Charmonium decays at BESIII

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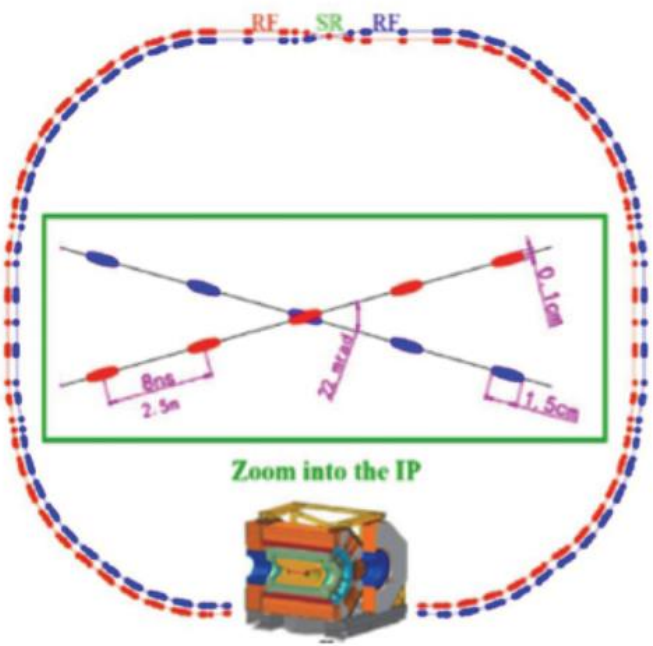
BESIII@BEPCII

BESIII

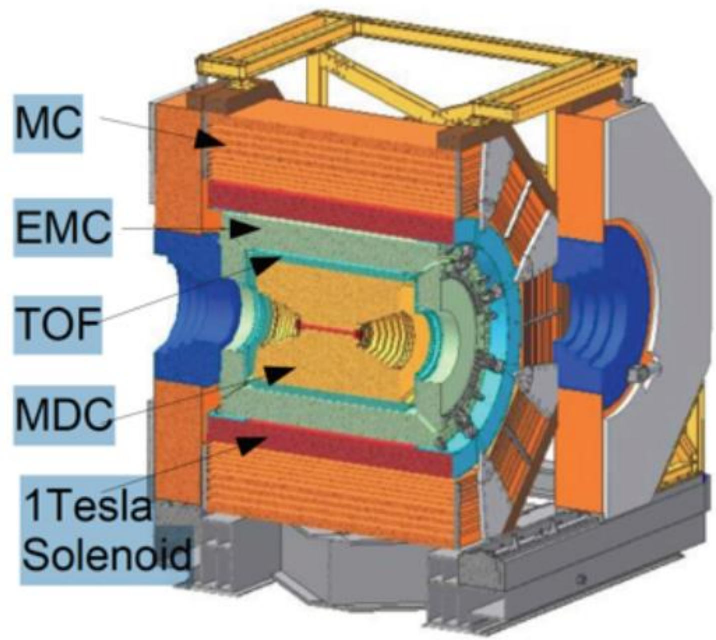
Double ring e^+e^- collider:



Achieved

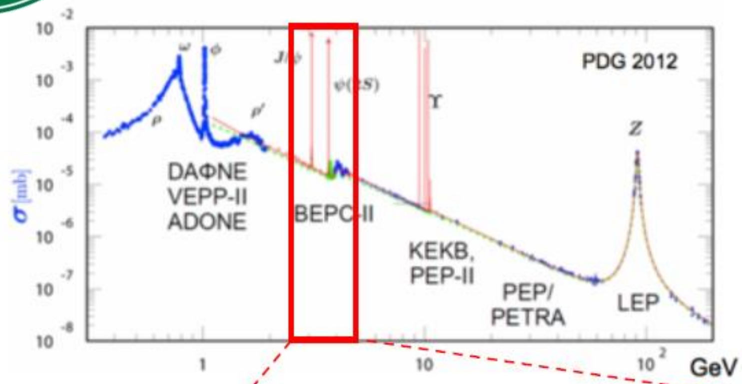
- **Beam energy:** 1.0 – 2.3 GeV
- **Design luminosity**: 10^{33} cm^{-2} s^{-1}
- **Energy spread**: 5.16×10^{-4}
- **Number of bunches**: 93
- **Total current**: 0.91 A
- **Bunch length**: 1.5 cm

Multi-purpose detector:



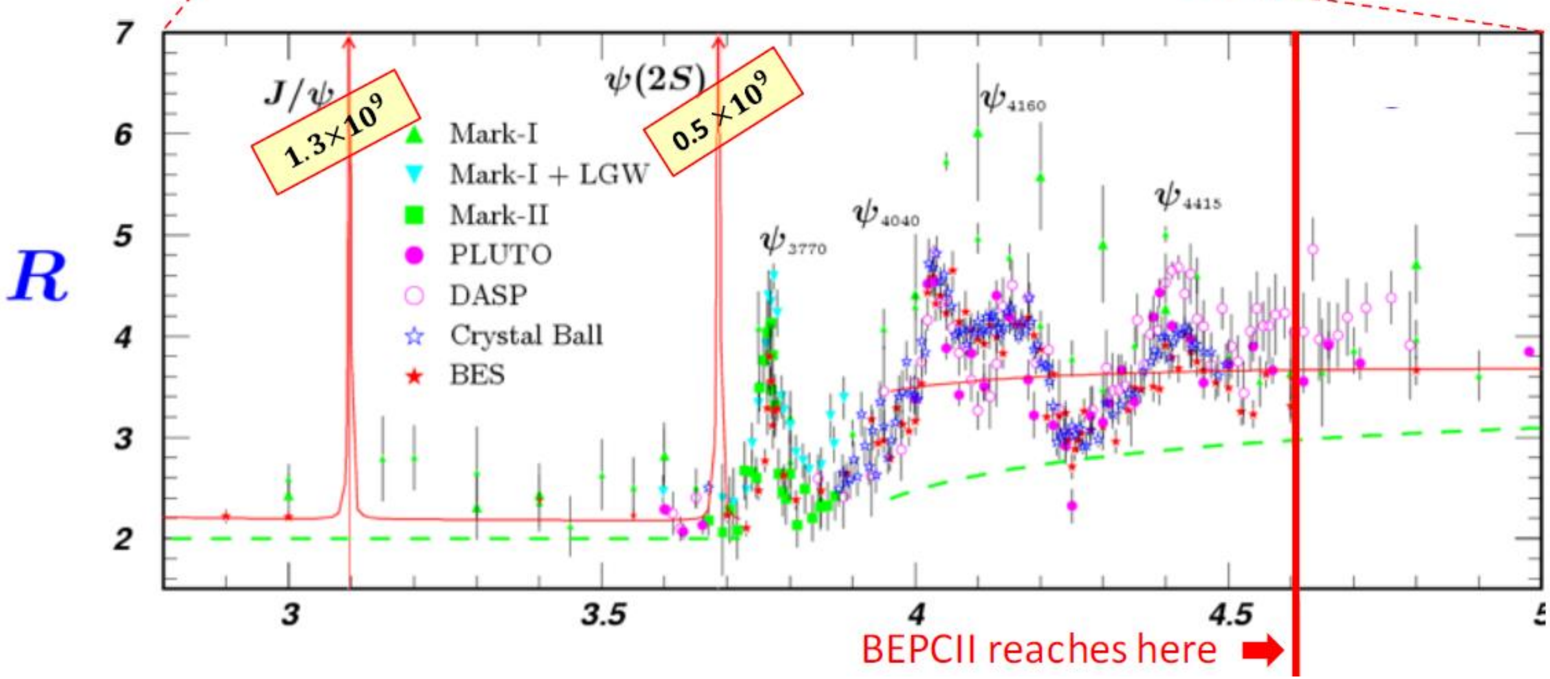
- **Multilayer Drift Chamber**
  $\sigma(p)/p < 0.5$ % for 1 GeV tracks, $\sigma(dE/dx)/dE/dx < 6\%$, $\sigma(xy) = 130$ μm
- **Time of Flight** $\sigma(t) \sim 90$ ps
- **EMCalorimeter** $\sigma(E)/E < 2.5$ %, $\sigma(x) <$ 6mm for 1 GeV e^-
- **Muon Counter** $\sigma(xy) < 2$ cm

BESIII data samples



BESIII detector has collected the largest data samples of the J/ψ & $\psi(3686)$ in the world.

What can we do with these data?



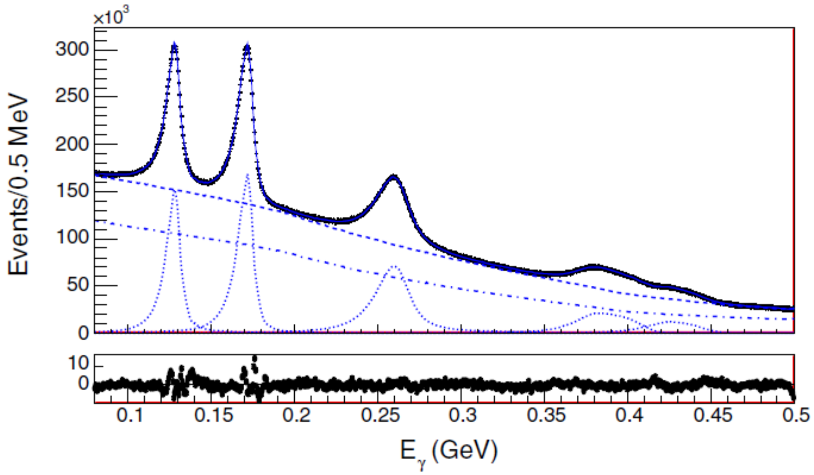
The results at BESIII

- Branching fraction measurements of $\psi(3686) \to \gamma\chi_{cJ}$
- Measurement of higher-order multipole amplitudes in $\psi(3686) \to \gamma\chi_{c1,2}$ with $\chi_{c1,2} \to \gamma J/\psi$ and search for the transition $\eta_c(2S) \to \gamma J/\psi$
- Observation of $\psi(3686) \to e^+e^-\chi_{cJ}$ and $\chi_{cJ} \to e^+e^- J/\psi$
- Study of J/ψ and $\psi(3686)$ decay to $\Lambda\bar{\Lambda}$ and $\Sigma^0\bar{\Sigma}^0$ final states
- Study of J/ψ and $\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$ and $\Xi^0\bar{\Xi}^0$
- Observation of h_c radiative decay $h_c \to \gamma\eta'$ and evidence for $h_c \to \gamma\eta$
- Improved measurements of branching fractions for $\eta_c \to \phi\phi$ and $\omega\phi$

Branching fraction measurements of $\psi(3686) \to \gamma\chi_{cJ}$

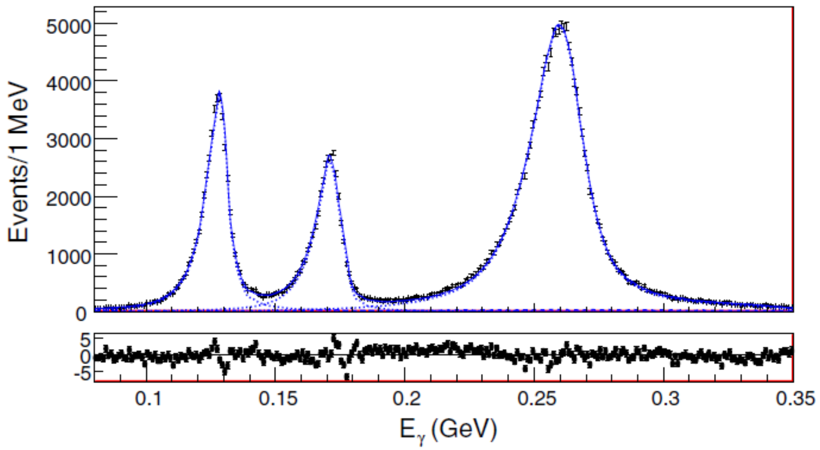
- Understand the inner structure of hadrons
- Help untangle the mysterious XYZ states
- More precise measurement

PRD 96, 032001 (2017)



$$\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ}) = \frac{N_{\psi(3686)\to\gamma\chi_{cJ}}}{\epsilon_{\psi(3686)\to\gamma\chi_{cJ}} \times N_{\psi(3686)}}$$

$$\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ}) \times \mathcal{B}(\chi_{cJ} \to \gamma J/\psi) = \frac{N_{\chi_{cJ}\to\gamma J/\psi}}{\epsilon_{\chi_{cJ}\to\gamma J/\psi} \times N_{\psi(3686)}},$$



$$\mathcal{B}(\chi_{cJ} \to \gamma J/\psi) = \frac{\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ}) \times \mathcal{B}(\chi_{cJ} \to \gamma J/\psi)}{\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ})} = \frac{\epsilon_{\psi(3686)\to\gamma\chi_{cJ}} \times N_{\chi_{cJ}\to\gamma J/\psi}}{\epsilon_{\chi_{cJ}\to\gamma J/\psi} \times N_{\psi(3686)\to\gamma\chi_{cJ}}}.$$

Branching fraction measurements of $\psi(3686) \to \gamma\chi_{cJ}$

Branching fraction results

PRD 96, 032001 (2017)

Branching Fraction	This analysis (%)	Other (%)	PDG [7] (%) Average	PDG [7] (%) Fit
$\mathcal{B}(\psi(3686) \to \gamma\chi_{c0})$	$9.389 \pm 0.014 \pm 0.332$	$9.22 \pm 0.11 \pm 0.46$ [9]	9.2 ± 0.4	9.99 ± 0.27
$\mathcal{B}(\psi(3686) \to \gamma\chi_{c1})$	$9.905 \pm 0.011 \pm 0.353$	$9.07 \pm 0.11 \pm 0.54$ [9]	8.9 ± 0.5	9.55 ± 0.31
$\mathcal{B}(\psi(3686) \to \gamma\chi_{c2})$	$9.621 \pm 0.013 \pm 0.272$	$9.33 \pm 0.14 \pm 0.61$ [9]	8.8 ± 0.5	9.11 ± 0.31
$\mathcal{B}(\psi(3686) \to \gamma\chi_{c0}) \times \mathcal{B}(\chi_{c0} \to \gamma J/\psi)$	$0.024 \pm 0.015 \pm 0.205$	$0.125 \pm 0.007 \pm 0.013$ [31] $0.151 \pm 0.003 \pm 0.010$ [15] $0.158 \pm 0.003 \pm 0.006$ [16]	0.131 ± 0.035	0.127 ± 0.006
$\mathcal{B}(\psi(3686) \to \gamma\chi_{c1}) \times \mathcal{B}(\chi_{c1} \to \gamma J/\psi)$	$3.442 \pm 0.010 \pm 0.132$	$3.56 \pm 0.03 \pm 0.12$ [31] $3.377 \pm 0.009 \pm 0.183$ [15] $3.518 \pm 0.01 \pm 0.120$ [16]	2.93 ± 0.15	3.24 ± 0.07
$\mathcal{B}(\psi(3686) \to \gamma\chi_{c2}) \times \mathcal{B}(\chi_{c2} \to \gamma J/\psi)$	$1.793 \pm 0.008 \pm 0.163$	$1.95 \pm 0.02 \pm 0.07$ [31] $1.874 \pm 0.007 \pm 0.102$ [15] $1.996 \pm 0.008 \pm 0.070$ [16]	1.52 ± 0.15	1.75 ± 0.04
$\mathcal{B}(\chi_{c0} \to \gamma J/\psi)$	$0.25 \pm 0.16 \pm 2.15$	$2 \pm 0.2 \pm 0.2$ [32]		1.27 ± 0.06
$\mathcal{B}(\chi_{c1} \to \gamma J/\psi)$	$34.75 \pm 0.11 \pm 1.70$	$37.9 \pm 0.8 \pm 2.1$ [32]		33.9 ± 1.2
$\mathcal{B}(\chi_{c2} \to \gamma J/\psi)$	$18.64 \pm 0.08 \pm 1.69$	$19.9 \pm 0.5 \pm 1.2$ [32]		19.2 ± 0.7

$$\mathcal{B}(\psi(3686) \to \gamma\chi_{c0})/\mathcal{B}(\psi(3686) \to \gamma\chi_{c1}) = 0.948 \pm 0.002 \pm 0.044$$

$$\mathcal{B}(\psi(3686) \to \gamma\chi_{c0})/\mathcal{B}(\psi(3686) \to \gamma\chi_{c2}) = 0.976 \pm 0.002 \pm 0.040$$

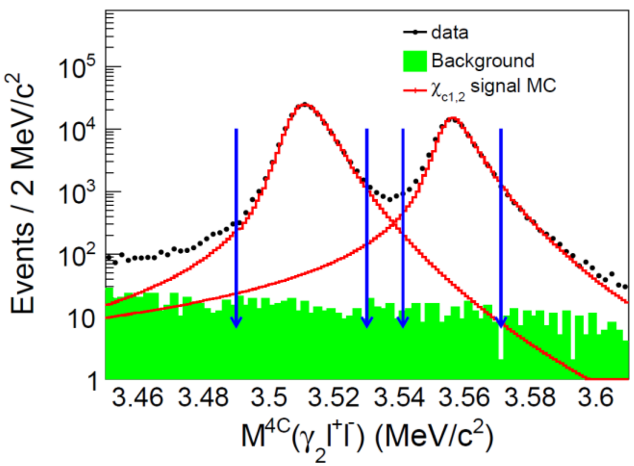
$$\mathcal{B}(\psi(3686) \to \gamma\chi_{c2})/\mathcal{B}(\psi(3686) \to \gamma\chi_{c1}) = 0.971 \pm 0.002 \pm 0.040$$

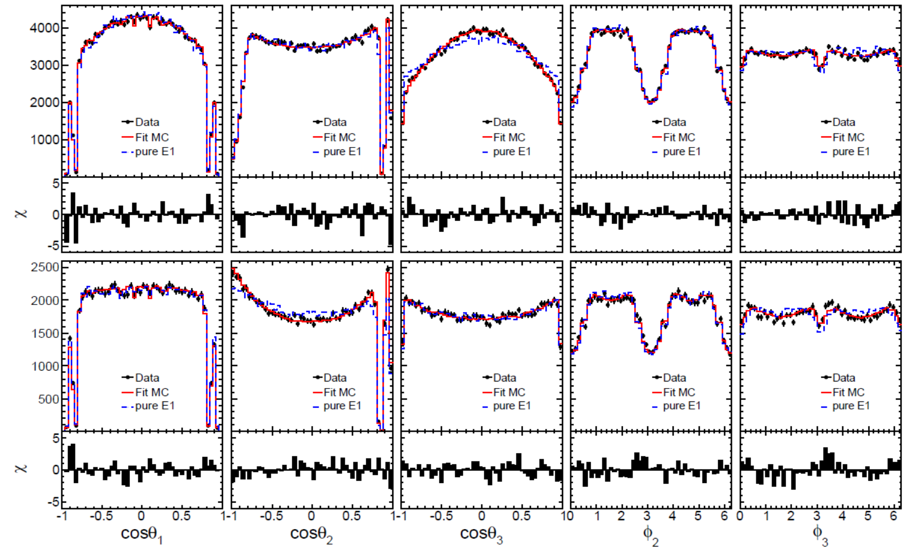
Theoretical prediction and experimental measurement

		Γ_{E1} (keV)					Γ_{EM} (keV)		
Initial State	Final State	RQM [33]	NR/GI [34]	$\mathrm{SNR}_{0/1}$ [35]	LP [8]	SP [8]	LP [8]	SP [8]	This Analysis
$\psi(3686)$	χ_{c0}	26.3	63/26	74/25	27	26	22	22	26.9 ± 1.8
	χ_{c1}	22.9	54/29	62/36	45	48	42	45	28.3 ± 1.9
	χ_{c2}	18.2	38/24	43/34	36	44	38	46	27.5 ± 1.7
χ_{c0}	J/ψ	121	152/114	167/117	141	146	172	179	
χ_{c1}		265	314/239	354/244	269	278	306	319	306 ± 23
χ_{c2}		327	424/313	473/309	327	338	284	292	363 ± 41

Experimental results have become accurate enough to become sensitive to fine details of the potentials, e.g. relativistic effects, screening effects, and higher partial waves.

Measurement of higher-order multipole amplitudes in $\psi(3686) \to \gamma\chi_{c1,2}$ with $\chi_{c1,2} \to \gamma J/\psi$ and search for the transition $\eta_c(2S) \to \gamma J/\psi$ PRD 95, 072004 (2017)

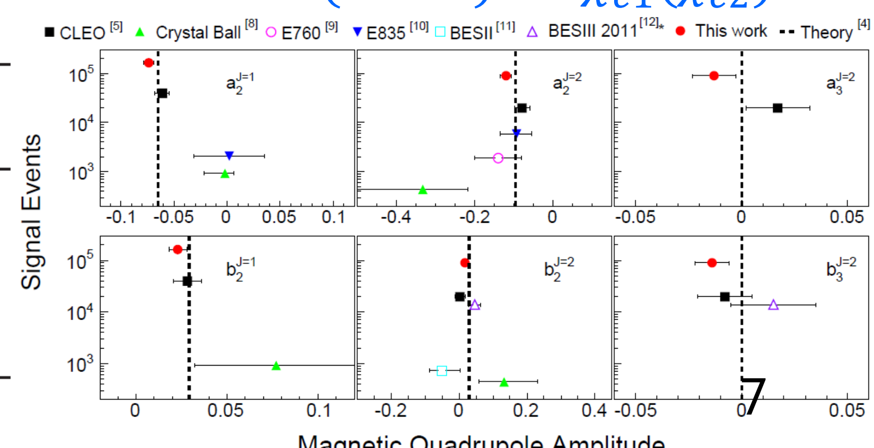




The normalized M2($\chi_{c1,2}$) and E3(χ_{c2}) contribution

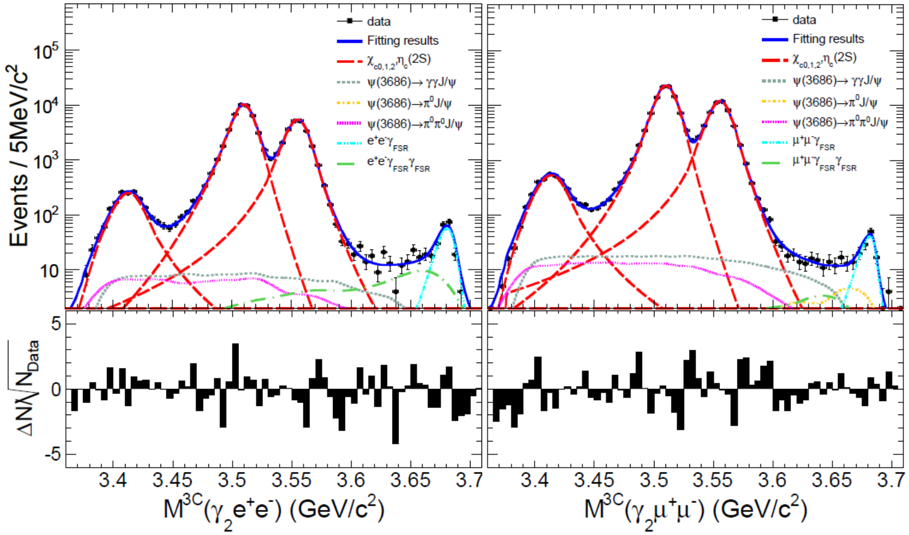
The statistical significance of nonpure E1 transition is $24.3\sigma(13.4\sigma)$ for $\chi_{c1}(\chi_{c2})$

χ_{c1}	$a_2^1 = -0.0740 \pm 0.0033 \pm 0.0034,\ b_2^1 = 0.0229 \pm 0.0039 \pm 0.0027$ $\rho^1_{a_2 b_2} = 0.133$
χ_{c2}	$a_2^2 = -0.120 \pm 0.013 \pm 0.004,\ b_2^2 = 0.017 \pm 0.008 \pm 0.002$ $a_3^2 = -0.013 \pm 0.009 \pm 0.004,\ b_3^2 = -0.014 \pm 0.007 \pm 0.004$ $\rho^2_{a_2 b_2} = -0.605,\ \rho^2_{a_2 a_3} = 0.733,\ \rho^2_{a_2 b_3} = -0.095$ $\rho^2_{a_3 b_2} = -0.422,\ \rho^2_{b_2 b_3} = 0.384,\ \rho^2_{a_3 b_3} = -0.024$



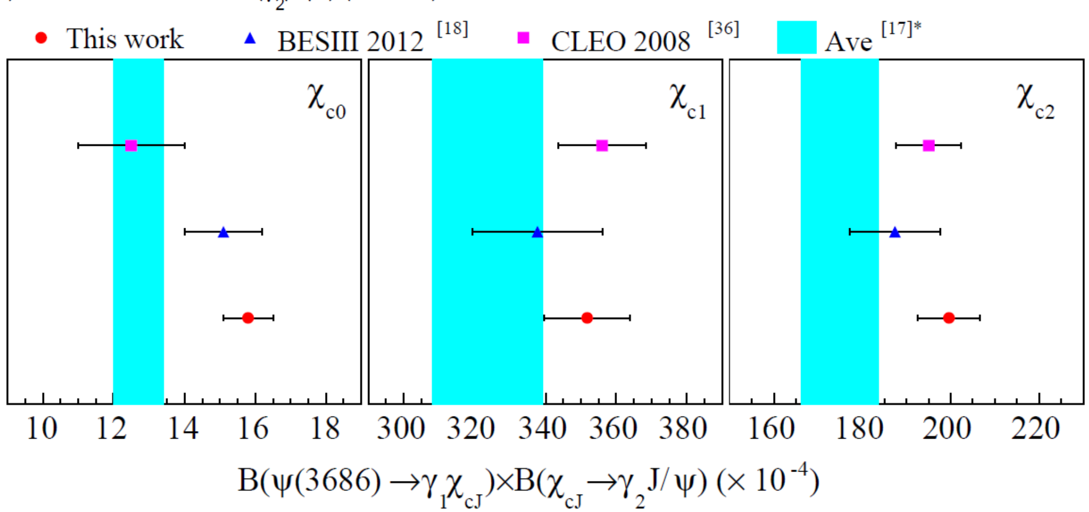
Measurement of higher-order multipole amplitudes in $\psi(3686) \to \gamma\chi_{c1,2}$ with $\chi_{c1,2} \to \gamma J/\psi$ and search for the transition $\eta_c(2S) \to \gamma J/\psi$ PRD 95, 072004 (2017)

A simultaneous fit to invariant mass distribution

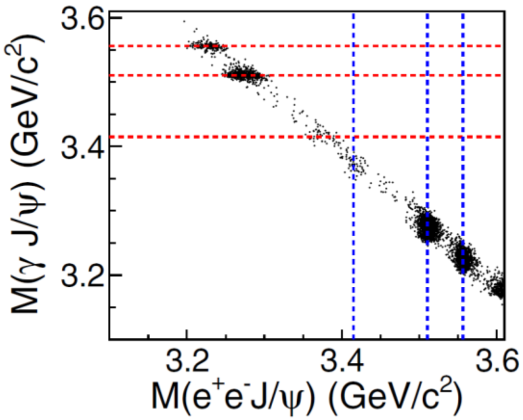


Mode	Branching fraction measurement ($\times 10^{-4}$)
$\mathcal{B}(\psi' \to \gamma\chi_{c0}) \cdot \mathcal{B}(\chi_{c0} \to \gamma J/\psi)$	$15.8 \pm 0.3 \pm 0.6$
$\mathcal{B}(\psi' \to \gamma\chi_{c1}) \cdot \mathcal{B}(\chi_{c1} \to \gamma J/\psi)$	$351.8 \pm 1.0 \pm 12.0$
$\mathcal{B}(\psi' \to \gamma\chi_{c2}) \cdot \mathcal{B}(\chi_{c2} \to \gamma J/\psi)$	$199.6 \pm 0.8 \pm 7.0$

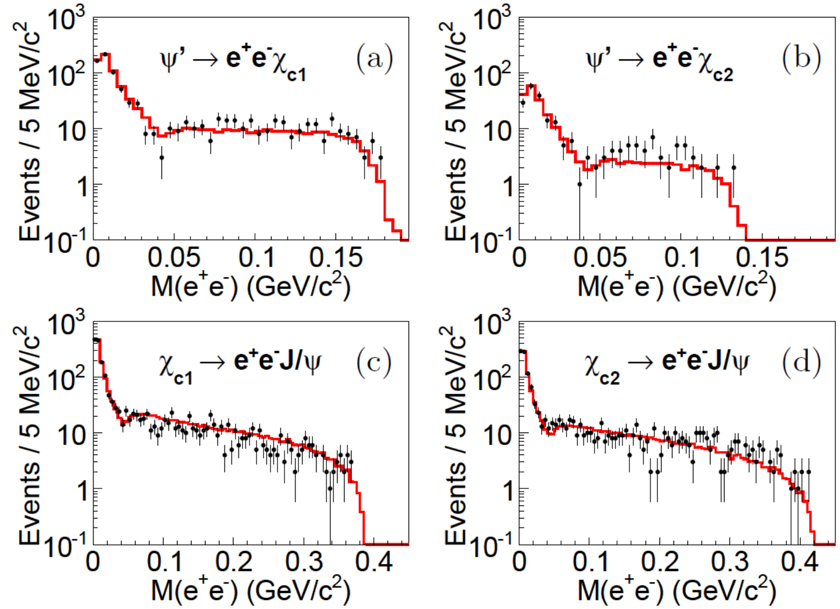
$\mathcal{B}(\psi' \to \gamma\eta_c(2S)) \cdot \mathcal{B}(\eta_c(2S) \to \gamma J/\psi)$
$< 9.7 \times 10^{-6}$ at 90% C.L.

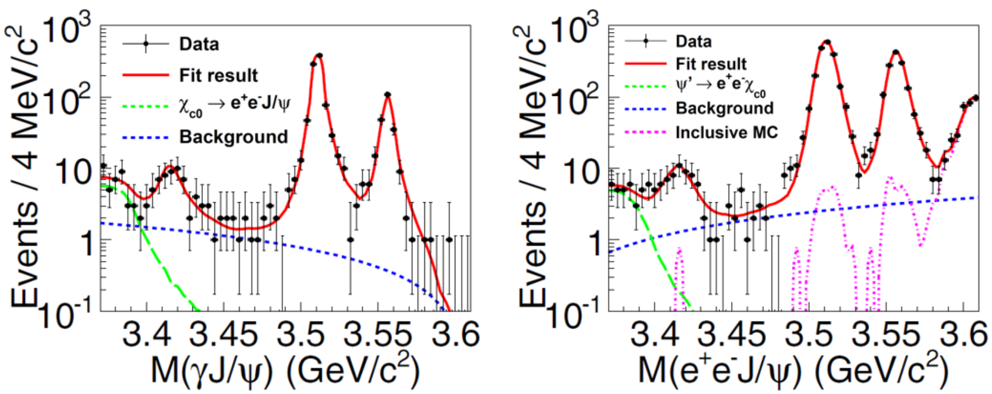


Observation of $\psi(3686) \to e^+e^-\chi_{cJ}$ and $\chi_{cJ} \to e^+e^- J/\psi$



PRL 118, 221802 (2017)





Mode	Yields	Efficiency(%)	Branching fraction	$\mathcal{B}(\psi(3686) \to e^+e^-\chi_{cJ})/$ $\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ})$	$\mathcal{B}(\chi_{cJ} \to e^+e^-J/\psi)/$ $\mathcal{B}(\chi_{cJ} \to \gamma J/\psi)$
$\psi(3686) \to e^+e^-\chi_{c0}$	48 ± 10	6.06	$(11.7 \pm 2.5 \pm 1.0) \times 10^{-4}$	$(9.4 \pm 1.9 \pm 0.6) \times 10^{-3}$	⋯
$\psi(3686) \to e^+e^-\chi_{c1}$	873 ± 30	5.61	$(8.6 \pm 0.3 \pm 0.6) \times 10^{-4}$	$(8.3 \pm 0.3 \pm 0.4) \times 10^{-3}$	⋯
$\psi(3686) \to e^+e^-\chi_{c2}$	227 ± 16	3.19	$(6.9 \pm 0.5 \pm 0.6) \times 10^{-4}$	$(6.6 \pm 0.5 \pm 0.4) \times 10^{-3}$	⋯
$\chi_{c0} \to e^+e^-J/\psi$	56 ± 11	6.95	$(1.51 \pm 0.30 \pm 0.13) \times 10^{-4}$	⋯	$(9.5 \pm 1.9 \pm 0.7) \times 10^{-3}$
$\chi_{c1} \to e^+e^-J/\psi$	1969 ± 46	10.35	$(3.73 \pm 0.09 \pm 0.25) \times 10^{-3}$	⋯	$(10.1 \pm 0.3 \pm 0.5) \times 10^{-3}$
$\chi_{c2} \to e^+e^-J/\psi$	1354 ± 39	11.23	$(2.48 \pm 0.08 \pm 0.16) \times 10^{-3}$	⋯	$(11.3 \pm 0.4 \pm 0.5) \times 10^{-3}$

Study of J/ψ and $\psi(3686)$ decay to $\Lambda\bar{\Lambda}$ and $\Sigma^0\bar{\Sigma}^0$ final states

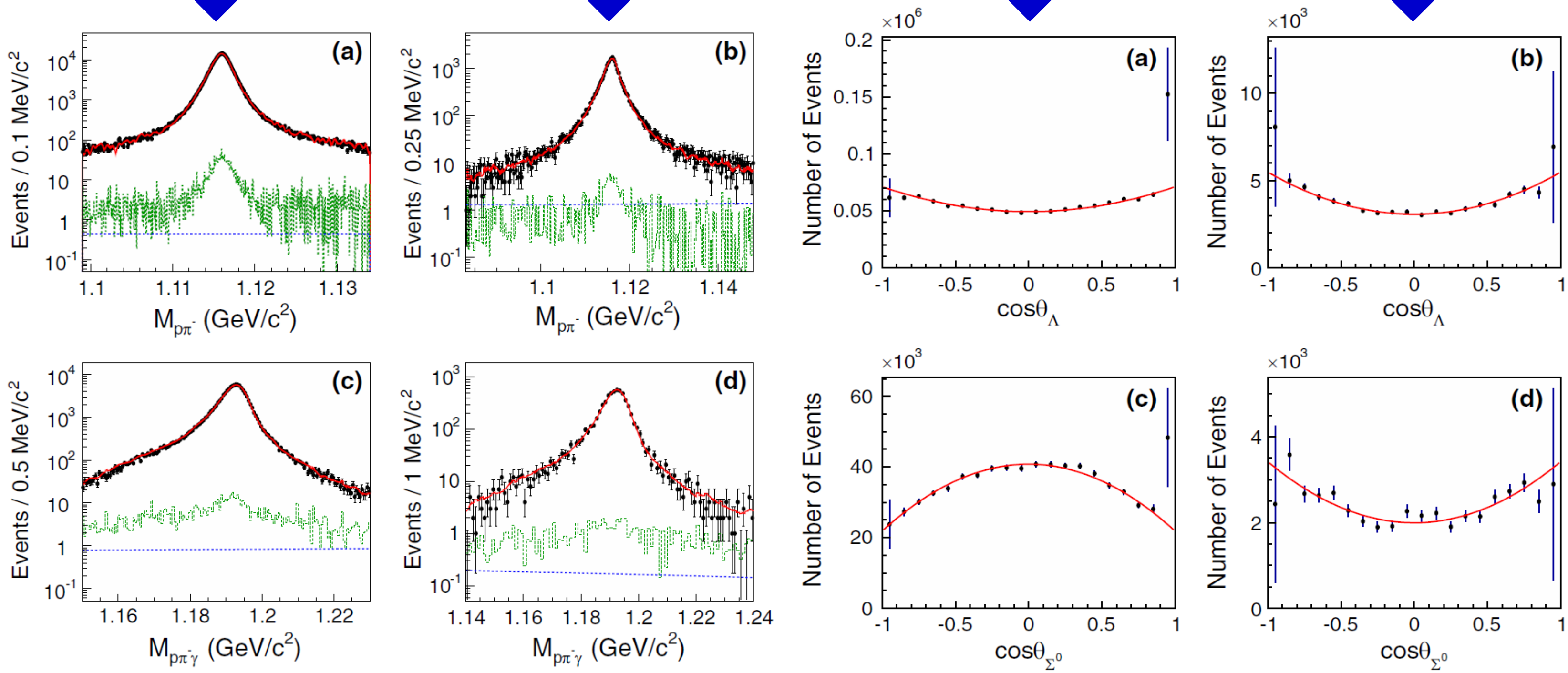
- Test of the "12% rule"
- Test of the helicity conservation rule
- First or more precise measurement

PRD 95, 052003 (2017)

J/ψ | $\psi(3686)$ | J/ψ | $\psi(3686)$

$\Lambda\bar{\Lambda}$

$\Sigma^0\bar{\Sigma}^0$



Study of J/ψ and $\psi(3686)$ decay to $\Lambda\bar{\Lambda}$ and $\Sigma^0\bar{\Sigma}^0$ final states

Test of the "12% rule"

$$\frac{\mathcal{B}(\psi(3686)\to\Lambda\bar{\Lambda})}{\mathcal{B}(J/\psi\to\Lambda\bar{\Lambda})} = (20.43 \pm 0.11 \pm 0.58)\%$$

PRD 95, 052003 (2017)

$$\frac{\mathcal{B}(\psi(3686)\to\Sigma^0\bar{\Sigma}^0)}{\mathcal{B}(J/\psi\to\Sigma^0\bar{\Sigma}^0)} = (20.96\pm0.27\pm0.92)\%$$

Results for this work

Channel	α	$\mathcal{B}$ ($\times 10^{-4}$)
$J/\psi \to \Lambda\bar{\Lambda}$	$0.469 \pm 0.026 \pm 0.008$	$19.43 \pm 0.03 \pm 0.33$
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	$-0.449 \pm 0.020 \pm 0.008$	$11.64 \pm 0.04 \pm 0.23$
$\psi(3686) \to \Lambda\bar{\Lambda}$	$0.82 \pm 0.08 \pm 0.02$	$3.97 \pm 0.02 \pm 0.12$
$\psi(3686) \to \Sigma^0\bar{\Sigma}^0$	$0.71 \pm 0.11 \pm 0.04$	$2.44 \pm 0.03 \pm 0.11$

Theoretical prediction and previous measurements of α

	$\alpha_{J/\psi\to\Lambda\bar{\Lambda}}$	$\alpha_{J/\psi\to\Sigma^0\bar{\Sigma}^0}$
Theory	0.32	0.31 [16]
	0.51	0.43 [17]
Experiment	0.72 ± 0.36	0.70 ± 1.10 [5]
	0.62 ± 0.22	0.22 ± 0.31 [6]
	0.65 ± 0.14	-0.22 ± 0.19 [10]

Branching fraction results of other experiments

	$J/\psi \to \Lambda\bar{\Lambda}$	$\psi(3686) \to \Lambda\bar{\Lambda}$	$J/\psi \to \Sigma^0\bar{\Sigma}^0$	$\psi(3686) \to \Sigma^0\bar{\Sigma}^0$
MARKII Collaboration [5]	$15.8 \pm 0.8 \pm 1.9$	...	$15.8 \pm 1.6 \pm 2.5$	...
DM2 Collaboration [6]	$13.8 \pm 0.5 \pm 2.0$	...	$10.6 \pm 0.4 \pm 2.3$	...
BES Collaboration [7,8]	$10.8 \pm 0.6 \pm 2.4$	$1.8 \pm 0.2 \pm 0.3$	...	$1.2 \pm 0.4 \pm 0.4$
CLEO Collaboration [9]	...	$3.3 \pm 0.3 \pm 0.3$	...	$2.6 \pm 0.4 \pm 0.4$
BESII Collaboration [10,11]	$20.3 \pm 0.3 \pm 1.5$	$3.4 \pm 0.2 \pm 0.4$	$13.3 \pm 0.4 \pm 1.1$	$2.4 \pm 0.4 \pm 0.4$
BABAR Collaboration [12]	$19.3 \pm 2.1 \pm 0.5$	$6.4 \pm 1.8 \pm 0.1$	$11.5 \pm 2.4 \pm 0.3$	...
Dobbs *et al.* [13]	...	$3.8 \pm 0.1 \pm 0.3$	...	$2.3 \pm 0.2 \pm 0.2$
PDG [15]	16.1 ± 1.5	3.6 ± 0.2	12.9 ± 0.9	2.3 ± 0.2

Study of J/ψ and $\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$ and $\Xi^0\bar{\Xi}^0$

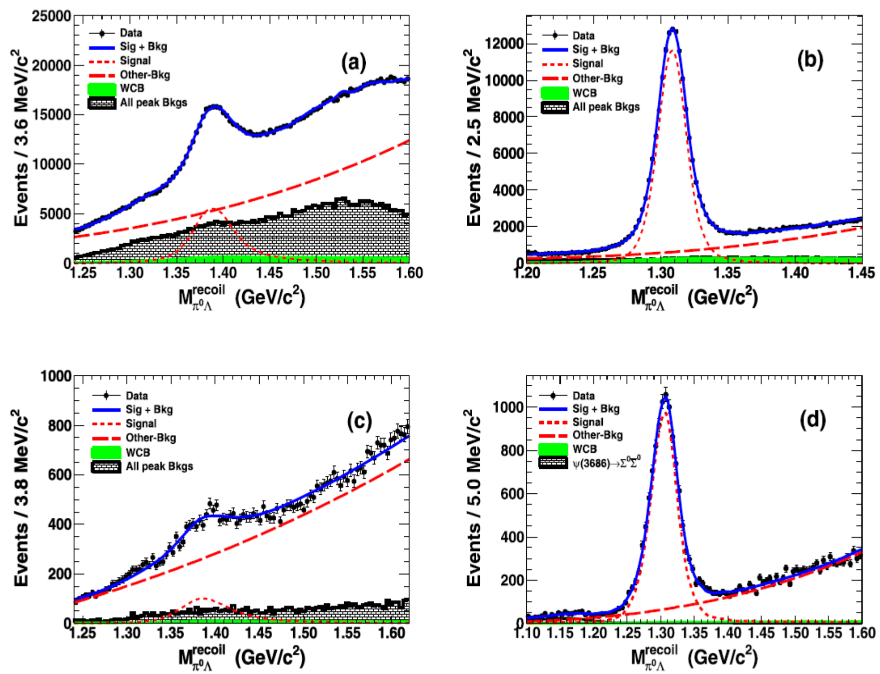
- Test of the "12% rule"
- Test of the helicity conservation rule
- First or more precise measurement
- Test of isospin symmetry

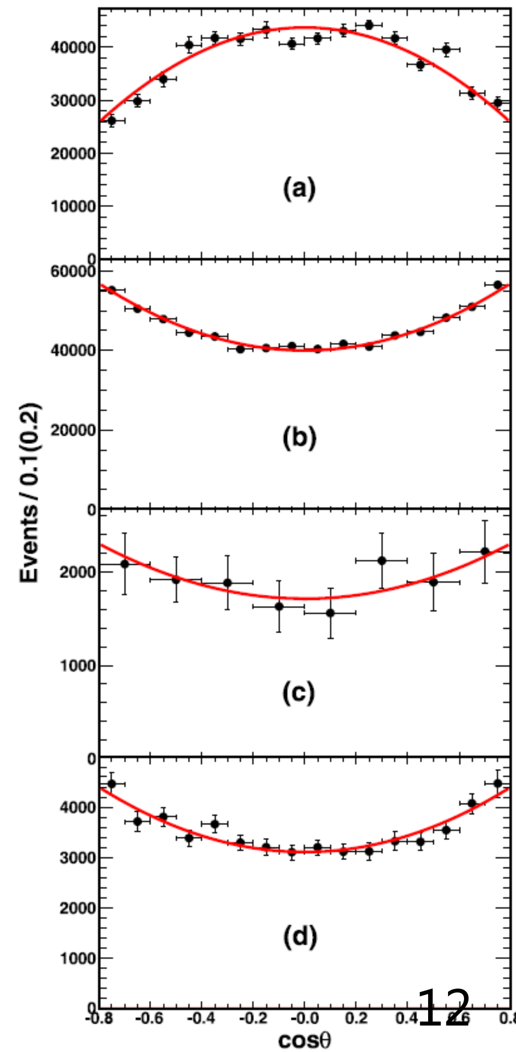
PLB 770, 217 (2017)

$\Sigma(1385)^0\bar{\Sigma}(1385)^0$ $\quad\quad$ $\Xi^0\bar{\Xi}^0$

J/ψ

$\psi(3686)$





Study of J/ψ and $\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$ and $\Xi^0\bar{\Xi}^0$

Test of the "12% rule"

$$\frac{\mathcal{B}(\psi(3686)\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}{\mathcal{B}(J/\psi\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}=(6.44 \pm 0.47 \pm 0.64)\%$$

$$\frac{\mathcal{B}(\psi(3686)\to\Xi^0\bar{\Xi}^0)}{\mathcal{B}(J/\psi\to\Xi^0\bar{\Xi}^0)}=(23.43 \pm 0.26 \pm 1.09)\%$$

PLB 770, 217 (2017)

Test of isospin symmetry

Mode	$\frac{\mathcal{B}(\psi\to\Xi^0\bar{\Xi}^0)}{\mathcal{B}(\psi\to\Xi^-\bar{\Xi}^+)}$	$\frac{\mathcal{B}(\psi\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}{\mathcal{B}(\psi\to\Sigma(1385)^-\bar{\Sigma}(1385)^+)}$	$\frac{\mathcal{B}(\psi\to\Sigma(1385)^0\bar{\Sigma}(1385)^0)}{\mathcal{B}(\psi\to\Sigma(1385)^+\bar{\Sigma}(1385)^-)}$
J/ψ	$1.12 \pm 0.01 \pm 0.07$	$0.98 \pm 0.01 \pm 0.08$	$0.85 \pm 0.02 \pm 0.09$
$\psi(3686)$	$0.98 \pm 0.02 \pm 0.07$	$0.81 \pm 0.12 \pm 0.12$	$0.82 \pm 0.11 \pm 0.11$

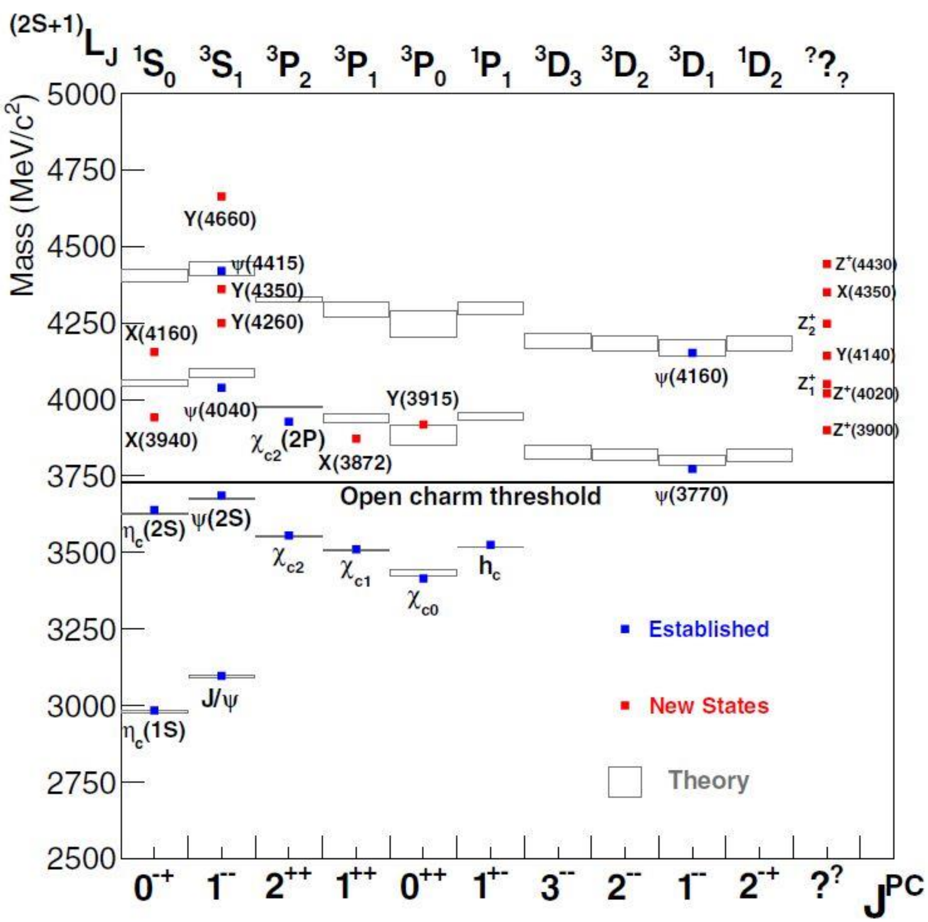
Branching fractions

Mode	$J/\psi \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	$J/\psi \to \Xi^0\bar{\Xi}^0$	$\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	$\psi(3686) \to \Xi^0\bar{\Xi}^0$
This work	$10.71 \pm 0.09 \pm 0.82$	$11.65 \pm 0.04 \pm 0.43$	$0.69 \pm 0.05 \pm 0.05$	$2.73 \pm 0.03 \pm 0.13$
BESII [23]	–	$12.0 \pm 1.2 \pm 2.1$	–	–
CLEO [24]	–	–	–	$2.75 \pm 0.64 \pm 0.61$
Dobbs et al. [25]	–	–	–	$2.02 \pm 0.19 \pm 0.15$
PDG [4]	–	12.0 ± 2.4	–	2.07 ± 0.23

Angular distributions

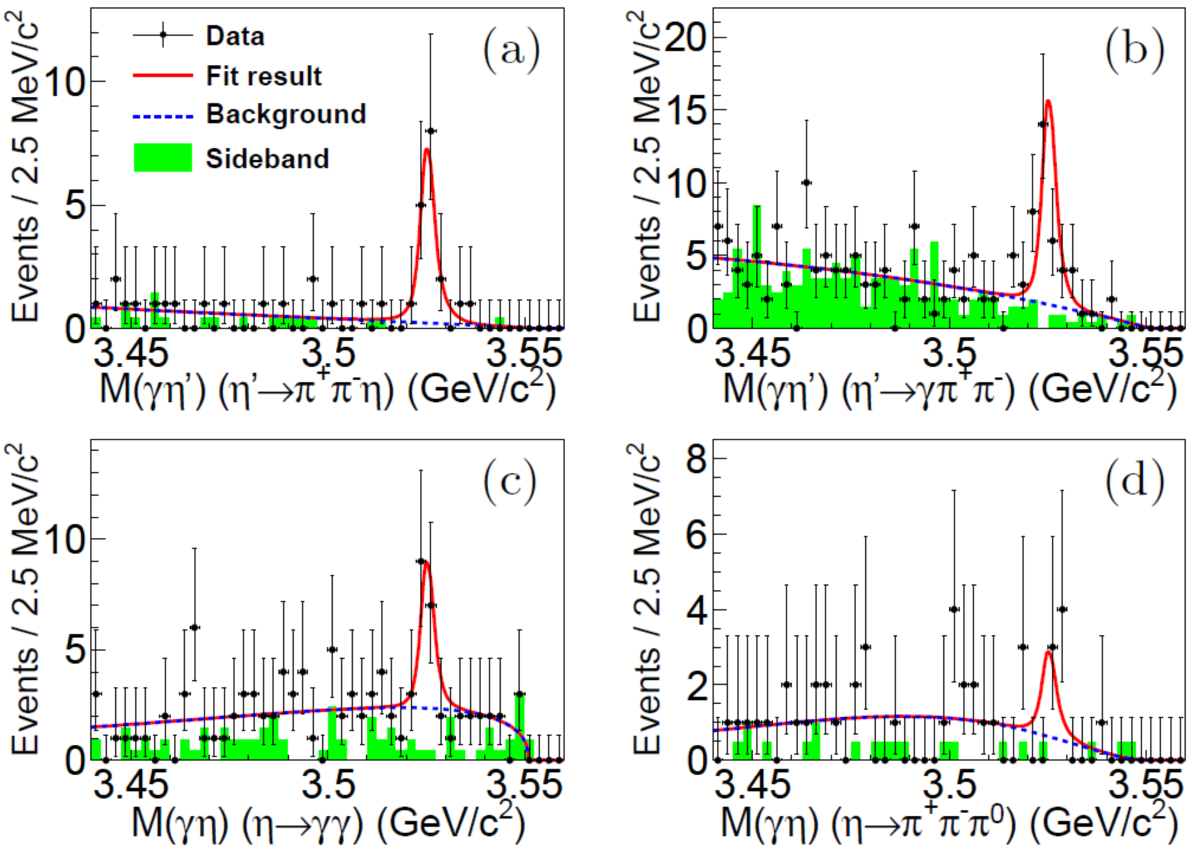
Mode	$J/\psi \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	$J/\psi \to \Xi^0\bar{\Xi}^0$	$\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	$\psi(3686) \to \Xi^0\bar{\Xi}^0$
This work	$-0.64 \pm 0.03 \pm 0.10$	$0.66 \pm 0.03 \pm 0.05$	$0.59 \pm 0.25 \pm 0.25$	$0.65 \pm 0.09 \pm 0.14$
Carimalo et al. [6]	0.11	0.16	0.28	0.33
Claudson [7]	0.19	0.28	0.46	0.53

Observation of h_c radiative decay $h_c \to \gamma\eta'$ and evidence for $h_c \to \gamma\eta$



- All charmonium below the $D\bar{D}$ threshold have been observed experimentally and can be well described by potential models. However, knowledge is still sparse on the P-wave spin-singlet state h_c.
- Only a few decay modes of h_c have been observed, radiative transition $h_c \to \gamma\eta_c$ ($\mathcal{B}$~50%) and hadronic decay $h_c \to 2(\pi^+\pi^-)\pi^0$ ($\mathcal{B}$~2%). Searches for new h_c decay modes, such as $h_c \to \gamma\eta(\eta')$, are useful for providing constraints to theoretical models.
- The ratio of the branching fraction $\mathcal{B}(h_c \to \gamma\eta)$ over $\mathcal{B}(h_c \to \gamma\eta')$ can also be used to study the η-η' mixing angle, which is important to test SU(3)-flavor symmetries in QCD.

Observation of h_c radiative decay $h_c \to \gamma\eta'$ and evidence for $h_c \to \gamma\eta$



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$h_c \to \gamma\eta'$

Using 09 and 12 ψ' data

$h_c \to \gamma\eta$

Branching fraction

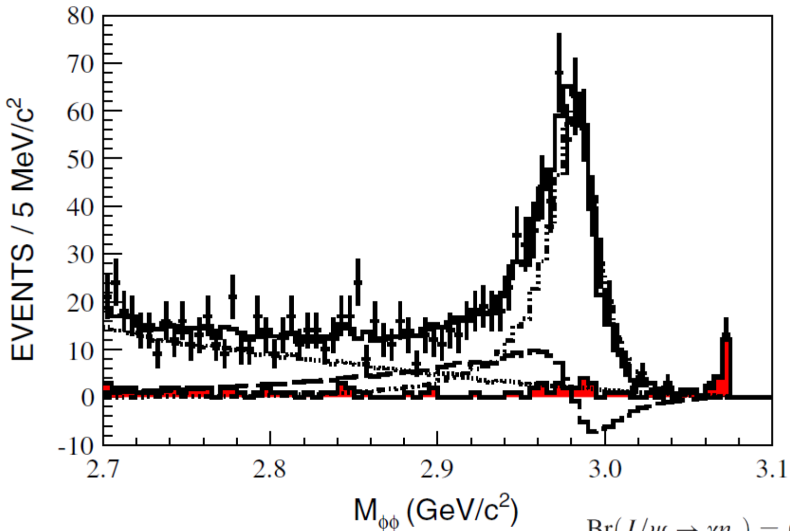
Ratio

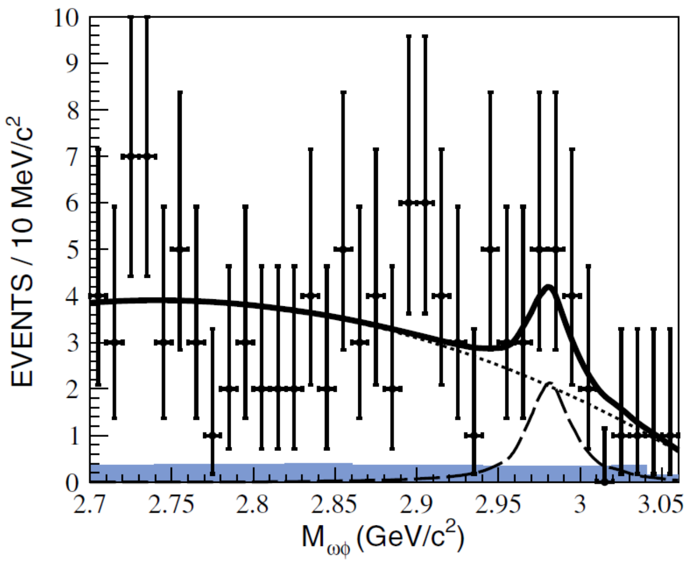
Mode	$N_{h_c\to\gamma\eta'(\eta)}$	$W_{\eta'(\eta)}(\times 10^{-2})$	$\mathcal{B}(h_c \to \gamma\eta'(\eta))$	Significance	$\frac{\mathcal{B}(h_c\to\gamma\eta)}{\mathcal{B}(h_c\to\gamma\eta')}(\%)$
$h_c \to \gamma\eta'$	$44.3 \pm 7.8(\text{stat.})$	$7.67 \pm 0.38(\text{sys.})$	$(1.52 \pm 0.27(\text{stat.}) \pm 0.29(\text{sys.}))\times 10^{-3}$	8.4σ	$30.7 \pm 11.3(\text{stat.}) \pm 8.7(\text{sys.})$
$h_c \to \gamma\eta$	$18.1 \pm 5.8(\text{stat.})$	$10.22 \pm 0.55(\text{sys.})$	$(4.7 \pm 1.5(\text{stat.}) \pm 1.4(\text{sys.}))\times 10^{-4}$	4.0σ	

Improved measurements of branching fractions for $\eta_c \to \phi\phi$ and $\omega\phi$

- Knowledge of the η_c properties is still relatively poor
- Help understand the η_c decay mechanism
- More precise measurement

PRD 95, 092004 (2017)





$\mathrm{Br}(J/\psi \to \gamma\eta_c) = (1.7 \pm 0.4)\%$

Experiment	$\mathrm{Br}(J/\psi \to \gamma\eta_c)$ $\mathrm{Br}(\eta_c \to \phi\phi)(\times 10^{-5})$	$\mathrm{Br}(\eta_c \to \phi\phi)(\times 10^{-3})$
BESIII	$4.3 \pm 0.5^{+0.5}_{-1.2}$	$2.5 \pm 0.3^{+0.3}_{-0.7} \pm 0.6$
BESII [5]	3.3 ± 0.8	1.9 ± 0.6
DM2 [30]	3.9 ± 1.1	2.3 ± 0.8
Theoretical	Prediction	$\mathrm{Br}(\eta_c \to \phi\phi)$ $(\times 10^{-3})$
	pQCD [10]	(0.7–0.8)
	$^3P_0$ quark model [13]	(1.9–2.0)
	Charm meson loop [14]	2.0

$$\mathrm{Br}(\eta_c \to \omega\phi) < 2.5 \times 10^{-4}$$

The measured $\mathcal{B}(\eta_c \to \phi\phi)$ is close to the predictions of the $^3P_0$ quark model and the meson loop effects.

Summary

- BESIII has collected the largest data samples of J/ψ and $\psi(3686)$ in the world, and continues to take data
- It is an excellent laboratory to study charmonium spectroscopy:
  - High statistics
  - Low background
- Many interesting results have been obtained, only few of them are covered in this talk
- Future:
  - More data will be collected
  - More detailed studies will be done

More results will come out !!!

Thanks for your attention!