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Recent Progresses on η_c Decays at BESIII

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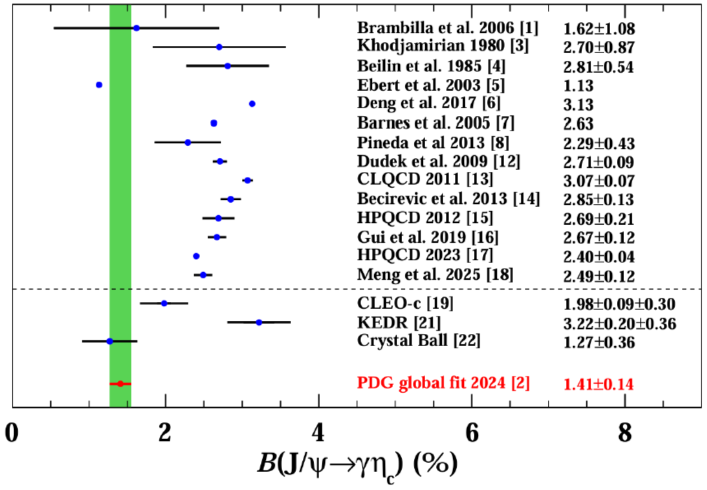
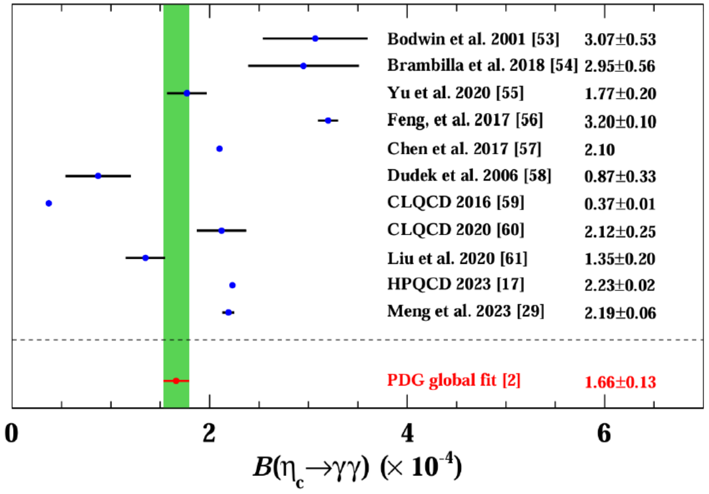
- **Summary**

Introduction

- The decay rate of charmonium can offer access to the strong coupling constant at the charmonium scale within the framework of perturbative QCD, and also provide a sensitive test to the application of the LQCD and NRQCD.





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

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

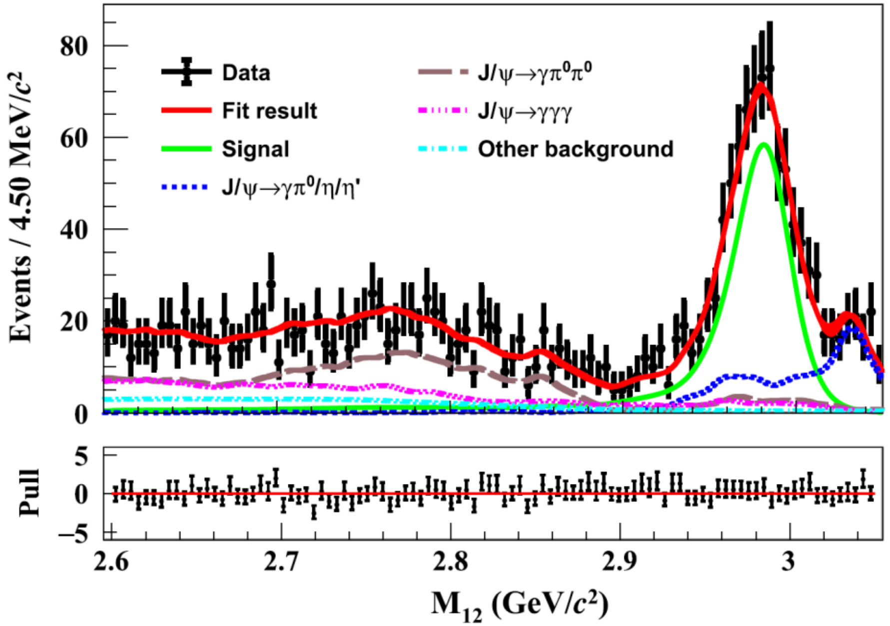
- In BESIII, η_c can be produced via three different radiative transition: $J/\psi \to \gamma\eta_c$, $\psi(3686) \to \gamma\eta_c$, and $h_c \to \gamma\eta_c$.

Productions	$J/\psi \to \gamma\eta_c$	$\psi(3686) \to \gamma\eta_c$	$h_c \to \gamma\eta_c$
Statistics	~200M	~10M	~1M
EM decay	M1	M1	E1
Interference	Y	Y	N
Background	High	Medium	Low

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



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

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

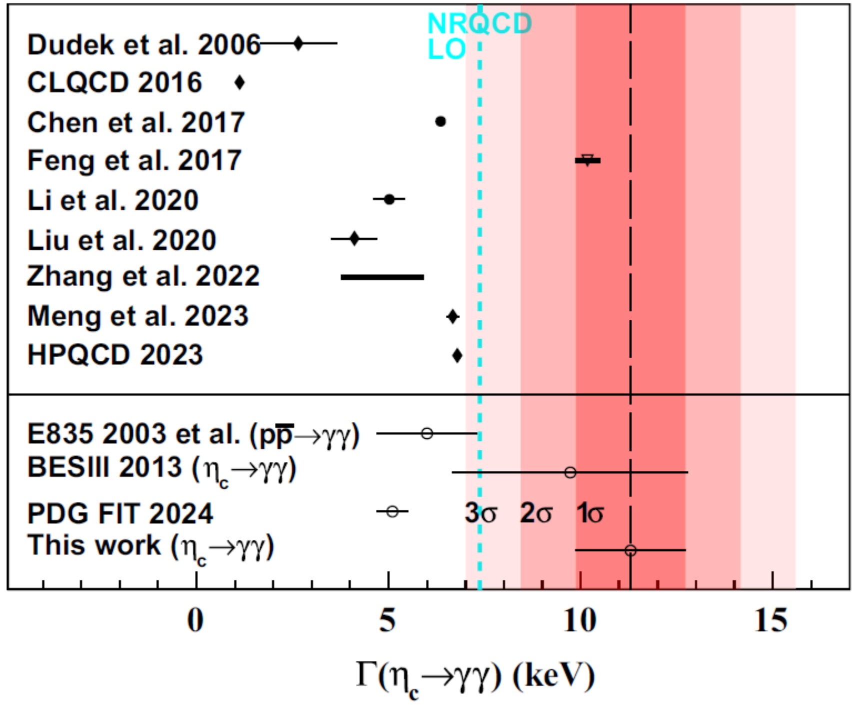
Stat. Syst.

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.

- It is crucial to note that several theoretical calculations of $\mathcal{B}(J/\psi \to \gamma\eta_c)$ are significantly larger than the $\mathcal{B}^{PDG}(J/\psi \to \gamma\eta_c)$, and the interference between the η_c-included process and the nonresonance process is ignored in most of η_c measurements.

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

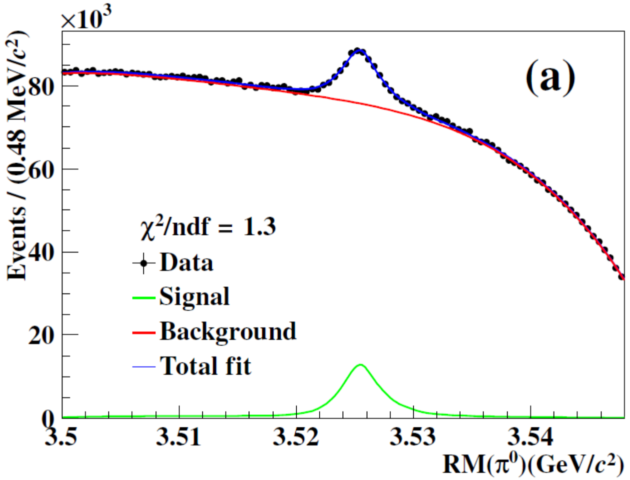
Measurement of $\eta_c \to \gamma\gamma$ via $h_c \to \gamma\eta_c$

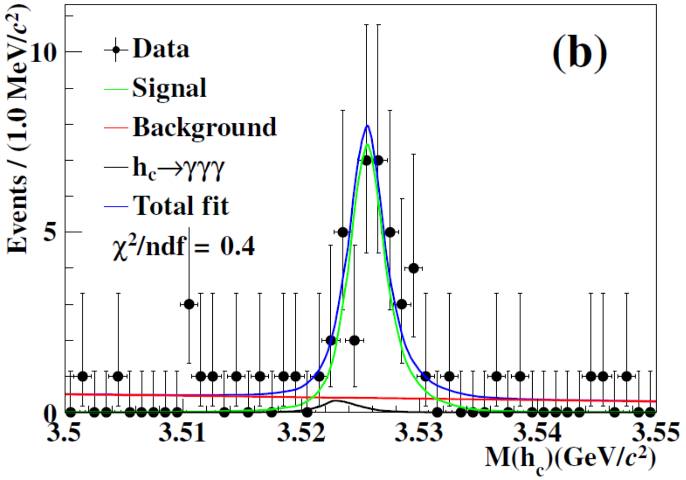
arXiv: 2601. 11236

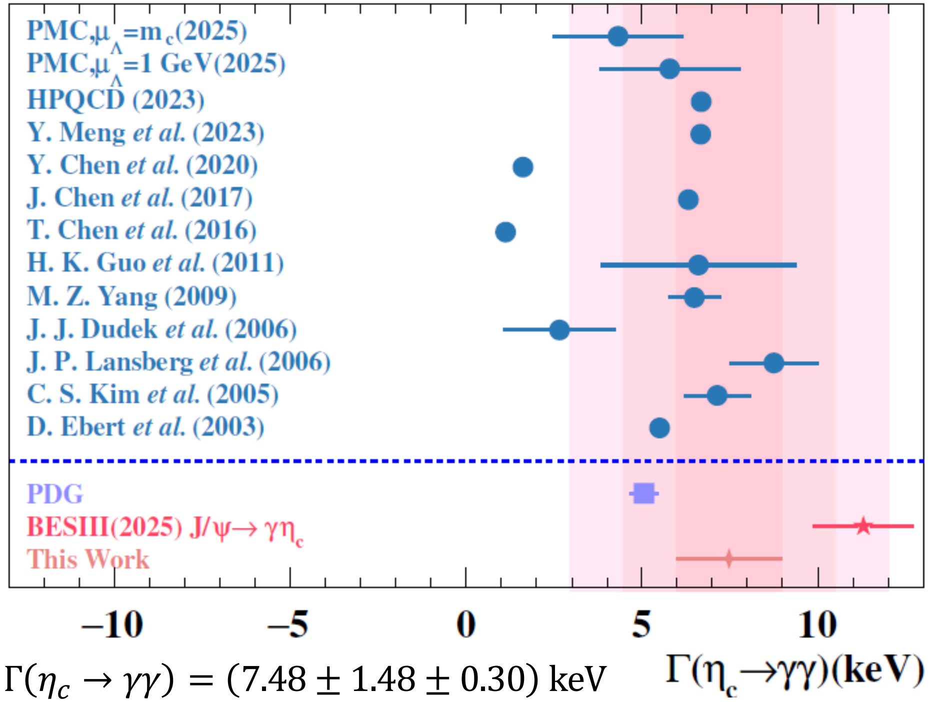
- The $\psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c$ process provides an extremely low background level and negligible interference effect environment for the measurement of η_c
- The absolute BF of $\eta_c \to \gamma\gamma$ is measured for the first time by a tag-and-probe method:

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

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







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

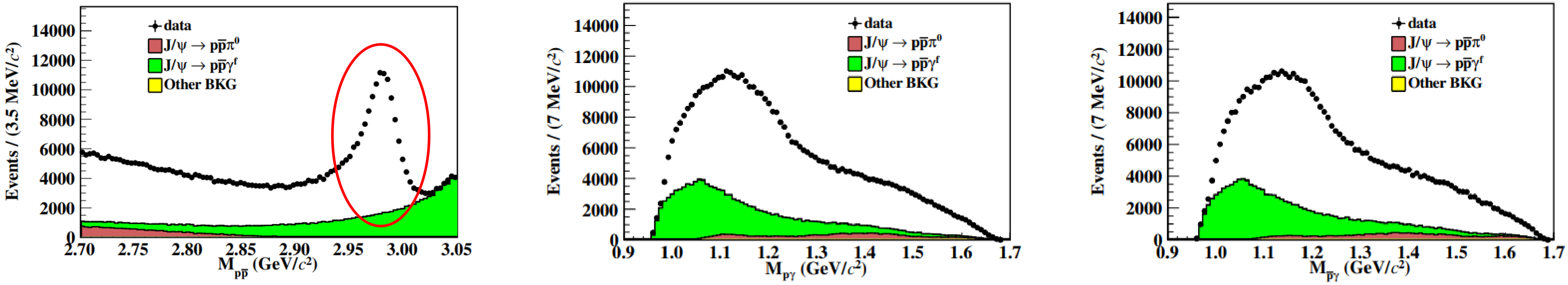
$$\frac{\Gamma(J/\psi \to e^+e^-)}{\Gamma(\eta_c \to \gamma\gamma)} = (0.74 \pm 0.15)$$

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)

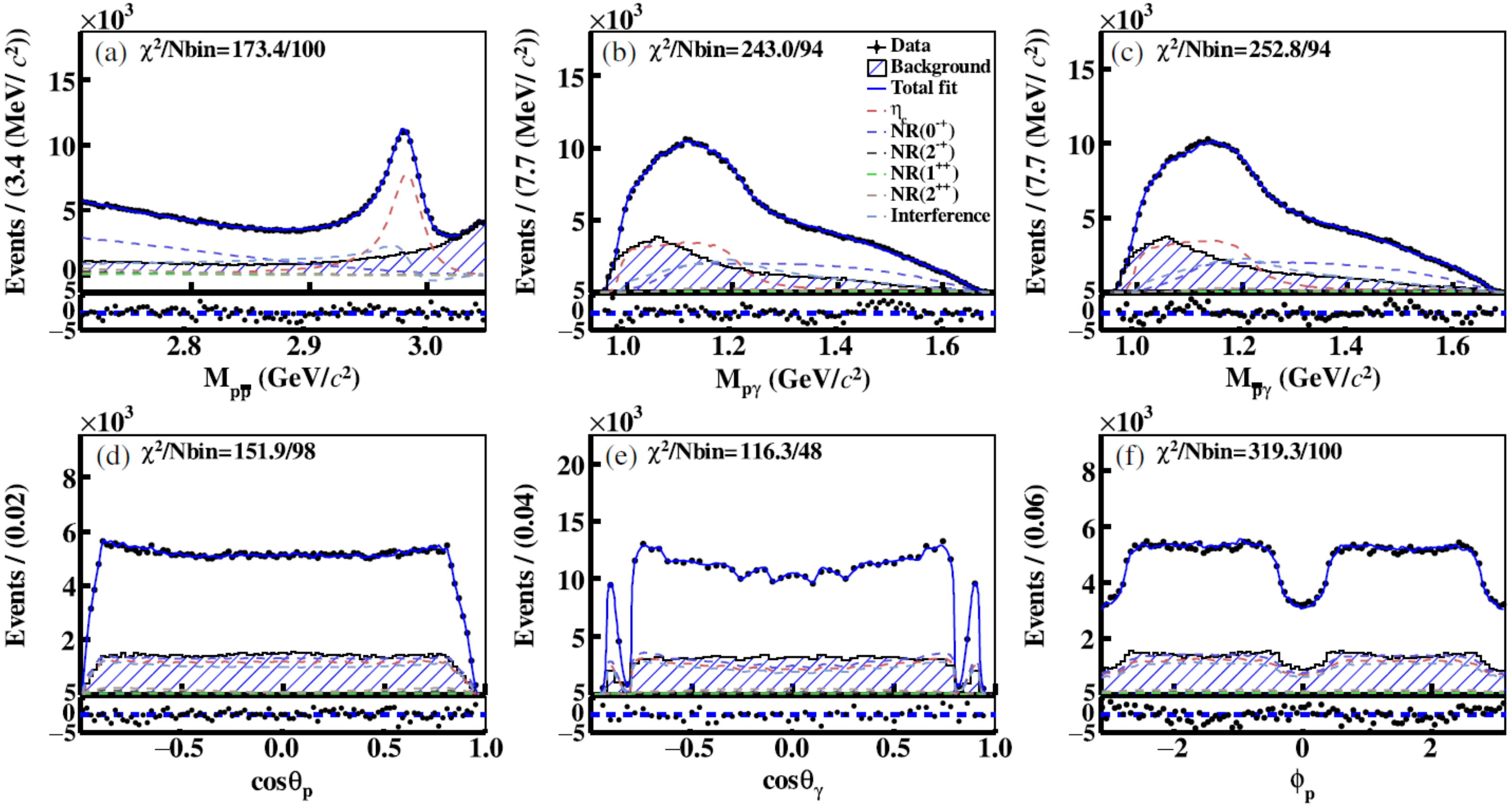
- Using about 10 billion J/ψ sample
- Amplitude analysis of $J/\psi \to \gamma p\bar{p}$ process in the η_c mass region.
- The main background contributions come from $J/\psi \to \gamma_{FSR} p\bar{p}$ and $J/\psi \to p\bar{p}\pi^0$.



η_c signal has an obviously asymmetric shape: M1 form factor (E_γ^3) and interference effects

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

- Amplitude analysis result:



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 $\eta_c \to \gamma\gamma$

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

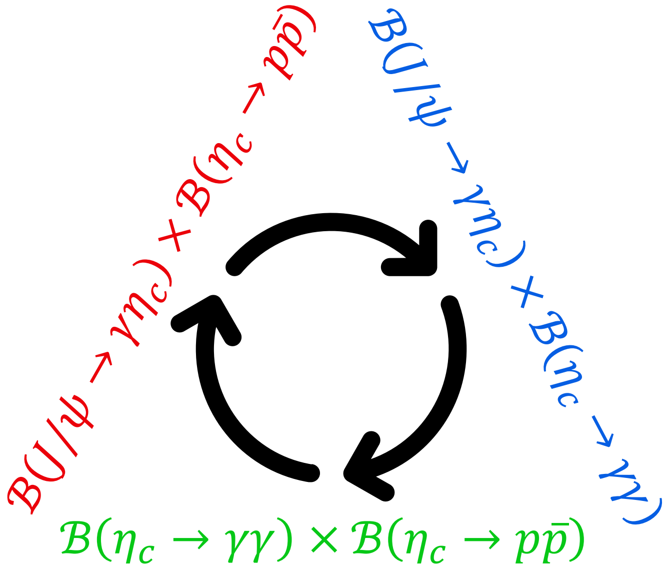
$$\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to p\bar{p}) = (2.11 \pm 0.02 \pm 0.07) \times 10^{-5}$$

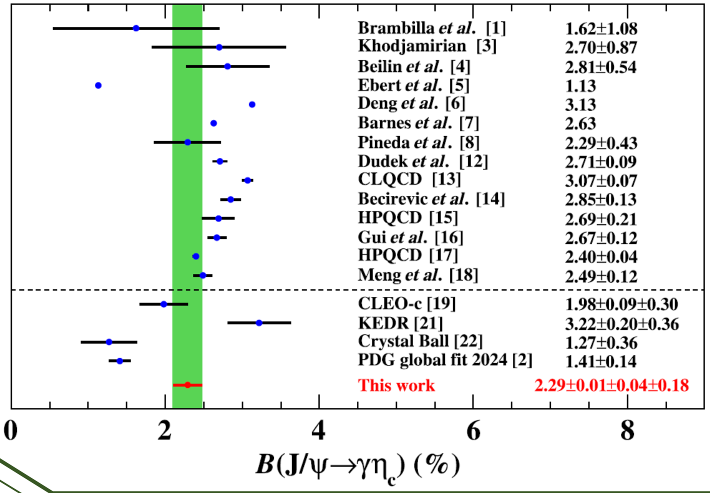
$$\mathcal{B}(\eta_c \to \gamma\gamma) \times \mathcal{B}(\eta_c \to p\bar{p}) = (2.1 \pm 0.3) \times 10^{-7}$$ [1-3]

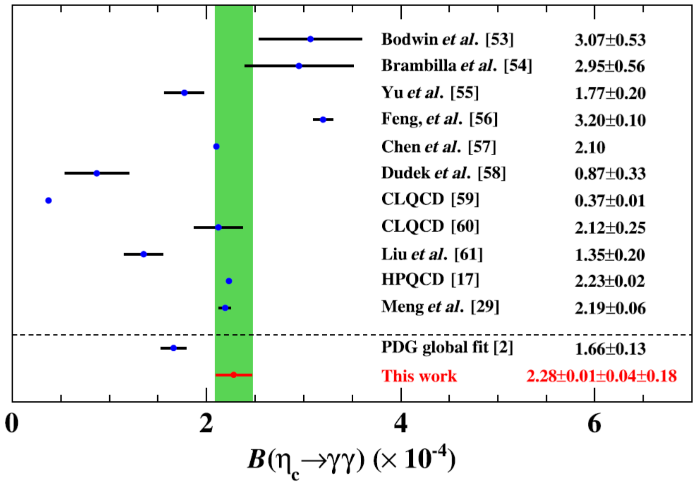
$$\mathcal{B}(J/\psi \to \gamma\eta_c) = (2.29 \pm 0.19)\%$$

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

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







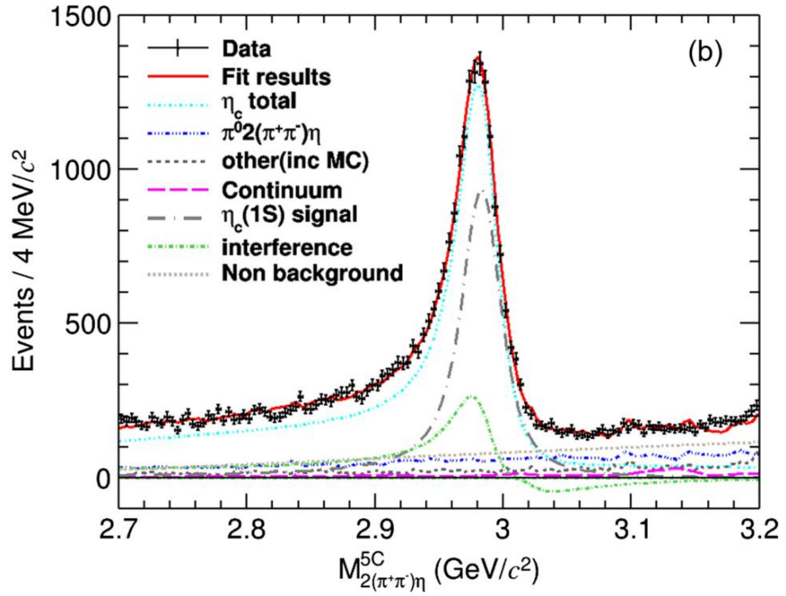
The results deviate from the PDG global fit values by 3σ, but are in good agreement with the latest LQCD calculations.

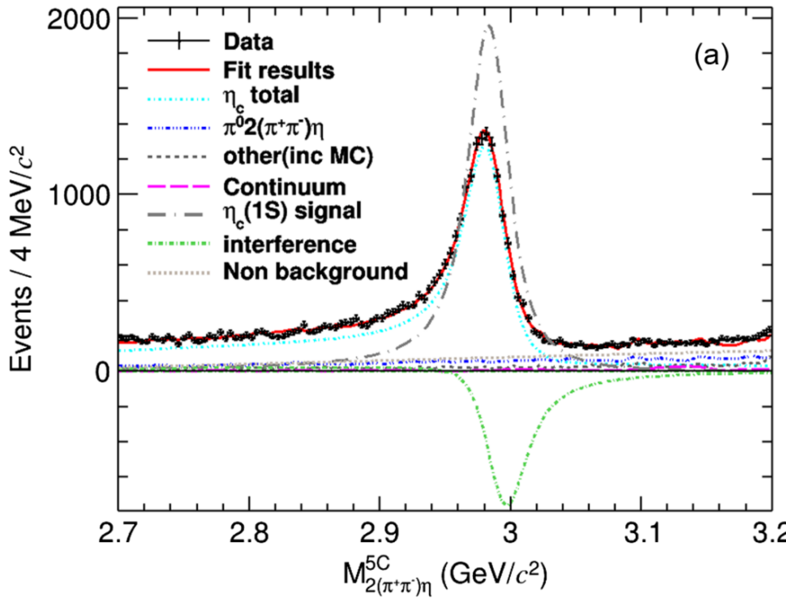
[1] Phys. Rev. D **52**, 4839 (1995)
[2] Phys. Lett. B **621**, 41 (2005)
[3] Phys. Lett. B **566**, 45 (2003)

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

Phys. Rev. D **111**, 052013 (2025)

- 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.





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

$\mathcal{B}(\eta_c \to 2(\pi^+\pi^-)\eta) = (2.6 \pm 0.4 \pm 1.3)\%$ $\qquad$ $\mathcal{B}(\eta_c \to 2(\pi^+\pi^-)\eta) = (5.5 \pm 0.5 \pm 1.9)\%$

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

Study of $\eta_c \to 2(\pi^+\pi^-)\eta$

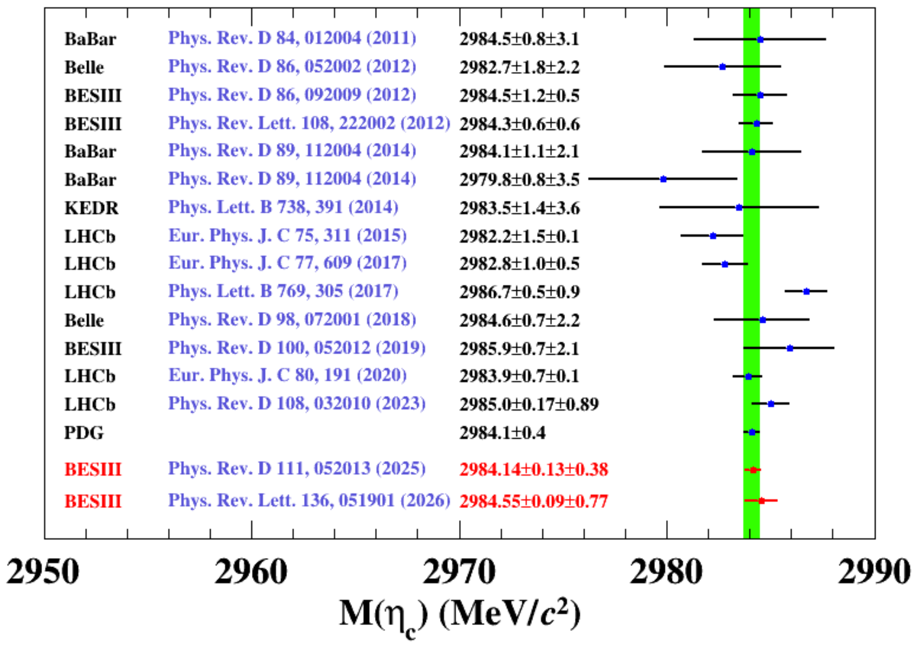
- Precise measurements of the η_c mass and width:

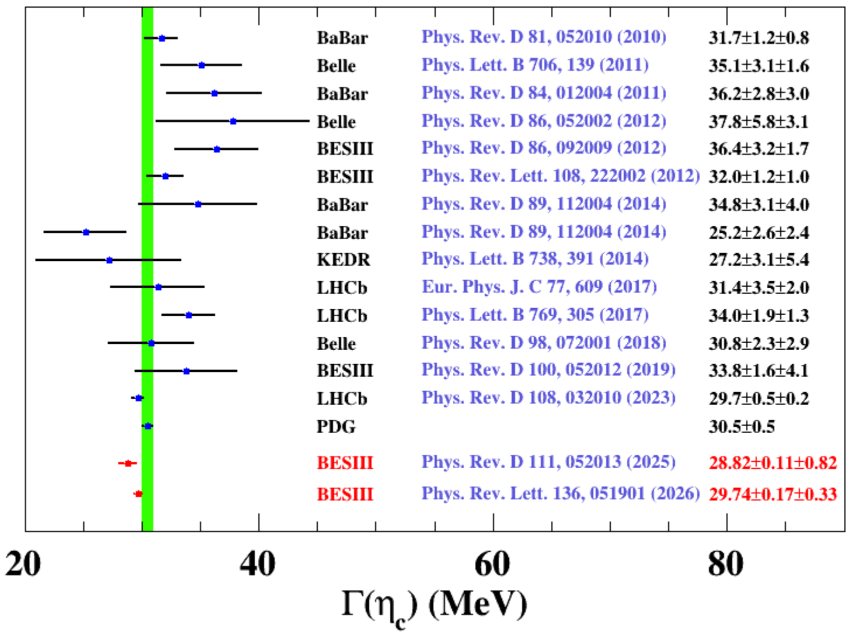
$$J/\psi \to \gamma\eta_c, \eta_c \to p\bar{p}\text{: } \mathrm{M}_1 = (2984.55 \pm 0.09 \pm 0.77)\ \mathrm{MeV}/c^2; \Gamma_1 = (29.74 \pm 0.17 \pm 0.33)\ \mathrm{MeV}$$

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

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

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

Phys. Rev. D **112**, 012012 (2025)

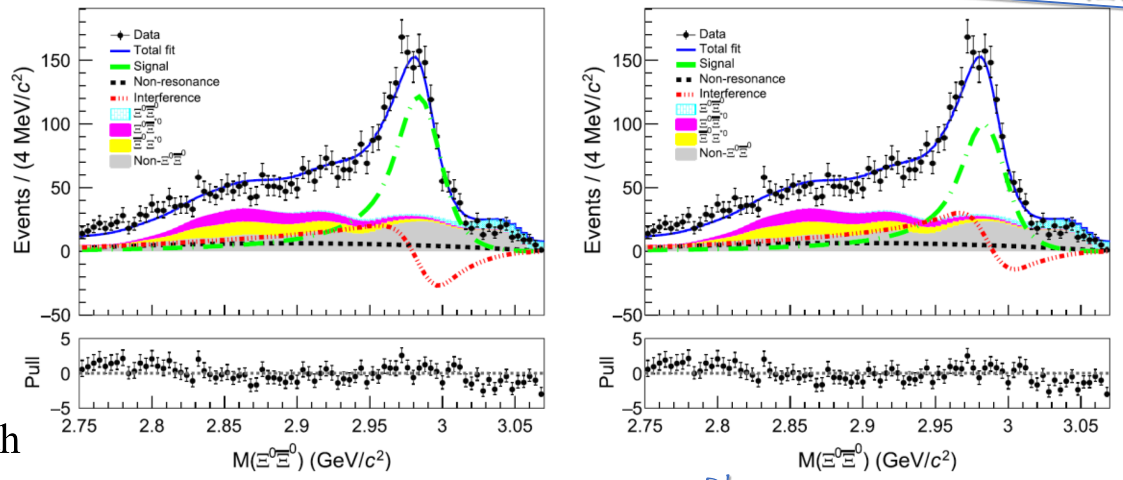
- First observation of $\eta_c \to \Xi^0\bar{\Xi}^0$ via $J/\psi \to \gamma\eta_c$

  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]

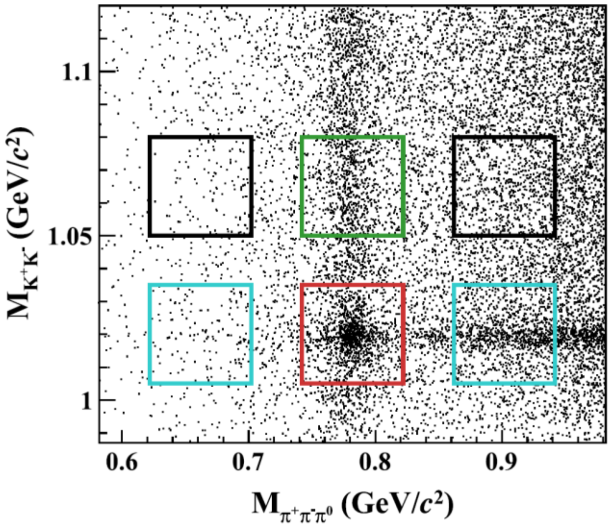
$\frac{\mathcal{B}(\eta_c \to \Xi^0\bar{\Xi}^0)}{\mathcal{B}(\eta_c \to \Xi^-\bar{\Xi}^+)}$ is consistent within 2σ with isospin symmetry expectations [3]

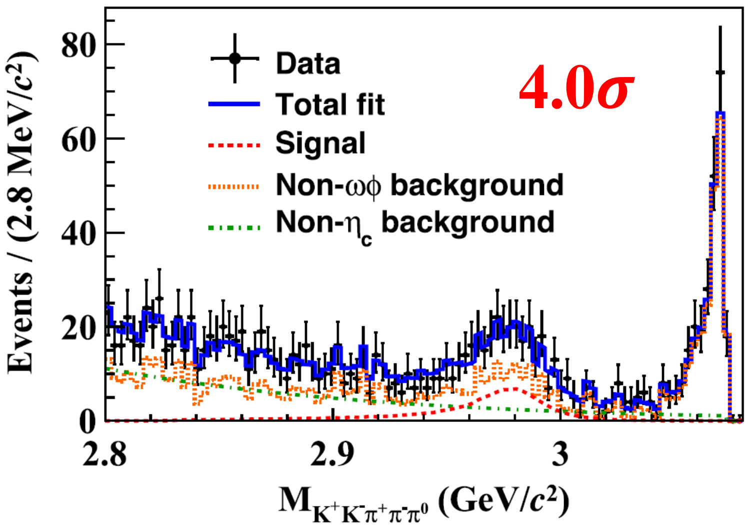


Phys. Rev. D **113**, 072003 (2026)

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

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





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

Summary

BESIII has achieved significant progress in the study of η_c decay:

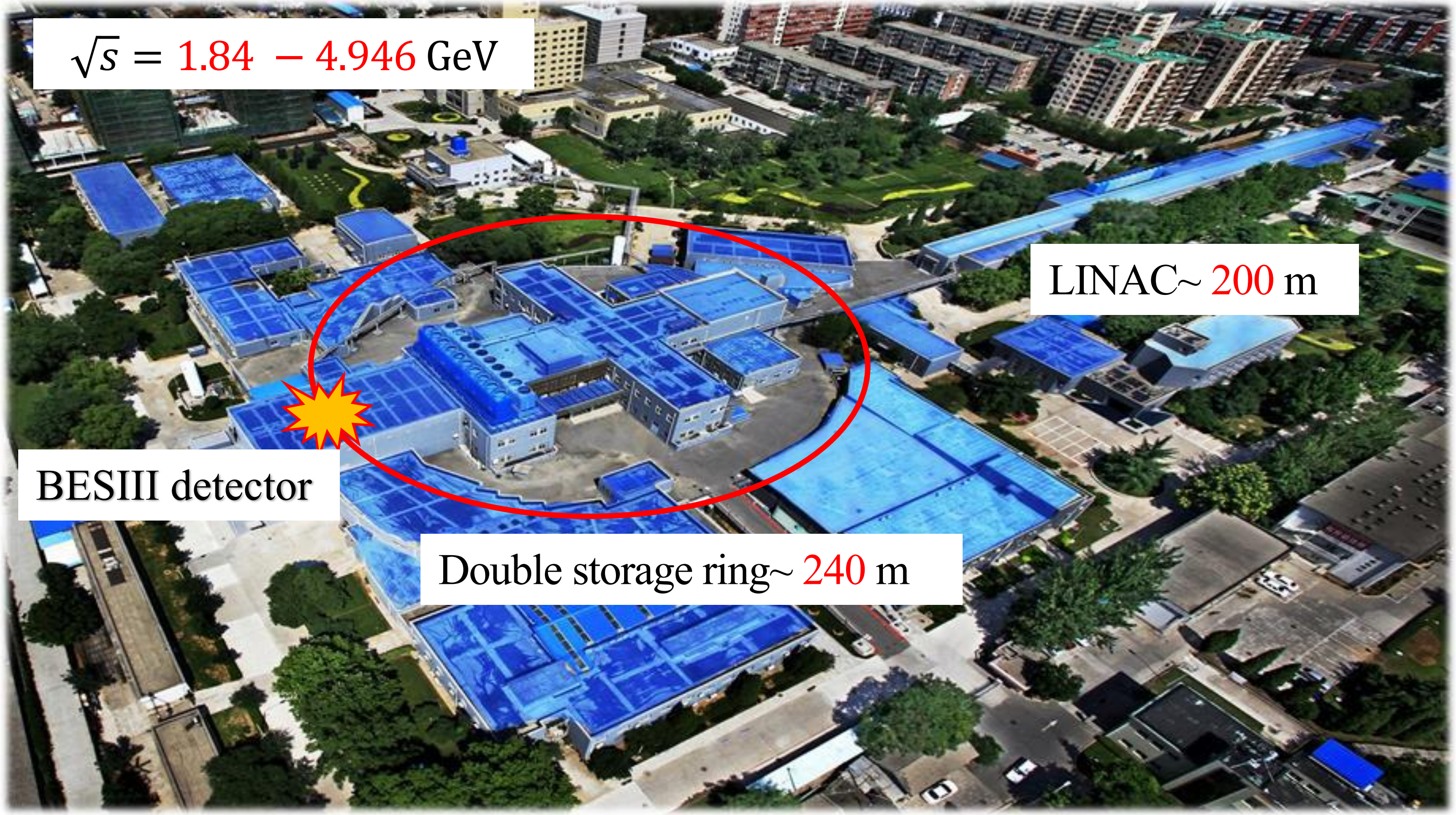
- By combining three production BFs, the absolute BFs of $J/\psi \to \gamma\eta_c$ and $\eta_c \to \gamma\gamma$ can be determined with uncertainties < 10%.
- The absolute BF of $\eta_c \to \gamma\gamma$ is firstly measured via $\psi(3686) \to \pi^0 h_c, h_c \to \gamma\eta_c$, and consistent with most theoretical estimates and that in $J/\psi \to \gamma\eta_c$.
- By fully considering interference effects, significantly different constructive and destructive solutions for the BFs are obtained with 1D fit.
- The measurement precision of the η_c mass and width has been improved.
- The first observation/evidence for unknow η_c decay modes are reported, and more measurements will be presented.
- The upgraded 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.

Thanks for your attention!

Backup

BEPCII & BESIII

Design Luminosity $L_D = 1 \times 10^{33}\ cm^{-2}s^{-1}$ @3.773 GeV
(2016 achieved; 2022-2024 achieved $1.1 \times L_D$)

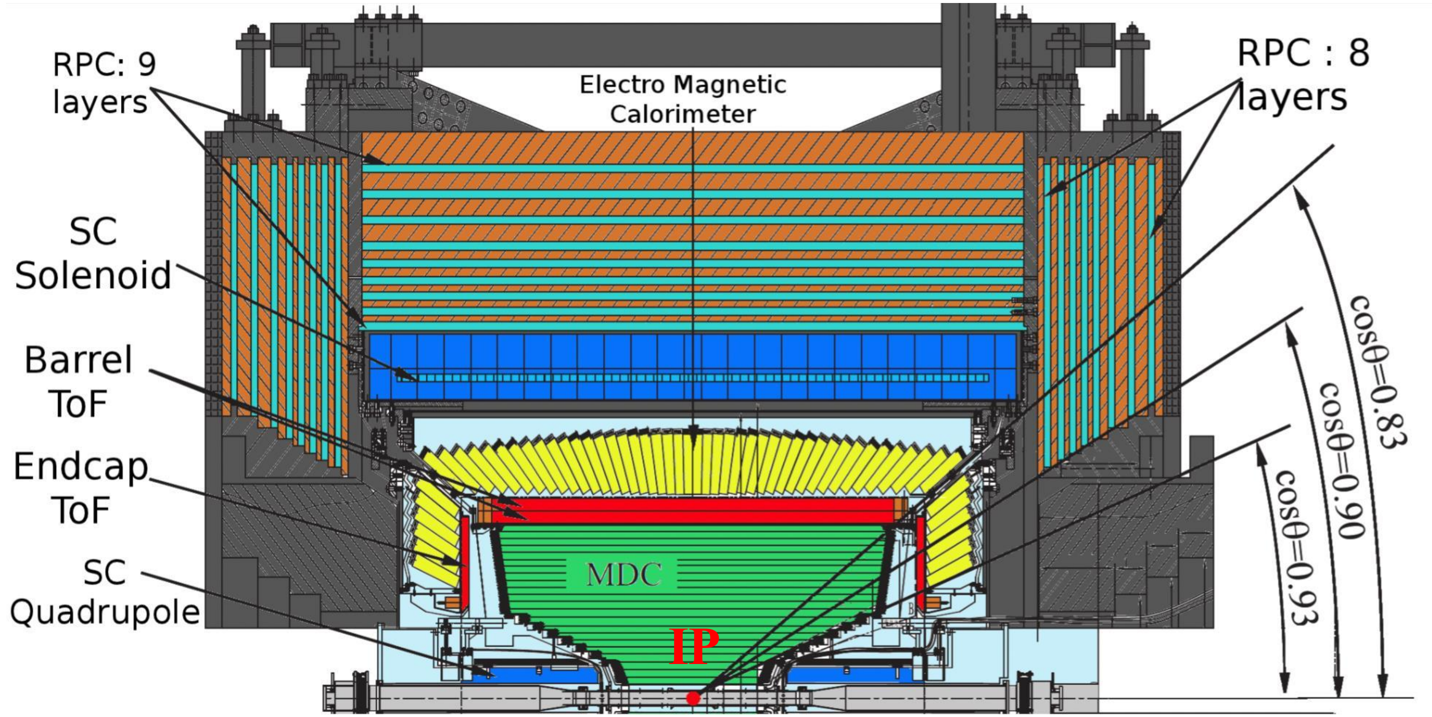


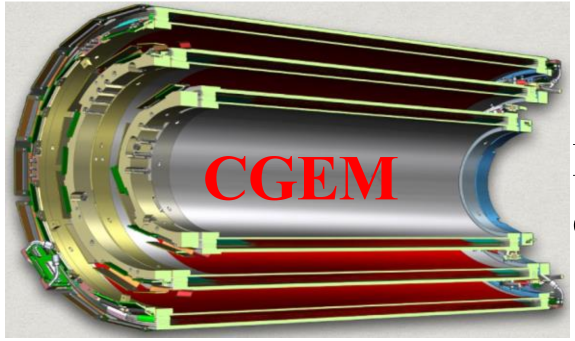
2024.12: BEPCII upgrade to BEPCII-U

- Beam energy up to 2.8 GeV
- Increase luminosity by a factor of 3 @4.68 GeV

2026.04: The peak collision luminosity for online operation at a beam energy of 2.35 GeV has reached the designed $1.06 \times 10^{33} cm^{-2}s^{-1}$ ($3.5 \times 10^{32} cm^{-2}s^{-1}$ before the upgrade)

BESIII detector





BESIII has replaced the inner part of the drift chamber with a three layers of CGEM detector.

Multi-layer Drift Chamber

Single wire $\sigma_{r\phi}$(1 GeV)	130 μm
σ_z (1 GeV)	~2 mm
σ_z (1 GeV)	0.5 %
$\sigma_{dE/dx}$(1 GeV)	6%

Time of Flight Detector

σ_t	~68 ps (barrel)
	~60 ps (end cap)

EM Calorimeter

σ_E/E (1 GeV)	2.5%
Position resolution (1 GeV)	0.6 cm

Muon Detector

No. of layers (barrel/end cap)	9/8
Cut – off momentum	0.4 GeV/c