Recent results from Charmonium decays at BESIII

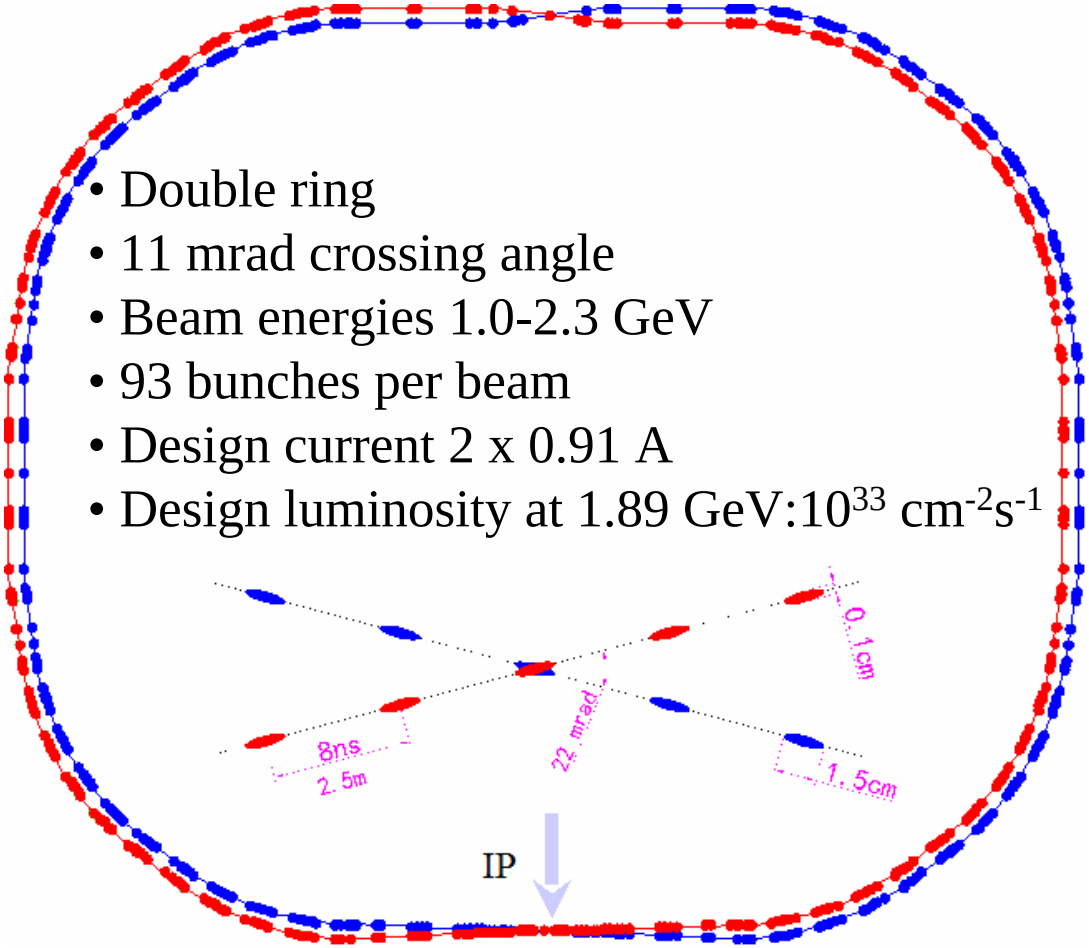
Bin Zhong
Institute of High Energy Physics
(For the BESIII Collaboration)

23rd Rencontre de Blois
Particle Physics and Cosmology
29th May . -3rd June., 2011, Blois, France

Outline

- BEPCII and BESIII
- Observation of h_c
- Evidence for $\psi' \rightarrow \gamma P$ ($P=\pi^0, \eta$)
- $\psi' \rightarrow \gamma\chi_{cJ}$
  - $\chi_{cJ} \rightarrow \gamma V$ ($V=\rho,\omega,\phi$)
  - $\chi_{cJ} \rightarrow VV$ ($V=\omega,\phi$)
- Summary

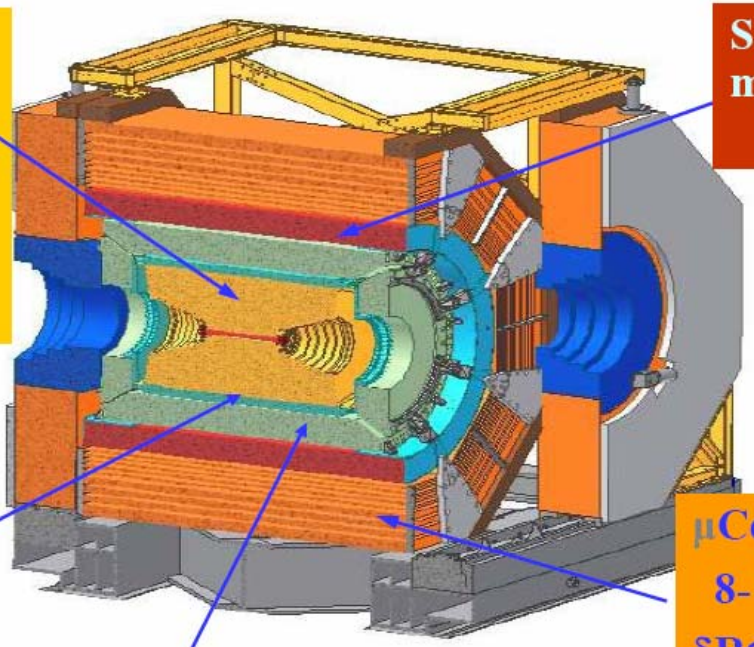
The Beijing Electron-Positron Collider II



BEPC II achievements

parameters	design	Achieved	
		BER	BPR
Energy (GeV)	1.89	1.89	1.89
Beam curr. (mA)	910	650	700
Bunch curr. (mA)	9.8	>10	>10
Bunch number	93	93	93
RF voltage	1.5	1.5	1.5
* ν_s @1.5MV	0.033	0.032	0.032
β_x^*/β_y^* (m)	1.0/0.015	~1.0/0.0135	~1.0/0.0135
Inj. Rate (mA/min)	200 e^-/50 e^+	>200	>50
Lum. ($\times 10^{33}cm^{-2}s^{-1}$)	1	*0.65*	

The Beijing Spectrometer III



Main Drift Chamber
(MDC)
$\sigma(p_T)/p_T$=0.32%⊕0.37%
(1 GeV)
$\sigma_{dE/dx}$ = 5.3%

Super-conducting
magnet
1.0 tesla

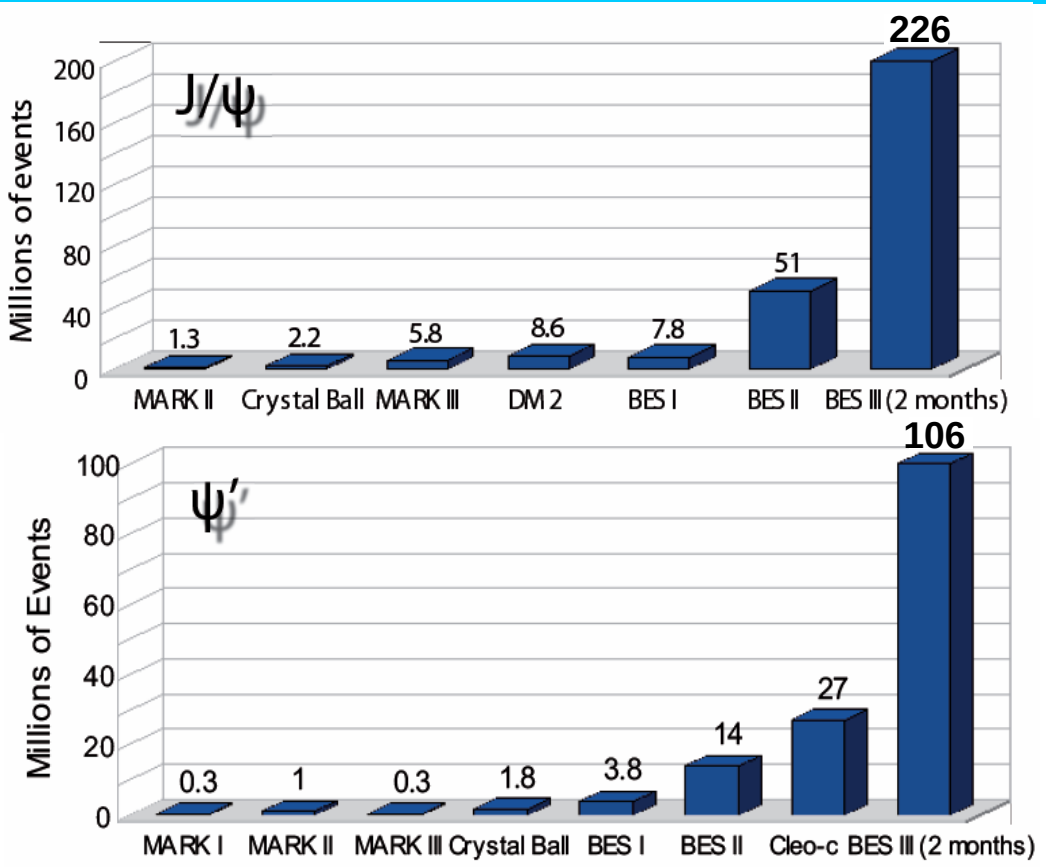
Time Of Flight
(TOF)
σ_T = 80ps Barrel
100ps endcap

μCounter
8- 9 layers
δRΦ=1.4 cm~1.7 cm

EMC: $\Delta E/\sqrt{E}$ = 2.5 % @ 1 GeV
$\sigma_{z,\phi}$ = 0.6 cm /$\sqrt{E}$

BESIII data samples

2009:



2010: ~ 900 pb^{-1} $\psi(3770)$ data taken at 3.773GeV

~ 70 pb^{-1} energy scan data taken from 3.646 to 3.892 GeV

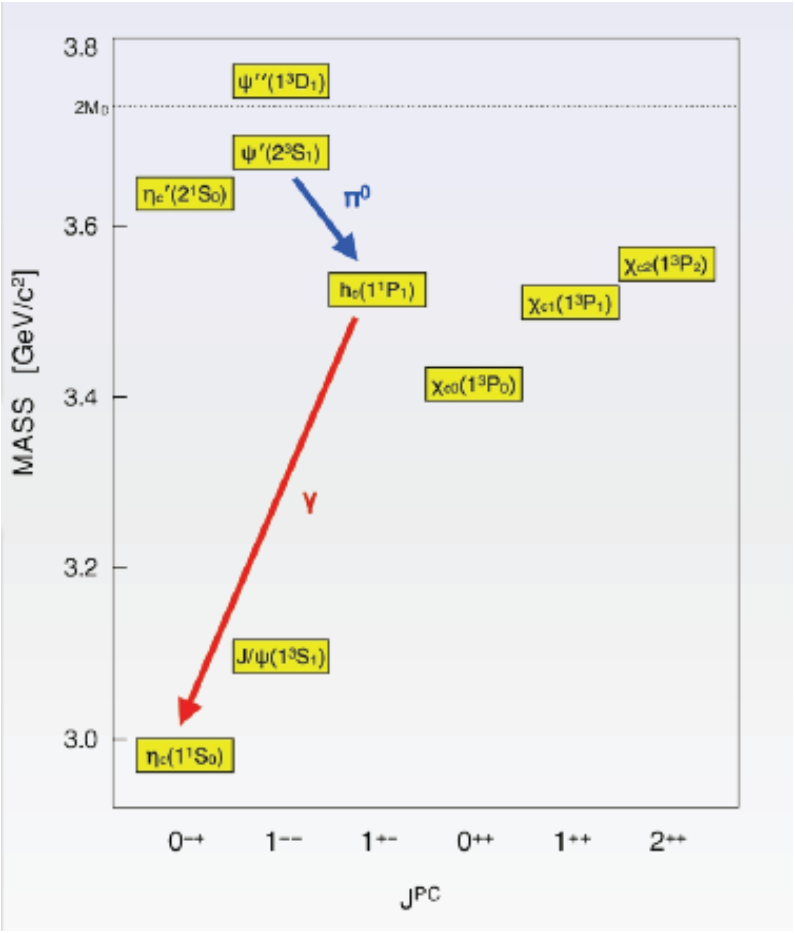
2011: ~ 1800 pb^{-1} $\psi(3770)$ data taken at 3.773GeV

~ 500 pb^{-1} $\psi(4040)$ data taken at 4.01 GeV

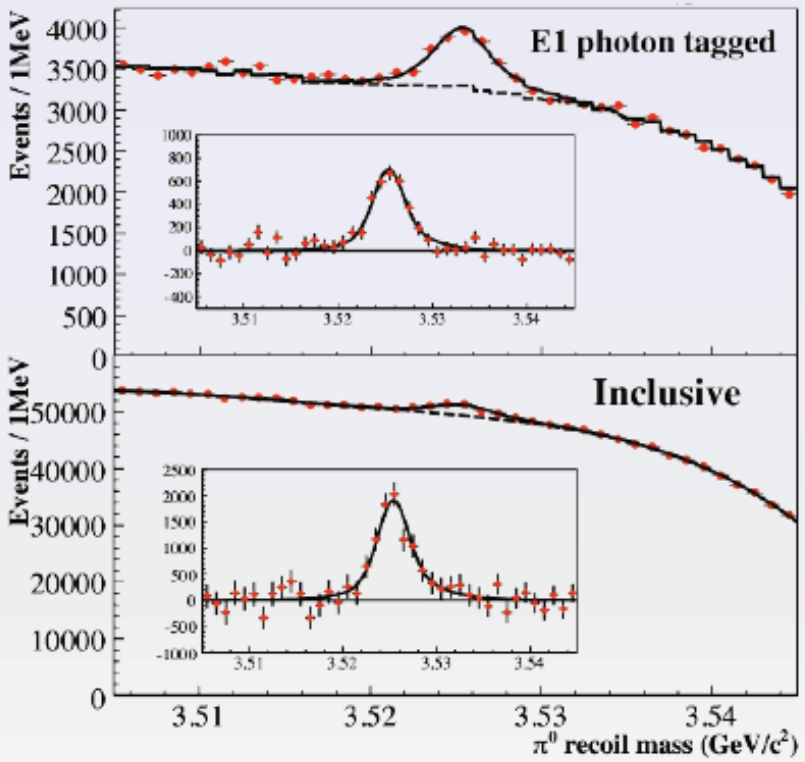
Observation of h_c (1)

- $B(\psi' \to \pi^0 h_c)$; 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)



Observation of h_c (2)



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 the 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

Observation of h_c (3)

	BESIII	CLEOc
$Br(\psi' \to \pi^0 h_c) \times Br(h_c \to \gamma \eta_c)$ $[10^{-4}]$	$4.58 \pm 0.40 \pm 0.50$	$4.19 \pm 0.32 \pm 0.40$
M [MeV/c^2]	$3525.40 \pm 0.13 \pm 0.18$	$3525.80 \pm 0.19 \pm 0.11$
Γ [MeV]	$0.73 \pm 0.45 \pm 0.28$ < 1.44 @ 90%CL	1.1 (NRQCD) Kuang 0.51 (PQCD) Kuang
$\Delta M_{hf}(1P)$ [MeV/c^2]	$0.10 \pm 0.13 \pm 0.18$	$0.08 \pm 0.18 \pm 0.12$

	BESIII	theoretical prediction
$Br(\psi' \to \pi^0 h_{c)}$ $[10^{-4}]$	$8.4 \pm 1.3 \pm 1.0$	4 - 13
$Br(h_c \to \gamma \eta_c)$	$54.3 \pm 6.7 \pm 5.2$	41 (NRQCD) Kuang 88 (PQCD) Kuang 38 Godfrey, Rosner

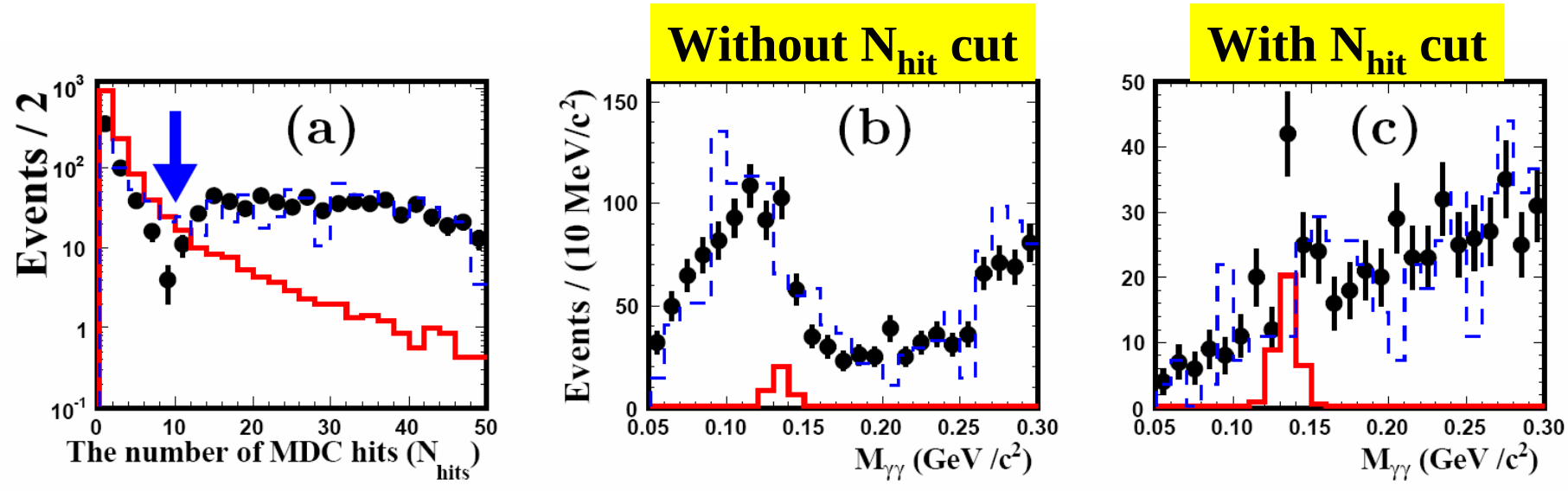
Evidence for $\psi' \rightarrow \gamma P$ ($P=\pi^0, \eta$) (1)

PRL105, 261801 (2010)

- Test for various phenomenological mechanisms
- The first order of perturbation theory predicts:
  $R_{J/\psi}=B(J/\psi \rightarrow \gamma\eta)/B(J/\psi \rightarrow \gamma\eta')=R_{\psi'}$
- Measurements from CLEO (PRD79,111101(2009)):
  $R_{\psi'}<1.8\%$ (90% C.L.) and $R_{J/\psi}=(21.1 \pm 0.9)\%$
- The suppressed decay mode $\psi' \rightarrow \gamma\pi^0$ is calculated in PRD79,097301:
  $B(\psi' \rightarrow \gamma\pi^0)=2.19 \times 10^{-7}$
- CLEO gives $B(\psi' \rightarrow \gamma\pi^0)<5.0 \times 10^{-6}$ (90% C.L.)

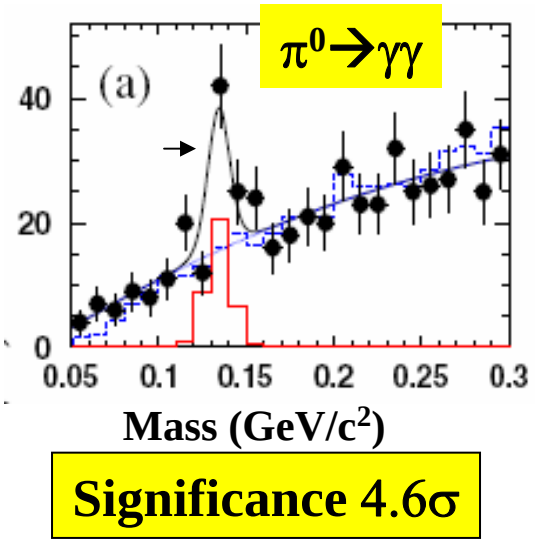
Evidence for $\psi' \rightarrow \gamma P$ ($P=\pi^0, \eta$) (2)

- One dangerous background for $\psi' \rightarrow \gamma\pi^0(\gamma\gamma)$ is $ee \rightarrow \gamma\gamma$ events with one photon conversion but the produced ee pair is not well reconstructed.
- So special requirement $N_{hits}<=10$ is applied, where N_{hits} is the number of hits in the MDC sector between the two shower positions.



Red histogram: MC signal, dashed histogram: continuum BG, Points: ψ' data

Evidence for ψ'→γP (P=π^0, η) (3)

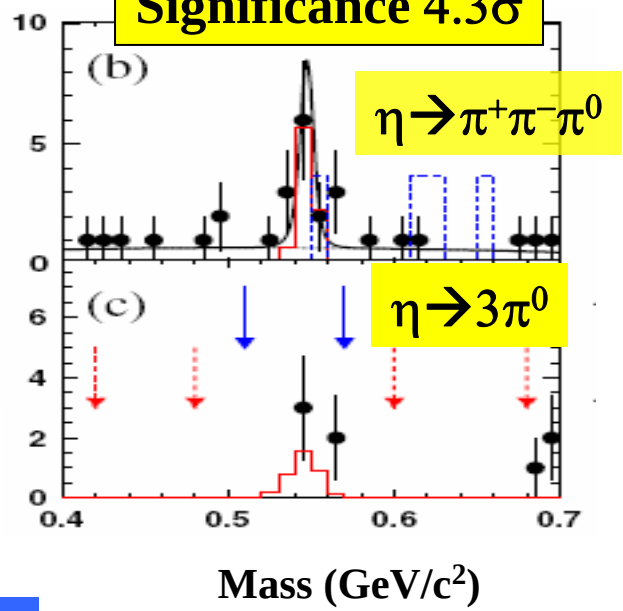


$\pi^0\to\gamma\gamma$

Mass (GeV/c^2)

Significance 4.6σ

Significance 4.3σ

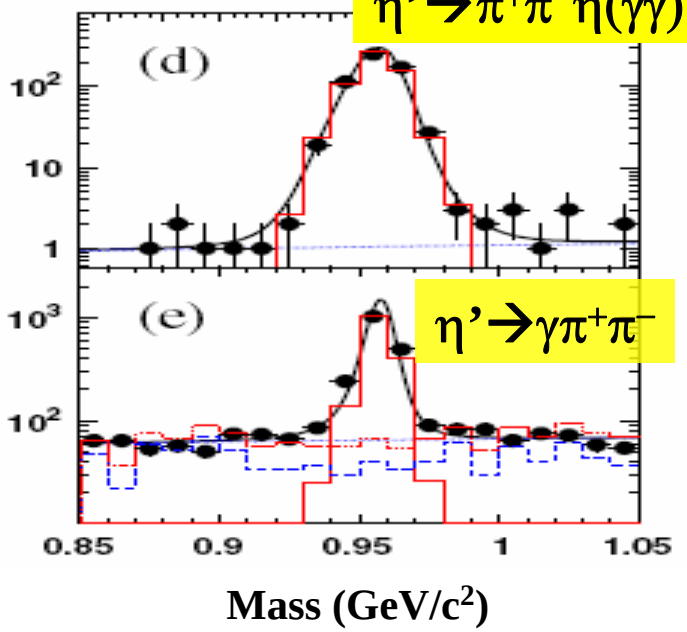


$\eta\to\pi^+\pi^-\pi^0$

$\eta\to3\pi^0$

Mass (GeV/c^2)

$\eta'\to\pi^+\pi^-\eta(\gamma\gamma)$



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

Mass (GeV/c^2)

Branching ratios (10^{-6}):

Mode	BESIII	Combined BESIII	PDG
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta(\pi^+\pi^-\pi^0)$	$1.78 \pm 0.72 \pm 0.17$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$		
$\psi' \to \gamma\eta'(\pi^+\pi^-\eta)$	$120 \pm 5 \pm 8$	$126 \pm 3 \pm 8$	121 ± 8
$\to \gamma\eta'(\pi^+\pi^-\gamma)$	$129 \pm 3 \pm 8$		

The first measurement:

$$R_{\psi'} = (1.10 \pm 0.38 \pm 0.07)\%$$

much smaller than

$$R_{J/\psi} = (21.1 \pm 0.9)\%$$

Study of $\chi_{cJ} \rightarrow \gamma V$ (V=ρ, ω, ϕ) (1)

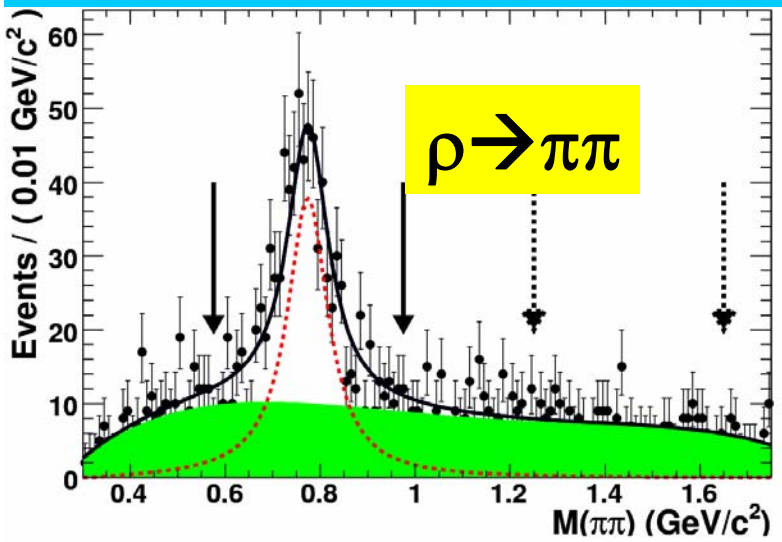
A favorable process to validate theoretical techniques

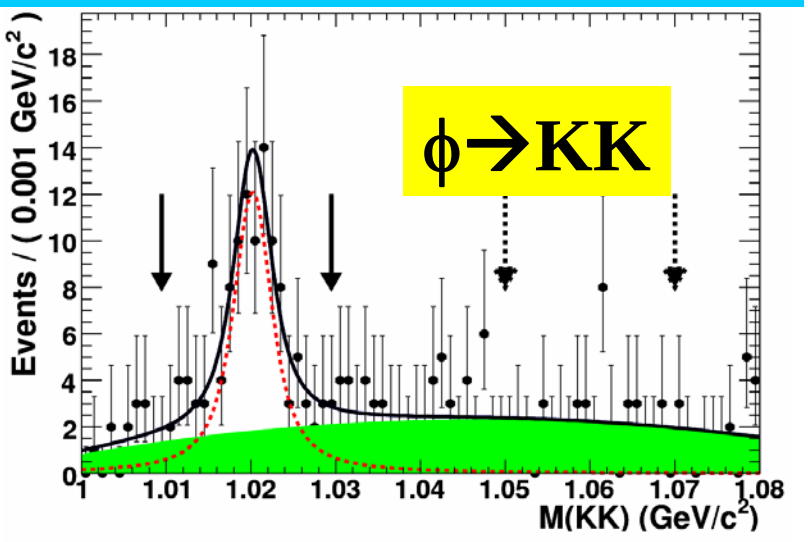
Theoretical predictions and results from CLEO-c on Br($\chi_{cJ} \rightarrow \gamma V$) ($10^{-6}$):

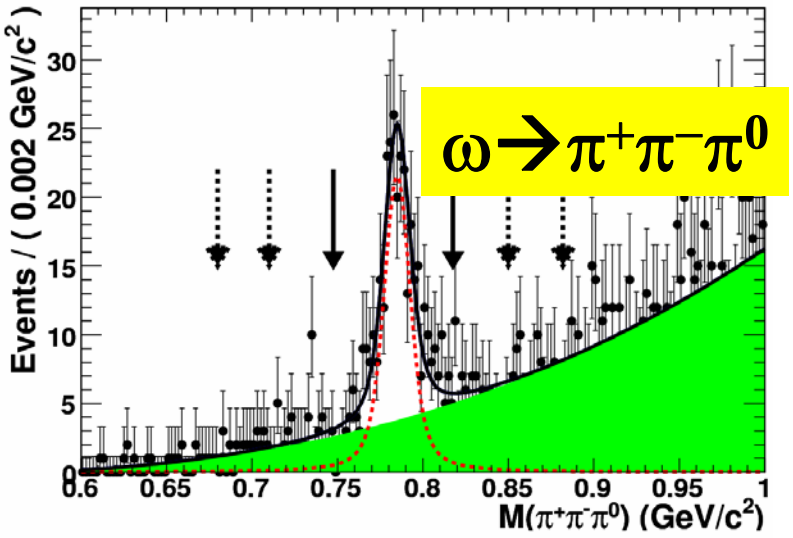
Mode	CLEO[1]	pQCD[2]	QCD[3]	QCD+QED[3]
$\chi_{c0} \rightarrow \gamma\rho^0$	< 9.6	1.2	3.2	2.0
$\chi_{c1} \rightarrow \gamma\rho^0$	$243 \pm 19 \pm 22$	14	41	42
$\chi_{c2} \rightarrow \gamma\rho^0$	< 50	4.4	13	38
$\chi_{c0} \rightarrow \gamma\omega$	< 8.8	0.13	0.35	0.22
$\chi_{c1} \rightarrow \gamma\omega$	$83 \pm 15 \pm 12$	1.6	4.6	4.7
$\chi_{c2} \rightarrow \gamma\omega$	< 7.0	0.5	1.5	4.2
$\chi_{c0} \rightarrow \gamma\phi$	< 6.4	0.46	1.3	0.03
$\chi_{c1} \rightarrow \gamma\phi$	< 26	3.6	11	11
$\chi_{c2} \rightarrow \gamma\phi$	< 13	1.1	3.3	6.5

1. PRL 101,151801 (2008). 2. Chin. Phys. Lett. 23, 2376 (2006). 3. hep-ph/0701009

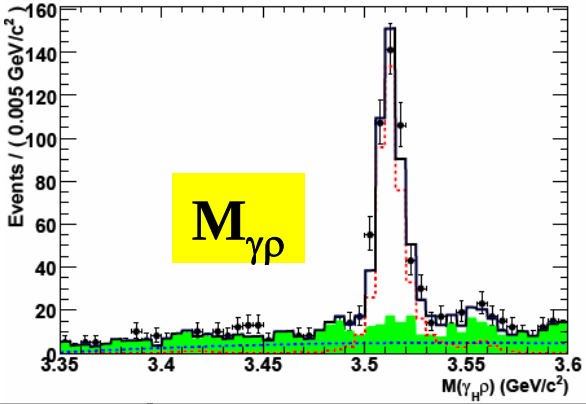
Study of $\chi_{cJ} \rightarrow \gamma V$ (V=ρ, ω, ϕ) (2)

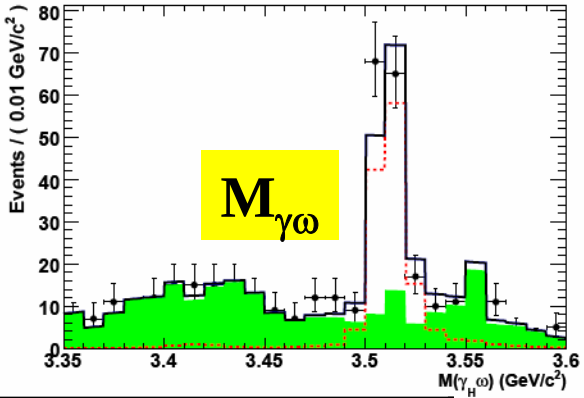


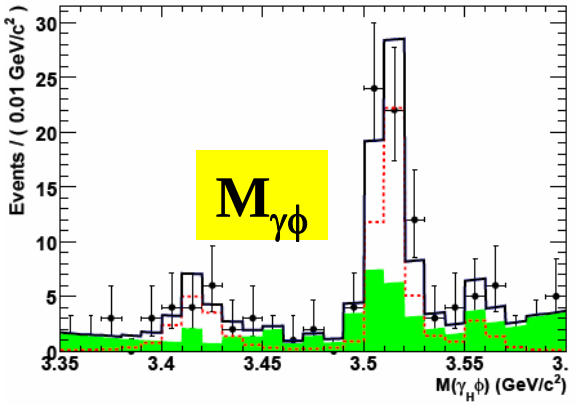




Study of $\chi_{cJ} \to \gamma V$ (V=ρ, ω, ϕ) (3)







B(10^{-6})	BESIII	CLEOc	PQCD
$\chi_{c0} \to \gamma\rho^0$	<10.5	<9.6	1.2
$\chi_{c1} \to \gamma\rho^0$	228±13±22	243 ±19 ±22	14
$\chi_{c2} \to \gamma\rho^0$	<20.8	<50	4.4
$\chi_{c0} \to \gamma\omega$	<12.9	<8.8	0.13
$\chi_{c1} \to \gamma\omega$	69.7±7.2±6.6	83 ±15 ±12	1.6
$\chi_{c2} \to \gamma\omega$	<6.1	<7.0	0.5
$\chi_{c0} \to \gamma\phi$	<16.2	<6.4	0.46
$\chi_{c1} \to \gamma\phi$	25.8±5.2±2.3	<26	3.6
$\chi_{c2} \to \gamma\phi$	<8.1	<13	1.1

- **$\chi_{c1} \to \gamma\phi$ observed for the first time.**
- **pQCD predictions ×10 too low.**
- **Difference may be explained by non-perturbative QCD "loop corrections". D.Y Chen *et al*, arXiv:1005.0066v2[hep-ph].**

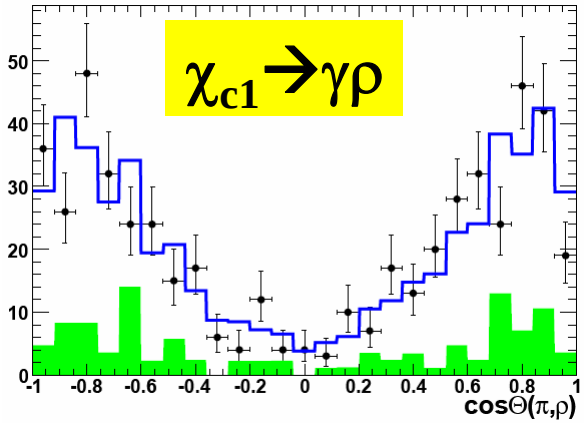
CLEOc: PRL 101, 151801 (2008)
pQCD: Y.J. Gao et al., hep-ph/0701009

Study of $\chi_{cJ} \to \gamma V$ (V=ρ, ω, ϕ) (4)

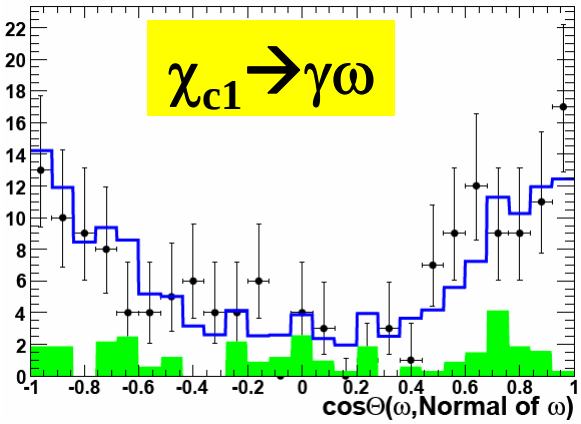
- **L: Longitudinal polarization, T: Transverse polarization, θ: Helicity angle**

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

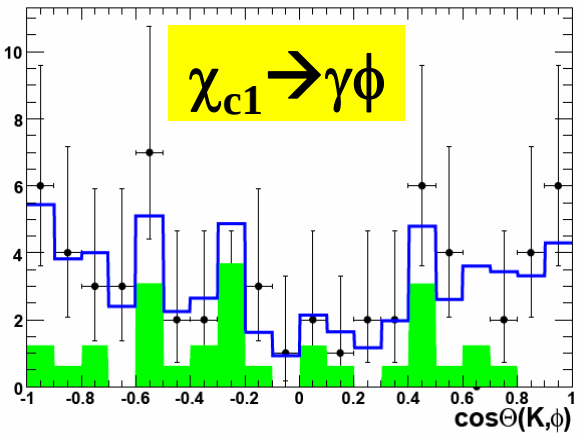
- **The longitudinal polarization dominates in the $\chi_{c1} \to \gamma V$:**



$f_T = 0.158 \pm 0.034^{+0.015}_{-0.014}$



$f_T = 0.247^{+0.090+0.044}_{-0.087-0.026}$



$f_T = 0.29^{+0.13+0.10}_{-0.12-0.09}$

Study of $\chi_{c1} \rightarrow VV$ (V=ω, ϕ)

- **Previous measurements from BESII.**

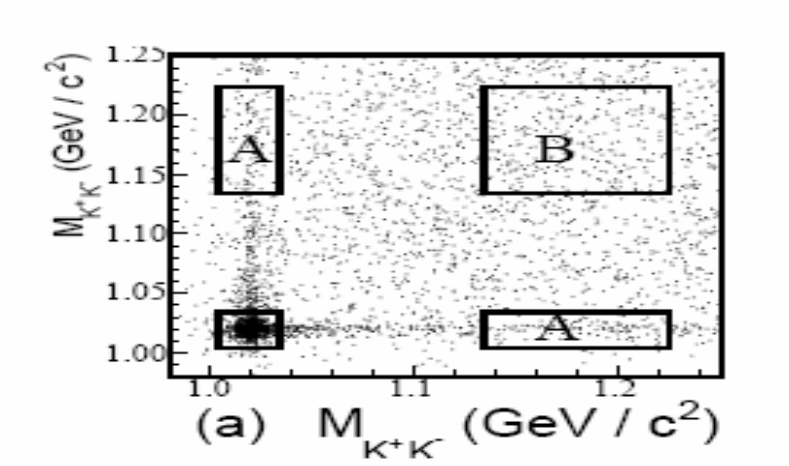
  Only χ_{c0} and χ_{c2} decays into ϕϕ and ωω are observed.

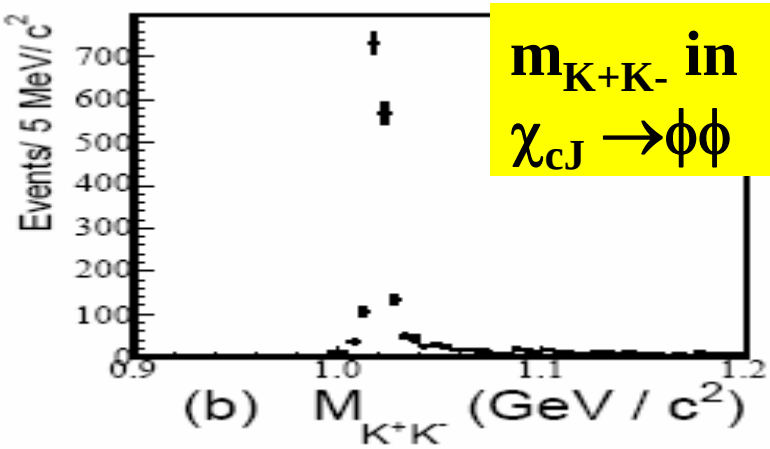
BR(10^{-3})	χ_{c0}	χ_{c2}
→ϕϕ BESII, PLB 642, 197 (2006)	0.94±0.21±0.13	1.70±0.30±0.25
→ωω BESII, PLB 630, 7 (2005)	2.29±0.58±0.41	1.77±0.47±0.36

- **$\chi_{c1} \rightarrow VV$ is suppressed due to helicity selection rule in pQCD**
- **$\chi_{cJ} \rightarrow \omega\phi$ is doubly OZI suppressed.**

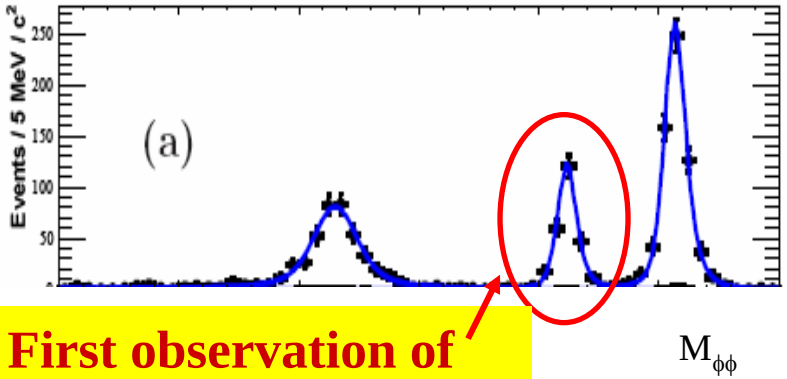
$\chi_{cJ} \rightarrow \phi\phi$, $\phi \rightarrow K^+K^-$

- Using kinematic fit to select $\gamma 2(K^+K^-)$ candidates
- $\phi\phi$ pair reconstruction: minimize $[M^{(1)}(K^+K^-)-m_\phi]^2+ [M^{(2)}(K^+K^-)-m_\phi]^2$





m_{K+K-} in $\chi_{cJ} \rightarrow \phi\phi$

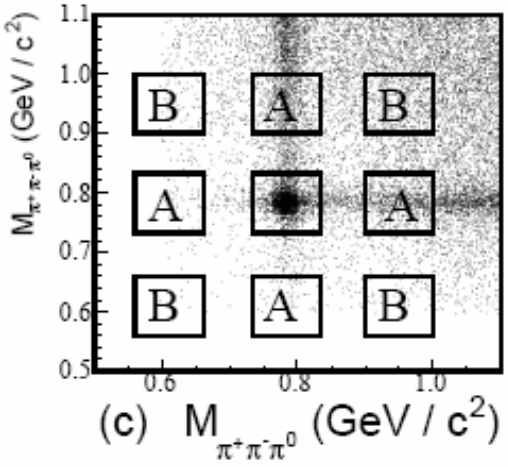


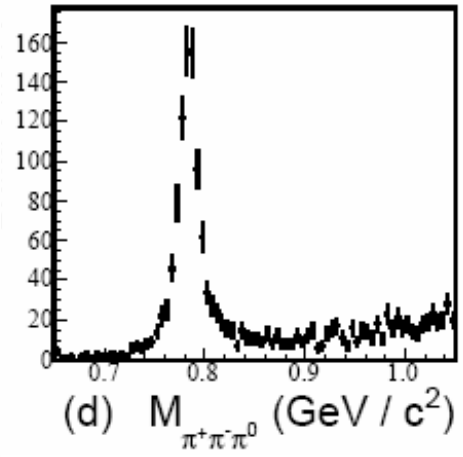
First observation of $\chi_{c1} \rightarrow \phi\phi$

BR(10^{-4})	BESIII	PDG08
$\chi_{c0} \rightarrow \phi\phi$	$7.8 \pm 0.4 \pm 0.8$	9.2 ± 1.9
$\chi_{c1} \rightarrow \phi\phi$	$4.1 \pm 0.3 \pm 0.4$	----
$\chi_{c2} \rightarrow \phi\phi$	$10.7 \pm 0.4 \pm 1.1$	14.8 ± 2.8

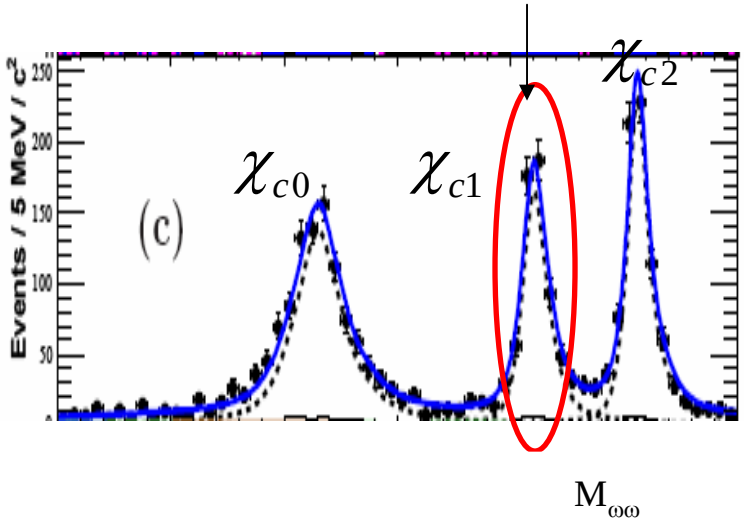
$\chi_{cJ} \rightarrow \omega\omega$, $\omega \rightarrow \pi^+\pi^-\pi^0$

- Using kinematic fit to select $5\gamma 2(\pi^+\pi^-)$ candidates
- $\pi^0\pi^0$ pair reconstruction: minimize $[M^{(1)}(\gamma\gamma)-m_{\pi 0}]^2+ [M^{(2)}(\gamma\gamma)-m_{\pi 0}]^2$ loop over 5 γ
- ω reconstruction: minimize $|m(\pi^+\pi^-\pi^0)-m_\omega|$, then remained $\pi^+\pi^-\pi^0$ reconstruct the other ω



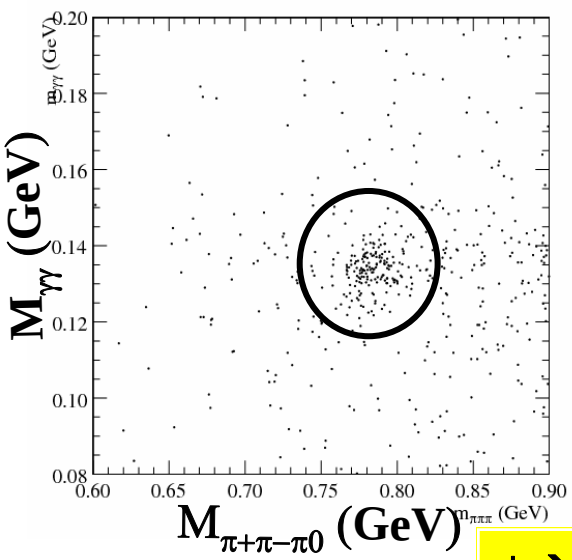


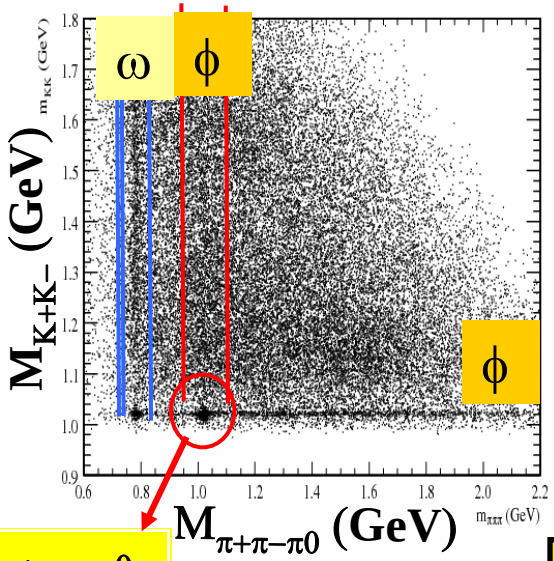
First observation of $\chi_{c1} \rightarrow \omega\omega$



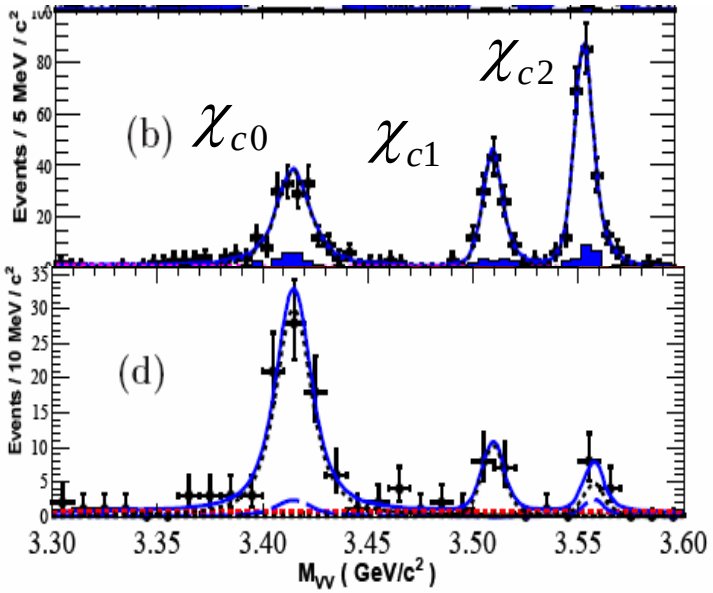
$\chi_{cJ} \to \omega\phi(\phi\phi)$, $\omega(\phi) \to \pi^+\pi^-\pi^0$, $\phi \to K^+K^-$

- K^+K^- are identified : minimize $|M(K^+K^-)-m_\phi|$
- Using kinematic fit to select $3\gamma 2K 2\pi$ candidates
- ω reconstruction: minimize $[M_{\gamma\gamma}-m_{\pi 0}]^2+ [M_{\gamma\gamma\pi+\pi-}-m_\omega]^2$ loop over 3γ





$\phi \to \pi^+\pi^-\pi^0$



Doubly OZI suppressed $\chi_{cJ} \to \omega\phi$ signals are observed for the first time.

2011-06

Conclusion of the $\chi_{c1}\rightarrow VV$ (V=ω, ϕ) Study

- **Latest measurements from BESIII.**
- **Helicity selection rule violated process $\chi_{c1}\rightarrow VV$ is observed.**
- **Doubly OZI suppressed process $\chi_{cJ}\rightarrow\omega\phi$ is also observed.**

Final states	Channel	$\mathcal{B}(\times10^{-4})$	PDG$(\times10^{-4})$
$\gamma 2(K^+K^-)$	$\chi_{c0}\rightarrow\phi\phi$	$7.8\pm0.4\pm0.8$	9.2 ± 1.9
	$\chi_{c1}\rightarrow\phi\phi$	$4.1\pm0.3\pm0.4$	—
	$\chi_{c2}\rightarrow\phi\phi$	$10.7\pm0.4\pm1.1$	14.8 ± 2.8
$\gamma K^+K^-\pi^+\pi^-\pi^0$	$\chi_{c0}\rightarrow\phi\phi$	$9.2\pm0.7\pm1.0$	9.2 ± 1.9
	$\chi_{c1}\rightarrow\phi\phi$	$5.0\pm0.5\pm0.6$	—
	$\chi_{c2}\rightarrow\phi\phi$	$10.7\pm0.7\pm1.2$	14.8 ± 2.8
Combined	$\chi_{c0}\rightarrow\phi\phi$	$8.0\pm0.3\pm0.8$	9.2 ± 1.9
	$\chi_{c1}\rightarrow\phi\phi$	$4.4\pm0.2\pm0.5$	—
	$\chi_{c2}\rightarrow\phi\phi$	$10.7\pm0.3\pm1.2$	14.8 ± 2.8
$\gamma 2(\pi^+\pi^-\pi^0)$	$\chi_{c0}\rightarrow\omega\omega$	$9.5\pm0.3\pm1.1$	22 ± 7.0
	$\chi_{c1}\rightarrow\omega\omega$	$6.0\pm0.2\pm0.7$	—
	$\chi_{c2}\rightarrow\omega\omega$	$8.9\pm0.3\pm1.1$	19.0 ± 6.0
$\gamma K^+K^-\pi^+\pi^-\pi^0$	$\chi_{c0}\rightarrow\omega\phi$	$1.2\pm0.1\pm0.2$	—
	$\chi_{c1}\rightarrow\omega\phi$	$0.22\pm0.06\pm0.02$	—
	$\chi_{c2}\rightarrow\omega\phi$	<0.2	—

Summary

- With the largest ψ' data sample in the world and good performance of BEPCII and BESIII, several recent results about charmonium decay came out:
  - Observation of h_c
  - First evidence for $\psi' \rightarrow \gamma P$ ($P=\pi^0, \eta$)
  - Study of $\chi_{cJ} \rightarrow \gamma V$ ($V=\rho,\omega,\phi$)
  - Study of $\chi_{cJ} \rightarrow VV$ ($V=\omega,\phi$)
- More exciting results are coming soon from BESIII.

Thank you / Merci !