Recent Progresses on η_c Decays at BESIII

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(On behalf of the BESIII Collaboration)

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Outline

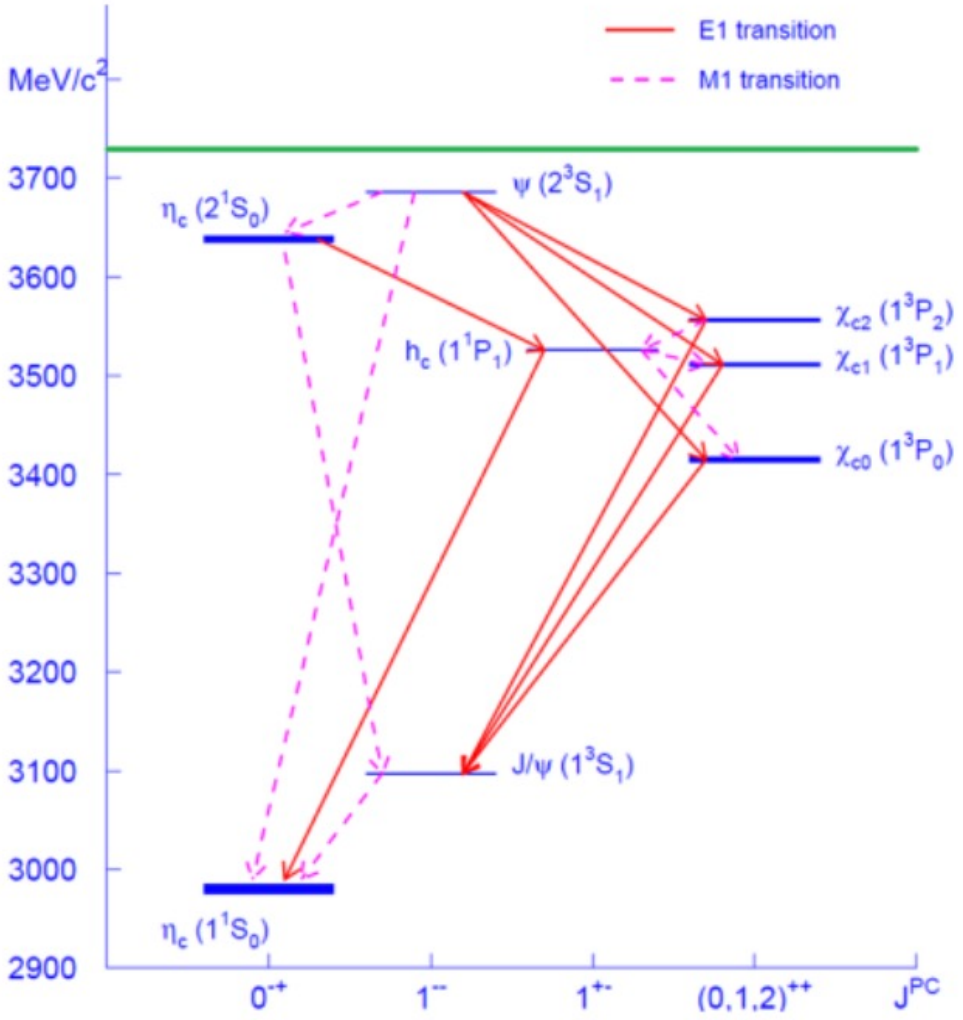
Introduction

Summary

Recent measurements on η_c decay

- Measurement of $\eta_c \to \gamma\gamma$ in $J/\psi \to \gamma\eta_c$
- Amplitude analysis of $J/\psi \to \gamma\eta_c \to \gamma p\bar{p}$
- Measurement of $\eta_c \to \gamma\gamma$ via $h_c \to \gamma\eta_c$
- Measurement of $\eta_c \to 2(\pi^+\pi^-)\eta$ in $\psi(3686) \to \gamma\eta_c$
- Measurement of $\eta_c \to B\bar{B}/VV$

Introduction



- The lowest-lying charmonium state

  Friendly for theoretical studies: Lattice QCD, effective field theories, QCD sum rules, non-relativistic potential models…

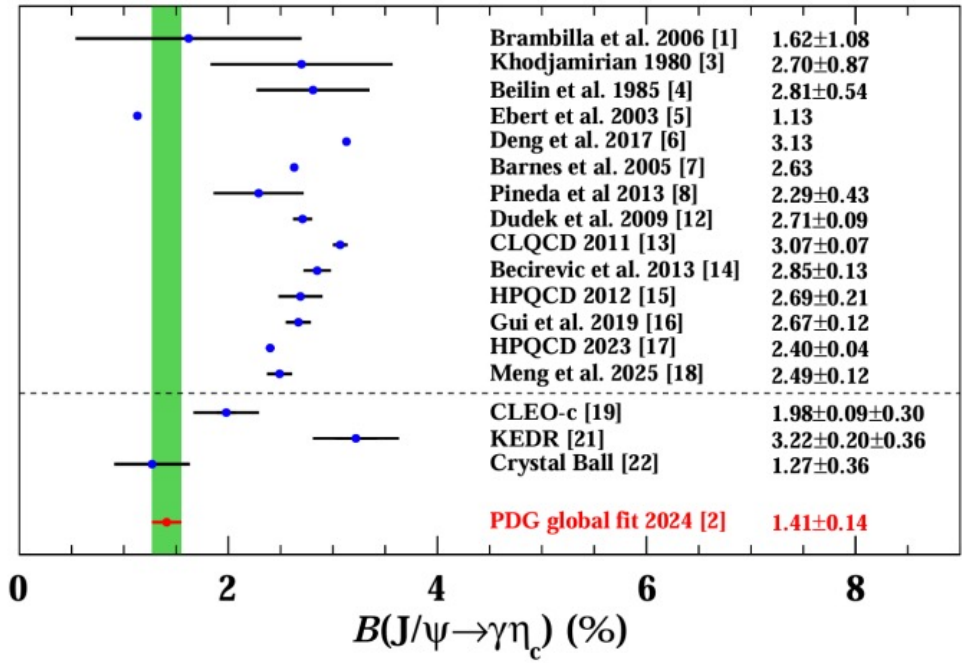
- Several interesting observables

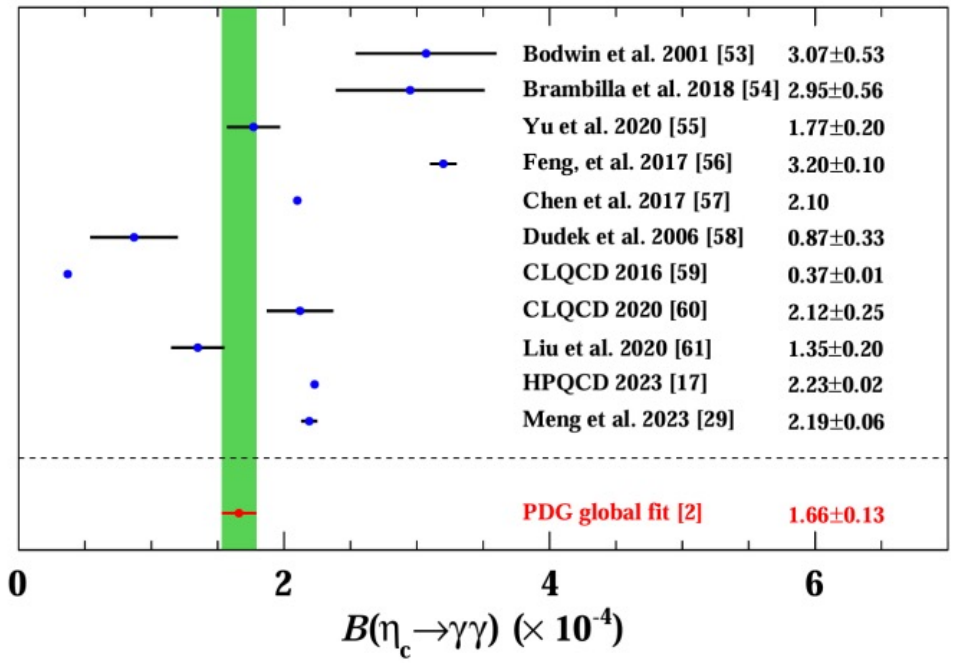
  Radiative transition $J/\psi \to \gamma\eta_c$, two photon decay $\eta_c \to \gamma\gamma$ and hyperfine mass splitting between J/ψ and η_c, serve as a unique window to the inner structure of charmonium

Introduction

➢ Puzzle on the decay rates

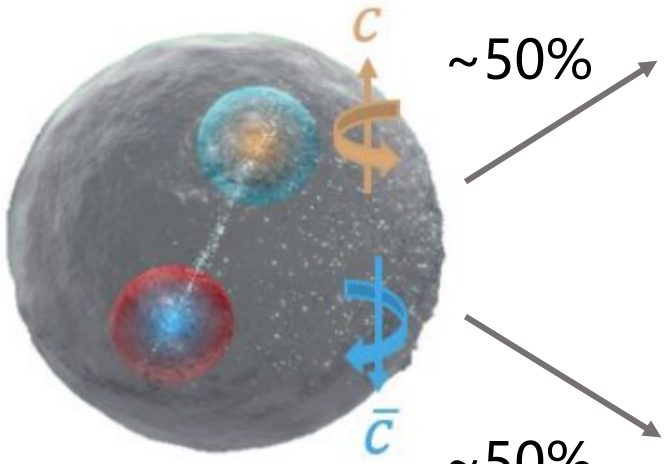
Significant discrepancy between **PDG global fit** and **theoretical calculations**





Introduction

➢ Unknown decay modes



Γ_{37}	$K\bar{K}\pi$	$(5.9 \pm 0.5)\ \%$
Γ_{38}	$K\bar{K}\eta$	$(1.11 \pm 0.15)\ \%$
Γ_{39}	$\eta\pi^+\pi^-$	$(1.5 \pm 0.4)\ \%$
Γ_{40}	$\eta 2(\pi^+\pi^-)$	$(4.0 \pm 1.2)\ \%$
Γ_{41}	$K^+K^-\pi^+\pi^-$	$(6.7 \pm 1.8) \times 10^{-3}$
Γ_{42}	$K^+K^-\pi^+\pi^-\pi^0$	$(2.8 \pm 0.5)\ \%$
Γ_{43}	$K^0K^-\pi^+\pi^-\pi^+$ + c.c.	$(5.1 \pm 1.4)\ \%$
Γ_{44}	$K^+K^-2(\pi^+\pi^-)$	$(6.9 \pm 2.0) \times 10^{-3}$
Γ_{45}	$2(K^+K^-)$	$(1.2 \pm 0.4) \times 10^{-3}$

- ~50% of η_c decay modes remain unobserved
- Most of the measured BFs suffer from large uncertainties
- Almost all measurements neglect the interference effect

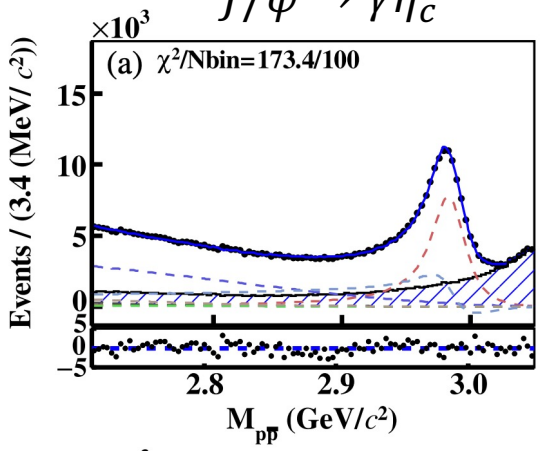
Introduction

➢ η_c measurement at BESIII

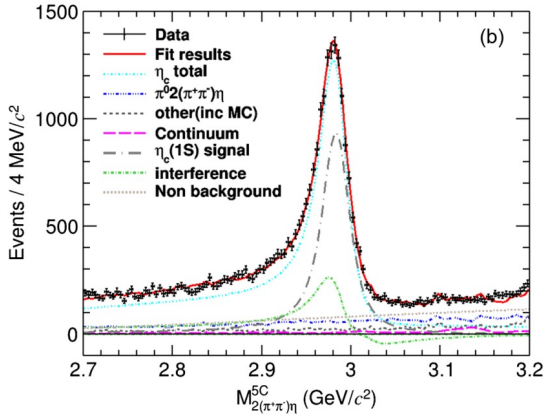
At BESIII, the η_c is mainly produced in radiative transitions

Productions	$J/\psi \to \gamma\eta_c$	$\psi(3686) \to \gamma\eta_c$	$h_c \to \gamma\eta_c$
Statistics	$\sim 2\times10^8$	$\sim 1\times10^7$	$\sim 1\times10^6$
Interference	✓	✓	×
Electromagnetic decay	M1	M1	E1
Background level	High	Medium	Low

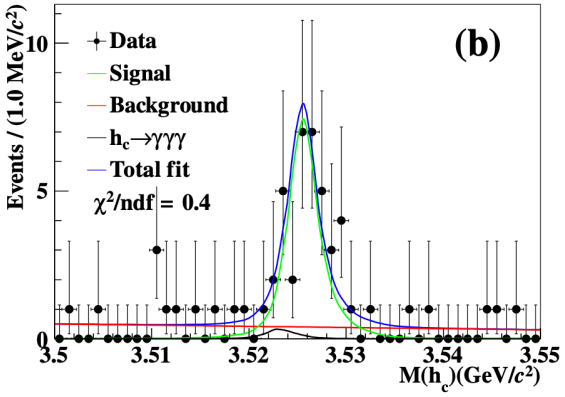
$J/\psi \to \gamma\eta_c$



$\psi(3686) \to \gamma\eta_c$



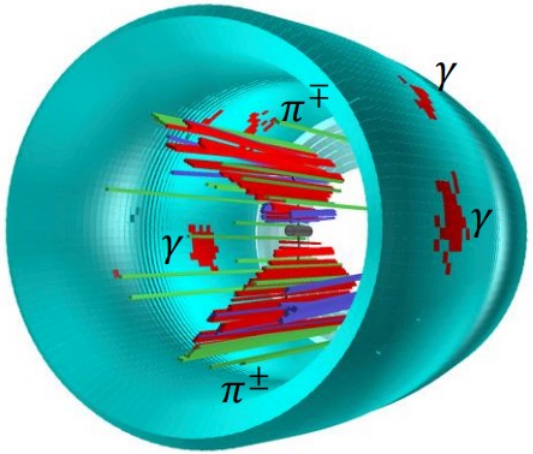
$h_c \to \gamma\eta_c$

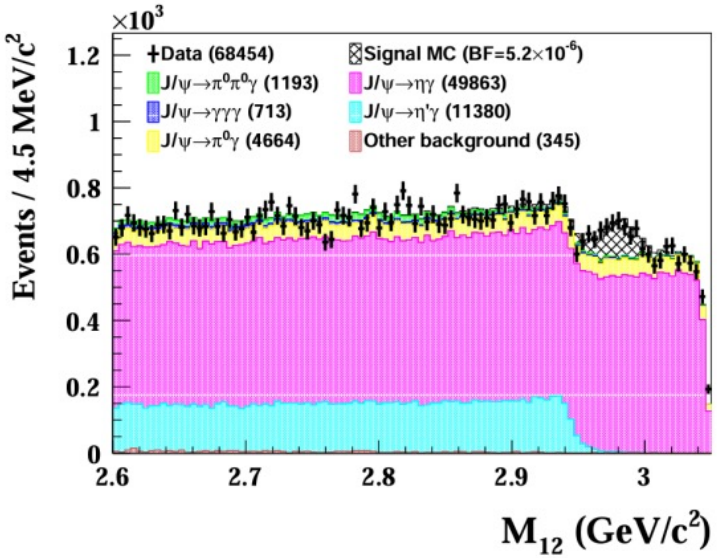


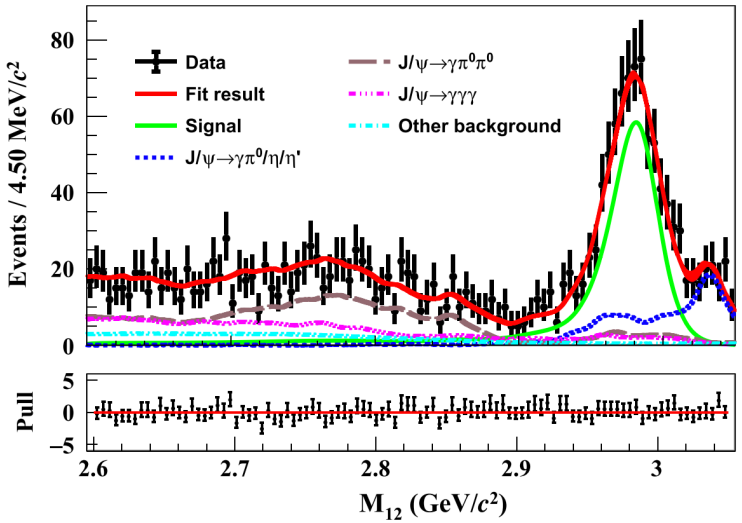
Measurement of $\eta_c \to \gamma\gamma$ in $J/\psi \to \gamma\eta_c$

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

- Using 2.7 billion $\psi(3686)$ sample
- Measured via $\psi(3686) \to \pi^+\pi^- J/\psi$, avoid background from $e^+e^- \to \gamma_{ISR}\gamma\gamma$ in J/ψ sample
- Background from $J/\psi \to \gamma(P = \eta', \eta, \pi^0)$ and $J/\psi \to \gamma\pi^0\pi^0$
- Some non-resonant $J/\psi \to \gamma\gamma\gamma$ observed, but no significant interference with η_c
- First observation of $J/\psi \to \gamma\eta_c, \eta_c \to \gamma\gamma, B(J/\psi \to \gamma\eta_c) \times B(\eta_c \to \gamma\gamma) = (5.23 \pm 0.26 \pm 0.30) \times 10^{-6}$

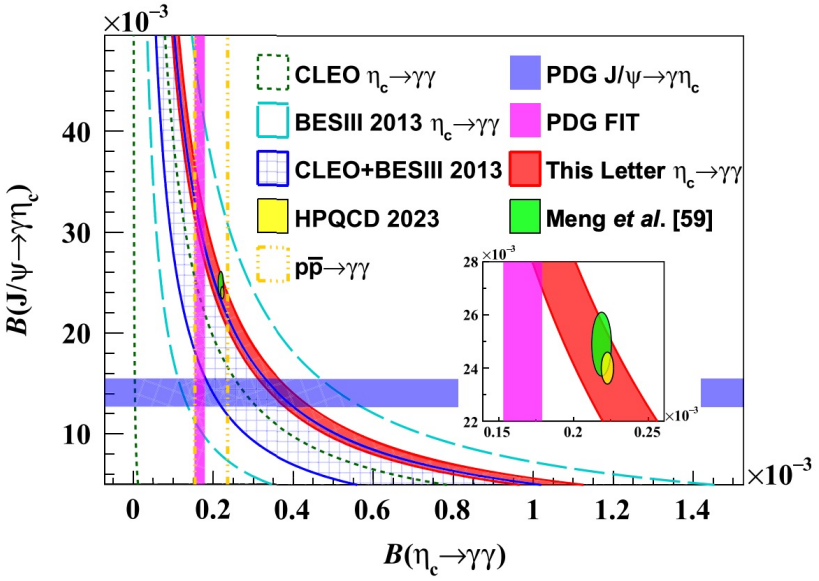


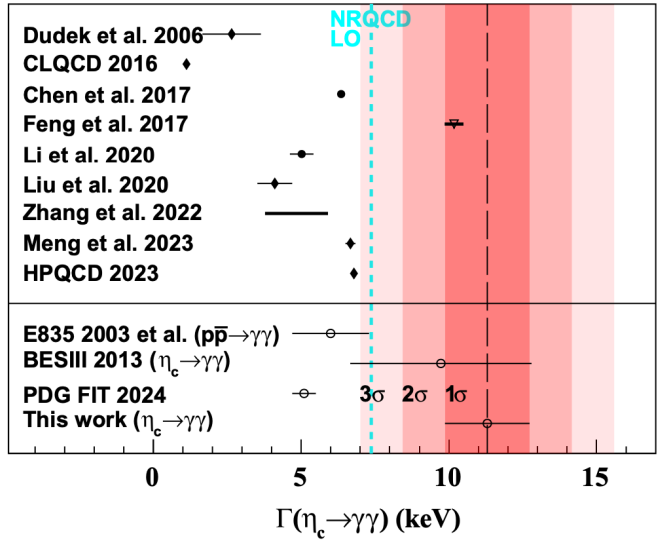




Measurement of $\eta_c \to \gamma\gamma$ in $J/\psi \to \gamma\eta_c$

- $B(J/\psi \to \gamma\eta_c)\times B(\eta_c \to \gamma\gamma) = (5.23 \pm 0.26 \pm 0.30)\times 10^{-6}$, consistent with Lattice QCD calculation
- Using PDG value $B(J/\psi \to \gamma\eta_c)$ input, $\Gamma(\eta_c \to \gamma\gamma) = (11.30 \pm 0.56 \pm 0.66 \pm 1.14)$ keV, consistent with the non-relativistic QCD calculation, inconsistent with Lattice QCD, PDG global fit, and the process $p\bar{p} \to \gamma\gamma$
- Question: Do we really have a reliable quoted $B(J/\psi \to \gamma\eta_c)$?





$B(J/\psi \to \gamma\eta_c)$ in PDG global fit

Potential source of discrepancy : Interference effect is ignored in most of measurements

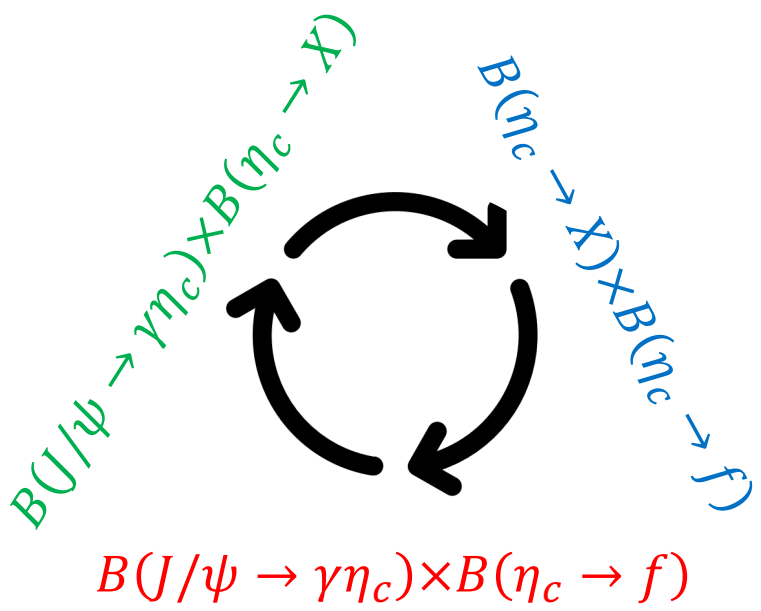
	Mode	Rate	Scale factor
Γ_1	$\eta_c(1S) \to \eta'(958)\pi\pi$	$(1.59 \pm 0.34) \times 10^{-2}$	1.7
Γ_6	$\eta_c(1S) \to K^*(892)\overline{K}^*(892)$	$(5.5 \pm 1.1) \times 10^{-3}$	1.2
Γ_9	$\eta_c(1S) \to \phi\phi$	$(1.4 \pm 0.4) \times 10^{-3}$	2.9
Γ_{16}	$\eta_c(1S) \to \omega\omega$	$(2.1 \pm 0.8) \times 10^{-3}$	2.4
Γ_{18}	$\eta_c(1S) \to f_2(1270)f_2(1270)$	$(8.4 \pm 2.4) \times 10^{-3}$	1.2
Γ_{37}	$\eta_c(1S) \to K\overline{K}\pi$	$(5.9 \pm 0.5) \times 10^{-2}$	1.8
Γ_{38}	$\eta_c(1S) \to K\overline{K}\eta$	$(1.11 \pm 0.15) \times 10^{-2}$	1.3
Γ_{41}	$\eta_c(1S) \to K^+K^-\pi^+\pi^-$	$(6.7 \pm 1.8) \times 10^{-3}$	2.4
Γ_{45}	$\eta_c(1S) \to 2(K^+K^-)$	$(1.2 \pm 0.4) \times 10^{-3}$	1.6
Γ_{48}	$\eta_c(1S) \to 2(\pi^+\pi^-)$	$(7.5 \pm 1.3) \times 10^{-3}$	1.6
Γ_{52}	$\eta_c(1S) \to p\overline{p}$	$(1.11 \pm 0.12) \times 10^{-3}$	1.4
Γ_{54}	$\eta_c(1S) \to p\overline{p}\pi^+\pi^-$	$(3.4 \pm 0.5) \times 10^{-3}$	1.2
Γ_{55}	$\eta_c(1S) \to \Lambda\overline{\Lambda}$	$(9.4 \pm 1.8) \times 10^{-4}$	1.2
Γ_{60}	$\eta_c(1S) \to \gamma\gamma$	$(2.13 \pm 0.15) \times 10^{-4}$	1.5
$\Gamma_{30}^{h_c(1P)}$	$h_c(1P) \to \gamma\eta_c(1S)$	$(64 \pm 5) \times 10^{-2}$	1.2
$\Gamma_{199}^{\psi(2S)}$	$\psi(2S) \to \gamma\eta_c(1S)$	$(3.6 \pm 0.5) \times 10^{-3}$	1.3
$\Gamma_{248}^{J/\psi(1S)}$	$J/\psi(1S) \to \gamma\eta_c(1S)$	$(1.82 \pm 0.15) \times 10^{-2}$	1.6
$\Gamma_{274}^{B^\pm}$	$B^+ \to \eta_c K^+$	$(1.20 \pm 0.08) \times 10^{-3}$	1.3
$\Gamma_{\eta_c(1S)}$	$\eta_c(1S)$ WIDTH	30.0 ± 0.5 (MeV)	1.2

Negative correlation: mainly contributed by $B(J/\psi \to \gamma\eta_c) \times B(\eta_c \to f)$

	x_1	x_6	x_9	x_{16}	x_{18}	x_{37}	x_{38}	x_{41}	x_{45}	x_{48}	x_{52}	x_{54}	x_{55}	x_{60}	$x^{h_c(1P)}_{30}$	$x^{\psi(2S)}_{199}$	$x^{J/\psi(1S)}_{248}$
x_1	100																
x_6	16	100															
x_9	13	14	100														
x_{16}	8	9	8	100													
x_{18}	10	12	12	7	100												
x_{37}	32	30	26	15	20	100											
x_{38}	19	18	15	9	12	59	100										
x_{41}	9	9	8	5	6	19	12	100									
x_{45}	7	6	6	3	4	17	10	5	100								
x_{48}	14	18	18	10	15	29	17	10	6	100							
x_{52}	22	23	21	12	17	45	27	13	12	25	100						
x_{54}	10	10	10	5	7	28	17	7	13	11	22	100					
x_{55}	9	11	13	7	10	22	13	7	7	16	20	16	100				
x_{60}	-41	-37	-29	-17	-22	-76	-45	-20	-16	-33	-51	-23	-20	100			
$x^{h_c(1P)}_{30}$	-12	-12	-10	-6	-8	-36	-25	-25	-12	13	-21	-15	-9	29	100		
$x^{\psi(2S)}_{199}$	-1	-1	-1	-1	-1	-3	-2	-3	-1	-3	-3	-1	-1	3	2	100	
$x^{J/\psi(1S)}_{248}$	-20	-30	-34	-20	-30	-42	-25	-16	-10	-46	-43	-17	-32	43	18	2	100
$x^{B^\pm}_{274}$	-18	-18	-19	-9	-12	-50	-30	-11	-23	-19	-39	-55	-30	41	21	2	30
$\Gamma^{\eta_c(1S)}$	-2	-1	-1	-1	-1	-3	-2	-1	-1	-1	1	-1	-1	-15	0	0	2

Combination of three BFs

While PDG global fit is not reliable, a combination of three product BFs may work



What we have

- $B(J/\psi \to \gamma\eta_c)\times B(\eta_c \to X)$ (Measured in radiative decay)
- $B(\eta_c \to X)\times B(\eta_c \to f)$ ($X = \gamma\gamma/p\bar{p}$, Measured in two-photon process or $p\bar{p}$ annihilation)

What we need

- $B(J/\psi \to \gamma\eta_c)\times B(\eta_c \to f)$ (Measured in J/ψ decays)

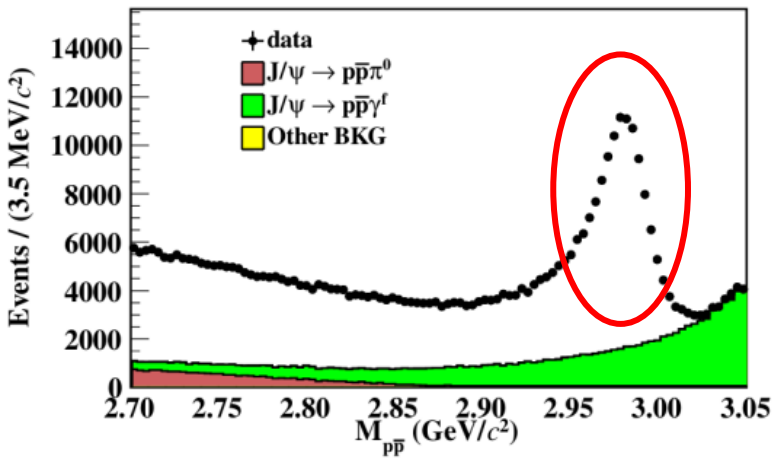
$$B(\eta_c \to X) = \sqrt{\frac{[B(J/\psi \to \gamma\eta_c)\times B(\eta_c \to X)]\times[B(\eta_c \to X)\times B(\eta_c \to f)]}{B(J/\psi \to \gamma\eta_c)\times B(\eta_c \to f)}}$$

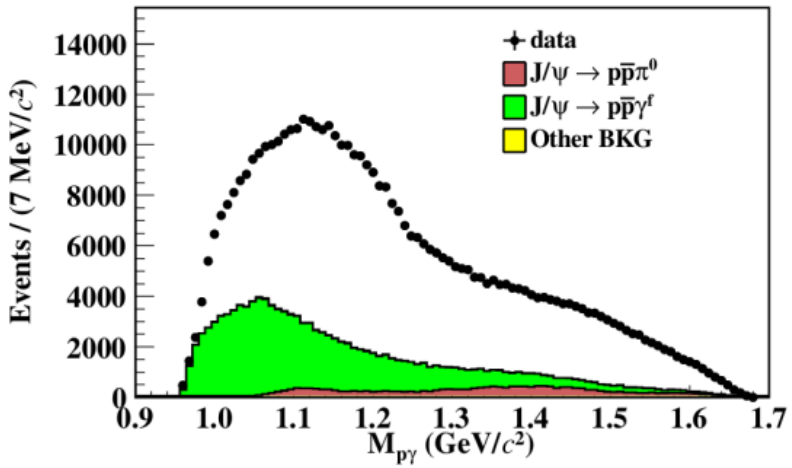
$$B(J/\psi \to \gamma\eta_c) = \sqrt{\frac{[B(J/\psi \to \gamma\eta_c)\times B(\eta_c \to X)]\times B(J/\psi \to \gamma\eta_c)\times B(\eta_c \to f)}{B(\eta_c \to X)\times B(\eta_c \to f)}}$$

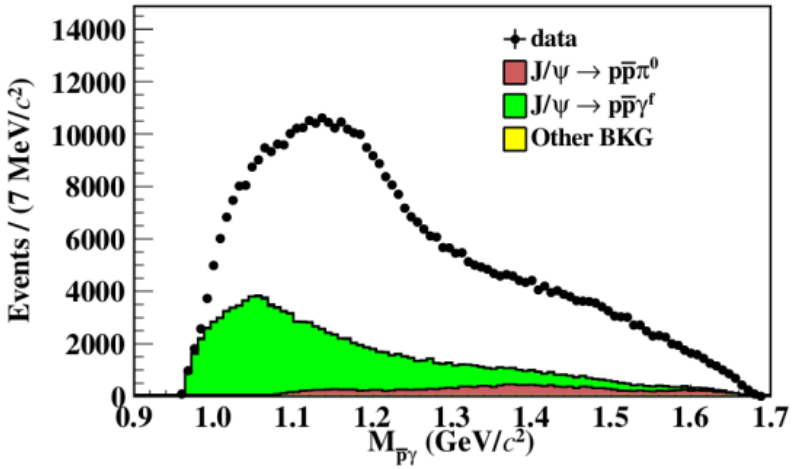
Amplitude analysis of $J/\psi \to \gamma\eta_c \to \gamma p\bar{p}$

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

- Using 10 billion J/ψ sample
- Amplitude analysis of $J/\psi \to \gamma p\bar{p}$ process in the η_c mass region (2.7,3.05) GeV/c²
- Background from $J/\psi \to \gamma^{FSR} p\bar{p}$ and $J/\psi \to \pi^0 p\bar{p}$
- Significant η_c asymmetric shape: M1 form factor (E_γ^3) and interference effects
- No significant $N^* \to \gamma p$ observed.

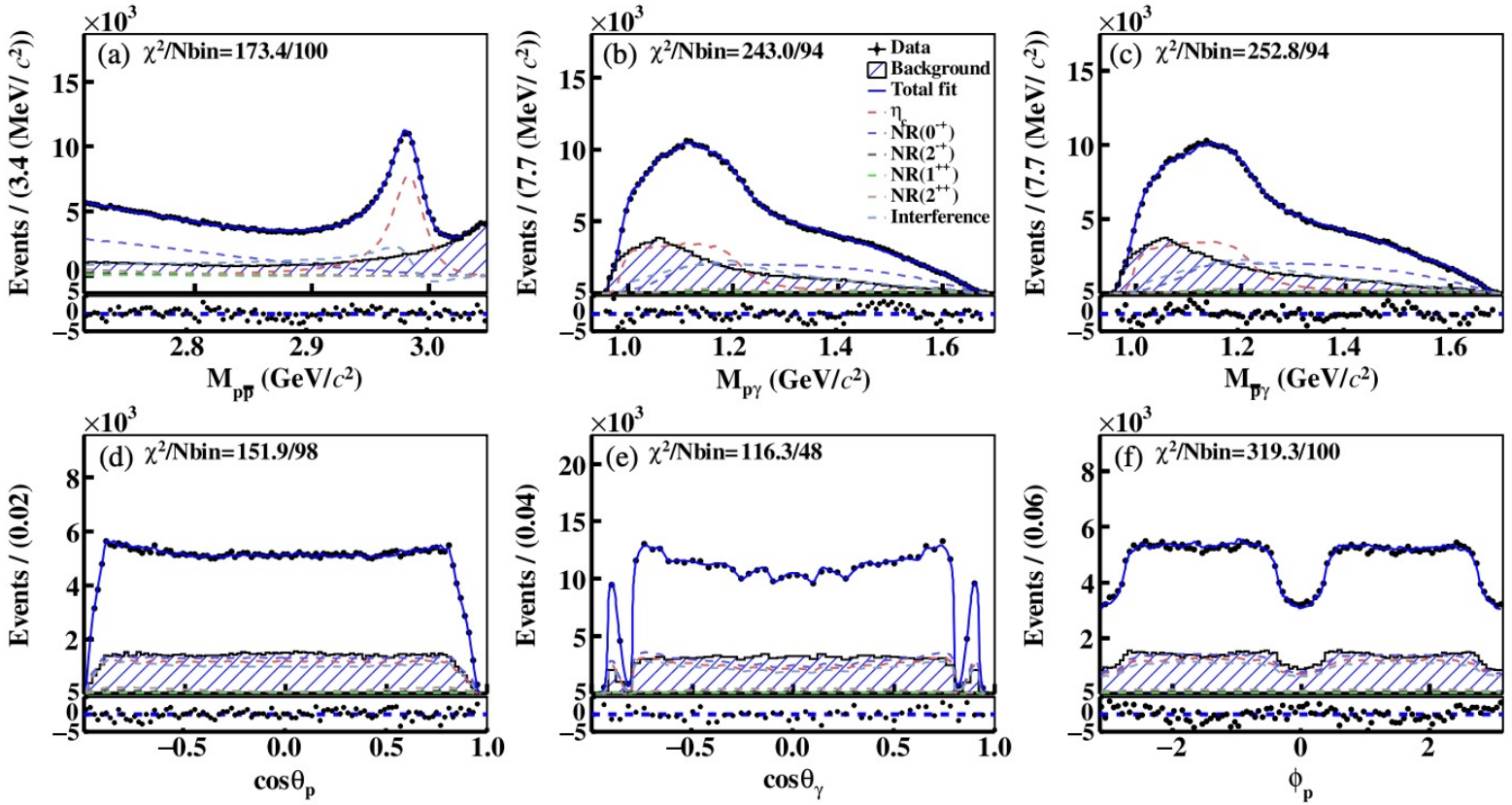






Amplitude analysis of $J/\psi \to \gamma\eta_c \to \gamma p\bar{p}$

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



- Angular distributions effectively distinguish different J^P non-resonant components
- Interference with η_c arises almost entirely from 0^- non-resonant component
- Full available information distinguish the multi-solution issue observed in 1D fit

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

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

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

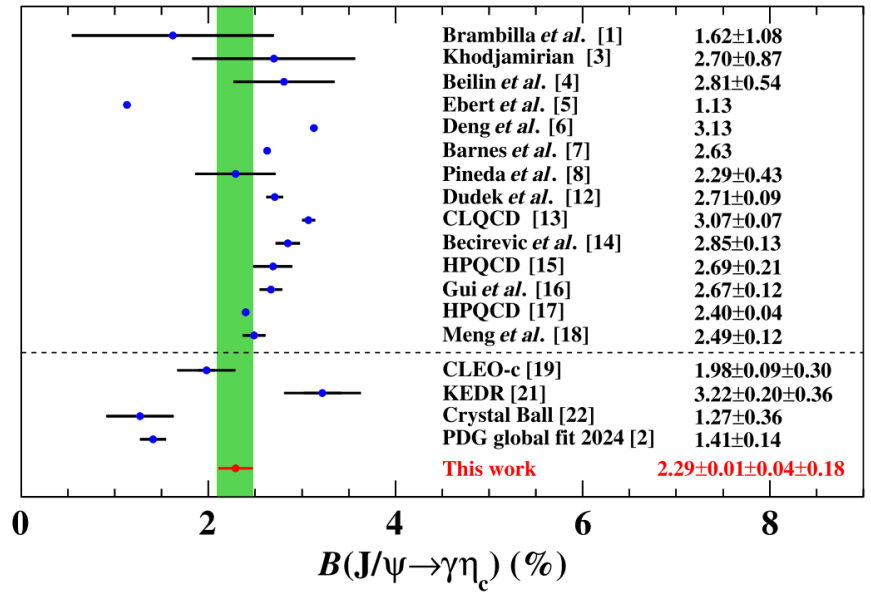
$$B(J/\psi \to \gamma\eta_c)\times B(\eta_c \to p\bar{p}) = (2.11 \pm 0.02 \pm 0.07)\times 10^{-5}$$

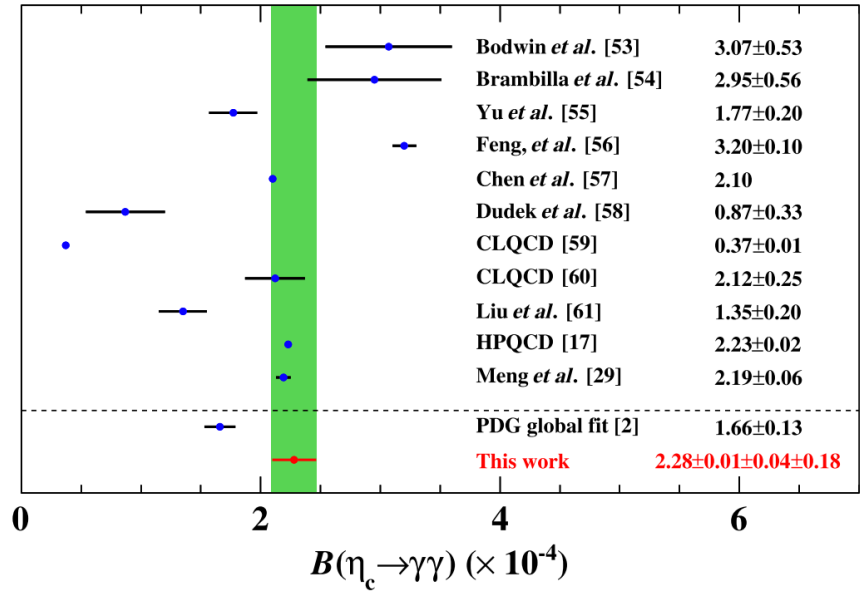
$\Longrightarrow$

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

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

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

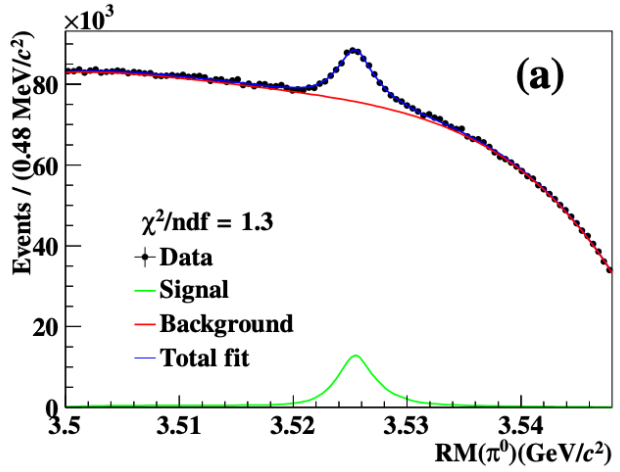


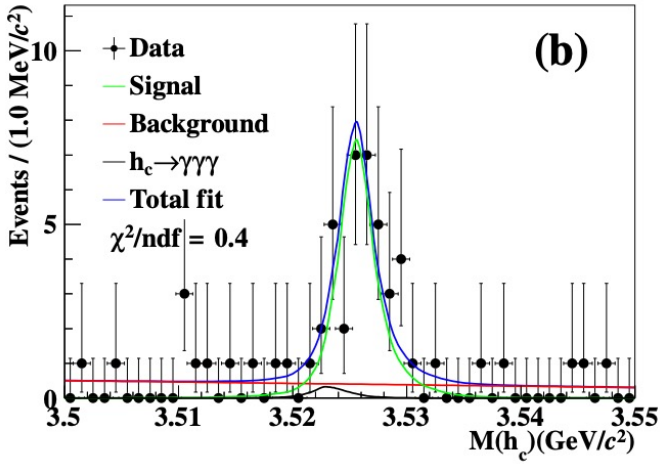


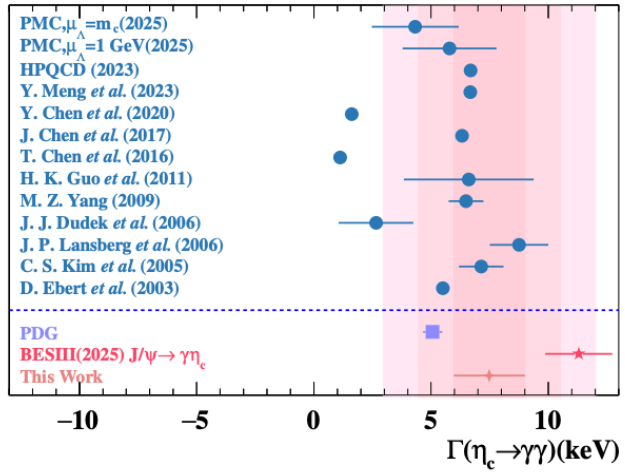
Measurement of $\eta_c \to \gamma\gamma$ via $h_c \to \gamma\eta_c$

arxiv: 2601.11236

- $\psi(3686) \to \pi^0 h_c$, $h_c \to \gamma\eta_c$ provides a clean environment with low background and negligible quantum interference for studying η_c
- Absolute BF measurement by tagging η_c recoiling system of $(\pi^0\gamma)_{tag}$, N_{tag}~1.6×10^5
- Based on the $(\pi^0\gamma)_{tag}$, select signal $\eta_c \to \gamma\gamma$, $N_{sig} = (32.5 \pm 6.4)$
- $B(\eta_c \to \gamma\gamma) = (2.45 \pm 0.48 \pm 0.09)\times10^{-4}$, consistent with most theoretical calculations and 2.5σ deviation from combined BFs in J/ψ radiative decay





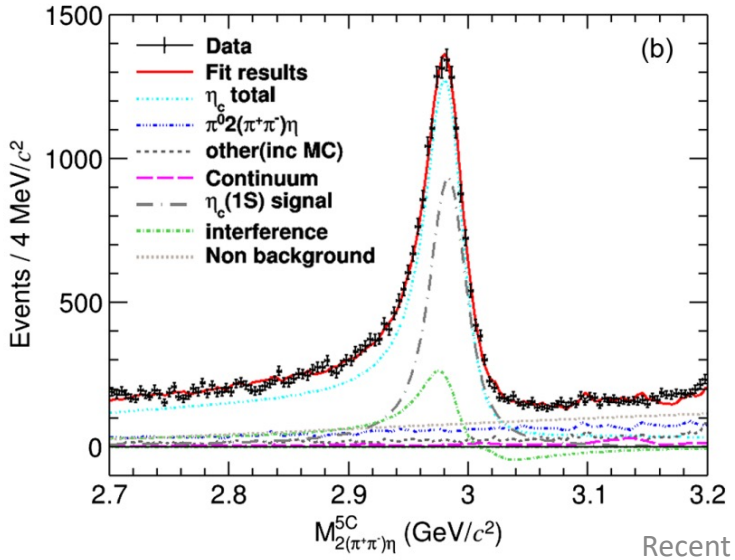


Measurement of $\eta_c \to 2(\pi^+\pi^-)\eta$ in $\psi(3686) \to \gamma\eta_c$

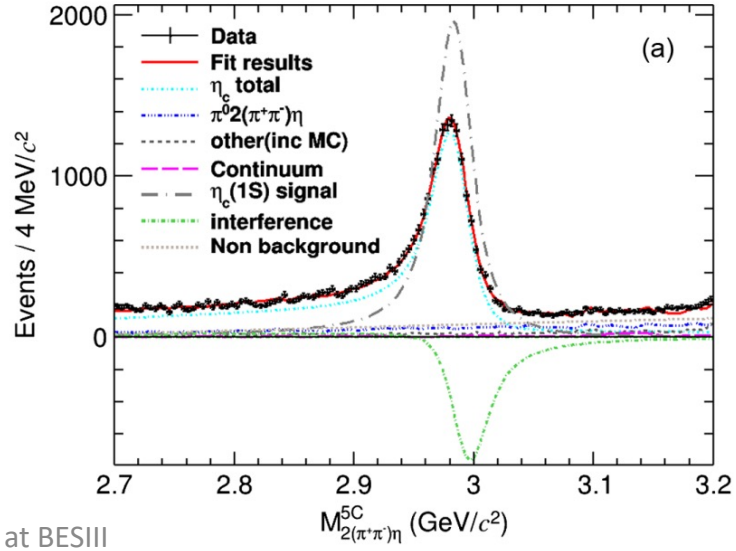
Phys. Rev. D. 111, 052031 (2025)

- Measured in $\psi(3686) \to \gamma\eta_c$, $\eta_c \to 2(\pi^+\pi^-)\eta$
- Significant η_c asymmetric shape: M1 form factor (E_γ^7) and interference effects
- Two indistinguishable solutions: one constructive, one destructive
- Large uncertainty ~40% due to non-resonant component: 1D fits can not distinguish J^P of non-resonant background

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



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

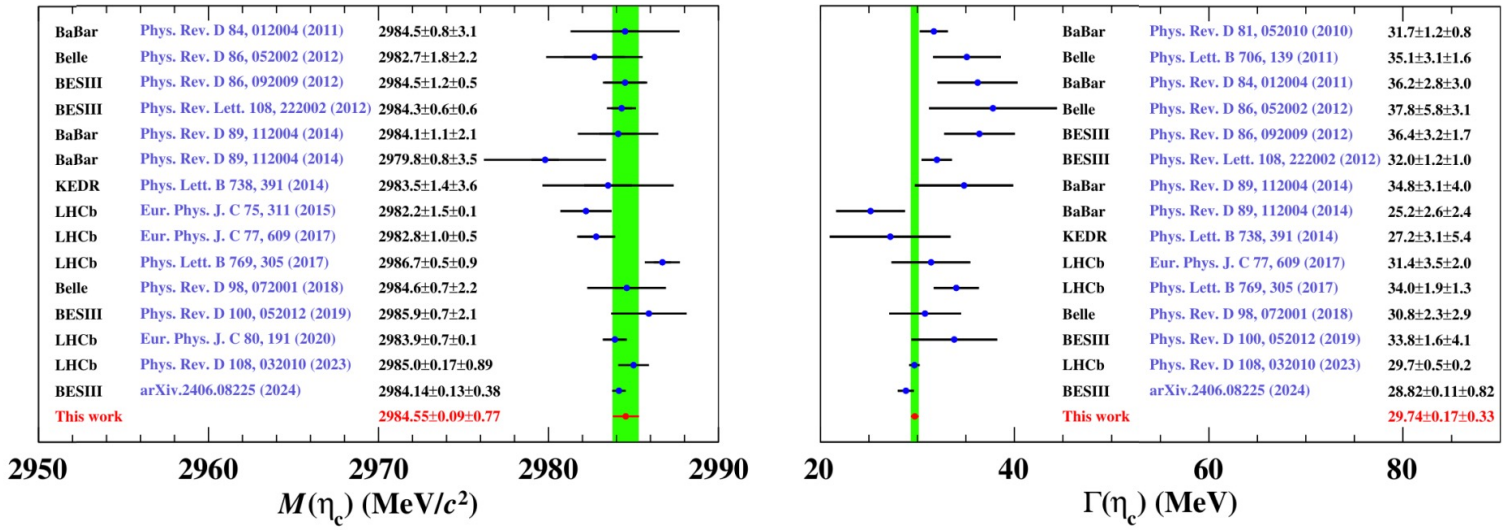


Measurement of $\eta_c \to 2(\pi^+\pi^-)\eta$ in $\psi(3686) \to \gamma\eta_c$

- Precise measurements of the η_c mass and width

Decay mode	M (MeV/c^2)	Γ (MeV)
$J/\psi \to \gamma\eta_c,\ \eta_c \to p\bar{p}$	$2984.55 \pm 0.09 \pm 0.37$	$29.74 \pm 0.17 \pm 0.33$
$\psi(3686) \to \gamma\eta_c,\ \eta_c \to 2(\pi^+\pi^-)\eta$	$2984.14 \pm 0.13 \pm 0.38$	$28.82 \pm 0.11 \pm 0.82$

- $(M_{J/\psi} - M_{\eta_c}) = 112.4 \pm 0.8$ MeV/c^2 in $p\bar{p}$ and 112.8 ± 0.4 MeV/c^2 in $2(\pi^+\pi^-)\eta$, consistent with Lattice QCD predictions



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

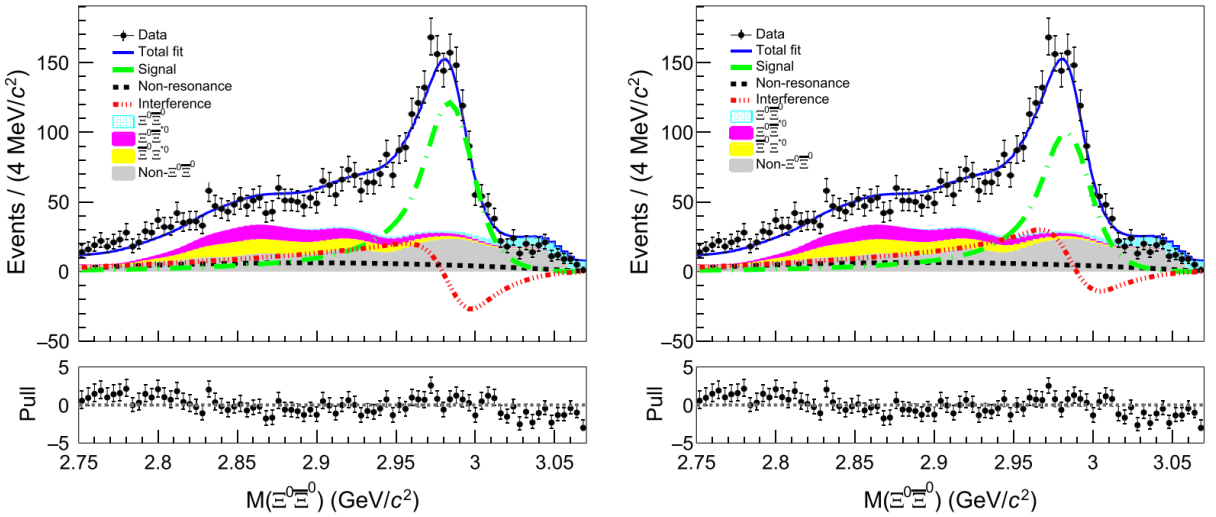
$J/\psi \to \gamma\eta_c, \eta_c \to \Xi^0\bar{\Xi}^0$

Phys. Rev. D. 113, 072003 (2026)

- First observation of $\eta_c \to \Xi^0\bar{\Xi}^0$
- Two indistinguishable solutions

$$B(\eta_c \to \Xi^0\bar{\Xi}^0\ )_{des} = (1.63 \pm 0.22)\times10^{-3}$$

$$B(\eta_c \to \Xi^0\bar{\Xi}^0\ )_{con} = (1.33 \pm 0.20)\times10^{-3}$$



$J/\psi \to \gamma\eta_c, \eta_c \to \omega\phi$

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- First evidence for doubly OZI-suppressed decay mode $\eta_c \to \omega\phi$
- $B(\eta_c \to \omega\phi) = (3.86 \pm 0.92 \pm 0.62)\times10^{-5}$

$B\left(\psi(3686) \to \gamma\eta_c(2S)\right)\times B(\eta_c(2S) \to \omega\phi) < 1.85\times10^{-7}$

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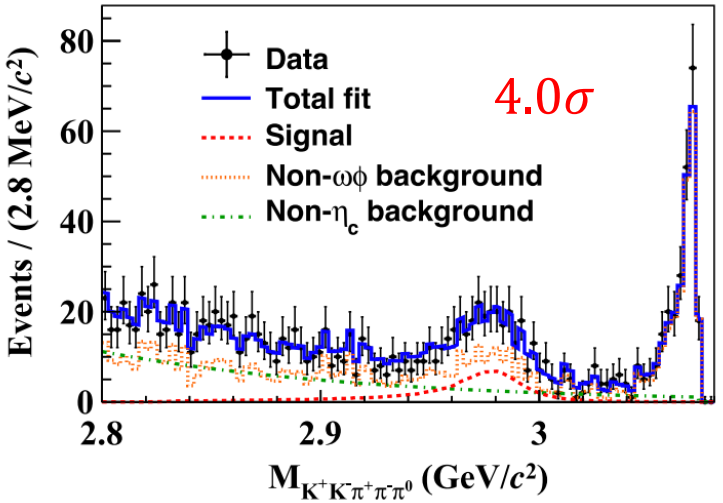

Summary

- Precision BF measurements of two decays $J/\psi \to \gamma\eta_c$ and $\eta_c \to \gamma\gamma$ by combining three processes with uncertainty $< 10\%$.
- $\psi(3686) \to \pi^0 h_c$, $h_c \to \gamma\eta_c$ allows absolute measurement on η_c decays, consistent with most theoretical calculations, more hadronic decays are on-going.
- The measurement precision of the η_c mass and width has been improved.
- First observation/search for unknown η_c decay modes are reported, more works are on-going.
- The upgraded BESIII detector has completed a new round of data taking on $\psi(3686)$ $(\sim 1.37\ fb^{-1}(\text{online}))$ and BESIII experiment will provide a more powerful platform for studying of η_c in the future.

Thank You!