Recent Progress on Charmonium Decays at BESIII

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List of Contents:

- Introduction
- BEPCII/BESIII Experiment
- Study of $\psi' \to \gamma P$ ($P=\pi^0,\eta,\eta'$)
- Study of Hadronic and Radiative Decays of χ_{cJ}
- Study of $\eta'_c \to VV$ ($V=\rho,K^*,\phi$)
- Study of CP and P Violation through $P \to \pi\pi$ ($P=\eta, \eta', \eta_c$)
- Summary

Why Charmonium Insteresting: onium states

- Strongly bound $q\bar{q}$ states
- Non-relativistic QM applicable (Appelquist, Politzer)
  - QCD analog to positronium
  - Provide insight into QCD
- Low Q^2, non-perturbative

? **Masses**

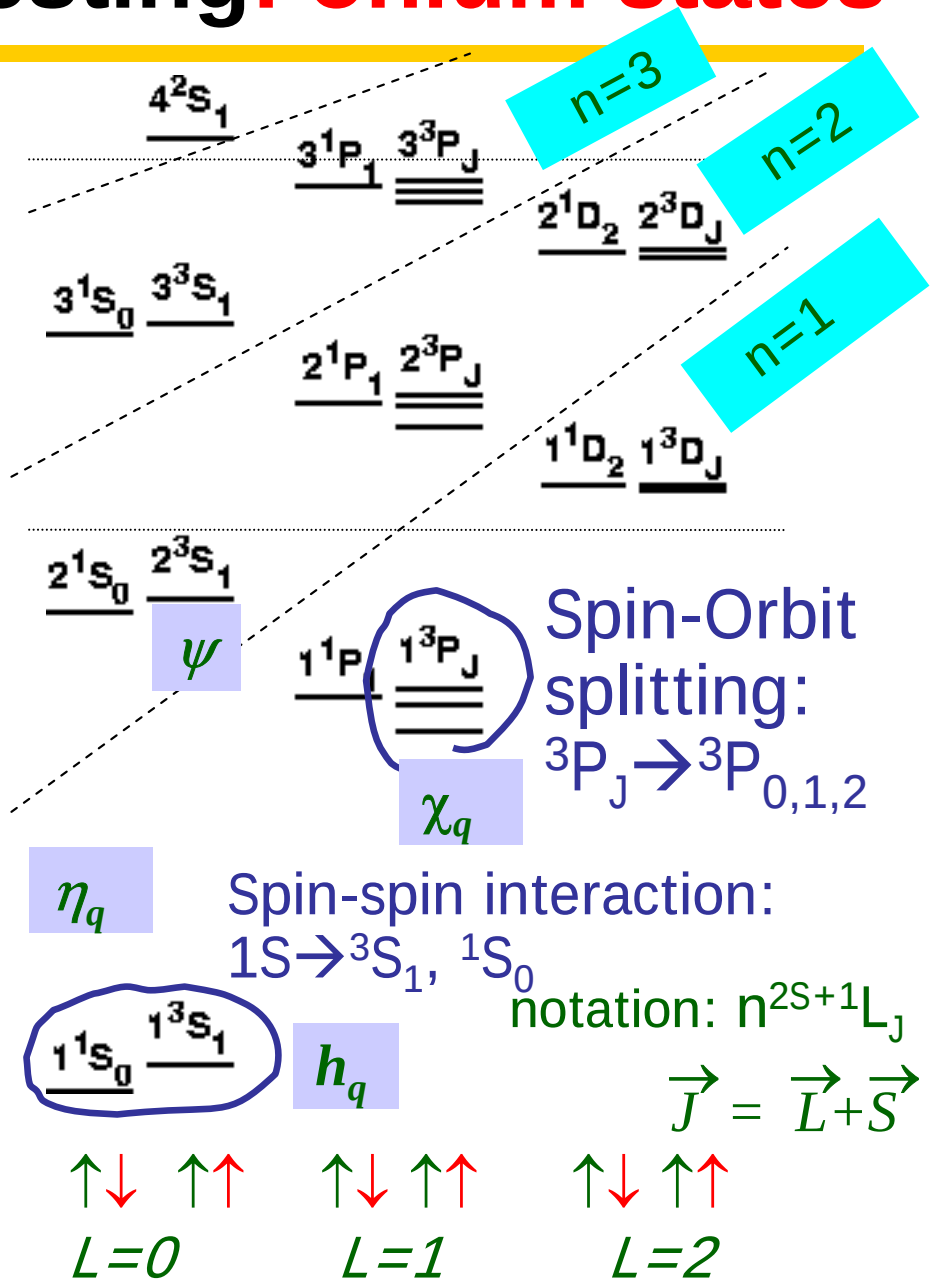
? **Widths**

? **Production and decay dynamics**

Partly discovery, partly precision measurements

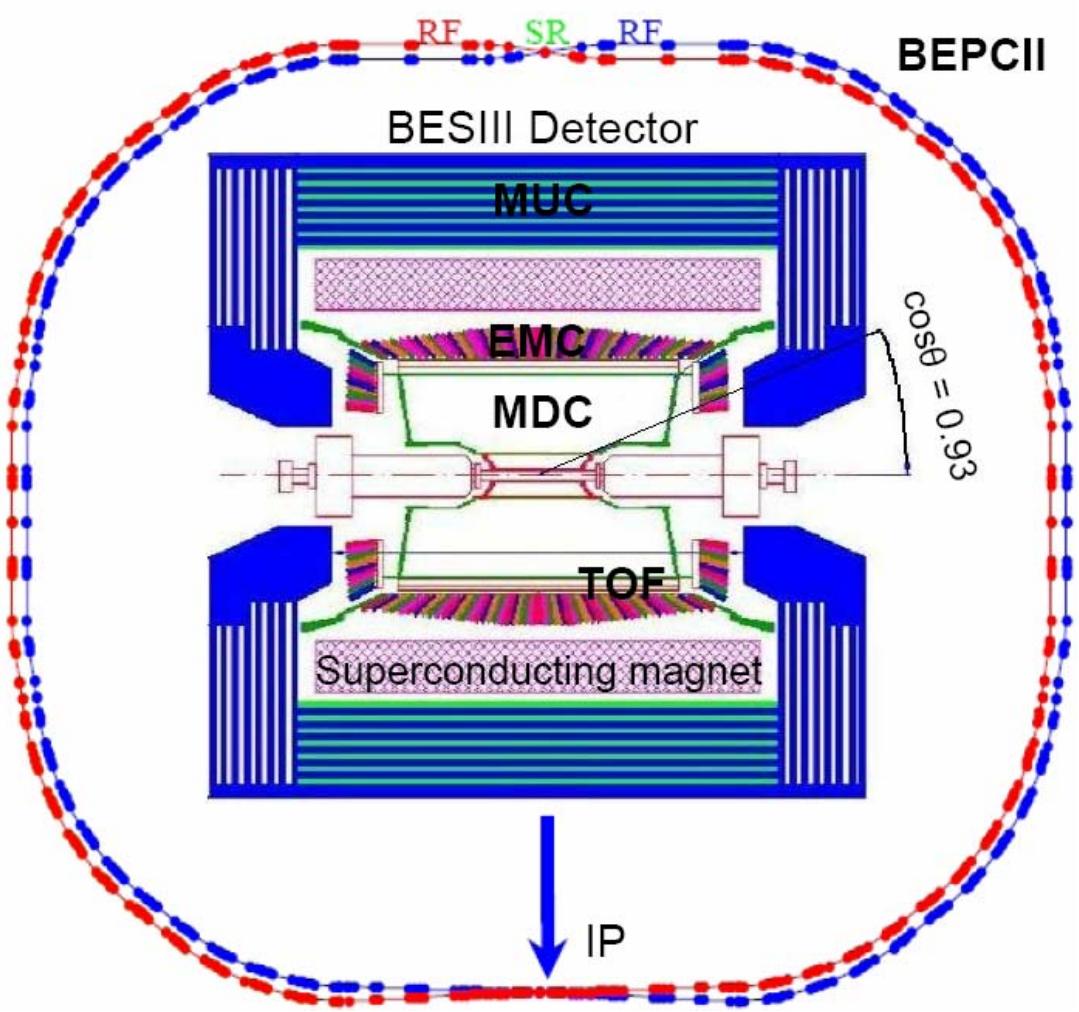
$c\bar{c}$: 589MeV

e^+e^-:5×10^{-6}MeV



BEPCII and BESIII

world-solo charm-factory



BEPCII:

- double ring
- Beam energy: 1.0 ~ 2.3 GeV
- Luminosity: 1×10^{33} $cm^{-2}s^{-1}$
- Optimum energy: 1.89 GeV

BESIII Spectrometer:

MDC: $\sigma(p_T)/p_T$ = 0.5% @ 1GeV
dE/dx_{reso} < 6%

TOF: 80 ps (for bhabha, barrel)

EMC: $\sigma(E)/E = 2.5\% \times \sqrt{E}$

July 20, 2008: first e^+e^- collision event in BESIII

April 14, 2009: took ~104M $\psi(2S)$ events (~40 days)

May 29, 2009: took ~41 pb^{-1} continuum data @3.65GeV

more in Prof. Shan Jin's talk

Data Samples at BESIII

Until July 2011:

Type	BES-III ($\times 10^6$)	BESII ($\times 10^6$)	CLEO-c ($\times 10^6$)
J/ψ	225	58	-
$\psi(2S)$	106	14	27
DDbar	~19.5(2.9fb^{-1})	0.2(0.03fb^{-1})	5.4(0.8fb^{-1})
DsDs	~0.5fb^{-1}@4.01GeV	-	Scan
DsDs*	-	-	0.55(0.6fb^{-1})

And BESIII will continue collecting

- **more J/ψ, ψ', $\psi(3770)$**
- **data at higher energies (for *XYZ* searches, *R* scan and *Ds* physics)**

the world largest resonance-produced charmonium dataset

➔ facilitate to study the charmonium-related physics:

✓ Hadron spectroscopy and charmonium decays

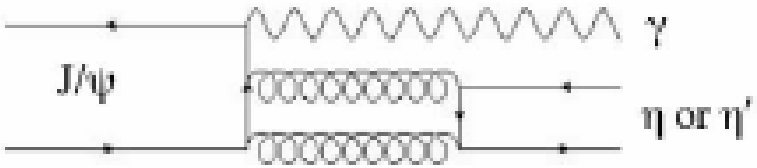
✓ New hidden charm

ψ' Radiative Decays into a Pesudoscalar Meson

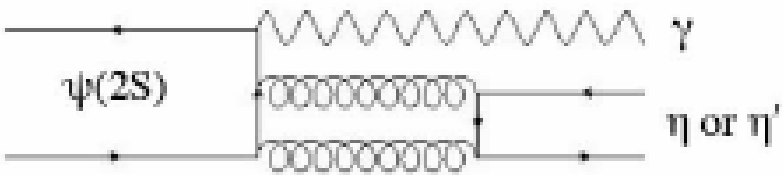
Study of $\psi' \to \gamma$ P, P=π^0,η,η' (i)

- $\psi' \to \gamma$ P are important tests for various mechanisms:

Vector meson Dominance Model (VDM); Couplings & form factor; Mixing of η-η'(-η_c); FSR by light quarks; 12% rule and "$\rho\ \pi$ puzzle".



VS



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

LO-pQCD

$\Downarrow$

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

PRP 112,173 (1984)

Theory

CLEO-c: PRD 79, 111101 (2009)

J/ψ, ψ', ψ'' $\to \gamma$ P

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

No Evidence for $\psi' \to \gamma\ \pi^0$ or $\gamma\ \eta$

Br($\psi' \to \gamma\eta'$)=(1.19 $\pm$ 0.09)%

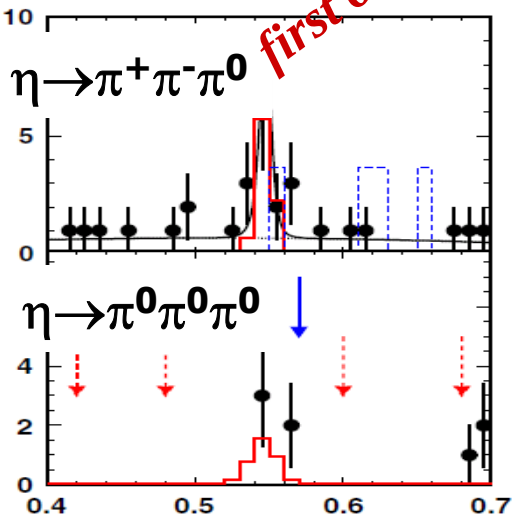
$R_{\psi'}$ < 1.8% at 90% C.L.

$R_{\psi'} << R_{J/\psi}$

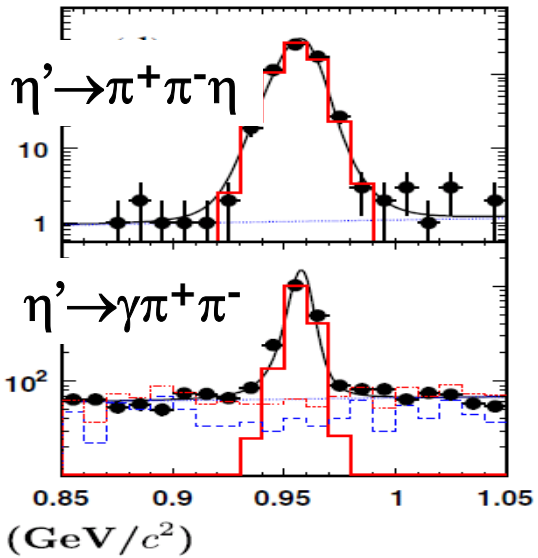
Experiment

Study of $\psi' \to \gamma$ P, P=π^0,η,η' (ii)

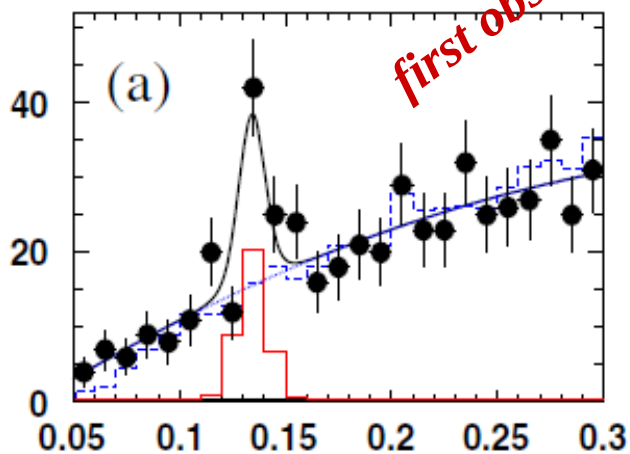
$\psi' \to \gamma\,\eta$:



$\psi' \to \gamma\,\eta'$



$\psi' \to \gamma\,\pi^0$



$R_{\psi'}$ = 1.10±0.38±0.07% << $R_{J/\psi}$

PRL 105, 261801 (2010)

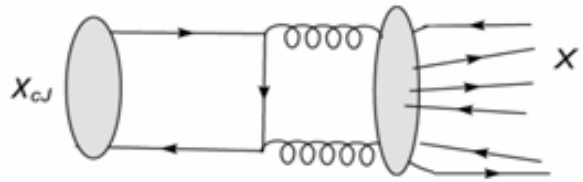
Mode	B(ψ') [x10^{-6}]	B(J/ψ) [x10^{-4}]	Q (%)
$\gamma\pi^0$	1.58±0.42	0.35±0.03	4.5 ± 1.3
$\gamma\eta$	1.38±0.49	11.04±0.34	0.13 ± 0.04
$\gamma\eta'$	126±9	52.8±1.5	2.4 ± 0.2

***Possible interpretation: Q. Zhao*, Phys. Lett. B697, 52 (2011)**

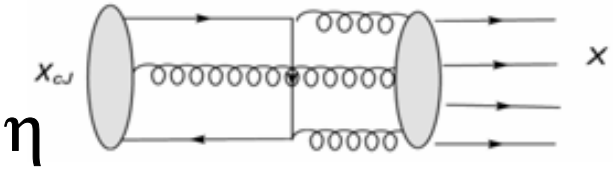
Hadronic Decays of χ_{cJ}

Hadronic Decays of χ_{cJ}

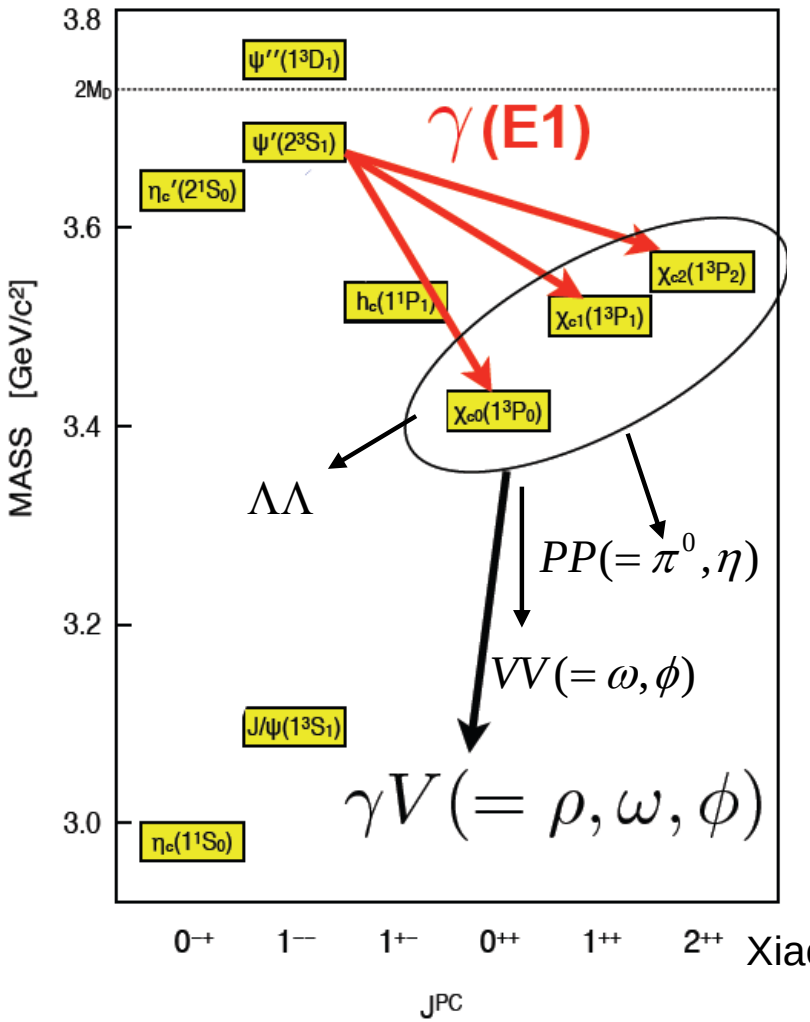
- most hadronic decay channels of χ_{cJ} not known
- to understand the P-wave charmonium decay dynamic
- a good laboratory to test singlet/octet mechanism at χ_{cJ} hadronic decays



Leading-order QCD

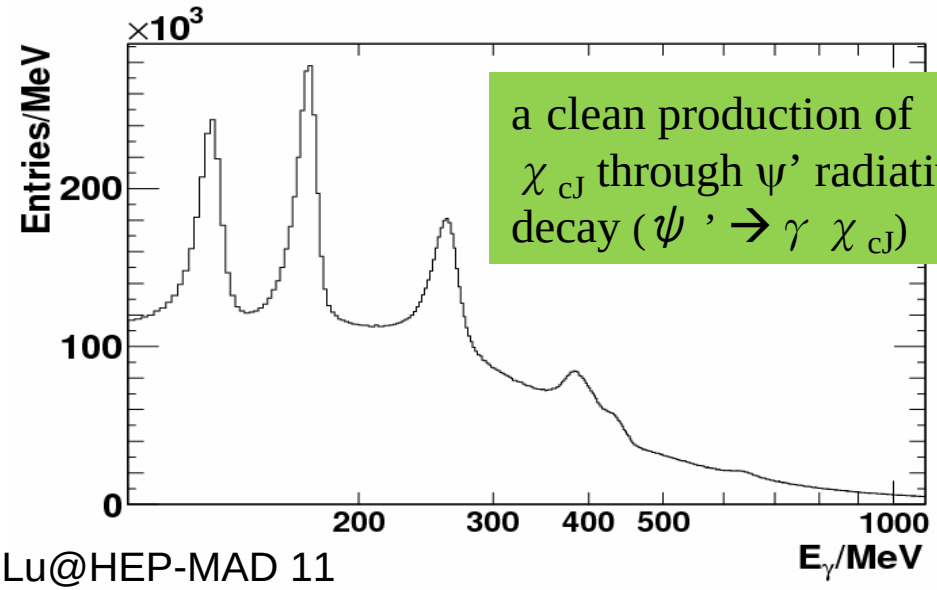


Color octect theory



BESIII measured:

- ✓ $\chi_{cJ} \rightarrow$ **PP, P=π^0, η**
- ✓ $\chi_{cJ} \rightarrow$ **VV, V=ω,ϕ**
- ✓ $\chi_{cJ} \rightarrow$ **$p\bar{p}K^+K^-$**



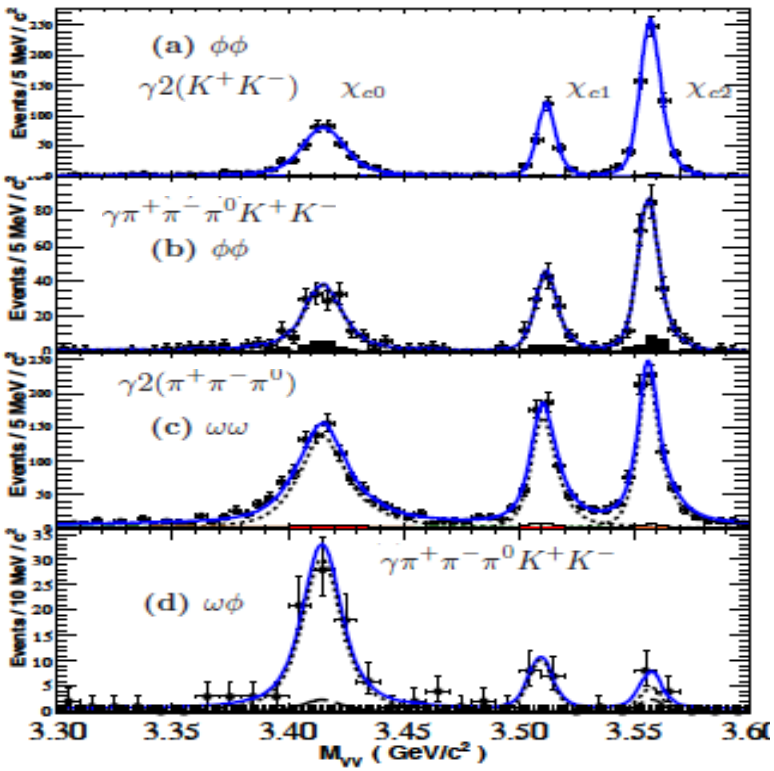
a clean production of χ_{cJ} through ψ' radiative decay ($\psi' \rightarrow \gamma\ \chi_{cJ}$)

$\chi_{cJ} \rightarrow VV$, $V=\omega,\phi$

Accepted by PRL

- Test QCD-based theory at χ_{cJ} decays
- Puzzles for $\chi_{c0} \rightarrow VV$: no helicity suppress
- $\chi_{c1} \rightarrow \phi\phi$, $\omega\omega$ is only allowed for L=2, suppression?
- $\chi_{cJ} \rightarrow \phi\omega$ OZI doubly suppressed

BESII [PLB 642,197(2006); PLB 630,7 (2005)]		
BR(10^{-3})	χ_{c0}	χ_{c2}
$\phi\phi$	**0.93±0.20**	**1.5±0.3**
$\omega\omega$	**2.3±0.7**	**2.0±0.7**



Mode	N_{net}	ϵ (%)	$\mathcal{B}(\times 10^{-4})$
$\chi_{c0} \rightarrow \phi\phi$	433 ± 23	22.4	$7.8 \pm 0.4 \pm 0.8$
$\chi_{c1} \rightarrow \phi\phi$	254 ± 17	26.4	$4.1 \pm 0.3 \pm 0.4$
$\chi_{c2} \rightarrow \phi\phi$	630 ± 26	26.1	$10.7 \pm 0.4 \pm 1.1$
$\rightarrow 2(K^+K^-)$			
$\chi_{c0} \rightarrow \phi\phi$	179 ± 16	1.9	$9.2 \pm 0.7 \pm 1.0$
$\chi_{c1} \rightarrow \phi\phi$	112 ± 12	2.3	$5.0 \pm 0.5 \pm 0.6$
$\chi_{c2} \rightarrow \phi\phi$	219 ± 16	2.2	$10.7 \pm 0.7 \pm 1.2$
$\rightarrow K^+K^-\pi^+\pi^-\pi^0$			
Combined:			
$\chi_{c0} \rightarrow \phi\phi$	—	—	$8.0 \pm 0.3 \pm 0.8$
$\chi_{c1} \rightarrow \phi\phi$	—	—	$4.4 \pm 0.3 \pm 0.5$
$\chi_{c2} \rightarrow \phi\phi$	—	—	$10.7 \pm 0.3 \pm 1.2$
$\chi_{c0} \rightarrow \omega\omega$	991 ± 38	13.1	$9.5 \pm 0.3 \pm 1.1$
$\chi_{c1} \rightarrow \omega\omega$	597 ± 29	13.2	$6.0 \pm 0.3 \pm 0.7$
$\chi_{c2} \rightarrow \omega\omega$	762 ± 31	11.9	$8.9 \pm 0.3 \pm 1.1$
$\rightarrow 2(\pi^+\pi^-\pi^0)$			
$\chi_{c0} \rightarrow \omega\phi$	76 ± 11	14.7	$1.2 \pm 0.1 \pm 0.2$
$\chi_{c1} \rightarrow \omega\phi$	15 ± 4	16.2	$0.22 \pm 0.06 \pm 0.02$
$\chi_{c2} \rightarrow \omega\phi$	< 13	15.7	< 0.2
$\rightarrow K^+K^-\pi^+\pi^-\pi^0$			

First observ.

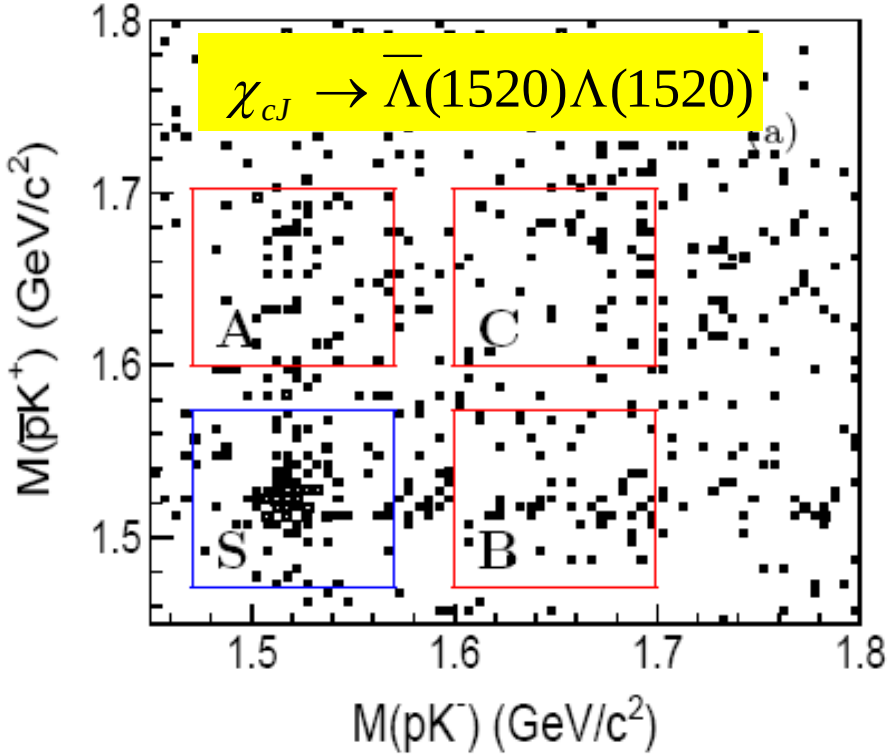
Evidence

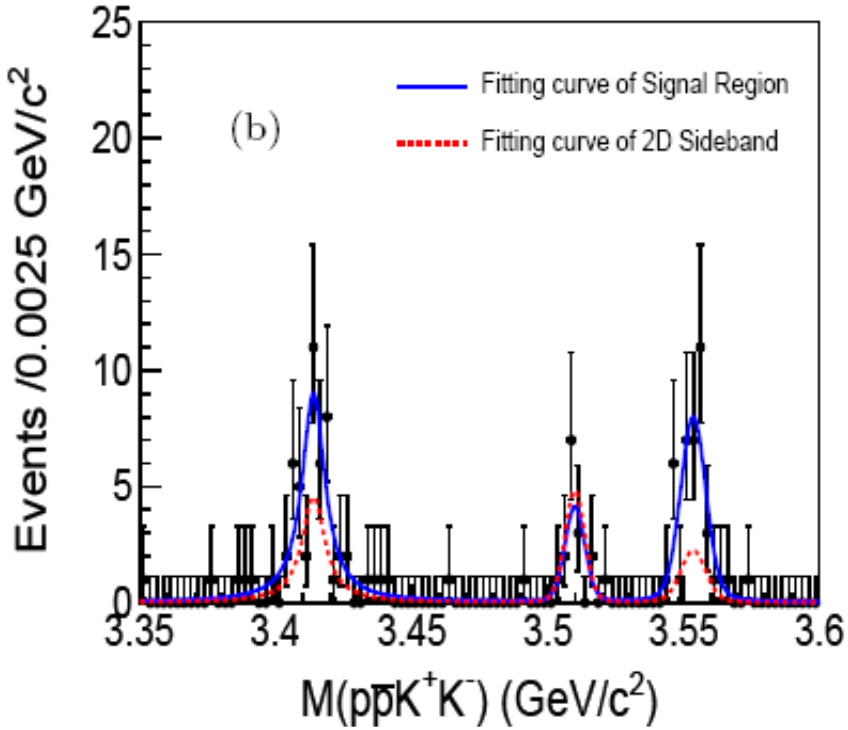
$\chi_{cJ} \to p\bar{p}K^+K^-$

PRD83, 112009(2011)

- $\chi_{cJ} \to p\bar{p}$: theoretical prediction is OK;
  $\chi_{cJ} \to \Lambda\bar{\Lambda}$: theoretical prediction is small
- χ_{cJ} decays into a pair of excited baryons: (NOT YET measured)

process	theory	experiment
$\mathcal{B}(\chi_{c0} \to p\,\bar{p})$	–	22.4 ± 2.7
$\mathcal{B}(\chi_{c1} \to p\,\bar{p})$	6.4 [395]	7.2 ± 1.3
$\mathcal{B}(\chi_{c2} \to p\,\bar{p})$	7.7 [395]	6.8 ± 0.7
$\mathcal{B}(\chi_{c0} \to \Lambda\bar{\Lambda})$	–	47 ± 16
$\mathcal{B}(\chi_{c1} \to \Lambda\bar{\Lambda})$	3.8 [395]	26 ± 12
$\mathcal{B}(\chi_{c2} \to \Lambda\bar{\Lambda})$	3.5 [395]	34 ± 17



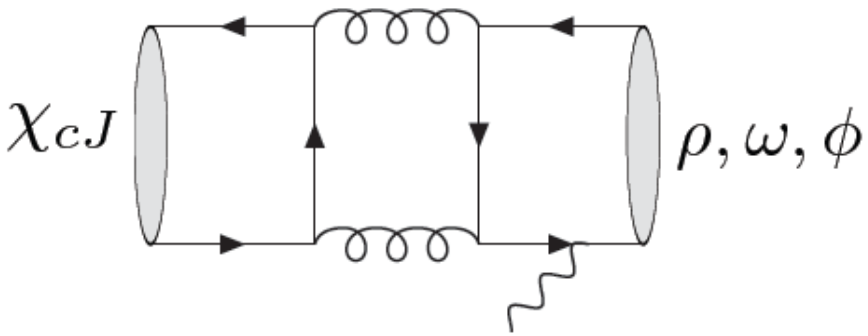


$\mathcal{B}(\chi_{cJ} \to \Lambda(1520)\bar{\Lambda}(1520))$ $(10^{-4}$

χ_{c0}	χ_{c1}	χ_{c2}
3.18 ± 1.11	< 0.86	5.05 ± 1.29

χ_{cJ} Radiative Decays into a Vector Meson

$\chi_{cJ} \to \gamma\, V(\rho,\omega,\phi)$: prediction by pQCD



- Information of C-even state
- Two gluon coupling
- Possible glue-ball or hybrid states
- Hadronization

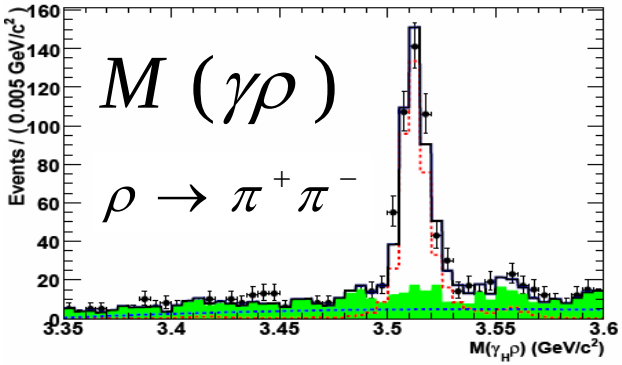
BRs. are in unit of 10^{-6}.

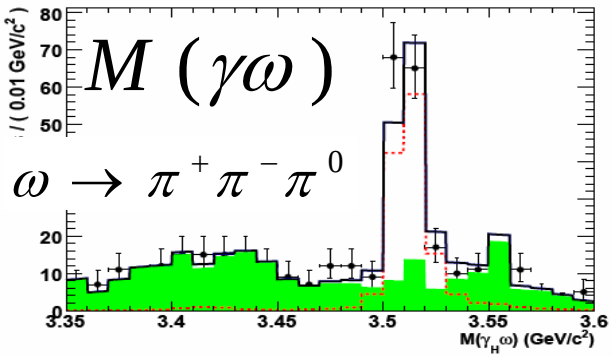
Mode	CLEO[1]	pQCD[2]	QCD[3]	QCD+QED[3]
$\chi_{c0} \to \gamma\rho^0$	< 9.6	1.2	3.2	2.0
$\chi_{c1} \to \gamma\rho^0$	$243 \pm 19 \pm 22$	14	41	42
$\chi_{c2} \to \gamma\rho^0$	< 50	4.4	13	38
$\chi_{c0} \to \gamma\omega$	< 8.8	0.13	0.35	0.22
$\chi_{c1} \to \gamma\omega$	$83 \pm 15 \pm 12$	1.6	4.6	4.7
$\chi_{c2}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

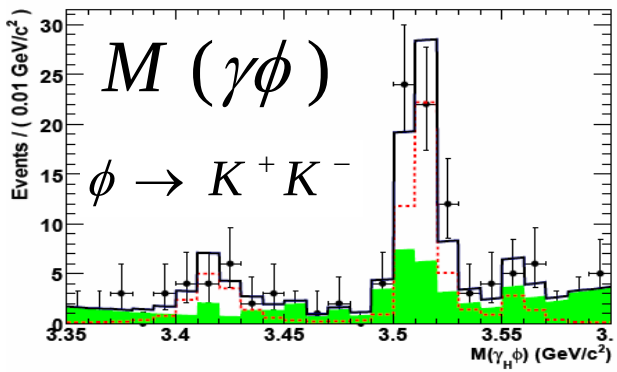
1. PRL 101,151801 (2008). 2. Chin. Phys. Lett. 23, 2376 (2006). 3. hep-ph/0701009

$\chi_{cJ} \to \gamma\, V(\rho,\omega,\phi)$ at BESIII

PRD83, 112005(2011)







Mode	CLEO[1]	pQCD[2]	QCD[3]	QCD+QED[3]	BESIII
$\chi_{c0} \to \gamma\rho^0$	< 9.6	1.2	3.2	2.0	<10.5
$\chi_{c1} \to \gamma\rho^0$	$243 \pm 19 \pm 22$	14	41	42	228±13±16
$\chi_{c2} \to \gamma\rho^0$	< 50	4.4	13	38	<20.8
$\chi_{c0} \to \gamma\omega$	< 8.8	0.13	0.35	0.22	<12.9
$\chi_{c1} \to \gamma\omega$	$83 \pm 15 \pm 12$	1.6	4.6	4.7	69.7±7.2±5.6
$\chi_{c2} \to \gamma\omega$	< 7.0	0.5	1.5	4.2	<6.1
$\chi_{c0} \to \gamma\phi$	< 6.4	0.46	1.3	0.03	<16.2
$\chi_{c1} \to \gamma\phi$	< 26	3.6	11	11	25.8±5.2±2.0
$\chi_{c2} \to \gamma\phi$	< 13	1.1	3.3	6.5	<8.1

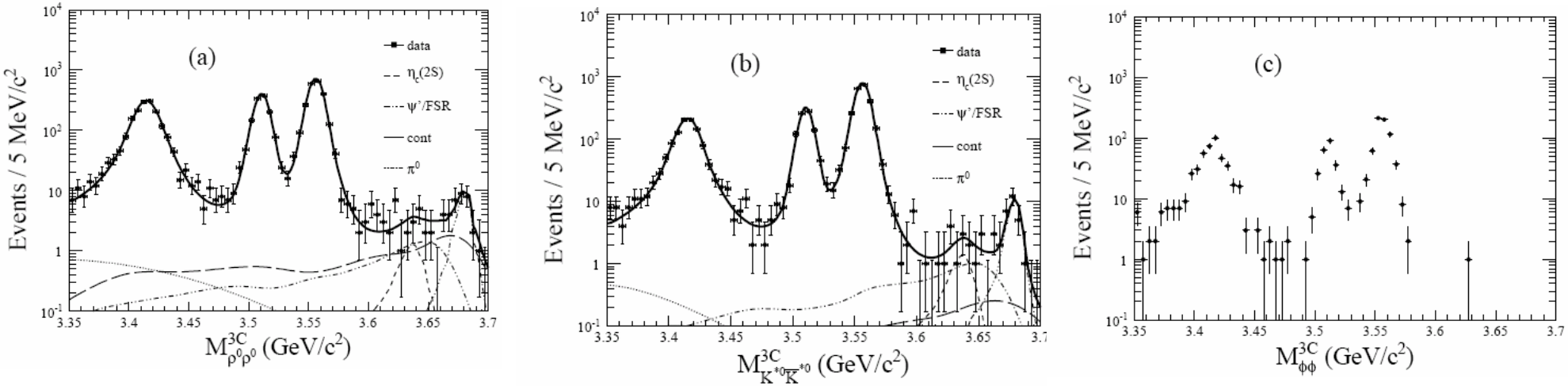
prediction by pQCD much lower than experiment

first observation

η'_c Decays into Two Vector Mesons

$\eta'_c \to VV$ ($V=\rho, K^*, \phi$)

- BESIII Preliminary: $B(\psi' \to \gamma\eta_c(2S)) = (4.7 \pm 0.9_{stat} \pm 3.0_{syst}) \times 10^{-4}$
- Highly suppressed by the helicity selection rule
- Possible contributions from intermediate charmed meson loops *[PRD81, 014017]*
- Predictions of BRs of $\eta'_c \to VV$ *[arXiv:1010.1343]*



V	$N^{up}_{\gamma VV}$	ε (%)	$\mathcal{B}^{up}(\psi' \to \gamma\eta_c(2S) \to \gamma VV)$ (10^{-7})	$\mathcal{B}^{up}(\eta_c(2S) \to VV)$ (10^{-3})	$\mathcal{B}^{theory}(\eta_c(2S) \to VV)$ (10^{-3})
ρ^0	17.3	14.3	11.4	3.1	6.4~28.9
K^{*0}	15.1	16.5	19.4	5.3	7.9~35.8
ϕ	3.9	19.9	7.8	2.0	2.1~9.8

- **No obvious signals of the decay $\eta'_c \to VV$**
- **Experimental results seems to be smaller than the theoretical predictions**

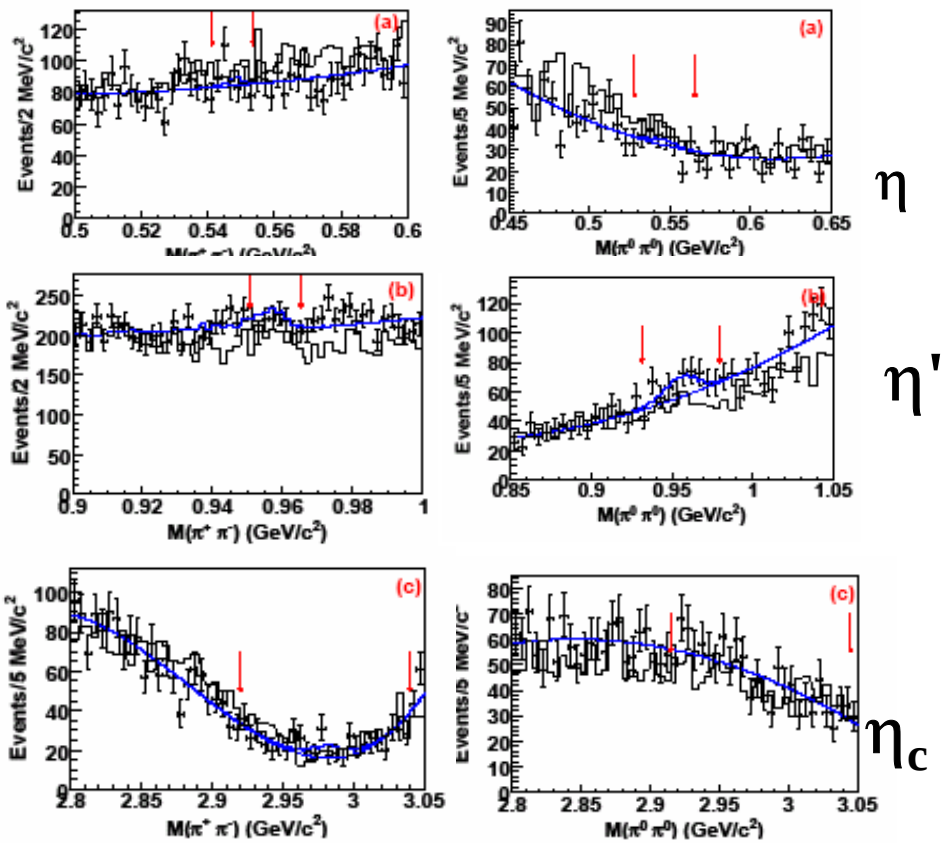
Study of CP and P Violation through $P \to \pi\pi$ ($P=\eta, \eta', \eta_c$)

PRD84:032006(2011)

CP and P Violation in P→ ππ (P=η, η', η_c)

- P→ ππ is CP and P violating process
- In Standard Model (SM), this can proceed only via the weak interaction with a branching fraction of order 10^{-27}; Imporved QCD only allow up to 10^{-15}
- The decay rates of P and CP invariance process can be experimentally tested
- Any higher level will trigger new physics beyond SM

Process	$N_{\rm sig}^{\rm UP}$	ε (%)	$\sigma_{\rm sys}$(%)	S	$\mathcal{B}^{\rm UP}$	$\mathcal{B}^{\rm UP}_{PDG}$
$\eta \to \pi^+\pi^-$	48	54.28	7.3	0.8σ	3.9×10^{-4}	1.3×10^{-5}
$\eta' \to \pi^+\pi^-$	32	53.81	8.6	0.1σ	5.5×10^{-5}	2.9×10^{-3}
$\eta_c \to \pi^+\pi^-$	92	25.27	27	1.5σ	1.3×10^{-4}	6×10^{-4}
$\eta \to \pi^0\pi^0$	36	23.75	8.6	0.6σ	6.9×10^{-4}	3.5×10^{-4}
$\eta' \to \pi^0\pi^0$	110	23.18	8.5	2.6σ	4.5×10^{-4}	9×10^{-4}
$\eta_c \to \pi^0\pi^0$	40	35.70	28	0.1σ	4.2×10^{-5}	4×10^{-4}



- **BESIII tightens many of the UP-LIMITs**
- **provide experimental limits for theoretical predictions on how much CP and P violation there may be in η' and η_c meson decays**

Summary

- Charmonium results help in understanding non-perturbative QCD
- High-luminosity and high-quality of BEPCII/BESIII data makes the rich results of charmonium decays:
  - Study of $\psi' \to \gamma P$ ($P=\pi^0,\eta,\eta'$) provides rich information for theoretcial understanding of non-perturbative QCD
  - Study of χ_{cJ} hadronic decays: $\chi_{cJ} \to$ **PP** (**P**=π^0, η); $\chi_{cJ} \to$ **VV** (**V**=ω,ϕ); $\chi_{cJ} \to$ **ppKK**: many new observations and many puzzles
  - Study of $\chi_{cJ} \to \gamma V$ ($V=\rho,\omega,\phi$) challenges the current QCD predictions
  - Up-limit of the decays of $\eta'_c \to VV$ ($V=\rho,K^*,\phi$)
  - CP Violation through $P \to \pi\pi$ ($P=\eta, \eta', \eta_c$): up-limit is given
  - More outputs are promising …

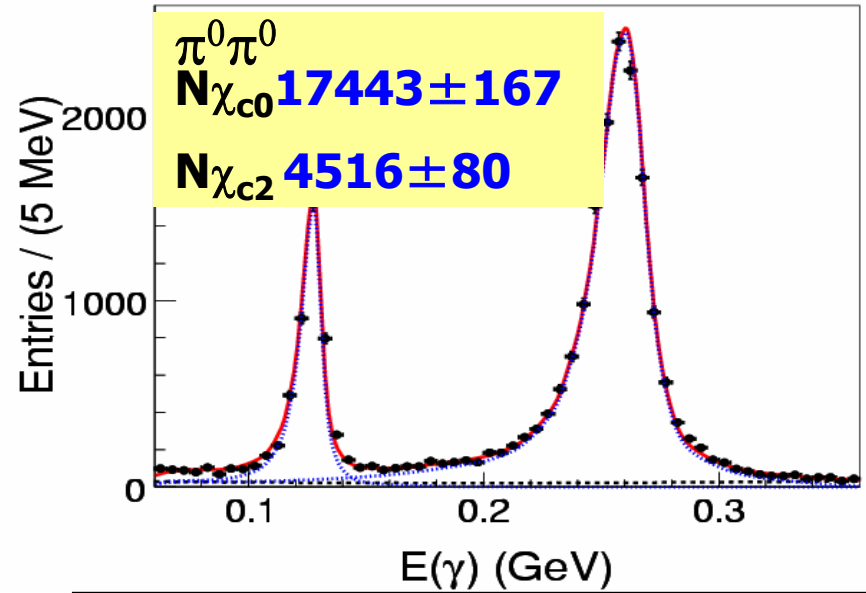
Thank You!

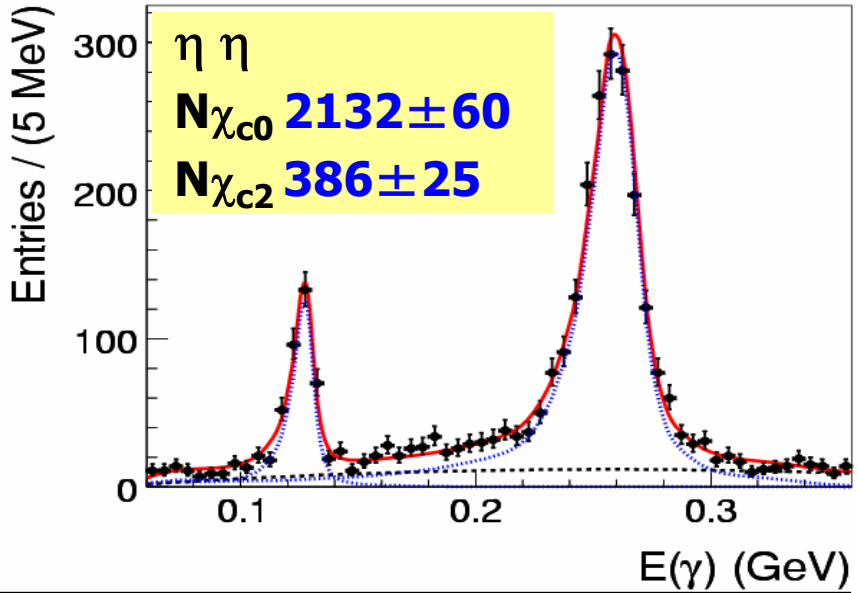
BACKUP

$\chi_{cJ} \rightarrow$ PP, P= π^0, η

PRD81:052005 (2010)

Interesting Channels for glueball searches.





BR (10^{-3})		χ_{c0}	χ_{c2}
$\pi^0\pi^0$	BESIII	3.23±0.03±0.23±0.14	0.88±0.02±0.06±0.04
	CLEO-c	2.94±0.07±0.32±0.15	0.68±0.03±0.07±0.04
	PDG10	2. 43±0.20	0.71±0.08
ηη	BESIII	3.44±0.10±0.24±0.13	0.65±0.04±0.05±0.03
	CLEO-c	3.18±0.13±0.31±0.16	0.51±0.05±0.05±0.03
	PDG10	2.4±0.4	<0.5

Note: the third error are due to the branching fractions of $\psi' \rightarrow \gamma\ \chi_{cJ}$