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

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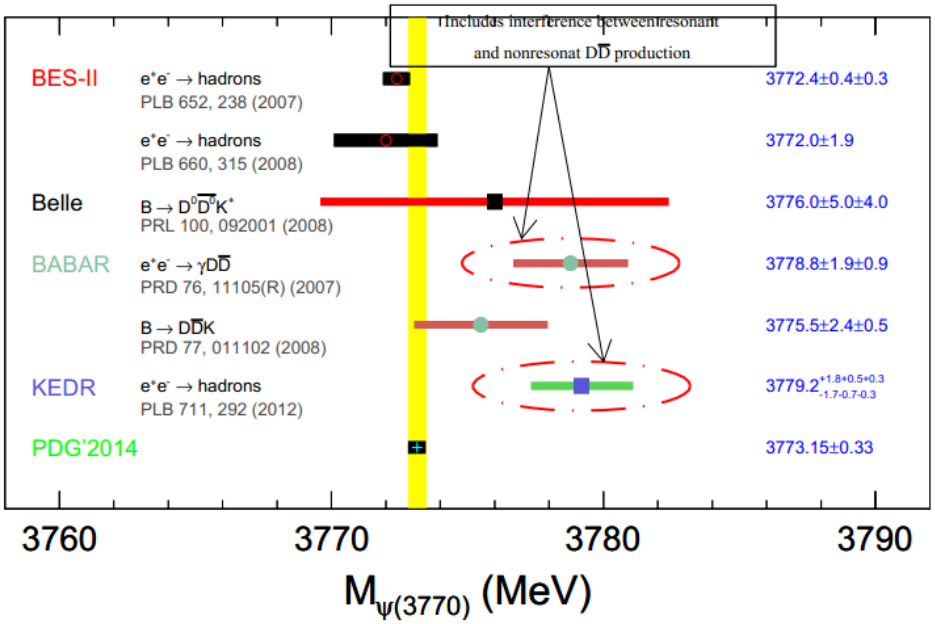
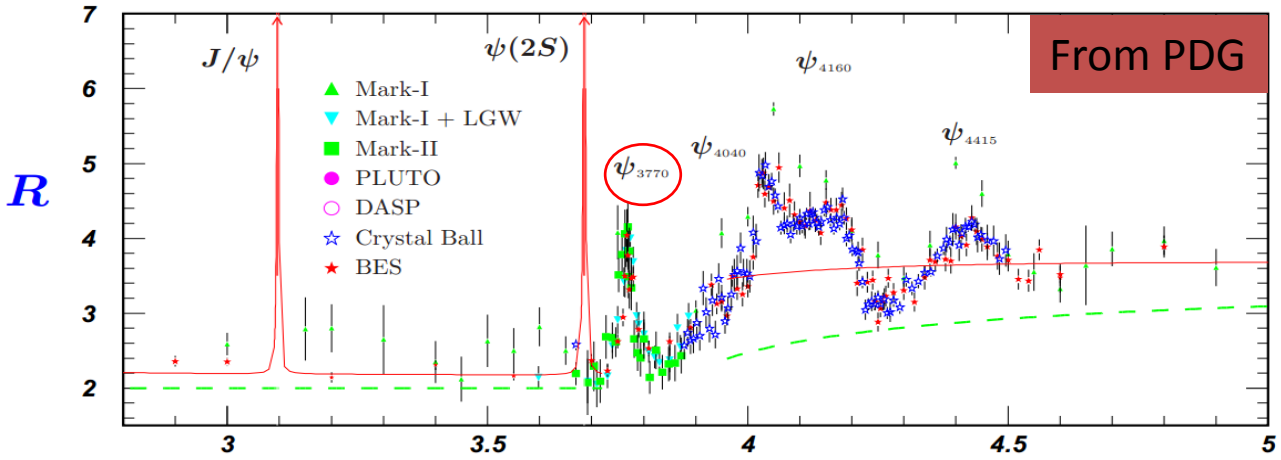
Introduction

- Since the discovery of $\psi(3770)$, it is a long-standing puzzle in understanding of $\psi(3770)$ production and decays.



- Discrepant results of $\psi(3770)$ parameters are observed.

Introduction

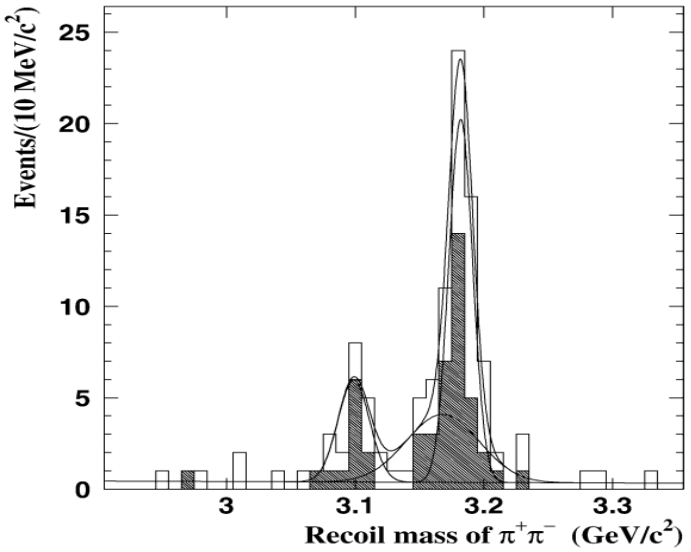


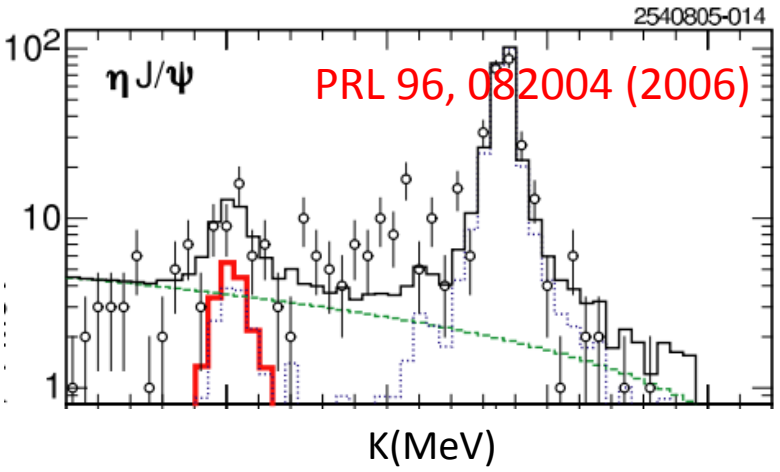
- The $\psi(3770)$ resonance is the lowest-mass charmonium resonance above the $D\overline{D}$ threshold.
- It has been popularly interpreted as a mixture of dominated 1^3D_1 and small 2^3S_1.
- If the $\psi(3770)$ is really a pure cc bound state, the potential model expects that more than 99% of $\psi(3770)$ decay into $D\overline{D}$ final states. But …

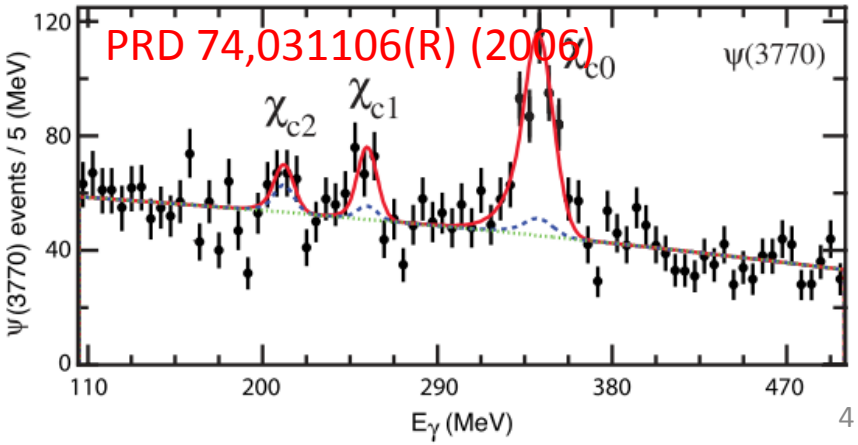
Introduction

- BESII observed the first non-$D\overline{D}$ decays of $\psi(3770)$ to $\pi^+\pi^- J/\psi$ in 2003.
- Then CLEO reported more exclusive non-$D\overline{D}$ decays of $\psi(3770)$:
  - $\psi(3770) \rightarrow \pi^0\pi^0 J/\psi$
  - $\psi(3770) \rightarrow \eta J/\psi$
  - $\psi(3770) \rightarrow \gamma\chi_{c0,1}$
  - $\psi(3770) \rightarrow \phi\eta$.

PLB 605,63(2005)







Introduction

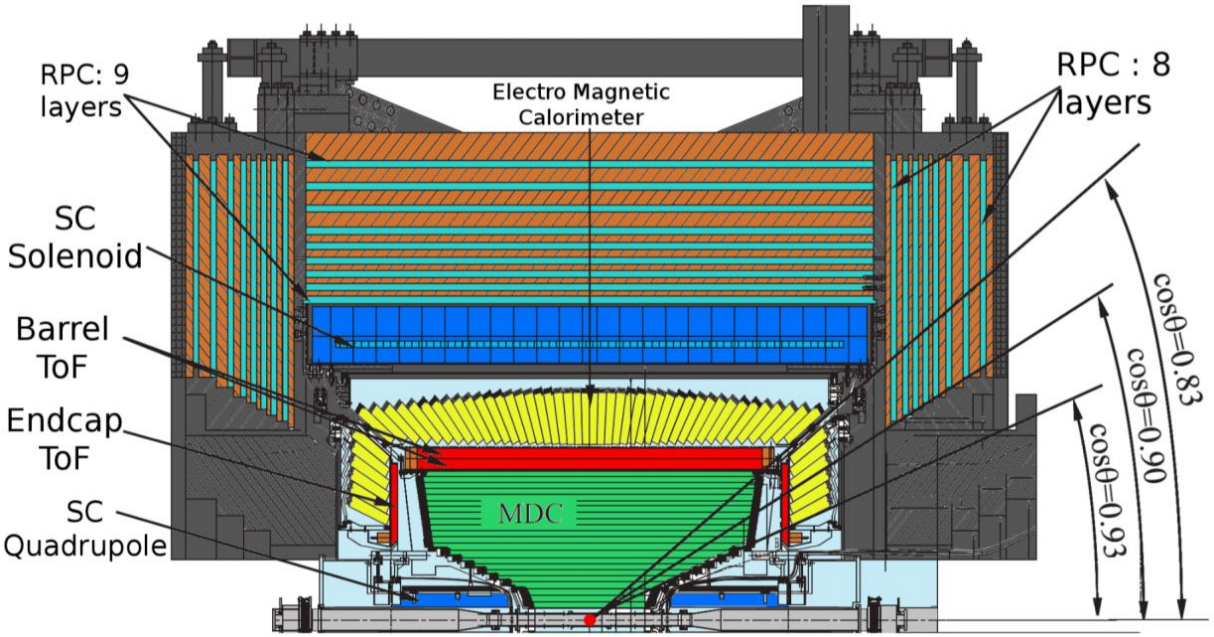
- Even though both collaborations did made huge efforts in searching for non-$D\overline{D}$ decays modes of $\psi(3770)$, the sum of the exclusive non-$D\overline{D}$ branching fractions is less than 2 %.
- BESII measured branching fractions of $\psi(3770)$ to non-$D\overline{D}$:
  - $BR(\psi(3770) \rightarrow \text{non}-D\overline{D}) = (14.7 \pm 3.2)\%$
- CLEO-c also measured $BR(\psi(3770) \rightarrow \text{non}-D\overline{D})$:
  - Without interference: $\sim 7\%$
  - With interference: $(-3.3 \pm 1.4(stat) + 6.6 - 4.4(sys))\%$
  - Upper limit with interference: $BR(\psi(3770) \rightarrow \text{non}-D\overline{D})$<9% @ 90%CL
- Clarify difference → need to search for more exclusive non-$D\overline{D}$ decays modes .

BESIII Experiment

BEPCII Collider

- Symmetric e^+e^- collider, double-rings, 2.0 GeV<ECM<4.6 GeV
- Design luminosity: $10^{33}\ cm^{-2}s^{-1}$ @ 1.89GeV, achieved on 5th April, 2016!

BESIII Detector



Data set for this talk:

- 2.92 fb^{-1} @ 3.773GeV

The largest $\psi(3770)$ data sample.

- 106 M $\psi(3686)$ data.
- 44.5 pb^{-1} @ 3.65GeV

Used to subtract the continuum background.

- 60 pb^{-1} $\psi(3770)$ line-shape scan data.

Searching for Baryonic decays of $\psi(3770)$

Experimental Method: PRD87, 112011 (2013)

$$N^{S}_{\psi(3770)\to \mathrm{f}} = N^{f}_{\mathrm{obs}} - N^{f}_{\mathrm{B}} - N^{f}_{q\bar{q}}$$

- N^{f}_{obs} is the observed number of baryonic final-state events in the $\psi(3770)$ data
- N^{f}_{B} is the backgrounds number of $\gamma\psi(3686)$, $\gamma J/\psi$ and misidentified $\psi(3770)$ decays($f_{\gamma\psi\,(3686)}$, $f_{\gamma J/\psi}$, $f_{D\bar{D}}$ are the scale factors for the Monte Carlo samples):

$$N^{f}_{\mathrm{B}} = f_{\gamma\psi\,(3686)} N^{f}_{\gamma\psi\,(3686)} + f_{\gamma J/\psi} N^{f}_{\gamma J/\psi} + f_{D\bar{D}} N^{f}_{D\bar{D}}$$

- $N^{f}_{q\bar{q}}$ is the continuum events number:

$$N^{f}_{q\bar{q}} = f_{co} \times [N^{f}_{\mathrm{obs}}\ (3.650) - N^{f}_{\mathrm{B}}\ (3.650)]$$

f_{co} is the scaling factor:

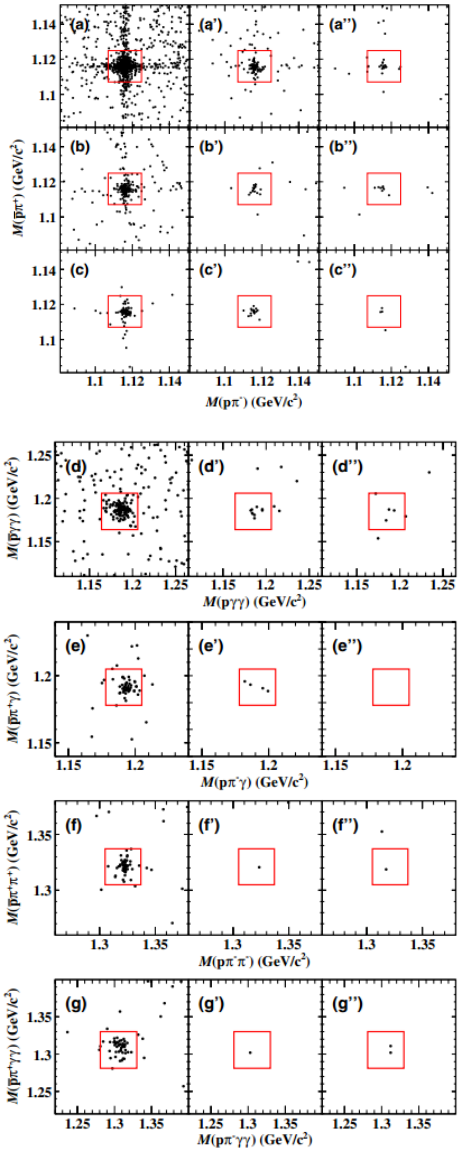
$$f_{co} = \left(\frac{3.65}{3.773}\right)^{2} \times \frac{\mathcal{L}_{3.773}}{\mathcal{L}_{3.650}} \times \frac{\epsilon^{3.773}_{e^+e^-\to f}}{\epsilon^{3.650}_{e^+e^-\to f}}$$

- No significant events are observed
- Estimate a 90% C.L. upper limit of the branching ratio of $\psi(3770)$ decays to each modes :

$$\mathcal{B}_{\psi(3770)\to \mathrm{f}} = \frac{N^{S}_{\psi(3770)\to \mathrm{f}}}{\epsilon_{\psi(3770)\to \mathrm{f}} \times \mathcal{B}_{\mathrm{f}} \times N_{\psi(3770)} \times (1-\Delta_{sys})}$$

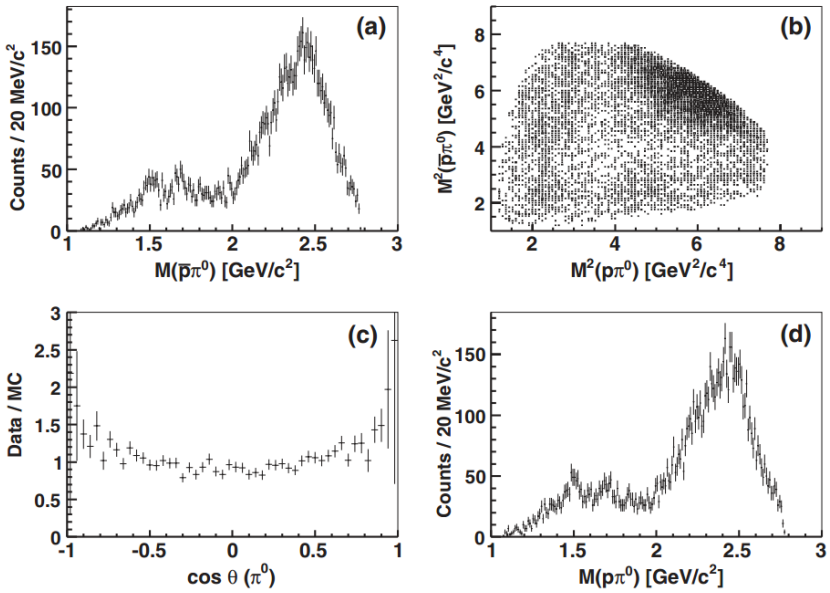
Mode f	$N^f_{\rm obs}$ (3.773)	$N^f_{\rm B}$ (3.773)	$N^f_{\rm obs}$ (3.650)	$N^f_{\rm B}$ (3.650)	$f_{\rm co}^{3.773}$	$N^S_{\psi(3770)\to f}$	$N^{\rm up}_{\psi(3770)\to f}$	ϵ	$\Delta_{\rm sys}$	$\mathcal{B}_{\psi(3770)\to f}$ [$\times 10^{-4}$]	$\mathcal{B}^{\rm up}$ [$\times 10^{-4}$]
$\Lambda\bar{\Lambda}\pi^+\pi^-$	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

PRD 87, 112011 (2013)

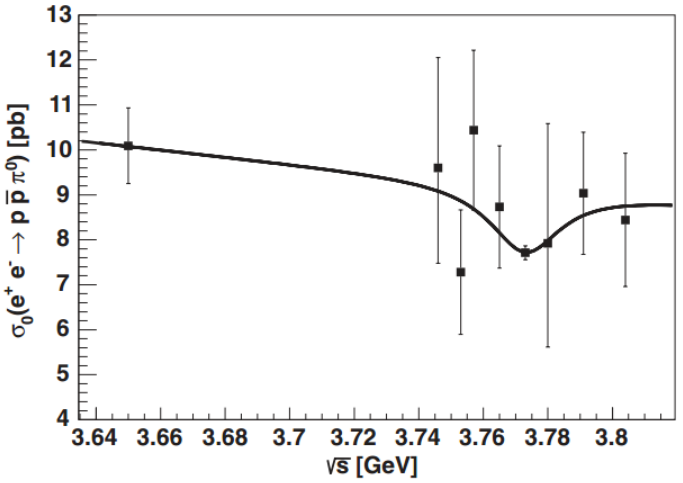


$\psi(3770) \rightarrow p\bar{p}\pi^0$

PRD90, 032007 (2014)



$$\sigma(s) = \left|\sqrt{\sigma_{con}} + \sqrt{\sigma_{\psi}}\frac{m\Gamma}{s-m^2+im\Gamma}\exp(i\phi)\right|^2$$

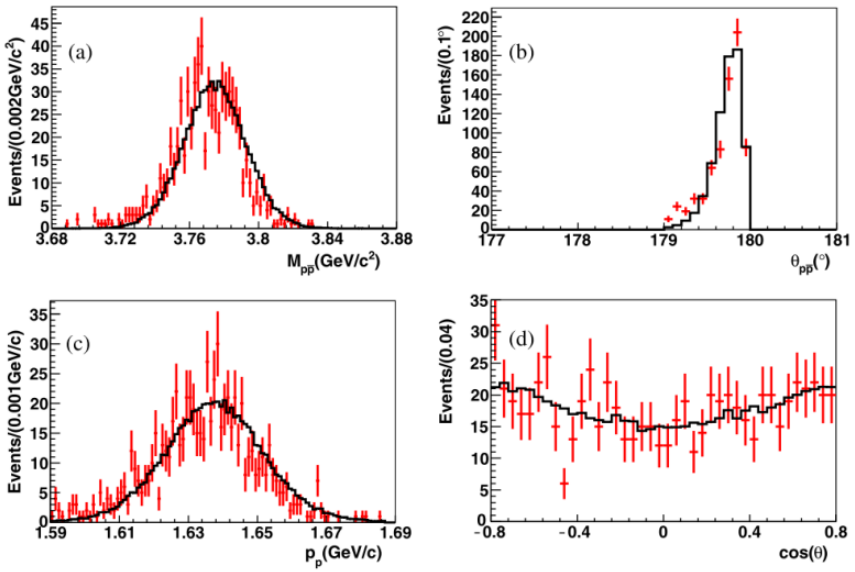


Data sets: 2.9 fb^{-1}@3.773GeV, 44.5 pb^{-1}@3.65, 60 pb^{-1} $\psi(3770)$ line−shape scan date

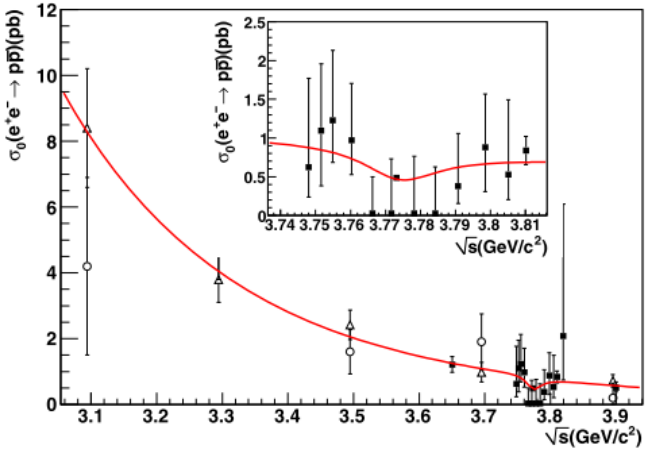
Solution	$\sigma_0^{\psi(3770)\to p\bar{p}\pi^0}$ [pb]	$\phi_{\rm Fit}$ [°]	$\sigma_0^{p\bar{p}\to\psi(3770)\pi^0}$ [nb] at 5.26 GeV
1	< 0.22	$269.8^{+52.4}_{-48.0} \pm 11.0$	< 0.79
2	$33.8 \pm 1.8 \pm 2.1$	$269.7 \pm 2.3 \pm 0.3$	122 ± 10

For $\overline{\rm P}$ANDA

$\psi(3770) \rightarrow p\bar{p}$



$$\sigma(s) = \left| \sqrt{\sigma_{con}(s)} + \sqrt{\sigma_{\psi}} \frac{m_{\psi}\Gamma_{\psi}}{s - m_{,\psi}^{2} + i m_{\psi}\Gamma_{\psi}} \right|^{2}$$



Solution	$\sigma^{dressed}_{(\psi(3770)\rightarrow p\bar{p})}$ (pb)	ϕ (°)
(1)	$0.059^{+0.070}_{-0.020} \pm 0.012$	$255.8^{+39.0}_{-26.6} \pm 4.8$
	(< 0.166 at 90% C.L.)	
(2)	$2.57^{+0.12}_{-0.13} \pm 0.12$	$266.9^{+6.1}_{-6.3} \pm 0.9$

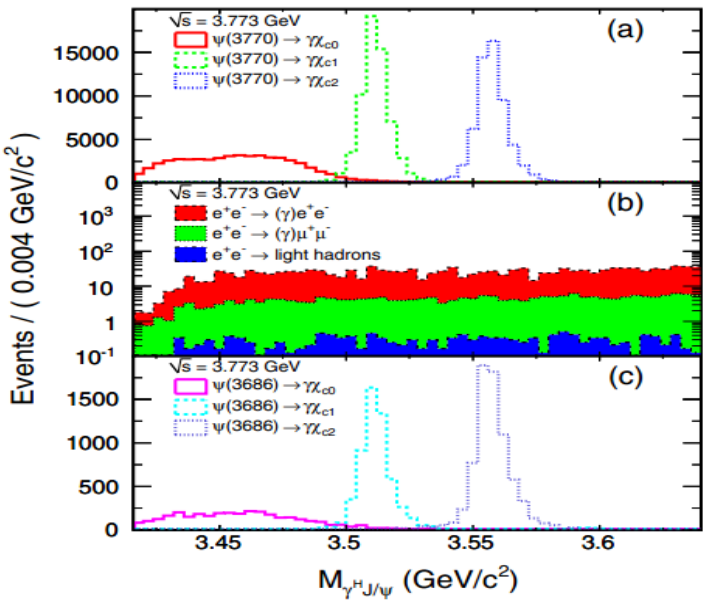
$$\sigma_{p\bar{p}\rightarrow\psi(3770)}(s) = \frac{4\pi(2J+1)}{(s-4m_p^2)} \frac{B_{\psi(3770)\rightarrow p\bar{p}}}{1+[2(\sqrt{s}-M_{\psi})/\Gamma_{\psi}]^2}$$

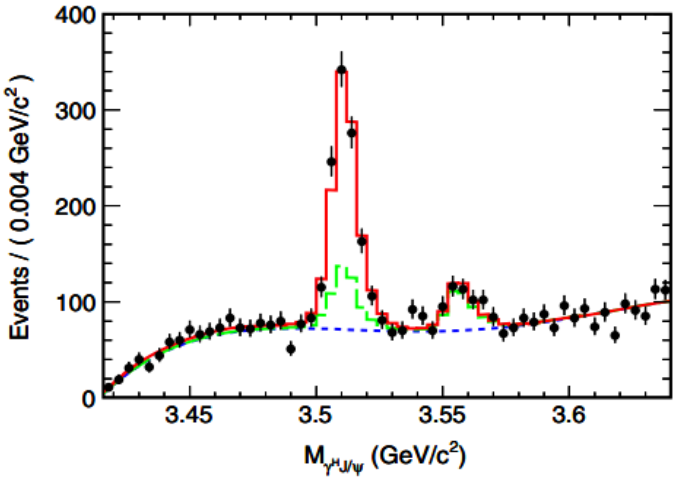
For $\overline{\text{P}}$ANDA

$=(9.8^{+11.8}_{-3.9})$ nb(<27.5 nb at 90% C.L.) *or* $(425.6^{+42.9}_{-43.7})$ nb

Measurement of B($\psi(3770) \rightarrow \gamma\chi_{c1}$) and search for $\psi(3770) \rightarrow \gamma\chi_{c2}$

PRD 91, 092009 (2015)





- The $\chi_{c1,2}$ are reconstructed with the decay

$$\chi_{c1,2} \rightarrow \gamma J/\psi \, , J/\psi \rightarrow l^+l^-$$

$\mathcal{B}(\psi(3770) \rightarrow \gamma\chi_{c1}) = (2.48 \pm 0.15 \pm 0.23) \times 10^{-3}$
$\mathcal{B}(\psi(3770) \rightarrow \gamma\chi_{c2}) < 0.64 \times 10^{-3}$ at 90% C.L.

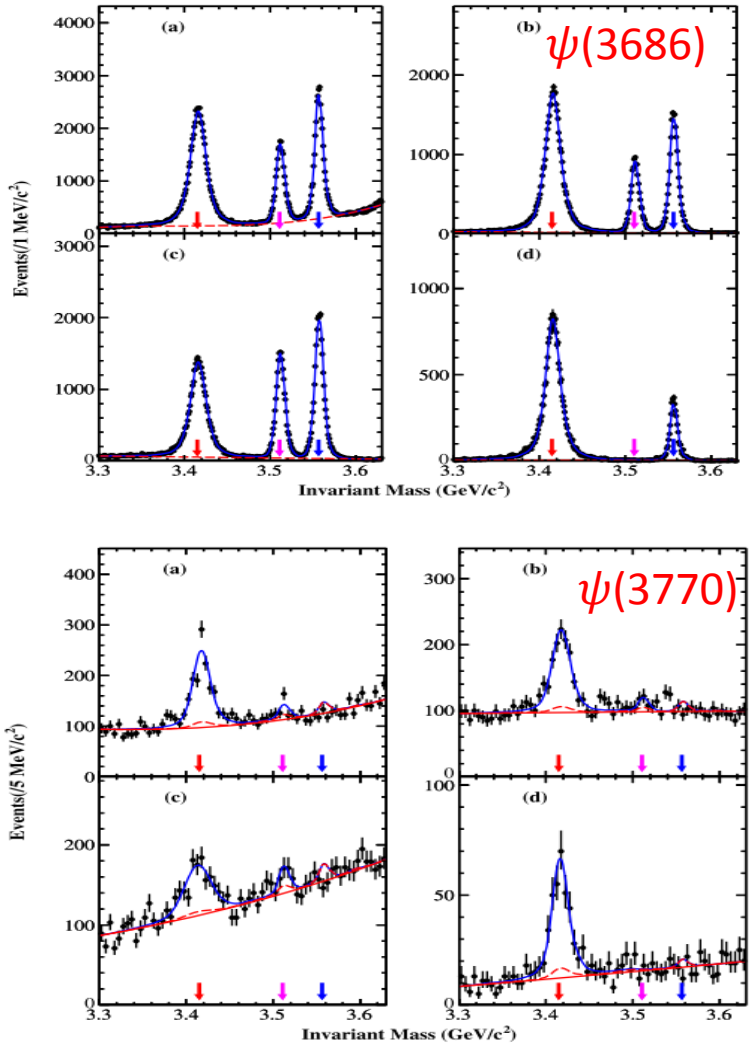
Experiment/theory	$\Gamma(\psi(3770) \rightarrow \gamma\chi_{cJ})$ (keV)	
	$J = 1$	$J = 2$
This work	$67.5 \pm 4.1 \pm 6.7$	< 17.4
Ding-Qin-Chao [12]		
Nonrelativistic	95	3.6
Relativistic	72	3.0
Rosner *S-D* mixing [13]		
$\phi = 12°$ [13]	73 ± 9	24 ± 4
$\phi = (10.6 \pm 1.3)°$ [32]	79 ± 6	21 ± 3
$\phi = 0°$ (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

Measurement of the $\mathcal{B}(\psi(3770) \rightarrow \gamma\chi_{c0})$

PLB 753 (2016) 103–109

Experiment Method:

- The analysis is based on the 2.92 fb^{-1} $\psi(3770)$ data and 106 million $\psi(3686)$ data .
- Via $\chi_{cJ} \rightarrow LH(2(\pi^+\pi^-),\ K^+K^-\pi^+\pi^-,\ 3((\pi^+\pi^-),\ K^+K^-)$.
- Obtained by taking the relative strength to the $\psi(3686)$ E1 transition, avoiding introducing large uncertainties of the branching fractions for $\chi_{cJ} \rightarrow LH$.



- The ratio of the $\mathcal{B}(\psi(3770) \rightarrow \gamma\chi_{cJ})$ and $\mathcal{B}(\psi(3686) \rightarrow \gamma\chi_{cJ})$ is determined channel by channel:

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

BEII PLB 650(2006)111

$N^{tot}_{\psi(3686)} = 106$ M $N^{tot}_{\psi(770)} = \sigma^{3.773\ \mathrm{GeV}}_{\psi(770)} \times L$ $\sigma^{3.773\ \mathrm{GeV}}_{\psi(770)}$ = (7.15 ± 0.27 ± 0.27) nb

	R_{cJ}[%]		
	χ_{c0}	χ_{c1}	χ_{c2}
$2(\pi^+\pi^-)$	6.64 ± 0.45	2.13 ± 0.69	-
$K^+K^-\pi^+\pi^-$	7.56 ± 0.57	2.00 ± 1.04	-
$3((\pi^+\pi^-)$	6.86 ± 0.74	1.94 ± 0.69	-
K^+K^-	6.65 ± 0.57	-	-
Weighted R_{cJ}	6.89 ± 0.28 ± 0.65	2.03 ± 0.44 ± 0.66	N/A
CLEO 281 pb^{-1}[%]	7.9 ± 0.8 ± 0.6	4.3 ± 1.6 ± 0.6	<2.2

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

$$\mathcal{B}\left(\psi(3770) \rightarrow \gamma\chi_{cJ}\right) = R_{cJ} \times \mathcal{B}\left(\psi(3686) \rightarrow \gamma\chi_{cJ}\right)$$

From PDG

Experiments	$J=0$	$J=1$
$\mathcal{B}^{\mathrm{BESIII}}(\times 10^{-3})$	$6.88 \pm 0.28 \pm 0.67$	$1.94 \pm 0.42 \pm 0.64$
$\mathcal{B}^{\mathrm{BESIII}}(\times 10^{-3})$ [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
$\Gamma^{\mathrm{CLEO}}_{\mathrm{corrected}}$	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	225	59
corrections		
Barnes–Godfrey–Swanson [5]		
non-relativistic	403	125
relativistic	213	77
NRCQM [6]	218	70

This work

$\psi(3770) \rightarrow \gamma\eta_c(1S, 2S)$

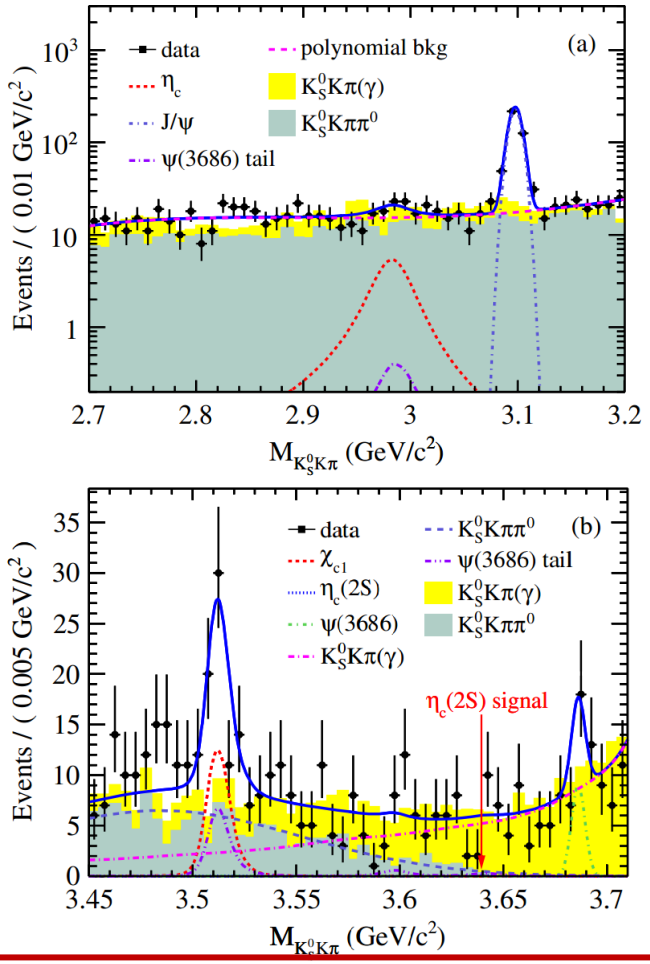
- Via $\eta_c(1S, 2S) \rightarrow K_S^0 K^{\pm}\pi^{\mp}$
- M1 transition should be forbidden but higher multipoles may contribute.

Theoretical predictions
$\Gamma(\psi(3770) \rightarrow \gamma\eta_c) = 17.14^{+22.93}_{-12.03}$ keV
$\Gamma(\psi(3770) \rightarrow \gamma\eta_c(2S)) = 1.82^{+1.95}_{-1.19}$ keV
IML model PRD 84, 074005 (2011)
$\Gamma(\psi(3770) \rightarrow \gamma\eta_c) = 10 \pm 11$ keV
LQCD PRD 79, 094504 (2009)

- No clear signals are observed. Upper limit on BF is set at 90% C.L.

Branching fraction
$BF(\psi(3770) \rightarrow \gamma\eta_c \rightarrow \gamma K_S K\pi) < 1.6 \times 10^{-5}$
$BF(\psi(3770) \rightarrow \gamma\eta_c(2S) \rightarrow \gamma K_S K\pi) < 5.8 \times 10^{-6}$
Using PDG's BF($\eta_c(1S, 2S) \rightarrow K_S^0 K^{\pm}\pi^{\mp}$):
$BF(\psi(3770) \rightarrow \gamma\eta_c) < 6.7 \times 10^{-4}$
$BF(\psi(3770) \rightarrow \gamma\eta_c(2S)) < 2.1 \times 10^{-3}$

PRD 89, 112005 (2014)



Also measured E1 transition:
$BF(\psi(3770) \rightarrow \gamma\chi_{c1}) = (3.03 \pm 0.65 \pm 0.44) \times 10^{-3}$
Consistent with PDG value:
$BF(\psi(3770) \rightarrow \gamma\chi_{c1}) = (2.9 \pm 0.6) \times 10^{-3}$

Summary

- By using BESIII data sets taken at $\psi(3770)$ peak, we study the Non-$D\overline{D}$ decays of the $\psi(3770)$

  - ✓ No significant decays of $\psi(3770) \to \Lambda\overline{\Lambda}\pi^+\pi^-, \Lambda\overline{\Lambda}\pi^0, \Lambda\overline{\Lambda}\eta, \Sigma^+\bar{\Sigma}^-, \Sigma^0\bar{\Sigma}^0, \Xi^+\bar{\Xi}^-$ and $\Xi^0\bar{\Xi}^0$ are observed.
  - ✓ $e^+e^- \to p\bar{p}\pi^0$ and $e^+e^- \to p\bar{p}$ in the vicinity of the $\psi(3770)$ have been studied.
  - ✓ The measurement of $\mathcal{B}(\psi(3770) \to \gamma\chi_{c0})$ and $\mathcal{B}(\psi(3770) \to \gamma\chi_{c1})$ are improved.
  - ✓ No significant decays of $\psi(3770) \to \gamma\eta_c(1S, 2S)$ are observed.

- We may improve the result of $\psi(3770) \to \pi\pi J/\psi, \eta J/\psi, \pi^0 J/\psi$ using 2.9 fb^{-1}$\psi(3770)$ data of BESIII

- More Non-$D\overline{D}$ decays of the $\psi(3770)$ results with larger data set will come soon!

Thank you!