Recent results on conventional charmonia at BESIII

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Main contents

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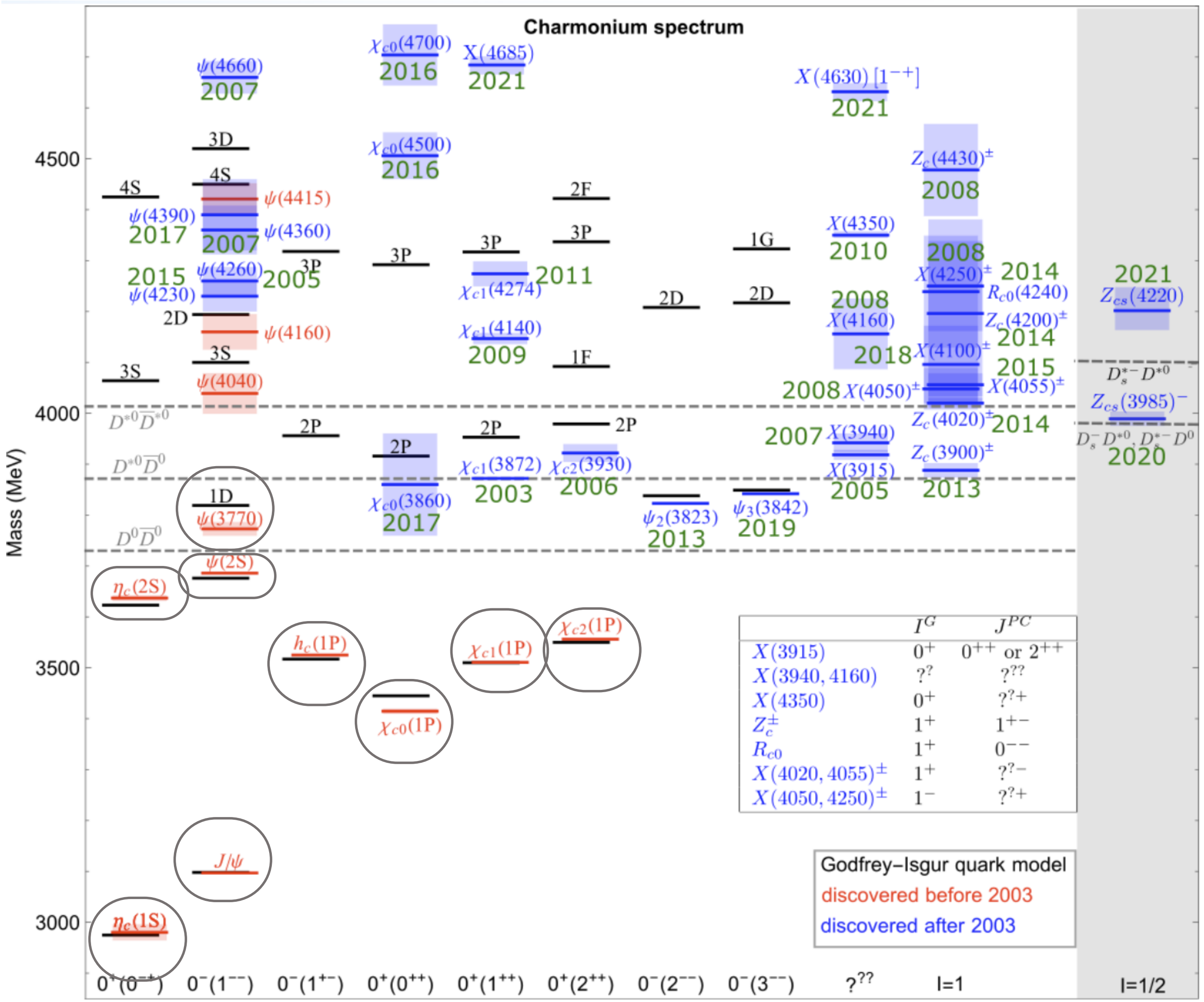
- Decays or production of $\psi(3770)$、J/ψ、 $\psi(3686)$
- Decays of $\eta_c(1S)$、$\eta_c(2S)$、 χ_{cJ} via ψ radiative decays
- Decays of h_c via $\psi(3686) \rightarrow h_c\pi^0$
- Summary

Introduction and data samples

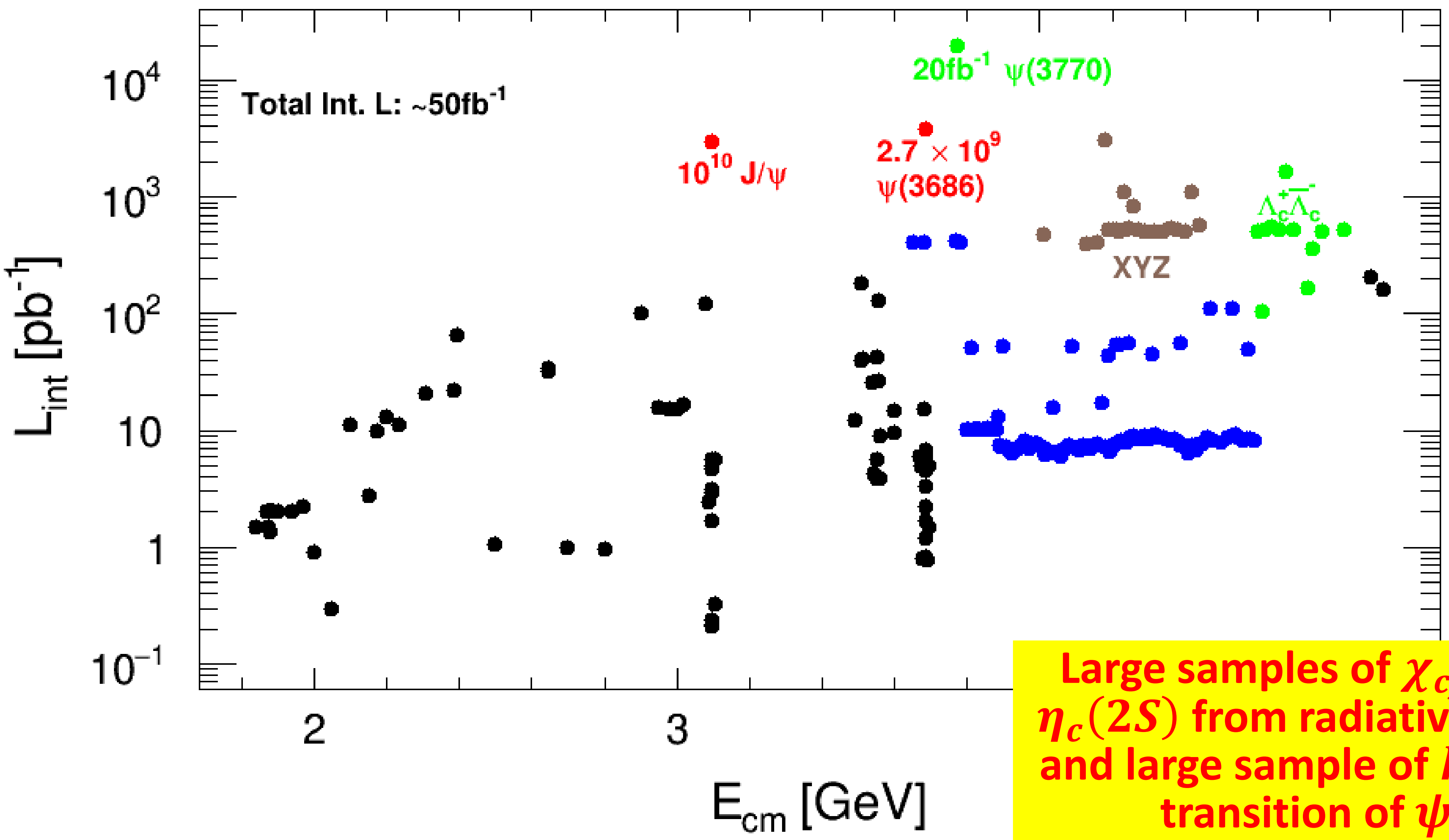
Charmonium spectroscopy



From F. K. Guo

- **Charmonium resonances lie in a transition region perturbative and non-perturbative QCD**
- **Experimental measurements → test theoretical predictions in the low energy regime of QCD**

World largest J/ψ、ψ(3686)、ψ(3770) data samples



Large samples of χ_{cJ}、$\eta_c(1S)$、$\eta_c(2S)$ from radiative decays of ψ, and large sample of h_c from pionic transition of $\psi(3686)$

One selected topic: $\psi(3770) \to \mathrm{non}-D\bar{D}$ decays

- **The decays of ψ(3770) are dominated by $D\bar{D}$ mode:**

  BESII[PLB641(2006)145]**:** $B[\psi(3770) \to \mathrm{non}-D\bar{D}] = (\mathbf{14.7} \pm \mathbf{3.2})\%$

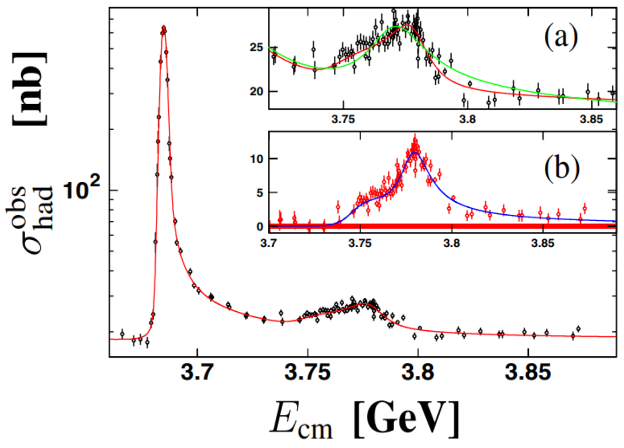
  CLEO[PRD96(2006)092002]**:** $B[\psi(3770) \to \mathrm{non}-D\bar{D}] = (-\mathbf{3.3} \pm \mathbf{1.4}^{+6.6}_{-1.8})\%$

  PDG24: $B[\psi(3770) \to D\bar{D}] = (\mathbf{93}^{+8}_{-9})\%$

- **NRQCD calculation**[PRL101, 112001] **gives an upper limit of 5% for light hadron decays, while other phenomenological model, e.g., hadron loops give large fraction**[PRL102, 172001]

Search for ψ decays at BESII and CLEO were usually made by comparing ψ and off-resonance data, will these affect test of 12% rule and search for $\psi(3770) \to \mathrm{non}-D\bar{D}$ decays?

BESII PRL101, 102004 (2008)



Abnormal structure around $\psi(3770)$ was observed at BESII. Will this anomalous structure affect the BFs of exclusive $\psi(3770) \to \mathrm{non}-D\bar{D}$ decays?

- **Search for ψ decays via fine scan data is helpful and highly desirable**

Other physics topics

- **Test of the 12% rule, understand ρπ puzzle in ψ decays**

$$\frac{\mathrm{Br}(\eta_c(2S)\to h)}{\mathrm{Br}(\eta_c\to h)} \approx \frac{\mathrm{Br}(\psi(3686)\to h)}{\mathrm{Br}(J/\psi\to h)} = 0.128$$

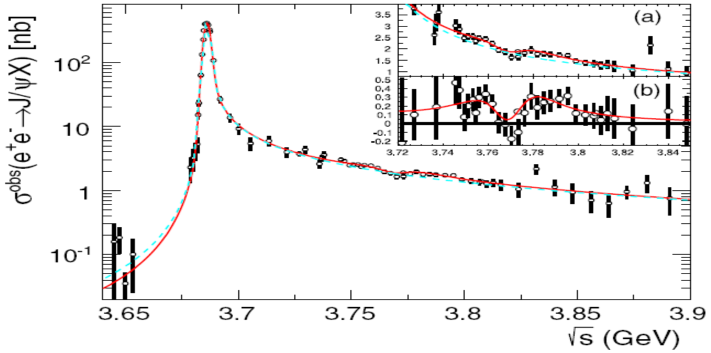
- **Radiative, rare or suppressed decays → test theoretical calculations**
- PP、VV、$B\bar{B}$ **decays → parameters and properties**
- $B\bar{B}X(X=P$、$V)$ **decays → threshold structure and excited baryons**
- **Large room for unmeasured BFs → search for their new decay modes**

Decays or production of $\psi(3770)$、J/ψ、 $\psi(3686)$

Production and decays around $\psi(3770)$

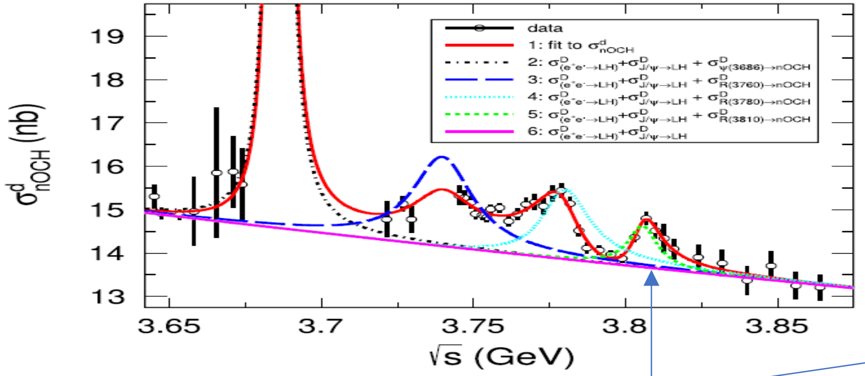
$e^+e^- \to J/\psi X$

PRL127, 082002 (2021)



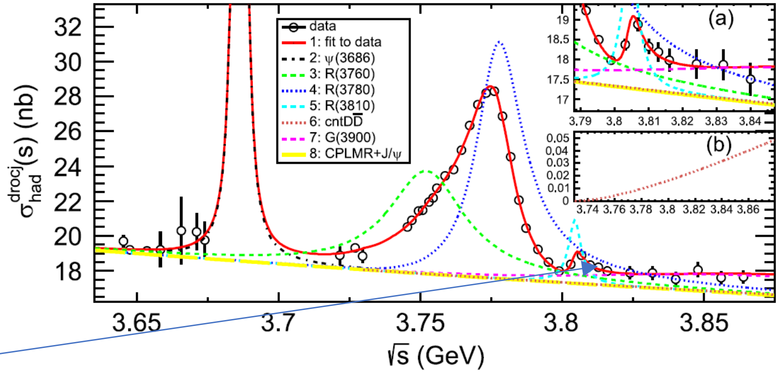
$e^+e^- \to hadrons[non - D\bar{D}]$

PRL132, 191902 (2024)



$e^+e^- \to hadrons$

PRL133, 241902 (2024)



- Strange structures other simple BW of ψ(3770) are found in different processes
- Structure@~3.81 GeV is found in papers 2 and 3
- $B[R \to non - D\bar{D}]$ are extracted in papers 1 and 2

$$\sigma^{\text{dress}}(s') = |A_{\psi(3686)}(s') + e^{i\phi_1}A_{\psi(3770)}(s')^2 + e^{i\phi_2}A_S(s')|^2$$

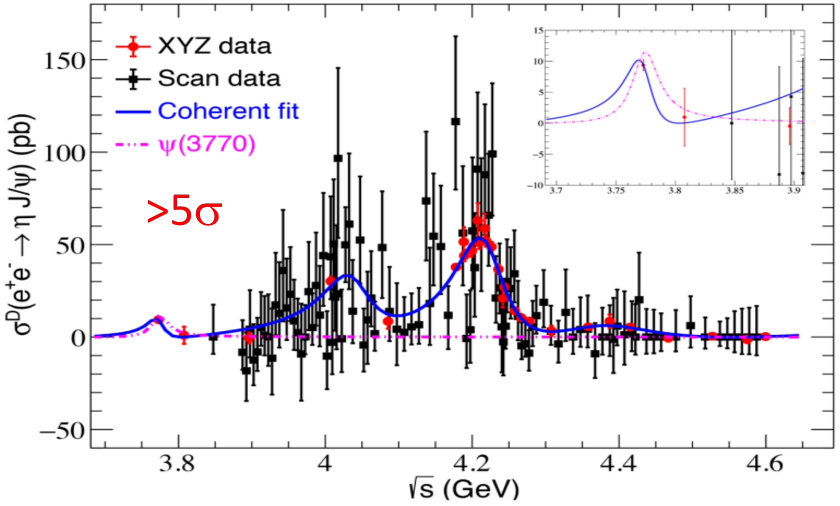
Parameter	Solution I	Solution II
$\mathcal{B}(\mathcal{R}_1 \to f)$	$62.8 \pm 0.6 \pm 1.7$	$62.3 \pm 0.8 \pm 1.6$
$M_{\mathcal{R}_2}$	3773.13	3773.13
$\Gamma^{\text{tot}}_{\mathcal{R}_2}$	27.2	27.2
$\mathcal{B}(\mathcal{R}_2 \to f)$	$55.1 \pm 36.2 \pm 6.3$	$38.1 \pm 41.4 \pm 4.3$
ϕ_1 (degree)	$175 \pm 30 \pm 30$	$60 \pm 37 \pm 10$
$M_{\mathcal{R}_3}$	$3766.2 \pm 3.1 \pm 0.4$	$3766.2 \pm 3.8 \pm 0.4$
$\Gamma^{\text{tot}}_{\mathcal{R}_3}$	$22.1 \pm 5.2 \pm 1.4$	$22.2 \pm 5.9 \pm 1.4$
$\Gamma^{ee}_{\mathcal{R}_3}\mathcal{B}(\mathcal{R}_3 \to f)$	$110.2 \pm 134.4 \pm 16.2$	$79.4 \pm 85.5 \pm 11.7$
ϕ_2	$322 \pm 34 \pm 30$	$213 \pm 48 \pm 20$

Parameters	Result I	Result II
$M_{\mathcal{R}(3760)}$	$3739.9 \pm 4.2 \pm 2.6$	$3739.7 \pm 3.9 \pm 2.6$
$\Gamma^{\text{tot}}_{\mathcal{R}(3760)}$	$23.9 \pm 8.2 \pm 4.8$	$22.5 \pm 8.3 \pm 4.5$
$\Gamma^{ee}_{\mathcal{R}(3760)}\mathcal{B}_{\mathcal{R}(3760)}$	$46.8 \pm 29.9 \pm 25.1$	$11.9 \pm 9.0 \pm 6.4$
$\phi_{\mathcal{R}(3760)}$	$228 \pm 52 \pm 58$	$113 \pm 51 \pm 29$
$\Gamma^{ee}_{\mathcal{R}(3780)}\mathcal{B}_{\mathcal{R}(3780)}$	$29.9 \pm 16.1 \pm 3.7$	$25.3 \pm 11.6 \pm 3.1$
$\phi_{\mathcal{R}(3780)}$	$82 \pm 126 \pm 17$	$250 \pm 119 \pm 52$
$M_{\mathcal{R}(3810)}$	$3805.7 \pm 1.1 \pm 2.7$	$3805.7 \pm 1.1 \pm 2.7$
$\Gamma^{\text{tot}}_{\mathcal{R}(3810)}$	$11.6 \pm 2.9 \pm 1.9$	$11.5 \pm 2.8 \pm 1.9$
$\Gamma^{ee}_{\mathcal{R}(3810)}\mathcal{B}_{\mathcal{R}(3810)}$	$10.9 \pm 3.8 \pm 2.5$	$11.0 \pm 3.4 \pm 2.5$
$\phi_{\mathcal{R}(3810)}$	$52 \pm 149 \pm 25$	$215 \pm 148 \pm 103$
f	$2.28 \pm 0.01 \pm 0.07$	$2.28 \pm 0.01 \pm 0.07$
$\mathcal{B}[\mathcal{R}(3760) \to \text{nOCH}]$	$25.2 \pm 16.1 \pm 30.4$	$6.4 \pm 4.8 \pm 7.7$
$\mathcal{B}[\mathcal{R}(3780) \to \text{nOCH}]$	$12.3 \pm 6.6 \pm 8.3$	$10.4 \pm 4.8 \pm 7.0$
$\mathcal{B}[\mathcal{R}(3760) \to \text{OC}]$	$74.8 \pm 16.1 \pm 30.4$	$93.6 \pm 4.8 \pm 7.7$
$\mathcal{B}[\mathcal{R}(3780) \to \text{OC}]$	$87.7 \pm 6.6 \pm 8.3$	$89.6 \pm 4.8 \pm 7.0$

Parameters	Solution I	Solution II
$M_{\mathcal{R}(3760)}$	$3752.6 \pm 4.2 \pm 2.8$	$3751.9 \pm 3.8 \pm 2.8$
$\Gamma^{\text{tot}}_{\mathcal{R}(3760)}$	$31.7 \pm 5.7 \pm 8.4$	$32.8 \pm 5.8 \pm 8.7$
$\Gamma^{ee}_{\mathcal{R}(3760)}$	$206 \pm 83 \pm 96$	$184 \pm 75 \pm 86$
ϕ_1	$-70 \pm 23 \pm 39$	$-49 \pm 29 \pm 27$
$M_{\mathcal{R}(3780)}$	$3778.6 \pm 0.5 \pm 0.3$	$3778.7 \pm 0.5 \pm 0.3$
$\Gamma^{\text{tot}}_{\mathcal{R}(3780)}$	$20.3 \pm 0.8 \pm 1.7$	$20.3 \pm 0.8 \pm 1.7$
$\Gamma^{ee}_{\mathcal{R}(3780)}$	$243 \pm 61 \pm 76$	$265 \pm 69 \pm 83$
ϕ_2	$131 \pm 16 \pm 15$	$151 \pm 23 \pm 17$
$M_{\mathcal{R}(3810)}$	$3804.5 \pm 0.9 \pm 0.9$	$3804.5 \pm 0.9 \pm 0.9$
$\Gamma^{\text{tot}}_{\mathcal{R}(3810)}$	$5.6 \pm 3.6 \pm 3.4$	$5.4 \pm 3.5 \pm 3.2$
$\Gamma^{ee}_{\mathcal{R}(3810)}$	$2.3 \pm 0.8 \pm 1.4$	$19.4 \pm 7.4 \pm 12.1$
ϕ_3	$81 \pm 22 \pm 18$	$-11 \pm 20 \pm 2$
f_c	$2.743 \pm 0.019 \pm 0.081$	$2.741 \pm 0.019 \pm 0.081$

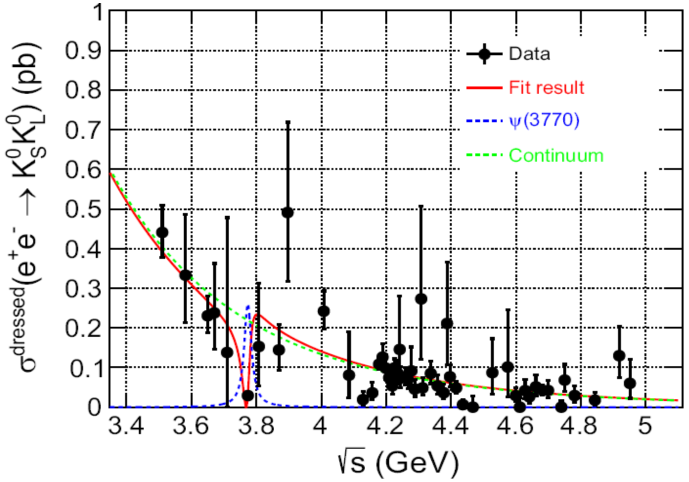
Measured exclusive non-$D\bar{D}$ decays of $\psi(3770)$

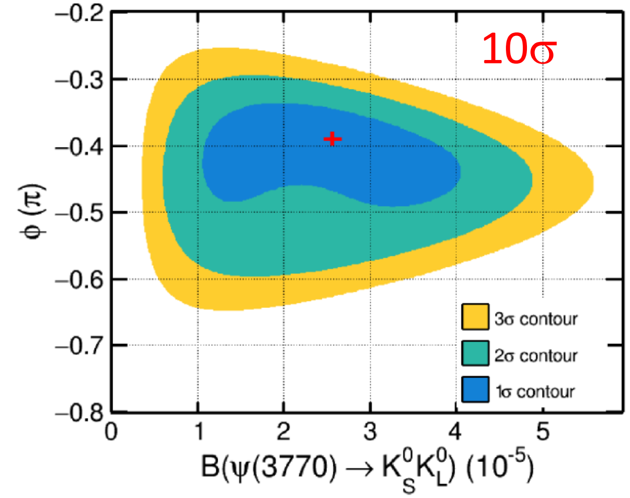
$\psi'' \to J/\psi\eta$ PRD 107, L091101 (2023)



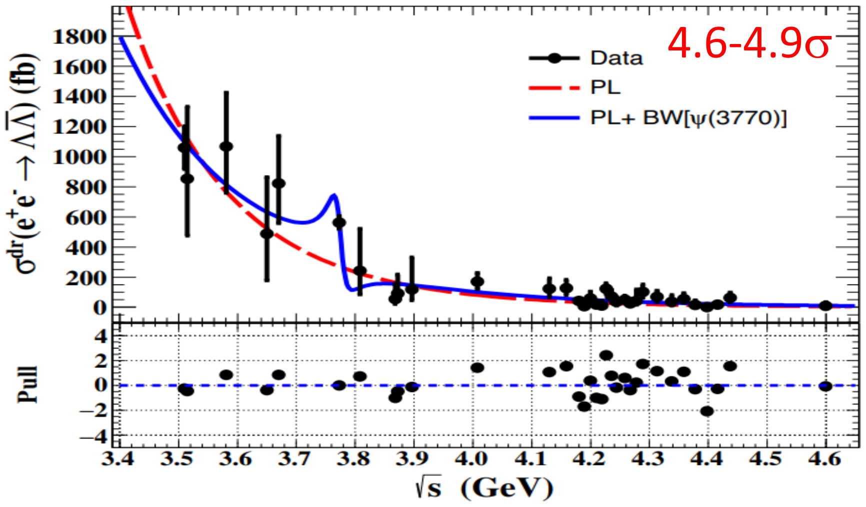
$$\sigma^{\text{dressed}} = \left| BW \cdot e^{i\phi} + \frac{a}{(\sqrt{s})^n} \cdot \sqrt{\Phi(\sqrt{s})} \right|^2$$

$\psi'' \to K_S^0 K_L^0$ PRL 132, 131901 (2024)

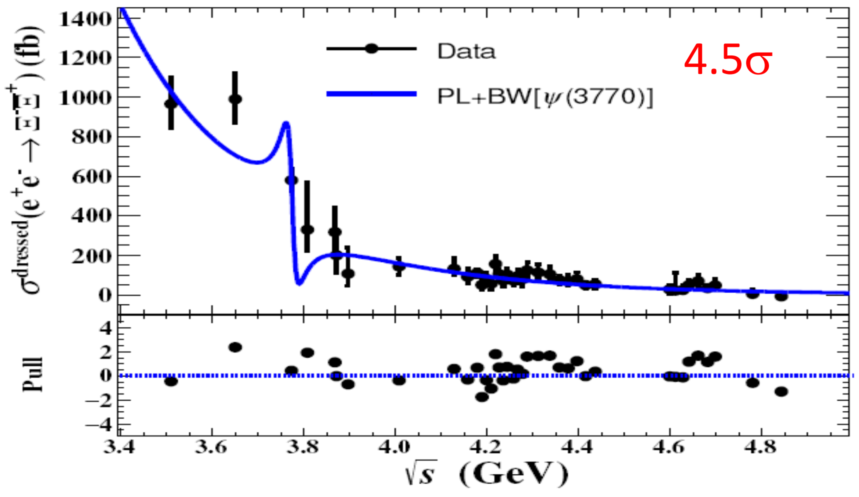




$\psi'' \to \Lambda\bar{\Lambda}$ PRD 104, L091104 (2021)

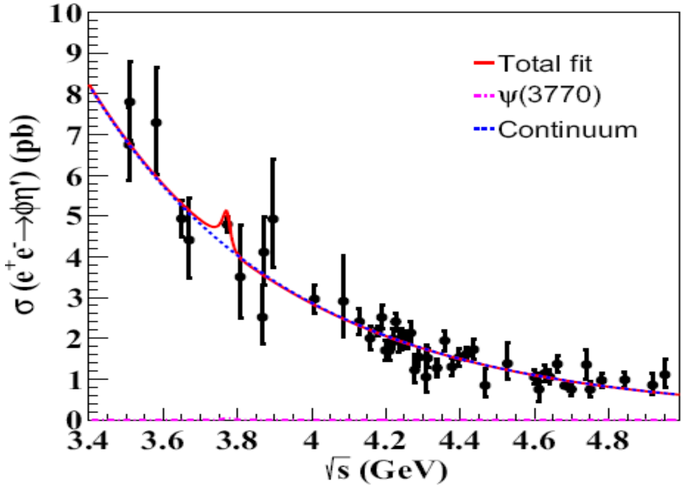


$\psi'' \to \Xi^-\bar{\Xi}^+$ JHEP11(2023)228

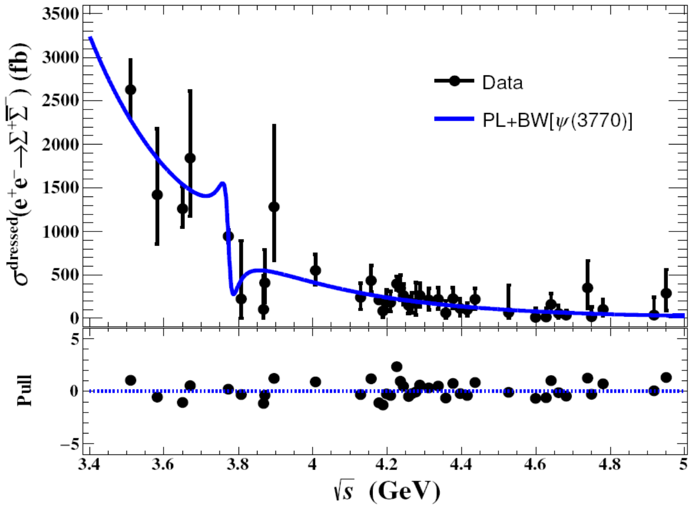


Search for exclusive non-$D\bar{D}$ decays of $\psi(3770)$

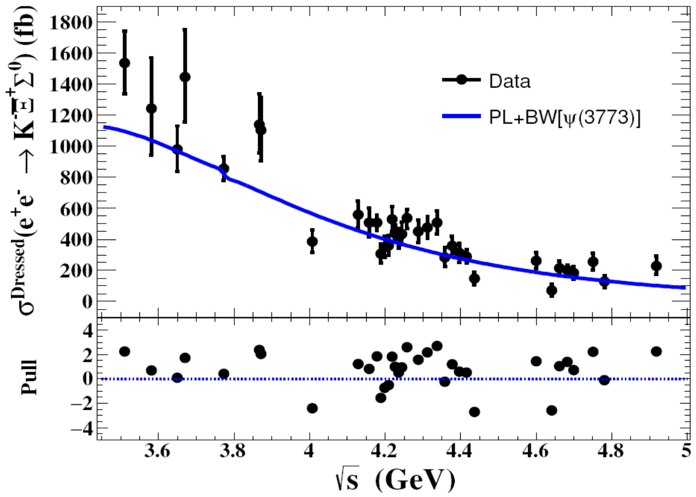
$\psi'' \to \phi\eta'$ PRD108, 052015 (2023)



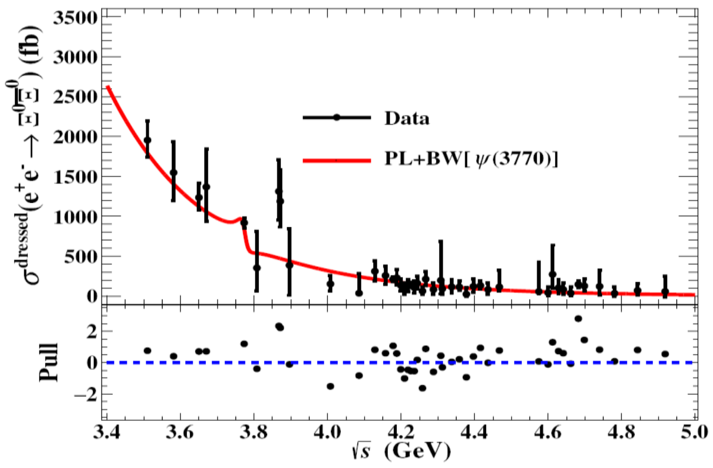
$\psi'' \to \Sigma^+\bar{\Sigma}^-$ JHEP05(2024)022



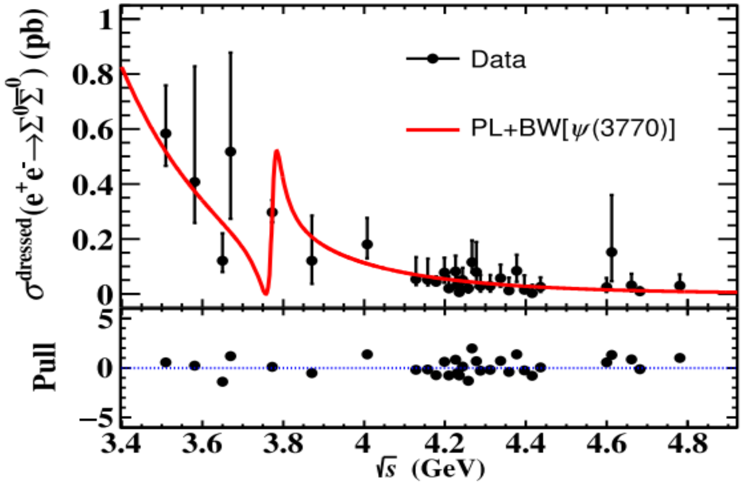
$\psi'' \to K^-\Lambda\bar{\Xi}^+ + c.c.$ JHEP07(2024)258



$\psi'' \to \Xi^0\bar{\Xi}^0$ JHEP11(2024)062

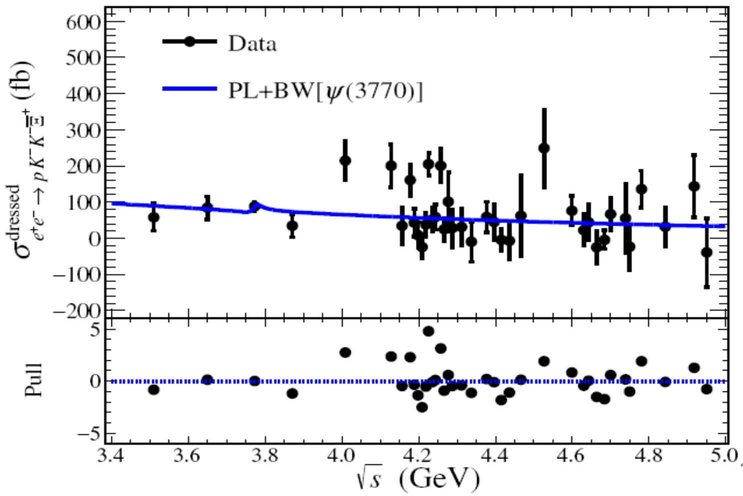


$\psi'' \to \Sigma^0\bar{\Sigma}^0$ PRD 111, L051502 (2025)



$\psi'' \to pK^-K^-\bar{\Xi}^+ + c.c.$

arXiv:2508.11276



BFs of exclusive non-$D\bar{D}$ decays of $\psi(3770)$

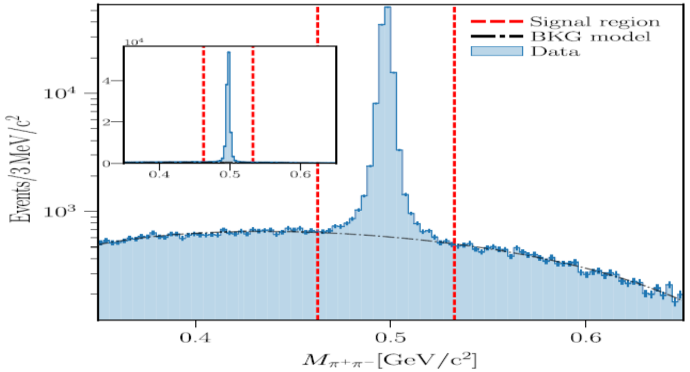
Decay	B	Φ	Reference
$\psi'' \to J/\psi\eta$ (10^{-4})	$11.3 \pm 5.9 \pm 1.1$	$(3.9 \pm 0.6 \pm 0.1)\,\pi$	PRD107, L091101
$\psi'' \to K_S^0 K_L^0$ (10^{-5})	$2.6^{+1.4}_{-1.6}$	$(-0.39^{+0.05}_{-0.10})\pi$	PRL132, 131901
$\psi'' \to \Lambda\bar{\Lambda}$ (10^{-5})	$2.4^{+15.0}_{-1.9}/14.4^{+2.7}_{-14.0}$	$(183^{+57}_{-40})^\circ/(240^{+17}_{-115})^\circ$	PRD104, L091104
$\psi'' \to \Xi^-\bar{\Xi}^+$ (10^{-6})	136.0 ± 35.2	$(59 \pm 14)^\circ$	JHEP11(2023)228
$\psi'' \to \phi\eta'$	$<2.3\times10^{-5}$	$\sim2.8\pi$	PRD108, 052015
$\psi'' \to \Xi^0\bar{\Xi}^0$	$<3.4\times10^{-4}$	$(-1.7 \pm 0.2)\pi$	JHEP11(2024)062
$\psi'' \to \Sigma^+\bar{\Sigma}^-$	$<3.9\times10^{-4}$	$(-2.0 \pm 0.4)\pi$	JHEP05(2024)022
$\psi'' \to \Sigma^0\bar{\Sigma}^0$	$<3.7\times10^{-5}$	$(-0.8 \pm 0.1)\pi$	PRD111, L051502
$\psi'' \to K^-\Lambda\bar{\Xi}^+ + c.c.$	$<3.4\times10^{-4}$	$(-1.6 \pm 0.2)\pi$	JHEP07(2024)258
$\psi'' \to pK^-K^-\bar{\Xi}^+ + c.c.$	$<3.7\times10^{-5}$	$(-1.6 \pm 0.2)\pi$	arXiv:2508.11276

- The BF of $\psi'' \to K_S^0 K_L^0$ agrees well with the prediction via S- and D-wave charmonia mixing scheme[PRD78, 077505 (2004)], proposed to interpret "ρπ puzzle" between J/ψ and ψ(3686) decays
- The BF of $\psi'' \to \Xi^-\bar{\Xi}^+$ is higher than theoretical calculation by an order of magnitude[PRD96, 092004 (2017)]
- The measured BFs of $\psi'' \to$ light hadrons may be up to the same level as their ψ' counterparts

Measurements of $B\bar{B}X$ decays of J/ψ

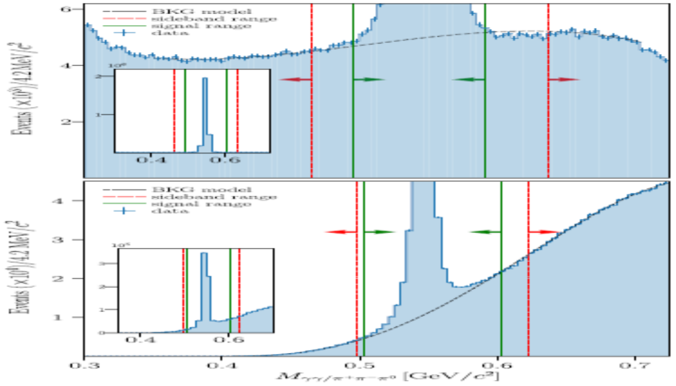
$J/\psi \to \bar{p}\Sigma^+K_S^0 + c.c$

首次测量　PRD109, 012006 (2024)



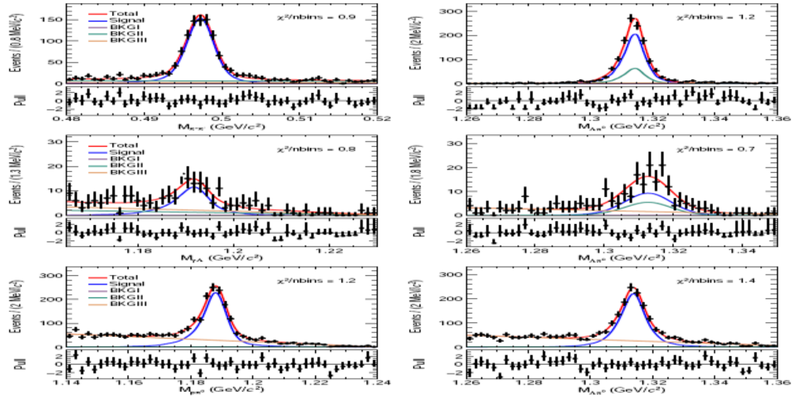
$J/\psi \to p\bar{p}\eta$

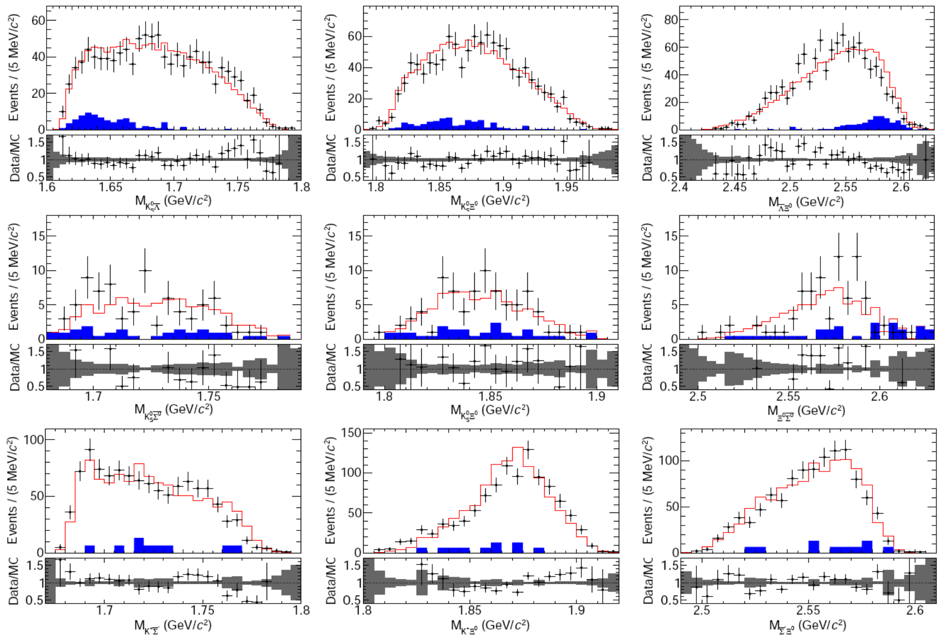
PRD110, 072021 (2024)



$J/\psi \to \Xi^0\bar{\Lambda}/\bar{\Sigma}K$+c.c.

首次测量　arXiv:2510.08147v1





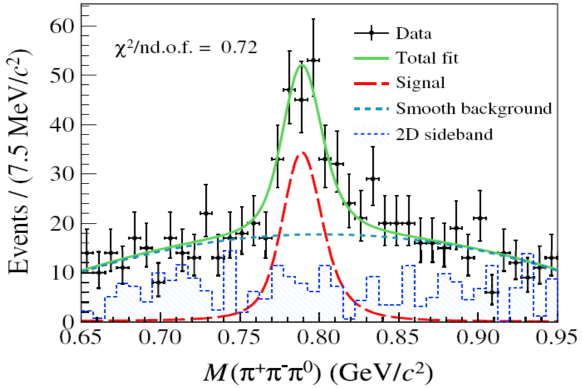
Decay	B (10^{-4})	Reference	B^{PDG} (10^{-4})
$J/\psi \to \bar{p}\Sigma^+K_S^0 + c.c.$	$2.725 \pm 0.009 \pm 0.050$	PRD109, 012006	NA
$J/\psi \to p\bar{p}\eta$	$1.495 \pm 0.001 \pm 0.023$	PRD110, 072021	1.91 ± 0.17
$J/\psi \to \Xi^0\bar{\Lambda}K_S^0 + c.c.$	$0.376 \pm 0.014 \pm 0.022$	arXiv:2510.08147v1	NA
$J/\psi \to \Xi^0\bar{\Sigma}^0K_S^0 + c.c.$	$0.224 \pm 0.032 \pm 0.022$		NA
$J/\psi \to \Xi^0\bar{\Sigma}^-K^+ + c.c$	$0.564 \pm 0.017 \pm 0.027$		NA

No obvious structures under current statistics

Observation of $B\bar{B}X$ decays of $\psi(3686)$

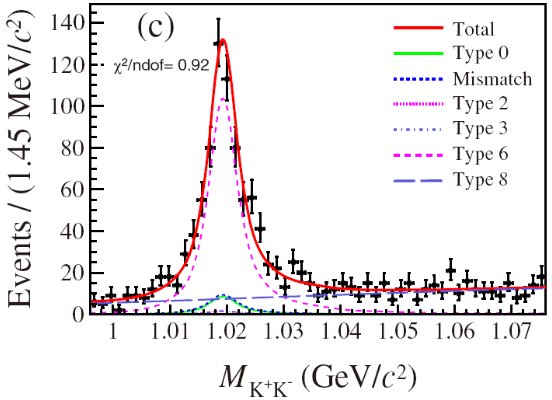
PRD111, 092007 (2025)

$\psi' \to \Sigma^0\bar{\Sigma}^0\omega$



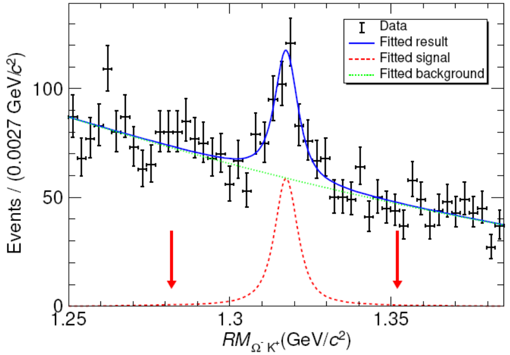
PRD111, 052012 (2025)

$\psi' \to \Sigma^0\bar{\Sigma}^0\phi$



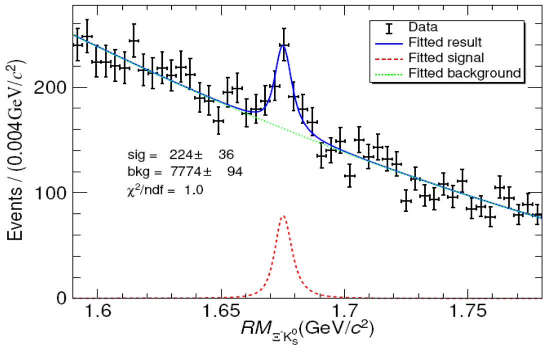
JHEP04(2024)013

$\psi' \to \Omega^- K^+ \bar{\Xi}^0 + c.c$



JHEP06(2025)233

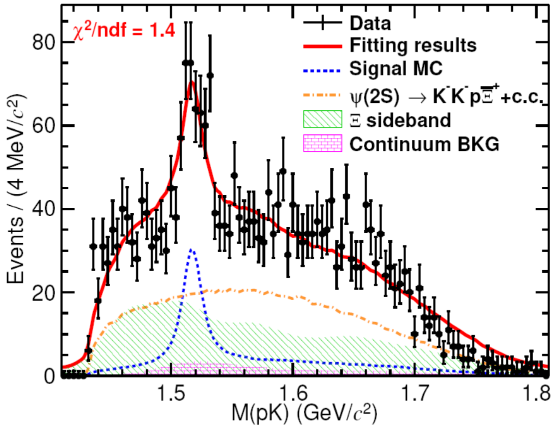
$\psi' \to \Xi^- K_S^0 \bar{\Omega}^+ + c.c$



$$\frac{B[\psi' \to \Xi^- K_S^0 \bar{\Omega}^+ + c.c.]}{B[\psi' \to \Xi^0 K^- \bar{\Omega}^+ + c.c.]} = 1.05 \pm 0.23 \pm 0.14$$

JHEP03(2025)145

$\psi' \to K^- \Lambda(1520)\bar{\Xi}^+ + c.c.$

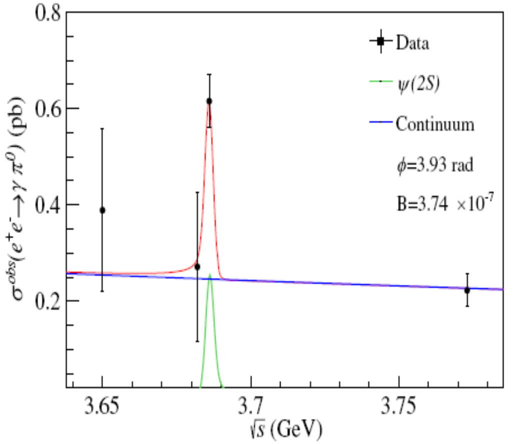


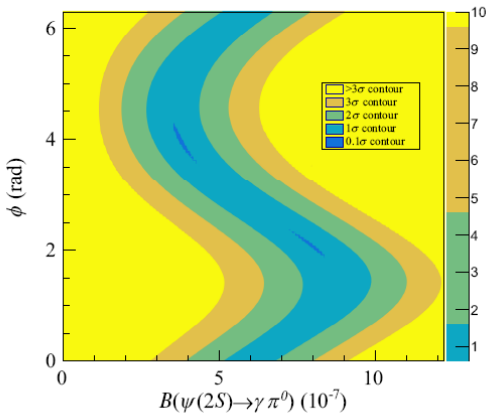
Decay	B (10^{-6})	Reference
$\psi' \to \Sigma^0\bar{\Sigma}^0\omega$	$26.4 \pm 3.2 \pm 1.2$	PRD111, 052012
$\psi' \to \Sigma^0\bar{\Sigma}^0\phi$	$12.6 \pm 1.6 \pm 1.1$	PRD111, 092007
$\psi' \to \Omega^- K^+ \bar{\Xi}^0$	$2.78 \pm 0.40 \pm 0.18$	JHEP04(2024)013
$\psi' \to \Xi^- K_S^0 \bar{\Omega}^+$	$2.91 \pm 0.47 \pm 0.33$	JHEP06(2025)233
$\psi' \to K^- \Lambda(1520)\bar{\Xi}^+$	$0.95 \pm 0.08 \pm 0.10$	JHEP03(2025)145

BFs of $\psi(3686)$ decays via scan data

$\psi(3686) \to \gamma\pi^0$

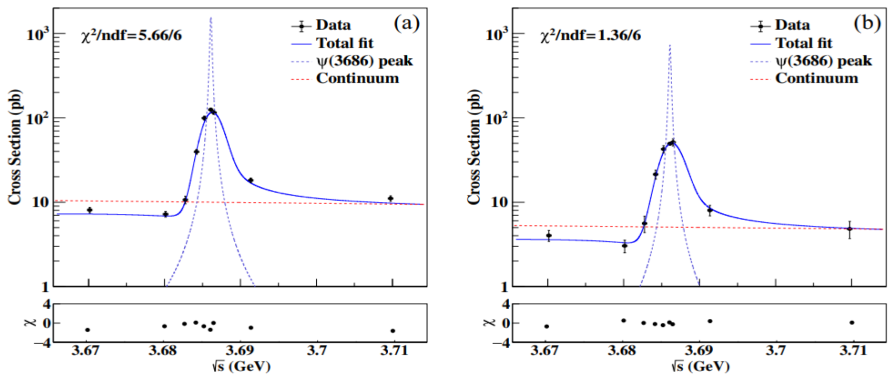
PRD 110, 052011 (2024)





PRD 111, 032011 (2025)

$\psi(3686) \to p\bar{p}\pi^0$ $\psi(3686) \to p\bar{p}\eta$



B$[\psi(3686) \to \gamma\pi^0]$ is determined to be in the range $[2.7,9.7] \times 10^{-7}$ within 1σ of the contour region.

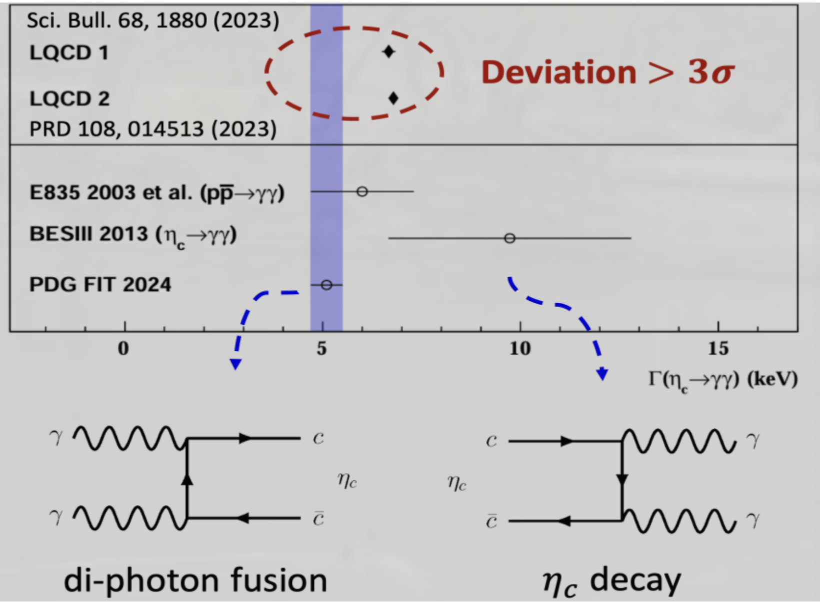
It tends to be smaller than the previous BESIII measurement, $(9.7 \pm 1.6) \times 10^{-7}$, due to interference effects, and is consistent with the VMD prediction within uncertainties

Decay	Solution I		Solution II		Reference
	B (10^{-6})	Φ	B (10^{-6})	ϕ	
$\psi' \to \gamma\pi^0$	0.374	3.93	0.787	2.08	PRD 110, 052011
$\psi' \to p\bar{p}\pi^0$	$133.9 \pm 11.2 \pm 2.3$	$(65 \pm 7)^\circ$	$183.7 \pm 13.7 \pm 3.2$	$(-69 \pm 6)^\circ$	PRD 111, 032011
$\psi' \to p\bar{p}\eta$	$61.5 \pm 6.5 \pm 1.1$	$(59 \pm 14)^\circ$	$84.4 \pm 6.9 \pm 1.4$	$(-64 \pm 12)^\circ$	

Interference between 1^{--} charmonium and continuum amplitudes significantly affects the BF measurement for some charmonium decays

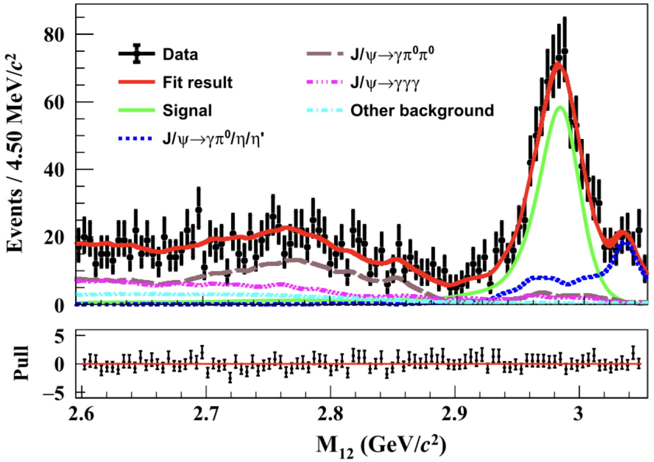
Decays of $\eta_c(1S)$、$\eta_c(2S)$、 χ_{cJ} via ψ radiative decays

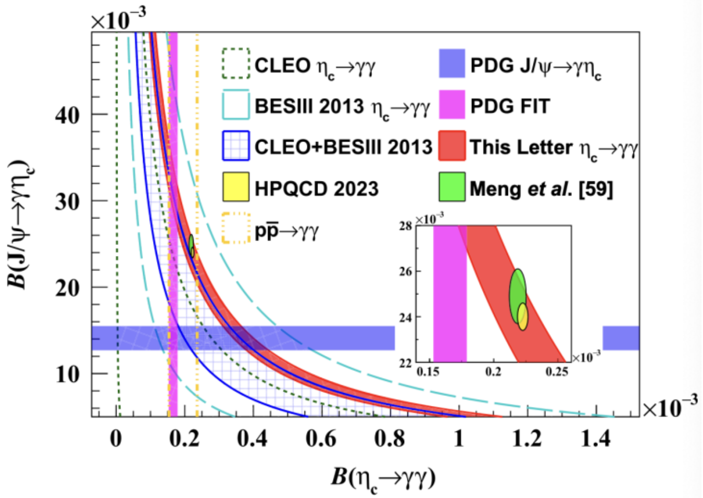
Observation of $\eta_c(1S) \to \gamma\gamma$



- Measurements with the time-inversion process are more precise
- Large discrepancies between different measurements of $\boldsymbol{\gamma\gamma \to \eta_c}$
- **Longstanding puzzle:** theoretical predictions for $\Gamma(\eta_c \to \gamma\,\gamma)$ do not agree with each other or the PDG value

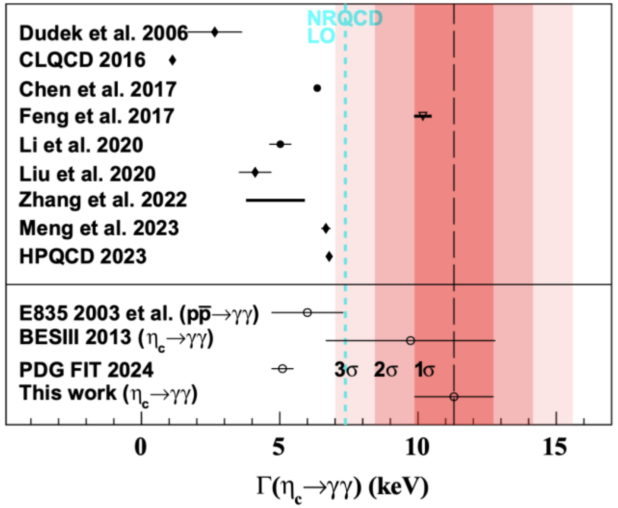
PRL 134 (2025) 181901





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

$$\Gamma[\eta_c \to \gamma\gamma] = \frac{\mathbf{B}[J/\psi \to \gamma\eta_c]\mathbf{B}[\eta_c \to \gamma\gamma]}{\mathbf{B}^{\mathrm{PDG}}[J/\psi \to \gamma\eta_c]} \times \Gamma_{\eta_c}^{\mathrm{PDG}} = (11.3 \pm 0.6 \pm 0.7 \pm 1.1)\ \mathbf{keV}$$

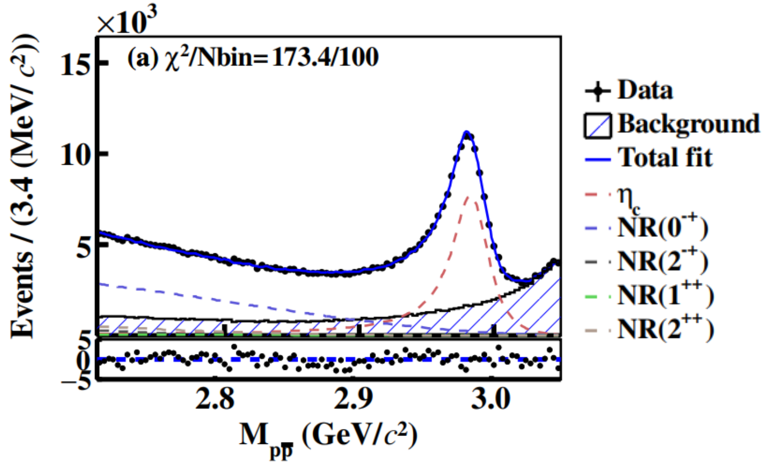


- It is consistent with the LQCD calculation from HPQCD in 2023
- The obtained $\Gamma(\eta_c \to \gamma\gamma)$ deviates from the PDG value by 3.4σ

Study of $J/\psi \to \gamma\eta_c(1S)$ via $\eta_c(1S) \to p\bar{p}$

- 基态粲偶素的辐射跃迁是**研究粲偶素内部结构**的黄金道
- **长期疑难：** $J/\psi \to \gamma\eta_c$和$\eta_c \to \gamma\gamma$分支比，近二十年的**实验测量和格点计算之间存在显著差异**

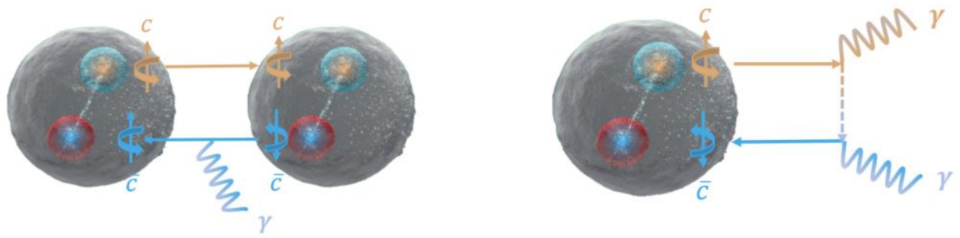
arXiv:2510.15247

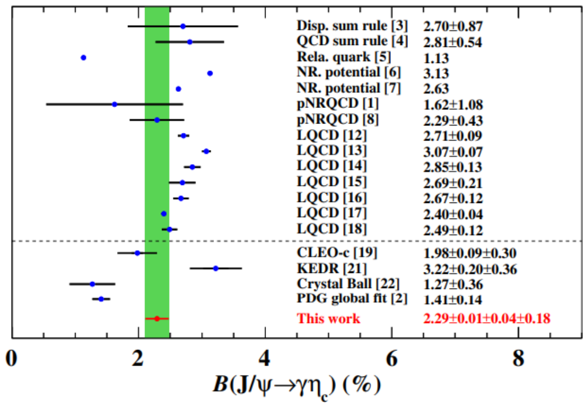


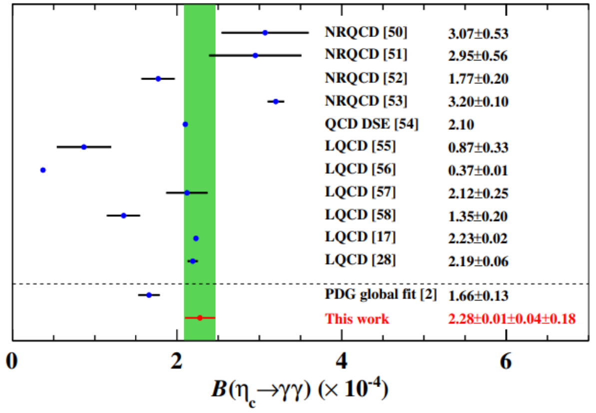
$$\mathcal{B}(J/\psi \to \gamma\eta_c) = \sqrt{\frac{[\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to p\bar{p})] \times [\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to \gamma\gamma)]}{[\mathcal{B}(\eta_c \to p\bar{p}) \times \mathcal{B}(\eta_c \to \gamma\gamma)]}} = (2.29 \pm 0.01 \pm 0.04 \pm 0.18)\%$$

$$\mathcal{B}(\eta_c \to \gamma\gamma) = \sqrt{\frac{[\mathcal{B}(\eta_c \to p\bar{p}) \times \mathcal{B}(\eta_c \to \gamma\gamma)] \times [\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to \gamma\gamma)]}{[\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to p\bar{p})]}} = (2.28 \pm 0.01 \pm 0.04 \pm 0.18) \times 10^{-4}$$

$$\mathcal{B}(\eta_c \to p\bar{p}) = \sqrt{\frac{[\mathcal{B}(\eta_c \to p\bar{p}) \times \mathcal{B}(\eta_c \to \gamma\gamma)] \times [\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to p\bar{p})]}{[\mathcal{B}(J/\psi \to \gamma\eta_c) \times \mathcal{B}(\eta_c \to \gamma\gamma)]}} = (0.92 \pm 0.01 \pm 0.02 \pm 0.07) \times 10^{-3}$$





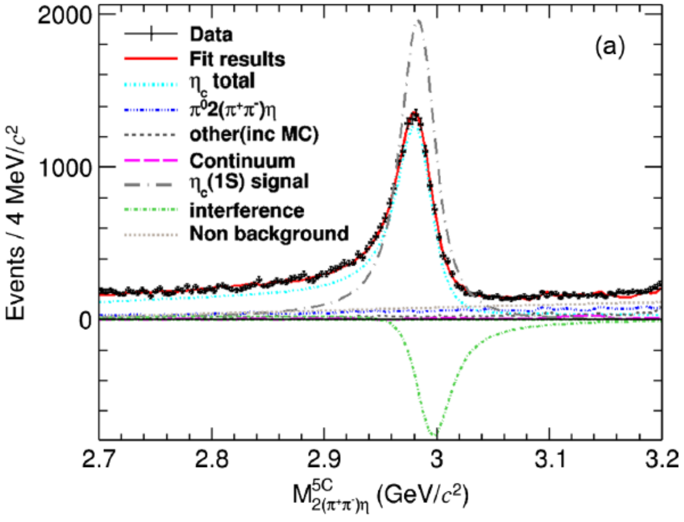


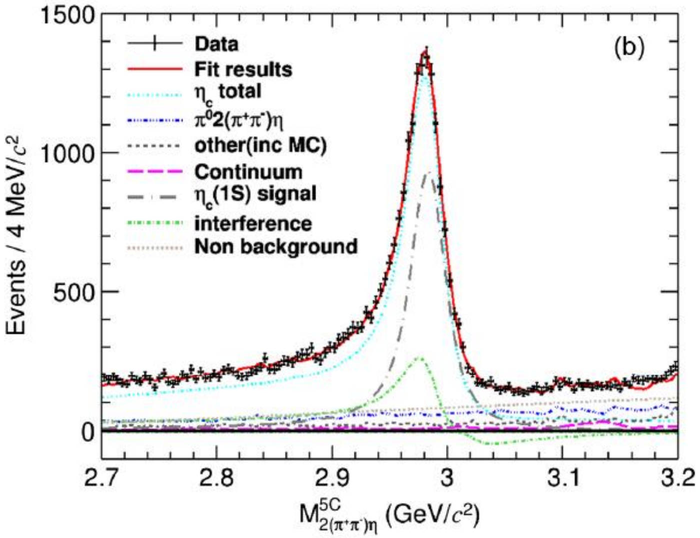
- 首次采用**振幅分析方法**，在$J/\psi \to \gamma p\bar{p}$抽取过程中抽取了$\eta_c$的贡献**（分支比、质量、宽度）**
- 联合两个其他级联过程，**给出了**$J/\psi \to \gamma\eta_c$以及$\eta_c \to \gamma\gamma$的分支比
- **测量结果与最新的格点计算符合，与PDG值偏离3σ**

Precise measurement of mass and width of η_c

Observation of $\eta_c(1S) \to 2\pi^+2\pi^-\eta$

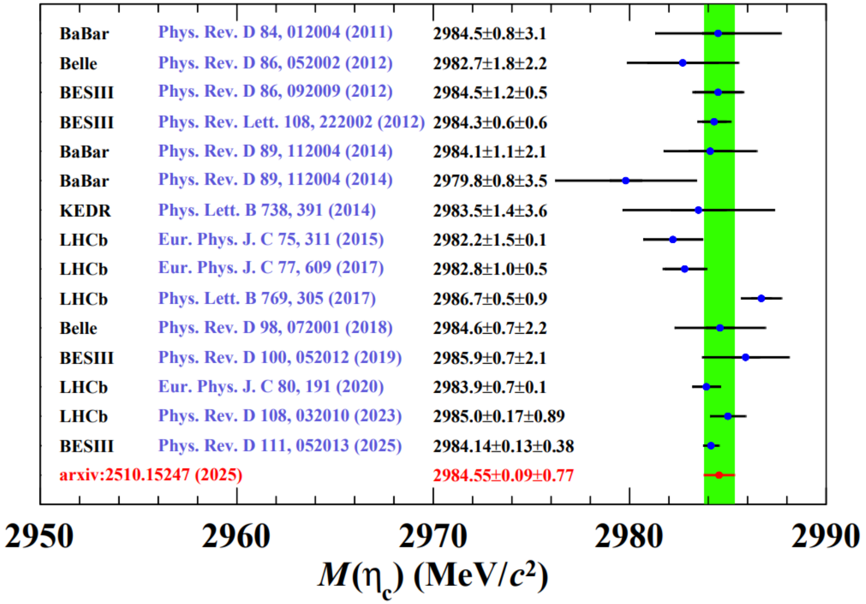
PRD 111, 052013 (2025)

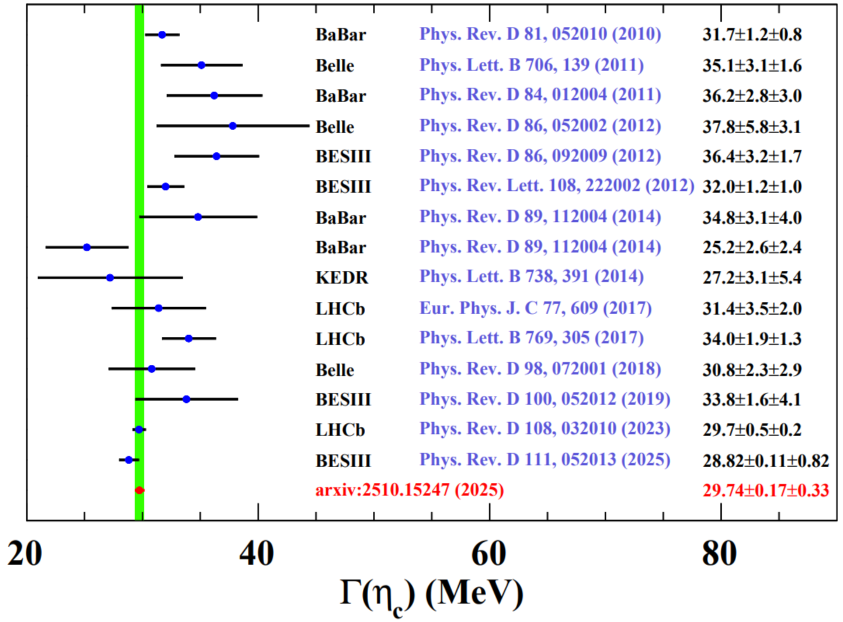




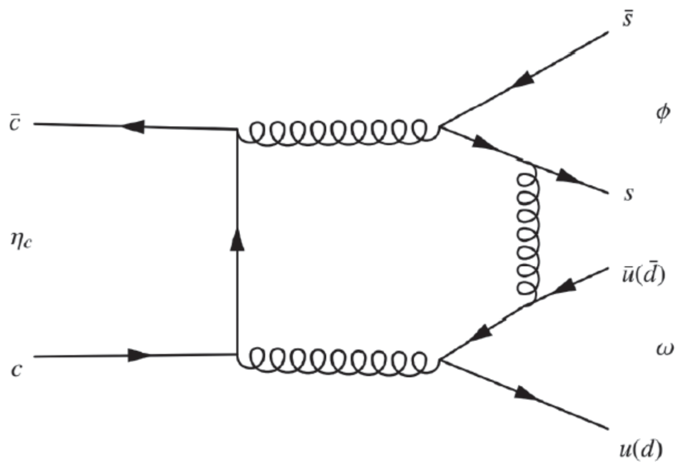
Solution	Destructive	Constructive
Mass (MeV/c^2)	$2984.14 \pm 0.12 \pm 0.34$	$2984.13 \pm 0.13 \pm 0.38$
Width (MeV)	$28.82 \pm 0.11 \pm 0.81$	$28.81 \pm 0.11 \pm 0.82$
$\mathcal{B}$ (%)	$5.5 \pm 0.5 \pm 1.9$	$2.6 \pm 0.4 \pm 1.3$

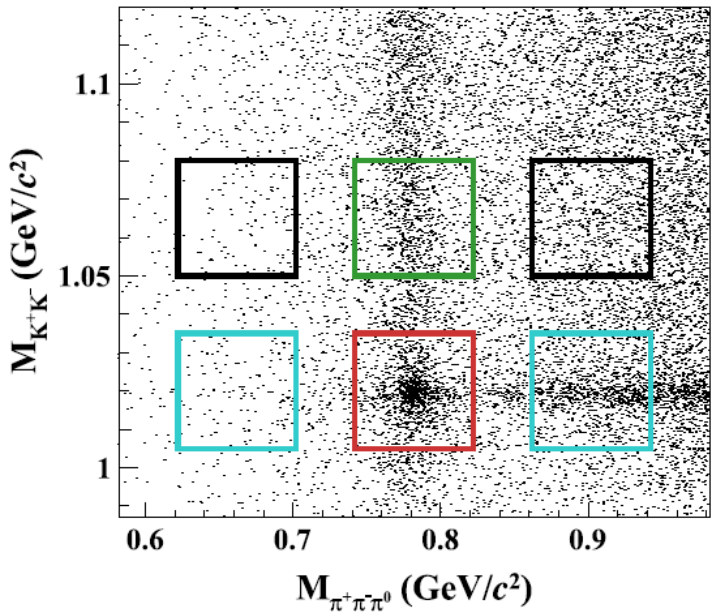
$$\frac{\mathcal{B}(\eta_c(2S) \to 2(\pi^+\pi^-)\eta)}{\mathcal{B}(\eta_c \to 2(\pi^+\pi^-)\eta)} = \begin{cases} 0.22 \pm 0.14 & \text{(destructive)} \\ 0.47 \pm 0.34 & \text{(constructive)} \end{cases}$$





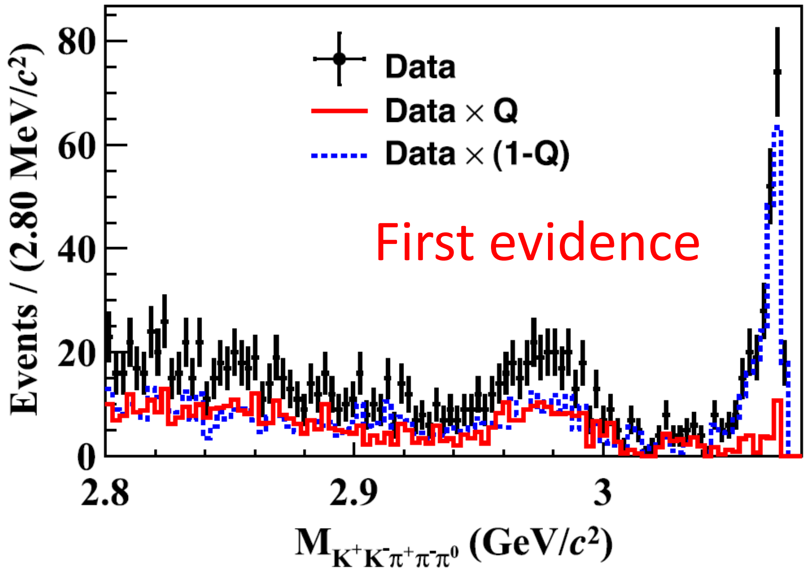
Evidence for double OZI decay $\eta_c(1S) \to \omega\phi$





- The decays $\boldsymbol{\eta_c} \to VV$ are OZI suppressed
- Previously, the decays of $\boldsymbol{\eta_c} \to \omega\omega$ and $\boldsymbol{\eta_c} \to \phi\phi$ have been well measured, but only upper limit on $\boldsymbol{\eta_c} \to \omega\phi$

PRD 112 (2025) 012012

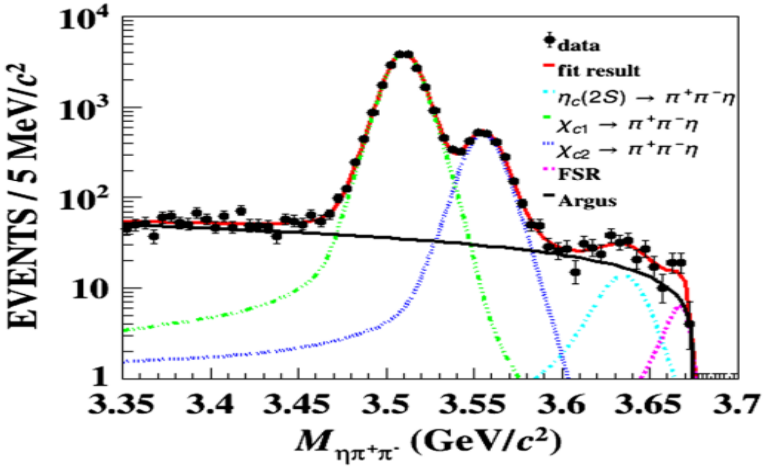


$$\mathcal{B}(\eta_c \to \omega\phi) = \frac{N_{\text{obs}}}{N_{J/\psi} \cdot \mathcal{B}_{J/\psi} \cdot \mathcal{B}_\phi \cdot \mathcal{B}_\omega \cdot \mathcal{B}_{\pi^0} \cdot \epsilon}$$

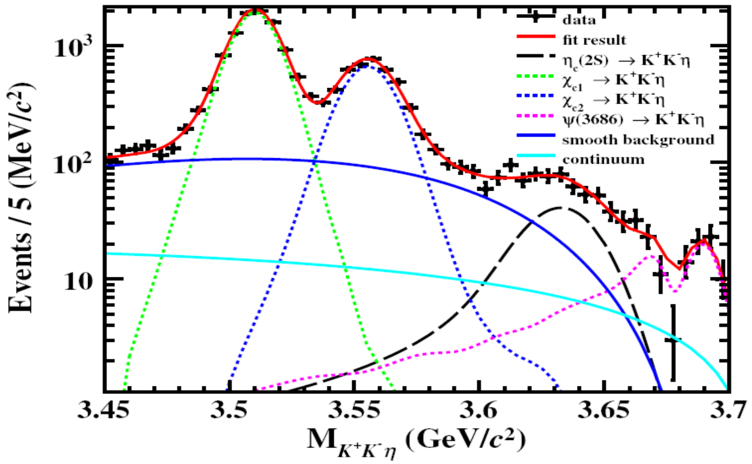
$$\mathbf{B}[\boldsymbol{\eta_c} \to \boldsymbol{\omega\phi}] = (\mathbf{3.9 \pm 0.9 \pm 0.6}) \times \mathbf{10^{-5}}$$

2/3-body decays of $\eta_c(2S)$ and χ_{cJ}

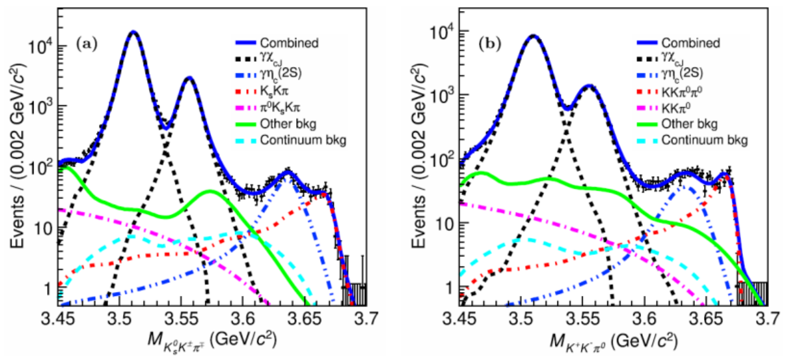
$R \to \pi^+\pi^-\eta$ PRD 107, 052007 (2023)



$R \to K^+K^-\eta$ PRD 110, 092003 (2024)



$R \to K\bar{K}\pi$ PRD 110, 092003 (2024)

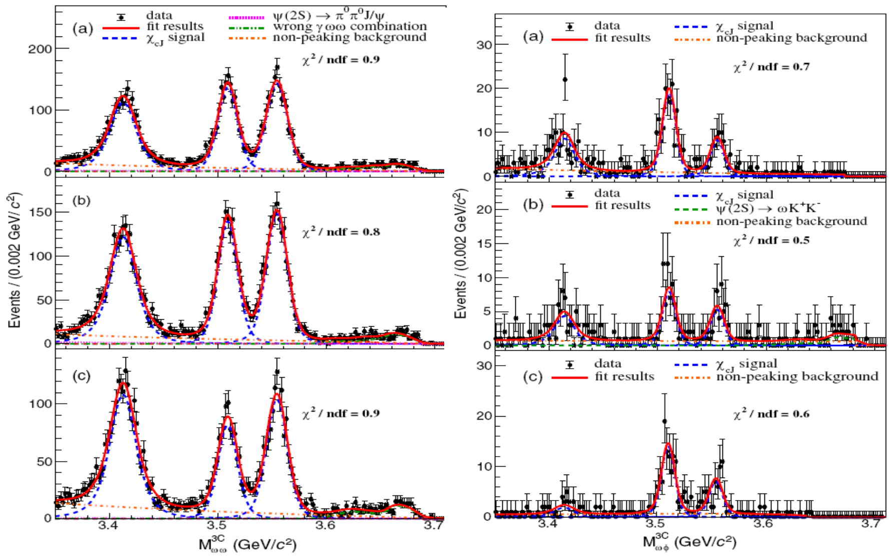


$$M[\eta_c(2S)] = (3637.8 \pm 0.8 \pm 0.2)\ \mathrm{MeV}/c^2$$

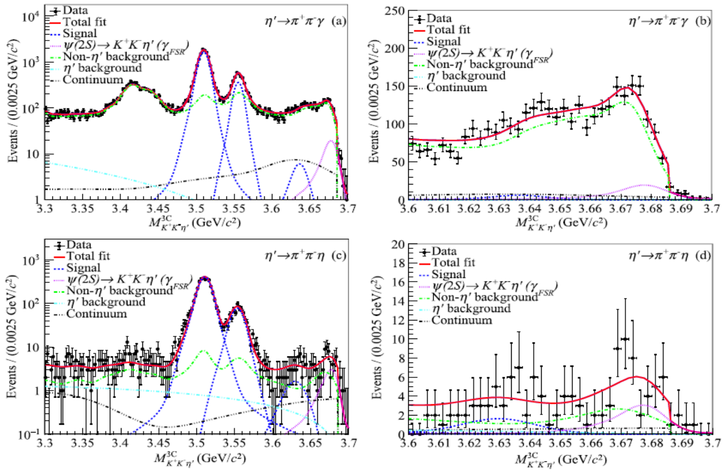
$$\Gamma[\eta_c(2S)] = (10.5 \pm 1.7 \pm 3.5)\ \mathrm{MeV}$$

$$\mathrm{B}[\psi' \to \gamma\eta_c(2S)] = (5.2 \pm 0.3 \pm 0.5^{+1.9}_{-1.4}) \times 10^{-4}$$

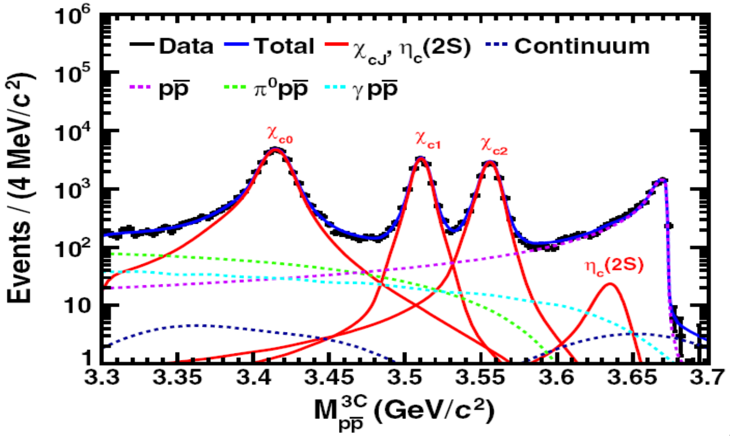
$R \to \omega\omega$、$\omega\phi$ PRD 111, 032001 (2025)



$R \to K^+K^-\eta'$ PRD 111, 012004 (2025)

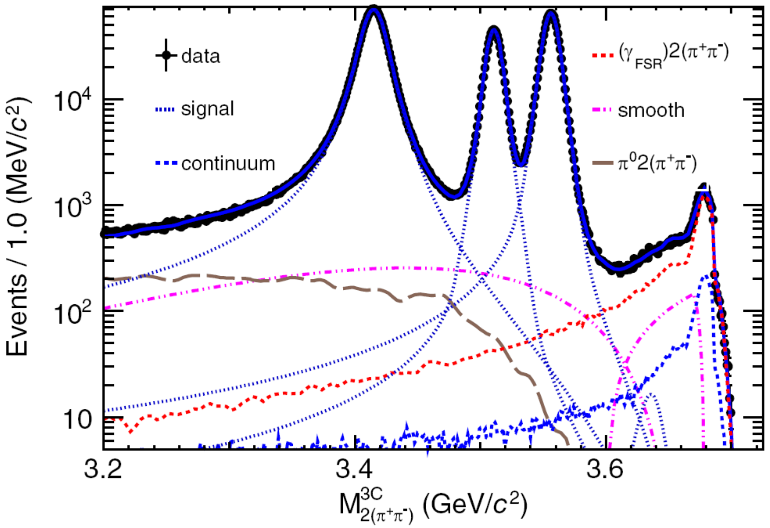


$R \to p\bar{p}$ PRD 111, 012003 (2025)

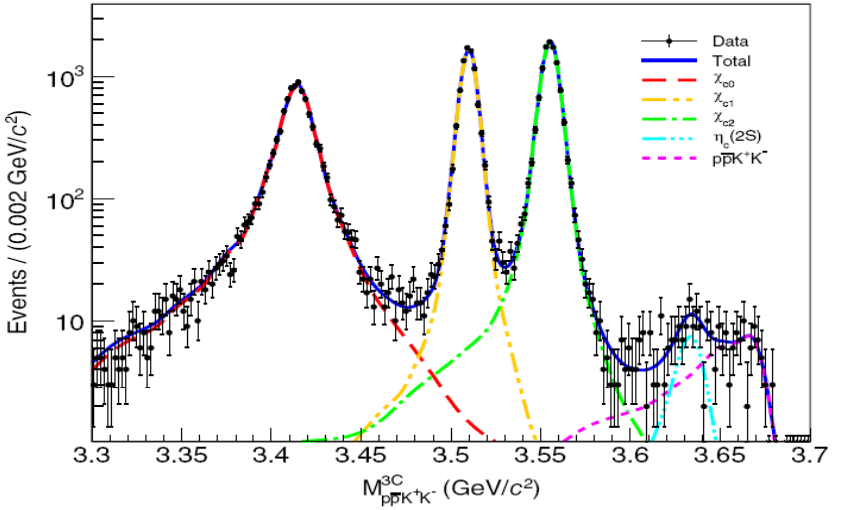


4/5-body decays of $\eta_c(2S)$ and χ_{cJ} $(J = 0, 1, 2)$

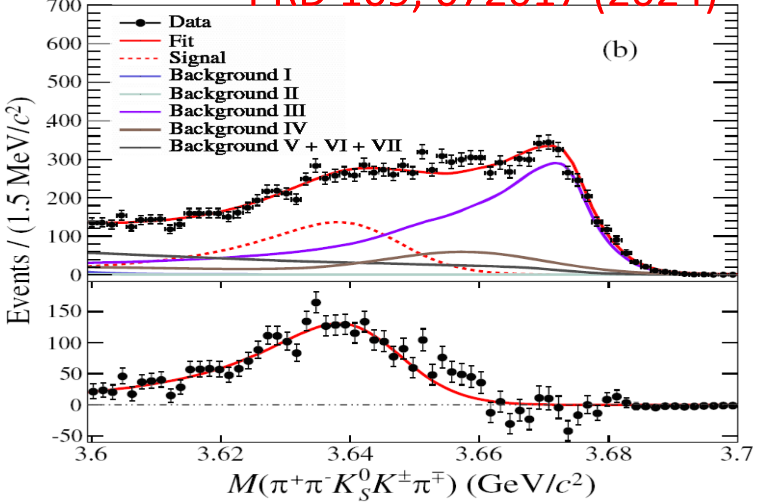
$R \to 2\pi^+ 2\pi^-$ PRD 110, 072009 (2024)



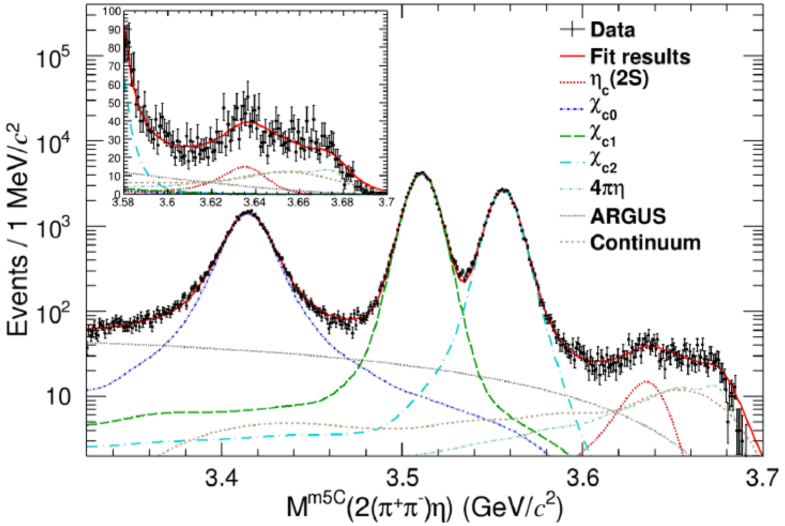
$R \to p\bar{p}K^+K^-$ PRD 111, 072001 (2025)



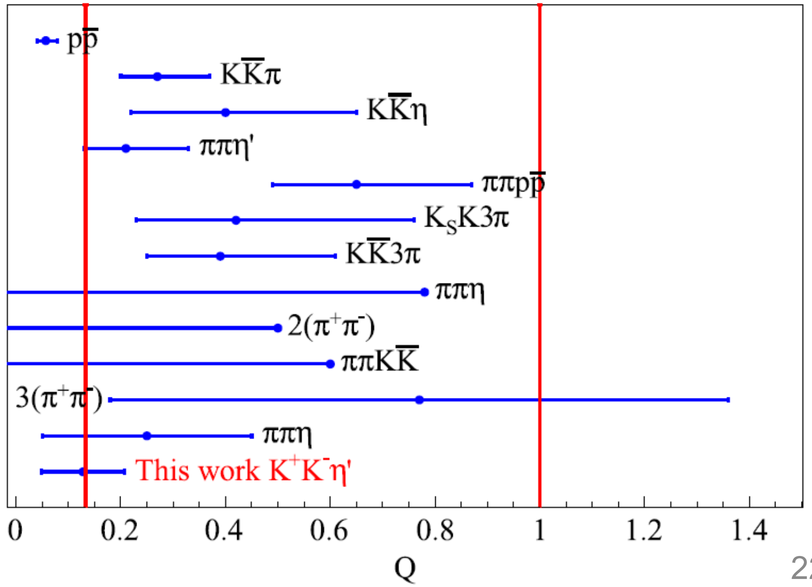
$R \to K^0_S K^\pm \pi^\mp \pi^+ \pi^-$ PRD 109, 072017 (2024)



$R \to 2\pi^+ 2\pi^- \eta$ PRD 111, 052013 (2025)



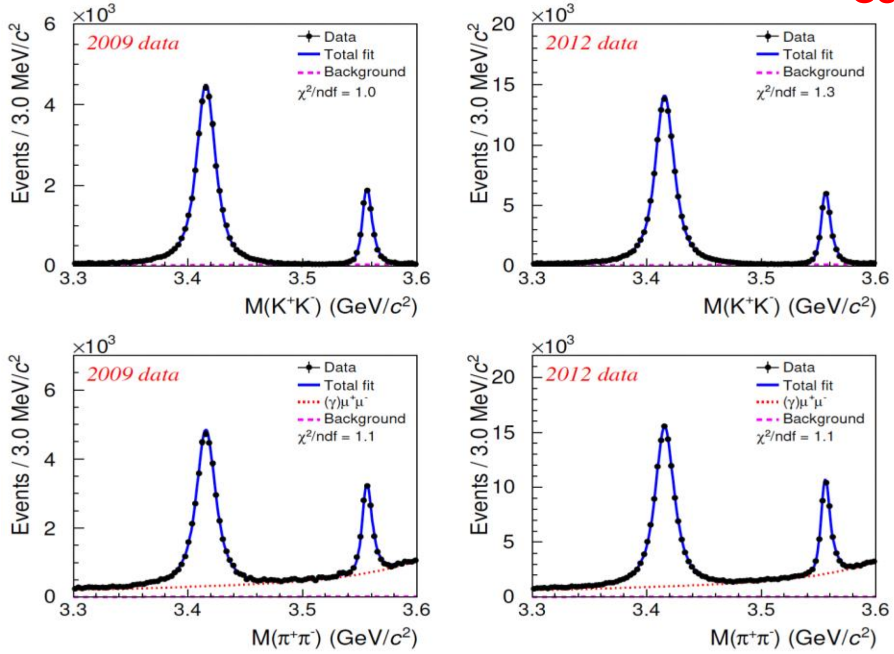
$$\frac{\mathrm{Br}(\eta_c(2S) \to h)}{\mathrm{Br}(\eta_c \to h)} \approx \frac{\mathrm{Br}(\psi(3686) \to h)}{\mathrm{Br}(J/\psi \to h)} = 0.128$$



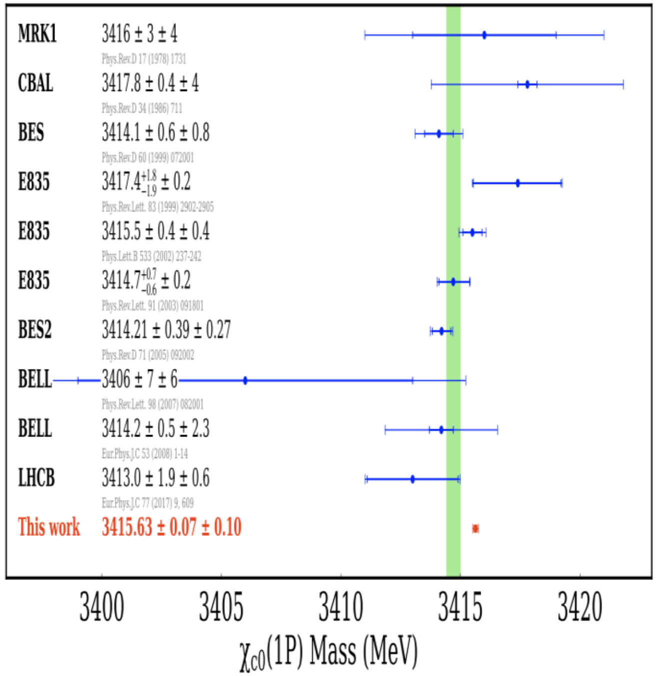
BFs of $\eta_c(2S)$ and χ_{cJ} decays

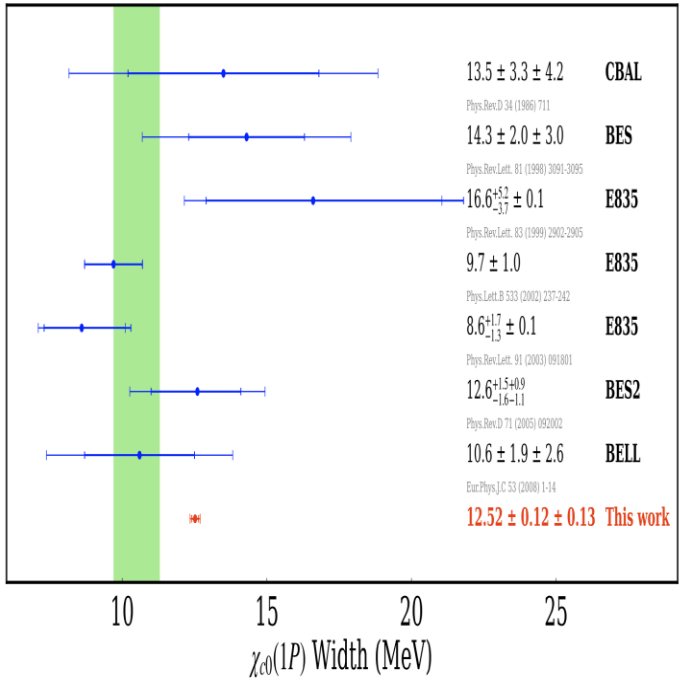
Decay	B(χ_{c0}) (10^{-4})	B(χ_{c1}) (10^{-4})	B(χ_{c2}) (10^{-4})	B(η_{c2}(2S))(10^{-4})	Reference
$R \to p\bar{p}$	$2.51 \pm 0.02 \pm 0.08$	$0.82 \pm 0.01 \pm 0.03$	$0.83 \pm 0.01 \pm 0.02$	<7.5	arXiv:2508.18761
$R \to \omega\omega$	$10.66 \pm 0.11 \pm 0.57$	$6.43 \pm 0.07 \pm 0.31$	$8.75 \pm 0.08 \pm 0.42$	$<1.04\times 10^{-2}$	PRD 111, 032001
$R \to \omega\phi$	$1.18 \pm 0.03 \pm 0.07$	$0.20 \pm 0.02 \pm 0.01$	$0.10 \pm 0.01 \pm 0.01$	$<1.85\times 10^{-3}$	PRD 111, 032001
$R \to \pi^+\pi^-\eta$	NA	$4.30 \pm 0.05 \pm 0.47$	$1.84 \pm 0.04 \pm 0.08$	$42.4 \pm \pm 11.6 \pm 3.8 \pm 30.3$	PRD110, 092003
$R \to K^+K^-\eta'$	NA	$8.48 \pm 0.10 \pm 0.47$	$1.53 \pm 0.04 \pm 0.08$	$11.11 \pm 4.67 \pm 1.82 \pm 4.24$	PRD111, 012004
$R \to K^+K^-\eta$	NA	$4.30 \pm 0.05 \pm 0.47$	$1.84 \pm 0.04 \pm 0.08$	$34.2 \pm \pm 4.6 \pm 4.8 \pm 24.4$	PRD110, 092003
$R \to K_S^0 K^\pm \pi^\mp$	NA	NA	NA	$0.97 \pm 0.06 \pm 0.09(*)$	PRD 110, 092003
$R \to 2\pi^+2\pi^-$	$212.7 \pm 0.2 \pm 10.1$	$68.5 \pm 0.1 \pm 3.1$	$115.3 \pm 0.1 \pm 6.3$	$<1.43\times 10^{-2}(*)$	PRD110, 072009
$R \to 2\pi^+2\pi^-\eta$	$4.44 \pm 0.03 \pm 0.37$	$7.87 \pm 0.03 \pm 0.74$	$5.53 \pm 0.03 \pm 0.53$	$0.085 \pm 0.004 \pm 0.013(*)$	PRD110, 072009
$R \to K_S^0 K^\pm \pi^\mp \pi^+\pi^-$	NA	NA	NA	$0.093 \pm 0.007 \pm 0.028$	PRD109, 072017
$R \to p\bar{p}K^+K^-$	$0.249 \pm 0.003 \pm 0.015$	$0.183 \pm 0.002 \pm 0.011$	$0.243 \pm 0.002 \pm 0.015$	$0.0020 \pm 0.0004 \pm 0.010$	PRD111, 052013

Study of $\chi_{cJ} \to P\bar{P}$ ($P = K^+$、π^+， $J = 0, 1, 2$)



Cover letter in CPC 107, 092004 (2025)

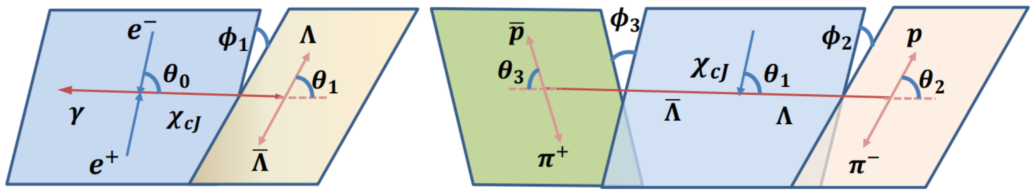


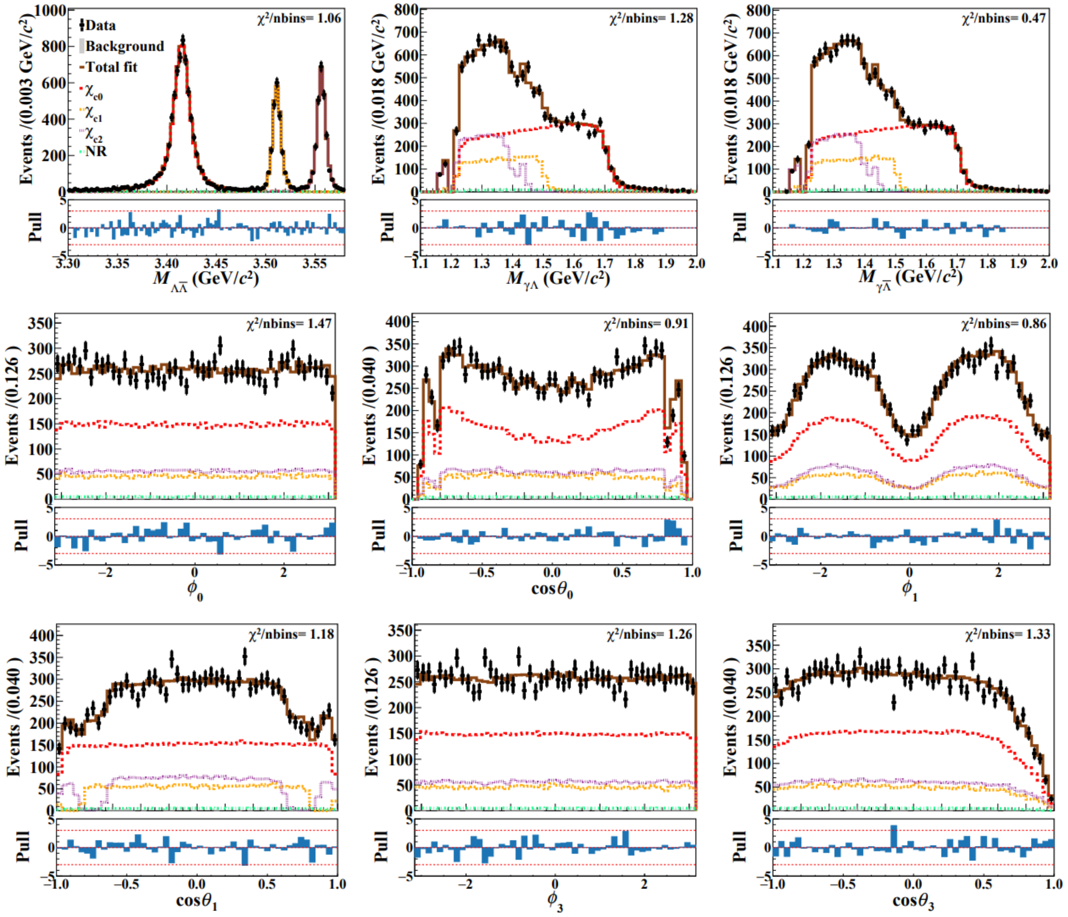


- The mass split between χ_{c2} and χ_{c0} is measured.
- Taking the PDG mass of χ_{c2} as input → the most precise χ_{c0} mass/width measurement to date
- $$\left.\begin{aligned}\mathcal{B}(\chi_{c0} \to K^+K^-) &= (6.36 \pm 0.02 \pm 0.08 \pm 0.13) \times 10^{-3} \\ \mathcal{B}(\chi_{c0} \to \pi^+\pi^-) &= (6.06 \pm 0.02 \pm 0.07 \pm 0.13) \times 10^{-3}\end{aligned}\right\} \quad \mathcal{R} = \frac{\mathcal{B}(\chi_{c0}\to\pi^+\pi^-)}{\mathcal{B}(\chi_{c0}\to K^+K^-)} = (0.95 \pm 0.01 \pm 0.01)$$
  $$\mathcal{B}(\chi_{c2} \to K^+K^-) = (1.22 \pm 0.01 \pm 0.02 \pm 0.03) \times 10^{-3}$$
  $$\mathcal{B}(\chi_{c2} \to \pi^+\pi^-) = (1.61 \pm 0.01 \pm 0.02 \pm 0.04) \times 10^{-3}$$

Helicity amplitude analysis of $\chi_{cJ} \to \Lambda\bar{\Lambda}$

arXiv:2509.00289v1





Parameters	Value	Unit
r_1	$1.037 \pm 0.047 \pm 0.029$	-
r_2	$1.48 \pm 0.13 \pm 0.07$	-
r_3	$1.85 \pm 0.15 \pm 0.10$	-
$\Delta\Phi_{r_1}$	$0.042 \pm 0.107 \pm 0.032$	rad
$\Delta\Phi_{r_2}$	$0.37 \pm 0.12 \pm 0.17$	rad
$\Delta\Phi_{r_3}$	$0.13 \pm 0.12 \pm 0.05$	rad
$R_{\chi_{c2}}$	$0.575 \pm 0.048 \pm 0.018$	-
$\Delta\Phi_{\chi_{c2}}$	$0.37 \pm 0.15 \pm 0.05$	rad
$FF_{\chi_{c0}}$	$0.5459 \pm 0.0052 \pm 0.0076$	-
$FF_{\chi_{c1}}$	$0.1755 \pm 0.0036 \pm 0.0034$	-
$FF_{\chi_{c2}}$	$0.2470 \pm 0.0046 \pm 0.0047$	-
$FF_{NR(2^+)}$	$0.0265 \pm 0.0040 \pm 0.0098$	-
$\alpha_{\chi_{c1}}$	$-0.301 \pm 0.042 \pm 0.026$	-
$\alpha_{\chi_{c2}}$	$-0.211 \pm 0.100 \pm 0.050$	-
$\beta_{\chi_{c2}}$	$-0.039 \pm 0.089 \pm 0.033$	-
$\Gamma_{\chi_{c0}}$	$12.31 \pm 0.26 \pm 0.12$	MeV

See definitions of variables in backup slides

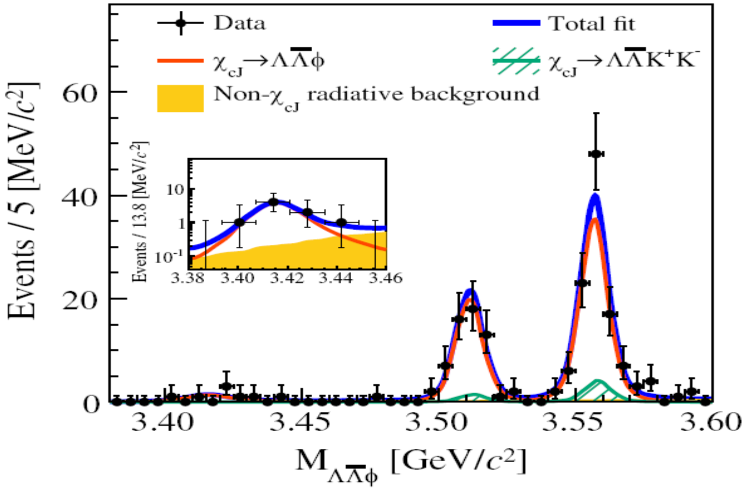
First measurement

Precision measurement

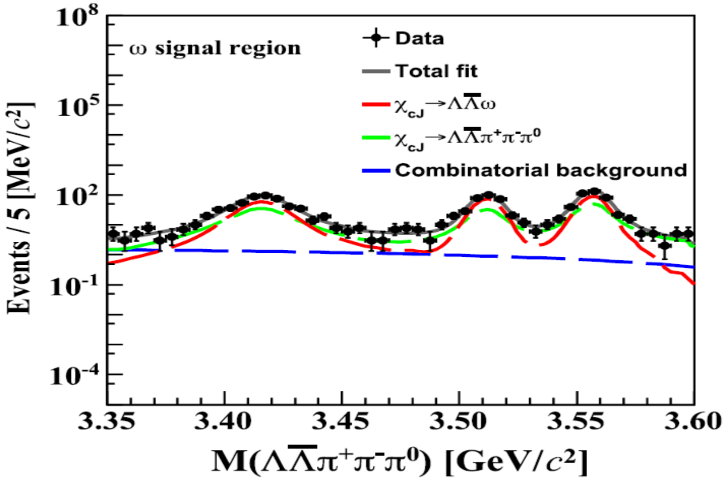
Chan	Events	Meas. $\mathcal{B}_1\mathcal{B}_2$ ($\times10^{-5}$)	PDG $\mathcal{B}_1$ ($\times10^{-2}$)	Meas. $\mathcal{B}_2$($\times10^{-4}$)	PDG $\mathcal{B}_2$($\times10^{-4}$)
χ_{c0}	7437 ± 64	$3.585 \pm 0.047 \pm 0.080$	9.79 ± 0.20	$3.662 \pm 0.048 \pm 0.111$	3.61 ± 0.16
χ_{c1}	2278 ± 45	$1.152 \pm 0.025 \pm 0.030$	9.75 ± 0.24	$1.182 \pm 0.026 \pm 0.042$	1.27 ± 0.09
χ_{c2}	2787 ± 56	$1.622 \pm 0.033 \pm 0.042$	9.52 ± 0.20	$1.704 \pm 0.035 \pm 0.057$	1.86 ± 0.16

Observation of $\chi_{cJ} \to B\bar{B}X, B\bar{B}PP$ decays

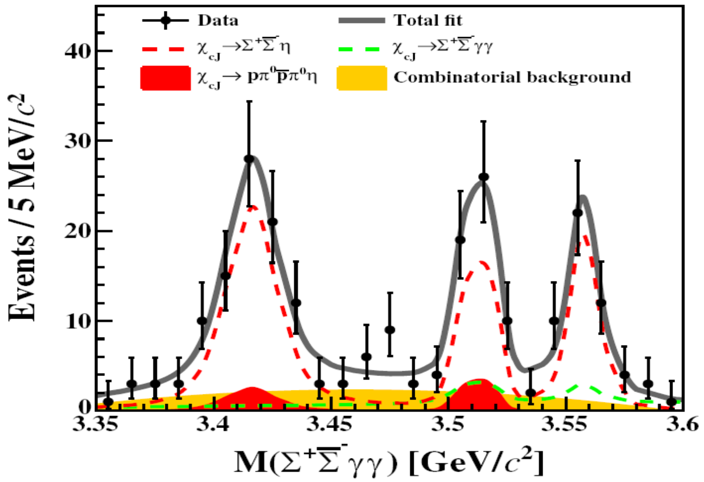
$\chi_{cJ} \to \Lambda\bar{\Lambda}\phi$ PRD 110, 032016 (2024)



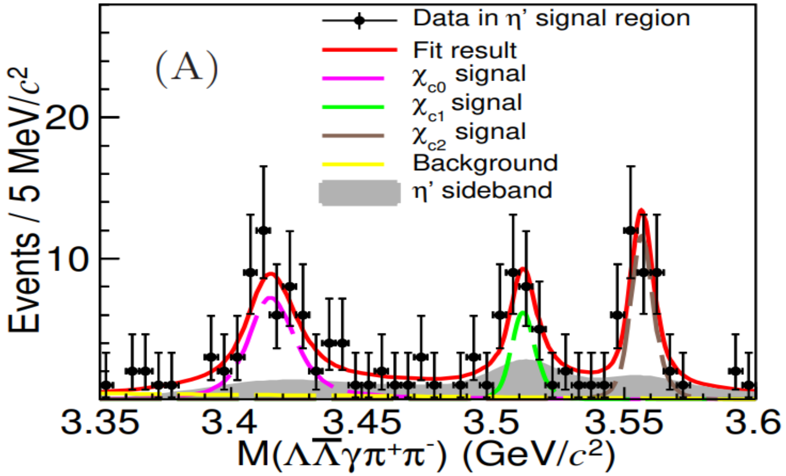
$\chi_{cJ} \to \Lambda\bar{\Lambda}\omega$ PRD 110, 032022 (2024)



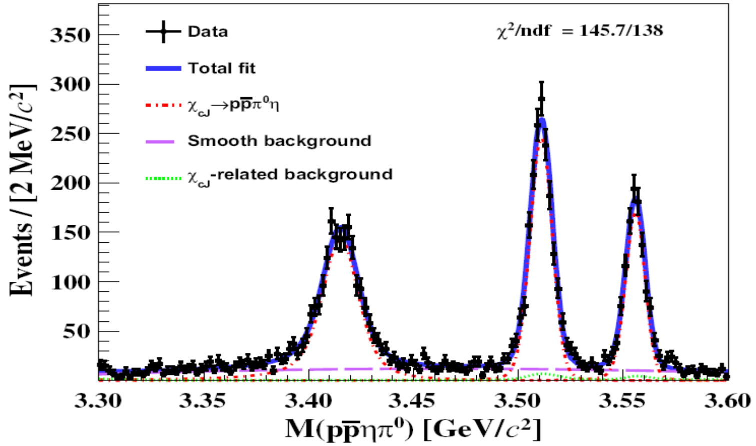
$\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-\omega$ PRD 110, 112013 (2024)



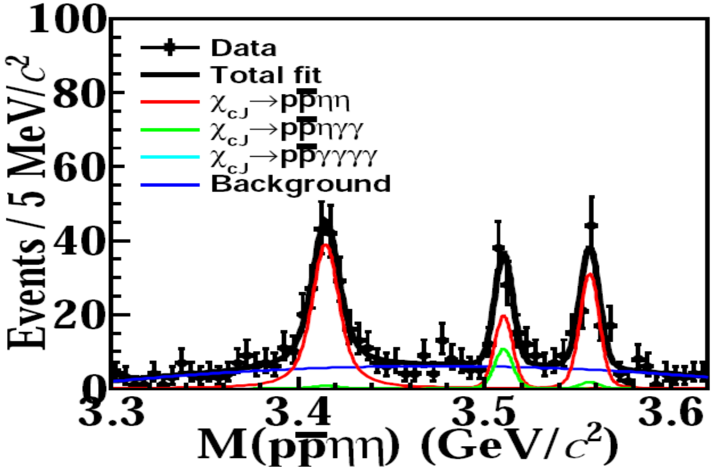
$\chi_{cJ} \to \Lambda\bar{\Lambda}\eta'$ 2508.18761v1



$\chi_{cJ} \to p\bar{p}\pi^0\eta$ PRD 111, 032008 (2025)

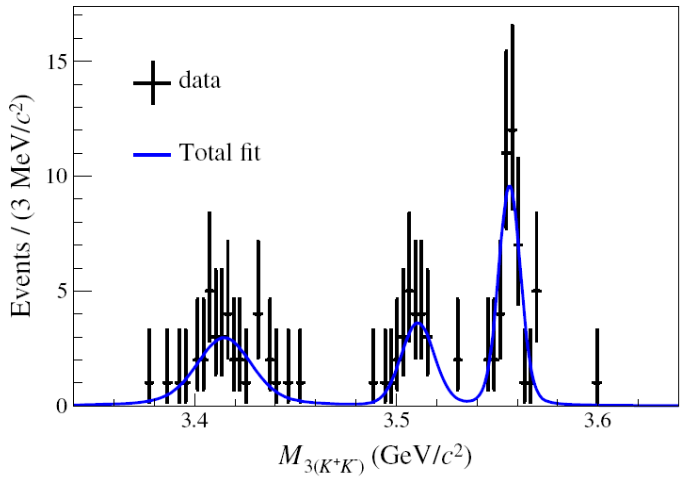


$\chi_{cJ} \to p\bar{p}\eta\eta$ arXiv:2505.12234v2

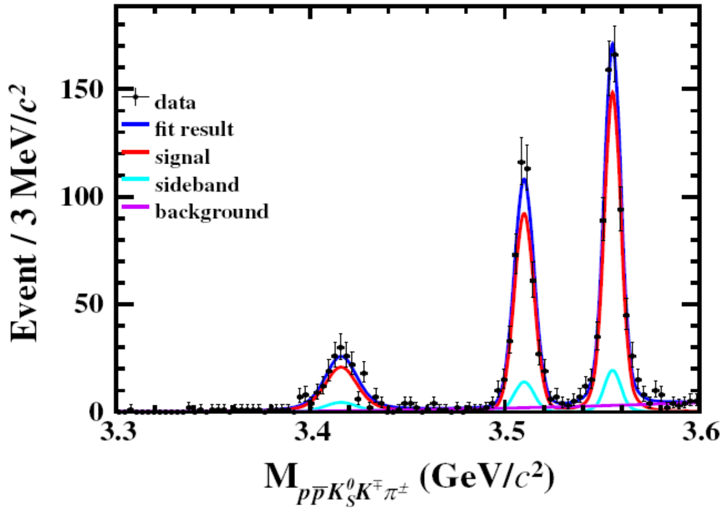


5/6-body and rare χ_{cJ} decays

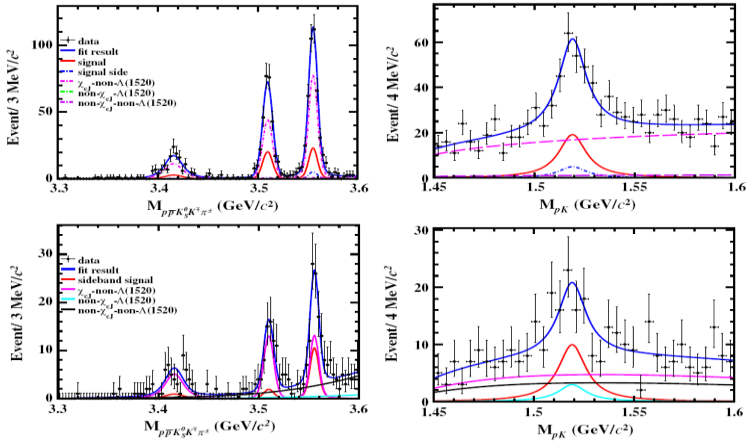
$\chi_{cJ} \to 3K^+3K^-$ PRD 109, 072016 (2024)



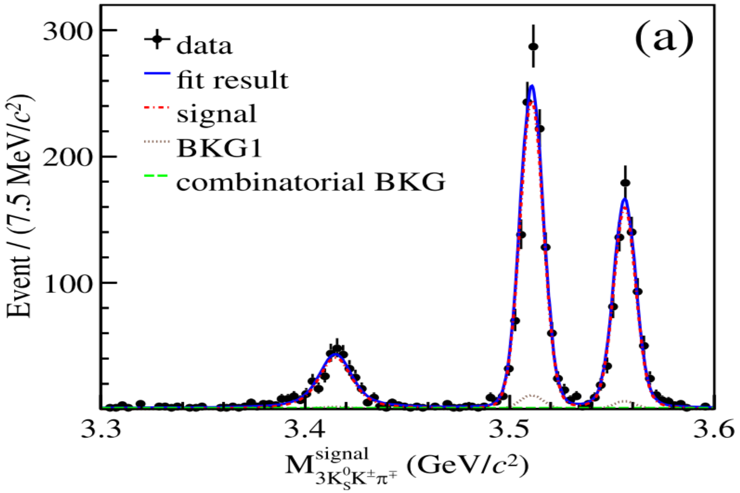
$\chi_{cJ} \to p\bar{p}K_S^0K^{\pm}\pi^{\mp}$ PRD110, 112009 (2024)



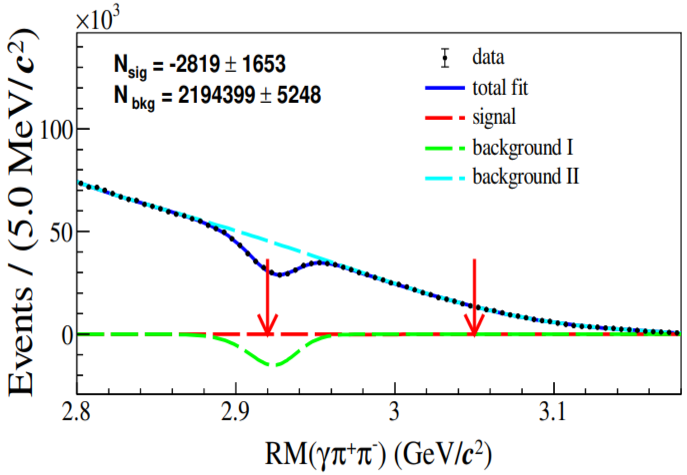
$\chi_{cJ} \to p\bar{\Lambda}(1520)K_S^0\pi^+ + c.c.$



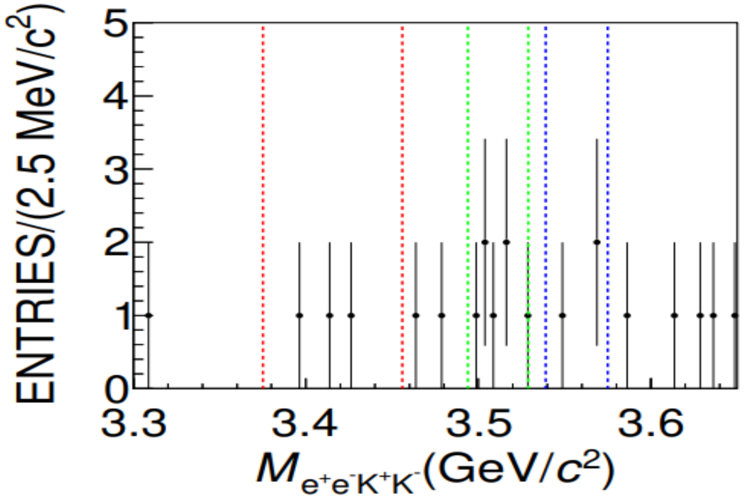
$\chi_{cJ} \to 3K_S^0K^{\pm}\pi^{\mp}$ PRD 112, 012007 (2025)



$\chi_{cJ} \to e^+e^-\phi$ arXiv:2508.18601v1



$\chi_{cJ} \to \pi^+\pi^-\eta_c$ arXiv:2509.23386v1



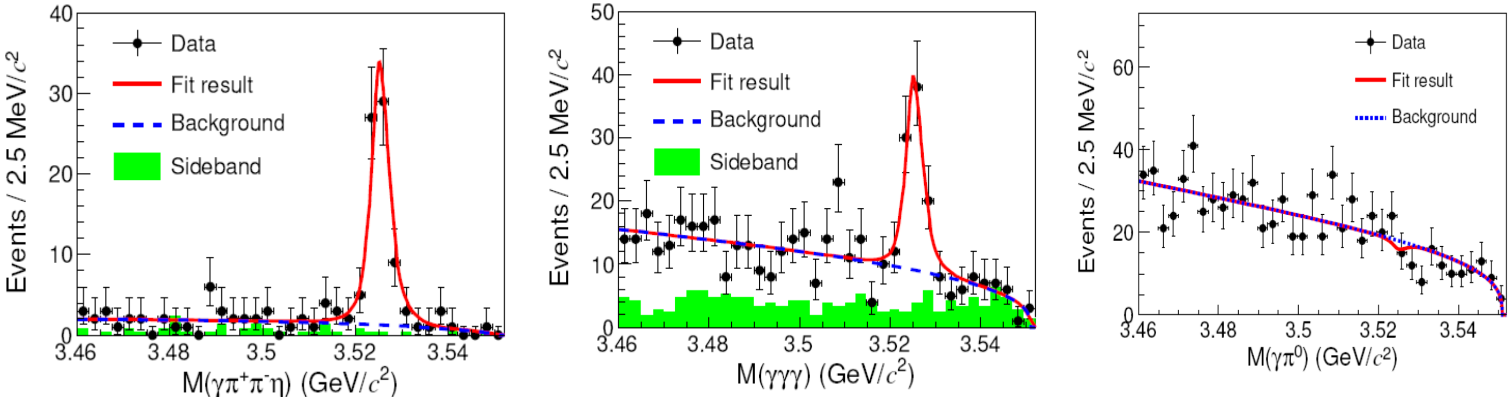
BFs of these χ_{cJ} decays

Decay	B(χ_{c0}) (10^{-4})	B(χ_{c1}) (10^{-4})	B(χ_{c2}) (10^{-4})	Reference
$\chi_{cJ} \to \Lambda\bar{\Lambda}\phi$	$0.30 \pm 0.12 \pm 0.02$	$0.60 \pm 0.09 \pm 0.04$	$0.71 \pm 0.08 \pm 0.04$	PRD 110, 032016
$\chi_{cJ} \to \Lambda\bar{\Lambda}\omega$	$2.37 \pm 0.22 \pm 0.25$	$1.01 \pm 0.10 \pm 0.11$	$1.40 \pm 0.13 \pm 0.17$	PRD 110, 032022
$\chi_{cJ} \to \Lambda\bar{\Lambda}\eta'$	$0.76 \pm 0.14 \pm 0.09$	$0.15 \pm 0.05 \pm 0.02$	$0.30 \pm 0.06 \pm 0.03$	arXiv:2508.18761
$\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-\eta$	$1.26 \pm 0.20 \pm 0.13$	$0.51 \pm 0.12 \pm 0.07$	$0.55 \pm 0.12 \pm 0.05$	PRD110,112003
$\chi_{cJ} \to p\bar{p}\pi^0\eta$	$2.42 \pm 0.07 \pm 0.19$	$1.95 \pm 0.05 \pm 0.12$	$1.33 \pm 0.05 \pm 0.08$	PRD111, 032008
$\chi_{cJ} \to p\bar{p}\eta\eta$	$0.58 \pm 0.06 \pm 0.04$	$0.14 \pm 0.03 \pm 0.02$	$0.26 \pm 0.04 \pm 0.03$	arXiv:2505.12234
$\chi_{cJ} \to p\bar{p}K_S^0K^\pm\pi^\mp$	$0.26 \pm 0.03 \pm 0.03$	$0.42 \pm 0.02 \pm 0.05$	$0.56 \pm 0.03 \pm 0.05$	PRD110,112009
$\chi_{cJ} \to p\bar{\Lambda}(1520)K_S^0\pi^+ + c.c.$	$0.16 \pm 0.07 \pm 0.02$	$0.41 \pm 0.08 \pm 0.05$	$0.41 \pm 0.09 \pm 0.04$	PRD110,112009
$\chi_{cJ} \to 3K_S^0K^\pm\pi^\mp$	$0.80 \pm 0.05 \pm 0.07$	$2.52 \pm 0.08 \pm 0.19$	$1.72 \pm 0.07 \pm 0.15$	PRD112,012007
$\chi_{cJ} \to 3K^+3K^-$	$0.11 \pm 0.02 \pm 0.01$	$0.04 \pm 0.01 \pm 0.01$	$0.07 \pm 0.01 \pm 0.01$	PRD 109, 072016
$\chi_{cJ} \to e^+e^-\phi$	$< 2.4 \times 10^{-3}$	$< 6.7 \times 10^{-3}$	$< 4.1 \times 10^{-3}$	arXiv:2509.23386v1
$\chi_{cJ} \to \pi^+\pi^-\eta_c$	NA	< 3.1	NA	arXiv:2508.18601v1

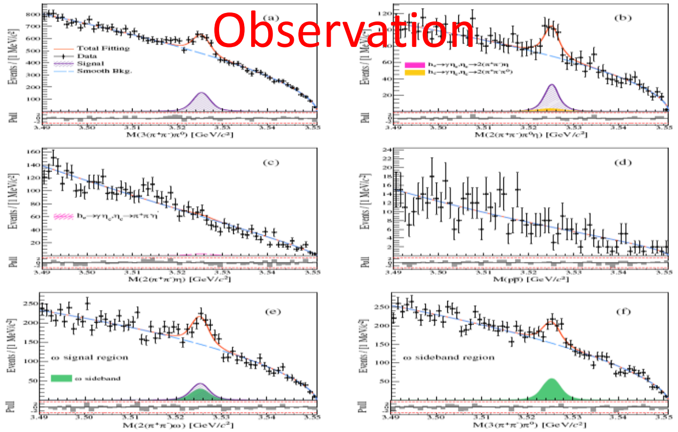
Decays of h_c via $\psi(3686) \to h_c \pi^0$

Study of/search for some h_c decays

$h_c \to \gamma\eta'$、$\gamma\eta$、$\gamma\pi^0$ JHEP08(2024)180

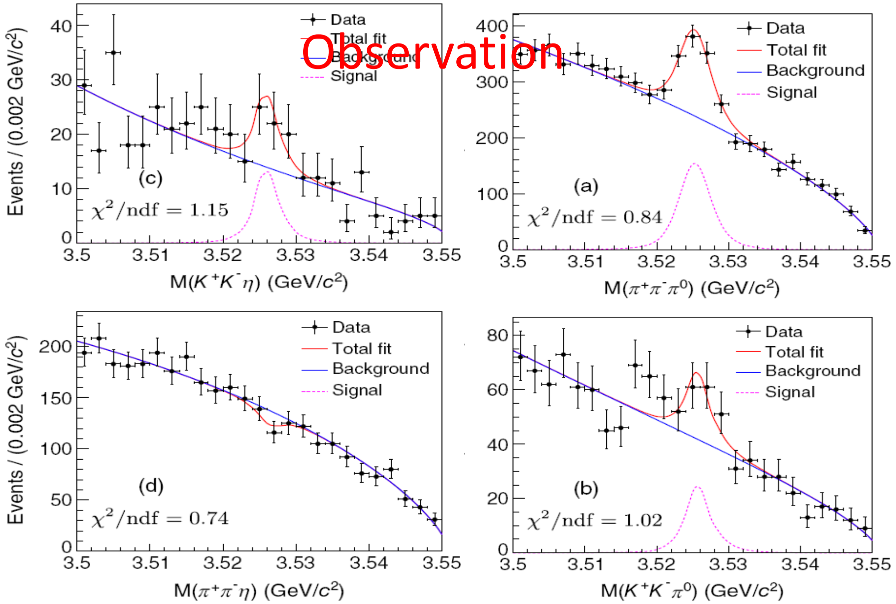


$h_c \to$ 多π hadrons PRD 109, 072018 (2024)



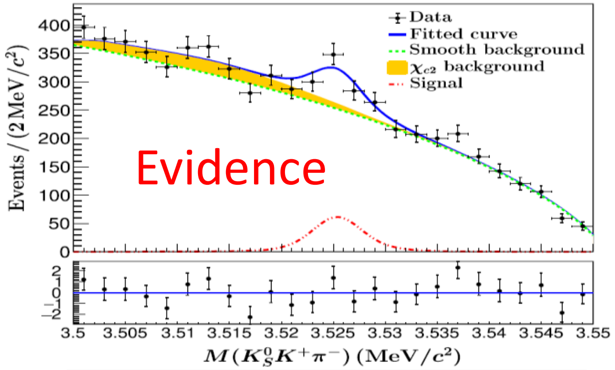
$h_c \to h^+h^-\pi^0/\eta$

PRD 110, 032023 (2024)



$h_c \to K_S^0 K^\pm \pi^\mp$

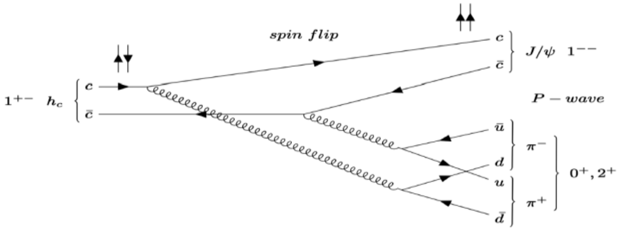
PRD 110, 012007 (2024)

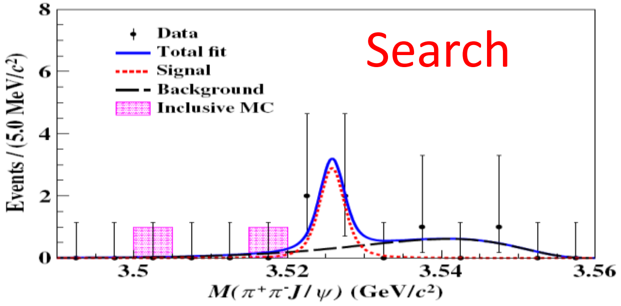


Item	Value (%)	Source
$\mathcal{B}(h_c \to K\bar{K}\pi)$	1.4 ± 0.9	pQCD [4]
$\mathcal{B}(h_c \to K\bar{K}\pi)$	5.5 ± 3.3	NRQCD [4]
$\mathcal{B}(h_c \to K\bar{K}\pi)$	0.22 ± 0.06	This work
$\Gamma(h_c \to 3g)/\Gamma(\eta_c \to 2g)$	1.0 ± 0.1	pQCD [4]
$\Gamma(h_c \to 3g)/\Gamma(\eta_c \to 2g)$	8.3 ± 1.8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

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

PRD 110, 112010 (2024)



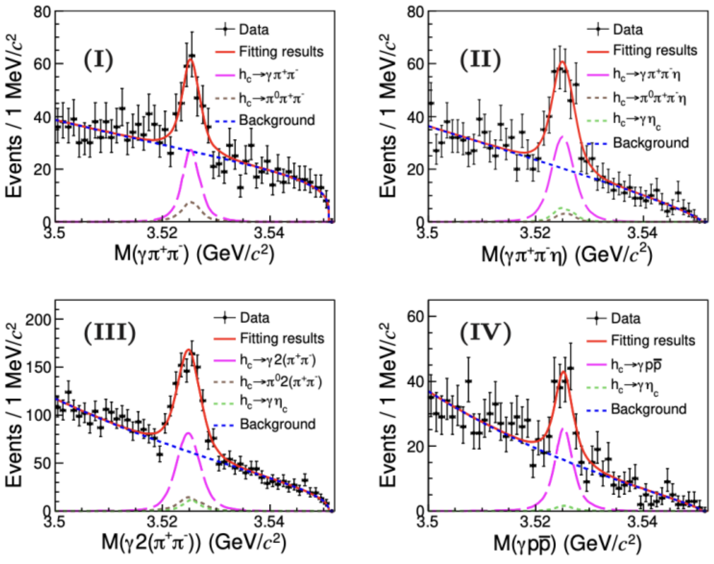


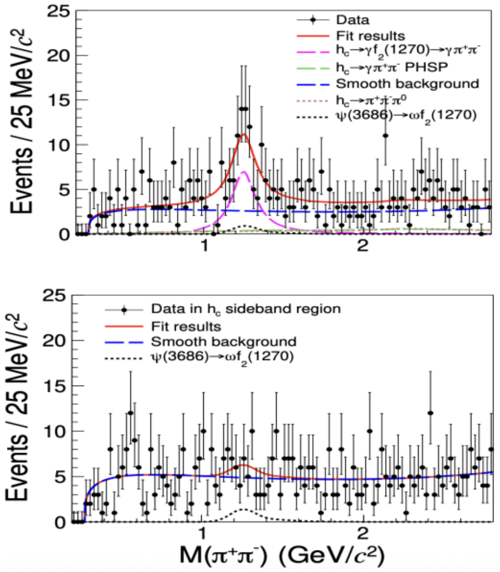
BFs of these h_c decays

Decay	B	Reference	$B^{\text{PDG/previous BESIII}}$
$h_c \to \gamma\eta$ (10^{-4})	$3.77 \pm 0.55 \pm 0.13 \pm 0.26$	JHEP08,180	$4.7 \pm 1.5 \pm 1.4$
$h_c \to \gamma\eta'$ (10^{-3})	$1.40 \pm 0.11 \pm 0.04 \pm 0.10$		$1.52 \pm 0.27 \pm 0.29$
$h_c \to \gamma\pi^0$ (10^{-5})	<5		UL
$h_c \to K^+K^-\eta$ (10^{-3})	$1.36 \pm 0.16 \pm 0.14$	PRD 110, 032023	1.95 ± 0.5
$h_c \to \pi^+\pi^-\pi^0$ (10^{-4})	$3.26 \pm 0.84 \pm 0.36$		<6
$h_c \to \pi^+\pi^-\eta$ (10^{-4})	$3.13 \pm 1.08 \pm 0.38$		<1
$h_c \to K^+K^-\pi^0$ (10^{-4})	<4		
$h_c \to p\bar{p}$ (10^{-5})	<4.4	PRD 109,072018	UL
$h_c \to 3\pi^+3\pi^-\pi^0$ (10^{-3})	$9.28 \pm 1.14 \pm 0.77$		UL
$h_c \to 2\pi^+2\pi^-\pi^0\eta$ (10^{-3})	$7.55 \pm 1.51 \pm 0.77$		
$h_c \to 2\pi^+2\pi^-\eta$ (10^{-4})	<6.19		
$h_c \to 2\pi^+2\pi^-\omega$ (10^{-3})	$4.40 \pm 0.86 \pm 0.35$		
$h_c \to K_S^0K^\pm\pi^\mp$ (10^{-4})	$7.3 \pm 1.8 \pm 0.8$	PRD 110, 012007	
$h_c \to \pi^+\pi^-J/\psi$ (10^{-5})	<1.2	PRD 110, 112010	NA

Observation of radiative decays $h_c \to \gamma X$

- h_c has the same C-parity as J/ψ but different orbital angular momentum → improving our understanding of charmonium radiative decays and searching for exotic states
- QCD predicts $\mathcal{B}(h_c \to \gamma + 2g) \sim 5.5\%$, while experiments measure $\mathcal{B}(h_c \to \gamma + \eta/\eta') \sim 0.2\%$





PRL134, 241902 (2025)

- The first observation of h_c radiative decay to a tensor state
- The BF of $\boldsymbol{h_c \to \gamma f_2(1270) \to \gamma\pi^+\pi^-}$ is an order of magnitude smaller than that in J/ψ decay

- Total BF of these measured h_c radiative decay, $\sim 0.6\%$, is significantly lower than the predicted 5.5% of $\mathcal{B}(h_c \to \gamma + 2g)$
- Further exploration of h_c radiative decays is desirable

Decay model	Branching fraction	Signal yield	Efficiency (%)	Significance (σ)
$h_c \to \gamma\pi^+\pi^-$	$(3.06 \pm 0.54 \pm 0.37 \pm 0.21) \times 10^{-4}$	127.0 ± 22.2	20.9	5.4
$h_c \to \gamma f_2(1270) \to \gamma\pi^+\pi^-$	$(1.81 \pm 0.35 \pm 0.19 \pm 0.12) \times 10^{-4}$	71.8 ± 13.8	20.0	5.1
$h_c \to \gamma\pi^+\pi^-\eta$	$(3.52 \pm 0.50 \pm 0.30 \pm 0.24) \times 10^{-3}$	191.6 ± 27.1	7.0	7.5
$h_c \to \gamma 2(\pi^+\pi^-)$	$(2.19 \pm 0.20 \pm 0.16 \pm 0.15) \times 10^{-3}$	494.9 ± 44.5	11.4	11.8
$h_c \to \gamma p\bar{p}$	$(3.34 \pm 0.53 \pm 0.33 \pm 0.23) \times 10^{-4}$	127.4 ± 20.1	19.3	6.4

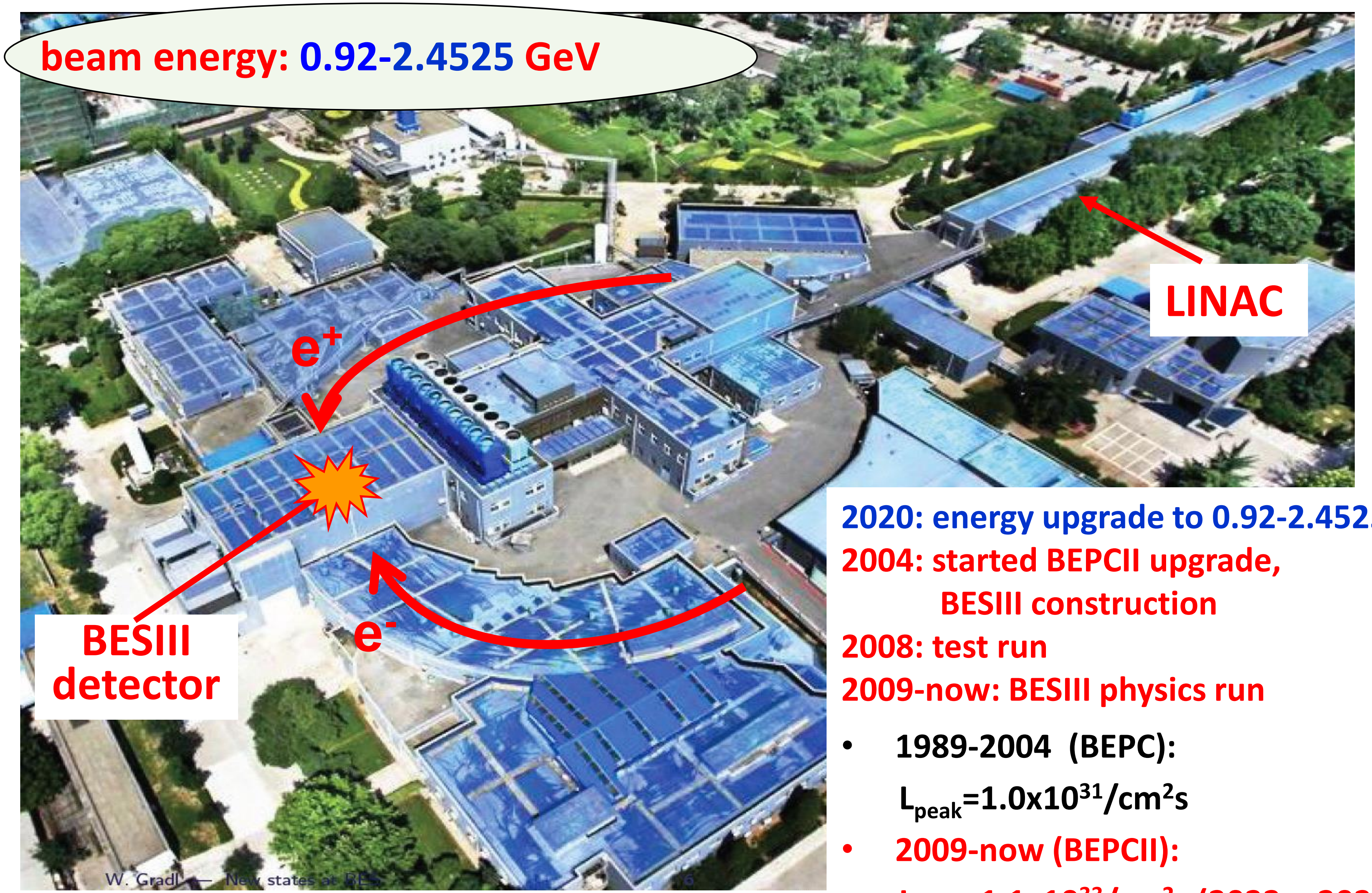
Summary

- **Lots of results on traditional charmonia at BESIII have been published**

- **More results are expected in the near future**

Thank you!

Beijing Electron Positron Collider (BEPCII)



2020: energy upgrade to 0.92-2.4525 GeV

2004: started BEPCII upgrade,
BESIII construction

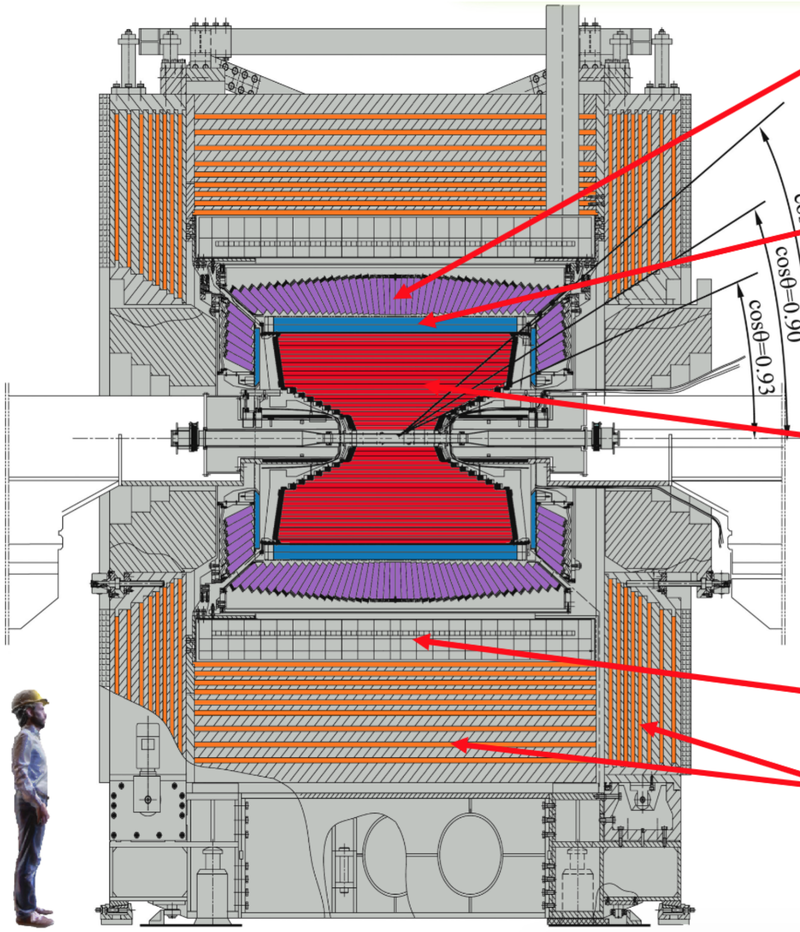
2008: test run

2009-now: BESIII physics run

- 1989-2004 (BEPC):
  L_{peak}=1.0x10^{31}/cm^{2}s
- 2009-now (BEPCII):
  L_{peak}=1.1x10^{33}/cm^{2}s (2022、2023)

BESIII detector

NIMA614(2010)345



EMC: CsI crystals
$\Delta E/E$ = 2.5% @ 1 GeV - Barrel
$\Delta E/E$ = 5.0% @ 1 GeV - Endcaps

TOF:
σ_T = 80 ps Barrel
σ_T = 110 (60) ps Endcap

MDC: small cell & He gas
σ_{xy}= 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

Magnet: 1T Super conducting

Muon ID: 9 layer RPC

Trigger: Tracks & Showers

Excellent resolution, particle identification, and large coverage for neutral and charged particles

BESIII collaboration

Europe (19)

Germany(6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy(3): Ferrara University, INFN, University of Turin,

Netherlands(1):KVI/University of Groningen

Russia(3): Budker Institute of Nuclear Physics, Dubna JINR, Lebedev Physical Institute

Sweden(1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK(3): University of Manchester, University of Oxford, University of Bristol

Poland(1): National Centre for Nuclear Research

USA(3)

Carnegie Mellon University
Indiana University
University of Hawaii

Mongolia(1)

Institute of Physics and Technology

Pakistan(2)

Institute of Business Administration,
University of the Punjab

Korea(1)

Chung-Ang University

Thailand(1)

Suranaree University of Technology

India(1)

Indian Institute of Technology madras

China (62)

Beihang University, Central China Normal University, Central South University, Chengdu University of Technology, China Center of Advanced Science and Technology, China University of Geosciences, Fudan University, Guangxi Normal University, Guangxi University, Guangxi University of Science and Technology, Hangzhou Normal University, Hebei University, Henan University, Henan Normal University, Henan University of Science and Technology, Henan University of Technology, Hengyang Normal University, Huangshan College, Hunan University, Hunan Normal University, Inner Mongolia University, Institute of High Energy Physics, Institute of Modern Physics, Jiangsu Ocean University, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Longyan University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University,Peking University, Qufu Normal University, Renmin University of China, Shaanxi Normal University, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Management University, Shandong Normal University, Shandong University, handong University of Technology, Shanghai Jiao Tong University, Soochow University,South China Normal University, Southeast University, Southwest University of Science and Technology, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xi'an Jiaotong University, Yantai University , Yunnan University , Zhejiang University, Zhengzhou University

Chile(2)

University of Tarapaca,
University of La Serena

>600 members
From 92 institutions in
16 countries

Data samples at BESIII

2009: 106M $\psi(3686)$
225M J/ψ
2010: 0.98 fb^{-1} $\psi(3770)$
2011: 2.93 fb^{-1} $\psi(3770)$ ($D^{0(+)}$, total)
0.48 fb^{-1} @4.01 GeV
2012: 0.45B $\psi(3686)$ (total)
1.30B J/ψ (total)
2013: 1.09 fb^{-1} @4.23 GeV (XYZ&D_s^+)
0.83 fb^{-1} @4.26 GeV
0.54 fb^{-1} @4.36 GeV
10×0.05 fb^{-1} XYZ scan@3.81-4.42 GeV
2014: 1.03 fb^{-1} @4.42 GeV
0.11 fb^{-1} @4.47 GeV
0.11 fb^{-1} @4.53 GeV
0.05 fb^{-1} @4.575 GeV
0.57 fb^{-1} @4.60 GeV (XYZ&Λ_c^+)
0.80 fb^{-1} R scan @3.85-4.59 GeV
2009: 106M $\psi(3686)$
2015: R-scan 2-3 GeV+2.175 GeV

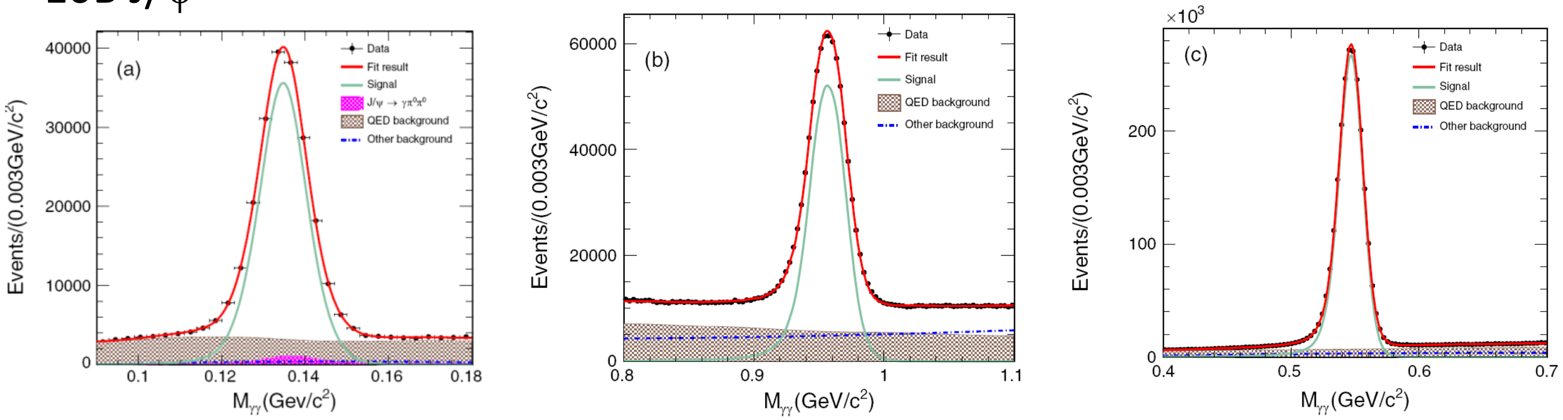
2016: 3.20 fb^{-1} @4.178 GeV (XYZ&D_s^+)
2017: 7×0.50 fb^{-1} @4.19-4.22 GeV (XYZ&D_s^+),
@4.24-4.27 (XYZ)
2018: More J/ψ+tuning new RF cavity
2019: 10B J/ψ (total)
8×0.50 fb^{-1} XYZ scan@4.13, 4.16 (XYZ&D_s^+),
4.29-4.44 GeV
2020: 3.8 fb^{-1} @ 4.61-4.7 GeV (XYZ&Λ_c^+)
2021: 2.0 fb^{-1} @ 4.74-4.946 GeV
2.7B $\psi(3686)$ (total)
2022: 0.4 fb^{-1} @3.650 GeV
0.4 fb^{-1} @3.682 GeV
2.9→7.9 fb^{-1} $\psi(3770)$ ($D^{0(+)}$, total)
2023-2024: 7.9→20.3 fb^{-1} $\psi(3770)$ (for $D^{0(+)}$, total)
2×0.42 fb^{-1} $\psi(3770)$ scan
0.14 fb^{-1} @3.800-3.885 GeV
0.13 fb^{-1} @3.554 GeV
0.025 fb^{-1} @1.84-2.00 GeV

>50 fb^{-1} at E_{cm} between 1.84 and 4.95 GeV in 15 year running

Two-body decays of J/ψ

$J/\psi \to \gamma\pi^0$、$\gamma\eta$、$\gamma\eta'$ PRD 108, 092002 (2023)

10B J/ψ



$$\mathcal{B}(J/\psi \to \gamma P) = \frac{N_{\mathrm{obs}}}{N_{J/\psi} \times \mathcal{B}(P \to \gamma\gamma) \times \varepsilon}$$

γP	$N^{\mathrm{obs}}_{J/\psi\to\gamma P}$	ε (%)	$\mathcal{B}(J/\psi \to \gamma P)(\times 10^{-4})$		
			This work	BESIII	PDG [31]
$\gamma\pi^0$	175893 ± 839	52.90 ± 0.03	$0.334 \pm 0.002 \pm 0.009$	$0.361 \pm 0.012 \pm 0.016$ [16]	0.356 ± 0.017
$\gamma\eta$	2209063 ± 2592	50.78 ± 0.03	$10.96 \pm 0.01 \pm 0.19$	$10.67 \pm 0.05 \pm 0.23$ [17]	10.85 ± 0.18
$\gamma\eta'$	638206 ± 1061	50.77 ± 0.03	$54.0 \pm 0.1 \pm 1.1$	$52.7 \pm 0.3 \pm 0.5$ [18]	52.5 ± 0.7

$\eta - \eta'$ mixing angle:

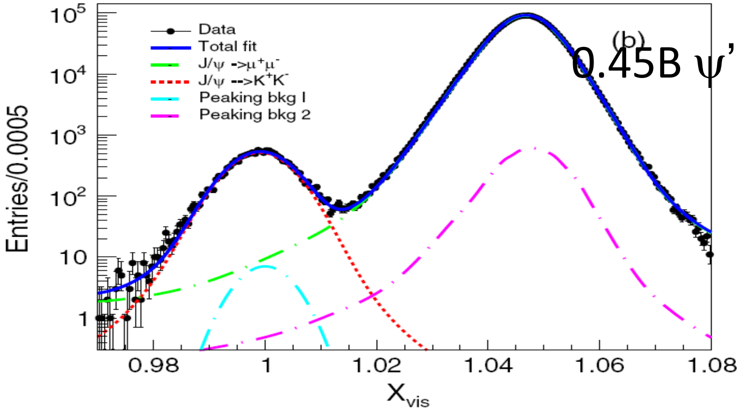
$$R = \frac{\Gamma(J/\psi \to \gamma\eta')}{\Gamma(J/\psi \to \gamma\eta)} = \left(\frac{p_{\eta'}}{p_\eta}\right)^3 \cdot \cot^2\theta_P$$

$$\phi_p = -(22.11 \pm 0.26)^\circ$$

$$\phi_p = -(19.34 \pm 0.34)^\circ$$

$J/\psi \to K^+K^-$ PRD110, 032006 (2024)

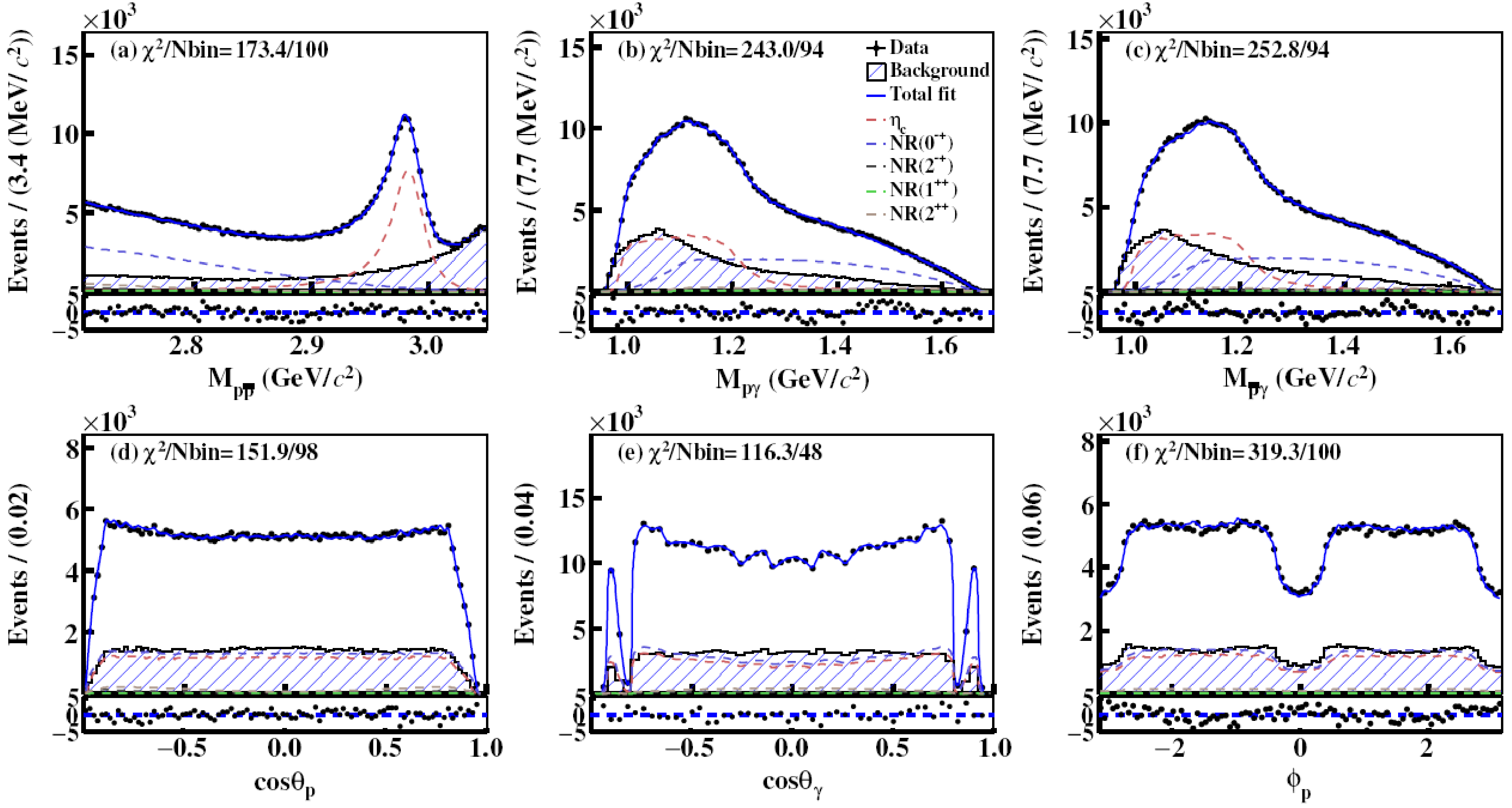
$\psi(3686) \to \pi^+\pi^- J/\psi(\to K^+K^-)$



Advantage: The measurement of BF of J/ψ with $\psi(3686) \to \pi^+\pi^- J/\psi$ avoids potential interference between resonance and continuum production amplitudes

Study of $J/\psi \to \gamma\eta_c(1S)$ via $\eta_c(1S) \to p\bar{p}$

arXiv:2510.15247

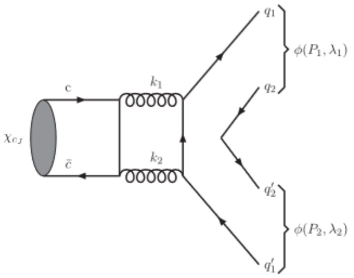


Helicity amplitude analysis of $\chi_{cJ} \to \phi\phi$

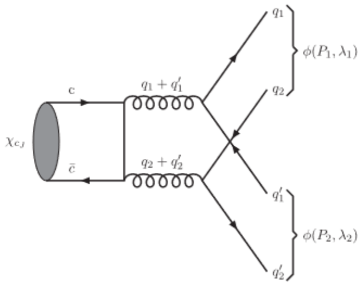
- pQCD prediction for a charmonia decaying into two hadr $\mathcal{B}[\psi(\lambda) \to h_1(\lambda_1)h_2(\lambda_2)] \sim \left(\frac{\Lambda_{QCD}^2}{m_c^2}\right)^{|\lambda_1+\lambda_2|+2}$
- If the light-quark mass is neglected, the vector-gluon coupling conserves quark helicity leading to the helicity selection rule (HSR), i.e.
  - $\lambda_1 + \lambda_2 = 0$
  - if the helicity configuration does not satisfy it, the BF will be suppressed, as in the case of $\chi_{c1} \to \phi\phi$
- BESIII observed similar BFs of three decays, contrary to HSR
  - Many models have been proposed to interpret this result (and have used data as input)
  - Ratios of the helicity amplitudes F_{λ_1,λ_2} are found to be effective in the discrimination between them

Decay channel	$\chi_{c0} \to \phi\phi$		$\chi_{c2} \to \phi\phi$	
Parameter	x	ω_1	ω_2	ω_4
pQCD	0.293 ± 0.030	0.812 ± 0.018	1.647 ± 0.067	0.344 ± 0.020
$^3P_0$	0.515 ± 0.029	1.399 ± 0.580	0.971 ± 0.275	0.406 ± 0.017
$D\bar{D}$ loop	0.359 ± 0.019	1.285 ± 0.017	5.110 ± 0.057	0.465 ± 0.002
	$\lvert F^0_{1,1}\rvert / \lvert F^0_{0,0}\rvert$	$\lvert F^2_{0,1}\rvert / \lvert F^2_{0,0}\rvert$	$\lvert F^2_{1,-1}\rvert / \lvert F^2_{0,0}\rvert$	$\lvert F^2_{1,1}\rvert / \lvert F^2_{0,0}\rvert$

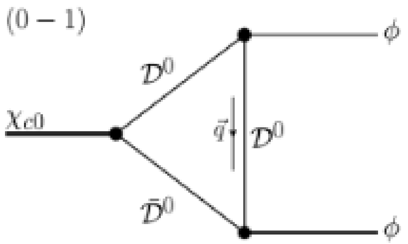
pQCD



$^3P_0$



$D\bar{D}$ loop



Helicity amplitude analysis of $\chi_{cJ} \to \phi\phi$

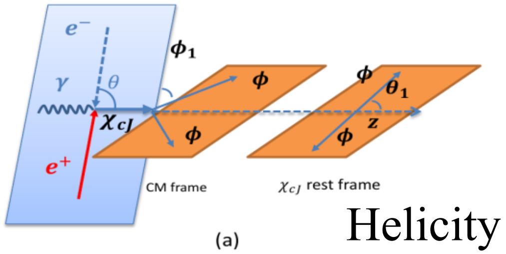
- Amplitude analysis
  - Formula: Helicity amplitude expanded with covariant t
  - Resonance:
    - Relativistic Breit-Wigner function with damping factors
    - Mass resolution is considered
  - Non resonance (NR)
    - Only consider 0^+ and 0^-
    - χ_{c1} and χ_{c2} widths are quite narrow → their interference with a non-resonant contribution is neglected

$$
\begin{aligned}
A &= \langle \vec{p}\lambda_1; -\vec{p}\lambda_2 \,|\mathcal{M}|\, JM\rangle \\
&= 4\pi \left(\frac{\mu}{p}\right)^{\frac{1}{2}} \langle \phi\theta\lambda_1\lambda_2 | JM\lambda_1\lambda_2\rangle \, \langle JM\lambda_1\lambda_2 \,|\mathcal{M}|\, JM\rangle \\
&= N_J F^J_{\lambda_1,\lambda_2} D^{J*}_{M,\lambda}(\phi,\theta,0), \lambda = \lambda_1 - \lambda_2,
\end{aligned}
$$

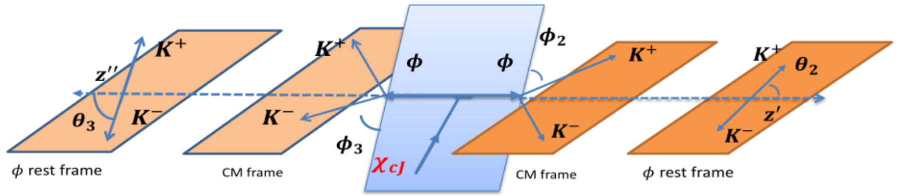
$$
F_{\lambda_1,\lambda_2} = \sum_{LS} g_{LS} \sqrt{\frac{2L+1}{2J+1}} \langle L0S\lambda|J\lambda\rangle\langle \eta_1\lambda_1\eta_2 - \lambda_2|S\lambda\rangle r^L B_L(r)/B_L(r_0)
$$

Partial waves

Decay	Partial waves (LS)
$\psi(3686) \to \gamma\chi_{c0}$	(01) , (21)
$\psi(3686) \to \gamma\chi_{c1}$	(01) , (21) , (22)
$\psi(3686) \to \gamma\chi_{c2}$	(01) , (21) , (22) , (23) , (43)
χ_{c0} or $\mathrm{NR}(0^+) \to \phi\phi$	(00) , (22)
χ_{c1} or $\mathrm{NR}(1^+) \to \phi\phi$	(01) , (21) , (22)
χ_{c2} or $\mathrm{NR}(2^+) \to \phi\phi$	(02) , (20) , (21) , (22) , (42)
$\mathrm{NR}(0^-) \to \phi\phi$	(11)
$\phi \to K^+K^-$	(10)



Helicity angle system



Helicity amplitude anslysis of $\chi_{cJ} \to \phi\phi$

- χ_{c0} mass and width float in the fit, χ_{c1} and χ_{c2} ones are fixed to PDG
- BF results are consistent with BESIII previous results and PDG values

Decay Mode	2011 BESIII [8]	this work	PDG value [22]
$\mathcal{B}[\chi_{c0} \to \phi\phi](\times 10^{-4})$	7.8±0.4±0.8	$8.59 \pm 0.27 \pm 0.20$	8.0±0.7
$\mathcal{B}[\chi_{c1} \to \phi\phi](\times 10^{-4})$	4.1±0.3±0.5	$4.26 \pm 0.13 \pm 0.15$	4.2±0.5
$\mathcal{B}[\chi_{c1} \to \phi\phi](\times 10^{-4})$	10.7±0.4±1.2	$12.67 \pm 0.28 \pm 0.33$	10.6±0.9

- Helicity amplitude ratios
  - $|F^0_{1,1}|/\,|F^0_{0,0}| = 0.299 \pm 0.003 \pm 0.019$
  - $|F^2_{0,1}|/\,|F^2_{0,0}| = 1.265 \pm 0.054 \pm 0.079$
  - $|F^2_{1,-1}|/\,|F^2_{0,0}| = 1.450 \pm 0.097 \pm 0.104$
  - $|F^2_{1,1}|/\,|F^2_{0,0}| = 0.808 \pm 0.051 \pm 0.009$
  - The $D\bar{D}$ loop model can be ruled out
  - Other predictions also have sizeable difference

With $(27.12 \pm 0.14) \times 10^8$ $\psi(3686)$ events, a fuller understanding of this inconsistency can be provided!

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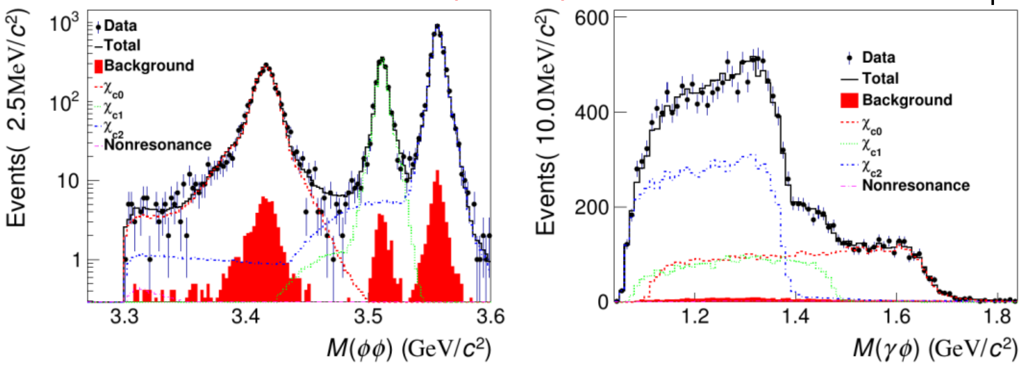
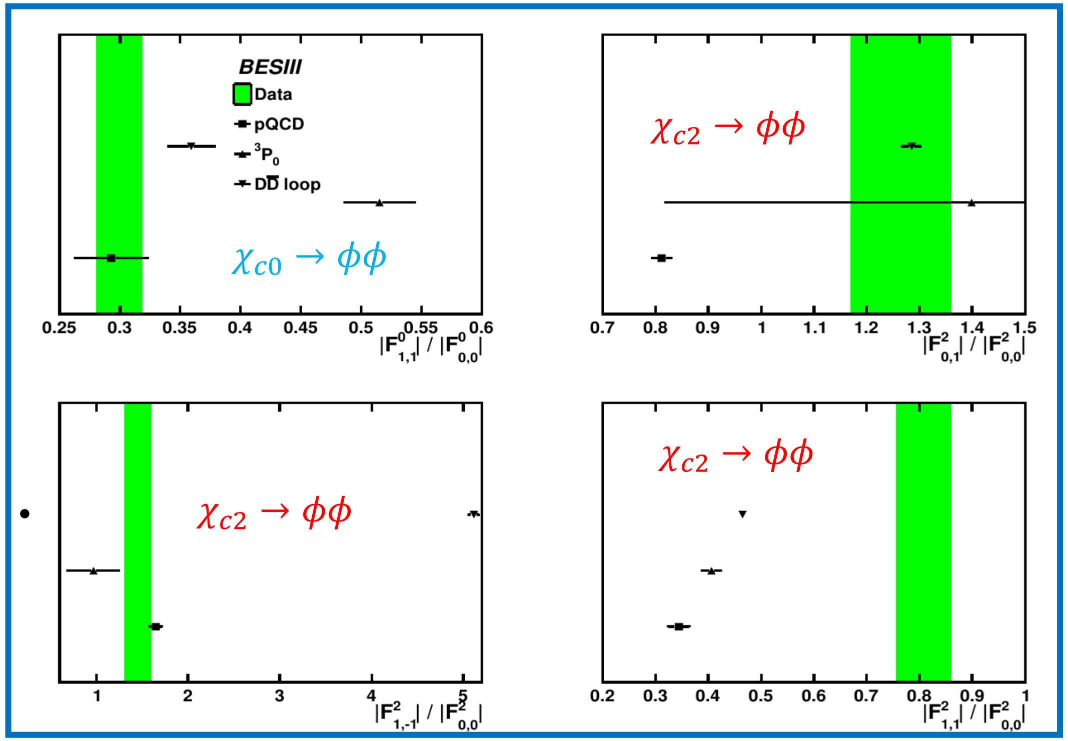
0.45B ψ’





Helicity amplitude analysis of $\chi_{cJ} \to \Lambda\bar{\Lambda}$

Decays	Angles	Amplitudes
$\psi(3686)(M) \to \gamma(\lambda_1)\chi_{cJ}(\lambda_2)$	$\Omega_0 = (\theta_0, \phi_0)$	$A^{(J)}_{\lambda_1,\lambda_2}$
$\chi_{cJ} \to \Lambda(\lambda_3)\bar{\Lambda}(\lambda_4)$	$\Omega_1 = (\theta_1, \phi_1)$	$B^{(J)}_{\lambda_3,\lambda_4}$
$\Lambda \to p(\lambda_5)\pi^-$	$\Omega_2 = (\theta_2, \phi_2)$	F_{λ_5}
$\bar{\Lambda} \to \bar{p}(\lambda_6)\pi^+$	$\Omega_3 = (\theta_3, \phi_3)$	G_{λ_5}

TABLE II. Fit results with statistical and systematic uncertainties where r_1, r_2, r_3, R_2 are the modulus of amplitude ratios for $A^{(1)}_{1,1}/A^{(1)}_{1,0}$, $A^{(2)}_{1,1}/A^{(2)}_{1,0}$, $A^{(2)}_{1,2}/A^{(2)}_{1,0}$ and $B^{(2)}_{++}/B^{(2)}_{+-}$, $\Delta\Phi_{r_1}$, $\Delta\Phi_{r_2}$, $\Delta\Phi_{r_3}$, $\Delta\Phi_{R_2}$ are the corresponding relative phase angles. $FF_{\chi_{c0}}$, $FF_{\chi_{c1}}$, $FF_{\chi_{c2}}$, $FF_{NR(2^+)}$ are the fit fractions of χ_{c0}, χ_{c1}, χ_{c2}, $NR(2^+)$, respectively. $\alpha_{\chi_{c1}}$, $\alpha_{\chi_{c2}}$, $\beta_{\chi_{c2}}$ are the angular parameters of χ_{c1} and χ_{c2} in Eq. 7 and $\Gamma_{\chi_{c0}}$ is the width of χ_{c0}.

$$
\begin{aligned}
\alpha_{\chi_{c1}} &= \frac{-2r_1^2R_1^2 + r_1^2 + 4R_1^2 - 2}{2r_1^2R_1^2 + r_1^2 + 2}, \\
\alpha_{\chi_{c2}} &= \frac{12r_2^2R_2^2 - 6r_3^2R_2^2 - 6r_2^2 - 12R_2^2 + 12}{3r_3^2R_2^2 + 2r_2^2 + 2r_3^2 + 2R_2^2}, \\
\beta_{\chi_{c2}} &= \frac{-12r_2^2R_2^2 + 3r_3^2R_2^2 + 8r_2^2 - 2r_3^2 + 18R_2^2 - 12}{3r_3^2R_2^2 + 2r_2^2 + 2r_3^2 + 2R_2^2},
\end{aligned}
\tag{7}
$$

where $r_1| = |A^{(1)}_{1,1}|/|A^{(1)}_{1,0}|$, $r_2 = |A^{(2)}_{1,1}|/|A^{(2)}_{1,0}|$, $r_3 = |A^{(2)}_{1,2}|/|A^{(2)}_{1,0}|$, $R_1 = |B^{(1)}_{++}|/|B^{(1)}_{+-}|$, $R_2 = |B^{(2)}_{++}|/|B^{(2)}_{+-}|$, $R_1 = 0$ due to the CP conservation in $\chi_{c1} \to \Lambda\bar{\Lambda}$ decay.

$$
FF_i = \frac{\int |\mathcal{A}_i|^2 \, d\Phi}{\int |\mathcal{A}(\mathbf{x})|^2 \, d\Phi}
$$