Recent Processes on η_c/h_c Decays at BESIII

Tengjiao(腾蛟) Zhu(朱)

(Xinyang Normal University)

On behalf of the BESIII Collaboration

Outline

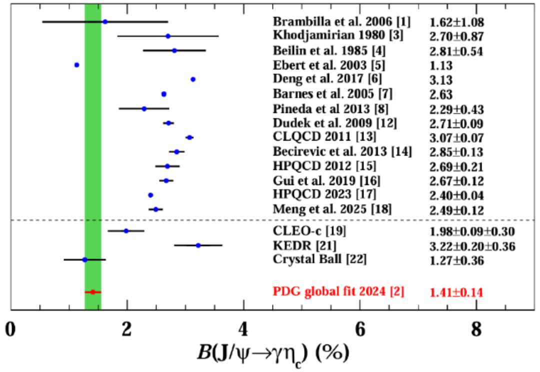
- **Introduction**
- **Recent new measurements on $\boldsymbol{\eta_c}$ decay**
  - Measurements of $\eta_c \to \gamma\gamma$
  - Amplitude analysis of $J/\psi \to \gamma\eta_c \to \gamma p\bar{p}$
  - Study of $\eta_c \to \pi^+\pi^-\pi^+\pi^-\eta$
- **Recent new measurements on $\boldsymbol{h_c}$ decay**
  - Measurements of h_c radiative decays
  - Measurements of $h_c \to hadrons$
- **Summary**

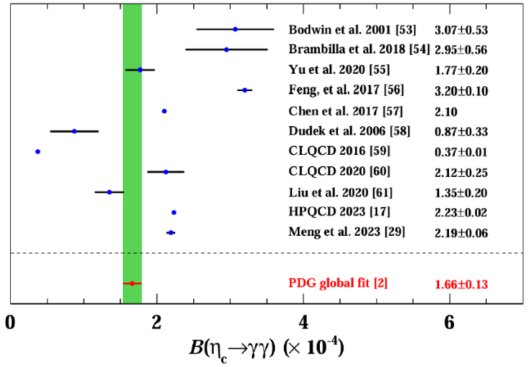
Introduction

The decay rates of charmonium systems not only permit the determination of the strong coupling constant at the charmonium scale under perturbative QCD, but also furnish a highly sensitive testbed to assess the validity of lattice QCD and NRQCD implementations.

~40% of η_c/h_c decay modes remain unobserved, and most of the measured BFs suffer from large uncertainties. More importantly, most of η_c decay modes neglect the interference effects.

$J/\psi \to \gamma\eta_c$ and $\eta_c \to \gamma\gamma$ are of great theoretical interest, with precise predictions. Experimental measurements, however, remain challenging.





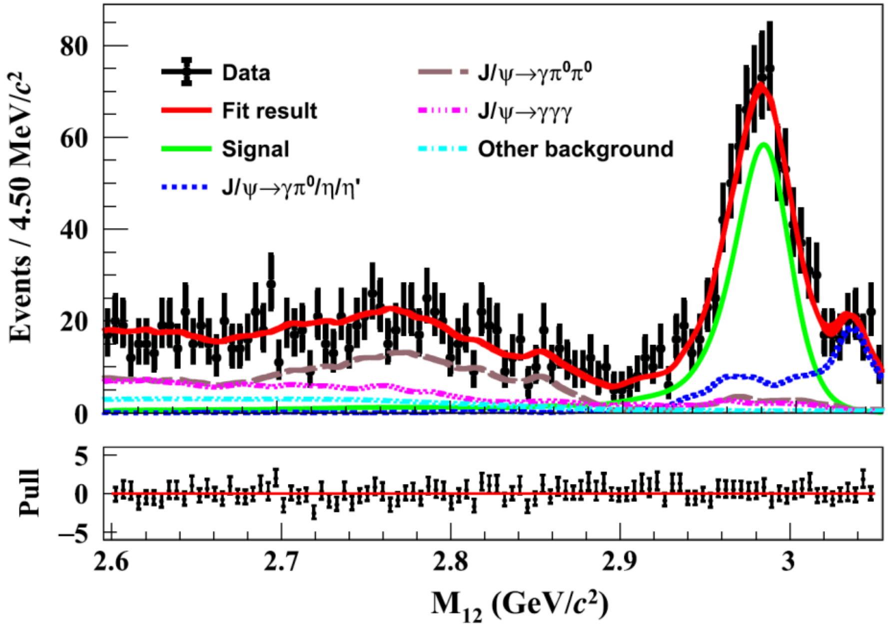
In BESIII, η_c can be produced via three different radiative transition: $J/\psi \to \gamma\eta_c$, $\psi(3686) \to \gamma\eta_c$, and $h_c \to \gamma\eta_c$. The h_c can be produced via $\psi(3686) \to \pi^0 h_c$ process.

Productions	$J/\psi \to \gamma\eta_c$	$\psi(3686) \to \gamma\eta_c$	$h_c \to \gamma\eta_c$	$\psi(3686) \to \pi^0 h_c$
Statistics	~200M	~10M	~1M	~2M
EM decay	M1	M1	E1	-

Measurement of $\eta_c \to \gamma\gamma$ in $J/\psi \to \gamma\eta_c$

Phys. Rev. Lett. 134, 181901 (2025)

- Using about 2.7 billion $\psi(3686)$ sample
- Measured via $\psi(3686) \to \pi^+\pi^- J/\psi$, avoid background from $e^+e^- \to \gamma_{ISR}\gamma\gamma$ with J/ψ sample
- First observation of $J/\psi \to \gamma\eta_c \to \gamma\gamma\gamma$



$$\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to \gamma\gamma) = \frac{N_{sig}}{N_{\psi(3686)} \times \epsilon_{sig} \times \mathcal{B}(\psi(3686) \to \pi^+\pi^- J/\psi)}$$

$$= (5.23 \pm 0.26 \pm 0.30) \times 10^{-6}$$

Stat. Syst.

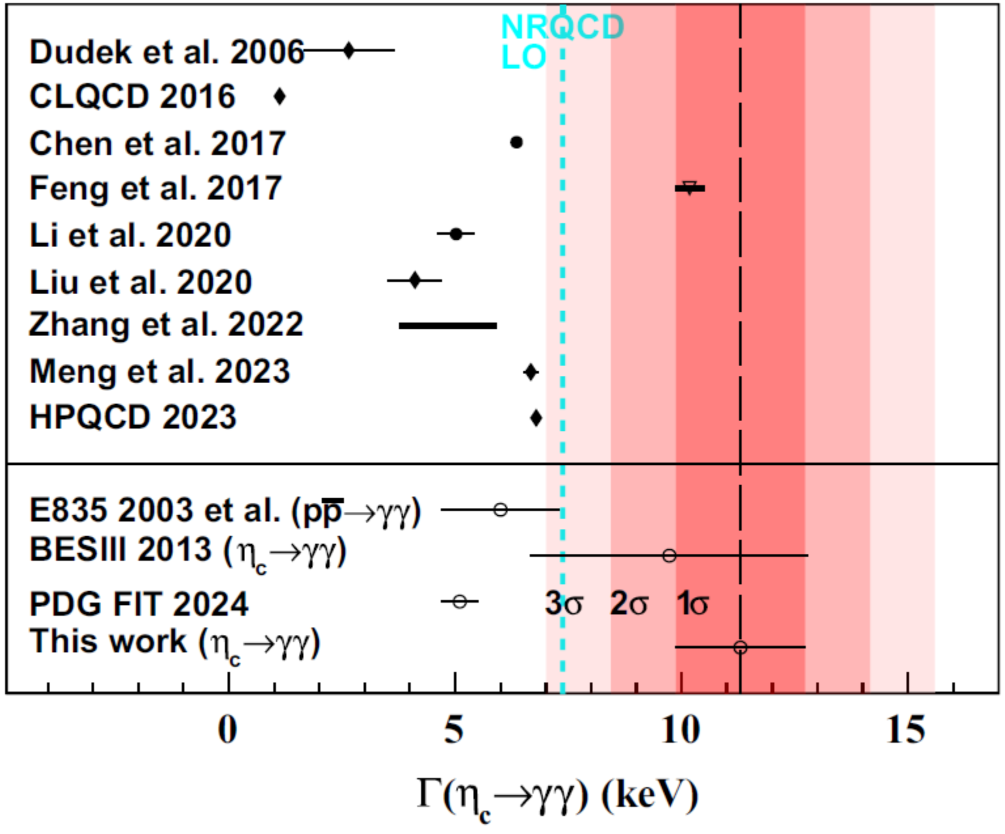
The result is consistent with the LQCD calculation $(5.34 \pm 0.16) \times 10^{-6}$ [1].

[1] Phys. Rev. D **108**, 014513 (2023)

Measurement of $\eta_c \to \gamma\gamma$ in $J/\psi \to \gamma\eta_c$

- $\Gamma(\eta_c \to \gamma\gamma) = \frac{\mathcal{B}(J/\psi\to\gamma\eta_c)\times\mathcal{B}(\eta_c\to\gamma\gamma)}{\mathcal{B}^{PDG}(J/\psi\to\gamma\eta_c)} \times \Gamma_{\eta_c}^{\mathrm{PDG}} = (11.30 \pm 0.56 \pm 0.66 \pm 1.14)$ keV

Stat. Syst. Ref.



The result is consistent with the NRQCD calculation [1], but significantly deviates from other calculations by more than 3σ.

[1] Phys. Rev. Lett. **119**, 252001 (2017)

Measurement of $\eta_c \to \gamma\gamma$ via $h_c \to \gamma\eta_c$

BESIII

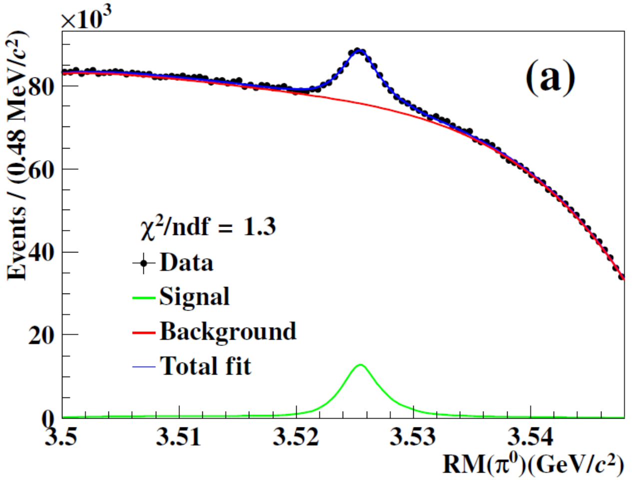
- The $\psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c$ process provides an extremely low background level and negligible interference effect environment for the measurement of η_c

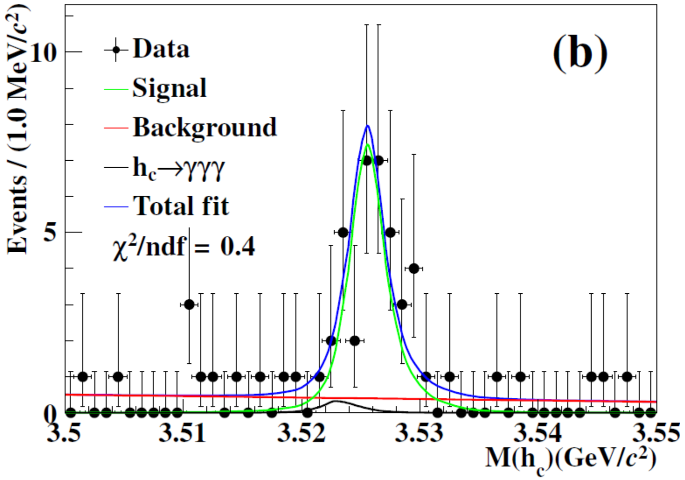
arXiv: 2601.11236
Accepted by PRL

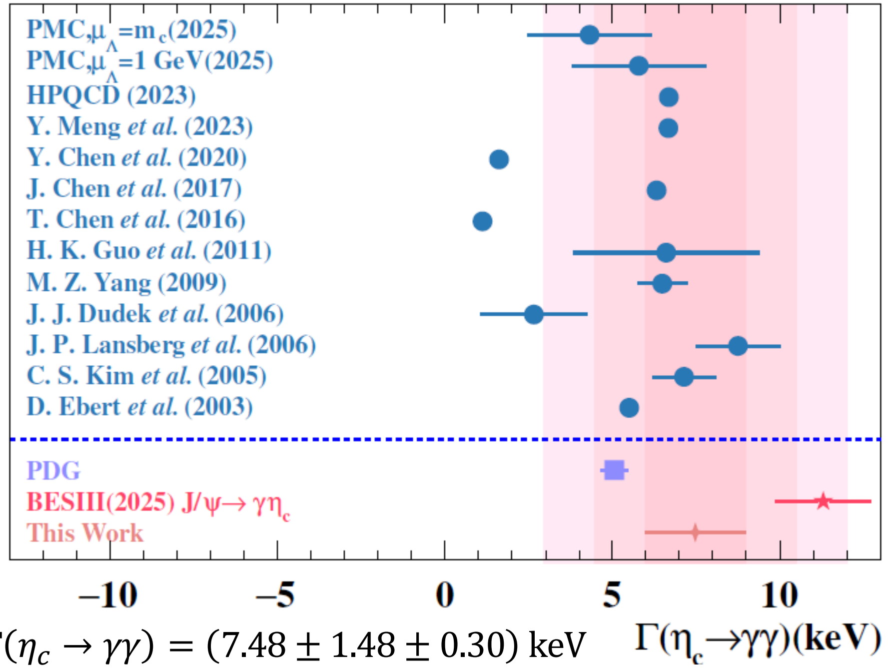
- The absolute BF of $\eta_c \to \gamma\gamma$ is measured for the first time by a tag-and-probe method:

$$\begin{cases} \text{tag side: } \psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c \text{ by reconstructing } (\pi^0\gamma)_{tag}, N_{tag} \sim 0.16\text{ M} \\ \text{signal side:} \psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c, \eta_c \to \gamma\gamma, N_{sig} = 32.5 \pm 6.4 \end{cases}$$

$$\mathcal{B}(\eta_c \to \gamma\gamma) = \frac{N^{sig}_{\eta_c}}{N^{tag}_{\eta_c}} = \frac{N^{sig}_{rec}/\varepsilon^{sig}_{rec}}{N^{tag}_{rec}/\varepsilon^{tag}_{rec}} = (2.45 \pm 0.48 \pm 0.09) \times 10^{-4}$$







$$\Gamma(\eta_c \to \gamma\gamma) = (7.48 \pm 1.48 \pm 0.30)\text{ keV}$$

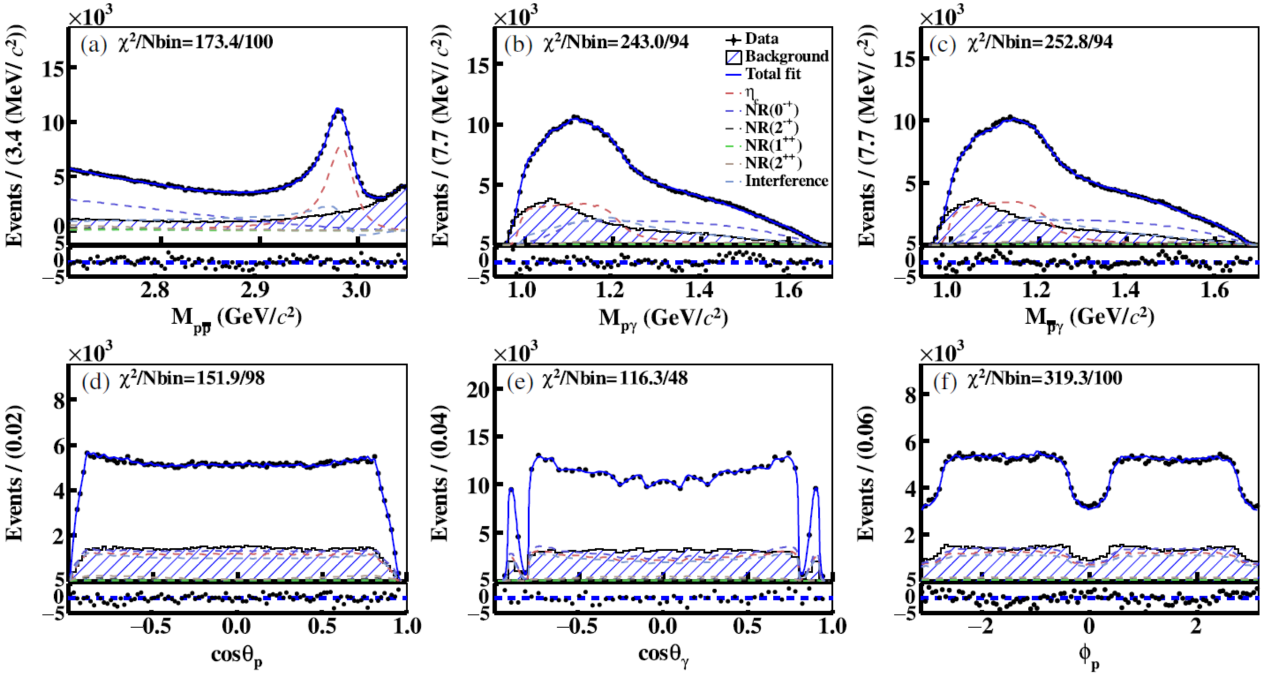
$$\frac{\Gamma(J/\psi \to e^+e^-)}{\Gamma(\eta_c \to \gamma\gamma)} = (0.74 \pm 0.15)$$

The result is consistent with most theoretical estimates and 2.5σ deviation from the previous work.

Amplitude analysis of $J/\psi \to \gamma\eta_c \to \gamma p\bar{p}$

Phys. Rev. Lett. 136, 051901 (2026)

- Using about 10 billion J/ψ sample
- Amplitude analysis of $J/\psi \to \gamma p\bar{p}$ process in the η_c mass region.
- The main background contributions come from $J/\psi \to \gamma_{FSR}p\bar{p}$ and $J/\psi \to p\bar{p}\pi^0$.



Different J^P non-resonant components can be distinguished by angular distribution information.

The interference involving η_c arises almost entirely from the 0^- NR.

$$\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to p\bar{p}) = (2.11 \pm 0.02 \pm 0.07) \times 10^{-5}$$

Amplitude analysis of $J/\psi \to \gamma\eta_c \to \gamma p\bar{p}$

- The absolute BFs of $J/\psi \to \gamma\eta_c$ and $\eta_c \to \gamma\gamma$

$\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to \gamma\gamma) = (5.23 \pm 0.26 \pm 0.30) \times 10^{-6}$

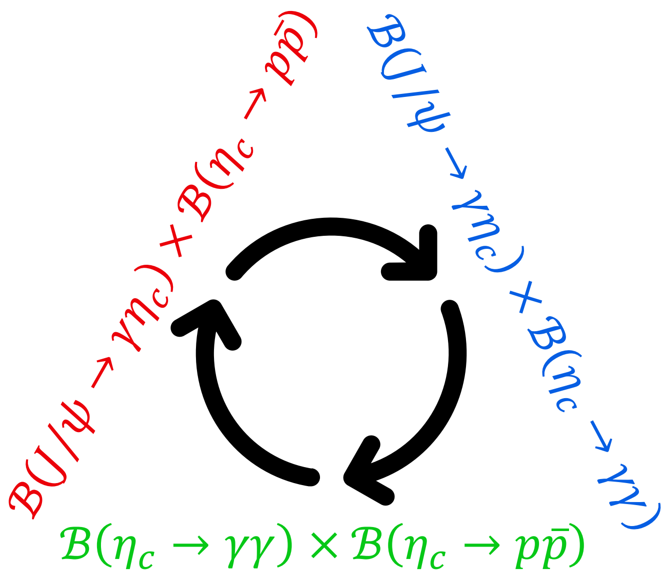
$\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to p\bar{p}) = (2.11 \pm 0.02 \pm 0.07) \times 10^{-5}$

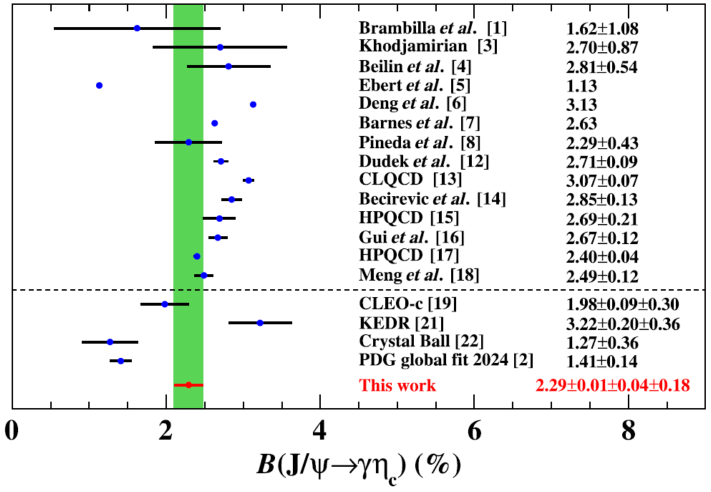
$\mathcal{B}(\eta_c \to \gamma\gamma) \times \mathcal{B}(\eta_c \to p\bar{p}) = (2.1 \pm 0.3) \times 10^{-7}$ [1-3]

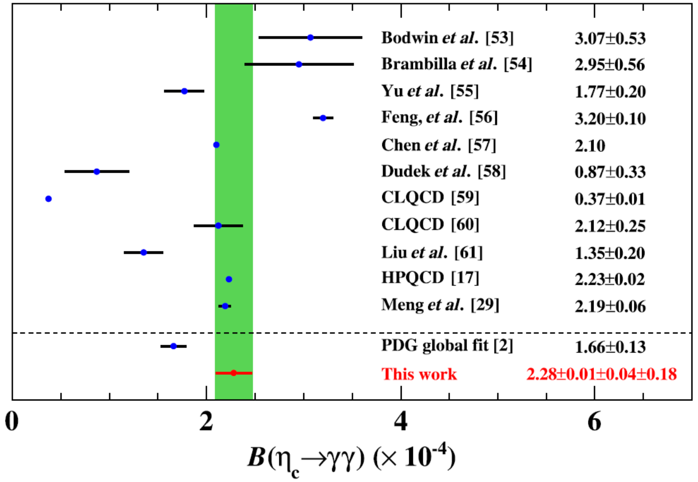
$\mathcal{B}(J/\psi \to \gamma\eta_c) = (2.29 \pm 0.19)\%$

$\mathcal{B}(\eta_c \to \gamma\gamma) = (2.28 \pm 0.19) \times 10^{-4}$

$\mathcal{B}(\eta_c \to p\bar{p}) = (0.92 \pm 0.08) \times 10^{-3}$







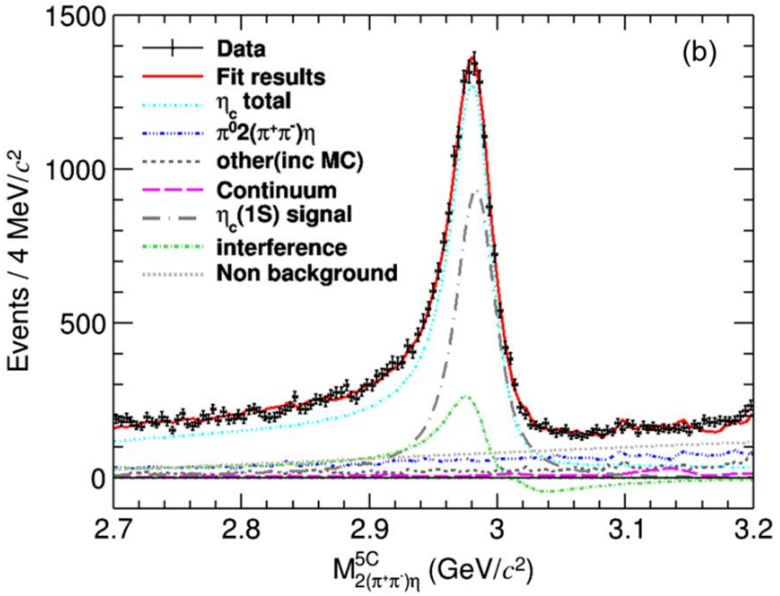
The results deviate from the PDG global fit values by 3σ, but are in good agreement with the latest LQCD calculations.

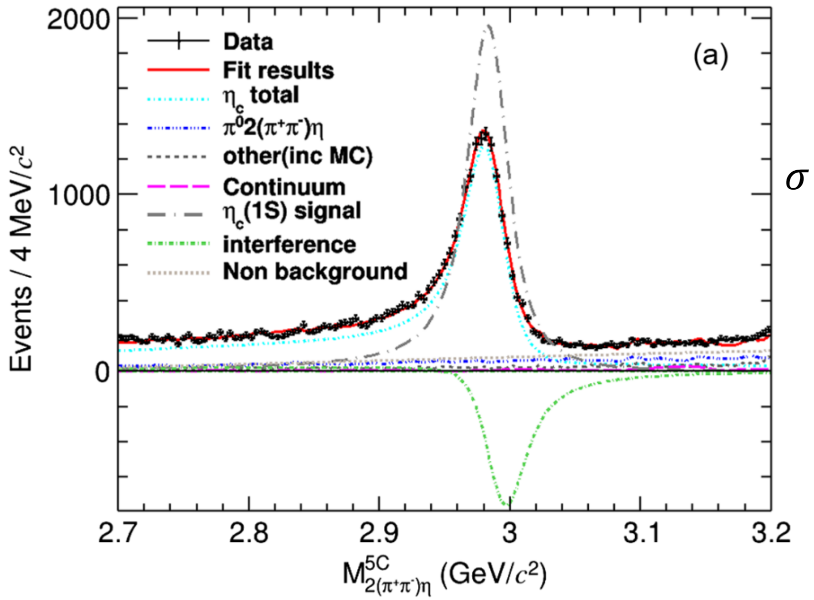
[1] Phys. Rev. D **52**, 4839 (1995)
[2] Phys. Lett. B **621**, 41 (2005)
[3] Phys. Lett. B **566**, 45 (2003)

Study of $\eta_c \to \pi^+\pi^-\pi^+\pi^-\eta$

- Measured via $\psi(3686) \to \gamma\eta_c, \eta_c \to \pi^+\pi^-\pi^+\pi^-\eta$
- Significant η_c asymmetric shape: M1 form factor (E_γ^7) and interference effects
- Two indistinguishable solutions by fully considering interference with NR: constructive and destructive.

Phys. Rev. D 111, 052013 (2025)





$$\sigma \otimes \left(\epsilon(m)\left|e^{i\phi}E_\gamma^2 BW(m) + NR\right|^2 E_\gamma^3\right) + f_{BKG}$$

$\mathcal{B}(\eta_c \to 2(\pi^+\pi^-)\eta) = (2.6 \pm 0.4 \pm 1.3)\%$

$\mathcal{B}(\eta_c \to 2(\pi^+\pi^-)\eta) = (5.5 \pm 0.5 \pm 1.9)\%$

1D fit can not distinguish J^P of NR: The uncertainty caused by fully considering interference amounts to ~40%.

Resonance parameters of η_c

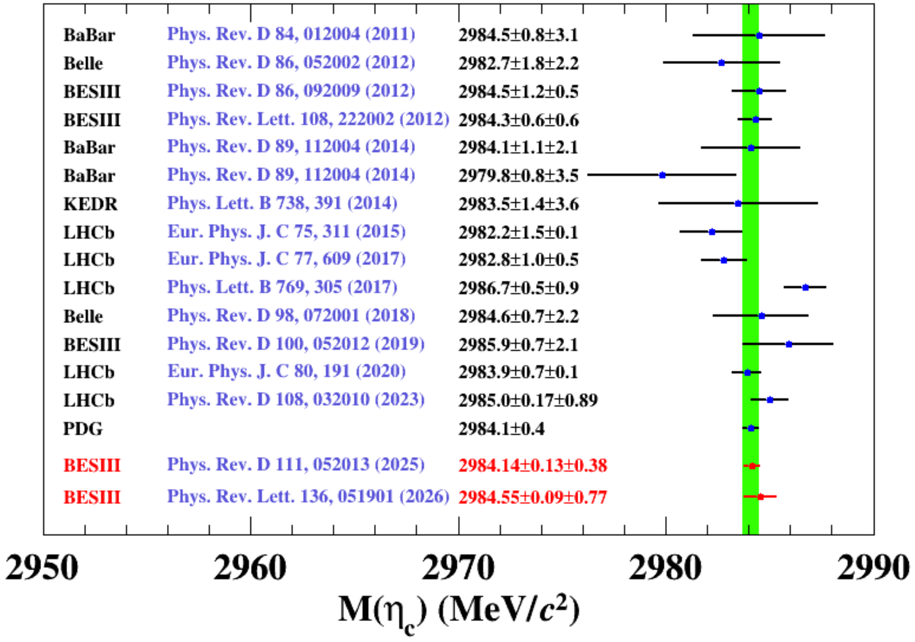
- Precise measurements of the η_c mass and width:

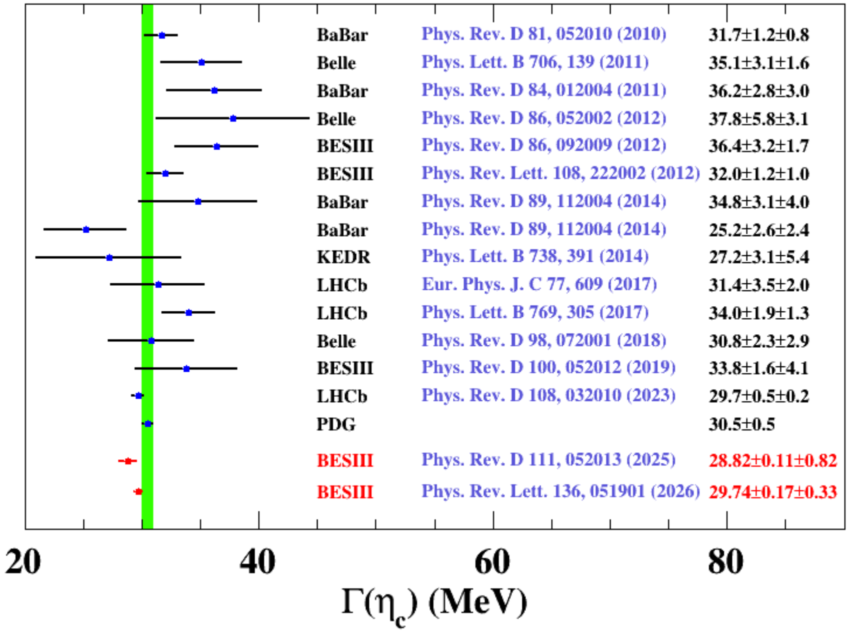
$$J/\psi \to \gamma\eta_c, \eta_c \to p\bar{p}\text{: } \mathrm{M}_1 = (2984.55 \pm 0.09 \pm 0.77)\ \mathrm{MeV}/c^2; \Gamma_1 = (29.74 \pm 0.17 \pm 0.33)\ \mathrm{MeV}$$

$$\psi(3686) \to \gamma\eta_c, \eta_c \to 2(\pi^+\pi^-)\eta\text{: } \mathrm{M}_2 = (2984.14 \pm 0.13 \pm 0.38)\ \mathrm{MeV}/c^2; \Gamma_2 = (28.82 \pm 0.11 \pm 0.82)\ \mathrm{MeV}$$

$$\begin{cases} \mathrm{M}_{J/\psi} - \mathrm{M}_1 = 112.4 \pm 0.8\ \mathrm{MeV}/c^2 \\ \mathrm{M}_{J/\psi} - \mathrm{M}_2 = 112.8 \pm 0.4\ \mathrm{MeV}/c^2 \end{cases}$$

The results are consistent with LQCD predictions [1,2].





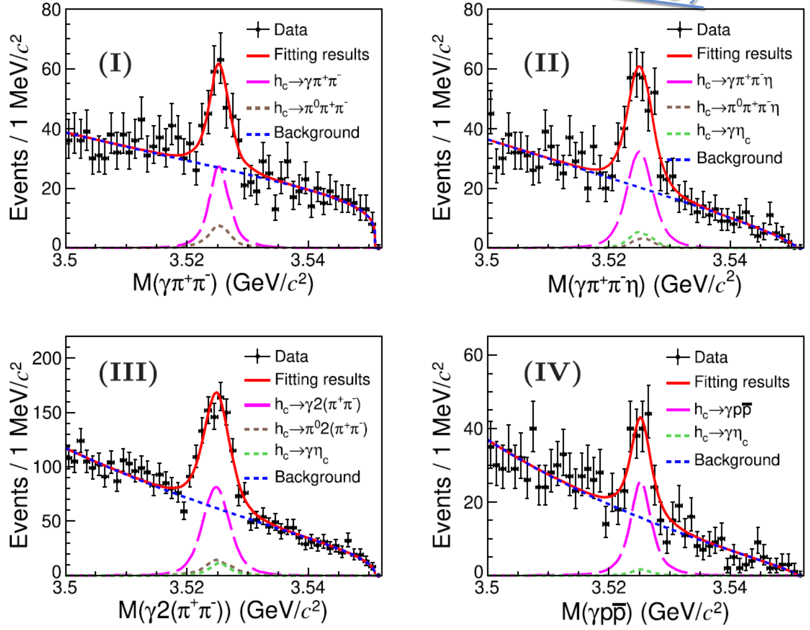
[1] Phys. Rev. D **81**, 034508 (2010)

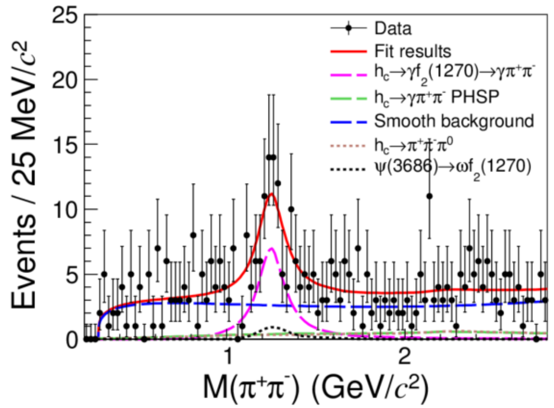
[2] Phys. Rev. D **85**, 091503 (2012)

Measurements of h_c radiative decays

- Observation of four h_c radiative decays to multiple light hadrons decay modes for the first time.
- The total measurement branching fraction[~0.8%] are significantly lower than the predicted value 5.5% of $\mathcal{B}(h_c \to \gamma + 2g)$[1].
- The branching fraction of $h_c \to \gamma f_2(1270) \to \gamma\pi^+\pi^-$ is an order of magnitude smaller than that in J/ψ decay[2].
- This measurement could be employed to investigate the quark and glueball mixing parameters of $f_2(1270)$[3].

PRL 134, 241902 (2025)





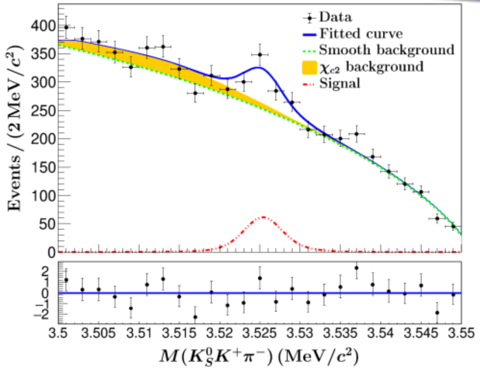
Decay mode	Branching fraction	Significance
$h_c \to \gamma\pi^+\pi^-$	$(3.06 \pm 0.54 \pm 0.37 \pm 0.21) \times 10^{-4}$	5.4σ
$h_c \to \gamma\pi^+\pi^-\eta$	$(3.52 \pm 0.50 \pm 0.30 \pm 0.24) \times 10^{-3}$	7.5σ
$h_c \to \gamma 2(\pi^+\pi^-)$	$(2.19 \pm 0.20 \pm 0.16 \pm 0.15) \times 10^{-3}$	11.8σ
$h_c \to \gamma p\bar{p}$	$(3.34 \pm 0.53 \pm 0.33 \pm 0.23) \times 10^{-3}$	6.4σ
$h_c \to \gamma f_2(1270) \to \gamma\pi^+\pi^-$	$(1.81 \pm 0.35 \pm 0.19 \pm 0.12) \times 10^{-3}$	5.1σ

[1] Phys. Rev. D 66, 014012 (2002).
[2] Phys. Rev. D 91, 052006 (2015).
[3] Phys. Rev. D 40, 1517 (1989).

Measurements of $h_c \to hadrons$

- Evidence for $h_c \to K_S^0 K^+\pi^- + c.c.$ is found with a significance of 4.3σ.
  $\mathcal{B}(h_c \to K_S^0 K^+\pi^- + c.c.) = (7.3 \pm 1.8 \pm 0.8) \times 10^{-4}$

Phys. Rev. D 110, 012007 (2024)



Item	Value (%)	Source
$\mathcal{B}(h_c \to K\bar{K}\pi)$	1.4 ± 0.9	pQCD [4]
$\mathcal{B}(h_c \to K\bar{K}\pi)$	5.5 ± 3.3	NRQCD [4]
$\mathcal{B}(h_c \to K\bar{K}\pi)$	0.22 ± 0.06	This work
$\Gamma(h_c \to 3g)/\Gamma(\eta_c \to 2g)$	1.0 ± 0.1	pQCD [4]
$\Gamma(h_c \to 3g)/\Gamma(\eta_c \to 2g)$	8.3 ± 1.8	NRQCD [4]
$\Gamma(h_c \to 3g)/\Gamma(\eta_c \to 2g)$	0.93 ± 0.54	Refs. [7,33]
$\Gamma(h_c \to K\bar{K}\pi)/\Gamma(\eta_c \to K\bar{K}\pi)$	0.069 ± 0.062	This work

1.3σ*

1.6σ*

*Only the leading-order terms are evaluated in the theoretical calculations from both pQCD and NRQCD.

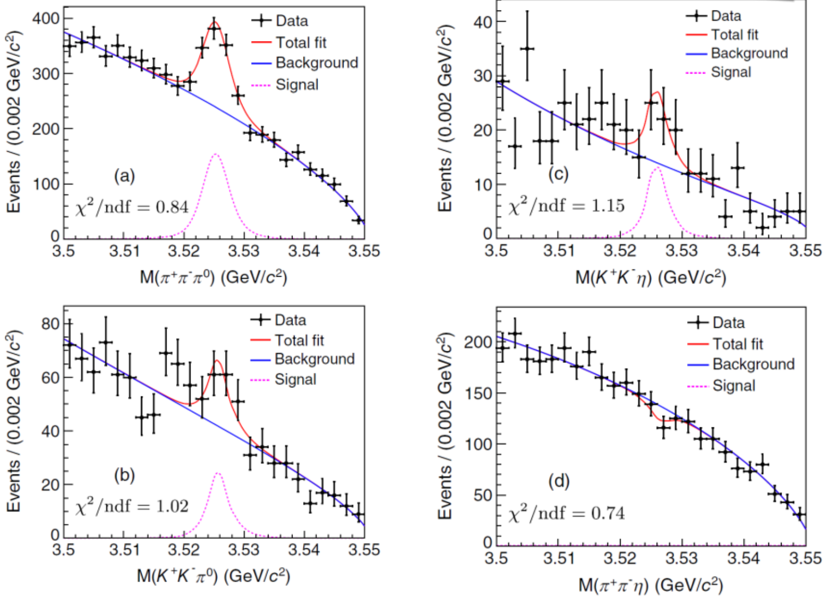
[4] Phys. Rev. D **65**, 094024 (2002).

- First observation of $h_c \to \pi^+\pi^-\pi^0$ and evidence for $h_c \to K^+K^-\pi^0$ and $h_c \to K^+K^-\eta$ via $\psi(3686) \to \pi^0 h_c$

$$\begin{cases} \mathcal{B}(h_c \to \pi^+\pi^-\pi^0) = (1.36 \pm 0.16 \pm 0.14) \times 10^{-3} & (9.6\sigma) \\ \mathcal{B}(h_c \to K^+K^-\pi^0) = (3.26 \pm 0.84 \pm 0.36) \times 10^{-4} & (3.5\sigma) \\ \mathcal{B}(h_c \to K^+K^-\eta) = (3.13 \pm 1.08 \pm 0a.38) \times 10^{-4} & (3.3\sigma) \\ \mathcal{B}(h_c \to \pi^+\pi^-\eta) < 4.0 \times 10^{-4} \text{ at the 90\% C.L.} & \end{cases}$$

- Based on isospin conservation, $\mathcal{B}(h_c \to K\bar{K}\pi) = (0.20 \pm 0.05)\%$, consistent with previous measurement.

Phys. Rev. D 110, 032023 (2024)

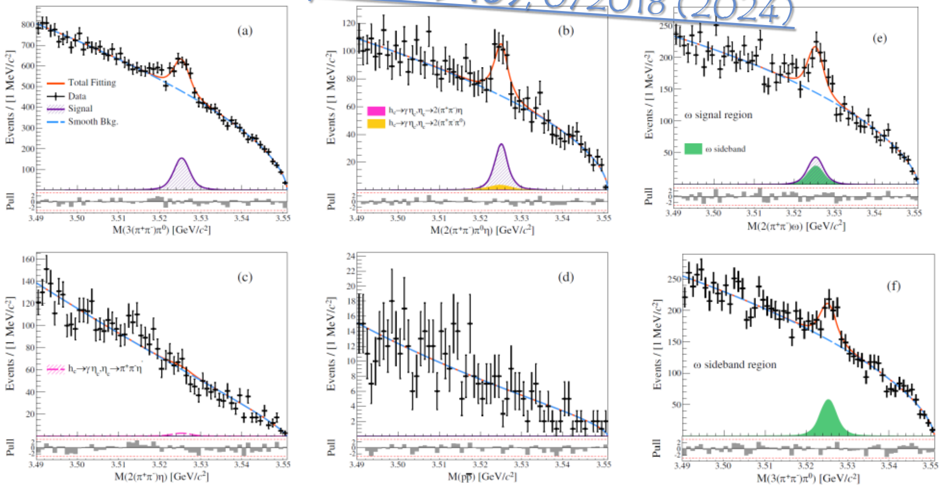


Measurements of $h_c \to hadrons$

- First observation of $h_c \to 3(\pi^+\pi^-)\pi^0$ and evidence for $h_c \to 2(\pi^+\pi^-)\pi^0\eta$ and $h_c \to 2(\pi^+\pi^-)\omega$ via $\psi(3686) \to \pi^0 h_c$

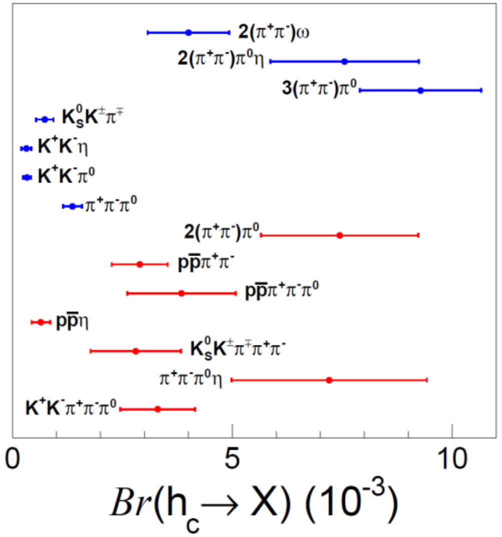
Phys. Rev. D 109, 072018 (2024)

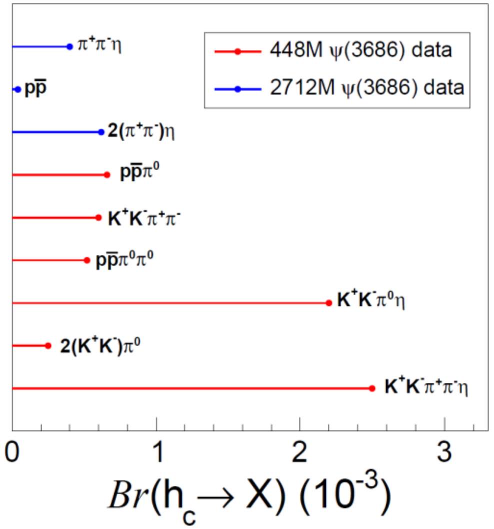
Decay mode	Branching fraction	Significance
$h_c \to 3(\pi^+\pi^-)\pi^0$	$(9.28 \pm 1.14 \pm 0.77) \times 10^{-3}$	$> 5\sigma$
$h_c \to 2(\pi^+\pi^-)\pi^0\eta$	$(7.55 \pm 1.51 \pm 0.77) \times 10^{-3}$	4.8σ
$h_c \to 2(\pi^+\pi^-)\omega$	$(4.00 \pm 0.86 \pm 0.35) \times 10^{-3}$	4.7σ



- The limit of $\mathcal{B}(h_c \to p\bar{p}) < 4.4 \times 10^{-5}$ is a factor of 100 lower than the predictions found in Refs. [1, 2], which indicates the need for improved theoretical calculations as well as more sensitive measurements.

[1] J. Phys. G **38**, 035007 (2011).
[2] Phys. Rev. D **88**, 034011 (2012).





Summary

BESIII has achieved significant progress in the study of η_c/h_cdecay:

- The absolute BFs of $J/\psi \to \gamma\eta_c$ and $\eta_c \to \gamma\gamma$ can be determined with uncertainties < 10%.
- The absolute BF of $\eta_c \to \gamma\gamma$ is firstly measured via $\psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c$, and consistent with most theoretical estimates.
- The first observation for unknow η_c/h_c decay modes are reported, which are important to test the QCD theory, and more measurements will be presented.
- The radiative decay modes of h_c to multiple light hadrons provide a potential avenue for the search of exotic particles.
- The BESIII detector has completed a new round of data taking on $\psi(3686)$ (~1.37 fb^{-1} (online)), and BESIII experiment will provide a more powerful platform for future studies of η_c/h_c.

Thanks for your attention!

BAK UP

Measurements of $\eta_c \to B\bar{B}/VV$

- First observation of $\eta_c \to \Xi^0\bar{\Xi}^0$ via $J/\psi \to \gamma\eta_c$

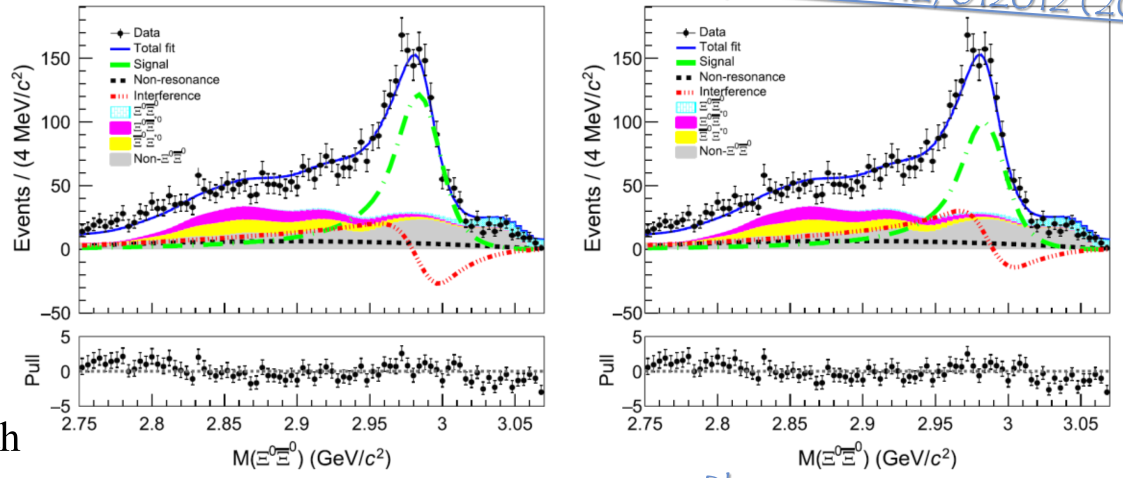
  Two indistinguishable solutions by 1D fit.

$$\begin{cases} \mathcal{B}(\eta_c \to \Xi^0\bar{\Xi}^0)_{des} = (1.63 \pm 0.22) \times 10^{-3} \\ \mathcal{B}(\eta_c \to \Xi^0\bar{\Xi}^0)_{con} = (1.33 \pm 0.20) \times 10^{-3} \end{cases}$$

Compatible with IML model [1]
Larger than the quark-diquark model [2]

$\frac{\mathcal{B}(\eta_c \to \Xi^0\bar{\Xi}^0)}{\mathcal{B}(\eta_c \to \Xi^-\bar{\Xi}^+)}$ is consistent within 2σ with isospin symmetry expectations [3]

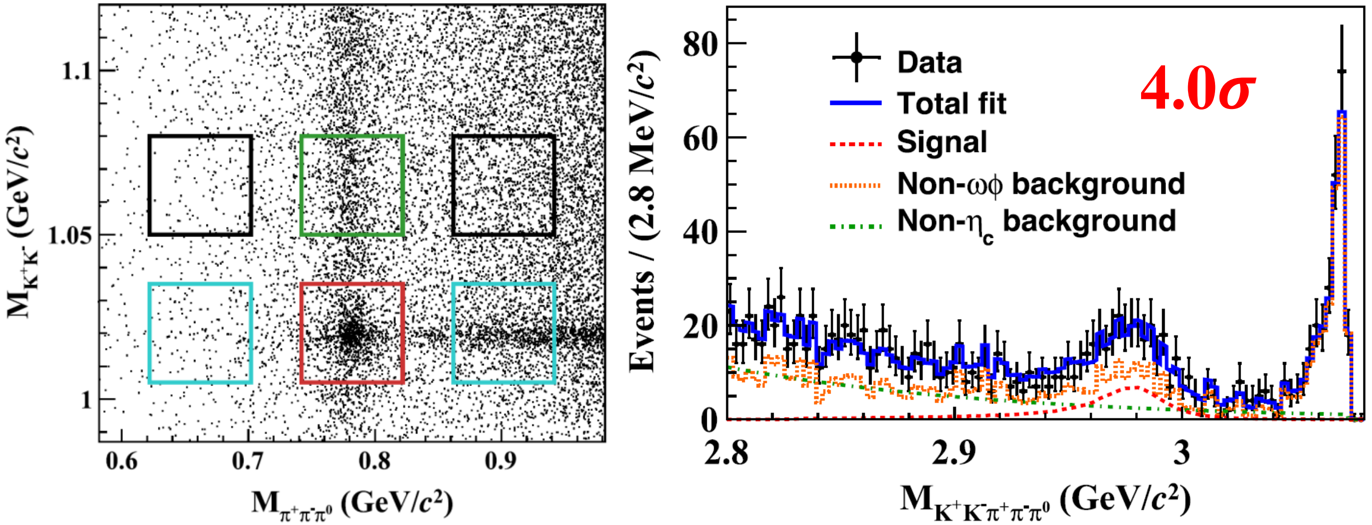
Phys. Rev. D 112, 012012 (2025)



- First evidence for the doubly OZI-suppressed decay $\eta_c \to \omega\phi$ via $J/\psi \to \gamma\eta_c$

$$\mathcal{B}(\eta_c \to \omega\phi) = (3.86 \pm 0.92 \pm 0.62) \times 10^{-5}$$

Phys. Rev. D 113, 072003 (2026)



[1] J. Phys. G **38**, 035007 (2011)
[2] Phys. Rev. D **38**, 3516 (1988)
[3] Phys. Rev. D **87**, 012003 (2013)

Search for $h_c \to \pi^+\pi^- J/\psi$

Phys. Rev. D **110**, 112010 (2024)

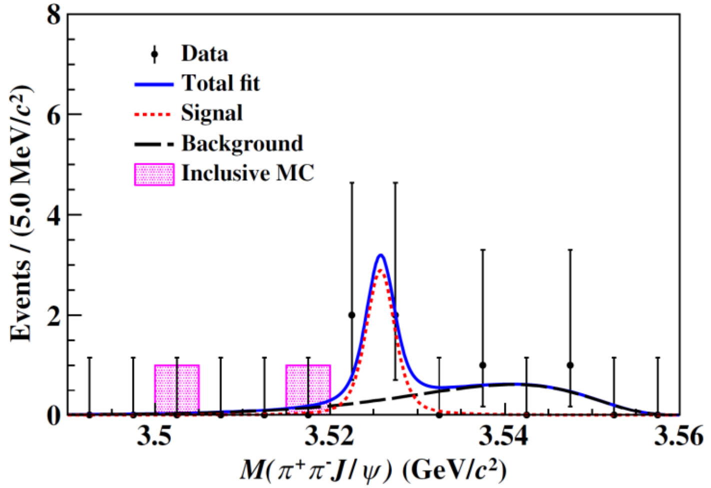
- Search for $h_c \to \pi^+\pi^- J/\psi$ via $\psi(3686) \to \pi^0 h_c$, no significant signal is observed.

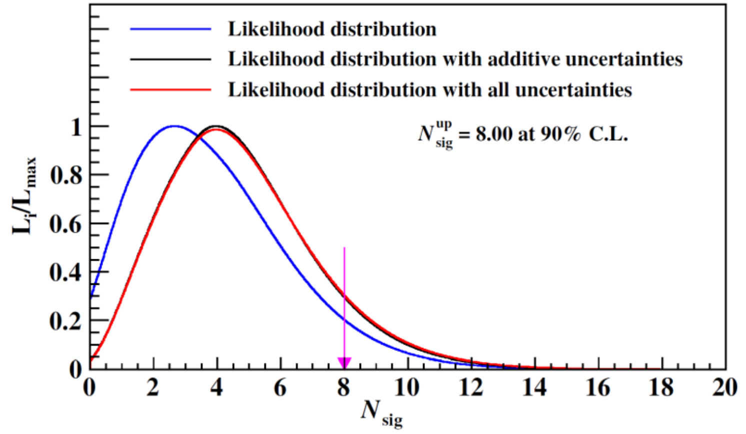
$$\begin{cases} \mathcal{B}(\psi(3686) \to \pi^0 h_c) \cdot \mathcal{B}(h_c \to \pi^+\pi^- J/\psi) < 6.7 \times 10^{-7} \text{ at the 90\% C. L} \\ \mathcal{B}(h_c \to \pi^+\pi^- J/\psi) < 9.4 \times 10^{-4} \text{ at the 90\% C. L.} \end{cases}$$

- This result is above the predicted upper limit of $\mathcal{B}(h_c \to \pi^+\pi^- J/\psi)$ of 1.2×10^{-5} in Ref[1].

- $\mathcal{B}(h_c \to \pi\pi J/\psi) < 1.41 \times 10^{-3}$ (neglecting the small difference between phase space for charged and neutral $\pi\pi$ modes).

- The result is an order of magnitude smaller than the BF predicted by Kuang et al. (about 2%) [2], and closer to the prediction calculated by Pyungwon Ko (0.05%) [3].





[1] Phys. Rev. D **86**, 074033 (2012).
[2] Phys. Rev. D **37**, 1210 (1988).
[3] Phys. Rev. D **52**, 1719 (1995).

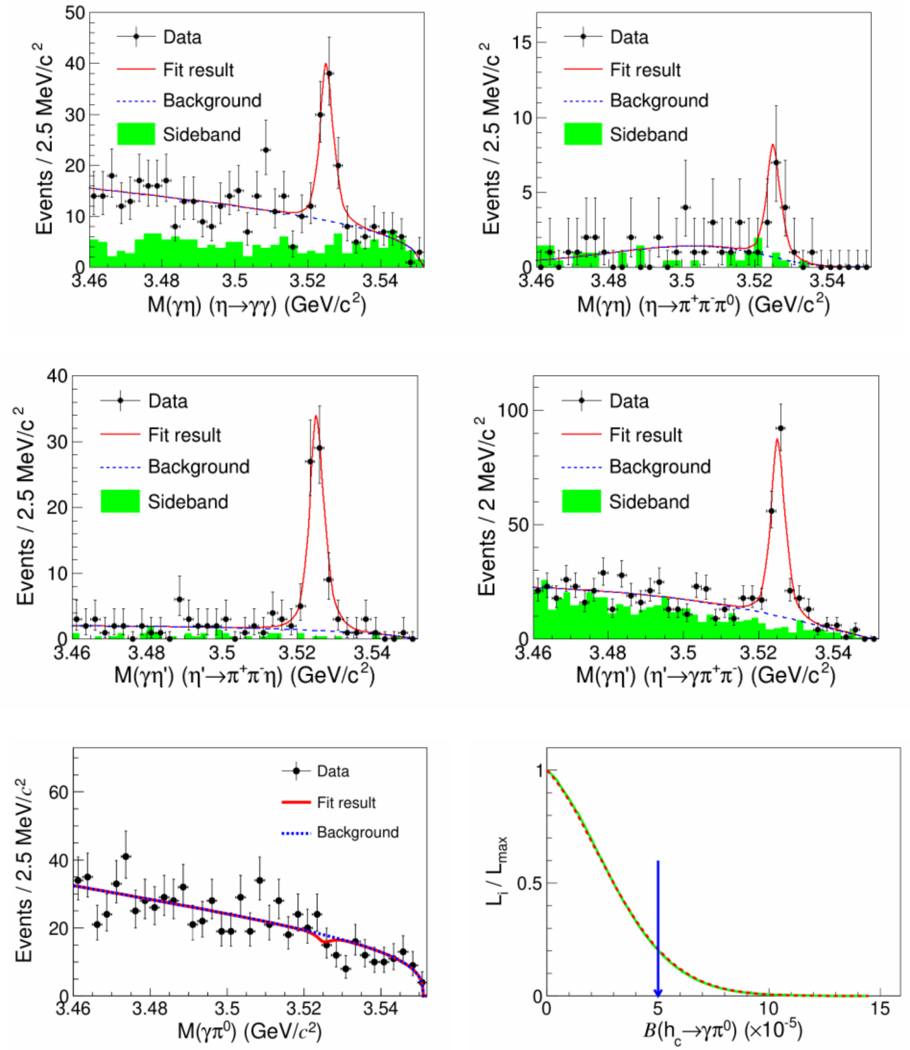
Measurements of h_c radiative decays

JHEP 08, (2024) 180

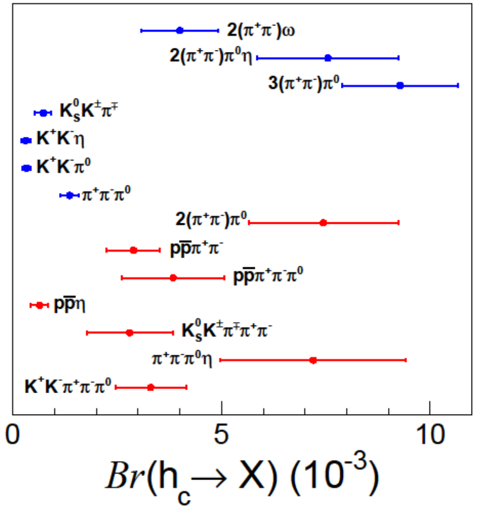
- First observation of $h_c \to \gamma\eta$ with a significance of 9.0σ.
- A measurement of $\mathcal{B}(h_c \to \gamma\eta')$ is obtained with the improved precision by more than a factor of two.
- No significant $h_c \to \gamma\pi^0$ signal is found, $\mathcal{B}(h_c \to \gamma\pi^0) < 5.0 \times 10^{-5}$ at the 90% C.L.

	$\mathcal{B}(h_c \to \gamma\eta')(\times 10^{-3})$	$\mathcal{B}(h_c \to \gamma\eta)(\times 10^{-4})$	$\mathcal{B}(h_c \to \gamma\eta)/\mathcal{B}(h_c \to \gamma\eta')$ (%)
This work	$1.40 \pm 0.11 \pm 0.04 \pm 0.10$	$3.77 \pm 0.55 \pm 0.13 \pm 0.26$	$27.0 \pm 4.4 \pm 1.0$
BESIII[1]	$1.52 \pm 0.27 \pm 0.29$	$4.7 \pm 1.5 \pm 1.4$	$30.7 \pm 11.3 \pm 8.7$

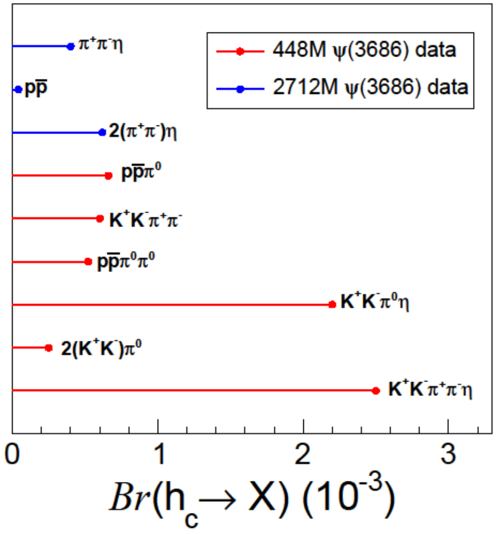
- Our result prefers the prediction in Ref.[1], which indicates the contributions from both the quark-antiquark content and the gluonic content are at the same level in $\eta(')$.
- The improved measurements can be used to test the SU(3)-flavor symmetries in QCD theory[2].



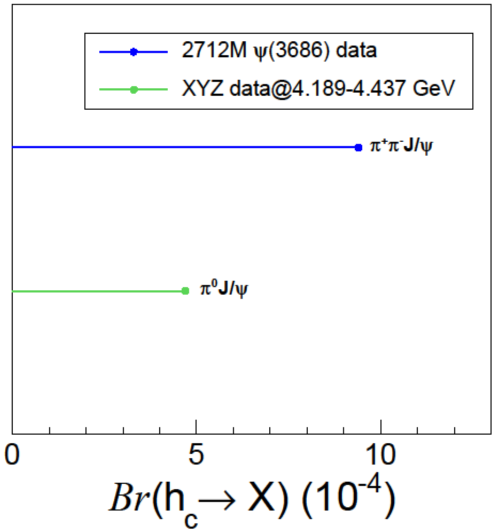
[1] Phys. Rev. Lett. 116, 251802 (2016).
[2] Phys. Rev. D 103, 114006 (2021).
[3] Phys. Rev. D 36, 2761 (1987); Int. J. Mod. Phys. A 15, 159 (2000); Phys. Lett. B 807, 135534 (2020).



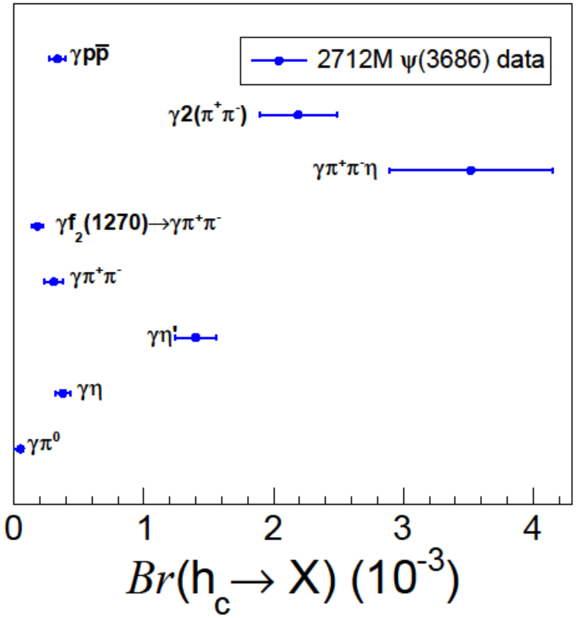
$2(\pi^+\pi^-)\omega$
$2(\pi^+\pi^-)\pi^0\eta$
$3(\pi^+\pi^-)\pi^0$
$K_S^0K^\pm\pi^\mp$
$K^+K^-\eta$
$K^+K^-\pi^0$
$\pi^+\pi^-\pi^0$
$2(\pi^+\pi^-)\pi^0$
$p\bar{p}\pi^+\pi^-$
$p\bar{p}\pi^+\pi^-\pi^0$
$p\bar{p}\eta$
$K_S^0K^\pm\pi^\mp\pi^+\pi^-$
$\pi^+\pi^-\pi^0\eta$
$K^+K^-\pi^+\pi^-\pi^0$
0 5 10
$Br(h_c\to X)\ (10^{-3})$



448M $\psi(3686)$ data
2712M $\psi(3686)$ data
$\pi^+\pi^-\eta$
$p\bar{p}$
$2(\pi^+\pi^-)\eta$
$p\bar{p}\pi^0$
$K^+K^-\pi^+\pi^-$
$p\bar{p}\pi^0\pi^0$
$K^+K^-\pi^0\eta$
$2(K^+K^-)\pi^0$
$K^+K^-\pi^+\pi^-\eta$
0 1 2 3
$Br(h_c\to X)\ (10^{-3})$



2712M $\psi(3686)$ data
XYZ data@4.189-4.437 GeV
$\pi^+\pi^-J/\psi$
π^0J/ψ
0 5 10
$Br(h_c\to X)\ (10^{-4})$



2712M $\psi(3686)$ data
$\gamma p\bar{p}$
$\gamma 2(\pi^+\pi^-)$
$\gamma\pi^+\pi^-\eta$
$\gamma f_2(1270)\to\gamma\pi^+\pi^-$
$\gamma\pi^+\pi^-$
$\gamma\eta'$
$\gamma\eta$
$\gamma\pi^0$
0 1 2 3 4
$Br(h_c\to X)\ (10^{-3})$