Open-Charm Physics at the BESIII Experiment

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Outline

Introduction

Leptonic and Semileptonic Decays of Charmed Mesons

Quantum Correlated Decays of $D^0\overline{D}^0$ pairs

Studies of Charmed Baryons

Future Prospects & Summary

Outline

Why heavy flavour physics?

- Studying the properties of hadrons containing heavy quarks gives insight into two fundamental questions:
  - Does physics beyond the Standard Model affect the interactions of quarks?
    - Is the Cabibbo-Kobayashi-Maskawa matrix unitary?
    - Do heavy hadron decay rates follow the predictions of the Standard Model?
  - How do quarks bind to form hadrons?
    - Can we accurately predict the spectroscopy, form factors, and decay constants of heavy hadrons?

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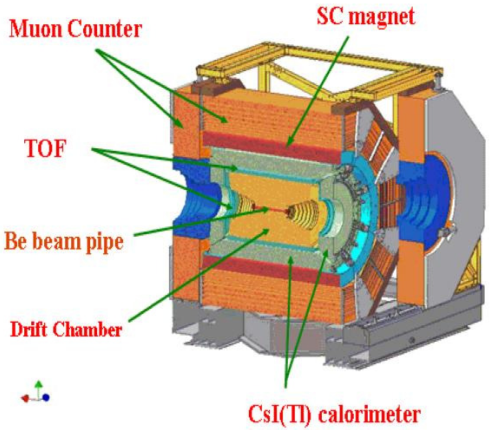
    - Do heavy hadron decay rates follow the predictions of the Standard Model?
  - How do quarks bind to form hadrons?
    - Can we accurately predict the spectroscopy, form factors, and decay constants of heavy hadrons?
- Precision measurements of hadrons probes new physics energy scales much higher than those achievable from direct searches with modern colliders (10^4 GeV–10^{10} GeV), but in practice we need to disentangle these two questions when interpreting measurements!

Beijing Electron-Positron Collider Mk. II (BEPCII)

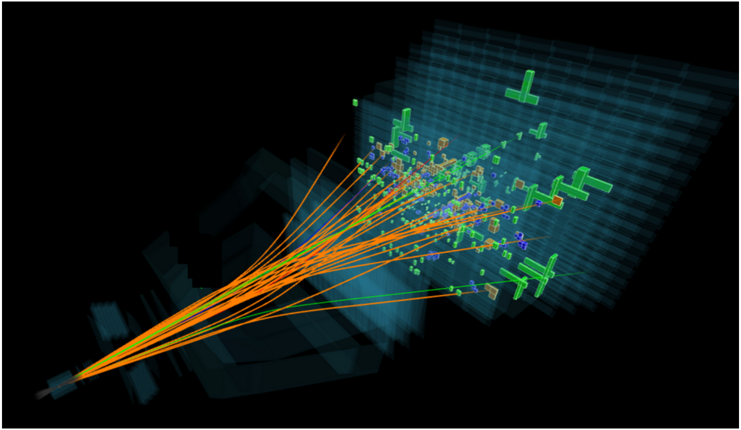
- Symmetric e^+e^- collider
- Diameter of storage rings: $\sim$ 75 m (LHC: $\sim$ 8 km)
- E_{CM}: $2 - 5$ GeV

Beijing Electron Spectrometer III (BESIII)

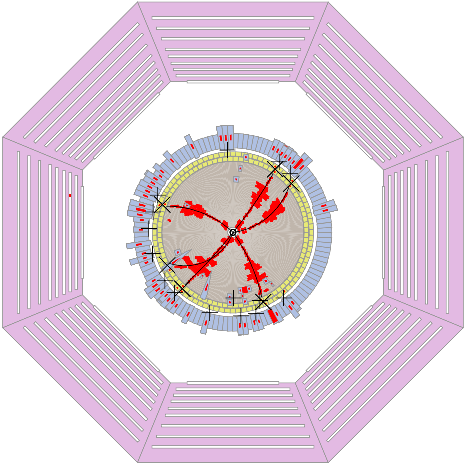


- "Onion"-style detector designed for studies of charm hadrons
- Hermeticity: 93% of 4π
- Gaseous Drift Chamber for tracking charged particles: $\frac{\sigma_p}{p} \sim 0.5\%$
- Time-of-Flight system for particle identification: $\sigma_{TOF} = 80$ ps
- Calorimeter for e^- identification and neutral particle reconstruction: $\sigma_E/E \sim 2.5\%$
- Some notable differences with a typical LHC experiment:
  - Low boost $\Rightarrow$ (almost) no displaced vertices
  - Momentum of final state particles in the lab frame: $50 - 1500$ MeV$/c$
  - $\sim 100\%$ trigger efficiency
  - Muons more challenging than electrons

LHCb Event Reconstruction



BESIII Event Reconstruction



Simulated $D_s^{*+} D_s^-$ event

BESIII Physics Program

- In March 2025, BESIII published its 700th paper. Primary topics of interest:
  - Light Hadron Physics
    - e.g. Weak phases in double-strange baryons, *Nature* 606, 64-69 (2022)
  - R-value inputs to $g-2$
    - e.g. PRL 128, 062004 (2022)
  - Precision τ Physics
    - Projected uncertainty on τ mass $< 0.1\,\mathrm{M}e\mathrm{V}$
  - Charmonium and Exotic Hadron Spectroscopy
    - e.g. Discovery of $Z_c(3900)/\ T^b_{\psi 1}(3900)$ in 2013
  - **Open-Charm Physics:** **(**$D^0(c\overline{u}), D^+(c\overline{d}), D_s^+(c\overline{s}), \Lambda_c^+(cdu), ...$**)**

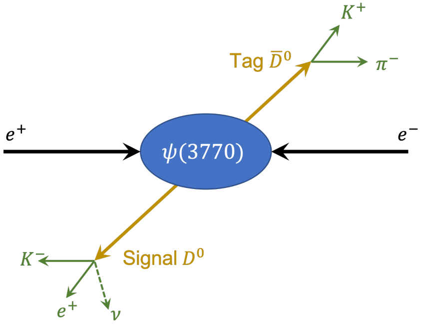
Open Charm at BESIII

- Threshold e^+e^- machines are complementary to physics program at hadron colliders and B-factories. Advantages include:
  - Full event reconstruction
  - Improved neutral reconstruction efficiency
  - Precision measurements of absolute branching fractions
  - Inference of missing particles (e.g. neutrinos or K_L^0)
  - Leveraging quantum entanglement of the initial state
- My goal is to give an overview of Open-Charm Physics at BESIII, giving a sense of measurement design and capabilities, and highlight selective physics outputs – highly non-exhaustive!

Pair-produced Open-Charm Datasets @ BESIII

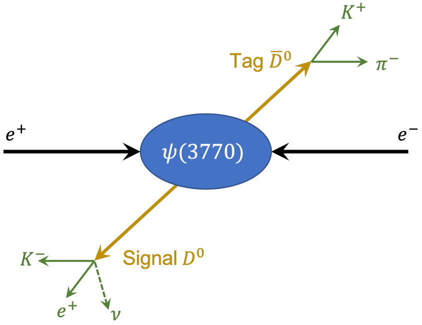
- $D^{+(0)}$ 20.3 fb^{-1} $E_{cm} = 3.773$ GeV, near $\psi(3770) \to D\bar{D}$
  - 2.9 fb^{-1} in 2011
  - 5.0 fb^{-1} in 2022
  - 12.1 fb^{-1} in 2023-2024
- D_s^+ 7.33 fb^{-1} @ $E_{cm} = 4.13 - 4.23$ GeV. Collected 2013-2017
  - D_s^+ collected through $D_s^{*+}D_s^-$, $D_s^{*+} \to \gamma/\pi^0 D_s^+$ due to larger $\sigma\left(e^+e^- \to D_s^{*+}D_s^-\right) \approx 3\sigma\left(e^+e^- \to D_s^+D_s^-\right)$ at threshold
- Λ_c^+ 6.4 fb^{-1} @ $E_{cm} = 4.600 - 4.951$ GeV. Collected 2019-2022

Double Tag Method @ BESIII



- Reconstruct $\overline{D}$ through clean decay mode (the tag)

Double Tag Method @ BESIII



- Reconstruct $\overline{D}$ through clean decay mode (the tag)
- Search for signal process of the D. Can identify missing particles with

$$M^2_{\text{miss}} \text{ or } U_{\text{miss}} \equiv E_{\text{miss}} - p_{\text{miss}}$$

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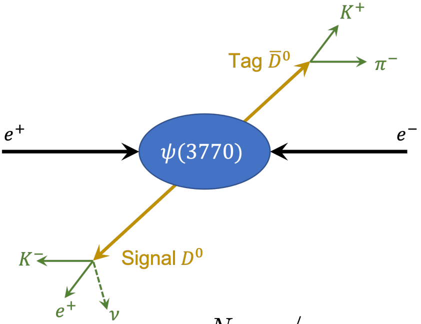

$$\mathcal{B}(D \to \text{signal}) = \frac{N_{\text{Signal}}/\epsilon_{\text{Tag \& Signal}}}{N_{\text{Tag}}/\epsilon_{\text{Tag}}}$$

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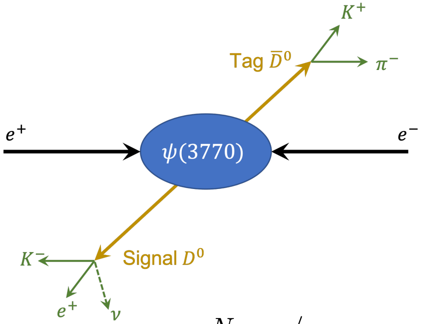

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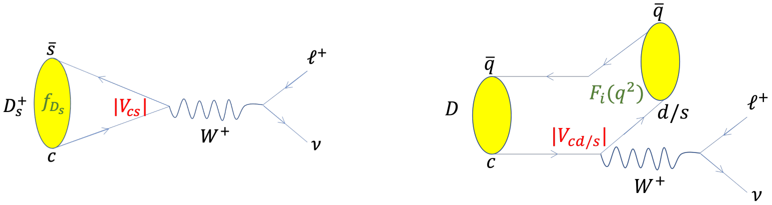
- Reconstruct $\overline{D}$ through clean decay mode (the tag)
- Search for signal process of the D. Can identify missing particles with
$$M^2_{\text{miss}} \text{ or } U_{\text{miss}} \equiv E_{\text{miss}} - p_{\text{miss}}$$
- Advantages: Don't need to know $N_{D\overline{D}}$, removes backgrounds, allows access to recoil variables

Outline

What can we learn from (semi)leptonic decays?

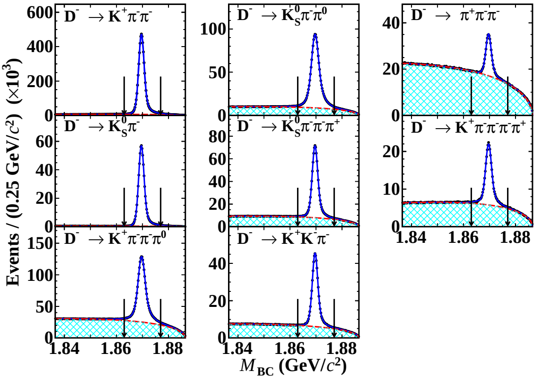


$\Gamma\left(D^+_{(s)} \to \ell^+\nu\right) \propto f^2_{D_{(s)}}\left|V_{cd/s}\right|^2$ $\quad \frac{d\Gamma}{dq^2} \propto \sum_i F_i(q^2)^2 |V_{cd/s}|^2$, $q^2 \equiv \ell^+\nu$ 4-mom.

- Charmed hadrons provide a rigorous testing ground for our understanding of heavy-quark physics and provide:
  - Test of CKM unitarity with $|V_{cd}|$ and $|V_{cs}|$
  - Study QCD, e.g. f_{D_s} and $F_i(q^2)$
  - Search for new physics through tests lepton universality, forward-backward asymmetries, etc.
  - Provide laboratory for light hadron physics

$D^+ \to \mu^+\nu_\mu$: PRL 135 (2025) 061801

- Analysing full $20.3\ \text{fb}^{-1}$ sample @ $E_{\text{CM}} = 3.77$ GeV
- Nine D^- tag modes employed, tag yields from fit to $M_{BC} \equiv \sqrt{E^2_{\text{beam}} - |p_D|^2}$



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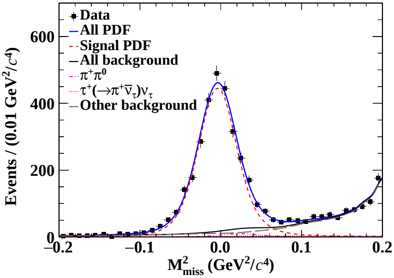
- Identify μ^+ with selections on EMC deposition and MUC penetration



$\mathcal{B}(D^+ \to \mu^+\nu_\mu) =$
$(4.034 \pm 0.080 \pm 0.040) \times 10^{-4}$

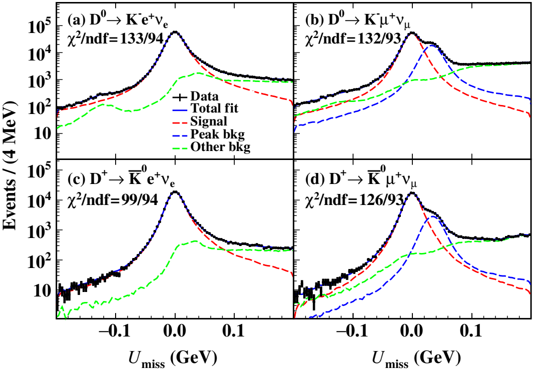
$f_{D^+}|V_{cd}| =$
$(48.02 \pm 0.48 \pm 0.24 \pm 0.12_{\mathrm{ext}} \pm 0.15_{\mathrm{EM}})$
with PDG2024 τ_{D^+}

$2.3\times$ improved precision

Complemented by new $D^+ \to \tau^+\nu$ with 8 fb^{-1}: JHEP 01 (2025) 089

$D \to K\ell^+\nu$: arXiv:2601.21196

- $D^0 \to K^-(e^+/\mu^+)\nu$ and $D^+ \to K^0_S(e^+/\mu^+)\nu$ with 20 fb^{-1} @ $E_{\text{CM}} = 3.77$ GeV
- Golden Channel for $|V_{cs}|$
- Six $\overline{D}^0$ tag decays and six D^- tag decays
- Signal yields from fits to $U_{\text{miss}} \equiv E_{\text{miss}} - p_{\text{miss}}$



Peaking backgrounds in μ sample from challenges of low-p μ/π separation

$\mathcal{B}_{D\to K\ell\nu}$ Rel. Precision: $0.5\% - 0.7\%$

Most precise charm LFU test

$R^{D+}_{\mu/e} = 0.982(2)_{\text{stat.}}(4)_{\text{syst}}$

$R^{D^0}_{\mu/e} = 0.972(3)_{\text{stat.}}(4)_{\text{syst}}$

Consistent with SM[a]: $0.975(1)$

[a] L. Riggio, G. Salerno, S. Simula, EPJC 78 (2018) 501

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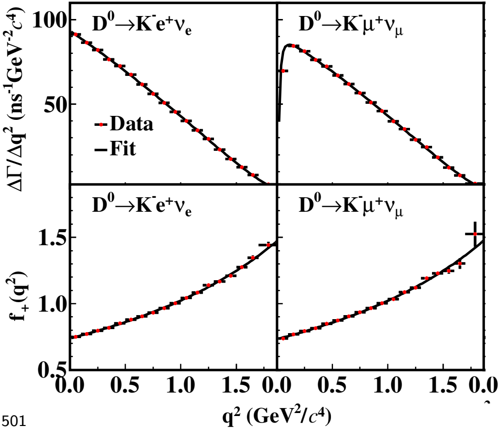
$\frac{d\Gamma}{dq^2}$ measured ($q \equiv p_{\ell\nu}$)
Form factors parametrized with power-series expansion
Simultaneous fit to $D \to K\ell\nu$:
$f_+^{D\to K}(0)|V_{cs}| = 0.7355(07)_{\text{stat}}(14)_{\text{sys}}$



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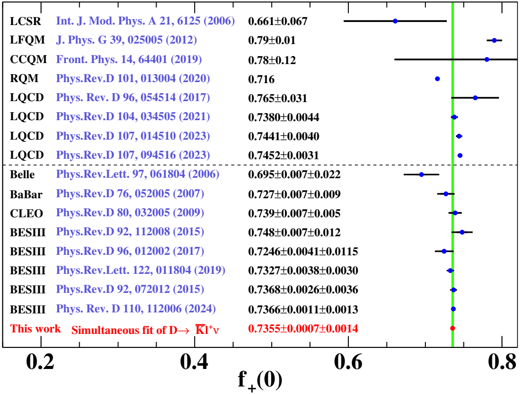


With $|V_{cs}|$ from PDG2024

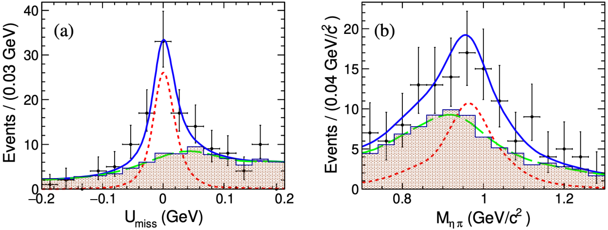
$f_+^{D\to K}(0) = 0.7355(07)_{\text{stat}}(14)_{\text{sys}}$

FLAG2024 Average: 0.7430(27)

[a] L. Riggio, G. Salerno, S. Simula, EPJC 78 (2018) 501

$D^0 \to a_0(980)^- e^+ \nu$: PRD 111 (2025) L091501

- Analysis of 7.9 fb^{-1} sample @ $E_{\text{CM}} = 3.77$ GeV, six D^- tag modes
- $a_0(980)^-$ studied through $\eta[\gamma\gamma]\pi^-$
- Signal yields from 2-D fit to U_{miss} and $m_{\eta\pi^-}$,
- $a_0(980)$ parameterized with Flatté, N.R. $\eta\pi^-$ found to be negligible



$$\mathcal{B}\left(a_0(980^-[\eta\pi^-]e^+\nu_e)\right) = (0.86 \pm 0.17 \pm 0.05) \times 10^{-4}$$

See appendix for citations.

$D^0 \to a_0(980)^- e^+ \nu$: PRD 111 (2025) L091501

- Analysis of 7.9 fb^{-1} sample @ $E_{\text{CM}} = 3.77$ GeV, six D^- tag modes
- $a_0(980)^-$ studied through $\eta[\gamma\gamma]\pi^-$
- Signal yields from 2-D fit to U_{miss} and $m_{\eta\pi^-}$,
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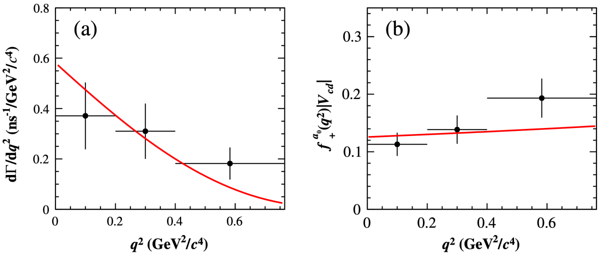

With $|V_{cd}|$ from PDG2024

$$f_0^{D\to a_0} = (0.550 \pm 0.056 \pm 0.013) \times 10^{-4}$$

See appendix for citations.

$D^0 \to a_0(980)^- e^+ \nu$: PRD 111 (2025) L091501

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- $a_0(980)^-$ studied through $\eta[\gamma\gamma]\pi^-$
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- $a_0(980)$ parameterized with Flatté, N.R. $\eta\pi^-$ found to be negligible

Theory or experiment	$f_+^{a_0}(0)$	$\mathcal{B}(D^0 \to a_0(980)^- e^+ \nu_e, a_0(980)^- \to \eta\pi^-)$ $(\times 10^{-4})$
CCQM [25]	$0.55^{+0.02}_{-0.02}$	1.43 ± 0.13[a]
Ads/QCD [26]	0.72 ± 0.09	2.08 ± 0.26[a]
LCSR 2017 [27]	$1.75^{+0.26}_{-0.27}$	$3.48^{+1.17}_{-1.04}$[a]
LCSR 2021 [28]	$0.85^{+0.10}_{-0.11}$	1.15
LCSR 2023 [29]	$1.058^{+0.068}_{-0.035}$	$1.330^{+0.216}_{-0.134}$
SU(3) flavor symmetry [20]	0.46 ± 0.06	...
BESIII 2018 [24]	...	$1.33^{+0.33}_{-0.29\,\text{stat}} \pm 0.09_{\text{syst}}$
This work	$0.559 \pm 0.056_{\text{stat}} \pm 0.013_{\text{syst}}$	$0.86 \pm 0.17_{\text{stat}} \pm 0.05_{\text{syst}}$

[a]The narrow width approximation is further applied to estimate the $\mathcal{B}\ l$ for uncomputed cases (denoted by the superscript *).

Important information to discriminate models[b] of $a_0(980)$

See appendix for citations.

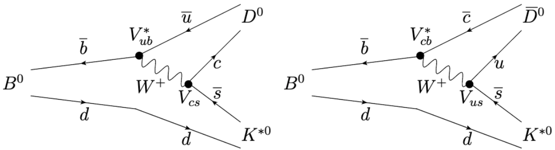
Summary of Impacts and Prospects in SL Decays

- Impacts on CKM elements:
  - $|V_{cs}|$:
    - $D_s^+ \to \ell^+\nu$:$< 1\%$ uncertainty, limited by exp. uncertainty
    - $D \to K\ell^+\nu$:$< 1\%$ uncertainty, limited by lattice
  - $|V_{cd}|$:
    - $D^+ \to \ell^+\nu$: 1% uncertainty, limited by exp. uncertainty
    - $D \to \pi\ell^+\nu$:Soon to achieve 1% uncertainty, limited by lattice
- Cut for time:
  - Amplitude analyses and branching fraction measurements of $D \to K\pi\ell\nu$
  - Inclusive studies of semileptonic decays : e.g. $D_s \to X\ell\nu$

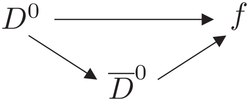
Outline

D^0 Amplitude Parameters

- CP-violation in $B \to D^0 h$ and D^0-mixing depend on parameters of the D^0 decay:
  - Ratio of $D^0 \to X$ and $\overline{D}^0 \to X$ amplitudes r_D^X
  - Strong phase between amplitudes δ_D^X

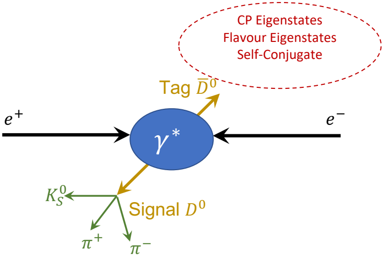


$$\Gamma\left(\overline{B} \to DK\right) - \Gamma\left(B \to DK\right) \propto r_D \sin\left(\delta_B + \delta_D\right) \sin\gamma$$



$$y_{CP} = r_D \left(x_{12} \cos\phi_2^M \sin\delta_D + y_{12} \cos\phi_2^\Gamma \cos\delta_D\right)$$

Quantum Correlations @ $\psi(3770)$



- Production through virtual photon constrains $D\overline{D}$ state to be C-odd
- BESIII collects data at the $D\overline{D}$ threshold, so it is guaranteed that there are no other particles in the final state
- C-constraint correlates D^0 and $\overline{D}^0$:

$$\frac{P(D\overline{D} \to X_1 X_2)}{P(D^0 \to X_1)P(\overline{D}^0 \to X_2)} = 1 + \left(r_D^{X_1} r_D^{X_2}\right)^2 - 2 r_D^{X_1} r_D^{X_2} \cos\left(\delta_D^{X_1} + \delta_D^{X_2}\right)$$

Quantum-Correlated Tag Decay Modes

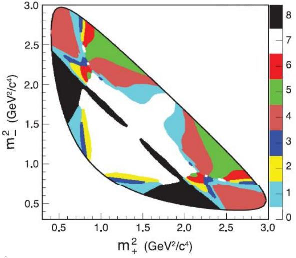
- Flavour Tags
  - $\overline{D}^0 \to K^+ e^- \nu$, is flavour-definite, so allow for a normalising determination of $P\left(D^0 \to X\right)$
  - Cabibbo-favoured decays, e.g. $\overline{D}^0 \to K^+\pi^-$, used as quasi-flavour tags
- CP Tags
  - $\overline{D}^0 \to \pi\pi, K^+K^-, K_S^0\pi^0$, etc. are CP-eigenstates (neglecting $\mathcal{O}(10^{-3})$ CP violation)

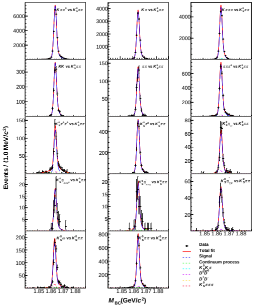
$$\frac{P(D\overline{D} \to X\ k_{CP})}{P(D^0 \to X)P(\overline{D}^0 \to k_{CP})} = 1 + \left(r_D^X\right)^2 \mp 2r_D^X \cos\left(\delta_D^X\right)$$

- Note that other tags with non-trivial phases needed to determine $\sin\left(\delta_D^X\right)$, e.g. $K_{S/L}^0\pi^+\pi^-$

Updated $D^0 \to K^0_{S/L}\pi^+\pi^-$ phases: JHEP 06 (2025) 086

- Measurement of $D^0/\overline{D}^0 \to K^0\pi^+\pi^-$ parameters $c_i\,[s_i] \equiv$ amplitude-weighted $\cos\,[\sin]\;\;\delta_D$ in phase-space bin i with $7.93\,\text{fb}^{-1}$ @ $E_{cm} = 3.773$ GeV
- Phase space described by $m_\pm \equiv m\left(K^0\pi^\pm\right)$
- 20 tag modes employed, yields determined with 2-D fits to $M_{\text{BC}} \equiv \sqrt{E^2_{\text{beam}} - p^2_D}$





'Optimal γ' Binning scheme from CLEO PRD 82,112006 (2010)

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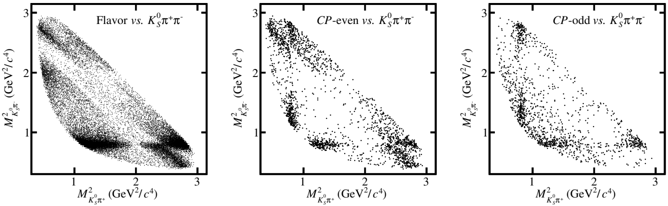
- Phase space described by $m_\pm \equiv m\left(K^0\pi^\pm\right)$
- In terms of fractional yields of flavour-tagged $K^0_S\pi^+\pi^- \equiv K_i$
- $K^0_S\pi^+\pi^-$ vs. CP tag: $M_i^\pm = h_{CP}\left(K_i + K_{-i} - 2c_i\sqrt{K_iK_{-i}}\right)$
- $K^0_S\pi^+\pi^-$ vs. $K^0_{S,L}\pi^+\pi^-$ tag:
  $$M_{ij} = h_{DT}\left(K_iK^{(\prime)}_{-j} + K_{-i}K^{(\prime)}_j \mp 2\sqrt{K_iK^{(\prime)}_{-j}K_{-i}K^{(\prime)}_j}\left(c_ic^{(\prime)}_j + s_is^{(\prime)}_j\right)\right)$$



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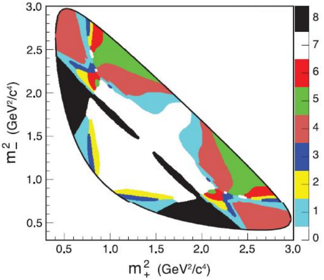

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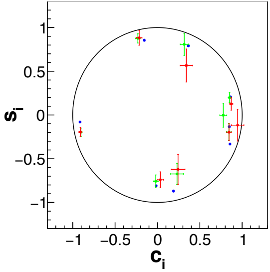


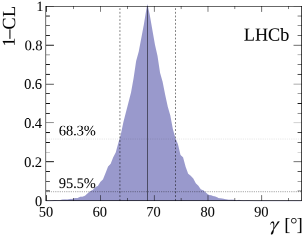
Green crosses: Model-constrained U-spin between $K^0_S\pi^+\pi^-$ and $K^0_L\pi^+\pi^-$
Red crosses: No U-spin constraints
Blue circles: Predictions from BaBar and Belle, PRD 98, 110212(2018)

Impacts on beauty-sector CPV Measurements

With $3\,\mathrm{fb}^{-1}$ BESIII $\psi(3770)$ data

$B^+ \to D[K_S^0 h^+ h^-]K^+$

LHCb, JHEP02 (2021), 169



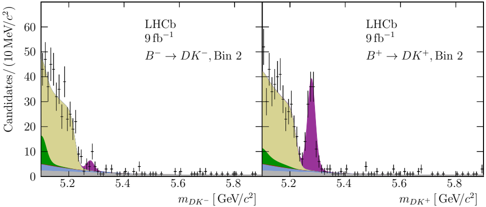
$$\gamma = \left(68.7^{+5.2}_{-5.1}\right)^\circ$$

from $\Delta\delta_D^{K_S^0 h^+ h^-} \sim \pm 1^\circ$

$B^+ \to D[K3\pi]K^+$

using $K3\pi$ binning

LHCb-PAPER-2022-017

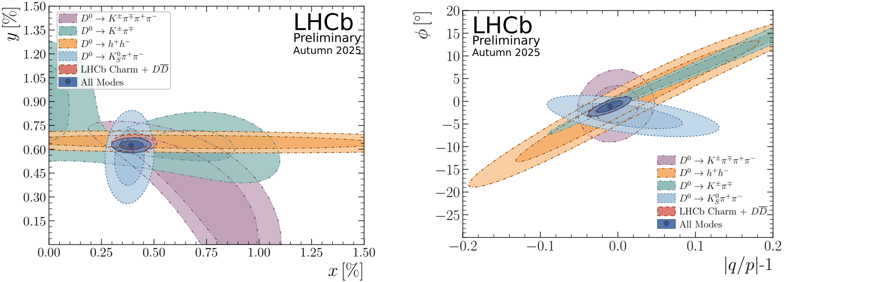


$$\gamma = \left(54.8^{+6.0\,+0.6\,+6.7}_{-5.8\,-0.6\,-4.7}\right)^\circ$$

from $\Delta\delta_D^{K3\pi} =^{+6.7}_{-4.7}$!

Impacts on charm-sector CPV/Mixing Measurements

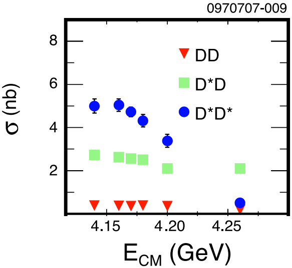
- LHCb Average from LHCb-CONF-2025-003



With $3\,\text{fb}^{-1}$ BESIII $\psi(3770)$ data and $9\,\text{fb}^{-1}$ LHCb data $\Delta\delta_D \sim 50\%$ of total uncertainty on x (small contribution to y) and small contribution to CPV-in-mixing params.

Correlations beyond $\psi(3770) \to D\overline{D}$

- QC $D^0\overline{D}^0$ pairs should exist at higher energies from $e^+e^- \to XD^0\overline{D}^0$ with $C = (-1)^{n_\gamma+1}$ for X with n_γ photons.



	Final State	$D\overline{D}$ C
	$D\overline{D}$	-1
$D^*\overline{D}$	$\gamma D\overline{D}$	$+1$
	$\pi^0 D\overline{D}$	-1
$D^*\overline{D}^*$	$\pi^0\gamma D\overline{D}$	$+1$
	$\gamma\gamma D\overline{D}$	-1
	$\pi^0\pi^0 D\overline{D}$	-1
$D^{*+}D^{*-}$	$\pi^+\pi^- D^0\overline{D}^0$	0 (Uncorrelated)

M. Goldhaber and J. Rosner, PRD 15 (1977) 1254 | CLEO PRD 80 (2008) 072001,

Correlations beyond $\psi(3770) \to D\overline{D}$

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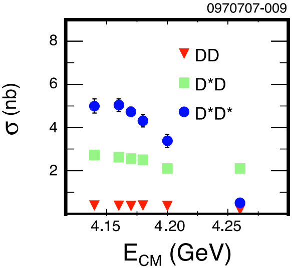

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	$\gamma\gamma D\overline{D}$	-1
	$\pi^0\pi^0 D\overline{D}$	-1
$D^{*+}D^{*-}$	$\pi^+\pi^- D^0\overline{D}^0$	0 (Uncorrelated)

- C-even constrained pairs have linear sensitivity to charm-mixing effects, enhanced $2\times$ relative to flavour-definite D mesons.

$$\frac{P([D^0\overline{D}^0]_C \to X_1X_2)}{P(D^0 \to X_1)P(\overline{D}^0 \to X_2)} = 1 + \left(r_D^{X_1} r_D^{X_2}\right)^2 + 2C r_D^{X_1} r_D^{X_2} \cos\left(\delta_D^{X_1} + \delta_D^{X_2}\right) + (1+C)\mathcal{O}(x,y)$$

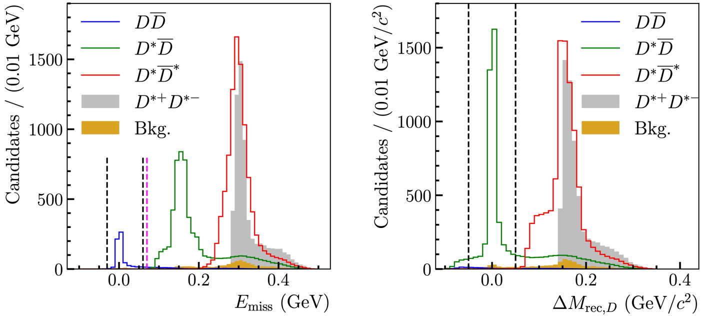
M. Goldhaber and J. Rosner, PRD 15 (1977) 1254 | CLEO PRD 80 (2008) 072001,

Identifying $e^+e^- \to XD\overline{D}$

PRL 135 (2025), 171901 PRD 112, (2025) 072006

- Analysis of $7.3\ \text{fb}^{-1}$ of data @ $E_{CM} = 4.13 - 4.23$ GeV
- Reconstruct $D\overline{D}$ pair
- Identify $D\overline{D}$ production mechanism with kinematic selection variables:

$$e^+e^- \to D\overline{D}\ \&\ e^+e^- \to D^*\overline{D}$$



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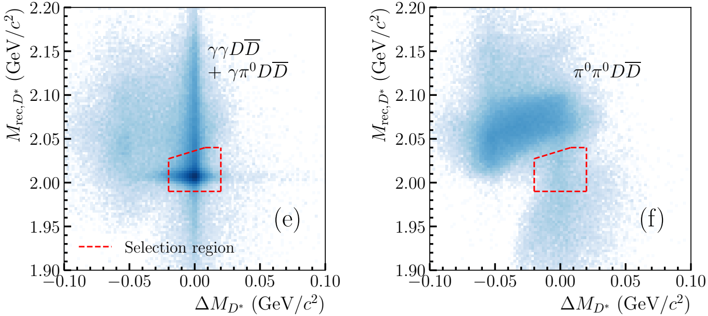
- For $D^*\overline{D}^*$ ID, reconstruct a $D^* \to \gamma D$ candidate and veto $D^{*+} \to \pi^+ D^0$

$e^+e^- \to D^*\overline{D}^*$



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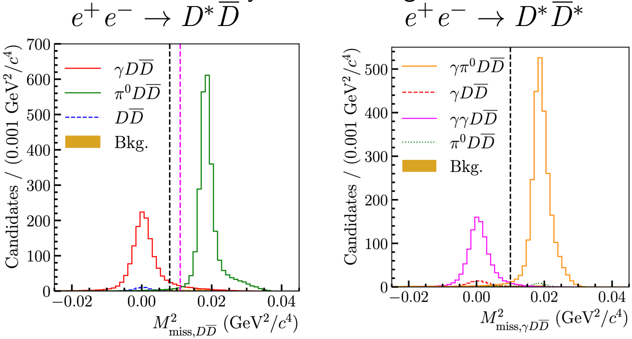
- Identify $D\overline{D}$ production mechanism with kinematic selection variables:
- For $D^*\overline{D}^*$ ID, reconstruct a $D^* \to \gamma D$ candidate and veto $D^{*+} \to \pi^+ D^0$
- Separate intermediate decays with missing-mass variables



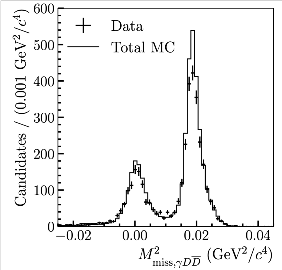
Measuring correlations in $e^+e^- \to XD\overline{D}$

PRL 135 (2025), 171901 PRD 112, (2025) 072006

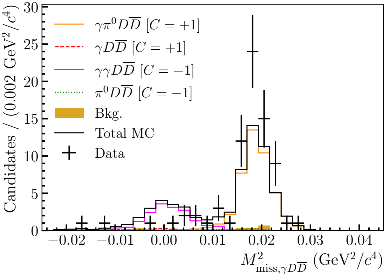
- Analysis of 7.3 fb^{-1} of data @ $E_{CM} = 4.13 - 4.23$ GeV
- Reconstruct $D\overline{D}$ pairs: Normalization $D\overline{D} \to K^-\pi^+$ vs. $K^+\pi^-$ and CP vs. CP final states: $D \to \pi^+\pi^-, K^+K^-, \pi^+\pi^-\pi^0$, and $K^0_S\pi^0$
- Sort into $e^+e^- \to XDD$ production hypotheses

$e^+e^- \to D^*\overline{D}^*$

$D\overline{D} \to K^+\pi^-$ vs. $K^-\pi^+$



$D\overline{D} \to K^0_S\pi^0$ vs. $K^0_S\pi^0$



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- Sort into $e^+e^- \to XDD$ production hypotheses
- Fit to $M(D^0)$ to determine yields, account for efficiencies and production mechanism cross-feed

$$\vec{n}_{\text{true}} = \mathbf{A}^{-1}\vec{N}_{\text{meas.}}$$

$$\mathbf{A}_{ij} \equiv \text{prob. of prod. mech } i \text{ being identified as } j$$

		Identified as				
		$D\overline{D}$	$D^*\overline{D} \to \gamma D\overline{D}$	$D^*\overline{D} \to \pi^0 D\overline{D}$	$D^*\overline{D}^* \to \gamma\pi^0 D\overline{D}$	$D^*\overline{D}^* \to \gamma\gamma/\pi^0\pi^0 D\overline{D}$
True	$D\overline{D}$	32.45	2.98	0	0	0.07
	$D^*\overline{D} \to \gamma D\overline{D}$	0	25.44	1.57	0	1.94
	$D^*\overline{D} \to \pi^0 D\overline{D}$	0	0.40	30.06	0.55	0.50
	$D^*\overline{D}^* \to \gamma\pi^0 D\overline{D}$	0	0	0	25.23	1.04
	$D^*\overline{D}^* \to \gamma\gamma/\pi^0\pi^0 D\overline{D}$	0	0	0	0.25	8.83

(for $D \to K^+\pi^-$ vs. $K^-\pi^+$)

Measuring correlations in $e^+e^- \to XD\overline{D}$

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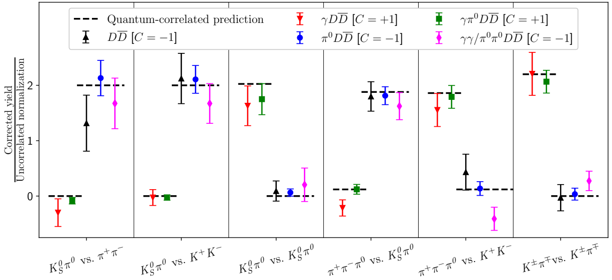
- Sort into $e^+e^- \to XDD$ production hypotheses
- Fit to $M(D^0)$ to determine yields, account for efficiencies and production mechanism cross-feed
- Compare corrected yields of $D\overline{D} \to$ CP vs. CP to normalization



Demonstration of correlations: ✓ Procedure verified for strong-phase measurements ✓

$\delta^D_{K\pi}$ with $e^+e^- \to XD\overline{D}$

PRL 135 (2025), 171901 PRD 112, (2025) 072006

- Analysis of 7.3 fb^{-1} of data @ $E_{CM} = 4.13 - 4.23$ GeV
- With similar procedure, can measure $\delta_D^{K\pi}$ with $D\overline{D} \to K^+\pi^-$ vs. Y, where Y is a CP-eigenstate or $K^0_S\pi^+\pi^-$

$$\delta^D_{K\pi} = \left(192.8^{+11.0+1.9}_{-12.4-2.4}\right)^\circ$$

Compare to

$$\delta^D_{K\pi} = \left(187.6^{+8.9+5.4}_{-9.7-6.4}\right)^\circ$$

with 2.9 fb^{-1} @ $\psi(3770)$

- Higher stat. error per fb^{-1} due to exclusion of $D^*\overline{D}^* \to \pi^0\pi^0 D\overline{D}$ and part. reco. tags, e.g. $D \to K^0_L\pi^+\pi^-$
- Significantly reduced syst. error due to mixed C-even and C-odd sample.

$\delta^D_{K\pi}$ with $e^+e^- \to XD\overline{D}$

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BESIII combination
of 7.3 fb^{-1} of data @ $E_{CM} = 4.13 - 4.23$ GeV
and 2.9 fb^{-1} of data @ $E_{CM} = 3.77$ GeV:

$$\delta^D_{K\pi} = \left(189.2^{+6.9+3.4}_{-7.4-3.8}\right)^\circ$$

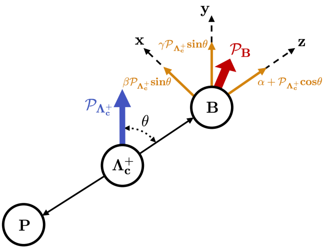
Outline

Polarization in $e^+e^- \to \Lambda_c^+\Lambda_c^-$: arXiv:2508.11400

- $\sigma\left(e^+e^- \to \Lambda_c^+\Lambda_c^-\right)$ parametrized by electric FF G_E and magnetic FF G_M
- If G_E and G_M have a relative phase $\Delta\Phi$ and $\frac{|G_E|}{|G_M|} \neq 1$, transverse polarization can occur:

$$P_y(\theta_0) = \frac{3}{2(3+\alpha_0)}\sqrt{1-\alpha_0^2}\sin\theta_0\cos\theta_0\sin\Delta\Phi, \quad \alpha_0 = \alpha_0\left(\frac{|G_E|}{|G_M|}\right)$$

- Measured in $\Lambda_c^+ \to BP$ (Baryon+Pseudoscalar) decays: $pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+, \Sigma^+\pi^-$
- $\Lambda_c^+ \to pK^-\pi^+$ included with inputs from LHCb[a]



[a] LHCb, JHEP 07 (2023) 228 | LHCb, PRD 108 (2023) 012023

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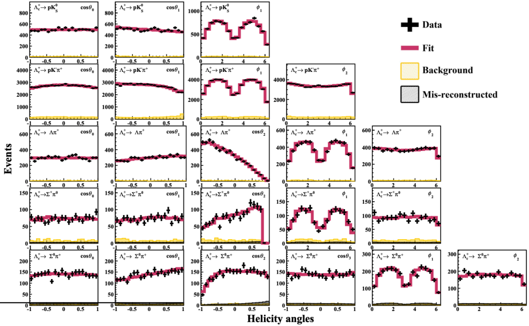
- Simultaneous fit of helicity angles in all decays



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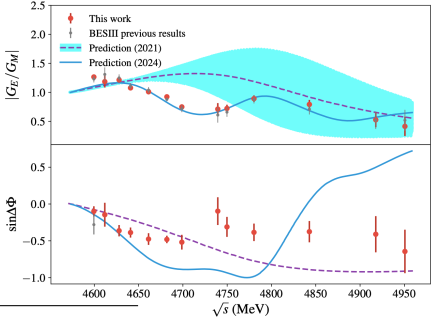
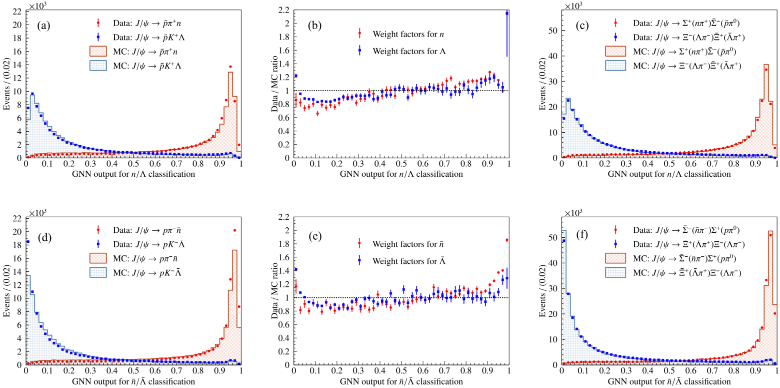


2021: J.y. Yao, Y.l. Yang, Z. Lu, EPJP 136 (2021) 949 | 2024: C. Chen, B. Yan, J.j. Xie, CPL 41, (2024) 021302

Observation of $\Lambda_c^+ \to n e^+ \nu_e$: Nature Comm. 16 (2025) 681

- Analysis of 4.5 fb^{-1} of data @ $E_{CM} = 4.6 - 4.7$ GeV
- Major background: $\Lambda_c^+ \to \Lambda[n\pi^0]e^+\nu_e$
- GNN trained on J/ψ control samples for $n/\Lambda[n\pi^0]$ discrimination



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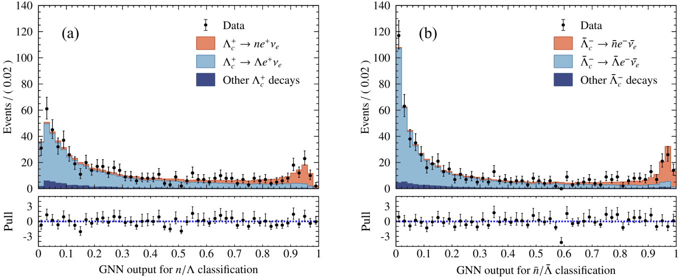
- Simultaneous fit to corrected GNN output of $\Lambda_c^+ \to n e^+ \nu$ and $\Lambda_c^- \to \overline{n} e^- \nu$ to determine branching fraction



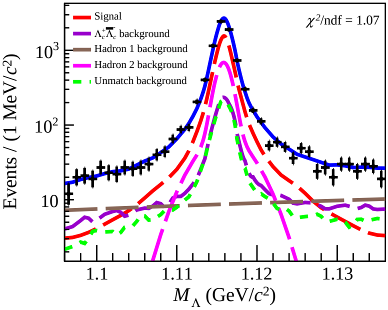
$$\mathcal{B}\left(\Lambda_c^+ \to n e^+ \nu\right) = (0.357 \pm 0.034 \pm 0.014)\,\%$$

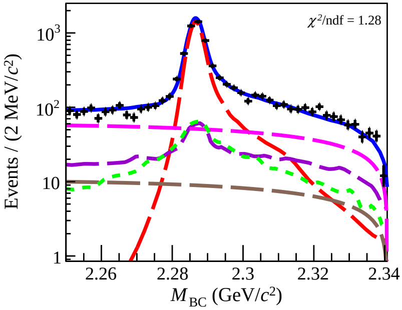
With LQCD input and $\tau_{\Lambda_c^+}$[a], $|V_{cd}| = 0.208 \pm 0.011_{\text{exp}} \pm 0.007_{\text{LQCD}} \pm 0.001_{\tau_{\Lambda_c}}$

[a] S. Meinel, Phys. PRD 97 (2018) 034511 | Belle II, PRL 130 (2023) 071802

Studies of Inclusive $\Lambda_c \to \Lambda X$ decays: arXiv:2602.24089

- Analysis of 4.5 fb^{-1} of data @ $E_{CM} = 4.6 - 4.7$ GeV
- Double-tag analysis with 11 Λ_c^- tag modes
- $\Lambda \to p\pi^-$ decays identified with displaced vertices
- Fit to M_Λ vs. M_{BC} to determine signal yields





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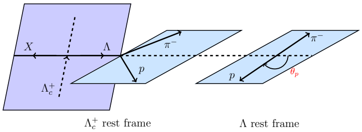
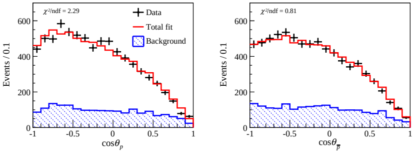
- Examine yields in bins of $\cos\theta_p$, efficiency correct yields assumed to satisfy $\frac{d\Gamma}{d\cos\theta_p} = 1 + \mathcal{P}_\Lambda \alpha_- \cos\theta_p$ (& C.C.)





with $\alpha_\pm$ from PDG2024

$\mathcal{P}_\Lambda = -0.393 \pm 0.055 \pm 0.020$

$\mathcal{P}_{\overline{\Lambda}} = 0.288 \pm 0.056 \pm 0.017$

Studies of Inclusive $\Lambda_c \to \Lambda X$ decays: arXiv:2602.24089

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- Examine yields in bins of $\cos\theta_p$, efficiency correct yields assumed to satisfy $\frac{d\Gamma}{d\cos\theta_p} = 1 + \mathcal{P}_\Lambda \alpha_- \cos\theta_p$ (& C.C.)

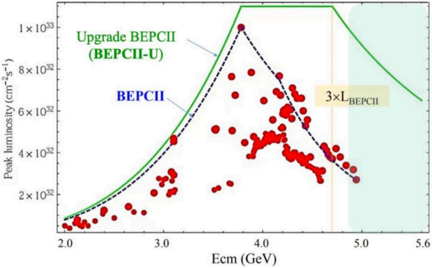
- $\mathcal{B}(\Lambda_c \to \Lambda X) = (38.07 \pm 0.38 \pm 0.49)\,\%$, with exclusive modes from PDG 2024 implies unobserved Λ branching fraction of $(6.71 \pm 1.25)\,\%$
- Measurement CP-asymmetry in both integrated decay width and polarization

$$\mathcal{A}_{CP}^{dir} = (1.5 \pm 1.0 \pm 1.0)\,\% \qquad \mathcal{A}_{CP}^{pol} = (0.15 \pm 0.12 \pm 0.04)\,\%$$

Outline

Future Prospects

- Much more analysis to come of BESIII data samples discussed today, particularly $20\,\text{fb}^{-1}$ $\psi(3770)$ sample
- BEPCII Upgrade has been completed
- Much higher instantaneous luminosity at higher energies, and access to E_{CM} up to 5.6 GeV
  - Access to $\Sigma_c, \Xi_c, \Omega_c,$ pair-production
- Currently collecting 9 fb more Λ_c^+ data
- Collection at > 5 GeV in 2028



Summary

- BESIII has collected large samples of D^0, D^+, D_s^+ and Λ_c^+ hadrons.
- These provide unique opportunities in the study of open-charm hadrons:
  - Detailed studies of charm semileptonic decays
  - Demonstration and leverage of entanglement of $D\overline{D}$ pairs due to C-symmetry
  - Studies of charm baryon production, polarization, and decays
- BEPCIII accelerator upgrade achieves higher luminosity at higher energies:
  - Much larger Λ_c^+ samples to come, and access to heaver charm baryons: $\Sigma_c, \Xi_c, \Omega_c$

$D \to a_0 \ell \nu$ Theory References

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