

Recent results from Charmonium decays at BESIII

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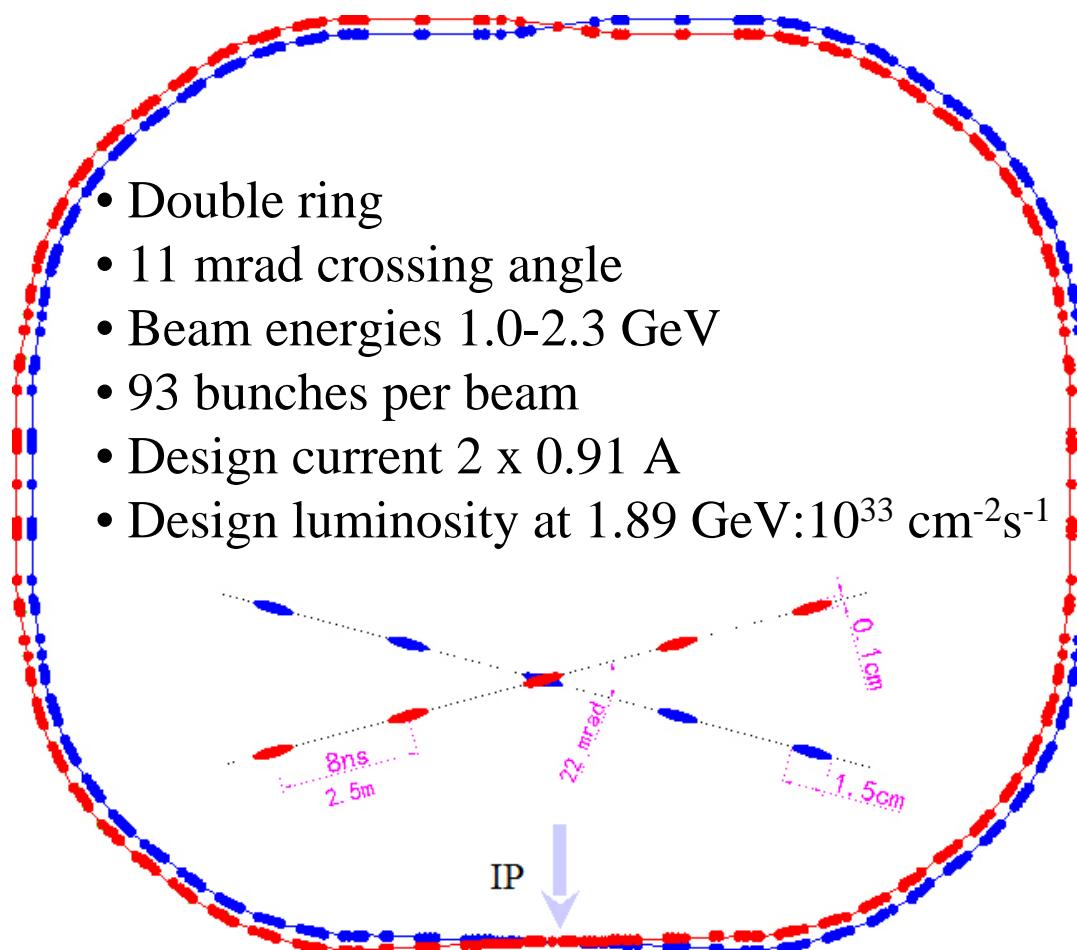
China Center of Advanced Science and Technology
(For BESIII Collaboration)

Outline

- BEPCII and BESIII
- Double radiative transition $\psi' \rightarrow \gamma\gamma J/\psi$
- Evidence for $\psi' \rightarrow \gamma P$ ($P = \pi^0, \eta$)
- $\psi' \rightarrow \gamma \chi_{cJ}$
 - $\chi_{cJ} \rightarrow 4\pi^0$
 - $\chi_{cJ} \rightarrow \gamma V$ ($V = \rho, \omega, \phi$)
 - $\chi_{cJ} \rightarrow VV$ ($V = \omega, \phi$)
- Summary

For detailed status of BEPCII and BESIII, and the published results $\psi' \rightarrow \pi^0 h_c$, $\chi_{cJ} \rightarrow \pi^0 \pi^0$, $\eta \eta$, please refer to Mr. H.M. Liu's talk "Status of the BESIII experiment" on 21st morning.

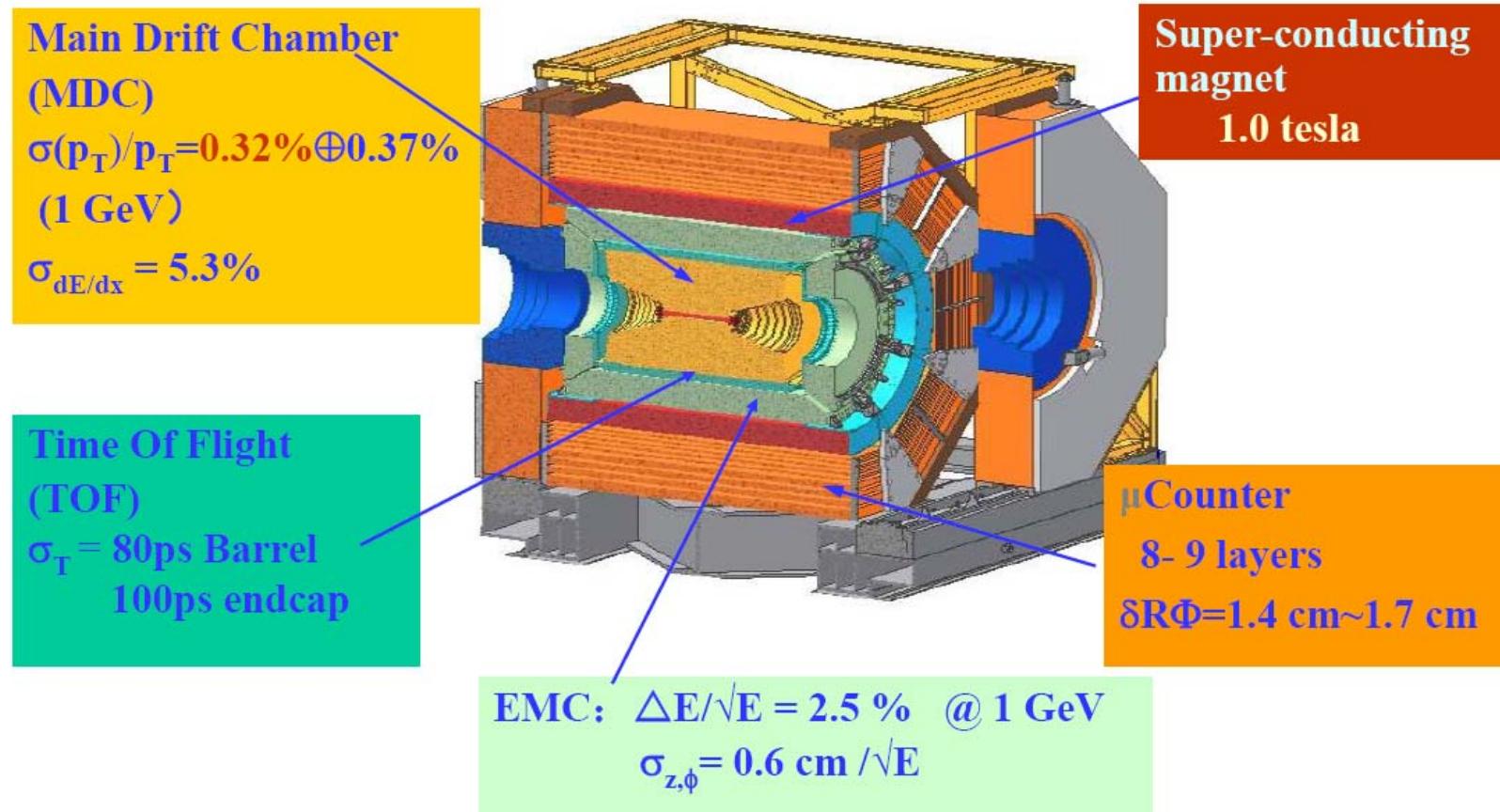
The Beijing Electron-Positron Collider II



BEPC II achievements

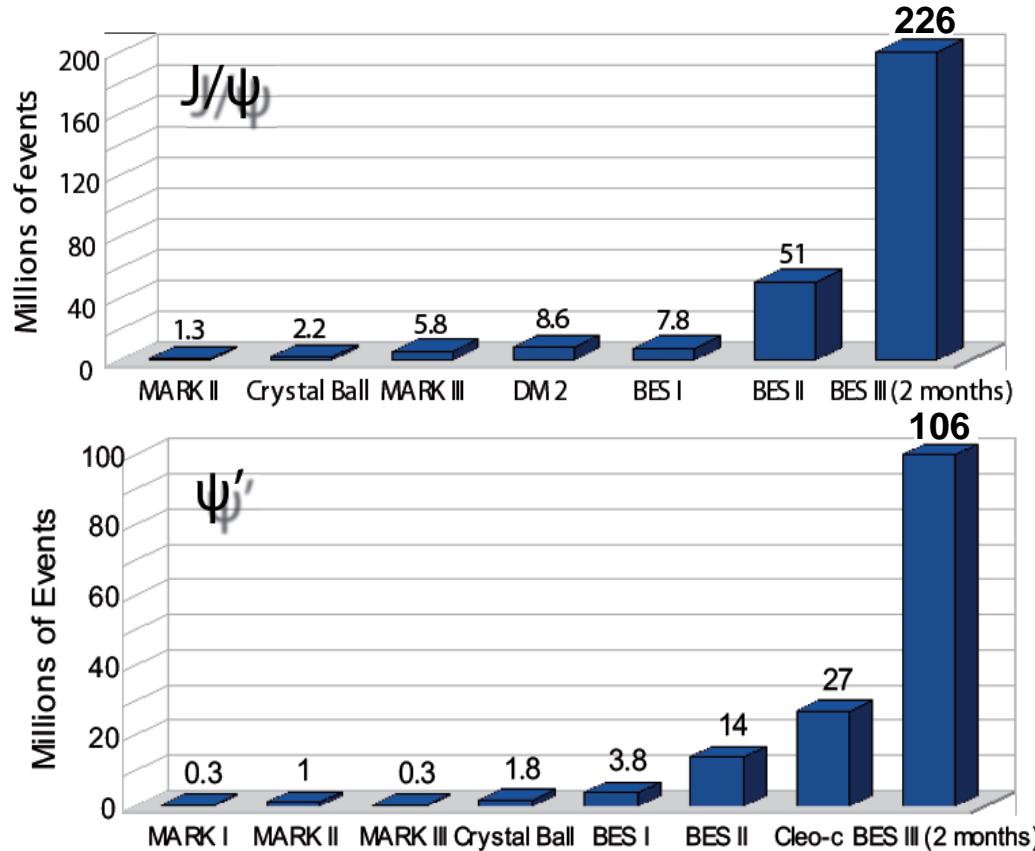
| parameters | design | Achieved | |
|--|---------------------------------------|-------------|-------------|
| | | BER | BPR |
| Energy (GeV) | 1.89 | 1.89 | 1.89 |
| Beam curr. (mA) | 910 | 650 | 700 |
| Bunch curr. (mA) | 9.8 | >10 | >10 |
| Bunch number | 93 | 93 | 93 |
| RF voltage | 1.5 | 1.5 | 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 | 0.33 | |

The Beijing Spectrometer III



BESIII data samples

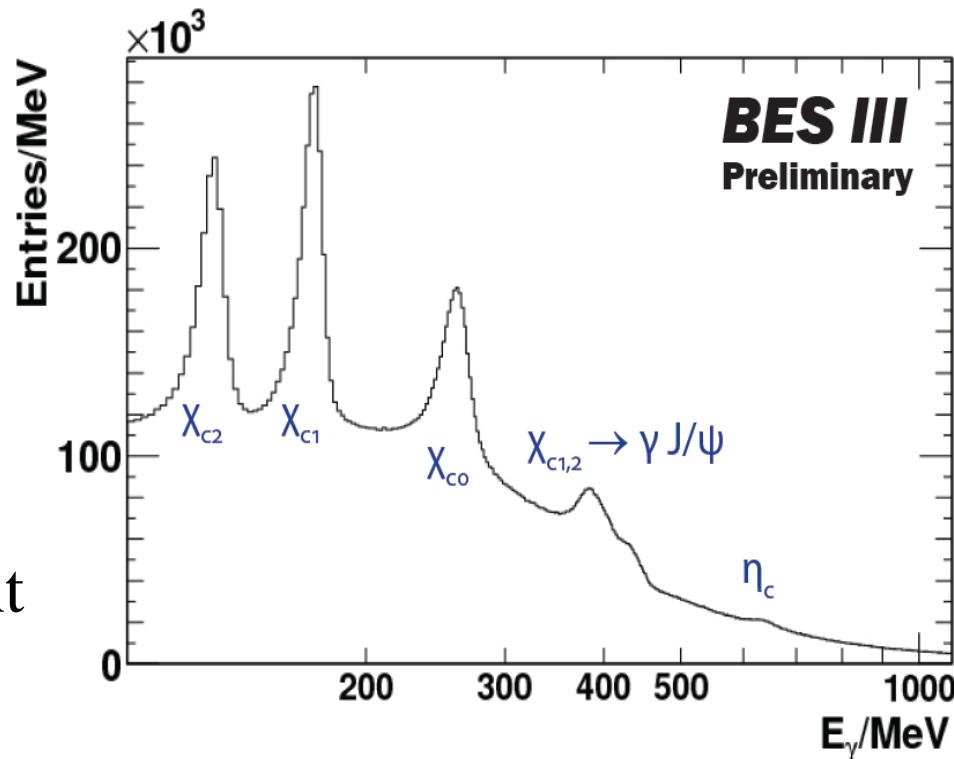
2009:



2010: $\sim 910 \text{ pb}^{-1} \psi(3770)$ data taken at 3.773GeV
 $\sim 70 \text{ pb}^{-1}$ energy scan data taken from 3.646 to 3.892 GeV

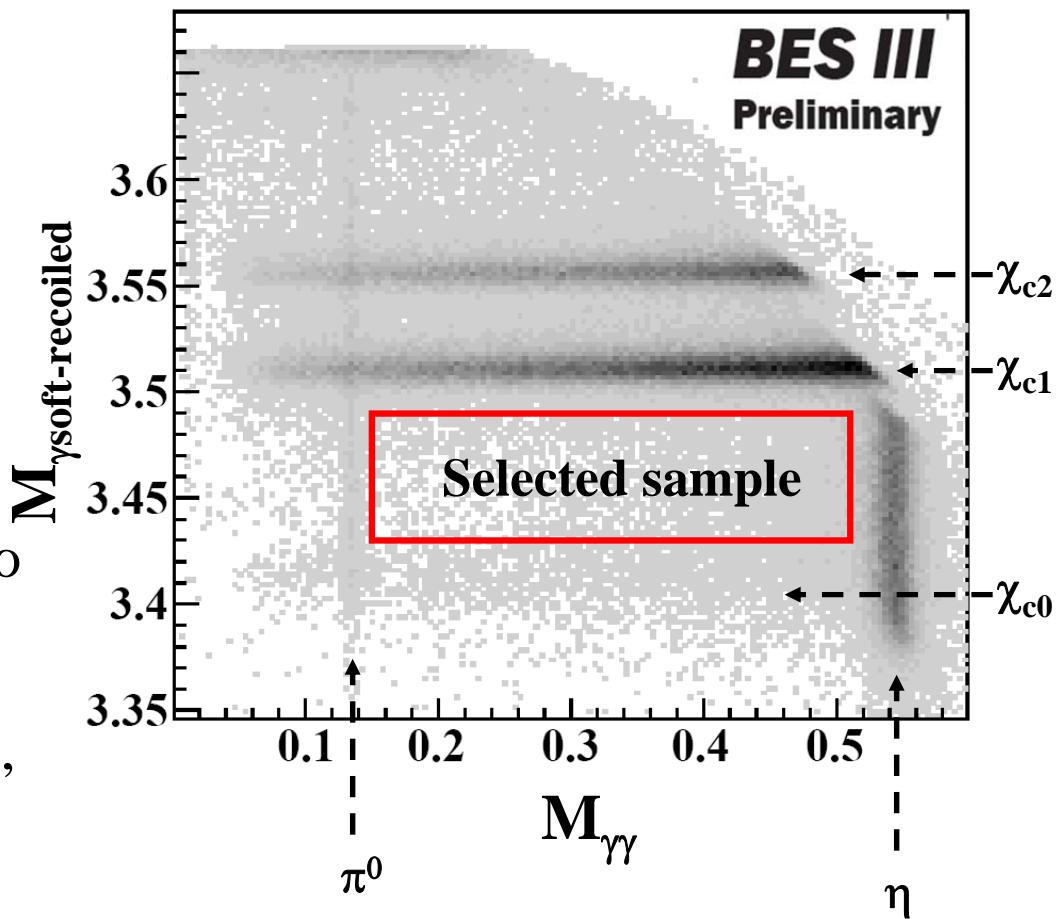
Radiative ψ' decay at BESIII

- Inclusive photon spectrum
- Good photon energy resolution
- Large statistics
- provide a clean environment to study transition between different charmonia and other decay of charmonia

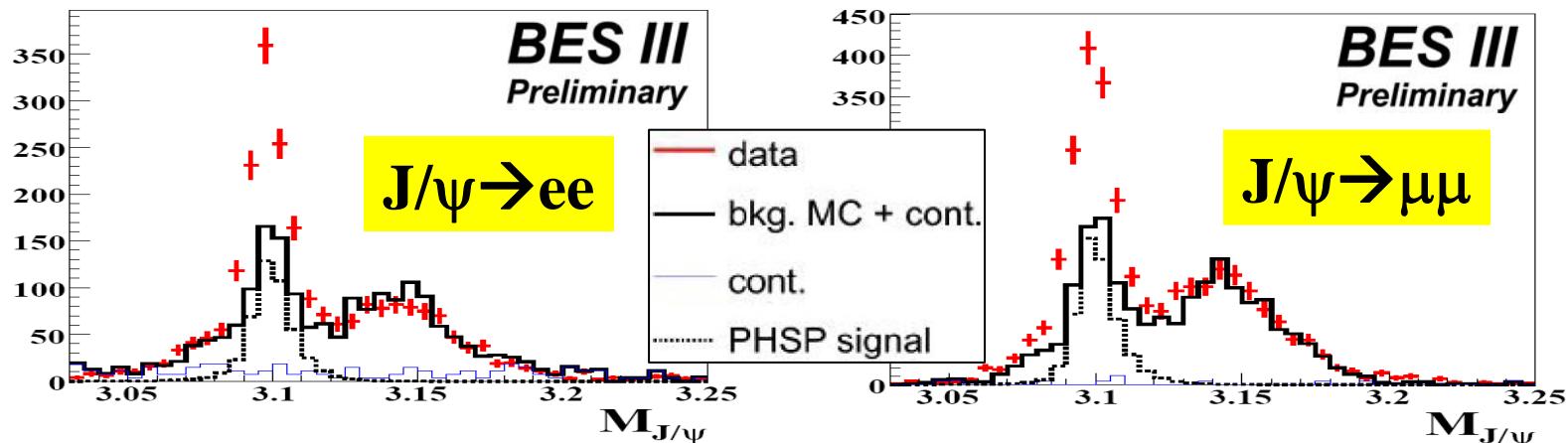


Double radiative transition $\psi' \rightarrow \gamma\gamma J/\psi$ (1)

- Two photon spectrum a powerful tool to study the excitation level (e.g. atomic hydrogen, positronium)
- CLEO:
 $\Upsilon(3S) \rightarrow \gamma\gamma \Upsilon(2S)$
- Two-photon transition in charmonium still escaped from experimental measurement due to small branching ratios
- With the largest ψ' data sample, two-photon transition between ψ' and J/ψ is studied through $\gamma\gamma ee$ and $\gamma\gamma \mu\mu$ decay modes.



Double radiative transition $\psi' \rightarrow \gamma\gamma J/\psi$ (2)



- Understood BG: QCD BG from ψ' decay ($\psi' \rightarrow \pi^0\pi^0 J/\psi$, $\psi' \rightarrow \gamma\chi_{cJ} \rightarrow \gamma\gamma J/\psi$) continuum processes
- Significant enhancement on the J/ψ peak

$$Br(\psi(2S) \rightarrow \gamma\gamma J/\psi)_{ee} = (1.09 \pm 0.08(\text{stat.})^{+0.22}_{-0.18}(\text{syst.})) \times 10^{-3}$$

$$Br(\psi(2S) \rightarrow \gamma\gamma J/\psi)_{\mu\mu} = (1.02 \pm 0.07(\text{stat.})^{+0.24}_{-0.21}(\text{syst.})) \times 10^{-3}.$$

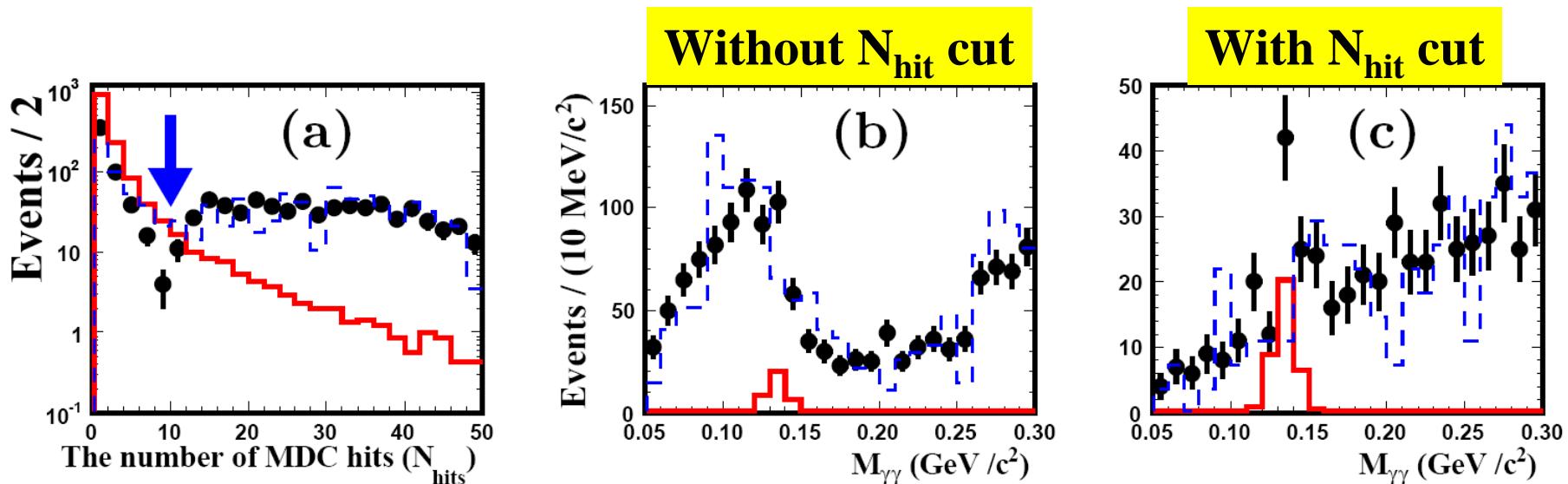
$$Br(\psi(2S) \rightarrow \gamma\gamma J/\psi) = (1.05 \pm 0.05(\text{stat.})^{+0.23}_{-0.20}(\text{syst.})) \times 10^{-3}.$$

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

- 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.)

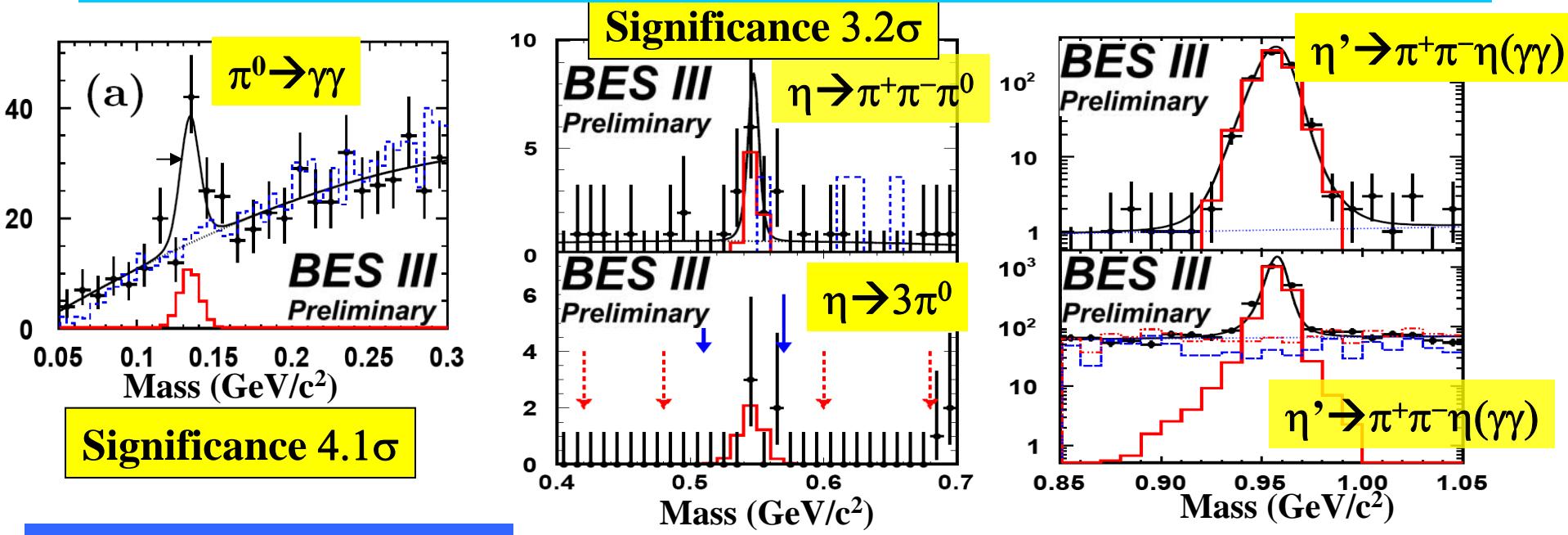
Evidence for $\psi' \rightarrow \gamma P$ ($P = \pi^0, \eta$) (2)

- One dangerous background for $\psi' \rightarrow \gamma \pi^0 (\gamma\gamma)$ is $e e \rightarrow \gamma\gamma$ events with one photon conversion but the produced ee pair are not well reconstructed.
- So special requirement $N_{\text{hits}} \leq 10$ 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 $\psi' \rightarrow \gamma P$ ($P = \pi^0, \eta$) (3)



Branching ratios (10^{-6}):

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

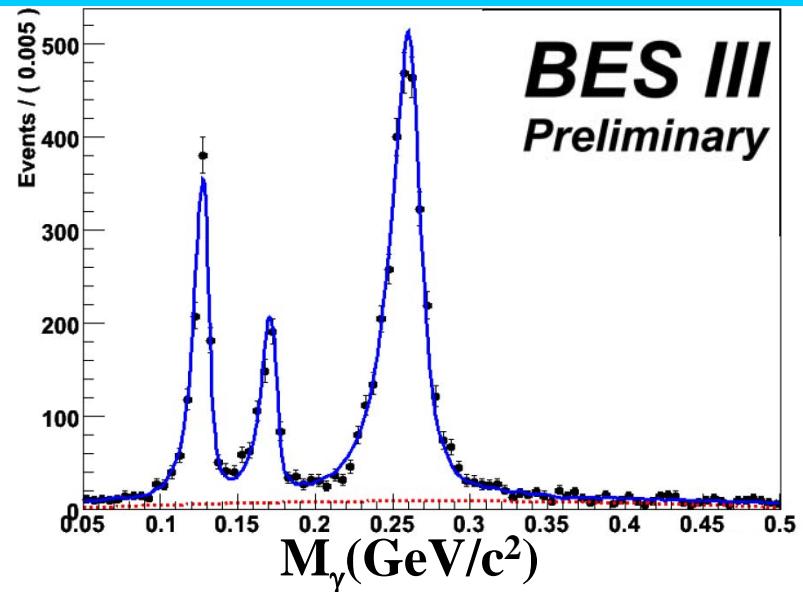
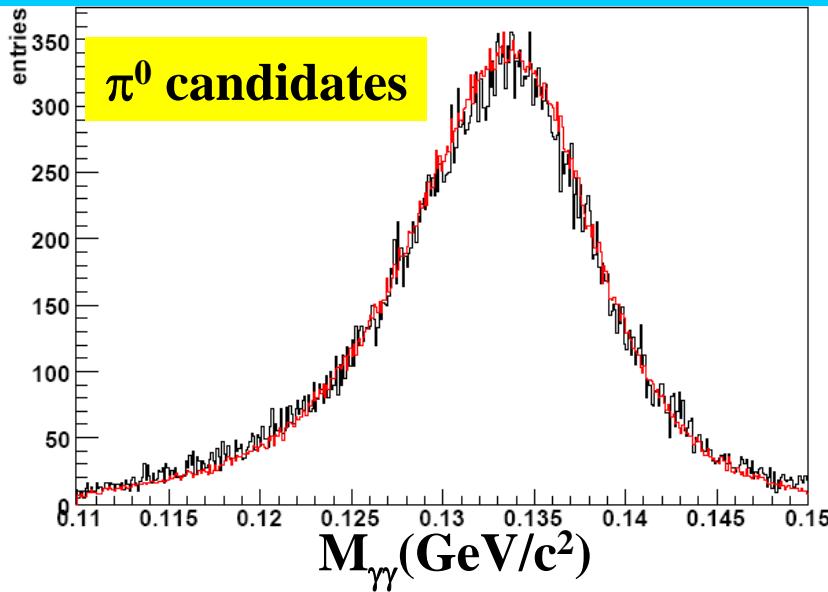
The first measurement:

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

much smaller than

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

First measurement of $\text{Br}(\chi_{cJ} \rightarrow 4\pi^0)$



| | $\text{BR}(\chi_{c0} \rightarrow K_s K_s)$ | $\text{BR}(\chi_{c2} \rightarrow K_s K_s)$ |
|--------------------|---|---|
| BESIII preliminary | $(4.1 \pm 0.4 \pm 0.4) \cdot 10^{-3}$ | $(0.6 \pm 0.2 \pm 0.1) \cdot 10^{-3}$ |
| PDG | $(2.82 \pm 0.28) \cdot 10^{-3}$ | $(0.68 \pm 0.11) \cdot 10^{-3}$ |
| CLEO-c [14] | $(3.49 \pm 0.08 \pm 0.17 \pm 0.17) \cdot 10^{-3}$ | $(0.53 \pm 0.03 \pm 0.03 \pm 0.03) \cdot 10^{-3}$ |

Excluding KsKs:

$$\text{Br}(\chi_{c0} \rightarrow 4\pi^0) = (3.42 \pm 0.06_{\text{stat}} \pm 0.45_{\text{syst}}) \cdot 10^{-3}$$

$$\text{Br}(\chi_{c1} \rightarrow 4\pi^0) = (0.59 \pm 0.03_{\text{stat}} \pm 0.08_{\text{syst}}) \cdot 10^{-3}$$

$$\text{Br}(\chi_{c2} \rightarrow 4\pi^0) = (1.28 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}}) \cdot 10^{-3}$$

Study of $\chi_{cJ} \rightarrow \gamma V$ ($V=\rho, \omega, \phi$) (1)

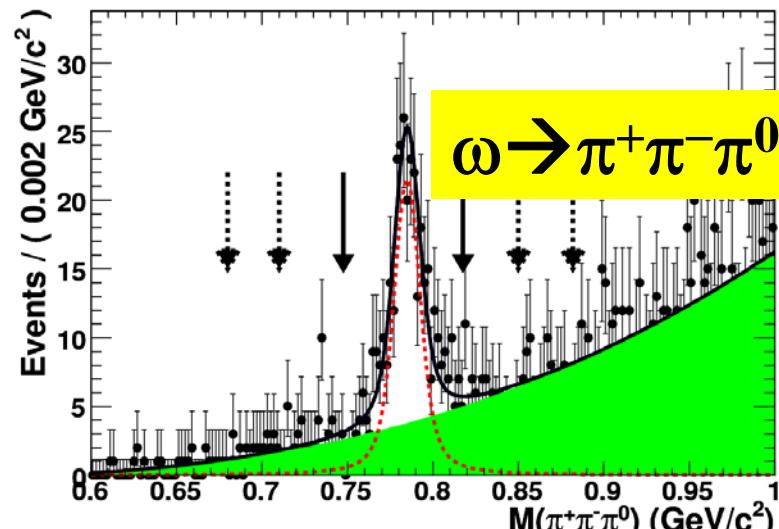
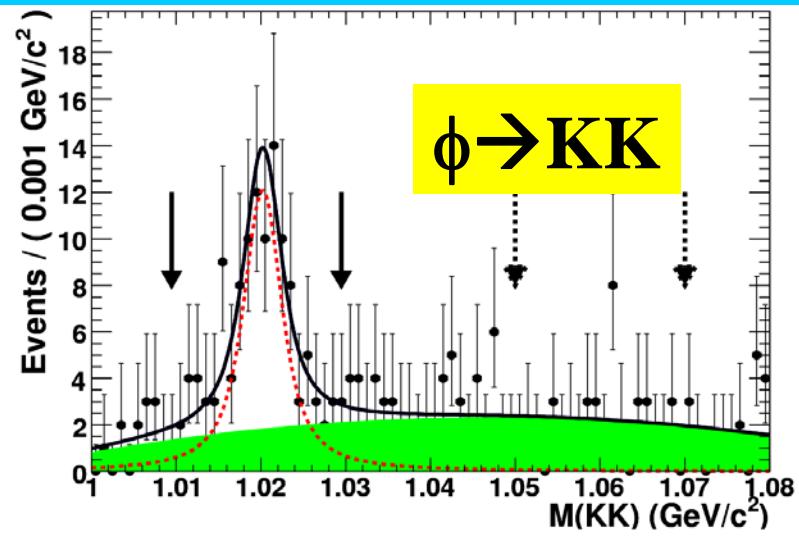
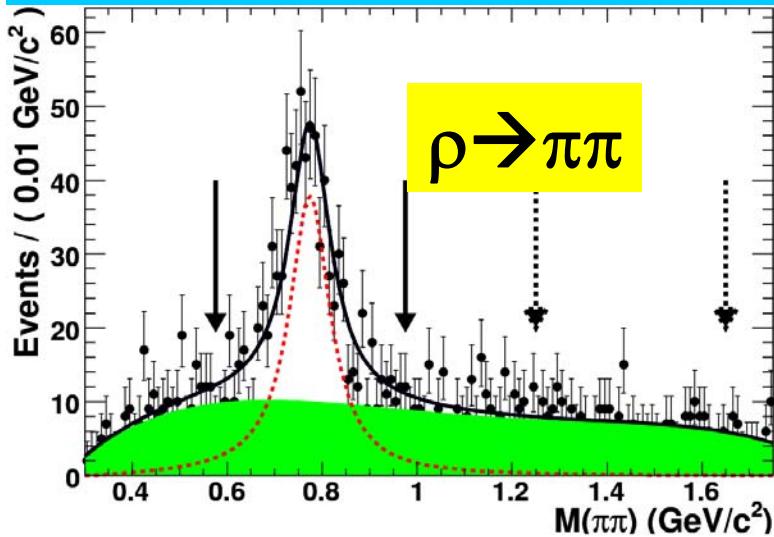
A favorable process to validate theoretical techniques

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

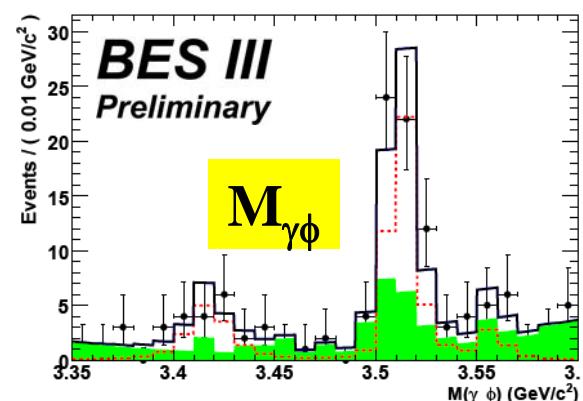
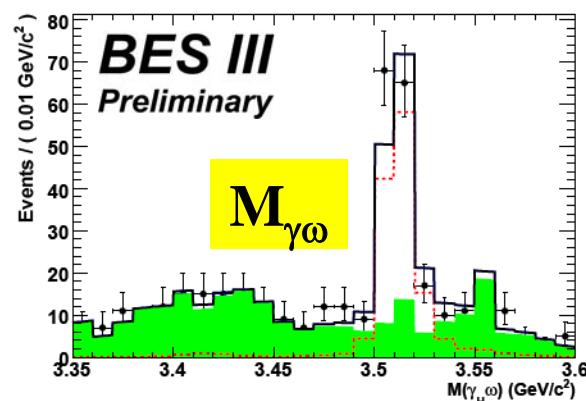
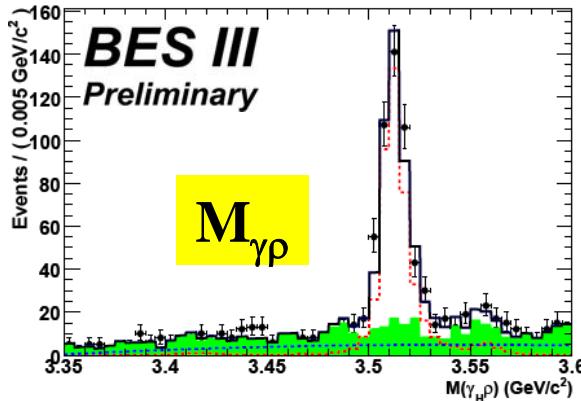
| Mode | CLEO ¹ | pQCD ² | QCD ³ | QCD+QED ³ |
|---------------------------------------|---------------------|-------------------|------------------|----------------------|
| $\chi_{c0} \rightarrow \gamma \rho^0$ | < 9.6 | 1.2 | 3.2 | 2.0 |
| $\chi_{c1} \rightarrow \gamma \rho^0$ | $243 \pm 19 \pm 22$ | 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 $\chi_{cJ} \rightarrow \gamma V$ ($V=\rho, \omega, \phi$) (2)



Study of $\chi_{cJ} \rightarrow \gamma V$ ($V = \rho, \omega, \phi$) (3)



| $B(10^{-6})$ | BESIII preliminary | CLEOc | pQCD |
|---------------------------------------|--------------------|---------------------|------|
| $\chi_{c0} \rightarrow \gamma \rho^0$ | <9.5 | <9.6 | 1.2 |
| $\chi_{c1} \rightarrow \gamma \rho^0$ | 241 ± 14 | $243 \pm 19 \pm 22$ | 14 |
| $\chi_{c2} \rightarrow \gamma \rho^0$ | <19.7 | <50 | 4.4 |
| $\chi_{c0} \rightarrow \gamma \omega$ | <11.7 | <8.8 | 0.13 |
| $\chi_{c1} \rightarrow \gamma \omega$ | 73.5 ± 7.6 | $83 \pm 15 \pm 12$ | 1.6 |
| $\chi_{c2} \rightarrow \gamma \omega$ | <5.8 | <7.0 | 0.5 |
| $\chi_{c0} \rightarrow \gamma \phi$ | <14.8 | <6.4 | 0.46 |
| $\chi_{c1} \rightarrow \gamma \phi$ | 27.3 ± 5.5 | <26 | 3.6 |
| $\chi_{c2} \rightarrow \gamma \phi$ | <7.8 | <13 | 1.1 |

- $\chi_{c1} \rightarrow \gamma \phi$ observed for the first time.
- pQCD predictions $\times 10$ 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)

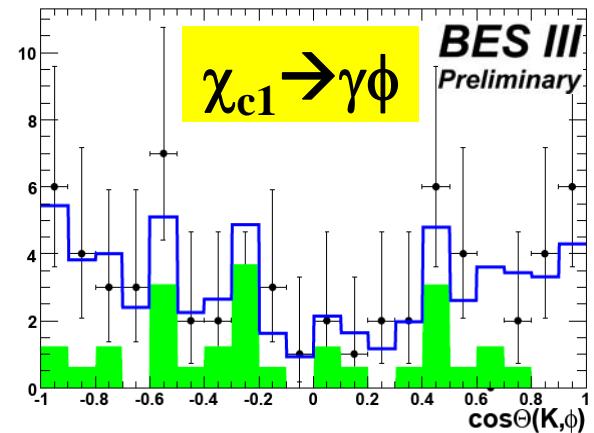
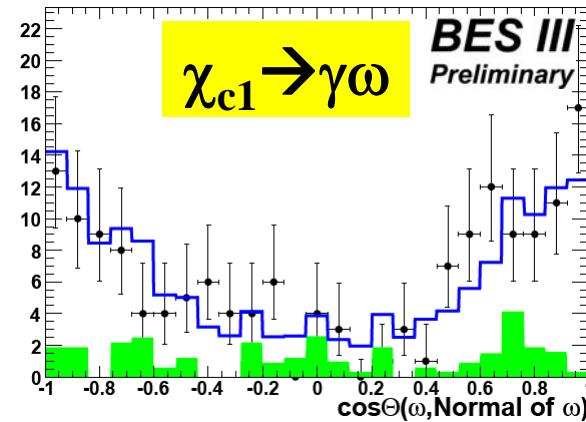
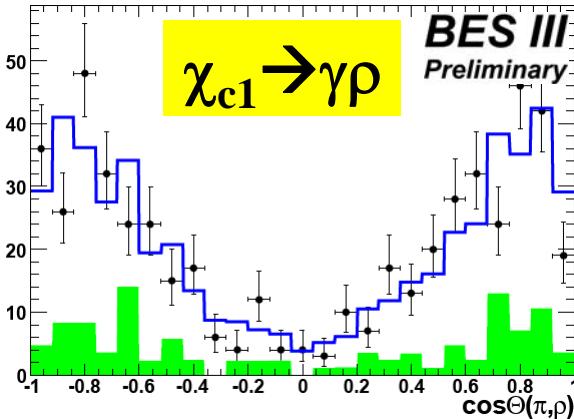
pQCD: Y.J. Gao *et al*, hep-ph/0701009

Study of $\chi_{cJ} \rightarrow \gamma V$ ($V=\rho, \omega, \phi$) (4)

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

$$\frac{dN}{dcos\theta} \propto |A_L|^2 cos^2\theta + \frac{1}{2}|A_T|^2 sin^2\theta \quad f_T = \frac{|A_T|^2}{|A_T|^2 + |A_L|^2}$$

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



$$f_T = 0.155 \pm 0.033 \pm 0.014$$

$$f_T = 0.240^{+0.091+0.044}_{-0.086-0.027}$$

$$f_T = 0.27^{+0.13+0.08}_{-0.12-0.08}$$

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Study of $\chi_{c1} \rightarrow VV$ ($V=\omega, \phi$)

- Previous measurements from BESII.

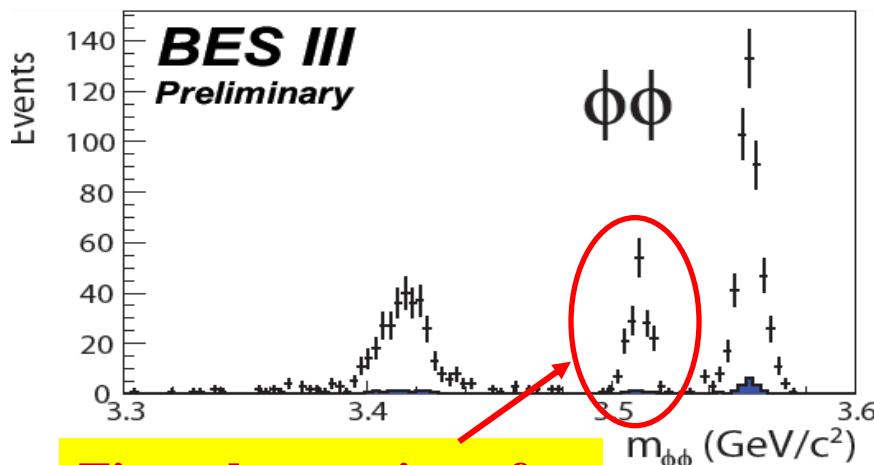
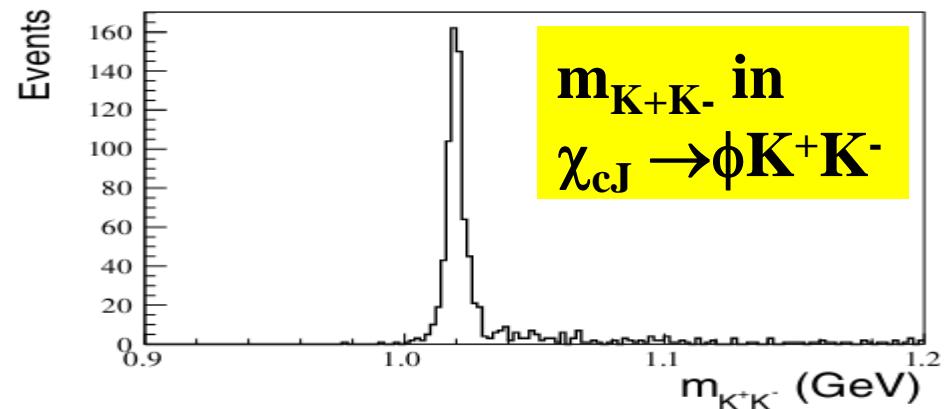
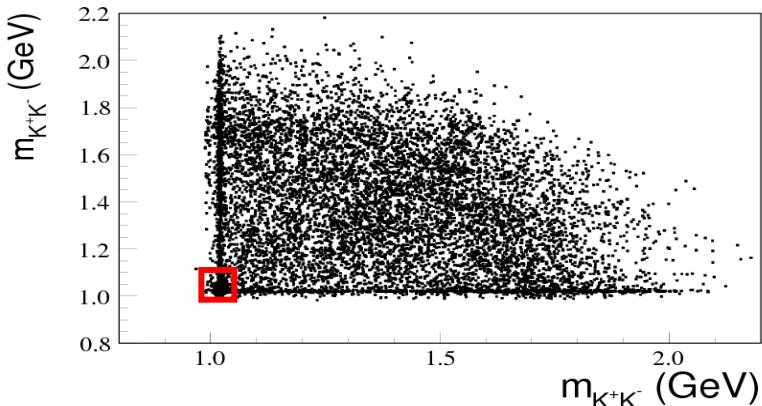
Only χ_{c0} and χ_{c2} decays into $\phi\phi$ and $\omega\omega$ are observed.

| $BR(10^{-3})$ | χ_{c0} | χ_{c2} |
|---|--|--|
| $\rightarrow\phi\phi$ BESII, PLB 642, 197 (2006) | $0.94 \pm 0.21 \pm 0.13$ | $1.70 \pm 0.30 \pm 0.25$ |
| $\rightarrow\omega\omega$ BESII, PLB 630, 7 (2005) | $2.29 \pm 0.58 \pm 0.41$ | $1.77 \pm 0.47 \pm 0.36$ |

- $\chi_{c1} \rightarrow VV$ is suppressed due to helicity selection rule in pQCD
- $\chi_{c1} \rightarrow \omega\phi$ 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 $[M^{(1)}(K^+K^-) - m_\phi]^2 + [M^{(2)}(K^+K^-) - m_\phi]^2$



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

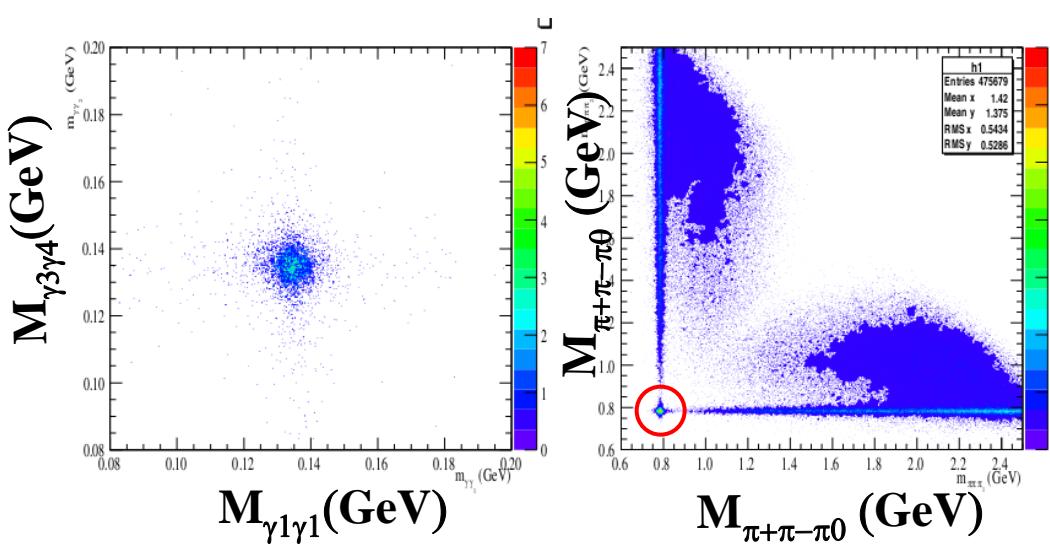
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| $BR(10^{-3})$ | BESIII | PDG08 |
|----------------------------------|-----------------|-----------------|
| $\chi_{c0} \rightarrow \phi\phi$ | 0.80 ± 0.04 | 0.93 ± 0.20 |
| $\chi_{c1} \rightarrow \phi\phi$ | 0.42 ± 0.03 | ---- |
| $\chi_{c2} \rightarrow \phi\phi$ | 1.15 ± 0.04 | 1.54 ± 0.30 |

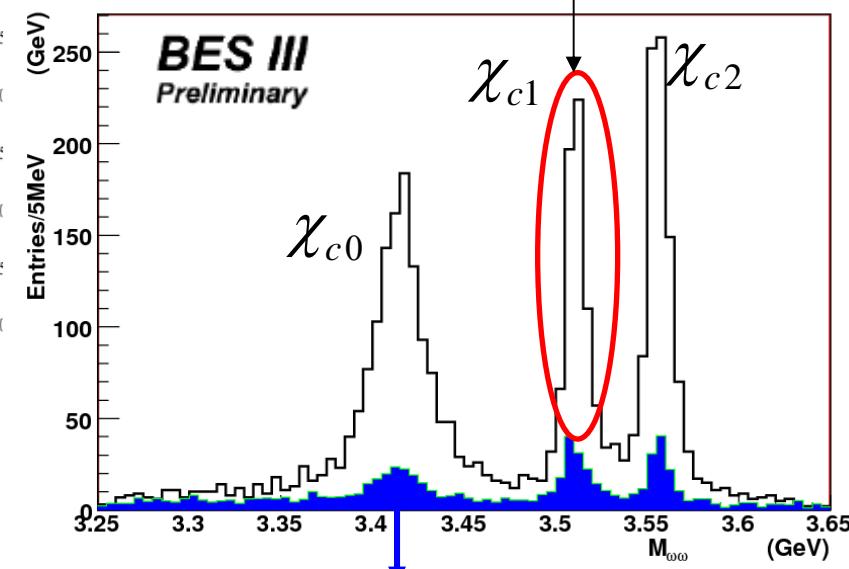
Errors statistical only.

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

- 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 $\pi^+ \pi^- \pi^0$ reconstruct another ω

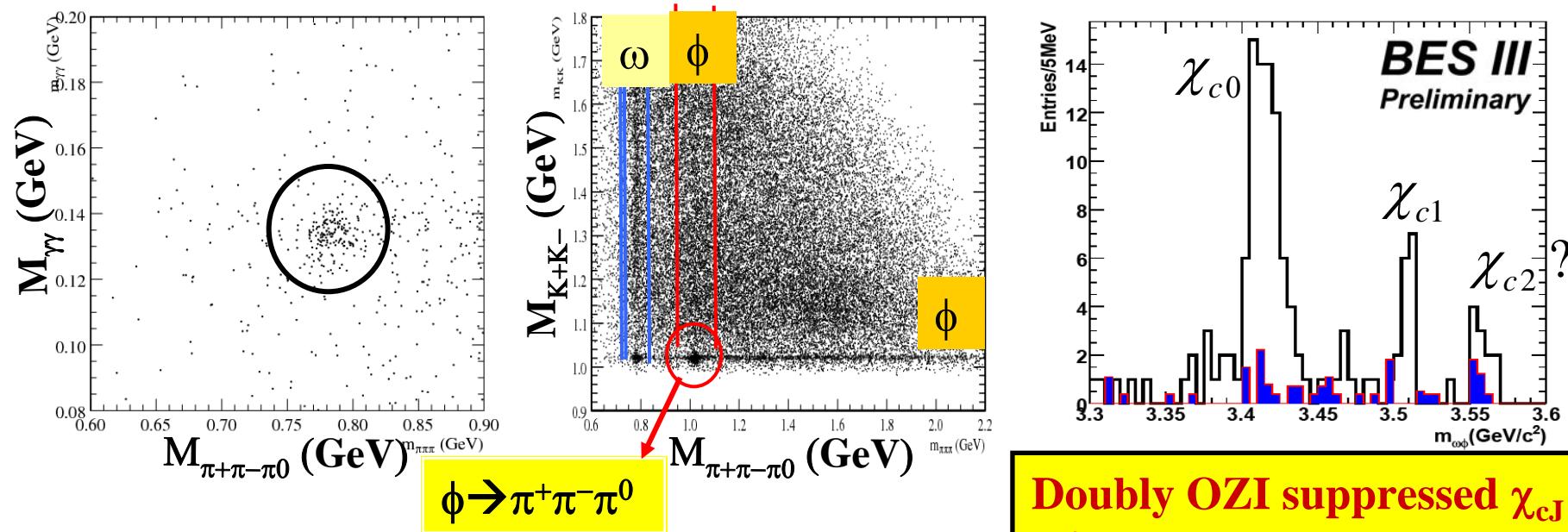


First observation of $\chi_{c1} \rightarrow \omega\omega$



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

- K^+K^- are identified : minimize $|M(K^+K^-) - m_\phi|$
- Using kinematic fit to select $3\gamma 2K2\pi$ candidates
- ω reconstruction: minimize $[M_{\gamma\gamma} - m_{\pi^0}]^2 + [M_{\gamma\gamma\pi^+\pi^-} - m_\omega]^2$ loop over 3γ



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

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:
 - First evidence of $\psi' \rightarrow \gamma\gamma J/\psi$
 - First evidence for $\psi' \rightarrow \gamma P$ ($P = \pi^0, \eta$)
 - First measurement of $\chi_{cJ} \rightarrow 4\pi^0$
 - 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!