Charmonium decays at the BESIII experiment

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Outline

- BEPCII/BESIII status
- Recent Results of Charmonium Decays

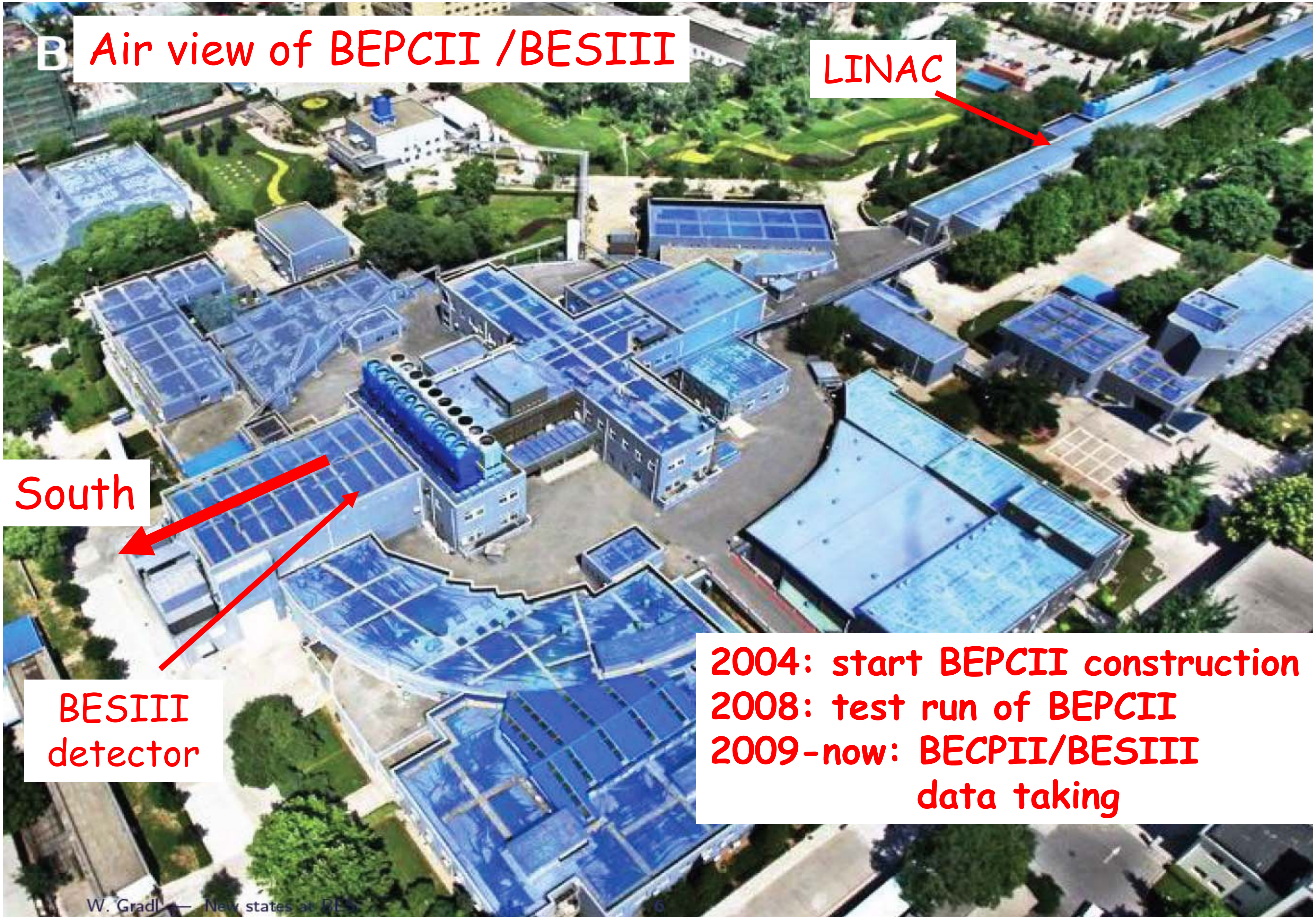
  $\chi_{cJ} \to VV[V = \phi, \omega]$

  $\chi_{cJ} \to \gamma V[V = \rho, \phi, \omega]$

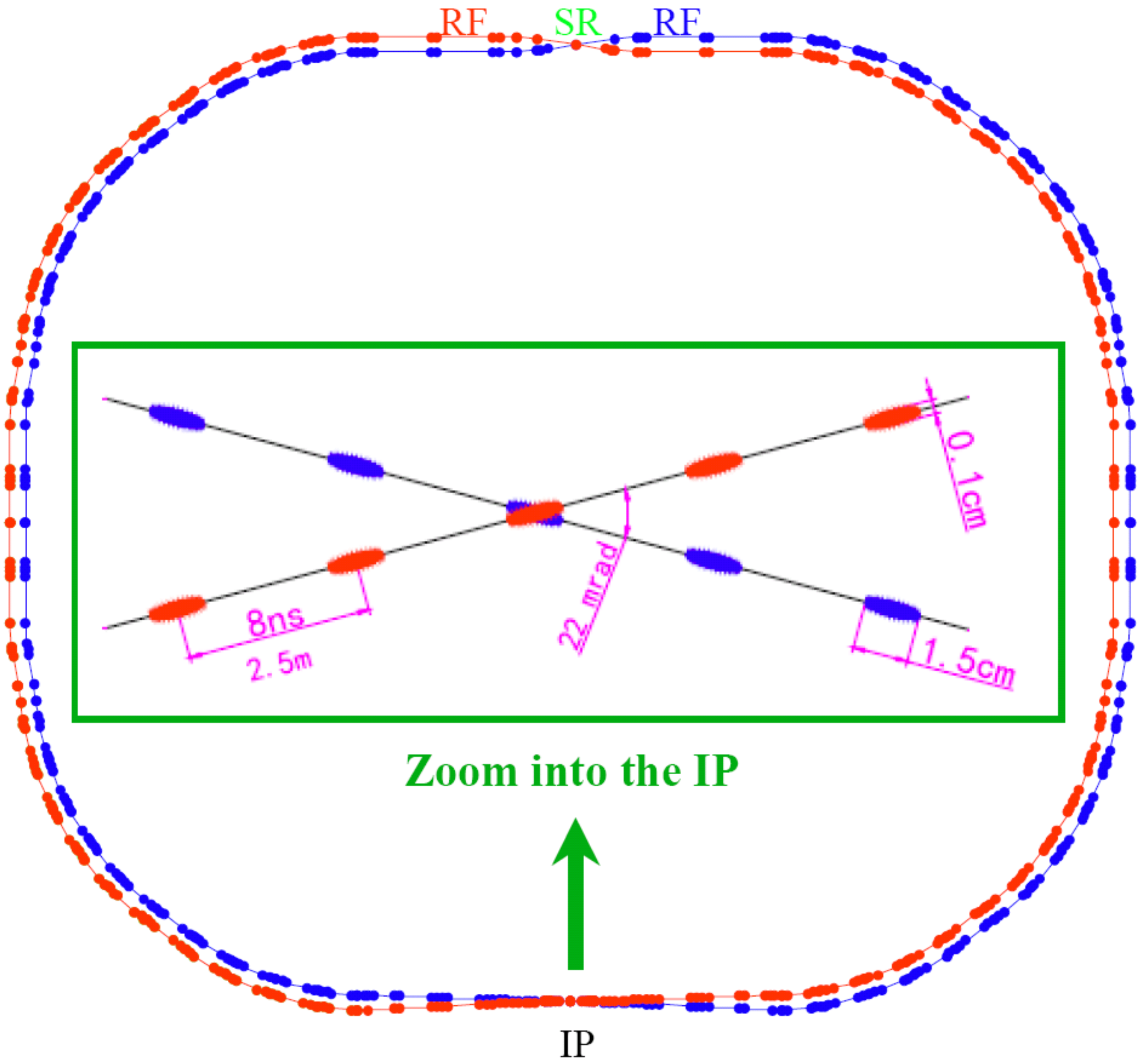
  $\chi_{cJ} \to p\bar{p}K^+K^-$

  $\psi' \to \gamma P[P = \pi^0, \eta, \eta']$

- Summary

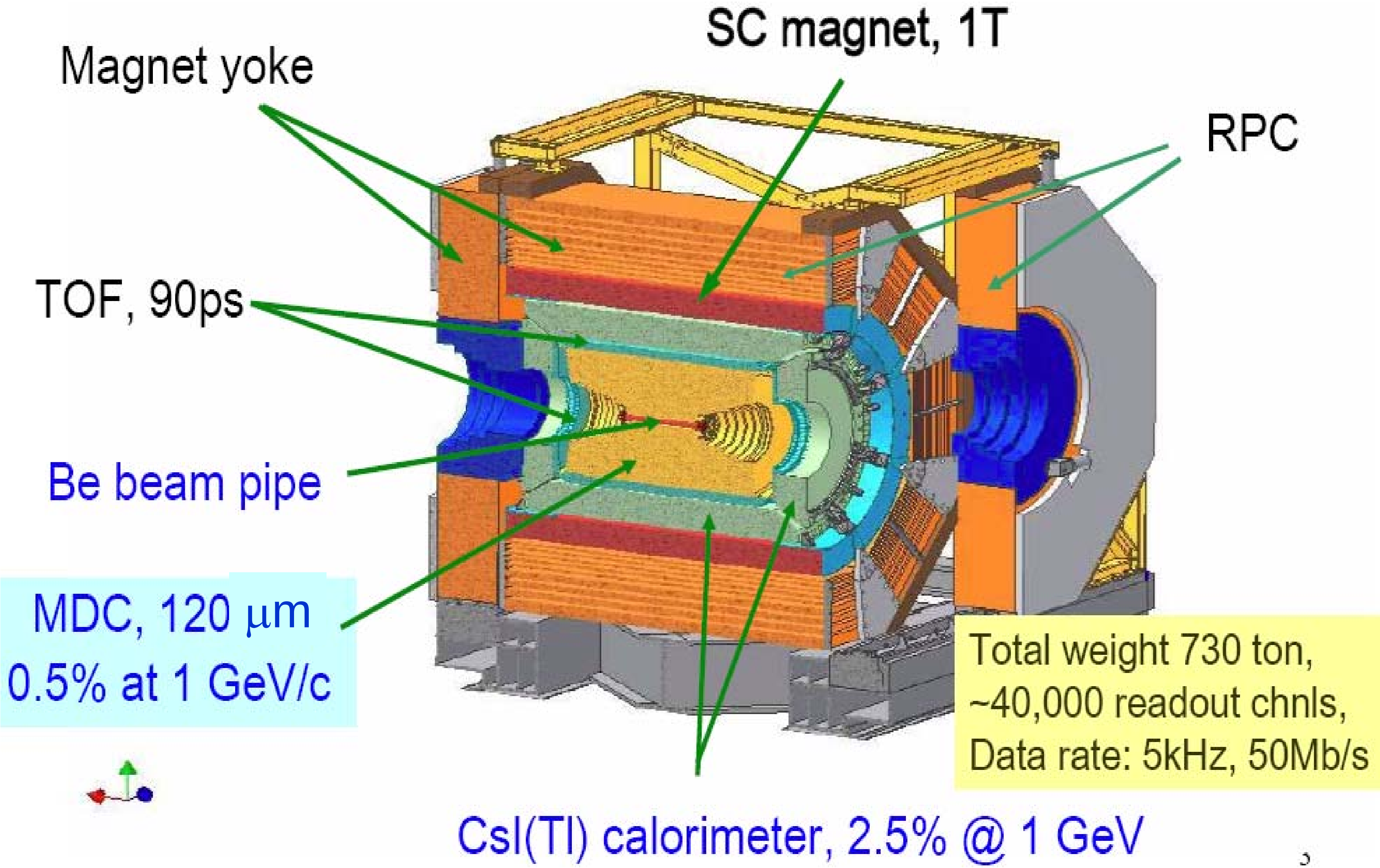

B
Air view of BEPCII /BESIII
LINAC
South
BESIII detector
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking
W. Gradl — New states at BES

BEPCII storage rings

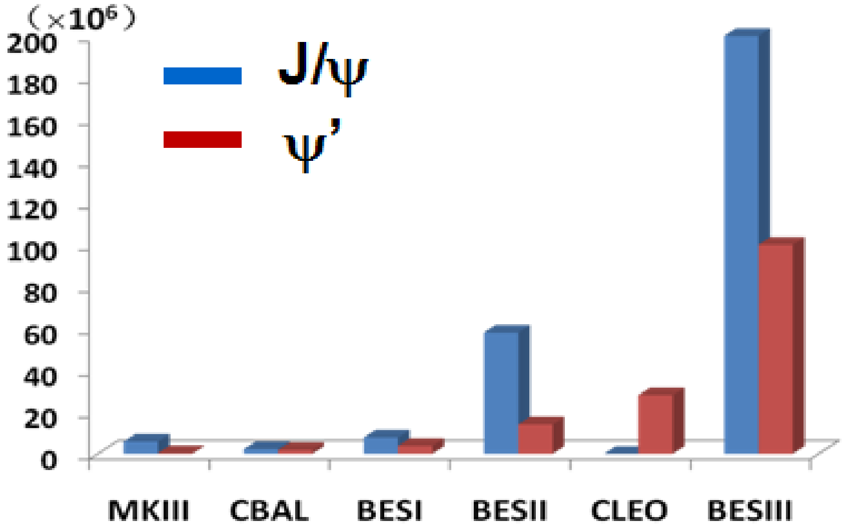


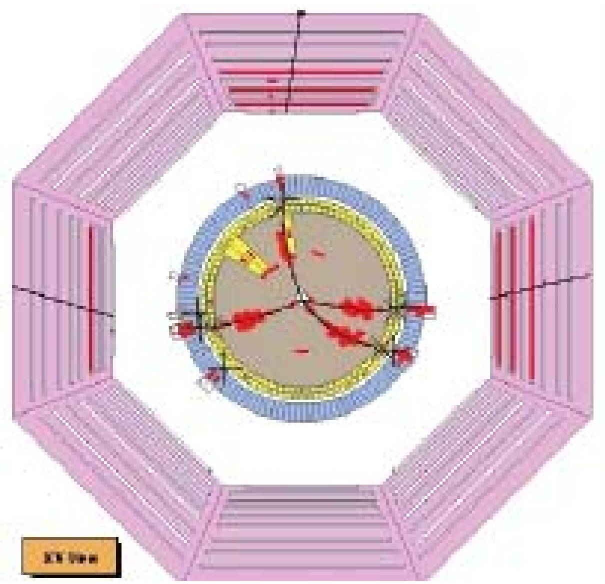
Beam energy:
1.0-2.3 GeV
Design Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
Circumference：
237m

BESIII detector



BESIII@BEPCII status





So far world largest data samples:

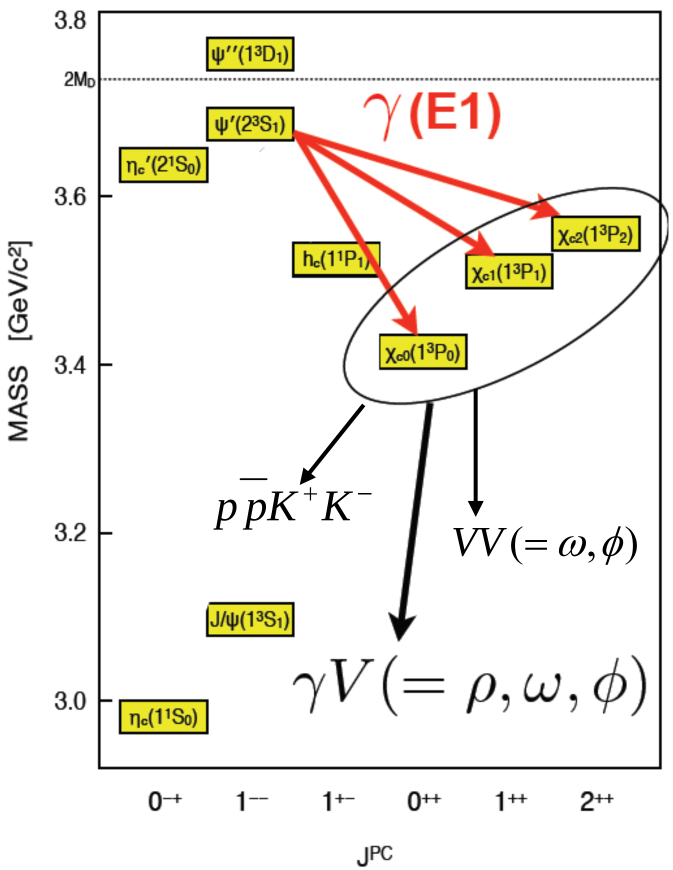
- ~225 Million J/Ψ
- ~106 Million Ψ
- ~2.9 fb^{-1} Ψ(3770)
- ~0.5 fb^{-1} at 4.01GeV

Very soon also data at higher energies to search for XYZ states and Ds physics, etc

- **First collisions: March 2008**
- **First collisions in BESIII: July 2008**
- **Massive physics run in BESIII: March 2009**
- **Record luminosity : $6.5x10^{32}cm^{-2}s^{-1}$**

Hadronic decays of χ_{cJ}

- Motivation
  - Study gluonium $\chi_{cJ} \to gg \to (q\bar{q})(q\bar{q})$ → C. Amsler and F. E. Close, PRD 53:295(1996)
  - Study Color Octet Mechanism → G. T. Bodwin eta al., PRL 51:1125(1995); H.-W. Huang and K.T. Chao, PRD 54:6850(1996); J. Bolza et al., Eur. Phys. J. C 2:705(1998)



Theory:

1. Color Octet Mechanism (COM) agrees reasonably well with experimental measurements for pseudoscalar or baryon pairs, but leaves some exceptions, for example, $\chi_{cJ} \to \Lambda\bar{\Lambda}$ etc.
2. $\chi_{cJ} \to VV$, to test COM.

BESIII Experiment:

1. χ_{cJ} cannot directly originate from ee collisions.
2. Ψ' radiative decay ($\Psi' \to \gamma\chi_{cJ}$) provides a clean environment to study these questions.

$\chi_{cJ} \rightarrow \phi\phi$, $\omega\omega$, and $\omega\phi$

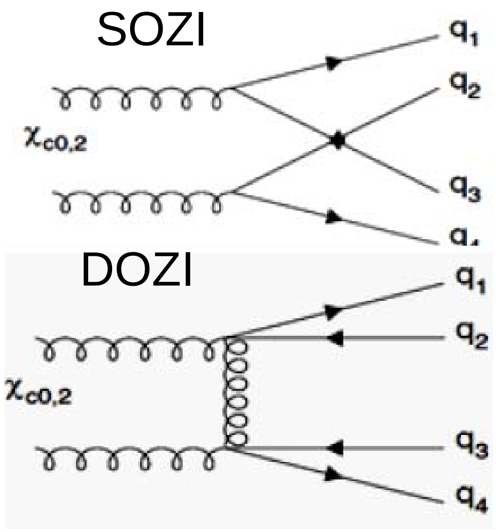
arXiv: 1104. 5068, submitted to PRL

$\chi_{c1} \rightarrow VV$ is suppressed due to helicity selection rule *Nucl. Phys. B201,492*

$\chi_{cJ} \rightarrow \omega\phi$ is doubly OZI suppressed.

BESII measurements

BR(10^{-3})	χ_{c0}		χ_{c2}	
	Exp.	Th.	Exp.	Th.
$\rightarrow \phi\phi$	0.94±0.21±0.13	0.086	1.70±0.30±0.25	0.154
$\rightarrow \omega\omega$	2.29±0.58±0.41	-	1.77±0.47±0.36	-



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

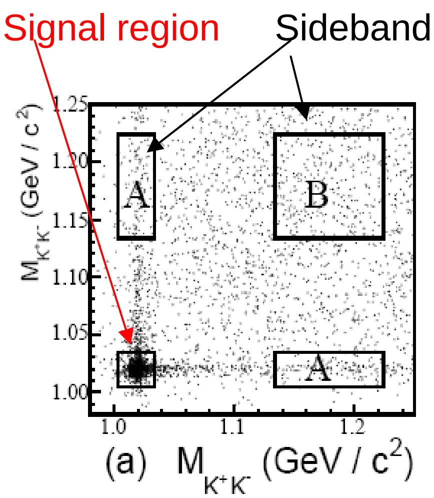
Q. Zhao, PLB659, 221(2008)

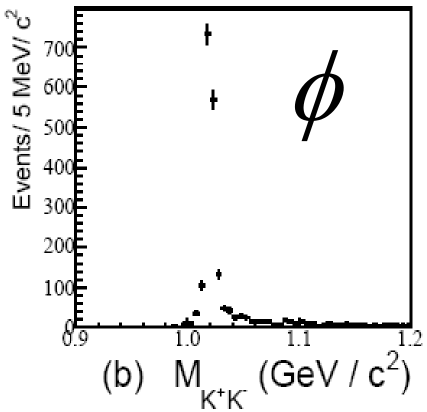
Experimental values are much larger than that from pQCD predictions.

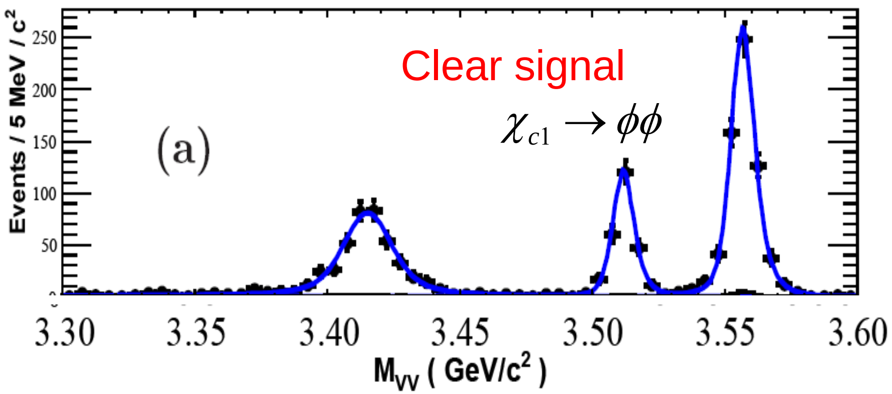
Does Color octet mechanism have a better interpretation in theory?

$\chi_{cJ} \to \phi\phi, \phi \to K^+K^-$ @ BESIII

arXiv: 1104. 5068, submitted to PRL







1. Using kinematic fit to select γ 2(K^+K^-) candidates
2. KK pairs reconstructed by minimizing :

$$\sum (M_{K^+K^-} - M_\phi)^2$$

3. Fitting M(VV) spectrum to extract Br.

Signal: χ_{cJ} shape from MC

Backgrounds:

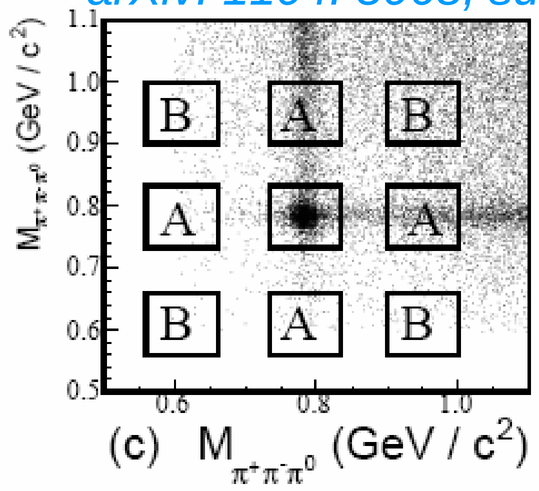
- Normalized sidebands
- Phase-space for non- χ_{cJ} .
- 2-nd order polynomial or combinatorial bg.

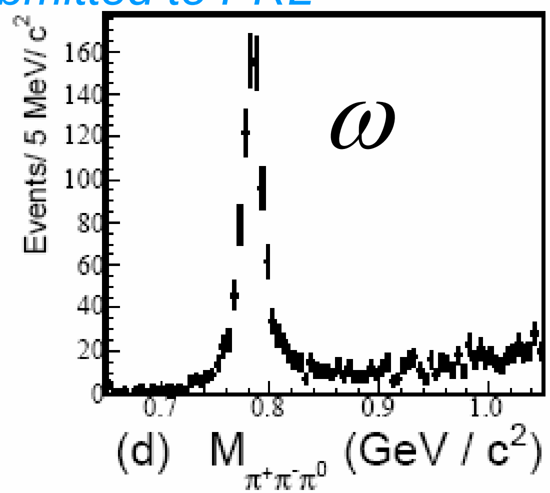
Channel	$\mathcal{B}(\times 10^{-4})$	PDG$(\times 10^{-4})$
$\chi_{c0} \to \phi\phi$	$7.8 \pm 0.4 \pm 0.8$	9.2 ± 1.9
$\chi_{c1} \to \phi\phi$	$4.1 \pm 0.3 \pm 0.4$	—
$\chi_{c2} \to \phi\phi$	$10.7 \pm 0.4 \pm 1.1$	14.8 ± 2.8

First observation

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

arXiv: 1104. 5068, submitted to PRL

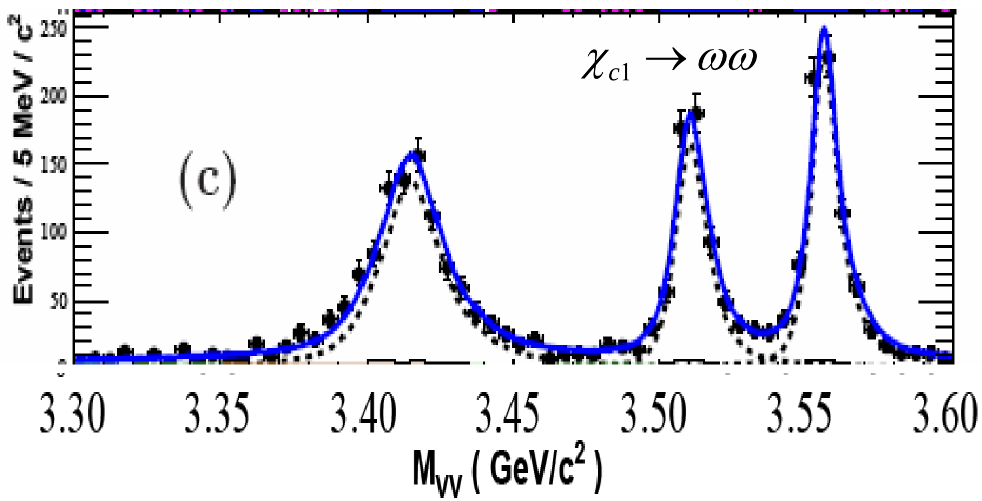




1. Using kinematic fit to select $5\gamma\ 2(\pi^+\pi^-)$ candidates.

2. Two π^0 pair reconstruction: minimizing $\sum(M_{\gamma\gamma} - M_{\pi^0})^2$

by looping over 5γ.



3. ω reconstruction: minimizing

$$\sum(M_{\pi^+\pi^-\pi^0} - M_{\omega})^2$$

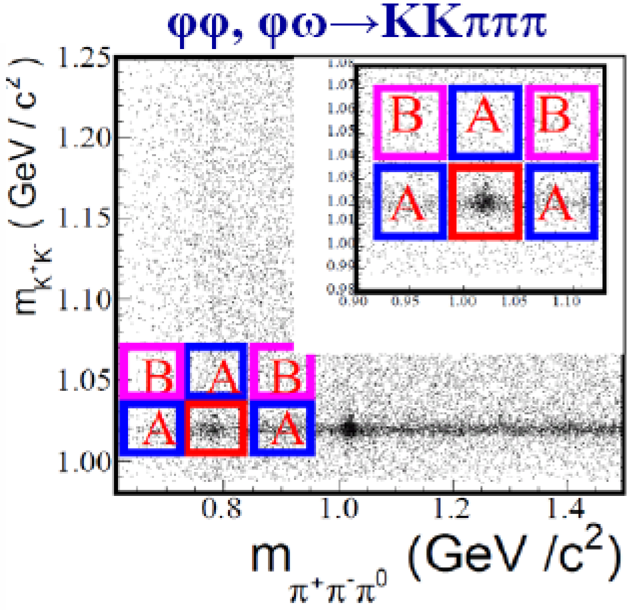
Fitting strategy follows the previous

Channel	$\mathcal{B}(\times 10^{-4})$	PDG$(\times 10^{-4})$
$\chi_{c0} \to \omega\omega$	$9.5 \pm 0.3 \pm 1.1$	22 ± 7.0
$\chi_{c1} \to \omega\omega$	$6.0 \pm 0.2 \pm 0.7$	—
$\chi_{c2} \to \omega\omega$	$8.9 \pm 0.3 \pm 1.1$	19.0 ± 6.0

First observation

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

arXiv: 1104. 5068, submitted to PRL



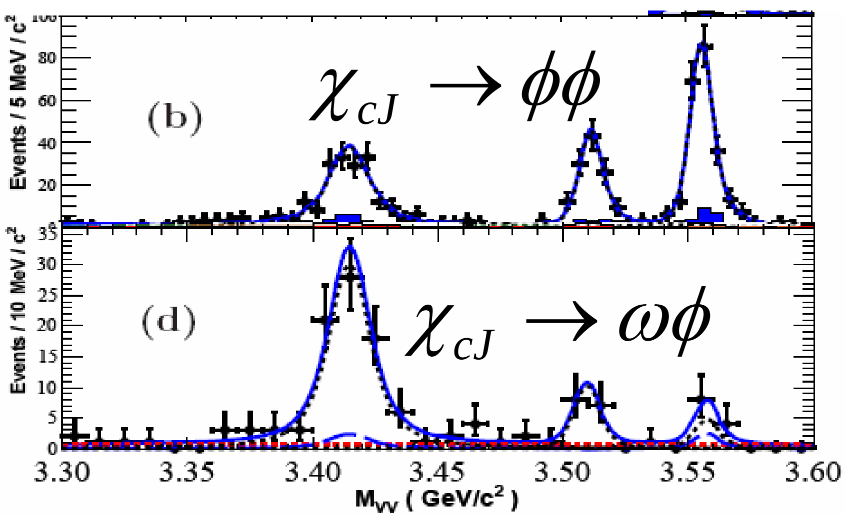
1. Using kinematic fit to select $3\gamma\, 2K 2\pi$ candidates.

2. K+K- are identified by minimizing

$$\sum (M_{KK} - M_{\phi})^2$$

3. $\pi^0\,\omega$ are reconstructed by minimizing $(M_{\gamma\gamma} - M_{\pi^0})^2 + (M_{\gamma\gamma\pi^+\pi^-} - M_{\omega})^2$

Channel	$\mathcal{B}(\times 10^{-4})$	PDG$(\times 10^{-4})$
$\chi_{c0} \to \phi\phi$	$9.2 \pm 0.7 \pm 1.0$	9.2 ± 1.9
$\chi_{c1} \to \phi\phi$	$5.0 \pm 0.5 \pm 0.6$	—
$\chi_{c2} \to \phi\phi$	$10.7 \pm 0.7 \pm 1.2$	14.8 ± 2.8
$\chi_{c0} \to \omega\phi$	$1.2 \pm 0.1 \pm 0.2$	—
$\chi_{c1} \to \omega\phi$	$0.22 \pm 0.06 \pm 0.02$	—
$\chi_{c2} \to \omega\phi$	< 0.2	—



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

Summary for χ_{cJ}→VV

arXiv: 1104. 5068, submitted to PRL

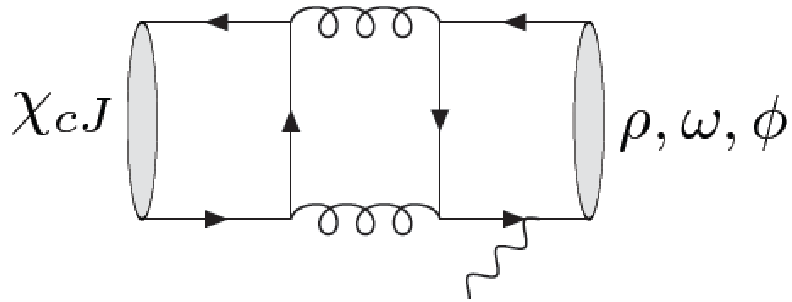
Final states	Channel	$N_{\rm net}$	ϵ (%)	$\mathcal{B}(\times10^{-4})$	PDG($\times10^{-4}$) [11]
$\gamma 2(K^+K^-)$	$\chi_{c0}\to\phi\phi$	432 ± 23	22.4	$7.8\pm0.4\pm0.8$	9.2 ± 1.9
	$\chi_{c1}\to\phi\phi$	254 ± 17	26.4	$4.1\pm0.3\pm0.4$	—
	$\chi_{c2}\to\phi\phi$	629 ± 26	26.1	$10.7\pm0.4\pm1.1$	14.8 ± 2.8
$\gamma K^+K^-\pi^+\pi^-\pi^0$	$\chi_{c0}\to\phi\phi$	179 ± 16	1.9	$9.2\pm0.7\pm1.0$	9.2 ± 1.9
	$\chi_{c1}\to\phi\phi$	112 ± 12	2.3	$5.0\pm0.5\pm0.6$	—
	$\chi_{c2}\to\phi\phi$	219 ± 16	2.2	$10.7\pm0.7\pm1.2$	14.8 ± 2.8
Combined	$\chi_{c0}\to\phi\phi$	—	—	$8.0\pm0.3\pm0.8$	9.2 ± 1.9
	$\chi_{c1}\to\phi\phi$	—	—	$4.4\pm0.2\pm0.5$	—
	$\chi_{c2}\to\phi\phi$	—	—	$10.7\pm0.3\pm1.2$	14.8 ± 2.8
$\gamma 2(\pi^+\pi^-\pi^0)$	$\chi_{c0}\to\omega\omega$	991 ± 38	13.1	$9.5\pm0.3\pm1.1$	22 ± 7.0
	$\chi_{c1}\to\omega\omega$	597 ± 29	13.2	$6.0\pm0.2\pm0.7$	—
	$\chi_{c2}\to\omega\omega$	762 ± 31	11.9	$8.9\pm0.3\pm1.1$	19.0 ± 6.0
$\gamma K^+K^-\pi^+\pi^-\pi^0$	$\chi_{c0}\to\omega\phi$	76 ± 11	14.7	$1.2\pm0.1\pm0.2$	—
	$\chi_{c1}\to\omega\phi$	15 ± 4	16.2	$0.22\pm0.06\pm0.02$	—
	$\chi_{c2}\to\omega\phi$	<13	15.7	<0.2	—

Motivation and Status

Phys. Rev. D 83, 112005 (2011)

Relation:

- two gluon coupling
- possible glueball or hybrid states
- hadronization

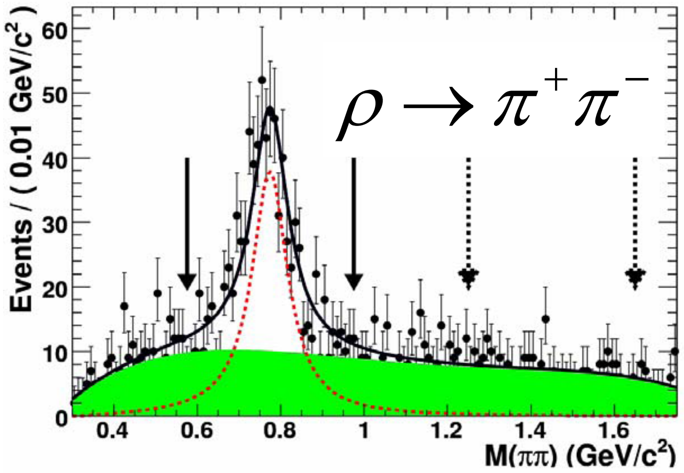


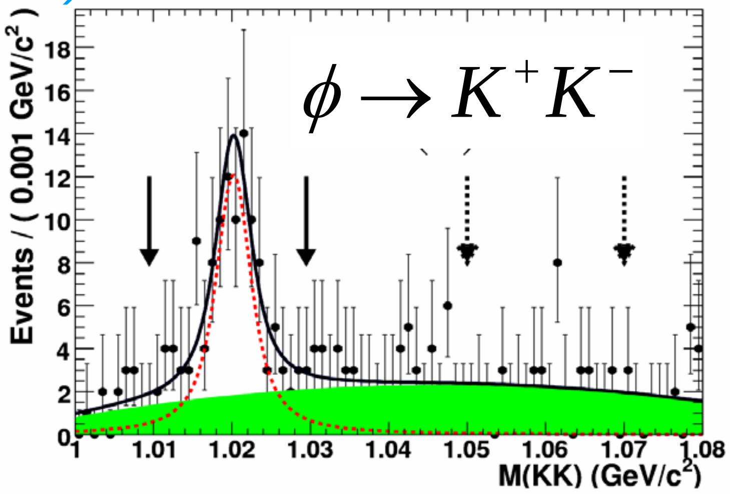
Mode	CLEO[1]	pQCD[2]	QCD[3]	QCD+QED[3]
$\chi_{c0} \to \gamma\rho^0$	< 9.6	1.2	3.2	2.0
$\chi_{c1} \to \gamma\rho^0$	$243 \pm 19 \pm 22$	14	41	42
$\chi_{c2} \to \gamma\rho^0$	< 50	4.4	13	38
$\chi_{c0} \to \gamma\omega$	< 8.8	0.13	0.35	0.22
$\chi_{c1} \to \gamma\omega$	$83 \pm 15 \pm 12$	1.6	4.6	4.7
$\chi_{c2} \to \gamma\omega$	< 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

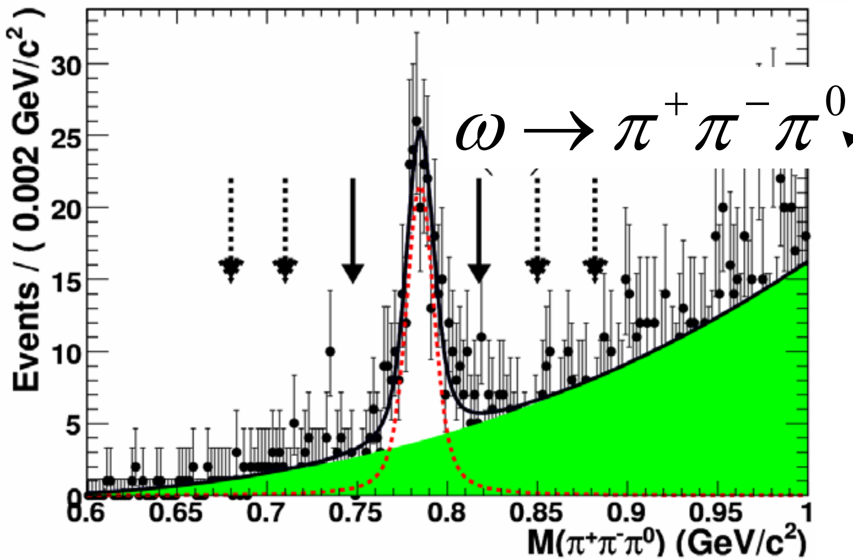
ρ, ω, ϕ Reconstruction

Phys. Rev. D 83, 112005 (2011)





Applying 4C kinematic fit to $\gamma\gamma\pi^+\pi^-$ or $\gamma\gamma K^+K^-$.



Using 5C(4-momentum+ π^0 mass) kinematic fit for 4 $\gamma\pi^+\pi^-$ candidates.

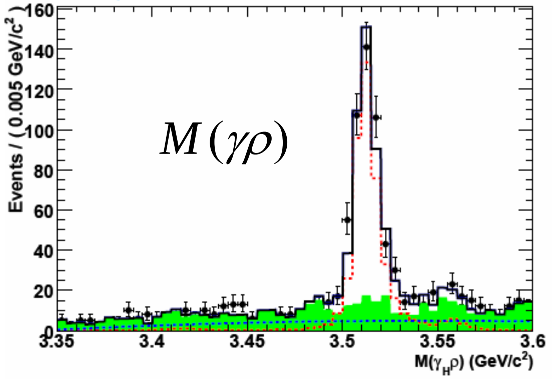
π^0 reconstruction:

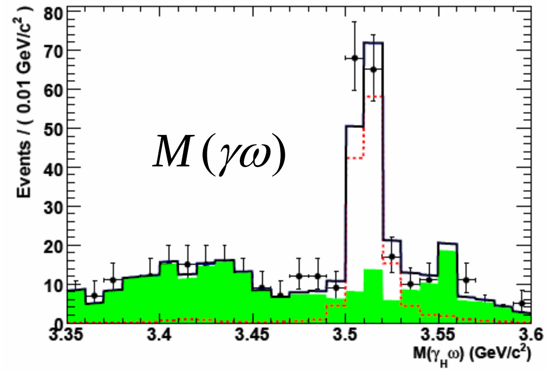
$$\left(\frac{M_{\gamma_1\gamma_2} - M_{\pi^0}}{\sigma_{\pi^0}}\right)^2 + \left(\frac{M_{\pi^+\pi^-\gamma_1\gamma_2} - M_{\omega}}{\sigma_{\omega}}\right)^2$$

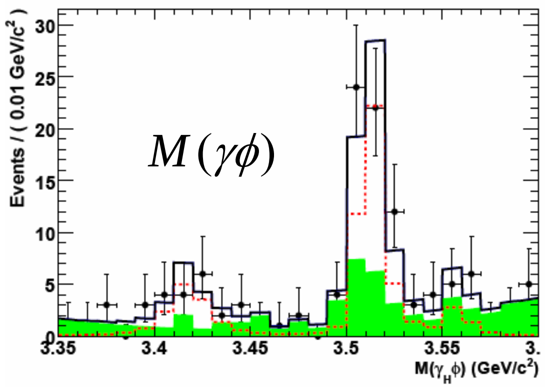
Fitting:
Signal shape: BW
Background: Polynomial

Analysis Results

Phys. Rev. D 83, 112005 (2011)







Fitting:
Signal shape: MC
Background: sideband + polynomial

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

Mode	BESIII	CLEO	pQCD
$\chi_{c0}\to\gamma\rho^0$	<10.5	<9.6	1.2
$\chi_{c1}\to\gamma\rho^0$	$228\pm13\pm22$	$243\pm19\pm22$	14
$\chi_{c2}\to\gamma\rho^0$	<20.8	<50	4.4
$\chi_{c0}\to\gamma\omega$	<12.9	<8.8	0.13
$\chi_{c1}\to\gamma\omega$	$69.7\pm7.2\pm6.6$	$83\pm15\pm12$	1.6
$\chi_{c2}\to\gamma\omega$	<6.1	<7.0	0.5
$\chi_{c0}\to\gamma\phi$	<16.2	<6.4	0.46
$\chi_{c1}\to\gamma\phi$	$25.8\pm5.2\pm2.3$	<26	3.6
$\chi_{c2}\to\gamma\phi$	<8.1	<13	1.1

consistent

new

pQCD predictions too lower than experimental measurements.

See an non-pQCD explanation “hadronic loop correction”, D.Y Chen et al. arXiv:1005.0066v2[hep-ph]

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

Helicity Angle

Phys. Rev. D 83, 112005 (2011)

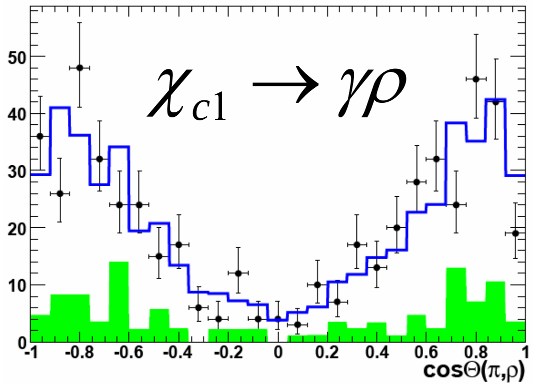
L: Longitudinal polarization, T: Transverse polarization,

θ : **Helicity angle**

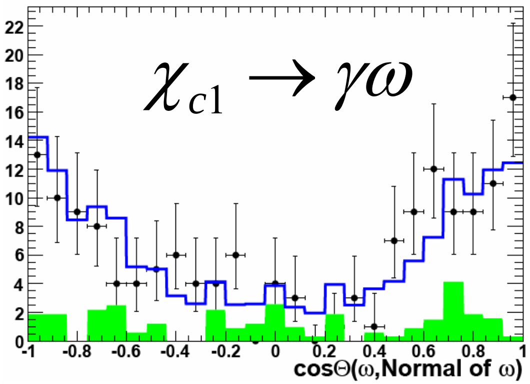
$$\frac{d\Gamma}{\Gamma d\cos\theta} \propto (1-f_T)\cos^2\theta + \frac{1}{2} f_T \sin^2\theta \qquad f_T = \frac{|A_T|^2}{|A_T|^2+|A_L|^2}$$

- Longitudinal polarization dominates in the $\chi_{c1} \to \gamma V$

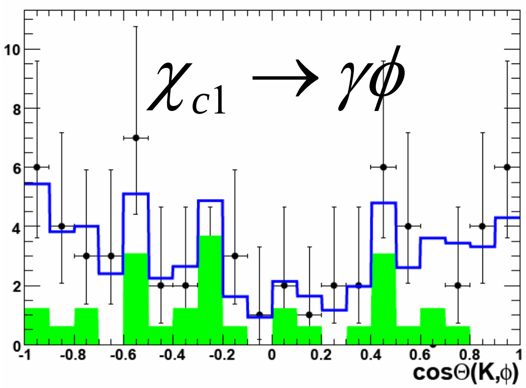
  ⇨ As expected in axial-vector particle radiative decaying to a vector.



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



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



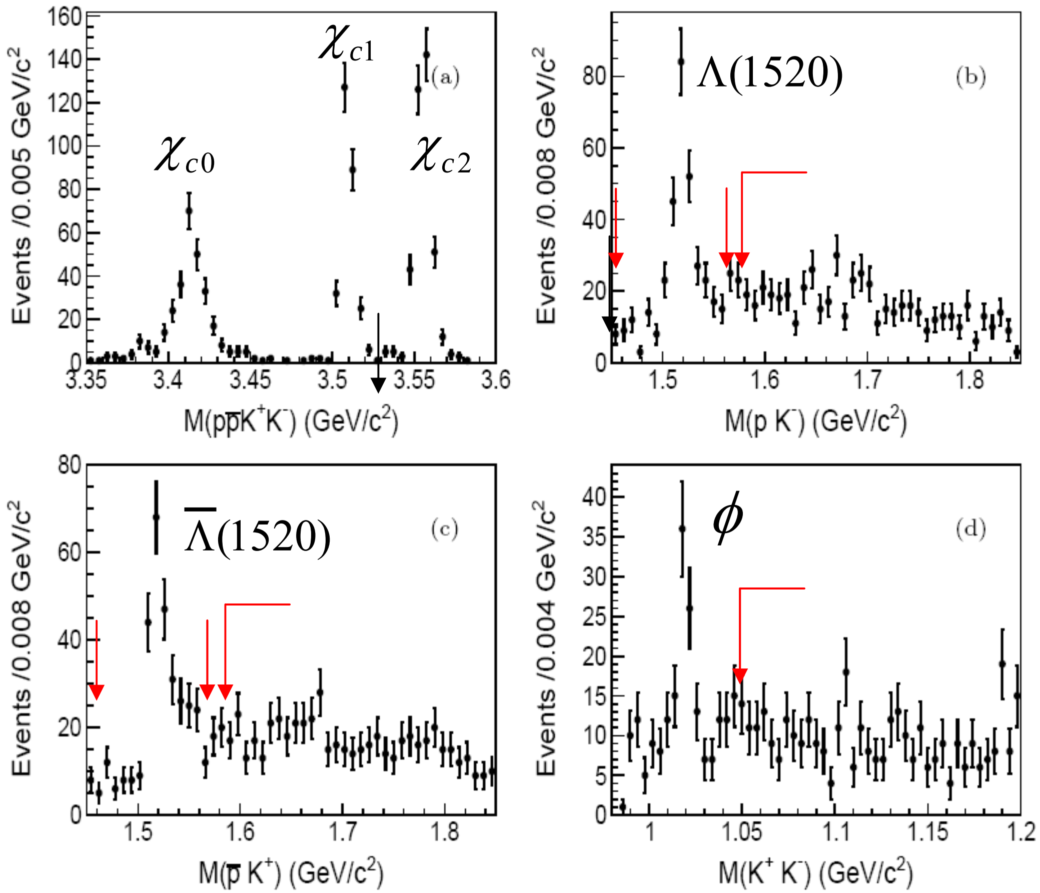
$$f_T = 0.29^{+0.13}_{-0.12}{}^{+0.10}_{-0.09}$$

$\chi_{cJ} \rightarrow \bar{p}pK^+K^-$ final state

arXiv:11032661 Accepted by PRD

First observation

$\psi' \rightarrow \gamma\chi_{cJ} \rightarrow \gamma p\bar{p}KK$



1. Using 4C kinematic fit to select γ pp̄KK candidates.

$$|M(pK^-)-1.52|>0.07GeV$$
$$|M(\bar{p}K^+)-1.52|>0.07GeV$$
$$|M(K^-K^+)-1.02|>0.03GeV$$

$\chi_{cJ} \rightarrow p\bar{p}K+K-$

Non-resonance

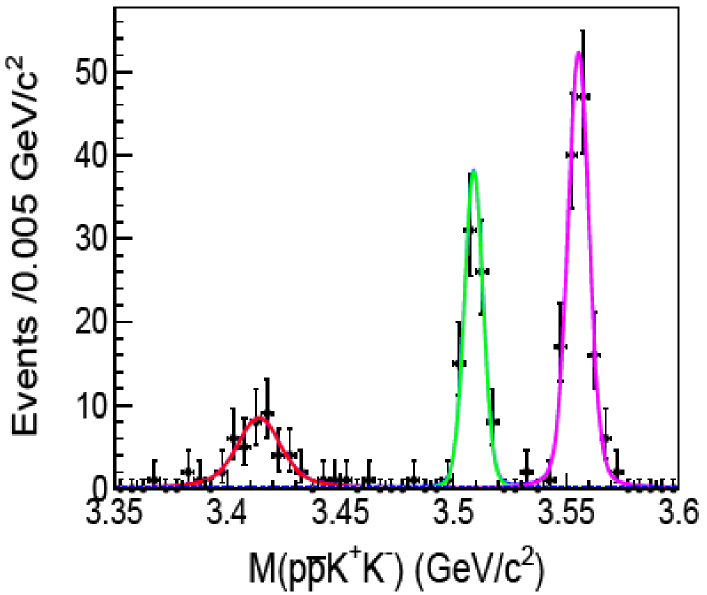
$$|M(pK^-)-1.52|<0.05GeV$$
$$|M(\bar{p}K^+)-1.52|<0.05GeV$$

$\chi_{cJ} \rightarrow \bar{\Lambda}(1520)\Lambda(1520)$

baryon pairs

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

Non-resonance



$\mathcal{B}(\chi_{cJ} \to p\bar{p}K^+K^-)\ (10^{-4})$

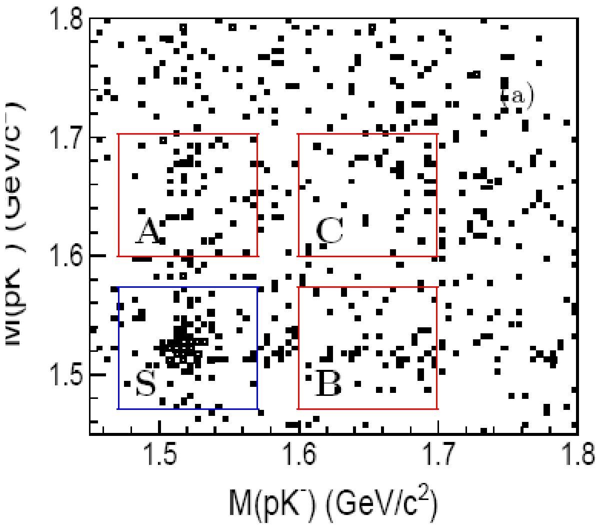
χ_{c0}	χ_{c1}	χ_{c2}
1.24 ± 0.20	1.35 ± 0.15	2.08 ± 0.19

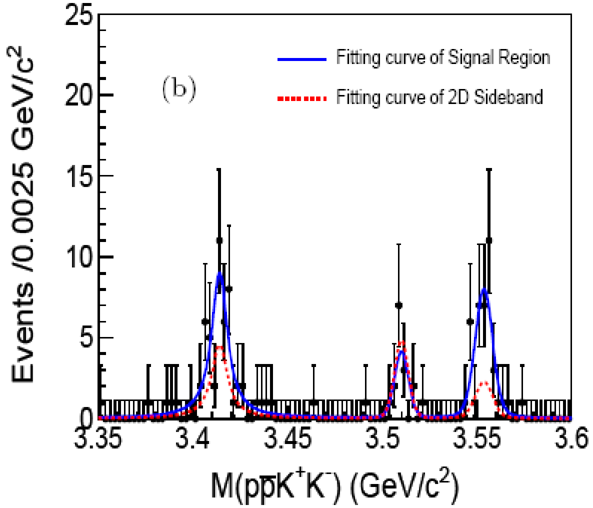
$\chi_{cJ} \to \bar{\Lambda}(1520)\Lambda(1520)$

double resonances

$\Lambda(1520)\bar{\Lambda}(1520)$ selections

$|M(pK^-) - 1.52| < 0.05GeV \quad |M(\bar{p}K^+) - 1.52| < 0.05GeV$

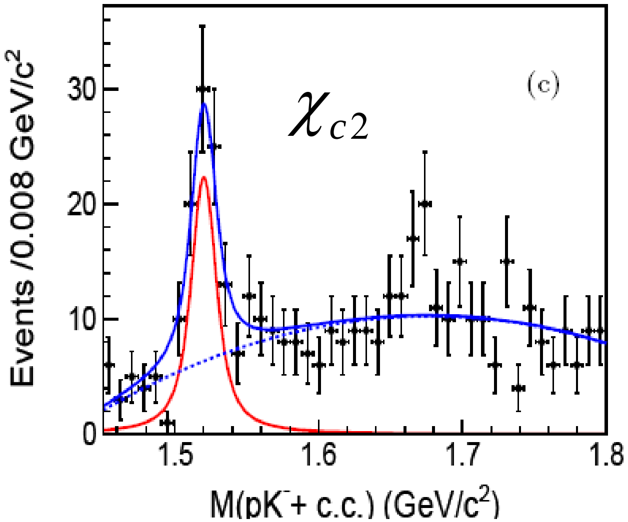


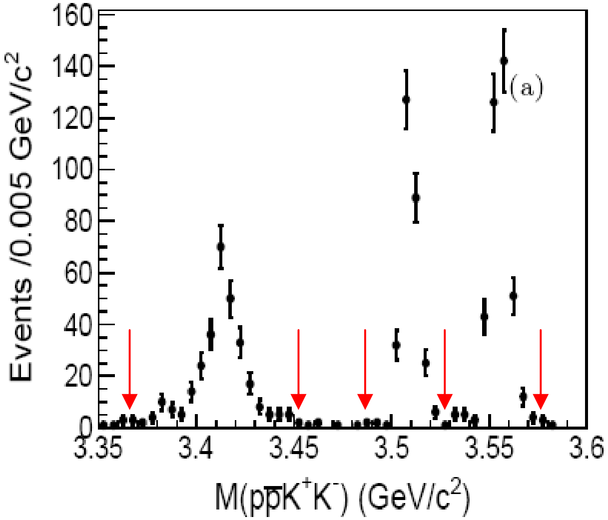


$\mathcal{B}(\chi_{cJ} \to \Lambda(1520)\bar{\Lambda}(1520))\ (10^{-4})$

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

$\chi_{cJ} \to \overline{p}K^{+}\Lambda(1520) + c.c.$

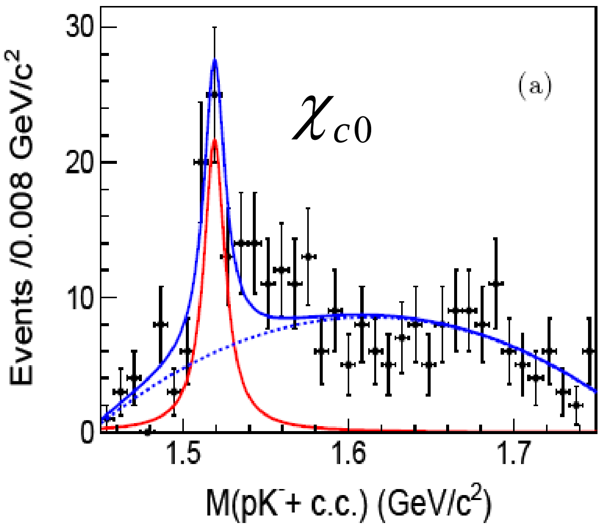


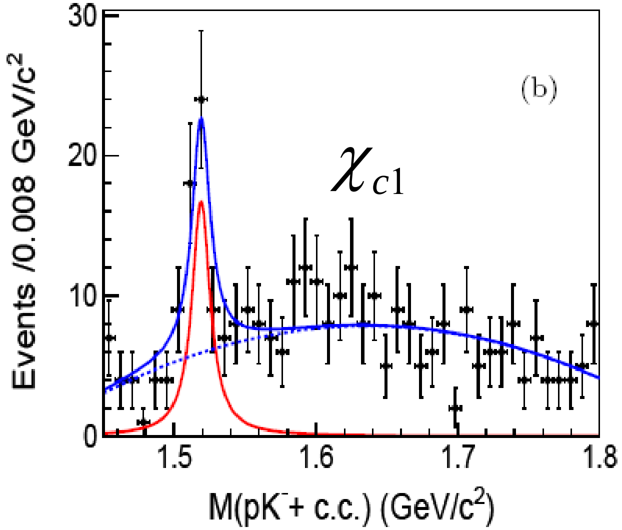


$3.365 < M(p\overline{p}K^{+}K^{-}) < 3.455$

$3.490 < M(p\overline{p}K^{+}K^{-}) < 3.530$

$3.530 < M(p\overline{p}K^{+}K^{-}) < 3.580$





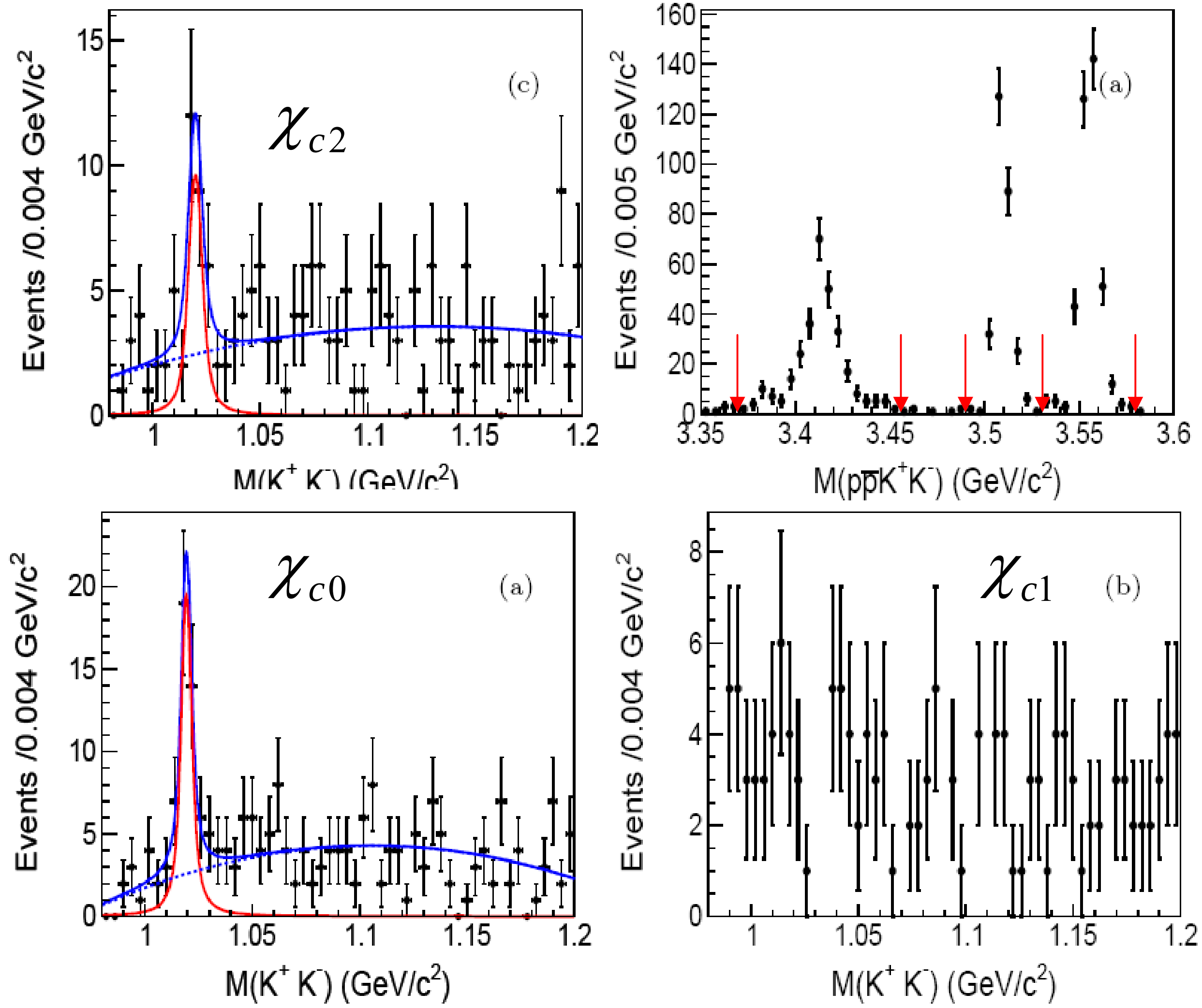
Fitting:

$BW \otimes Gaussian(0, \sigma)$

Branching fractions in unit of 10^{-4}

χ_{c0}	3.00 ± 0.58
χ_{c1}	1.81 ± 0.38
χ_{c2}	3.06 ± 0.50

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



$3.365 < M(p\bar{p}K^+K^-) < 3.455$

$3.490 < M(p\bar{p}K^+K^-) < 3.530$

$3.530 < M(p\bar{p}K^+K^-) < 3.580$

Fitting:

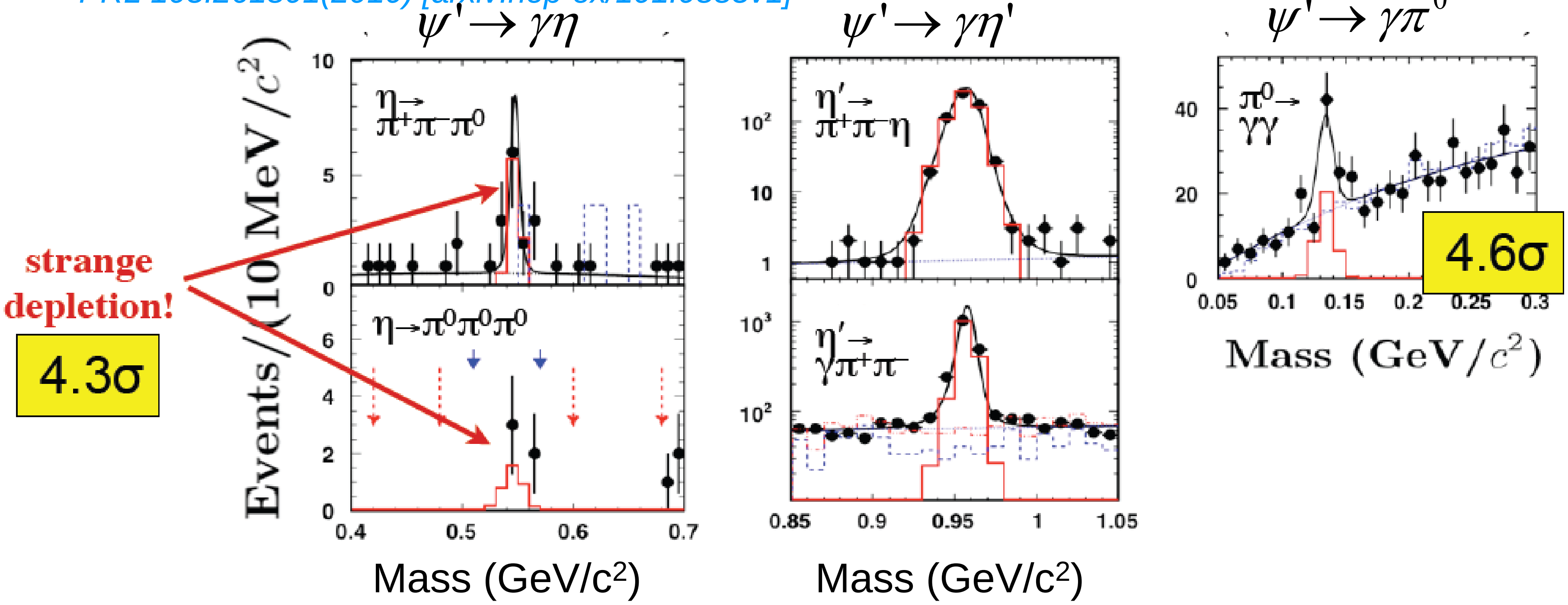
$BW \otimes Gaussian(0,\sigma)$

Branching fractions in unit of 10^{-5}

χ_{c0}	6.12 ± 1.18
χ_{c1}	< 1.58
χ_{c2}	3.04 ± 0.85

Evidence for $\psi' \rightarrow \gamma\, \pi_0 / \gamma\, \eta$

PRL 105:261801(2010) [arxiv:hep-ex/101.0885v1]

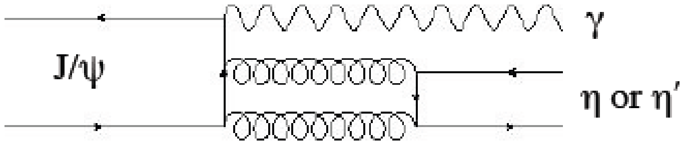


Mode	BESIII	Combined BESIII	PDG
$\psi' \rightarrow \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \rightarrow \gamma\eta(\pi^+\pi^-\pi^0)$	$1.78 \pm 0.72 \pm 0.17$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\rightarrow \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$		
$\psi' \rightarrow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

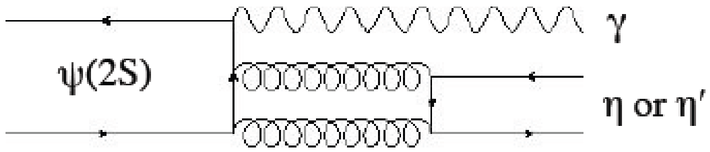
Branching fractions in units of 10^{-6}

Discussion

PRL 105:261801(2010) [arxiv:hep-ex/101.0885v1]



VS



Theory

Experiment

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

LO-pQCD

$$\Downarrow$$

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

PRP 112,173 (1984)

- Related to rho-pi puzzle?

CLEO-c

PRD79, 111101 (2009)

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

(consistent with other measurements of η-η′ mixing angle and LO-pQCD)

BESIII

$$R_{\Psi'} = \frac{B(\psi(2S) \to \gamma\eta)}{B(\psi(2S) \to \gamma\eta')} = (1.10 \pm 0.38 \pm 0.07)\ \%$$

(consistent with upper limit from CLEO-c)

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

Summary

- BEPCII/BESIII:
  - Peak luminosity > 6.3X10^{-32} pb^{-1}s^{-1} achieved.
  - 106M ψ’, the largest data sample in the world.
- Rich studies
  - $\chi_{cJ} \to VV[V = \phi, \omega]$ *arXiv:1104. 5068, submit to PRL*
  - $\chi_{cJ} \to \gamma V[V = \rho, \phi, \omega]$ *Phys. Rev. D 83, 112005 (2011)*
  - $\chi_{cJ} \to p\bar{p}K^+K^-$ *arXiv:1103.2661 Accepted by PRD*
  - $\psi' \to \gamma P[P = \pi^0, \eta, \eta']$ *PRL 105:261801(2010)*

Thanks for your attention

backup

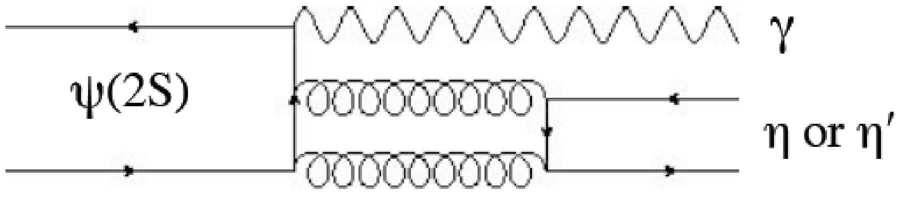
Radiative decays of ψ’

PRL 105:261801(2010) [arxiv:hep-ex/101.0885v1]

- What can I learn?
  - two-gluon coupling to cc states
  - mixing of η_c - η
  - final-state radiation of light quarks
  - π_0 form factor in time-like region

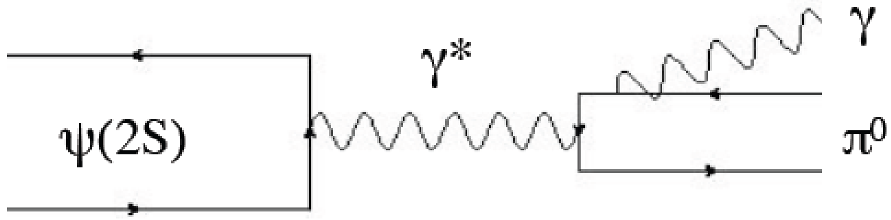
- Experimental challenges:
  - ψ’ → γ η anomalously suppressed
  - Tiny branching fraction ~10^{-6}

$\psi(2S) \to \gamma\eta^{(\prime)}$



η-η’ mixing angle

$\psi(2S) \to \gamma\pi^0$

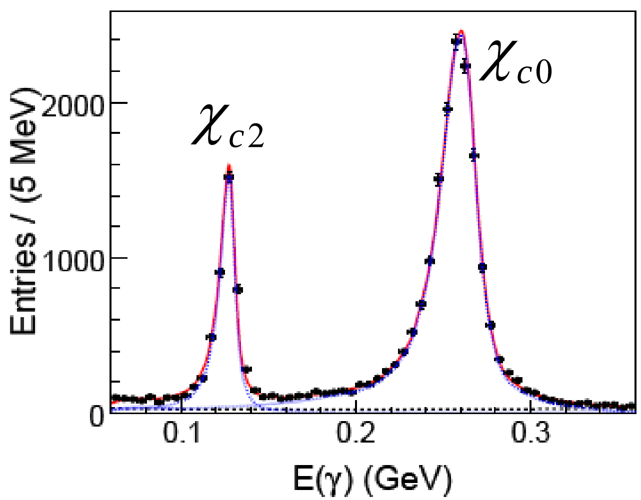


form factor: $\gamma^* - \gamma - \pi^\circ$

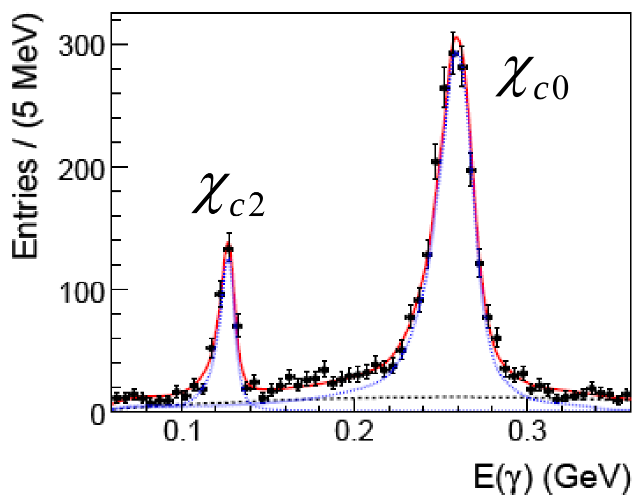
Branching fraction measurements of χ_{c0} and χ_{c2} to $\pi^0\pi^0$ and $\eta\eta$

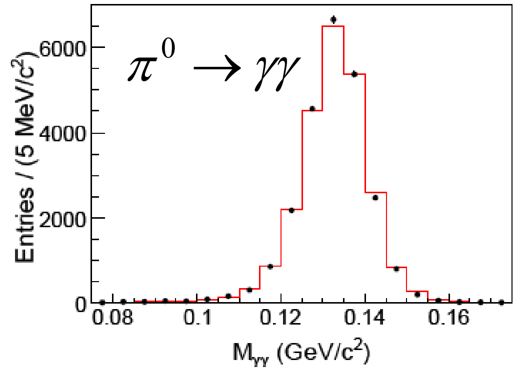
PRD 81:052005(2010) [arxiv:hep-ex/1001.5360v2]

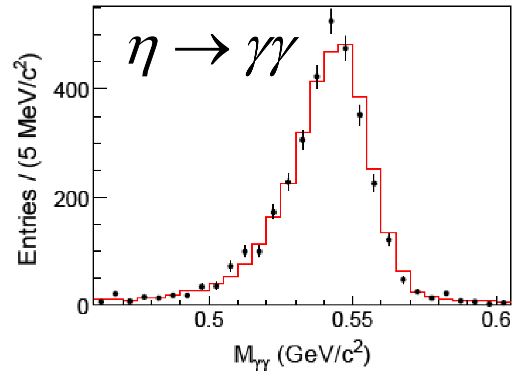
$\psi' \to \gamma\pi^0\pi^0$



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







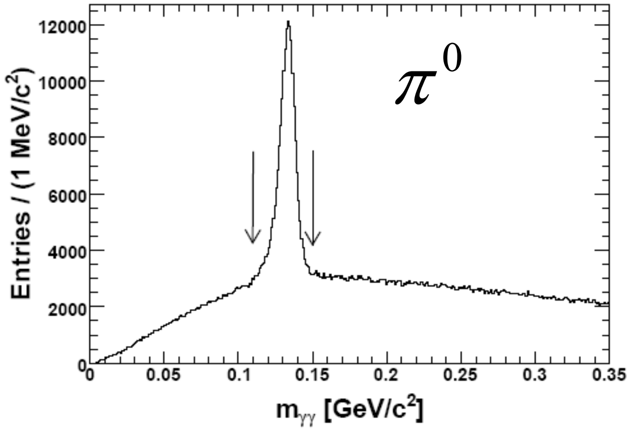
Decay mode		χ_{c0} (10^{-3})	χ_{c2} (10^{-3})
$\pi^0\pi^0$	BESIII	$3.23 \pm 0.03 \pm 0.23 \pm 0.14$	$0.88 \pm 0.02 \pm 0.06 \pm 0.04$
	PDG10	2.80 ± 0.13	0.80 ± 0.05
	Theory	2.3	0.95
$\eta\eta$	BESIII	$3.44 \pm 0.10 \pm 0.24 \pm 0.20$	$0.65 \pm 0.04 \pm 0.05 \pm 0.03$
	PDG10	2.68 ± 0.28	0.54 ± 0.08
	Theory	3.2	1.3

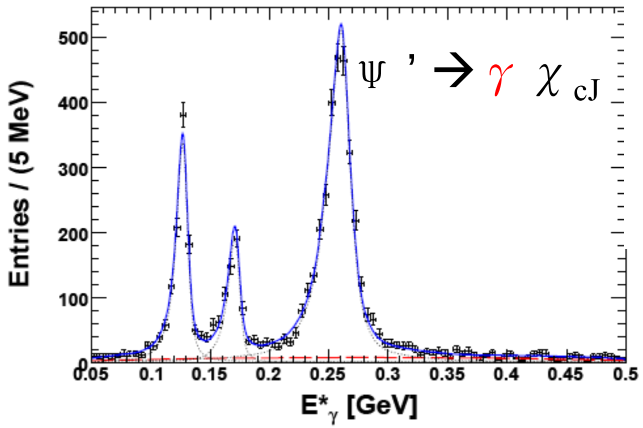
Theory: J. Bolz et al., Eur. Phys. J. C 2:705(1998)

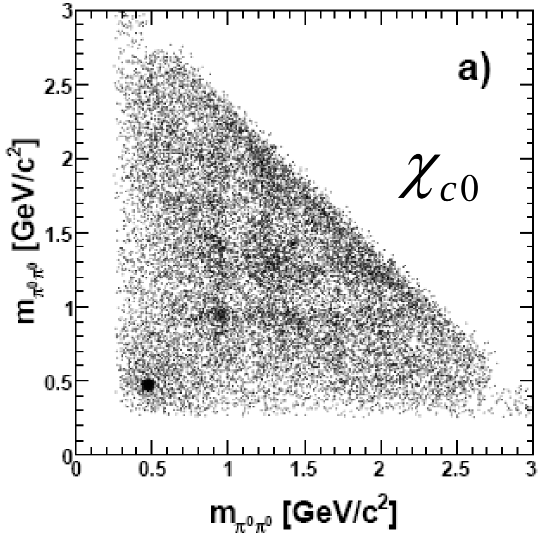
First Observation of the decays $\chi_{cJ} \rightarrow \pi^0\pi^0\pi^0\pi^0$

PRD 83:012006(2011) [arxiv:hep-ex/1011.6556v2]

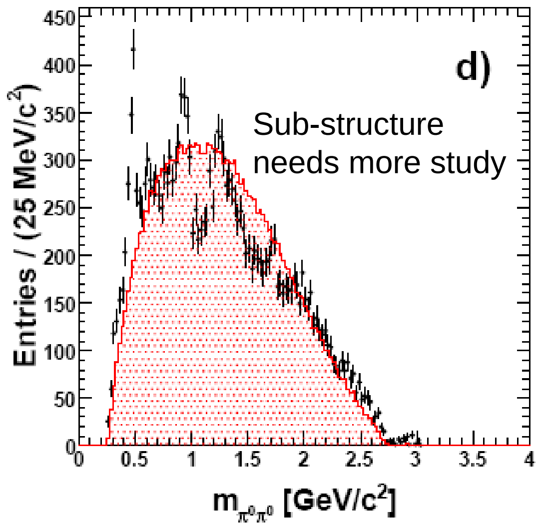
- Events with 9 photon candidates
- $\chi^2_{4\pi} = \sum_i \frac{(m_{\gamma\gamma,i} - m_{\pi^0})^2}{\sigma^2}$ < 15







projection



Branching fractions excluding $\chi_{cJ} \rightarrow K_s K_s$, $K_s \rightarrow \pi^0\pi^0$

$$B(\chi_{c0} \rightarrow \pi^0\pi^0\pi^0\pi^0) = (3.34 \pm 0.06 \pm 0.44) \times 10^{-3}$$

$$B(\chi_{c1} \rightarrow \pi^0\pi^0\pi^0\pi^0) = (0.57 \pm 0.03 \pm 0.08) \times 10^{-3}$$

$$B(\chi_{c2} \rightarrow \pi^0\pi^0\pi^0\pi^0) = (1.21 \pm 0.05 \pm 0.16) \times 10^{-3}$$

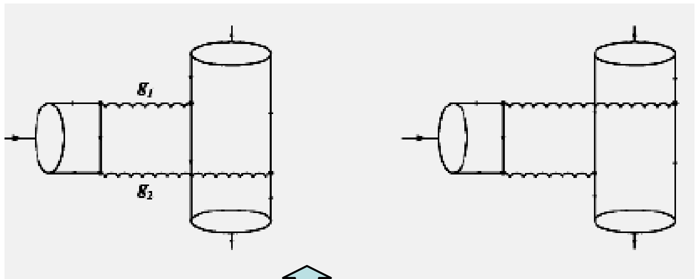
Hadronic decays of χ_{cJ}

PRD 83:012006(2011) [arxiv:hep-ex/1011.6556v2]

- Motivation
  - Study gluonium $\chi_{cJ} \to gg \to (q\bar{q})(q\bar{q})$ → *C. Amsler and F. E. Close, PRD 53:295(1996)*
  - Study Color Octet Mechanism → *G. T. Bodwin eta al., PRL 51:1125(1995)*, *H.-W. Huang and K.T. Chao, PRD 54:6850(1996)*, *J. Bolz et al., Eur. Phys. J. C 2:705(1998)*

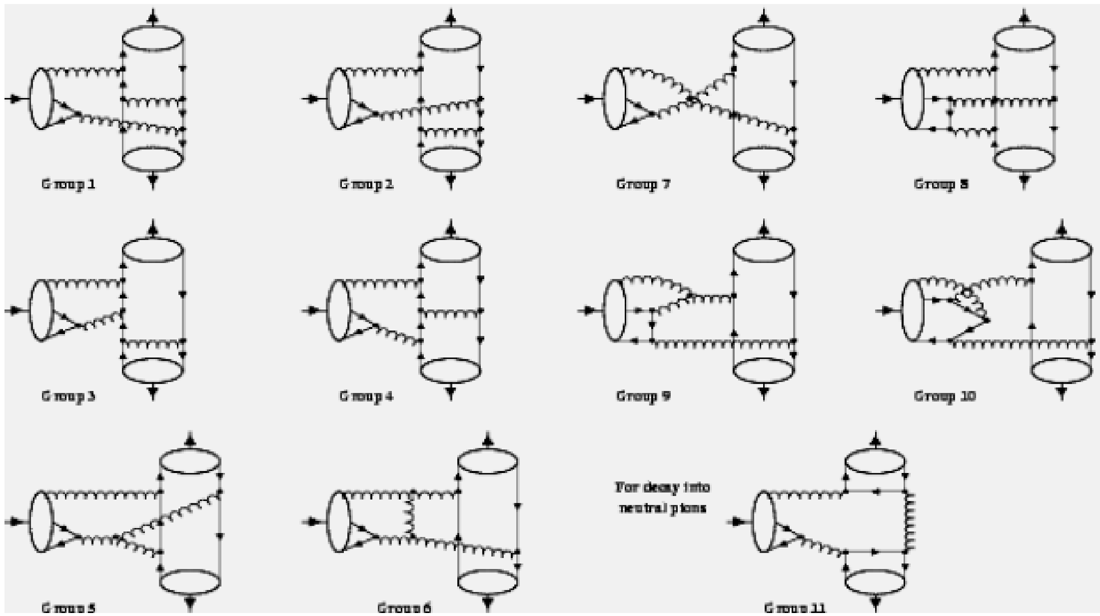
- BESIII experiment:
  - $\psi' \to \gamma \chi_{cJ}$

Color Octet Mechanism have large contribution to the decays of P-wave charmonium states?



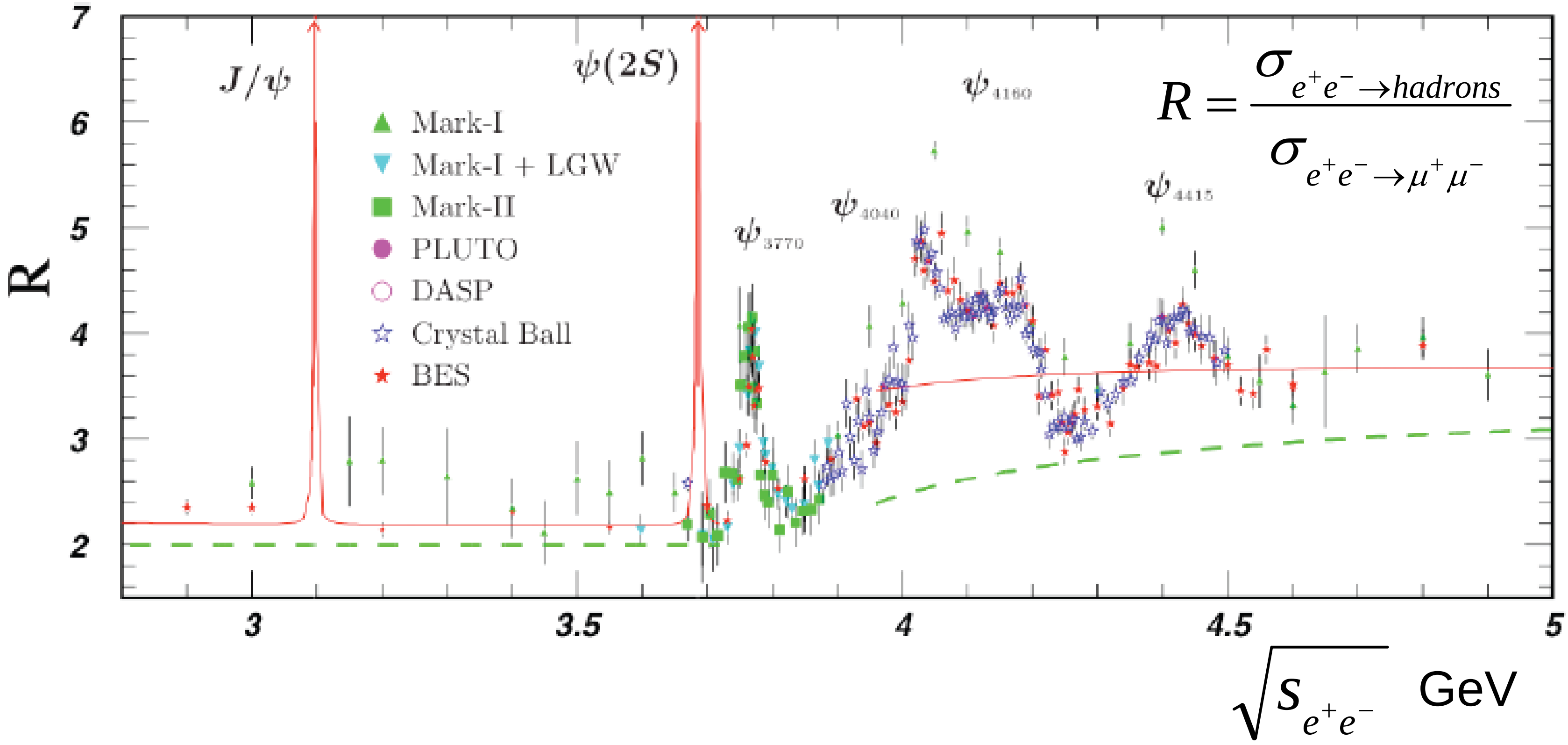
Color singlet graphs(qq̄)

Color octet graphs(qq̄g) →



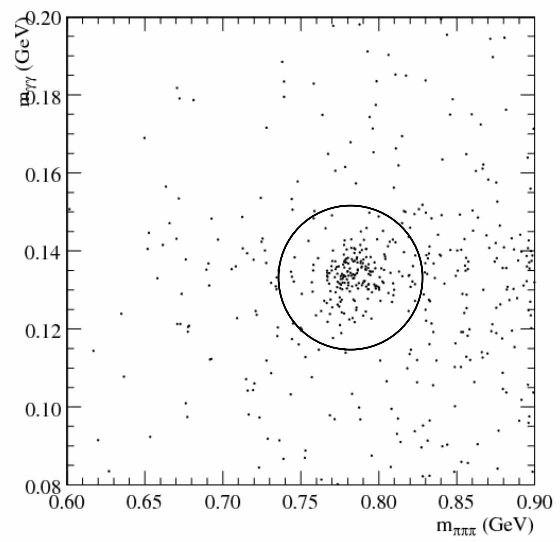
Reasonably well for pseudoscalar or baryon pairs

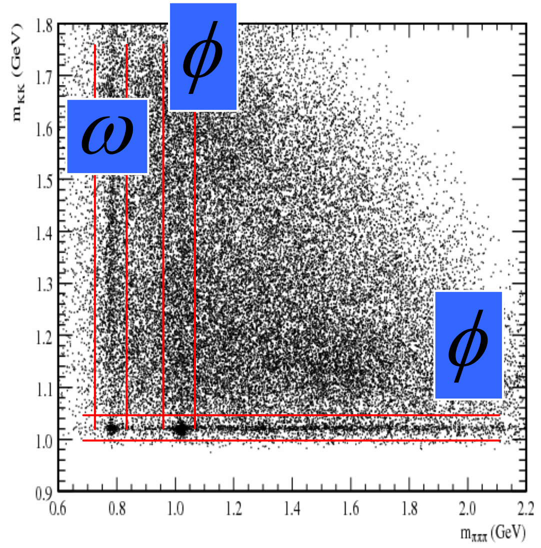
Introduction to the BESIII Experiment



- Their properties and their decays ➡ QCD

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





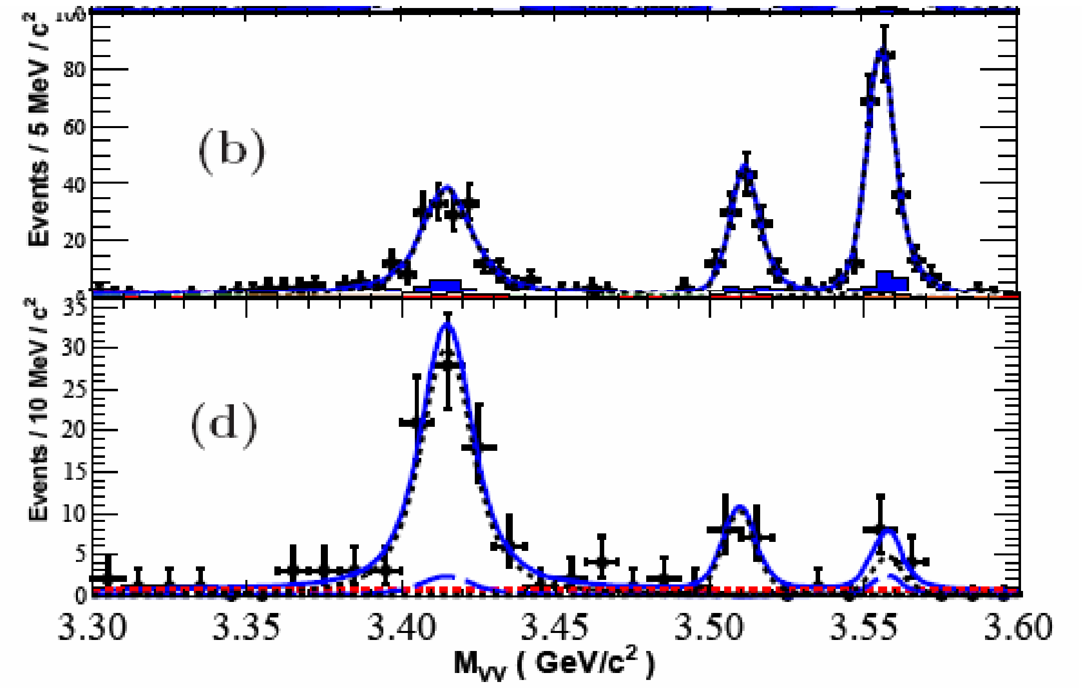
1. Using kinematic fit to select $3\gamma\ 2K2\pi$ candidates.

2. K+K- are identified by minimizing

$$\sum (M_{KK} - M_{\phi})^2$$

3. $\pi^0\omega$ are reconstructed by minimizing

$$(M_{\gamma\gamma} - M_{\pi^0})^2 + (M_{\gamma\gamma\pi^+\pi^-} - M_{\omega})^2$$



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

$$\eta / \eta' / \eta_c \rightarrow \pi^+\pi^-, \pi^0\pi^0$$

Search the CP or P violation through pseudoscalar decays to $\pi\pi$

A branching fraction of order 10^{-27} exists only in weak interaction in SM.
Higher branching fractions are possible
New source existed?