Non-$D\bar{D}$ decays of the $\psi(3770)$ at BESIII

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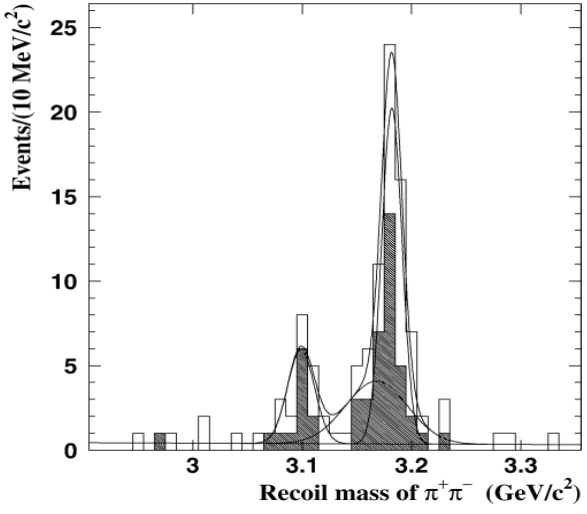
Introduction

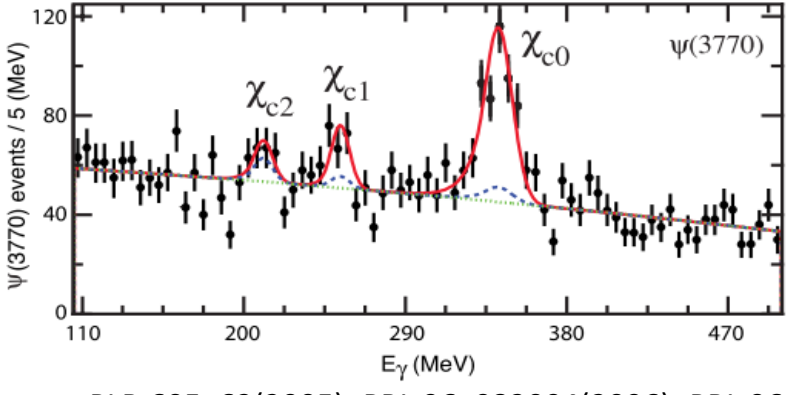
- The $\psi(3770)$ resonance is the lowest-mass $c\bar{c}$ resonance above the $D\bar{D}$ threshold. There is a long-standing puzzle in understanding of $\psi(3770)$ production and decays.
- The potential model expects that more than 99% of $\psi(3770)$ decay into $D\bar{D}$ final states.
- BES-II measured $Br[\psi(3770) \rightarrow \text{non-}D\bar{D}] = (15 \pm 5)\%$ by utilizing varied methods under the hypothesis that only one simple $\psi(3770)$ resonance exists in 3.70~3.87 GeV.
- CLEO-c obtained $Br[\psi(3770) \rightarrow \text{non-}D\bar{D}] = (-3.3 \pm 1.4^{+6.6}_{-4.8})\%$, which corresponds to $Br[\psi(3770) \rightarrow \text{non-}DD] < 9\%$ at 90% C.L.
- Large non-$D\bar{D}$ component conflicts with theoretical prediction.

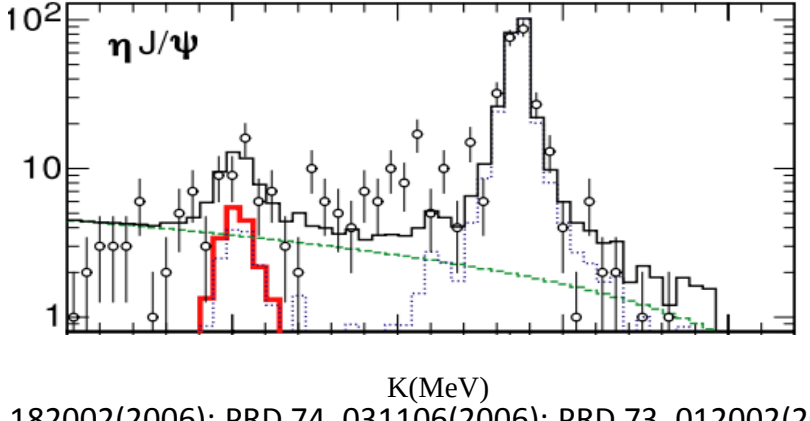
Reference: PLB 641, 145(2006); PRL 97, 121801(2006); PRD 76, 122002(2007); PLB 659, 74(2008); PRL 104, 159901(2010)

Introduction

- The BES-II Collaboration observed the first non-$D\overline{D}$ decay of $\psi(3770)\rightarrow\pi^+\pi^- J/\psi$ in 2003.
- In 2005, the CLEO Collaboration confirmed the BES-II observation of $\psi(3770) \rightarrow \pi^+\pi^- J/\psi$ and observed more exclusive non-$D\overline{D}$ decays of $\psi(3770)$:
  - $\psi(3770)\rightarrow\pi^0\pi^0 J/\psi$
  - $\psi(3770)\rightarrow\eta J/\psi$
  - $\psi(3770)\rightarrow\gamma\chi_{c0,1}$
  - $\psi(3770)\rightarrow\phi\eta$
- Precision measurements of non-$D\overline{D}$ decays of $\psi(3770)$ are critical to test theoretical predictions, and to better understand the nature of the $\psi(3770)$.



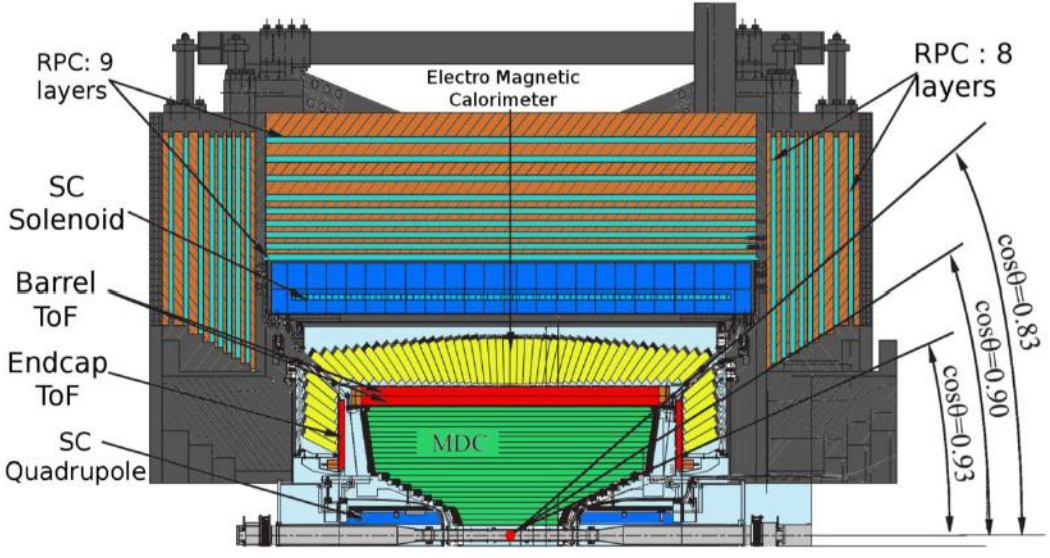




Reference: PLB 605, 63(2005); PRL 96, 082004(2006); PRL 96, 182002(2006); PRD 74, 031106(2006); PRD 73, 012002(2006)

BESIII Experiment

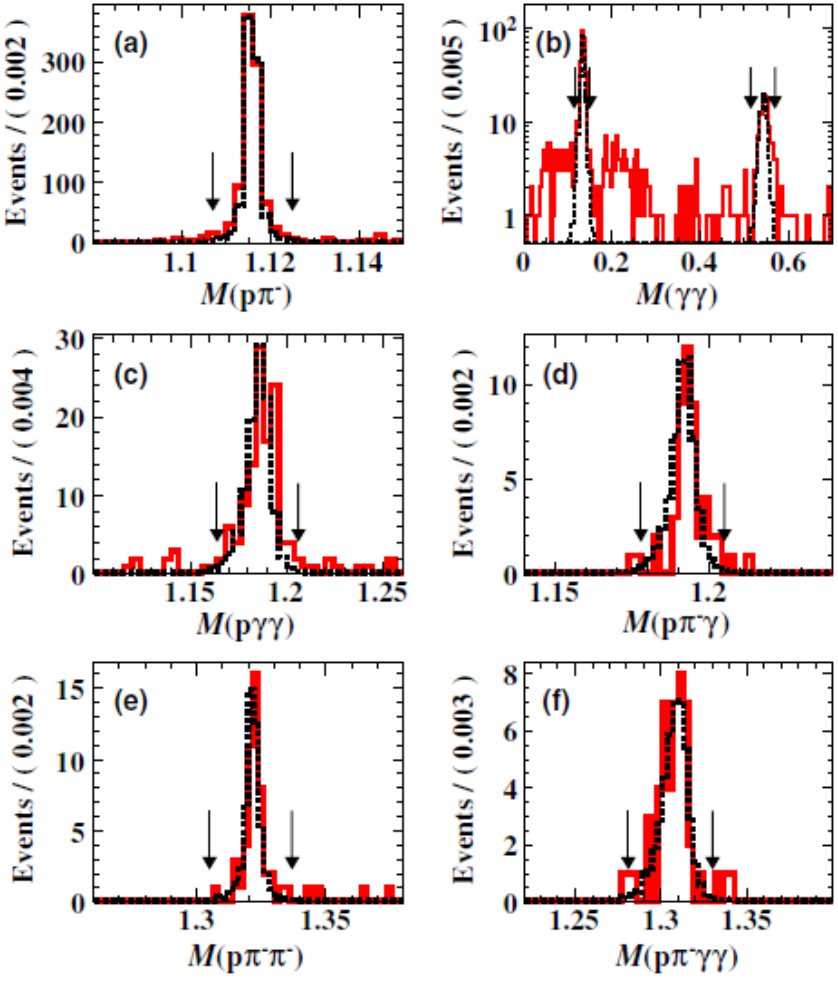
- **BEPCII Collider:**
  - Double ring e^+e^- collider, 2.0 GeV < E_{cm} < 4.6 GeV;
  - The designed peak luminosity, 10^{33} $cm^{-2}s^{-1}$ at the beam energy of 1.89 GeV , has been achieved on 5th April, 2016.
- **BESIII Detector**



Data sets related to this talk:

-- 2.92 fb^{-1} @3.773 GeV;
-- 106.41 M ψ(3686) data;
-- 44.5 pb^{-1} @3.65 GeV;
-- 67 pb^{-1} @ 3.542, 3.554, 3.561, 3.600 and 3.650 GeV.

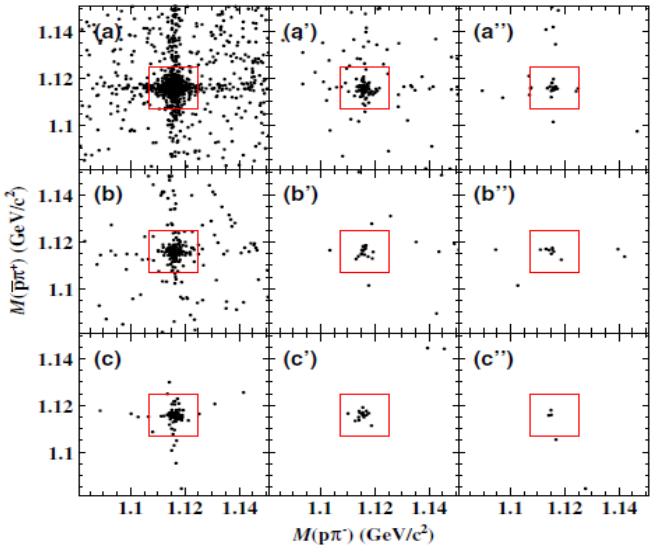
Baryonic decays of ψ(3770)

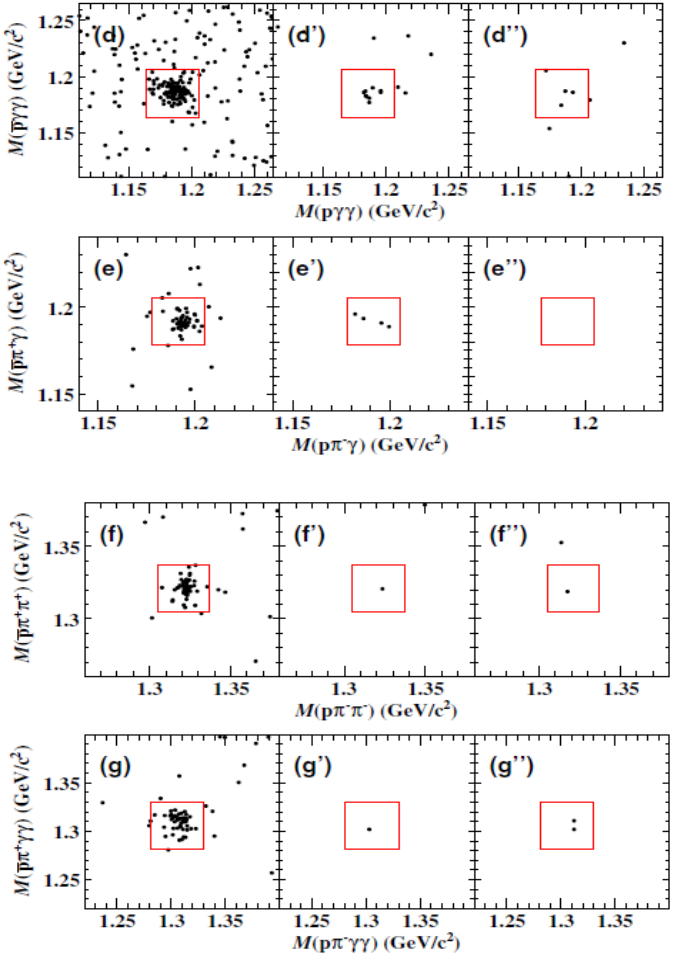


- **Baryonic final states of $\Lambda\bar{\Lambda}\pi^+\pi^-$, $\Lambda\bar{\Lambda}\pi^0$, $\Lambda\bar{\Lambda}\eta$, $\Sigma^+\bar{\Sigma}^-$, $\Sigma^0\bar{\Sigma}^0$, $\Xi^-\bar{\Xi}^+$ and $\Xi^0\bar{\Xi}^0$ are searched for.**
- **Reconstructed via**
  - $\Lambda \rightarrow p\pi^-$
  - $\pi^0 \rightarrow \gamma\gamma$
  - $\eta \rightarrow \gamma\gamma$
  - $\Sigma^+ \rightarrow p\pi^0$ $(\pi^0 \rightarrow \gamma\gamma)$
  - $\Sigma^0 \rightarrow \Lambda\gamma$ $(\Lambda \rightarrow p\pi^-)$
  - $\Xi^- \rightarrow \Lambda\pi^-$ $(\Lambda \rightarrow p\pi^-)$
  - $\Xi^0 \rightarrow \Lambda\pi^0$ $(\Lambda \rightarrow p\pi^-, \pi^0 \rightarrow \gamma\gamma)$

PRD 87, 112001(2013)

Baryonic decays of ψ(3770)





- **Ignoring interference effects between continuum and resonance.**

PRD 87, 112001(2013)

Baryonic decays of ψ(3770)

- **None are observed, and upper limits are set at the 90% confidence level.**

$$B^{\rm up} = \frac{N^{\rm up}_{\psi(3770)/\psi(4040)\to f}}{\epsilon \times B_f \times N_{\psi(3770)/\psi(4040)} \times (1-\Delta_{\rm sys})}$$

Mode f	$N^f_{\rm obs}$ (3.773)	$N^f_{\rm B}$ (3.773)	$N^f_{\rm obs}$ (3.650)	$N^f_{\rm B}$ (3.650)	$f^{3.773}_{\rm co}$	$N^S_{\psi(3770)\to f}$	$N^{\rm up}_{\psi(3770)\to f}$	ϵ	$\Delta_{\rm sys}$	$\mathcal{B}_{\psi(3770)\to f}$ [$\times 10^{-4}$]	$\mathcal{B}^{\rm up}$ [$\times 10^{-4}$]
$\Lambda\bar{\Lambda}\pi^+\pi^-$	844.0 ± 33.6	5.2	$14.2^{+5.6}_{-4.2}$	0.1	45.27	$200.6^{+193.1}_{-255.7} \pm 42.0$	481.2	0.1321	8.0	$1.80^{+1.74}_{-2.30} \pm 0.40$	<4.7
$\Lambda\bar{\Lambda}\pi^0$	124.9 ± 14.4	3.4	$7.1^{+5.0}_{-2.2}$	0.0	42.50	$-180.3^{+94.6}_{-213.0} \pm 16.2$	83.6	0.1694	8.0	$-1.28^{+0.67}_{-1.51} \pm 0.15$	<0.7
$\Lambda\bar{\Lambda}\eta$	74.0 ± 9.5	0.9	$3.0^{+3.6}_{-1.6}$	0.0	44.76	$-61.2^{+72.2}_{-161.4} \pm 7.9$	87.7	0.1518	8.1	$-1.22^{+1.44}_{-3.21} \pm 0.19$	<1.9
$\Sigma^+\bar{\Sigma}^-$	100.5 ± 11.9	0.7	$3.3^{+4.3}_{-1.7}$	0.1	38.27	$-22.7^{+66.1}_{-165.0} \pm 5.1$	96.0	0.1975	8.0	$-0.21^{+0.63}_{-1.56} \pm 0.05$	<1.0
$\Sigma^0\bar{\Sigma}^0$	43.5 ± 6.7	0.0	$0.0^{+2.2}_{-0.0}$	0.0	38.69	$43.5^{+6.7}_{-85.4} \pm 5.8$	56.6	0.1752	8.0	$0.30^{+0.05}_{-0.58} \pm 0.05$	<0.4
$\Xi^-\bar{\Xi}^+$	48.5 ± 7.0	0.0	$0.5^{+2.8}_{-1.4}$	0.0	41.74	$27.6^{+58.9}_{-117.1} \pm 3.7$	119.7	0.1060	8.1	$0.31^{+0.66}_{-1.32} \pm 0.05$	<1.5
$\Xi^0\bar{\Xi}^0$	43.5 ± 6.6	1.3	$2.0^{+3.2}_{-1.2}$	0.0	40.13	$-38.1^{+48.6}_{-128.6} \pm 5.6$	60.7	0.0581	8.2	$-0.80^{+1.03}_{-2.72} \pm 0.14$	<1.4

First measurement!

Baryonic decays of ψ(3770)

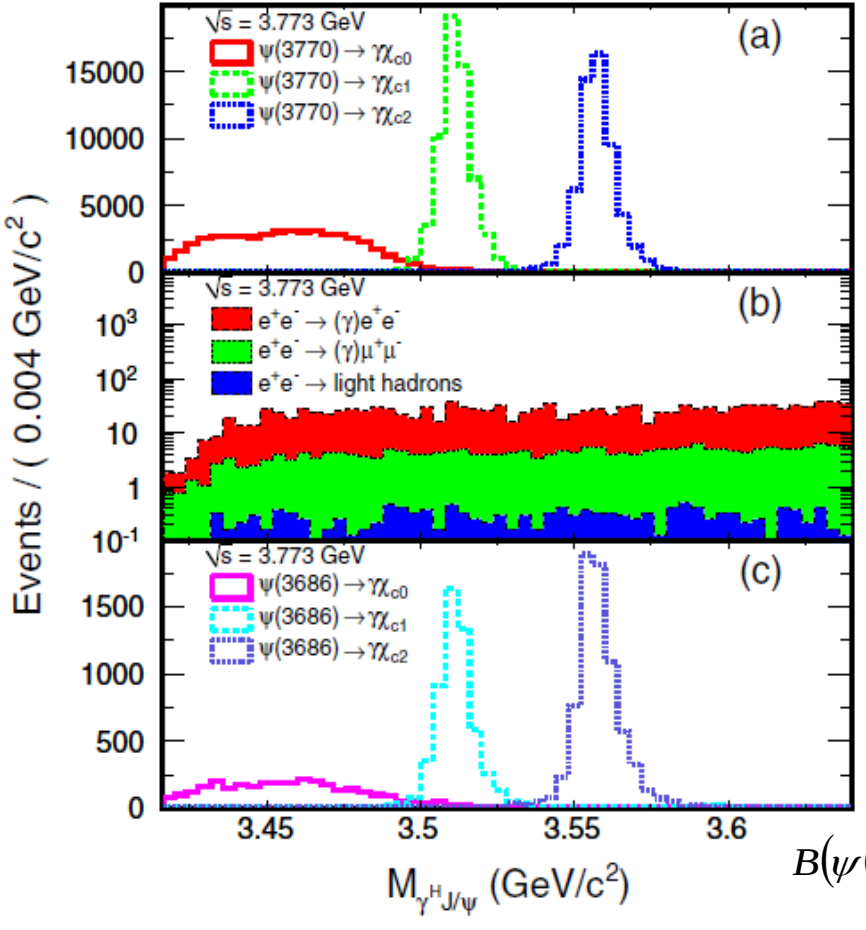
- **In this work, baryonic decays of ψ(4040) are also searched for. No significant signal is observed, upper limits are set at 90% C.L..**

$$B^{\rm up} = \frac{N^{\rm up}_{\psi(3770)/\psi(4040)\to f}}{\epsilon \times B_f \times N_{\psi(3770)/\psi(4040)} \times (1-\Delta_{\rm sys})}$$

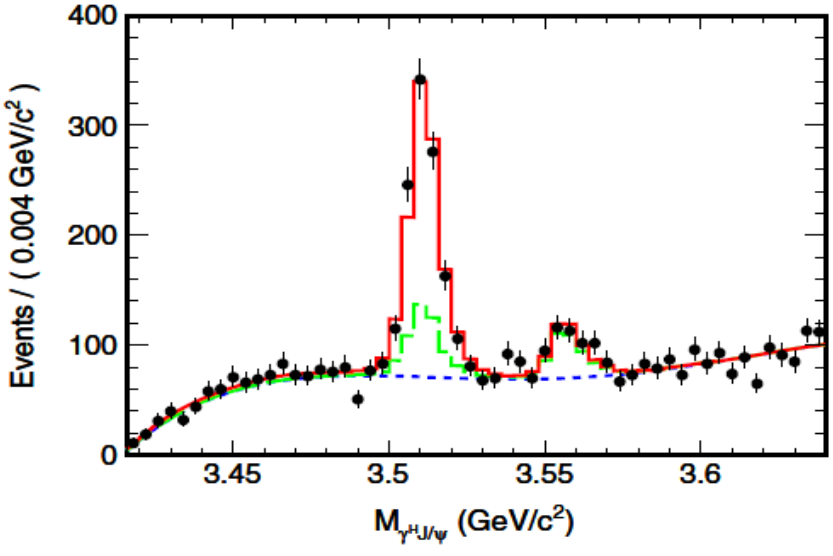
Mode f	$N^f_{\rm obs}$ (4.009)	$N^f_{\rm B}$ (4.009)	$N^f_{\rm obs}$ (3.650)	$N^f_{\rm B}$ (3.650)	$f^{4.009}_{\rm co}$	$N^S_{\psi(4040)\to f}$	$N^{\rm up}_{\psi(4040)\to f}$	ϵ	$\Delta_{\rm sys}$	$\mathcal{B}_{\psi(4040)\to f}$ [$\times 10^{-4}$]	$\mathcal{B}^{\rm up}$ [$\times 10^{-4}$]
$\Lambda\bar{\Lambda}\pi^+\pi^-$	79.2 ± 10.0	20.0	$14.2^{+5.6}_{-4.2}$	0.1	7.69	$-49.2^{+33.8}_{-44.2} \pm 9.8$	35.6	0.1492	9.9	$-3.57^{+2.45}_{-3.21} \pm 0.79$	<2.9
$\Lambda\bar{\Lambda}\pi^0$	$14.5^{+4.1}_{-4.3}$	0.5	$7.1^{+5.0}_{-2.2}$	0.0	6.80	$-34.3^{+15.5}_{-34.3} \pm 3.0$	12.6	0.1753	9.9	$-2.14^{+0.97}_{-2.14} \pm 0.28$	<0.9
$\Lambda\bar{\Lambda}\eta$	$16.0^{+4.2}_{-4.3}$	3.6	$3.0^{+3.6}_{-1.6}$	0.0	7.38	$-9.8^{+12.5}_{-26.9} \pm 3.3$	16.2	0.1674	9.9	$-1.60^{+2.06}_{-4.43} \pm 0.57$	<3.0
$\Sigma^+\bar{\Sigma}^-$	$8.5^{+3.0}_{-3.2}$	0.2	$3.3^{+4.3}_{-1.7}$	0.1	4.92	$-7.5^{+8.9}_{-21.4} \pm 1.5$	11.0	0.1704	9.9	$-0.74^{+0.89}_{-2.14} \pm 0.17$	<1.3
$\Sigma^0\bar{\Sigma}^0$	$4.0^{+3.2}_{-1.9}$	0.0	$0.0^{+2.2}_{-0.0}$	0.0	5.03	$4.0^{+3.2}_{-11.2} \pm 0.5$	8.9	0.1537	9.9	$0.28^{+0.23}_{-0.79} \pm 0.04$	<0.7
$\Xi^-\bar{\Xi}^+$	$1.0^{+2.2}_{-0.8}$	0.0	$0.5^{+2.8}_{-1.4}$	0.0	5.61	$-1.8^{+8.2}_{-15.7} \pm 0.3$	12.5	0.0941	9.9	$-0.21^{+0.94}_{-1.81} \pm 0.04$	<1.6
$\Xi^0\bar{\Xi}^0$	$1.0^{+2.2}_{-0.8}$	0.0	$2.0^{+3.2}_{-1.2}$	0.0	5.36	$-9.7^{+6.8}_{-17.2} \pm 1.3$	7.0	0.0490	10.0	$-2.22^{+1.55}_{-3.93} \pm 0.37$	<1.8

First measurement!

$\psi(3770)\rightarrow\gamma\chi_{c1,2}$



PRD 91, 092009(2015)



- **Reconstructed using the decay chain**

$$\chi_{cJ}\rightarrow\gamma J/\psi, J/\psi\rightarrow\ell^+\ell^-(\ell=e,\mu)$$

- **Branching fractions are determined with**

$$B(\psi(3770)\rightarrow\gamma\chi_{c1,2})=\frac{N_{\psi(3770)\rightarrow\gamma\chi_{c1,2}}}{N_{\psi(3770)}B_{\chi_{c1,2}\rightarrow\gamma J/\psi}B_{J/\psi\rightarrow\ell^+\ell^-}\varepsilon_{\psi(3770)\rightarrow\gamma\chi_{c1,2}}}$$

$\psi(3770) \rightarrow \gamma\chi_{c1,2}$

- **Results:**

$$\mathcal{B}(\psi(3770) \to \gamma\chi_{c1}) = (2.48 \pm 0.15 \pm 0.23) \times 10^{-3}$$

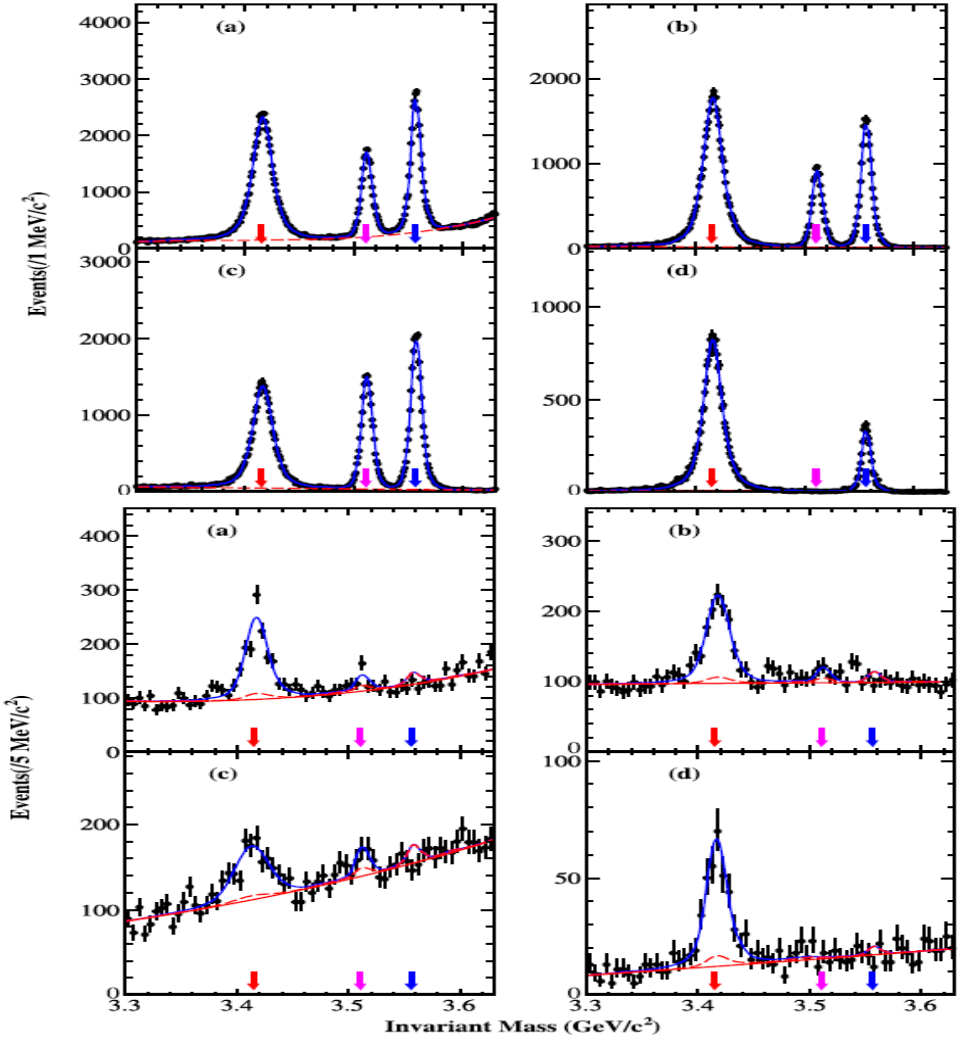
The most precise measurement !

$$\mathcal{B}(\psi(3770) \to \gamma\chi_{c2}) < 0.64 \times 10^{-3} \text{ (at 90\% C.L.)}$$

Experiment/theory	$\Gamma(\psi(3770) \to \gamma\chi_{cJ})$ (keV)	
	$J = 1$	$J = 2$
This work	$67.5 \pm 4.1 \pm 6.7$	< 17.4
Ding-Qin-Chao [12]		
Nonrelativistic	95	3.6
Relativistic	72	3.0
Rosner *S-D* mixing [13]		
$\phi = 12°$ [13]	73 ± 9	24 ± 4
$\phi = (10.6 \pm 1.3)°$ [32]	79 ± 6	21 ± 3
$\phi = 0°$ (pure 1^3D_1 state) [32]	133	4.8
Eichten-Lane-Quigg [14]		
Nonrelativistic	183	3.2
With coupled-channel corr.	59	3.9
Barnes-Godfrey-Swanson [15]		
Nonrelativistic	125	4.9
Relativistic	77	3.3

Precision measurement of partial width of $\psi(3770) \rightarrow \gamma\chi_{c1,2}$ are critical to test theoretical models !

$\psi(3770) \rightarrow \gamma\chi_{c0}$



- **Reconstructed via**
  $\chi_{c0} \rightarrow 2(\pi^+\pi^-), K^+K^-\pi^+\pi^-, 3(\pi^+\pi^-), K^+K^-$
- **Taking relative strength with respect to $\psi(3686)$ radiative E1 transition to avoid large uncertainties in χ_{cJ} decay branching fractions.**
- **The ratio of the branching fraction for $\psi(3770) \rightarrow \gamma\chi_{cJ}$ and $\psi(3686) \rightarrow \gamma\chi_{cJ}$ is determined channel by channel.**

$$R_{cJ} = \frac{\mathcal{B}[\psi(3770) \rightarrow \gamma\chi_{cJ}]}{\mathcal{B}[\psi(3686) \rightarrow \gamma\chi_{cJ}]} = \frac{N_{\psi(3770)} \cdot N^{tot}_{\psi(3686)} \cdot \epsilon_{\psi(3686)}}{N_{\psi(3686)} \cdot N^{tot}_{\psi(3770)} \cdot \epsilon_{\psi(3770)}}$$

PLB 753(2016) 103-109

$\psi(3770) \rightarrow \gamma\chi_{c0}$

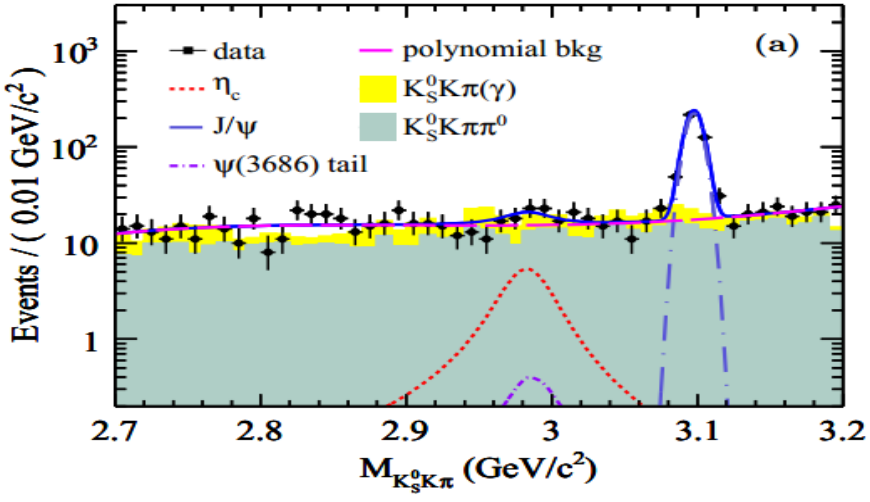
- **Branching fraction for $\psi(3770) \rightarrow \gamma\chi_{c0}$:**

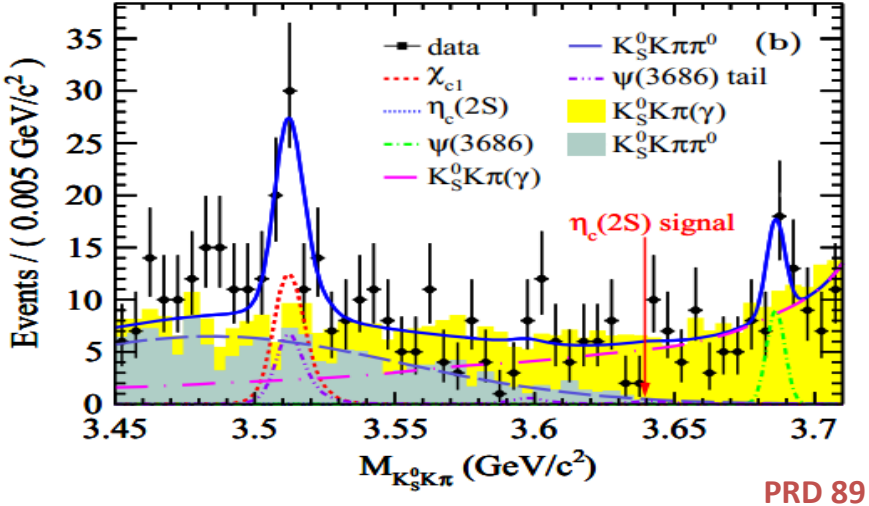
$$B(\psi(3770) \rightarrow \gamma\chi_{cJ}) = R_{cJ} \times B(\psi(3686) \rightarrow \gamma\chi_{cJ}) \longrightarrow \text{Quoted from PDG}$$

Experiments	$J=0$	$J=1$
$\mathcal{B}^{\text{BESIII}}(\times 10^{-3})$	$6.88 \pm 0.28 \pm 0.67$	$1.94 \pm 0.42 \pm 0.64$
$\mathcal{B}^{\text{BESIII}}(\times 10^{-3})$ [10]	–	$2.48 \pm 0.15 \pm 0.23$
Γ^{BESIII}	$187 \pm 8 \pm 19$	$53 \pm 12 \pm 18$
Γ^{BESIII} [10]	–	$67.5 \pm 4.1 \pm 6.7$
Γ^{CLEO} [7,8]	172 ± 30	70 ± 17
$\Gamma^{\text{CLEO}}_{\text{corrected}}$	192 ± 24	72 ± 16
Theories		
Rosner [2] (non-relativistic)	523 ± 12	73 ± 9
Ding–Qing–Chao [3]		
non-relativistic	312	95
relativistic	199	72
Eichten–Lane–Quigg [4]		
non-relativistic	254	183
with coupled channels corrections	225	59
Barnes–Godfrey–Swanson [5]		
non-relativistic	403	125
relativistic	213	77
NRCQM [6]	218	70

The most precise measurement !

$\psi(3770)\rightarrow\gamma\eta_c$ and $\gamma\eta_c(2S)$





- The processes of $\psi(3770)\rightarrow\gamma\eta_c$ and $\gamma\eta_c(2S)$ are supposed to be highly suppressed. If the $\psi(3770)$ is a pure D-wave state, the M1 transition is forbidden. However, higher multipoles beyond the leading one could contribute.
- Reconstructed via

$$\eta_c(\eta_c(2S)) \rightarrow K^0_S K^{\pm}\pi^{\mp}$$

PRD 89 112005 (2014)

$\psi(3770) \rightarrow \gamma\eta_c$ and $\gamma\eta_c(2S)$

- **No significant excess of signal events above background is observed. We set limits at a 90% confidence level.**

$$\mathcal{B}(\psi(3770) \to \gamma\eta_c(\eta_c(2S)) \to \gamma K_S^0 K^{\pm}\pi^{\mp}) < \frac{N_{\rm up}/(1-\sigma_{\rm syst})}{\epsilon \cdot \mathcal{L} \cdot \sigma^0_{\psi(3770)} \cdot (1+\delta) \cdot \mathcal{B}(K_S^0 \to \pi^+\pi^-)}$$

Quantity	η_c	$\eta_c(2S)$	χ_{c1}
$N_{\rm obs}$	29.3 ± 18.2	0.4 ± 8.5	34.9 ± 9.8
$N_{\rm up}$	56.8	16.1	…
ϵ (%)	27.87	25.24	28.46
$\mathcal{B}(\psi(3770) \to \gamma X \to \gamma K_S^0 K^{\pm}\pi^{\mp})$ $(\times 10^{-6})$	< 16	< 5.6	$8.51 \pm 2.39 \pm 1.42$
$\mathcal{B}(\psi(3770) \to \gamma X)$ $(\times 10^{-3})$	< 0.68	< 2.0	$2.33 \pm 0.65 \pm 0.43$
$\mathcal{B}_{\rm CLEO}(\psi(3770) \to \gamma X)$ $(\times 10^{-3})$	…	…	$2.9 \pm 0.5 \pm 0.4$
$\Gamma(\psi(3770) \to \gamma X)$ (keV)	< 19	< 55	…
$\Gamma_{\rm IML}$ (keV)	$17.14^{+22.93}_{-12.03}$	$1.82^{+1.95}_{-1.19}$	…
$\Gamma_{\rm LQCD}$ (keV)	10 ± 11	…	…

Summary

- **By analyzing the data samples collected using BESIII detector, we searched for the non-$D\bar{D}$ decays of the $\psi(3770)$;**
  - No significant baryonic decays are observed;
  - The measurement of $B(\psi(3770)\rightarrow\gamma\chi_{c0})$ and $B(\psi(3770)\rightarrow\gamma\chi_{c1})$ are improved;
  - No significant decays of $\psi(3770)\rightarrow\gamma\eta_c(\eta_c(2S))$ are observed.
- **More results on non-$D\bar{D}$ decays of the $\psi(3770)$ are coming soon!**

Thank you !