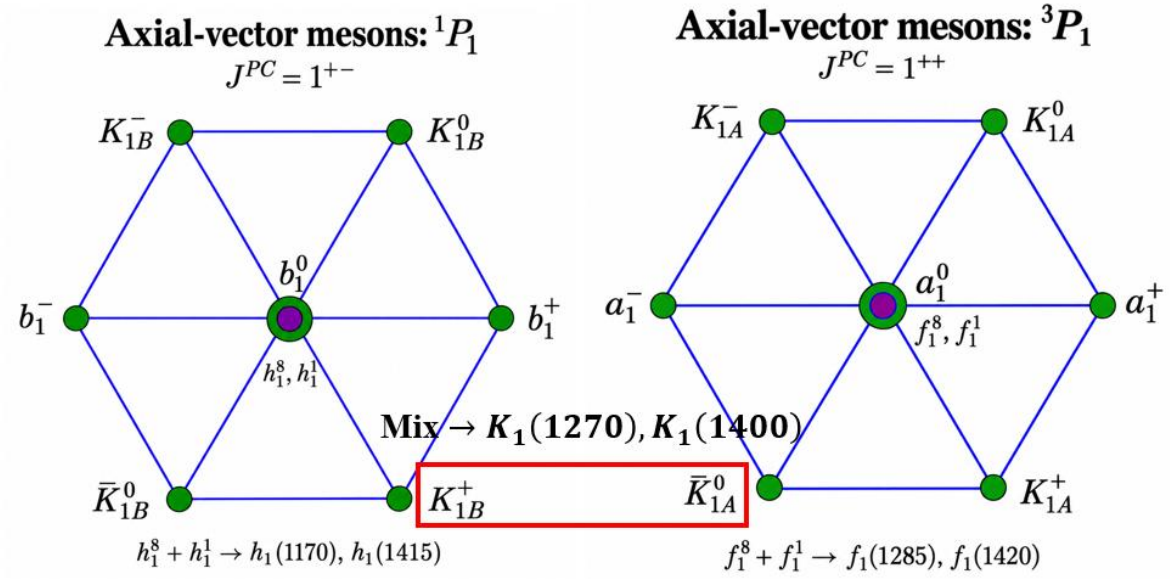




- arXiv: 2601.16938, based on 7.33 fb^{-1} $D_s^{\pm}D_s^{*\mp}$ at $\sqrt{s} \in (4.128, 4.226)\ GeV$
- Sensitive to internal $s\bar{s}$ component
- $f_1(1420) \to K^+K^-\pi^0$ & $f_1(1285) \to \pi^+\pi^-\eta$
- First evidence of $D_s^+ \to f_1(1420)e^+\nu_e$ with 3.4σ
- $B(D_s^+ \to f_1(1420)e^+\nu_e) \times B(f_1(1420) \to K^+K^-\pi^0) = (4.5^{+2.0}_{-1.7} \pm 0.4) \times 10^{-4}$
- $B(D_s^+ \to f_1(1285)e^+\nu_e) \times B(f_1(1285) \to \pi^+\pi^-\eta) < 1.7 \times 10^{-4}$

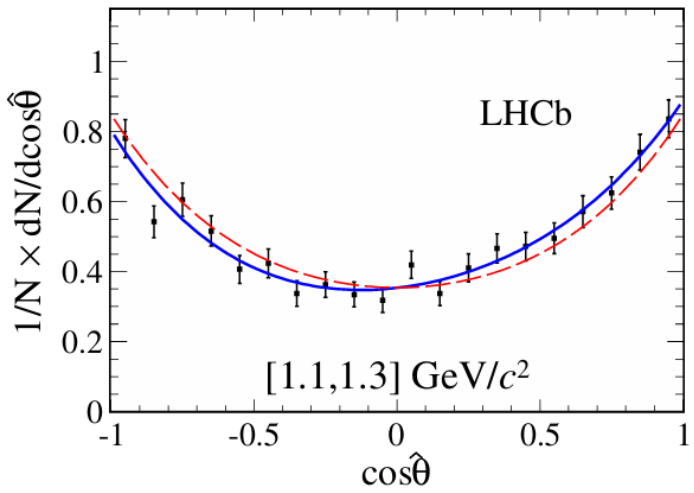
Summary

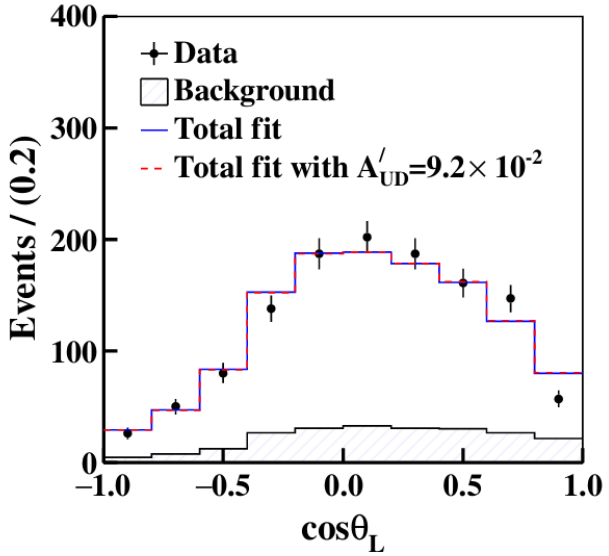
- Massive studies are performed for $D \to \bar{K}_1(1270)$: FFs & BFs & secondary decays
- Observation of $D \to b_1(1235)$: Further study with larger statistics ongoing
- Evidence of $D_s^+ \to f_1(1420)$ & upper limit of $f_1(1285)$: larger $s\bar{s}$ components in $f_1(1420)$

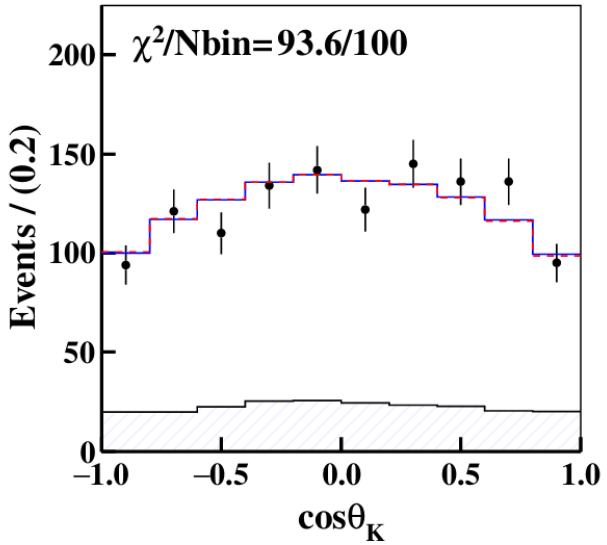


Backup

First study of $D^{0(+)} \to K^-\pi^+\pi^{0(-)}e^+\nu_e$





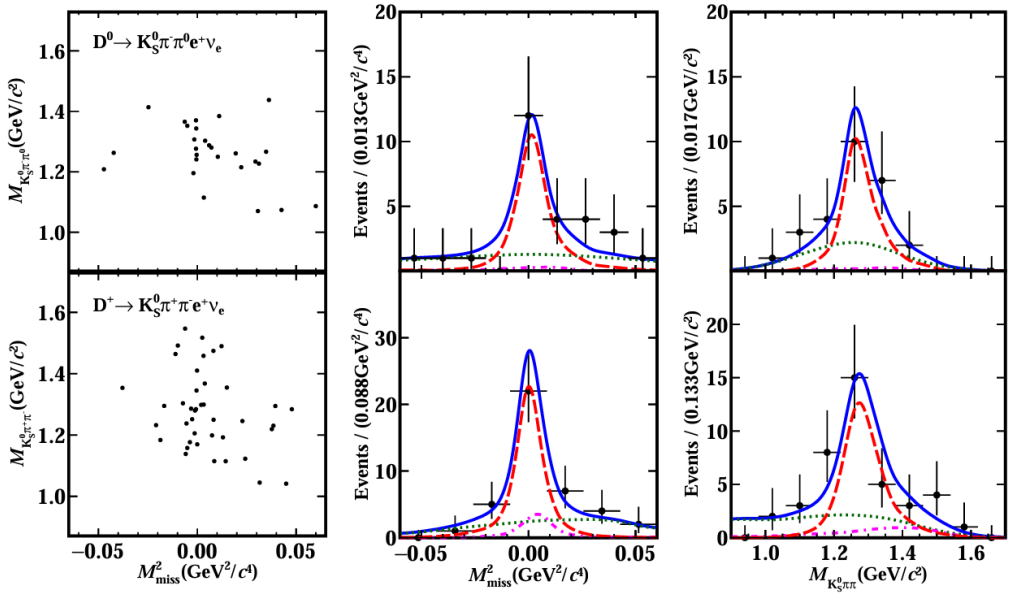


- $\bar{b} \to \bar{s}\gamma$: polarization of photon $\lambda_\gamma \sim +1$, any deviation indicates NP effects
- LHCb observed photon polarization in $B^+ \to K_1^+(1270)(\to K\pi\pi)\gamma$ with up-down asymmetry

$$A_{ud} = f_h\lambda_\gamma = (6.9 \pm 1.7) \times 10^{-2}$$

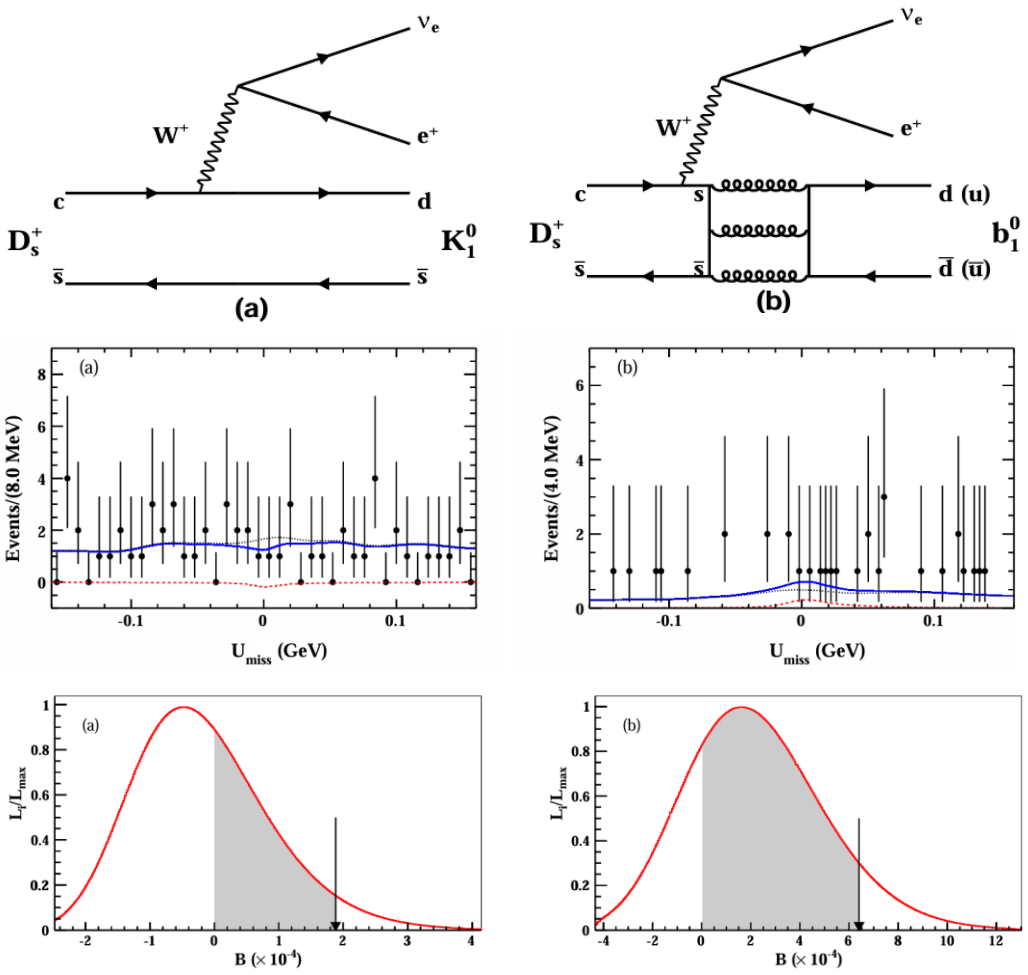
- Theoretical calculation of f_h suffers from limited knowledge of current J^μ in $K_1 \to K\pi\pi$.
- PRL 125 051802 (2020) suggests up-down asymmetry in $D \to K_1(1270)e^+\nu_e$: $A'_{ud} = \frac{4}{3}f_h$
- 2D Angular fit → $A'_{ud} = 0.01 \pm 0.11$, consistent with SM prediction $\frac{4}{3}A_{ud} = (0.092 \pm 0.022)$

Observation of $D^{0(+)} \to K_S^0 \pi^- \pi^{0(+)} e^+ \nu_e$



- JHEP 09, 089 (2024), based on 2.93 fb^{-1} data sample @3.773 GeV, N_{DT}~40
- $B(D^+ \to \bar{K}_1^0(1270) e^+ \nu_e) = (1.3 \pm 0.4 \pm 1.8 \pm 1.5) \times 10^{-3}$,
  $B(D^0 \to K_1^-(1270) e^+ \nu_e) = (1.1 \pm 0.3 \pm 1.2 \pm 1.2) \times 10^{-3}$,

Search for $D_s^+ \to K_1(1270)/b_1(1235)e^+\nu_e$



- PRD 108, 112002 (2023), based on 7.33 fb^{-1} $D_s^{\pm}D_s^{*\mp}$ at $\sqrt{s} \in (4.128, 4.226)\ GeV$
- $K_1^0(1270) \to K^-\pi^+\pi^0$ & $b_1^0(1235) \to \omega\pi^0$
- $B(D_s^+ \to K_1^0 e^+\nu_e) \times B(K_1^0 \to K^-\pi^+\pi^0) < 1.9 \times 10^{-4}$
- $B(D_s^+ \to b_1^0 e^+\nu_e) \times B(b_1^0 \to \omega\pi^0) < 6.4 \times 10^{-4}$