BESIII上粲强子辐射衰变的实验测量

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BESIII 粲强子物理研讨会

oultline

- ✓Introduction
- ✓BESIII dataset and double-tag method
- ✓Radiative decays
- ✓Summary

Introduction

Why radiative charm decays?

- Radiative charm decays are strongly suppressed in the SM — a sensitive probe of both long-distance and new physics.
- Short-distance contributions are GIM-suppressed to $\sim 10^{-8}$, far below experimental measurement.
- Long-distance (LD) effects— VMD and FSI — enhance the BF by orders of magnitude, up to $\sim 10^{-4}$.
- Measured BF are therefore dominated by non-perturbative QCD and directly test VMD, FSI loops and the strong-phase structure.

Physics goals

- Test VMD: photon saturation via ϕ / ρ^0 / ω — and, for the first time, axial-vector mesons (K_1, b_1).
- Constrain LD models (VMD, HQET, LCSR, NPQCD) and discriminate among competing frameworks.
- Probe new physics through photon polarization, helicity structure and CP asymmetries.
- Complement B physics: radiative B decays are short-distance dominated, radiative D decays long-distance dominated .

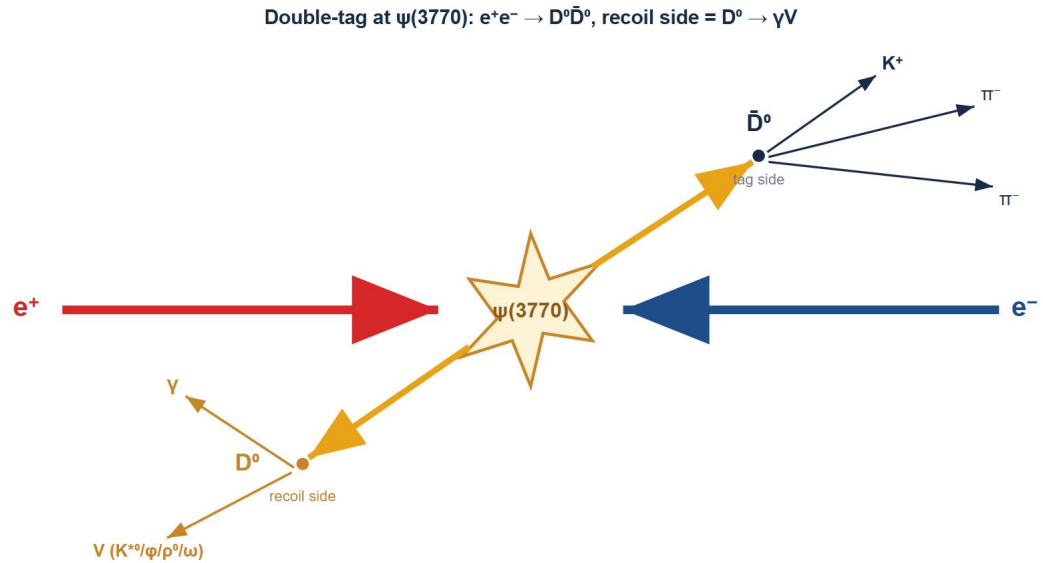
BESIII dataset and double-tag method

✓ e^+e^- annihilation data near threshold

⏩ Double-tag method & Clean environment

✓ BF with double-tag method: $\mathcal{B} = \frac{N_{DT}}{N_{ST}\,\epsilon_{DT}/\,\epsilon_{ST}}$

⏩ Systematic uncertainties on the ST mostly canceled

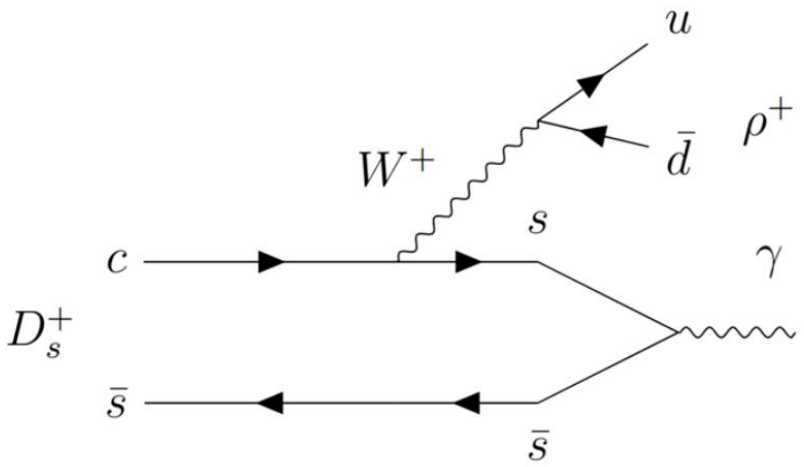


Data sample	$E_{\rm cm}$ (GeV)	$\mathcal{L}_{\rm int}$ ($\rm fb^{-1}$)	Single tag yields ($\times 10^6$)
$e^+e^- \to \psi(3770) \to D\bar{D}$	3.773	20.3	$\bar{D}^0$ ~16.9; D^- ~11.0
$e^+e^- \to D_s^{\pm} D_s^{*\mp}$	4.128-4.226	7.33	D_s^- ~0.8
$e^+e^- \to D_s^{*+} D_s^{*-}$	4.237-4.669	10.64	D_s^- ~0.12

$D_s^+ \to \gamma\rho(770)^+$

JHEP11(2024)119

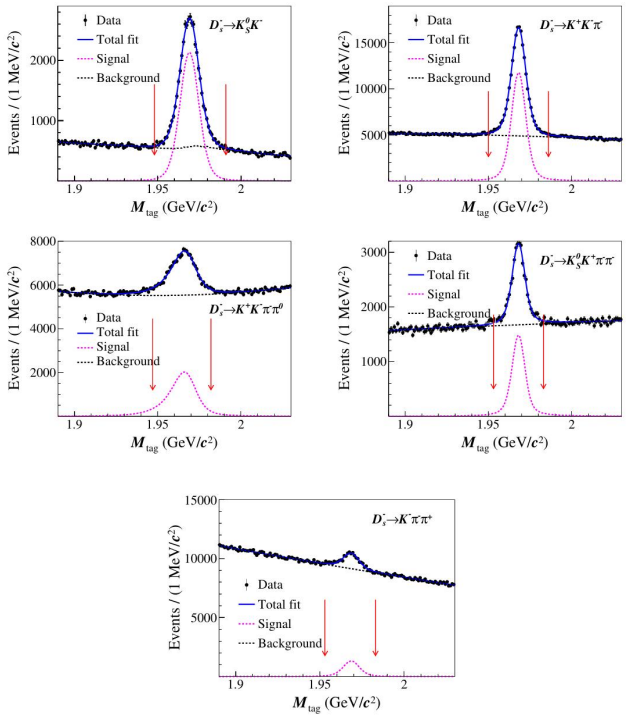
- ✓ Non-perturbative processes dominate the $c \to u\gamma$ processes, potentially enhancing BFs up to 10^{-3}.
- ✓ Expected BF of $D_s^+ \to \gamma\rho(770)^+$ ranges from $\mathcal{O}(10^{-5})$ to $\mathcal{O}(10^{-3})$, according to different theoretical models.
- ✓ The BF of $D_s^+ \to \gamma\rho(770)^+$ can be used to examine the predictions regarding CP asymmetry in charmed meson decays.



$D_s^+ \to \gamma\rho(770)^+$

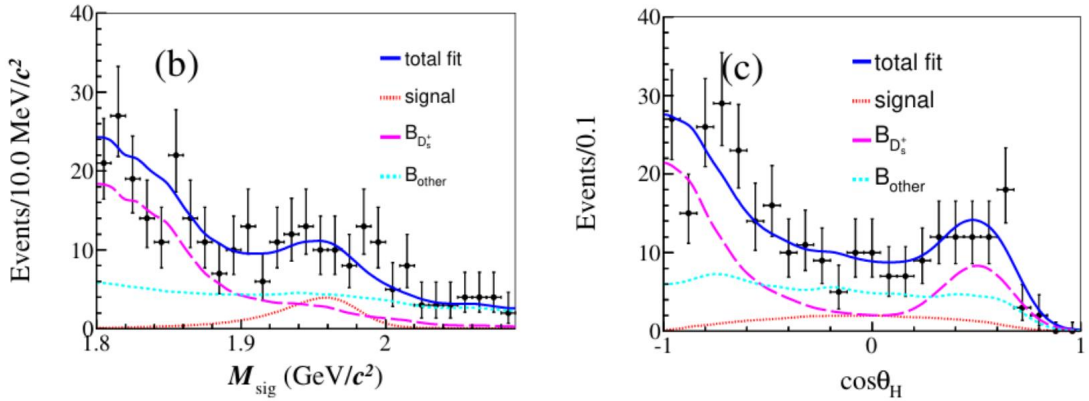
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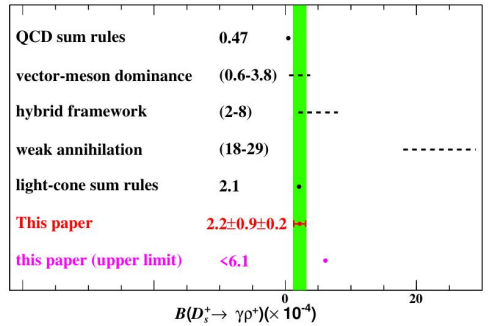
- ✓ data sample:$e^+e^- \to D_s^{\pm}\, D_s^{*\pm}$, 7.33fb^{-1} @4.128-4.226GeV
- ✓ $D_s^+ \to \gamma\rho(770)^+$with $\rho(770)^+ \to \pi^+\,\pi^0$
- ✓ Double-tag method with D_s^- reconstructed in 5 hadronic decay modes



First search

- ✓ 2D fit to the M_{sig} and $\cos\theta_{\text{H}}$ distributions
- ✓ Obtain N_{DT}=33±14
- ✓ $\mathcal{B}(D_s^+ \to \gamma\rho(770)^+) = (2.2 \pm 0.9_{\text{stat}} \pm 0.2_{\text{syst}})$, 2.5σ

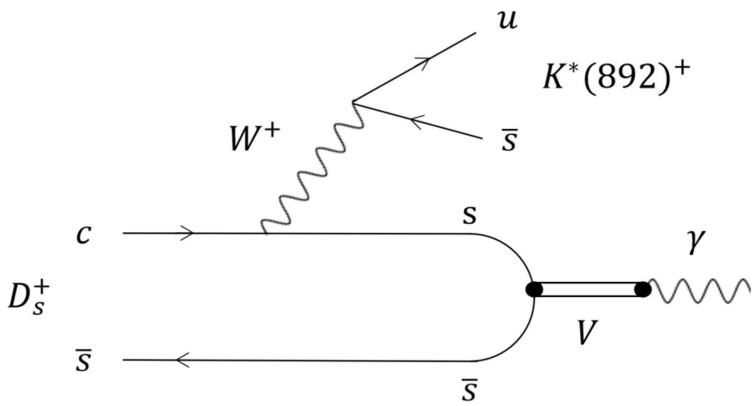




$D_s^+ \to \gamma K^{*+}$

JHEP07(2026)266

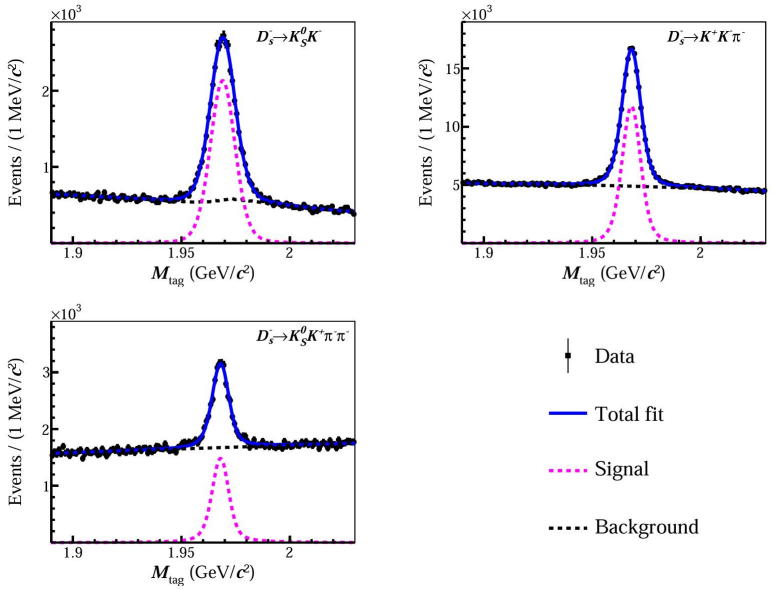
- ✓ Various models have predicted the BF of the Cabibbo-suppressed process $D_s^+ \to \gamma K^{*+}$ with values ranging from $\mathcal{O}(10^{-5})$–$\mathcal{O}(10^{-4})$.
- ✓ These predictions are based on the Standard Model and employ different theoretical frameworks, including hard spectator interaction (HSI) and weak annihilation (WA), light-cone sum rules (LCSR) , hybrid framework , VMD.



$D_s^+ \to \gamma K^{*+}$

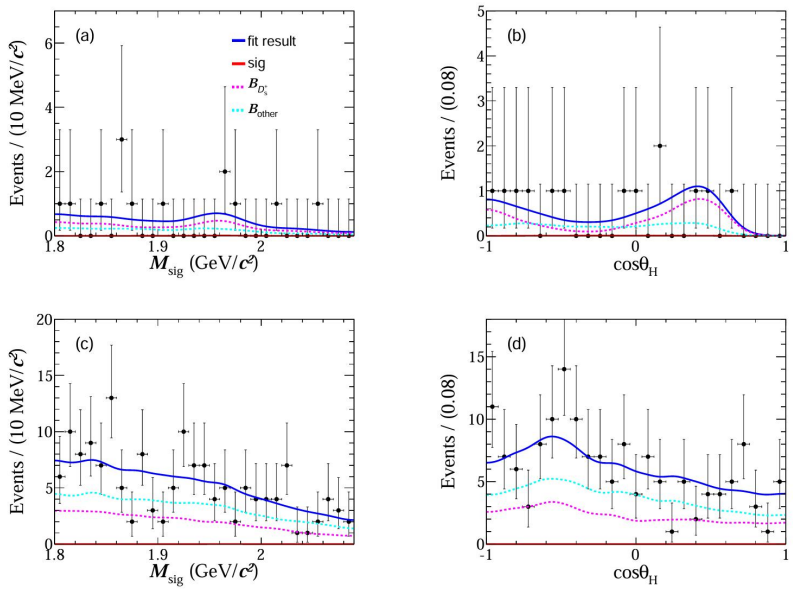
JHEP07(2026)266

- ✓ data sample:$e^+e^- \to D_s^{\pm}\, D_s^{*\pm}$, 7.33fb^{-1} @4.128-4.226GeV
- ✓ $D_s^+ \to \gamma K^{*+}$with $K^{*+} \to K^+\pi^0$ or $K_S^0\pi^+$
- ✓ Double-tag method with D_S^- reconstructed in 3 hadronic decay modes



First search

- ✓ 2D fit to the $M_{\rm sig}$ and $\cos\theta_{\rm H}$ distributions
- ✓ $\mathcal{B}(D_S^+ \to \gamma K^{*+}) < 2.3 \times 10^{-4}$ @ 90% C.L



Theory or experiment	$D_s^+ \to \gamma K^*(892)^+$ $(\times 10^{-4})$
HSI+WA [5]	$1.0 - 1.4$
LCSR [6]	0.17
Hybrid [1, 7]	$0.1 - 0.5$
VMD [8]	$0.1 - 0.3$
This work	< 2.3

$D^0 \to \gamma \bar{K}^{*0}$ and $D^0 \to \gamma \phi^0$

PRD114,072002(2026)

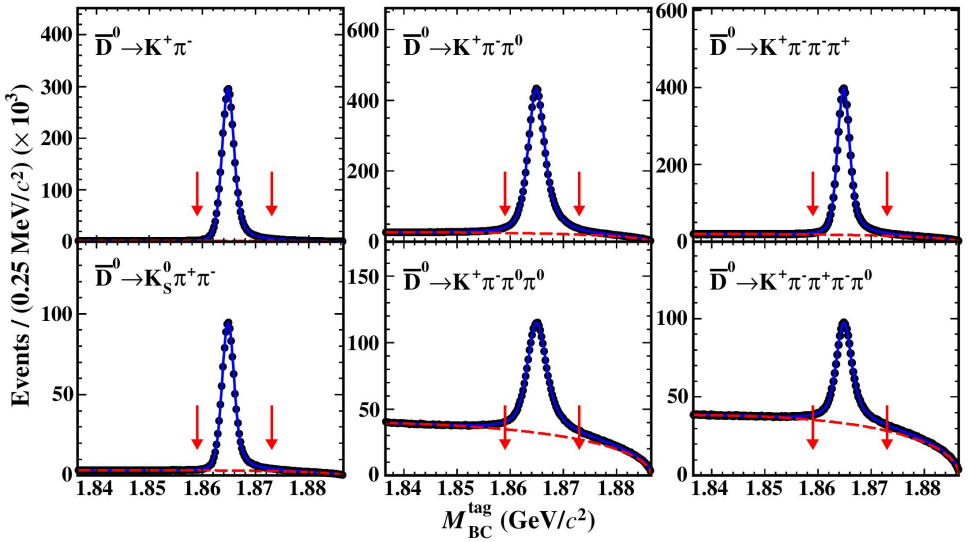
- ✓ $D^0 \to \gamma \bar{K}^{*0}$ is the CF channel with the BF about 10^{-4}, highest statistics; resolves the BaBar–Belle $>3\sigma$ tension.
- ✓ Previous BaBar/Belle results were relative measurements, BESIII can provide the absolute branching fraction via double-tag at ψ(3770), with independent systematics.
- ✓ Measurements of CP asymmetries in radiative charm decays provide comple-mentary information on weak decay mechanisms.

Theoretical calculation	$D^0 \to \gamma \bar{K}^{*0}$	$D^0 \to \gamma\phi$
VMD 1 [1]	7-12	0.1-3.4
VMD 2 [2]	16-34	-
HQET 1 [3]	21-43	-
HQET 2 [4]	20-40	-
HQET 3 [5]	2.6-46	0.24-2.8
HQET 4 [6]	$\leq$3.0	2.0
HQET 5 [7]	7-20	0.4-3
ELA [8]	11	-
NPQCD [9]	$3.59^{+0.20}_{-0.22}$	$2.76^{+0.36}_{-0.35}$
EFT [10]	6-36	0.1-1.9
LRSM [11]	4.6-18	0.48-0.64
Experimental measurement	$D^0 \to \gamma \bar{K}^{*0}$	$D^0 \to \gamma\phi$
BaBar [12]	$33.3 \pm 2.0 \pm 2.8$	$2.82 \pm 0.31 \pm 0.27$
Belle [13]	$46.9 \pm 2.0 \pm 2.0$	$2.71 \pm 0.19 \pm 0.09$

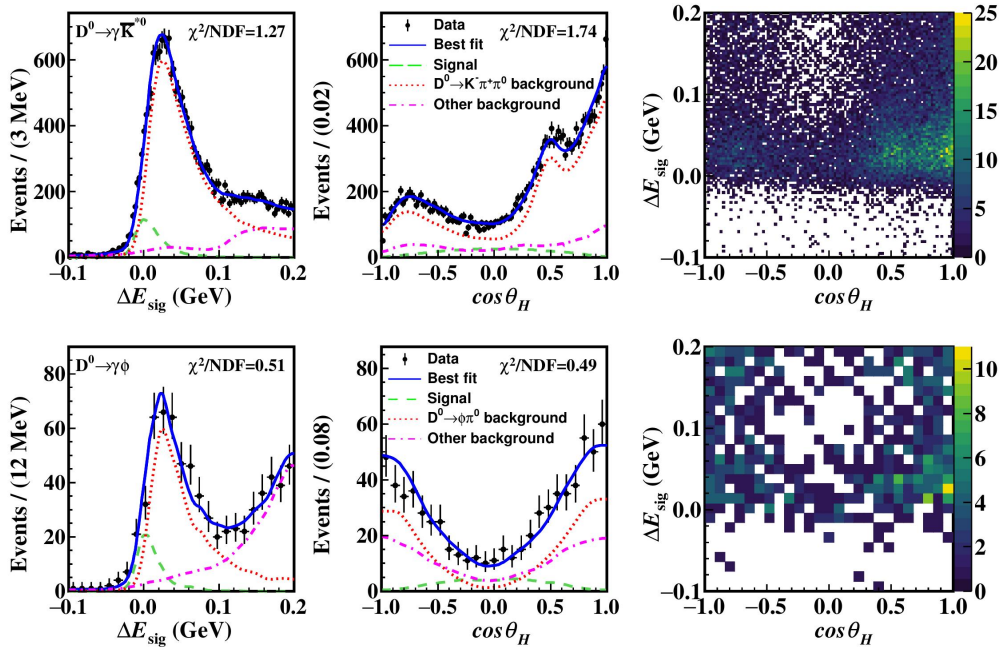
$D^0 \to \gamma \bar{K}^{*0}$ and $D^0 \to \gamma \phi^0$

PRD114,072002(2026)

- ✓ data sample: 20.3fb^{-1} @3.773 GeV
- ✓ $D^0 \to \gamma \bar{K}^{*0}$ with $\bar{K}^{*0} \to K^- \pi^+$ and $D^0 \to \gamma \phi^0$ with $\phi^0 \to K^+ K^-$
- ✓ Double-tag method with $\bar{D}^0$ reconstructed in 6 hadronic decay modes



- ✓ 2D fit to the ΔE_{sig} and cosθ_H distributions



1653±77

69±12

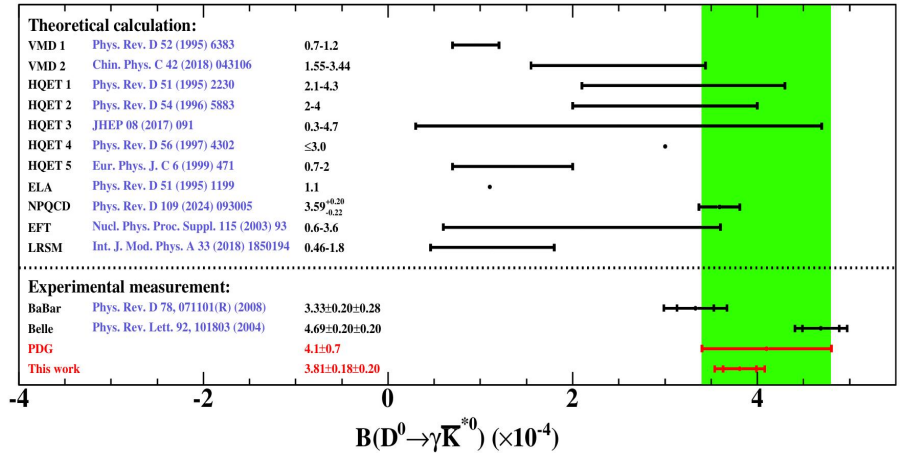
Decay mode	N_{DT}	Significance	ϵ_{sig} (%)	$\mathcal{B}_{sig}$ (This work)	$\mathcal{B}_{sig}$ (Belle) [13]	$\mathcal{B}_{sig}$ (BaBar) [12]
$D^0 \to \gamma \bar{K}^{*0}$	1653 ± 77	26.8σ	32.17 ± 0.07	$38.1 \pm 1.8 \pm 2.0$	$46.9 \pm 2.0 \pm 2.0$	$33.3 \pm 2.0 \pm 2.8$
$D^0 \to \gamma\phi$	69 ± 12	7.9σ	27.29 ± 0.07	$2.51 \pm 0.44 \pm 0.11$	$2.71 \pm 0.19 \pm 0.09$	$2.83 \pm 0.31 \pm 0.27$

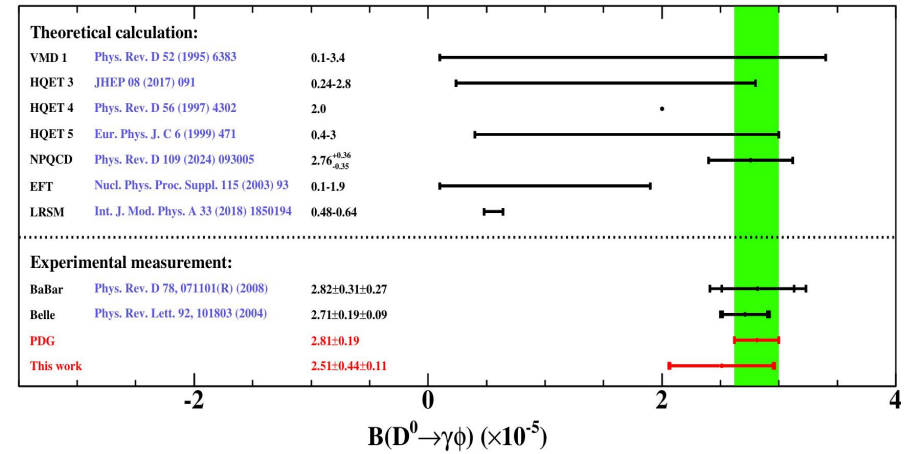
$D^0 \to \gamma \overline{K}^{*0}$ and $D^0 \to \gamma \phi^0$

PRD114,072002(2026)

- ✓ The CP asymmetry between $D^0 \to \gamma \overline{K}^{*0}$ and $\overline{D}^0 \to \gamma K^{*0}$ is measured to be$(\mathbf{-0.7 \pm 5.0_{stat.} \pm 4.1_{syst.}})\%$.
- ✓ It is consistent with CP conservation.

Decay mode	$N_{\rm net}$	$\mathcal{B}$ $(\times 10^{-4})$	$\mathcal{A}_{CP}$ (%)	$\mathcal{A}_{CP}$ (Belle) (%)
$\mathcal{B}^+$	754.4 ± 53.4	$3.72 \pm 0.26 \pm 0.20$	$-0.7 \pm 5.0 \pm 4.1$	$-0.3 \pm 2.0 \pm 0.0$
$\mathcal{B}^-$	769.6 ± 53.2	$3.77 \pm 0.26 \pm 0.21$		

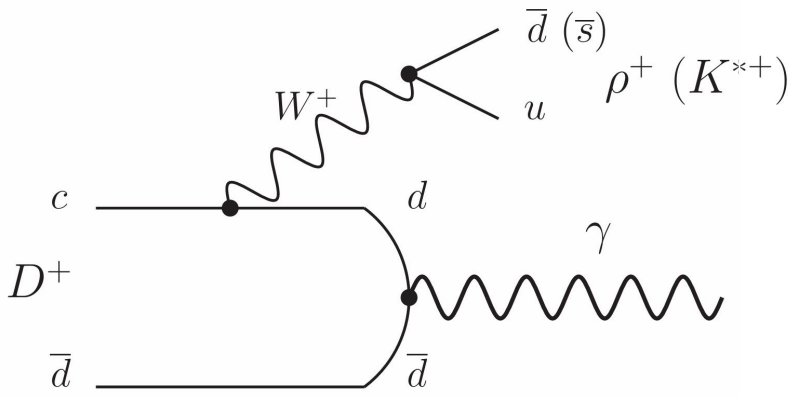




$D^+ \to \gamma\rho^+$ and $D^+ \to \gamma K^{*+}$

JHEP12(2024)206

- ✓ The D meson can be considered “pure”with respect to long-range effects, which are not sensitive to $c \to u$ transitions, unlike the neutral mesons.
- ✓ Predicted BF of the Cabibbo-suppressed process $D^+ \to \gamma\rho^+$ is up to 10^{-5}.
- ✓ Expected BF of the doubly Cabibbo-suppressed process $D^+ \to \gamma K^{*+}$ is one order of magnitude lower than that of $D^+ \to \gamma\rho^+$.

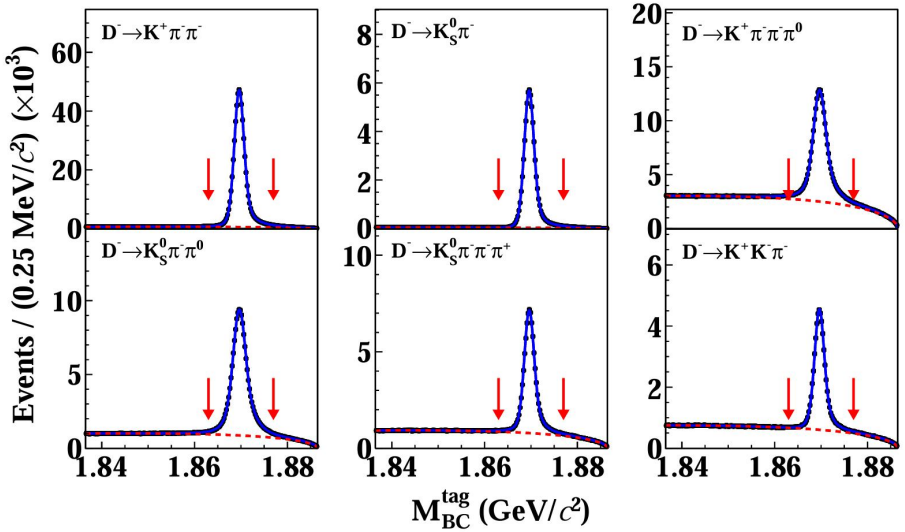


$D^+ \to \gamma\rho^+$ and $D^+ \to \gamma K^{*+}$

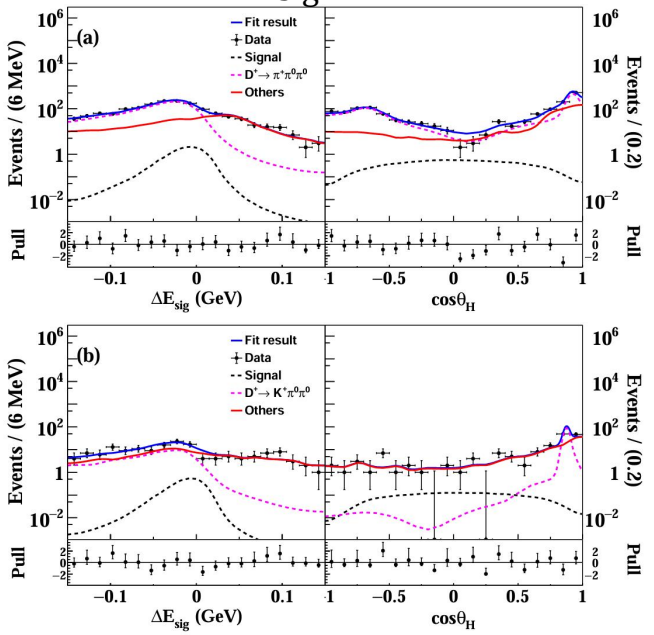
JHEP12(2024)206

First search

- ✓ data sample: 20.3fb^{-1} @3.773 GeV
- ✓ $D^+ \to \gamma\rho^+$ with $\rho(770)^+ \to \pi^+\pi^0$ and $D^+ \to \gamma K^{*+}$ with $K^{*+} \to K^+\pi^0$
- ✓ Double-tag method with D^- reconstructed in 6 hadronic decay modes



- ✓ 2D fit to the $\Delta E_{\rm sig}$ and $\cos\theta_{\rm H}$ distributions



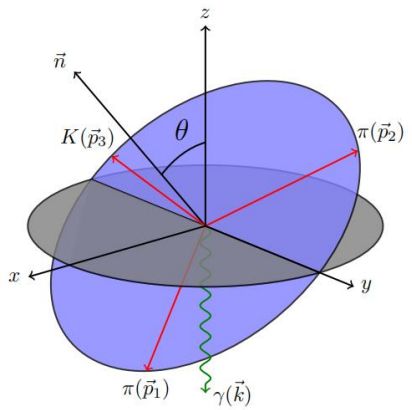
Result	$D^+ \to \gamma\rho^+$	$D^+ \to \gamma K^{*+}$
PoleDiagram and VMD [1]	$2-6$	$0.1-0.3$
SM [8]	5.0 ± 0.9	–
QCD SM [9]	0.46	–
Hybrid [10]	$0.017-2.33$	$0.048-0.76$
FS [11]	$1.8-4.1$	$0.25-0.5$
Factorization [12]	$0.4-6.3$	$0.03-0.44$
This work	< 1.3	< 1.8

3.6 σ deviation

$D^+ \to \gamma K_1^+$ and $D^0 \to \gamma \bar{K}_1^0$

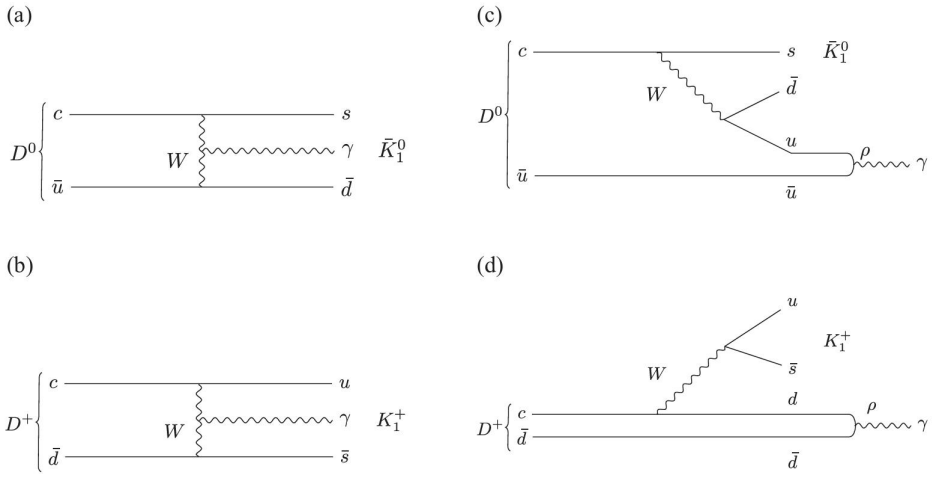
PRD114, 012020(2026)

- ✓ $D^+ \to \gamma K_1^+$ and $D^0 \to \gamma \bar{K}_1^0$ are radiative decays to the axial-vector K_1 mesons.
- ✓ Photon polarization: left-/right-handed photon asymmetry appears only in a parity-odd observable, requiring the pseudoscalar triple product $\vec{p}_1.(\vec{p}_2 \times \vec{p}_3)$ is required — accessible in the 4-body decay.
- ✓ $D_s^+ \to \gamma K_1^+$ (SCS,) as U-spin partner: predicted ratio $A_{UD}(D_s^+)/A_{UD}(D^+) \approx 1$` — deviations signal NP.
- ✓ $D^+ \to \gamma K_1^+$ predicted at $[(1.3\pm0.3),(1.5\pm0.4)]\times10^{-5}$; $D^0 \to \gamma \bar{K}_1^0$ constrained to $\mathcal{O}(10^{-6})$–$\mathcal{O}(10^{-4})$.



$$\hat{n} = \frac{\vec{p}_1 \times \vec{p}_2}{|\vec{p}_1 \times \vec{p}_2|}, \qquad \cos\theta = \hat{k} \cdot \hat{n} = \frac{\vec{k} \cdot (\vec{p}_1 \times \vec{p}_2)}{|\vec{k}||\vec{p}_1 \times \vec{p}_2|}$$

$$A_{UD} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$



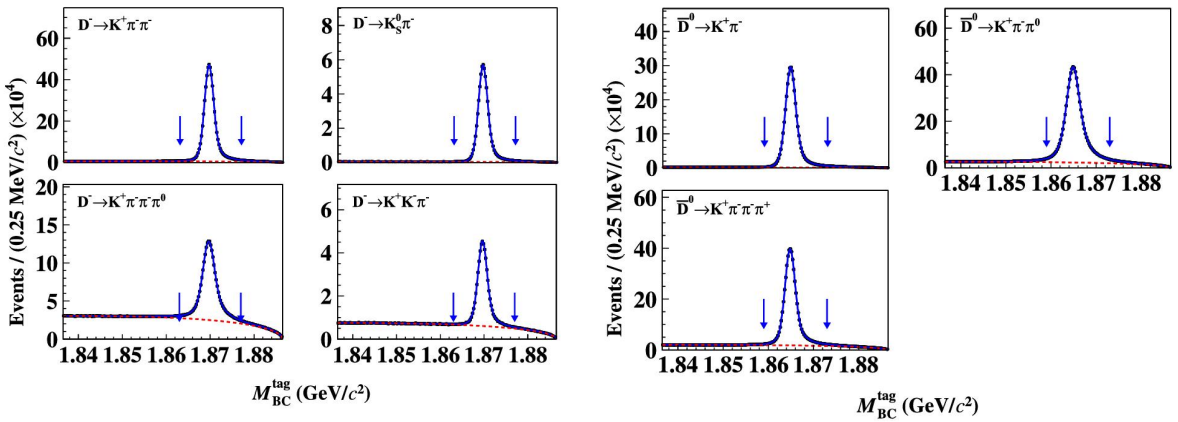
$D^+ \to \gamma K_1^+$ and $D^0 \to \gamma \bar{K}_1^0$

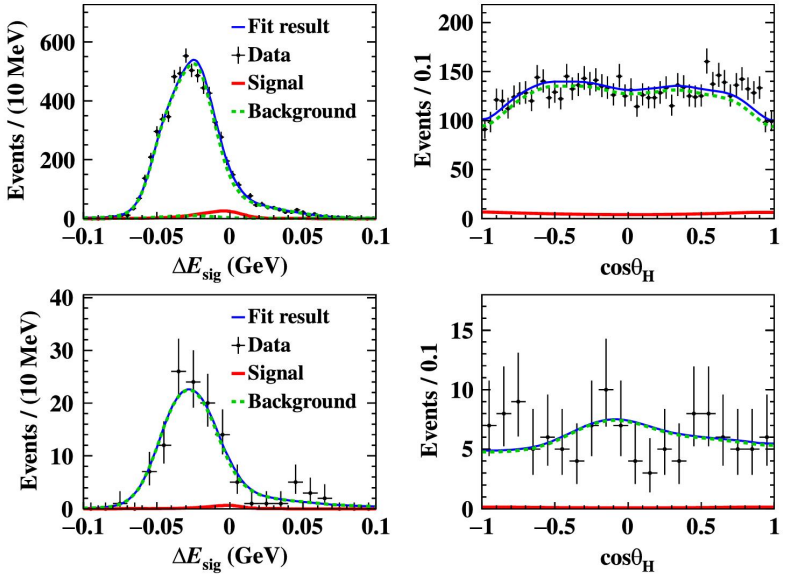
PRD114, 012020(2026)

- ✓ data sample: 20.3fb^{-1} @3.773 GeV
- ✓ $D^+ \to \gamma K_1^+$ with $K_1^+ \to K^+ \pi^+ \pi^-$
- ✓ $D^0 \to \gamma \bar{K}_1^0$ with $\bar{K}_1^0 \to K^- \pi^+ \pi^0$
- ✓ Double-tag method with D^-/ $\bar{D}^0$ reconstructed in 4/3 hadronic decay modes

First search

- ✓ 2D fit to the $\Delta E_{\rm sig}$ and $\cos\theta_{\rm H}$ distributions
- ✓ $\mathcal{B}(D^+ \to \gamma K_1^+) < 3.9 \times 10^{-5}$ @ 90% C.L
- ✓ $\mathcal{B}(D^0 \to \gamma \bar{K}_1^0) < 7.8 \times 10^{-4}$ @ 90% C.L





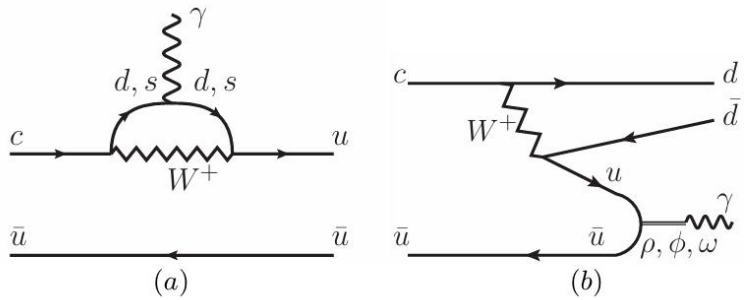
$D^0 \to \gamma\omega$

arXiv:2610.21982

- ✓ ω is an isospin singlet, — comparing $D^0 \to \gamma\omega$ with $D^0 \to \gamma\rho^0$. isolates the short-distance contribution via $\{\omega - \rho\}$, sensitive to NP.
- ✓ $D^{\omega-\rho}$ isolates the SD penguin contribution → NP probe:

$$\mathcal{D}^{\omega-\rho} \equiv \frac{\Gamma(D^0\to\gamma\omega)/(m_D^2-m_\omega^2)^3 - \Gamma(D^0\to\gamma\rho^0)/(m_D^2-m_{\rho^0}^2)^3}{\Gamma(D^0\to\gamma\omega)/(m_D^2-m_\omega^2)^3},$$

- ✓ SD penguin photons are mostly left-handed; an unusually large right-handed fraction would signal NP
- ✓ Previously only CLEO upper limit: $\mathcal{B} < 2.4\times10^{-4}$ — the ω channel completes the $D^0 \to \gamma$V family .



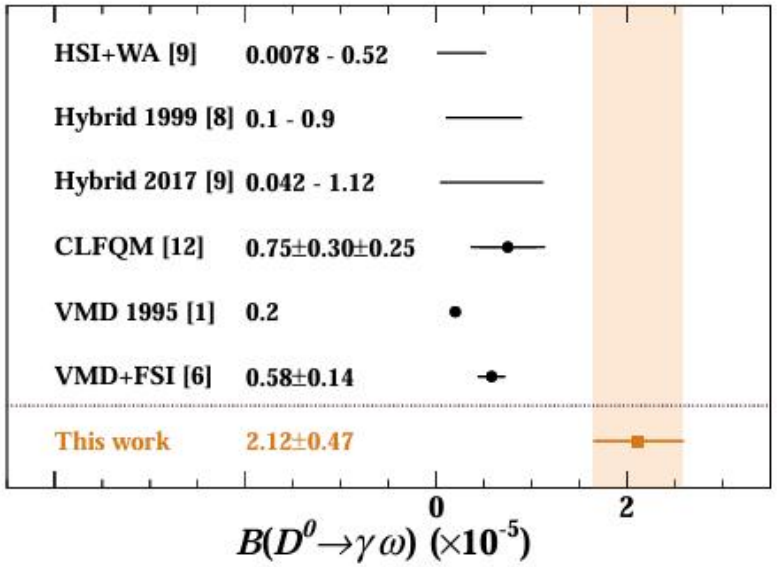
$D^0 \to \gamma\omega$

arXiv:2610.21982

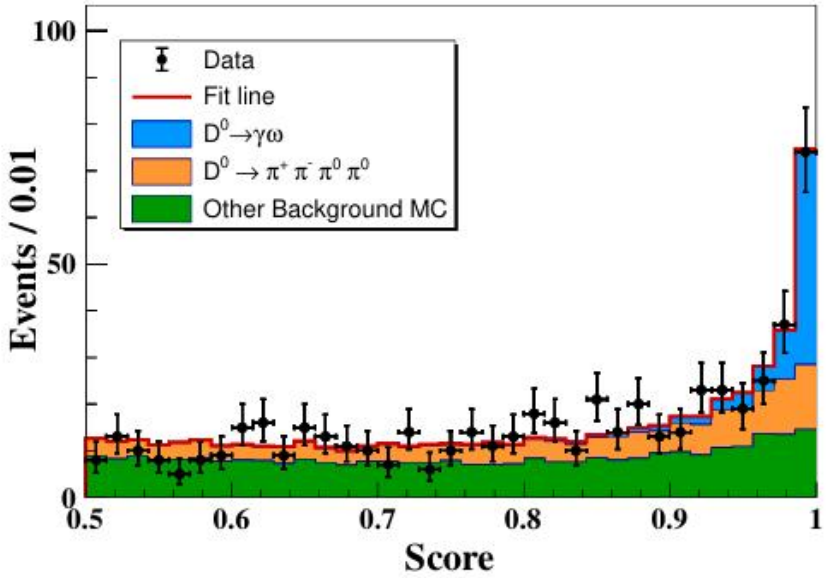
- ✓ data sample: 20.3fb^{-1} @3.773 GeV
- ✓ $D^0 \to \gamma\omega$ with $\omega \to \pi^0\,\pi^+\pi^-$
- ✓ Double-tag method with $\bar{D}^0$ reconstructed in 3 hadronic decay modes

First Observation

- ✓ 1D fit to the Score distribution
- ✓ Obtain N_{DT}=79.8±14.9
- ✓ $\mathcal{B}(D^0 \to \gamma\omega)$=(2.12± 0.40stat±0.25syst)×10^{-5}.
- ✓ Determine $D^{\omega-\rho}$, $D^{\omega-\rho}$ =0.15±0.24.



DNN methond 6σ



Summary

Works about rare charm hadron decays ongoing:

- Search for Doubly Cabibbo Suppressed decay $D^0 \to \gamma\, K^{*0}$ (draft stage)
- First measurement of the absolute BF for the radiative decay $D^0 \to \gamma\, \rho^0$ (memo stage)
- Search for the radiative decay $D^0 \to \gamma\, b_1^0$ (memo stage)
- Search for the radiative decay $D_s^+ \to \gamma K_1^+$ (memo stage)
- Search for the radiative decay $D_s^+ \to \gamma\, b_1^+$ (charm review stage)

Summary

- BESIII has performed wide range studies of rare charm hadron decays, with many first searches or best limits.
- BESIII has collected the 20.3fb^{-1} $\psi(3773)$ data samples. BESIII possesses great potentials in searches for rare charm hadron decays.
- The application of new techniques (e.g., deep learning, novel charm meson tagging method) enhances search sensitivity.

Thanks!