

# Recent Charmonium Results from BESIII

Yaqian WANG<sup>1</sup>

(for BESIII Collaboration)

<sup>1</sup>Mainz University

X<sub>th</sub> Quark Confinement and the Hadron Spectrum  
8-12 October 2012

# Outline

Introduction of BEPCII and BESIII

Charmonium related results

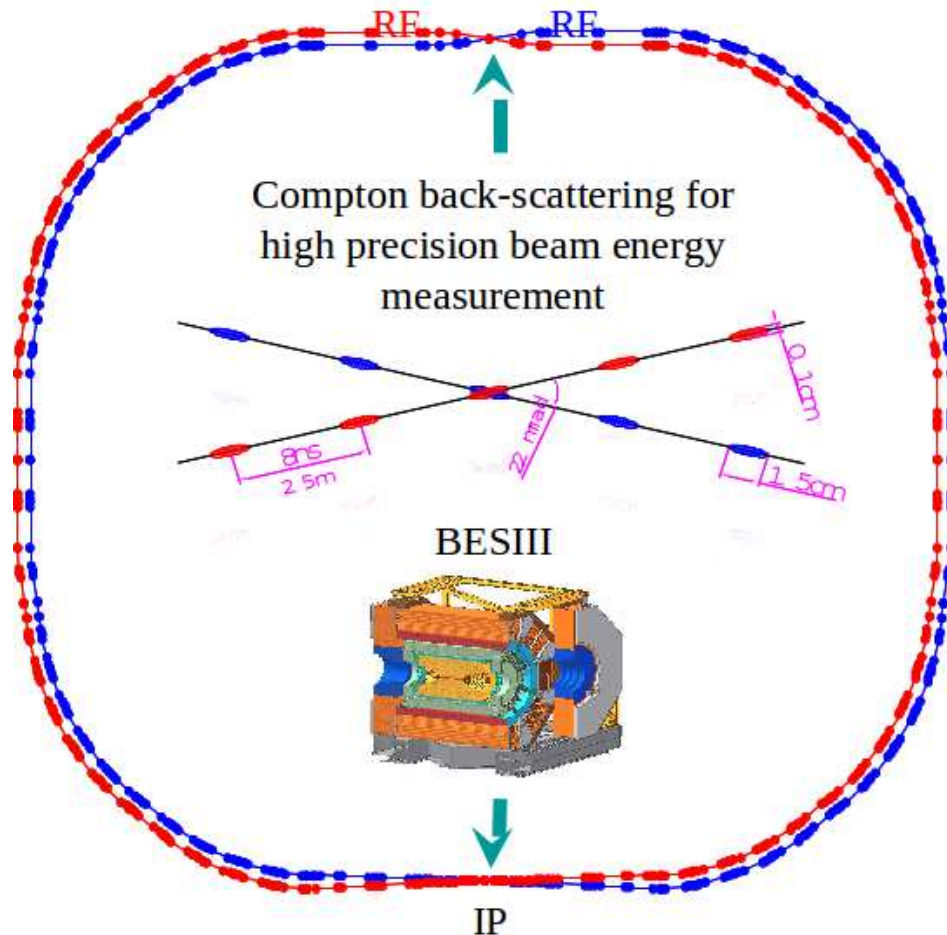
$h_c$

$\eta_c$

$\eta'_c$

Summary

# BEPCII and BESIII



## BEPCII

$E_{\text{beam}}$ :	1-2.3 GeV
$L_{\text{design}}$ :	$1 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$
$E_{\text{opt}}$ :	1.89 GeV
$E_{\text{spread}}$ :	$5.16 \times 10^{-4}$
$N_{\text{bunch}}$ :	93
$L_{\text{bunch}}$ :	1.5 cm
$I_{\text{total}}$ :	0.91 A

## BESIII

He-based drift chamber:  
0.5% @ 1 GeV/c,  $dE/dx \sim 6\%$

plastic scintillator TOF:  
80 ps (B), 110 ps (E)

CsI EM calorimeter:  
2.5% (B), 5% (E) @ 1 GeV

1T Superconducting magnet

Muon system: 39 layers of RPC

# Data samples

First e+e- collision event on 19th July, 2008

- ▶ 2009: 106 million  $\psi'$   
225 million  $J/\psi$
- ▶ 2010:  $\sim 900 \text{ pb}^{-1} \psi(3770)$
- ▶ 2011:  $\sim 2000 \text{ pb}^{-1} \psi(3770)$   
 $470 \text{ pb}^{-1} @ 4.01 \text{ GeV}$
- ▶ 2012:  $\sim 0.4 \text{ billion } \psi'$   
 $\sim 1.0 \text{ billion } J/\psi$

Peak luminosity reached  $0.65 \times 10^{33} @ \psi(3770)$

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$h_c$ 

- ▶ P-wave spin singlet (S=0, L=1)
- ▶ First evidence: E835 in  $p\bar{p} \rightarrow h_c \rightarrow \gamma\eta_c$
- ▶ Potential model:  
Non-vanishing P-wave spin-spin interaction

$$\Rightarrow \Delta M_{hf}(1P)=M_{h_c} - \langle M(1^3P_J) \rangle \neq 0,$$

$$\text{where } \langle M(1^3P_J) \rangle = \frac{1}{9}(M_{\chi_{c0}} + 3M_{\chi_{c1}} + 5M_{\chi_{c2}})$$

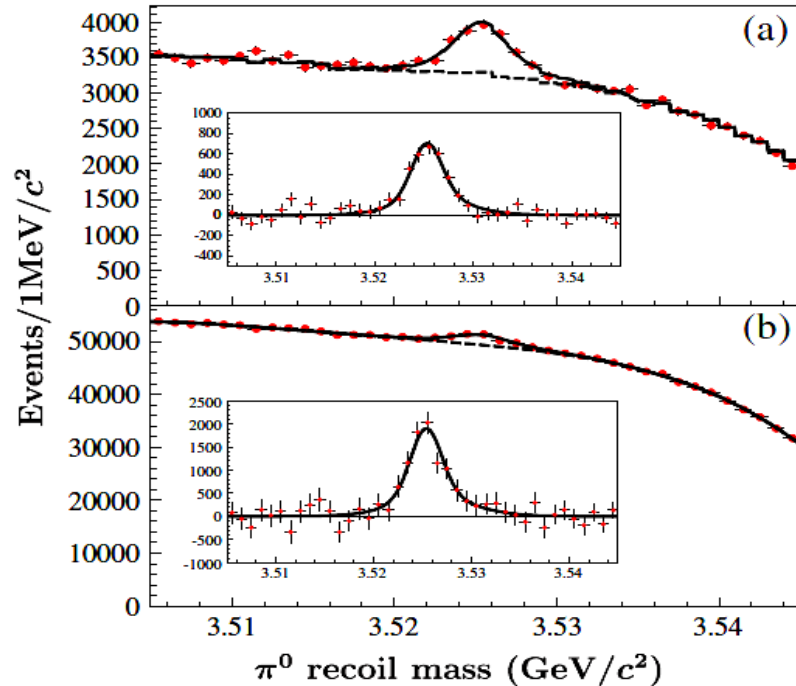
- ▶ CLEO-c observed  $h_c$  in  $e^+e^- \rightarrow \psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma\eta_c$

$$\Delta M_{hf}(1P) = 0.08 \pm 0.18 \pm 0.12 \text{ MeV}/c^2$$

consistent with 1P hyperfine splitting = 0

- ▶ Theoretical predictions:

- ▶  $\mathcal{B}(\psi' \rightarrow \pi^0 h_c) = (0.4-1.3) \times 10^{-3}$ ,  $\mathcal{B}(h_c \rightarrow \gamma\eta_c) = 48\%$  (NPQCD)
- ▶  $\mathcal{B}(h_c \rightarrow \gamma\eta_c) = 88\%$  (PQCD) Y. P. Kuang, [PRD 65, 094024 (2002)]
- ▶  $\mathcal{B}(h_c \rightarrow \gamma\eta_c) = 38\%$  Godfrey and Rosner, [PRD 66, 014012 (2002)]

$h_c$  inclusive [PRL 104, 132002 (2010)]

E1 tagged:

$$(\psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c)$$

$$M_{h_c} = 3525.40 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$$

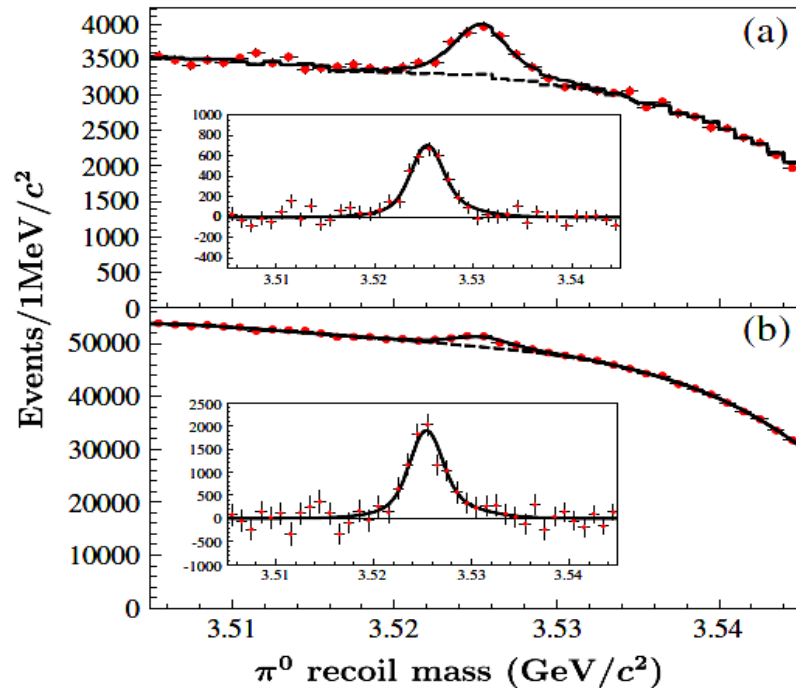
$$\Gamma_{h_c} = 0.73 \pm 0.45 \pm 0.28 \text{ MeV}$$

(< 1.44 MeV@90% C.L.)

inclusive:

$$(\psi' \rightarrow \pi^0 h_c)$$

$$\Delta M_{hf} = M(h_c) - \langle M(^3P_3) \rangle = 0.10 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$$

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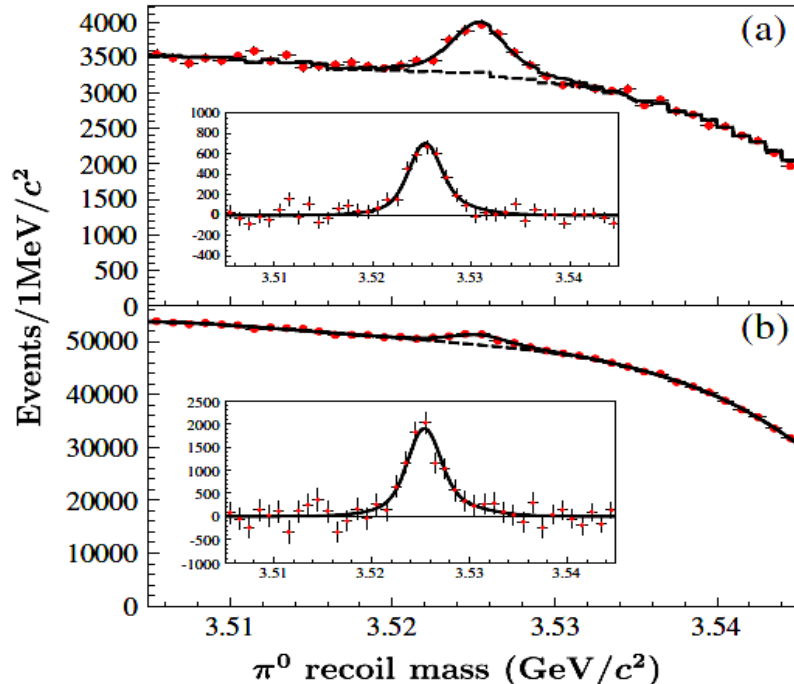
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Agree with zero within  $\sim 0.5 \text{ MeV}/c^2$



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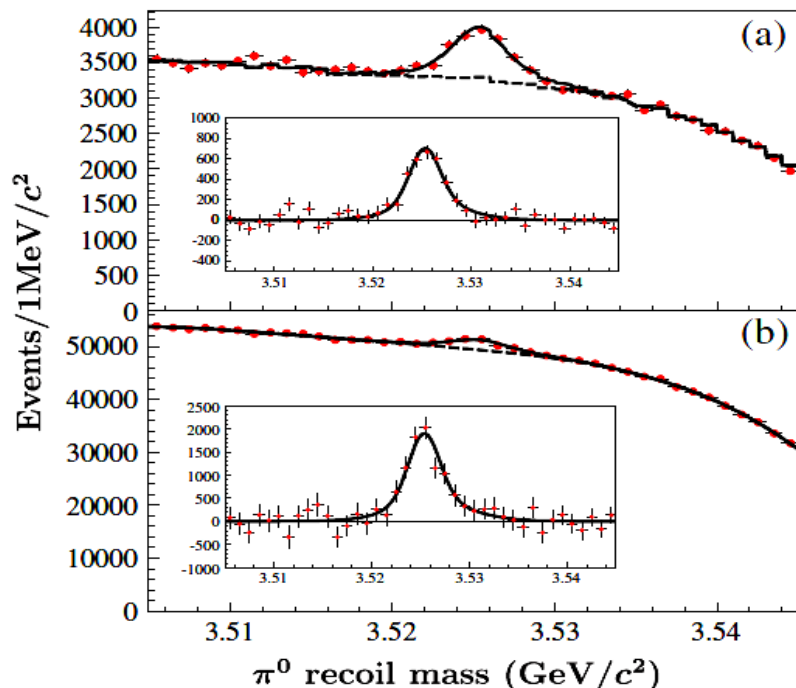
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Branching fraction results:

$$\mathcal{B}(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$$

$$\mathcal{B}(h_c \rightarrow \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$$

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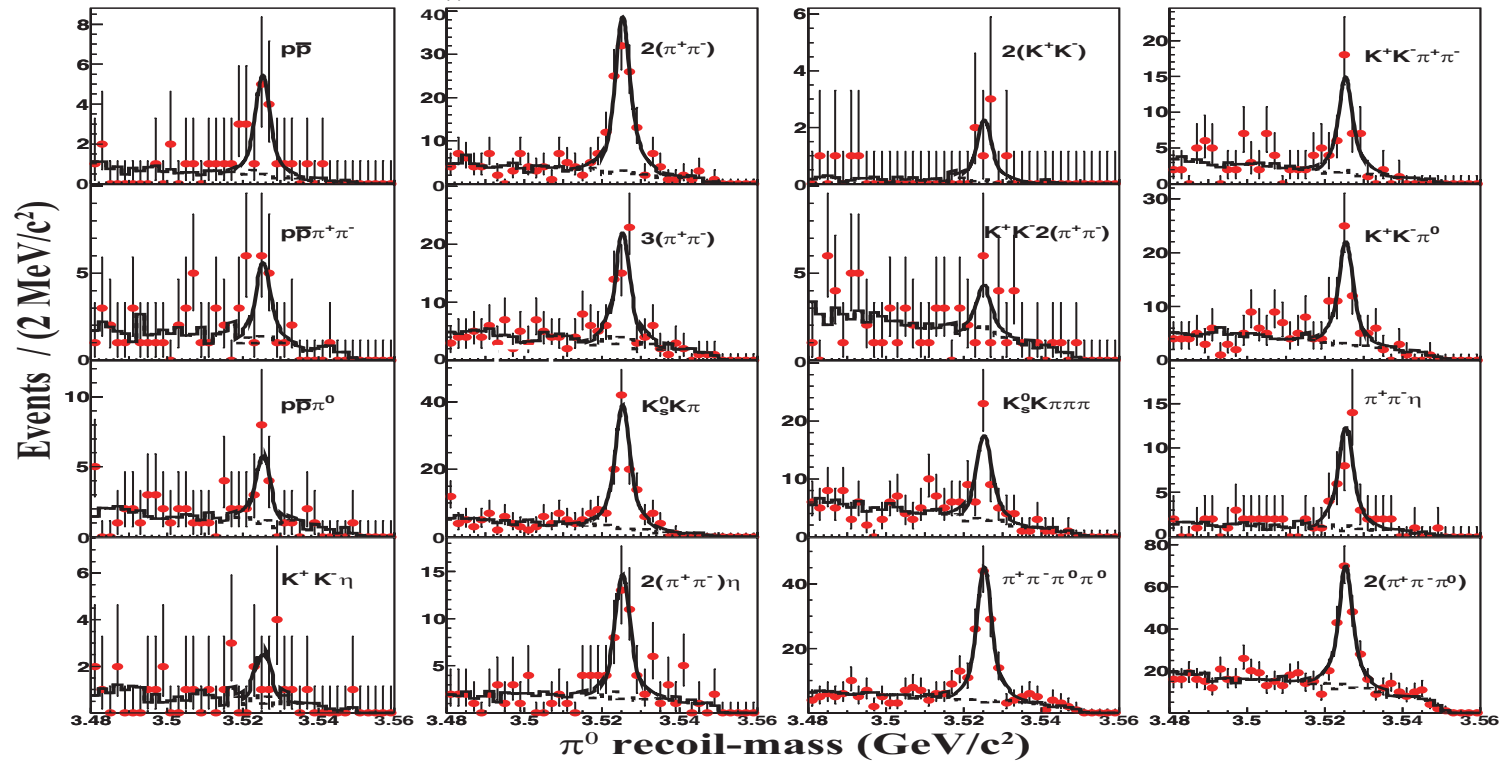
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Agree with theoretical predictions

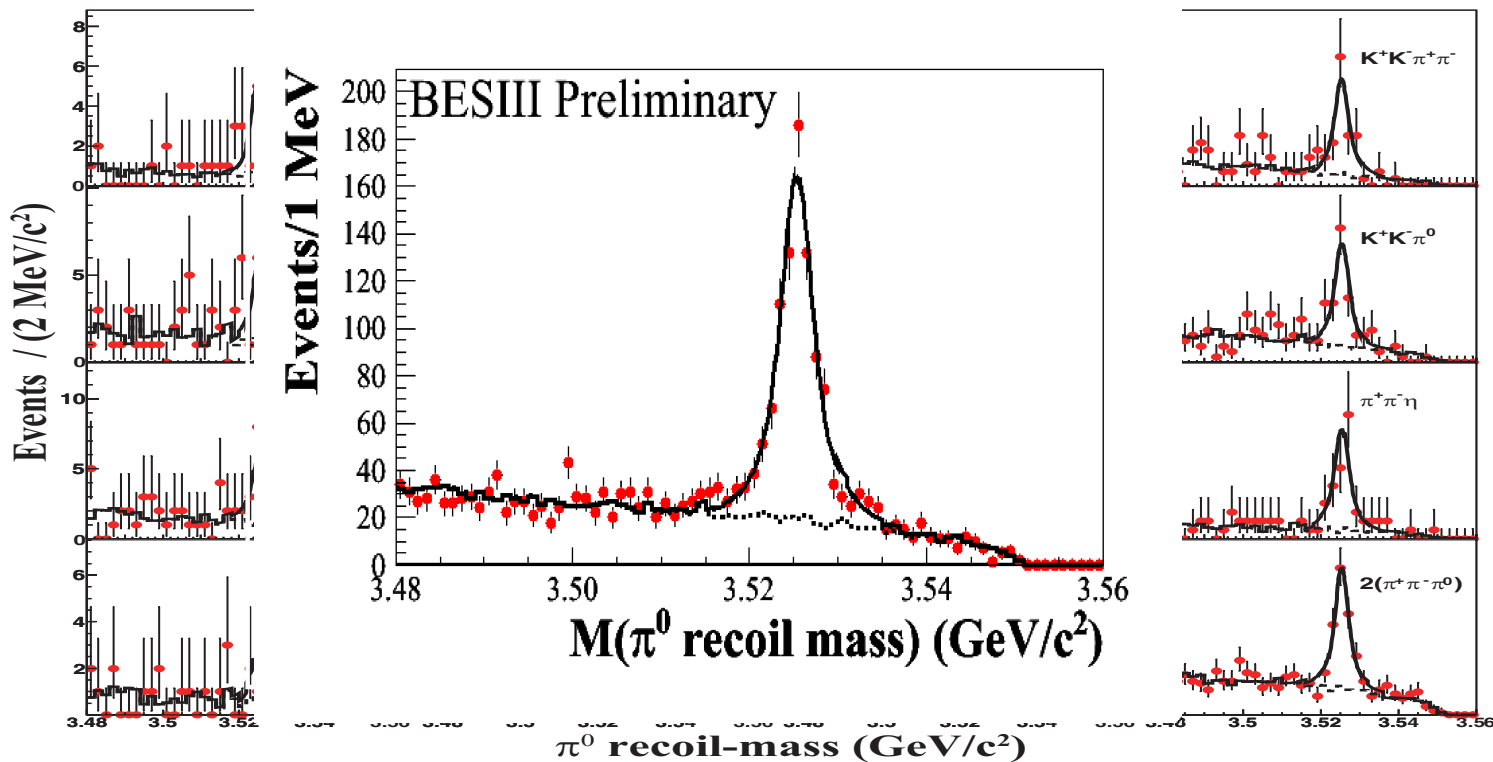
$h_c$  exclusive [arXiv:1209.4963]

- Simultaneous fit to  $M_{\pi^0}^{\text{recoil}}$ ,  $\chi^2/\text{ndf} = 32/46$



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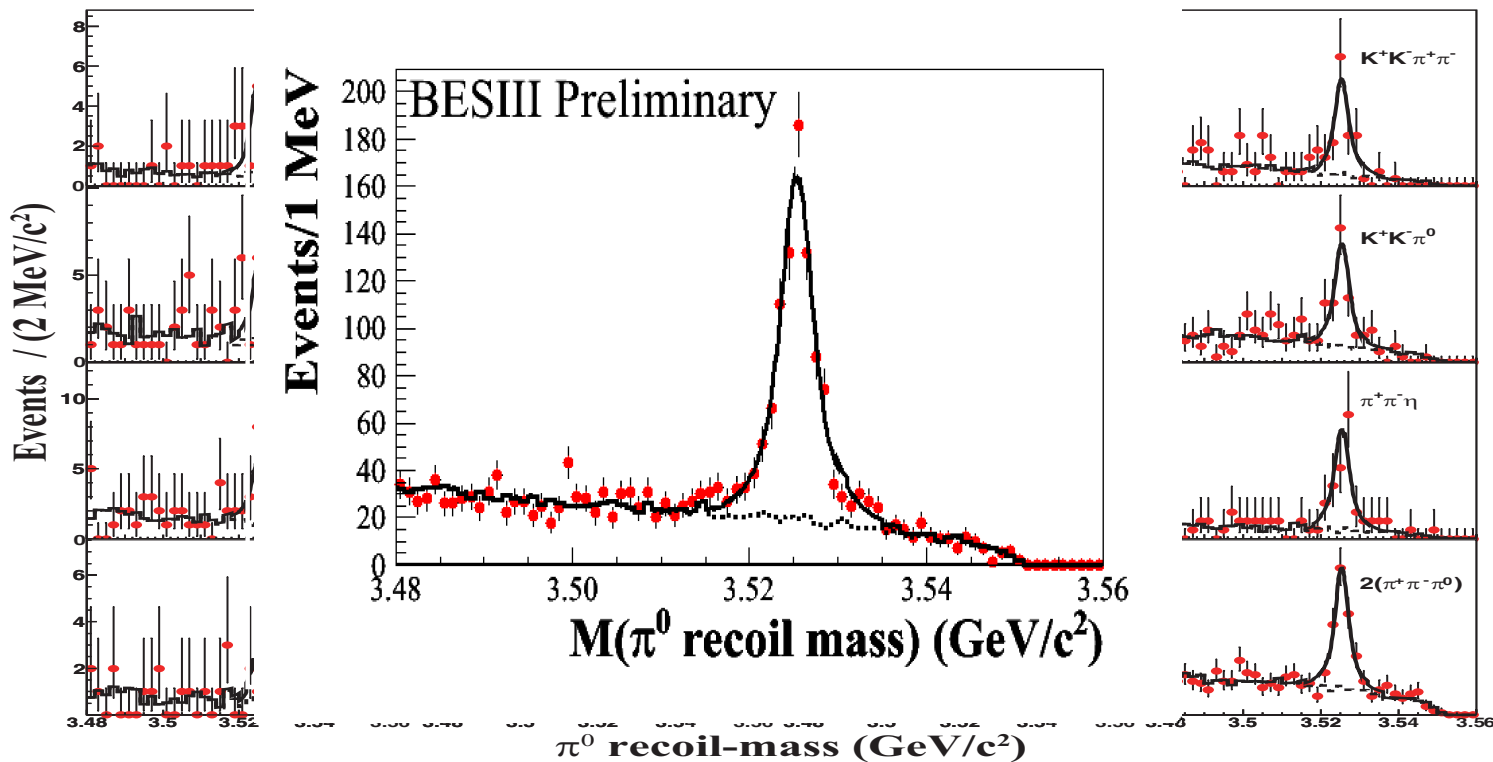
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Parameters	BESIII	CLEO-c [PRL 101, 182003(2008)]
Mass ( $\text{MeV}/c^2$ )	$3525.31 \pm 0.11 \pm 0.15$	$3525.21 \pm 0.27 \pm 0.14$
Width (MeV)	$0.70 \pm 0.28 \pm 0.25$	-
No. of signals	$832 \pm 35$	$136 \pm 14$

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Consistent!

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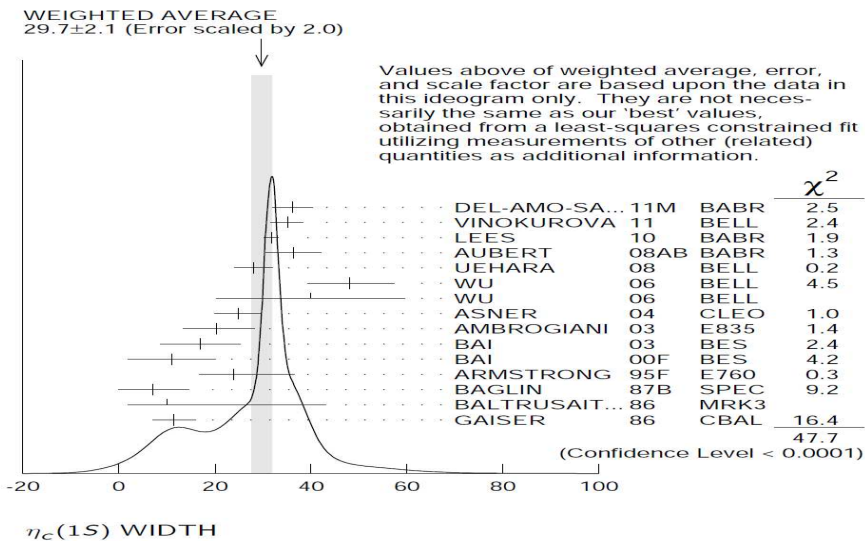
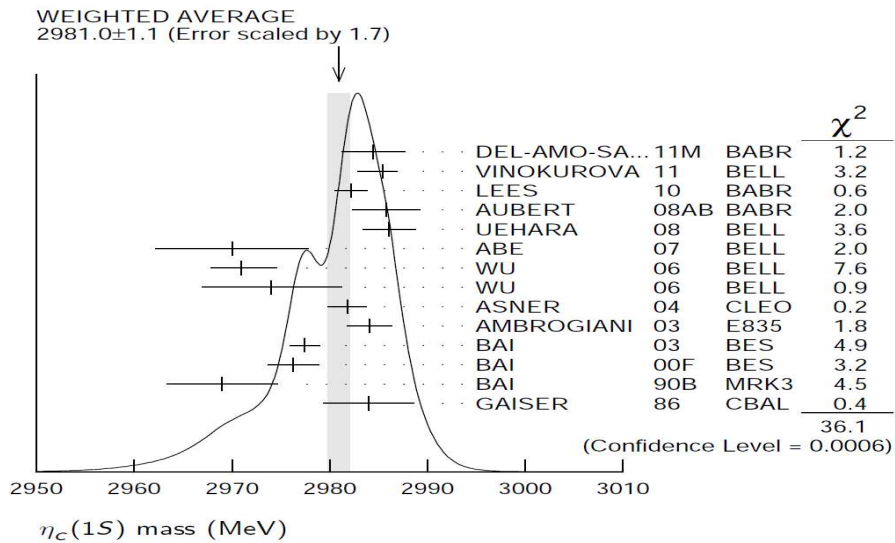
Charmonium related results

$h_c$

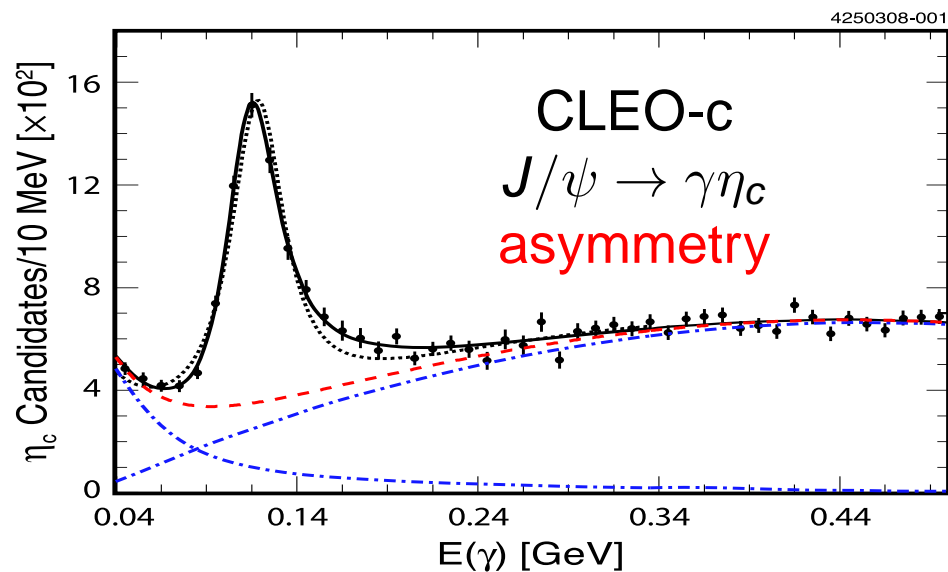
$\eta_c$

$\eta'_c$

Summary

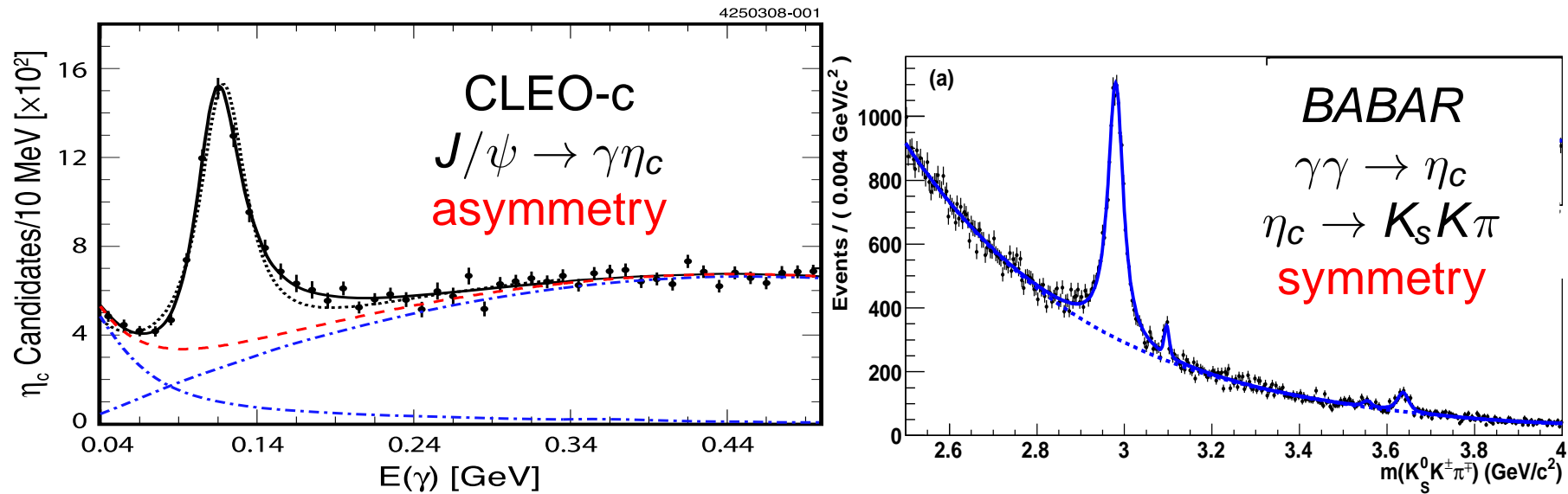
$\eta_c$ 

- ▶ Ground state of  $c\bar{c}$  system
- ▶ Discrepancies between different experiments
  - ▶ Charmonium radiative decay
  - ▶ Two-photon fusion or  $B$  decay
- ▶ Provide information on the hyperfine splitting:  $M_{J/\psi} - M_{\eta_c}$
- ▶ Important experimental input to tests of lattice QCD

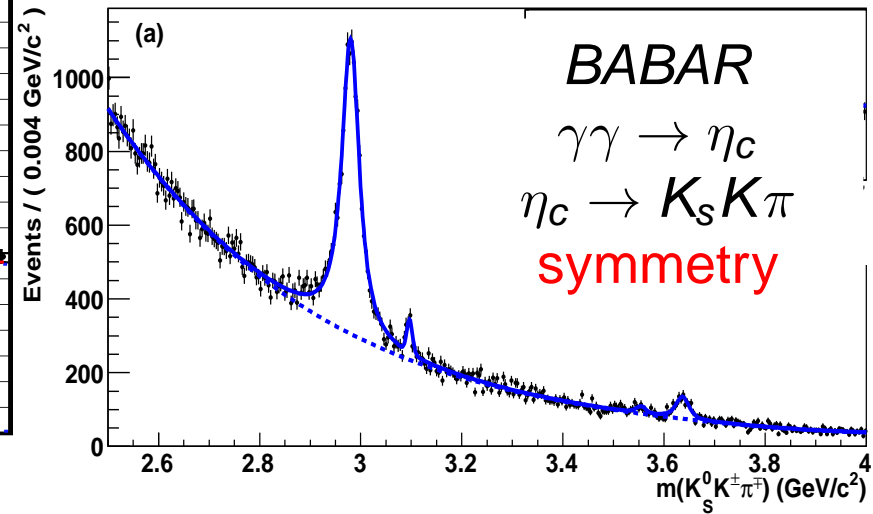
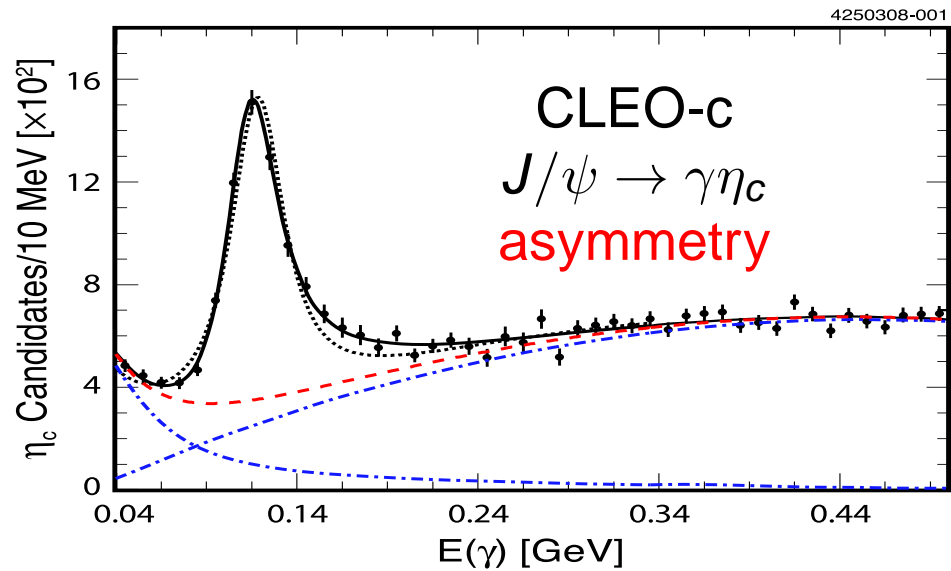
$\eta_c$  line shape

- ▶ Distortion of  $\eta_c$  from CLEO-c  
 [PRL 102, 011801 (2009)]
- ▶ Line shape of  $\eta_c$  from *BABAR*  
 [PRD 84, 012004 (2011)]
- ▶  $\eta_c$  from BESIII [arXiv:1209.4963]

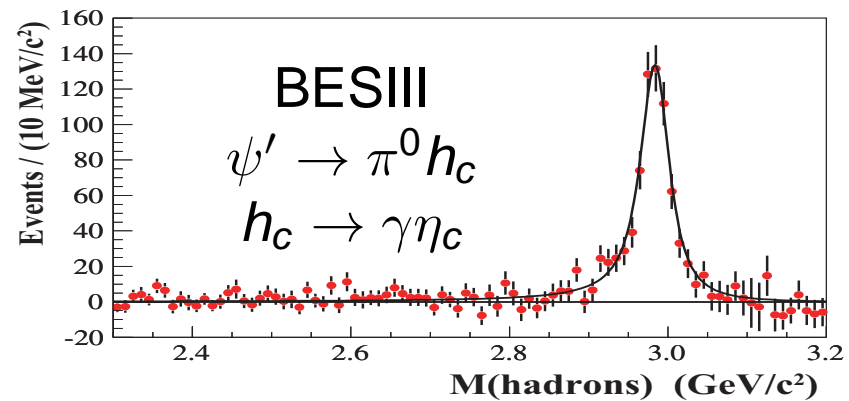


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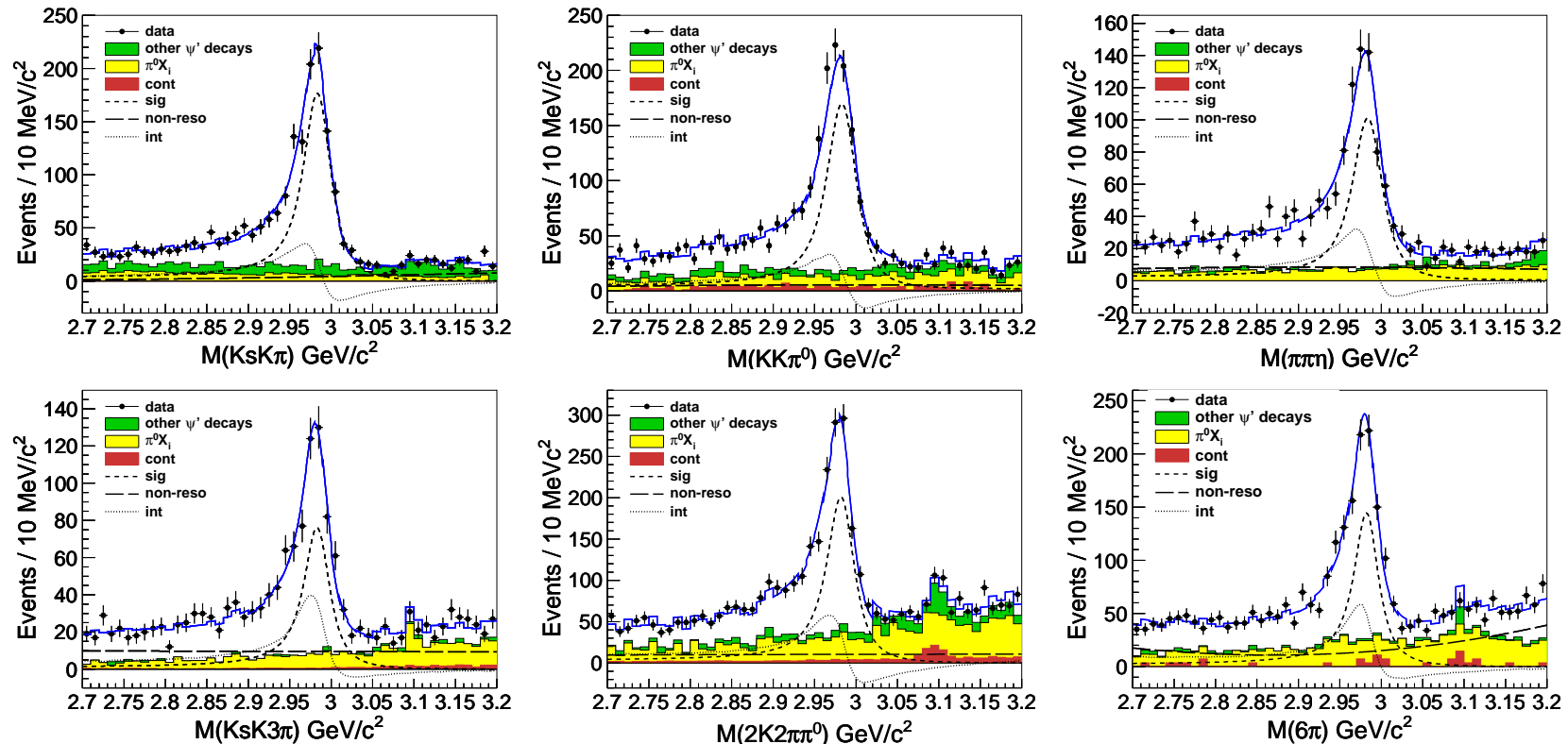
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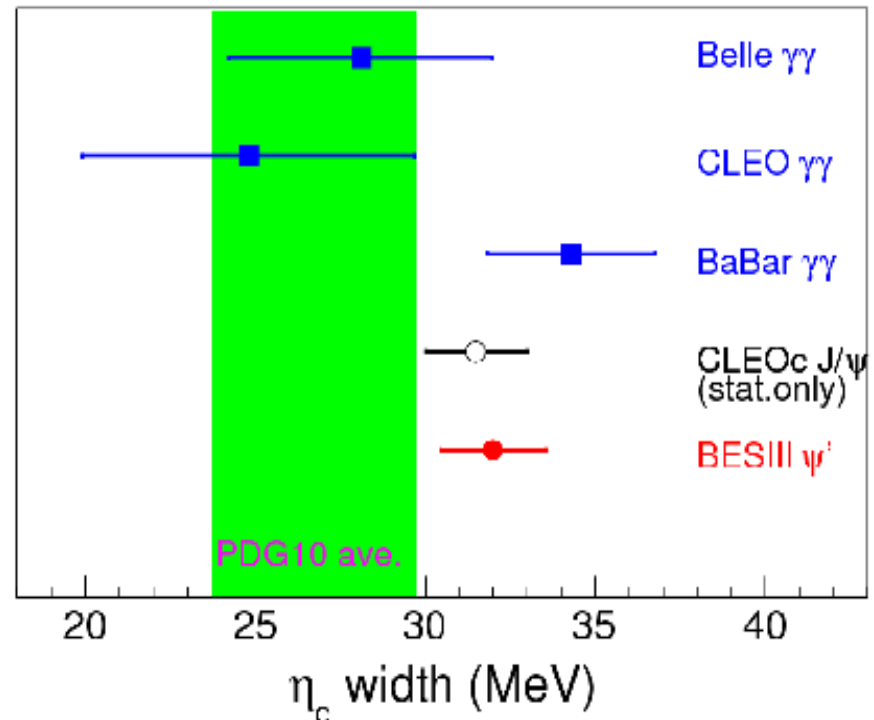
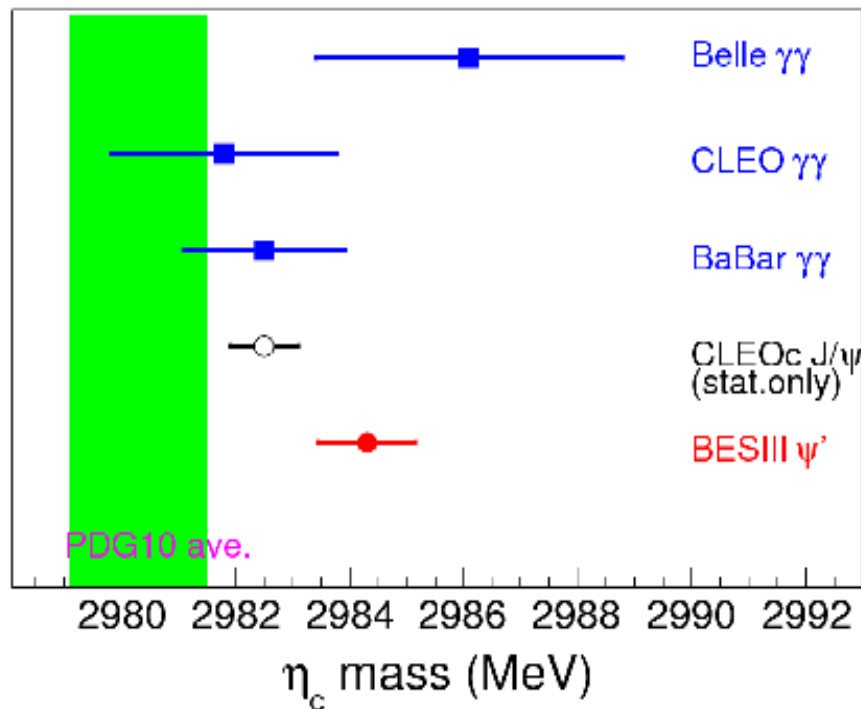
$$\psi' \rightarrow \gamma \eta_c \text{ [PRL 108, 222002 (2012)]}$$



- ▶ Modified Breit-Wigner (hindered M1)
- ▶ Possible interference between  $\eta_c$  and non- $\eta_c$  decays
- ▶ Simultaneous fit

# Properties of $\eta_c$

- ▶  $M_{\eta_c} = 2984.3 \pm 0.6 \pm 0.6 \text{ MeV}/c^2$
- ▶  $\Gamma_{\eta_c} = 32.0 \pm 1.2 \pm 1.0 \text{ MeV}$
- ▶ Two solutions of the interference
  - ▶  $\phi_1 = 2.40 \pm 0.07 \pm 0.08 \text{ rad}$
  - ▶  $\phi_2 = 4.19 \pm 0.03 \pm 0.09 \text{ rad}$



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# M1 transition

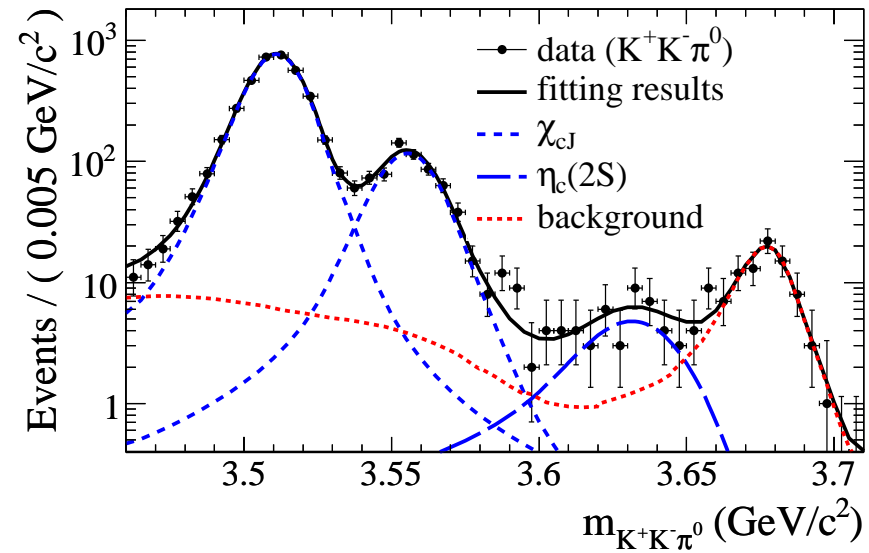
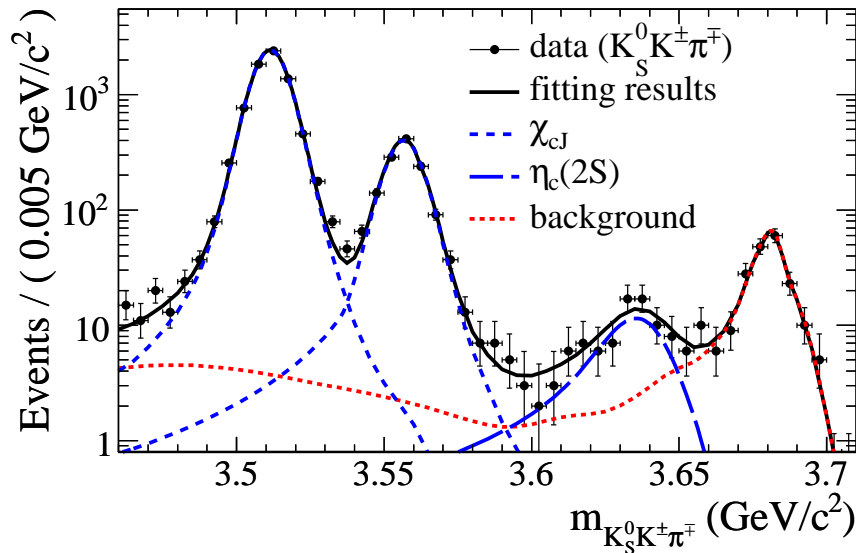
Search for  $\psi' \rightarrow \gamma\eta'_c$

- ▶ Access to spin-singlet states
- ▶ Rather weaker than E1  $\iff$  largest  $\psi'$  sample
- ▶ Disagreement between theory and experiment
  - ▶  $\psi' \rightarrow \gamma\eta_c$ :  $\mathcal{B}^{theo} = (1.6/3.4)\% \gg \mathcal{B}^{exp} = 0.34\%$
  - ▶  $\psi' \rightarrow \gamma\eta'_c$ :  $\mathcal{B}^{theo} = (5.9/7.3) \times 10^{-4}$
- ▶ Other potential models:  $\mathcal{B}(\psi' \rightarrow \gamma\eta'_c) = (0.1 \sim 6.2) \times 10^{-4}$   
[arXiv:0909.2812]

$\eta'_c$ 

- ▶ First reported by Crystal Ball in 1982
- ▶ Other published results:
  - ▶  $B \rightarrow K\eta'_c$ 
    - ▶ PRL 89 102001 (2002);  
PRL 92 142001 (2004);  
PRD 72 031101 (2005)
  - ▶  $\gamma\gamma \rightarrow \eta'_c \rightarrow KK\pi$ 
    - ▶ PRL 92 142002 (2004);  
PRD 84 012004 (2011)
  - ▶ double  $c\bar{c}$  production
    - ▶ PRD 72 031101 (2005)
- ▶  $\sim 50$  MeV photon in  $\psi' \rightarrow \gamma\eta'_c$

$$\eta'_c \rightarrow K\bar{K}\pi \text{ [PRL 109, 042003 (2012)]}$$



► Simultaneous fit:

- $\eta'_c$  signal: BW (M1) (Mass resolution extrapolated from  $\chi_{cJ}$ )
- $\chi_{cJ}$  signal: MC shape smeared with Gaussian
- BG from  $e^+e^- \rightarrow K\bar{K}\pi$  (ISR),  $\psi' \rightarrow K\bar{K}\pi$  (FSR),  $\psi' \rightarrow K\bar{K}\pi$
- Statistical significance  $> 10\sigma$  [PRL 109, 042003 (2012)]



# Results of $\psi' \rightarrow \gamma\eta'_c \rightarrow \gamma K\bar{K}\pi$

► Mass and width:

►  $M(\eta'_c) = 3637.6 \pm 2.9 \pm 1.6 \text{ MeV}/c^2$

►  $\Gamma(\eta'_c) = 16.9 \pm 6.4 \pm 4.8 \text{ MeV}$

► Branching fractions:

►  $\mathcal{B}(\psi' \rightarrow \gamma\eta'_c \rightarrow \gamma K\bar{K}\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$

► Using  $\mathcal{B}(\eta'_c \rightarrow K\bar{K}\pi) = (1.9 \pm 0.4 \pm 1.1)\%$  (*BABAR*)

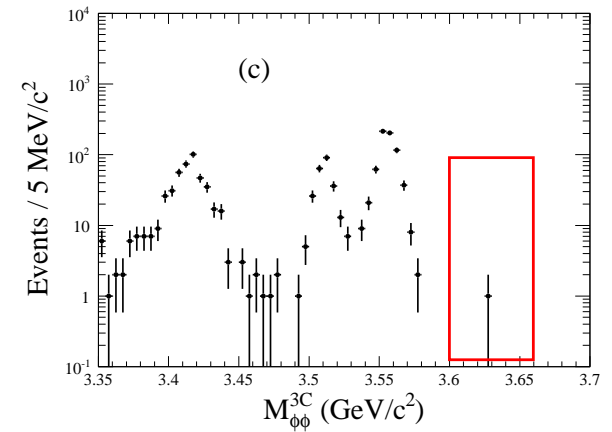
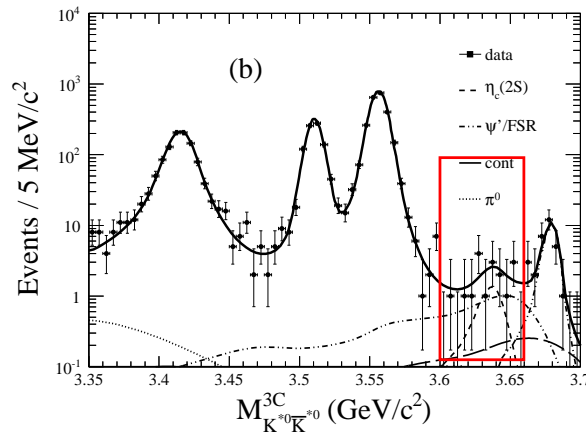
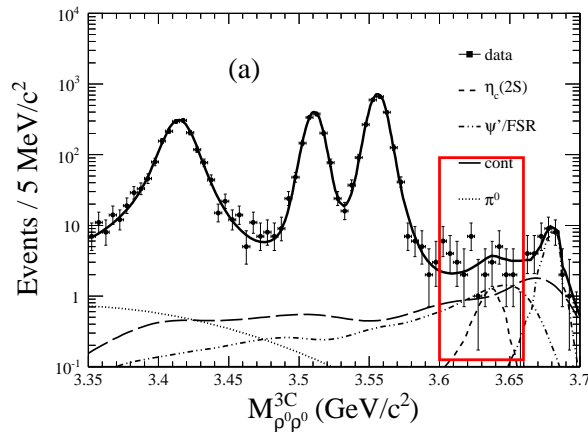
$\mathcal{B}(\psi' \rightarrow \gamma\eta'_c) = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$

► CLEO-c:  $< 7.6 \times 10^{-4}$  [PRD 81, 052002 (2010)]

► Potential models:  $(0.1 \sim 6.2) \times 10^{-4}$  [arXiv:0909.2812]

$$\eta'_c \rightarrow VV(\rho^0\rho^0, K^{*0}\bar{K}^{*0}, \phi\phi) \text{ [PRD 84, 091102 (2011)]}$$

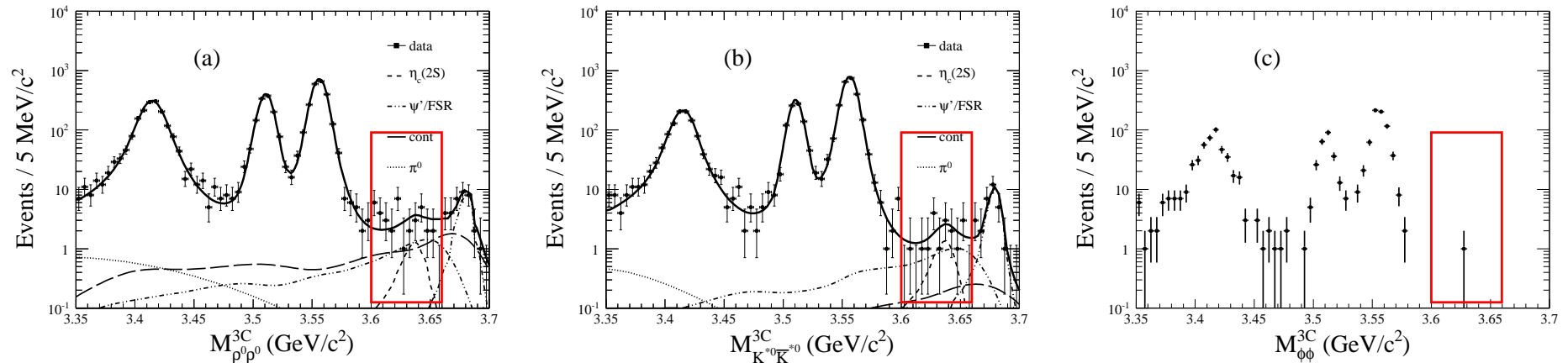
“Intermediate charmed meson loops” to evade helicity selection rule



$V$	$\mathcal{B}^{up}(\psi' \rightarrow \gamma \eta'_c \rightarrow \gamma VV)$ ( $10^{-7}$ )	$\mathcal{B}^{up}(\eta'_c \rightarrow VV)$ ( $10^{-3}$ )	$\mathcal{B}^{\text{theory}}(\eta'_c \rightarrow VV)$ ( $10^{-3}$ )
$\rho^0$	12.7	3.1	6.4 to 28.9
$K^{*0}$	19.6	5.4	7.9 to 35.8
$\phi$	7.8	2.0	2.1 to 9.8

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Upper limits smaller than the theoretical predictions.

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  - ▶ The branching fractions of  $\psi' \rightarrow \pi^0 h_c$ ,  $h_c \rightarrow \gamma \eta_c$  are determined, besides the mass and width of  $h_c$
  - ▶ Parameters of  $\eta_c$  are measured with high precision, interference between  $\eta_c$  and the non-resonant amplitudes around the  $\eta_c$  mass is considered for the first time.
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