Charmonium transitions at BESIII

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On behalf of BESIII Collaboration

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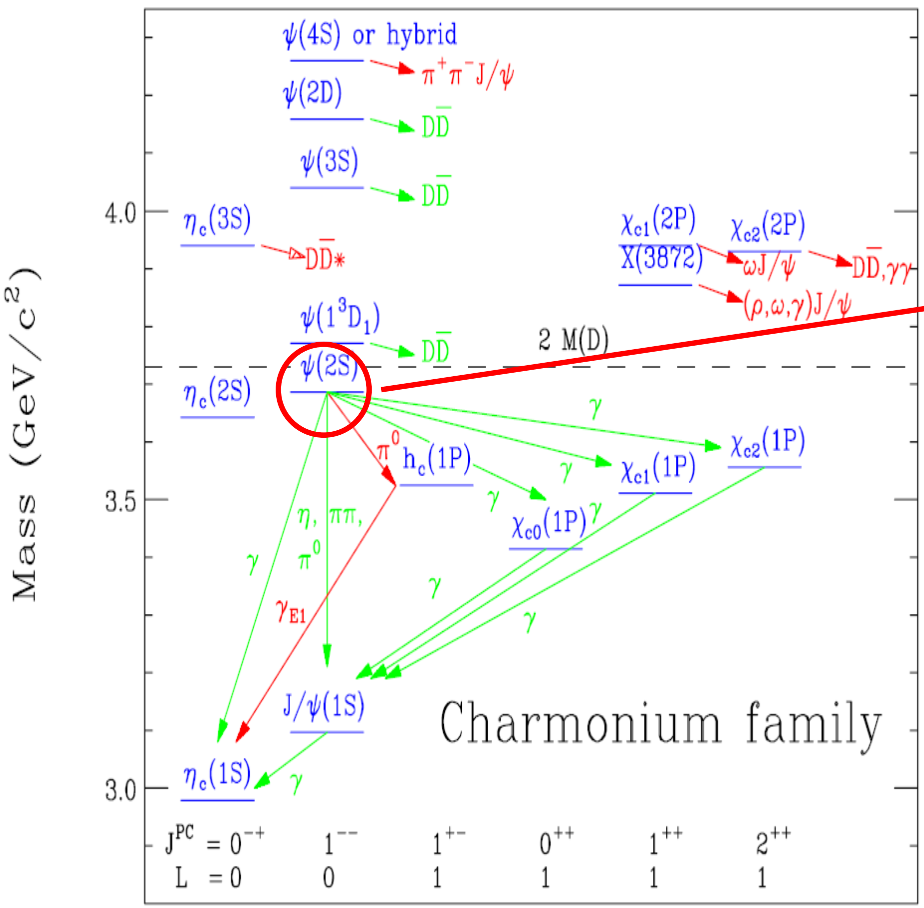
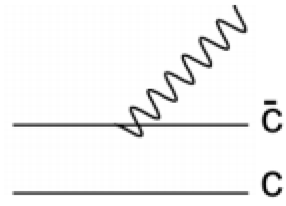
Outline

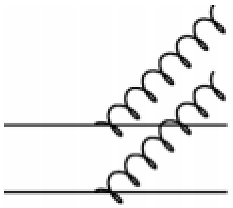
- Introduction
- Data samples
- Recent highlights
  - ✓ Study of EM Dalitz decays $\chi_{cJ} \to \mu^+\mu^-$J/ψ
  - ✓ Search for $h_c \to \pi^+\pi^-$J/ψ via ψ(3686) $\to \pi^+\pi^-\pi^0$J/ψ
  - ✓ Updates of ψ$(2S) \to \gamma\chi_{cJ}$ at BESIII
- Summary

Introduction





A) Radiative transition



B) Hadonic transition

Psi(2S)

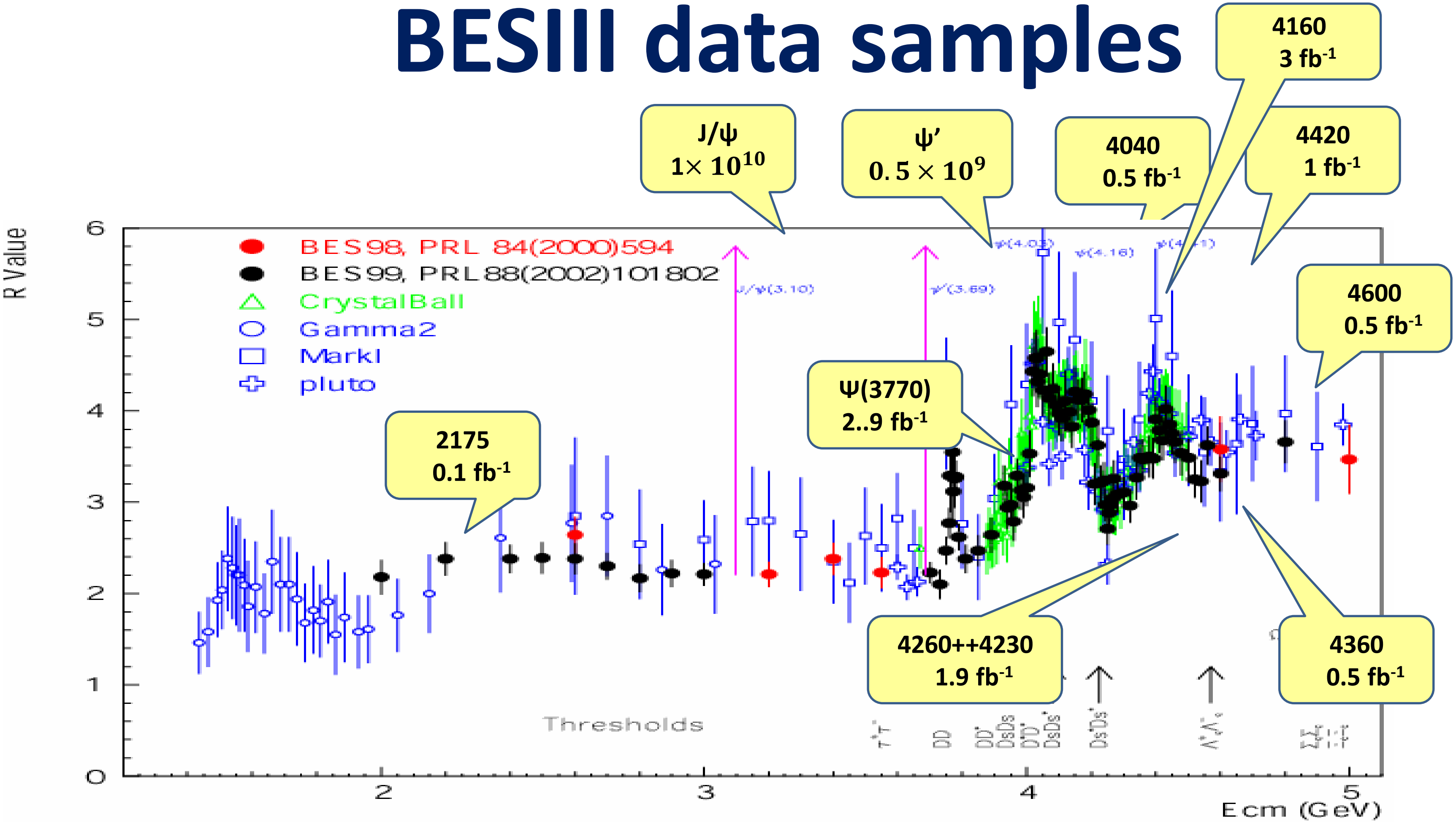
A) Radiative 29%

1. They are sensitive to inner structure of hadrons, quite straightforward to evaluate in $\overline{cc}$ potential models.
2. E1 transition is well measured in general, but still no one model explain all the exp. results. Eur. phy. J.491 C76, 601 (2016)

B) Hadronic 56%

1. The QCD multipole expansion (QCDME) is a feasible approach to hadronic transitions.
2. The calculation depends on experimental inputs and works well for transitions of heavy qq states below open flavor threshold.

BESIII data samples



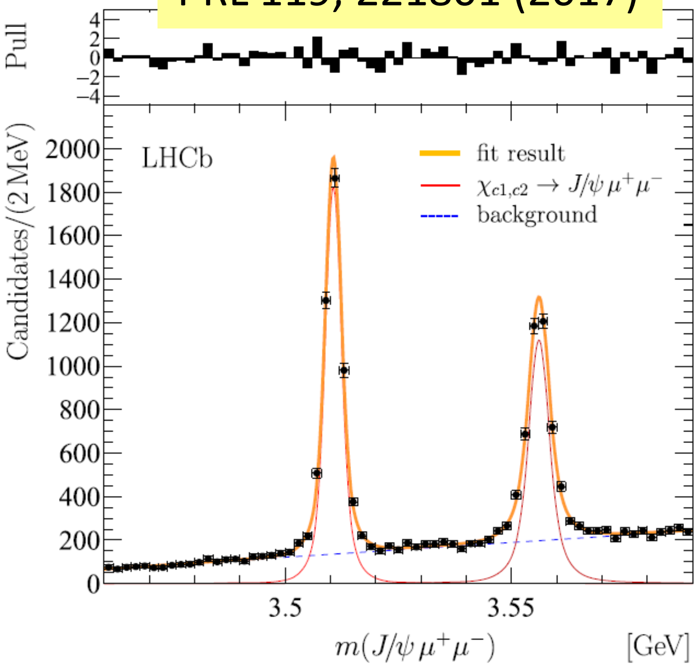
World largest J/ψ, ψ(3686), ψ(3770), … samples

The following charmonium transition analysis at BESIII will be reported.

- ✓ Study of electromagnetic Dalitz decays $\chi_{cJ} \to \mu^+\mu^-$ J/ψ
- ✓ Search $for\ h_c \to \pi^+\pi^-$ J/ψ via ψ(3686) → $\pi^+\pi^-\pi^0$ J/ψ
- ✓ Updates of ψ(2S)→$\gamma\chi_{cJ}$ at BESIII

Study of electromagnetic Dalitz decays $\chi_{cJ} \to \mu^+\mu^- J/\psi$

PRL 119, 221801 (2017)



- **The decays $\chi_{c1} \to \mu^+\mu^- J/\psi$ and $\chi_{c2} \to \mu^+\mu^- J/\psi$ are observed firstly at LHCb.**
- **Study of EM Dalitz decays plays an important role in revealing the structure of mesons and the interactions of the mesons with the electromagnetic field.**
- **The EM Dalitz decays in charmonium transitions have access to the EM transition form factors (TFFs) of charmonium states.**

Study of electromagnetic Dalitz decays $\chi_{cJ} \to \mu^+\mu^- J/\psi$

PRD 99, 051101(R) (2019)

- Using 4.48×10^8 $\psi(3686)$ events at BESIII.
- Decay channel: $\psi(2S) \to \gamma\chi_{cJ}$, $\chi_{cJ} \to \mu^+\mu^- J/\psi$, $J/\psi \to e^+e^- / \mu^+\mu^-$.

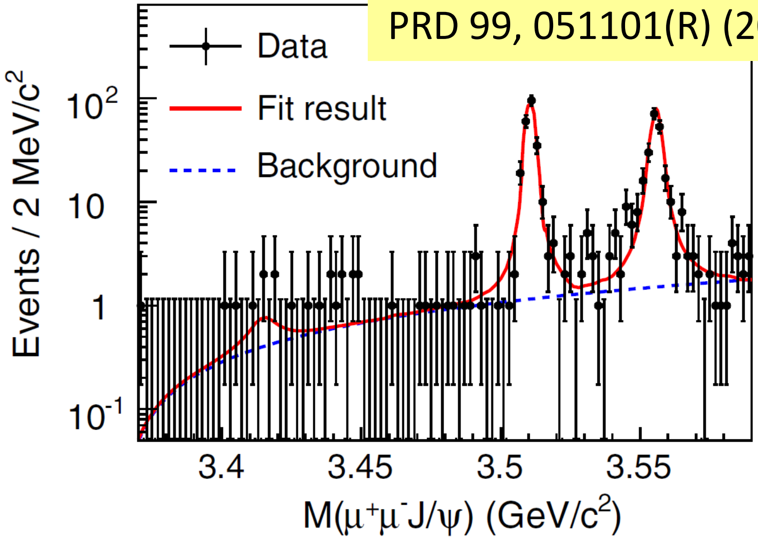


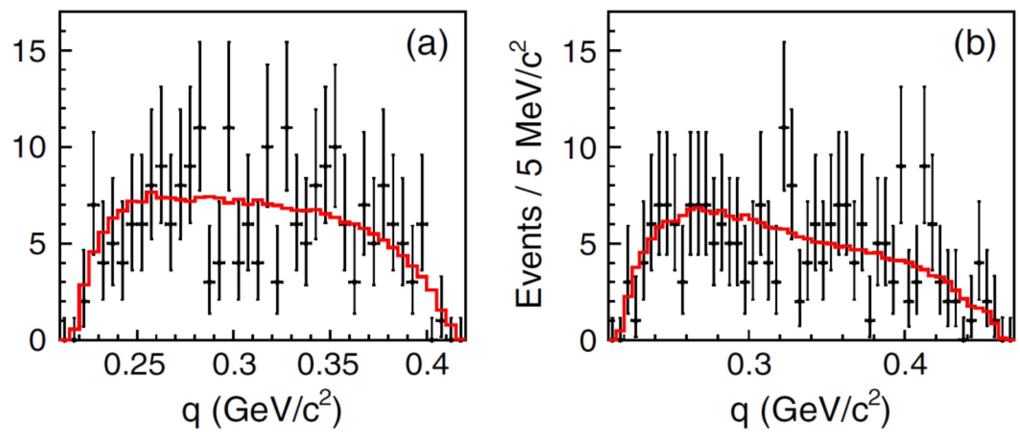
TABLE I. Signal yields, detection efficiency, branching fraction (or upper limit at 90% C.L.) and ratio of the branching fractions for each decay channel. Here the first uncertainty is statistical and the second systematic.

Decay mode	Yields	Efficiency (%)	Branching fraction	$\frac{\mathcal{B}(\chi_{cJ}\to\mu^+\mu^- J/\psi)}{\mathcal{B}(\chi_{cJ}\to e^+e^- J/\psi)}$
$\chi_{c0} \to \mu^+\mu^- J/\psi$	<9.5	9.40	$< 2.0 \times 10^{-5}$	< 0.14
$\chi_{c1} \to \mu^+\mu^- J/\psi$	221.9 ± 15.3	16.94	$(2.51 \pm 0.18 \pm 0.20) \times 10^{-4}$	$(6.73 \pm 0.51 \pm 0.50) \times 10^{-2}$
$\chi_{c2} \to \mu^+\mu^- J/\psi$	218.9 ± 16.1	18.42	$(2.33 \pm 0.18 \pm 0.29) \times 10^{-4}$	$(9.40 \pm 0.79 \pm 1.15) \times 10^{-2}$

Study of electromagnetic Dalitz decays $\chi_{cJ} \to \mu^+\mu^- J/\psi$

PRD 99, 051101(R) (2019)

Transition form factor measurement



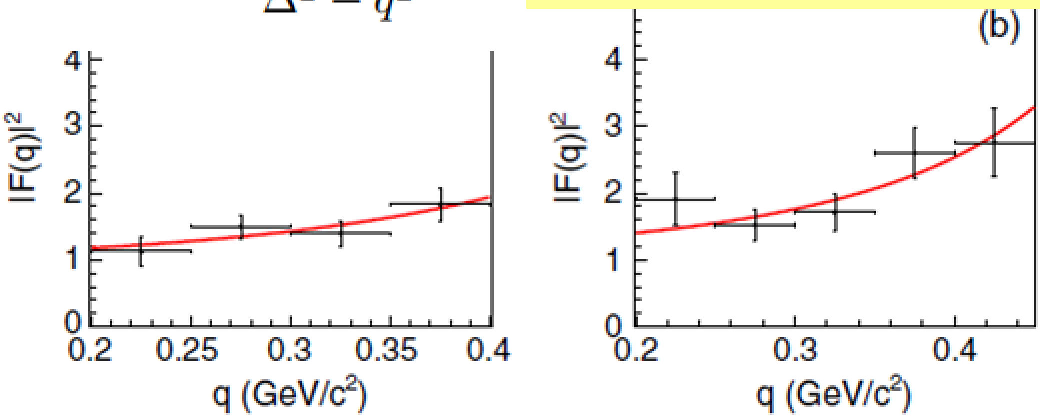
- The q distributions in the decays $\chi_{c1,2} \to \mu^+\mu^- J/\psi$ are divided into 4 and 5 regions, respectively.
- Parametrization formula:

$$F(q) = \frac{1}{1-q^2/\Lambda^2}$$

is used to o fit TFF distributions.

$$F(q^2) = \frac{\Delta^2}{\Delta^2 - q^2}\,.$$

Mod. Phys. Lett. A 33, 1850001 (2018)



Fit results:

$\Lambda_{\chi_{c1}} = 0.76 \pm 0.18\ \mathrm{GeV}/c^2$

$\Lambda_{\chi_{c2}} = 0.71 \pm 0.10\ \mathrm{GeV}/c^2$

The $F(q)$ values deviate from one significantly. This indicates that the TFF should be considered in the branching fraction calculation.

Search for $h_c \to \pi^+\pi^-$J/ψ via ψ(3686) $\to \pi^+\pi^-\pi^0$J/ψ

PRD 97, 052008 (2018)

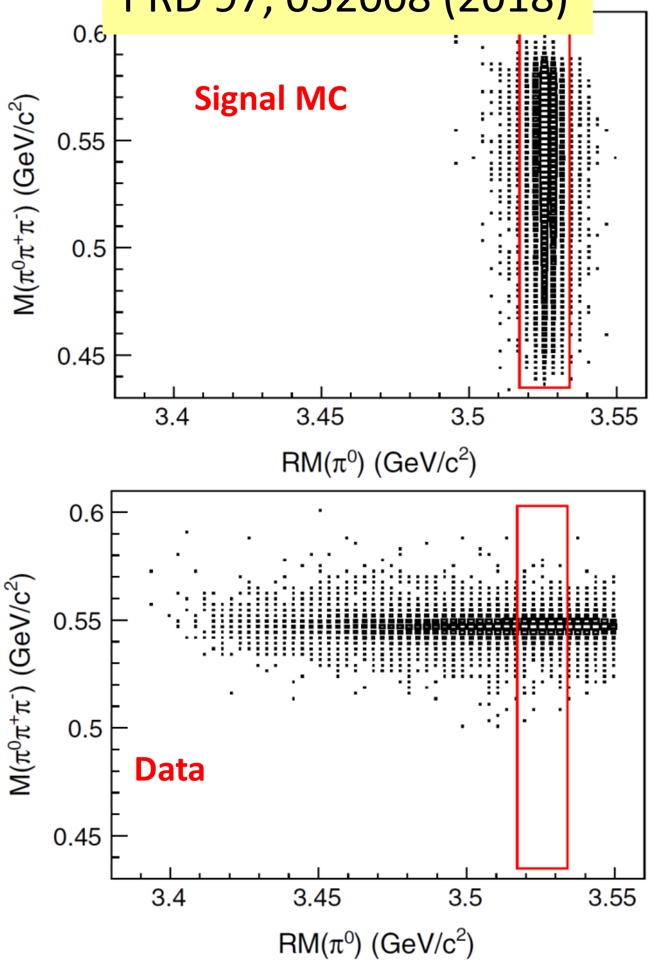
- The hadronic transitions of the spin-singlet P-wave state hc(1P$_1$) are **one of the best places to test the spin-spin interaction between heavy quarks**.

- In the framework of QCDME, the branching fraction of $h_c \to \pi^+\pi^-$J/ψ (including charged and neutral modes) is predicted to **be 2%**, while it is predicted **to be 0.05%** when neglecting the nonlocality in time. PRD 37, 1210 (1988) Phys. Rev. D 52, 1710 (1995)

- The first observation of the h_c was reported by CLEO in a study of the cascade decay ψ(3686)$\to \pi^0 h_c$; $h_c \to \gamma\eta_c$; the branching fractions $\mathcal{B}$(ψ(3686) $\to \pi^0 h_c$) and $\mathcal{B}(h_c \to \gamma\eta_c)$ were measured for the first time by BESIII .

Search for $h_c \to \pi^+\pi^- J/\psi$ via $\psi(3686) \to \pi^+\pi^-\pi^0 J/\psi$

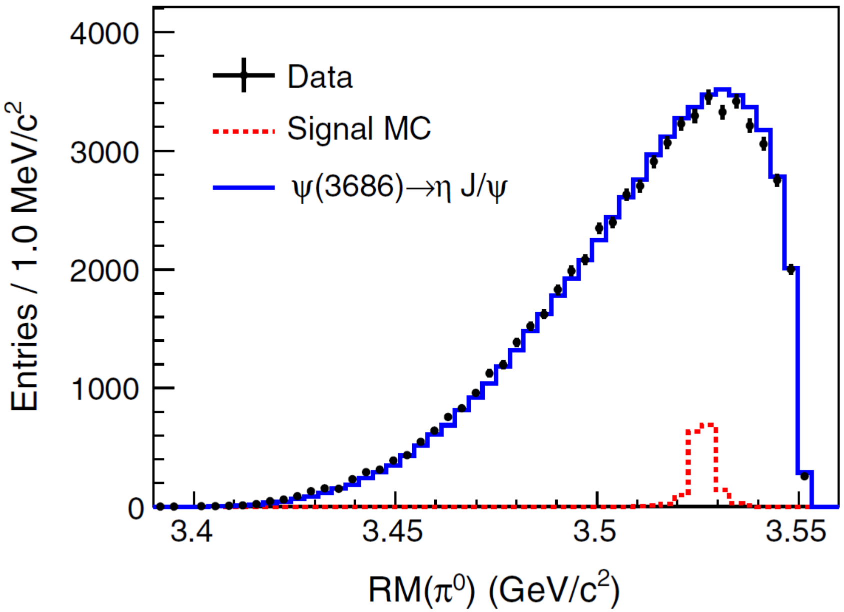
PRD 97, 052008 (2018)



- 4.48×10^8 ψ(3686) events at BESIII are used.
- The J/ψ is reconstructed in its decay to an e^+e^- or $\mu^+\mu^-$ pair.

Dominant component: $\psi(3686) \to \eta J/\psi$

Search for $h_c \to \pi^+\pi^- J/\psi$ via $\psi(3686) \to \pi^+\pi^-\pi^0 J/\psi$



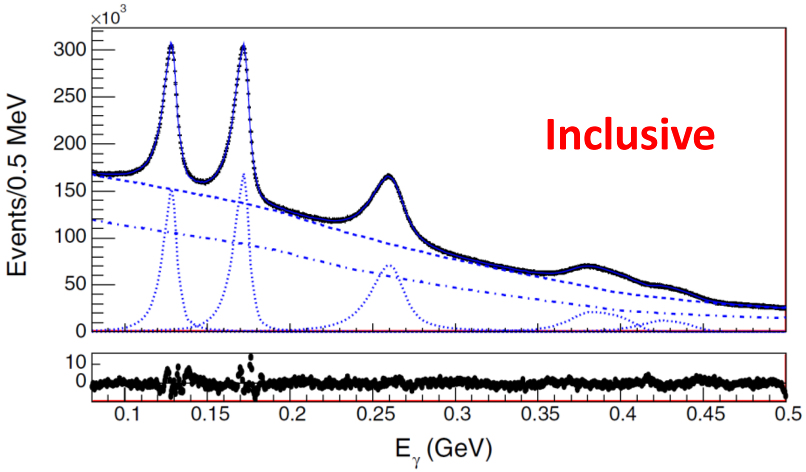
- No signal is observed.
- The upper limit of the product of branching fractions $\mathcal{B}(\psi(3686) \to \pi^0 h_c) \cdot \mathcal{B}(h_c \to \pi^+\pi^- J/\psi)$ at the 90% C.L. is determined to be 2.0×10^{-6}.
- Using the PDG value for the branching fraction of $\psi(3686) \to \pi^0 h_c$, the upper limit on $\mathcal{B}(h_c \to \pi^+\pi^- J/\psi)$ is determined to be 2.4×10^{-3}.

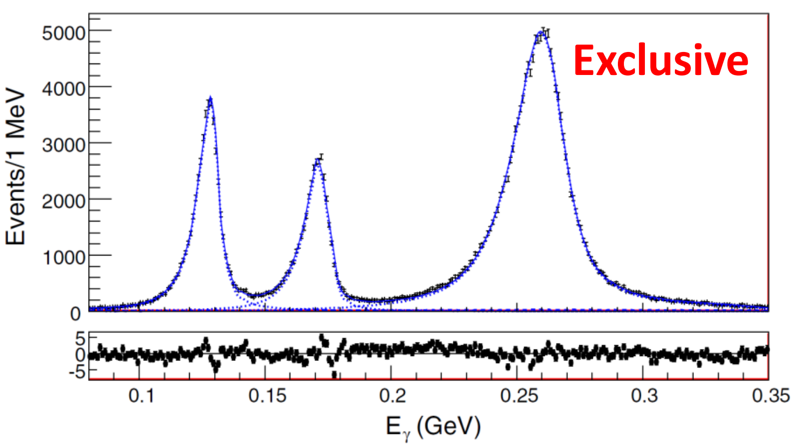
It is the most stringent upper limit to date.

It is noted that the measured branching fraction is smaller than the prediction(2.0%) in theory by one order in magnitude,
but does not contradict the prediction(0.05%).

Updates of $\psi(2S) \to \gamma\chi_{cJ}$ at BESIII

Inclusive: $\psi(2S) \to \gamma X$; **Exclusice:** $\psi(2S) \to \gamma\chi_{cJ}, \chi_{cJ} \to$ **2/4 prong**





PRD 96, 032001 (2017)

- **Using 1.06 × 10⁸ ψ(3686) events at BESIII.**
- **Unbinned maximum simultaneous fits to the photon energy distributions of data.**
- $\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ}) = \frac{N_{\psi(3686)\to\gamma\chi_{cJ}}}{\epsilon_{\psi(3686)\to\gamma\chi_{cJ}} \times N_{\psi(3686)}}$
- $\mathcal{B}(\psi(3686) \to \gamma\chi_{cJ}) \times \mathcal{B}(\chi_{cJ} \to \gamma J/\psi)$

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

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

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

Updates of $\psi(2S) \to \gamma\chi_{cJ}$ at BESIII

PRD 96, 032001 (2017)

TABLE IV. Our branching fraction results, other results, and PDG compilation results.

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]	0.131 ± 0.035	0.127 ± 0.006
		$0.151 \pm 0.003 \pm 0.010$ [15]		
		$0.158 \pm 0.003 \pm 0.006$ [16]		
$\mathcal{B}(\psi(3686) \to \gamma\chi_{c1}) \times \mathcal{B}(\chi_{c1} \to \gamma J/\psi)$	$3.442 \pm 0.010 \pm 0.132$	$3.56 \pm 0.03 \pm 0.12$ [31]	2.93 ± 0.15	3.24 ± 0.07
		$3.377 \pm 0.009 \pm 0.183$ [15]		
		$3.518 \pm 0.01 \pm 0.120$ [16]		
$\mathcal{B}(\psi(3686) \to \gamma\chi_{c2}) \times \mathcal{B}(\chi_{c2} \to \gamma J/\psi)$	$1.793 \pm 0.008 \pm 0.163$	$1.95 \pm 0.02 \pm 0.07$ [31]	1.52 ± 0.15	1.75 ± 0.04
		$1.874 \pm 0.007 \pm 0.102$ [15]		
		$1.996 \pm 0.008 \pm 0.070$ [16]		
$\mathcal{B}(\chi_{c0} \to \gamma J/\psi)$	$0.25 \pm 0.16 \pm 2.15$	$2 \pm 0.2 \pm 0.2$ [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

New results are consistent with previous measurements, but more precise.

Summary

- BESIII has obtained many results about charmonium transitions since its first physics run started from 2009.
- The decays $\chi_{cJ} \to \mu^+\mu^-$J/ψ through the radiative transitions ψ$(2S) \to \gamma\chi_{cJ}$ have been observed.
- A search for the hadronic transition $h_c \to \pi^+\pi^-$J/ψ is carried out via ψ(3686) $\to \pi^+\pi^-\pi^0$J/ψ. No signal is observed.
- Using a sample of 106 million ψ(3686) decays, the branching fractions of ψ$(2S) \to \gamma\chi_{cJ}$ are measured with improved precision.
- After 2018's J/ψ data taking, the amount of total J/ψ events has increased from 1.3 billion to 10 billion. More and more interesting results are expected in the near future.

Thanks!

Backup

Study of electromagnetic Dalitz decays $\chi_{cJ} \to e^+e^- J/\psi$

PRL 118, 221802 (2017)

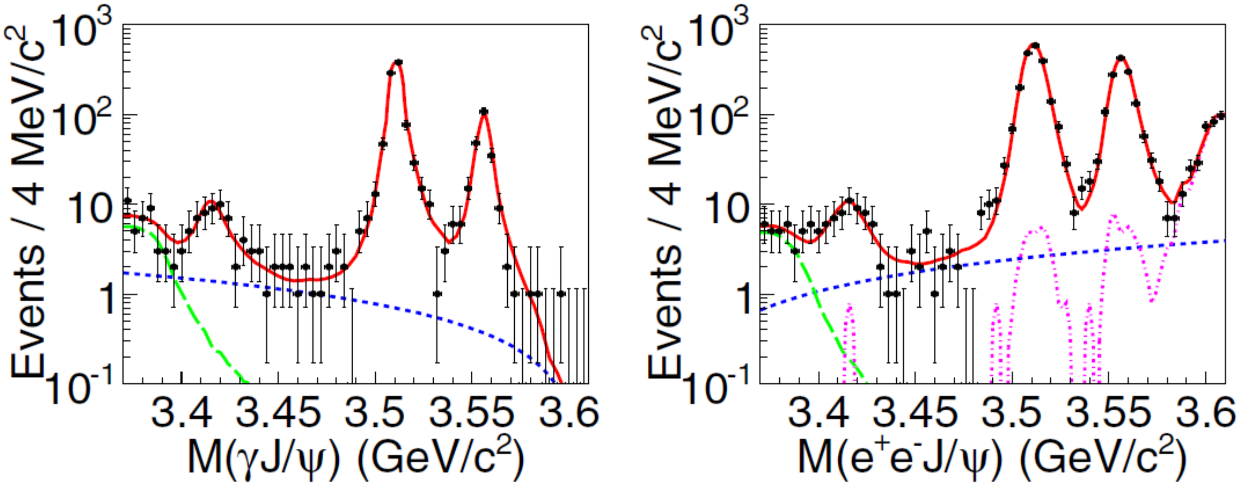


TABLE I. Signal yields, detection efficiencies, the branching fractions, and the ratios of the branching fractions. Here, the first uncertainty is statistical and the second systematic.

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	$(2.48 \pm 0.08 \pm 0.16) \times 10^{-3}$	...	$(11.3 \pm 0.4 \pm 0.5) \times 10^{-3}$