Recent results of charmonium radiative decay from BESIII

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For the BES collaboration

- **Motivation**
- **Physics results**

  $\psi' \to \gamma \chi_{cJ}$

  - $\chi_{cJ} \to \pi^0\pi^0, \eta\eta$
  - $\chi_{cJ} \to 4\,\pi^0$
  - $\chi_{cJ} \to \gamma V$ (V=ω, ρ, ϕ)
  - $\chi_{cJ} \to \phi\,\phi, \omega\,\omega, \omega\,\phi$
- **Summary**

My talk is based on 106 million ψ' data

Motivation

χ_{cJ} decays could be a good place to

- study gluonium: $\chi_c \rightarrow gg \rightarrow (qq)(qq)$.

C. Amsler and F. E. Close,Phys. Rev. D 53, 295 (1996).

- test color octet mechanism.

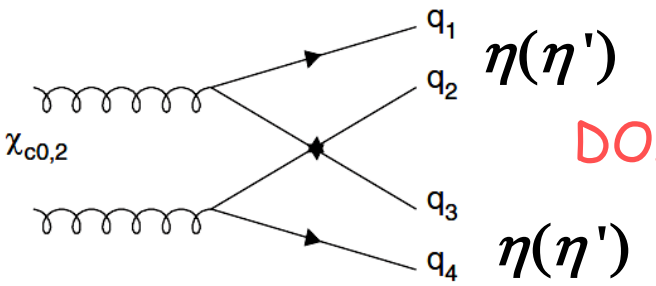
G. T. Bodwin *et al*., Phys Rev. Lett. **D51**, 1125 (1995).
H.-W. Huang and K.-T. Chao, Phys. Rev. **D54**, 6850 (1996).
J. Bolz *et al*., Eur. Phys. J. C **2**, 705 (1998).

decay width	theory[3]	PDG08
$\Gamma[\chi_{c0} \rightarrow \pi^\circ \pi^\circ]$ / keV	23.5	25 ± 2
$\Gamma[\chi_{c2} \rightarrow \pi^0 \pi^0]$ / keV	1.93	1.4 ± 0.2
$\Gamma[\chi_{c0} \rightarrow \eta\eta]$ / keV	32.7	25 ± 4
$\Gamma[\chi_{c2} \rightarrow \eta\eta]$ / keV	2.66	

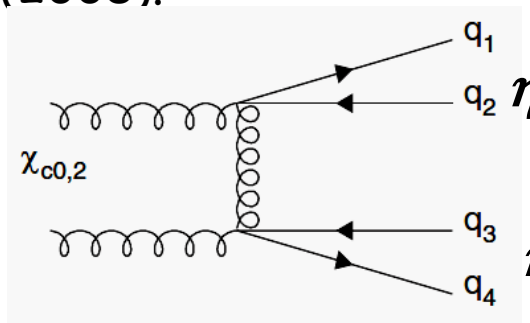
- investigate doubly-OZI suppressed decays, which may compete with the singly-OZI suppressed decays.

Q. Zhao, Phys. Lett. B **659**, 221 (2008).

SOZI



DOZI

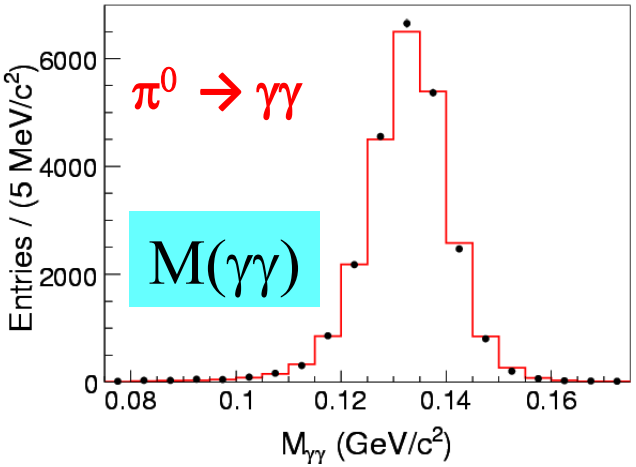


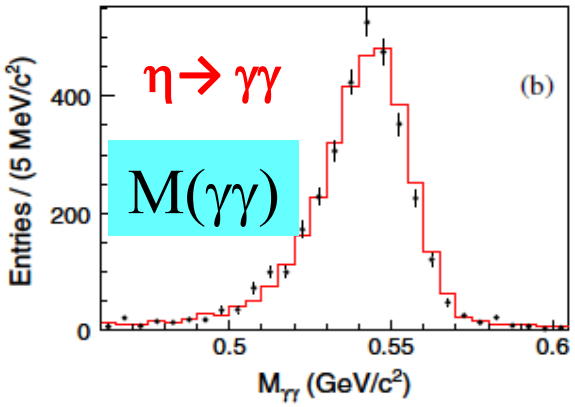
Study of $\psi' \rightarrow \gamma\chi_{cJ}$; $\chi_{cJ} \rightarrow \pi^0\pi^0$, $\eta\eta$

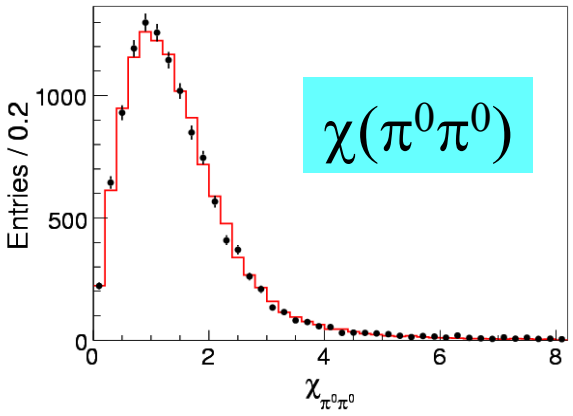
$\pi^0\pi^0$, $\eta\eta$ candidates are reconstructed from 5 selected photons by minimizing:

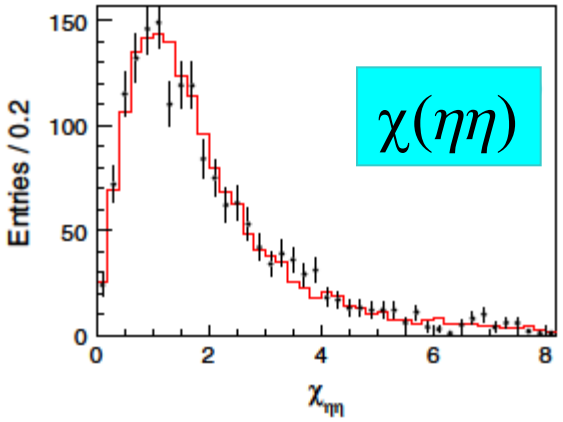
$$\chi(\pi^0\pi^0/\eta\eta) = \sqrt{P_1^2(\eta/\pi^0) + P_1^2(\eta/\pi^0)}$$

$$\text{with } P_1(\eta/\pi^0) = [M_{\gamma\gamma} - m_{\pi_i^0/\eta_i}]/\sigma_{\gamma\gamma}$$



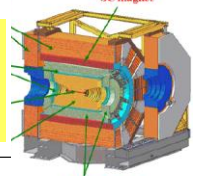




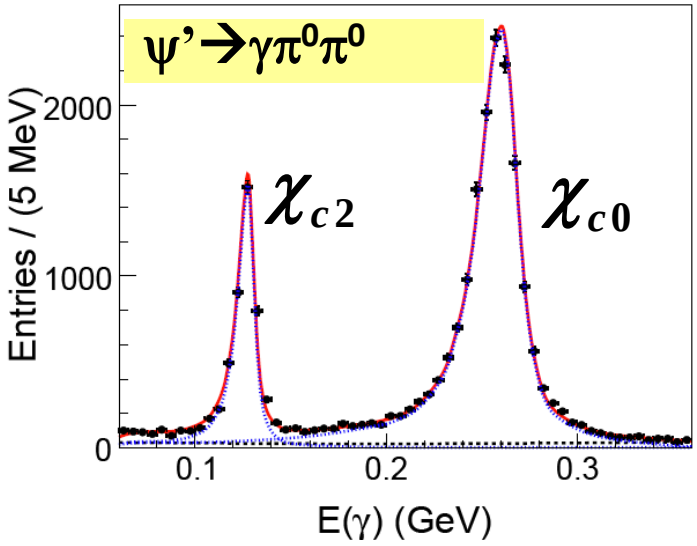


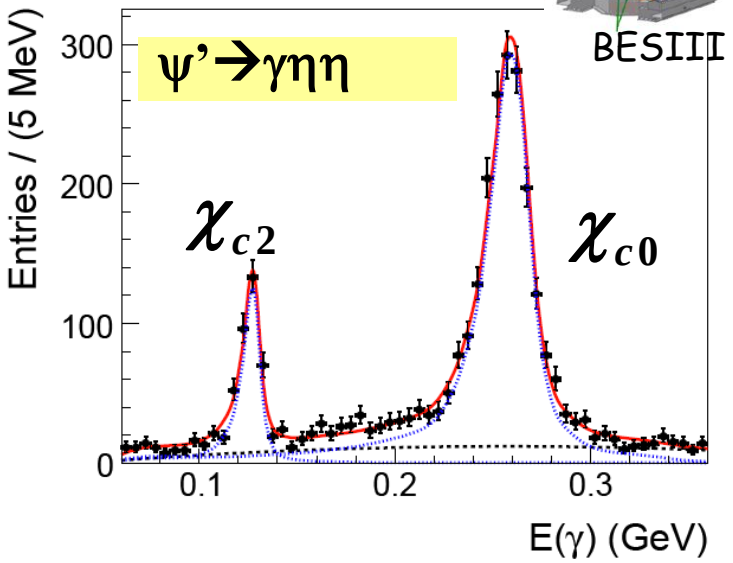
Good agreement between data & MC

Study of $\psi' \to \gamma\chi_{cJ}$; $\chi_{cJ} \to \pi^0\pi^0$, $\eta\eta$



BESIII:
PRD 81, 052005 (2010).





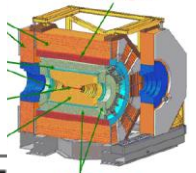
$\chi_{c1} \to \pi\pi$, $\eta\eta$ not allowed by parity conservation.

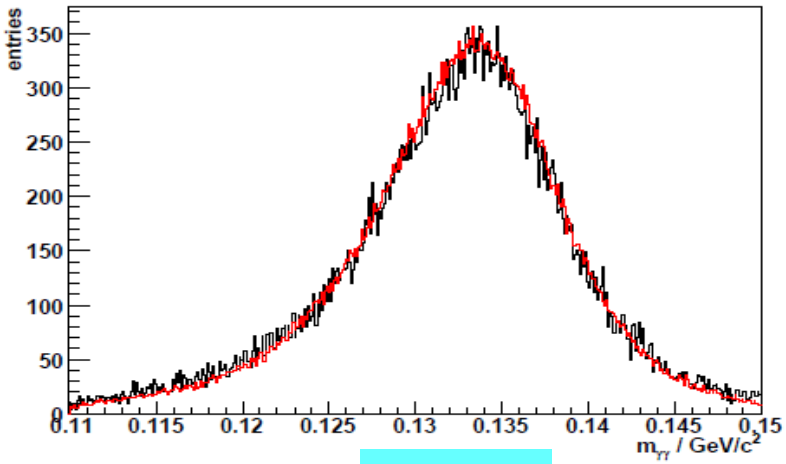
Decay mode		χ_{c0} (10^{-3})	χ_{c2} (10^{-3})
$\pi^0\pi^0$	BESIII	**$3.23\pm0.03\pm0.23\pm0.14$**	**$0.88\pm0.02\pm0.06\pm0.04$**
	PDG08	2.43 ± 0.20	0.71 ± 0.08
	CLEOc	$2.94\pm0.07\pm0.32\pm0.15$	$0.68\pm0.03\pm0.07\pm0.04$
$\eta\eta$	BESIII	**$3.44\pm0.10\pm0.24\pm0.20$**	**$0.65\pm0.04\pm0.05\pm0.03$**
	PDG08	2.4 ± 0.4	< 0.5
	CLEOc	$3.18\pm0.13\pm0.31\pm0.16$	$0.51\pm0.05\pm0.05\pm0.03$

CLEOc:
PRD 79, 072007 (2009).

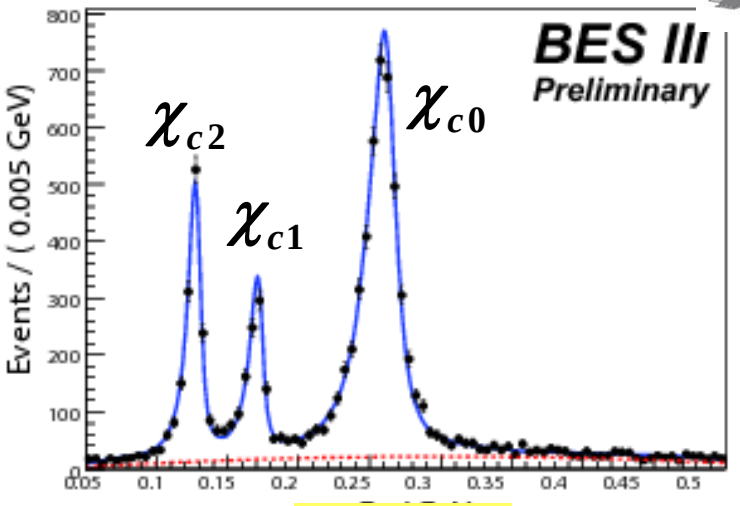
CLEOc used their own branching ratios for $\psi' \to \gamma\chi_{cJ}$.

$\chi_{cJ} \to 4\pi^0$ from $\psi' \to \gamma\chi_{cJ}$ decays





M(γγ)



E_γ (GeV)

- **Branching fraction excluding Ks → $\pi^0\pi^0$**

$Br(\chi_{c0} \to 4\pi^0) = (3.42 \pm 0.07 \pm 0.45) \times 10^{-3}$

$Br(\chi_{c1} \to 4\pi^0) = (0.60 \pm 0.03 \pm 0.09) \times 10^{-3}$

$Br(\chi_{c2} \to 4\pi^0) = (1.13 \pm 0.04 \pm 0.15) \times 10^{-3}$

- **Branching fraction for $\chi_{cJ} \to$ KsKs**

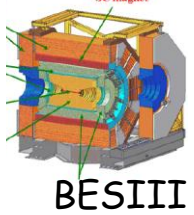
$Br(\chi_{c0} \to K_S K_S) = (4.1 \pm 0.4(stat.)) \times 10^{-3}$

$Br(\chi_{c2} \to K_S K_S) = (0.6 \pm 0.2(stat.)) \times 10^{-3}$

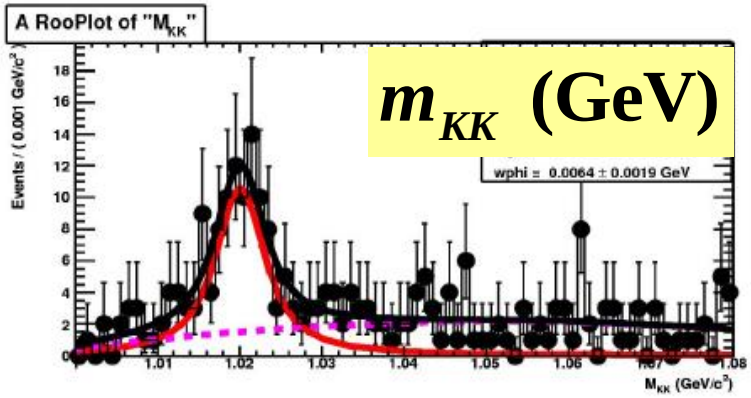
$B(\chi_{c0} \to K_S K_S)$	χ_{c0} (10^{-3})	χ_{c2} (10^{-3})
BESIII	$4.1 \pm 0.4_{stat}$	$0.6 \pm 0.2_{stat}$
PDG08	2.82 ± 0.28	0.65 ± 0.08
CLEOc	$3.49 \pm 0.08 \pm 0.18 \pm 0.17$	$0.53 \pm 0.03 \pm 0.03 \pm 0.03$

CLEO Collaboration, Phys. Rev. D79: 072007 (2009).

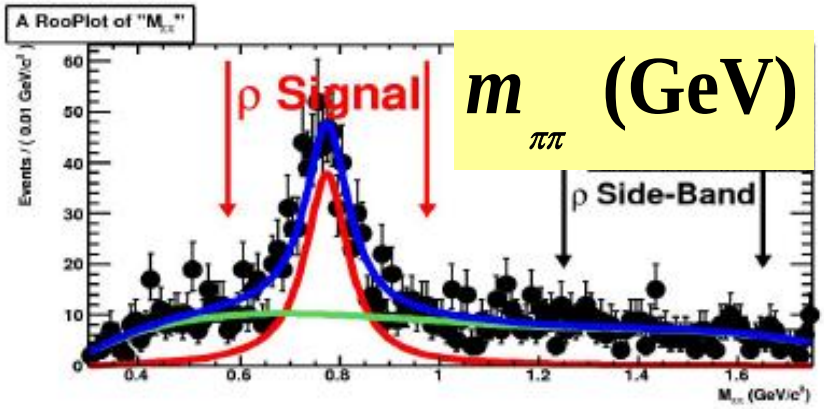
Measurements of $\chi_{cJ} \to \gamma V$, V=ϕ, ρ^0,ω



- $\phi \to K^+K^-, \rho^0 \to \pi^+\pi^-$



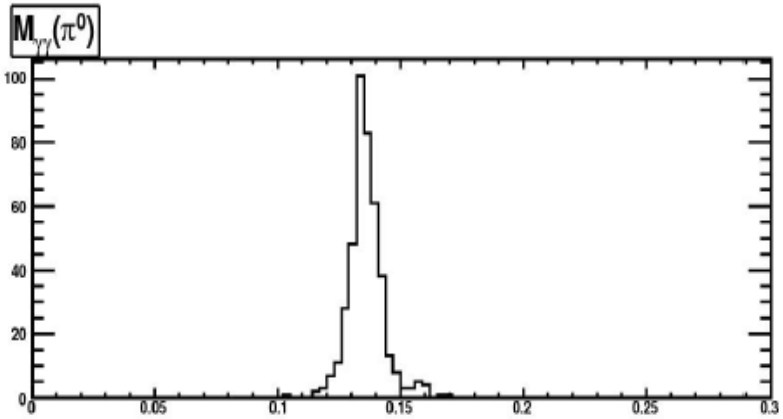
m_{KK} (GeV)



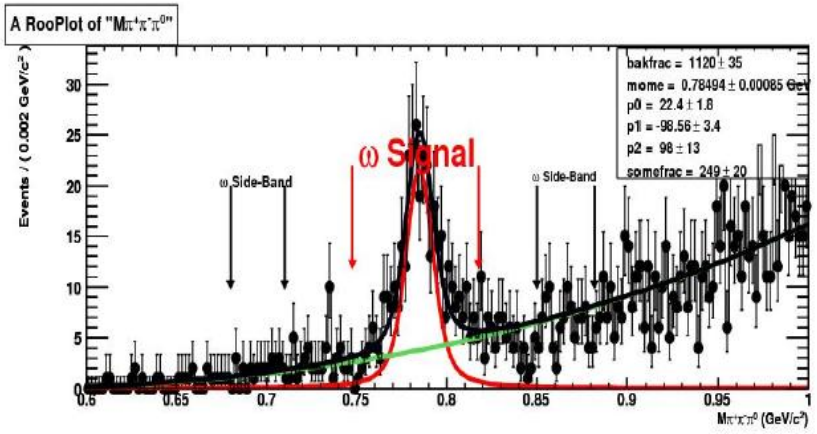
$m_{\pi\pi}$ (GeV)

- $\omega \to \pi^+\pi^- \pi^0, \pi^0 \to \gamma\gamma$

ω : to minimize $\sqrt{\left(\frac{M_{\gamma\gamma}-M_{\pi^0}}{\sigma_{\pi^0}}\right)^2+\left(\frac{M_{\pi^+\pi^-\gamma\gamma}-M_{\omega}}{\sigma_{\omega}}\right)^2}$

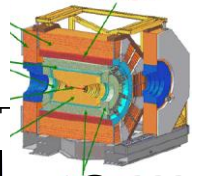


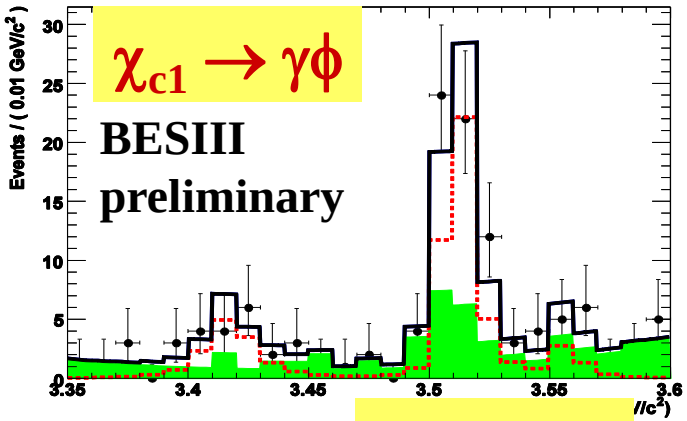
$M_{\gamma\gamma}$(GeV)

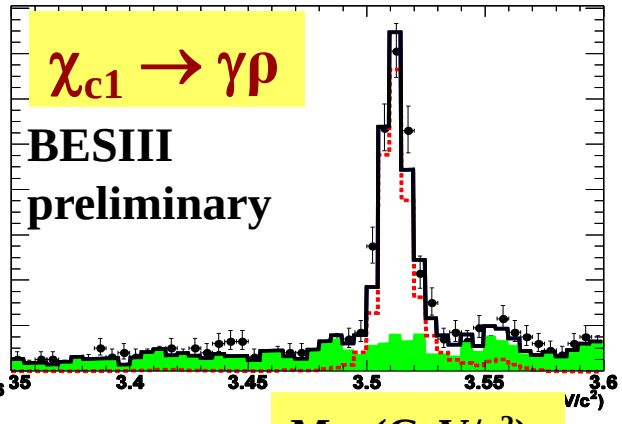


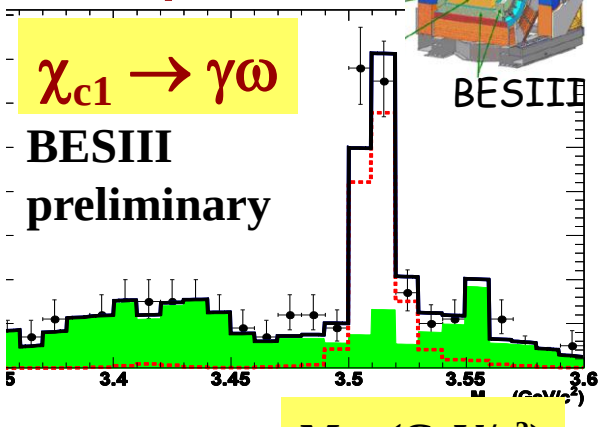
$M_{\pi+\pi-\pi0}$ (GeV)

Measurements of $\chi_{cJ} \to \gamma V$, V=ϕ,ρ,ω









These decays are important for evaluating theoretical techniques.

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

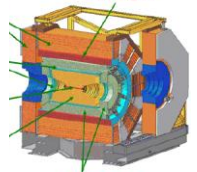
BESIII: Only statistical errors are shown

- **$\chi_{c1} \to \gamma\phi$ observed for 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

Measurements of $\chi_{cJ} \to \gamma V$, V=ϕ,ρ,ω



- **Vector production is dominated by the longitudinal polarization in the $\chi_{c1} \to \gamma V$**

$$\text{Amplitude}: \ \varepsilon_{\alpha\beta\mu\nu} P^{\alpha} \varepsilon^{\beta}(\lambda_{\chi}) \varepsilon^{\mu}(\lambda_{\gamma}) \varepsilon^{\nu}(\lambda_{V})$$

$$\sim \vec{\varepsilon}(\lambda_{\chi}) \bullet [\vec{\varepsilon}(\lambda_{\gamma}) \times \vec{\varepsilon}(\lambda_{V})]$$

$$\lambda_{\gamma} = \pm 1 \ \text{(Transverse)},$$

$$\text{so } \lambda_{V} = 0 \quad \text{(Longitudinal)}$$

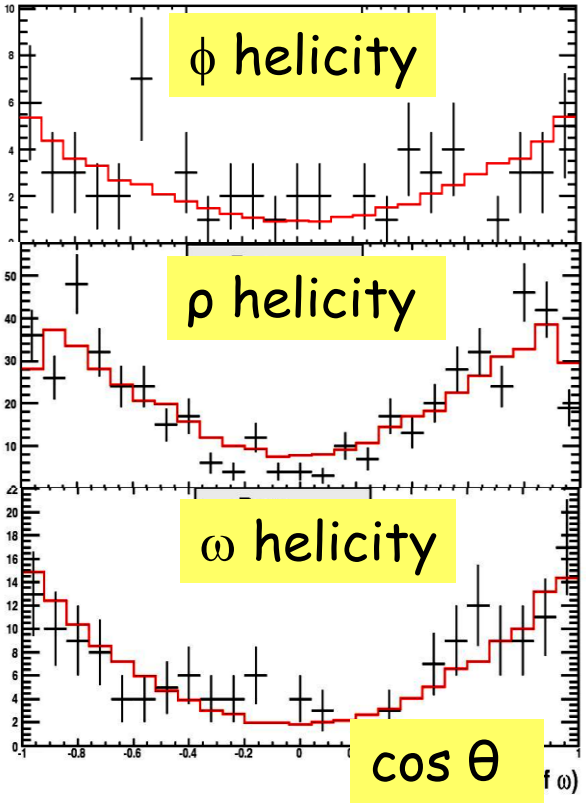
- **Polarization of vector mesons can be observed in the helicity angular distribution**

helicity angle: $(\vec{P}_{meson}, \vec{P}_{V})$ (V=ϕ,ρ); $(\vec{P}_{V}, \vec{n}_{V})$ (V=ω)

where $\vec{P}_i$ is the momentum evaluated in their mother rest frame, $\vec{n}_{\omega}$ is the normal to the ω decay plane.

Longitudinal polarization : $\cos^2\theta$ (dominant)

Transverse polarization: $\sin^2\theta$



BESIII preliminary

Study of $\chi_{cJ} \to VV$, V = ω,ϕ

Important laboratory to test QCD:

- **Previous measurements from BESII.**
- **Only χ_{c0} and χ_{c2} decays into ϕϕ and ωω are observed.**

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

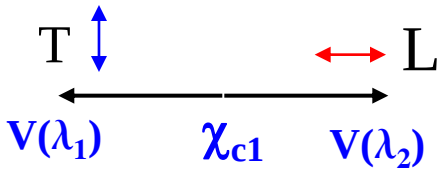
BESII, PLB 642, 197 (2006)

BESII, PLB 630, 7 (2005)

- **$\chi_{c1} \to V\,V$ is suppressed due to helicity selection rule in pQCD**

$$\mathbf{Br}[\chi_{c1} \to V(\lambda_1)V(\lambda_2)] \sim \left(\frac{\Lambda^2_{QCD}}{m_c^2}\right)^{|\lambda_1+\lambda_2|+2}$$

Nucl. Phys. B201,492



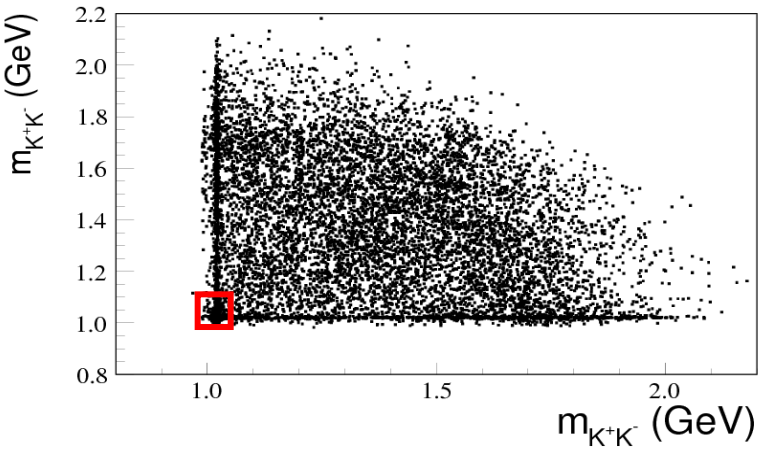
P-parity conservation requires the two vectors having different polarization, so it is suppressed.

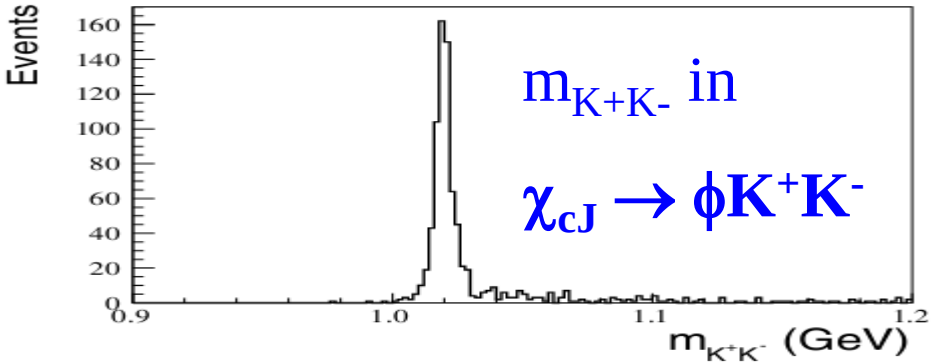
So $\lambda_1+\lambda_2 \neq 0$

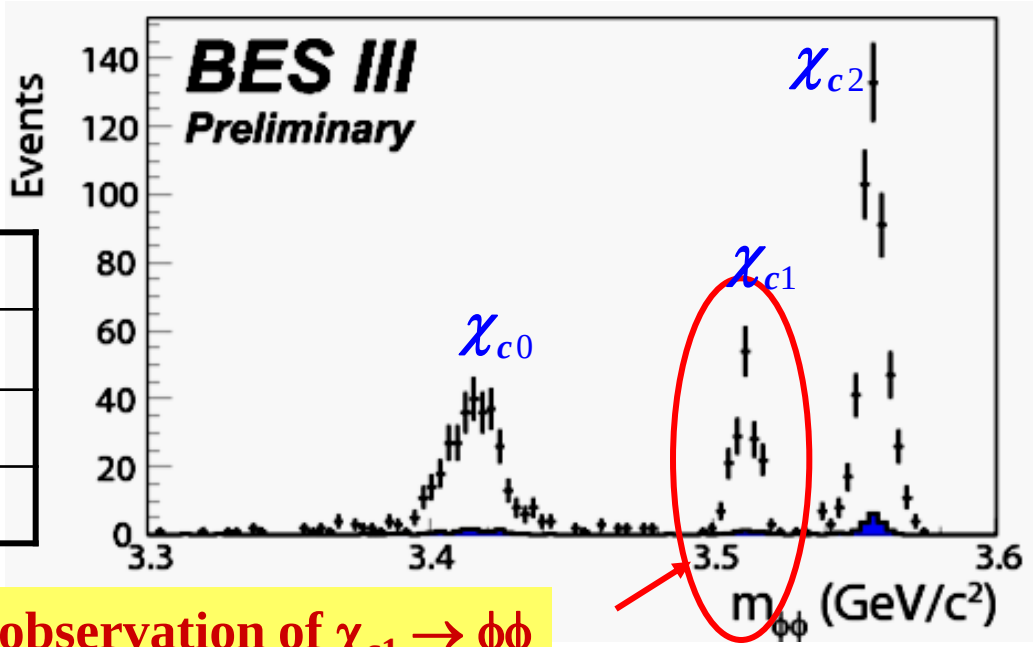
- **$\chi_{cJ} \to \omega\phi$ is doubly OZI suppressed.**

Study of $\chi_{cJ} \to \phi\phi \to 2(K^+K^-)$ in $\psi \to \gamma\chi_{cJ}$,

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







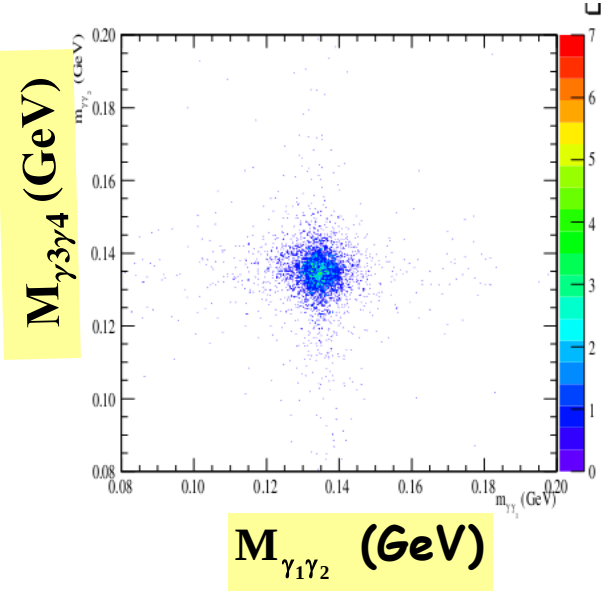
BR(10^{-3})	BESIII	PDG08
$\chi_{c0} \to \phi\phi$	0.80 ± 0.04	0.93 ± 0.20
$\chi_{c1} \to \phi\phi$	0.42 ± 0.03	----
$\chi_{c2} \to \phi\phi$	1.15 ± 0.04	1.54 ± 0.30

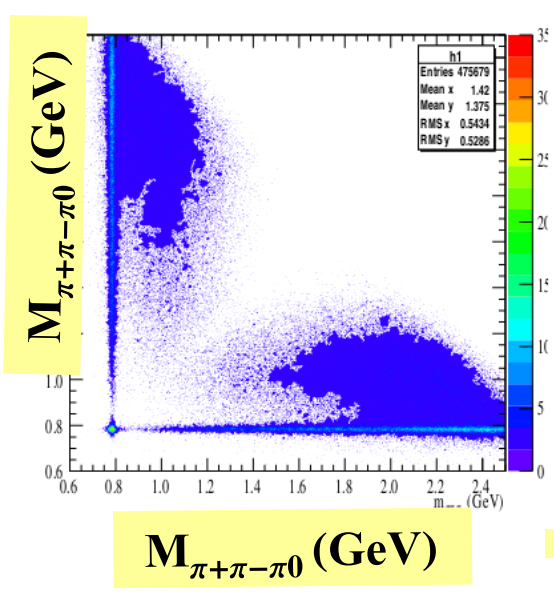
Errors statistical only.

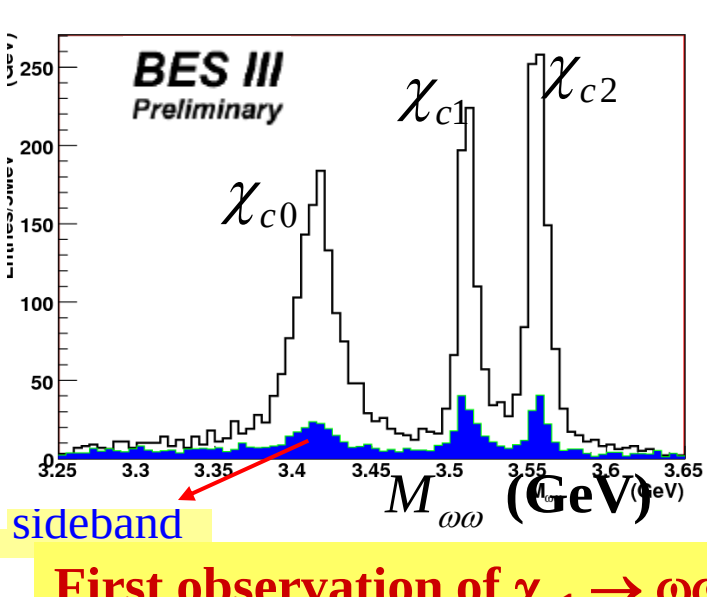
First observation of $\chi_{c1} \to \phi\phi$

Study of $\chi_{cJ} \to \omega\omega \to 2(\pi^+\pi^-\pi^0)$ in $\psi \to \gamma\chi_{cJ}$

- 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



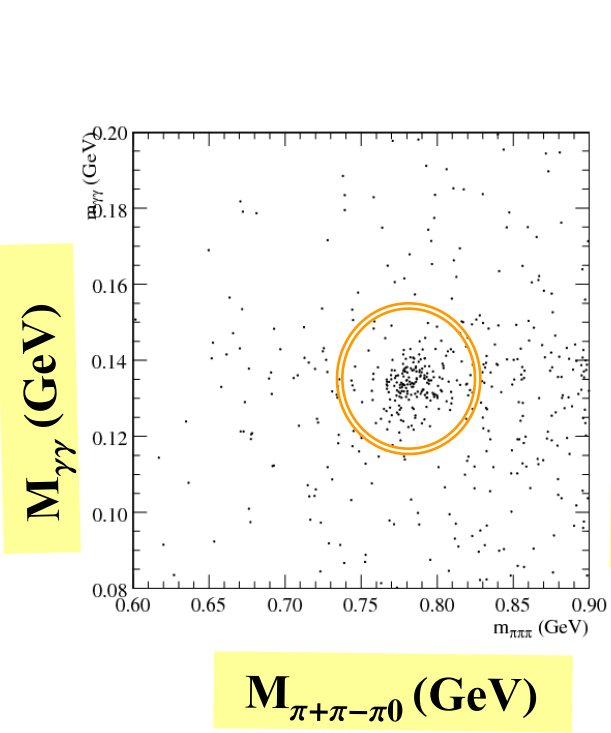


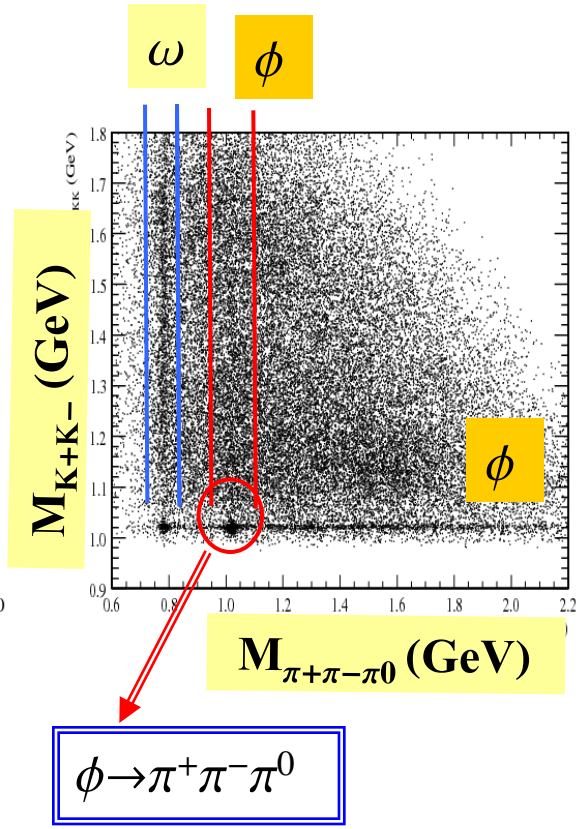


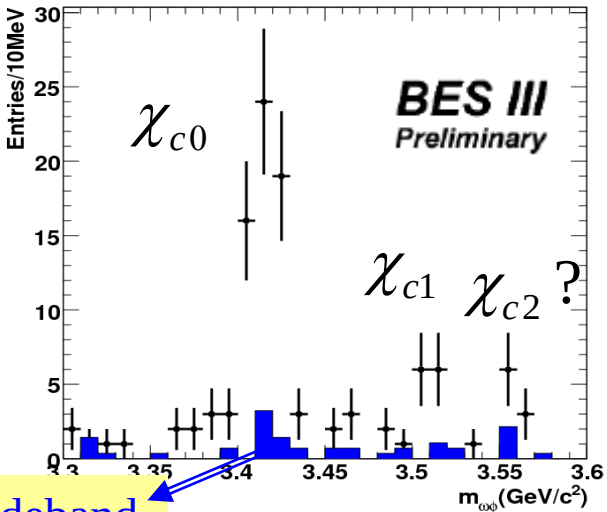
First observation of $\chi_{c1} \to \omega\omega$.

Study of $\chi_{cJ} \to \omega\phi \to K^+K^-\pi^+\pi^-\pi^0$ in $\psi \to \gamma\chi_{cJ}$

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







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

Summary

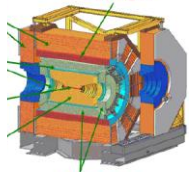
- **Some nice results of χ_{CJ} decays are obtained with the ψ' data**

- **$\psi' \to \gamma\chi_{cJ}$ could be χ_{cJ} factory. More χ_{cJ} results will come soon**

Thank you for your attention.

Backup

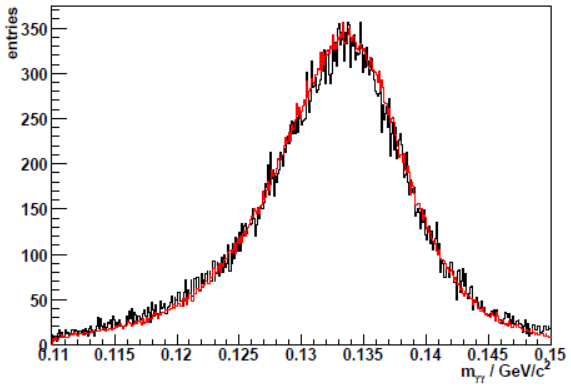
$\chi_{cJ} \to 4\pi^0$ from $\psi' \to \gamma\chi_{cJ}$ decays



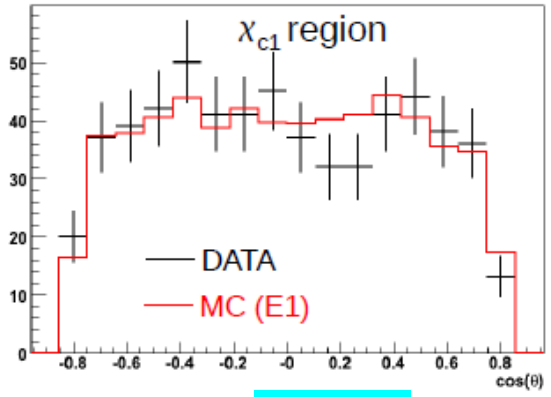
- $\gamma_{E1}\, 4\pi^0$ candidates are reconstructed from $\psi' \to 9\gamma$ with totally 945 combinations.

$$\chi^2_{4\pi^0} = \frac{(m_{\gamma_1\gamma_2} - m_{\pi^0})^2}{\sigma^2_{\pi^0}} + \frac{(m_{\gamma_3\gamma_4} - m_{\pi^0})^2}{\sigma^2_{\pi^0}} + \frac{(m_{\gamma_5\gamma_6} - m_{\pi^0})^2}{\sigma^2_{\pi^0}} + \frac{(m_{\gamma_7\gamma_8} - m_{\pi^0})^2}{\sigma^2_{\pi^0}}$$

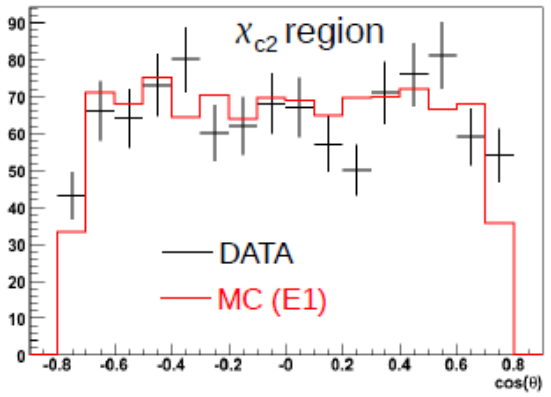
- Veto background $\psi' \to \gamma$ J/$\psi \to \gamma 4\pi^0$: $|m(\pi^0\pi^0\text{–rec.}) - m_{J/\psi}| > 0.1$ GeV, no peaking backgrounds.
- KsKs selection: $R = [m(\pi^0_1\pi^0_2) - m(Ks)]^{2+} [m(\pi^0_3\pi^0_4) - m(Ks)]^2$



M($\gamma\gamma$)



cosθ



cosθ