Recent Charmonium Results from BESIII

Marco Maggiora*
on behalf of the BESIII Collaboration

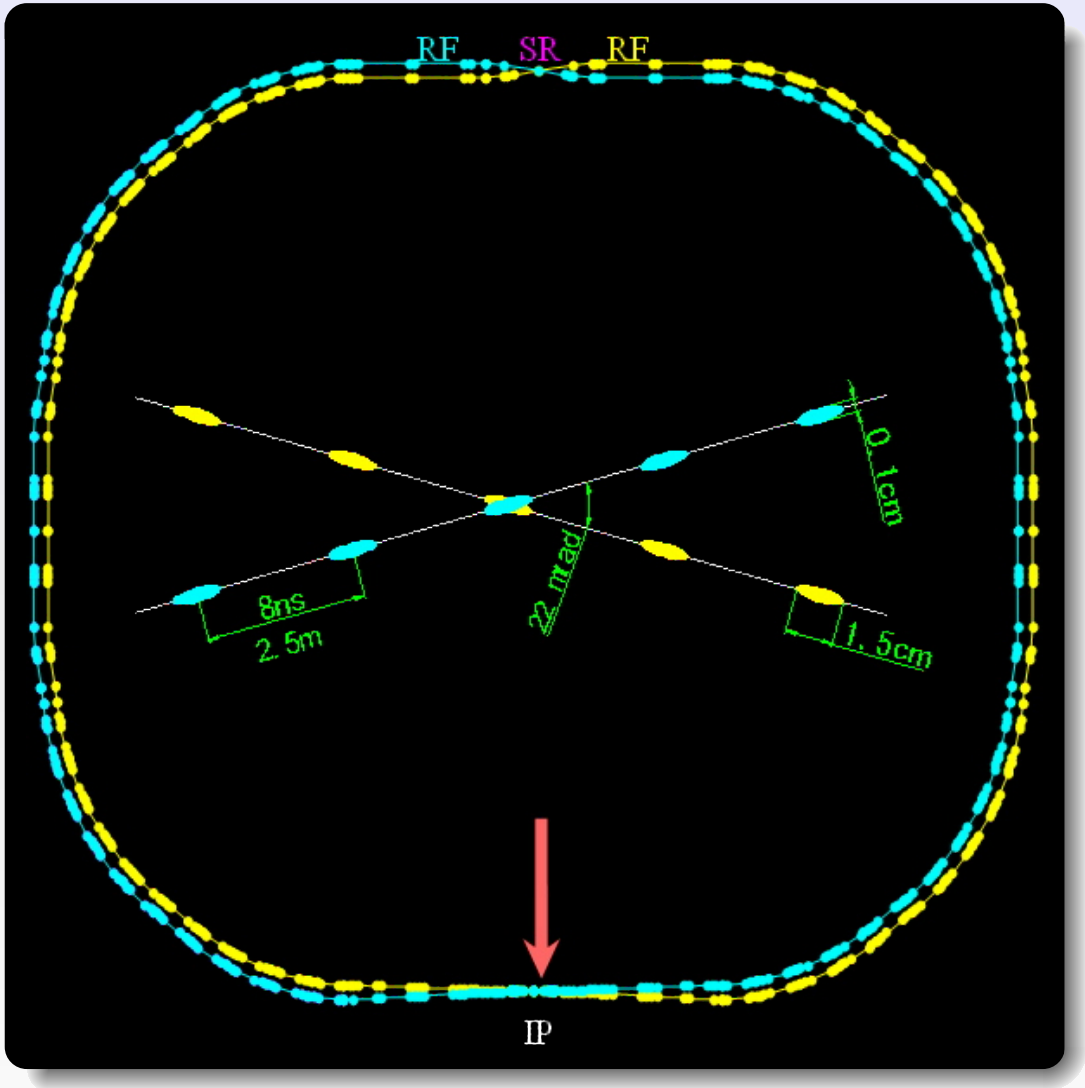
* Dep. of Physics, University of Turin and INFN, Turin

Meeting GDR PH-QCD Groupe 2

Scattering and annihilation electromagnetic processes

Orsay, October 3rd - 5th, 2011

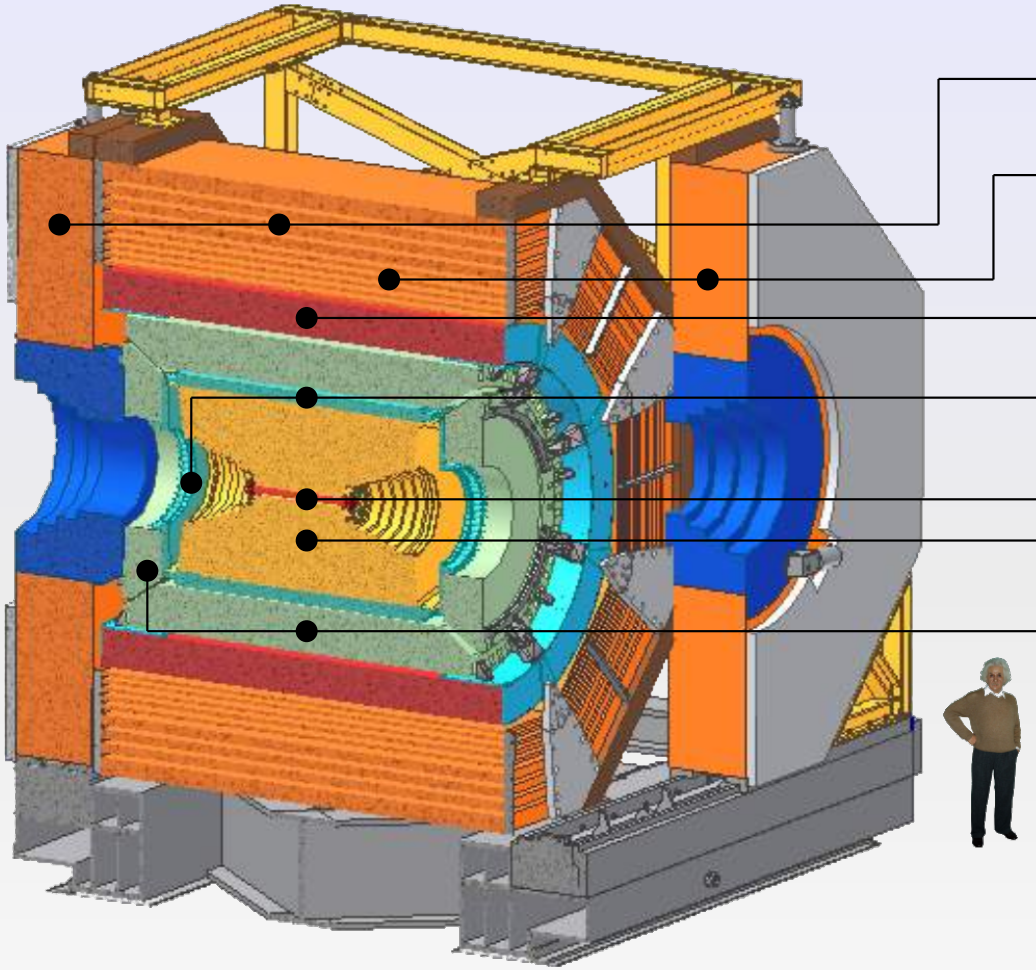
BEPCII: e^+e^- double ring collider



Design Features

- Beam energy: **1.0** - **2.3** GeV
- Crossing angle: **22** mrad (DAΦNE 50 mrad)
- **Luminosity: 10^{33} cm^{-2}s^{-1}**
- **Optimum energy: 1.89 GeV**
- Energy spread: **5.16** $\times$ **10^{-4}**
- Number of bunches: **93**
- Bunch length: **1.5** cm
- Total current: **0.91** A

The **BESIII** detector

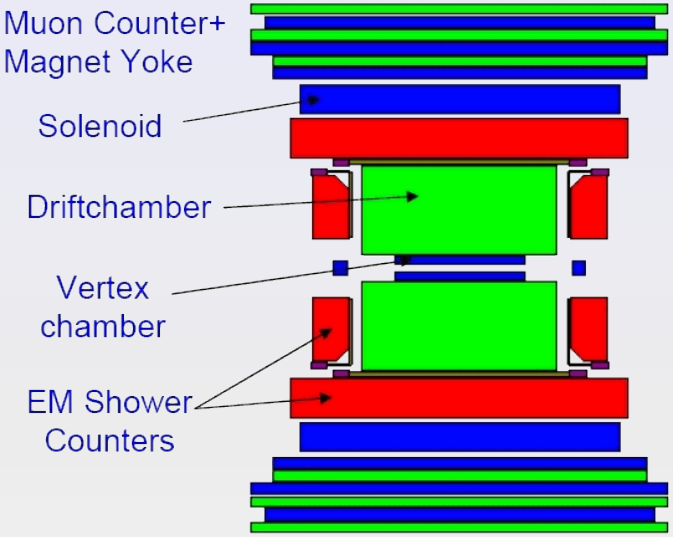


- Magnet yoke
- RPC (9/8 layers Barrel/Endcaps)
- SC magnet, 1 Tesla
- TOF (scintillators), 90 ps
- Be beam pipe
- MDC, 120μm
- CsI(Tl) calorimeter, 2.5% at 1 GeV

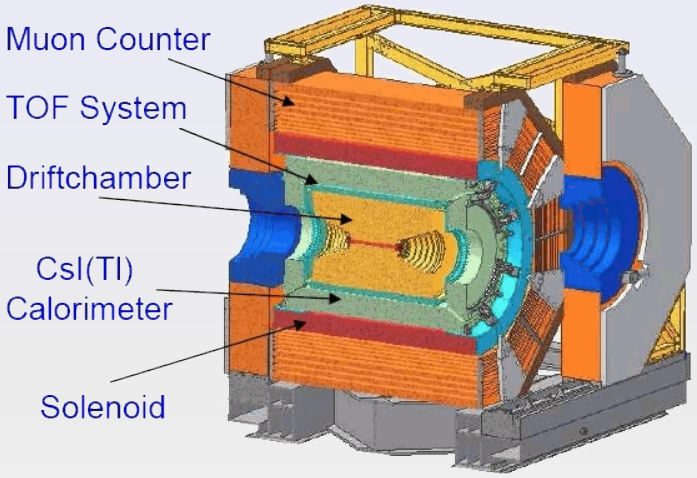
A significant improvement with respect to BESII

The **BESII** and **BESIII** detectors

BESII @ BEPC



BESIII @ BEPCII



Device	Performance
MDC	$\sigma_p/p = 1.7\%\sqrt{1+p^2}$, $dE/dx = 8\%$
TOF	180 ps (bhabha)
EMC	$\sigma_E/E < 22\%/\sqrt{E}$
MUC	3 layers
Magnet	0.4 T Solenoidal

Device	Performance
MDC	$\sigma_p/p = 0.5\%$, $dE/dx < 6\%$
TOF	80 ps barrel (bhabha), 100 ps endcap
EMC	$\sigma_E/E < 2.5\%/\sqrt{E}$
MUC	9 barrel + 8 endcap layers
Magnet	1 T Solenoidal

Physics at **BEPCII/BESIII**

arXiv:0809.1869 [hep-ex]
IJMP A V24, No1(2009)supp

- R_{had} and precision test of Standard Model
- Light hadron spectroscopy
- Charm and charmonium physics
- τ physics
- Precision measurements of CKM matrix elements
- Search for new physics / new particles

Physics Channels	Energy (GeV)	Luminosity (10^{33} cm^{-2} s^{-1})	Events/year
J/Ψ	3.10	0.6	1.0×10^{10}
τ	3.67	1.0	1.2×10^{7}
Ψ'	3.69	1.0	3.0×10^{9}
D^*	3.77	1.0	2.5×10^{7}
D_s	4.03	0.6	1.0×10^{6}
D_s	4.14	0.6	2.0×10^{6}

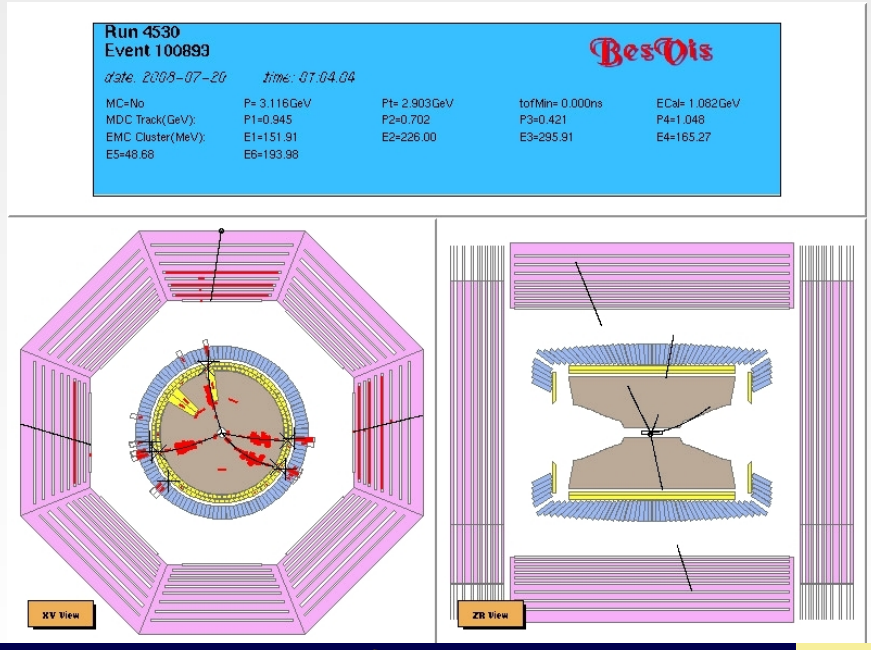
BEPCII: e^+e^- double ring collider

2011 STATUS

Parameter	Design	Achieved	
		BER	BPR
Energy (GEV)	1.89	1.89	1.89
Beam curr. (mA)	910	660	700
Bunch curr. (mA)	9.8	> 10	> 10
Bunch number	93	93	93
RF voltage	1.5	1.5	1.5
$*\nu_s$ @ 1.5 MV	0.033	0.032	0.032
β_x^*/β_y^* (m)	1.0/0.015	$\sim$ 1.0/0.016	$\sim$ 1.0/0.016
Inj. Rate (mA/min)	200 e^- / 50 e^+	> 200	> 50
Lum. ($10^{33} cm^{-2} s^{-1}$)	1	0.65	

BEPCII / BESIII milestones

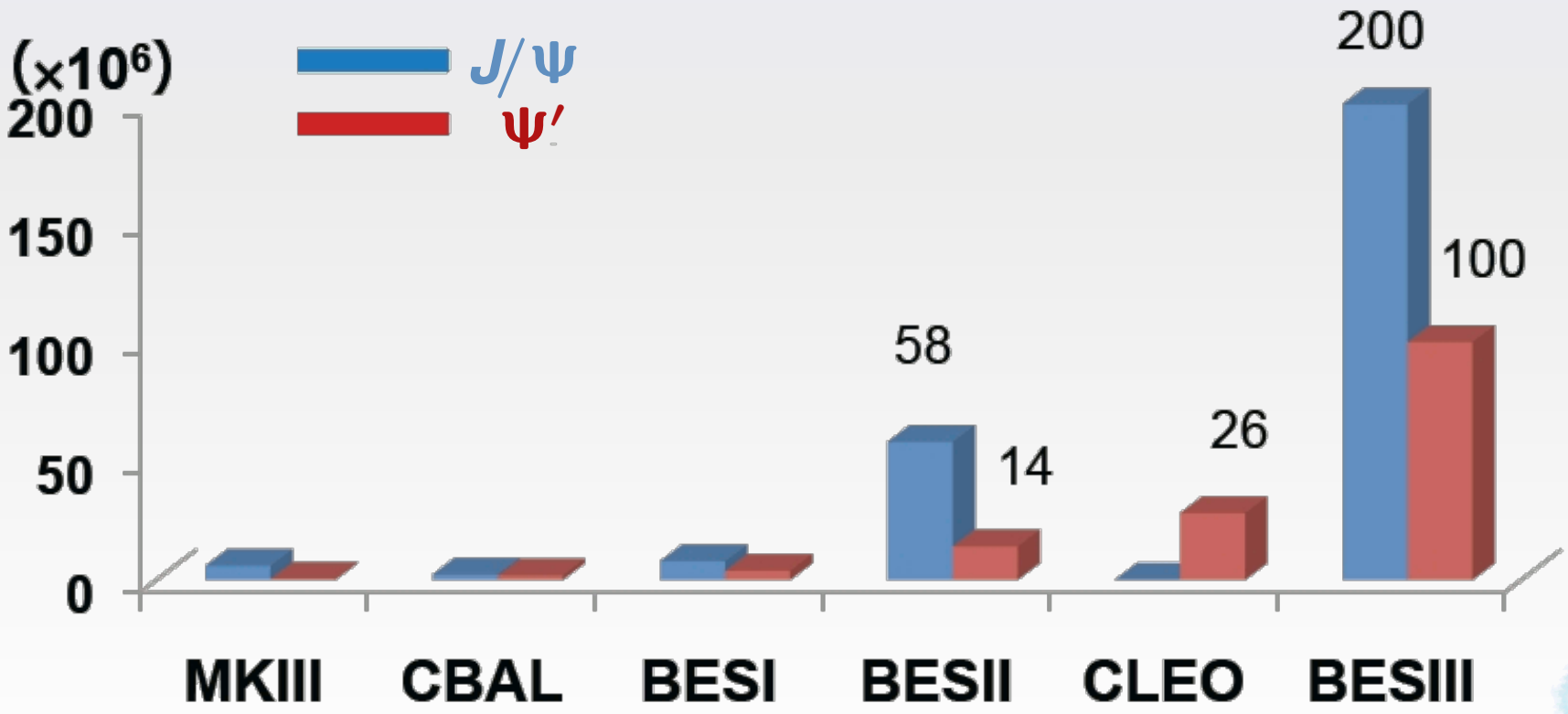
- **Mar. 2008:** Collisions at 500 mA $\times$ 500 mA, Luminosity: $1 \times 10^{32} cm^{-2} s^{-1}$
- **Apr. 30, 2008:** Move BESIII to IP
- **July 18, 2008:** First e^+e^- collision event in BESIII
- **Apr. 14, 2009:** $\sim$ 106 M Ψ' events ($150 pb^{-1}$) ($\sim 42 pb^{-1}$ at 3.65 GeV)
- **July 28, 2009:** $\sim$ 225 M J/Ψ events ($65 pb^{-1}$)
- **2010-2011:** $\sim 2.9 fb^{-1}$ at ψ'' (3.5$\times$CLEO-c 0.818 fb^{-1}) ($\sim 70 pb^{-1}$ scanning in the ψ'' energy region)
- **May, 2011:** $\sim 0.5 fb^{-1}$ at 4.01 GeV (Ds and XYZ spectroscopy)



Record Luminosity on Apr 7, 2011
$6.5 \times 10^{32} cm^{-2} s^{-1}$
or
$9 \times$ CESRc
$50 \times$ BEPC

World J/Ψ and Ψ' Samples ($\times 10^6$)

- **BESIII:** $\sim$ 106 M Ψ'events (150pb^{-1})
  BESII: $\sim$ 14 M Ψ'events
- **BESIII:** $\sim$ 225 M J/Ψ events (65pb^{-1})
  BESII: $\sim$ 58 M J/Ψ events



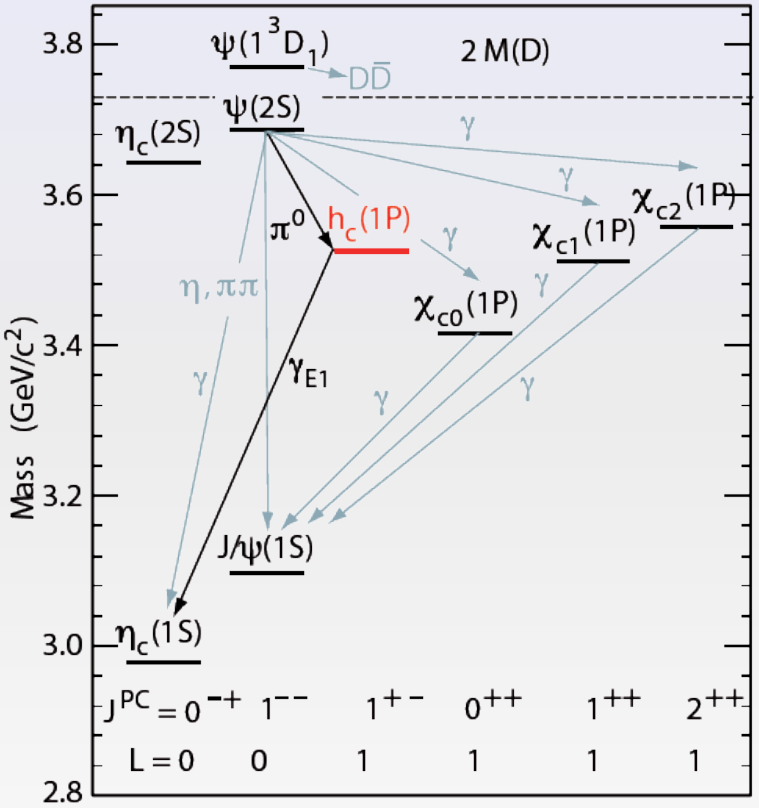
Charmonium investigation deep under way at BESIII:

- **Charmonium Spectroscopy and Transitions**
  - **Properties of the h_c:** ..... PRL 104, 132002 (2010)
  - **Properties of the η_c:** ..... preliminary
  - $\Psi' \to \gamma\eta_c'$: ..... preliminary
- **Charmonium Decays**
  - $\chi_{cJ} \to \pi^0\pi^0,\ \eta\eta$: ..... PRD 81, 052005 (2010)
  - $\chi_{cJ} \to 4\pi^0$: ..... PRD 83, 012006 (2011)
  - $\chi_{cJ} \to \gamma\rho,\ \gamma\omega,\ \gamma\phi$: ..... PRD 83, 112005 (2011)
  - $\chi_{cJ} \to \omega\omega,\ \phi\phi,\ \omega\phi$: ..... PRL 107, 092001 (2011)
  - $\chi_{cJ} \to p\bar{p}K^+K^-$: ..... PRD 83, 112009 (2011)
  - $\Psi' \to \gamma\pi^0,\ \gamma\eta,\ \gamma\eta'$: ..... PRL 105, 261801 (2010)
  - $\eta_c \to \pi\pi$: ..... PRD 84, 032006 (2011)
  - $\eta_c \to \rho\rho, K^*K^*, \phi\phi$: ..... preliminary

Observation of h_c

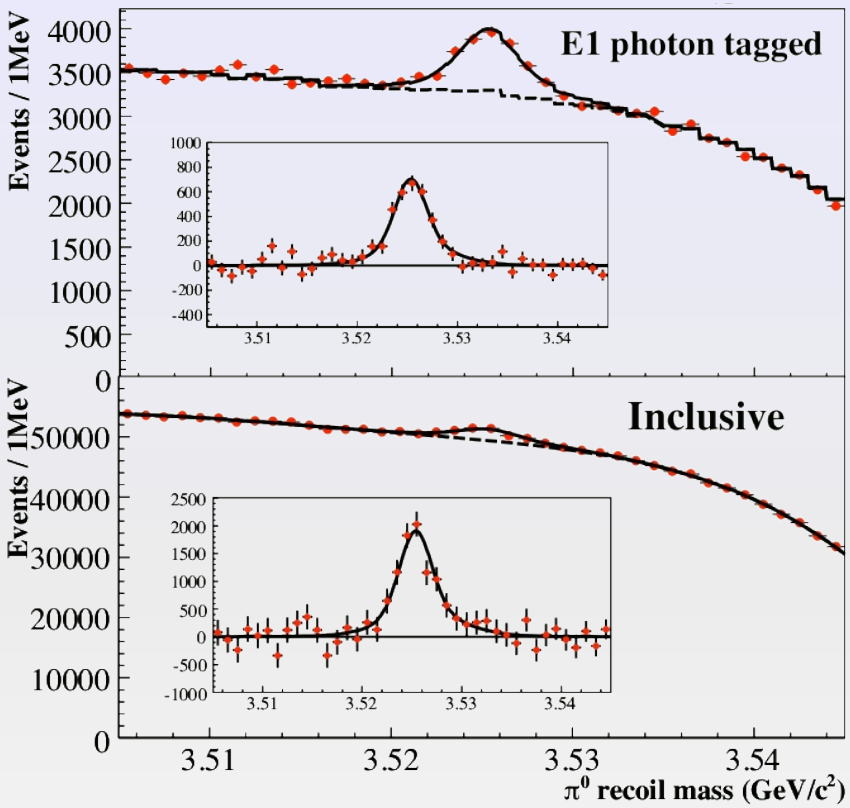
- $B(\Psi' \to \pi^0 h_c)$;
  measure of isospin violation
- $B(h_c \to \gamma\eta_c)$:
  large $E1$ transition
- $M(h_c)$ gives access to hyperfine splitting of 1P states:
  $M(h_c(1P)) - < M(\chi_{cJ}(1P)) >_{\text{spin-weighted}}$

- first evidence: E385 in $\bar{p}p \to h_c \to \eta_c\gamma$
  PRD 72, 092004 (2005)
- CLEO-c could only access
  $B(\Psi' \to \pi^0 h_c) \times B(h_c \to \gamma\eta_c)$:
  PRL 101, 182003 (2008)
- BESIII could access
  individual B and B, $M(h_c)$, $\Gamma(h_c)$:
  PRL 104, 132002 (2010)



The $h_c(1P)$ at BESIII

PRL 104, 132002 (2010)
$106M$ Ψ' decays



Tag the photon to access

$B(\Psi' \to \pi^0 h_c) \times B(h_c \to \gamma\eta_c)$
$= (4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$

(consistent with CLEO-c)

Don't tag the photon to access

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

(first measurement)

- **Combining branching fractions leads to $B(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$ (first measurement)**
- **$M(h_c) = 3525.40 \pm 0.13 \pm 0.18$ *MeV*** *(consistent with CLEO-c)*;
  $\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28$ *MeV* (first measurement)
- **$M(h_c)$ vs $< M(\chi_{cJ}(1P)) >_{\text{spin-weighted}} = 3525.30 \pm 0.11$ *MeV*(PDG)**
  $\Longrightarrow$ small hyperfine splitting of 1P states

h_c experimental results and theoretical predictions

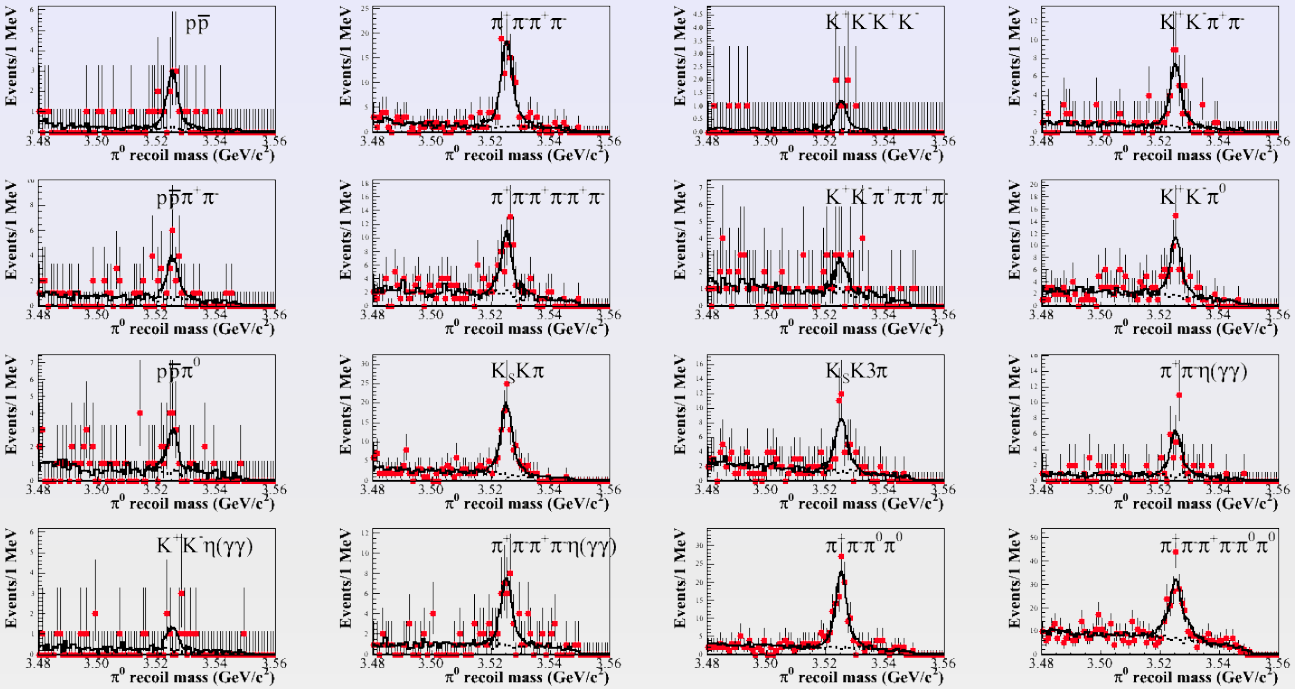
	BESIII	CLEO-c	Theoretical predictions
$B(\Psi' \to \pi^0 h_c) \times B(h_c \to \gamma\eta_c)$ $[10^{-4}]$	$4.58 \pm 0.40 \pm 0.50$	$4.16 \pm 0.30 \pm 0.37$	
$B(\Psi' \to \pi^0 h_c)$ $[10^{-4}]$	**$8.4 \pm 1.3 \pm 1.0$**		$4 \div 13$ Kuang
$B(h_c \to \gamma\eta_c)$ [%]	**$54.3 \pm 6.7 \pm 5.2$**		41 (NRQCD) Kuang 88 (PQCD) Kuang 38 Godfrey, Rosner
$M(h_c)$ $[MeV/c^2]$	$3525.40 \pm 0.13 \pm 0.18$	$3525.20 \pm 0.18 \pm 0.12$	
$\Delta M_{hf}(1P)$ $[MeV/c^2]$	$-0.10 \pm 0.13 \pm 0.18$	$0.08 \pm 0.18 \pm 0.12$	
$\Gamma(h_c)$ $[MeV]$	**$0.73 \pm 0.45 \pm 0.28$ < 1.44 @ 90%CL**		1.1 (NRQCD) Kuang 0.51 (PQCD) Kuang

- BESIII: PRL 104, 132002 (2010)
- CLEO-c: PRL 101, 182003 (2008)
- Kuang: PRD65, 094024 (2002)
- Godfrey & Rosner: PRD 66, 014012 (2002)

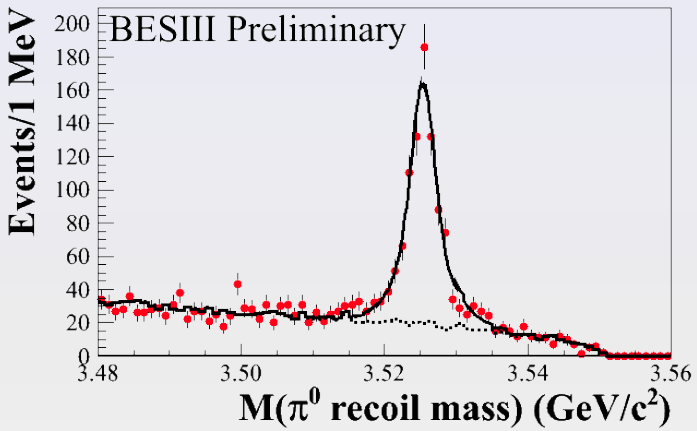
$\Psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$, η_c exclusively from 16 decay modes

preliminary
$106M$ Ψ' **decays**

BESIII preliminary



Summed π^0 recoil mass



BESIII preliminary

Simultaneous fit to π^0 recoiling mass

$$M(h_c) = 3525.31 \pm 0.11 \pm 0.15 \text{ MeV}/c^2$$
$$\Gamma(h_c) = 0.70 \pm 0.28 \pm 0.25 \text{ MeV}$$
$$N_{Ev} = 832 \pm 35$$
$$\chi^2/d.o.f. = 32/46$$

Consistent with BESIII inclusive meas.
PRL 104 132002 (2010)

$$M(h_c) = 3525.40 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$$
$$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28 \text{ MeV}$$

Consistent with CLEO-c exclusive meas.
PRL 101 182003 (2008)

$$M(h_c) = 3525.21 \pm 0.27 \pm 0.14 \text{ MeV}/c^2$$
$$N_{Ev} = 136 \pm 14$$

Observation of η_c

- **discovered in 1980 by Mark-II;**
  PDG2011

  $M(\eta_c)$ and $\Gamma(\eta_c)$ precision one order of magnitude worse than J/Ψ, Ψ' and χ_{cJ}

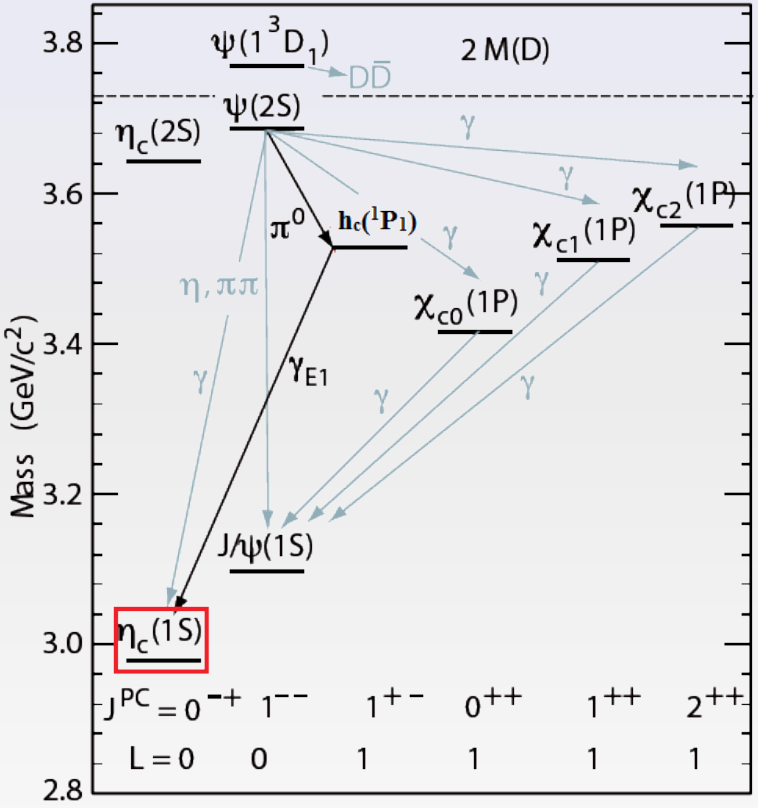
- **earlier measurements from J/Ψ radiative transitions:**
  PRD 33, 629 (1986) [Mark-III]
  PLB 555, 174 (2003) [BES]

  $$M(\eta_c) \sim 2789.0 \text{ MeV}/c^2$$
  $$\Gamma(\eta_c) \sim 10 \text{ MeV}$$

- **recent studies with $\gamma\gamma$ processes:**
  PRL 92, 142001 (2004) [CLEO]
  PRL 92, 142002 (2004) [BABAR]
  EPJC 53, 1 (2008) [BELLE]

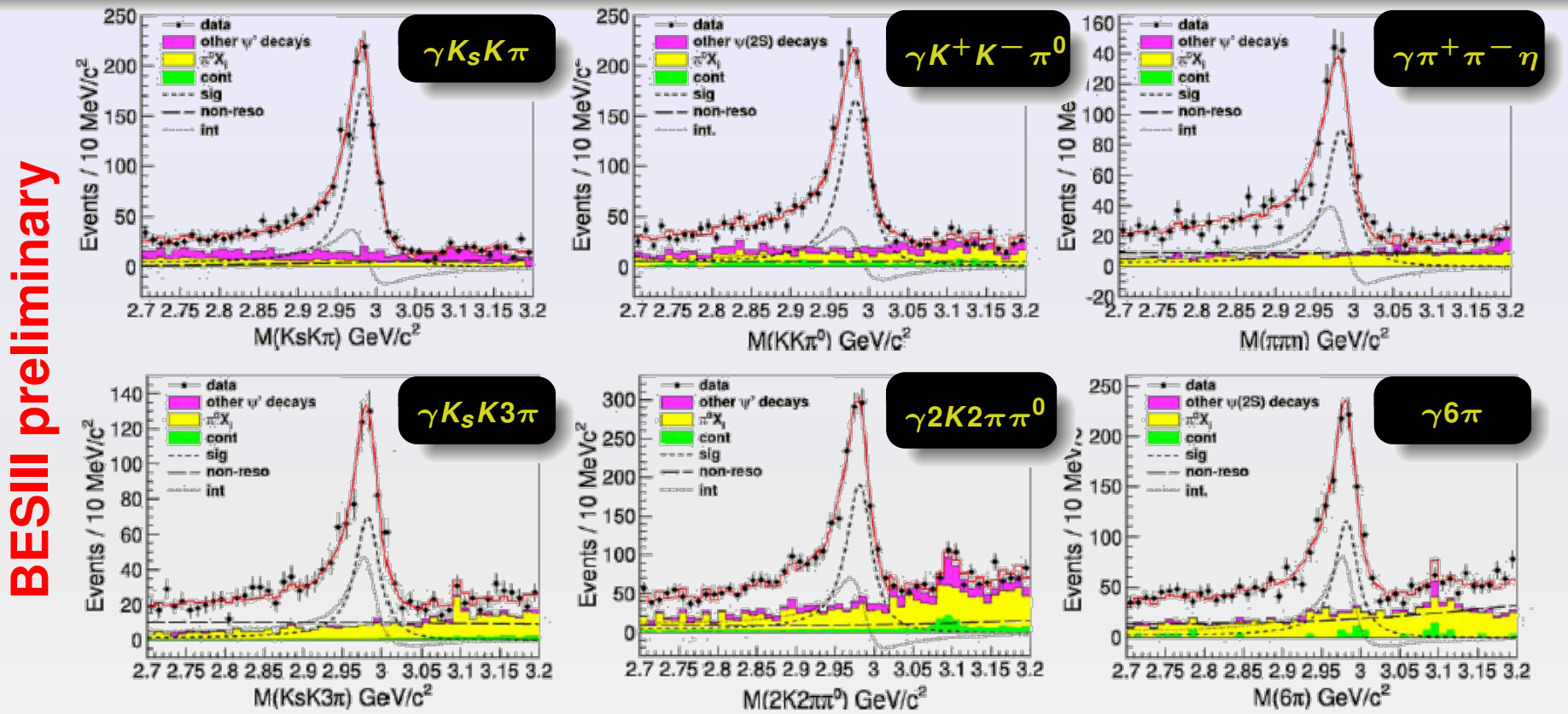
  $$M(\eta_c) = 2983.1 \pm 1.0 \text{ MeV}/c^2$$
  $$\Gamma(\eta_c) = 31.3 \pm 1.9 \text{ MeV}$$

- **η_c lineshape distorsion in Ψ' decays**
  PRL 102, 011801 (2009) [CLEO-c]



η_c resonance parameters from $\Psi' \to \gamma\eta_c$

preliminary
106M Ψ' decays



Simultaneous fit of different η_c decay modes

- modified BW: $M1$ accounted for
- $M(\eta_c)$, $\Gamma(\eta_c)$ and phase ϕ: constrained to be the same
- ϕ, universal phase: interference η_c,non-η_c decays

BESIII preliminary

$$M(\eta_c) = 2984.4 \pm 0.5_{stat} \pm 0.6_{sys}\ \mathrm{MeV}/c^2$$

$$\Gamma(\eta_c) = 30.5 \pm 1.0_{stat} \pm 0.9_{sys}\ \mathrm{MeV}$$

$$\phi = 2.35 \pm 0.05_{stat} \pm 0.04_{sys}\ rad$$

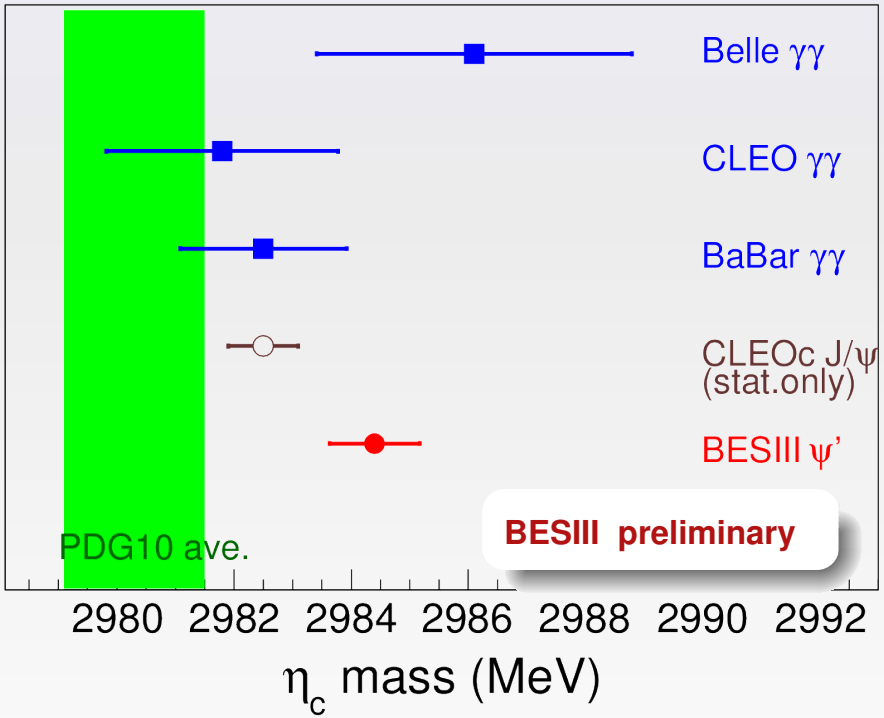
The most precise measurement!

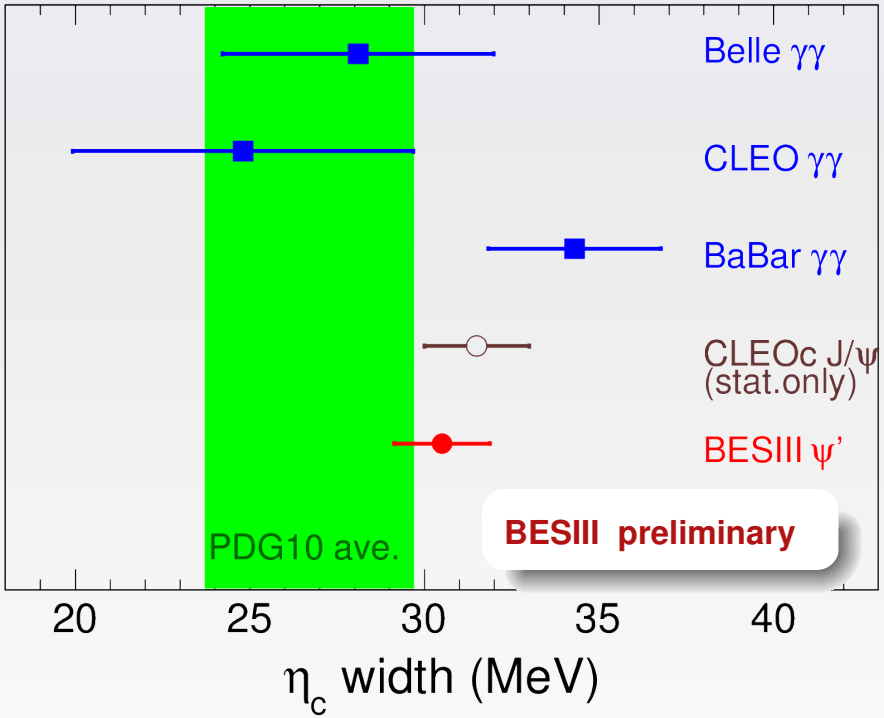
BESIII: stat. and syst. errors included

most precise measurement!

relevant interference b/w η_c and non-resonant decays

PDG2010 world average obtained with earlier results





NPBPS 184, 220 (2008) [BELLE]; PRL 92, 142001 (2009) [CLEO];
PRL 92, 142002 (2009) [BABAR]; PRL 102, 011801 (2009) [CLEO]

Observation of η_c'

- **first obs. [Cristal Ball] never confirmed:**
  PRL 48, 70 (1982)

$$M(\eta_c') = 3592 \pm 5 \text{ MeV}/c^2$$
$$B = 0.2\% \div 1.3\% \text{ from } \Psi' \to \gamma X$$

- **observed in B decays and $\gamma\gamma$ processes:**
  PRL 89, 102001 (2002) [BELLE]
  PRL 92, 142001 (2004) [CLEO]
  PRL 96, 052002 (2006) [BABAR]
  PRL 98, 082001 (2007) [BELLE]
  PDG2011

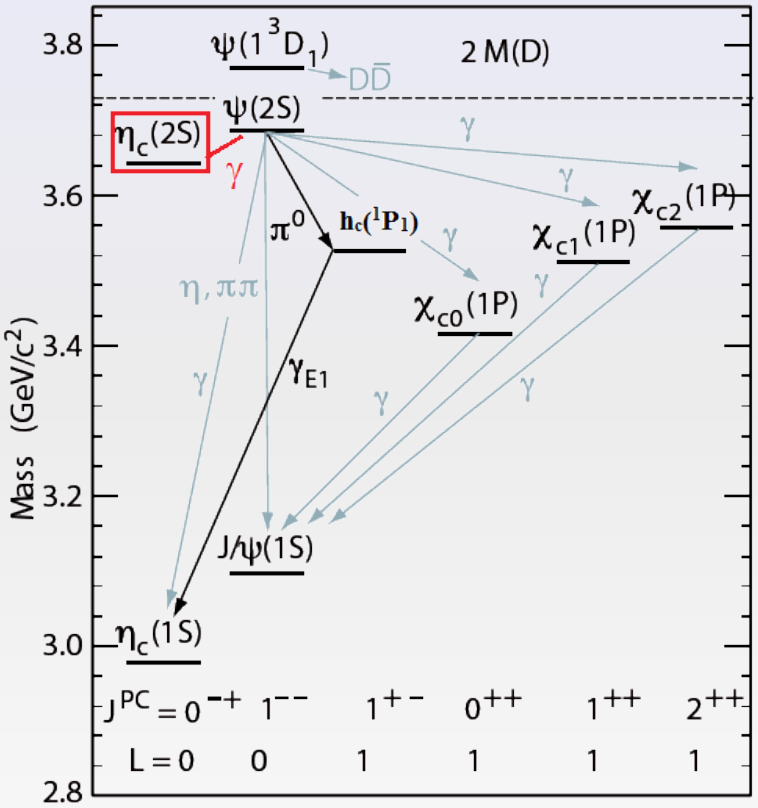
$$M(\eta_c') = 3637 \pm 4 \text{ MeV}/c^2$$
$$\Gamma(\eta_c') = 14 \pm 7 \text{ MeV}$$

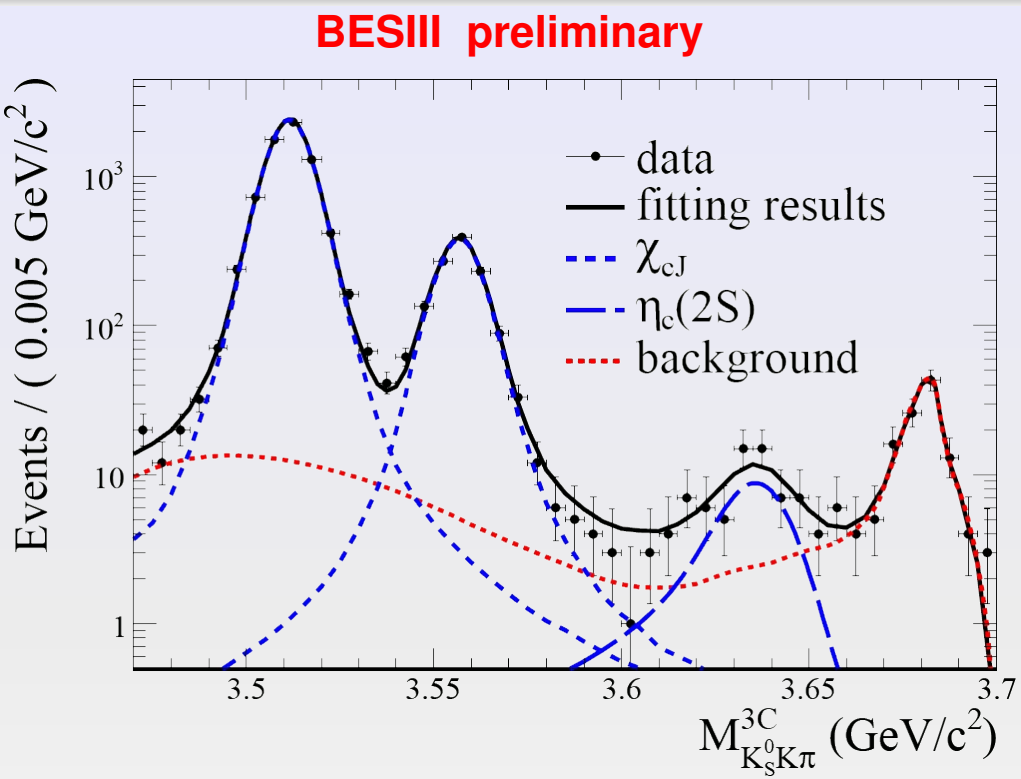
- **new world average from most recent results:**
  PoS(ICHEP2010), 144 (2010) [BABAR]
  PoS(ICHEP2010), 162 (2010) [BELLE]

$$\Gamma(\eta_c') = 12 \pm 3 \text{ MeV}$$

- **$M1$ transition $\Psi' \to \gamma\eta_c'$ experimentally challenging**

search for real γ, $\sim$ 50 MeV





First observation for the $M1$ transition $\Psi' \to \gamma\eta_c'$

BESIII preliminary

$$M(\eta_c') = 3638.5 \pm 2.3 \pm 1.0 \text{ MeV/c}^2$$
$$N_{Ev}(\eta_c') = 50.6 \pm 9.7$$
$$\chi^2/n.d.f. = 0.9$$

Statistical significance $> 6\sigma$

Total significance $> 5\sigma$

$BR(\Psi' \to \gamma\eta_c' \to \gamma K_s K\pi) = (2.98 \pm 0.57_{stat} \pm 0.48_{sys}) \times 10^{-6}$ [BESIII preliminary]

$+$

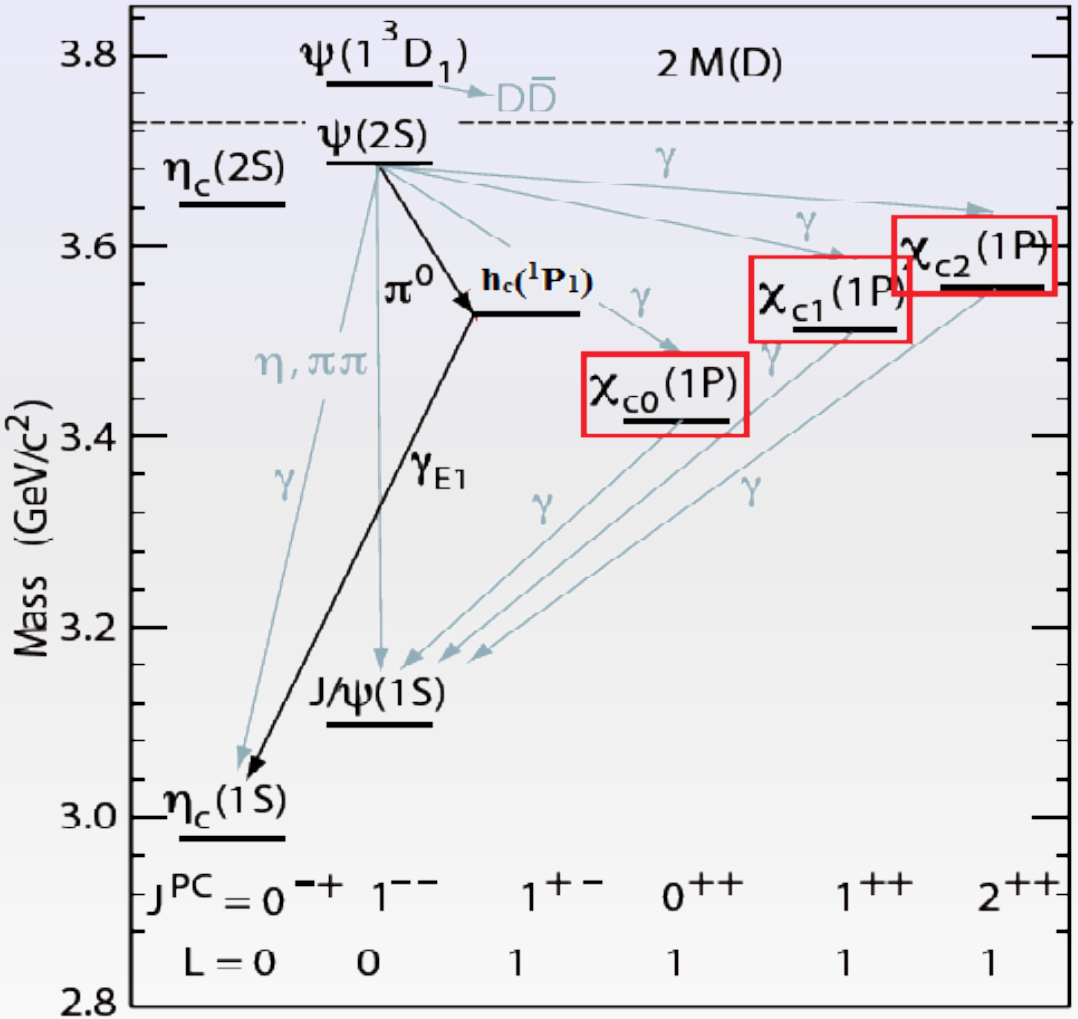
$Br(\eta_c' \to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$ PRD78, 012006 (2008) [BABAR]

$BR(\Psi' \to \gamma\eta_c') = (4.7 \pm 0.9_{stat} \pm 3.0_{sys}) \times 10^{-4}$

$BR(\Psi' \to \gamma\eta_c') < 7.6 \times 10^{-4}$ PRD81, 052002 (2010) [CLEO-c]

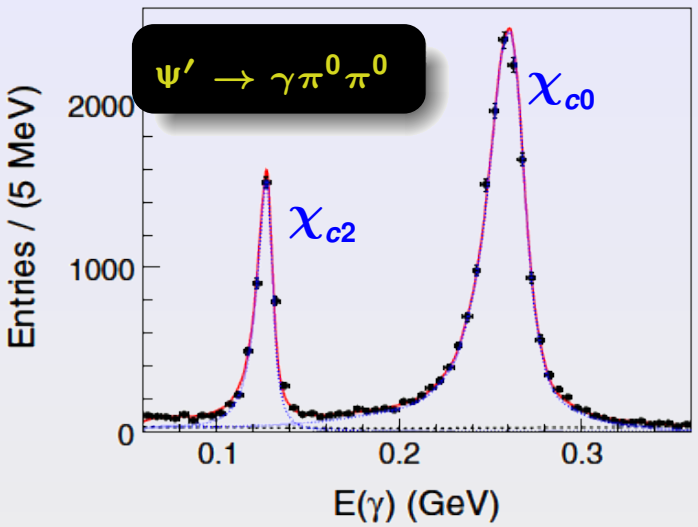
$BR(\Psi' \to \gamma\eta_c') = (0.1 \div 6.2) \times 10^{-4}$ PRL89, 162002 (2002) [Potential model]

$\psi' \to \gamma\chi_{cJ}$; χ_{cJ} decays

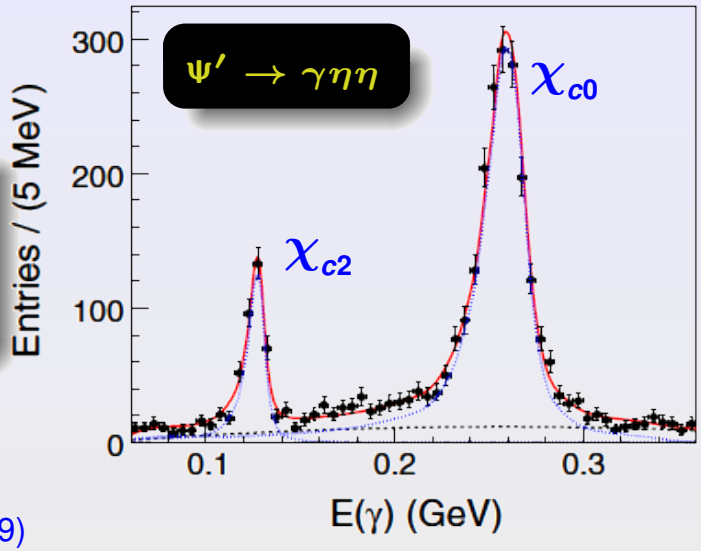


$\Psi' \to \gamma\chi_{cJ}$; $\chi_{c0,2} \to \pi^0\pi^0, \eta\eta$ $(\eta, \pi^0 \to \gamma\gamma)$

PRD 81, 052005 (2010)
$106M$ Ψ' decays



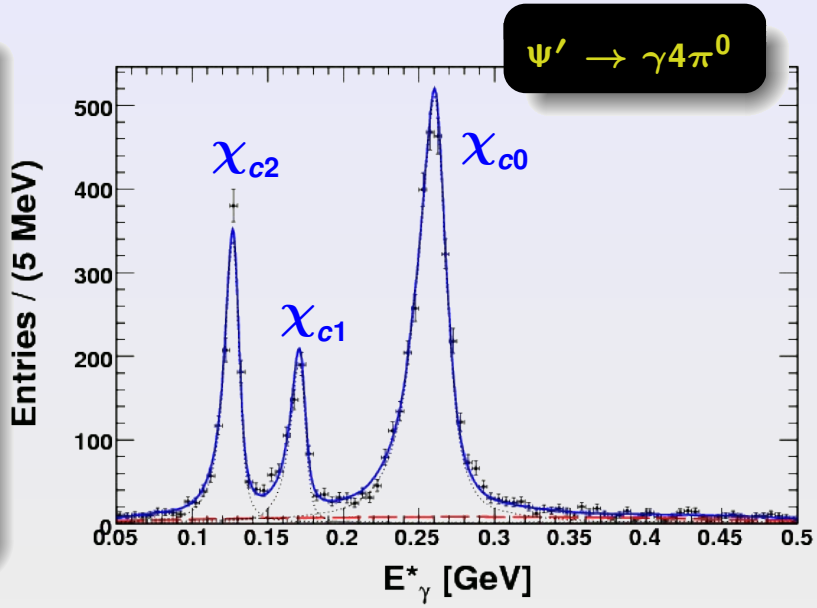
$\chi_{c1} \to \pi^0\pi^0, \eta\eta$
forbidden
(parity conservation)



CLEO-c: PRD 79, 072007 (2009)

Decay mode		$\chi_{c0}[10^{-3}]$	$\chi_{c2}[10^{-3}]$
$\pi^0\pi^0$	**BESIII**	$3.23 \pm 0.03 \pm 0.23 \pm 0.14$	$0.88 \pm 0.02 \pm 0.06 \pm 0.04$
	PDG10	2.8 ± 0.1	0.80 ± 0.05
	CLEO-c	$2.94 \pm 0.07 \pm 0.32 \pm 0.15$	$0.68 \pm 0.03 \pm 0.07 \pm 0.04$
$\eta\eta$	**BESIII**	$3.44 \pm 0.10 \pm 0.24 \pm 0.20$	$0.65 \pm 0.04 \pm 0.05 \pm 0.03$
	PDG10	2.68 ± 0.28	0.54 ± 0.08
	CLEO-c	$3.18 \pm 0.13 \pm 0.31 \pm 0.16$	$0.51 \pm 0.05 \pm 0.05 \pm 0.03$

- **Branching fraction excluding $K_S \to \pi^0\pi^0$**
  - $\chi_{c0} \to 4\pi^0 = Br(3.34 \pm 0.06 \pm 0.44) \times 10^{-3}$
  - $\chi_{c1} \to 4\pi^0 = Br(0.57 \pm 0.03 \pm 0.08) \times 10^{-3}$
  - $\chi_{c2} \to 4\pi^0 = Br(1.21 \pm 0.05 \pm 0.16) \times 10^{-3}$
- **Branching fraction for $\chi_{cJ} \to K_S K_S$**
  - $\chi_{c0} \to 4\pi^0 = Br(4.1 \pm 0.4_{stat}) \times 10^{-3}$
  - $\chi_{c2} \to 4\pi^0 = Br(0.6 \pm 0.2_{stat}) \times 10^{-3}$

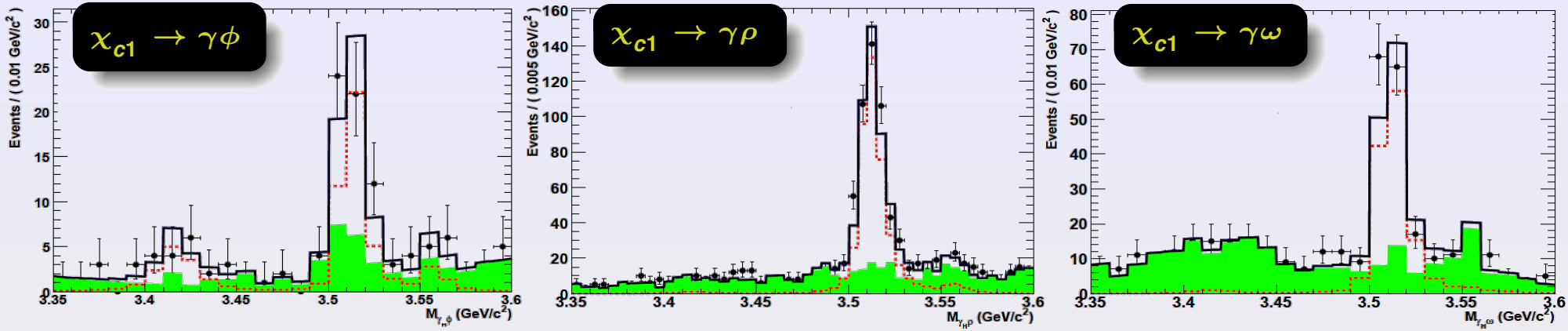


CLEO-c: PRD 79, 072007 (2009)

$Br(\chi_{cJ} \to K_S K_S)$	χ_{c0} $[10^{-3}]$	χ_{c2} $[10^{-3}]$
BESIII	$4.1 \pm 0.4_{stat}$	$0.6 \pm 0.2_{stat}$
PDG10	3.16 ± 0.18	0.58 ± 0.05
CLEO-c	$3.49 \pm 0.08 \pm 0.18 \pm 0.17$	$0.53 \pm 0.03 \pm 0.03 \pm 0.03$

$\chi_{cJ} \to \gamma V$, $V = \phi(K^+K^-), \rho^0(\pi^+\pi^-), \omega(\pi^+\pi^-\pi^0_{(\gamma\gamma)})$

PRD 83, 112005 (2011)
$106M\ \Psi'$ decays

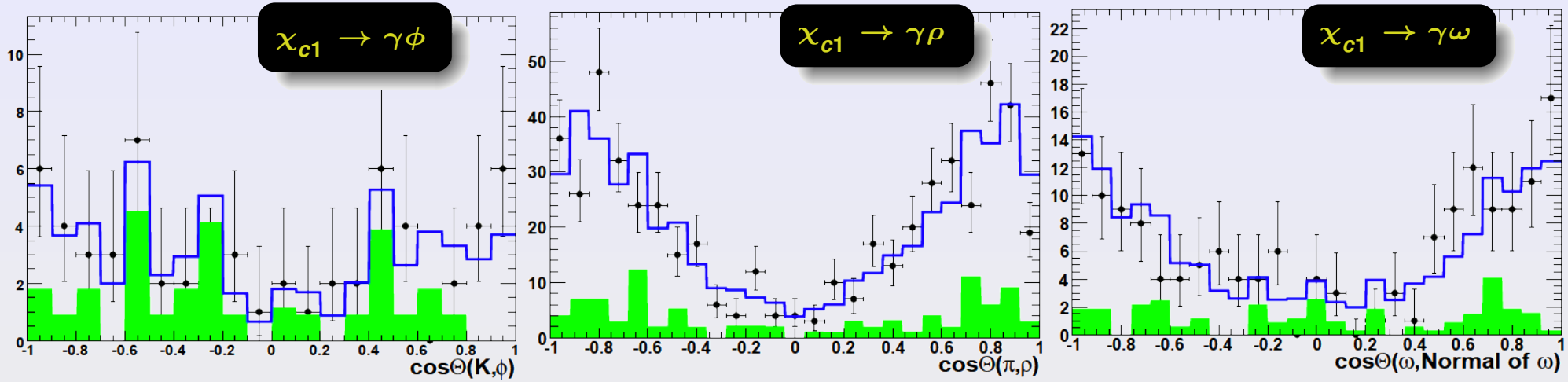


CLEO-c: PRL 101, 151801 (2008)
pQCD: Y.J. Gao et al., arxiv:0701009 [hep-ph]

B [10^-6]	**BESIII**	CLEO-c	pQCD
$\chi_{c0} \to \gamma\phi$	< 16.1	< 6.4	0.46
$\chi_{c1} \to \gamma\phi$	$25.8 \pm 5.2 \pm 2.0$	< 26	3.6
$\chi_{c2} \to \gamma\phi$	< 8.0	< 13	1.1
$\chi_{c0} \to \gamma\rho^0$	< 10.2	< 9.6	1.2
$\chi_{c1} \to \gamma\rho^0$	$228 \pm 13 \pm 16$	$243 \pm 19 \pm 22$	14
$\chi_{c2} \to \gamma\rho^0$	< 20.3	< 50	4.4
$\chi_{c0} \to \gamma\omega$	< 12.7	< 8.8	0.13
$\chi_{c1} \to \gamma\omega$	$69.7 \pm 7.2 \pm 5.6$	$83 \pm 15 \pm 12$	1.6
$\chi_{c2} \to \gamma\omega$	< 6.0	< 7.0	0.5

- **first evidence of $\chi_{c1} \to \gamma\phi$**
- **pQCD predictions $<<$ exp. data. May be explained by non-perturbative QCD loop corrections**
  Chen et al, arXiv:1005.0066v2 [hep-ph]

$\chi_{cJ} \to \gamma V$, $V = \phi(K^+K^-), \rho^0(\pi^+\pi^-), \omega(\pi^+\pi^-\pi^0_{(\gamma\gamma)})$



Vector meson polarisation

$$\frac{dN}{d\cos\theta} \propto |A_L|^2 \cos^2\Theta + \frac{1}{2}|A_T|^2 \sin^2\Theta \propto (1 - f_T)\cos^2\Theta + \frac{1}{2} f_T \sin^2\Theta$$

A_L and A_T being the longitudinal and transverse polarization amplitudes

BESIII preliminary	$f_T = \frac{\lvert A_T\rvert^2}{\lvert A_T\rvert^2 + \lvert A_L\rvert^2}$
$\chi_{c1} \to \gamma\phi$	$0.29^{+0.13+0.10}_{-0.12-0.09}$
$\chi_{c1} \to \gamma\rho^0$	$0.158 \pm 0.034^{+0.015}_{-0.014}$
$\chi_{c1} \to \gamma\omega$	$0.247^{+0.090+0.044}_{-0.087-0.026}$

Longitudinal polarisation dominant in $\chi_{c1} \to \gamma V$ decays

Consistent with theoretical predictions
ZPC 66, 71 (1995)
PR 77, 242 (1950)

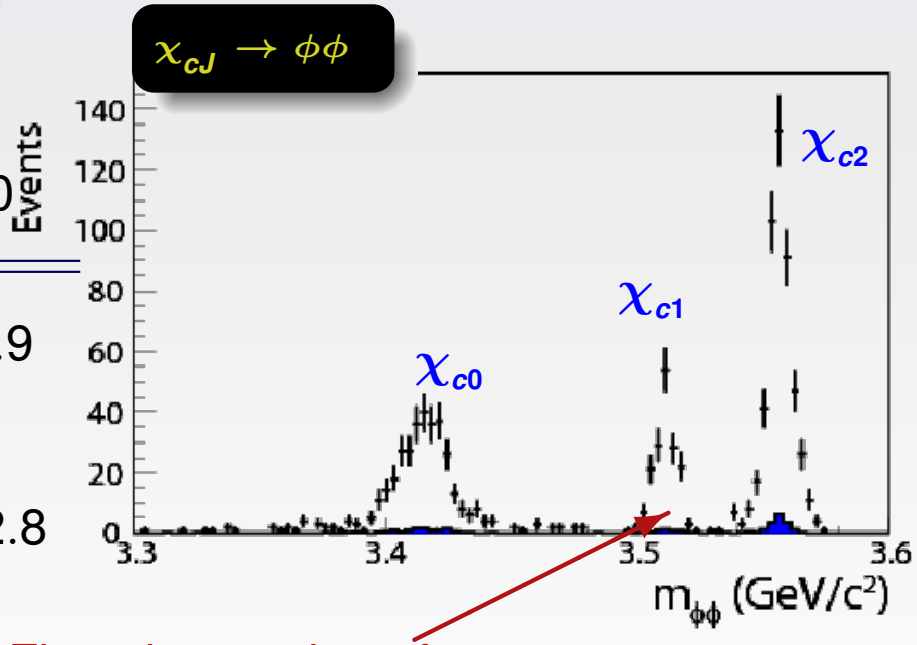
$\chi_{cJ} \to VV\ ,\ V = \phi(K^+K^-),\ \omega(\pi^+\pi^-\pi^0_{(\gamma\gamma)})$

- **Important test on QCD**
  - **previous measurements from BESII:** $\chi_{c0}, \chi_{c2} \to \phi\phi, \omega\omega$
  - **they do not show expected helicity suppression**
- $\chi_{c1} \to \phi\phi, \omega\omega$ **highly suppressed since C-parity requires** $L = 2$
- $\chi_{cJ} \to \omega\phi$ **doubly OZI suppressed**

BR $[10^{-3}]$	χ_{c0}	χ_{c2}
$\to \phi\phi$	$0.94 \pm 0.21 \pm 0.13$	$1.70 \pm 0.30 \pm 0.25$
$\to \omega\omega$	$2.29 \pm 0.58 \pm 0.41$	$1.77 \pm 0.47 \pm 0.36$

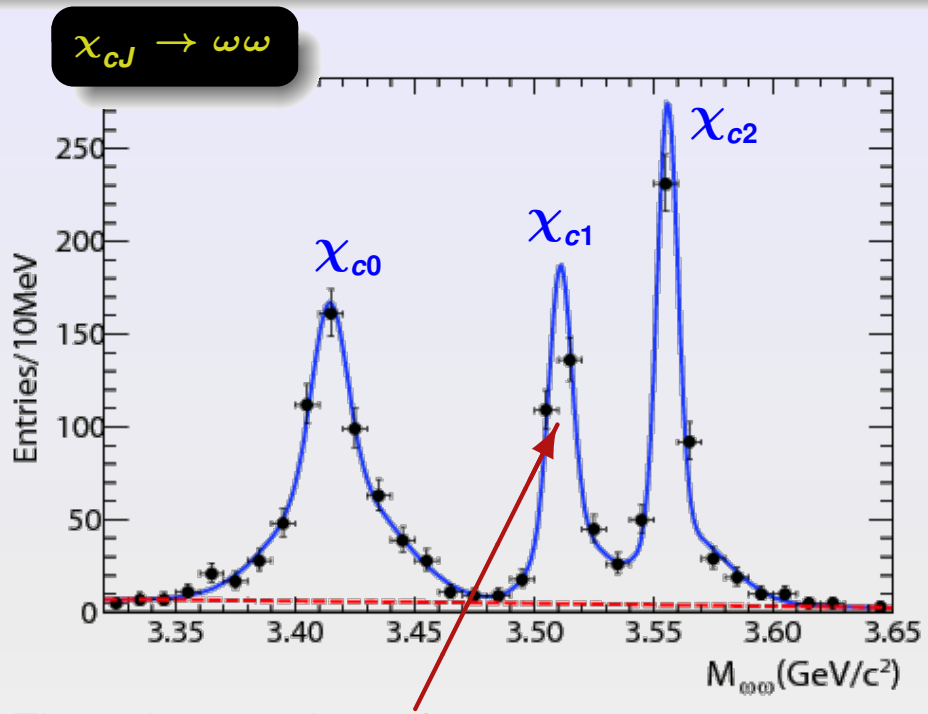
BESII: PLB 642, 197 (2006)
BESII, PLB 630, 7 (2005)

BR $[10^{-4}]$	BESIII	PDG10
$\chi_{c0} \to \phi\phi$	$8.00 \pm 0.35 \pm 0.80$	9.2 ± 1.9
$\chi_{c1} \to \phi\phi$	$4.30 \pm 0.23 \pm 0.49$	
$\chi_{c2} \to \phi\phi$	$10.67 \pm 0.38 \pm 0.15$	14.8 ± 2.8

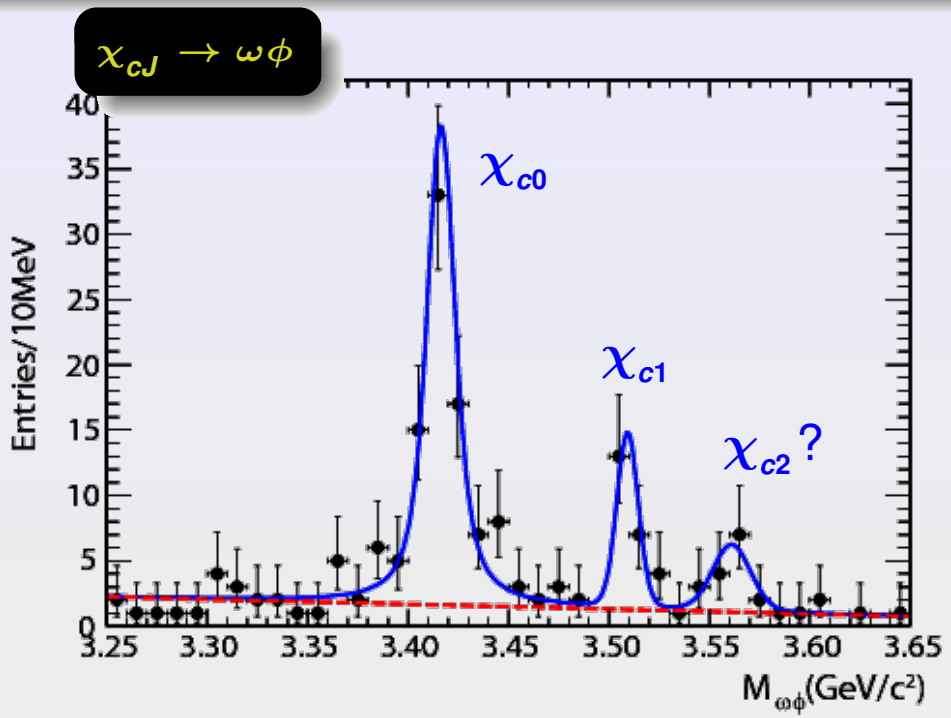


First observation of $\chi_{c1} \to \phi\phi$

$\chi_{cJ} \to VV$, $V = \phi(K^+K^-)$, $\omega(\pi^+\pi^-\pi^0_{(\gamma\gamma)})$



First observation of $\chi_{c1} \to \omega\omega$



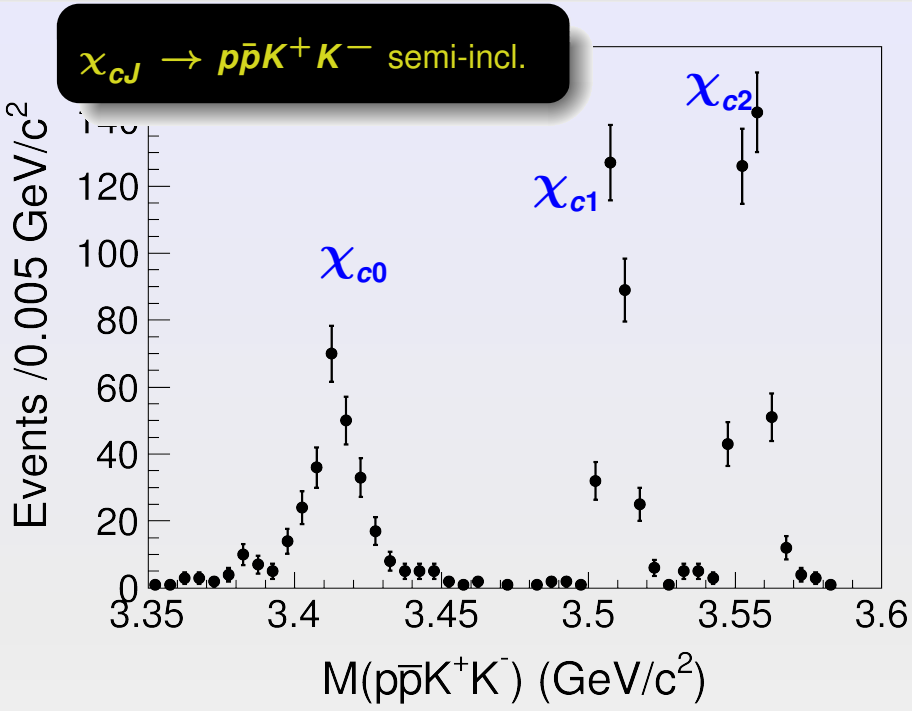
First observation of $\chi_{cJ} \to \omega\phi$

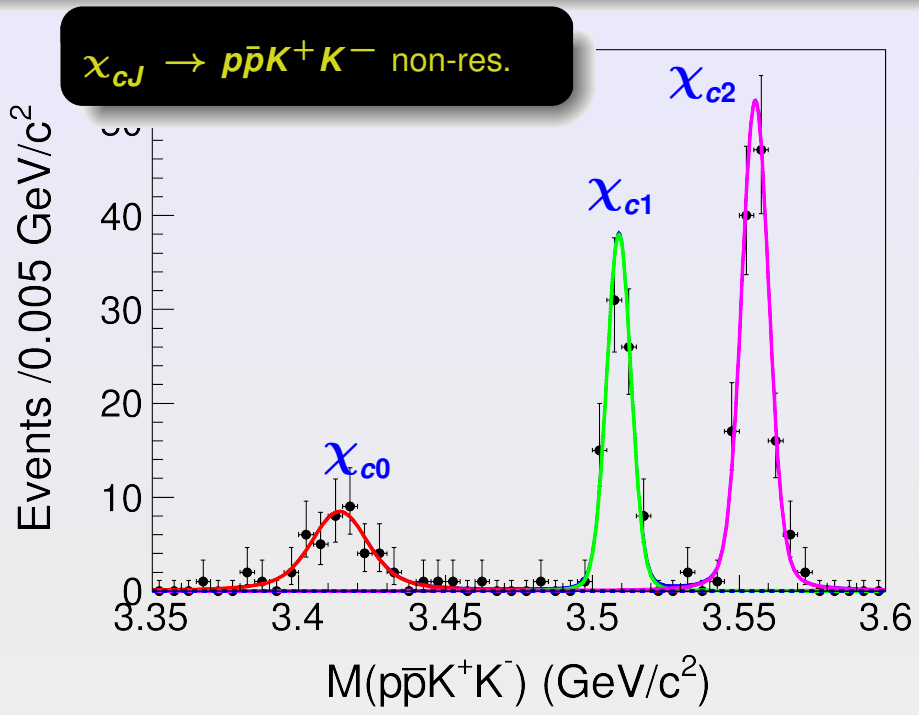
Doubly OZI suppressed!

BR $[10^{-4}]$	**BESIII**	PDG10
$\chi_{c0} \to \omega\omega$	$9.53 \pm 0.37 \pm 1.11$	22 ± 7
$\chi_{c1} \to \omega\omega$	$5.96 \pm 0.28 \pm 0.70$	
$\chi_{c2} \to \omega\omega$	$8.90 \pm 0.36 \pm 1.08$	19 ± 6

BR $[10^{-4}]$	**BESIII**
$\chi_{c0} \to \omega\phi$	$1.18 \pm 0.17 \pm 0.15$
$\chi_{c1} \to \omega\phi$	$0.23 \pm 0.06 \pm 0.03$
$\chi_{c2} \to \omega\phi$	< 0.23

$\chi_{cJ} \to p\bar{p}K^+K^-$





Semi-inclusive spectrum:
contains intermediate resonances

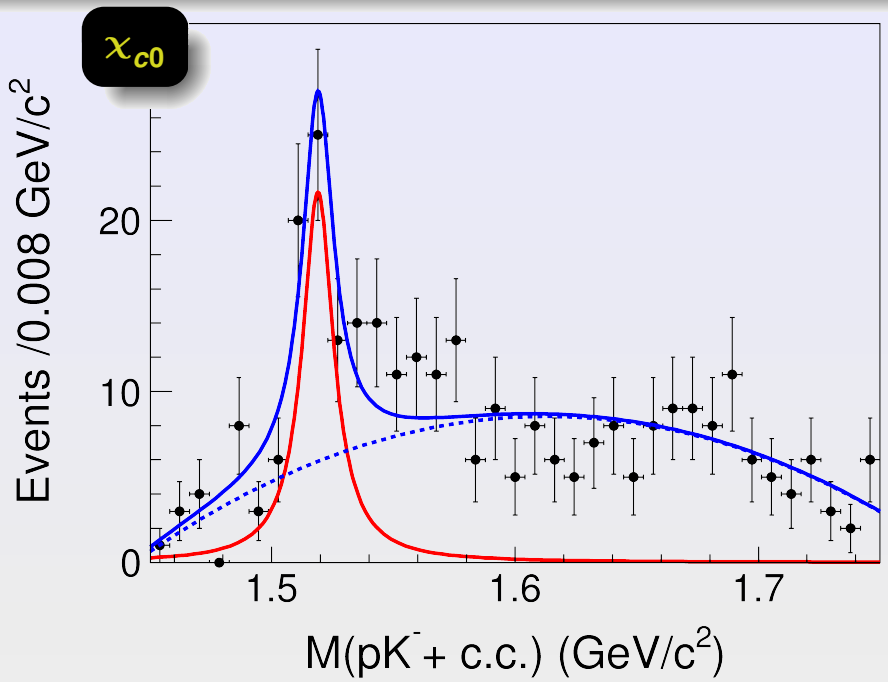
Resonances veto:
Φ, $\Lambda_{(1520)}$, $\bar{\Lambda}_{(1520)}$

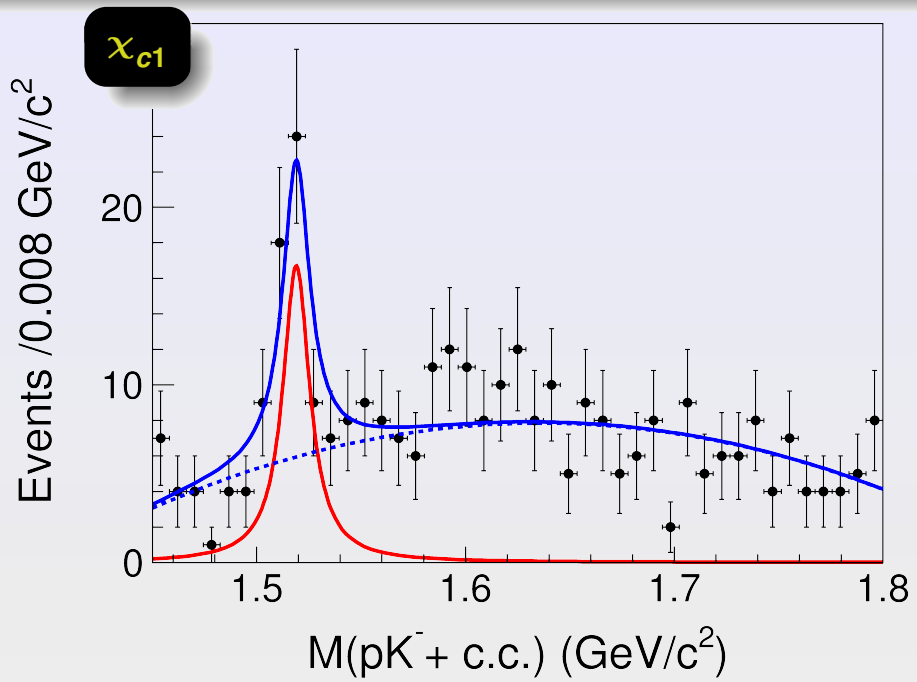
First observation of non-resonant $\chi_{cJ} \to p\bar{p}K^+K^-$

	BR $[10^{-4}]$	**BESIII**
	$\chi_{c0} \to p\bar{p}K^+K^-$	$1.24 \pm 0.20 \pm 0.18$
	$\chi_{c1} \to p\bar{p}K^+K^-$	$1.35 \pm 0.15 \pm 0.19$
	$\chi_{c2} \to p\bar{p}K^+K^-$	$2.08 \pm 0.19 \pm 0.30$

$\chi_{cJ} \to \bar{p}K^+\Lambda_{(1520)} + c.c.\ ,\ \Lambda_{(1520)} \to pK^-, \bar{\Lambda}_{(1520)} \to \bar{p}K^+$

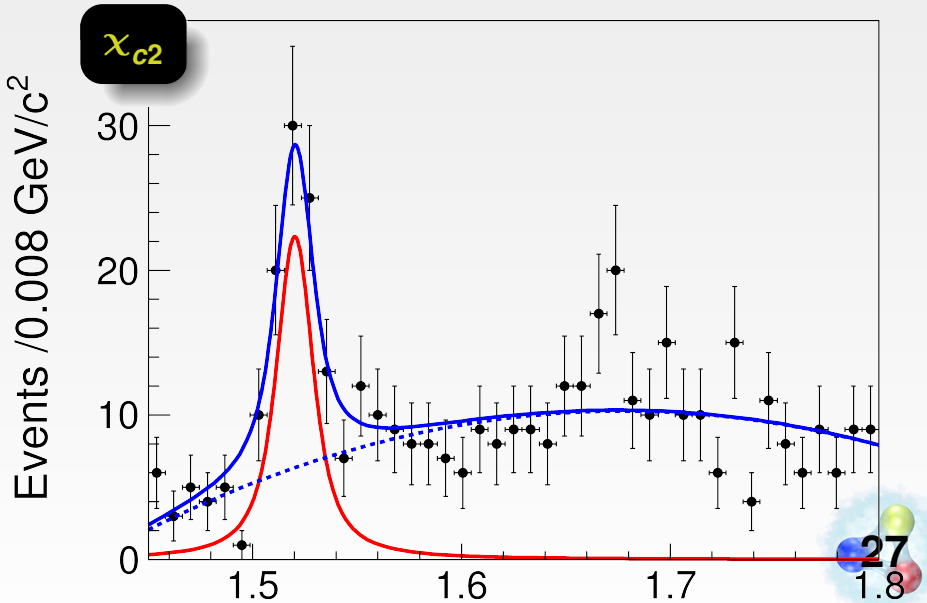
PRD 83, 112009 (2011)
$106M\ \Psi'$ decays





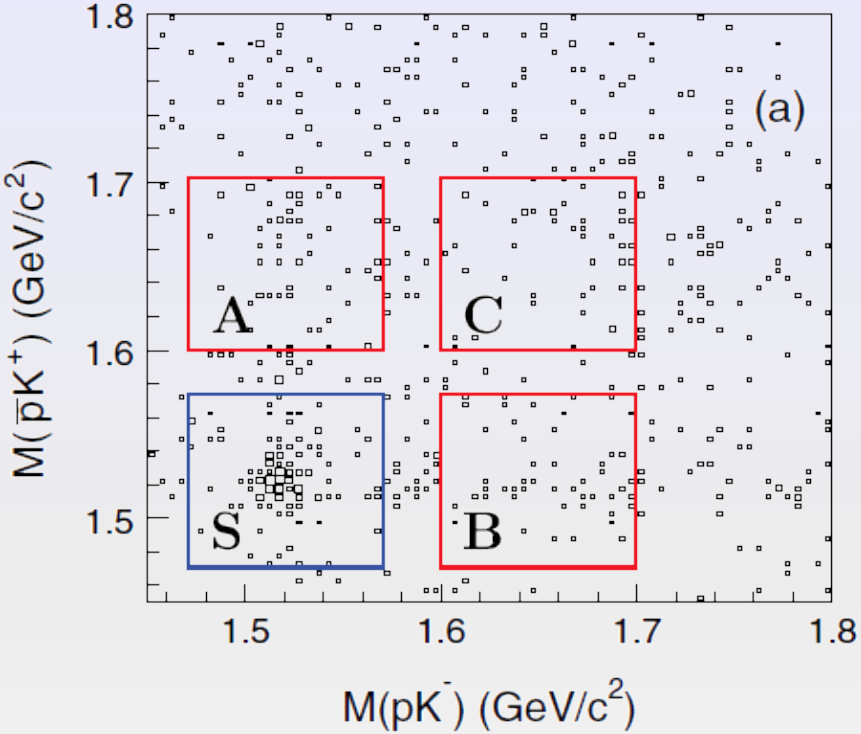
First observation of
$\chi_{cJ} \to \bar{p}K^+\Lambda_{(1520)} + c.c.$

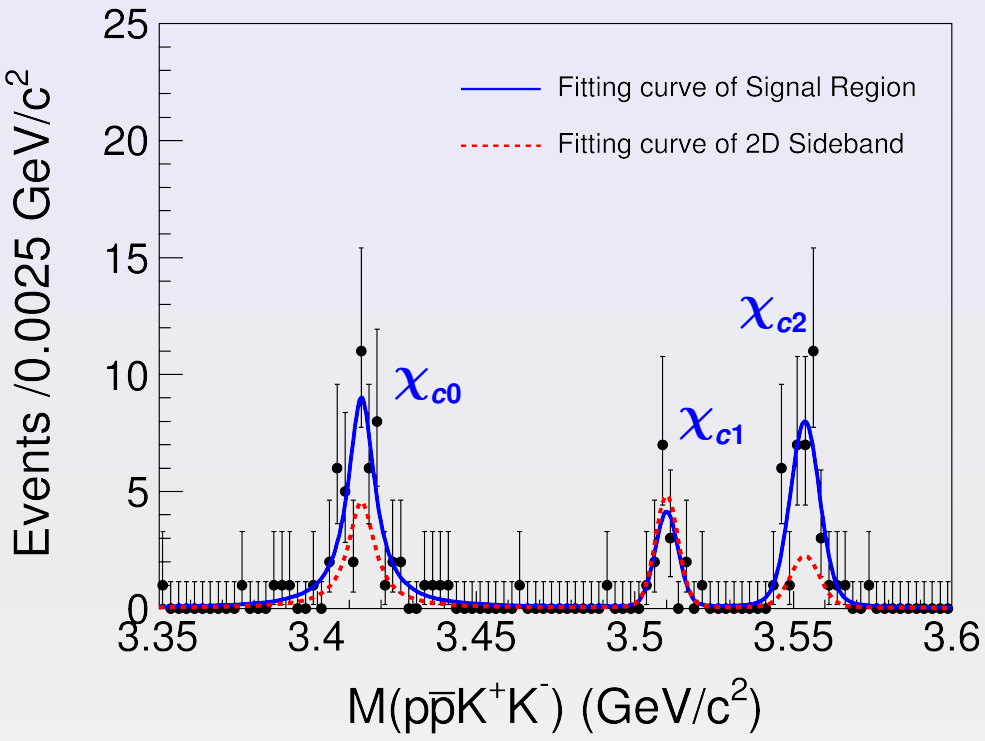
BR $[10^{-4}]$	BESIII
χ_{c0}	$3.00 \pm 0.58 \pm 0.50$
χ_{c1}	$1.81 \pm 0.38 \pm 0.28$
χ_{c2}	$3.06 \pm 0.50 \pm 0.54$



$\chi_{cJ} \to \Lambda_{(1520)}\bar{\Lambda}_{(1520)}$, $\Lambda_{(1520)} \to pK^-, \bar{\Lambda}_{(1520)} \to \bar{p}K^+$

PRD 83, 112009 (2011)
106M Ψ' **decays**



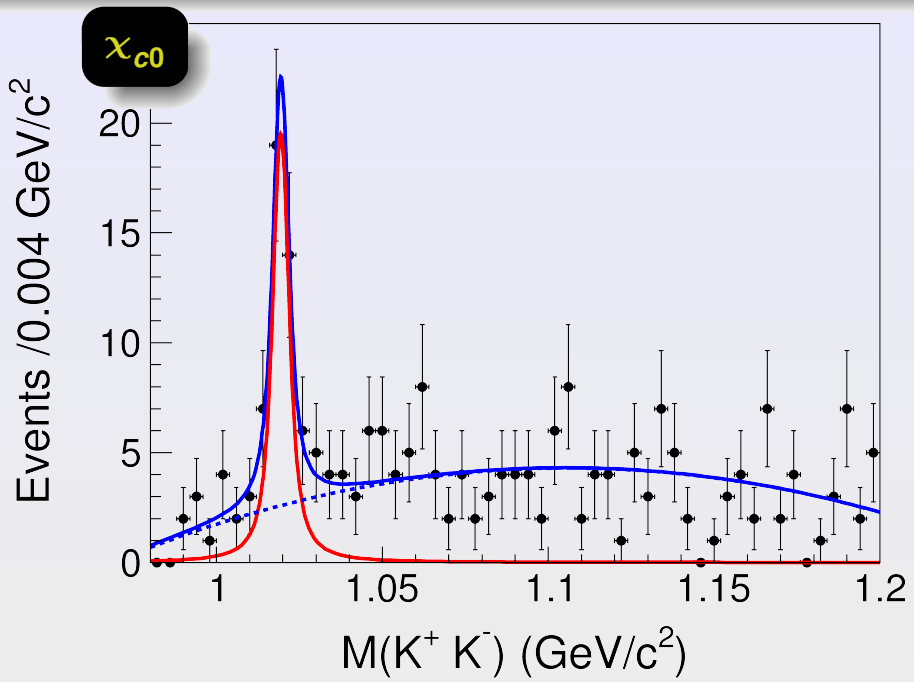


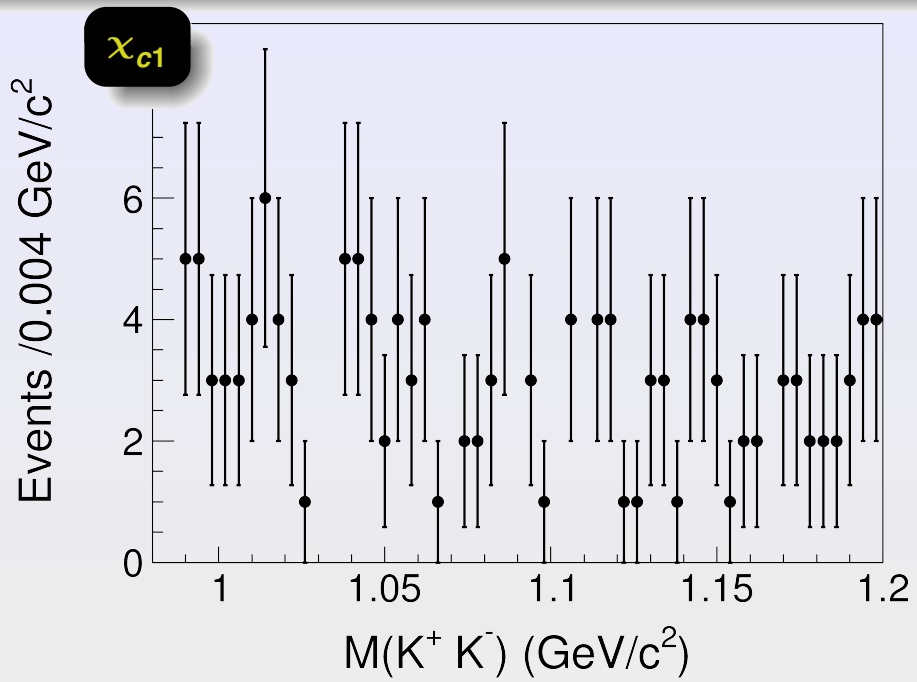
First observation of
$\chi_{cJ} \to \Lambda_{(1520)}\bar{\Lambda}_{(1520)}$

BR $[10^{-4}]$	**BESIII**
$\chi_{c0} \to \Lambda_{(1520)}\bar{\Lambda}_{(1520)}$	$3.18 \pm 1.11 \pm 0.53$
$\chi_{c1} \to \Lambda_{(1520)}\bar{\Lambda}_{(1520)}$	< 1.00
$\chi_{c2} \to \Lambda_{(1520)}\bar{\Lambda}_{(1520)}$	$5.05 \pm 1.29 \pm 0.93$

$\chi_{cJ} \to p\bar{p}\Phi$, $\Phi \to K^+K^-$

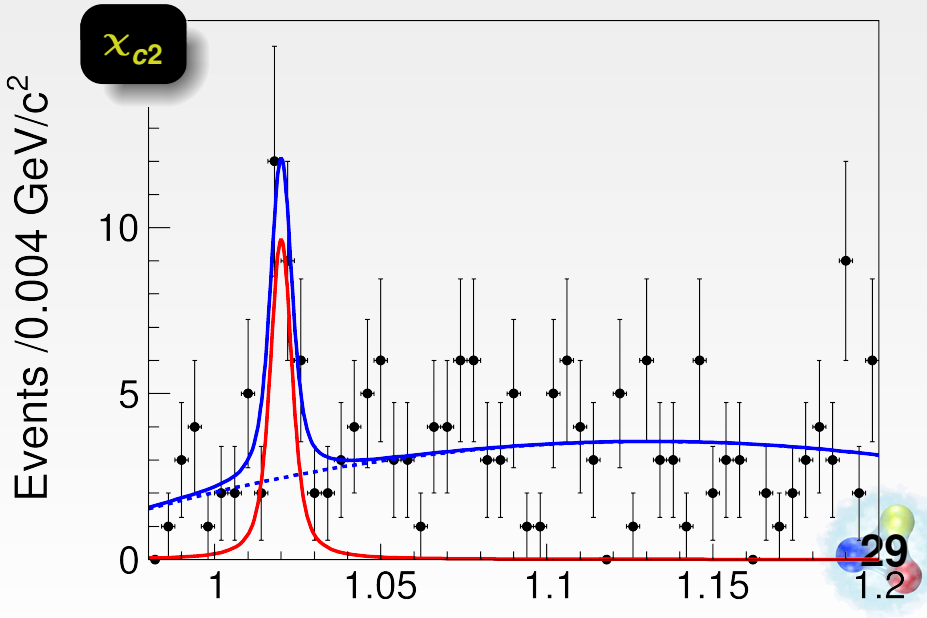
PRD 83, 112009 (2011)
$106M\ \Psi'$ decays





First observation of
$\chi_{cJ} \to p\bar{p}\Phi$

BR $[10^{-5}]$	BESIII
$\chi_{c0} \to p\bar{p}\Phi$	$6.12 \pm 1.18 \pm 0.86$
$\chi_{c1} \to p\bar{p}\Phi$	< 1.82
$\chi_{c2} \to p\bar{p}\Phi$	$3.04 \pm 0.85 \pm 0.43$



$\Psi' \to \gamma P, P = \pi^0_{(\gamma\gamma)}, \eta_{(\pi^+\pi^-\pi^0, 3\pi^0)}, \eta'_{(\gamma\pi^+\pi^-, \pi^+\pi^-\eta_{(\gamma\gamma)})}$

PRL 105, 261801 (2010)
106M Ψ' decays

$R_{(c\bar{c})} = \frac{Br((c\bar{c})\to\gamma\eta)}{Br((c\bar{c})\to\gamma\eta')}$

LO-pQCD

$\Downarrow$

$R_{\Psi'} \simeq R_{J/\Psi}$

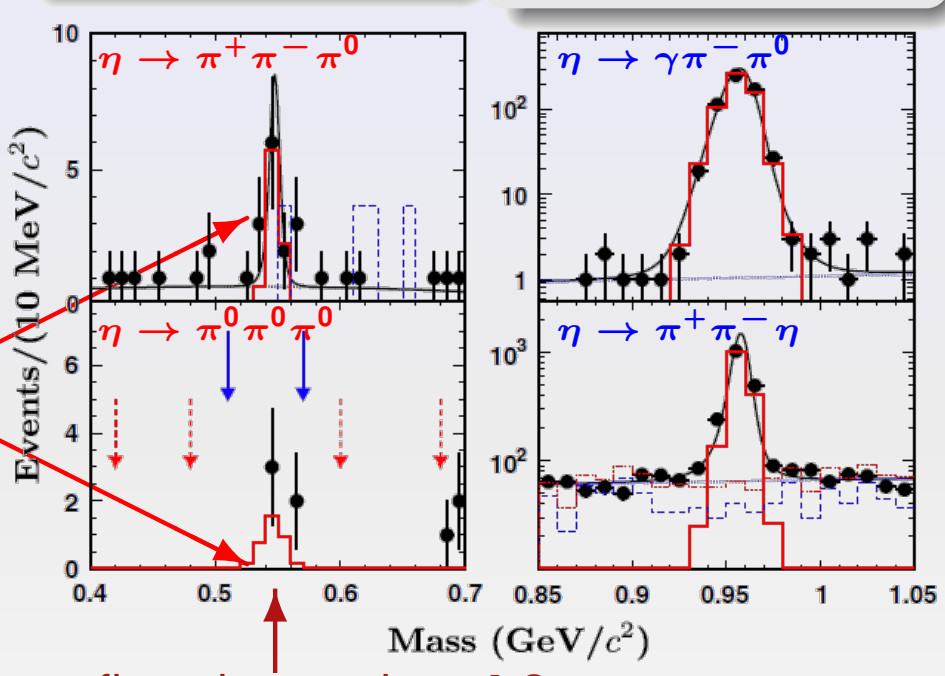
PRP 112,173 (1984)

$\Psi' \to \gamma\eta$
$\eta \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$

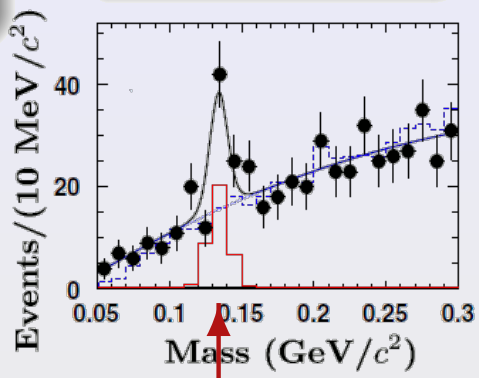
$\Psi' \to \gamma\eta'$
$\eta' \to \gamma\pi^+\pi^-$
$\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$

$\Psi' \to \gamma\pi^0$
$\pi^0 \to \gamma\gamma$

strange depletion!



first observation: **4.3σ**



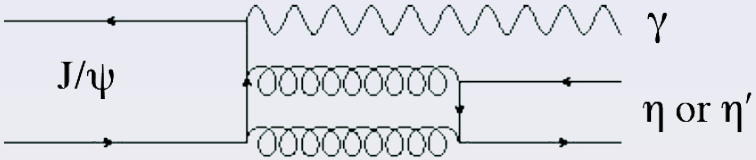
first observation: **4.6σ**

BR $[10^{-6}]$	**BESIII**	Combined **BESIII**	PDG10
$\Psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\Psi' \to \gamma\eta(\pi^+\pi^+\pi^0)$	$1.78 \pm 0.72 \pm 0.17$		
$\Psi' \to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\Psi' \to \gamma\eta'_{(958)}(\pi^+\pi^+\eta)$	$120 \pm 5 \pm 8$		
$\Psi' \to \gamma\eta'_{(958)}(\pi^+\pi^+\gamma)$	$129 \pm 3 \pm 8$	$126 \pm 3 \pm 8$	121 ± 8

Suppression of $\Psi' \to \gamma\eta$

PRL 105, 261801 (2010)
106M Ψ' decays

$J/\Psi \to \gamma\eta\,,\ \gamma\eta'$



- **J/Ψ: CLEO-c** PRD79, 111101 (2009)

$$R_{J/\Psi}\,\frac{Br(J/\Psi\to\gamma\eta)}{Br(J/\Psi\to\gamma\eta')} = (21.1 \pm 0.9)\ \%$$

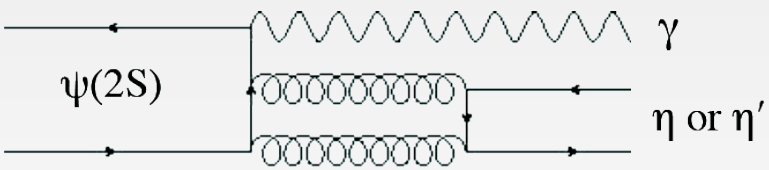
  - consistent with other measurements of the $\eta - \eta'$ mixing angle
  - predicted by LO-pQCD

- **Ψ': BESIII first measurement**

$$R_{\Psi'}\,\frac{Br(\Psi'\to\gamma\eta)}{Br(\Psi'\to\gamma\eta')} = (1.10 \pm 0.38 \pm 0.07)\ \%$$

  - CLEO-c: $R_{\Psi'} < 1.8\%$ at 90% CL PRD79, 111101 (2009)
  - $R_{\Psi'} << R_{J/\Psi}$ confirmed!

$\Psi' \to \gamma\eta\,,\ \gamma\eta'$



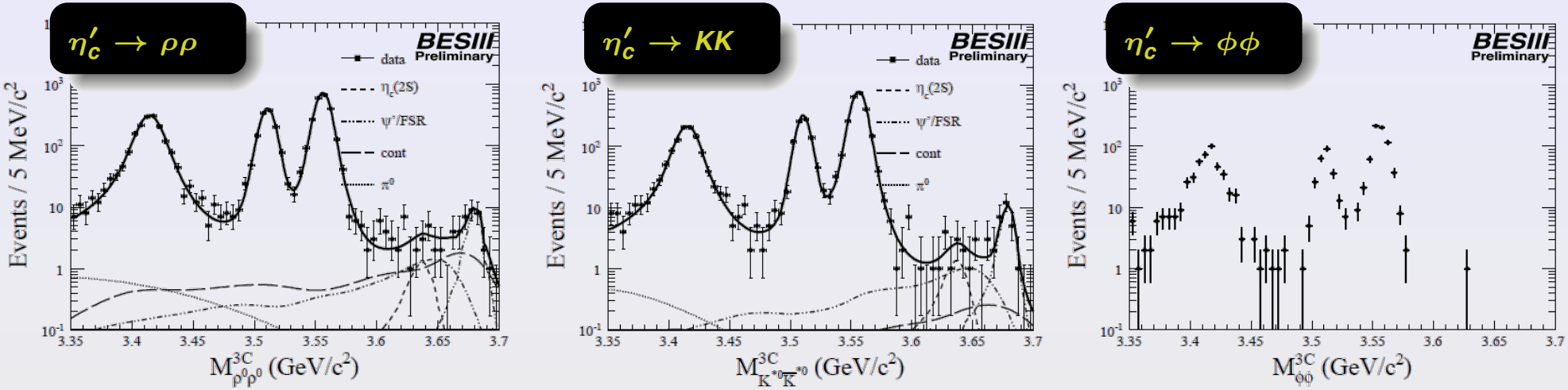
$R_{\Psi'} << R_{J/\Psi}$ interpreted by balancing VMD contributions and $\eta_c - \eta(\eta')$ mixings due to AGA

PLB 697, 52 (2011)

$\eta_c' \to VV$, $V = \rho^0_{(\pi^+\pi^-)}$, $K^{*0}_{(K\pi)}$, $\bar{K}^{*0}_{(K\pi)}$, $\Phi_{(K^+K^-)}$

preliminary
106M Ψ' **decays**

BESIII preliminary: $BR(\Psi' \to \gamma\eta_c') = (4.7 \pm 0.9_{stat} \pm 3.0_{sys}) \times 10^{-4}$



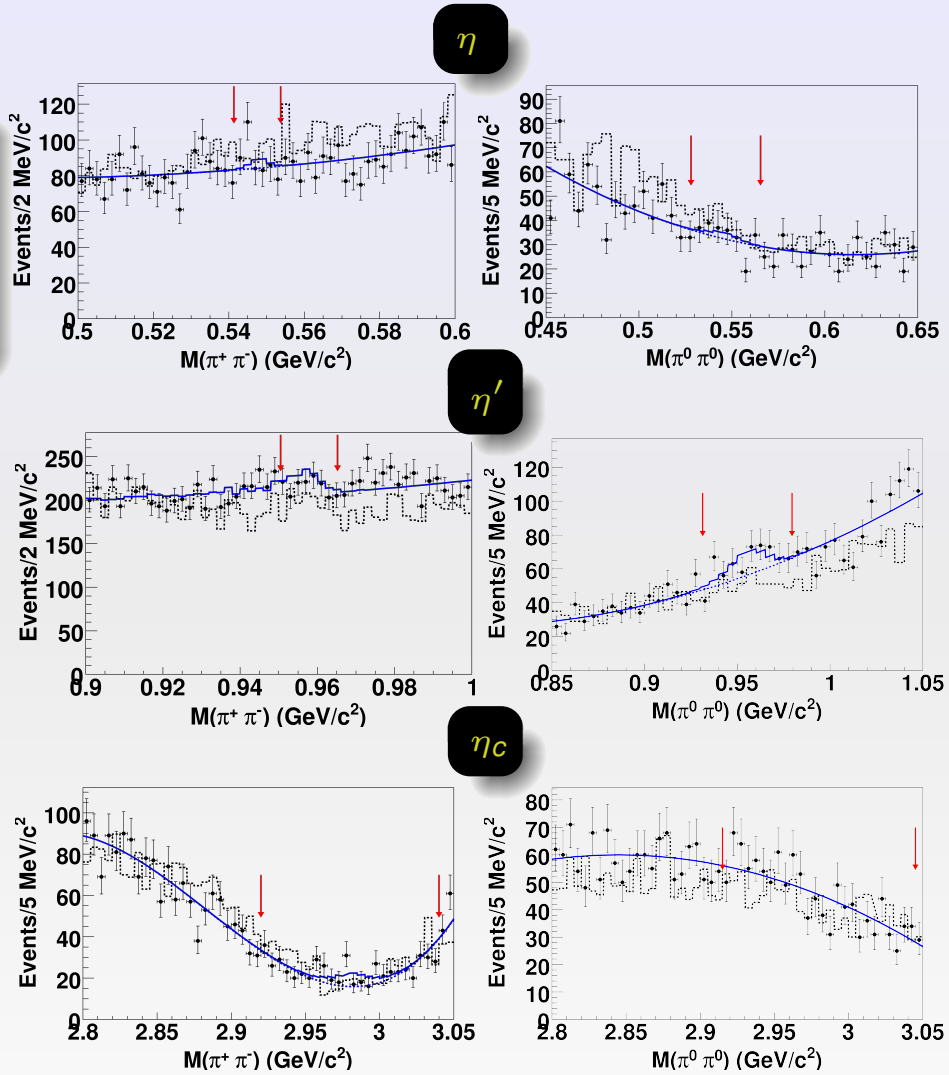
V	$BR(\Psi' \to \gamma\eta_c' \to \gamma VV)$ [10^{-7}]	$BR(\eta_c' \to VV)$ [10^{-3}]	$BR^{theory}(\eta_c' \to VV)$ arXiv:1010.1343 [10^{-3}]
$\eta_c' \to \rho\rho$	< 11.4	< 3.1	$6.4 \div 28.9$
$\eta_c' \to K^{*0}\bar{K}^{*0}$	< 19.4	< 5.3	$7.9 \div 35.8$
$\eta_c' \to \phi\phi$	< 7.8	< 2.0	$2.1 \div 9.8$

- **strongly suppressed by HSR**
- **no clear evidence of $\eta_c' \to VV$**
- **possible contribution from intermediate charmed meson loops** [PRD 81, 014017 (2010)]
- **experimental upper limits smaller than thoeretical predictions**

$P \to \pi\pi$, $P = \eta,\ \eta',\ \eta_c$: *CP* and *P* violation

- $P \to \pi\pi$ violates *CP* and *P*
- SM allow weak $BR \sim 10^{-27}$
- QCD modifications up to $BR \sim 10^{-15}$

	Sig.	*BR*	PDG *BR*
$\eta \to \pi^+\pi^-$	0.8σ	$< 3.9 \times 10^{-4}$	$< 1.3 \times 10^{-5}$
$\eta' \to \pi^+\pi^-$	0.1σ	$< 5.5 \times 10^{-5}$	$< 2.9 \times 10^{-3}$
$\eta_c \to \pi^+\pi^-$	1.5σ	$< 1.3 \times 10^{-4}$	$< 6 \times 10^{-4}$
$\eta \to \pi^0\pi^0$	0.6σ	$< 6.9 \times 10^{-4}$	$< 3.5 \times 10^{-4}$
$\eta' \to \pi^0\pi^0$	2.6σ	$< 4.5 \times 10^{-4}$	$< 9 \times 10^{-4}$
$\eta_c \to \pi^0\pi^0$	0.1σ	$< 4.2 \times 10^{-5}$	$< 4 \times 10^{-4}$



BESIII tightens limits of *CP* and *P* violation in η, η' and η_c decays

Summary

BESIII and BEPCII offer an exciting experimental scenario:

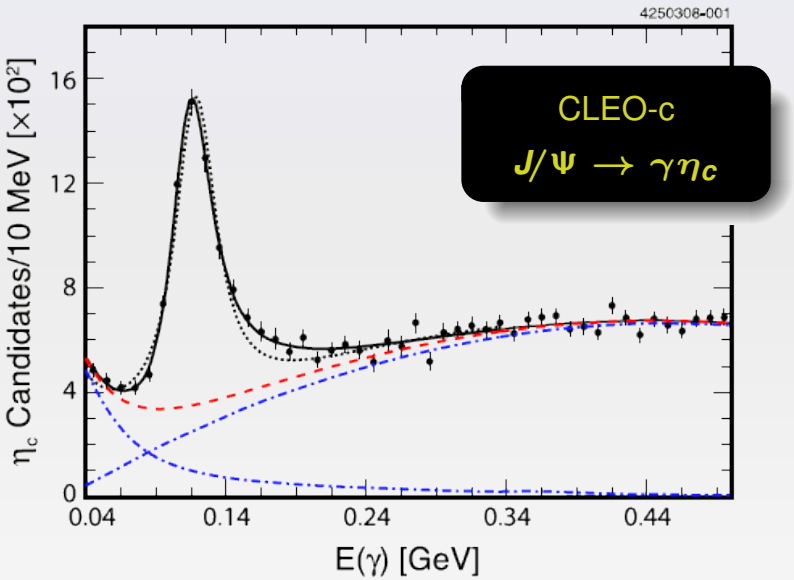
- **BESIII** now fully operational
- **BEPCII** luminosity increasing continuosly
- world record statistics already collected
- a wide physics program, not only charmonium
- many analyses have already been published or submitted
- even more are underway (as well as many systematic studies)
- **BESIII** has already made many contributions beyond the reach of CLEO-c
- some results already quite unexpected

BACK-UP SLIDES

Observation of η_c: lineshape

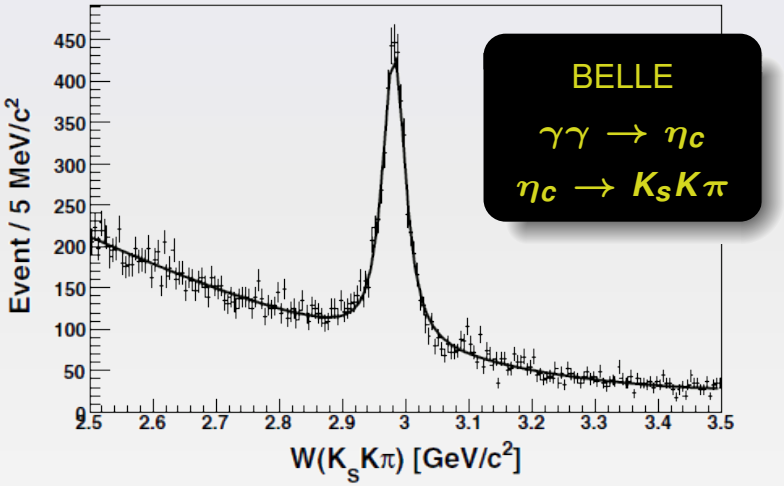
CLEO-c: η_c lineshape distorsion in Ψ' decays

energy dependence of $M1$ transition element?



asymmetric

PRL 102, 011801 (2009)



symmetric

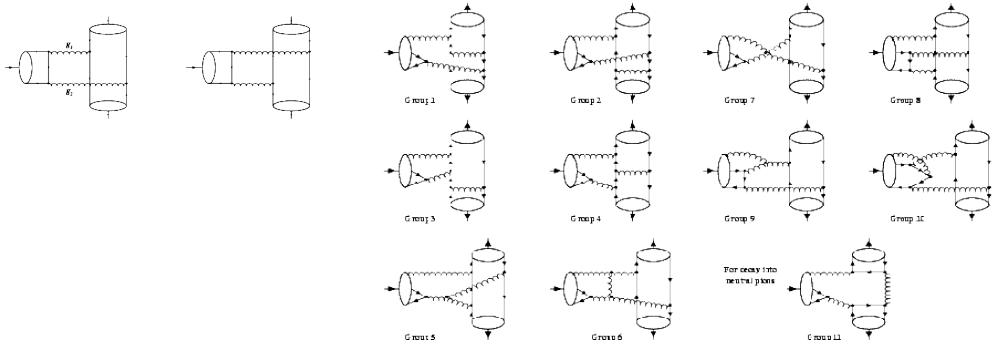
NPBPS 184, 220 (2008)

χ_{cJ} decays

- gluonium investigation: $\chi_{cJ} \to gg \to (q\bar{q})(q\bar{q})$
  Amsler/Close PRD 53, 295 (1996)

- test of color singlet/octet mechanism:
  Bodwin et al. PRLD 51, 1125 (1995) Huang/Chao PRD 54, 6850 (1996) Bolz et al. EPJC 2, 705 (1998)

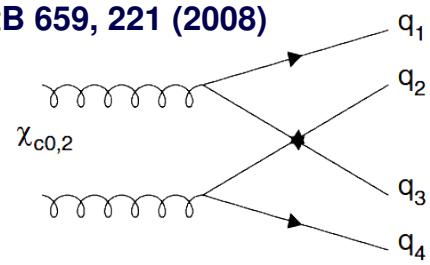
$(q\bar{q})$ graphs for $\chi_{cJ} \to \pi\pi$ $(q\bar{q}g)$ graphs for $\chi_{cJ} \to \pi\pi$



Decay width	Boltz	PDG10
$\Gamma(\chi_{c0} \to \pi^0\pi^0)/KeV$	23.5	29 ± 1
$\Gamma(\chi_{c2} \to \pi^0\pi^0)/KeV$	1.93	1.6 ± 0.1
$\Gamma(\chi_{c0} \to \eta\eta)/KeV$	32.7	28 ± 3
$\Gamma(\chi_{c2} \to \eta\eta)/KeV$	2.66	

- probe singly and doubly OZI suppressed decays of charmonium states
  Zhao, PLettB 659, 221 (2008)

SOZI



DOZI